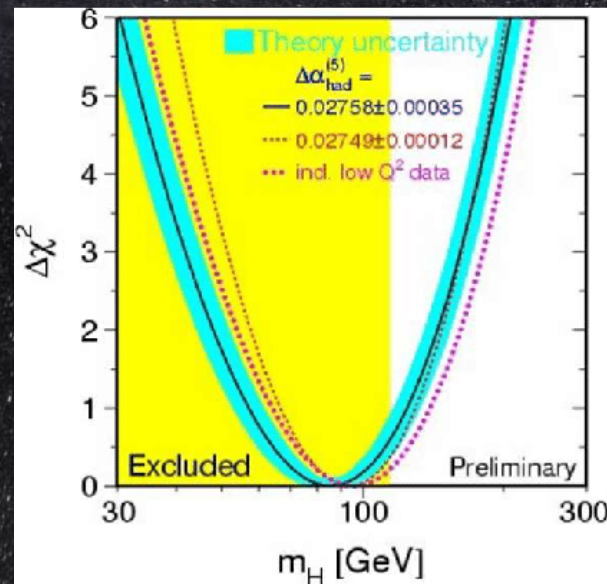


Positivity Bounds without Vanishing Couplings



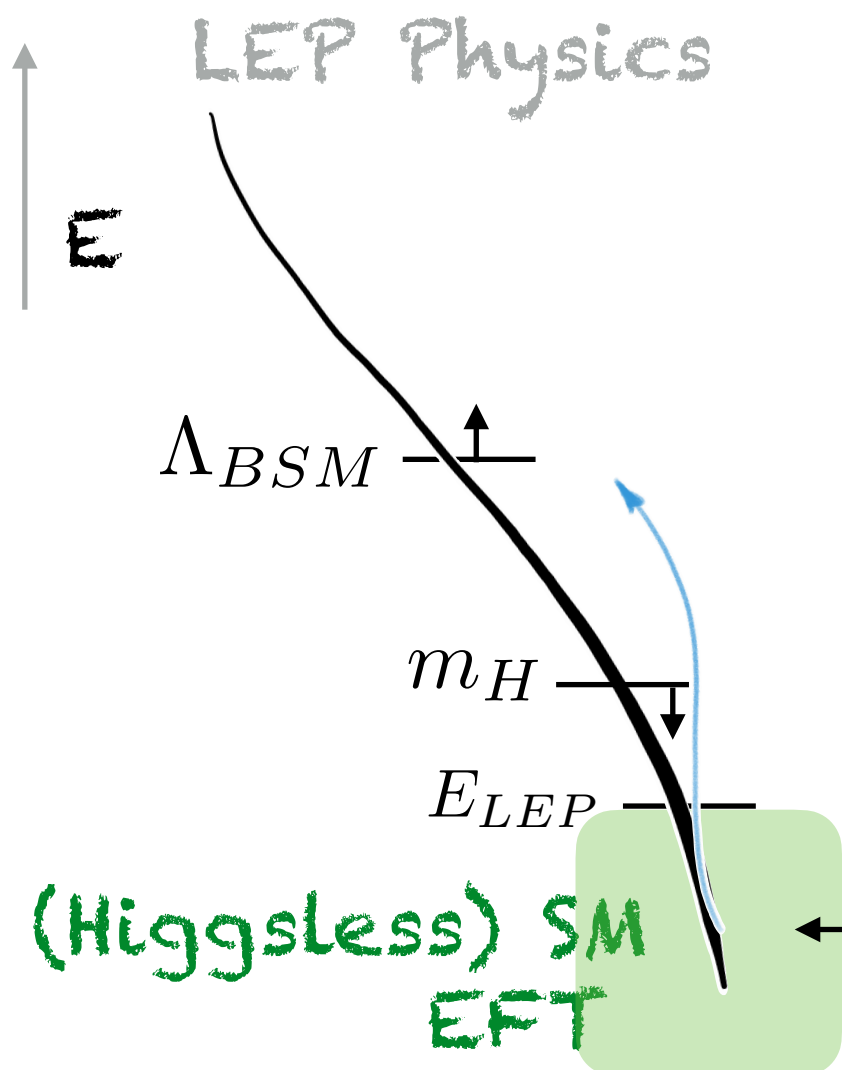
Francesco Riva
(Geneva University)

UV $\rightarrow$ IR

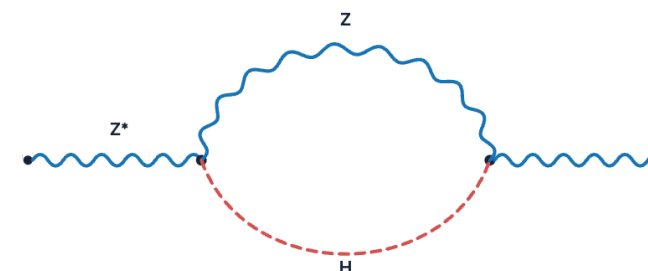
High-Energy Physics

Precise questions emerge when scales separated

(Effective Field Theory)

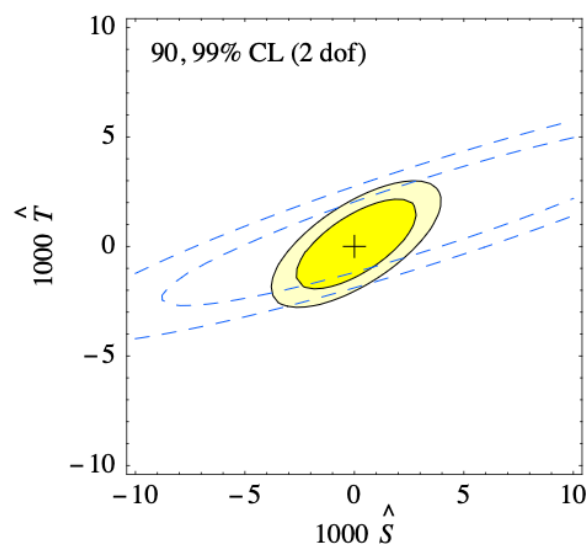
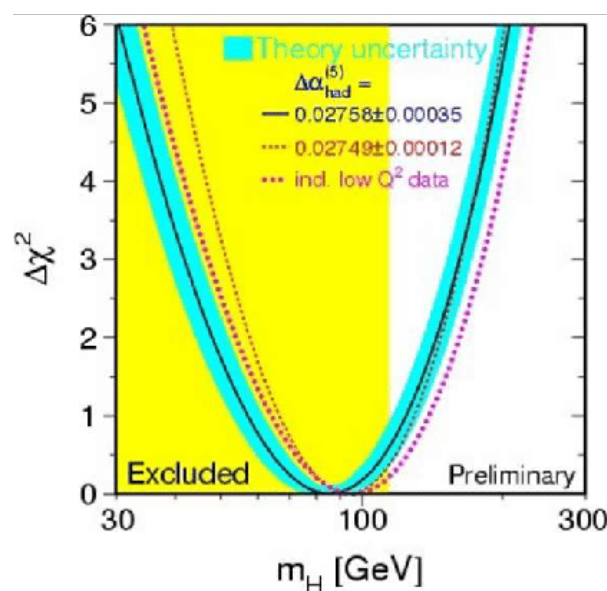


Weakly coupled



Precise predictions

Precision experiments

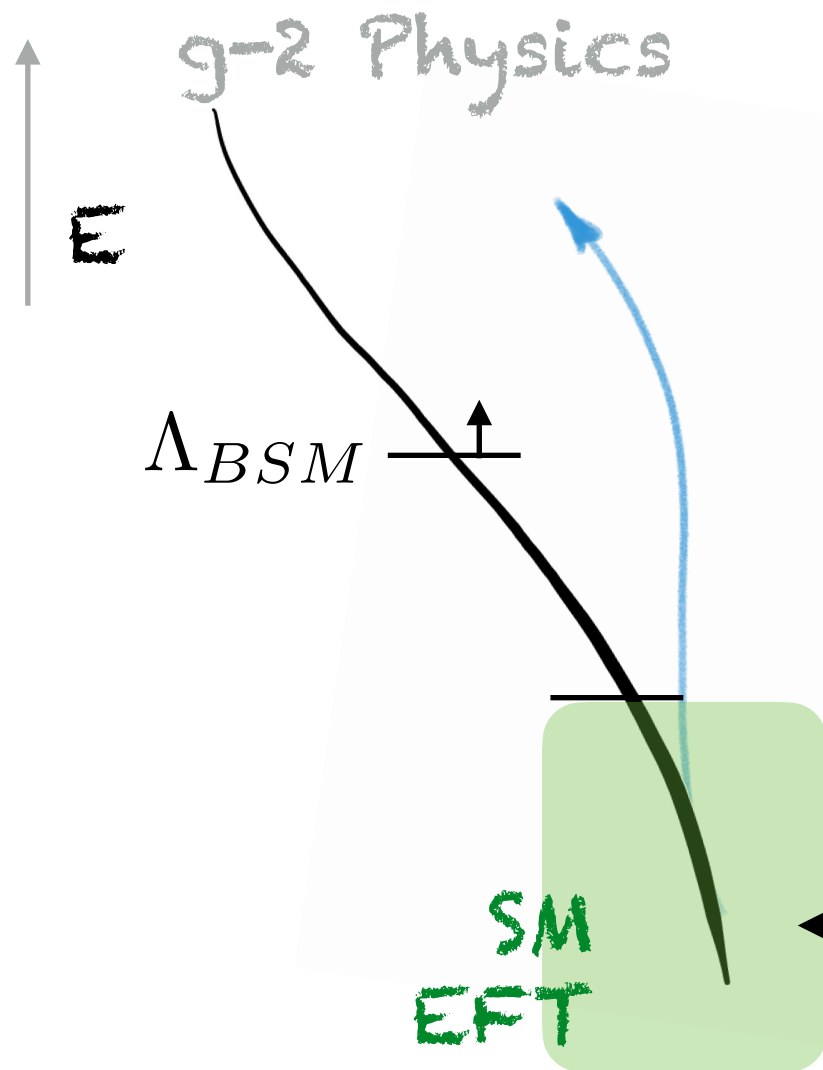


Learn something about Nature at scales we cannot yet explore

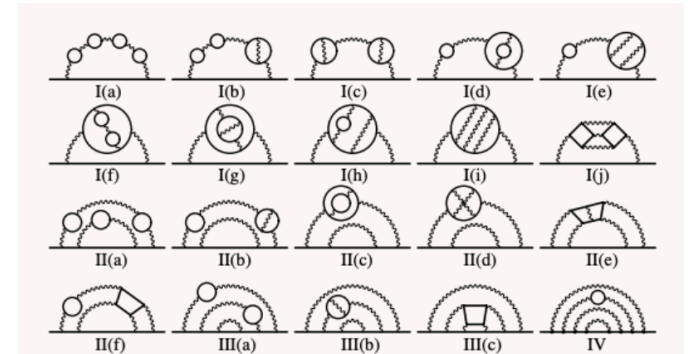
UV $\rightarrow$ IR

High-Energy Physics

Precise questions emerge when scales separated

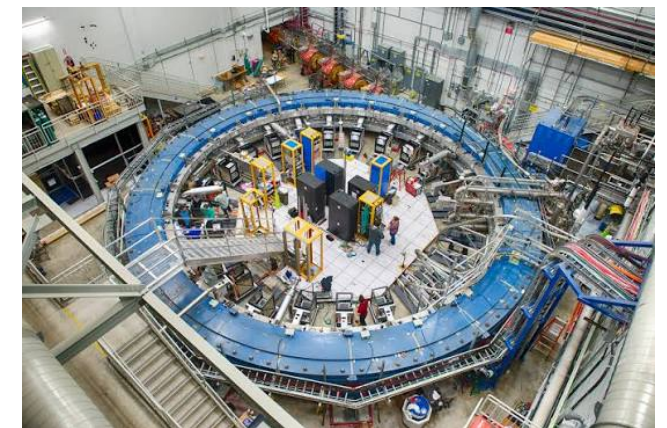


Weakly coupled



► Precise predictions

► Precision experiments

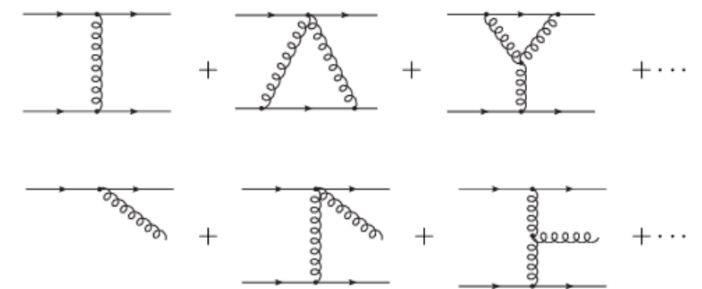
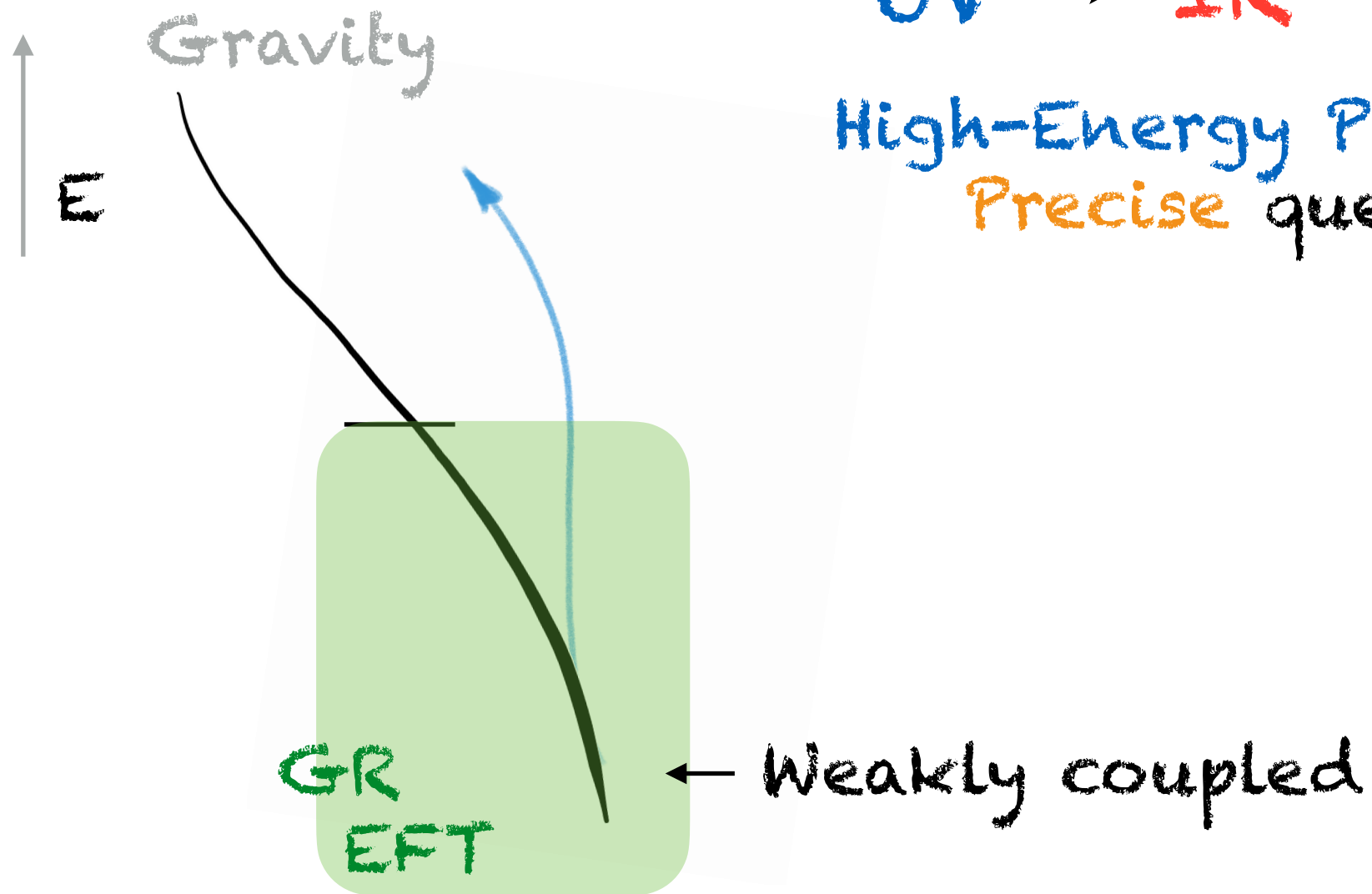


► Learn something about Nature at scales we cannot yet explore

UV $\rightarrow$ IR

High-Energy Physics

Precise questions emerge when scales separated



- Precise predictions
- Precision experiments

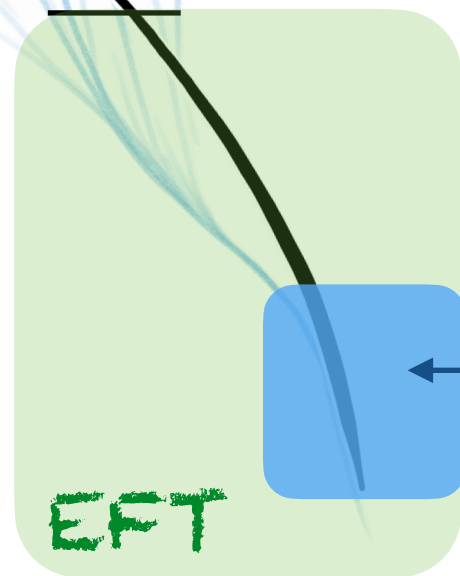


► Learn something about Nature at scales we cannot yet explore

Bootstrap @ Weak coupling

Conversely: a striking fact...

Even when built with simple,
weakly coupled QFT tools,
not all these EFTs exist!



