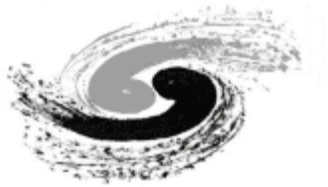
# Updates on the Higgs boson invisible decay

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- New sample generation
- Efficiency and yield study

# New sample generation

## ➢ Previous samples

- Simulated with Whizard 1.9.5 + Pythia 6 + CEPCSW 25.3

| | Processes | Location at lxlogin | Events |
|---|---|---|---|
| Signal | Z(→ee/μμ/qq)H(→4ν) | /cefs/higgs/liugeliang/CEPC/202503/Production/Hinvi | 100k per final state |
| 4-fermion backgrounds | single-Z, single-W, Z-or-W, ZZ, WW, ZZ-or-WW (41 final states in total) | /cefs/higgs/zhangkl/Production/25036/4fermions | 400k per final state |
| 2-fermion backgrounds | ee, μμ, ττ, qq | /cefs/higgs/zhangkl/Production/25036/E240_e1e1(e2e2, e3e3, qq) | 100k – 400 k per final state |
| ZH | Z(→ee/μμ/ττ/νν/qq) H(→incl) | /cefs/higgs/zhangkl/Production/25036/E240_*HX | 1M per sample |

## ➢ New samples

- Whizard 3.1.7 + Pythia 8: https://code.ihep.ac.cn/shuohan/Whizard3_at_IHEP
- CEPCSW 25.8.0 + PID in rec: 943b96
  - PID information during reconstruction in the new collection CyberPFOPID
  - Following Ntuple production can be processed quickly with negligible memory consumption.

# Whizard 3.1.7: cross section computation

## ➢ Higgs boson production at LO

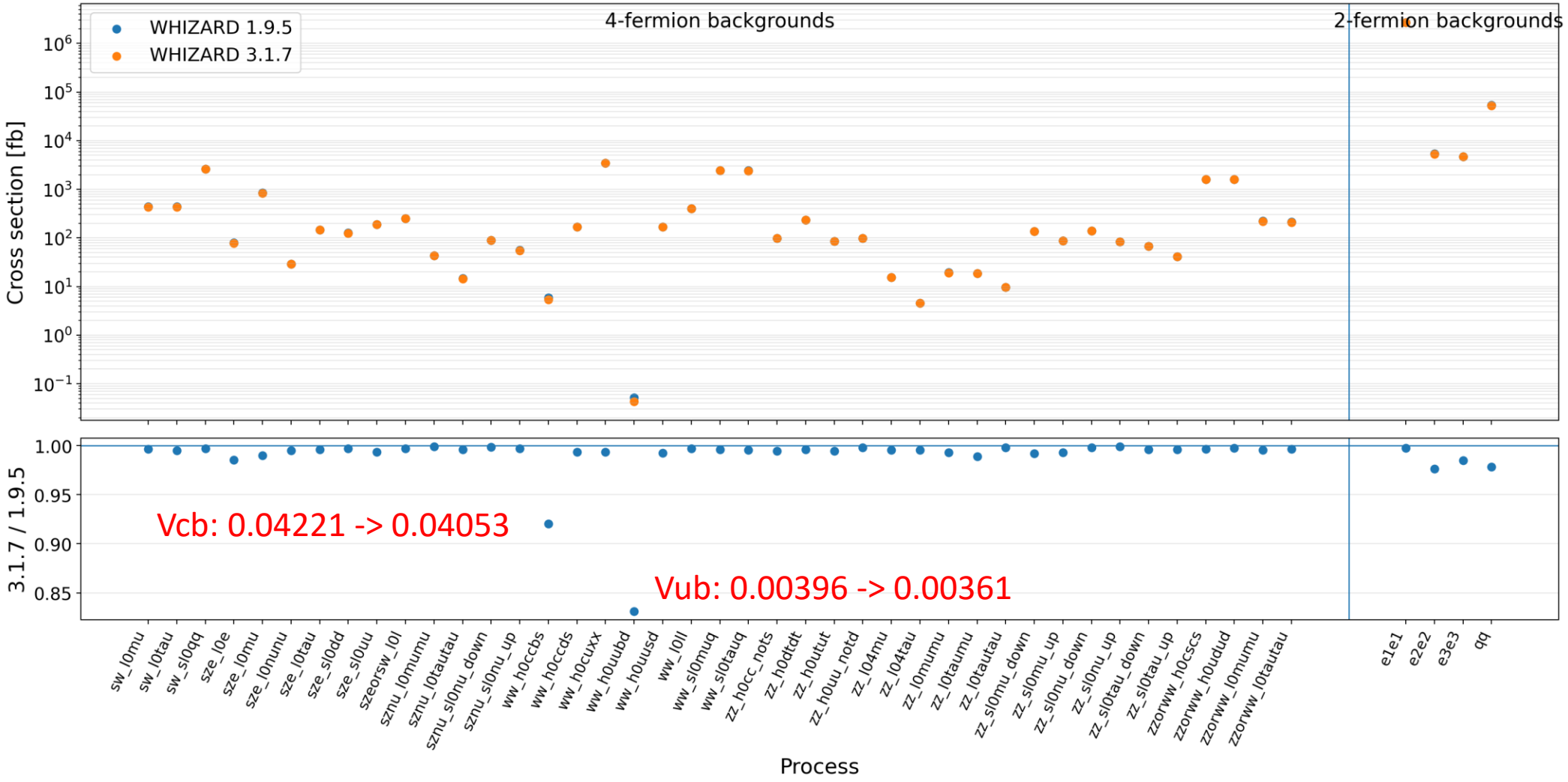
| Final state | WHIZARD 1.95 [fb] | WHIZARD 3.1.7 [fb] | Change |
|---|---|---|---|
| $e^+e^-H$ | 7.04680 ± 0.00521 | 7.18060 ± 0.00775 | +1.90% |
| $\mu^+\mu^-H$ | 6.77424 ± 0.00423 | 6.72662 ± 0.00433 | -0.70% |
| $\tau^+\tau^-H$ | 6.75262 ± 0.00420 | 6.71504 ± 0.00433 | -0.56% |
| $\nu\bar{\nu}H$ | 46.34592 ± 0.03170 | 45.98975 ± 0.02940 | -0.77% |
| $q\bar{q}H$ | 136.76249 ± 0.08740 | 136.08787 ± 0.08960 | -0.49% |
| Sum | 203.68207 ± 0.09331 | 202.69988 ± 0.09482 | -0.48% |

## ➢ Higgs boson production at NLO EW

- Tried to install the NLO calculator openloops and Recola.
- Tried to calculate the Higgs boson production cross sections, all with Recola.
- The cross sections are 7-20% lower than the LO ones: not sure if the results are trustworthy.

# Whizard 3.1.7: cross section computation

- Four-fermion and two-fermion backgrounds



# New samples

| | Processes | Location of Hep files | Location of Rec files | Events |
|---|---|---|---|---|
| Signal | Z(→ee/μμ/qq)H(→4v) | /scratchfs2/cms/liugeliang/whizard/Hinvi/outputs | /cms/user/liugeliang/CEPC/202608/Production/Hinvi | 200k per final state |
| 4-fermion | single-Z, single-W, Z-or-W, ZZ, WW, ZZ-or-WW | /scratchfs2/cms/liugeliang/whizard/4fermions/outputs | /cms/user/liugeliang/CEPC/202608/Production/4fermions<br>Only 9 major backgrounds are simulated and reconstructed | 100k per final state |
| 2-fermion | ee, μμ, ττ, qq | /scratchfs2/cms/liugeliang/whizard/2fermions/outputs | /cms/user/liugeliang/CEPC/202608/Production/2fermions | 100k per final state |

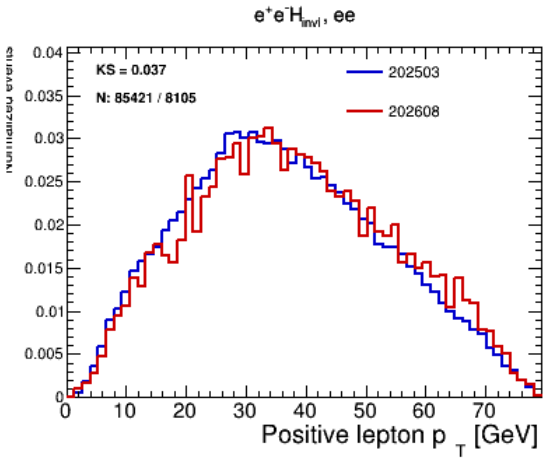
## ➢ Issues

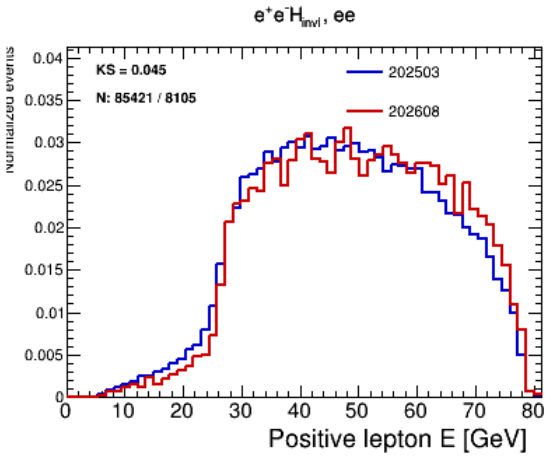
- If a generated final state particle has a vertex outside of the detector world, when the vertex is picked up by Geant4, it crashes: added a protection in Simulation/DetSimCore/src/G4PrimaryCnvTool.cpp
- A few more issues happening only in 2-fermion backgrounds, still under investigation.

