資料４

超対称性理論の現状と展望について、宇宙論等の観点から概観

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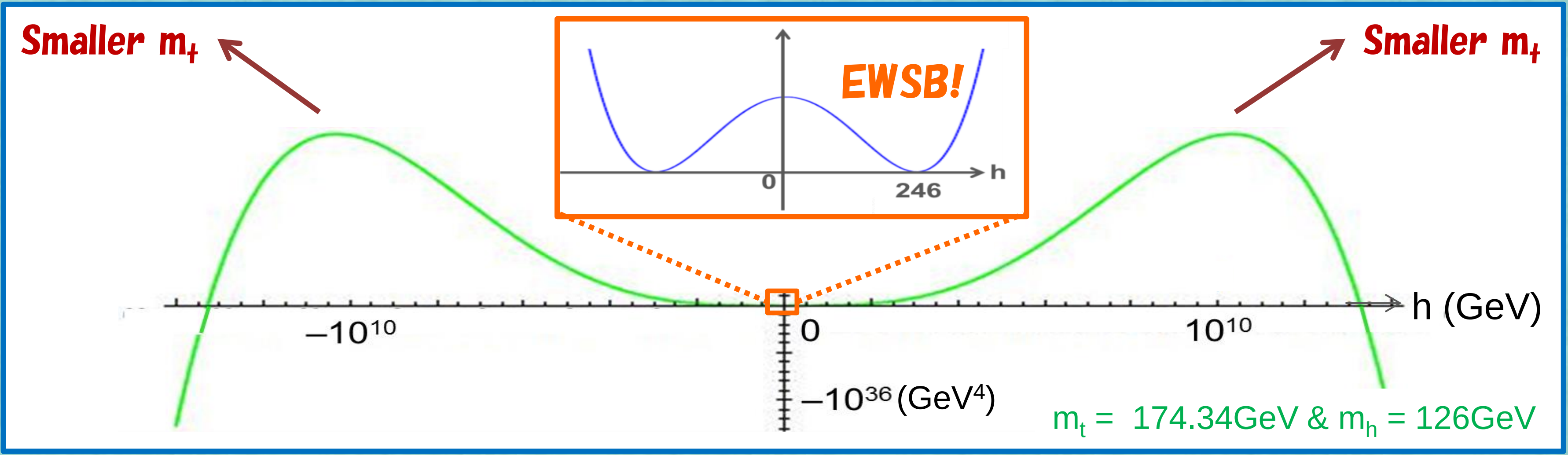
Physics behind EW symmetry breaking



Analogy to the superconductivity

Ginzburg-Landau theory

↓

BCS theory (Higgs = :ee:)

$U(1)_{EM}$ breaking occurs because of condensation of cooper pairs.

(Extended) Technicolor models

EW sym. breaking occurs because of condensation of new fermions.

→ Several problems emerged.

⇒

EW sym. breaking by two steps

Some sym. breaking (SUSY, etc.)

↓

↓ ···RGE (Radiative corrections)

↓ [K. Inoue, et. al, PTP,1982]

EM sym. breaking is induced!

