Theory Group

Masahiro Kawasaki

Current members of theory group

- Staffs
  - Masahiro Kawasaki (2004~) cosmology
  - Masahiro Ibe (2011~) particle physics
- Postdoctoral Fellows
  - Shuichiro Yokoyama
  - Shohei Sugiyama
  - Daisuke Yamauchi
- Graduate students
  - 6 students in PhD course
  - 3 students in master course

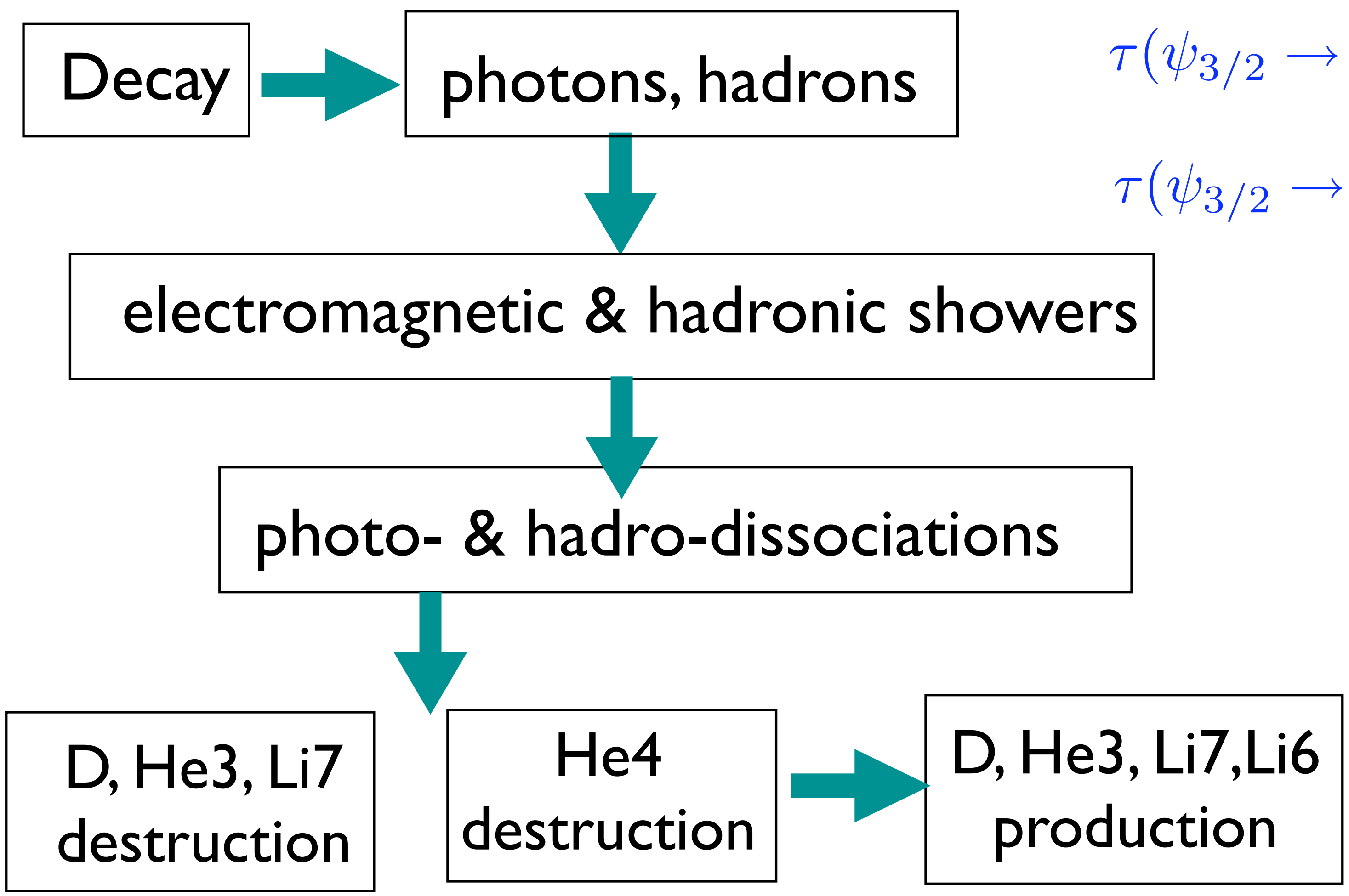
Research Activities

- Theory group is making theoretical studies on phenomenology-oriented particle physics, astro/cosmoparticle physics and cosmology including
  - Higgs physics
  - Flavor physics in SUSY
  - Dark matter
  - Axion cosmology
  - Inflation models
  - Baryogenesis
  - Big-bang nucleosynthesis
  - Generation of density perturbations
  - ....
- We published 168 papers in refereed journals during 2006-2012

Big-bang nucleosynthesis and gravitinos

Kawasaki, Kohri, Moroi, Yotsuyanagi (2008) arXiv: 0804.3745

- In supersymmetry theories, a gravitino appears as superpartner of the graviton
- Unstable gravitinos affect abundances of light elements



$$\tau(\psi_{3/2} \to \tilde{\gamma} + \gamma) \simeq 4 \times 10^{8}\,\mathrm{sec}\left(\frac{m_{3/2}}{100\mathrm{GeV}}\right)^{-3}$$

$$\tau(\psi_{3/2} \to \tilde{g} + g) \simeq 6 \times 10^{7}\,\mathrm{sec}\left(\frac{m_{3/2}}{100\mathrm{GeV}}\right)^{-3}$$

- Gravitinos are produced during reheating after inflation

$$Y_{3/2} = \frac{n_{3/2}}{s} \simeq 2.3 \times 10^{-14}\left(\frac{T_R}{10^{8}\mathrm{GeV}}\right)$$

