Lattice Field Theory with MILC on Summit

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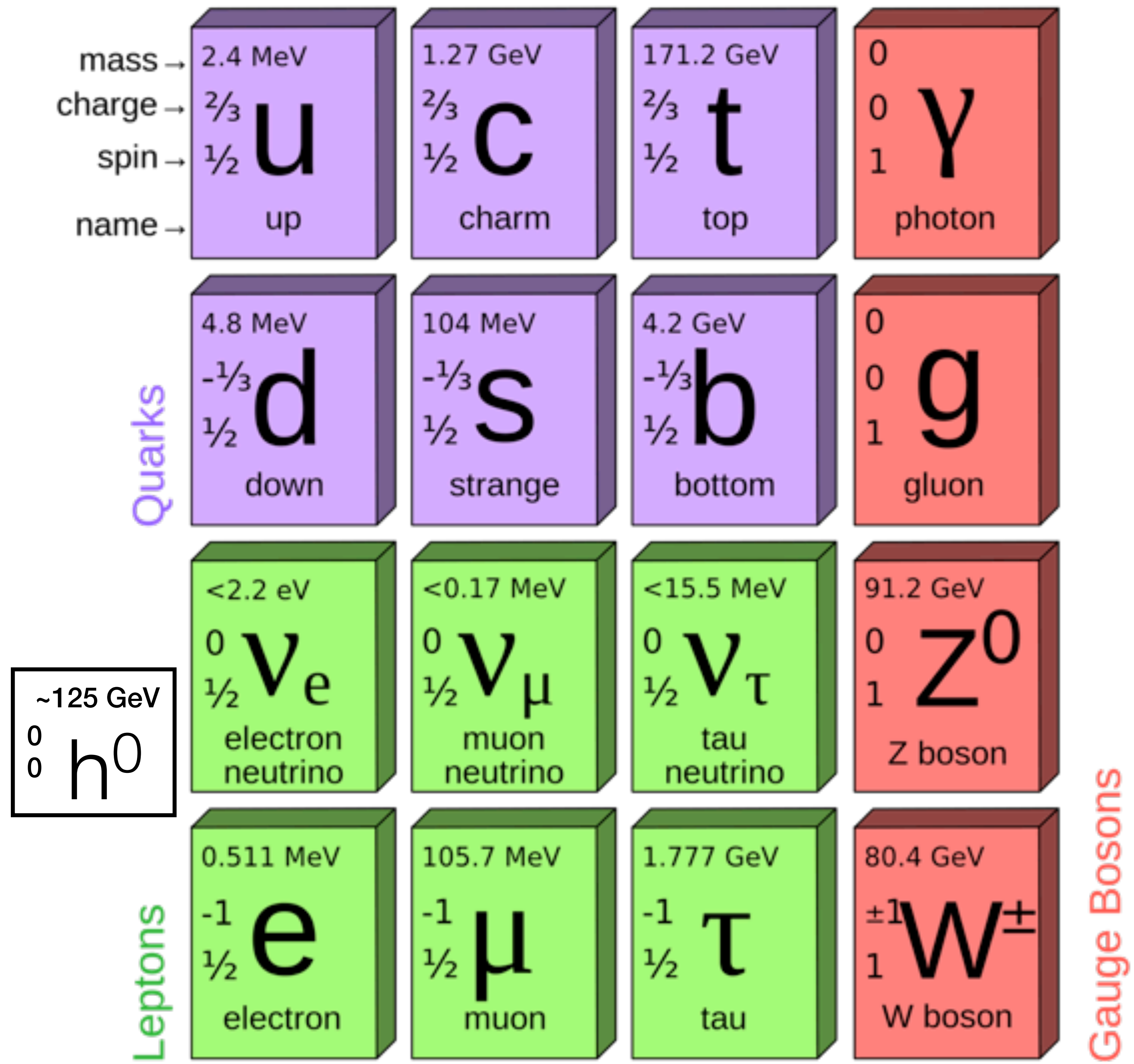
The Standard Model

- My work involves the subatomic particles and their interactions. The **Standard Model** describes all known particles and forces.

- There are hints of new physics beyond what we know (e.g., dark matter). Study of the SM at high precision can reveal inconsistencies that point to something missing!



SM at High Precision

- For certain quantities, the SM has proven to be fantastically accurate. A famous example is the electron's **magnetic moment**, which determines how it responds to a magnetic field.

$$g_e^{\text{theory}} = 2.002\,319\,304\,363\,286(1528)$$
$$g_e^{\text{exp}} = 2.002\,319\,304\,361\,460(560)$$

- Agreement better than one part per *trillion* (10^{-12})!

