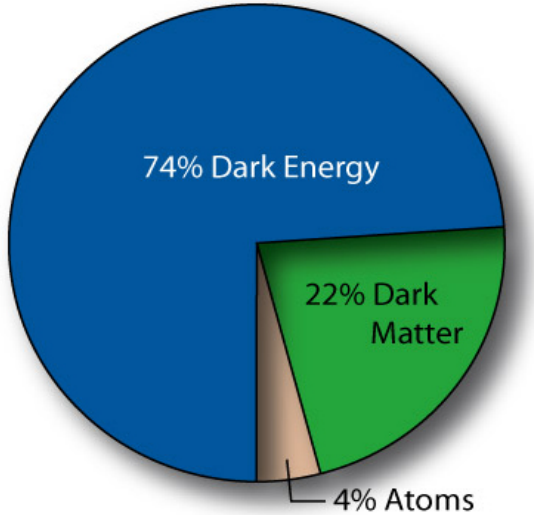
Detection Possibilities of Thermally Produced Wino Dark Matter

Minoru Nagai
(ICRR, Univ. of Tokyo)

in preparation

Collaborated with:
J.Hisano (ICRR), S.Matsumoto(KEK)
M.Senami (ICRR), O.Saito(ICRR)

1. Introduction



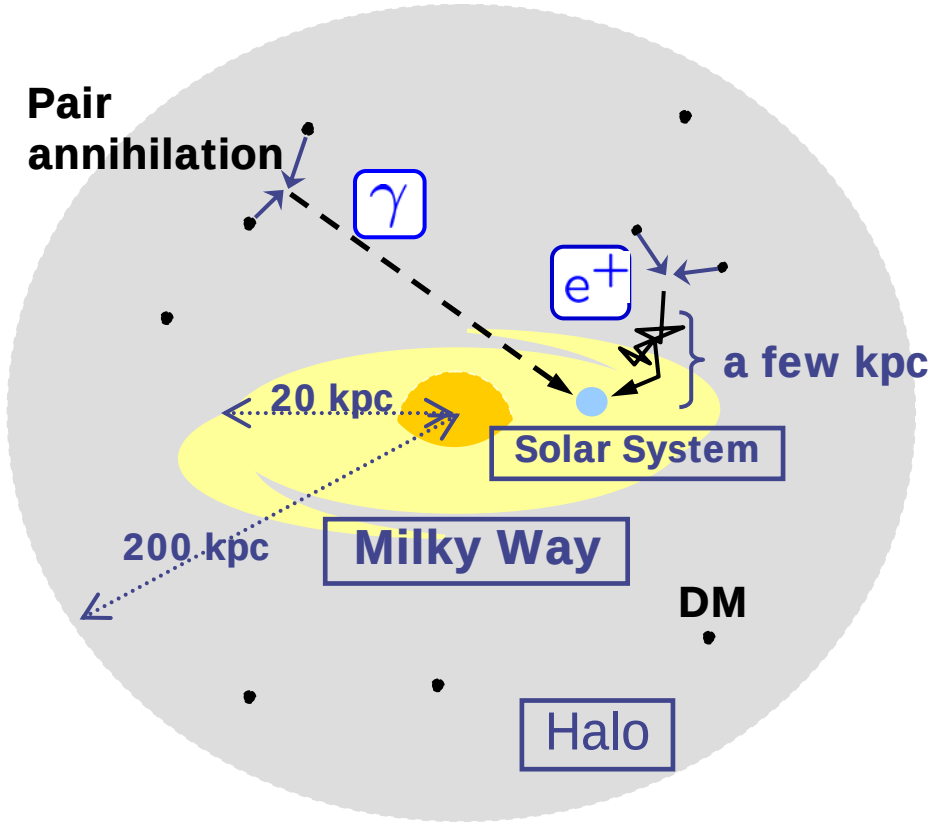
- WMAP established the existence of non-baryonic cold dark matter (DM).

$$\Omega_{\rm DM} h^2 = 0.105 \; {}^{+0.014}_{-0.026}$$

What is this dark matter?

