BSM interpretation of LHCb results and future prospects

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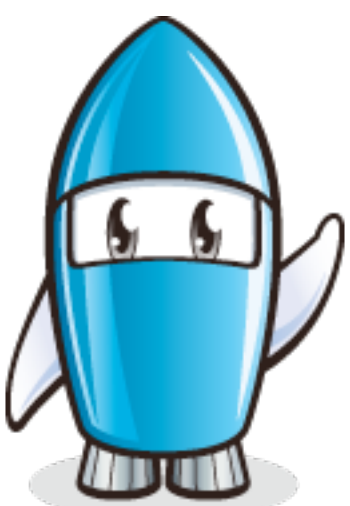


16/8/2014 Physics at LHC and Beyond @Quy nhon, Vietnam

Introduction

Physics beyond the SM

A new particle is discovered

&

Its properties are consistent with a SM Higgs boson

↓

The SM seems to be established

However, it's not the end of the story

We still require the NP beyond the SM

- Baryon asymmetry of the Universe?
- What's the Dark Matter?
- Origin of tiny neutrino mass?
- Charge quantisation? ⟵ Unified theory ? (Hierarchy problem)
- …

There should be NP!!

Scale of the NP?

How far is the new physics ?

- BAU : depending on the models
  - EWBG: TeV
  - Leptogenesis: ~10^9GeV
- DM : depending on the thermal history, properties of DM
  - WIMP: TeV
  - WIMPzilla: 10^{16}GeV
- m_ν : depending on the models
  - Seesaw: keV~10^{15}GeV
  - Radiative mechanism:TeV
- Hierarchy problem : should be around TeV!

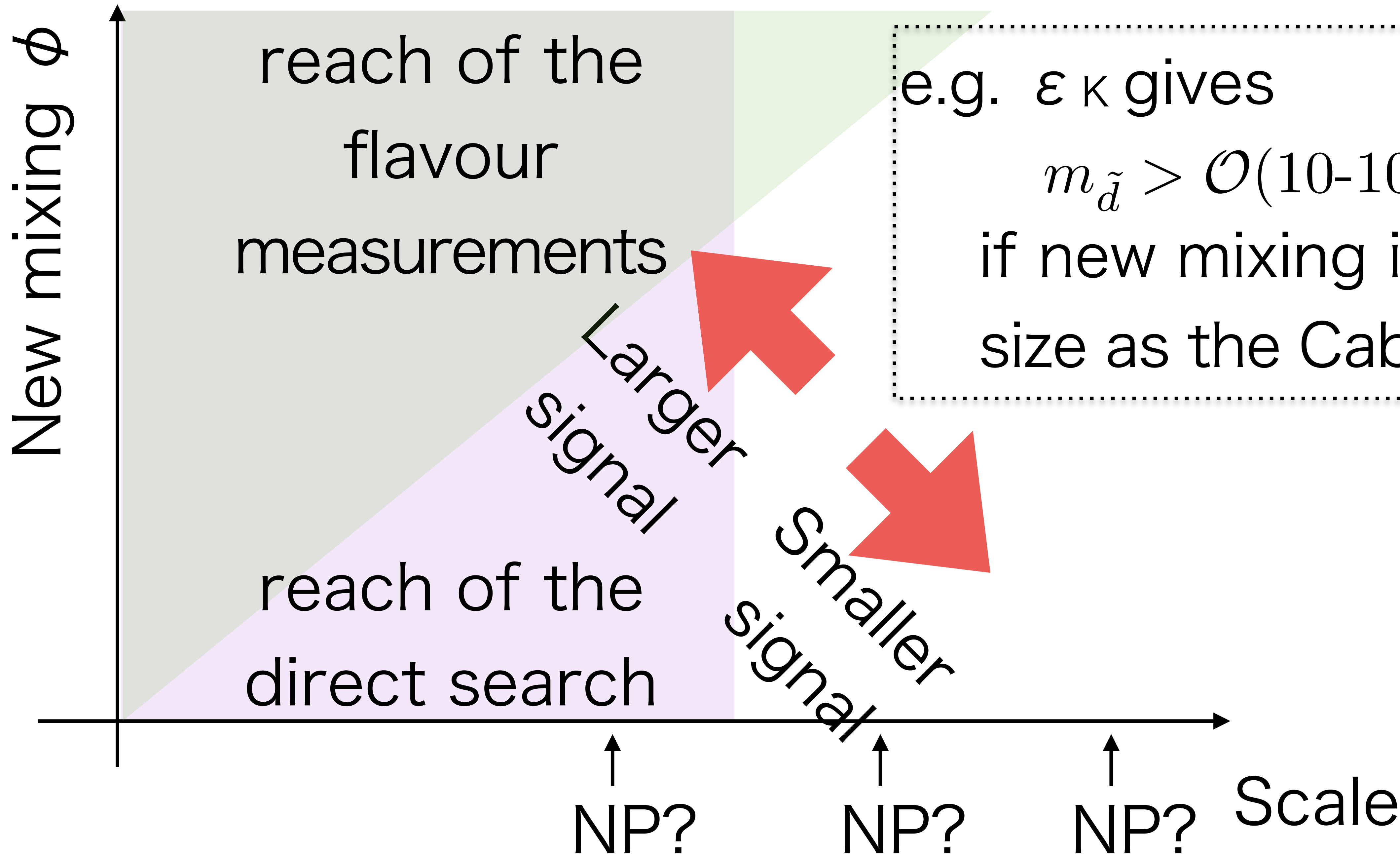
Can you bet everything on the hierarchy problem?

We don't have enough knowledge on the NP scale

Anomalies from exp. suggests NP@TeV scale

Flavour is powerful tool

The reach of the flavour physics is sometimes much higher than the direct search



e.g. ε_K gives

$$m_{\tilde{d}} > \mathcal{O}(10\text{-}100)\mathrm{TeV}$$

if new mixing is same size as the Cabibbo angle

How to probe NP by flavour physics

参

How to probe NP by flavour physics

All the flavour processes can be described in terms of the effective theory

- $SU(3)_C \times U(1)_{em}$ invariant (QCD with 5 flavours&QED)
  - Leptons + 5 quarks(u,d,s,c,b) + photon + gluons (t,W,Z,h are integrated out)
- Write down the higher dimensional operators such as the 4-quark operators, dipole operators,⋯

$$\mathcal{H}_{\rm eff} = \sum_i C_i Q_i$$

Wilson coefficients → C_i

Higher diminutional operators → Q_i

e.g. $(\bar{s}\gamma^\mu P_L b)(\bar{s}\gamma_\mu P_L b), \quad m_b \bar{s}\sigma^{\mu\nu} P_R b F_{\mu\nu} \ \ldots$

How to probe NP by flavour physics

A flavour measurement can determine the value of a combination of the Wilson coefficients

$$\langle Y|\mathcal{H}_{\text{eff}}|X\rangle = C_a r_a + C_b r_b + C_c r_c + \cdots$$

Hadronic matrix elements
(A main origin of theoretical uncertainty)

It is important to see as many processes as possible.
CPVs give informations of phases of Wilson coefficients.

How to probe NP by flavour physics

Let's consider the NP contributions

At the scale of NP mass:

$$C_i(\mu) = C_i(\mu)^{\rm SM} + C_i(\mu)^{\rm NP}$$

All the Informations of New Physics are encoded in this part

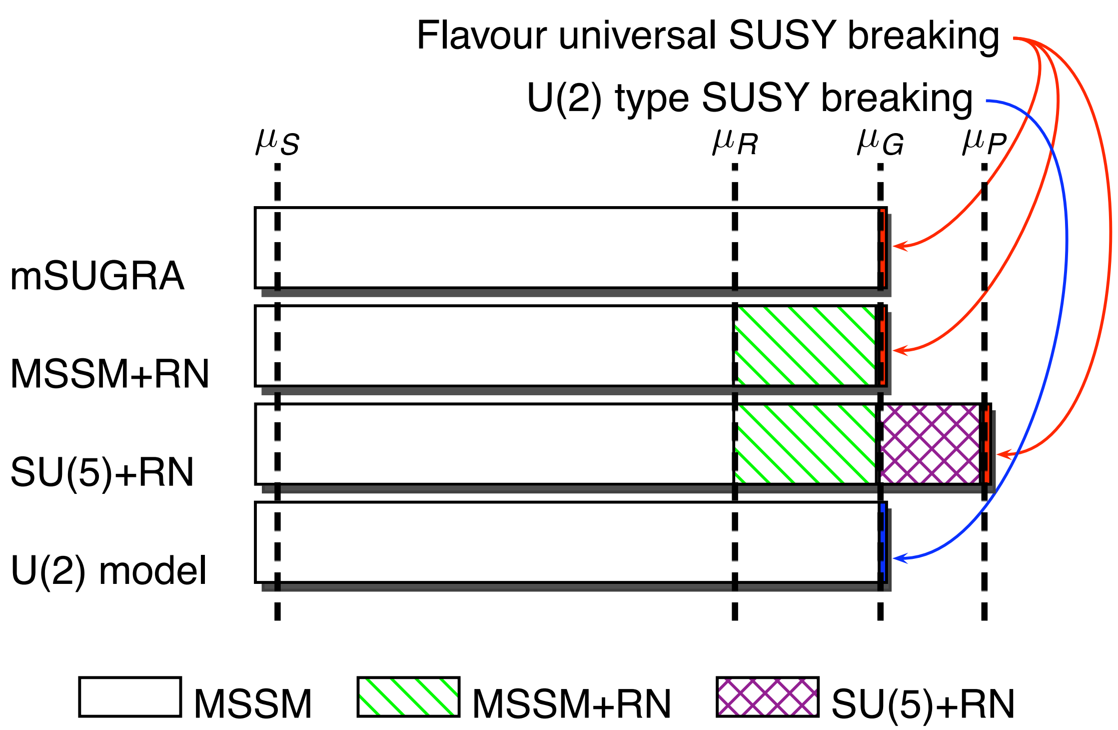
Sometimes, NP provides a new type of operator which does not appear (or strongly suppressed)in the SM $(C_i^{\rm SM} \simeq 0)$

SUSY as an example of BSM

- SUSY is still attractive candidate of physics BSM
  - SUSY is the only possible extension of the 4-dim space-time symmetry.
  - In SUSY theory, spin-0 particle (the Higgs boson) is naturally introduced
- A SUSY model (especially MSSM) is a useful benchmark model.
  - It contains extra scalars, fermions, new flavour structures etc.

Example in SUSY

Mediation of SUSY breaking (CMSSM, FS, ⋯)



Goto, Okada, T.S. and Tanaka, PRD77, 095010

RGE

Physics in the scale between ~~SUSY~~ mediation and $m_{\rm SUSY}$ scale (GUT, seesaw, ⋯)

Integrating out the SUSY particles

$$C_i^{\rm SUSY}$$

Example in SUSY

Let's see how is the flavour mixing is affected by the theory between the mediation scale and m_{SUSY}

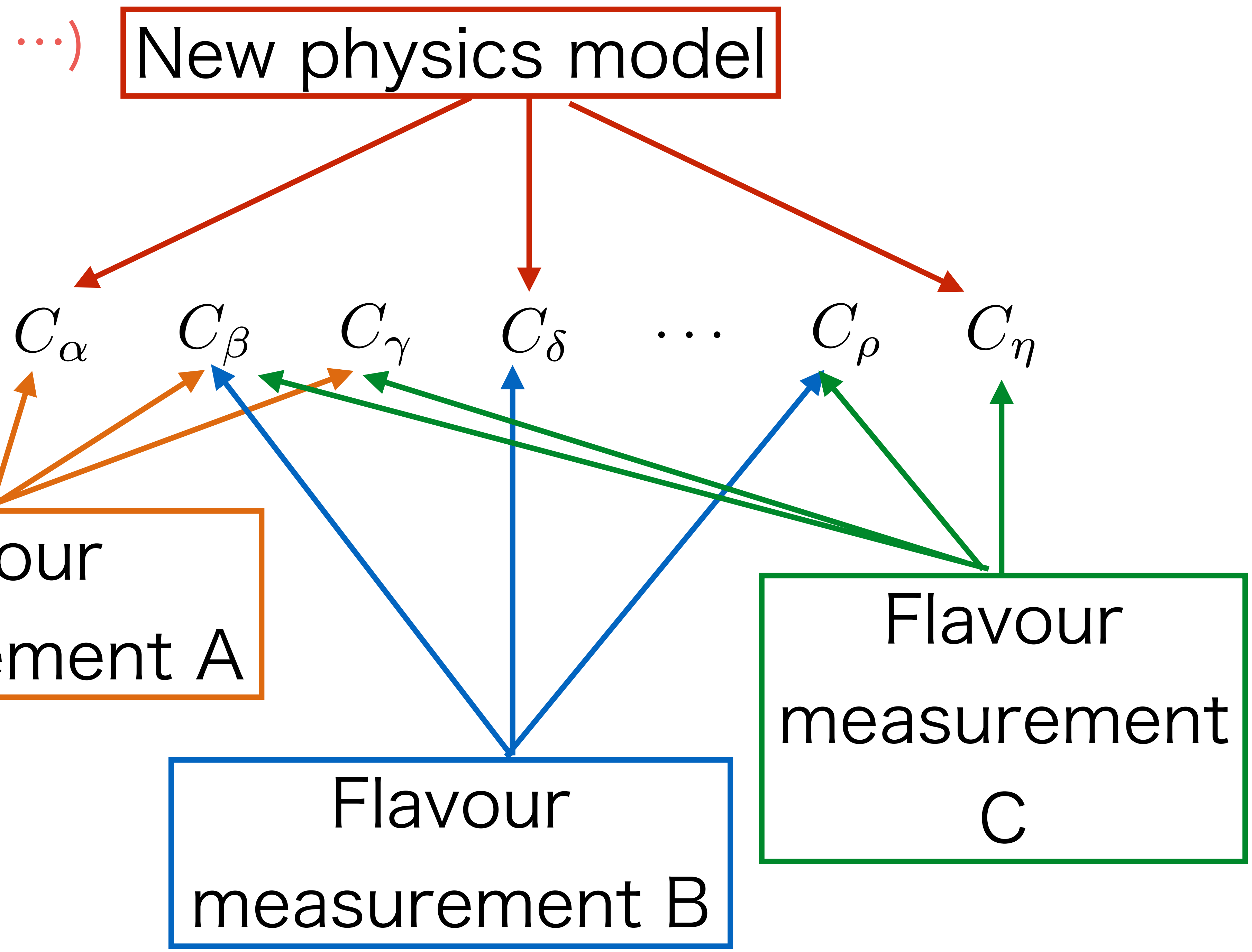
- MSSM: CKM mixing affects the Left-squark mixing
- MSSM+RH neutrinos: Neutrino Yukawa coupling affects the Left-slepton mixing
- SU(5) SUSY GUT with Y_N: Y_N affects the Right-sdown sector mixing
- …