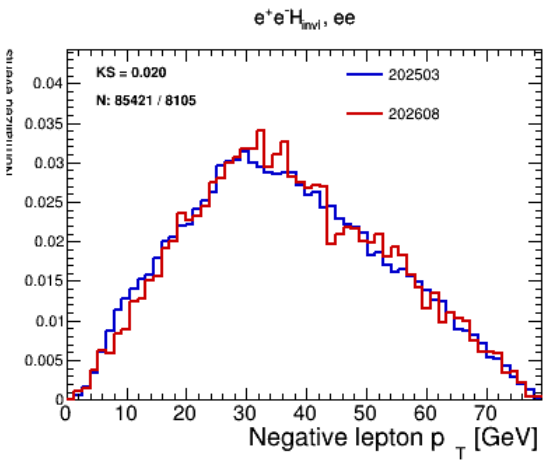
# Compare kinematics

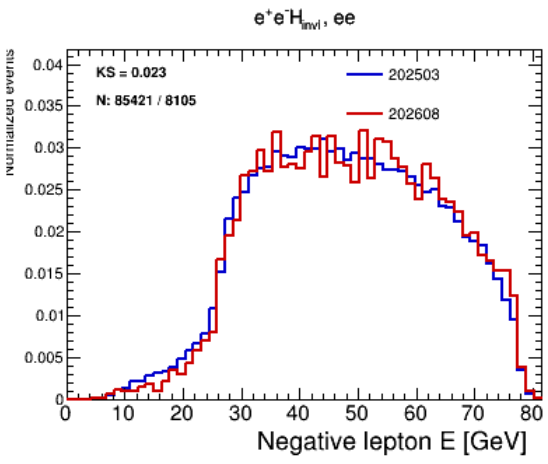
## ➢ ee channel

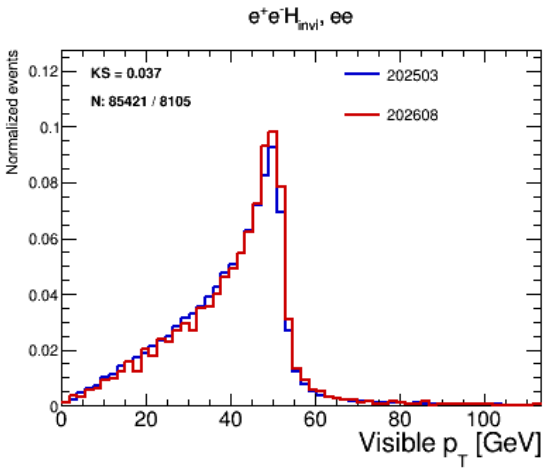
- Signal

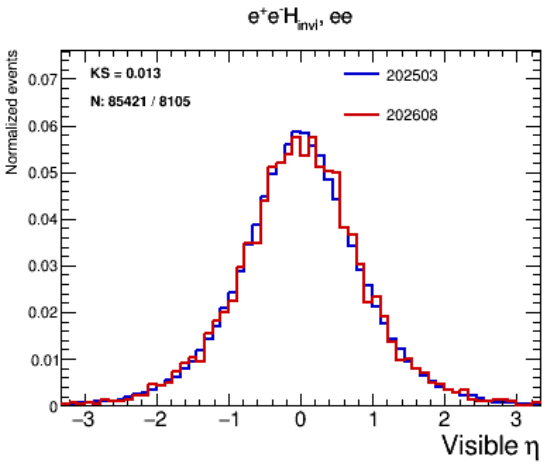


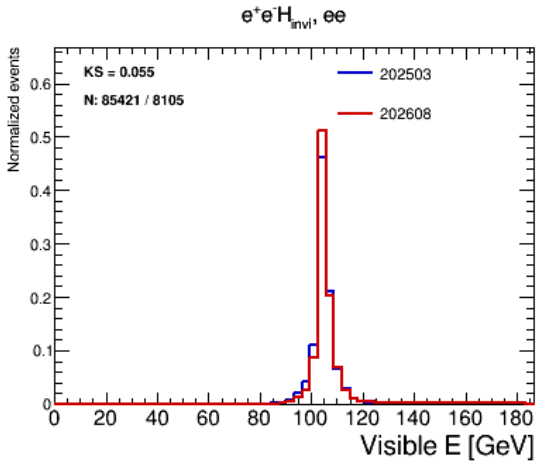



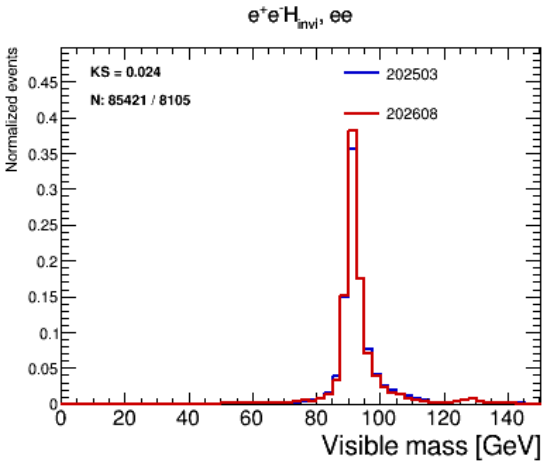



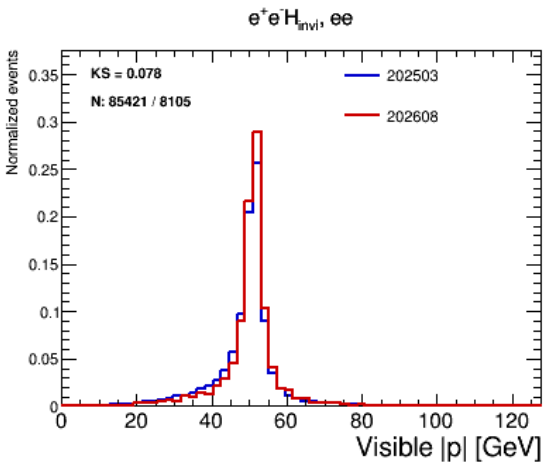



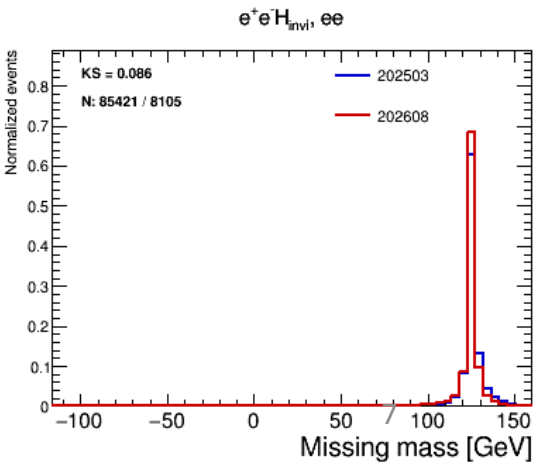



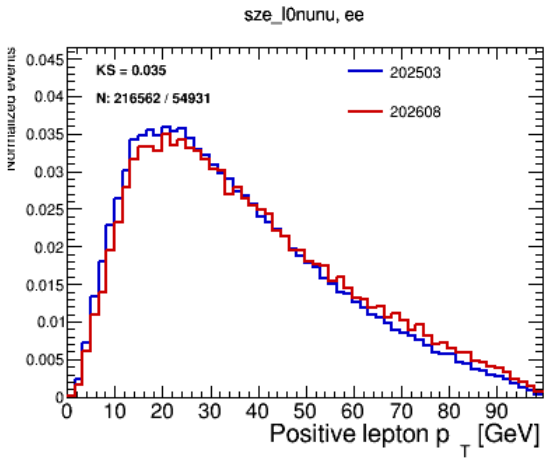



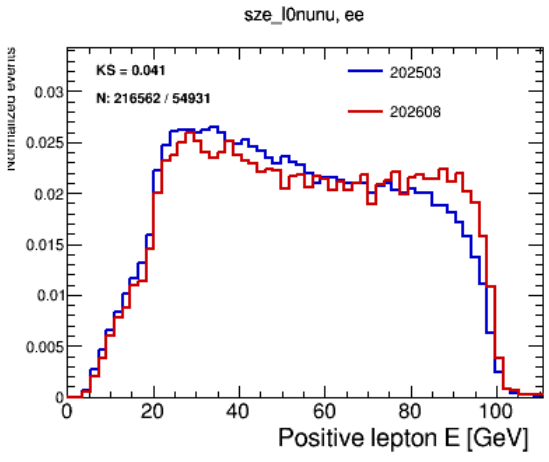



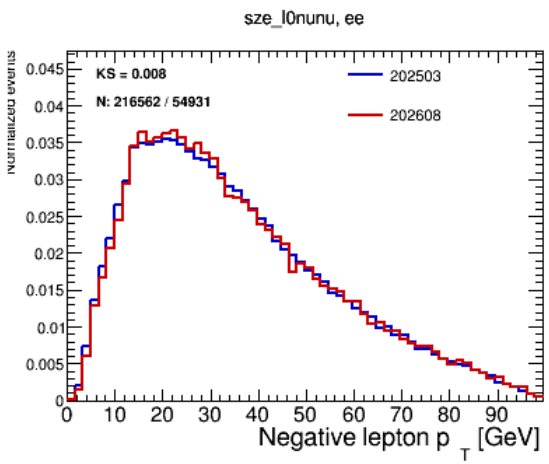
# Compare kinematics

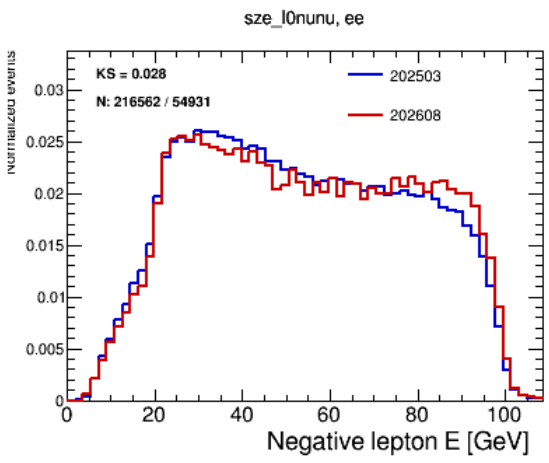
