Light relic neutralinos in Dark Matter direct and indirect searches and at the Large Hadron Collider

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(based on:
A. Bottino, F. Donato, N. Fornengo, S.S., PRD77(2008)015002
A. Bottino, N. Fornengo, G. Polesello, S.S., arXiv:0801.3334, to appear on PRD)

16th International Conference on Supersymmetry and the unification of fundamental interactions 16-21 june 2008


MSSM
A huge parameter space to explore!

Effective MSSM scheme (effMSSM) – Independent parameters

- M_1 U(1) gaugino soft breaking term
- M_2 SU(2) gaugino soft breaking term
- μ Higgs mixing mass parameter
- $\tan\beta$ ratio of two Higgs v.e.v.'s
- m_A mass of CP odd neutral Higgs boson (the extended Higgs sector of MSSM includes also the neutral scalars h, H, and the charged scalars $H^{\pm}$)
- $m_{\tilde{q}}$ soft mass common to all squarks
- $m_{\tilde{l}}$ soft mass common to all sleptons
- A common dimensionless trilinear parameter for the third family ($A_{\tilde{b}} = A_{\tilde{t}} \equiv A m_{\tilde{q}}$; $A_{\tilde{\tau}} \equiv A m_{\tilde{l}}$)
- $R \equiv M_1/M_2$

SUGRA$\rightarrow R=0.5$

The neutralino

- The neutralino is defined as the lowest-mass linear superposition of bino $\widetilde{B}$, wino $\widetilde{W}^{(3)}$ and the two higgsino states $\widetilde{H}_1^0$, $\widetilde{H}_2^0$:

$$\chi \equiv a_1 \widetilde{B} + a_2 \widetilde{W}^{(3)} + a_3 \widetilde{H}_1^0 + a_4 \widetilde{H}_2^0$$

- neutral, colourless, only weak-type interactions
- stable if R-parity is conserved, thermal relic
- non relativistic at decoupling $\rightarrow$ Cold Dark Matter (required by CMB data + structure formation models)
- relic density can be compatible with cosmological observations: $0.095 \leq \Omega_\chi h^2 \leq 0.131$

  $\rightarrow$IDEAL CANDIDATE FOR COLD DARK MATTER

Can the neutralino be *light*?

Lower limits on the neutralino mass from accelerators

- Indirect limits from chargino production ($e^+e^- \to \chi^+\chi^-$):

$$m_{\chi^\pm} \gtrsim 100 \text{ GeV} \Rightarrow m_\chi \gtrsim 50 \text{ GeV} \quad \text{if} \quad R \equiv \frac{M_1}{M_2} = \frac{5}{3}\tan^2\theta_w$$

- Direct limits from $e^+e^- \to \chi_0^i \chi_0^j$ $\quad (\chi_0^1 \equiv \chi,\, m_{\chi_0^1} < m_{\chi_0^2} < m_{\chi_0^3} < m_{\chi_0^4})$ †:
  - Invisible width of the Z boson (upper limit on number N_ν of neutrino families)
  - Missing energy + photon(s) or $f\bar{f}$ from $\chi_0^{i>1} \to \chi_0^1$ decay

- Direct limits from $\tilde{t} \to c\,\chi$ and $\tilde{b} \to b\,\chi$ at Tevatron ‡

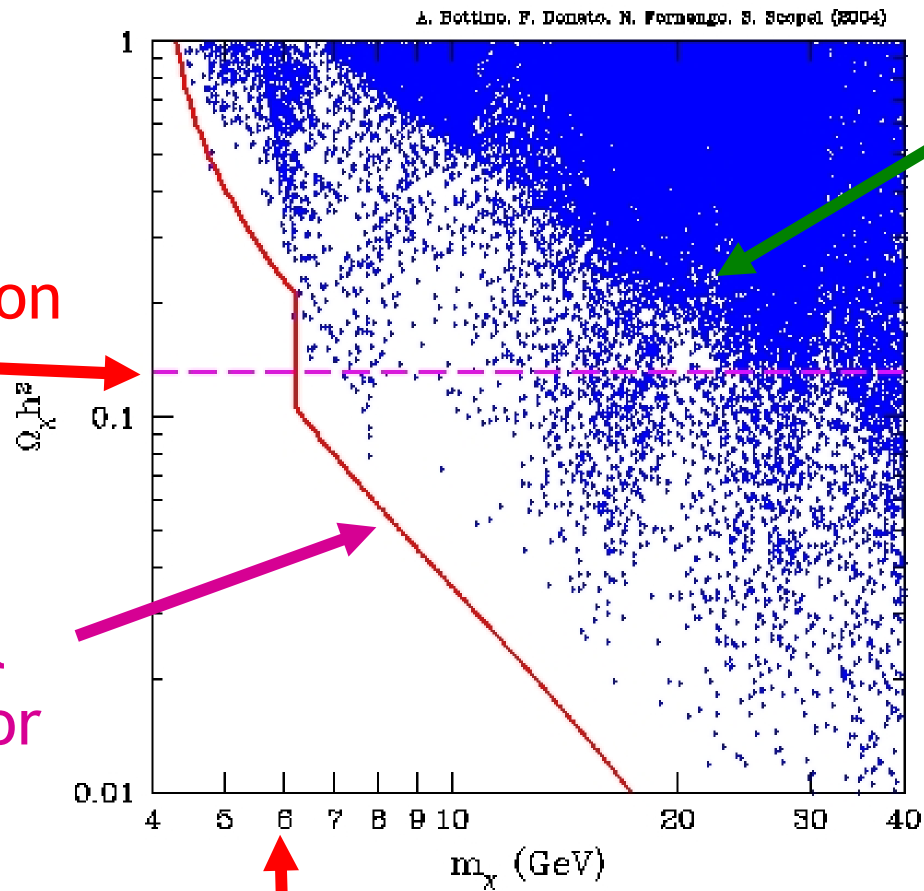
† small production cross sections

‡ light squark masses ($\lesssim 100$ GeV) required

➠ No absolute direct lower bounds on m_χ

Cosmological lower bound on m_χ (low m_A)

A. Bottino, F. Donato, N. Fornengo, S. Scopel, Phys. Rev. D 68, 043506 (2003)



scatter plot: full calculation

In the following:

LHC benchmark (scenario A)

upper bound on $\Omega_{CDM}h^2$

curve: analytical approximation for minimal $\Omega_{CDM}h^2$

$$m_\chi\, [1 - m_b^2/m_\chi^2]^{1/4} \gtrsim 5.3\ \mathrm{GeV}\, \left(\frac{m_A}{90\ \mathrm{GeV}}\right)^2$$

Cosmological lower bound on m_χ ($m_A > 200$ GeV)

A. Bottino, F. Donato, N. Fornengo, S. Scopel, Phys. Rev. D 68, 043506 (2003)

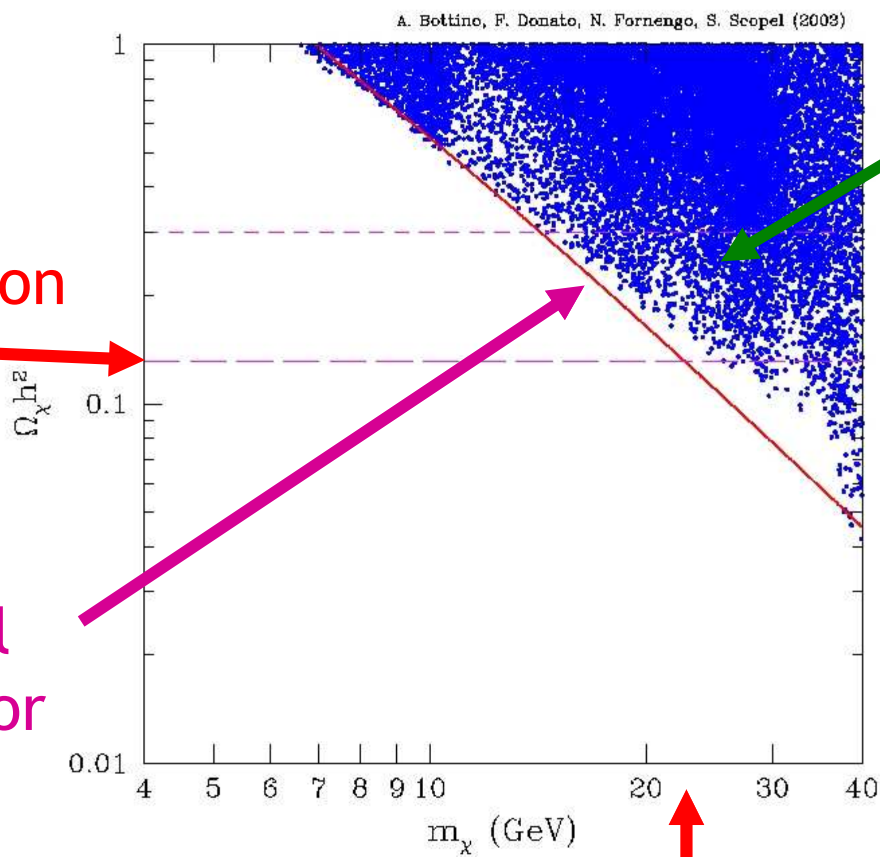
scatter plot: full calculation

In the following:

LHC benchmark (scenario B)

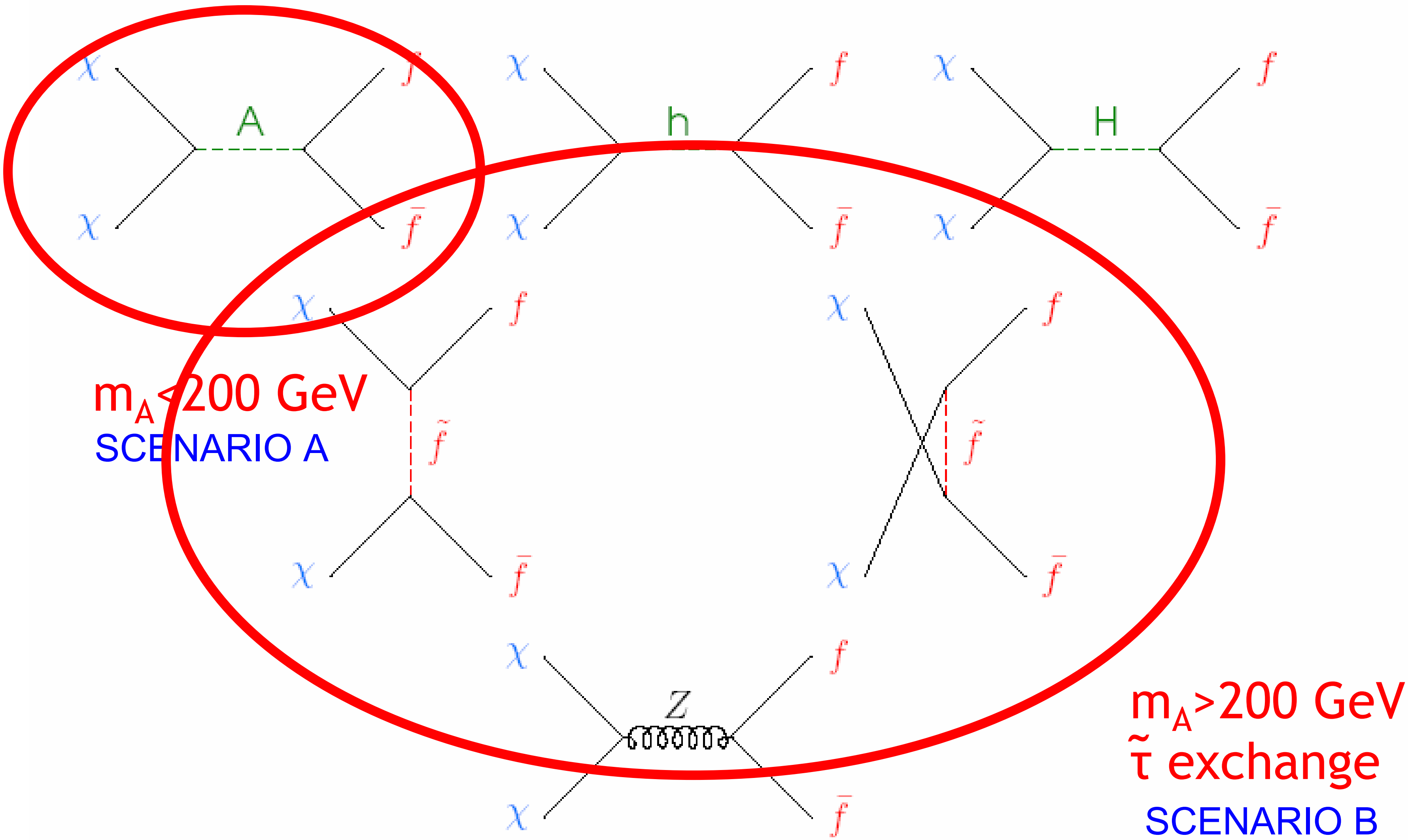
upper bound on $\Omega_{CDM}h^2$

curve: analytical approximation for minimal $\Omega_{CDM}h^2$



$$m_\chi\,[1 - m_{\tilde\tau}^2/m_\chi^2]^{1/4} \gtrsim 22\ \mathrm{GeV}\ \left(\frac{m_{\tilde\tau}}{90\ \mathrm{GeV}}\right)^2$$

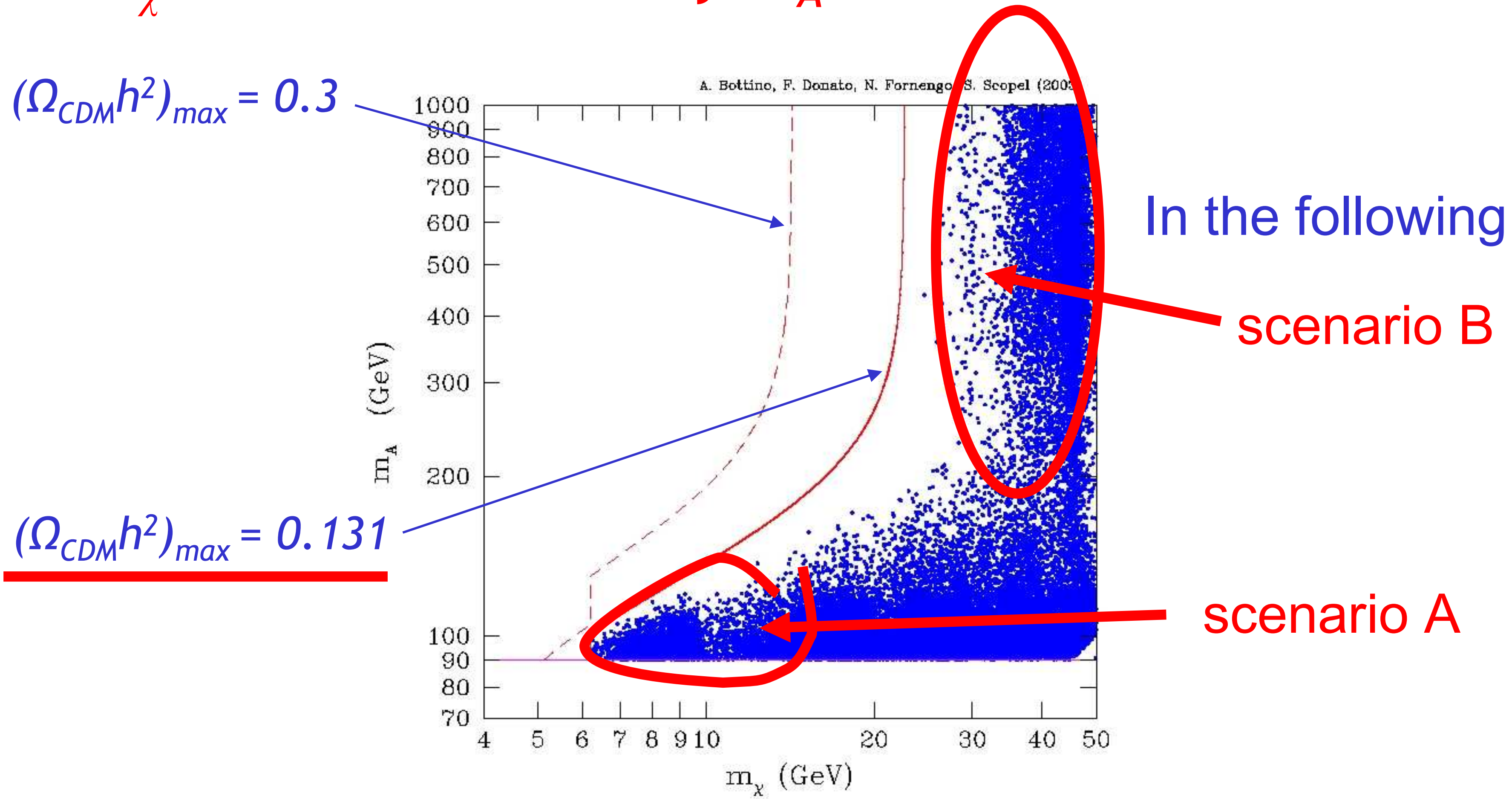
χ–$\chi \rightarrow f\bar{f}$ annihilation cross section - Diagrams (low m_χ)



