Low- vs High-Energy Precision

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CERN

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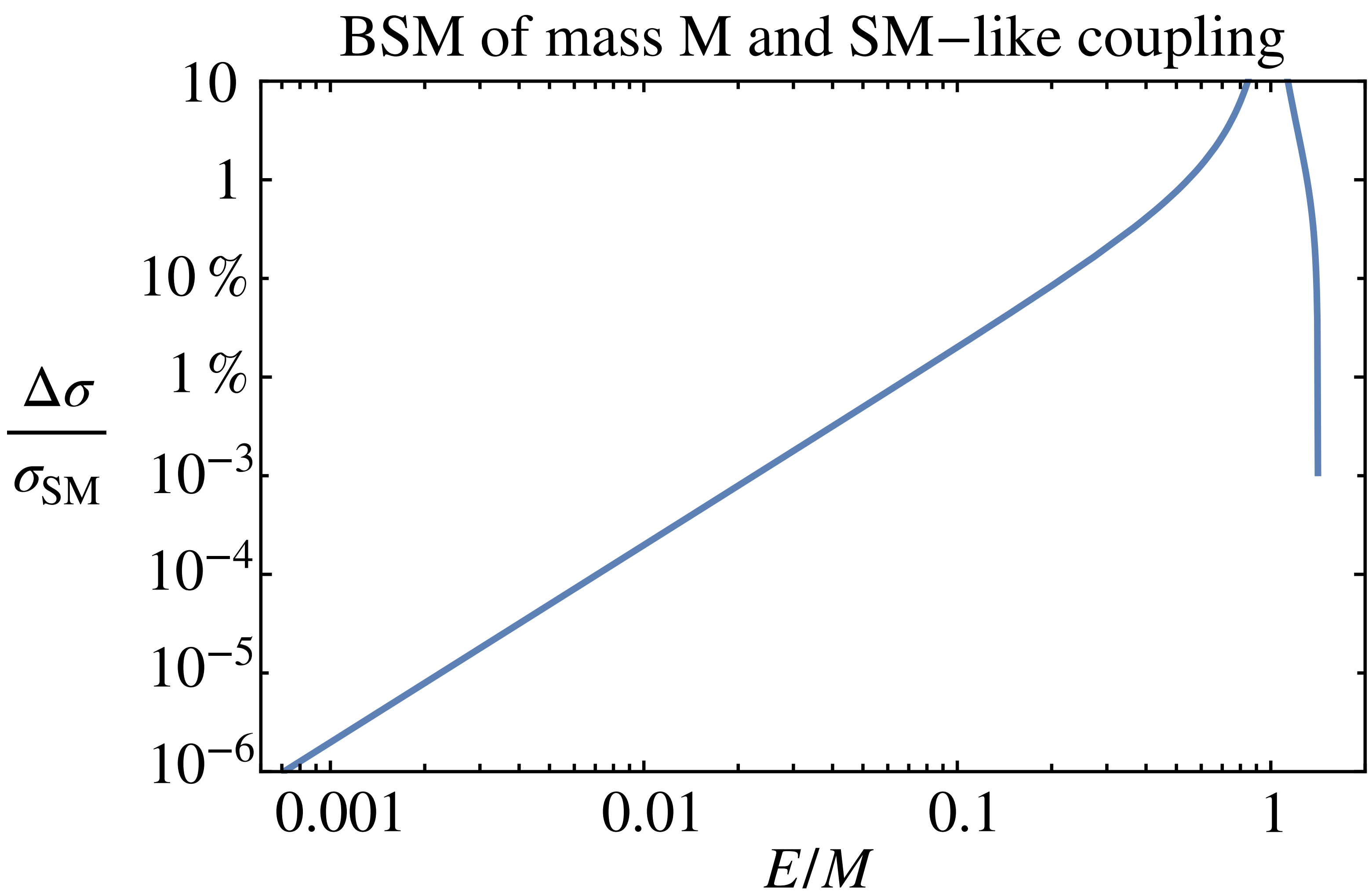
High Energy Probes



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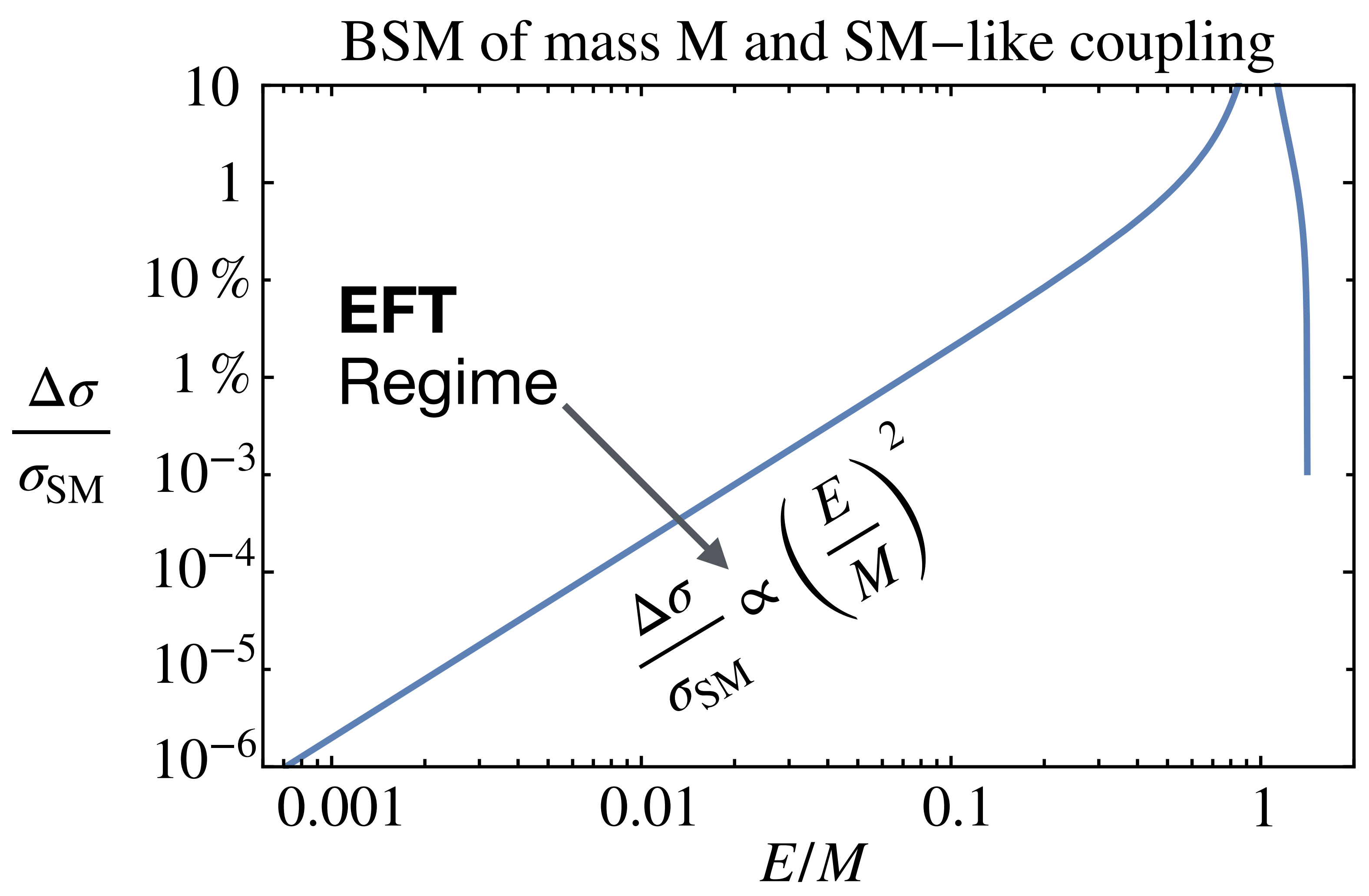

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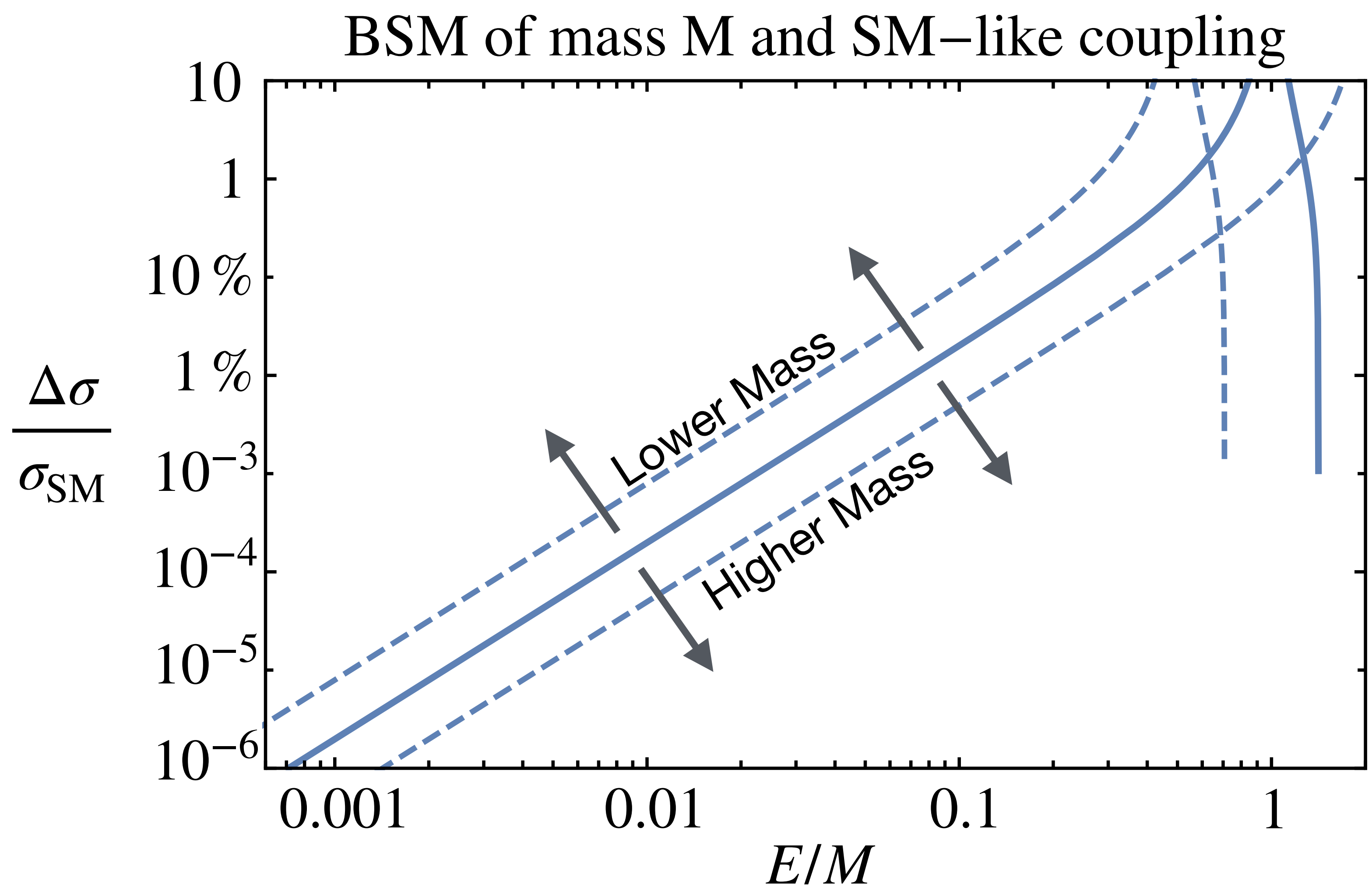

