



Exploring the frontiers of knowledge
Explorer les frontières du savoir

The Large Hadron Collider *the discovery machine*



Dr James Gillies, Head of communication, CERN

The challenge....

guardian.co.uk

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Shortcuts

The mother who never goes out without her daughters

A royal child's relationship with its parents is always going to be an intriguing one. Take Charles: a middle-aged man whose life purpose cannot commence until his mother pushes off, either off the throne or into the next dimension.

But it's Princesses Beatrice and Eugenie who provide the most fodder for thought on this account. These two young ladies, perfectly pleasant by all accounts, seem to have a relationship with their mother, the indefatigable Fergie, that is so close as to be downright stifling. The three are frequently photographed at parties and premieres together and this week Fergie and her ex-husband were photographed leaving a restaurant together. She did leave the girls at home but they were present in spirit, thanks to Fergie's Anya Hindmarch handbag, which was emblazoned with a picture of her daughters.

For New Year's Eve, Beatrice and Eugenie, 18 and 16 respectively, went to Thailand for the party where Pete Doherty sort-of-but-not-really married Kate Moss. Quite a good gig for two teenagers, you would think. Except that their mother went with them. Fergie has hosted in interviews about how she and Beatrice like to go "on the pull together" and Beatrice recently cooed that her ambition was to be "a mini-mummy (because) her behaviour is one I'd really like to follow". Ah-toe-sucking choo!

In this day of family breakdowns and the end of the nuclear unit, isn't it heartening to see two teenagers so happily close to their mother? Others have been spotted partying with their mothers, too: Moss herself was photographed at Manumission in Ibiza with her mum. None the less, we all remember what it was like to be 18: the idea of going to a party with one's mother was pretty much up there with joining the after-school physics club in terms of social humiliation. So either they are doing this under



Integratable... Fergie with Beatrice and Eugenie and, left, her bag with their picture on

In this day of family breakdowns, isn't it heartening to see two teenagers so close to their mother?

PHOTOGRAPH BY LINDSAY COOPER FOR GETTY IMAGES

GuardianUnlimited
think of escaping

2 The Guardian 18.01.07

“We all remember what it was like to be 18: the idea of going to a party with one's mother was pretty much up there with joining the after school physics club in terms of social humiliation.



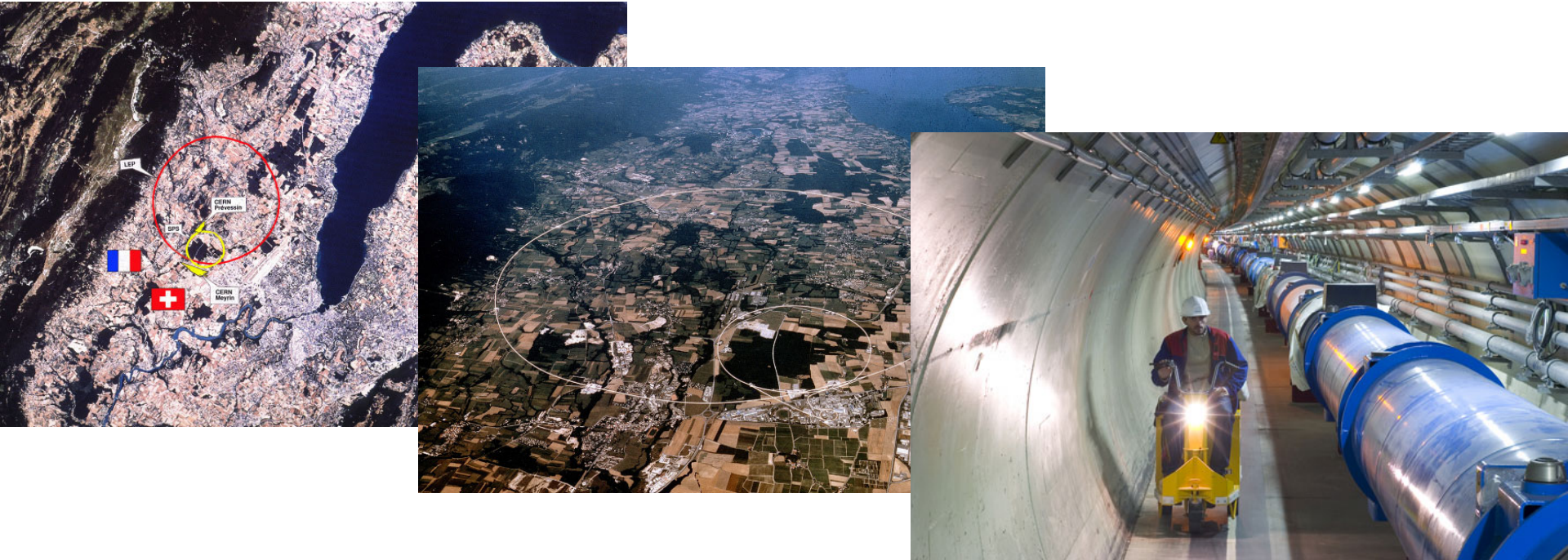
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What is it?



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The fastest racetrack on the planet...

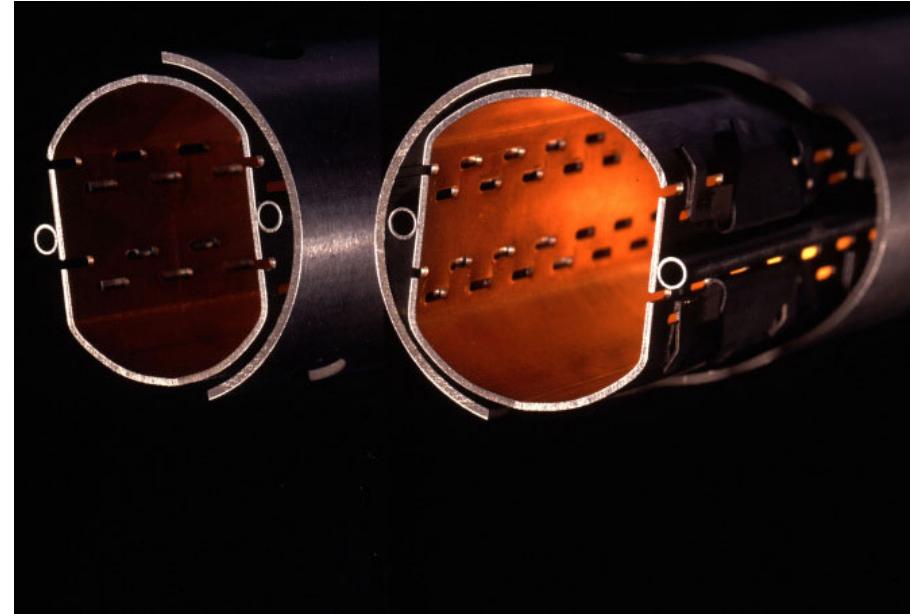
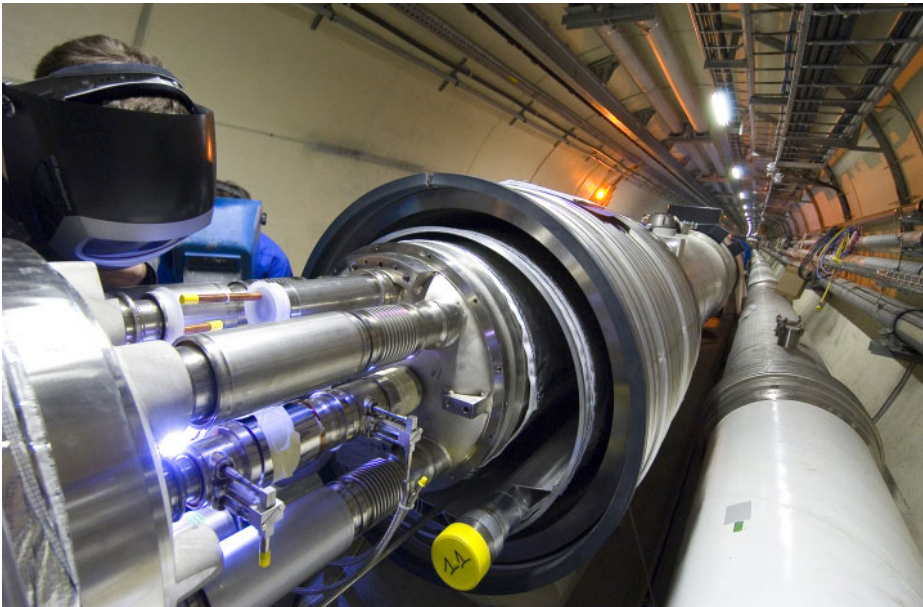


Trillions of protons will race around the 27km ring in opposite directions over 11,000 times a second, travelling at 99.9999991 per cent the speed of light.



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One of the emptiest places in the solar system...



To accelerate protons to almost the speed of light requires a vacuum almost as empty as interplanetary space.



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One of the coldest places in the universe...

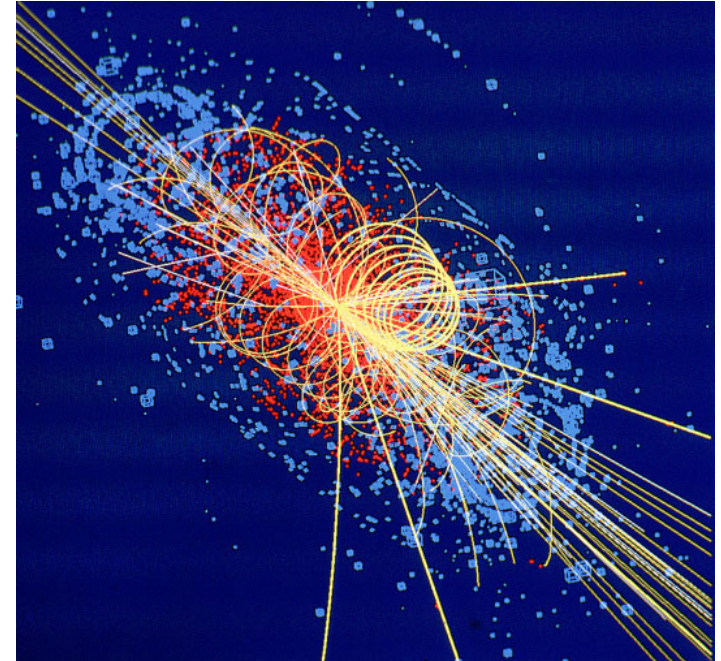
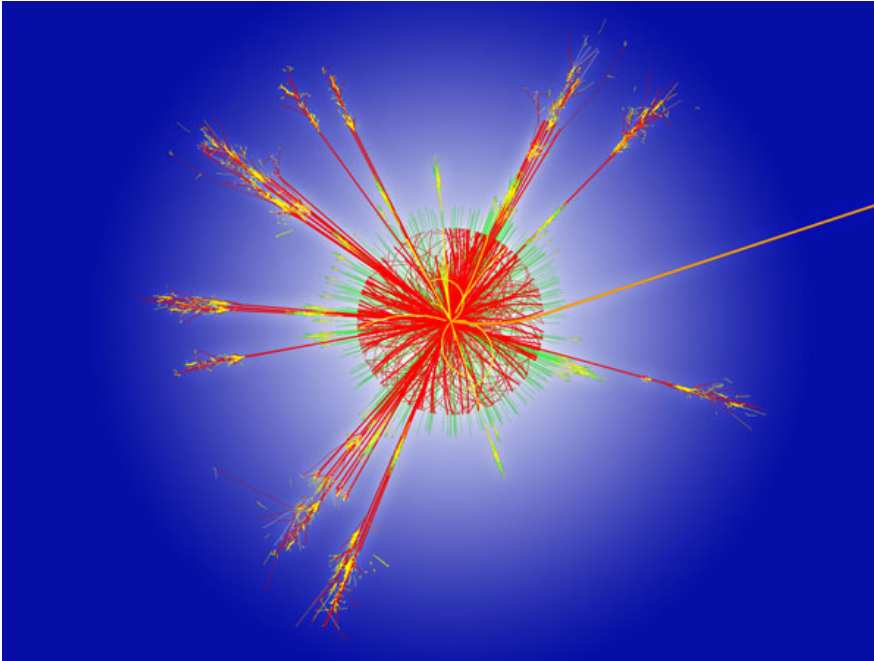


With an operating temperature of about -271 degrees Celsius, just 1.9 degrees above absolute zero, the LHC is colder than outer space.



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The hottest spots in the galaxy...

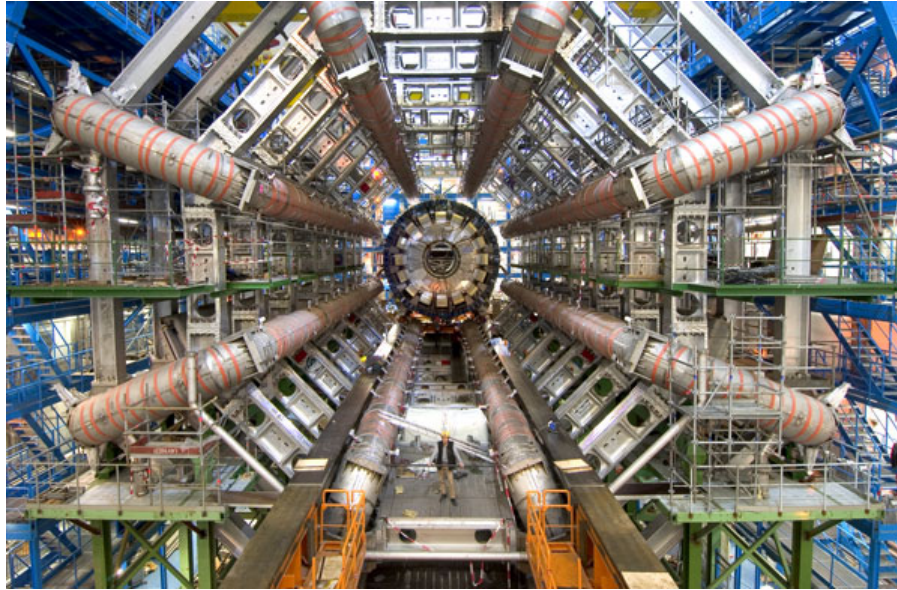


When two beams of protons collide, they will generate temperatures 1000 million times hotter than the heart of the sun, but in a minuscule space.



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The biggest most sophisticated detectors ever built...



