

Title: Where is M-theory?

Speakers: Andrea Guerrieri

Series: Quantum Fields and Strings

Date: March 14, 2023 - 2:00 PM

URL: <https://pirsa.org/23030105>

Abstract: I will use the S-matrix Bootstrap to carve out the space of unitary, crossing symmetric, and supersymmetric graviton scattering amplitudes in nine, ten, and eleven dimensions. I will introduce a novel extension of positivity for massless particles beyond the forward limit called "positivity in the sky" that significantly improves the convergence of the bootstrap algorithm.

I will show the bounds on the first leading correction to maximal supergravity, study the physics of the extremal amplitudes and compare them with the available nonperturbative String and M-theory results.

Zoom link: <https://pitp.zoom.us/j/99182927406?pwd=bWxIazFvUzhVQkpBdWluZURIM21wUT09>

$$A^{(2)} = \int d^D x \sqrt{g} \left[R + c_1 R^2 + c_2 R^3 + \underbrace{c_3 R^4}_{\text{...}} + \dots \right]$$

$$\text{max Susy} \quad c_2 = c_3 = 0$$

• crossing, unitarity, analyticity, $\lim_{s \rightarrow \infty} \frac{T(s, t \leq 0)}{|s|^2} = 0$

$$\underline{D=10} \quad \alpha \geq \alpha_{\min} = 0.13 \pm 0.02$$

$$\underline{D=10} \quad \underline{\alpha \geq \alpha_{\min} = 0.13 \pm 0.02}$$

Q: St. theory only U completion?

1) Precision

2) $D=9, 10, 11$

3) higher operators?

$$\bullet \underline{D \geq 5}$$

$$\bullet \underline{\max S_{\text{asy}}}$$

$$A_{z \rightarrow z}(s, t, u) = \left(R^4 A(s, t, u) \right) 8\pi G_N^{(D)}$$

$$A(s, t, u) = \frac{1}{stu} +$$

$$s' + t' + u'$$

$$s'$$

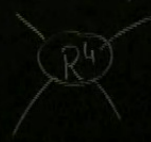
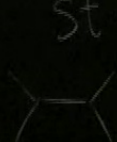
$$\bullet \underline{D \geq 5}$$

$$\bullet \underline{\text{max Susy}}$$

$$A_{z \rightarrow z}(s, t, u) = \underbrace{(\mathbb{R}^4)}_{s^4 + t^4 + u^4} A(s, t, u) 8\pi G_N^{(D)}$$

$$9 \leq D \leq 11$$

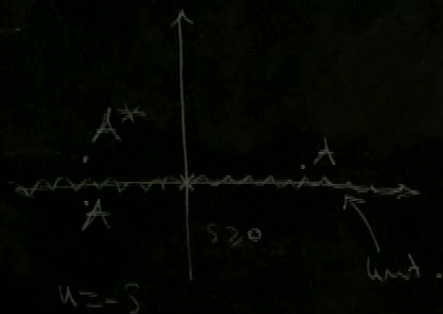
$$A(s, t, u) = \frac{1}{stu} + \alpha^{(D)} l_p^6 + f_1(s, t, u) + \beta^{(D)} l_p^{10} (s^2 + t^2 + u^2) + \mathcal{O}(s^{D/2-4} l_p^{D-2})$$



Analyticity

$t=0$

not analytic



$$D=10 \quad \alpha \geq \alpha_{\min} = 0.13 \pm 0.02$$

• Consistency ✓

• Unitarity :

$$2 \operatorname{Im}_s A_{2 \rightarrow 2} = \int dL_{\text{IPS}} \sum_{\text{susy}} A_{2 \rightarrow 2} \times A_{2 \rightarrow 2}^*$$

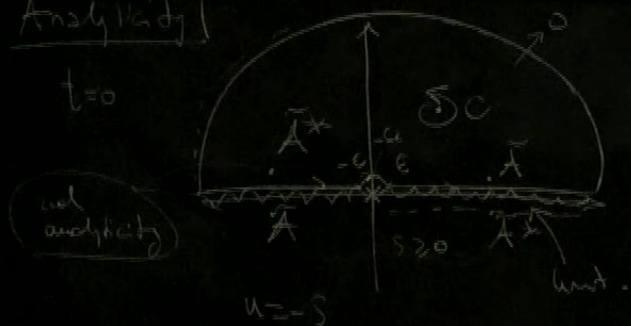
duplication formula

$$\sum_{\text{susy}} \mathbb{R}^4 \times \mathbb{R}^4 = \mathbb{S}^4 \mathbb{R}^4$$

$$2 \operatorname{Im}_r A(s, t, u) = \int dL_{\text{IPS}} \mathbb{S}^4 A \times A^*$$

