$K_L \to \pi^0\nu\nu$ Beyond Grossman-Nir Bound

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July 24 @ EPS-HEP2015, Wien

Outline

I. Kaon: the Oldest Frontier

Fixation on Grossman-Nir Bound — Shake It Off !

II. Blind Senses

Stupid is as stupid does / KOTO Could Win Big

III. Explicit Model (existence proof)

Gauged $L_\mu - L_\tau$ related to muon g - 2 + ...

IV. Where Else? — an Illustration

"Exotic" Rare K & B Decays

V. Conclusion

Fuyoto, WSH, Kohda, 1412.4397 (PRL'15)
and to appear [see also talk by M. Kohda]

mostly τ_{K_L}/τ_{K^+}

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

68+

I. Kaon: the Oldest Frontier

Fixation: Grossman-Nir Bound — Shake It Off !

1997

Shake It Off !

mostly τ_{K_L}/τ_{K^+}

$$\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu}) \lesssim 4.3 \times \mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$$
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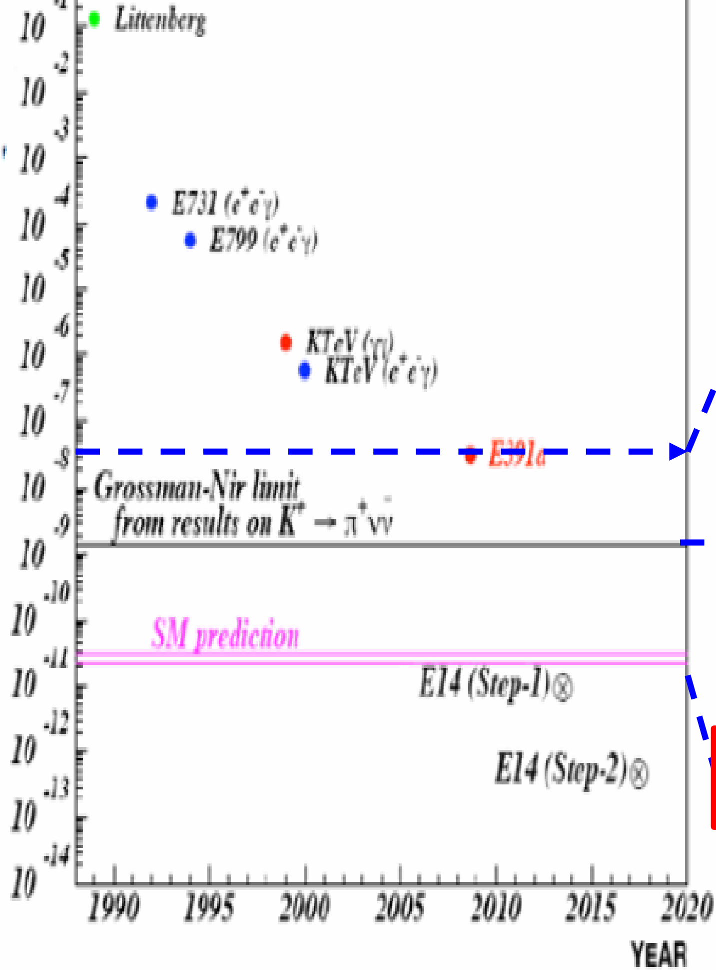
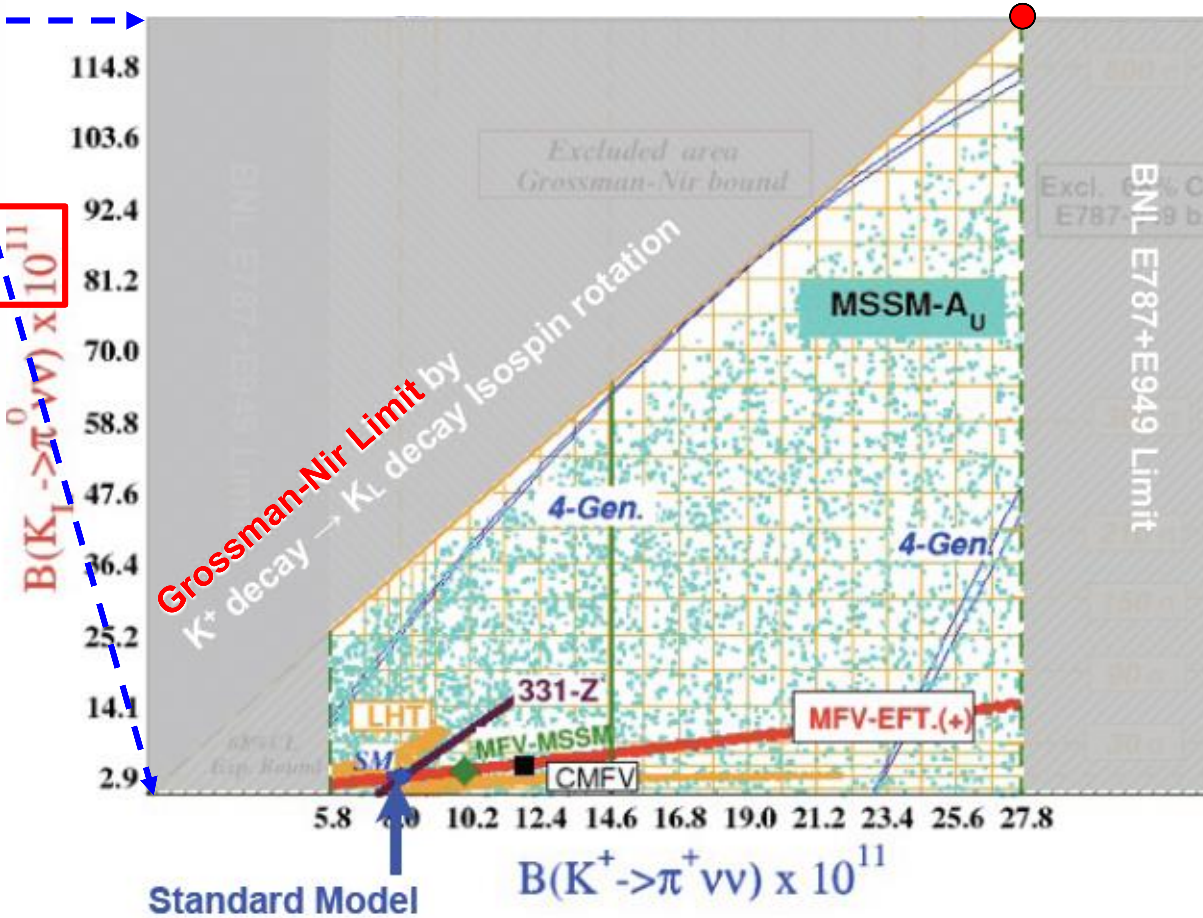


KOTO @ 100 hrs (2013) ~ E391a, but ...



