Pythonic Data Analysis

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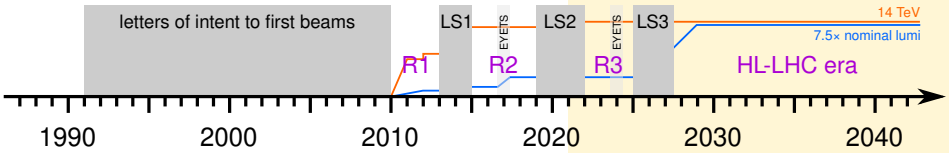
May the 4th be with you

Part 1: Trends in data analysis software

Part 2: Status of Pythonic HEP software

Pythonic data analysis in the HL-LHC era?



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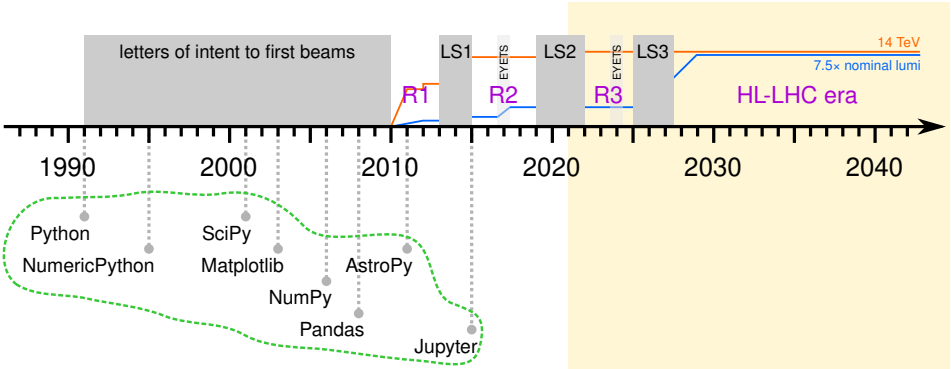

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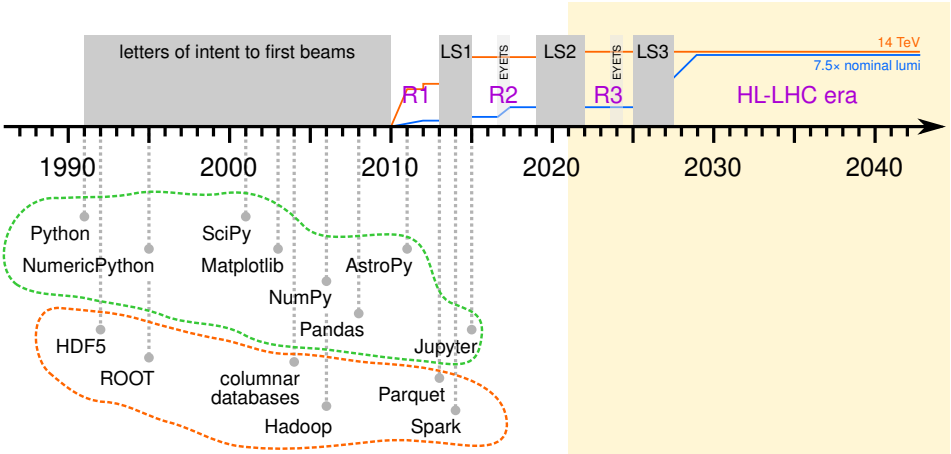

