MONO-HIGGS DETECTION OF DARK MATTER AT THE LHC

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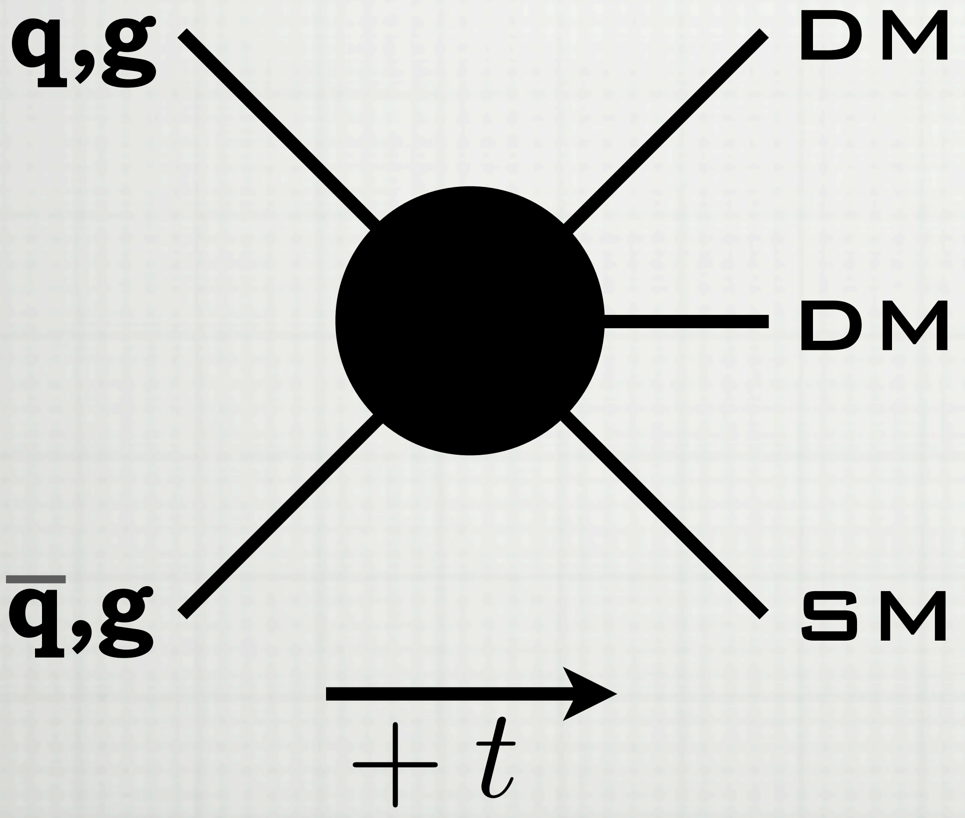
arXiv:1402.7074 [hep-ph]

THE UNIVERSITY OF CHICAGO

(Also, see Carpentar et al., arXiv:1312.2592
and Petrov et al., arXiv:1311.1511

Dark Matter Production at Colliders



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- Mono-Jet
- Mono-Z/W
- Mono-b

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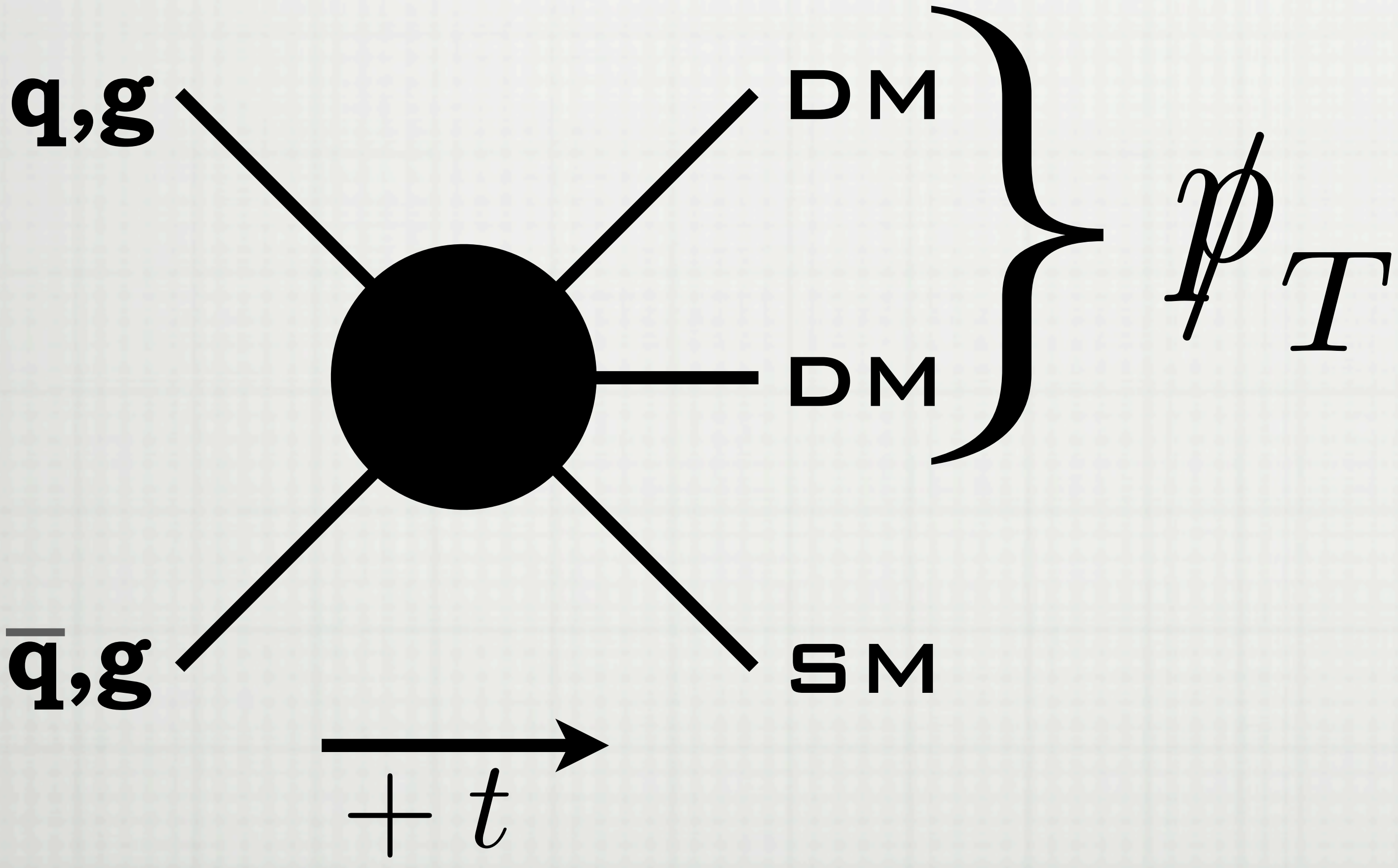