Analyticity

$t=0$



$$\lim_{s \rightarrow \infty} \frac{T(s, t=0)}{|s|^2} = \lim_{s \rightarrow \infty} \frac{s^4 A(s, t=0)}{|s|^2} = 0$$

$$\tilde{A} = A - \frac{1}{s t u}$$

$$\text{Im} \tilde{A} = \text{Im} A$$

$$\frac{1}{2\pi i} \oint \frac{\tilde{A}(s, t=0)}{s} ds = 0$$

$$\frac{1}{2\pi i} \left(\int_{-\infty}^{-\epsilon} + \int_{\epsilon}^{\infty} \right) \frac{\tilde{A}(s, t=0)}{s} ds = \frac{1}{2\pi i} \int_{C_\epsilon} \frac{\tilde{A}}{s} ds$$

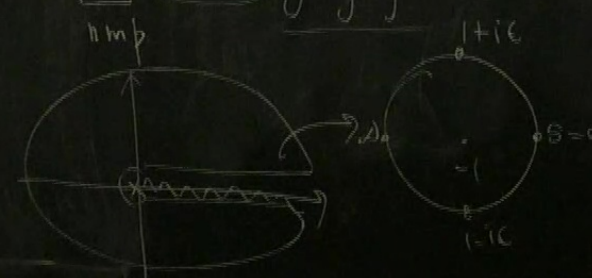
$$\alpha^{(0)} = \frac{2}{\pi} \int_0^\infty ds \frac{\text{Im} A(s, t=0)}{s} \geq 0$$

$$A = \frac{1}{s t u}$$

$\min \alpha^{(D)}$ (primal)

- 1) crossing + analytic ✓
- 2) impose numerically unitarity

$$1) A^{\text{ans}} = \frac{1}{s+u} + \sum_{nmp}^N \rho_s^n \rho_t^m \rho_u^p$$

$$\rho_s = \frac{1-\sqrt{-s}}{1+\sqrt{-s}}$$


$D=10$

$$S_e^{\text{ans}} = 1 + \frac{i s^3}{3 \times 2^{13} \pi^4} \int_{-1}^1 dz (1-z^2)^3 s^4 A(s, t(z))$$

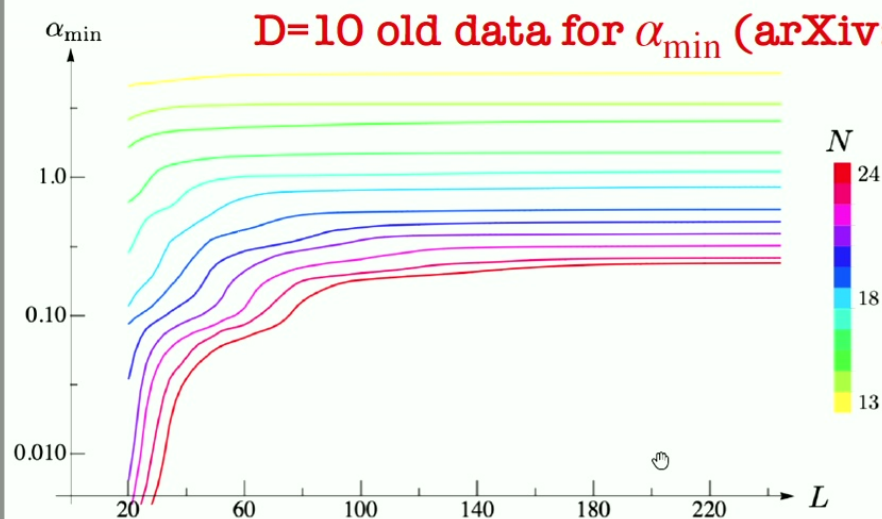
$$|S_e|^2 \leq 1 \quad f_e \quad (\forall L, \forall s > 0)$$

