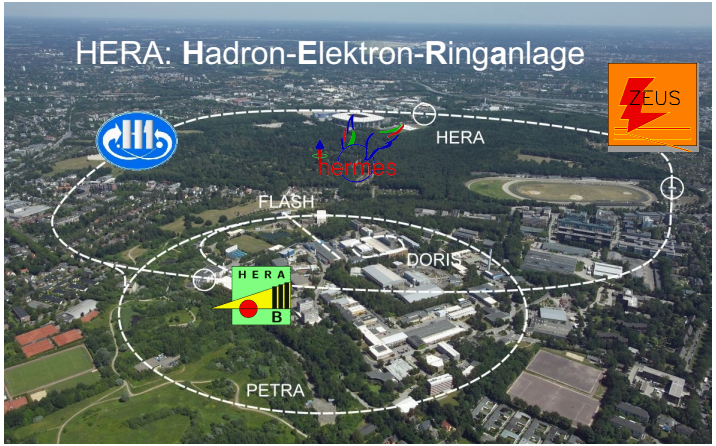
AGENT-ASSISTED DATA ANALYSIS AT HERA

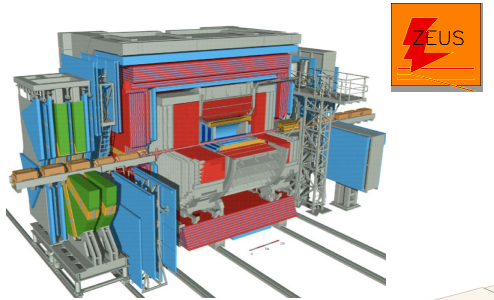
HENRY KLEST

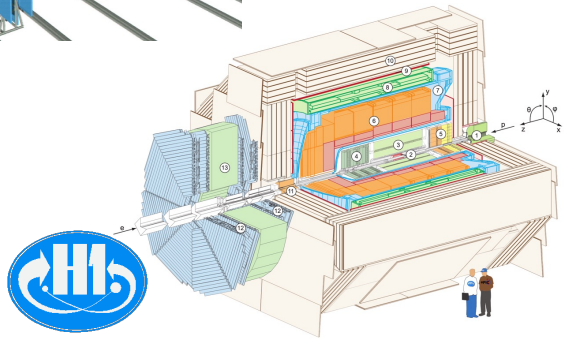
BNP DAP Meeting
8/27/26

HERA

- HERA: World's **only** (so-far) electron + proton particle collider
  - Ran from **1992-2007**
  - Located at DESY in Hamburg, Germany
  - Delivered ~ 1 fb^{-1} of data to two general-purpose hermetic detectors, **H1** and **ZEUS**
  - Scattered **28 GeV electrons** on **920 GeV protons**

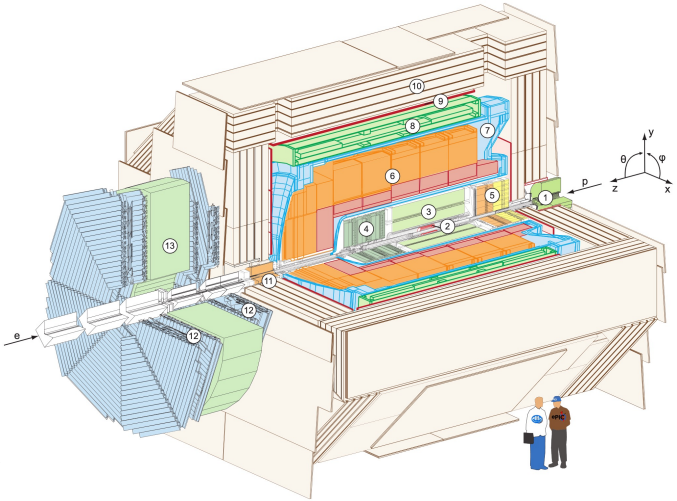






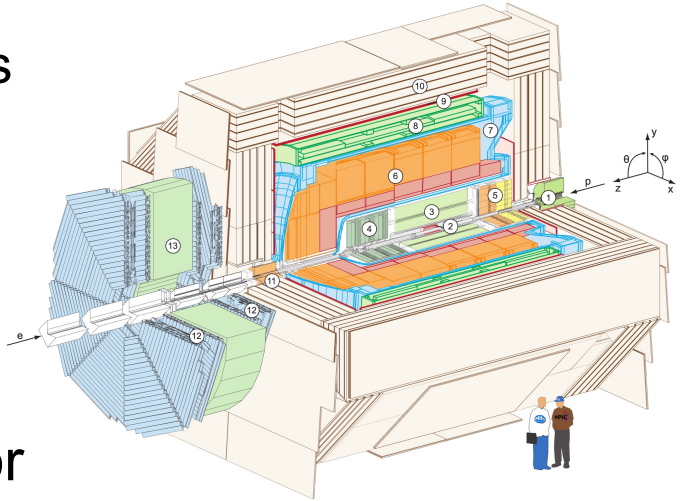
HERA & THE H1 EXPERIMENT

- H1 very much resembles ePIC
  - Hermetic detector, full coverage up to $|\eta|$ <4 for tracking, EM calorimetry, hadronic calorimetry
  - Drift chamber + (early) silicon tracking
  - High-resolution LAr calorimeter
    - One of the best resolution HCals ever
  - Ideal detector for jet studies!
    - Much of the H1 re-analysis has focused on jets for this reason
  - Data very well preserved; all analysis tools modernized to C++



