Event Rates for Direct Dark Matter Detection

Exploiting the signatures of the WIMP interaction

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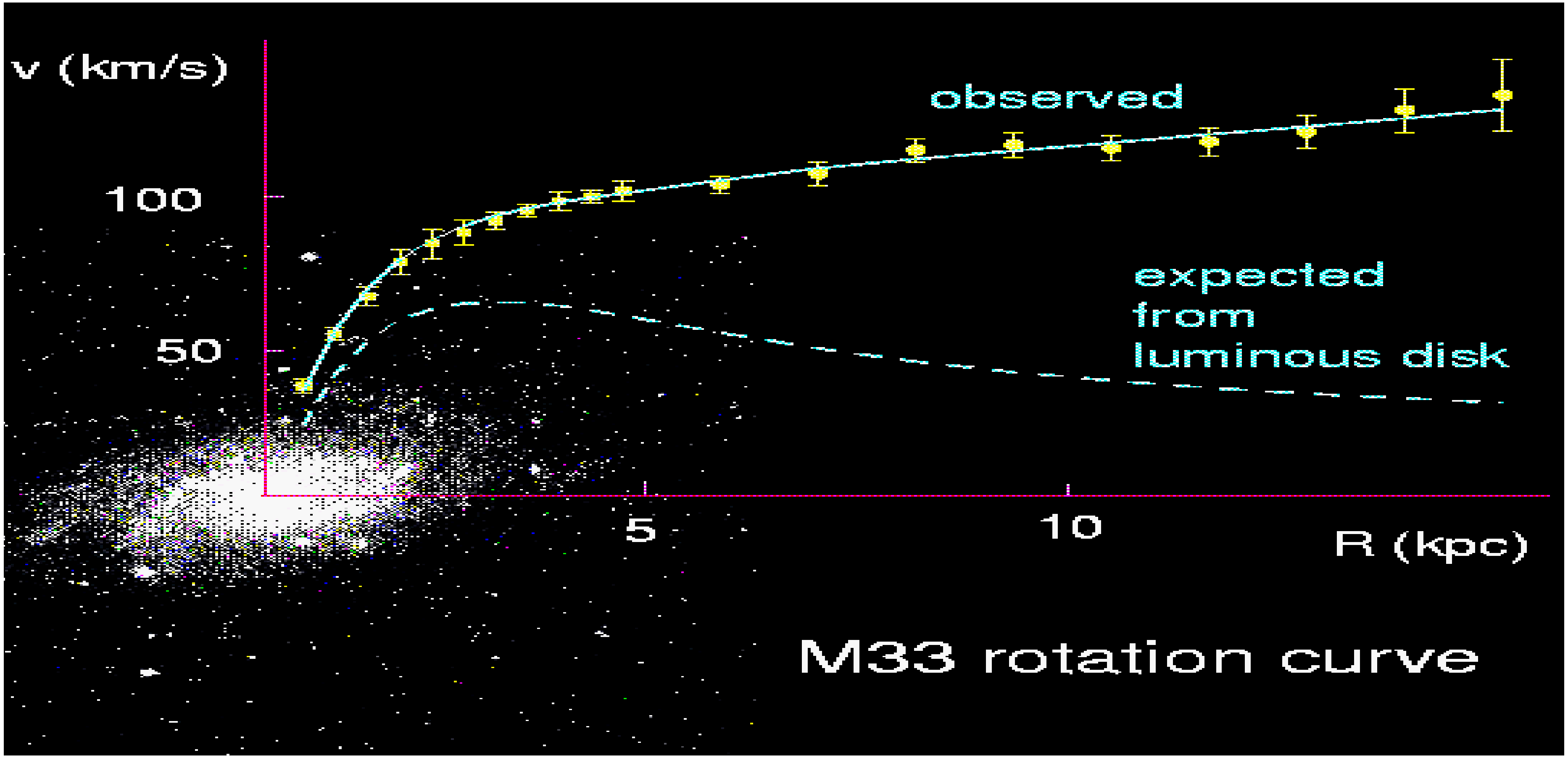
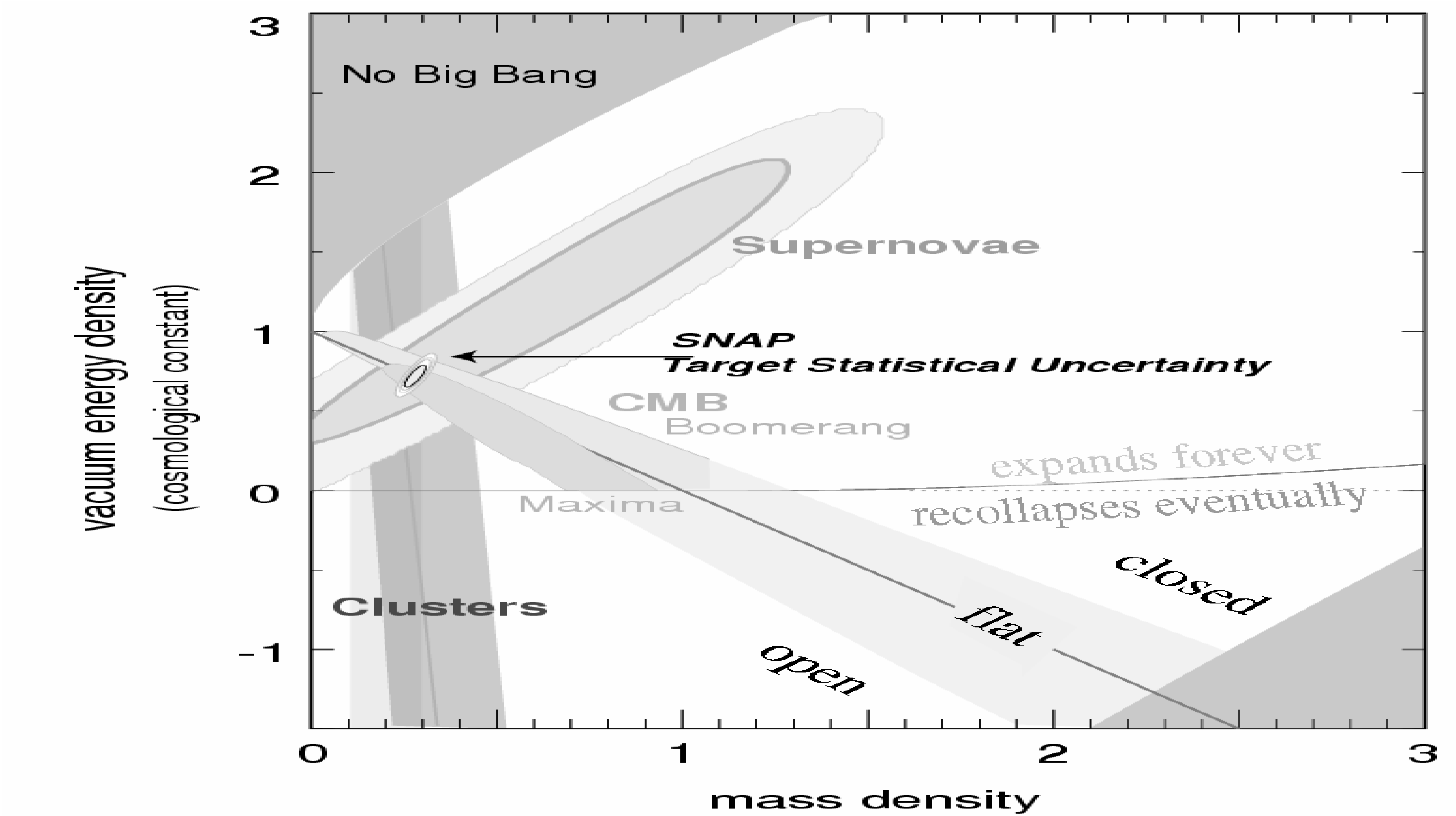
EVIDENCE FOR THE EXISTENCE OF DARK MATTER

- Gravitational effects around galaxies
- Cosmological Observations

I. The Rotational Velocities (u^2 does not fall as 1/r outside the galaxies)



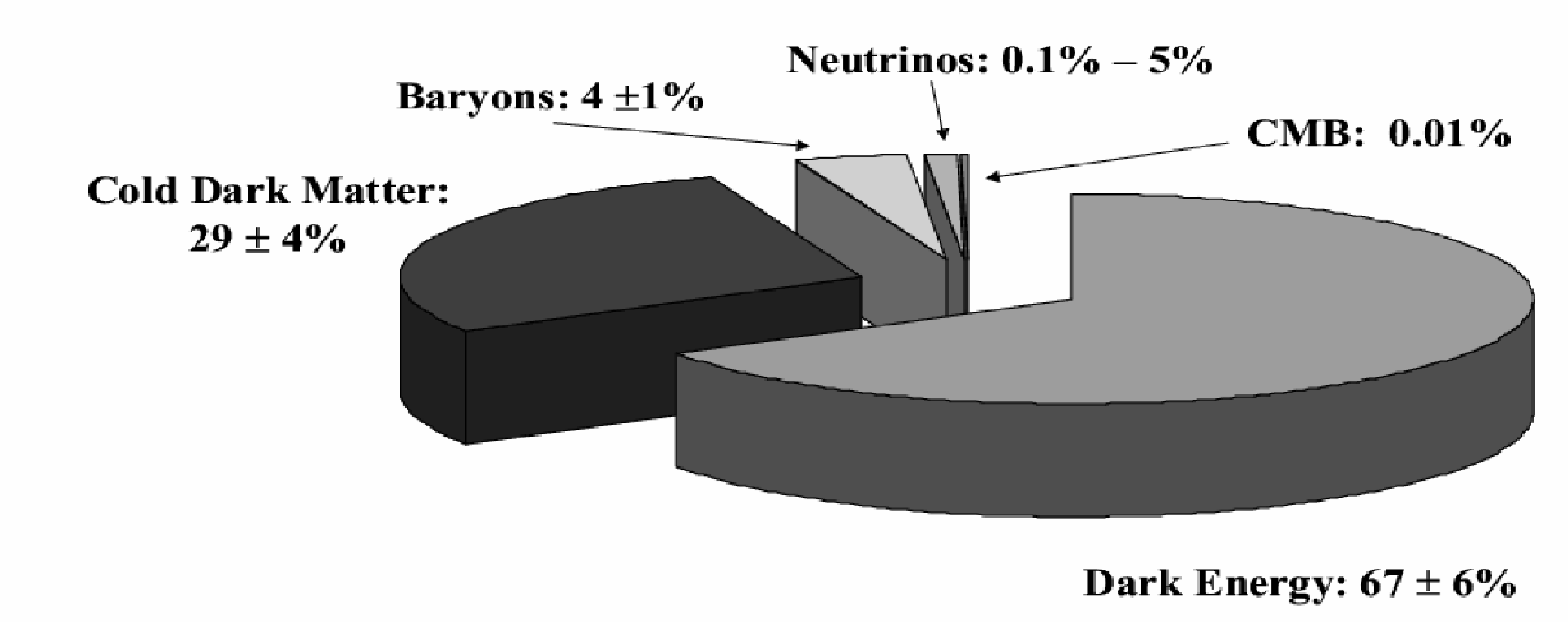
Cosmological Constraints in the (Ω,Λ) Plane



Slicing the Pie of the Cosmos

WMAP3: $\Omega_{CDM} = 0.24 \pm 0.02$, $\Omega_\Lambda = 0.72 \pm 0.04$, $\Omega_b = 0.042 \pm 0.003$

WMAP1 yielded:



What is the nature of dark matter?

It is not known. However:

- It possesses gravitational interactions (from the rotation curves)
- No other long range interaction is allowed. Otherwise it would have formed “atoms” and , hence, stars etc. So

  It is electrically neutral
- It does not interact strongly (if it did, it should have already been detected)
- It may (hopefully) posses some very weak interaction

  This will depend on the assumed theory
- Such an interaction may be exploited for its direct detection
- The smallness of the strength of such an interaction and its low energy makes its direct detection extremely difficult.

DARK MATTER CANDIDATES

- The axion: 10^{-6} eV<m_a <10^{-3} eV
- The neutrino: It is not dominant. It is not cold, not CDM.
- Supersymmetric particles.

  Three possibilities:

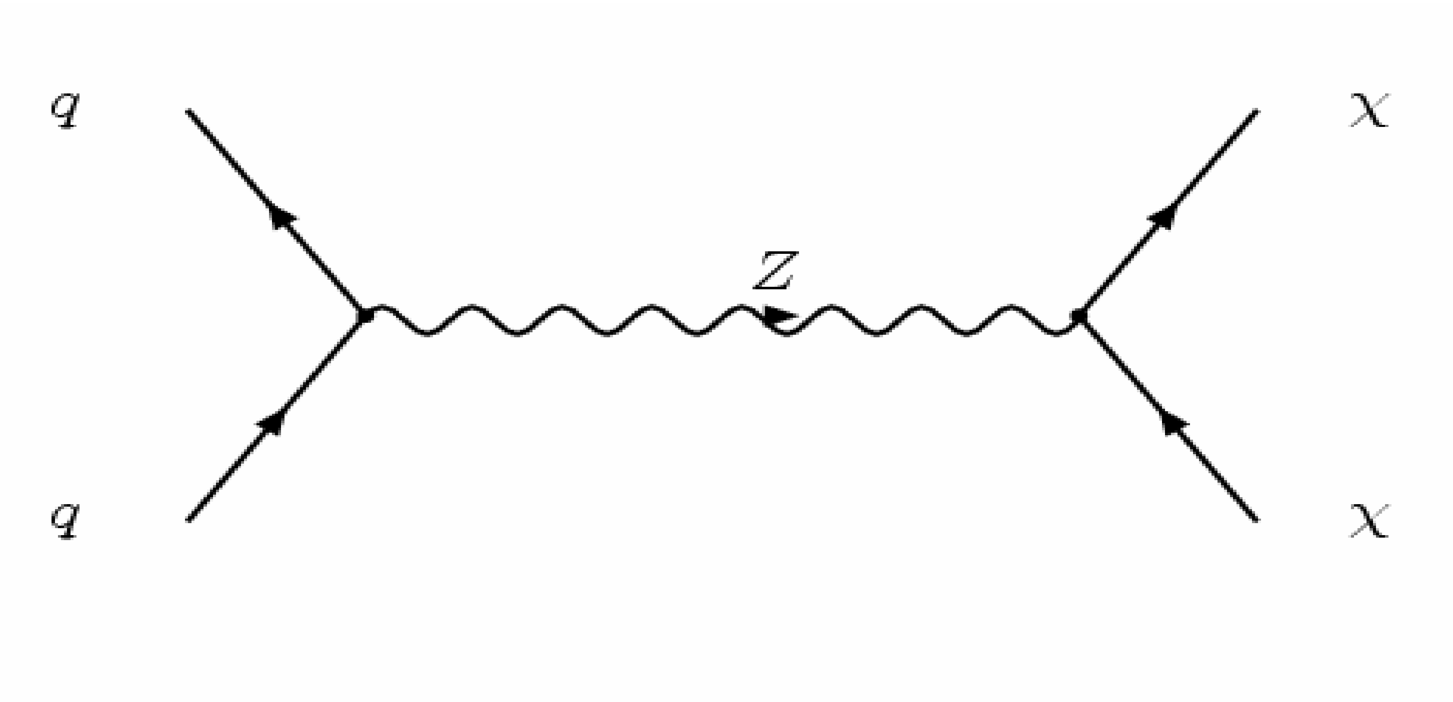
  i) s-νετρίνο: Excluded on the basis of results of underground experiments and accelerator experiments (LEP)

  ii) Gravitino: Not directly detectable

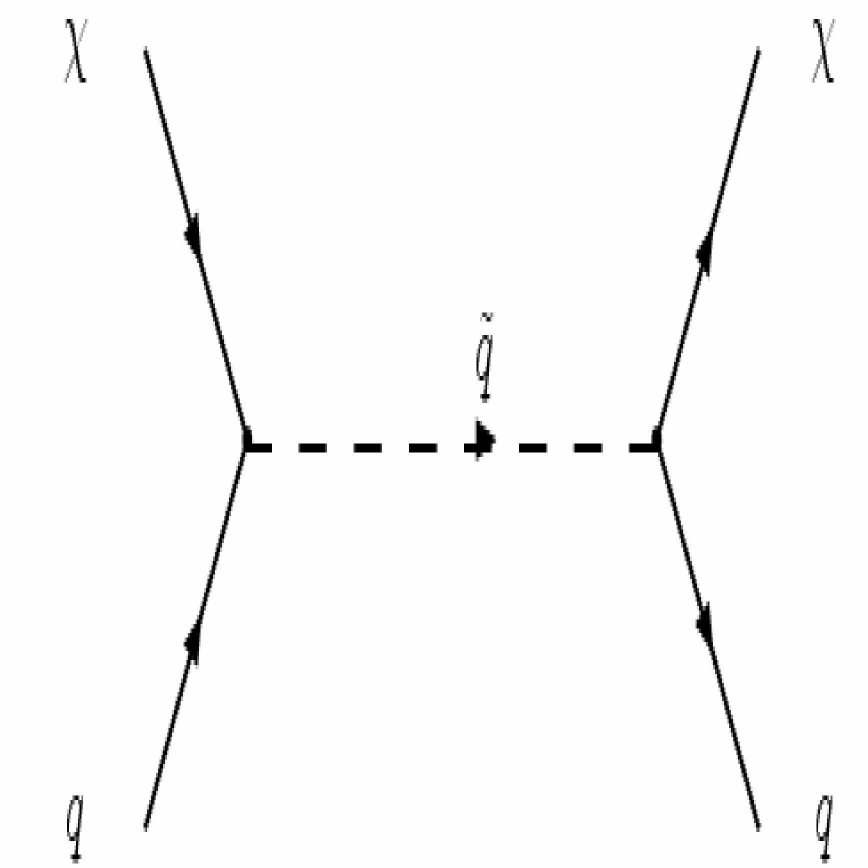
  iii) Axino: Not directly detectable

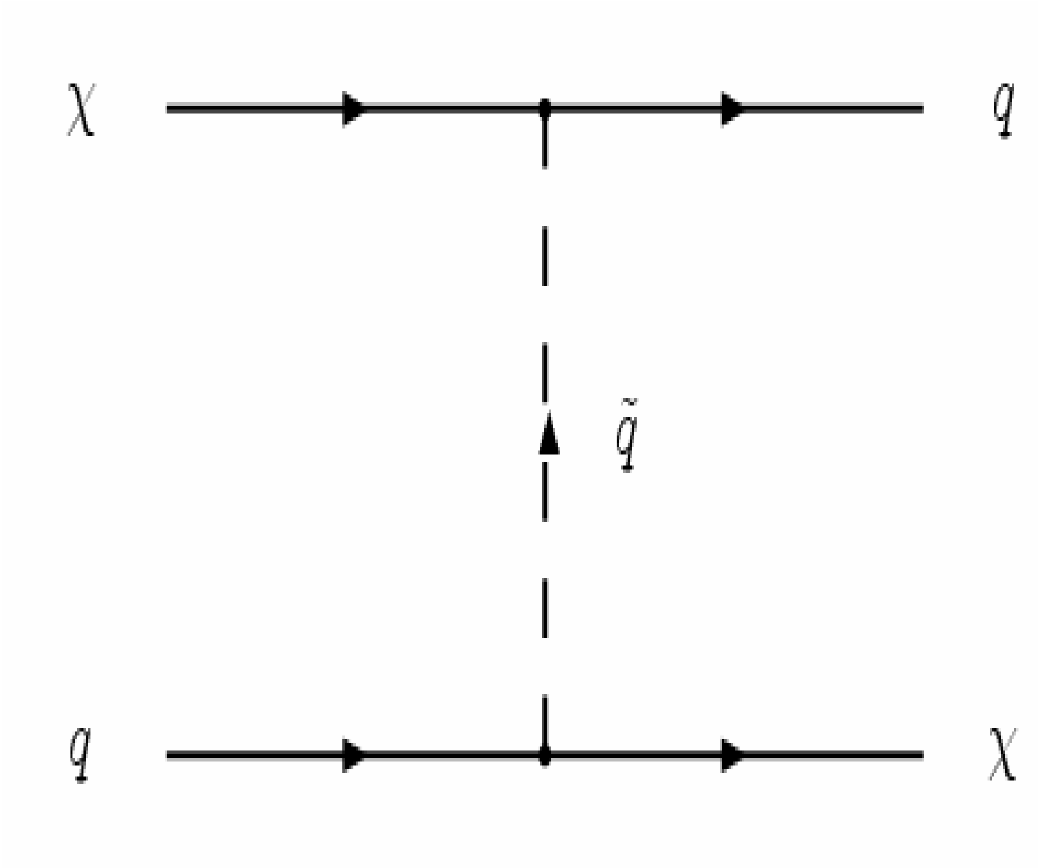
  iv) A Majorana fermion, the neutralino or LSP (The lightest supersymmetric particle): A linear combination of the 2 neutral gauginos and the 2 neutral Higgsinos. MOST FAVORITE CANDIDATE!
- Particles from theories in extra dimensions (Kaluza-Klein WIMPs)

A1. SUSY MODELS: The neutralino (Z-exchange $\Leftrightarrow$ Axial current)

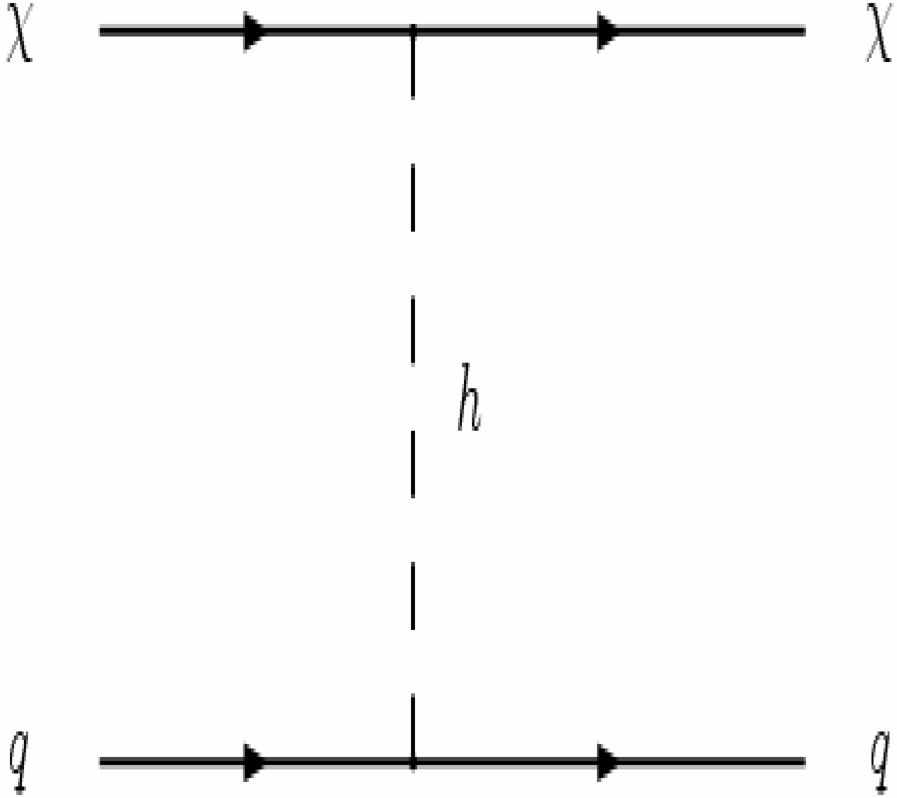


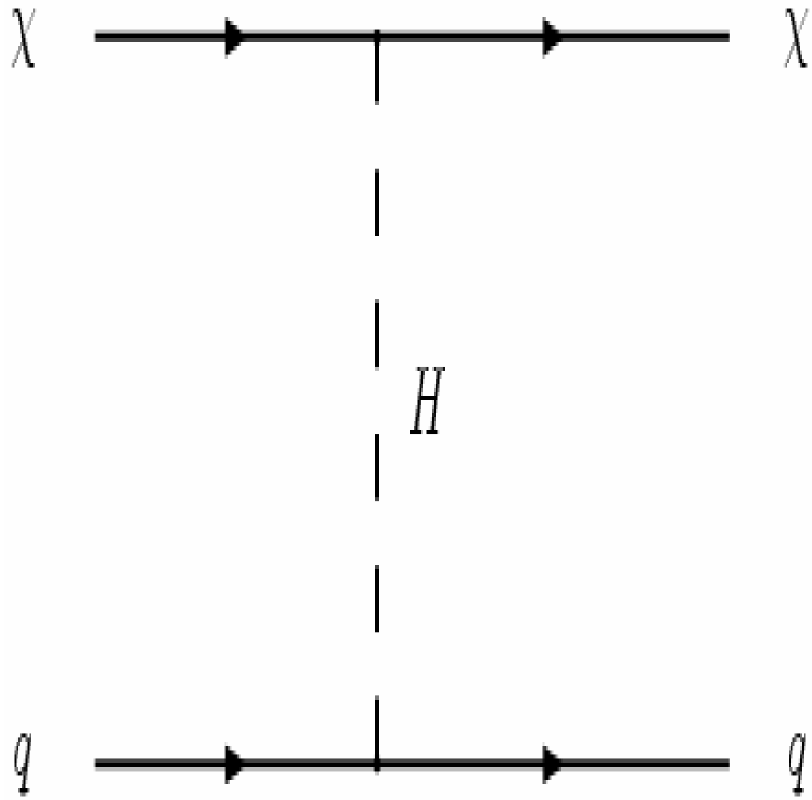
A2. SUSY MODELS: The neutralino (squark-exchange ⇔Axial +scalar)





A3. SUSY MODELS: The neutralino (Higgs-exchange⇔Scalar ⇔coherent cross section)

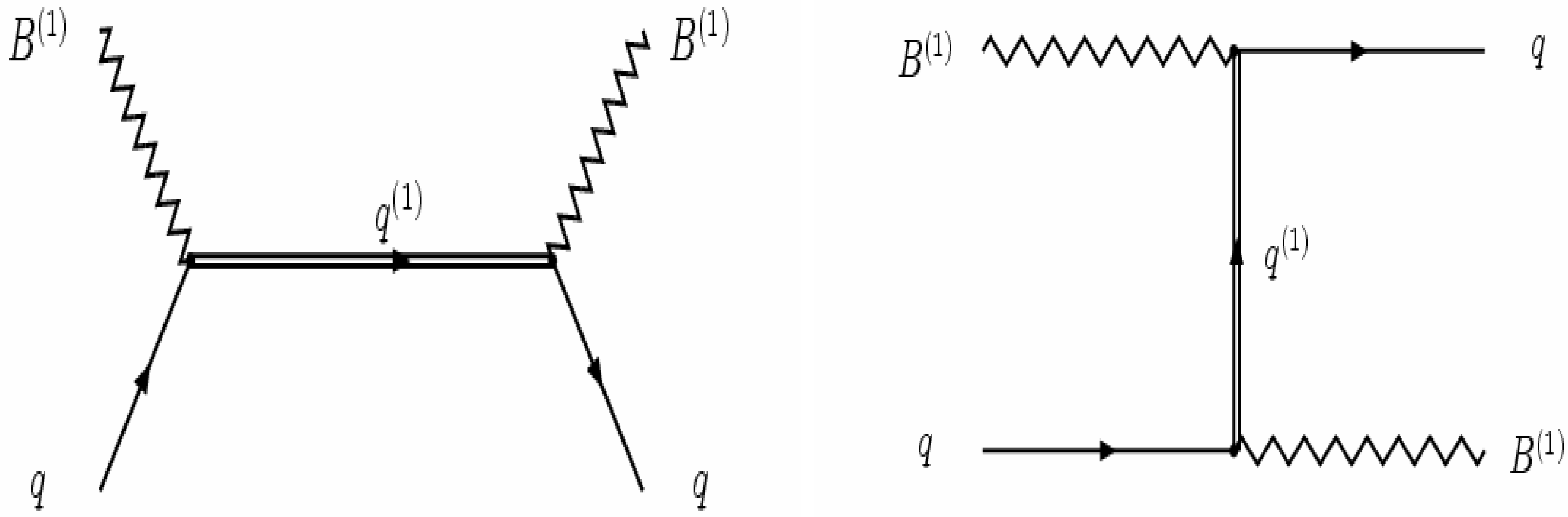




B. Universal Extra Dimension Theories (e.g. Servant et al)

- Kaluza-Klein Theories: A tower of new particles
- Postulate a discreet symmetry: K-K parity
- The even modes (ordinary particles) have K-K parity +1
- The odd modes (exotic) have K-K parity -1
- The lightest odd mode is absolutely stable
- The interactions of the new particles are the same with those of SM
- Essentially only the particle's mass is unknown parameter

B1 Kaluza-Klein theories
The lightest particle is the brother of the B boson, the $B^{(1)}$.
K-K quark exchange.



