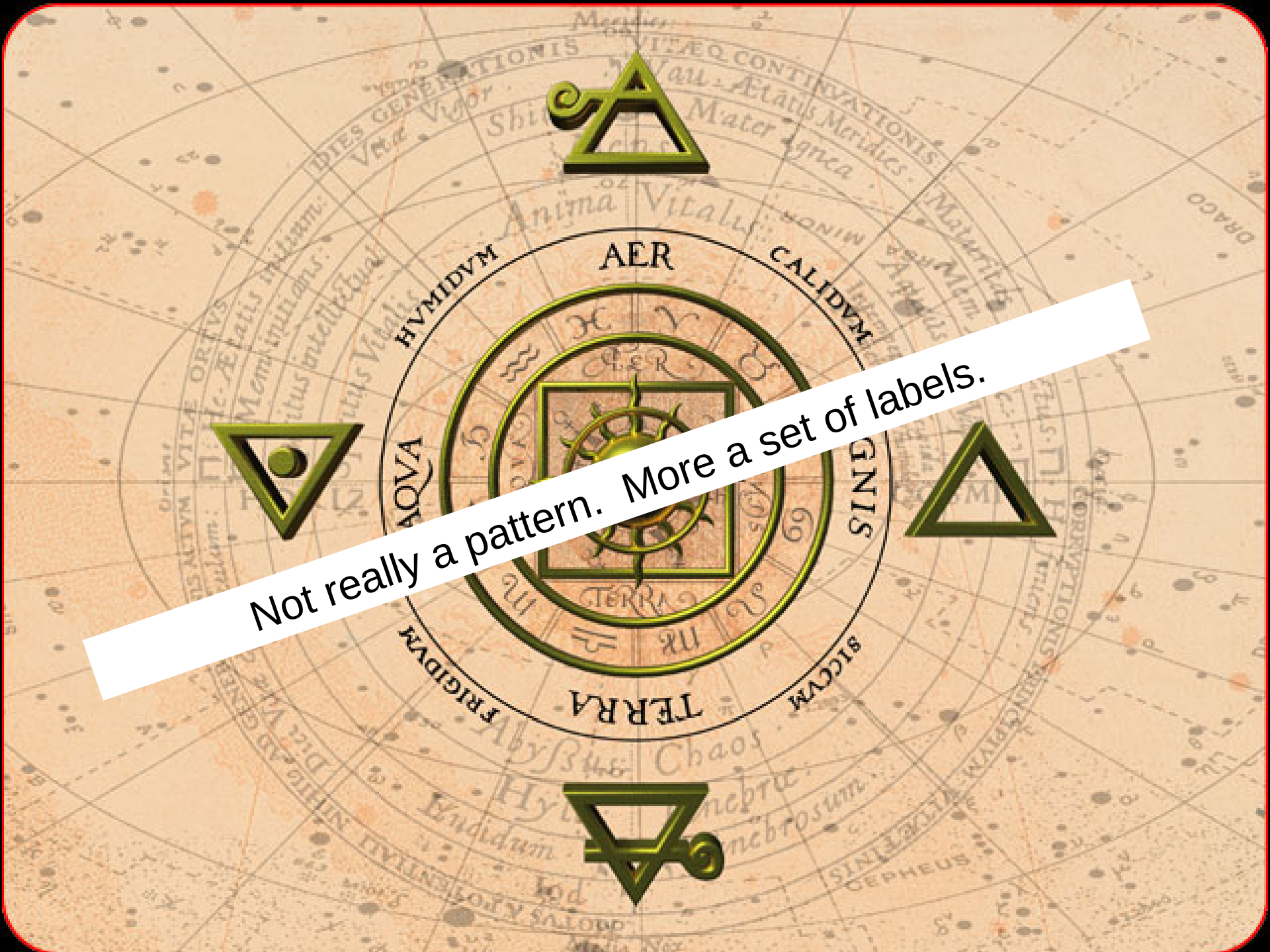
Recent results from the Large Hadron Collider and CERN

Dr Christopher Lester


Peterhouse Cambridge

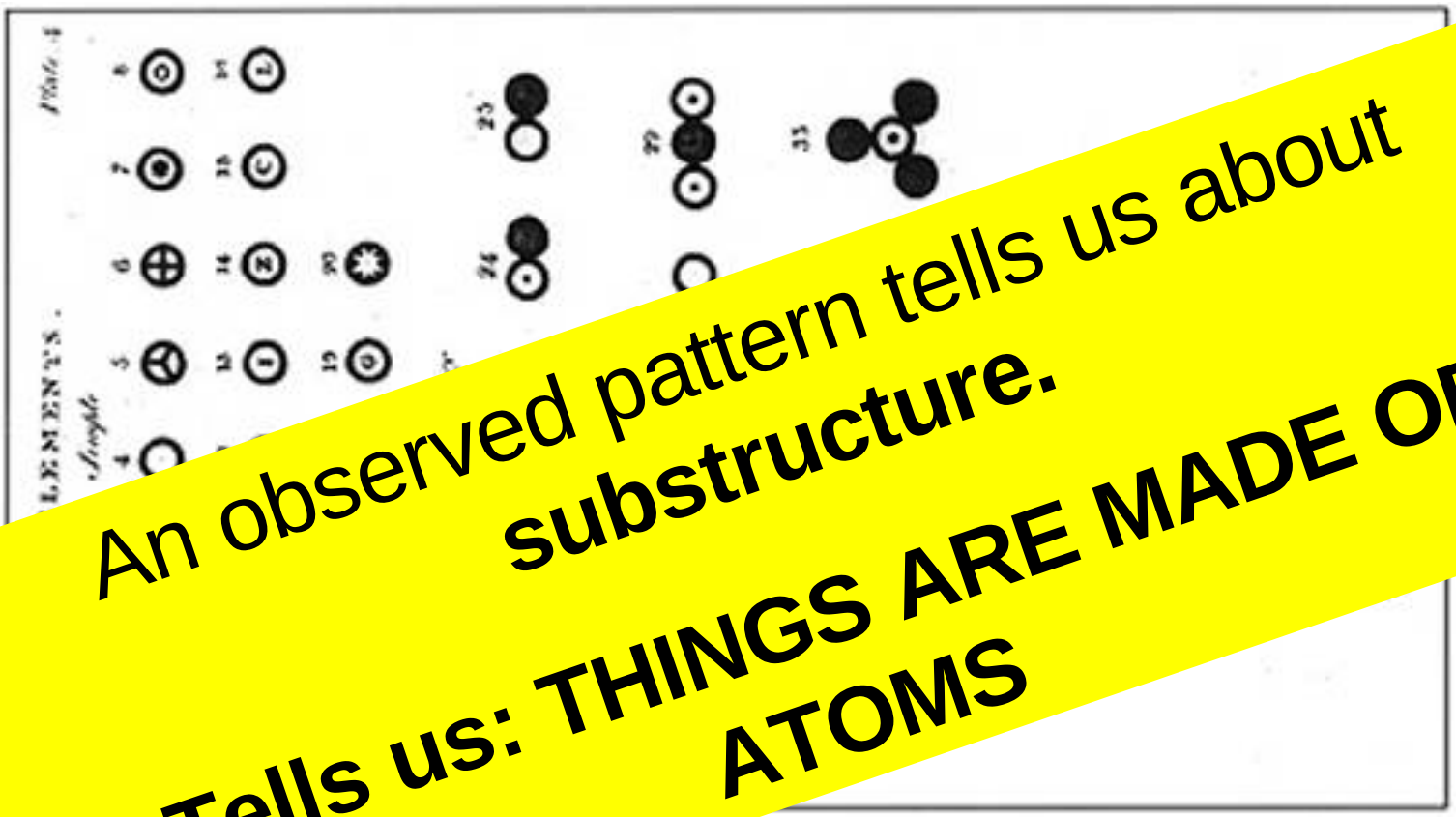
Recap: Particle Physics, The “State of Play” and “Why we bother!”

(patterns betray sub-structure)


AER
CALIDVM
SICCVM
TERRA
FRIGIDVM
HVMIDVM
AQVA
GENIS
Not really a pattern. More a set of labels.

John Dalton: "Atomic Theory".

Elements: Atoms come in different types (1803)



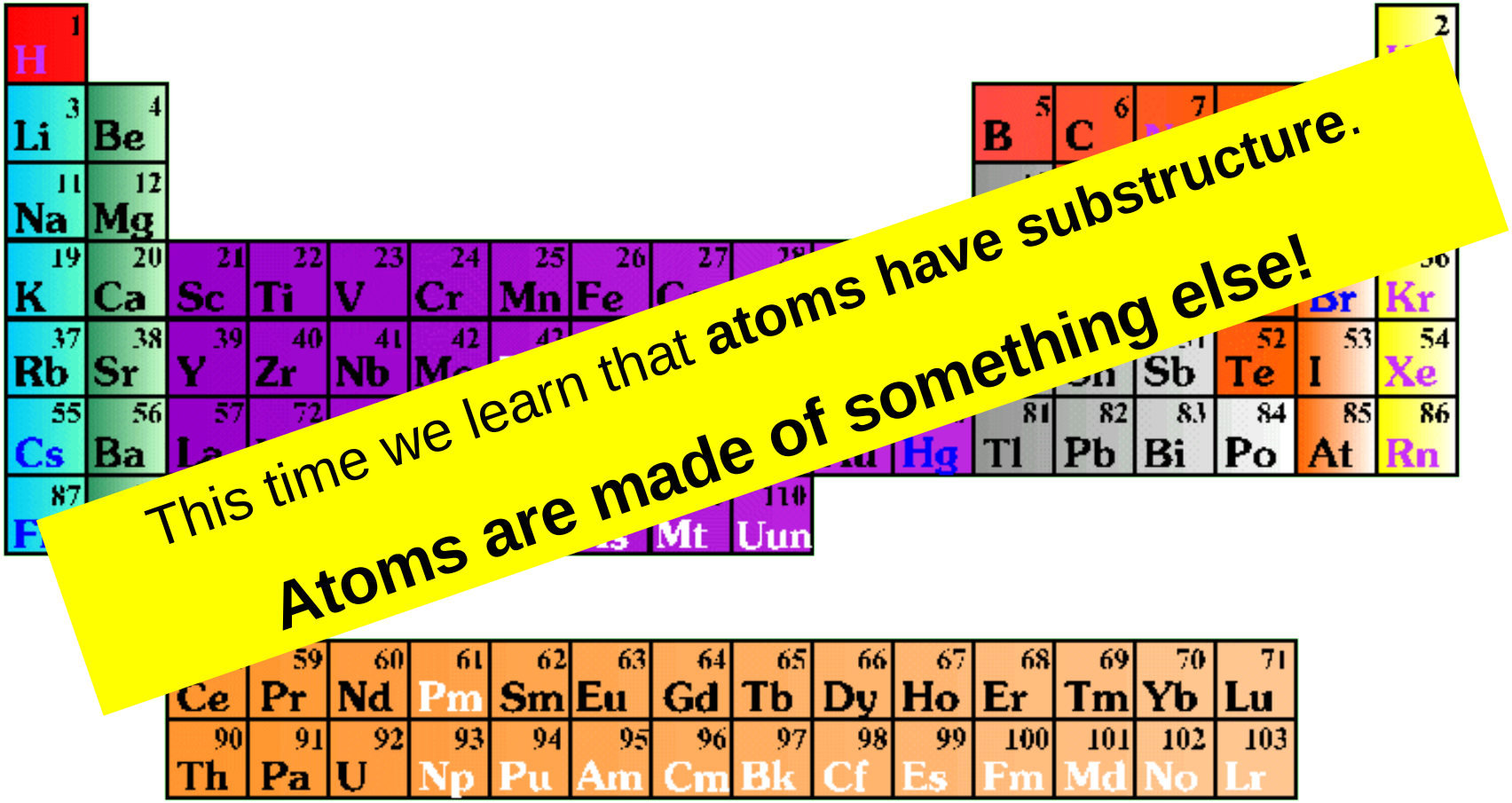
An observed pattern tells us about **substructure.**