HERA & THE H1 EXPERIMENT

- HERA operated until 2007
  - LHC & issues with the HERA-II luminosity upgrade resulted in a major outflux of personpower for HERA in the early/mid 2000s
  - Many statistically limited analyses only performed with the 50 pb^{-1} of HERA-I data instead of the 7x larger dataset from HERA-II
  - **Lots of science left on the table!**



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  - Data are well preserved
    - **Including simulation & software!**

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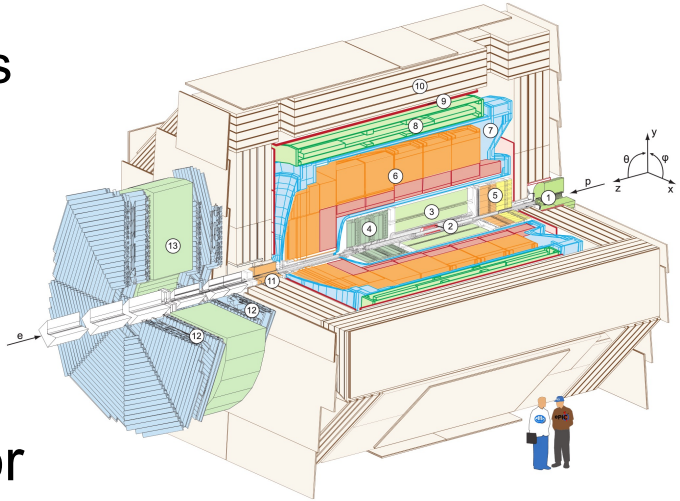

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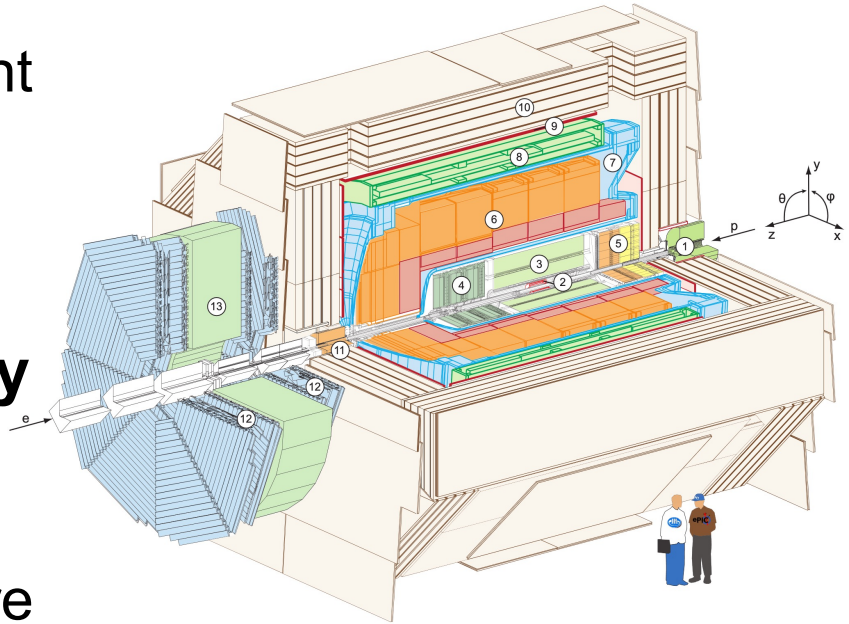
I see the HERA data as an **"EIC detector 2",** it will be the only place we can look for cross-check of EIC results

HERA & THE H1 EXPERIMENT

- Precision measurements of proton structure are a flagship measurement of the EIC

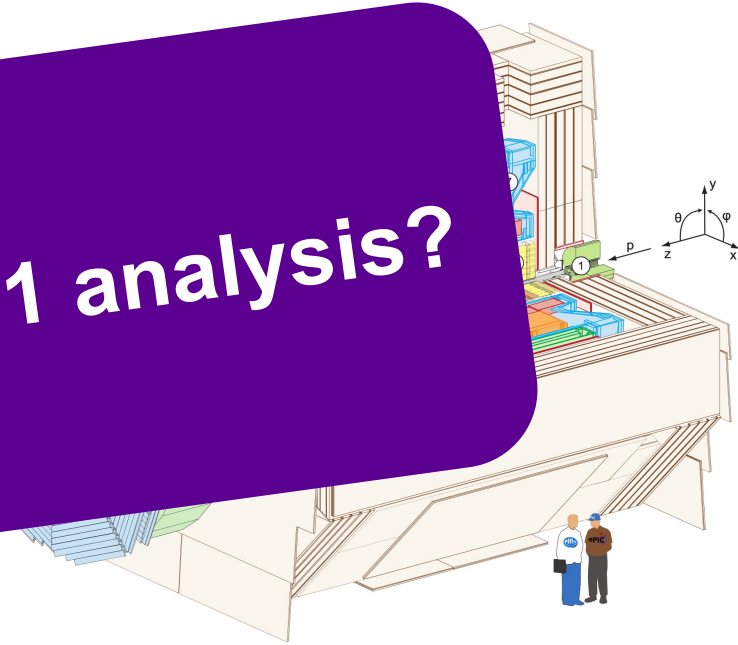
- Before the EIC turns on, can use the HERA data to test **new theory developments!**
  - —Lots of progress made in the phenomenology of proton structure since HERA shut down
  - —**But no workforce to test it…**



HERA & THE H1 EXPERIMENT

- Precision measurements of proton structure are a flagship measurement of the EIC
- [illegible] proton structure since HERA shut down
  - —**But no workforce to test it…**

Can AI agents do a full H1 analysis?



