Jet quenching hard sector (Hands on)

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Canada

WAYNE STATE UNIVERSITY

Pre-requisites for the hands-on

- % = host machine
- $ = docker container
- % mkdir ~/MATTER_LBT_results
- Download and run the docker container

  Mac OS

  - % docker run -it -v ~/MATTER_LBT_results:/home/jetscape-user/JETSCAPE/MATTER_LBT_results -p 8888:8888 gvujan/jetscape-school:latest

  Linux

  - % docker pull gvujan/jetscape-school:latest
  - % docker run -it -v ~/MATTER_LBT_results:/home/jetscape-user/JETSCAPE/MATTER_LBT_results -p 8888:8888 --user $(id -u):$(id -g) gvujan/jetscape-school:latest

The exercise

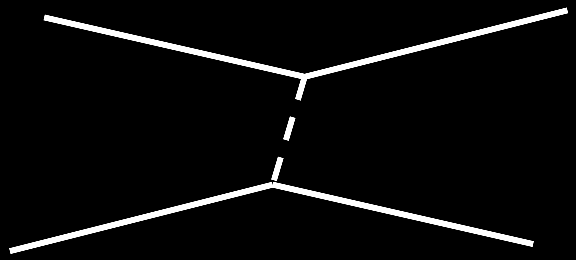
- Calculate the cross-section of pion production in a nuclear medium, i.e. $d\sigma_{AA}^{(\pi)}/dp_T d\eta$.
- In theory, one can calculate the nuclear modification function R_{AA} as:

$$R_{AA}^{(\pi)}(p_T, \eta) = \frac{d\sigma_{AA}^{(\pi)}/dp_T d\eta}{d\sigma_{pp}^{(\pi)}/dp_T d\eta}$$

- To obtain R_{AA} the most complicated piece is the calculation of the numerator, as the denominator can be calculated using Pythia.
- To calculate $\frac{d\sigma_{AA}^{(\pi)}}{dp_T d\eta}$ we need to bin particles in finite intervals

$$\frac{1}{\sigma_{inel}} \frac{d\sigma_{AA}^{(\pi)}}{2\pi p_T \Delta p_T \Delta\eta} = \sum_{k=1}^{N} \frac{dN\left(\hat{p}_{T;k}\right)}{2\pi p_T \Delta p_T \Delta\eta} \frac{\hat{\sigma}(\hat{p}_{T;k})}{\sigma_{inel}}$$

- What is $\hat{p}_T$? It's the p_T of the propagator ‒ ‒ ‒ ‒ ‒ in a 2 → 2 scattering ⇒



Erratum

```
$ cd ~JETSCAPE/config/
$ vim jetscape_user.xml
```

- I accidentally commented out the entire Initial State <IS> module on Friday. Only Trento was supposed to be commented out.

```xml
<?xml version="1.0"?>

<jetscape>

  <nEvents> 500 </nEvents>
  <nReuseHydro> 500 </nReuseHydro>

  <Random>
    <seed>1</seed>
  </Random>

  <outputCrossSectionFile>cross_section</outputCrossSectionFile>
  <outputFilename>test_out</outputFilename>

  <JetScapeWriterAscii> on </JetScapeWriterAscii>

  <!-- Inital State Module  -->
  <IS>
    <!--Trento> </Trento-->
    <initial_profile_path>../examples/sample_hydro_files</initial_profile_path>
  </IS>

  <!-- Hard Process -->
  <Hard>
    <PythiaGun>
      <pTHatMin>50</pTHatMin>
      <pTHatMax>70</pTHatMax>
      <eCM>5020</eCM>
    </PythiaGun>
  </Hard>

  <!--Preequilibrium Dynamics Module -->
  <!--Preequilibrium>
    <NullPreDynamics> </NullPreDynamics>
  </Preequilibrium-->

  <!-- Hydro  Module  -->
  <Hydro>
    <!--Brick bjorken_expansion_on="false" start_time="0.6"> </Brick-->
    <hydro_from_file>
      <hydro_files_folder>../examples/sample_hydro_files</hydro_files_folder>
    </hydro_from_file>
  </Hydro>

  <!--Eloss Modules -->
  <Eloss>
    <Matter>
      <in_vac> 0 </in_vac>
    </Matter>
    <Lbt>
      <in_vac> 0 </in_vac>
    </Lbt>
  </Eloss>

  <!-- Jet Hadronization Module -->
  <JetHadronization>
    <name>colorless</name>
  </JetHadronization>

</jetscape>
```

Editing jetscape_user.xml

```
$ cd ~JETSCAPE/config/
$ vim jetscape_user.xml
```

- Edit the lines <nEvents> and <nReuseHydro>

```
<nEvents>40</nEvents>
<nReuseHydro>40</nReuseHydro>
```

