Quantum computing and CERN openlab

CERN openlab Technical Workshop

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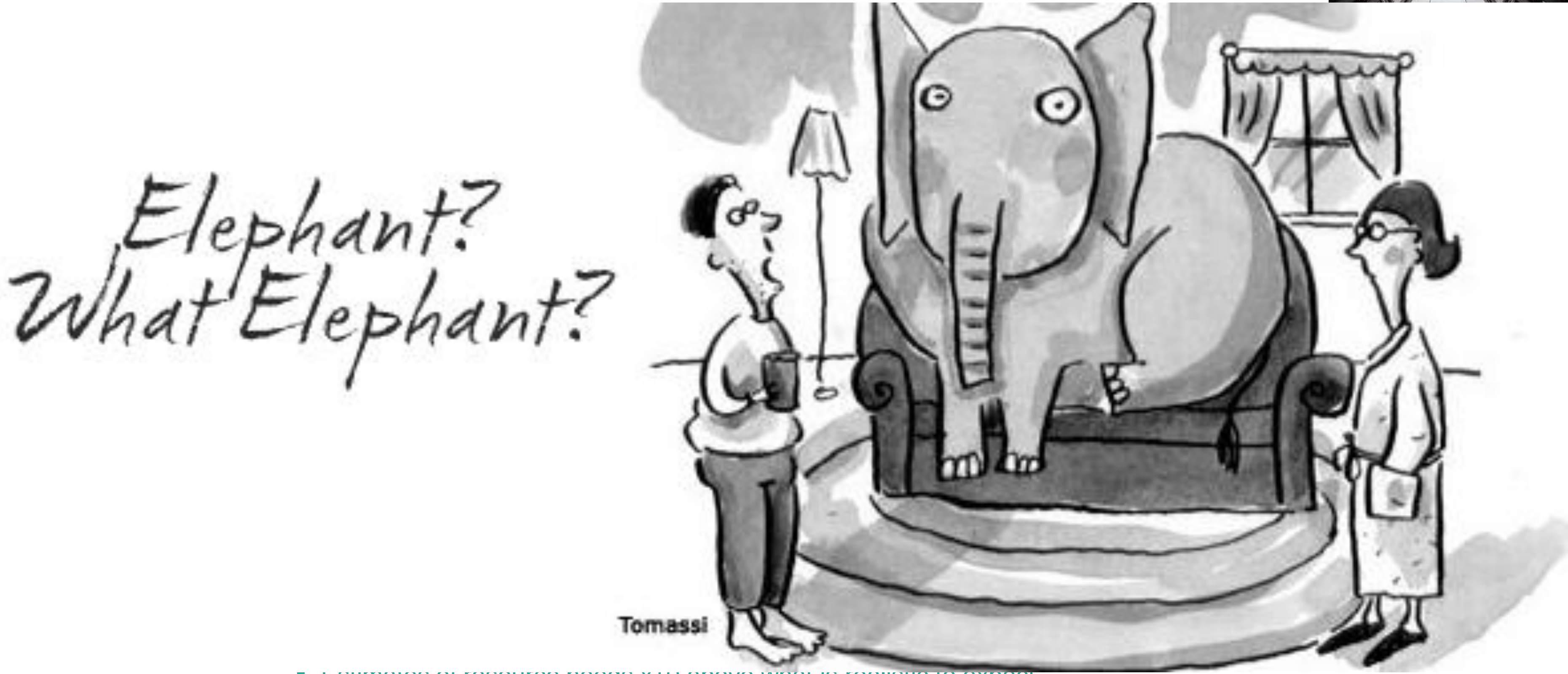
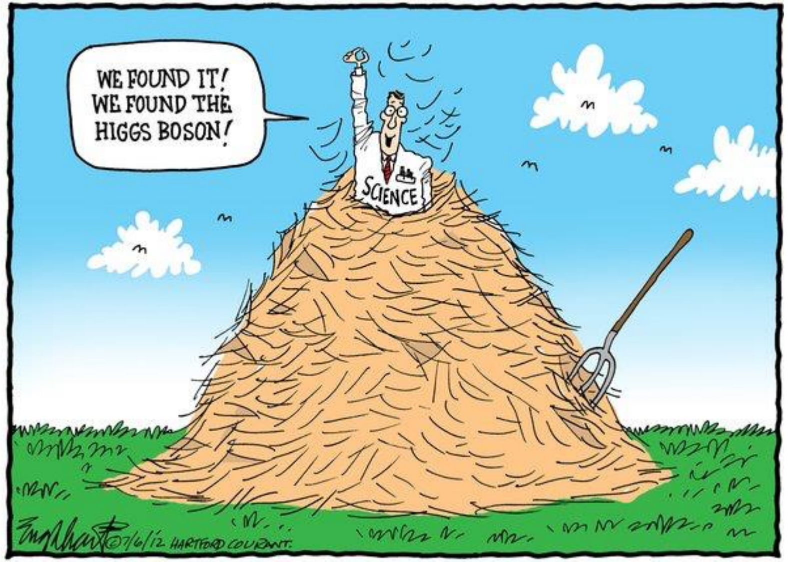
January 24th, 2019

