Pythia for DM indirect detection

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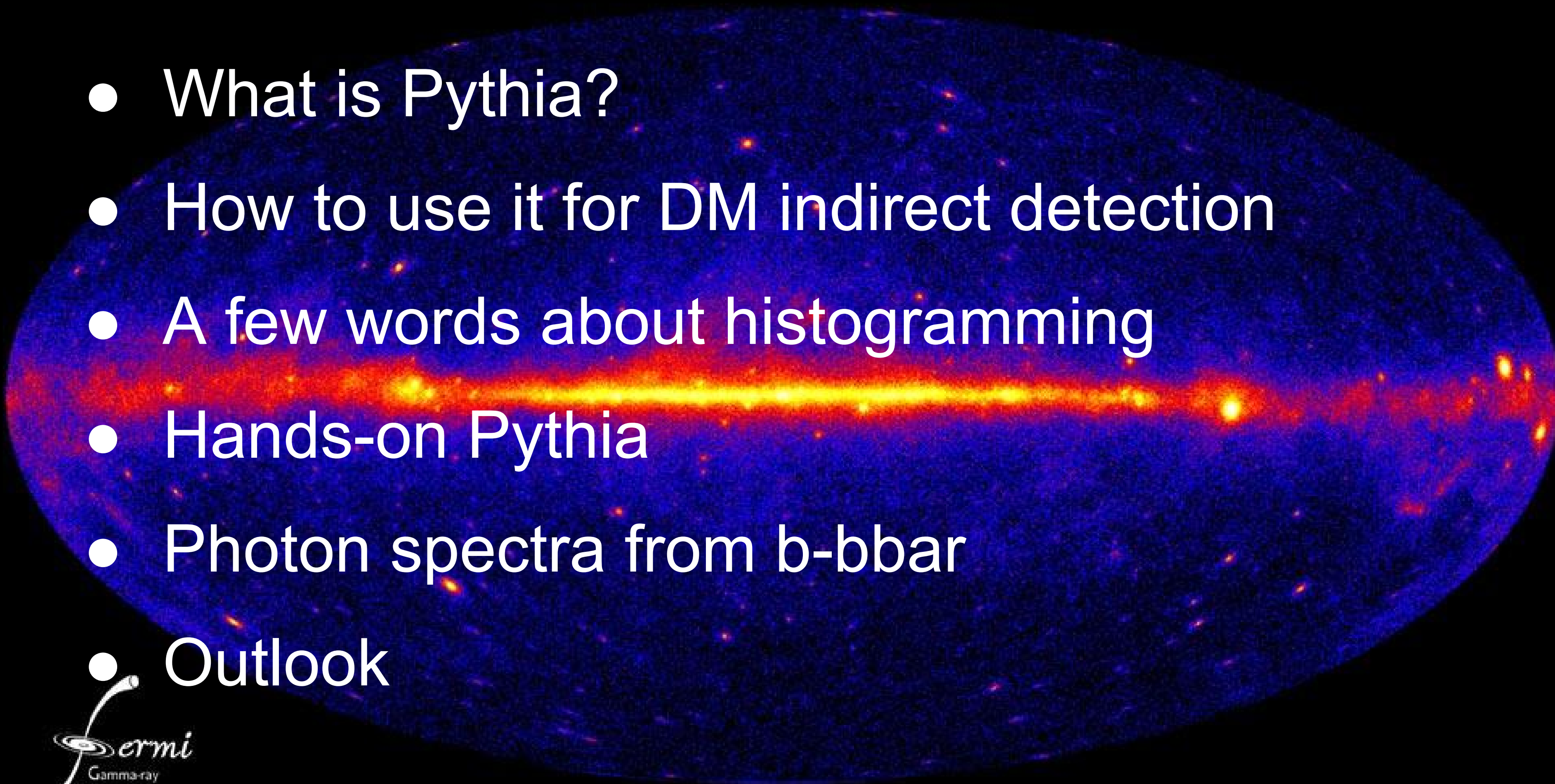
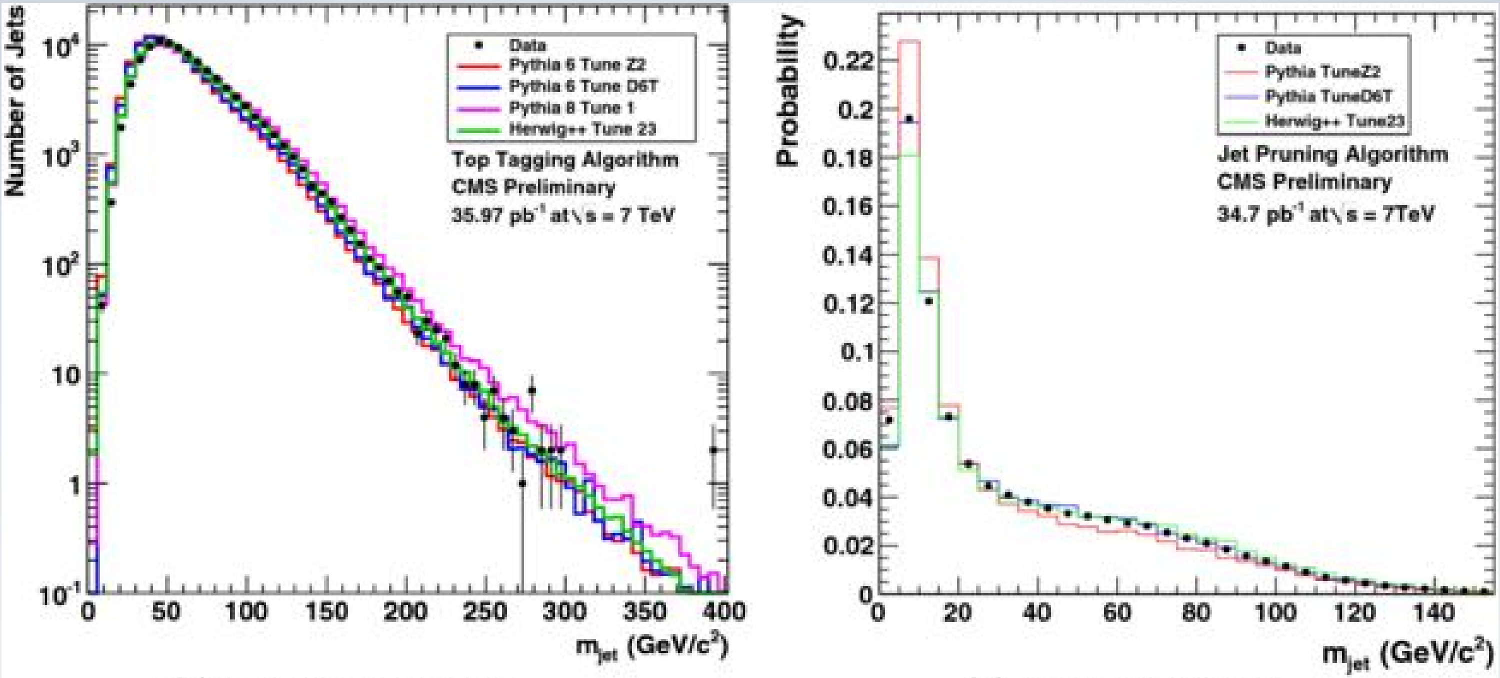
Workshop on DM tools and hands-on Fermi data analysis tools
Valencia 22-26 April

The roadmap



- What is Pythia?
- How to use it for DM indirect detection
- A few words about histogramming
- Hands-on Pythia
- Photon spectra from b-bbar
- Outlook

What is Pythia?