Hint: DM detection

- Direct detection
- Indirect detection



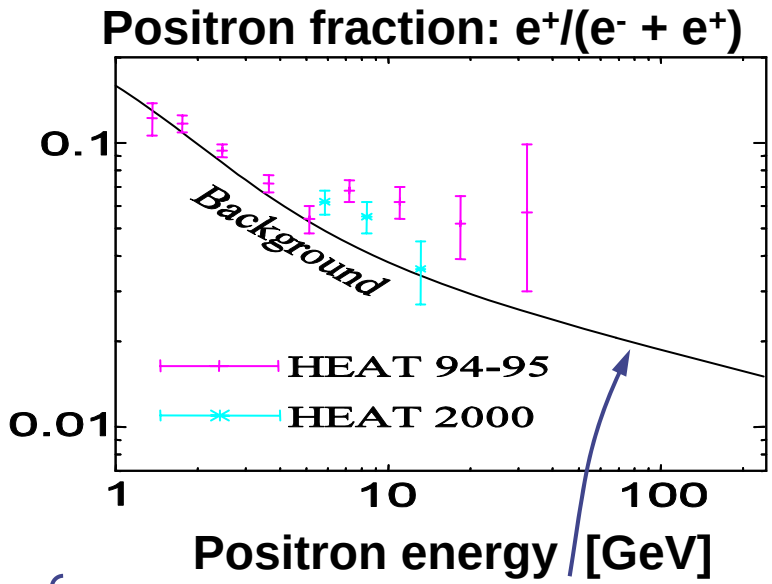
- Indirect detection of DM

Detection of the cosmic-ray particles which are produced by DM pair-annihilation.

$ex)$ γ, e^+, $\bar{p}$, $\bar{\nu}$

- <u>HEAT anomaly</u>

  HEAT is a balloon experiment that observe cosmic-ray positrons and reported a positron excess.



P (primary) + H (interstellar medium) $\rightarrow \pi^+ + \cdots \rightarrow e^+$

- <u>A Puzzle</u>

  If dark matters are thermally produced,

$$\langle \sigma v \rangle_{\text{relic}} \sim 10^{-26}\ [\text{cm}^3/\text{s}]$$

  If the positron excess reported by the Heat experiment is attributed to the annihilation of dark matters,

$$\langle \sigma v \rangle_{\text{posi.}} \sim 10^{-24}\ [\text{cm}^3/\text{s}]$$

Wino-like neutralino in SUSY models

- In SUSY models, neutralino is a good candidate of the DM.

$$\tilde{\chi}^0 = N_{\tilde{B}}\tilde{B} + N_{\tilde{W}}\tilde{W} + N_{\tilde{H}_1}\tilde{H}_1 + N_{\tilde{H}_2}\tilde{H}_2$$

Wino-like neutralino DM ← Anomaly med.

Thermally produced ⇨ $m \sim 2\,\mathrm{TeV}$

- When the mass of the wino-like neutralino is heavy and the relative velocity is tiny, the annihilation cross section can be enhanced by several orders of magnitude due to non-perturbative effect. [Hisano, Matsumoto, Nojiri, Saito (2005)]

⇨ At decoupling (v~1/3), $\langle \sigma v \rangle \sim 10^{-26}$ [cm^3/s]

At present (v~10^{-3}), $\langle \sigma v \rangle \sim 10^{-24}$ [cm^3/s] ← **enhanced by non-pert. eff.**

But, this non-perturbative effect potentially can make a fractional change of the thermal relic abundance. So we calculate the thermal abundance including this effect and discuss its detection possibility by positron signals.

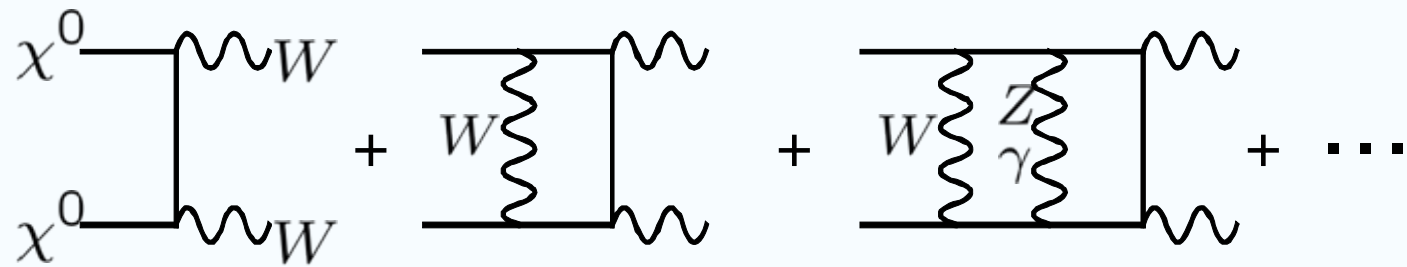
Plan of my talk

1. Introduction
2. Annihilation cross section
3. Thermal relic abundance
4. Positron signature
5. Summary

2. Annihilation cross section

When the mass of wino-like neutralino is heavy (m>1 TeV), usual perturbative calculations can't be applied.