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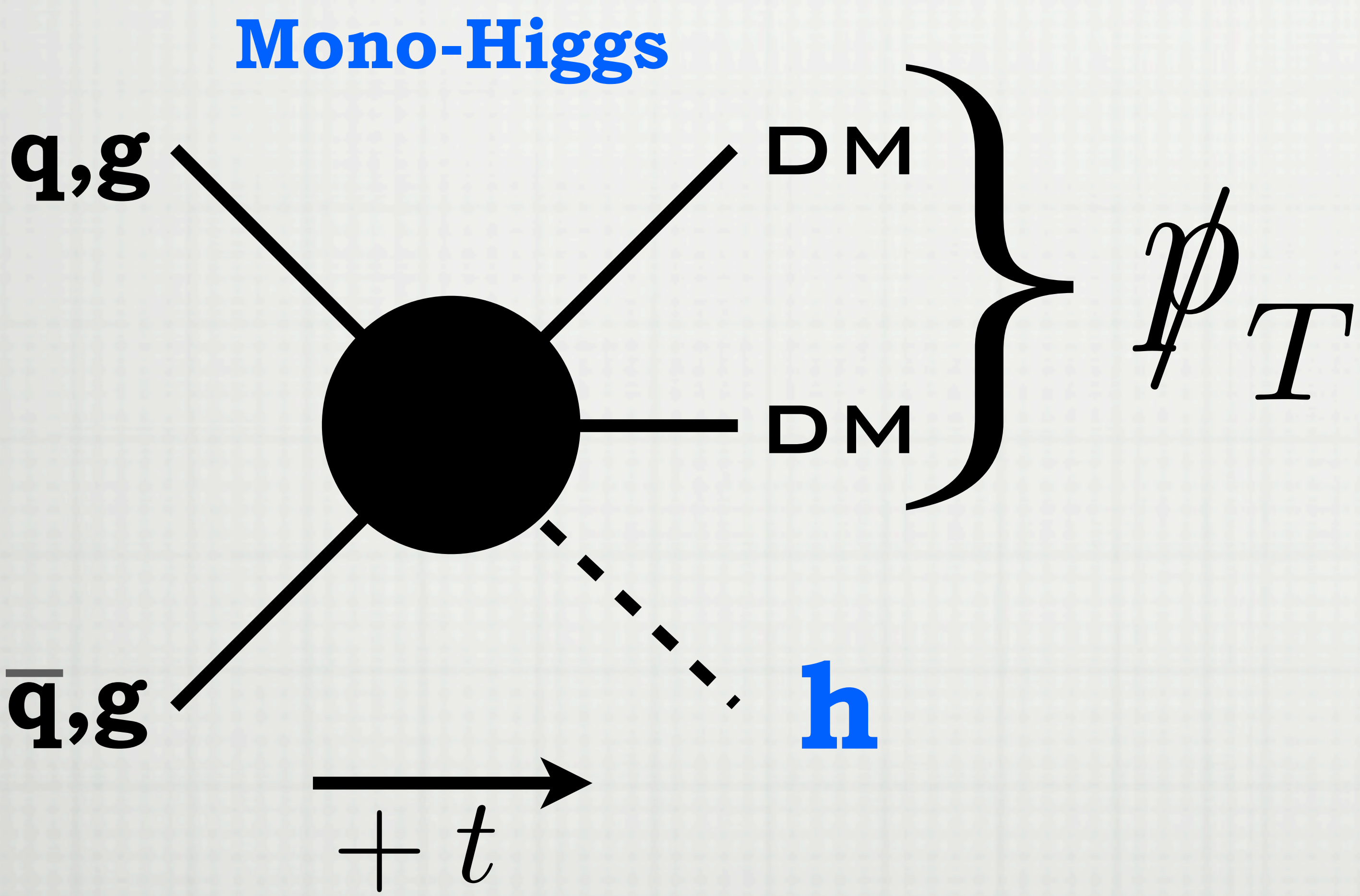

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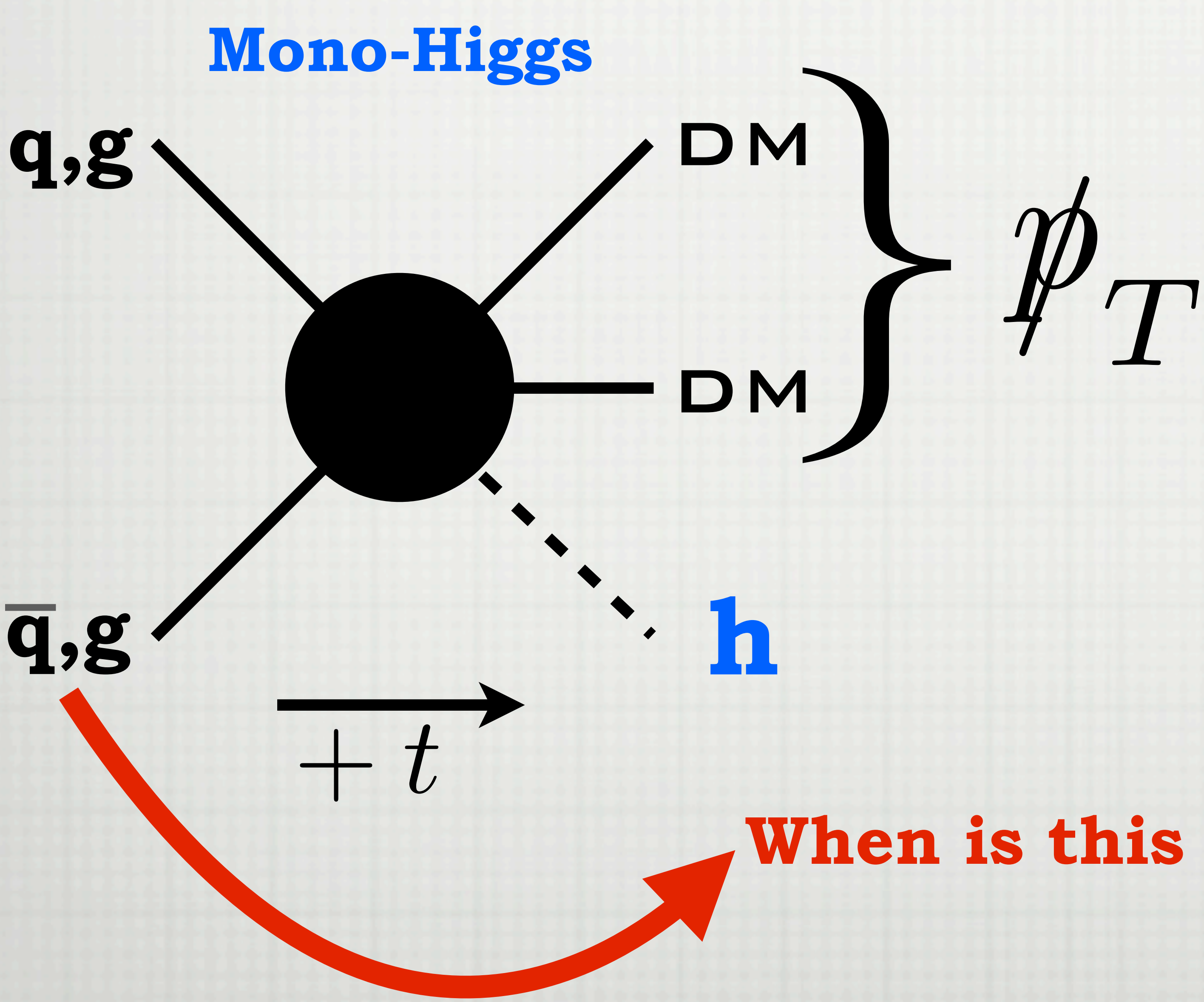

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When is this process dominant ?

Higgs + MET at the LHC

- **Dominant irreducible background = Z+h production with Z$\rightarrow \nu\bar{\nu}$.**

$$BF(h \rightarrow b\bar{b}) \approx 0.6$$

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- **What Higgs decay channels will be most sensitive?**

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- **Depending on the Higgs decay channel, other SM backgrounds can be comparable or larger.**
- **What Higgs decay channels will be most sensitive?**
- **We consider decay to $b\bar{b}$ or $\gamma\gamma$.**