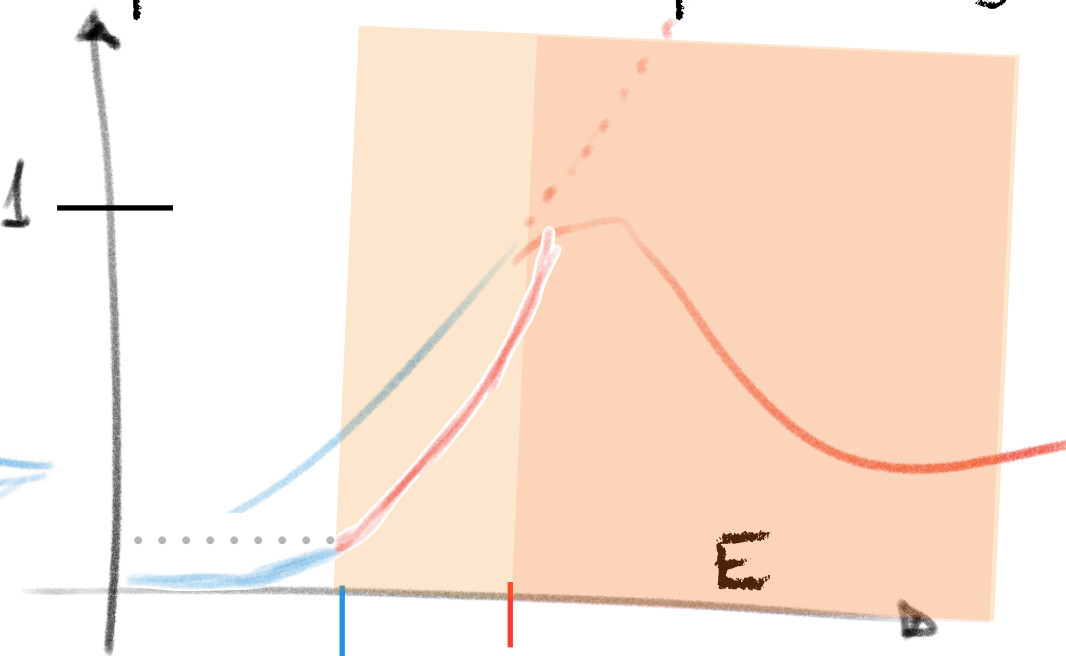
← EFT with a UV completion

Bootstrap: Bound on amplitudes growth-rate

LHC
EFT Spectra

Gravity?

$\text{Amp} \sim 1$

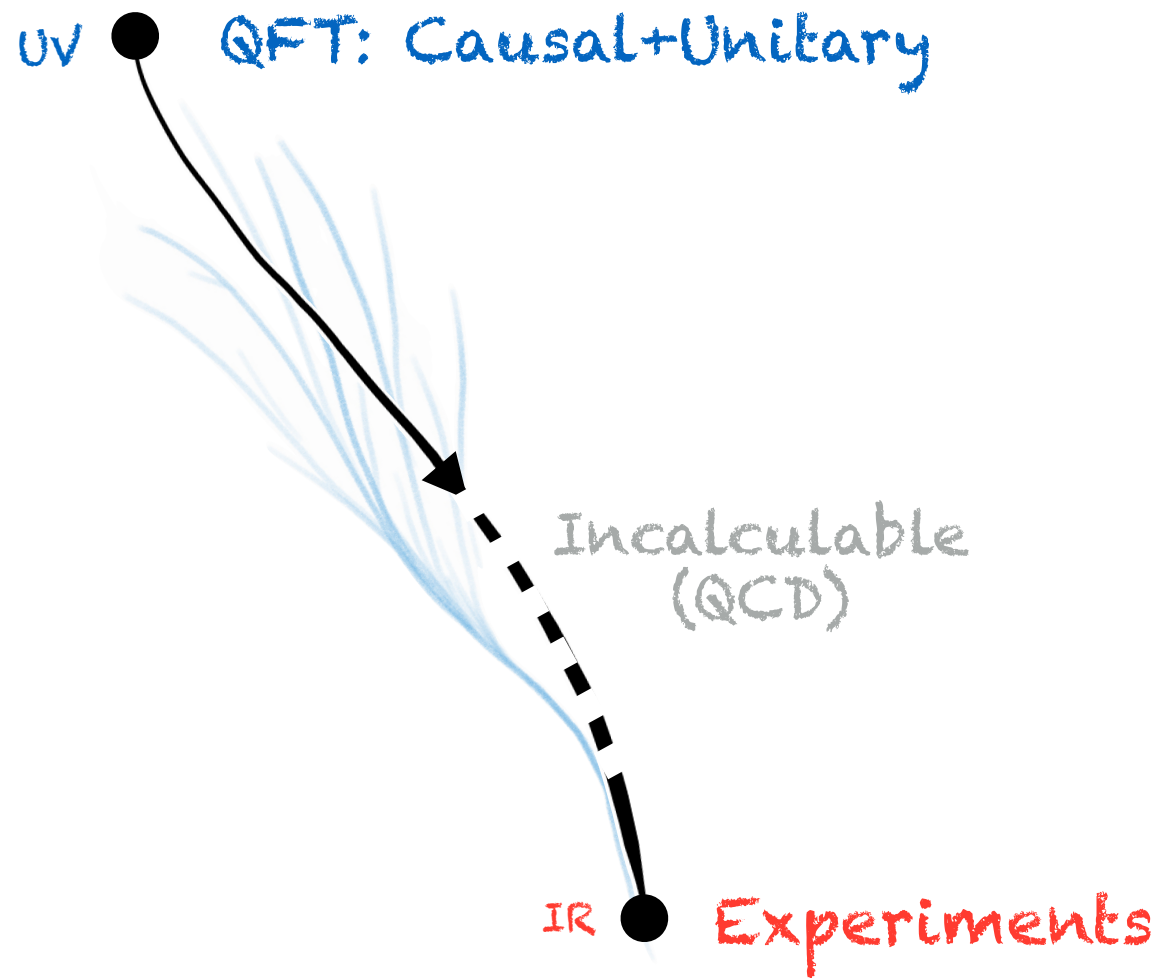


$\Lambda_{\text{bootstrap}}$ Weak coupling
(well controlled)

$\Lambda_{\text{Cutoff}}^{\text{max}}$

Strong coupling

UV → IR



UV $\rightarrow$ IR

UV ● QFT: Causal+Unitary

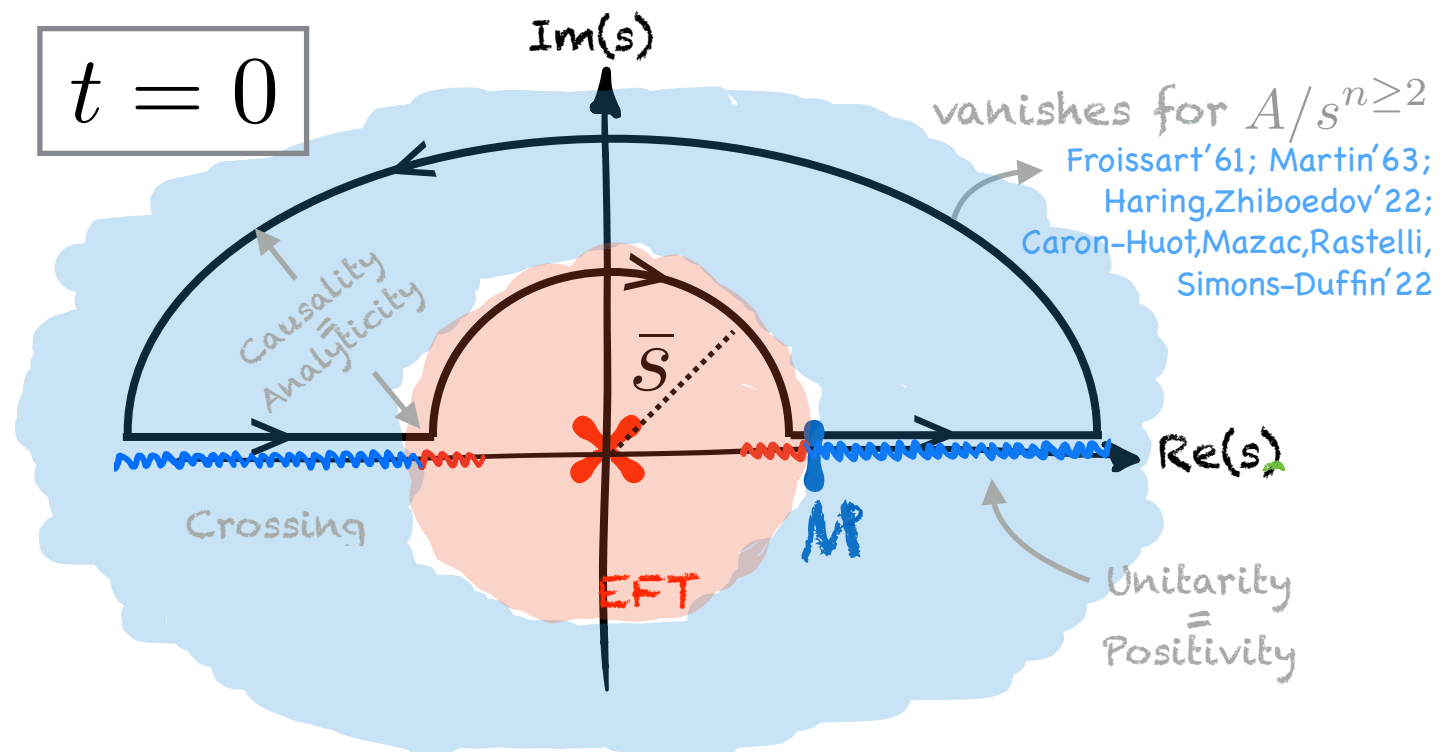
$$A_n(\bar{s}) \equiv \frac{2}{\pi} \int_{\bar{s}}^{\infty} ds \frac{\text{Positive Im}A(s)}{s^{n+1}}$$

$A_{2 \rightarrow 2}(s, t)$

Incalculable
(QCD)

IR ● Experiments

$$A_n(\bar{s}) \equiv \int_{\cap \bar{s}} \frac{ds}{\pi i} \frac{A(s)}{s^{n+1}}$$



UV $\rightarrow$ IR

UV ● QFT: Causal+Unitary

$A_{2 \rightarrow 2}(s, t)$

Incalculable
(QCD)

IR ● Experiments

$$A_n(\bar{s}) \equiv \int_0^1 d\mu(x) x^n$$

Positive Moments

Positive polynomials in $[0,1]$

Positivity relations for arcs

$$0 < \int_0^1 d\mu(x) \left(\sum \alpha_i x^i \right)^2 = \sum_{i,j=0}^{N/2} \alpha_i A_{i+j} \alpha_j$$

Hankel:
$$\begin{pmatrix} A_0 & A_1 & A_2 \\ A_1 & A_2 & A_3 \\ A_2 & A_3 & A_4 \\ \vdots & \vdots & \vdots \end{pmatrix} \succ 0$$

$t = 0$

Im(s)

vanishes for $A/s^n \geq 2$

Froissart'61; Martin'63;

Haring,Zhiboedov'22;

Caron-Huot,Mazac,Rastelli,

Simons-Duffin'22

Causality
Analyticity

Crossing

EFT

M

Unitarity
Positivity

Re(s)

$\bar{s}$

UV $\rightarrow$ IR

UV ● QFT: Causal+Unitary

$A_{2 \rightarrow 2}(s, t)$

Incalculable
(QCD)

IR ● Experiments

Positive Moments

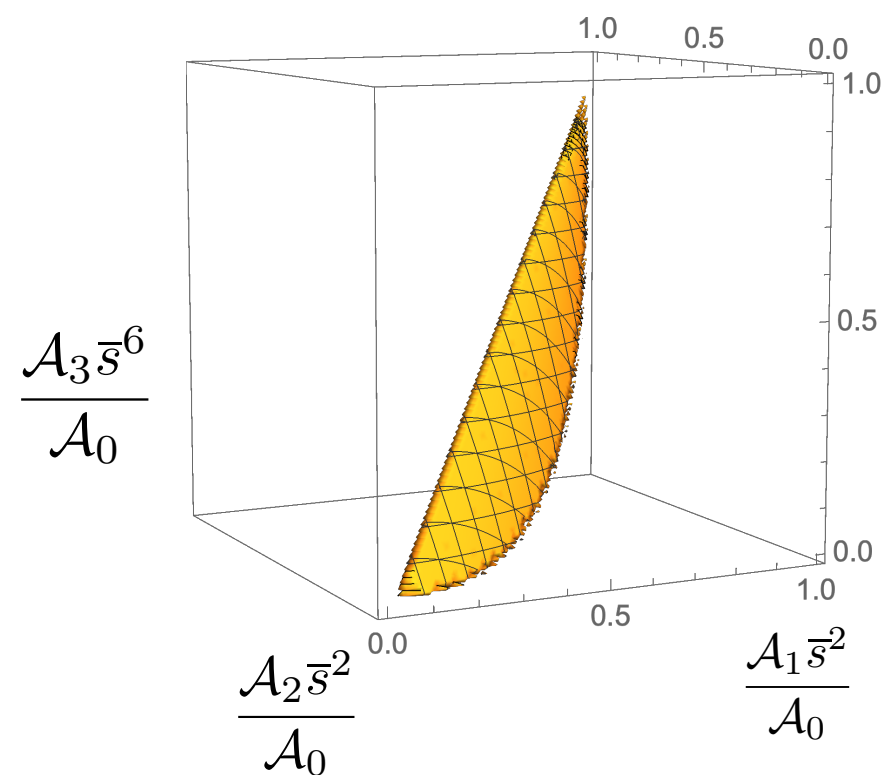
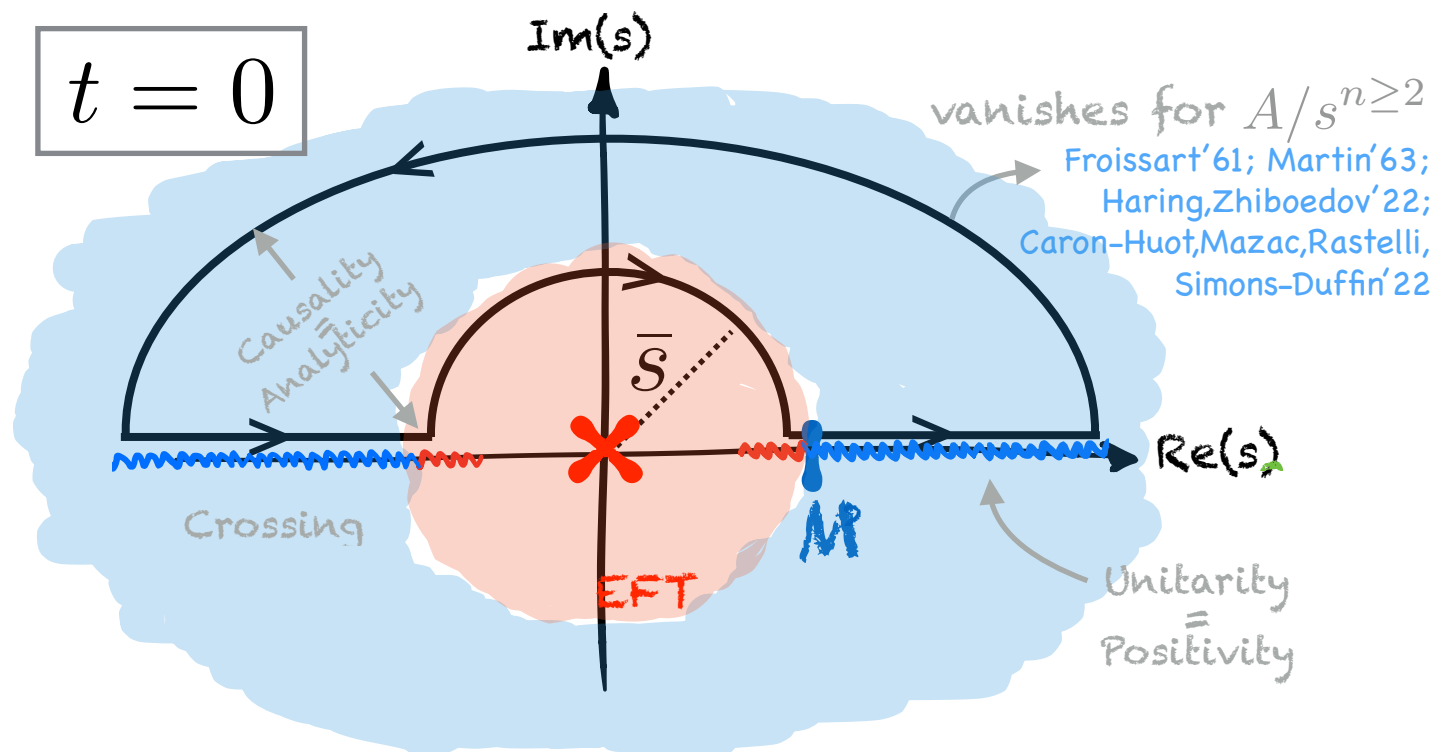
$$\mathcal{A}_n(\bar{s}) \equiv \frac{2}{\pi} \int_{\bar{s}}^{\infty} ds \frac{\text{Im} A(s)}{s^{n+1}}$$

Double-Sided bounds

$$\mathcal{A}_2 \geq \bar{s}^2 \mathcal{A}_4 \geq \bar{s}^4 \mathcal{A}_6 \geq \dots \geq 0$$

Adams, Arkani-Hamed, Dubovsky, Nicolis, Rattazzi'06
Bellazzini, Elias-Miro, Rattazzi, Riembau, FR'20
Arkani-Hamed, Huang, Huang'20

$$\mathcal{A}_n(\bar{s}) \equiv \int_{\cap \bar{s}} \frac{ds}{\pi i} \frac{A(s)}{s^{n+1}}$$



The relations are non perturbative, but the ansatz we use to compute arcs requires weak coupling in IR

UV $\rightarrow$ IR implications at weakest coupling

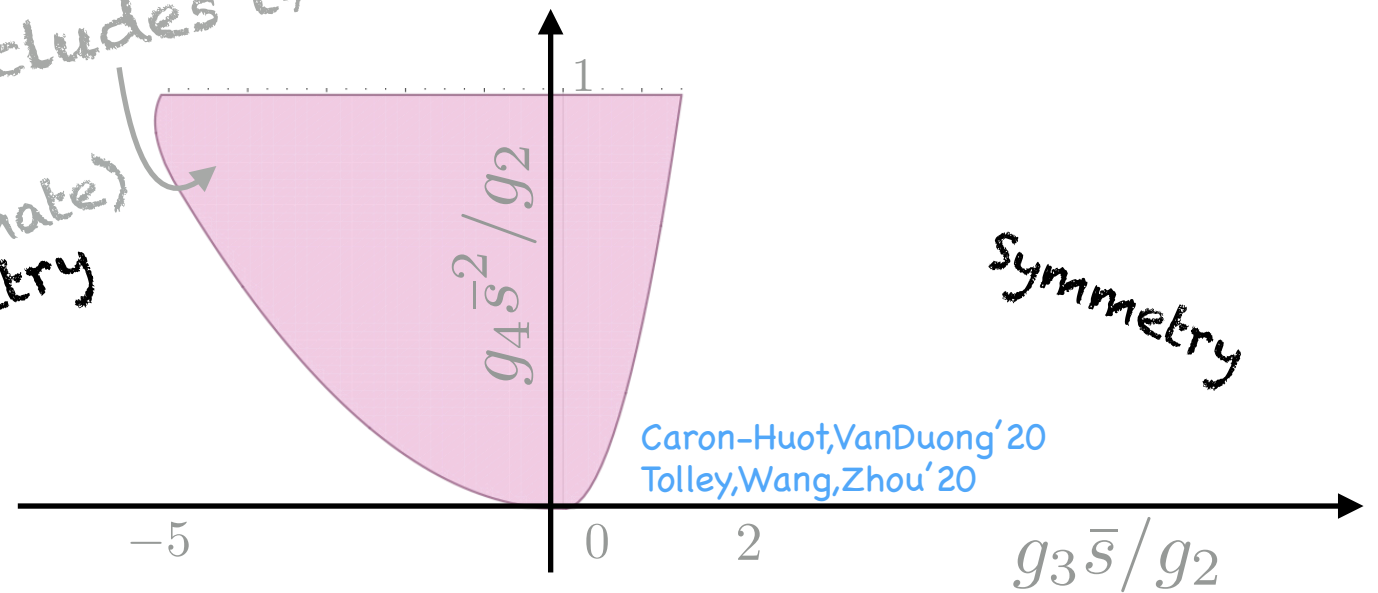
UV $\rightarrow$ IR with finite coupling effects

UV $\rightarrow$ IR implications: symmetries

UV ?



