



Evolving Research Software towards Next-Generation High-Energy Physics Experiments

Peter Elmer

Princeton University

13 May 2025 - IIT Bombay



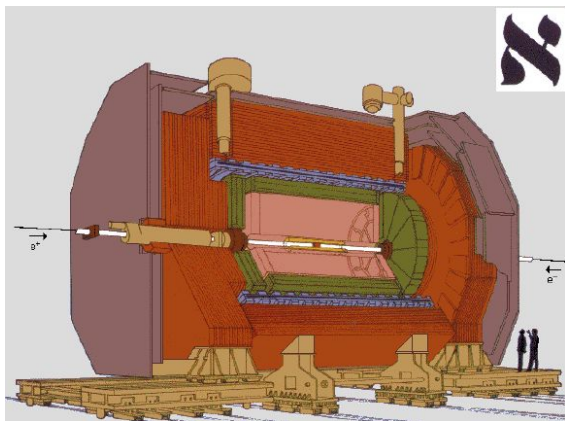
Introductions.... Who am I?

I am an experimental particle physicist (Princeton Physics since 2001, but based in Geneva, Switzerland) focused on computational and data science problems in my field, along with the software/computing systems to solve them.



Researchers in experimental particle physics tend to introduce themselves to each other with reference to the series of experiments with which they have collaborated. So here is my own version of that:

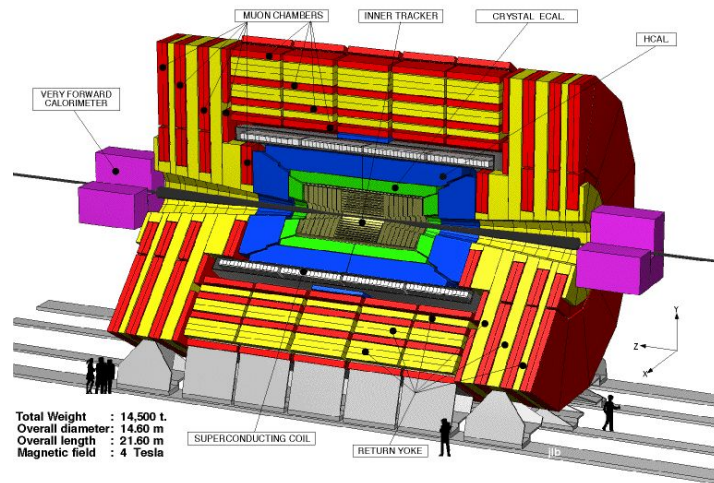
Aleph@CERN



BaBar@SLAC



CMS@CERN



Total Weight : 14,500 t.
Overall diameter: 14.60 m
Overall length : 21.60 m
Magnetic field : 4 Tesla

Fundamental Particles of Matter - “Particle Zoo”

1937: Discovery of the muon (Anderson and Neddermeyer)

a copy of the electron but with 200 times the mass ($m_\mu = 200 \times m_e$)

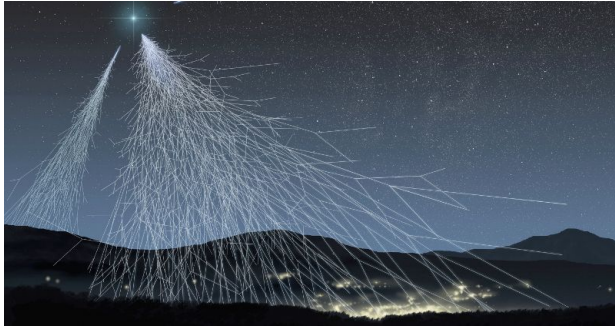
-and- the positron (Anderson) in cosmic rays

1947: Charged pion discovery and Kaon discovery, 1949: neutral pion discovery

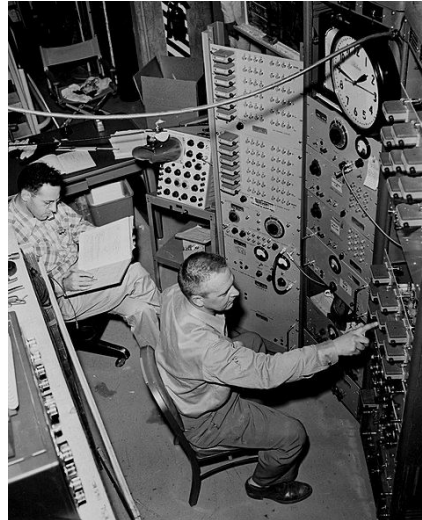
1955: Discovery of the antiproton, at the Bevatron

1956: Discovery of the neutrino (Cowan, Reines, et al), using nuclear reactor

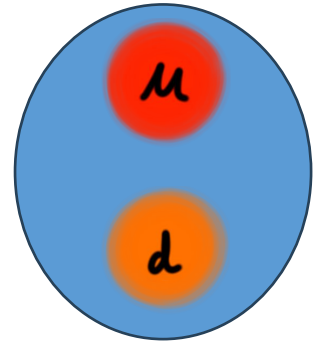
1960s: Quark Model and Deep Inelastic Scattering Experiments (SLAC)



**A first surprise -
Muons “Who ordered
that?”**



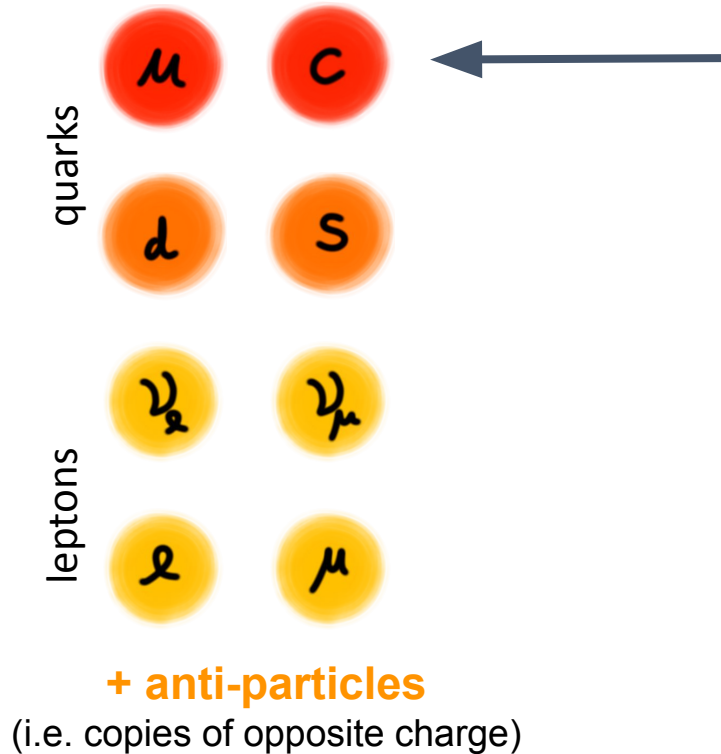
Proton +
neutron



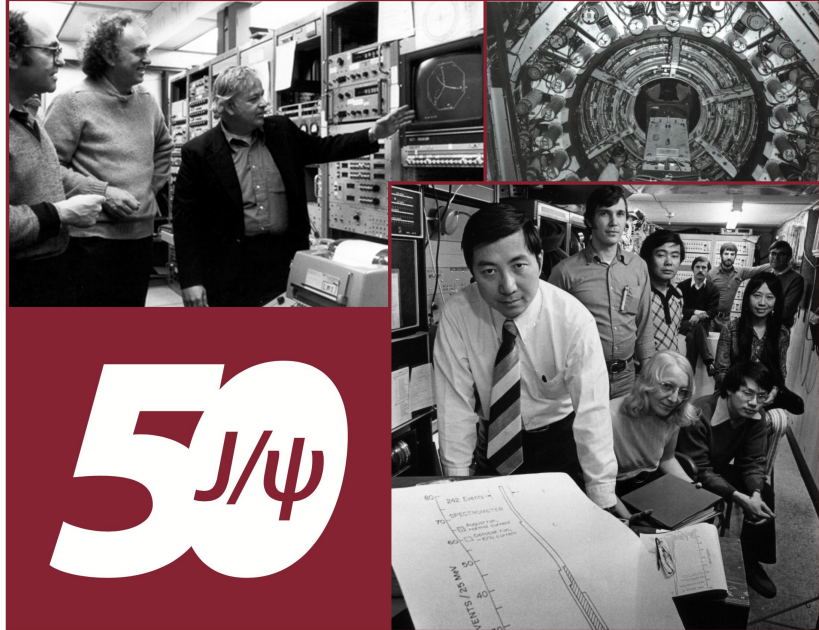
leptons



November “Charm” Revolution: Two families of fermions?



Symposium on the 50th Anniversary of the November Revolution



50 J/ψ

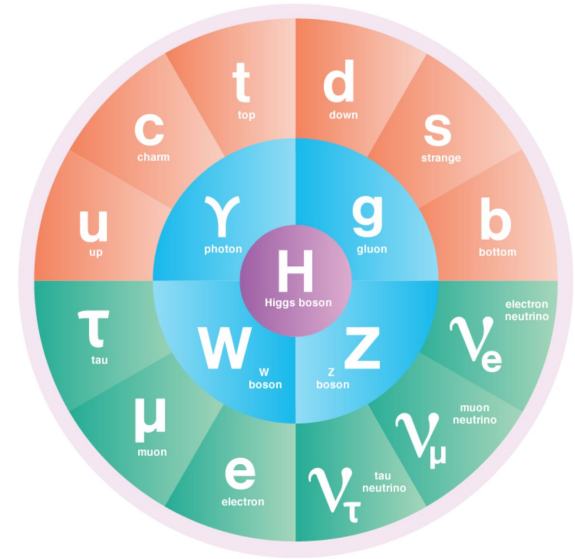
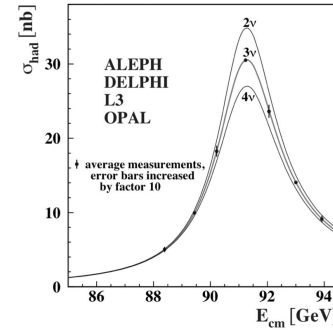
Fast forward....

