Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

Simon Armstrong

Institute of Particle Physics Phenomenology, Durham University

January 14, 2016

Introduction 000 0	Tree Level 00	One Loop oo oooo	Rational Parts 00	Conclusions O







Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

Introduction 000 0	Tree Level 00	One Loop oo o oooo	Rational Parts 00	Conclusions O



2 Tree Level - BCFW Recursion Relation

Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

Introduction 000 0	Tree Level 00	One Loop oo o oooo	Rational Parts 00	Conclusions O



- 2 Tree Level BCFW Recursion Relation
- 3 One Loop Generalised Unitarity

Introduction	Tree Level	One Loop	Rational Parts	Conclusions
		00 0 0000		



- 2 Tree Level BCFW Recursion Relation
- 3 One Loop Generalised Unitarity

4 Rational Parts

Introduction	Tree Level	One Loop	Rational Parts	Conclusions
		0000		



- 2 Tree Level BCFW Recursion Relation
- 3 One Loop Generalised Unitarity
- 4 Rational Parts



Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

<ロ> < 部> < 語 > < 語 > < 語 > < 部 > < の < の </p>

Introduction ●○○ ○	Tree Level 00	One Loop 00 00000	Rational Parts 00	Conclusions O
Motivation				

Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

うんら 正則 スポット 小田 > スピ > シック

IPPP

Introduction ●○○ ○	Tree Level 00	One Loop oo oooo	Rational Parts 00	Conclusions O
Motivation				



- Why loops?
 - Amplitudes and effects that first appear at NLO
 - More precise theory predictions
 - ...

<ロ> < 部> < 語 > < 語 > < 語 > < 部 > < の < の </p>

Introduction ●○○ ○	Tree Level 00	One Loop 00 00000	Rational Parts 00	Conclusions O
Motivation				



- Why loops?
 - Amplitudes and effects that first appear at NLO
 - More precise theory predictions
 - ...
- Why high multiplicity?
 - Important at LHC where lots of Jets is normal
 - Important background to other processes

(▲ ■) ▲ ■) ▲ (■

< 17 >

Introduction	Tree Level	One Loop	Rational Parts	Conclusions
000 0		00 0 0000		
Motivation				

For tree level and low multiplicity - nothing!

(ロ) (日) (日) (日) (日) (日) (日)

Introduction ○●○ ○	Tree Level 00	One Loop 00 0 0000	Rational Parts 00	Conclusions O
Motivation				

For tree level and low multiplicity - nothing!

But even then not the most efficient representation
 e.g. 4 gluon amplitude
 Parke-Taylor
 Feynman Rules

$$\frac{\langle 13\rangle^4}{\langle 12\rangle\langle 23\rangle\langle 34\rangle\langle 41\rangle} \begin{pmatrix} \epsilon_1^{\mu}\epsilon_2^{\nu}\epsilon_3^{\sigma}\epsilon_4^{\rho}\frac{-i\eta^{\alpha\beta}}{(p_1+p_2)^2} \\ (\eta_{\mu\nu}(p_1-p_2)_{\alpha}-2\eta_{\nu\alpha}p_{2\mu}+2\eta_{\alpha\mu}p_{1\nu}) \\ (\eta_{\sigma\rho}(p_3-p_4)_{\beta}-2\eta_{\rho\beta}p_{4\sigma}+2\eta_{\beta\sigma}p_{3\rho})+\dots \end{pmatrix}$$

▲口▶ ▲圖▶ ▲臣▶ ▲臣▶ 토目 わえの

Introduction O●O ○	Tree Level 00	One Loop OO OOOO	Rational Parts 00	Conclusions O
Motivation				