## ➢ ee channel

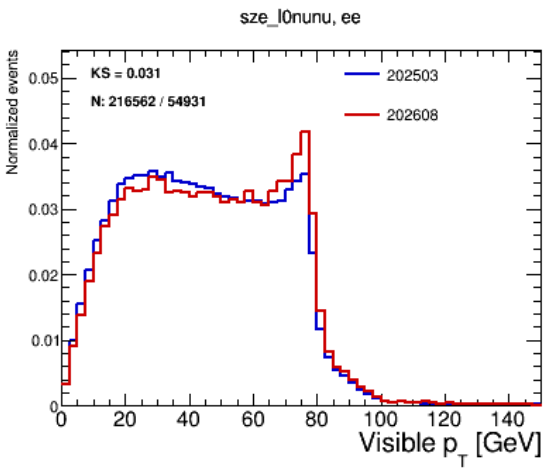
- Major background

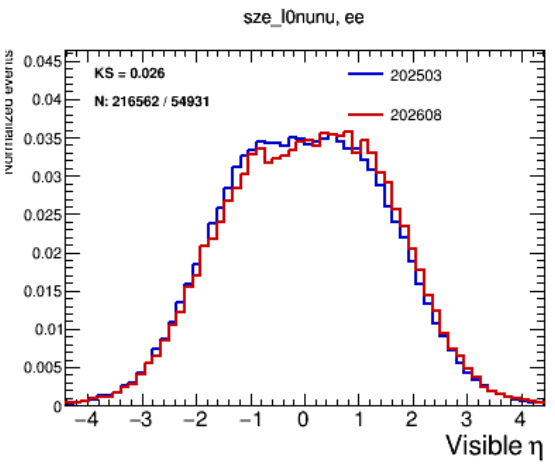


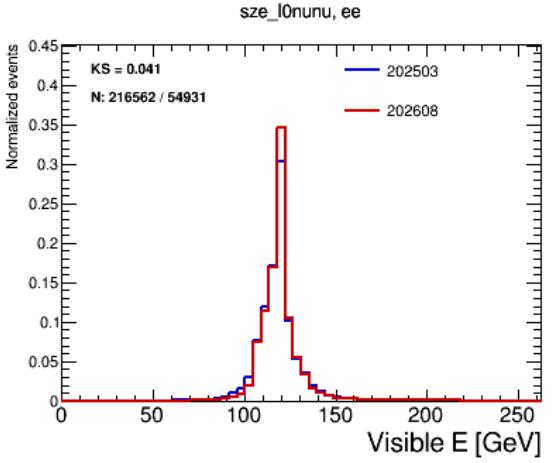



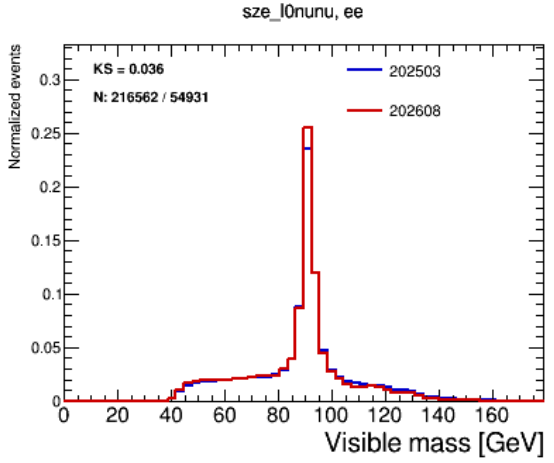



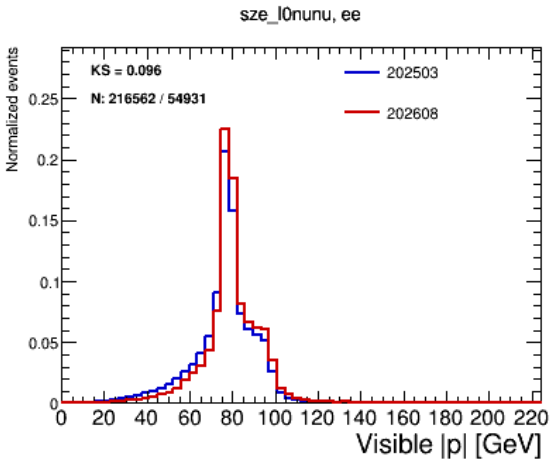



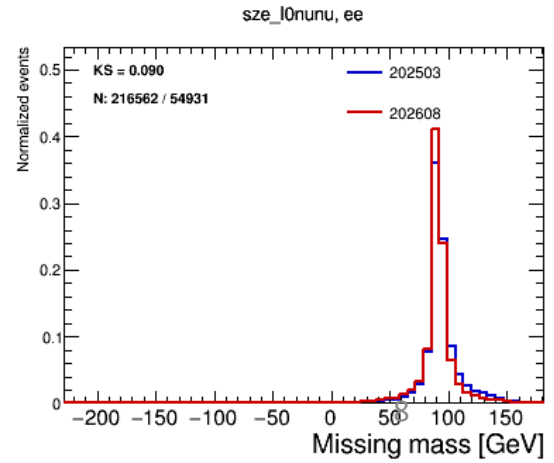



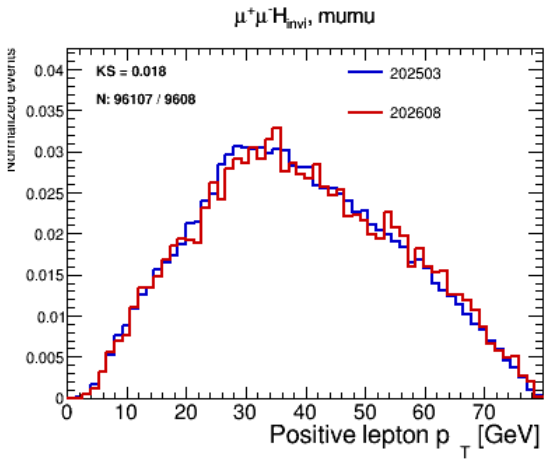



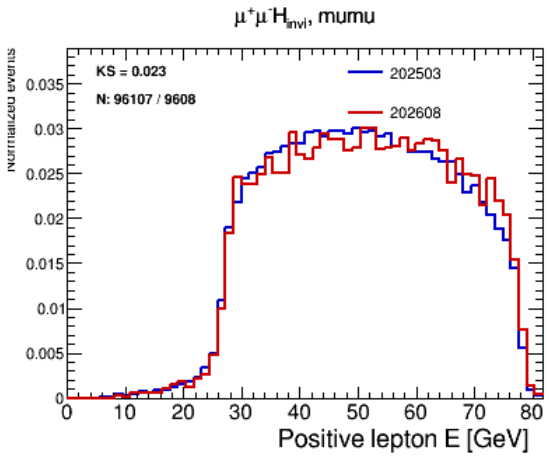



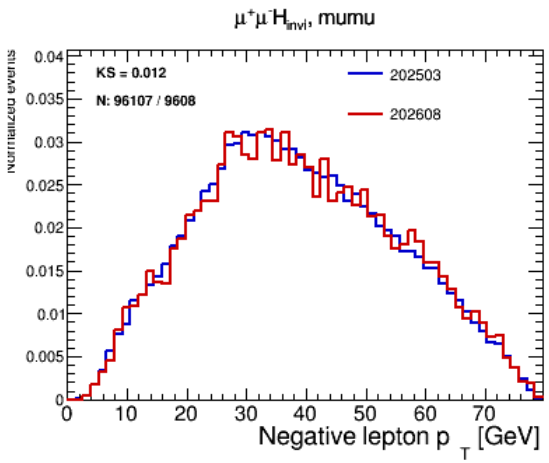



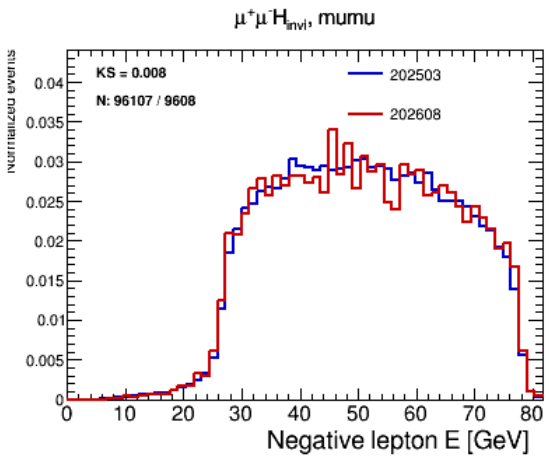
# Compare kinematics

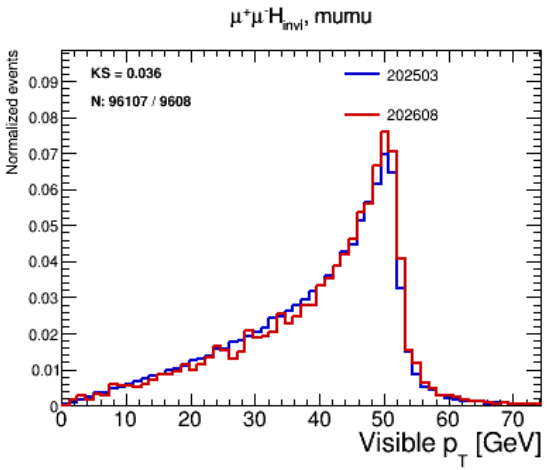
- **μμ channel**
  - Signal

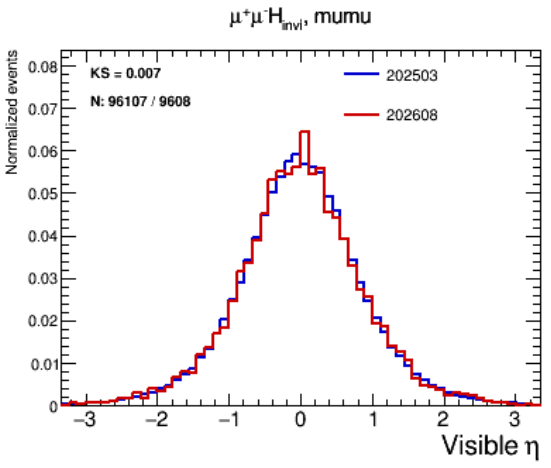