Three complete families of fermions

quarks	μ	c	t	Electrical Charge $+2/3$	Spin $1/2$
	d	s	b		
	ν_d	ν_μ	ν_τ		
leptons	e	μ	τ	0	$1/2$

+ anti-particles
(i.e. copies of opposite charge)

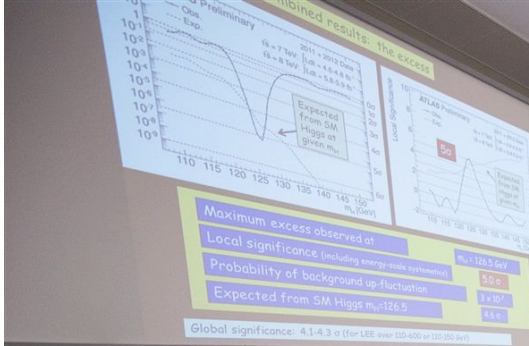
Intrinsic Angular
Momentum



QUARKS LEPTONS BOSONS HIGGS BOSON

Higgs Particle Discovery Announcement July 4th, 2012

ICHEP,
Melbourne



CERN, Geneva

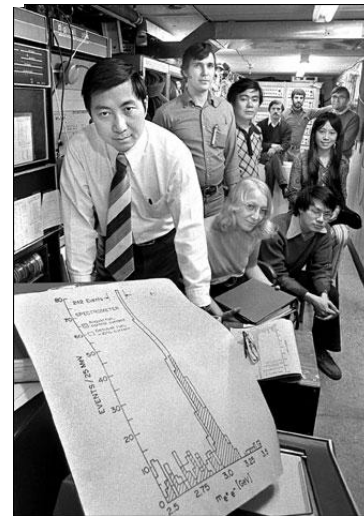
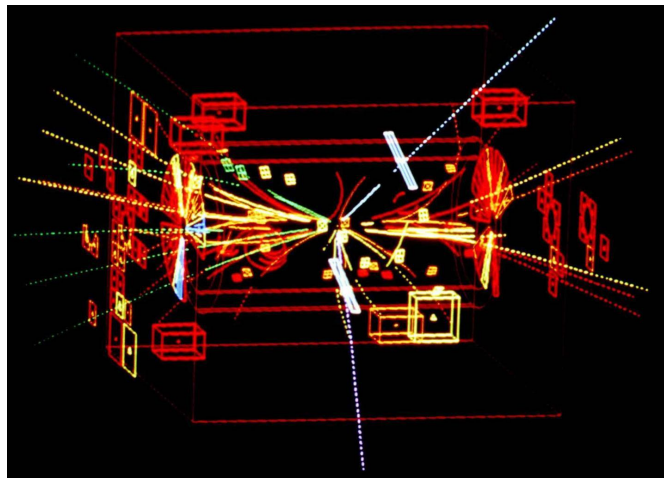
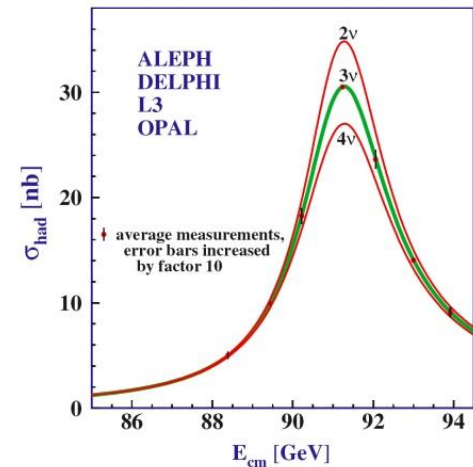
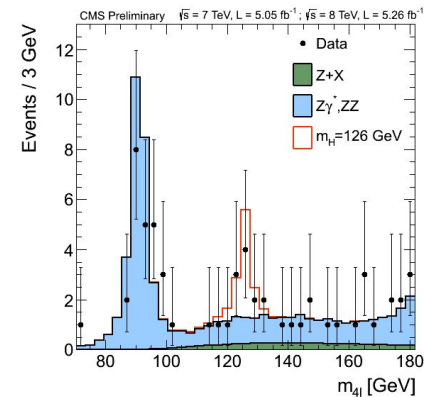
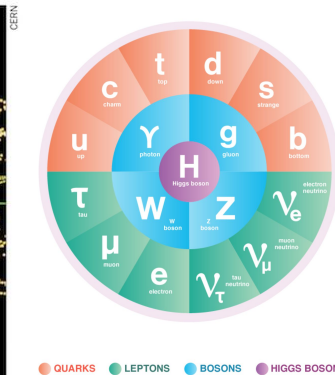
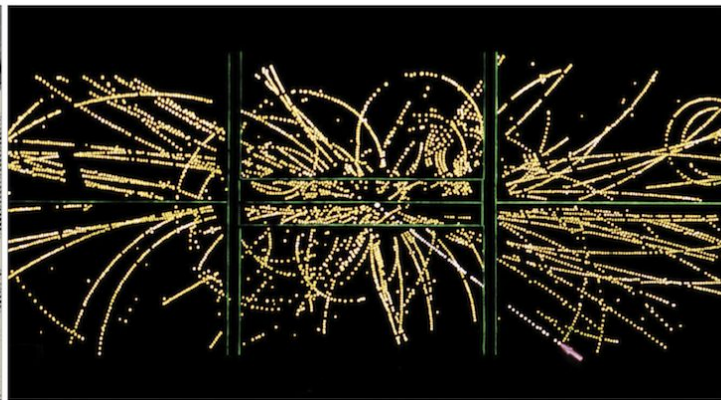


Something that looks like the Standard Model Higgs boson was discovered in 2012, Mass $\sim 125 \text{ GeV}$



Nobel prize in physics in 2013

Experimental Development of the Standard Model



**How did we get here?
(As experimentalists)**

Tools \longleftrightarrow Discoveries

1895 - Roentgen discovers x-rays using cathode ray tubes



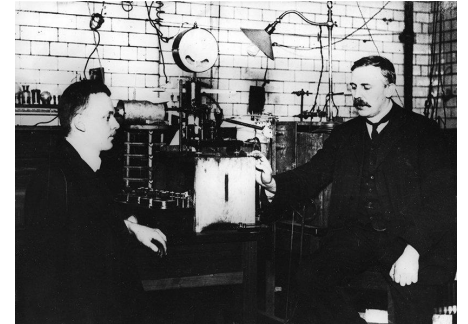
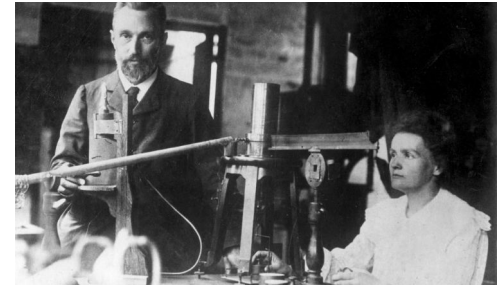
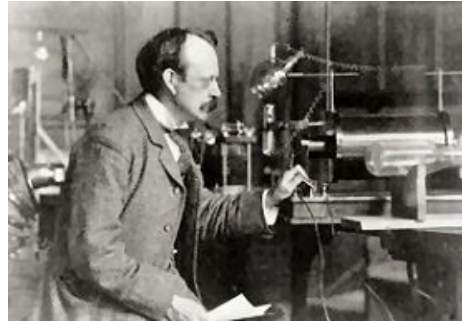
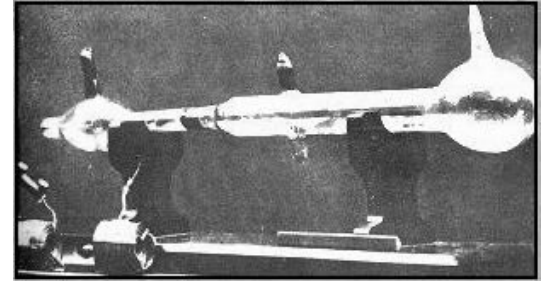
1896 - Becquerel accidentally discovers radioactivity in uranium, trying to explain x-rays



1898+ - Marie and Pierre Curie discover and explore radioactivity in other elements (polonium, thorium, radium)



1911 - Rutherford, Geiger, Marsden use radioactivity to explore atomic structure and discover the nucleus

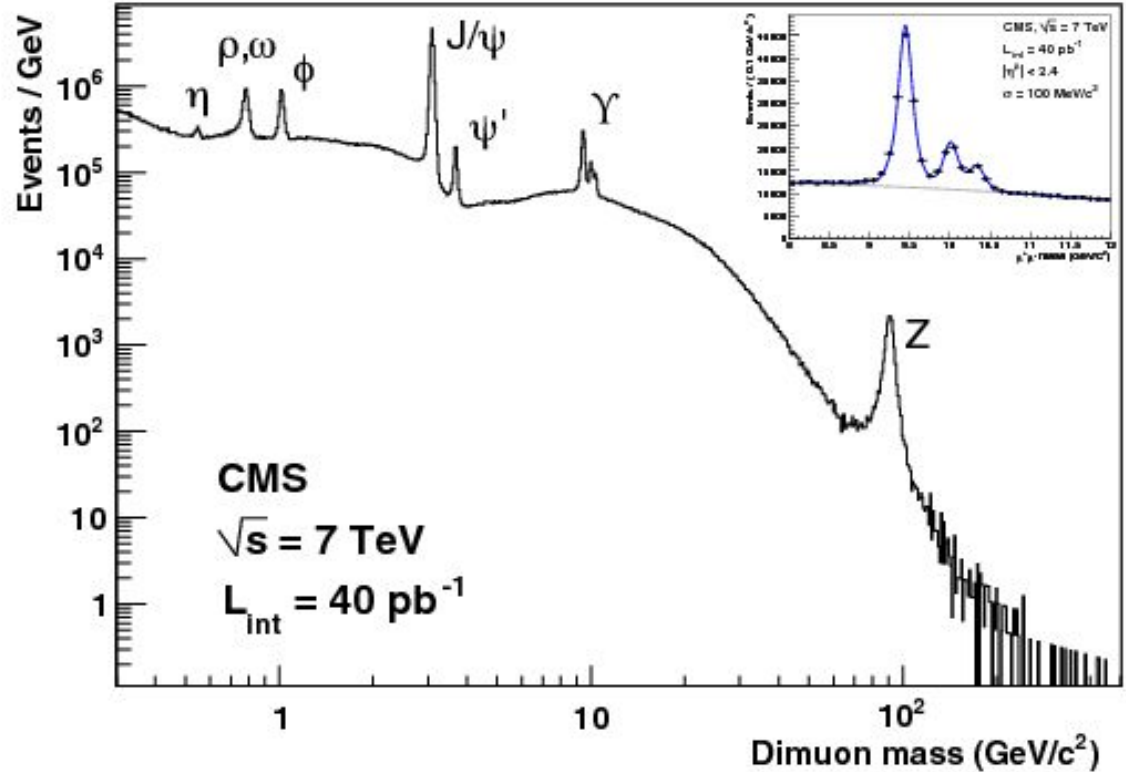


Evolution in particle physics

Discovery of a particle leads to Nobel prize and full exploration of the properties of the particle.

On the subsequent experiments the particle is used for calibration or as a tool itself (e.g. in a beam).

On later experiments the particle becomes a background.



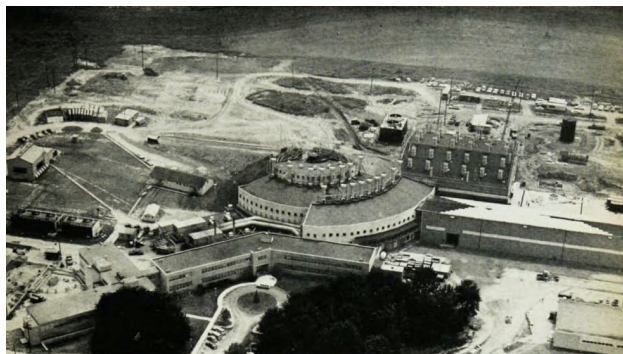
Big Science and Accelerators - larger and larger facilities



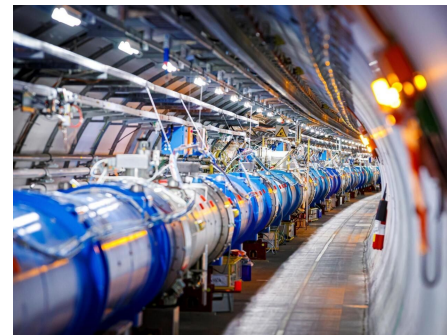
E.O. Lawrence and the cyclotron
at U.C. Berkeley



The birth of the “National Accelerator
Laboratory” in the US (now Fermilab)



The Princeton-Pennsylvania Accelerator,
Milton White 1964 Physics Today 17(8): 27



