Cosmological Connection to LHC & ILC Physics

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Contents

1. Cosmological connection to LHC & ILC physics via Dark Matter problem
2. How important the collider physics is to determine the property of Dark Matter.
3. Recent progress on this subject.

1-1 Cosmology & High energy physics

Cosmological problems
related to
high energy physics

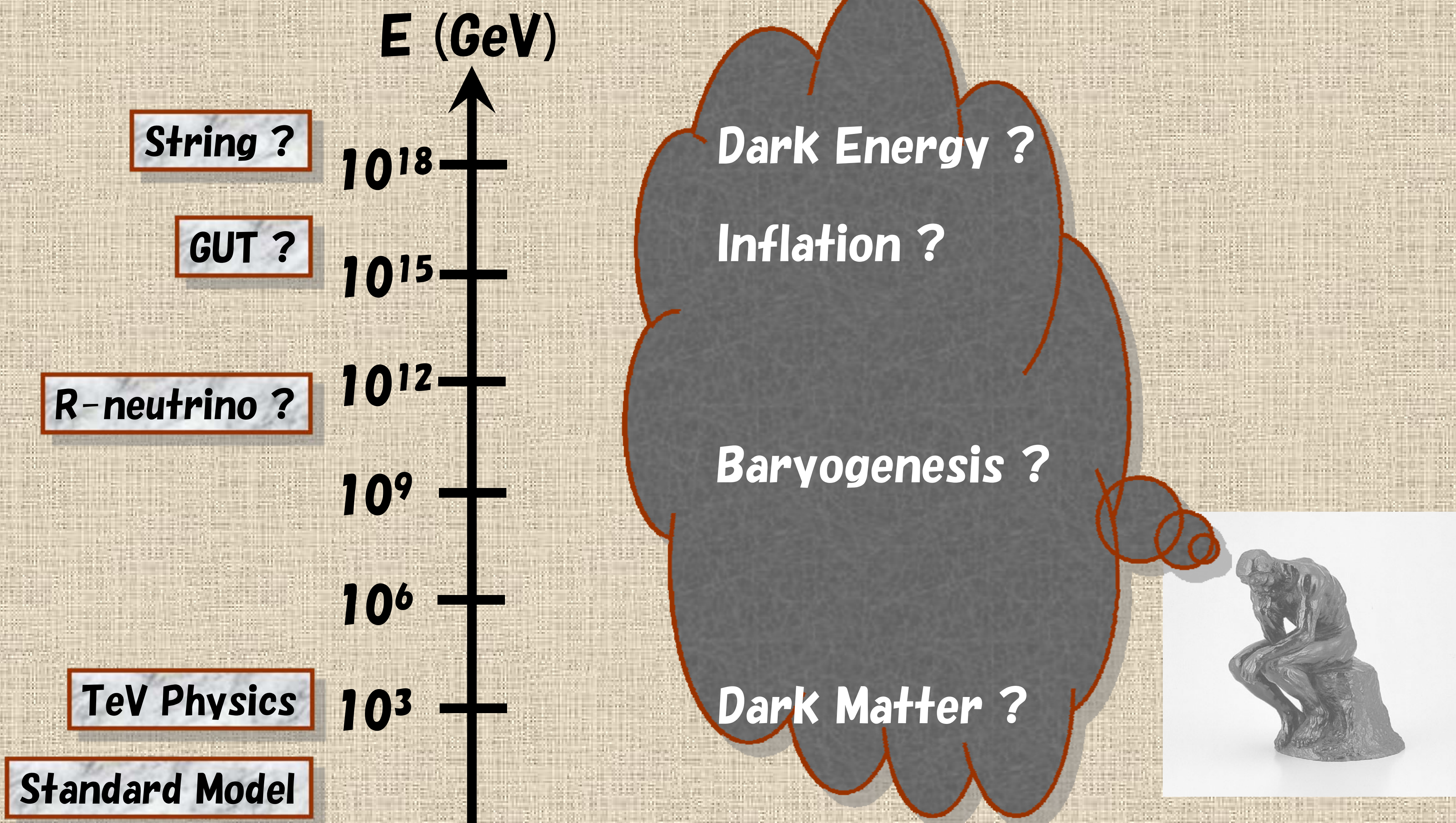
Dark Energy ?

Inflation ?

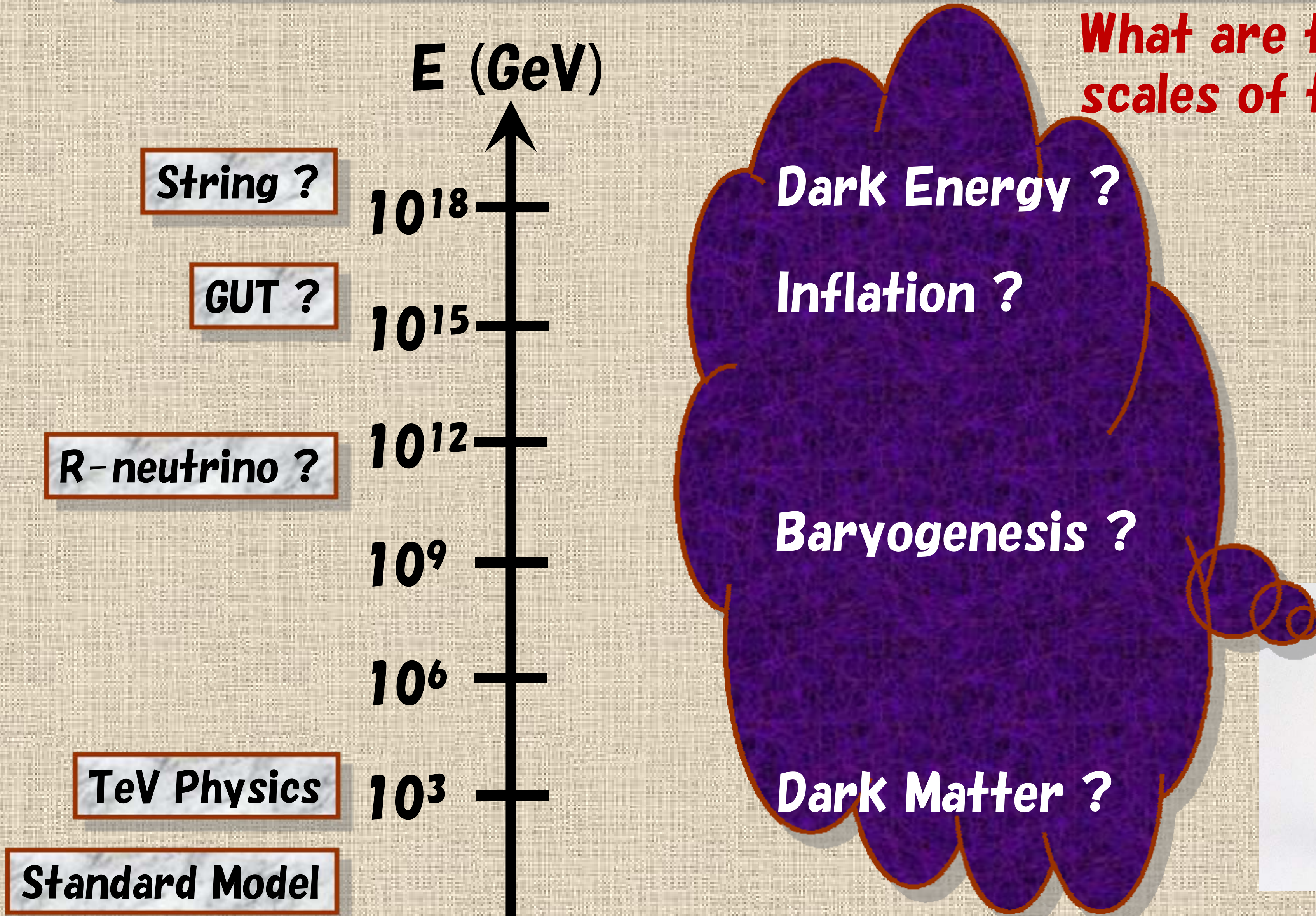
Baryogenesis ?

Dark Matter ?

