MULTIPURPOSE MONOJETS AT THE LHC: NEUTRINOS & DARK MATTER

Ian M. Shoemaker

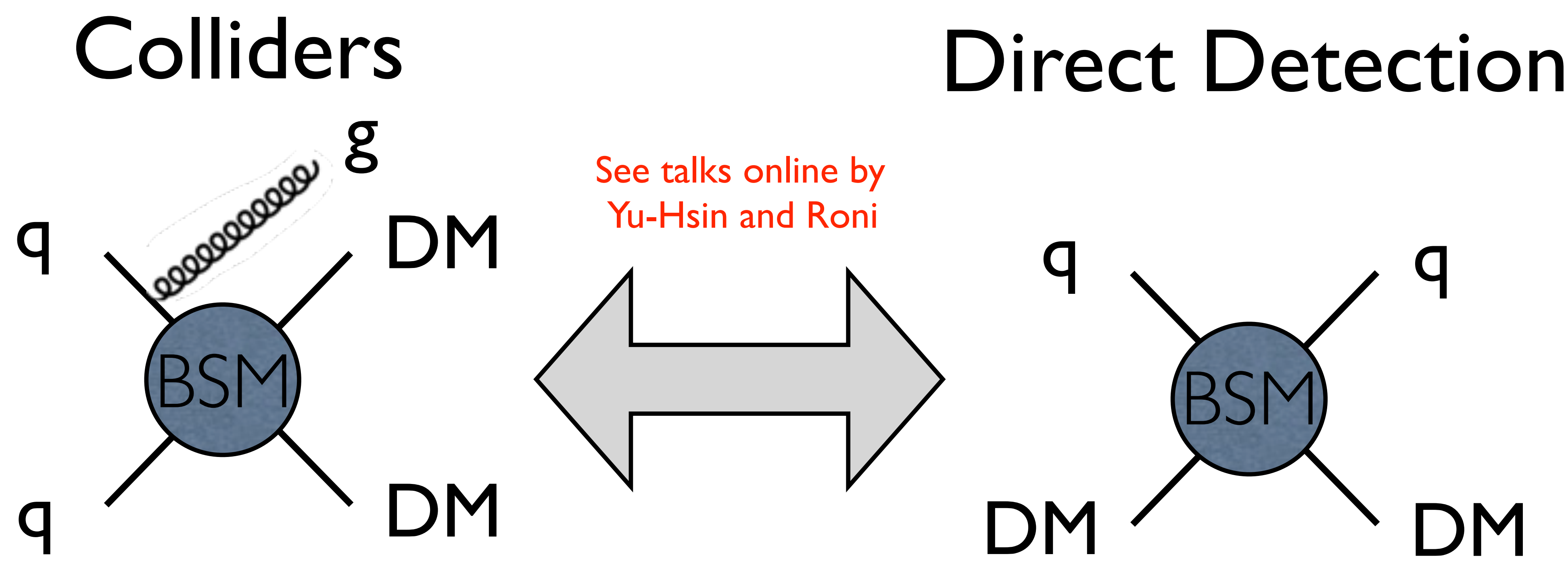
April 13, 2012

Los Alamos NATIONAL LABORATORY

[arXiv: 1111.5331, PLB in press] Alex Friedland, Michael Graesser, **IMS**, and Luca Vecchi

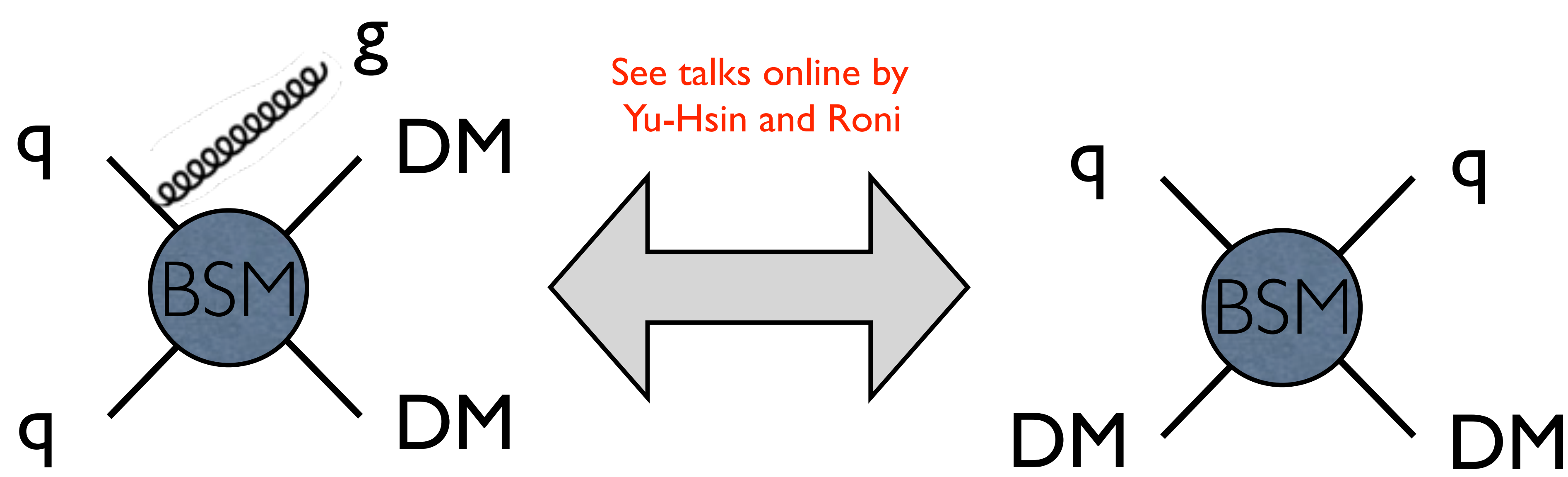
[arXiv: 1112.5457] **IMS** and Luca Vecchi

More complementarity

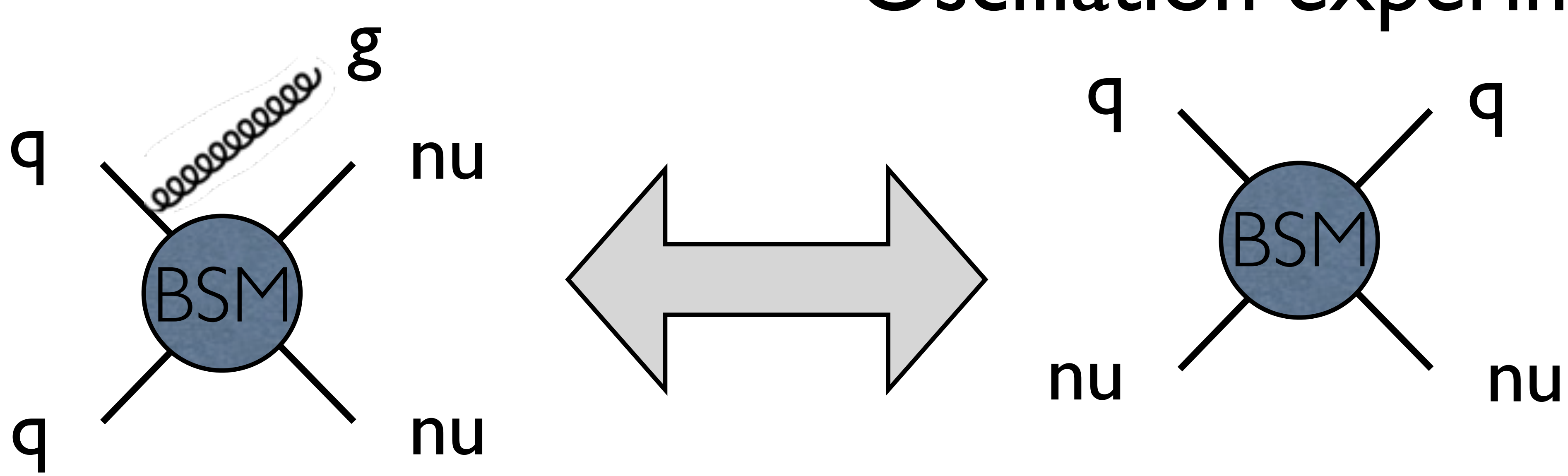


More complementarity

Colliders ⟷ Direct Detection



Colliders ⟷ Oscillation experiments



Why do you care?

- Neutrinos certainly exist in Nature.
- Solar neutrino hints.
- Weakly constrained so far.
- The LHC can set *world's best limits*.

Generalizing Fermi

PHYSICAL REVIEW D VOLUME 17, NUMBER 9 1 MAY 1978

Neutrino oscillations in matter

L. Wolfenstein
Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213
(Received 6 October 1977; revised manuscript received 5 December 1977)

The effect of coherent forward scattering must be taken into account when considering the oscillations of neutrinos traveling through matter. In particular, for the case of massless neutrinos for which vacuum oscillations cannot occur, oscillations can occur in matter if the neutral current has an off-diagonal piece connecting different neutrino types. Applications discussed are solar neutrinos and a proposed experiment involving transmission of neutrinos through 1000 km of rock.

$$\mathcal{L}_{\rm NSI} = -2\sqrt{2}G_F\, \epsilon^{fP}_{\alpha\beta}(\overline{\nu}_\alpha \gamma^\rho \nu_\beta)(\overline{f}\gamma_\rho P f)$$

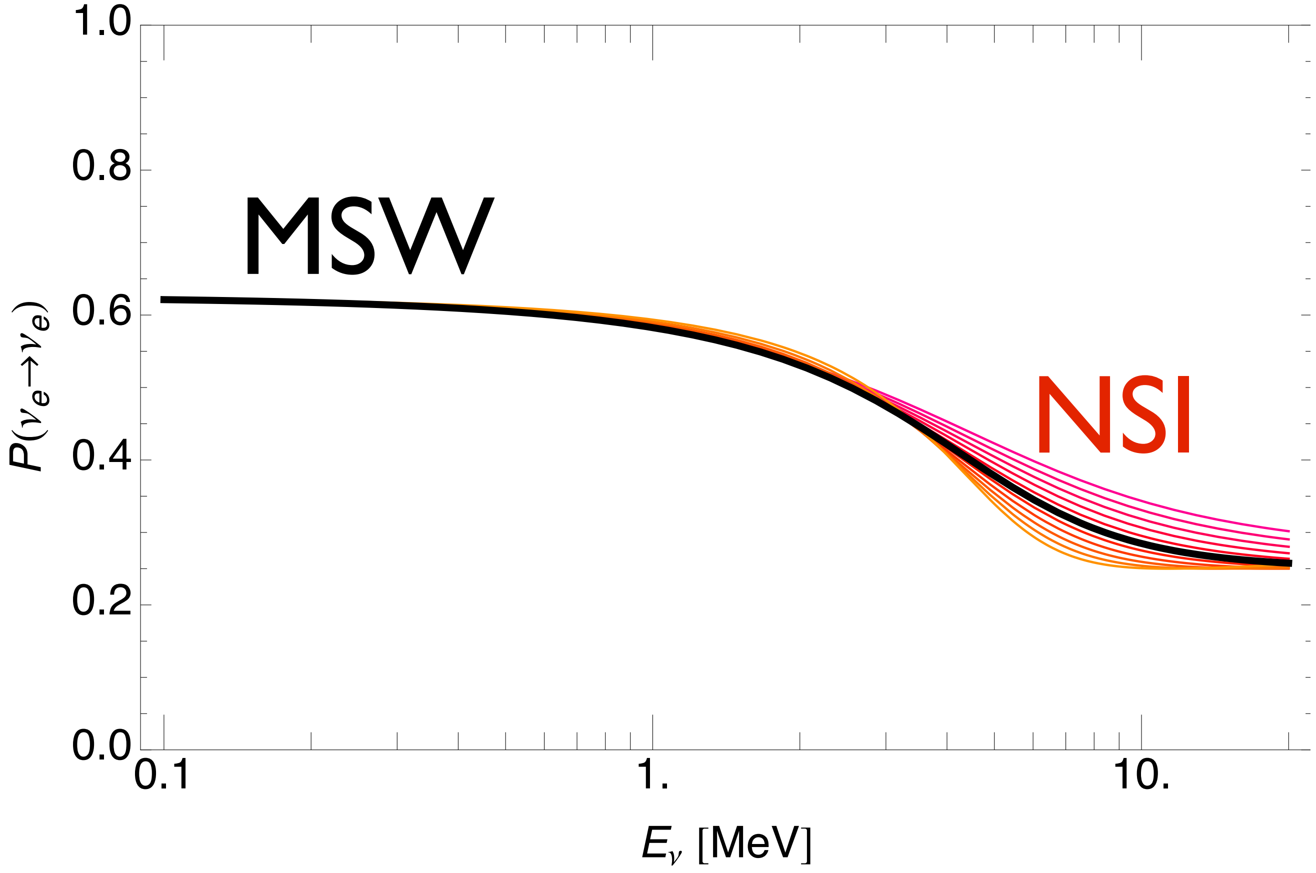
Neutrino Flavor

f =SM fermion
P=L,R

Laid the foundation for the MSW effect and pointed out that NSI can modify neutrino propagation.

