The Coming Revolutions in Particle Physics

Chris Quigg

IMSA Great Minds Lecture · 10 September 2009

CERN

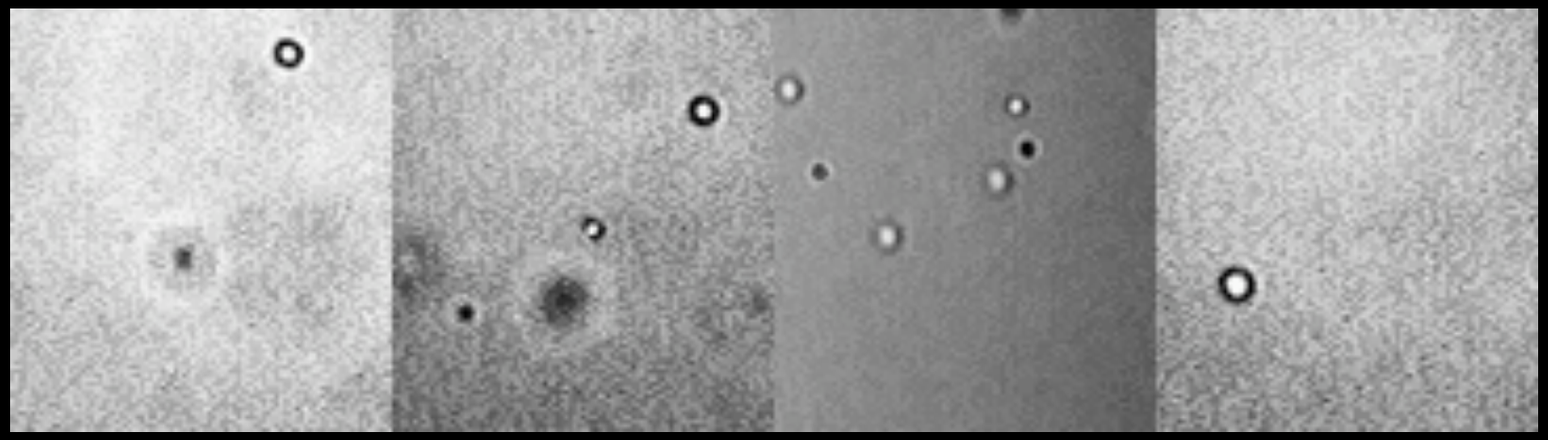
Jean Perrin, *Atoms* (1913)

Studying a machine, we don't limit ourselves to thinking about the visible parts, which are the only objective reality we can establish short of taking the machine apart. We observe the visible parts as best we can, but we also try to guess what hidden gears and levers might explain the machine's movements.

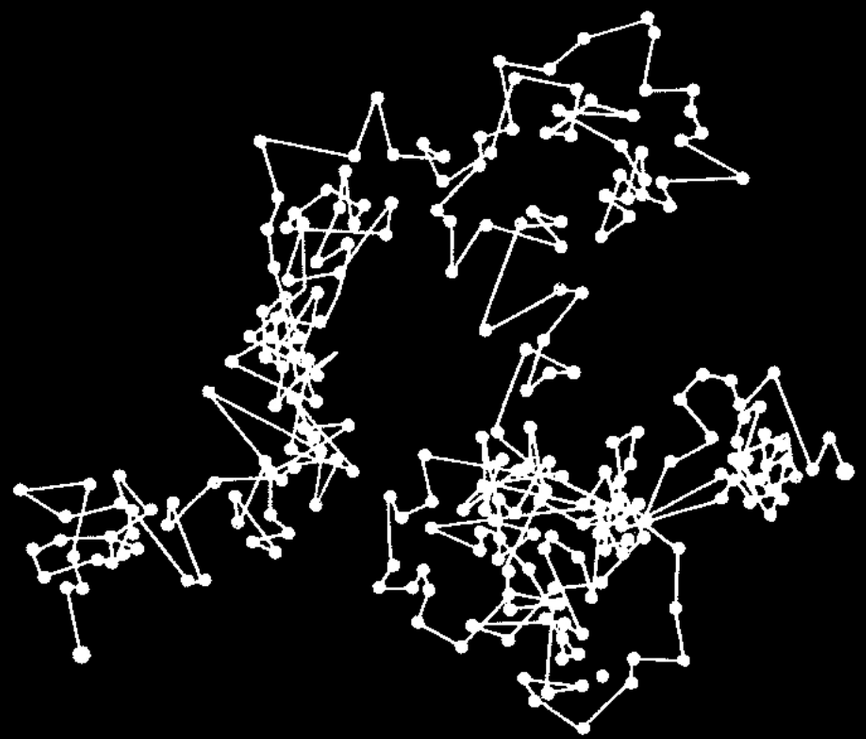
To divine in this way the existence or the properties of objects that we haven't yet experienced directly—*to explain a complicated visible by a simple invisible*—that is the kind of intuitive intelligence to which, thanks to men such as Dalton or Boltzmann, we owe the doctrine of atoms ...

Nobel Prize 1926
for his work on the discontinuous structure of matter

To explain a complicated visible by a simple invisible



Eric Weeks, Emory U.



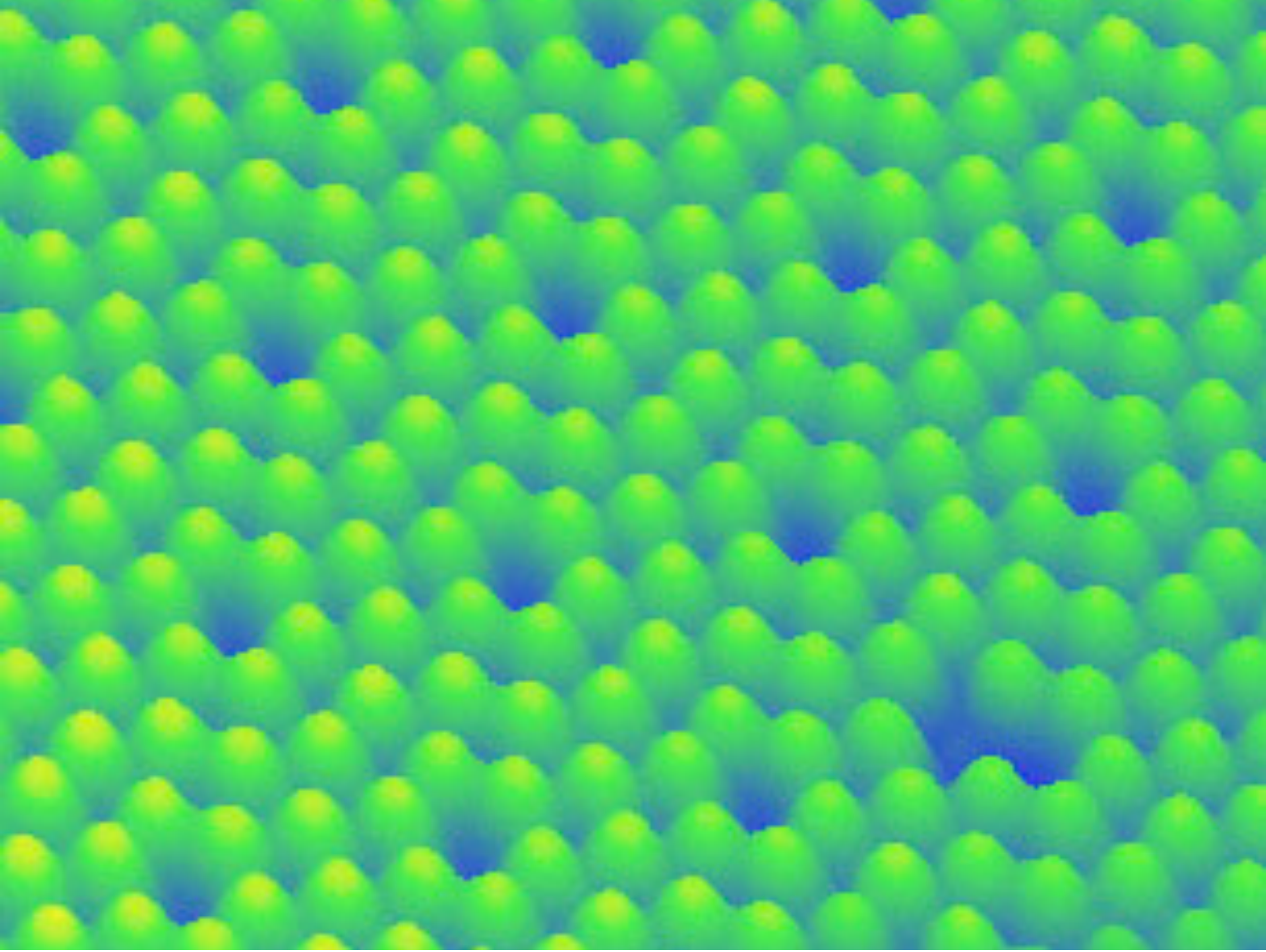
5. *Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen;*
von A. Einstein.

In dieser Arbeit soll gezeigt werden, daß nach der molekularkinetischen Theorie der Wärme in Flüssigkeiten suspendierte Körper von mikroskopisch sichtbarer Größe infolge der Molekularbewegung der Wärme Bewegungen von solcher Größe ausführen müssen, daß diese Bewegungen leicht mit dem Mikroskop nachgewiesen werden können. Es ist möglich, daß die hier zu behandelnden Bewegungen mit der sogenannten „Brownschen Molekularbewegung" identisch sind; die mir erreichbaren Angaben über letztere sind jedoch so ungenau,
[1] daß ich mir hierüber kein Urteil bilden konnte.

Wenn sich die hier zu behandelnde Bewegung samt den für sie zu erwartenden Gesetzmäßigkeiten wirklich beobachten läßt, so ist die klassische Thermodynamik schon für mikroskopisch unterscheidbare Räume nicht mehr als genau gültig anzusehen und es ist dann eine exakte Bestimmung der wahren Atomgröße möglich. Erwiese sich umgekehrt die Voraussage dieser Bewegung als unzutreffend, so wäre damit ein schwerwiegendes Argument gegen die molekularkinetische Auffassung
[2] der Wärme gegeben.

