素粒子物理学の進展2015, 9/14-18

真空崩壊確率の完全な1-LOOP ORDERでの計算とその応用について

〜スケール不定性を減らせるか〜

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Now ongoing…

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- 1-loop orderでの計算 - Toy model -
- SM + STAU SYSTEM - Top loop -
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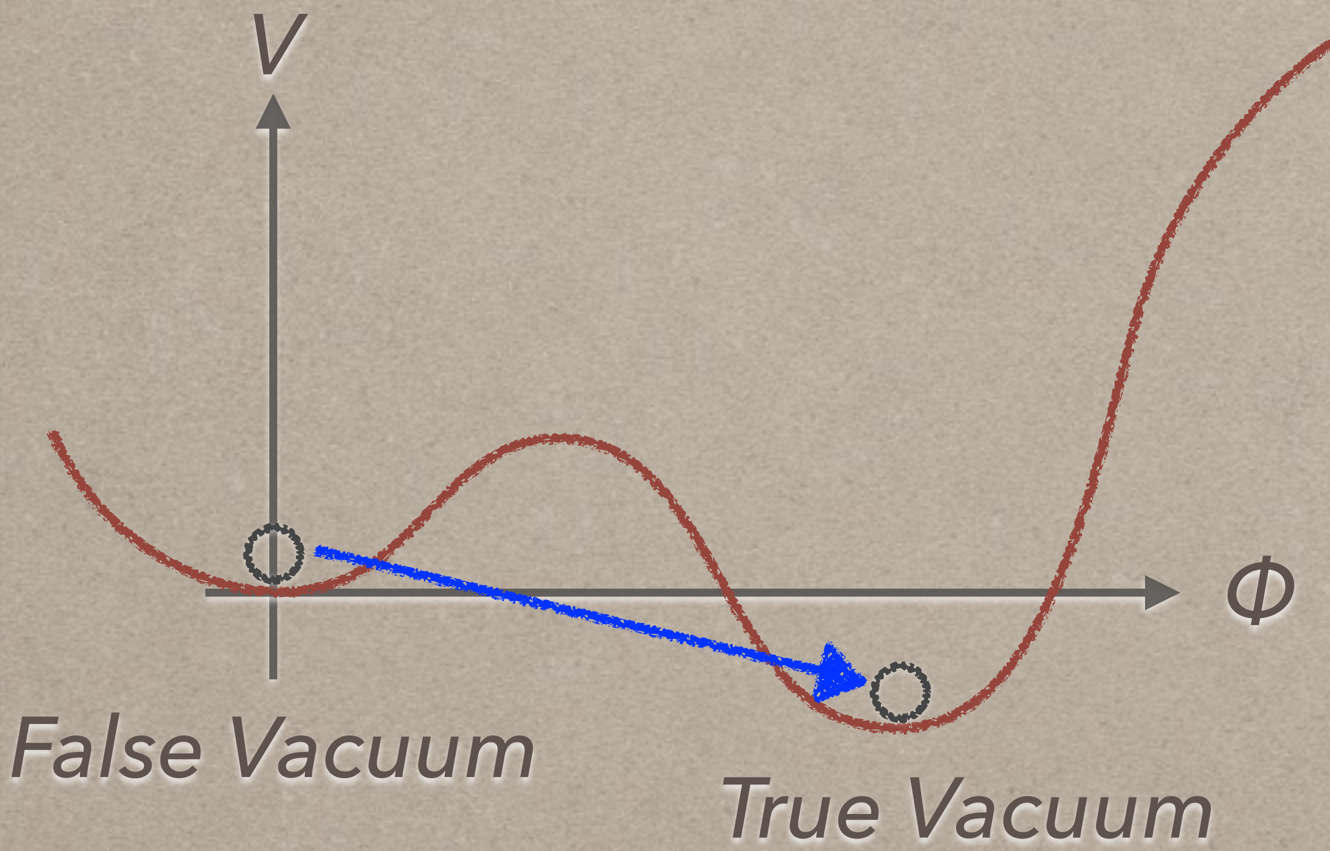
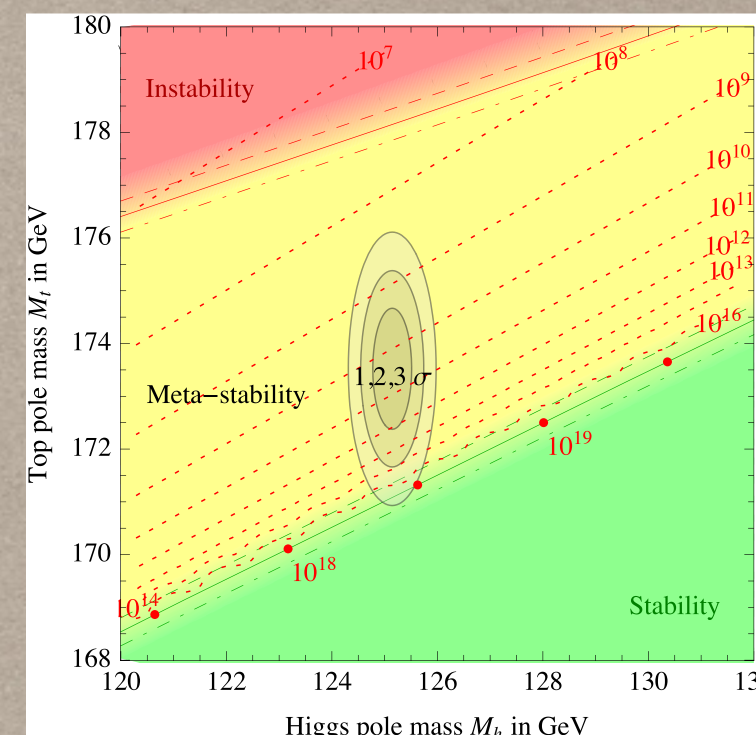
導入

核生成確率とスケール不定性

準安定真空の崩壊



Standard Model



D. Buttazzo, et. al. 1307.3536/hep-ph

Minimal Supersymmetric Standard Model

Top quark	SUSY	Stop	$h\tilde{t}_L\tilde{t}_R$	Higgs mass, hgg, hγγ, …
Leptons		Sleptons	$h\tilde{\ell}_L\tilde{\ell}_R$	muon g-2, hγγ, …

Charge and/or Color Breaking Minima

真空の崩壊確率

Bubble Nucleation Rate

At the Leading order,

Bounce action

$$\gamma = Ae^{-B}$$

$B = S_E(\phi_B)$

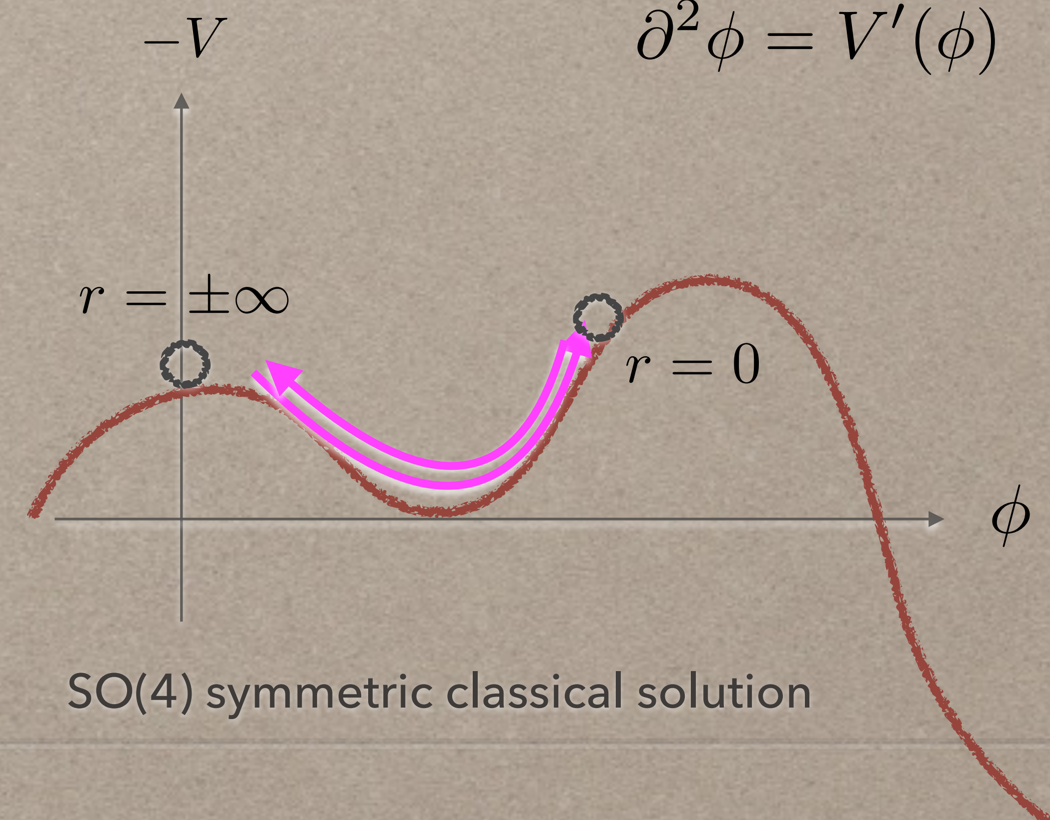
dim: [1/(time*volume)]