- For the muon (the electron's heavier cousin), the situation is different:

$$g_\mu^{\text{theory}} = 2.002\,331\,836\,300(980)$$
$$g_\mu^{\text{exp}} = 2.002\,331\,841\,820(1260)$$

$$\Delta g_\mu = 0.000000005520(1600)$$ <u>- over 3σ discrepancy!</u>

http://muon-g-2.fnal.gov/

50-foot muon storage ring moved from Brookhaven to Fermilab in 2013, for a new experimental measurement of the muon magnetic moment.

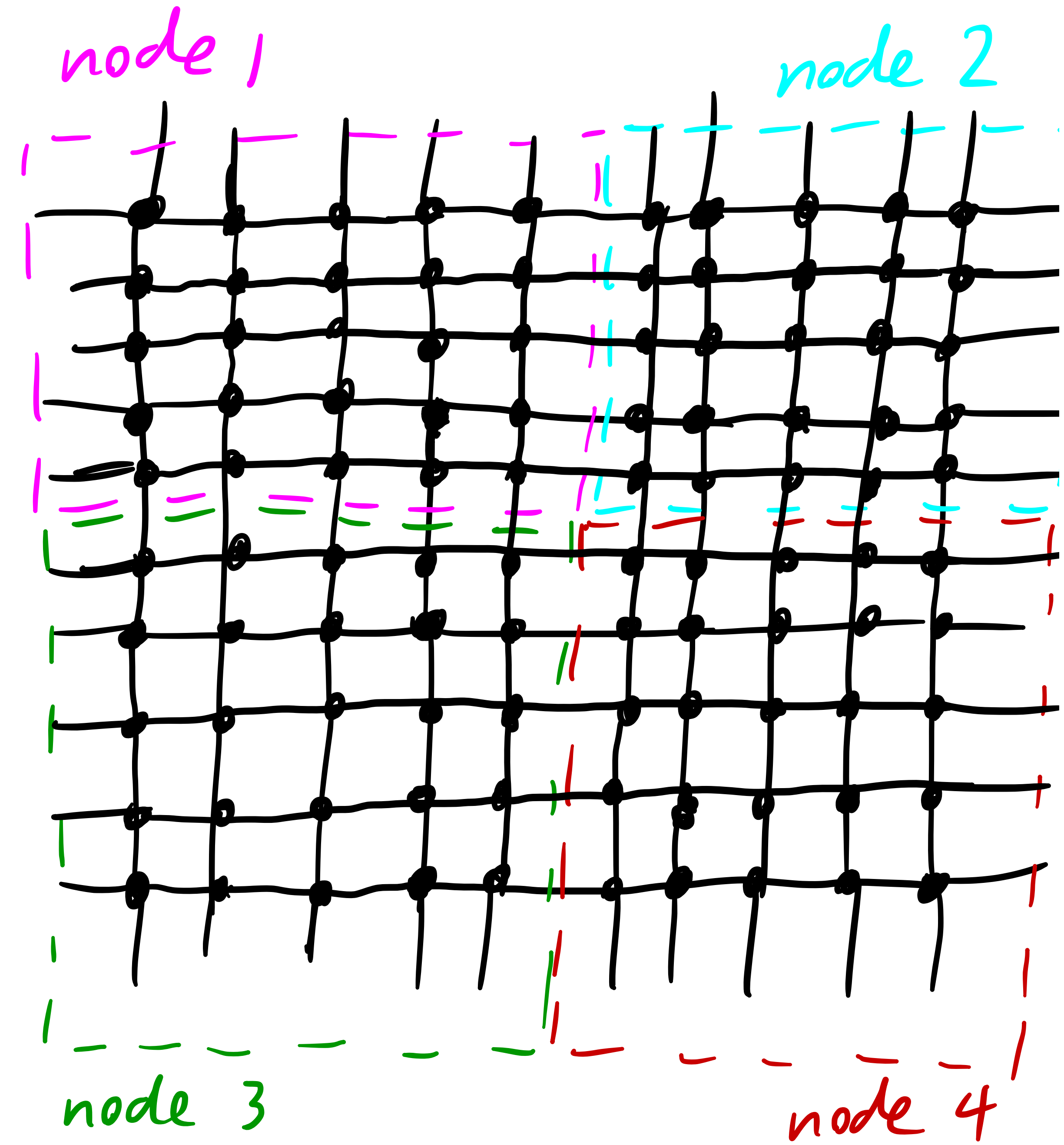
Theory prediction needs to be refined as well!