Whole picture

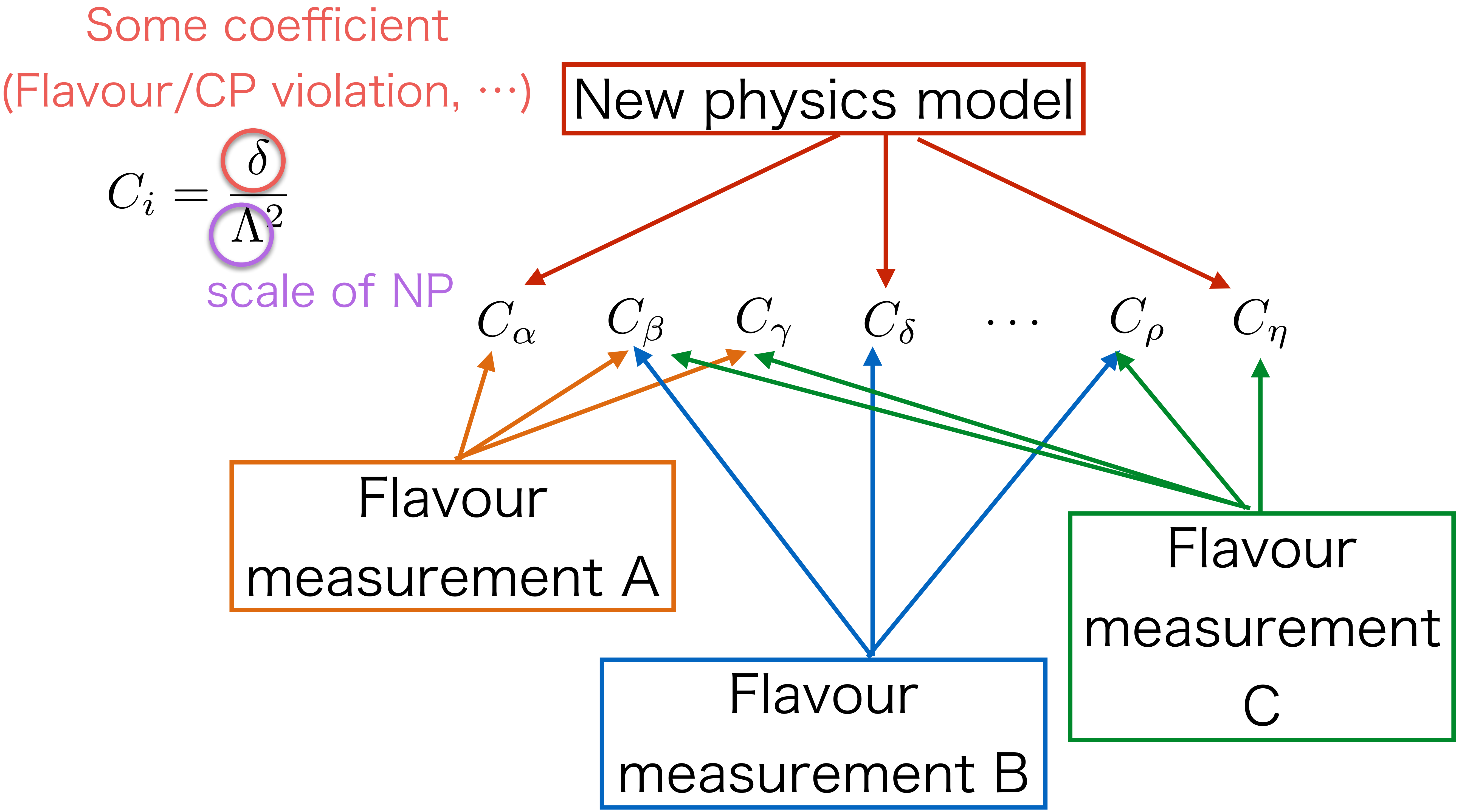
Some coefficient
(Flavour/CP violation, ⋯)

$$C_i = \frac{\delta}{\Lambda^2}$$

scale of NP



Whole picture



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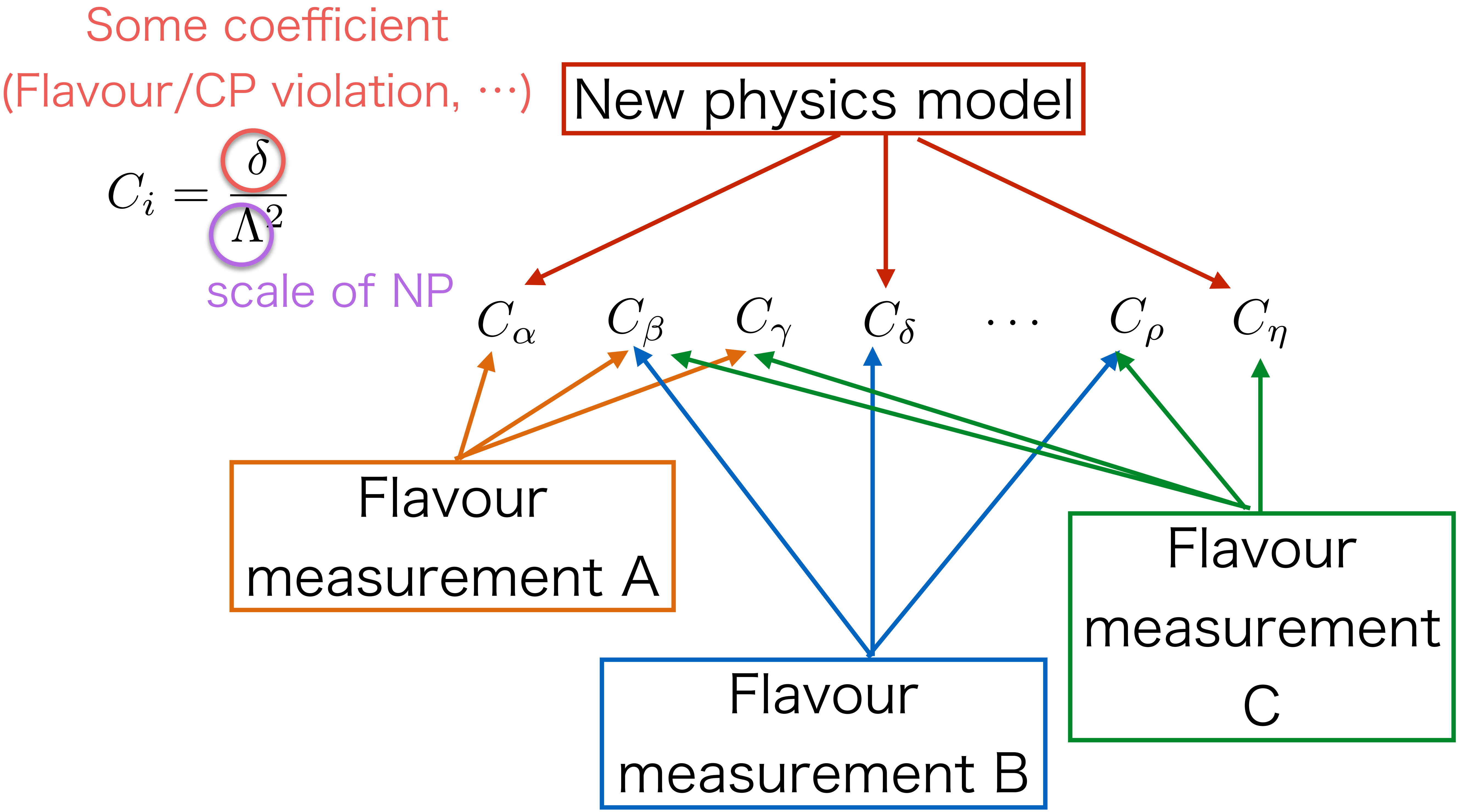
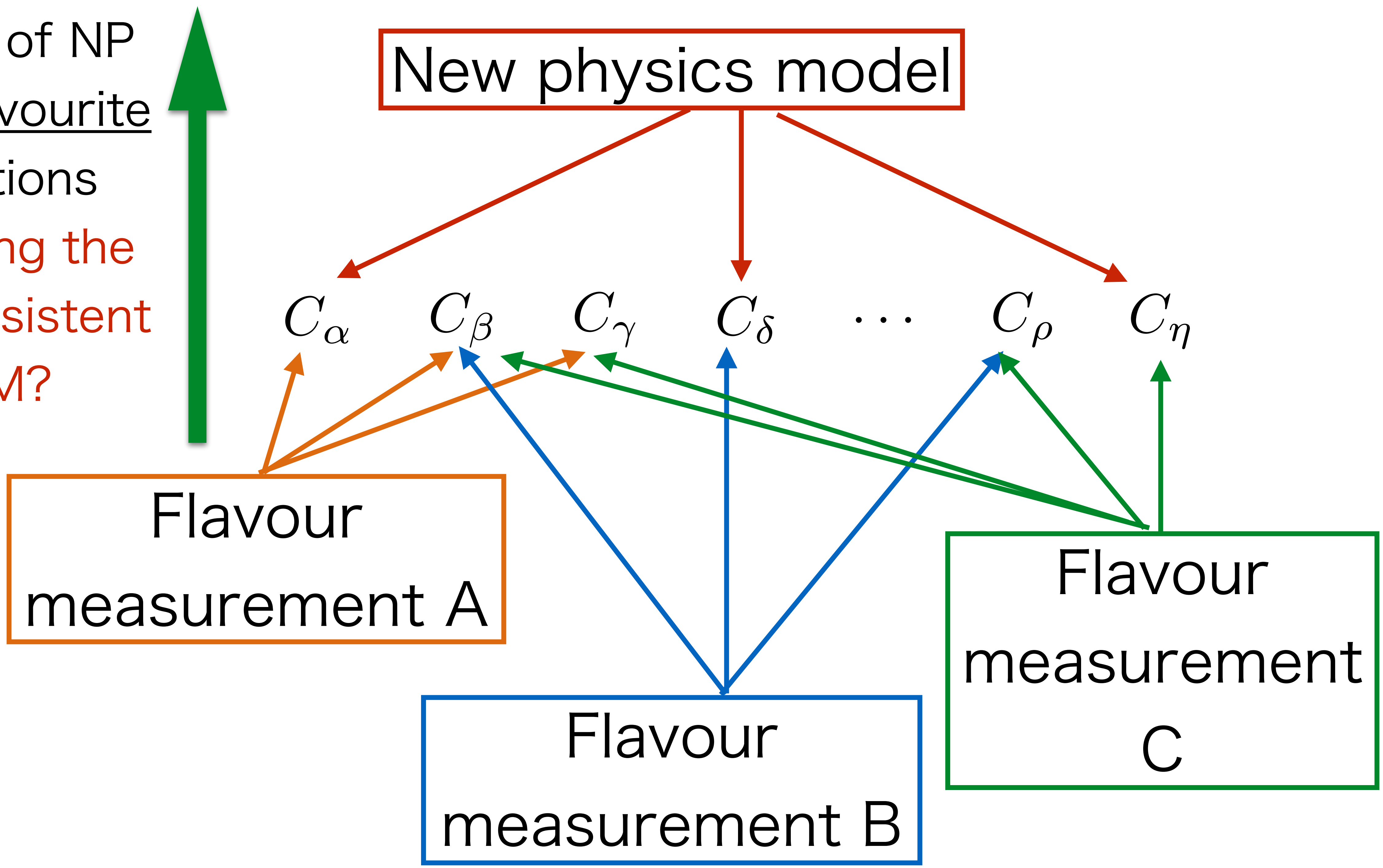


There are two types for approaching NP from flavour

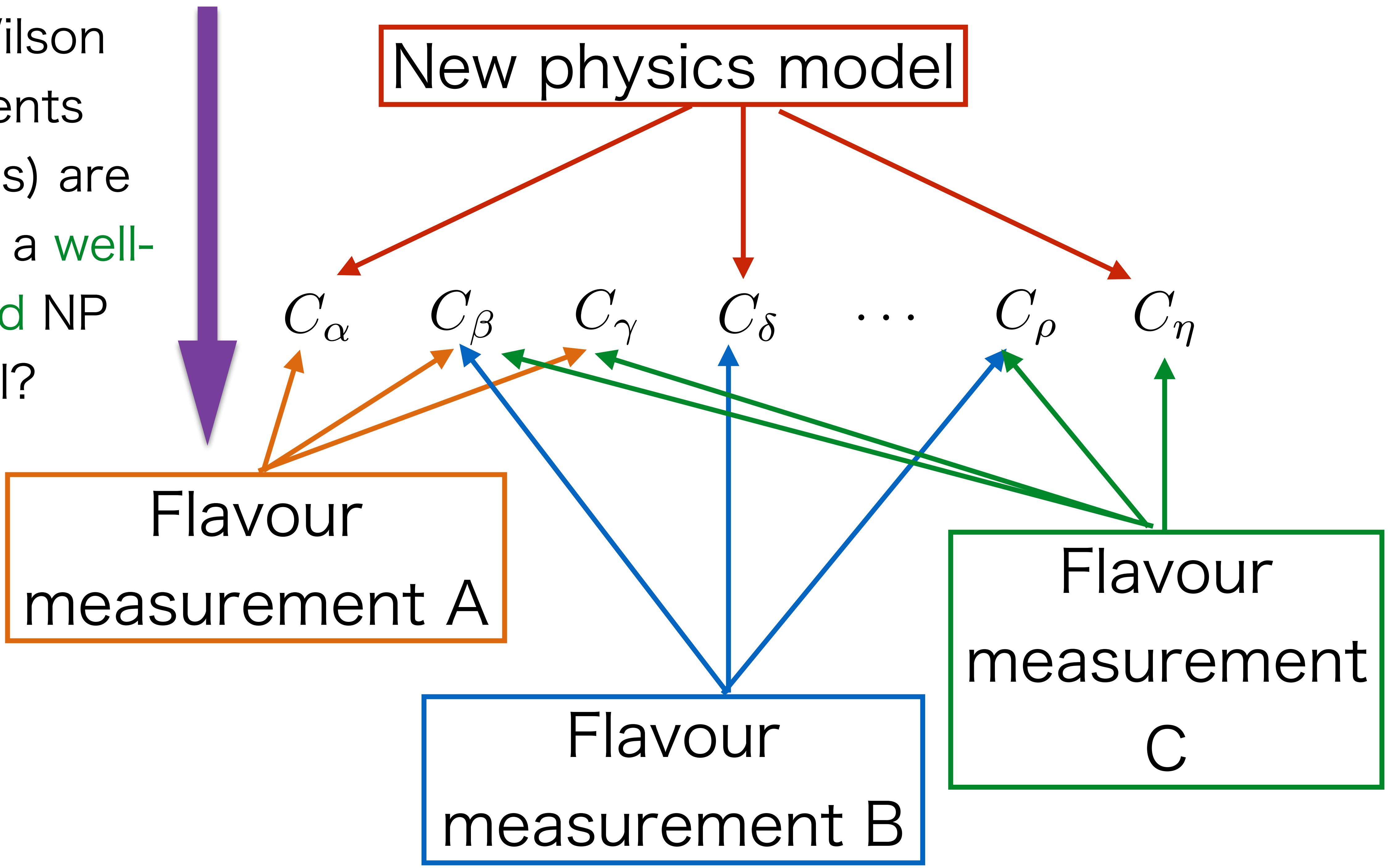
Bottom-Up

What kind of NP can give favourite contributions with keeping the others consistent with SM?



Top-down

Which Wilson coefficients (processes) are affected in a well-motivated NP model?



