Tools for perturbative high-precision calculations

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public, reusable, composable, hackable

something that aids in accomplishing a task

Mathematica, Maple, FORM, GiNaC, . . .

Amplitudes in terms of loop integrals

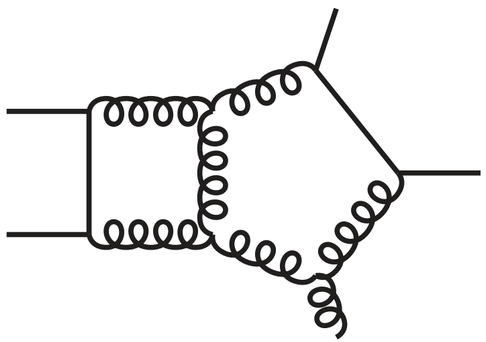
IR finite results: subtraction methods

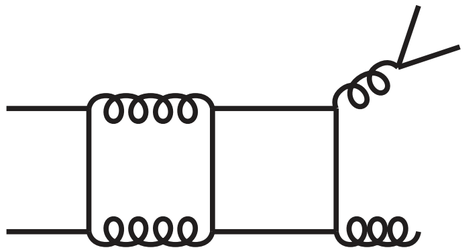
Hadronic cross-section: PDFs

"Events": parton shower, hadronization, matching and merging (see Marek)

Amplitudes

FORM, Mathematica, ...





..., Caravel *Abreu, Dormans, Febres Cordero, Ita, Kraus, Page, Pascual, Ruf, Sotnikov '20*

..., FiniteFlow *Peraro '19*

Loop Integrals: IBP Reduction

Reduze

Manteuffel, Studerus '12

Fire

Smirnov, Smirnov, Chukharev '08-'19

Kira+FireFly

Maierhöfer, Usovitsch, Uwer, Klappert, Lange '17-'20

multivariate partial fractioning: Singular/PFD

Bendle, Boehm, Heymann, Ma, Rahn Ristau, Wittmann, Wu, Zhang '21

Loop Integrals: Evaluation

Loopedia

Bogner, Borowka, Hahn, Heinrich, Jones, Kerner, von Manteuffel, Michel, Panzer, Papara '17

example for very successful "tool": VVAmp

Gehrmann, von Manteuffel, Tancredi '15 (110 citations)

Current gold standard: ODE with canonical basis

$$\partial_x \vec{f} = \epsilon A(x) \vec{f}$$

HPL's: TDHPL *Gehrmann, Remiddi '01*, Chaplin *Buehler, Duhr '11*, HPL4 *Czakon, Gluza, Riemann '05*

MPL's: PolyLogTools *Duhr, Dulat '19*, GiNaC *Kreckel, Vollinga, Weinzierl, et al. '00-'21*, ...

numerical evaluation: DiffExp *Hidding '20*

canonical basis, one scale: epsilon *Prausa '17*, Fuchsia *Gituliar, Magerya '17*, Libra *Lee '20*

canonical basis, multiple scales: Canonica *Meyer '18*

Other tools

Direct integration: HyperInt *Panzer '15*

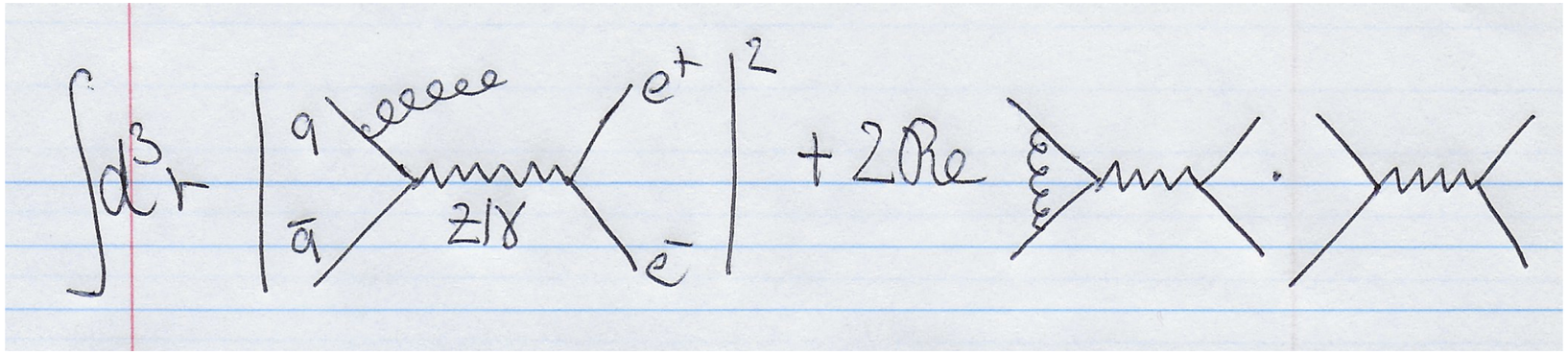
Multiple nested sums: Sigma, EvaluateMultiSums, .. *Schneider '07-'14*

Mellin Barnes rep: Ambre *Dubovyk, Gluza, Kajda, Riemann '07-'16*, MB.m *Czakon '05*, MBresolve.m *Smirnov, Smirnov '09*

Fully numerical, sector decomposition

pySecDec *Borowka, Heinrich, Jahn, Jones, Kerner, Poldaru, Schlenk, Zirke '10-'17*, FIESTA *Smirnov, Smirnov, Tentyukov '08-'18*

Getting a cross-section



All subtraction schemes are tools! (multiple slides of citations)

(steps on automatizing soft functions: SoftServe *Bell, Rahn, Talbert '18-'19*)

One-Loop amplitude & integral libraries

Recola *Denner, Lang, Uccirati, Actis, Hofer, Scharf, Uccirati '12-'17*

OpenLoops *Buccioni, Lang, Lindert, Maierhoefer, Pozzorini, Zhang, Zoller, Cascioli '13-'19*

GoSam *Heinrich, Jones, Kerner, Magerya, Mastrolia, Ossola, Peraro, Schlenk, Scyboz, Tramontano '11-'14*

Samurai *Mastrolia, Ossola, Reiter, Tramontano '10*

QCDLoop *Carrazza, Ellis, Zanderighi '07 '16*

Collier *Denner, Dittmaier, Hofer '16*

OneLOop *Hameren '10*

PDFs

$$\mathrm{d}\hat{\sigma} \otimes f_a \otimes f_b$$

LHAPDF *Buckley; Ferrando, Hall, Lloyd, Nordstrom, Ruefenacht, Watt '15*

fastNLO

Britzger, Rabbertz, Sieber, Stober, Wobisch '12

APPLgrid

Sutton, Starovoitov, Carli, Gwenlan, Salam '13-'21

PineAPPL

Carazza, Nocera, Schwan, Zaro '20

Hoppet

Salam, Rojo '08

Apfel

Bertone, Carrazza, Rojo, '13

Public fitting frameworks soon? NNPDF 4.0?

Machine learning and GPUs

Machine learning mostly useful to improve typical fitting situations

GPUs: Multi-loop calculations are not linear algebra problems

PDFFlow

Carazza, Cruz-Martinez, Rossi '20

Conclusions

Useful tools: public, reusable, composable, hackable

Not only computer codes, also integrals and amplitudes: machine-readable!

Don't *try* to create *s*wiss army knives or MadGraph@NNLO!

complementary talks: event generators, Marek Schönherr (this session);
precision multi-loop QCD: Claude Duhr (Friday)