Solar Neutrinos and the LHC: a UV-IR duality?

$$|\varepsilon| \lesssim 0.05$$



Recently, both SNO and Super-K lowered thresholds to discover the MSW "upturn:"

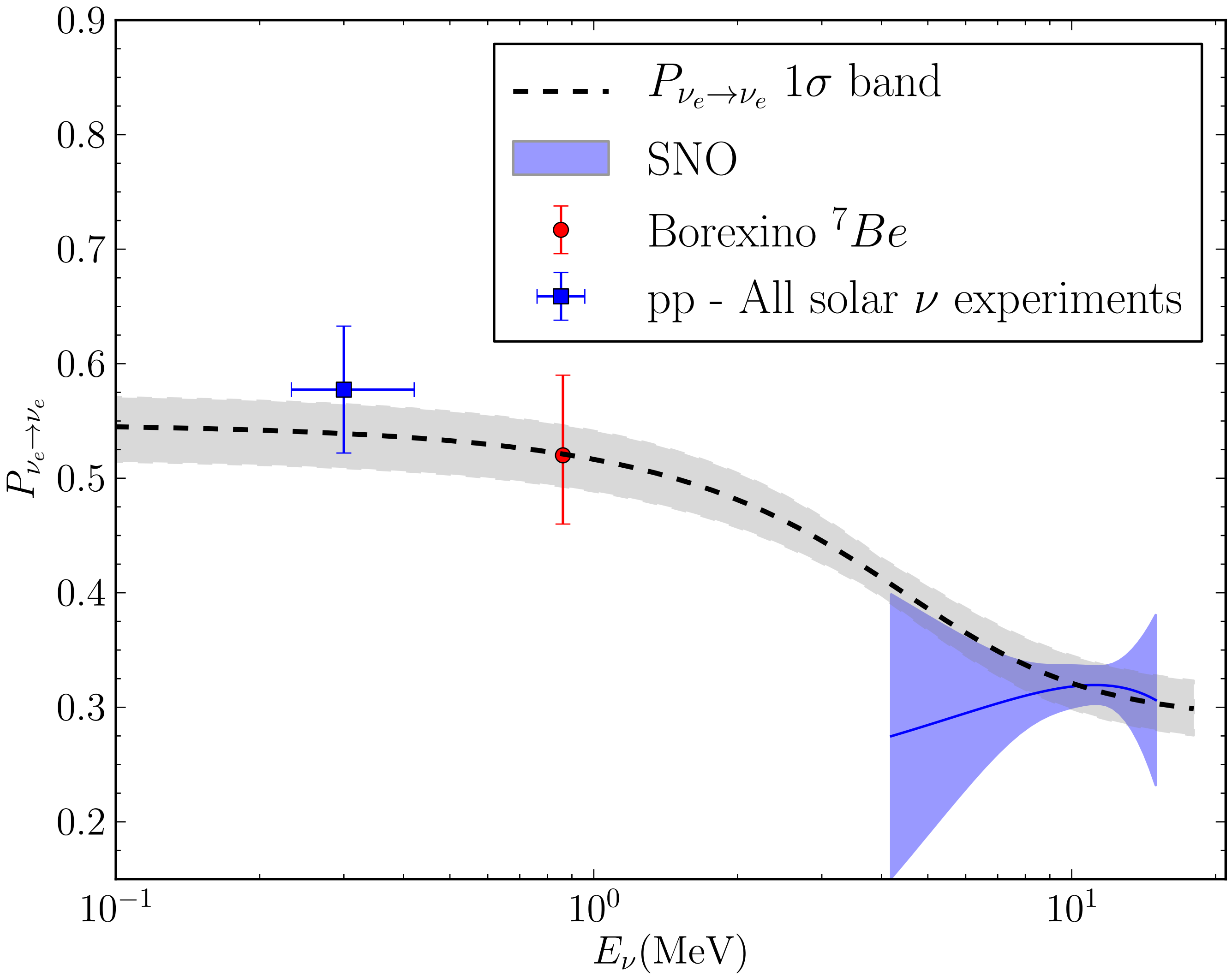
neither see it

Borexino recently targeted 8B neutrinos and also found *no evidence*.

Combined >2σ discrepancy.

Palazzo [arXiv:1101.3875]

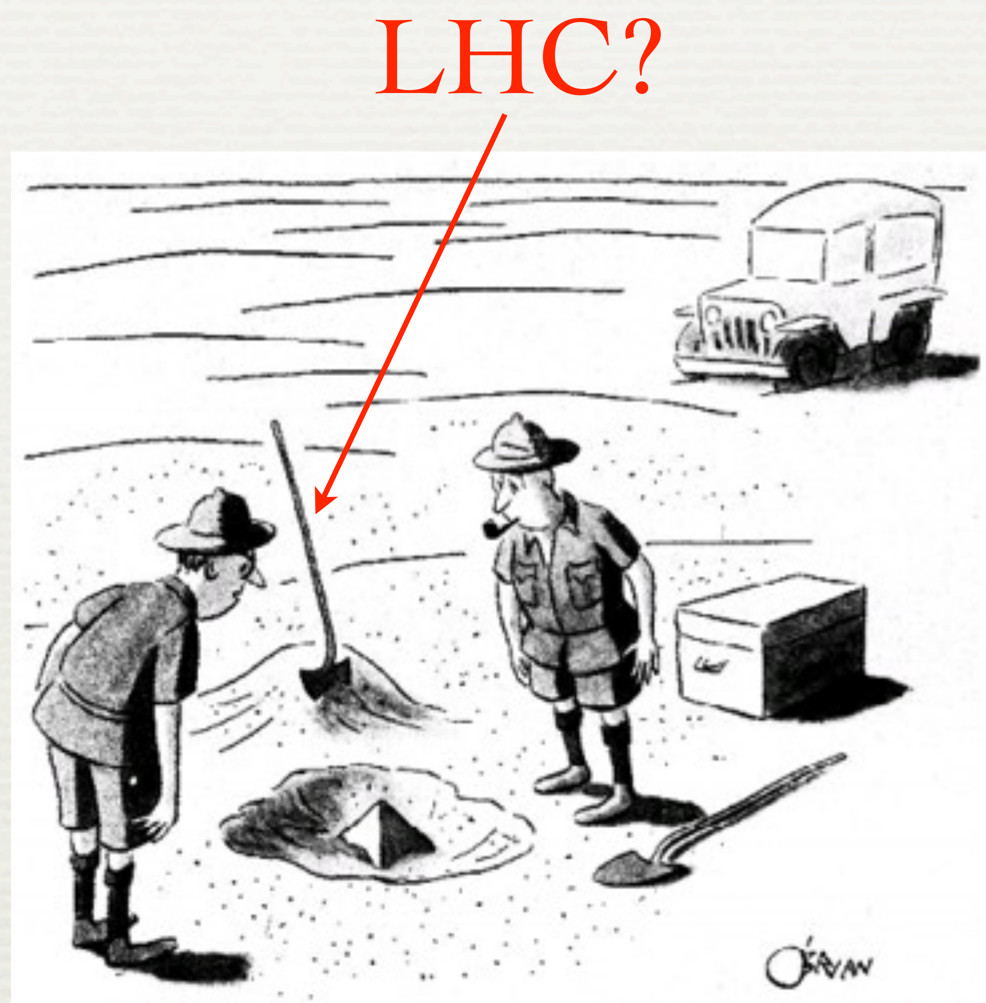
A SNO-ball's chance?



Dashed line: best fit to LMA solution

Blue: SNO solar neutrino data

"This could be the discovery of the century. Depending, of course, on how far down it goes."



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Not all MET is created equal

Jets + MET searches can bound many invisible things, like ADD gravitons, DM, (sterile) neutrinos, unparticles.

1) Yet, only SM neutrinos can *interfere* with the SM:

$$\sigma(pp/p\overline{p} \to j{+}\mathrm{MET}) = \sigma_{\mathrm{SM}} + \epsilon\sigma_{\mathrm{int}} + \epsilon^2\sigma_{\mathrm{NSI}}$$

2) SM neutrinos have nonzero electroweak charge.

The nitty gritty

MadGraph for parton-level signal.

Pass to **Pythia** for hadronization/ showering and ultimately analysis.

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$$N_{obs} = 965$$

$$N_{bkg} = 1010 \pm 37 \pm 65$$

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$$N_{obs} = 965$$

$$N_{bkg} = 1010 \pm 37 \pm 65$$

$N_{BSM} < 192$

@ 95% CL

Tevatron and LHC constraints on NSI

$$\mathcal{L}_{\rm NSI} = -2\sqrt{2}G_F\, \epsilon^{fP}_{\alpha\beta} (\overline{\nu}_\alpha \gamma^\rho \nu_\beta)(\overline{f}\gamma_\rho P f)$$

95 % CL

		CDF		ATLAS [24]		
		GSNP [25]	ADD [4, 5]	LowPt	HighPt	veryHighPt
diagonal	$\varepsilon^{uP}_{\alpha\beta=\alpha}$	0.45	0.51	0.40	0.19	0.17
diagonal	$\varepsilon^{dP}_{\alpha\beta=\alpha}$	1.12	1.43	0.54	0.28	0.26
off-diag.	$\varepsilon^{uP}_{\alpha\beta\neq\alpha}$	0.32	0.36	0.28	0.13	0.12
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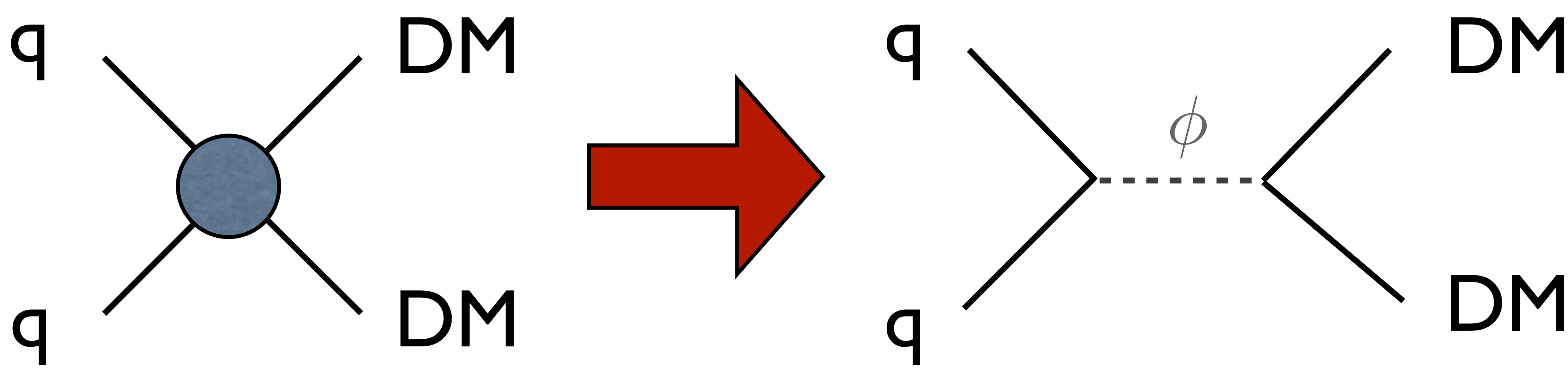
- Up-quark couplings more constrained.
- Off-diagonal couplings stronger by $(\sqrt{2})$.
- Most stringent bounds to date on electron and tau-type NSIs.

E.g. previously $\varepsilon^{ee}_{uR} < 0.7$ from DIS at CHARM (Davidson et al., 2003).

On-shellness



More model-independent, BUT only valid as long as the new physics scale is large compared to LHC energies.

