

# Building a Mini Computer Cluster for the Simulation of Particle Collisions

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# High-Energy Particle Colliders

Particle colliders smash particles together at extremely high energies!

**The goal:** to study the fundamental constituents of matter and energy!



An aerial view of the Large Hadron Collider (LHC) at CERN (Geneva, Switzerland).



The LHC tunnel, where particles are accelerated.

# Computer Clusters

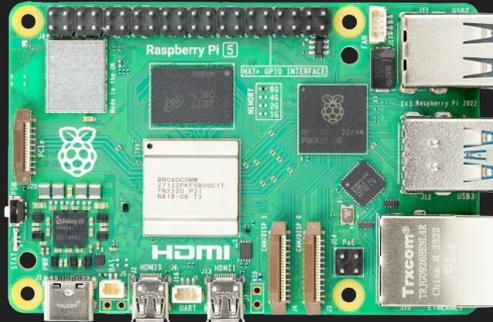
- **A computer cluster:** a set of computers that work together so that they can be viewed as a single system.
- Components of a cluster connected to each other through local area networks.
- Each computer that is part of the cluster is a “node” of the cluster.



Example of a computer cluster: the “Frontier”: \$600 million supercomputer installed at the Department of Energy’s Oak Ridge National Laboratory.

# Building a Raspberry Pi Cluster!

- **A Raspberry Pi:** A series of a single-board computer. It is cheap and low cost.



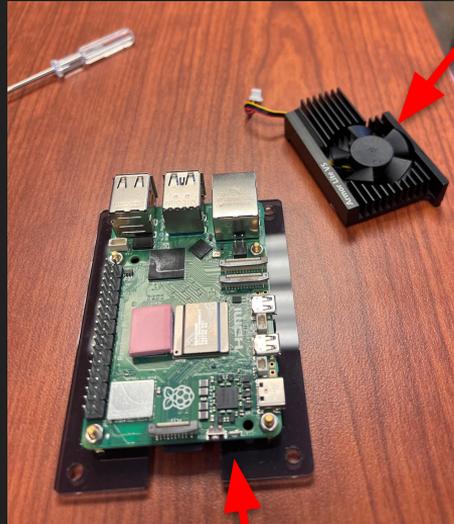
The latest Raspberry Pi:  
version 5.

- **Our Goals:**
  - Build a cluster consisting of 8 Raspberry computers (total cost ~\$1000).
  - Demonstrate the efficiency improvement of our cluster using “real-life” simulation codes.
  - Use the cluster to simulate collisions and compare to real data!

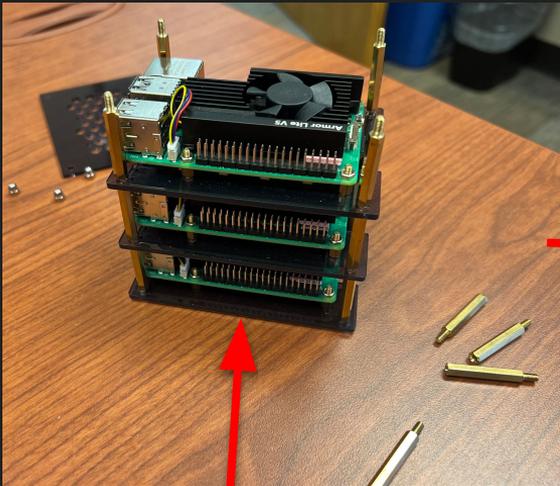
# Under Construction!