Quantum physics on a lattice

- Most of theory error in g_μ comes from the strong nuclear force, which (due to strong coupling) is inaccessible to traditional pen-and-paper calculations
- We use **lattice field theory** to compute numerically, where other methods fail!
- Markov chain Monte Carlo generates an ensemble representing the quantum fluctuations of empty space (which the muon sees as it spins around the storage ring, for example.)
- Four dimensions of space and time are reduced to a periodic lattice, with a finite number of points, to make the Monte Carlo process numerically tractable. Particles are represented as fields distributed over the lattice.

Quantum physics on a lattice

- MCMC ensemble generation needs evaluation of matrix-vector products over the lattice
- All interactions are **local**, so these calculations just need communications between neighboring sites. Ideally suited to parallel computing!
- Most expensive part is inversion of the **Dirac matrix**, which encodes interactions of quarks and gluons; sparse but huge (12Vx12V, where V is the number of lattice sites)



Lattice simulation on Summit

- Standard lattice library codes (we use one called "MILC") are well-adapted to parallel architectures; Summit isn't too different. Low-level libraries are optimized for repetitive nearest-neighbor comms over MPI.

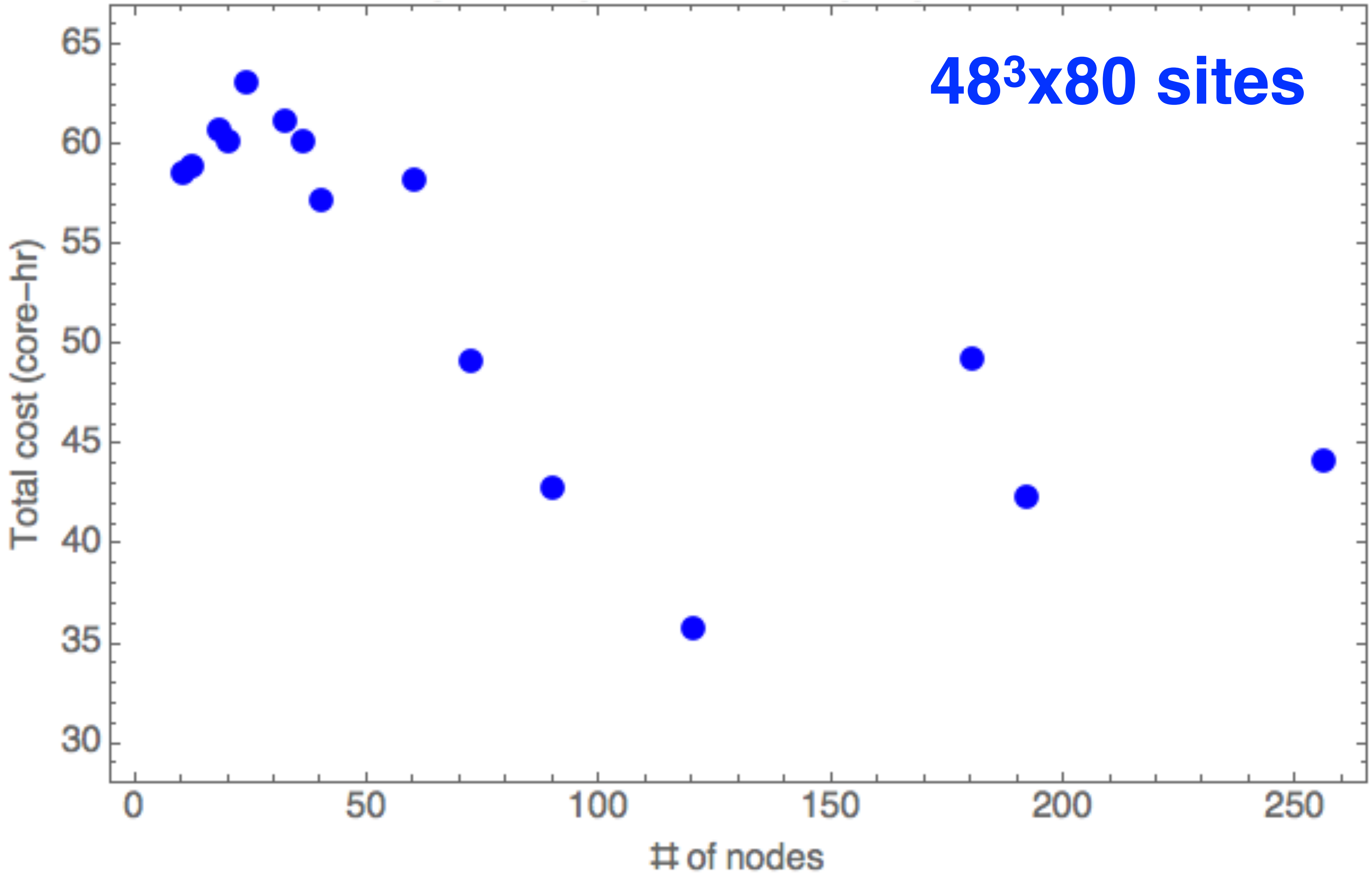
- Lattice calculations are very CPU intensive, so exclusive use of nodes for best performance (use --exclusive batch flag on Summit)