WHY AGENTS?

- **Agents have enormous benefits over humans for many analysis tasks!**
  - Can work **autonomously** and **in parallel** on tasks
  - Can digest huge bases of code in FORTRAN, C++, Java, Python, etc. **without documentation or input from experts**
  - Can **maximize HPC throughput** & efficiency, less "wasted" jobs
  - Can easily perform **"high-risk, high-reward" studies on the data**, that nominally a human wouldn't spend the time to do
    - I.e., "can we do things in a radically different way and achieve a more robust result?" Or "Is there new physics hiding over there?"
  - Gracefully handles **high-dimensional data** that confuses humans easily

AGENT-ASSISTED ANALYSIS

Examples:

- "Could you produce cross section predictions using the Sherpa, Rapgap, and Pythia8 event generators for the binning of our analysis?"
  - Agents dug in CVMFS for 30 minutes and **came back with predictions!**

- "Could you run those generated events through the H1 GEANT3 detector simulation package and write output data in the same format as our real data?"
  - Ancient codebase, written in early 90s, troublesome even for the only remaining experts
  - After ~ 1 hour of back and forth, agents managed to do it!

H1 ANALYSIS

- In **~2 months** working with agents, accomplished essentially **all analysis tasks** for a 4D cross section measurement
  - —Optimization of binning
  - —Unfolding
  - —Generating MC predictions
  - —Radiative corrections
  - —Backgrounds
  - —Uncertainties
  - —Writing the analysis note
- Biggest hurdles surround **poorly documented analysis components**
  - —Mostly regarding simulation & file locations

H1 ANALYSIS

- H1 benefits from a large body of ~ 1000 Ph.D & Masters theses
  - — Particularly those from German institutions, which are generally very detailed and high quality
  - — Many analysis aspects and procedures are described several times in detail
  - — Many written in other languages, mostly German, French, Russian, Polish, etc.
    - Not a problem for AI!
- Can direct an agent to read a 200 page Ph.D thesis and reproduce the results
  - — This is remarkably successful, once the context is known for the aspects which are not in theses (i.e. how to access the data, simulation, etc.)

Univ. Heidelberg Michael KOLLAK Entwicklung einer Stripline-Auslese
Diploma fuer Kathodensignale einer langen,
Univ. Heidelberg 9/98 zylindrischen Vieldrahtproportionalkammer
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II.Exp.Phys.Inst. Markus KAUSCHB-BLECKEN v. SCHMELING
Dissertation The Silicon Microvertex Detector of the H1
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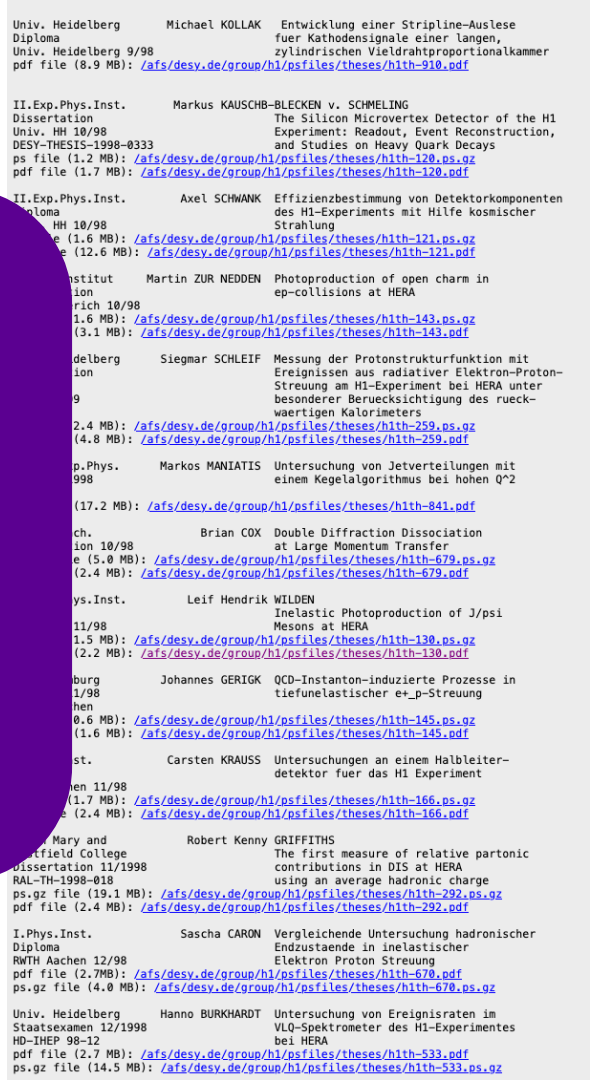
H1 ANALYSIS

- H1 benefits from a large body of ~ 1000

This huge knowledge base makes H1 an **ideal playground for agents!**

Usually don't need to invent new procedures, agents can easily reuse existing validated analysis procedures!

(i.e. how to access the data, simulation, etc.)