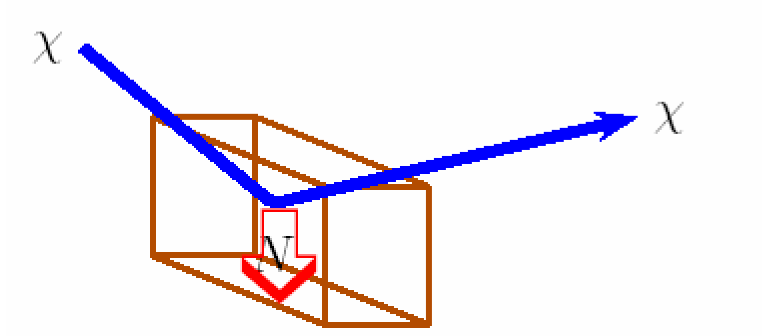
<u>The bottom line</u>: the cosmological lower bound on m_χ depends on the value of m_A:

✓ m_χ > 7 GeV for light m_A

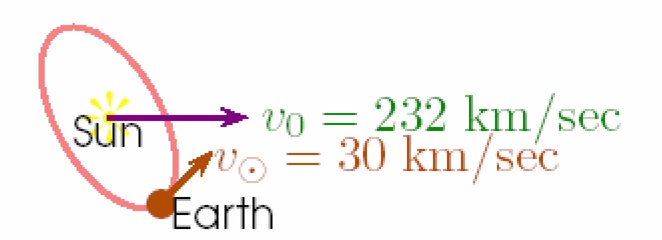
✓ m_χ > 22 GeV for heavy m_A



Neutralino direct detection



- Elastic recoil of non relativistic halo neutralinos off the nuclei of an underground detector
- Recoil energy of the nucleus in the keV range
- Yearly modulation effect due to the rotation of the Earth around the Sun (the relative velocity between the halo, usually assumed at rest in the Galactic system, and the detector changes during the year)



Differential detection rate

$$\frac{dR}{dE_R} = N_T \frac{\rho_\chi}{m_\chi} \int_{v_{\min}}^{v_{\max}} d\vec{v}\, f(\vec{v}) |\vec{v}| \frac{d\sigma(\vec{v},E_R)}{dE_R}$$

E_R=nuclear recoil energy
N_T=number of nuclear targets
$\vec{v}$=WIMP velocity in the Earth's rest frame

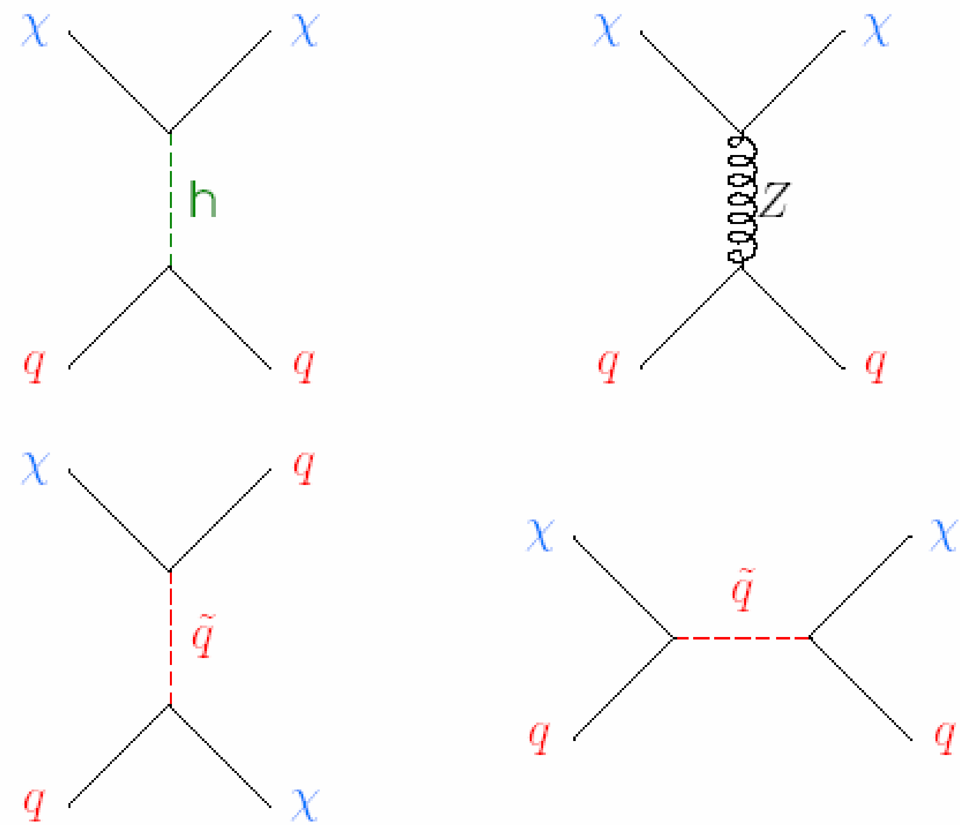
Astrophysics:
* ρ_χ=neutralino local density
* $f(\vec{v})$=neutralino velocity distribution function

Particle and nuclear physics:
* $\frac{d\sigma(\vec{v},E_R)}{dE_R}$=neutralino–nucleus elastic cross section

$$\frac{d\sigma(\vec{v},E_R)}{dE_R} = \left(\frac{d\sigma(\vec{v},E_R)}{dE_R}\right)_{\text{coherent}} + \left(\frac{d\sigma(\vec{v},E_R)}{dE_R}\right)_{\text{spin-dependent}}$$

usually dominates, $\propto$ (atomic number)^2

Neutralino–quark cross section - Diagrams



Neutralino – nucleon cross section

Color code from now on:

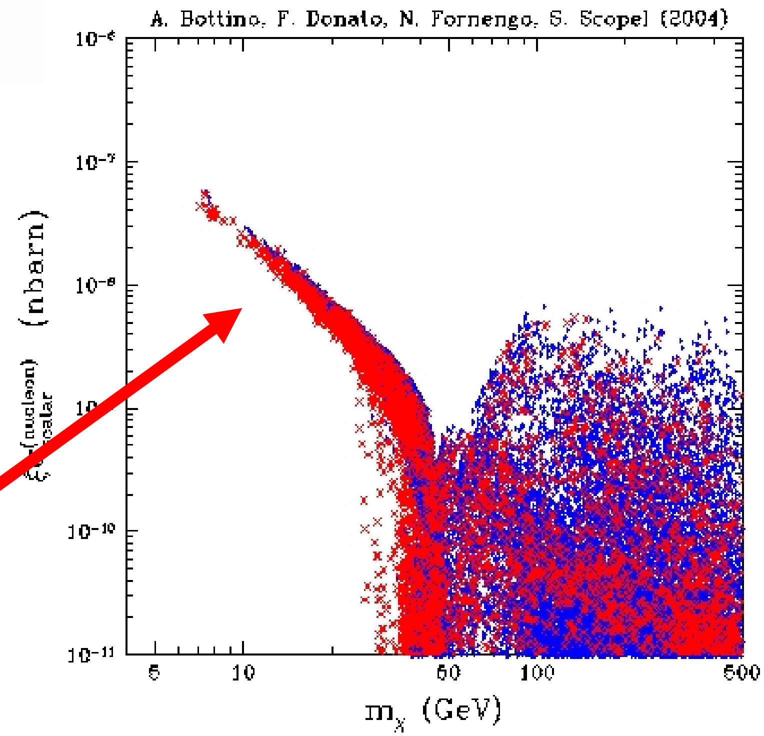
- $\Omega_\chi h^2 < 0.095$
- × $\Omega_\chi h^2 > 0.095$

$$\Omega_\chi h^2 \leq (\Omega_{CDM} h^2)_{max}$$

$$\sigma^{(\text{nucleon})}_{\text{scalar}} \gtrsim \frac{10^{-40} cm^2}{(\Omega_{CDM} h^2)_{max}} \frac{\text{GeV}^2}{m_\chi^2 \, [1 - m_b^2/m_\chi^2]^{1/2}} \quad \text{for } m_\chi \lesssim 20 \text{ GeV}$$

The elastic cross section is bounded from below:

→ "funnel" at low mass



Uncertainty due to velocity distribution

- ❒ Many possible departures from the isothermal sphere model, which is the parameterization usually adopted to describe the halo.

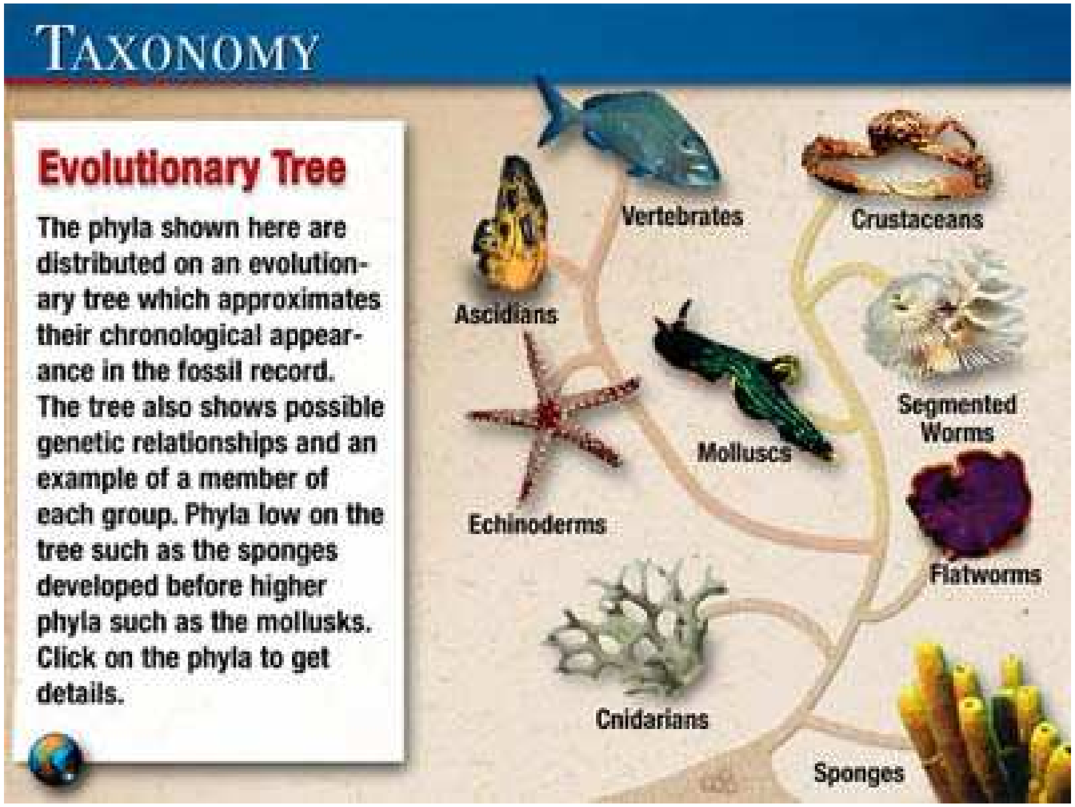
- ❒ Different density profiles, effects due to anisotropies of the velocity dispersion tensor, rotation of the galactic halo.

- ❒ Non thermal components:

  - ➥ numerical simulations, see for instance A. Helmi, S. D. M. White and V. Springel, Phys. Rev. D 66 063503 (2002); D. D. Stiff, L. M. Widrow and J. Frieman, Phys. Rev. D 64 , 083516 (2001) ☛ Size of the effect?
  - ➥ Sgr tidal stream, K. Freese, P. Gondolo and H. Newberg,

    PRD71,043516,2005

Too many models: some classification is needed



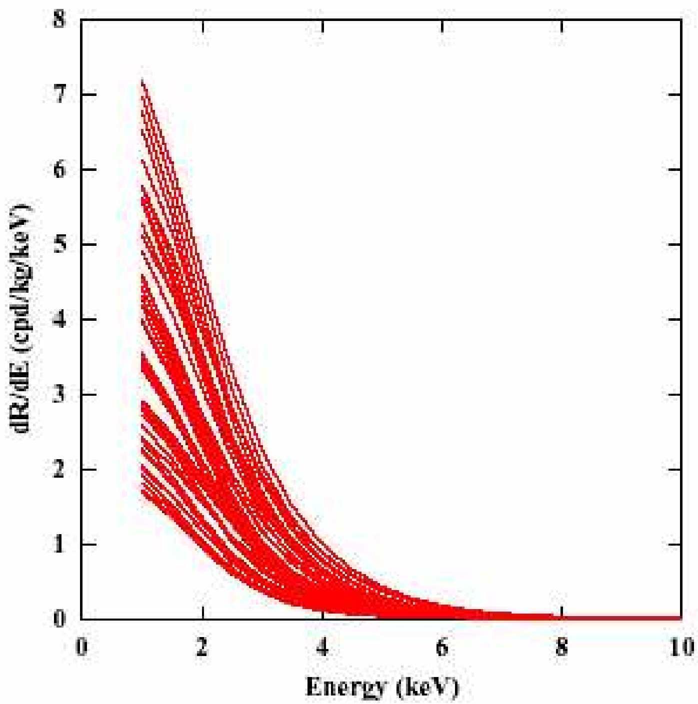
Class A: Spherical ρ_{DM}, isotropic velocity dispersion			
A0	Isothermal sphere		Eq. (20)
A1	Evans' logarithmic [15]	$R_c = 5$ kpc	Eq. (18)
A2	Evans' power-law [16]	$R_c = 16$ kpc, $\beta = 0.7$	Eq. (23)
A3	Evans' power-law [16]	$R_c = 2$ kpc, $\beta = -0.1$	Eq. (23)
A4	Jaffe [14]	Table I	Eq. (26)
A5	NFW [18]	Table I	Eq. (26)
A6	Moore *et al.* [19]	Table I	Eq. (26)
A7	Kravtsov *et al.* [20]	Table I	Eq. (26)
Class B: Spherical ρ_{DM}, non-isotropic velocity dispersion (Osipkov-Merrit, $\beta_0 = 0.4$)			
B1	Evans' logarithmic	$R_c = 5$ kpc	Eqs. (18),(28)
B2	Evans' power-law	$R_c = 16$ kpc, $\beta = 0.7$	Eqs. (23),(28)
B3	Evans' power-law	$R_c = 2$ kpc, $\beta = -0.1$	Eqs. (23),(28)
B4	Jaffe	Table I	Eqs. (26),(28)
B5	NFW	Table I	Eqs. (26),(28)
B6	Moore *et al.*	Table I	Eqs. (26),(28)
B7	Kravtsov *et al.*	Table I	Eqs. (26),(28)
Class C: Axisymmetric ρ_{DM}			
C1	Evans' logarithmic	$R_c = 0$, $q = 1/\sqrt{2}$	Eqs. (33),(34)
C2	Evans' logarithmic	$R_c = 5$ kpc, $q = 1/\sqrt{2}$	Eqs. (33),(34)
C3	Evans' power-law	$R_c = 16$ kpc, $q = 0.95$, $\beta = 0.9$	Eqs. (37),(38)
C4	Evans' power-law	$R_c = 2$ kpc, $q = 1/\sqrt{2}$, $\beta = -0.1$	Eqs. (37),(38)
Class D: Triaxial ρ_{DM} [17] ($q = 0.8, p = 0.9$)			
D1	Earth on major axis, radial anisotropy	$\delta = -1.78$	Eqs. (43),(44)
D2	Earth on major axis, tangential anis.	$\delta = 16$	Eqs. (43),(44)
D3	Earth on intermediate axis, radial anis.	$\delta = -1.78$	Eqs. (43),(44)
D4	Earth on intermediate axis, tangential anis.	$\delta = 16$	Eqs. (43),(44)