Includes $t \neq 0$
(approximate) symmetry

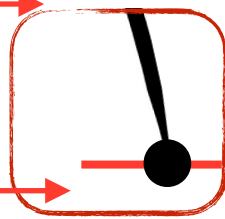


• $\bar{s} = M^2$

EFT:

• spin 0

• $m=0$



$$\mathcal{A}_n(\bar{s}) \equiv \int_{\cap_{M^2}} \frac{ds}{\pi i} \frac{A(s)}{s^{n+1}} = g_n$$

$$g_2 \geq \bar{s}^2 g_4 \geq \bar{s}^4 g_6 \geq \dots \geq 0$$

$$A_{2 \rightarrow 2}^{\text{Tree}} = \underbrace{g_0}_{\text{Pions}} + \underbrace{g_2(s^2 + t^2 + u^2)}_{\text{Galileons}} + \underbrace{g_3 stu}_{\text{Galileon-like}} + \underbrace{g_4(s^2 + t^2 + u^2)^2}_{\text{Galileon-like}} + \dots$$

Symmetry: $\pi \rightarrow \pi + \alpha x^n \rightarrow A \sim s^N$

► Amplitude growth faster than $\sim s^2$ is forbidden
(large high-derivative interactions)

► Theories with galilean-like symmetries...

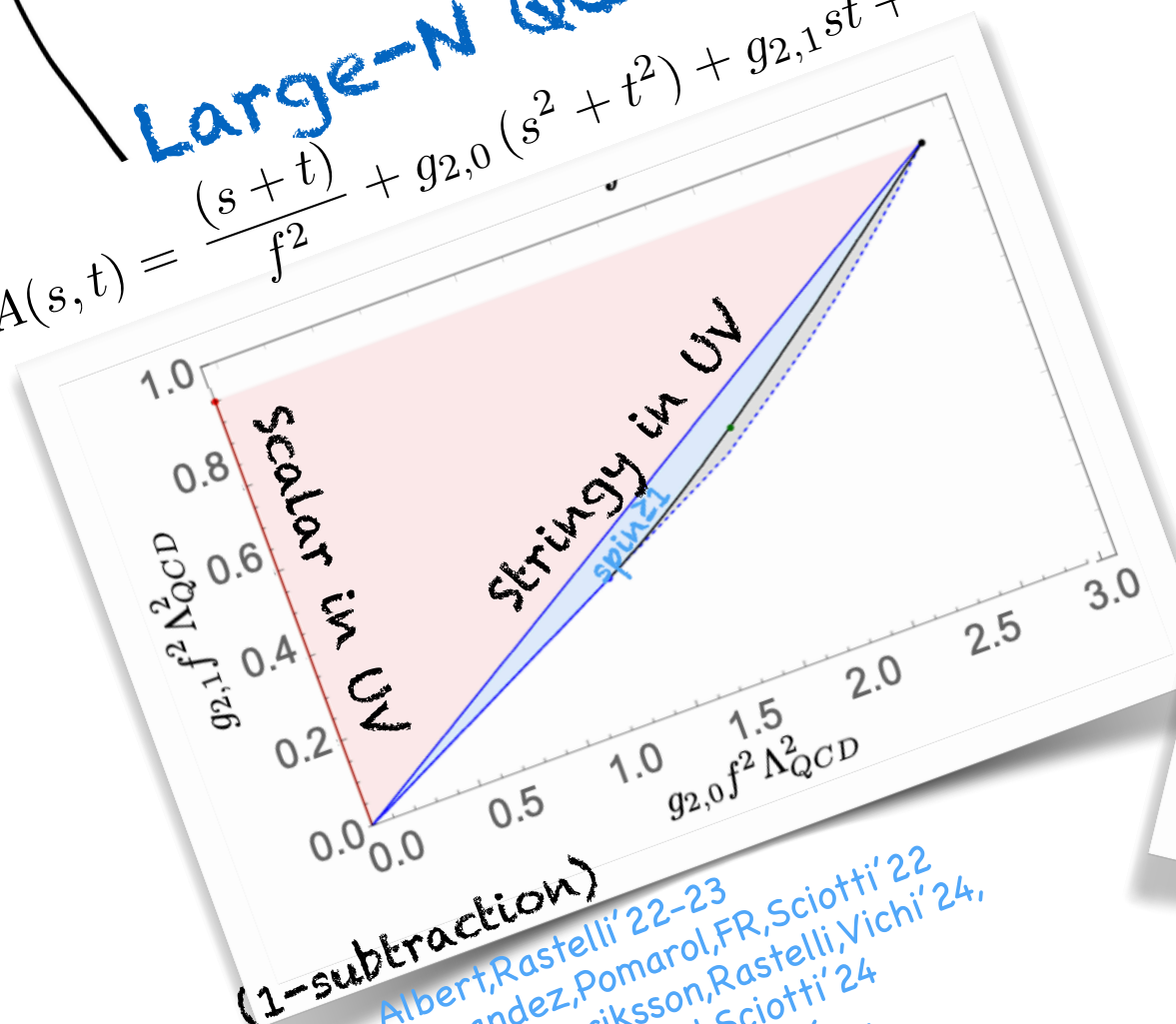
...don't have UV completions!

UV $\rightarrow$ IR implications: symmetries

UV ?

Large-N QCD

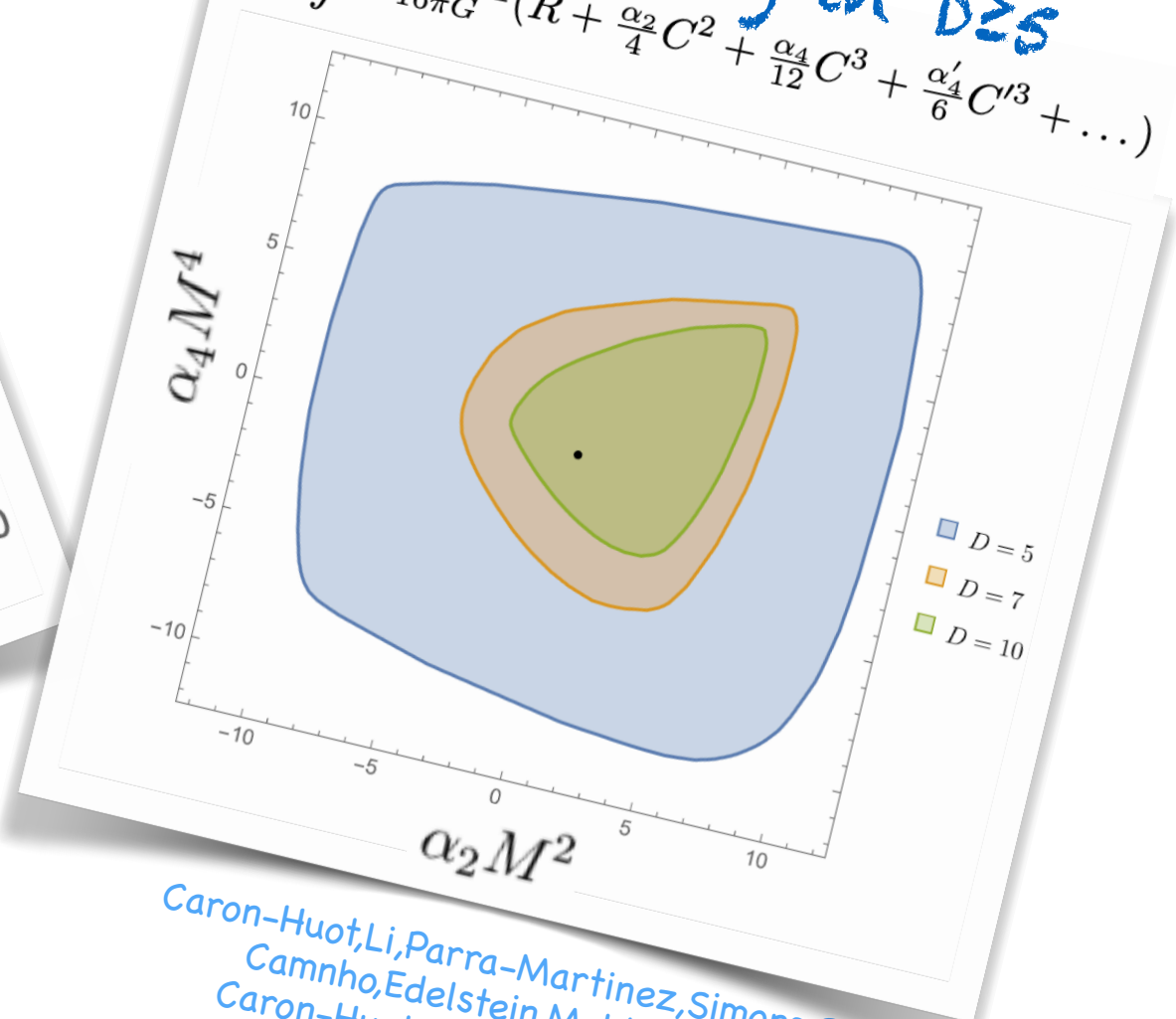
$$A(s,t) = \frac{(s+t)}{f^2} + g_{2,0}(s^2 + t^2) + g_{2,1}st + \dots$$



(1-subtraction)
 Albert, Rastelli'22-23
 Fernandez, Pomarol, FR, Sciotti'22
 Albert, Henriksson, Rastelli, Vichi'24,
 Dong, Ma, Pomarol, Sciotti'24
 Albert, Kosva, Rastelli'26 ...

Gravity in D=5

$$S = \int \frac{d^D x \sqrt{-g}}{16\pi G} (R + \frac{\alpha_2}{4} C^2 + \frac{\alpha_4}{12} C^3 + \frac{\alpha'_4}{6} C'^3 + \dots)$$



Caron-Huot, Li, Parra-Martinez, Simons-Duffin'22
 Camanho, Edelstein, Maldacena, Zhiboedov'14
 Caron-Huot, Mazac, Rastelli, Simons-Duffin'21

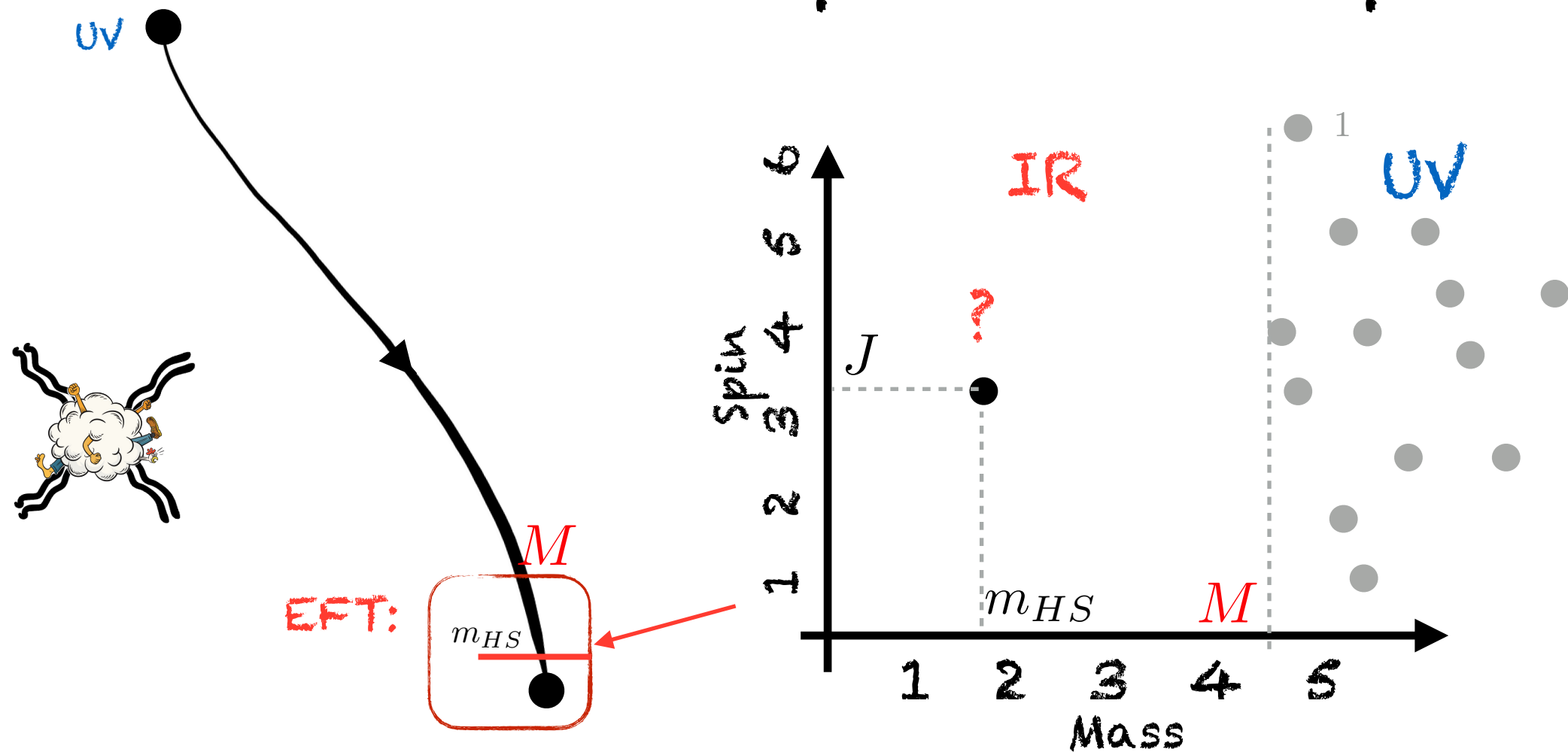
more irrelevant couplings $\leq O(1)$ x more relevant couplings

(e.g. in Black Hole inspiral experiments: no UV completion can induce effects larger than Einstein gravity, at any scale)

Caron-Huot, Li, Parra-Martinez, Simons-Duffin'22
 Serra, Serra, Trincherini, Trombetta'22