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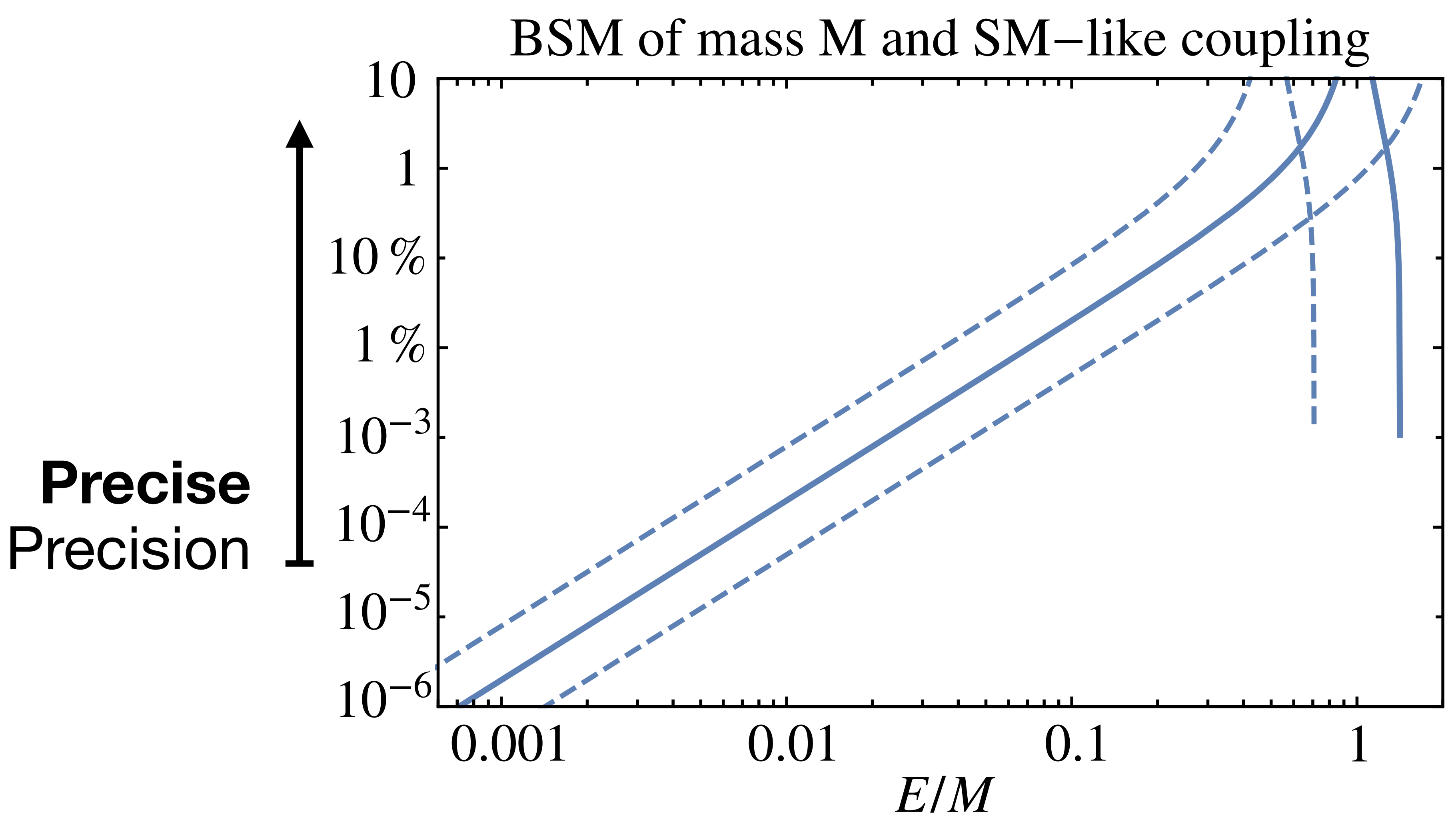

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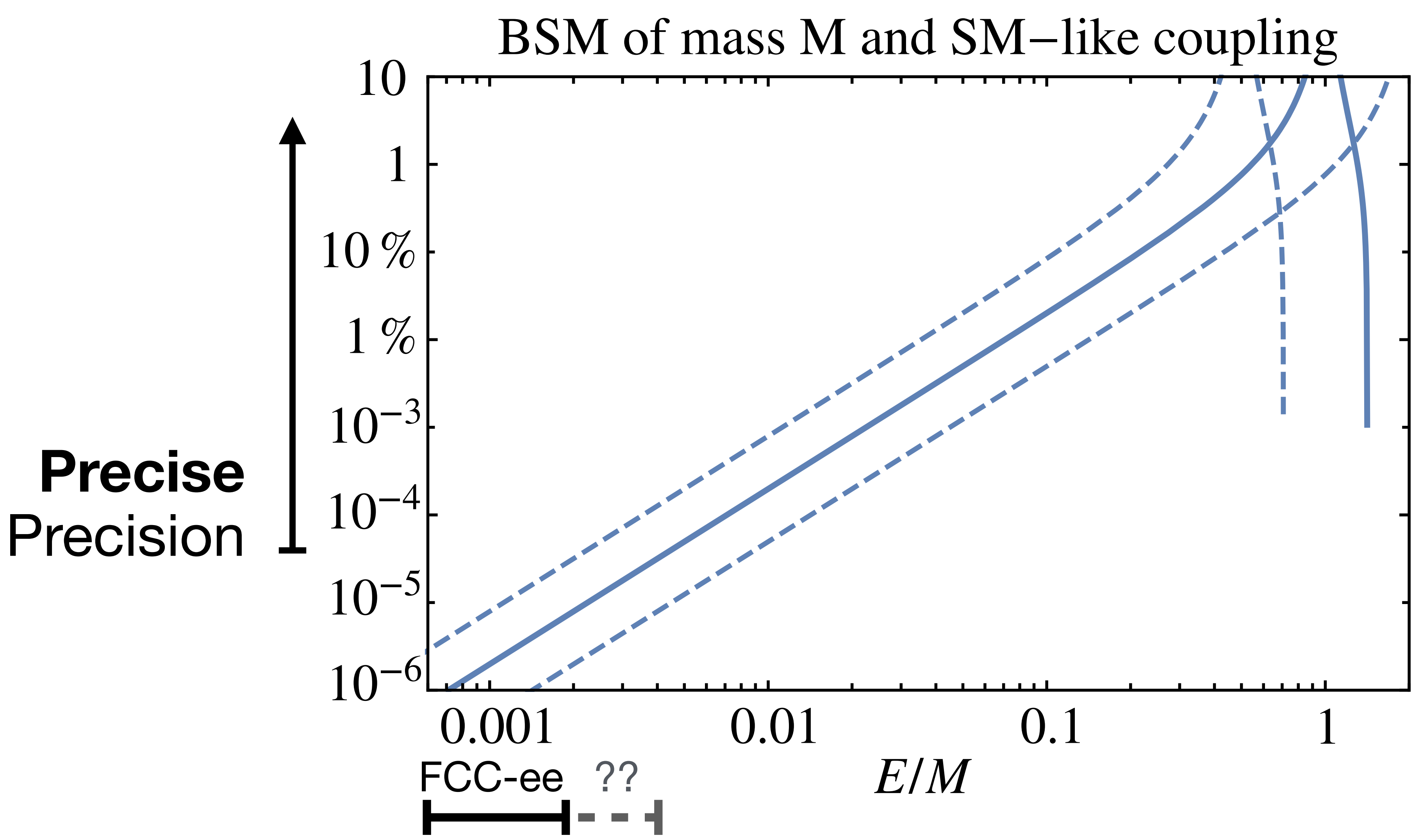