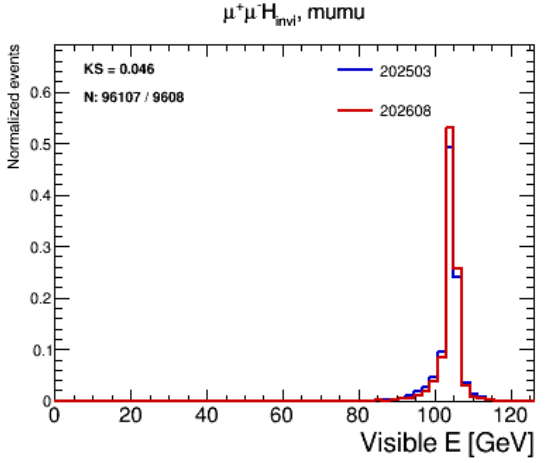



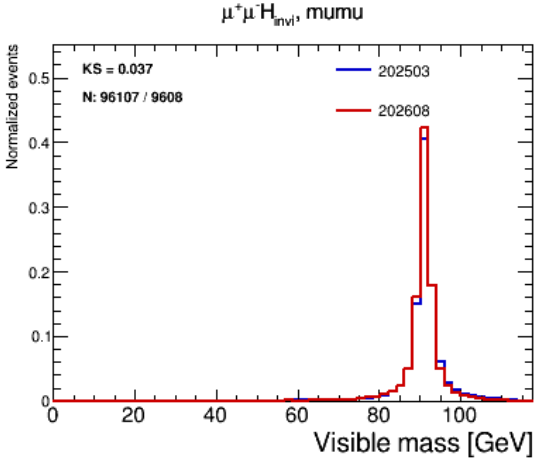



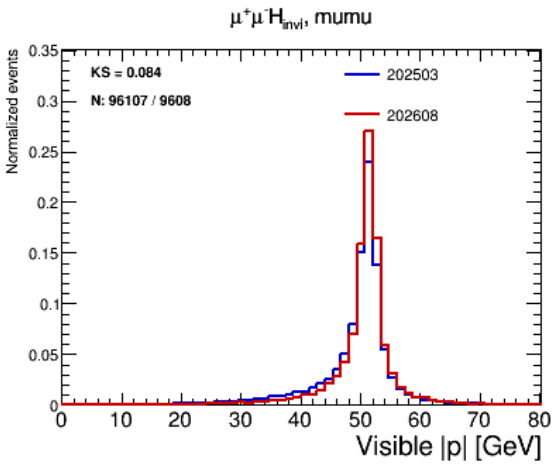



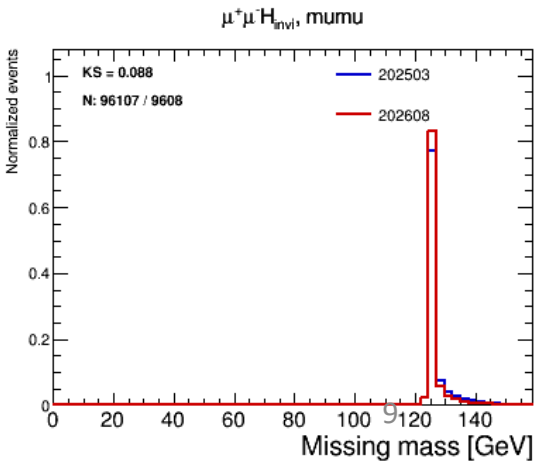



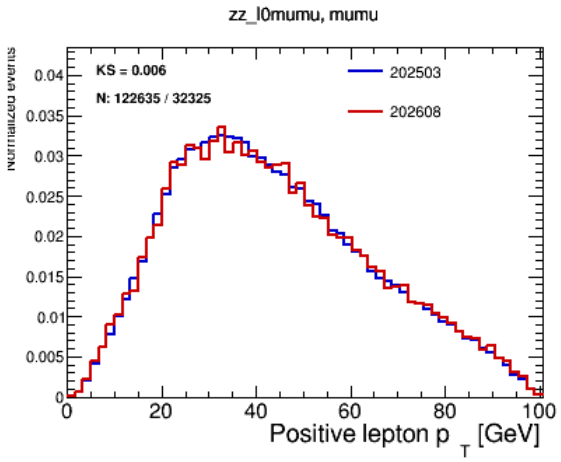



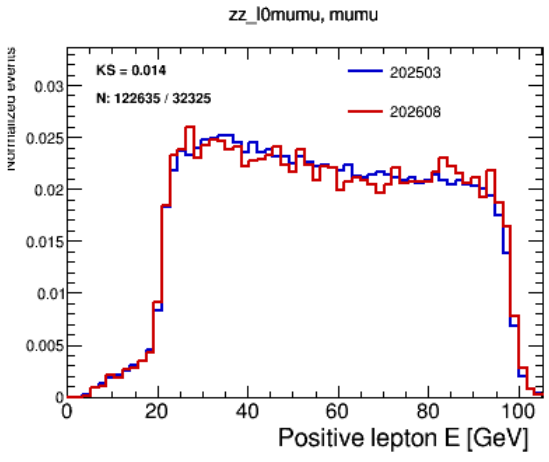



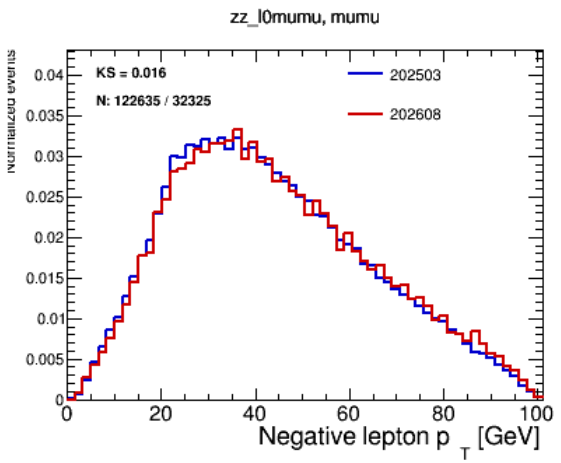



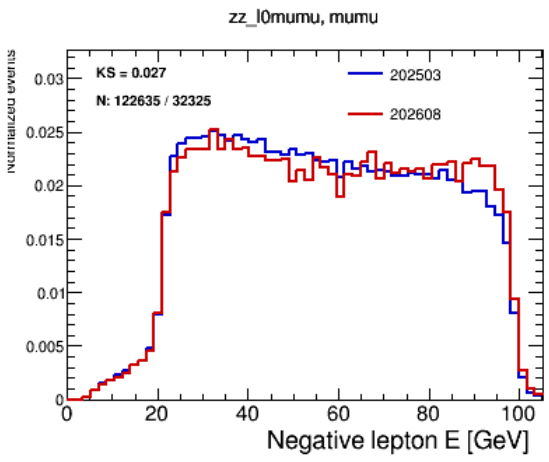
# Compare kinematics

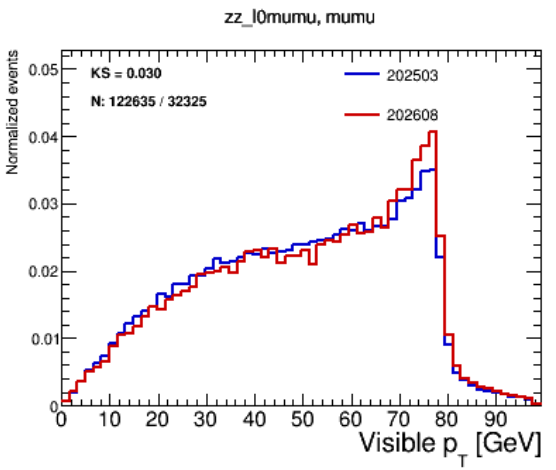
- μμ channel
  - Major background

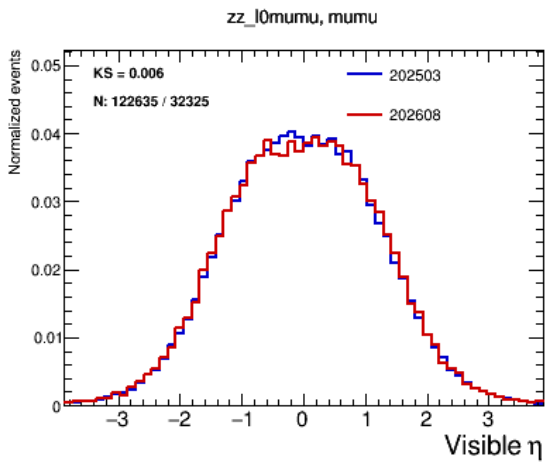


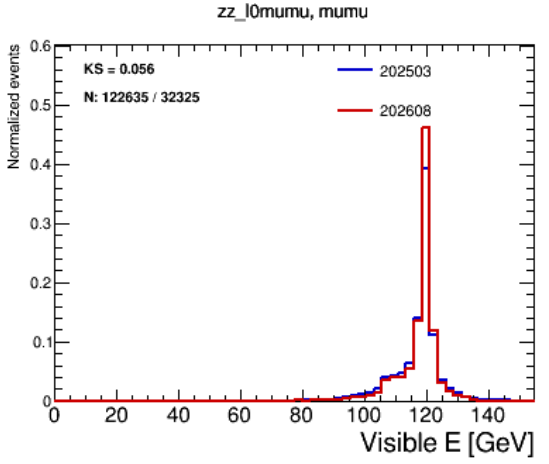



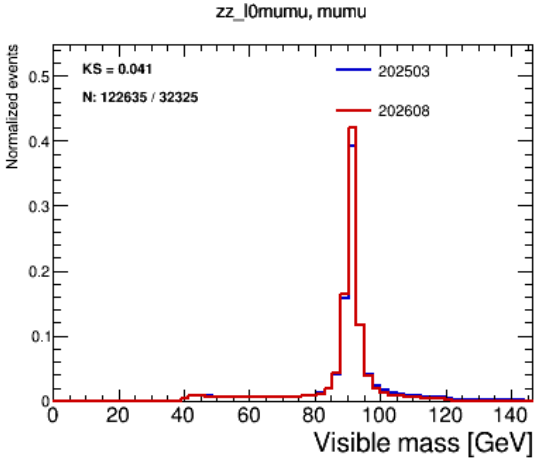



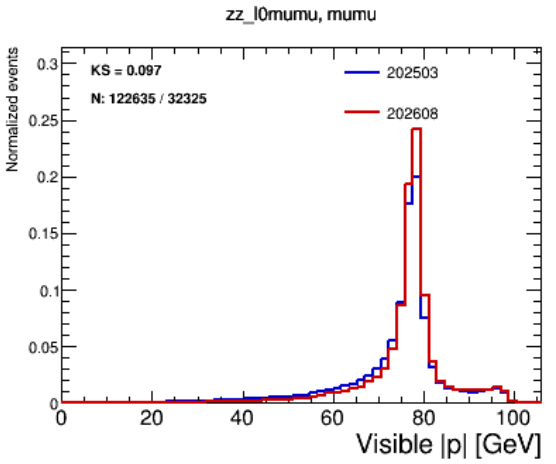