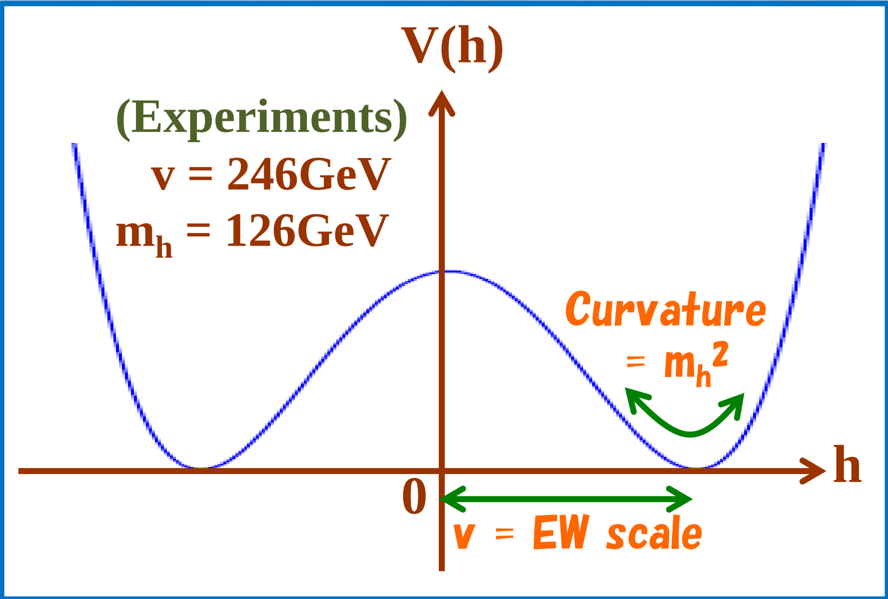
SUSY ··· Supersymmetry

CompH ··· Some global sym.

ExD(GHU) ··· High-Dim gauge sym.

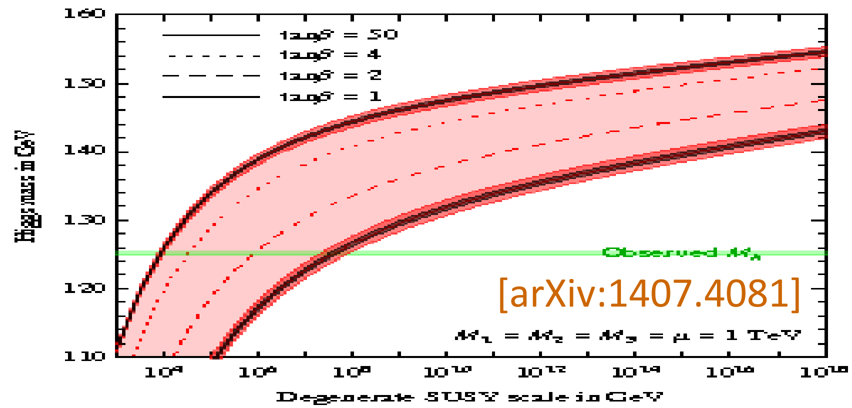
SM(FL) ··· Conformal sym.