- Whenever building on a new machine, try to have a working build using same compilers/versions on another machine to compare with. (This led me to find a compiler bug in icc v17 when troubleshooting for Summit.)

- Test compiler flag variations with your application, to find the best combination for a particular machine! For Summit and my code, the combination

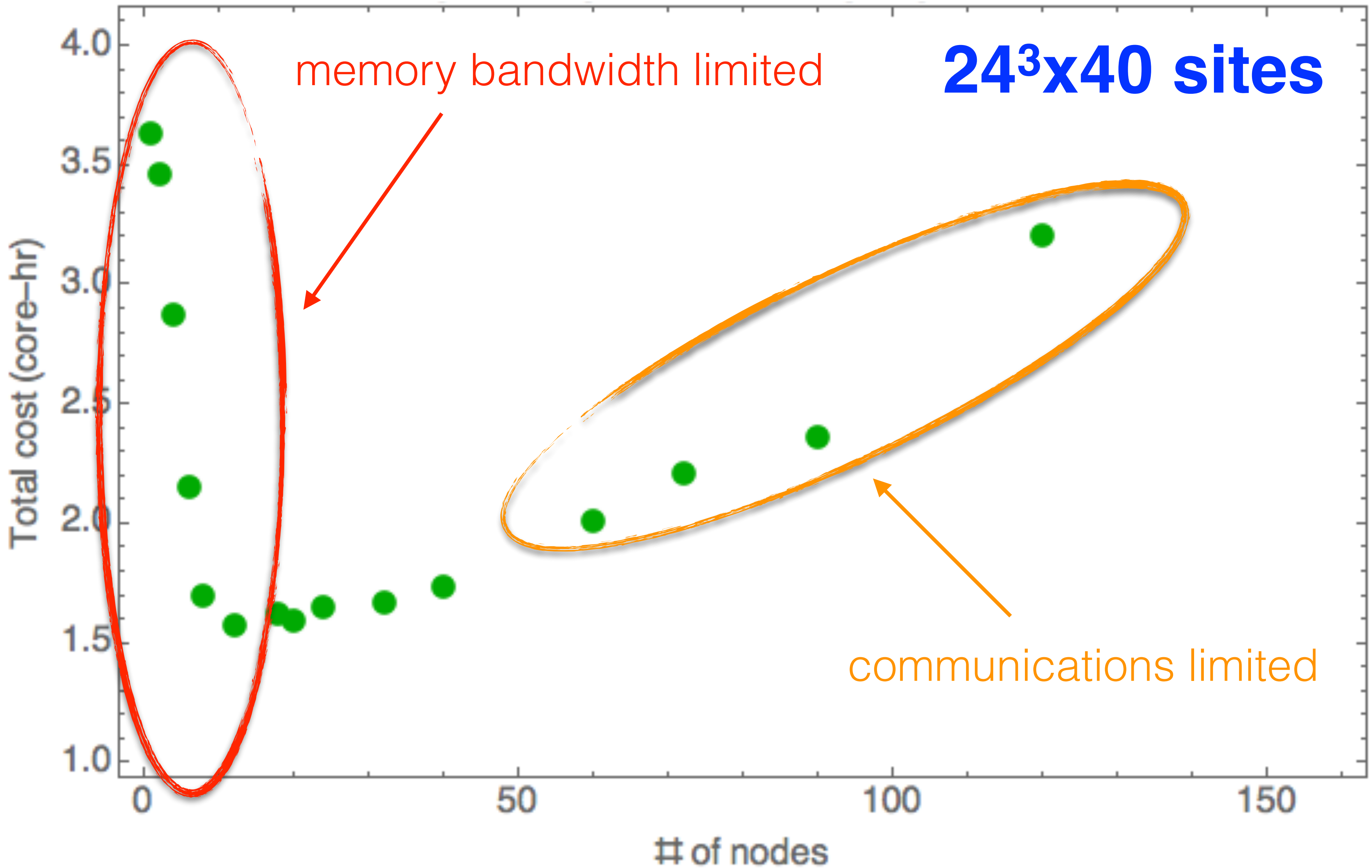
```
-O3 -axcore-avx2 -ipo
```

gave 10% speedup over just using -O2 -axcore-avx2.