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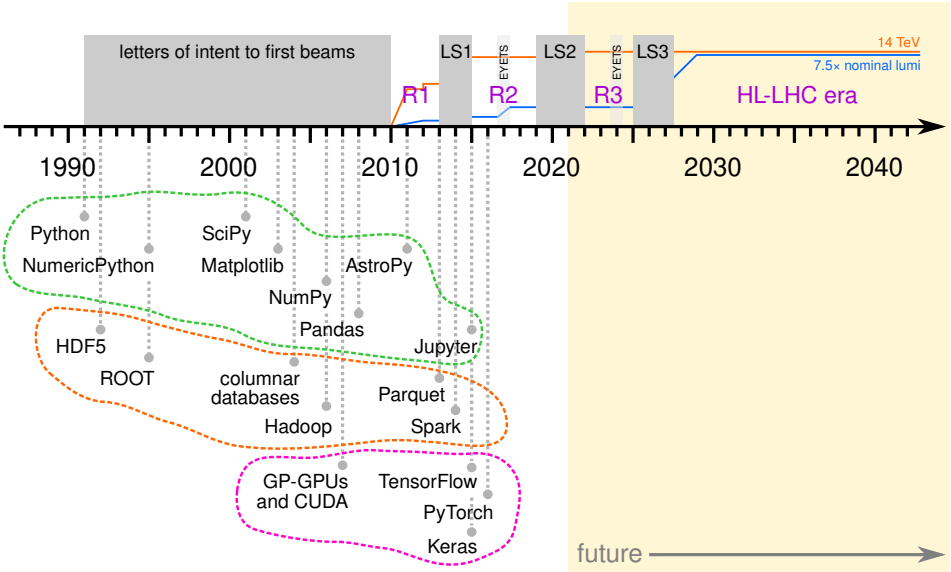

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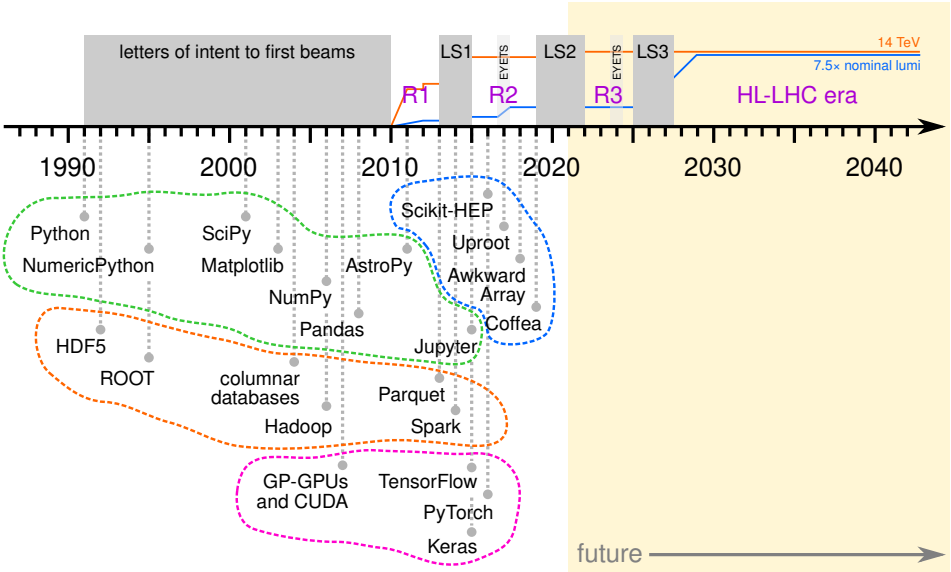