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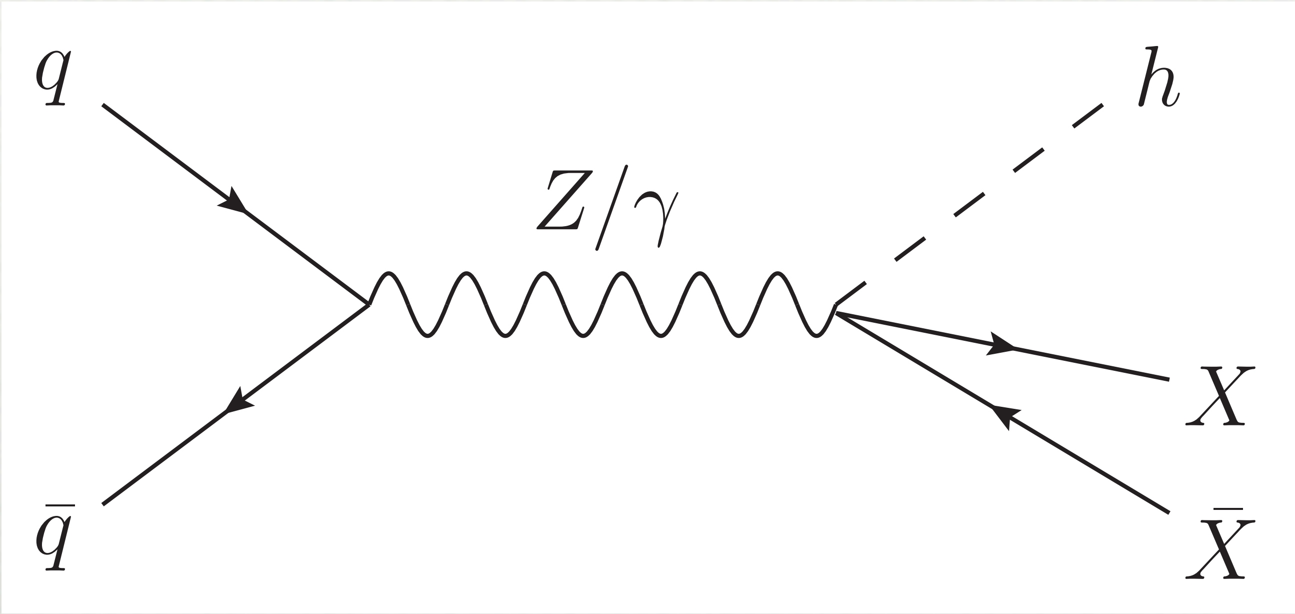
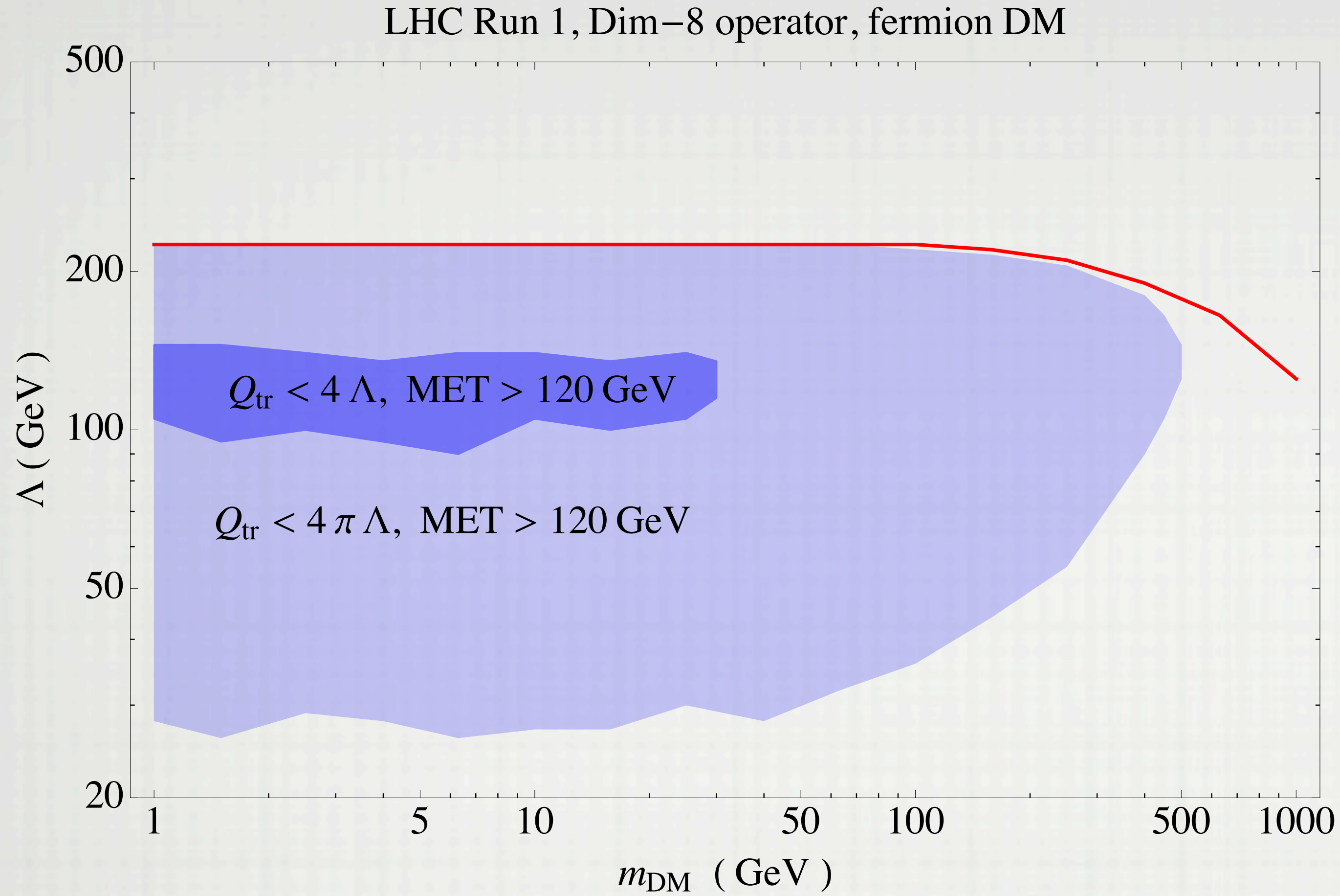
Effective Field Theory (EFT)

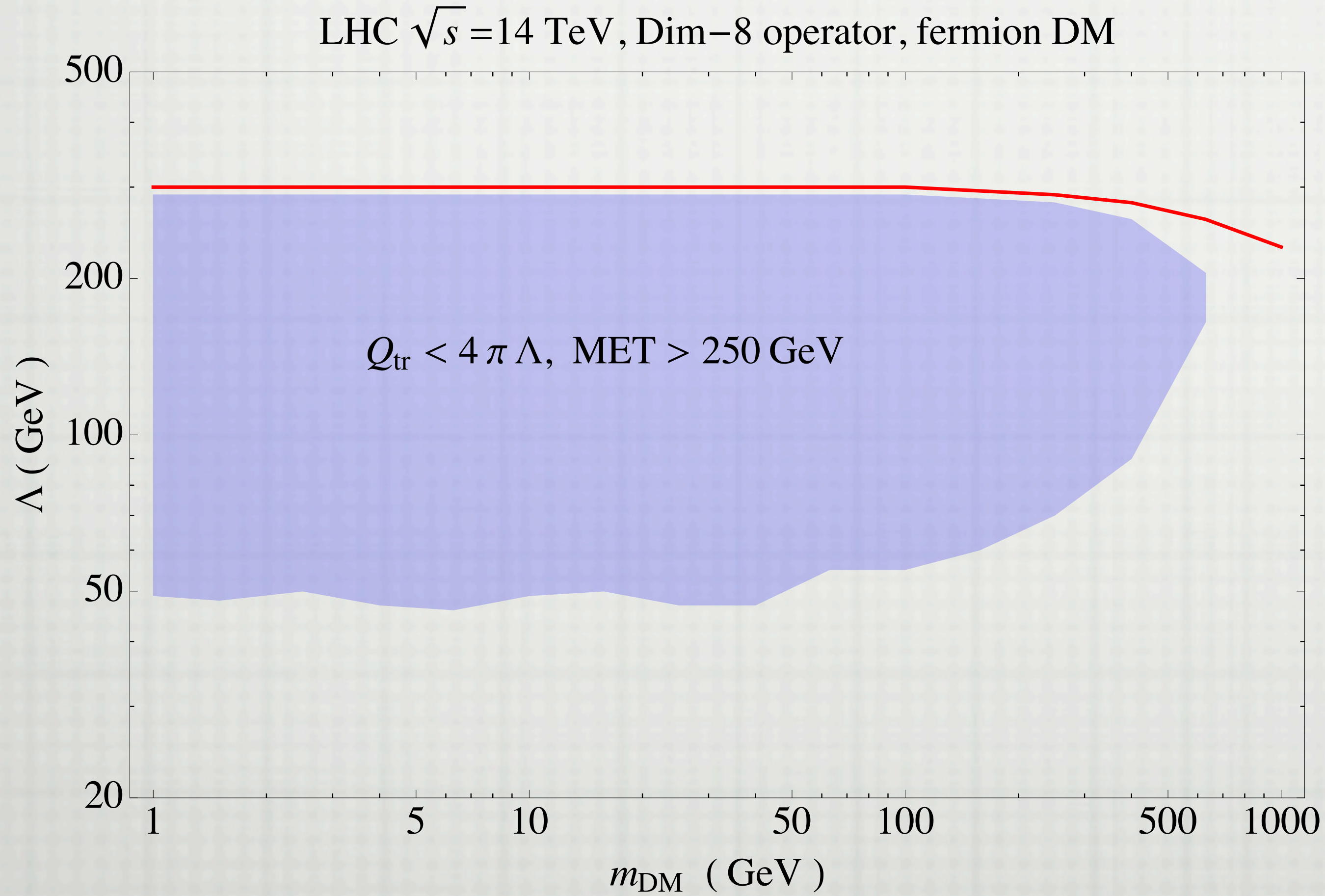
- ☐ **Dim. 6 : Direct Z+DM coupling. Direct detection and invisible Z width are very constraining.**

- ☐ **Dim. 7: Mild constraints on the cutoff. Softer momentum transfer dependence.**

- ☐ **Dim. 8: Stronger constraints on the cutoff. Harder momentum transfer dependence.**







95% CL Constraints on Cutoff from Mono-Higgs

- ☐ **Red Lines**: Lower bound from naive requirement.
- ☐ **Blue Regions**: Excluded regions after "unitarizing".