Uncertainty due to velocity distribution

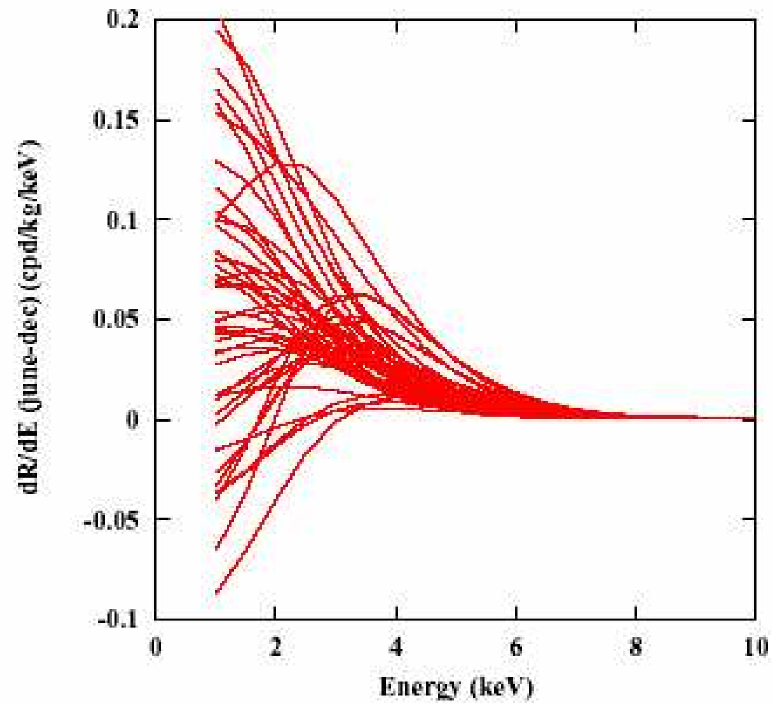
Sodium Iodide

m_{WIMP}=50 GeV
$\sigma^{\mathrm{nucleon}}_{\mathrm{scalar}}$=$10^{-8}$ nbarn
v_0= 220 km/sec

Each curve corresponds to a different halo model:



Time–independent component



Modulation amplitude

Neutralino-nucleon cross section – scalar contribution

$$\sigma^{(\mathrm{nucleon})}_{\mathrm{scalar}} = \frac{8G_F^2}{\pi} M_Z^2 m_{\mathrm{red}}^2 \left[\frac{F_h I_h}{m_h^2} + \frac{F_H I_H}{m_H^2} + \frac{M_Z}{2} \sum_q < N|\bar{q}q|N > \sum_i P_{\tilde{q}_i} (A_{\tilde{q}_i}^2 - B_{\tilde{q}_i}^2) \right]^2$$

Higgs-exchange

squark-exchange

squark exchange (four-Fermi approx):

propagators:

$$P_{\tilde{q}_i} = \frac{1}{2} \left(\frac{1}{m_{\tilde{q}_i}^2 - (m_\chi - m_q)^2} + \frac{1}{m_{\tilde{q}_i}^2 - (m_\chi + m_q)^2} \right)$$

couplings:

$$\begin{aligned}
A_{\tilde{q}_1} &= \cos\theta_q (X_q + Z_q) + \sin\theta_q (Y_q + Z_q) \\
B_{\tilde{q}_1} &= \cos\theta_q (X_q - Z_q) + \sin\theta_q (Z_q - Y_q) \\
X_q &= -\left(\cos\theta_W T_{3q} a_2 + \sin\theta_W \frac{Y_{qL}}{2} a_1 \right) \quad ; \quad Y_q = \sin\theta_W \frac{Y_{qR}}{2} a_1 \\
Z_{u-\mathrm{type}} &= -\frac{m_{u-\mathrm{type}} a_4}{2\sin\beta M_Z} \quad ; \quad Z_{d-\mathrm{type}} = -\frac{m_{d-\mathrm{type}} a_3}{2\cos\beta M_Z},
\end{aligned}$$

Higgs-exchange contribution:

neutralino-Higgs couplings:

$$F_h = (-a_1 \sin\theta_W + a_2 \cos\theta_W)(a_3 \sin\alpha + a_4 \cos\alpha)$$
$$F_H = (-a_1 \sin\theta_W + a_2 \cos\theta_W)(a_3 \cos\alpha - a_4 \sin\alpha)$$

α=Higgs-mixing angle:

$$\begin{cases} H = \cos\alpha H_1^0 + \sin\alpha H_2^0 \\ h = -\sin\alpha H_1^0 + \cos\alpha H_2^0 \end{cases}$$

quark-Higgs couplings:

$$I_{h,H} = \sum_q k_q^{h,H} m_q \langle N|\bar{q}q|N\rangle$$

	h	H	A
k_{u-type}	$\cos\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$1/\tan\beta$
k_{d-type}	$-\sin\alpha/\cos\beta - \epsilon\cos(\alpha-\beta)\tan\beta$	$\cos\alpha/\cos\beta - \epsilon\sin(\alpha-\beta)\tan\beta$	$\tan\beta(1+\epsilon)$

radiative corrections to down-type Yukawa couplings:

$$\begin{cases} m_d = h_d < H_0^1 > (1+\Delta) \\ \epsilon \equiv 1/(1+\Delta) \end{cases}$$

The hadronic matrix elements: $< N|\bar{q}q|N >$

introduce uncertainties in the final result [Bottino, Donato, Fornengo, Scopel, Astrop.Phys. 18(2002)205; ibidem 13(2000)215]

The Higgs-nucleon couplings can be rewritten as:

$$I_{h,H} = k^{h,H}_{u-\mathrm{type}} g_u + k^{h,H}_{d-\mathrm{type}} g_d$$

with:(l=light quark h=heavy quark):

$$\begin{aligned} g_u &\simeq m_l < N|\bar{l}l|N > + 2\, m_h < N|\bar{h}h|N > \\ &\simeq \frac{4}{27}(m_N + \frac{19}{8}\sigma_{\pi N} - \frac{1}{2} r(\sigma_{\pi N} - \sigma_0)) \end{aligned}$$

$$\begin{aligned} g_d &\simeq m_l < N|\bar{l}l|N > + m_s < N|\bar{s}s|N > + m_h < N|\bar{h}h|N > \\ &\simeq \frac{2}{27}(m_N + \frac{23}{4}\sigma_{\pi N} + \frac{25}{4} r(\sigma_{\pi N} - \sigma_0)) \end{aligned}$$

$\sigma_{\pi N}$= pion-nucleon sigma term

$$r \equiv \frac{2m_s}{m_u + m_d}$$

$$\sigma_0 \equiv \frac{1}{2}(m_u + m_d) < N|\bar{u}u + \bar{d}d - 2\bar{s}s|N >$$

Relevant parameters:

$r \sim 25$

30 MeV < σ_0 < 40 MeV

Two determinations of $\sigma_{\pi N}$:

(A. Bottino et al., Astrop. Phys. 13 (2000) 215)

41 MeV < $\sigma_{\pi N}$ < 57 MeV

$$\Rightarrow 98 \text{ MeV} \lesssim g_d \lesssim 406 \text{ MeV}$$

(M. M. Pavan et al., PiN Newslett. 16(2002)110, hep-ph/0111066)

55 MeV < $\sigma_{\pi N}$ < 73 MeV

$$\Rightarrow 266 \text{ MeV} \lesssim g_d \lesssim 598 \text{ MeV}$$

N.B.: combining various measurements, the quantity

$$y \equiv 2\frac{<N|\bar{s}s|N>}{<N|\bar{u}u+\bar{d}d|N>} = 1 - \frac{\sigma_0}{\sigma_{\pi N}}$$ (squark content of the nucleon)

can be sizeable ($y<0.6$)

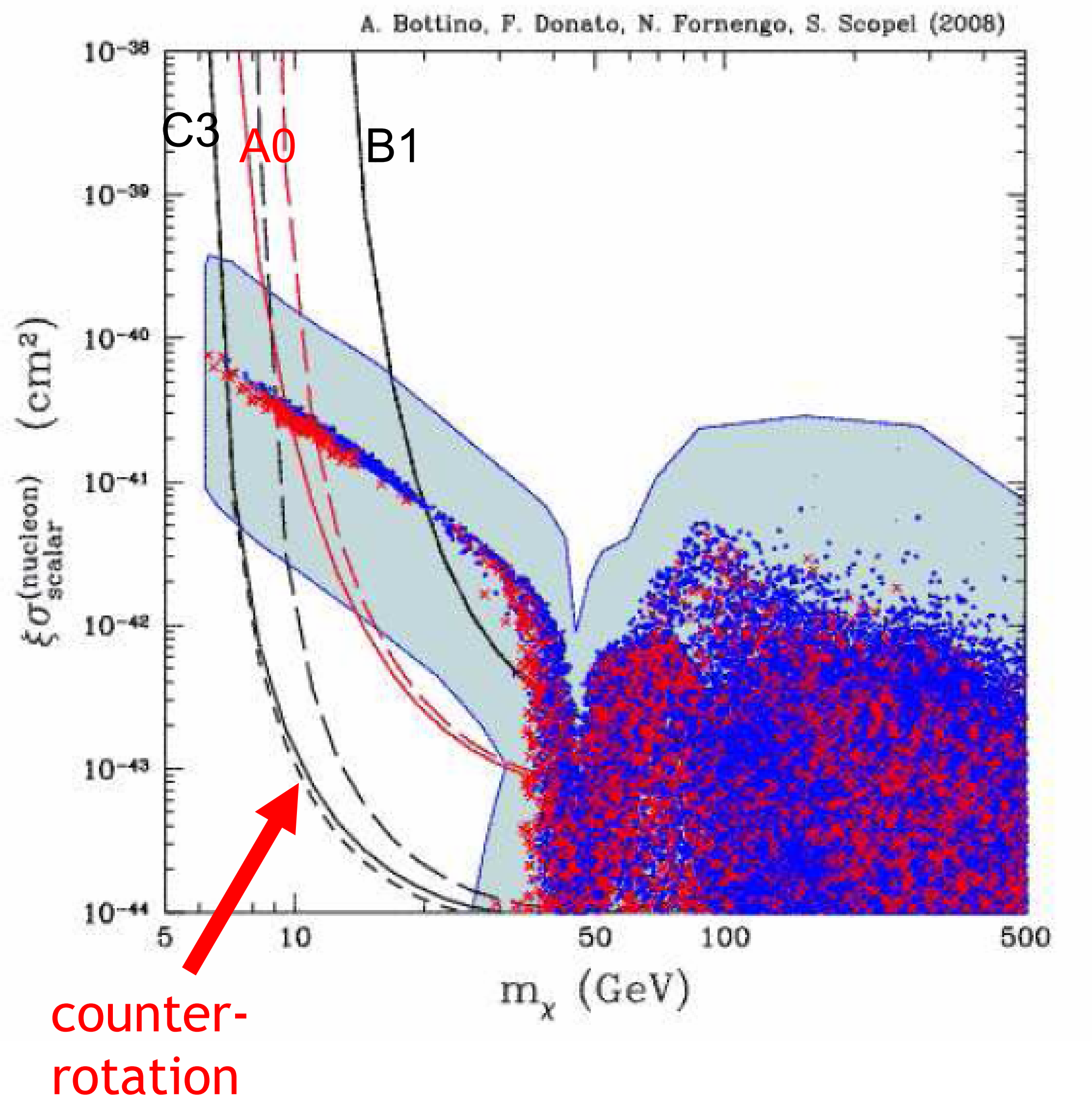
cross section depends on g_d^2, factor $\sim(600/100)^2 \sim 36$ uncertainty

[recent re-analysis, including uncertainties on SM inputs: Ellis, Olive, Savage, arXiv:0801.3656]

Hadronic matrix elements reference values (compatible with overlap of two different determinations)

$$
\begin{aligned}
g_{u,ref} &= 123 \ \mathrm{MeV} \\
g_{d,ref} &= 290 \ \mathrm{MeV}
\end{aligned}
$$

Neutralino-nucleon cross section & CDM limit (including astrophysical uncertainties) [exp. data: Ahmed et al., arXiv:0802.3530]



solid: v_{esc}=650 km/sec

long dashes: v_{esc}=450 km/sec

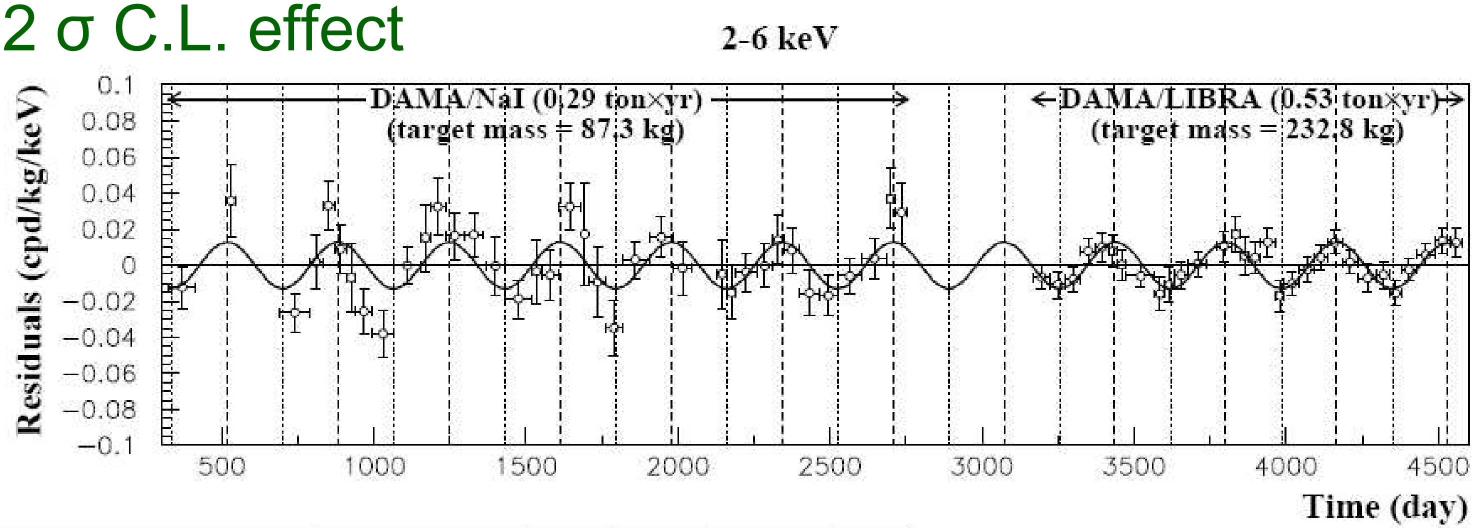
eff-MSSM

(including uncertainties due to hadronic matrix elements)

scatter plot: reference choice of hadronic matrix elements

New DAMA result (Bernabei et al., arXiv:0804.2741)