$$L = 100, 200, \dots$$

$$\text{Im} f_e \geq |f_e|^2 \geq 0$$

$$N, L \rightarrow \infty$$

$$N \rightarrow \infty$$

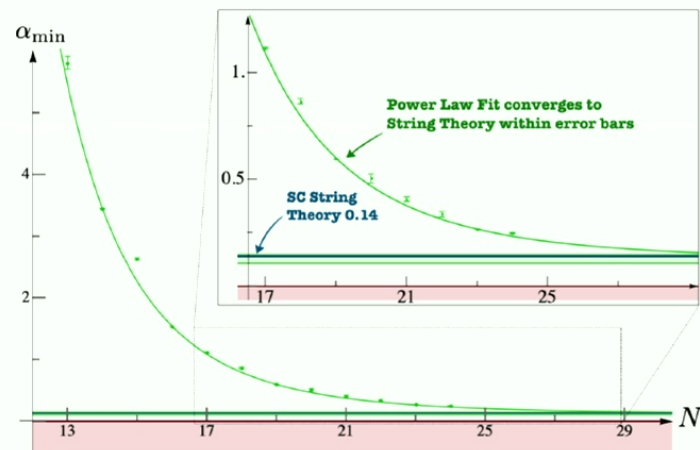


First we send the number of spin constraints to infinity
 $L \rightarrow \infty$

Adventurous extrapolation in N

$$\alpha \geq 0.13 \pm 0.02$$

$$\alpha^{ST} \gtrsim 0.14$$



Cerca 'Compilare'

Esporta PDF

Adobe Export PDF

Converti file PDF in Word o Excel online

Seleziona il file PDF

PI_Mar_14_23.pdf

Converti in

Microsoft Word (*.docx)

Lingua documento:

Italiano [Cambia](#)

Converti

Modifica PDF

Crea PDF

Commento

Combinare i file

Organizza pagine

Comprimi PDF

Redigere

Converti, modifica e firma elettronicamente moduli e contratti in PDF

Prova gratuita di 7 giorni

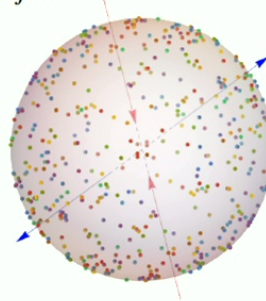
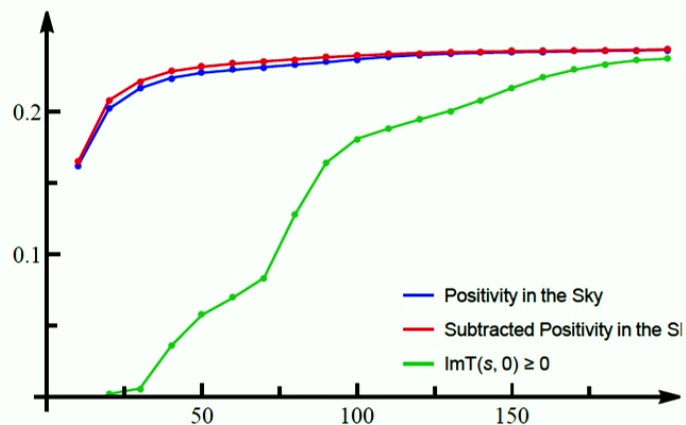


Positivity in the Sky

Going beyond positivity in the amplitudes of massless particles: $2 \operatorname{Im} \hat{T} = \hat{T}^\dagger \hat{T} \geq 0$

Consider a set of momentum eigenstates such that $p_i^2 = 0$ and $|\vec{p}_i| = \frac{\sqrt{s}}{2}$

Impose $\operatorname{Im} T(s, \cos \theta_{ij}) \geq 0$, where $\cos \theta_{ij} = \frac{p_i \cdot p_j}{|p_i| |p_j|}$



New Data Asymptotic
at L=60 vs L=200

Cerca 'Compilare'

Esporta PDF

Adobe Export PDF

Converti file PDF in Word o Excel online

Seleziona il file PDF

PI_Mar_14_23.pdf

Converti in

Microsoft Word (*.docx)

Lingua documento:

Italiano [Cambia](#)