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$U(1)_{Z'}$	0	1/2	0	0	1/2

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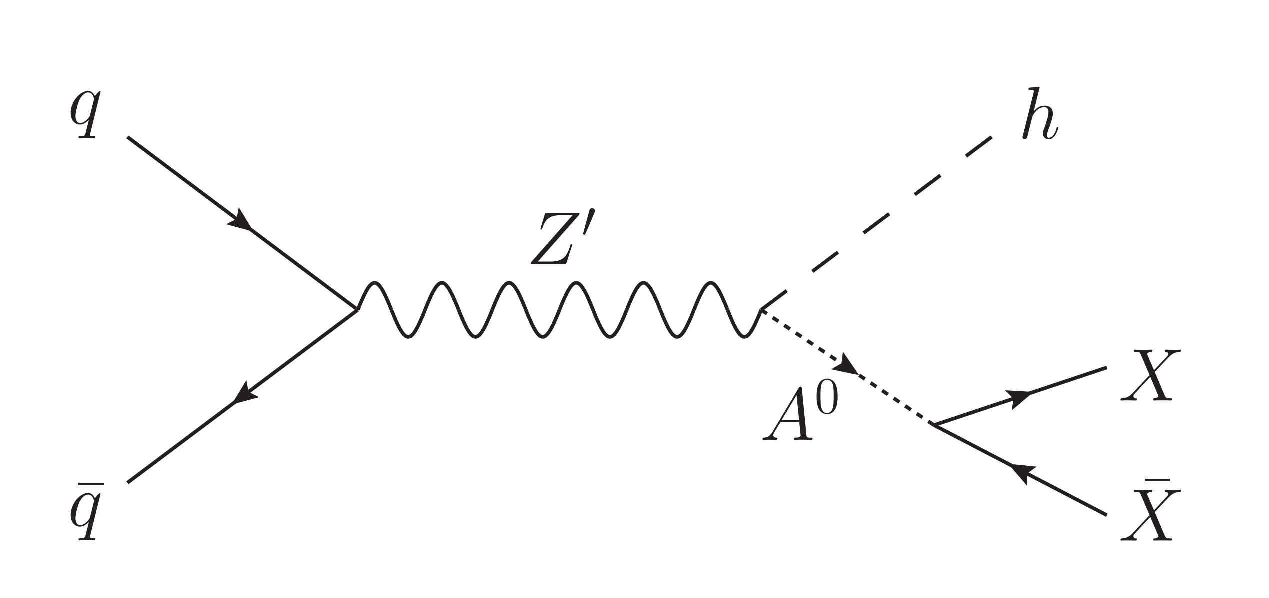

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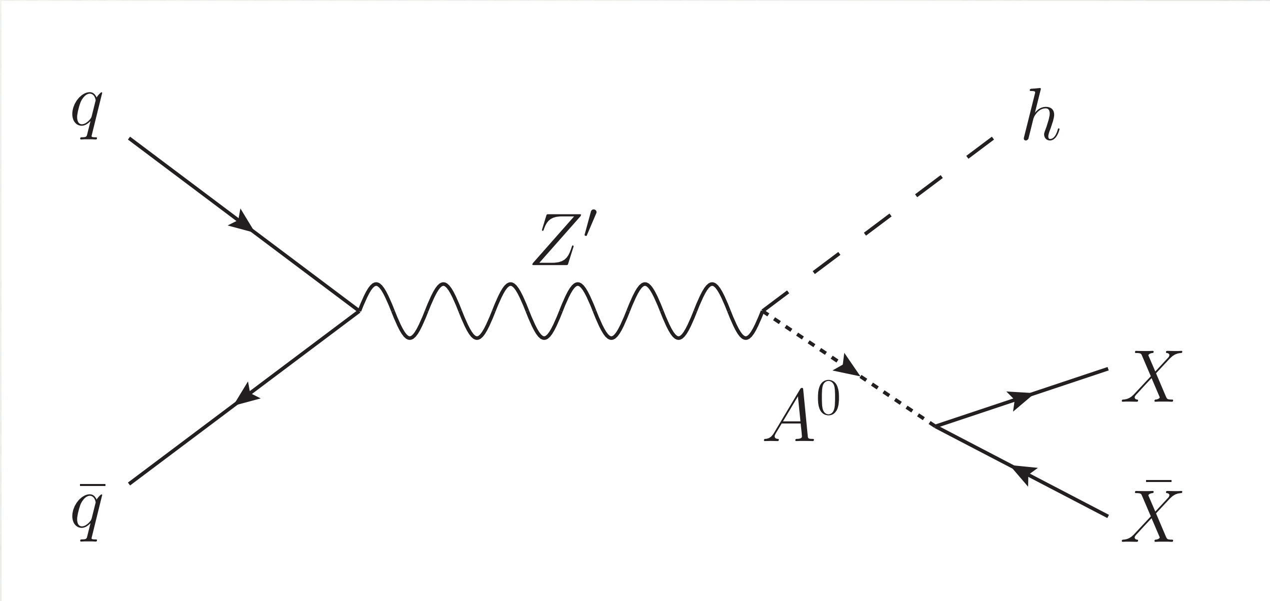

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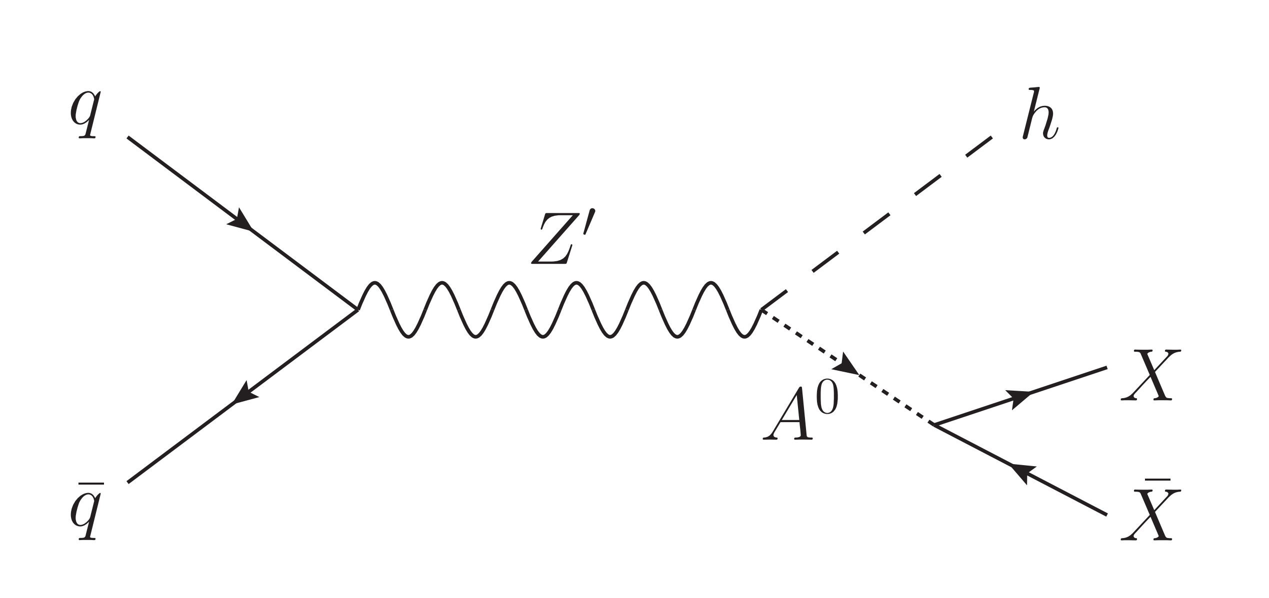

$$\epsilon \equiv \frac{1}{M_{Z'}^2 - M_Z^2} \frac{g g_z}{2\cos\theta_w}(z_d v_d^2 + z_u v_u^2)$$

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Yet another form of Higgs + MET is Z+h production via Z' resonance!