To sample and record the debris from up to 600 million proton collisions per second, scientists are building gargantuan devices that measure particles with micron precision.



The most extensive computer system in the world...



To analyse the data, tens of thousands of computers around the world are being harnessed in the Grid. The laboratory that gave the world the web, is now taking distributed computing a big step further.

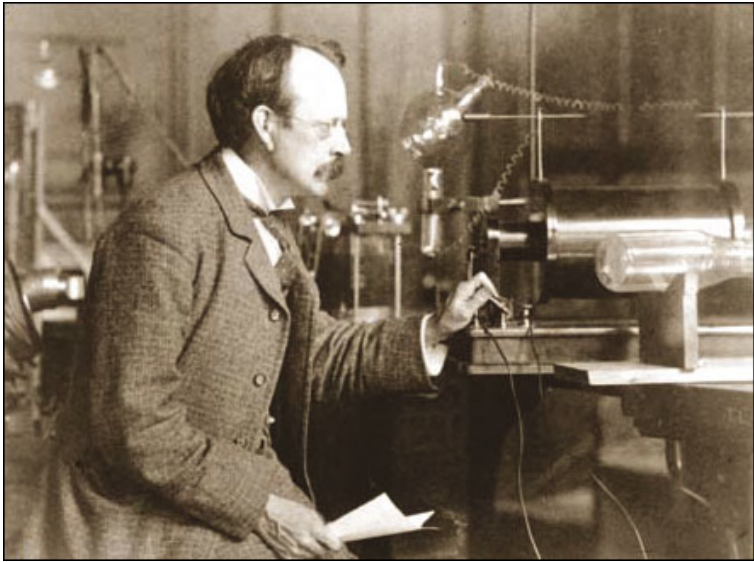


The accelerator



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Early accelerators...



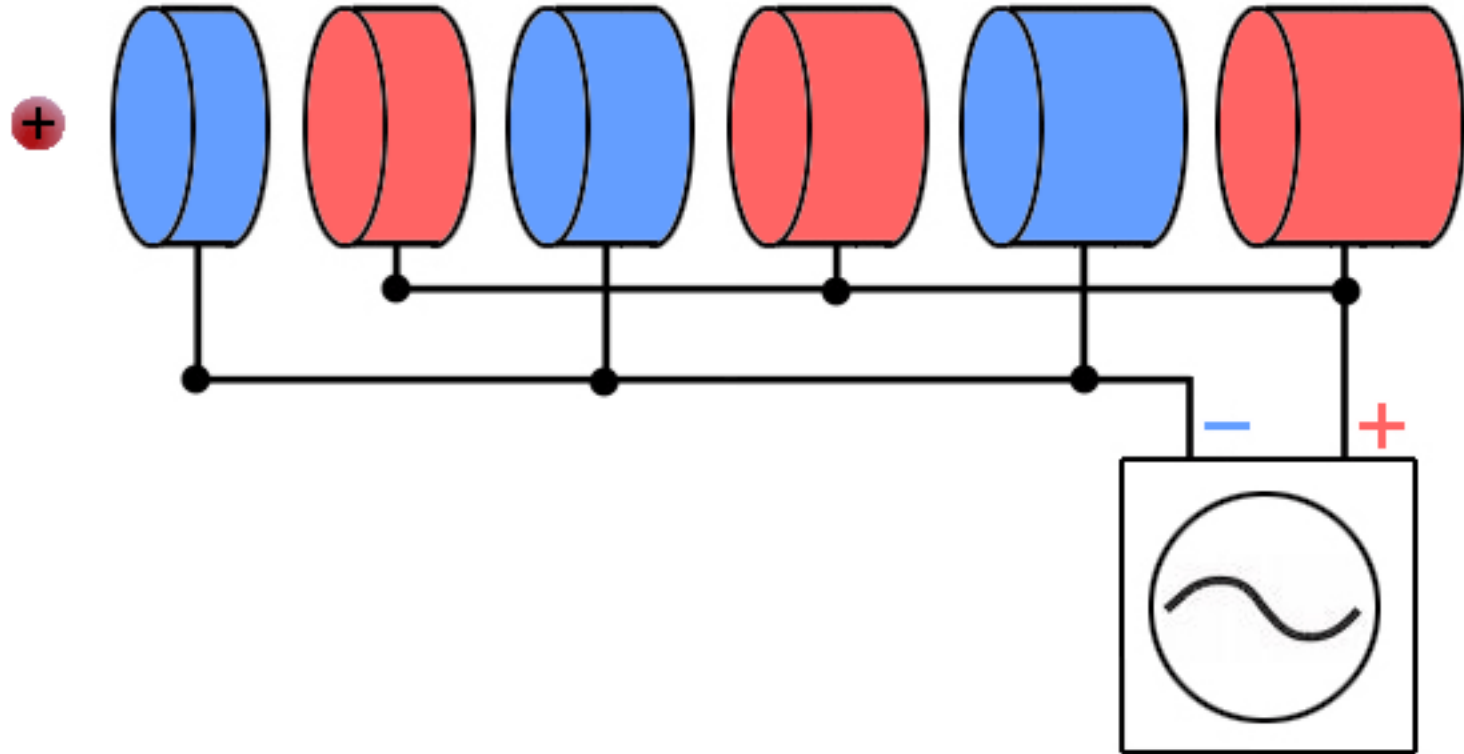
J. J. Thomson
Cathode ray tube
Discovered electrons in
1897



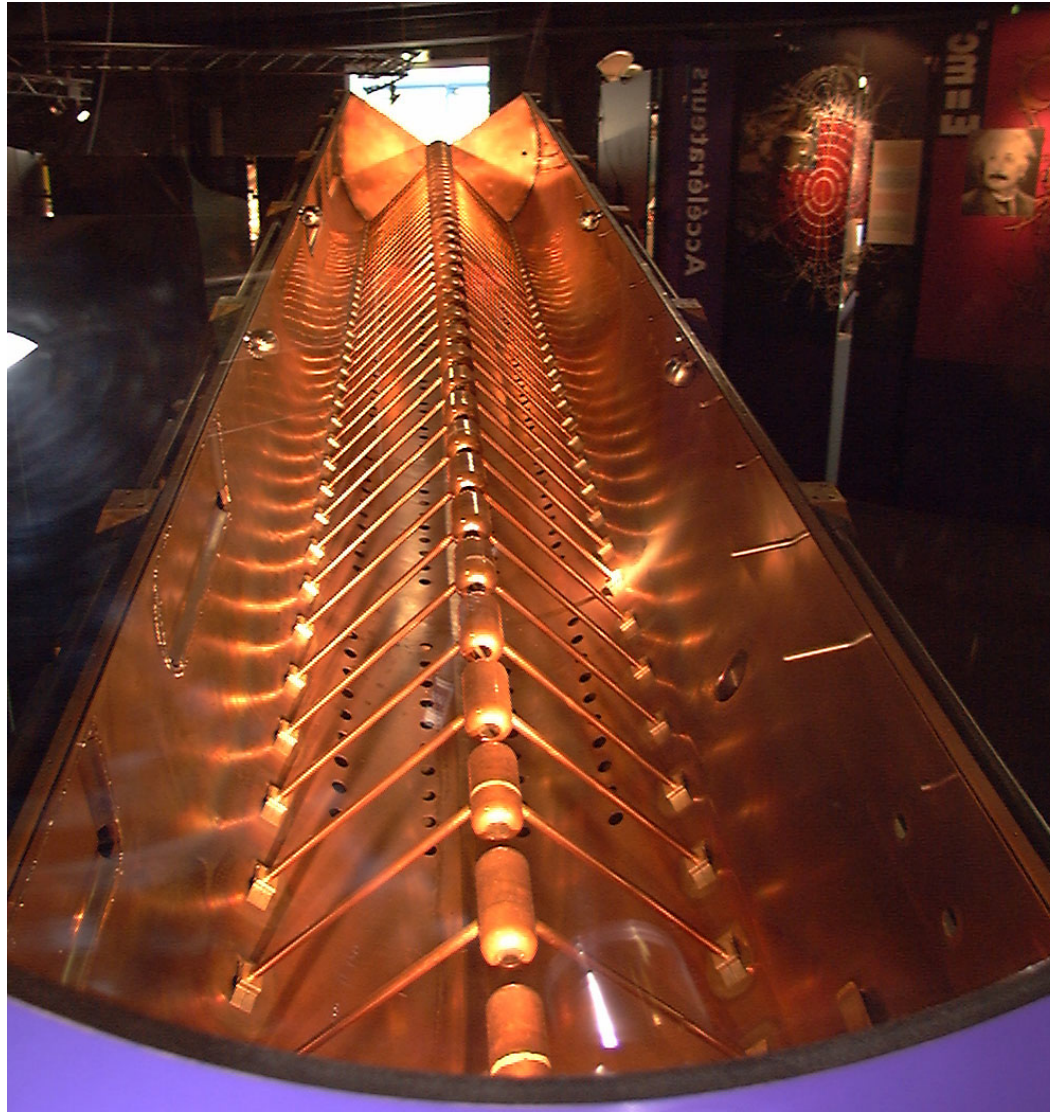
Van de Graaf generator
Invented in 1929



Linacs...



Linacs...



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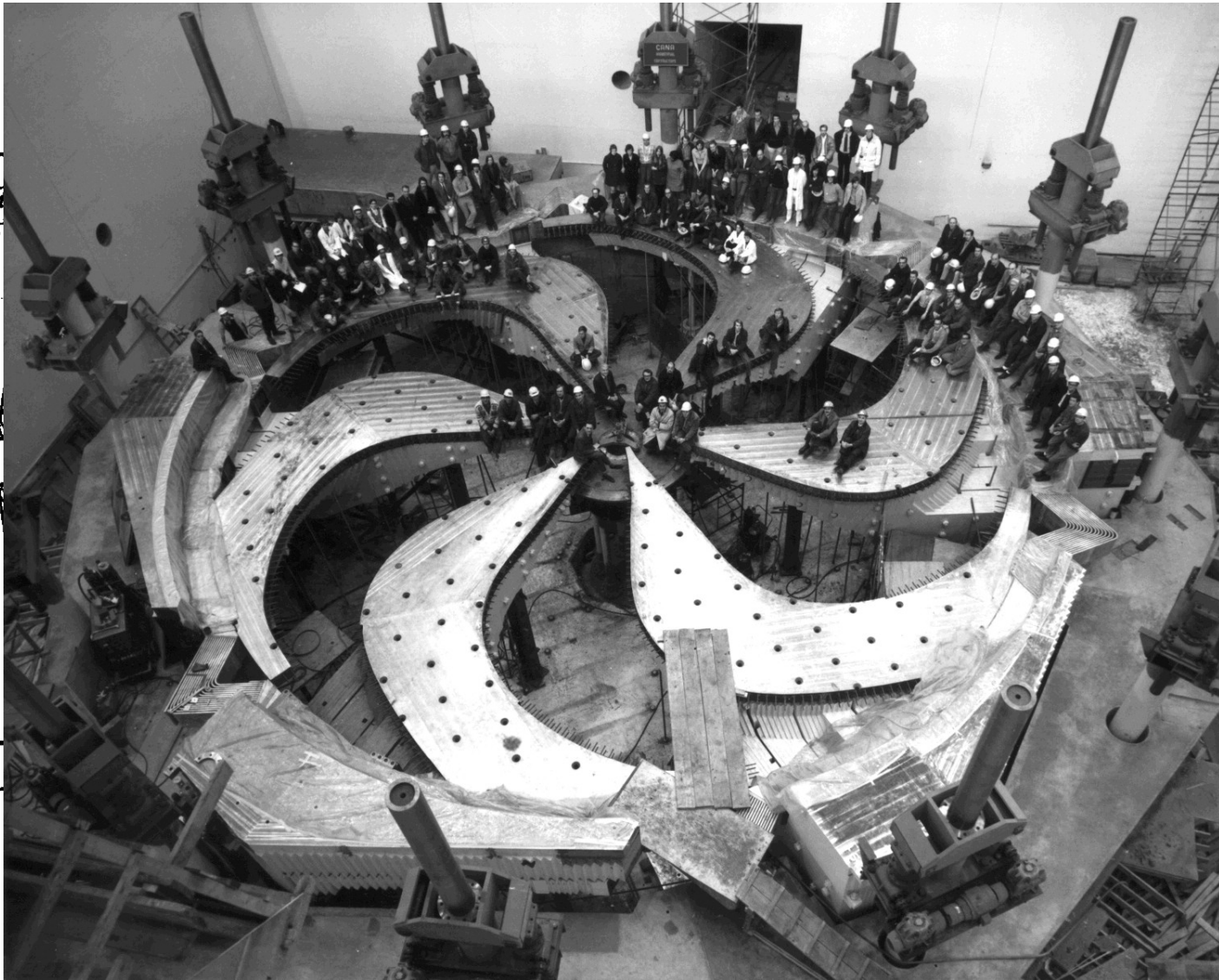
The motion of particles in a magnetic field



Want more clout? Make it round...

