N-Tuples for NNLO

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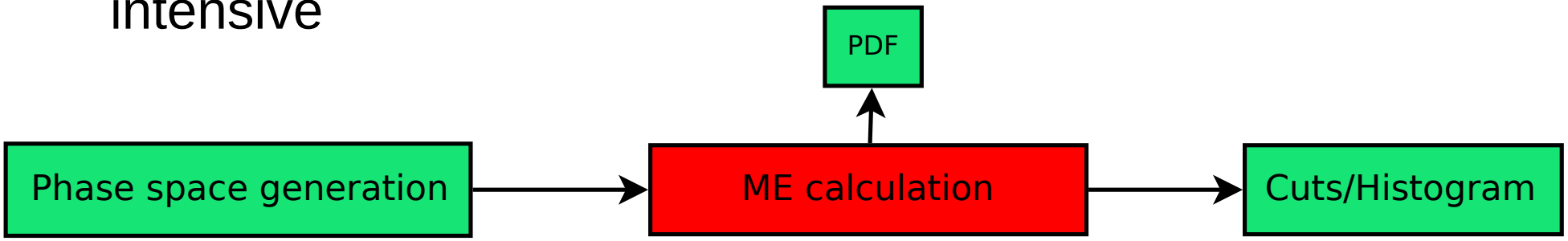
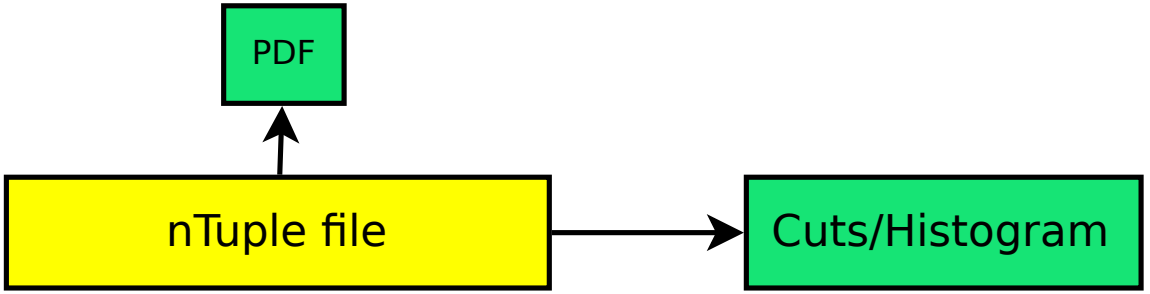
n-Tuple files [arXiv:1310.7439]

- High multiplicity NLO calculations are computationally intensive



- Matrix elements are expensive
- Jet clustering, observables, PDF evaluation are relatively cheap
- Store matrix element, PS point and the information necessary to change scales

