Tutorial of Full Simulation

1. Computing setup:

1) singularity run --bind `echo $HOME` --bind /data/pku/home/rjiang/pku/home/rjiang:/data /cvmfs/unpack ed.cern.ch/registry.hub.docker.com/infnpd/mucoll-ilc-framework:1.6-centos8

(use pwd to view your own path.)

2) Source /opt/ilcsoft/muonc/init_ilcsoft.sh

3) in singularity: git clone https://github.com/MuonColliderSoft/MuC-Tutorial.git

```
jrb@DESKTOP-BG3MH3R:~$ ssh rjiang@hepfarm02.phy.pku.edu.cn
Last login: Thu Mar 30 20:14:19 2023 from 10.4.16.95
==============================================================
 - Welcome to farm.phy.pku.edu.cn
 - User Manual : http://wiki.hep.pku.edu.cn/zh-hans/computing
==============================================================
 - CPU Usage               :  38.30, 37.00, 41.51 (1, 5, 15 min)
 - Memory Usage            :  26023 MB / 128676 MB
 - Disk Usage /data/pku    :  73T / 73T
 - Disk Usage /data/pubfs  :  63T / 107T
 - Disk Usage /data/bond   :  13T / 98T
 - Users Logged on         :  18 user(s)
==============================================================
Note: Port 9001 has now been directed to "farm" instead of "atlas" node.
Reminder: Use `ssh atlas`, `ssh node01`, ..., `ssh node06` to switch nodes.
[ 20:44:48 rjiang@farm ~] (0) $ singularity run --bind `echo $HOME` --bind /data/pku/home/rjiang/pku/home/rjiang:/data /
cvmfs/unpacked.cern.ch/registry.hub.docker.com/infnpd/mucoll-ilc-framework:1.6-centos8
Singularity>
```

2.Input samples generation: MadGraph+Pythia8

Output: xxxx.hepmc

Use muon collider software as simulation detector in full simulation instead of Delphes in fast simulation.

3. Submit xxxx.hepmc to PKU farm:

1) Log in farm: ssh username@hepfarm02.phy.pku.edu.cn
2) Submit: scp d1TeV.hepmc rjiang@hepfarm02.phy.pku.edu.cn:/data/pku/home/rjiang/pku/home/rjiang/MuC-Tutorial/simulation

4.simulation:

1) Some settings in xxxx.py:

- the path of xml file, the path of input file(xxxx.hepmc).
- set the number of simulation events.
- the output file: xxxx.slcio.

2) ddsim --steeringFile steer_sim_mumu.py > sim.log 2>&1

```
## The compact XML file
SIM.compactFile = "/opt/ilcsoft/muonc/detector-simulation/geometries/MuColl_v1/MuColl_v1.xml"
```

```
SIM.inputFiles = ["/data/MuC-Tutorial/simulation/d1TeV.hepmc"]
## Macro file to execute for runType 'run' or 'vis'
SIM.macroFile = ""
## number of events to simulate, used in batch mode. -1 all
SIM.numberOfEvents = 10000
## Outputfile from the simulation,only lcio output is supported
SIM.outputFile = "d1TeV.slcio"
```

5.Reconstruction: input file is xxxx.slcio.

1) If jet reconstruction is needed:

- /data/MuC-Tutorial/reconstruction/advanced/jet_reco/jet_reco.xml
- Marlin --global.LCIOInputFiles=xxxx.slcio jet_reco.xml
- Output: Output_REC.slcio , lctuple_jets.root (histograms)

2) If there is no jet reconstruction:

- /data/MuC-Tutorial/reconstruction/steer_reco_mumu.xml(set input file: xxxx.slcio)

```
<global>
  <parameter name="LCIOInputFiles">back5.slcio</parameter>
  <!-- Limit the number of processed records (run+evt): -->
  <parameter name="MaxRecordNumber" value="-1" />
  <parameter name="SkipNEvents" value="0" />
  <parameter name="SupressCheck" value="false" />
  <parameter name="Verbosity" options="DEBUG0-9,MESSAGE0-9,WARNING0-9,ERROR0-9,SILENT">MESSAGE </parameter>
  <parameter name="RandomSeed" value="1234567890" />
</global>
```

- Marlin steer_reco_mumu.xml > reco.log 2>&1
- Output: Output_DST.slcio (it can be used for analysis), Output_REC.000.slcio, histograms.root

Output_REC. slcio : contains all the collections produced by the executed processors.

