nTuples and applications

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Outline

- nTuples
  - NLO
  - NNLO
- Strong coupling constant from high multiplicity processes

n-Tuple files [arXiv:1310.7439]

- High multiplicity NLO calculations are computationally intensive
- It would not be possible to rerun a high multiplicity W+jet calculation every time a new interesting observable comes up
- Matrix elements are expensive, while
  - Jet clustering
  - Observables
  - PDF evaluation

  are relatively cheap
- Store each matrix element, PS point and the information necessary to change the factorisation and renormalisation scales in large files we call n-Tuple files
- We use ROOT file as storage

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 $\rightarrow$ efficiency cost

nTupleReader library [arXiv:1310.7439]

- We provide a C++ library to facilitate the use of the n-Tuple files
- Allows:
  - Change of factorisation and renormalisation scales
  - Change of pdf (from LHAPDF set), including error sets
- Has a Python interface
- Template for a customised implementation
- Available on hepforge

  https://blackhat.hepforge.org/trac/wiki/BlackHatSherpaNtuples

Rivet for NLO

- Rivet is an analysis framework developed to facilitate the validation of MC with experimental data
- Many experimental analyses provide a Rivet analysis
- So far Rivet could not easily be used to analyse NLO predictions because correlated weights were not treated correctly. [Buckley,Grellscheid,Pollard,Schulz,Siegert]
- New version of Rivet will allow for the correct treatment of
  - Correlated events
  - Weight vectors (pdf errors)
- It will be easier to compare NLO predictions with data
- Test version on the Les Houches wiki

Analysis program

- With the new features of Rivet nTuple files can be used as input for the analysis
- New nTupleReader library contain the necessary ingredients to integrate with these new features
- Allows to run

```
> analyse   \
>     RIVET_ANALYSIS \
>     nTupleFile1.root  \
>     nTuplesFile2.root...
```

```
int main(int argc,char *argv[]){

  Rivet::AnalysisHandler rivet;
  Rivet.addAnalysis(argv[1]);

  nTupleReader r;

  for (int ii=2;ii<argc;ii++){
    r.addFile(argv[ii]);
  }

  r.setPDF("CT10nlo.LHgrid");
  r.setCMSEnergy(7000);
  r.setColliderType(pp);

  while(r.nextEntry()){
    HepMC::GenEvent evt;
    r.setHepMC(evt);
    rivet.analyze(evt);
  }

  rivet.setCrossSection(r.getCrossSection());
  rivet.finalize();
  rivet.writeData(std::string(argv[1])+".yoda");
}
```