Tells us: THINGS ARE MADE OF ATOMS

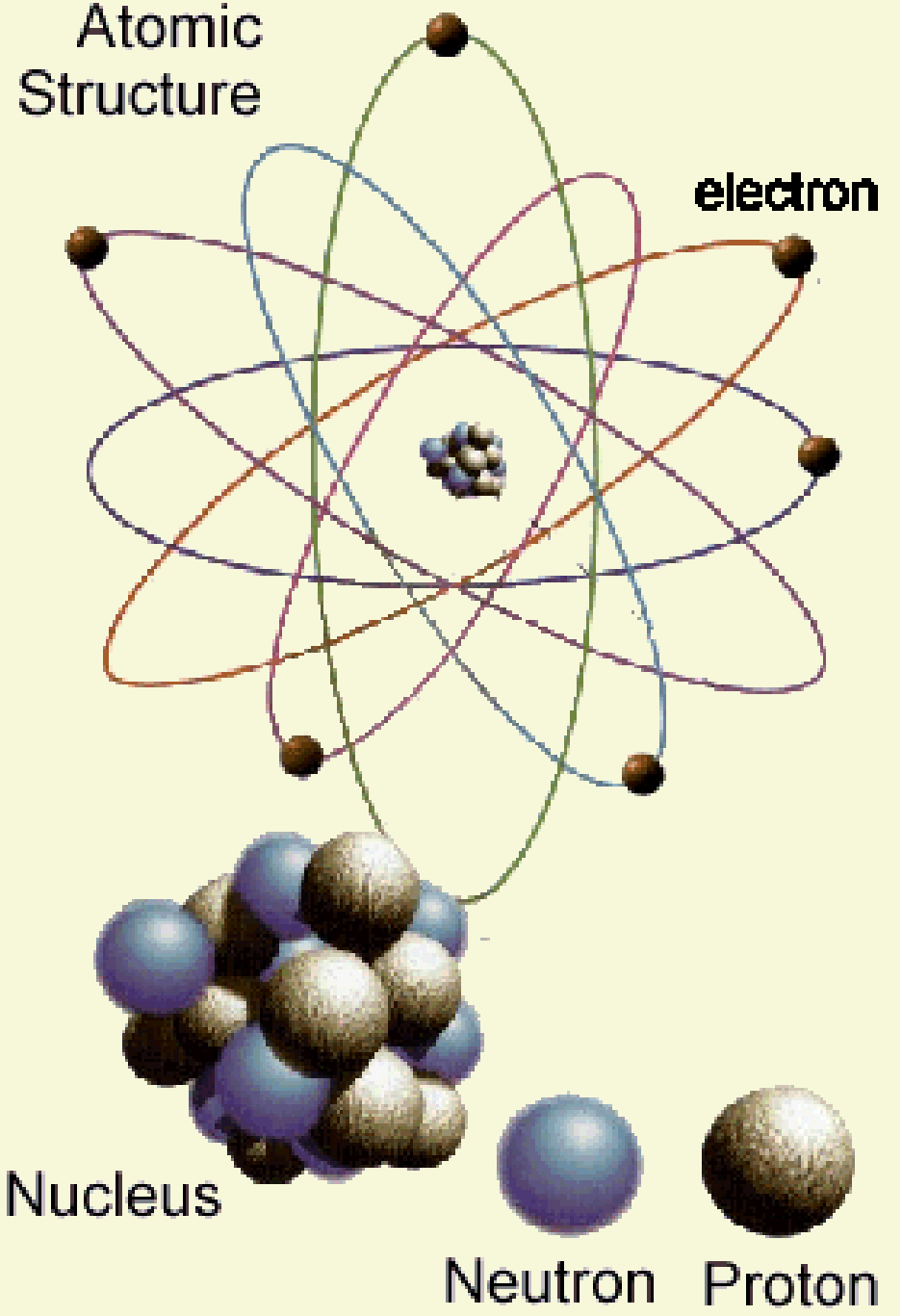
- Law of simple proportions:

  2 O_2 + 1 CH_4 -> 1 CO_2 + 2 H_2O

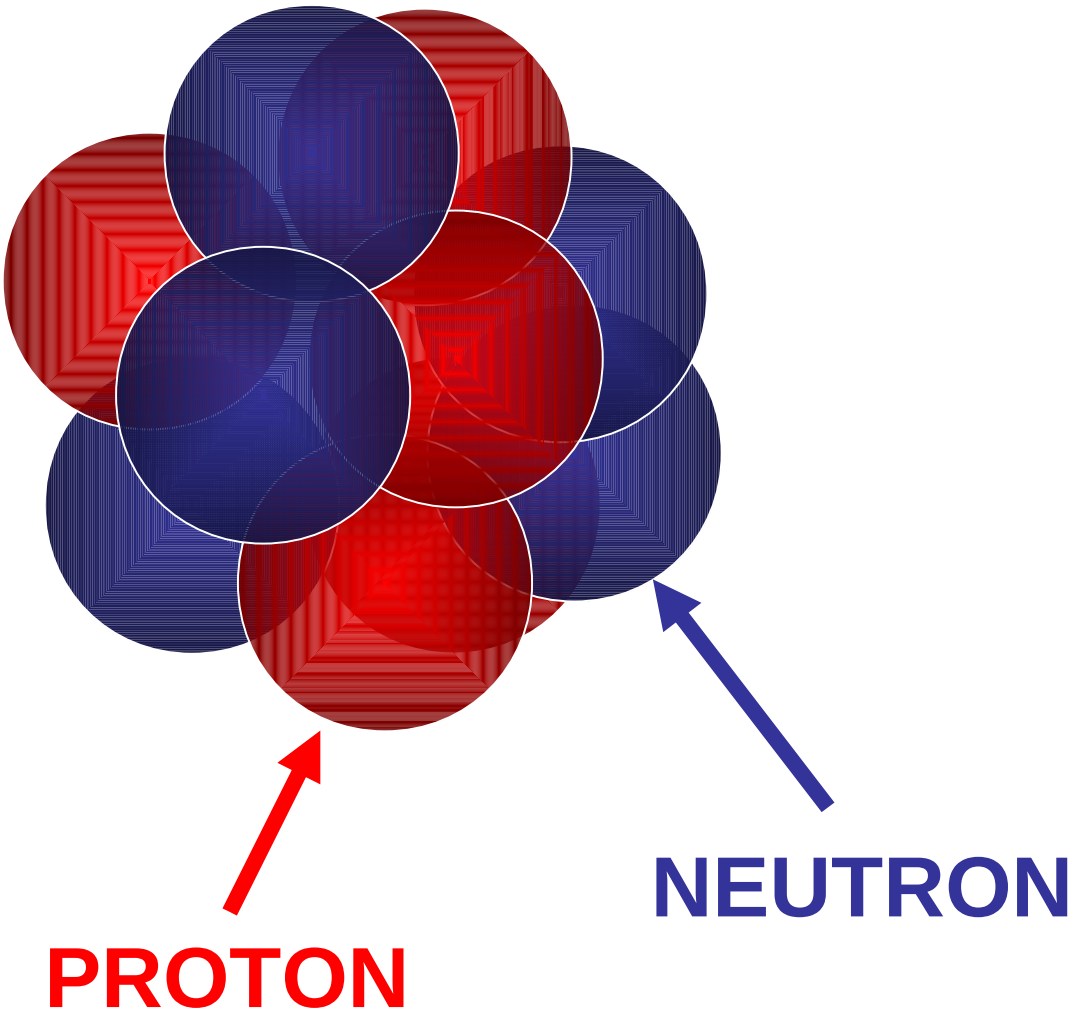
More patterns in Mendeleev's Periodic Table of Elements (1869)

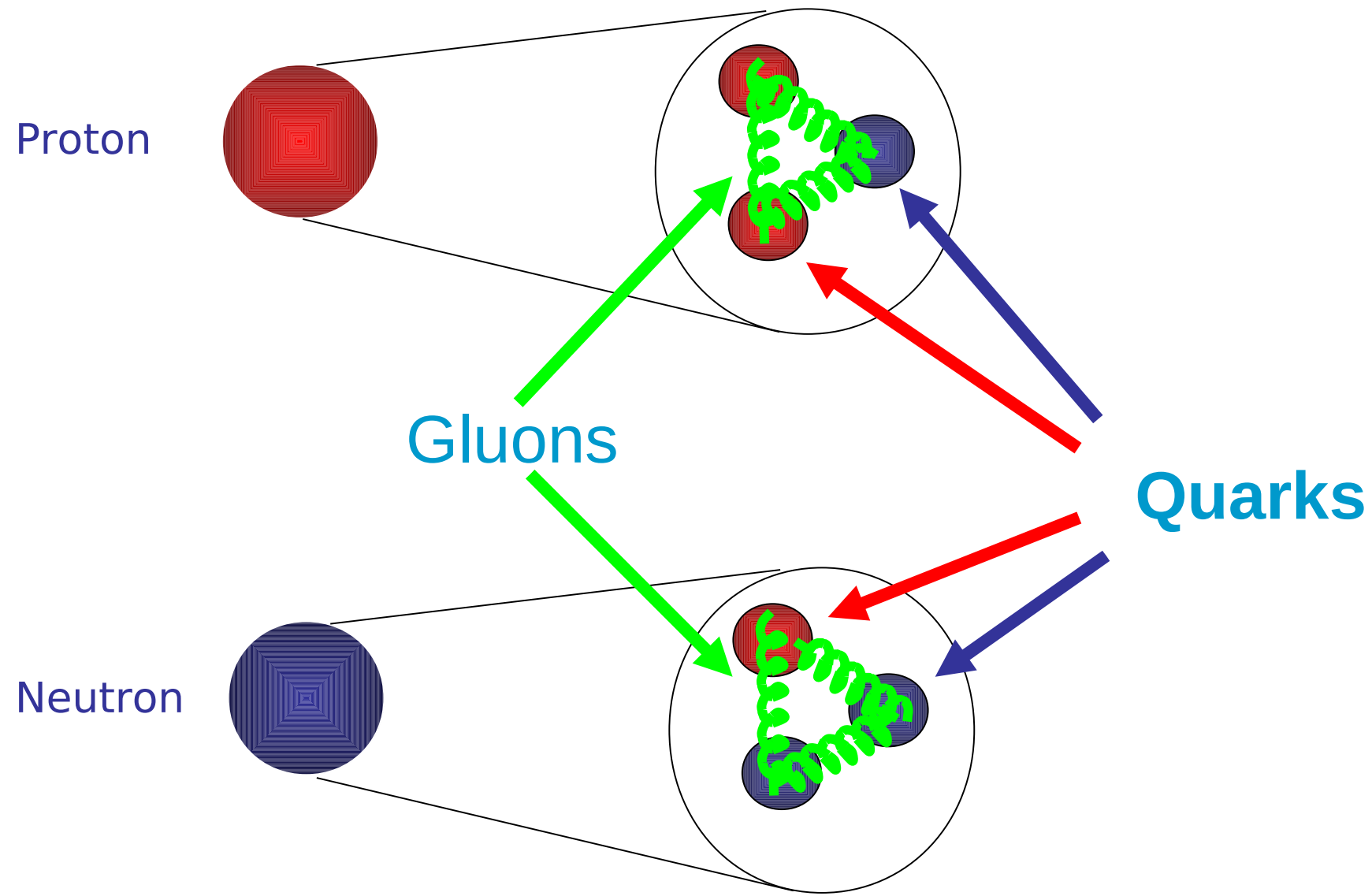


Differences between materials are due simply to the number of protons and electrons in their atoms.

