Neutralino dark matter in MSSM with CPV

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LAPTH-Annecy

PLAN

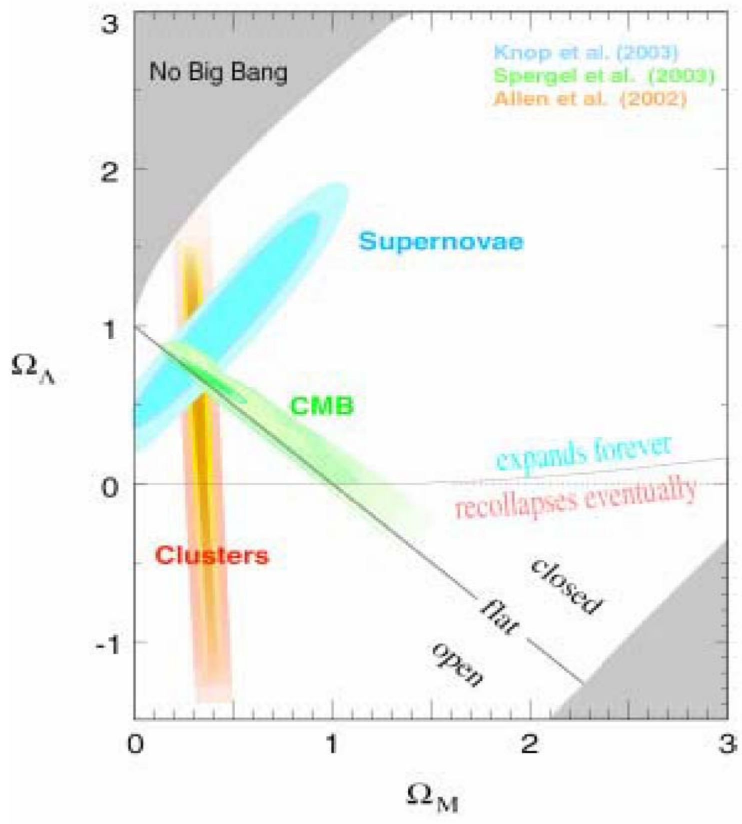
- Relic density of DM
- The CPV-MSSM
- Dark matter in the CPV-MSSM : impact of phases
- Some remarks on indirect detection
- Conclusion

Based on

GB, Boudjema, Kraml, Pukhov, Semenov, Phys.Rev.D60 (2006)

Dark matter: measurements

- In recent years : new precise determination of cosmological parameters
- Data from CMB (WMAP) agree with the one from clusters and supernovae
  - Dark matter: 23+/- 4%
  - Baryons: 4+/-.4%
  - Dark energy 73+/-4%
  - Neutrinos < 1%

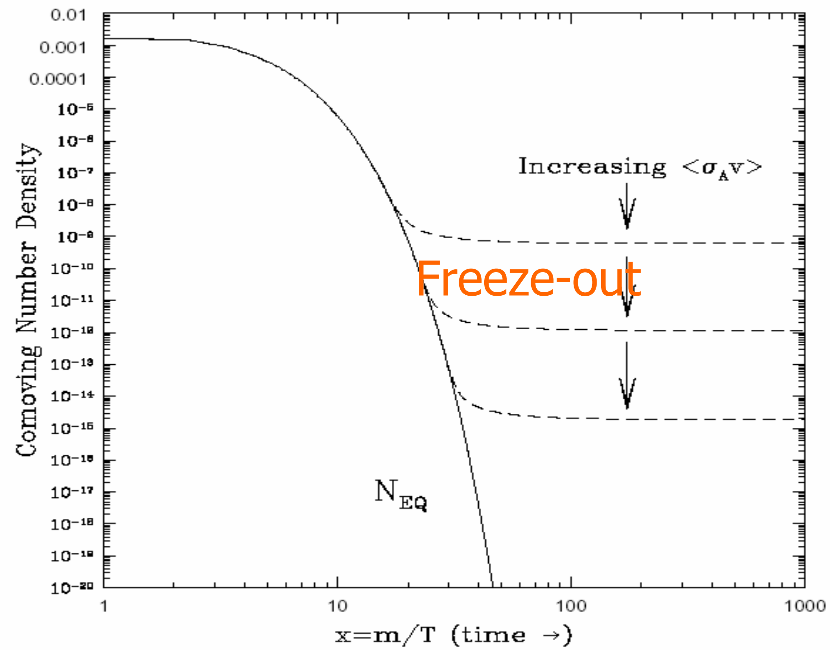


Relic density of SUSY DM

- The precise measurement of WMAP $0.095<\Omega h^2<.128$ provides strong constraints on candidates for DM in particular neutralino.
- At the moment predictions for Ωh^2 in MSSM varies by orders of magnitude (unknown parameters)
- Colliders will search for SUSY, might discover and measure properties of sparticles
  - refine predictions for relic density
  - see whether fits with measurements or is it necessary to modify cosmological model.

