CSW rules for massive matter legs and glue loops

Rutger Boels

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Loops and Legs in Quantum Field Theory

Based On

- R.B. and Christian Schwinn, arXiv:0712.3409 [hep-th]
- R.B. and Christian Schwinn, arXiv:0804.xxxx [hep-th]

What is this talk about?

- ... in Quantum Field Theory $\rightarrow$ fields, Lagrangians
- Lagrangians beat 'analytic S-matrix? ... because of symmetry
- how much of 'twistor inspired' ideas can one find from the Lagrangian?

CSW rules [Cachazo-Svrček-Witten, 04]

promote gluon MHV amplitudes to vertices for Feynman diagrams, take $p_{\dot{\alpha}} \rightarrow \eta^{\alpha} p_{\alpha\dot{\alpha}}$ + massless propagator

- literature: massless matter through susy, Higgs-glue couplings, vector boson currents
- calculates cut-constructable terms at loop level [Brandhuber-Spence-Travaglini]
- limited progress rational terms [RB, 07], [BST-Zoubos, 07], [Ettle-Fu-Fudger-Mansfield-Morris, 07]

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Lagrangian derivations of CSW rules - I

$$S = \frac{1}{2}\mathrm{Tr}\int_{\mathbb{R}^4} d^4x\, F_{\mu\nu}F^{\mu\nu}$$

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(derivation through modified momentum shifts [Risager, 05])

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canonical transformation [Mansfield, 05], [Gorsky-Rosly, 05]

- take lightcone Lagrangian,

$$L_{\mathrm{lc}} = A\bar{A} + AA\bar{A} + A\bar{A}\bar{A} + AA\bar{A}\bar{A}$$

- find canonical transformation s.t. $A\bar{A} + AA\bar{A} = B\bar{B}$
- explicit formulae $A(B)$, $\bar{A}(B, \bar{B})$ [Ettle-Morris, 06]
- $L_{\mathrm{new}} = B\bar{B} + "\bar{B}\bar{B}B's"$
- LSZ issue $\rightarrow$ equivalence theorem
- applied to $\mathcal{N} = 4$, Einstein gravity (4pt)

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Lagrangian derivations of CSW rules - II

$$S = \frac{1}{2}\mathrm{Tr}\int_{\mathbb{R}^4} d^4x\, F_{\mu\nu}F^{\mu\nu}$$

action on twistor space [Mason, 05]

- '$\int_{\mathbb{R}^4} \rightarrow \int_{\mathbb{CP}^3}$' (conformal group in 4d is $SU(4)$)
- Euclidean signature: $(x_{\alpha\dot{\alpha}}, \pi_{\dot{\alpha}}$?
- larger gauge symmetry $\rightarrow \exists$ more flexibility
- $L_{\mathrm{CSW\ gauge}} = B\bar{B} + "\bar{B}\bar{B}B's"$
- applied to $\mathcal{N} = 4$, selfdual $\mathcal{N} = 8$
- explicit formulae $A(B)$, $\bar{A}(B, \bar{B}) \rightarrow$ equivalence [RB, 07][RB - Schwinn, 08]

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Massive legs

- study massive scalars (susy: massive quarks and glue loops)
- transformation for mass-less scalars, eliminates $AA\bar{A} + \bar{\phi}A\phi$

$$V_{\text{CSW}}(\bar{B}_1, B_2, \ldots \bar{B}_i, \ldots, B_n) \sim \frac{\langle 1i \rangle^4}{\langle 12 \rangle \ldots \langle (n-1)n \rangle \langle n1 \rangle}$$

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$$: \xi\bar{\xi} :\sim \frac{1}{p^2 - m^2} \qquad : B\bar{B} :\sim \frac{1}{p^2}$$

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Applications

- less diagrams than ordinary Feyman diagrams
- reproduces known massive tree amplitudes ('all plus' satisfies BCFW)
- including the 3 point googly MHV from m^2 vertex (no equivalence theorem violations)
- 'localisation' of massive amplitudes in twistor space:

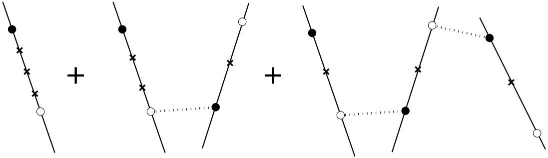

Figure: 2 massive scalars and 3 positive helicity gluons

- simple proof of BCFW recursion

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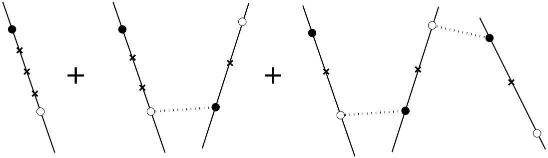

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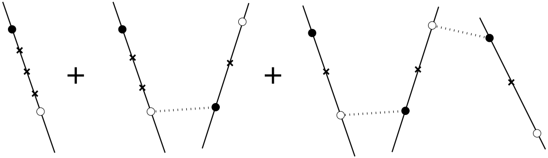

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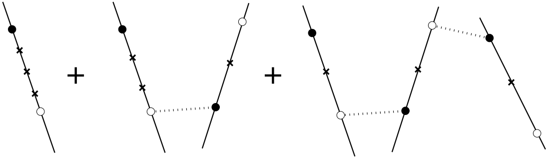

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Glue loops

- scalar loops calculate rational parts of pure glue amplitudes
- explicit check 4 point all-plus with massive scalar CSW rules. collinear/soft limits: all-plus (up to 5 point)
- all-minus $\rightarrow$ ordinary lightcone calculation
- all-plus and one minus integrand is proportional to $\mu^2 \rightarrow$ anomaly in conformal symmetry

A pure glue regulator

$$\mu^2 \bar{A}A \rightarrow \mu^2 \bar{B}B' \mathrm{s}$$

- resurrects Yang-Mills three tree amplitude (first LSZ, then $\mu^2 = 0$)
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Higgs-glue coupling

- top quark loop couples glue and Higgs, summarized by effective interaction:

$$S \sim \int HF^2 + AF\tilde{F} \sim \phi F_+^2 + \phi^\dagger F_-^2$$

- $\rightarrow \phi$-MHV amplitudes, CSW rules [Dixon-Glover-Khoze, 04]:

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- any matter through Noether procedure on twistor space, can do more general vertices (e.g. F_+^3)
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