Output_DST. slcio :contains a subset of output collections, which are relevant for later analysis.(exact selection of collections is defined in the Output_DST section of the steering file)

6.Analysis：

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1) If jet reconstruction is needed:

- /data/MuC-Tutorial/reconstruction/advanced/alternative/lctuple_steer.xml(set input file from reconstruction: Output_REC.slcio)

```xml
<global>
  <parameter name="LCIOInputFiles">
    Output_REC.slcio
  </parameter>
  <parameter name="SkipNEvents" value="0" />
  <parameter name="SupressCheck" value="false" />
  <parameter name="Verbosity" options="DEBUG0-4,MESSAGE0-4,WARNING0-4,ERROR0-4,SILENT"> MESSAGE  </parameter>
</global>
```

- Marlin lctuple_steer.xml > ntuples.out 2>&1
- Output: xxxx.root(include the variables of jets)

```
njet              = 5
jmox              = -3.46141,
                    38.8436, -11.8719, -1.1188, 5.94236
jmoy              = -78.5506,
                    8.86343, -14.8886, 7.36721, 1.54263
jmoz              = 104.097,
                    66.4019, -17.8511, 14.2471, -2.98806
jmas              = 8.65817,
                    5.62509, 0.105817, 2.39232, 1.3889
jene              = 130.741,
                    77.6417, 26.1014, 16.2552, 6.9677
```

```
jevis             = 257.707
jPxvis            = 28.3339
jPyvis            = -75.6659
jPzvis            = 163.906
jmom              = 130.454,
                    77.4377, 26.1012, 16.0781, 6.82787
jcost             = 0.797956,
                    0.857488, -0.683918, 0.886114, -0.437627
jcosTheta         = 0.896944
jTheta            = 0.457988
jPtvis            = 80.7969
jmvis             = 181.713
jmmax             = 130.454
jEmiss            = -257.707
jMmissq           = 33019.5
jMmiss            = 181.713
```

2) There is no jet reconstruction:

- /data/MuC-Tutorial/MuC-Tutorial/analysis/lctuple/ lctuple_steer.xml
- Marlin --global.LCIOInputFiles=Output_DST.slcio --MyAIDAProcessor.FileName=lctuple_example lctuple_steer.xml
- Output: xxxx.root (include variables about reconstruction, mc,……)

The meaning of each branch: https://github.com/iLCSoft/LCTuple/tree/master/src

problem: How to get the root file includes both reconstruction variables and jet variables?

```
nrec            = 8
rcori           = 0,
                  0, 0, 0, 0, 0, 0, 0
rccid           = 0,
                  0, 0, 0, 0, 0, 0, 0
rctyp           = -211,
                  211, 22, 22, 22, 22, -13, -13
rccov           = 0,
                  0, 0, 0, 0, 0,
                  0, 0, 0, 0, 0,
                  0, 0, 0, 0, 0,
                  0, 0, 0, 0
rcrpx           = 25.854,
                  37.8772, 1324.65, 1267.72, 1305.51, 1291.46,
                  -9.10409, 35.5533
rcrpy           = -16.8058,
                  -11.3637, -810.404, -875.862, -867.772, -846.997,
                  28.8793, 3.74549
rcrpz           = 39.7769,
                  120.14, 2031.5, 1934.85, 1949.54, 1935.01,
                  10.9688, 80.14
```

```
rcmox           = 26.0539,
                  0.873903, 11.3577, 2.98798, 19.3792, 4.38371,
                  -31.4725, 46.5799
rcmoy           = -16.9459,
                  -0.239515, -6.96526, -2.06438, -12.9043, -2.87503,
                  99.6751, 4.93579
rcmoz           = 40.0999,
                  2.7577, 17.3899, 4.56037, 29.0315, 6.56816,
                  37.8711, 105.035
rcmas           = 0.13957,
                  0.13957, 0, 0, 0, 0,
                  0.105658, 0.105658
rcene           = 50.7345,
                  2.90611, 21.907, 5.8298, 37.2143, 8.40377,
                  111.175, 115.006
```

How to get the root file includes both reconstruction variables and jet variables?