- Neutralino velocity: $v \ll 1$
- Mass degeneracy between the neutralino and charginos

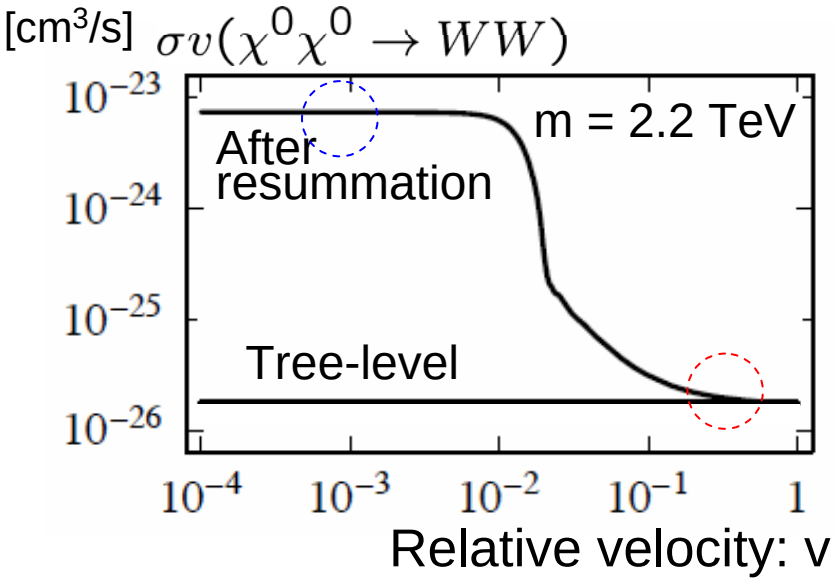


Threshold singularity

$m \gtrsim m_W/\alpha_2$

We need to make a resummation of these diagrams.

The parameter dependence of the cross section



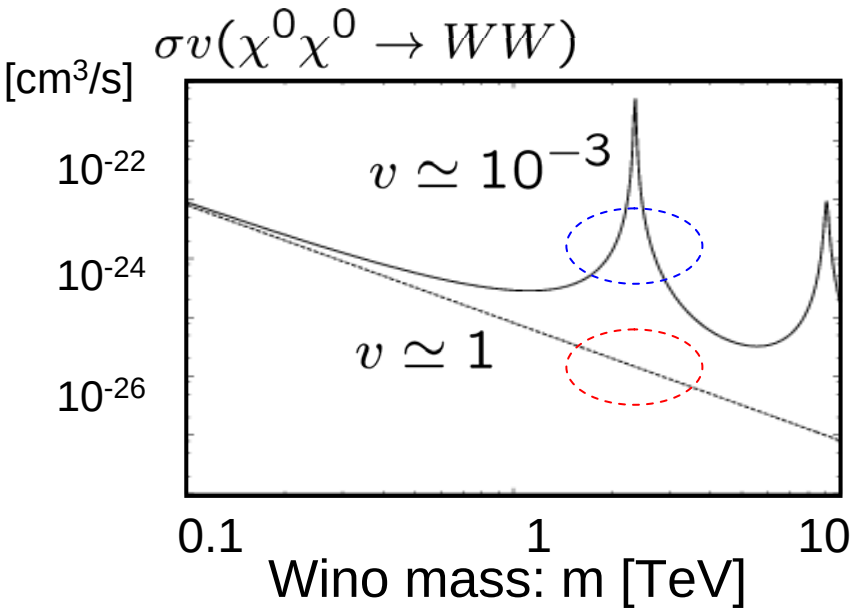
This enhancement occurs only when the dark matter velocity is small.