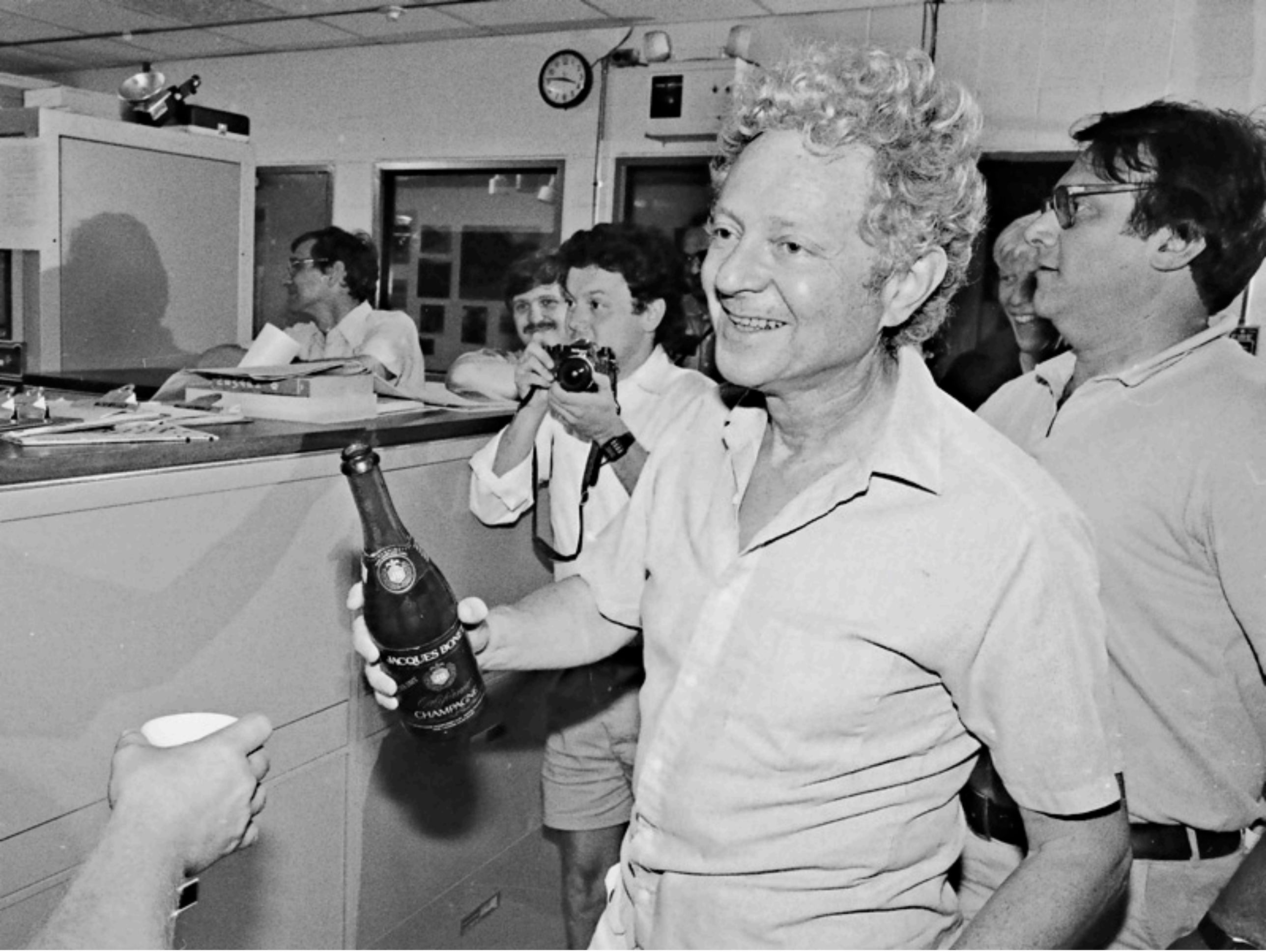
§ 1. Über den suspendierten Teilchen zuzuschreibenden osmotischen Druck.

Im Teilvolumen V^* einer Flüssigkeit vom Gesamtvolumen V seien z-Gramm-Moleküle eines Nichtelektrolyten gelöst. Ist das Volumen V^* durch eine für das Lösungsmittel, nicht aber für die gelöste Substanz durchlässige Wand vom reinen Lösungs-



Great Lesson of XXth Century Science

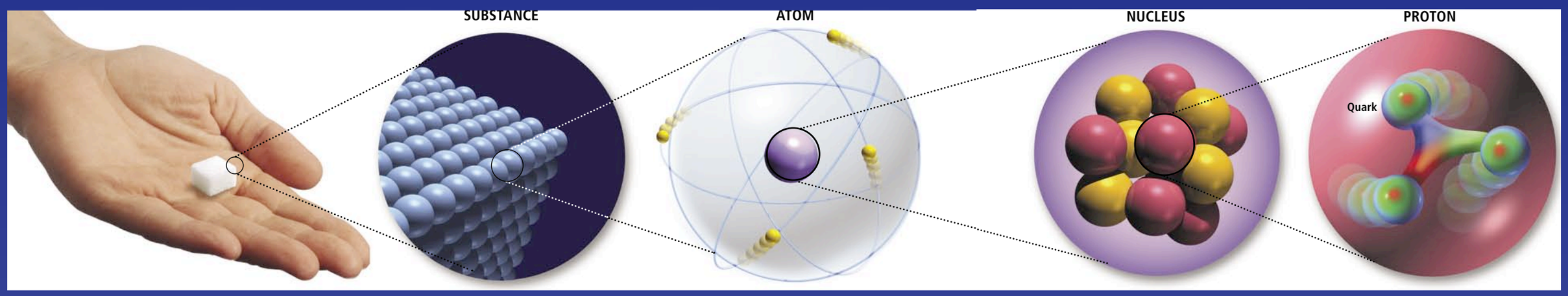
The human scale of space & time is not privileged for understanding Nature . . . and may even be disadvantaged

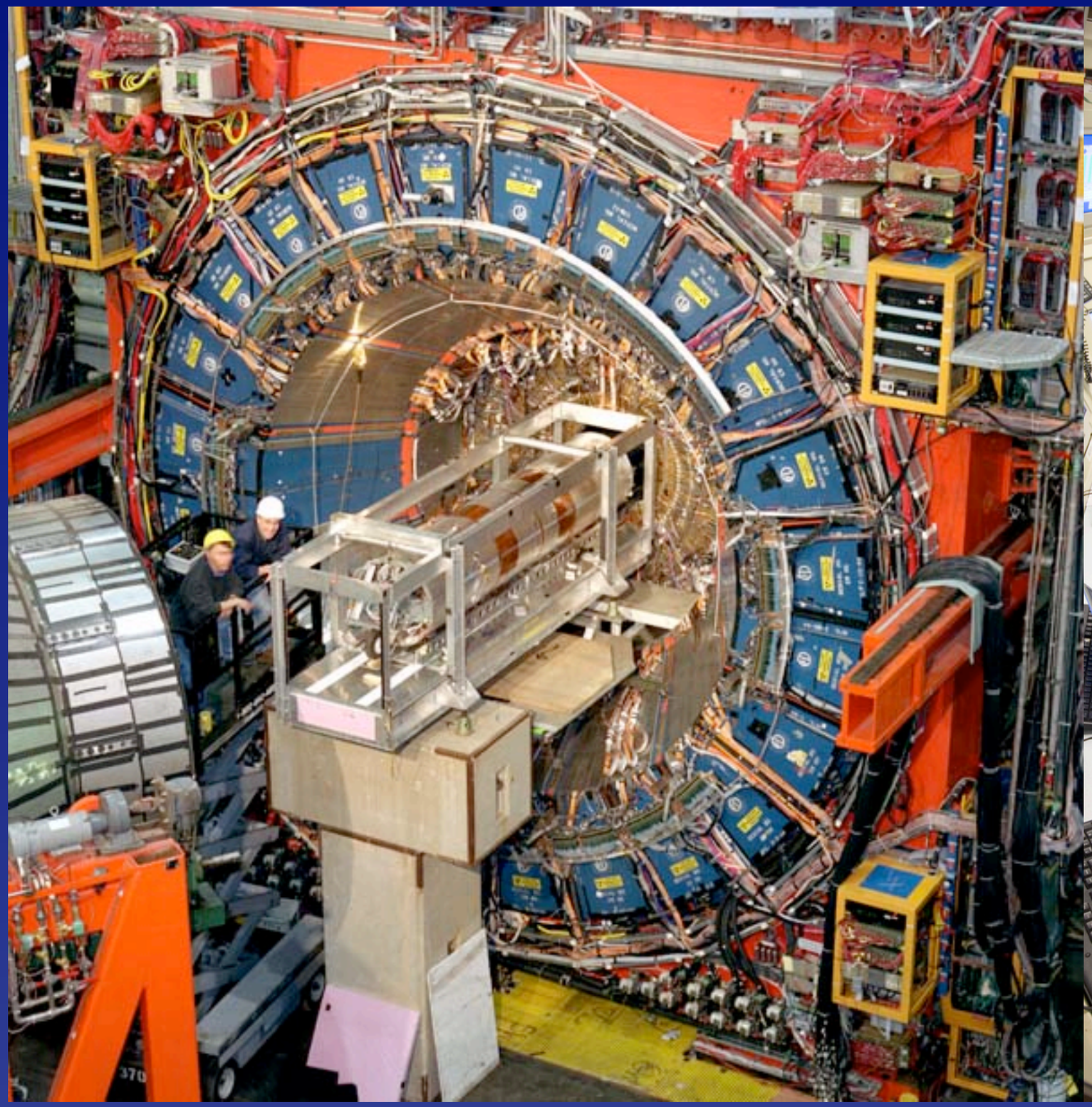

JACQUES BIONNET
CHAMPAGNE

The world's most powerful microscope
… home to *nanonanophysicists!*

Tevatron collider at Fermilab
protons on antiprotons at 1+1 TeV
speed of light: $c \approx 10^9$ km/h
speed of proton: c – 495 km/h

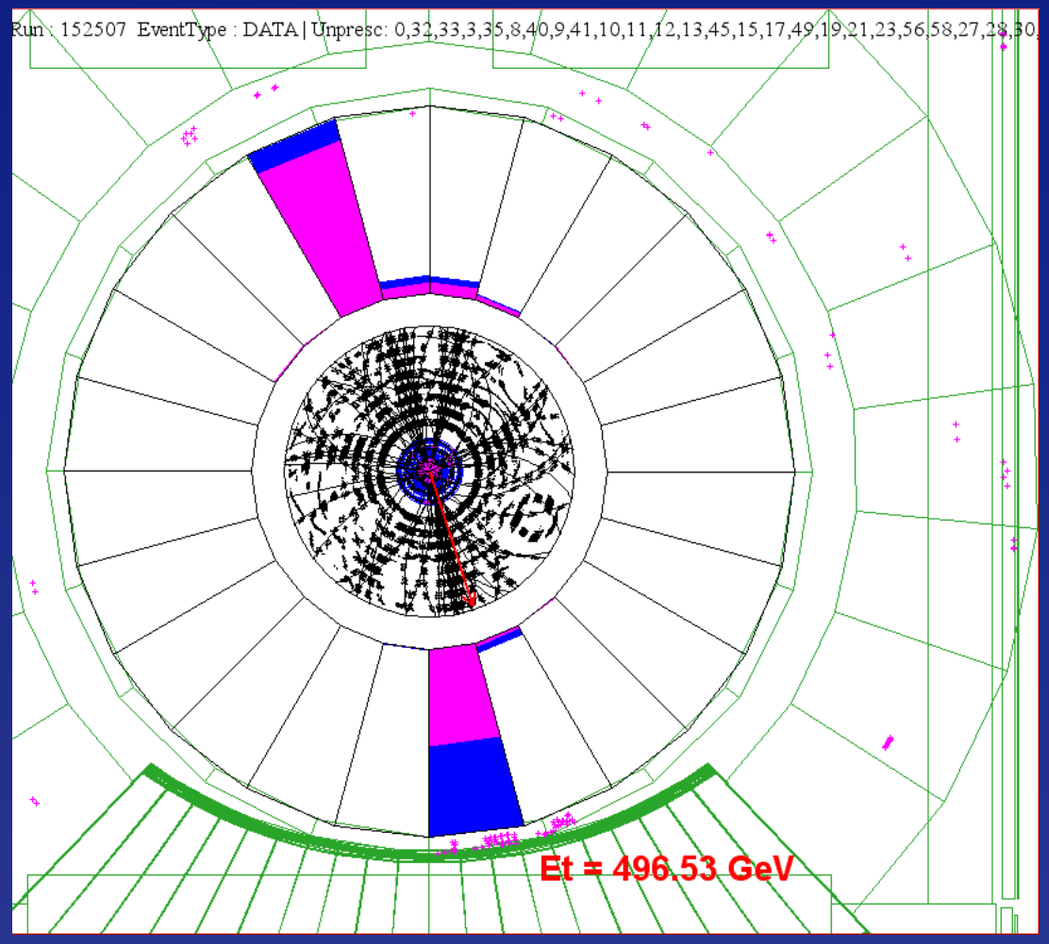
Protons pass my window 45,000 times / second
>10 million collisions per second