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Merge analysis files (in P6 and P7), especially the setting of ReconstructedParticles. Such as below:

```
<!--Name of the ReconstructedParticle collection-->
<parameter name="RecoParticleCollection" type="string" lcioInType="ReconstructedParticle"> MergedRecoParticles </parameter>
```

```
--Name of the ReconstructedParticle collection-->
arameter name="RecoParticleCollection" type="string" lcioInType="ReconstructedParticle"> PandoraPFOs </parameter>
```

[Configuration files]

```
rctyp          = -13
rccov          = 0,
                  0, 0, 0, 0, 0,
                  0, 0, 0, 0
rcrpx          = 1.79998
rcrpy          = -30.165
rcrpz          = 4.60898
rcgpi          = 0
rcpiu          = -1
rcnpi          = 0
rcfpi          = -1
rcmox          = 5.04769
rcmoy          = -84.177
rcmoz          = 12.881
rcmas          = 0.105658
rcene          = 85.3064
rccha          = 1
rcntr          = 1
rcncl          = 1
rcnrp          = 0
rcftr          = 0
rcvts          = -1
rcvte          = -1
rccom          = 0
npid           = 0
njet           = 1
jmox           = 5.04769
jmoy           = -84.177
jmoz           = 12.881
jmas           = 0.103008
jene           = 85.3064
```

Some examples:

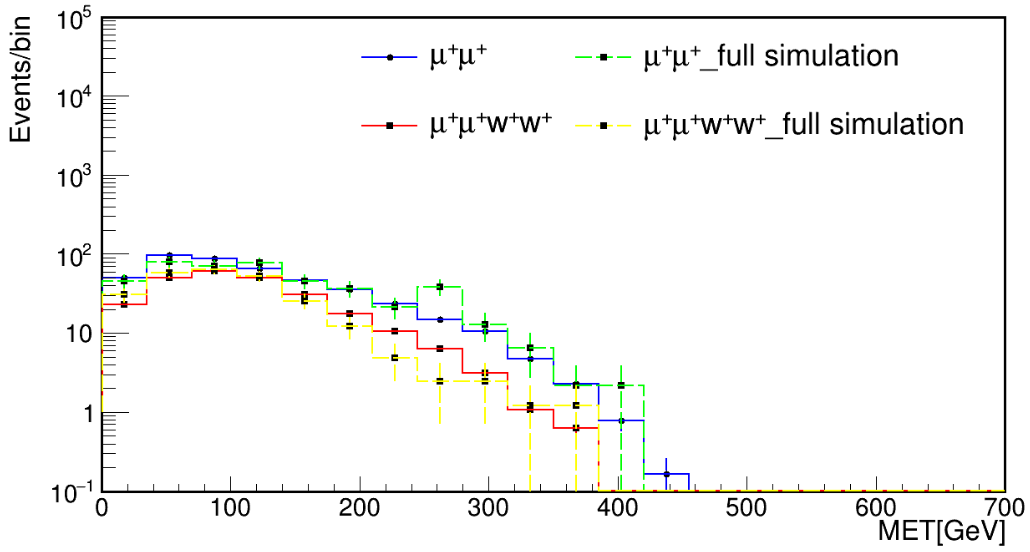
MET reconstruction:

A. Consider W bosons only decay to muons :

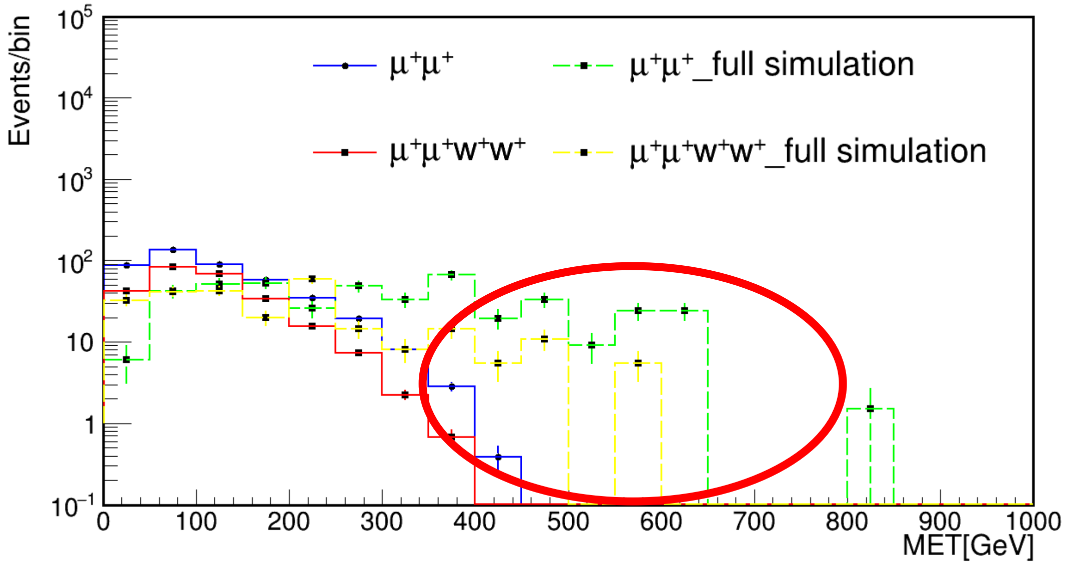
- Signal: $\mu^+\mu^+ \to W^+W^+, W^+ \to \mu^+\nu_\mu, W^+ \to \mu^+\nu_\mu$.
- Background: $\mu^+\mu^+ \to W^+W^+\bar{\nu}_\mu\bar{\nu}_\mu, W^+ \to \mu^+ + \nu_\mu, W^+ \to \mu^+\nu_\mu$.

Only use muons and jets to reconstruct MET.

(a) Final states include muons



(b)Final states include muons and jets



When the jets are considered, the difference between fast simulation and full simulation is more obvious than before. It probably means that there are more inefficient particles in Fig. (b).

Output the momentum and energy of several jets and muons to research if muons are included in jets.

Jet:

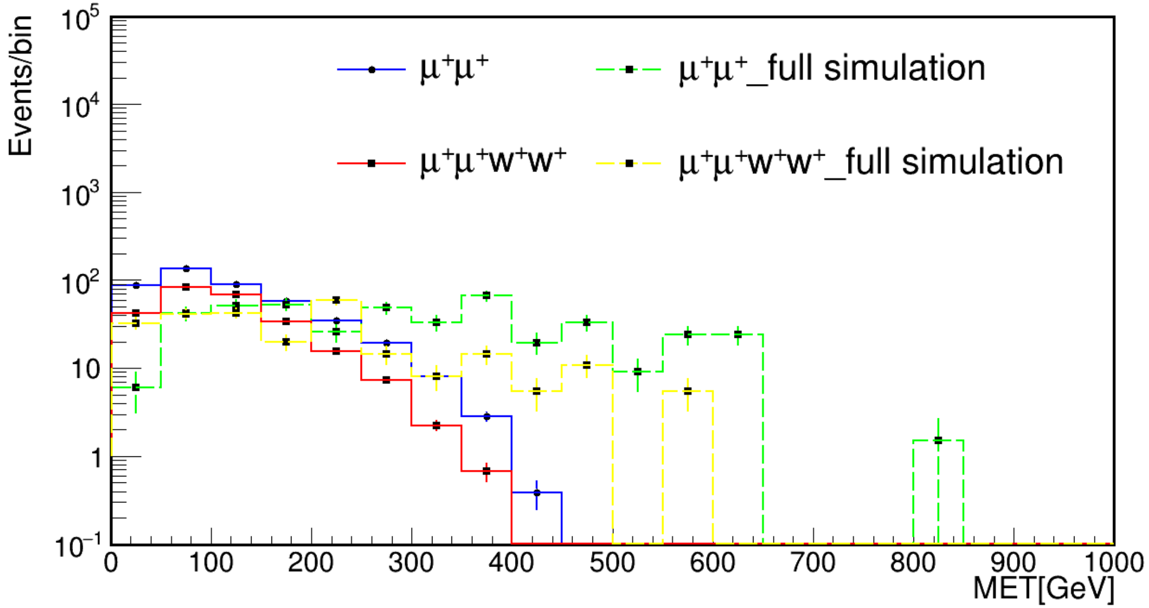
```
pxj1                = -241.479
pxj2                = 143.579
pyj1                = 46.6608
pvj2                = -28.5365
pzj1                = 146.549
pzj2                = -128.605
enj1                = 286.297
enj2                = 194.855
```

