Implication of ALEPH 30 GeV dimuon excess at the LHC

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Collaboration with P. Ko (KIAS) , Jinmian Li (KIAS)

Based on arXiv:1610.07526

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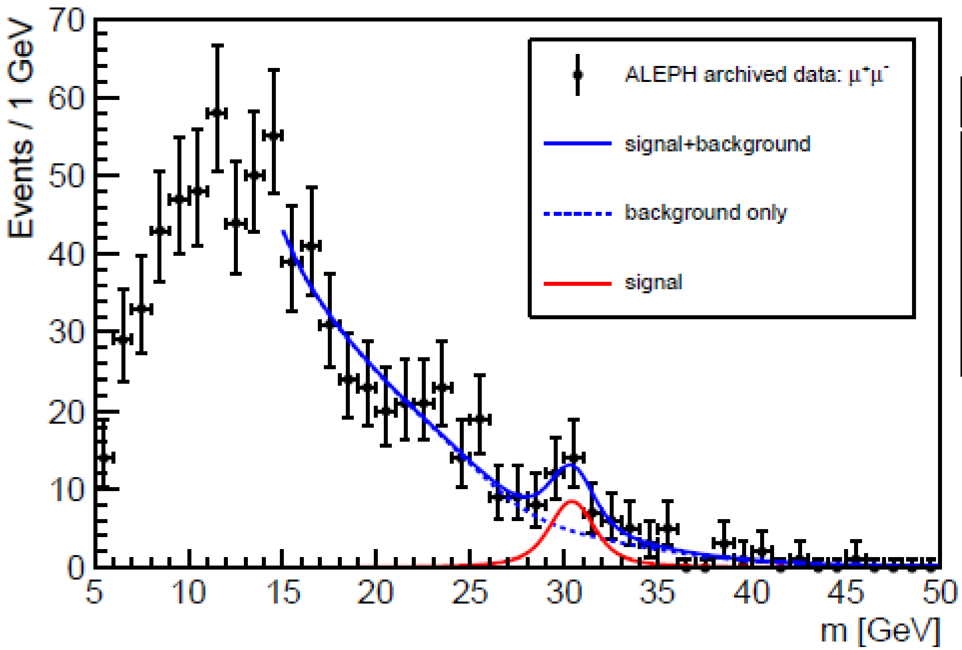
Dimuon excess at Z decay



Parameter	Value	Error
# signal events	32.31	± 10.87
# background events (overall)	1457.06	± 89.71
mass [GeV]	30.40	± 0.46
width (Breit-Wigner) [GeV]	1.78	± 1.14
width (Gaussian) [GeV]	0.74	± 0.10

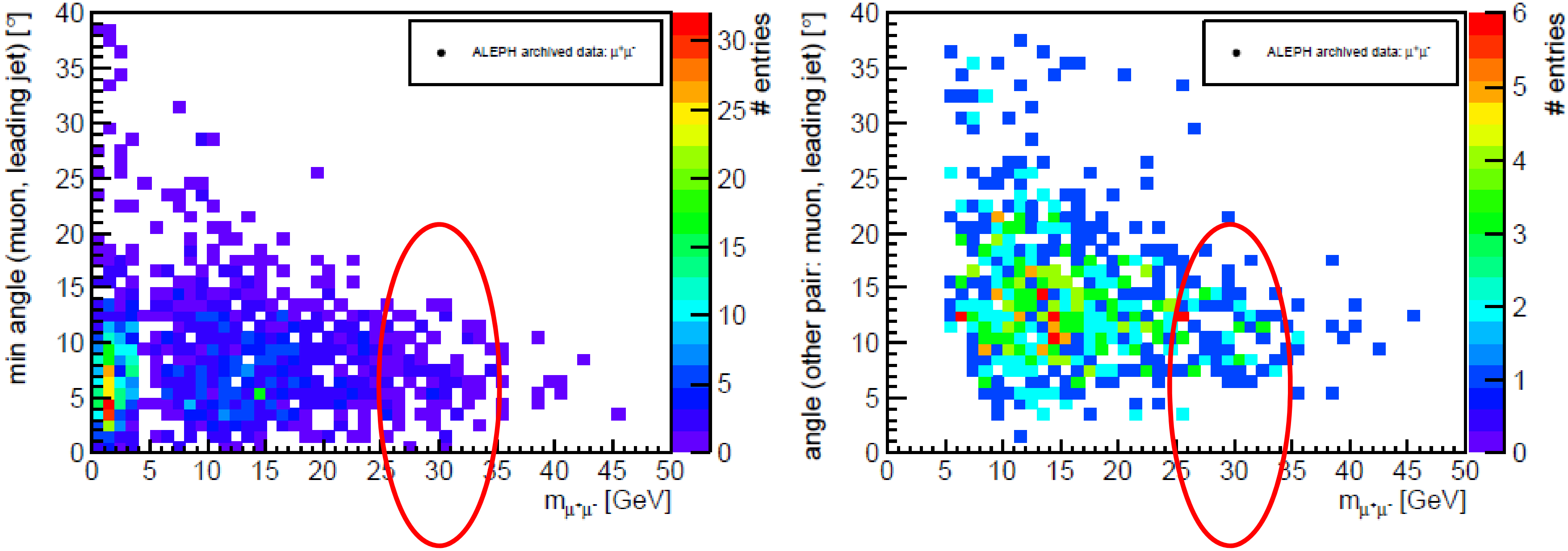
Arno Heister, arXiv:1610.06536

- re-analyze the archived ALEPH data at the Z resonance
- dimuon excess observed in $Z \to b\bar{b}\mu^+\mu^-$ at m_X = 30.40 GeV
- significance = 2.6σ

$$\mathrm{Br}(Z \to b\bar{b}\mu^+\mu^-) \sim 1.1 \times 10^{-5}$$

$$\Gamma_{\mathrm{tot}}(X) = (1.78 \pm 1.14)\ \mathrm{GeV}$$

Minimum angle of b jet and μ

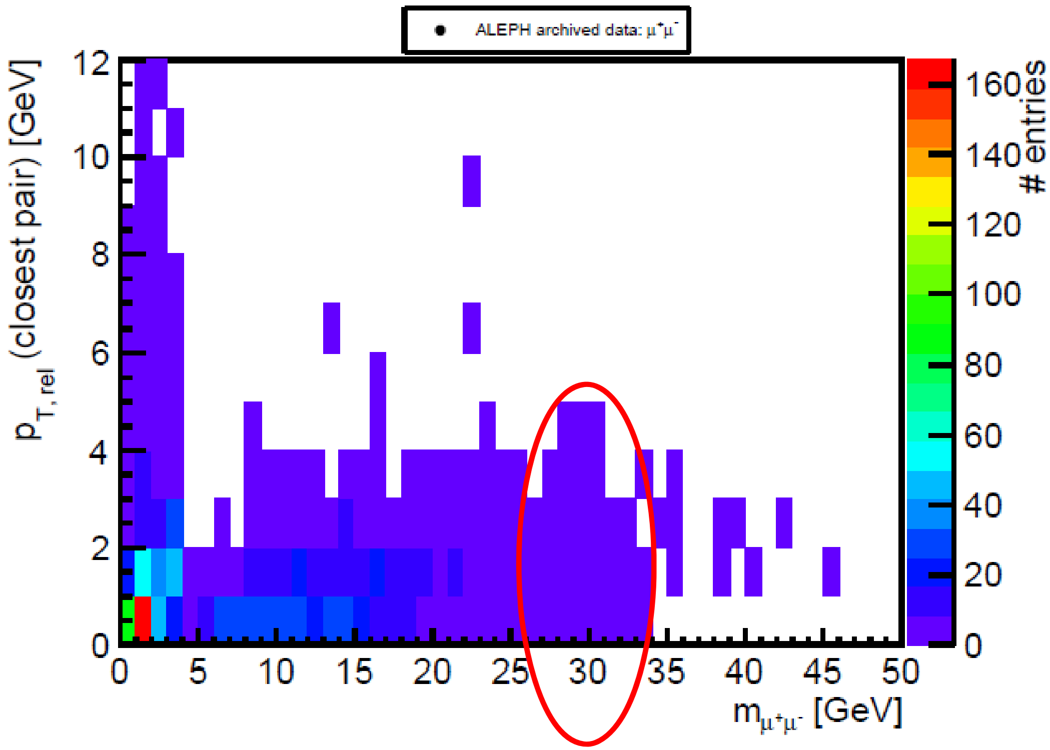


Arno Heister, arXiv:1610.06536

- Left: the minimum angle between a muon and the leading b jet < 15°

- Right: the angle of the other muon-jet combination is in the range of 5° and 20 °