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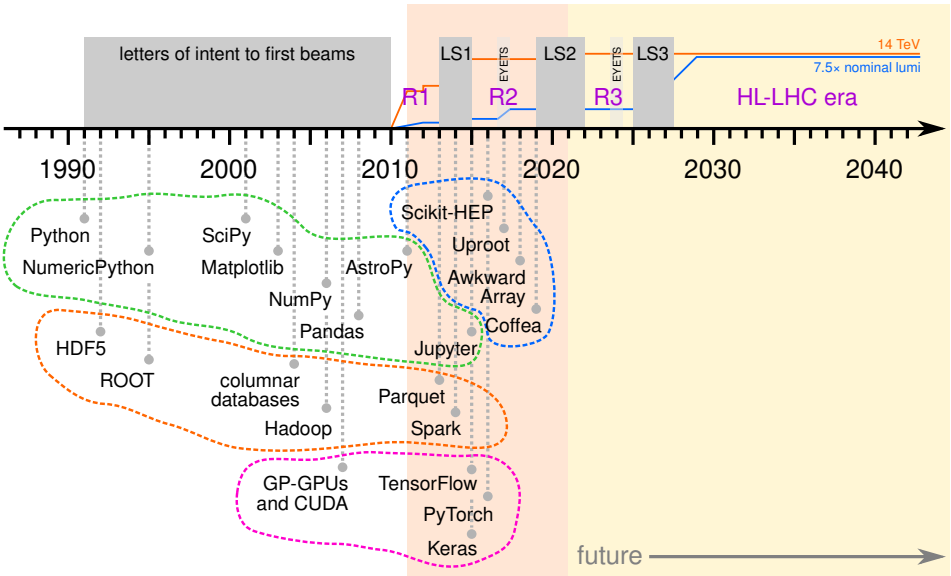
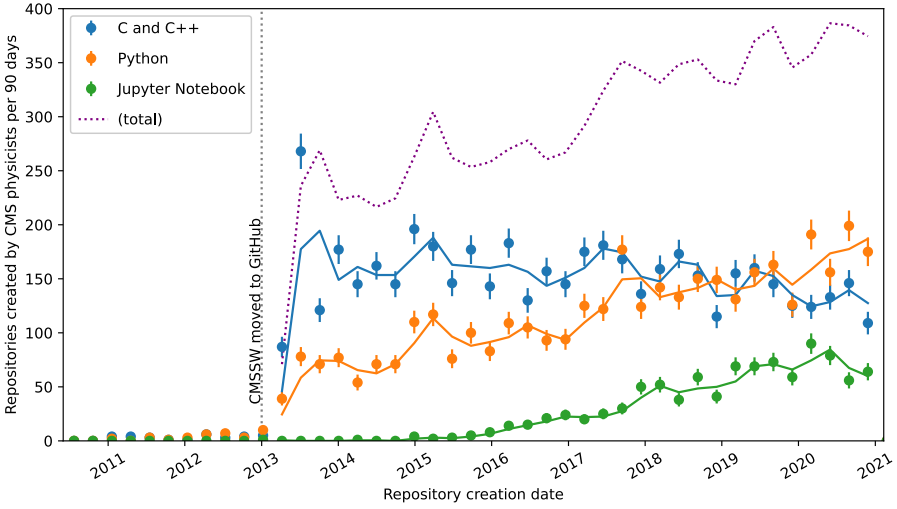


What were the physicists doing in this decade?

Primary language of GitHub repos created by users who forked CMSSW:



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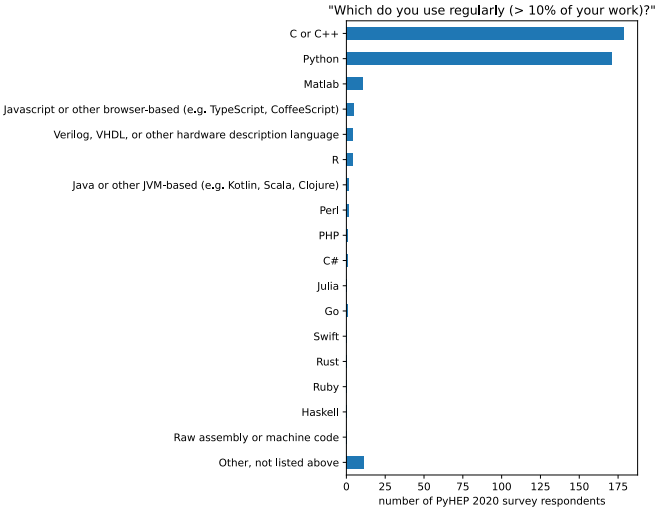