At decoupling (v~1/3),

$\langle \sigma v \rangle \sim 10^{-26}$ [cm^3/s]

At present (v~10^{-3}),

$\langle \sigma v \rangle \sim 10^{-24}$ [cm^3/s]



Zero energy resonance

m = 2, 9, ･･･[TeV]

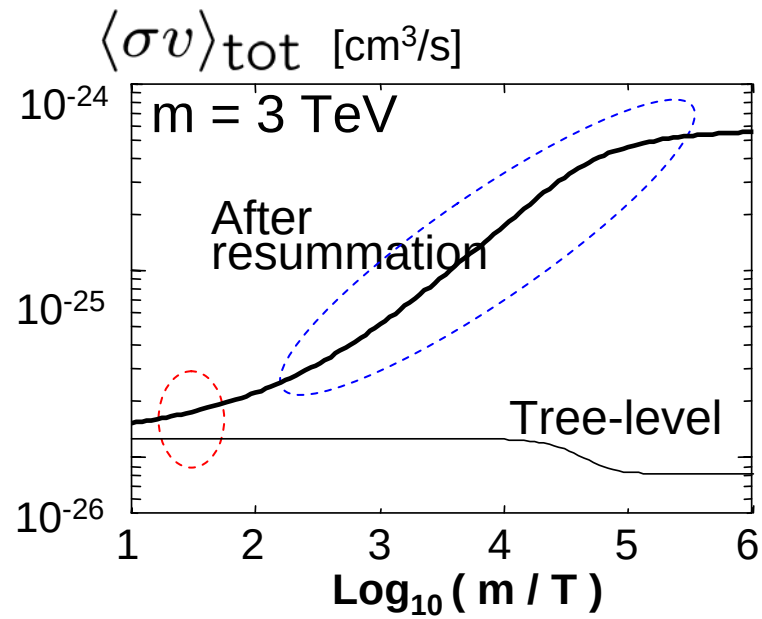
Binding energy = 0

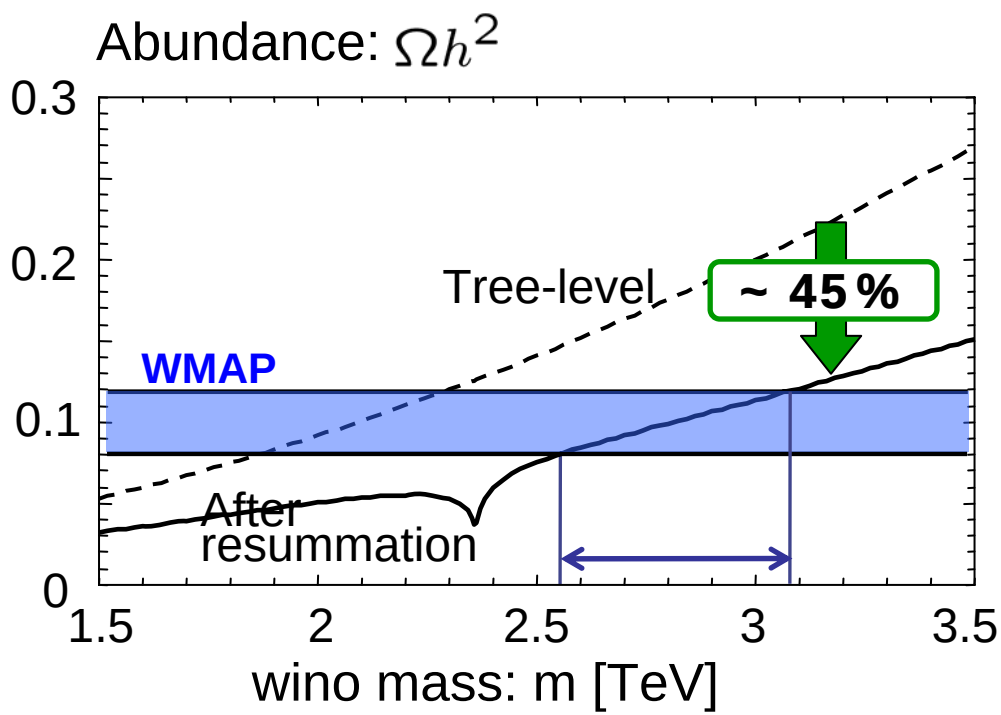
The existence of binding states can modify the thermal relic abundance significantly.