High Freq
Oscilla

High



Electric Lines
Force

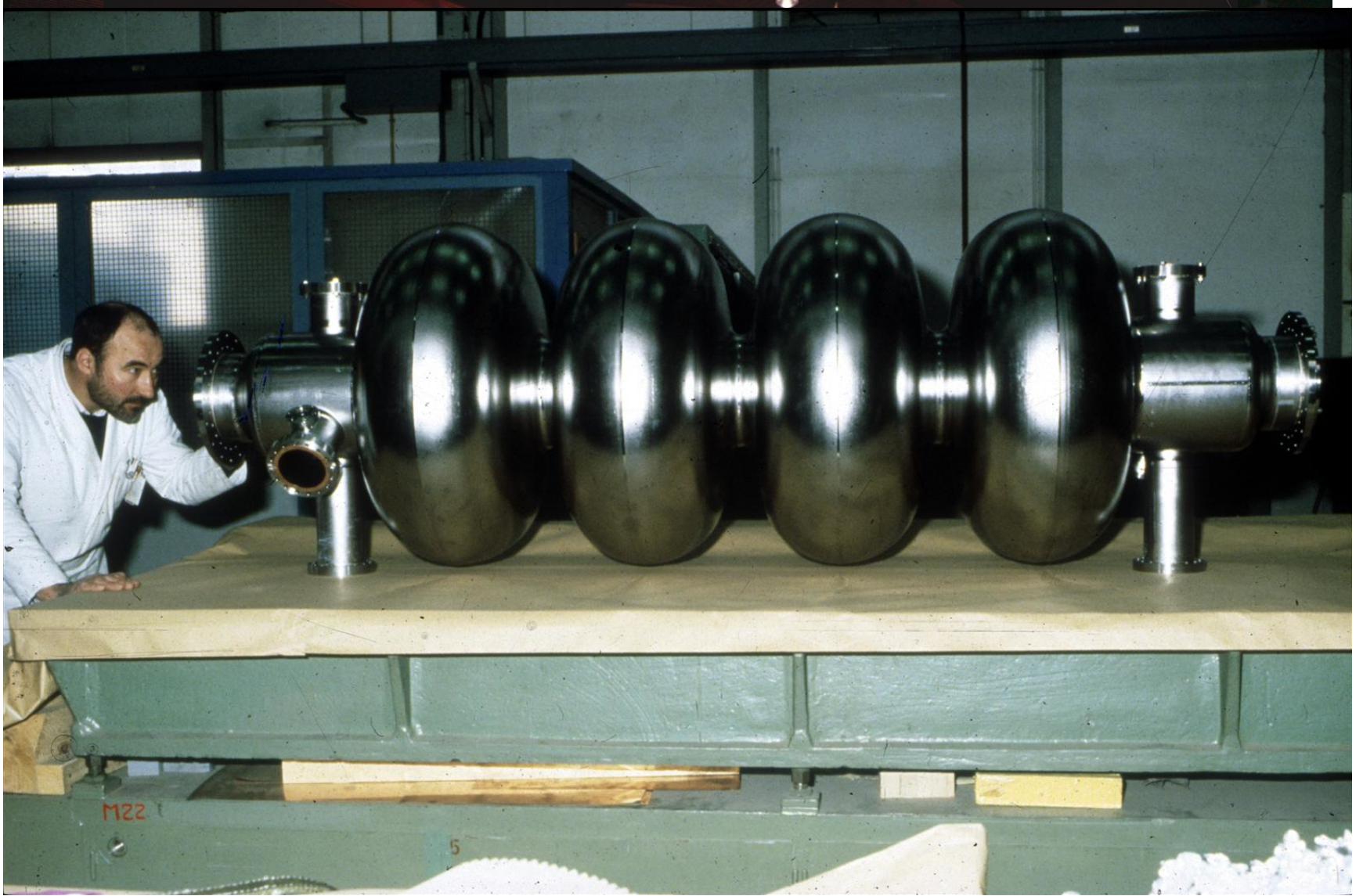
Electric
Lines of
Force

e



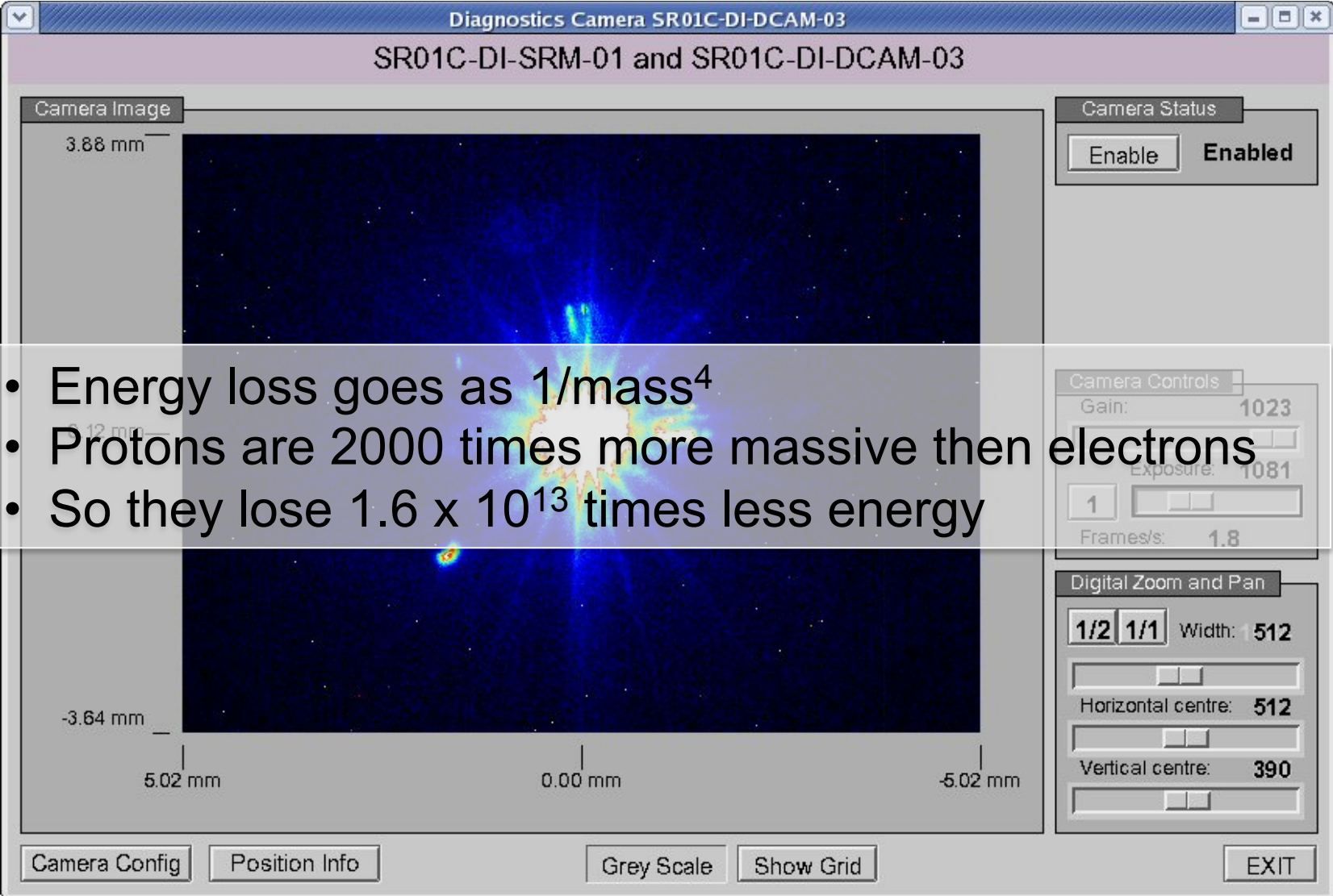
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synchrotrons



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Leptons or hadrons?




The screenshot shows a software window titled "Diagnostics Camera SR01C-DI-DCAM-03" with a subtitle "SR01C-DI-SRM-01 and SR01C-DI-DCAM-03". The main area displays a camera image of a particle detector. The image shows a central bright spot with a vertical track of light extending upwards and downwards. The image is overlaid with a semi-transparent text box containing three bullet points. The interface includes several control panels: "Camera Status" with an "Enable" button (status: "Enabled"), "Camera Controls" with "Gain: 1023", "Exposure: 1081", and "Frames/s: 1.8", and "Digital Zoom and Pan" with "Width: 512", "Horizontal centre: 512", and "Vertical centre: 390". At the bottom, there are buttons for "Camera Config", "Position Info", "Grey Scale", "Show Grid", and "EXIT".

- Energy loss goes as $1/\text{mass}^4$
- Protons are 2000 times more massive than electrons
- So they lose 1.6×10^{13} times less energy

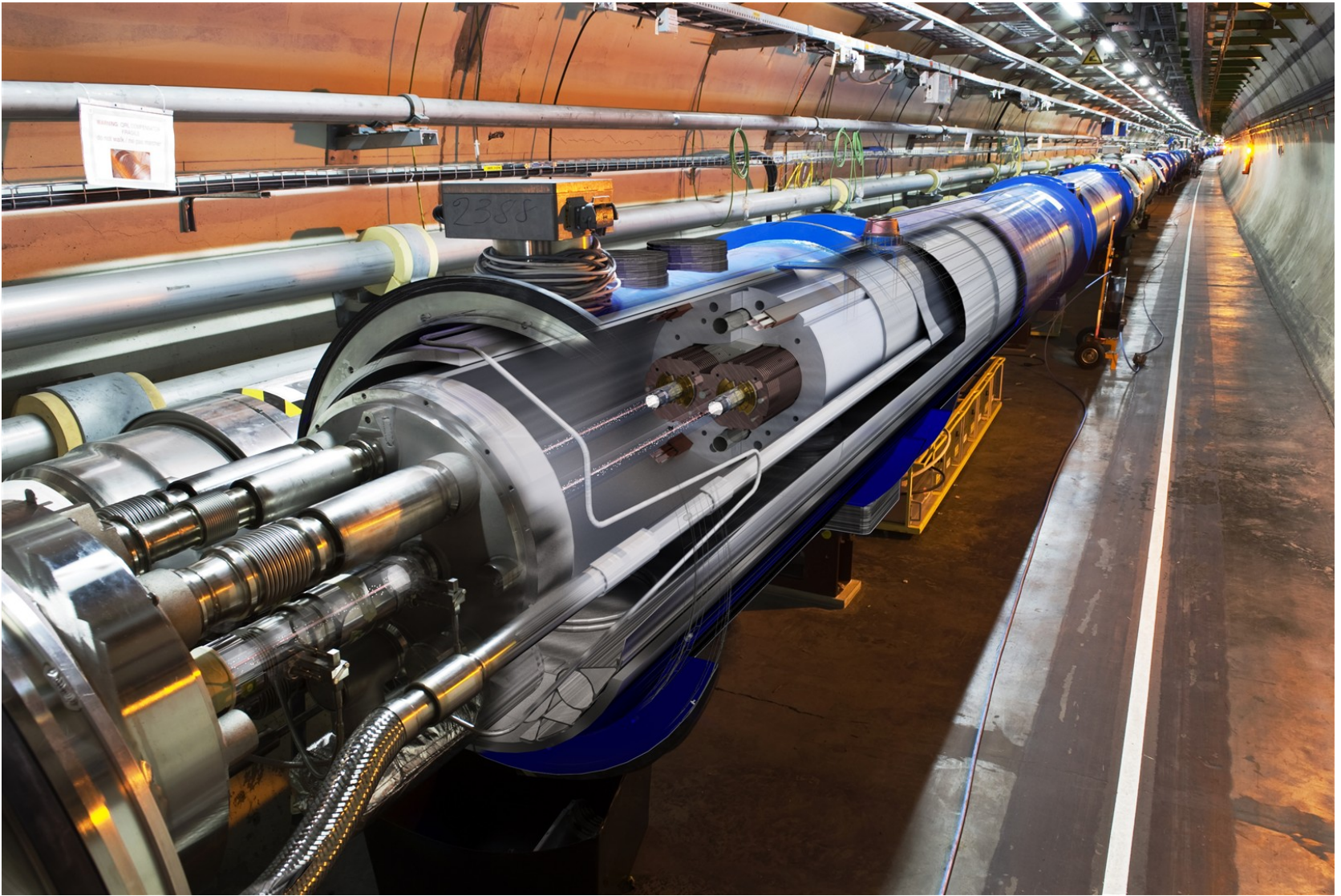


Leptons or hadrons?

- 
- Hadron machines are discovery machines
 - Lepton machines are precision machines



CERN's accelerator complex



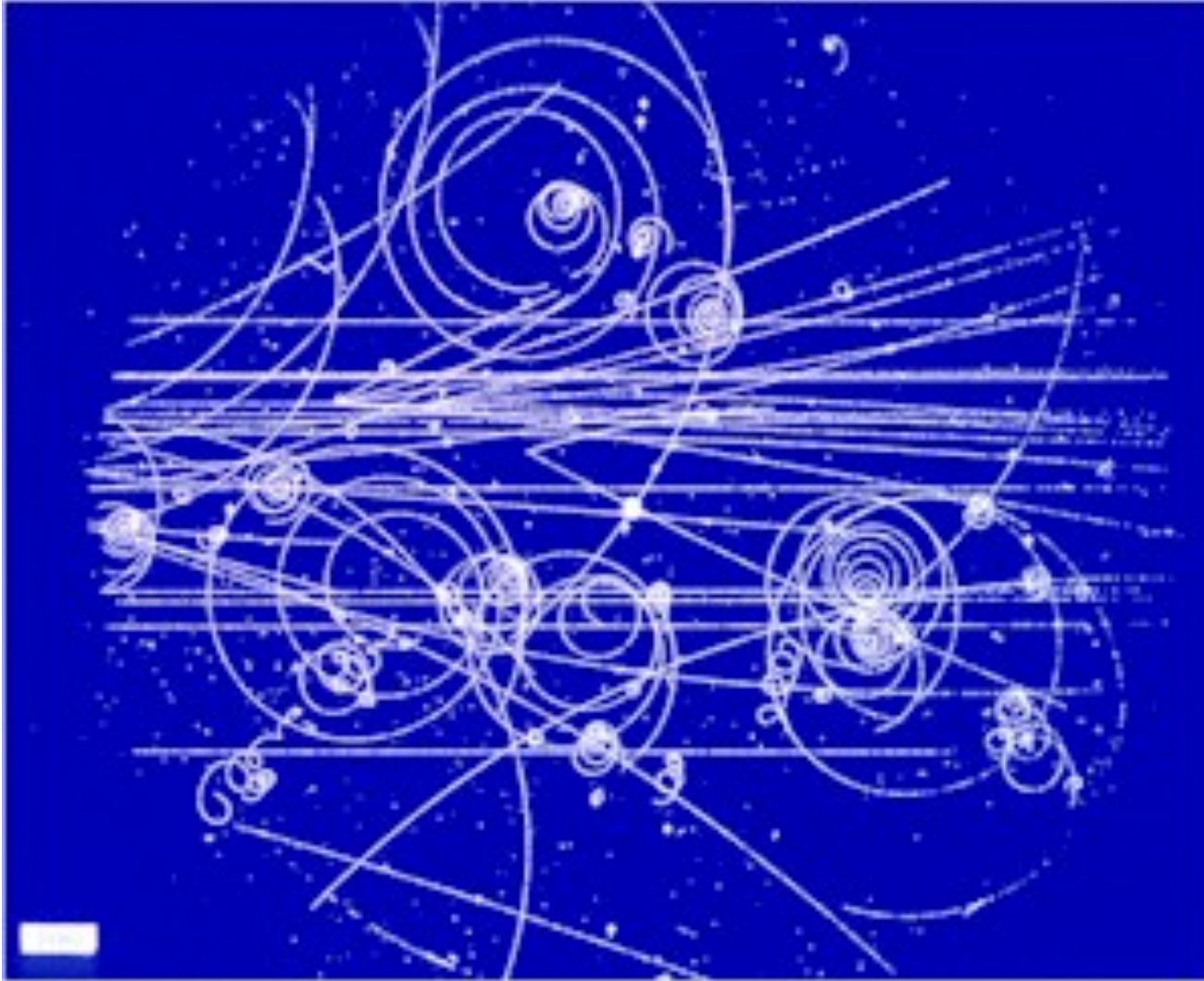
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The detectors