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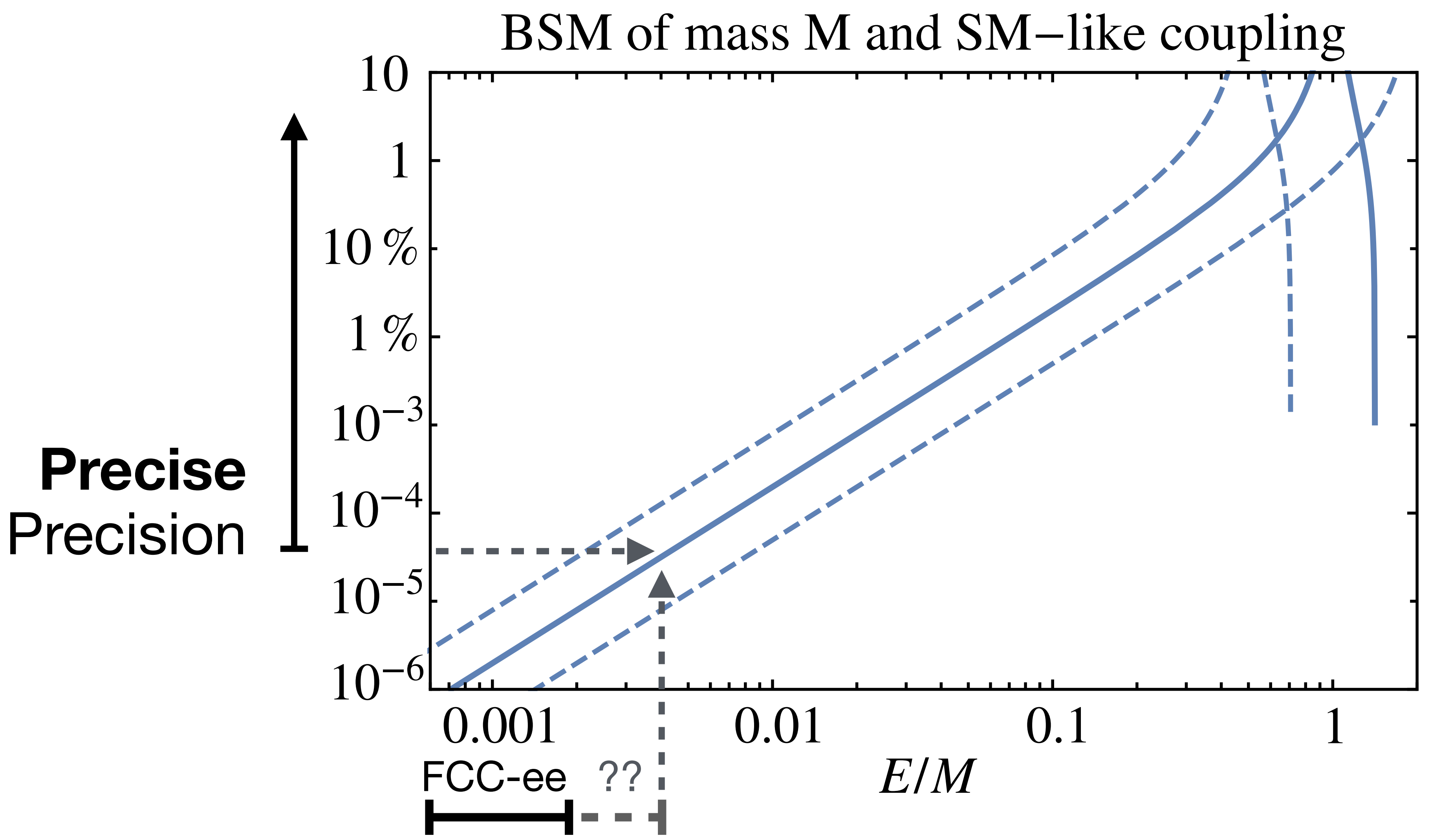
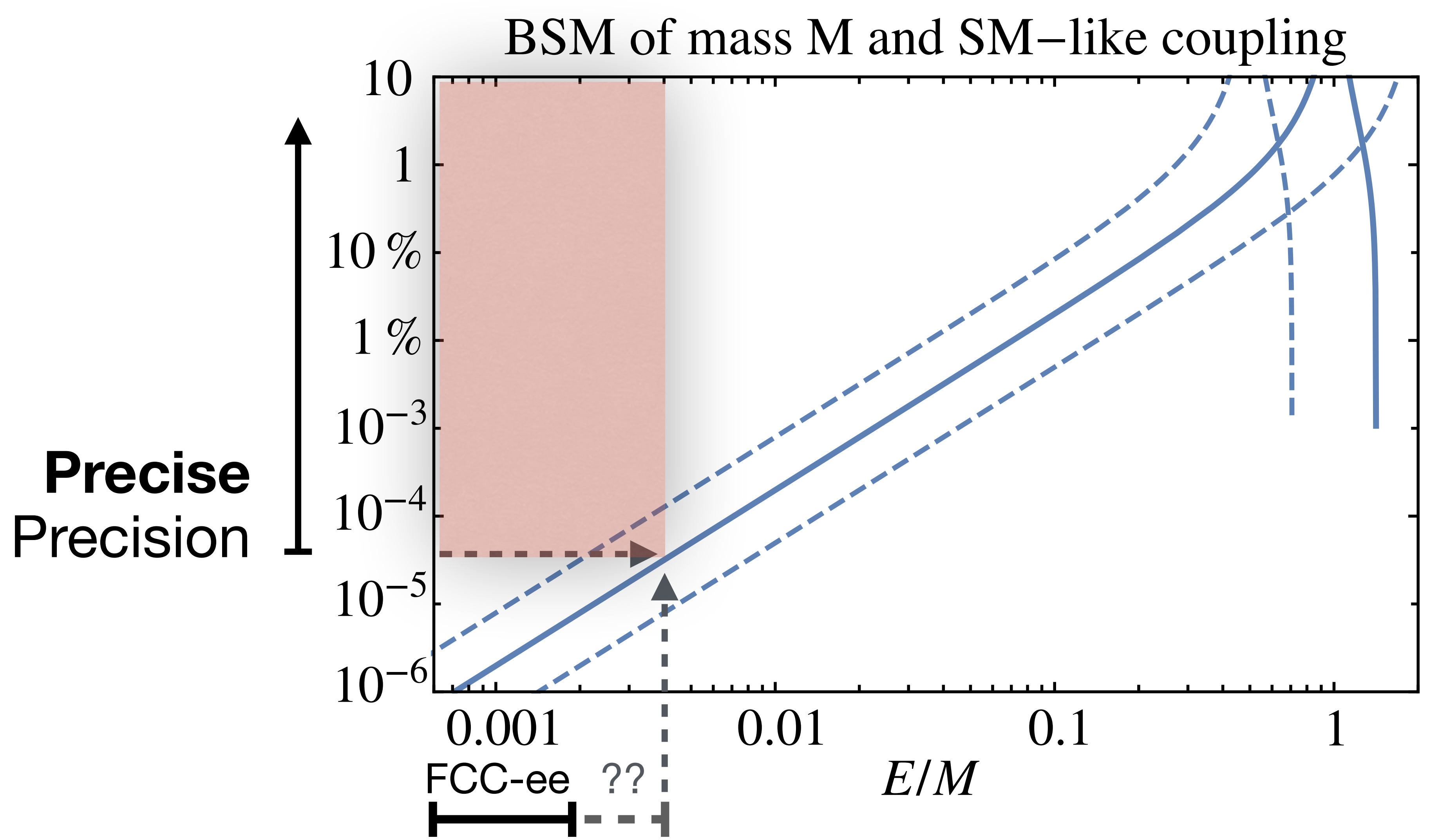