@ J-PARC

$K_L \to \pi^0 \nu\nu$ > GN ?

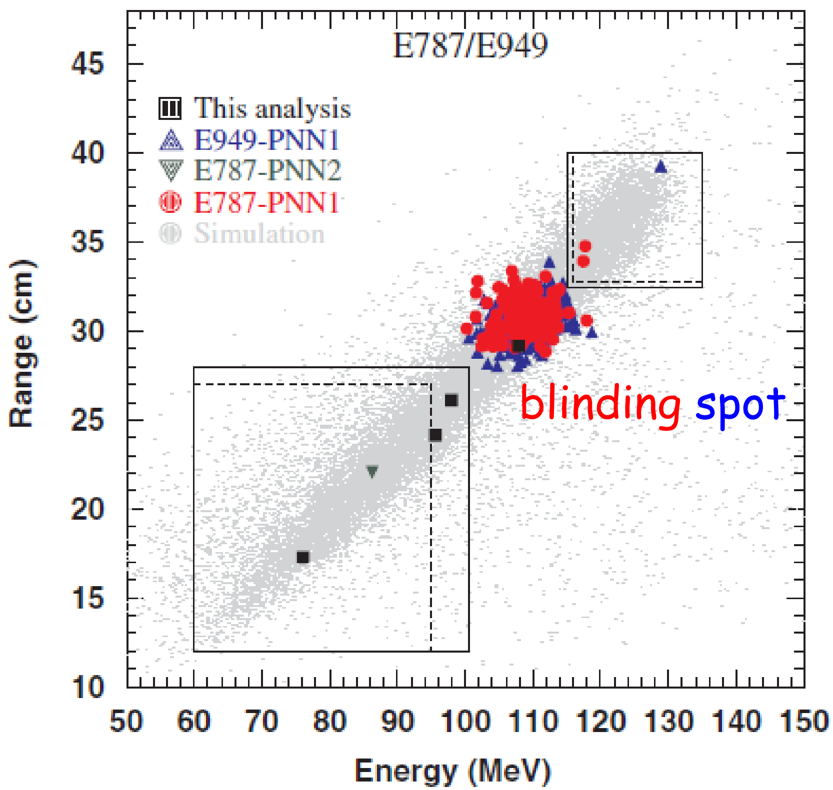
II. Blind Senses

Stupid is as stupid does.

[Forrest Can Run;
'nd became Rich!]

Bound on $K \to \pi X^0$

PHYSICAL REVIEW D 79, 092004 (2009)