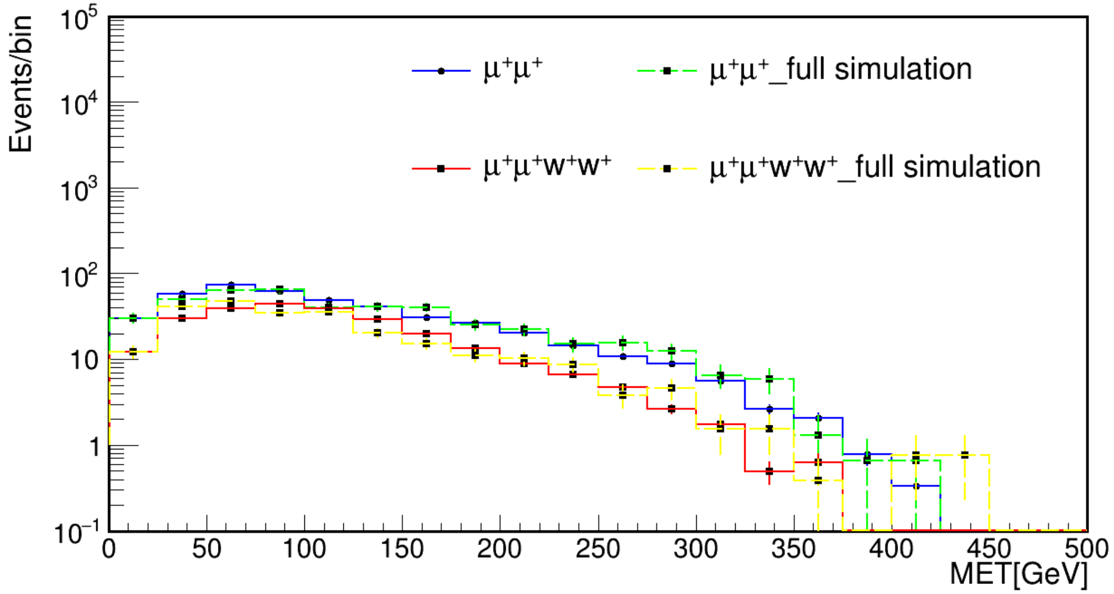
muon:

```
pxmu1               = 143.579
pxmu2               = -241.479
pymu1               = -28.5365
pymu2               = 46.6608
pzmu1               = -128.605
pzmu2               = 146.549
enmu1               = 194.855
enmu2               = 286.297
```

Muons are included in jets when nj$\geq$ 2 in final states. So, this part should be cut.