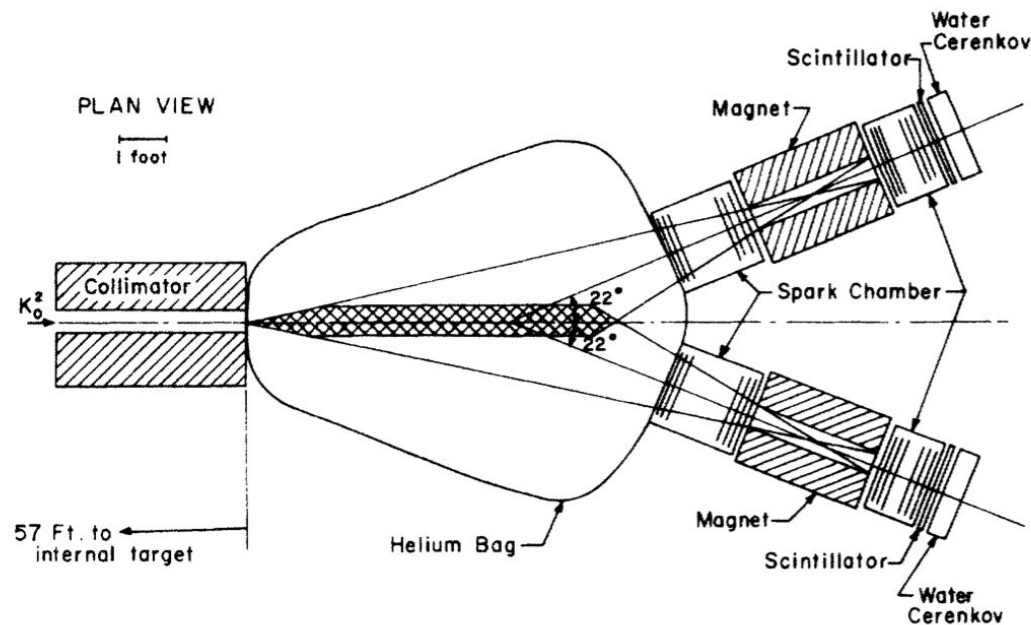
The Large Hadron Collider and
CERN first as a European laboratory
and then as a “world laboratory”

EVIDENCE FOR THE 2π DECAY OF THE K_2^0 MESON*†

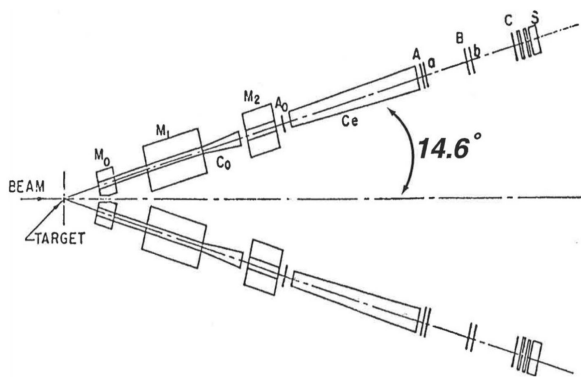
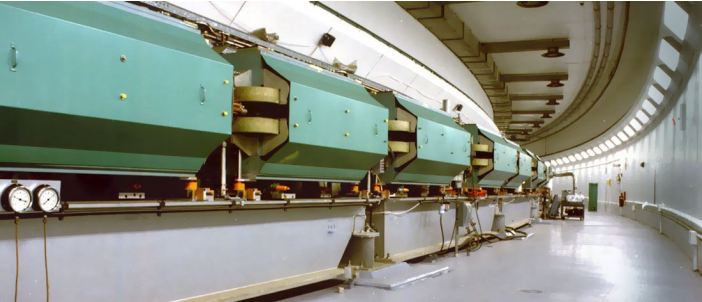
J. H. Christenson, J. W. Cronin,† V. L. Fitch,† and R. Turlay§

Princeton University, Princeton, New Jersey

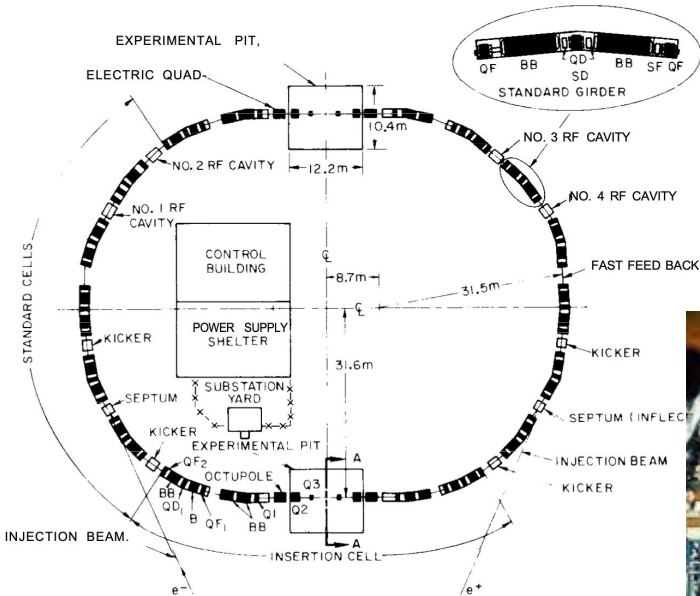
(Received 10 July 1964)



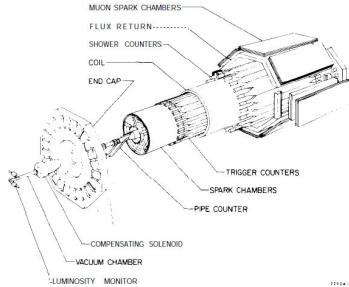
AGS at BNL delivering protons on a fixed target



Spear e+e- collider at SLAC and Mark 1 detector

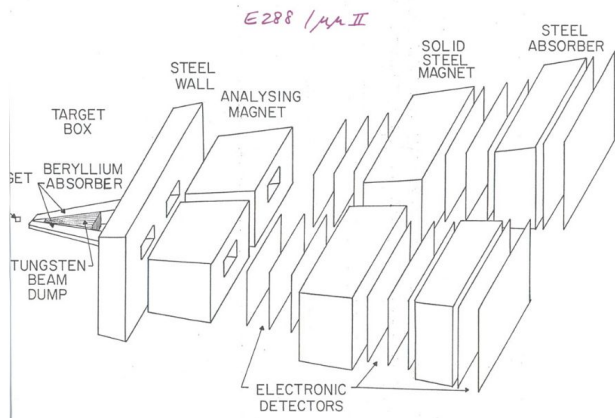


1. Schematic of the SPEAR storage ring.

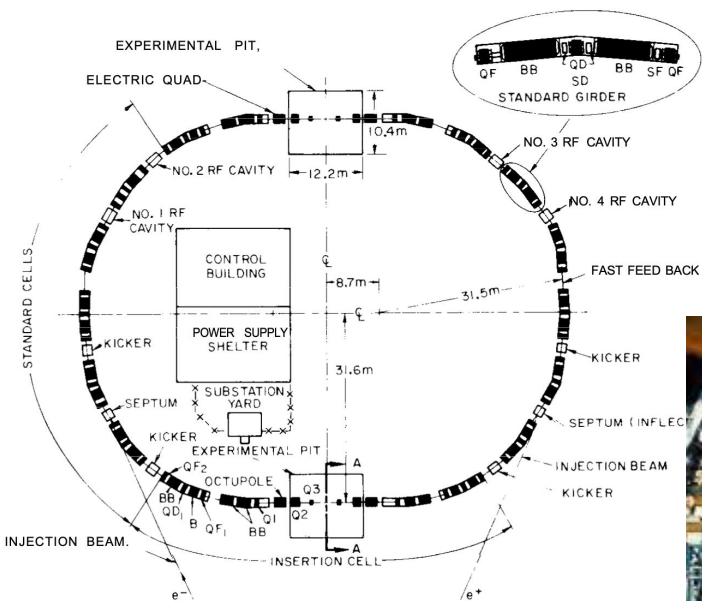


J and Psi discoveries in 1974

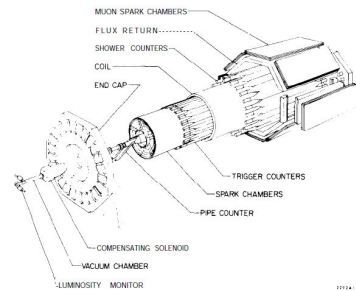
Protons at FNAL on a Uranium fixed target



Spear e+e- collider at SLAC and Mark 1 detector



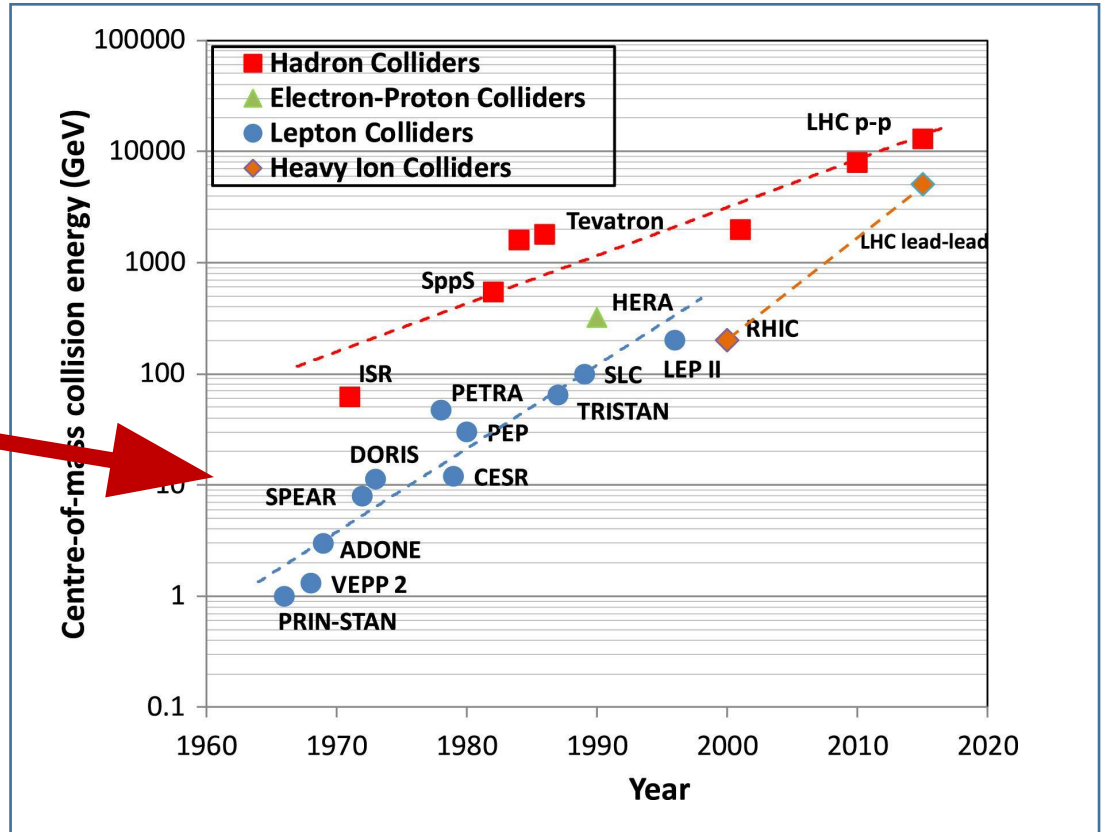
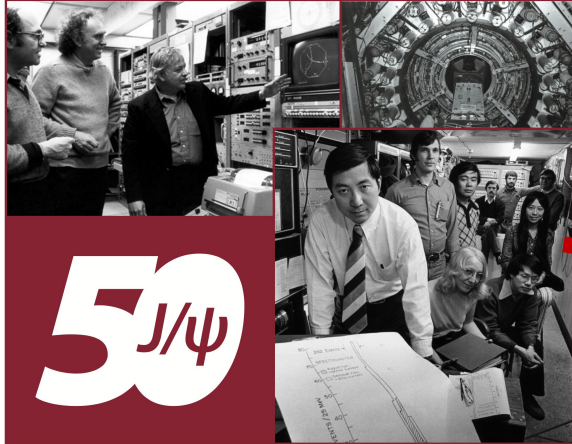
1. Schematic of the SPEAR storage ring.