Relic density of wimps

- In early universe WIMPs are present in large number and they are in thermal equilibrium
- As the universe expanded and cooled their density is reduced through pair annihilation
- Eventually density is too low for annihilation process to keep up with expansion rate
  - Freeze-out temperature
- LSP decouples from standard model particles, density depends only on expansion rate of the universe



$$\frac{dn}{dt} = -3Hn - <\sigma v> \left[n^2 - n_{eq}^2\right]$$

Coannihilation

- If M(NLSP)~M(LSP) then $\chi + X \rightarrow \chi' + Y$ maintains thermal equilibrium between NLSP-LSP even after SUSY particles decouple from standard ones
- Relic density depends on rate for all processes involving LSP/NLSP → SM
- All particles eventually decay into LSP, calculation of relic density requires summing over all possible processes

Exp(- ΔM)/T

$$<\sigma v> = \frac{\sum_{i,j} g_i g_j \int_{(m_i+m_j)^2} ds \sqrt{s} K_1(\sqrt{s}/T) p_{ij}^2 \sigma_{ij}(s)}{2T\left(\sum_i g_i m_i^2 K_2(m_i/T)\right)^2}$$

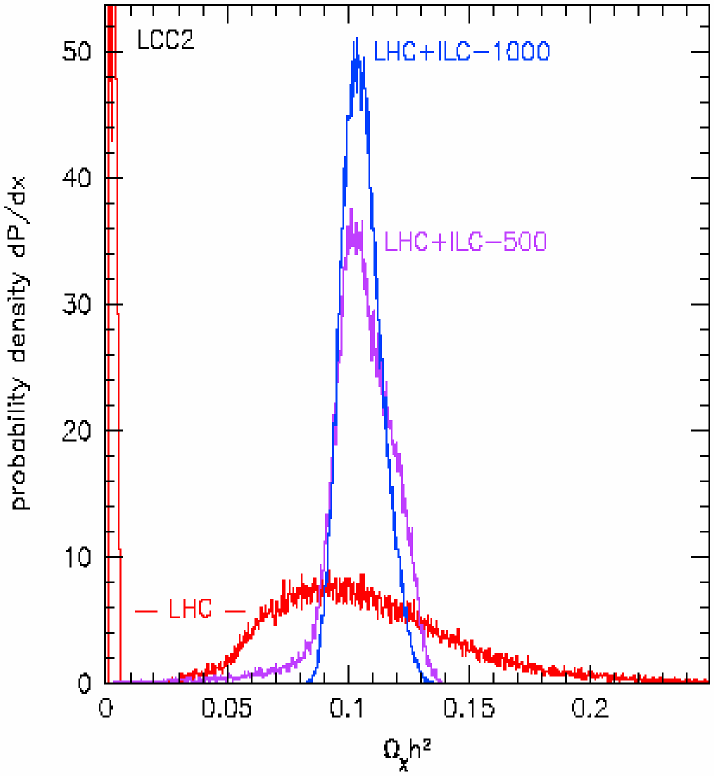
- Important processes are those involving particles close in mass to LSP
- Public codes to calculate relic density: micrOMEGAs, DarkSUSY, IsaRED

Probing cosmology using collider information

- Whether prediction for relic density can have sufficient precision (within the context of a given model) to be useful (at the level of WMAP(15%) or PLANCK (6%)) depends on the SUSY or New physics scenario.
- Many parameters enter computation of relic density, only a handful of relevant ones for each scenario – work is going on in North America, Asia and Europe to determine both the LHC and ILC potential
  - Moroi, Bambade, Richard, Zhang, Martyn, Tovey, Polesello, Lari, D. Zerwas, Allanach, Belanger, Boudjema, Pukhov, Battaglia, Birkedal, Gray, Matchev, Alexander, Fields, Hertz, Jones, Meyraiban, Pivarski, Peskin, Dutta, Kamon, Arnowitt, Khotilovith, Nojiri…

An example in MSSM … bino/Higgsino LSP

- Improving precision on prediction of relic density using collider information
- Recent study of determination of parameters and reconstruction of relic density in a few scenarios: e.g. bino/Higgsino
- LHC: not enough precision
- ILC: chargino pair production sensitive to bino/Higgsino mixing parameter
- ILC: roughly 15% precision on Ωh^2



Baltz et al hep-ph/0602187

Precise prediction of relic density…

- But this assumes that all SUSY parameters are real…
- Phases can induce large shifts in relic density.