Converti

Modifica PDF

Crea PDF

Commento

Combinate i file

Organizza pagine

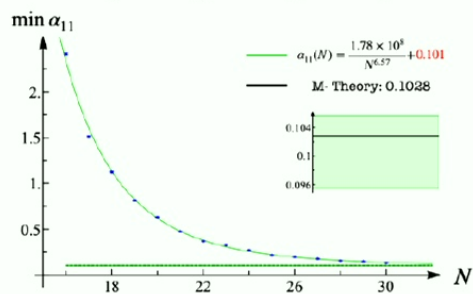
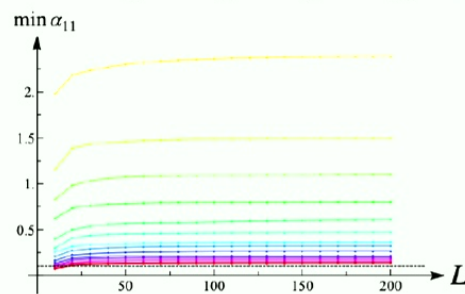
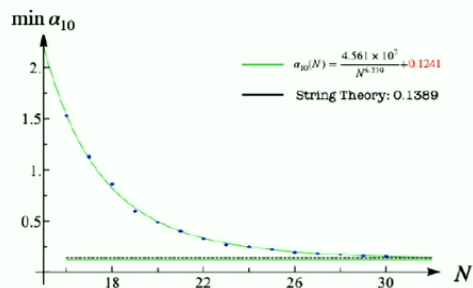
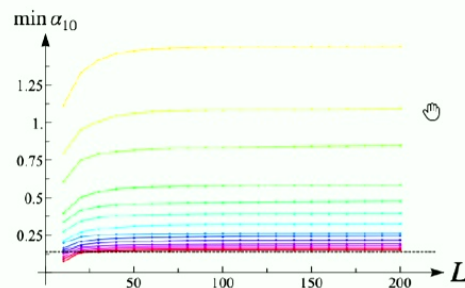
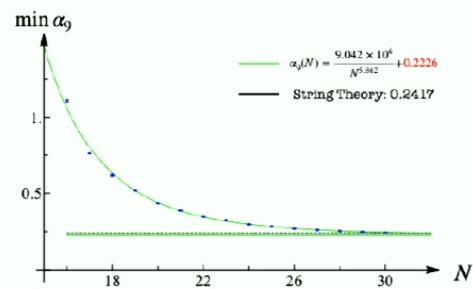
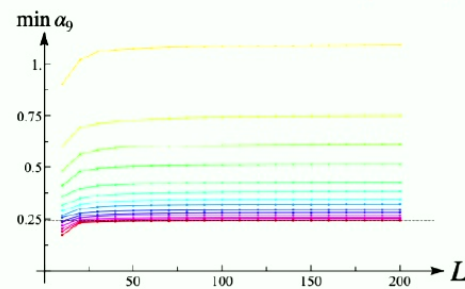
Comprimi PDF

Redigere

Converti, modifica e firma elettronicamente
moduli e contratti in PDF

Prova gratuita di 7 giorni

D=9,10,11 results



16 20 24 28 N

Cerca 'Compilare'

Esporta PDF

Adobe Export PDF

Converti file PDF in Word o Excel online

Seleziona il file PDF

PI_Mar_14_23.pdf

Converti in

Microsoft Word (*.docx)

Lingua documento:

Italiano [Cambia](#)

Converti

Modifica PDF

Crea PDF

Commento

Combinare i file

Organizza pagine

Comprimi PDF

Redigere

Converti, modifica e firma elettronicamente
moduli e contratti in PDF

Prova gratuita di 7 giorni

D=9,10,11 results summary

Dimension	Bootstrap	String/M-Theory
9	0.223 ± 0.002	0.241752
10	0.124 ± 0.003	0.138949
11	0.101 ± 0.005	0.102808

1) String Theory in 9, and 10 dimensions almost saturates the allowed region for α

Gap compatible with other UV completions?

Gap due to particle production?

2) α for M-theory is on the boundary of the allowed region, but no sign of an upper bound!

Cerca 'Compilare'

Esporta PDF

Adobe Export PDF

Converti file PDF in Word o Excel online

Seleziona il file PDF

PI_Mar_14_23.pdf

Converti in

Microsoft Word (*.docx)

Lingua documento:

Italiano [Cambia](#)