**Bottom and Tau discoveries
in 1977 and 1975**

High Energy Physics is a facilities driven science

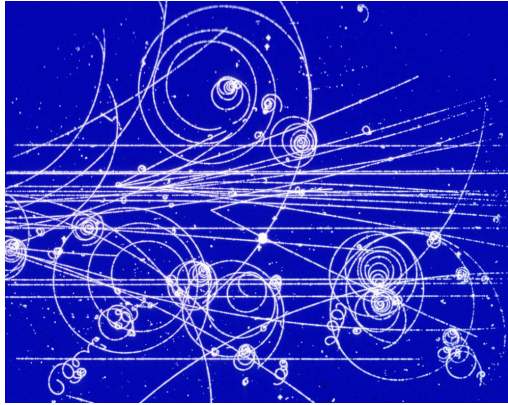
Symposium on the 50th Anniversary
of the November Revolution



Last month:

<https://indico.slac.stanford.edu/event/9040/>

Instrumentation - Detectors (+ Electronics)

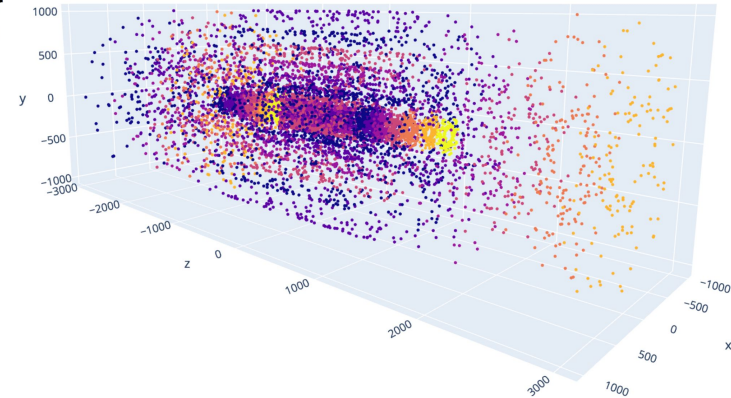
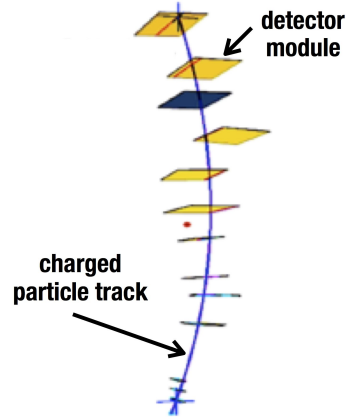
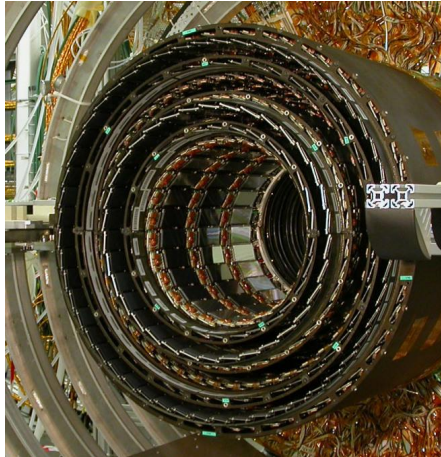


Bubble chamber
photography

By-hand
“scanning” of
the photos



Modern
detectors with
(digital)
electronic
readout



"New directions in science are launched by new tools much more often than by new concepts. The effect of a concept-driven revolution is to explain old things in new ways. The effect of a tool-driven revolution is to discover new things that have to be explained." - *Freeman Dyson*



Physics Nobel Prizes → Tools open doors to new research avenues

- **2024** (Hopfield, Hinton) - foundational discoveries and inventions that enable machine learning with artificial neural networks
- **2023** (Agostini, Krausz, L'Huillier) - development of experimental methods that generate attosecond pulses of light for the study of electron dynamics in matter
- **2018** (Ashkin) - invention of optical tweezers and their application to biological systems
- **2018** (Mourou, Strickland) - invention of a method of generating high-intensity ultra-short optical pulses
- **2014** (Isamu, Hiroshi, Nakamura) - invention of efficient blue light-emitting diodes, which has enabled bright and energy-saving white light sources
- **2012** (Haroche, Winelar) - development of methods that enable measuring and manipulation of individual quantum systems
- **2009** (Boyle, Smith) - invention of the CCD sensor, an imaging semiconductor circuit
- **2009** (Kao) - achievements concerning the transmission of light in fibres for optical communication
- **2005** (Glauber) - contributions to the field of optics
- **2005** (Hall, Hänsch) - contributions to the development of laser spectroscopy
- **2000** (Kilby) - development of the integrated circuit (microchip)
- **2000** (Alferov, Kroemer) - development of fast semiconductors for use in microelectronics
- **1997** (Chu, Cohen-Tannoudji, Phillips) - process of trapping atoms with laser cooling
- **1992** (Charpak) - invention of a detector that traces subatomic particles
- **1989** (Dehmelt, Paul) - development of methods to isolate atoms and subatomic particles for study
- **1989** (Ramsey) - development of the atomic clock

Large Hadron Collider
proton-proton collisions
Center of mass energy: 7-8-13-**13.6**-14
TeV

Lake
Geneva



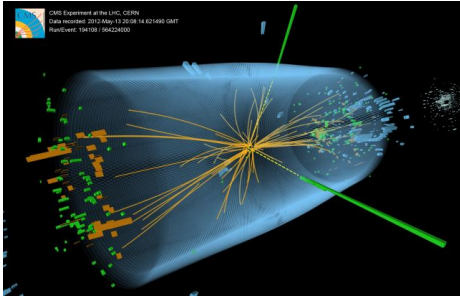
LHC ring:
27 km
circumference

SPS
ring

Airport

CERN

Large Hadron Collider Experiments Are Massive Data Generators



CMS DETECTOR

- Total weight : 14,000 tonnes
- Overall diameter : 15.0 m
- Overall length : 28.7 m
- Magnetic field : 3.8 T

STEEL RETURN YOKE

12,500 tonnes

SILICON TRACKERS

Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID

Niobium titanium coil carrying ~18,000A

MUON CHAMBERS

Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER

Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER

Steel + Quartz fibres ~2,000 Channels

CMS

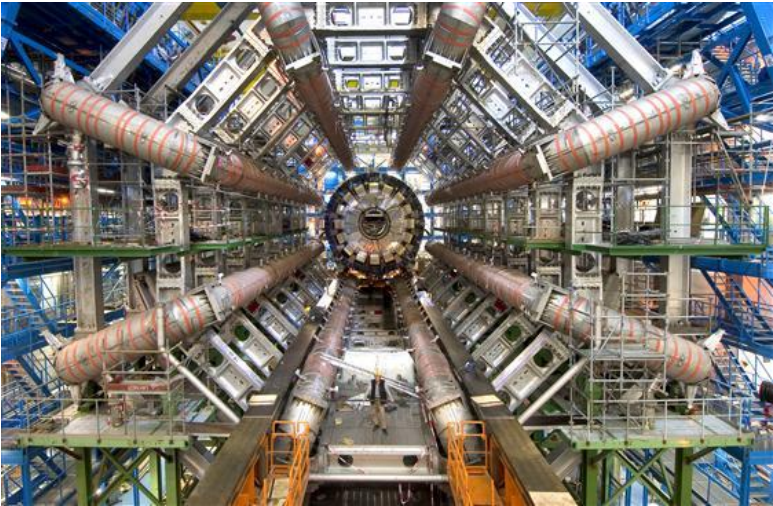
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)

~76,000 scintillating PbWO₄ crystals

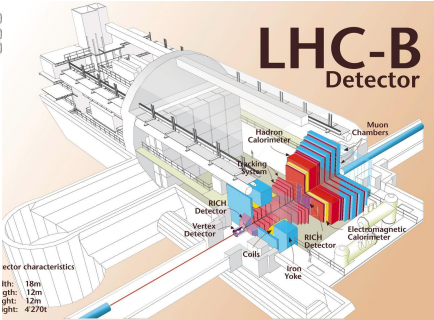
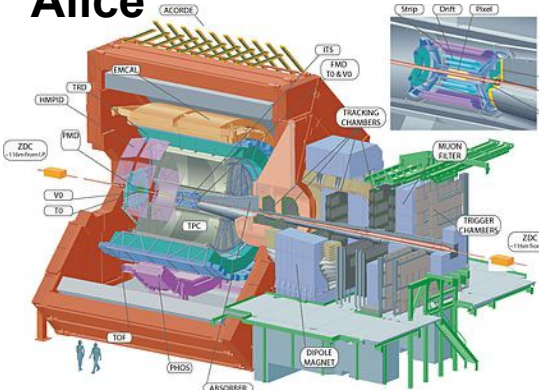
HADRON CALORIMETER (HCAL)

Brass + Plastic scintillator ~7,000 channels

Atlas

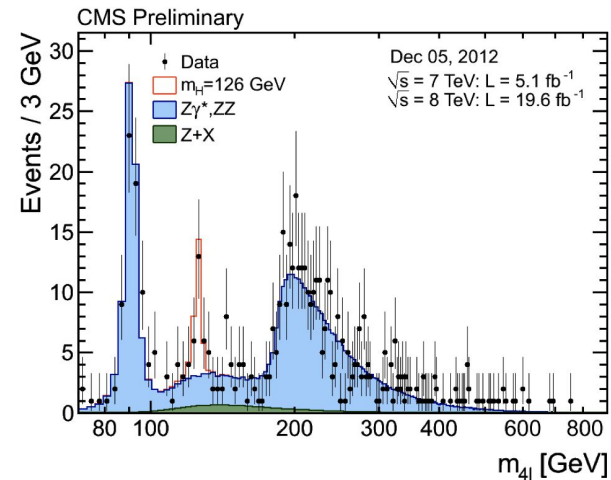
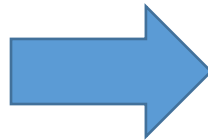
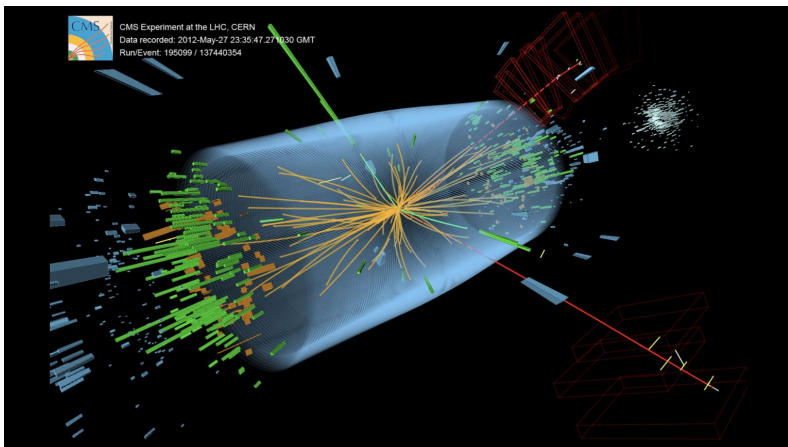


Alice



Detector characteristics
lth: 18m
gth: 12m
dth: 12m
ght: 4.270t

Just as with facilities, HEP scientists rely on large computing infrastructures to do their science



Large scale software
and computing
infrastructures

LAST DATA UPDATE

9.7 MB Downloaded Wednesday, 11 September 2019 14:05:12
Last transfer was on: Monday, 29 July 2019 08:00:00

LOADING

100 %

VOLUME TRANSFERS

VOLUME FILES

VOLUME DATA

The Worldwide LHC Computing Grid (WLCG)