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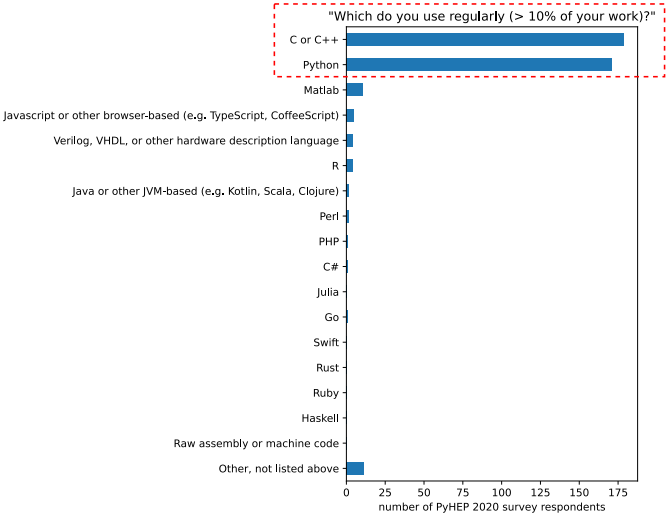

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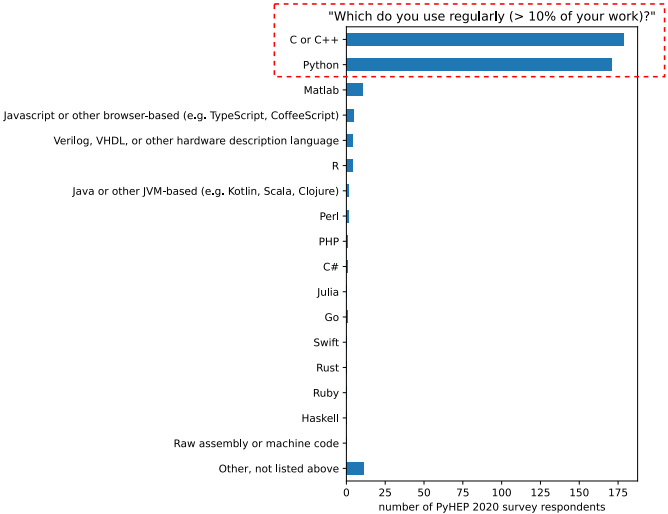

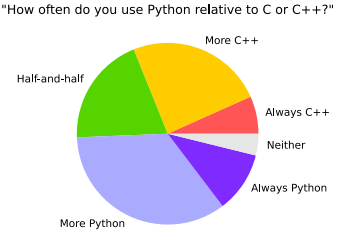

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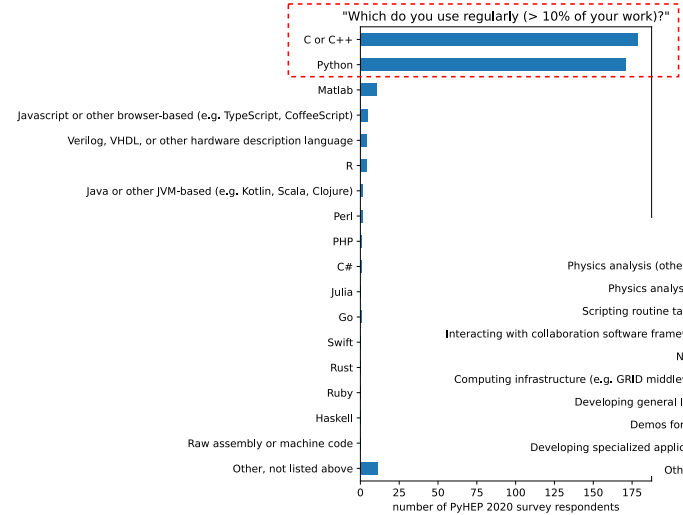