B1 K-K theories WIMP: $B^{(1)}$. K-K $q^{(1)}$ exchange. (with Moustakides and Oikonomou)

$$\mathcal{M}_{coh} = i4\sqrt{2}G_F m_W \tan^2\theta_W (\epsilon^{*\prime}.\epsilon)\mathcal{A}_{coh}$$

$$\mathcal{A}_{coh} = N\left[\left(\frac{11}{18} + \frac{2}{3}\tau_3\right)\frac{1}{3}\frac{m_p m_W}{(m_{B^{(1)}})^2} f_1(\Delta)\right] N + N\left[\frac{1}{3} + \frac{1}{3}\tau_3)\frac{m_W}{m_{B^{(1)}}} f_2(\Delta)\right] N \qquad (0.1)$$

The first term comes from L-L and R-R contributions

$$f_1(\Delta) = \frac{1+\Delta+\Delta^2/2}{\Delta^2(1+\Delta/2)^2}$$

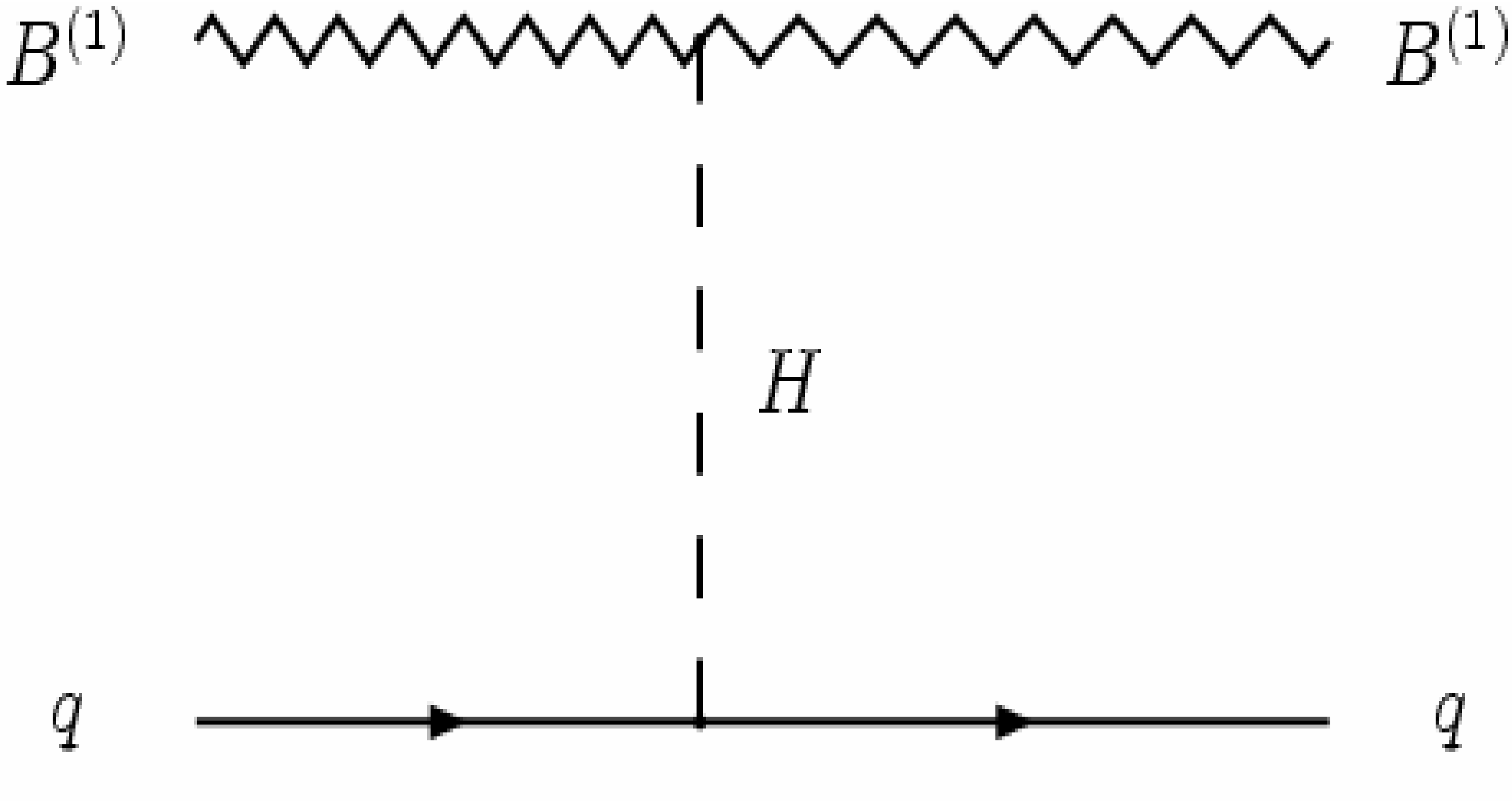
while the second comes from L-R and R-L contributions

$$f_2(\Delta) = \frac{1+\Delta}{\Delta(1+\Delta/2)}$$

with

$$\Delta = \frac{m_{q^{(1)}}}{m_{B^{(1)}}} - 1$$

B1. Kaluza-Klein theories (cont.)
The lightest particle is the $B^{(1)}$.
Higgs-Exchange.



B1. Kaluza-Klein theories (cont.) WIMP is the $B^{(1)}$. Higgs-Exchange.

$$\mathcal{M}_N(h) = -i\ 4\sqrt{2}G_F m_W^2 \tan^2\theta_W$$
$$\left[\frac{1}{4}\frac{m_p}{m_h^2}\left(-\epsilon^{*\prime}.\epsilon\right) \prec N|N \succ \sum_q f_q\right]$$

with "the quark content of the nucleon":

$$\prec N|m_q\ q\bar{q}|N \succ = f_q m_p$$

$$f_d = 0.041,\ f_u = 0.028,\ f_s = 0.400,$$

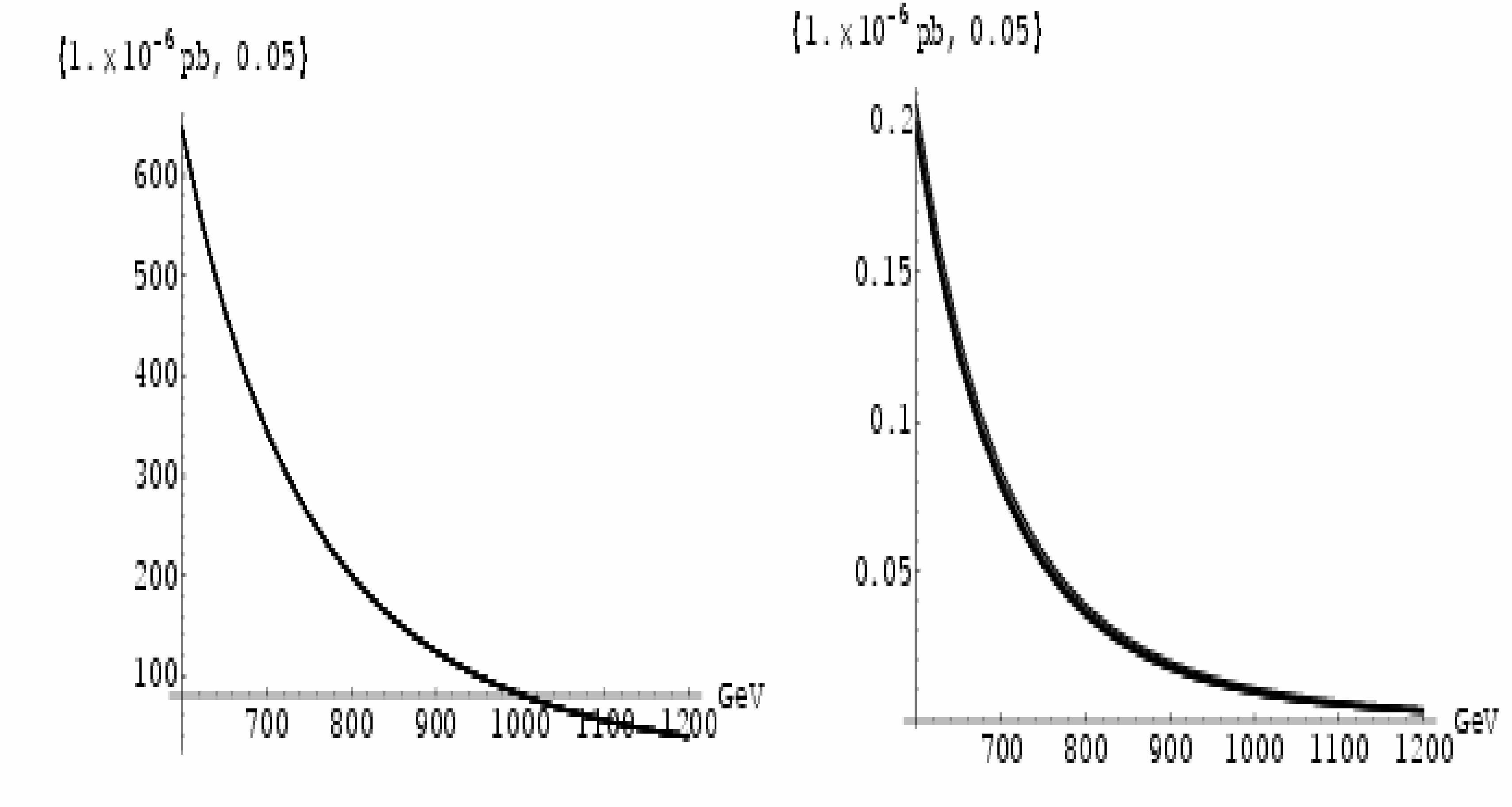
$$f_c = 0.051,\ f_b = 0.055,\ f_t = 0.095 \Rightarrow$$

$$\sum_q f_q = 0.67 \text{ optimistic choice}$$

B1. Kaluza-Klein theories (cont.)

WIMP is the $B^{(1)}$. Δ=0.05. m_h invisible

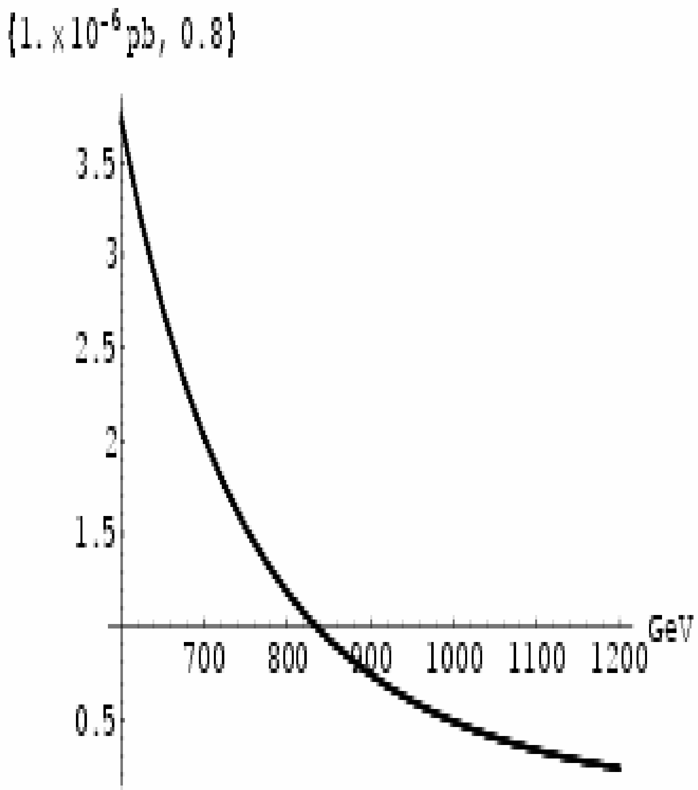
σ_p on the left, σ_n on the right.

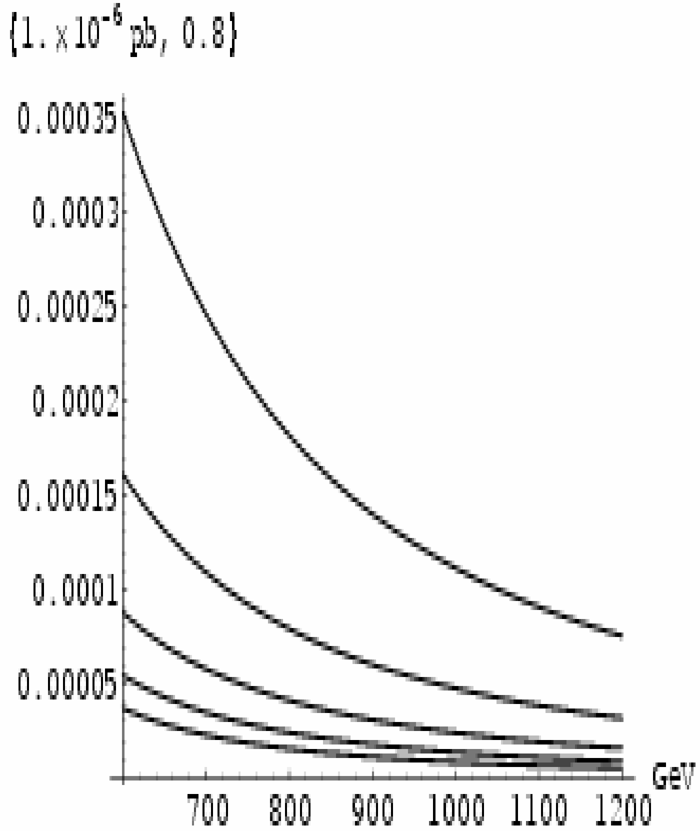


B1. Kaluza-Klein theories (cont.)

WIMP is the $B^{(1)}$. Δ=0.8 m_h 100-200 GeV

σ_p on the left, σ_n on the right.





B2 WIMP is the $\nu^{(1)}$. Z-Exchange Dominates.

- Majorana neutrino. Only spin. $\sigma_p = \sigma_n$

$$\sigma_N(spin) = \frac{1}{\pi}\frac{G_F^2}{8} m_p^2 3 g_A^2 = 8.0 \times 10^{-3} pb \qquad (0.4)$$

- Dirac neutrino. Spin $\sigma_p = \sigma_n$

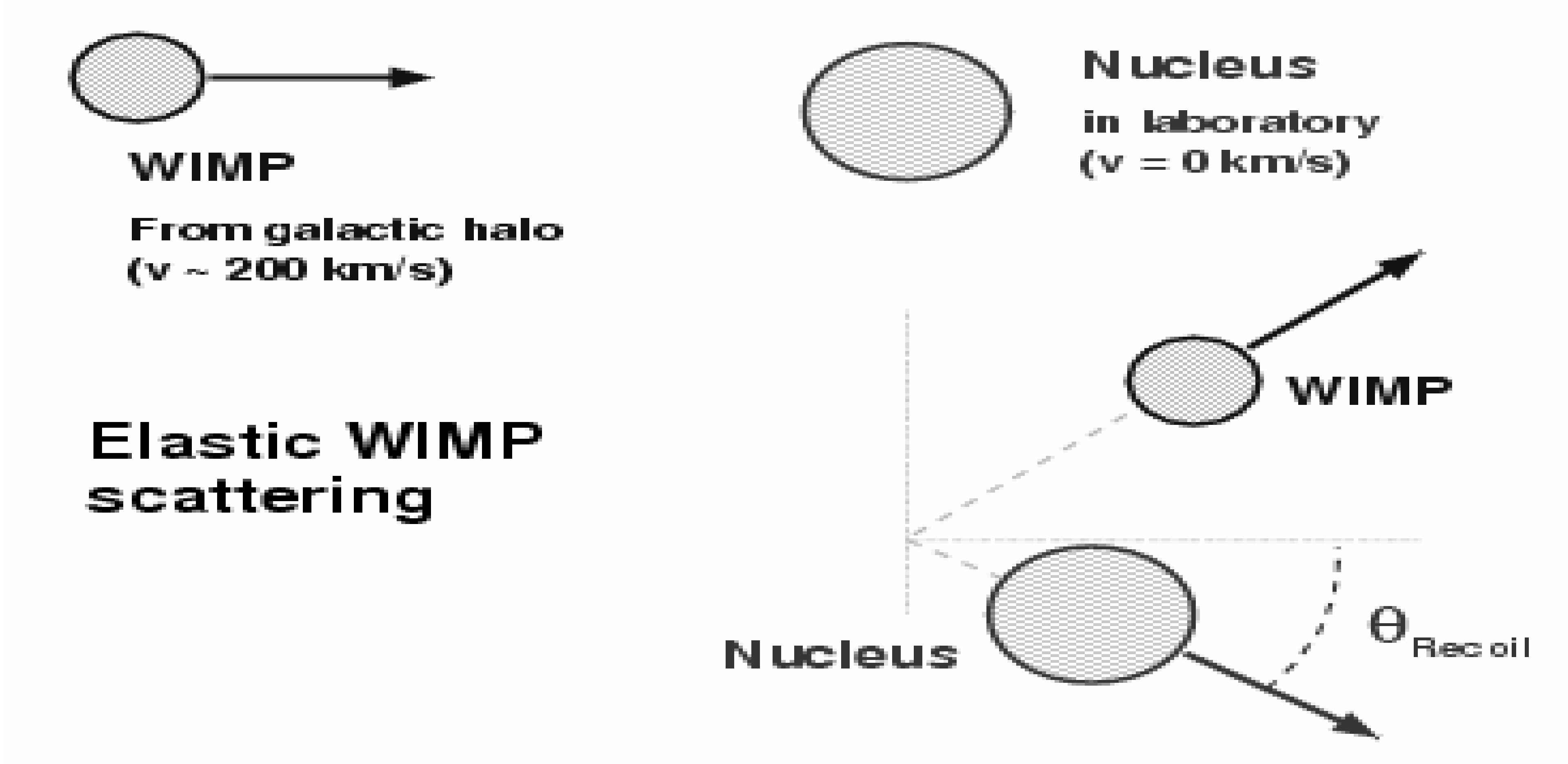
$$\sigma_p \simeq \sigma_p(spin) = \frac{1}{\pi}\frac{G_F^2}{8} m_p^2 \; 3 \; 2 \; g_A^2 = 1.6 \times 10^{-2} pb \qquad (0.5)$$

- Dirac neutrino. Coherent $\sigma_p \simeq 0$

$$\sigma_n(coh) = \frac{1}{\pi}\frac{G_F^2}{8} m_p^2 \; 2 \; = 3.5 \times 10^{-3} pb \qquad (0.6)$$

A Majorana neutrino is perhaps viable!

Nuclear Recoil after the LSP-nucleus collision
(Elastic for SUSY WIMPS)



Conversion of the energy of the recoiling nucleus into detectable form (light, heat, ionization etc.)

- The neutralino (LSP) is non relativistic.

$$\langle T_{\tilde{\chi}}^{0} \rangle = 50keV \frac{m_{\tilde{\chi}}^{0}}{100GeV}$$

- With few exceptions, it cannot excite the nucleus. It only scatters off elastically:

$$\tilde{\chi}^{0}(\mathbf{p}_0) + (A,Z)(0) \longrightarrow \tilde{\chi}^{0}(\mathbf{p}_0 - \mathbf{q}) + (A,Z)(\mathbf{q})$$

- Measuring the energy of the recoiling nucleus is extremely hard:
  -Low event rate (much less than 30 per Kg of target per year are expected).
  -Bothersome backgrounds (the signal is not very characteristic).
  -Threshold effects.
  -Quenching factors.

Novel approaches: Exploitation of other signatures of the reaction

- The modulation effect: The seasonal due to the motion of the Earth dependence of the rate.
- The excitation of the nucleus (in some cases , heavy WIMP etc, that this is realistic) and detection of the subsequently emitted de-excitation γ rays.
- Asymmetry measurements in directional experiments (the direction of the recoiling nucleus must also be measured).
- Detection of other particles (electrons, X-rays), produced during the LSP-nucleus collision

The SUSY INPUT

- Allowed parameter space: Universality at GUT scale:
  - One mass m_0 for the scalars
  -One mass $m_{1/2}$ for the fermions
  -Tanβ, the ratio of vacuum expectation values of the
  Higss H_u ,H_d , i.e. $<v_u>/ <v_d>$
  -The cubic coupling A_0 (or m_t)
  -The sign of μ, in $\mu H_u H_d$
- These parameters are constrained via the renormalization group equations from the observable low energy quantities (all related to the above five parameters).
- (see, e.g.,: Ellis, Arnowitt, Nath, Bottino, Lazarides, Munoz, Gomez and their collaborators)

LSP Velocity Distributions

- Conventional: Isothermal models
- (1) Maxwell-Boltzmann (symmetric or axially symmetric)
- with characteristic velocity equal to the sun's velocity around the galaxy, $v_m = v_0 = 220$ km/s,
- and escape velocity $v_{esc} = 2.84 v_0$ put in by hand.
- (2) Modification of M-B characteristic velocity
  Interaction of dark matter with dark energy: $\upsilon_m = n v_0$,
  $v_{esc} = n2.84_{mesc}$ n>1
  (Tetradis and JDV)
- Adiabatic models employing Eddington's theory:
  $\rho(\mathbf{r}) \Rightarrow \Phi(\mathbf{r}) \Rightarrow f(\mathbf{r},\mathbf{v})$ (JDV-Owen)
- Other non-thermal models:
  Caustic rings (Sikivie , JDV), wimps in bound orbits etc
  Sgr Dwarf galaxy, anisotropic flux, (Green & Spooner)

Coupling of Dark Matter and Dark Energy (N. Tetradis, P.L. B 632 (2006) 463

- A scalar field (massless up to Hubble distances).
- At the galactic scale it generates a new long range scalar interaction between DM & DE.
- This leads to an interaction between DM particles above gravity determined by κ:
- $\kappa^2 = 4m_P((1/m(\Phi))(d(m(\Phi))/d\,\Phi)|_{(\,\Phi=\varphi 0)})^2$

Coupling of Dark Matter and Dark Energy (N. Tetradis, P.L. B 632 (2006) 463

- Energy momentum tensor for DM
  diag(-ρ,p,p,p) with Eq. of state: $p(r)=\rho(r) \langle \upsilon^2 \rangle$
- Solution of Einstein Eqs ⇒ gravitational Potential
  such that: $\Phi' = (2/3)(1+\kappa^2)\langle \upsilon^2 \rangle 1/r \Rightarrow$
  matter rotational velocity: $(\upsilon_0)^2 = (2/3(1+\kappa^2))\langle \upsilon^2 \rangle$
- ⇒DM: MB ~ $\mathrm{Exp}[-\upsilon^2 / (n\, \upsilon_0)^2]$; $n^2 = (1+\kappa^2)$
- And escape velocity:
- $\upsilon_{esc} = 2.84\upsilon_0$ (matter) ⇒ $\upsilon_{esc} = 2.84 n \upsilon_0$ (DM)
- BEFORE WE EXPLOIT THIS EFFECT

  SOME REMINDERS ARE NEEDED

The event rate for the coherent mode

- Can be cast in the form:

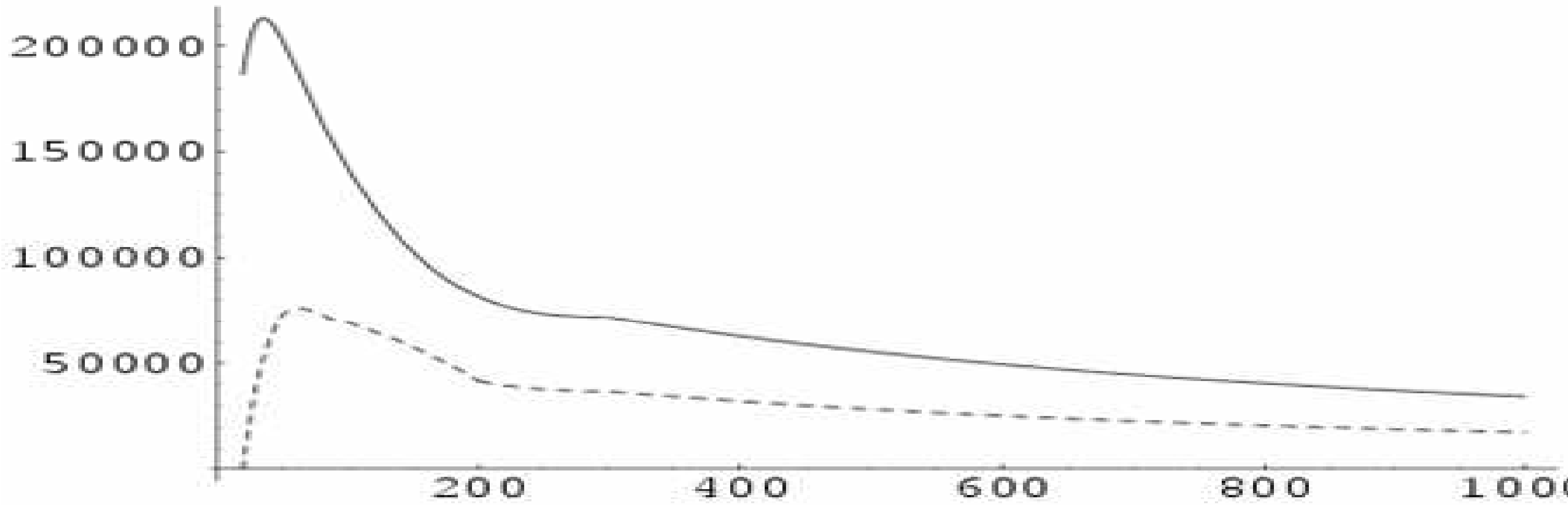
$$R \simeq 160\ 10^{-4}\ (pb)^{-1} y^{-1} \frac{\rho(0)}{0.3 GeV cm^{-3}} \frac{m}{1Kg} \frac{\sqrt{\langle v^2 \rangle}}{280 kms^{-1}} \times$$

$$f_{coh}(A, \mu_r(A)) \sigma^S_{p,\chi^0}$$

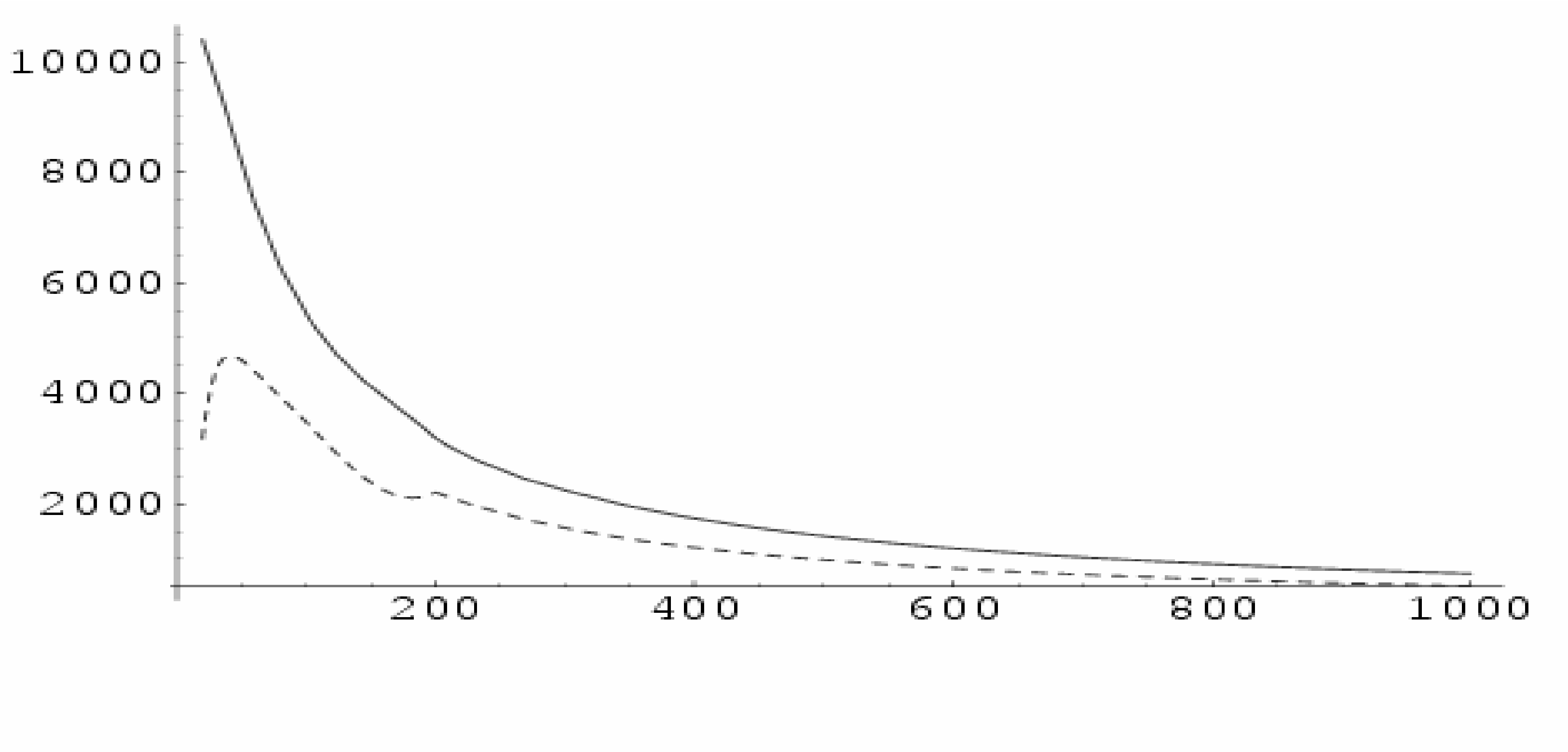
$$f_{coh}(A, \mu_r(A)) = \frac{100\mathrm{GeV}}{m_{\chi^0}} \left[\frac{\mu_r(A)}{\mu_r(p)} \right]^2 A\, t_{coh}\, (1 + h_{coh} cos\alpha)$$

- Where:
  $\rho(0)$: the local WIMP density≈0.3 GeV/cm^3.
  $\sigma^S_{p,\chi}$: the WIMP-nucleon cross section. It can be extracted from the data once f_{coh} (A,m_χ) is known.

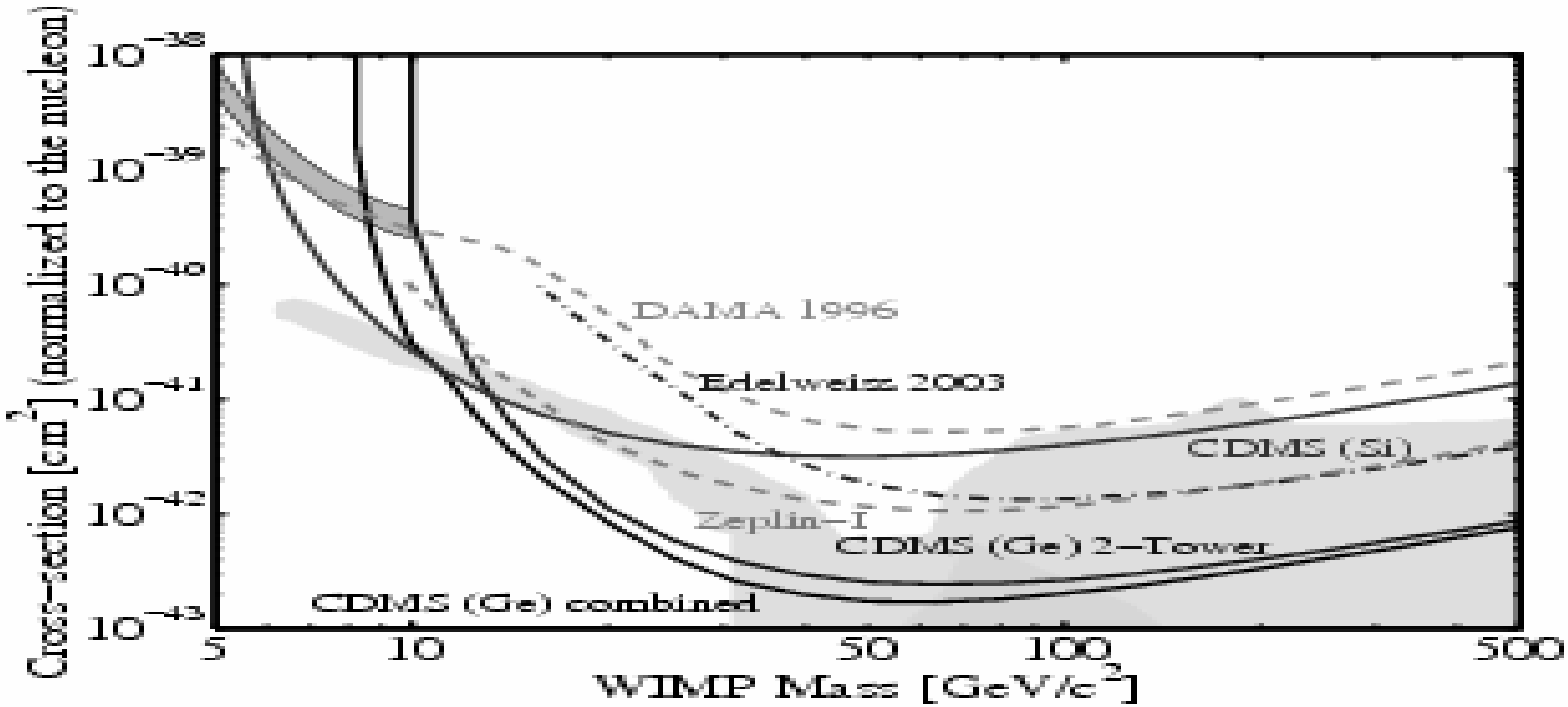
The factor $f_{coh}(A,m_\chi)$ for A=127 (I) vs the LSP mass (The dashed for threshold 10keV)



The factor $f_{coh}(A,m_\chi)$ for A=19 (F) (The Dashed for threshold 10keV)



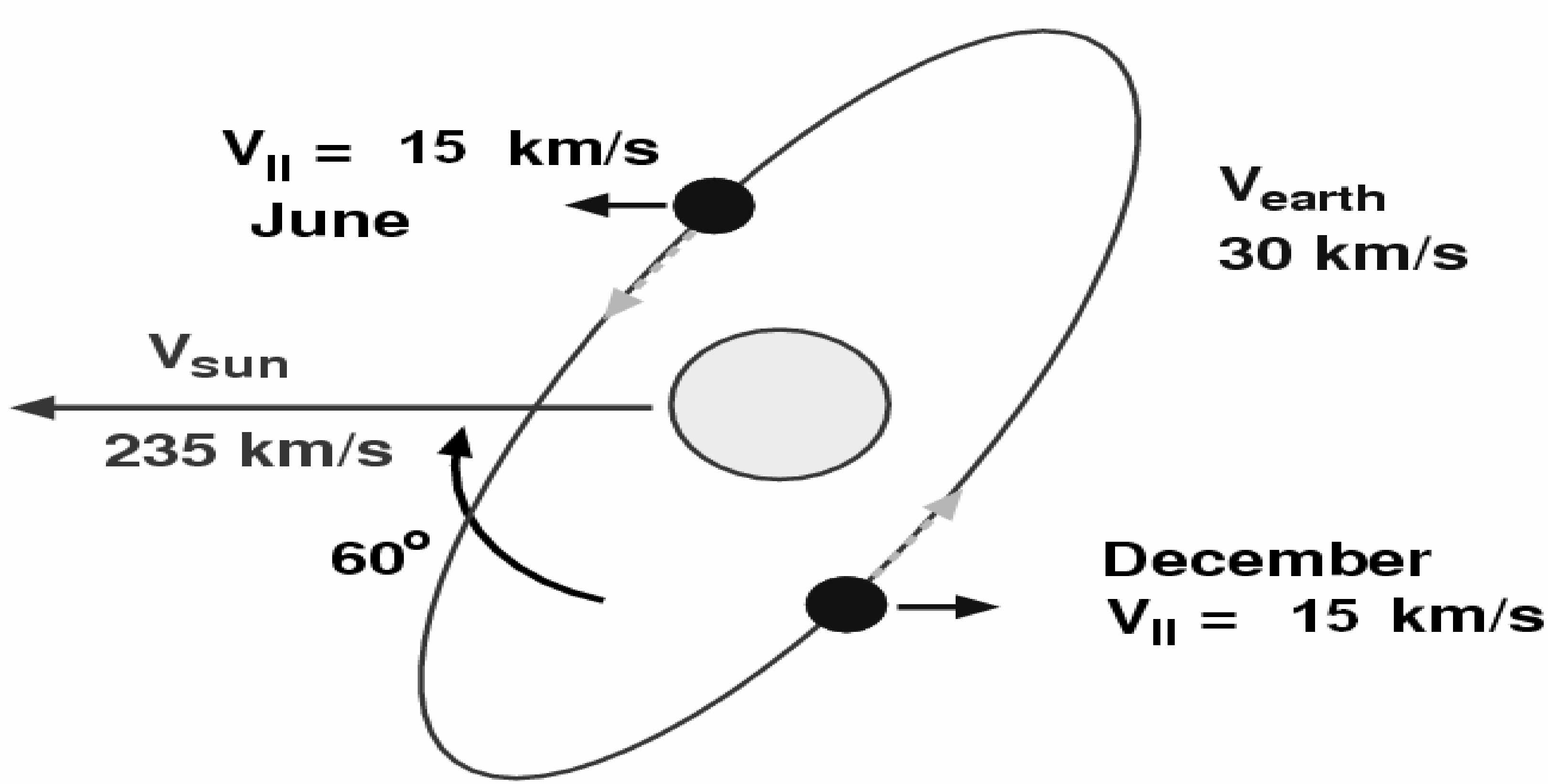
Current Limits on coherent proton cross section (astro-ph/0509259)



THE MODULATION EFFECT

v_{June}=235+15=250km/s

v_{Dec}=235-15=220km/s



THE MODULATION EFFECT* (continued)

- $R = R_0 (1 + b \sin\gamma \cos\alpha) = R_0 (1 + h \cos\alpha)$

 ($\alpha = 0$ around June 3nd)
- $\gamma = \gamma' - \pi/3$, γ' is the angle between the axis of galaχy and the axis of the ecliptic.
- h=modulation amplitude.
- R_0 =average rate.
- * with N. Tetradis (calculations with non standard M-B)

The Differential Rate (Reminders)

The differential rate is proportional to:

$$\frac{dr}{du} = \frac{dt}{du} + \frac{dh}{du}\cos\alpha$$

Unmodulated rate:

$$\frac{dt}{du} = \sqrt{\frac{2}{3}}a^2F^2(u)\Psi_0(a\sqrt{u})$$

Modulated rate:

$$\frac{dh}{du} = \sqrt{\frac{2}{3}}a^2F^2(u)H(a\sqrt{u})$$

where α is the phase of the Earth
$F(u)$ the nuclear form factor

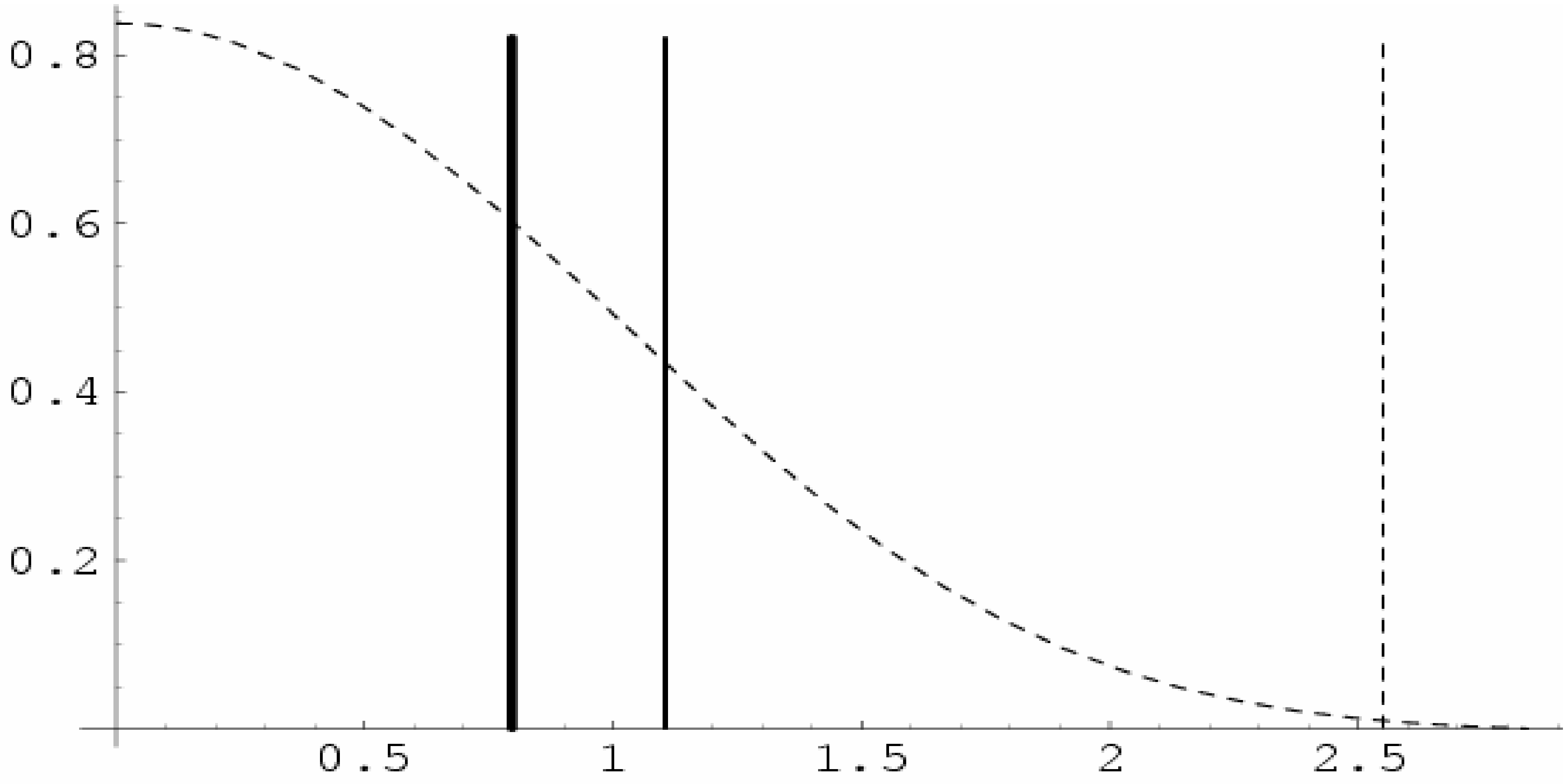
$$a = \left[\sqrt{2}\mu_r b \upsilon_0\right]^{-1}$$

u is proportional to the energy transfer Q

$$u = \frac{1}{2}(qb)^2 \Rightarrow u = \frac{Q}{Q_0} \quad , \quad Q_0 = 4.1 \times 10^4 \ A^{-4/3} \ \text{KeV}$$

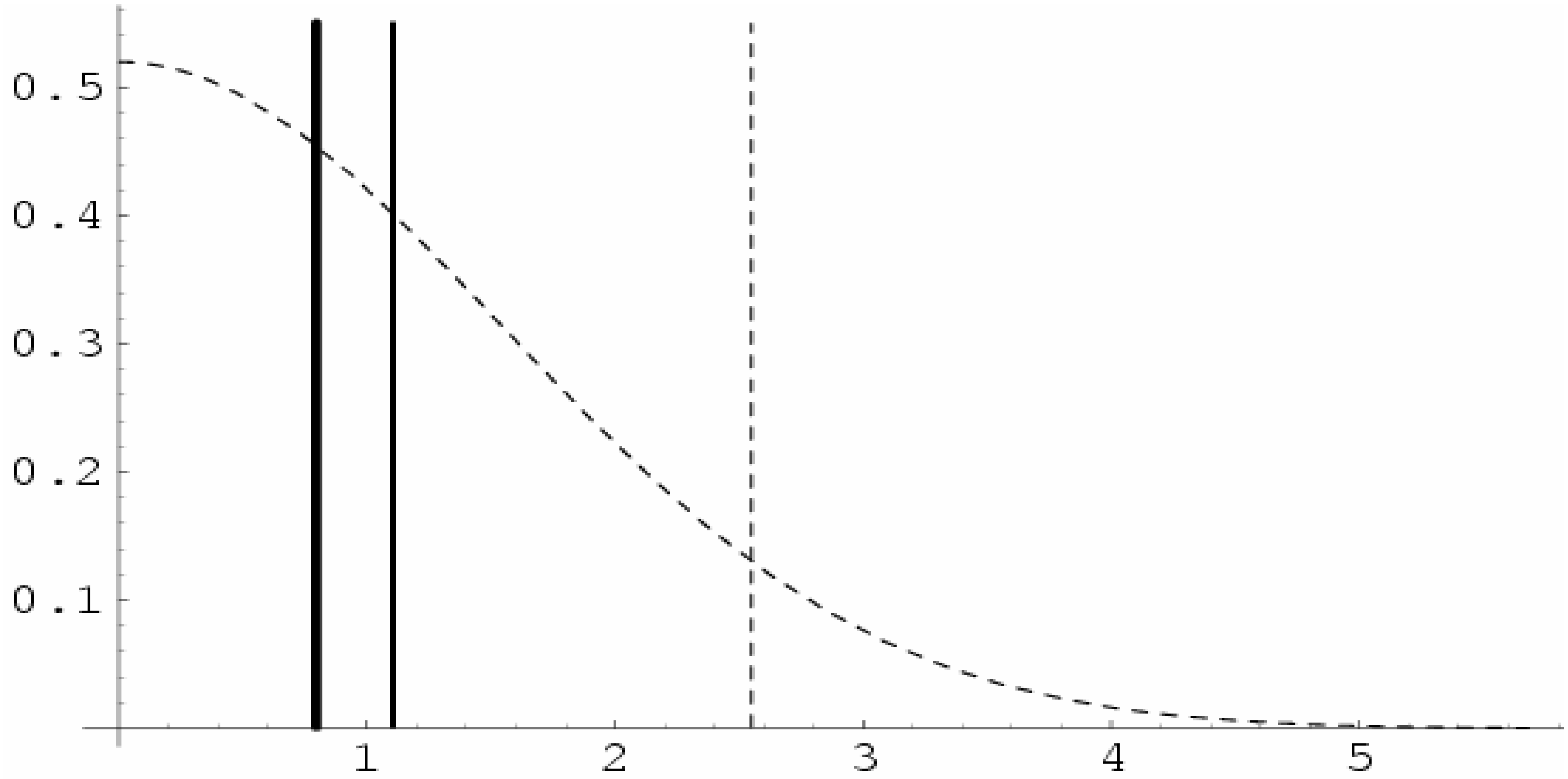
The Function $\Psi_0(x)$; n=1

(dotted $\Leftrightarrow m_{WIMP}$ 30GeV, thick $\Leftrightarrow m_{WIMP}$ 200GeV)

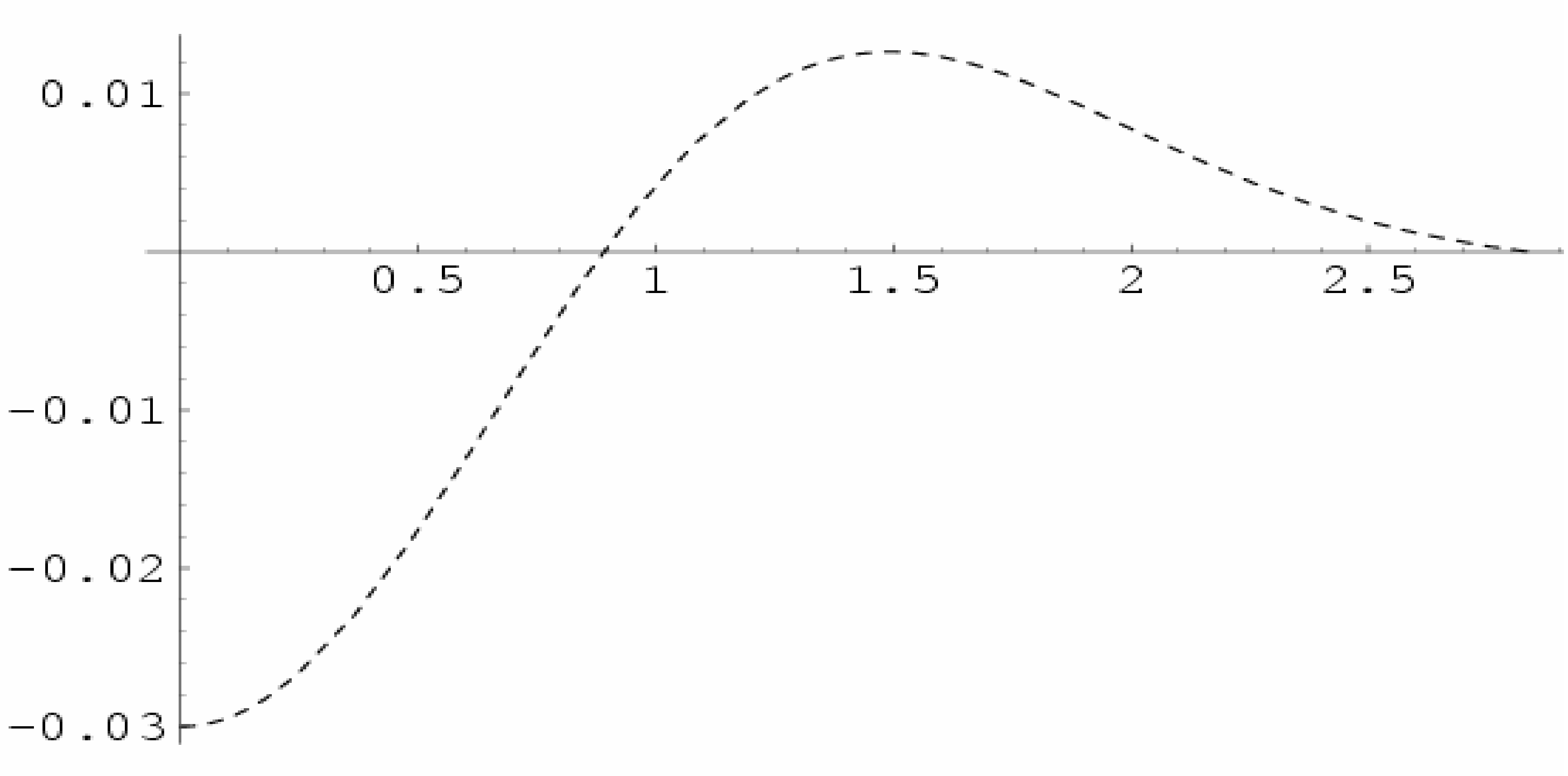


The Function $\Psi_0(x)$; n=2

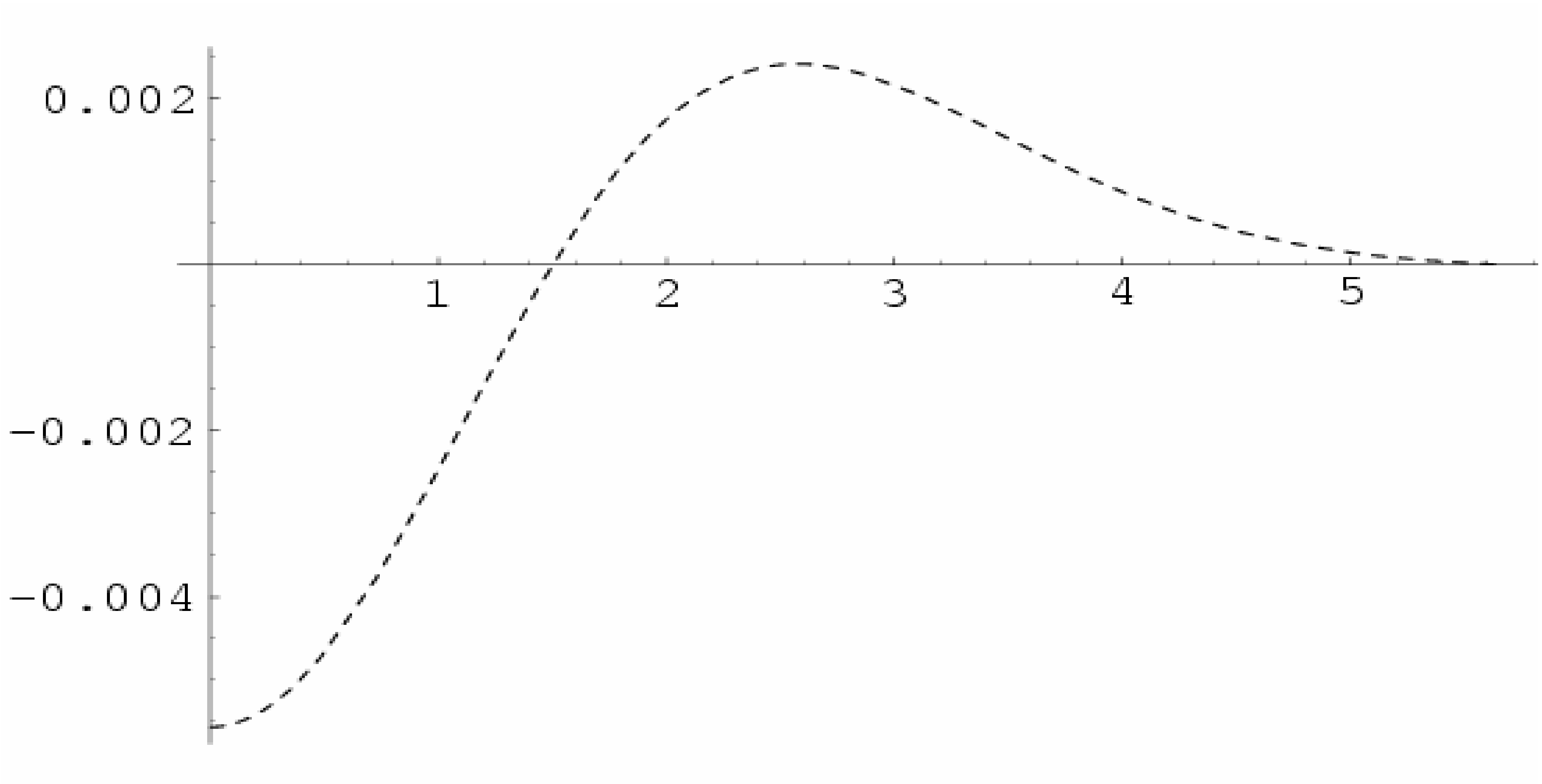
(dotted$\Leftrightarrow m_{WIMP}$ 30GeV, thick $\Leftrightarrow m_{WIMP}$ 200GeV)