Relative P_T of closest μ-jet pair



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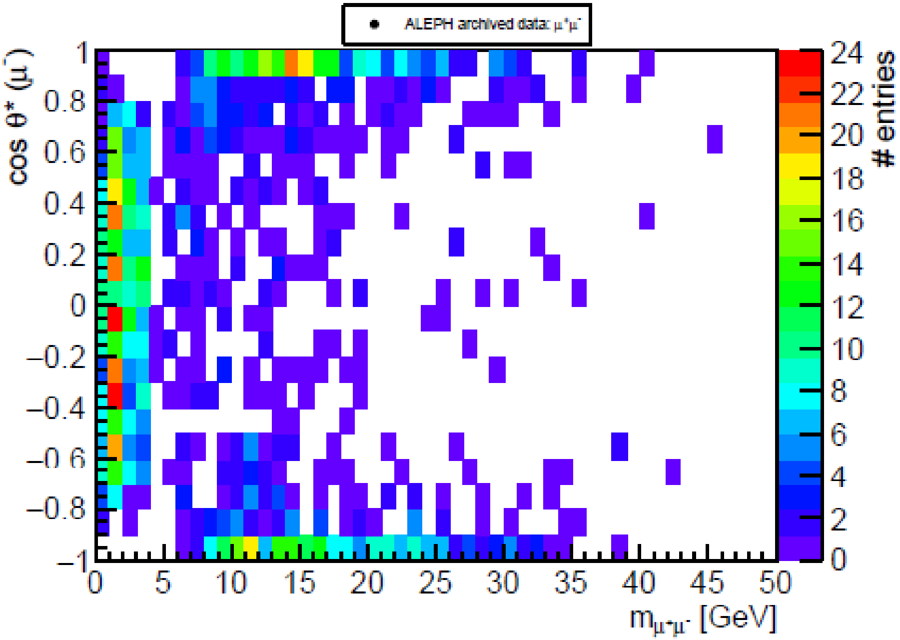
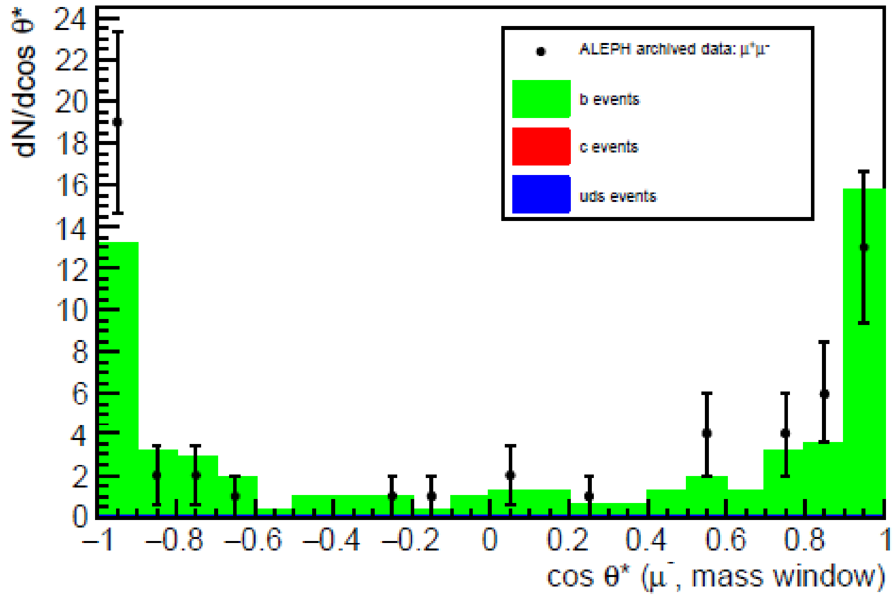
$$p_T^{\mathrm{rel}} \leq 4 \text{ GeV}$$

$\cos\theta_\mu^*$ distribution





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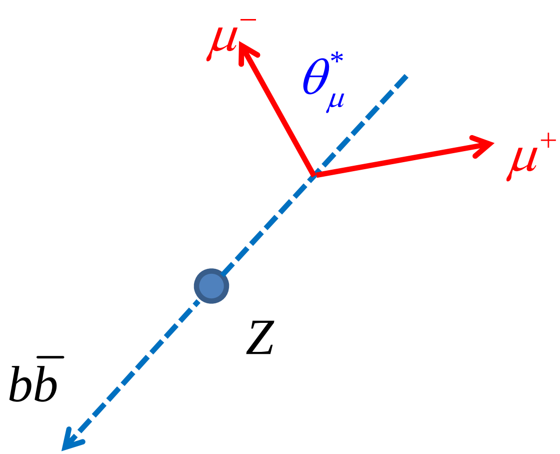


- peaks at $\cos\theta_\mu^* \approx \pm 1$
- would prefer X being a spin-1 particle
- close to the b jets

Short summary

• The distribution of dimuon invariant mass seems to imply a resonance X at 30 GeV with 2.6σ significance

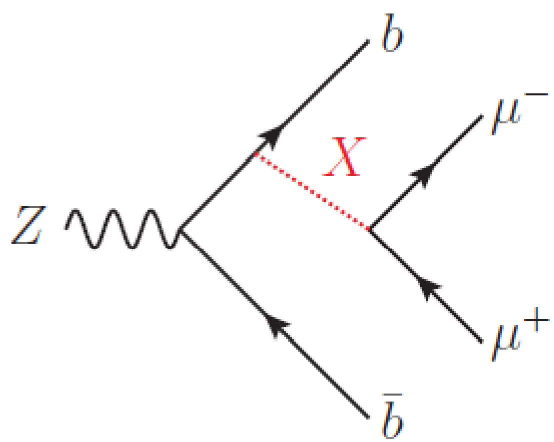
$$\mathrm{BR}(Z \to b\bar{b}\mu^+\mu^-) \sim 10^{-5}$$

$$\Gamma(Z \to b\bar{b}\mu^+\mu^-) \sim 1.7\ \mathrm{GeV}$$

• But, some kinematical distributions disfavor the resonance interpretation of the excess

• We assume the resonance interpretation and find its implication to the LHC phenomenology in a few simplified models

Simplified Model I



$$\mathcal{L}_{\text{scalar}} = s\sum_f g_f^s \bar{f} f,$$
$$\mathcal{L}_{\text{pseudoscalar}} = ia\sum_f g_f^a \bar{f}\gamma_5 f,$$
$$\mathcal{L}_{\text{vector}} = -V_\mu \sum_f g_f^V \bar{f}\gamma^\mu f,$$
$$\mathcal{L}_{\text{axial vector}} = -A_\mu \sum_f g_f^A \bar{f}\gamma^\mu\gamma_5 f.$$

- Assume X (=s,a,V,A) couples with b and μ
- X decays into a $b\bar{b}$ or $\mu^+\mu^-$ pair