→ Upper bound on T_R

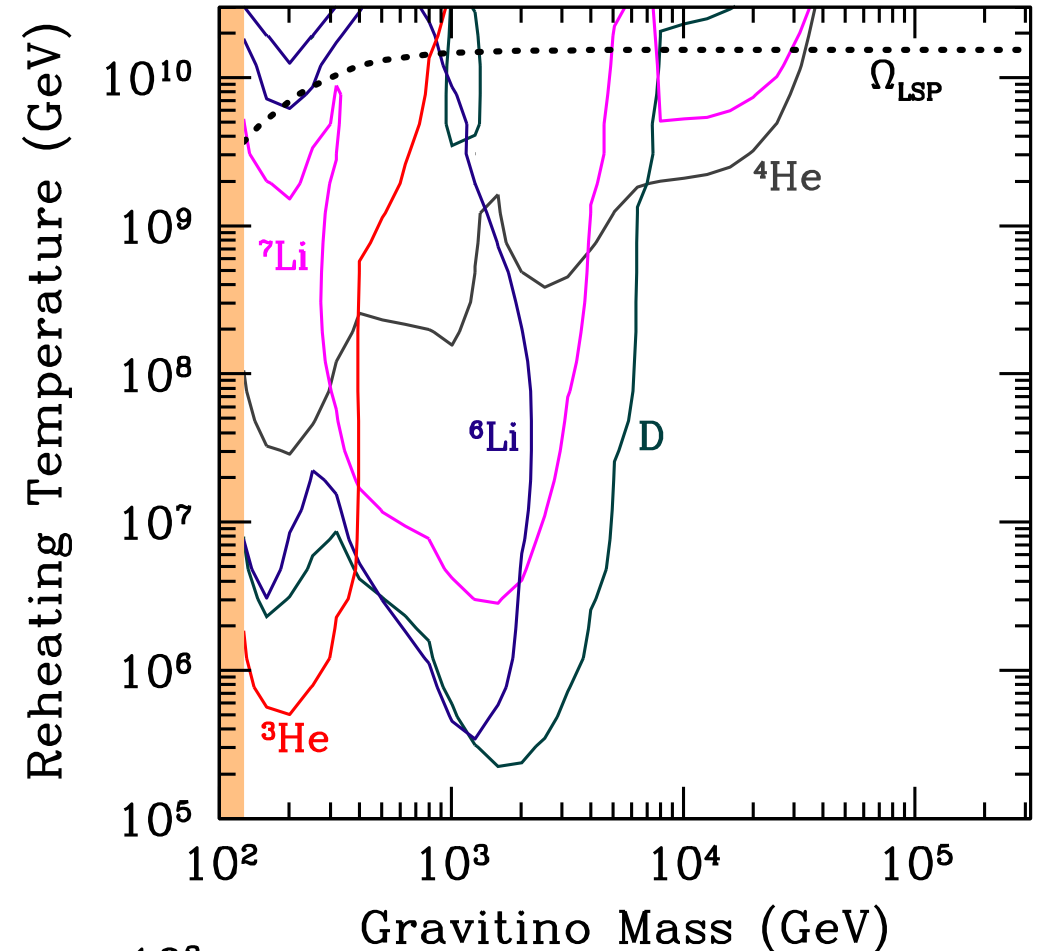
Big-bang nucleosynthesis and gravitinos

- Unstable gravitinos

  → upper bound on T_R

$$T_R \lesssim 10^6\,\text{GeV} \quad \text{for} \quad m_{3/2} \lesssim 300\,\text{GeV}$$

  - This result affects many cosmological scenarios like Leptogenesis



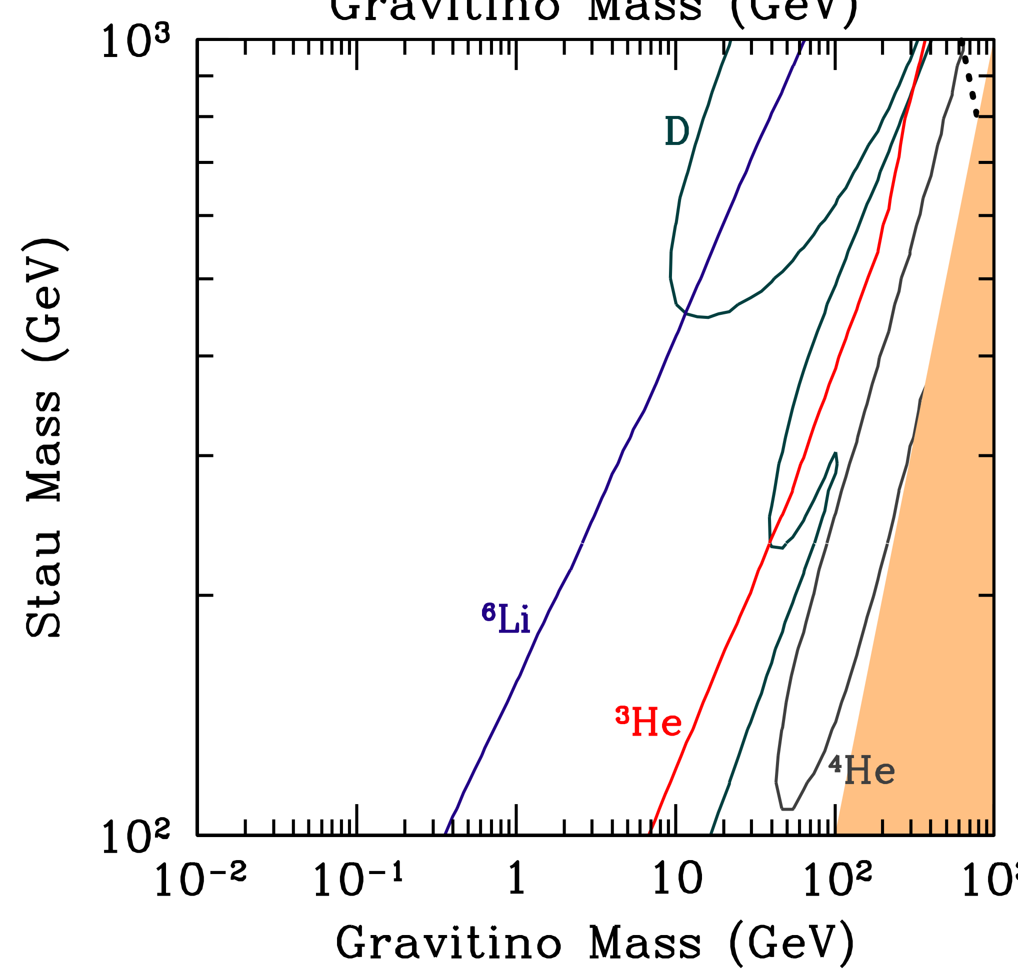
- Stable gravitinos

  gravitinos are dark matter

  - NLSPs decay into gravitinos

    (NLSP = bino or stau or sneutrino)

  - We obtained constraints on NLSP properties



Constraint on dark matter annihilation

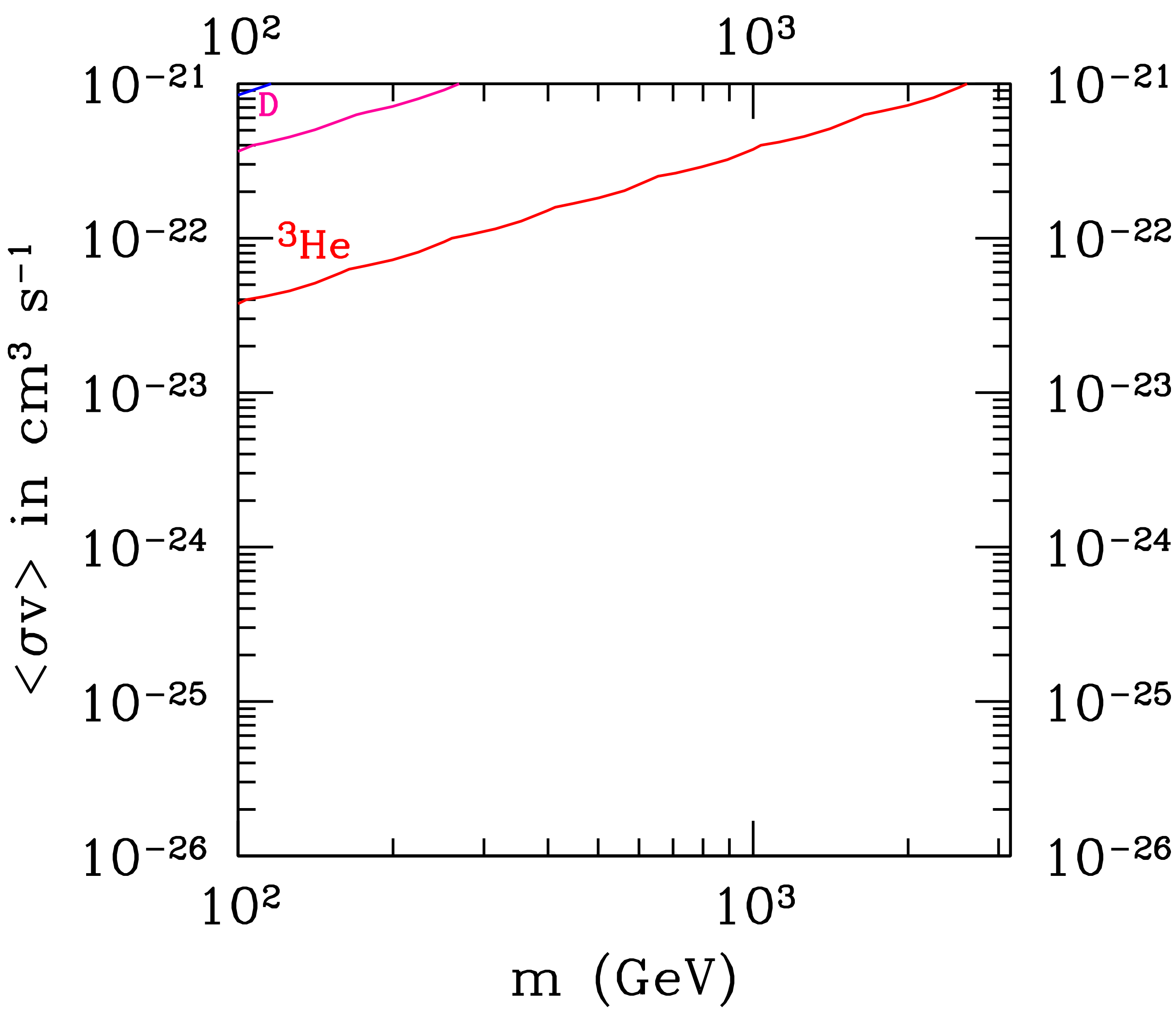
Hisano, Kawasaki, Kohri, Moroi, Nakayama (2009) arXiv: 0901.3582