Pre-exponential factor

$$A \simeq m^4$$

m: “typical” mass scale

ϕ_B: Bounce solution



SO(4) symmetric classical solution

TOY MODEL

Potential

$$V = \frac{m^2}{2}\phi^2 - \frac{A}{2}\phi^3 + \frac{\alpha}{8}\phi^4$$

⬇

Bounce

$$\partial^2\phi = V'(\phi)$$

⬇

Action

$$B = S_E(\phi_B) = \int d^4x \left[\frac{1}{2}(\partial\phi_B)^2 + V(\phi_B)\right]$$

⬇

Nucleation Rate

$$\gamma \simeq m^4 e^{-B}$$

TOY MODEL

In fact, the potential is scale-dependent.

Potential $$V = -\bar{t}(Q)\phi + \frac{\bar{m}^2(Q)}{2}\phi^2 - \frac{\bar{A}(Q)}{2}\phi^3 + \frac{\bar{\alpha}(Q)}{8}\phi^4$$

↓

Bounce $$\partial^2\phi = \underline{V'(\phi)}$$

↓

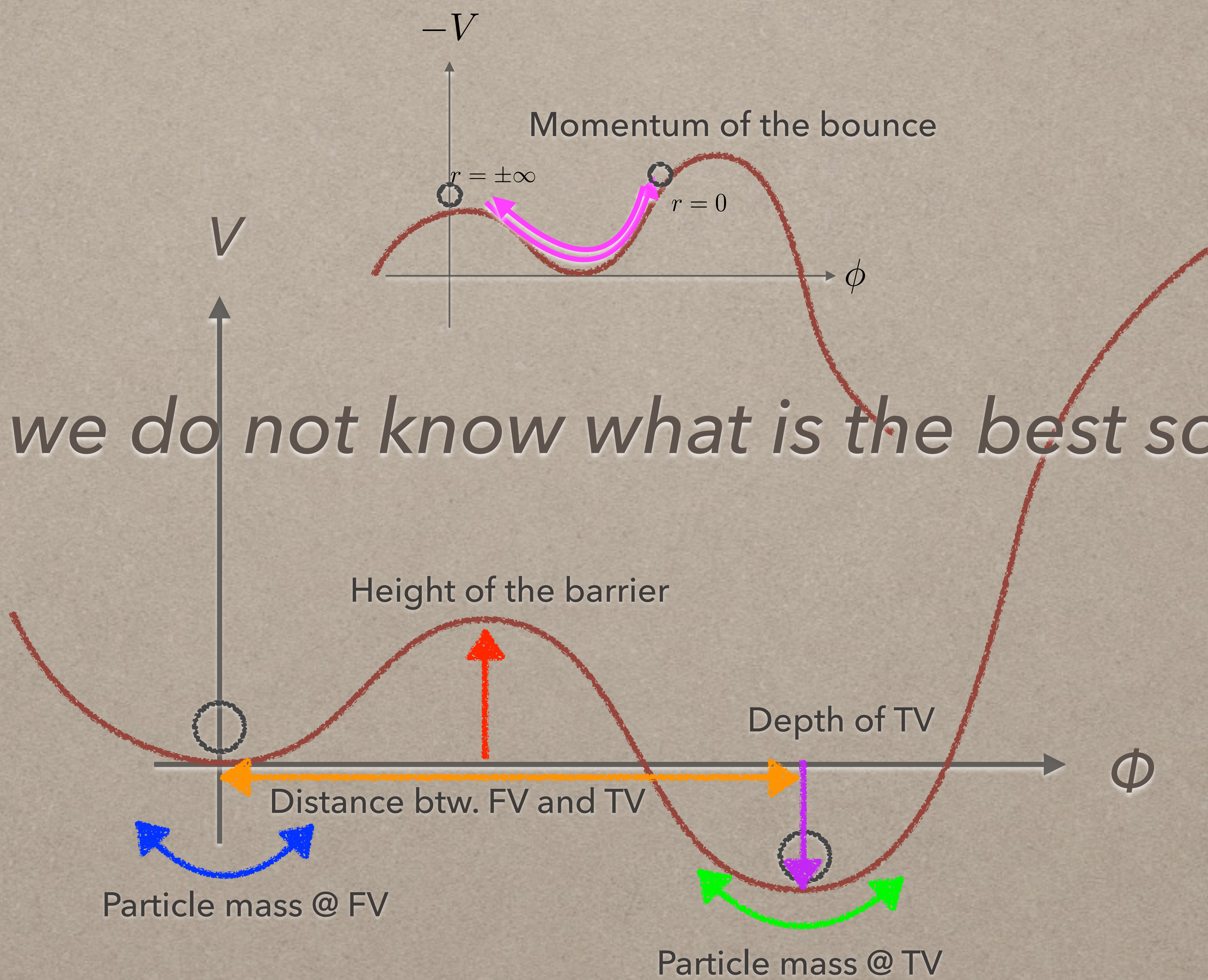
Action $$B = S_E(\phi_B) = \int d^4x \left[\frac{1}{2}(\partial\underline{\phi_B})^2 + \underline{V(\phi_B)}\right]$$

↓

Nucleation Rate $$\gamma \simeq m^4 e^{-\underline{B}}$$

Maybe, the best Q is a "typical" scale…

繰り込み点



But, we do not know what is the best scale

スケール依存性の大きさ

$$V = -\bar{t}(Q)\phi + \frac{\bar{m}^2(Q)}{2}\phi^2 - \frac{\bar{A}(Q)}{2}\phi^3 + \frac{\bar{\alpha}(Q)}{8}\phi^4$$

Beta functions

$$\beta_t = \frac{3Am^2}{16\pi^2} \qquad \beta_{m^2} = \frac{3}{16\pi^2}(\alpha m^2 + 3A^2)$$