This change will reduce the statistics and speed-up the code

- Save and quit

- Then make 4 copies:

```
$ cp jetscape_user.xml jetscape_user_100_125.xml
$ cp jetscape_user.xml jetscape_user_125_150.xml
$ cp jetscape_user.xml jetscape_user_150_175.xml
$ cp jetscape_user.xml jetscape_user_175_200.xml
```

```xml
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Editing jetscape_user.xml

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- Save and quit
- Then make 4 copies:

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$ cp jetscape_user.xml jetscape_user_125_150.xml
$ cp jetscape_user.xml jetscape_user_150_175.xml
$ cp jetscape_user.xml jetscape_user_175_200.xml
```

- A reason why we need to have multiple $\hat{p}_T$ bins:
  - The cross section is a steeply falling spectrum and we have quite limited statistics (2000 for people who've done this over the week-end and only 160 now)
  - We would need on the order of 10^5 samples to cover the 100-200 GeV range in one large bin.
  - Best if we split the distribution up into smaller pieces to do get a better idea of the underlying distribution.

```xml
<?xml version="1.0"?>

<jetscape>

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  <nReuseHydro> 500 </nReuseHydro>

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    <seed>1</seed>
  </Random>

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  <!-- Jet Hadronization Module -->
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</jetscape>
```

Editing jetscape_user.xml

- open `jetscape_user_100_125.xml`

```
<outputCrossSectionFile>cross_section_100_125</outputCrossSectionFile>
<outputFilename>test_out_100_125</outputFilename>
```

- Then edit the $\hat{p}_T$ hat bin width

```
<pTHatMin>100</pTHatMin>
<pTHatMax>125</pTHatMax>
```

- Repeat 3 more times for

```
jetscape_user_125_150.xml
jetscape_user_150_175.xml
jetscape_user_175_200.xml
```

```xml
<?xml version="1.0"?>

<jetscape>

  <nEvents> 40 </nEvents>
  <nReuseHydro> 40 </nReuseHydro>

  <Random>
    <seed>1</seed>
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  </Eloss>

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  </JetHadronization>

</jetscape>
```

Running JETSCAPE code

- Change to the build directory

```
$ ./runJetscape ../config/jetscape_user_100_125.xml
$ ./runJetscape ../config/jetscape_user_125_150.xml
$ ./runJetscape ../config/jetscape_user_150_175.xml
$ ./runJetscape ../config/jetscaep_user_175_200.xml
```

- Copy the files over to the MATTER_LBT_results folder

```
$ cp test_out_100_125.dat cross_section_100_125.dat ~/JETSCAPE/MATTER_LBT_results
$ cp test_out_125_150.dat cross_section_125_150.dat ~/JETSCAPE/MATTER_LBT_results
$ cp test_out_150_175.dat cross_section_150_175.dat ~/JETSCAPE/MATTER_LBT_results
$ cp test_out_175_200.dat cross_section_175_200.dat ~/JETSCAPE/MATTER_LBT_results
```

- Extracting the final state hadrons

```
$ ./FinalStateHadrons test_out_100_125.dat final_hadrons_100_125.dat
$ ./FinalStateHadrons test_out_125_150.dat final_hadrons_125_150.dat
$ ./FinalStateHadrons test_out_150_175.dat final_hadrons_150_175.dat
$ ./FinalStateHadrons test_out_175_200.dat final_hadrons_175_200.dat
```

- Copy the final hadrons over to the MATTER_LBT_results folder

```
$ cp final_hadrons_100_125.dat ~/JETSCAPE/MATTER_LBT_results
$ cp final_hadrons_125_150.dat ~/JETSCAPE/MATTER_LBT_results
$ cp final_hadrons_150_175.dat ~/JETSCAPE/MATTER_LBT_results
$ cp final_hadrons_175_200.dat ~/JETSCAPE/MATTER_LBT_results
```

Running the analysis script

- Copy over the analysis script and make file

```
% cp ~/JETSCAPE/cross_section_example/Makefile ~/JETSCAPE/MATTER_LBT_results/
% cp ~/JETSCAPE/cross_section_example/analysis_script.cxx ~/JETSCAPE/MATTER_LBT_results/
```

- We don't need the docker container for analysis, so you have 2 options:
  - Edit the `analysis_script.cxx` edit the analysis script inside the docker container using an editor (e.g. vim or emacs) or
  - Edit the `analysis_script.cxx` outside the docker container in the folder ~/MATTER_LBT_results on your machine
- Slight editing of the analysis script is needed (as the script was written to work with the default xml file).