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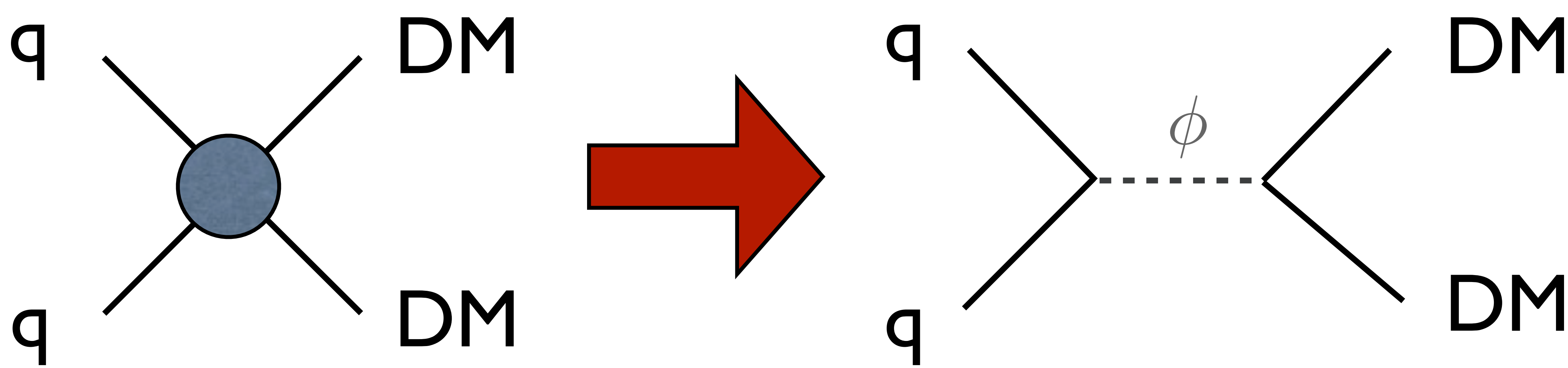

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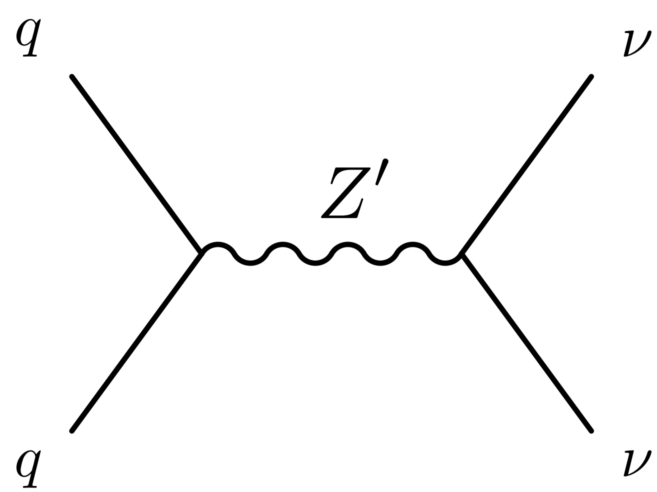
What if it's not?

A simple leptophobic Z' model



Minimal width, Z' only couples to one quark flavor, chirality and a neutrino pair.

$$\varepsilon \sim g_{Z'}^2/M_{Z'}^2$$

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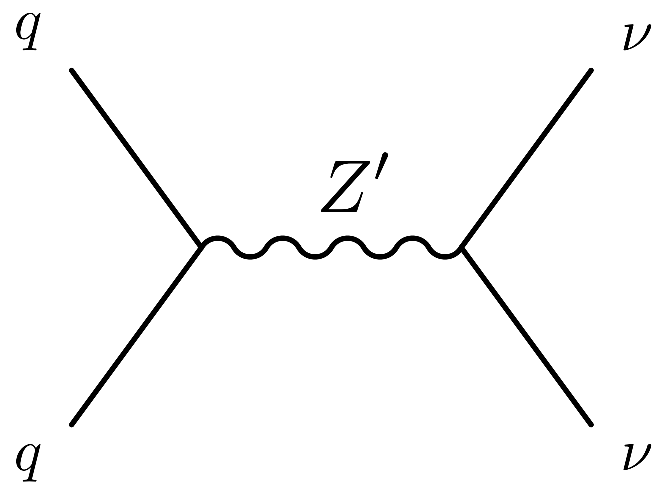

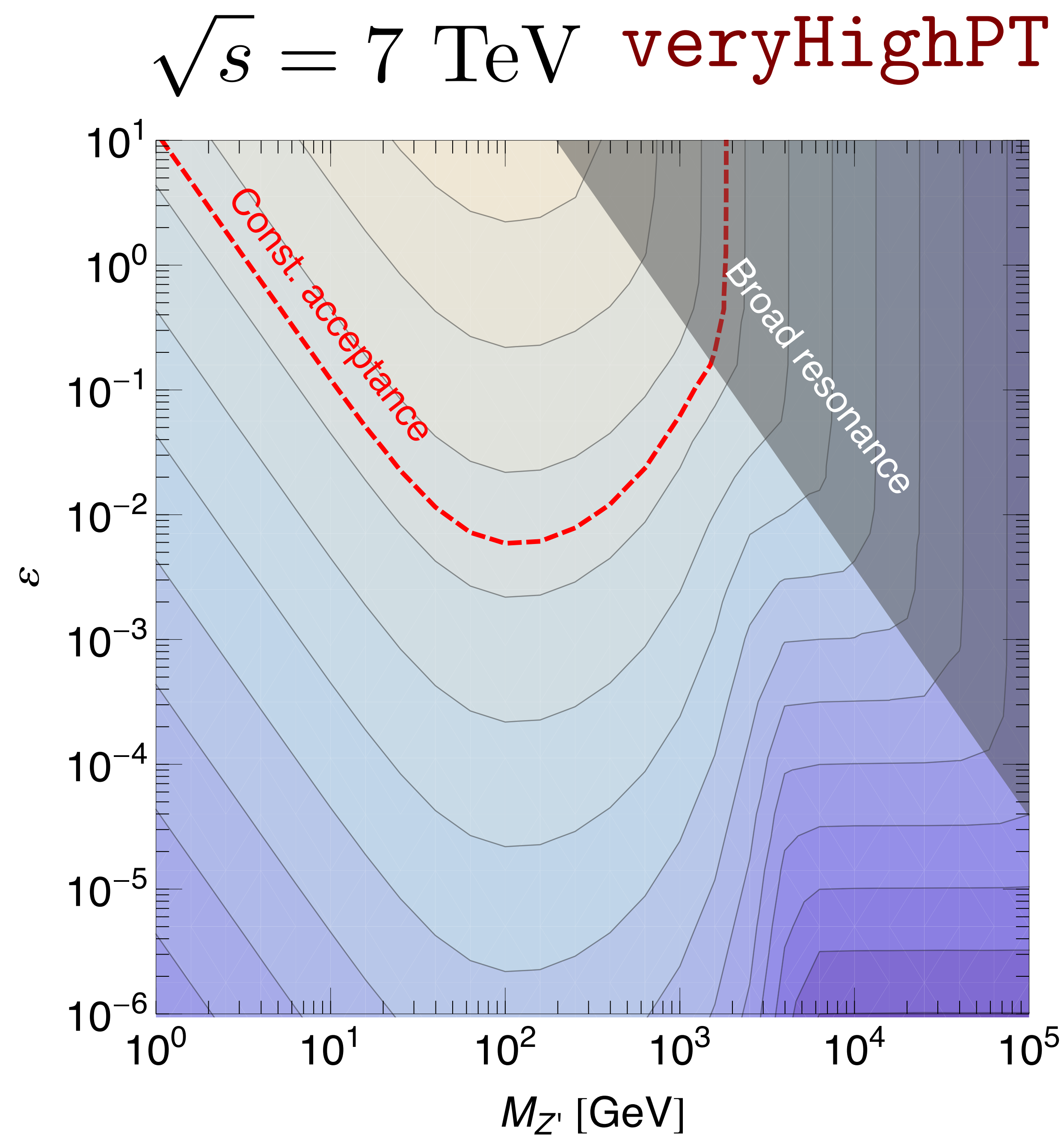

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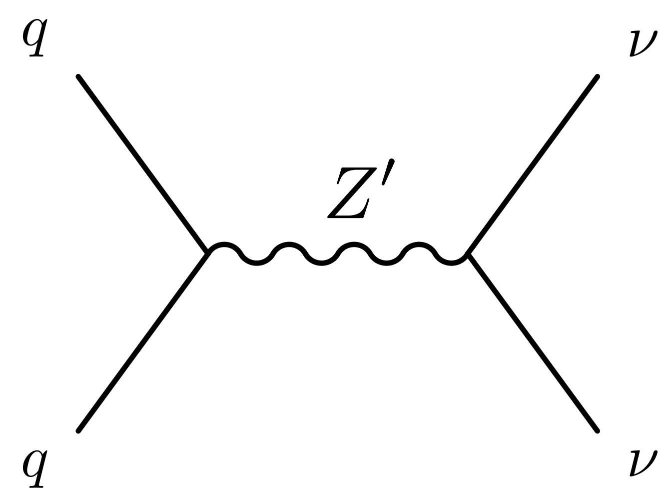

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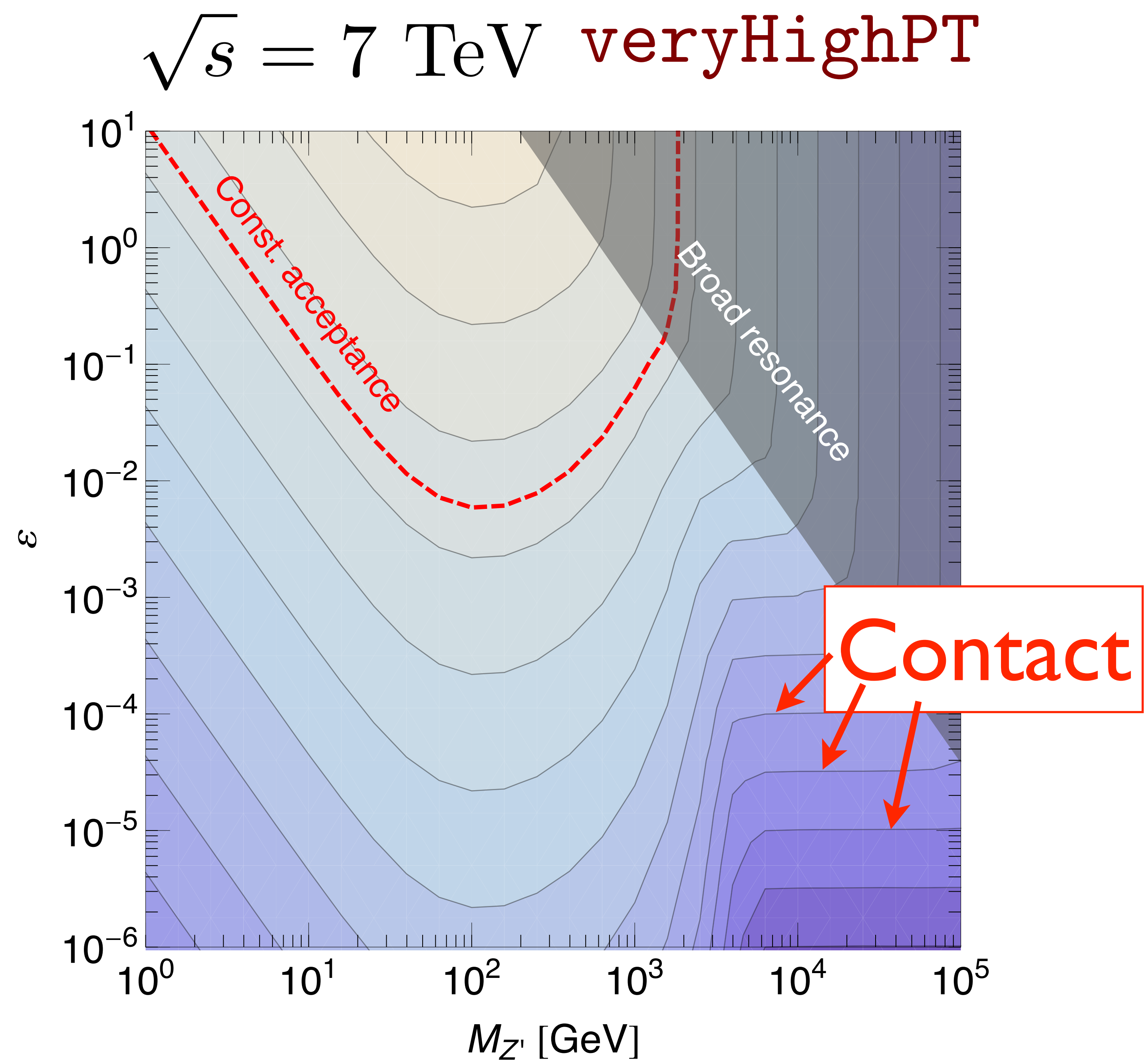