Only experiments with $\ll O(1)$ precision detect New Physics

UV $\rightarrow$ IR implications: spectra



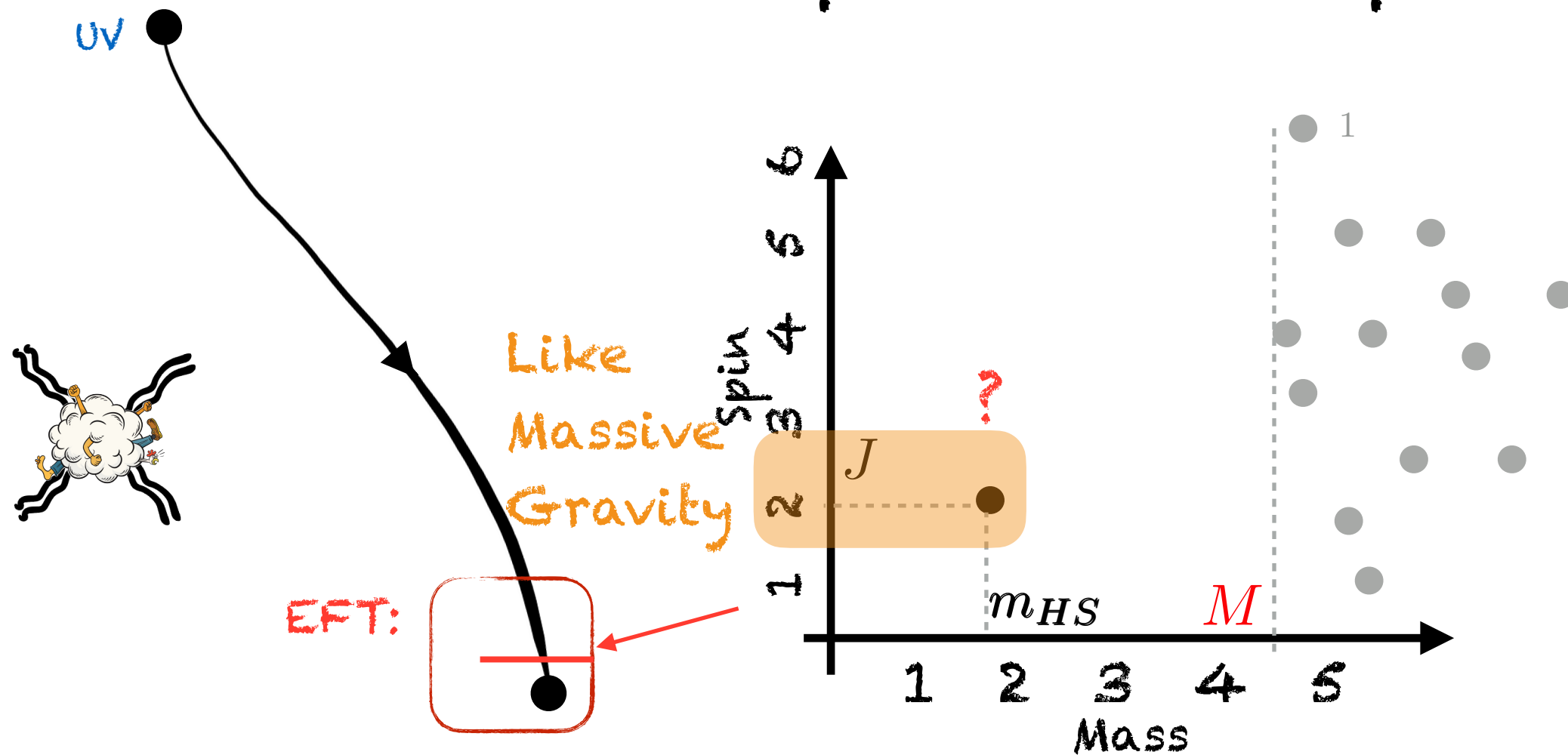
Longitudinal Interactions grow with $m_{HS} \leq E \lesssim M$
 $\epsilon_0 = (k, 0, 0, E)/m_{HS}$

$$A(HS_L HS_L \rightarrow HS_L HS_L) \propto \# \frac{s^2}{m_{HS}^4} + \dots + \# \frac{s^{2J}}{m_{HS}^{4J}}$$

$m_{HS} \gtrsim M \leftarrow \propto g_2 > M^{4J-4} g_{2J}$

► Higher spin never isolated

UV $\rightarrow$ IR implications: spectra



Longitudinal Interactions grow with $m_{HS} \leq E \lesssim M$

$\epsilon_0 = (k, 0, 0, E)/m_{HS}$

$$A(hh \rightarrow hh) \sim \frac{(c_3, d_5)}{\Lambda_3^6} [m_g^2 s^2 + s^2 t]$$

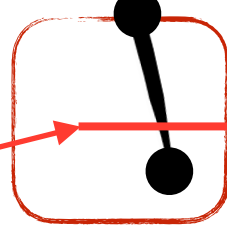
vanishes at $t=0$

UV $\rightarrow$ IR implications: spectra

$t = 0$



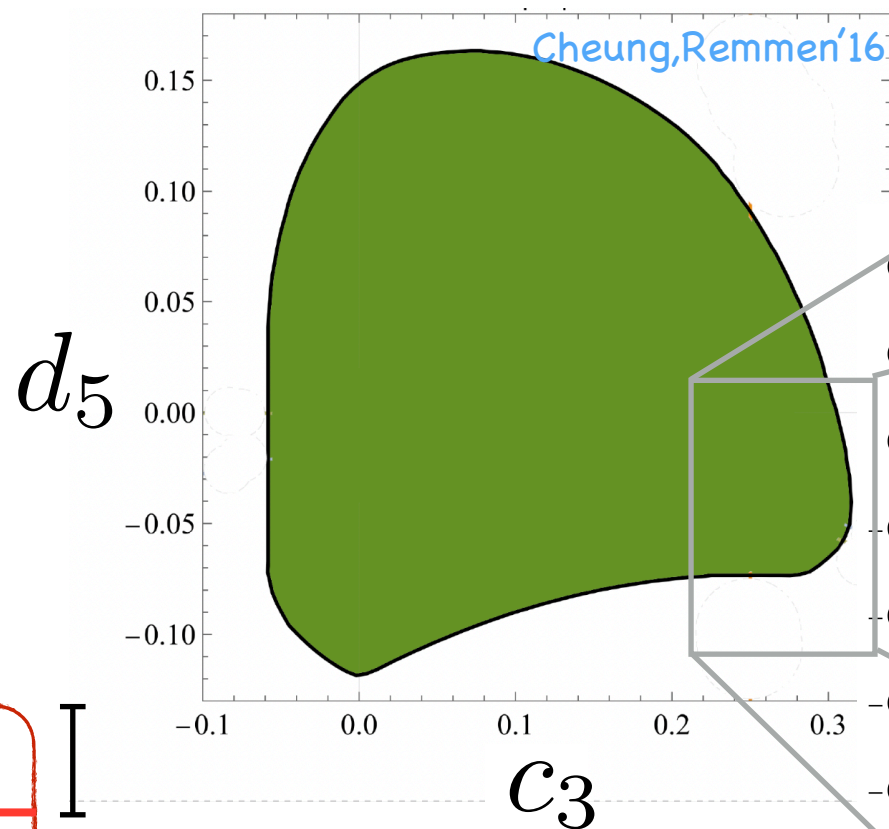
UV



EFT: $\bullet$ spin 2
 $\bullet$ $m \neq 0$

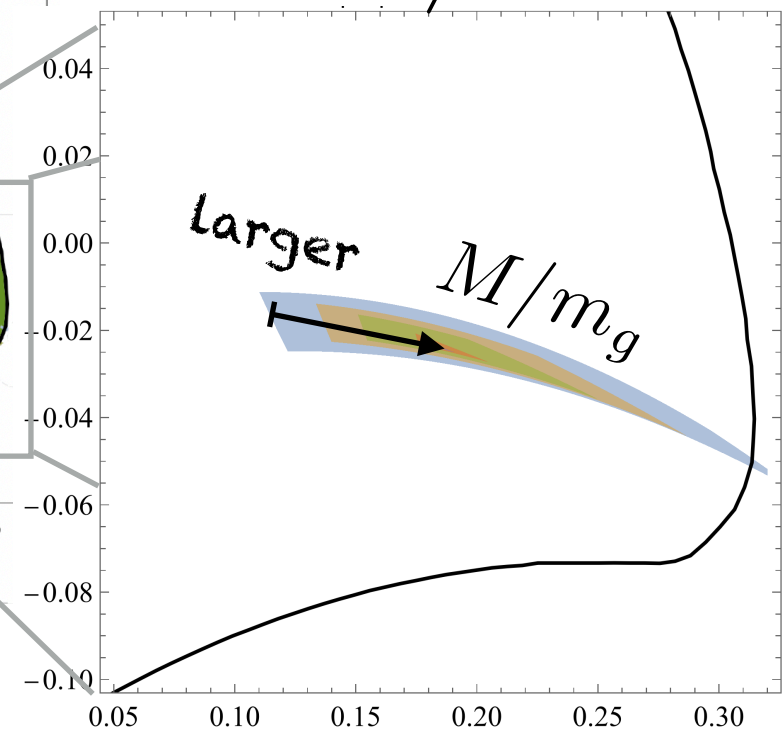
Massive Gravity: $A(hh \rightarrow hh) \sim \frac{(c_3, d_5)}{\Lambda_3^6} [m_g^2 s^2 + s^2 t]$

Fierz, Pauli '1930s
 Arkani-Hamed, Georgi, Schwartz '02
 deRham, Gabadatz, Tolley '10



1

$t \neq 0$

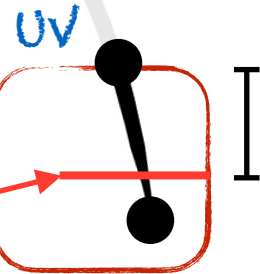


Bellazzini, Isabella, Ricossa, FR '23

► Massive gravity only consistent over range $M \lesssim 30m_g$

UV $\rightarrow$ IR implications: spectra

Bellazzini, Pomarol, Romano, Sciotti '25



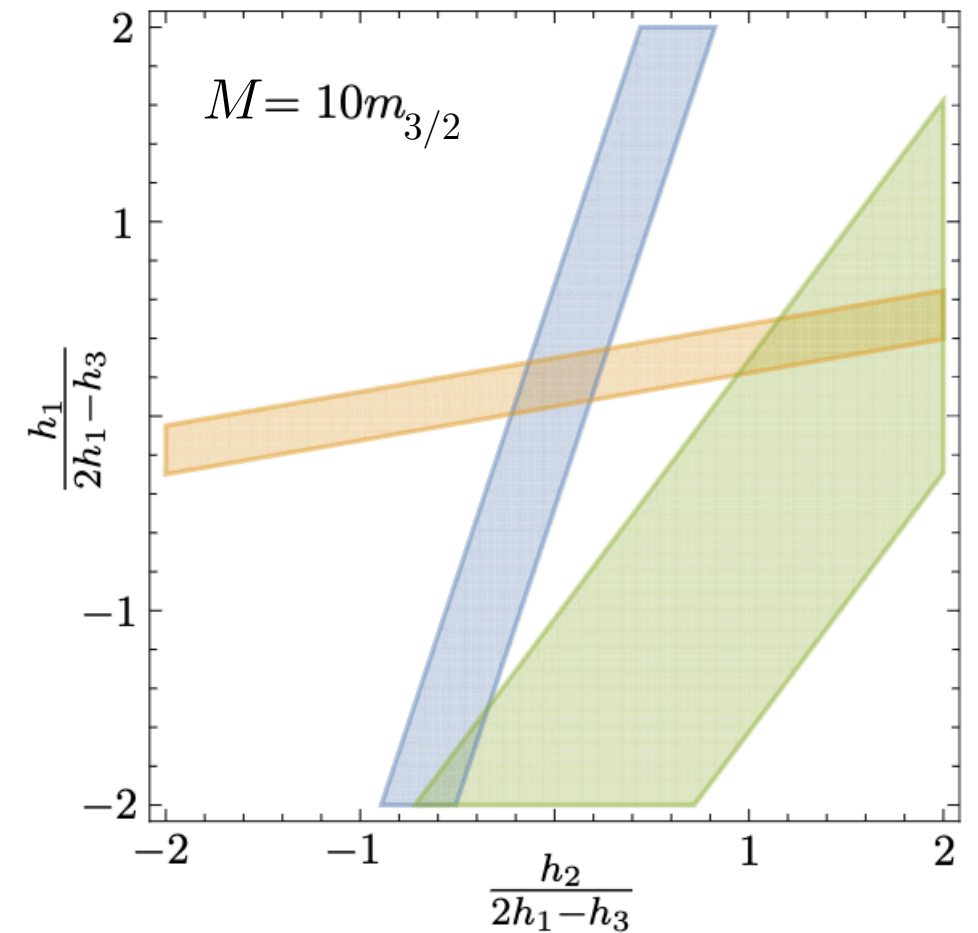
EFT: • spin 3/2

• $m \neq 0$

Massive spin-3/2:

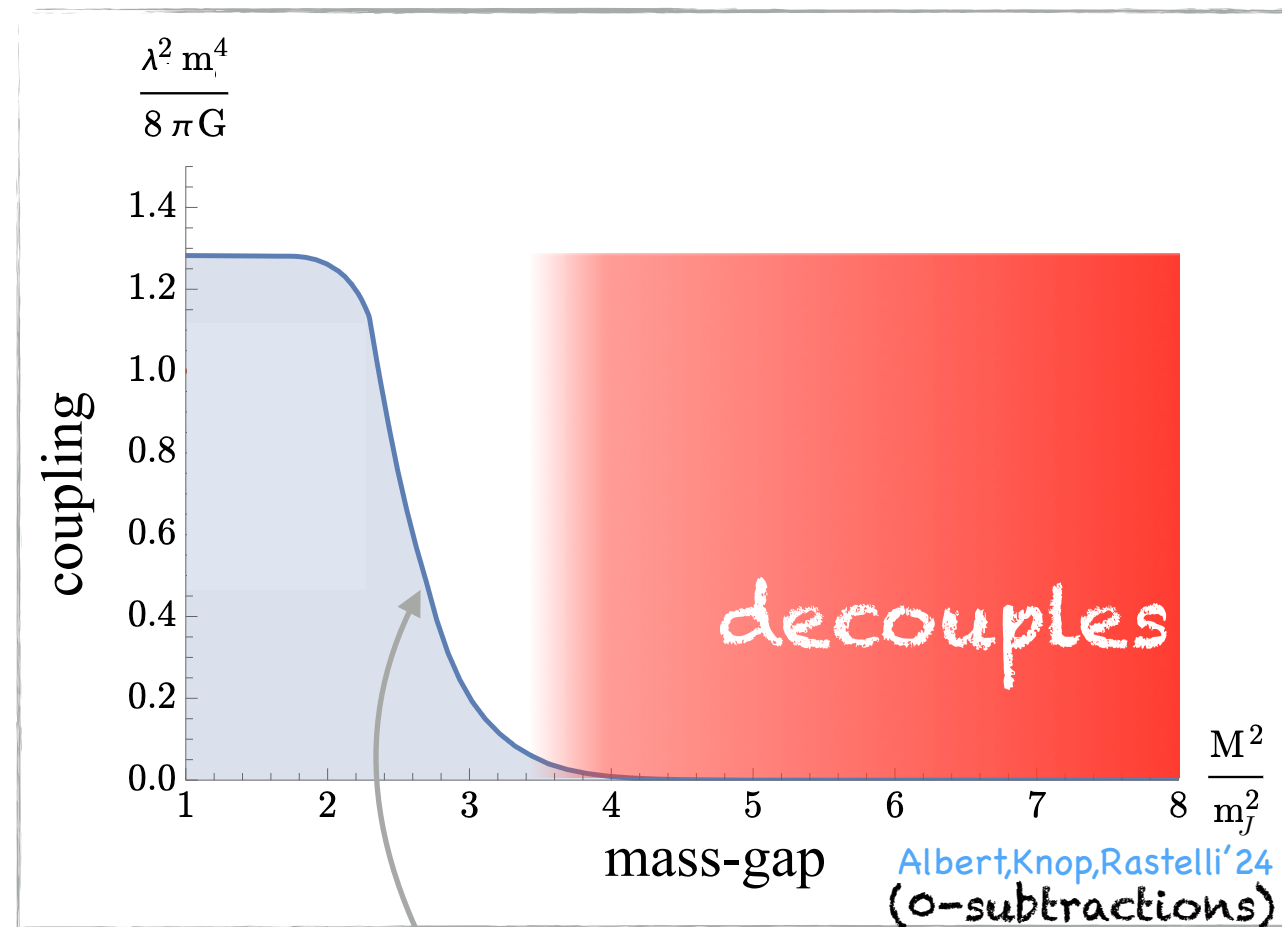
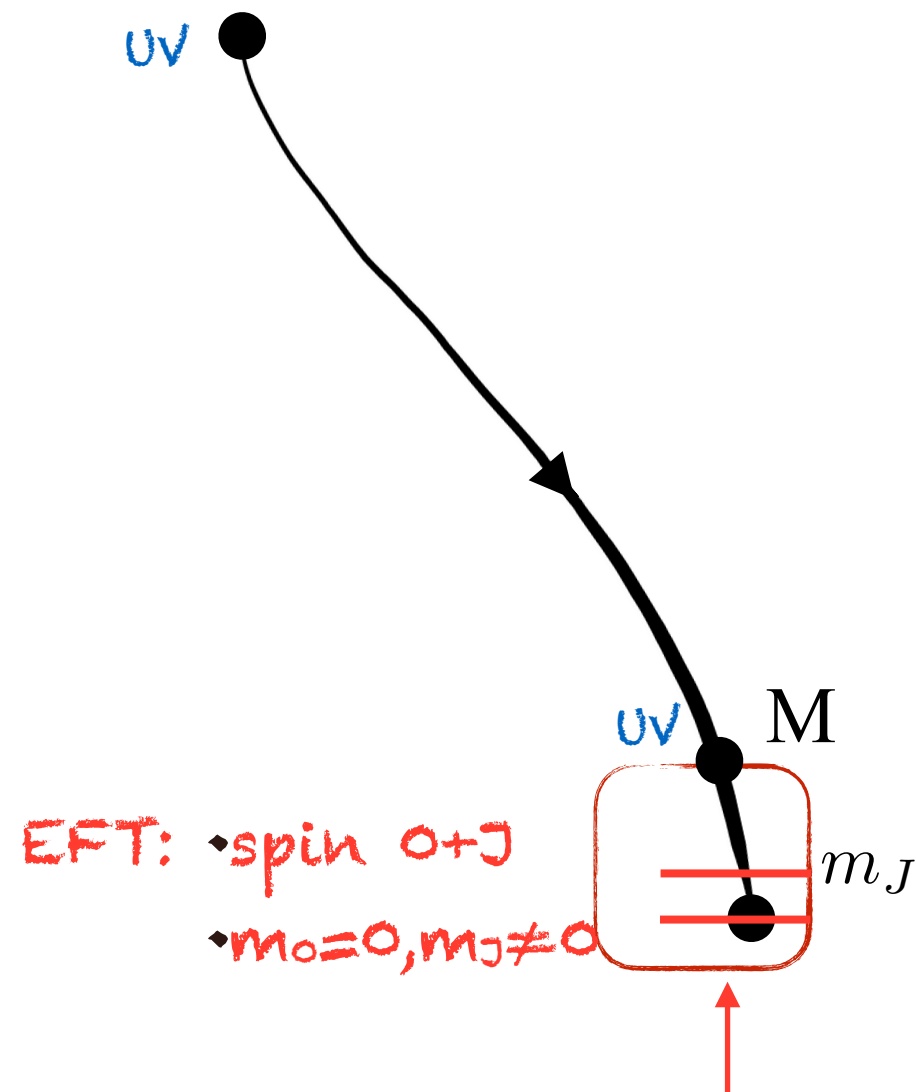
$$A^{--} = -\frac{2h_2 s^3 + h_3 s[s^2 + 2t(s+t)]}{18M^6} + \dots$$

$$A^{+-} = -\frac{h_1 st(s+t)}{3M^6} + \dots$$

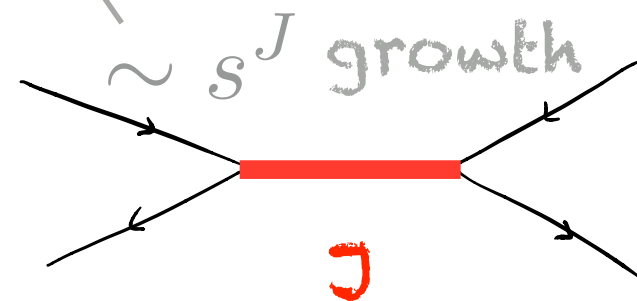


► Massive spin-3/2 only for $M \lesssim 10m_{3/2}$
 ($M \rightarrow \infty$ with graviton and tuned couplings)