Fine-tuning problem for the EW scale

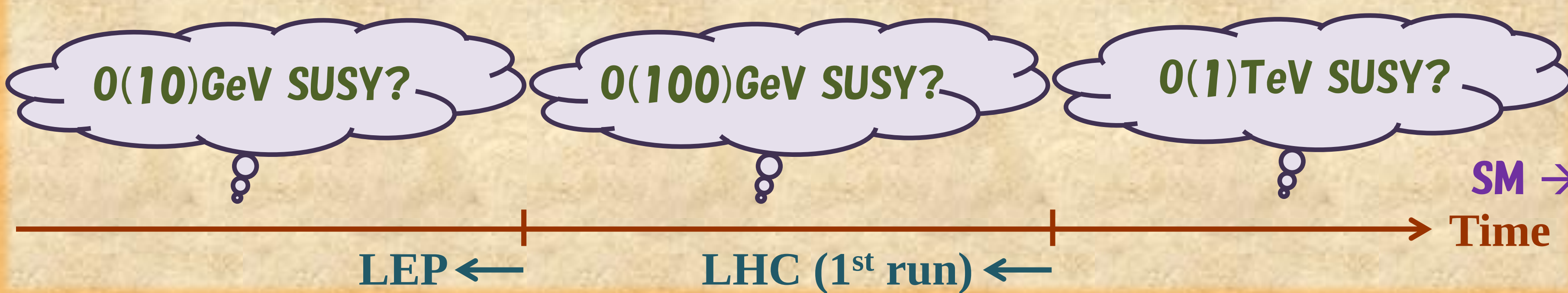


Relation between v and m_h in SUSY

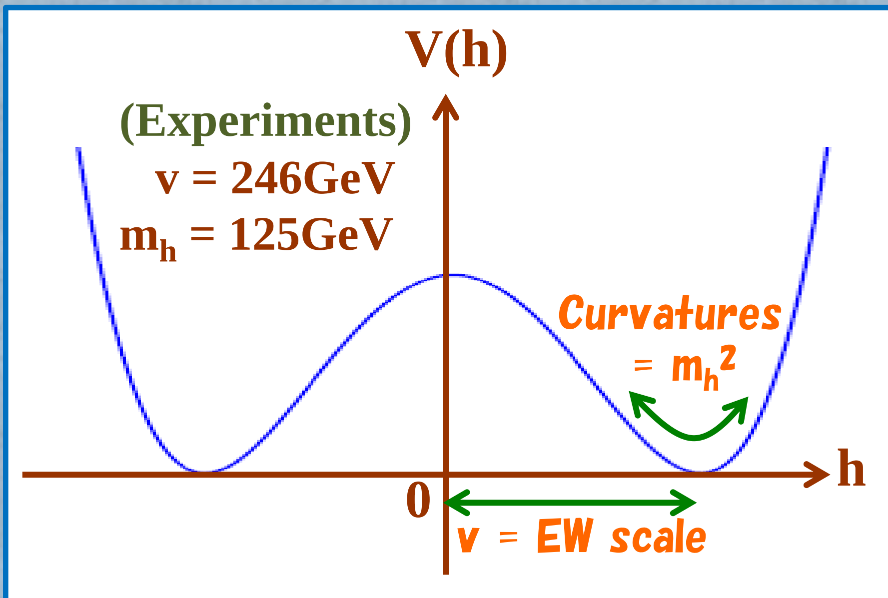
[Okada, Yamaguchi, Yanagida (1990);
Ellis et al (1990); Haber et al (1990)]

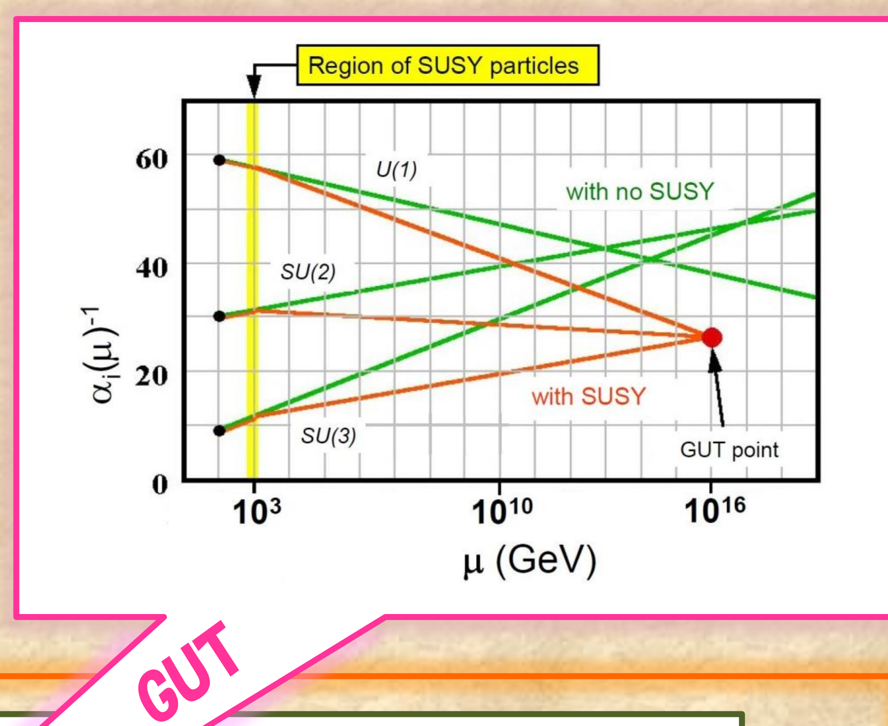


$$(65\ \mathrm{GeV})^2 \quad \cdots\cdots\rightarrow \quad \frac{g^2+g'^2}{4}v^2 \simeq -\mu^2 - M_{\rm SUSY}^2 + \frac{3y_t^2}{4\pi^2}M_{\rm SUSY}^2 \log\frac{\Lambda}{\rm TeV} + \cdots$$