- Motivated by the observation of cosmic ray positrons and electrons by the PAMELA satellite

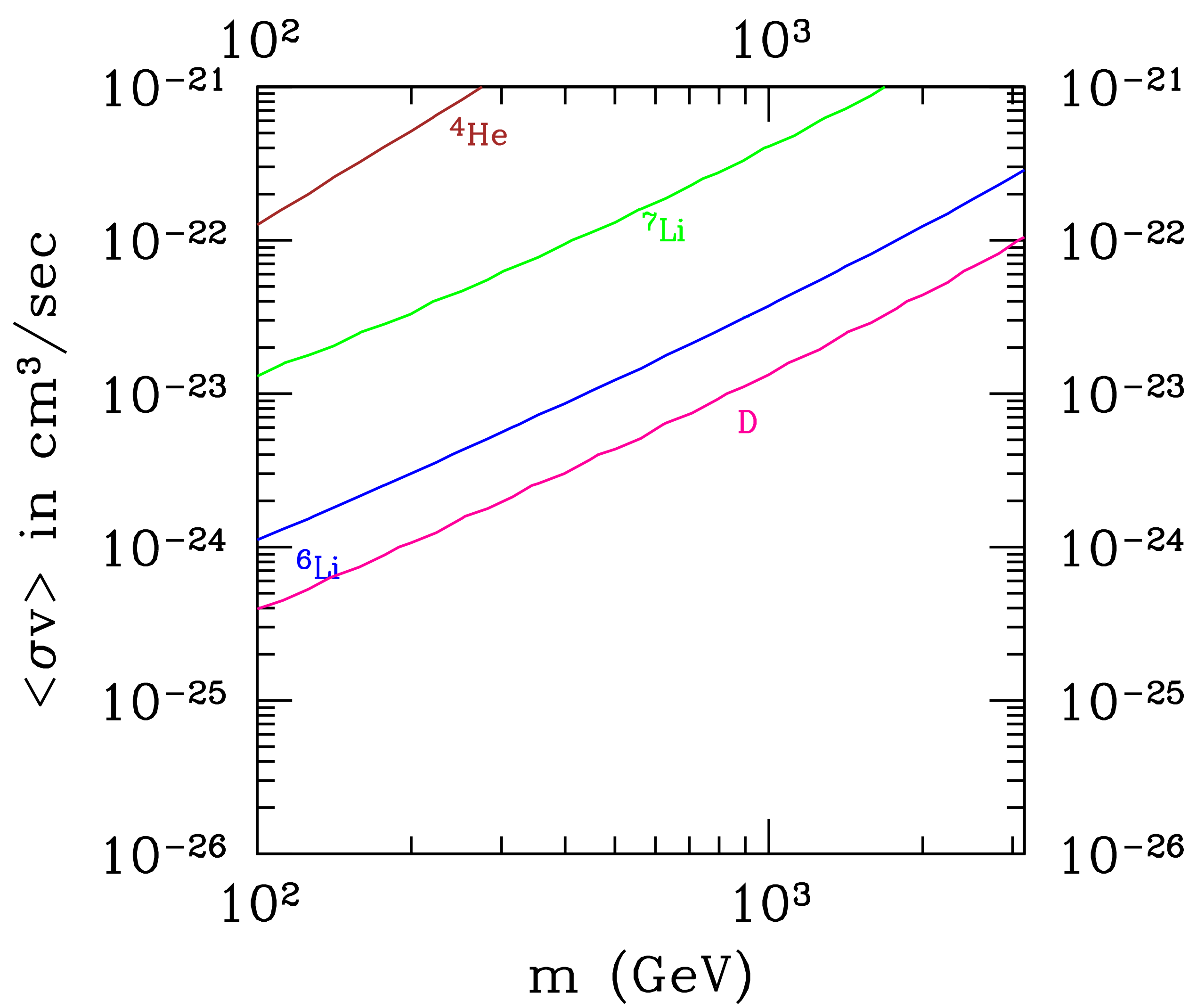
  large annihilation cross section $\langle \sigma v \rangle \sim 10^{-23}\ \mathrm{cm^3 s^{-1}}$

- Dark matter annihilation affects BBN

annhilate into $e^+ e^-$



annhilate into $W^+ W^-$



Constraint on dark matter annihilation

- Dark matter annihilation around the recombination epoch

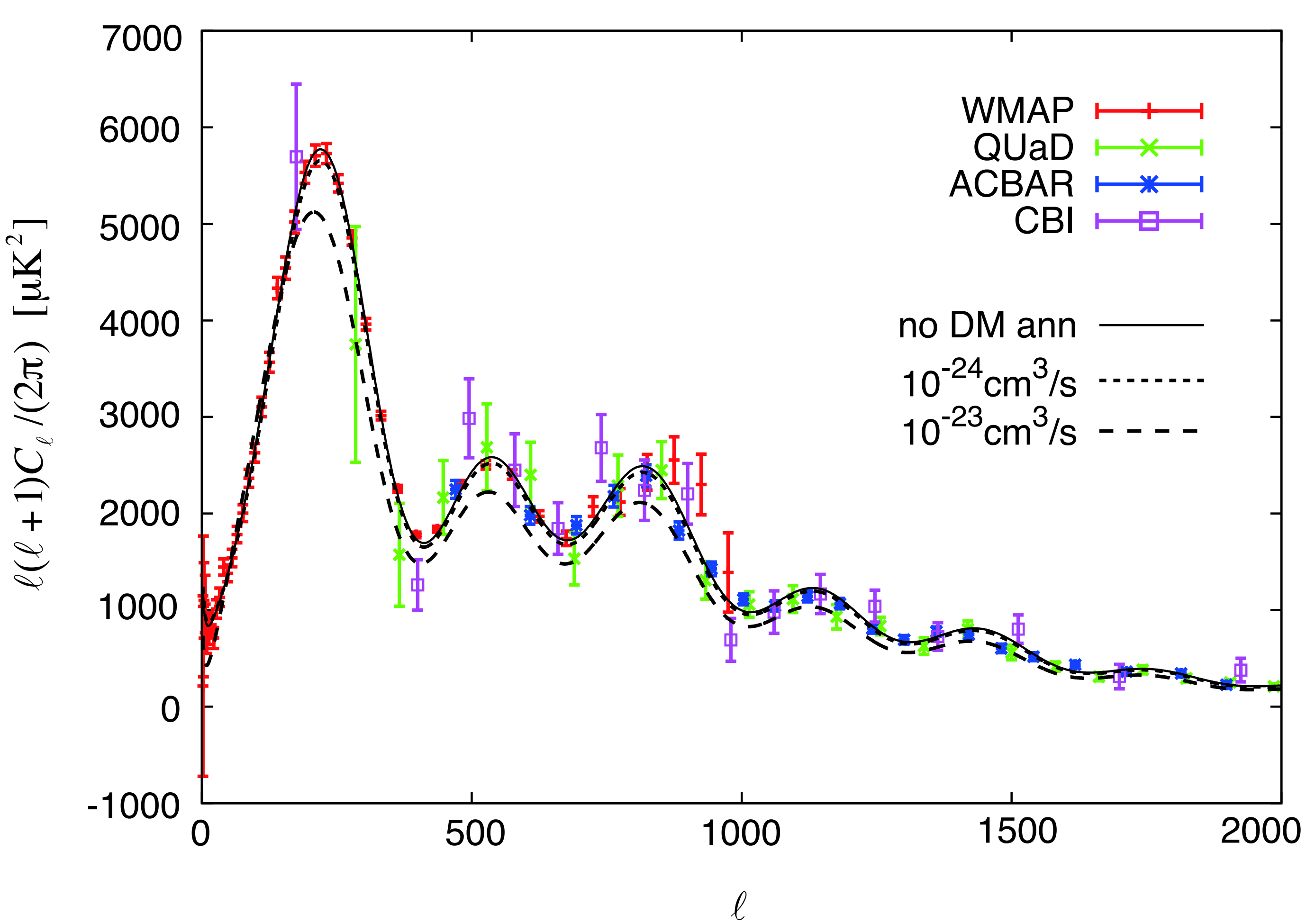
  ➡ can reionize neutral hydrogens and modify the recombination history