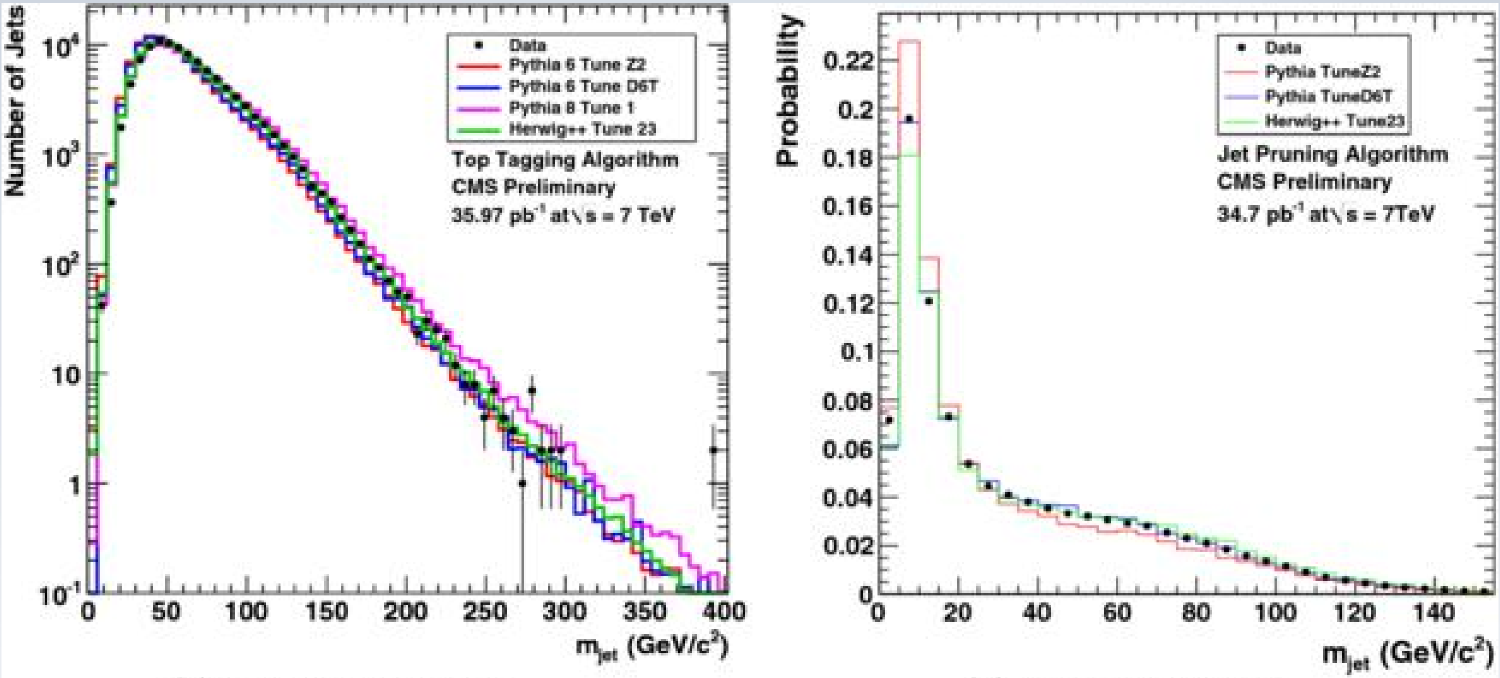
(a) Top-tagged jet mass.

(b) W-tagged jet mass.

It is a particle physics Monte Carlo generator that is mainly used for event simulation and statistical analysis in colliders like LHC (LEP, TeVatron, etc.)

There are alternatives: HERWIG and SHERPA.

What is Pythia?

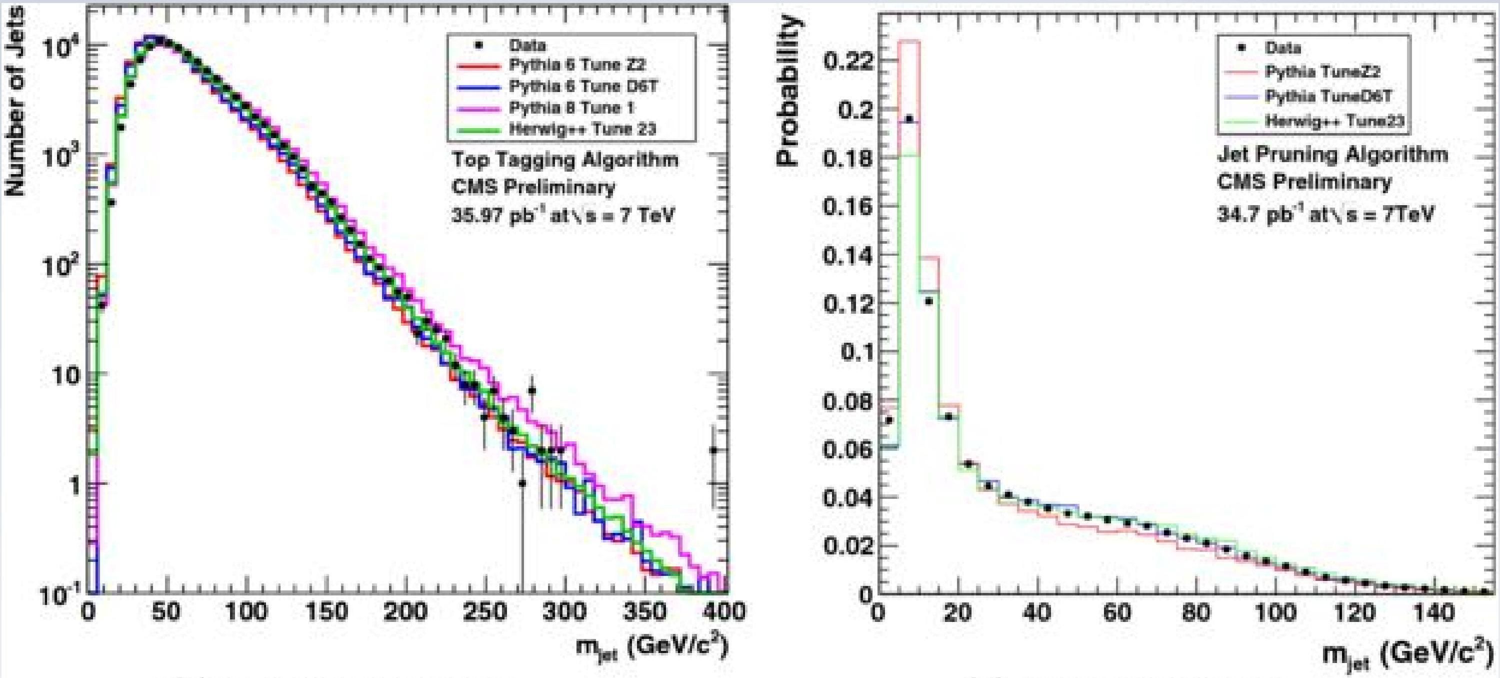


(a) Top-tagged jet mass. (b) W-tagged jet mass.

There are currently two branches:

- Pythia 6.4 written in Fortran
- Pythia 8 written in C/C++

What is Pythia?



(a) Top-tagged jet mass. (b) W-tagged jet mass.

We will work on the Fortran version, because it is easier to learn and produces output similar to the C/C++ version.

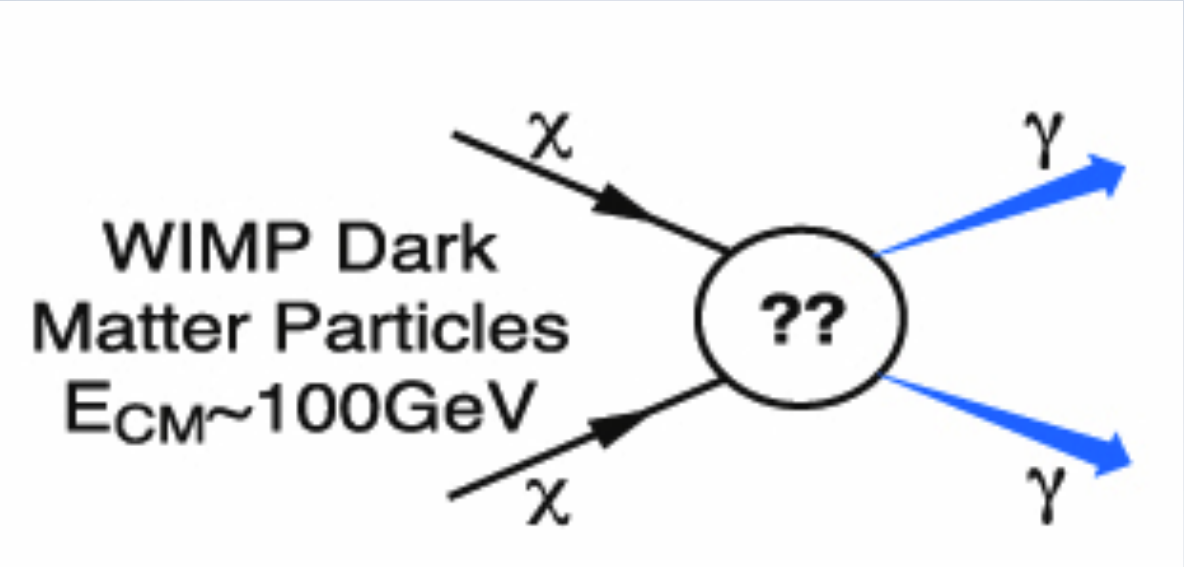
Particle spectra from DM

DM annihilation (decay) signal depends on:

- DM distribution
- annihilation cross section (or lifetime)
- emission spectra of particles (e.g. photons)

$$Q(E,\vec{r}) = \begin{cases} \rho^2(\vec{r})\,\dfrac{\langle\sigma v\rangle_{\rm DM}}{2m_{\rm DM}^2}\displaystyle\sum_f \frac{dN^f}{dE}B_f \\ \\ \rho(\vec{r})\,\dfrac{1}{m_{\rm DM}\tau_{\rm DM}}\displaystyle\sum_f \frac{dN^f}{dE}B_f \end{cases}$$

Photon spectra from DM



$$\frac{dN^f}{dE}.$$ = number of photons per unit energy per annihilation/decay event

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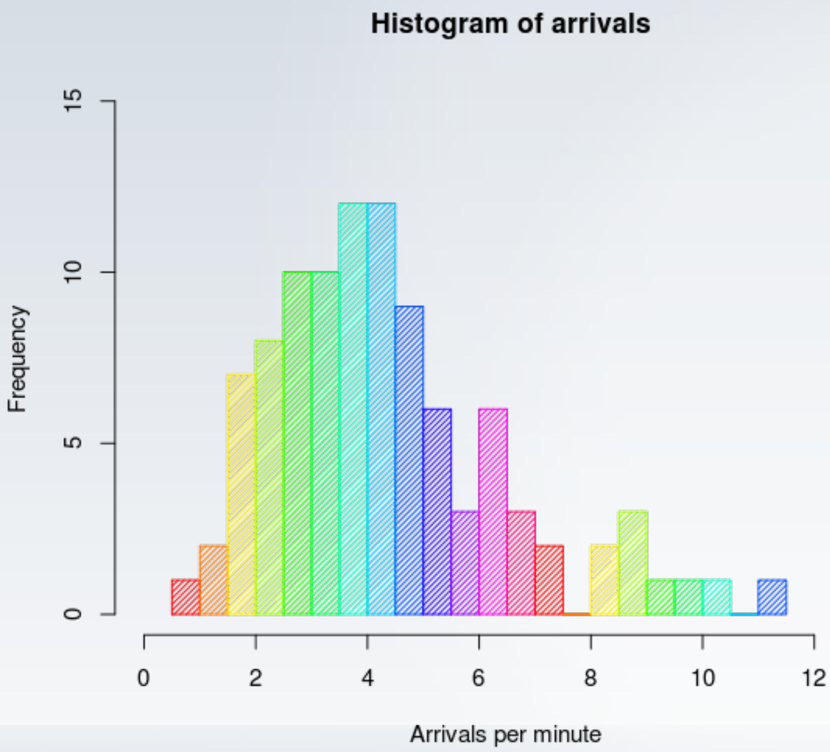
OPEN PARENTHESIS

Histograms



The basic brick in the construction of a spectrum

The main issues:

- have enough statistics
- the "dx" binning scheme

small dx → better resolution but requires more simulated events

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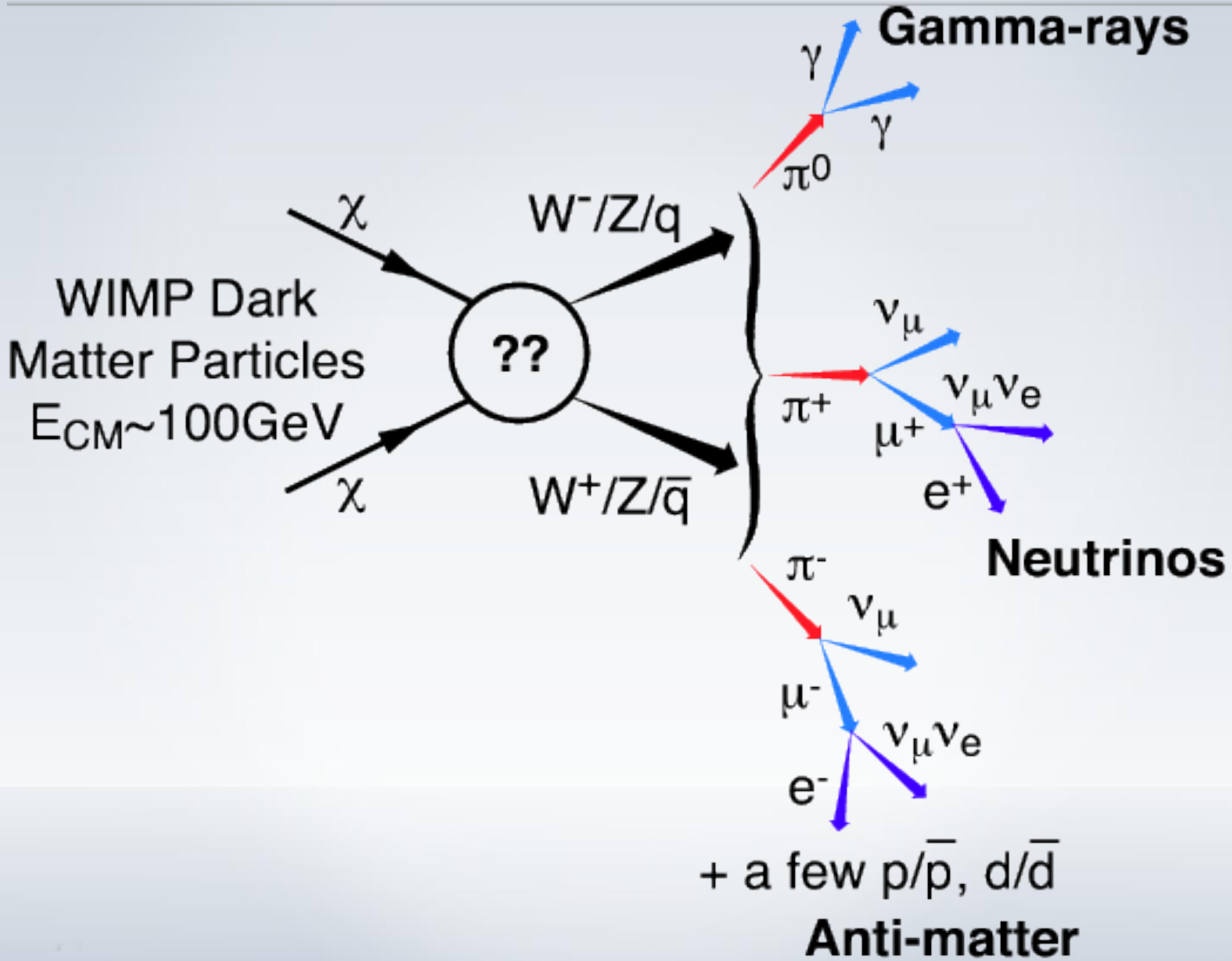
CLOSED PARENTHESIS

Annihilation channel



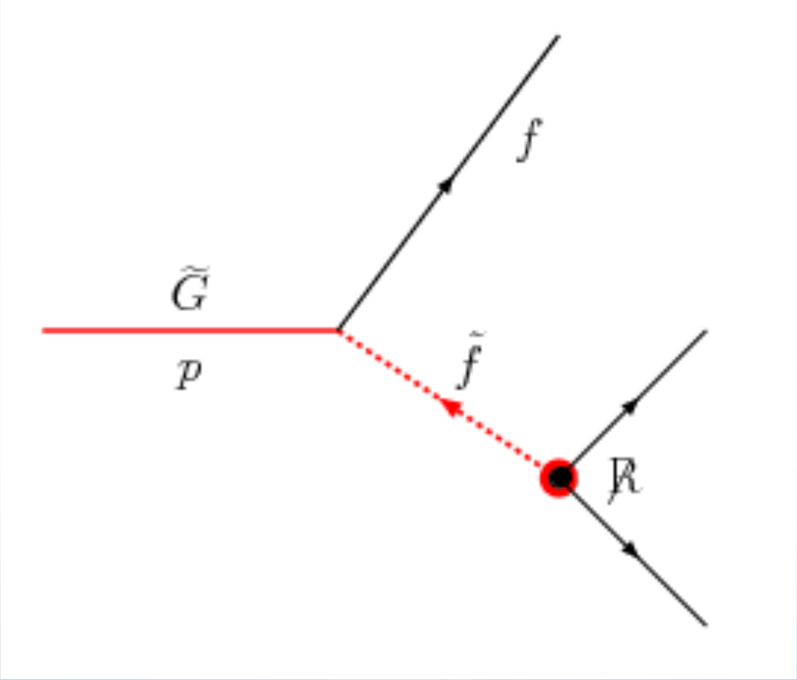
Annihilation (decay) channels: 2-body

$$ZZ,\ W^+W^-,\ hh,\ b\bar{b},\ c\bar{c},\ e^+e^-,\ \mu^+\mu^-,\ \tau^+\tau^-,\ \nu_e\bar{\nu}_e,\ \nu_\mu\bar{\nu}_\mu,\ \nu_\tau\bar{\nu}_\tau,\ \ldots$$

- Kinematics fixed, so model independent?
- Not completely: no spin correlations in Pythia!
- For scalar mediators correct.
- For other cases only approximation.
- However, reasonable approximation that is applicable to many models.