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

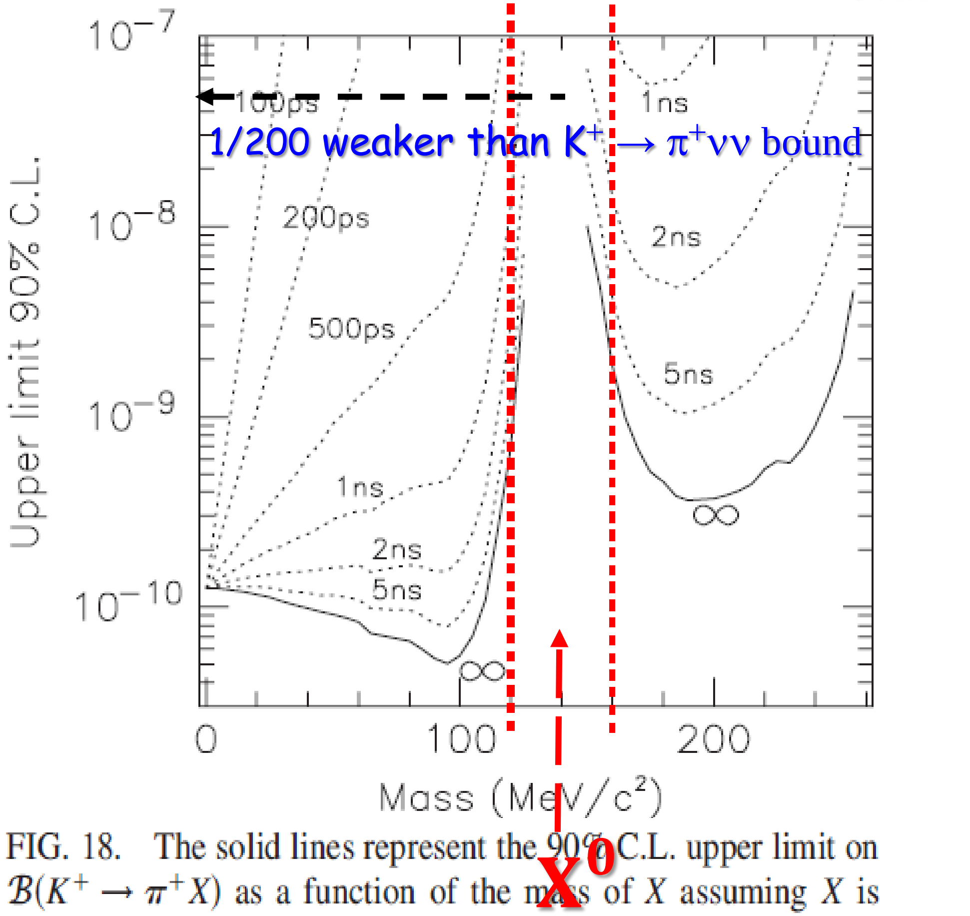


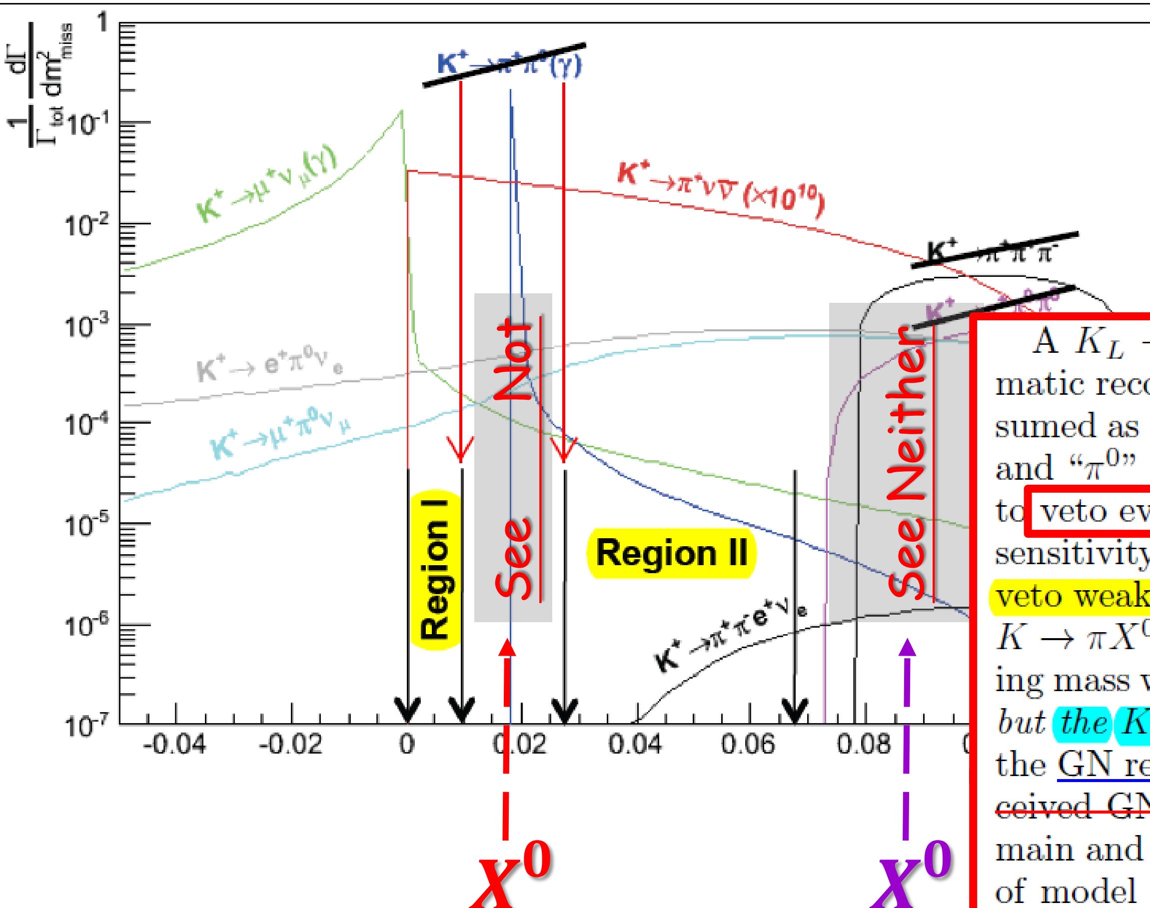
FIG. 18. The solid lines represent the 90% C.L. upper limit on $\mathcal{B}(K^+ \to \pi^+ X)$ as a function of the mass of X assuming X is

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

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 Starting "Now"!

Shake It Off !

mostly τ_{K_L}/τ_{K+}

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

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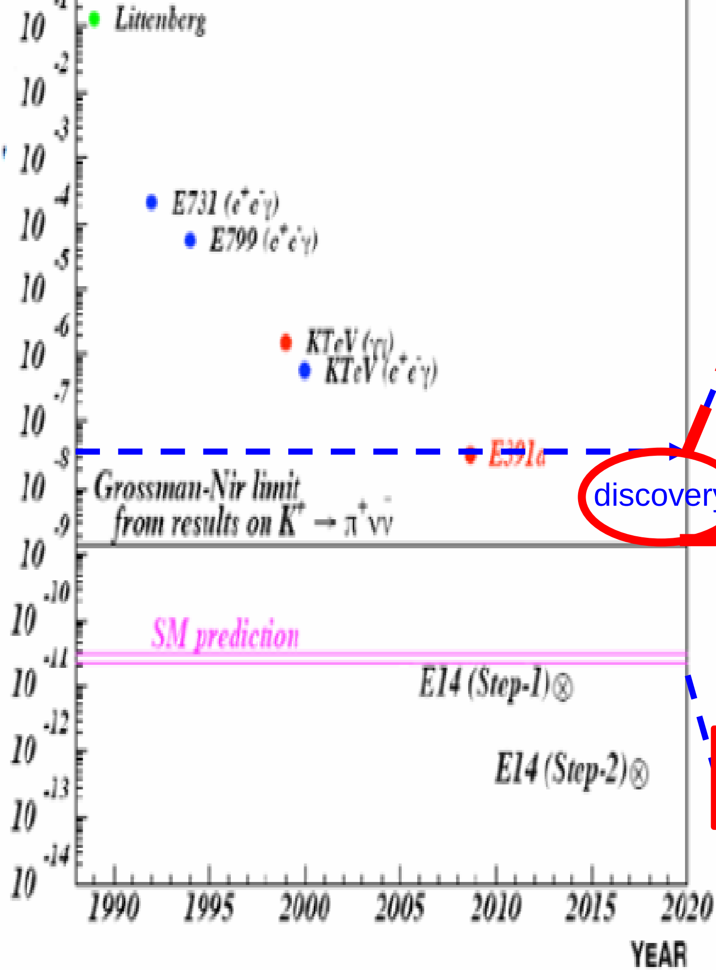
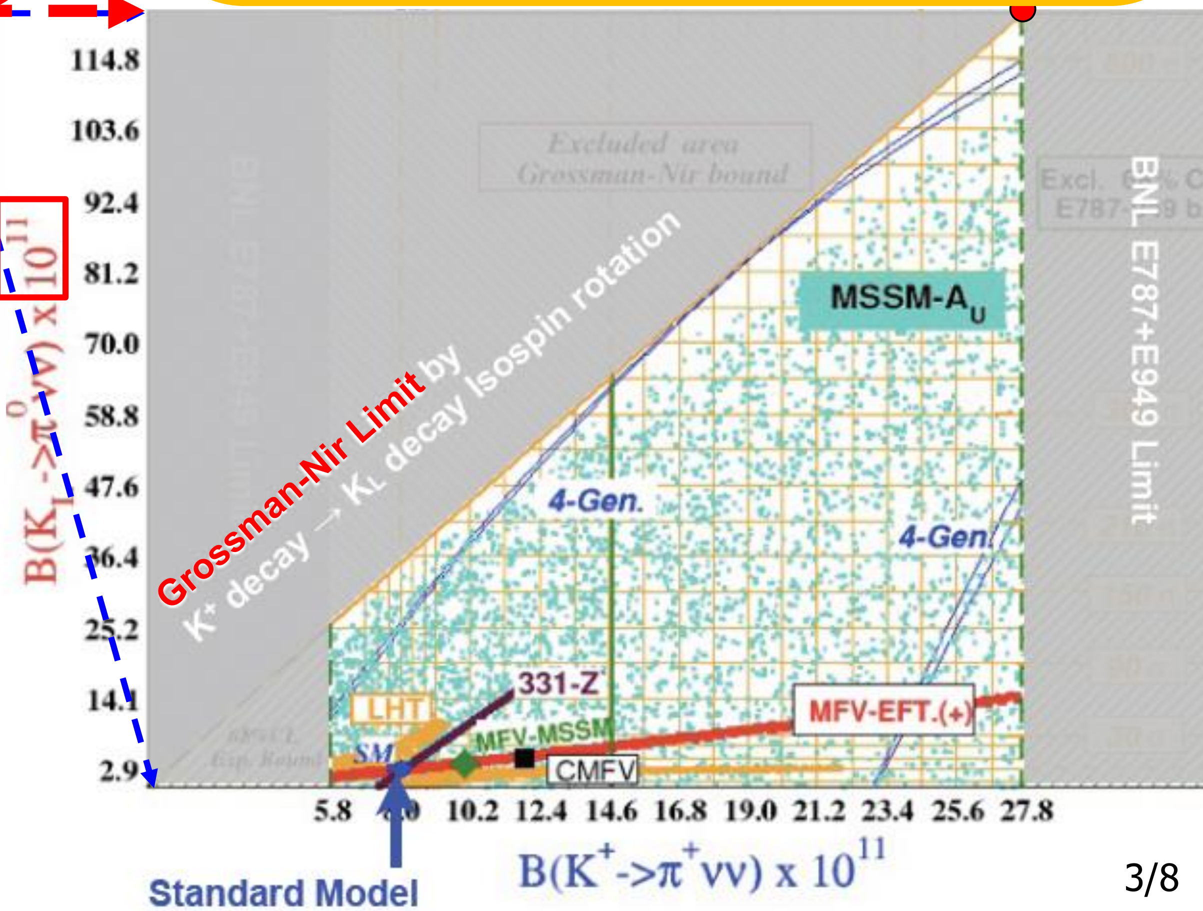