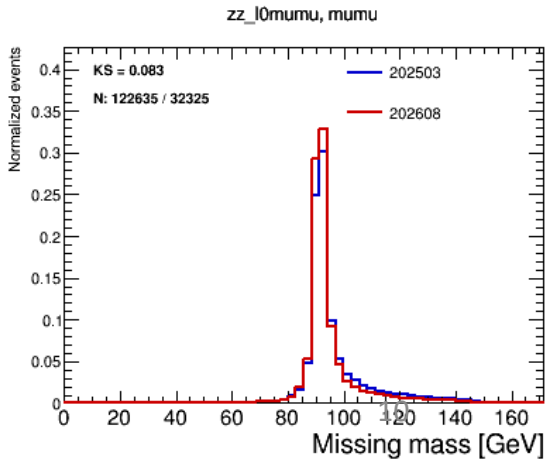



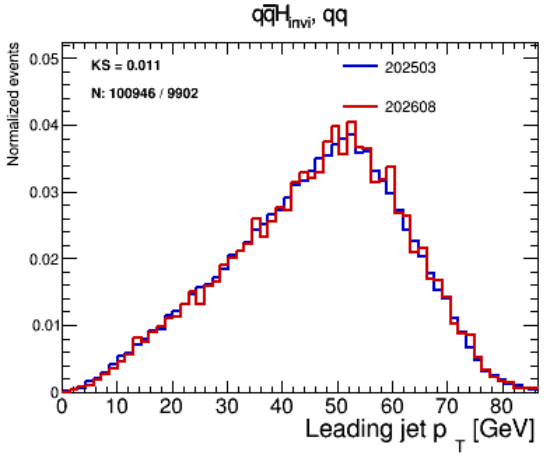



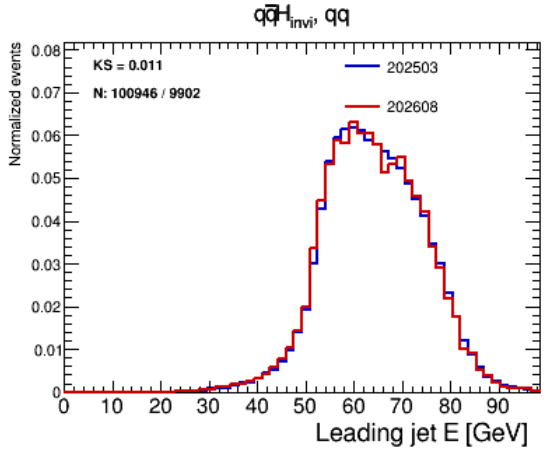



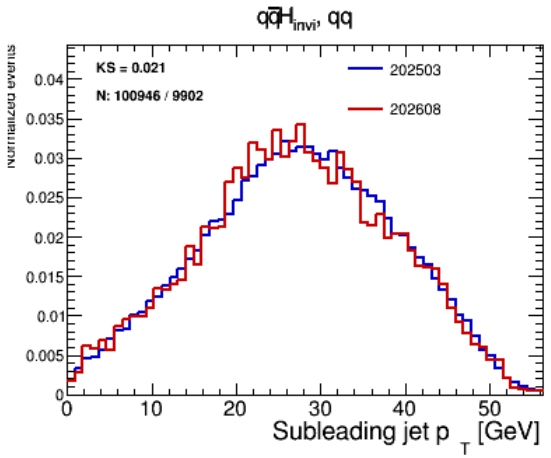



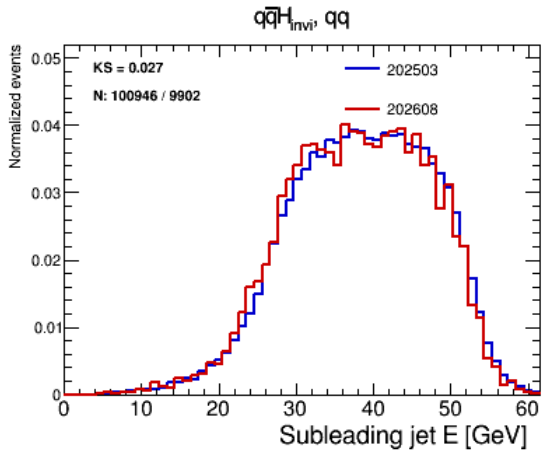
# Compare kinematics

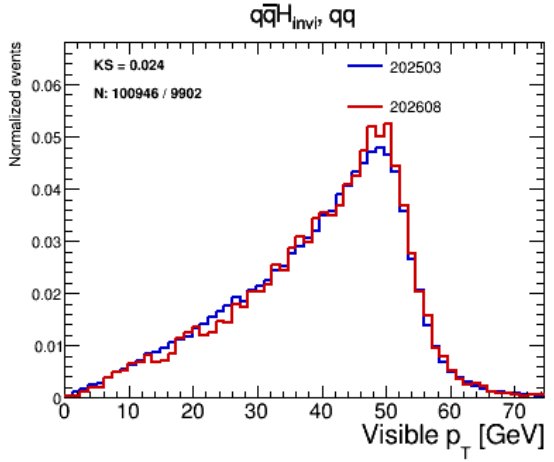
- qq channel
  - Signal

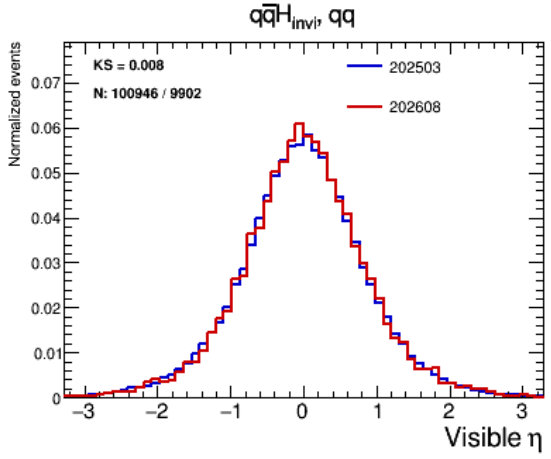


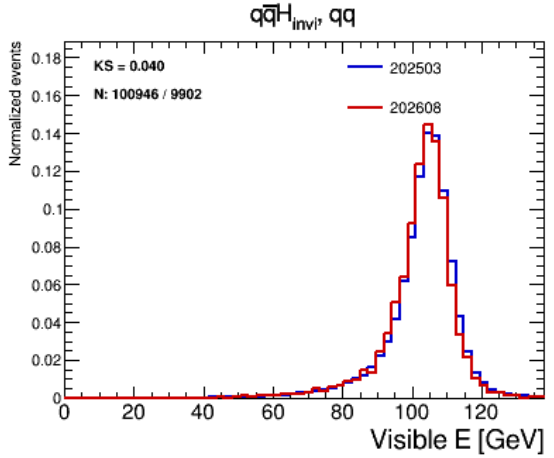



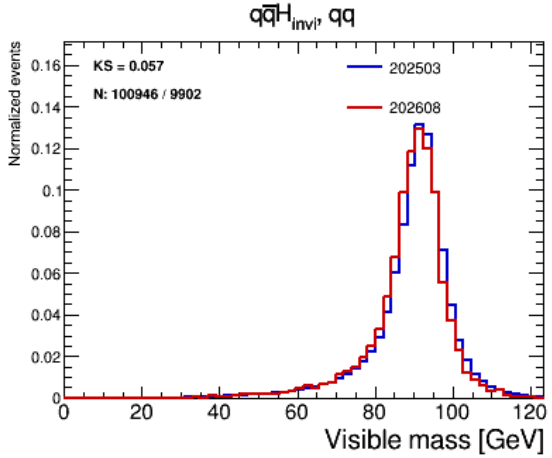



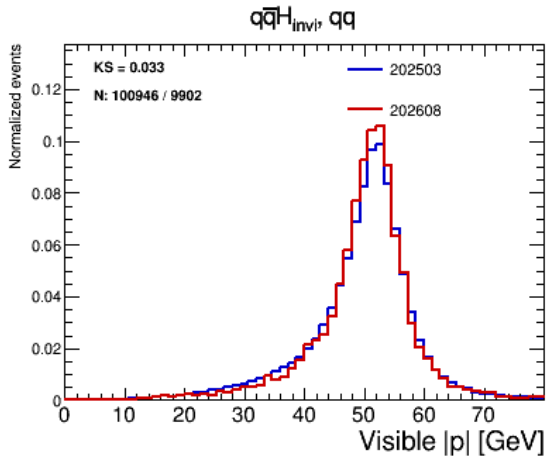



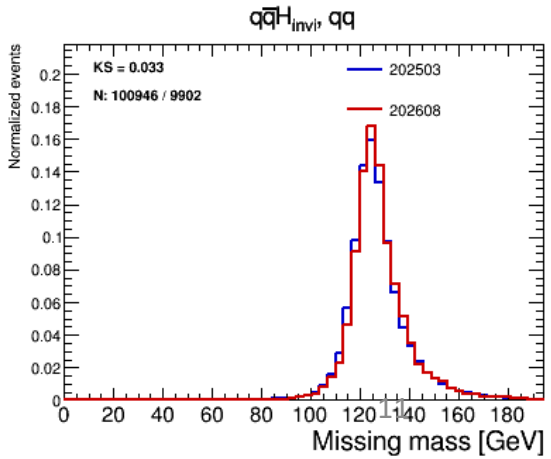



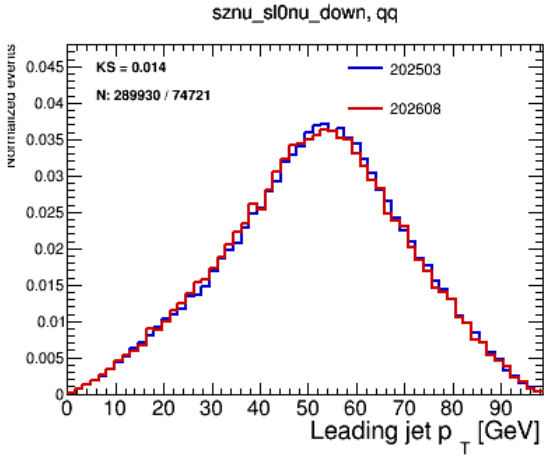