Annihilation (decay) channels: 3-body etc.

- Kinematics are more complex.
- Model-dependent (matrix element needed)
- Strategy: Use Lanhep + Madgraph + Pythia



Running Pythia

Compile Pythia:

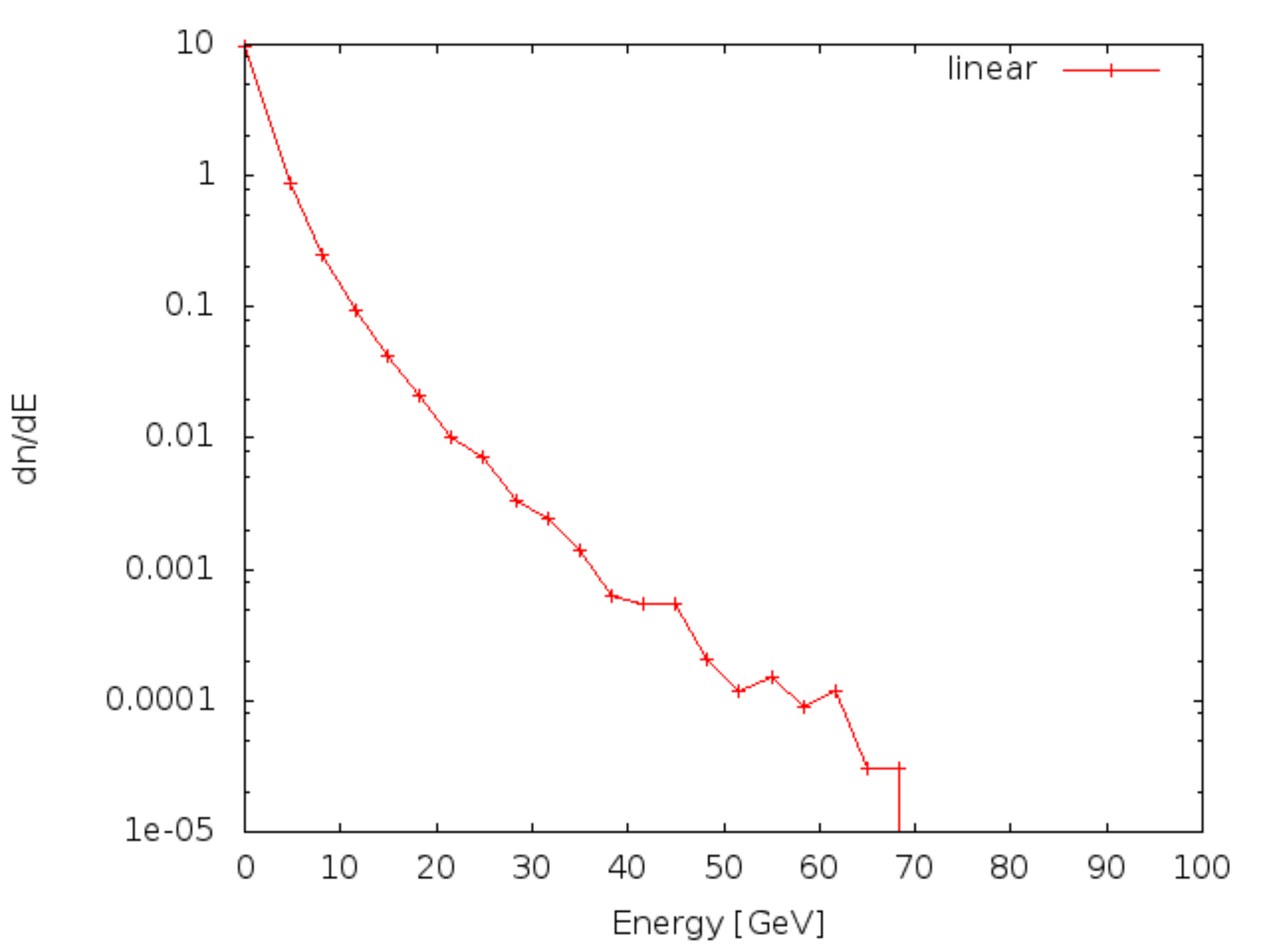
- `gfortran -c pythia-6.4.27.f`
- creates `pythia-6.4.27.o`

Compile the project file:

- `gfortran dmspectra.f pythia-6.4.27.o`
- `./a.out` runs the MC and produces a histogram file as defined in `dmspectra.f`

Hands-on!

- Run the template, plot the spectrum



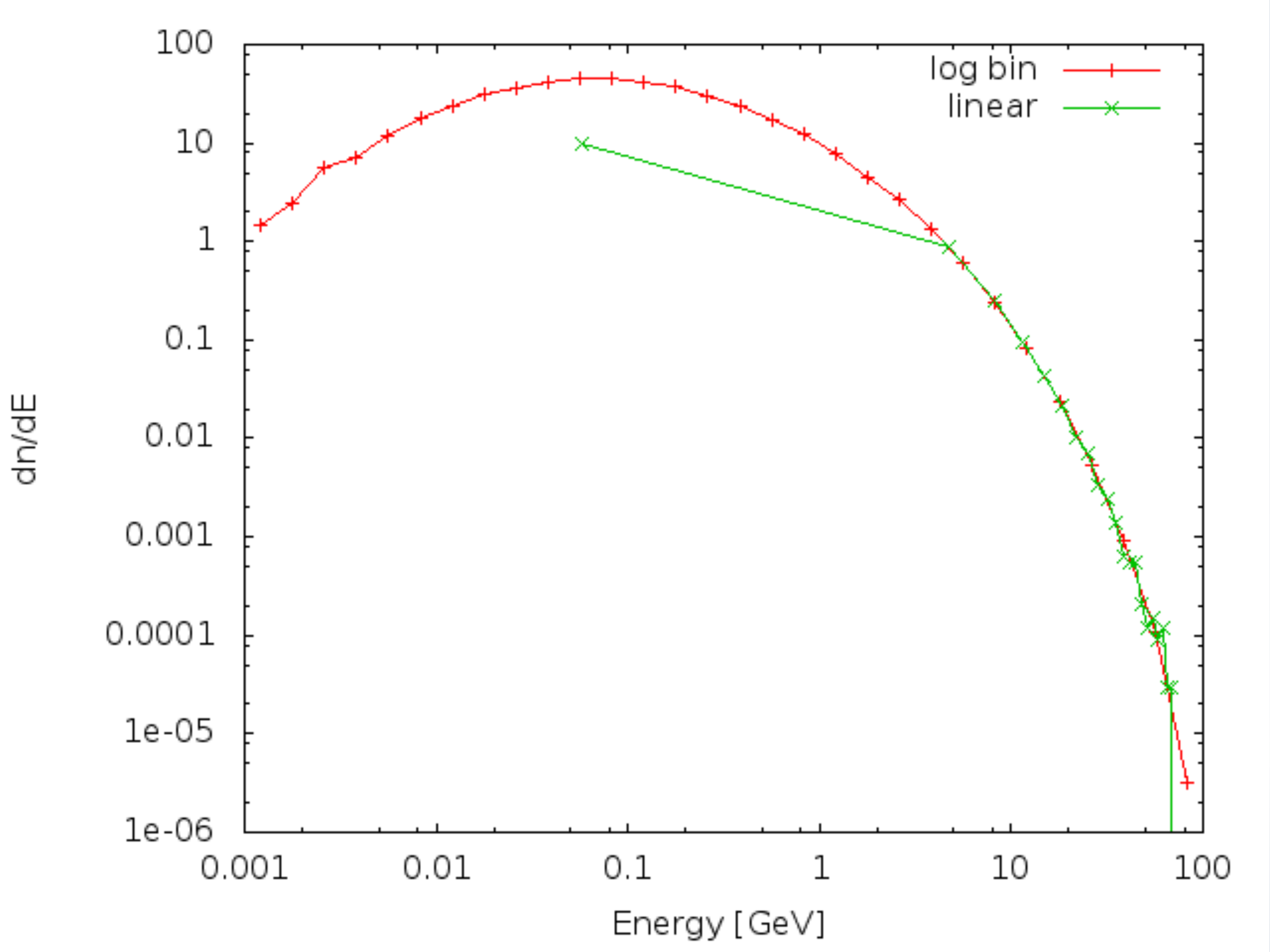
The right choice of binning

- Information lost in the lowest energy bin!