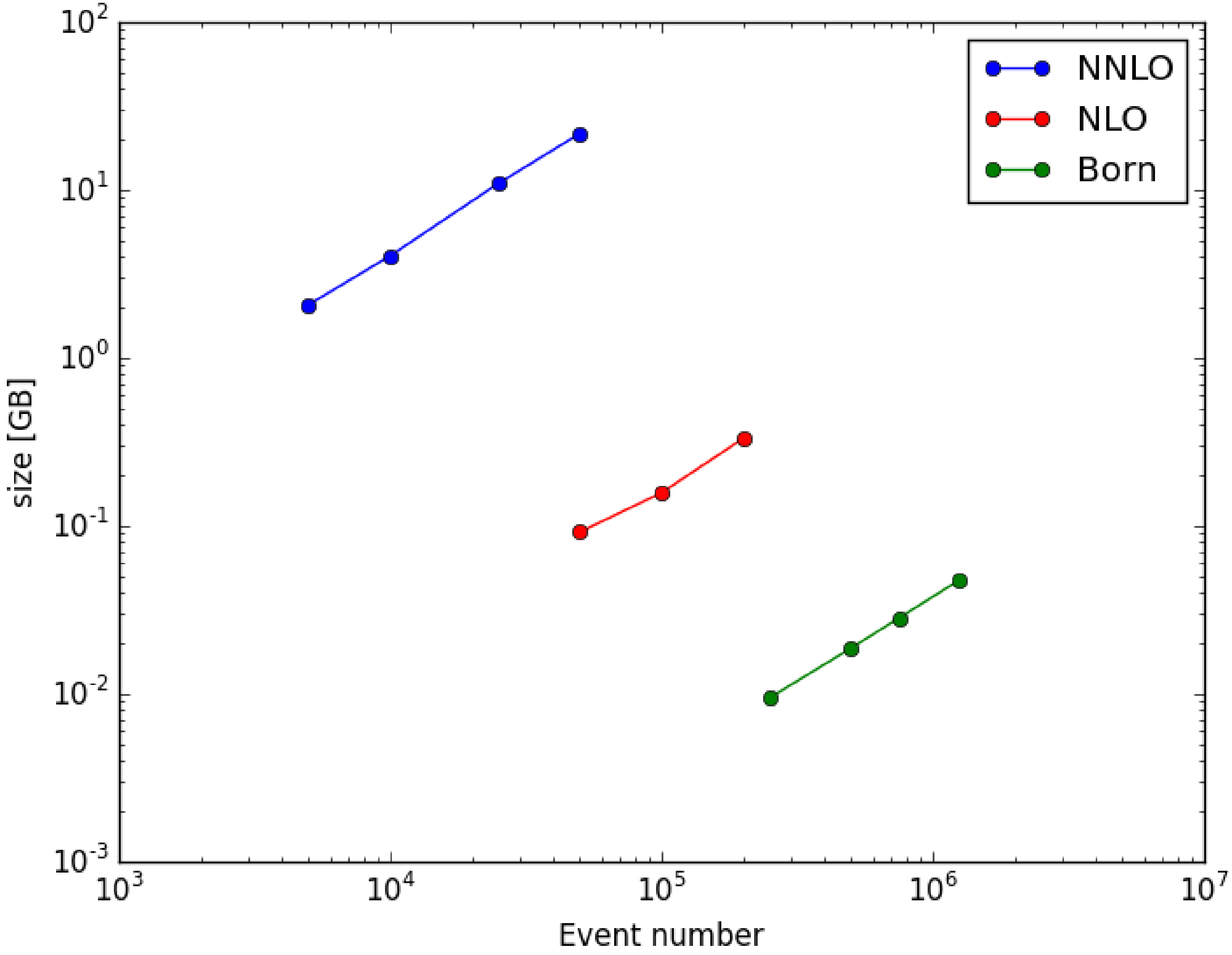
nTuples for NNLO

- 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?

Experiment in Les Houches

- Used EErad3 [Gehrmann-De Ridder, Gehrmann, Glover, Heinrich; arXiv:0710.0346] to generate NNLO ntuples for $e^+e^- \rightarrow 3$ jets
- Storage structure very similar to NLO nTuples
- Easier than hadronic :
  - No initial state information
  - Strong coupling dependence trivial (no real need to store coefficients of logarithms)