Fan module



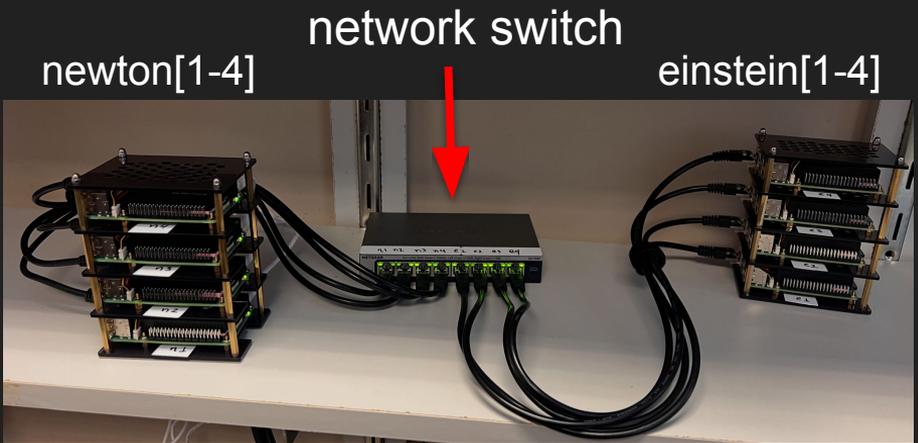
Raspberry Pi Board



Almost there!



Complete!



newton[1-4]

network switch

einstein[1-4]

# How does it work?



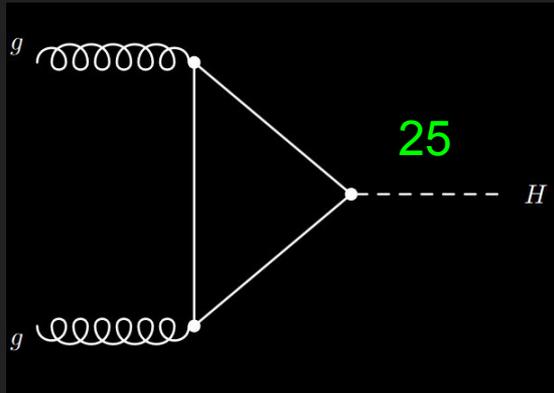
Operating system: Raspbian Linux,

Batch management system: **SLURM** → distributes/manages “jobs” around nodes.

# Monte Carlo Event Generators for Particle Physics

- Monte Carlo Event Generators (MCs) are essential tools in particle physics.
- They provide detailed simulations that describe particle collisions.
- This is accomplished through high-precision calculations and consist of millions of lines of computer code.
- Popular MCs: **MadGraph5\_aMC@NLO**, **Herwig 7**, **Pythia 8**, [...].