0.53 ton x year (0.82 ton x year combining previous data)
8.2 σ C.L. effect



	A (cpd/kg/keV)	$T = \frac{2\pi}{\omega}$ (yr)	t_0 (day)	C.L.
DAMA/NaI				
(2–4) keV	0.0252 ± 0.0050	1.01 ± 0.02	125 ± 30	5.0σ
(2–5) keV	0.0215 ± 0.0039	1.01 ± 0.02	140 ± 30	5.5σ
(2–6) keV	0.0200 ± 0.0032	1.00 ± 0.01	140 ± 22	6.3σ
DAMA/LIBRA				
(2–4) keV	0.0213 ± 0.0032	0.997 ± 0.002	139 ± 10	6.7σ
(2–5) keV	0.0165 ± 0.0024	0.998 ± 0.002	143 ± 9	6.9σ
(2–6) keV	0.0107 ± 0.0019	0.998 ± 0.003	144 ± 11	5.6σ
DAMA/NaI+ DAMA/LIBRA				
(2–4) keV	0.0223 ± 0.0027	0.996 ± 0.002	138 ± 7	8.3σ
(2–5) keV	0.0178 ± 0.0020	0.998 ± 0.002	145 ± 7	8.9σ
(2–6) keV	0.0131 ± 0.0016	0.998 ± 0.003	144 ± 8	8.2σ

$A \cos[\omega\,(t-t_0)]$

$\omega = 2\pi/T_0$

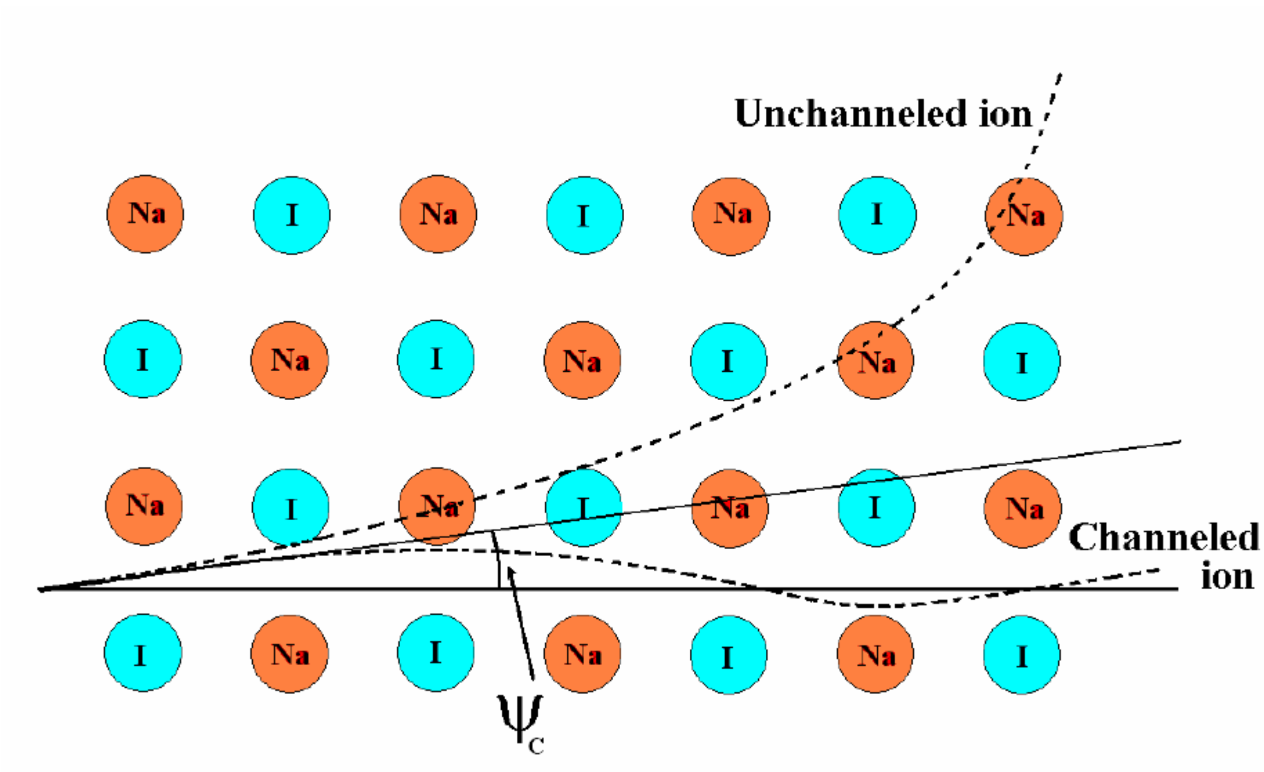
preliminary results using these data are included in the present analysis (private communication) – work in progress

Quenching

- in ionizators or scintillators the energy of a recoiling nucleus is partially transferred to electrons which carry the signal
- q = quenching factor = fraction of nuclear recoil energy converting to ionization or scintillation (q=1 for γ's from calibration)
- simplistic view: recoiling nucleus experiences low stopping power of surrounding electronic cloud for kinematical reasons (mass mismatch between nucleus and single electrons)
- most of the energy is converted to lattice vibrations (heat)
- q~0.09 for I, q~0.23 for Na, q~0.3 for Ge. Measured with monoenergetic neutron beam
- standard theory: Lindhard et al., Mat. Fys. Medd. K. Dan. Vidensk. Selsk. 33 (1963) 1; SRIM code
- a useful application: dual read-out (bolometer + ionizator, bolometer + scintillator) allows discrimination between nuclear recoils (signal) and background (γ's and β's) (CDMS, Edelweiss)

One possible exception: channeling effect in crystals

(Dobryshevsky, arXiv:0706.3095, Bernabei et al., arxiv:07100288)



critical angle:

$$\Psi_c = \sqrt{\frac{C a_{TF}}{d\sqrt{2}}\Psi_1}$$

$$\Psi_1 = \sqrt{\frac{2Z_1 Z_2 e^2}{Ed}}$$

C^2~3, d=interatomic spacing

$$a_{TF} = \frac{0.8853 a_0}{\left(\sqrt{Z_1}+\sqrt{Z_2}\right)^{2/3}}$$

a_0=0.529 Å (Bohr radius)

- anomalous deep penetration of ions into crystalline targets discovered a long time ago (1957, 4 keV $^{134}CS^+$ observed to penetrate λ~ 1000 Å in Ge, according to Lindhard theory λ~ 44 Å)
- when the ion recoils along one crystallographic axis <u>it only encounters electrons</u> → <u>long penetration depth and q~1</u>

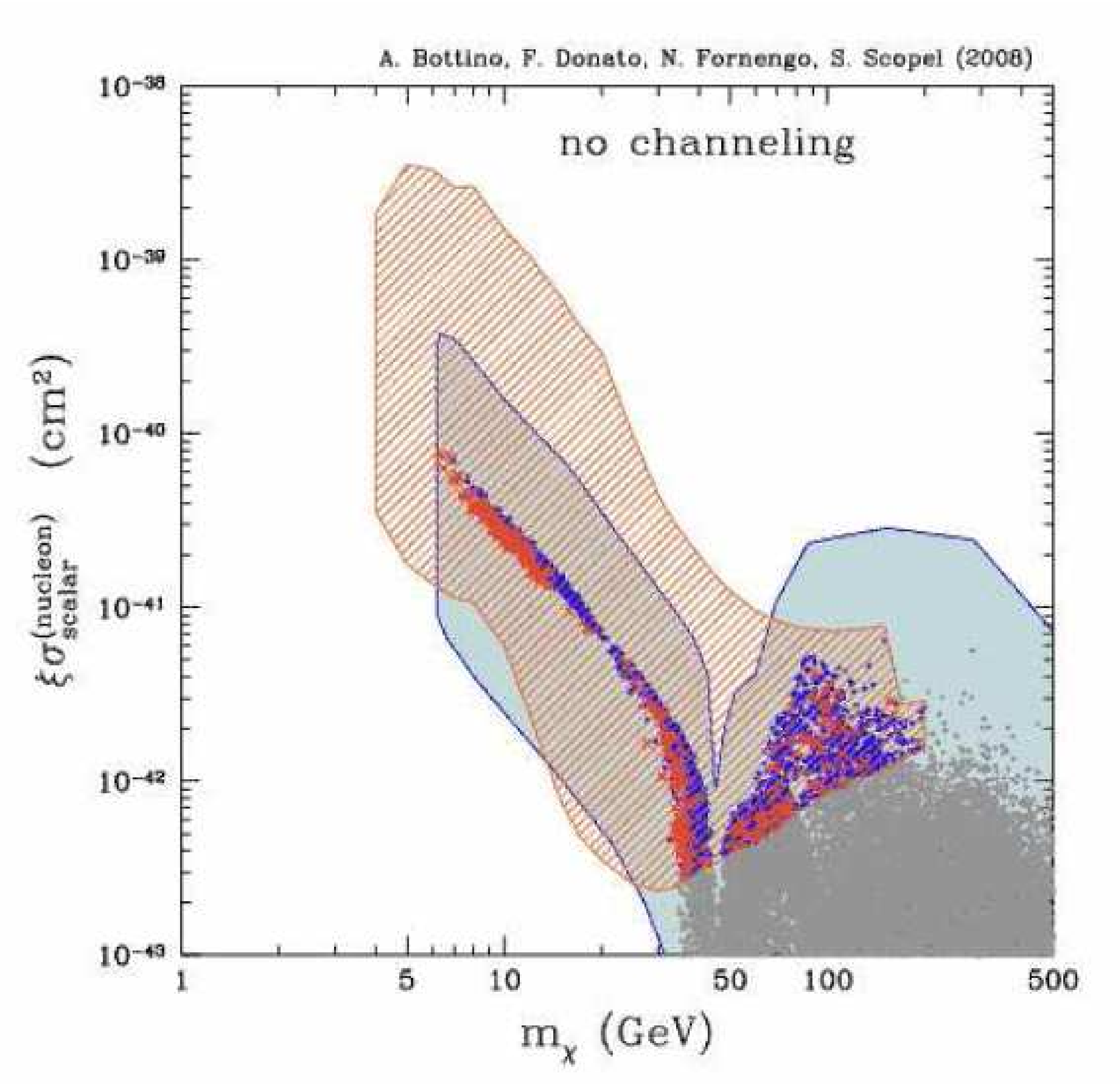
One possible exception: channeling effect in crystals

- the channeling effect is only relevant at low recoil energies (<150 keV)
- detector response enhanced → smaller WIMP cross sections needed to produce the same effect → smaller threshold on recoil energy and sensitivity to lighter masses

N.B.:

- this effect was neglected so far in the analysis of WIMP searches. It is expected in crystal scintillators and ionizators (Ge, NaI)
- no enhancement in liquid noble gas experiments (XENON10, ZEPLIN)
- channeled events are lost using PSD in scintillators
- channeled events are lost using double read-out discrimination (CDMS, Edelweiss)
- quenching measurements are not sensitive enough to see channeled events (q=1 peak broadened by energy resolution)

Comparing the model with latest DAMA/Libra data (preliminary)



channeling not included

DAMA/Libra

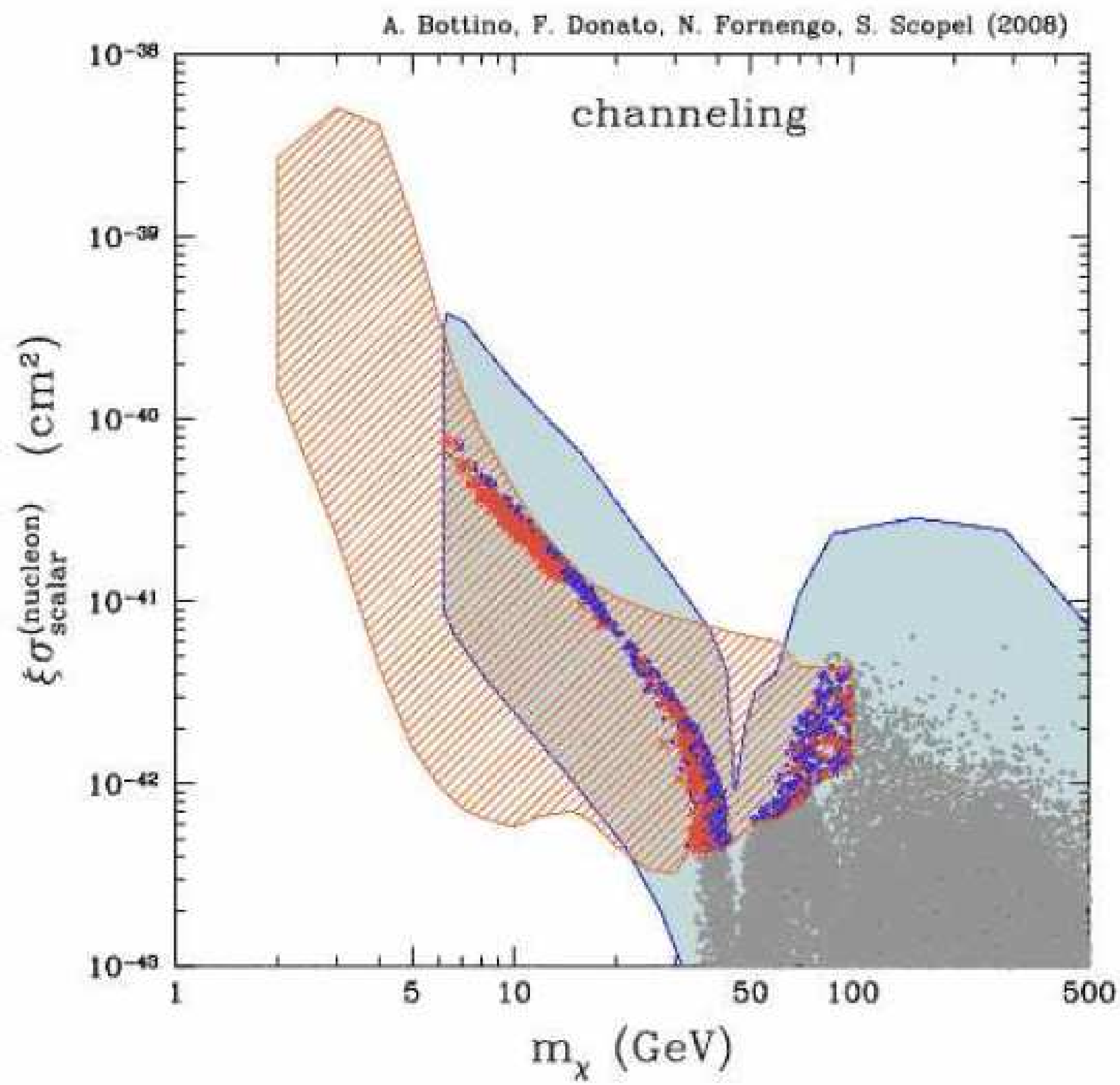
6.5 σ away from null ipothesis, convoluted on different halo models (private communication)

eff-MSSM

(including uncertainties due to hadronic matrix elements)

scatter plot: reference choice of hadronic matrix elements

Comparing the model with latest DAMA/Libra data (preliminary)



channeling included

DAMA/Libra

6.5 σ away from null ipothesis, convoluted on different halo models(private communication)

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Compatibility of DAMA/LIBRA region with low mass neutralinos (PRELIMINARY)