About 1 million processing cores

170 data centres in 42 countries

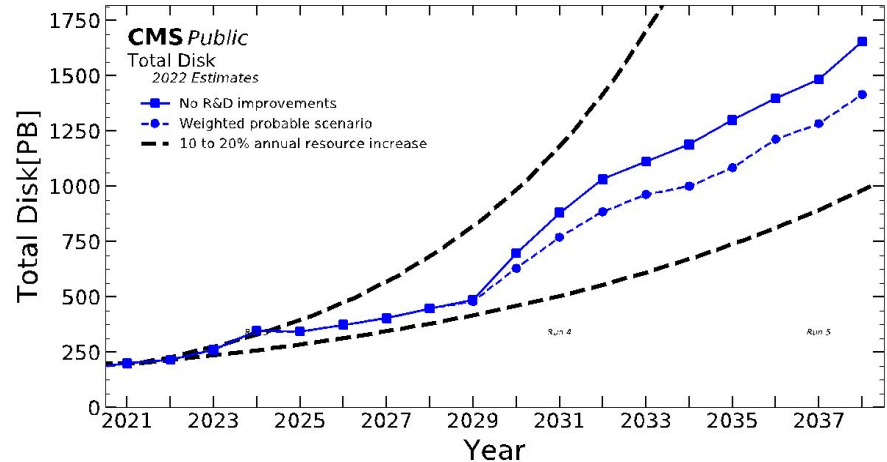
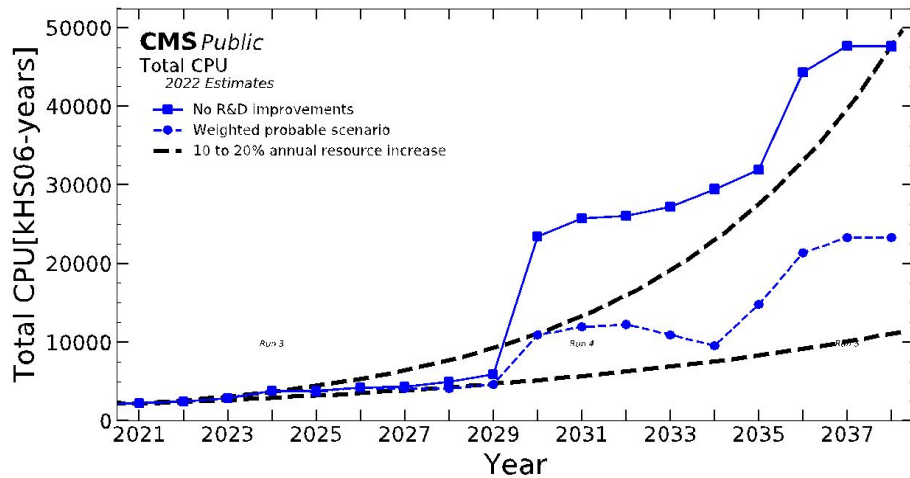
>1000 Petabytes of CERN data stored worldwide

DATA TRANSFER CONSOLE

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0 From UCSD072 To INFN-T1 Monday, 29 July 2019 04:05:40
0 From Vandelim To Nebraska Monday, 29 July 2019 04:06:06
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7638510255 From INFN-T1 To GLOW Monday, 29 July 2019 04:08:36
1322912923 05 From INDIACMS-IFR To pc Monday, 29 July 2019 04:08:43
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5020919503 From INFN-T1 To CERN-PROD Monday, 29 July 2019 04:10:11
26418203 From CERN-PROD To INFN-T1 Monday, 29 July 2019 04:10:04
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0 From INFN-CA-2 To INFN-CA-2 Monday, 29 July 2019 04:12:25
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0 From BNL-CA-2 To CERN-PROD Monday, 29 July 2019 04:14:30
0 From Vandelim To UCSD072 Monday, 29 July 2019 04:14:57
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18844974 From CERN-LAT2 To RU-Proton-HEP Monday, 29 July 2019 04:15:45

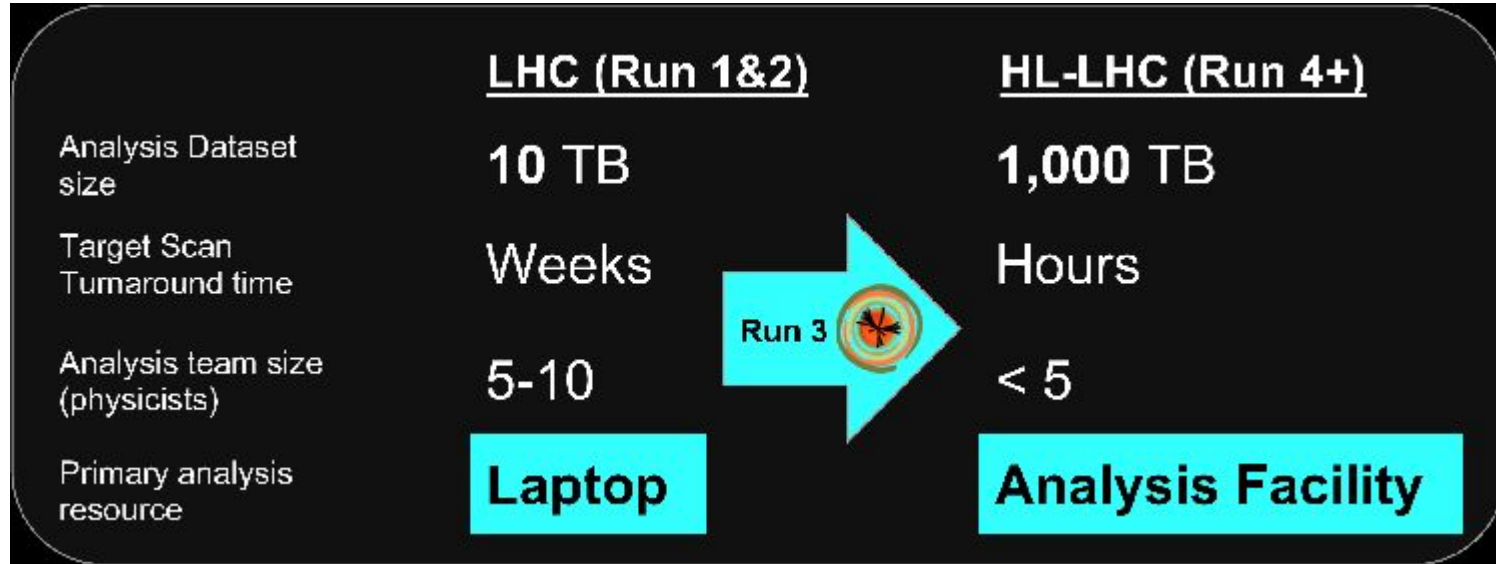
“Cyberinfrastructure”

Future experiments pose even larger computing challenges



- A naive extrapolation from today's computing model and techniques, even after assuming Moore's Law increases in capabilities, is insufficient to meet the expected resource needs for HL-LHC
 - Technology evolution for processors and storage is an additional challenge
 - New ideas and methods are needed, and software is the key ingredient

Human time is critical: Optimizing analysis is about more than just about pure resources



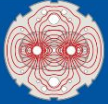
LHC analysis:

- Search & Precision Physics
- Simple ML techniques (BDT)
- Reproducibility in its infancy

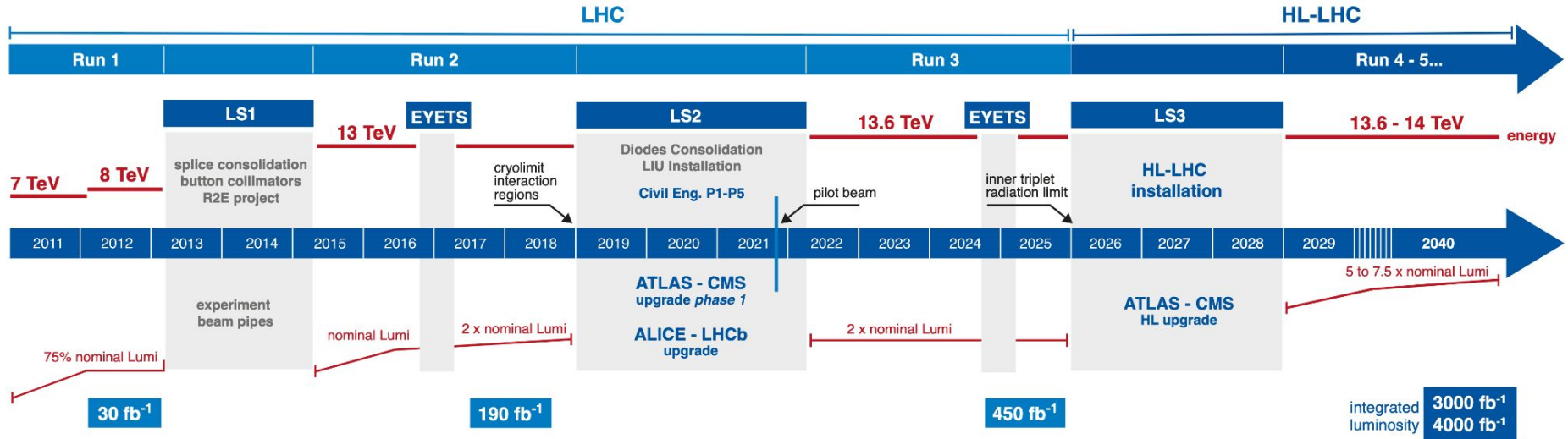
HL-LHC analysis:

- Very High Precision Physics
- Modern ML (Deep Learning)
- Reproducible and Open Data

Experimental timescales span decades



LHC / HL-LHC Plan



Experiment designs start far before data taking. CMS was formed in 1992 (more than 30 years ago!), expects to run through 2040 and do data analysis for years after that

Experimental Observation of a Heavy Particle J^\dagger

J. J. Aubert, U. Becker, P. J. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen,
J. Leong, T. McCorriston, T. G. Rhoades, M. Rohde, Samuel C. C. Ting, and Sau Lan Wu
*Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology,
Cambridge, Massachusetts 02139*

and

Y. Y. Lee

Brookhaven National Laboratory, Upton, New York 11973

(Received 12 November 1974)

We report the observation of a heavy particle J , with mass $m = 3.1$ GeV and width approximately zero. The observation was made from the reaction $p + \text{Be} \rightarrow e^+ + e^- + x$ by measuring the e^+e^- mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory's 30-GeV alternating-gradient synchrotron.