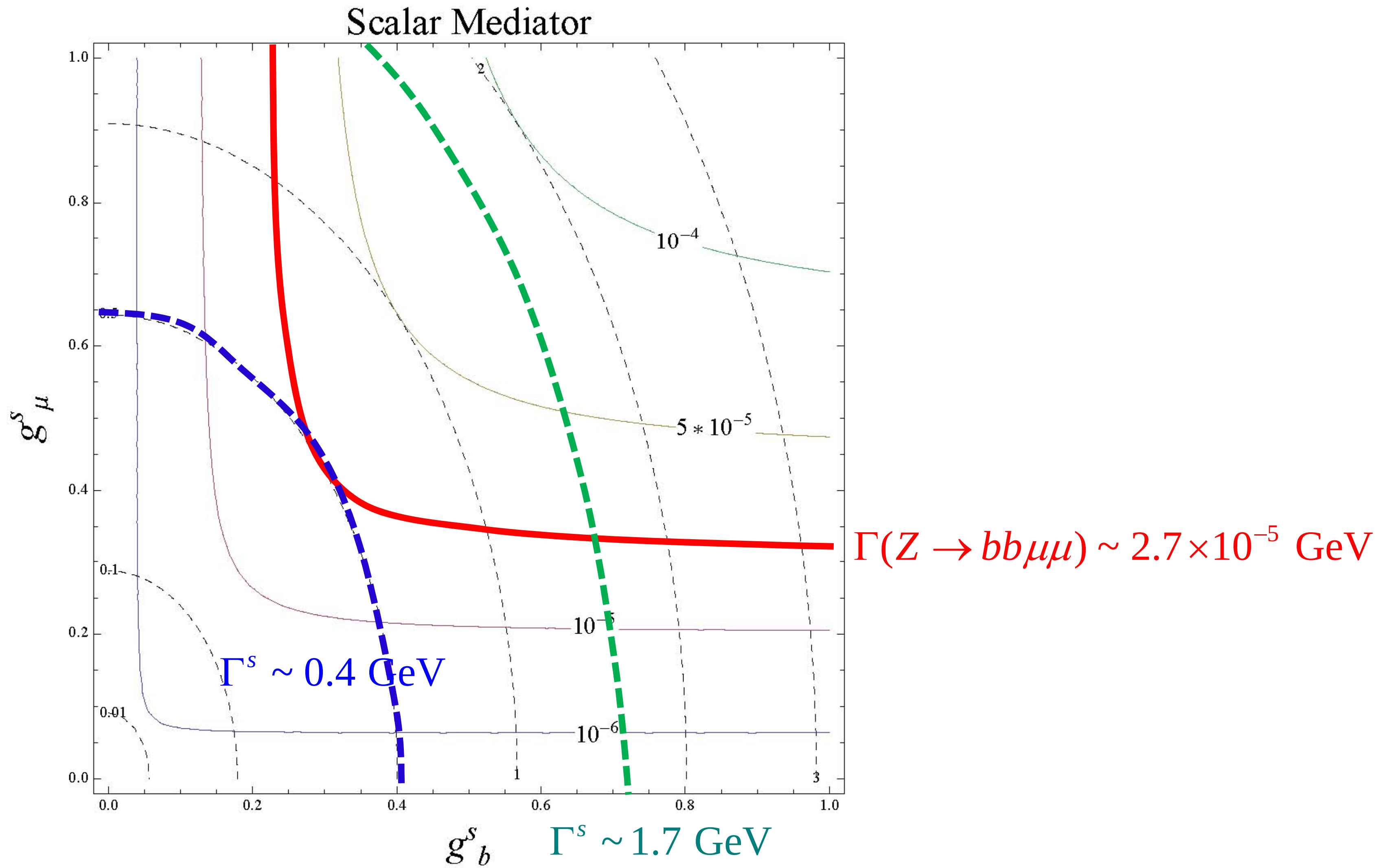
$$\Gamma^X \sim 1 \text{ GeV for } g_f^s \sim 0.5 \text{ or } g_f^V \sim 0.6$$

- but may yield large decay widths for $Z \to 4b, 4\mu$

$g_b^s \lesssim 0.7$ $\quad$ $g_b^V \lesssim 0.5$ $\quad$ from $\quad Z \to 4b$

$g_\mu^V \lesssim 0.03$ $\quad$ from $\quad Z \to 4\mu$ in the U(1)$_\mu$-U(1)$_\tau$

Scalar Mediator Model



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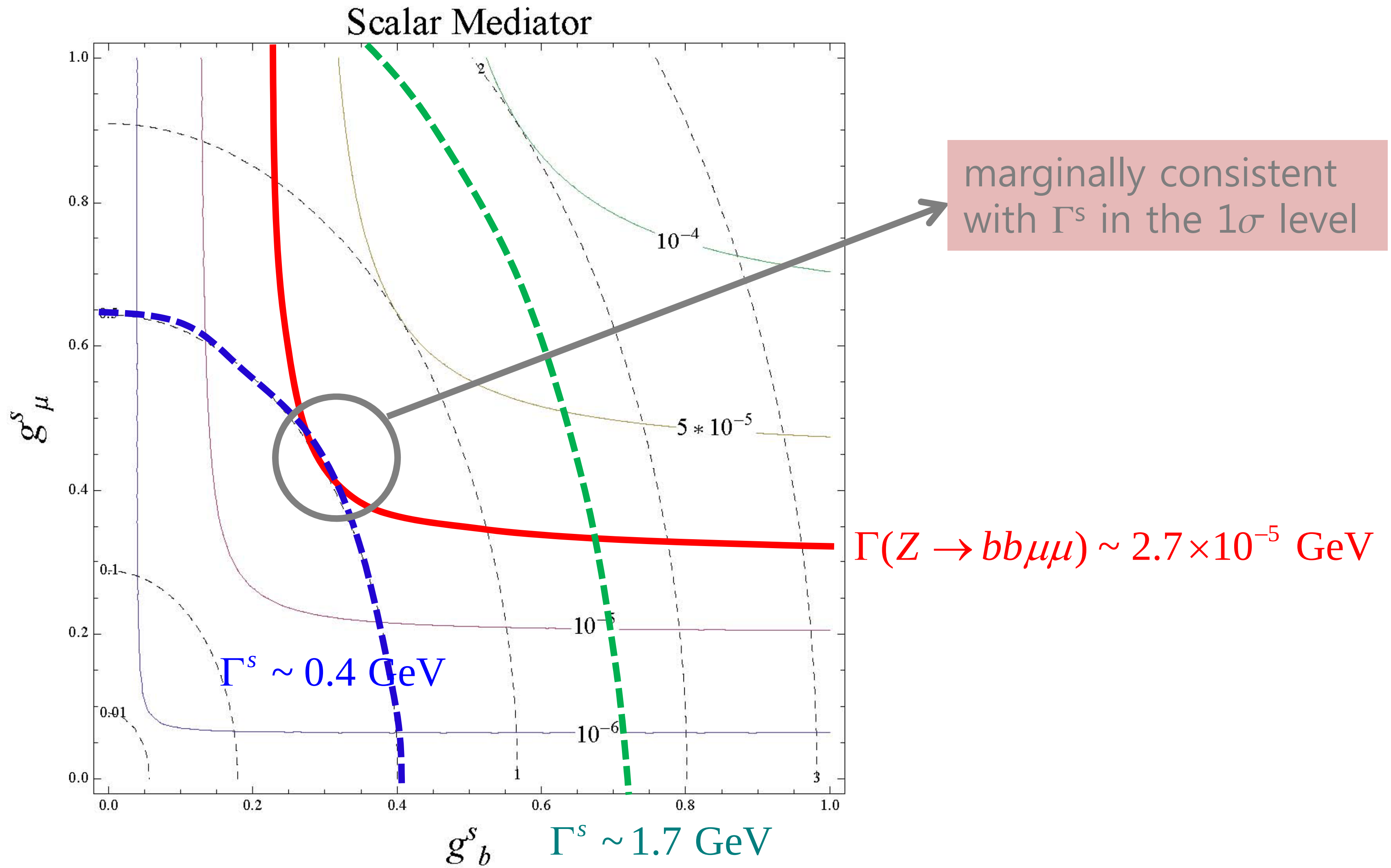

