HEP Science Goals for the Next Decade

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The Big Questions and Where They Lead us Today

• What are we? and How did we get here?

• These questions are at the heart of the sciences. For HEP they are particle, astro-particle, and cosmology questions.

• r-process nucleosynthesis

• cosmic evolution
Science Drivers

• Concentrating on the decadal drivers, we have:
  • Fully exploit the Higgs using it as a tool for further discovery, electroweak and flavor physics
  • Investigate the neutrino mass and hierarchy
  • Investigate dark matter and it’s role in cosmic evolution
  • Investigate cosmic acceleration, dark energy, quantum gravity
  • Explore the unknown
Instrumentation

- Large scientific achievements in the past decades have been enabled by large advances in instrumentation.
- Large silicon detectors and cameras with high granularity are driving us to large computing and data challenges.
- Large costs of these projects require an international scope.
Data Movement

- International science requires international data movement and storage.
- Going forward the LHC will not be alone in using this infrastructure.
International Big Data Science

- LHC, SKA, DUNE, LIGO, LSST

- For each of these I will have one slide on the science case and one slide on the data needs

- While we know the computing challenges are equally large, others outside of HEP are planning to build exescale compute

- Most likely our community will have to build exescale data along with our partners.
Thoroughly investigate the mass generation mechanism
– Measure the Higgs properties as accurately as possible
– Are there heavier partners of the 125GeV Higgs boson?
– Does Higgs moderate the vector boson scattering cross section @~1TeV?

Explore the multi-TeV (and sub-TeV!) region as thoroughly as possible
– Go to as high masses and as low cross sections as possible

Search for/observe rare processes that would signal deviations from the Standard Model
– E.g. flavor changing neutral currents in top decays, or rare B decays

The only program in the next 20 years that can contribute in all of these fronts.
LHC Current Data Projections

- From the CWP; the plots themselves show that data models have to change.
- The concept of cold storage for RAW is already embedded in CMS.

Data on disk by tier

- Run1 & 2
- Ops space
- RAW
- GENSIM
- AOD
- MINIAOD
- USER

Resource needs (2017 Computing model) +15%/year

ATLAS Preliminary

- Disk Storage [PB/years]
SKA Science

- The SKA will investigate this expansion after the Big Bang by mapping the cosmic distribution of hydrogen.

- SKA will investigate the nature of gravity and challenge the theory of general relativity.

- SKA will create three-dimensional maps of cosmic magnets to understand how they stabilize galaxies, influence the formation of stars and planets, and regulate solar and stellar activity.

- SKA will look back to the Dark Ages, a time before the Universe lit up, to discover how the earliest black holes and stars were formed.

- SKA will be able to detect very weak extraterrestrial signals and will search for complex molecules, the building blocks of life, in space.
SKA Data

- SKA is a software telescope
- Very flexible and potentially easy to reconfigure
- Major software and computing challenge
- Bottom line: will collect 300PB/year
Aiming for groundbreaking discoveries

**Origin of Matter**  Neutrino Oscillations
Could neutrinos be the reason that the universe is made of matter rather than antimatter? By exploring the phenomenon of neutrino oscillations, DUNE seeks to revolutionize our understanding of neutrinos and their role in the universe.

**Unification of Forces**  Proton Decay
With the world’s largest cryogenic particle detector located deep underground, DUNE can search for signs of proton decay. This could reveal a relation between the stability of matter and the Grand Unification of forces, moving us closer to realizing Einstein’s dream.

**Black Hole Formation**  Neutrino Astrophysics
DUNE’s observation of thousands of neutrinos from a core-collapse supernova in the Milky Way would allow us to peer inside a newly-formed neutron star and potentially witness the birth of a black hole.
DUNE Data

• Full Stream Data for DUNE is impossibly large, order 150EB/year

• Much of the detector research will go into reducing that to reasonable levels

• suppression of $^{39}$Ar decay, cold electronics noise, space charge effects, argon purities all play a role

• above means that most challenging data needs for DUNE are during it’s prototyping phase - now until 2020

• Needs proposed at review: low/high = 4/59 PB, most probable 16PB

<table>
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<th>Storage (TB)</th>
<th>Tape (PB) low/high</th>
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LSST Science

- LSST will conduct a deep survey with a frequency that results in taking repeat images of every part of the sky every few nights in multiple bands for ten years.

- **Milky Way Structure & Formation:** by creating a map 1000 times the volume of past surveys, cataloging the colors and brightnesses of billions of new stars.

- Probe the nature of **dark matter and dark energy** using several billion galaxies

- Exploring the Changing Sky and Cataloging the Solar System
LSST Data

- LSST will collect 50PB/year of data.
LIGO Science

Is general relativity the correct theory of gravity?
How does matter behave under extreme densities and pressures?
How abundant are stellar-mass black holes?
What is the central engine driving gamma ray bursts?
What happens when a massive star collapses?

• With the discovery of gravitational waves LIGO has ushered in a new branch of astronomy
MULTI-MESSENGER ASTRONOMY

• Data science is not just about the large size of datasets it is also about the needed velocity of processing.

• Grid resources were used to search for the EM counterparts of GW events enabling the witnessing of r-process nucleosynthesis.
International Data Needs

- **LHC – 2016**: 50 PB raw data
- **LHC Science data**: ~200 PB
- **Google searches**: 98 PB
- **Facebook uploads**: 180 PB
- **Google Internet archive**: ~15 EB
- **SKA Phase 1 – 2023**: ~300 PB/year science data
- **SKA Phase 2 – mid-2020’s**: ~1 EB science data
- **HL-LHC – 2026**: ~1 EB Physics data
- **HL-LHC – 2026**: ~600 PB Raw data
- **Yearly data volumes**
Sharing Infrastructures

- Most science needs are spiky, a large number of users keeps utilization high.
Long Tail of Science

11 fields of science consumed more than 10M core–hrs

- Allowing opportunistic use of our large facilities is powerfully enabling
Conclusions

• The data and compute challenges of the next decade are large, even daunting.

• In order to satisfy the scientific needs, we will need to build unprecedented scientific facilities and capabilities.

• The scientific harvest that is arriving with this new era of big data science, is extremely compelling.

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