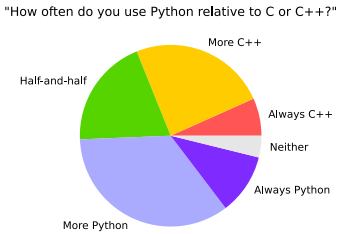

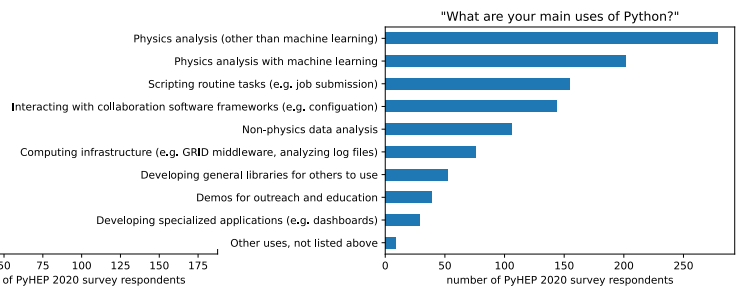

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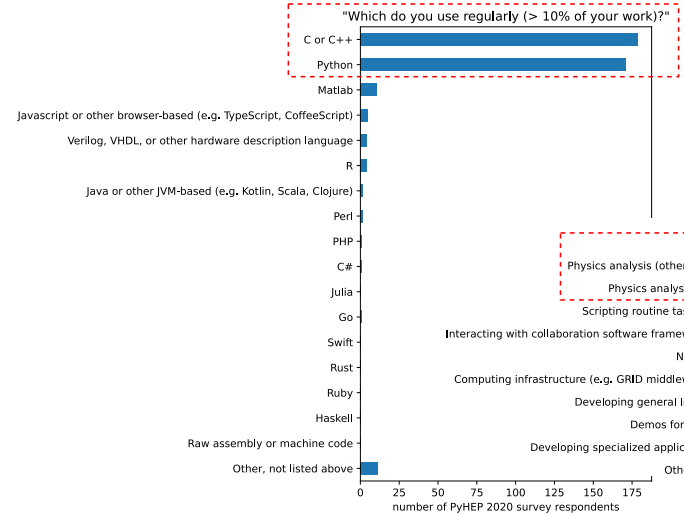
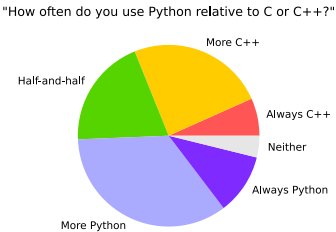
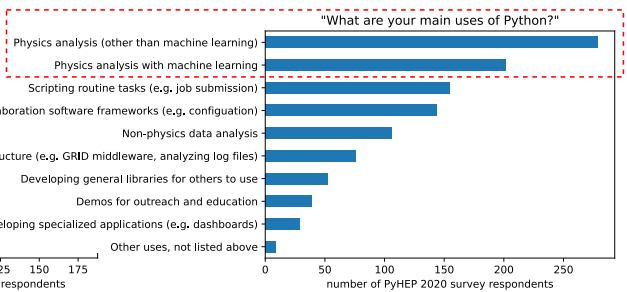
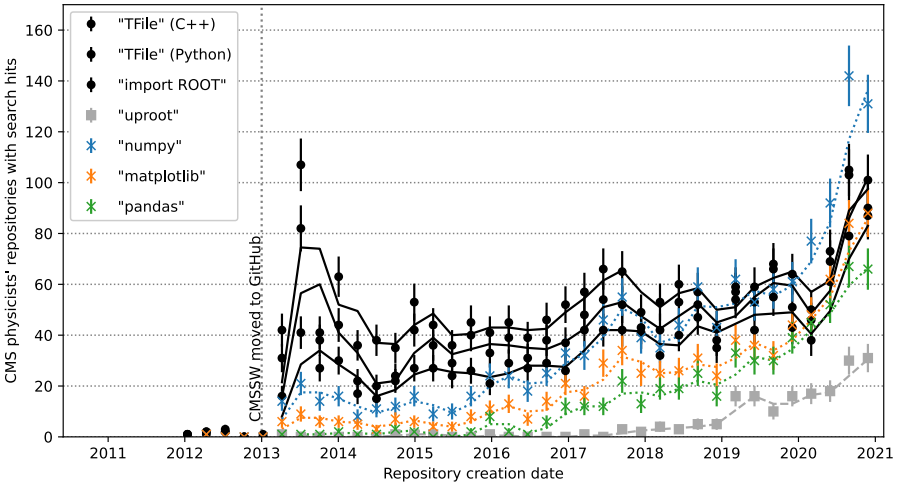




