SCUOLA NORMALE SUPERIORE

General bounds on hidden CFTs

Invisibles 2018 – 04/09/2018

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18xx.xxx with Roberto Contino & Rashmish Mishra.

What this talk is about

Generic setup:

approximate CFT with cut-off Λ_{UV} (+ IR breaking scale Λ_{IR})

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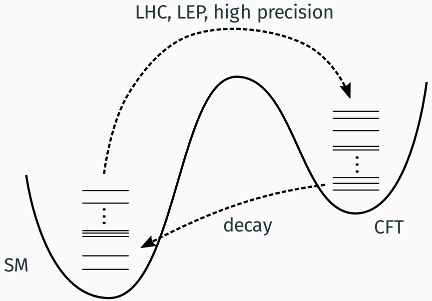
SM $\longleftrightarrow$ CFT



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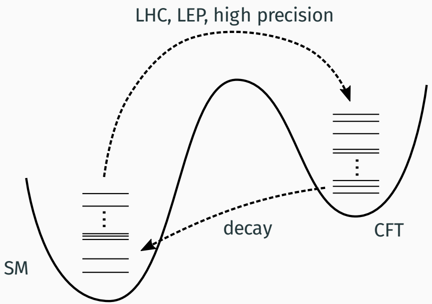


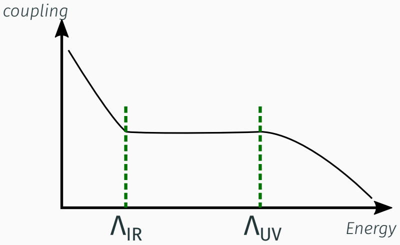
Given:

- # particles
- coupling to SM

$\Rightarrow$ We can give model-independent bounds on Λ_{UV}, Λ_{IR}

Defining the CFTs

Assume BSM sector with scale invariance between Λ_{UV} and Λ_{IR}



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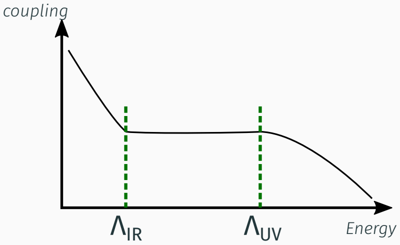

Examples:

- QCD-like in conformal window
- Supersymmetric models ($\mathcal{N} = 4$ or SQCD)
- CFT dual of 5D Randall-Sundrum models

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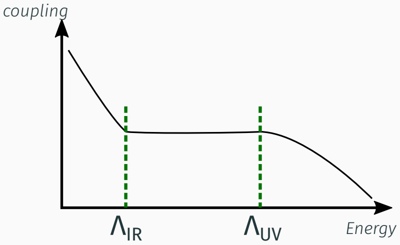

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For illustration, assume Banks-Zaks IR fixed point.

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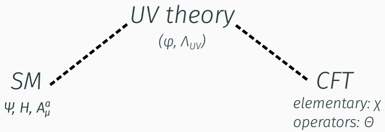

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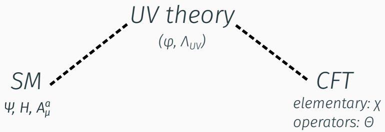
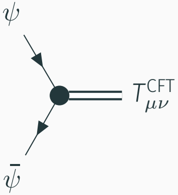


EFT interaction:



$$\equiv \frac{C_0}{\Lambda_{\text{UV}}^4} T_{\text{SM}}^{\mu\nu} T_{\mu\nu}^{\text{CFT}}, \qquad C_0 \equiv g_{\text{UV}}^2$$

How to describe dynamics of $T_{\mu\nu}^{\mathrm{CFT}}$?

The Unparticle description

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Operator in the CFT $\mathcal{O}_U$ of mass dim. d_U – spectral decomposition fixed by scale invariance:

$$\langle \Omega | \mathcal{O}_U(x) \mathcal{O}_U^\dagger(0) | \Omega \rangle = \int \frac{d^4 P_U}{(2\pi)^4} A_{d_U} \, \theta(p_U^0) \theta(p_U^2) (p_U^2)^{d_U - 2}$$

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Cf. phase space factor A_n for n massless particles:

$$A_n = \frac{16\pi^{5/2}}{(2\pi)^{2n}} \frac{\Gamma(n+1/2)}{\Gamma(n-1)\Gamma(2n)}$$