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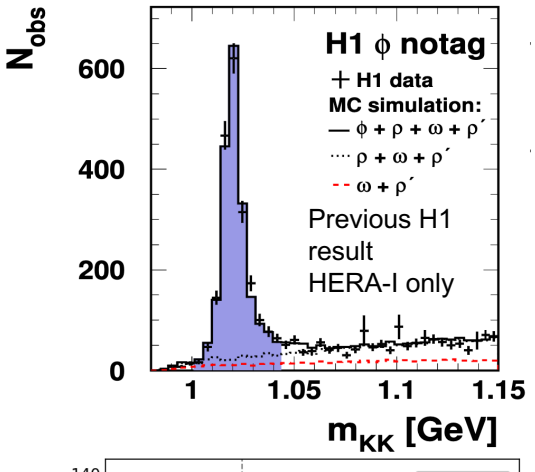
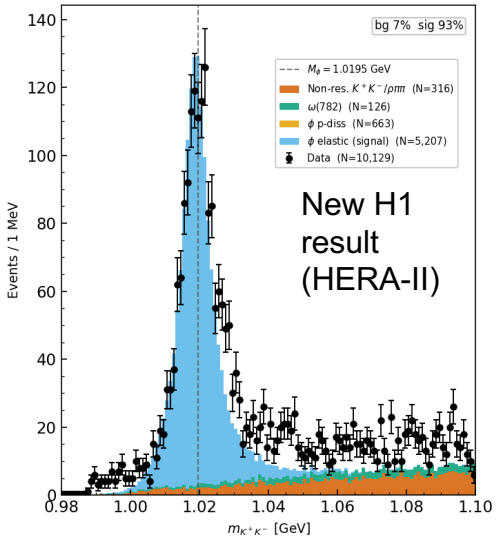
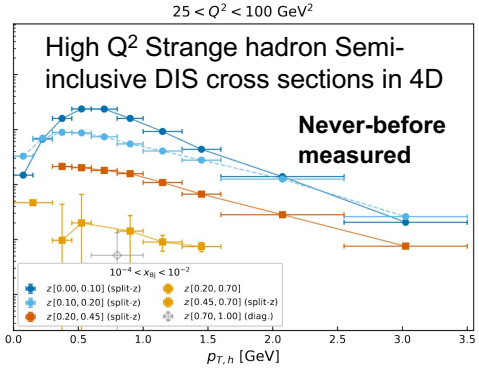
H1 ANALYSIS

- For example, asked Claude Opus 4.7 to repeat the existing HERA-I exclusive ϕ meson measurement on the HERA-II data
  - — After two prompts pointing it to the simulation I wanted to use, it arrived at the invariant mass distribution using the proper set of cuts
  - — One prompt later, was plotting background-subtracted reconstructed kinematic distributions!
  - — A few prompts more and had an acceptance corrected cross section
    - **Of course, this is where the real work starts ☺**
  - — Also, very useful for automating systematic uncertainty calculations (vary this cut, run the analysis again, etc.)

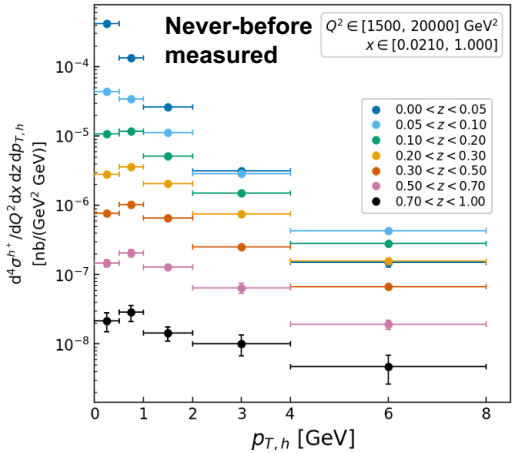


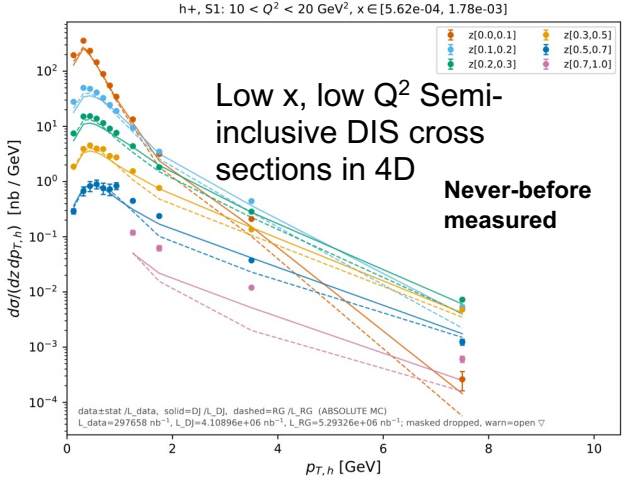


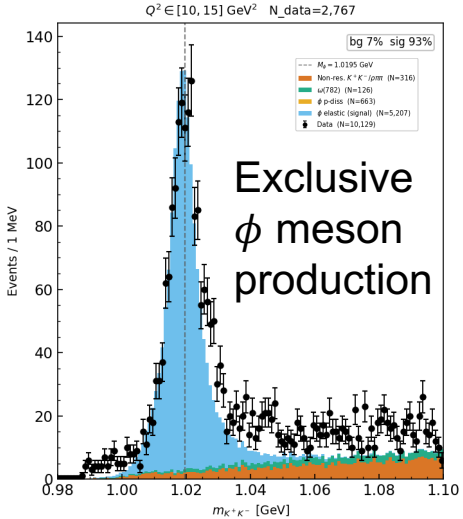
H1 ANALYSES UNDERWAY



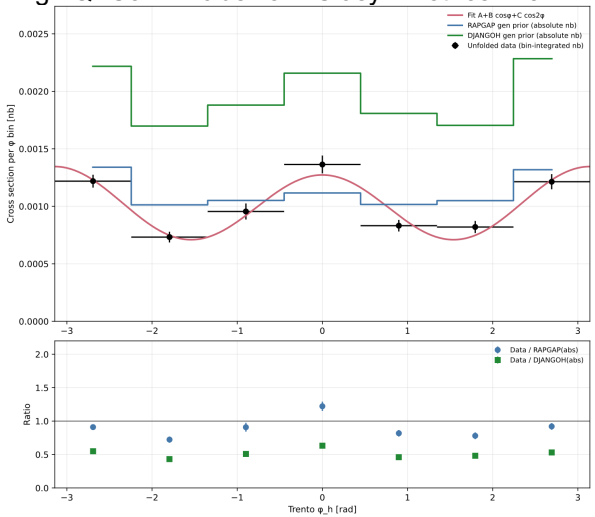
High Q^2 Semi-inclusive charged particle DIS cross sections in 4D