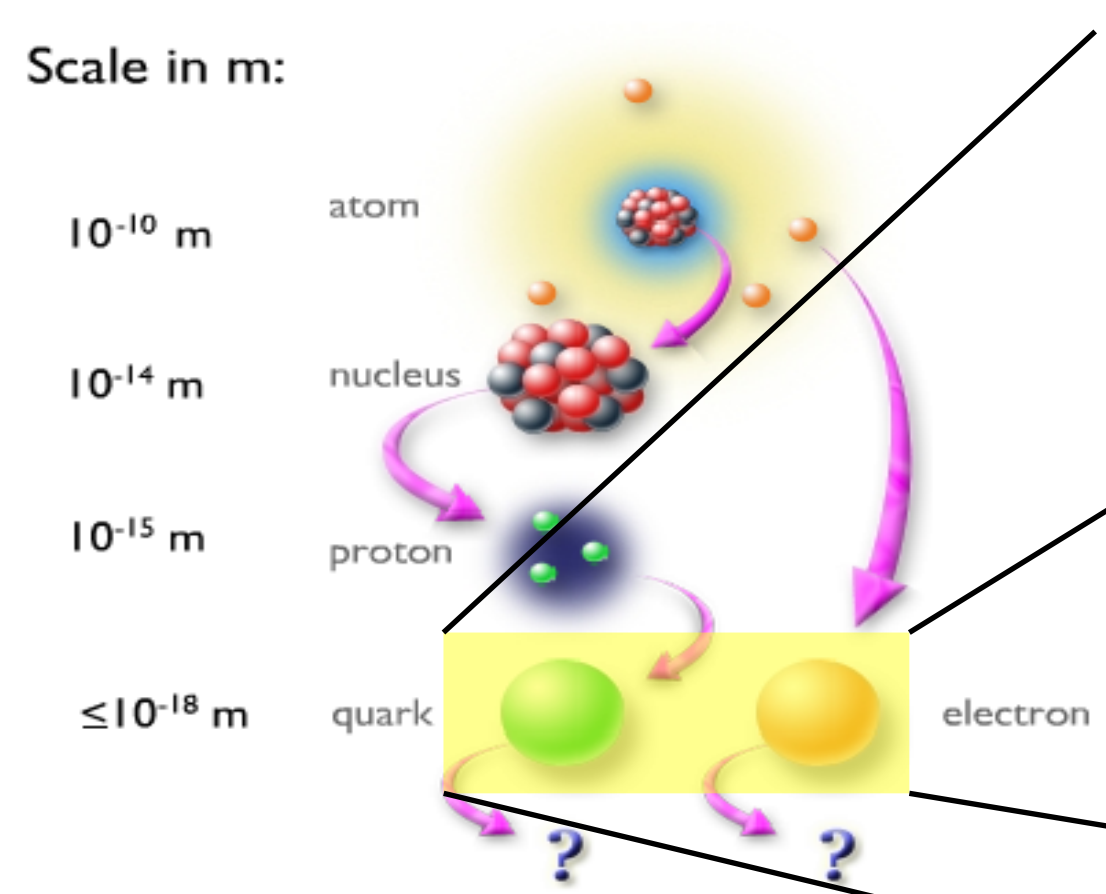

Atomic
Structure
electron
Nucleus
Neutron
Proton

Nucleus **at centre of atom**

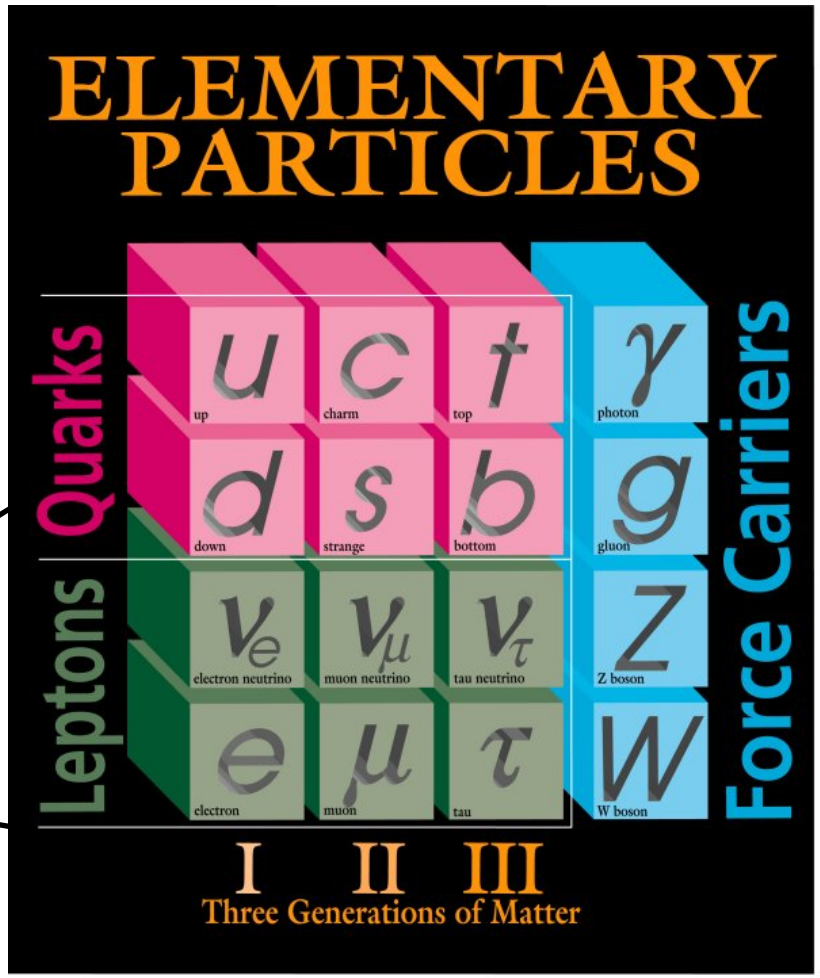



Proton
Gluons
Quarks
Neutron

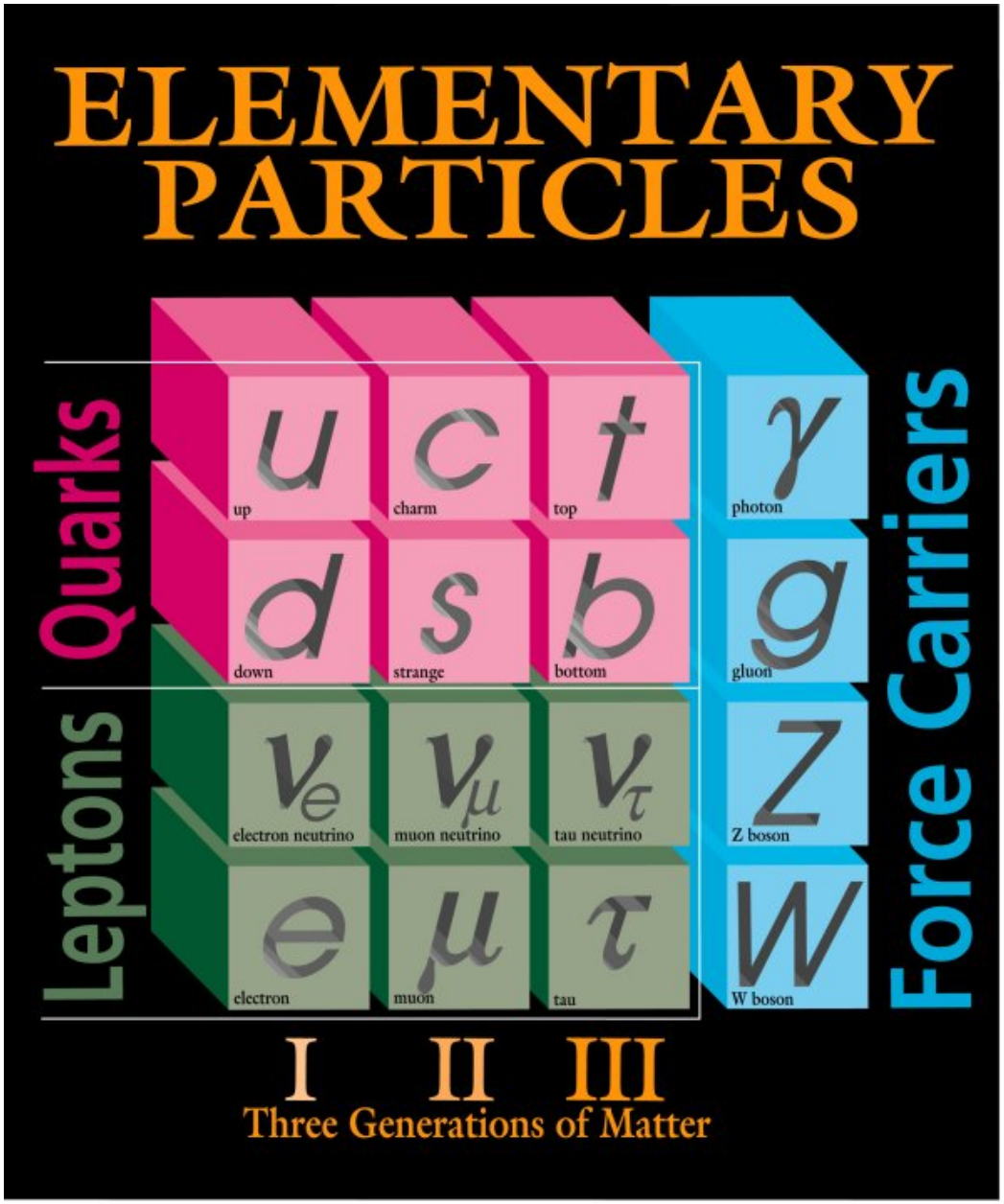
Where we are now …



The Standard Model



The STANDARD MODEL



Peterhouse


物　質　粒　子
ゲージ粒子
第１世代
第２世代
第３世代
クォーク
レプトン
u
アップ
c
チャーム
t
トップ
d
ダウン
s
ストレンジ
b
ボトム
νe
eニュートリノ
νμ
μニュートリノ
ντ
τニュートリノ
e
電子
μ
ミューオン
τ
タウ
強い力
g
グルーオン
電磁力
γ
光子
弱い力
W+
W−
Z
W ボソン
Z ボソン
ヒッグス場に伴う粒子
（未発見）
H
ヒッグス粒子

Mass and the Higgs Boson

The Higgs Field

Endows space with a kind of all-pervasive sticky-treacle

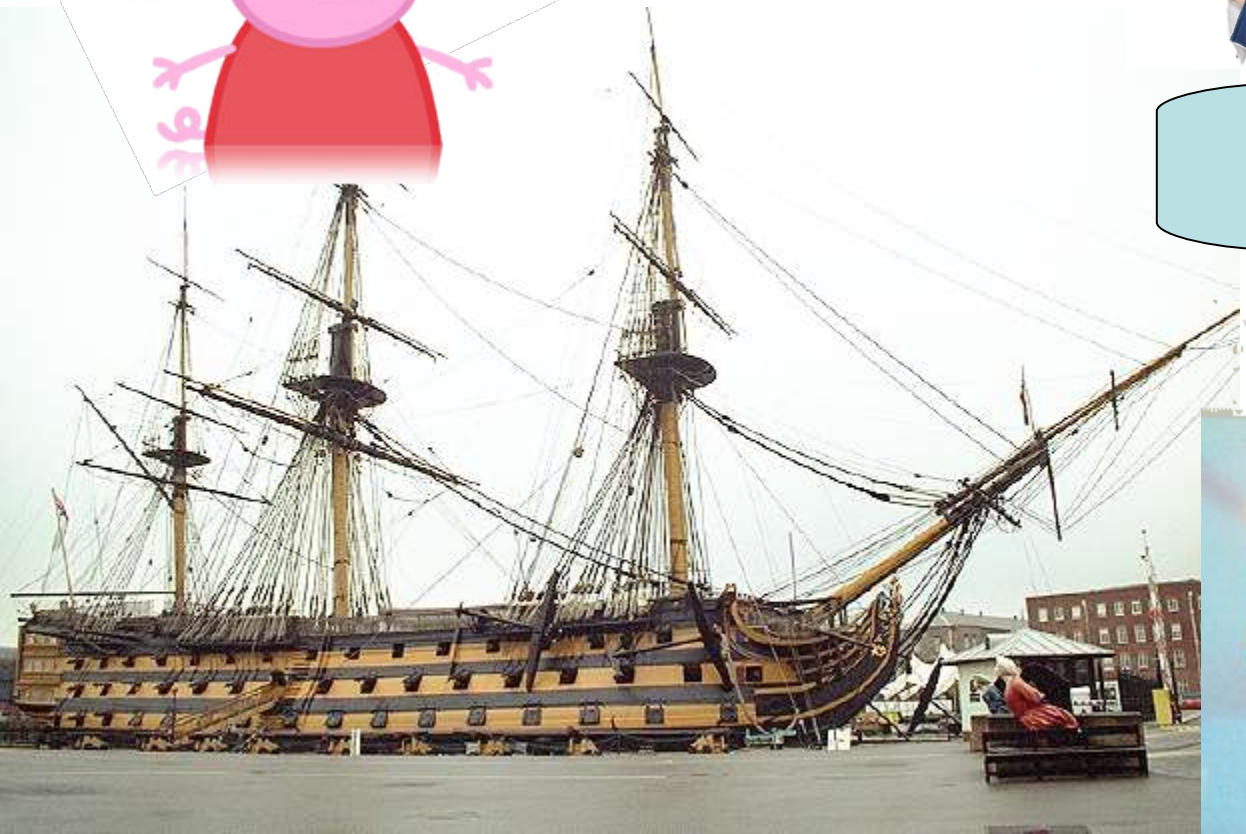
Interactions with this treacle gives mass to particles