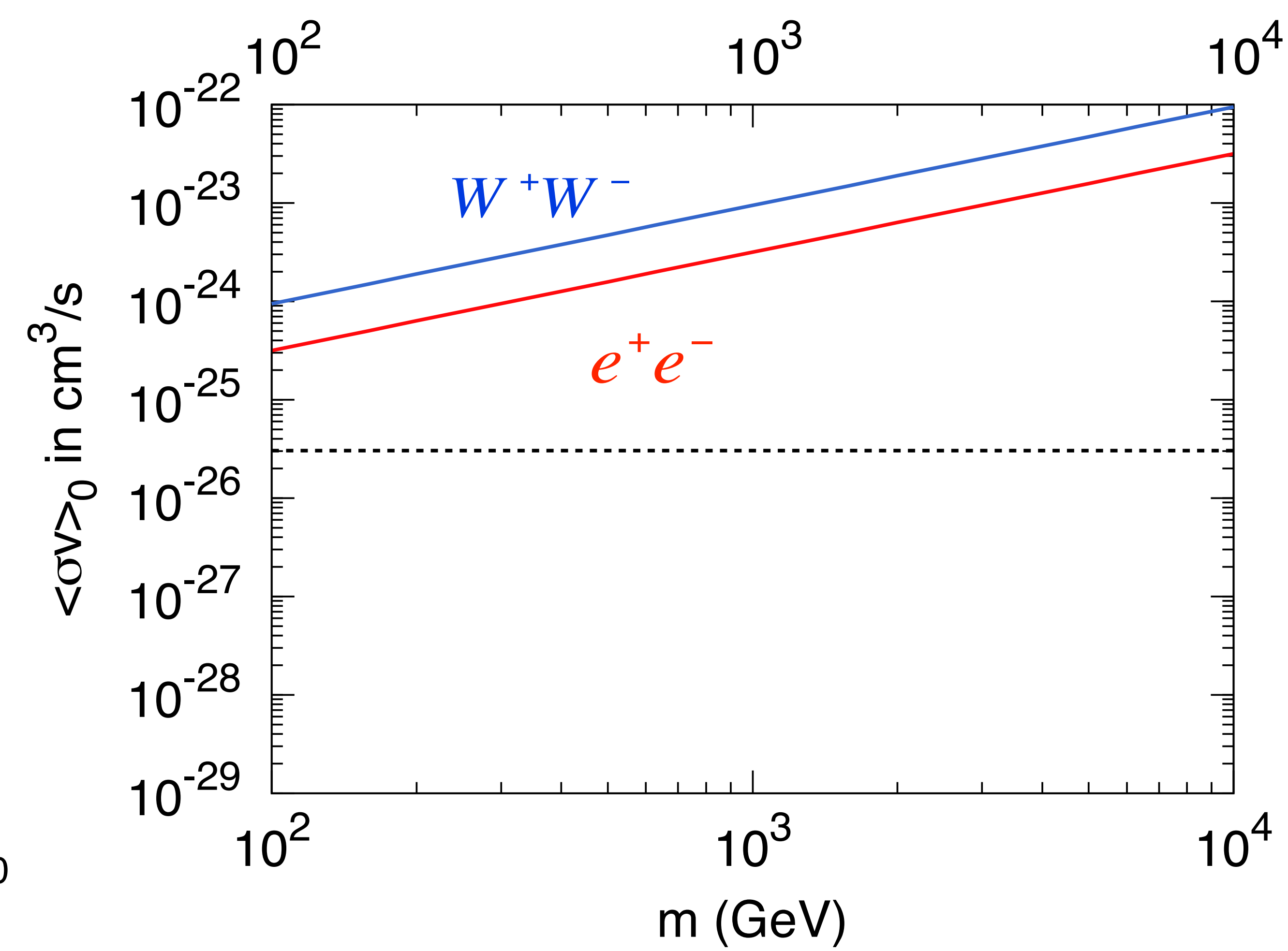
  - Larger optical depth for Thomson scattering

  ➡ decrease the amplitude of the CMB angular power spectrum

  - We can obtain a stringent constraint on annihilation cross section

Hisano, Kawasaki, Kohri, Moroi, Nakayama, Sekiguchi (2011) arXiv: 1102.4658



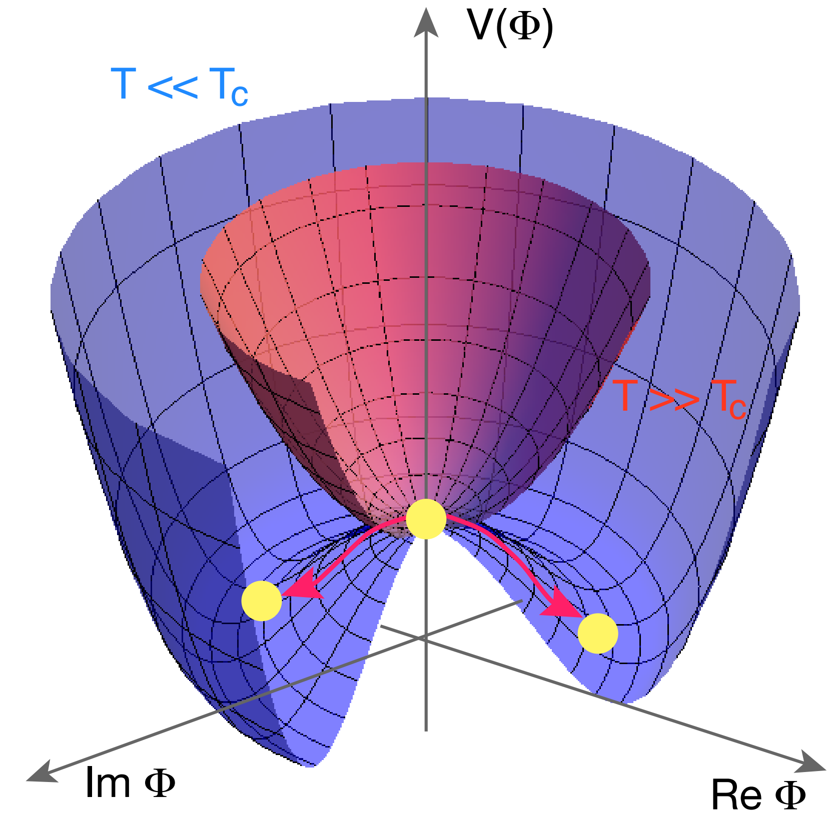


Axion emission from axionic strings and walls

- Axion is predicted in Peccei-Quinn mechanism which solves the strong CP problem in QCD
- In PQ mechanism a scalar field Φ_a with $U(1)_{PQ}$ is introduced
- $U(1)_{PQ}$ is spontaneously broken at some scale f_a and axion can be identified with the phase of Φ_a