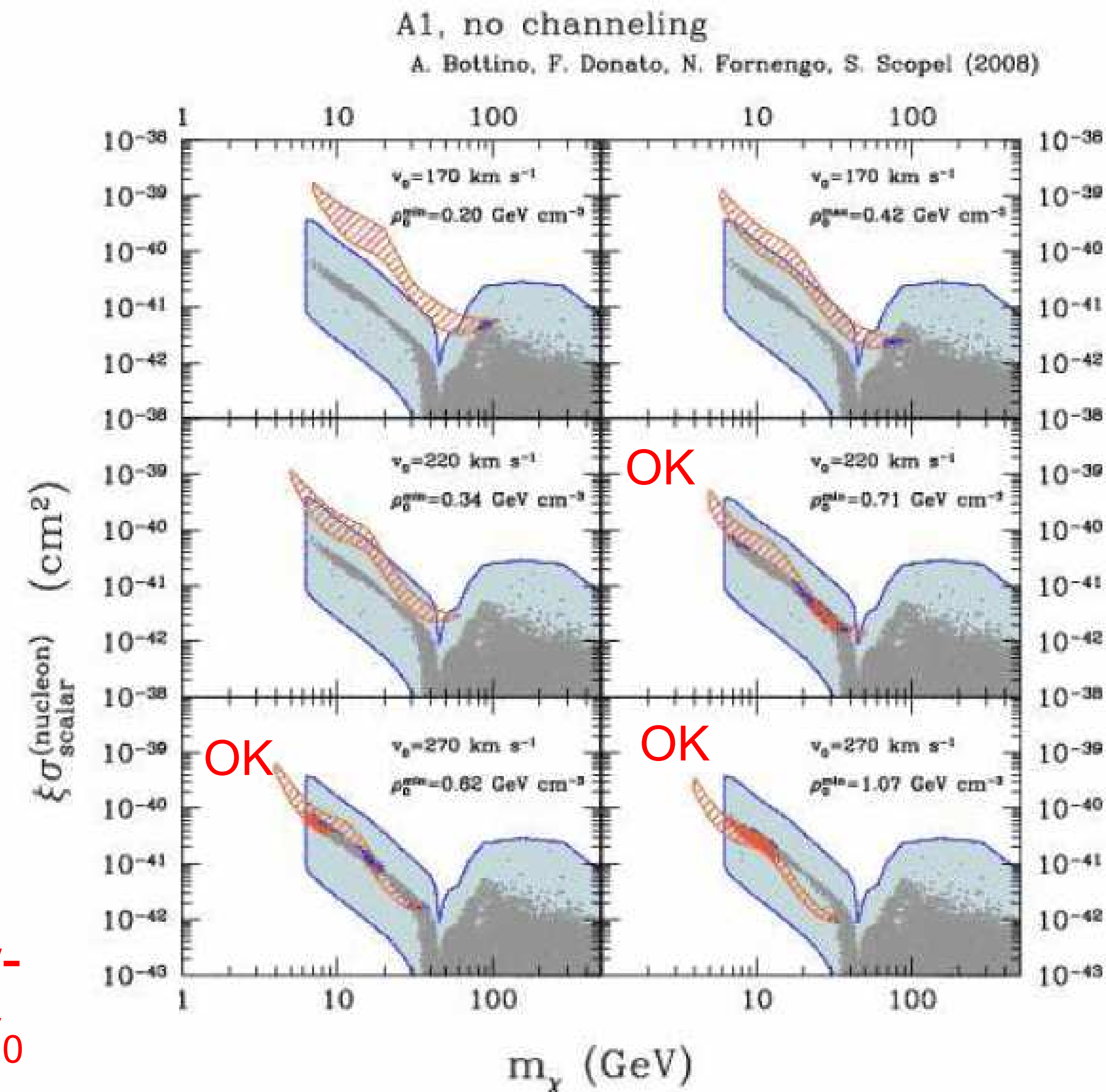
(Evan's logarithmic model (A1), R_c=5 kpc)

$$\rho(r) = \frac{v_0^2}{4\pi G}\frac{3R_c^2 + r^2}{(R_c^2 + r^2)^2}$$

$v_0 = v_{0,min}$

$v_0 = v_{0,central}$

$v_0 = v_{0,max}$



$\rho = \rho_{min}$ $\rho = \rho_{max}$

no channeling, low-medium range of v_0 and ρ_0 disfavoured

Compatibility of DAMA/lIBRA region with low mass neutralinos (PRELIMINARY)

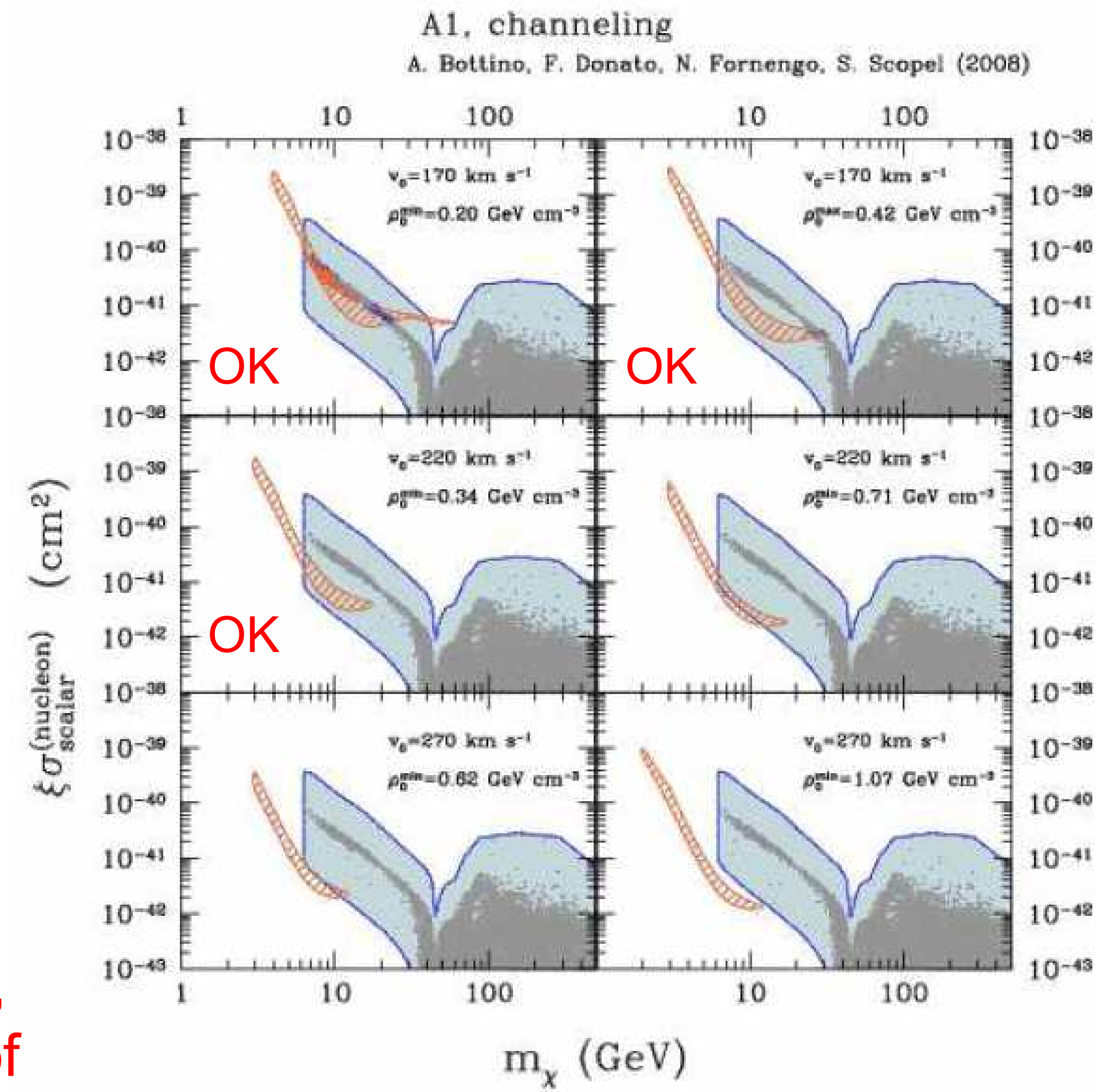
(Evan's logarithmic model (A1), R_c=5 kpc)

$$\rho(r) = \frac{v_0^2}{4\pi G}\frac{3R_c^2 + r^2}{(R_c^2 + r^2)^2}$$

$v_0=v_{0,min}$

$v_0=v_{0,central}$

$v_0=v_{0,max}$



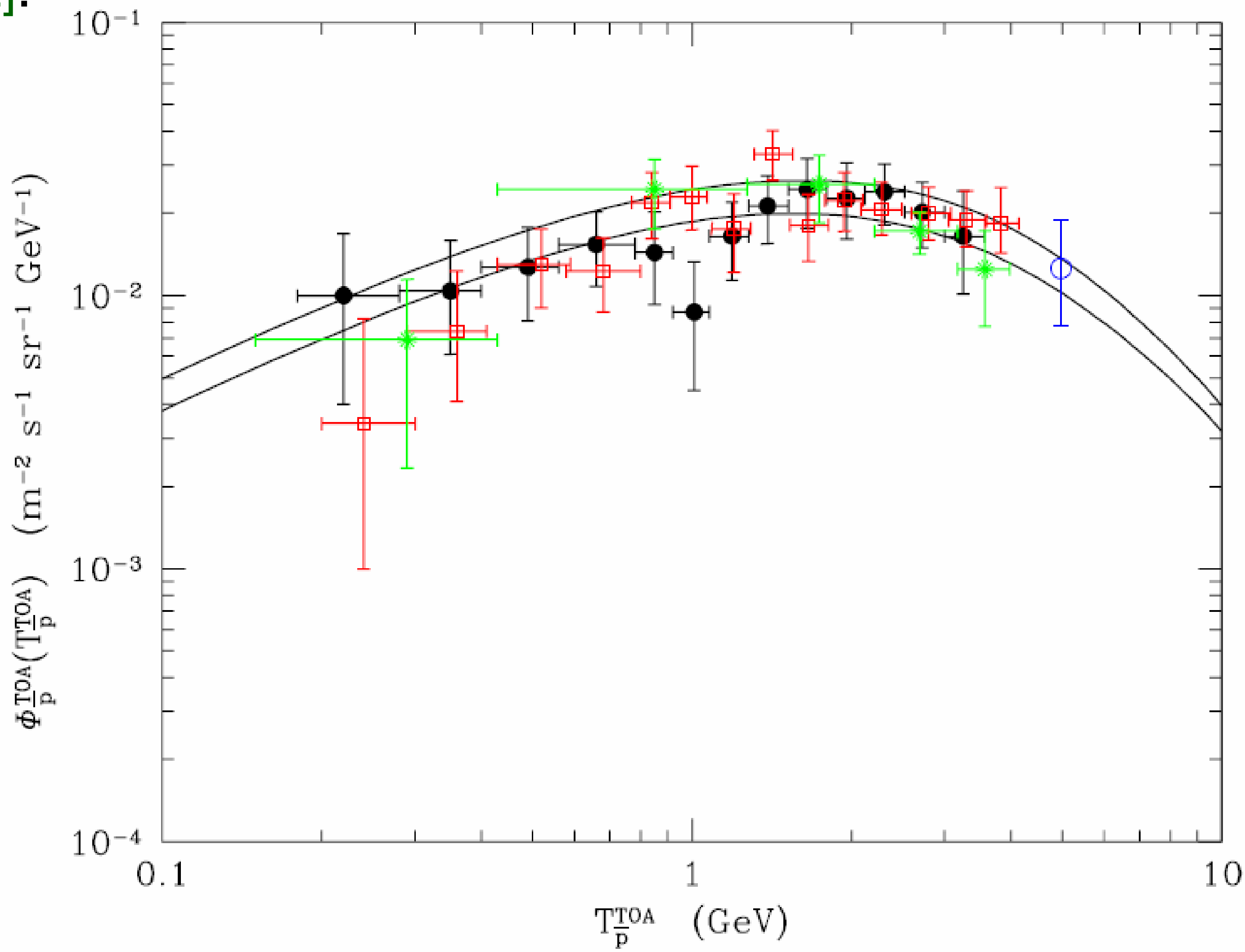
$\rho=\rho_{min}$ $\rho=\rho_{max}$

channeling included, low-medium range of v_0 and ρ_0 favoured

Antiprotons in cosmic rays due to neutralino annihilation

- $\bar{p}$ from hadronization of quarks and gluons created by the annihilation of neutralinos
- Antiproton data can be used to constrain the susy parameter space
- large uncertainties in propagation properties of primary *p's* (propagation of antiprotons treated in a two-zone diffusion model, D. Maurin, F. Donato, R. Taillet, P. Salati, Astrophys.J. **555**, 585 (2001); D. Maurin, R. Taillet, F. Donato, Astronom. and Astrophys. **394**, 1039 (2002))

Secondary production from CR’s fit present antiproton data (BESS, AMS, CAPRICE) rather well: [Donato et al., Astrophys. J. 563(2001)172]:



little room is left for antiprotons of exotic origin!

Exotic production

Example: pbar's from neutralino annihilations:

$$
\chi + \chi \;\rightarrow\;
\begin{array}{c}
g\,\underline{g} \\
f\,\bar{f} \\
W^{+}W^{-} \\
ZZ \\
HH,\, hh,\, AA,\, hH,\, hA,\, HA,\, H^{+}H^{-} \\
W^{+}H^{-},\, W^{-}H^{+} \\
Zh,\, ZH,\, ZA
\end{array}
\;\rightarrow\; \nu,\, \bar{\nu},\, \gamma,\, \bar{p},\, e^{+},\, \bar{d}
$$

$$
\frac{dN_{\bar{p}}}{dE} = \frac{1}{2}\left(\frac{\rho_\chi}{m_\chi}\right)^2 < \sigma v >_0 \sum_f B_f \frac{dN_{\bar{p}}^{f}}{dE}
$$

number density

susy

fragmentation
(Pythia)

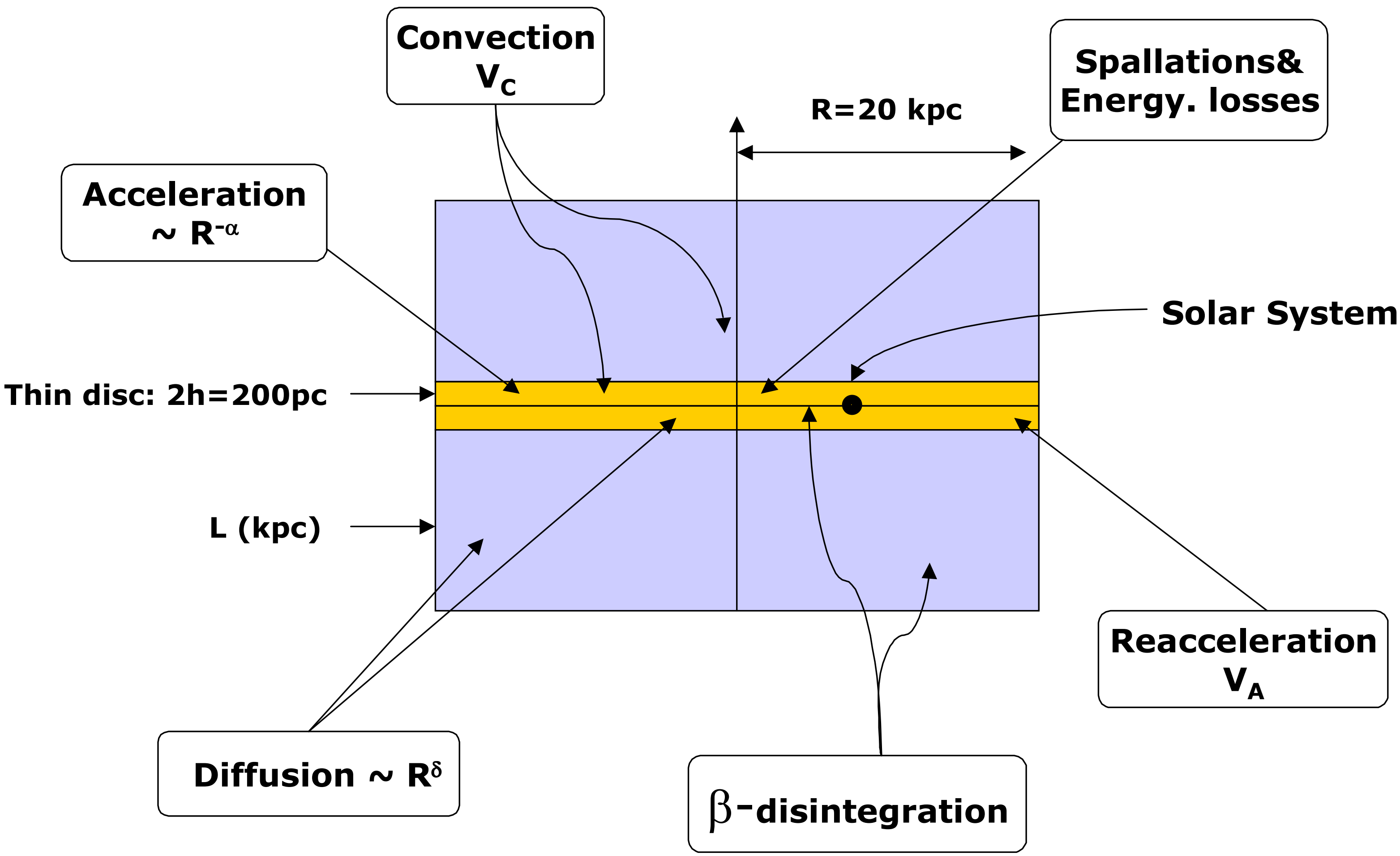
Major complication:

Antiprotons are charged particles and feel the magnetic field of the galaxy

→ directionality from source completely lost

→ complex physics involved between creation and detection

A SIMPLE VIEW OF THE GALAXY



Compatibility with antiprotons (work in progress)
No channeling, hadronic matrix elements in allowed range

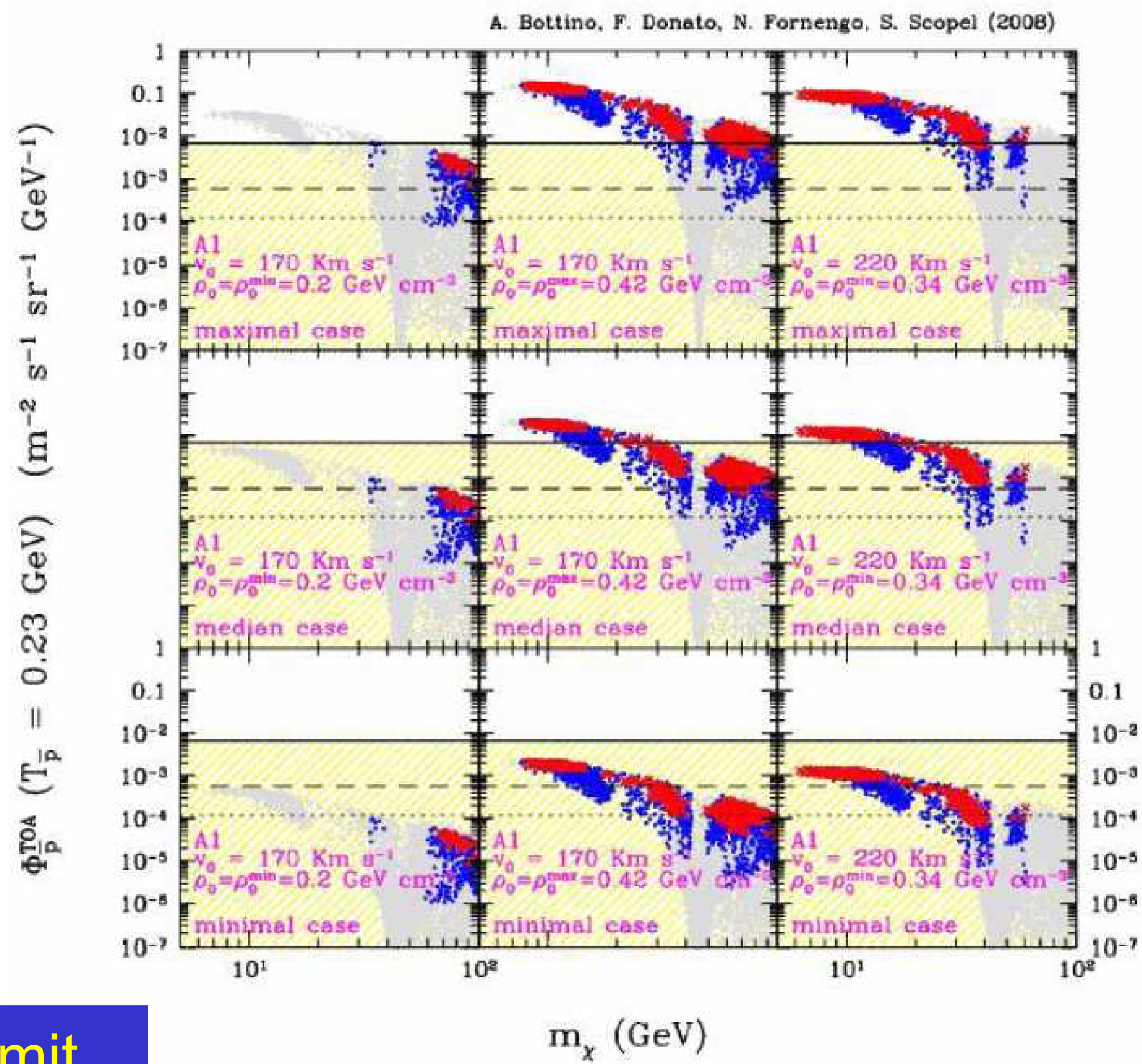
(Evan's logarithmic model (A1), R_c=5 kpc)

$$\rho(r) = \frac{v_0^2}{4\pi G}\frac{3R_c^2 + r^2}{(R_c^2 + r^2)^2}$$

maximal set for diffusion parameters

median set

minimal set



yellow band: BESS limit

Compatibility with antiprotons (work in progress)
Channeling included, hadronic matrix elements in allowed range

(Evan's logarithmic model (A1), R_c=5 kpc)

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maximal set for diffusion parameters

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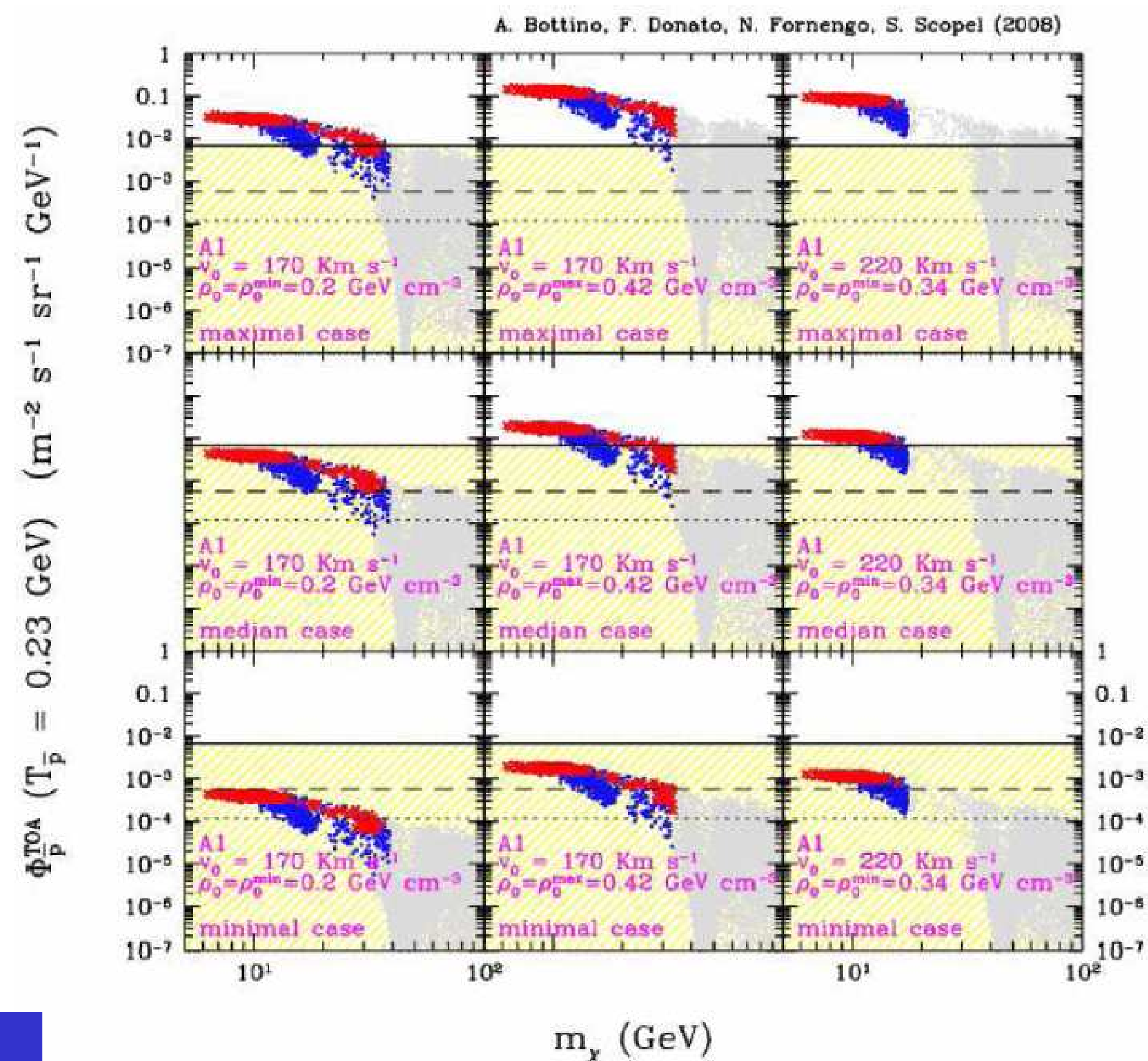


yellow band: BESS limit

N.B. :

- including channeling the fit of the experimental data of annual modulation with light neutralinos implies lower values of ρ
- the antiproton flux depends on the square of ρ^2
- present measurements of galactic antiprotons constrain higher range of ρ

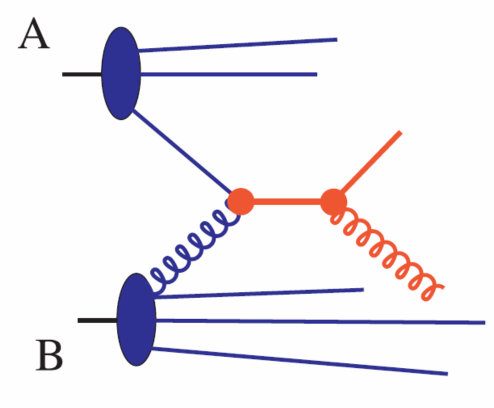
bottom line: the DAMA/Libra region with the inclusion of the channeling effect is more compatible with the constraints coming from indirect searches
however, large hadronic uncertainties
DAMA/Libra antideuterum analysis in progress

Light neutralinos @ accelerators?

Tevatron, Fermilab

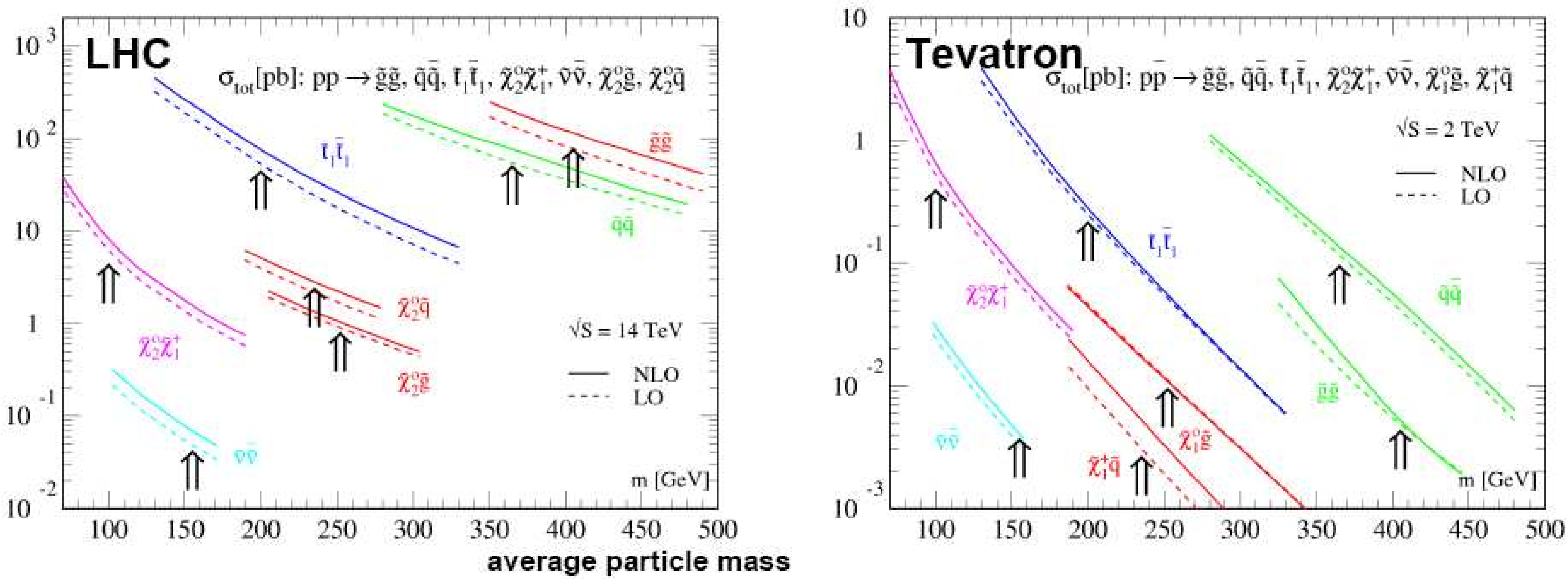
LHC, CERN

Production of susy particles @ LHC & Tevatron



$$pp, p\bar{p} \rightarrow \tilde{q}\tilde{q}, \tilde{q}\tilde{q}^*, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$$

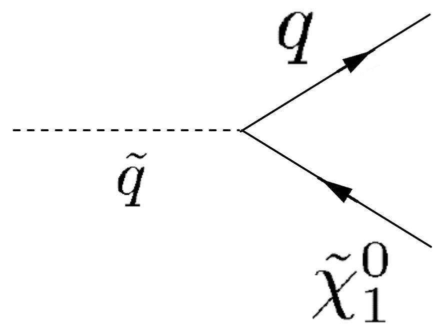
- Cross sections calculated to NLO, typically in pb range at LHC
  - Masses depend on how SUSY is broken, but otherwise, cross section is model-independent
- Production cross section at LHC increases dramatically relative to Tevatron, especially for squark/gluino



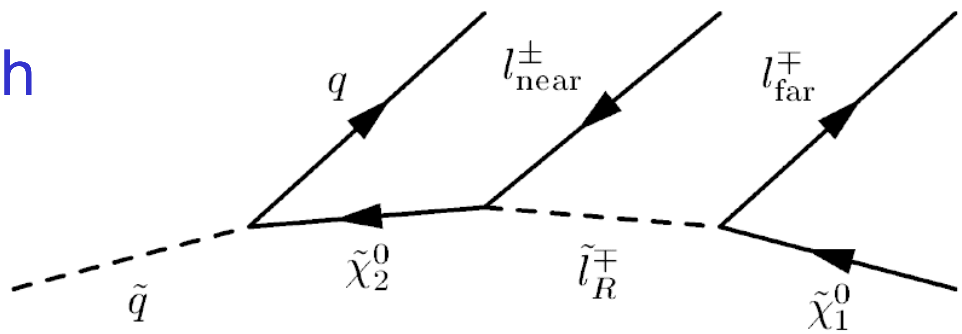
[Prospino]