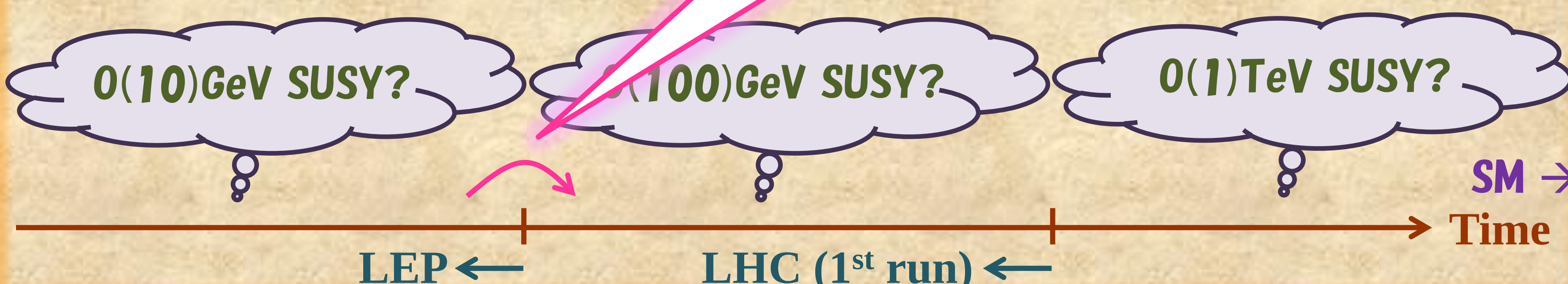


Fine-tuning problem for the EW scale





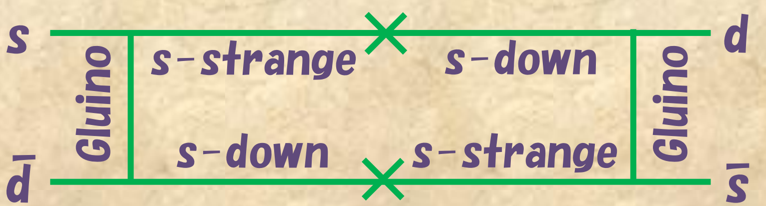
$$(65\ \text{GeV})^2 \dashrightarrow \frac{g^2+g'^2}{4}v^2 \simeq -\mu^2 \cdots {}_{\text{SUSY}} + \frac{3y_t^2}{4\pi^2}M^2_{\text{SUSY}}\log\frac{\Lambda}{\text{TeV}} + \cdots$$



Merits & Demerits of SUSY scenario

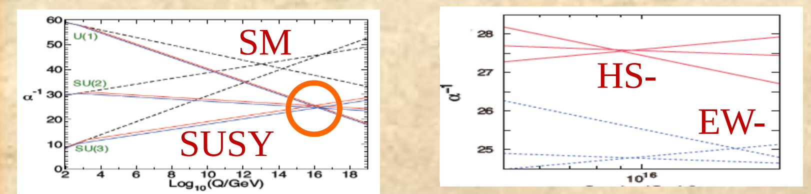
	Standard model	EW-SUSY	HS-SUSY
✓ Fine-tuning level	$10^{-32} \sim 10^{-36}$	$10^{-2} \sim 10^{-3}$	$10^{-4} \sim 10^{-6}$
✓ Flavor/CP problem	None	Serious	None or Mild
✓ Coupling unification	Not unified	Unified	Unified
✓ Proton decay	...	Serious	No problem
✓ Gravitino problem	None	Serious	No problem
✓ Plonyi problem	None	Serious	No problem
✓ Dark matter	Not OK	OK	OK