UV $\rightarrow$ IR implications: spectra

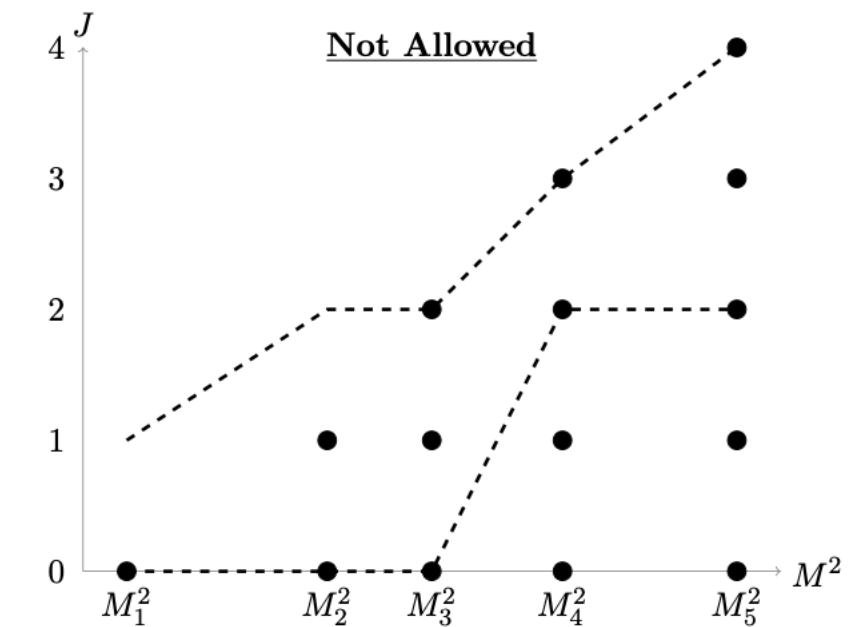
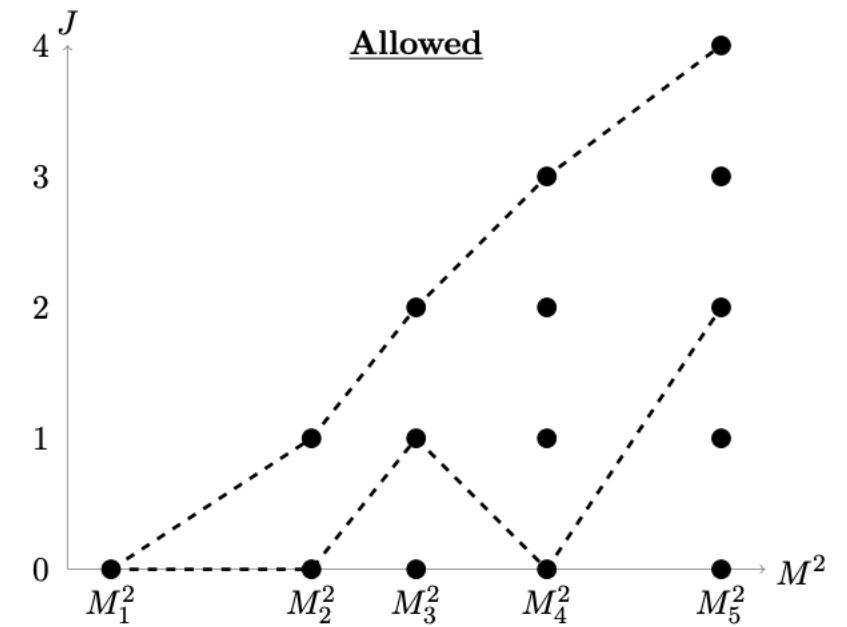
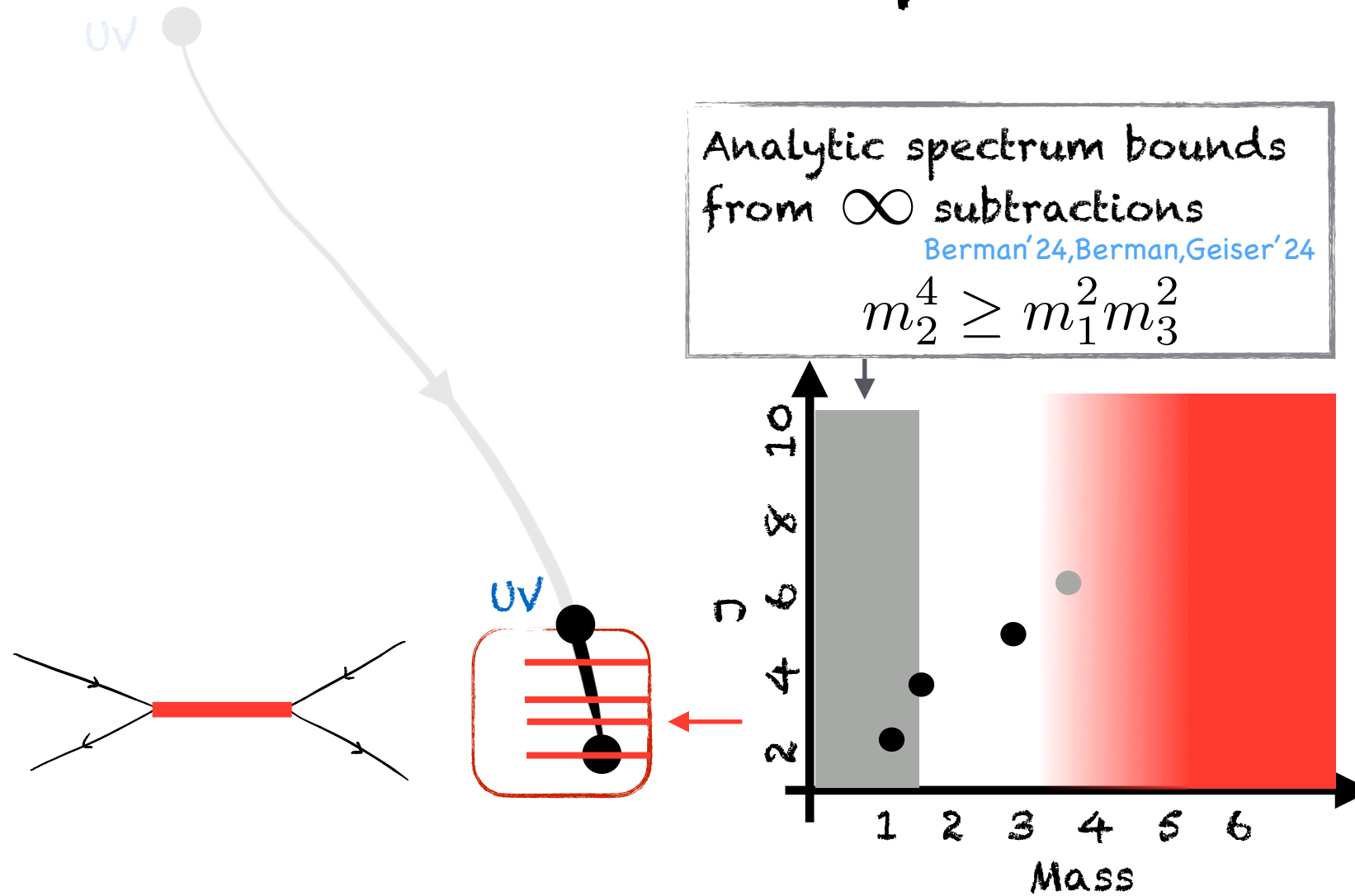


Higher spin easier probed as intermediate states in spin-0 scattering

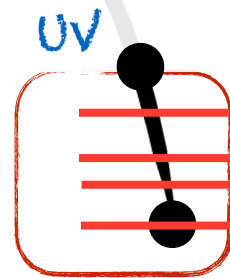


► Massive spin- $J > 2$ gap can be sharply computed

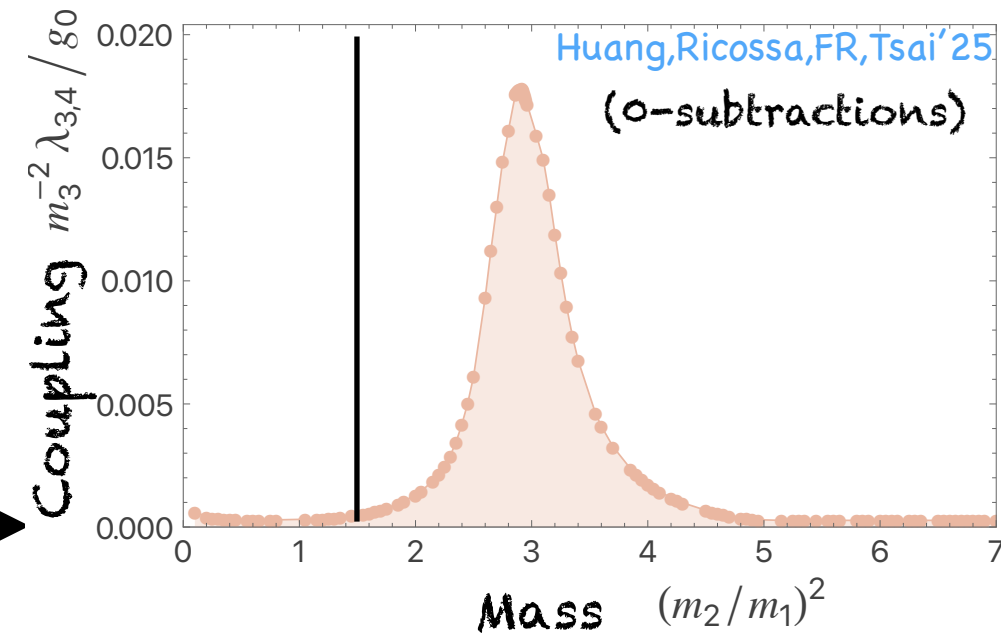
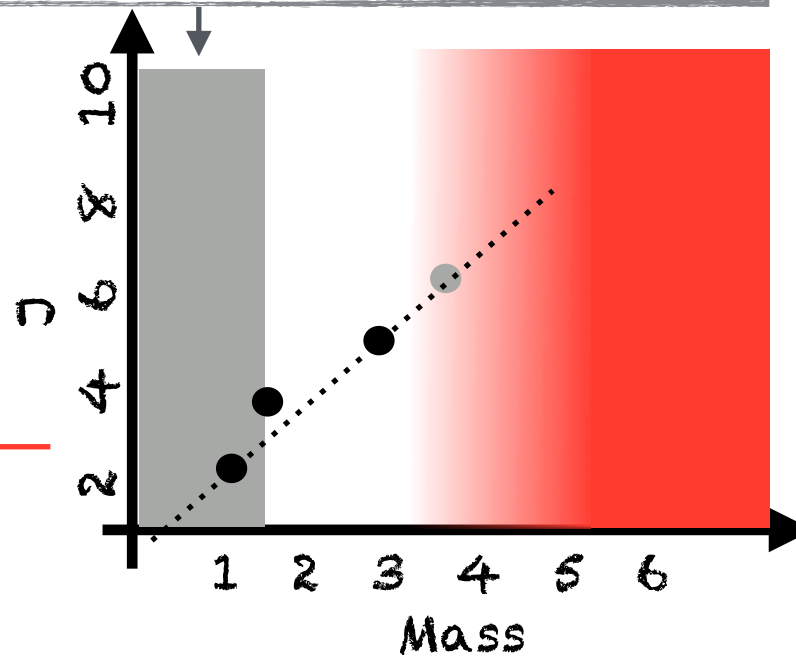
UV $\rightarrow$ IR implications: spectra



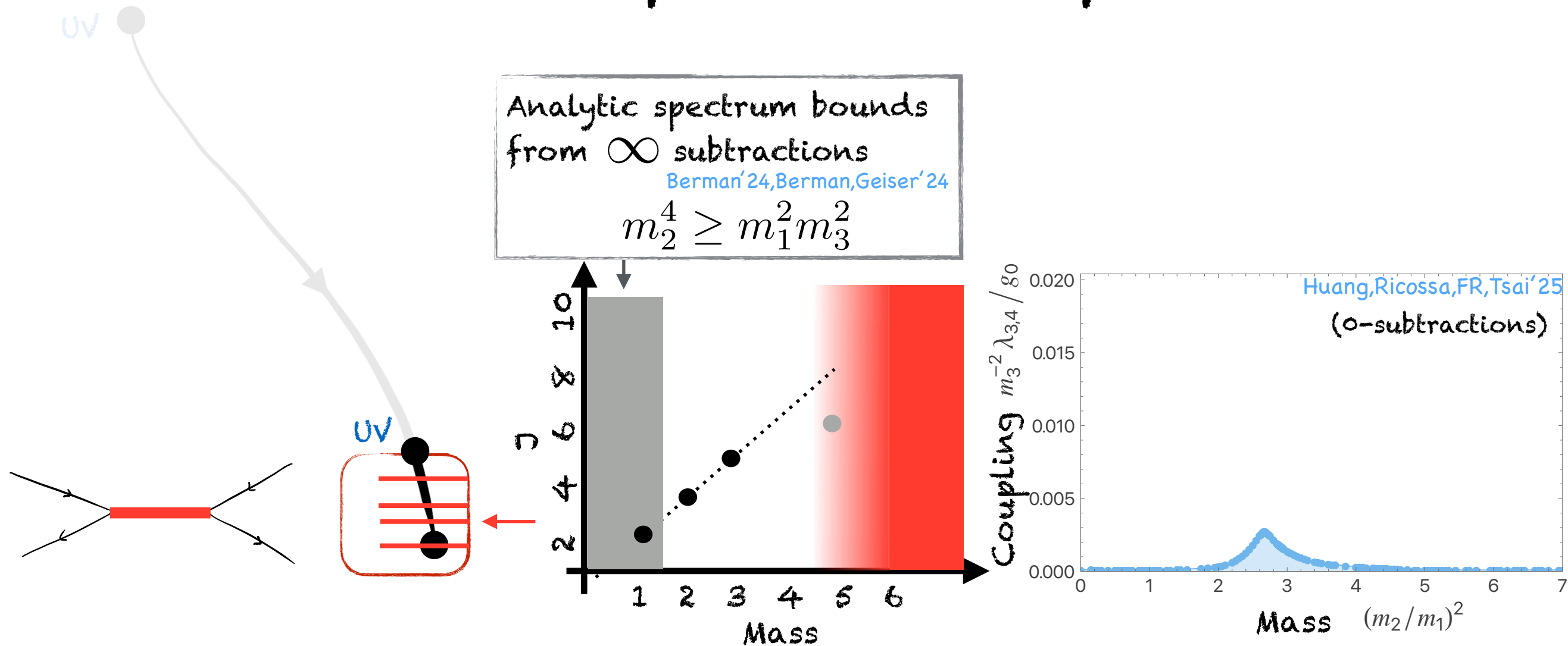
UV $\rightarrow$ IR implications: spectra



Analytic spectrum bounds
from ∞ subtractions
Berman'24, Berman, Geiser'24
$$m_2^4 \geq m_1^2 m_3^2$$



UV $\rightarrow$ IR implications: spectra



► Higher-spin spectra prefer to organise in linear trajectories

UV $\rightarrow$ IR implications at coupling $g \rightarrow 0$

- ▶ Theories with Galilean-like symmetries: no UV completion
- ▶ Only experiments with $\ll 0(1)$ precision detect New Physics
- ▶ Massive gravity only consistent over range $M \lesssim 30m_g$
- ▶ Massive spin-3/2 only for $M \lesssim 10m_{3/2}$
($M \rightarrow \infty$ with graviton and tuned couplings)
- ▶ Massive spin- $J > 2$ never isolated
- ▶ Higher-spin spectra organise in linear trajectories

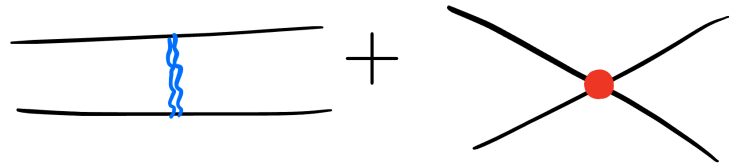
These results (and most literature):

based on tree-level/zero coupling EFT

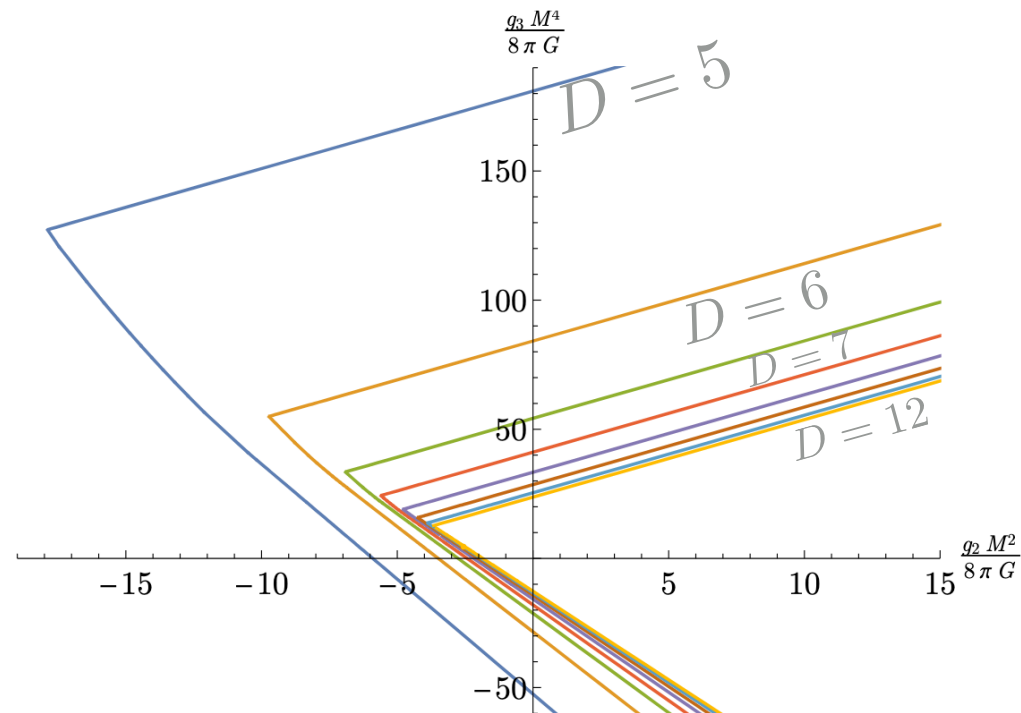
$$g_n \rightarrow 0 \qquad \frac{g_n}{g_m} = \text{finite}$$

Gravity?

