ePump in Top Pole Mass / PDF Snowmass Study

Jason Gombas-Salazar

Michigan State University - MSU

Overview

- Short introduction to top mass measurements
  - How it can measured
  - How might it be measured in the future
  - PDF significance to top mass measurements
- Technical details
  - Convert output root files to text ePump input
  - Scripts and technical details
- Overview of our results/conclusions to be presented by Jarrett and Sara

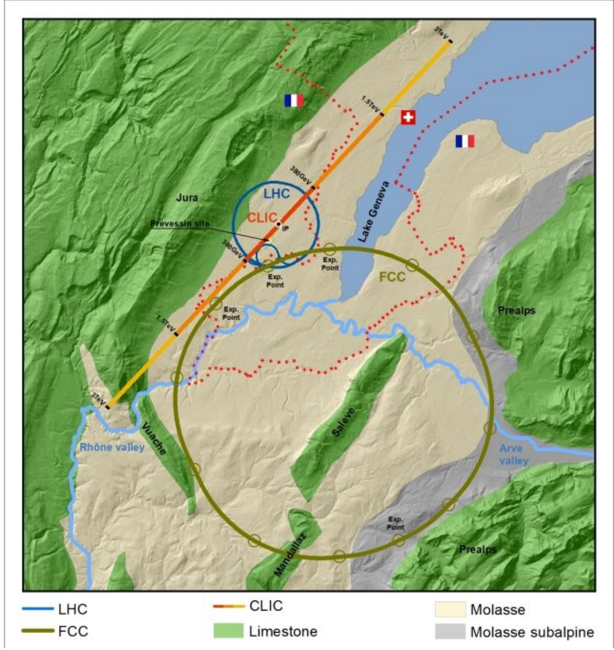
Top measurements at hadron colliders

- Beam energy known, but energy of colliding parton is unknown
- Also don't know particle ID of colliding partons
- Must fit data and fold in the probability distributions of PDFs

- Two Types of measurements
  - **Top "pole" mass** - well defined scheme, not sensitive to parton shower, but sensitive to PDFs and needs higher-order calculations
  - **Direct measurement of top mass** - insensitive to PDFs, but very sensitive to shower model

Future Colliders

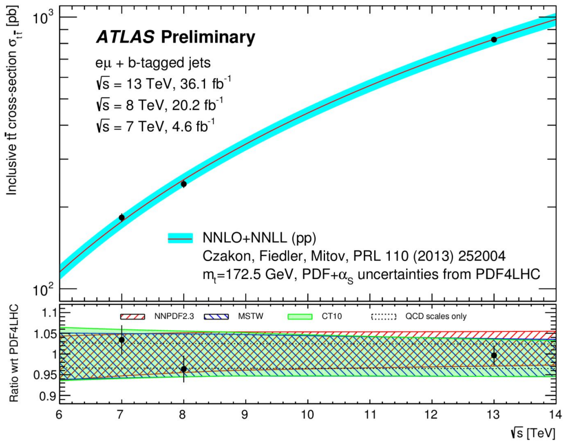
- Currently LHC
  - 13.6 TeV
  - Goal is to collect 300 fb^{-1} in ongoing Run 3
- HL-LHC: High Luminosity Large Hadron Collider
  - 14 TeV
  - Goal is to collect 3,000 fb^{-1}
- FCC: Future Circular Collider
  - 100 km tunnel, first tuned to ee collider, then 100 TeV hadron collider



Top pole mass measurements rely on theory calculations

PDF significance to top mass measurements

- Largest uncertainty in theory calculations is from parton distribution functions (PDFs)
  - About 5% uncertainty on the total cross-section
  - Gluon PDF at large x and large scale μ
- Goal: study the impact of PDF uncertainties on top mass extraction