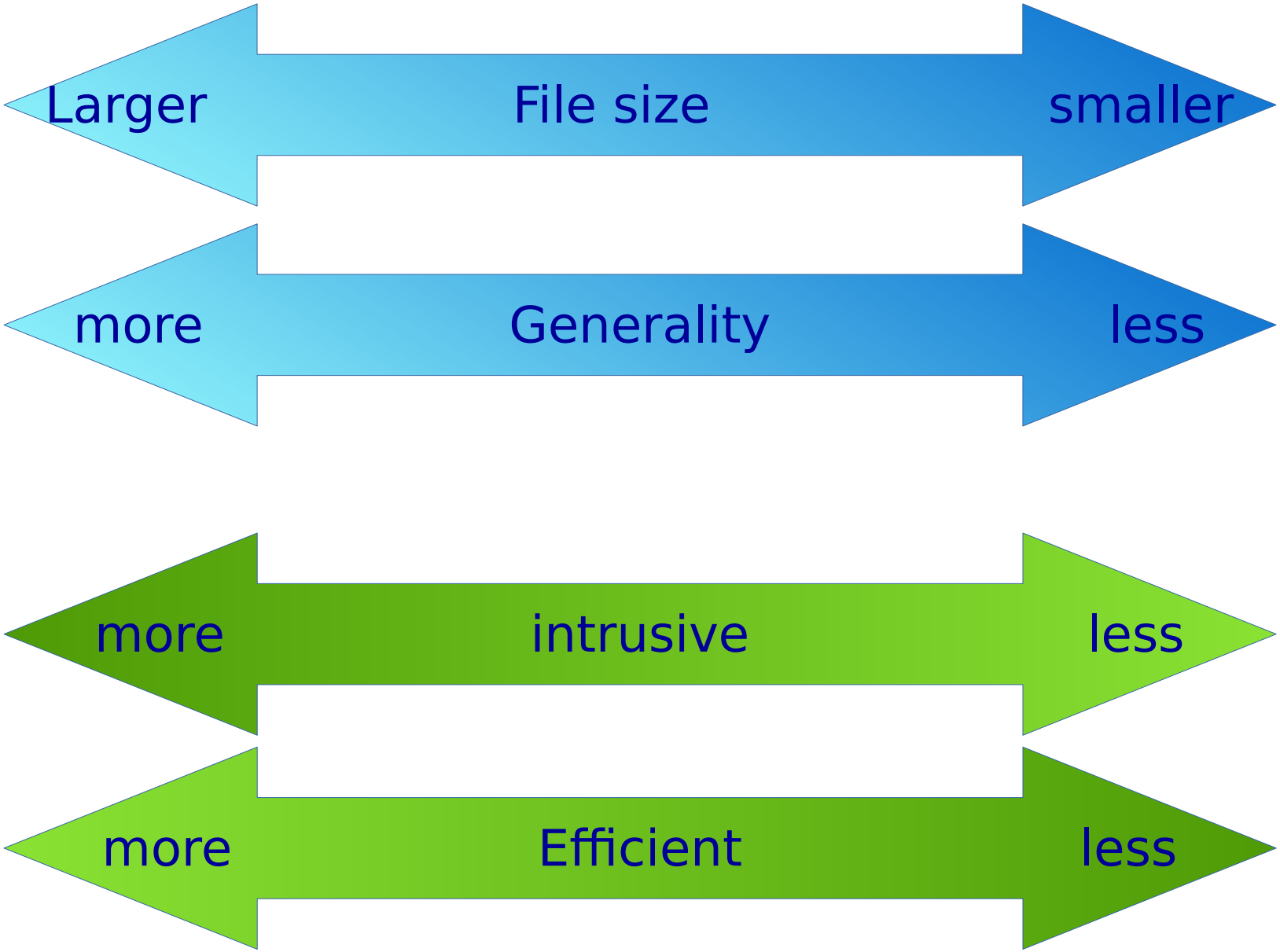


NLO nTuple files [arXiv:1310.7439]

- Advantages
  - One can change the analysis cuts, add observables
  - Cheap scale variation and PDF errors (otherwise extremely expensive)
  - Easy communication between theorists and experimenters
  - No need for specific know-how of the tool which produced the NLO calculation
  - Easier to “endorse” an event file than a program
- Disadvantage
  - Large files
  - Generation cuts need to be loose enough to accommodate many analysis → efficiency cost