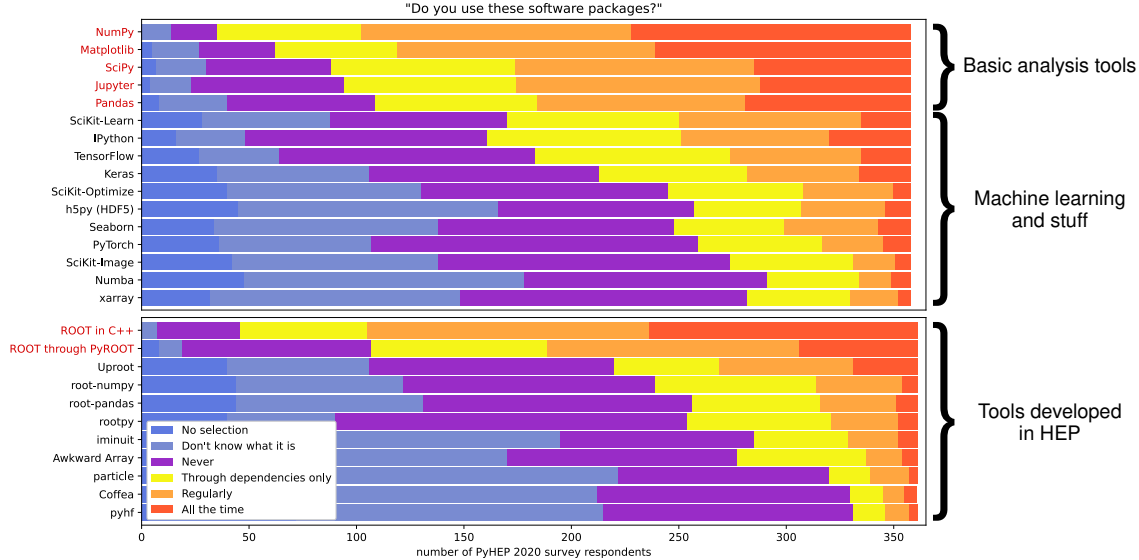


Pythonic analysis is mainstream, and the trend preceded Uproot

GitHub repos matching search strings: Pythonic analysis is as common as "TFile".