Technical Details

Madgraph

- Di-top production is a very simple process that has been studied extensively
- Add [QCD] after the generate statement to specify you want NLO corrections
- You end up with:
    - Included diagrams, several cards that you can change “run_card.dat”, “param_card.dat”, a python program that can be executed
    - See more details on this later in Keping’s Presentation

```
#************************************************************
#*                    MadGraph5_aMC@NLO                     *
#*                                                          *
#*                *                       *                 *
#*                  *        * *        *                   *
#*                    * * * * 5 * * * *                     *
#*                  *        * *        *                   *
#*                *                       *                 *
#*                                                          *
#*                                                          *
#*         VERSION 3.2.0                2021-08-22          *
#*                                                          *
#*    The MadGraph5_aMC@NLO Development Team - Find us at   *
#*    https://server06.fynu.ucl.ac.be/projects/madgraph     *
#*                                                          *
#************************************************************
#*                                                          *
#*               Command File for MadGraph5_aMC@NLO         *
#*                                                          *
#*     run as ./bin/mg5_aMC  filename                       *
#*                                                          *
#************************************************************
set group_subprocesses Auto
set ignore_six_quark_processes False
set low_mem_multicore_nlo_generation False
set complex_mass_scheme False
set include_lepton_initiated_processes False
set gauge unitary
set loop_optimized_output True
set loop_color_flows False
set max_npoint_for_channel 0
set default_unset_couplings 99
set max_t_for_channel 99
set zerowidth_tchannel True
set nlo_mixed_expansion True
import model sm
define p = g u c d s u~ c~ d~ s~
define j = g u c d s u~ c~ d~ s~
define l+ = e+ mu+
define l- = e- mu-
define vl = ve vm vt
define vl~ = ve~ vm~ vt~
import model loop_sm
generate p p > t t~ j [QCD]
output ttj_NLO
```

Madgraph Weights

- These can be viewed in **events.lhe** file
- Identify what the different weights are
  - First weights here are the scale variations
  - Followed by nominal PDF then error PDFs