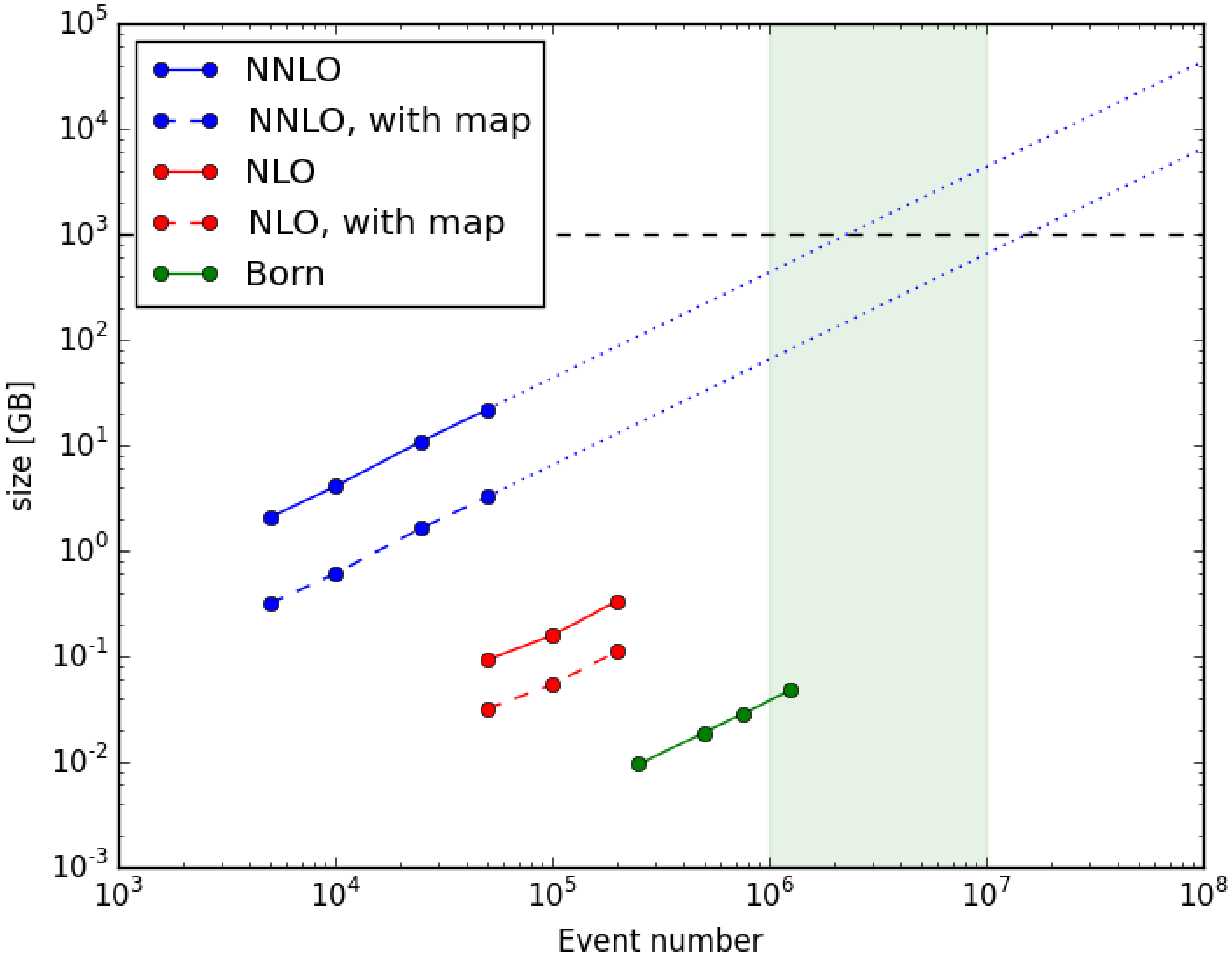
Size vs Event number



Using mapping information

- The most space-consuming part is the double real part
  - More final state momenta
  - Need much statistics because of subtraction terms
- For each real-real phase-space point we have many subtraction terms
- Each of them has a different set of momenta given by a $(n+2)\to n$ or $(n+1)\to n$ map
- We can save much space if we simply record the mapping that was used instead of the momenta
- The downside is that
  - there is more calculation at the moment of reading the nTuple
  - More coupling between nTuple file and code that produced it