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The basics - ionisation



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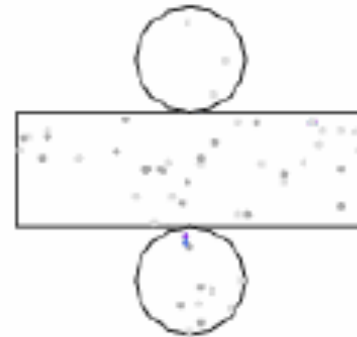
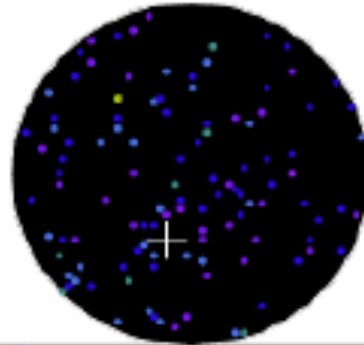
The basics - scintillation



The basics – Cerenkov light

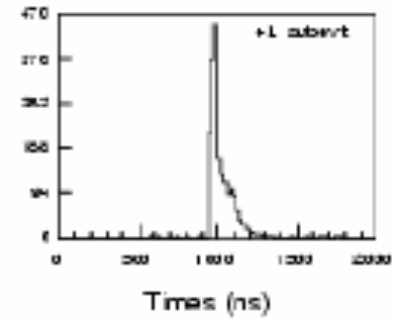
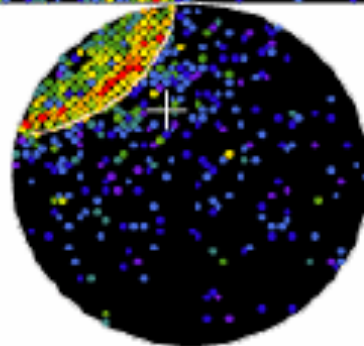
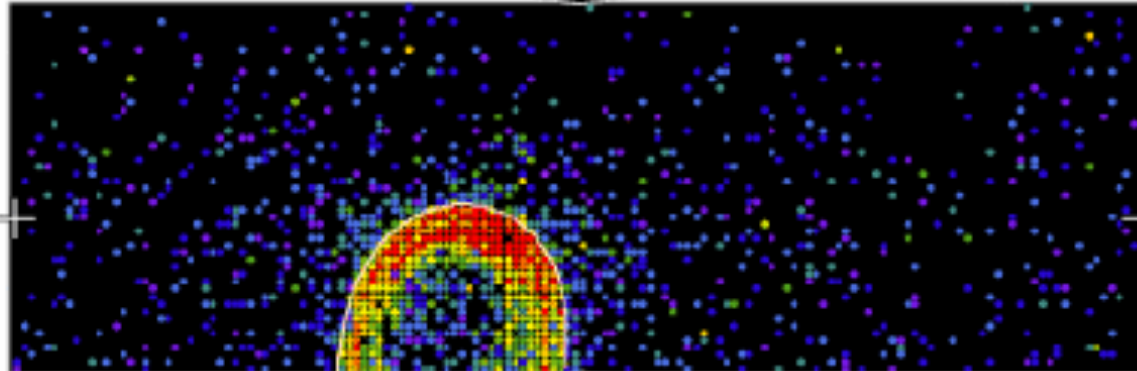
Super-Kamiokande

Run 10034 Sub 334 Ev 34818141
01-04-2008.02.10.07
Inner: 1076 hits, 10756 pE
Outer: 1 hits, 3 pE (non-time)
Trigger ID: Ds07
Quality: 991.1 use
IC no-like, $p = 1291.0 \text{ MeV}/c$

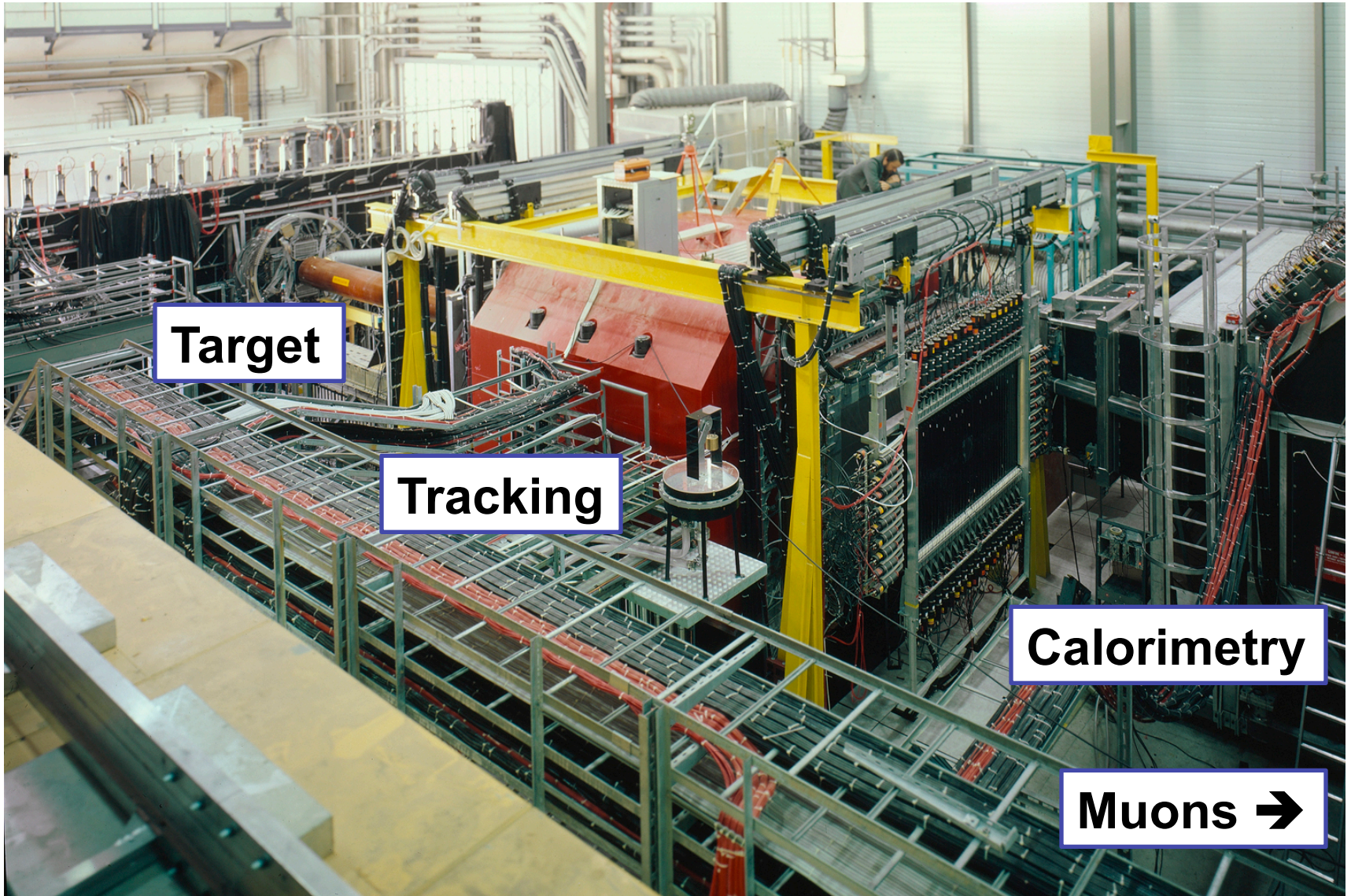


charge (pe)

- >26.7
- 23.3-26.7
- 20.2-23.3
- 17.3-20.2
- 14.7-17.3
- 12.2-14.7
- 10.0-12.2
- 8.0-10.0
- 6.2-8.0
- 4.7-6.2
- 3.3-4.7
- 2.2-3.3
- 1.3-2.2
- 0.7-1.3
- 0.2-0.7
- < 0.2

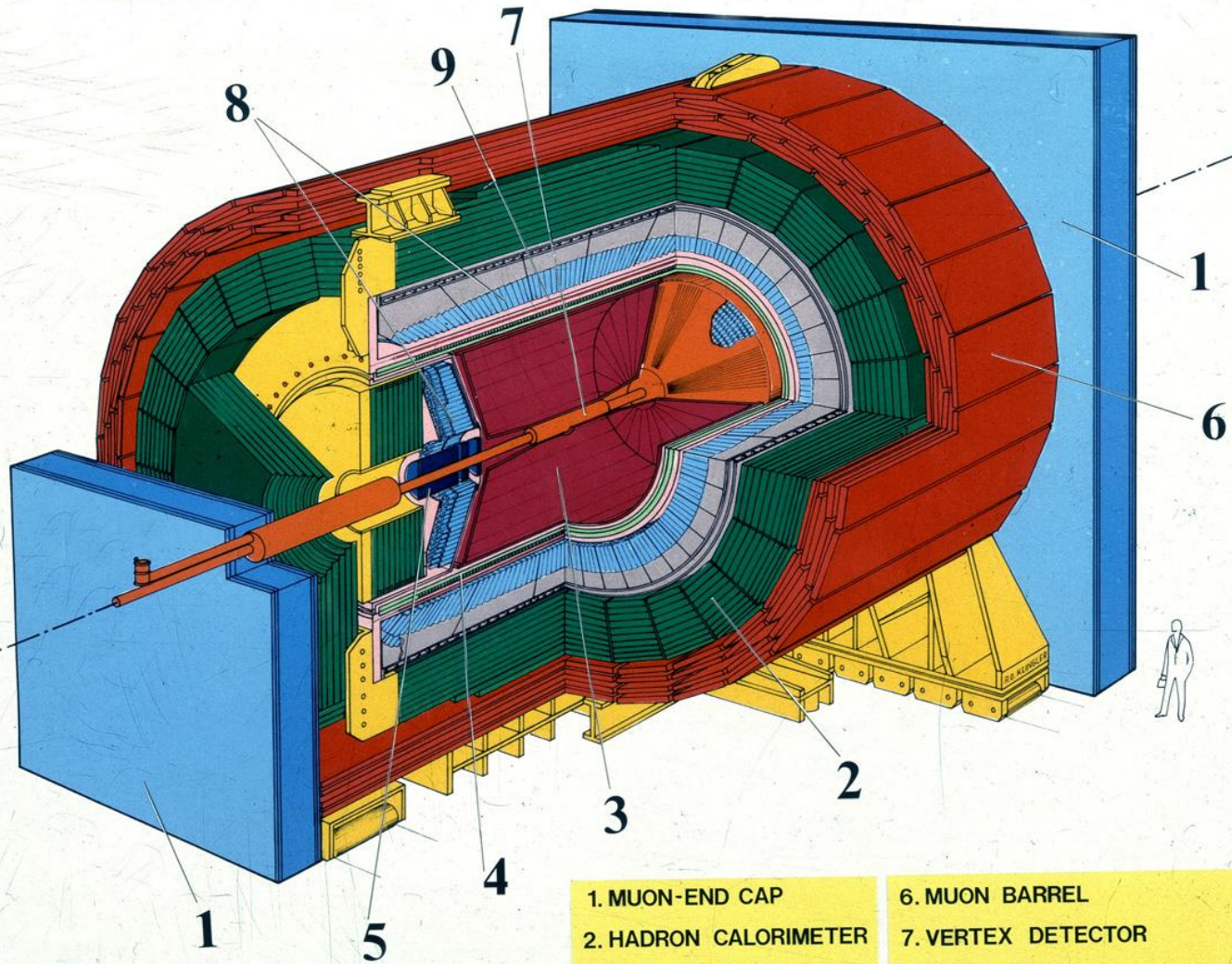


A layered approach



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OPAL



- 1. MUON-END CAP
- 2. HADRON CALORIMETER
- 3. JET CHAMBER
- 4. MAGNET COIL
- 5. FORWARD DETECTOR

- 6. MUON BARREL
- 7. VERTEX DETECTOR
- 8. LEAD GLASS
- 9. PRESAMPLER AND TIME-OF-FLIGHT DETECTOR



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The CMS detector at the Large Hadron Collider



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The computing



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1950s: CERN's human computer



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1958: Ferranti Mercury



17 hours...



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1960s-1990s: Norsk data, PDP, Vax, IBM mainframe, CRAY...



1 second...