The Modulation Amplitude H(x), n=1



The Modulation Amplitude H(x), n=2
Note a decrease by almost a factor of 5



Effect on Total Rates

The integrated rate is proportional to:

$$r_{coh} = t_{coh}\,(1 + h_{coh}\cos\alpha)$$

with

$$t_{coh} = \int_{u_{min}}^{u_{max}} \frac{dt_{coh}}{du}du$$

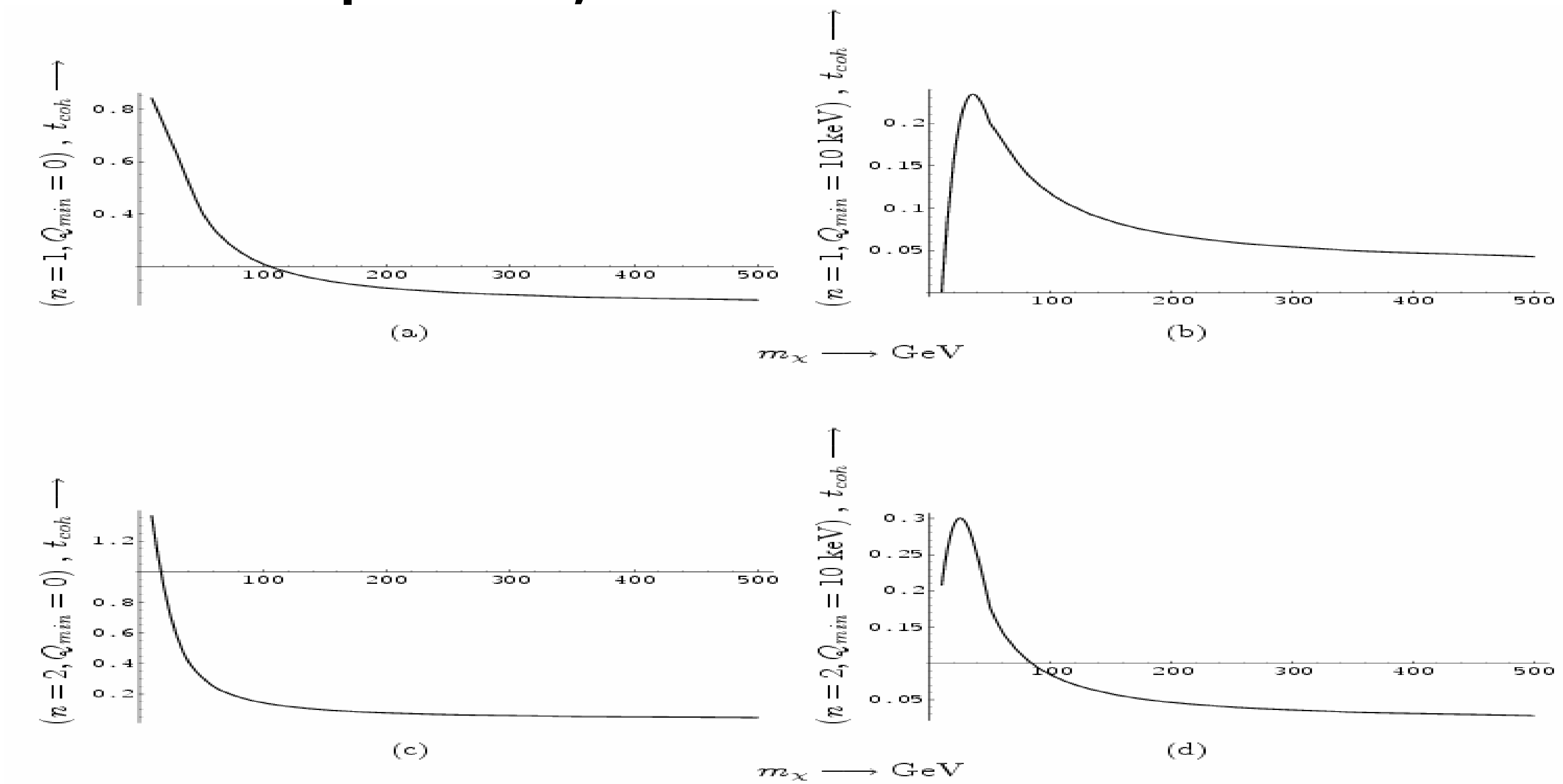
$$h_{coh} = \frac{1}{t_{coh}}\int_{u_{min}}^{u_{max}} \frac{dh_{coh}}{du}du$$

$$u_{min} \Leftrightarrow \text{detector threshold}$$

$$u_{max} = \frac{(ny_{esc})^2}{a^2} \Leftrightarrow \text{maximum WIMP velocity}$$

$(y_{esc} \simeq 2.84)$

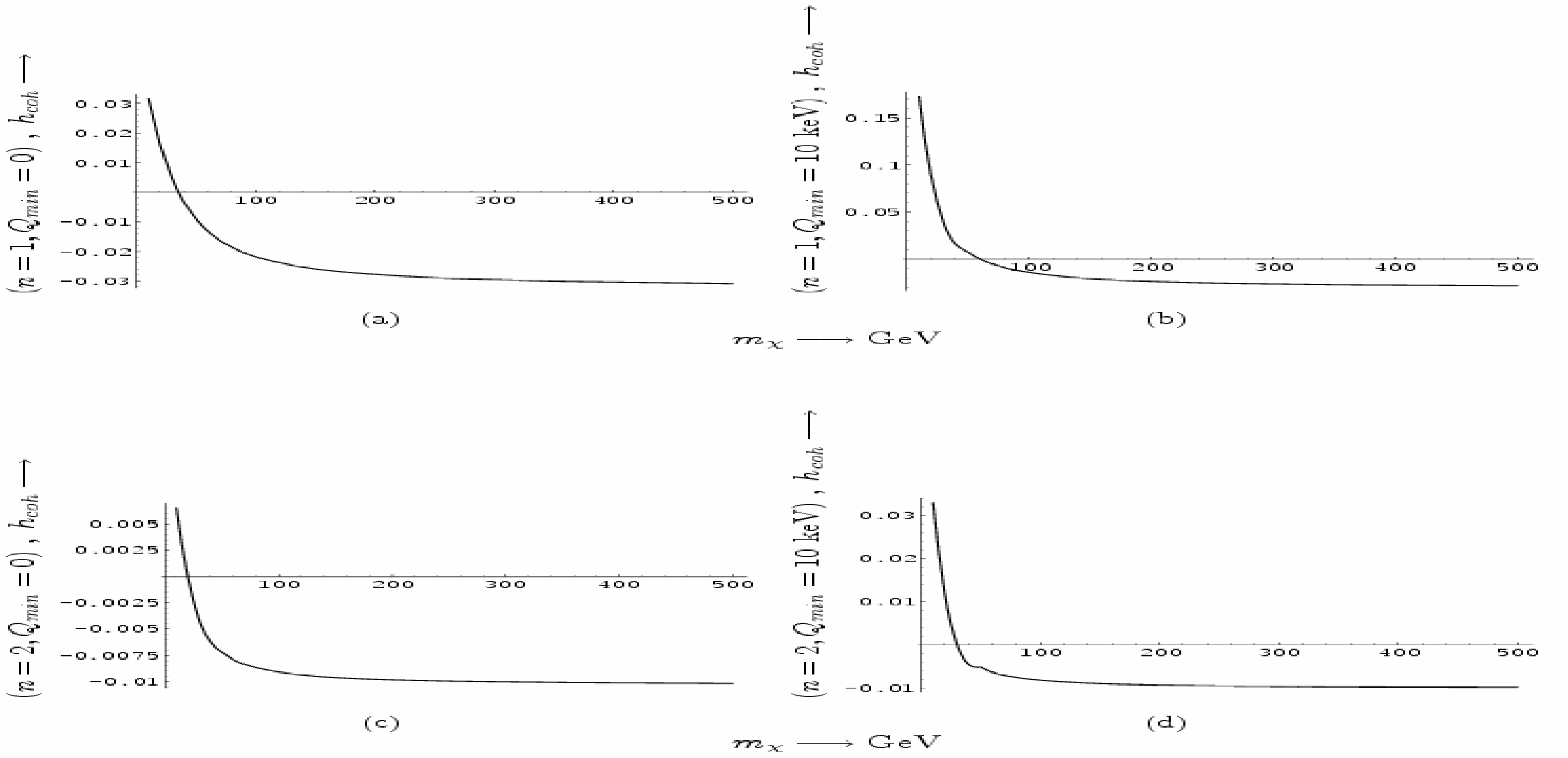
The factor t for ^{127}I (coherent mode) Q_{th}=0, 10 keV, Isothermal model (M-B), On top n=1, at the bottom n=2



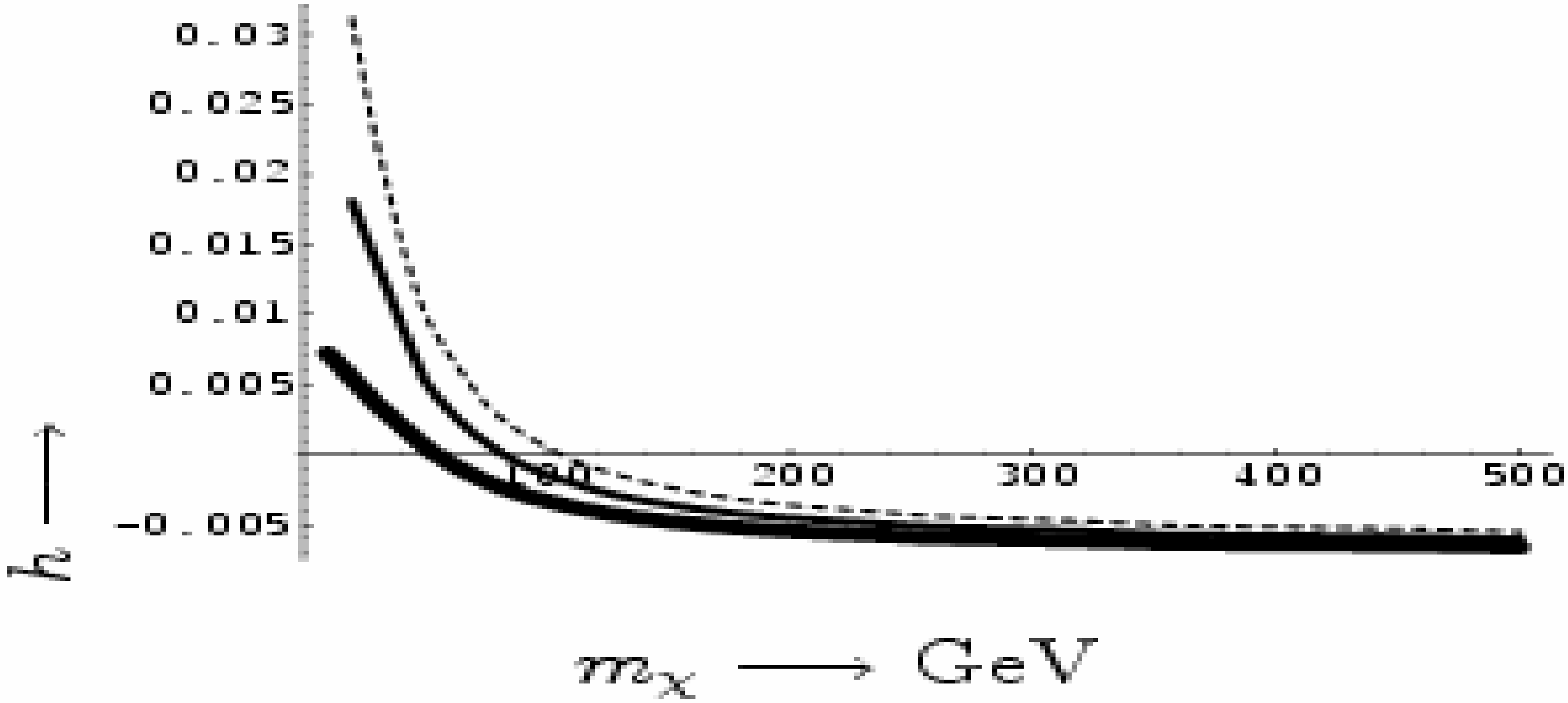
The Modulation Amplitude h for ^{127}I

Q_{th}=0, 10 keV, Isothermal model (M-B),

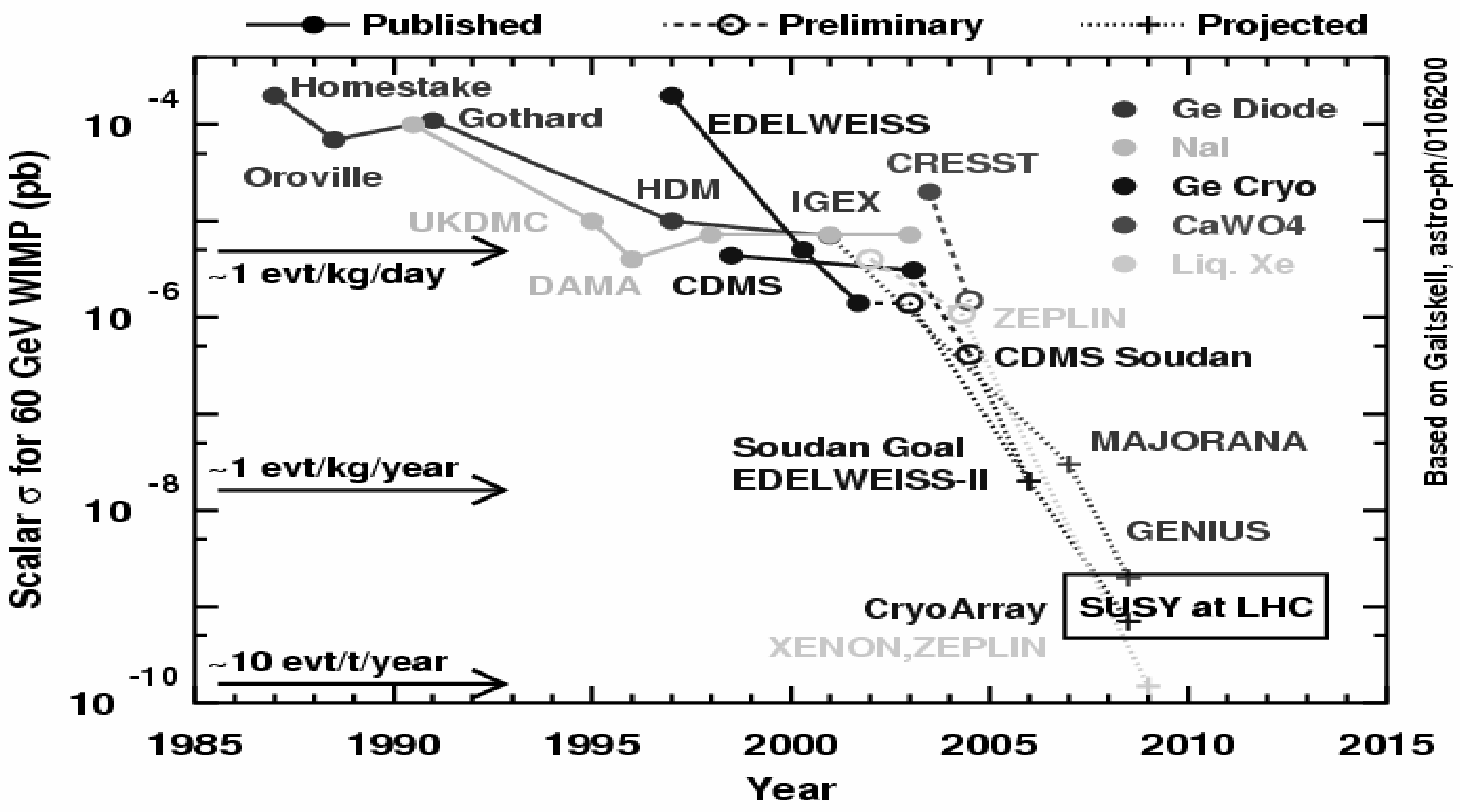
On top n=1, at the bottom n=2



The Modulation Amplitude h for ^{127}I Q_{th}=0⇔thick, Q_{th}=5keV⇔fine Q_{th}=10⇔dash; Eddington Theory



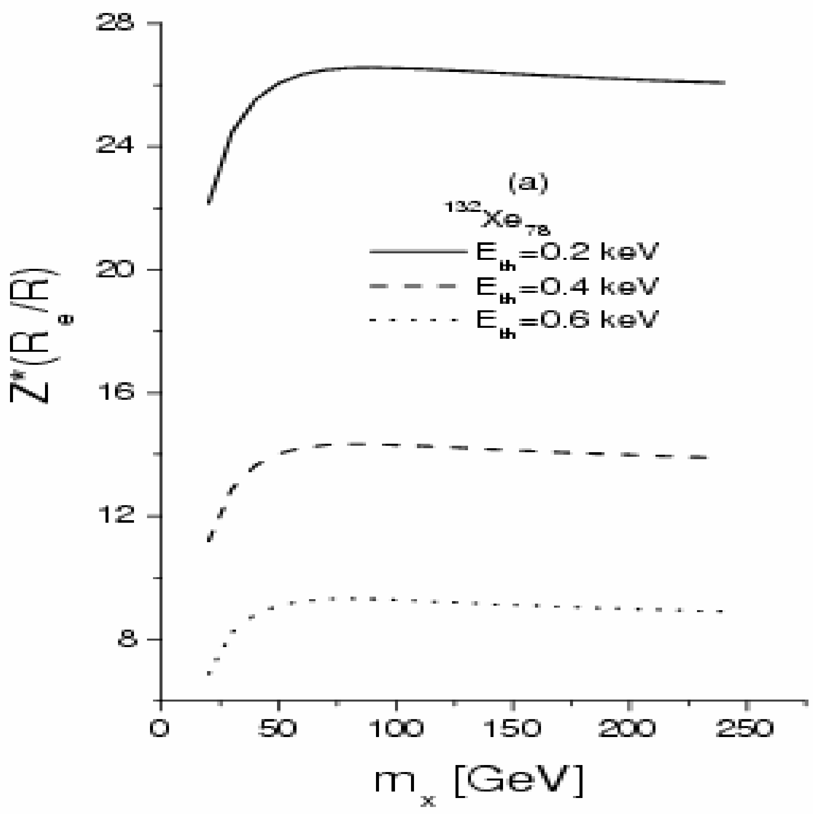
Conclusions:
Experimental ambitions for Recoils

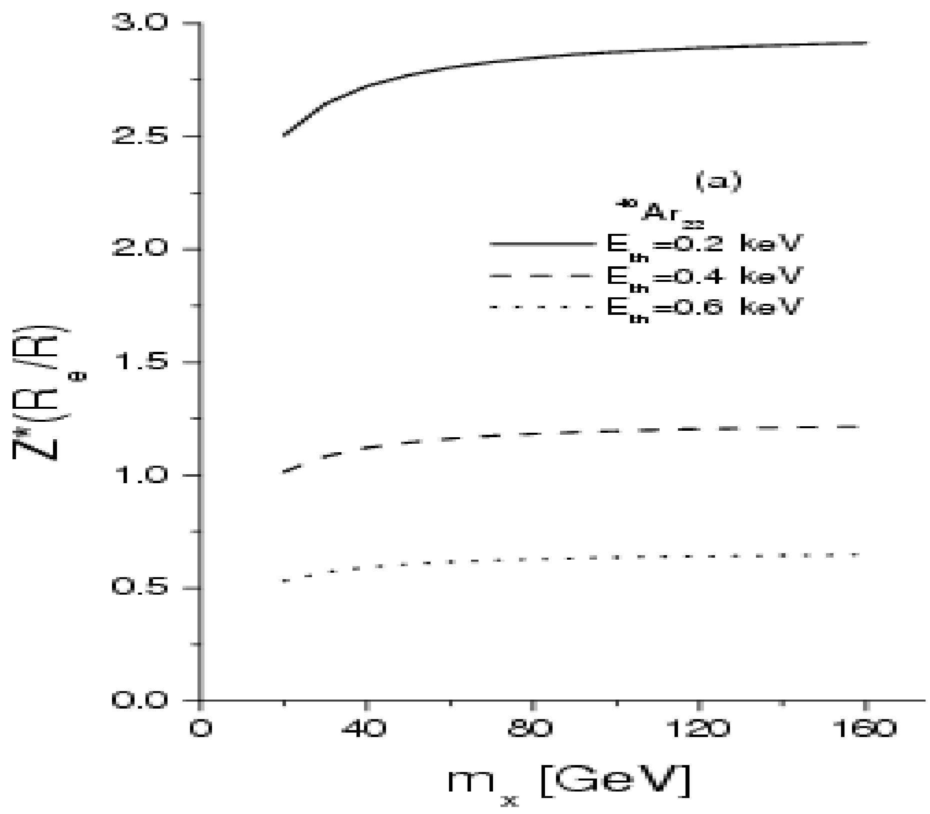


NON RECOIL MEASUREMENTS

- (a) Measurement of ionization electrons produced directly during the WIMP-nucleus collisions
- (b) Measurement of hard X-rays following the de-excitation of the atom in (a)
- (c) Excitation of the Nucleus and observation of the de-excitation γ rays

Relative rate for electron ionization
(there are Z electrons in an atom!)





Detection of hard X-rays

- After the ionization there is a probability for a K or L hole
- This hole de-excites via emitting X-rays or Auger electrons.
- Indicating with $b_{n\ell}$ the fluorecence ratio (determined experimentally)
- the fraction of X-rays per recoil is:

  $\sigma_{X(n\ell)}/\sigma_r = b_{nl}(\sigma_{n\ell}/\sigma_r)$ with $\sigma_{n\ell}/\sigma_r$ the relative ionization rate per orbit

The K Xray rates in WIMP interactions in ^{132}Xe for masses: L⇔30GeV, M⇔100GeV, H⇔300GeV

K X-ray	$E_K(K_{ij})$ keV	$B_K(K_{ij})$	$[\frac{\sigma_K(K_{ij})}{\sigma_r}]_L$	$[\frac{\sigma_K(K_{ij})}{\sigma_r}]_M$	$[\frac{\sigma_K(K_{ij})}{\sigma_r}]_H$
$K_{\alpha 2}$	29.5	0.284	0.0086	0.0560	0.0645
$K_{\alpha 1}$	29.8	0.527	0.0160	0.1036	0.1196
$K_{\beta 1}$	33.6	0.154	0.0047	0.0303	0.0350
$K_{\beta 2}$	34.4	0.034	0.0010	0.0067	0.0077

CONCLUSIONS: Excitation of the nucleus: Possible in the exotic models!

The average WIMP energy is:

$$\prec T \succ \approx 40KeV n^2 (m_{WIMP}/100GeV), n \succeq 1$$

The maximum energy is

$$T_{max} \approx 215KeV n^2 (m_{WIMP}/100GeV), n \succeq 1$$

In the case of neutralino (Standard M-B, $n = 1$):

$$\prec T \succ \approx 40KeV (m_{WIMP}/100GeV)$$

$$T_{max} \approx 215KeV (m_{WIMP}/100GeV)$$

Hard to excite the nucleus. While for $n = 2$

$$\prec T \succ \approx 160KeV (m_{WIMP}/100GeV)$$

$$T_{max} \approx 0.86 \text{ MeV} (m_{WIMP}/100GeV)$$

Possible with judicious targets.
In the case of Kaluza-Klein theories (n=1) :

$m_{WIMP} \geq 500$ GeV $\Rightarrow \prec T \succ \geq 0.2$MeV , $T_{max} \geq 1.1$ MeV

while for n=2

$m_{WIMP} \geq 500$ GeV $\Rightarrow \prec T \succ \geq 0.8$MeV , $T_{max} \geq 4.0$ MeV

CONCLUSIONS A: K-K WIMPS

- Theoretical advantages: Only the masses are unknown parameters
- Experimental advantages: The WIMP energy is an order of magnitude bigger

  The energy transfer to the nucleus is in the MeV region. WIMPS need not be detected via the hard recoil measurements. One can excite the nucleus
- Limits K-K Nucleon cross sections can be extracted from current limits via:
- $\sigma_{(K\text{-}K)}$ (coh) $\approx (A/Z)^2 10^{(-6)}$ pb $[m_{(K\text{-}K)}/200\text{GeV}]^{(1/2)}$
- $\sigma_{(K\text{-}K)}$ (spin) $\approx 10^{(-2)}$ pb $[m_{(K\text{-}K)}/200\text{GeV}]^{(1/2)}$

CONCLUSIONS- SUSY WIMPS Standard Rates (theory)

- Most of the uncertainties come the fact that the allowed SUSY parameter space has not been sufficiently sharpened.
- The other uncertainties (nuclear form factor, structure of the nucleon, quenching factor, energy threshold) could affect the results by an order of magnitude.
- Most of the parameter space yields undetectable rates.
- The coherent contribution due to the scalar interaction is the most dominant.