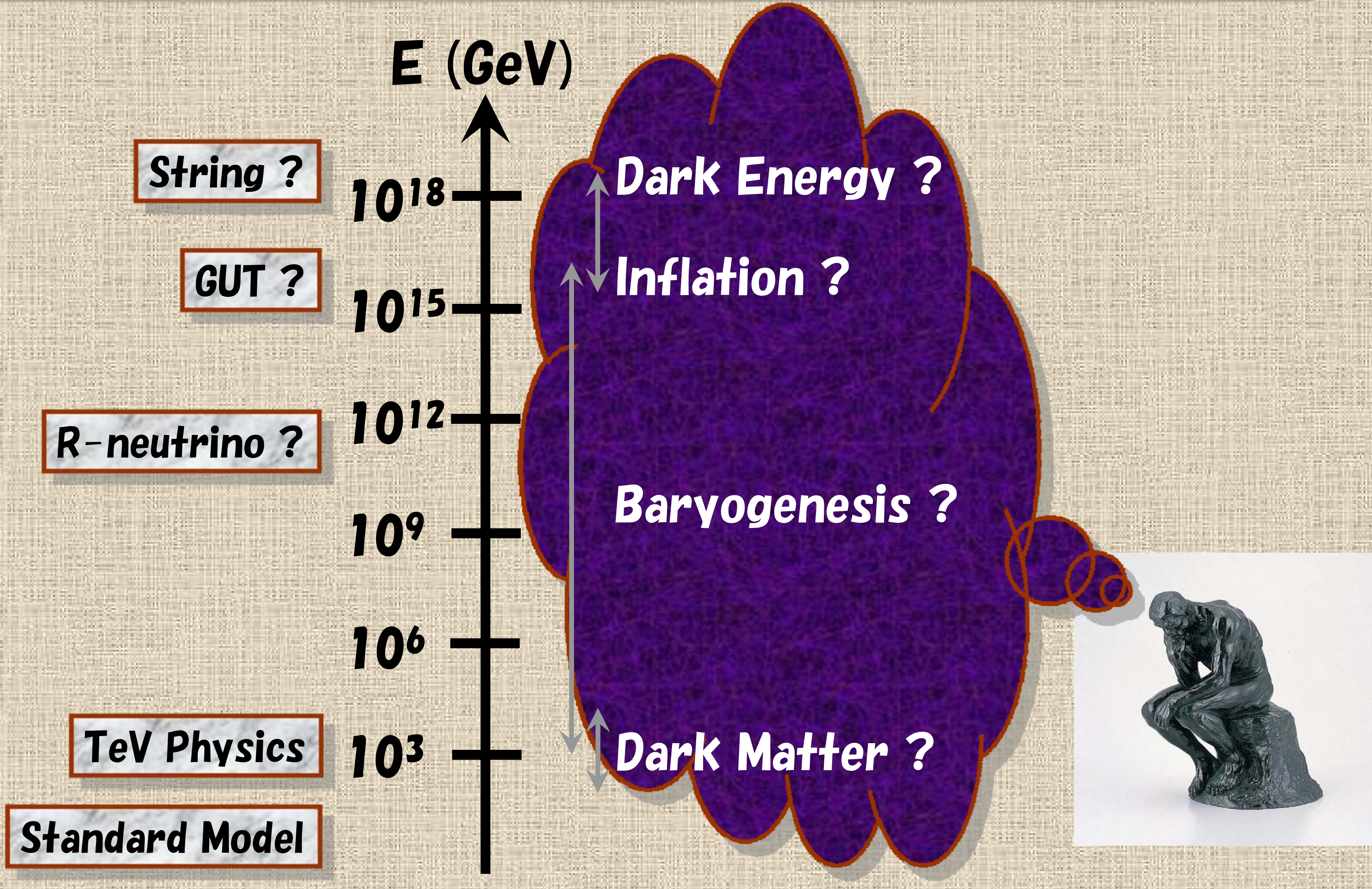
1-1 Cosmology & High energy physics



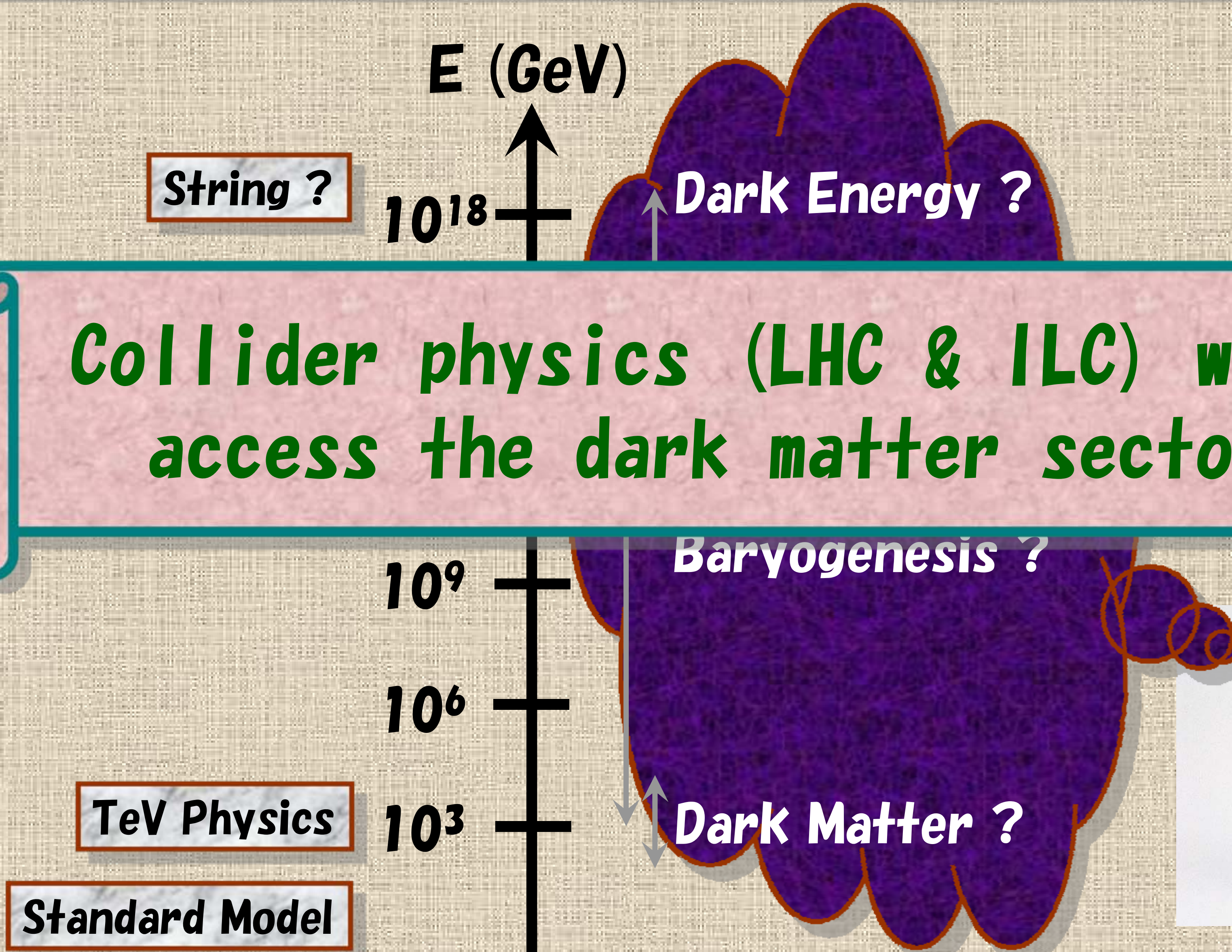
1-1 Cosmology & High energy physics



1-1 Cosmology & High energy physics



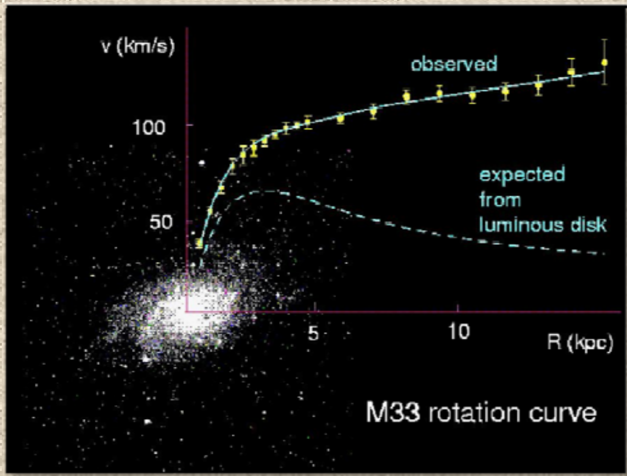
1-1 Cosmology & High energy physics

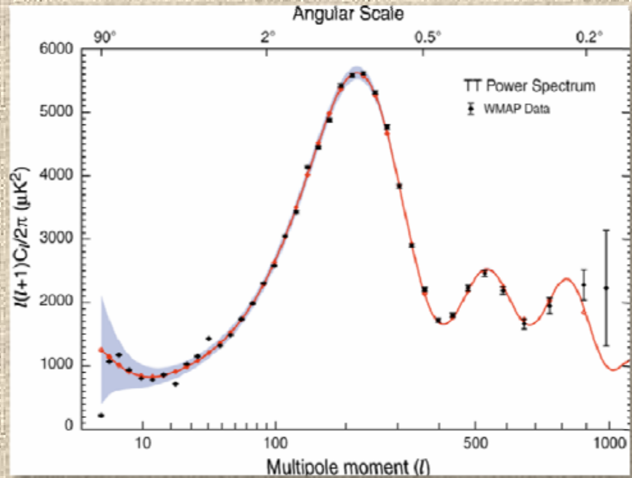


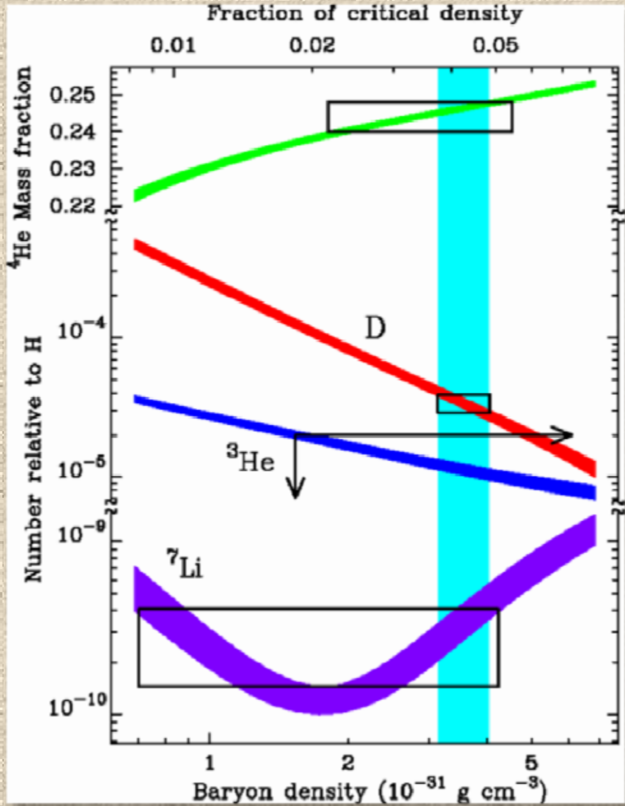
Collider physics (LHC & ILC) will access the dark matter sector!

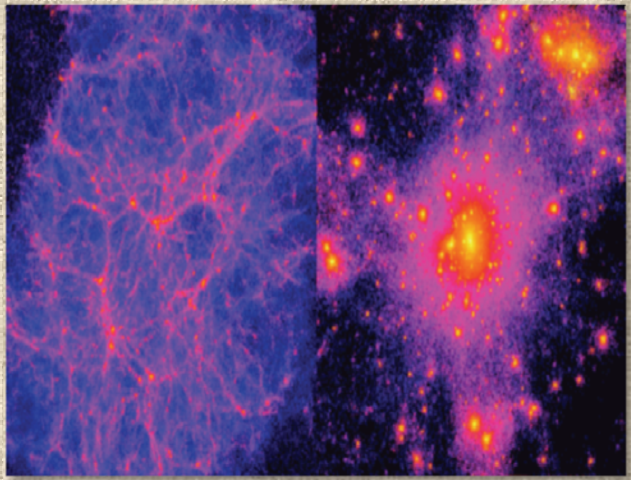
1-2 Why DM physics is related to TeV?

Existence of Dark Matter









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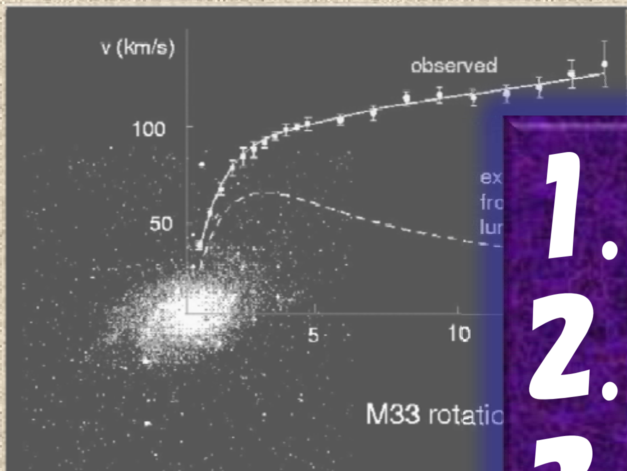

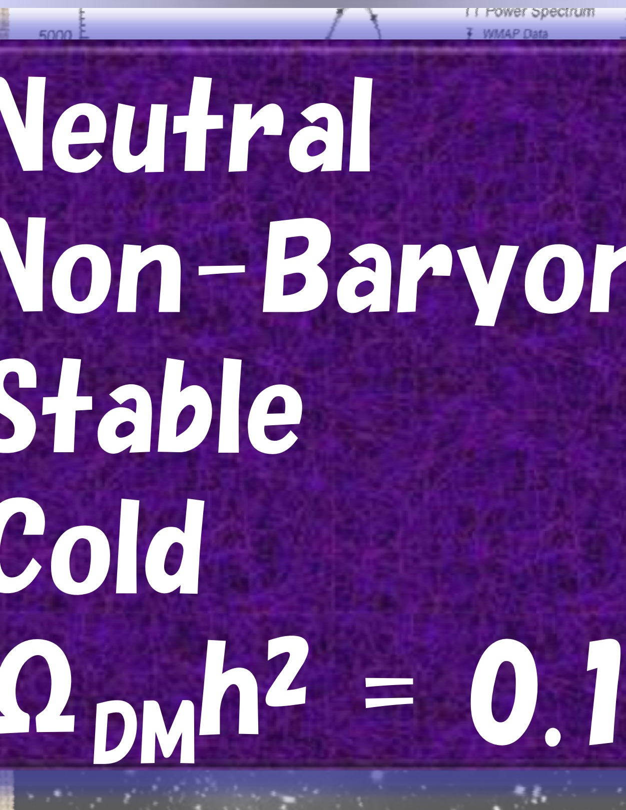

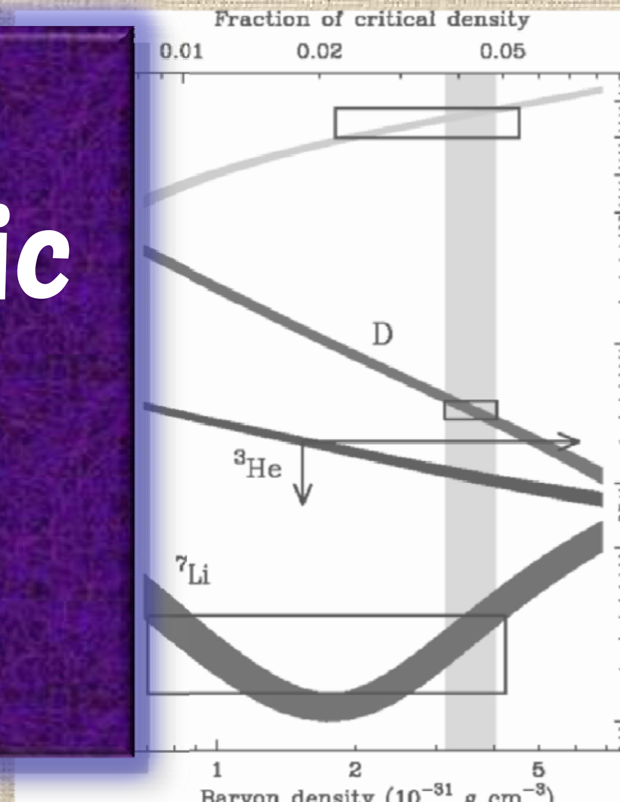

Dark Matter is

1. Neutral
2. Non-Baryonic
3. Stable
4. Cold
5. $\Omega_{DM}h^2 = 0.1$

No Dark Matter Candidate in the Standard Model

1-2 Why DM physics is related to TeV?

WIMP DM scenario explains the observations naturally!

Observations

1. Neutral
2. Non-Baryonic
3. Stable
4. Cold
5. $\Omega_{DM}h^2 = 0.1$

WIMP Dark Matter (DM) scenario

DM is
stable & neutral massive (~1 TeV) particle.
(Coupling consts. btw. DM & SMs are O(1))

I. First three conditions (1, 2, & 3) are satisfied by definition of WIMP DM.

II. Interestingly, last two conditions (4 & 5) are also satisfied in this scenario.

○ Freeze out at $T \sim m/20$

○ $\Omega_{DM}h^2 \sim 0.1\ \mathrm{pb}/(\sigma v)$

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WIMP Dark Matter (DM) scenario

WIMP DM candidates

1. Neutralino in the MSSM
2. 1^{st} KK photon in the UED
3. Heavy photon in the Little Higgs w/ T
4. Anti-periodic fermion in the GHU.
5. Dark Higgs in the inert doublet model

Notice: There are other attractive scenarios for dark matter such as axion, SuperWIMPs, ….

1-2 Why DM physics is related to TeV?

WIMP DM scenario explains the observations naturally!

WIMP Dark Matter (DM) scenario

WIMP DM candidates

Observations

1.
2.
3.
4. old
5. $\Omega_{DM}h^2 = 0.1$

TeV scale Collider (LHC & ILC)
will be the DM-factory!