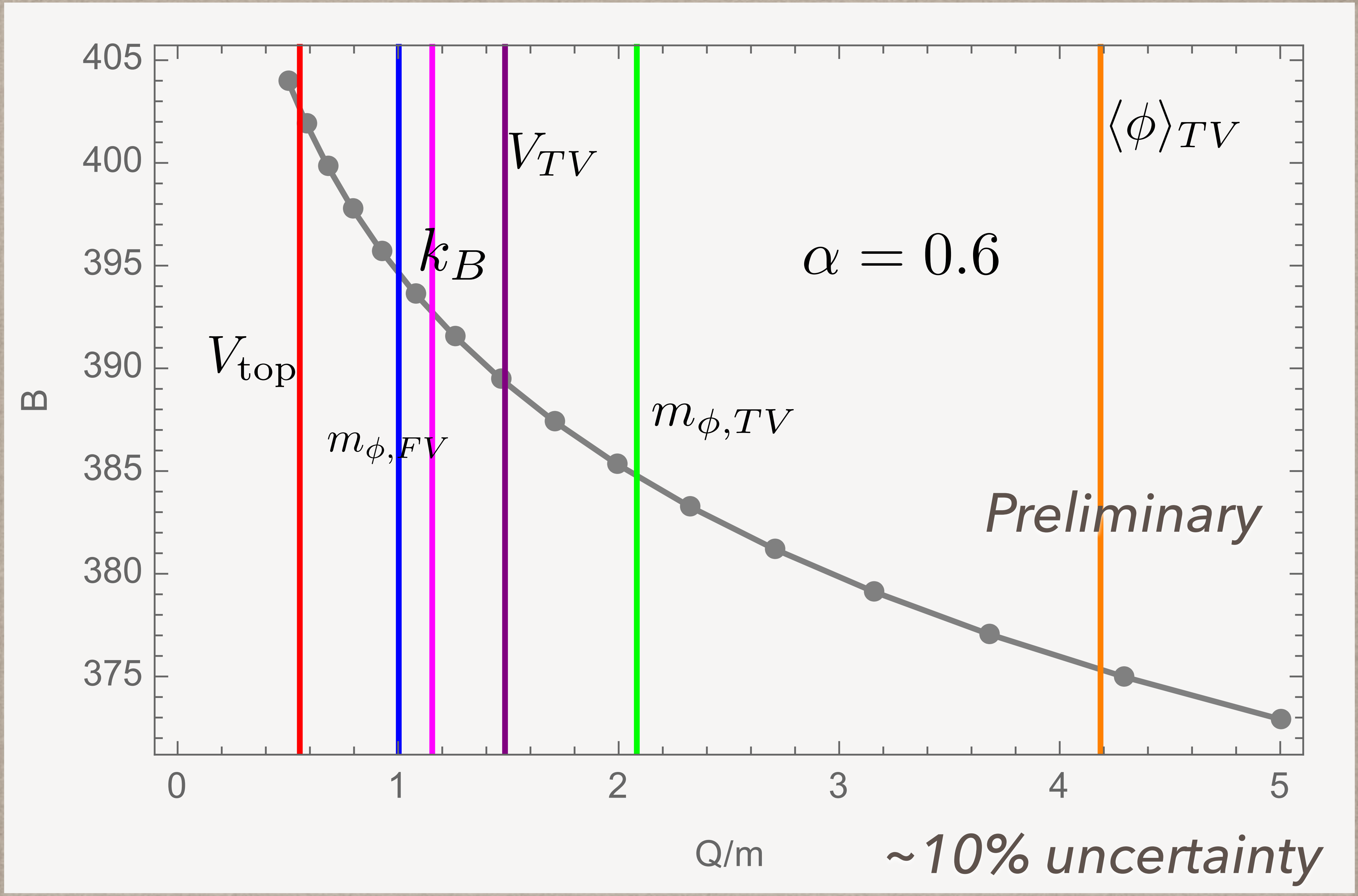
$$\beta_A = \frac{9\alpha A}{16\pi^2} \qquad \beta_\alpha = \frac{9\alpha^2}{16\pi^2}$$

Renormalization conditions

@ $Q = m$

$$\bar{m}^2(m) = m^2,\ \bar{A}(m) = m,\ \bar{t}(m) = 0,\ \bar{\alpha}(m) = \alpha$$

スケール依存性の大きさ

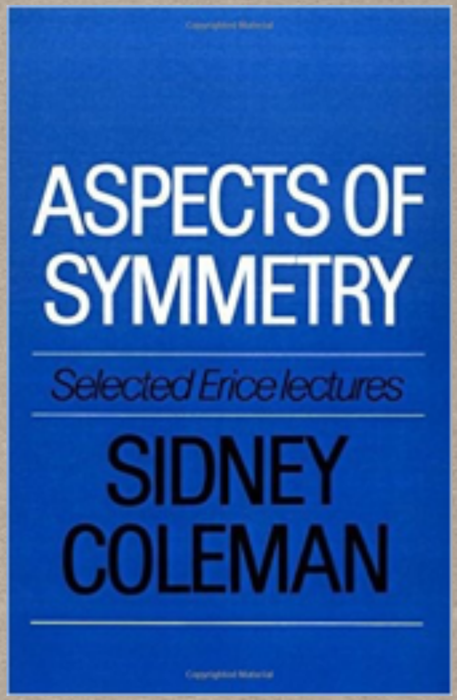


Much larger uncertainty in a realistic model (w/ top loop)

1-LOOP ORDERでの計算

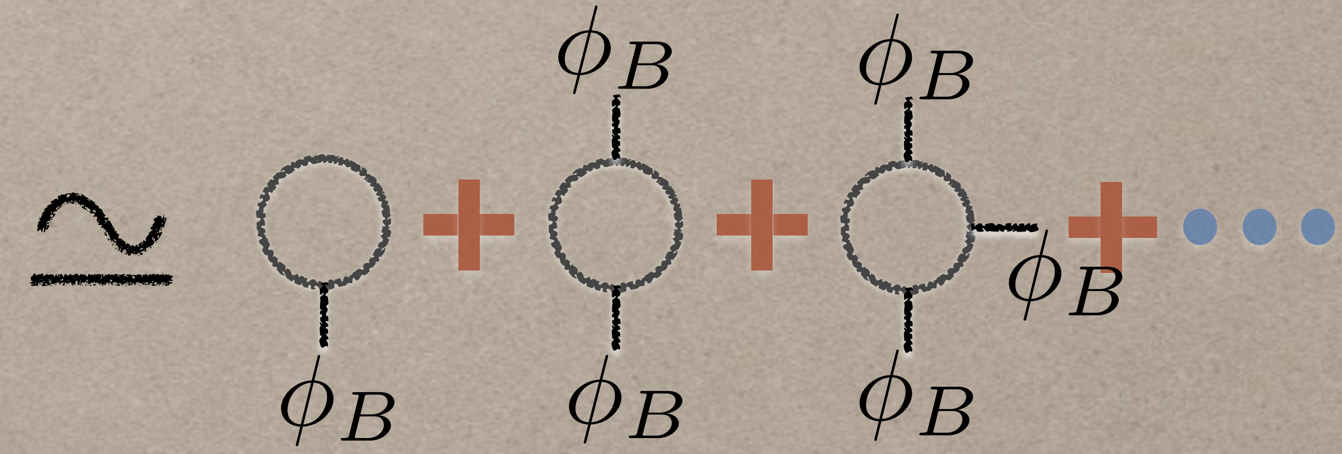
さて、どうしましょうか。

ちゃんと読み返してみると



$$\gamma = Ae^{-B}$$

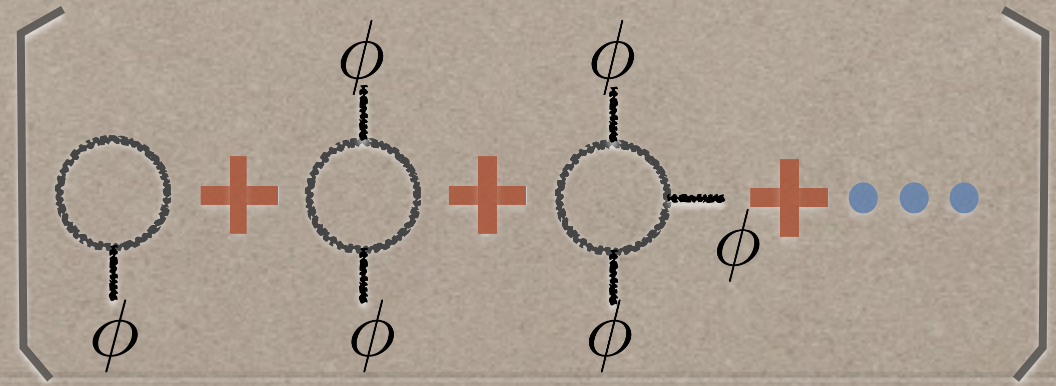
$$A = \frac{B^2}{4\pi^2}\left(\frac{\det' S''|_{\mathrm{Bounce}}}{\det S''|_{\mathrm{False}}}\right)^{-1/2}$$