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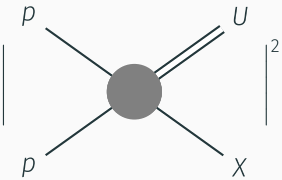
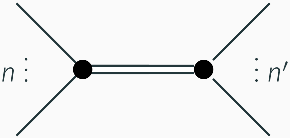
Georgi '07:

"Unparticle ≙ phase space of d_U (massless) particles"

Production at colliders:

$|\mathcal{M}_U|^2 =$  $\propto 2\,\mathrm{Im} \sum_{n-\text{states}}$ 

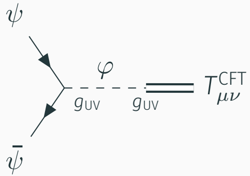
→ Using the Unparticle description & results on CFT correlators: (Grinstein et al. '08)

$$\langle 0|\mathcal{T}[T_{\mu\nu}^{CFT}(p)T_{\rho\sigma}^{CFT}(-p)]|0\rangle = i\, C_T N_T\, P_{\mu\nu\rho\sigma}^4(p)\,(p^2+i\epsilon)^2 \log(-p^2-i\epsilon) \quad (1)$$

Hidden sector signature as $\not{\vec{p}}_T$ at LHC and LEP

Parameters for collider searches

- UV cut-off Λ_{UV}
- IR breaking scale Λ_{IR}
- Perturbative coupling to SM $C_0 \sim g_{\text{UV}}^2$
- Coefficient of EMT 2-correlator, central charge C_T

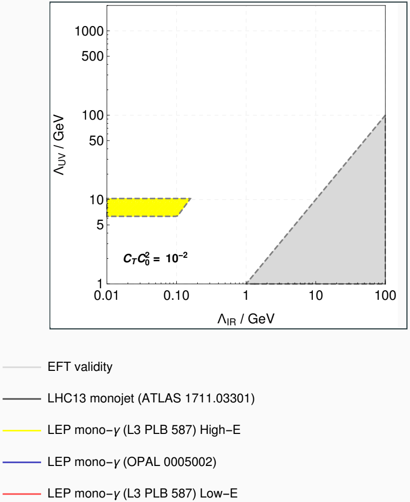


$$\langle 0|\mathcal{T}[T^{\text{CFT}}_{\mu\nu}(p)T^{\text{CFT}}_{\rho\sigma}(-p)]|0\rangle \propto C_T\,(p^2+i\epsilon)^2\ldots$$

E.g. QCD-like theory: $C_T \times C_0^2 \sim \frac{N_c^2}{16\pi^2} \times g_{\text{UV}}^4$

Bounds on $\frac{C_0}{\Lambda_{UV}^4} T^{\mu\nu}_{SM} T^{CFT}_{\mu\nu}$ – $(\Lambda_{IR}, \Lambda_{UV})$

Shaded regions are excluded at 95% probability



preliminary

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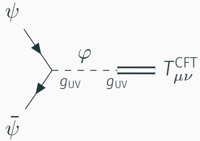

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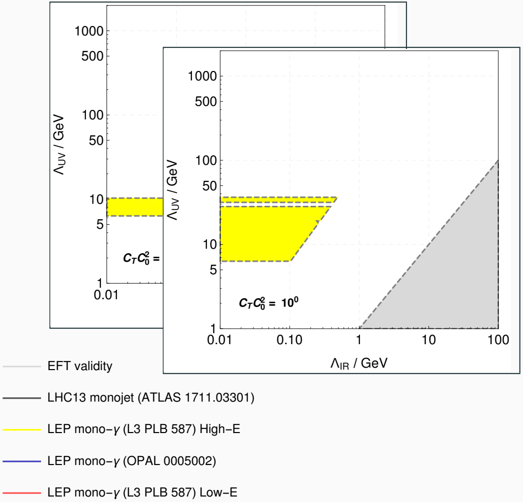

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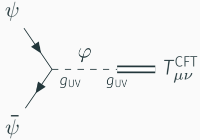

