Flavor Probes of New Physics

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National Taiwan University

Outline

I. BEAUTY & the BEACH — Whither the LHC

B_s & $B_d \to \mu^+\mu^-$ / φ_s / P_5'

$\hookrightarrow Z'$

II. B Factory Legacy: $B \to D^{(*)}\tau\nu$ "BaBar anomaly"

Comment(s) / $B \to \mu\nu$ $\hookrightarrow$ 2HDM-III

III. Top & Higgs: the New Flavor Frontier

$t \to cH$ ($H \to tc$) / $t \to cZ$ / $t \to cZ'$ (?) $H \to \mu\tau$

IV. Kaon: the Oldest Frontier

$K^+ \to \pi^+\nu\nu$ vs $K_L \to \pi^0\nu\nu$ ← possible KOTO surprise

V. Final Comments: BNV(-top); Origin of Flavor / BAU

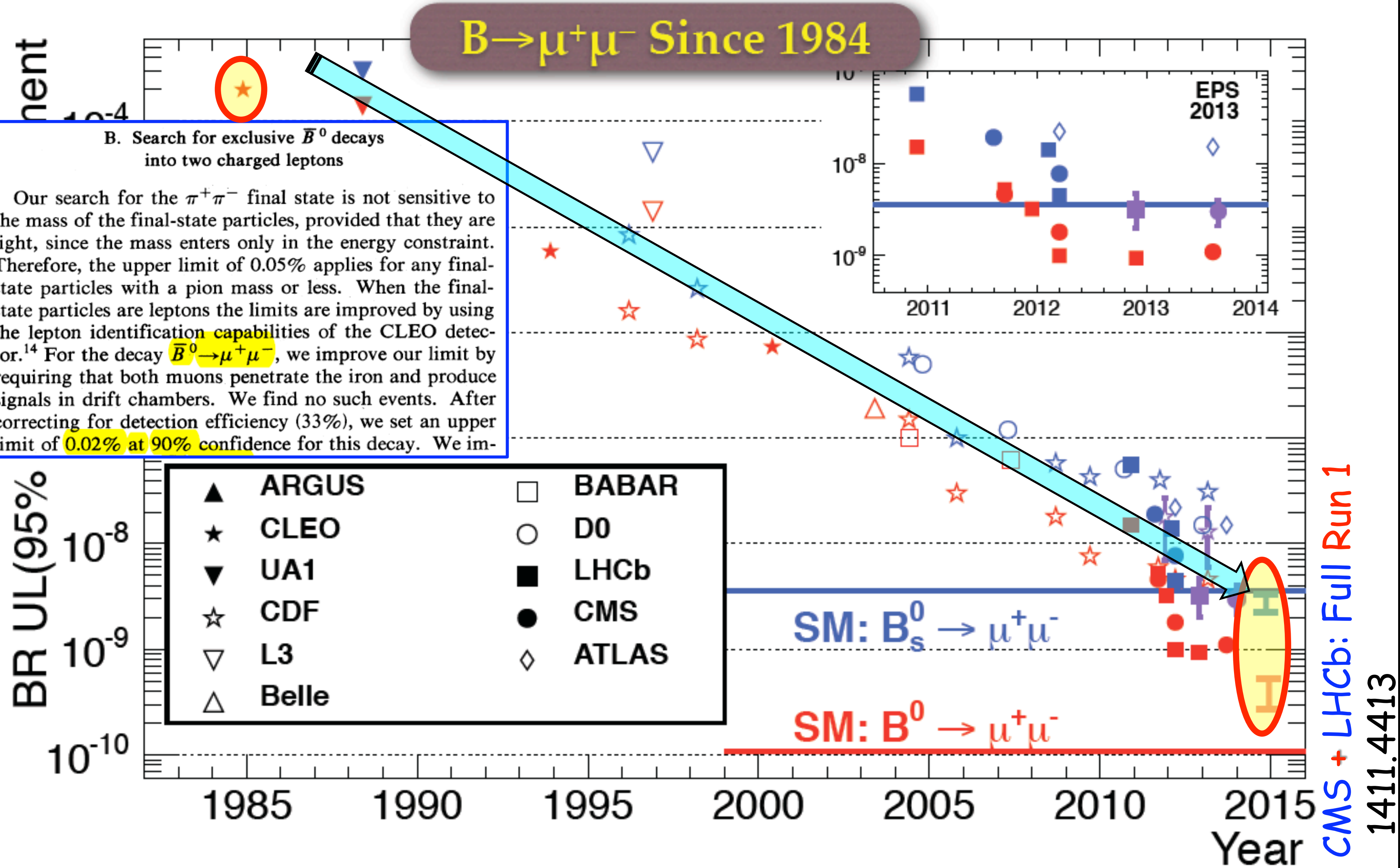
VI. Flavor Probes of NP during Run 2

LHCb: flavor powerhouse since LHC turn-on (trailed by **CMS**)

I. Beauty and the BEACH – Whither the LHC

- B_s & $B_d \to \mu^+\mu^-$ 2013, 2014
- φ_s 2013, 2014
- P_5' 2013, 2015

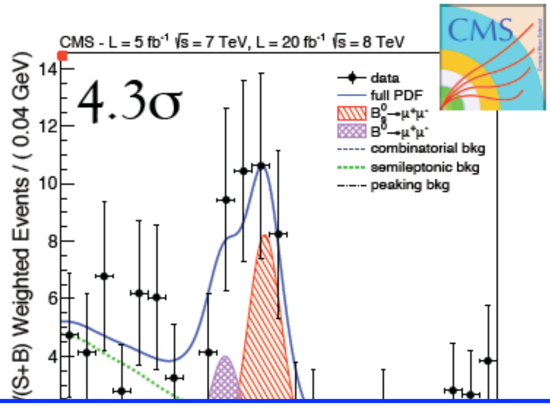
B_s & $B_d \to \mu^+\mu^-$

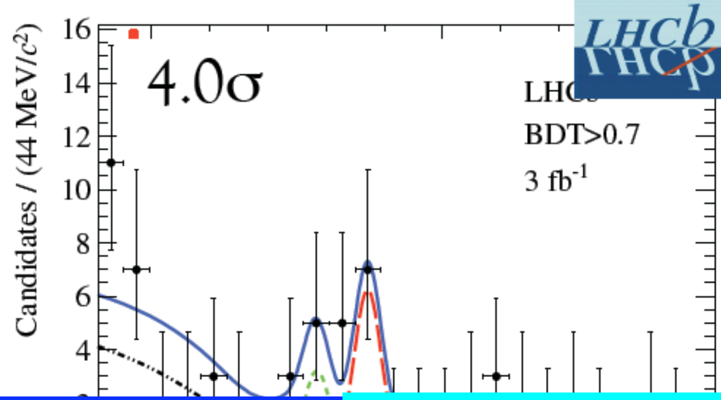

B→μ+μ- Since 1984
B. Search for exclusive $\overline{B}^0$ decays into two charged leptons
Our search for the $\pi^+\pi^-$ final state is not sensitive to the mass of the final-state particles, provided that they are light, since the mass enters only in the energy constraint. Therefore, the upper limit of 0.05% applies for any final-state particles with a pion mass or less. When the final-state particles are leptons the limits are improved by using the lepton identification capabilities of the CLEO detector.[14] For the decay $\overline{B}^0 \to \mu^+\mu^-$, we improve our limit by requiring that both muons penetrate the iron and produce signals in drift chambers. We find no such events. After correcting for detection efficiency (33%), we set an upper limit of 0.02% at 90% confidence for this decay. We im-
EPS 2013
ARGUS
CLEO
UA1
CDF
L3
Belle
BABAR
D0
LHCb
CMS
ATLAS
BR UL(95%
10^{-4}
10^{-8}
10^{-9}
10^{-10}
SM: $B_s^0 \to \mu^+\mu^-$
SM: $B^0 \to \mu^+\mu^-$
1985
1990
1995
2000
2005
2010
2015
Year
2011
2012
2013
2014
CMS + LHCb: Full Run 1
1411.4413

B_s & $B_d \to \mu^+\mu^-$

Full CMS + LHCb combination took … > a year

PRL 111 (2013) 101804





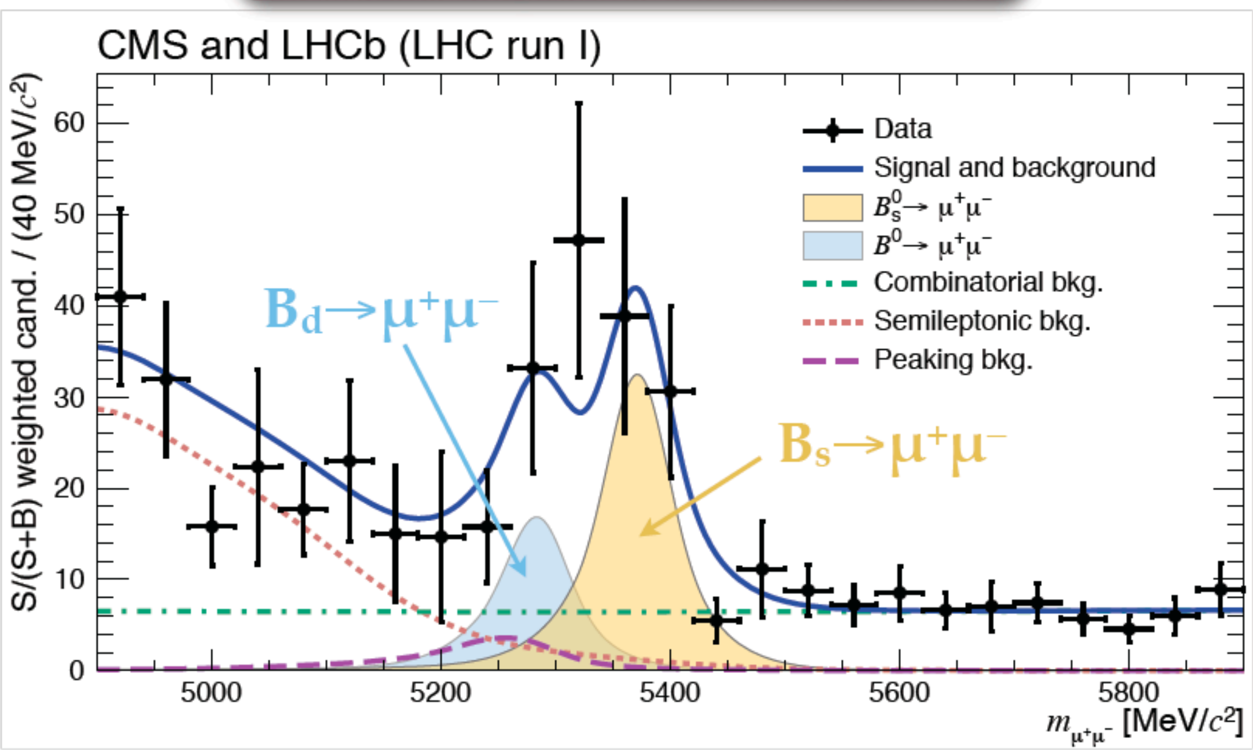
LHCb PRL 111 (2013) 1

CMS + LHCb: Full Run 1

1411.4413 → *Nature* this wk

6.2σ (7.4σ expected)

S/(S+B) weighted mass from 20 bins



Channel	Branching fraction
$B_s \to \mu^+\mu^-$	$(2.8^{+0.7}_{-0.6})\times 10^{-9}$
$B_d \to \mu^+\mu^-$	$(3.9^{+1.6}_{-1.4})\times 10^{-10}$

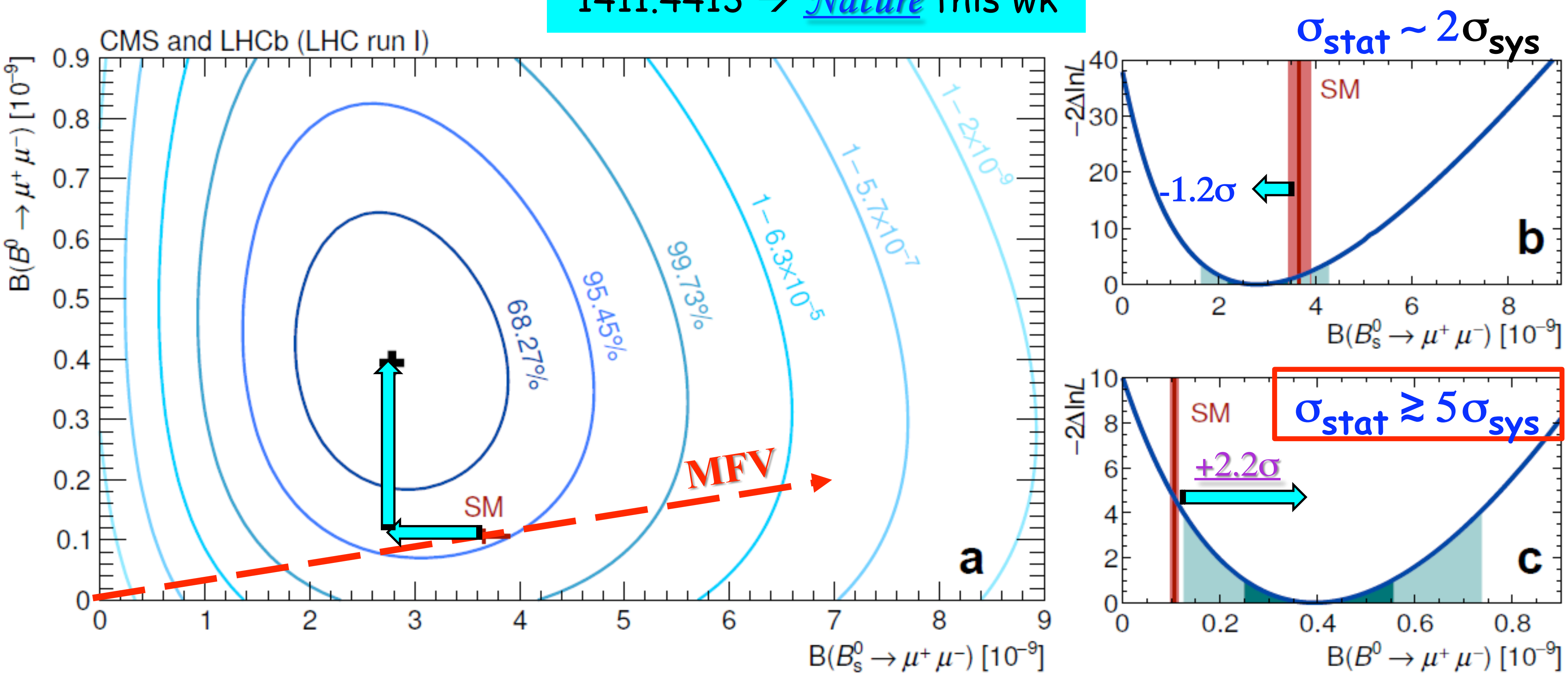
The uncertainties for both channels are reduced dramatically with the combined fit!