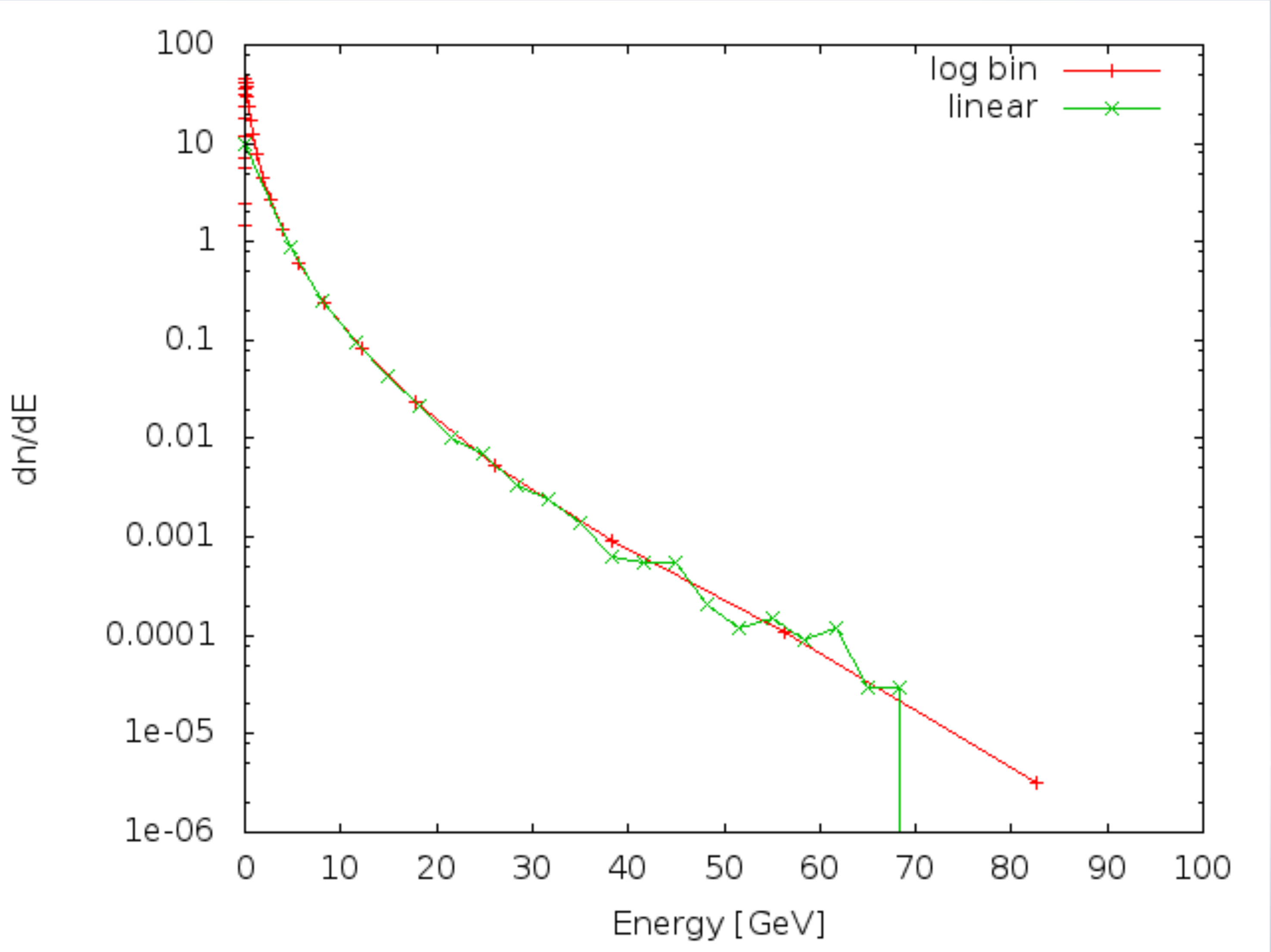
- Solution:
  Use a logarithmic scale for the histogram!

- Linear binning might be more appropriate if you want to resolve spectral features close to the high-energy end of the spectrum.

The right choice of binning



The right choice of binning



Try another annihilation channel

- Change the channel from $b\bar{b}$ to e^+e^- (the electron has pdg code 11)

- What happens?

- No final state photons!

- Missing piece: Switch on FSR `(MSTJ(41) = 2)`

Several DM masses

- How to do it?
- Loop over masses in Pythia

in fortran:

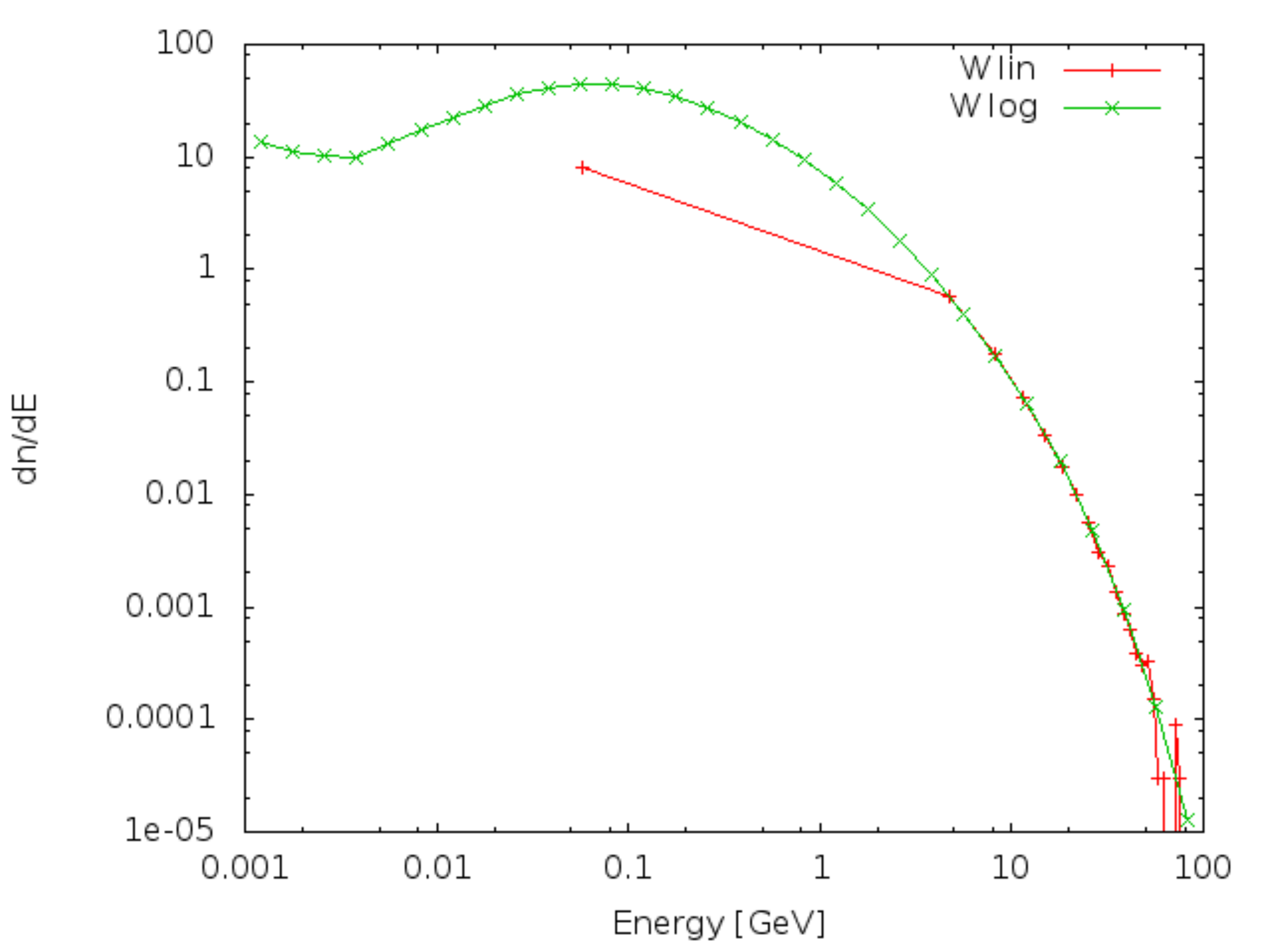
```
do i=1, 100
   ...
end do
```

Now the same with WW

- Change the annihilation channel to WW and generate the same set of spectra as for bb

- What differences do you observe?