- For tree level and low multiplicity nothing!
- But even then not the most efficient representation
 e.g. 4 gluon amplitude
 Parko Taulor

$$\frac{\langle 13\rangle^4}{\langle 12\rangle\langle 23\rangle\langle 34\rangle\langle 41\rangle} \begin{pmatrix} \epsilon_1^{\mu}\epsilon_2^{\nu}\epsilon_3^{\sigma}\epsilon_4^{\rho}\frac{-i\eta^{\alpha\beta}}{(\rho_1+\rho_2)^2} \\ (\eta_{\mu\nu}(\rho_1-\rho_2)_{\alpha}-2\eta_{\nu\alpha}p_{2\mu}+2\eta_{\alpha\mu}p_{1\nu}) \\ (\eta_{\sigma\rho}(\rho_3-\rho_4)_{\beta}-2\eta_{\rho\beta}p_{4\sigma}+2\eta_{\beta\sigma}p_{3\rho})+\dots \end{pmatrix}$$

■ For more particles number of terms and complexity increases very quickly (*n*!)

Introduction	Tree Level	One Loop	Rational Parts	Conclusions
0 00 0		00 0 0000		
Motivation				

- For tree level and low multiplicity nothing!
- But even then not the most efficient representation
 e.g. 4 gluon amplitude
 Parke-Taylor
 Feynman Rules

 $\frac{\langle 13\rangle^4}{\langle 12\rangle\langle 23\rangle\langle 34\rangle\langle 41\rangle} \begin{pmatrix} \epsilon_1^{\mu}\epsilon_2^{\nu}\epsilon_3^{\sigma}\epsilon_4^{\rho}\frac{-i\eta^{\alpha\beta}}{(p_1+p_2)^2} \\ (\eta_{\mu\nu}(p_1-p_2)_{\alpha}-2\eta_{\nu\alpha}p_{2\mu}+2\eta_{\alpha\mu}p_{1\nu}) \\ (\eta_{\sigma\rho}(p_3-p_4)_{\beta}-2\eta_{\rho\beta}p_{4\sigma}+2\eta_{\beta\sigma}p_{3\rho}) + \dots \end{pmatrix}$

- For more particles number of terms and complexity increases very quickly (*n*!)
- For loops we have to do an integral over the remaining loop momenta

Introduction	Tree Level	One Loop	Rational Parts	Conclusions
0 0 0 0		00 0 0000		
Motivation				

- For tree level and low multiplicity nothing!
- But even then not the most efficient representation
 e.g. 4 gluon amplitude
 Parke-Taylor
 Feynman Rules

 $\frac{\langle 13\rangle^4}{\langle 12\rangle\langle 23\rangle\langle 34\rangle\langle 41\rangle} \begin{pmatrix} \epsilon_1^{\mu}\epsilon_2^{\nu}\epsilon_3^{\sigma}\epsilon_4^{\rho}\frac{-i\eta^{\alpha\beta}}{(p_1+p_2)^2} \\ (\eta_{\mu\nu}(p_1-p_2)_{\alpha}-2\eta_{\nu\alpha}p_{2\mu}+2\eta_{\alpha\mu}p_{1\nu}) \\ (\eta_{\sigma\rho}(p_3-p_4)_{\beta}-2\eta_{\rho\beta}p_{4\sigma}+2\eta_{\beta\sigma}p_{3\rho}) + \dots \end{pmatrix}$

- For more particles number of terms and complexity increases very quickly (*n*!)
- For loops we have to do an integral over the remaining loop momenta
- Why is it so bad?

토▶ ▲토▶ 토|= •9<0

Introduction ○○● ○	Tree Level 00	One Loop 00 00000	Rational Parts 00	Conclusions O
Motivation				

Only work with on-shell amplitudes

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

Introduction ○○● ○	Tree Level 00	One Loop oo oooo	Rational Parts 00	Conclusions O
Motivation				

- Only work with on-shell amplitudes
- Build bigger and higher loop amplitudes from smaller amplitudes

<回> < E> < E> < E = 900</p>

Introduction ○○● ○	Tree Level 00	One Loop oo oooo	Rational Parts 00	Conclusions O
Motivation				

- Only work with on-shell amplitudes
- Build bigger and higher loop amplitudes from smaller amplitudes
- Generalised Unitarity to build one loop amplitudes from tree amplitudes

|▲□ ▶ ▲ 臣 ▶ ▲ 臣 ▶ 三日 = つへの

Introduction ○○● ○	Tree Level 00	One Loop oo oooo	Rational Parts 00	Conclusions O
Motivation				