CPV-MSSM

- Phases are generic

- MSSM with phases might explain baryonic asymmetry of the universe-electroweak baryogenesis
  - Need strong first order phase transition
  - Finite temperature effective potential
  - $V= AT^2\varphi^2 - ET\,\varphi^3 + \lambda\varphi^4$, condition : $2E/\lambda>1$
  - In SM requires Higgs mass < 50 GeV
  - New physics solution: light RH stops in MSSM + light neutralino/chargino +CP (Carena et al)

CPV-MSSM –The model

- Parameters of the model (universality)

  M_1, μ, $\tan\beta$, M_{H+} , M_S, A_t, A_f=1TeV
- Phases
  - $\Phi(\mu)$: strongly constrained by edm
  - $\Phi(M_1)$
  - $\Phi(M_3)$: mostly irrelevant for relic
  - $\Phi(A_t)$: Higgs mass and mixing + also stop sector (if stop NLSP)
  - $\Phi(A_\tau)$: relevant for relic if stau NLSP
  - $\Phi(A_e)$: irrelevant for relic, important for edm

Neutralino LSP

- Prediction for relic density depend on parameters of model
  - Mass of neutralino LSP
  - Nature of neutralino : determine the coupling to Z, h, A …
    - M1 <M2<μ bino
    - μ <M1,M2 Higgsino
    - M2<M1< μ Wino

$$\begin{pmatrix} M_1 & 0 & -m_Z\cos\beta\sin\theta_W & m_Z\sin\beta\sin\theta_W \\ 0 & M_2 & m_Z\cos\beta\cos\theta_W & -m_Z\sin\beta\cos\theta_W \\ -m_Z\cos\beta\sin\theta_W & m_Z\cos\beta\cos\theta_W & 0 & -\mu \\ m_Z\sin\beta\sin\theta_W & -m_Z\sin\beta\cos\theta_W & -\mu & 0 \end{pmatrix}$$

$$\tilde{\chi}_1^0 = Z_{11}\tilde{B}^0 + Z_{12}\tilde{W}_3^0 + Z_{13}\tilde{H}_d^0 + Z_{14}\tilde{H}_u^0 \ .$$

CPV-MSSM

- Higgs sector: mixing between 3 states (h,H,A), no longer eigenstates of CP: h1,h2,h3
- Neutralino couplings to Higgs

$$\mathcal{L}_{\tilde{\chi}_1^0\tilde{\chi}_1^0 h_i} = -\frac{g}{2}\sum_{i=1}^{3} \overline{\tilde{\chi}_1^0}\left(g^S_{h_i\tilde{\chi}_1^0\tilde{\chi}_1^0} + i\gamma_5 g^P_{h_i\tilde{\chi}_1^0\tilde{\chi}_1^0}\right)\tilde{\chi}_1^0 h_i$$

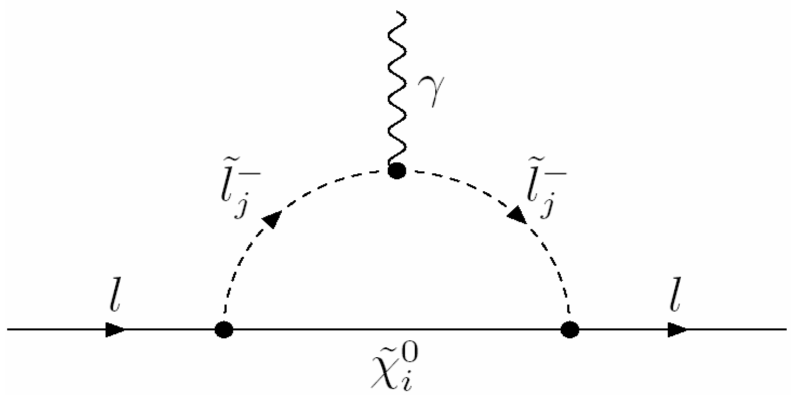
$$g^S_{h_i\tilde{\chi}_1^0\tilde{\chi}_1^0} = Re\left[\left(N^*_{12} - t_W N^*_{11}\right)\left(H_{1i}N^*_{13} - H_{2i}N^*_{14} - iH_{3i}(s_\beta N^*_{13} - c_\beta N^*_{14})\right)\right]$$