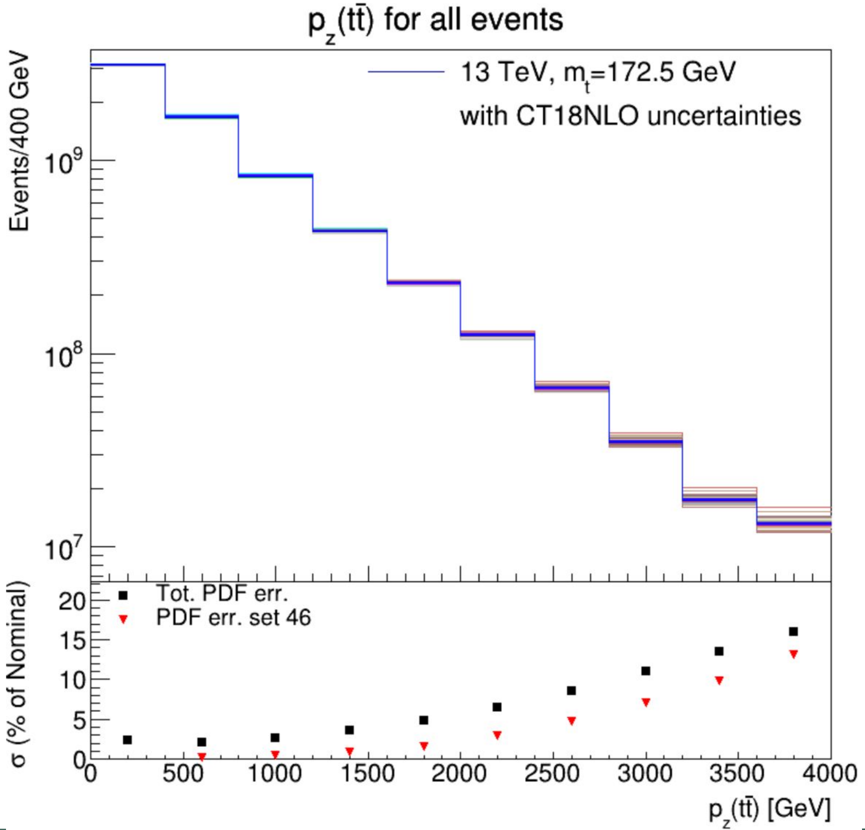

```
<initrwgt>
  <weightgroup name='scale_variation              0  -1' combine='envelope'>
    <weight id='1001'> tag=              0 dyn=  -1 muR=0.10000E+01 muF=0.10000E+01 </weight>
    <weight id='1002'> tag=              0 dyn=  -1 muR=0.20000E+01 muF=0.10000E+01 </weight>
    <weight id='1003'> tag=              0 dyn=  -1 muR=0.50000E+00 muF=0.10000E+01 </weight>
    <weight id='1004'> tag=              0 dyn=  -1 muR=0.10000E+01 muF=0.20000E+01 </weight>
    <weight id='1005'> tag=              0 dyn=  -1 muR=0.20000E+01 muF=0.20000E+01 </weight>
    <weight id='1006'> tag=              0 dyn=  -1 muR=0.50000E+00 muF=0.20000E+01 </weight>
    <weight id='1007'> tag=              0 dyn=  -1 muR=0.10000E+01 muF=0.50000E+00 </weight>
    <weight id='1008'> tag=              0 dyn=  -1 muR=0.20000E+01 muF=0.50000E+00 </weight>
    <weight id='1009'> tag=              0 dyn=  -1 muR=0.50000E+00 muF=0.50000E+00 </weight>
  </weightgroup>
  <weightgroup name='scale_variation              6  -1' combine='envelope'>
    <weight id='1010'> tag=              6 dyn=  -1 muR=0.10000E+01 muF=0.10000E+01 </weight>
    <weight id='1011'> tag=              6 dyn=  -1 muR=0.20000E+01 muF=0.10000E+01 </weight>
    <weight id='1012'> tag=              6 dyn=  -1 muR=0.50000E+00 muF=0.10000E+01 </weight>
    <weight id='1013'> tag=              6 dyn=  -1 muR=0.10000E+01 muF=0.20000E+01 </weight>
    <weight id='1014'> tag=              6 dyn=  -1 muR=0.20000E+01 muF=0.20000E+01 </weight>
    <weight id='1015'> tag=              6 dyn=  -1 muR=0.50000E+00 muF=0.20000E+01 </weight>
    <weight id='1016'> tag=              6 dyn=  -1 muR=0.10000E+01 muF=0.50000E+00 </weight>
    <weight id='1017'> tag=              6 dyn=  -1 muR=0.20000E+01 muF=0.50000E+00 </weight>
    <weight id='1018'> tag=              6 dyn=  -1 muR=0.50000E+00 muF=0.50000E+00 </weight>
  </weightgroup>
  <weightgroup name='scale_variation              8  -1' combine='envelope'>
    <weight id='1019'> tag=              8 dyn=  -1 muR=0.10000E+01 muF=0.10000E+01 </weight>
    <weight id='1020'> tag=              8 dyn=  -1 muR=0.20000E+01 muF=0.10000E+01 </weight>
    <weight id='1021'> tag=              8 dyn=  -1 muR=0.50000E+00 muF=0.10000E+01 </weight>
    <weight id='1022'> tag=              8 dyn=  -1 muR=0.10000E+01 muF=0.20000E+01 </weight>
    <weight id='1023'> tag=              8 dyn=  -1 muR=0.20000E+01 muF=0.20000E+01 </weight>
    <weight id='1024'> tag=              8 dyn=  -1 muR=0.50000E+00 muF=0.20000E+01 </weight>
    <weight id='1025'> tag=              8 dyn=  -1 muR=0.10000E+01 muF=0.50000E+00 </weight>
    <weight id='1026'> tag=              8 dyn=  -1 muR=0.20000E+01 muF=0.50000E+00 </weight>
    <weight id='1027'> tag=              8 dyn=  -1 muR=0.50000E+00 muF=0.50000E+00 </weight>
  </weightgroup>
  <weightgroup name='PDF_variation CT18NLO' combine='unknown'>
    <weight id='1028'> PDF=    14400 CT18NLO </weight>
    <weight id='1029'> PDF=    14401 CT18NLO </weight>
    <weight id='1030'> PDF=    14402 CT18NLO </weight>
    <weight id='1031'> PDF=    14403 CT18NLO </weight>
    <weight id='1032'> PDF=    14404 CT18NLO </weight>
    <weight id='1033'> PDF=    14405 CT18NLO </weight>
    <weight id='1034'> PDF=    14406 CT18NLO </weight>
    <weight id='1035'> PDF=    14407 CT18NLO </weight>
    <weight id='1036'> PDF=    14408 CT18NLO </weight>
    <weight id='1037'> PDF=    14409 CT18NLO </weight>
    <weight id='1038'> PDF=    14410 CT18NLO </weight>
    <weight id='1039'> PDF=    14411 CT18NLO </weight>
```