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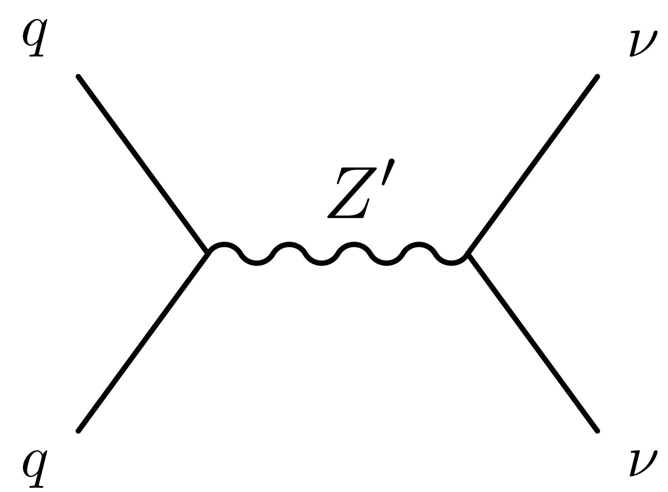

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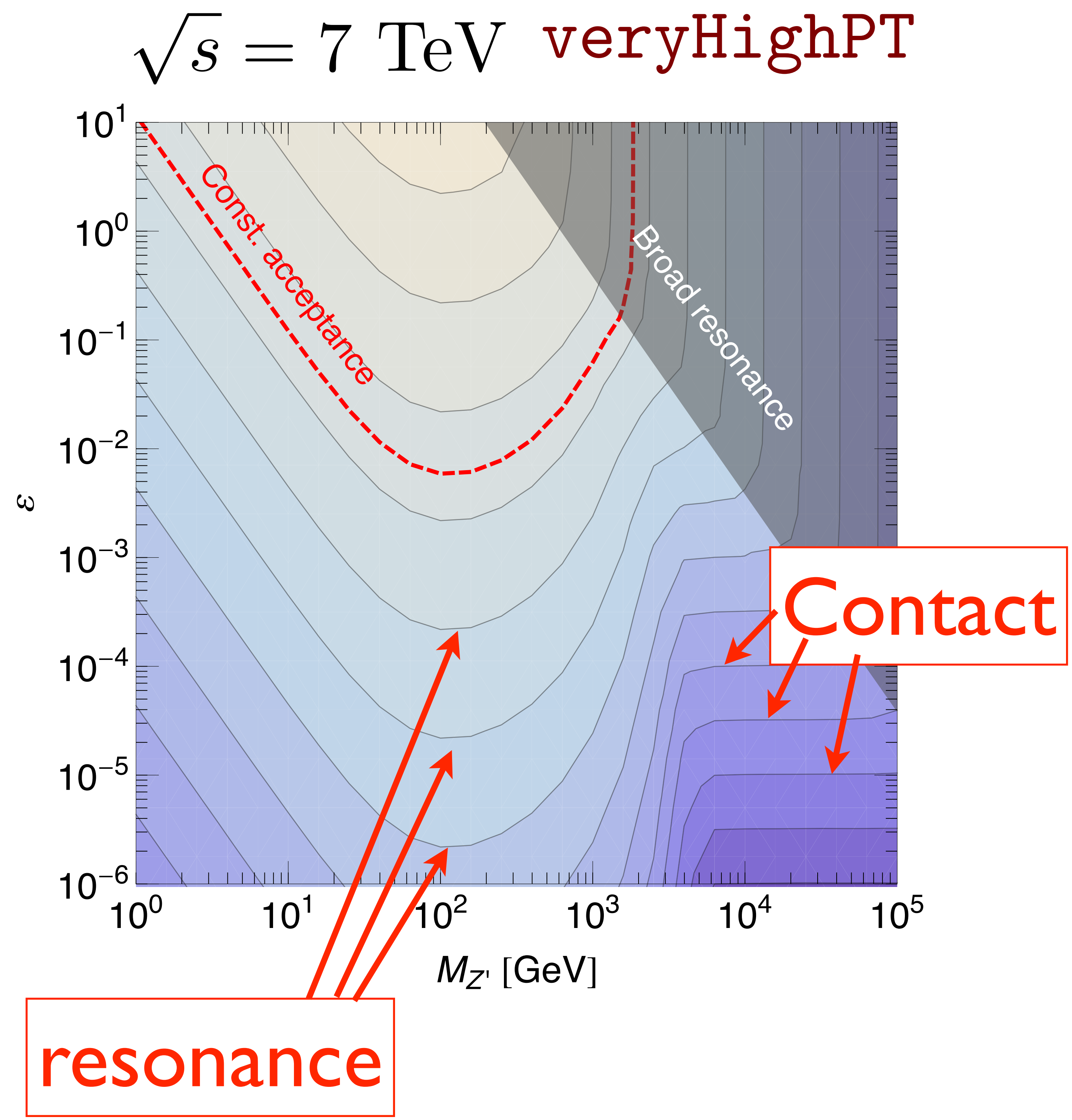

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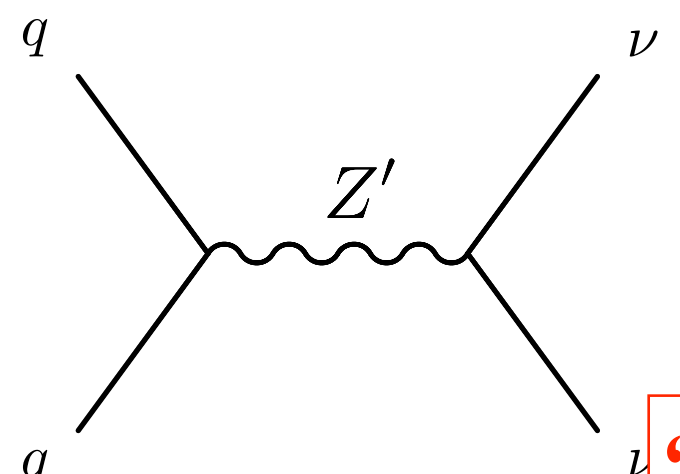

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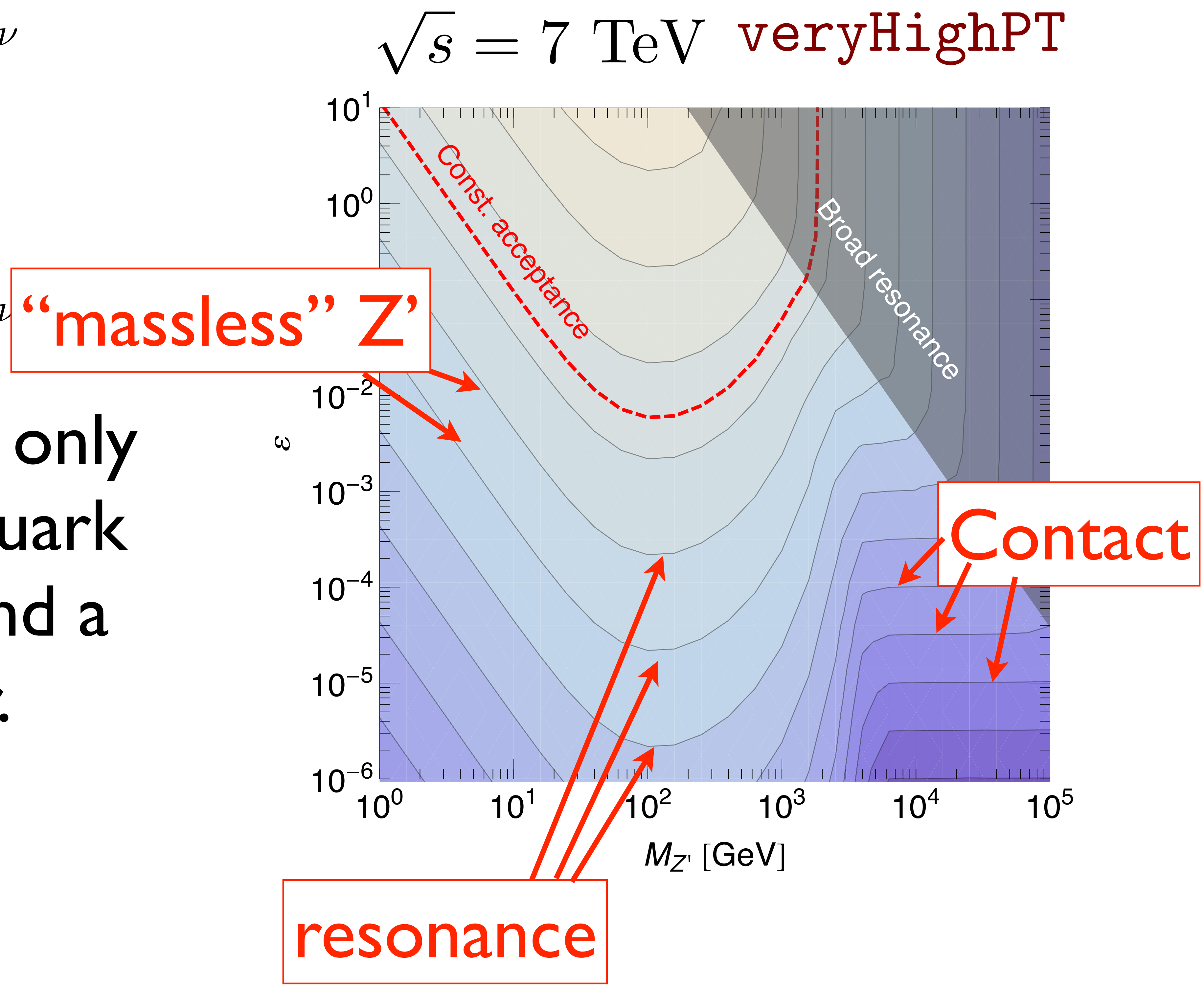
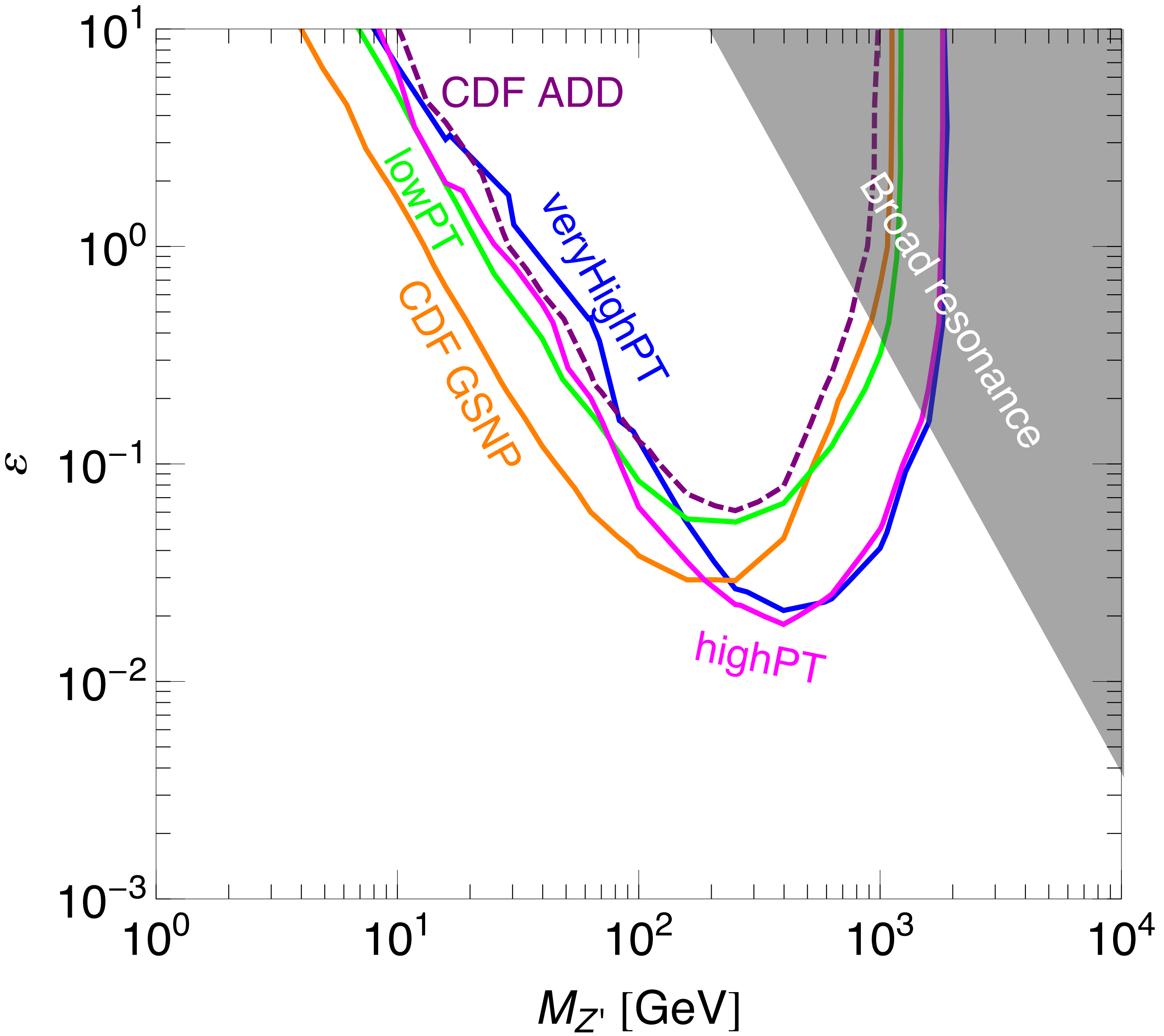