They then travel slower than the speed of light

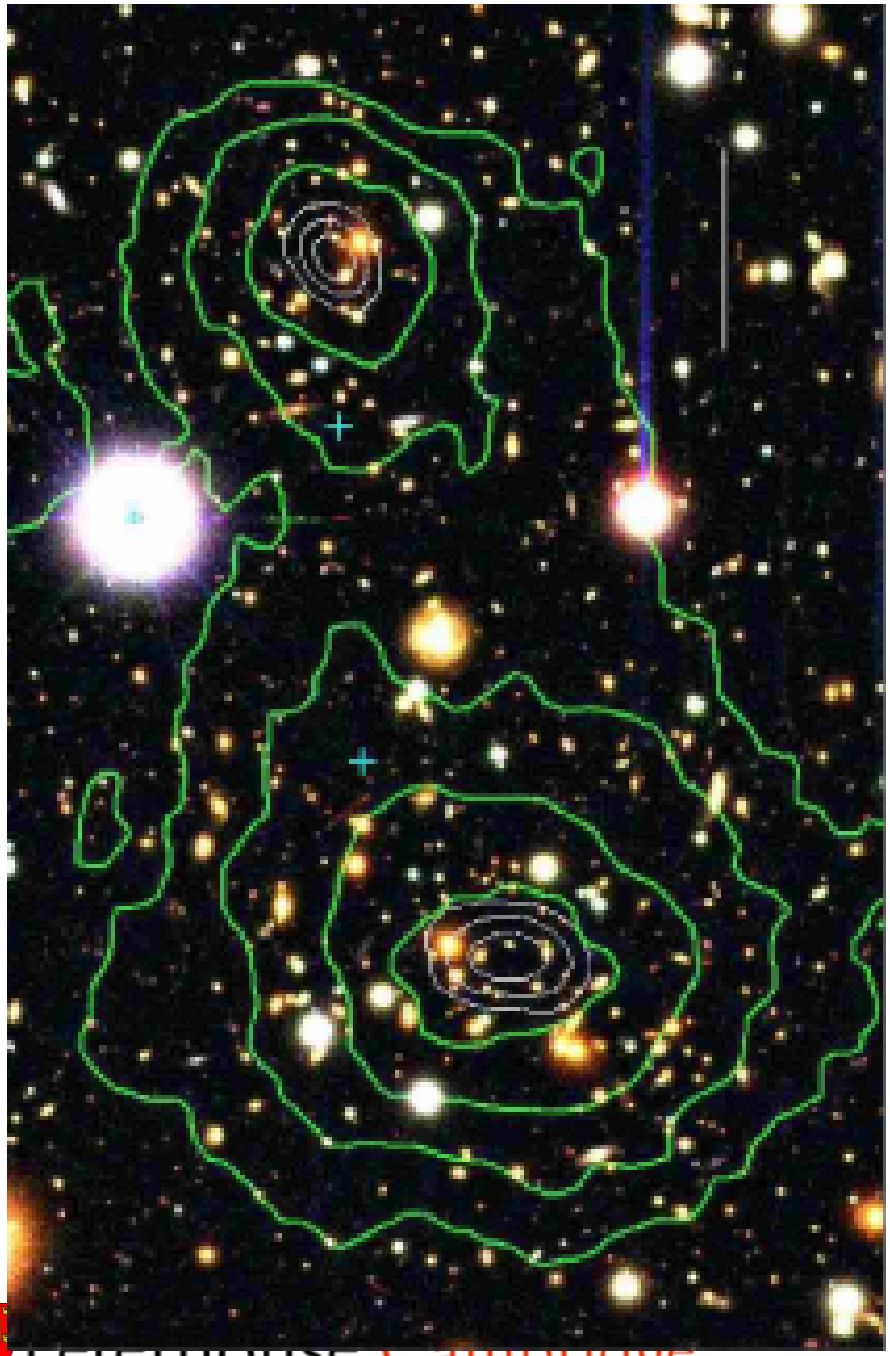
The Higgs Boson

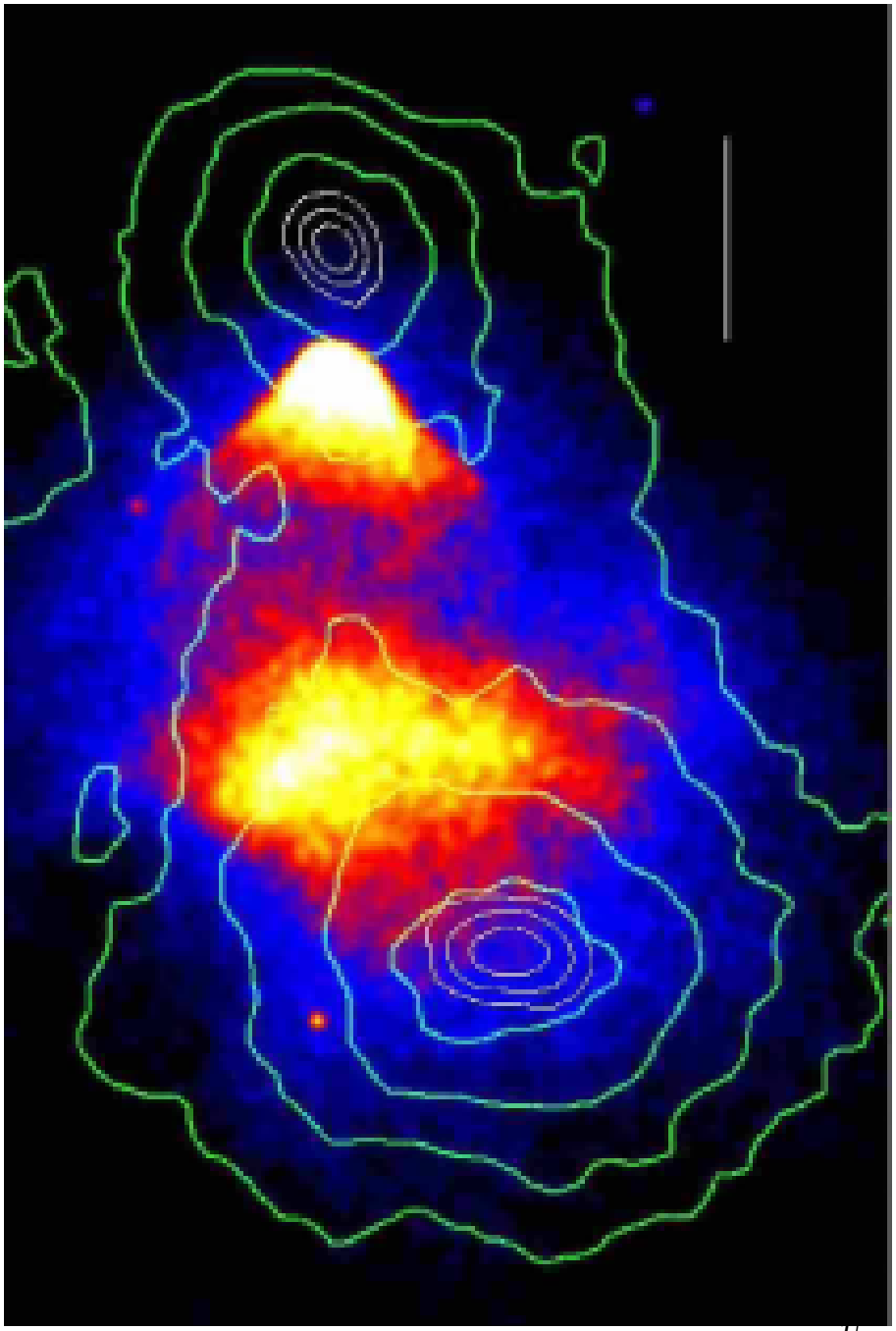
is a treacle-ball – something which allows us to see the treacle itself

Higgs Boson not Hog's Bosun

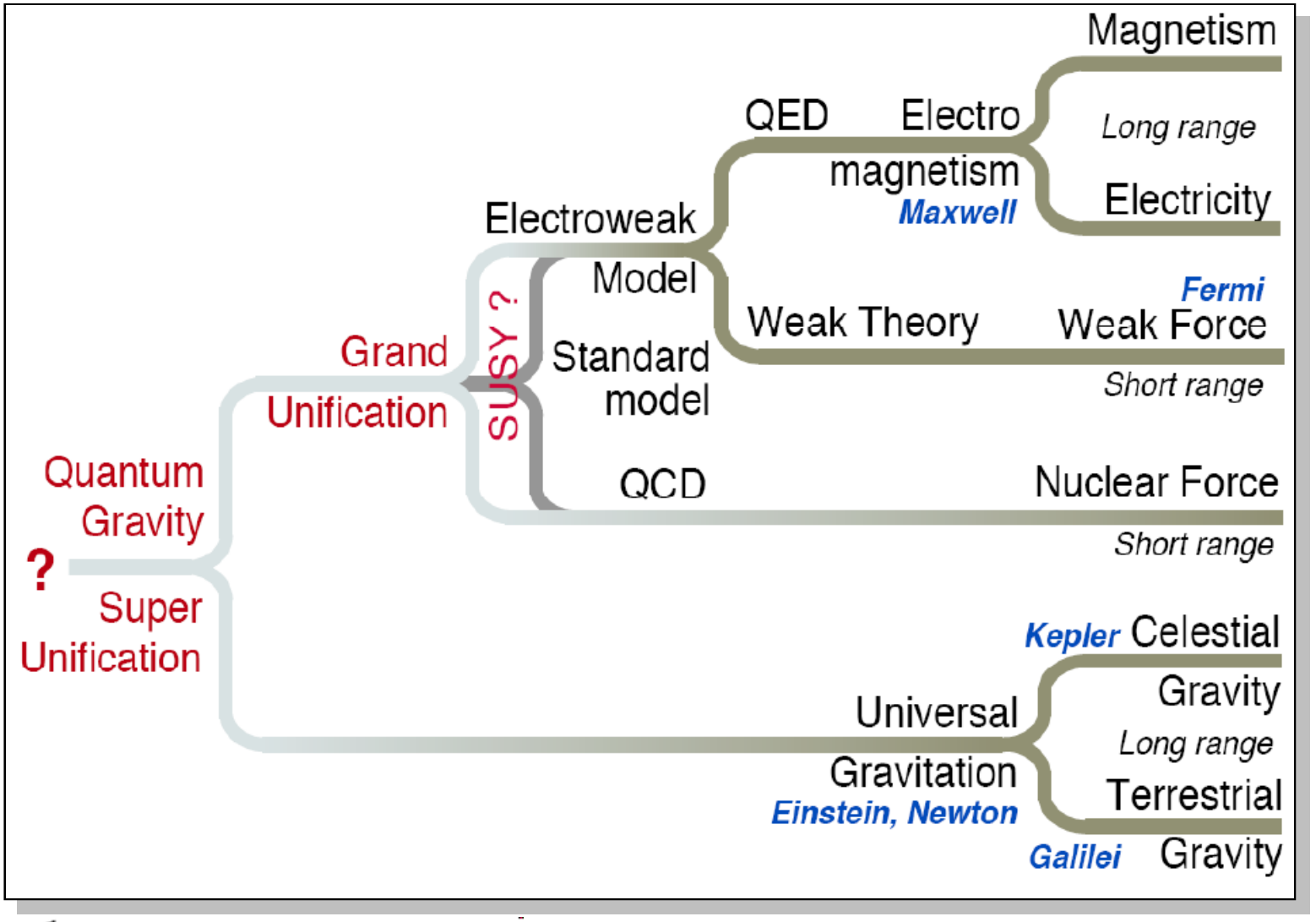


Is that it?



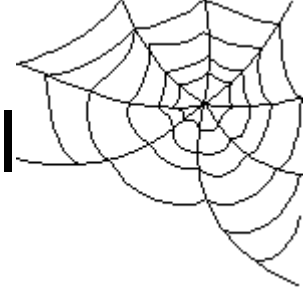


Do the forces unify?



Standard Model Good

- No conflict with experiment (yet)
- Parts (QED) in extremely good agreement with experiment – even with atomic physics!
- Agreement to twelve decimal places !
- Elementary parti
  "reasona



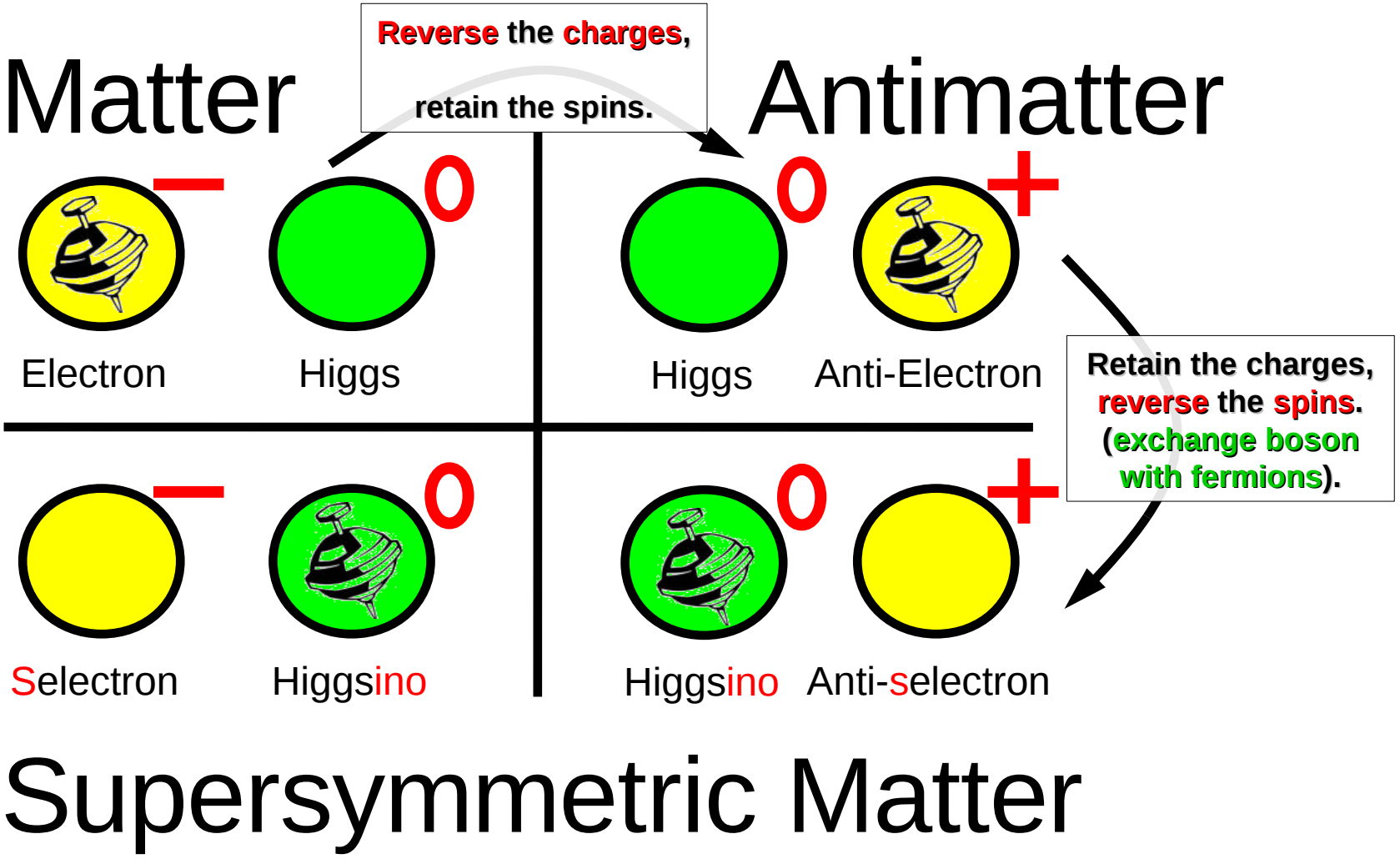
Standard Model Bad

- Higgs boson not yet found!
- Gravity is not involved!
- Dark matter
- Lo
  utrinos?
  generations?
  Why is "lepton flavour conserved" ?
- Other technical problems:
  - "Hierarchy problem"

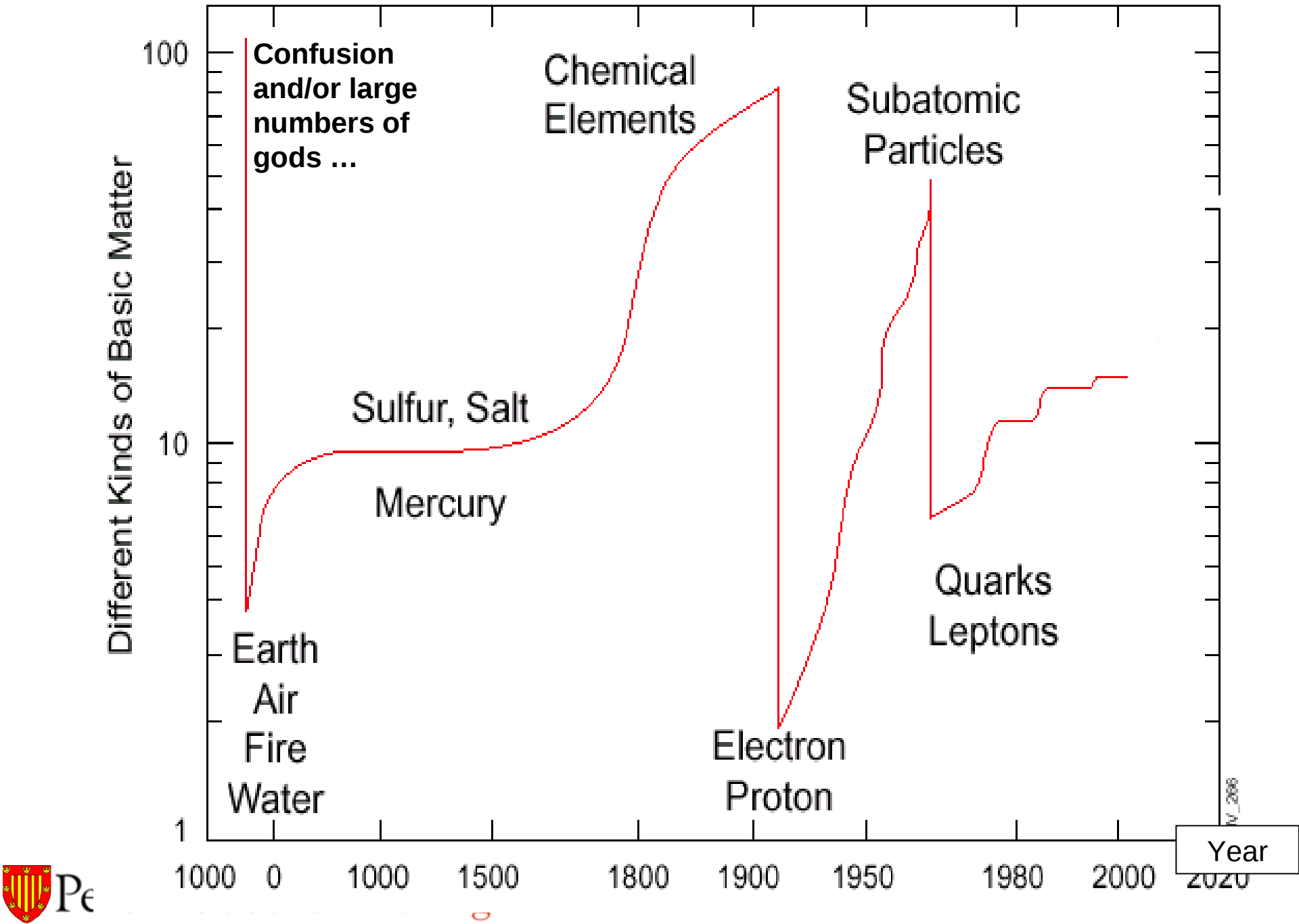
But regardless …

The patterns are jolly suspicious!