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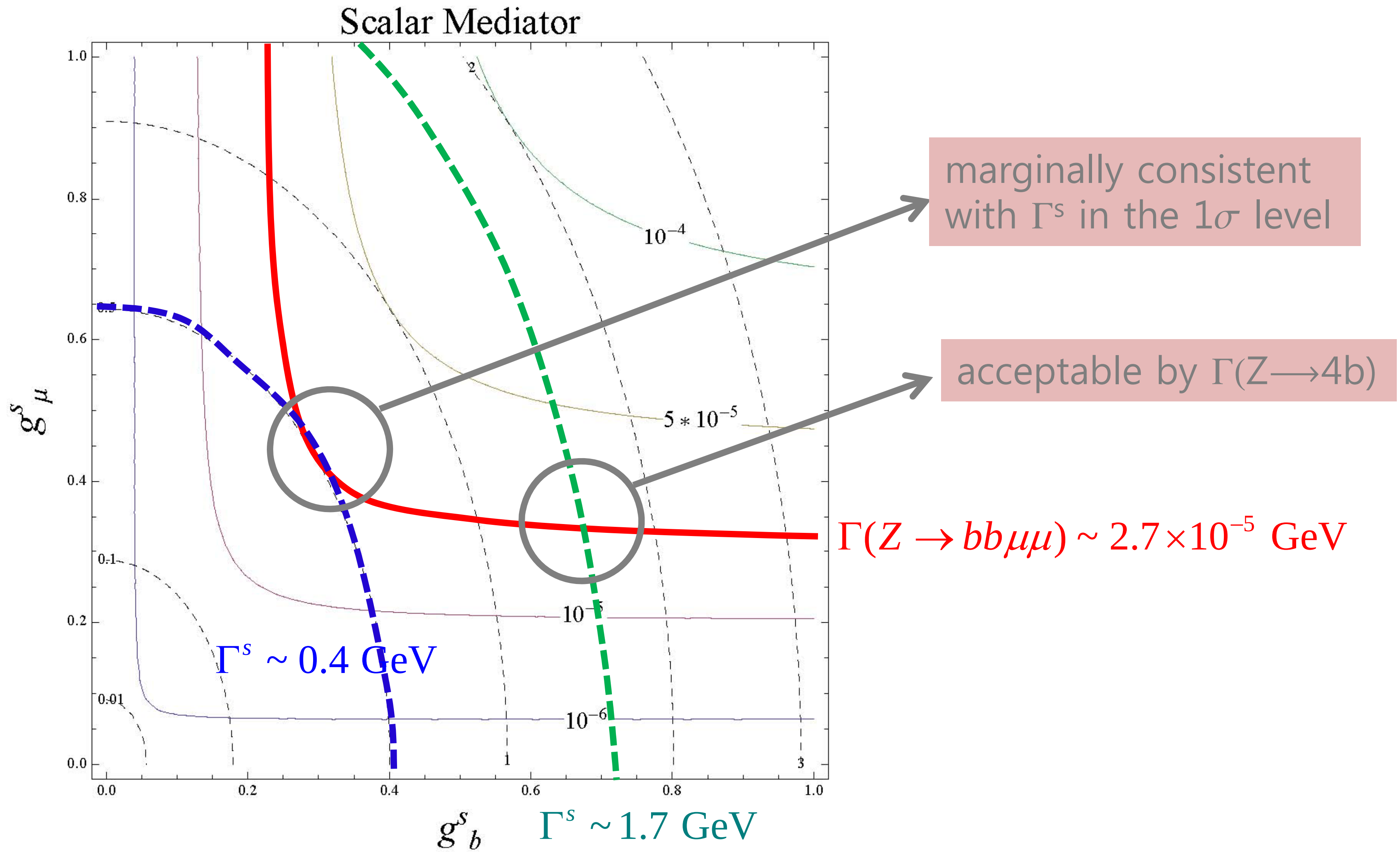
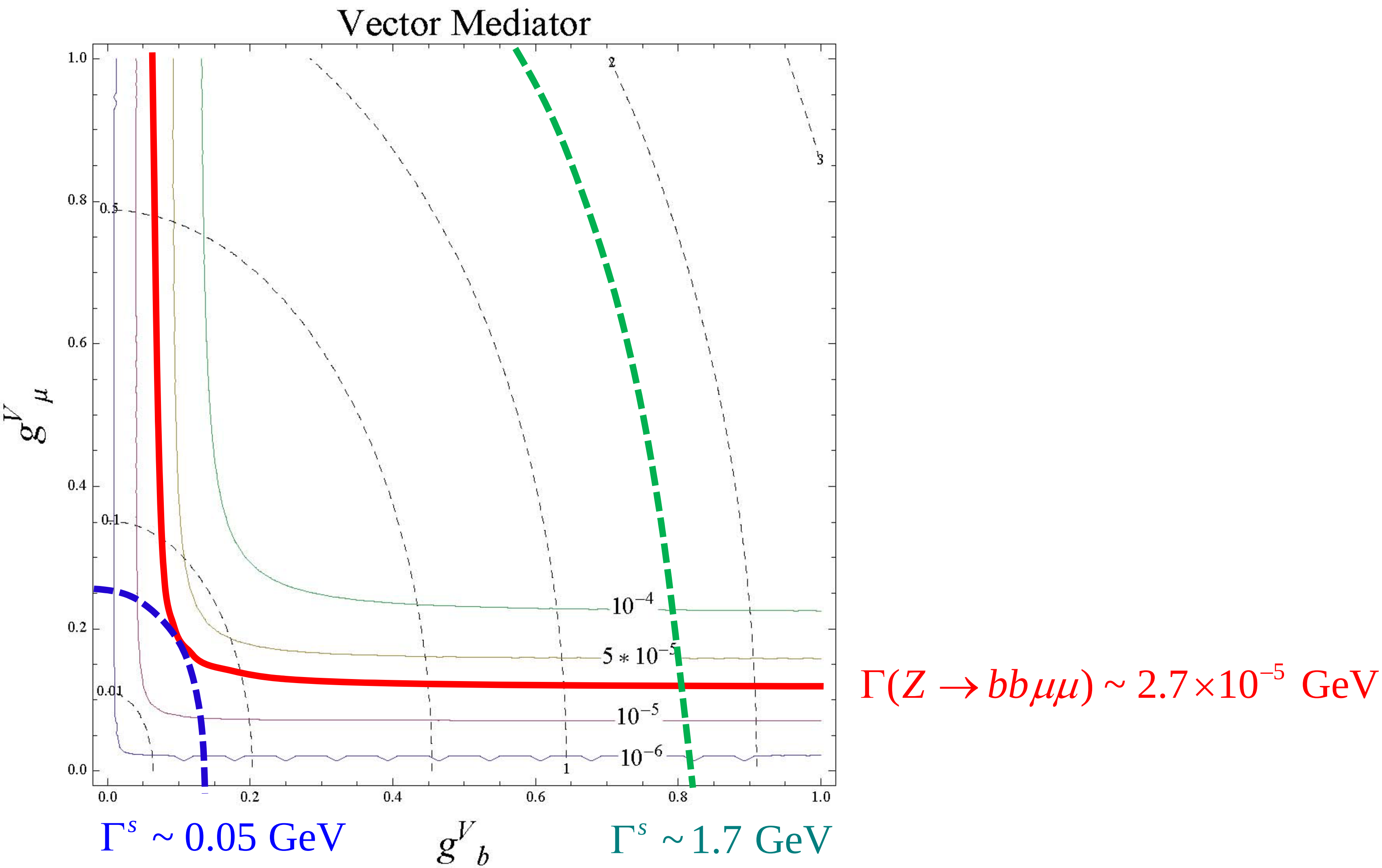