B_s & $B_d \to \mu^+\mu^-$

To Be Watched

CMS + LHCb: Full Run 1

1411.4413 → *Nature* this wk



~ 3.7 x SM

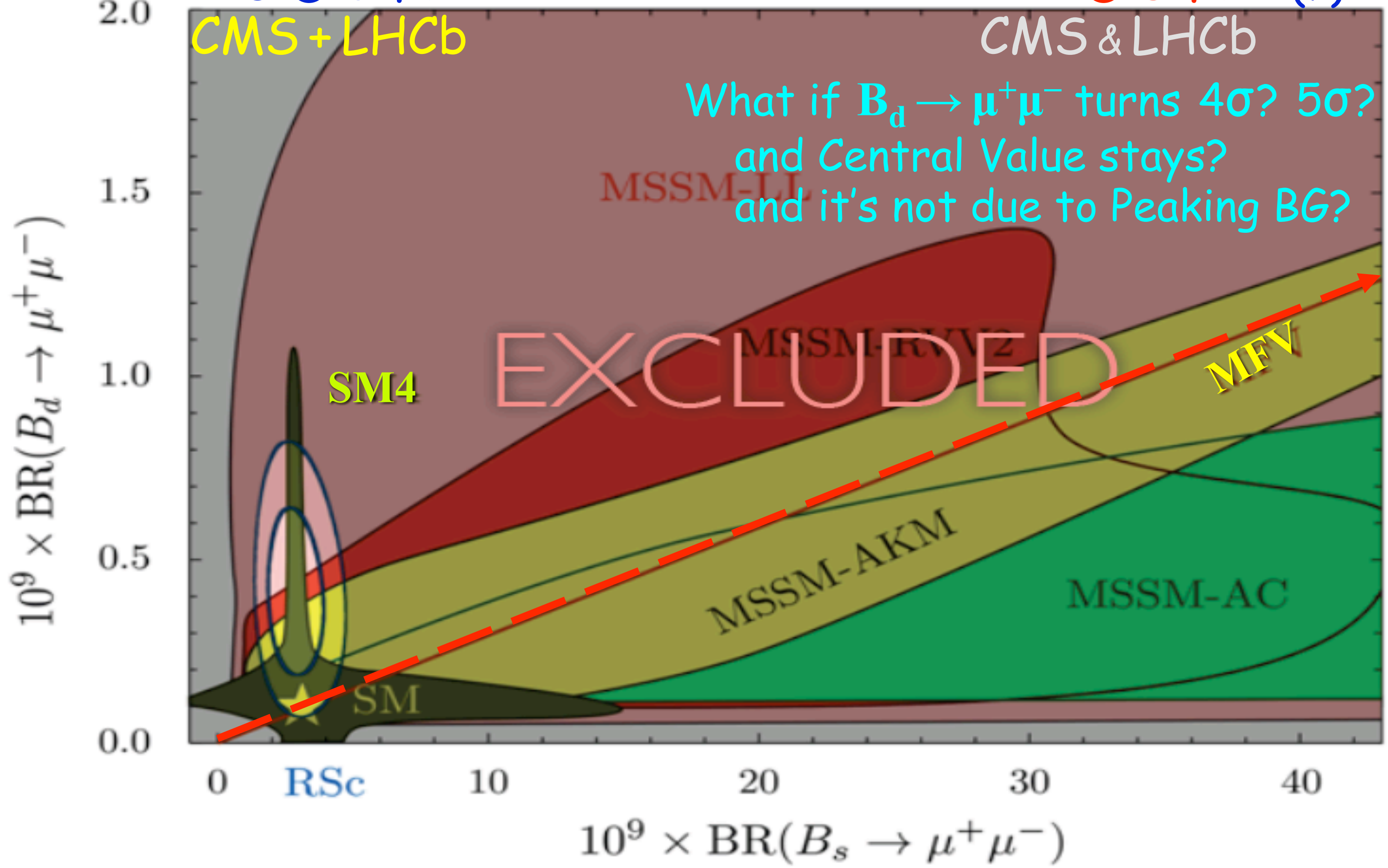
But: Peaking BG

MFV: Minimal Flavor Violation (only CKM as source)

hep-ph/0007085; hep-ph/0207036; 0807.5039 etc.

2014 → 2016? → 2017/18?

$25 \oplus 3\ \text{fb}^{-1}$ ~ $100 \oplus 8\ \text{fb}^{-1}$ (?)



"Challenge to Mimura san": find a model where $B_d \to \mu^+\mu^-$ is 3x SM!

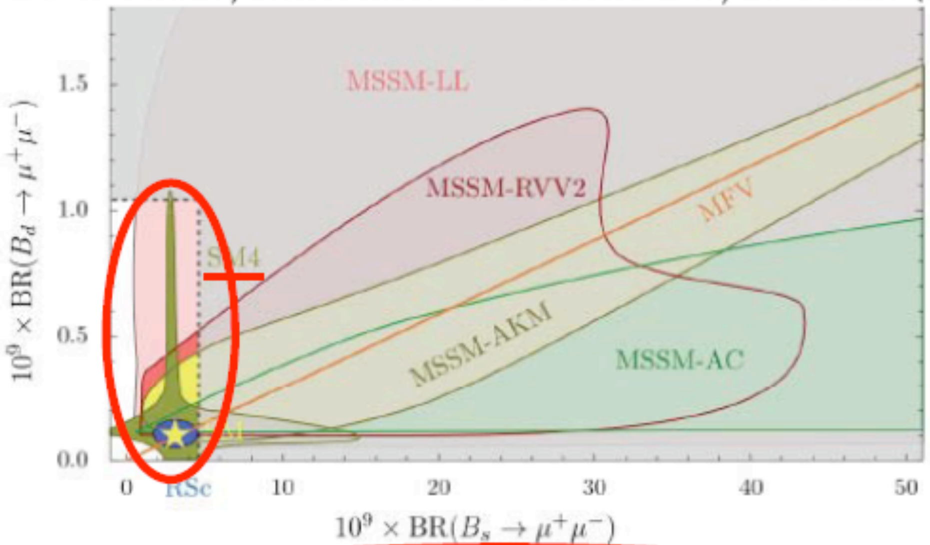
Disappointment: No New Physics

the $\sin\phi_s$ destroyer-of-hope …

Sheldon Stone @ ICHEP2012

Implications II

David Straub, Rencontres de Moriond EW, La Thuile (2012)



The 125 GeV Higgs observations kills off 4th generation models as the production cross-section would be 9x larger & decays to $\gamma\gamma$ suppressed

ICHEP, Melbourne, July 9, 2012 39

SM4 "walks" with a cannon ball hole thru …

But, it can do $B_d \to \mu\mu$!

R.I.P.

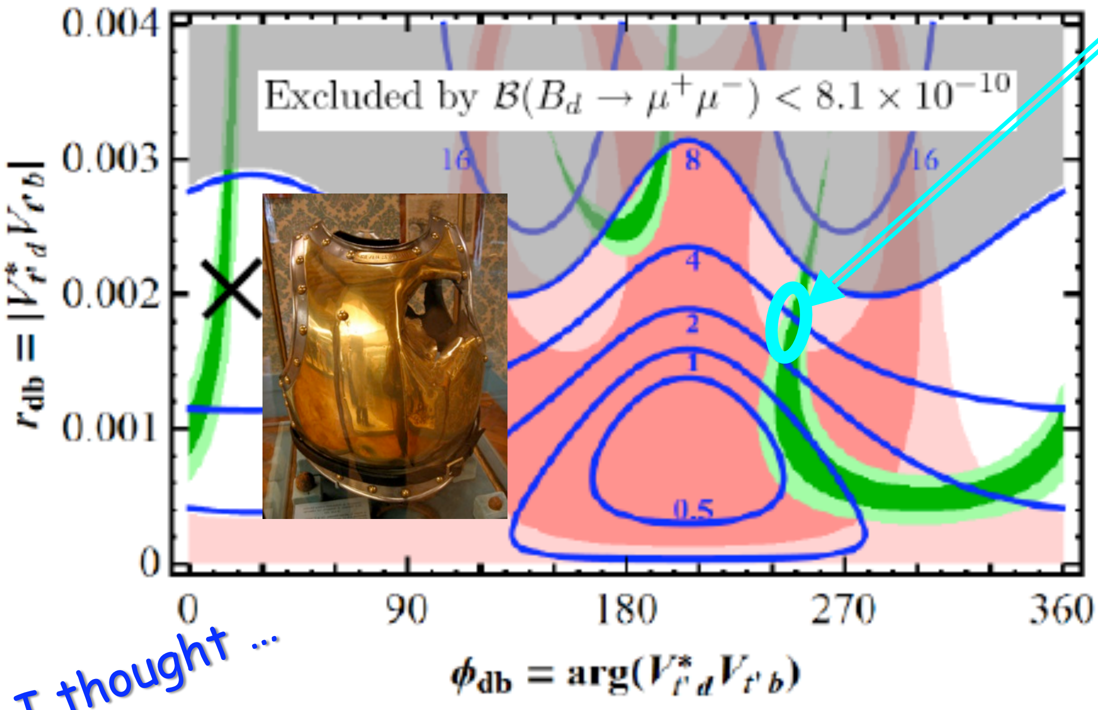
4G回馬槍?!

WSH, Kohda, Xu, PRD 2013

WSH, Kohda, Xu, PRD 2013 [1302.1471]

Allowed region for $\lambda_{t'} = V^*_{t'd} V_{t'b}$

$m_{t'} = 700\ \text{GeV}$ $\quad |V_{ub}|^{\text{ave.}} = 4.15 \times 10^{-3}$



mild tension here

Allowed by $\sin(2\beta/\phi_1)$

$1(2)\sigma$: darker(lighter) green

Allowed by Δm_{B_d}

$1(2)\sigma$: darker(lighter) pink

Or so I thought ...

Any "Mimura Model" will be full of bullet/cannon holes ...

$10^{10} \times \hat{\mathcal{B}}(B_d \to \mu^+\mu^-)$

"Mimura Model"!

(he took the challenge ☺)

New antisymmetric Yukawas

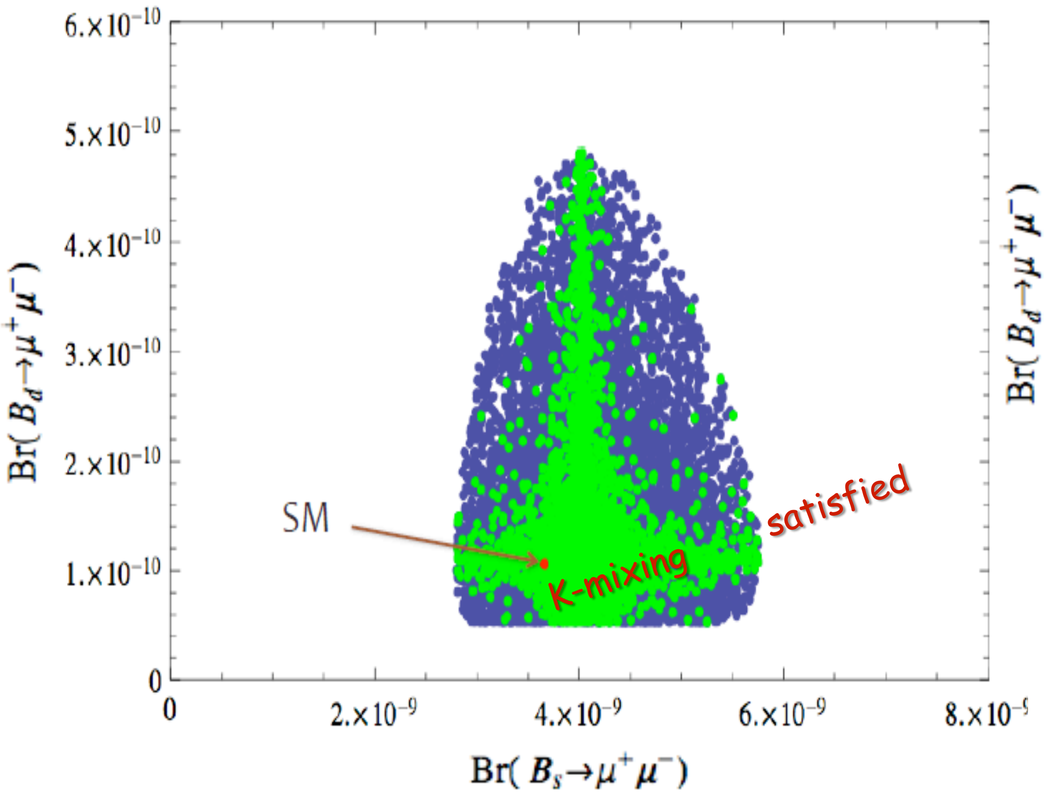
Dutta-Mimura, 1501.02044

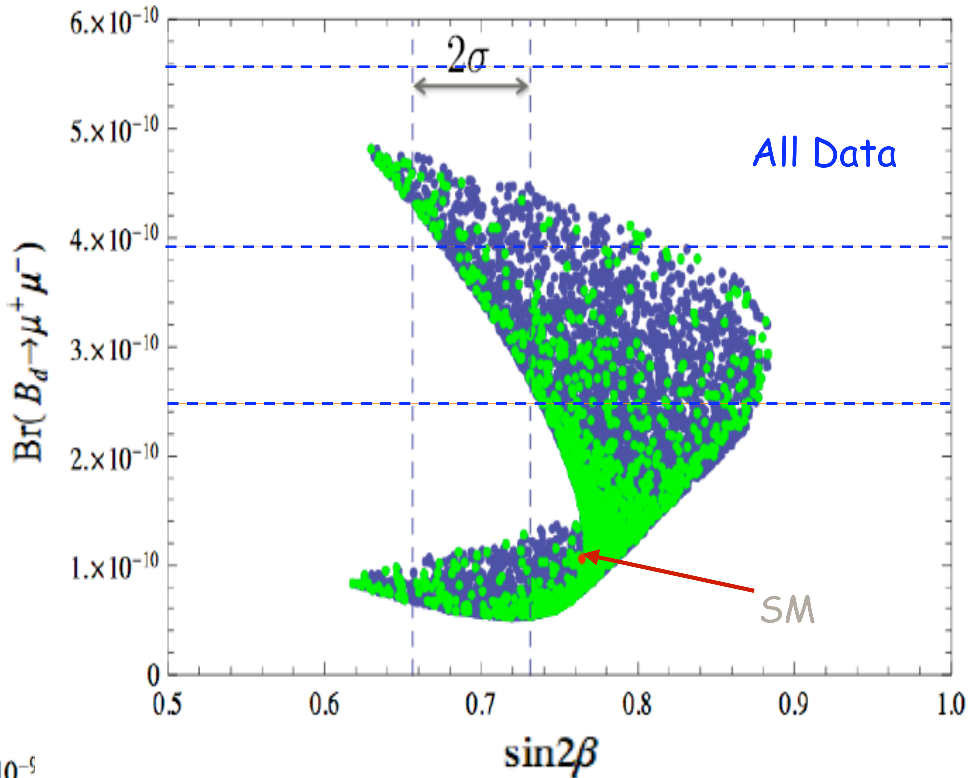
$$YY^\dagger = \begin{pmatrix} 0 & a & -b \\ -a & 0 & c \\ b & -c & 0 \end{pmatrix} \begin{pmatrix} 0 & -a^* & b^* \\ a^* & 0 & -c^* \\ -b^* & c^* & 0 \end{pmatrix}$$

$$= \begin{pmatrix} |a|^2+|b|^2 & -bc^* & -ac^* \\ -b^*c & |a|^2+|c|^2 & -ab^* \\ -a^*c & -a^*b & |b|^2+|c|^2 \end{pmatrix}$$

Can be realized with 45 of SU(5) or 120 of SO(10) SUSY-GUTs

Can have 12 & 23 small leaving 13 !





mild tension

Moral from φ_s

$J/\psi K^+K^-$ LHCb $J/\psi\pi^+\pi^-$

PRL2012, 0.37 fb^{-1}

$$\phi_s = 0.15 \pm 0.18(\text{stat}) \pm 0.06(\text{syst})$$

$$\phi_s = 0.07 \pm 0.09(\text{stat}) \pm 0.01(\text{syst})$$

2013, 1 fb^{-1}

PLB2012, 1 fb^{-1}

$$\phi_s = -0.019^{+0.173+0.004}_{-0.174-0.003}$$

$$\phi_s = -0.14^{+0.17}_{-0.16} \pm 0.01$$

2013, 1 fb^{-1}

— Tagging —

0.00 ± 0.07 PDG'14

$-0.058 \pm 0.049 \pm 0.006$

10/2014, 3 fb^{-1} [@ LHCb Implications Workshop]

1411.3104

$0.070 \pm 0.068 \pm 0.008$

5/2014, 3 fb^{-1}

-0.010 ± 0.039

SM ~ -0.04!