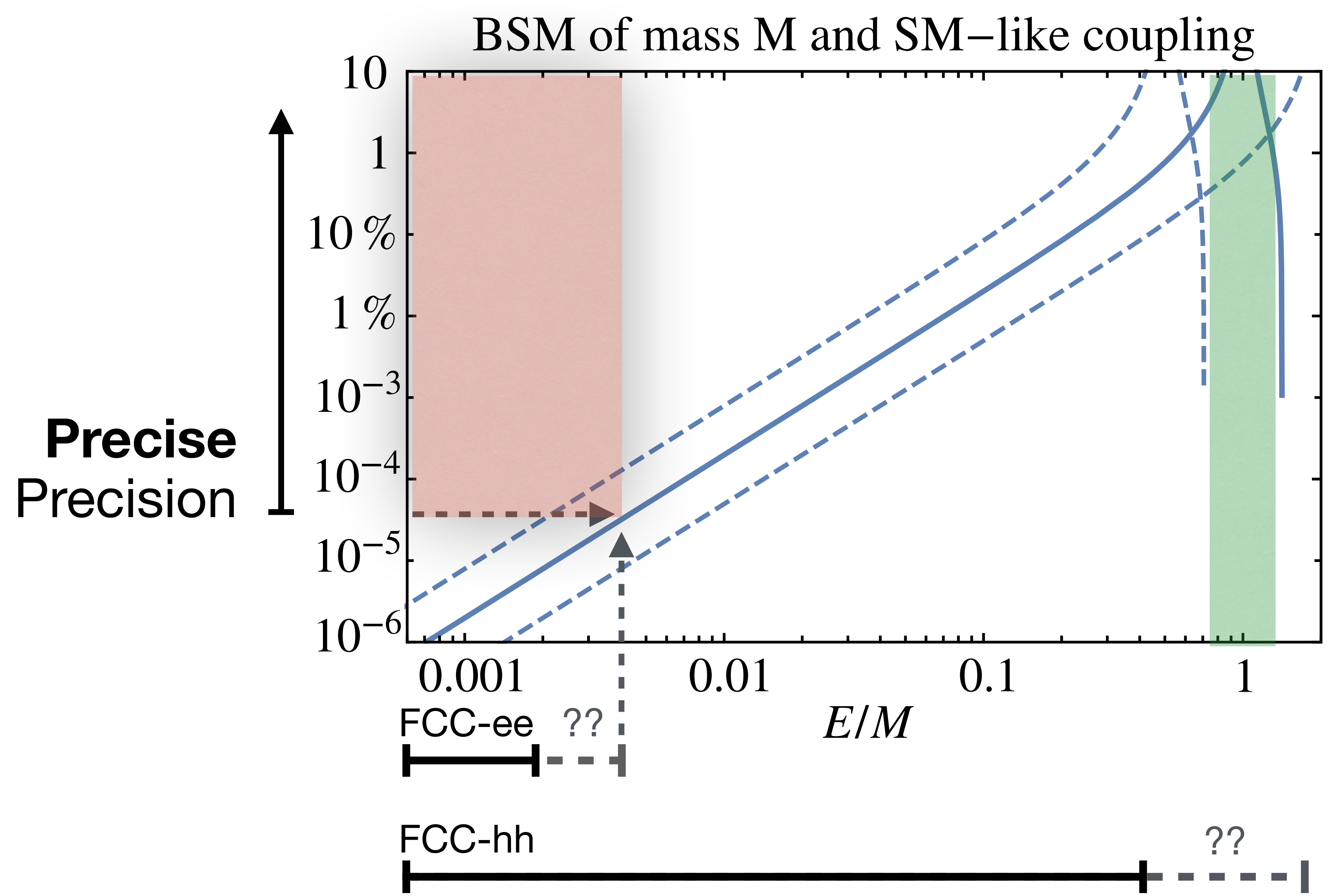
High Energy Probes

Low-Energy Probes



High Energy Probes

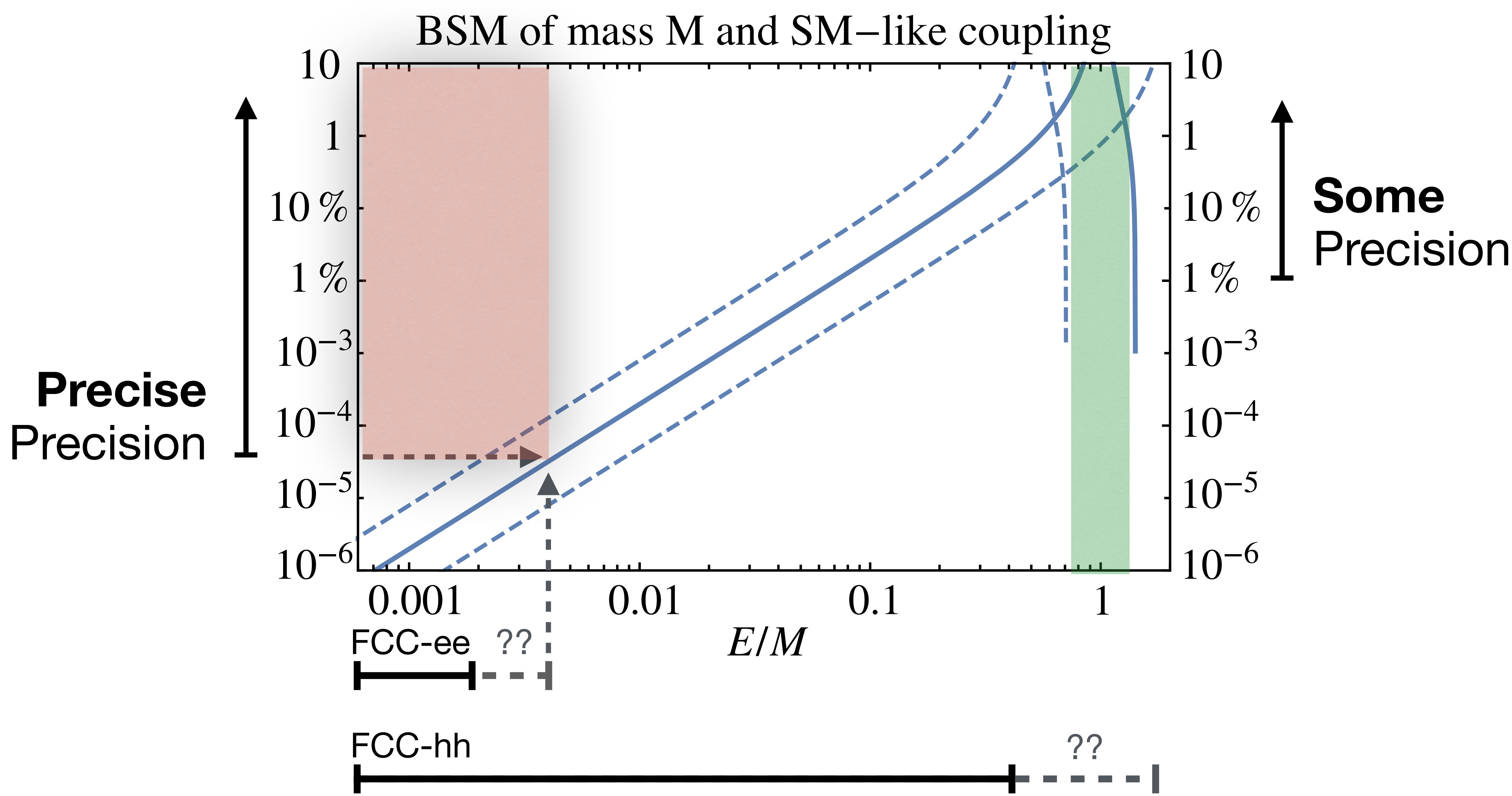
Low-Energy Probes   Direct Searches



High Energy Probes

Low-Energy Probes

Direct Searches



High Energy Probes

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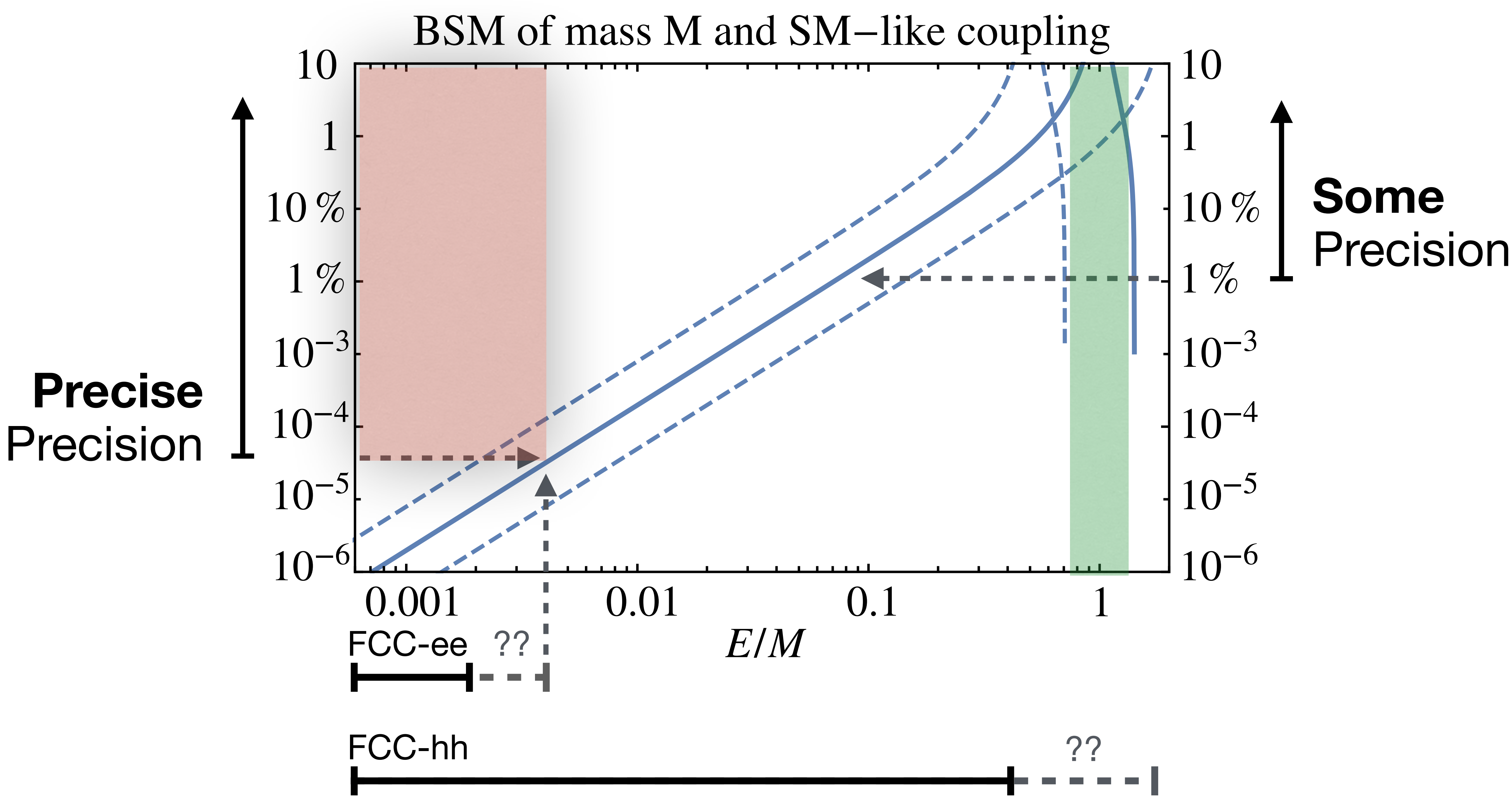

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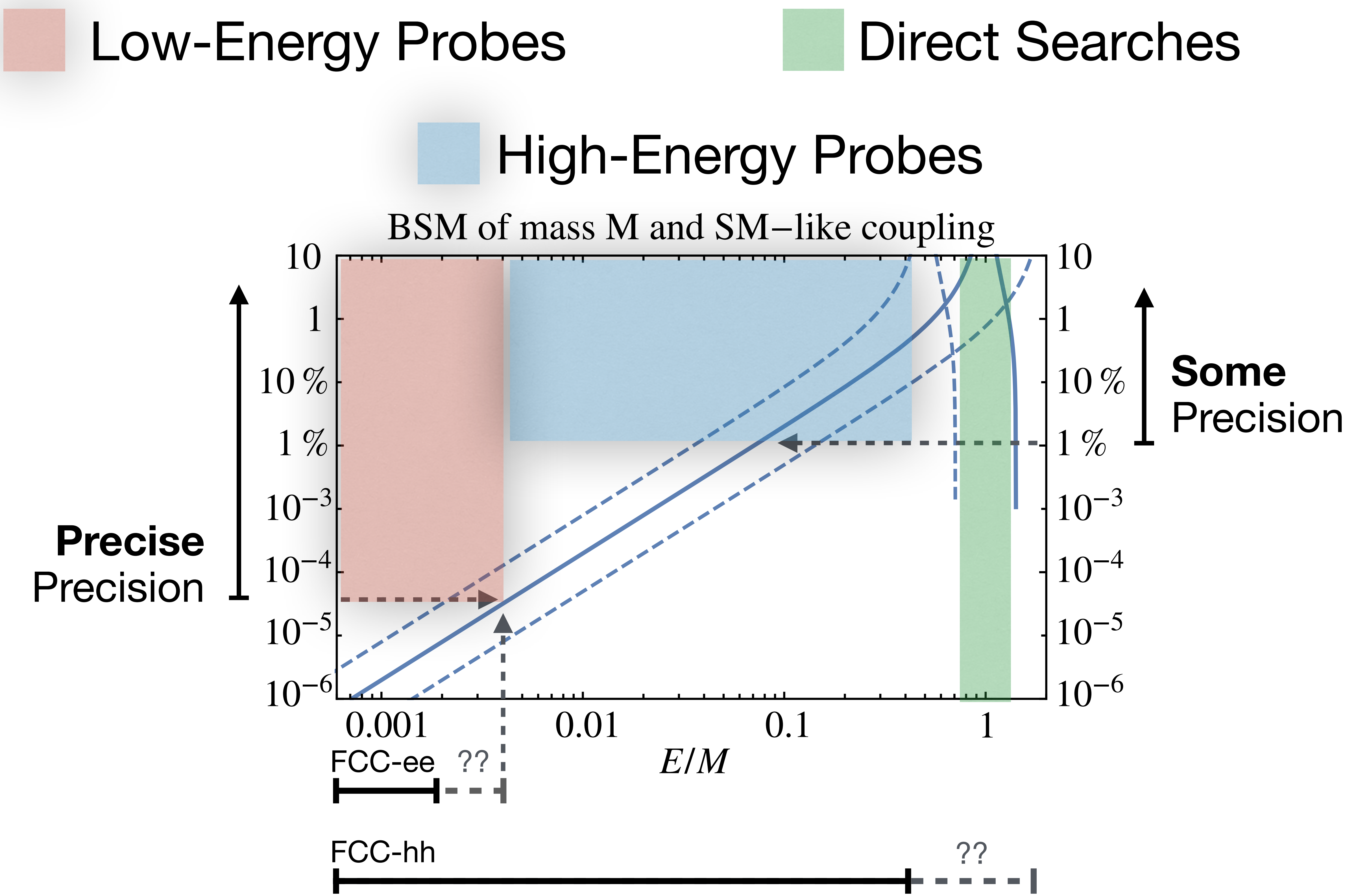