@ J-PARC



III. Explicit Model (existence proof)

gauged $L_\mu - L_\tau$ related to muon $g - 2$

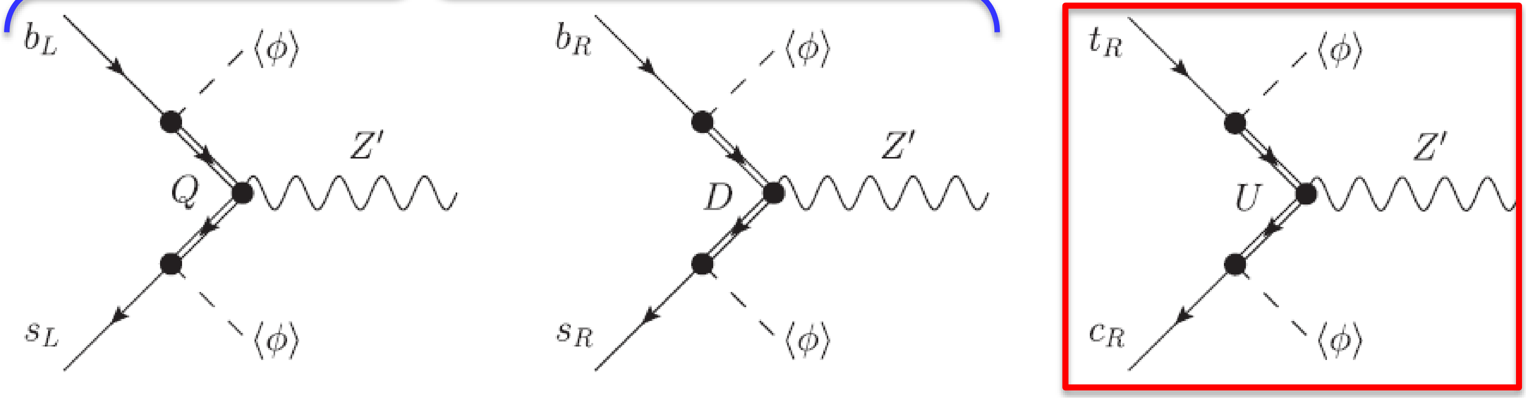
+ …

P'_5-motivated Z' induces $t \to cZ'$ also

$B \to K^* \mu^+ \mu^-$

Our Original Interest

ALTMANNSHOFER *et al.* PHYSICAL REVIEW D 89, 095033 (2014)



Q, *D*, *U*: vector-like quarks with *Z*′ charge

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

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

"unconstrained"

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

$Z' \to \mu^+\mu^-$

BR ~ 1/3!

"gauged $L_\mu - L_\tau$"

See M. Kohda's talk today, Top session.

Linking Leptonic Z' to Muon $g-2$

gauged $L_\mu - L_\tau$

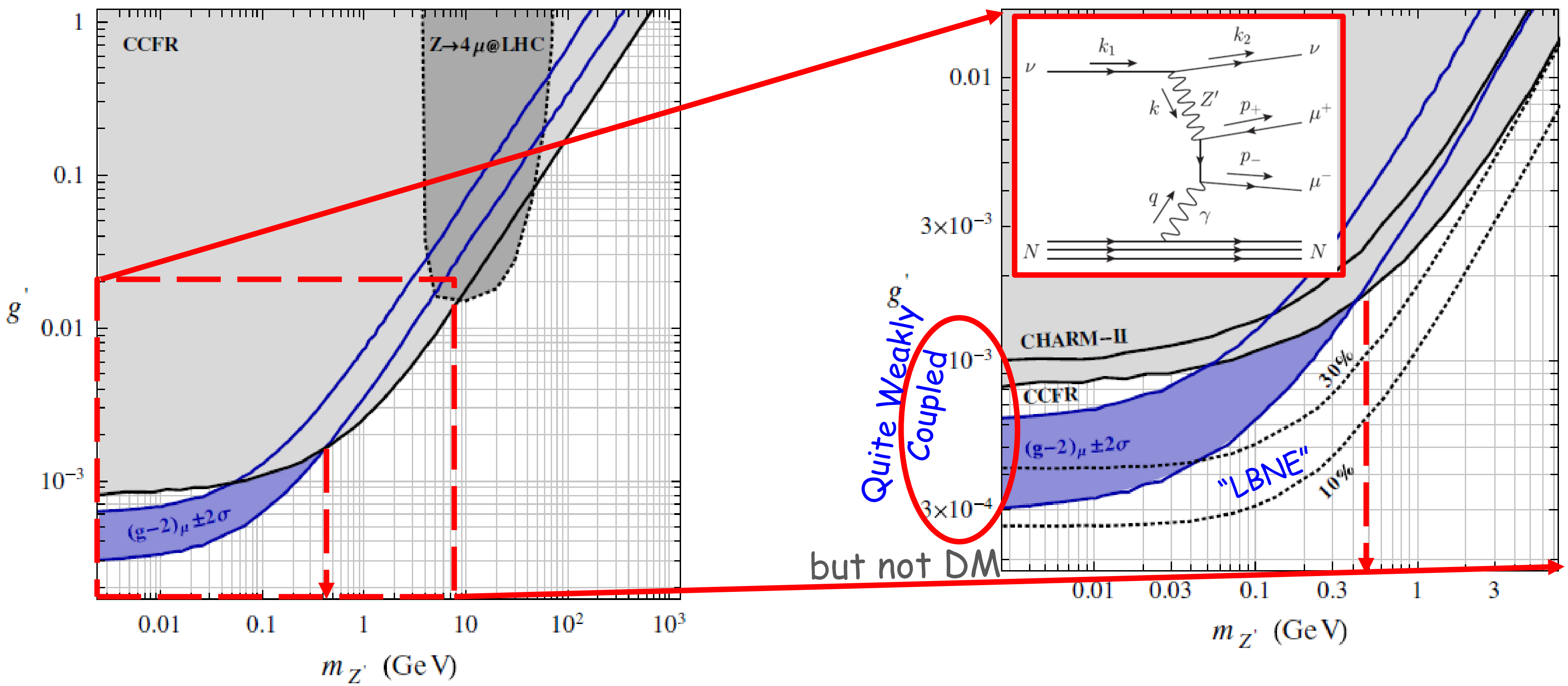
Cannot Affect P'_5

1406.2332

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

"Neutrino Trident Production"