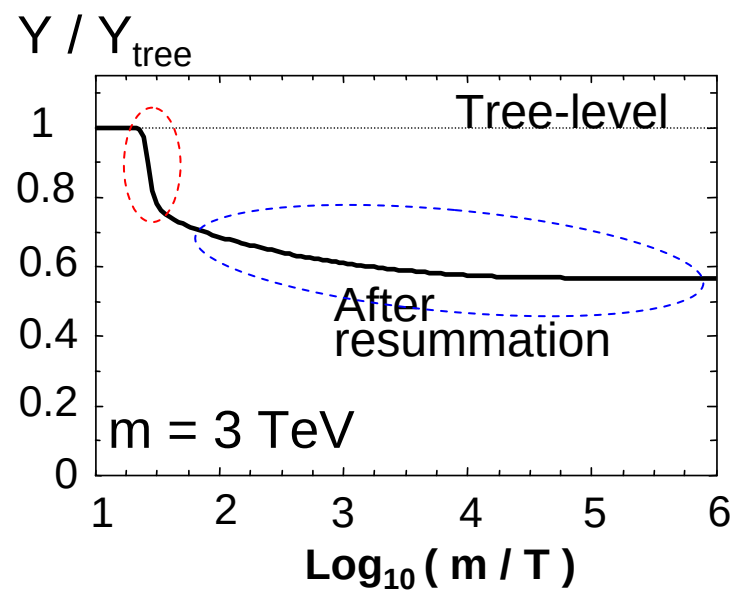
3. Thermal Relic Abundance

Two modifications:

- Larger cross section at decoupling
- Increase of the post-decoupling-annihilation







4. Positron signature

- Positrons are produced by the DM annihilation through cascade decays of the weak gauge bosons.

$$\chi^0\chi^0 \to W^+W^-$$
$$\hookrightarrow e^+\nu\nu\nu,\ e^+\nu$$
$$\hookrightarrow \pi^+ \to \mu^+ \to e^+$$

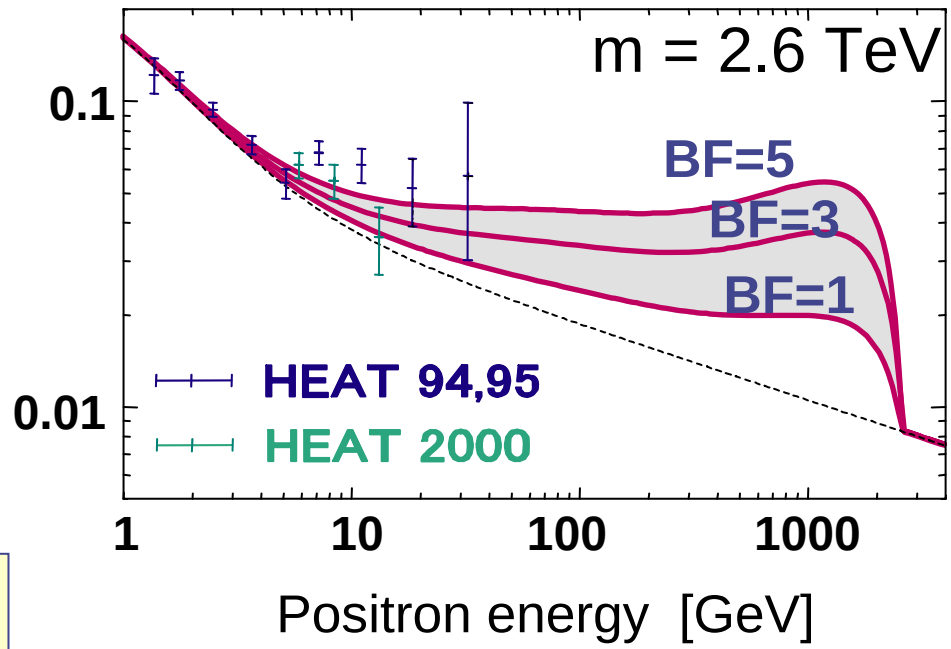
- The excess of the HEAT experiment can be explained by the annihilation of wino DMs.