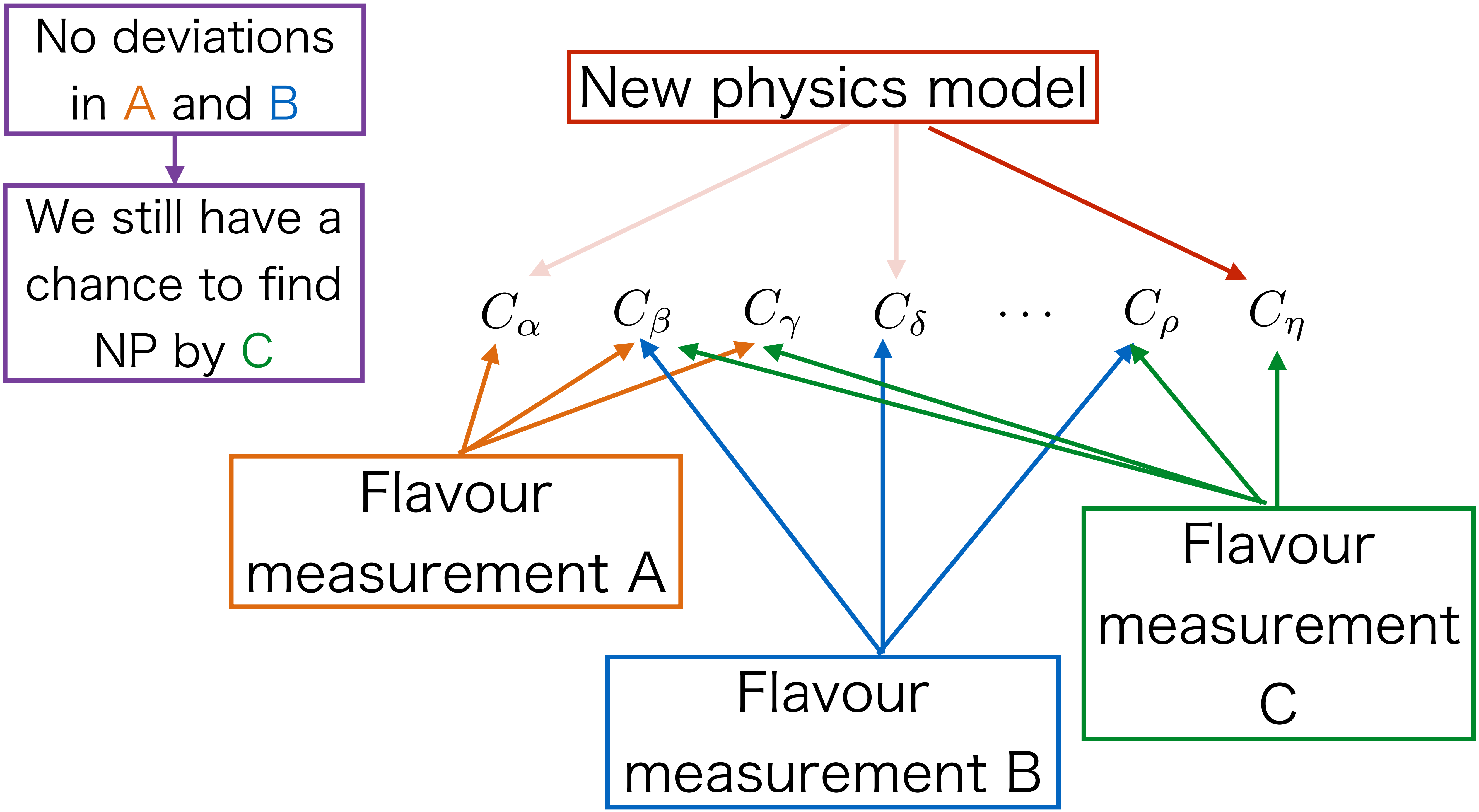
With satisfying the constraints

It becomes more and more difficult to consider models which predict significant deviations from the SM
with satisfying the other constraints

(e.g. Challenges given in G. Hou's talk)

- **Some flavour measurements provide strong constraint**
- LHC data also provides strong constraint (direct search of NP)
- (In MSSM based models) Higgs mass is also strong constraint
- …

Toward NP model



Toward a NP model with large signal

How to enhance a specific δ ??

How to keep Λ as low as possible ?

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Flavour problem

$$\epsilon_K, \mu \to e\gamma, d_n, \cdots$$

1-2 mixing should be strongly constrained!

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B_s-B_s mixing is consistent with SM

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Some new directions?

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- **LHC data also provides strong constraint (direct search of NP)**
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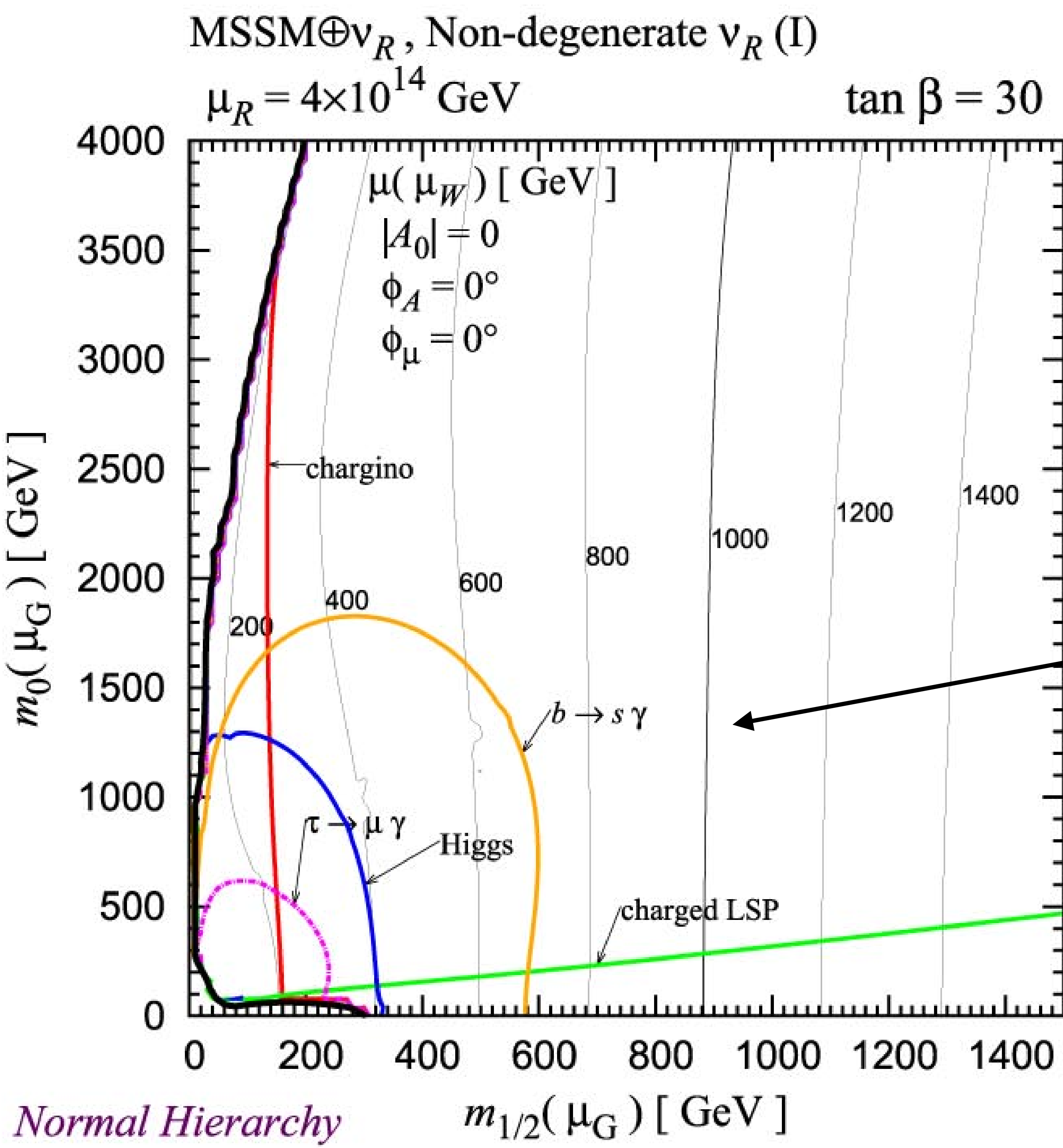
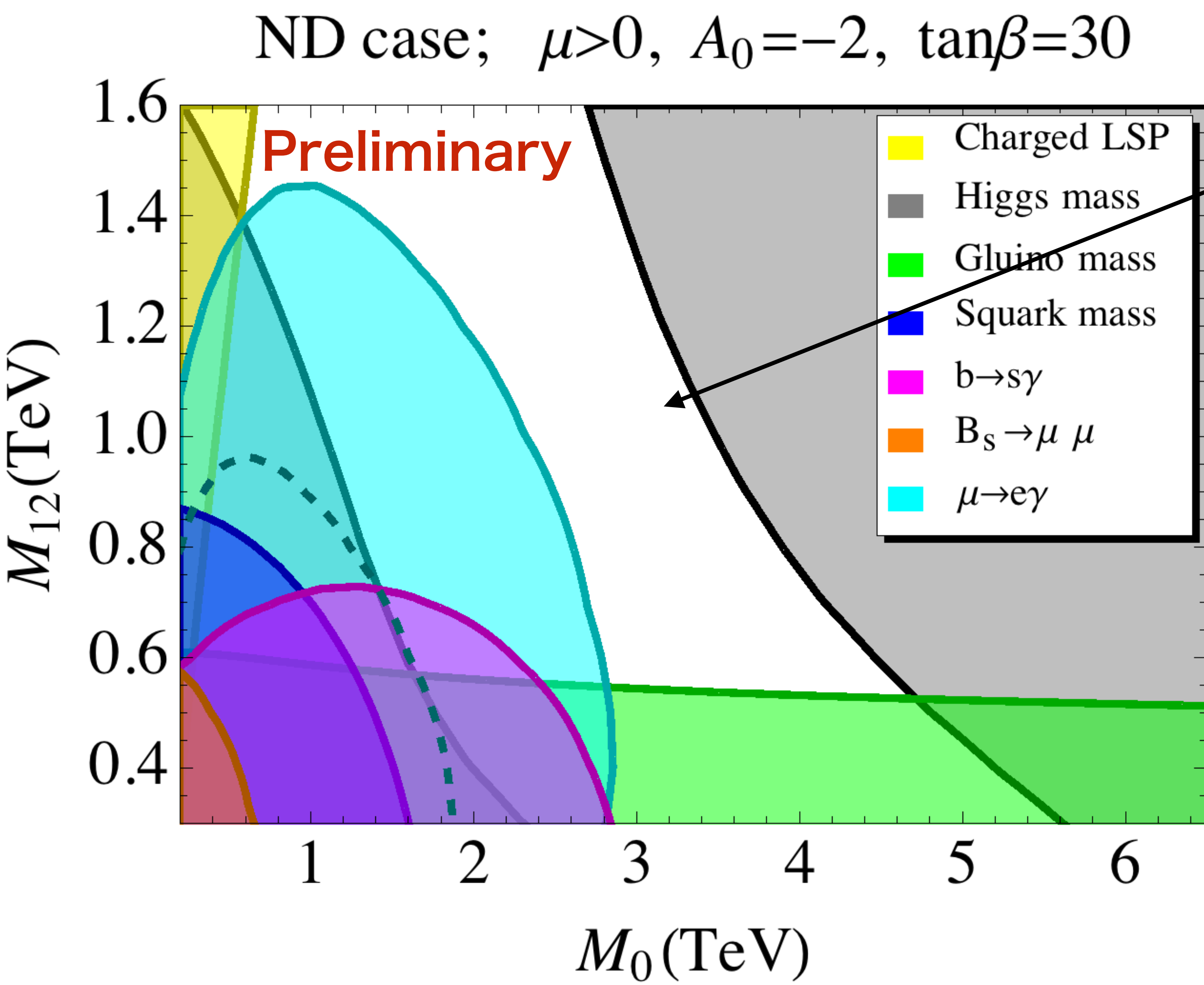
Six years ago…



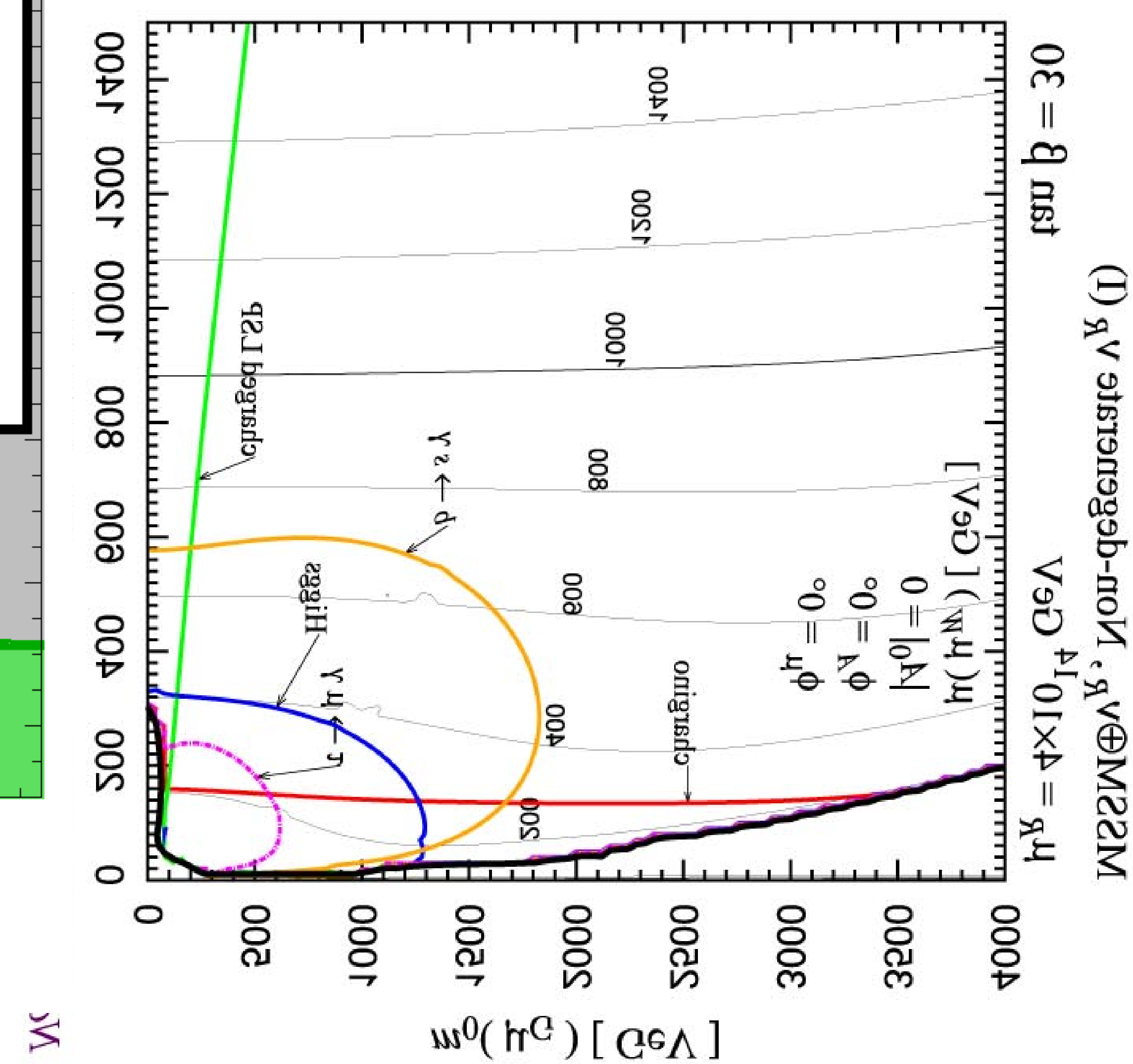
We could play game in this wide area

Goto, Okada,T.S, Tanaka, PRD77,095010

After LHC run I



m_h=124-128GeV



Goto, Okada,T.S, Tanaka, Watanabe, work in progress

Impacts of LHCb results

Impacts of LHCb results

We focus on several selected topics

My choice is very conservative···

- FCNC rare decay: $B_s^0 \to \mu^+ \mu^-$
- Measurement of CKM angle ϕ_3 (γ): $B \to DK$
- CP violation in B_s mixing: $B_s^0 \to J/\psi\phi$
- ···