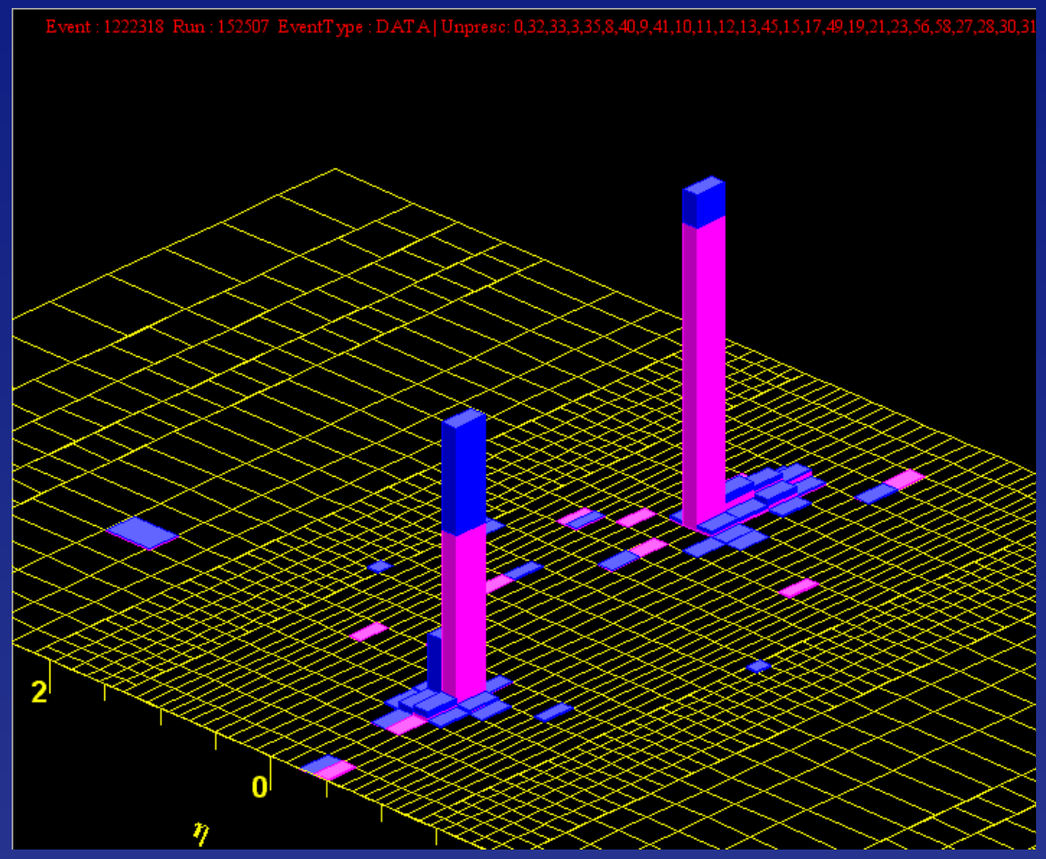




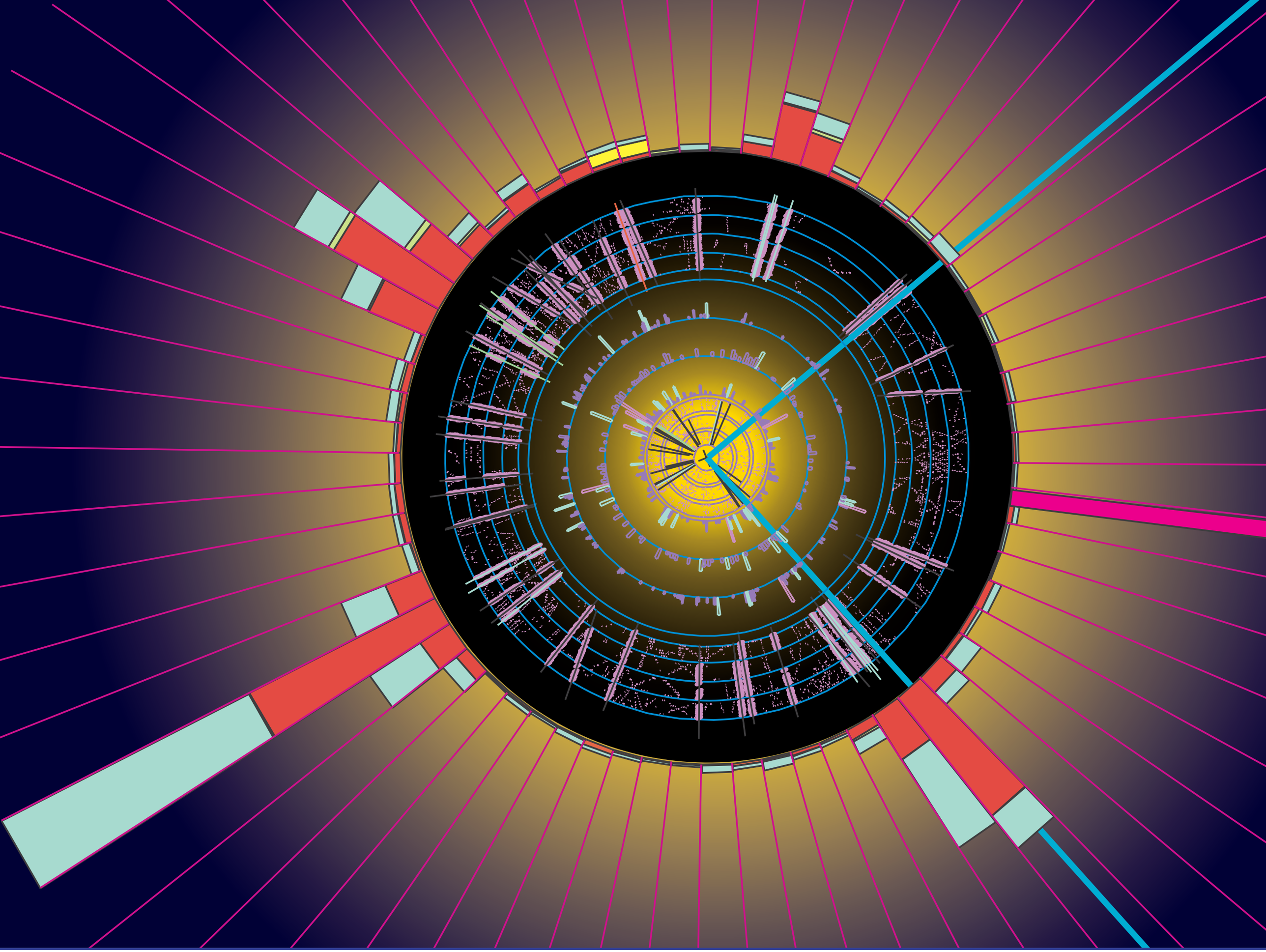
The World's Most Powerful Microscopes

nanonanophysics

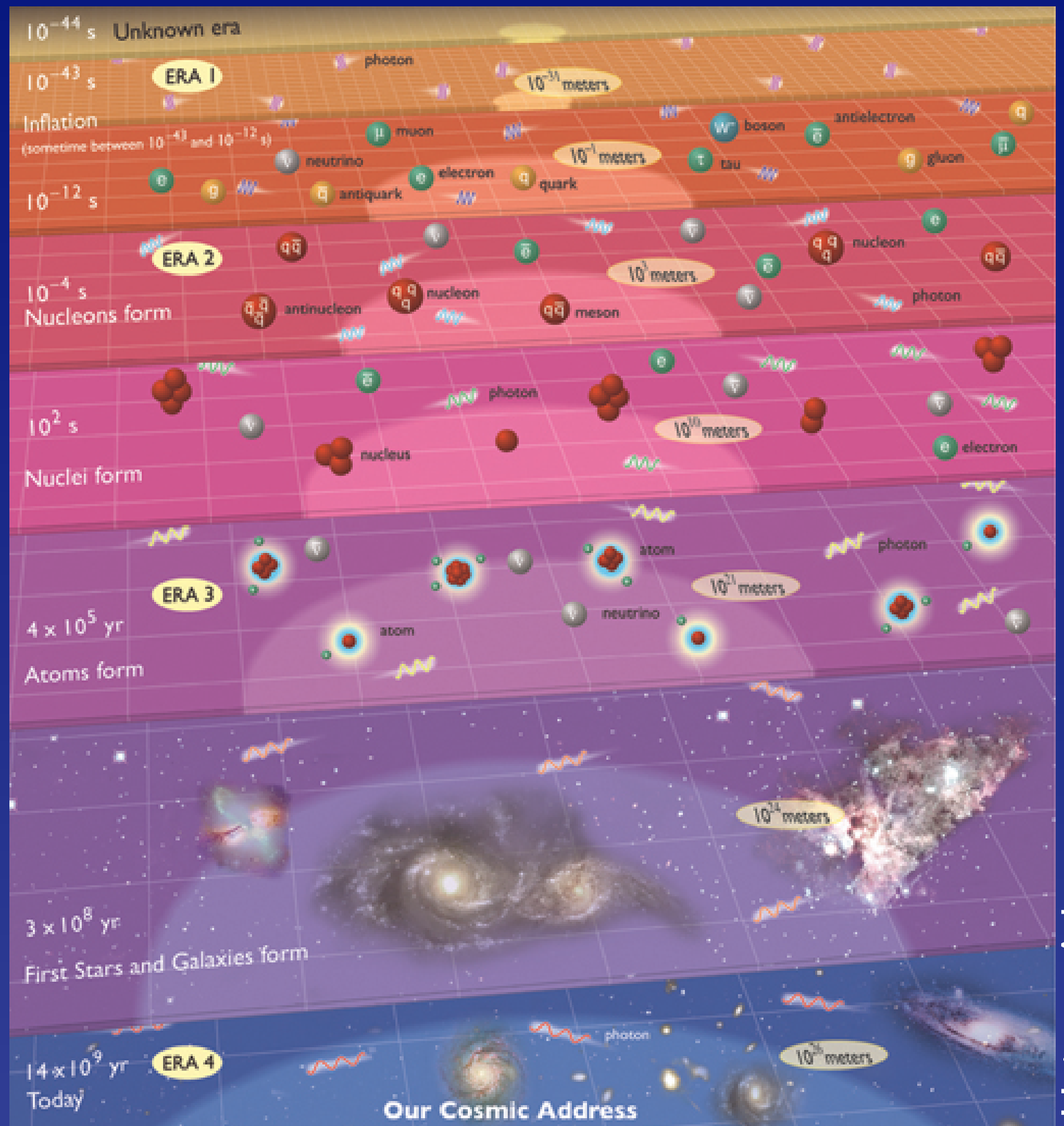




CDF dijet event ($\sqrt{s} = 1.96$ TeV): $E_T = 1.364$ TeV $\boxed{q\bar{q} \to \text{jet} + \text{jet}}$