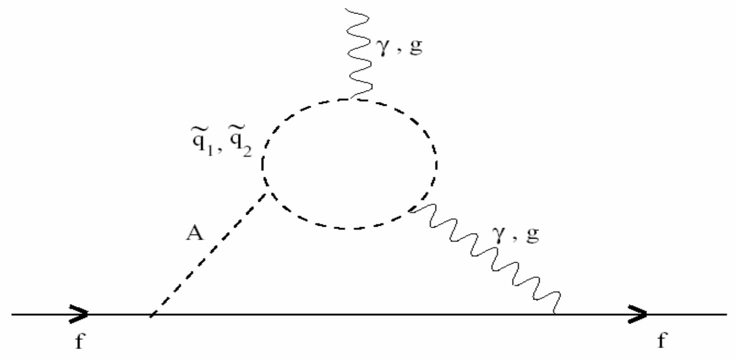
- Neutralino-Chargino W couplings

$$\mathcal{L}_{\tilde{\chi}_j^0\tilde{\chi}_i^+ W^-} = g W^-_\mu \overline{\tilde{\chi}_j^0}\gamma^\mu\left(O^L_{ji}P_L + O^R_{ji}P_R\right)\tilde{\chi}_i^+ + \text{h.c.} \qquad O^L_{ji} = N_{j2}V^*_{i1} - \frac{1}{\sqrt{2}}N_{j4}V^*_{i2}$$

Electric dipole moment

- One loop chargino/neutralino
- Two-loops t,b,stop,sbottom
  - Can be dominant at large tanβ
- At small tan β, strong constraints on Φμ, much less constraints on Φ_1 Φ_t





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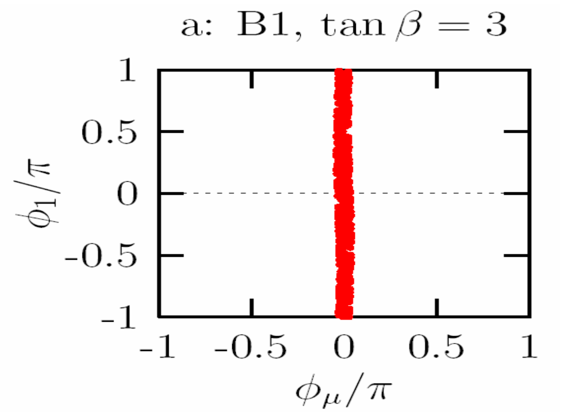
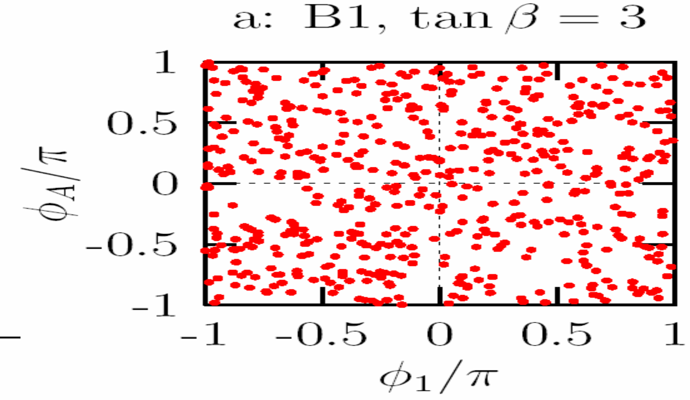




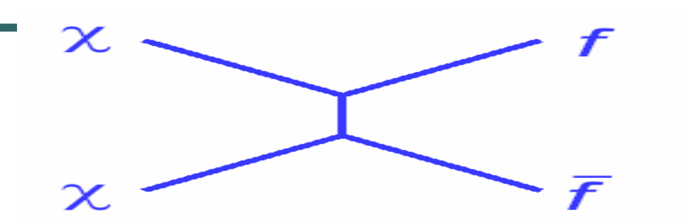
Choi, Drees, Gassmaier (2004)

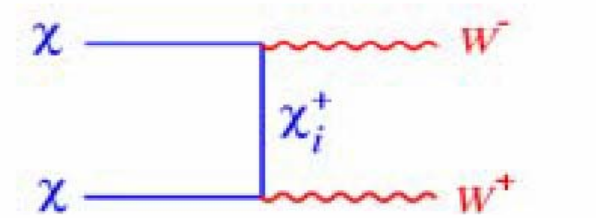
Neutralino dark matter - MSSM

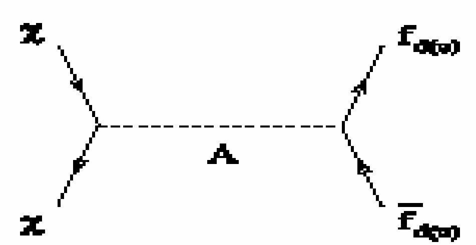
- bino LSP
- Bino/Higgsino
- Higgs resonance
- Sfermion coannihilation