$$\Phi_a = |\Phi_a| e^{i\theta_a} = |\Phi_a| e^{ia/f_a}$$

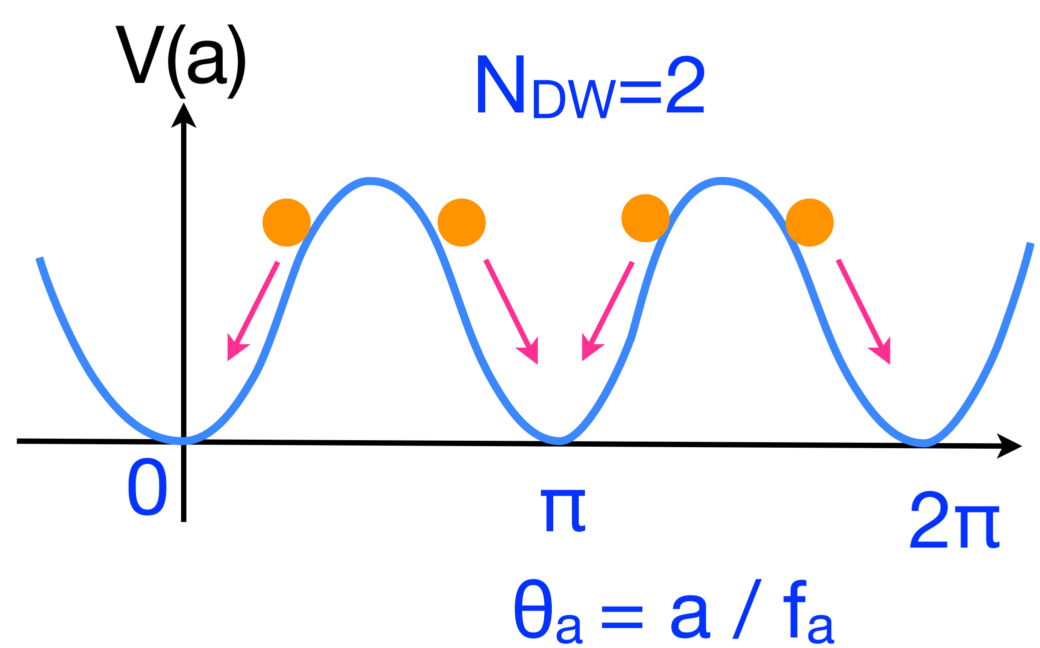
  - Axionic strings are formed



- At QCD scale axion acquires mass through QCD non-perturbative effect

$$m_a \simeq 0.6 \times 10^{-5} \mathrm{eV} \left(\frac{f_a}{10^{12} \mathrm{GeV}} \right)^{-1}$$

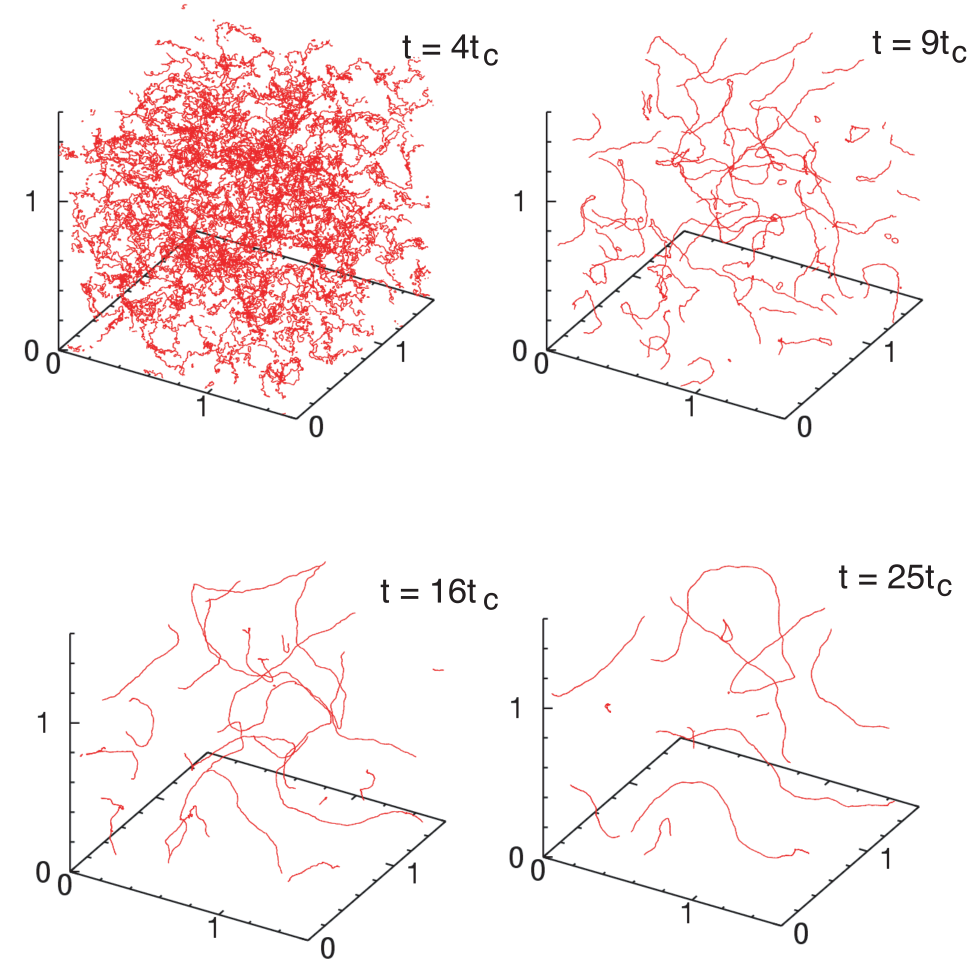
  - Domain walls are formed
  - Coherent oscillation ➡ dark matter



- We investigated the axion emission from strings and walls

Axions from axionic strings

Hiramatsu, Kawasaki, Sekiguchi, Yamaguchi, Yokoyama (2010) arXiv 1012.5502



- Axionic string networks evolve losing their energy by emitting axions

  Emitted axions can give a significant contribution to the matter density

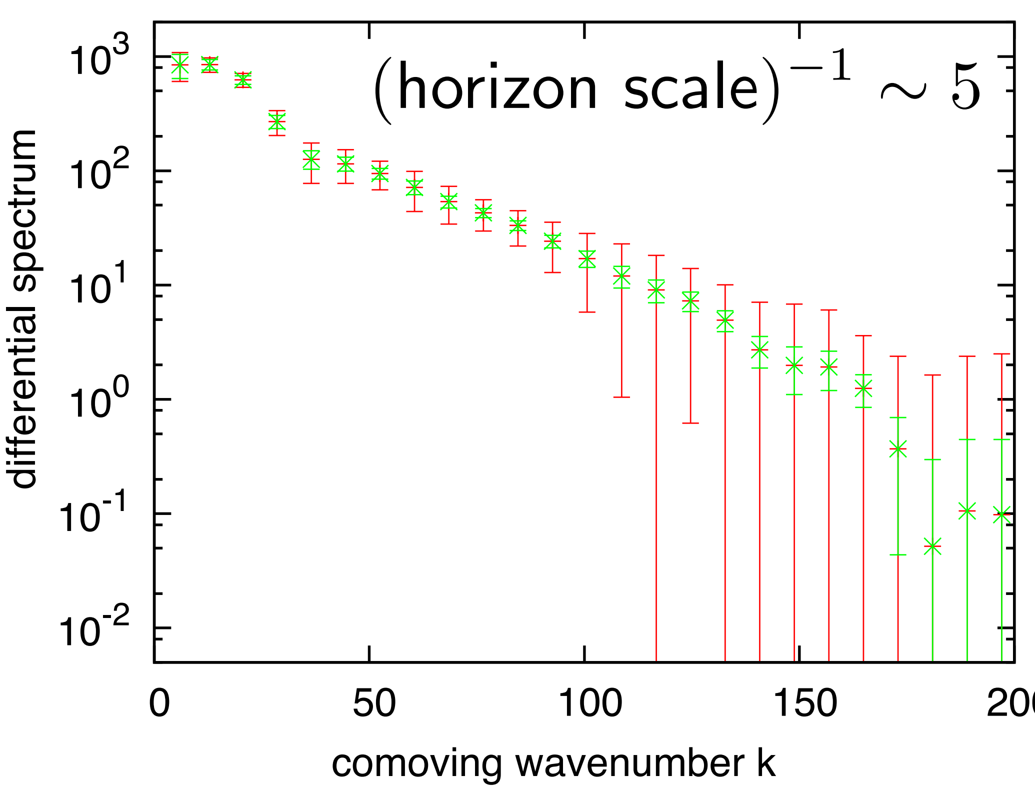
  However, there has been a controversy about the energy spectrum