Impact of $B_s \to \mu\,\mu$

$$\mathrm{B}(B_s \to \mu\mu) = (2.9^{+1.1}_{-1.0}) \times 10^{-9}$$

$$\mathrm{B}_{\mathrm{SM}} = (3.65 \pm 0.23) \times 10^{-9}$$

Bobeth, et al., PRL112,101801

Relevant operators:

$$Q_S = \frac{e^2}{(4\pi)^2}(\bar{s}^\alpha P_R b^\alpha)(\bar{\ell}\ell) \qquad Q'_S = \frac{e^2}{(4\pi)^2}(\bar{s}^\alpha P_L b^\alpha)(\bar{\ell}\ell)$$

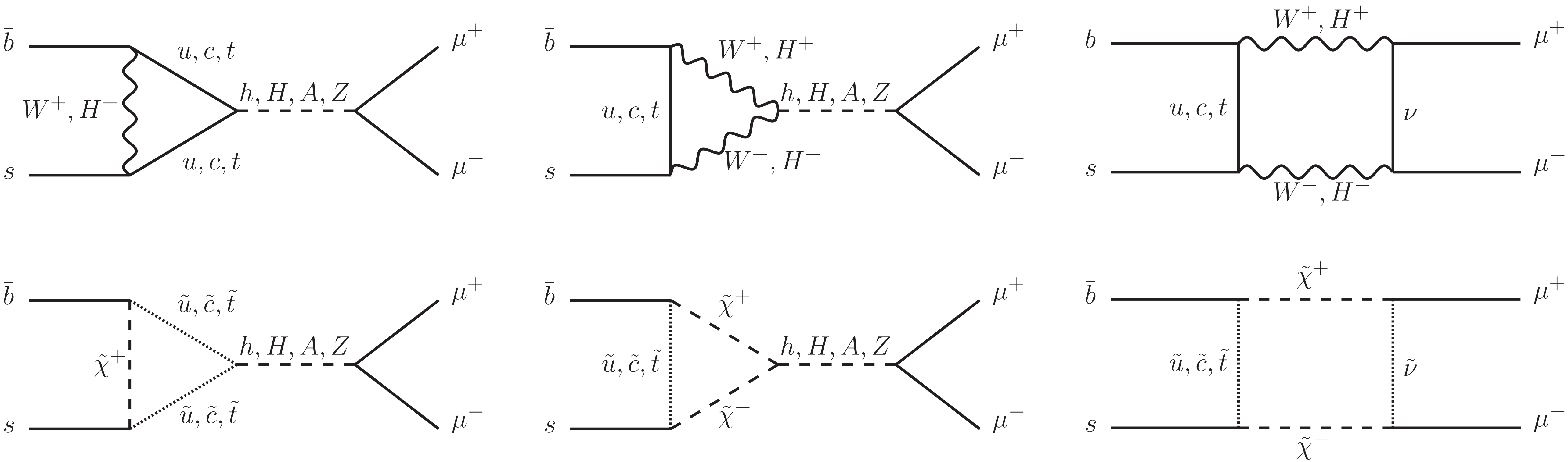
$$Q_P = \frac{e^2}{(4\pi)^2}(\bar{s}^\alpha P_R b^\alpha)(\bar{\ell}\gamma_5\ell) \qquad Q'_P = \frac{e^2}{(4\pi)^2}(\bar{s}^\alpha P_L b^\alpha)(\bar{\ell}\gamma_5\ell)$$

$$Q_{10} = \frac{e^2}{(4\pi)^2}(\bar{s}^\alpha \gamma^\mu P_R b^\alpha)(\bar{\ell}\gamma_\mu\gamma_5\ell) \qquad Q'_{10} = \frac{e^2}{(4\pi)^2}(\bar{s}^\alpha \gamma^\mu P_L b^\alpha)(\bar{\ell}\gamma_\mu\gamma_5\ell)$$

The branching ratio:

$$\mathrm{B}(B_s \to \mu\mu) = \frac{\alpha^2}{512\pi^3} f_{B_S}^2 \tau_{B_s} m_{B_s}^3 \sqrt{1 - \frac{4m_\mu^2}{m_{B_s}^2}} \left\{ \left(1 - \frac{4m_\mu^2}{m_{B_s}^2}\right) |C_S - C'_S|^2 + \left| (C_P - C'_P) + 2(C_{10} - C'_{10}) \frac{m_\mu}{m_{B_s}} \right|^2 \right\}$$

In the MSSM



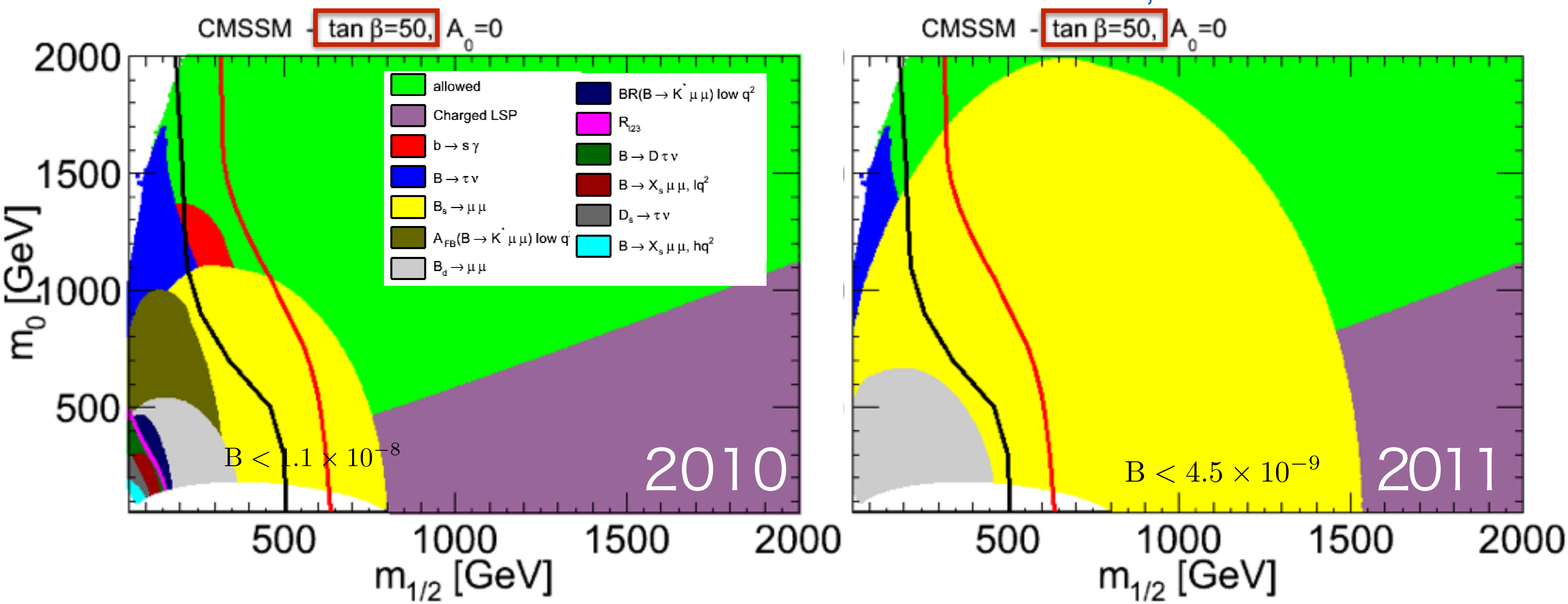
Diagrams are taken from
Arbey, Battaglia, Mahmoudi, Martinez Santos, PRD87, 035026

$C_S \simeq -C_P \propto \tan^3\beta$ in large $\tan\beta$ region

This process has very strong $\tan\beta$ enhancement!

In the MSSM

Mahmoudi, arXiv:1205.3099



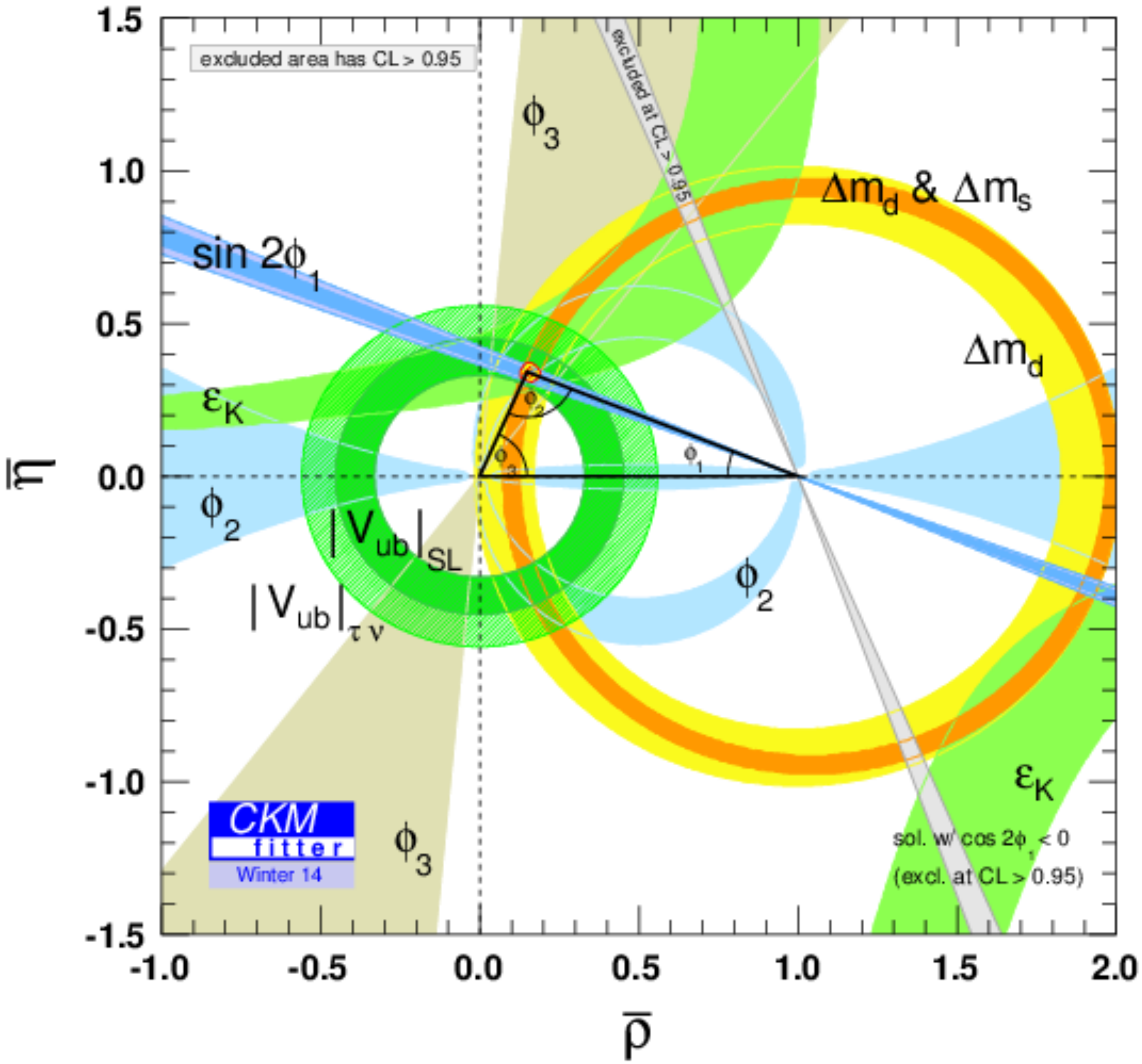
Wide region for large tan β is excluded

When a NP model is considered,

Contribution to $B_s \to \mu\mu$ should be seriously tested

in addition to contribution to the $b \to s\gamma$

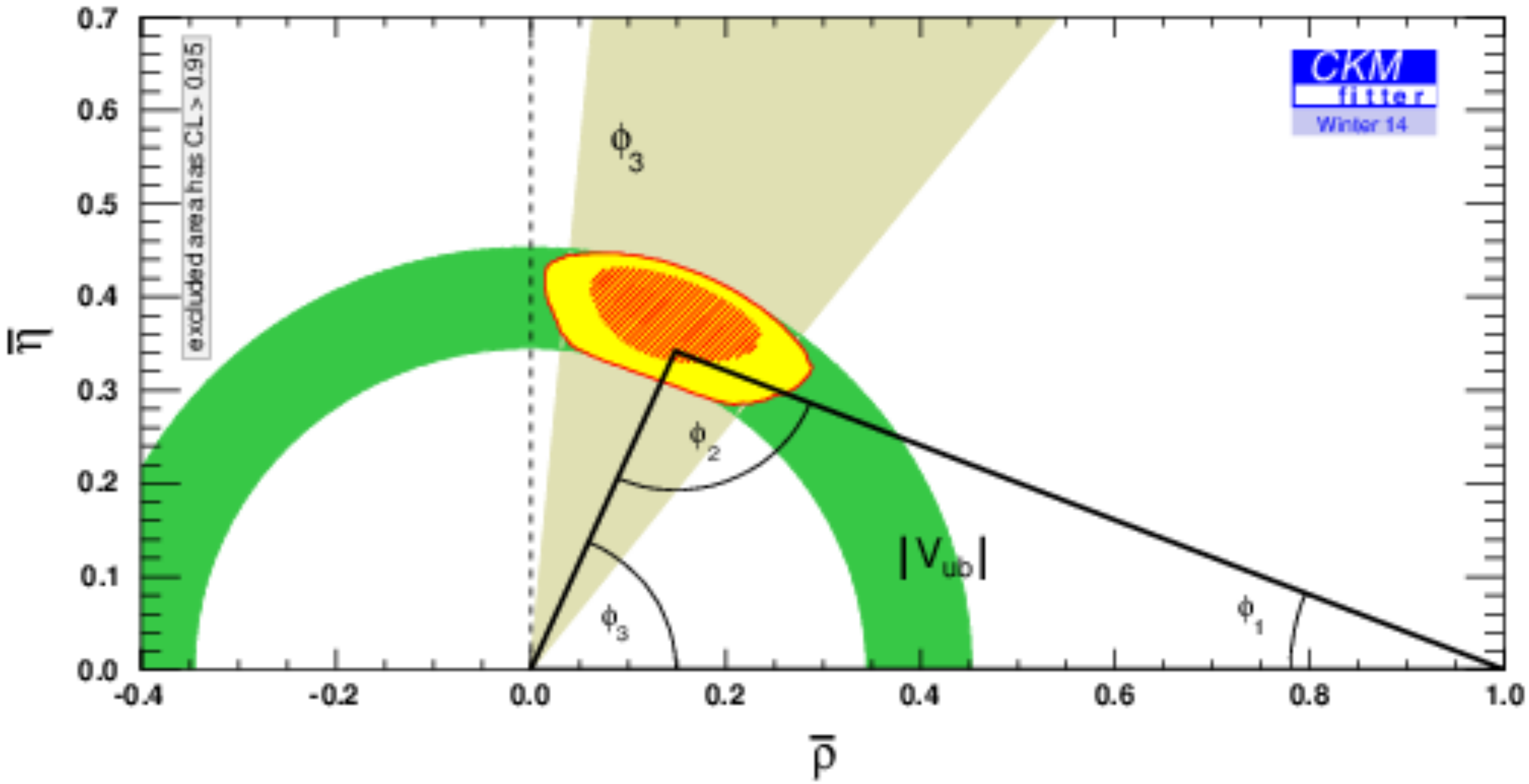
ϕ_3/γ determination



All the constraints seems consistent with the SM

However, there is a possibility that some loop processes are affected by the NP (It can be a mimic consistency)