The fate of a squark…

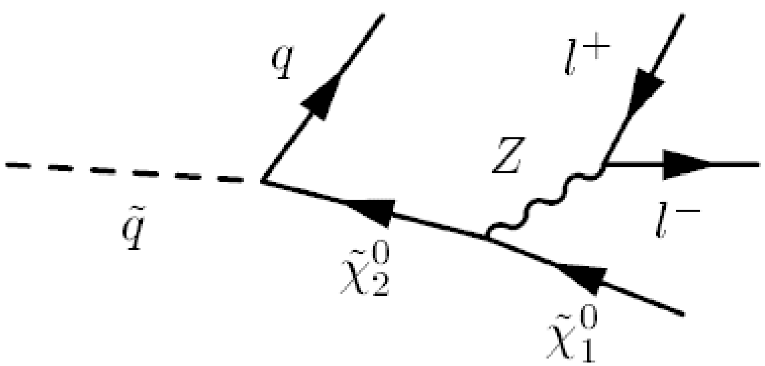
direct decay to a neutralino:
(early discovery channel, easy to see if kinematically accessible
(acoplanar jets+missing energy)

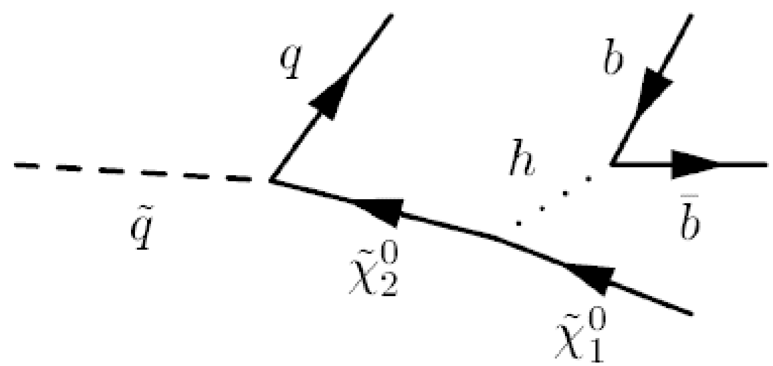


"sequential" chain through sleptons:

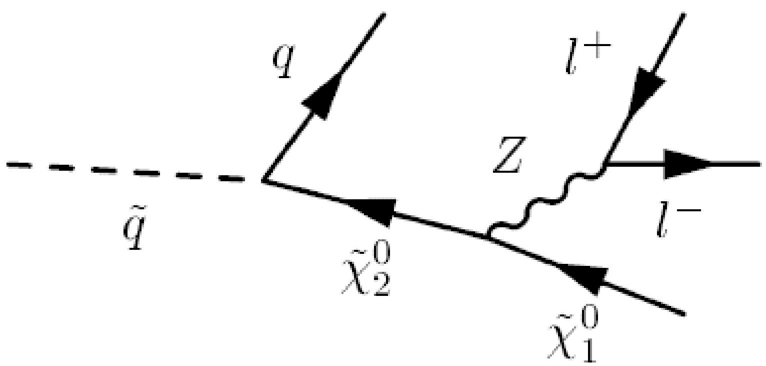


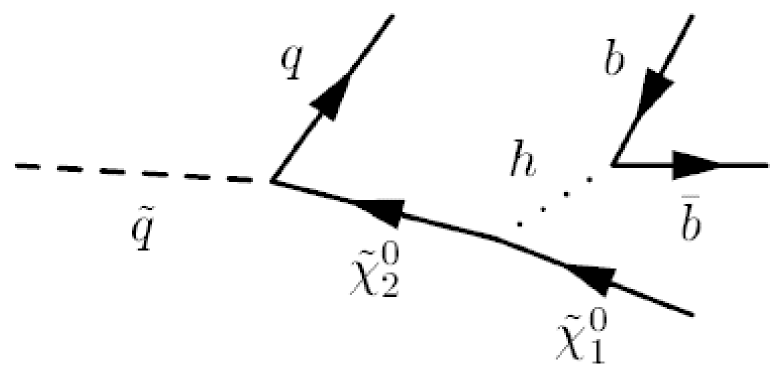
"branched" chain through gauge and Higgs bosons:





Selecting benchmarks for branched chains within scenarios A and B

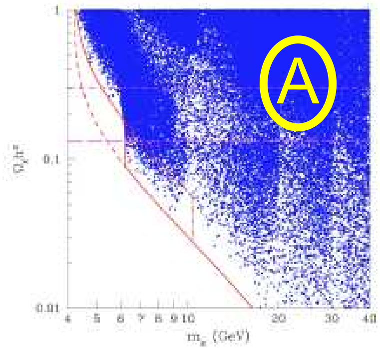




N.B.:

- M_2 (Wino soft mass) is the only parameter in the neutralino mass matrix which is not constrained by the relic abundance → free parameter, results plotted as a function of M_2
- our scenarios do not constrain SQCD parameters (m_{squark}, m_{gluino}) either
- squark production cross sections at LHC depend only on SQCD parameters (m_{squark}, m_{gluino}) → Sort of complementarity between LHC and Cosmology

In this analysis we fix: m_{squark} = 1 TeV, m_{gluino} = 2 TeV



Scenario A

- M_1<10 GeV
- m_A~90 GeV (annihilation cross section dominated by A exchange)
- tan(β)~ 30-45
- |μ| small to enhance the higgsino fraction of the lightest neutralino (a_3/a_1~0.4 → |μ|~100-200 GeV)
- other parameters (including $M_{slepton}$) not fixed a priori

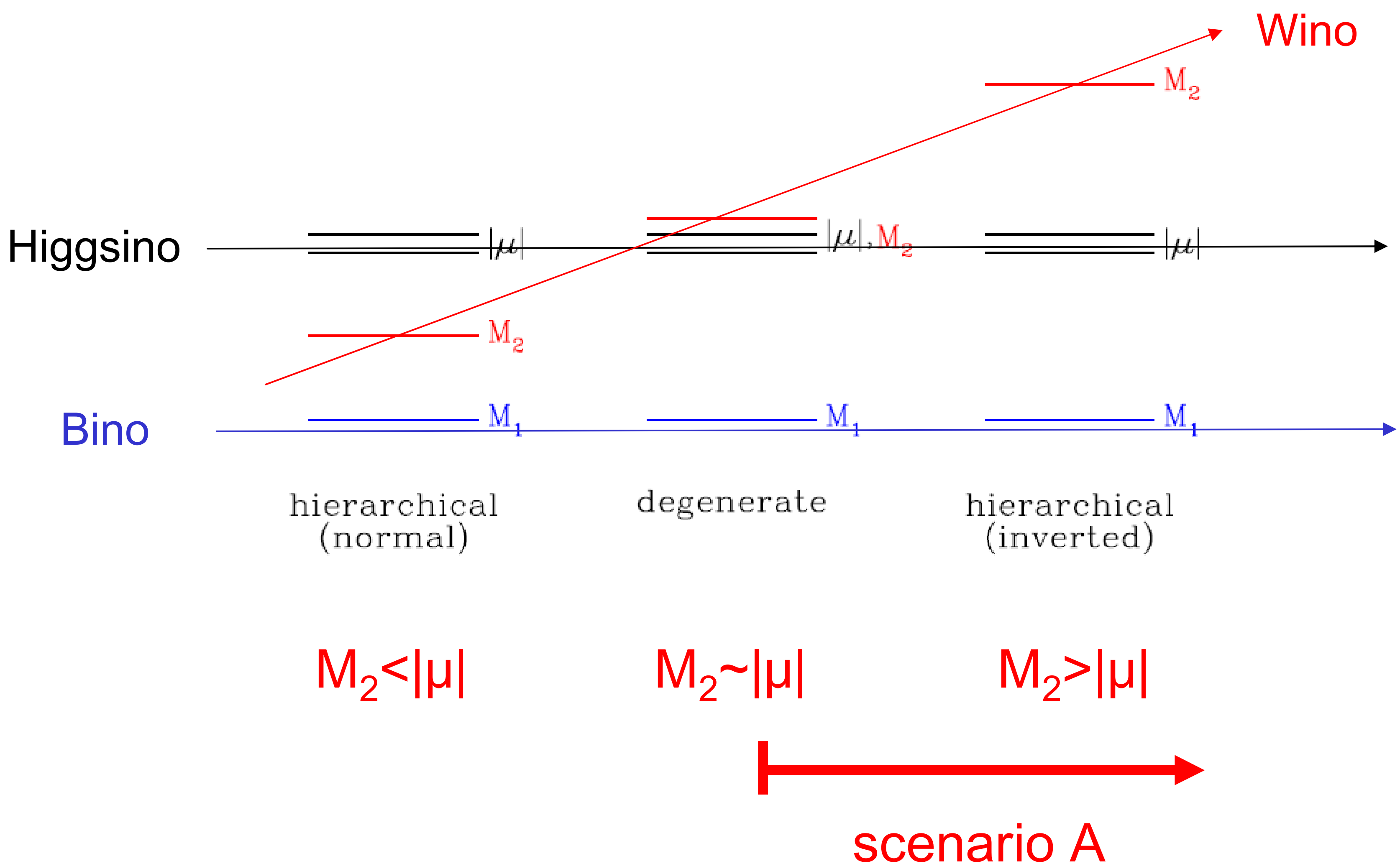
on the other hand, the sequential chain is sensitive to the hierarchy between $M_{slepton}$ and |μ|, since if |μ| < $M_{slepton}$ the decay $\chi_{2,3} \rightarrow l\,\tilde{l}$ is not allowed and only $\chi_4 \rightarrow l\,\tilde{l}$ is possible. This suggest to introduce the following two benchmarks:

$$\mathcal{A}\text{–seq1}: \ \ \mu = 110 \text{ GeV} \ \ m_{\tilde{l}} = 150, 300, 500, 700 \text{ GeV}$$ |μ| < $M_{slepton}$

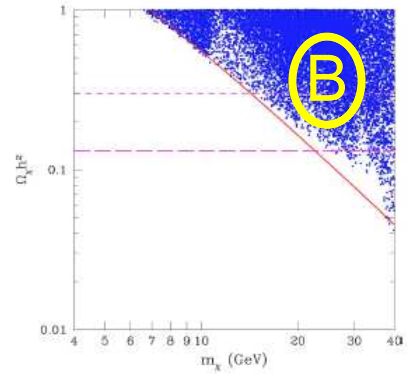
$$\mathcal{A}\text{–seq2}: \ \ \mu = 150 \text{ GeV} \ \ m_{\tilde{l}} = 120 \text{ GeV},$$ |μ| > $M_{slepton}$

N.B. typically |μ|<M_2, so $\chi_{2,3}$ always higgsinos and χ_4 always Wino

Depending on M_2, 3 asymptotic spectroscopic schemes for neutralino states:



Scenario B



- M_1~15-18 GeV
- m_{stau}~90 GeV (annihilation dominated by stau exchange)
- large stau mixing
- |μ| large, |μ|>500 GeV
- tan(β) < 10
- m_A > 200 GeV

Let's introduce the following benchmark:

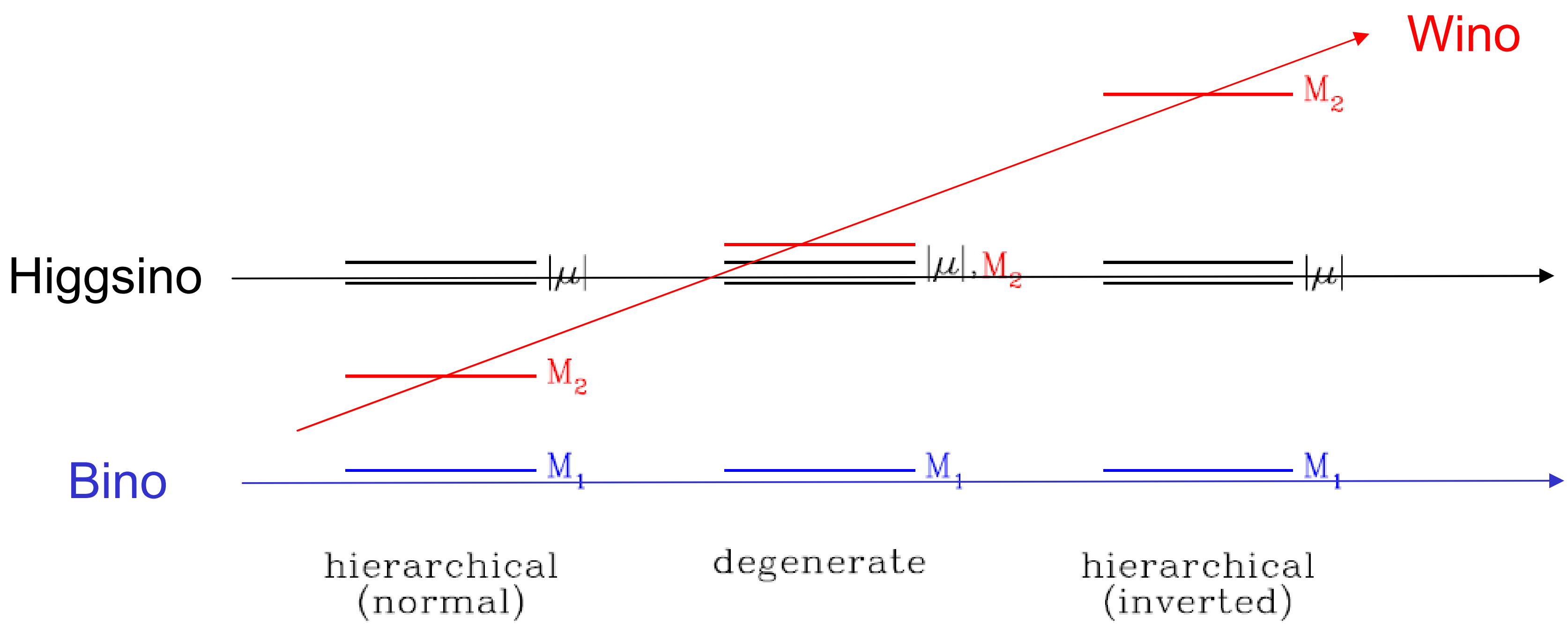
$$\mathcal{B}\text{−seq} \; : \; M_1 = 25 \text{ GeV} \quad \mu = -500 \text{ GeV} \quad \tan\beta = 10$$
$$m_{\tilde{\tau}} = 87 \text{ GeV} \;\; (m_{\tilde{l}} = 120 \text{ GeV}) \;\; A = 0.$$