HL-LHC: data volume



- Estimates of resource needs x10 above what is realistic to expect

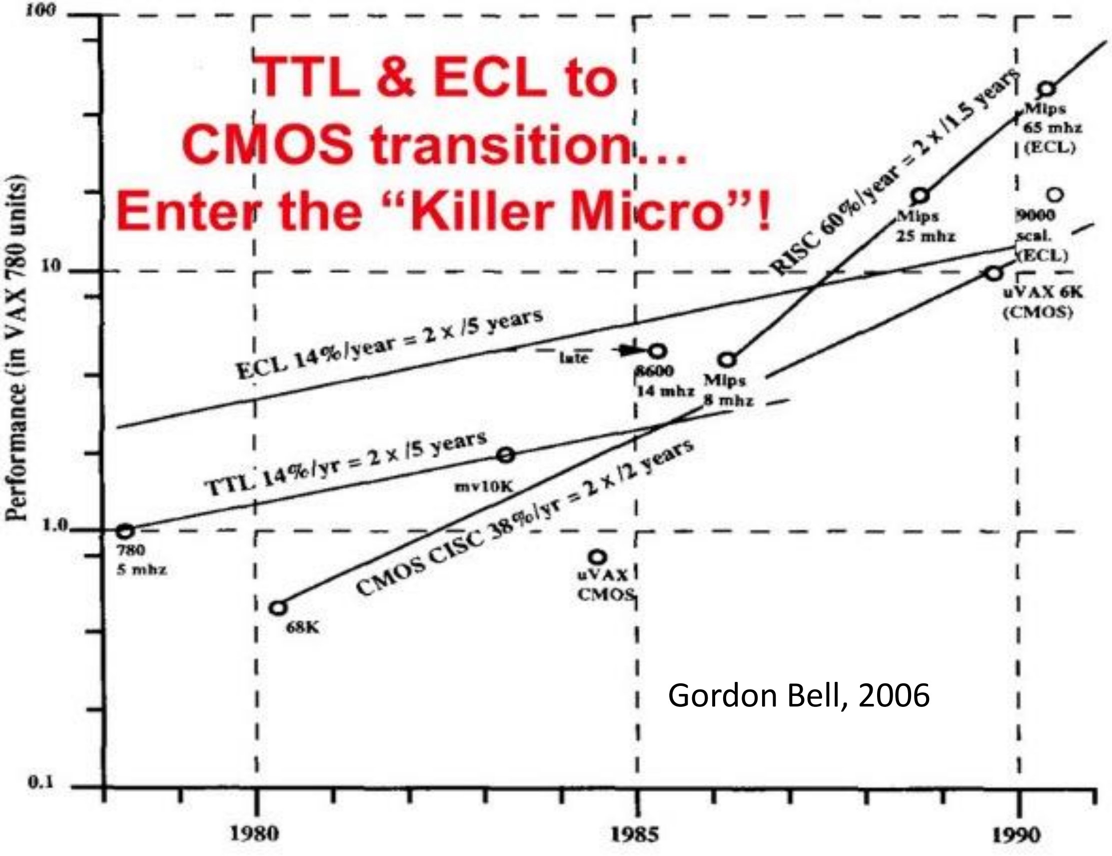
From ridiculously difficult…



…to almost impossible

History – LEP

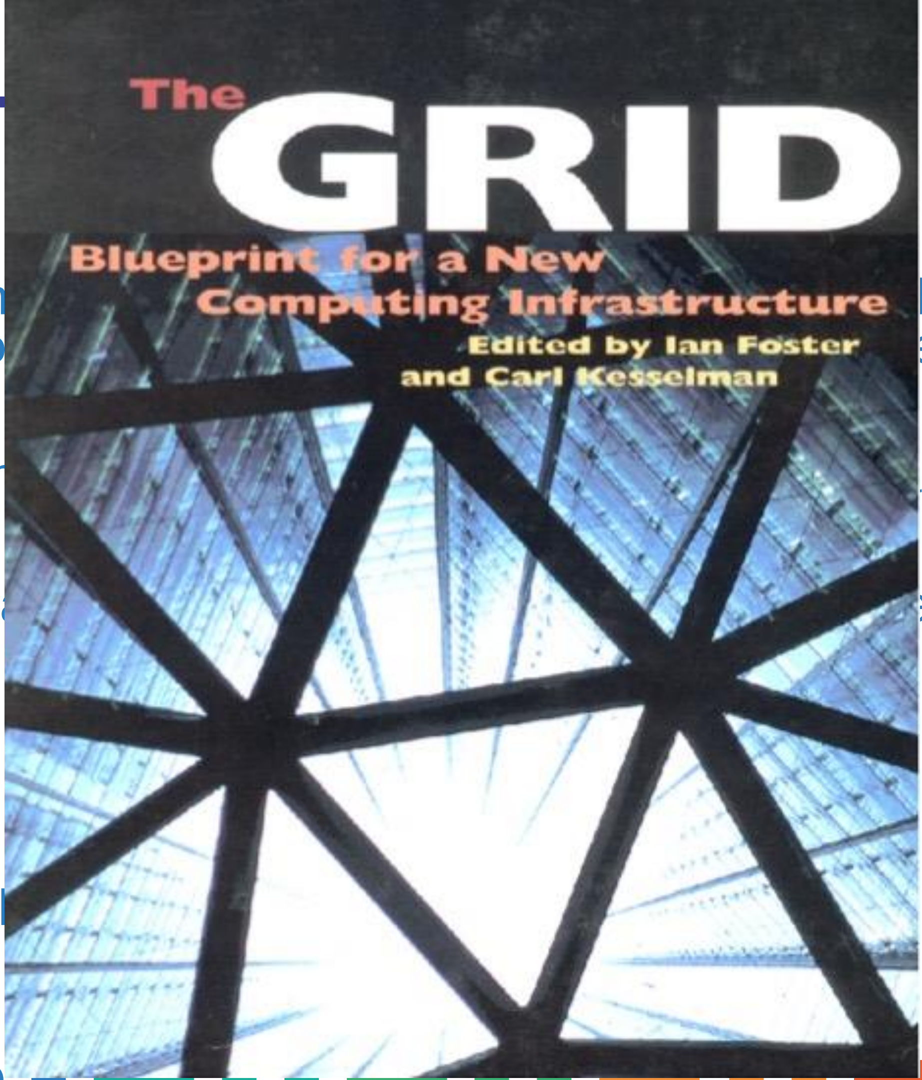
- The es contai throug
- It was mainfra ith
- Here c



Gordon Bell, 2006

History -

- The LHC com … l out in 2000-
  2001 (the “Ho … e committee
  was accused
- Putting this ar … ilable, would
  have created
- Working with … e Fiction
- Here comes th



History – conclusions

Moral of the story

- HEP has regularly faced “computer requirement walls” and the associated scaremongering
- We have been very good to “seize the opportunity” and turn emerging technologies into production facilities
- This has allowed us to survive (indeed very well) at a reasonable cost
- This has also provided a productive dialogue with the ICT community
- One essential element of the success is that we had people already investigating the field within HEP, i.e. the “seeds” were already there
- The only question (!) is what will be the next “savior(s)”

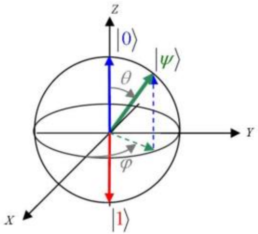
Quantum Computing?