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

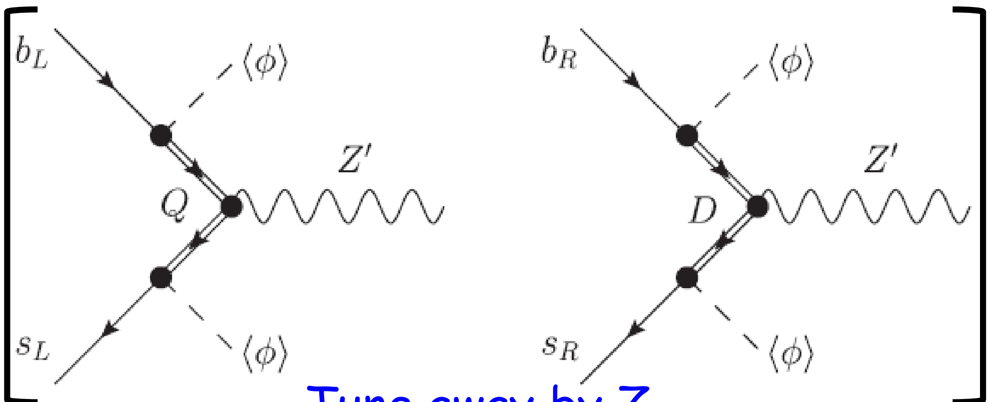


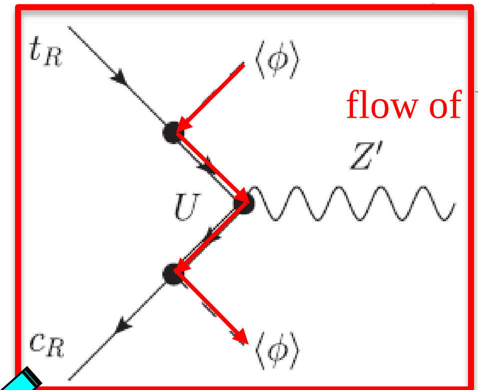
Muon g – 2 related Z' ≲ 400 MeV < m_K?

New Physics from Light Particle!?

Leptonic Z'_{g-2}-induced FCNC

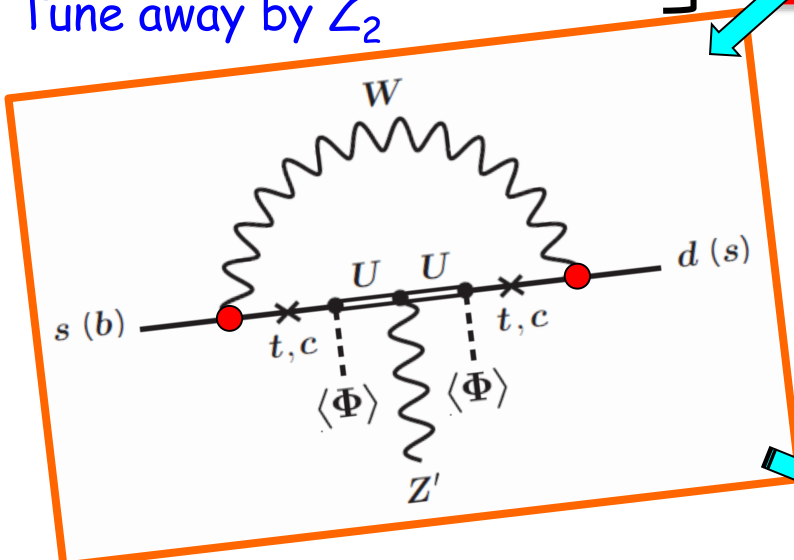
gauged $L_\mu - L_\tau$





flow of U(1)′ charge

Tune away by Z_2



Q, D, U : vector-like quarks with Z' charge
$\langle\phi\rangle$: generates Z' mass

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

Fuyoto, WSH, Kohda, 1412.4397

$K_L \to \pi^0 Z'$

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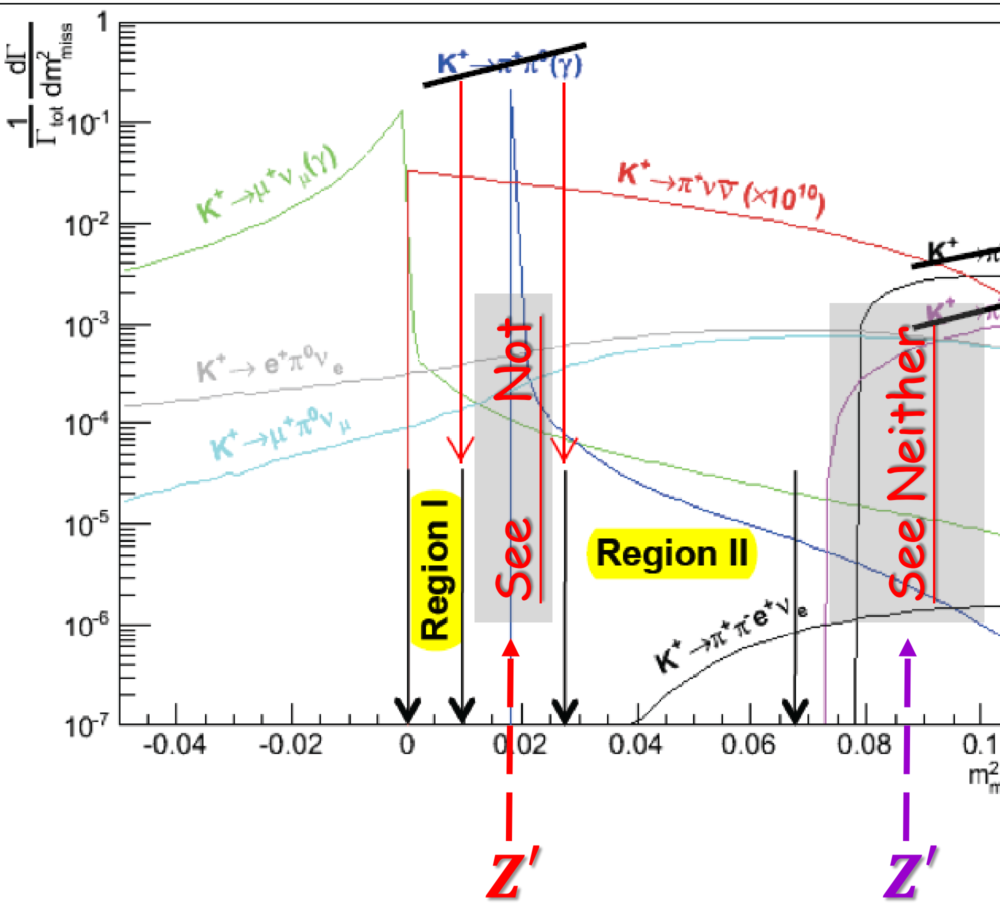