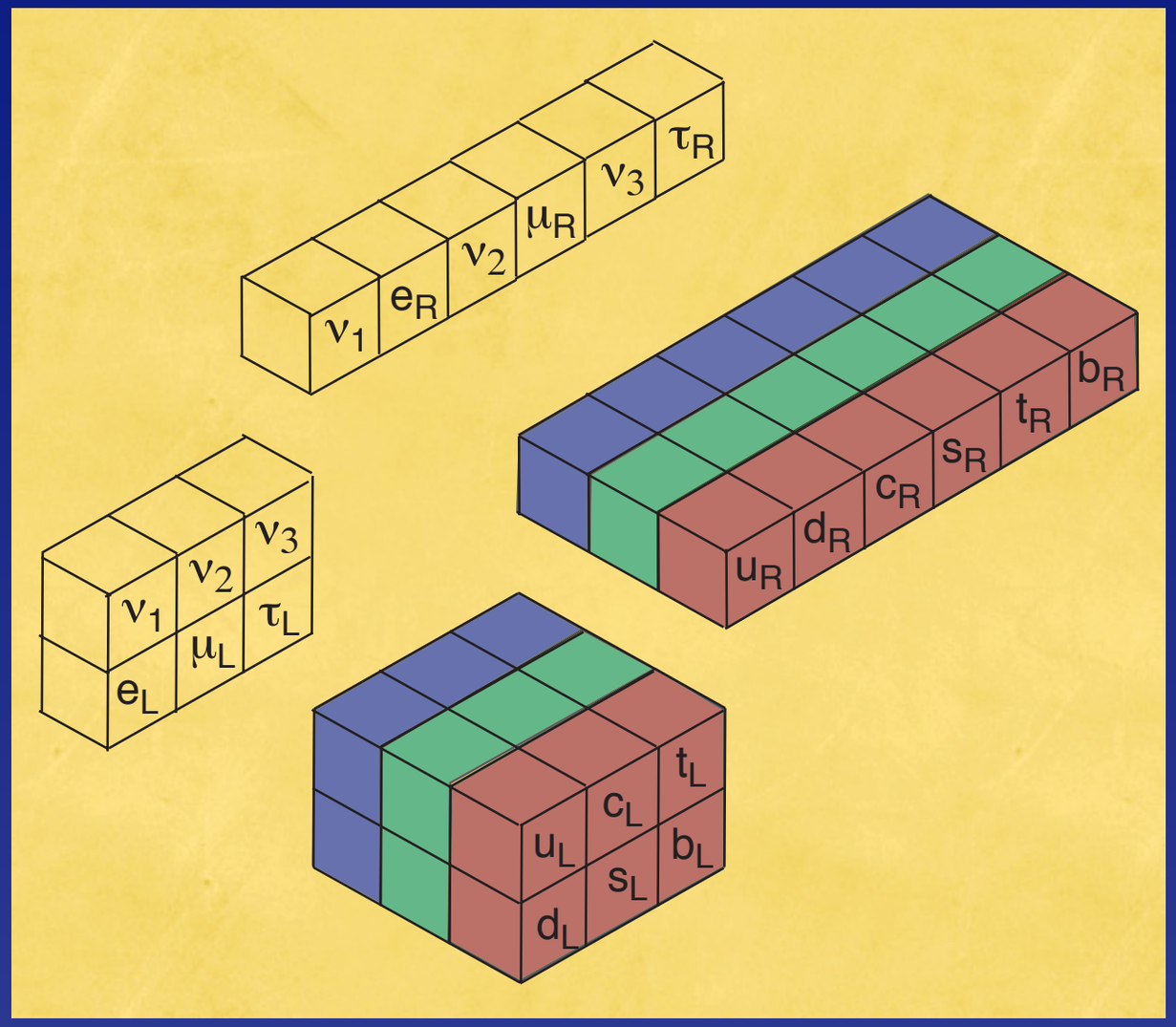
Accelerators as time machines …

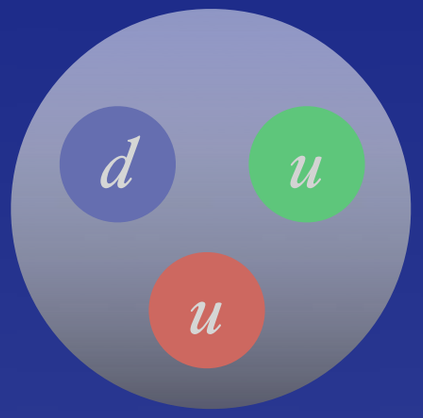


UniverseAdventure.org

Our Picture of Matter (the revolution just past)

Pointlike ($r \leq 10^{-18}$ m) quarks and leptons

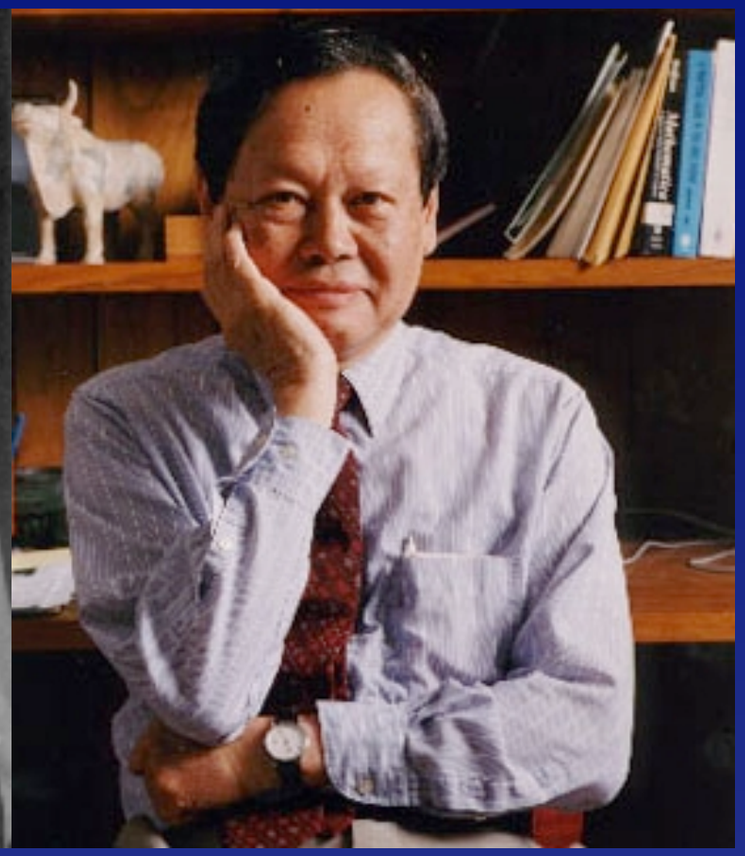




Gravitation, electromagnetism, radioactivity, strong interaction

Louis Sullivan, architect (1896)