CONCLUSIONS-Modulation (theory)

- The modulation amplitude h is small less than 2% and depends on the LSP mass.
- It crucially depends on the velocity distribution
- Its sign is also uncertain for intermediate and heavy nuclei.
- It may increase as the energy cut off remains big (as in the DAMA experiment), but at the expense of the number of counts. The DAMA experiment maybe consistent with the other experiments, if the spin interaction dominates.
- The modulation is reduced in exotic WIMP velocity distributions

CONCLUSIONS: Electron production during LSP-nucleus collisions

- During the neutralino-nucleus collisions, electrons may be kicked off the atom
- Electrons can be identified easier than nuclear recoils (Low threshold ~0.25keV TPC detectors)
- The branching ratio for this process depends on the threshold energies and the LSP mass.
- For a threshold energy of 0.25 keV the ionization event rate in the case of a heavy target can exceed the rate for recoils by an order of 10.
- Detection of hard X-rays also seams feasible

- THE END

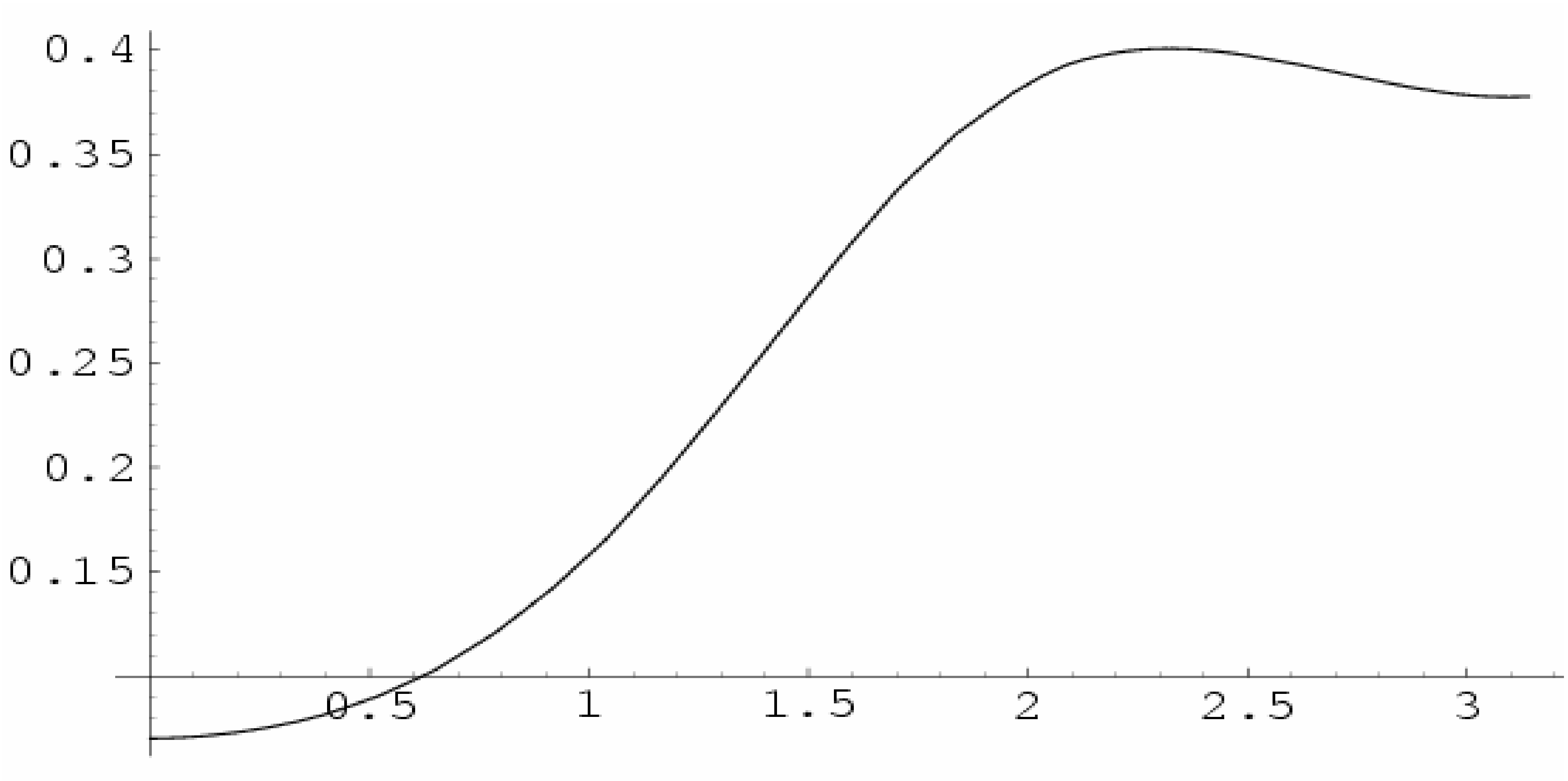
The directional event rate

- The event rate in directional experiments is:

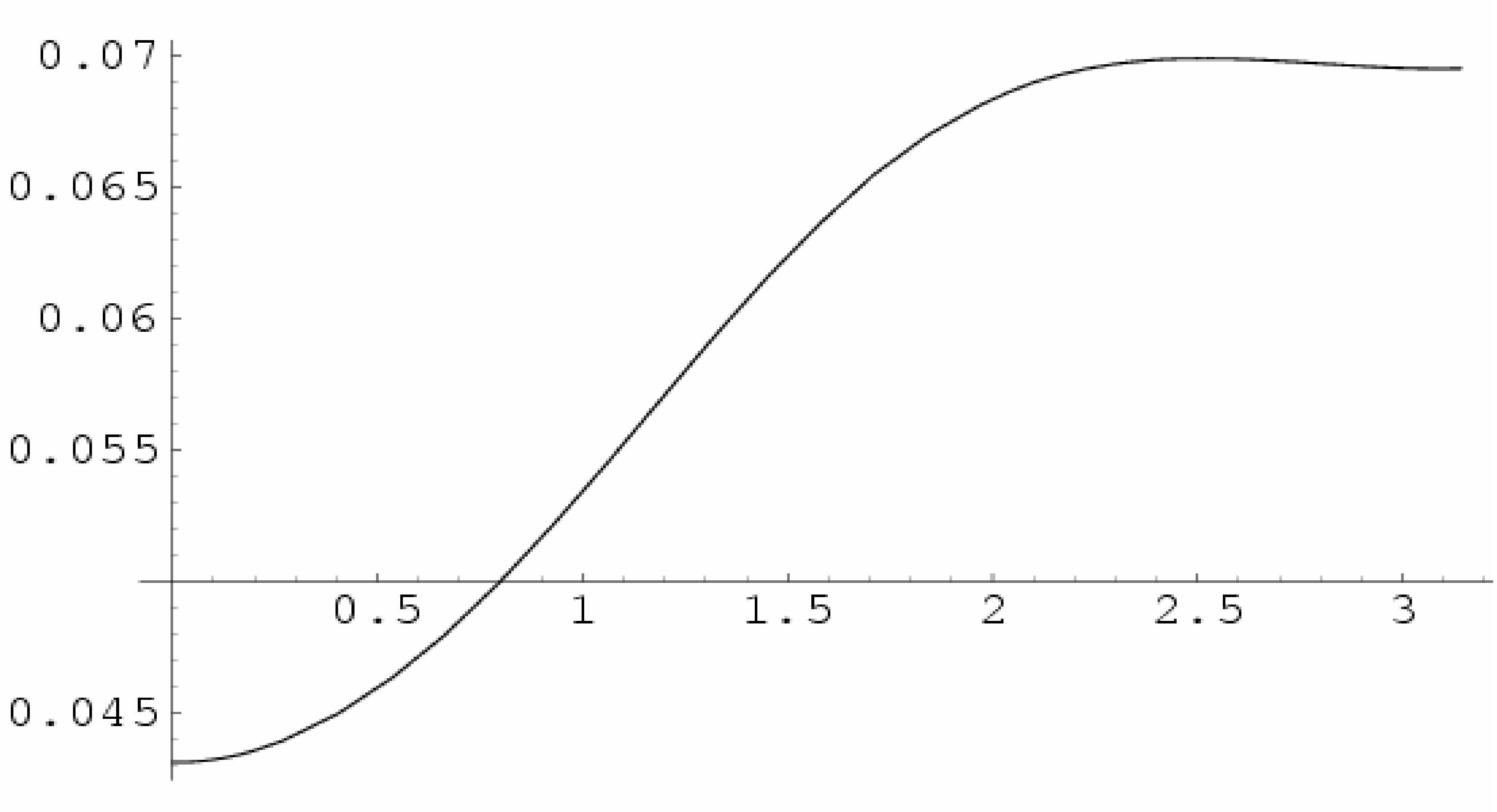
$$R_{dir}=(\kappa/2\pi)R_0[1+\cos(\alpha-\alpha_m\pi)]$$

- R_0 is the average usual (**non-dir**) rate
- α the phase of the Earth (as usual)
- α_m is the shift in the phase of the Earth (it depends on μ_r and the direction of observation)
- $\kappa/2\pi$ is the reduction factor (it depends on μ_r and the direction of observation)
- κ and α_m depend only slightly on SUSY

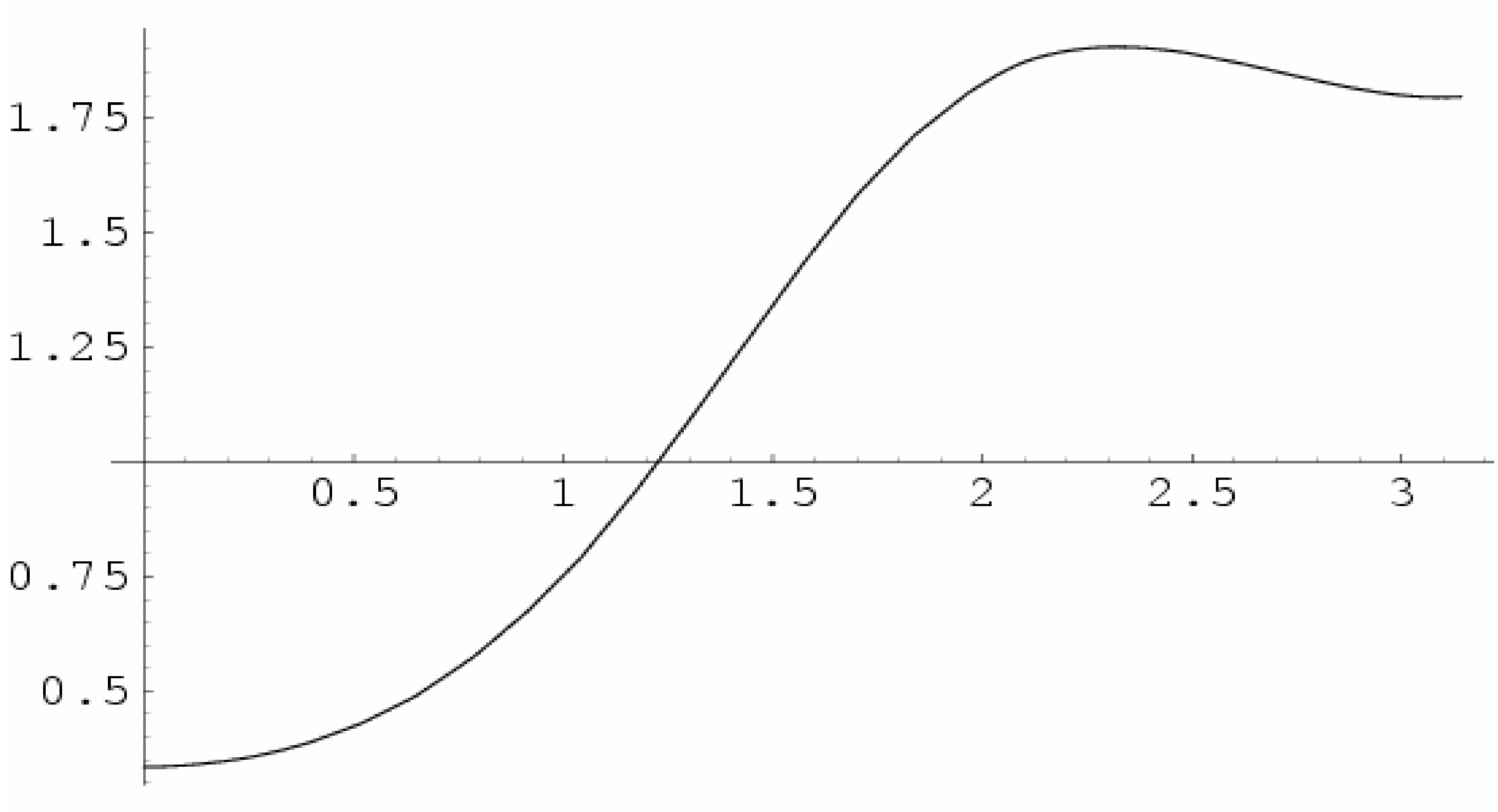
The Directional rate t_{dir} in the case of ^{127}I for wimp mass of 100 GeV M-B distribution m=1)



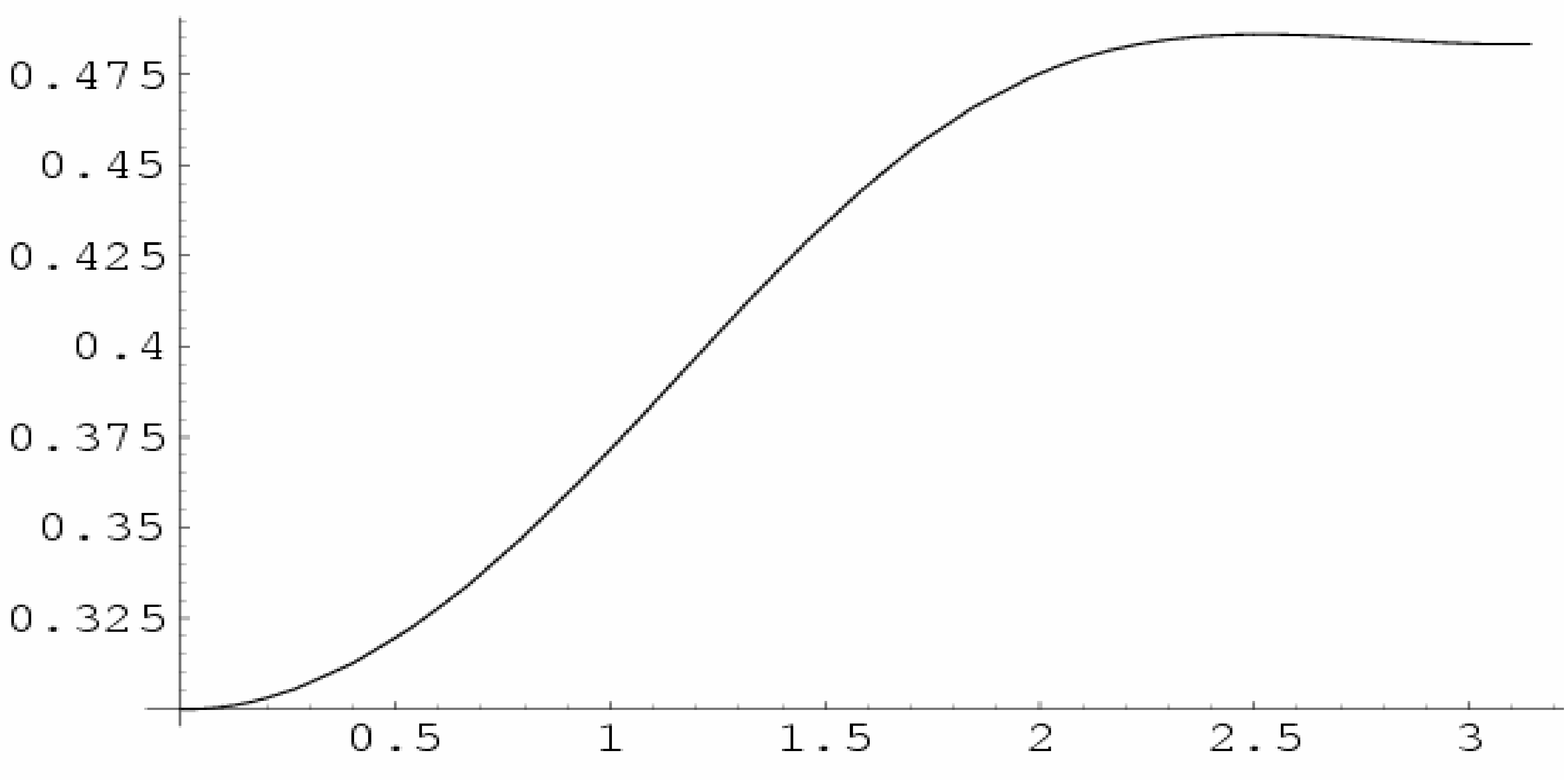
The Directional rate t_{dir} in the case of ^{127}I for wimp mass of 100 GeV M-B distribution m=2)



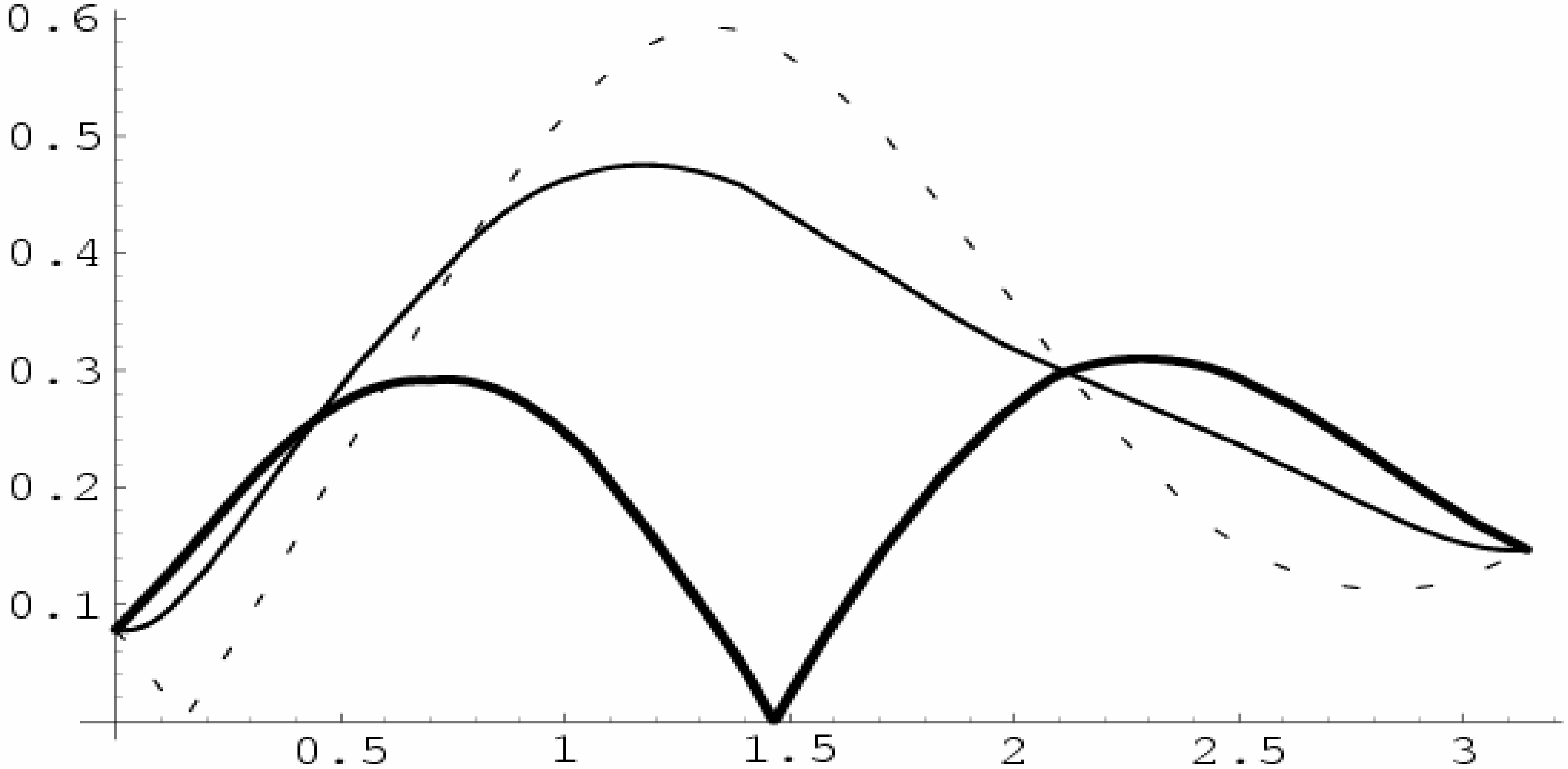
The parameter κ vs the polar angle in the case of A=127, right for m_χ=100 GeV(M-B distribution m=1)



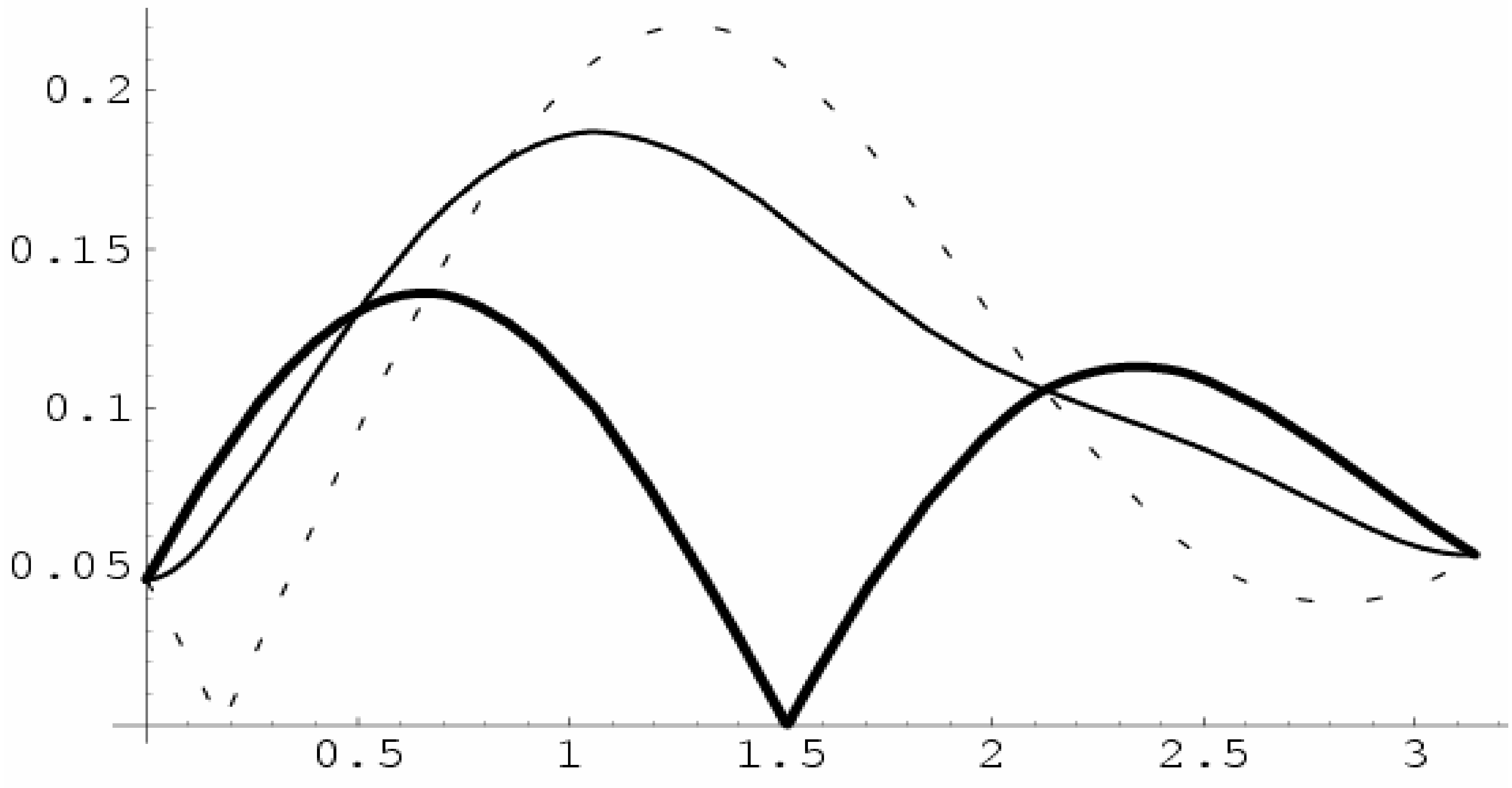
The parameter κ vs the polar angle in the case of A=127, right for m_χ=100 GeV(M-B distribution m=2)



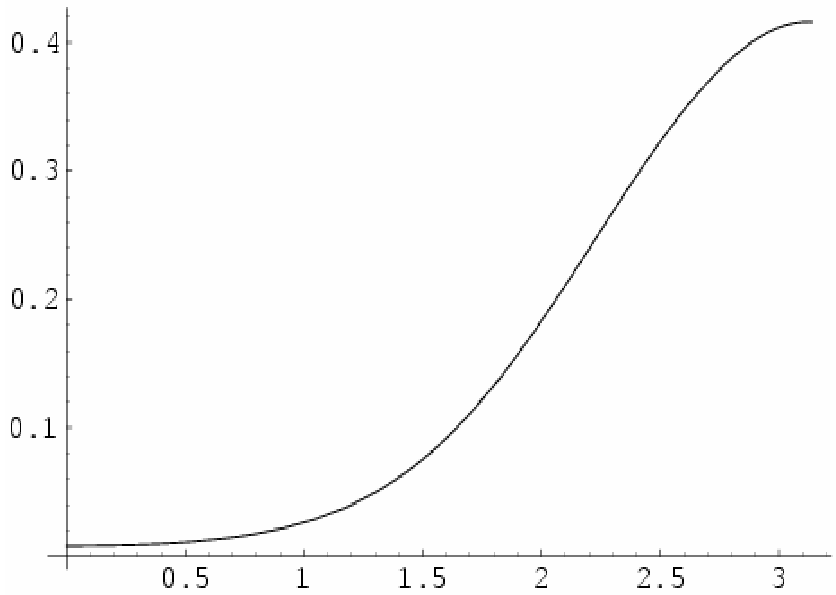
Directional Rate: Modulation vs Θ m_{wimp}=100 GeV,dotted⇔Φ=π, fine ⇔Φ=0, thick⇔Φ=π/2,3π/2 (m=1)