✔ Flavor/CP problem



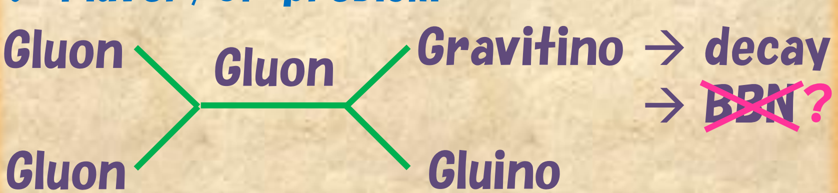
Heavy sparticles suppress the process!

✔ Coupling unification [Hisano, et.al. 2013]



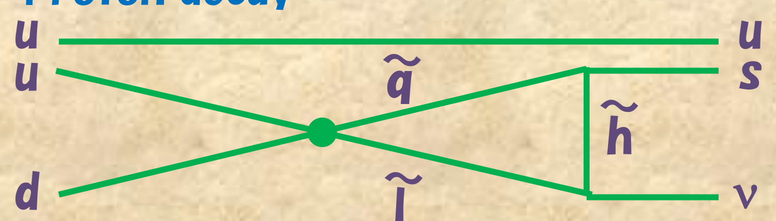
Unification is better for some HS-SUSY!

✔ Flavor/CP problem



Gravitino lifetime must be short enough!

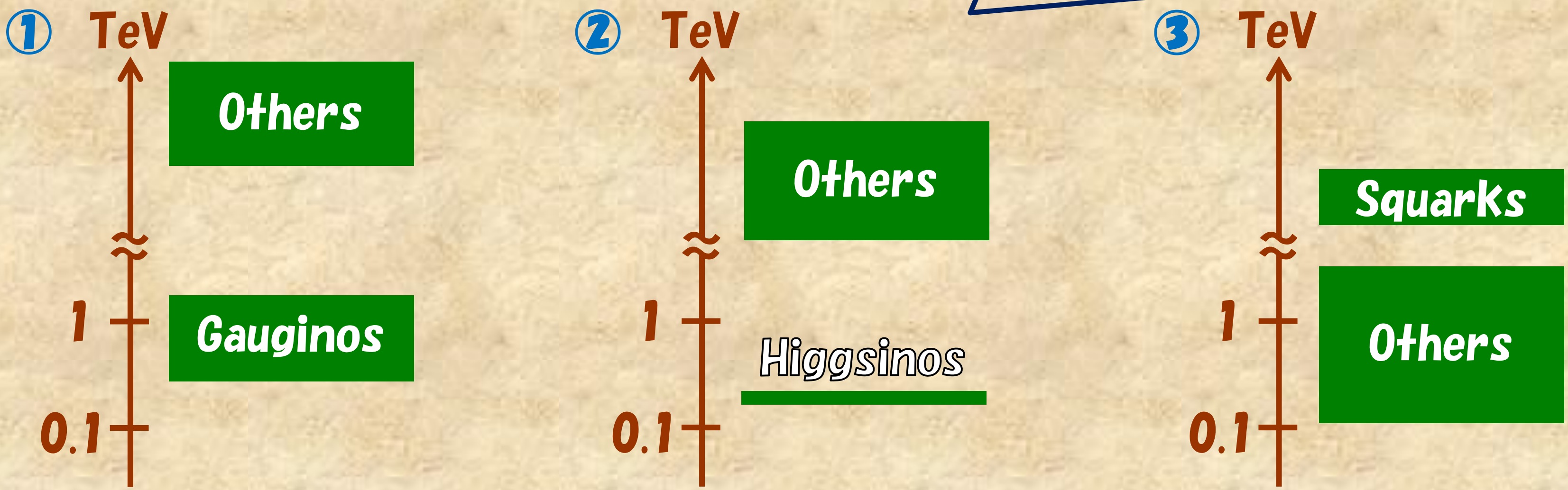
✔ Proton decay



Heavy sparticles suppress the process!