Extrapolated file size

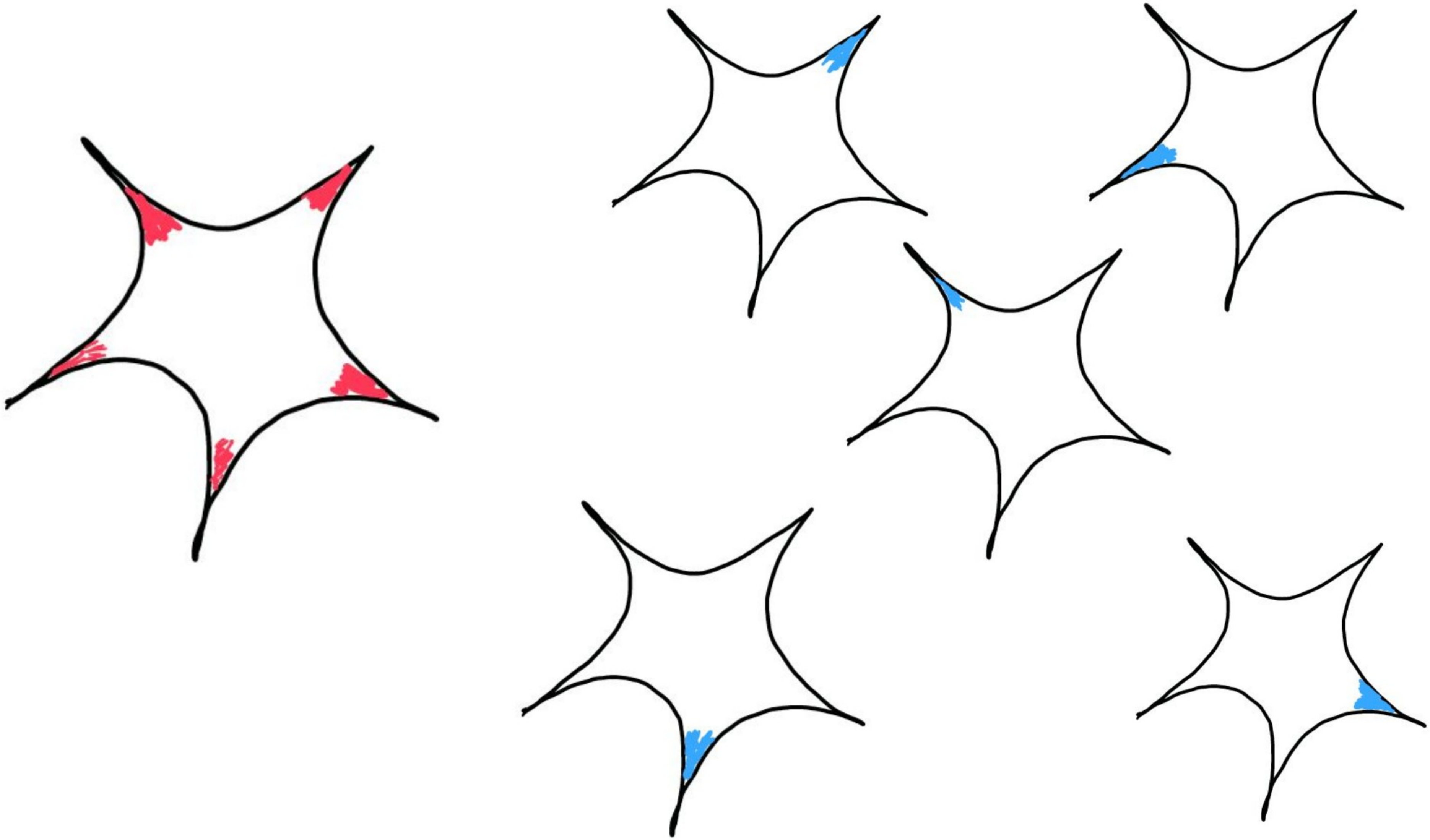


File sizes

- EErad3 “true” NNLO calculation with NNLO subtraction
- Processes calculated with the q_T subtraction or n-jettiness methods look more like two NLO calculations → could be more suitable for nTuple production
- Current programs are optimized for CPU usage, the trad-offs between “unweighting” and run time can be different if one wants to optimise the storage size

More effective storage

- Real phase space has many divergent regions
- Each is made finite by subtraction terms



More effective storage

- The cancellation between real matrix element and subtraction in the divergent part of the phase space requires a lot of statistics
- Much less is needed where the subtraction term is finite
- At NLO subtraction terms are routinely cut off where they are not needed.
- The subtraction term is integrated analytically as a function of the cut-off
- It is much harder to do at NNLO

More effective storage

- To optimise the storage one can separate the integration in two parts, one where the cancellations happen and one free of cancellations
- The former requires large statistics but the latter does not
- No analytical integration needed, just to run the program once above and once below the cut-off, with different statistics