Bounds on scalar couplings with gravity in D=5

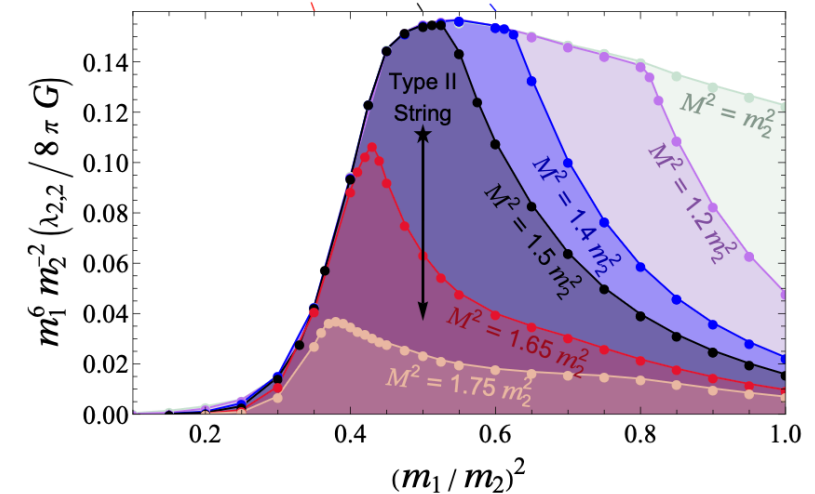
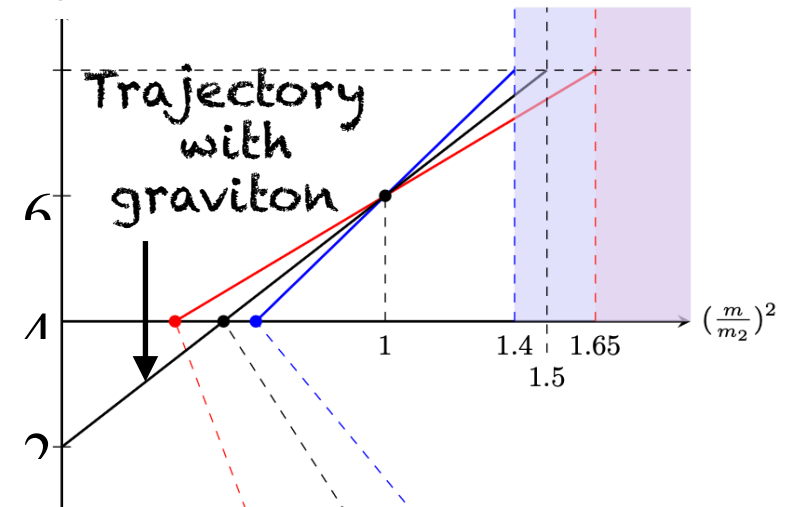
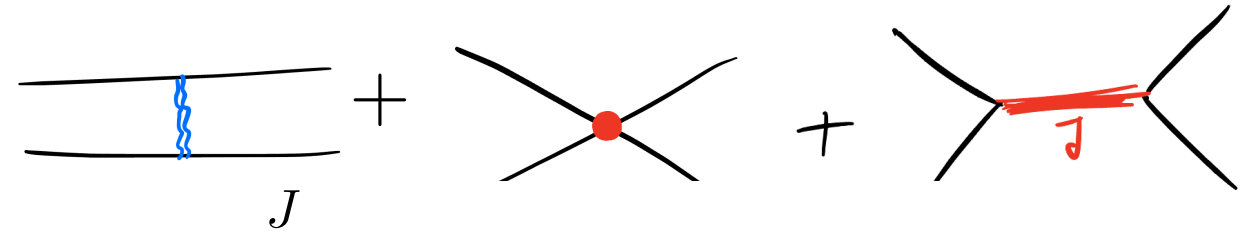


$$A(s, t) = G_N \left(\frac{tu}{s} + \frac{us}{t} + \frac{st}{u} \right) + g_2(s^2 + t^2 + u^2) + g_3 stu + \dots$$



Caron-Huot, Mazac, Rastelli, Simons-Duffin '22

Bounds on spectra with gravity in D=10



Huang, Ricossa, FR, Tsai '25

→ Graviton determines slope and intercept!

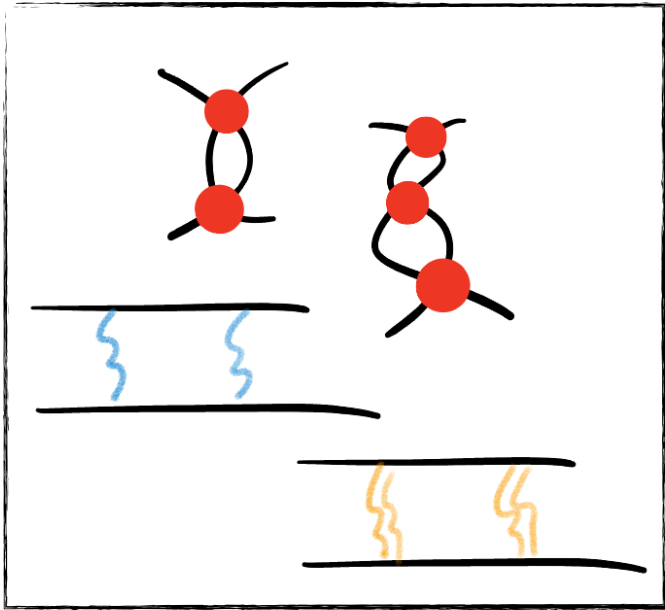
And in D=4???

UV $\rightarrow$ IR implications at weakest coupling

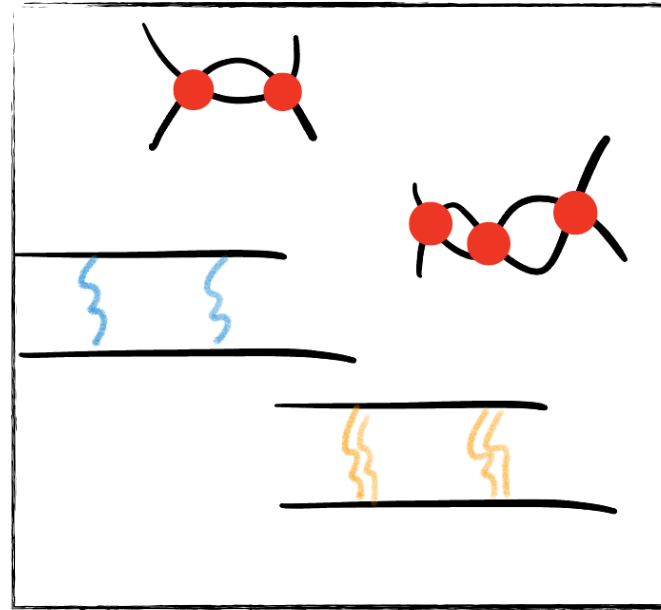
UV $\rightarrow$ IR with finite coupling effects

UV $\rightarrow$ IR Relations and IR effects

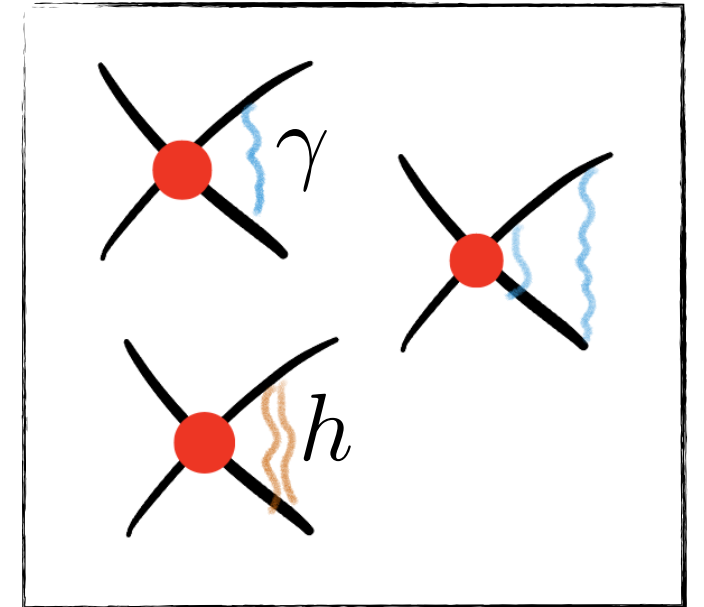
Massless particles (Goldstones, Gravitons, Photons,...): enhanced IR



Beadle, Isabella, Perrone, Ricossa, FR, Serra' 24-'25
Bellazzini, Riembau, FR '22
Chang, Parra-Martinez' 25



Bellazzini, Elias-Miro, Riembau, Rattazzi, FR' 20
Beadle, Isabella, Perrone, Ricossa, FR, Serra' 24-'25
Chang, Parra-Martinez' 25



Bellazzini, Berman, Isabella, FR, Romano, Sciotti' 25

$$A_n \sim \log t \xrightarrow{(t \rightarrow 0)} \infty$$

$$A_n \sim \log s \xrightarrow{(s \rightarrow 0)} \infty$$

$$A(s, t) = \frac{1}{\infty}$$

↑
long-range
forces, D=4

► Possible that bounds are $O(1)$ modified for $g_n, \alpha, G_N \neq 0$?
Maybe yes! After all these are UV/IR relations...

► Or are there modified dispersion relations for which NLO effects are truly small?

Negativity

Not all tree-level bounds are affected in the same way...

$$\pi^0 \pi^0 \rightarrow \pi^0 \pi^0$$

$$A_{2 \rightarrow 2}^{Tree} = g_0 + g_2(s^2 + t^2 + u^2) - g_3 stu + g_4(s^2 + t^2 + u^2)^2 + \dots$$

$$0 \leq \mathcal{A}_2 = g_2$$

$$0 \leq \mathcal{A}_4 = g_4$$

$$0 \leq \mathcal{A}_6 = g_6$$

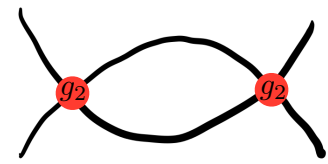
► Each coupling individually bounded, independently of others!

Negativity

Not all tree-level bounds are affected in the same way..

$$\pi^0 \pi^0 \rightarrow \pi^0 \pi^0$$

$$A_{2 \rightarrow 2} = g_0 + g_2(s^2 + t^2 + u^2) - g_3 stu + g_4(s^2 + t^2 + u^2)^2 + \dots$$



$$\beta_4 = \frac{7}{10} \frac{g_2^2}{16\pi^2}$$

exact at order $O(s^4)$

$$- \frac{\beta_4}{2} s^2 \left(s^2 - \frac{tu}{21} \right) \log(-s) + (s \leftrightarrow t, u) + \dots$$

► In amplitude: like running $g_4(s)$. In dispersion relation: more..

$$0 \leq \mathcal{A}_2 = g_2 + \frac{\beta_4}{2} s^2 + \dots$$

$$0 \leq \mathcal{A}_4 = g_4(s) + \dots$$

$$0 \leq \mathcal{A}_6 = \frac{\beta_4}{2s^2} + g_6 + \dots$$

► Negativity for irrelevant interactions
(running vs irrelevant are indistinguishable)

Long-range Interactions

Exclusive Amplitudes: Unitary and Analytic but...

$$A_{2 \rightarrow 2} = \text{diagram of a red circle with four external lines} \\ A_{2 \rightarrow 2}^{\text{Tree}}$$

Inclusive Cross-sections: IR finite, but no analyticity

$$\sigma(\Delta E < \mathcal{E}) = \sum^{\infty} |A|^2$$

diagram of a red circle with four external lines

diagram of a red circle with four external lines and a blue wavy line on one of the outgoing lines

diagram of a red circle with four external lines and two blue wavy lines on one of the outgoing lines + ...

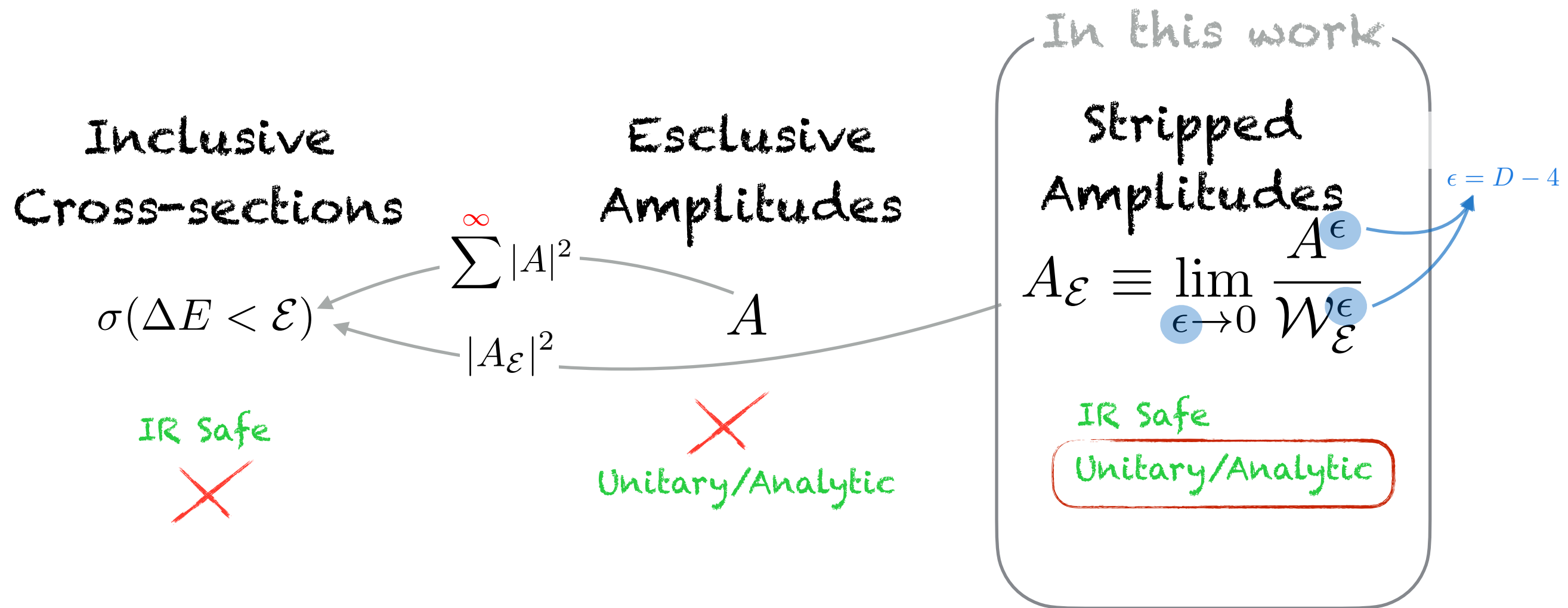
diagram of a red circle with four external lines

diagram of a red circle with four external lines and a blue wavy line on one of the incoming lines, labeled $\Delta E < \mathcal{E}$

diagram of a red circle with four external lines and two blue wavy lines on one of the incoming lines + ...

Stripped Amplitudes: IR Finite

Bellazzini, Berman, Isabella, FR, Romano, Sciotti'25



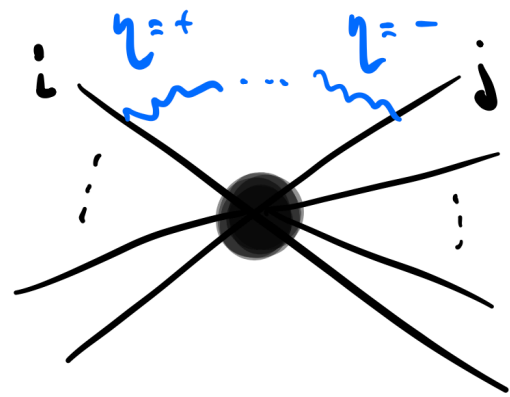
- ▶ $A_{\mathcal{E}}$ are formal amplitudes of finite size $\mathcal{E}^{-1}$ experiments
- ▶ Regulator ϵ disappears, physical $\mathcal{E}$ remains:
it specify initial/final states!

Stripped Amplitudes: Analytic

$$A_{\mathcal{E}} \equiv \lim_{\epsilon \rightarrow 0} \frac{A^{\epsilon}}{\mathcal{W}_{\mathcal{E}}^{\epsilon}}$$

QED:

Weinberg'65



$$\mathcal{W} = \exp \left\{ \frac{\alpha}{8\pi} \frac{(\mathcal{E}/\mu)^{2\epsilon}}{\epsilon} \left(\sum_{i,j} \eta_i \eta_j q_i q_j \frac{1}{\beta_{ij}} \log \frac{1 + \beta_{ij}}{1 - \beta_{ij}} - i \sum_{\substack{i \neq j \\ \eta_i \eta_j = 1}} q_i q_j \frac{2\pi}{\beta_{ij}} + O(\epsilon) \right) \right\}$$

$$\beta_{ij}^2 = \frac{[s_{ij} - (m_i - m_j)^2][s_{ij} - (m_i + m_j)^2]}{(s_{ij} - m_i^2 - m_j^2)^2}$$

only for real kinematics!