  (peal at horizon scale) vs. (1/k spectrum)

- We performed field theoretic lattice simulations and solved this controversy

  peak at horizon scale

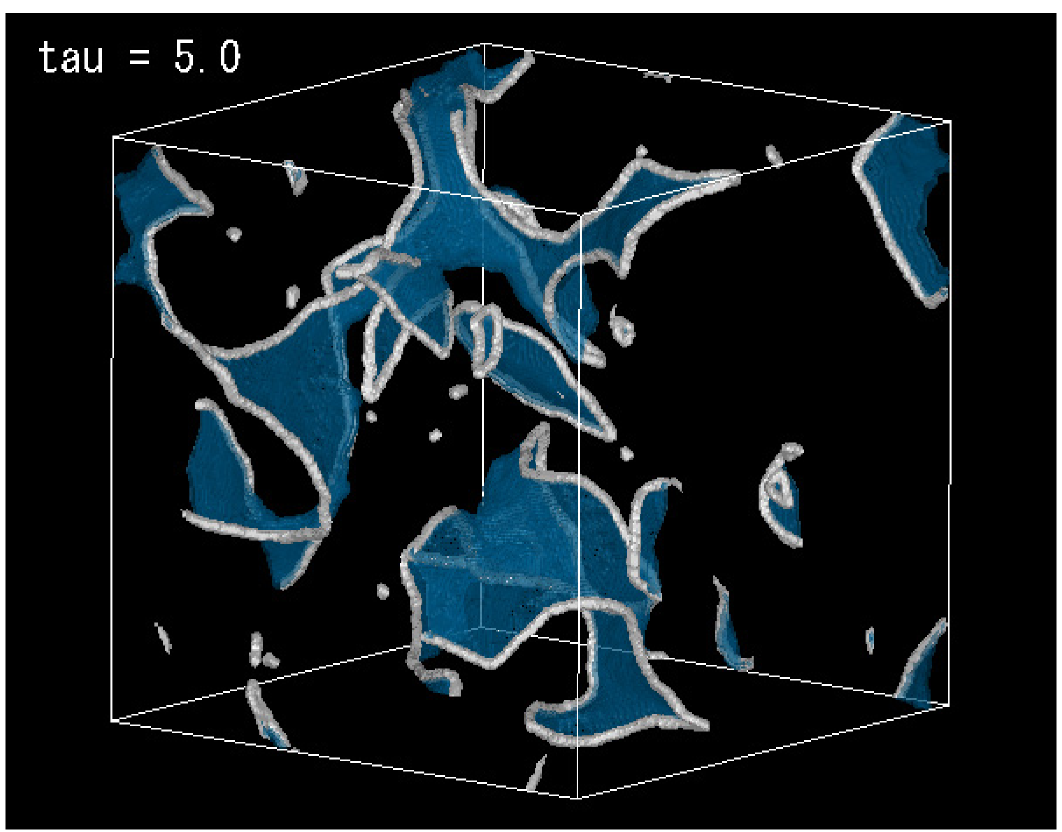
$$\Omega_{a,\mathrm{str}} h^2 \simeq (4.0 \pm 2.0) \left(\frac{f_a}{10^{12}\mathrm{GeV}} \right)^{1.19}$$

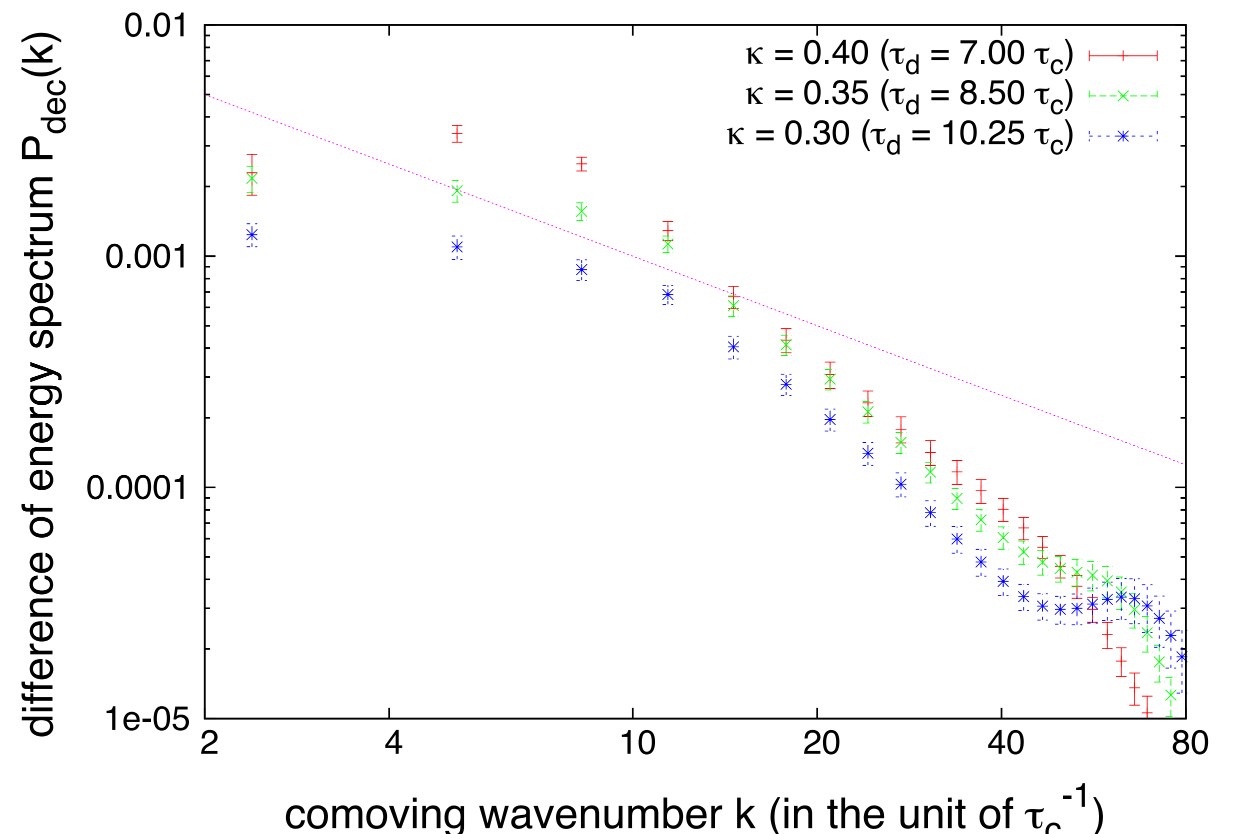


Axion from domain walls

Hiramatsu, Kawasaki, Saikawa, Sekiguchi (2012)
arXiv 1202.5851, 1207.3166

- Domain walls are formed at QCD scale
- Cosmological evolution is different between $N_{DW}=1$ and $N_{DW} > 1$
  - $N_{DW}=1$: domain walls are disk-like and collapse soon
  - $N_{DW} > 1$: domain wall-string networks are stable and cause the domain wall problem
- In both cases axions are emitted from the wall-string networks
- $N_{DW}=1$
  - We performed lattice simulations and obtained the energy spectrum