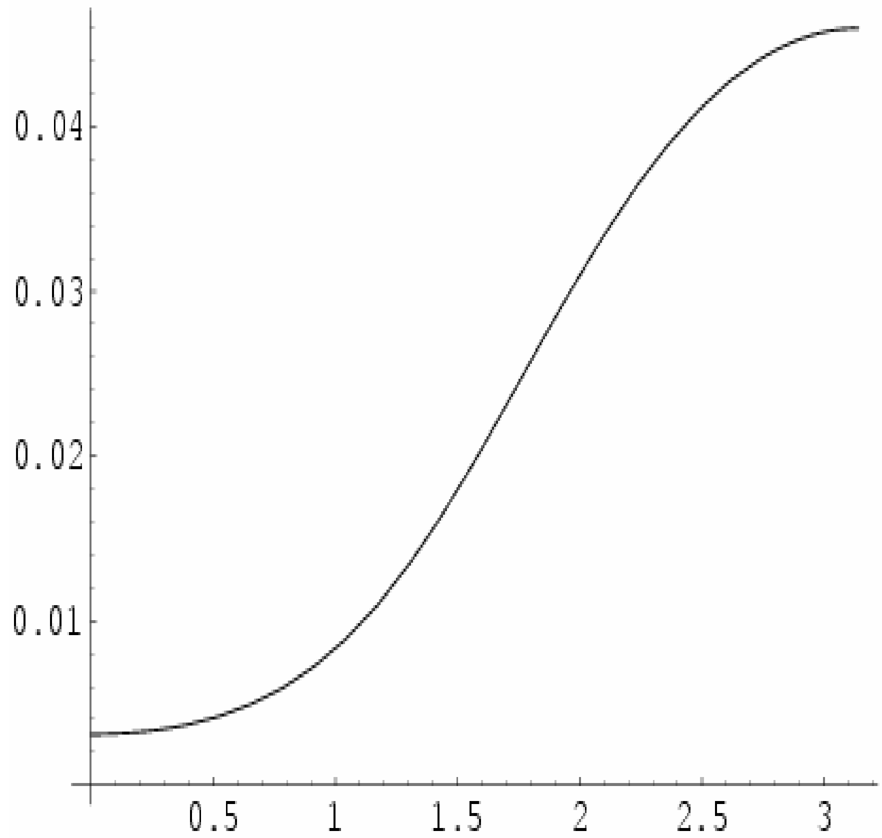


Directional Rate: Modulation vs Θ m_{wimp}=100 GeV,dotted⇔Φ=π, fine ⇔Φ=0, thick⇔Φ=π/2,3π/2 (m=2)

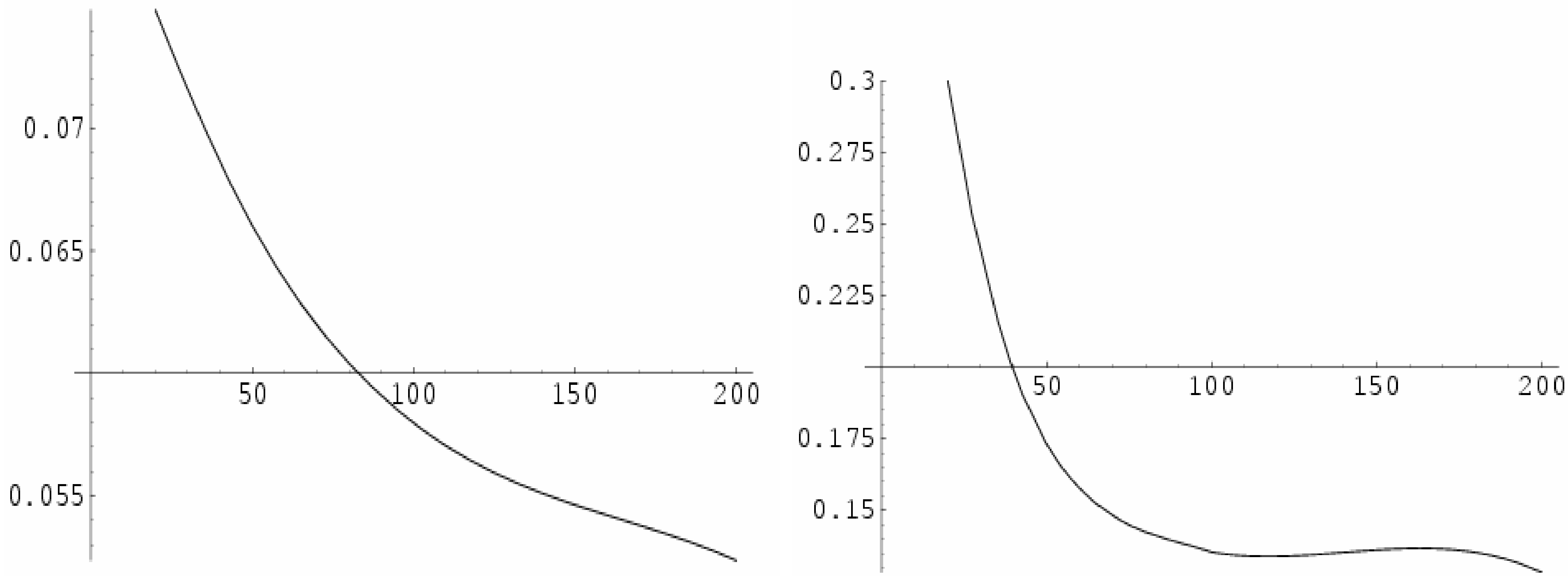


The event rate vs the polar angle (A=19, left) , (A=127, right) for m_χ=100 GeV and M-B distribution





The parameter κ vs the LSP mass: perpendicular to the sun’s velocity (left) and opposite to it (right)



A. SUSY MODELS WITH R-PARITY: The neutralino χ

- Standard model particles have R-parity=1
- All SUSY particles have R-parity -1
- Lightest SUSY particle absolutely stable
- A linear combination of the 4 neutral fermions
  (two gauginos and two Higgsinos) i.e.

$$\chi = Z_1 \tilde{B} + Z_2 \tilde{W}_3 + Z_3 \tilde{H}_1 + Z_4 \tilde{H}_2$$

From the quark level to the nucleon level (coherent)

The structure of the nucleon.

- The coherent process

$$A_{coh} = \sum_{q=u,d,s} A_q f_q + \sum_{Q=c,b,t} A_Q f_Q$$

A_q and A_Q the amplitudes at the quark level (SUSY)

$$f_q = \frac{1}{m_N} \langle N|m_q \; q\bar{q}|N\rangle \text{ pion nucleon } \sigma \text{ term}$$

$$f_Q \approx \frac{2}{27}[1 - \sum_q f_q] \text{ Zacharov approach}$$

The heavy quarks dominate. Typical values:

$$f_d = 0.041 \;,\; f_u = 0.028 \;,\; f_s = 0.400$$

$$f_c = 0.051 \;,\; f_b = 0.055 \;,\; f_t = 0.095$$

The Differential cross section at the nuclear level.

$$d\sigma(u,\upsilon) == \frac{du}{2(\mu_r b\upsilon)^2}[(\bar{\Sigma}_S F(u)^2 + \bar{\Sigma}_{spin} F_{11}(u)] \quad (0.1)$$

- u is the neutralino velocity and u stands essentially for the energy transfer Q:
- $u=Q/Q_0$, $Q_0=40A^{-4/3}$ MeV
- F(u): The nuclear form factor
- F_{11} (u): The isovector spin response function

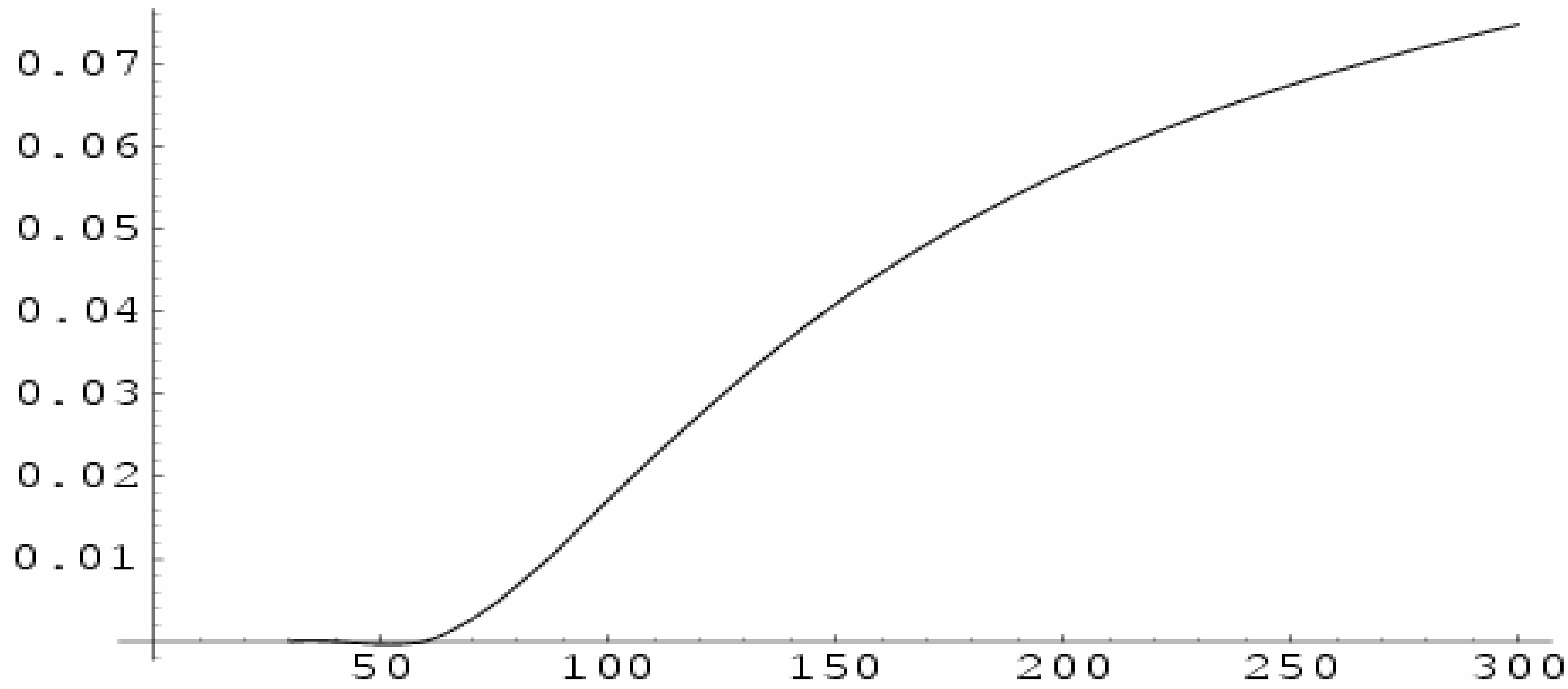
Expressions for the nuclear cross section (continued)

With

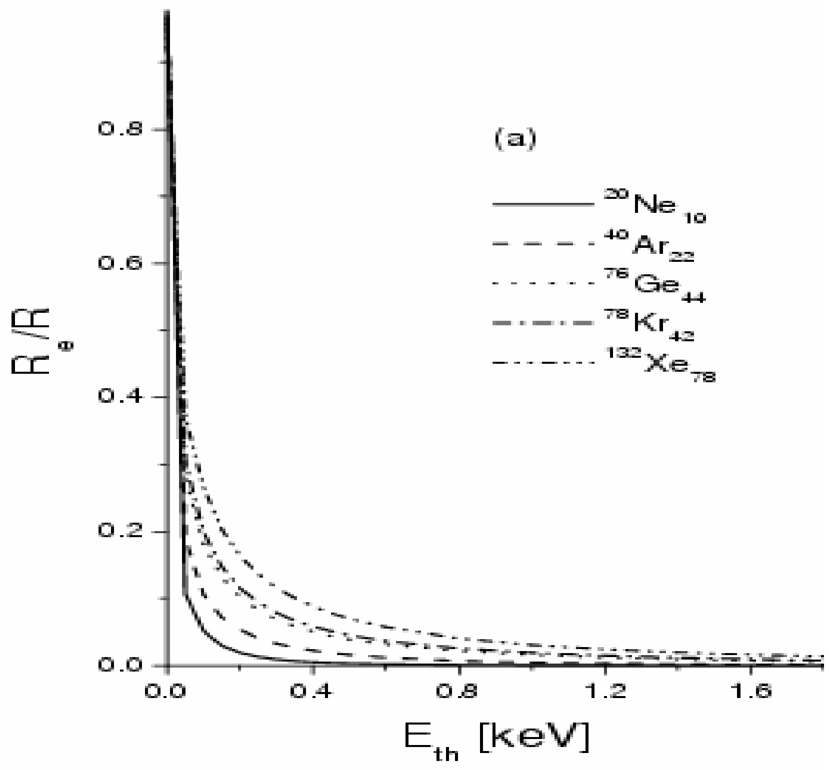
- $\Sigma_S=\sigma_p^s(\mu_r/m_p)^2A^2$ (scalar interaction)
- σ_p^s is the scalar proton-LSP cross section
- μ_r is the LSP-nucleus reduced mass
- A is the nuclear mass
- Σ_{Spin} is the expression for the spin induced cross section (to be discussed later).

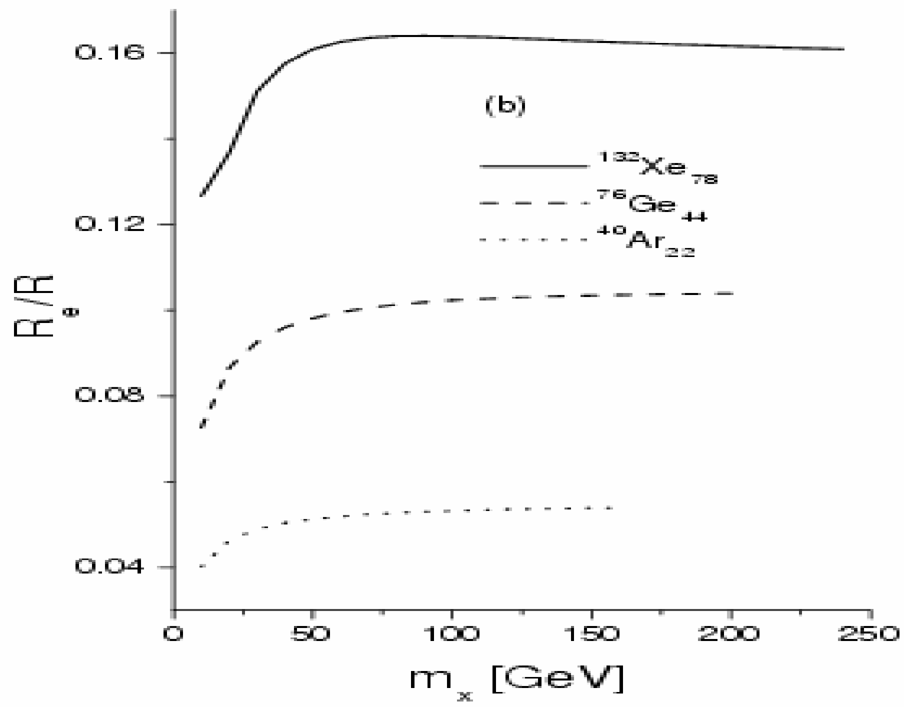
BR for transitions to the first excited state at 50 keV for I vs LSP mass (Ejiri; Quentin, Strottman and JDV)

Note: quenching of recoil ignored



The Relative (with respect to recoil) rate of ionization per electron vs: a) $E_{threshold}$ for m_χ =100Gev (left) and b) m_χ for $E_{threshold}$ = 0.2 keV (right)





Relative rate for inner electron hole production in the case of ^{132}Xe.

$n\ell$	$\varepsilon_{n\ell}$ (keV)	$(\sigma_{n\ell}/\sigma_r)_L$	$(\sigma_{n\ell}/\sigma_r)_M$	$(\sigma_{n\ell}/\sigma_r)_H$
is	34.56	0.034	0.221	0.255
2s	5.45	1.211	1.461	1.463
2p	4.89	3.796	4.506	4.513

- WIMP masses indicated by subscript:

  L⇔30GeV, M⇔100GeV, H⇔300GeV

CONCLUSIONS-Transitions to excited states

- For neutralino transitions to excited states are possible in few odd A nuclei*.
- When allowed, are kinematically suppressed
- The branching ratio depends on the structure of the nucleus and the LSP mass
- In the case of Iodine, a popular target for recoils, it can be as high as 7% for LSP mass higher than 200 GeV
- * For K-K WIMPS it is quite easy

II: Cosmological Evidence for dark matter

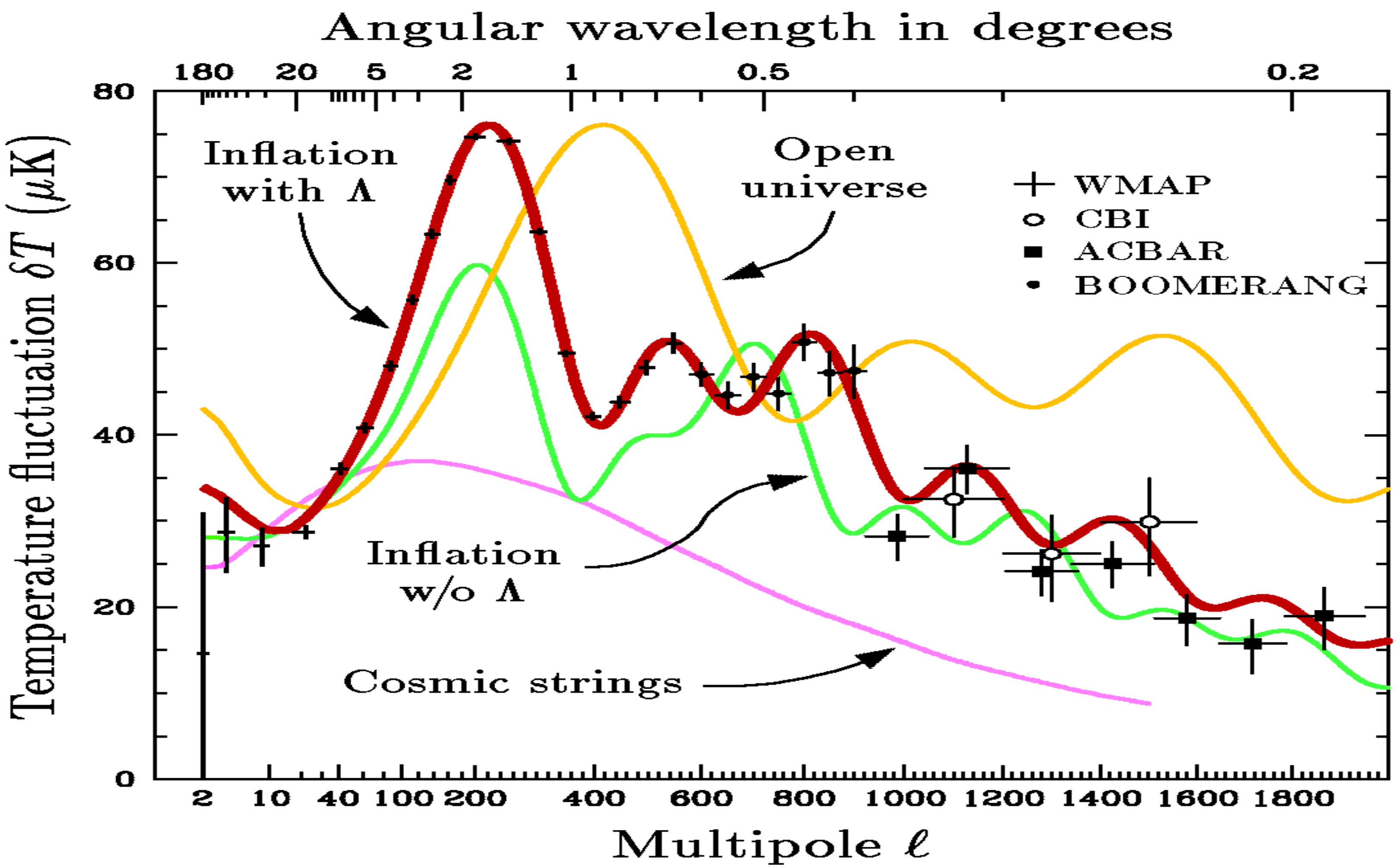
The 3 main reasons for the Big Bang Scenario:

- The receding of Galaxies (red shift) (Hubble 1929)
- The Microwave Background Radiation (CMBR – Penzias and Wilson 1964)
- The Big Bang Nucleosynthesis (BBN, 1946)

All bear a signature of dark matter

(BBN also gave the first argument for CMBR, but nobody paid any attention)

Anisotropy in the CMBR (cont.)



IIc: Light curves : d_L vs red shift z (Generalization of Hubble's Law to Large Distances)

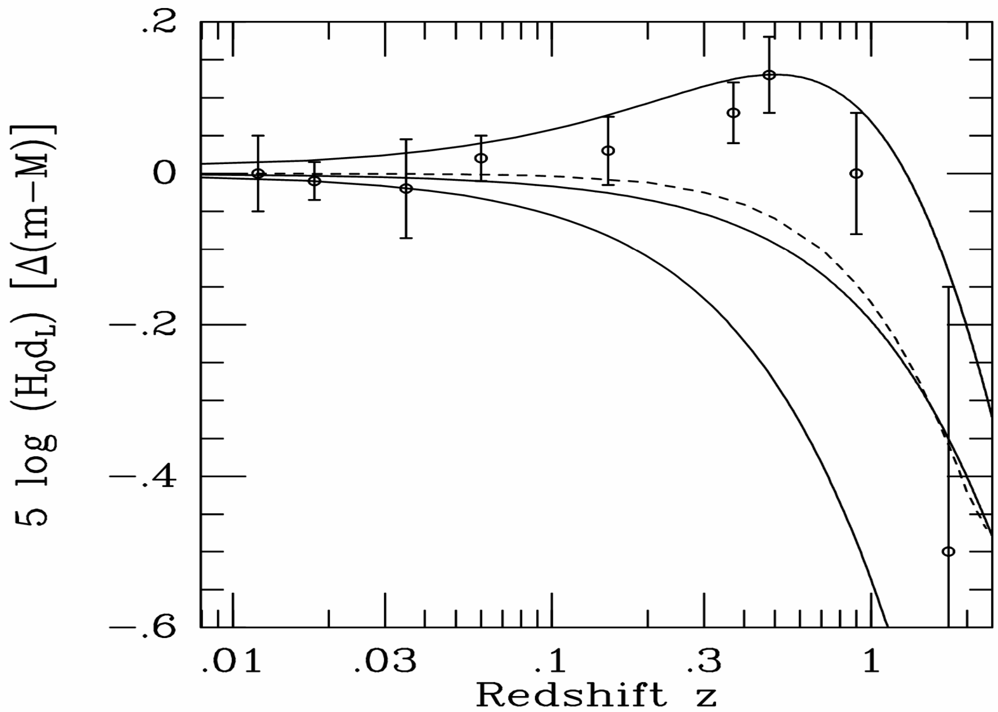
- Upper continuous

  $\Omega_\Lambda = 0.7, \Omega_M = 0.3$

- Middle continuous

- Lower continuous

- Dashed-
  Non accelerating
  universe



B1 Kaluza-Klein theories WIMP:$B^{(1)}$ K-K $q^{(1)}$exchange-The axial current.

$$\mathcal{M}_{spin} = -i4\sqrt{2}G_F m_W \tan^2\theta_W \frac{1}{3}\frac{m_p m_W}{(m_{B^{(1)}})^2} f_1(\Delta)$$

$$i(\boldsymbol{\epsilon}^{*\prime} \times \boldsymbol{\epsilon}).[N\boldsymbol{\sigma}(g_0 + g_1\tau_3)N] \qquad (0.2)$$

with

$$g_0 = \frac{17}{18}\Delta u + \frac{5}{18}\Delta d + \frac{5}{18}\Delta s$$

while the isovector part is:

$$g_1 = \frac{17}{18}\Delta u - \frac{5}{18}\Delta d$$

The quantities Δ_q are given by

$\Delta u = 0.78 \pm 0.02$, $\Delta d = -0.48 \pm 0.02$, $\Delta s = -0.15 \pm 0.02$

We thus find

$$g_0 = 0.26 \ , \ g_1 = 0.41$$

In the proton neutron representation we find:

$$a_p = 0.67 \ , \ a_n = -0.15$$

The picture is different for the neutralino case in which

$$g_0 = \Delta u + \Delta d + \Delta s = 0.15 \ , \ g_1 = \Delta u - \Delta d = 1.26$$

$$a_p = 1.41 \ , \ a_n = -1.11$$

B2 WIMP is the $\nu^{(1)}$. (continued) Z-Exchange Dominates.

The nuclear cross sections are:

$$\sigma(spin) = \frac{\mu_r^2}{m_p^2}\frac{\sigma_N(spin)}{3}\left[\Omega_p - \Omega_n\right]^2 F_{11}(q) \qquad (0.7)$$

where Ω_p and Ω_n are the nuclear spin ME associated with the proton and neutron component and $F_{11}(q)$ is the spin response function.