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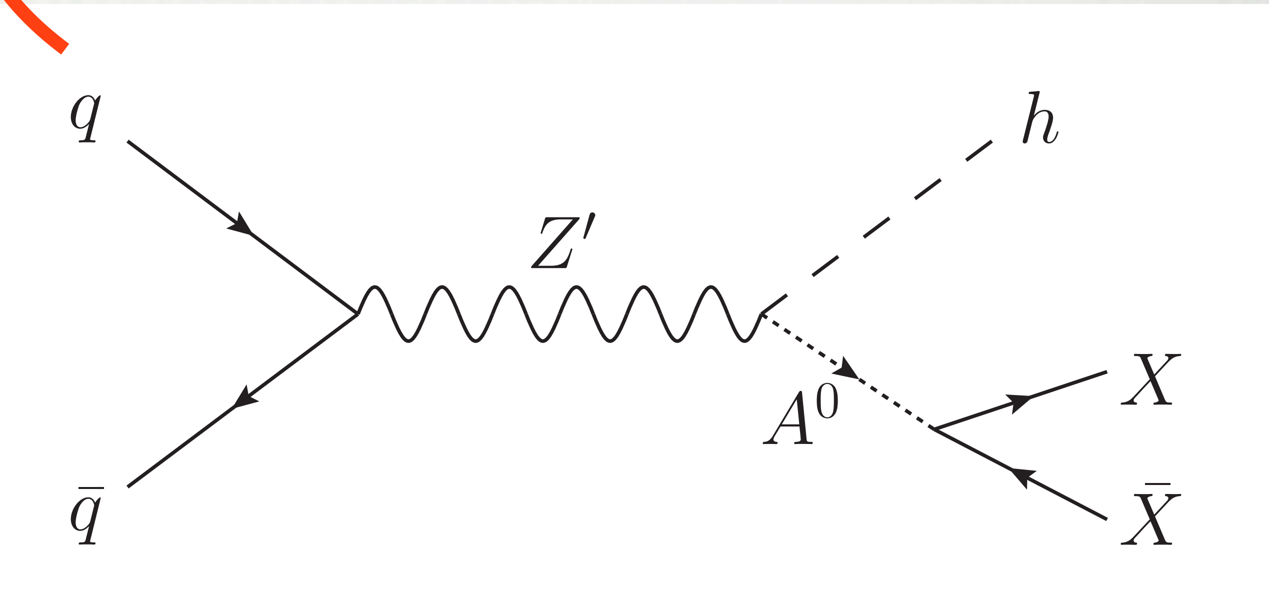

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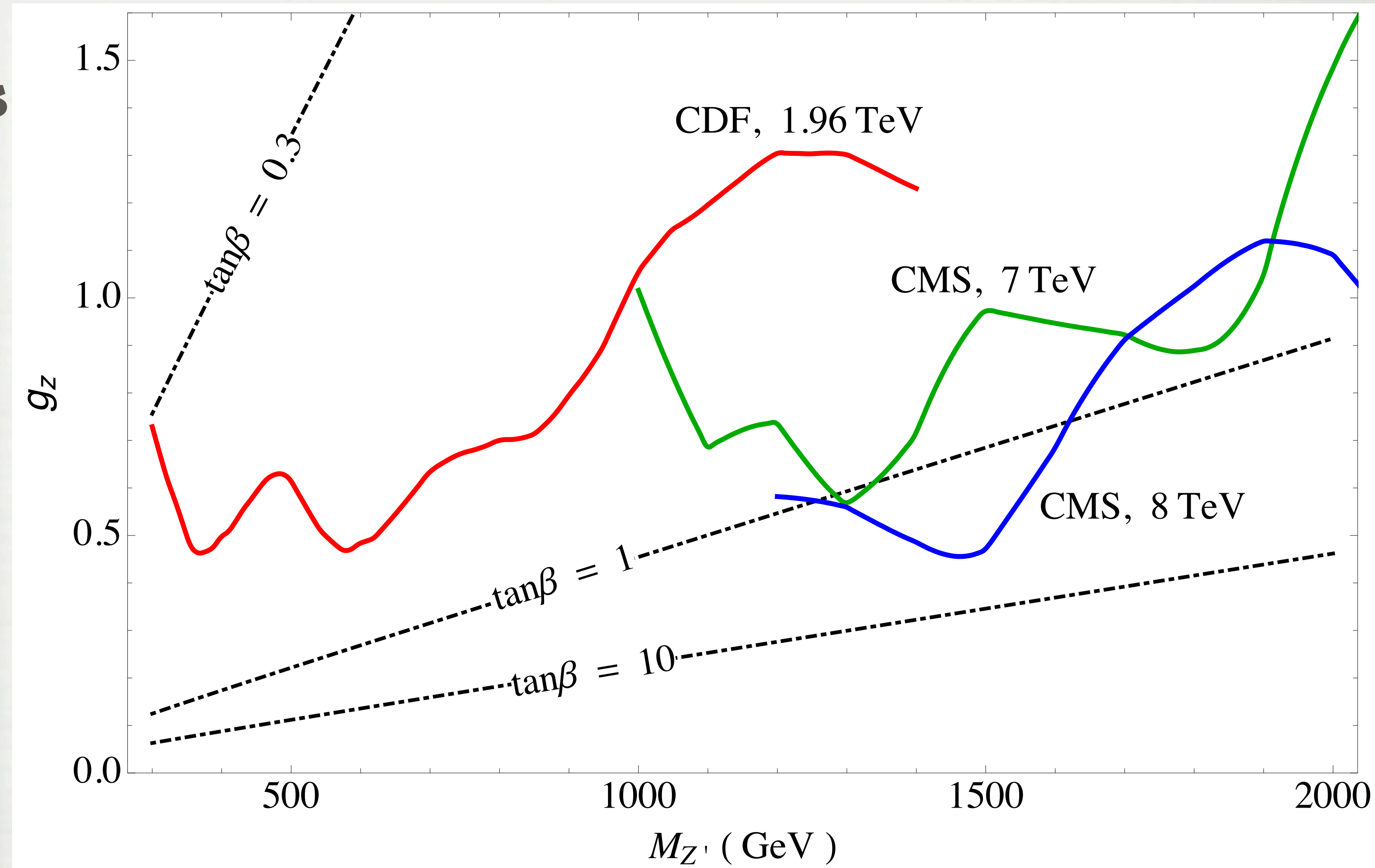
Experimental Constraints

- **New heavy scalars no lighter than 300 GeV.**
- **Alignment limit.**
- **tan β > 0.3**
- **Dijet resonance searches.**
- **EW precision:**



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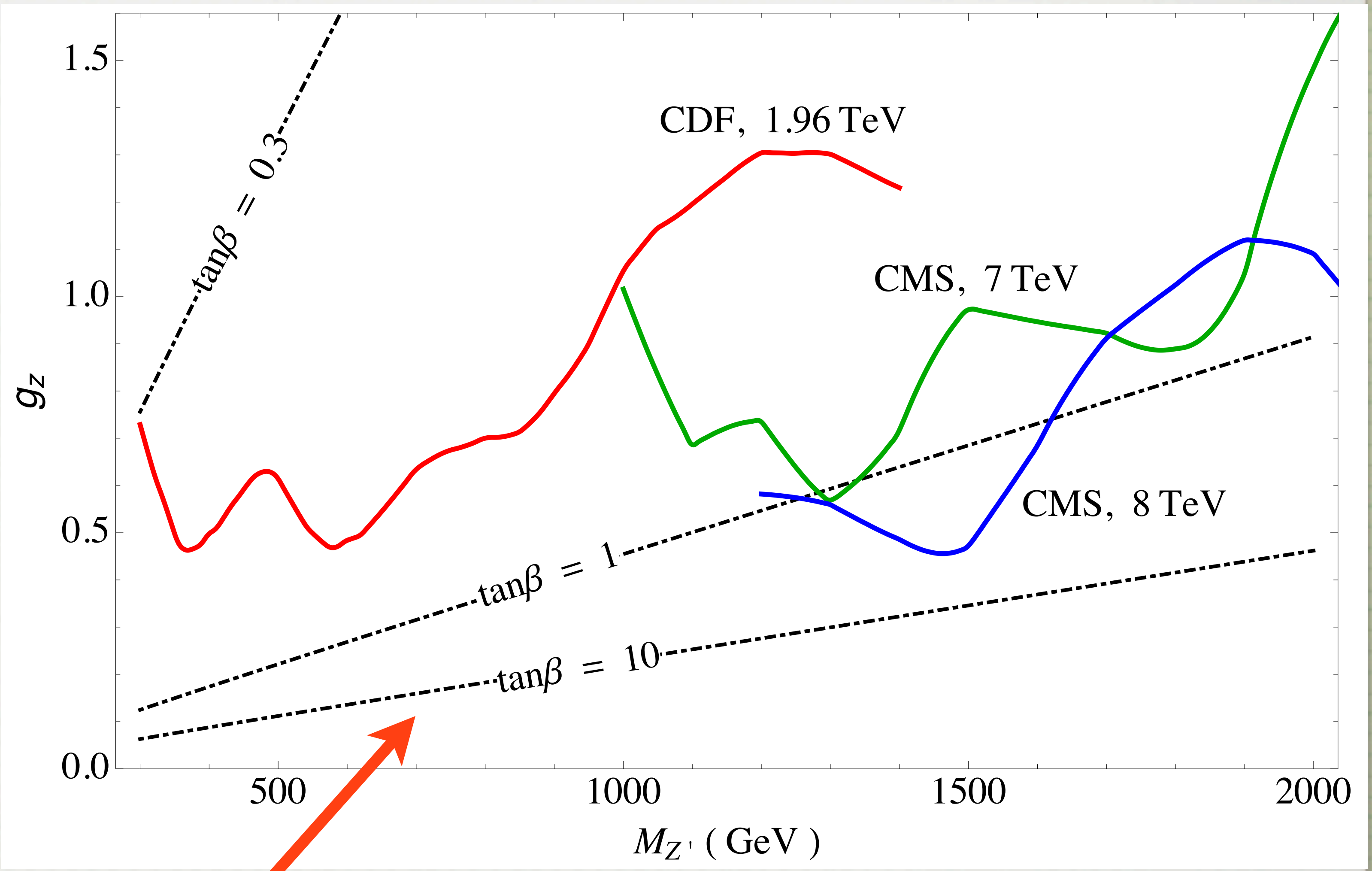