(for definiteness, m_A=1 TeV)

more variety in neutralino compositions, now also M_2<|μ| is possible

→ χ_3 always higgsino, χ_2 and χ_4 flip compositions

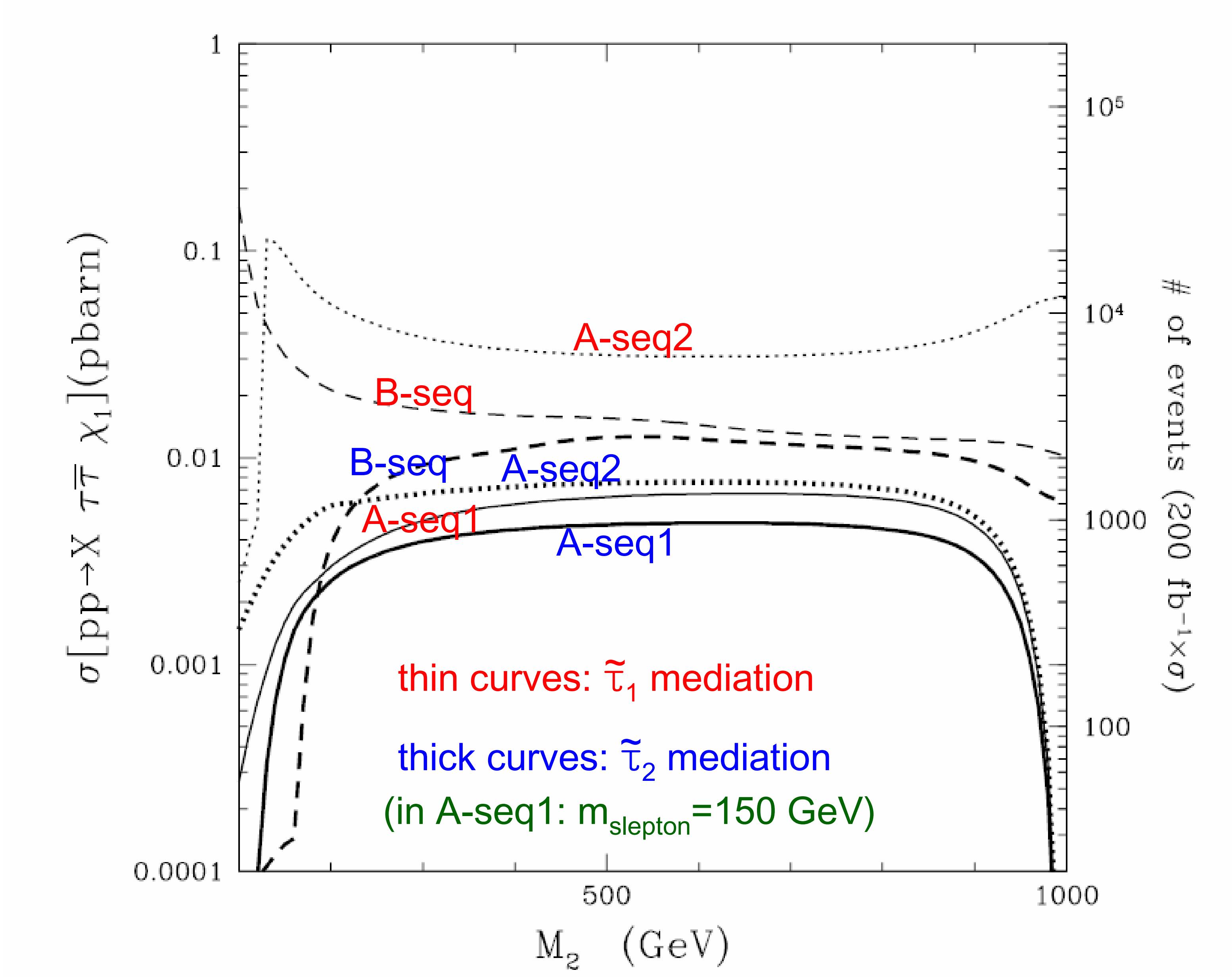
Depending on M_2, 3 asymptotic spectroscopic schemes for neutralino states:



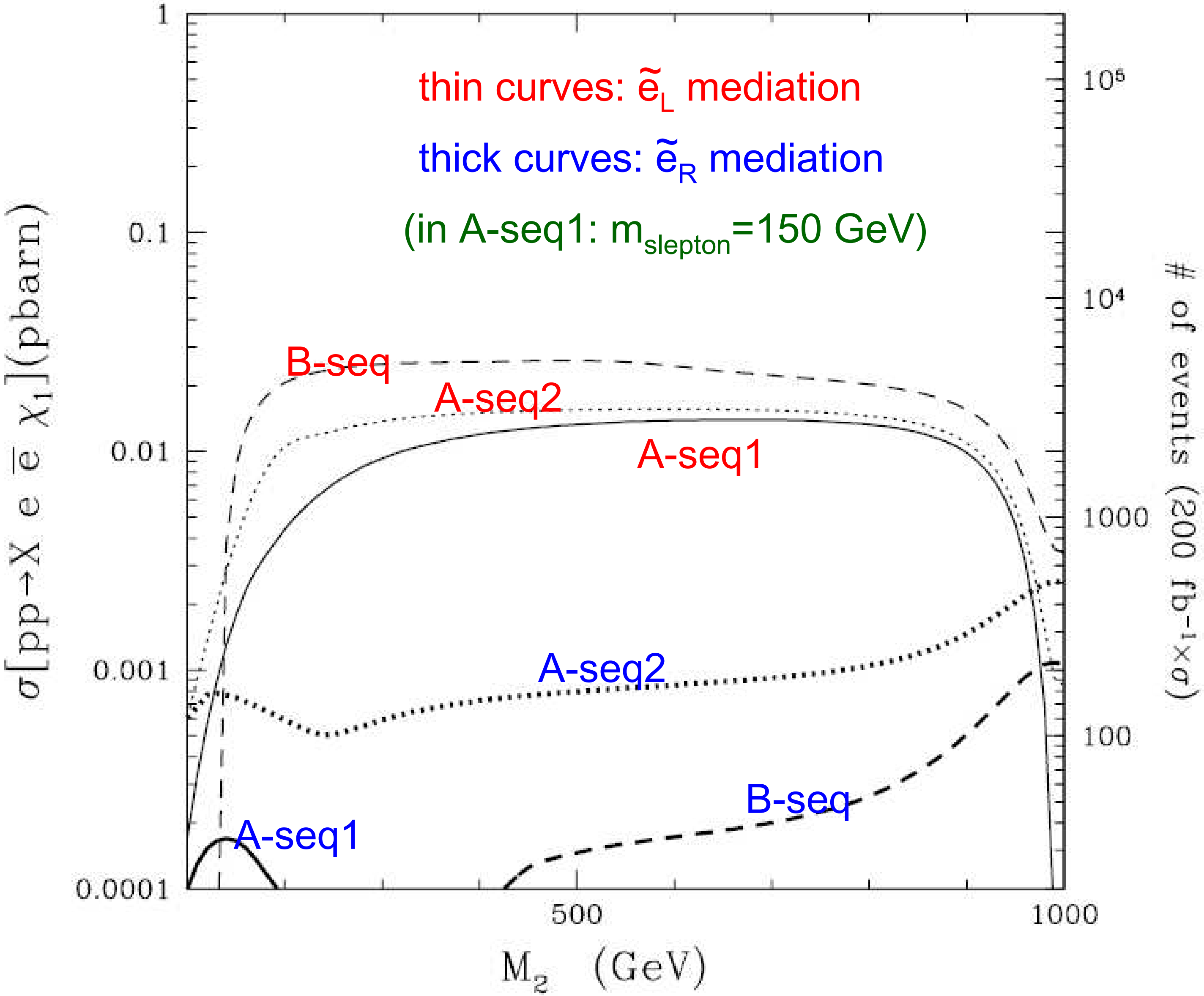
$M_2<|\mu|$ $M_2\sim|\mu|$ $M_2>|\mu|$

scenario B

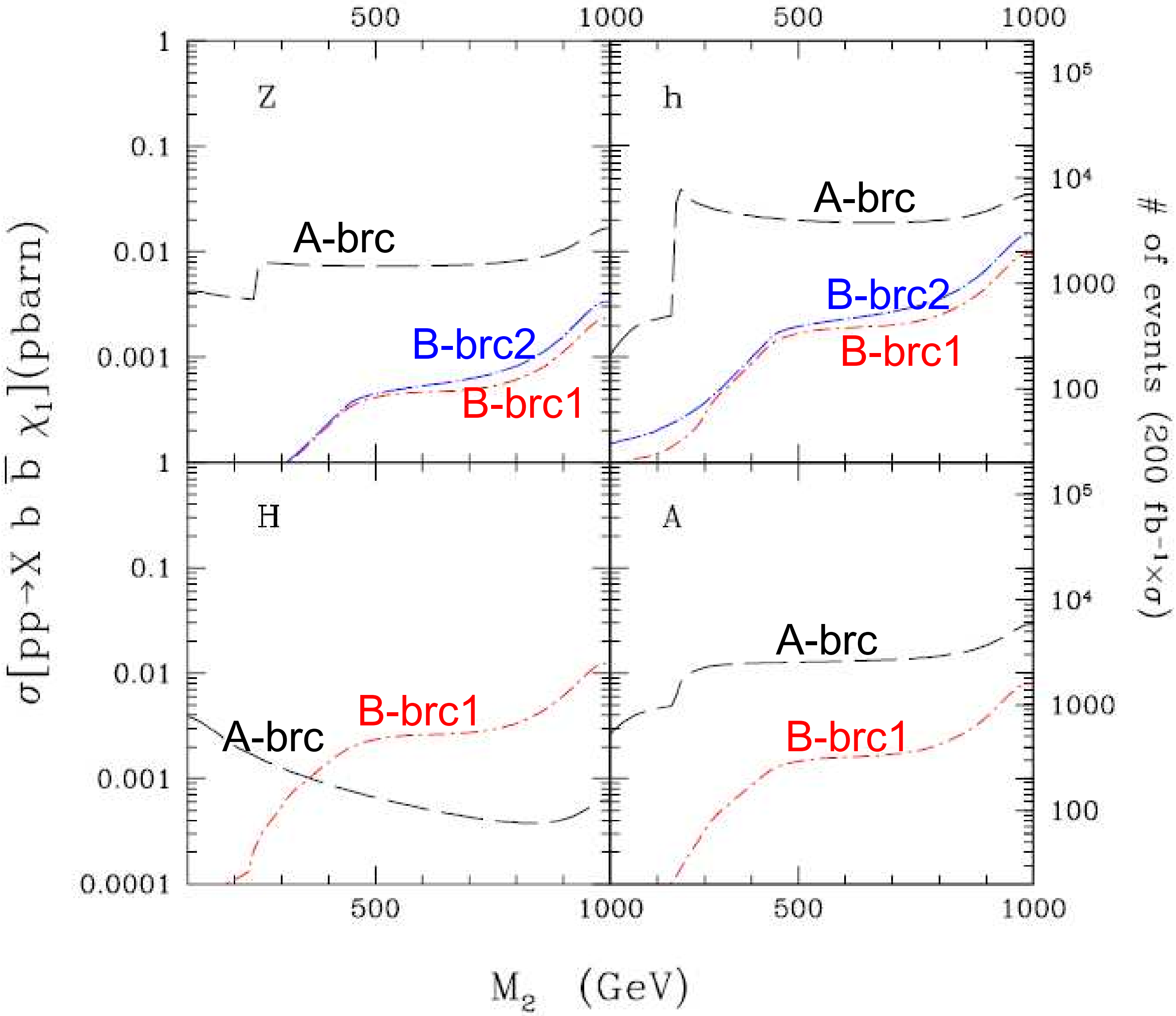
pp→ X $\tau\bar{\tau}\chi_1$: expected number of events for sequential chains



pp→ $Xe\bar{e}\chi_1$: expected number of events for sequential chains



pp→ X$b\bar{b}\chi_1$: expected number of events for branched chains



Light relic neutralino benchmarks involve
low-scale susy, just above the reach of LEP2

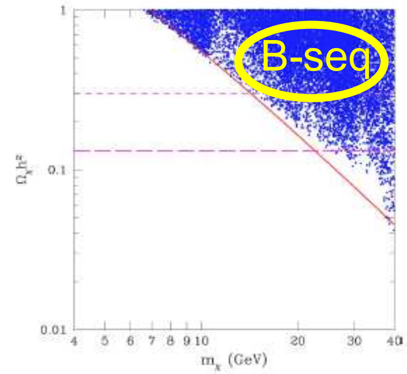
so, what about...

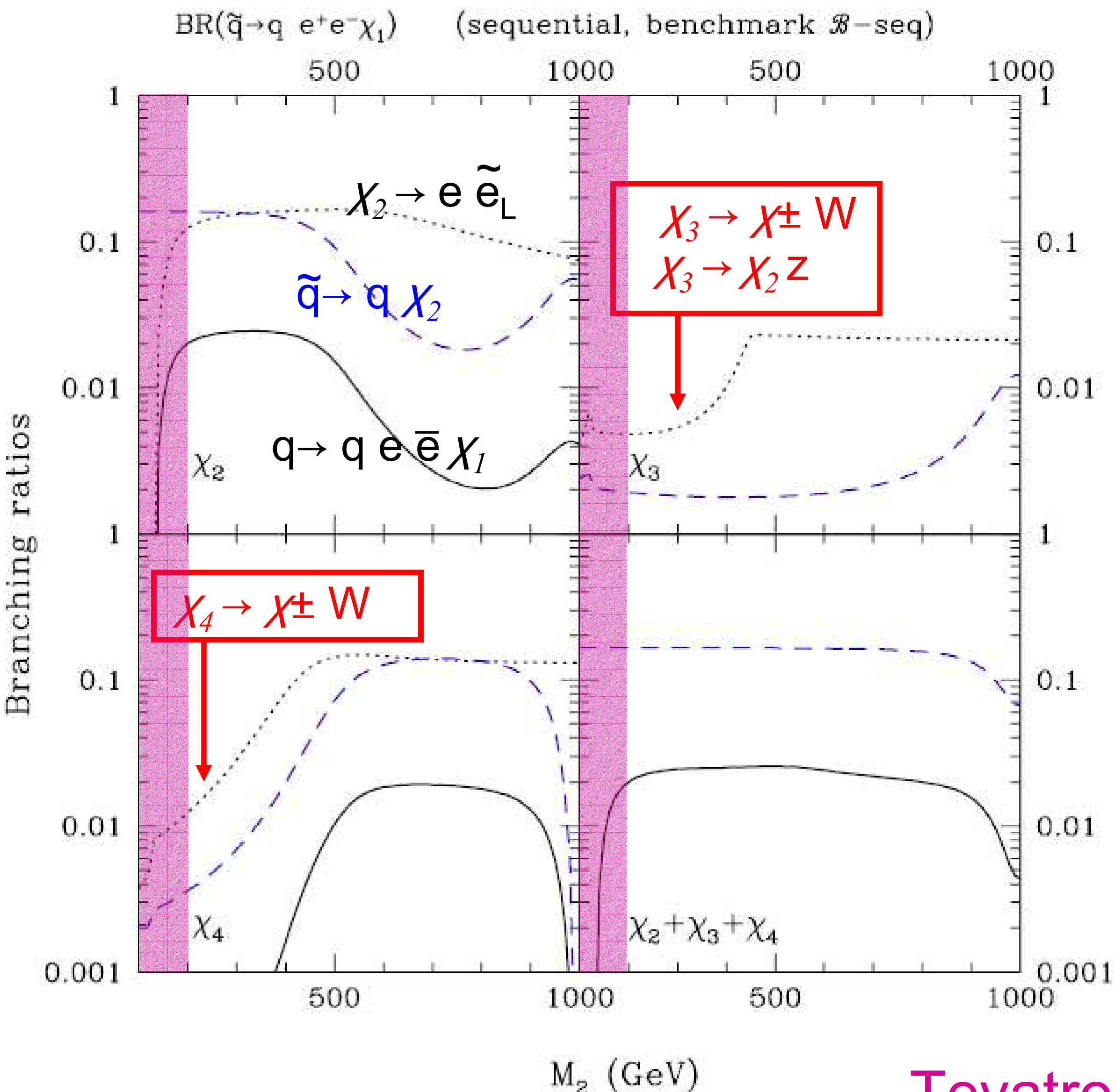
Run II @ Tevatron (1.96 TeV)

cdfii_logo

?

e^+e^- final state





- $\chi_{2,4}$ exchange role
- largest signal from whatever is gaugino

Tevatron, 8 fb^{-1}

Conclusions:

- neutralinos can be light
- they can explain the new DAMA/Libra result (preliminary analysis)
- DAMA/Libra favors m_χ ~(7-30) and low values of v_0 and ρ_0 including channeling. When channeling is not included m_χ ~(50-100) marginally involved and low values of v_0 and ρ_0 disfavored
- narrow compatibility with upper bounds from other experiments taken at face value for $m_\chi \lesssim 10$ GeV
- uncertainties from hadronic matrix elements in the calculation of neutralino-nucleon cross section
- uncertainties from galactic halo models
- for most of the light neutralinos that can explain DAMA/Libra a detectable signal both for antiprotons and for antideuterons is expected in future experiments (work in progress)

Conclusions (cntd):

Two light neutralino benchmarks singled up for LHC (don't think only abour SUGRA!):

Scenario A (m_χ~10 GeV): small mA, small |μ|, large tanβ

•Scenario B (m_χ~20 GeV): large mA, small $m_{slepton}$, moderate tanβ, large |μ|

•we have analyzed the discovery potential of each Scenario at the LHC focusing on chains generated by squark decays, assuming Msquarks=1 TeV and Mgluino=2 TeV – typically easy to detect (just beyond LEP sensitivity)

•the KIMS experiment in Korea is being taking data right now with ~100 kg of CsI – model independent test of modulation effect?