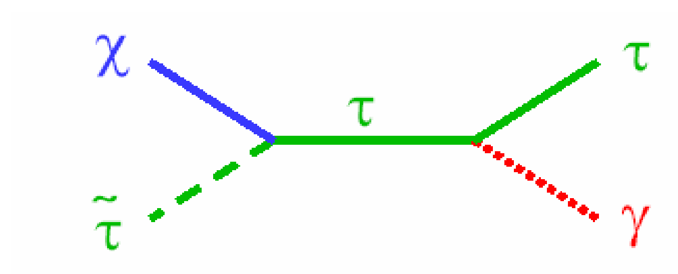
Neutralino annihilation

- Bino LSP annihilation into ff
  - $\sigma \sim m_\chi^2/m_f^4$
- Mixed bino-Higgsino (wino)
  - Coupling depends on Z_{12}, Z_{13}, Z_{14}, mixing of LSP
- Annihilation near resonance (Higgs)
  - Need some mixing with Higgsino
- Co-annihilation
  - Bino LSP (sfermion coannihilation)
  - Higgsino LSP- coannihilation with chargino and neutralinos



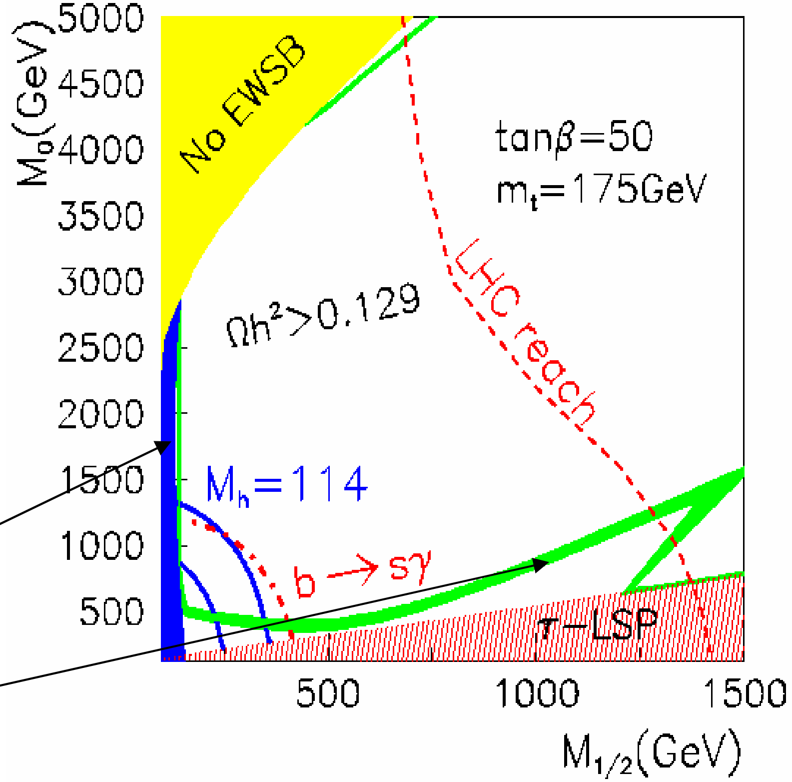






Neutralino in mSUGRA- WMAP

- bino – LSP
  - In most of mSUGRA parameter space
  - Works well for light sparticles but hard to reconcile with LEP/Higgs limit
- Mixed Bino-Higgsino
  - Annihilation into W pairs+coannihilation
  - More likely at large tanβ
- Resonance (Z, light/heavy Higgs)
  - LEP constraints for light Higgs/Z
  - Heavy Higgs at large tanβ (enhanced Hbb vertex)
- Sfermion coannihilation
  - Staus or stops
  - More efficient, can go to higher masses



Dark matter in CPV-MSSM

- Few studies of relic density of dark matter in MSSM with CP violation
  - Falk Olive Srednicki (1995), Nihei Sasagawa (2004), Argyrou et al (2004), Gomez et al (2005), Gondolo Freese (2002) Choi Kim (2006)
- Some report several orders of magnitude shifts in relic density due to phases -> these effects are mostly due to kinematic, e.g. LSP mass closer to Higgs resonance
- After taking into account the effects from shifts in masses, impact of phases on relic are more modest (still much larger than the uncertainty from WMAP).