21



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</event>
```

Feynman diagram for Higgs boson production at the LHC.

A portion of an event file generated in a simulation.

# Cluster vs. Single Computer

We compared run times of a popular Monte Carlo framework (MadGraph5\_aMC@NLO) on a single “node” (MultiCore) on our cluster vs. the whole cluster:

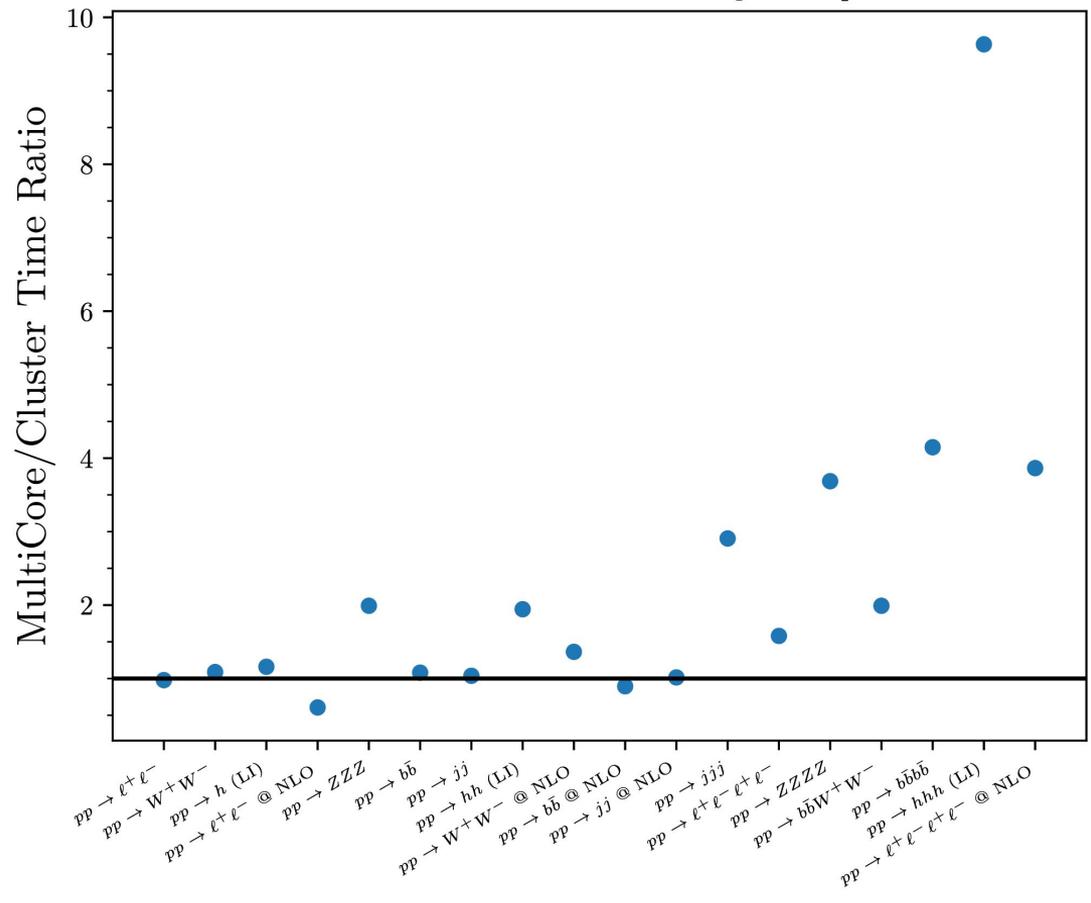
Pi Cluster versus MultiCore Run Times using MadGraph5\_aMC@NLO

Processes	Cluster Time (s)	MultiCore Time (s)	MultiCore/Cluster
$pp \rightarrow \ell^+ \ell^-$	50.61	49.52	0.9785
$pp \rightarrow W^+ W^-$	47.59	51.79	1.088
$pp \rightarrow h$ (LI)	55.63	64.54	1.16
$pp \rightarrow \ell^+ \ell^-$ @ NLO	126.6	76.76	0.6062
$pp \rightarrow ZZ Z$	98.31	195.7	1.991
$pp \rightarrow b \bar{b}$	45.42	49.06	1.08
$pp \rightarrow jj$	56.33	58.45	1.038
$pp \rightarrow hh$ (LI)	244.6	475.4	1.943
$pp \rightarrow W^+ W^-$ @ NLO	129.6	176.6	1.363
$pp \rightarrow b \bar{b}$ @ NLO	639.4	572.0	0.8946
$pp \rightarrow jj$ @ NLO	6149.0	6245.0	1.015
$pp \rightarrow jjj$	237.2	689.4	2.907
$pp \rightarrow \ell^+ \ell^- \ell^+ \ell^-$	290.0	458.3	1.58
$pp \rightarrow ZZZZ$	412.8	1522.0	3.686
$pp \rightarrow b \bar{b} W^+ W^-$	95.62	190.3	1.991
$pp \rightarrow b \bar{b} b \bar{b}$	576.0	2390.0	4.148