The coherent cross section becomes

$$\sigma_N(coh) = \sigma(spin) = \frac{\mu_r^2}{m_p^2}\sigma_n(coh)N^2\left[F(q)\right]^2 \qquad (0.8)$$

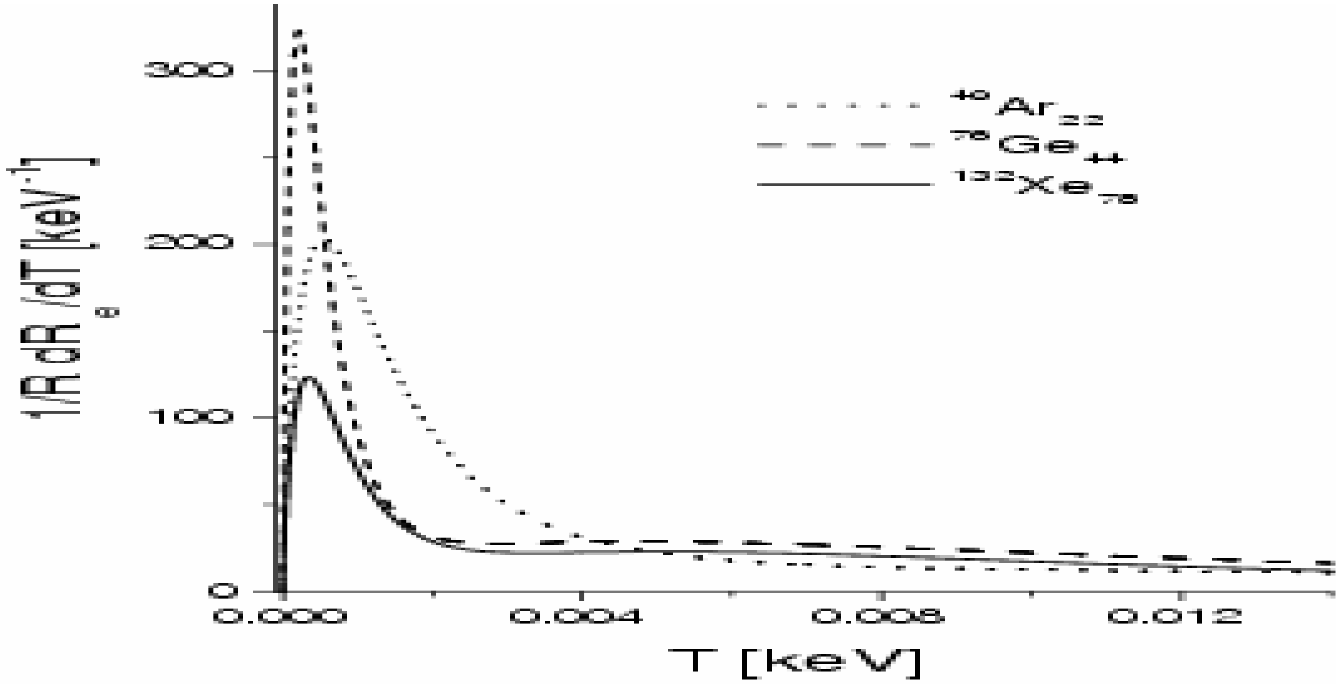
Where N is the neutron number and $F(q)$ the nuclear form factor.

A Majorana neutrino is perhaps viable!

Spin Contribution $\Leftrightarrow$ Axial Current

- Going from quark to the nucleon level for the isovector component is standard (as in weak interactions):
  $f^1_A(q) \Rightarrow f^1_A = g_A f^1_A(q)$, $g_A = 1.24$
- For the isoscalar this is not trivial. The naïve quark model fails badly (the proton spin crisis)
  $f^0_A(q) \Rightarrow f^0_A = g^0_A f^0_A(q)$, $g^0_A = 0.1$

The relative differential Rate, $(dR_e/dT_e)/R_{recoil}$, vs the electron energy T for electron production in LSP-nucleus (Moustakidis, Ejiri, JDV).



Detection of hard X-rays (events relative to recoil) (continued)

- The interesting quantity is:
- $(\sigma_K (K_{ij})/\sigma_r)=(\sigma_{1s}/\sigma_r)\, b_{1s}\, B(K_{ij})$
- Where:
- $b_{n\ell}$ =Fluorecence ratio, K_{ij} =K-ij branch

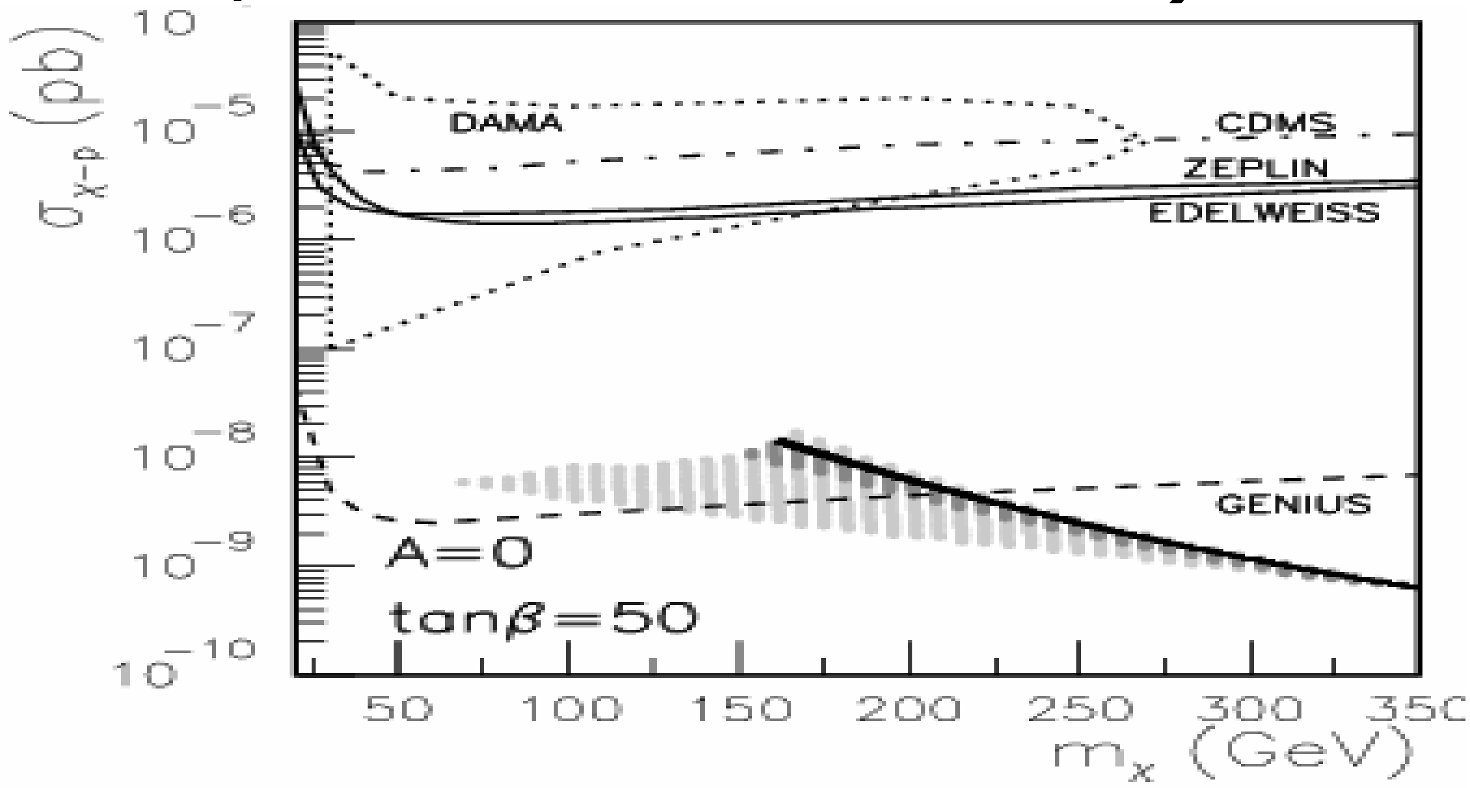
CONCLUSIONS-Directional Rates

- Good signatures, but the experiments are hard (the DRIFT experiment cannot tell the sense of direction of recoil)
- Large asymmetries are predicted
- The rates are suppressed by a factor $\kappa/2\pi$, $\kappa<0.6$
- For a given LSP velocity distribution, κ depends on the direction of observation
- In the most favored direction κ is approximately 0.6
- In the plane perpendicular to the sun's velocity κ is approximately equal to 0.2

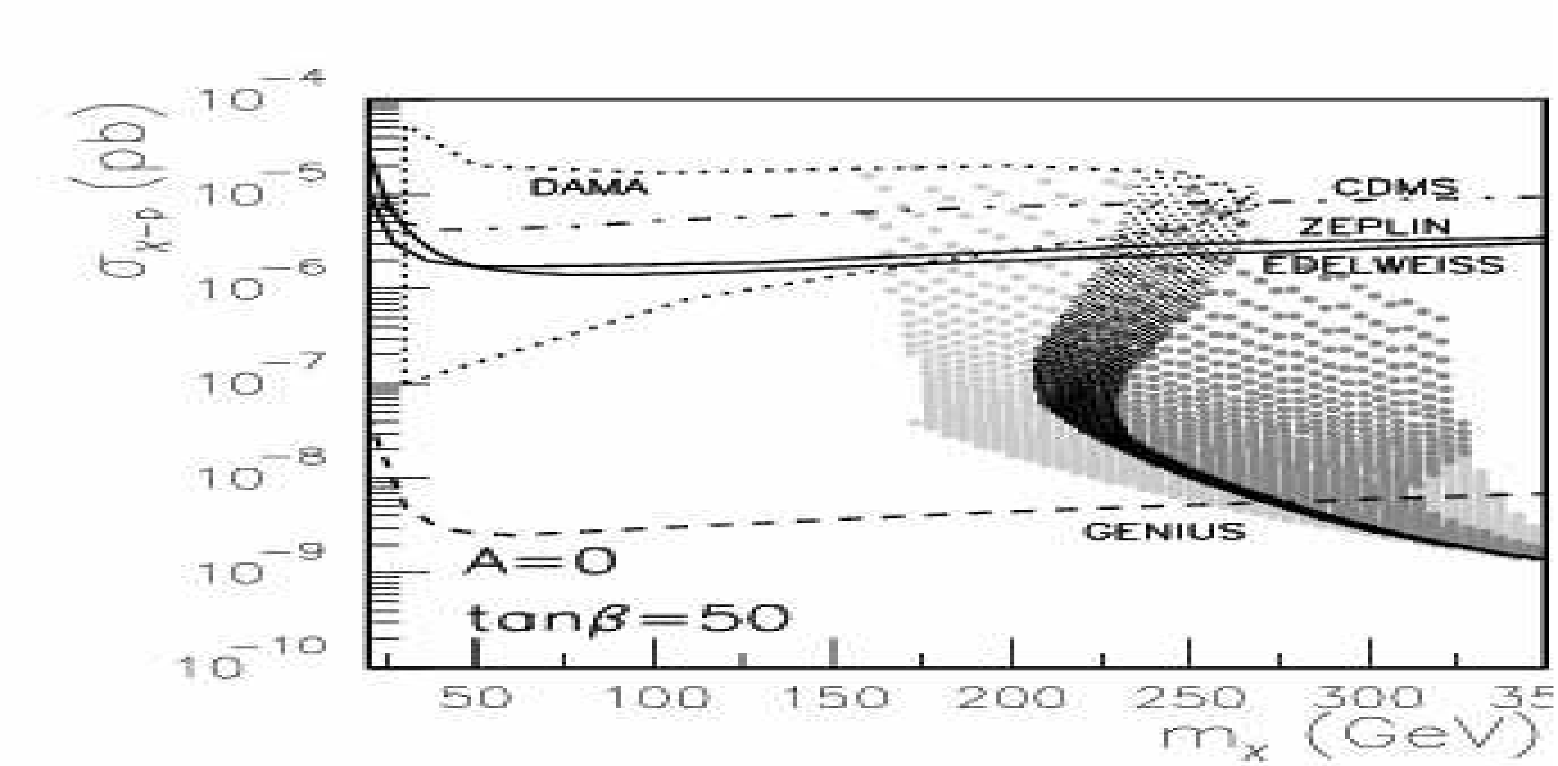
CONCLUSIONS- Modulation in Directional Experiments

- The Directional rates also exhibit modulation
- In the most favored direction of observation, opposite to the sun's motion, the modulation is now twice as large. (Maximum in June, Minimum in December)
- In the plane perpendicular to the sun's motion the modulation is much larger. The difference between the maximum and the minimum can be as high as 50%. It also shows a direction characteristic pattern (for observation directions on the galactic plane the maximum may occur in September or March, while normal behavior for directions perpendicular to the galaxy)

A typical Scatter Plot (Universal set of parameters) (Ceredeno, Gabrielli, Gomez and Munoz)



A Scatter Plot (Non Universal) (Ceredeno, Gabrielli, Gomez and Munoz)



The event rate due to the spin

$$\bar{\Sigma}_{spin} = (\frac{\mu_r}{\mu_r(p)})^2 \sigma_{p,\chi^0}^{spin} \ \zeta_{spin}, \zeta_{spin} = \frac{1}{3(1+\frac{f_A^0}{f_A^1})^2} S(u) \tag{0.1}$$

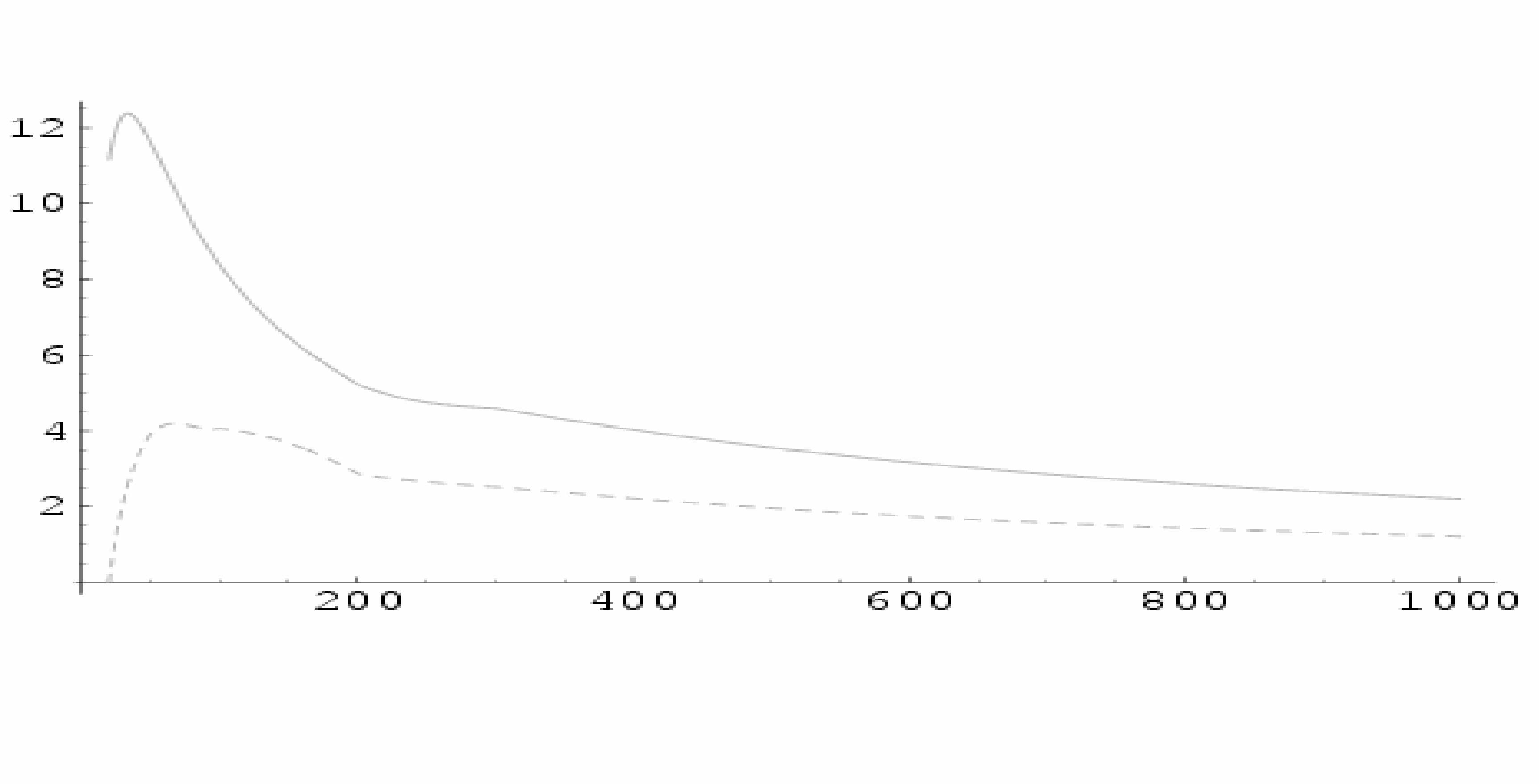
$$S(u) \approx S(0) = [(\frac{f_A^0}{f_A^1}\Omega_0(0))^2 + 2\frac{f_A^0}{f_A^1}\Omega_0(0)\Omega_1(0) + \Omega_1(0))^2\ ] \tag{0.2}$$

- Where $f^0_A = a_p + a_n$ (isoscalar) and $f^1_A = a_p - a_n$ (isovector) couplings at the nucleon level and $\Omega_0(0)$, $\Omega_1(0)$ the corresponding static spin matrix elements
- The event rate is cast in the form:

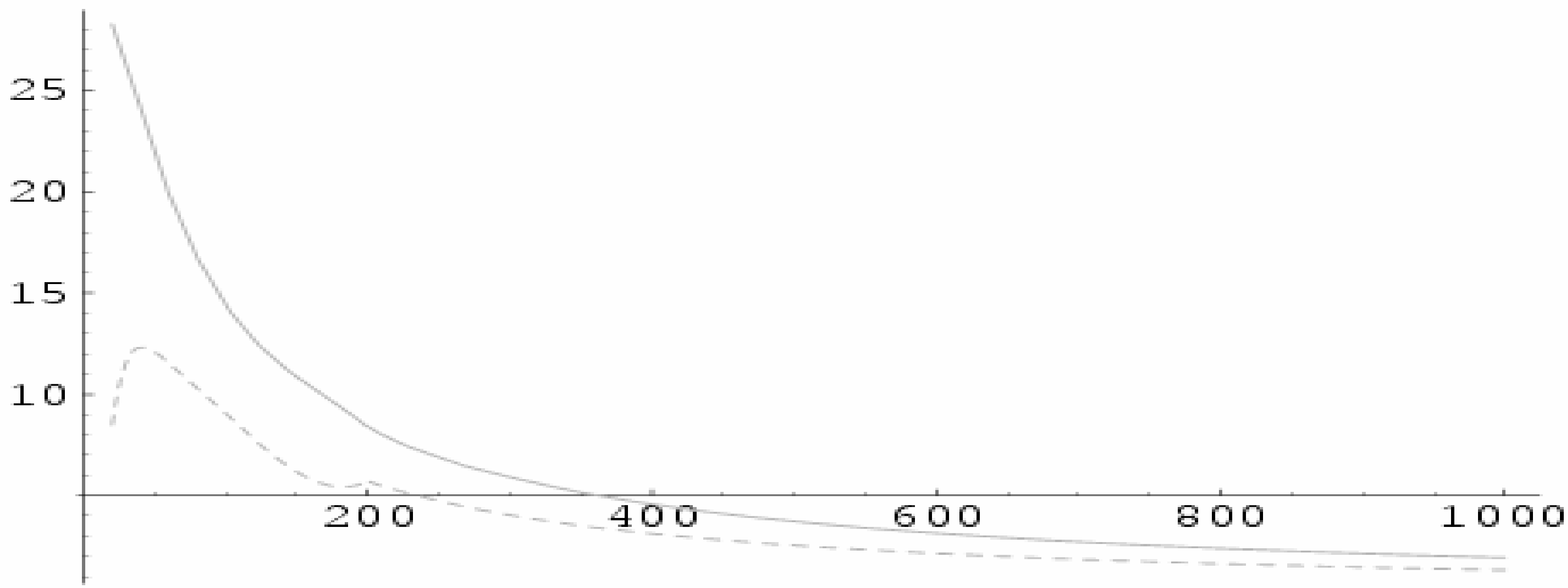
$$R = 160 \quad (10^{-5}pb)^{-1} y^{-1} \frac{\rho(0)}{0.3GeVcm^{-3}} \frac{m}{1Kg} \frac{\sqrt{\langle v^2 \rangle}}{280kms^{-1}}$$

$$f_{spin}(A, m_{\chi^0}) \sigma_{p,\chi^0}^{spin} \ \zeta_{spin}$$

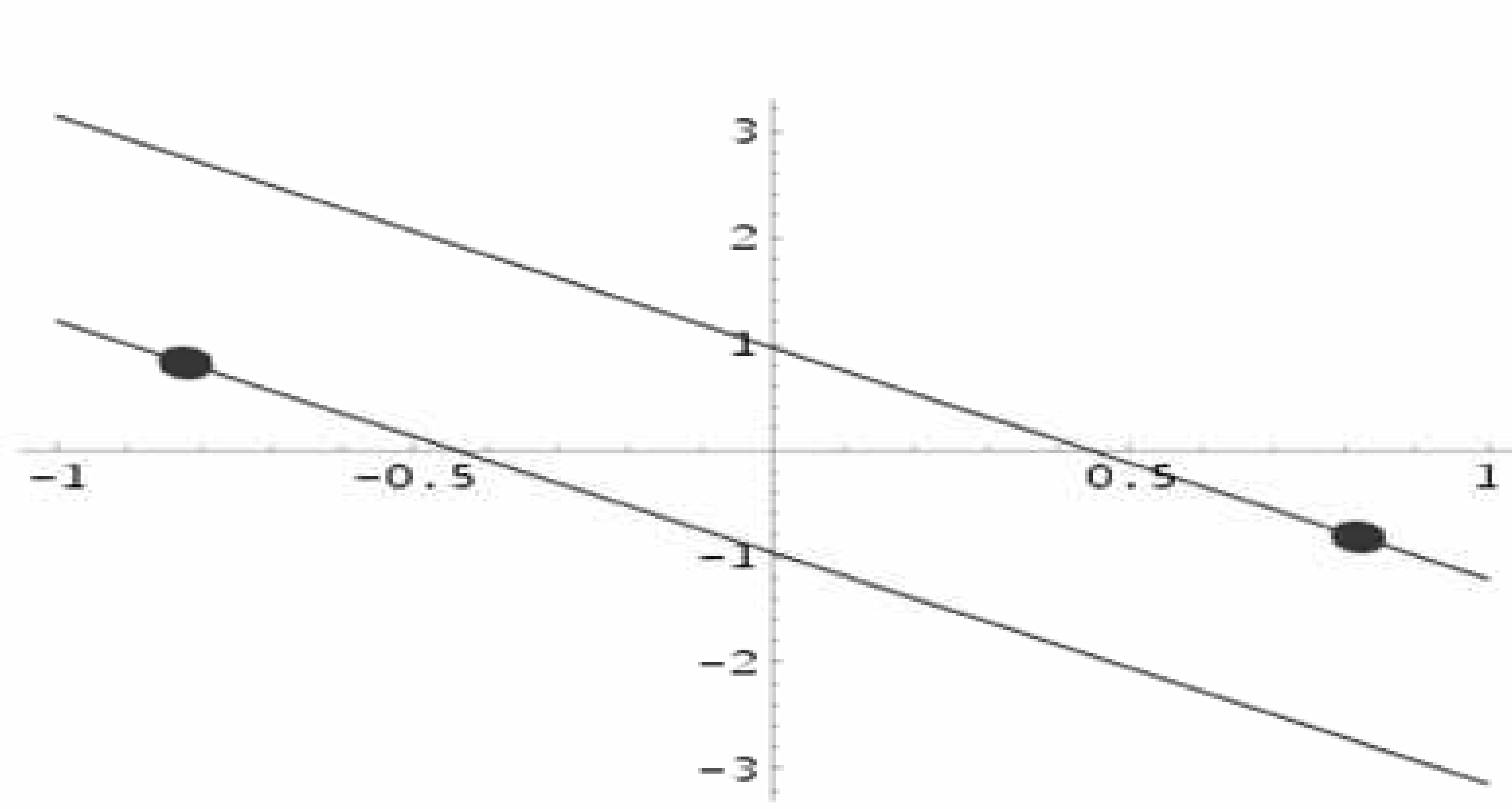
The factor $f_{spin}(A,m_\chi)$ for A=127 (I) (The Dashed for threshold 10keV)



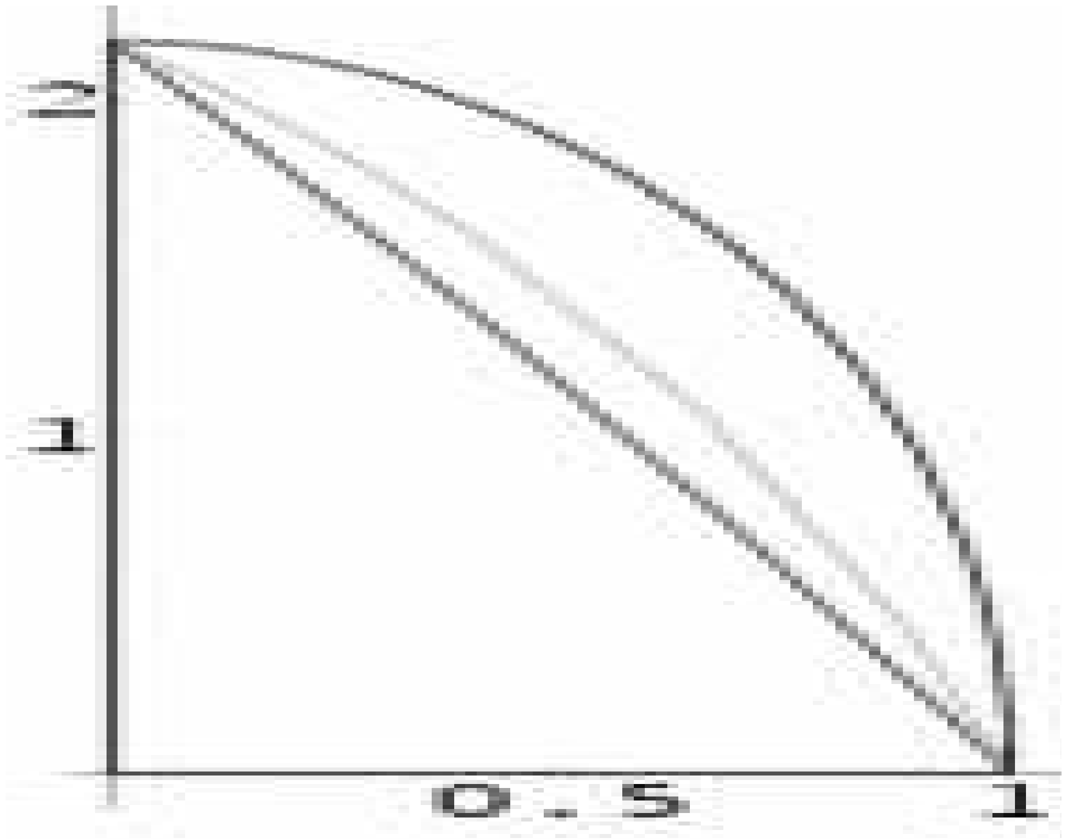
The factor $f_{spin}(A,m_\chi)$ for A=19 (F) (The Dashed for threshold 10keV)



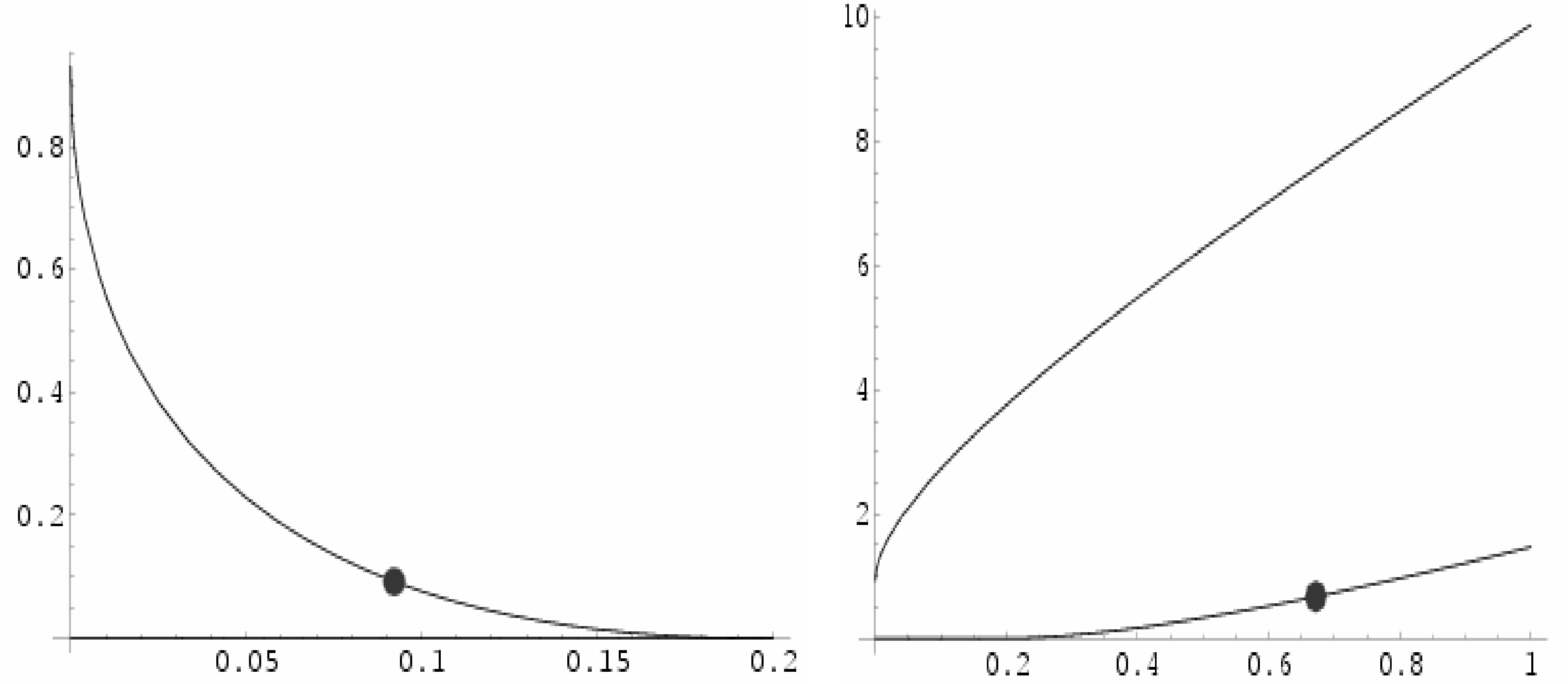
The constrained amplitude plane ($a_{p,\chi}$,$a_{n,\chi}$) for the A=127 system (arbitrary units), when they are relatively real.