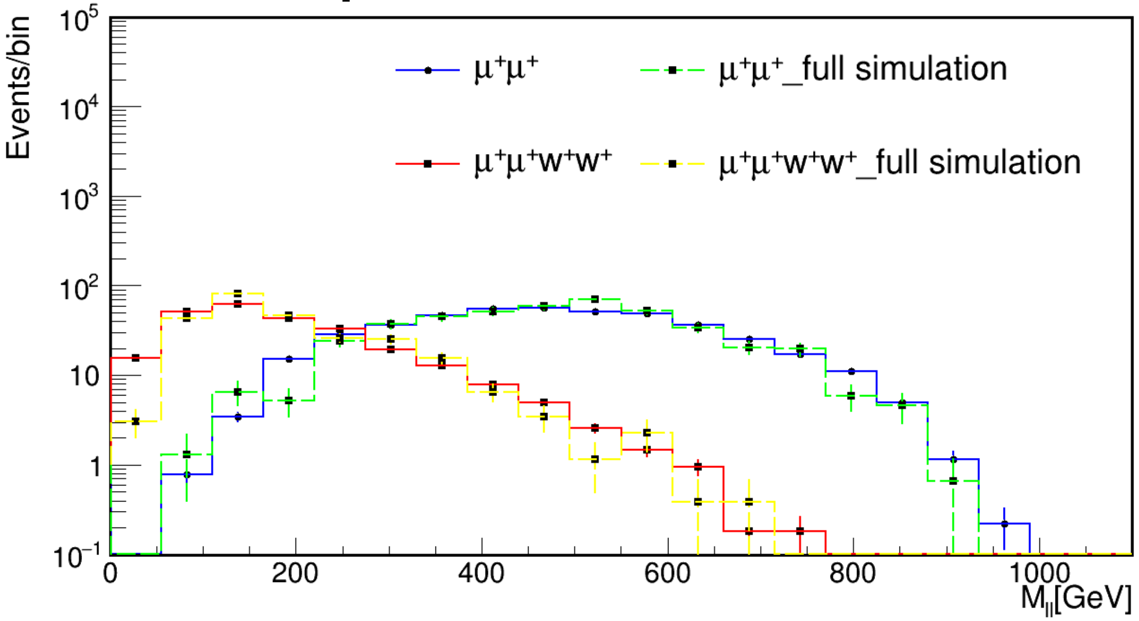
cut off the double-counted jets

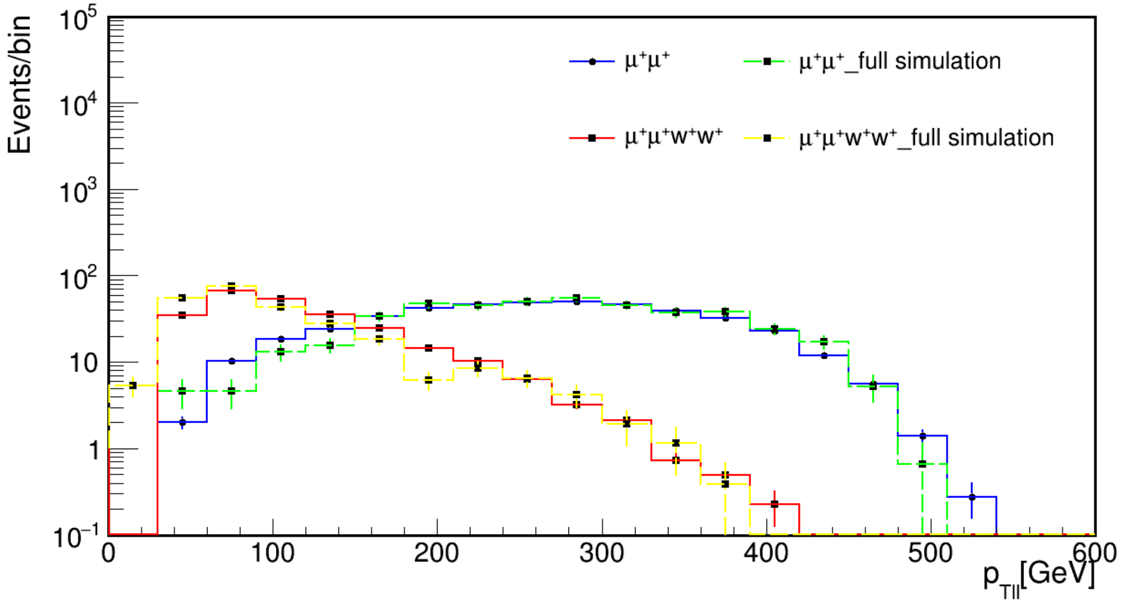


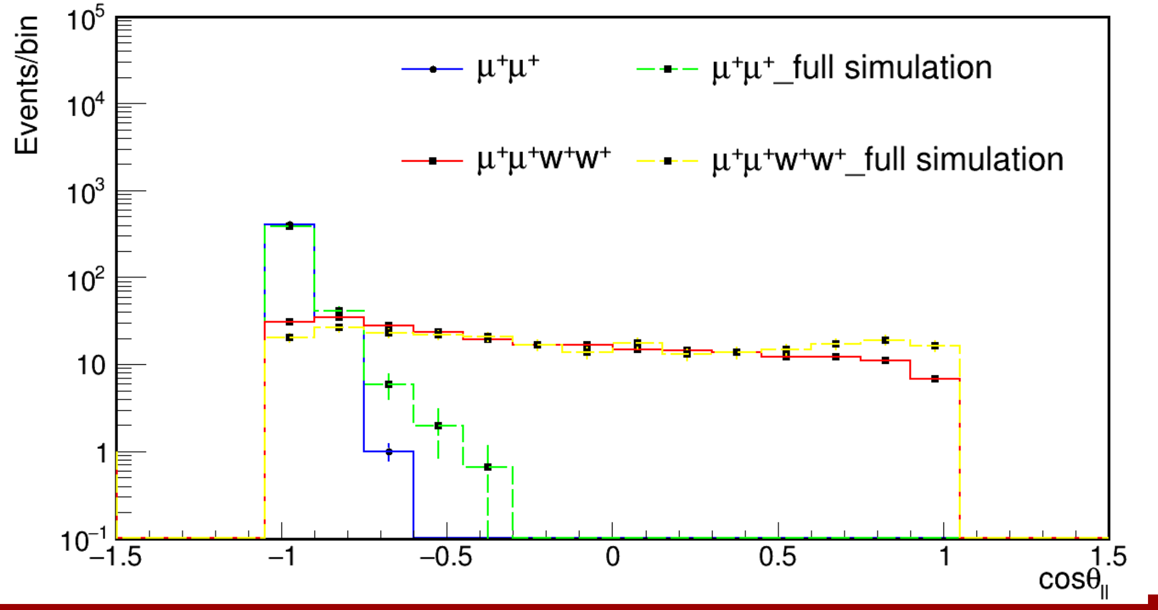


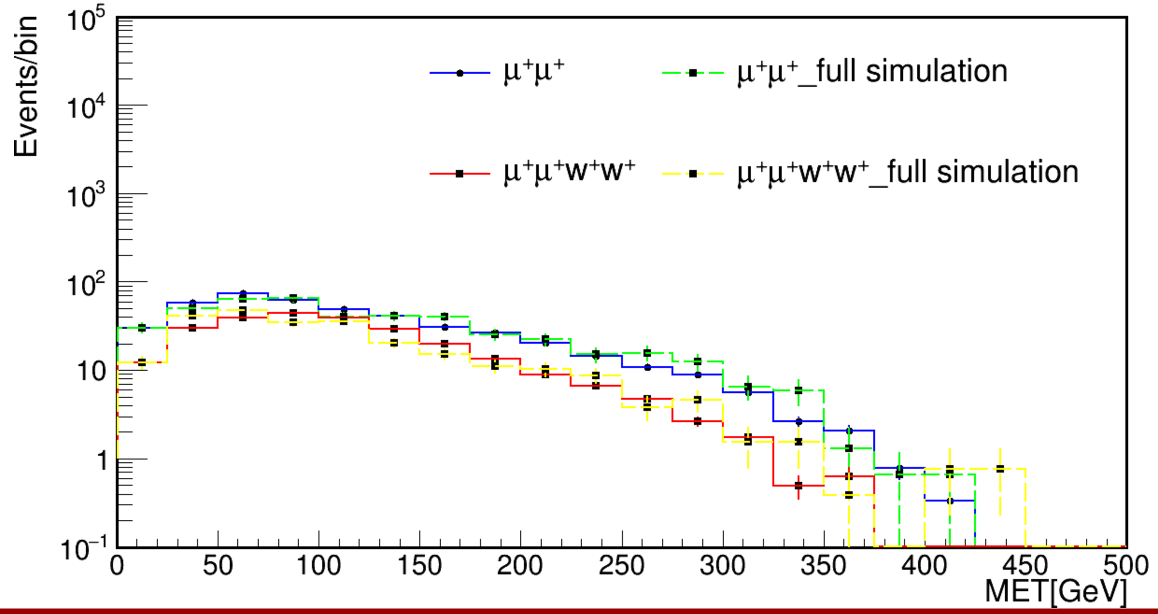
This result Improves a lot!

Total comparison results









Back UP

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1. Useful configuration files for reconstruction and analysis:

https://github.com/Ruobing2023/Muon-Collider-Software/blob/main/jet_reco2-jrb.xml

https://github.com/Ruobing2023/Muon-Collider-Software/blob/main/lctuple_steer-jrb.xml

2. My analysis program for output xxxxx.root and drawing program for comparison between fall simulation and fast simulation:

https://github.com/Ruobing2023/Muon-Collider-Software/blob/main/selection4.C

https://github.com/Ruobing2023/Muon-Collider-Software/blob/main/compare-mu.C

3. Detailed software introduction and jets reconstruction reference:

https://github.com/Ruobing2023/Muon-Collider-Software/blob/main/MuonCollider_Thesis_Paola_Mastrapasqua.pdf