High Energy Drell—Yan

[Farina, Panico, Pappadopulo, Ruderman, Torre, AW, 2016]

The simplest pp measurement: m_{ll} or $m_{T,l}$ distribution

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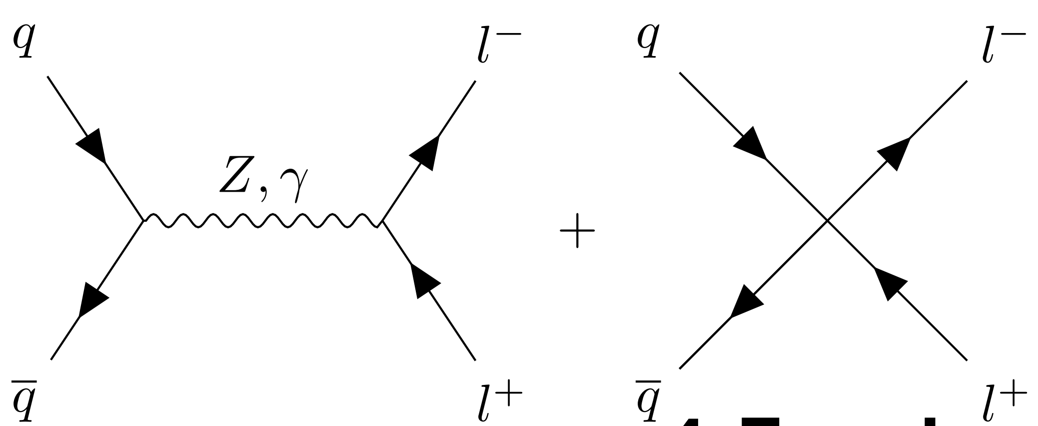

SM

4-Fermi cont. int.

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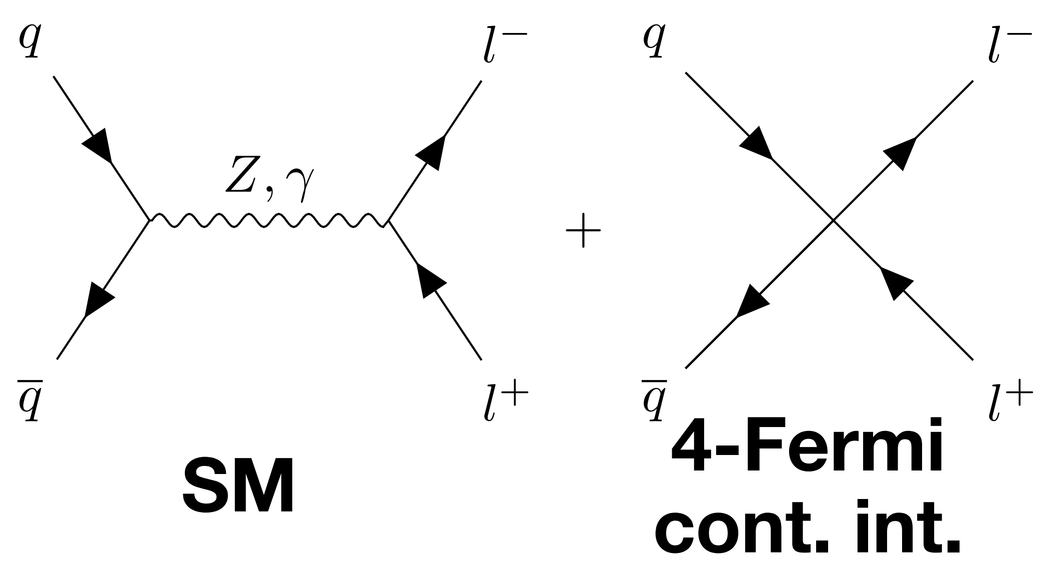