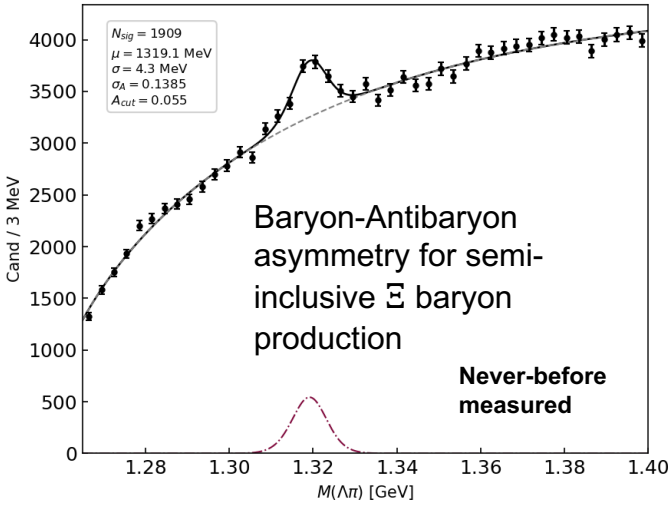






High Q^2 Semi-inclusive DIS asymmetries in 5D





MANAGING AGENTS

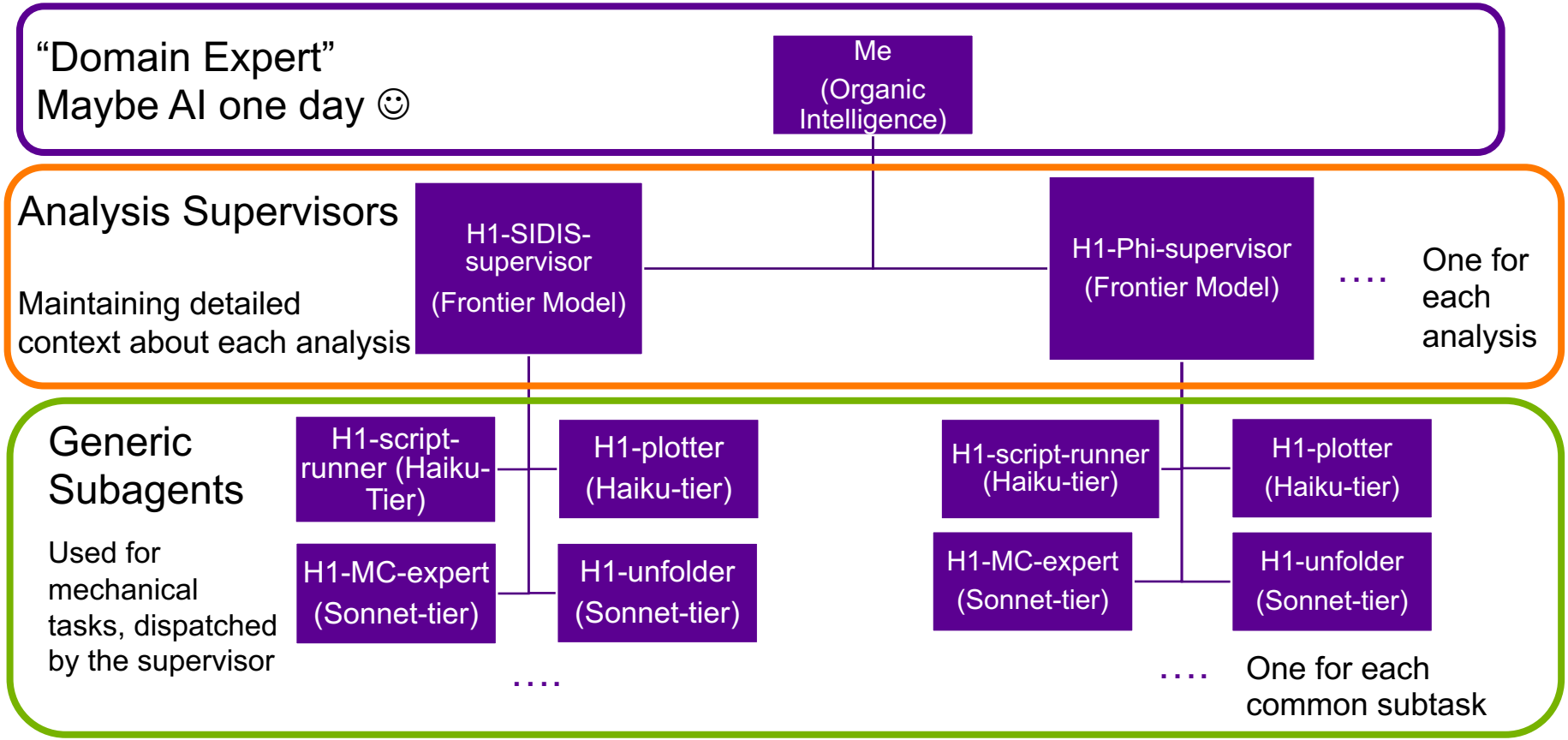
- **Loss of context is the primary challenge**
  - —The “skill” in doing lengthy analysis tasks with agents is **managing their context** to make sure they can handle their task
  - —If you feed **too little information**, agent won’t know what to do
  - —If you feed **too much information**, agent will run out of context (and cost lots of tokens!)
- **Both cases translate to a waste of time and money!**