SUSY spectra recently discussed

Cosmology (WIMP DM abundance) requires LSP should be O(0.1—1)TeV range.



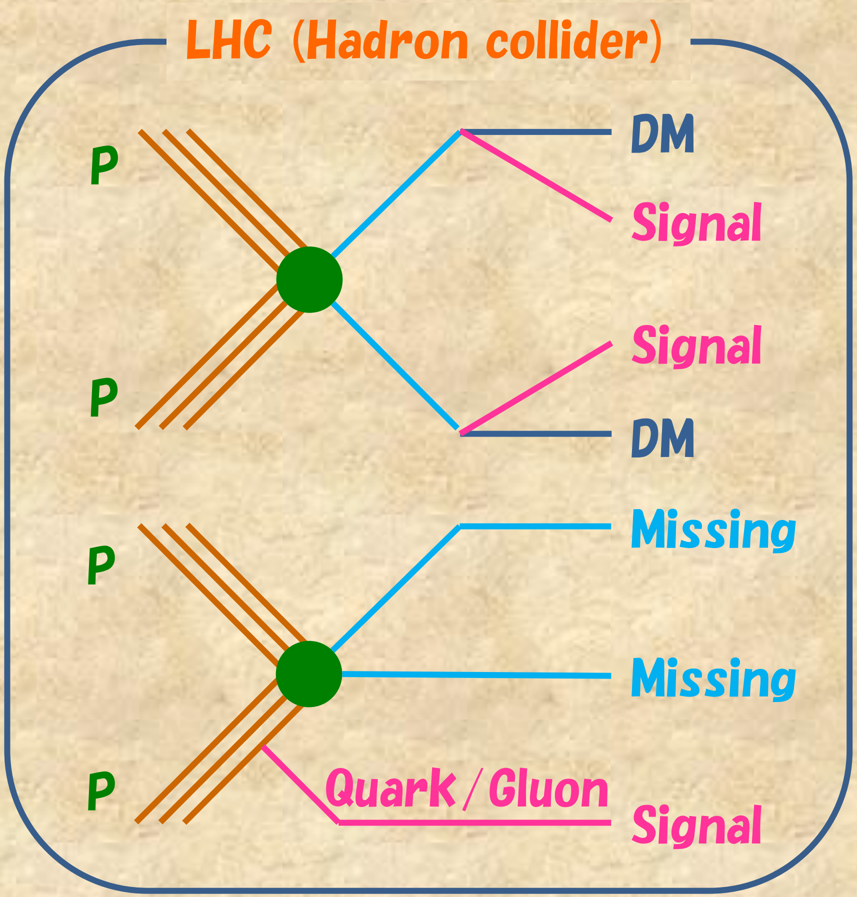
① PGM[Ibe, Moroi, Yanagida]/Minimal Split[N. Arkani-Hamed, et. al.] ··· Simplicity motivated.
Simplest SUSY breaking → Gauginos become 100 times lighter than other sparticles.
→ LSP is wino-like particle because of anomaly mediation.