Beating the LHC from beyond the grave



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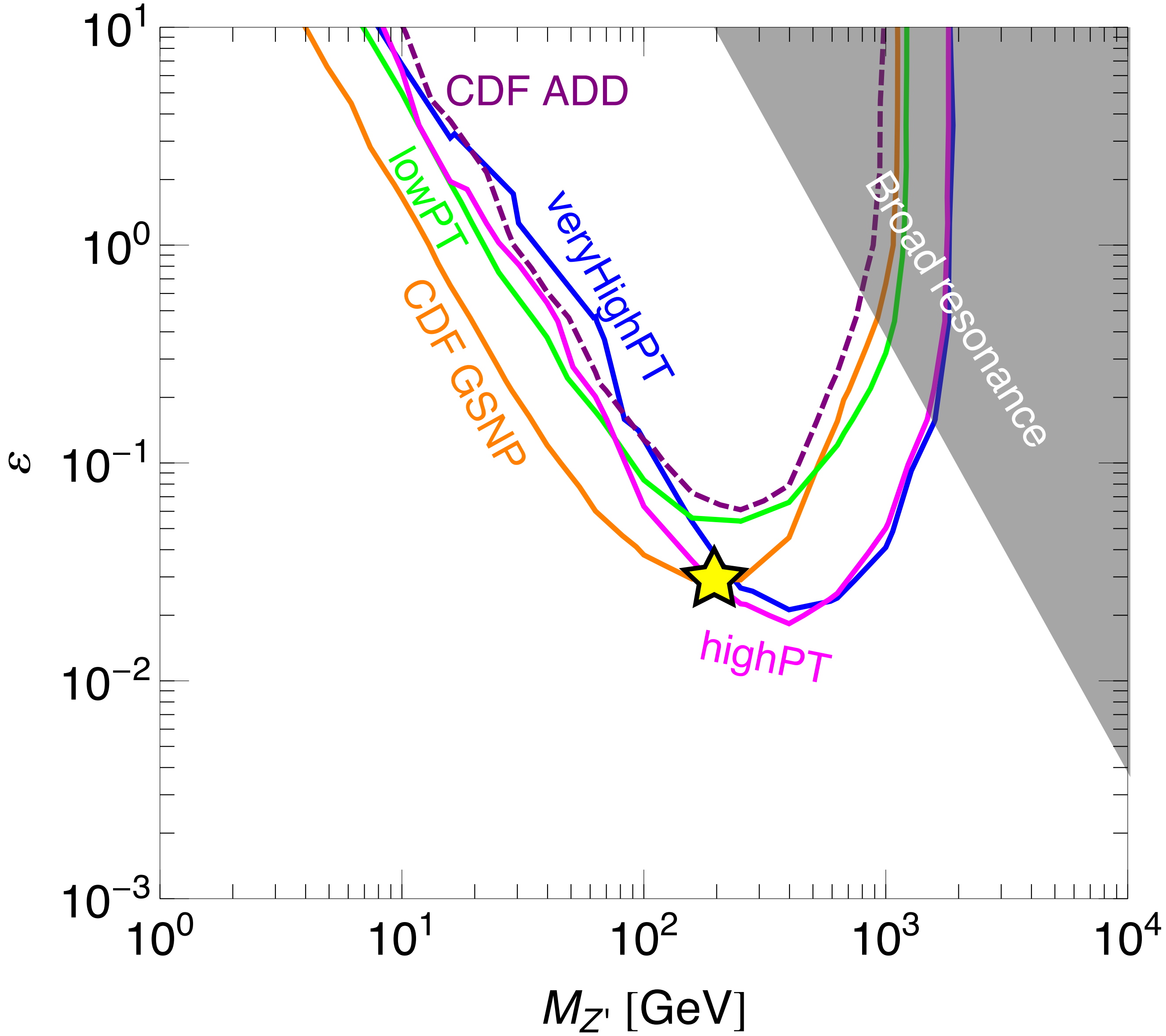

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$$m_{Z'} \lesssim 200 \text{ GeV}$$

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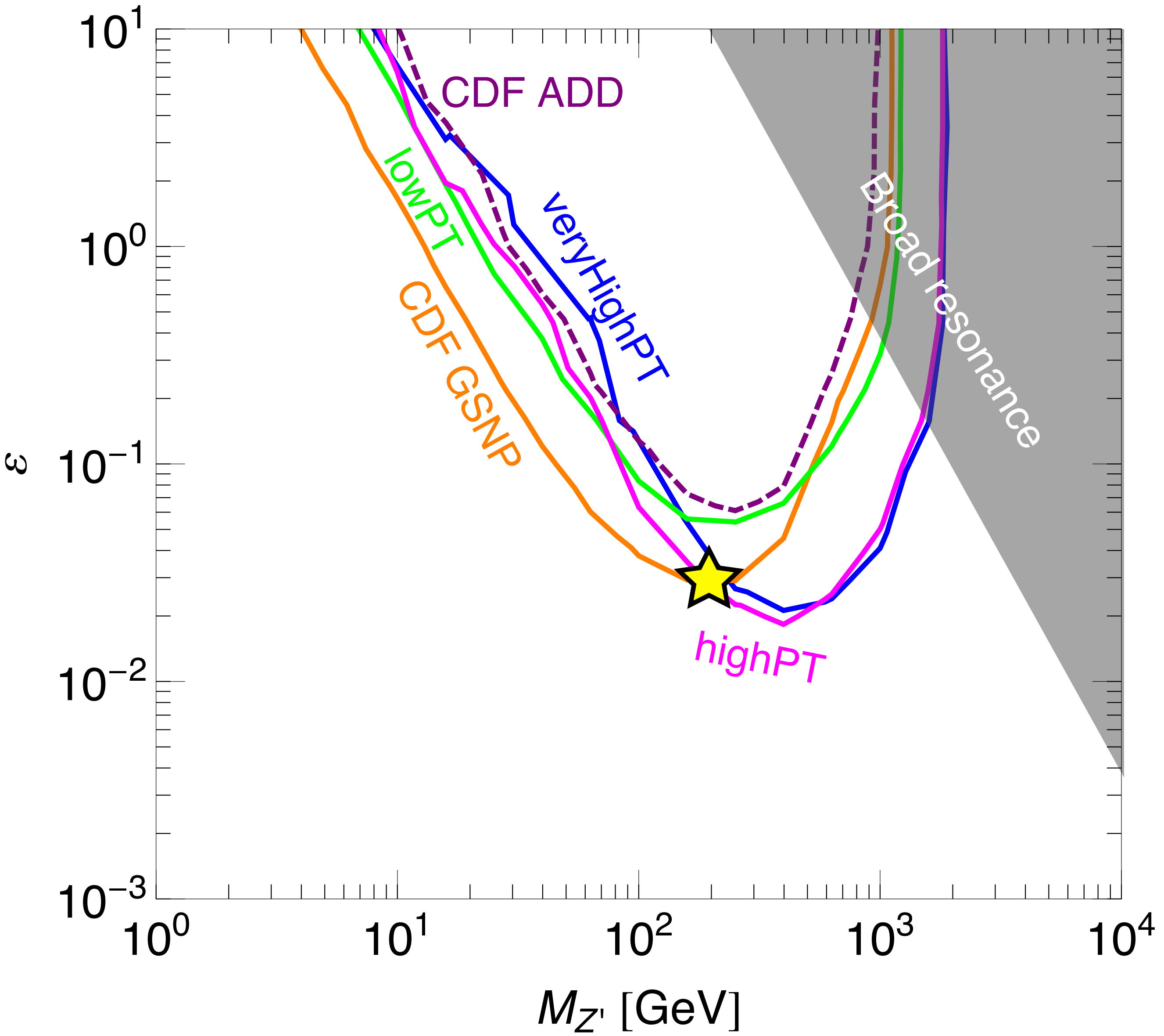

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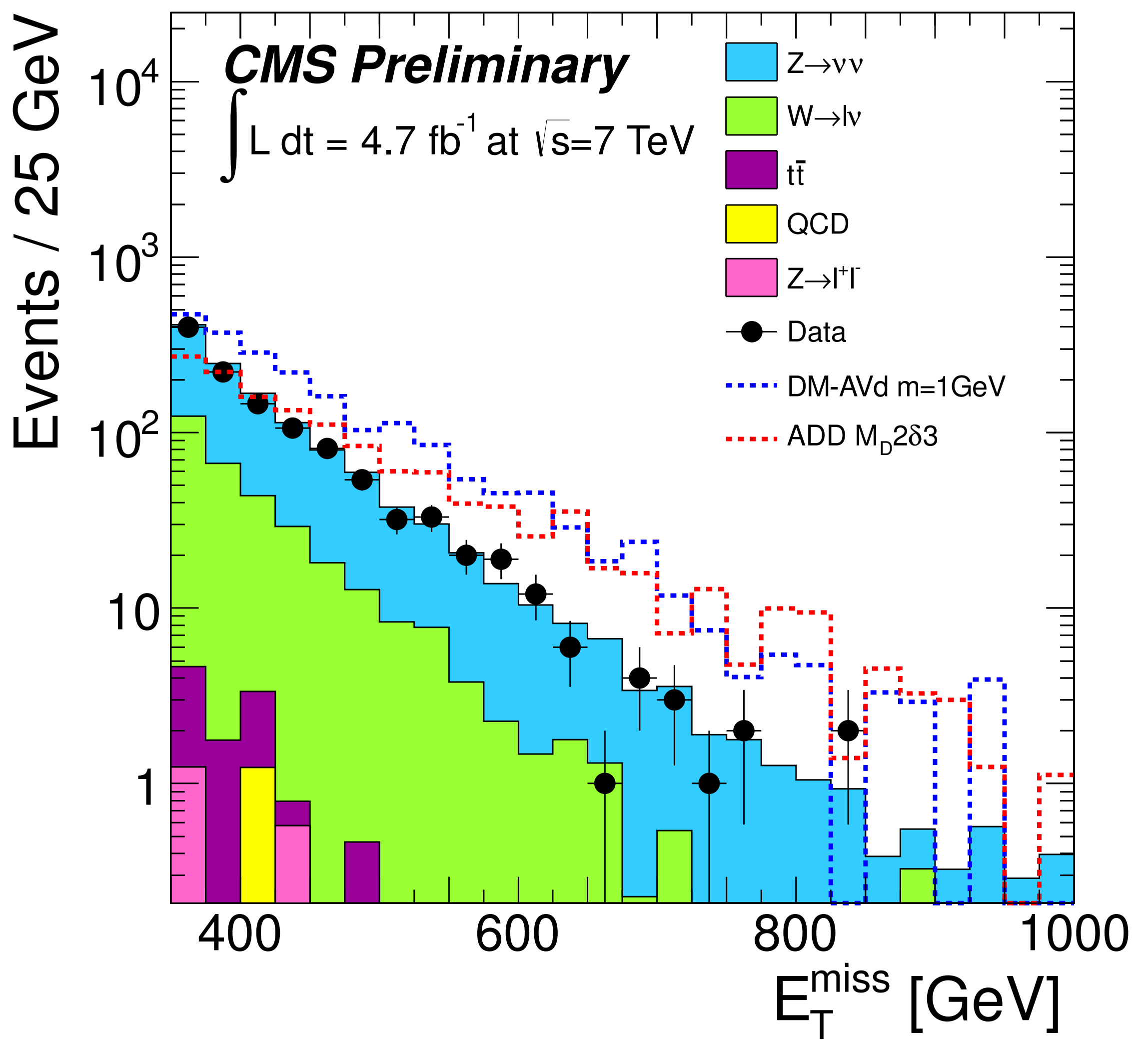
-Would a yet softer cut yield better bounds?