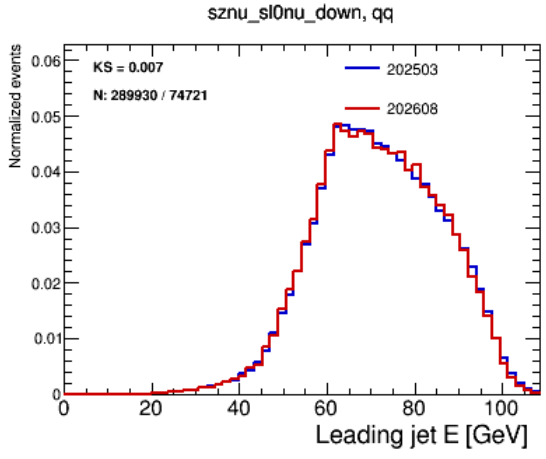



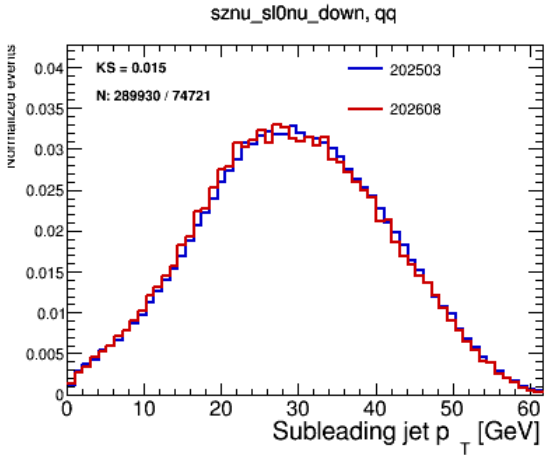
# Compare kinematics

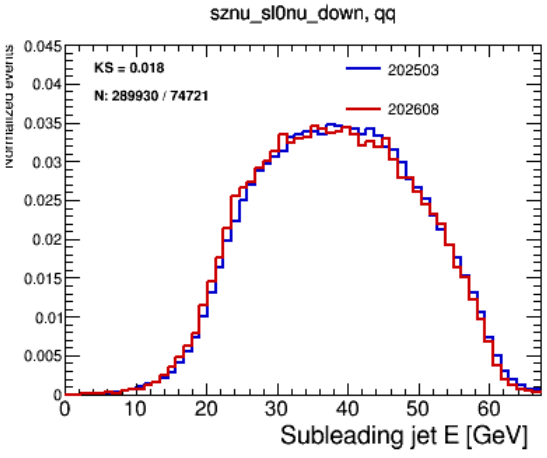
## ➢ qq channel

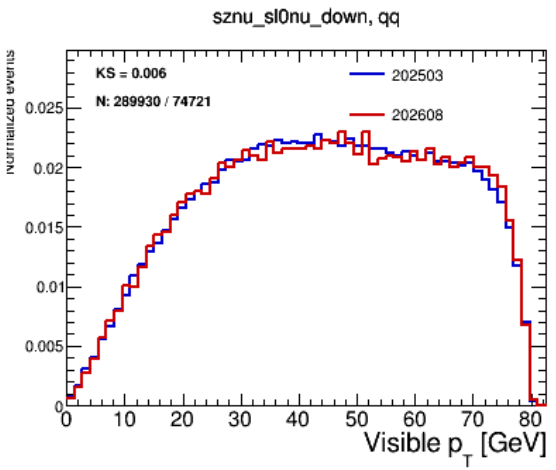
- Major background

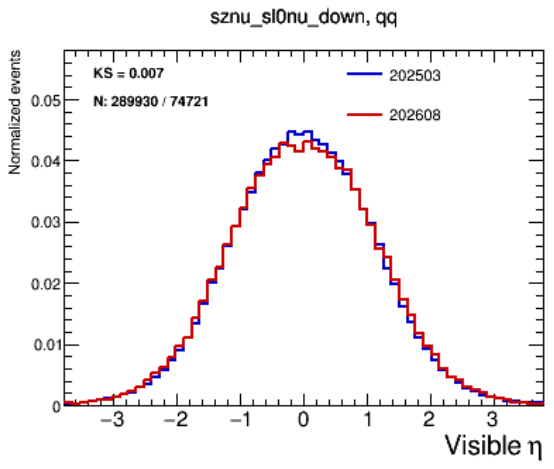


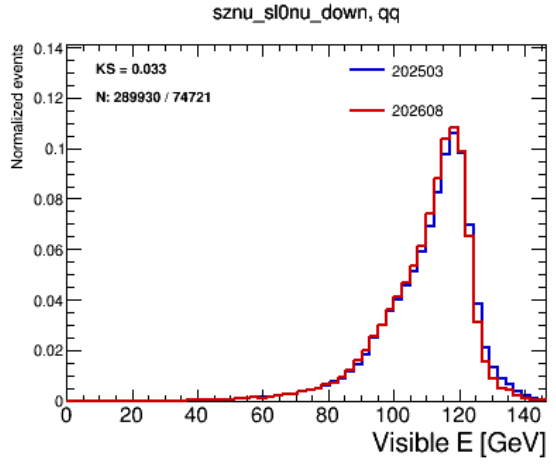



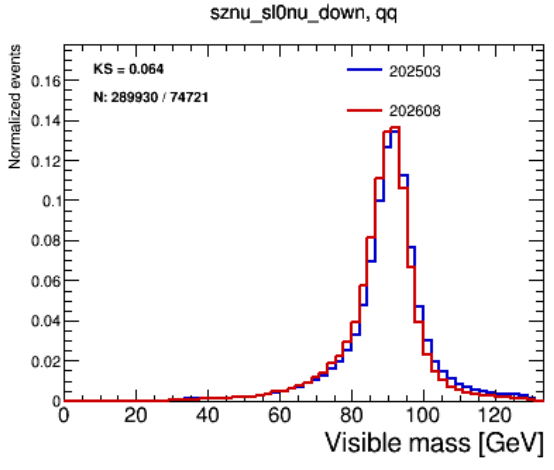



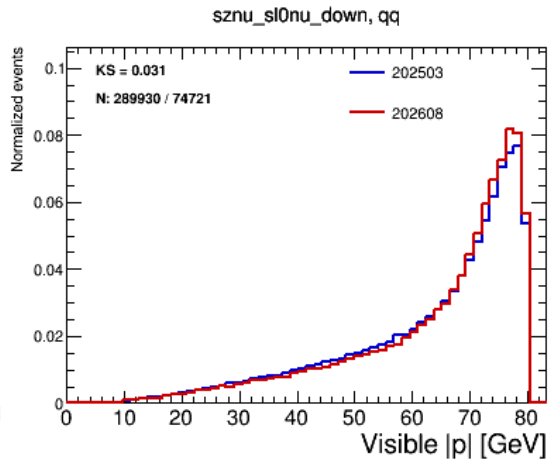



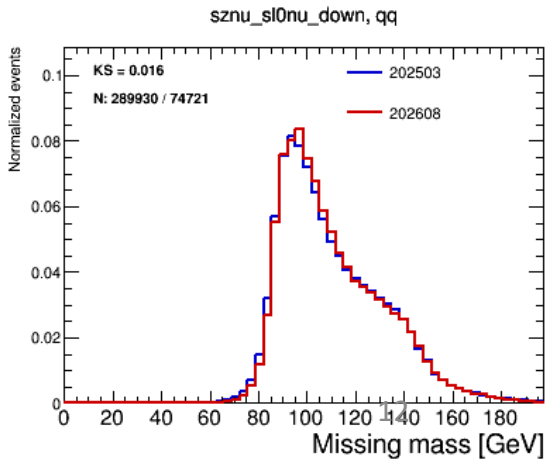



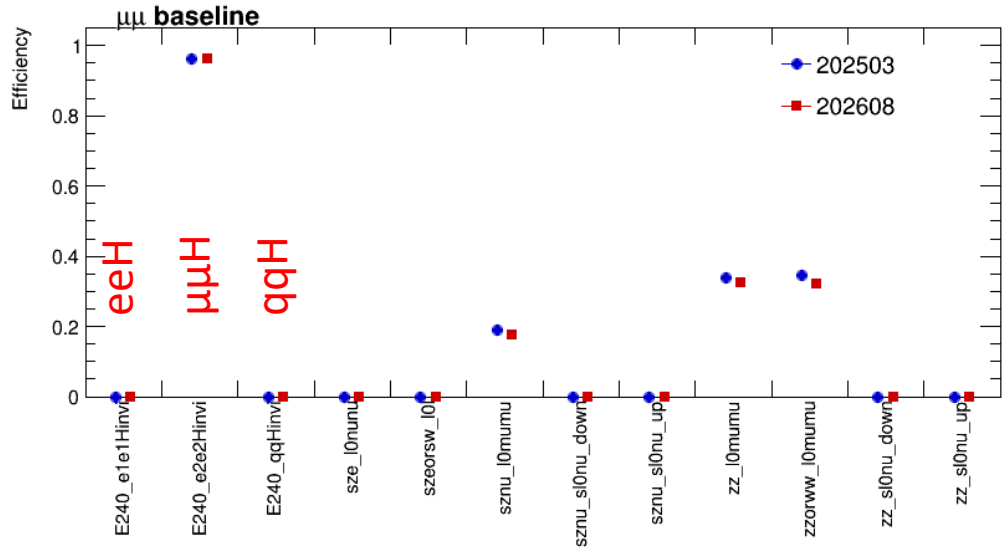



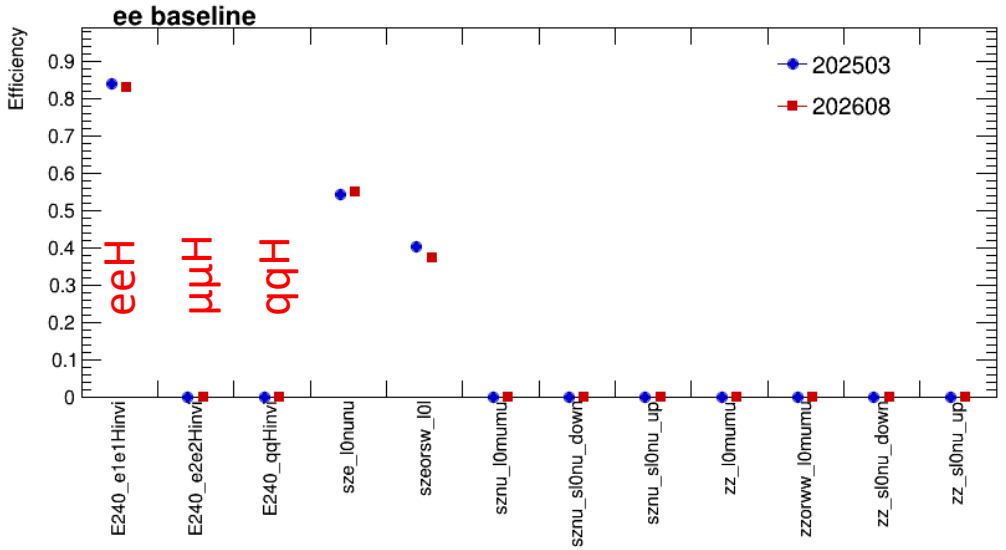



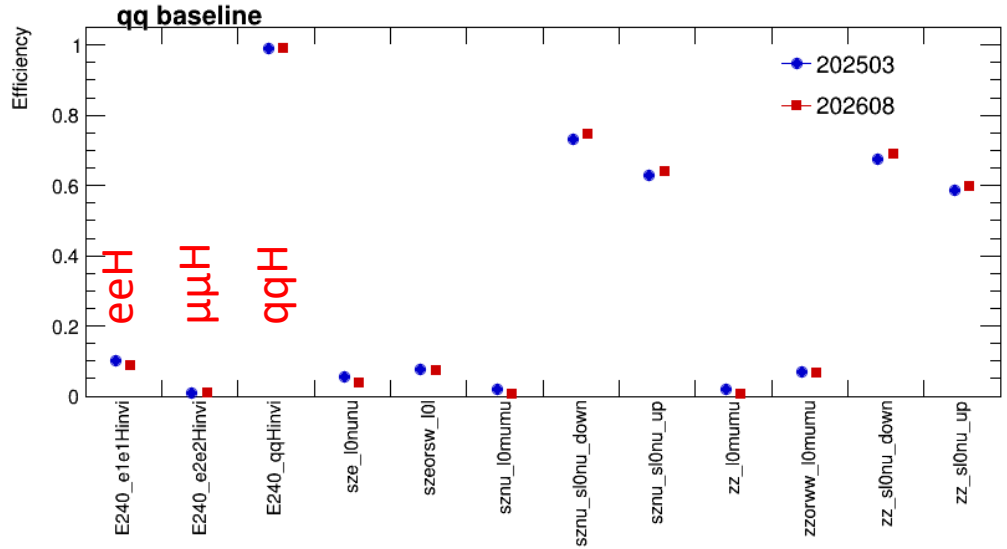



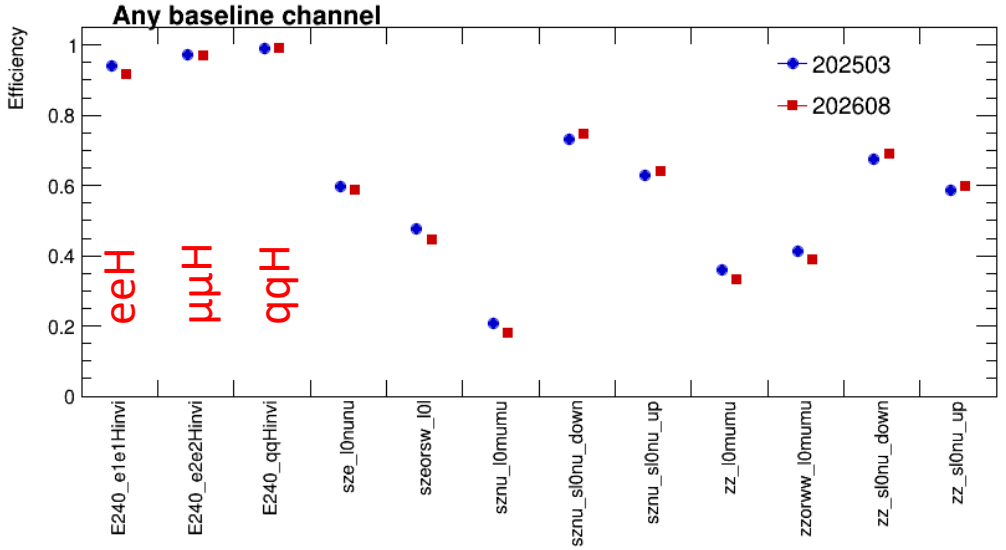



# Comparison of baseline selection efficiency



# Efficiency and yield study

## ➢ Aim

- In preparation for full simulation sample production, decide which (background) samples are more important and worth more events, and which samples are not needed at all.

## ➢ Procedure

- Based on the 202503 samples.
- For a given channel, compute the remaining yield for each background after both baseline and kinematic selections.
- If the yield is above 1% of the total background yield, rank this background as important -> 1M events.
- If the yield is above 0.01% of the total background yield, rank this background as unimportant -> 100k events.
- If the yield is below 0.01%, rank this background as useless -> 0 events.

## ➢ Total backgrounds required

- Important backgrounds: 19 * 1M
- Unimportant backgrounds: 20 * 100k
- Useless backgrounds: 12 * 0
- Total: 21M ~ 15 days if I can constantly use 500 cores

# Other preparations

## ➢ Fix bugs

- Fix the few bugs when simulating the 2fermion backgrounds.

## ➢ Optimization

- Explore potential improvements to speed up
- Explore if it is now possible to increase number of events per job (to save the initialization time)