Vector Mediator Model



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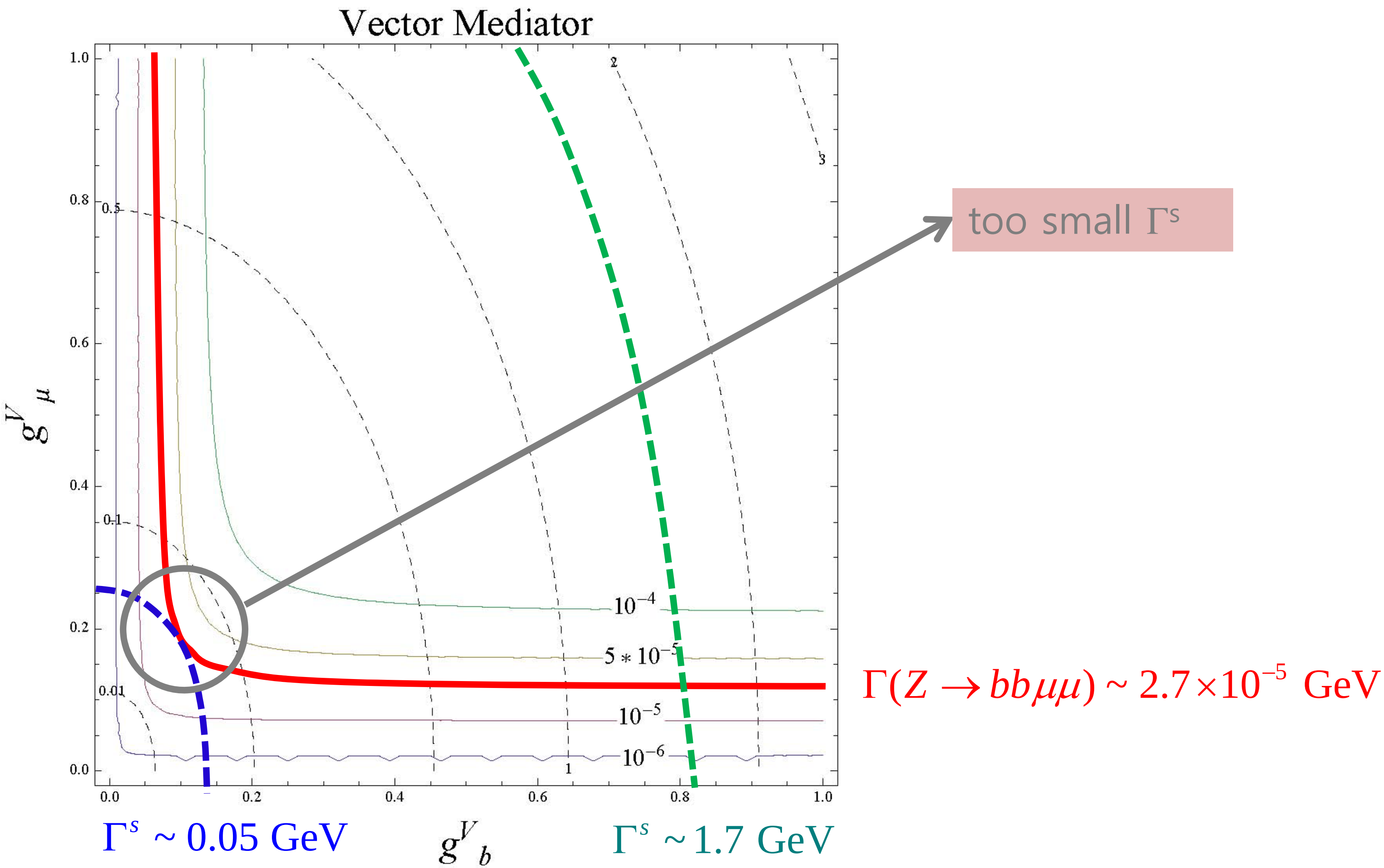

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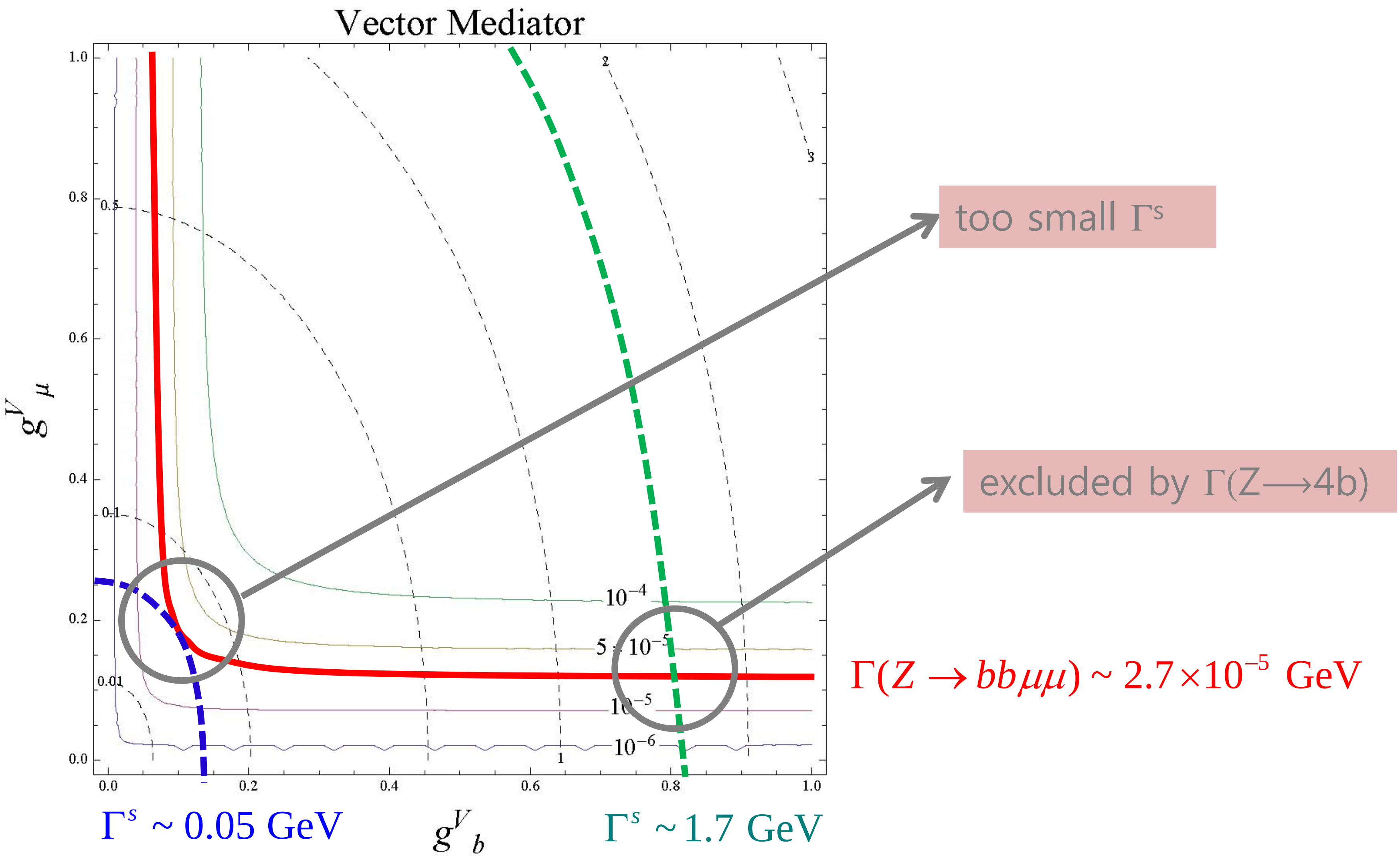

LHC Phenomenology (vector)

- the models can be constrained by DY, top decay, Z′bb production

Benchmark point I

$g_b^{Z'}$	$g_\mu^{Z'}$	$\Gamma^{Z'}(Z \to bb\mu\mu)$	$\Gamma(Z' \to bb, \mu\mu)$
0.1	0.1	2.72×10^{-5}	0.0322
$\sigma^{13}(\mu\mu)/\sigma^{1.96}(\mu\mu)$	$\Gamma(t \to bWZ')$	$\sigma(pp \to bbZ')$	$\mathrm{Br}(Z' \to \mu\mu)$
$714.5/55.8$ pb	1.267×10^{-4}	136.1 pb	0.25

Benchmark point II

$g_b^{Z'}$	$g_\mu^{Z'}$	$\Gamma^{Z'}(Z \to bb\mu\mu)$	$\Gamma(Z' \to bb, \mu\mu)$
0.7	0.1	3.036×10^{-5}	1.19
$\sigma^{13}(\mu\mu)/\sigma^{1.96}(\mu\mu)$	$\Gamma(t \to bWZ')$	$\sigma(pp \to bbZ')$	$\mathrm{Br}(Z' \to \mu\mu)$
$920.5/71.1$ pb	0.0062	6645 pb	0.0068

