Developing tools for precision physics

Pooja Mukherjee

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Starting of my journey :



Starting of my journey :

Starting of my journey:

Born in India



Starting of my journey:

Born in India



Masters at IIT



Starting of my journey:



Masters at IIT

Doctoral in IMSc









Postdoctoral in Hamburg

Ongoing projects:

Hadron-hadron

Observables ~ parton density \otimes Matrix element \otimes parton density

Ongoing projects:

Hadron-hadron

$$\sigma(p_A, p_B) = \sum_{a,b} \int_0^1 dx_a f_{a/A}(x_a, \mu_F^2) \int_0^1 dx_b f_{b/B}(x_b, \mu_F^2) \left[\sigma_{ab}^{LO}(p_a, p_b; \mu_R^2, \mu_F^2) + \sigma_{ab}^{NLO}(p_a, p_b; \mu_R^2, \mu_F^2) + \sigma_{ab}^{NLO}(p_a, p_b; \mu_R^2, \mu_F^2) + \sigma_{ab}^{NNLO}(p_a, p_b; \mu_R^2, \mu_F^2) + \cdots \right]$$

So far :

W/Z total, H total, Harlander, Kilgore H total, Anastasiou, Melnikov H total, Ravindran, Smith, van Neerven /WH total, Brein, Djouadi, Harlander /H diff., Anastasiou, Melnikov, Petriello H diff., Anastasiou, Melnikov, Petriello /W diff., Melnikov, Petriello /W/Z diff., Melnikov, Petriello /H diff., Catani, Grazzini /W/Z diff. Catani et al Ø σ o

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2002 2004 2006 2008 2010 20

VBF total, Bolzoni, Maltoni, Moch, Zaro WH diff., Ferrera, Grazzini, Tramontano Y-Y, Catani et al. Hj (partial), Boughezal et al. ttbar total, Czakon, Fiedler, Mitov /jj (partial), Currie, Gehrmann-De Ridder, Glover, Pires ZH diff., Ferrera, Grazzini, Tramontano ttbar diff., Czakon, Fiedler, Mitov Hj, Boughezal et al. Wj. Boughezal, Focke, Liu, Petriello Hj, Boughezal et al. VBF diff., Cacciari et al. Zj, Gehrmann-De Ridder et al. S 0 Hj, Caola, Melnikov, Schulze Zj, Boughezal et al. WH diff., ZH diff., Campbell, Ellis, Williams Y-Y, Campbell, Ellis, Li, Williams ptz, Gehrmann-De Ridder et al. MCFM at NNLO, Boughezal et al. single top, Berger, Gao, C.-Yuan, Zhu ptH, Chen et al. ptz, Gehrmann-De Ridder et al. jj, Currie, Glover, Pires yX, Campbell, Ellis, Williams yj, Campbell, Ellis, Williams VH, H->bb, Ferrera, Somogyi, Tramontano single top, Berger, Gao, Zhu VH, H->bb, Caola, Luisoni, Melnikov, Roentsch p_{tw}, Gehrmann-De Ridder et al. 2012 2016 2018 2014 VBF diff., Cruz-Martinez, Gehrmann, Glover, Huss Wj, Zj, Gehrmann-De Ridder et al. yj, Chen et al. H->bbj, Mondini, Williams

Further progress requires improvement in two-loop computations

VBF total, Bolzoni, Maltoni, Moch, Zaro W/Z total, H total, Harlander, Kilgore WH diff., Ferrera, Grazzini, Tramontano H total, Anastasiou, Melnikov Y-Y, Catani et al. H total, Ravindran, Smith, van Neerven Hj (partial), Boughezal et al. WH total, Brein, Djouadi, Harlander ttbar total, Czakon, Fiedler, Mitov /H diff., Anastasiou, Melnikov, Petriello jj (partial), Currie, Gehrmann-De Ridder, Glover, Pires H diff., Anastasiou, Melnikov, Petriello ZH diff., Ferrera, Grazzini, Tramontano W diff., Melnikov, Petriello ttbar diff., Czakon, Fiedler, Mitov W/Z diff., Melnikov, Petriello Hj. Boughezal et al. H diff., Catani, Grazzini Wj. Boughezal, Focke, Liu, Petriello W/Z diff. Catani et al Hj, Boughezal et al. VBF diff., Cacciari et al. Gehrmann-De Ridder et al. Ø 00 O Caola, Melnikov, Schulze Zj, Boughezal et al. WH diff., ZH diff., Campbell, Ellis, Williams y-y, Campbell, Ellis, Li, Williams ptz, Gehrmann-De Ridder et al. MCFM at NNLO, Boughezal et al. single top, Berger, Gao, C.-Yuan, Zhu PtH, Chen et al. ptz, Gehrmann-De Ridder et al. j. Currie, Glover, Pires yX, Campbell, Ellis, Williams Campbell, Ellis, Williams VH, H->bb, Ferrera, Somogyi, Tramontano single top, Berger, Gao, Zhu VH, H->bb, Caola, Luisoni, Melnikov, Roentsch prw, Gehrmann-De Ridder et al. 2002 2004 2006 2008 2010 2012 2014 2016 2018 WBF diff., Cruz-Martinez, Gehrmann, Glover, Huss Wj. Zj. Gehrmann-De Ridder et al. yj. Chen et al. H->bbj, Mondini, Williams

SALAM PLOT BY G.