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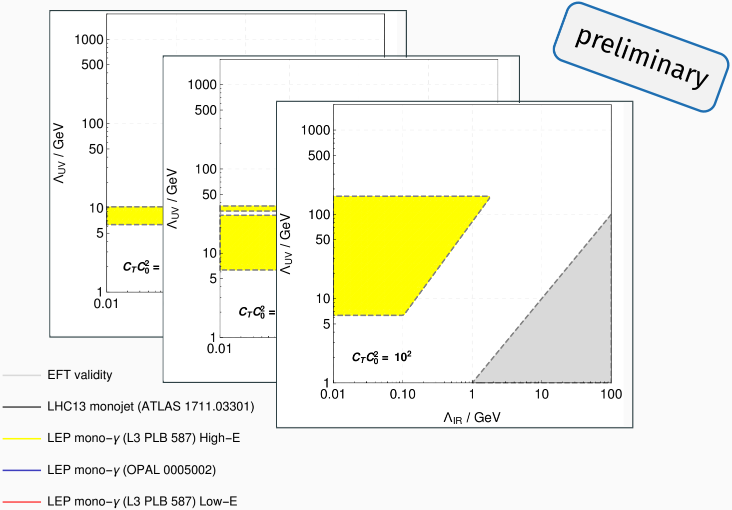

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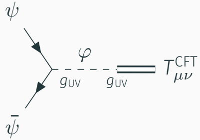

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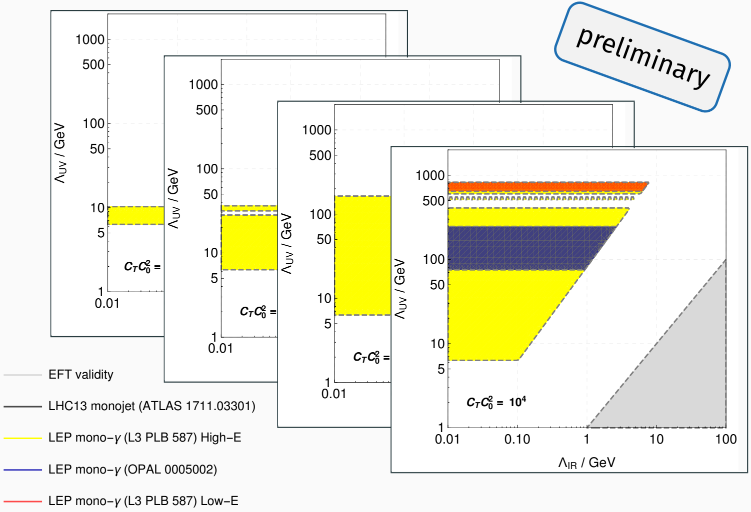

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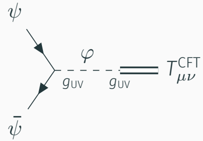

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Furthermore…

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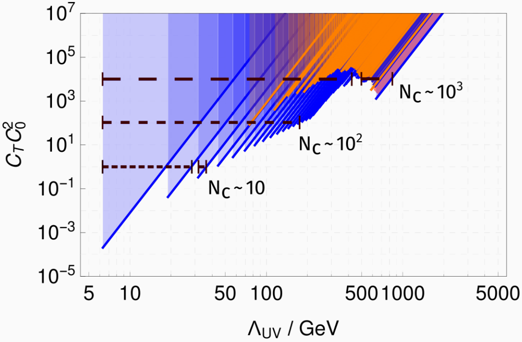
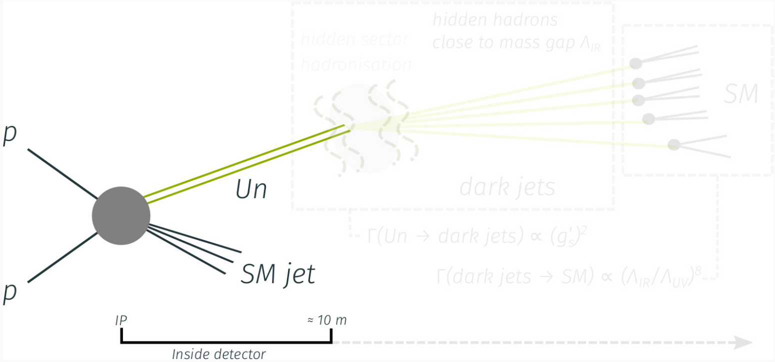
Excluded Λ_{UV}:

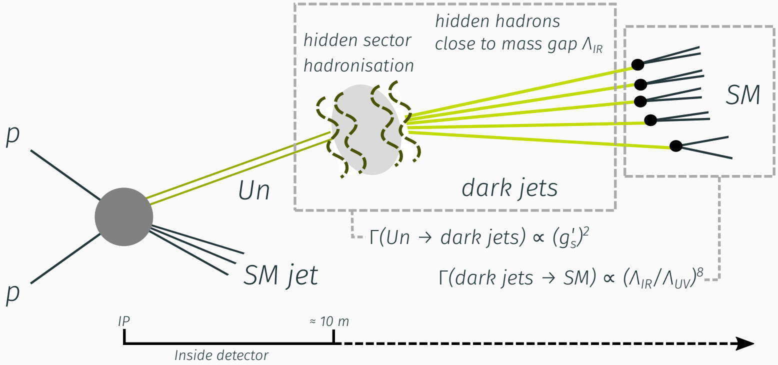


What we simulate



Hidden CFT as missing momentum at colliders

What we simulate vs. what we estimate:



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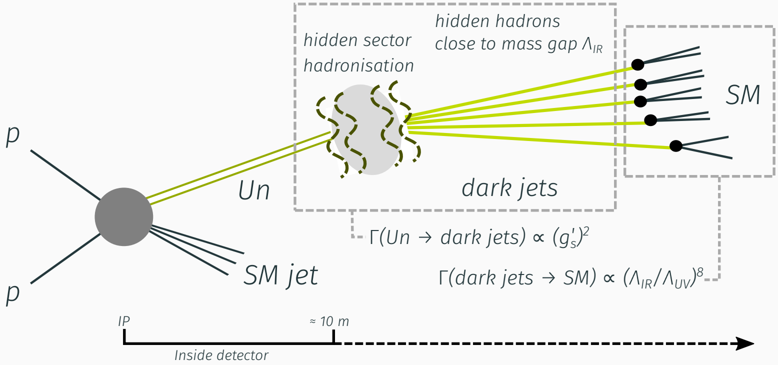

For $\not{\vec{p}}_T$ searches, estimate:

$$\Gamma(\text{lightest dark hadrons} \to \text{SM}) \approx \frac{1}{8\pi}\frac{\Lambda_{\text{IR}}^9}{\Lambda_{\text{UV}}^8} \gtrsim (10\text{m})^{-1}$$

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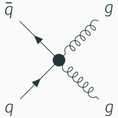
- lower (< 8)-dim. ops[a]?
- exotic jet signatures?
- stable hidden sector particles?



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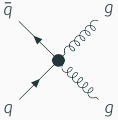

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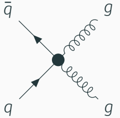

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- coupling only to $g/\gamma/q/l$? $\Rightarrow$ *work in progress*
- $\Lambda_{\rm IR} \approx \sqrt{S_{\rm LHC}}$ or $\sqrt{S_{\rm LEP}}$ $\Rightarrow$ ~~Unparticles~~ hidden valley
- CFT breaking operators, e.g. $|H|^2 \mathcal{O}$?
- $\Lambda_{\rm IR} \to 0$?

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Application to $\frac{C_0}{\Lambda_{\text{UV}}^4} T_{\text{SM}}^{\mu\nu} T_{\mu\nu}^{\text{CFT}}$

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with Lorentz index structure

$$\begin{aligned} P^{d_U}_{\mu\nu\rho\sigma}(p) = {} & d_U\,(d_U-1)\,(\eta_{\mu\rho}\eta_{\nu\sigma} + \mu \leftrightarrow \nu) + \frac{1}{2}\Big[4 - d_U(d_U+1)\Big]\eta_{\mu\nu}\eta_{\rho\sigma} \\ & - 2(d_U-1)(d_U-2)\left(\eta_{\mu\rho}\frac{p_\nu p_\sigma}{p^2} + \eta_{\mu\sigma}\frac{p_\nu p_\rho}{p^2} + \mu \leftrightarrow \nu\right) \\ & + 4(d_U-2)\left(\eta_{\mu\nu}\frac{p_\rho p_\sigma}{p^2} + \eta_{\rho\sigma}\frac{p_\mu p_\nu}{p^2}\right) + 8(d_U-2)(d_U-3)\frac{p_\mu p_\nu p_\rho p_\sigma}{(p^2)^2}\,. \end{aligned}$$

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Take away: not $(P_T)_{\mu\nu} = \eta_{\mu\nu} - \frac{p_\mu p_\nu}{p^2}$

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$$\lim_{d_U\to 4} \frac{\Gamma(2-d_U)}{4^{d_U-1}\Gamma(d_U+2)}(-p^2)^{d_U-2} \propto \lim_{\delta\to 0}\left[\frac{1}{\delta}+\text{const.}\right]\left[1+\delta\log(-p^2-i\epsilon)\right](p^2+i\epsilon)^2+\mathcal{O}(\delta).$$

Application to $\frac{C_0}{\Lambda_{\rm UV}^4} T^{\mu\nu}_{\rm SM}\, T^{\rm CFT}_{\mu\nu}$

We need the propagator $\langle 0|\mathcal{T}[T^{\rm CFT}_{\mu\nu}(p)T^{\rm CFT}_{\rho\sigma}(-p)]|0\rangle$.