NNLO nTuple files

- Trade offs

  - How intrusive

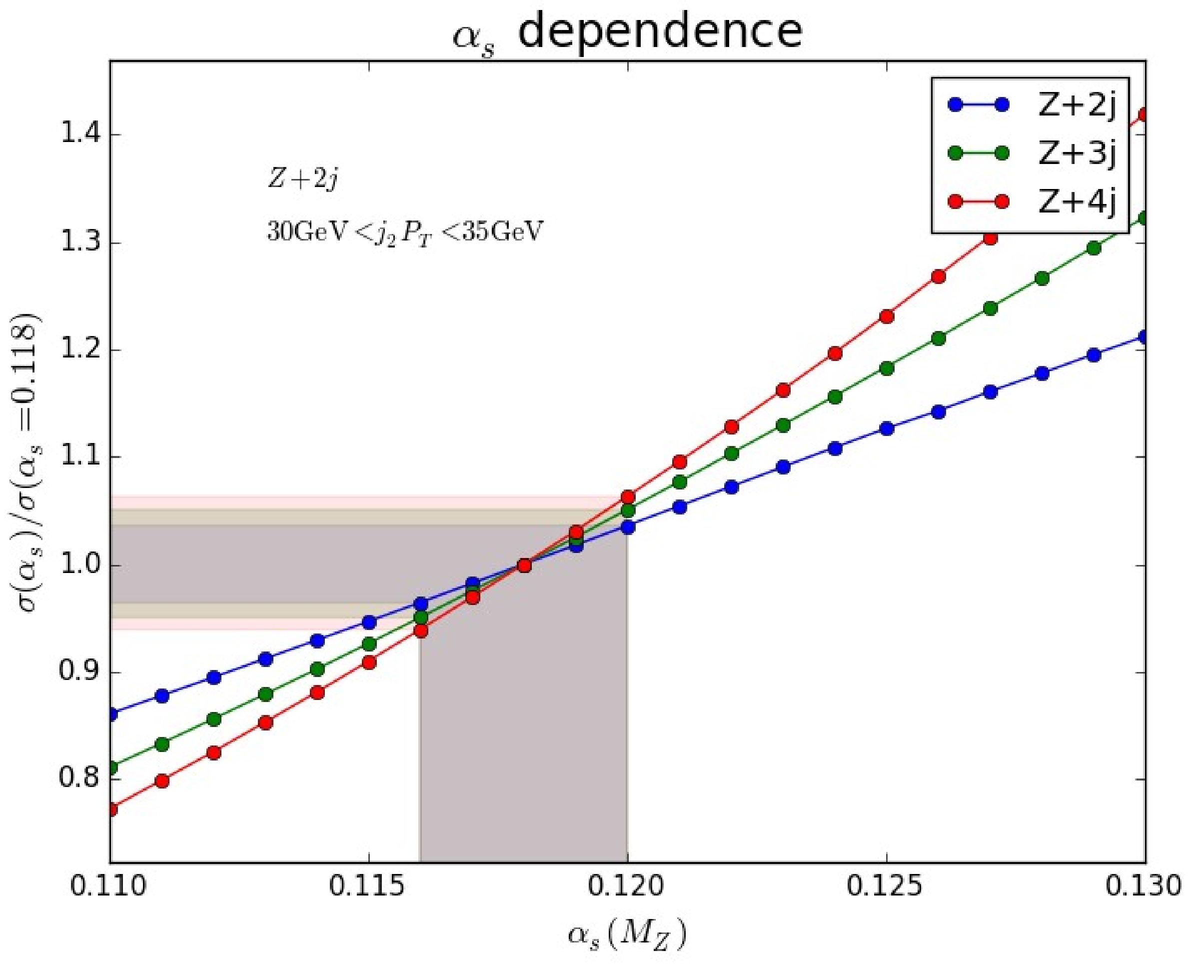
(almost) no modification	introduce cut-off	reorganise PS integration

  - How much calculation at read time/coupling to original code

no use of mapping information	use mapping information

Strong coupling determination

- Strong coupling determination are usually done using low multiplicity processes
  - High statistics
  - Well studied
  - Can have NNLO predictions
- High multiplicity processes have
  - A steeper coupling constant dependence
  - Less statistics



Strong coupling determination

- Here we look at the coupling constant dependence in Z+2,3,4 jets
- Compare BlackHat+Sherpa NLO results with Atlas measurement at 7 TeV [arXiv:1304.7098]
- To do this one needs to calculate the NLO theory prediction for several values of the coupling constant, for several pdfs and for all pdf sets to estimate the pdf uncertainty
- It is too much even with nTuples
- We used the BH+Sherpa public nTuples to create fastNLO tables [Britzger, Rabbertz, Sieber, Stober, Wobisch; arXiv:1208.3641]