Form follows function

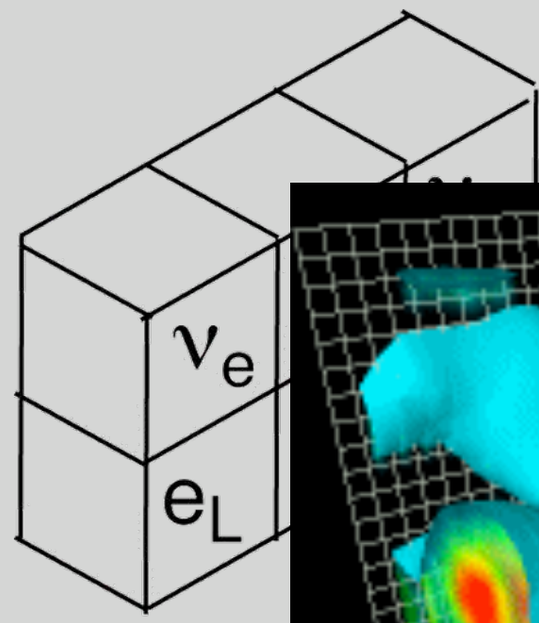


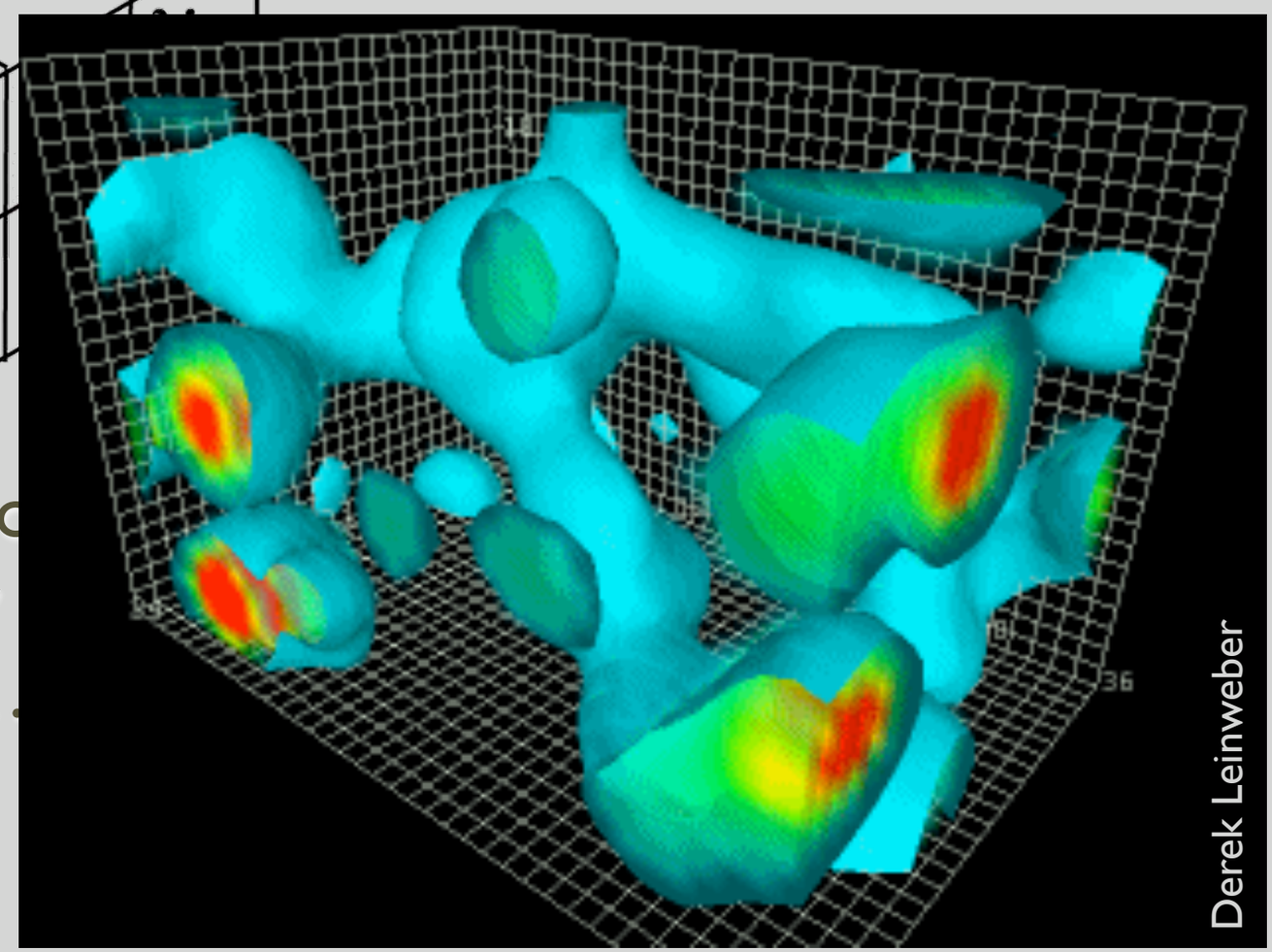
Robert Mills (1954) Yang Chen Ning

Function follows form

Interactions follow from symmetry

Quantum chromodynamics (QCD):
symmetry among quarks
red, green, blue



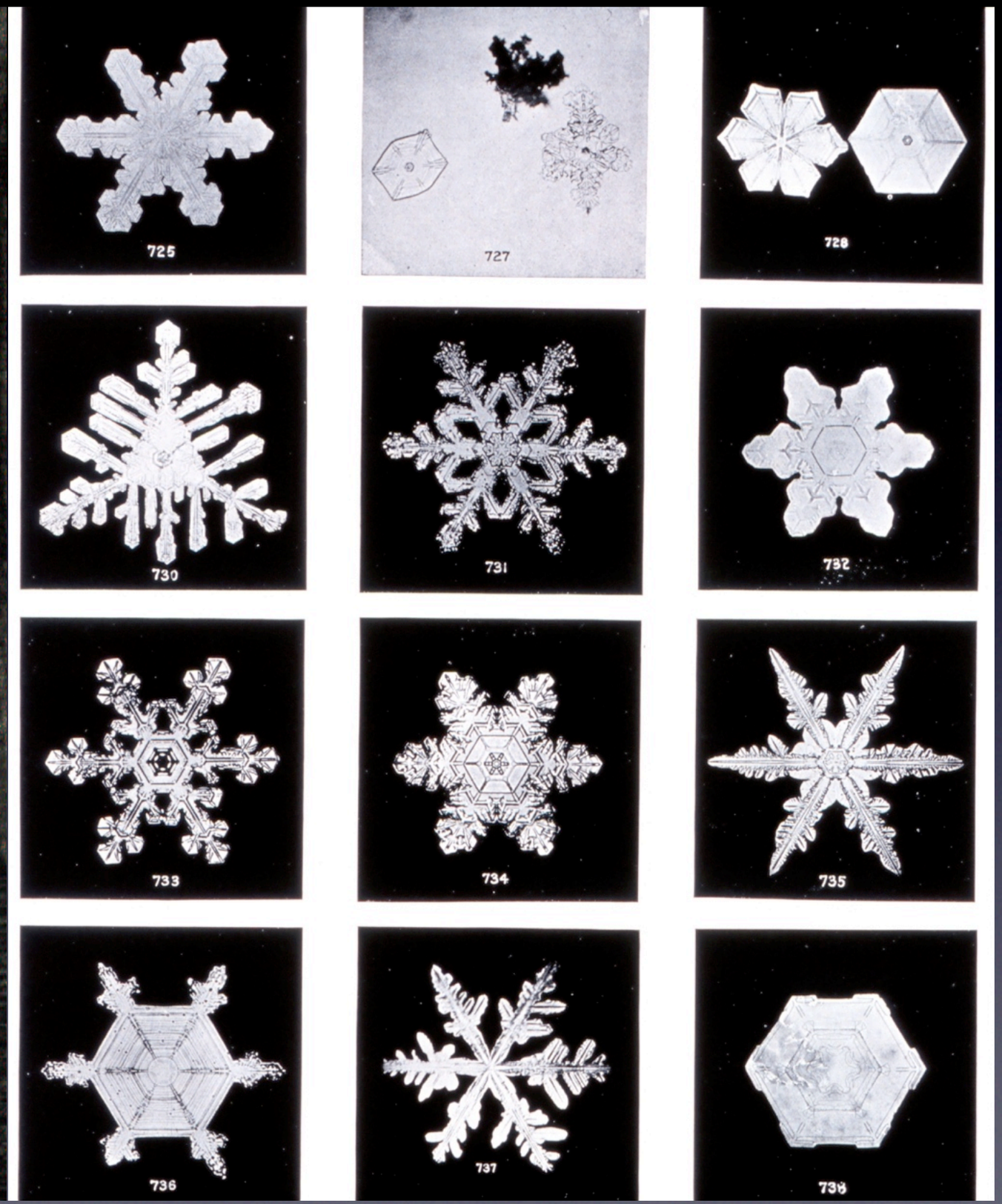


Electroweak theo
family symmetry
u ↔ d ; ν ↔ e ; …

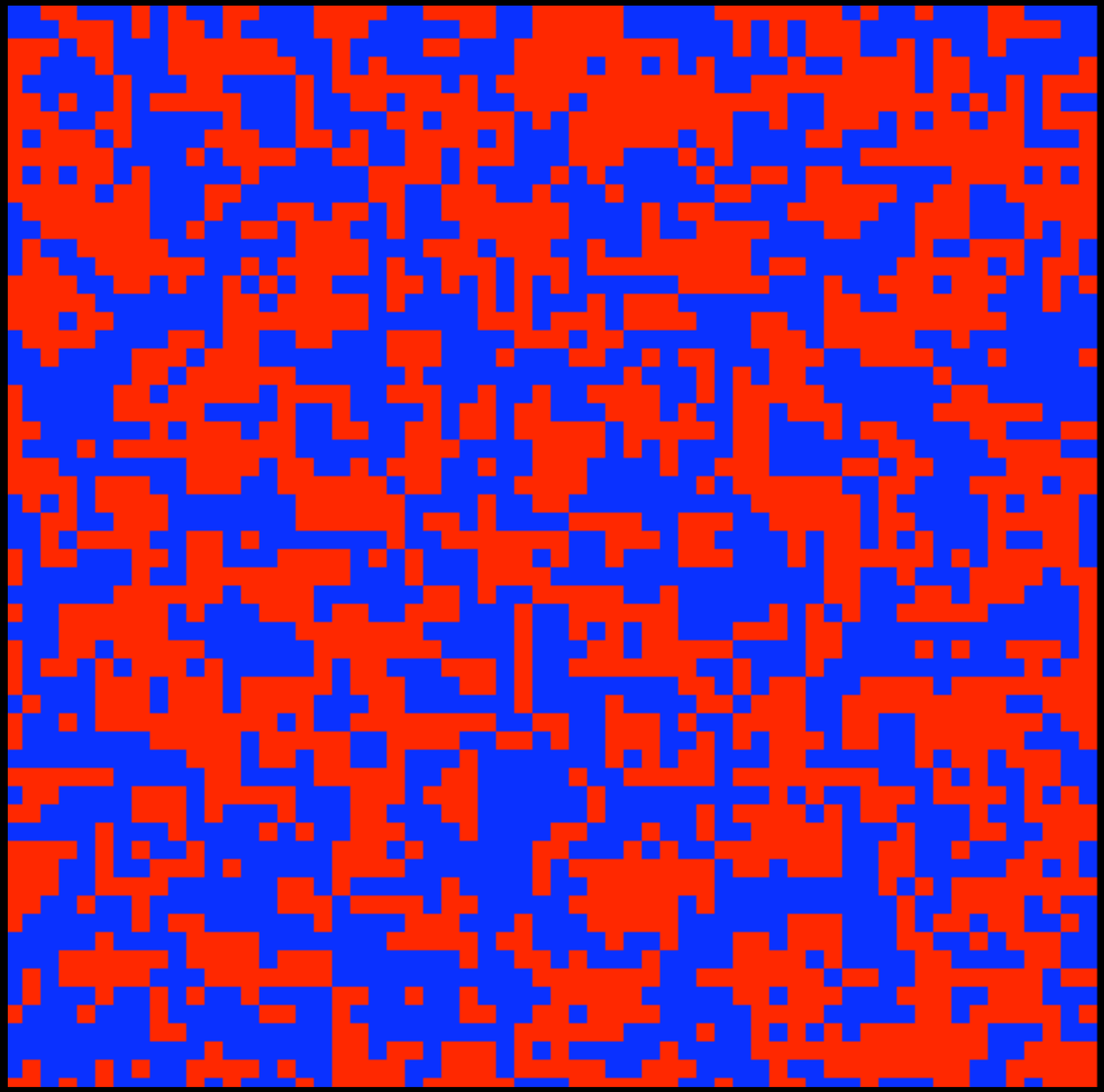
(hidden)

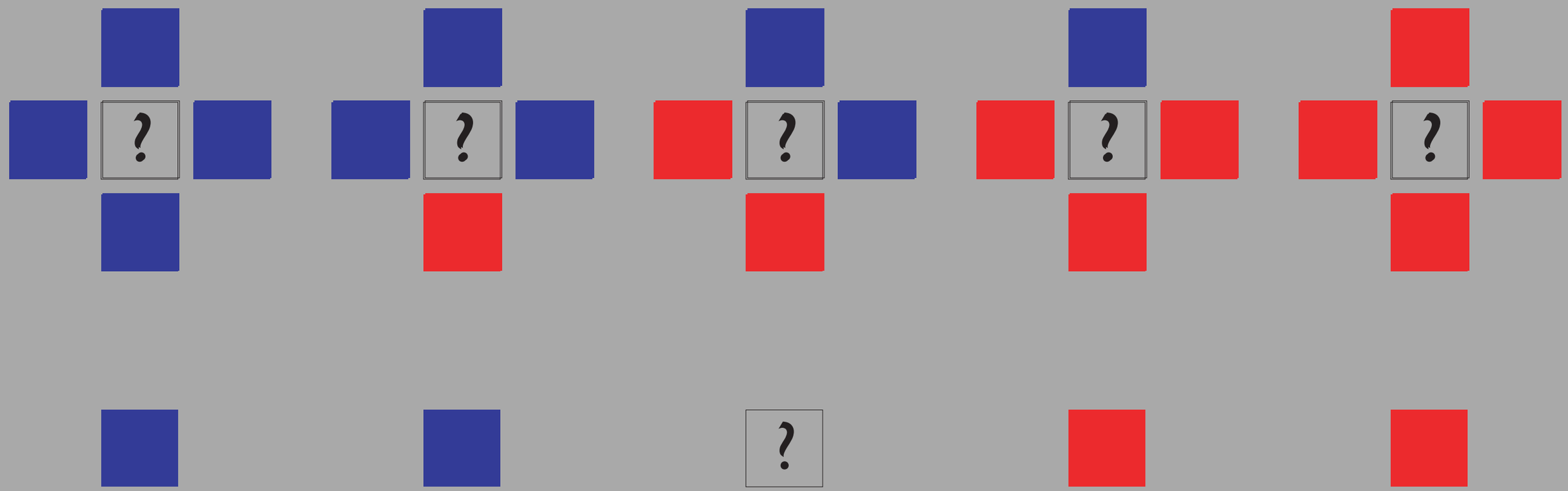
A symmetry among quarks and leptons …
… would have to be a hidden symmetry

Symmetry of laws $\not\Rightarrow$ symmetry of outcomes



Studies among the Snow Crystals ... by Wilson Bentley, via NOAA Photo Library





GEN NITROGEN NIT

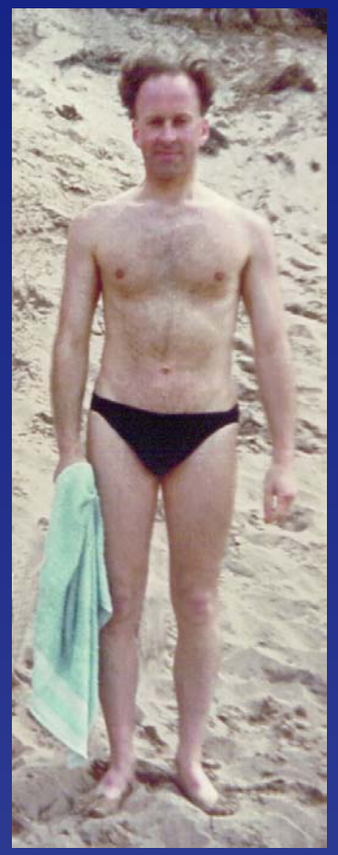
A mysterious new force hides electroweak symmetry

- New kind of force? Higgs field?
- New force from a new symmetry?
- Residual force from strong dynamics?
- Echo of extra spacetime dimensions?

Which path has nature taken?