NNLO nTuple files

- Trade offs

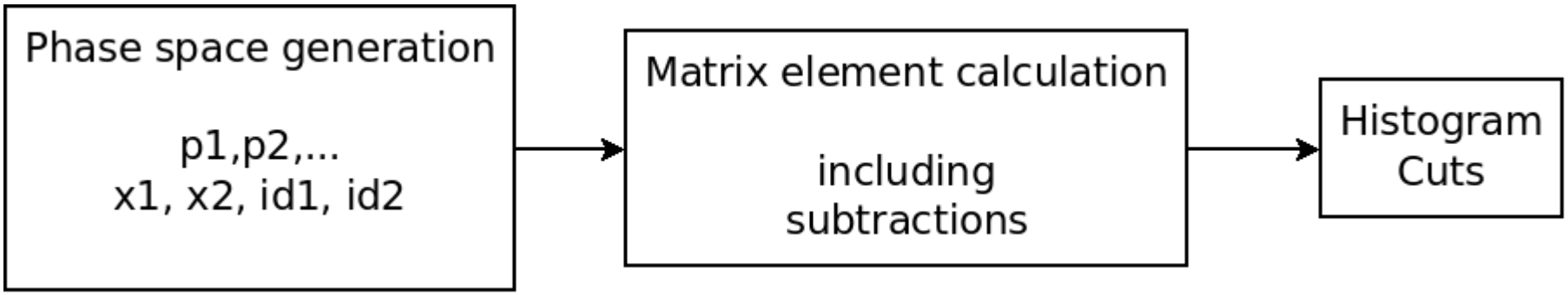


nTuples for NNLO

- nTuples have proven useful for NLO
- Can they be as useful for NNLO?
- Same advantages and same disadvantages but amplified:
  - Programs are more complex
  - Larger files:
    - Many more pieces in the calculation
    - More logarithm coefficients
- Main question: is the size reasonable?

Generic NNLO program

- A typical NNLO program can be decomposed into several parts



- The histograms/cuts part is typically quite easy to identify as users of the program are expected to implement their observables/cuts
- extract momenta and initial state information by inserting a line of code in NNLO phase space generation routine
- extract weights in the histogram routine
- subtraction terms evaluated with different momenta, I can use the routine for the cuts to siphon the PS information.

Information for nTuple

- I can get the weights from the histogram procedure, but if I want to change the PDFs and scale I need more information:
  - Coefficients of scale logarithms
  - PDF information
    - Initial state flavors
    - Momentum fractions x1, x2
    - Factorisation scale

$$\begin{aligned}\omega &= \alpha_S^n \; pdf(x_1, id_1) \; pdf(x_2, id_2) \\ &\quad \times \left(c_0 + c_1 \log(\mu^2 + \dots)\right)\end{aligned}$$

Initial state information

- LHAPDF is a good place to collect information:
  - Pdf information
    - Initial state flavors
    - Momentum fractions x1, x2
    - Factorisation scale
  - Often used to calculate alphas
    - Renormalisation scale

Scale dependence

- To get the scale dependence we need a different strategy
- Run parallel instances of the program with different scale compare the weights obtained and solve for the logarithm coefficients
- The part with the most scale logarithms are not the hardest, so the overhead of running multiple instance is not too bad

Multiple PDF terms

- There can be complications with pdfs:

$$\omega = c_1 pdf(x_1, x_2, id_1, id_2, Q) + c_2 pdf(x_1', x_2', id_1', id_2', Q)$$

- Could solve for the two coefficients with two parallel runs with different pdf scales
- Better solution is to modify the pdf function to return 0 instead of the pdf every second time

$$\begin{array}{lcllcll} \omega_1 & = & c_1 & pdf(x_1, x_2, id_1, id_2, Q) & + & c_2 & 0 \\ \omega_2 & = & c_1 & 0 & + & c_2 & pdf(x_1', x_2', id_1', id_2', Q) \end{array}$$