Axions from domain walls

- $N_{DW}=1$
  - Energy spectrum has a peak at the axion mass scale
  - Cosmic axion density

$$\Omega_{a,\mathrm{wall}} h^2 \simeq (11.8 \pm 5.7) \left(\frac{f_a}{10^{12}\,\mathrm{GeV}} \right)^{1.19}$$

  - Axions from the domain walls give a dominant contribution
- Total axion density

$$\Omega_{a,\mathrm{tot}} h^2 \simeq (17 \pm 6) \left(\frac{f_a}{10^{12}\,\mathrm{GeV}} \right)^{1.19}$$

$$f_a \lesssim (2-4) \times 10^{10}\,\mathrm{GeV}$$

- For $N_{DW} > 1$
  - No consistent scenario without fine tuning

stringent constraint in model building

Supersymmetry Breaking Model after the Higgs Discovery

Both the ATLAS and the CMS discovered a new boson with mass around 125-126GeV compatible with the SM Higgs boson!

[ATLAS:Phys.Lett.B716(2012)1, CMS:Phys.Lett.B716(2012)30]

What does 125-126GeV Higgs boson mean in the SUSY models?

In the minimal SUSY model, the Higgs boson mass is predicted to be around the Z-boson mass when the SUSY particle masses are in the hundreds GeV range.

$$M_{higgs} \sim M_Z = 91.2\text{GeV} \quad \text{for } M_{SUSY} \sim O(100)\text{GeV}$$

Heavier Higgs boson mass requires much heavier SUSY particle masses

$$M_{higgs} >> M_Z = 91.2\text{GeV} \quad \text{for } M_{SUSY} >> O(100)\text{GeV}$$

[Higgs mass depends on the SUSY particle mass only logarithmically...]

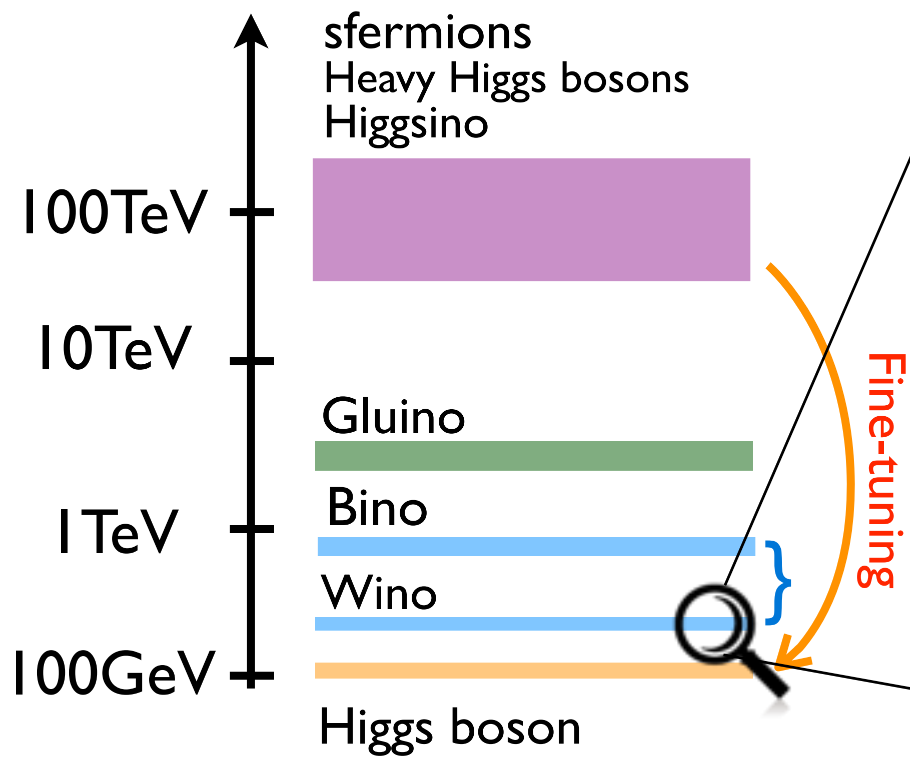
→ In the simplest case, $M_{higgs} \sim 125$GeV, suggests the sfermion masses above O(10-100)TeV!

Do we still have chances to discover SUSY particles at the LHC?

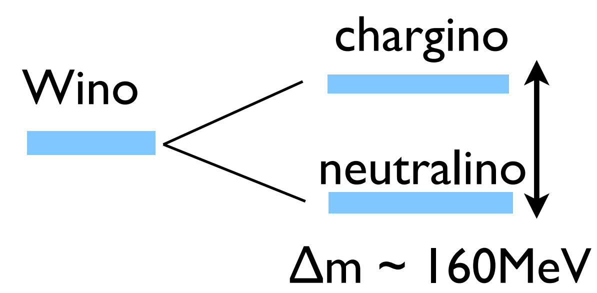
→ Gauginos can be within the reach of the LHC!

Supersymmetry Breaking Model after the Higgs Discovery

['11 Ibe, Yanagida, '12 Arkani-Hamed, ...]



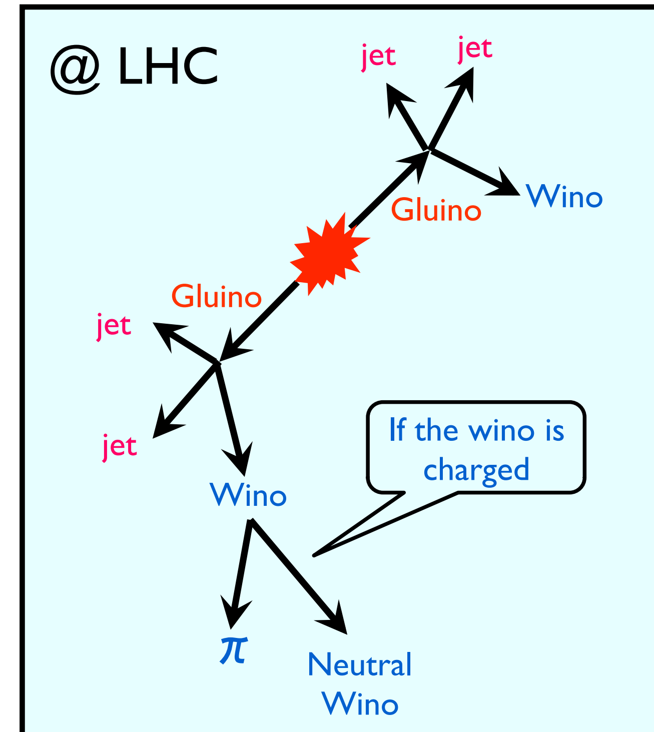
Wino (SU(2) triplet)
= neutralino + chargino



Main decay mode :

$\chi^\pm \rightarrow \chi^0 + \pi^\pm$

$\tau_{wino} = O(10^{-10})$ sec.



The wino is the lightest SUSY particle (LSP) → DM candidate, long-lived chargino

✔ When the gluino is within the reach of the LHC.

Future reach @ LHC (14TeV&300fb^{-1})

✔ Multi-jets + Missing E_T search (conventional SUSY search)

$m_{gluino} < 2.3$TeV for $m_{wino} < 1$TeV

✔ Disappearing chargino track information improves the reach...