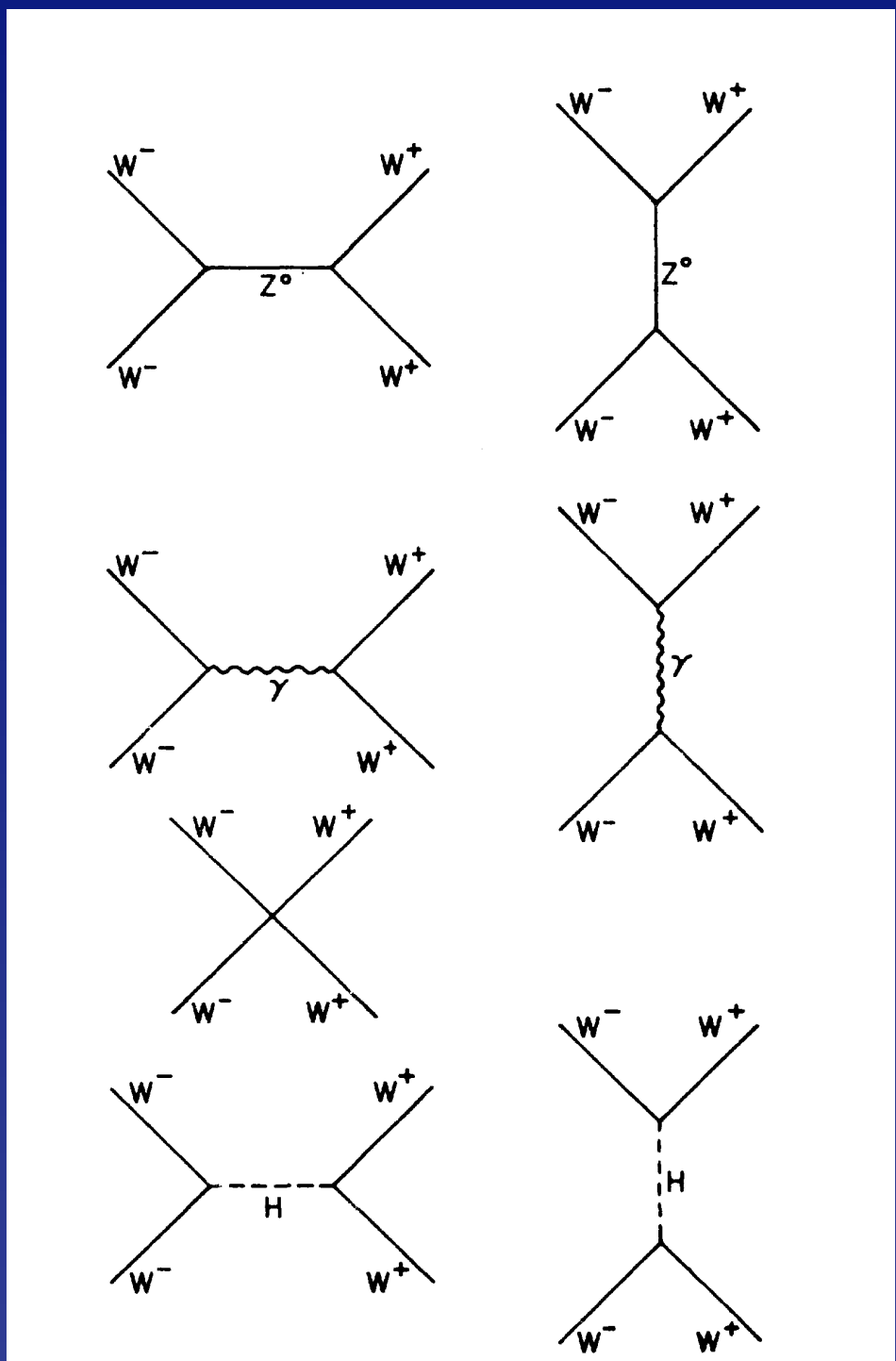
Searching for the *agent provocateur* of electroweak symmetry breaking

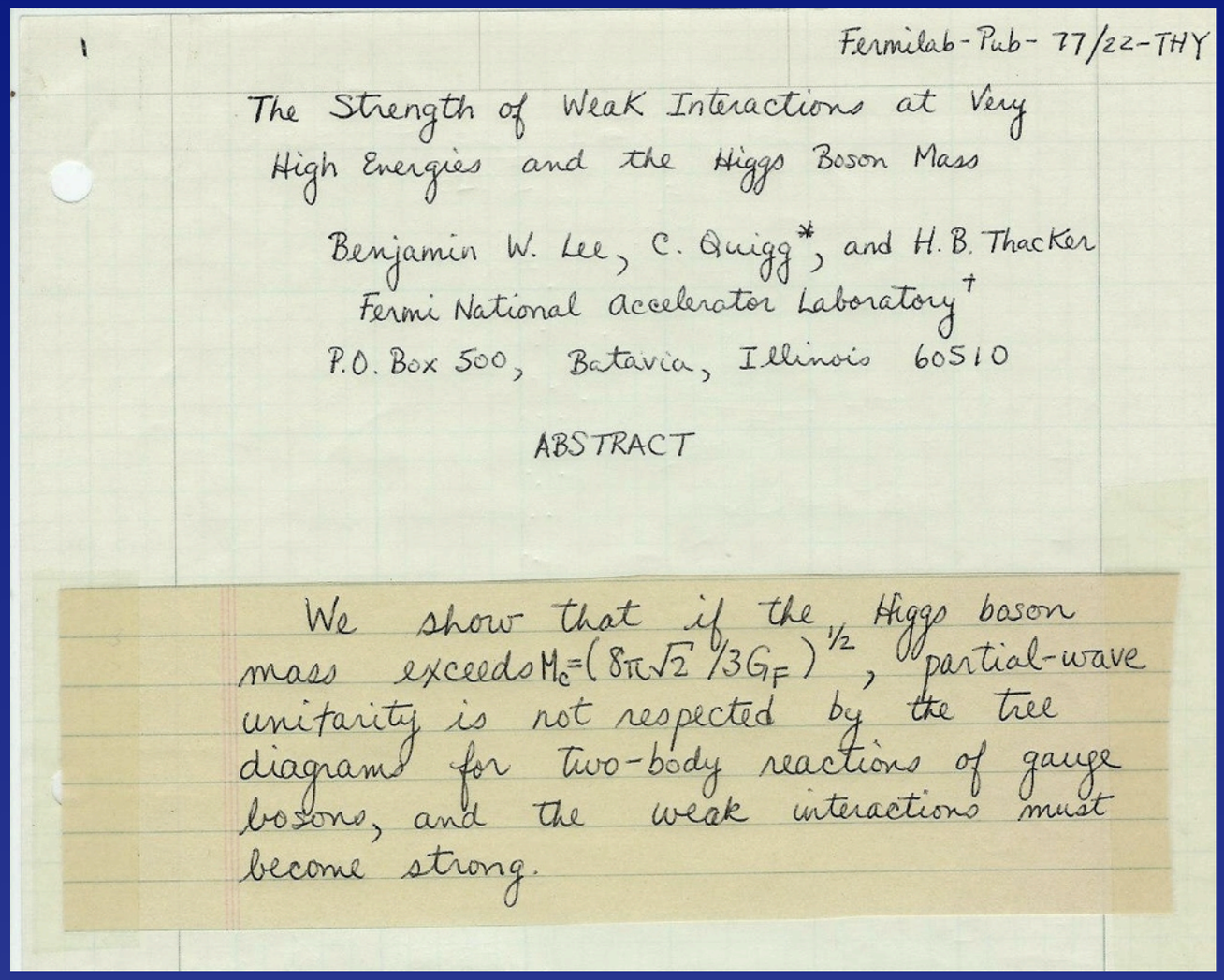
« the search for the Higgs boson »



Peter Higgs

Thought experiment





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Fermilab-Pub-77/22-THY

The Strength of Weak Interactions at Very High Energies and the Higgs Boson Mass

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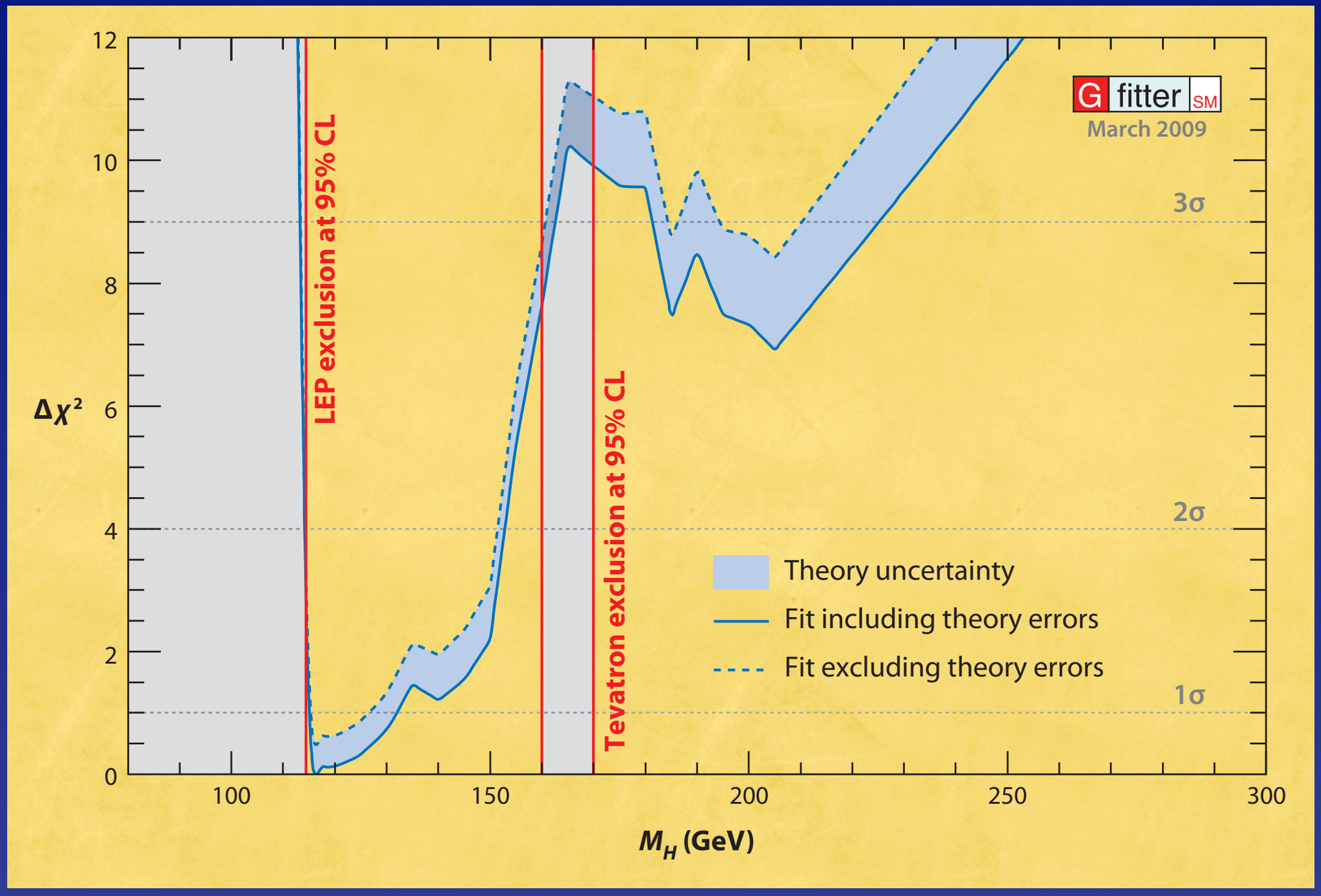
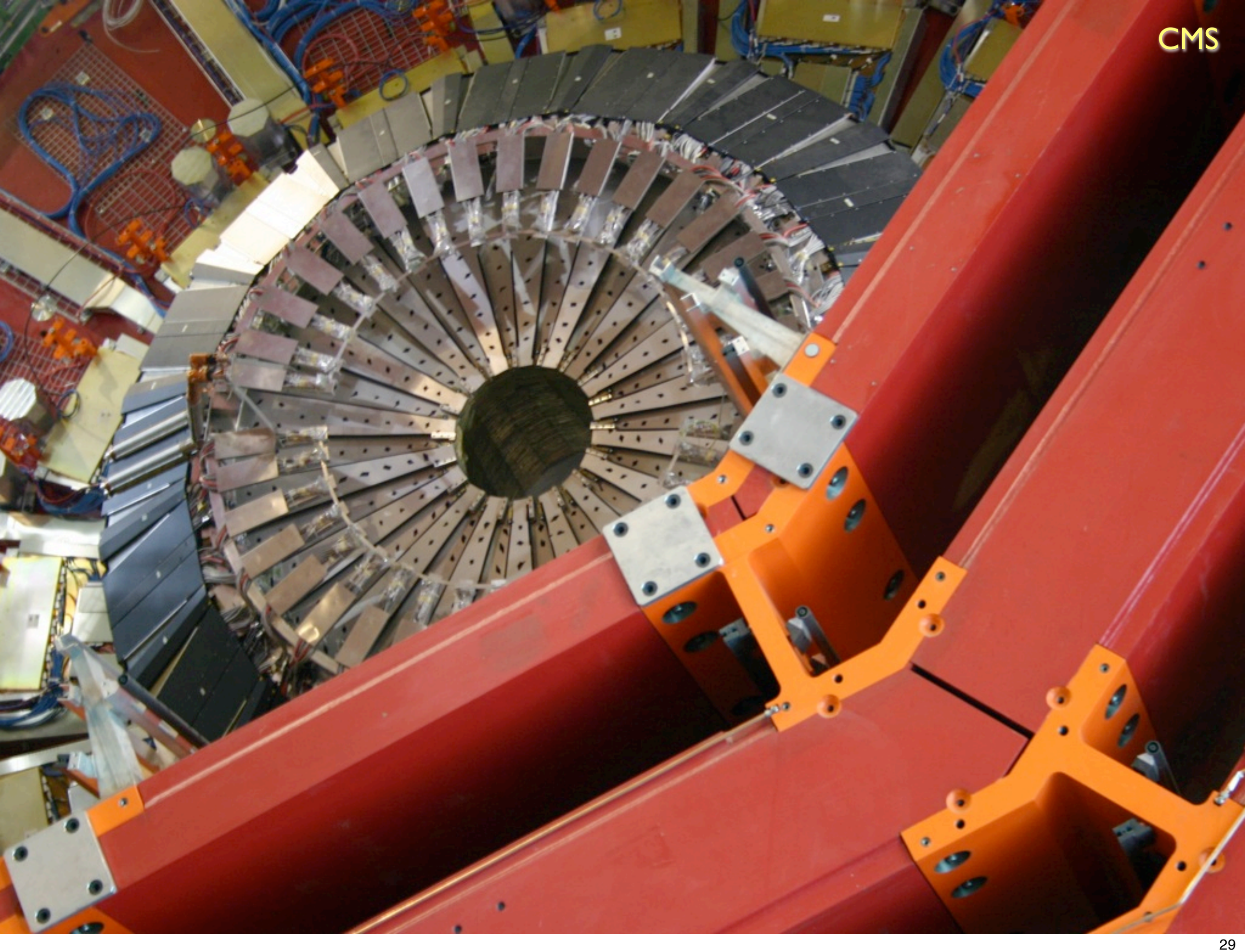
P.O. Box 500, Batavia, Illinois 60510