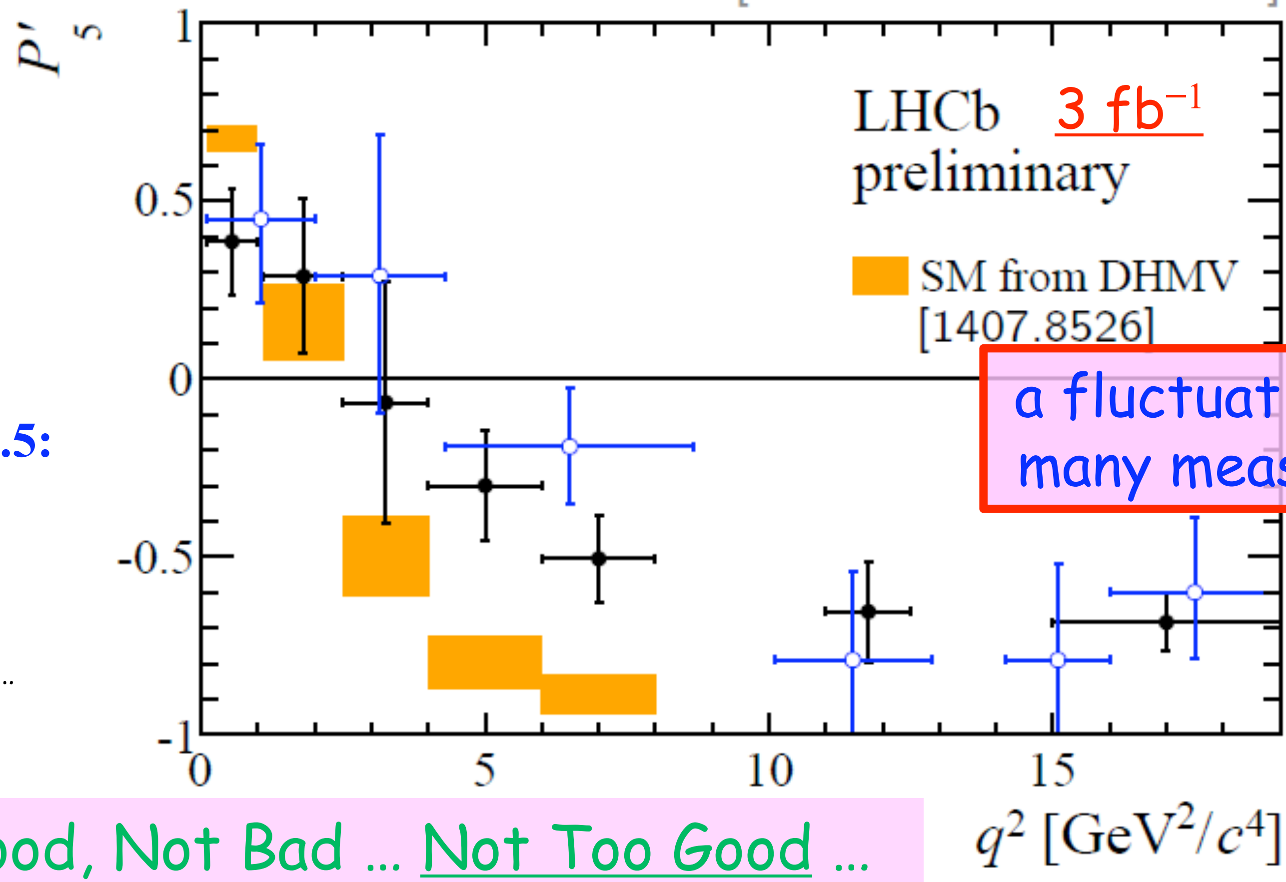
SM sensitivity

"Double Somersault"! ⇨ φ_s Really *Is* Small …

P'_5

C. Langenbruch @ Moriond EW

[LHCb-CONF-2015-002]



a fluctuation among many measurables?

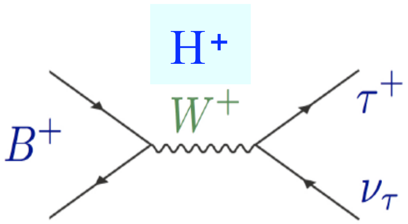
NP? $\Delta C_9 \sim -1.5$: heavy Z'

e.g. 1307.5683; 1308.1501; 1310.2478; 1310.3877; 1310.1082; 1311.6729 ...

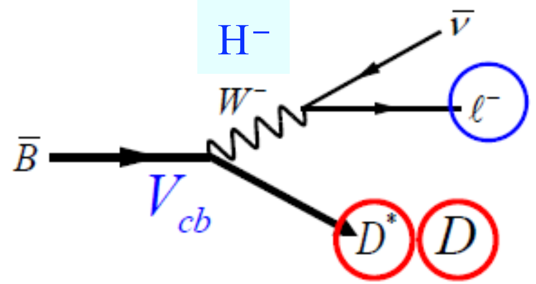
Not Good, Not Bad ... Not Too Good ...

- Tension seen in P'_5 in [PRL 111, 191801 (2013)] confirmed
- $[4.0, 6.0]$ and $[6.0, 8.0]$ GeV$^2/c^4$ show deviations of 2.9σ each
- Naive combination results in a significance of 3.7σ
- Compatible with $1\,\text{fb}^{-1}$ measurement 3.7σ

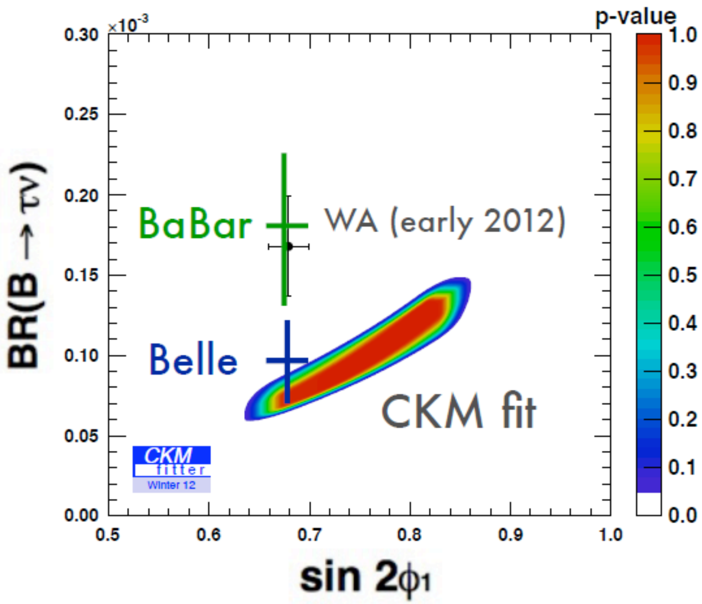
WSH, PRD’93



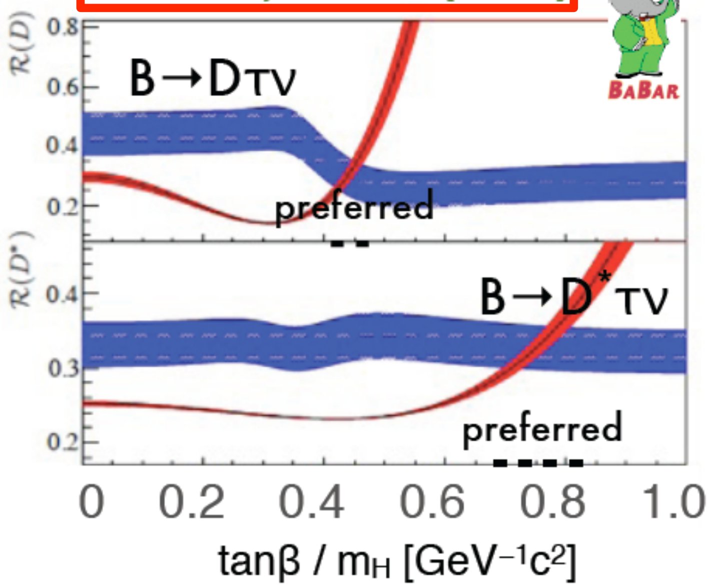
Grządkowski WSH, PLB’92



II. B Factory Legacy: $B \to D^{(*)}\tau\nu$ “BaBar anomaly”

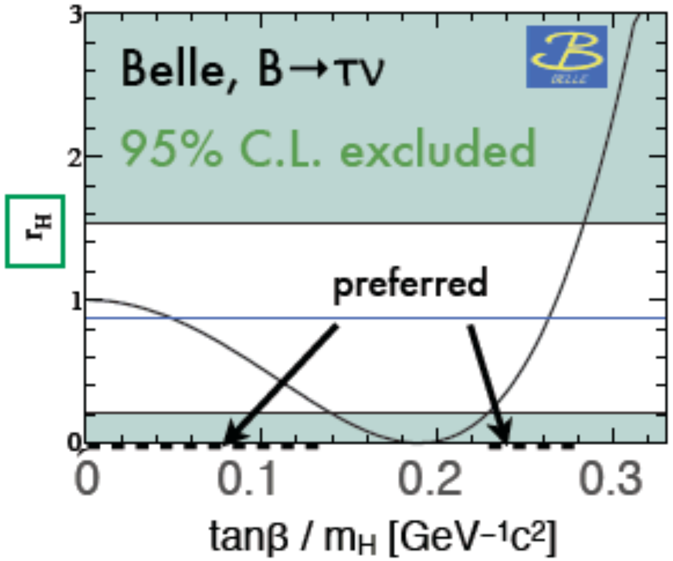


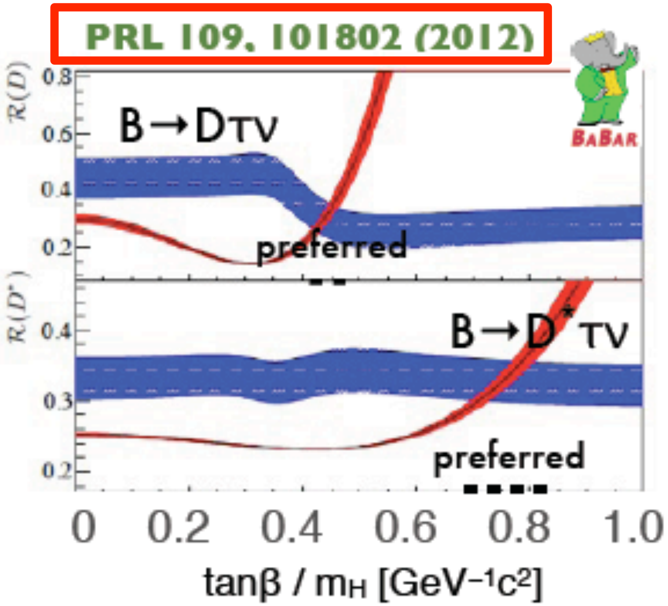
PRL 109, 101802 (2012)



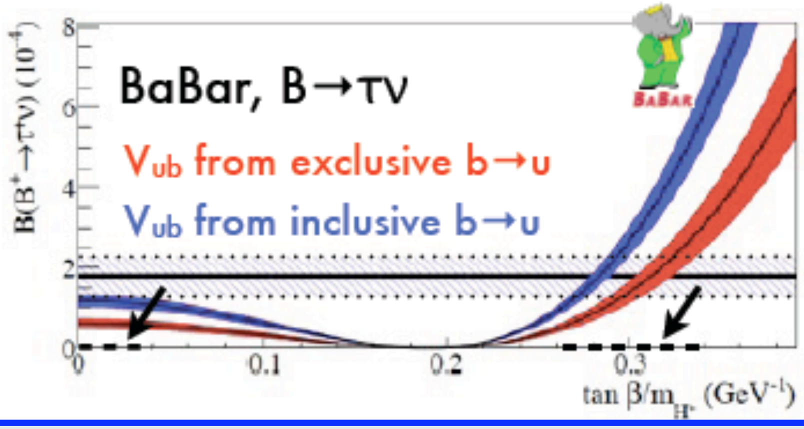
Whither 2HDM-II (MSSM)

$B^+ \to \tau^+\nu_\tau$ compared with $B \to D^{(*)}\tau^+\nu_\tau$





3.4σ dev. from SM



- $B^+ \to \tau^+\nu_\tau$, $D\,\tau^+\nu_\tau$, & $D^*\,\tau^+\nu_\tau$ prefer different regions of $\tan\beta/m_H$
  $\Rightarrow$ *stay tuned for Belle's update on* $B \to D^{(*)}\tau\nu$
- Is Type-II disfavored? … We'll need further studies.

Y. Kwon (Yonsei Univ.) Study of *B* decays with missing-*E* at *B*-factories BEAUTY 2014, July 14, 2014 19

$B \to D^{(*)}\tau\nu$ "BaBar anomaly"

- LHCb people do not "believe" this (since they cannot touch [?])

- Scalar Form Factor? Lattice seem OK (CKM2014) (El-Khadra)

- Belle working on it: Summer 2014? Winter 2015?

  heightened interest if concur with BaBar

$(m_\mu/m_\tau)^2 \times B \to \tau\nu$

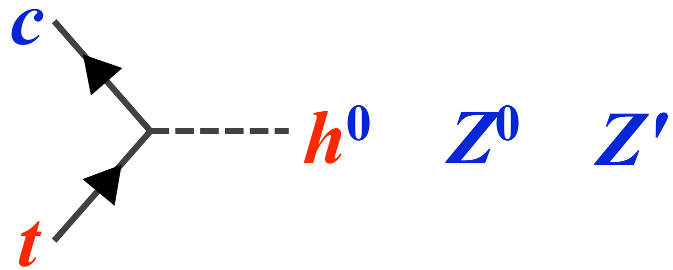
WSH @ FPCP2012, 1207.7275

- $\Gamma(\mu^+\nu_\mu)/\Gamma_{total}$ ~ (0.3-0.4) x 10^{-6} Γ_{28}/Γ

	VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN	COMMENT	
468 M	< 1.0	90	[1] AUBERT	09V	BABR	$e^+e^- \to \Upsilon(4S)$	untagged
	• • • We do not use the following data for averages, fits, limits, etc. • • •						
	<11	90	[1] AUBERT	10E	BABR	$e^+e^- \to \Upsilon(4S)$	
	< 5.6	90	[1] AUBERT	08AD	BABR	$e^+e^- \to \Upsilon(4S)$	full-recon.
277 M	< 1.7	90	[1] SATOYAMA	07	BELL	$e^+e^- \to \Upsilon(4S)$	untagged

$B \to \mu\nu$ can "sense" the H^+ enhancement, with indep. syst.

and Belle 2 early data (2018?)



III. Top & Higgs: the New Flavor Frontier

Tzeng, 8/2014
Recon. du Viet.

Interaction	Model	Result	
Charged Current	$\frac{B(t \to Wb)}{B(t \to Wq)}$	> 0.955 (19.7 fb^{-1} @8 TeV)	Phys. Lett. B 736 (2014) 33 (CMS)
FCNC	t→gc(u)	< 1.6×10^{-4} (3.1×10^{-5}) (14.2 fb^{-1} @8 TeV)	ATLAS CONF-2013-063
	t→γc(u)	<0.182% (0.0161%) (19.1 fb^{-1} @8 TeV)	CMS PAS-TOP-14-003
	t→Zq	< 0.05% (5.0 fb^{-1} + 19.7 fb^{-1} @7 and 8 TeV)	Phys. Rev. Lett. 112 (2014) 171802 (CMS)
	t→Hc(q)	< 0.56% (0.79%) (19.5 fb^{-1} @8 TeV (20.3+4.7 fb^{-1} @8 and 7 TeV))	CMS PAS-HIG-13-034 (ATLAS JHEP06(2014)008)
BNV	t→b u e (or b c μ)	< 0.15% (19.5 fb^{-1} @8 TeV)	Physics Letters B 731 (2014) 173 (CMS)

When Higgs meets Top: $t \to ch^0$ @LHC

2nd Place — Mass — 1st Place

Pro-found if Found

FCNH: verboten in SM
& ~~2HDM I/II~~

Glashow-Weinberg 1977

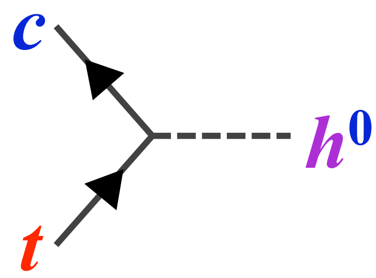
BaBar "Anomaly"

2HDM III?

$$\rho_{ct} \cos(\beta - \alpha)\, \bar{c} t h^0 + \text{h.c.}$$

Yuk.⊗Higgs-mix

Non-mass-giving doublet in general has FC Yukawa's



Physics Letters B 296 (1992) 179–184

Tree level $t \to ch^0$ or $h^0 \to t\bar{c}$ decays

Wei-Shu Hou [1]

Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland

In a third type of two Higgs model where neutral scalar bosons possess flavor changing $u_i u_j h^0$ couplings proportional to $\sqrt{m_i m_j}$, low energy constraints are evaded. With the top as the heaviest fermion, *tree level* flavor changing $t \to ch^0$ or $h^0 \to t\bar{c}$ decays may be competitive with, if not dominant over, the corresponding $t \to bW^*$ or $h^0 \to b\bar{b}$ decays. The CDF limit of $m_t > 91$ GeV may be evaded by the $t \to ch^0$ mode if $m_{h^0} < m_t < M_W$, while the $h^0 \to t\bar{c}$ mode may be useful for the study of intermediate mass Higgs bosons at hadronic supercolliders. The scenario can be distinguished from the existence of exotic quarks since flavor changing Z couplings are absent.