Discovery of a Narrow Resonance in $e^+ e^-$ Annihilation*

J.-E. Augustin,† A. M. Boyarski, M. Breidenbach, F. Bulos, J. T. Dakin, G. J. Feldman,
G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie,† R. R. Larsen, V. Lüth,
H. L. Lynch, D. Lyon, C. C. Morehouse, J. M. Paterson, M. L. Perl,
B. Richter, P. Rapidis, R. F. Schwitters, W. M. Tanenbaum,
and F. Vannucci‡

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

G. S. Abrams, D. Briggs, W. Chinowsky, C. E. Friedberg, G. Goldhaber, R. J. Hollebeek,
J. A. Kadyk, B. Lulu, F. Pierre,§ G. H. Trilling, J. S. Whitaker,
J. Wiss, and J. E. Zipse

Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720

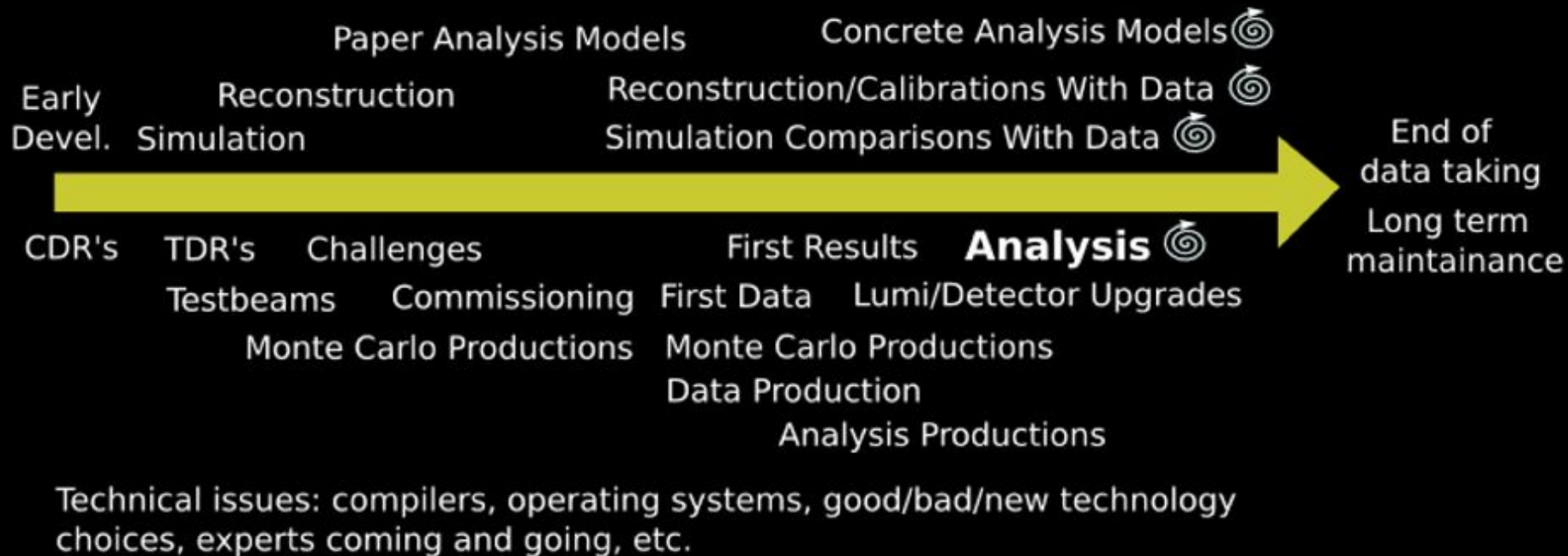
(Received 13 November 1974)

We have observed a very sharp peak in the cross section for $e^+ e^- \rightarrow \text{hadrons}$, $e^+ e^-$, and possibly $\mu^+ \mu^-$ at a center-of-mass energy of 3.105 ± 0.003 GeV. The upper limit to the full width at half-maximum is 1.3 MeV.

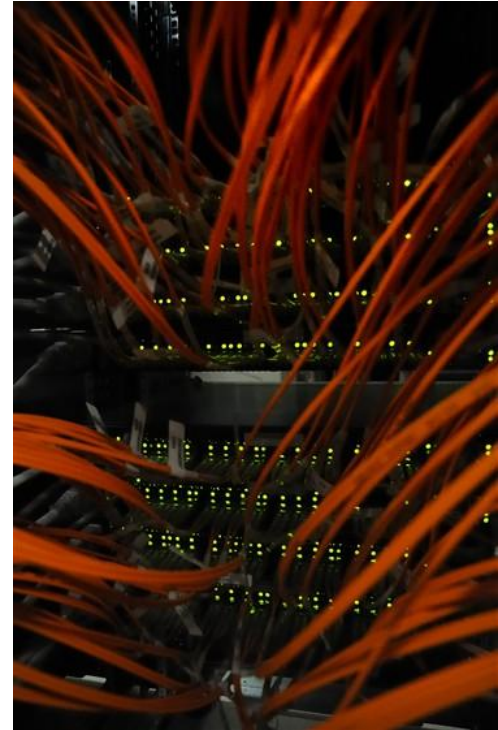


CMS has ~4300 Scientists, Engineers and technicians
(including 800 PhD students) from 41 Countries and 179 institutes

HEP software lifecycle



Cyberinfrastructure?



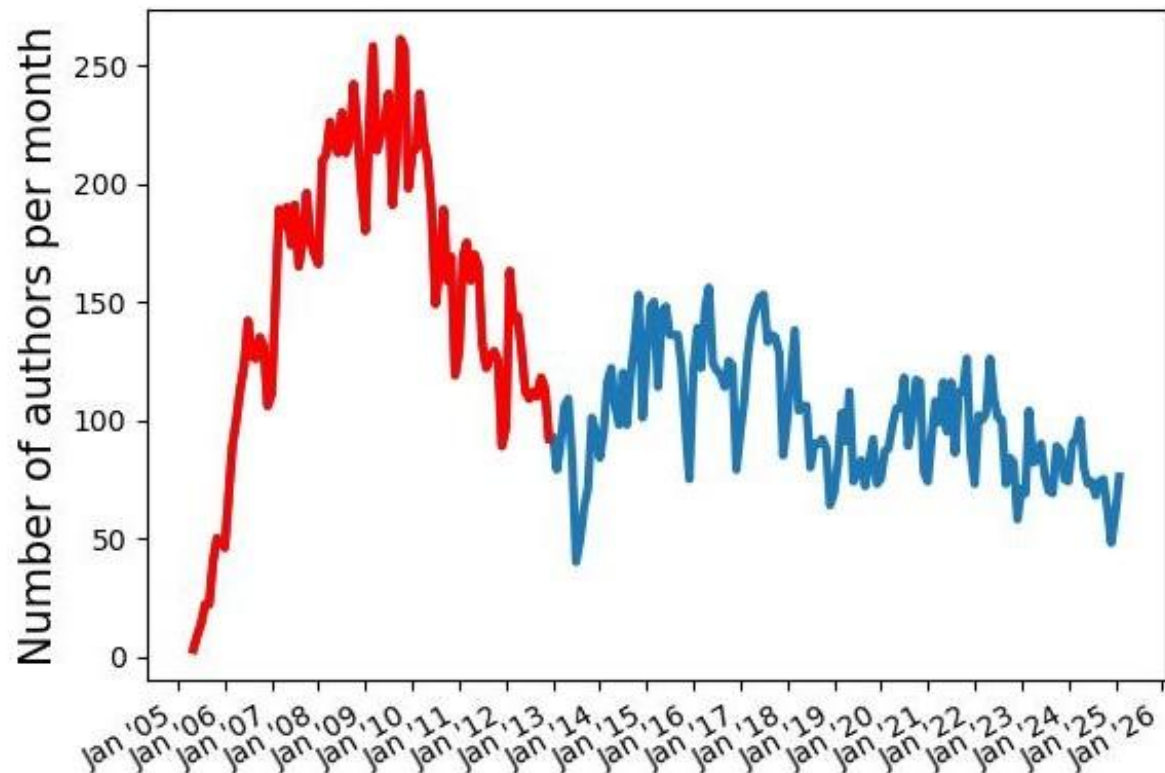
Conceptual motivations behind the HEP Software Foundation

Computer hardware is a consumable. Software is the actual "cyberinfrastructure" in the long run.

More importantly software is also an *intellectual product* of our research, not just a tool.



Large scale collaborative software development in HEP



Many developers, typically a handful of true experts

Millions of lines of code for CMS - And this excludes most data analysis code, event generators, detector simulation codes, and others...

Institute for Research and Innovation in Software for High Energy Physics (IRIS-HEP)

Computational and data science research to enable discoveries in fundamental physics

IRIS-HEP is a software institute funded by the National Science Foundation. It aims to develop the state-of-the-art software cyberinfrastructure required for the challenges of data intensive scientific research at the High Luminosity Large Hadron Collider (HL-LHC) at CERN, and other planned HEP experiments of the 2020's. These facilities are discovery machines which aim to understand the fundamental building blocks of nature and their interactions. [Full Overview](#)

News and Featured Stories:



IRIS-HEP Receives \$25M Funding for Another Five Years of Research

"IRIS-HEP received funding from the Office of Advanced Cyberinfrastructure and the Physics Division at the National Science Foundation for five years."

[Read more](#)



Out of harm's way: Physics research program supports Ukrainian students displaced by war

"Ukrainia students escape the war and pursue research at the Large Hadron Collider (LHC), under supervision from Princeton University faculty."

[Read more](#)

Upcoming Events:

May 24, 2024	CERN
IRIS-HEP / AGC Demo Day #5	
Jun 20-21, 2024	Princeton University
USCMS/IRIS-HEP Software Training	
Jul 8-14, 2024	Tacoma, Washington
Scientific Computing with Python (SciPy) 2024	
Jul 18-19, 2024	University of Washington
USATLAS/IRIS-HEP Software Training	
Jul 22-26, 2024	Princeton University
CoDaS-HEP 2024 - Computational and Data Science Training for High Energy Physics	
Aug 26-30, 2024	Aachen, Germany
PyHEP.dev 2024 - "Python in HEP" Developer's Workshop	
Sep 4-6, 2024	University of Washington
IRIS-HEP Institute Retreat	
Sep 23-25, 2024	Valencia (Spain)
Fourth MODE Workshop on Differentiable Programming for Experiment Design	

[View all past events](#)

<http://iris-hep.org>



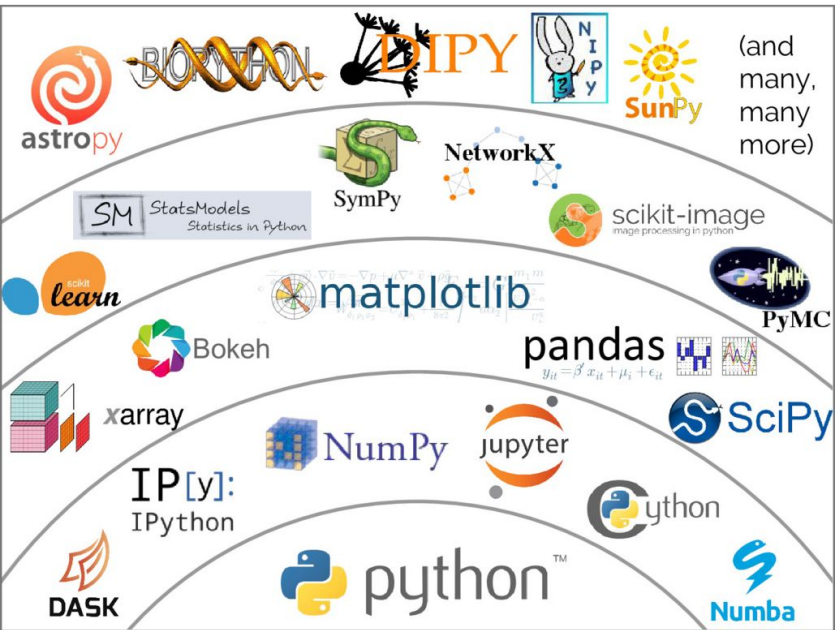
Conceived as a “**software upgrade**” project and guided initially by the “Community White Paper” roadmap developed in 2016-2017: it involves 21 universities, spanning ATLAS, CMS and LHCb.

IRIS-HEP is supported by the U.S. National Science Foundation through the **Office of Advanced CyberInfrastructure** in the Directorate for Computer and Information Science and Engineering and the **Division of Physics** in the Directorate for Mathematical and Physical Sciences.