ATLAS EXPERIMENT

What this looks like

- We use ExRootAnalysis to convert the .lhe file to a .root file
  - Then we use C++ ROOT to analyze the root file
- In root, for every event, you get access to:
  - All particles including initial partons, their 4 vectors and their ID
  - An array of weights, each weight is a double
- Makes it easy to fill histograms in event loop, you just need something like:
  - `hist->Fill(top_mass, weight[27]);`
- Next, we convert these histograms into ePump text files

Converting root histograms to ePump input




```
TH2D* histograms[59];
for(int i=0; i<59; i++){
    histograms[i] = (TH2D*) in_file->Get(TString::Format("h%d",i));
}

ofstream outfile;
ofstream newFile(outfilename);
outfile.open (outfilename);
outfile << "Theory Column" << endl;
outfile << "    1" << endl;
Int_t nBinX = histograms[0]->GetNbinsX();
Int_t nBinY = histograms[0]->GetNbinsY();

if(energy=="4000.0" && obs=="ttbar_pz_smallRap"){
    for(int i=0; i<59; i++){
        outfile << "Data : Obs." << std::setfill('0') << std::setw(2) << i << ".dta" << endl;
        for(int binX=1; binX<=nBinX-2; binX++){
            for(int binY=1; binY<=nBinY; binY++){
                outfile << histograms[i]->GetBinContent(binX, binY) << endl;
            }
        }
    }
} else {
    for(int i=0; i<59; i++){
        outfile << "Data : Obs." << std::setfill('0') << std::setw(2) << i << ".dta" << endl;
        for(int binX=1; binX<=nBinX; binX++){
            for(int binY=1; binY<=nBinY; binY++){
                outfile << histograms[i]->GetBinContent(binX, binY) << endl;
            }
        }
    }
}
outfile.close();
```

What the epump input files look like

data file

```
# of corr_err,  Data Column,    StatErr Column,  UncSys Column,   corr_err Column
0               1               2                3                4
pt  StatErr uncorSys    e01
3.13803e+08     0       3.13803e+06     0
1.68123e+08     0       1.68123e+06     0
8.18673e+07     0       818673      0
3.48311e+07     0       348311      0
1.18596e+07     0       118596      0
3.47401e+06     0       34740.1     0
869687      0       8696.87     0
239182      0       2391.82     0
67050.1     0       670.501     0
22338.8     0       223.388     0
```

theory file

```
Theory Column
    1
Data : Obs.00.dta
3.13803e+08
1.68123e+08
8.18673e+07
3.48311e+07
1.18596e+07
3.47401e+06
869687
239182
67050.1
22338.8
Data : Obs.01.dta
3.14061e+08
1.68437e+08
8.21087e+07
3.49603e+07
1.19119e+07
3.49197e+06
874846
240699
67532.7
22518.4
Data : Obs.02.dta
3.13568e+08
1.67833e+08
```

Conclusions

- Top mass measurements are limited by PDF uncertainties
- To make significant steps to reduce top mass, we can constrain the PDFs we use
- Once these PDF uncertainties are constrained, top mass uncertainty is significantly reduced (see Sara and Jarrett talks)
- It is expected that top mass measurements will be improved from the proposed ILC and the proposed FCC-ee because an energy scan is possible. But in the meantime, we can make progress with data that we will have much sooner

https://github.com/jpgombas/snowmass_ttbar_study/

* ILC - International Linear Collider