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A Surprise! "Trivial"

A $K_L \to \pi^0 \nu\bar{\nu}$ experiment, however, has no luxury for kinematic reconstruction: besides detecting two photons (assumed as π^0), it measures "nothing to nothing". Neither the K_L nor even the π^0 momentum is known. Thus, the approach is to veto everything, and to learn while pushing down the sensitivity. One, however, cannot veto weakly interacting light particles, or WILPs — the $\nu\bar{\nu}$ being the target. Thus, for $K \to \pi X^0$ where X^0 is a WILP that falls into the missing mass window, the K^+ experiment would be oblivious, *but the K_L experiment can have a blunt feel of it!* Although the GN bound of Eq. (3) is in no way violated, the perceived bound of Eq. (4) does not apply. This is the main and rather simple point of

Fuyoto, WSH, Kohda, 1412.4397

IV. Where Else? — an Illustration

Circumstantial Hints/Possibilities in Rare B & K Decays

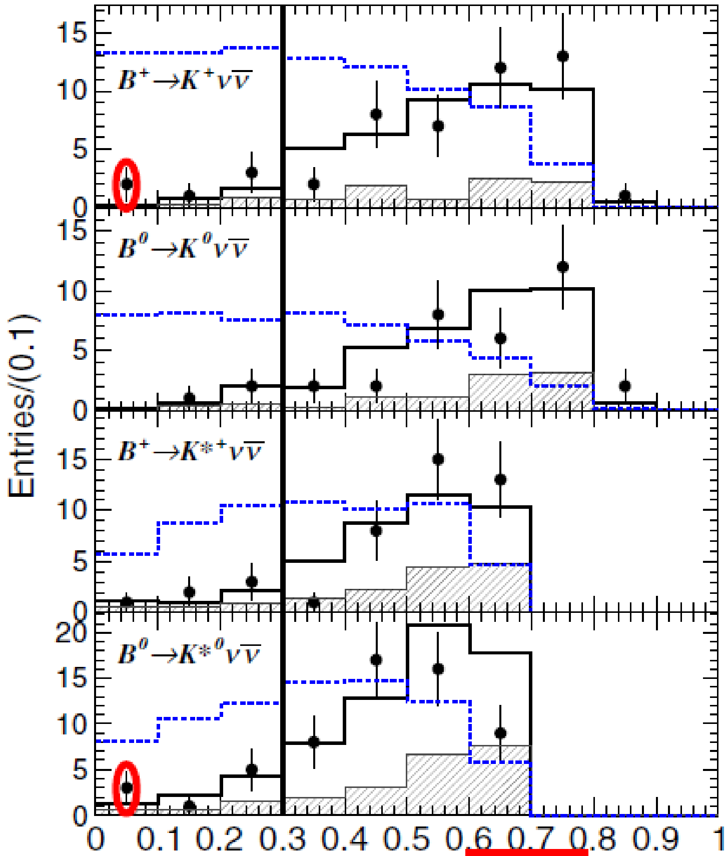
$Z' < 2m_\mu$: νν only

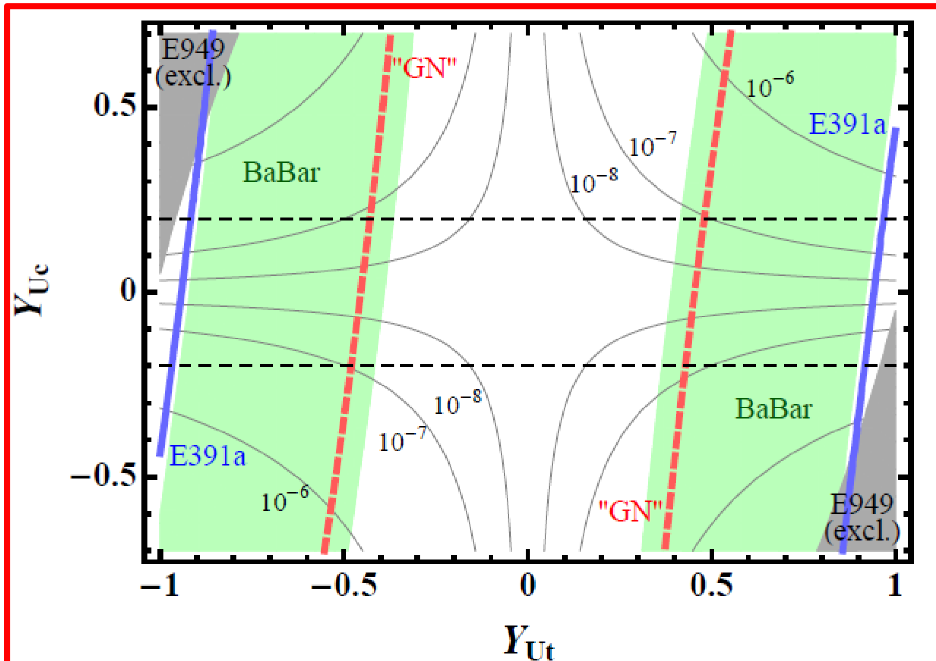
$Z' > 2m_\mu$: νν/μμ

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.