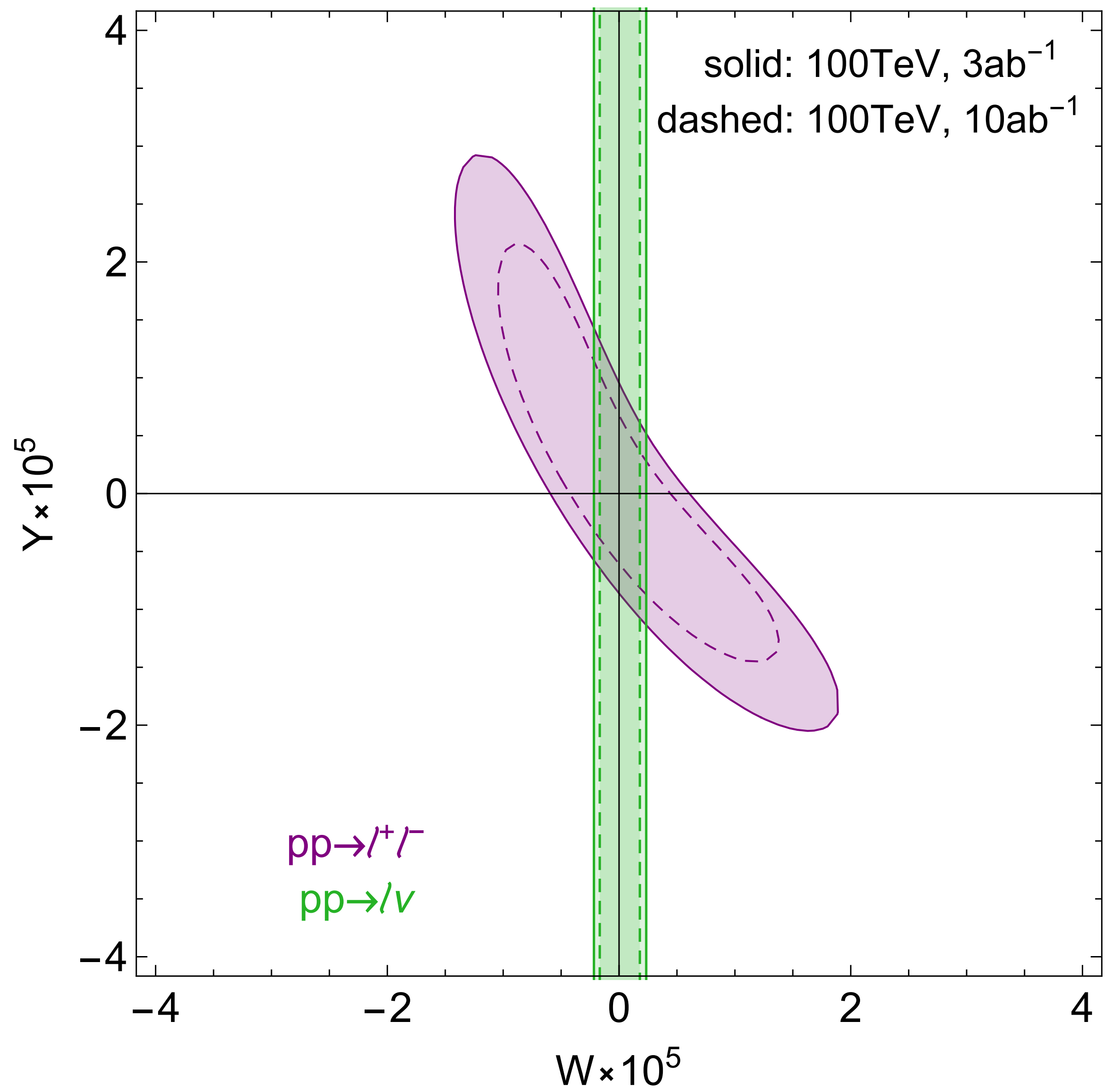

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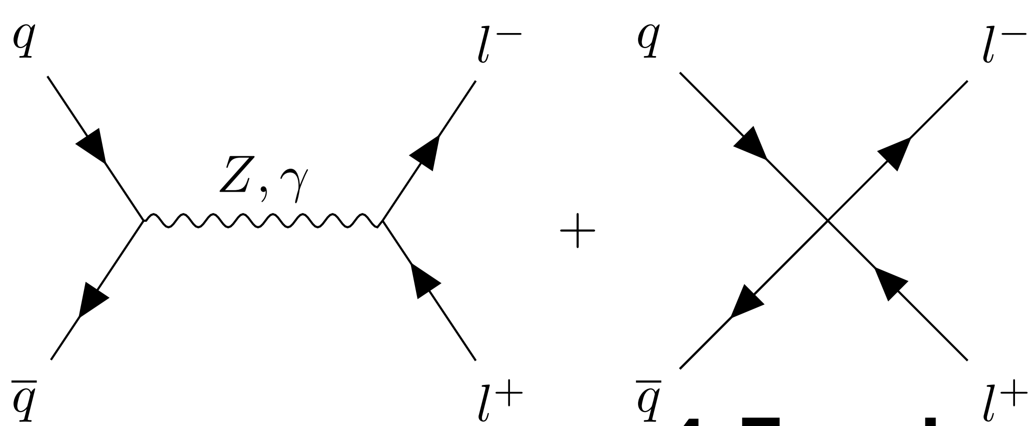
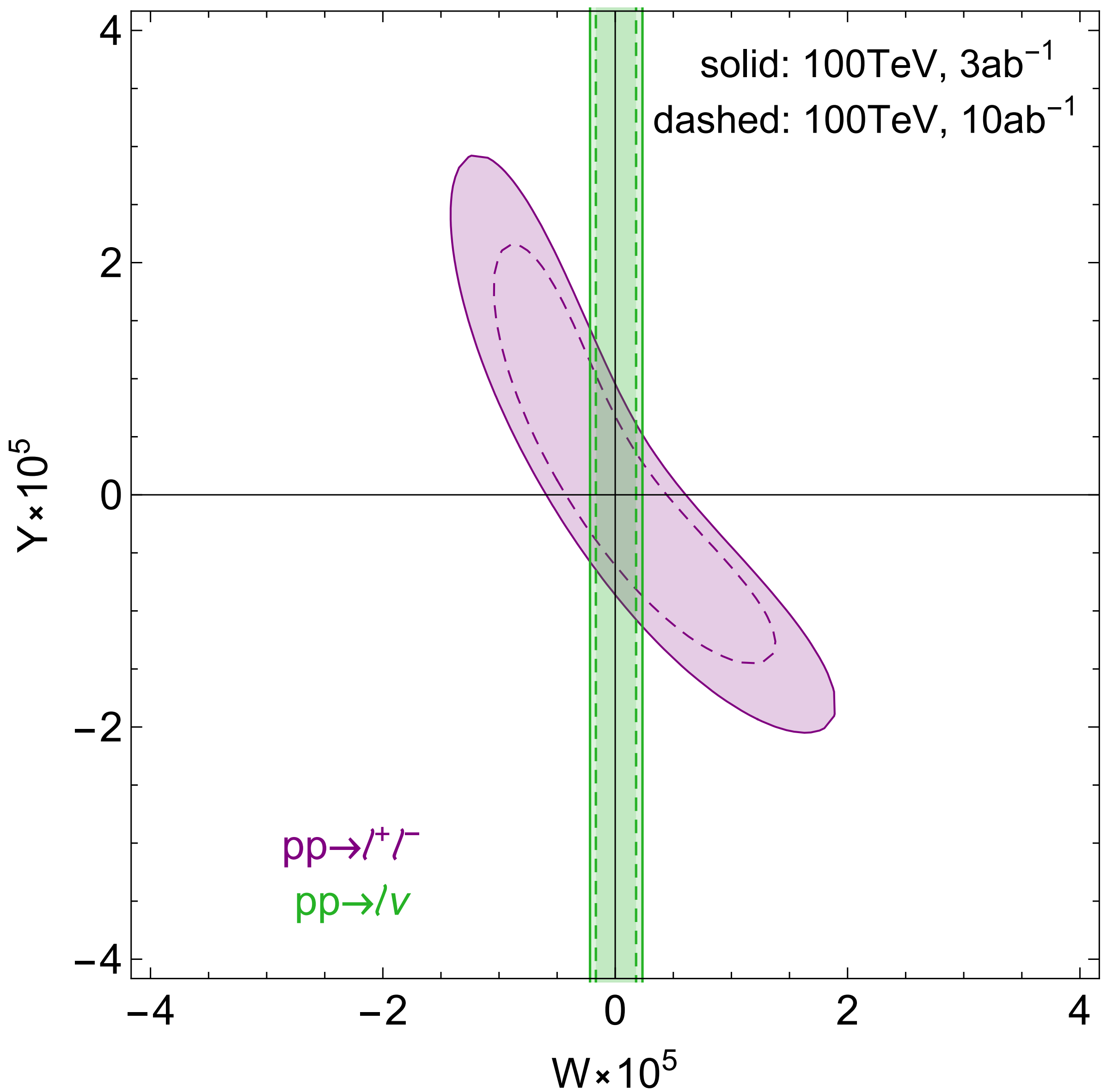


SM **4-Fermi cont. int.**

W&Y = Wilson coefficients normalised such that:

$$\left.\frac{\Delta\sigma}{\sigma_{SM}}\right|_{100\text{GeV}} \sim \begin{matrix}\text{few}\cdot\text{W}\\ \text{or}\\ \text{few}\cdot\text{Y}\end{matrix}$$



High Energy Drell—Yan

Y-Universal Z’ model Reach

[from Physics Briefing Book (EU Strategy Update 2020)]

Simply a massive U(1) with charges equal to SM Hypercharge.
Fully equivalent to a heavy Dark Photon:

$$\mathscr{L} = -\frac{1}{4g_{Z'}^2}\left(Z'_{\mu\nu}\right)^2 - \frac{1}{4g'^2}\left(B_{\mu\nu} - Z'_{\mu\nu}\right)^2 + \frac{M_{Z'}^2}{2g_{Z'}^2}\left(Z'_{\mu}\right)^2$$

Coupling (i.e., force strength) is a free parameter

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Indirect Searches:

Integrated out, produces only one, Universal, operator:

[Higgs WG notation] $$\frac{c_{2B}}{\Lambda^2} = \frac{g_{Z'}^2}{g'^4 M_{Z'}^2} = \frac{Y}{g'^2 m_W^2}$$

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Direct Searches:

Di-lepton final state dominates the sensitivity

High Energy Drell—Yan

Indirect F.C. Sensitivities:

[De Blas et.al., ECFA-Higgs report]

	HL-LHC +													
	HL-LHC	LHeC	HE-LHC		ILC			CLIC			CEPC	FCC-ee		FCC-ee/eh/hh
			S_2	S'_2	250	500	1000	380	1500	3000		240	365	
$\frac{c_\phi}{\Lambda^2}$ [TeV^{-2}]	0.53 (0.28)†	0.15 (0.11)	0.43 (0.21)†	0.31 (0.16)†	0.13 (0.061)	0.057 (0.041)	0.038 (0.033)	0.14 (0.076)	0.049 (0.04)	0.033 (0.027)	0.14 (0.038)	0.15 (0.044)	0.1 (0.038)	0.036 (0.029)
$\frac{c_T}{\Lambda^2}$ [TeV^{-2}]	0.0056 (0.002)	0.0056 (0.002)	0.0056 (0.002)	0.0055 (0.002)	0.0018 (0.0013)	0.0016 (0.0011)	0.0016 (0.001)	0.0029 (0.001)	0.0025 (0.001)	0.0023 (0.001)	0.00097 (0.0008)	0.0007 (0.0007)	0.0004 (0.0002)	0.0003 (0.0002)
$\frac{c_W}{\Lambda^2}$ [TeV^{-2}]	0.33 (0.022)	0.28 (0.022)	0.24 (0.0098)	0.19 (0.0098)	0.06 (0.011)	0.046 (0.0073)	0.037 (0.004)	0.065 (0.011)	0.042 (0.0037)	0.035 (0.0015)	0.092 (0.0076)	0.11 (0.0051)	0.072 (0.0036)	0.032 (0.0029)
$\frac{c_B}{\Lambda^2}$ [TeV^{-2}]	0.32 (0.028)	0.27 (0.028)	0.24 (0.028)	0.19 (0.028)	0.057 (0.011)	0.045 (0.0084)	0.037 (0.0053)	0.066 (0.013)	0.048 (0.0079)	0.041 (0.0035)	0.088 (0.0081)	0.11 (0.005)	0.069 (0.0035)	0.031 (0.0035)
$\frac{c_{\phi W}}{\Lambda^2}$ [TeV^{-2}]	0.32 (0.034)	0.27 (0.033)	0.24 (0.01)	0.19 (0.01)	0.07 (0.026)	0.058 (0.012)	0.041 (0.0047)	0.078 (0.02)	0.044 (0.0039)	0.036 (0.0014)	0.086 (0.021)	0.11 (0.021)	0.08 (0.015)	0.032 (0.0043)
$\frac{c_{\phi B}}{\Lambda^2}$ [TeV^{-2}]	0.32 (0.18)	0.28 (0.18)	0.24 (0.099)	0.19 (0.067)	0.086 (0.048)	0.054 (0.016)	0.039 (0.0066)	0.093 (0.035)	0.05 (0.0092)	0.04 (0.0034)	0.086 (0.062)	0.11 (0.066)	0.086 (0.042)	0.031 (0.011)
$\frac{c_\gamma}{\Lambda^2}$ [TeV^{-2}]	0.0052 (0.004)	0.0049 (0.004)	0.0042 (0.0031)	0.0026 (0.0021)	0.0043 (0.0039)	0.004 (0.0038)	0.0035 (0.0033)	0.0048 (0.004)	0.0042 (0.0039)	0.0036 (0.0035)	0.004 (0.0038)	0.0041 (0.0039)	0.004 (0.0038)	0.0012 (0.0010)
$\frac{c_g}{\Lambda^2}$ [TeV^{-2}]	0.0012 (0.0005)	0.0009 (0.0005)	0.001 (0.0004)	0.0006 (0.0003)	0.0006 (0.0004)	0.0005 (0.0003)	0.0003 (0.0002)	0.001 (0.0004)	0.0006 (0.0003)	0.0005 (0.0002)	0.0006 (0.0002)	0.0005 (0.0003)	0.0005 (0.0003)	0.0003 (0.0001)
$\frac{c_{y_e}}{\Lambda^2}$ [TeV^{-2}]	0.25 (0.2)	0.23 (0.18)	0.18 (0.13)	0.11 (0.091)	0.14 (0.096)	0.097 (0.079)	0.079 (0.07)	0.21 (0.17)	0.15 (0.13)	0.11 (0.1)	0.1 (0.072)	0.11 (0.078)	0.094 (0.071)	0.052 (0.044)
$\frac{c_{y_u}}{\Lambda^2}$ [TeV^{-2}]	0.57 (0.24)	0.42 (0.19)	0.44 (0.19)	0.26 (0.12)	0.26 (0.14)	0.19 (0.099)	0.12 (0.072)	0.42 (0.16)	0.23 (0.11)	0.19 (0.085)	0.25 (0.091)	0.2 (0.11)	0.19 (0.099)	0.11 (0.052)
$\frac{c_{y_d}}{\Lambda^2}$ [TeV^{-2}]	0.46 (0.25)	0.23 (0.13)	0.37 (0.19)	0.26 (0.14)	0.13 (0.084)	0.088 (0.066)	0.071 (0.059)	0.18 (0.098)	0.077 (0.063)	0.059 (0.055)	0.091 (0.064)	0.1 (0.068)	0.092 (0.064)	0.071 (0.057)
$\frac{c_{2B}}{\Lambda^2}$ [TeV^{-2}]	0.08 (0.069)	0.08 (0.069)	0.028† (0.013)	0.028† (0.013)	0.025 (0.023)	0.0083 (0.0078)	0.0029 (0.0027)	0.031 (0.028)	0.0064 (0.0059)	0.0023 (0.0021)	0.042 (0.034)	0.042 (0.029)	0.028 (0.021)	0.0034 (0.0034)
$\frac{c_{2W}}{\Lambda^2}$ [TeV^{-2}]	0.008 (0.0069)	0.008 (0.0069)	0.0053† (0.0024)†	0.0053† (0.0024)†	0.0062 (0.0058)	0.0032 (0.003)	0.0012 (0.0011)	0.0062 (0.0058)	0.0016 (0.0014)	0.0006 (0.0005)	0.0069 (0.0062)	0.0062 (0.0057)	0.0056 (0.0049)	0.0003 (0.0003)
$\frac{c_{3W}}{\Lambda^2}$ [TeV^{-2}]	1.7 (1.6)	1.6 (1.6)	1.6 (1.6)	1.6 (1.6)	0.023 (0.022)	0.011 (0.011)	0.0076 (0.0075)	0.024 (0.024)	0.0031 (0.0031)	0.001 (0.001)	0.036 (0.02)	0.034 (0.019)	0.026 (0.015)	0.021 (0.015)
$\frac{c_6}{\Lambda^2}$ [TeV^{-2}]	8.4 (7.8)	8.1 (7.7)	2.5 (2.4)	2.4 (2.3)	8.1 (4.7)	3.5 (3.1)	1.5 (1.4)	8.1 (7.7)	4.8 (4.5)	1.8 (1.7)	8. (2.8)	8. (3.2)	5.3 (3.1)	0.81 (0.79)

