Group A

Beyond the Standard Model

What we think is next?

Planck-weak hierarchy

baryogenesis

flavor hierarchy

dark matter

strong CP

neutrino mass

inflation

dark energy

strong dynamics

Supersymmetry

extra dimension

origin of the Higgs potential

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Higgs as a window to new physics! (Kanemura)

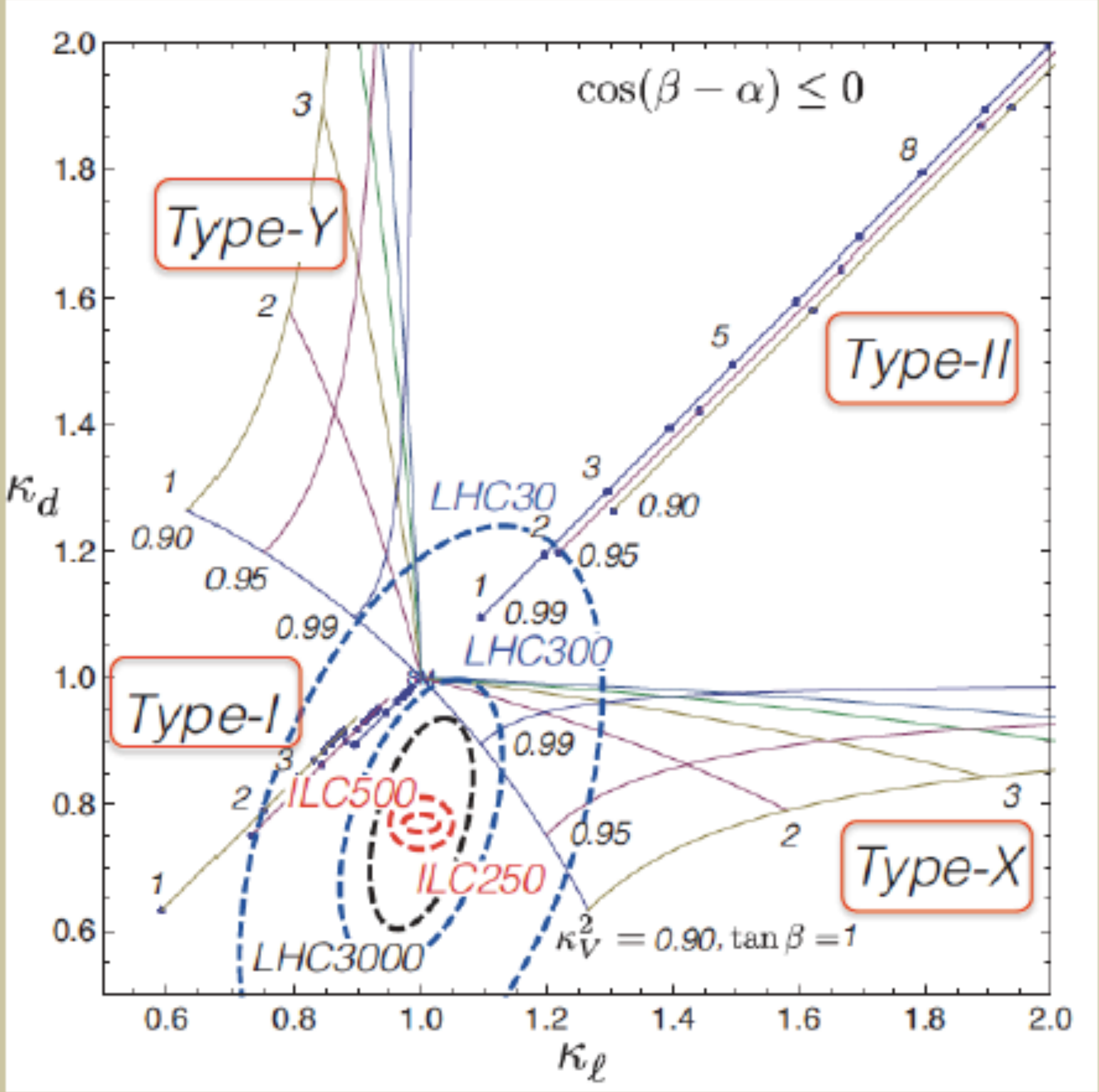
Fingerprinting the model (2HDM)