5. Dark Higgs in the inert doublet model

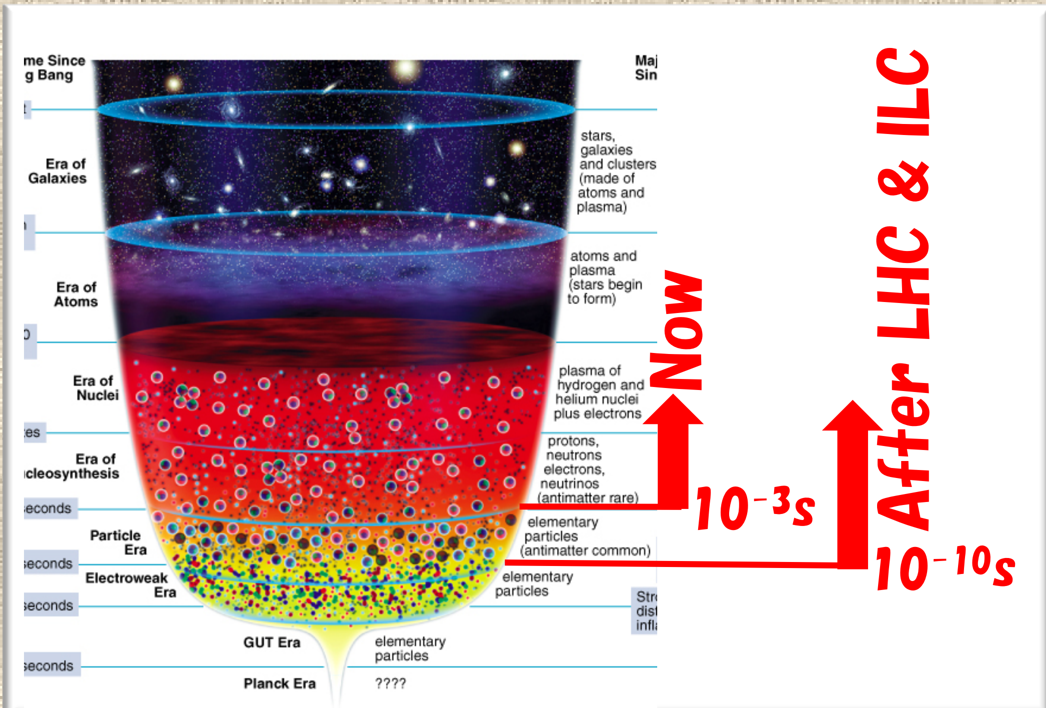
Notice: There are other attractive scenarios for dark matter such as axion, SuperWIMPs, ….

2. How important collider physics is for DM

Once Dark Matter is discovered at the LHC and its property is accurately determined at the ILC, the results of these experiments give great impact on

Cosmology & Astrophysics!

Cosmology & Collider physics



At the present time, we are understanding the thermal history of the Universe up to 0.01 sec.
(BBN and observations of He, D)

After LHC & ILC, it is possible to understand the history up to 10^{-10} sec.
(WMAP (Planck), LHC and ILC)

2. How important collider physics is for DM

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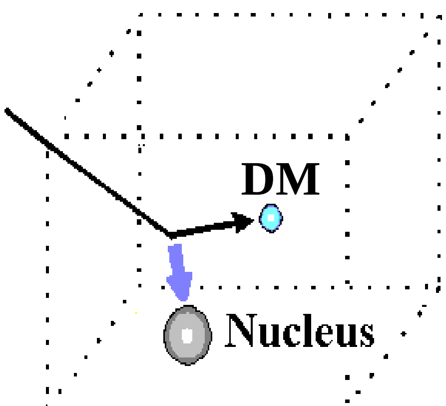
Cosmology & Astrophysics!

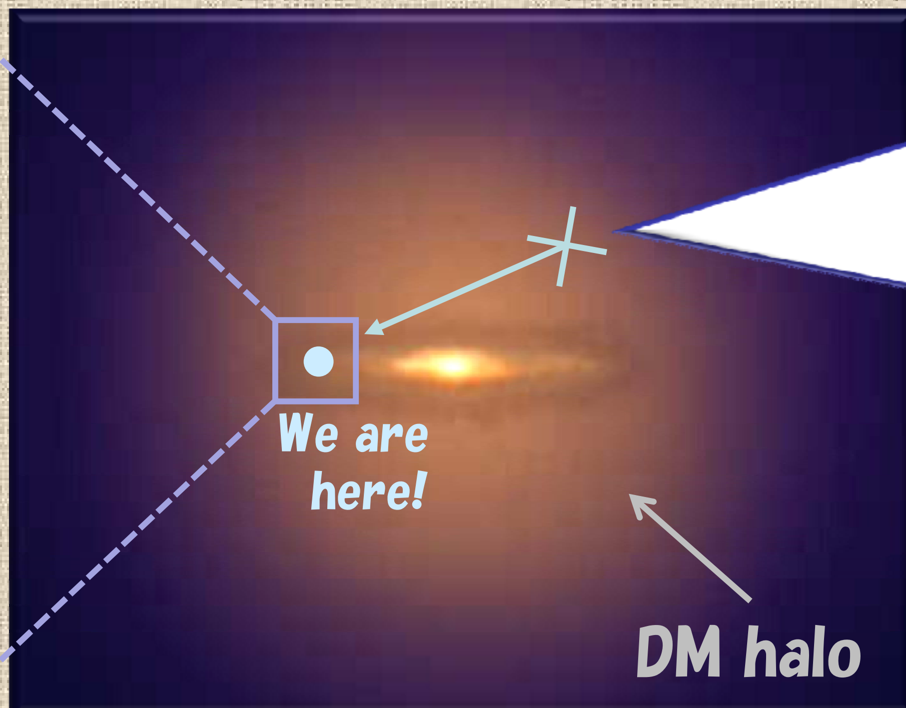
Astrophysics & Collider physics

DM scattering



Release energy !

Direct detection



DM annihilation

WIMP → ✶ ← WIMP

⇓

Energetic particles such as γ, e, p

Observing these visible particles

Indirect detection

2. How important collider physics is for DM

Once Dark Matter is discovered at the LHC and its property is accurately determined at the ILC, the results of these experiments give great impact on

Cosmology & Astrophysics!

For Astrophysics

1. Direct detection
2. Indirect detection (γ)
3. Indirect detection ($e^{\pm}$)
4. Indirect detection ($\bar{p}$)

⟷

1. Local DM density
2. DM density at G.C.
3. Small scale structure
4. Size of Diffusion zone

Signals in the detections suffer from astrophysical ambiguities!

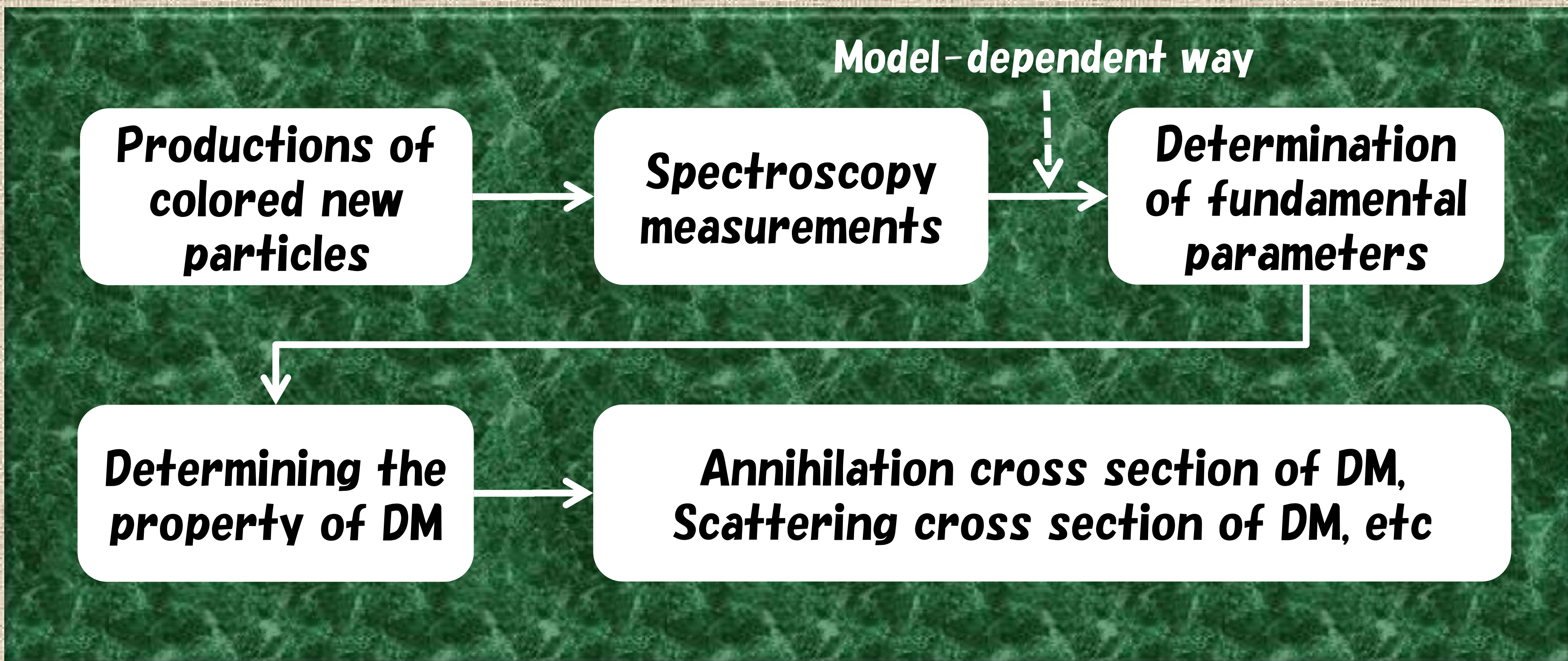
⇓

Once the property of DM is determined at the LHC and ILC, these detections give important information about the galaxy!