Expectation

Cancellation of
the scale dependence
@1-loop

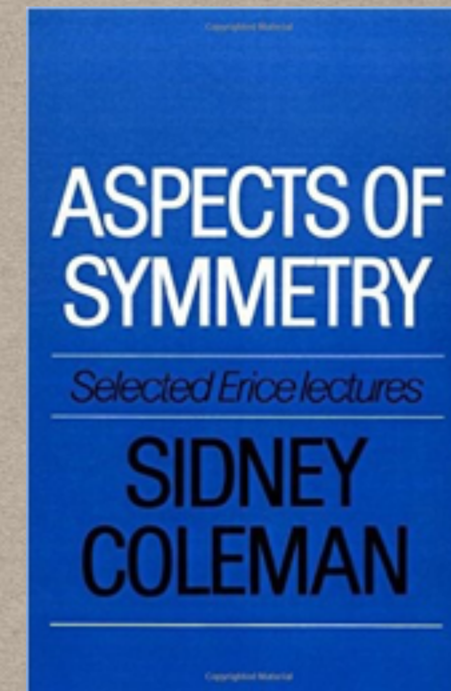
cf.) RGEs are related to



divergent part

もっと読み返してみると

$$\gamma = Ae^{-B}$$



$$A = \frac{B^2}{4\pi^2}\left(\frac{\det' S''|_{\text{Bounce}}}{\det S''|_{\text{False}}}\right)^{-1/2}$$

SOLVE corresponding Ordinary Differential Equations

Since 1928

I. M. Gelfand, A. M. Yaglom;
S. Coleman;
J. H. van Vleck;
R. H. Cameron, W. T. Martin;
R. Dashen, B. Hasslacher, A. Neveu;
R. Forman;
K. Kirsten, A. J. McKane;
...

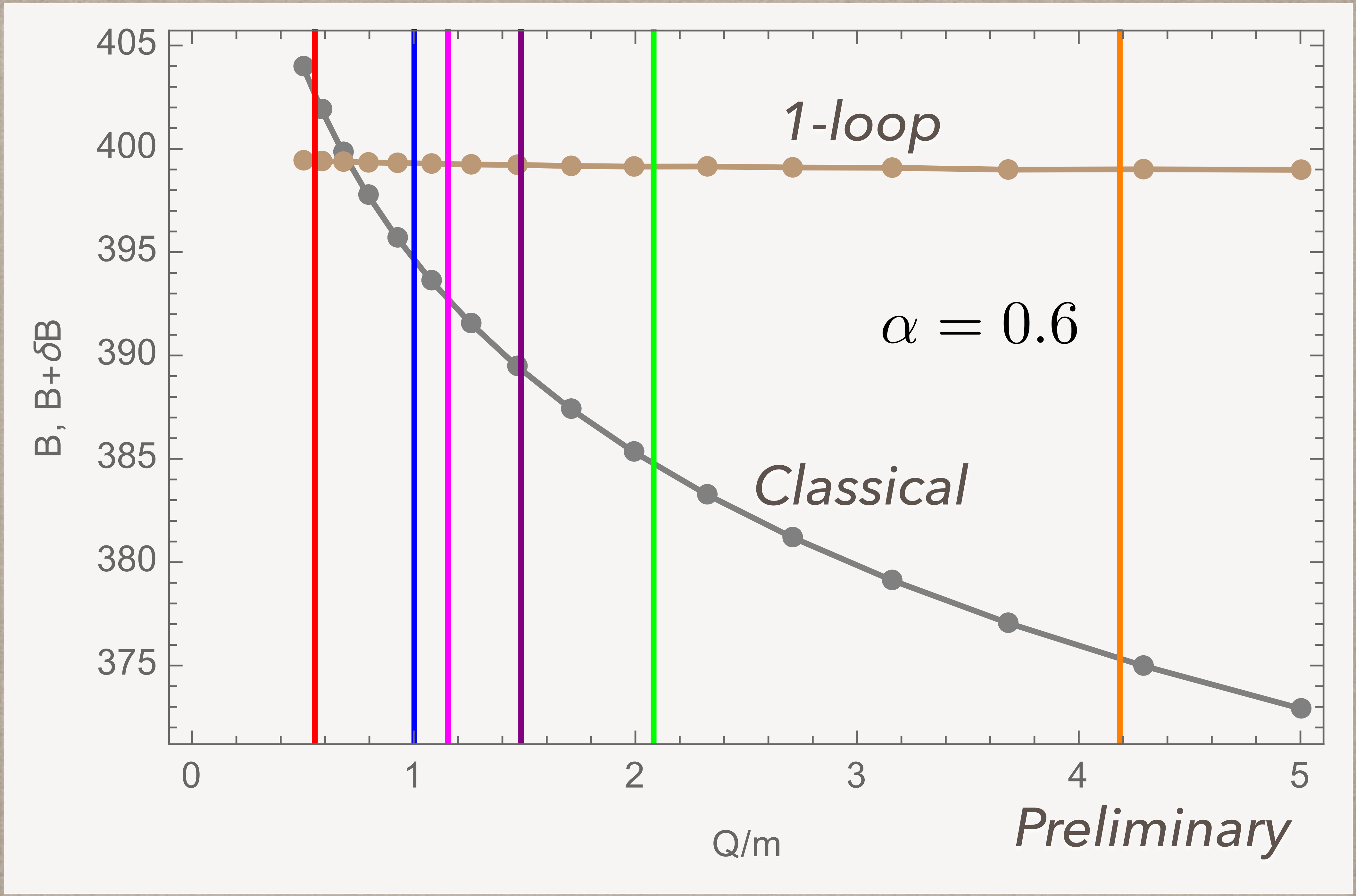
(Many mathematical proofs, but not so many pheno. results)

method, proof, renormalization, zero modes, fermions, implementation, …

Please invite me to your LAB!!