Physics of Computation Conference Endicott House MIT May 6-8, 1981

1 Freeman Dyson
2 Gregory Chaitin
3 James Crutchfield
4 Norman Packard
5 Panos Ligomenides
6 Jerome Rothstein
7 Carl Hewitt
8 Norman Hardy
9 Edward Fredkin
10 Tom Toffoli
11 Rolf Landauer
12 John Wheeler
13 Frederick Kantor
14 David Leinweber
15 Konrad Zuse
16 Bernard Zeigler
17 Carl Adam Petri
18 Anatol Holt
19 Roland Vollmar
20 Hans Bremerman
21 Donald Greenspan
22 Markus Buettiker
23 Otto Floberth
24 Robert Lewis
25 Robert Suaya
26 Stan Kugell
27 Bill Gosper
28 Lutz Priese
39 Madhu Gupta
30 Paul Benioff
31 Hans Moravec
32 Ian Richards
33 Marian Pour-El
34 Danny Hillis
35 Arthur Burks
36 John Cocke
37 George Michaels
38 Richard Feynman
39 Laurie Lingham
40 Thiagarajan
41 ?
42 Gerard Vichniac
43 Leonid Levin
44 Lev Levitin
45 Peter Gacs
46 Dan Greenberger

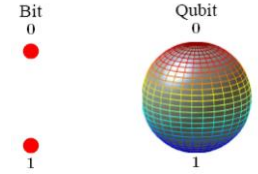
"Nature is quantum, goddamn it! So if we want to simulate it, we need a quantum computer."
R.Feynman, 1981, Endicott House, MIT

Use qubits instead of bits…
e.g. bits that exhibit quantum behavior



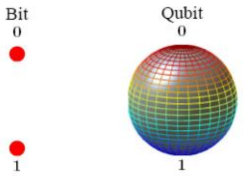
`Bloch's sphere

Qubits are great!



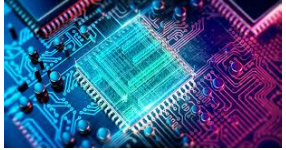
- *n* normal bits can be in one of 2^n states at a time
- *n* qbits can be in 2^n states at the same time: any quantum operation is in fact 2^n operations **in parallel**
  - 79 qubits can represent a number of Avogadro of states
  - 263 qubits can represent as many concurrent states as there are protons in the universe
  - 400 entangled qubits would contain the whole information of our universe.
- …and the icing on the cake is *entanglement* of the qubits: any operation on one part of the set has implications on the other

But qubits are also nasty…



- Extremely difficult to realize in practice
- You can only retrieve <u>one</u> quantum state at a time
- States cannot be copied exactly
- You can only use reversible (Unitary) logic gates, limiting the algorithms you can apply
- Quantum decoherence is always present
- Errors are more difficult to correct
  - you have to correct the phase too!
  - Current 2-qbit error rate > 10^{-3}

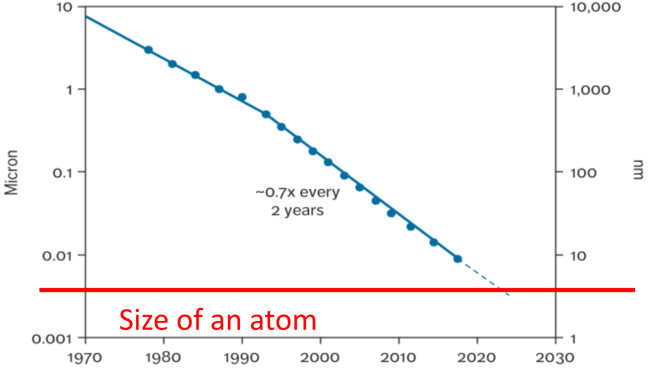
Quantum Computing



…or is the gain worth the pain?

Can we control complex quantum systems and if we can, so what?
(J.Preskill, 2012)

We could argue that Quantum Computing is a natural consequence of Moore's law



The three frontiers

- Short distance -> High Energy Physics
- Long distance -> Cosmology
- Entanglement (i.e. Complexity) -> Quantum Information Technology

Since Turing it was believed that the "hardness" was intrinsic to a problem

- Can QCs outperform classical computers on all or same algorithms?
- Can QCs do things that cannot be done by classical computers (Quantum Supremacy)?
- The golden apple is "superpolynomial speedup"
  - But polynomial speedup can be very appealing
- Has Quantum Supremacy been demonstrated?