driven by lowest bin

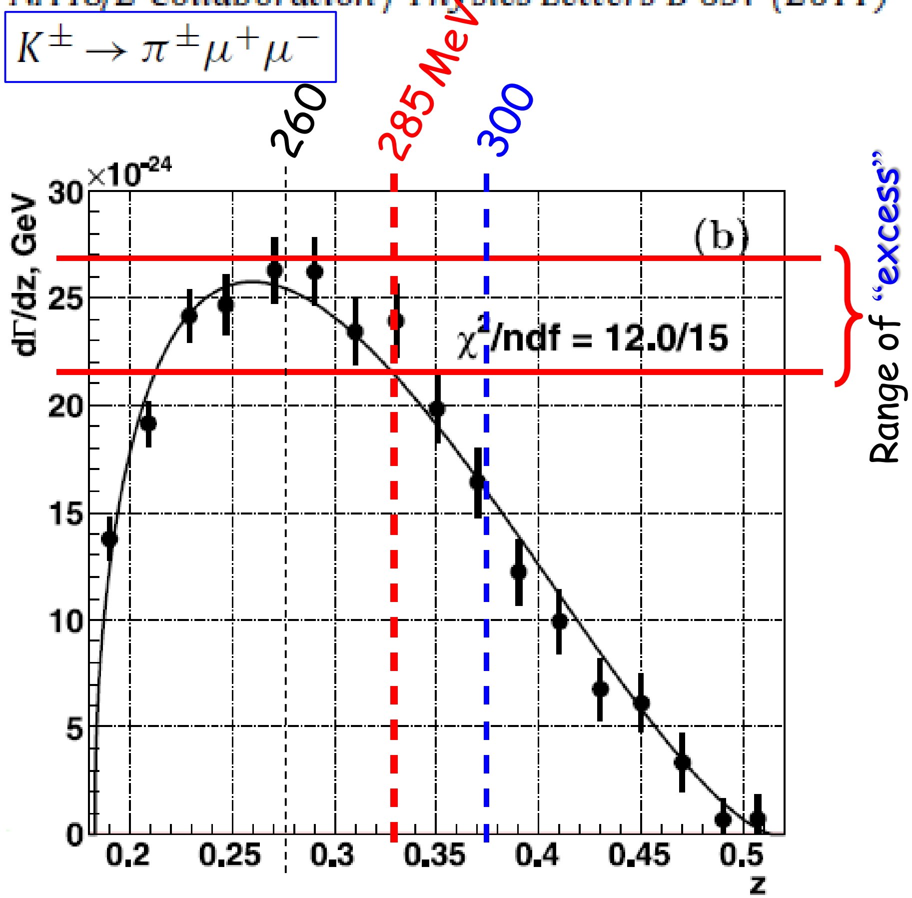
Gaussian significance of about 1.4σ. Therefore, this excess is not considered significant.

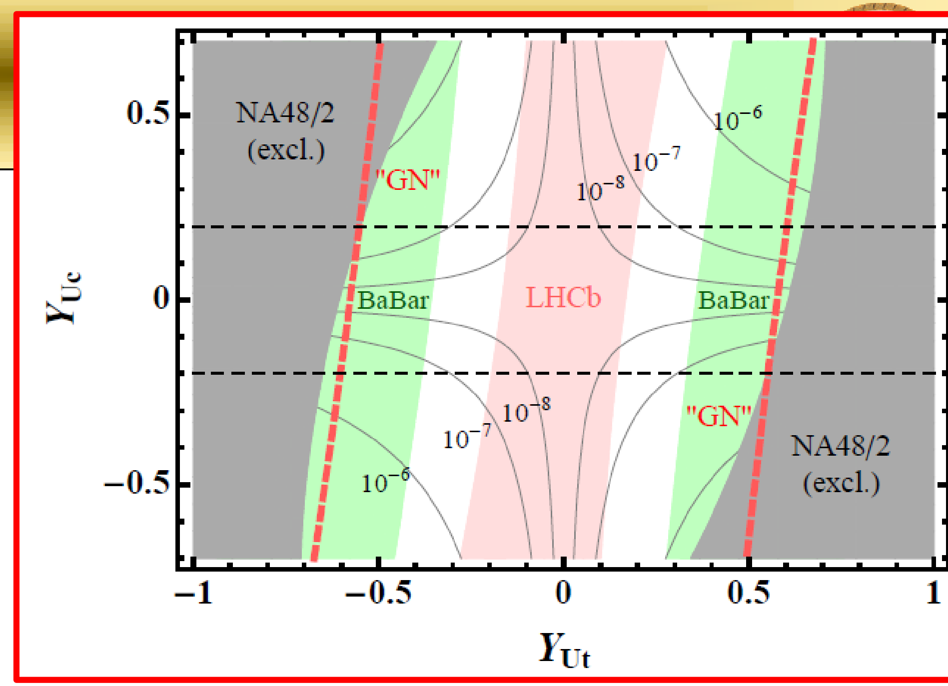
Belle needs to follow up with the Binned m_{mis} analysis. (→ Belle II)

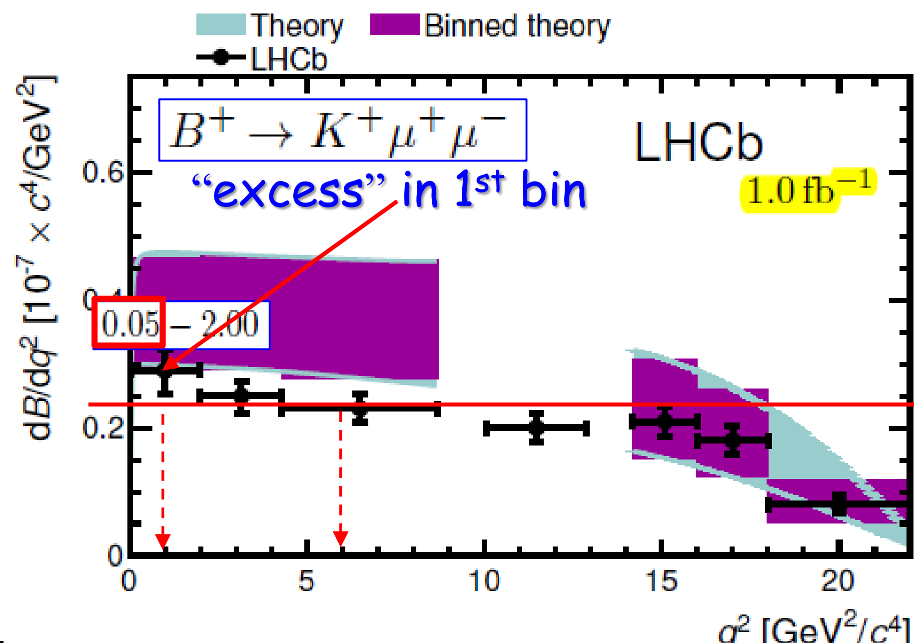
Fuyoto, WSH, Kohda, 1412.4397

The 2nd Window

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







Can be repeated by NA62

N.B. KTeV 2000 search for $K_L \to \pi^0 \mu^+ \mu^-$ is more stringent.

See M. Kohda's talk.