Converti

Modifica PDF

Crea PDF

Commento

Combinare i file

Organizza pagine

Comprimi PDF

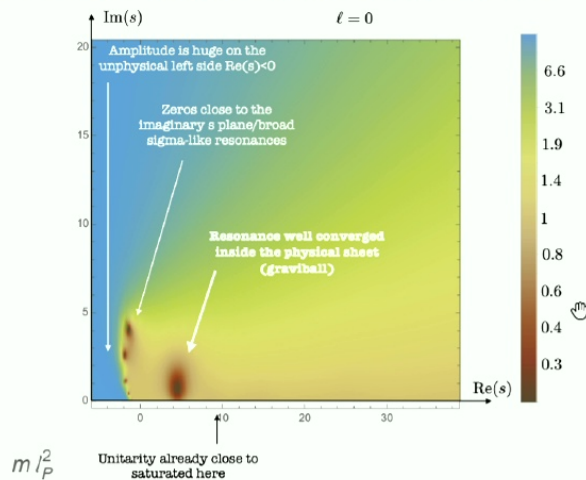
Redigere

Converti, modifica e firma elettronicamente moduli e contratti in PDF

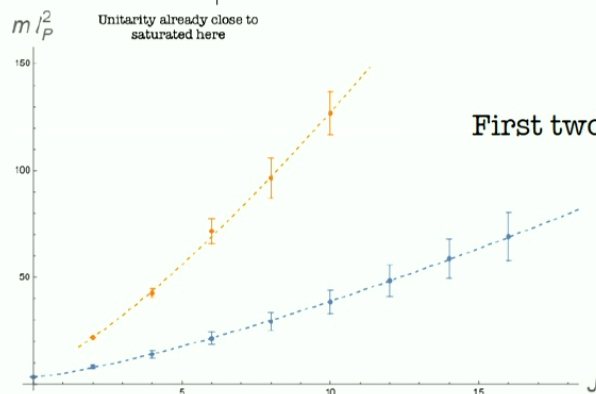
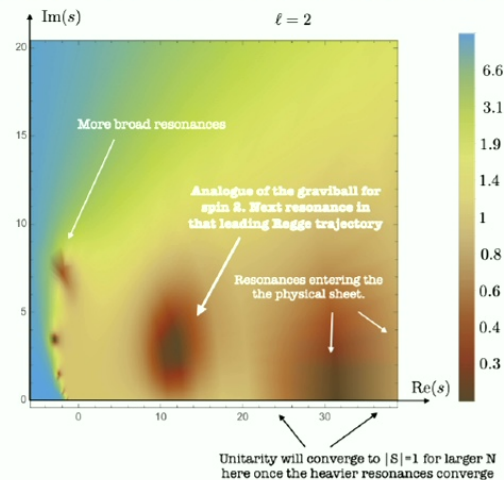
Prova gratuita di 7 giorni

Extremal amplitudes in the complex plane

- One single sharp resonance in the Spin-0



- Multiple resonances in the higher spins



First two Regge trajectories, well fitted by $s \sim J^{3/2}$

Cerca "Compilare"

Esporta PDF

Adobe Export PDF

Converti file PDF in Word o Excel online

Seleziona il file PDF

PI_Mar_14_23.pdf

Converti in

Microsoft Word (*.docx)

Lingua documento:

Italiano [Cambia](#)

Converti

Modifica PDF

Crea PDF

Commento

Combinare i file

Organizza pagine

Comprimi PDF

Redigere

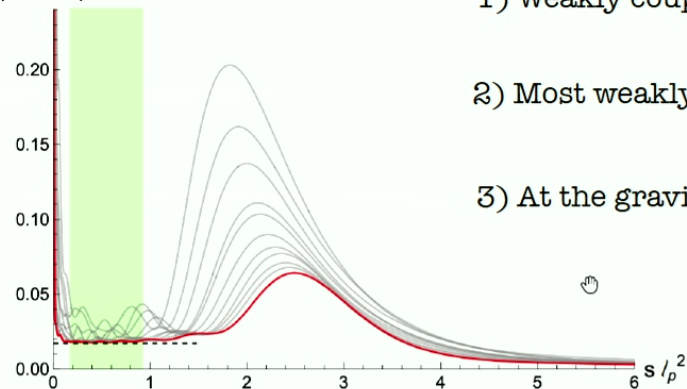
Converti, modifica e firma elettronicamente moduli e contratti in PDF