The “seeds” are already there

Most of what we do is optimisation / fitting / minimisation (superpolynomial speedup!)
- https://www.nature.com/news/quantum-machine-goes-in-search-of-the-higgs-boson-1.22860

Training of Deep Learning is revealing a bottleneck, Quantum Computing can help
- https://www.datasciencecentral.com/profiles/blogs/quantum-computing-deep-learning-and-artificial-intelligence

Combinatorial searches can be speeded up
- e.g. track reconstruction

We can simulate basic interactions with QC
- https://www.nature.com/news/quantum-computer-makes-first-high-energy-physics-simulation-1.20136
- https://mappingignorance.org/2017/01/27/simulating-particle-physics-quantum-computer/

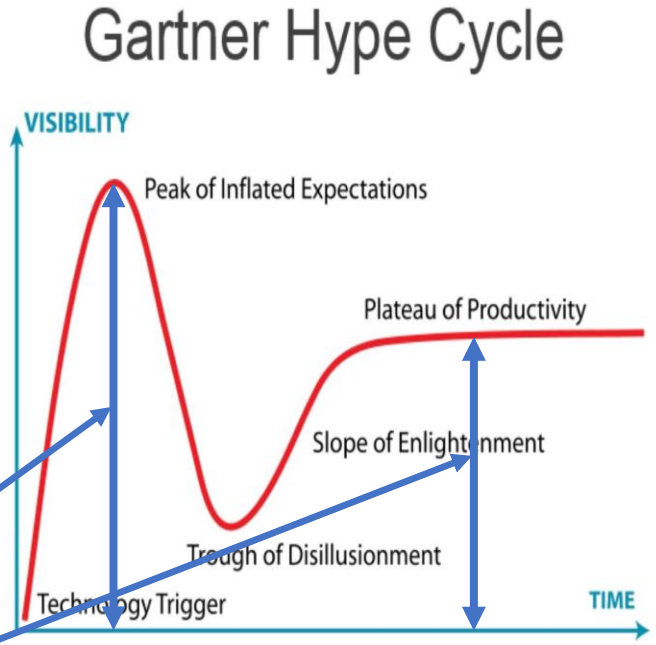
Lattice QCD calculations
- https://mappingignorance.org/2017/01/27/simulating-particle-physics-quantum-computer/

Very fast random number generators can be built
- https://www.osapublishing.org/viewmedia.cfm?r=1&uri=ICQI-2007-JWC49&seq=0

Quantum Detectors combined with Quantum Computing for online

… and money is flowing in…

- EU Quantum Flagship – large-scale initiative
  - funded at the 1b € level on a 10 years timescale.
- US-DoE Quantum Information Science Enabled Discovery (QuantISED) for High Energy Physics
  - Up to $13M total of awards in FY 2018 (FOA+LAB)
- US-DoE Quantum Information Science in FY 2019 HEP
  - President's Budget Request: $27.5M



What people laugh about

What matters at the end

Just for the skeptical

I think there can be a world market for maybe five computers. (Thomas Watson, CEO of IBM, 1943)

There is no reason for an individual to have a computer at home . (Ken Olsen , president, director and founder of Digital Equipment Corp., 1977)

I think that this thing that Tim (Berners-Lee) has shown me has no future (F.Carminati, 1989)

Google and Micron ioin CERN openla

Google and Micr
major US superc

23 NOVEMBER, 2018

View of the CERN data centre. CERN openlab is a public-private partnership to develop cutting-edge computing soluti
for the research community. (Image: Maximilien Brice/CERN)

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IBM Unveils World's First Integrated Quantum Computing System for Commercial Use

IBM to Open Quantum Computation Center for Commercial Clients in Poughkeepsie, NY

YORKTOWN HEIGHTS, N.Y., Jan. 8, 2019 /PRNewswire/ -- At the 2019 Consumer Electronics Show (CES), IBM (NYSE: IBM) today unveiled IBM Q System One™, the world's first integrated universal approximate quantum computing system designed for scientific and commercial use. IBM also announced plans to open its first IBM Q Quantum Computation Center for commercial clients in Poughkeepsie, New York in 2019.