- Can “tame” the intrinsic stochasticity of LLMs by supplying just the proper amount of context

THE SUPERVISOR

- The primary way to combat loss of context is to have a very high-level **supervisor** which delegates tasks to subagents
  - —The supervisor has: context about the status of the analysis & its dispatchable team of subagents
  - —The supervisor does **not** have: **the permissions to do anything by itself**
    - Otherwise, it will regress to doing tasks itself and eat up all of its context
- I essentially **only interact with the supervisor** when working on my analysis

MY AGENT SETUP “ORG CHART”



MY AGENT SETUP “ORG CHART”

“Domain Expert”
Maybe AI one day

Analysis Supervisors

Maintaining detailed context about each analys

Generic Subagents

Used for mechanical tasks, dispatched by the supervisor

H1-s runner T

H1-MC (Sonr

The new skillset needed for this is **how to be a good manager!**

For example:

Don’t want workers repeating work done by another worker;
Need to allocate tasks based on the skillset of the workers;
Have well-defined goals and milestones for the workers;
Need to be able to judge the quality of the worker’s work

common subtask

THE ELEPHANT IN THE ROOM

- The obvious question that will be asked is **“how do you know it’s right”**
  - We’re doing science, after all… **It needs to be right!**

- Treat the agents as a student with great coding skills but less physics intuition
  - Professors are rarely reading the code of their students!
  - **How do they know the results are correct?**
  - Need to ask them to reproduce existing results, make QA plots, etc., same for agents!

- One bonus of agents is that you can send waves of **critic agents** to critique the code implementation
  - Useful to give them different “personalities”, i.e. high temperature, low temperature
  - If 3 agents all say the implementation is correct, you have 1/sqrt(3) confidence that it’s right ☺

LESSONS FOR DATA PRESERVATION

- In 10 years, I doubt humans will be analyzing our data
  - Despite stochasticity, agents can dig much deeper into data and software than any human would have time for
  - Agents allow humans to do complete analyses in parallel
  - **IMO this makes the preservation even more important** because future AI systems will be able to mine the data extremely efficiently
    - i.e. analysis will not be limited by having 0 human FTEs to work on old data

- This H1 exercise has been successful thanks to the preserved knowledge base, software, and simulation
  - With agents, the language & volume of the software doesn't matter that much
  - Simulation files could be better organized and documented

CONCLUSION

- Can agents do a whole H1 analysis?
  - **Kind of**, currently needs constant supervision. Also, this was only possible
  - With the rate of improvement, could imagine in a couple years that a frontier model could do an entire analysis by itself ***(if proper documentation is available)***
  - Also important to note that these results were obtained with “unlimited” tokens at the time provided by Argonne
  - Working full-time on many analyses like this is quite expensive, O($5k/month)
  - IMO the investment is worth it for a 10-20x increase in productivity
  - But need a more sustainable model for paying for tokens within DOE (Argonne has already cut us off ☺)

- For existing experiments, agents will be extremely useful for producing documentation and helping to preserve the data!
  - Generally, produces too much output for a human to read, but future AI will be able to digest it

CONCLUSION

- **Agent-assisted analysis is the future**
  - Currently like riding a bucking bronco vs. walking, but we'll have cars someday ☺
  - Allows us to just do the fun part of science! (i.e. **the science**)
  - **Saves a huge amount of time and life force** that is generally spent on mechanical tasks and not actual data analysis
    - Running jobs on HPC clusters, writing plotting scripts, debugging segfaults
    - AI can performance optimize code significantly better than vast majority of physicists! Hopefully reduces HPC load.
  - Enables performing checks that otherwise may go undone and actually helps **make the analysis more rigorous**

Thanks! Questions?