$m_{gluino} < 2.5$TeV for $m_{wino} < 1$TeV

['12, Bhattacherjee, Feldstein, Ibe, Matsumoto, Yanagida]

Supersymmetry Breaking Model after the Higgs Discovery

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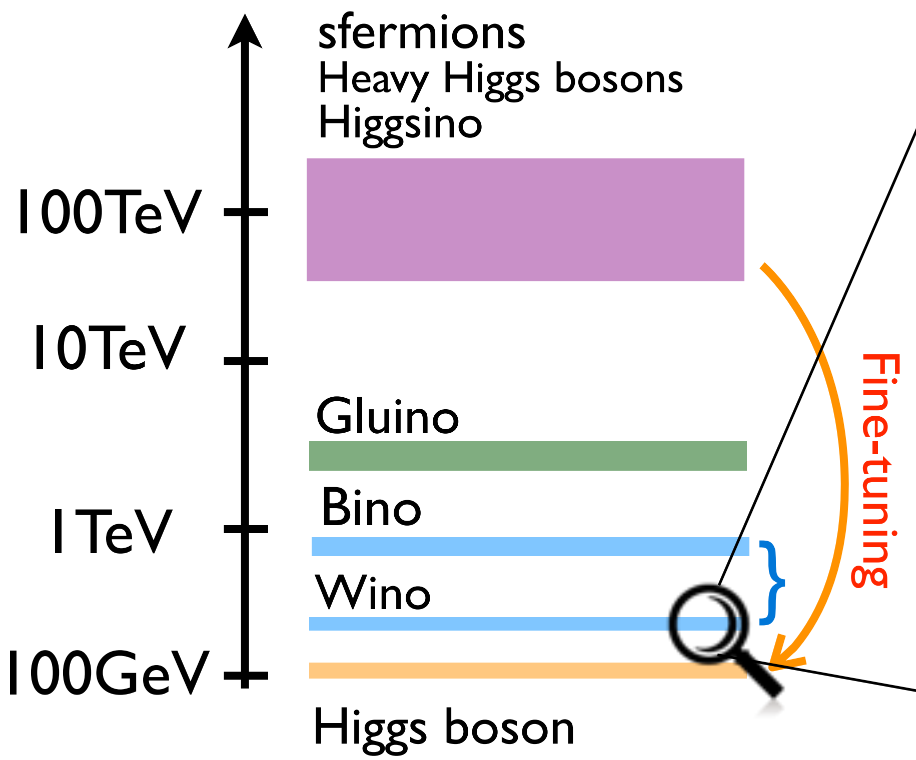

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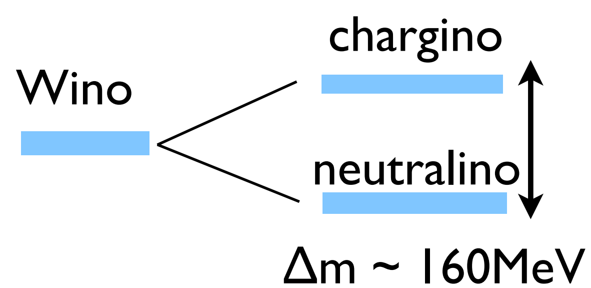

Main decay mode :
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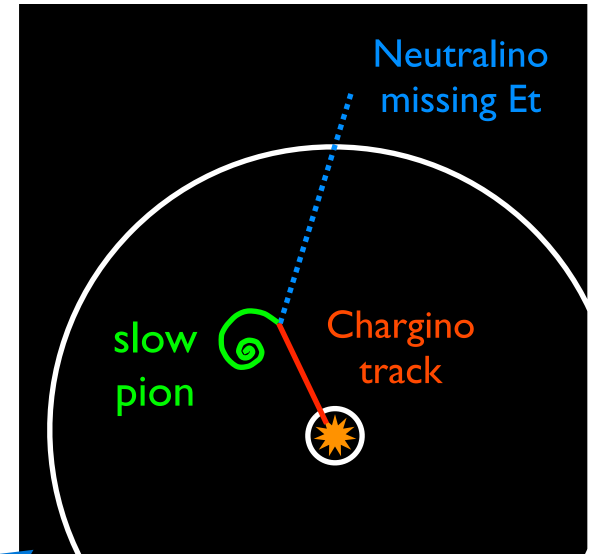
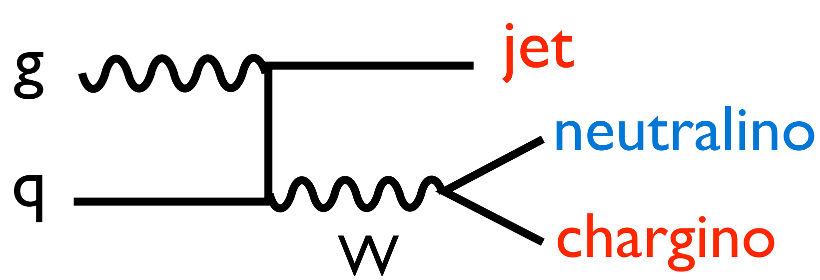
['06 Ibe, Moroi, Yanagida]



The charged wino produced at the LHC travels O(1-10)cm before it decays.

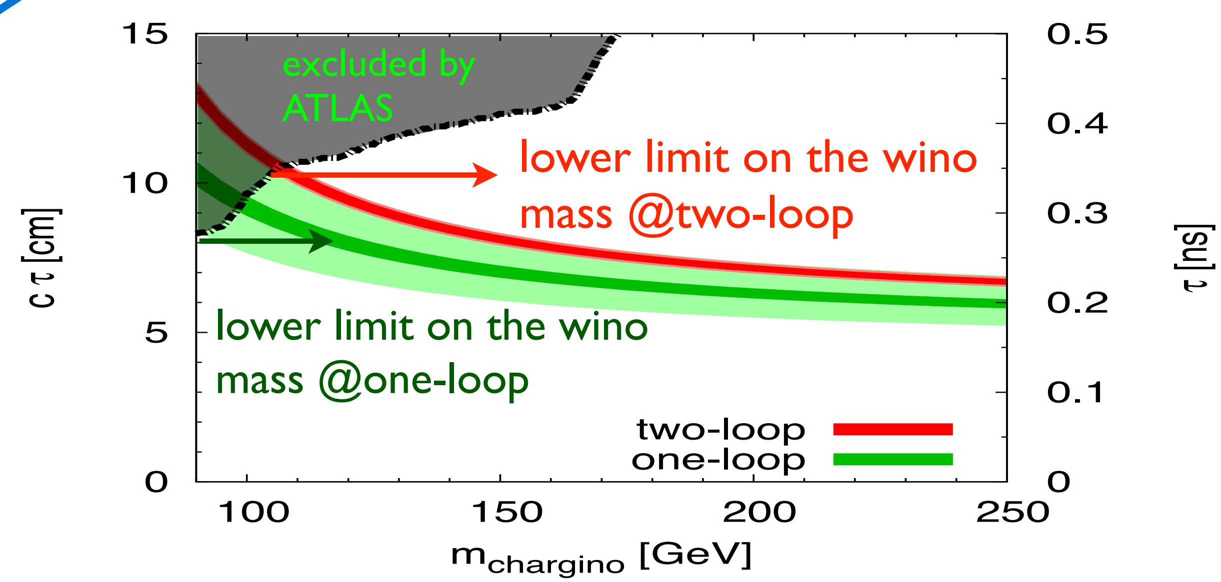
✔ When the gluino is out of reach at the LHC...

mono-jet + wino event



Charged track information is crucial since the event rate is much lower than the gluino production...

ATLAS constraint on decay length



With precise theoretical estimation of Δm, the ATLAS constraint on the wino mass is improved by about 20%!

['12 Ibe, Matsumoto, Sato]

Education

- We accept 2-3 graduate students every year
- 9 students were awarded doctor degrees (2006-2011)
- 19 students got master degrees (2006-2011)

	2006	2007	2008	2009	2010	2011
Master degree	3	2	3	3	4	1
Doctor degree	2	2	2	2	1	0

Summary

- We believe that Theory Group has kept high activity and given significant contributions to particle physics, cosmology and astrophysics