BF = Enhancement factor by inhomogeneity in the local DM distribution

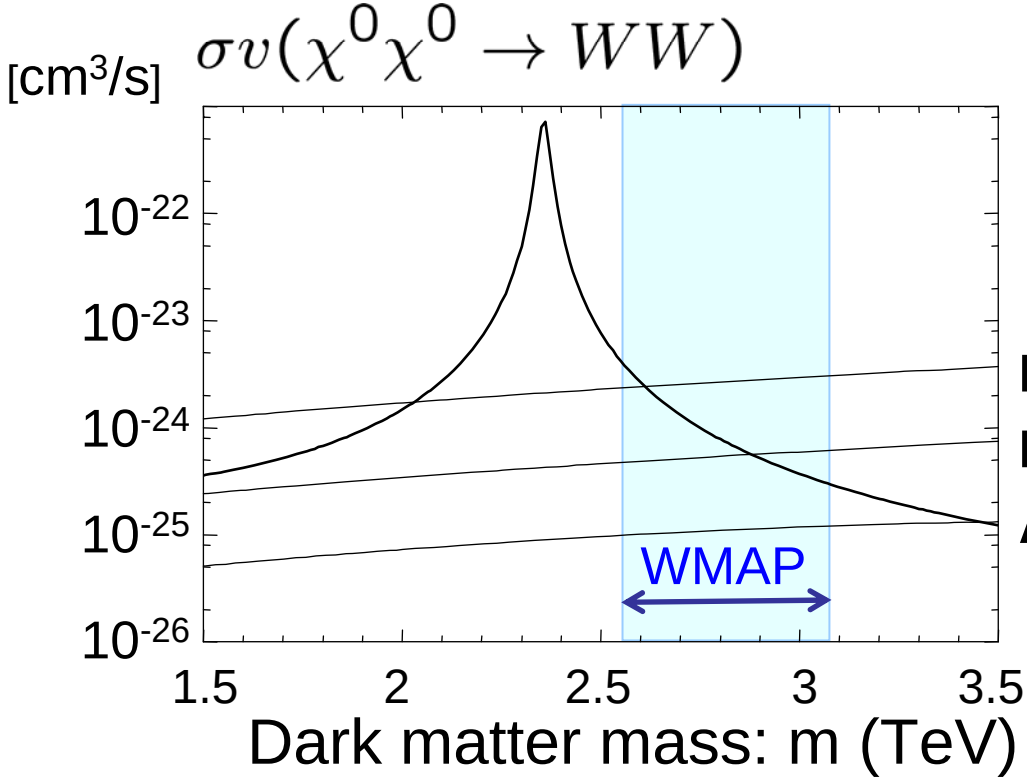
Simulation: BF=2~5

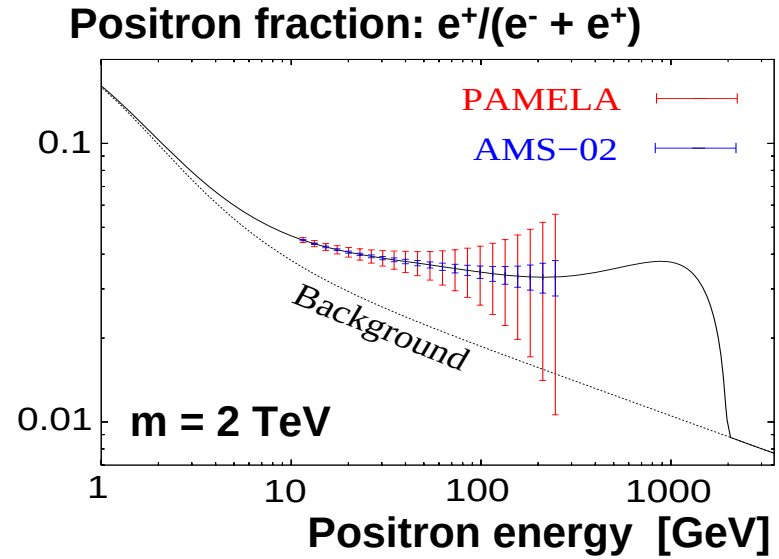
We need more sensitivities to conclude it.

Positron fraction: $e^+/(e^- + e^+)$



Up-coming experiments





PAMELA BF=1

PAMELA BF=5 (AMS-02 BF=1)

AMS-02 BF=5

Detection at the 5σ level

Future experiments such as PAMELA and AMS-02 will confirm or reject this scenario.

5. Summary

We consider the thermal wino DM scenario and its detection possibilities by cosmic-ray positrons.