WW @ 100 GeV



W lin
W log
dn/dE
Energy [GeV]
100
10
1
0.1
0.01
0.001
0.0001
1e-05
0.001
0.01
0.1
1
10
100

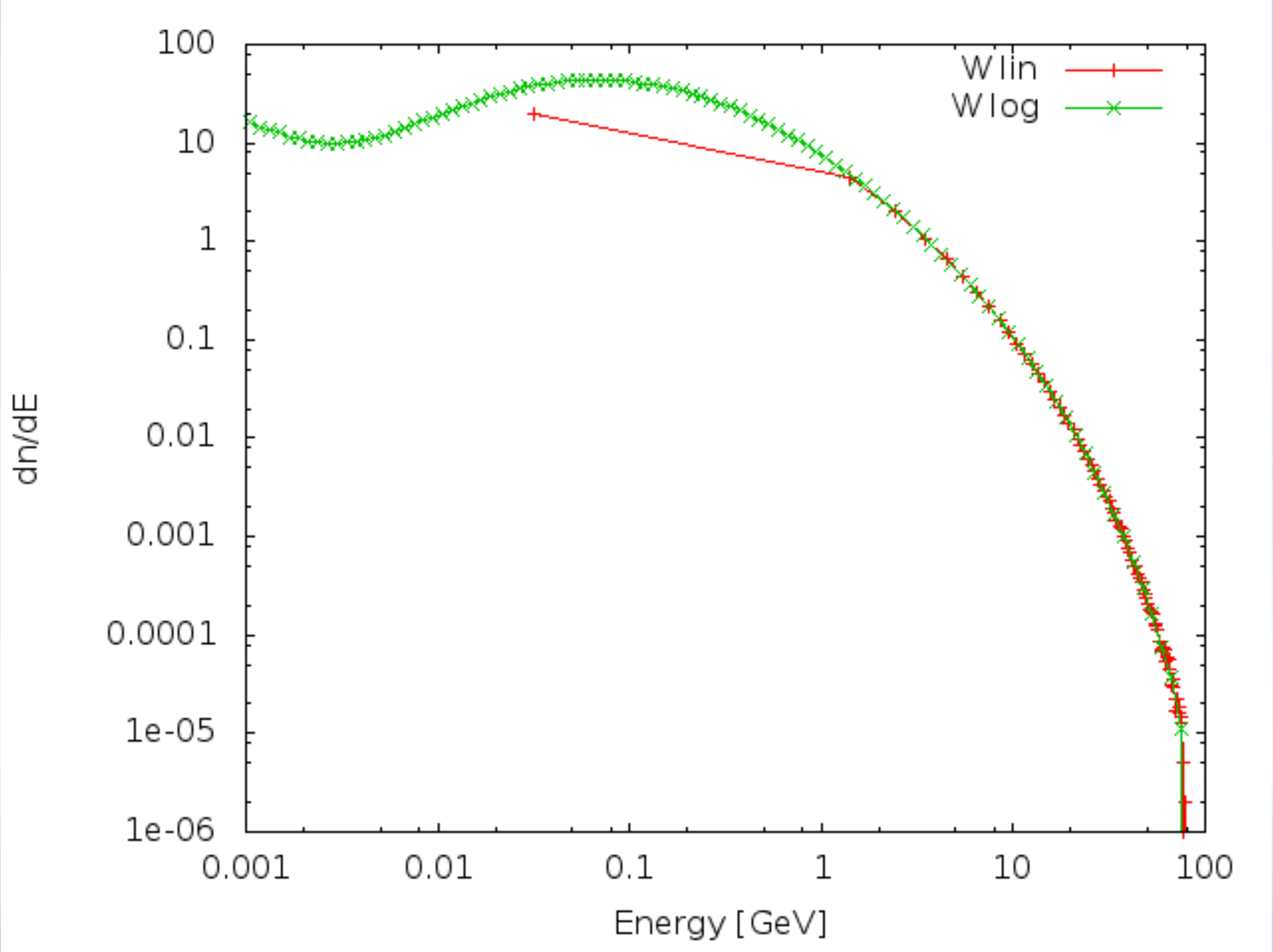
How many particles are produced?

- Multiplicity: N_gamma / N_events
- Does it change with mass?
- Check for bb and WW!
- bb: multiplicity rises with the DM mass
- WW: multiplicity is practically stable
- Why?

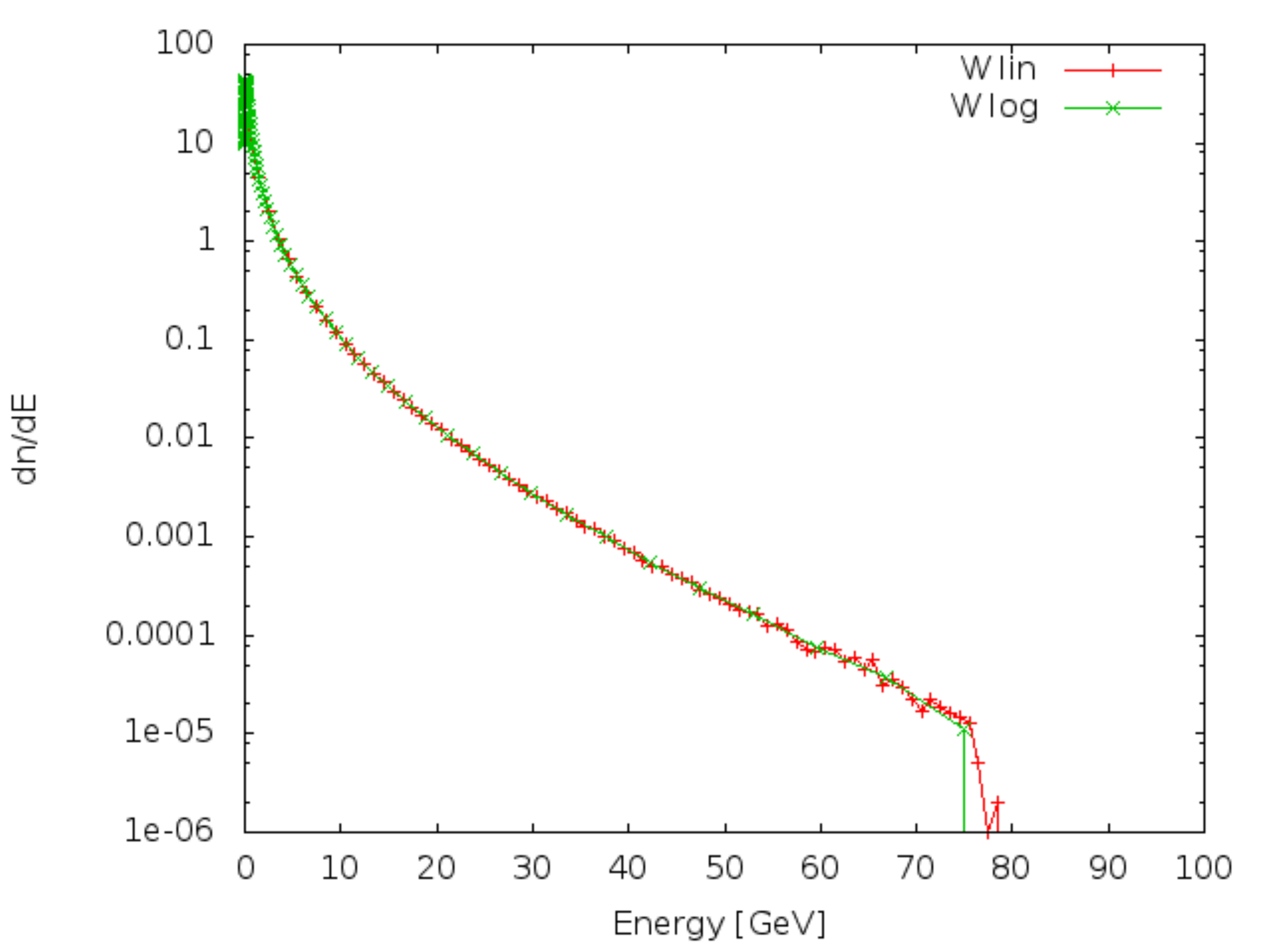
Improving quality

- Increase statistics to get a smoother spectrum
- Increase the number of bins to resolve spectral features
- Further increase statistics along with the number of bins :-)