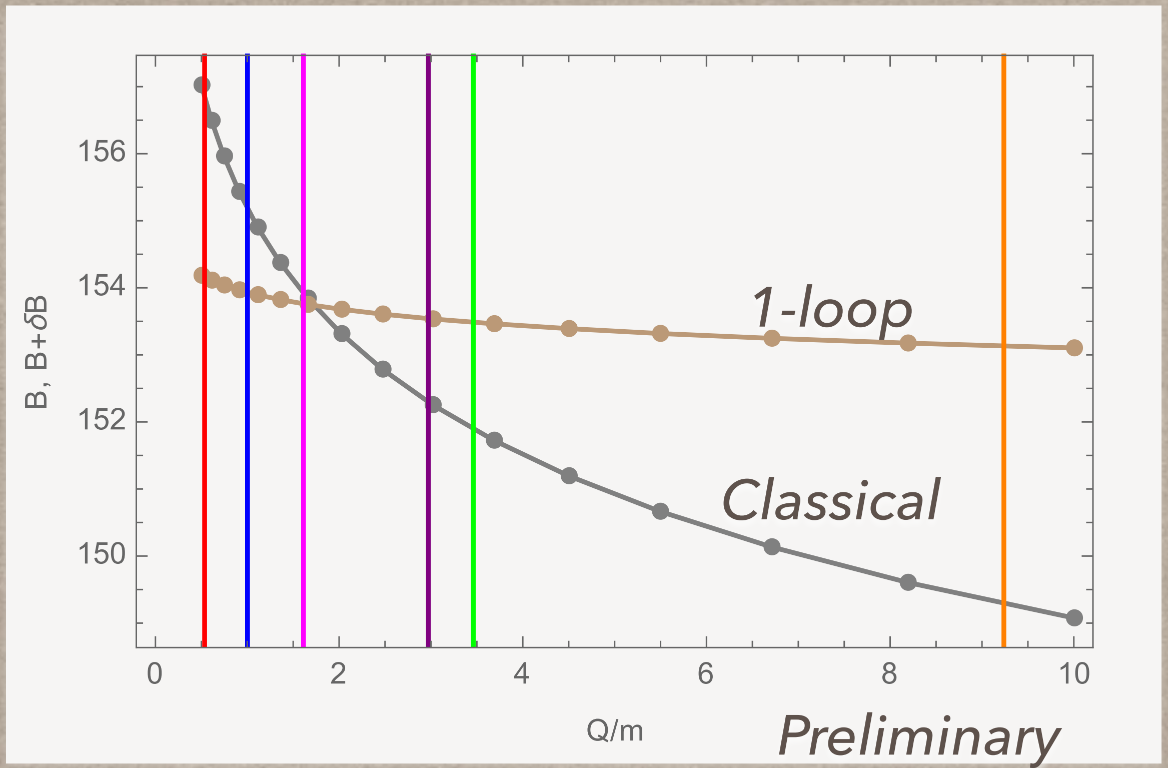
結果

$$\gamma = Ae^{-B} \equiv m^4 e^{-B-\delta B}$$

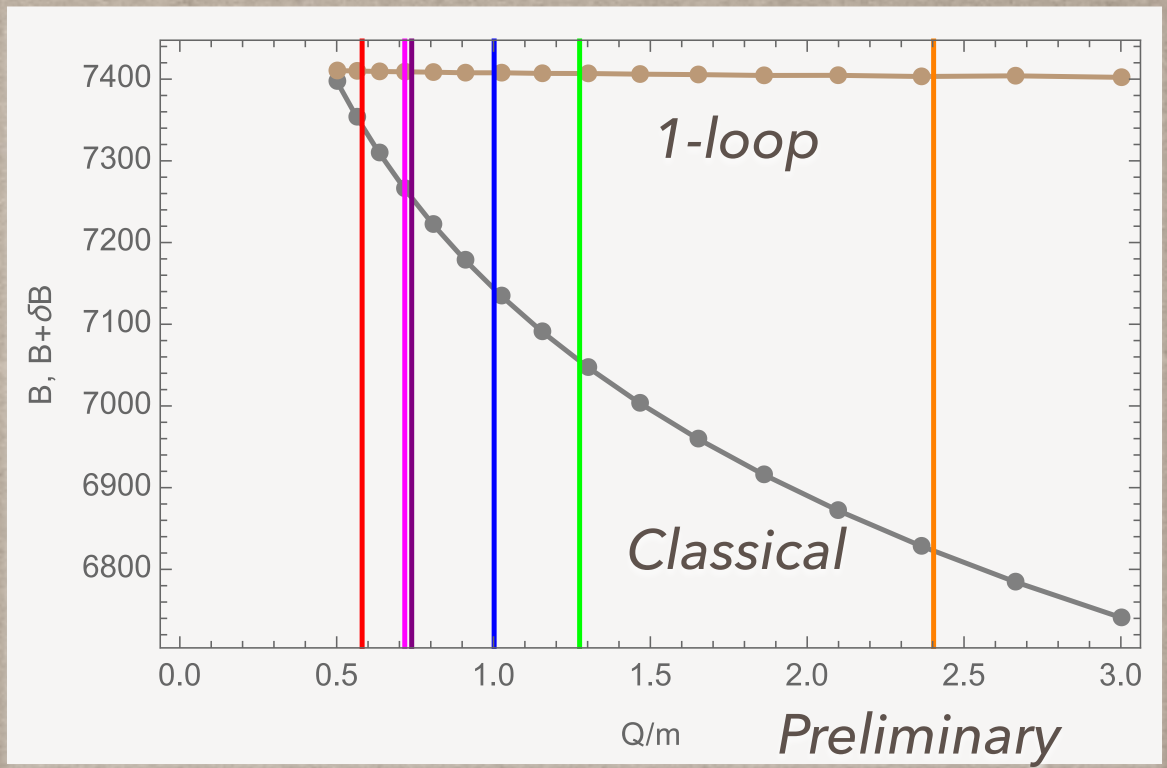


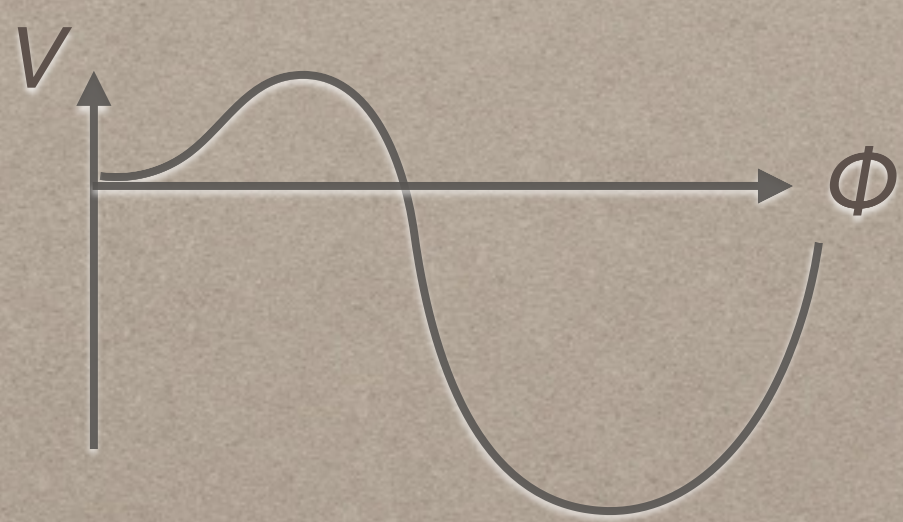
結果

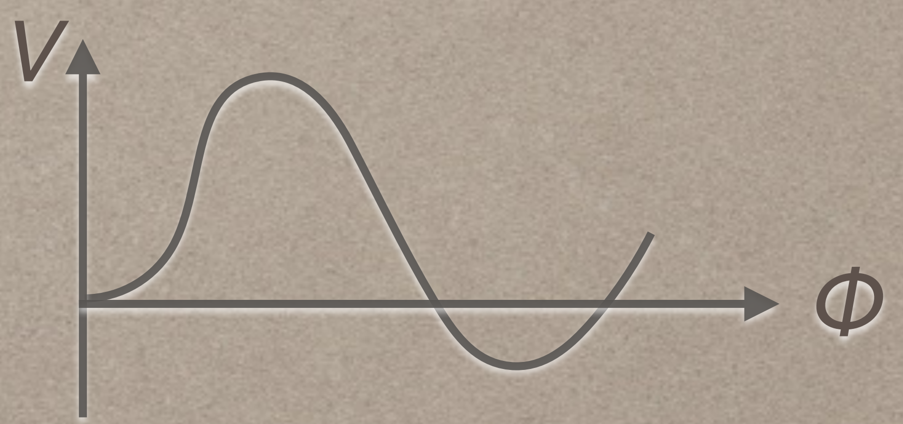
$\alpha = 0.3$



$\alpha = 0.9$







SM+STAU SYSTEM

TOP LOOP

軽いSTAU

Staus can be light

$$m_{\tilde{\tau}} > 103.5\mathrm{GeV}$$ (LEP)

→ hγγ coupling, co-annihilation with Bino, ...