3. Recent Progress on the connection

- How accurately the property of the DM is determined?
- There are many works to answer the question.
- Most of works have been done in some benchmark points of some New Physics scenarios (MSSM, LHT, ⋯).

~ The case of the LHC ~



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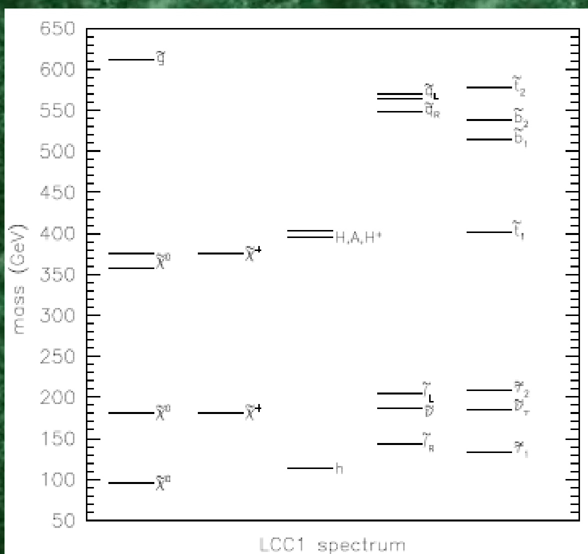
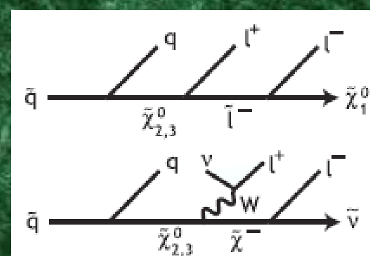
～ The case of the LHC ～

MSSM (LCC1)





$m(\tilde{\chi}_1^0)$	5.0 %
$m(\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0)$	1.4 %
$m(\tilde{e}_R) - m(\tilde{\chi}_1^0)$	2.1 %
$m(\tilde{\mu}_R) - m(\tilde{\chi}_1^0)$	13 %
$m(\tilde{\tau}_1) - m(\tilde{\chi}_1^0)$	1.1 %
$m(\tilde{e}_L) - m(\tilde{\chi}_1^0)$	1.1 %
$m(\tilde{\mu}_L) - m(\tilde{\chi}_1^0)$	1.1 %

[E. A. Baltz, M. Battaglia, M. E. Peskin, T. Wizansky, hep-ph/0602187]

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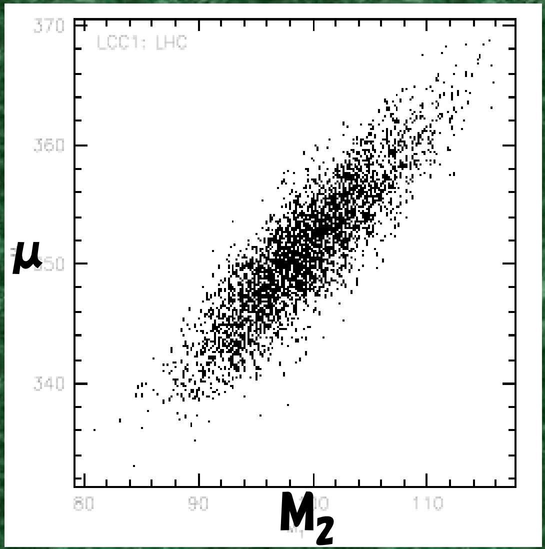
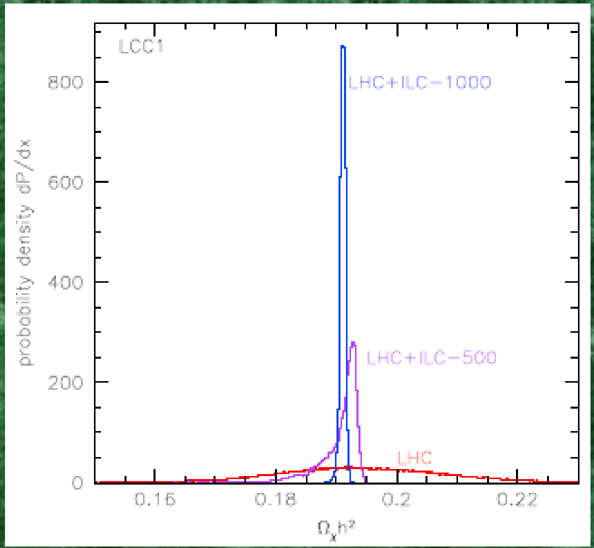
MSSM (LCC1)

$\Omega_{DM}h^2$: 7%



Mass, Spin, Interactions



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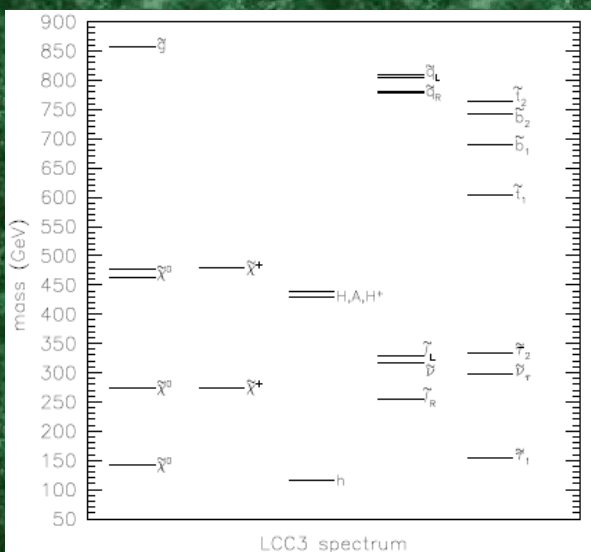
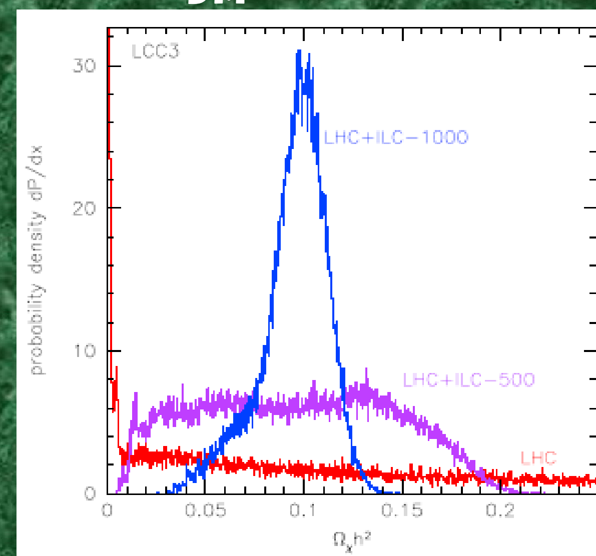
~ The case of the LHC ~

MSSM (LCC3)



→ in the same manner →

$\Omega_{DM}h^2$: none



[E. A. Baltz, M. Battaglia, M. E. Peskin, T. Wizansky, hep-ph/0602187]

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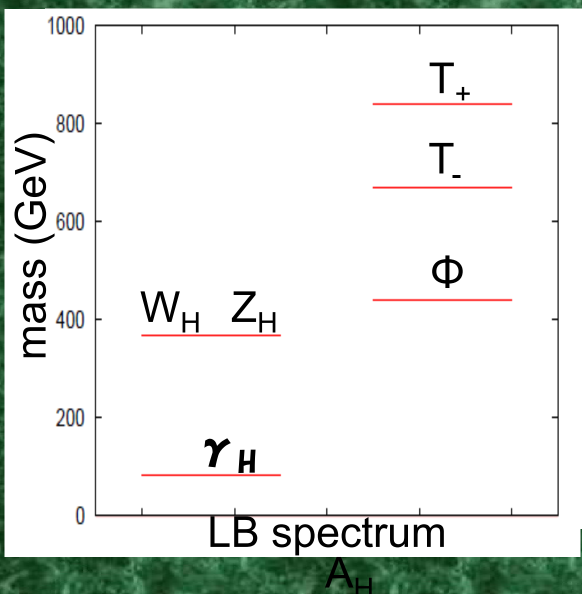
～ The case of the LHC ～

LHT (LB)



→

t-partners productions

$T_+ \rightarrow b\ W$

$T_- \rightarrow t\ \gamma_H$

→

$m(\gamma_H)$	5.7 %
$m(T_+)$	2.4 %
$m(T_-) - m(\gamma_H)$	3.5 %

Other new particles such as T-odd fermions are not relevant to DM.