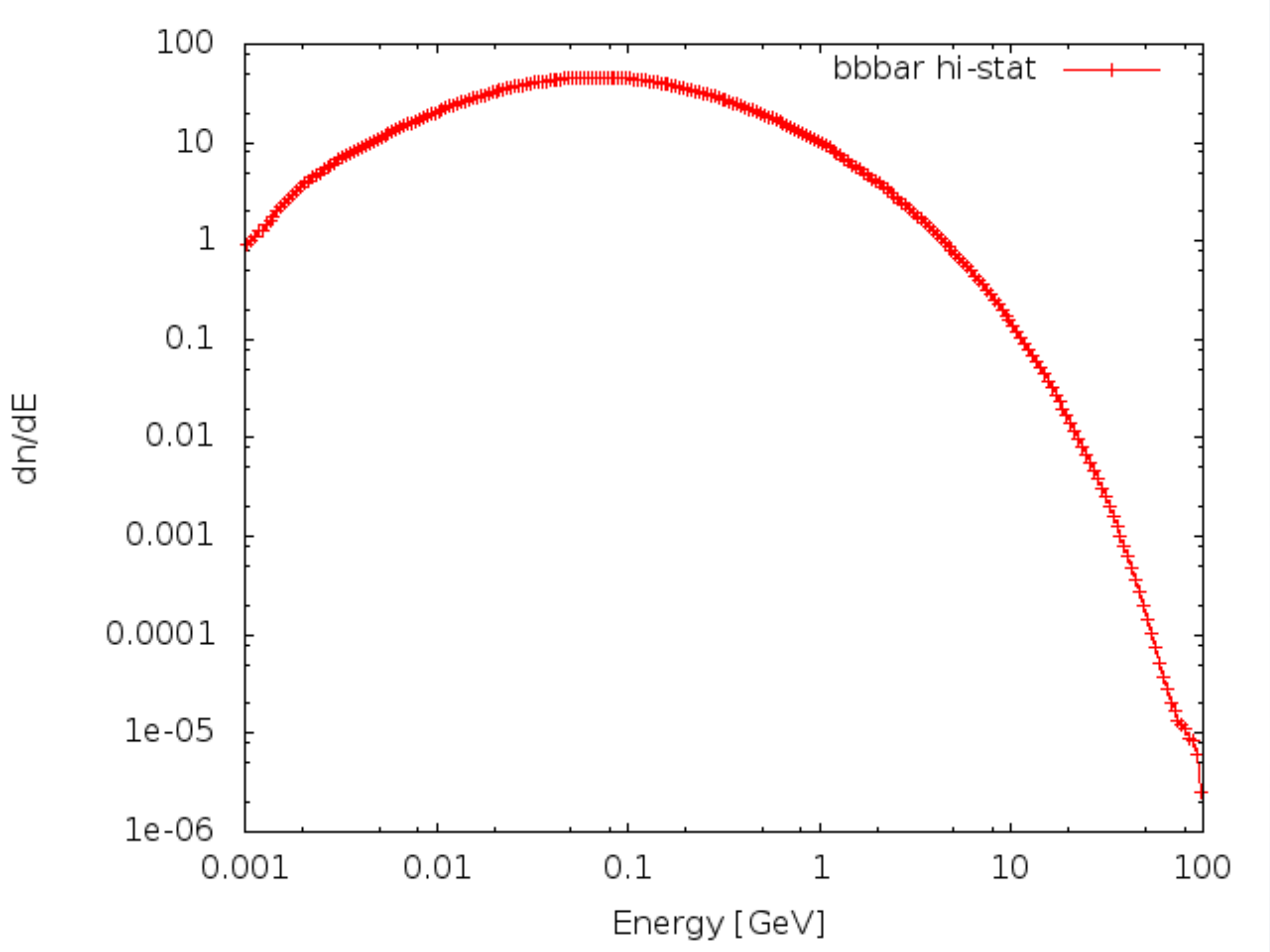
WW @ 100 GeV (high resolution, log)



WW @ 100 GeV (high resolution, linear)