Supersymmetry?



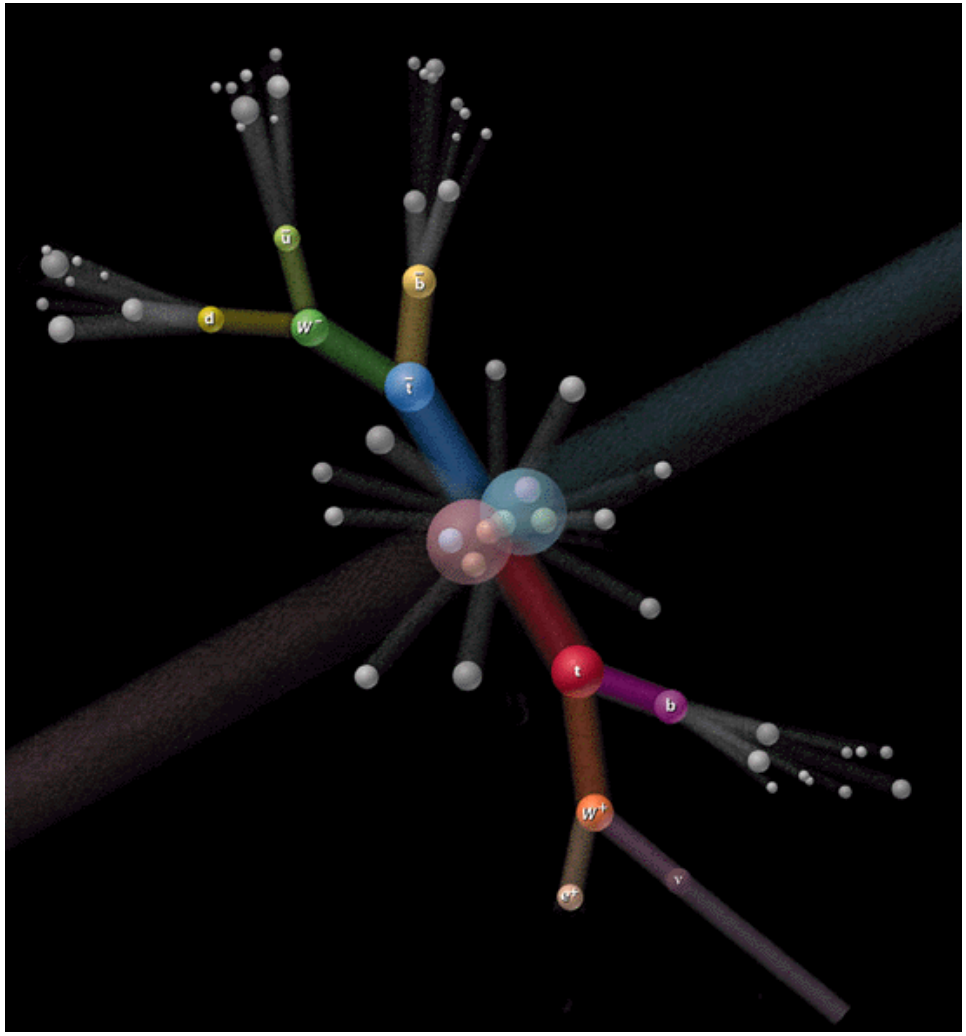
For technical reasons each sparticle can be heavier than its partner by no more than a TeV or so.


Different Kinds of Basic Matter
100
10
1
Confusion and/or large numbers of gods ...
Chemical Elements
Subatomic Particles
Sulfur, Salt
Mercury
Earth
Air
Fire
Water
Electron
Proton
Quarks
Leptons
1000
0
1000
1500
1800
1900
1950
1980
2000
2020
Year


?
ATLAS
EXPERIMENT

How do we find out more?

Sometimes only one experimental technique:

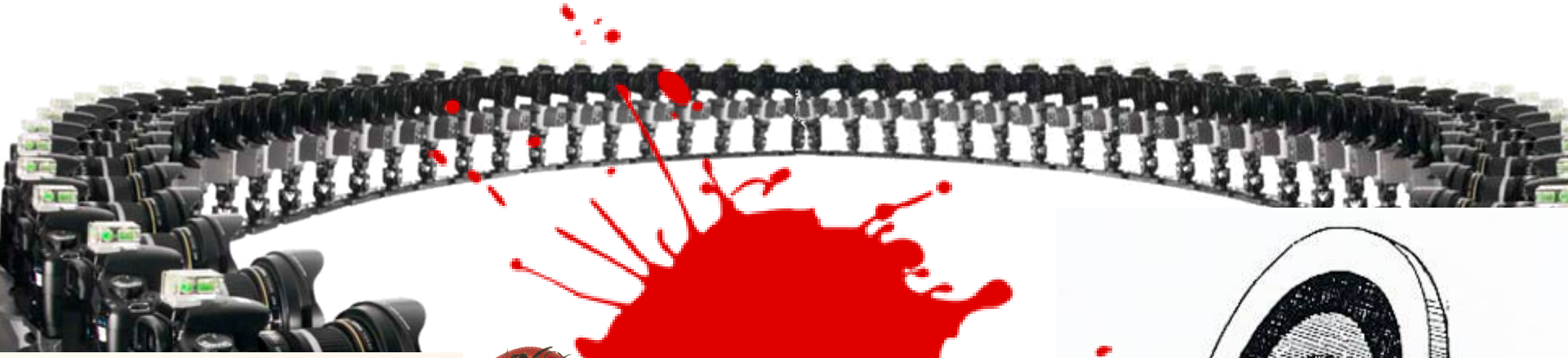


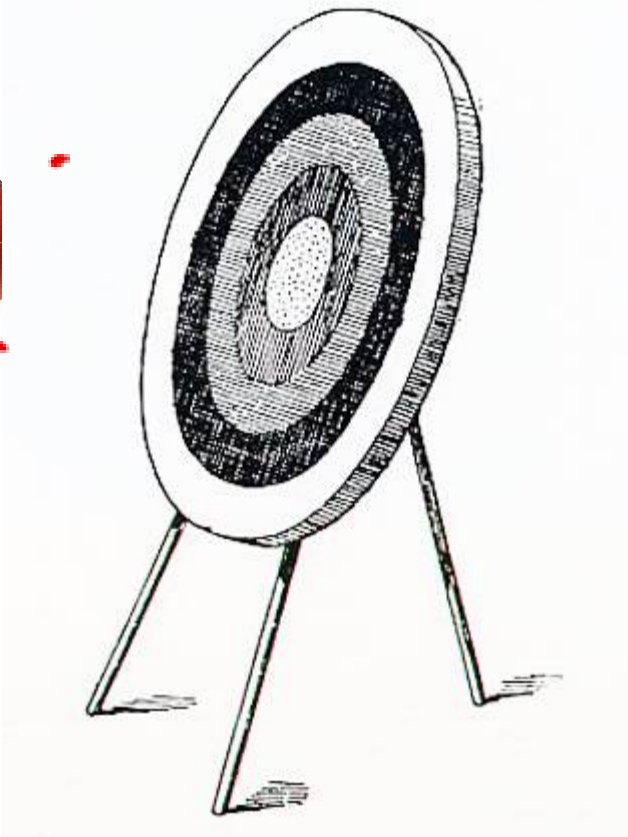
Collide things and see what happens.

Is this difficult?

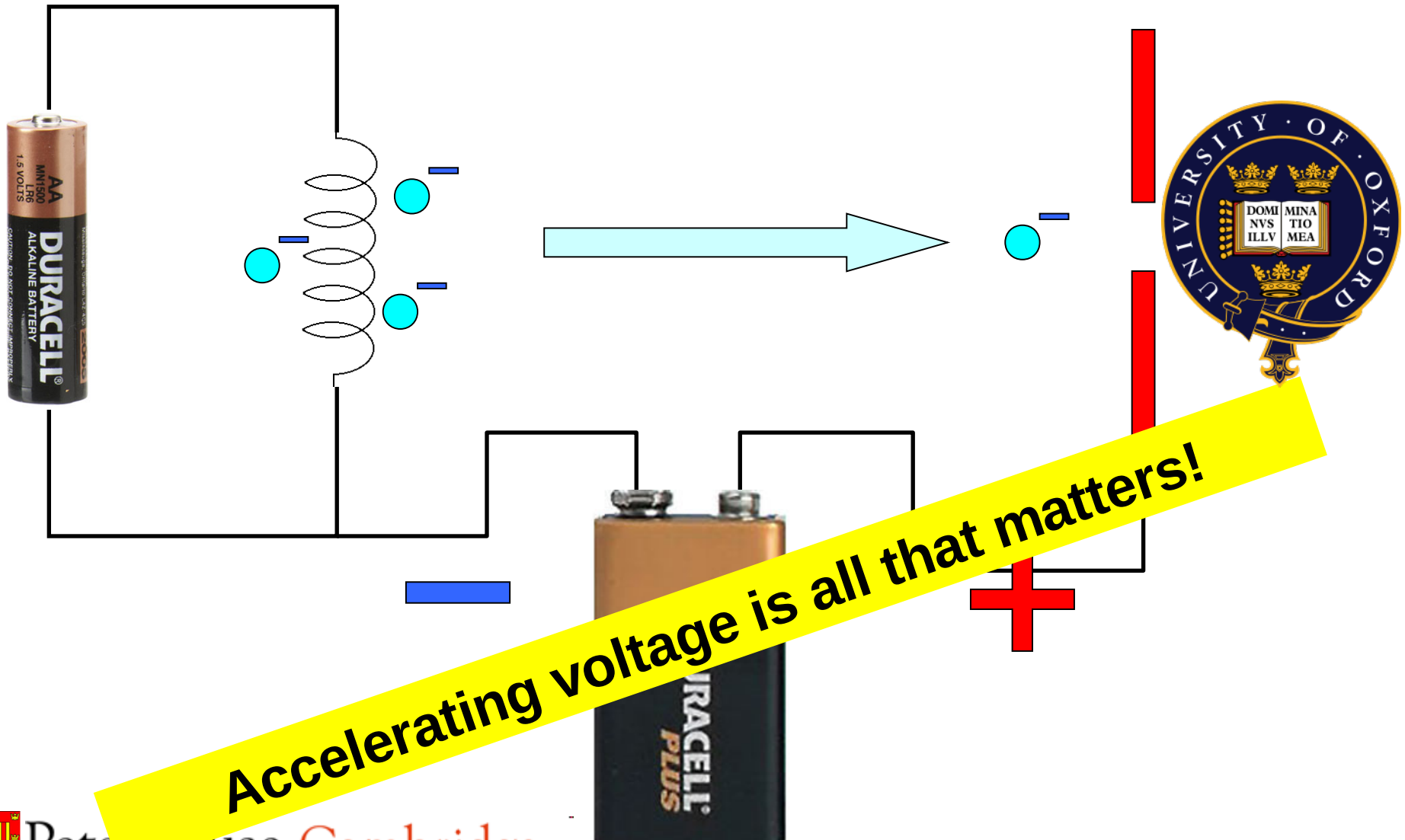
Will mention just collision and acceleration !