Prova gratuita di 7 giorni



EFT-ness and Low Spin Dominance

$$\frac{2}{\pi l_p^6} \frac{\text{Im} A(s, 0)}{s/l_p^2}$$

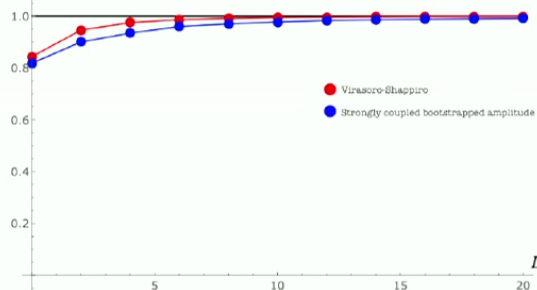


1) Weakly coupled EFT amplitude for $s \leq \frac{1}{\ell_p^2}$

2) Most weakly coupled UV completion of gravity

3) At the graviball scale we must see “new physics”

$$\frac{\alpha_{\text{truncated}}}{\alpha} = \frac{1}{\alpha} \sum_{l=0}^L \alpha^{(l)}$$



Spin-0 Dominance both for Virasoro-Shapiro and our nonperturbative amplitude

Cerca 'Compilare'

Esporta PDF

Adobe Export PDF

Converti file PDF in Word o Excel online

Seleziona il file PDF

PI_Mar_14_23.pdf

Converti in

Microsoft Word (*.docx)

Lingua documento:

Italiano [Cambia](#)

Converti

Modifica PDF

Crea PDF

Commento

Combinate i file

Organizza pagine

Comprimi PDF

Redigere

Converti, modifica e firma elettronicamente
moduli e contratti in PDF

Prova gratuita di 7 giorni



Effect of black-holes production

Start with the partial wave expansion

$$\alpha = \frac{16}{3\pi^4 \ell_P^{14}} \sum_l (l+1)_6 (2l+7) \int_0^\infty ds \frac{1 - \text{Re}(S_l(s))}{s^8}$$

$$1 - \text{Re}S_\ell \geq 1 - |S_\ell| \equiv 1 - \eta_\ell$$

Inelasticity definition

$$\alpha \geq \frac{16}{3\pi^4 \ell_P^{14}} \sum_\ell (\ell+1)_6 (2\ell+7) \int_0^\infty \frac{\eta_\ell(s)}{s^8} ds > 0$$

Analytic Lower bound

$$\eta = 1, \quad s \geq s_*(l)$$

$$b = R_s \implies s_*(l) \ell_P^2 = \left(\frac{2^6 l^7}{105 \pi^3} \right)^{1/4}$$

$$\alpha \gtrsim \frac{16}{3\pi^4 \ell_P^{14}} \sum_\ell (\ell+1)_6 (2\ell+7) \int_{s_*(\ell)}^\infty \frac{ds}{s^8}$$

Work in progress with L. Dixon, H. Murali, J. Penedones, and P. Vieira



Cerca 'Compilare'

Esporta PDF

Adobe Export PDF

Converti file PDF in Word o Excel online

Seleziona il file PDF

PI_Mar_14_23.pdf

Converti in

Microsoft Word (*.docx)

Lingua documento:

Italiano [Cambia](#)

Converti

Modifica PDF

Crea PDF

Commento

Combinare i file

Organizza pagine

Comprimi PDF

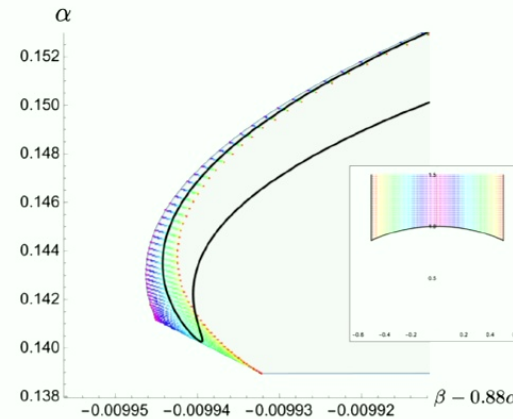
Redigere

Converti, modifica e firma elettronicamente
moduli e contratti in PDF

Prova gratuita di 7 giorni

Conclusions

- Look at higher dimensional operators



- Go to lower dimensions $5 \leq D \leq 8$, no string theory predictions. Other UV completions in lower dimensions?
- Including Black hole production
- **Dream**: D=5 gravity UV completions (no susy)

Cerca 'Compilare'

Esporta PDF

Adobe Export PDF

Converti file PDF in Word o Excel online

Seleziona il file PDF

PI_Mar_14_23.pdf

Converti in

Microsoft Word (*.docx)

Lingua documento:

Italiano [Cambia](#)

Converti

Modifica PDF

Crea PDF

Commento

Combinare i file

Organizza pagine

Comprimi PDF

Redigere

Converti, modifica e firma elettronicamente moduli e contratti in PDF

Prova gratuita di 7 giorni