The lines that need to be modified

```
// Created by Chathuranga Sirimanna (chathuranga.sirimanna@wayne.edu), Gojko Vujanovic (vujanovic@wayne.edu)
// Requires FinalState hadrons status, E, Px, Py, Pz, eta, phi as input, also requires pTHatCrossSection (in mb) as input
// Output is a txt file which contains p_T, Single hadron yield and statistical error

#include <iostream>
#include <fstream>
#include <cstdio>
#include <cmath>
#include "iomanip"
#include "string"
#include <sstream>

using namespace std;

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

    int StartTime = time(NULL);

    const double sigma_inel=70.0;//total inelastic p-p cross section at 5.02 TeV

    int NpTHatBin = 4; //Number of pTHat bins

    //These arrays are used to get the minimum and maximum values of current pTHat bin
    int pTHatMin[NpTHatBin] = {100,125,150,175};
    int pTHatMax[NpTHatBin] = {125,150,175,200};
```

Step 1 of the analysis script

- The instructions posted https://indico.bnl.gov/event/8660/timetable/
- Read the variable definitions along with the first 115 lines of code in analysis_script.cxx until Step 1.

    - Questions?

- For each $\hat{p}_T$-bin (index k in the code) whose range as specified in the jetscape_user.xml files, if a pion is found in final_hadrons.dat, add a +1 counter to the corresponding p_T (index j in the code).
- Put your answer in dNdpTCount_hard_ind[NpTHatBin][NpTBin].
- Hints:
    - Charged pions have PID = $\pm$ 211
    - Neutral pions have PID = 111
    - For other particles see https://pdg.lbl.gov/2007/reviews/montecarlorpp.pdf
    - Note that we are only binning particles with stat$\neq$-1
- Particles with stat=-1 are hydro sources or sinks.
- Recoil particles have stat=1. Recoils can be turned on/off via the xml flag in green in the jetscape_user.xml
    - If you have sources/sinks you also need to fill dNdpTCount_soft_ind[k][Hadbin] and remove those from the final spectrum.

```
<Eloss>
  <Matter>
    <in_vac> 0 </in_vac>
    <recoil_on> 1 </recoil_on>
  </Matter>
....
</Eloss>
```

Step 2 of the analysis script

- Uncorrelated gaussian uncertainty propagation, for two measurements $a \pm \sigma_a$ and $b \pm \sigma_b$ the uncertainty on $\sigma_{ab} = ab\sqrt{\left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{\sigma_b}{b}\right)^2}$
- Use the above formula in the calculation of the uncertainty on $\frac{\Delta\sigma_{AA;k}}{2\pi p_T \Delta p_T \Delta\eta}$ (see below), assuming σ_{inel} is exact.

$$\frac{1}{\sigma_{inel}} \frac{\Delta\sigma_{AA;k}}{2\pi p_T \Delta p_T \Delta\eta} = \frac{\Delta N(\hat{p}_{T;k})}{2\pi p_T \Delta p_T \Delta\eta} \frac{\hat{\sigma}(\hat{p}_{T;k})}{\sigma_{inel}}$$

- Assume that the variance coming from the first term in the equation above is the inverse of the count, i.e. $\sigma^2 = \frac{1}{\Delta \mathrm{N}}$, while the standard deviation on $\hat{\sigma}(\hat{p}_{T;k})$ is given as a second column of the cross_section file.
- Put your answer in the array CS_Err_hard_ind[k][j]
- Read the analysis_script.cxx between Step 1 and Step 2.
- Questions?

Step 3 of the analysis script

- Finally add the $\hat{p}_T$ bins together in the array TotalCS[j].

$$\frac{1}{\sigma_{inel}}\frac{\Delta\sigma_{AA}}{2\pi p_T \Delta p_T \Delta\eta} = \sum_{k=1}^{4}\frac{1}{\sigma_{inel}}\frac{\Delta\sigma_{AA;k}}{2\pi p_T \Delta p_T \Delta\eta} = \sum_{k=1}^{4}\frac{\Delta N(\hat{p}_{T;k})}{2\pi p_T \Delta p_T \Delta\eta}\frac{\hat{\sigma}(\hat{p}_{T;k})}{\sigma_{inel}}$$

- Assume that the uncertainty for each $\frac{\Delta\sigma_{AA;k}}{2\pi p_T \Delta p_T \Delta\eta}$ is uncorrelated when calculating the total uncertainty and use gaussian uncertainty propagation. Use the array TotalCSErr[j] to store the uncertainty.
- Read the rest of analysis_script.cxx.
- Questions?

If time permits start adding more $\hat{p}_T$ bins

- Use smaller $\hat{p}_T$ bins at low $\hat{p}_T$ and larger ones at higher $\hat{p}_T$.
  - 2 GeV intervals until 20 GeV
  - 5—10 GeV intervals until 100 GeV
  - 10—50 GeV intervals until 500 GeV
  - 100 GeV intervals beyond

Thank you!

Question?