SK, K. Tsumura, K. Yagyu, H. Yokoya 2013

hbb vs hττ

We can determine the type of Yukawa interacion in the 2HDM

Ellipse = 68.27% CL



Ibe's talk

$SU(2)_L$ charged dark matter
- $Y = 0$: minimal dark matter → a viable WIMP candidate !
- $Y \neq 0$: hypercharged minimal dark matter → a viable *WIMPZILLA* candidate !

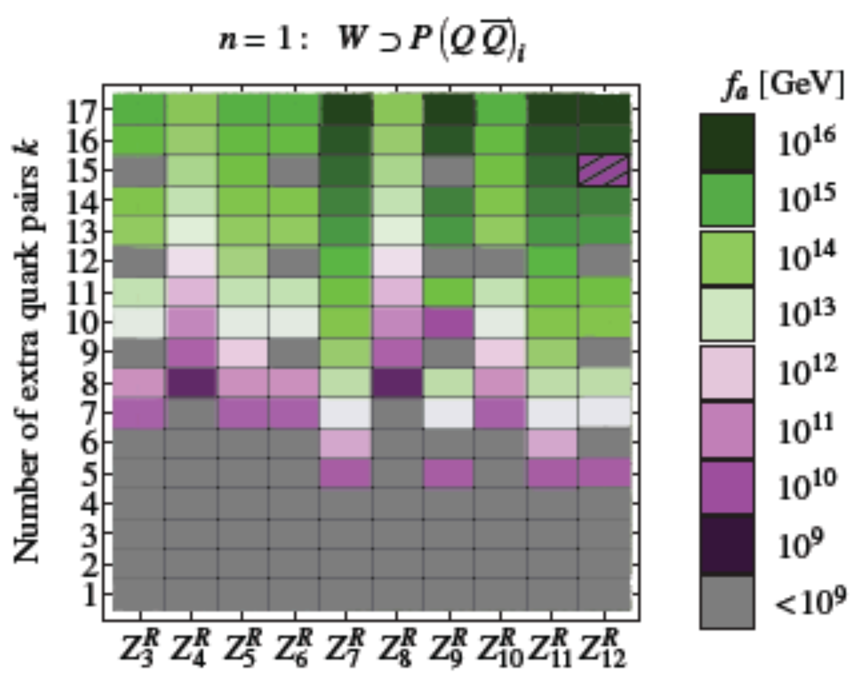
- Which scenario is more favorable ?
  - The WIMP scenario fits together well with the *Naturalness* arguments.
  - From the view point of *Simplicity* of the dark matter sector, however, both scenarios are equally acceptable !

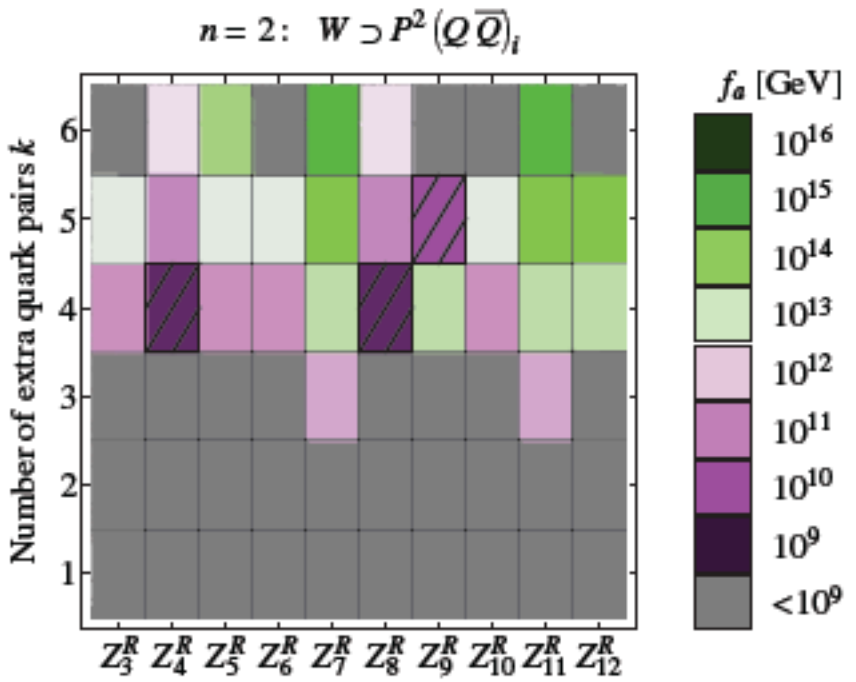
- Features of hypercharged minimal dark matter.
  - Next generation direct detection experiments reach to $M_{DM} = 10^{10\text{-}11}\,GeV$.
  - Through the direct detection experiments we can determine the reheating temperature to $T_R \sim 10^{7\text{-}9}\,GeV\,(M_{DM}/2\text{x}10^{10}\,GeV)$.
  - By collecting *O(100)* DM signal events on different target materials, we will get strong hints on the hypercharged DM through the test of the isospin violation !