- Only work with on-shell amplitudes
- Build bigger and higher loop amplitudes from smaller amplitudes
- Generalised Unitarity to build one loop amplitudes from tree amplitudes
- BCFW Recursion Relations to build the tree amplitudes from smaller known amplitudes

< 17 ▶

Introduction	Tree Level	One Loop	Rational Parts	Conclusions
000 •		00 0 0000		
Terminology		0000		

Spinor Helicity Formalism

Helicity Spinors

•
$$u_{\pm}(k) = P^{\pm}u(k) = \frac{1\pm\gamma_5}{2}u(k)$$

• $v_{\mp}(k) = P^{\pm}v(k) = \frac{1\pm\gamma_5}{2}v(k)$

Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

· 《 문 》 《 문 》 《 문 》 토 님 · 이 Q ()

Introduction	Tree Level	One Loop	Rational Parts	Conclusions
000	00	00 0 0000	00	
Terminology				

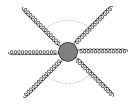
Spinor Helicity Formalism

Helicity Spinors $u_{\pm}(k) = P^{\pm}u(k) = \frac{1\pm\gamma_5}{2}u(k)$ $v_{\mp}(k) = P^{\pm}v(k) = \frac{1\pm\gamma_5}{2}v(k)$ Spinor Helicity Formalism $u^+(k_i) = v^-(k_i) \equiv |k_i^+\rangle \equiv |i\rangle$ $u^-(k_i) = v^+(k_i) \equiv |k_i^-\rangle \equiv |i|$ $\bar{u}^+(k_i) = \bar{v}^-(k_i) \equiv \langle k_i^+ | \equiv [i|$ $\bar{u}^-(k_i) = \bar{v}^+(k_i) \equiv \langle k_i^- | \equiv \langle i |$

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

《口》《聞》《臣》《臣》 王言 わらの

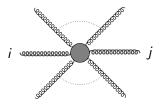
	Tree Level	One Loop	Rational Parts	Conclusions
	00	00 0 0000		
BCEW Recursion Rel:	ation			



Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

	Tree Level	One Loop	Rational Parts	Conclusions
	•0	00 0 0000		
BCEW Recursion Rela	ation			

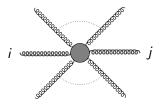


•
$$k_i^{\mu} \rightarrow k_i^{\mu} + z \cdot n^{\mu}, \ k_j^{\mu} \rightarrow k_j^{\mu} - z \cdot n^{\mu}$$

Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

	Tree Level	One Loop	Rational Parts	Conclusions
	•0	00 0 0000		
BCEW Recursion Rela	ation			

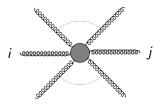


$$k_i^{\mu} \to k_i^{\mu} + z \cdot n^{\mu}, \ k_j^{\mu} \to k_j^{\mu} - z \cdot n^{\mu}$$
$$n^{\mu} \sim [i|\gamma^{\mu}|j\rangle$$

Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

	Tree Level	One Loop	Rational Parts	Conclusions
	•0	00 0 0000		
BCEW Recursion Rela	ation			



$$k_i^{\mu} \rightarrow k_i^{\mu} + z \cdot n^{\mu}, \ k_j^{\mu} \rightarrow k_j^{\mu} - z \cdot n^{\mu}$$

$$n^{\mu} \sim [i|\gamma^{\mu}|j\rangle$$

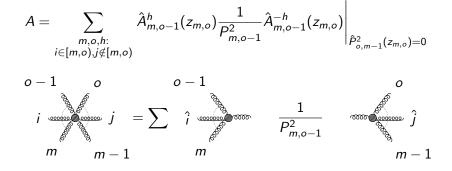
$$|i\rangle \rightarrow |i\rangle + z |j\rangle, \ |j] \rightarrow |j] - z |i]$$

Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

	Tree Level	One Loop	Rational Parts	Conclusions
000	00			

BCFW Recursion Relation



Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

Introduction 000 0	Tree Level 00	One Loop ●0 ○ ○○○○	Rational Parts 00	Conclusions O
Generalised Unitarity				
Generalise	d Unitarity			

We can write a one loop amplitude in terms of a set of basis integrals

★ 돈 ▶ 돈 돈 ♡ < @</p>

→ 伊ト → 三ト

Introduction 000 0	Tree Level 00	One Loop ●O ○ ○○○○	Rational Parts 00	Conclusions O
Generalised Unitarity				

We can write a one loop amplitude in terms of a set of basis integrals

$$\sum_{i}^{b_{i}} = \sum_{i} d_{i} + \sum_{i} c_{i} + \sum_{i} b_{i} + \sum_{i} a_{i}$$

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

○ ▲ 토 ▲ 토 ▲ 토 ★

< 17 ▶

< 2 →

Introduction 000 0	Tree Level 00	One Loop ●O ○ ○○○○	Rational Parts 00	Conclusions O
Generalised Unitarity				

We can write a one loop amplitude in terms of a set of basis integrals

$$\sum_{i}^{\infty} d_{i} + \sum_{i} c_{i} + \sum_{i} b_{i} + \sum_{i} a_{i}$$

 Scalar basis functions: Boxes, Triangles, Bubbles & Tadpoles (I ignore tadpoles as I have massless internal particles)

Introduction 000 0	Tree Level 00	One Loop O● 00000	Rational Parts 00	Conclusions O
Generalised Unitarity				

Extract coefficients with Generalised Unitarity

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

Introduction 000 0	Tree Level 00	One Loop O● 00000	Rational Parts 00	Conclusions O
Generalised Unitarity				

- Extract coefficients with Generalised Unitarity
- Cut the amplitudes on 4, 3 and 2 propagators.

$$rac{1}{l_i^2} o \delta(l_i^2)$$
 according to the construction of the

〇戶 비로 《王》《王》 《国》 (個)

Introduction 000 0	Tree Level 00	One Loop ○ ○ ○○○○	Rational Parts 00	Conclusions O
Generalised Unitarity				

- Extract coefficients with Generalised Unitarity
- Cut the amplitudes on 4, 3 and 2 propagators.

$$rac{1}{l_i^2} o \delta(l_i^2)$$
 accomposition o accomposition o

Cuts select out a specific basis integral

I = | = | = <0 < 0</p>

3 ×

Introduction 000 0	Tree Level 00	One Loop ○ ○ ○○○○	Rational Parts 00	Conclusions O
Generalised Unitarity				

- Extract coefficients with Generalised Unitarity
- Cut the amplitudes on 4, 3 and 2 propagators.

$$rac{1}{l_i^2} o \delta(l_i^2)$$
 according to the second seco

- Cuts select out a specific basis integral
- For more than two cuts need complex momenta

I = | = | = <0 < 0</p>

3 ×

Introduction 000 0	Tree Level 00	One Loop ○○ ● ○○○○○	Rational Parts 00	Conclusions O
Box Coefficients				

Box Coefficients

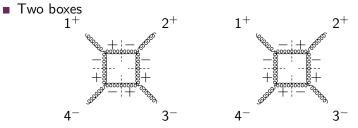
• 4 gluon amplitude
$$A(g^+g^+g^-g^-)$$

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

	Tree Level	One Loop	Rational Parts	Conclusions
		00		
Box Coefficients				

Box Coefficients

• 4 gluon amplitude $A(g^+g^+g^-g^-)$



Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

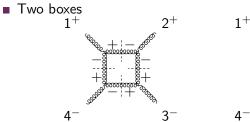
문제 문제

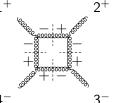
< 🗇 →

	Tree Level	One Loop	Rational Parts	Conclusions
000		00		
		0000		
Box Coefficients				

Box Coefficients

• 4 gluon amplitude $A(g^+g^+g^-g^-)$





< P.