When Higgs meets Top: $t \to ch^0$ @LHC

Mass

Pro-found if Found

FCNH: verboten in SM
& ~~2HDM I/II~~

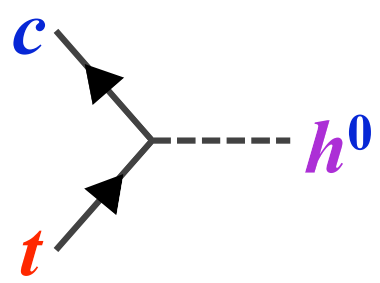
BaBar "Anomaly"

Glashow-Weinberg 1977

2HDM III?

$$\rho_{ct} \cos(\beta - \alpha)\, \bar{c} t h^0 + \text{h.c.}$$

Yuk.⊗Higgs-mix



Chen, WSH, Kao, Kohda, PLB'13

TABLE I. Light Higgs h^0 properties in 2HDM-III with $\rho_{ct} \sim 1$. Widths are in MeV units, with $\Gamma^{\rm SM}_{h^0} \simeq 4.55$ MeV.

	$\mathcal{B}^{\rm SM}$	$\Gamma^{\rm SM}$	Γ	Comment
WW^*	21.5%	0.98	hard to change	$\sin(\beta-\alpha) \simeq 1$
ZZ^*	2.7%	0.12	hard to change	$\sin(\beta-\alpha) \simeq 1$
$\gamma\gamma$	0.24%	0.011	hard to change	W-loop dom.
bb	59.4%	2.70	hard to change	$b \to s\gamma$
$\tau\tau$	5.7%	0.26	within fac. 2	direct
cc	2.6%	0.12	up to $\sim \Gamma_{b\bar{b}}$	not measured ($\rho_{cc} \lesssim 0.2$)
gg	7.7%	0.35	up to fac. 2	$\rho_{tt} \sim 1$

Stringent B Physics
& $H \to \tau\tau$ Constraints

Decouple from
BaBar "Anomaly" (!)

Upshot: ρ_{cc}, ρ_{ct}
ρ_{tc}, ρ_{tt}

New Sector to be probed at the LHC

tCNH

Interaction	Model	Result	
Charged Current	$\frac{B(t\to Wb)}{B(t\to Wq)}$	> 0.955 (19.7 fb^{-1} @8 TeV)	Phys. Lett. B 736 (2014) 33 (CMS)
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	$t\to\gamma c(u)$	<0.182% (0.0161%) (19.1 fb^{-1} @8 TeV)	CMS PAS-TOP-14-003
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BNV	$t\to b\,u\,e$ (or $b\,c\,\mu$)	< 0.15% (19.5 fb^{-1} @8 TeV)	Physics Letters B 731 (2014) 173 (CMS)

Other

ATLAS: $H\to\gamma\gamma$
CMS: multi-ℓ

Further dedicated studies ongoing

Sub-% a year after discovery!

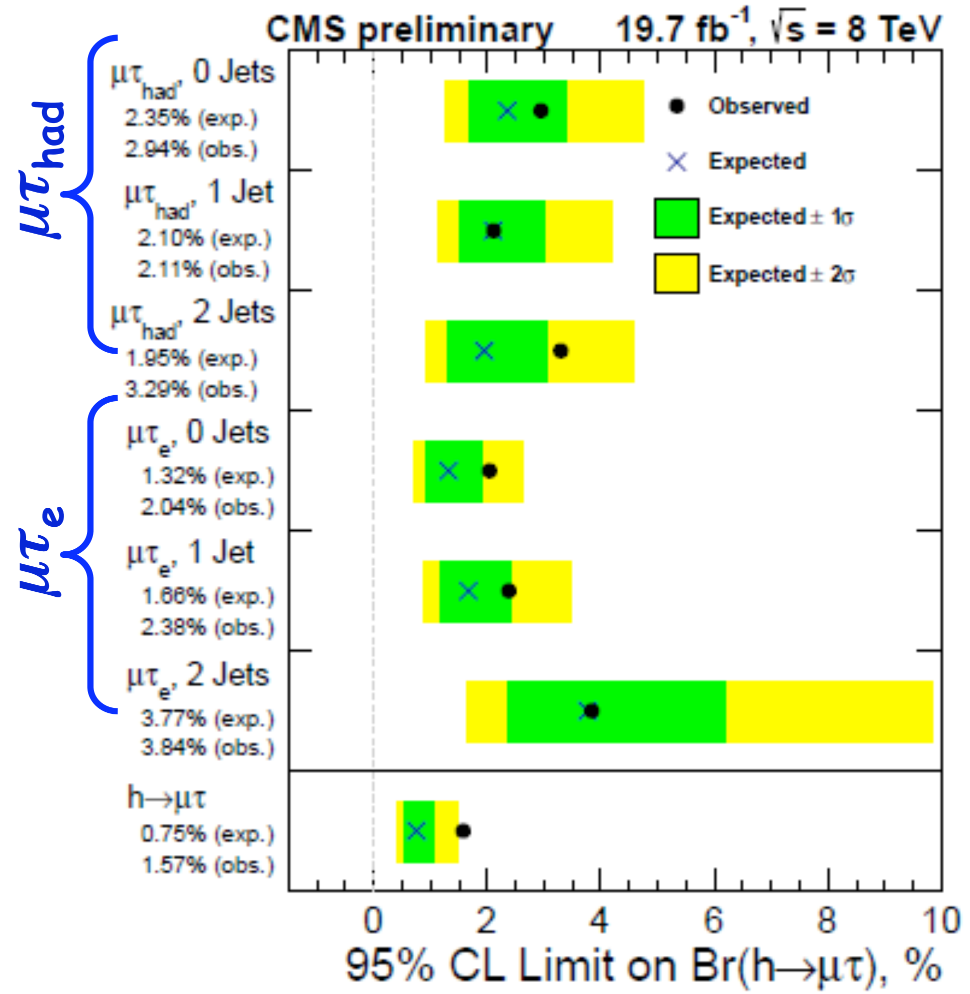
$$H^0, A^0 \to t\bar{c} + \bar{t}c$$

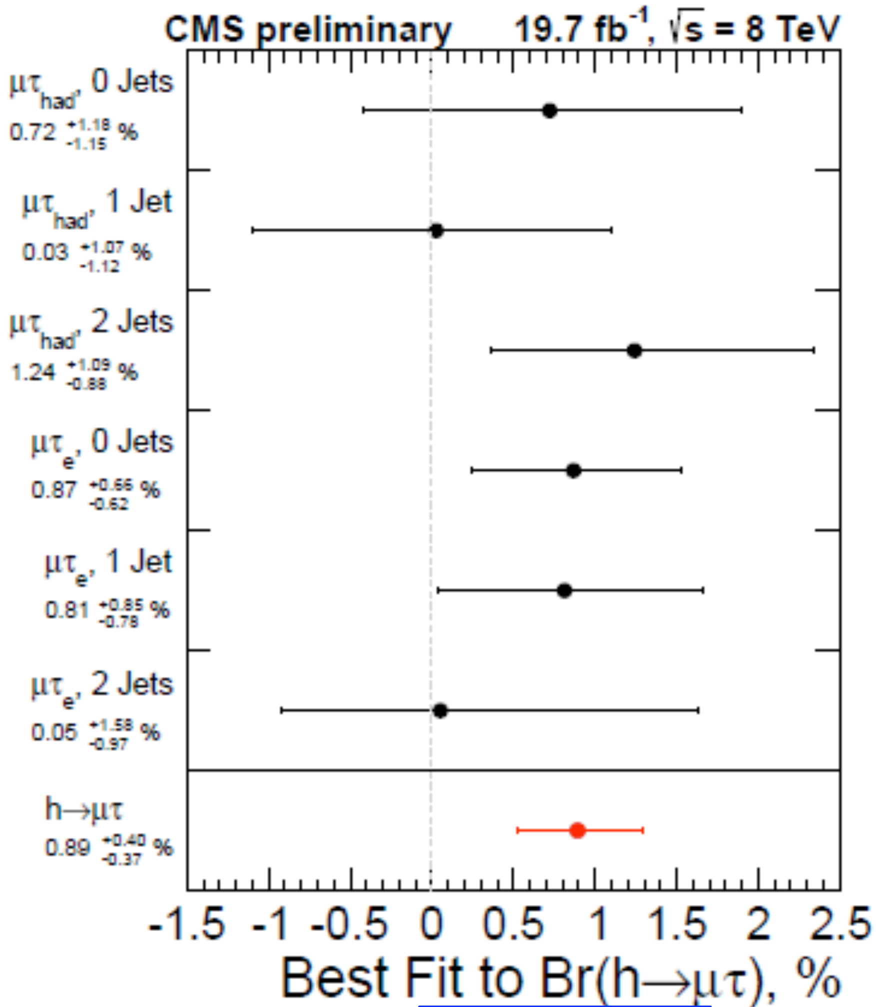
to appear, Altunkaynak, WSH, Kao, Kohda, Mccoy

τCNH: $h \to \mu\tau$

2.5σ excess

CMS PAS HIG-14-005





$$(0.89^{+0.40}_{-0.37})\%$$

τCNH: $h \to \mu\tau$

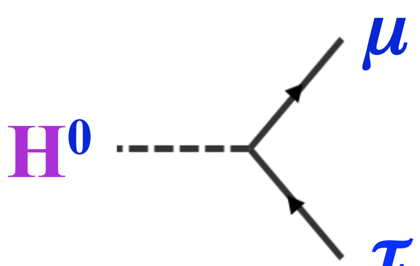
Caution: h-H mixing suppressed

2.5σ excess

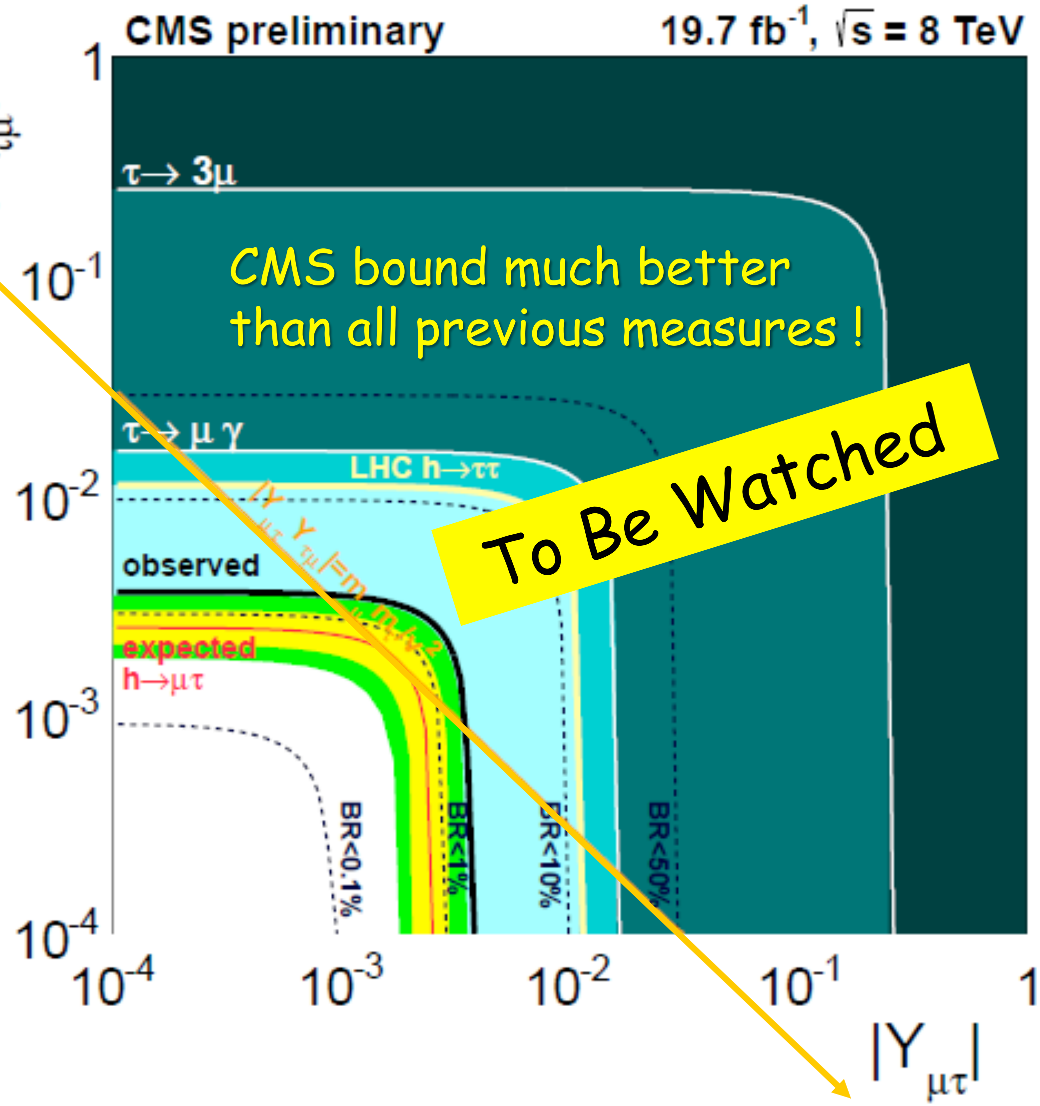
CMS PAS HIG-14-005

"Cheng-Sher" Ansatz

$m_\mu m_\tau / v^2$



$$\begin{matrix} Y_{\mu\mu} & Y_{\mu\tau} \\ Y_{\tau\mu} & Y_{\tau\tau} \end{matrix}$$



Motivated by
Harnik, Kopp, Zupan, JHEP'13

tCNC

"Challenge to Mimura san" #2: find a model where $t \to cZ > \underline{10^{-4}}$!

Some motivation from P'_5 (w/ VLQ) $t \to cZ'$?

Altmannshofer et al., 1403.1269

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	t→γc(u)	<0.182% (0.0161%) (19.1 fb⁻¹ @8 TeV)	CMS PAS
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BNV	t→b u e (or b c μ)	< 0.15% (19.5 fb⁻¹ @8 TeV)	Physics Letters B 731 (2014) 173 (CMS)

Other

... such as warped extra dimensions. Our limit can be translated into a constraint on the KK gluon to be heavier than 1.1 TeV [9].