Kai's talk

Phenomenologically Viable Scenarios

- Upper bounds on f_a due to the requirement that $\Delta\bar{\theta} \leq 10^{-10}$.
- Shaded squares: $\Delta\bar{\theta} \leq 10^{-10}$ satisfied, but $g_{\mathrm{GUT}} > \sqrt{4\pi}$.

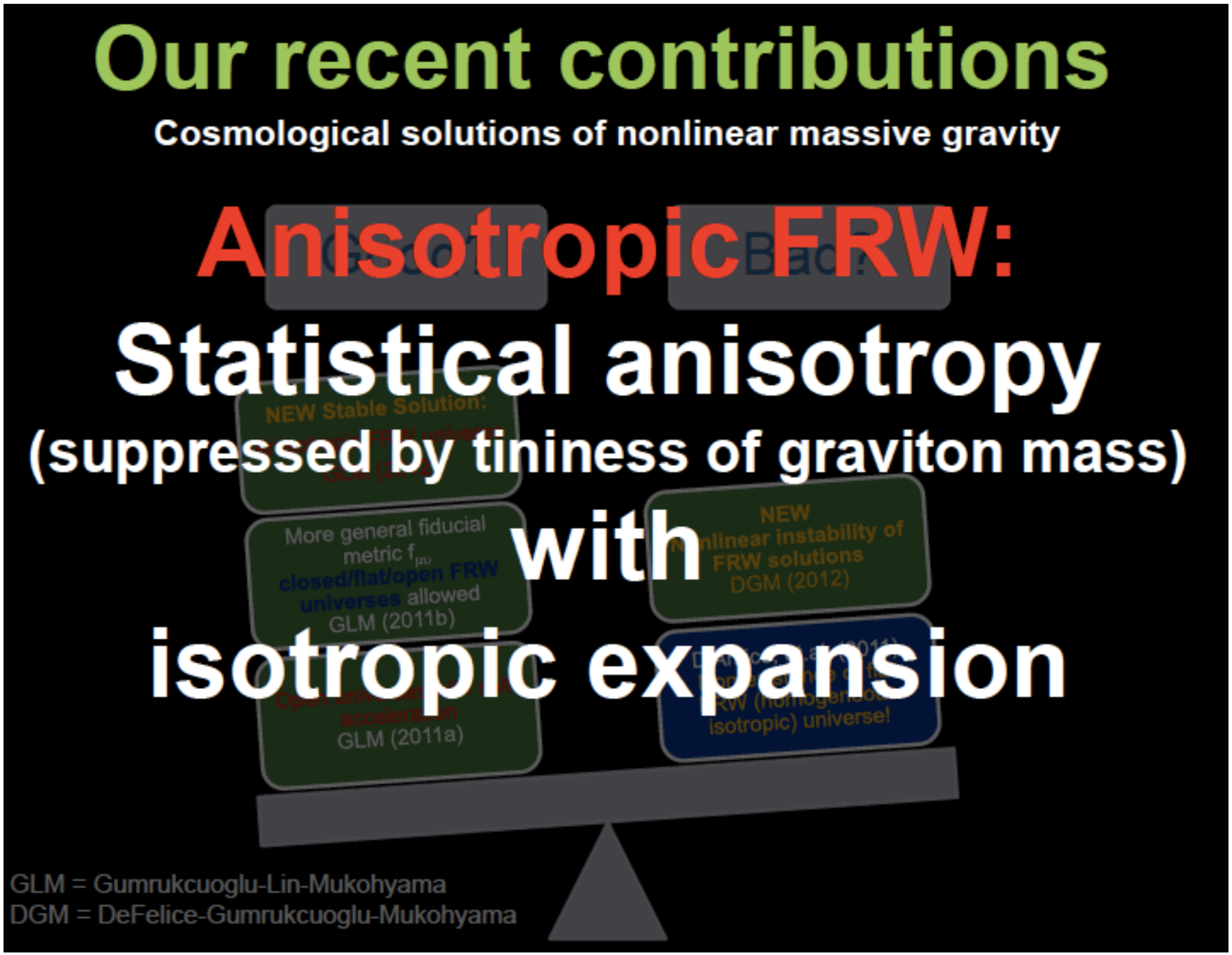




Large landscape of viable scenarios. ⇒ Works for any Z_N^R symmetry!

$f_a^{\max} \gtrsim 10^{12}\,\mathrm{GeV}$ in some cases. ⇒ Axion dark matter possible!