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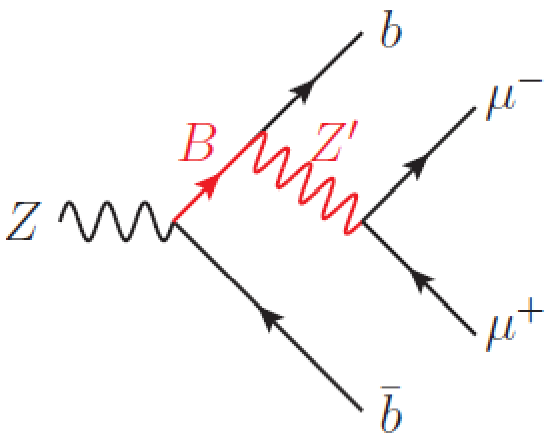
• too large Drell-Yan production cross section excludes this type of models

• similar features in the scalar, pseudoscalar, and axial-vector models

Simplified Model II

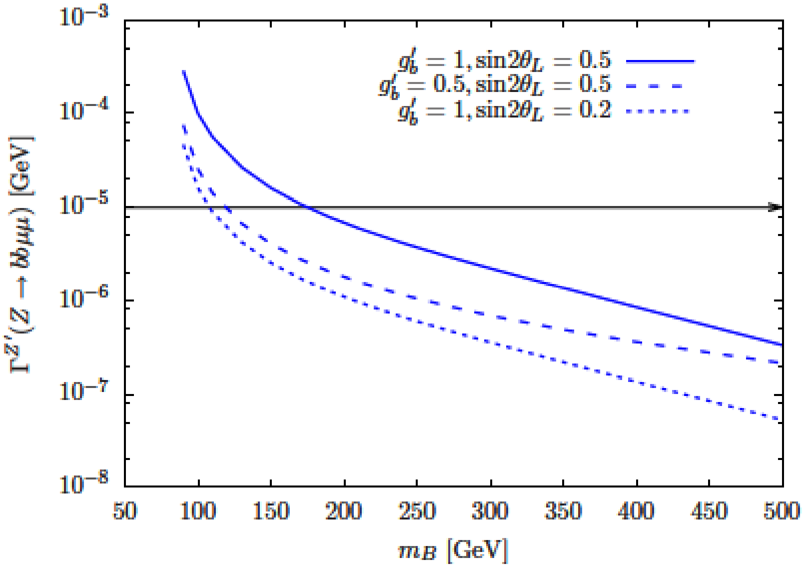


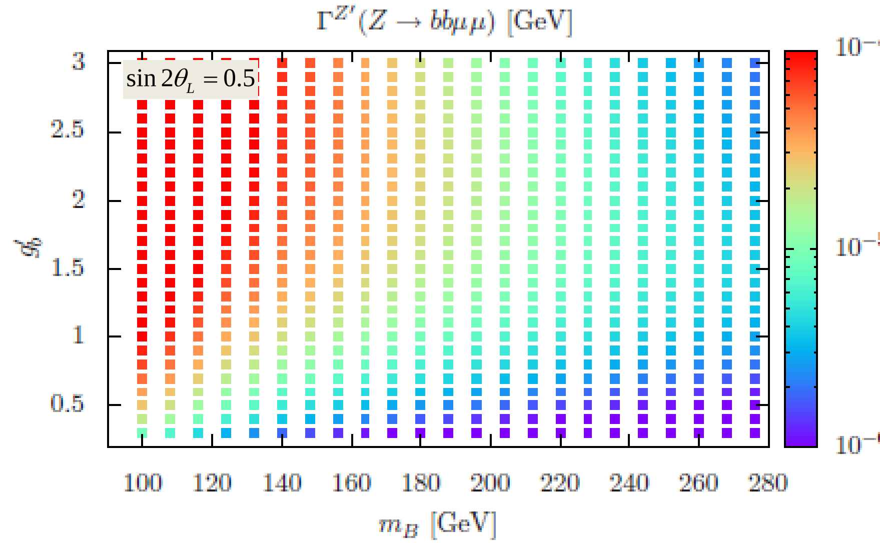
One way to avoid large DY cross section is to make Z′ decouple from bb and introduce a new vectorlike down-type quark B

$$\mathcal{L} = g'_\mu Z'_\rho \bar{\mu}\gamma^\rho \mu + g_s G^a_\mu \bar{B}\gamma^\mu T^a B - \left[\frac{1}{2} g'_b Z'_\rho \bar{b}\gamma^\rho B + \frac{g_W \sin 2\theta_L}{4 c_W} Z_\mu \bar{b}\gamma^\mu P_L B + h.c.\right]$$

- Z' decay: only $Z' \to \mu\mu$ is allowed kinematically by assuming $m_B \gg m_{Z'}$
- g'_μ is irrelevant to $\Gamma(Z \to bb\mu\mu)$ and is taken to be 0.01

Simplified Model II





- The dimuon excess could be explained for

$$\sin 2\theta_L = 0.5$$

$$m_B = 100 \sim 200 \text{ GeV}$$

$$g'_\mu = 0.5 \sim 3$$

Bench Mark Points (Model II)

- the models can be constrained by BB, bB, qB production at the LHC

Benchmark point III

g_b'	m_B	$\Gamma^{Z'}(Z \to bb\mu\mu)$	$\Gamma(B \to bZ')$
0.7	110 GeV	2.75×10^{-5}	3.4 GeV
$\mathrm{Br}(B \to bZ')$	$\sigma^{13}(BB)/\sigma^{8}(BB)$	$\sigma^{13}(bB)/\sigma^{8}(bB)$	$\sigma^{13}(qB)/\sigma^{8}(qB)$
1.0	3942/1203 pb	1.68/0.89 pb	7.49/3.2 pb

Benchmark point IV

g_b'	m_B	$\Gamma^{Z'}(Z \to bb\mu\mu)$	$\Gamma(B \to bZ')$
2.0	180	2.35×10^{-5} GeV	124.4 GeV
$\mathrm{Br}(B \to bZ')$	$\sigma^{13}(BB)/\sigma^{8}(BB)$	$\sigma^{13}(bB)/\sigma^{8}(bB)$	$\sigma^{13}(qB)/\sigma^{8}(qB)$
1.0	391/120 pb	0.21/0.1 pb	4.24/1.67 pb

- signals would be bb+4μ, bb+2μ, bj+2μ

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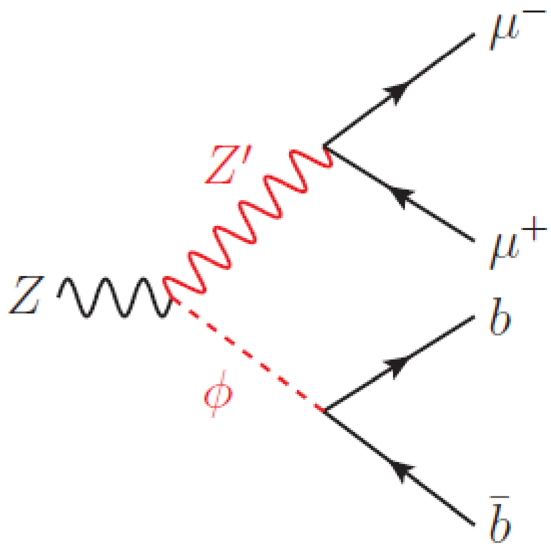
- signals would be bb+4μ, bb+2μ, bj+2μ
- too large BB production cross section (bb+4μ) disfavors this model

Simplified Model III (U(1)′)



U(1)′ could be $U(1)_\mu$-$U(1)_\tau$

A real scalar ϕ is charged under both $U(1)_Y$ and U(1)′

$$D_\mu \phi = \partial_\mu \phi - i g_1 Y_\phi B_\mu \phi - i g' Y'_\phi Z'_\mu \phi$$