The constrained $(a_{p,\chi}, a_{n,\chi})$ plane: relative phase of the amplitudes $\delta=\pi/6$ (-), $\delta=\pi/3$ (-)and $\delta=\pi/2$ (-)



The constrained $(\sigma_{p,\chi},\sigma_{n,\chi})$ plane for the A=127 system (arbitrary units). Under the curve on the left, if the amplitudes have the same sign and between the curves on the right for opposite sign.



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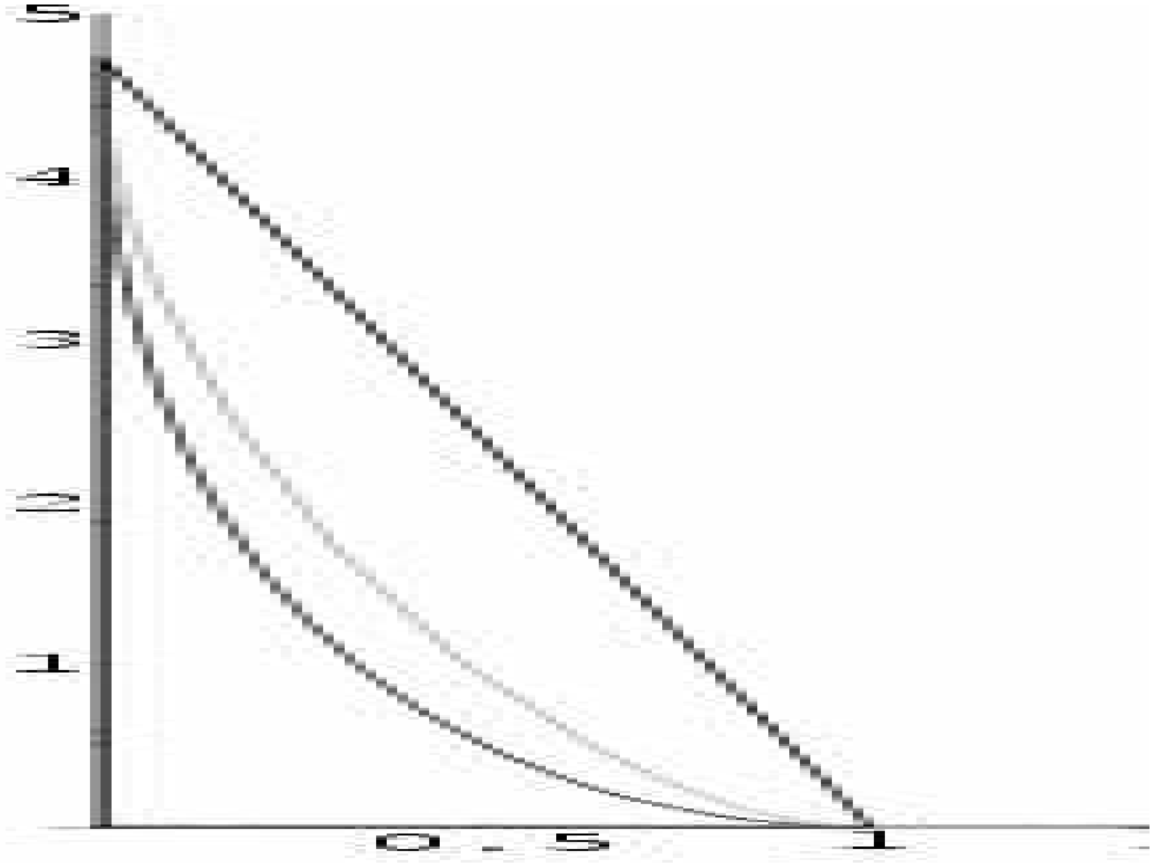

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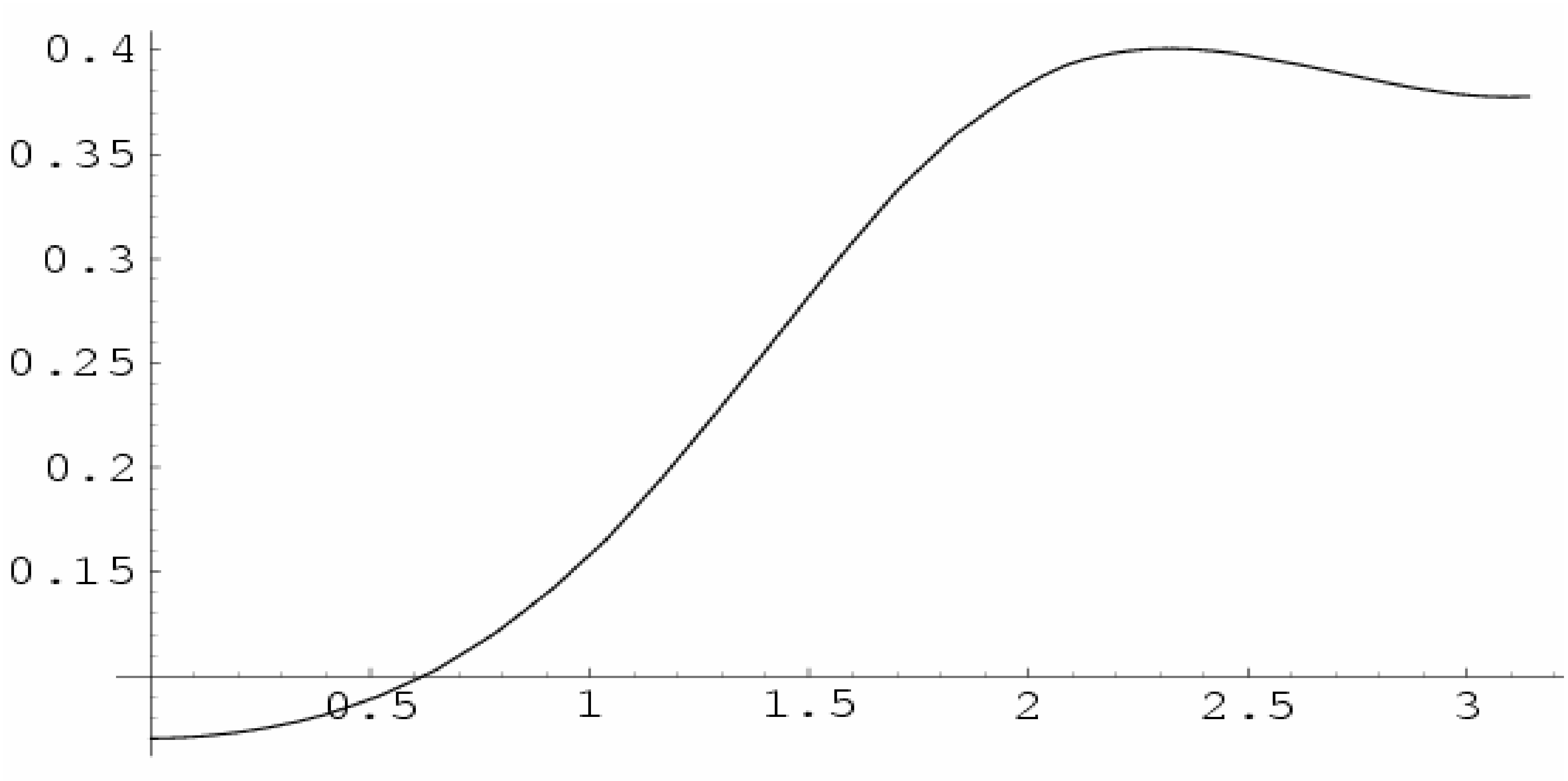
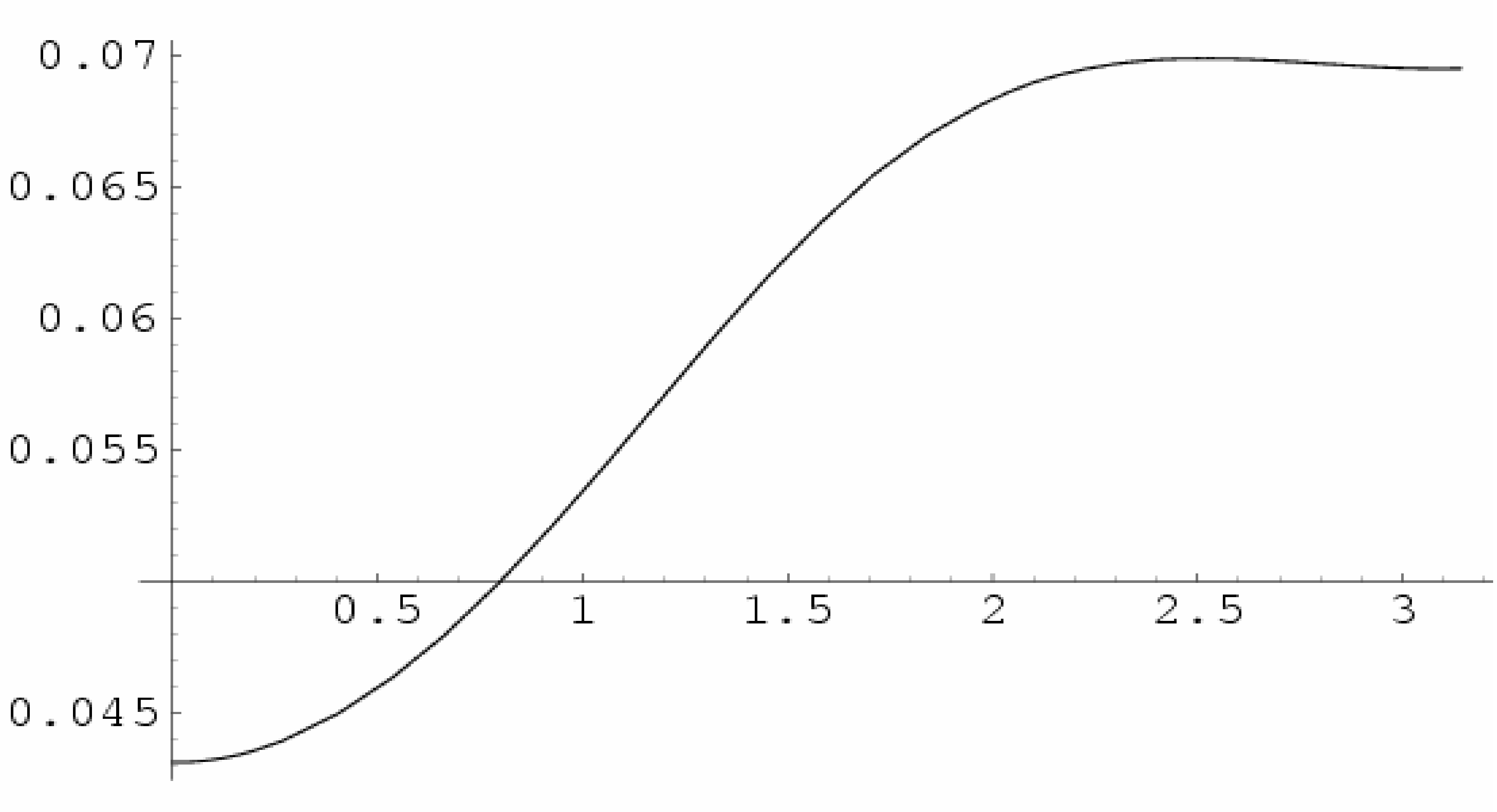
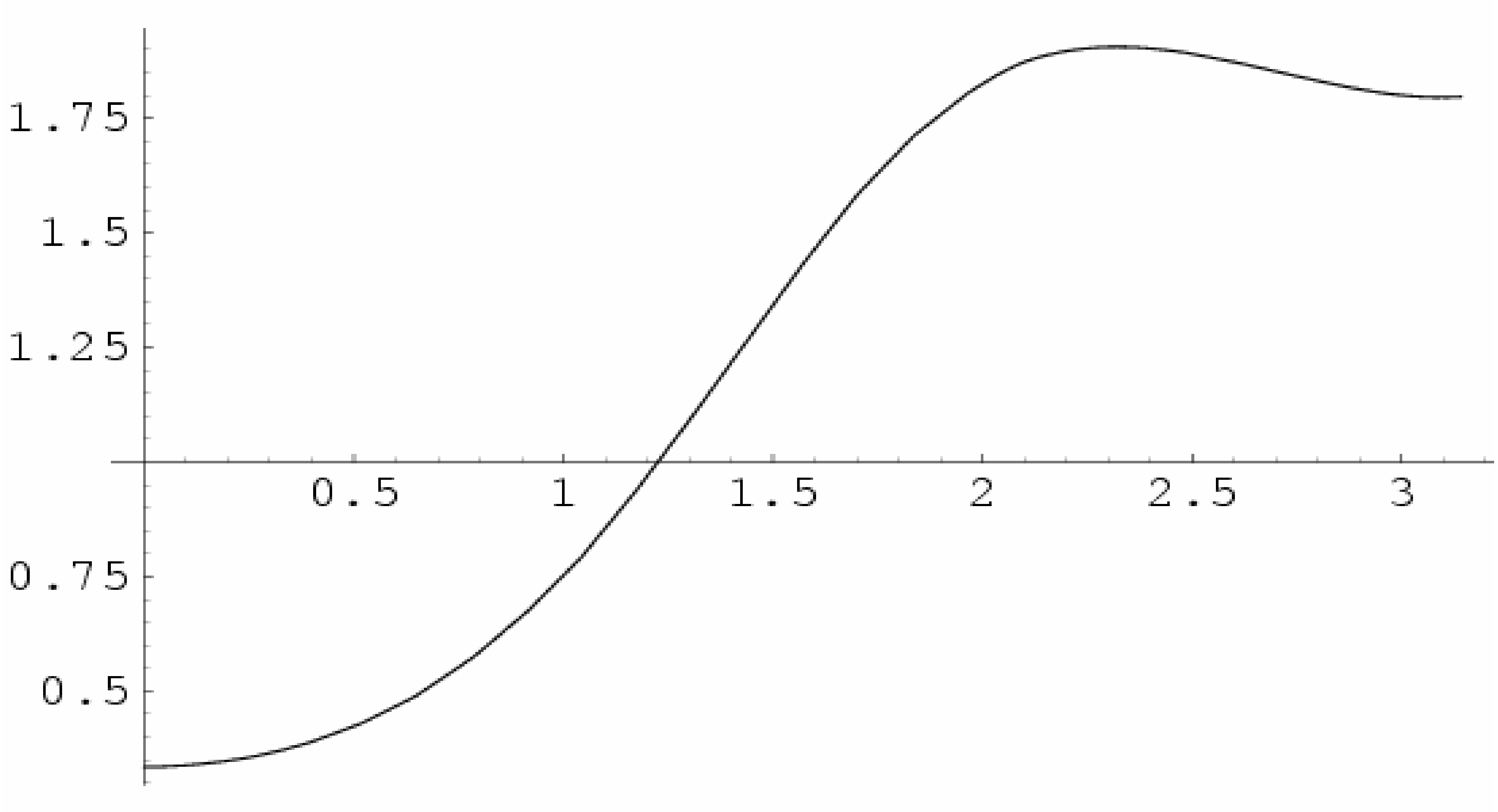


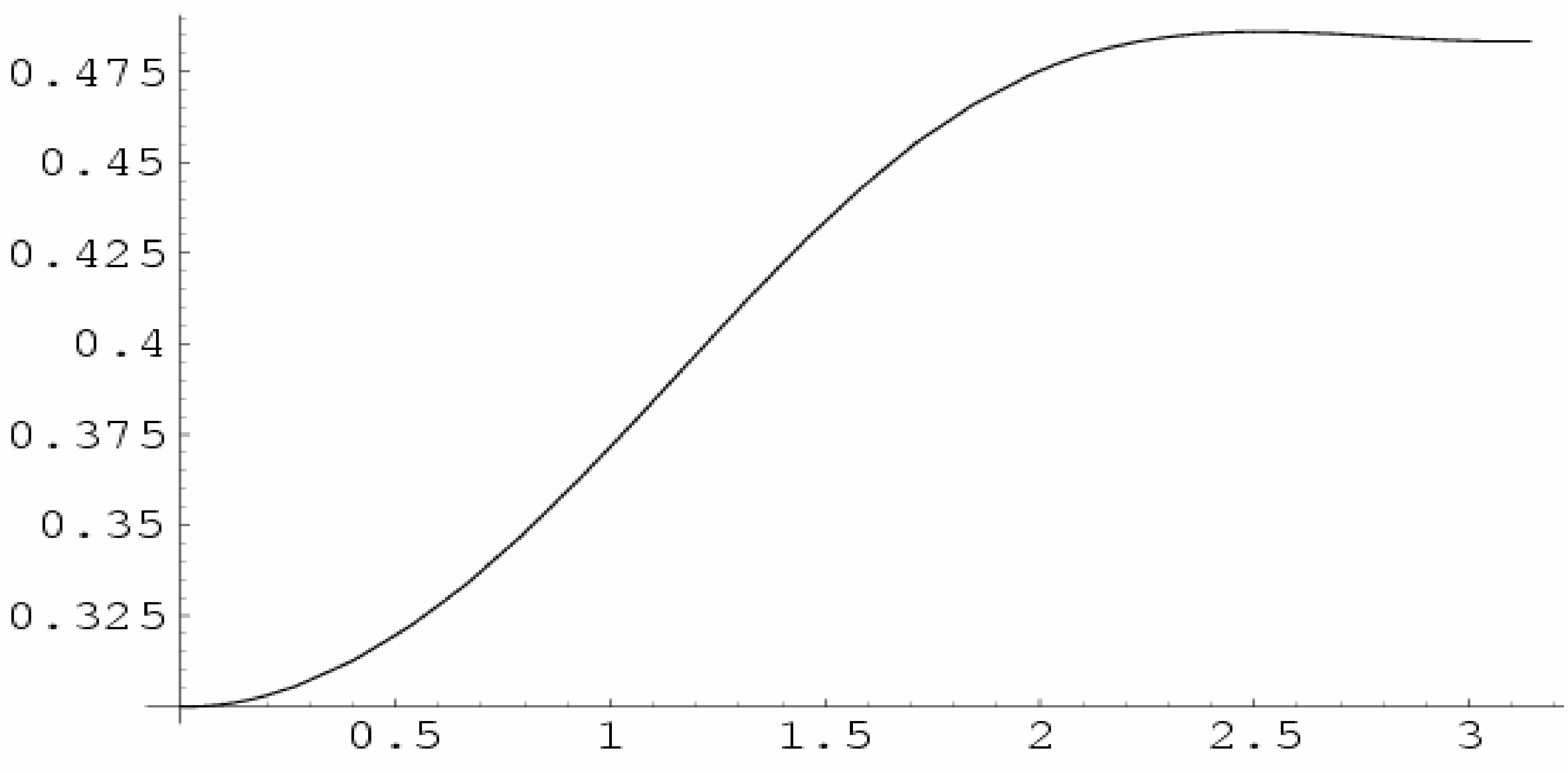
The Directional rate t_{dir} in the case of ^{127}I for wimp mass of 100 GeV M-B distribution m=2)



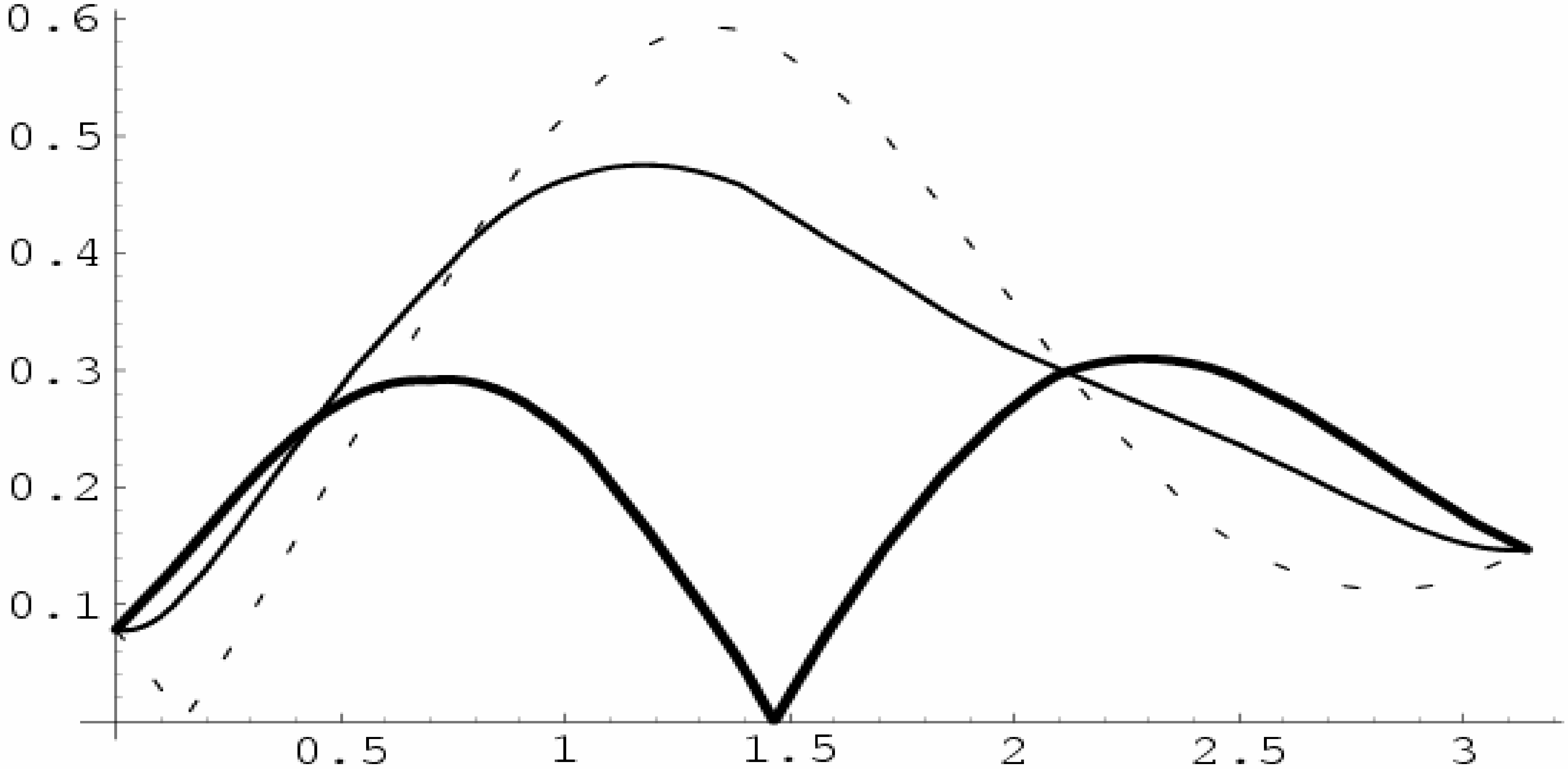
The parameter κ vs the polar angle in the case of A=127, right for m_χ=100 GeV(M-B distribution m=1)



The parameter κ vs the polar angle in the case of A=127, right for m_χ=100 GeV(M-B distribution m=2)



Directional Rate: Modulation vs Θ m_{wimp}=100 GeV,dotted⇔Φ=π, fine ⇔Φ=0, thick⇔Φ=π/2,3π/2 (m=1)



Directional Rate: Modulation vs Θ m_{wimp}=100 GeV,dotted⇔Φ=π, fine ⇔Φ=0, thick⇔Φ=π/2,3π/2 (m=2)