CPV-MSSM & micrOMEGAs2.0

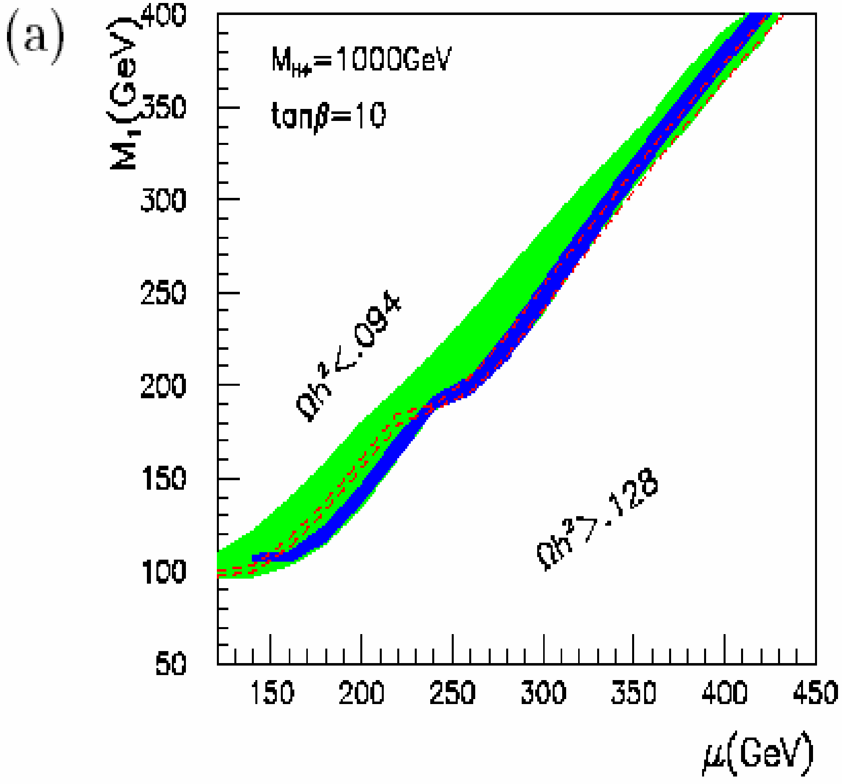
- Modify the model file in CalCHEP
- Complete tree-level matrix elements for all subprocesses from CalCHEP
- Automatically Include all possible annihilation and coannihilation channels
- Calculates the relic density for any LSP
- Solution of evolution equation and calculation of relic density with non-relativistic thermal averaging and proper treatment of poles and thresholds (Gondolo, Gelmini, NPB 360 (1991)145)
- Automatically check for presence of resonances and improves the accuracy near pole
- Interface to CPSuperH (J.S. Lee et al) : masses of Higgs and third generation and parameters of effective Higgs potential
- edm constraints are included

Neutralino dark matter – CPV-MSSM

- Same mechanisms for (co)-annihilation
- bino LSP
  - Phase itself does not impact much Ωh^2 (10-20%)
  - Higgs mass constraint is relaxed
  - If light sfermions exist LHC should tell us
- bino/Higgsino
- Higgs resonance
- Sfermion coannihilation

Bino/Higgsino

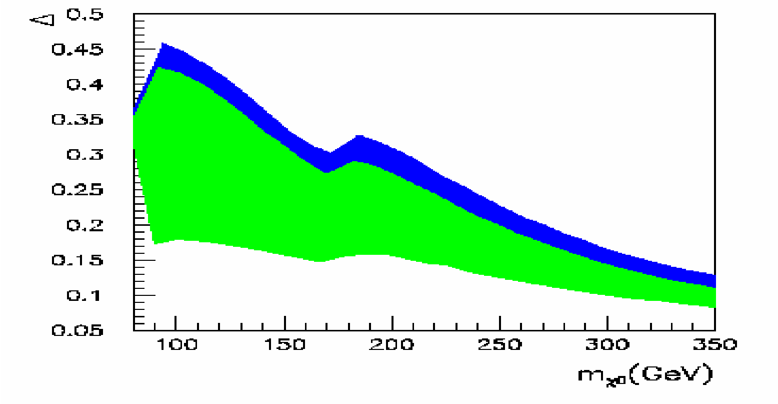
- With arbitrary phases, new allowed region where Ωh^2 below WMAP
- M(LSP) increases with φ_1
  - more chargino coannihilation
- $\chi 0 \chi + W$ coupling decreases with φ_1 -> smaller cross-section
  - Larger Higgsino fraction allowed