Strong coupling determination

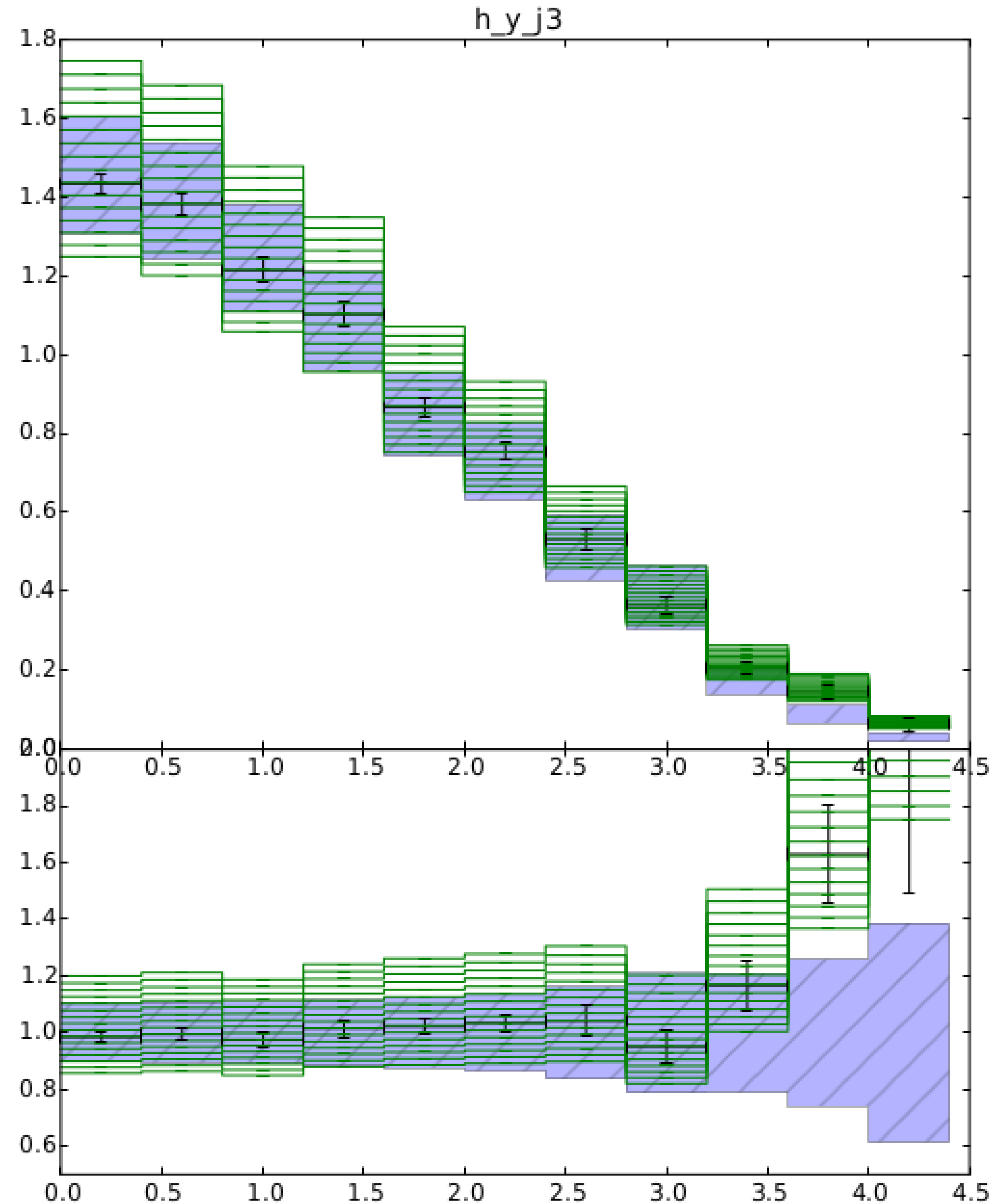
- Ingredients
  - Experimental data with error covariance matrix
  - Non-perturbative corrections
  - NLO prediction with error covariance
  - PDF uncertainties with covariance

$$\chi^2(\alpha_S) = \left(y_{theory}(\alpha_s) - y_{data}\right)^T C^{-1} \left(y_{theory}(\alpha_s) - y_{data}\right)$$