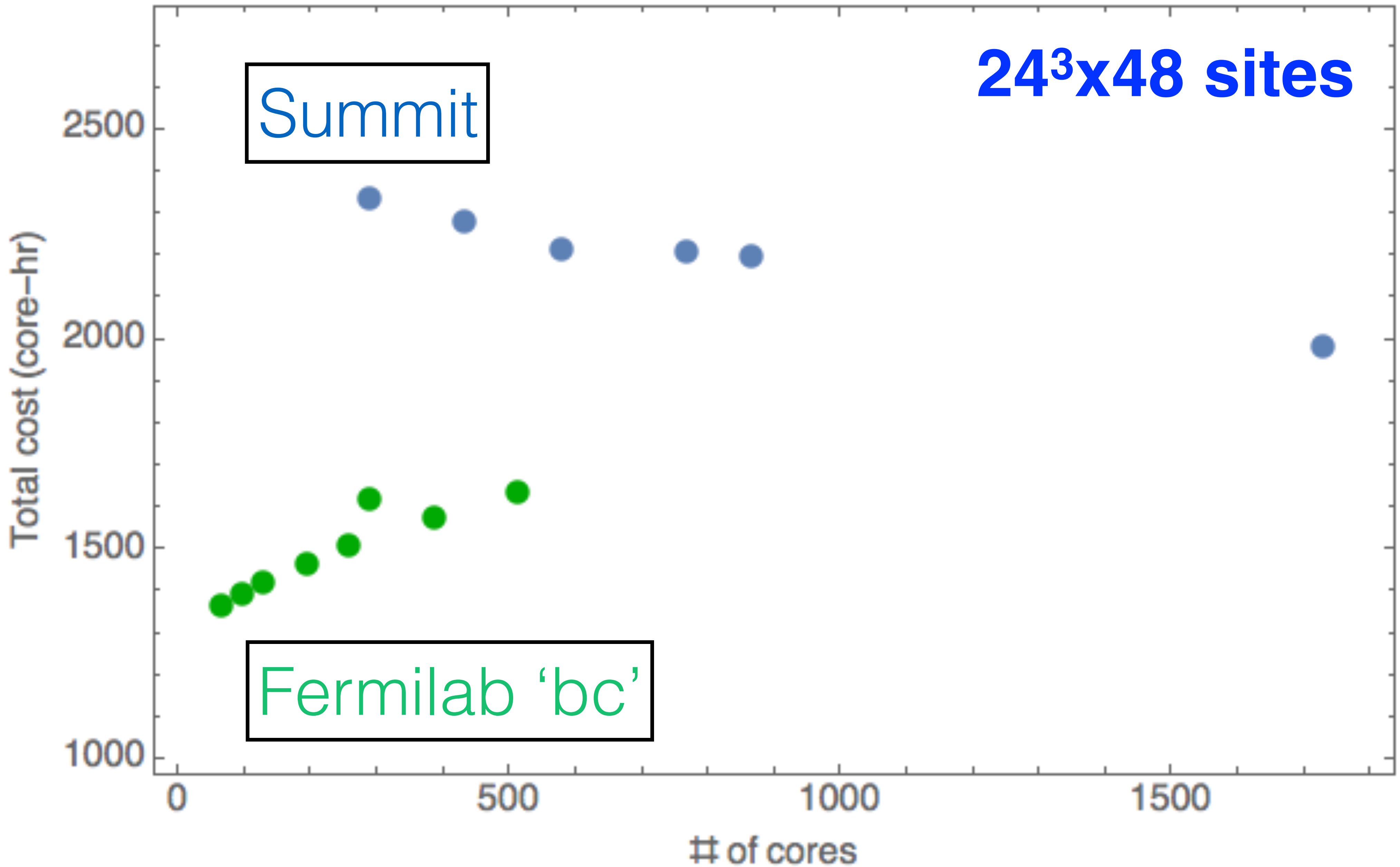


<u>Strong scaling</u>: fixed total problem size, spread out over many nodes.

Total cost = (wall time) * (# of cores); should be constant as problem spreads out, w/ideal comms.



Lattice benefits especially well from distributed computing; balance memory vs. comms bandwidth with many nodes.



Comparison with dedicated lattice hardware ‘bc’ at Fermilab; uses Infiniband vs. Summit’s Omnipath.

<u>Much better scaling seen on Summit</u>, no performance hit out to very large # cores!