Agashe, Perez, Soni, PRD'07

$$\mathrm{BR}(t \to cZ) \sim 10^{-5} \left(\frac{700}{M_*}\right)^4$$

Top Compositeness

Azatov, Panico, Perez, Soreq, JHEP2014

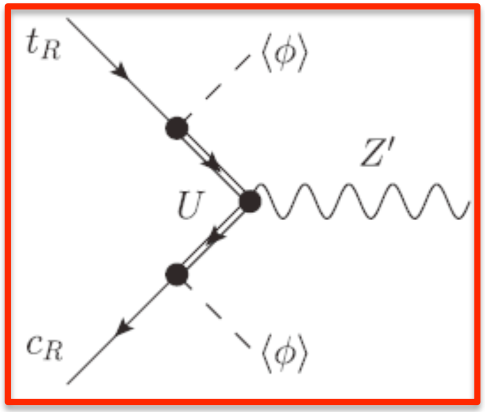
P_5'-motivated Z' induces $t \to cZ'$ also

ALTMANN ... PHYSICAL REVIEW D 89, 095033 (2014)

$$\delta_{Qq} \equiv \frac{Y_{Qq} v_\Phi}{\sqrt{2} m_Q}, \quad \delta_{\mathcal{U}q} \equiv \frac{Y_{\mathcal{U}q} v_\Phi}{\sqrt{2} m_{\mathcal{U}}} \quad (q = t, c).$$

recast the branching ratio as

$$\mathcal{B}(t \to cZ') \simeq \frac{(1-x')^2(1+2x')}{2(1-x)^2(1+2x)} \frac{v^2}{v_\Phi^2} \times \left(|\delta_{\mathcal{U}t} \delta^*_{\mathcal{U}c}|^2 + |\delta_{Qt} \delta^*_{Qc}|^2 \right)$$



Fuyuto
WSH
Kohda, 1412.4397

$$\mathrm{BR}(t \to Z'c) \simeq \frac{2(1-x')^2(1+2x')}{(1-x)^2(1+2x)} \times \left(|Y_{Q_t} Y^*_{Q_c}|^2 \frac{v^2 v_\Phi^2}{4m_Q^4} + |Y_{U_t} Y^*_{U_c}|^2 \frac{v^2 v_\Phi^2}{4m_U^4} \right)$$

$$x = \frac{m_W^2}{m_t^2}, \qquad x' = \frac{m_{Z'}^2}{m_t^2}$$

"unconstrained"

⇒ **Should Search for $t \to cZ' \to c\mu^+\mu^-$**

$\delta \simeq \lambda,\ \mathcal{B}(t \to cZ') \lesssim 0.8 \times 10^{-4}$

$Z' \to \mu^+\mu^-$
BR ~ 1/3!
"gauged $L_\mu - L_\tau$"

IV. Kaon: the Oldest Frontier

$K^+ \rightarrow \pi^+\nu\nu$ vs $K_L \rightarrow \pi^0\nu\nu$

possible KOTO surprise

and more …

Fuyoto, WSH, Kohda, 1412.4397

Linking Leptonic Z' to Muon g – 2

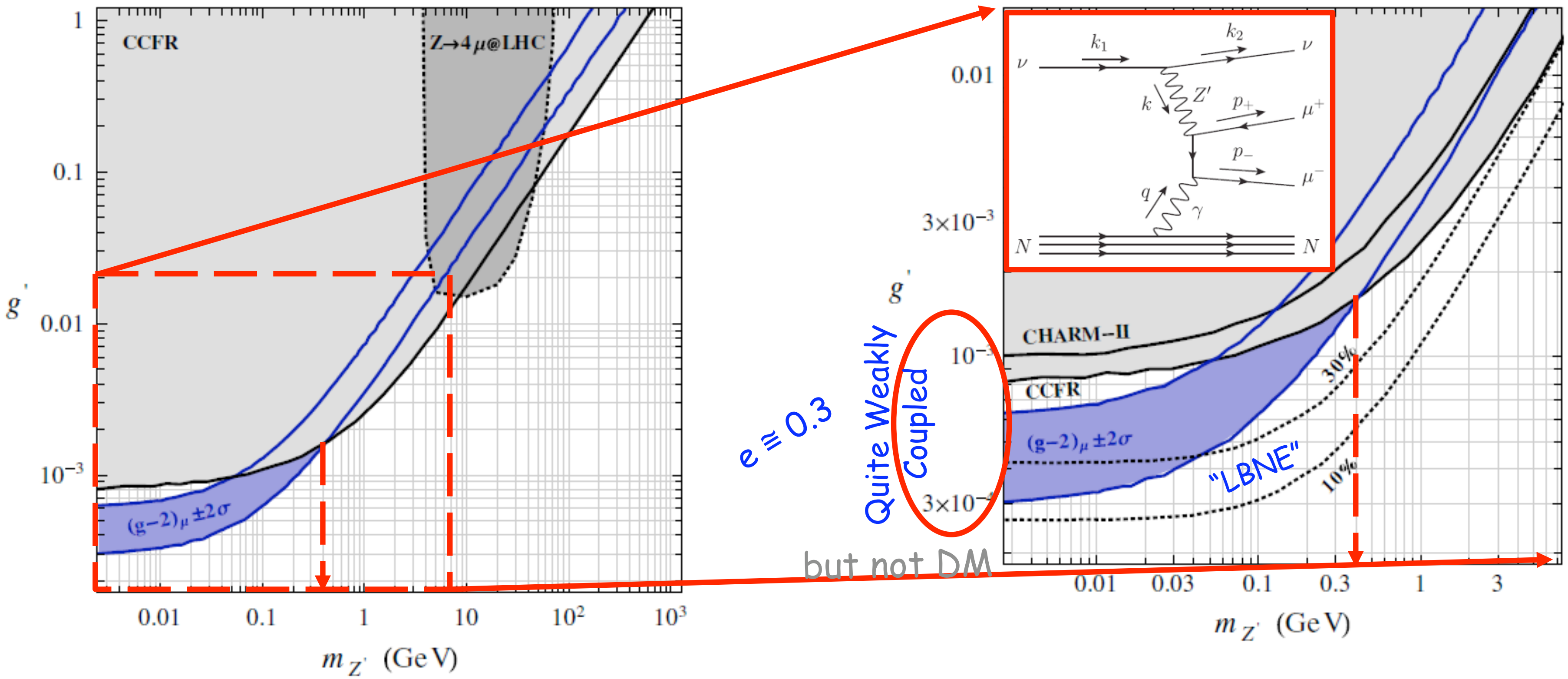
gauged $L_\mu - L_\tau$

1406.2332

Altmannshofer, Gori, Pospelov, Yavin [PRD → PRL]

"Neutrino Trident Production"

PRL 113, 091801 (2014) PHYSICAL REVIEW LETTERS week ending 29 AUGUST 2014

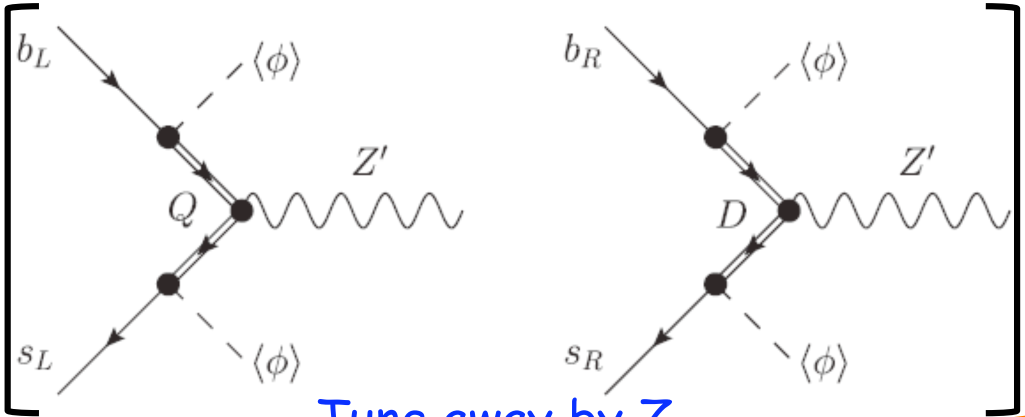


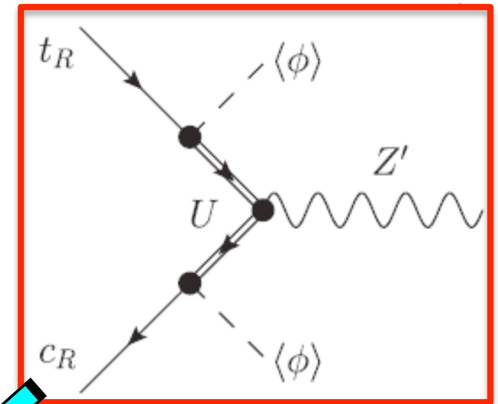
Muon g – 2 related $Z' \lesssim$ 400 MeV < m_K ?

New Physics from Light Particle !?

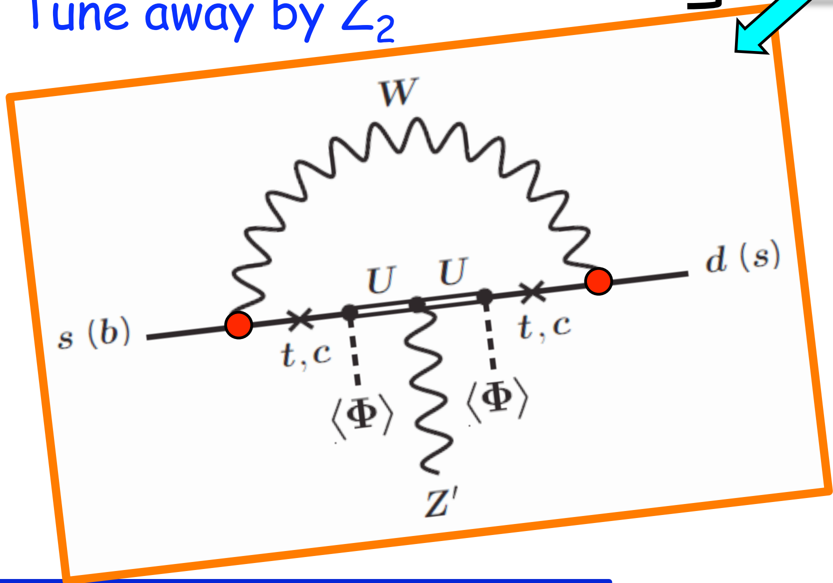
Linking Leptonic Z' to Muon g – 2

gauged $L_\mu - L_\tau$





Tune away by Z_2



SM-assisted loop
$s \to dZ'$; $b \to sZ'$

Fuyoto, WSH, Kohda, 1412.4397

Muon g – 2 related $Z' \lesssim$ 400 MeV < m_K!

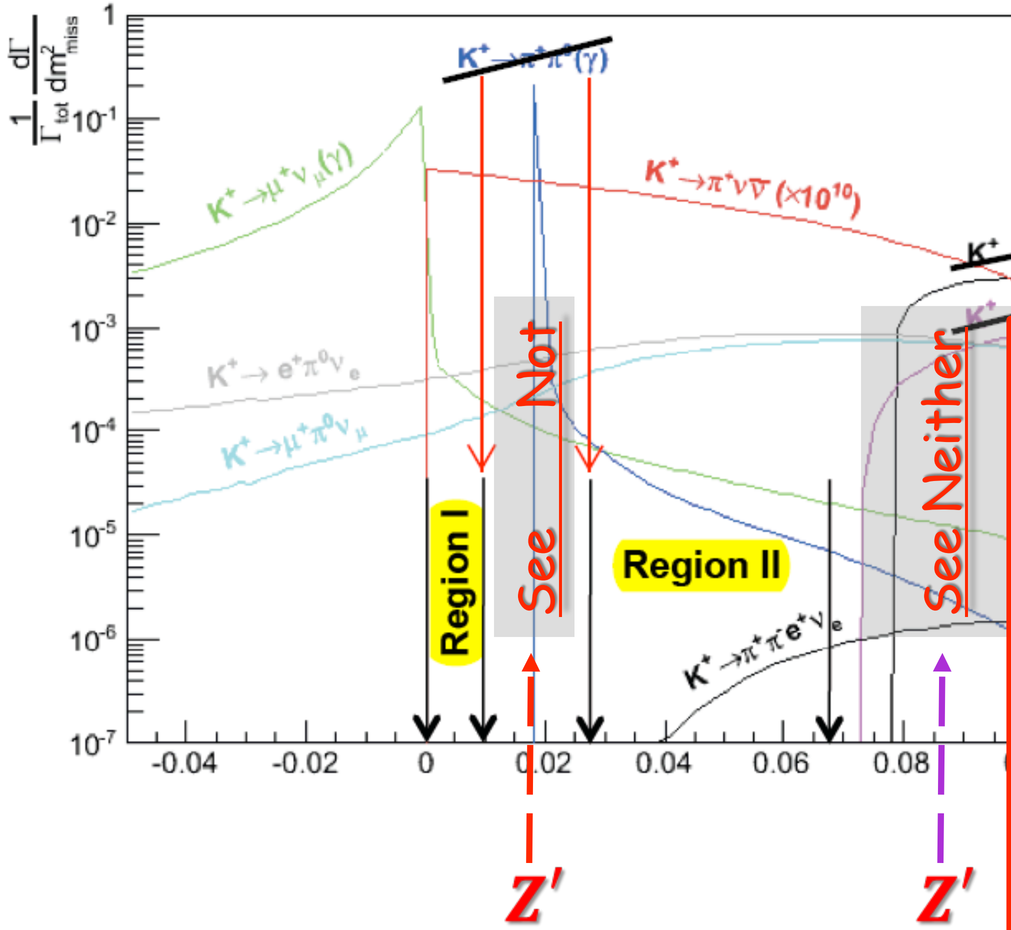
New Physics from Light Particle !?

$K^+ \to \pi^+$ "π^0" Loophole vs $K_L \to \pi^0 Z'$

NA62 @ CERN

Window basically Same as E787/949 @ BNL

Kinematic exclusion:
exclude 0.01 - 0.025 GeV^2 [(100)^2 - (160)^2 MeV^2]



The KOTO Expt at J-PARC can discover $K_L \to \pi^0 X^0$ above the Grossman-Nir Bound !

$$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu}) \lesssim 4.3 \times \mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})$$
$$< 1.4 \times 10^{-9}. \quad \text{(GN bound)}$$

"Blind man blessed by senses."

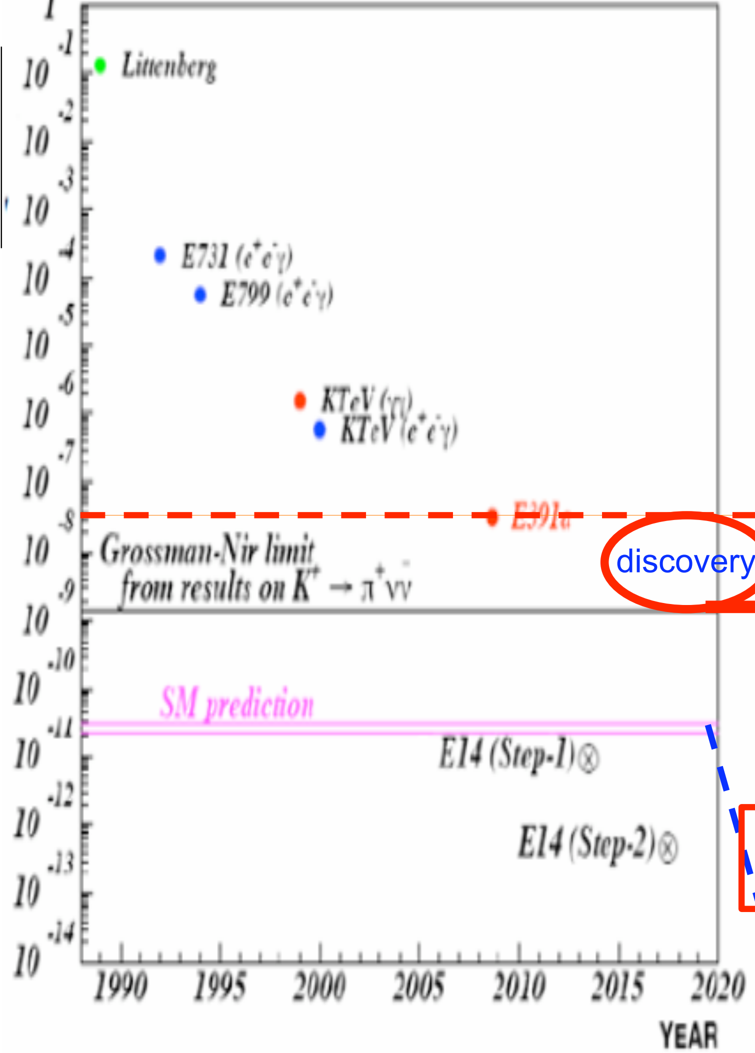
A Surprise! "Trivial"