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Early networking at CERN

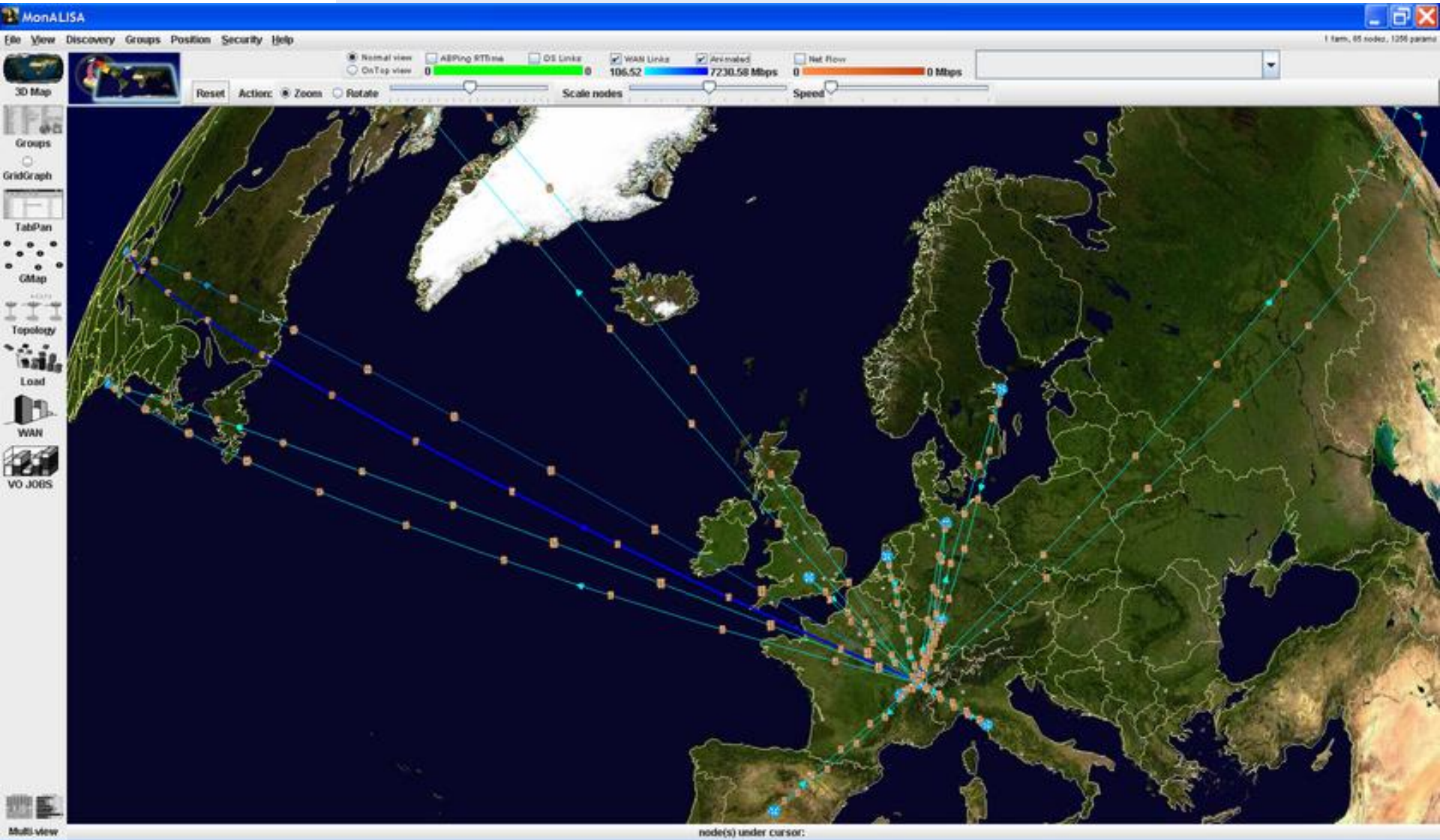


Top priority status at
computer centre:
Bicycle online



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The Grid: today's networking at CERN



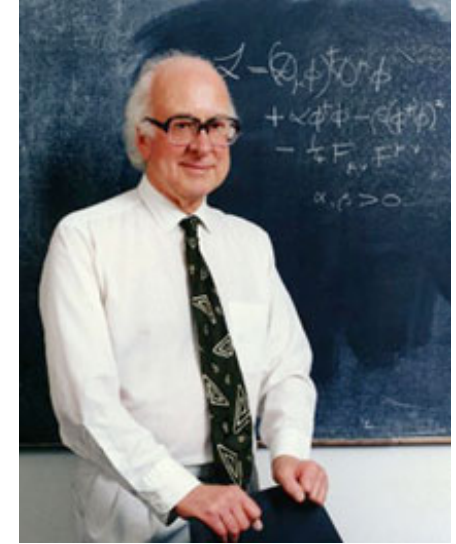
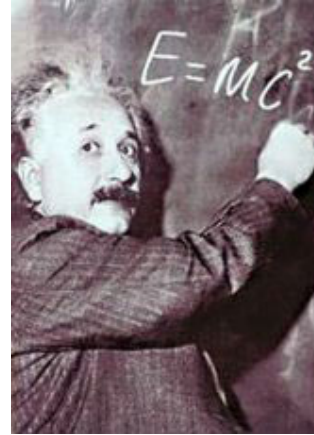
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Why?



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To push back the frontiers of knowledge...



Newton's unfinished business... what is mass?

Science's little embarrassment... what is 96% of the Universe made of?

Nature's favouritism... why is there no more antimatter?

The secrets of the Big Bang... what was matter like within the first second of the Universe's life?

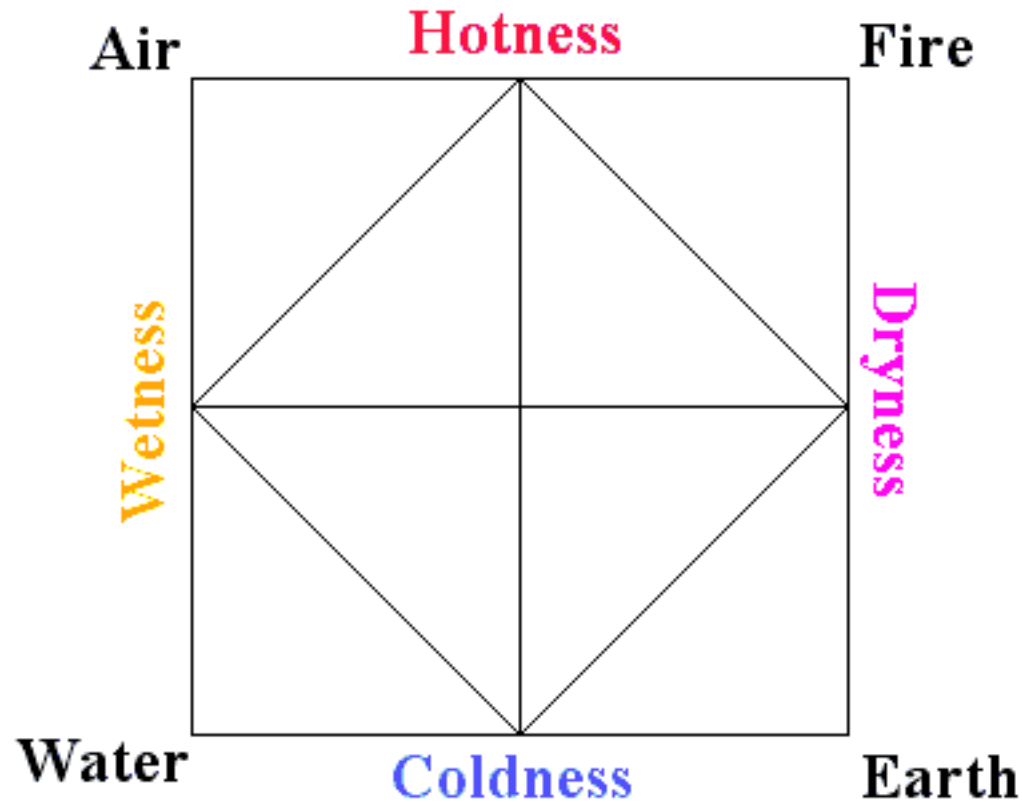


Particles



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Particle physicists like to keep things simple

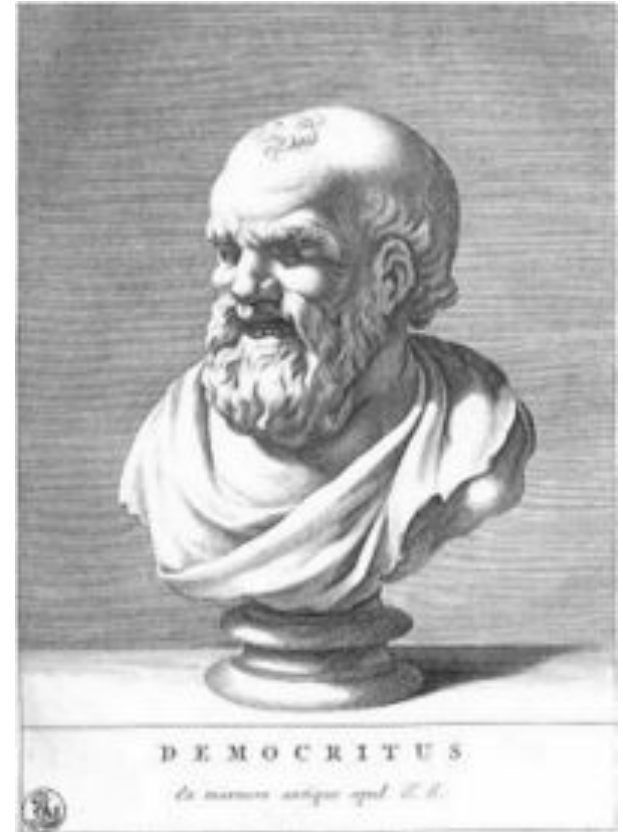


One problem: it's wrong...



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Particle physicists also like things to be right



5th century BC: Leucippus, Democritus “all matter is composed of small indivisible particles: atoms”



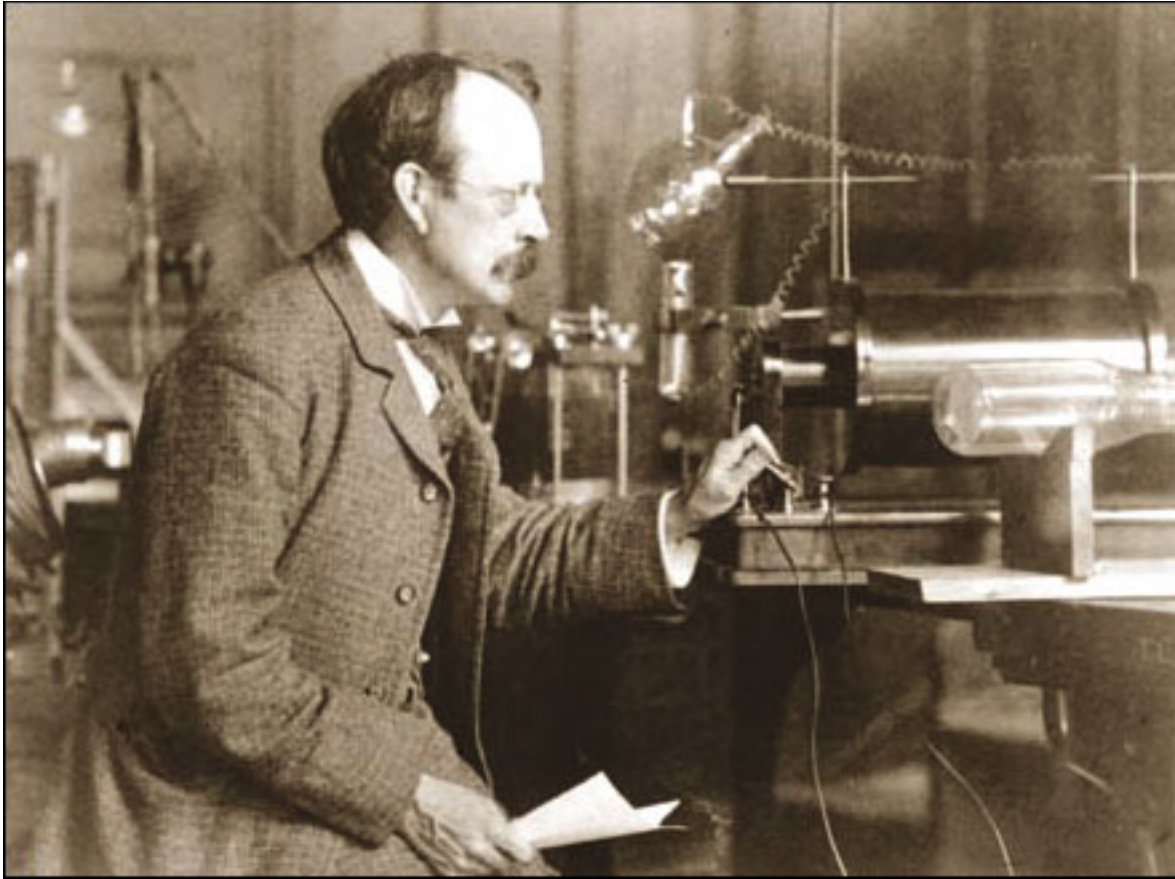
Fast forward to 19th century Russia

| Reihen | Gruppe I. — R'O | Gruppe II. — RO | Gruppe III. — R'O ³ | Gruppe IV. RH ⁴ RO ⁴ | Gruppe V. RH ⁵ R'O ⁵ | Gruppe VI. RH ⁶ RO ⁶ | Gruppe VII. RH R'O ⁷ | Gruppe VIII. — RO ⁸ |
|--------|-----------------------|-----------------------|--------------------------------------|--|--|--|---------------------------------------|--------------------------------------|
| 1 | H=1 | | | | | | | |
| 2 | Li=7 | Be=9,4 | B=11 | C=12 | N=14 | O=16 | F=19 | |
| 3 | Na=23 | Mg=24 | Al=27,3 | Si=28 | P=31 | S=32 | Cl=35,5 | |
| 4 | K=39 | Ca=40 | —=44 | Ti=48 | V=51 | Cr=52 | Mn=55 | Fe=56, Co=59, Ni=59, Cu=63. |
| 5 | (Cu=63) | Zn=65 | —=68 | —=72 | As=75 | Se=78 | Br=80 | |
| 6 | Rb=85 | Sr=87 | ?Yt=88 | Zr=90 | Nb=94 | Mo=96 | —=100 | Ru=104, Rh=104, Pd=106, Ag=108. |
| 7 | (Ag=108) | Cd=112 | In=113 | Sa=118 | Sb=122 | Te=125 | J=127 | |
| 8 | Cs=133 | Ba=137 | ?Di=138 | ?Ce=140 | — | — | — | — — — — |
| 9 | (—) | — | — | — | — | — | — | |
| 10 | — | — | ?Er=178 | ?La=180 | Ta=182 | W=184 | — | Os=195, Ir=197, Pt=198, Au=199. |
| 11 | (Au=199) | Hg=200 | Tl=204 | Pb=207 | Bi=208 | — | — | |
| 12 | — | — | — | Th=231 | — | U=240 | — | — — — — |

A plethora of elements. Mendeleev's periodic table of the elements indicated a simpler underlying structure...



The atoms turn out not to be fundamental...



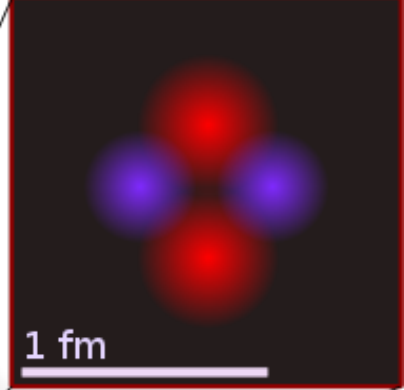
1897: Particle physics begins with the discovery of the electron



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The return of simplicity...
all the diversity of the elements can be
explained by just three fundamental (?)
particles: electrons, neutrons, protons.