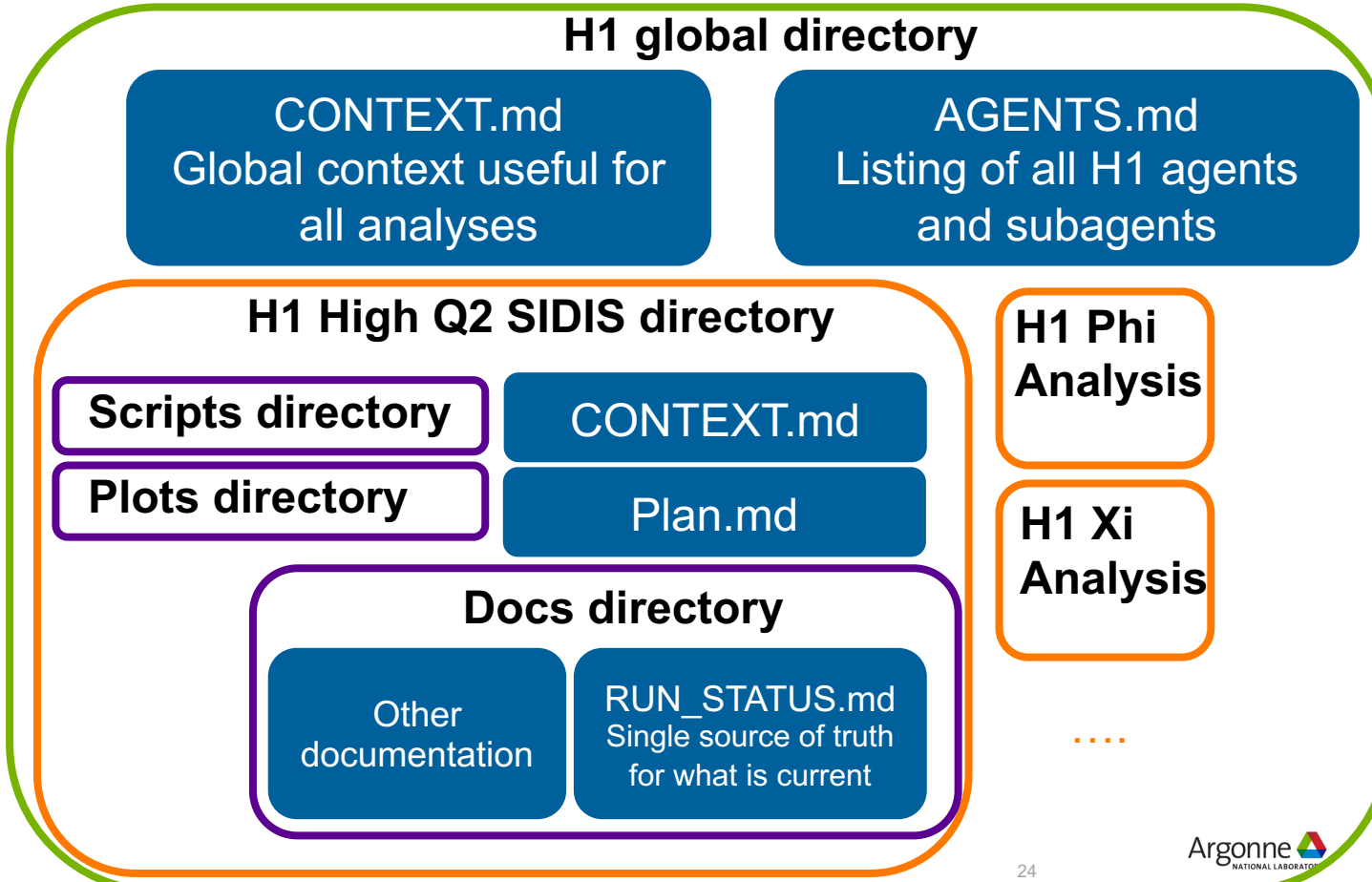
BACKUP

CONTEXT MANAGEMENT

Maintaining good documentation is absolutely critical, since we need to work across many sessions

Every directory should have a short manifest that tells agents what's there

Agents need to know what scripts to use, what files, etc.



TOKEN EFFICIENCY

- Token costs for heavy agent usage mitigated somewhat because ~90% of tokens are cached input tokens (cache hits)

- I switched to GPT5 models because Opencode doesn't show me any cached tokens for Anthropic models
  - Don't want to unnecessarily cost the lab 50x more!

Prices per 1M tokens.

	Short context			Long context		
Model	Input	Cached input	Output	Input	Cached input	Output
gpt-5.5	$5.00	$0.50	$30.00	$10.00	$1.00	$45.00
gpt-5.5-pro	$30.00	-	$180.00	$60.00	-	$270.00
gpt-5.4	$2.50	$0.25	$15.00	$5.00	$0.50	$22.50
gpt-5.4-mini	$0.75	$0.075	$4.50	-	-	-
gpt-5.4-nano	$0.20	$0.02	$1.25	-	-	-

Model	Base Input Tokens	5m Cache Writes	1h Cache Writes	Cache Hits & Refreshes	Output Tokens
Claude Fable 5	$10 / MTok	$12.50 / MTok	$20 / MTok	$1 / MTok	$50 / MTok
Claude Mythos 5 (limited availability)	$10 / MTok	$12.50 / MTok	$20 / MTok	$1 / MTok	$50 / MTok
Claude Opus 4.8	$5 / MTok	$6.25 / MTok	$10 / MTok	$0.50 / MTok	$25 / MTok
Claude Opus 4.7	$5 / MTok	$6.25 / MTok	$10 / MTok	$0.50 / MTok	$25 / MTok
Claude Opus 4.6	$5 / MTok	$6.25 / MTok	$10 / MTok	$0.50 / MTok	$25 / MTok
Claude Opus 4.5	$5 / MTok	$6.25 / MTok	$10 / MTok	$0.50 / MTok	$25 / MTok
Claude Opus 4.1 (deprecated)	$15 / MTok	$18.75 / MTok	$30 / MTok	$1.50 / MTok	$75 / MTok
Claude Opus 4 (retired, except on Vertex AI)	$15 / MTok	$18.75 / MTok	$30 / MTok	$1.50 / MTok	$75 / MTok
Claude Sonnet 4.6	$3 / MTok	$3.75 / MTok	$6 / MTok	$0.30 / MTok	$15 / MTok
Claude Sonnet 4.5	$3 / MTok	$3.75 / MTok	$6 / MTok	$0.30 / MTok	$15 / MTok