$$g_z \propto 1/\sin^2\beta$$

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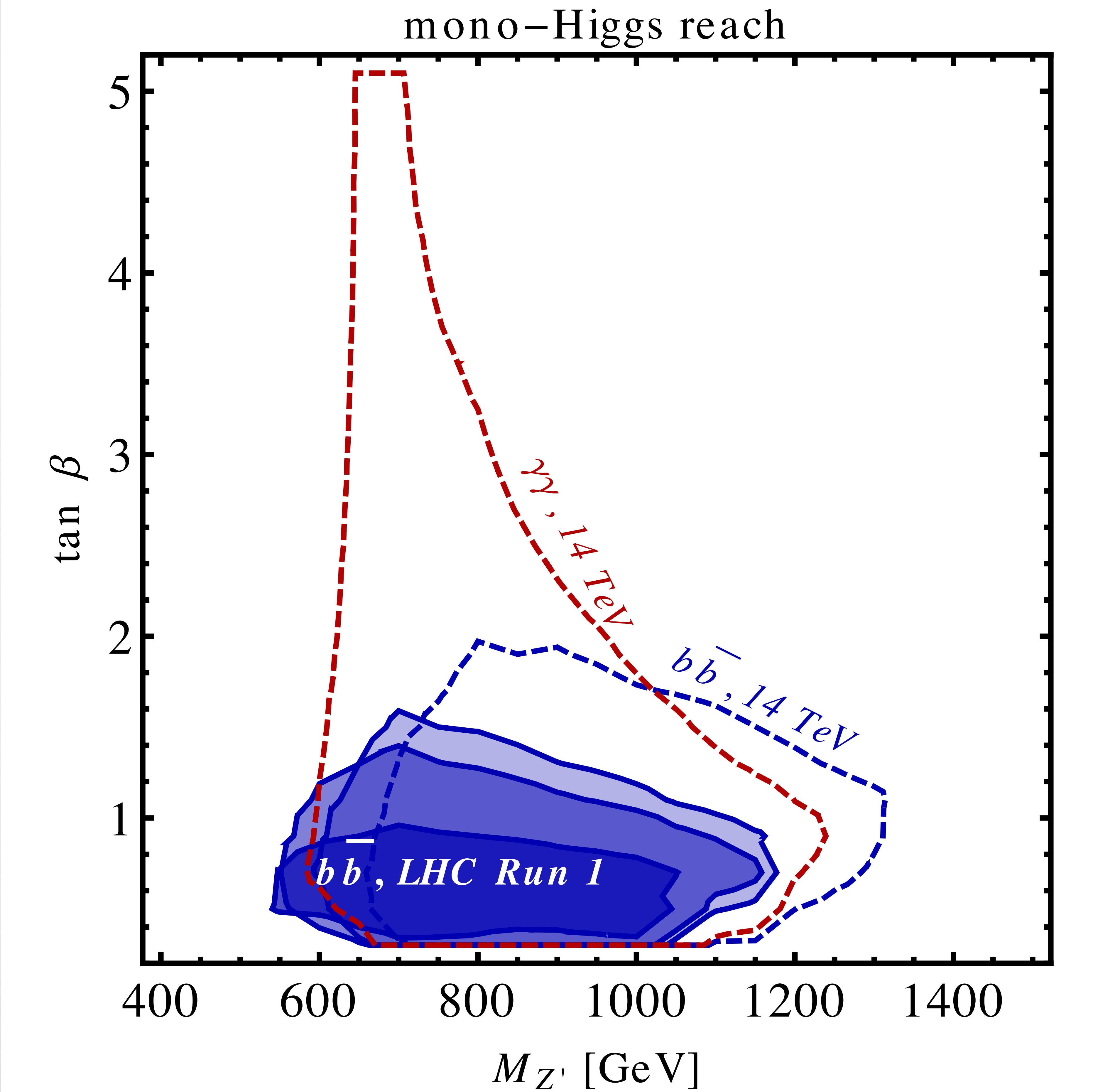

mono−Higgs reach
tan β
$M_{Z'}$ [GeV]
γγ , 14 TeV
$b\bar{b}$, 14 TeV
$b\bar{b}$, LHC Run 1
5
4
3
2
1
400
600
800
1000
1200
1400

QUESTIONS?

$h \to b\bar{b}$ + MET

- **Large branching fraction.**
- **Dominant irreducible background = Z+h production.**
- **Dominant reducible background =** $t\bar{t}$ **and** $Zb\bar{b}$ **.**
- $t\bar{t}$ **dominates at large energies.**
- **Consider MET cuts from 120-250 GeV.**

$h \to \gamma\gamma +$ MET

- **Very small branching fraction.**
- **Dominant irreducible background = Z+h production.**
- **Dominant reducible background =** $Z\gamma\gamma$**.**
- **Increased sensitivity at 14 TeV.**
- **Consider MET cuts from 100-250 GeV.**

Effective Field Theory (EFT)

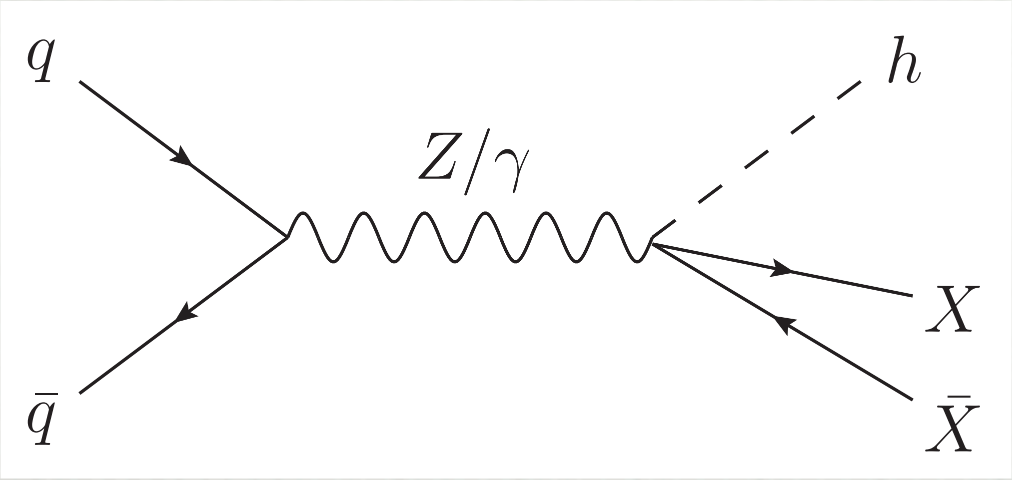
Dim. 7:

$$\frac{1}{\Lambda^3}\bar{X}\gamma^{\mu\nu}X \times i\left[(D_\mu H)^\dagger D_\nu H - \text{h.c.}\right]$$

Dim. 8:

$$\frac{1}{\Lambda^4}\frac{1}{2}(\phi^\dagger\partial^\mu\phi + \text{h.c.})\ (B_{\nu\mu}H^\dagger D^\nu H + \text{h.c.})$$