Shinji's talk



Motoi's talk

Reconstruction at ILC

Neutralino contribution to muon g-2 is reconstructed by measuring all the sleptons

$$\delta a_\mu^{(\mathrm{ILC})}/a_\mu^{(\mathrm{ILC})} \simeq 13\,\%$$

at the sample point with $\sqrt{s} = 500\,\mathrm{GeV},\ \mathcal{L} \sim 500\mathrm{fb}^{-1}$

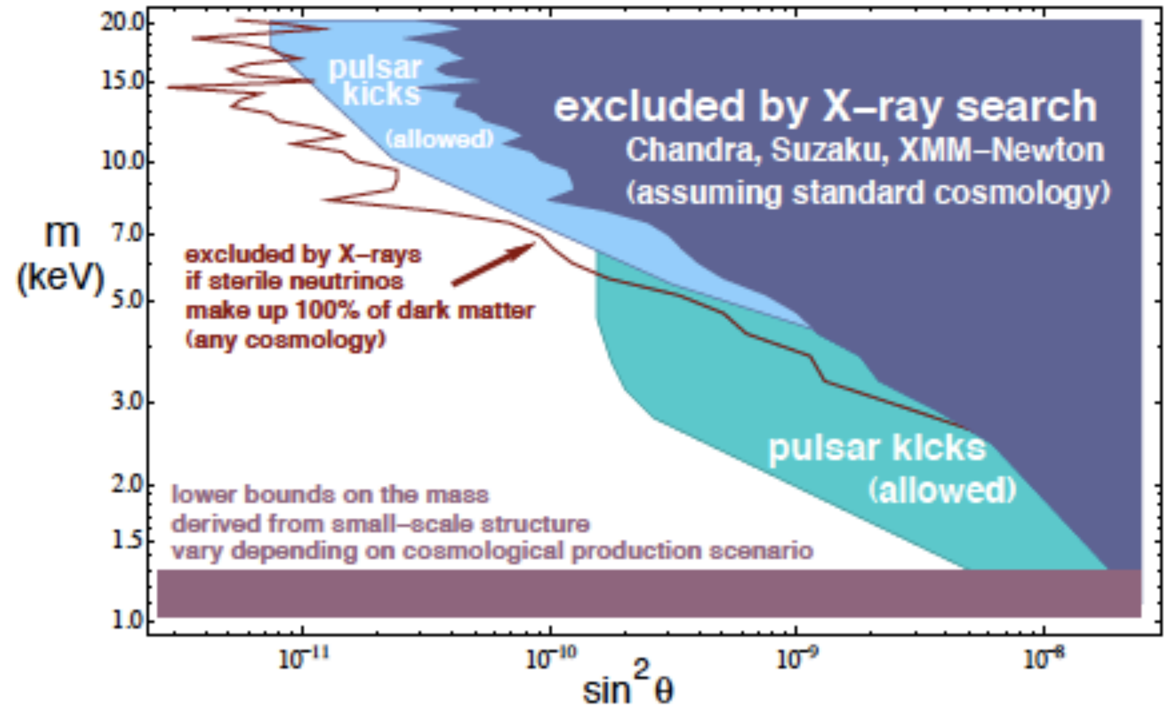
+ correction from Winos, Higgsinos is 4% (1%) for >1TeV (1.5TeV)