$pp \rightarrow hhh$ (LI)	785.7	7569.0	9.633
$pp \rightarrow \ell^+ \ell^- \ell^+ \ell^-$ @ NLO	896.4	3464.0	3.864



Increasing “complexity”

Pi Cluster versus MultiCore Run Times using MadGraph5\_aMC@NLO

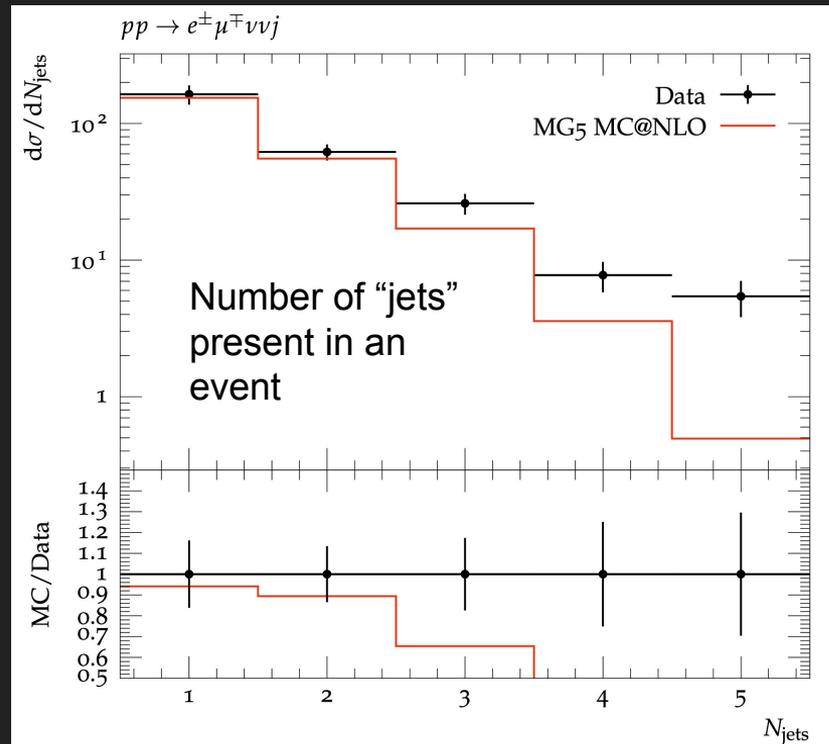
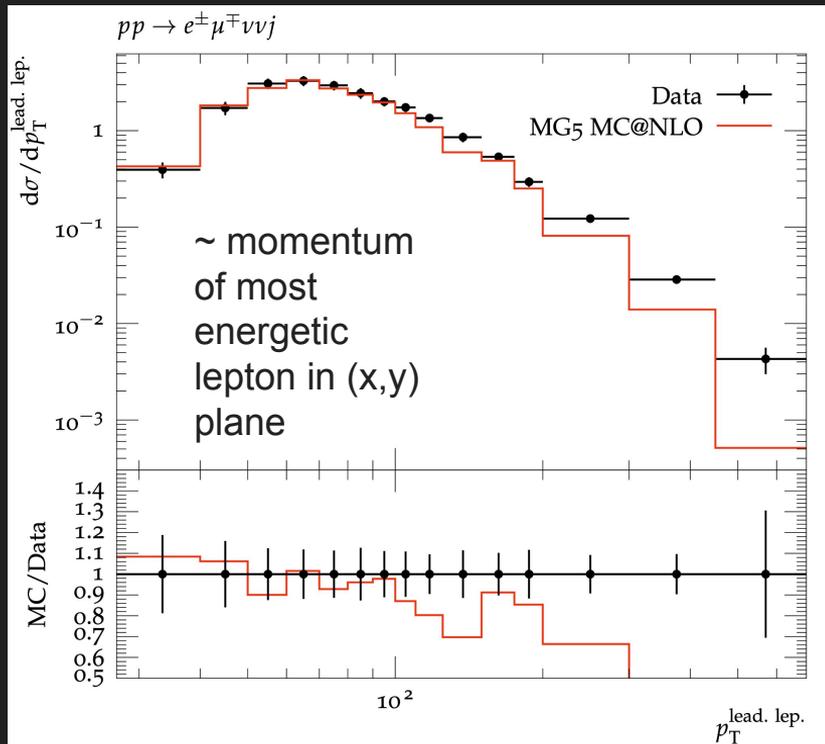


Clear advantage of Cluster vs. MultiCore for more complex processes! (loosely defined)

 Increasing "complexity"

# Simulations versus Data

We have also used MadGraph5\_aMC@NLO + Herwig 7 to compare simulations to real experimental data at the Large Hadron Collider!



# Conclusions & Outlook

- We have constructed a Raspberry Pi Cluster made out of 8 computers.
  - This cluster allows for fast computation and simulation of events at high-energy particle colliders, such as the CERN Large Hadron Collider.
  - We have used this cluster to compare simulations to real LHC data!
- 
- **Future Improvements & Directions:**
    - Install and assess the effectiveness of the cluster using other software: e.g. OpenMPI (a standard designed to function on parallel computing architectures).
    - Technical improvement: Use power-over-ethernet instead of individual power cables.
    - Make this cluster available to the Department of Physics for learning purposes!