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

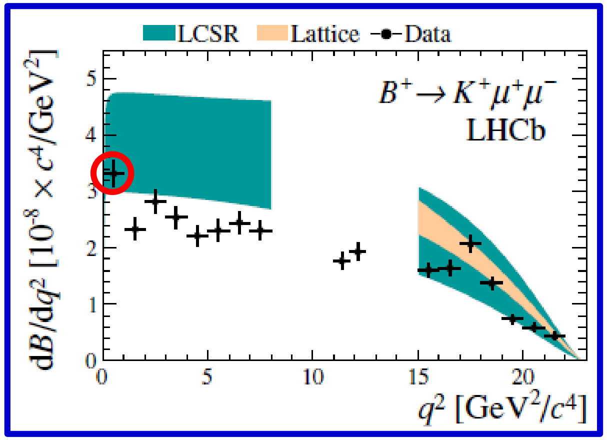
Fuyoto, WSH, Kohda, 1412.4397

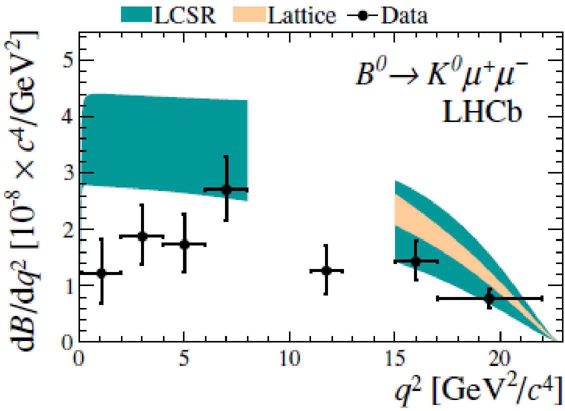
LHCb should do the "extra work"* for lowest q^2

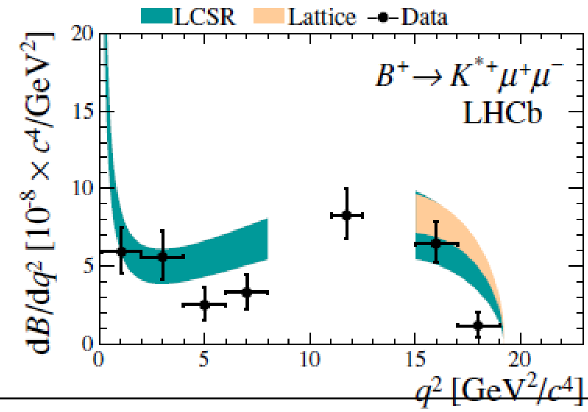
Z' ~ 0.285 GeV
→ q^2 ~ 0.09 GeV^2

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. Talk by A. Mauri 7/23 on LHCb Dark Boson search in $K^{*0}\mu^+\mu^-$ probably more constraining

* Private Communication with LHCb

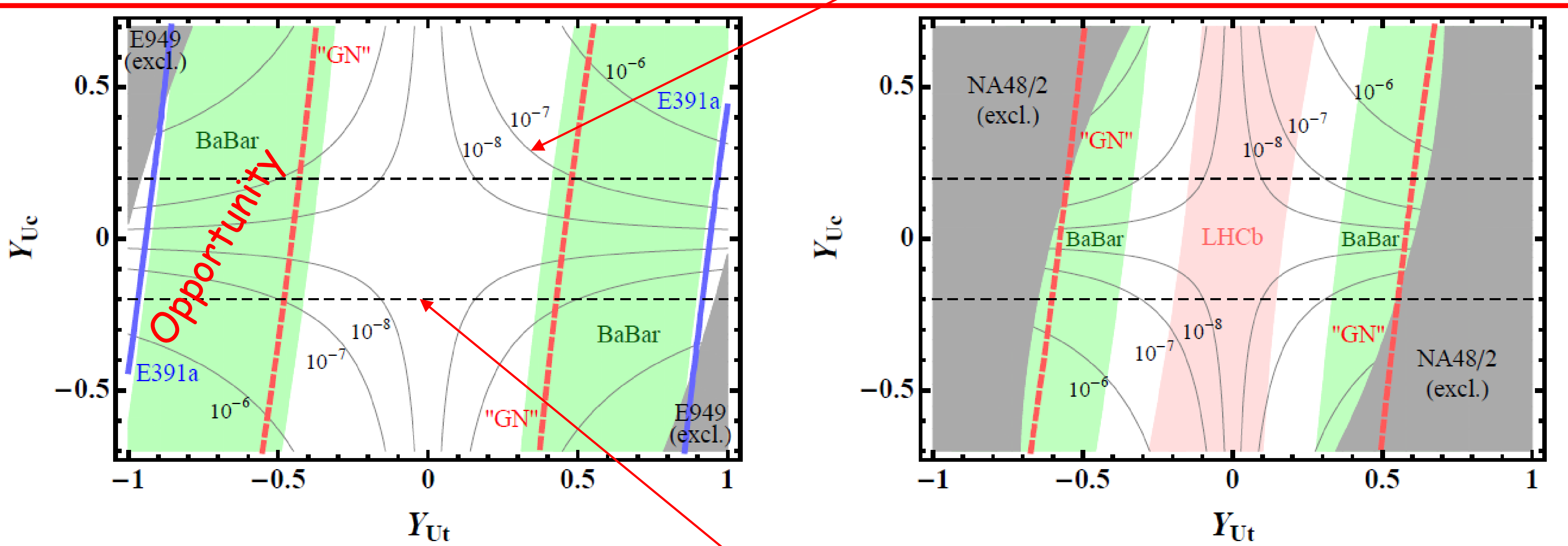
The Z'_{g-2} Landscape

Perhaps 100 TeV SPPC/FCChh Needed

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

See M. Kohda's talk in Top session.

135 MeV　　　　285 MeV



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

Fuyoto, WSH, Kohda, 1412.4397 and to appear

V. Conclusion

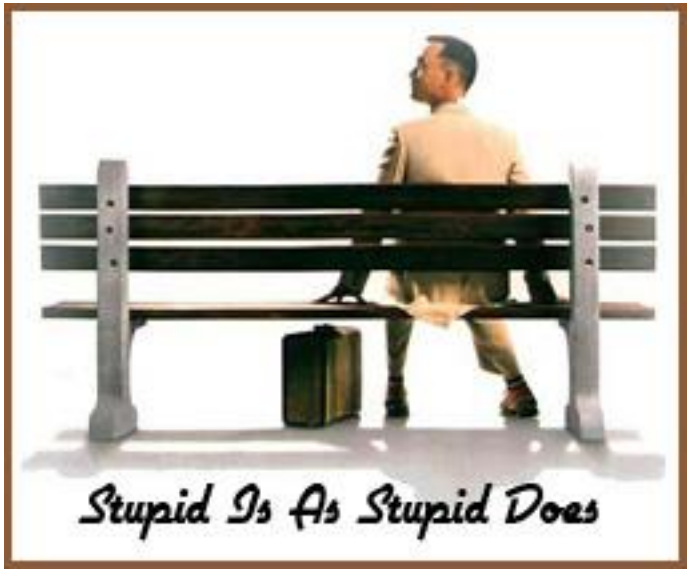
- $K_L \to \pi^0$ + nothing: can occur above Grossman-Nir Bound ➔ KOTO !

  If See Early Event(s), Try Hard to Kill ... But not Overly So.

- If above GN Bound, then likely "π^0" mass object (that slips thru NA62)

- When KOTO reaches below GN Bound, concept still effective.

  ➔ KOTO/NA62/LHCb/Belle(II) all in game.



Run, KOTO, Run !

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

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

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