This is also consistent with self-reported usage



Part 1: Trends in data analysis software

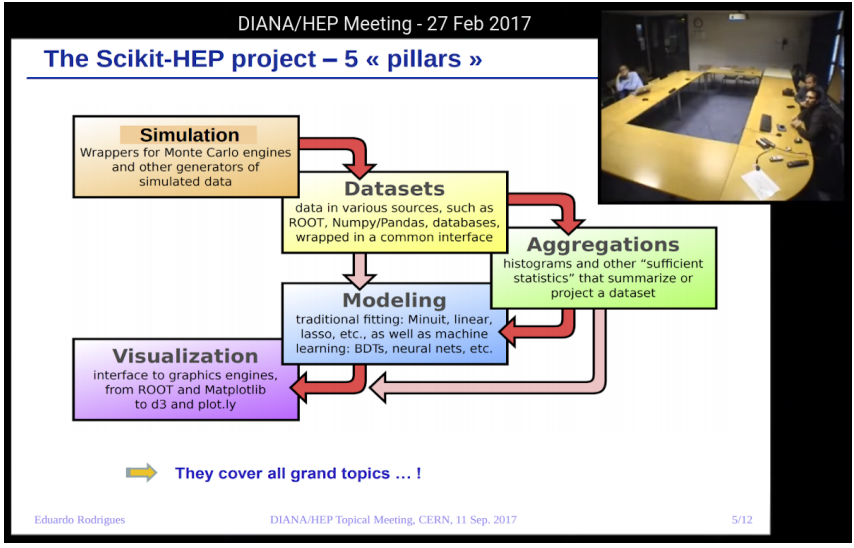
Part 2: Status of Pythonic HEP software

Not a single group, but mostly shared vision

Most of the developers of Pythonic HEP software

- aim for small package granularity, providing tools that address a well-defined class of problems at one level of abstraction,
- aim for interoperability with each other and the larger Pythonic ecosystem,
- avoid overlapping functionality, by communicating through HSF and IRIS-HEP channels,
- focus on domain-specific problems that won't be addressed by non-HEP software *or* focus on connecting HEP-specific tools to the larger ecosystem.

Scikit-HEP: a clearinghouse for Pythonic HEP software



Originally conceived as a core package with "affiliates" like AstroPy; now it's "just affiliates."

A common brand for packages that work together and with the Python ecosystem.

Scikit-HEP's 5 pillars today:

Simulation: other than `numpythia` and `pyhepmc`, this is mostly left to non-Python packages (which fill files that can be read with Python).

Datasets: `root-numpy`, `uproot`, `pylhe`, `awkward`, as well as `numpy` and `pandas`. Some use HDF5/`h5py` because of its recognition by ML tools.

Aggregations: `boost-histogram`/`hist`, `coffea`, `fast-carpenter`.

Modeling/fitting: by far, the most covered: `pyhf` (dozens of publications), `iminuit`, `zfit`, `hepstats`, `goofit`, `SModelS`, direct use of Pandas, ML...

Visualization: most modeling tools output to `matplotlib`, `mplhep` is widely used as a dependency. `coffea`, `hist`, `histoprint`.

Should also add Distributed computing: some `pyspark`, but more `dask`, often through `coffea` (future `coffea-casa`/ServiceX).

Should also add Acceleration/JIT-compilation: `numba`, `jax`, `ROOT.RDataFrame`.

Should also add HEP domain-specific: corrections in `coffea`, Lorentz vectors in `vector`, PDG in `particle`, jet clustering in `pyjet`...

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HEP domain-specific: `coffea` covers each use-case before it gets its own library.

Breakdown by strategy

Domain-specific stuff we do

- (super)histograms as fillable objects
- HEP-style plots (pulls, Brazil, efficiency...)
- ansatz fitting, limit setting, discovery significance
- applying corrections, clustering, Lorentz vector manipulation

Connections to externals

- ROOT, LHE files $\leftrightarrow$ arrays, Pandas, ML
- using ML packages to do HEP fits: `pyhf/combinetf`
- extending Numba for jagged arrays, Lorentz vectors, histogramming
- events $\rightarrow$ histograms workflow in distributed computing frameworks
- building Query Systems out of standard parts

External libraries we use

- machine learning
- distributed computing
- JIT-compilation
- autodifferentiation
- interactive notebooks

Conclusions

The question is not quite, "Will the whole ecosystem be ready for the HL-LHC?"

Many pieces are in-use *now*, and they're growing to fill real analysis needs *now*.

- I personally know of ∼10 analyses using Python almost exclusively (CMS $H \to \gamma\gamma$, $\to \mu\mu$, $\to c\bar{c}$, di-Higgs, top EFT, Dazsle analyses...).
- There is a wave of such analyses gradually approaching publication.

From current trends, it looks like Pythonic analysis will either predominate in Run 3 or stay evenly mixed with C++, it is today.