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[De Blas et.al., ECFA-Higgs report]

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$\frac{c_g}{\Lambda^2}$ [TeV^{-2}]	0.0012 (0.0005)	0.0009 (0.0005)	0.001 (0.0004)	0.0006 (0.0003)	0.0006 (0.0004)	0.0005 (0.0003)	0.0003 (0.0002)	0.001 (0.0004)	0.0006 (0.0003)	0.0005 (0.0002)	0.0006 (0.0002)	0.0005 (0.0003)	0.0005 (0.0003)	0.0003 (0.0001)
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$\frac{c_{3W}}{\Lambda^2}$ [TeV^{-2}]	1.7 (1.6)	1.6 (1.6)	1.6 (1.6)	1.6 (1.6)	0.023 (0.022)	0.011 (0.011)	0.0076 (0.0075)	0.024 (0.024)	0.0031 (0.0031)	0.001 (0.001)	0.036 (0.02)	0.034 (0.019)	0.026 (0.015)	0.021 (0.015)
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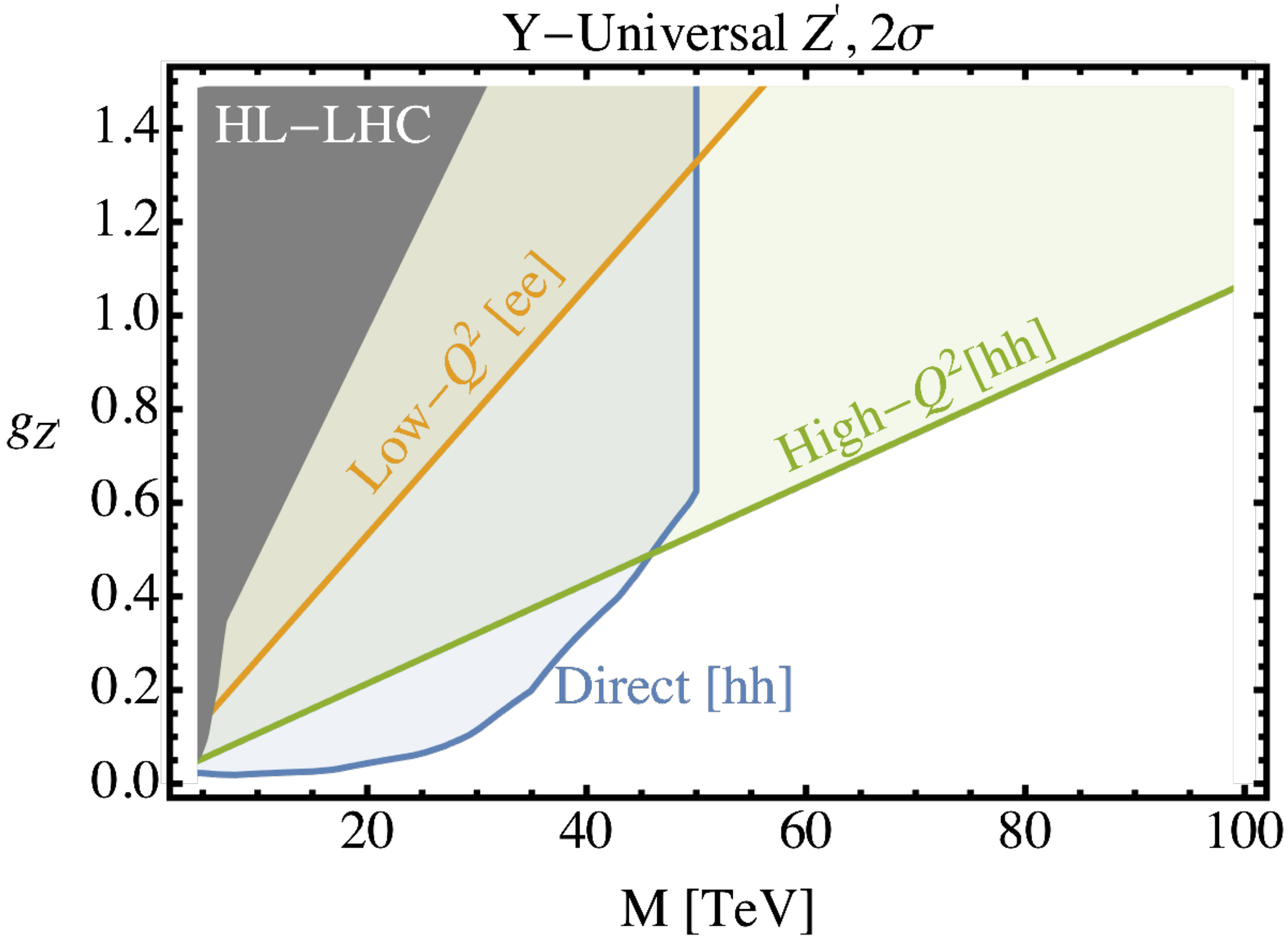

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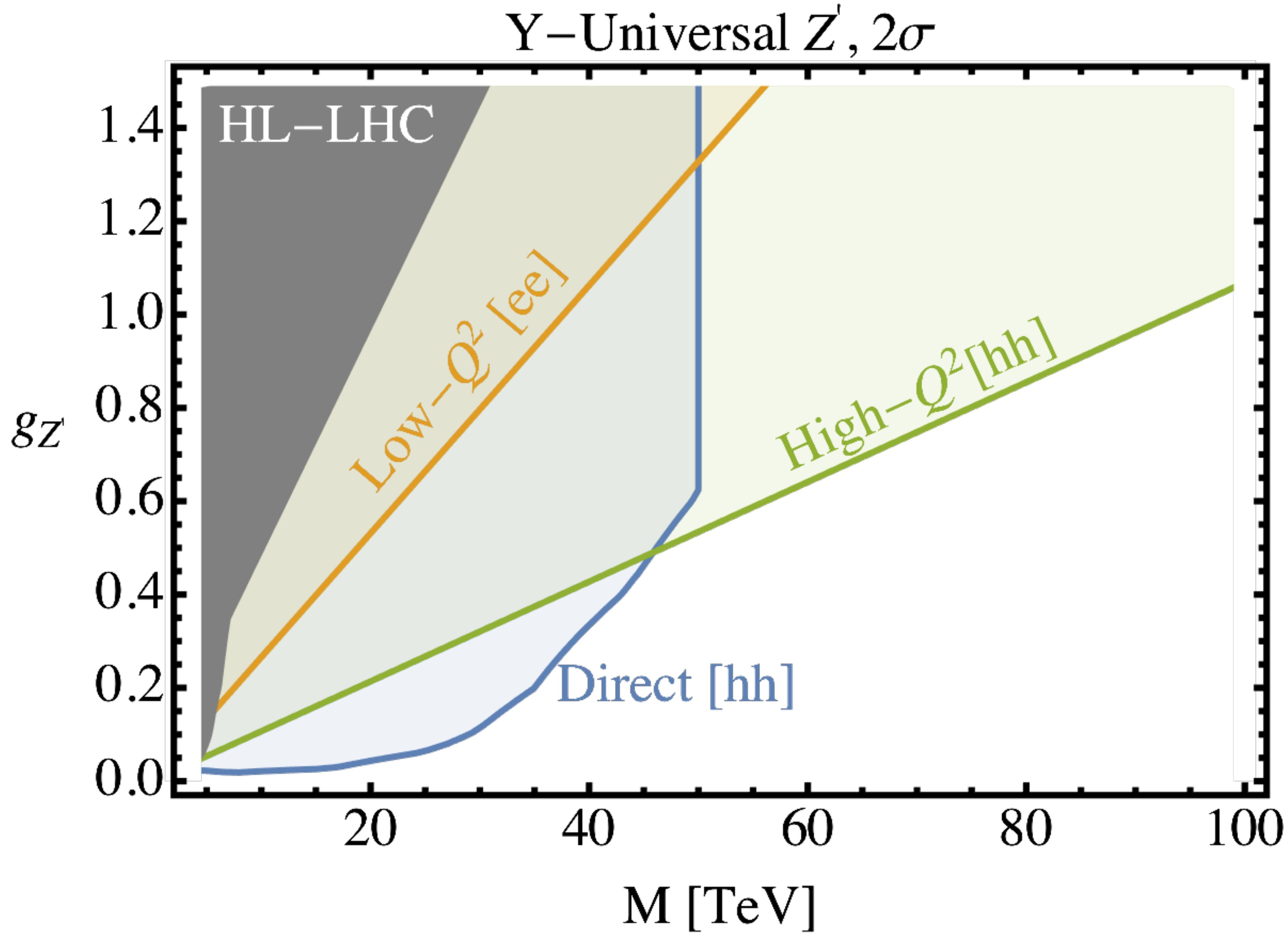