Latest CMS results



EXO-11-059

Background process	Events
$Z \to \nu\bar{\nu}$	900 ± 94
W+jets	312 ± 35
$t\bar{t}$	8 ± 8
$Z(\ell\ell)$+jets	2 ± 2
QCD multijet	1 ± 1
Single t	1 ± 1
Total background	1224 ± 101
Observed in data	1142

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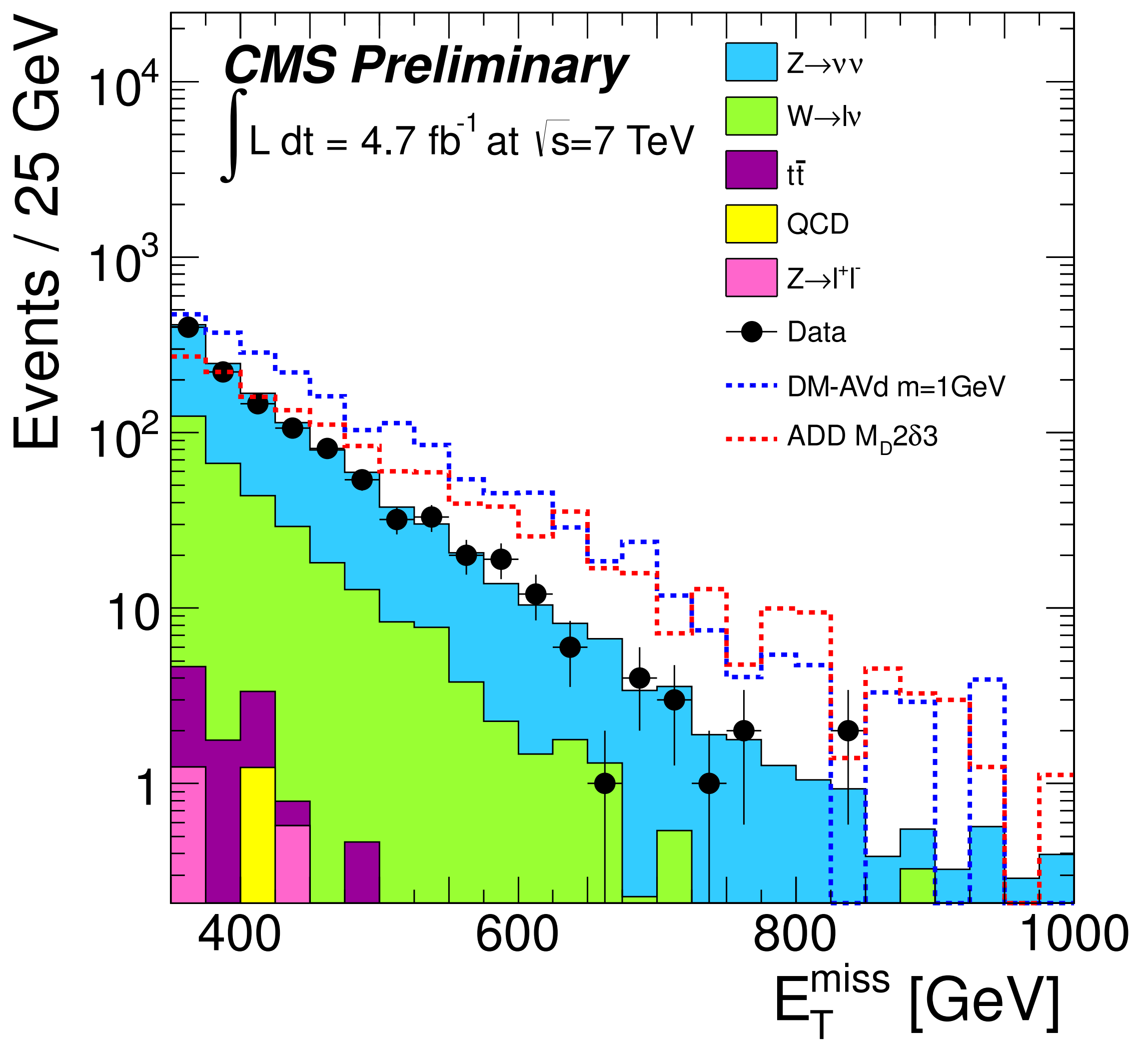

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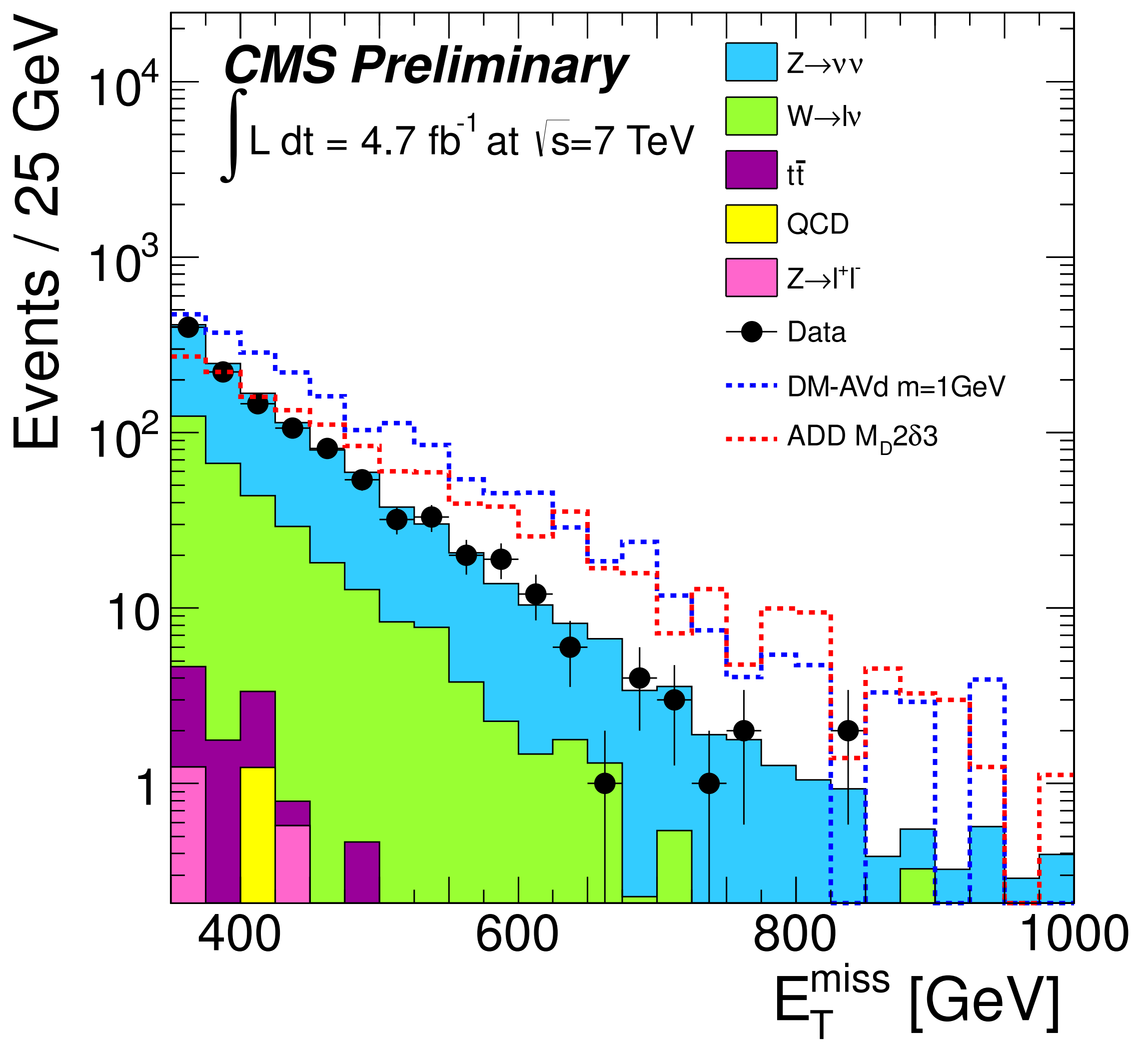

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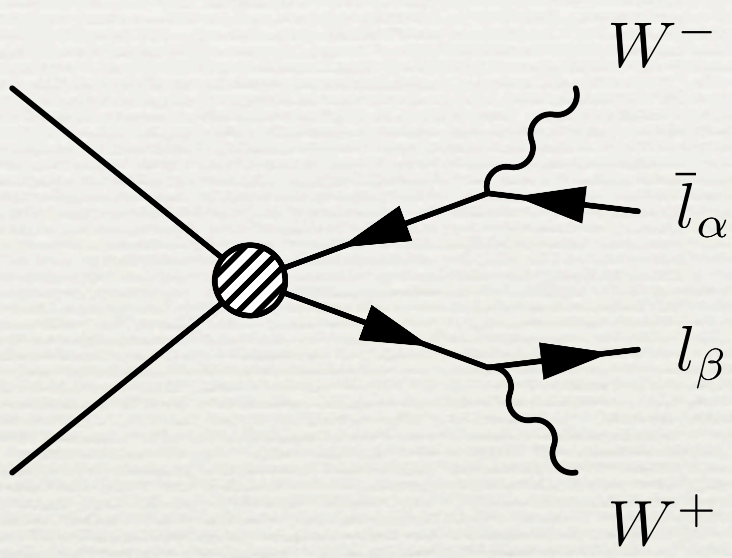
4.7/fb CMS: $\sigma_{BSM} < 0.018$ pb

Multileptons vs. monojets

NSI also produce...



Not as constraining as monojets

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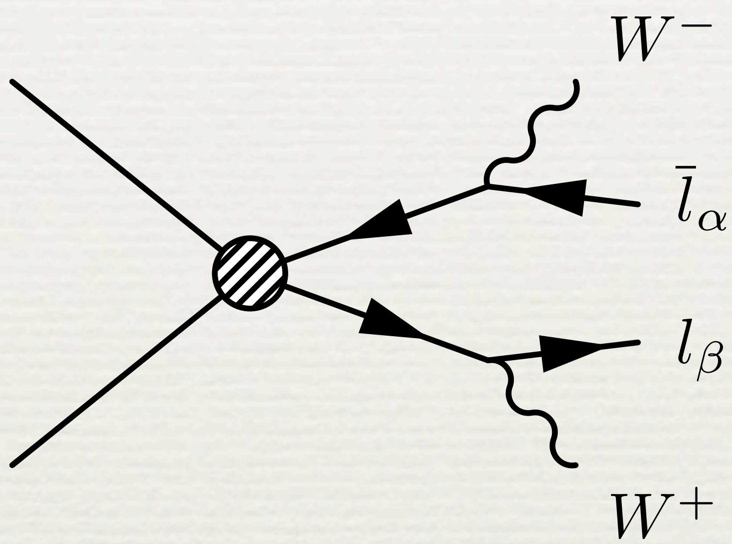

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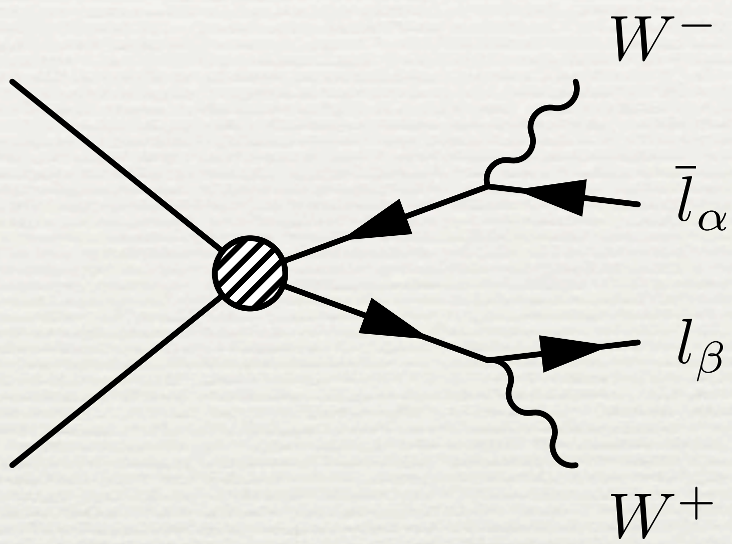

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- Clean lepton final states offer a probe on NSI with different systematics than monojets