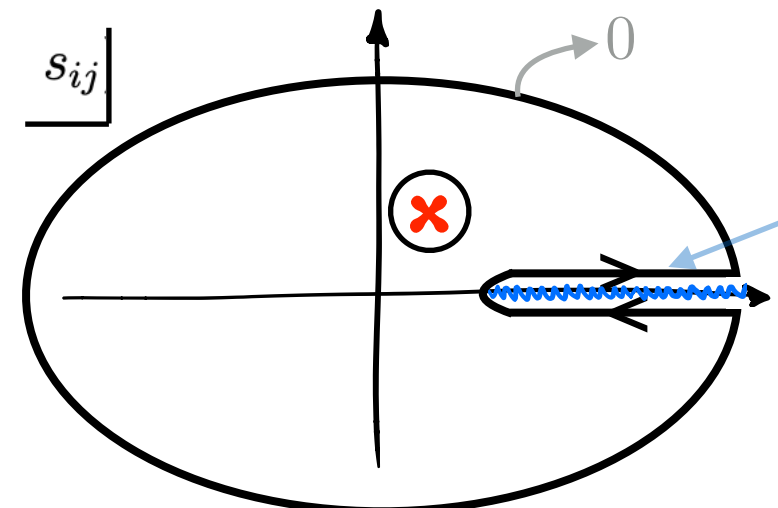
Analytic continuation:

Bellazzini, Berman, Isabella, FR, Romano, Sciotti'25

$$\mathcal{W} = \prod_{i,j} \mathcal{W}_{ij}(s_{ij})$$

$$\mathcal{W}_{ij}(s_{ij}) = \mathcal{W}_{ij}(s_0) + \int_{(m_1+m_2)^2}^{\infty} \frac{d\bar{s}}{2\pi i} \frac{s_{ij} - s_0}{(\bar{s} - s_0)(\bar{s} - s_{ij})} \text{Disc } \mathcal{W}_{ij}(\bar{s}),$$

$$= \exp \left[-\frac{\alpha q_i q_j}{2\pi} \frac{(\mathcal{E}/\mu)^{2\epsilon}}{\epsilon} \frac{s_{ij} - m_i^2 - m_j^2}{\sqrt{(s_{ij} - (m_i - m_j)^2)(-s_{ij} + (m_i + m_j)^2)}} \arctan \frac{\sqrt{s_{ij} - (m_i - m_j)^2}}{\sqrt{-s_{ij} + (m_i + m_j)^2}} \right] \xrightarrow{s \gg m} \exp \left[\frac{\alpha q_i q_j}{4\pi} \frac{(\mathcal{E}/\mu)^{2\epsilon}}{\epsilon} \log \left(-\frac{s_{ij}}{m^2} \right) \right]$$



► $A_{\mathcal{E}}$ has same analyticity as A and respects Froissart $A/s^2 \xrightarrow{s \rightarrow \infty} 0!$

... and similarly in Gravity!

Stripped Amplitudes: Unitary and Positive

Effectively 2 QED couplings:

$$\alpha \rightarrow 0$$

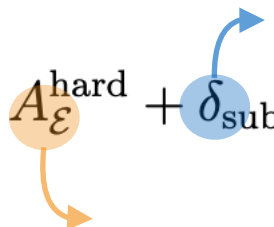
$$\mathcal{E} \rightarrow 0$$

$$\alpha_{\mathcal{E}} \equiv \alpha \log M/\mathcal{E} = \text{fixed} \quad \Downarrow$$


Captures finite perturbative effects

Captures leading IR effects

In gravity: $G \rightarrow 0, \mathcal{E} \rightarrow 0, G_{\mathcal{E}} \equiv GM^2 \log M/\mathcal{E} = \text{fixed}$

$$A_{\mathcal{E}} = A_{\mathcal{E}}^{\text{hard}} + \delta_{\text{sub. soft}}$$


α $\mathcal{E}$

Is unitary (equivalent to $m_{\gamma} = \mathcal{E}$ theory) $E_{\gamma} > \mathcal{E}$

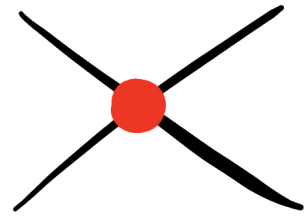
► Leads to positivity at **all orders** in $\alpha_{\mathcal{E}}$ and L.O. in α

$$\mathcal{A}_n(s, t) = \int_{M^2}^{+\infty} \frac{ds}{\pi} \left[\frac{\overline{\text{Im}} A_{\mathcal{E}}^s(s, t)}{s^{3+n}} + \frac{(-1)^n \overline{\text{Im}} A_{\mathcal{E}}^u(s, t)}{(s + t - 4m^2)^{3+n}} \right] \quad \text{e.g.} \quad \mathcal{A}_n \geq 0 + O(\alpha)$$

Bounds for charged/neutral pions

$$\pi^+ \pi^0 \rightarrow \pi^+ \pi^0$$

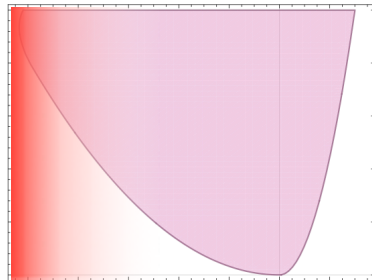
Tree level:



don't enter twice-subtracted relations

$$A_{+0}^{\text{tree}} = c_{0,0} + c_{1,1}t + c_{2,0}(s - m_{\pm}^2 + t/2)^2 + c_{2,2}t^2 + c_{3,1}t(s - m_{\pm}^2 + t/2)^2 + \dots$$

Positivity Bounds:



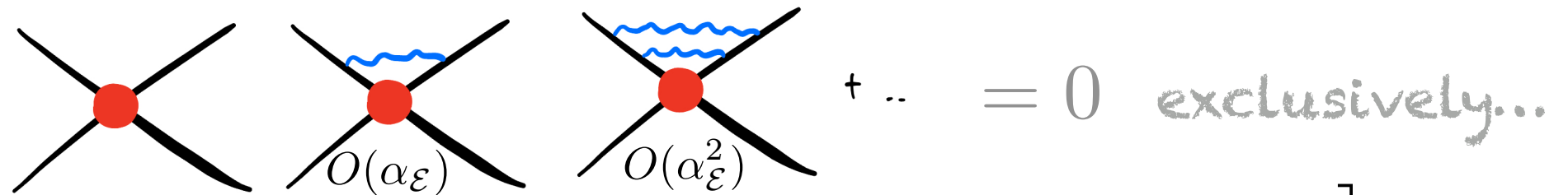
$$c_{20} > 0$$

$$(M^2 - m_{\pm}^2) \frac{c_{31}}{c_{20}} \geq -\frac{3}{2}$$

Bounds for charged/neutral pions

$$\pi^+ \pi^0 \rightarrow \pi^+ \pi^0$$

Loop level:



$$A_{\mathcal{E}} = \left[c_{0,0} + c_{1,1}t + c_{2,0}(s - m_{\pm}^2 + t/2)^2 + c_{2,2}t^2 + c_{3,1}t(s - m_{\pm}^2 + t/2)^2 + \dots \right] \times$$

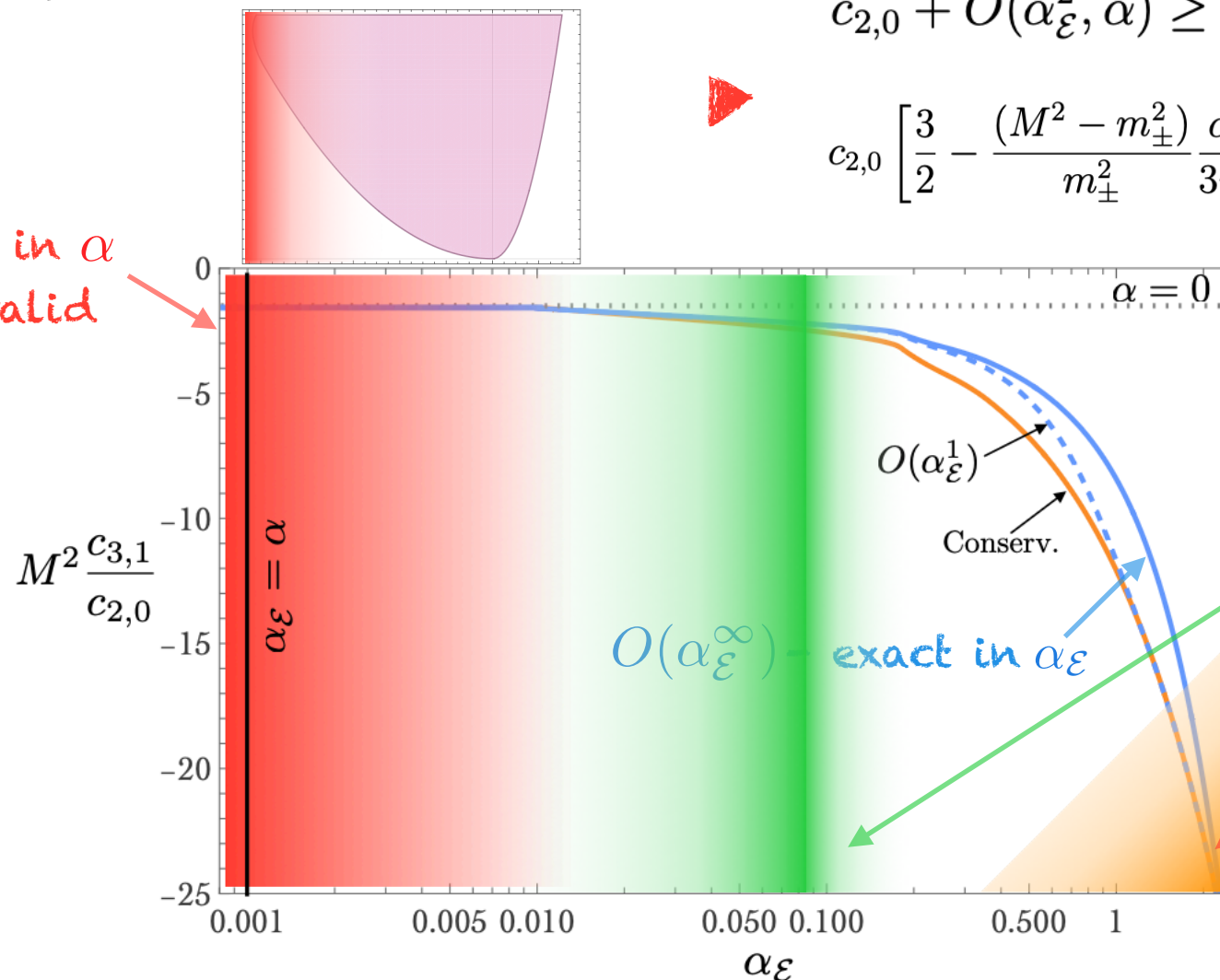
$$\left[1 + \frac{\alpha}{2\pi} \log \left(\frac{m_{\pm}^2(4m_{\pm}^2 - t)}{\mathcal{E}^4} \right) \frac{t - 2m_{\pm}^2}{\sqrt{t(4m_{\pm}^2 - t)}} \arctan \left(\frac{\sqrt{t}}{\sqrt{4m_{\pm}^2 - t}} \right) + \frac{\alpha}{2\pi} \log \frac{4\pi\mu^2}{\mathcal{E}^2} \right] + O(\alpha_{\mathcal{E}}^2)$$

Positivity Bounds:

$$c_{2,0} + O(\alpha_{\mathcal{E}}^2, \alpha) \geq 0$$

$$c_{2,0} \left[\frac{3}{2} - \frac{(M^2 - m_{\pm}^2)}{m_{\pm}^2} \frac{\alpha}{3\pi} \log \left(\frac{\mathcal{E}}{m_{\pm}} \right) \right] + (M^2 - m_{\pm}^2)c_{3,1} + O(\alpha_{\mathcal{E}}^2, \alpha) \geq 0$$

approx in α
not valid

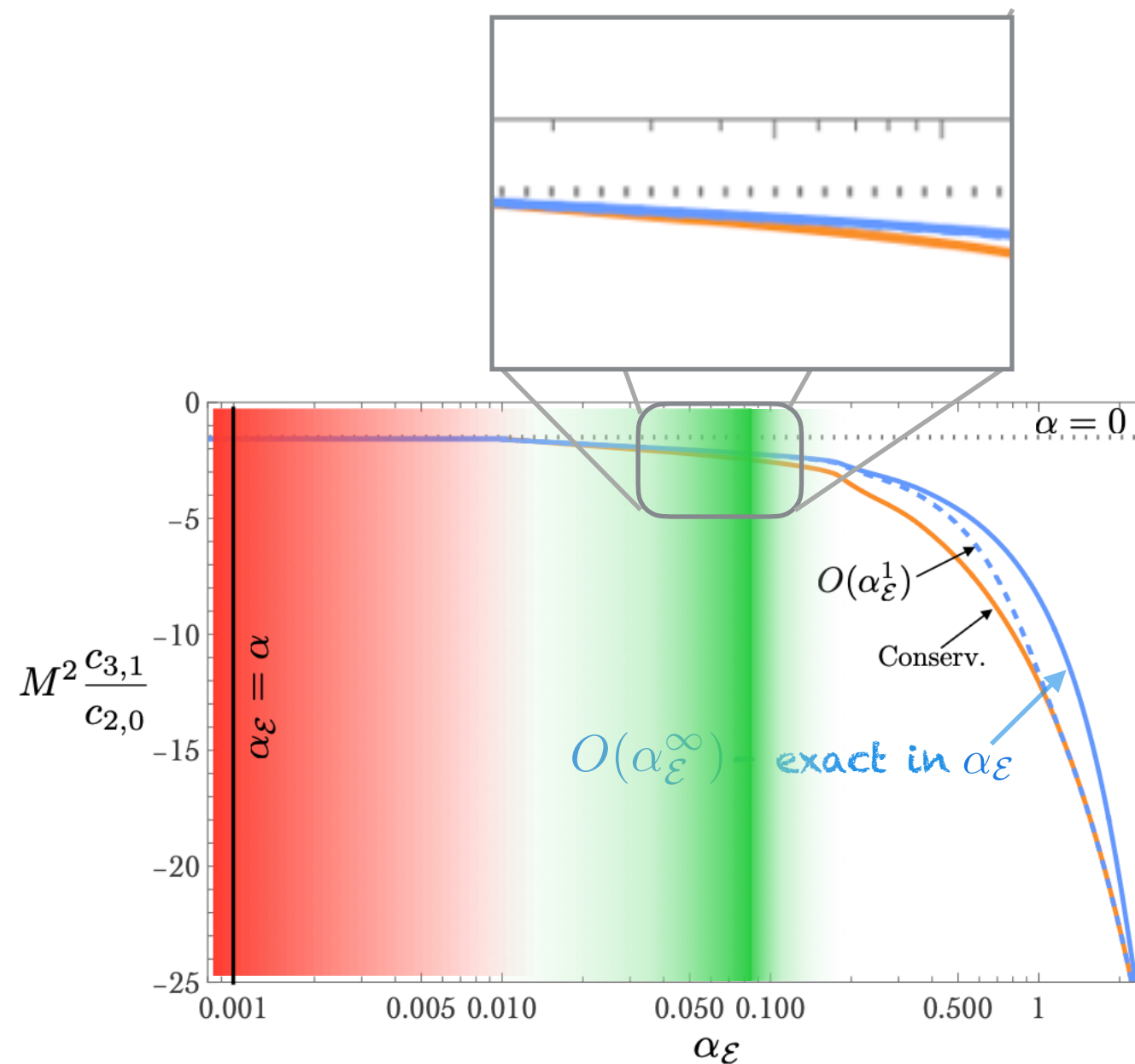


Bounds for charged/neutral pions

$$\pi^+\pi^0 \rightarrow \pi^+\pi^0$$

Positivity bounds survive to $\alpha \neq 0$ also in D=4...

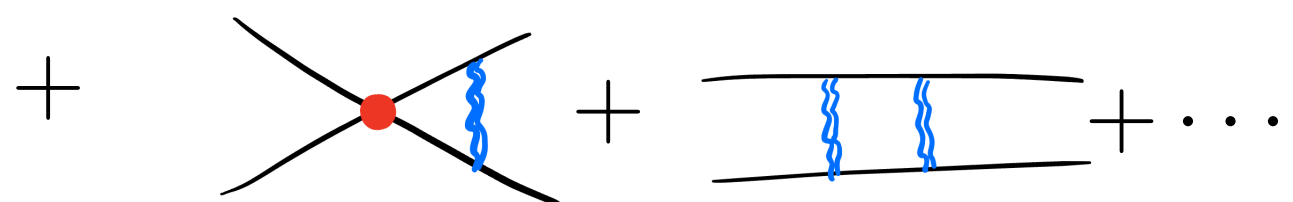
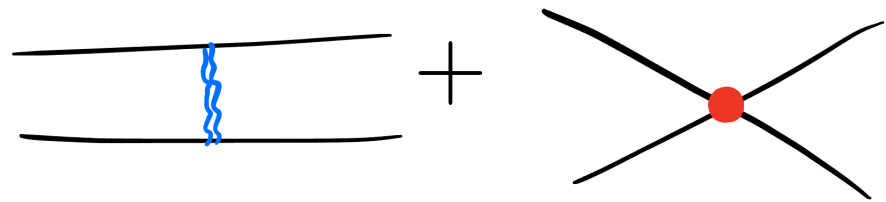
QED corrections are perturbative.