ϕ_3/γ determination



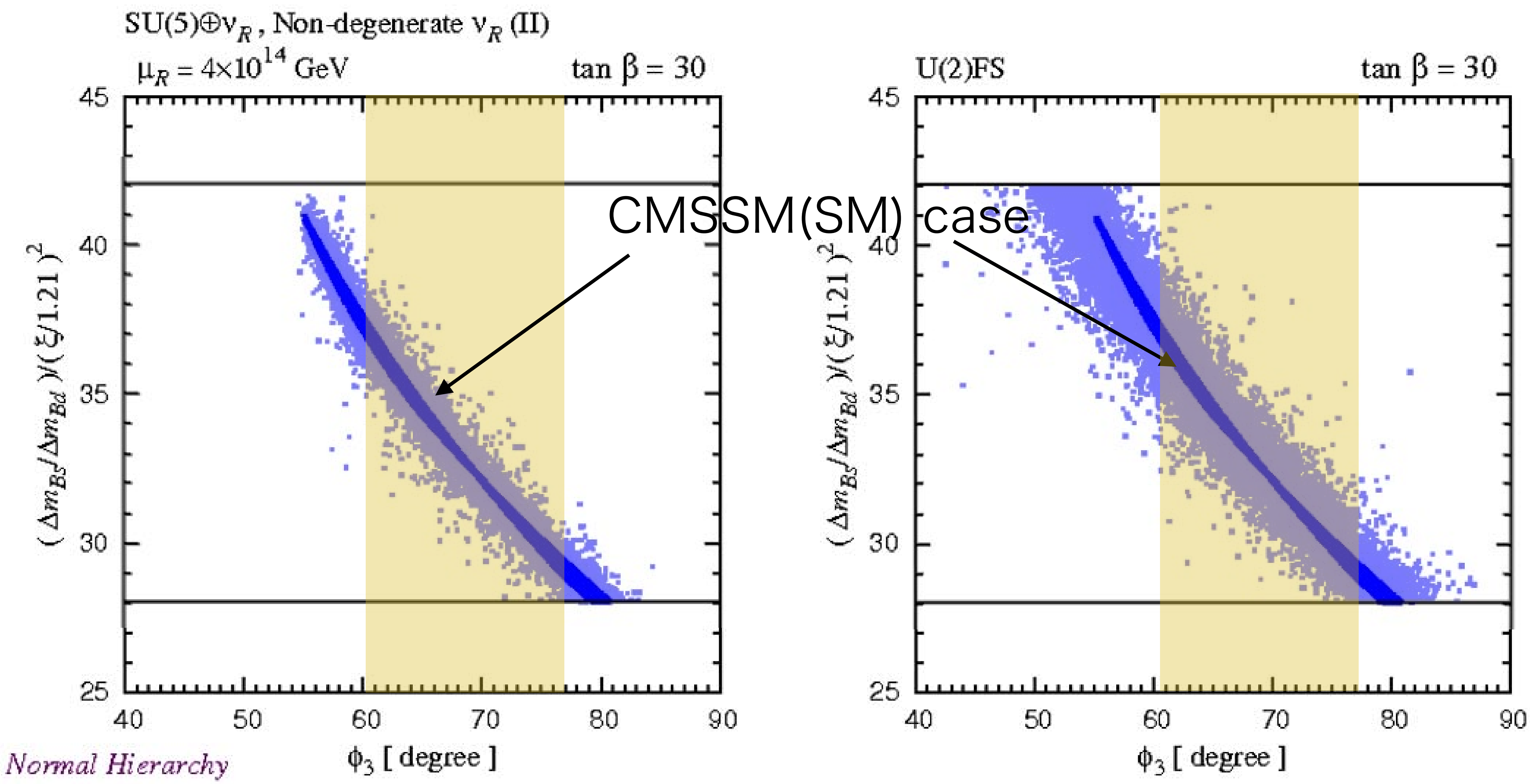
Tree level determination of the CKM angle will be important

After that, we can say everything is consistent with CKM

Example SUSY model

Goto, Okada,T.S, Tanaka, PRD77,095010

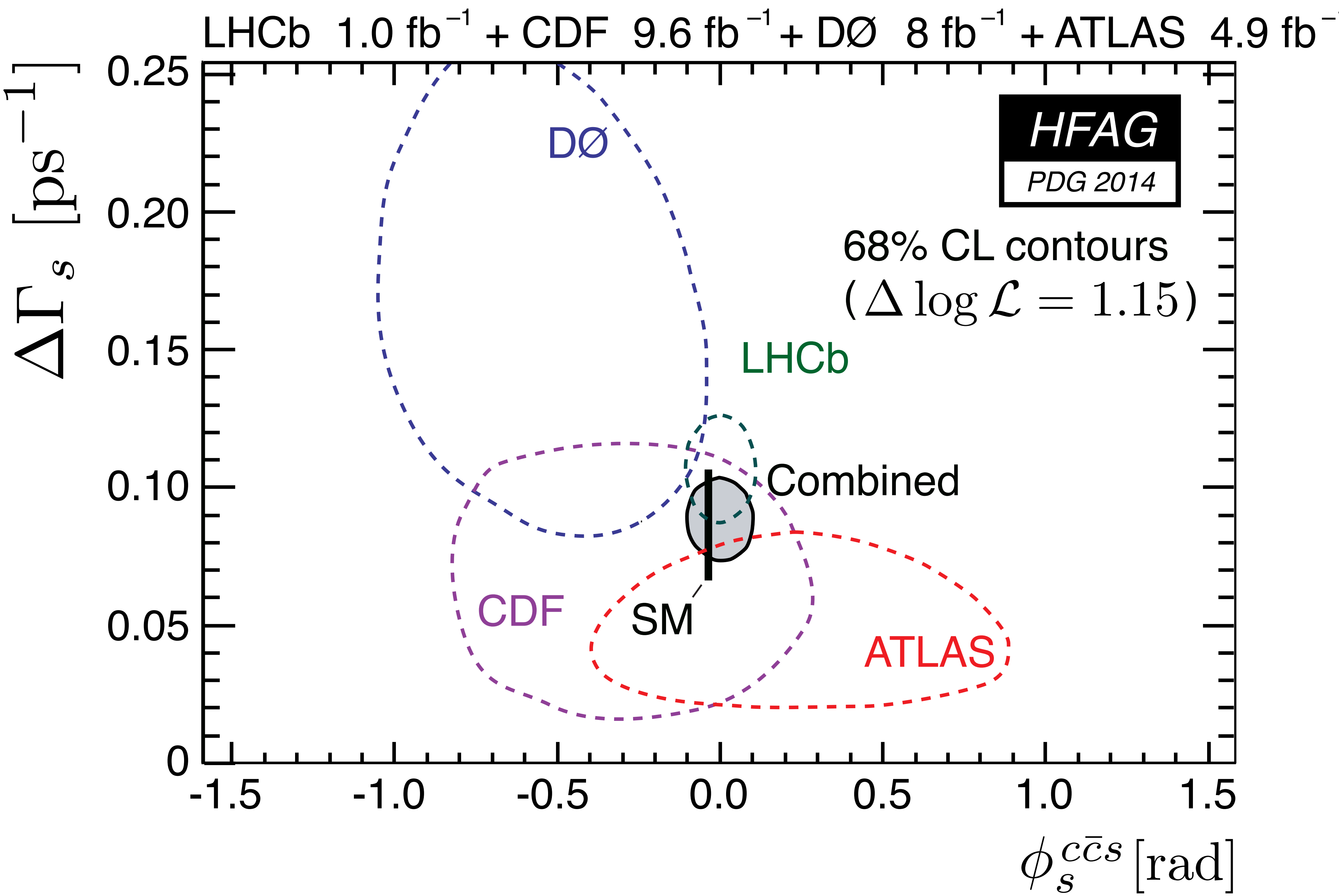
Significant loop contribution to ε_K



These figures are six years old. We plan to update these figures with recent LHC data(Goto, Okada,T.S, Tanaka, Watanabe, work in progress)

CPV in Bs sector

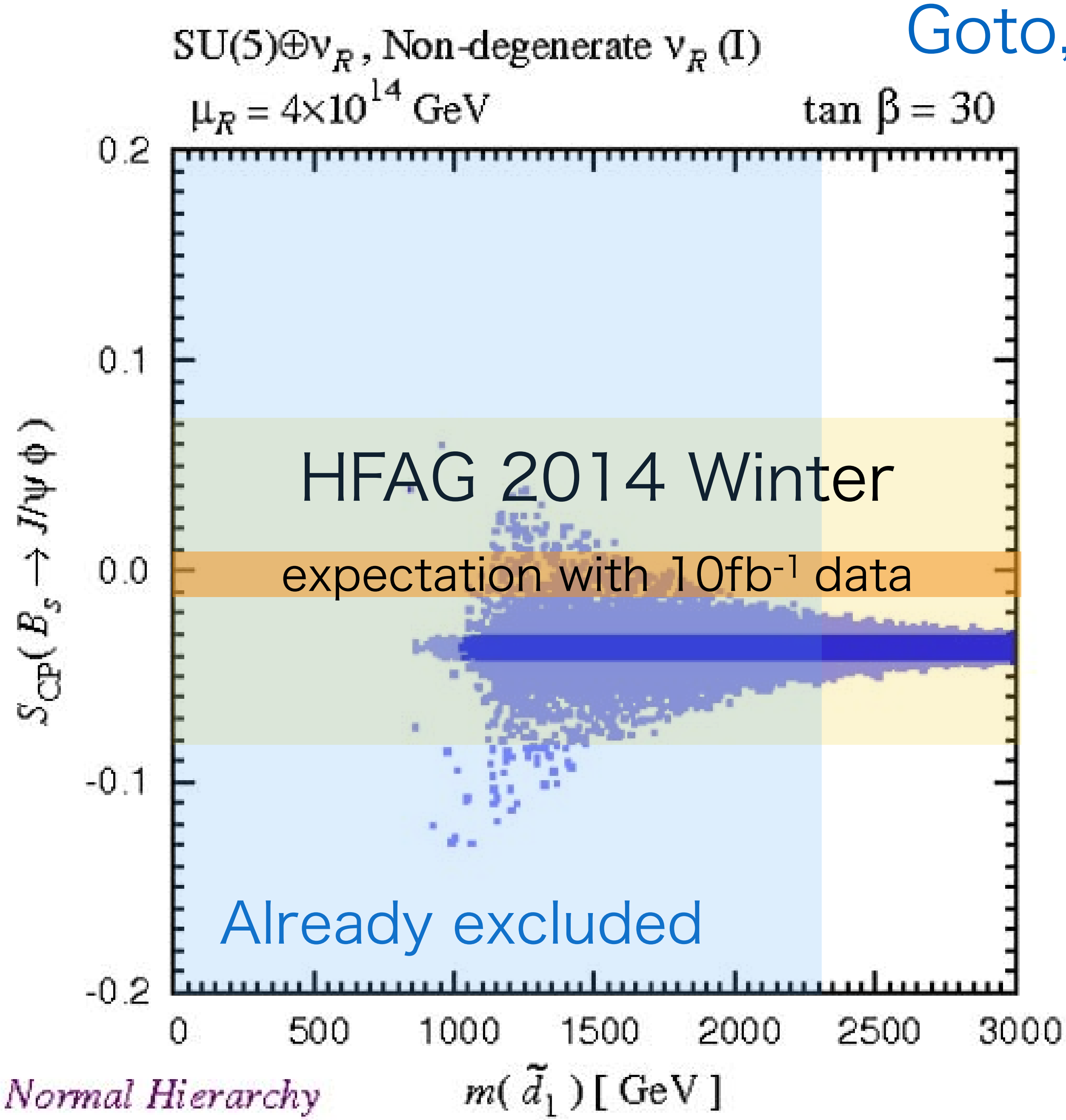
CP violation in Bs sector is also precisely measured

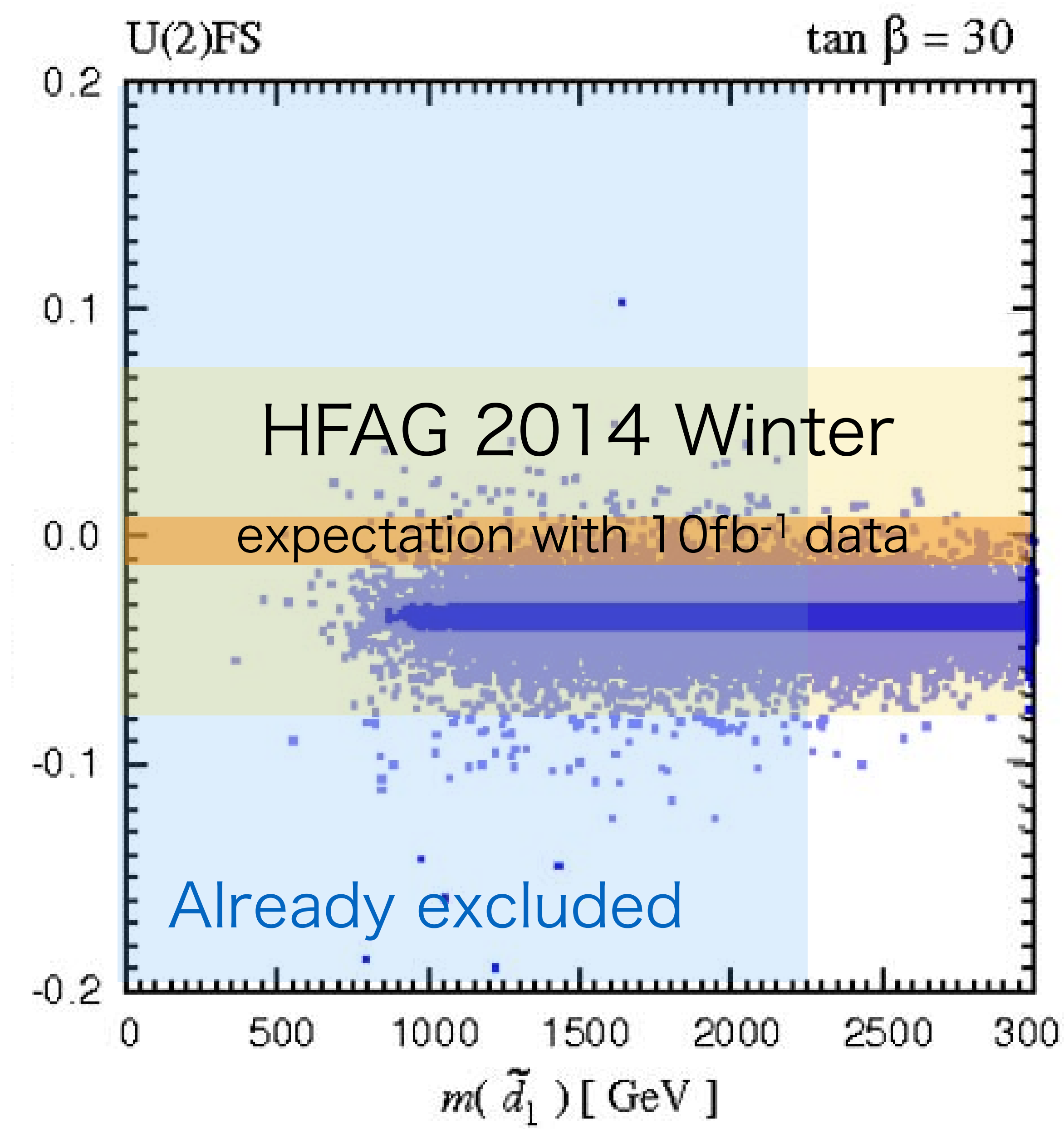


CPV in B_s sector

If the sensitivity is more, a deviation can be found?!