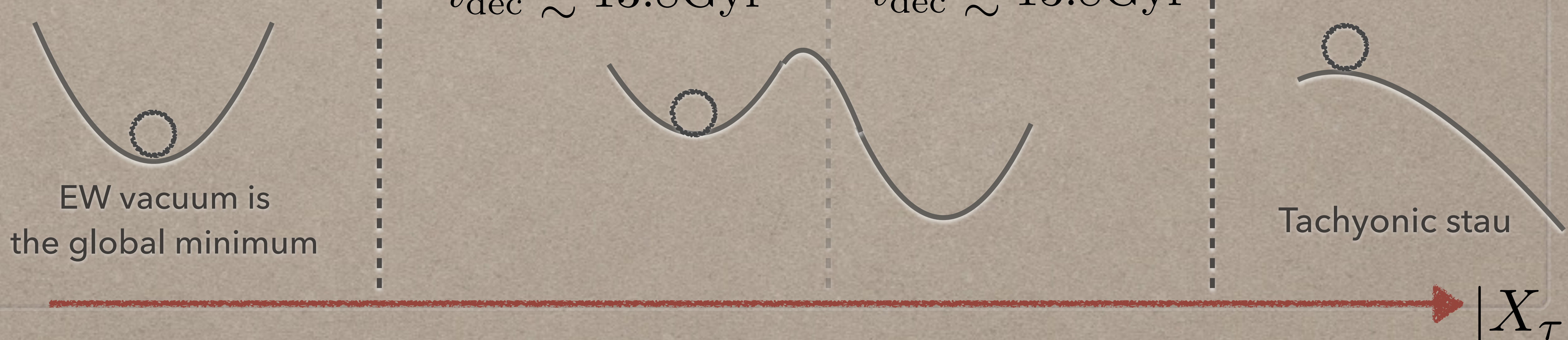
But, the potential may become unstable toward the stau direction

$$V = +\frac{1}{\sqrt{2}} y_\tau X_\tau \tilde{\tau}_L \tilde{\tau}_R h + \frac{m_L^2}{2}\tilde{\tau}_L^2 + \frac{m_R^2}{2}\tilde{\tau}_R^2 + \cdots$$

$$X_\tau = A_\tau - \mu \tan\beta$$

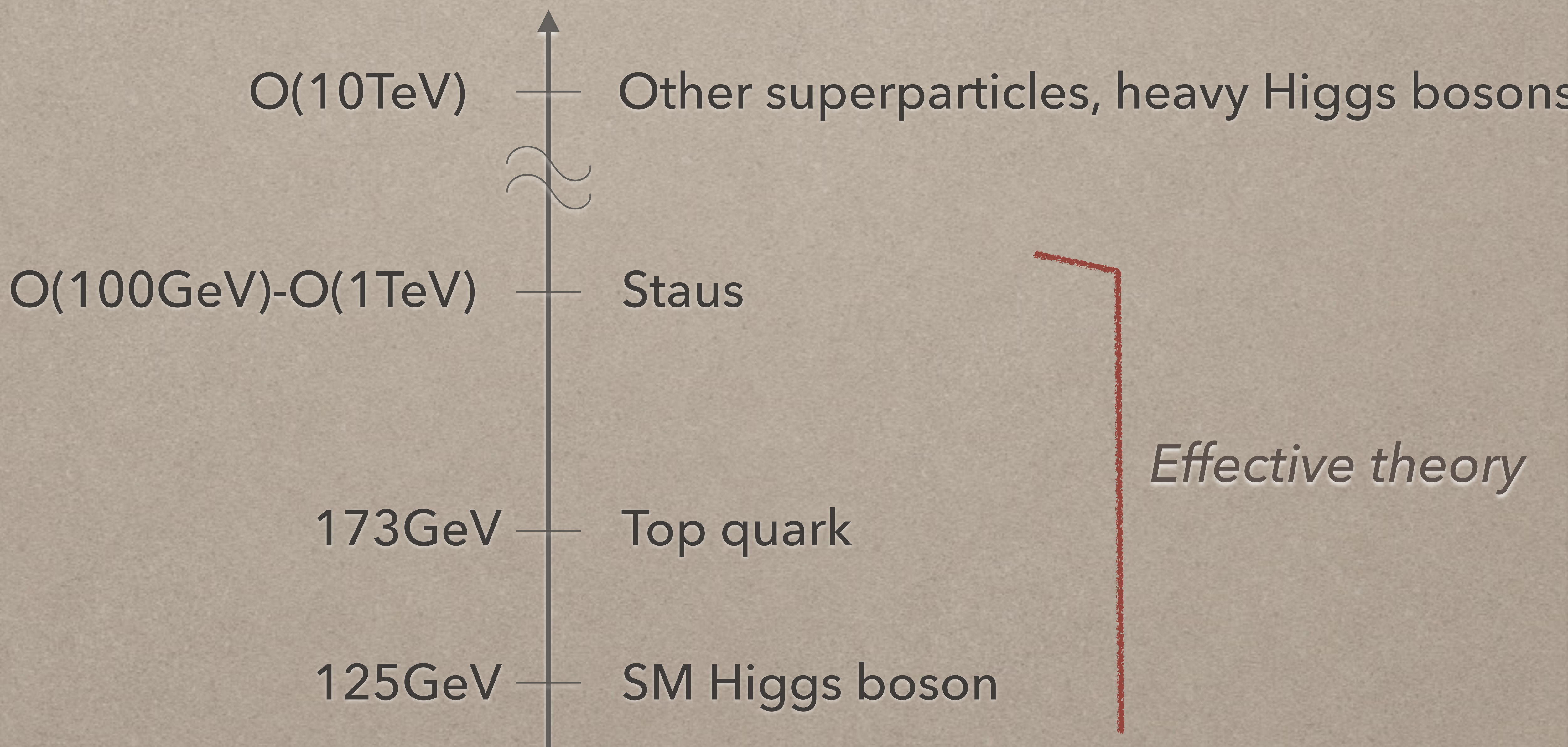
$$\tan\beta = \langle H_u^0 \rangle / \langle H_d^0 \rangle$$

Stable	*Meta-Stable*	*Unstable*	*No EW vac.*
	$t_{\mathrm{dec}} \gtrsim 13.8\mathrm{Gyr}$	$t_{\mathrm{dec}} \lesssim 13.8\mathrm{Gyr}$	



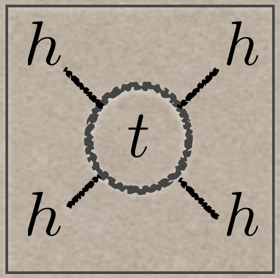
考えるスペクトラム

For simplicity,
we consider the case where only the staus are light



有効理論

SM+Staus



$$\beta_\lambda = \frac{3y_t^2\lambda}{4\pi^2} - \frac{3y_t^4}{8\pi^2}$$

dominant contrib.

$$-\mathcal{L} = +\frac{\lambda}{4}h^4 - \frac{y_t}{\sqrt{2}}h\bar{t}_R t_L$$

$$+\frac{1}{\sqrt{2}}y_\tau X_\tau \tilde{\tau}_L \tilde{\tau}_R h$$

$$X_\tau = A_\tau - \mu \tan\beta$$

$$\tan\beta = \langle H_u^0 \rangle / \langle H_d^0 \rangle$$

$$+\frac{M_h^2}{2}h^2 + \frac{m_L^2}{2}\tilde{\tau}_L^2 + \frac{m_R^2}{2}\tilde{\tau}_R^2$$

Inputs

$$+\frac{1}{4}\left(y_\tau^2 - \frac{g^2 - g'^2}{4}\cos 2\beta\right)\tilde{\tau}_L^2 h^2 + \frac{1}{4}\left(y_\tau^2 - \frac{g'^2}{2}\cos 2\beta\right)\tilde{\tau}_R^2 h^2$$