Bounds with Gravity: $\pi^0 \pi^0 \rightarrow \pi^0 \pi^0$

Tree Amplitude: $G_N \rightarrow 0$ $\frac{g}{G_N} = \text{finite}$

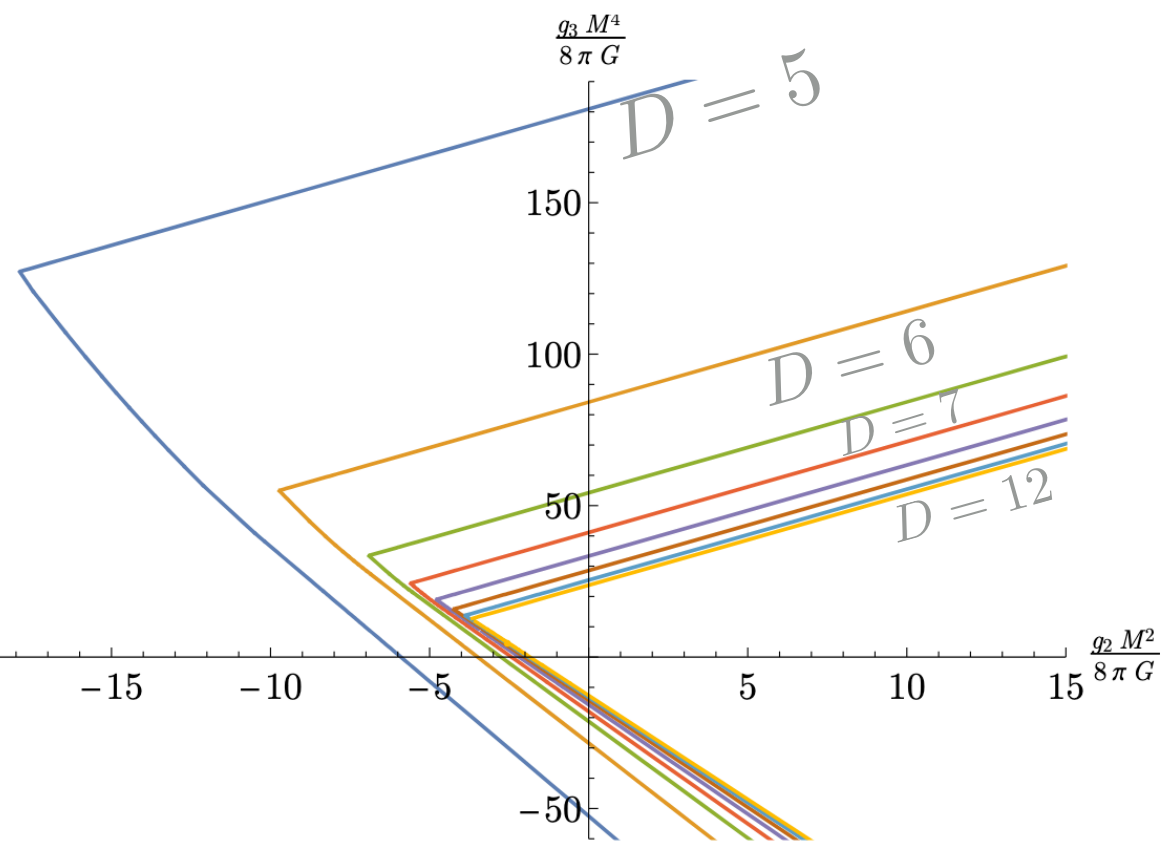
Stripped Amplitude: $G_N \rightarrow 0$ $\mathcal{E} \rightarrow 0$,
 $G_{\mathcal{E}} \equiv G M^2 \log M / \mathcal{E} = \text{fixed}$



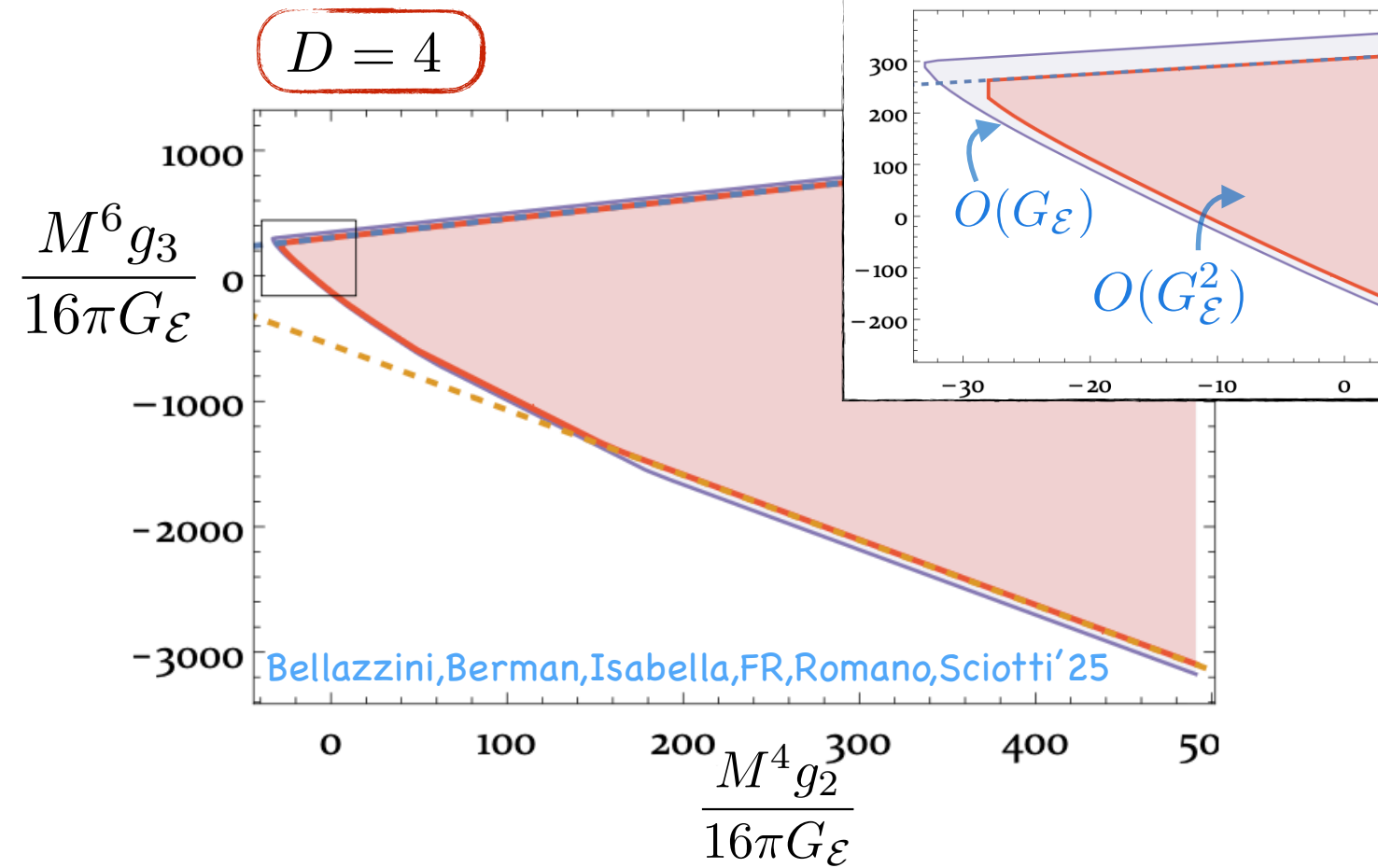
$$A(s, t) = G_N \left(\frac{tu}{s} + \frac{us}{t} + \frac{st}{u} \right) + g_2(s^2 + t^2 + u^2) + g_3 stu + \dots$$

$$A_{\mathcal{E}} = \frac{A}{\mathcal{W}_{GR}} \Big|_{\epsilon \rightarrow 0}$$

$$\mathcal{W}_{GR}(s, t) = \exp \left[-G \frac{(\mathcal{E}/\mu)^{2\epsilon}}{\pi\epsilon} (s \log(-s/\mu^2) + s \rightarrow t, u) \right]$$



Caron-Huot, Mazac, Rastelli, Simons-Duffin '22

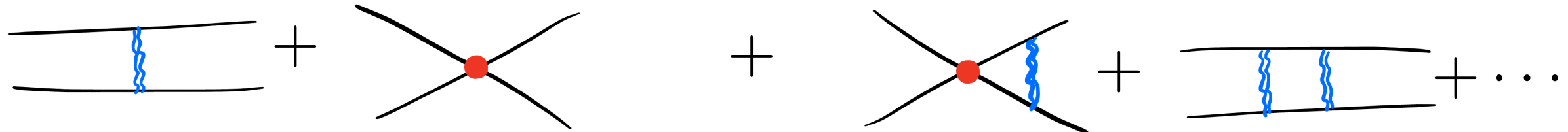


Bellazzini, Berman, Isabella, FR, Romano, Sciotti '25

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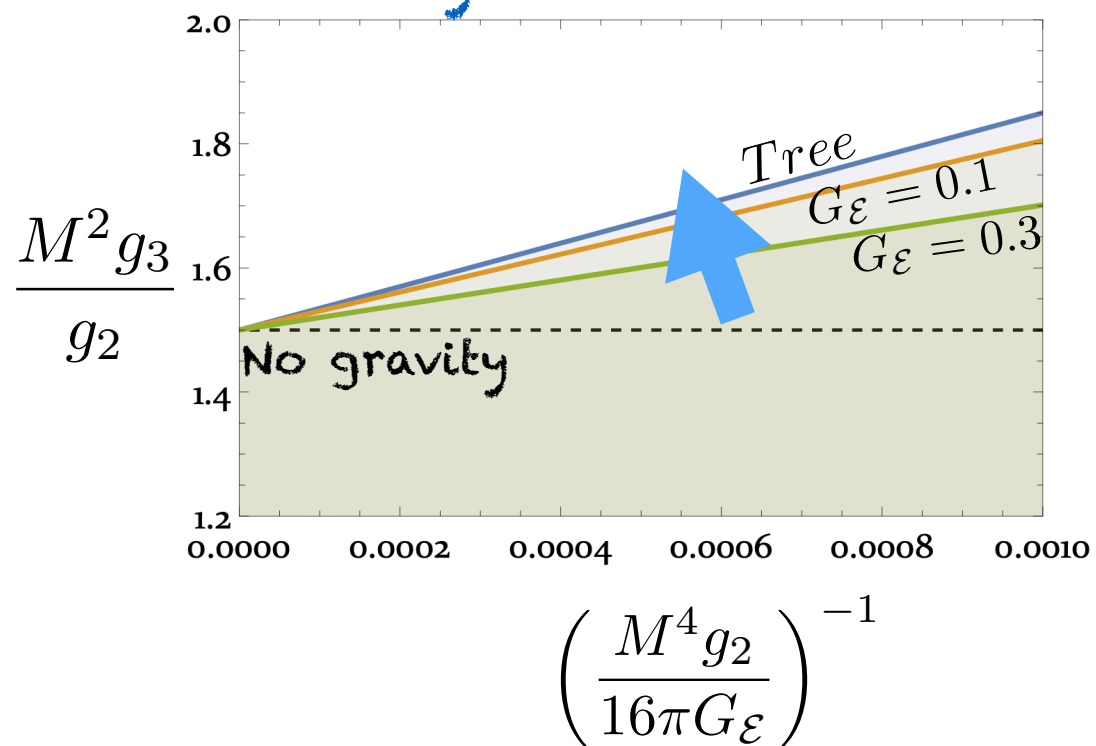


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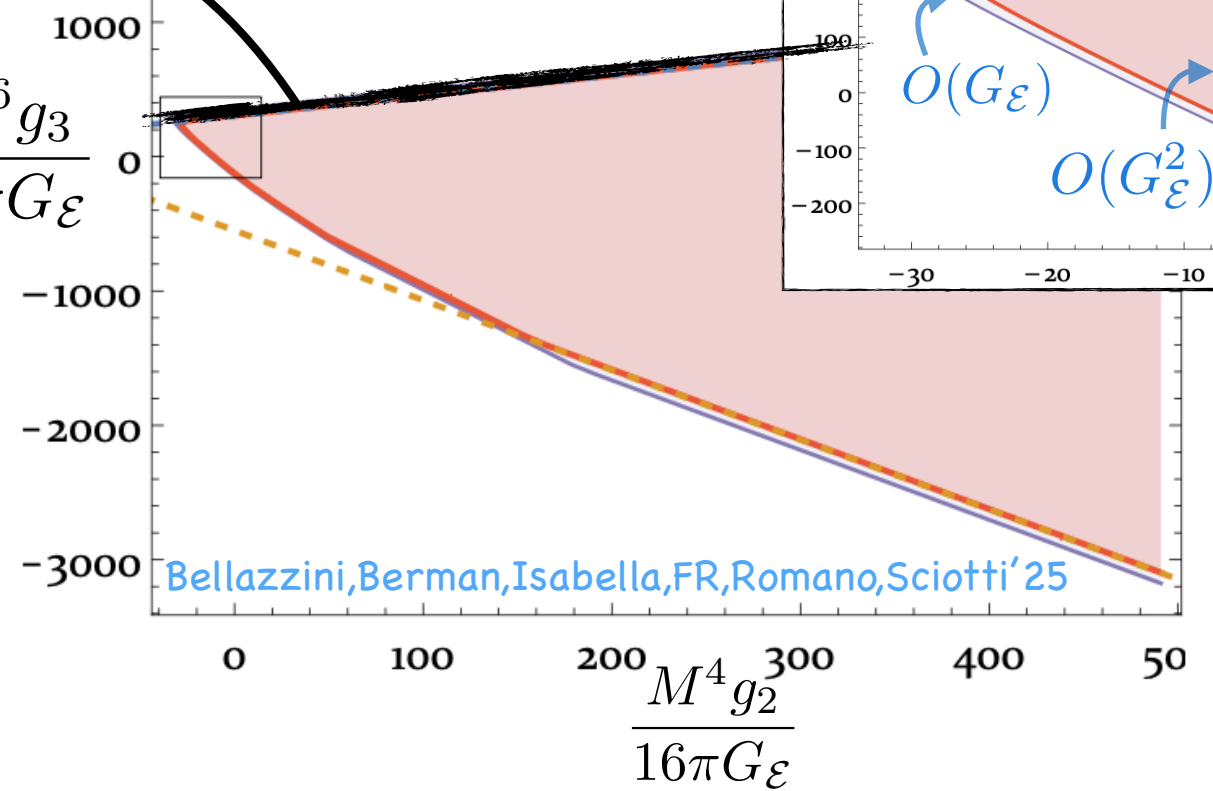
$$\mathcal{W}_{GR}(s, t) = \exp \left[-G \frac{(\mathcal{E}/\mu)^{2\epsilon}}{\pi\epsilon} (s \log(-s/\mu^2) + s \rightarrow t, u) \right]$$

Smoothly connects to $G=0$

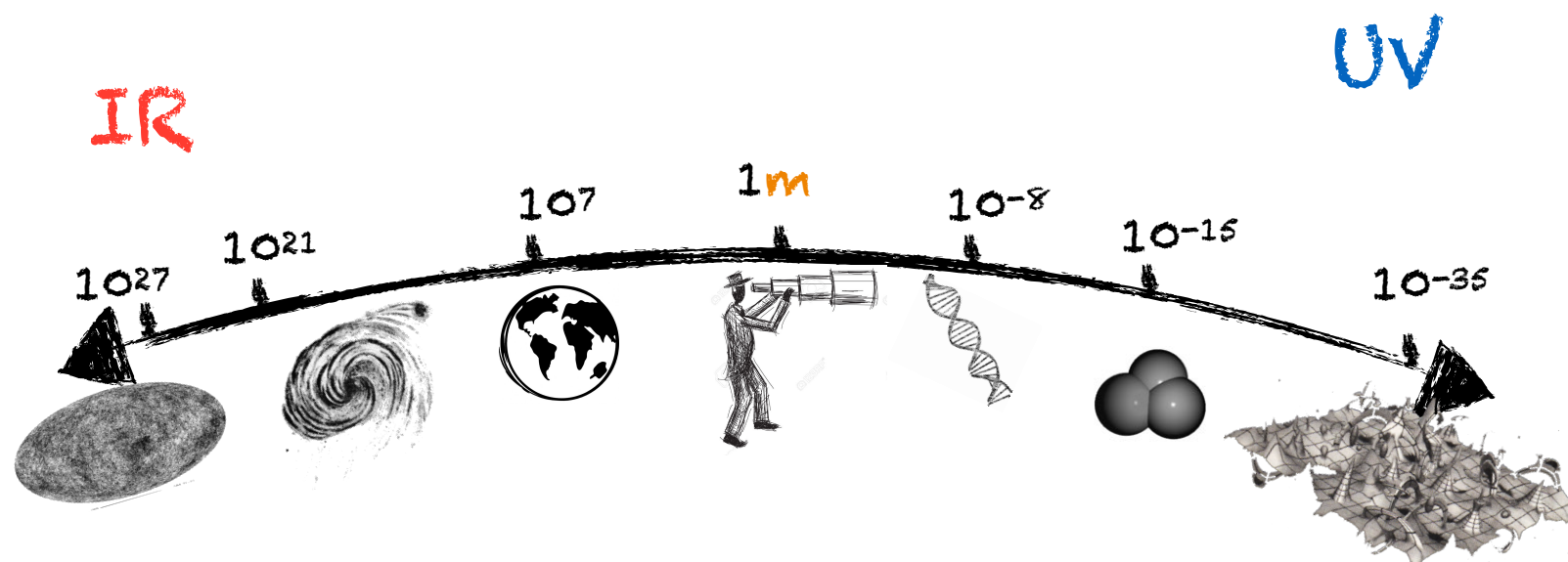


$D = 4$

$$\frac{M^6 g_3}{16\pi G_{\mathcal{E}}}$$



Summary/Outlook



- ▶ Bootstrap $\leftrightarrow$ UV completable EFTs
- ▶ EFT symmetries and spectra constrained
- ▶ Even with $D=4$ Long-Range interactions bounds smoothly connected to tree level ones: leading IR captured by stripped amplitude
- ▶ Physical experiment size enters; bounds on very irrelevant operators washed away
- ▶ Zero coupling: (analytic) understanding of infinite spectra amplitudes?
- ▶ Finite coupling: progress beyond scaling limit $\alpha, G, \mathcal{E} \rightarrow 0$?