Goto, Okada,T.S, Tanaka, PRD77,095010





Summary

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Summary

- Flavour measurements in various processes provide informations of NP contributions to Wilson coefficients
  - It is important to measure as many process as possible, and to consider as many models as possible.
  - What kind models affect which Wilson coefficients?
- We need more information about present anomaly-like events
  - Precise measurement with more statistics and less systematics
  - Theoretical uncertainty should be understood more
  - Are the anomalies real signals of NP or just fakes?

Physics Complementarity*)

LHCb

ATLAS & CMS

- Rare decays: $B_{d,s} \to \mu\mu$
- B_s system
- b-baryons
- Spectroscopy
- CKM phases (β, γ)
- Gluonic penguins
- EW penguins
- Charm physics
- Semileptonics: Mixing, A_{SL}
- Semileptonics: V_{xb}
- $B \to \tau\nu$, $D\tau\mu$,
- $B \to K^*\nu\nu$
- τ-physics

Some only LHCb, some only Belle II

On-going

Belle II

*) Caveat: I am probably missing "your" favored channel/field

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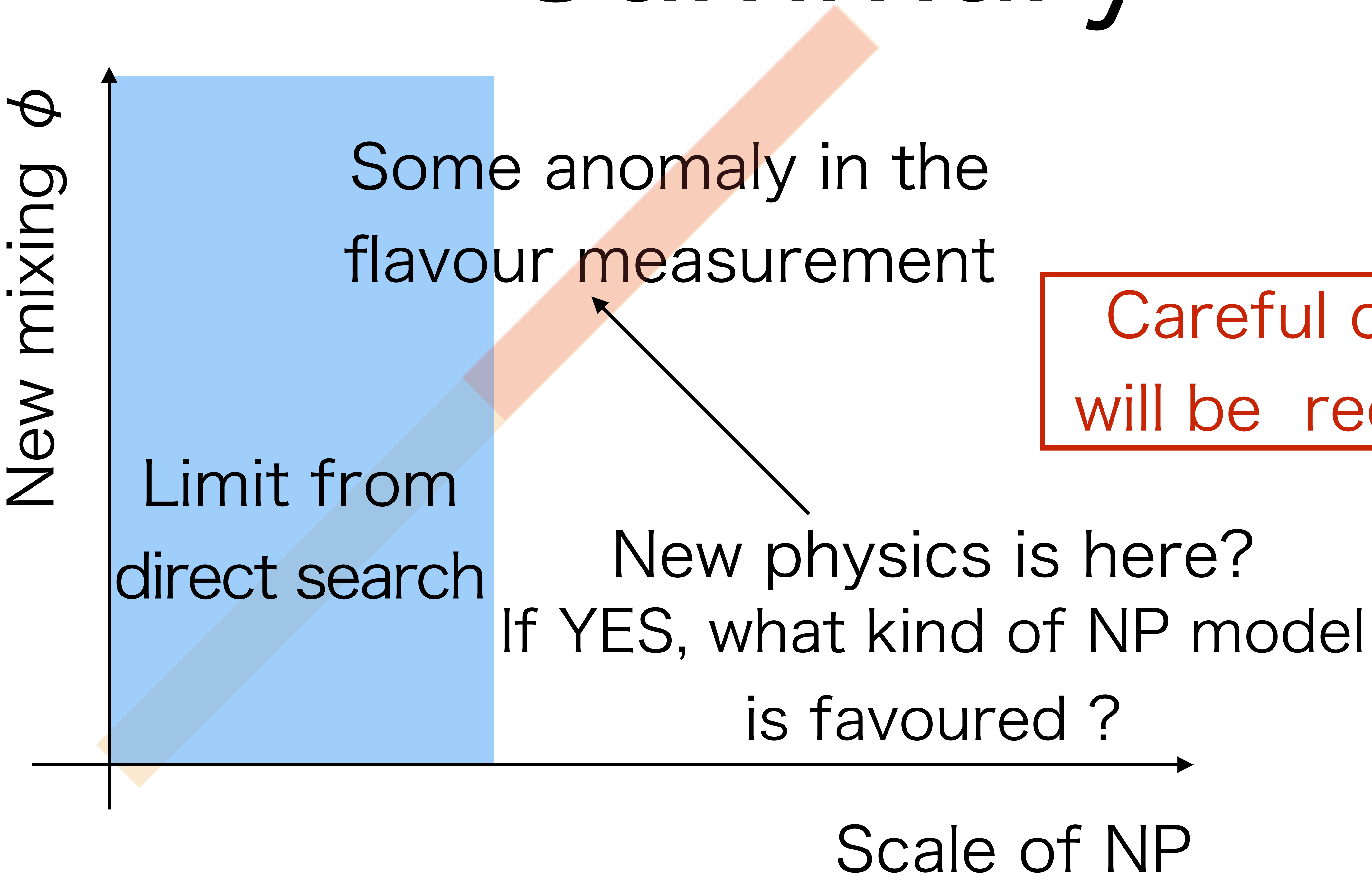

Careful check will be required

Summary

Needless to say,

in order to explore the BSM,

both direct search of new particles

and

precise measurements (like flavour physics)

are necessary

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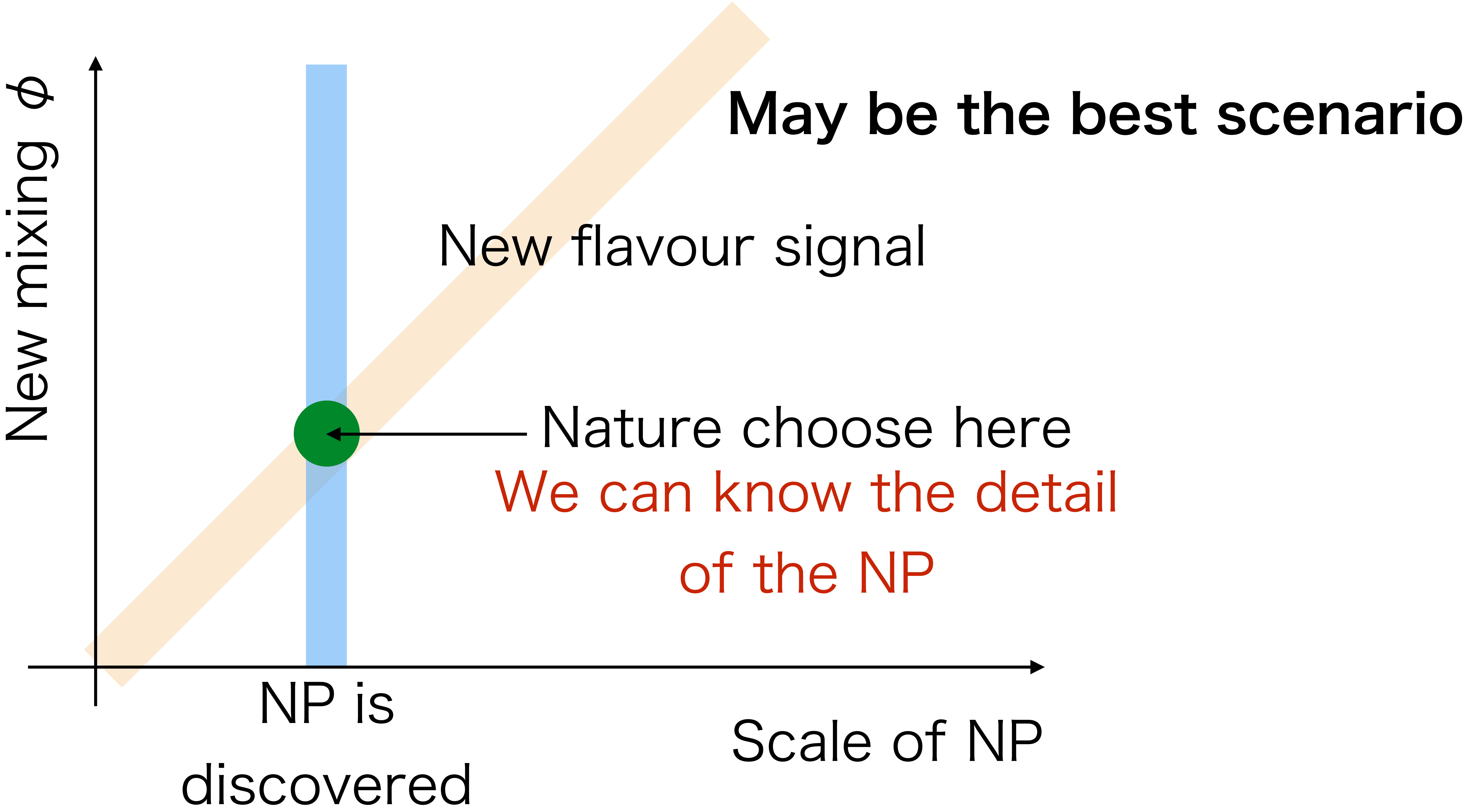
Let's consider several scenarios ···

If NP is discovered …



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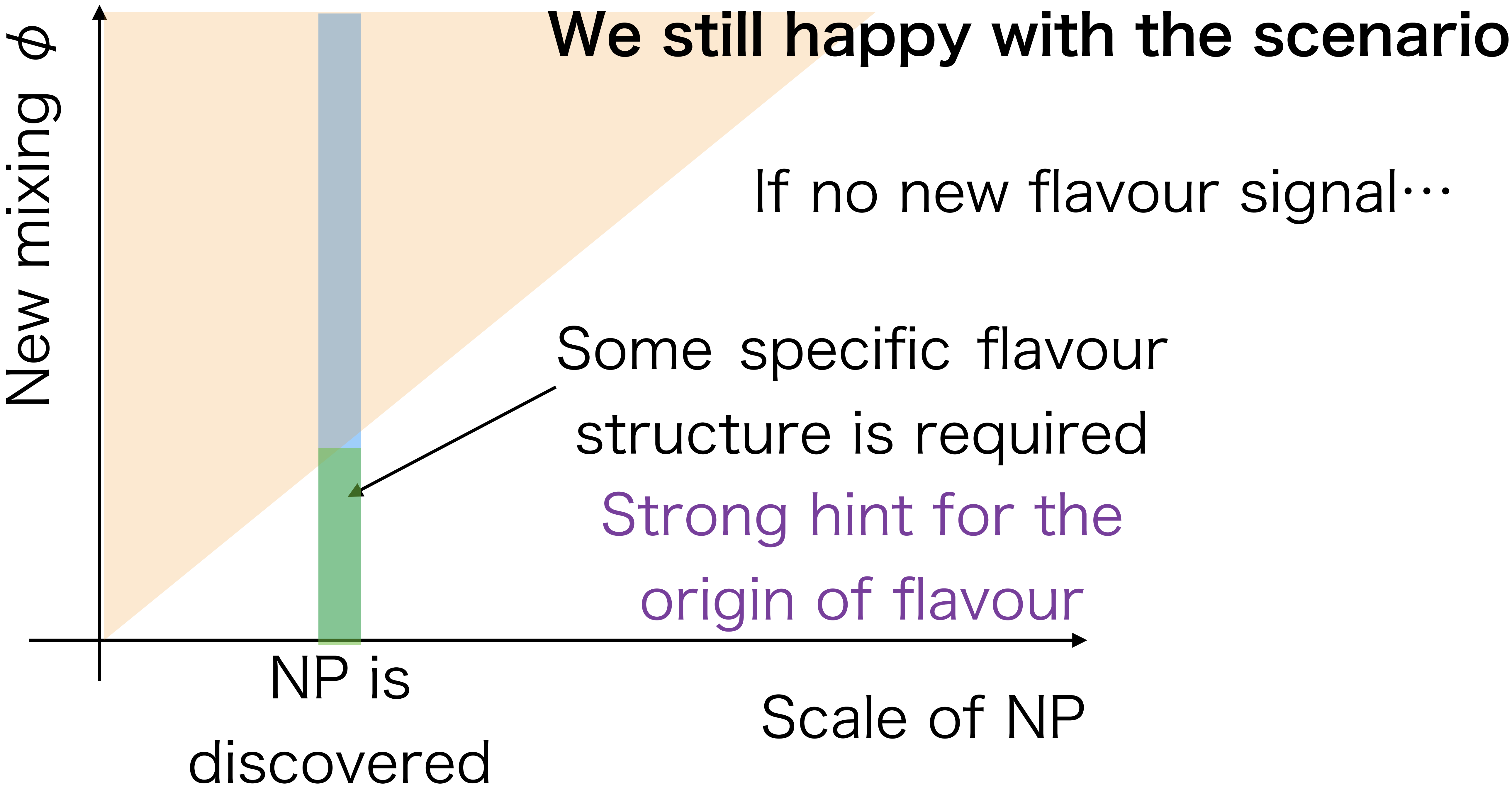
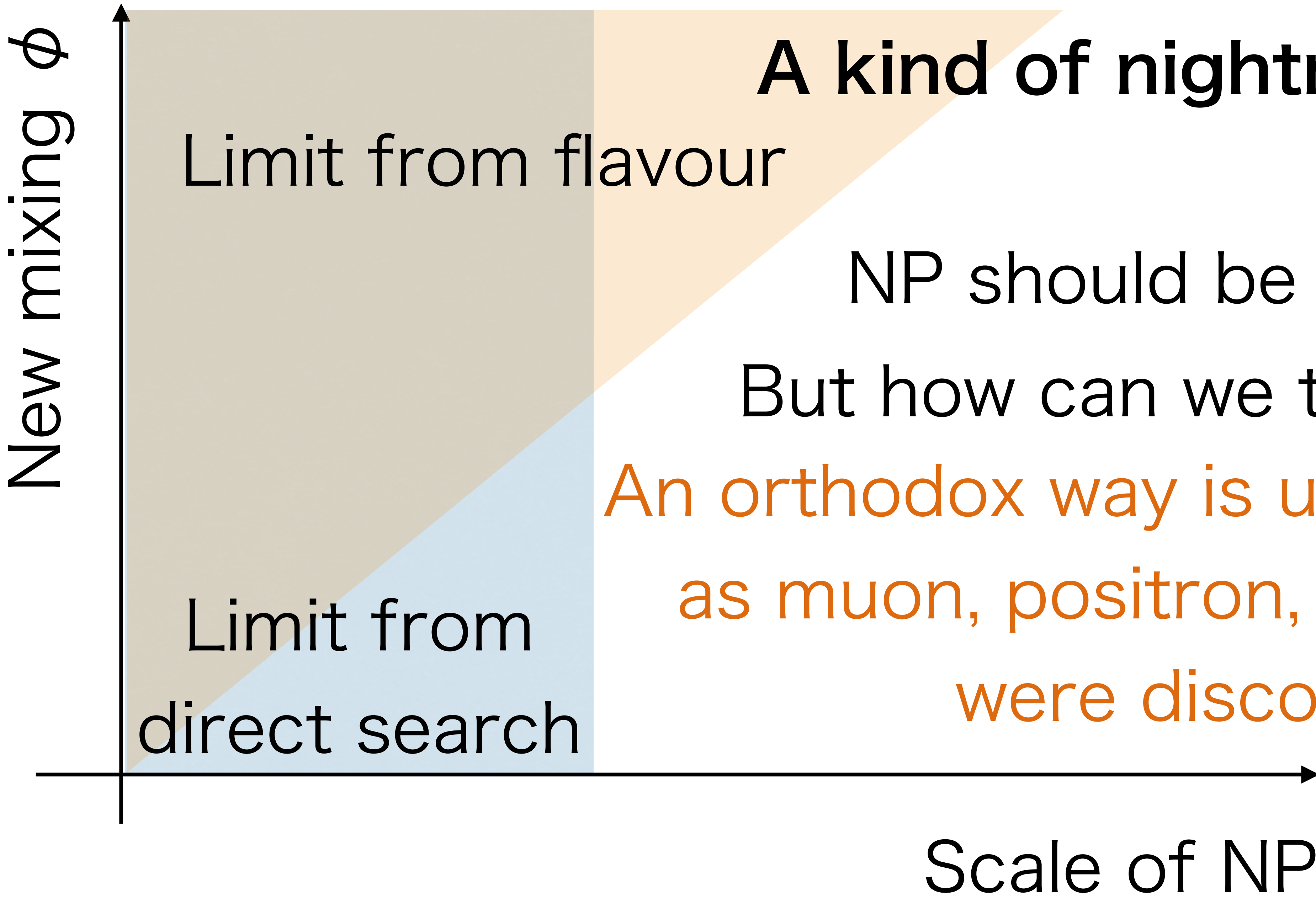


Flavour physics is a powerful tool to explore the physics beyond the SM

If NP is not discovered ⋯



A kind of nightmare scenario?