Multiple PDF terms

- Another problem is that the call to LHAPDF typically returns the value for all partons
  - we can't tell which one or which is used by the NNLO program
  - We can use the same strategy and run 13 different instances

$$
\begin{aligned}
f_1(x) &= (*,0,0,0,0,0,0,0,0,0,0,0,0) \\
f_2(x) &= (0,*,0,0,0,0,0,0,0,0,0,0,0) \\
f_3(x) &= (0,0,*,0,0,0,0,0,0,0,0,0,0) \\
f_4(x) &= (0,0,0,*,0,0,0,0,0,0,0,0,0) \\
f_5(x) &= (0,0,0,0,*,0,0,0,0,0,0,0,0) \\
f_6(x) &= (0,0,0,0,0,*,0,0,0,0,0,0,0) \\
f_7(x) &= (0,0,0,0,0,0,*,0,0,0,0,0,0) \\
f_8(x) &= (0,0,0,0,0,0,0,*,0,0,0,0,0) \\
f_9(x) &= (0,0,0,0,0,0,0,0,*,0,0,0,0) \\
f_{10}(x) &= (0,0,0,0,0,0,0,0,0,*,0,0,0) \\
f_{11}(x) &= (0,0,0,0,0,0,0,0,0,0,*,0,0) \\
f_{12}(x) &= (0,0,0,0,0,0,0,0,0,0,0,*,0) \\
f_{13}(x) &= (0,0,0,0,0,0,0,0,0,0,0,0,*)
\end{aligned}
$$

Guessing the PDF

- The individual pdfs are useful to understand what the NNLO program does but quite costly, instead one can have two runs, one with the original PDF, one with the pdf values replaced by 1

$$\begin{array}{rcccccc} \omega_1 & = & c_1 & pdf(x_1,x_2,id_1,id_2,Q) & + & c_2 & 0 \\ \omega_2 & = & c_1 & 0 & + & c_2 & pdf(x_1',x_2',id_1',id_2',Q) \\ \omega_1^{pdf=1} & = & c_1 & 1 & + & c_2 & 0 \\ \omega_2^{pdf=1} & = & c_1 & 0 & + & c_2 & 1 \end{array}$$

- We obtain the coefficient and the pdf part, which we can compare with combinations we expect

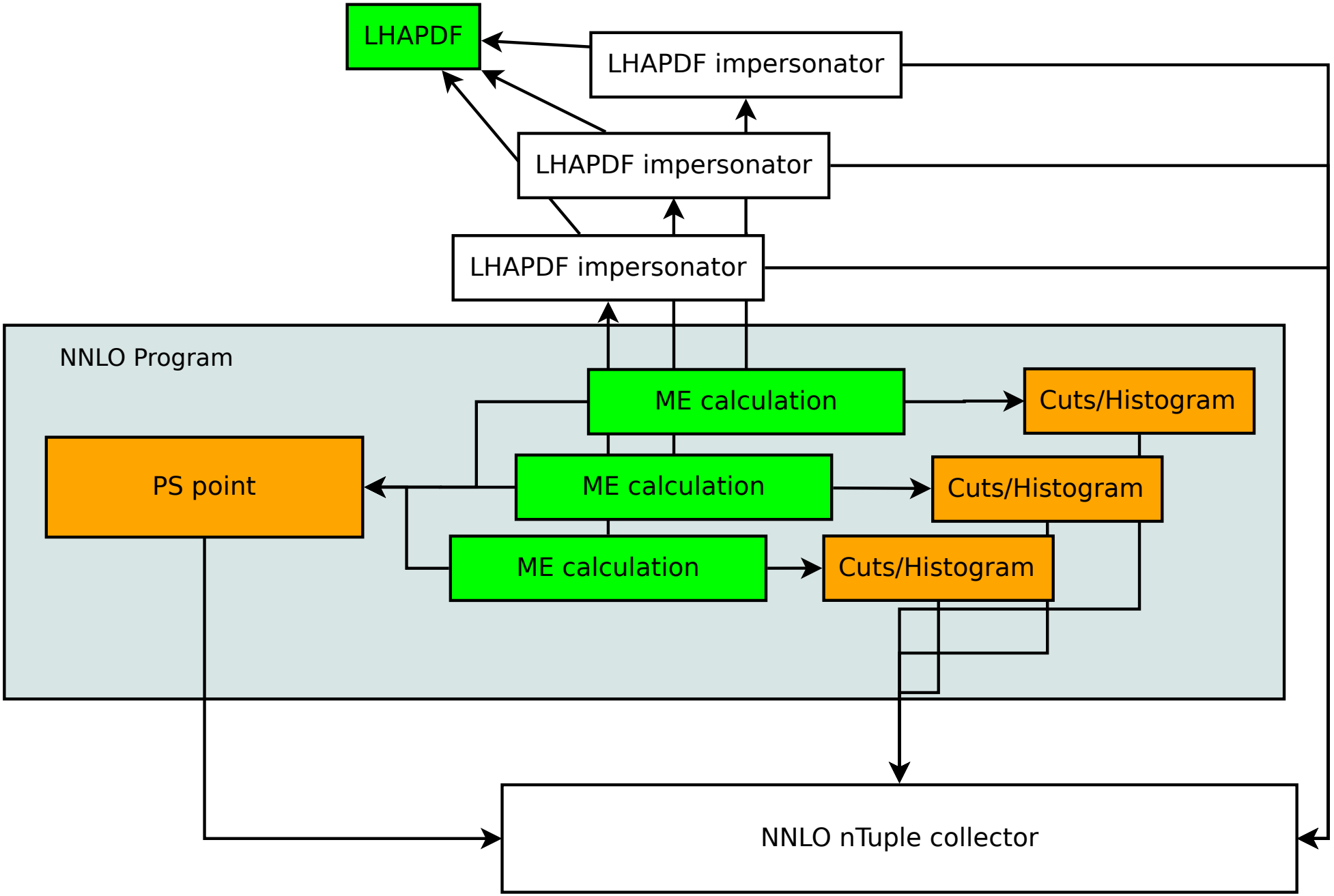
$$pdf = g(x_1)u(x_2), \left(\sum_q q(x_1)\right) g(x_2), \left(\sum_q q(x_1)\bar{q}(x_2)\right), ...$$