IBM Q systems are designed to one day tackle problems that are currently seen as too complex and exponential in nature for classical systems to handle. Future applications of quantum computing may include finding new ways to model financial data and isolating key global risk factors to make better investments, or finding the optimal path across global systems for ultra-efficient logistics and optimizing fleet operations for deliveries.

Designed by IBM scientists, systems engineers and industrial designers, IBM Q System One has a sophisticated, modular and compact design optimized for stability, reliability and continuous commercial use. For the first time ever, IBM Q System One enables universal approximate superconducting quantum computers to operate beyond the confines of the research lab.

Exploring quantum computing ...s

...ntum computing

Eckhard Elsen, Director for Research and Computing at CERN, at the CERN openlab workshop on quantum computing in high-energy physics (Image: Andrew Purcell/CERN)

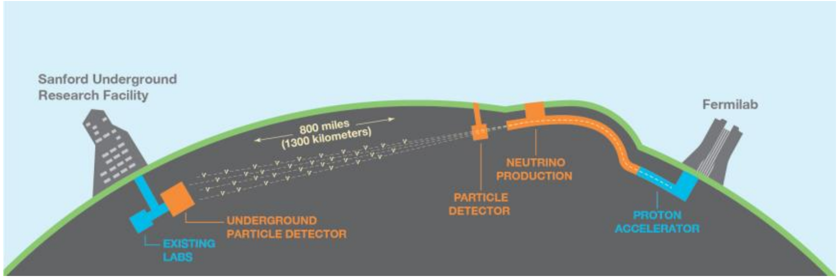
Research paths in QC

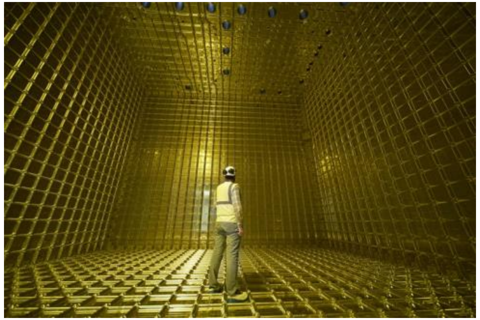
- Get access to emulators and simulators to start assessing development tools and methodology, develop proof-of-concept algorithms for HEP workloads
- Get access to real devices, benchmark, compare results
- Investigate and collaborate in the development of APIs and user interfaces to access QC systems
- Discuss collaboration on engineering aspects of QC installation, primarily cryogenics and material science
- Understand the role that CERN can play as part of broader QC development initiatives

Three examples – 1

DUNE experiment

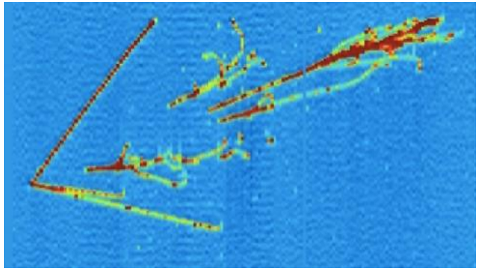
- Origin of Matter
- Unification of forces
- Black hole formation





- Supervised Quantum Learning to reconstruct neutrino interactions with a Quantum Computer

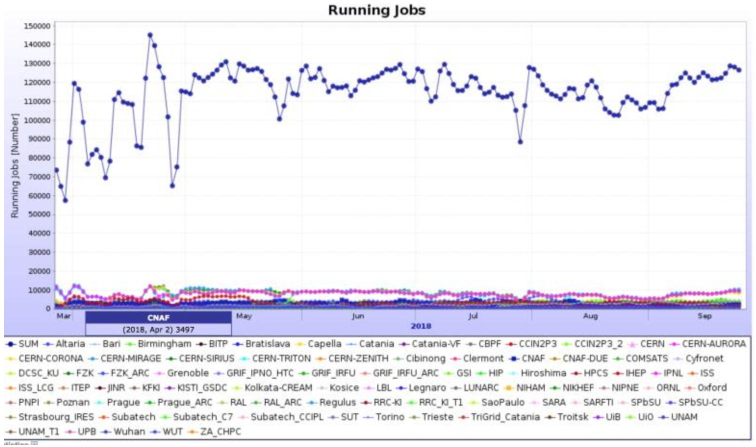
- Unsupervised learning to analyze the simulated and real event structures