ϕ couples with bb via a mixing with H

- mass terms in the interaction eigenstates with g_1, g, g′ for $U(1)_Y$, $SU(2)_L$, U(1)′

$$M_V^2 = \begin{pmatrix} g_1^2 \frac{v^2}{8} + g_1^2 Y_\phi^2 v_\phi^2 & -g g_1 \frac{v^2}{8} & g_1 g' Y_\phi Y'_\phi v_\phi^2 \\ -g g_1 \frac{v^2}{8} & g^2 \frac{v^2}{8} & 0 \\ g_1 g' Y_\phi Y'_\phi v_\phi^2 & 0 & g'^2 Y'^2_\phi v_\phi^2 \end{pmatrix}$$

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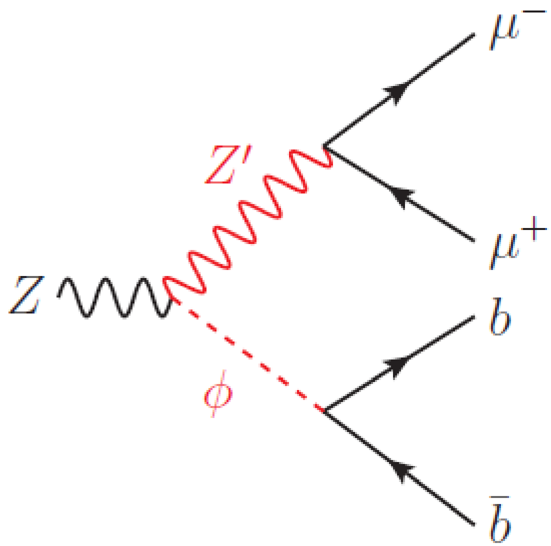

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$$\sim \frac{1}{2} m_{Z'}^2 \Rightarrow v_\phi = \frac{m_{Z'}}{\sqrt{2} g' Y'_\phi}$$

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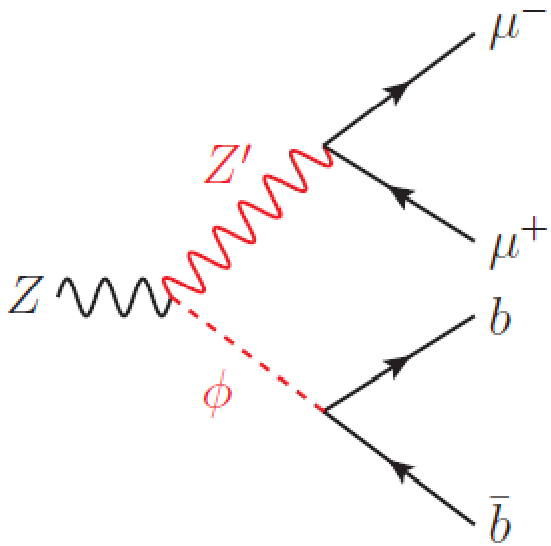

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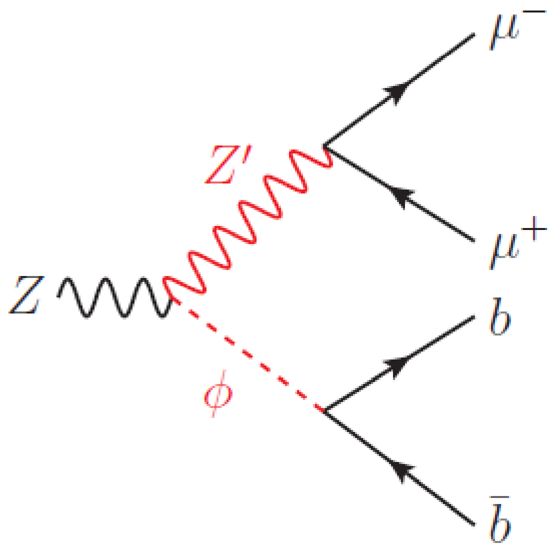
$\sim \sin\theta_{ZZ'} < 10^{-2}$

$\Rightarrow \quad \dfrac{Y_\phi}{Y'_\phi} \le 3.2\times 10^{-2} g'$

Simplified Model III (U(1)′)



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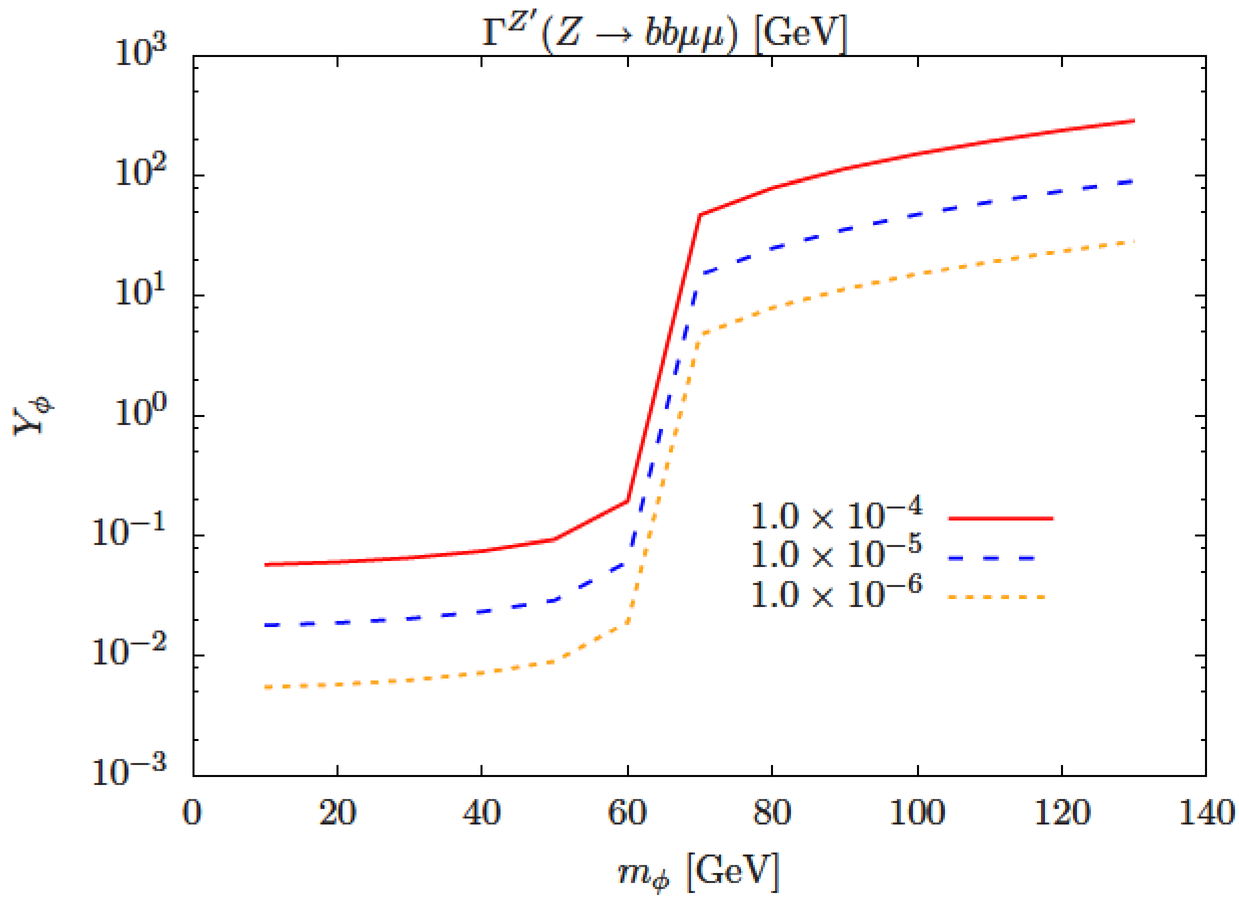
$\sim \sin\theta_{ZZ'} < 10^{-2}$