What you need:

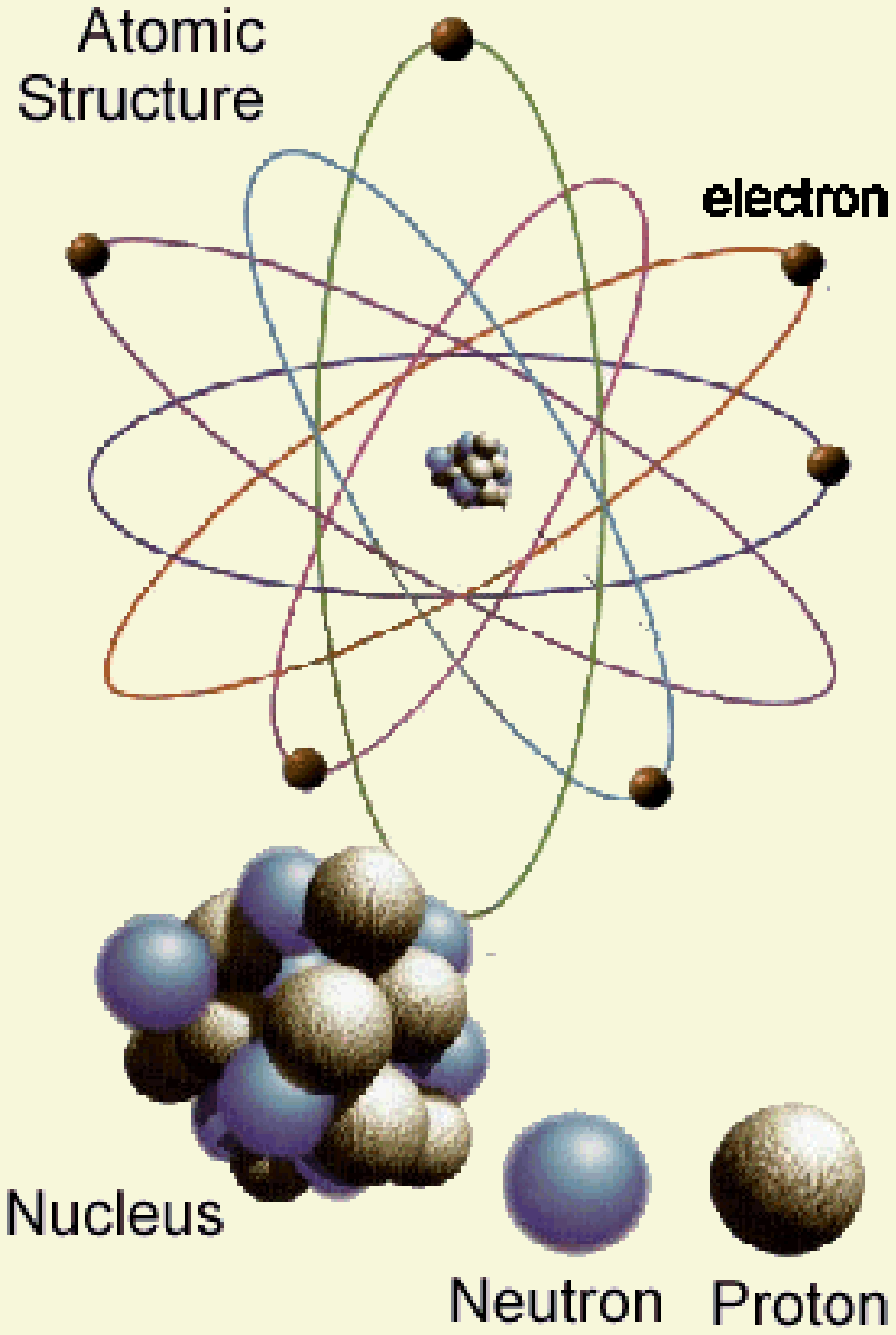




A simple accelerator:



Accelerating voltage is all that matters!



Progression in energy:

16 volts to pull an electron off an atom

↓

100 million volts to break up a nucleus into protons + neutrons

↓

100 billion volts to knock a quark out of a proton

To make progress, it was decided to try for …

FOURTEEN THOUSAND BILLION VOLTS

Spark could jump 5000 km in air
(~radius of The Earth)

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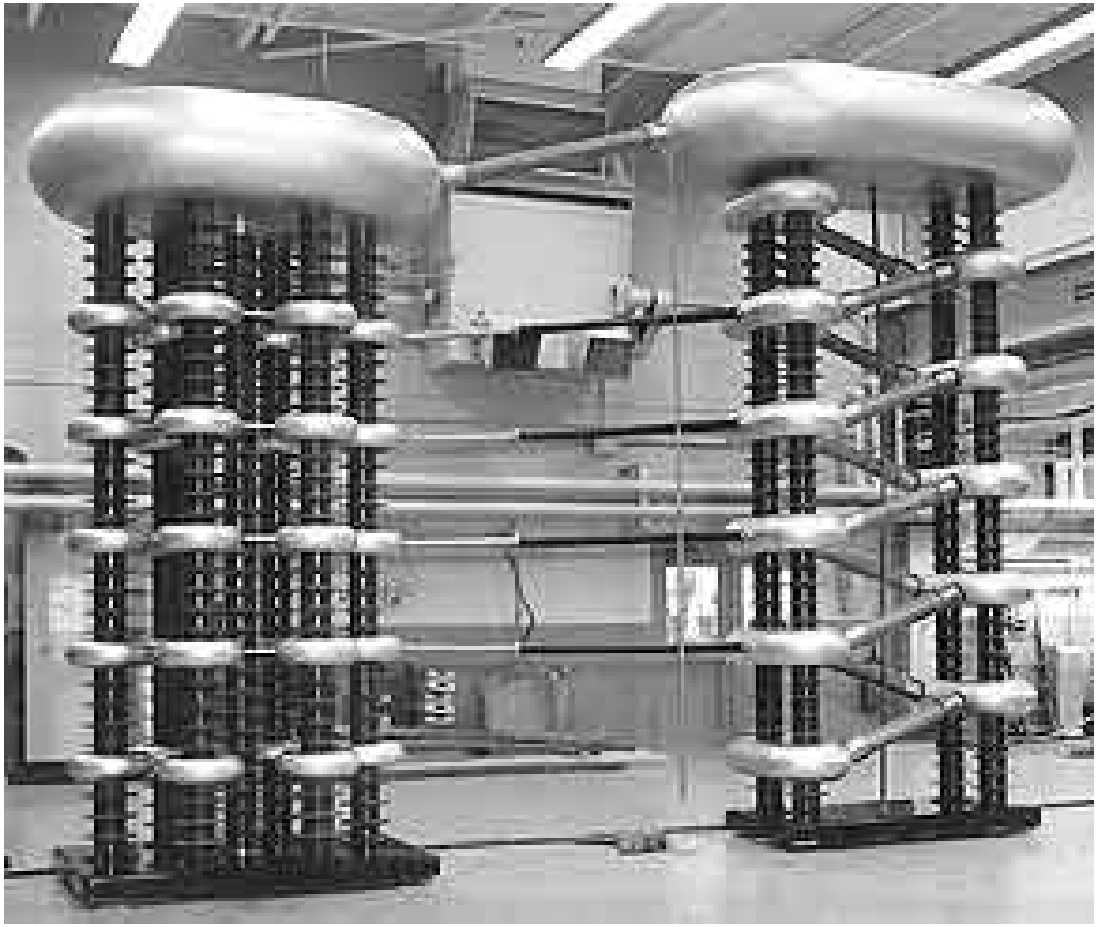
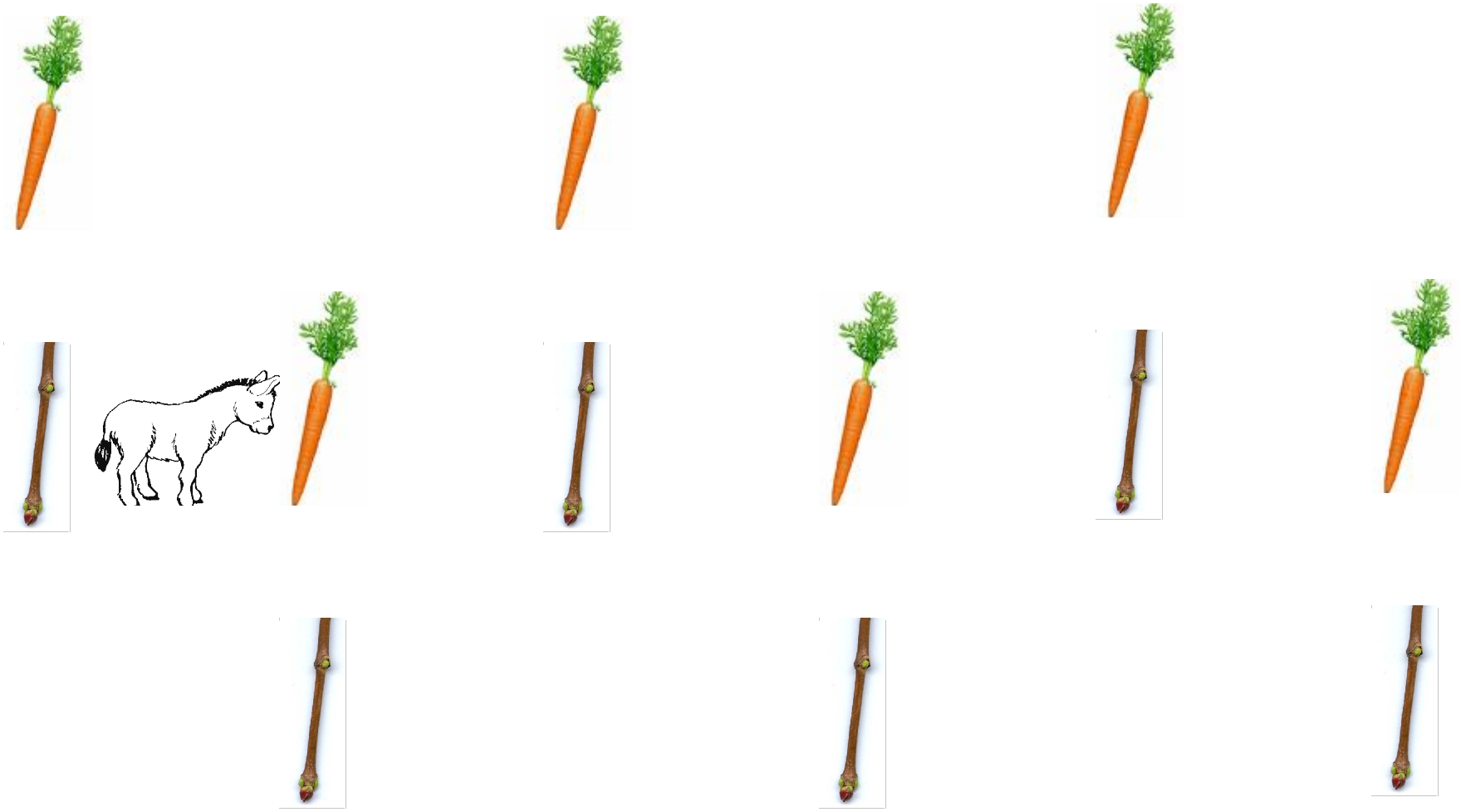
Can get to 1 million volts with this:



For 100 million volts or more need

“carrot and stick”

Donkey accelerator



Principle of Radio Frequency Cavity (RF Cavity)