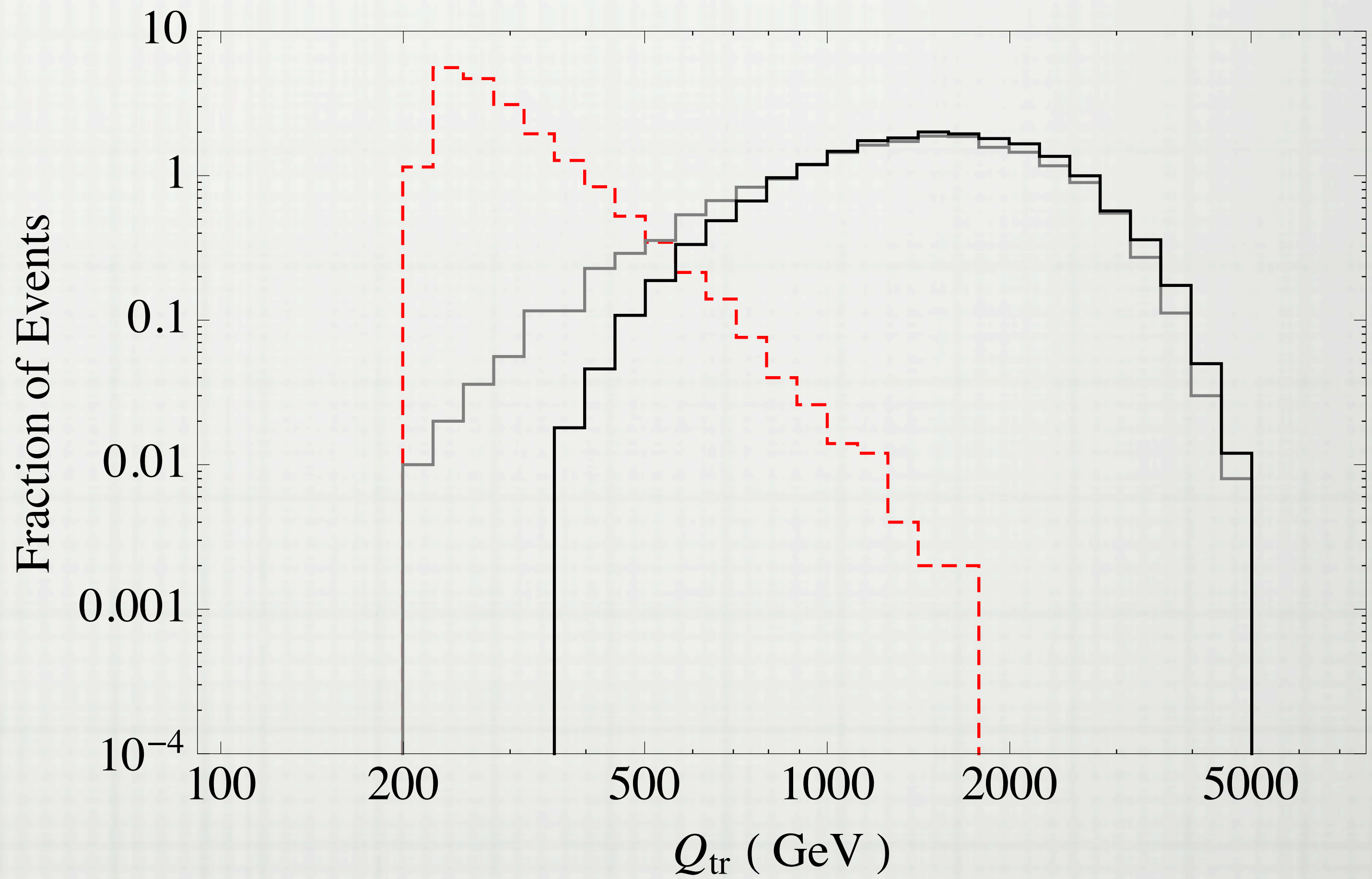
$$\frac{1}{\Lambda^4}\bar{X}\gamma^\mu X\ (W^a_{\nu\mu}H^\dagger t^a D^\nu H + \text{h.c.})$$



- Rate is smaller when DM couples to 2 Higgs
- These same operators give Mono-Z/W. This is weaker due to s-channel Higgs production.
- When is this EFT valid to order 1?

EFT Unitarity

- Mono-Higgs signal comes from high momentum transfer region.
- Constraints on cutoff often of order 100 GeV (if even). Can see that momentum transfer exceeds this easily.
- We should worry about the unitarity of our EFT description!



Momentum Transfer at 8 TeV, for10 GeV (gray) or 100 (black) GeV DM, from Mono-Higgs process of Dim.-8 fermionic operator. Zh production (red) is the irreducible SM background.

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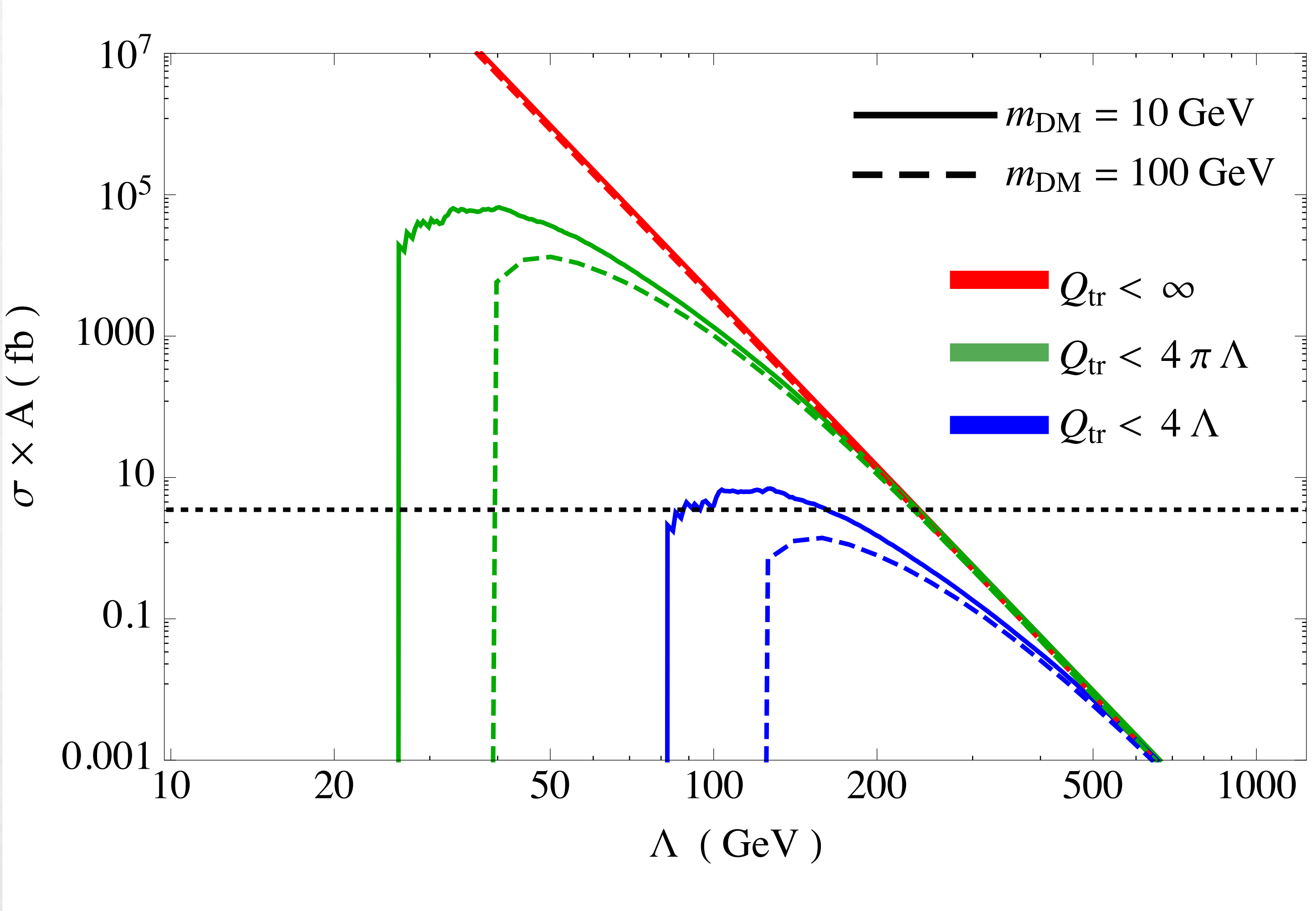