Hires b-bbar @ 100 GeV



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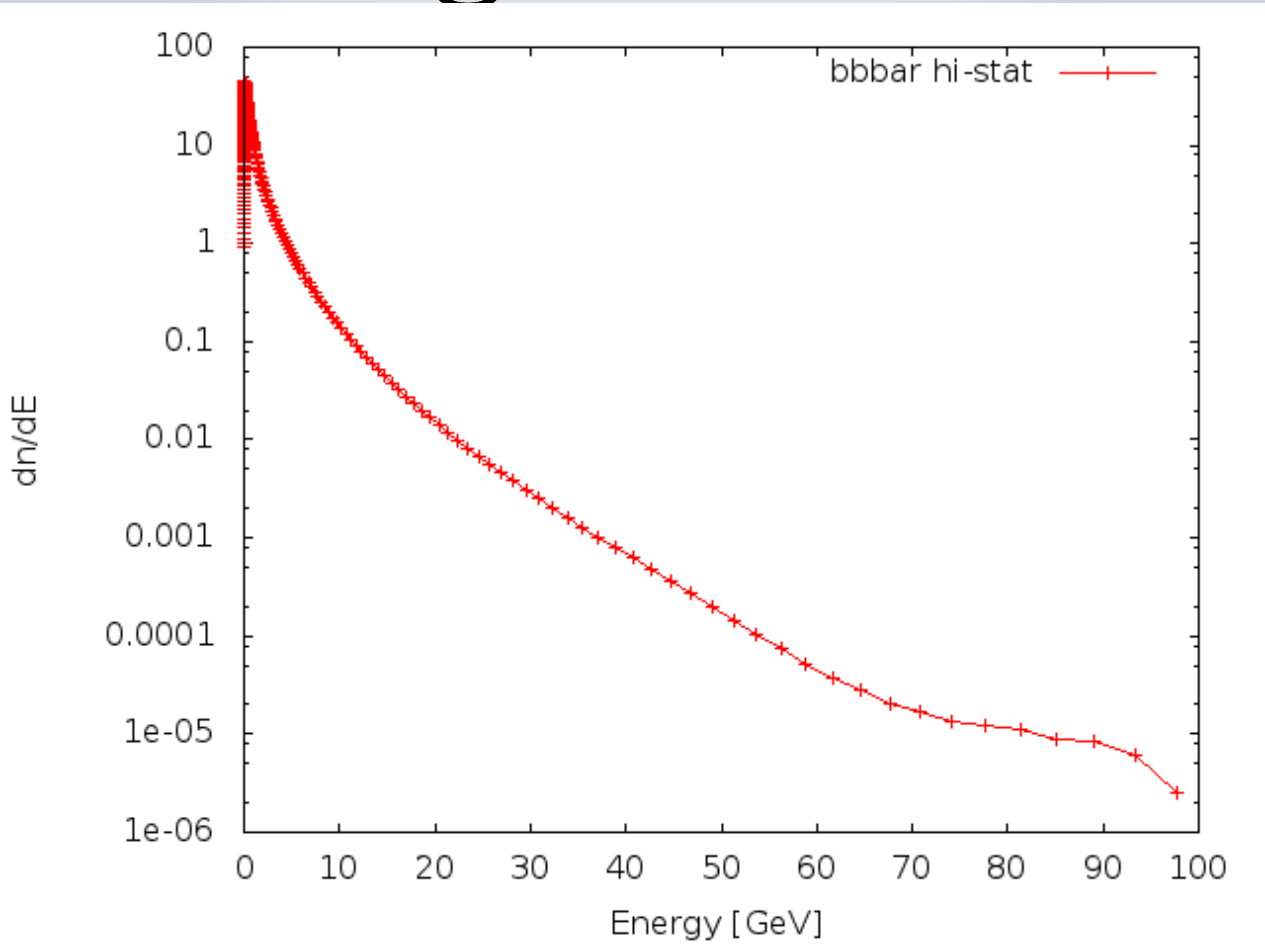
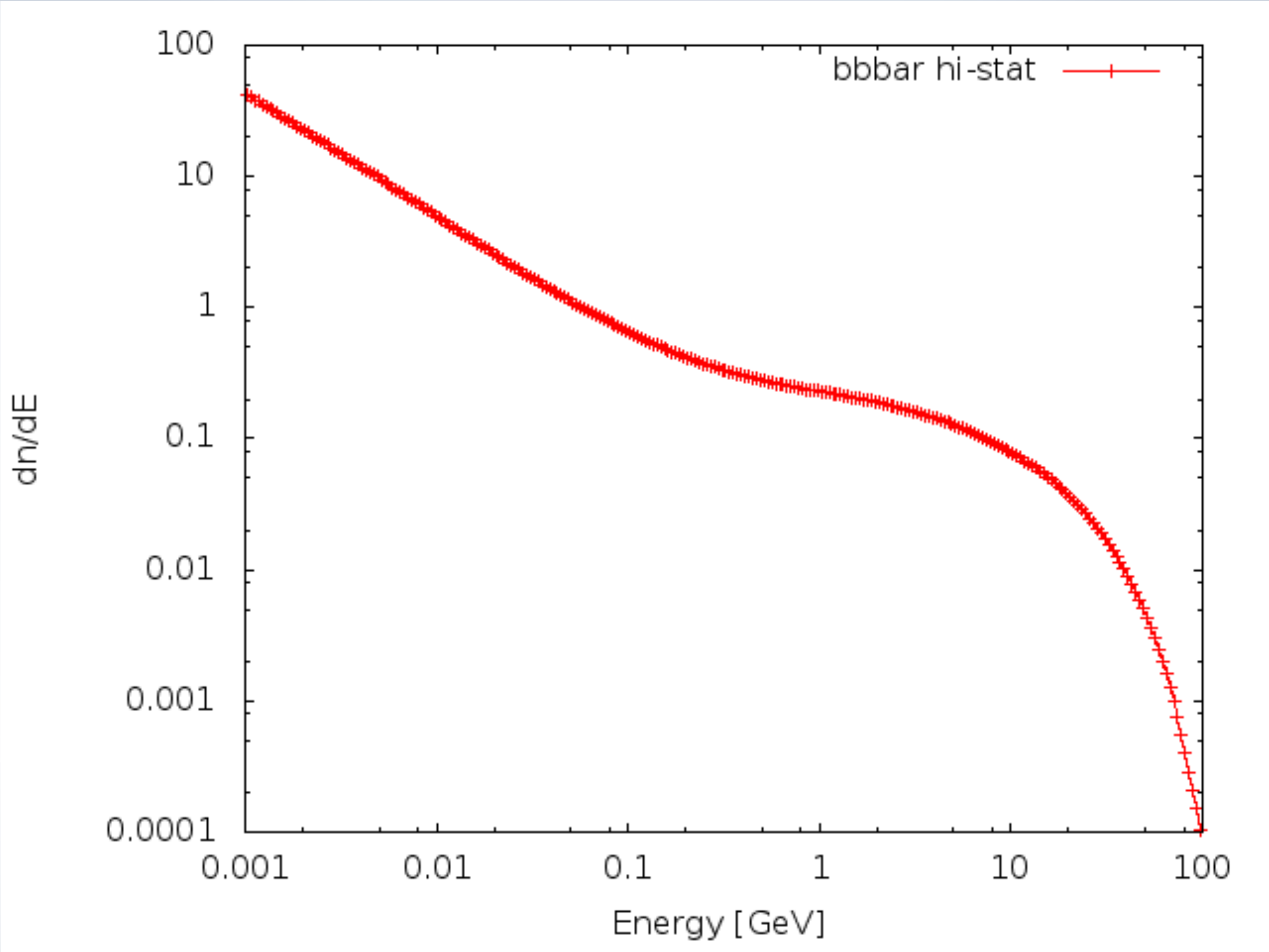
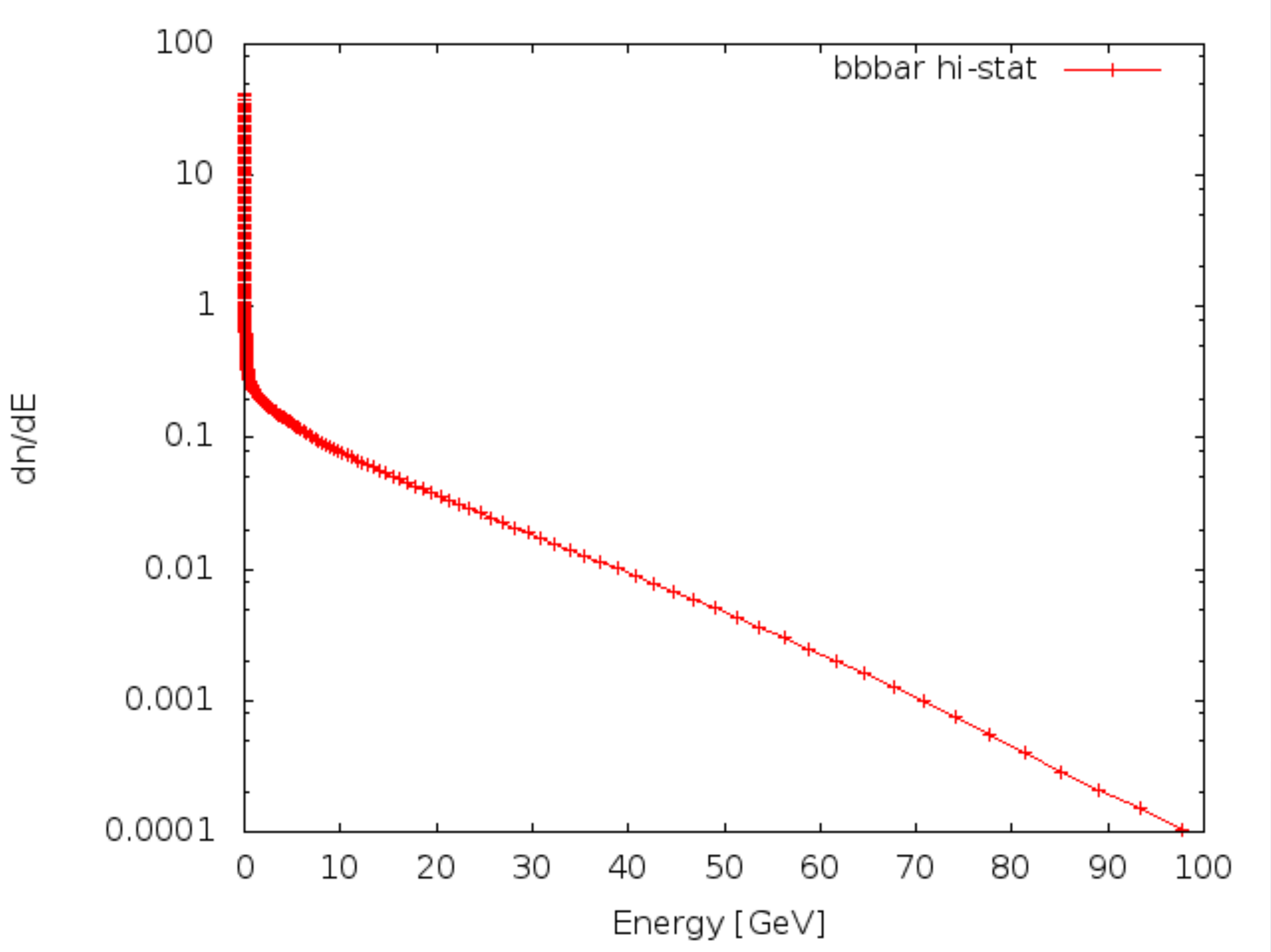


Hires tau-tau @ 100 GeV



Hires tau-tau @ 100 GeV



Spectra of other final state particles

- For instance you might be interested in the electron/positron spectrum for AMS-02
- ¡Ojo! Writing all particle species in one shot saves a lot of time! Think about how to do it!
- Complete list of (stable!) final state particles: photons, electrons, protons, neutrinos
- Also deuterons, but needs more effort!

Thank you!

Further information

- FSR from initial particles only when PYSHOW routine is called after PY2ENT

- Other starting points:
  PY1ENT (redefine particle to mimick DM)
  PY3ENT (model dependence)

- Neutron decay?
- Antideuteron?
- Other generators? Herwig etc.

Further information

- allow decay of long-lived particles (stable on collider time scales)

- widths of W/Z? can lead to kinematic issues in PY2ENT close to threshold
- in that case PY1ENT can help