Electron: 1897
Proton: 1919
Neutron: 1932

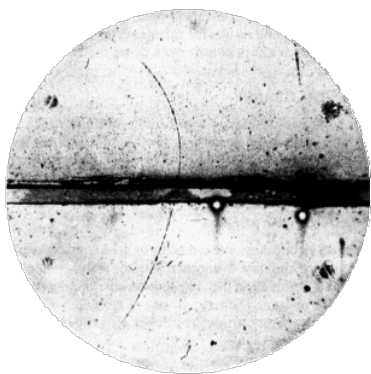


100 000 fm (= 1 Å)



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Complexity' s return...



Positron: 1932



Who ordered that?

Muon: 1937

1947: Pion

1947: Kaon

The PARTICLE ZOO

1956: Electron neutrino

1962: Muon neutrino...



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Quarks and partons

Gell-Mann

“Three quarks for
muster Mark”



Scanned at the American
Institute of Physics

Emilio Segrè Visual Archives

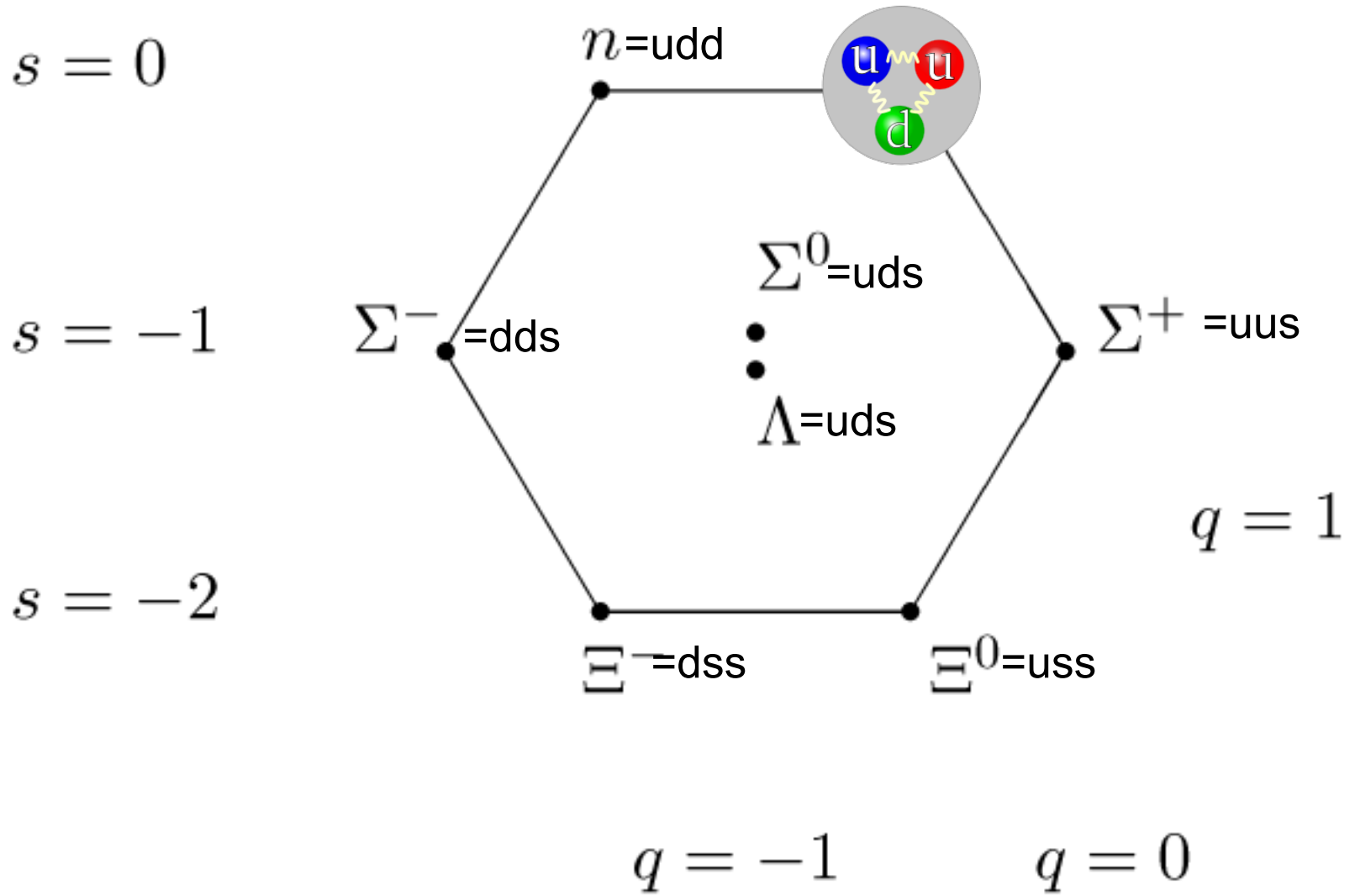
Feynman

Rather more
prosaic...



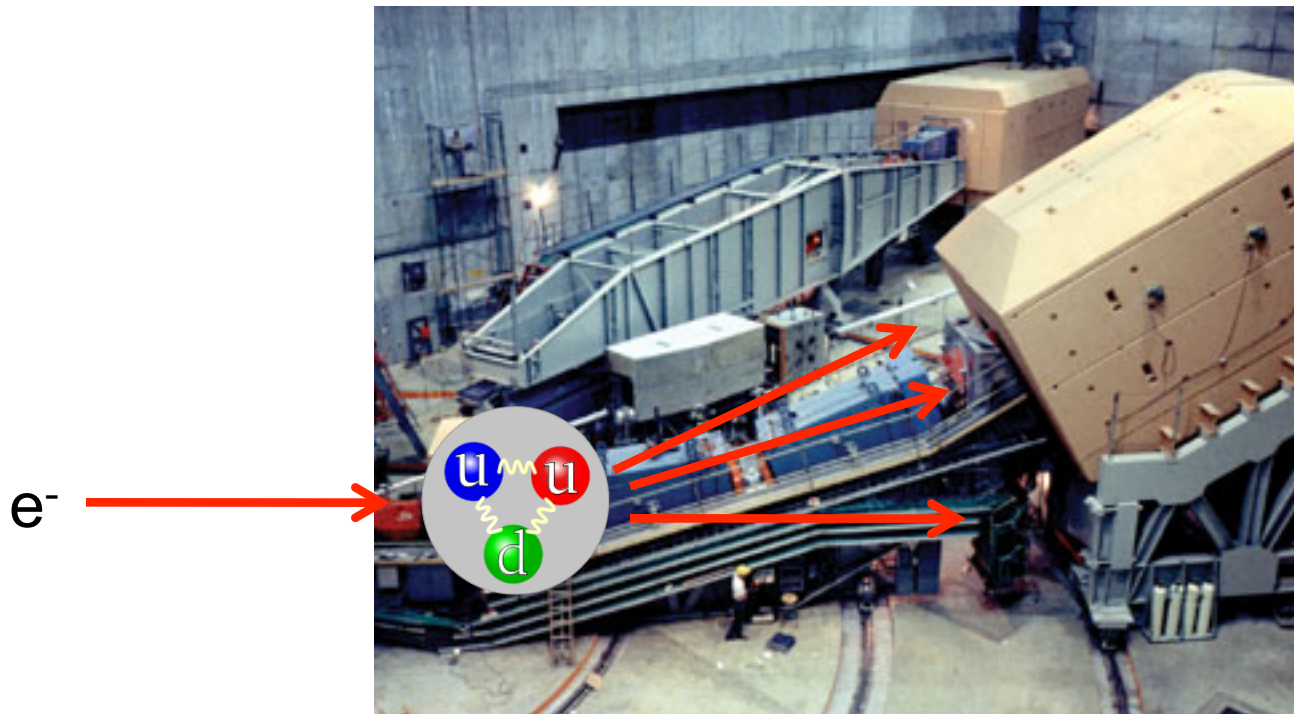
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The eightfold way...



But are quarks real, or just book-keeping?

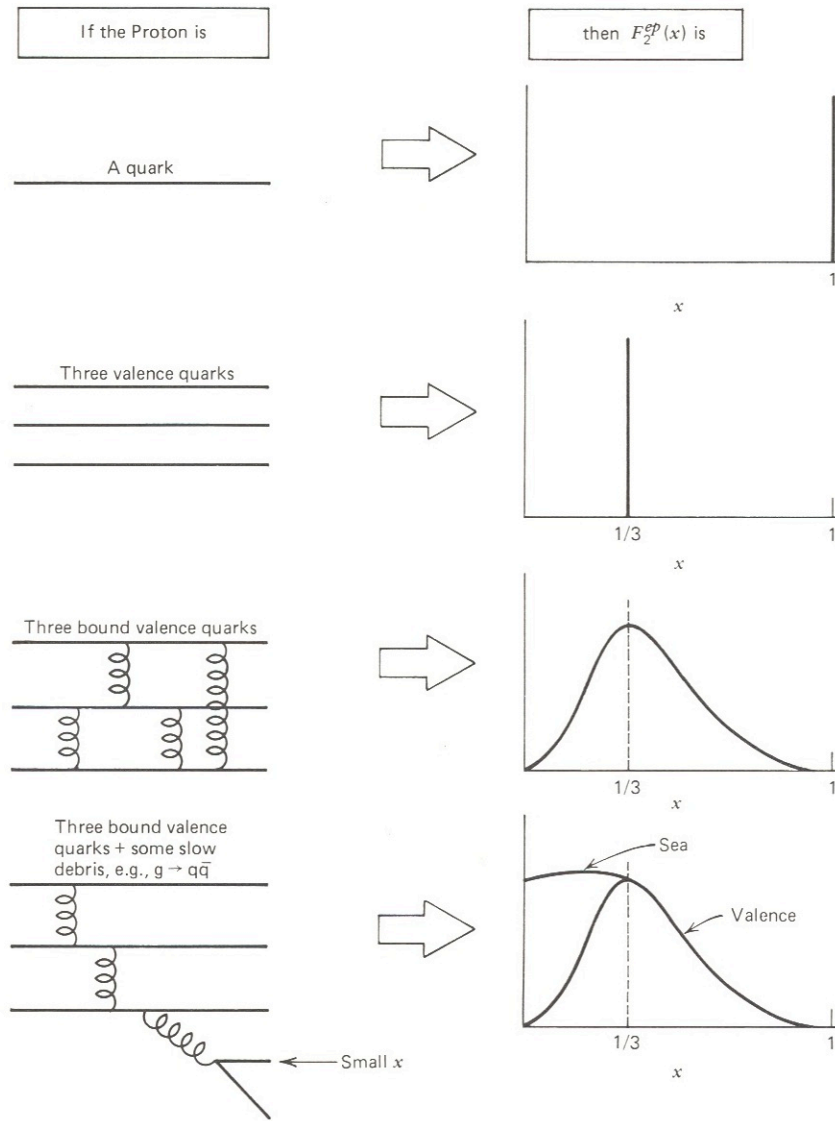
SLAC End station A, 1968...



Nobel Prize 1990:
Jerome Fiedman
Henry Kendall
Richard Taylor

What can we learn from this kind of experiment?

Theory:

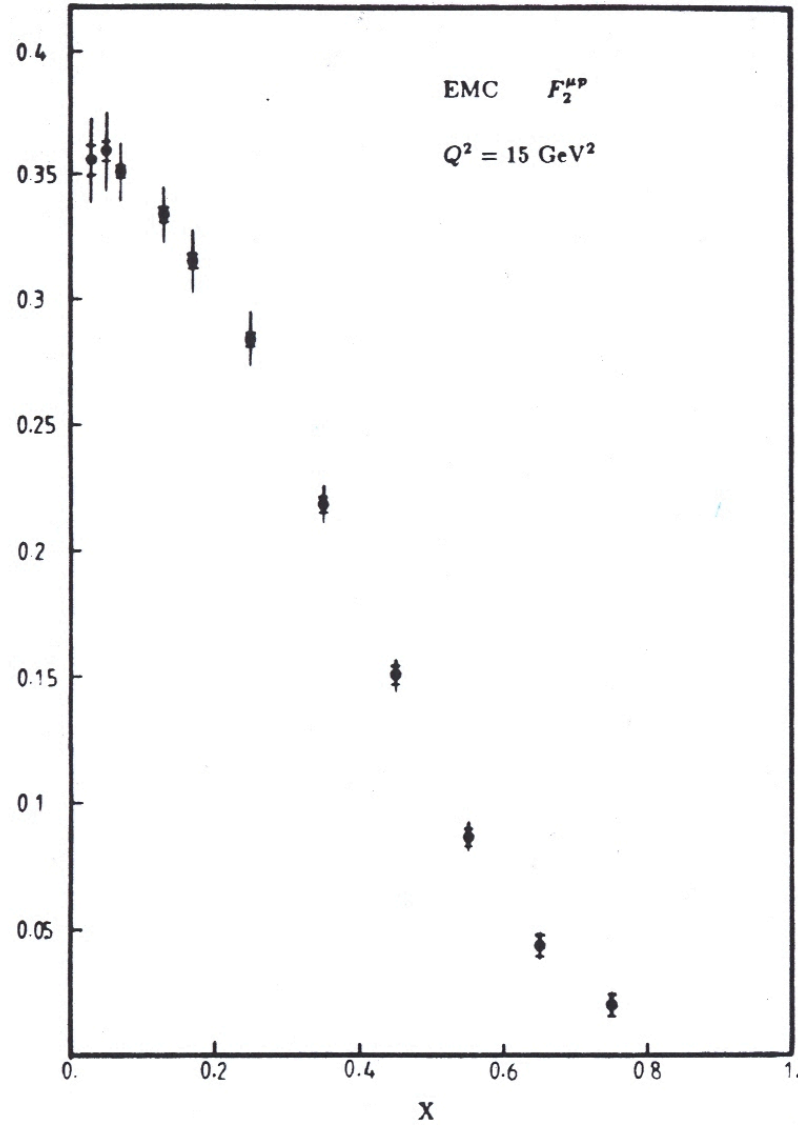


Halzen & Martin
Quarks and Leptons
Wiley 1984

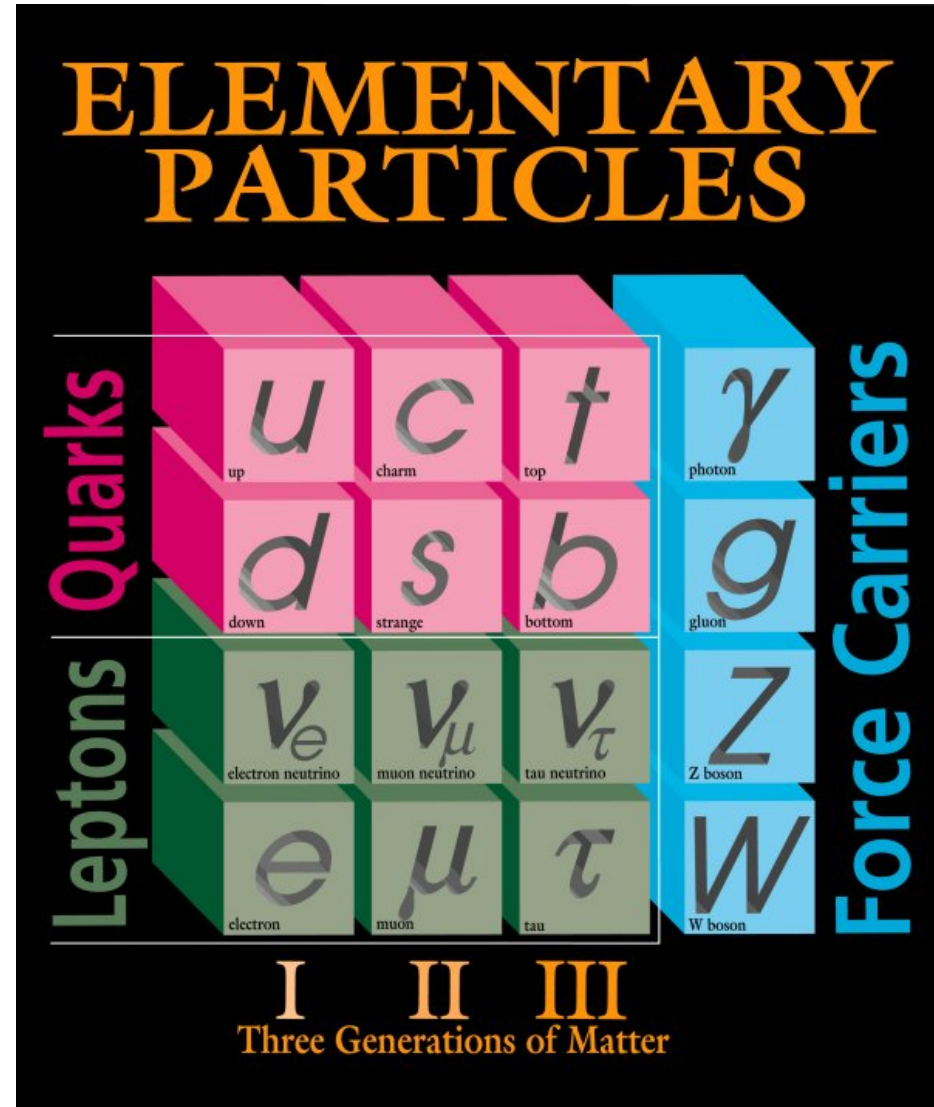
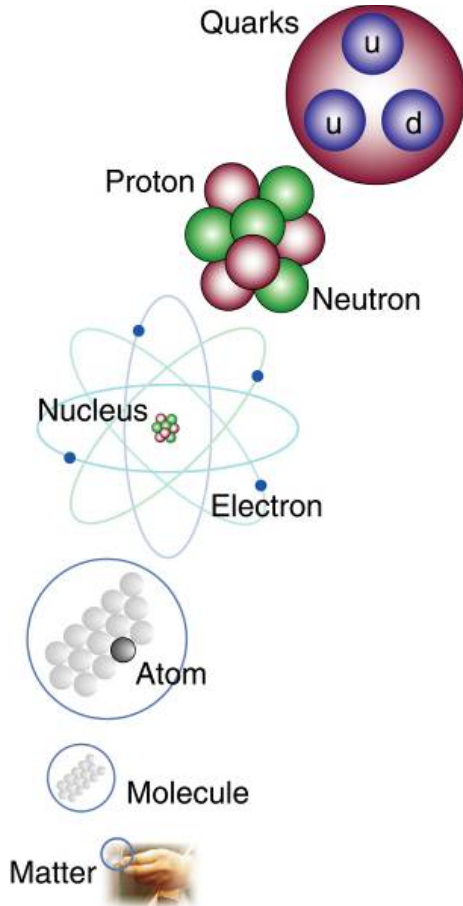


What can we learn from this kind of experiment?

Experiment:



The Standard Model



Forces



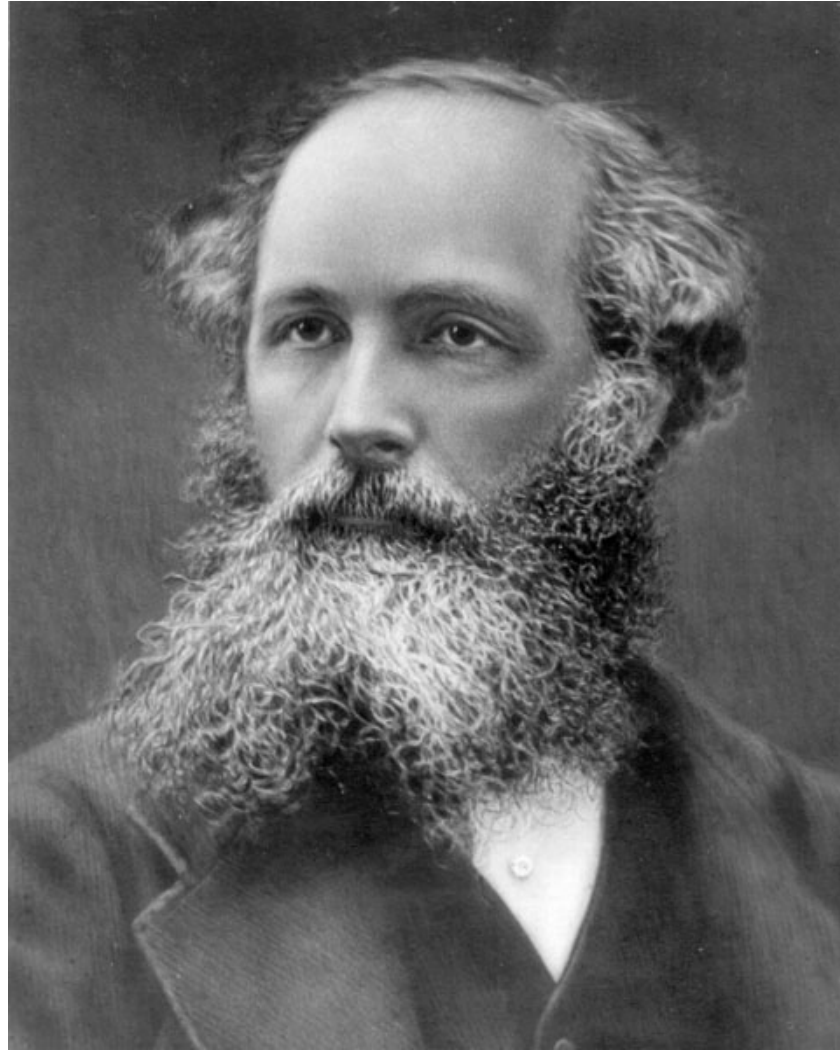
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Gravity: 1687



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Electromagnetism: 1861



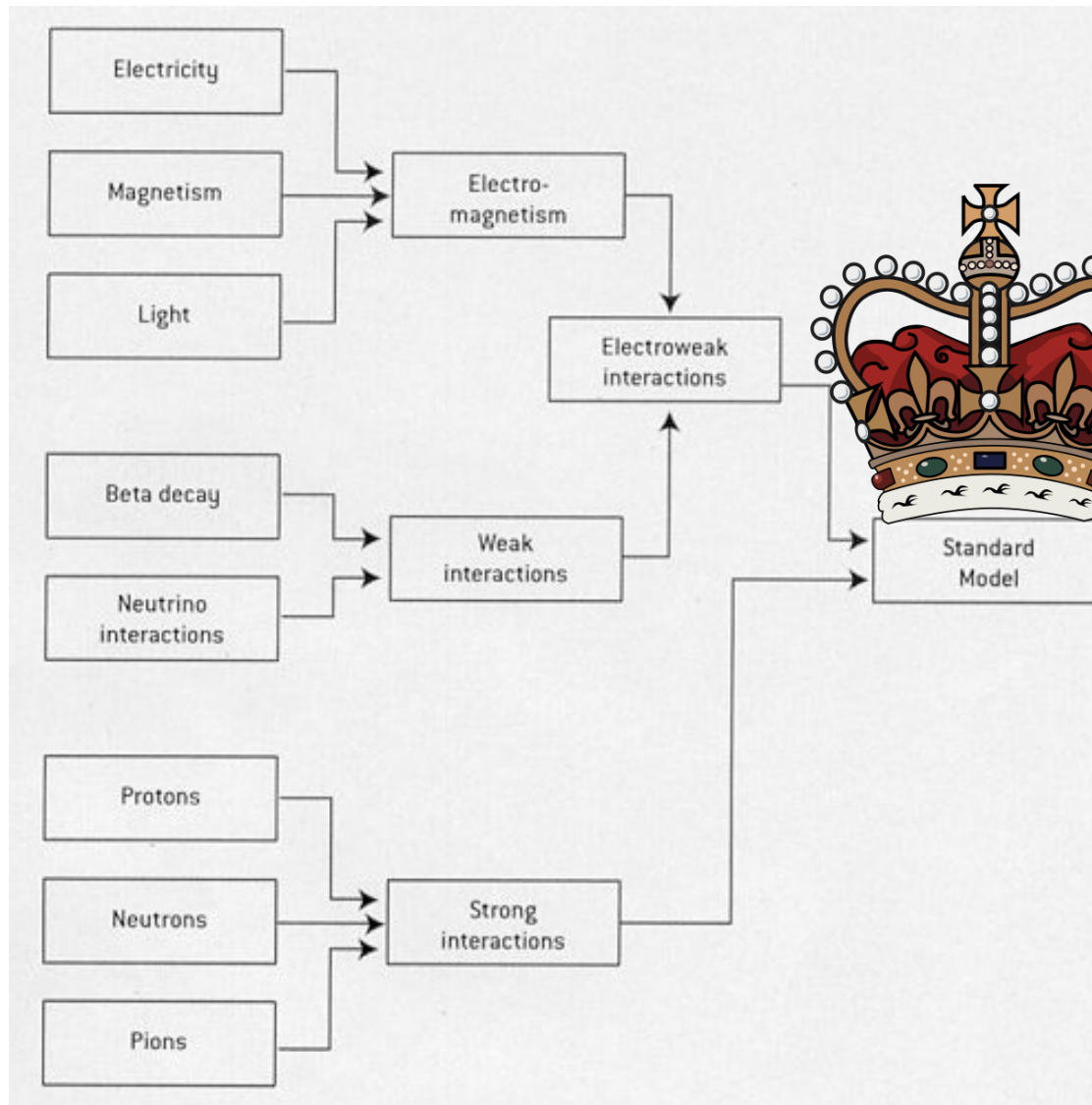
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Electroweak: 1960s