Dim. 8 operator, fermion DM, 8 TeV

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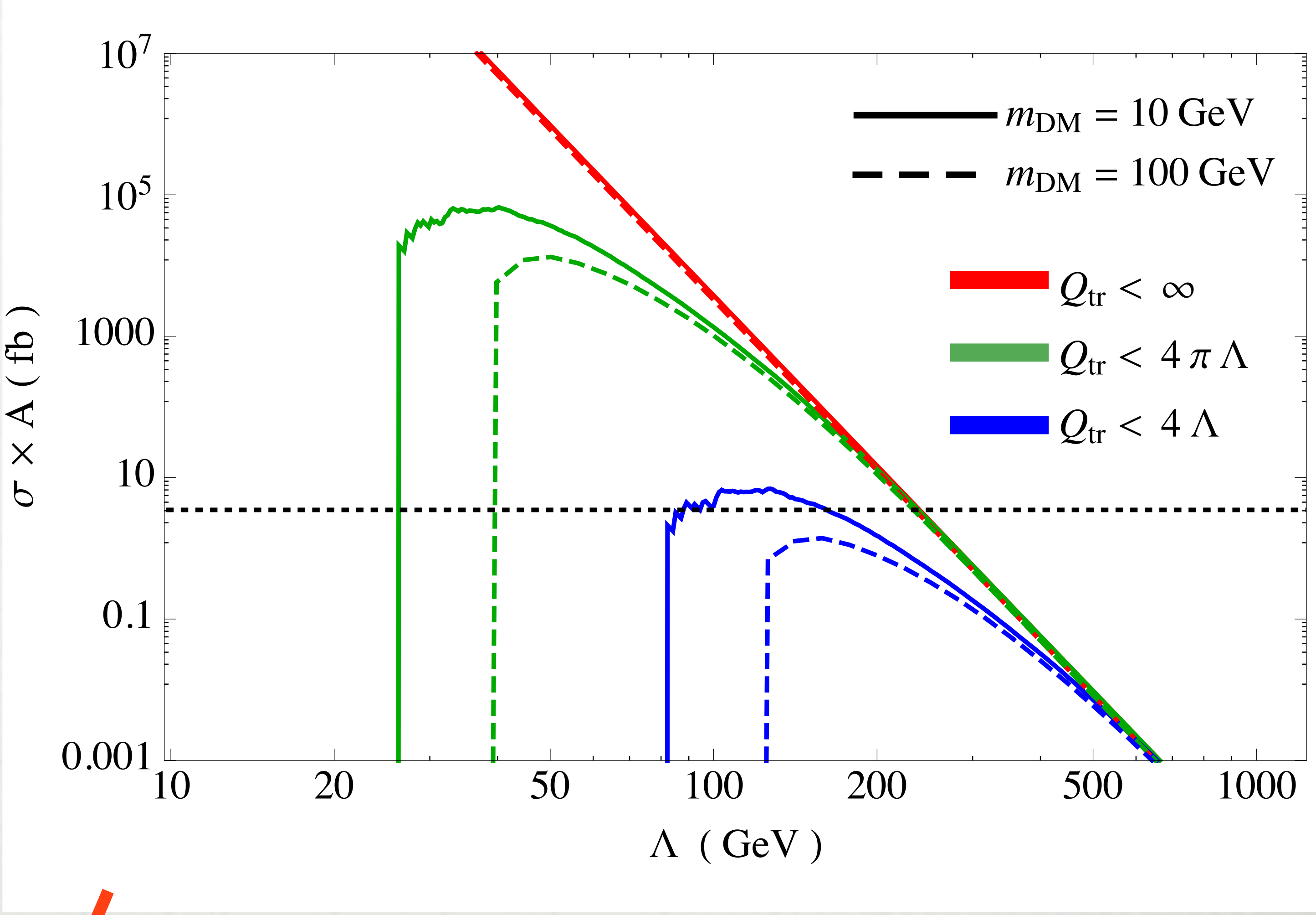

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Don’t take too literally. Only illustrates (conservatively) error in assuming 1 operator is relevant.

Mono-Higgs Signal

- **Higgs+DM:** $\Gamma_{Z' \to hA^0} = (g_z \sin\beta \cos\beta)^2 \frac{|p|}{24\pi} \frac{|p|^2}{M_{Z'}^2}$

- **Additional source of Higgs+MET:** $\Gamma_{Z' \to hZ} = \left(g_z \sin^2\beta\right)^2 \frac{|p|}{24\pi} \left(\frac{|p|^2}{M_{Z'}^2} + 3\frac{M_Z^2}{M_{Z'}^2}\right)$

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  <u>For small tan β:</u> rate ~ $\tan^4\beta$

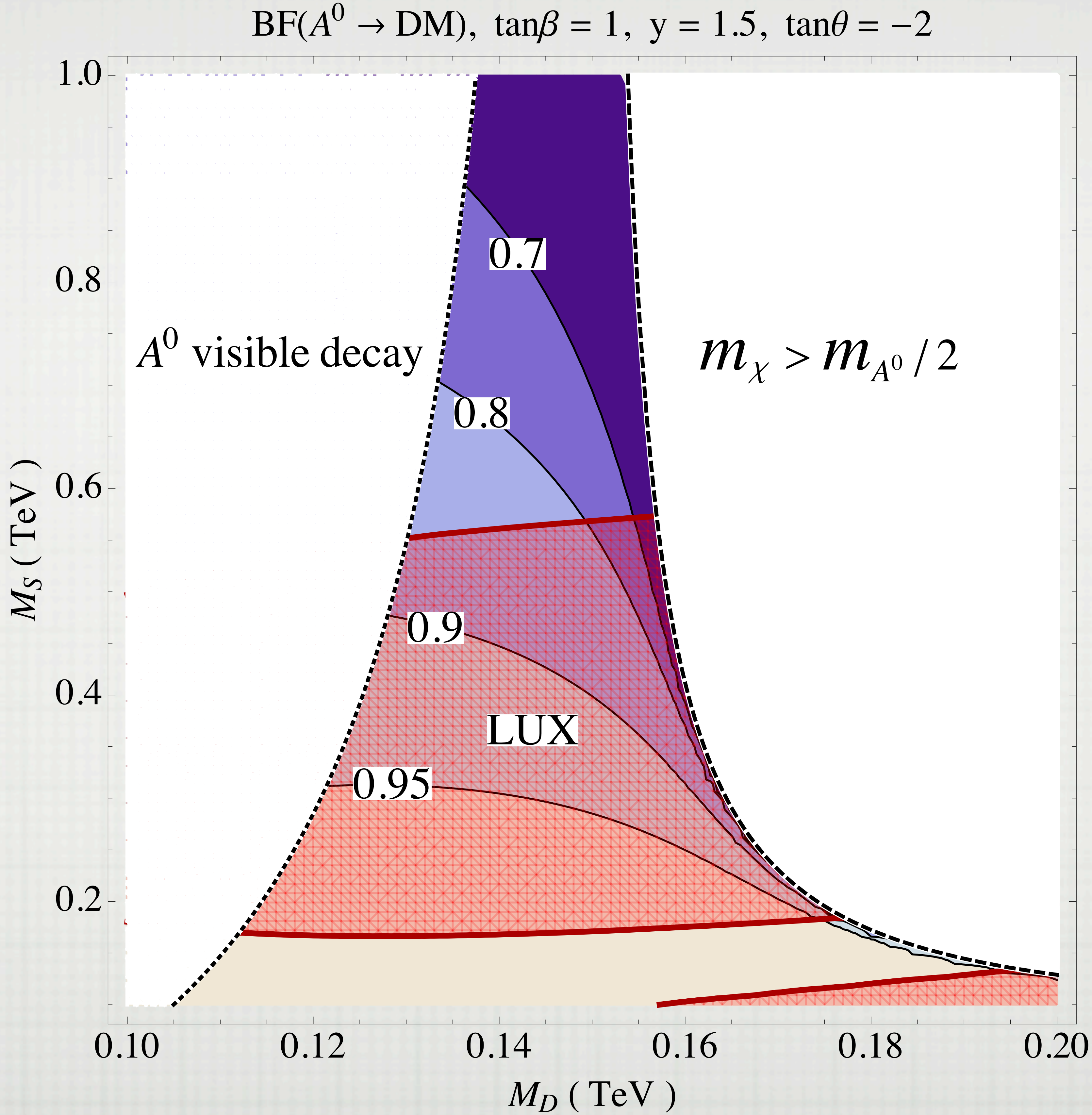
  <u>For large tan β:</u> rate ~ 1

  Increases for smaller $M_{Z'}$

Dark Matter Coupling

- **Want order 1 BF of pseudoscalar to DM**
- **Singlet-Doublet Fermionic Dark Matter (Cheung and Sanford arXiv 1311.5896 [hep-ph])**
- **Introduce two SU(2) doublet Weyls with hypercharge ±1/2, D_2 and D_1, respectively**
- **Introduce total gauge singlet Weyl S**
- **Assume all are neutral under $U(1)_{Z'}$**

$$-\mathcal{L} \supset \frac{1}{2} M_S^2 S^2 + M_D D_1 D_2 + y_1 S D_1 \Phi_d + y_2 S \Phi_d^\dagger D_2 + \text{h.c.}$$



BF($A^0 \to$ DM), tanβ = 1, y = 1.5, tanθ = −2
1.0
0.8
0.6
0.4
0.2
M_S (TeV)
0.10
0.12
0.14
0.16
0.18
0.20
M_D (TeV)
A^0 visible decay
$m_\chi > m_{A^0}/2$
0.7
0.8
0.9
0.95
LUX