Note: ee does not loose because “not precise enough”:

$$\Delta\sigma/\sigma_{\rm SM}\Big|_{1\sigma} \sim \text{few} \cdot Y_{1\sigma} \sim \text{few} \cdot 2\,10^{-5}$$

Looses because has **not energetic enough**

High Energy Dibosons

[Franceschini, Panico, Pomarol, Riva, AW, 2018]

WW, WZ, WH, ZH “QCD” production (**not** VBS)

Energy growth from quark-Higgs contact operators, e.g.

$$\mathcal{O}_L^{(3)} = (\bar{Q}_L \sigma^a \gamma^\mu Q_L)(i H^\dagger \sigma^a \overleftrightarrow{D}_\mu H) \sim \mathcal{O}_W = \frac{ig}{2} \left(H^\dagger \sigma^a \overleftrightarrow{D}^\mu H \right) D^\nu W^a_{\mu\nu}$$

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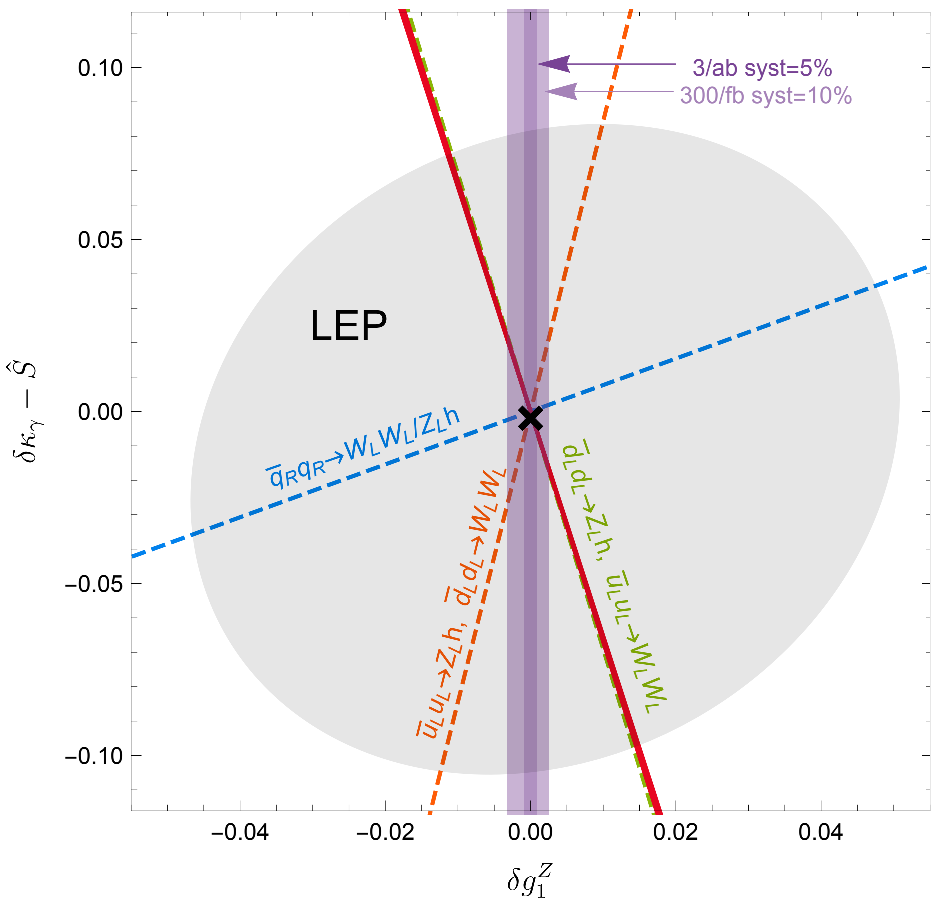
HL-LHC vs LEP



High Energy Dibosons

[Franceschini, Panico, Pomarol, Riva, AW, 2018]

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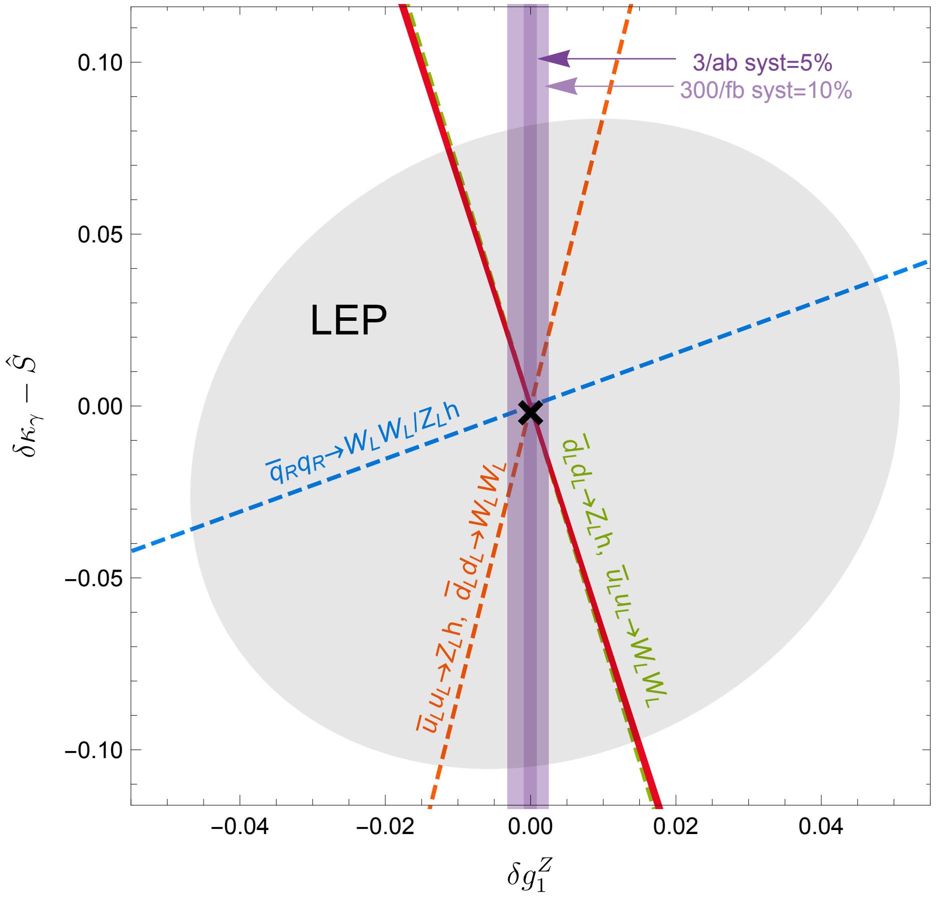

FCC-hh vs FCC-ee

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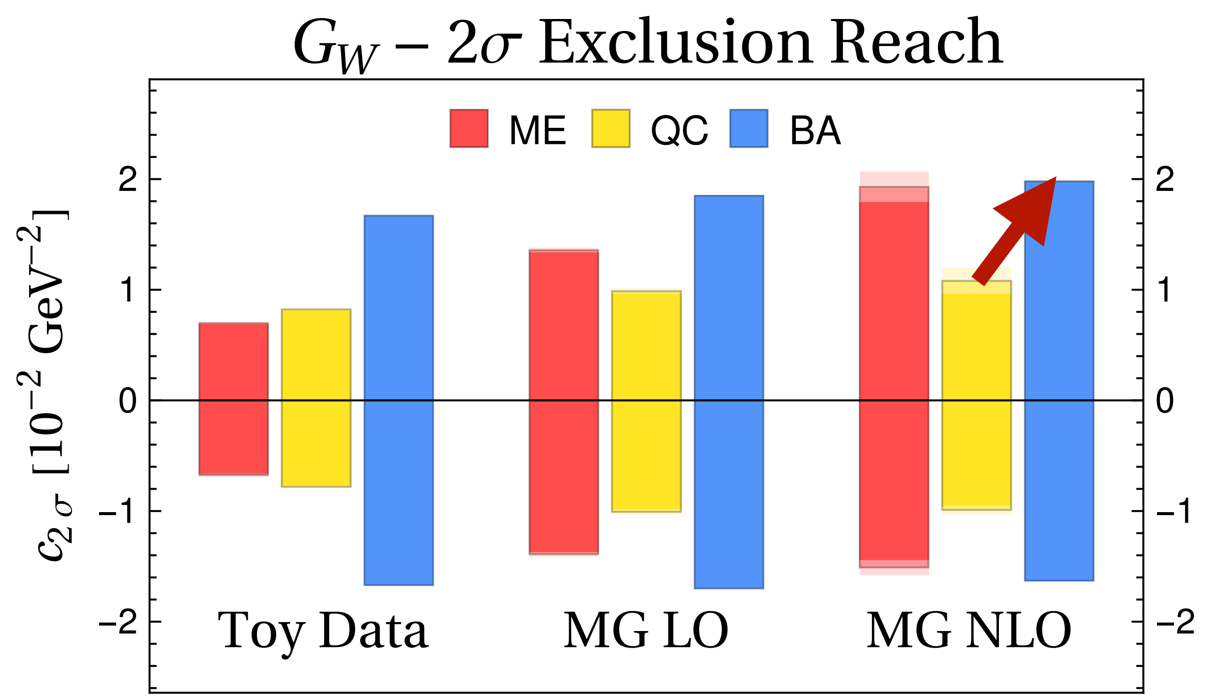
Chen, Glioti, Panico, AW, 2020



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  Could play essential role to **“give a name”** to FCC-ee discoveries, or to Direct discoveries at FCC-hh.

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Thank You !