1]

문어 문

Momentum Solutions

$$(l_1^+)^{\mu} = \frac{\langle 1|2\,3\,4\,\gamma^{\mu}|1\rangle}{2\,\langle 1|2\,4|1\rangle} \qquad (l_1^-)^{\mu} = \frac{[1|2\,3\,4\,\gamma^{\mu}}{2\,[1|2\,4|1\rangle}$$

Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

	Tree Level	One Loop	Rational Parts	Conclusions
000		00		
		0000		
Triangle Coefficients				

Triangle Coefficients

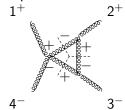
Ten triangles

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

<ロ> < 部> < 語 > < 語 > < 語 > < 部 > < の < の </p>

	Tree Level	One Loop	Rational Parts	Conclusions
		00 0 0000		
Triangle Coefficients				

- Ten triangles
- Choose one as an example



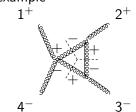
Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

문어 문제

< 🗇 →

	Tree Level	One Loop	Rational Parts	Conclusions
		00 0 0000		
Triangle Coefficients				

- Ten triangles
- Choose one as an example



• One free degree of freedom in loop momentum, t

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

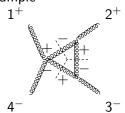
< 17 ▶

-

문제 문제

	Tree Level	One Loop	Rational Parts	Conclusions
		00 0000		
Triangle Coefficients				

- Ten triangles
- Choose one as an example



- One free degree of freedom in loop momentum, t
- Solve by choosing a basis of \tilde{k}_1^{μ} , \tilde{k}_3^{μ} , $n_1^{\mu} = \frac{1}{2} \left\langle \tilde{k}_1 | \gamma^{\mu} | \tilde{k}_3 \right]$ and $n_3^{\mu} = \frac{1}{2} \left\langle \tilde{k}_3 | \gamma^{\mu} | \tilde{k}_1 \right]$

Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

	Tree Level	One Loop	Rational Parts	Conclusions
000				
		0000		
Triangle Coefficients				

Solutions for with massless corners

$$(l_1^+)^{\mu} = -\frac{K_3^2}{K_3 \cdot k_1} k_1^{\mu} + t n_1^{\mu} \quad (l_1^-)^{\mu} = -\frac{K_3^2}{K_3 \cdot k_1} k_1^{\mu} + \frac{1}{t} n_3^{\mu}$$

	Tree Level	One Loop	Rational Parts	Conclusions
		o o●oo		
Triangle Coefficients				

Solutions for with massless corners

$$(l_1^+)^{\mu} = -\frac{K_3^2}{K_3 \cdot k_1} k_1^{\mu} + t n_1^{\mu} \quad (l_1^-)^{\mu} = -\frac{K_3^2}{K_3 \cdot k_1} k_1^{\mu} + \frac{1}{t} n_3^{\mu}$$

$$\begin{aligned} \left\langle l_{1}^{+} \right| &= \left\langle k_{1} \right| & \left\langle l_{1}^{-} \right| &= -\frac{K_{3}^{2}}{K_{3} \cdot k_{1}} \left\langle k_{1} \right| + \frac{1}{t} \left\langle \tilde{k}_{3} \right| \\ \left[l_{1}^{+} \right] &= -\frac{K_{3}^{2}}{K_{3} \cdot k_{1}} \left[k_{1} \right] + t \left[\tilde{k}_{3} \right] & \left[l_{1}^{-} \right] &= \left[k_{1} \right] \end{aligned}$$

Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

000 00 00 00 0	
Ŭ õ€oo	
Triangle Coefficients	

Solutions for with massless corners

$$(l_1^+)^\mu = -rac{K_3^2}{K_3 \cdot k_1}k_1^\mu + tn_1^\mu$$

$$egin{aligned} &\langle l_1^+ ig| = \langle k_1 ig| \ & \left[l_1^+ ig| = -rac{\mathcal{K}_3^2}{\mathcal{K}_3 \cdot k_1} \left[k_1
ight] + t \left[ilde{\mathcal{K}}_3
ight] \end{aligned}$$

Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

Introduction 000 0	Tree Level 00	One Loop ○○ ○○○○○	Rational Parts 00	Conclusions O
Triangle Coefficients				
-	<i>cc</i>			

Get Function of *t* for the product of the amplitudes

	Tree Level	One Loop	Rational Parts	Conclusions
000				
		0000		
Triangle Coefficients				

- Get Function of t for the product of the amplitudes
- Form is

$$C_{3}(t) = A_{1}A_{2}A_{3}|_{t=t}$$
$$= c_{-3}t^{-3} + c_{-2}t^{-2} + c_{-1}t^{-1} + c_{0} + c_{1}t + c_{2}t^{2} + c_{3}t^{3}$$

●●● ●■ ●●● ●●● ● ● ● ● ●●●

	Tree Level	One Loop	Rational Parts	Conclusions
000				
		0000		
Triangle Coefficients				

- Get Function of *t* for the product of the amplitudes
- Form is

1

$$C_{3}(t) = A_{1}A_{2}A_{3}|_{I=I(t)}$$

= $c_{-3}t^{-3} + c_{-2}t^{-2} + c_{-1}t^{-1} + c_{0} + c_{1}t + c_{2}t^{2} + c_{3}t^{3}$

	Tree Level	One Loop	Rational Parts	Conclusions
000				
		0000		
Triangle Coefficients				

- Get Function of *t* for the product of the amplitudes
- Form is

$$C_{3}(t) = A_{1}A_{2}A_{3}|_{I=I(t)}$$

= $c_{-3}t^{-3} + c_{-2}t^{-2} + c_{-1}t^{-1} + c_{0} + c_{1}t + c_{2}t^{2} + c_{3}t^{3}$

- Triangle coefficient is *c*₀
- Extract using either contour integration or discrete Fourier projection

$$c_0 = \frac{1}{2\pi i} \oint \frac{dt}{t} C_3(t) = \frac{1}{2p+1} \sum_{j=-p}^{p} C_3(t_0 e^{2\pi i j/(2p+1)})$$

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

Introduction 000	Tree Level 00	One Loop ००	Rational Parts 00	Conclusions
		° 000●		
Triangle Coefficients				

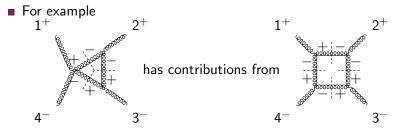
Box Substraction for Triangle Coefficients

 Most triangles have extra poles in t due to contributions from boxes

Introduction 000 0	Tree Level 00	One Loop ○○ ○○○○	Rational Parts 00	Conclusions O
Triangle Coefficients				
			.	



 Most triangles have extra poles in t due to contributions from boxes



Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

≺ 문 ≻ 문

Introduction 000 0	Tree Level 00	One Loop oo oooo	Rational Parts ●0	Conclusions O
Rational Parts				
Is that all?)			

Is that everything?

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

- ▲ @ ▶ - ▲ 臣

Introduction 000 0	Tree Level 00	One Loop oo oooo	Rational Parts ●0	Conclusions O
Rational Parts				
Is that all?				

- Is that everything?
- Sadly not In 4D some terms don't have any cuts and so aren't accessible.

○오오 비로 《로》 《토》 《□ 》 ○

Introduction 000 0	Tree Level 00	One Loop oo oooo	Rational Parts ●0	Conclusions O
Rational Parts				
Is that all?)			

- Is that everything?
- Sadly not In 4D some terms don't have any cuts and so aren't accessible.
- Work in more than 4 dimensions?

○오오 비로 《로》 《토》 《□ 》 ○

Introduction 000 0	Tree Level 00	One Loop oo oooo	Rational Parts ●0	Conclusions O
Rational Parts				
Is that all?				

- Is that everything?
- Sadly not In 4D some terms don't have any cuts and so aren't accessible.
- Work in more than 4 dimensions?
- Hard.