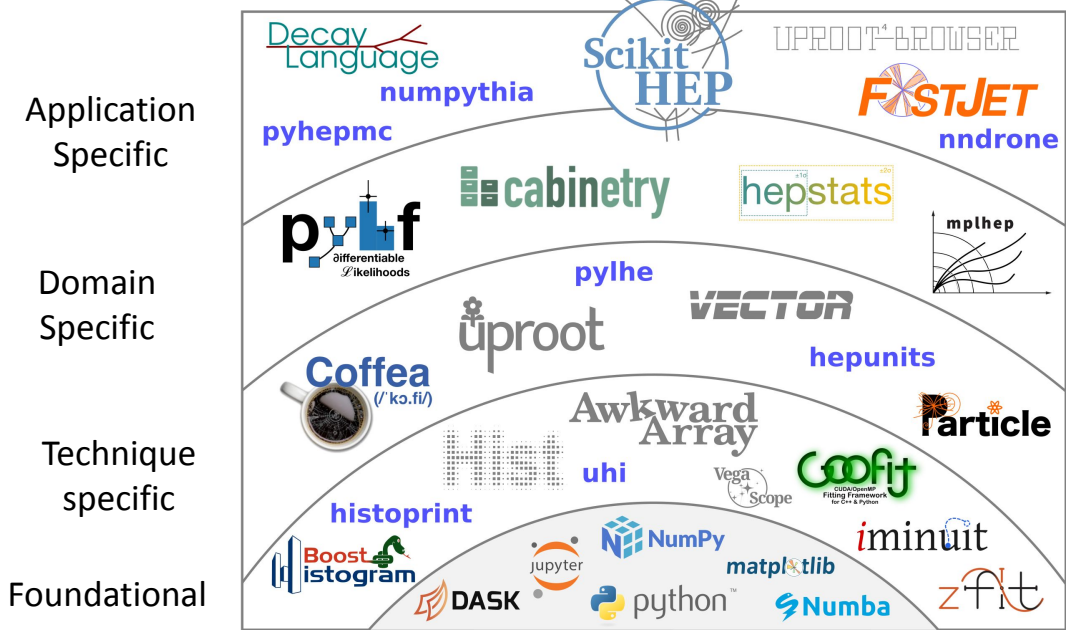
10-year project: Originally funded in 2018 as OAC-1836650 and renewed in 2023 through 2028 as PHY-2323298.

Leveraging data science for HEP analysis

Scientific Python / PyData vision/ecosystem



Developing HEP data analysis ecosystem



PyHEP development

[HSF](#)[Activities](#)[Meetings](#)[Communication](#)[Projects & Support](#)[About](#)

PyHEP - Python in HEP

The PyHEP working group brings together a community of developers and users of Python in Particle Physics, with the aim of improving the sharing of knowledge and expertise. It embraces the broad community, from HEP to the Astroparticle and Intensity Frontier communities.

Conveners

- Eduardo Rodrigues (LHCb, University of Liverpool)
- Jim Pivarski (CMS and IRIS-HEP, Princeton)
- Matthew Felckert (ATLAS and IRIS-HEP, University of Wisconsin-Madison)
- Nikolai Hartmann (Belle II, LMU Munich)

All coordinators can be reached at hsf-pyhep-organisation@googlegroups.com.

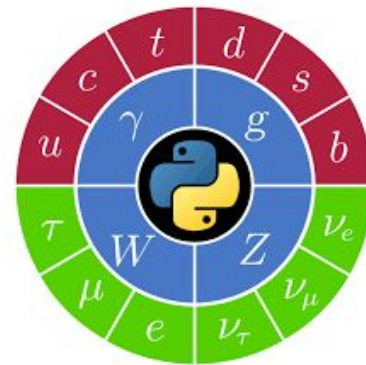
Getting Involved

Everyone is welcome to join the community and participate, contribute, to the organised meetings and by means of the following communication channels:

- [Gitter channel PyHEP](#) for any informal exchanges.
- [GitHub repository of resources](#), e.g., Python libraries of interest to Particle Physics.
- PyHEP Workshop Twitter handle: [@PyHEPConf](#)

Extra Gitter channels have been created by and for the benefit of the community:

- [PyHEP-newcomers](#) for newcomers support (very low entry threshold).

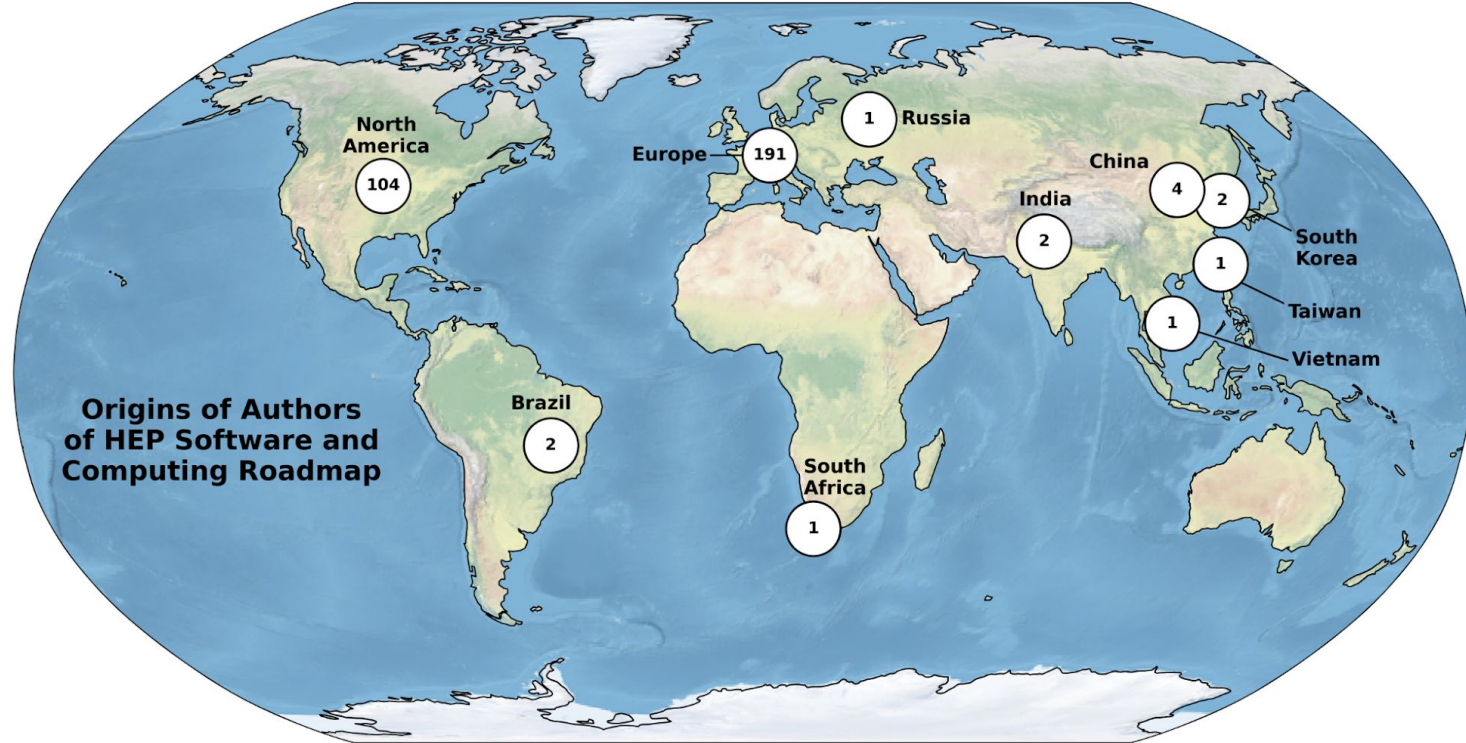




The HSF-India Project

<http://research-software-collaborations.org/>

However, nearly all authors of the HSF Community Roadmap were from institutions in Europe and the US



Team – We wrote a proposal to the US National Science Foundation aiming to broaden this community to include Asia – Starting with India



Princeton University: Peter Elmer, David Lange (PI)
University of Massachusetts, Amherst: Rafael Coelho Lopes de Sa,
Verena Martinez Outschoorn

Facilitating international research software: The “HSF-India” project

- Given the growing complexity of our scientific data and collaborations, building and fostering collaborations are increasingly important to raise the collective productivity of our research community.
- HSF-India project aims to build international research software collaborations between US, European, and India based researchers to reach the science goals of experimental particle, nuclear and astroparticle research.

Intended as a long-term investment in international team science with a broad research scope

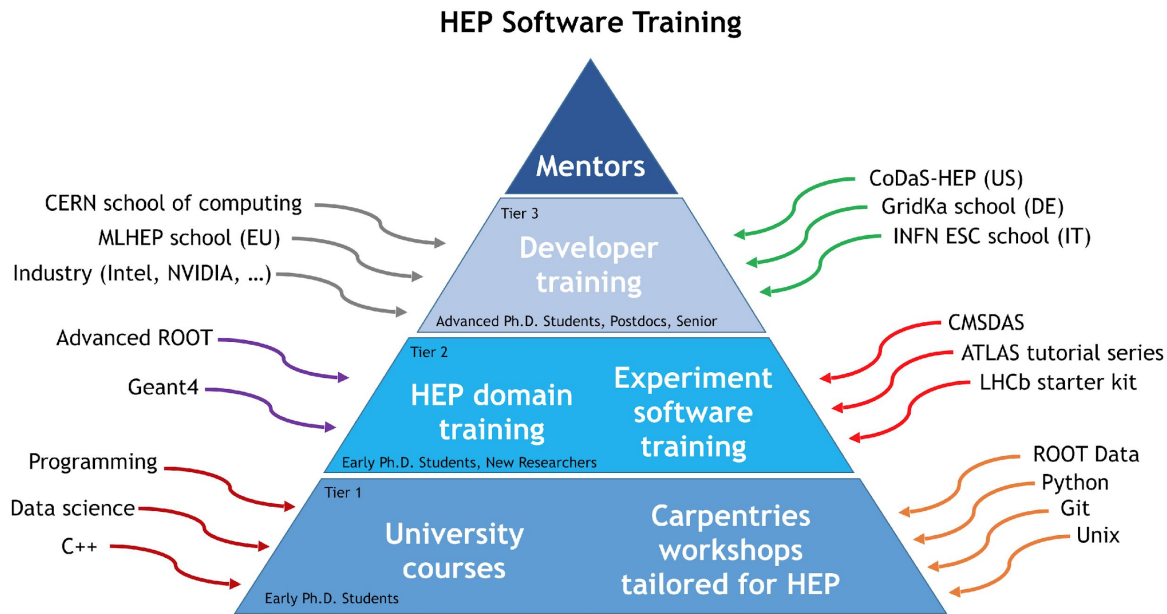


Rather than directly fund a specific research activities, much of our funding is to facilitate research collaborations

- Training in research software skills
- Bidirectional research exchanges
- Student programs



Bootstrap collaboration through software training



- A vision for training in HEP: researchers progress (vertically) from basic skills training, through user training in existing software to training in skills needed to develop new research software.

We have run software workshops in Mumbai (TIFR), Bhubaneswar (NISER), Delhi (University of Delhi), Kolkata (VECC) and U.Hyderabad

- Regionally organized, primarily targeting MS/PhD level students.
- Mix of lectures and hands-on exercises
- Mix of local and US instructors
- Jupyter notebook based materials derived from/patterned after HSF training courses



We want to organize these events regionally to make it easier for interested students to attend

Recent and upcoming events



Chief Patron
Prof. B. J. Rao
Hon. Vice Chancellor
University of Hyderabad

Special Invitee
Prof. M. Ghanashyam Krishna
IOE Director
University of Hyderabad

Organizing Committee
Prof. M. Ghanashyam Krishna, UoH
Prof. James Raju, UoH
Prof. Samrat Sabat, UoH
Prof. Nageswara Rao, UoH
Prof. Rukmani Mohanta, UoH
Prof. Soma Sanyal, UoH
Dr. Bhawna Gamber, UoH
Dr. Pratap Kallu, UoH
Dr. Arpita Priya, UoH
Dr. David Lange, Princeton University, USA
Dr. Peter Elmer, Princeton University, USA
Prof. Rafael Coelho Lopes de Sa, UMass-Amherst, USA
Prof. Verena Martinez Outschoorn, UMass-Amherst, USA

HSF-INDIA HEP SOFTWARE WORKSHOP

January 13th to 17th, 2025
Centre for Advanced Studies in
Electronics Science and Engineering
School of Physics
University of Hyderabad, Hyderabad, India

Topics
Scientific Python
Parallel Programming & GPUs
Basics of Machine Learning
Real-time triggering software

The workshop primarily targets masters & early stage PhD students

Registration
<https://indico.cern.ch/event/1394564/>
Deadline: November 1, 2024





HSF
HEP Software Foundation

The HSF-India project aims to promote the development of international research software collaborations. This is the fifth in a series of workshops for software and data analysis skills essential for doing research software in physics.