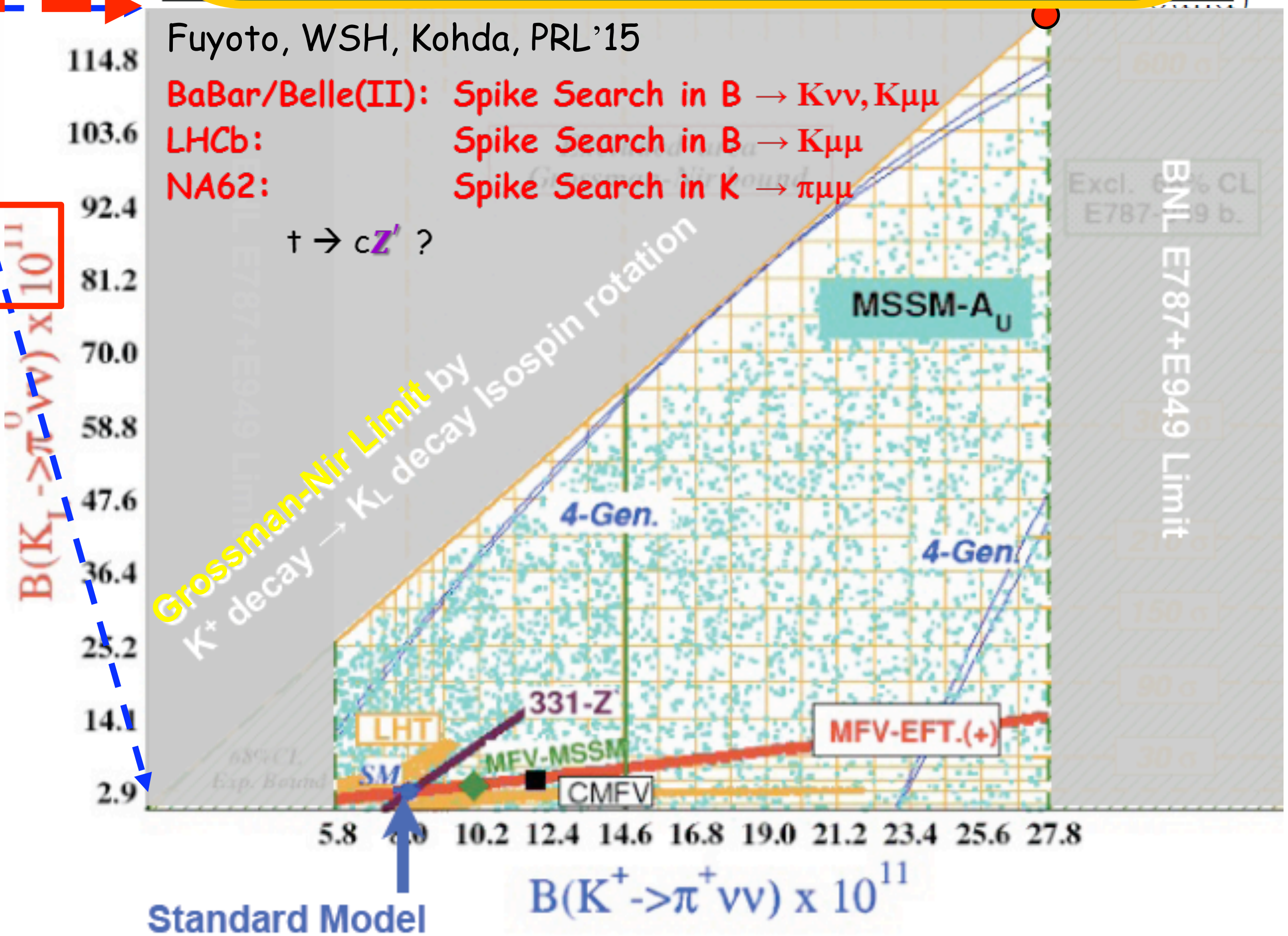
A $K_L \to \pi^0\nu\bar{\nu}$ experiment, however, cannot do kinematic reconstruction: besides detecting two photons (assumed as π^0), it measures "nothing to nothing". The K_L and "π^0" momenta are not known. The approach is thus to veto everything and to learn while pushing down the sensitivity. However, the $\nu\bar{\nu}$ being the target, one cannot veto weakly interacting light particles (WILP). Thus, for $K \to \pi X^0$ where X^0 is *any* WILP that falls into the missing mass window, the K^+ experiment would be oblivious, *but the K_L experiment can have a blunt feel!* Although the GN relation of Eq. (4) is in no way violated, ~~the perceived GN bound of Eq. (2)~~ does not apply. This is the main and rather simple point of this Letter, independent of model discussion. The X^0 need not be the leptonic force, as it simply goes undetected. Fuyoto, WSH, Kohda

Discovery 'X'one, "Now"!

The KOTO Expt at J-PARC can discover $K_L \to \pi^0 X^0$ above the Grossman-Nir Bound !

KOTO achieved nearly the same sensitivity as KEK E391a experiment with only 100 hours of data CKM2014





@ J-PARC

Flavor→NP "Run 2"

V. Final Comments: BNV(-top); Origin of Flavor / BAU

9. Summary

CMS Collaboration / Physics Letters B 731 (2014) 173–196

Data recorded by the CMS detector have been used to search for baryon number violation in top-quark decays. The data correspond to an integrated luminosity of $19.52 \pm 0.49\ \text{fb}^{-1}$ at $\sqrt{s} = 8$ TeV. No significant excess is observed over the SM expectation for events with one isolated lepton (either a muon o[...] an electron), at least five jets of which at least one is b [...] low missing transverse energy. These results a[...] an upper limit of 0.0016 (0.0017) at 95% c[...] on the branching fraction of a hypotheti[...]ber violating top-quark decay into a muon (electro[...] 2 jets. The combination of the two channels under the assumption of lepton universality yields an upper limit of 0.0015. These limits on baryon number violation are the first that have been obtained for a process involving the top quark.

Search should Boldy Continue!

WSH, Nagashima, Soddu, PRD'05: less than 10^{-27} (proton decay constraint)

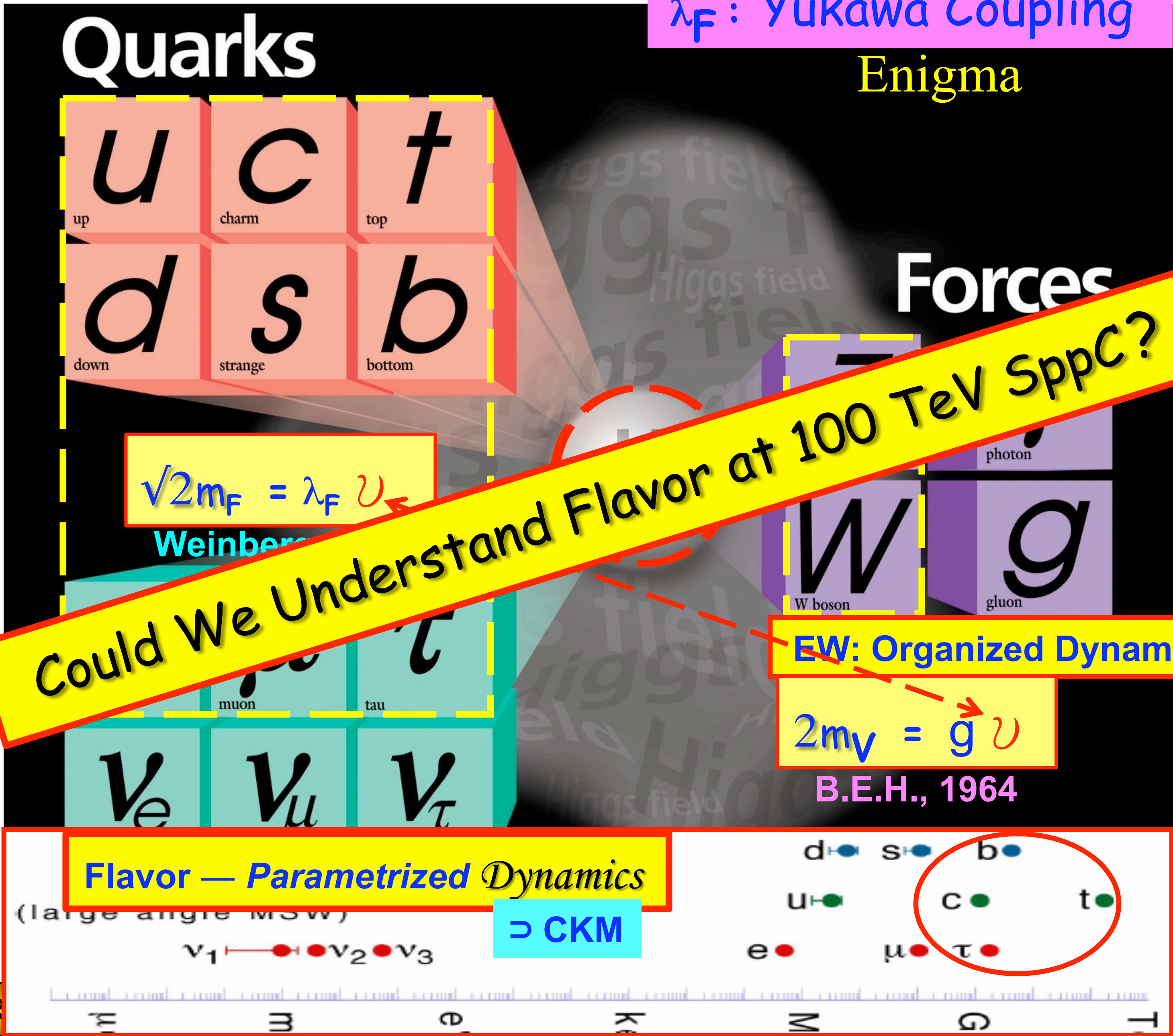
Dong, Durieux, Gérard, Han, Maltoni, PRD'12: could have cancellation mech.

The “God” Particle: the Origin of Mass

λ_F : Yukawa Coupling

Enigma

fortuitous or intended?



$\sqrt{2} m_F = \lambda_F\, v$

Weinberg

Could We Understand Flavor at 100 TeV SppC?

EW: Organized Dynamics

$2 m_V = g\, v$

B.E.H., 1964

g

gauge coupling

Flavor — *Parametrized Dynamics*

⊃ CKM

	EW Theory		KM3	KM4
• Baryon # Violation	't Hooft/Sphaleron	✓	✓	Strong
• CP Violation	Kobayashi-Maskawa	✓	✓	"Weak" ?
• Out of Thermal Equilibrium ("boil")	$m_H \lesssim 50$ GeV	✗	?	

1-2-3

$$J = (m_t^2 - m_u^2)(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_b^2 - m_d^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2)\, A$$

Jarlskog Invariant

2-3-4

$$J^{sb}_{(2,3,4)} \simeq (m_{t'}^2 - m_c^2)(m_{t'}^2 - m_t^2)(m_t^2 - m_c^2)(m_{b'}^2 - m_s^2)(m_{b'}^2 - m_b^2)(m_b^2 - m_s^2)\, A^{sb}_{234}$$

$$\sim \frac{m_{t'}^2}{m_c^2}\left(\frac{m_{t'}^2}{m_t^2} - 1\right)\frac{m_{b'}^4}{m_b^2 m_s^2}\,\frac{A^{sb}_{234}}{A}\, J$$

> ~~10^{+15}~~ 10^{+17}

Strong Yukawa

$\mathcal{O}(1)$

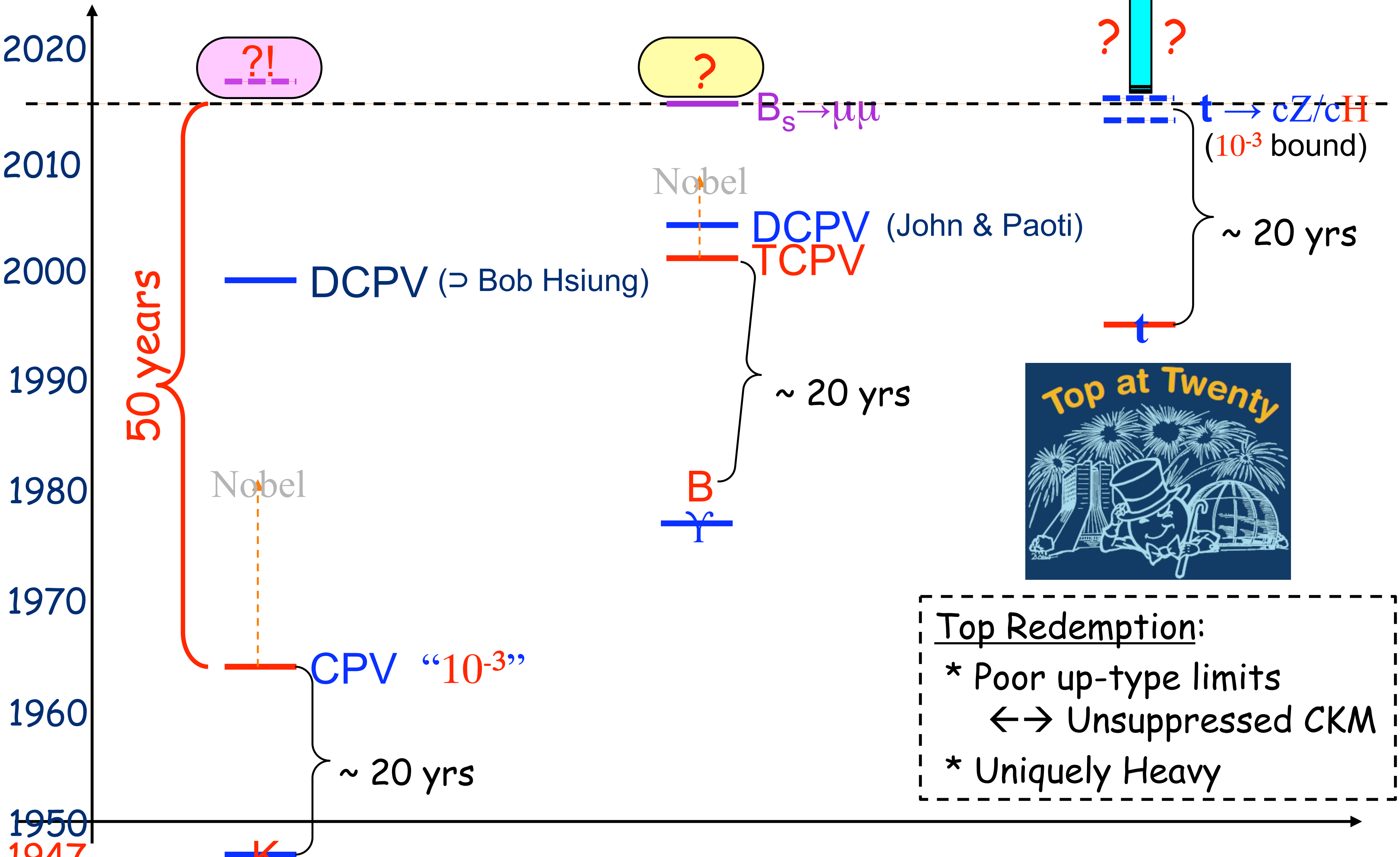
Main (Yukawa !) Enhancement

CPV for Universe w/ spare change ?

WSH, arXiv:0803.1234

Chin.J.Phys. 47 (2009) 134

VI. Flavor Probes of NP during Run 2



Top Redemption:

* Poor up-type limits
  ←→ Unsuppressed CKM
* Uniquely Heavy

Flavor violating Higgs decays

Roni Harnik[a] Joachim Kopp[a,b] Jure Zupan[c]

also Blankenburg, Ellis, Isidori, 1202.5704

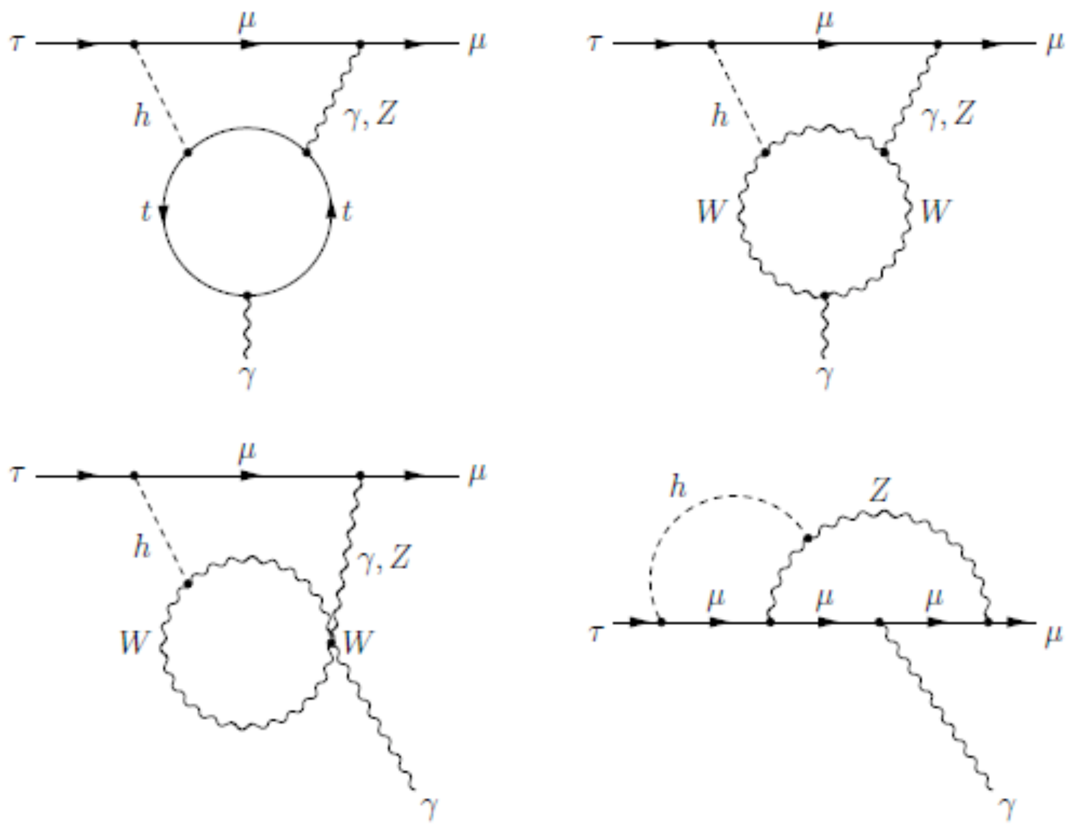
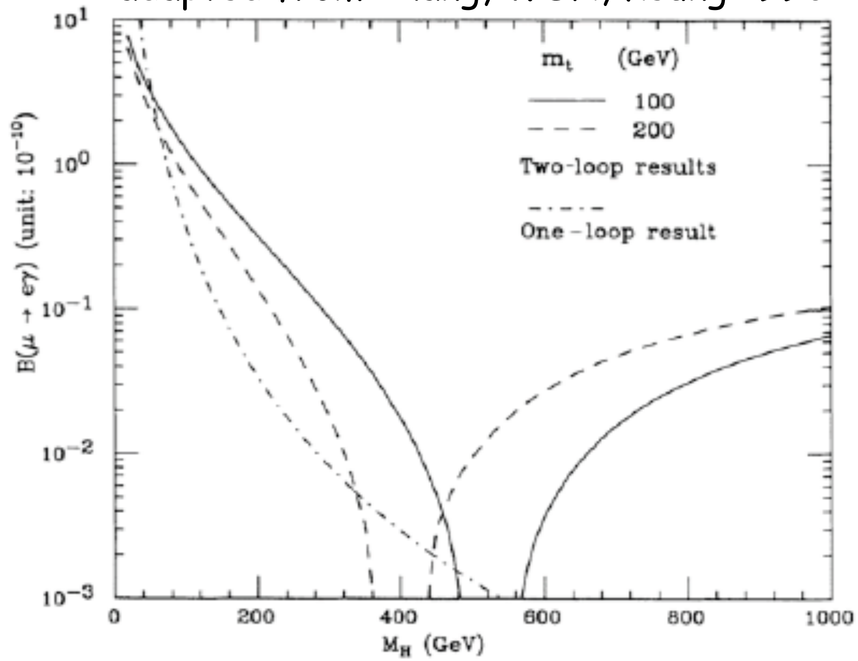


Figure 12. 2-loop diagrams contributing to $\tau \to \mu\gamma$.