- If the combination is not found, we can investigate with the previous technique.

Guessing coupling constant

- In most cases we know the power of the coupling constant from the part (born, real, double real) of the NNLO program we are running
- if not we can use two parallel instances of the program, one normal and one with the coupling constant set to 1 and compare the ratio

Implementation



LHAPDF impersonator

- Allows to alternate vanishing and real pdf to disentangle different pdf terms
- Allows to filter specific initial state
- Reports pdf arguments to the nTuple collector
- Allows to set coupling constant values to one
- Is implemented using a hacking technique so there is no need to modify either
  - the NNLO program
  - the LHAPDF code

Minimum invasive

```
new_orig/NNLOJET_dev/driver/core/bino.f
83c83
<         call register_histogram_call(partons,kinwt*rnormcurr*wgtcurr*relfac*jfac,ip1_chan,ip2_chan)
---
>


diff -r new/NNLOJET_dev/driver/core/ecuts.f new_orig/NNLOJET_dev/driver/core/ecuts.f
334c334
<       use KinData_mod
---
>       !use KinData_mod
362c362
<       call register_momenta_call(p3,p4,p5,p6,p7,p8,p9,p10,npar)
---
>


diff -r new/NNLOJET_dev/driver/core/NNLOJET.f new_orig/NNLOJET_dev/driver/core/NNLOJET.f
39c39
<       call nnlontupleinit()
---
>


diff -r new/NNLOJET_dev/driver/makefile new_orig/NNLOJET_dev/driver/makefile
473c473
<         @$(LD) -o $@ $^ $(LDFLAGS) -L/home/daniel/Projects/NNLOntuples/plugin/build/install_dir/lib/ -linterceptNNLOjet -lNNLOntuples
---
>         @$(LD) -o $@ $^ $(LDFLAGS)
```

Additional difficulties

- Caching can cause confusion when the order of pdf, alphas, cuts and histograms are perturbed.
- Need to avoid grid adaptation to ensure synchronisation of the threads