X	δX	$\delta_X a_\mu^{(\mathrm{ILC})}$	Process	
$m^2_{\tilde{\mu}LR}$	12 %	13 %	$e^+e^- \to \tilde{\tau}^+\tilde{\tau}^-$	(cross section, endpoint)
$(\sin 2\theta_{\tilde{\tau}})$	(9 %)	–	$e^+e^- \to \tilde{\tau}_1^+\tilde{\tau}_1^-$	(cross section)
$(m_{\tilde{\tau}2})$	(3 %)	–	$e^+e^- \to \tilde{\tau}_2^+\tilde{\tau}_2^-$	(endpoint)
$m_{\tilde{\mu}1}$, $m_{\tilde{\mu}2}$	200 MeV	0.3 %	$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-$	(endpoint)
$m_{\tilde{\chi}_1^0}$	100 MeV	< 0.1 %	$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-/\tilde{e}^+\tilde{e}^-$	(endpoint)
$\tilde{g}_{1,L}^{(\mathrm{eff})}$	a few+1 %	a few+1 %	$e^+e^- \to \tilde{e}_L^+\tilde{e}_R^-$	(cross section)
$\tilde{g}_{1,R}^{(\mathrm{eff})}$	1 %	0.9 %	$e^+e^- \to \tilde{e}_R^+\tilde{e}_R^-$	(cross section)

Alex’s talk

Alexander Kusenko (UCLA/Kavli IPMU) *Tohoku University, 2013*

Limits from X-ray searches



[Loewenstein, A.K., Biermann, ApJ 700, 426 (2009);
Loewenstein, A.K., ApJ 714 (2010) 652; ApJ. 751 (2012) 82]

Kitano's talk

Summary

the current situation may be indicating physics beyond the MSSM.

- stop should be light. We should find it soon.
- There may be many resonances waiting for us around TeV scale.
- Higgsino should be light. Discovery at ILC?

I hope that's the case! Thank you.

Natsumi's talk

Effective Lagrangian for Majorana DM

$$\mathcal{L}_q = d_q \bar{\tilde{\chi}}^0 \gamma^\mu \gamma_5 \tilde{\chi}^0 \bar{q} \gamma_\mu \gamma_5 q$$

← Spin-dependent (SD)

$$+ f_q m_q \bar{\tilde{\chi}}^0 \tilde{\chi}^0 \bar{q} q + \frac{g_q^{(1)}}{M} \bar{\tilde{\chi}}^0 i\partial^\mu \gamma^\nu \tilde{\chi}^0 \mathcal{O}^q_{\mu\nu} + \frac{g_q^{(2)}}{M^2} \bar{\tilde{\chi}}^0 i\partial^\mu i\partial^\nu \tilde{\chi}^0 \mathcal{O}^q_{\mu\nu}$$

$$\mathcal{L}_G = f_G \bar{\tilde{\chi}}^0 \tilde{\chi}^0 G^a_{\mu\nu} G^{a\mu\nu} + \frac{g_G^{(1)}}{M} \bar{\tilde{\chi}}^0 i\partial^\mu \gamma^\nu \tilde{\chi}^0 \mathcal{O}^g_{\mu\nu} + \frac{g_G^{(2)}}{M^2} \bar{\tilde{\chi}}^0 i\partial^\mu i\partial^\nu \tilde{\chi}^0 \mathcal{O}^g_{\mu\nu}$$