Conveners
Dr. Bhawna Gamber
(bhawna.gamber@cern.ch)
Dr. David Lange
(David.Lange@cern.ch)

Sponsored by IOE, University of Hyderabad and HSF-India (NSF/USA)




CISE-2201990

HSF-India Software Workshop
U.Hyderabad - 13-17 Jan 2025
<https://indico.cern.ch/event/1394564/>

Also: CMSDAS IIT Hyderabad - 23-27 June 2025
(perhaps a collaboration with HSF-India)

HSF-India/ePIC Workshop @IIT Bombay
May 13 - 17, 2025

Goals of the Workshop:

- Collaborative planning for EIC simulation projects in India
- Introduction to EIC physics and the ePIC detector
- Hands-on tutorials with ePIC software
- Training and working sessions on simulation, tracking, PID, and analysis

Highlights of Workshop:

- Interactive sessions with the experts in the field of Deep Inelastic Scattering and Collider Physics
- Hands-on session on the simulation of electron-proton collisions
- Coding-Jam group exercise


Organizing Committee

- Sadhana Dash
- Rishant Kumar Mandi
- Asmita Mukherjee
- Chitrasen Jena
- Hs. Nasim
- David Lange
- Peter Elmer
- Verena Martinez Outschoorn
- Rafael Coelho Lopes de Sa

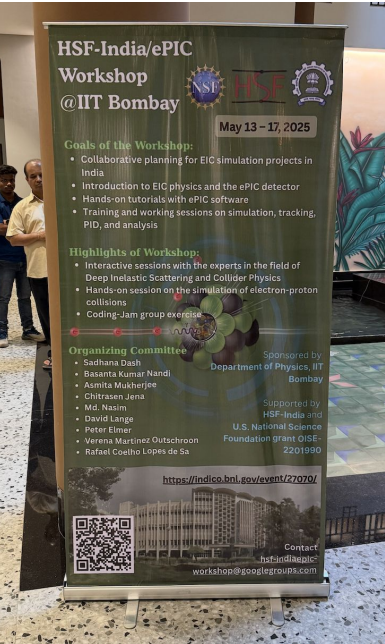
Sponsored by
Department of Physics, IIT Bombay

Supported by
HSF-India and U.S. National Science Foundation grant OISE-2201990

<https://indico.bnl.gov/event/22070/>



Contact: hsfindia@cern.ch
workshop@googlegroups.com



EIC Detector and Physics Simulation Workshop and Tutorial at IIT Bombay
13 -17 May 2025



Centre for High Energy Physics
INDIAN INSTITUTE OF SCIENCE

HSF-India

Scientific Computing Workshop

The Centre for High Energy Physics (CHEP), IISc, is organizing a Scientific Computing Workshop in association with the HSF-India project for the first time. The HSF-India project aims to promote the development of international research software collaborations in experimental High-Energy Physics (HEP), nuclear physics and particle astrophysics. This is the sixth in a series of workshops for software and data analysis skills essential for doing research software in physics. This workshop primarily targets master's and early-stage PhD level students. However, anyone is welcome to attend.

Workshop Topics

1. Scientific Python
2. Parallel programming and Hardware Accelerators
3. Basics of machine learning
4. Real-time triggering software (Includes FPGA)

Workshop Dates

2-Day Introductory HEP Bootcamp
15th - 16th June, 2025

5-Day Advanced Deep Dive
17th - 21st June 2025

The workshop includes a valuable hands-on component, facilitated by leading researchers from Princeton University, Stanford University, and Fermi National Accelerator Laboratory.

Auditorium, New Physical Sciences Building

Organizing Committee

Prof. Jyothsna Komaragiri, IISc
Prof. Sudhir Vempati, IISc
Dr. Minakshi Nayak, IISc
Dr. David Lange, Princeton University, USA
Dr. Peter Elmer, Princeton University, USA
Prof. Rafael Coelho Lopes de Sa, UMass-Amherst, USA
Prof. Verena Martinez Outschoorn, UMass-Amherst, USA

Conveners

Prof. Jyothsna Komaragiri
(jyothsna@isc.ac.in)
Dr. David Lange
(David.Lange@cern.ch)

Registration
<https://indico.cern.ch/e/IISCHSF>



Sponsored by




Axis Bank Centre for Mathematics & Computing

HSF-India workshop in IISc Bangalore
16-22 June 2025
<https://indico.cern.ch/event/1519117/>

We are exploring additional possibilities for “hackathon” events to further build skills, as well as Physics/CS collaborations.










3-6 month project Fellows Program

- **Project focused** aiming to bring students into contact with “mentors” to work on a specific, pre-defined project, allowing them to grow their software skills and experience working in large projects
- These short term projects that build **longer term collaborations** in research software and foster **scientific career progression**
- Our program is open for applications for either full time (eg, during semester breaks) or part time expressions of interest

[HSF-India Research](#)

















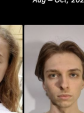
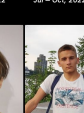
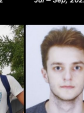
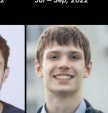
















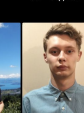



[Software Trainees](#)

Current and Former Trainees

 Vigul Cariappa Ramiah University of Applied Sciences Sep. 2024 – Feb. 2025	 Sanjeev Kumar TIFR, Mumbai Mar – Jul. 2024	 Prayag Yadav University of Hyderabad Jun – Jun. 2024	 Podem Sal Krishna IIT Hyderabad May – Aug. 2024	 Juhl Poddar Tata Institute of Fundamental Research Feb. 2024 – Feb. 2025
 Durbat Chakrabarty National Institute of Technology Durgapur Jul – Nov. 2023	 Chitrakshya Yede Savitribai Phule Pune University Jun – Nov. 2023	 Ananya Gupta Indira Gandhi Delhi Technical University for Women Jun – Sep. 2023	 Adam Zacharia Indian Institute of Science Education and Research, Thiruvananthapuram Jul – Dec. 2023	

Also IRIS-HEP Fellows:

<https://iris-hep.org/fellows.html>

 Sophia Korte Florida State University Jun – Sep. 2022	 Anni Li University of California, San Diego Jun – Sep. 2022	 Haoran Sun University of Washington Jun – Sep. 2022	 Zhe Wang University of Wisconsin-Madison Jun – Sep. 2022	 Jake Li University of Illinois at Urbana-Champaign Jun – Aug. 2022	 Volodymyr Svitetskiy Taras Shevchenko National University of Kyiv Jun – Sep. 2022	 Ernest Sorokun Taras Shevchenko National University of Kyiv Aug – Oct. 2022	 Volodymyr Shabanov V. N. Karazin Kharkiv National University Jul – Oct. 2022	 Igor Bogomolov Institute of NAS of Ukraine Jul – Sep. 2022	 Bogdan Tyshchenko Taras Shevchenko National University of Kyiv Jul – Sep. 2022
 Ameya Thete BITS, Pilani - K.K. Birla Goa Campus Jun – Aug. 2022	 Saranah Chagga Cluster Innovation Centre, University of Delhi Jun – Aug. 2022	 Scott Demarest Florida Institute of Technology Jun – Aug. 2022	 Jay Gohil School of Technology PDEU Jun – Sep. 2022	 Phillip Templeman University of Notre Dame May – Aug. 2022	 Tatiana Yushkevych Odessa Polytechnic National University Jun – Aug. 2022	 Igor Prishko Kyiv Academic University Jun – Aug. 2022	 Dmytro Horyshchuk Kyiv Academic University Jun – Aug. 2022	 Dmitrii Brovarenykh National Technical University "Kharkiv Polytechnic Institute" (NTU) Kharkiv Jun – Aug. 2022	 Dmitrii Khov Igor Skorsky Kyiv Polytechnic Institute Jun – Aug. 2022
 Ziyang Ye University of Wisconsin-Madison May – Aug. 2022	 Max Zhao University of California, Berkeley May – Aug. 2022	 Aryan Roy Manipur Institute of Technology Apr – Aug. 2021 May – Jul. 2022	 Natalie Bruhlwiler University of California, Berkeley May – Aug. 2022	 Surya Somayajula University of Wisconsin-Madison May – Aug. 2022	 Kateryna Skurativska Kyiv Academic University Jul – Sep. 2022	 Kyrylo Melushko Taras Shevchenko National University of Kyiv Jul – Sep. 2022	 Maxym Nemyshchuk Igor Skorsky Kyiv Polytechnic Institute Jul – Aug. 2022	 Andrii Falko Taras Shevchenko National University of Kyiv Jun – Sep. 2022	 Artem Havryliuk National Technical University of Ukraine (Igor Skorsky Kyiv Polytechnic Institute) Jun – Sep. 2022
 Maya Wallach Michigan State University May – Jul. 2022	 Zoë Bilodeau Skidmore College May – Aug. 2022	 Katie Edwards Iowa State University May – Aug. 2022	 Elliott Kauffman Duke University May – Aug. 2022	 Ben Kuchma University of Massachusetts - Amherst May – Aug. 2022	 Andrii Koval Taras Shevchenko National University of Kyiv Jun – Sep. 2022	 Vladislav Kucherenko Kyiv Academic University (KAU) Jun – Aug. 2022	 Andrii Len Taras Shevchenko National University of Kyiv Jun – Sep. 2022	 Jerry Ling Harvard University Jun – Sep. 2022	 Attili-Yahor Krasnopolski Taras Shevchenko National University of Kyiv Jun – Sep. 2022

Bidirectional Research Exchange Program

We also have funding for “research exchanges” that support travel costs for 1-3 months. These are meant for very senior PhD students and more senior researchers that have already

Who can we support?

- Researchers affiliated to a US university/lab exchange based in India
- Researchers affiliated to an university/lab in India exchange based in US or CERN to work with a US affiliated group

We are looking for either project/host ideas or those interested in doing an exchange. If you have ideas for projects that interest you, we can help identify matches with US researchers

Conclusion and Opportunities

- Experimental science is enabled by tools innovation, which become facilities enabling further science. Our science has been driven by accelerator and detector innovation.
- As facilities get larger, scientific collaborations are created to build and exploit those facilities. These large international collaborations of scientists allow experimental endeavors to exploit regional strengths.
- Just as with other aspects of our science, software teams that are inherently international are most likely to develop performant, highly usable, and sustainable **research software ecosystems**, which are a new kind of “facility” and an *intellectual product* of our research.
- HSF-India is a project which aims to further catalyze global collaboration in research software in Physics.
 - <http://research-software-collaborations.org>



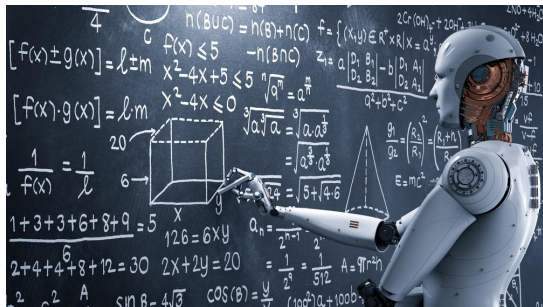
And the Future for HEP?



The **Worldwide LHC Computing Grid (WLCG)** project is a global collaboration of around 170 computing centres in more than 40 countries, linking up national and international grid infrastructures. The mission of the WLCG project is to provide global computing resources ... **[2000's and 2010's era]**



The **HEP Software Foundation** facilitates cooperation and **common efforts** **[2010's and 2020's era]** in High Energy Physics software and computing internationally.



What collaborative research efforts will the rest of the 2020's and the 2030's produce for the future “facilities” for the HEP community?