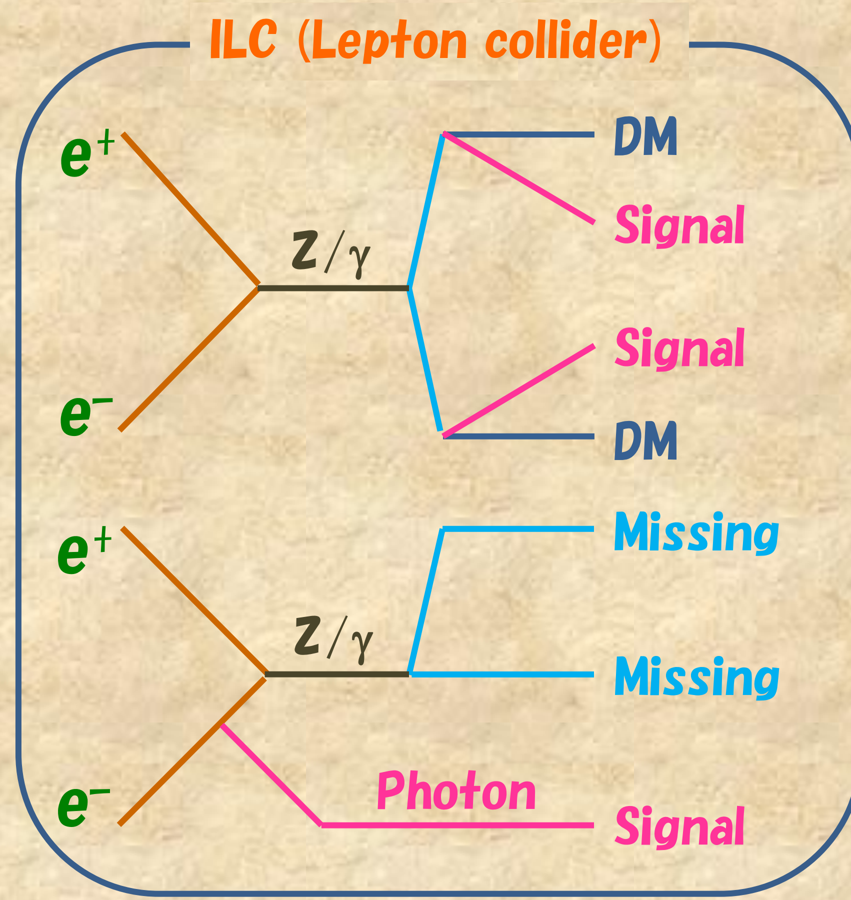
② Focus Point [J. Feng, et.al.]/EW naturalness[H. Baer, et. al.] ··· Naturalness motivated.
$v^2 \sim \mu^2$ + others controlled by some high-scale parameters, giving small correction.
→ LSP is higgsino-like particle because of small μ^2.

③ Heavy squarks & light sleptons[N. Yokozaki, et. al., etc.] ··· $(g-2)_\mu$ motivated.
Light sleptons/neutralinos/charginos are required for the anomalous muon g-2.
→ LSP is gravitino if we adopt the framework of GMSB.

Implication to collider experiments

Non-colored but EW-charged particles are expected to be within TeV-scale!





At LHC, new particles can be searched for when its production cross section is large enough or its decay products are very visible (lepton and γ with large p).

At ILC, new particles can be efficiently searched for up to half the COM energy.

Summary

- 超対称模型は、素粒子論及び宇宙論の様々な問題に系統的に回答し得る事が具体的に確認されているほぼ唯一の模型であり、電弱対称性の破れの背後にある物理の最有力候補である。

- LHC実験が始まる以前は以下の二つの超対称性シナリオがあった。

  超対称粒子はTeVスケール以下にある一方、超対称性を導入する事により発生する問題は幾つかの特別な機構を用いて解決されるシナリオ。

  超対称粒子の幾つかはTeVを超えるスケールにあり、超対称性の導入で発生する問題は抑制されるが、幾ばくかの微調整が必要なシナリオ。

  現在前者のシナリオがLHC実験において検証されつつある。

- 後者のシナリオでは、カラー電荷は持たないがEW電荷を持つ粒子がTeVスケールに予言される。ILCをはじめとするレプトン型加速器はこれらのTeVスケールの粒子を系統的かつ効率的に検証可能。