	Tree Level	One Loop	Rational Parts	Conclusions
		00 0 0000	0•	
Rational Parts				

Want to remain numeric so need well defined spinors

Introduction 000 0	Tree Level 00	One Loop 00 0000	Rational Parts ○●	Conclusions O
Rational Parts		0000		

Want to remain numeric so need well defined spinors -6,8,10,... dimensions

Introduction 000 0	Tree Level 00	One Loop oo oooo	Rational Parts 0●	Conclusions O
Rational Parts				

- Want to remain numeric so need well defined spinors -6,8,10,... dimensions
- Only actually need one fixed dimension then can extrapolate down with known forms of dependence on d.

Introduction 000 0	Tree Level 00	One Loop oo oooo	Rational Parts 0●	Conclusions O
Rational Parts				

- Want to remain numeric so need well defined spinors -6,8,10,... dimensions
- Only actually need one fixed dimension then can extrapolate down with known forms of dependence on d.
- Can simply and write in terms of massive 4 dimensional spinors.

	Tree Level	One Loop	Rational Parts	Conclusions
		00 0 0000	00	
Rational Parts				

- Want to remain numeric so need well defined spinors -6,8,10,... dimensions
- Only actually need one fixed dimension then can extrapolate down with known forms of dependence on d.
- Can simply and write in terms of massive 4 dimensional spinors.
- Can show that tree amplitudes depend on the phase of the mass in a very well defined way
 - Loop amplitudes can't depend on phase
 - Can remove a degree of freedom

Introduction 000 0	Tree Level 00	One Loop oo oooo	Rational Parts 00	Conclusions •
Conclusions				
Conclusio	าร			

We have efficient ways of calculating tree level, one loop cut parts and rational terms and therefore the complete one loop amplitude

↓ ∃ | = | < ∩ Q ∩</p>

< 17 >

3 ×

Introduction 000 0	Tree Level 00	One Loop oo oooo	Rational Parts 00	Conclusions •
Conclusions				
Conclusio	ns			

- We have efficient ways of calculating tree level, one loop cut parts and rational terms and therefore the complete one loop amplitude
- Tree and cut parts extend to interactions with the Higgs Boson easily

I = | = | = √Q(0)

Introduction 000 0	Tree Level 00	One Loop oo oooo	Rational Parts 00	Conclusions •
Conclusions				
Conclusion	nc			

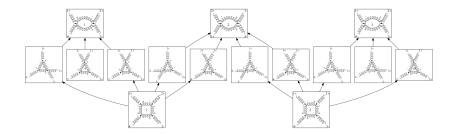
- We have efficient ways of calculating tree level, one loop cut parts and rational terms and therefore the complete one loop amplitude
- Tree and cut parts extend to interactions with the Higgs Boson easily
- Not fully implemented rational parts for Higgs Boson but progressing well

Tree Level	One Loop	Rational Parts	Conclusions
	00 0 0000		

- L. J. Dixon, "Calculating scattering amplitudes efficiently," arXiv:hep-ph/9601359 [hep-ph].
- R. Britto, F. Cachazo, B. Feng, and E. Witten, "Direct proof of tree-level recursion relation in Yang-Mills theory," *Phys.Rev.Lett.* 94 (2005) 181602, arXiv:hep-th/0501052 [hep-th].
- C. F. Berger, Z. Bern, L. J. Dixon, D. Maître, F. Febres Cordero, D. Forde, H. Ita, and D. A. Kosower, "Automated implementation of on-shell methods for one-loop amplitudes," *Physical Review D* 78 no. 3, (Aug., 2008) 036003, arXiv:0803.4180 [hep-ph].

◆□▶ ◆□▶ ◆ヨ▶ ◆ヨ▶ ●□ ◆○

Cut Part Dependancies

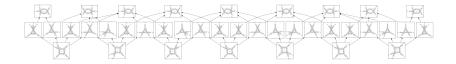


Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

문어 문제

Cut Part Dependancies



Simon Armstrong

Blackhat - Efficient Calculation of NLO amplitudes for Higgs + many jets

IPPP

н

- -

< 🗇 →