$\Rightarrow \frac{Y_\phi}{Y'_\phi} \le 3.2 \times 10^{-2} g'$

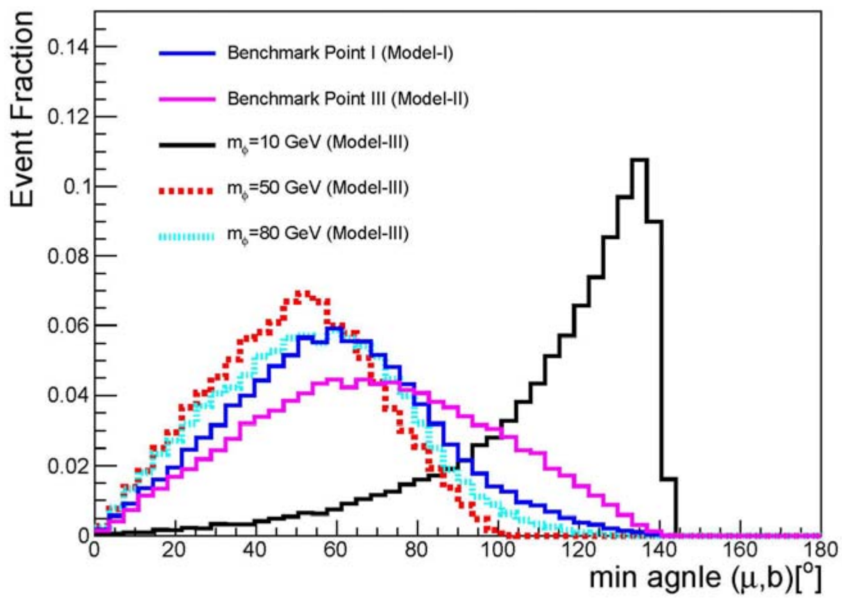
$g' \le 0.02 \Rightarrow \frac{Y'_\phi}{Y_\phi} \ge 1575$

Simplified Model III (U(1)′)

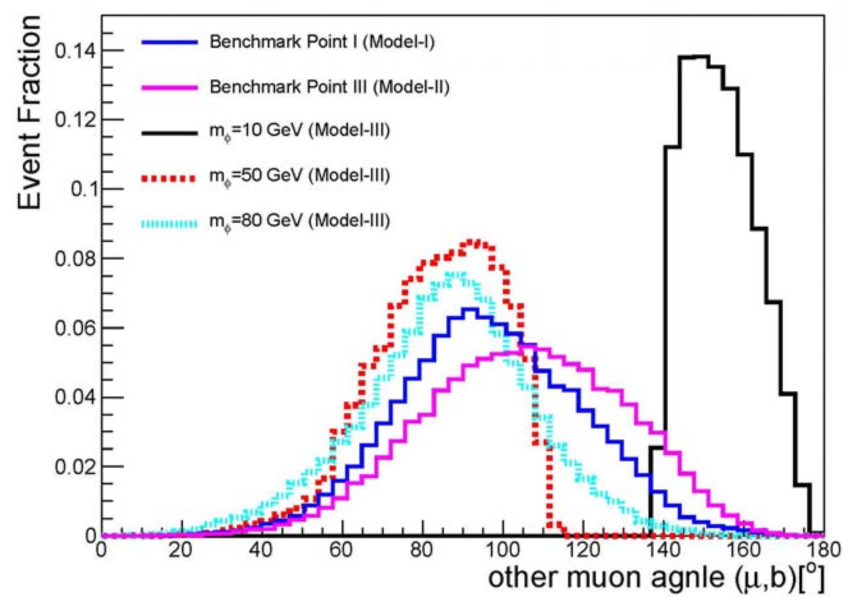


- The partial decay width strongly depends on the mass of ϕ

Kinematical distributions



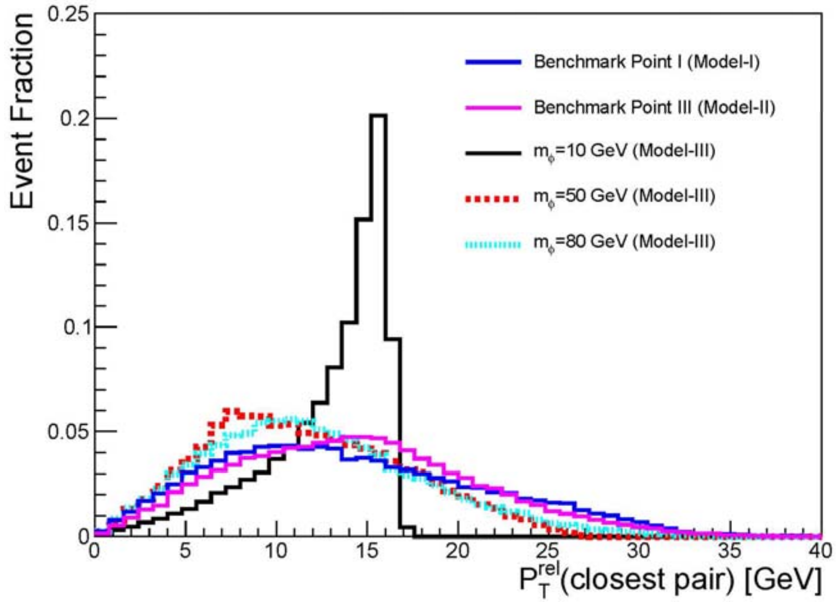
the minimum angle between a μ and the leading jet

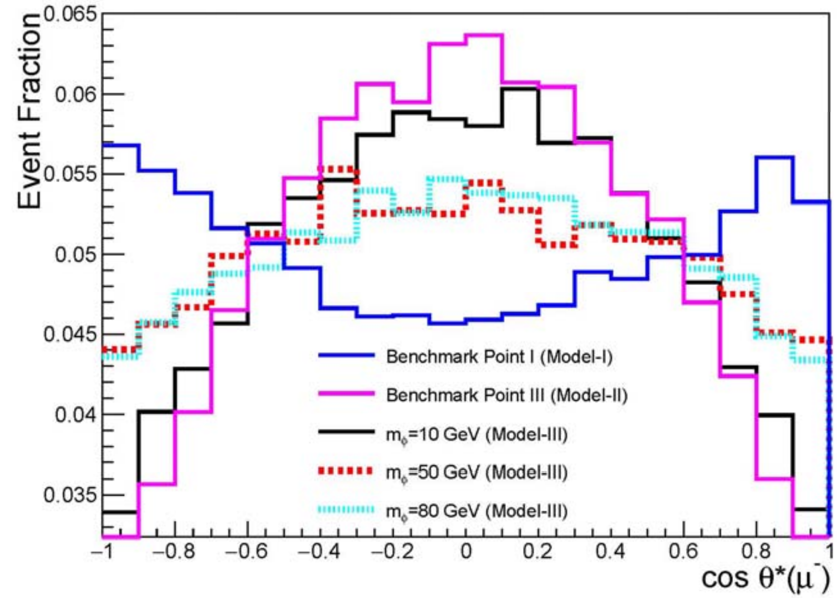


the angle of the other muon-jet combination

- black line: muon's directions tend to be opposite to those of b jets
- other lines: milder, but still have larger angles than data

Kinematical distributions





relative transverse momentum

$\cos\theta_\mu^*$

- the relative transverse momentum of closest pair has a peak at more than 5 GeV
- only blue lines has peaks at $\cos\theta_\mu^* \approx \pm 1$

Dark matter

- Z′ might decay into extra particles or dark matter candidates according to the model building

- Then some experimental bounds (DY, BB production) might be avoided, for example, by reducing the branching ratio of Z′ to a muon pair

- However it does not help resolving the problem because it increases the total decay width of Z′ and we cannot obtain the correct partial Z decay width

- Kinematical distributions are not affected by the extra decay channels and disfavor a resonance interpretation of X

Conclusions

• We consider three types of simplified models for a resolution of the dimuon excess observed in the re-analysis of archived ALEPH data

• One can find the parameter spaces satisfying the ALEPH data, but

• Model I predicts too large Drell-Yan prodcution rate at the LHC

• Model II predicts too large BB prodcution rate at the LHC

• Model III might be consistent with LHC data, but we need a large U(1)′ charge for ϕ, which means that the model-building is not easy

• Kinematical distributions of the dimuon excess disfavor the interpretation of dimuon excess as a resonance