ABSTRACT

We show that if the Higgs boson mass exceeds $M_c = (8\pi\sqrt{2}/3G_F)^{1/2}$, partial-wave unitarity is not respected by the tree diagrams for two-body reactions of gauge bosons, and the weak interactions must become strong.

Where the (standard) Higgs boson might be

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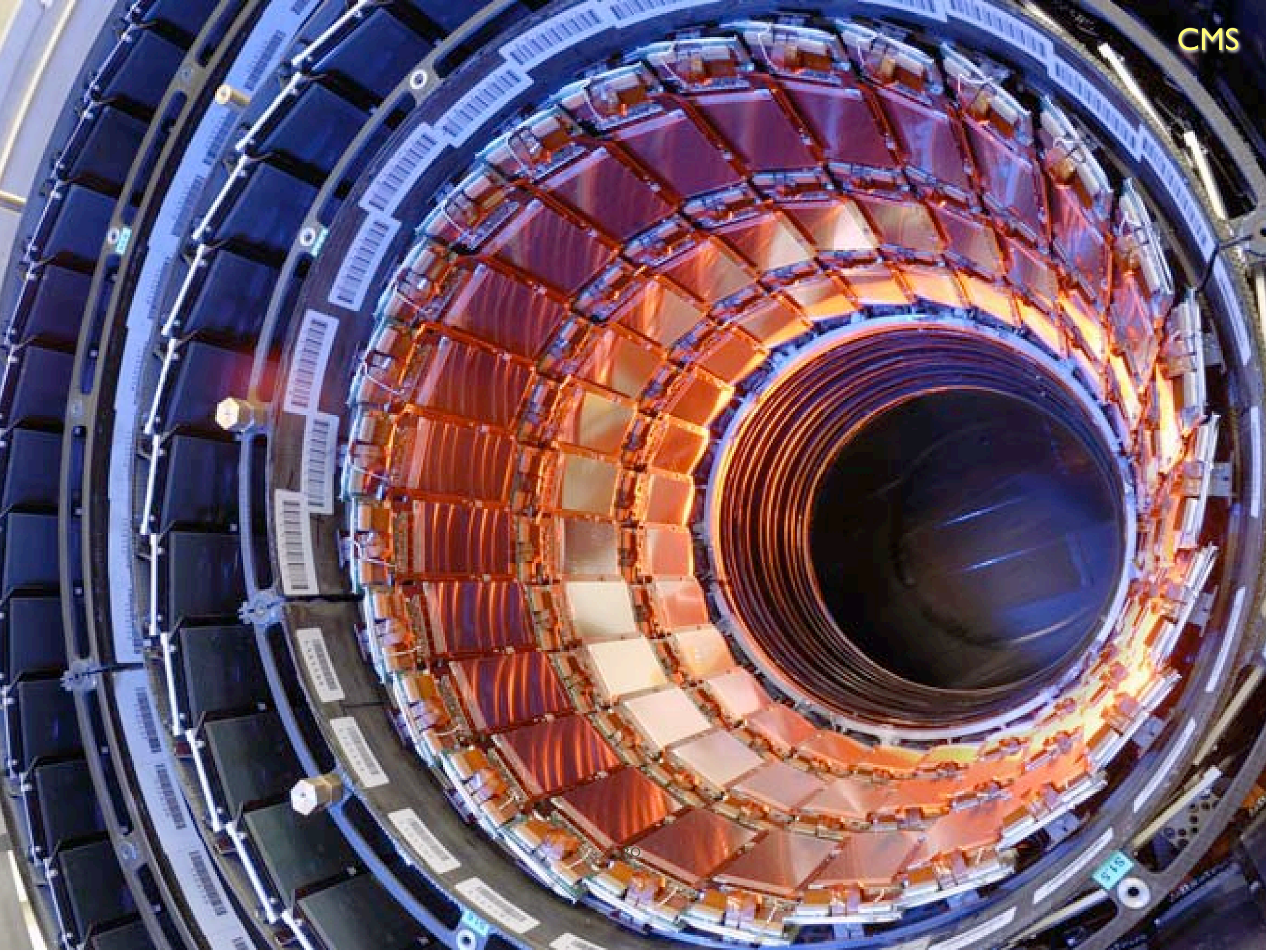
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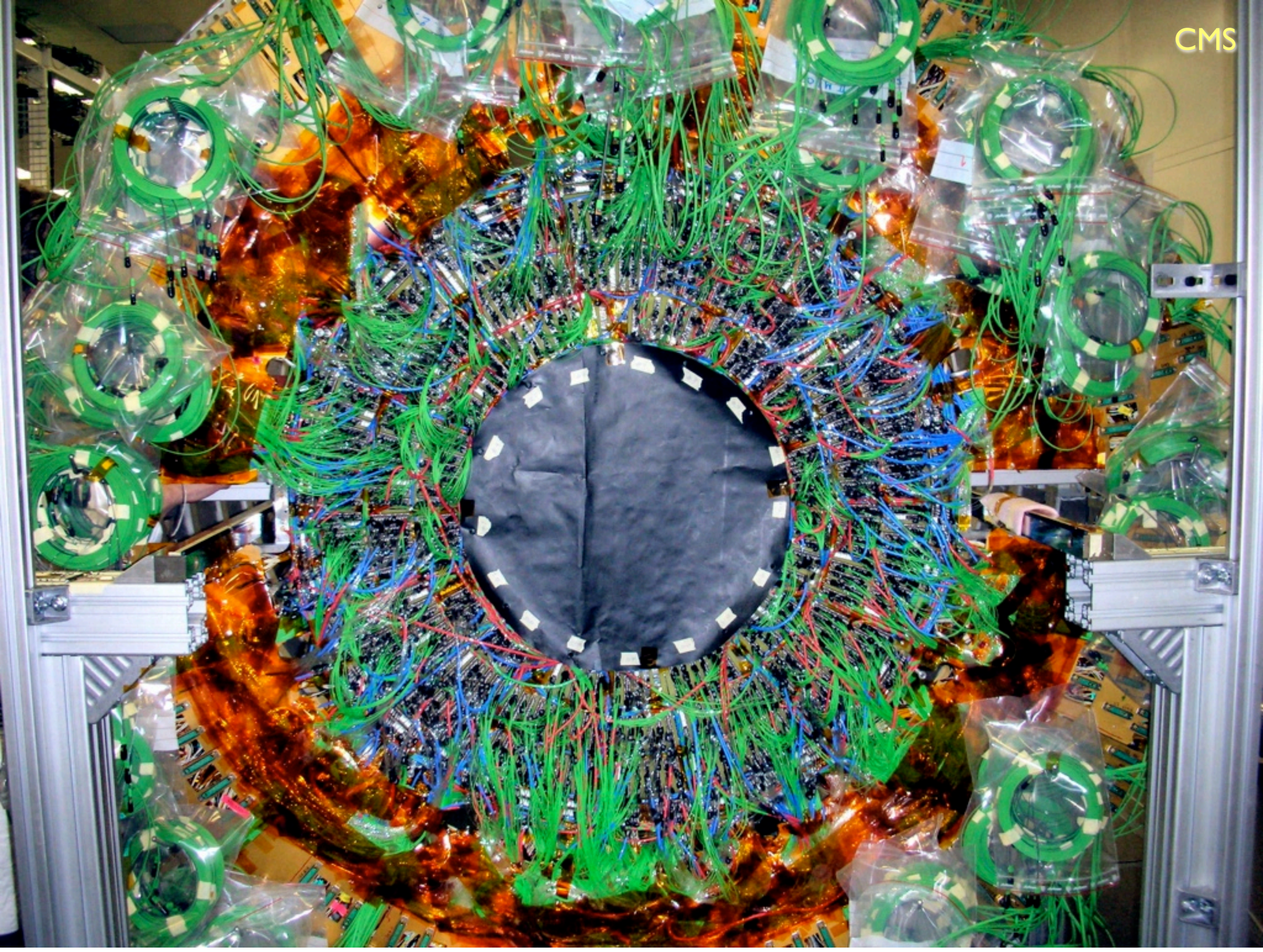
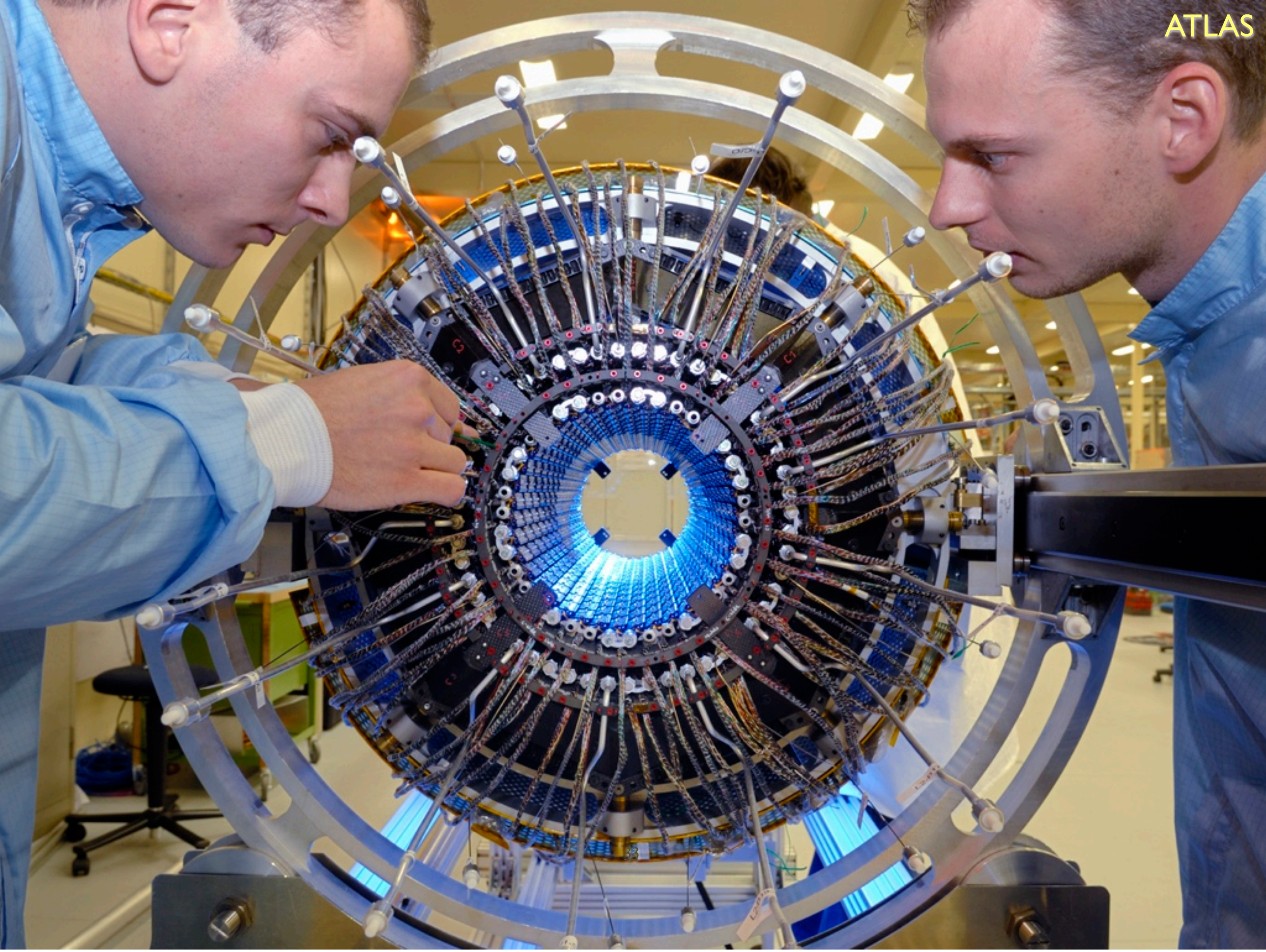