Two-loopDominace:
one-loop highly suppressed

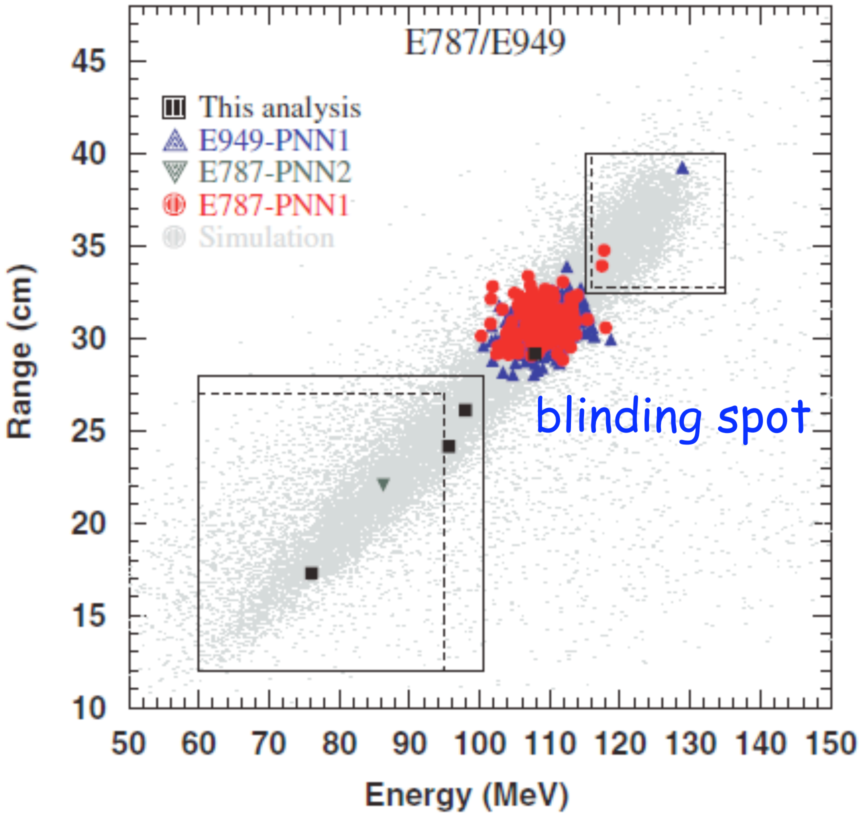
adapted from Chang, WSH, Keung 1993



Linking Z'_{g-2} to $K \to \pi X^0$

BV. The E949 limit of $\mathcal{B}(\pi^0 \to \nu\bar{\nu}) < 2.7 \times 10^{-7}$ at 90% C.L. [60] can be combined with the world average value of $\mathcal{B}(K^+ \to \pi^+\pi^0)$ [24] to set a 90% C.L. limit of $\mathcal{B}(K^+ \to \pi^+ X) < 5.6 \times 10^{-8}$ for $M_X = M_{\pi^0}$ with X stable

PHYSICAL REVIEW D 79, 092004 (2009)



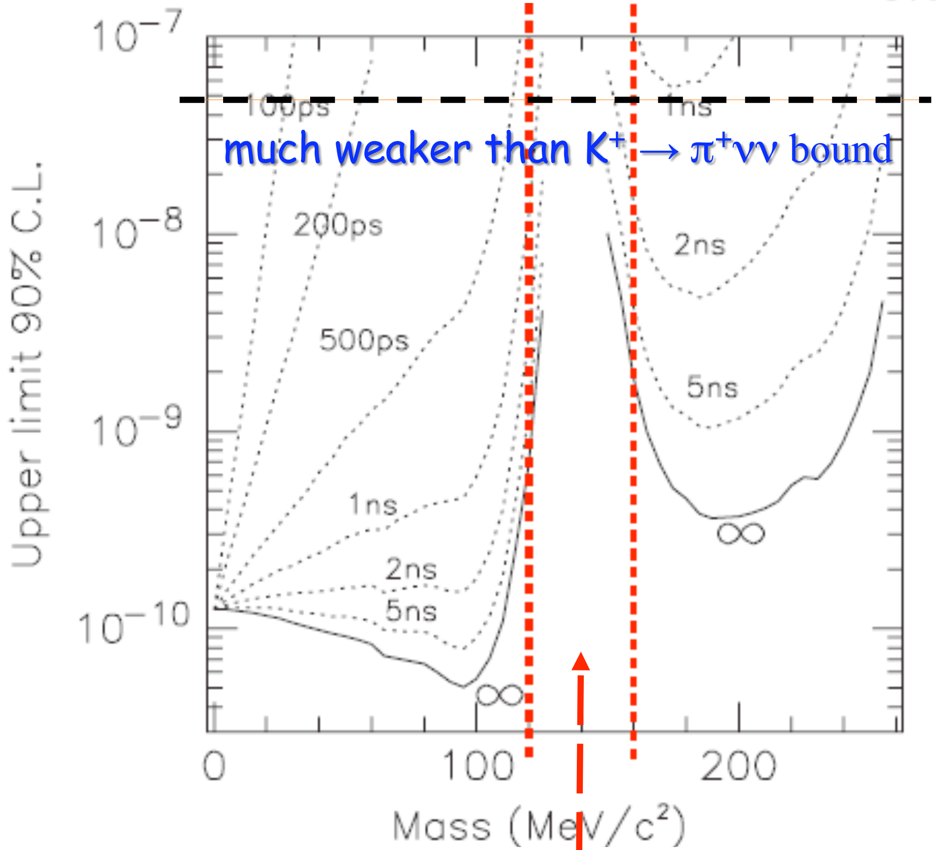
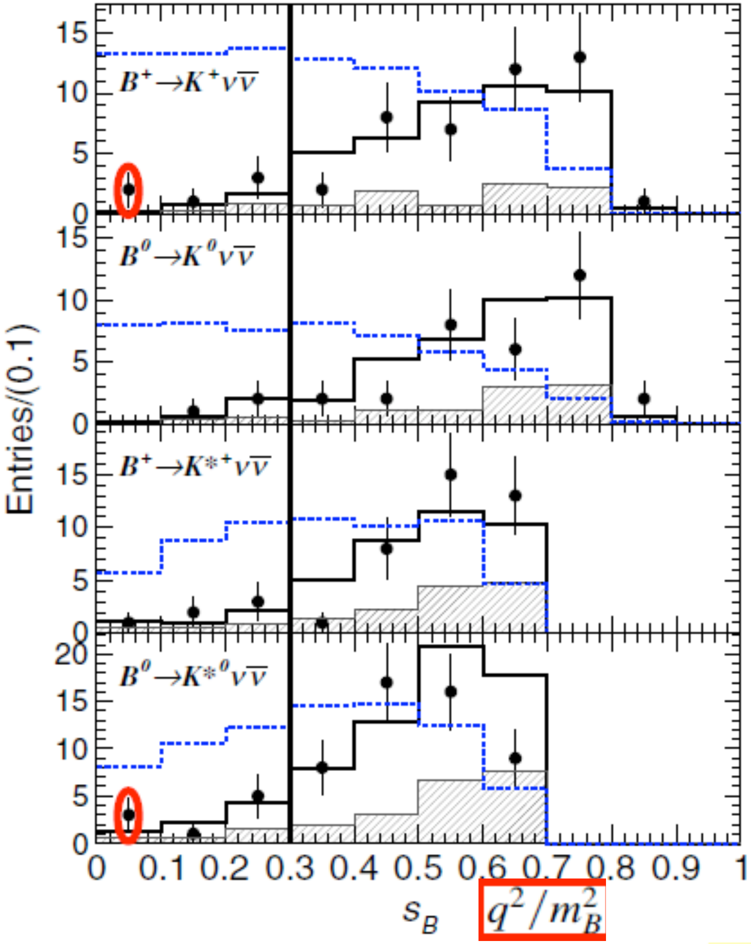


FIG. 18. The solid lines represent the 90% C.L. upper limit on $\mathcal{B}(K^+ \to \pi^+ X)$ as a function of the mass of X assuming X is

BaBar: mild hint in $B^+ \to K^+\nu\nu$

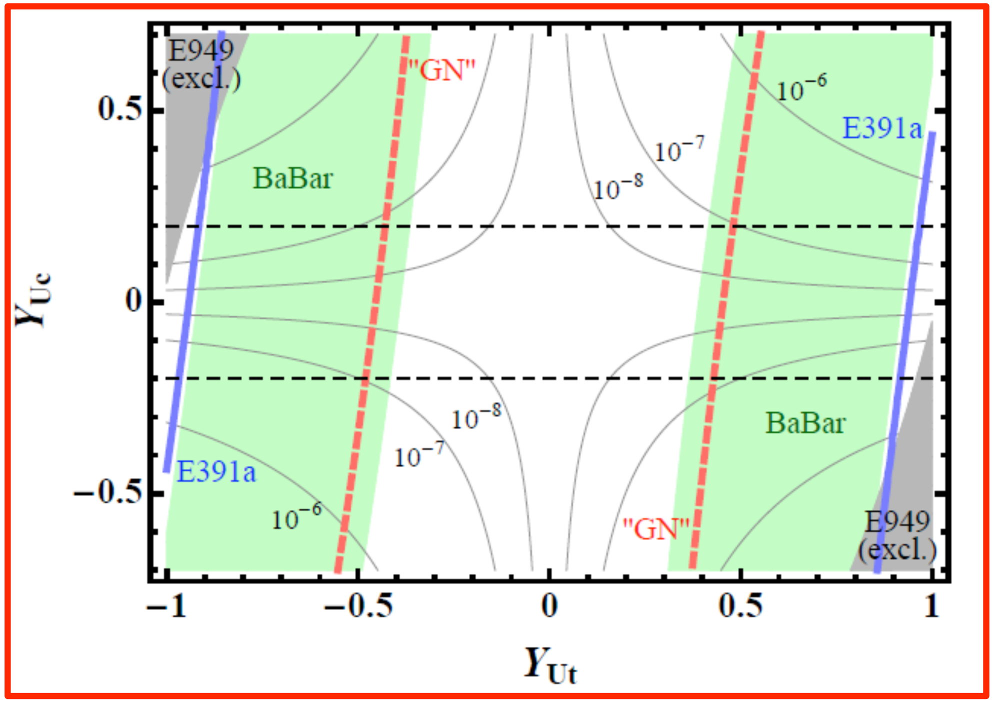
N.B. $B(B \to K\pi^0) \ll B(K \to \pi\pi^0)$

SEARCH FOR $B \to K^{(*)}\nu\bar{\nu}$ AND … BaBar'13 (471M BB(bar))



small excess over the expected background in the K^+ channel, we report a two-sided 90% confidence interval.

Gaussian significance of about 1.4σ. Therefore, this excess is not considered significant.



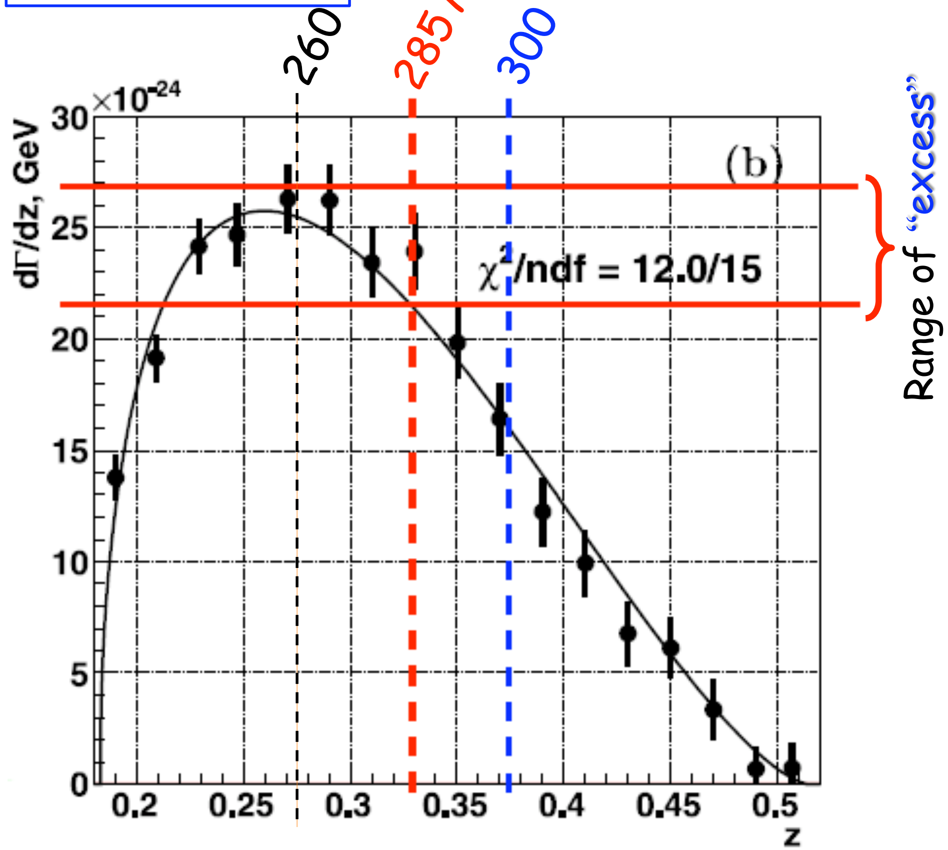
Belle needs to follow up with the Binned m_{mis} analysis. (→ Belle II)