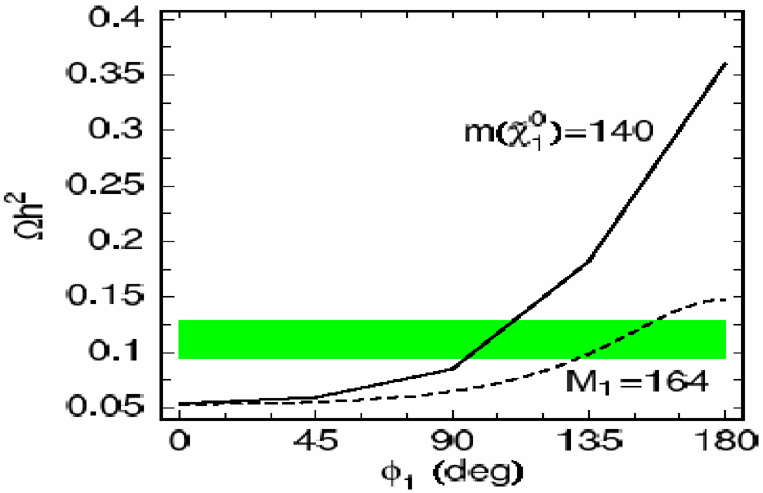
μ=500GeV,MS=1TeV

Bino/Higgsino

- Smaller mass splitting than expected in MSSM

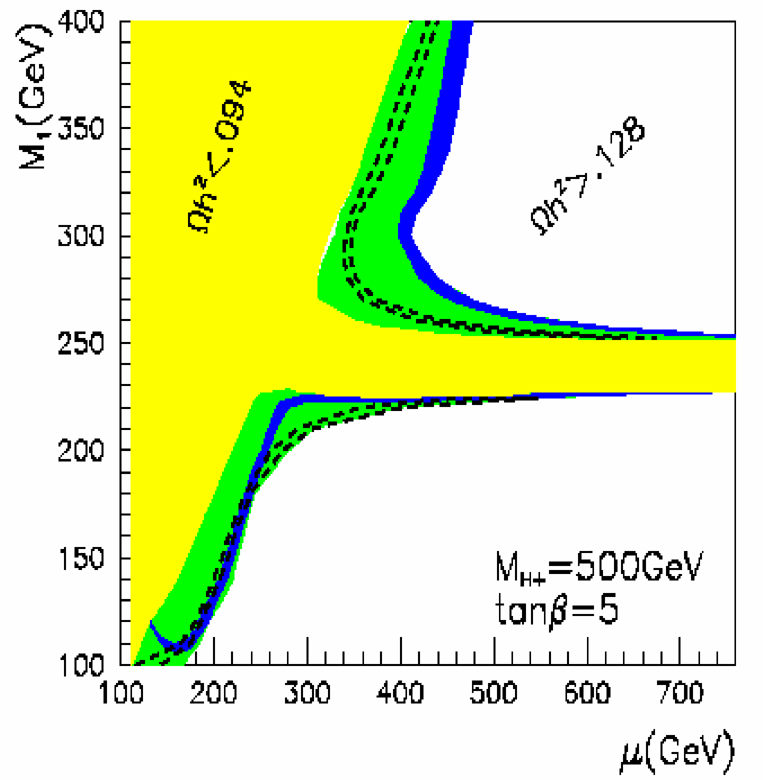


- In this scenario once mass effects are taken into account -> Shift in Ωh^2 more important



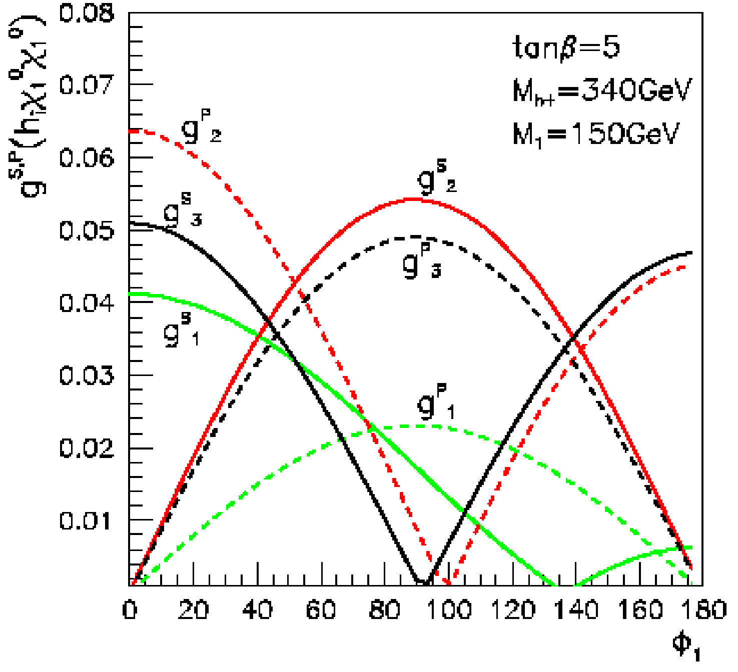
Lower M_H+=500GeV

- Higgs funnel (large μ OK)
- Allowed region varying all phases
- In bino/Higgsino much wider WMAP allowed region especially near Higgs resonance
  - much larger Higgsino fraction is allowed
  - Sensitivity to mass difference $2m_\chi - m_h$