NP should be here!

But how can we test it⋯?

An orthodox way is using cosmic-ray, as muon, positron, pion, Kaon, ⋯ were discovered

Summary

Anyway,
after the Higgs dynamics is understood,
we should understand the origin of the flavour!

One more thing
(An announcement)

We will have a workshop on Higgs physics, TeV-scale NP, and there relationship

Feb. 11-15, 2015

@University of Toyama, Japan

Registration will open soon

http://jodo.sci.u-toyama.ac.jp/theory/HPNP2015/

HPNP2015

The 2nd Toyama International Workshop on
"Higgs as a Probe of New Physics 2015"

February 11–15, 2015, University of Toyama, Japan

- Home
- Program
- Slides
- Abstract Submission
- Registration
- Participants
- Social Events
- Accommodations
- Venue
- Practical Info
- Proceedings
- Contact
- Grants

Welcome to HPNP2015

The 2nd Toyama International Workshop on
"Higgs as a Probe of New Physics 2015" (HPNP2015)
will be hosted by the University of Toyama.
The workshop will be held from February 11-15, 2015 on
the Gofuku Campus of the University of Toyama, Toyama, Japan

On July 4th, 2012, the CERN Large Hadron Collider (LHC) reported
the discovery of a new particle consistent with the Higgs boson,
which is the origin of mass in our world as well as a window to physics at the terascale.
The aim of this workshop is to bring together Higgs hunters from around the world to discuss
the relation between Higgs physics and models beyond the Standard Model.

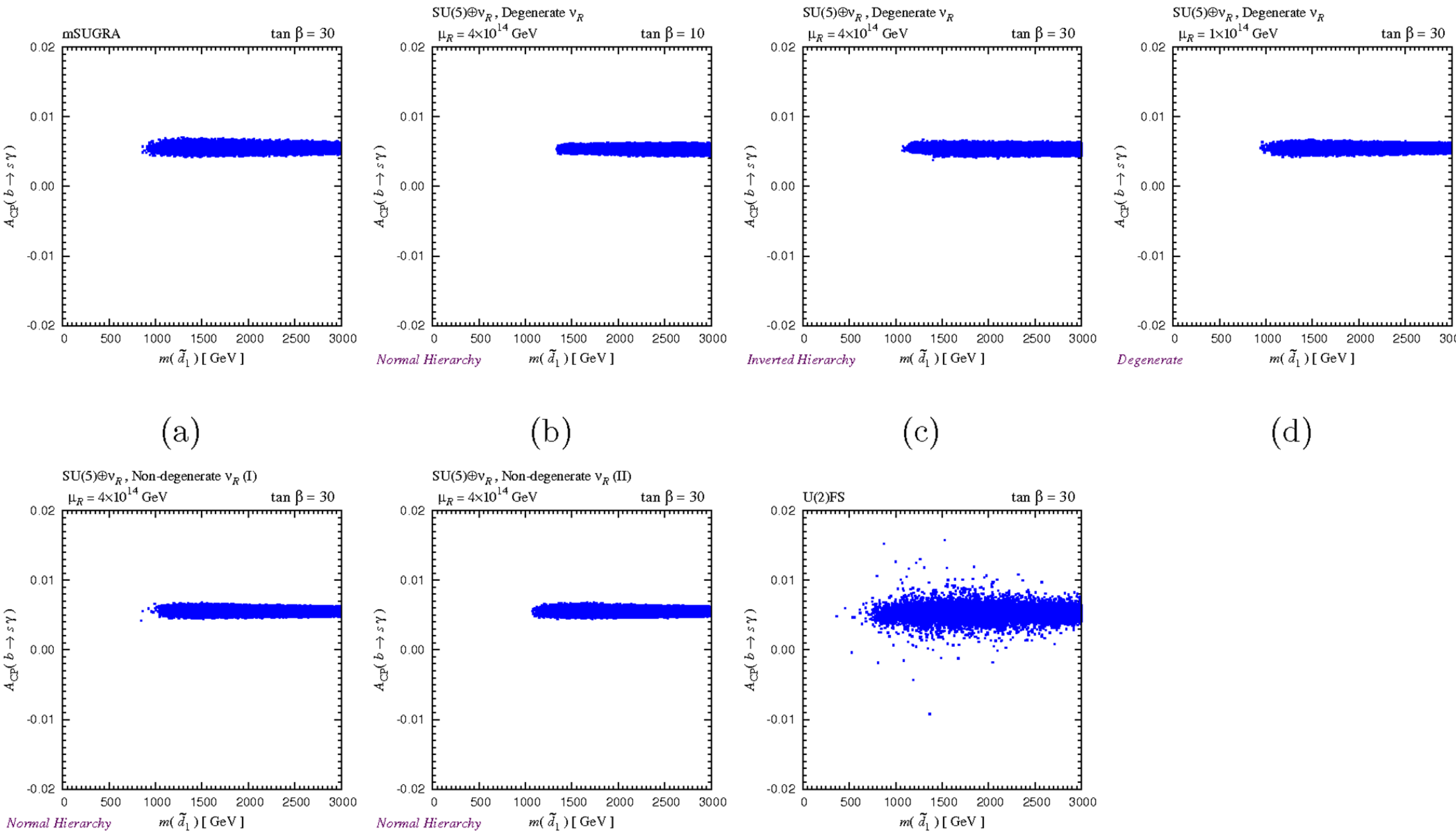
Important Dates

- **Registration will begin in September 2014.**
- **November 11, 2014: Deadline for Abstract Submission**
- **December 11, 2014: Deadline for Registration**

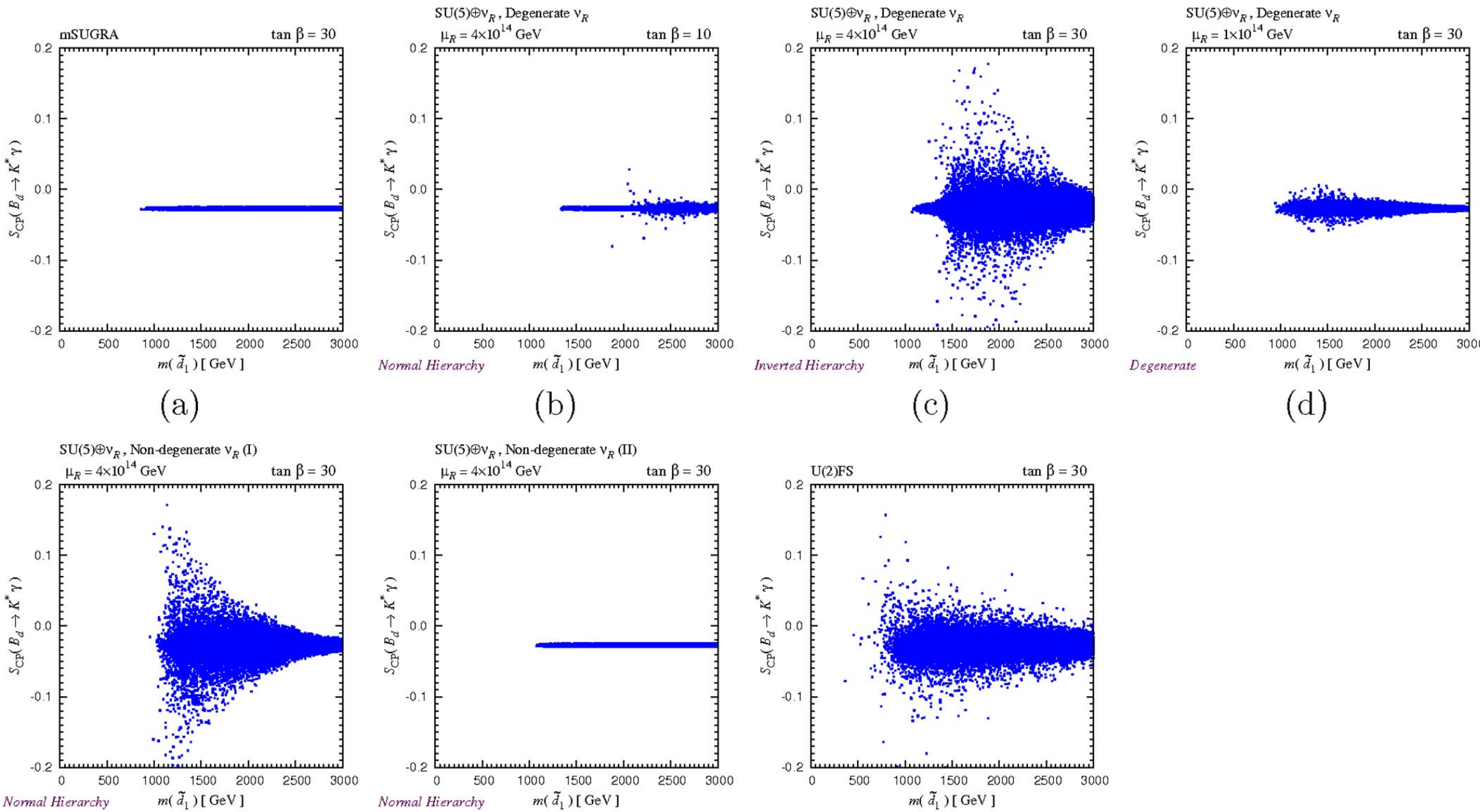
POSTER (PDF)

Backup slides

Goto, Okada,T.S, Tanaka, PRD77,095010



Goto, Okada,T.S, Tanaka, PRD77,095010



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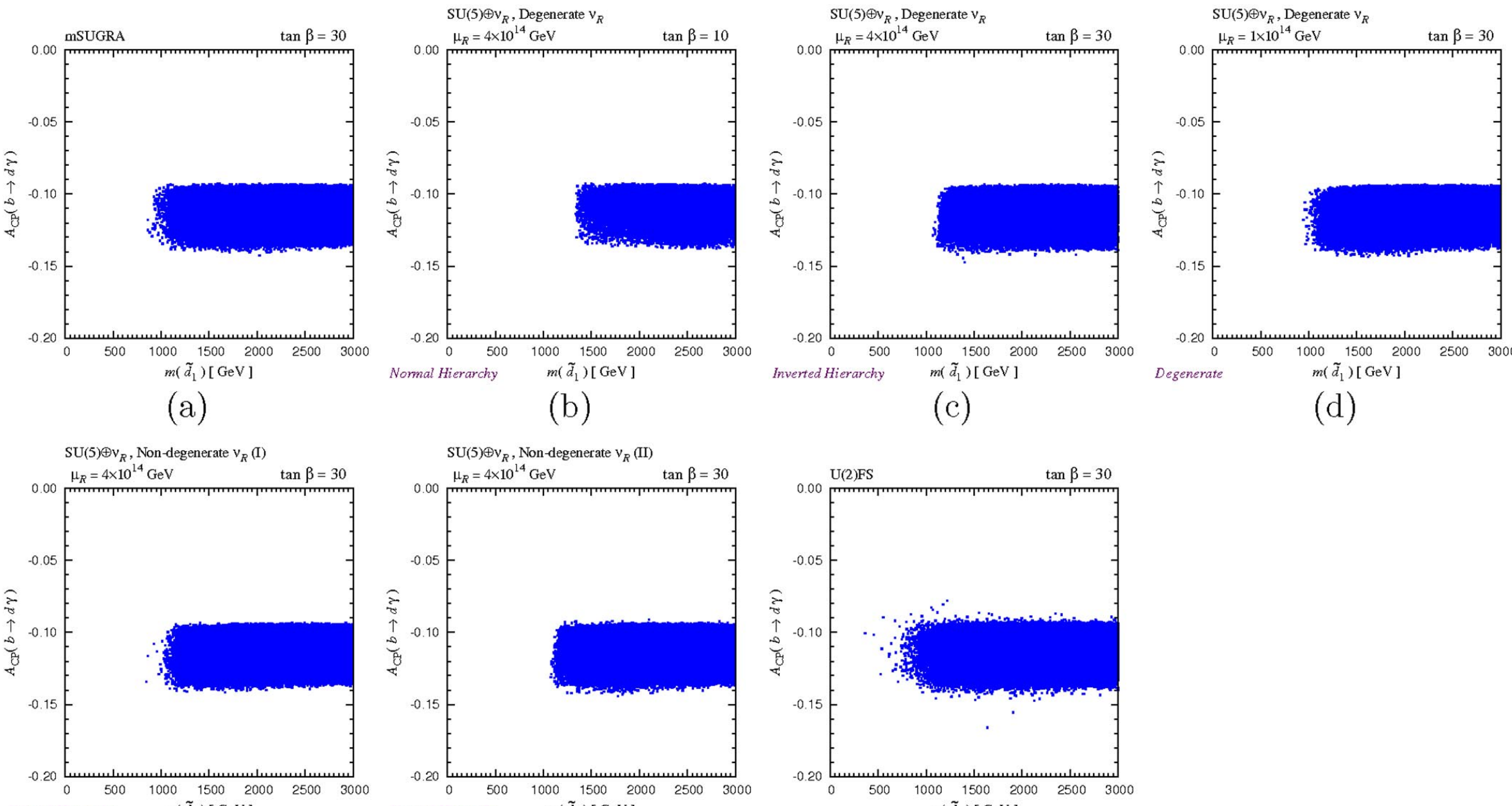