CoLoRFul NNLO Subtraction Scheme

- **To do so:** Phase space (PS) integrals must be performed numerically
- **Problem:** IR singularities at intermediate stages
- Solution: Treat them using a subtraction method

Aim: To construct a fully general local subtraction scheme for differential NNLO cross-section.

$$\sigma^{\text{NNLO}} = \sigma_{m+2}^{\text{RR}} + \sigma_{m+1}^{\text{RV}} + \sigma_m^{\text{VV}} = \int_{m+2} \mathrm{d}\sigma_{m+2}^{\text{RR}} J_{m+2} + \int_{m+1} \mathrm{d}\sigma_{m+1}^{\text{RV}} J_{m+1} + \int_m \mathrm{d}\sigma_m^{\text{VV}} J_m$$

- Matrix element for σ_{m+2}^{RR} (tree) and σ_{m+1}^{RV} for many processes.
- σ_m^{VV} (2-loop) know for 4 parton, V+3 parton processes, higher multiplicities are on the horizon.
- The three contributions are separately infrared divergent in d = 4dimensions.

The Scheme: Consider the NNLO correction to a generic *m*-jet observable

• J_m is infrared (IR) and collinear safe *m* final-state parton jet function.

Double Real: σ_{m+2}^{RR}

- from PS integration.
- No explicit ϵ pole

Real Virtual : σ_{m+1}^{RV}

- PS integration.
- Explicit ϵ pole up to $\mathcal{O}(\epsilon^{-2})$.

Double Virtual: σ_m^{VV}

- Kinematic singularities screened by jet function: PS integration finite \bullet
- Explicit ϵ pole up to $\mathcal{O}(\epsilon^{-4})$.

• Kinematic singularities as one or two partons unresolved: up to $\mathcal{O}(\epsilon^{-4})$ poles

• Kinematic singularities as one partons unresolved: up to $\mathcal{O}(\epsilon^{-2})$ poles from

Rewrite the NNLO correction as a sum of three terms

$$\sigma^{\text{NNLO}} = \sigma_{m+2}^{\text{RR}} + \sigma_{m+1}^{\text{RV}} + \sigma_m^{\text{VV}} = \sigma_{m+2}^{\text{NNLO}} + \sigma_{m+1}^{\text{NNLO}} + \sigma_m^{\text{NNLO}}$$

each integrable in four dimensions

$$\begin{split} \sigma_{m+2}^{\rm NNLO} &= \int_{m+2} \left\{ \mathrm{d}\sigma_{m+2}^{\rm RR} J_{m+2} - \mathrm{d}\sigma_{m+2}^{\rm RR,A_2} J_m - \left[\mathrm{d}\sigma_{m+2}^{\rm RR,A_1} J_{m+1} - \mathrm{d}\sigma_{m+2}^{\rm RR,A_{12}} J_m \right] \right\} \\ \sigma_{m+1}^{\rm NNLO} &= \int_{m+1} \left\{ \left[\mathrm{d}\sigma_{m+1}^{\rm RV} + \int_1 \mathrm{d}\sigma_{m+2}^{\rm RR,A_1} \right] J_{m+1} - \left[\mathrm{d}\sigma_{m+1}^{\rm RV,A_1} + \left(\int_1 \mathrm{d}\sigma_{m+2}^{\rm RR,A_1} \right)^{A_1} \right] J_m \right\} \\ \sigma_m^{\rm NNLO} &= \int_m \left\{ \mathrm{d}\sigma_m^{\rm VV} + \int_2 \left[\mathrm{d}\sigma_{m+2}^{\rm RR,A_2} - \mathrm{d}\sigma_{m+2}^{\rm RR,A_{12}} \right] + \int_1 \left[\mathrm{d}\sigma_{m+1}^{\rm RV,A_1} + \left(\int_1 \mathrm{d}\sigma_{m+2}^{\rm RR,A_1} \right)^{A_1} \right] \right\} J_m \end{split}$$

The **counterterms** are constructed as:

- $d\sigma_{m+2}^{RR,A_2}$ regularizes the doubly-unresolved limits of $d\sigma_{m+2}^{RR}$.
- $d\sigma_{m+2}^{RR,A_1}$ regularizes the singly-unresolved limits of $d\sigma_{m+2}^{RR}$.
- $d\sigma_{m+2}^{\text{RR},A_{12}}$ accounts for the overlap of $d\sigma_{m+2}^{\text{RR},A_1}$ and $d\sigma_{m+2}^{\text{RR},A_2}$.
- $d\sigma_{m+1}^{\text{RR},A_1}$ regularizes the singly-unresolved limits of $d\sigma_{m+1}^{\text{RV}}$.

• $\left(\int_{1} d\sigma_{m+2}^{\text{RR},A_{1}}\right)^{A_{1}}$ regularizes the singly-unresolved limits of $\int_{1} d\sigma_{m+2}^{\text{RR},A_{1}}$.

The **Phase space integrals** are then solved as :

- choose explicit parametrization of phase space.
- write the parametric integral representation in chosen variables.
- resolve the ϵ poles by sector decomposition.
- pole coefficients are finite parametric integrals.
- evaluate the parametric integrals in terms of multiple polylogs
- simplify the result by converting all polylogarithms in terms of : lacksquare

$$G[a,b;x] = \operatorname{Li}_2\left[\frac{b-x}{b-a}\right] - \operatorname{Li}_2\left[\frac{b}{b-a}\right] + \log\left(1-\frac{x}{b}\right)\log\left(\frac{x-a}{b-a}\right).$$

Numerical Implementation

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Package for automatizing steps of loop computation

AN Automated Tool for Higher order Amplitude

P.C. Andres & Paarth

End of my journey:

P.C. Yashasvee Goel

End of my journey :