LHC RF Cavity

The Large Hadron Collider

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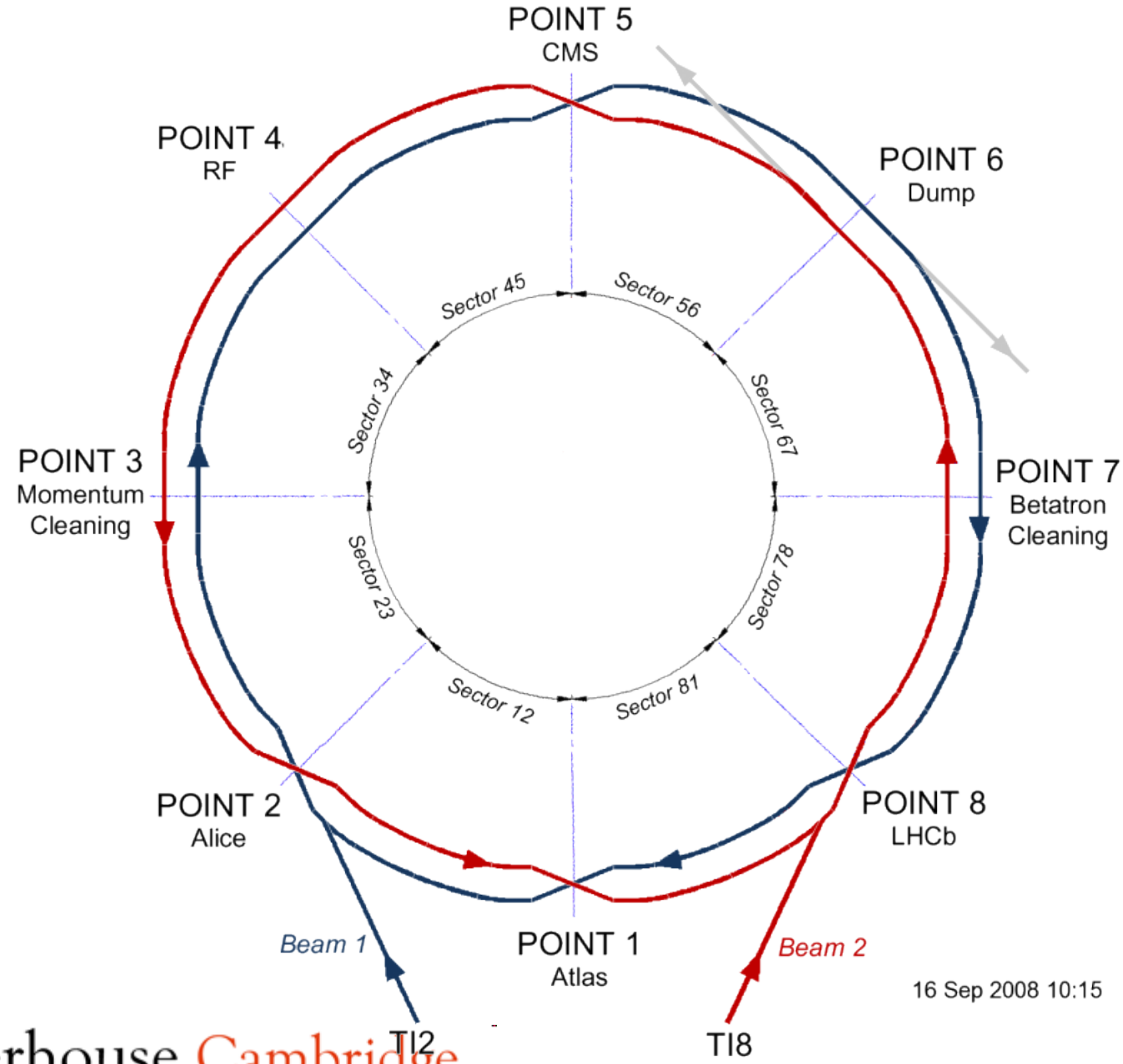
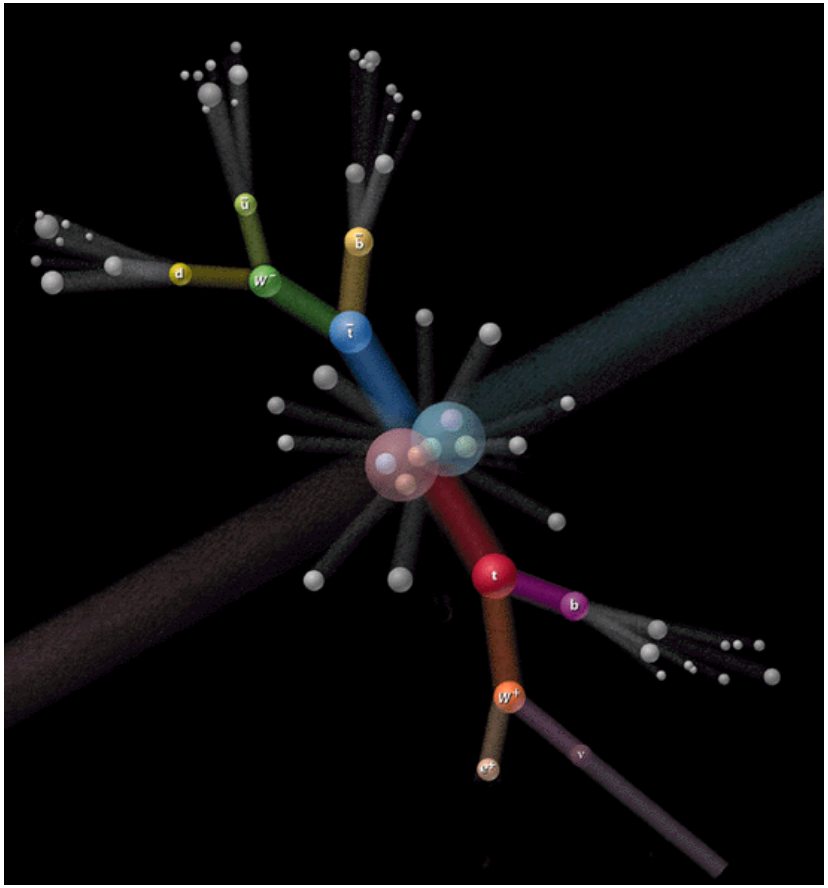
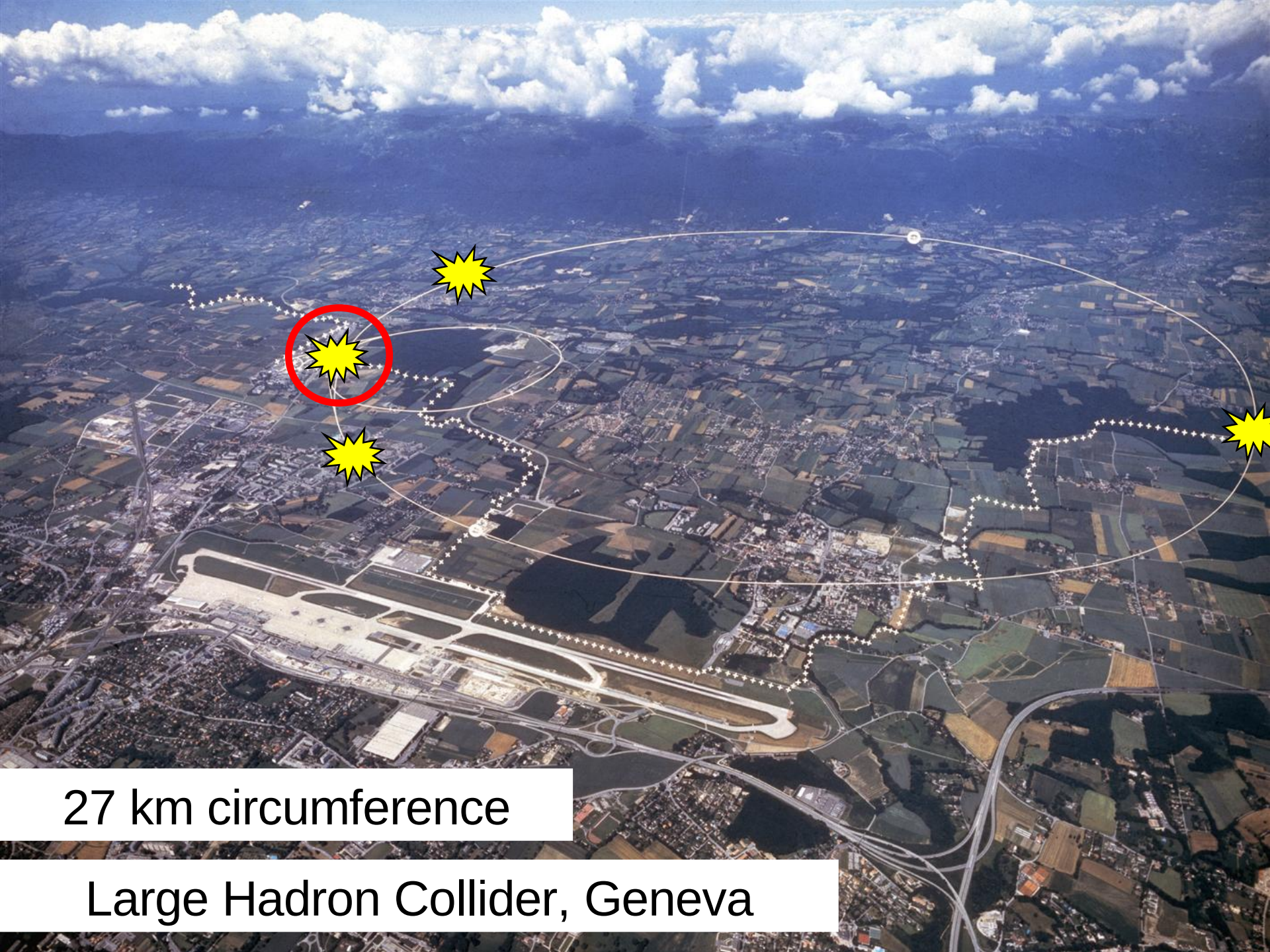
Structure of the Large Hadron Collider



Simple experimental technique:



Collide PROTONS and see what happens.

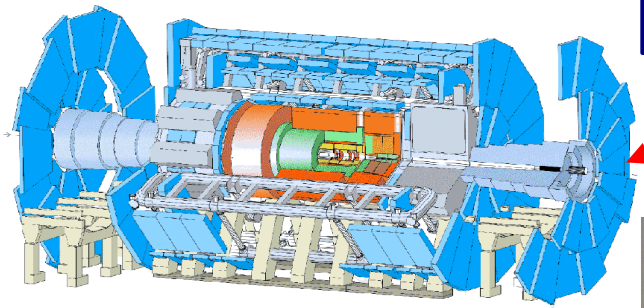

27 km circumference
Large Hadron Collider, Geneva


Key to lines
Bakerloo
Central
Circle
District
Jubilee
Northern
Piccadilly
Finchley Road
Camden Town
Kensal Green
Queen's Park
Kilburn Park
Swiss Cottage
Mornington Crescent
King's Cross St. Pancras
Caledonian Road & Barnsbury
St. John's Wood
Edgware Road
Marylebone
Baker Street
Great Portland Street
Euston
Angel
Paddington
Paddington
Edgware Road
Warren Street
Euston Square
Farringdon
Old Street
Barbican
Liverpool Street
Regent's Park
Bayswater
Goodge Street
Russell Square
Moorgate
Holland Park
Queensway
Marble Arch
Oxford Circus
Holborn
Shepherd's Bush
Notting Hill Gate
Lancaster Gate
Bond Street
Tottenham Court Road
Chancery Lane
St. Paul's
Bank
Covent Garden
Kensington (Olympia)
High Street Kensington
Green Park
Cannon Street
Aldgate
Leicester Square
Mansion House
Hyde Park Corner
Piccadilly Circus
Monument
Tower Hill
Knightsbridge
Charing Cross
Barons Court
Gloucester Road
Sloane Square
St. James's Park
Blackfriars
River Thames
Temple
London Bridge
West Kensington
Earl's Court
South Kensington
Victoria
Westminster
Embankment
Bermondsey
West Brompton
Waterloo
Southwark
Fulham Broadway
Lambeth North
Borough
East Putney
Vauxhall
Elephant & Castle
Circle Line …
22.5 km circumference


Way out

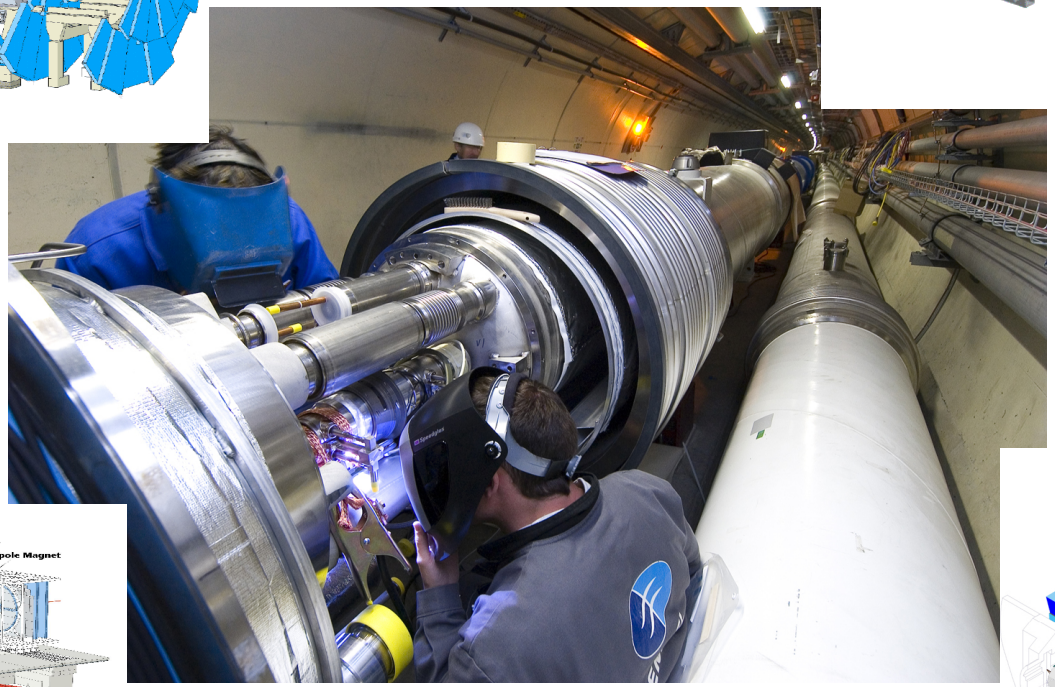
LHC Detectors

General purpose detectors (good for everything...)