$$C = C_{exp} + C_{pdf} + C_{theory}$$

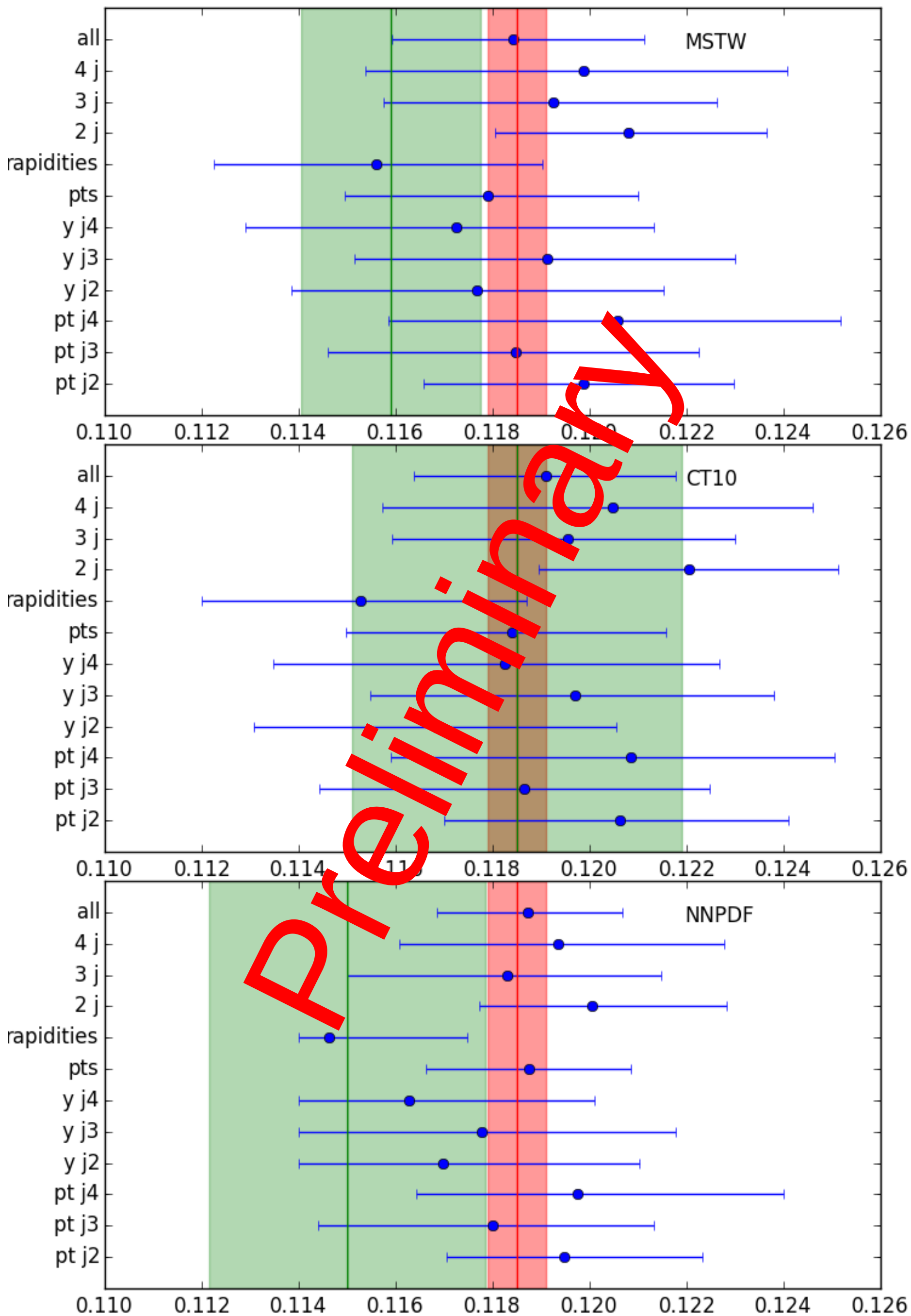
Strong coupling determination

- Look at
  - 2^{nd} jet pt
  - 3^{rd} jet pt
  - 4^{th} jet pt
  - 2^{nd} jet rapidity
  - 3^{rd} jet rapidity
  - 4^{th} jet rapidity



Strong coupling determination

- The high multiplicity processes are not quite competitive
- High multiplicity processes are a good place to investigate scale setting issues between predictions and pdfs
- No scale variation



Red: World average
Green: CMS inclusive jets [arXiv:1410.6765]

Conclusion

- nTuples could be a viable option for NNLO
  - Storage can be made more efficient at the cost of read-time speed or changes to the original code
  - Can help disseminate NNLO results
- High multiplicity processes can be used to determine the strong coupling constant