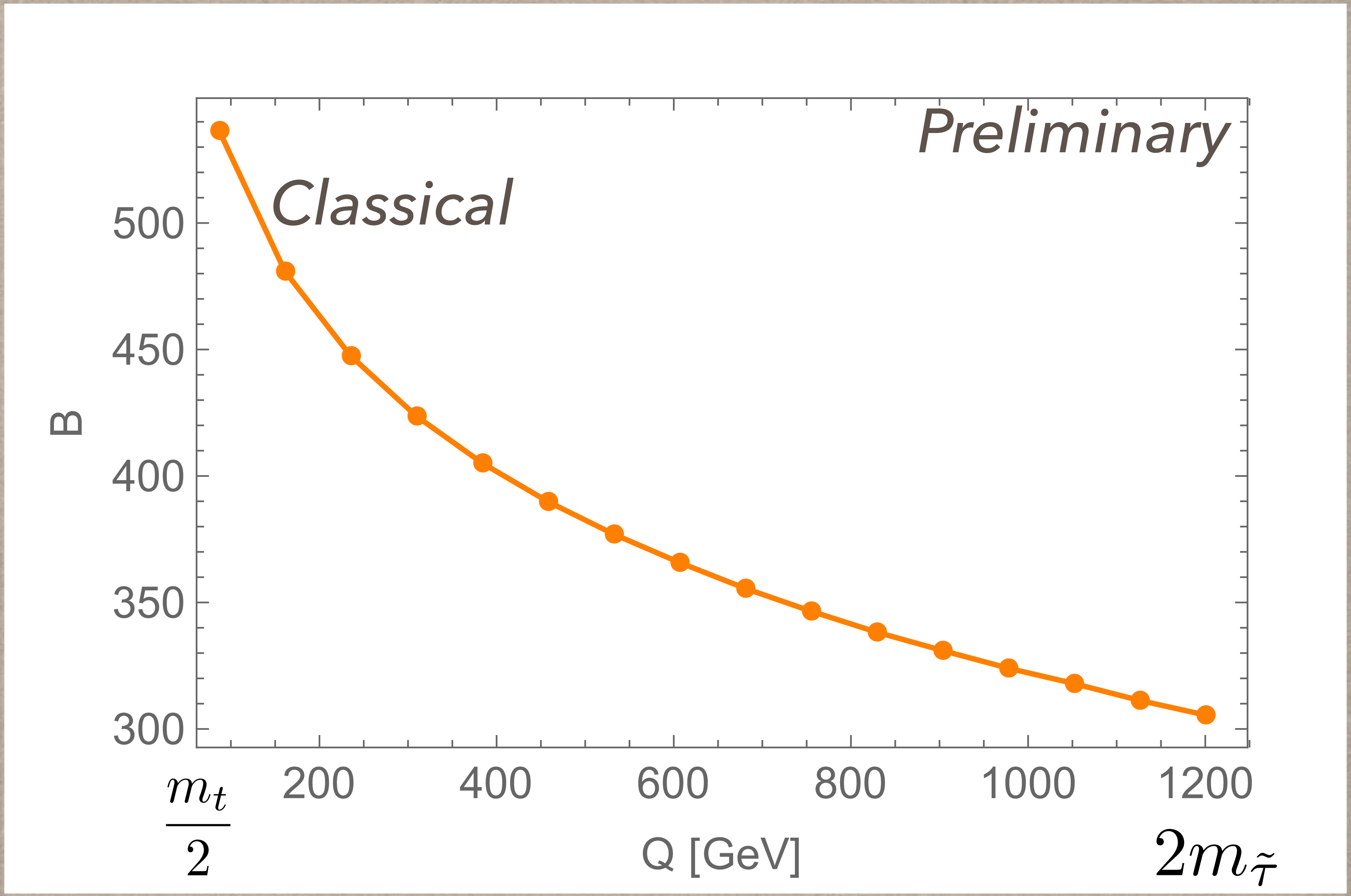
$$+\frac{g'^2}{32}(2\tilde{\tau}_R^2 - \tilde{\tau}_L^2)^2 + \frac{g^2}{32}\tilde{\tau}_L^4$$

RGE, Det: Calculated up to leading in y_t

=> Overall factor of Det is NOT determined!

結果 其の壱

$$m_L = m_R = 600\text{GeV},\ \ X_\tau = 95\text{TeV},\ \ \tan\beta = 15$$



結果 其の壱

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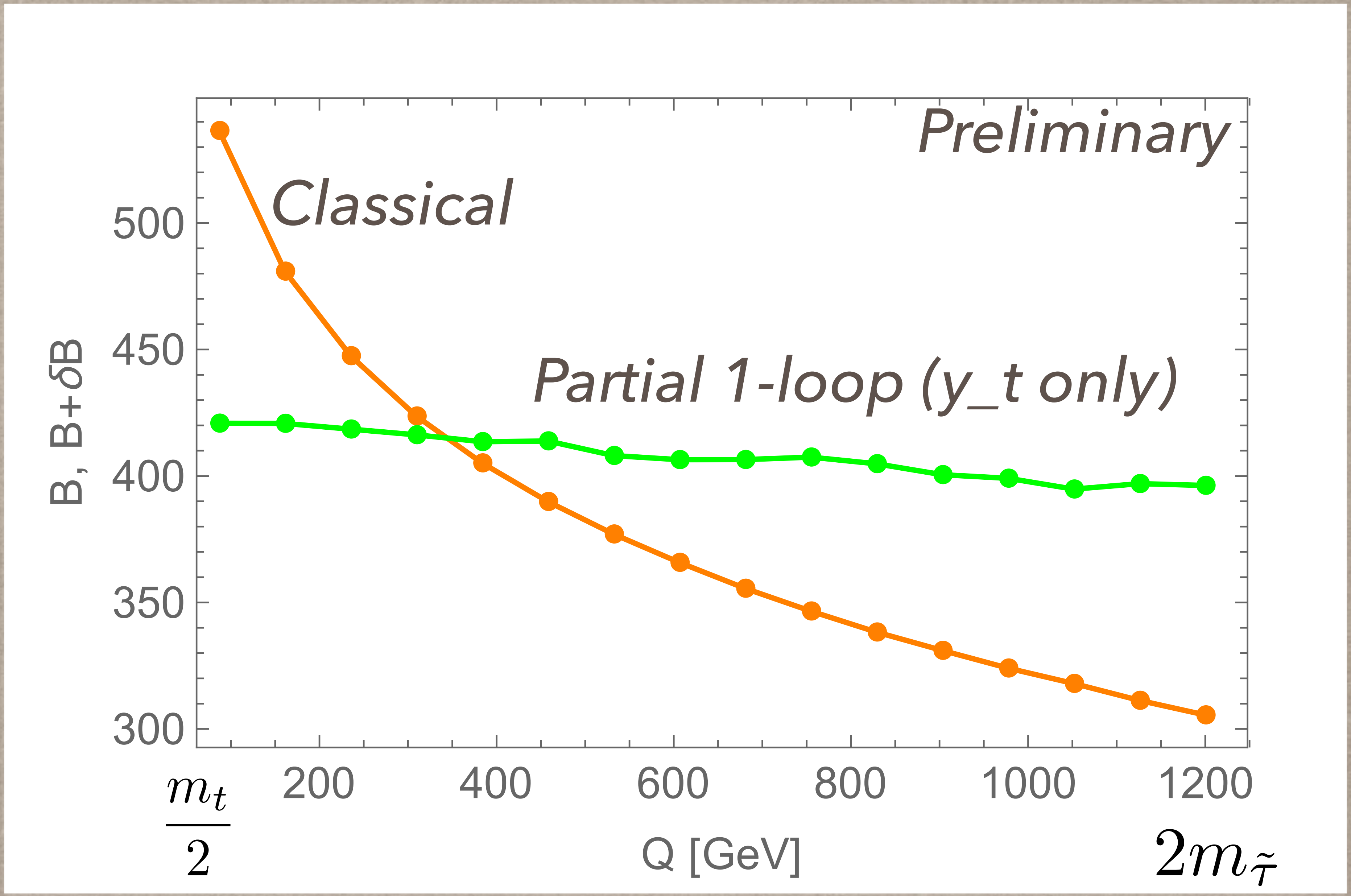
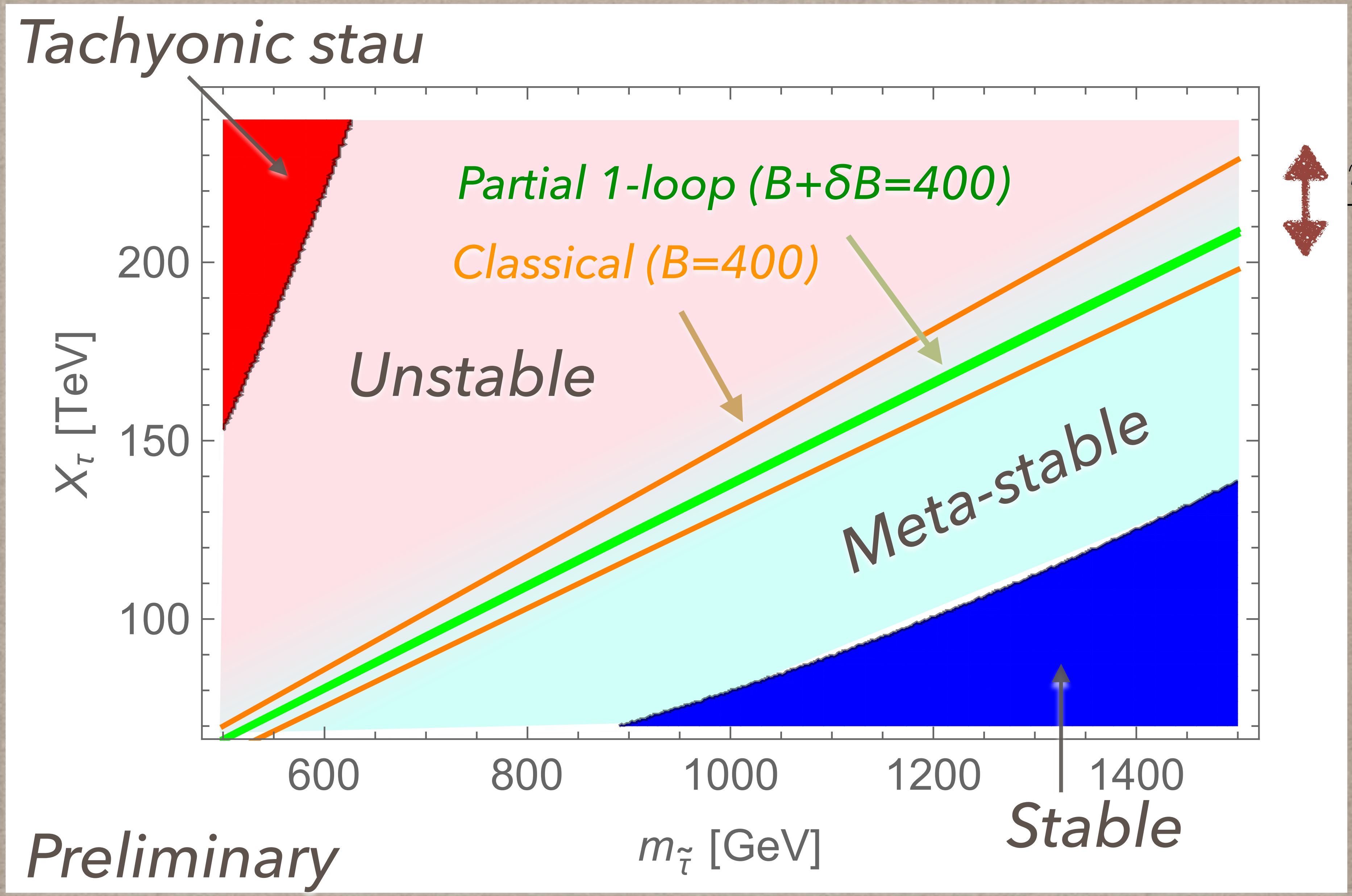