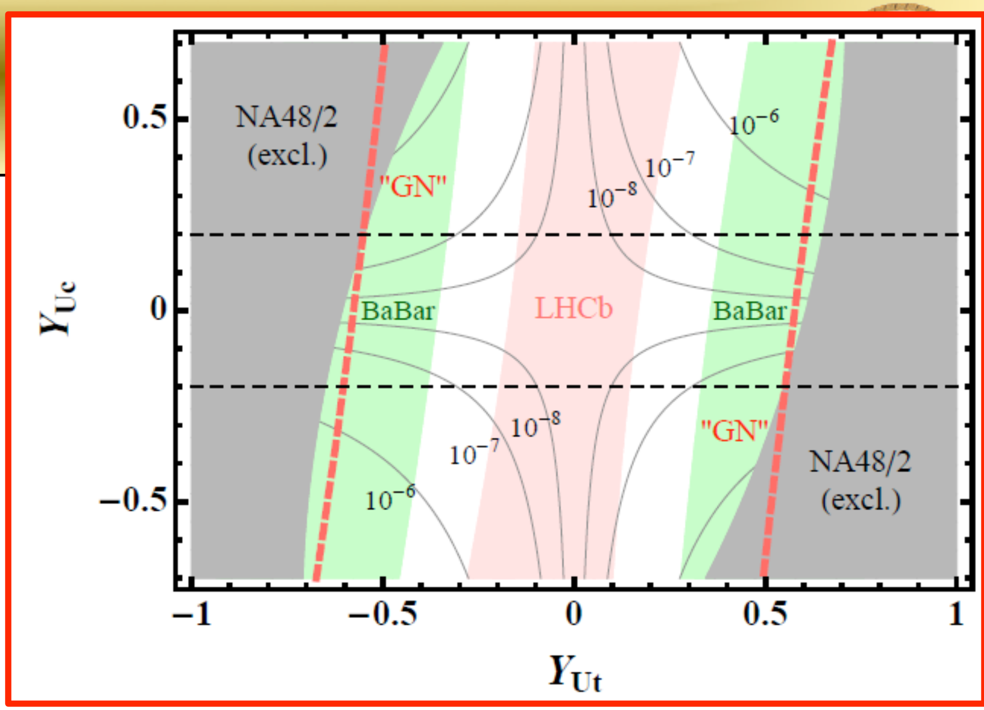
Fuyoto, WSH, Kohda, 1412.4397

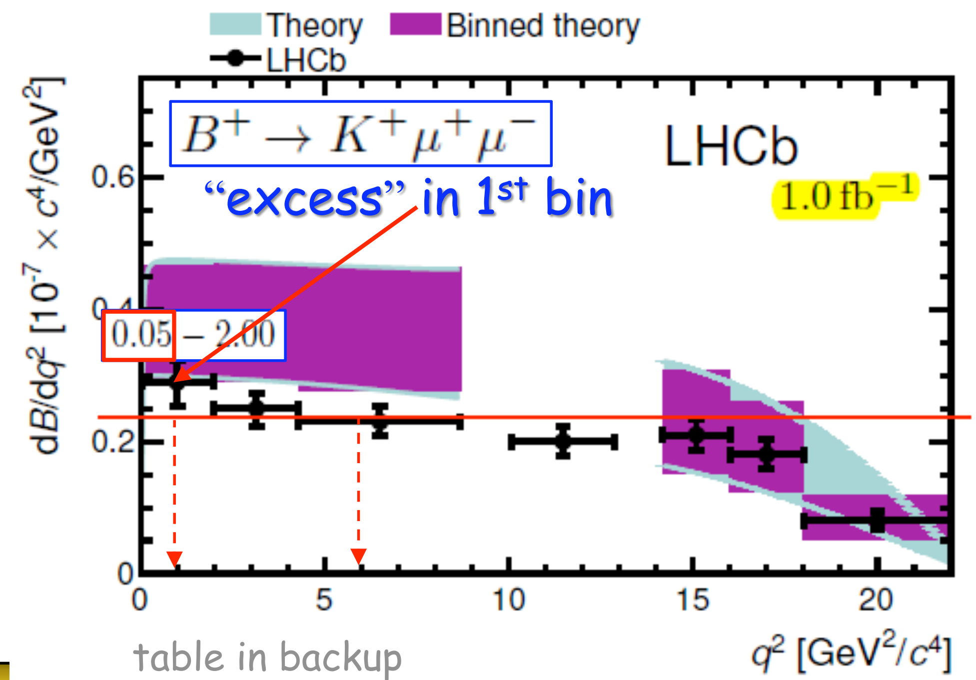
The 2nd Window

NA48/2 Collaboration / Physics Letters B 697 (2011)

$K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$







Can be repeated by NA62

Low q^2 Spike Search in $B^+ \to K^+\mu^+\mu^-$

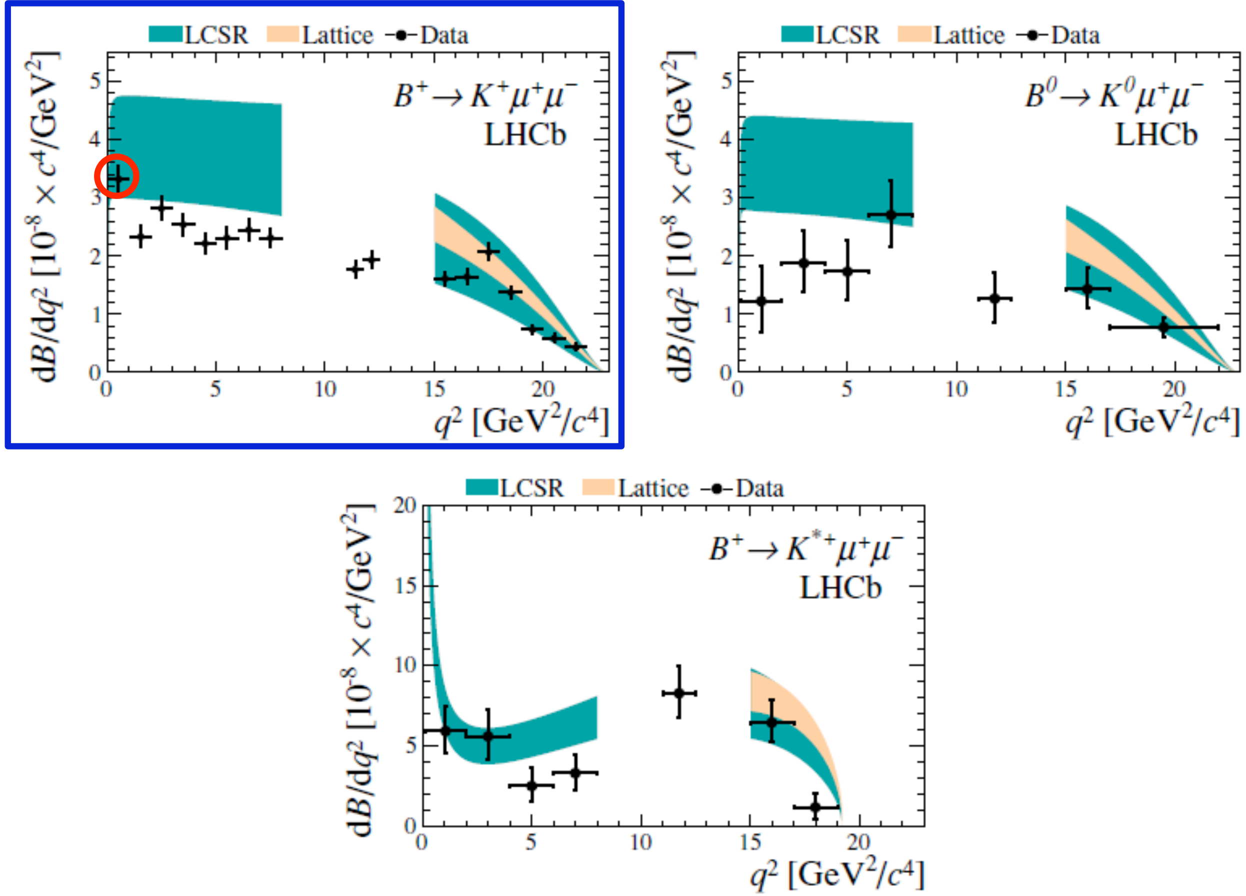
Fuyoto, WSH, Kohda, 1412.4397

LHCb should do the extra work for lowest q^2

Z' ~ 0.3 GeV
→ q^2 ~ 0.09 GeV^2

q^2 range (GeV$^2/c^4$)	central value	stat	syst
$0.1 < q^2 < 0.98$	33.2	1.8	1.7
$1.1 < q^2 < 2.0$	23.3	1.5	1.2
$2.0 < q^2 < 3.0$	28.2	1.6	1.4
$3.0 < q^2 < 4.0$	25.4	1.5	1.3
$4.0 < q^2 < 5.0$	22.1	1.4	1.1
$5.0 < q^2 < 6.0$	23.1	1.4	1.2
$6.0 < q^2 < 7.0$	24.5	1.4	1.2
$7.0 < q^2 < 8.0$	23.1	1.4	1.2
$11.0 < q^2 < 11.8$	17.7	1.3	0.9
$11.8 < q^2 < 12.5$	19.3	1.2	1.0
$15.0 < q^2 < 16.0$	16.1	1.0	0.8
$16.0 < q^2 < 17.0$	16.4	1.0	0.8
$17.0 < q^2 < 18.0$	20.6	1.1	1.0
$18.0 < q^2 < 19.0$	13.7	1.0	0.7
$19.0 < q^2 < 20.0$	7.4	0.8	0.4
$20.0 < q^2 < 21.0$	5.9	0.7	0.3
$21.0 < q^2 < 22.0$	4.3	0.7	0.2

LHCb 3 fb^{-1}, JHEP **1406**



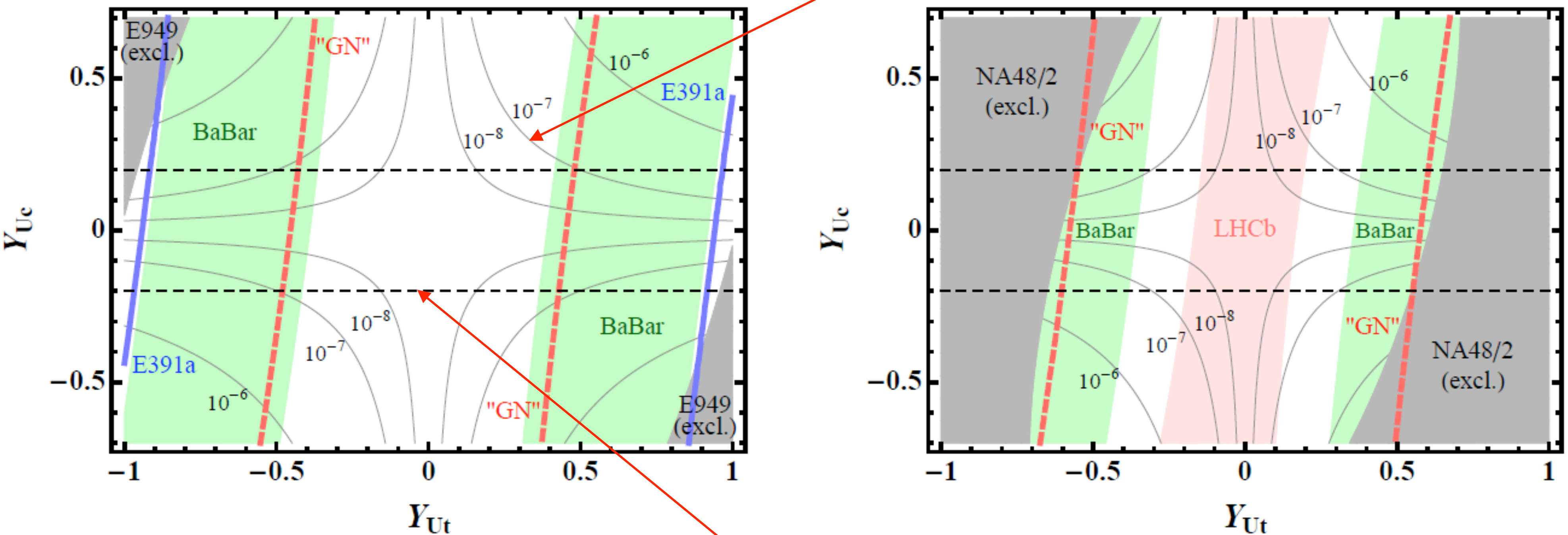
N.B. K^{*0} not yet updated

The Z'_{g-2} Landscape

Perhaps 100 TeV SPPC Needed

Contour in backdrop is $t \to cZ'_{g-2}$

135 MeV | 285 MeV



Y_{Uc} & Y_{Ut} should be reasonable in strength

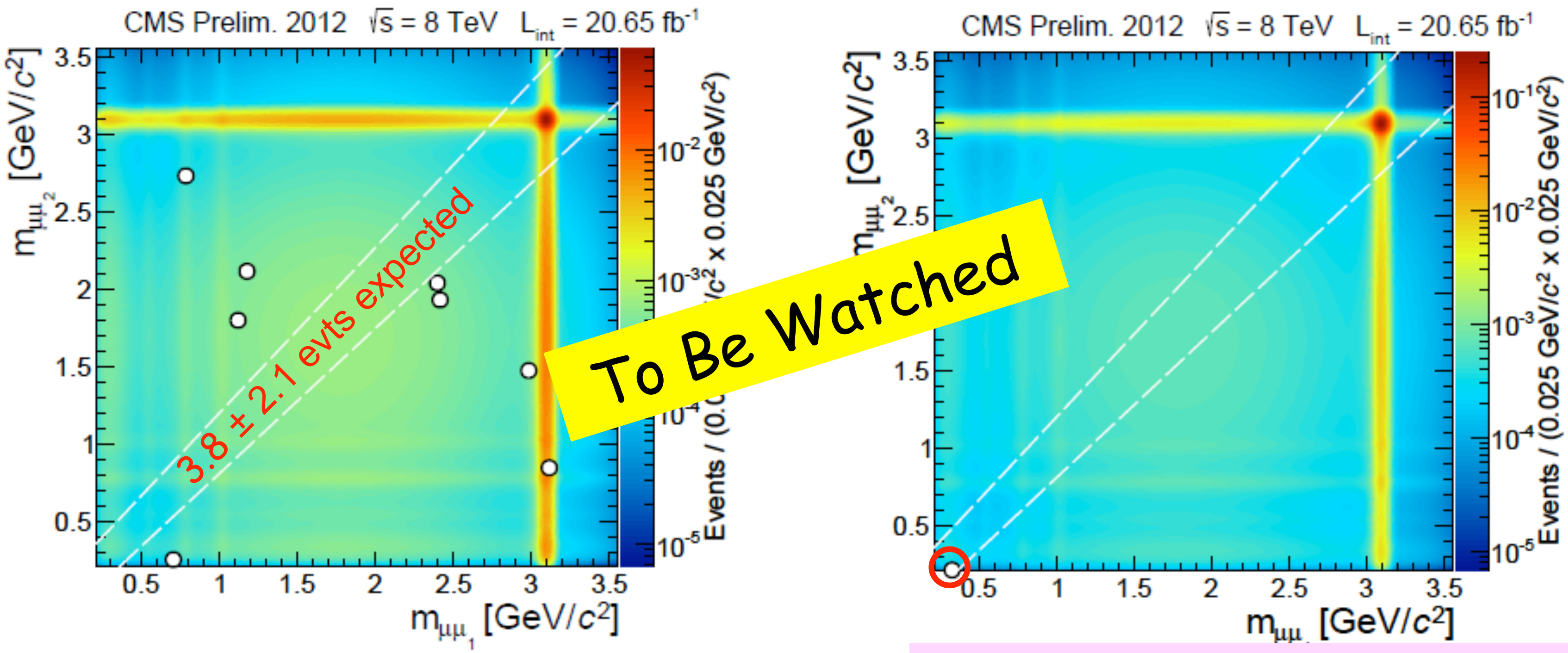
Fuyoto, WSH, Kohda, 1412.4397

Very Light Z′ Pair Production thru "it's Higgs"

Fuyoto, WSH, Kohda, 1412.4397

~ 0.3 GeV

* Z′ mass from "exotic" $\langle \phi \rangle = v_\phi$, light because g′ ≲ 10^{-3}.
  - ➡ m_ϕ ~ Weak Scale
* ϕ has Yukawa coupling to top! (suppressed by vector-like quark mass)
  - ➡ ϕ Production via gg-fusion ➡ $\phi \to Z'Z' \to [\mu\mu][\mu\mu]$



"Sideband" Study

ONE Double $\mu\mu$ ~ 0.2-0.3 GeV evt …

CMS PAS HIG-13-010: $h \to 2a \to 4\mu$

Light "g-2" Z′ decay is prompt, even when highly boosted.

$Z' \to \nu\nu$ 100% $Z' \to \mu\mu, \nu\nu$ 50:50

$$\Gamma(Z' \to \nu_\ell \bar{\nu}_\ell) = \frac{g'^2}{24\pi} m_{Z'}$$