Part Two: Dark Matter

Validity of Effective Description

Suppose by analogy to the NSI case, we wish to constrain DM-quark interactions of the form:

$$\mathcal{O} = \frac{\overline{q}\gamma^\mu q \overline{X}\gamma_\mu X}{\Lambda^2}$$

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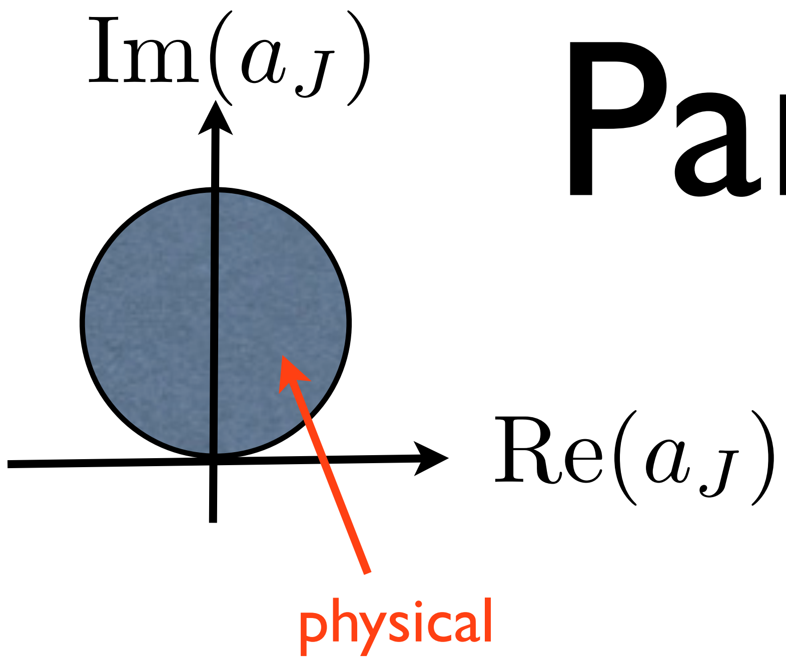
Can we be more rigorous than $E \sim \Lambda$?

Partial-wave unitarity



$$\mathcal{M} = 16\pi \sum_j (2j+1)\, P_j\, (\cos\theta)\, a_J(s)$$

Unitarity: $(\mathrm{Re}(a_J))^2 + (\mathrm{Im}(a_J) - 1/2)^2 \leq 1/4$

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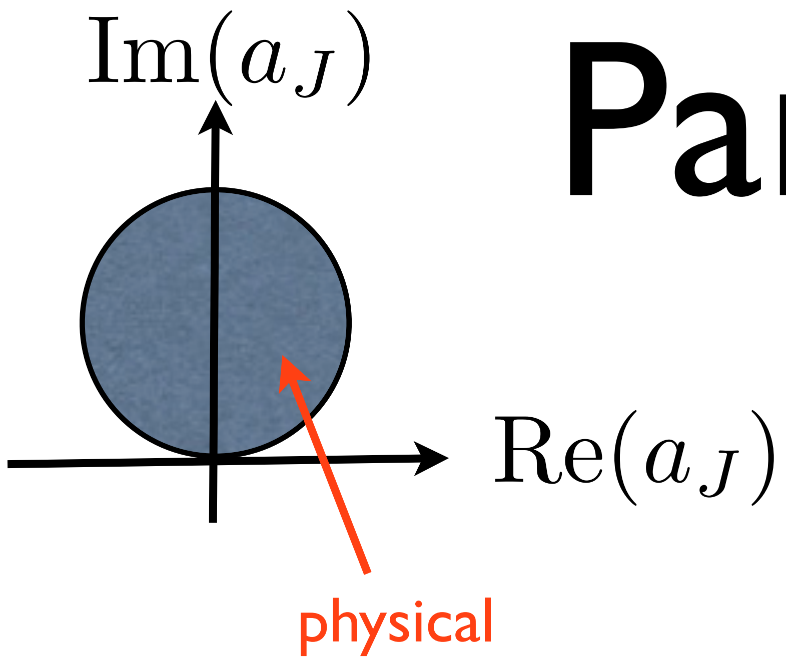

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E.g. Higgs mass (Lee, Quigg, Thacker 1977)

$$W^+W^- \to W^+W^- \qquad m_h \leq \sqrt{\frac{8\pi}{5\sqrt{2}G_F}} \approx 780 \text{ GeV}$$

Effective dark matter interactions

Assume heavy particles can be integrated out:

$$\mathcal{O} = \frac{\overline{q}\gamma^\mu q \ \overline{X}\gamma^\mu X}{\Lambda^2}$$

$$\Rightarrow \ \mathcal{M}(q\overline{q} \to X\overline{X}) = 2\sqrt{N_c}\frac{s}{\Lambda^2}$$

Unitarity implies: $\Lambda \gtrsim 2 \ \mathrm{TeV}$

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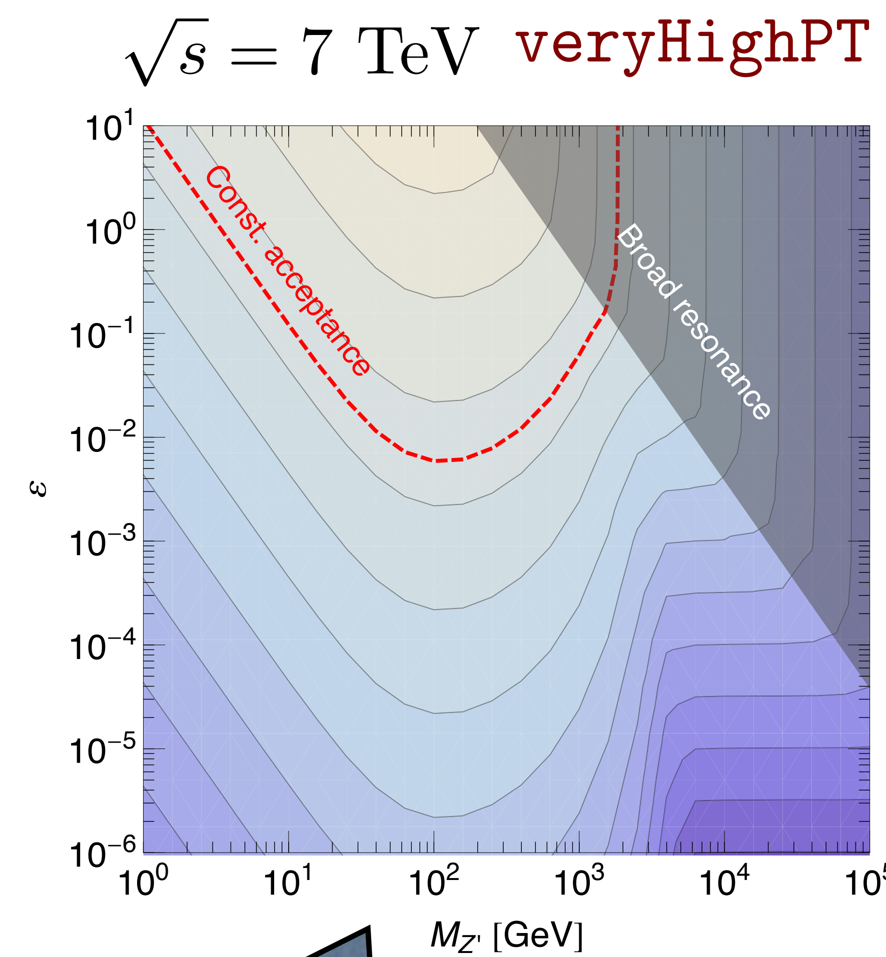

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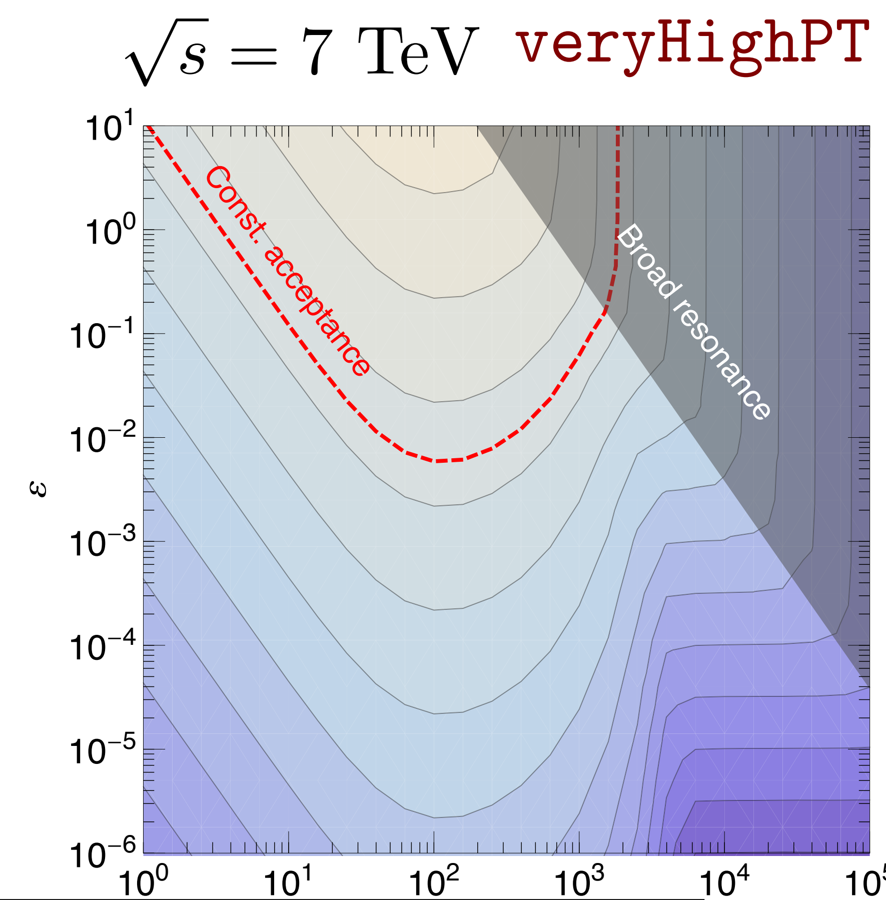

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Unitarit

Said differently, an effective DM theory with a 500 GeV cutoff is consistent if:

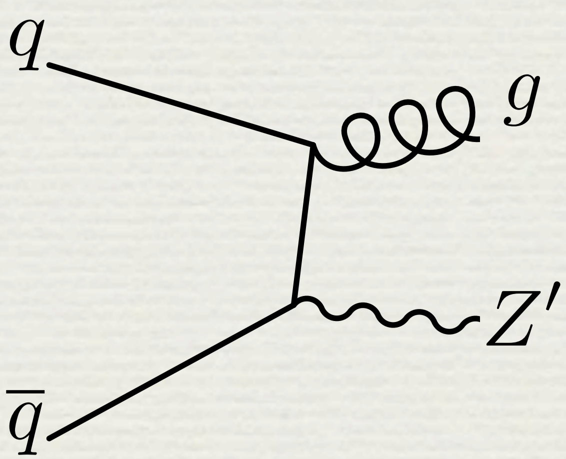
$$s \lesssim 1.3 \text{ TeV}$$

Accessible Z's

With a Z' coupling to DM and a single quark flavor there are 4 parameters in the full parameter space:

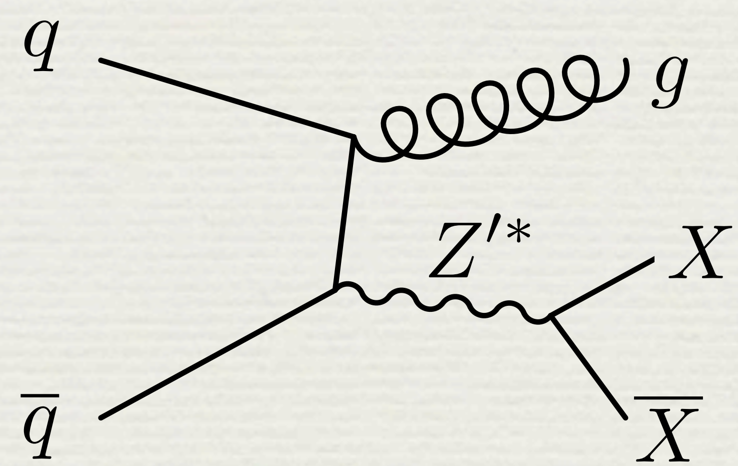
$$\left(m_X, m_{Z'}, \sqrt{g_X g_q}, \Gamma_{Z'}\right)$$

light DM



$$\sigma \propto g_q^2 \times \mathrm{BR}\left(Z' \to \overline{X} X\right)$$

light Z'