[S.M, T. Moroi, K. Tobe, arXiv:0806.3837]

3. Recent Pr

○ How accurately t
○ There are many v
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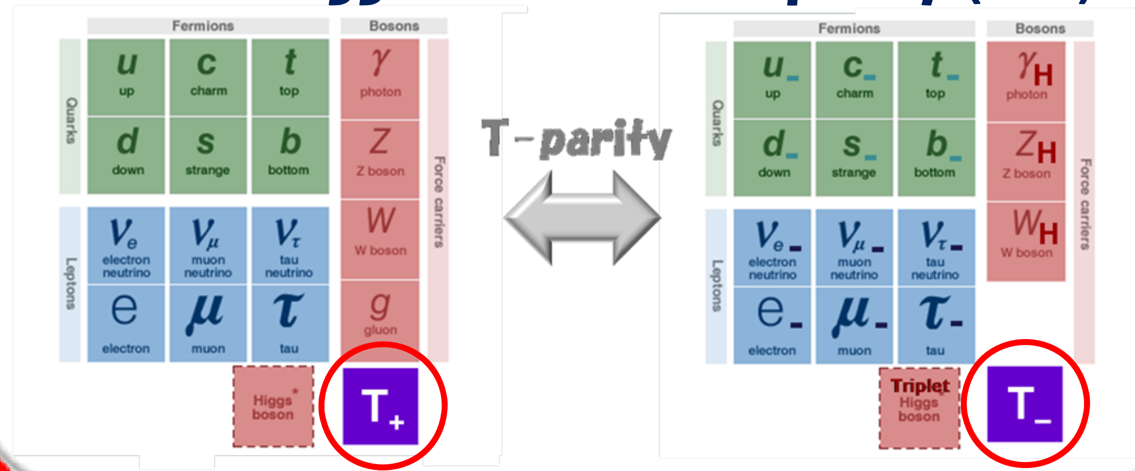
points of some N

~ The

Littlest Higgs model with T-parity (LHT)



LHT (LB)

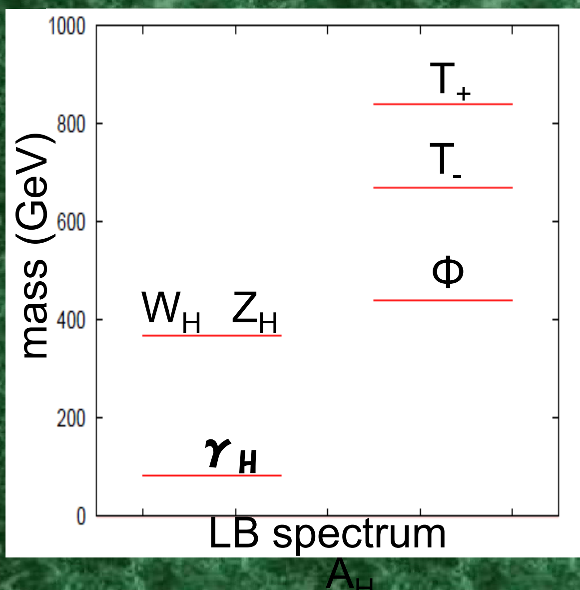


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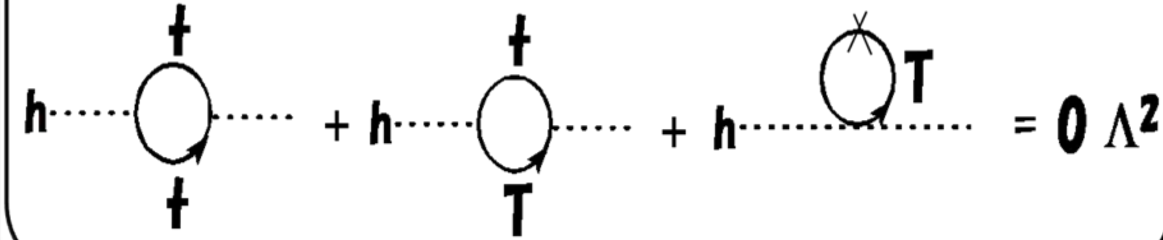
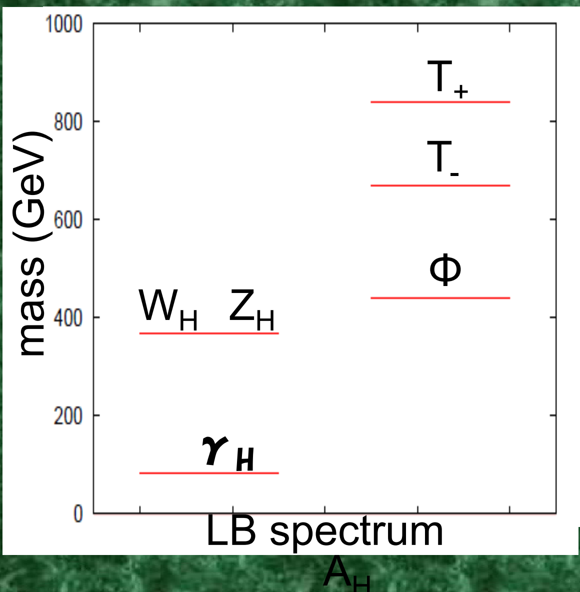
Diagram Cancellations



LHT (LB)



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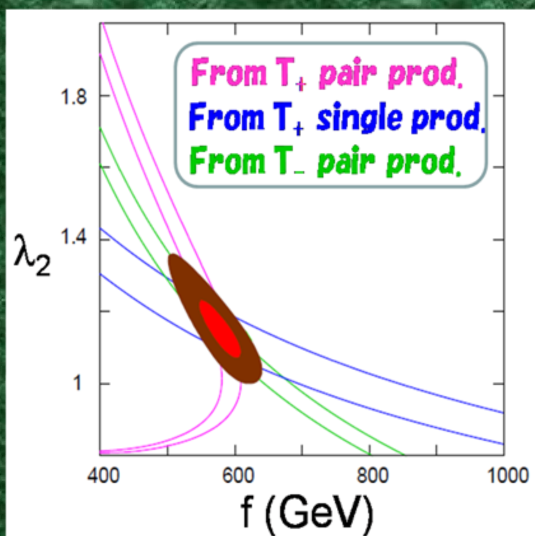
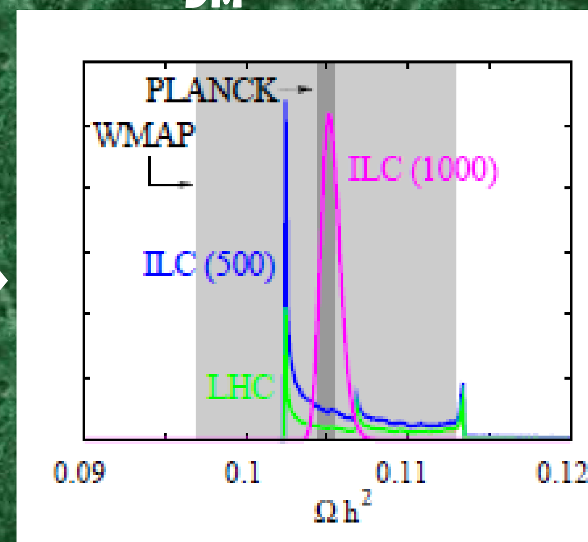


Mass, Spin, Interactions

$\Omega_{DM}h^2$: 10%



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~ The case of the ILC ~

Productions of new particles lighter than $s^{1/2}$ → Spectroscopy, Threshold, Angular distributions, (w/ Polarized beam) etc → Determination of fundamental parameters

Spectroscopy, Threshold, Angular distributions, (w/ Polarized beam) etc → Mass and spin of DM, Gauge charges of DM, Interactions btw DM & SMs

Model-independent way?