→ From conformal symmetry (Grinstein et al. '08):

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⇒ local term $\partial^2\delta(x)$

⇒ finite piece:

$$\langle 0|\mathcal{T}[T^{\rm CFT}_{\mu\nu}(p)T^{\rm CFT}_{\rho\sigma}(-p)]|0\rangle = i\, C_T N_T\, P^4_{\mu\nu\rho\sigma}(p)\,(p^2+i\epsilon)^2\log(-p^2-i\epsilon) \qquad (3)$$

Statistics

Inputs:

- n_{BSM} (predicted @ $\Lambda_{\text{UV}} = 1$ TeV), n_{SM} (from data), n_{obs} for i different bins
- Parameters to optimise, here: Λ_{UV}
- Prior $\pi(\Lambda_{\text{UV}})$, here: $\pi(\Lambda_{\text{UV}}) = \Theta(\Lambda_{\text{UV}})$

Bayesian likelihood analysis:

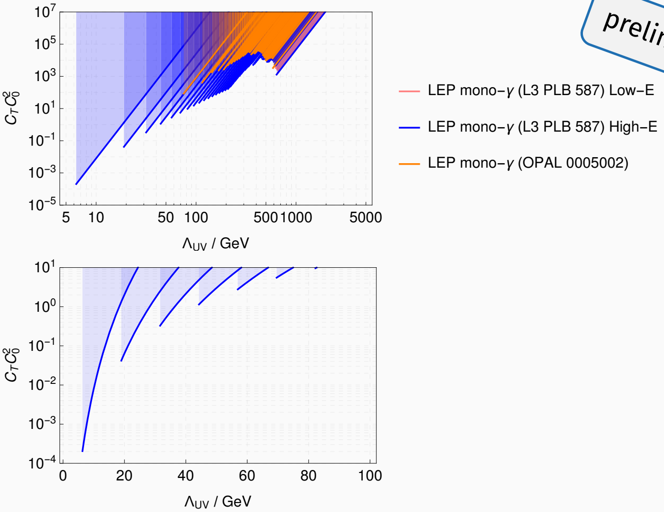
$$\underbrace{p(\Lambda_{\text{UV}}|n_{\text{obs}})}_{\text{Posterior prob.}} = \text{Norm} \cdot \underbrace{\Big(\prod_i L_i\Big)}_{\text{Likelihoods}} \cdot \pi(\Lambda_{\text{UV}}) \quad \text{w/} \quad L_i \equiv p(n^i_{\text{obs}}|\Lambda_{\text{UV}}) = \text{Poisson}\left(n^i_{\text{SM}} + \frac{n^i_{\text{BSM}}}{\Lambda^8_{\text{UV}}}, n^i_{\text{data}}\right)$$

$$0.95 \stackrel{!}{=} \int_{\Lambda^{95\%}_{\text{UV}}}^{\infty} d\Lambda_{\text{UV}}\, p(\Lambda_{\text{UV}}|n_{\text{obs}})$$

see *Bayesian reasoning in data analysis* by D'Agostini

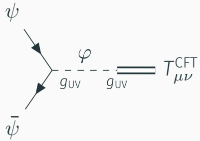
Bounds on $\frac{C_0}{\Lambda_{UV}^4} T^{\mu\nu}_{SM} T^{CFT}_{\mu\nu}$ – $(\Lambda_{UV}, C_T C_0^2)$

Shaded regions are excluded at 95% probability



preliminary

YM: $C_T \times C_0^2 \sim \frac{N_c^2}{16\pi^2} \times g_{UV}^4$



Bounds on $\frac{C_0}{\Lambda_{\rm UV}^4} T^{\mu\nu}_{\rm SM} T^{\rm CFT}_{\mu\nu}$ – $(\Lambda_{\rm UV}, C_T C_0^2)$

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