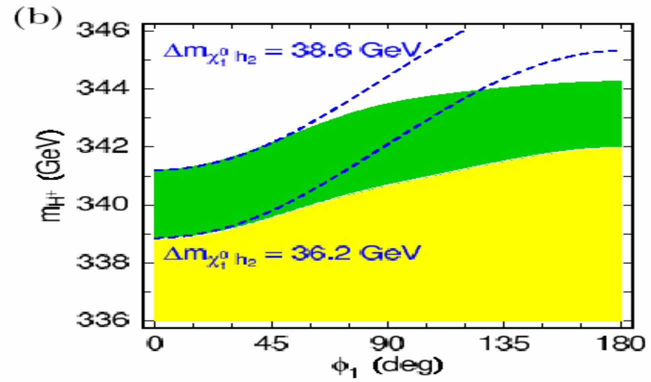
Annihilation near Higgs

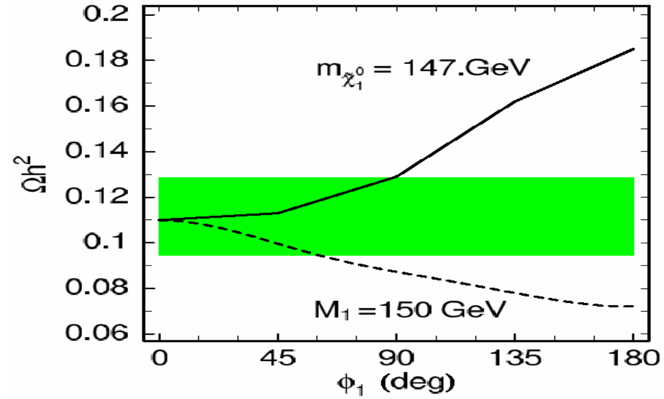
- Neutralino are Majorana, at v->0 only pseudoscalar exchange, thermal averaging some scalar contribution
- Phase affects $\chi\chi h$ couplings and relative contribution of h2 and h3
- Phase affects mass difference $2m_\chi - m_h$



Annihilation near Higgs

- Contours of constant Ωh^2 do not follow precisely contours of constant mass difference
- Once readjusting the LSP mass so that $2m_\chi - m_h$ is constant- large corrections with φ_1
- Also large shifts in masses with φ_t, even when keeping mass difference constant shifts in Ωh^2 can be one order of magnitude.



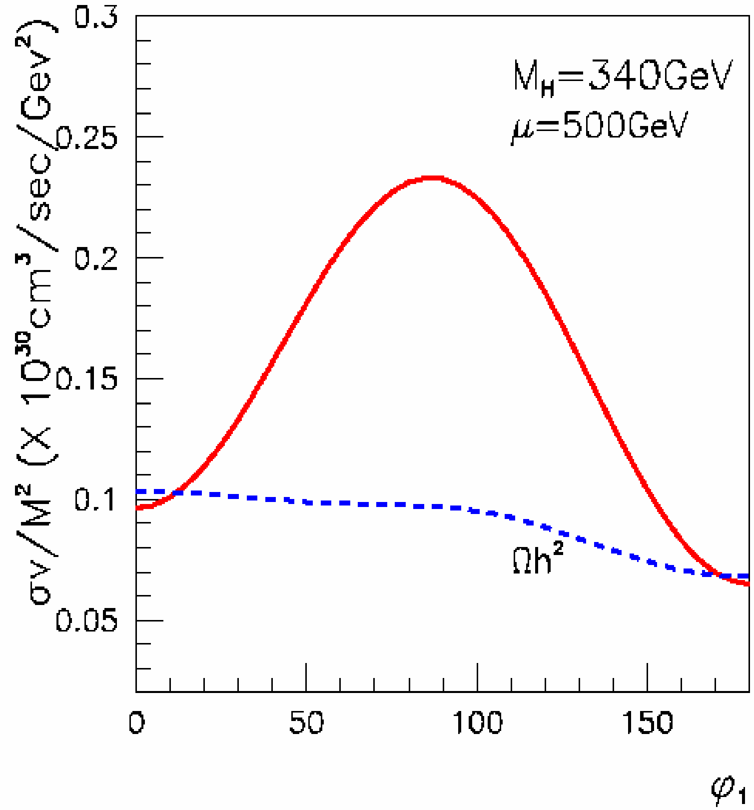


Indirect detection

- Phases should also have effect on rate for indirect detection (annnihilation of neutralinos through γ,e^+,anti-p)
- Depends on σv, with v~0.001
- But $\Omega \sim 1/<\sigma v>$
- When v->0 only pseudoscalar contribution for Majorana neutralinos
- Effect of phase expected to be larger than for Ω
  - Especially when phase changes pseudoscalar content of h

Indirect detection

- Expect when Ω increases, σv decreases
- Often the case but not always
  - Example: Annihilation near Higgs resonance
  - Interference effect χχ-hh



GB, Boudjema, Kraml, Pukhov in progress

Conclusions

- Phases have strong effect on relic density up to one order of magnitude
- To have a precise prediction of DM relic density important to know precisely the masses but also measure precisely couplings and in particular phases.
- How well can this be done in scenarios interesting for DM remains to be seen
- Phases also impact indirect detection (and direct detection)