Mass and spin of DM
Gauge charges of DM
Interactions btw DM & SMs
→ Annihilation cross section of DM, Scattering cross section of DM, etc

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MSSM (LCC1)

cross section		LCC1 Value (fb)		ILC 500	ILC 1000
$\sigma(e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-)$	LR	431.5 (0.758)	$\pm$	1.1%*	
	RL	13.1 (0.711)	$\pm$	3.5%*	
$\sigma(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0)$	LR	172.2	$\pm$	2.1%*	
	RL	20.6	$\pm$	7.5%*	
$\sigma(e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0)$	LR	189.9	$\pm$	2.0%*	
	RL	5.3	$\pm$	10.2%*	
$\sigma(e^+e^- \to \tilde{\tau}_1^+\tilde{\tau}_1^-)$	LR	45.6	$\pm$	7%	
	RL	142.1	$\pm$	4%	
$\sigma(e^+e^- \to \tilde{e}_R^+\tilde{e}_R^-)$	LR	57.3 (0.696)	$\pm$	6%	
	RL	879.9 (0.960)	$\pm$	1.5%	
$\sigma(e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1)$	LR	9.8	$\pm$		15%
	RL	11.1	$\pm$		14%

⇒

$m(\tilde{\chi}_1^0)$	0.05 %
$m(\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0)$	0.08 %
$m(\tilde{e}_R) - m(\tilde{\chi}_1^0)$	0.42 %
$m(\tilde{\mu}_R) - m(\tilde{\chi}_1^0)$	0.42 %
$m(\tilde{\tau}_1) - m(\tilde{\chi}_1^0)$	0.78 %
$m(\tilde{e}_L) - m(\tilde{\chi}_1^0)$	0.18 %
$m(\tilde{\mu}_L) - m(\tilde{\chi}_1^0)$	0.92 %

[E. A. Baltz, M. Battaglia, M. E. Peskin, T. Wizansky, hep-ph/0602187]

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$\sigma(e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1)$	LR	9.8	±		15%
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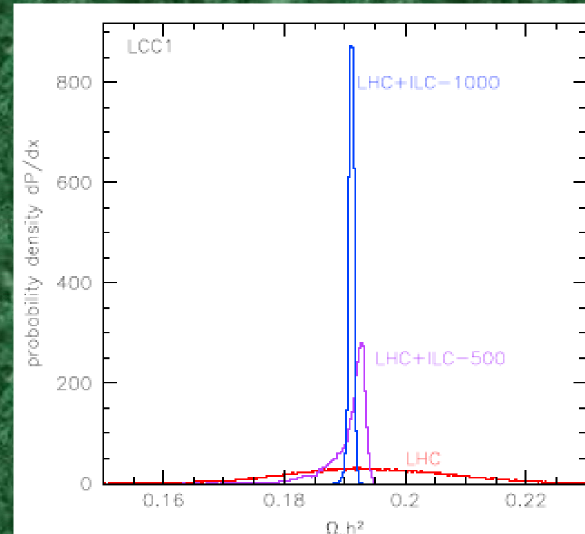
$\Omega_{DM}h^2$: 2% & 0.25 %



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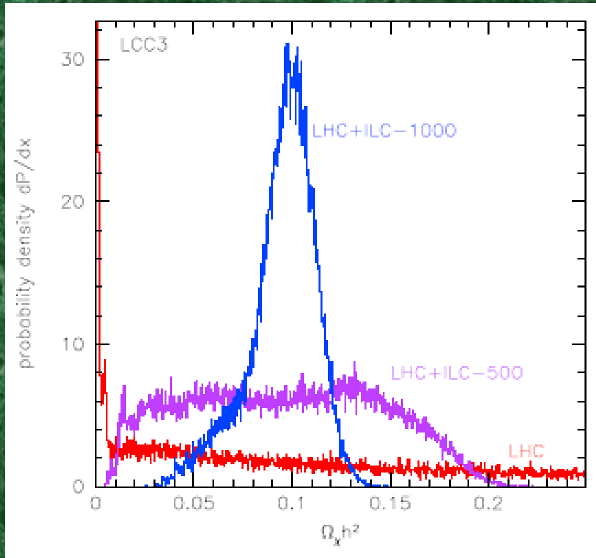
~ The case of the ILC ~

MSSM (LCC3)

cross section		LCC3 value		ILC 500	ILC 1000
minimal set					
$\sigma(e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2)$	LR	34.4	$\pm$	8%*	
	RL	2.1	$\pm$	-	
$\sigma(e^+e^- \to \tilde{\tau}^+_1\tilde{\tau}^-_1)$	LR	45.6	$\pm$	100%*	
	RL	103.4	$\pm$	4%*	
$\sigma(e^+e^- \to \tilde{\chi}^+_1\tilde{\chi}^-_1)$	LR	212.3 (0.808)	$\pm$		3%
	RL	6.3 (0.774)	$\pm$		-
$\sigma(e^+e^- \to \tilde{\chi}^0_2\tilde{\chi}^0_2)$	LR	88.7	$\pm$		5%
	RL	2.5	$\pm$		-
$\sigma(e^+e^- \to \tilde{e}^+_R\tilde{e}^-_R)$	LR	19.5 (0.735)	$\pm$	10%	
	RL	350.5 (0.971)	$\pm$	3%	

⇒

$\Omega_{DM}h^2$: 18 % (1TeV)



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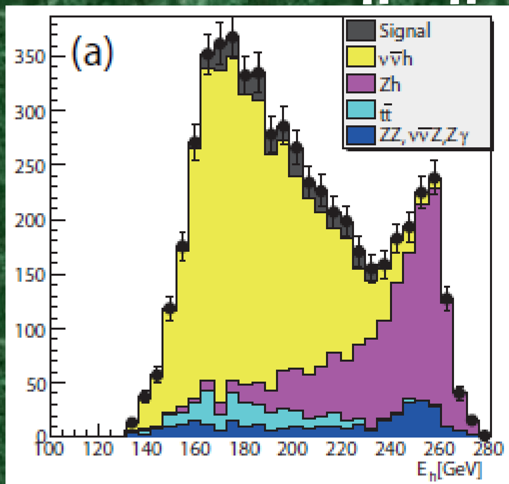
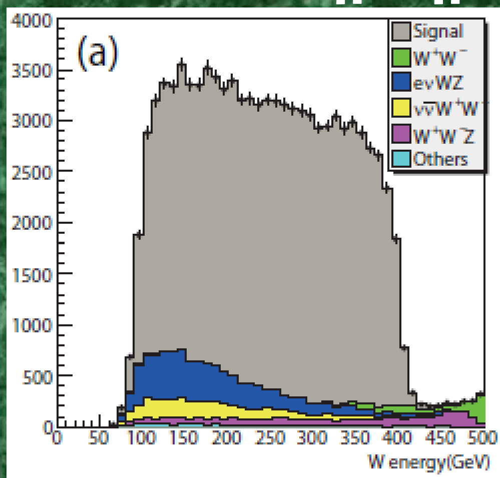
LHT (LB)

$e^+ e^- \to \gamma_H Z_H$



$e^+ e^- \to W_H W_H$



f: 4.3 % & 0.12 %

ILC (500 GeV)	
$m(\gamma_H)$	16 %
$m(Z_H)$	4.4 %

ILC (1 TeV)	
$m(A_H)$	0.87 %
$m(Z_H)$	0.16 %

[E. Asakawa, M. Asano, K. Fujii, T. Kusano, S. Matsumoto, R. Sasaki, Y. Takubo, H. Yamamoto, arXiv:0901.1081]

→Talk (Takubo) tomorrow!

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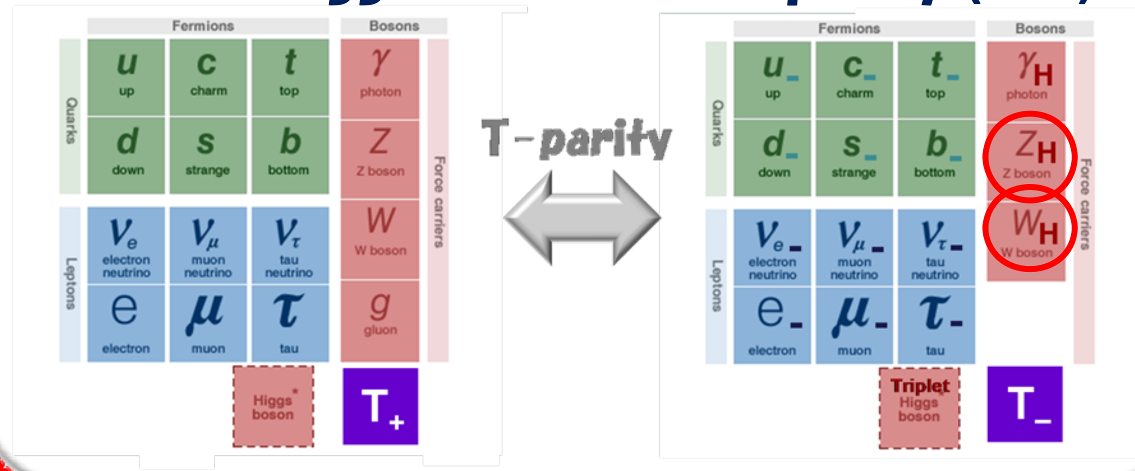
  points of some N