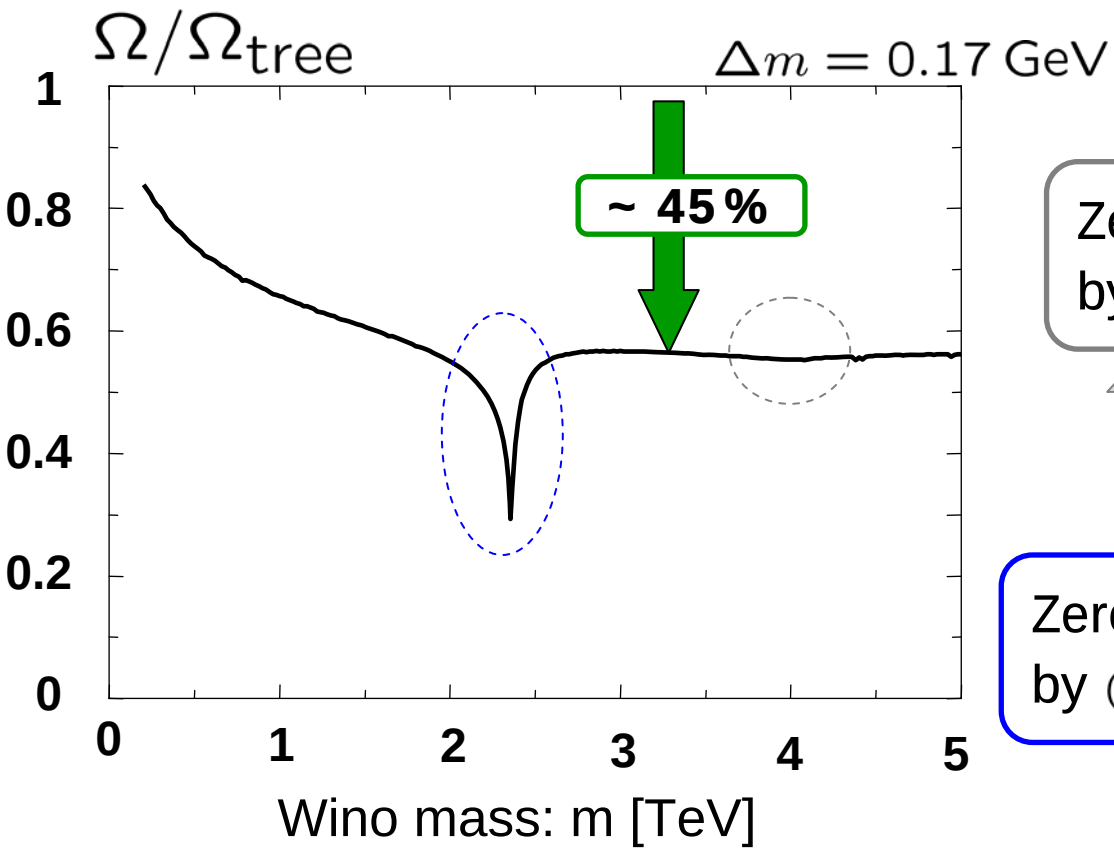
- Winos and charginos form binding states by non-perturbative effect and it can modify the thermal relic abundance. We find its thermal relic abundance is decreased by about 45% by non-perturbative effect.

- Despite its huge mass, we can explain both the thermal relic abundance and the HEAT anomaly simultaneously because its present annihilation cross section is enhanced by several orders of magnitude.

- This scenario will be confirmed or rejected by up-coming experiments such as PAMELA, AMS-02.