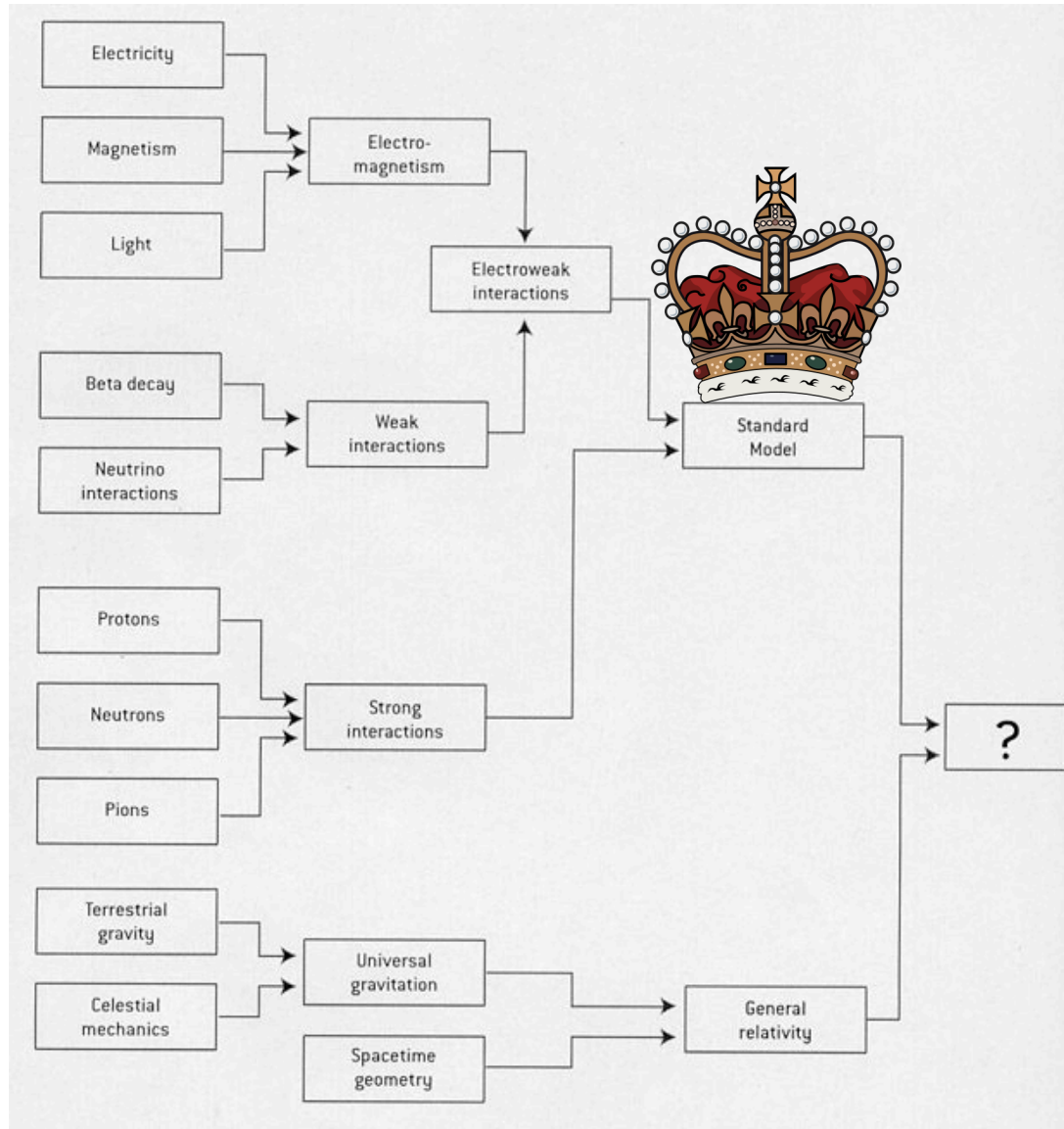


Sheldon Glashow, Abdus Salam, and Steven Weinberg sharing the Nobel Prize, 1979

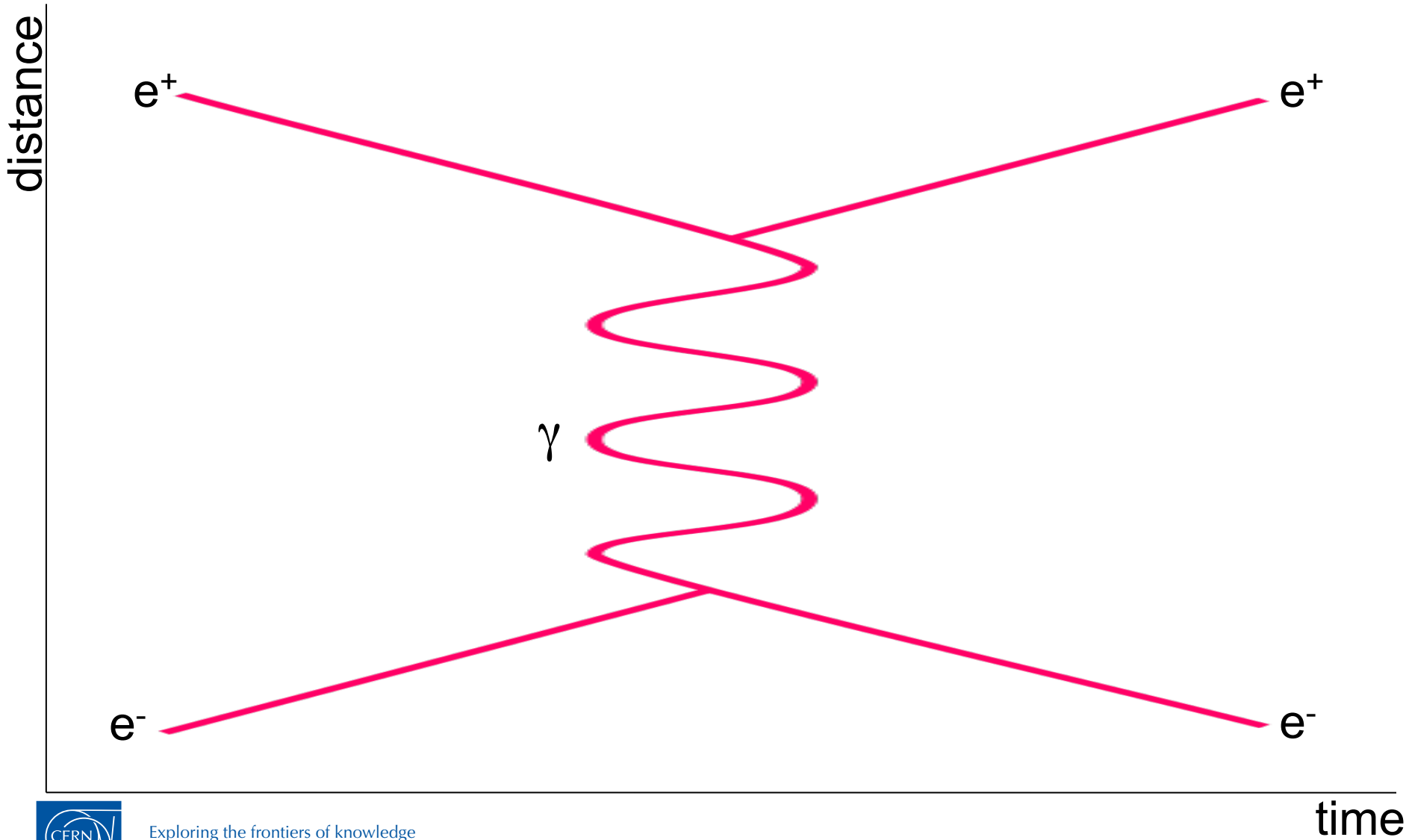
Standard Model



So where's gravity?

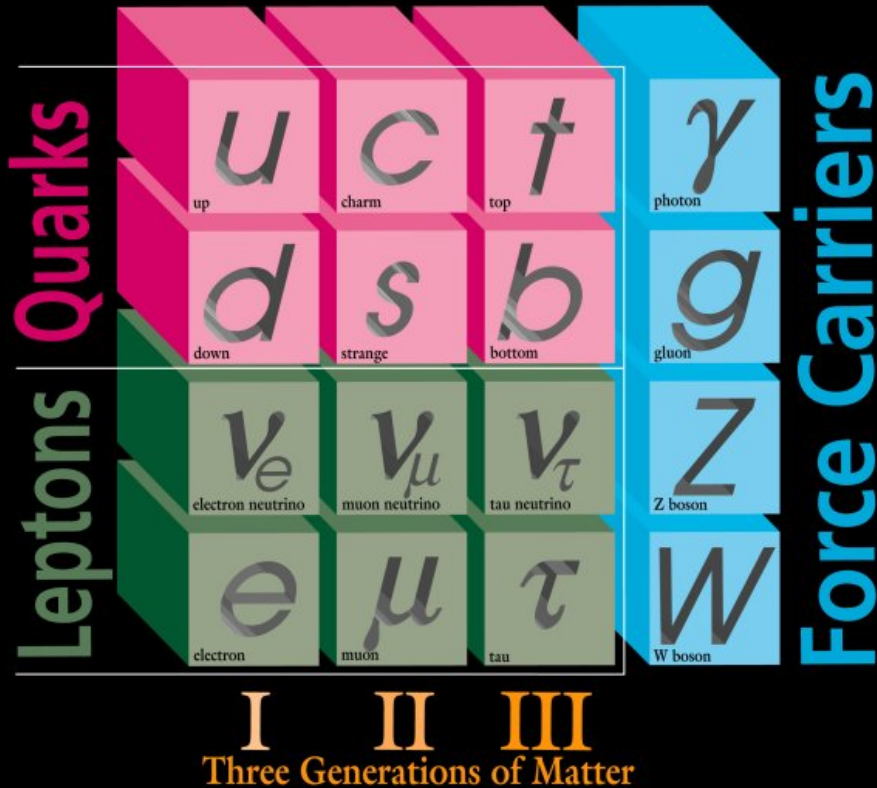


What's happening?



The forces

ELEMENTARY PARTICLES



Electromagnetic

Strong

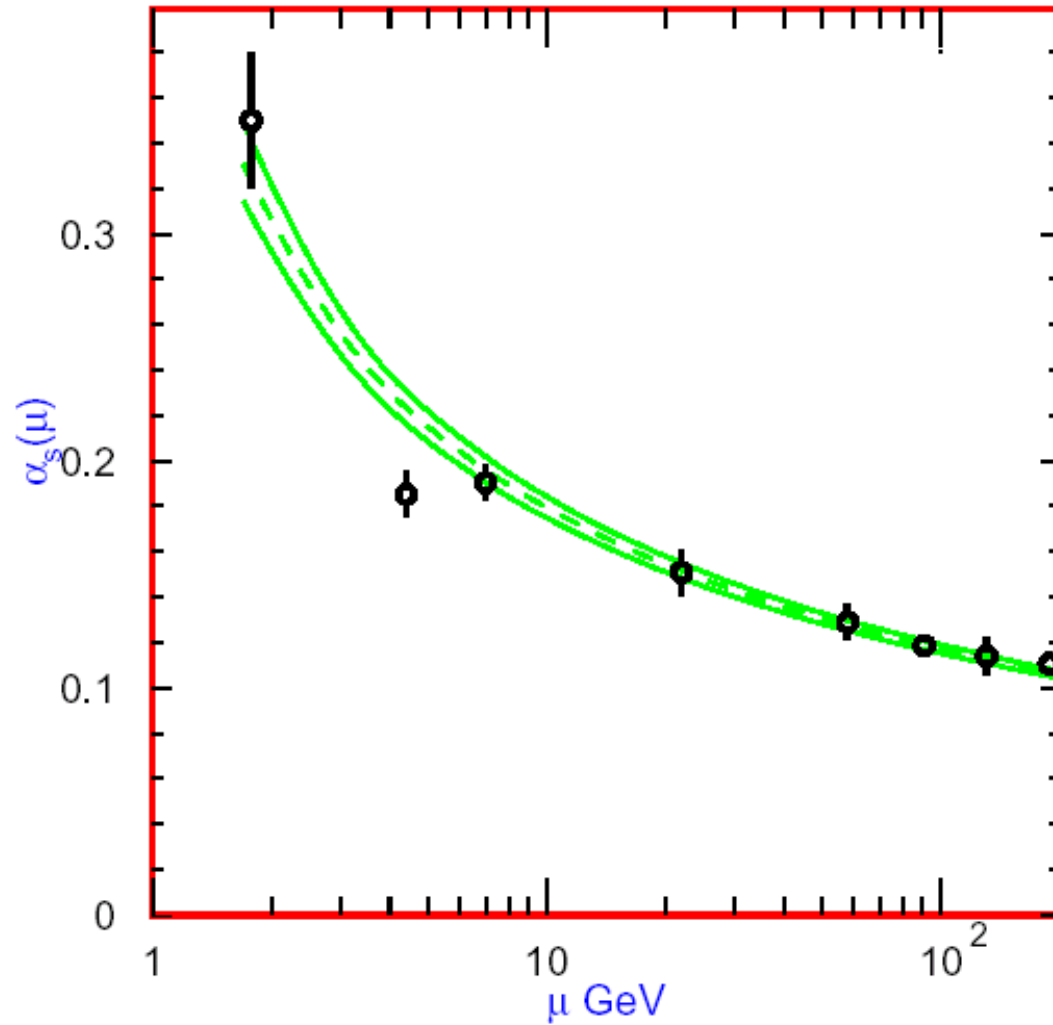
Weak

Fermilab 95-759

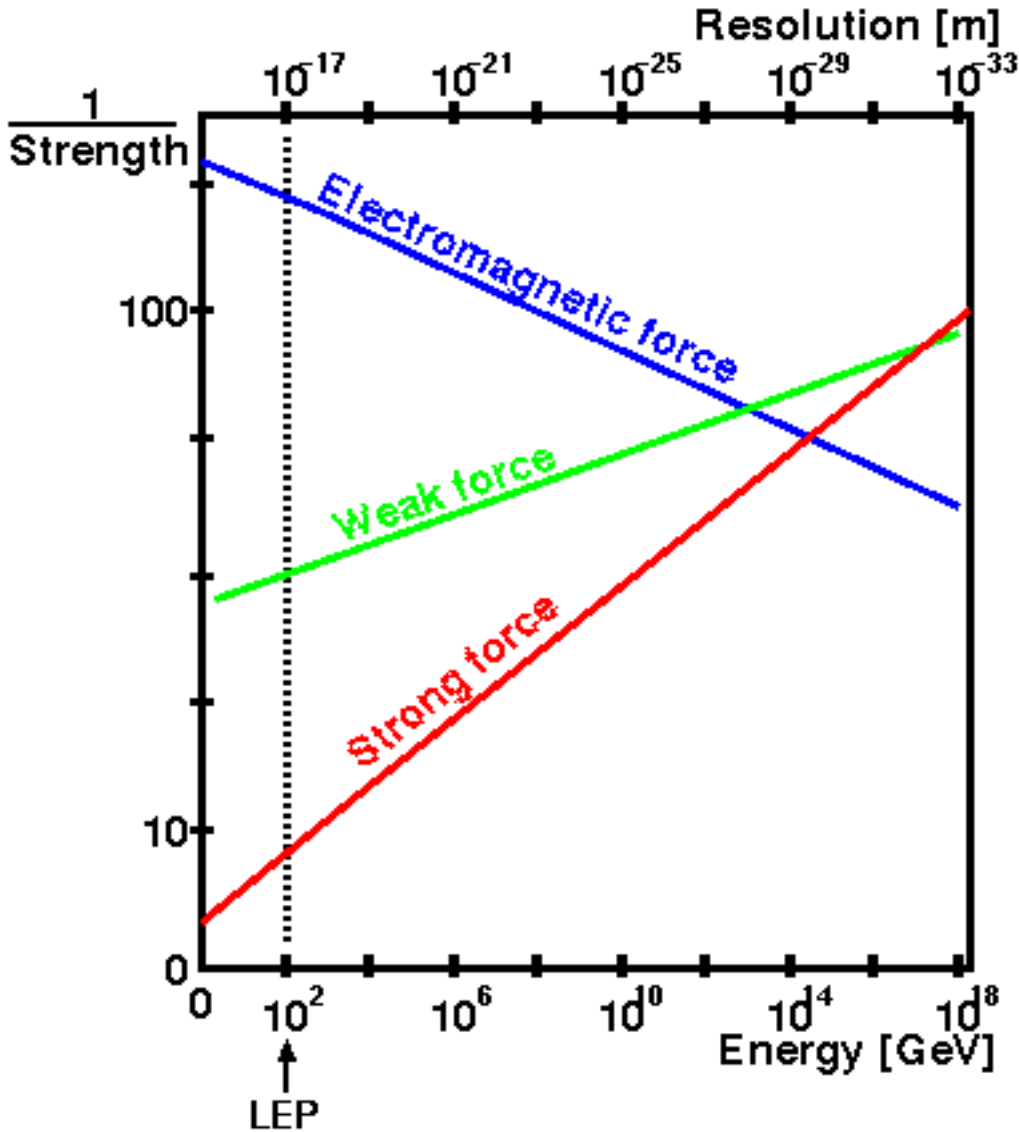


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Running coupling constants



Running coupling constants



Summary....

Particle physics requires three tools....

Accelerators

Detectors

Computing

We do it to continue a tradition of
exploration that's as old as humanity itself....



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What's missing from the Standard Model?



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Tune in for my third talk!



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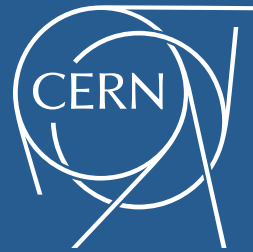
Next time: The Story of CERN



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