Caveat: Overall factor is NOT determined!

結果 其の弐

$$\tan\beta = 15 \qquad m_L = m_R = m_{\tilde{\tau}}$$

$$t_{\rm dec} \gtrsim 13.8\text{Gyr} \Leftrightarrow B(+\delta B) \gtrsim 400$$

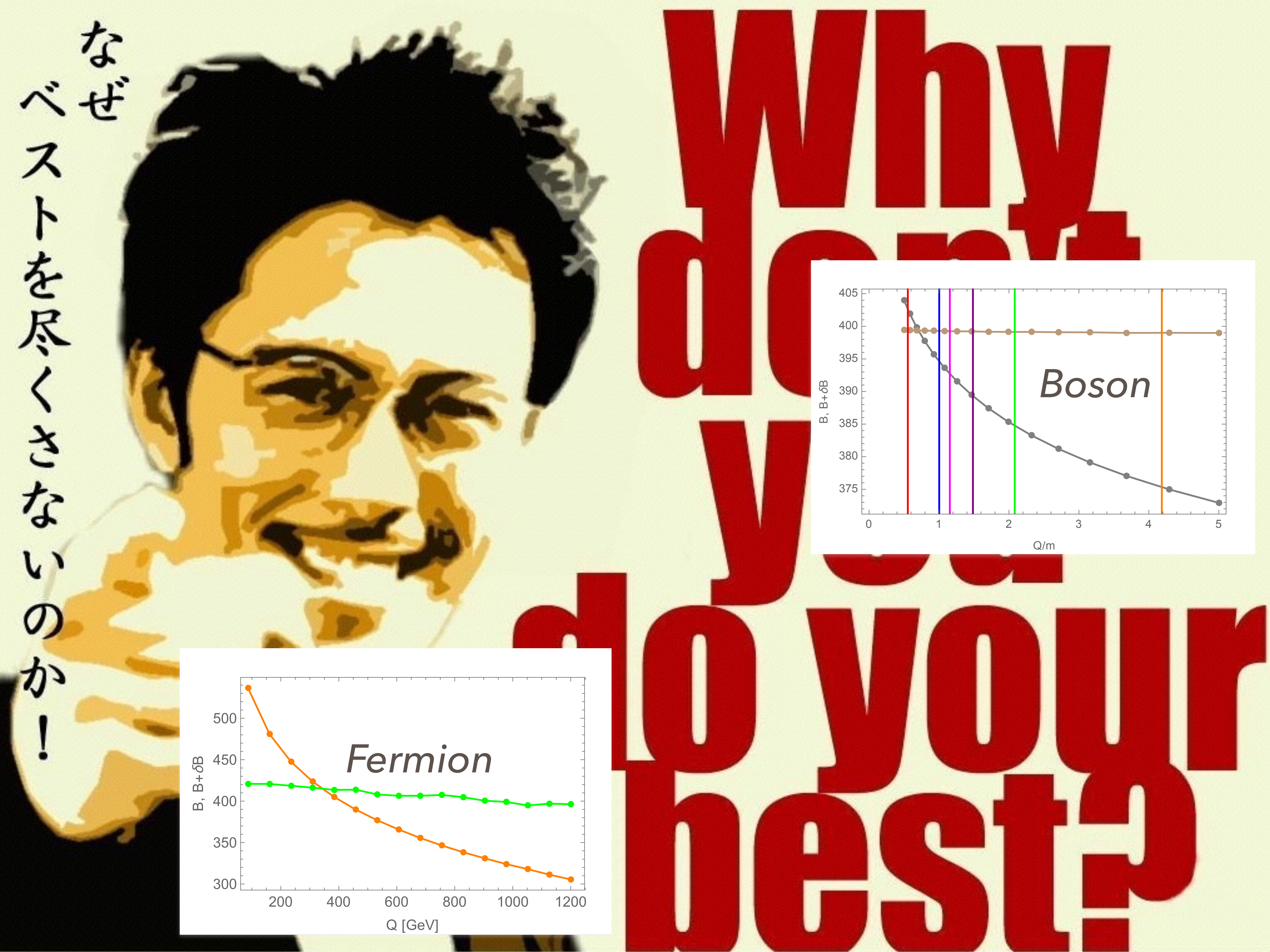


$$\frac{m_t}{2} < Q < 2m_{\tilde{\tau}}$$

Caveat: The position of the green lines can be changed!

まとめ

- The bubble nucleation rate has often been estimated without calculating the pre-exponential factor.
- This estimate involves uncertainty in the renormalizaiton scale, which, we showed, results in O(10%) uncertainty in the exponent of the bubble nucleation rate.
- To reduce the uncertainty, we explicitly calculated the pre-exponential factor and showed that it is greatly reduced.
- Scalars and fermions have already been implemented, but the gauge bosons are now ongoing.


なぜ
ベストを尽くさないのか！
Why don't you do your best?
Boson
B, B+δB
405
400
395
390
385
380
375
0
1
2
3
4
5
Q/m
Fermion
B, B+δB
500
450
400
350
300
200
400
600
800
1000
1200
Q [GeV]

“Backup called Trash”

One thing I’m concerned about is the file size…