Back Up Slide

Decrease of wino thermal abundance by NP effect



Zero energy resonance by $(\chi^0\chi^-)$ system

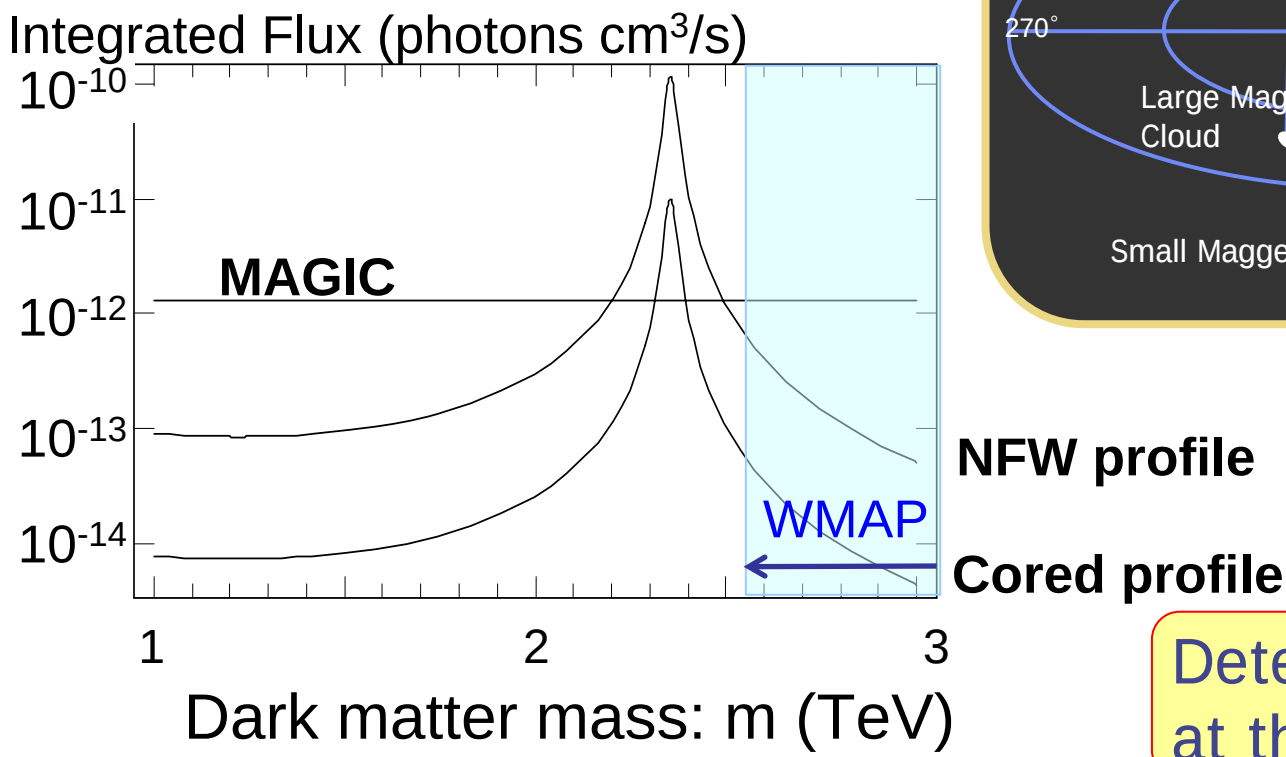
Not so important because of chargino decoupling

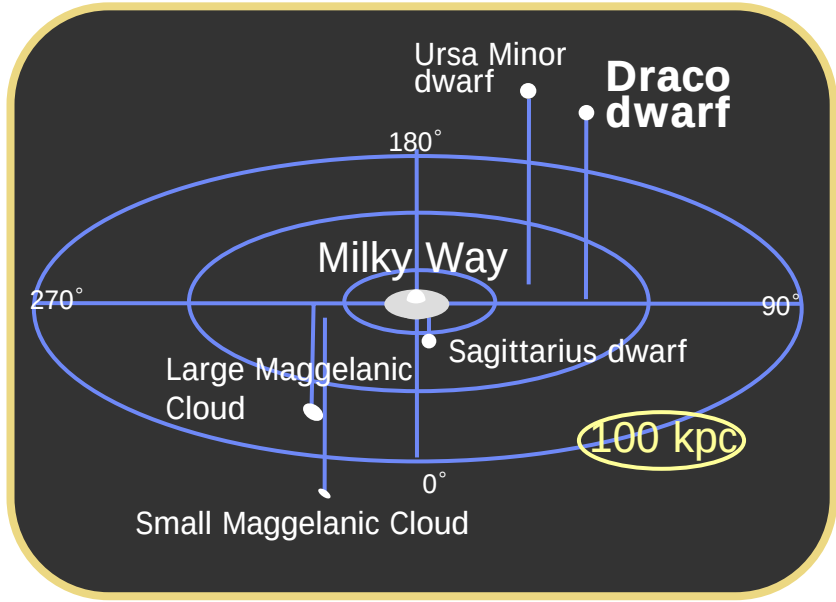
Zero energy resonance by $(\chi^0\chi^0), (\chi^+\chi^-)$ (spin0) system

As wino mass becomes smaller, non-perturbative effect by W and Z boson exchange ladder diagrams become less important. But photon exchange ladder diagrams is still operative. So even in rather small mass(~500GeV), the relic abundance is decreased about 25%.

Gamma rays from Draco

The signal flux and the MAGIC sensitivity





Draco

- Dark matter rich
- Density profile is fairly constrained

Detection at the 5σ level

The signal flux is enhanced by non-perturbative effect, but it's quite difficult to detect it if all of DM is explained by thermally produced wino DM.