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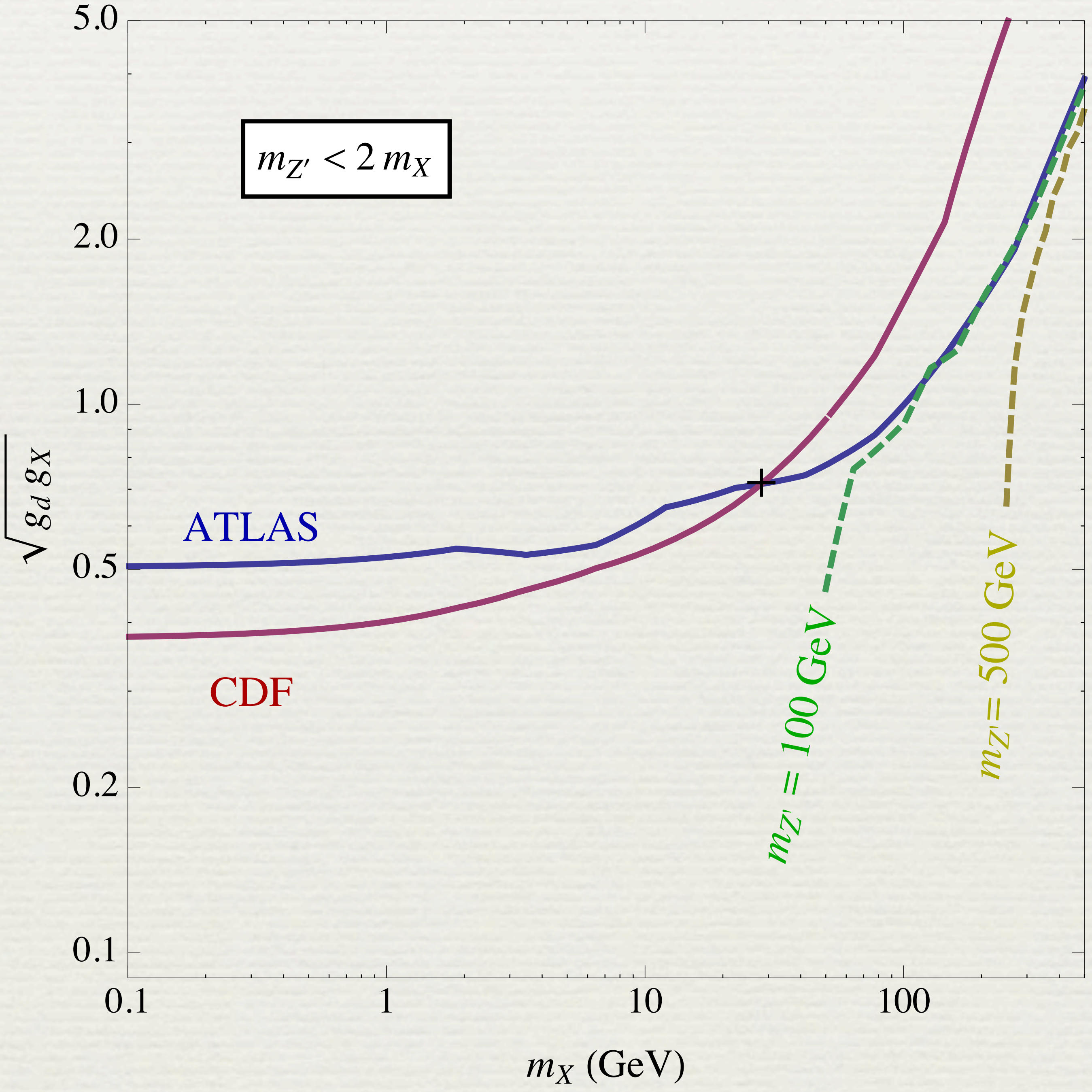
Tevatron wins even in the off-shell regime



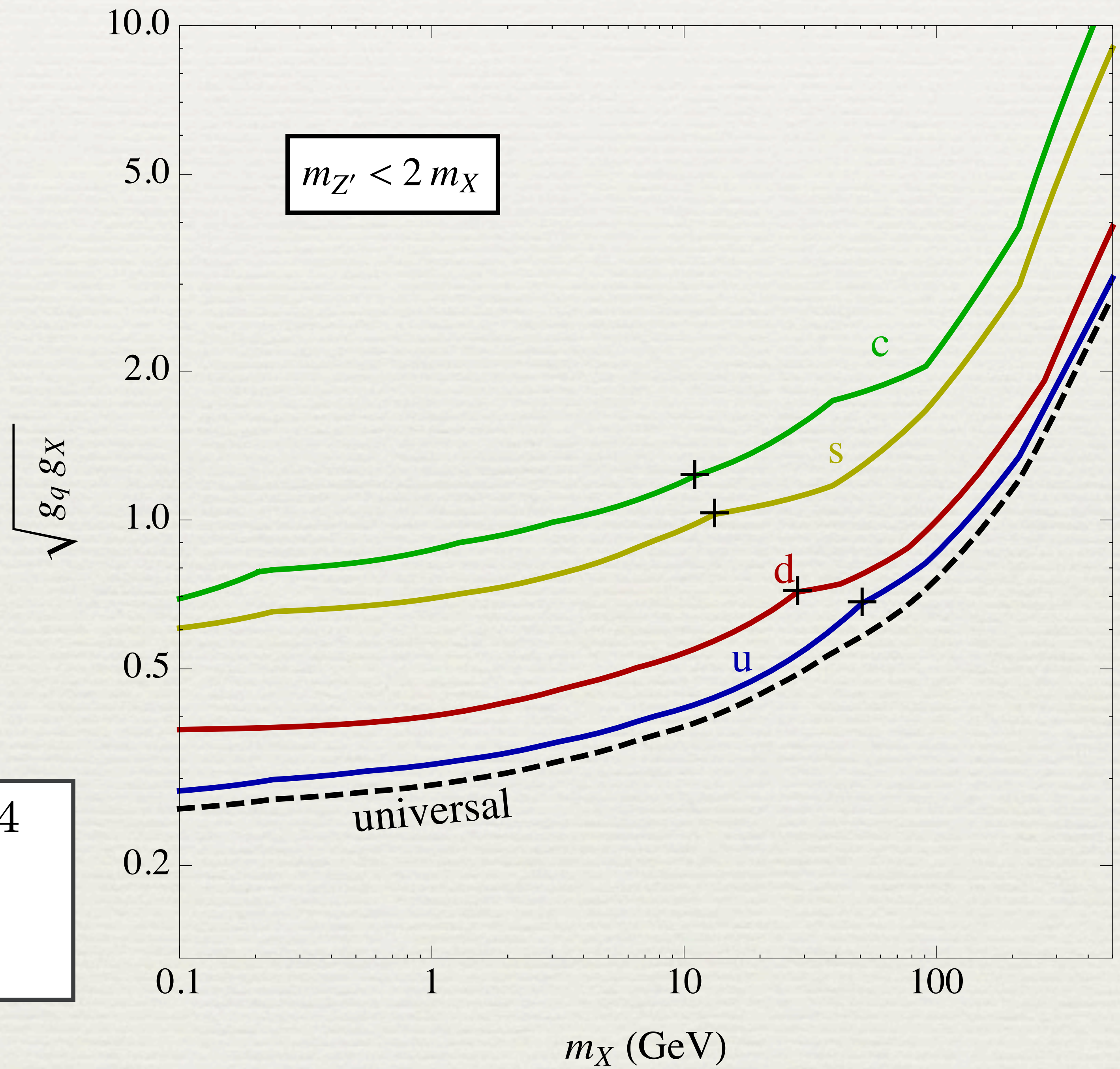
Soft cuts are good for light particles.

Upper bounds on quark-DM coupling

+ = where ATLAS overtakes CDF

Quarks with a large PDF delay the +

$$\sigma_{nX} \lesssim 10^{-34}\text{cm}^2 \left(\frac{20\ \text{GeV}}{m_{Z'}}\right)^4$$

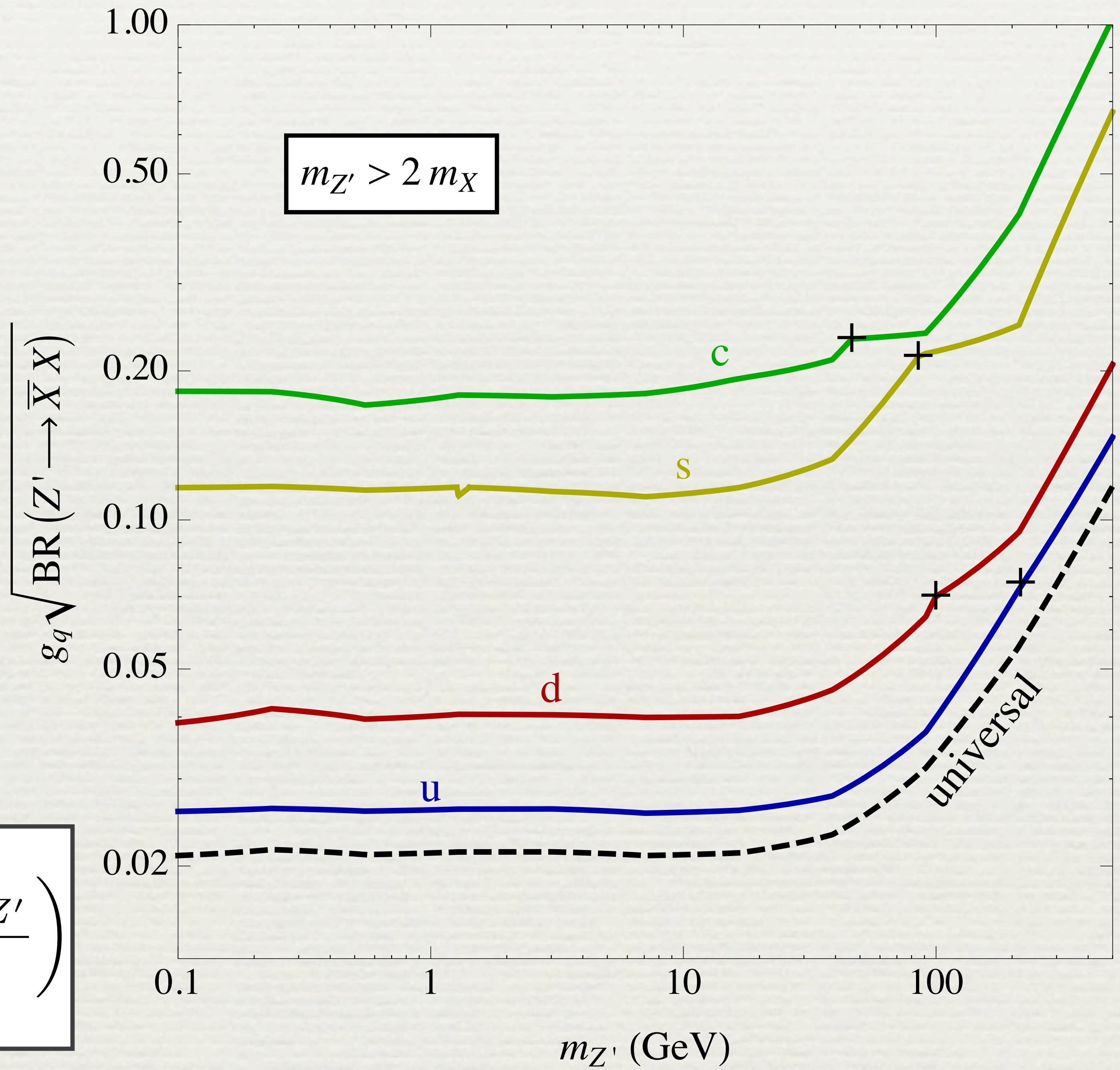


Quark-DM bounds

+ = where ATLAS overtakes CDF

Bounds are more constraining when Z' is on-shell.

$$\sigma_{nX} \lesssim 10^{-36}\text{cm}^2 \left(\frac{20\text{ GeV}}{m_{Z'}}\right)^4 \left(\frac{\Gamma_{Z'}/m_{Z'}}{10^{-2}}\right)$$



Take aways

- Neutrinos aren't just a background. Could hide new physics.
- Solar data give hints. Test this hypothesis at the LHC.
- The Tevatron 1/fb reigns supreme at low masses. Who can beat them?