CMS

Jim Virdee & Felicitas Pauss (CMS), President Guebuza (Mozambique)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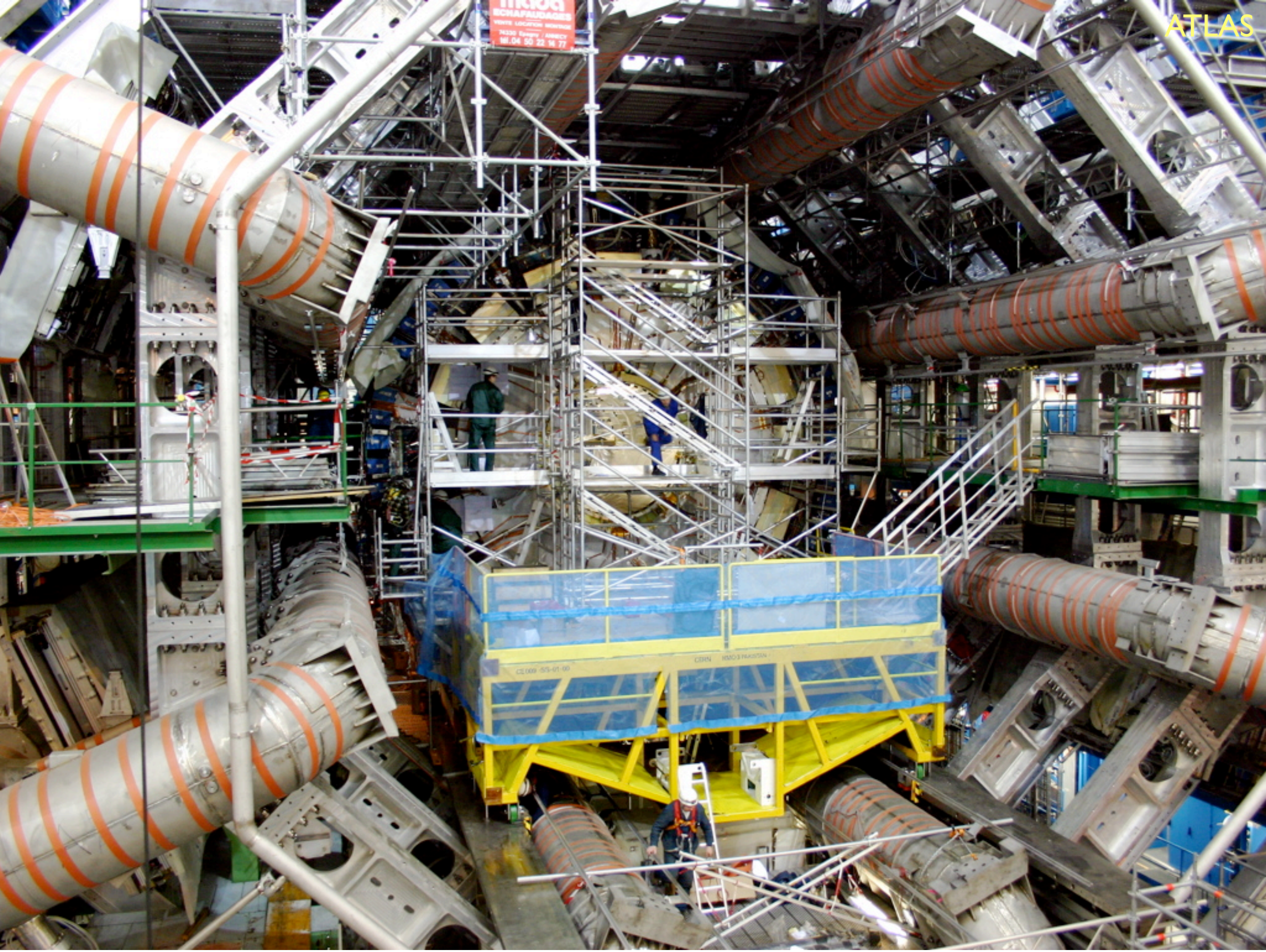
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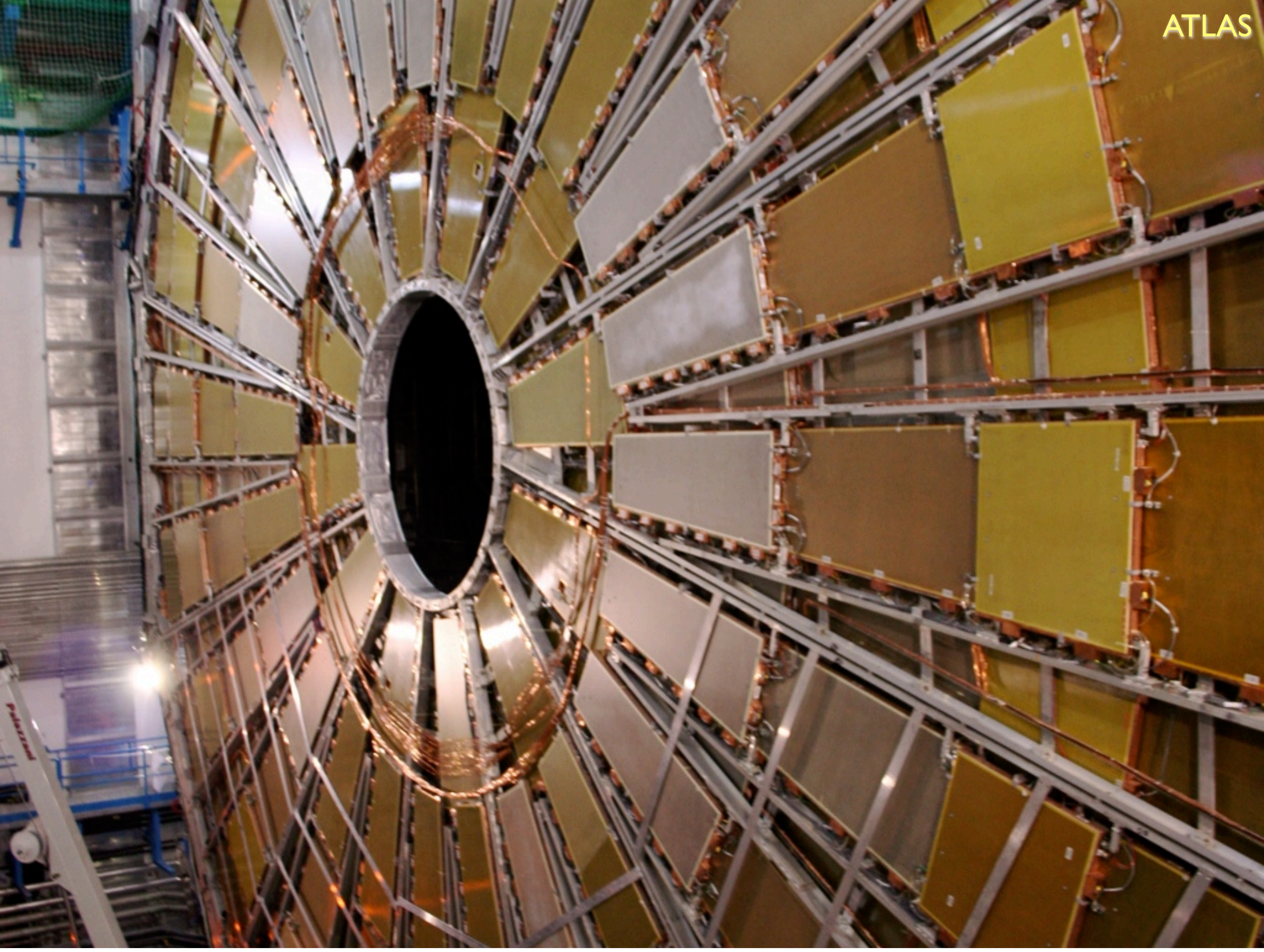
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Fabiola Gianotti (ATLAS) : *If we do not find the Higgs boson, that means that the theory is just wrong!*

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Revolution:

Understanding the Everyday

- ▷ Why are there atoms?
- ▷ Why chemistry?
- ▷ Why stable structures?

Imagine a world without a Higgs mechanism

If electroweak symmetry were not hidden …

- Massless quarks and leptons
- QCD confines quarks into protons, pions, etc.
- *Nucleon mass little changed*
- QCD breaks EW symmetry, gives tiny W, Z masses;
- *proton might outweigh neutron*

  $\Rightarrow$ lightest nucleus is *neutron* … no hydrogen atom

- Some light elements from BBN, but ∞ Bohr radius
- No atoms means no chemistry, no stable composite structures like liquids, solids, …

… character of the physical world
would be profoundly changed

Cellular Invaders: Who Is Inside You? (page 72)
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Thanks to …

Eric Weeks for the film of Brownian motion
www.physics.emory.edu/~weeks

Derek Leinweber for the QCD lava lamp
www.physics.adelaide.edu.au/~dleinweb/

Angela Gonzales for the pearl in a bottle

J. D. Jackson for the photo of Peter Higgs