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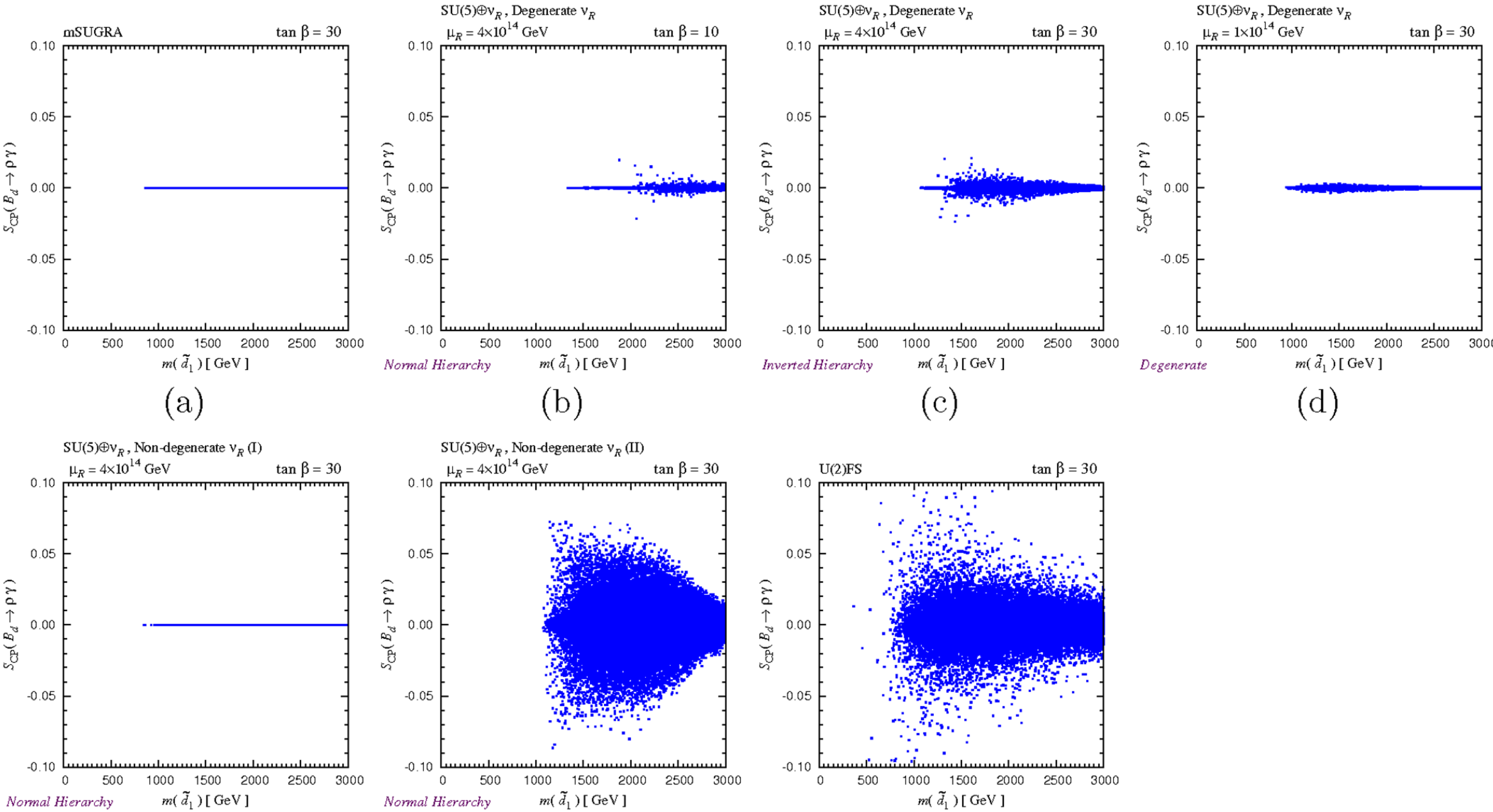

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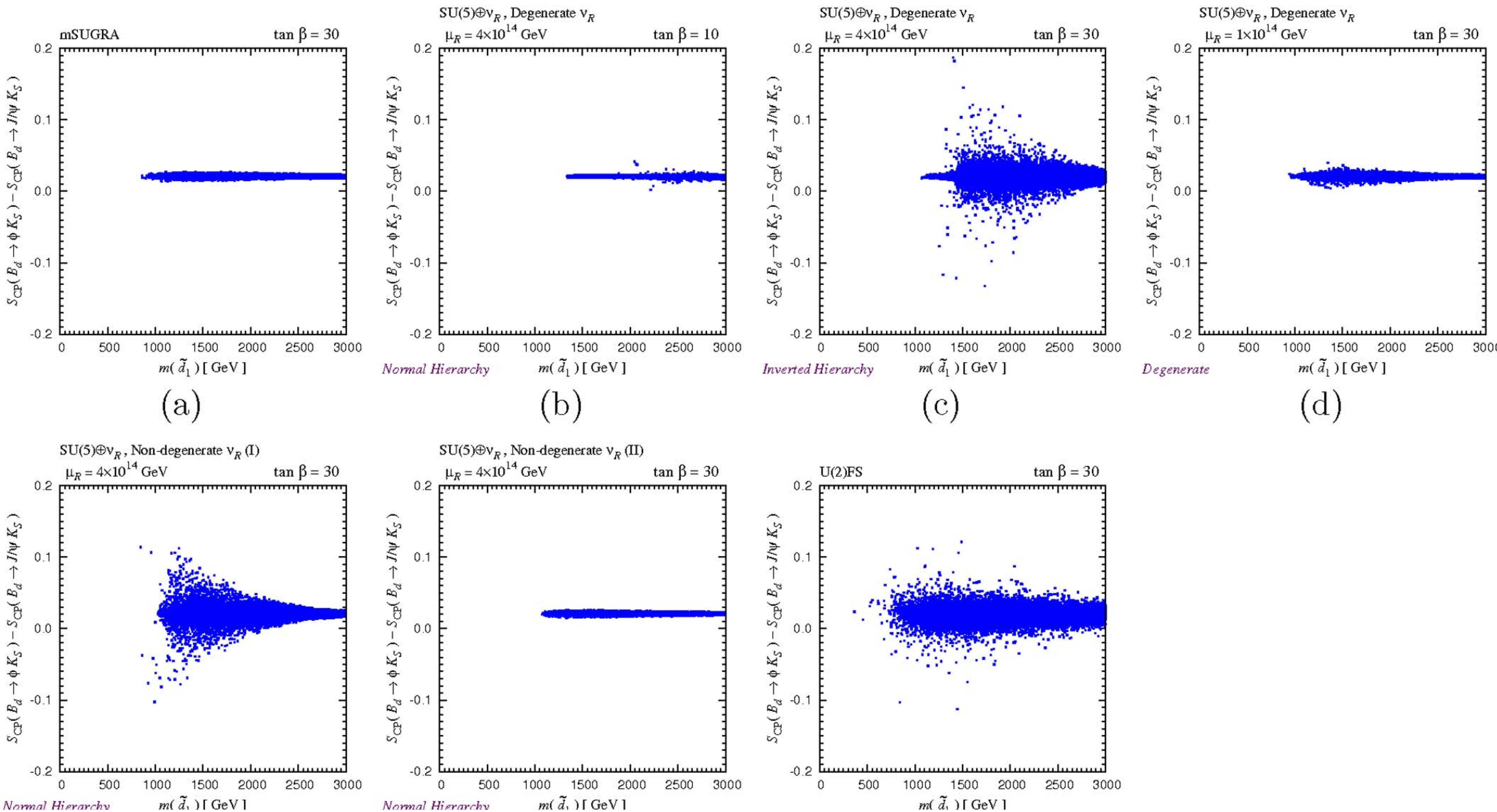

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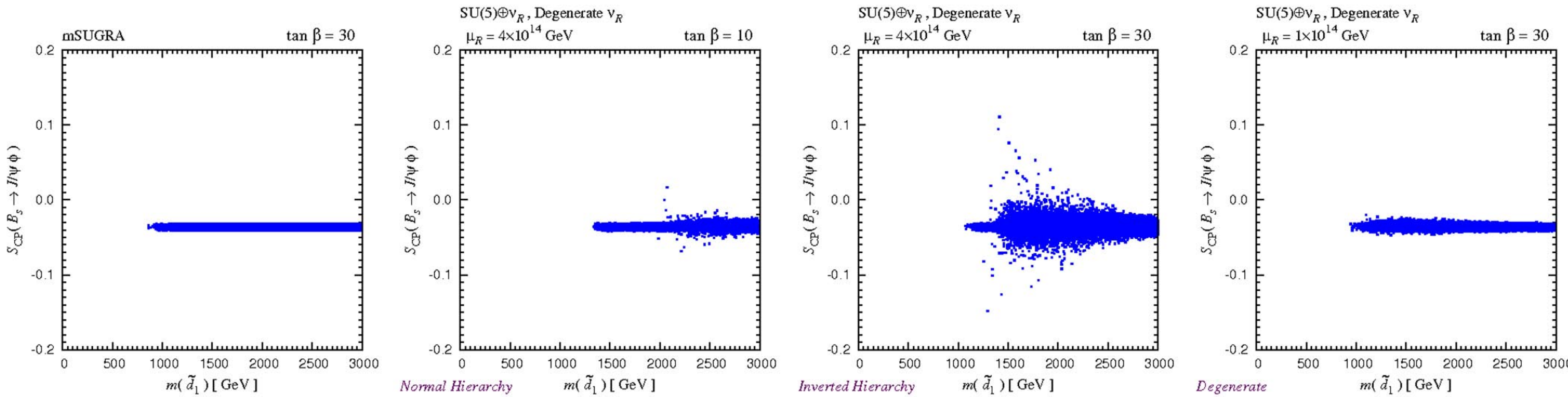

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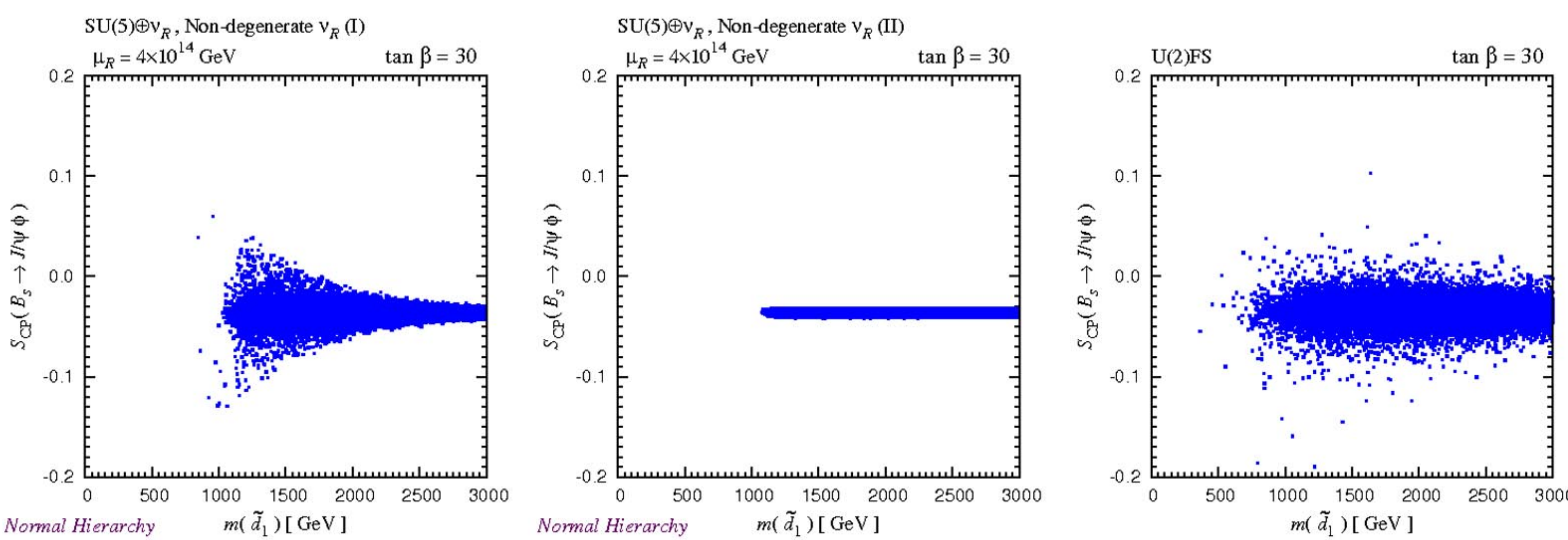

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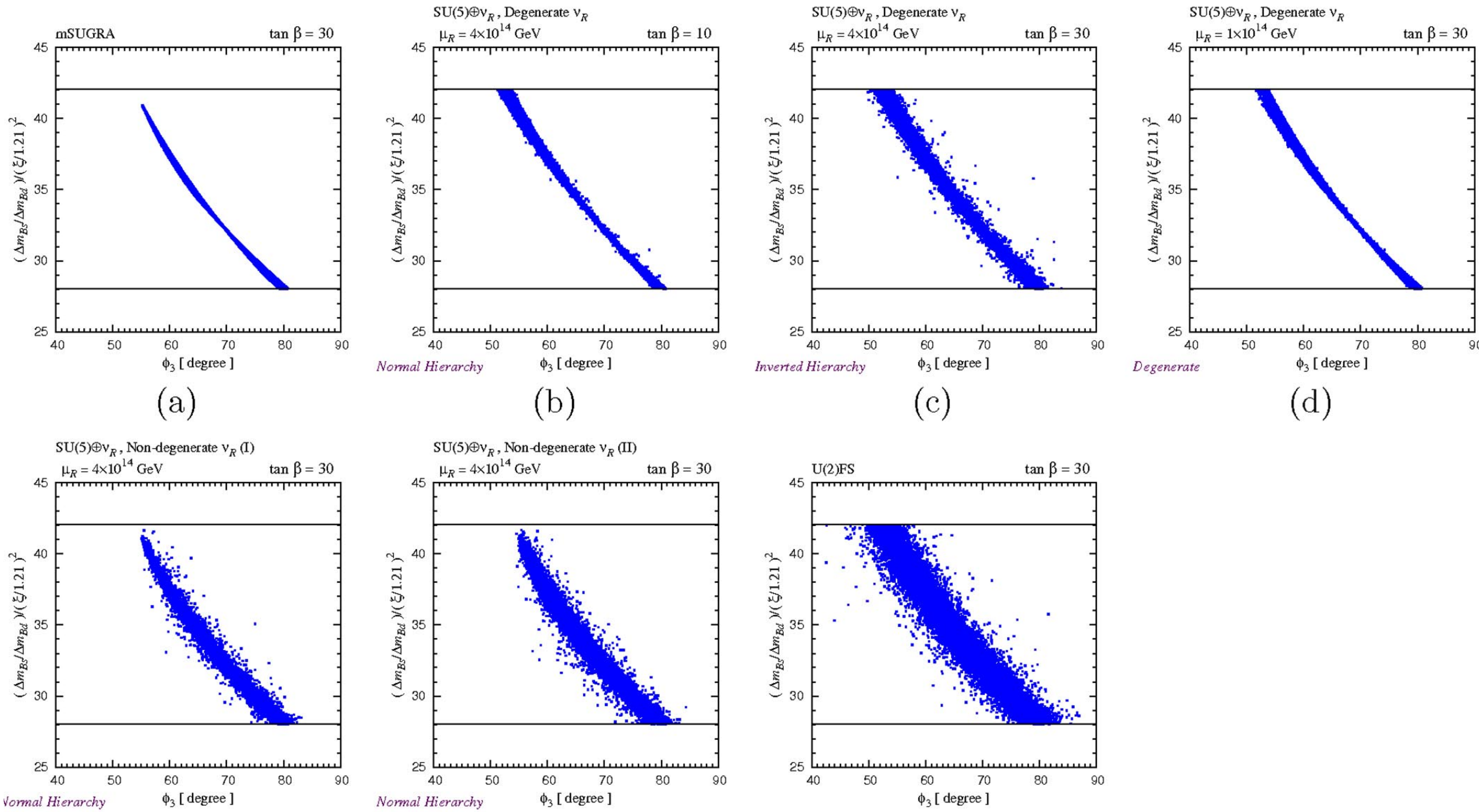

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