AGENT-ASSISTED ANALYSIS IN H1

- One analysis typically takes **3-4 years** from beginning to publication
  - —Usually, would pay one full Ph.D student FTE, part of a lab staff/professor during that period
- Since beginning of May, have been performing **5 unique experimental analyses in parallel by myself** using agents
  - —3 of 5 are now under collaboration review for public release
  - —Agents self-document, update an analysis note/paper draft as they go that can be shared with collaboration referees
  - —Usually takes ~2 years of analysis effort to get to this point! **With agents, ~ 1 month**

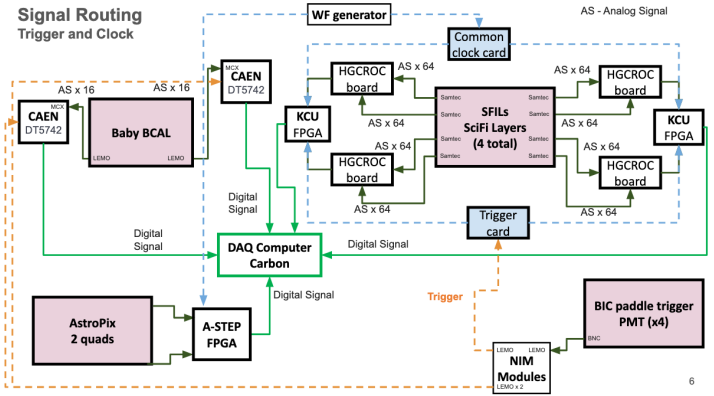
AGENT-ASSISTED ANALYSIS IN H1

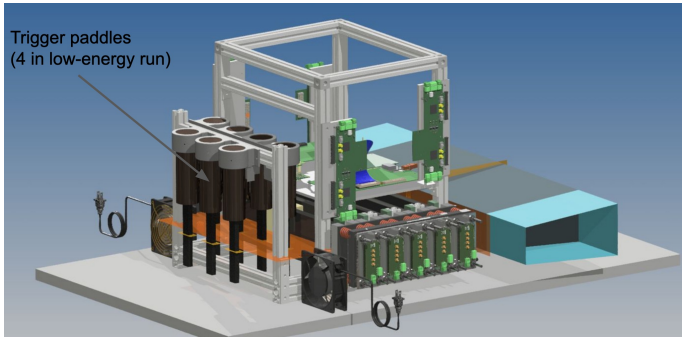
- Argonne's current API approach gives us an enormous **competitive advantage over other labs & universities**

- **Other labs will pay for a student or postdoc FTE to take three years to complete an analysis that $20k in tokens can complete in a couple months**
  - —This is clearly the future of physics data analysis, and we have a head start

TEST BEAM AT JEFFERSON LAB

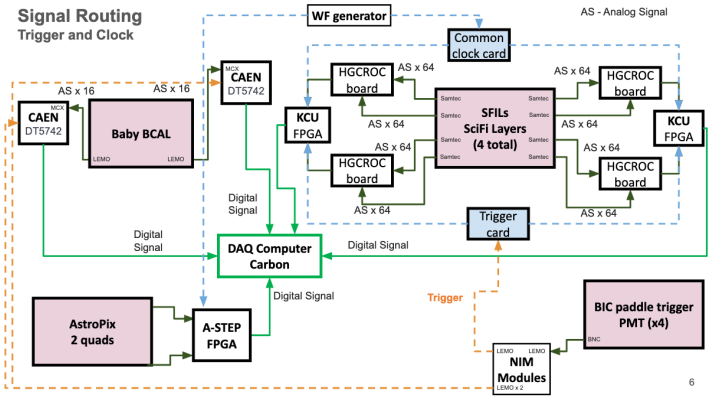
- In March & April, had a prototype of the Barrel Imaging Calorimeter that our group is building for the EIC exposed to beam parasitically at Jefferson Lab
  - Very complicated readout setup employing 3 heterogenous readout systems, 2 different ASICs, 5 FPGAs
  - Senior data acquisition expert from BNL who wrote our DAQ software was oversubscribed and mostly not available to help during running
  - Had no direct access to setup, agents were instrumental in keeping all systems functioning remotely

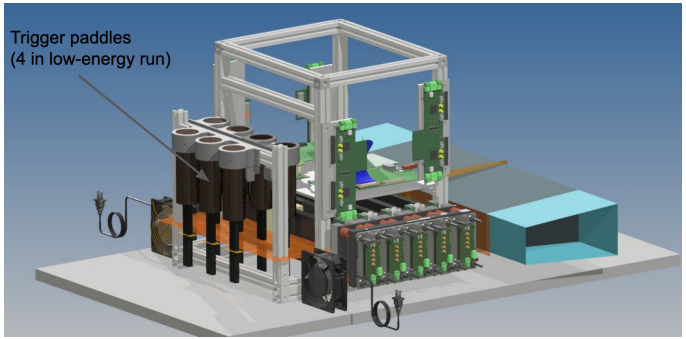




TEST BEAM AT JEFFERSON LAB

- Claude was able to digest the entire data acquisition software chain & replace the expert.
  - —Suggested and implemented improvements on the DAQ software that allowed us to run at a 3x higher data rate
- Agents also instrumental in analysis of the very large dataset, finding O(10-100x) speed improvements in decoding, data processing, etc.
  - —Saving huge amount of CPU hours





PHENOMENOLOGY

- Currently 3 agent-assisted papers in the works on possible physics opportunities at the EIC and JLab

- Less mechanical than data analysis, requires strong reasoning capabilities + cross check
  - —Generally less token-heavy overall since the task set is smaller and less heterogeneous