Littlest Higgs model with T-parity (LHT)



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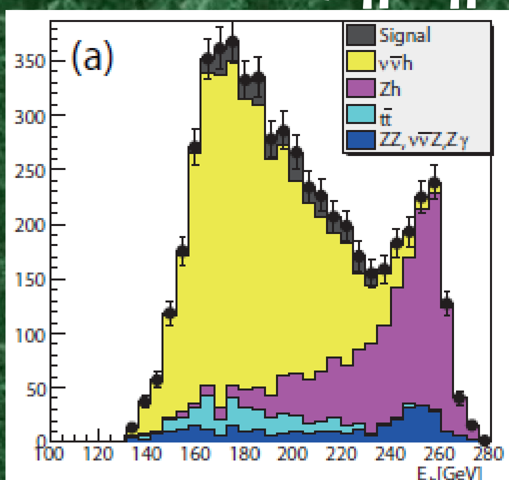
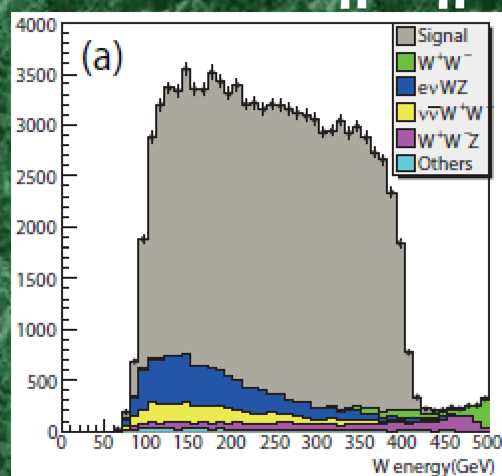
LHT (LB)

$e^+ e^- \to \gamma_H Z_H$



$e^+ e^- \to W_H W_H$



f: 4.3 % & 0.12 %

ILC (500 GeV)	
$m(\gamma_H)$	16 %
$m(Z_H)$	4.4 %

ILC (1 TeV)	
$m(A_H)$	0.87 %
$m(Z_H)$	0.16 %

[E. Asakawa, M. Asano, K. Fujii, T. Kusano, S. Matsumoto, R. Sasaki, Y. Takubo, H. Yamamoto, arXiv:0901.1081]

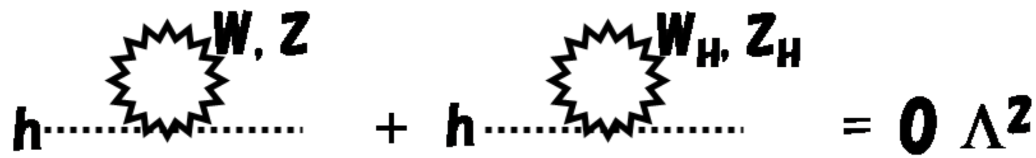
→Talk (Takubo) tomorrow!

3. Recent Pr

- How accurately t
- There are many v
- Most of works ha
  points of some N

~ The

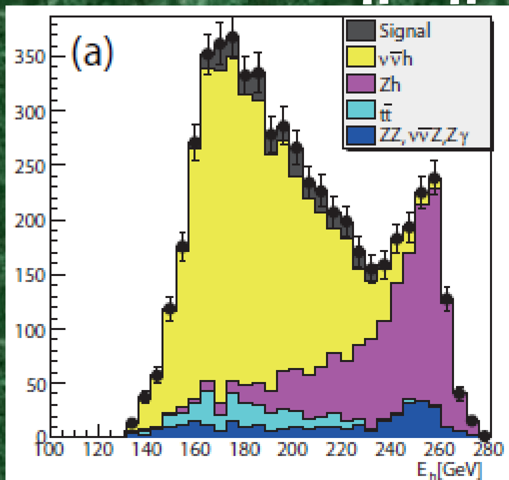
Diagram Cancellations



$Z_H \to h\ \gamma_H$ $W_H \to W\ \gamma_H$

LHT (LB)

$e^+ e^- \to \gamma_H Z_H$



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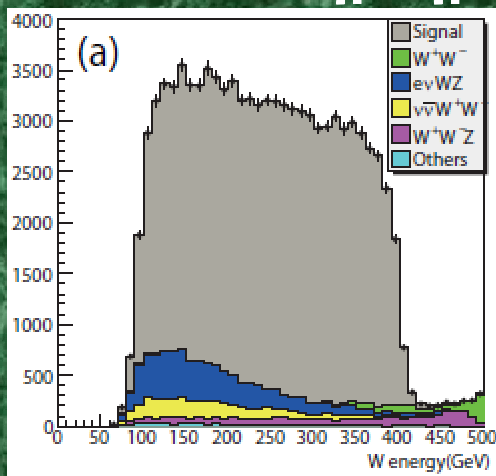

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→Talk (Takubo) tomorrow!

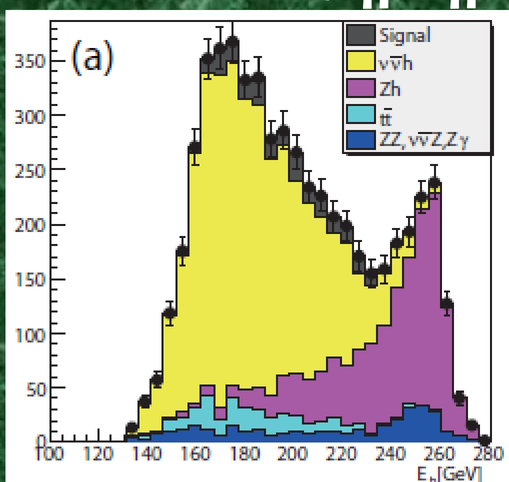
3. Recent Progress on the connection

- How accurately the property of the DM is determined?
- There are many works to answer the question.
- Most of works have been done in some benchmark points of some New Physics scenarios (MSSM, LHT, …).

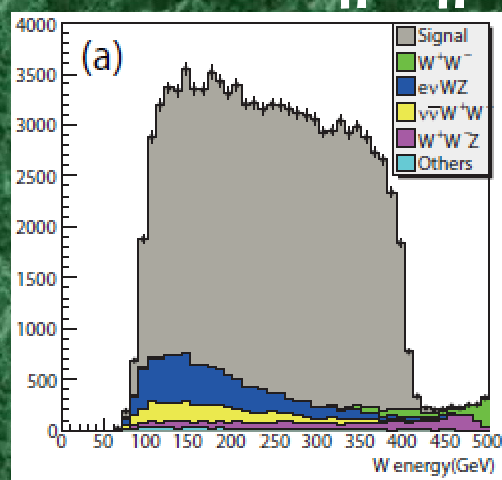
~ The case of the ILC ~

LHT (LB)

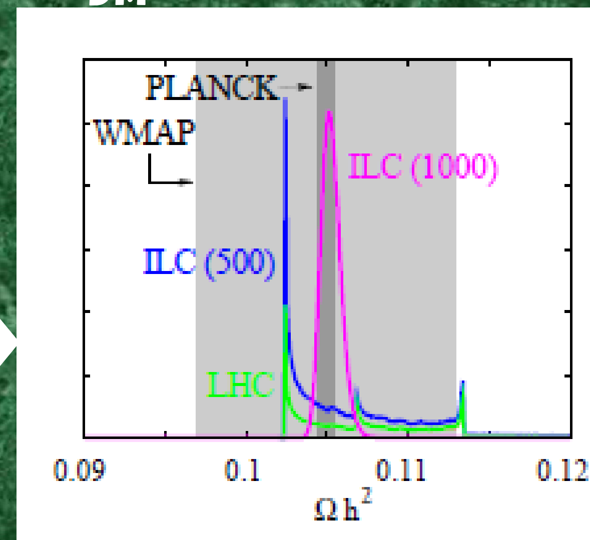
$e^+ e^- \to \gamma_H Z_H$



$e^+ e^- \to W_H W_H$



$\Omega_{DM}h^2$: 10% & 1 %



[E. Asakawa, M. Asano, K. Fujii, T. Kusano, S. Matsumoto, R. Sasaki, Y. Takubo, H. Yamamoto, arXiv:0901.1081]

→Talk (Takubo) tomorrow!

Summary

1. Collider Physics is strongly expected to be related with Dark Matter problem.
2. Results of Collider physics will give great impact on Cosmology and Astrophysics!
3. In particular, the ILC is very important to establish the dark matter astrophysics.
4. There are some works investigating how accurately the property of DM is determined at the LHC and ILC.

Discussions

For the cosmological connection to LHC & ILC physics

1. More studies benchmark points in the MSSM.
2. More studies in extended Supersymmetric scenarios.
3. More studies in other new physics models.
4. To establish the model-independent way
   to determine the property of DM. → Talk(Asano) tomorrow!