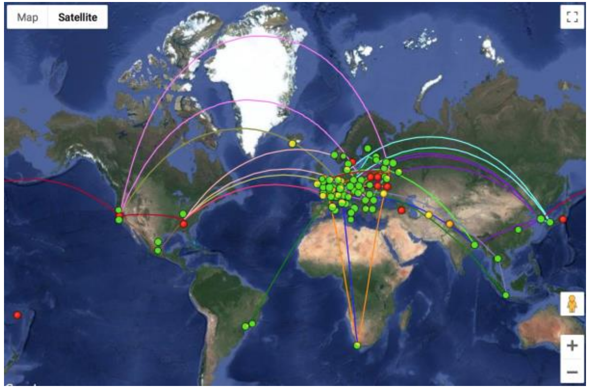


Three examples – 2

Optimize Grid workflow

- ALICE Grid
  - 70 computing centres in 40 countries
  - 150,000 CPU cores and 120 PB of storage
  - ~140.000 jobs running 24 x 7 x 365



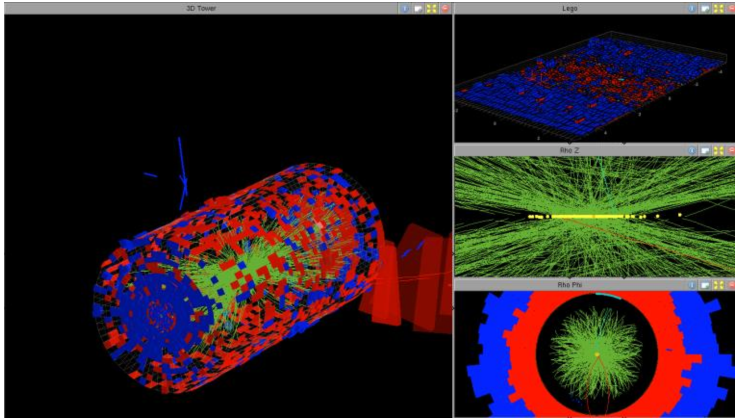


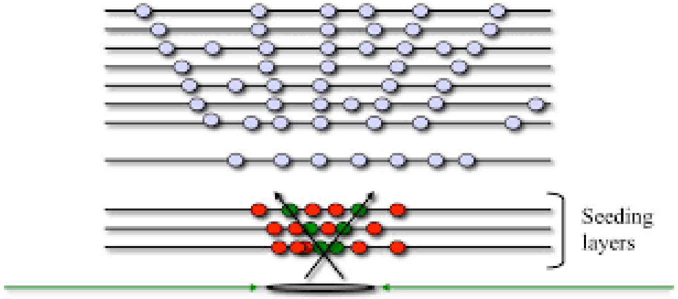
- Optimize storage location and job workflow
- Use Quantum Computing algorithms to find best distribution in a dynamic environment

Three examples – 3

Track reconstruction in dense environments

- Track candidates are identified via combinatorial search
- And then “followed” via Kalmnan filters
- The track is no better than its seeds!





- Use Quantum Computing to speed up combinatorial searches
- And Genetic Algorithms to quickly optimize the search

Quantum Computing Initiatives

- CERN openlab has organized a kick-off event of its Quantum Computing initiative on **November 5th-6th**
  - https://indico.cern.ch/event/719844/
- > 400 registered participants from the HEP physics community, companies and worldwide research laboratories and beyond
- Create a database of QC projects to foster collaborations between interested user groups, CERN openlab and industry
- Continue to seek funding opportunities for QC projects

Conclusions

- CERN openlab is a unique public – private infrastructure fostering collaboration between research and ICT industry
- We have presented two specific fields of investigation that have a high relevance both for fundamental research and for society at large
- Deep Learning has emerged in recent years as a very interesting discipline that has already proved its worth in many fields, but that is still an active domain of research and investigation
- While still not a ready for prime-time production, Quantum Computing holds the promise to herald a revolution in ICT
- CERN openlab intends to investigate the opportunities offered by these and other advanced ICT fields, fostering collaborations between scientists and industry

Thanks for your attention!

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