Spin-independent (SI)

$\tilde{\chi}^0$: DM $\quad m_q$: quark mass $\quad M$: DM mass

Majorana condition

$$\bar{\tilde{\chi}}^0 \gamma^\mu \tilde{\chi}^0 = 0$$

$$\bar{\tilde{\chi}}^0 \sigma^{\mu\nu} \tilde{\chi}^0 = 0$$

Twist-2 operator

$$\mathcal{O}^q_{\mu\nu} \equiv \frac{1}{2} \bar{q} i \left(D_\mu \gamma_\nu + D_\nu \gamma_\mu - \frac{1}{2} g_{\mu\nu} \not{D} \right) q$$

$$\mathcal{O}^g_{\mu\nu} \equiv G^{a\rho}_{\mu} G^a_{\rho\nu} + \frac{1}{4} g_{\mu\nu} G^a_{\alpha\beta} G^{a\alpha\beta}$$

Strategies?

naturalness

Andy
Kitano
Kai

we can predict something!
but nature looks unnatural...

simplicity/minimality

Joe
Yukawa
Redondo
Weinberg?
Alex

we can predict something!
what's simple? why minimal?

beauty

Higaki
David
Dirac

theory must be beautiful!
but nature actually looks ugly...

scanning all the logical possibilities

Kanemura
Nakayama
Shinji
Natsumi
Tomo
Ibe
Endo?

Of course!
but how far should we go?

theorists freedom

There are many different attitudes.

We grouped up by the favorite strategies
and discussed what would be the most important approach
to physics beyond the Standard Model and Cosmology

by hoping some collaborations start from here.

model based approach (naturalness, beauty)

Little Higgs

MSSM

Split SUSY

composite Higgs

SUSY GUT

String Pheno

PQ model

minimal dark matter

Randall-Sundrum

flatland

ADD

νMSM

model grading (1-5)

(5 is the best)

	SM+DM	νMSM	MSSM	Split SUSY	PQ model	extra dim.
naturalness	1	1	4	2	2	3
Simplicity	5	4	3	4	3	3
Beauty	3	3	4	4	3	3
Predictability	4	4	2	1	4	3
Testability	4	4	3	2	3	3
problems	3	4	2	3	4	2

	composite Higgs	$\lambda=0@M_{pl}$	SUSY GUT	String based
naturalness	3	1	3	3
Simplicity	1	5	2	1
Beauty	4	3	5	5
Predictability	3	5	4	2
Testability	3	2	4	2
problems	2	2	1	1

equal weight

	Weight	SM+DM	nuMSM	MSSM	Split SUSY	PQ	Extra dim.	composite/LH	Flatland	SUSY GUT	String
Naturalness	1	1	1	4	2	2	3	3	1	3	3
Simplicity	1	5	4	3	4	3	3	1	5	2	1
Beauty	1	3	3	4	4	3	3	4	3	5	5
Predictability	1	4	4	2	1	4	3	3	5	4	1
Testability	1	4	4	3	2	3	3	3	2	4	1
# of problems	1	3	4	2	3	4	2	2	2	1	1
total (weighted)		20	20	18	16	19	17	16	18	19	12

Kitano weight

	Weight	SM+DM	nuMSM	MSSM	Split SUSY	PQ	Extra dim.	composite/LH	Flatland	SUSY GUT	String
Naturalness	5	1	1	4	2	2	3	3	1	3	3
Simplicity	3	5	4	3	4	3	3	1	5	2	1
Beauty	4	3	3	4	4	3	3	4	3	5	5
Predictability	2	4	4	2	1	4	3	3	5	4	1
Testability	2	4	4	3	2	3	3	3	2	4	1
# of problems	2	3	4	2	3	4	2	2	2	1	1
total (weighted)		18	17.6667	19.6667	16.6667	17.6667	17.3333	16.6666667	16.6667	19.6667	14.6667

BSM

SM is done.

Many possible BSM and many possible strategies.

Higgs, neutrino, DM as windows to new physics.

In some sense, particle physics came back to a healthy situation. We clearly need BSM and don't know what it is.