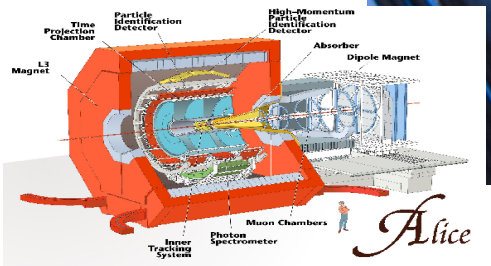


ATLAS

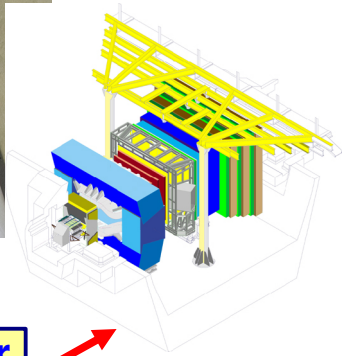
CMS



ALICE



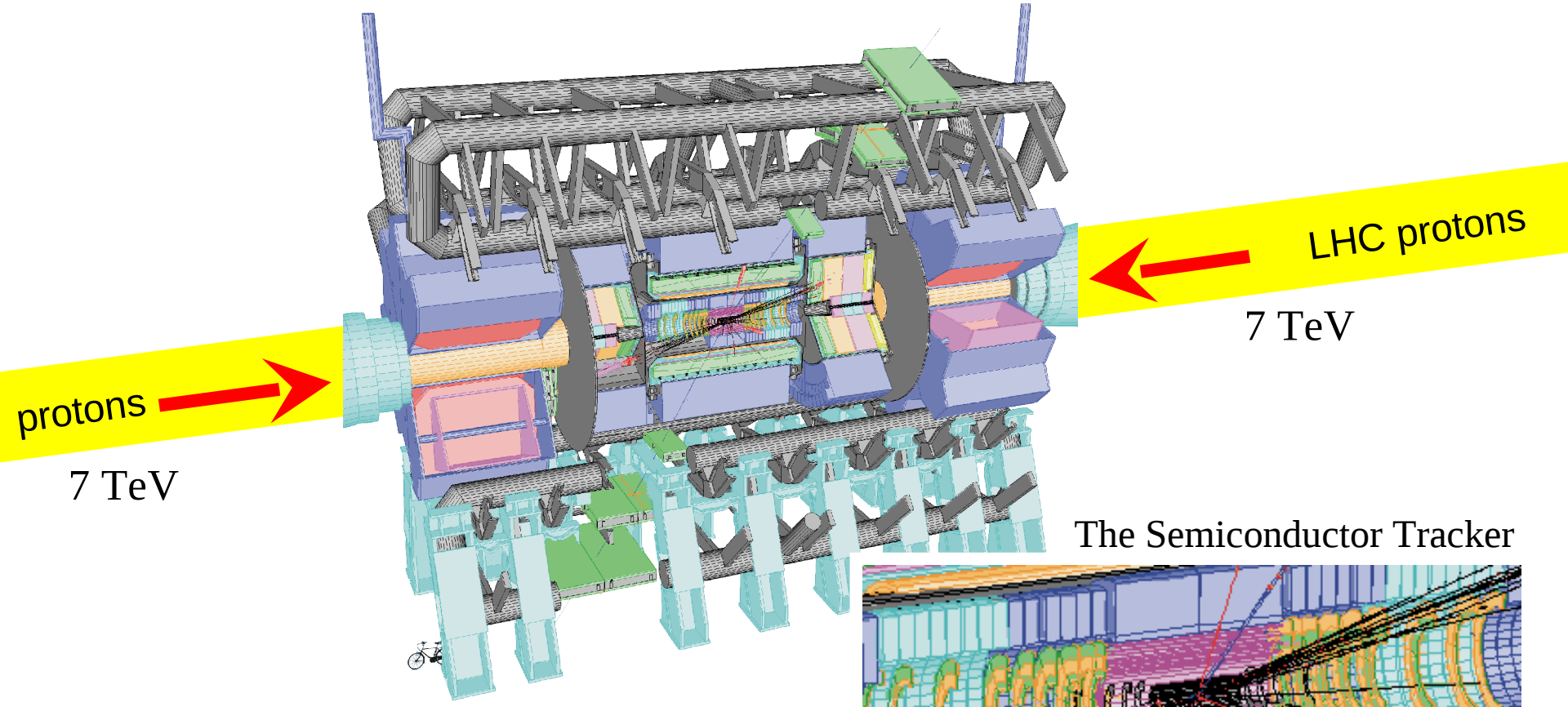
LHCb



dedicated for Heavy Ion collisions

dedicated for b-physics

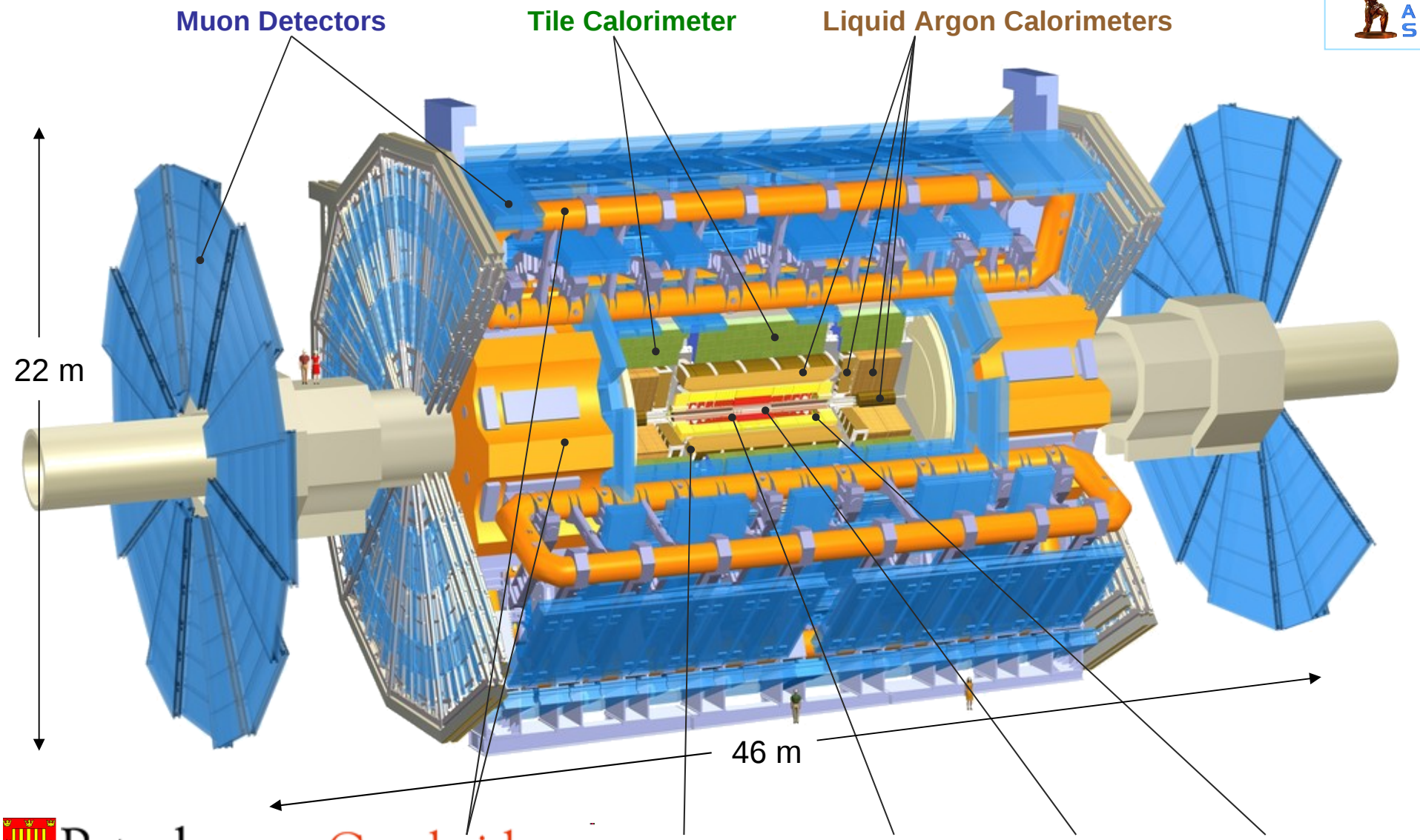
The “ATLAS” Experiment

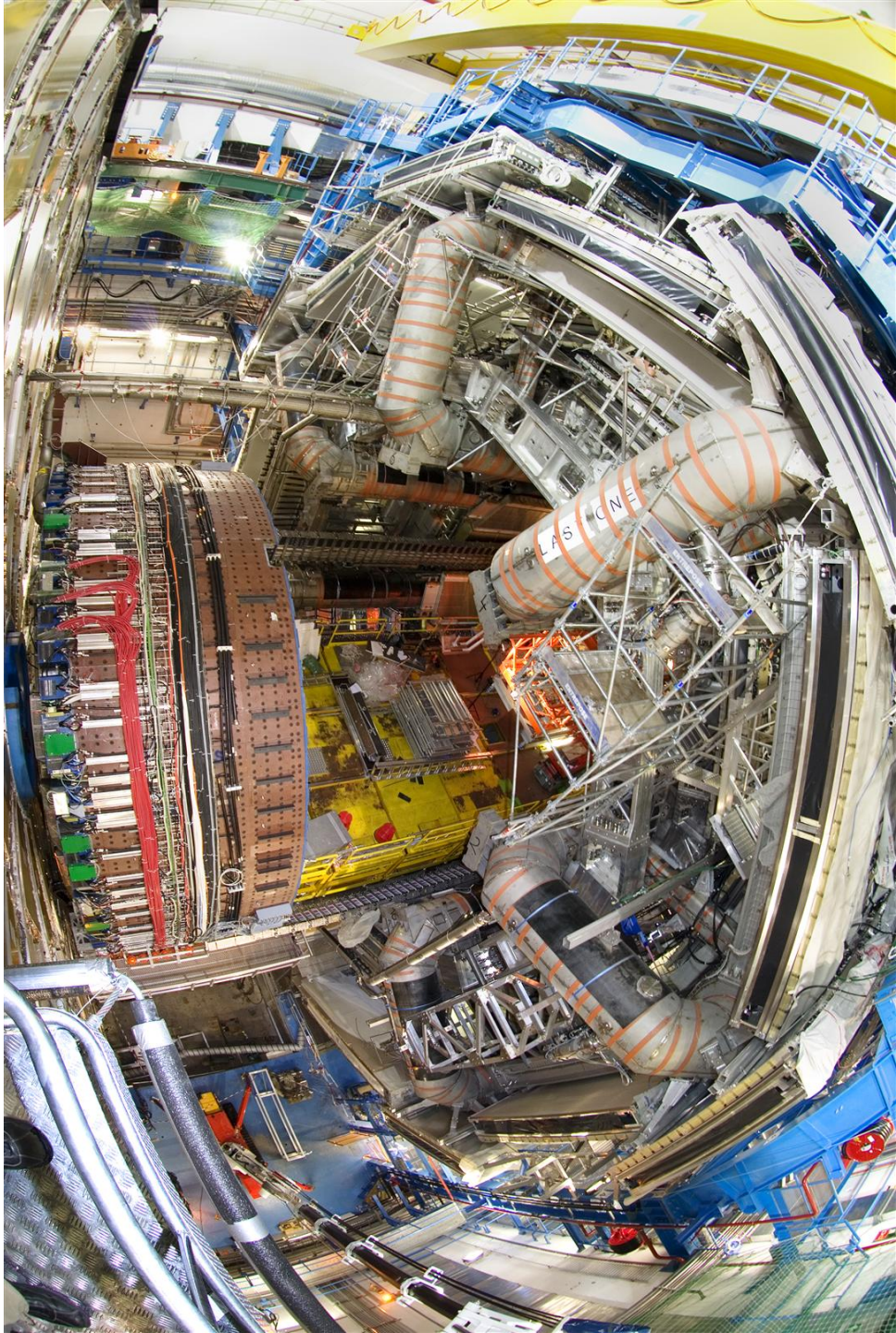


The Semiconductor Tracker

Designed to “photograph” and then filter 40 million collisions per second.

A closer look at “ATLAS”:





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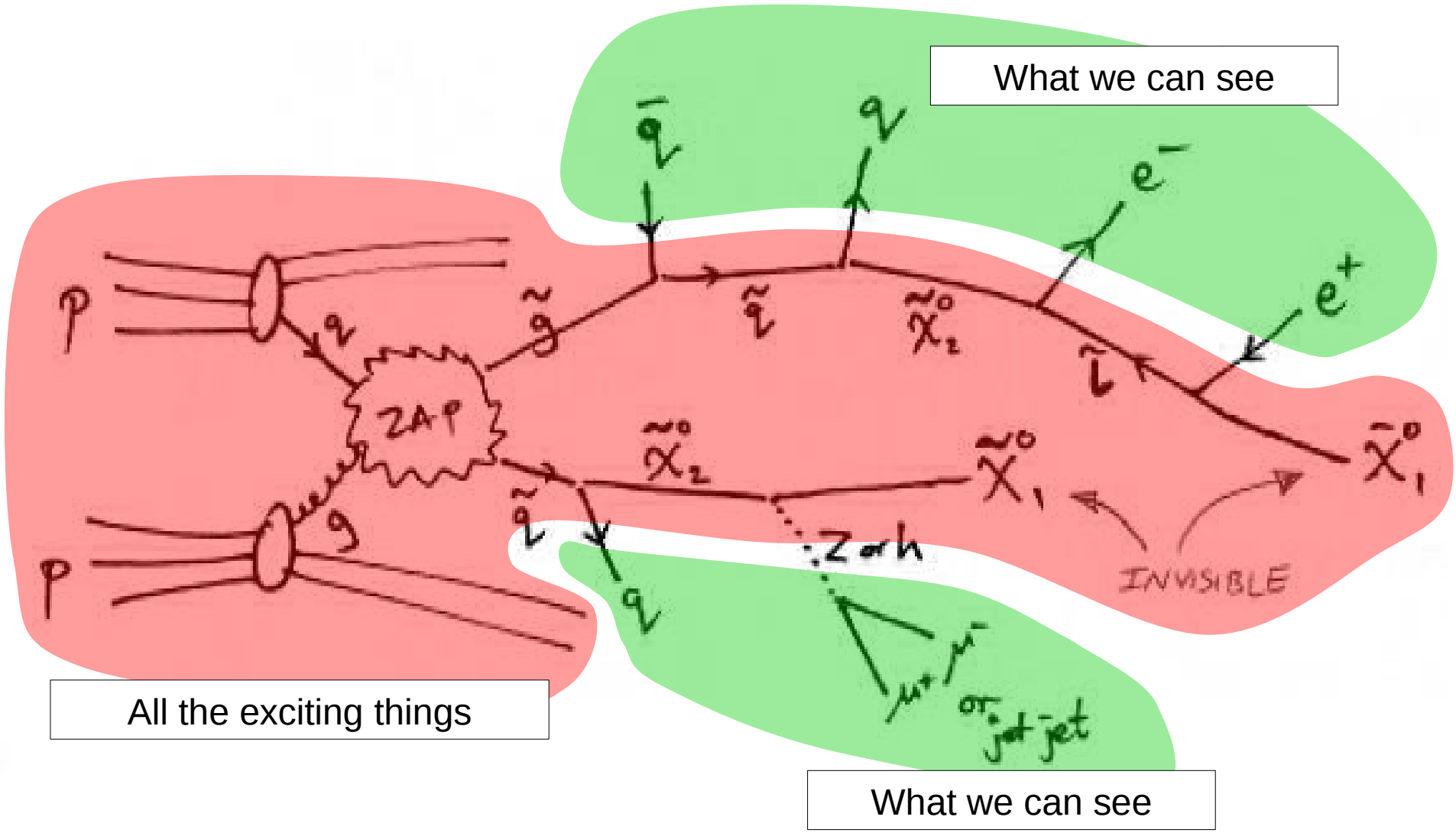
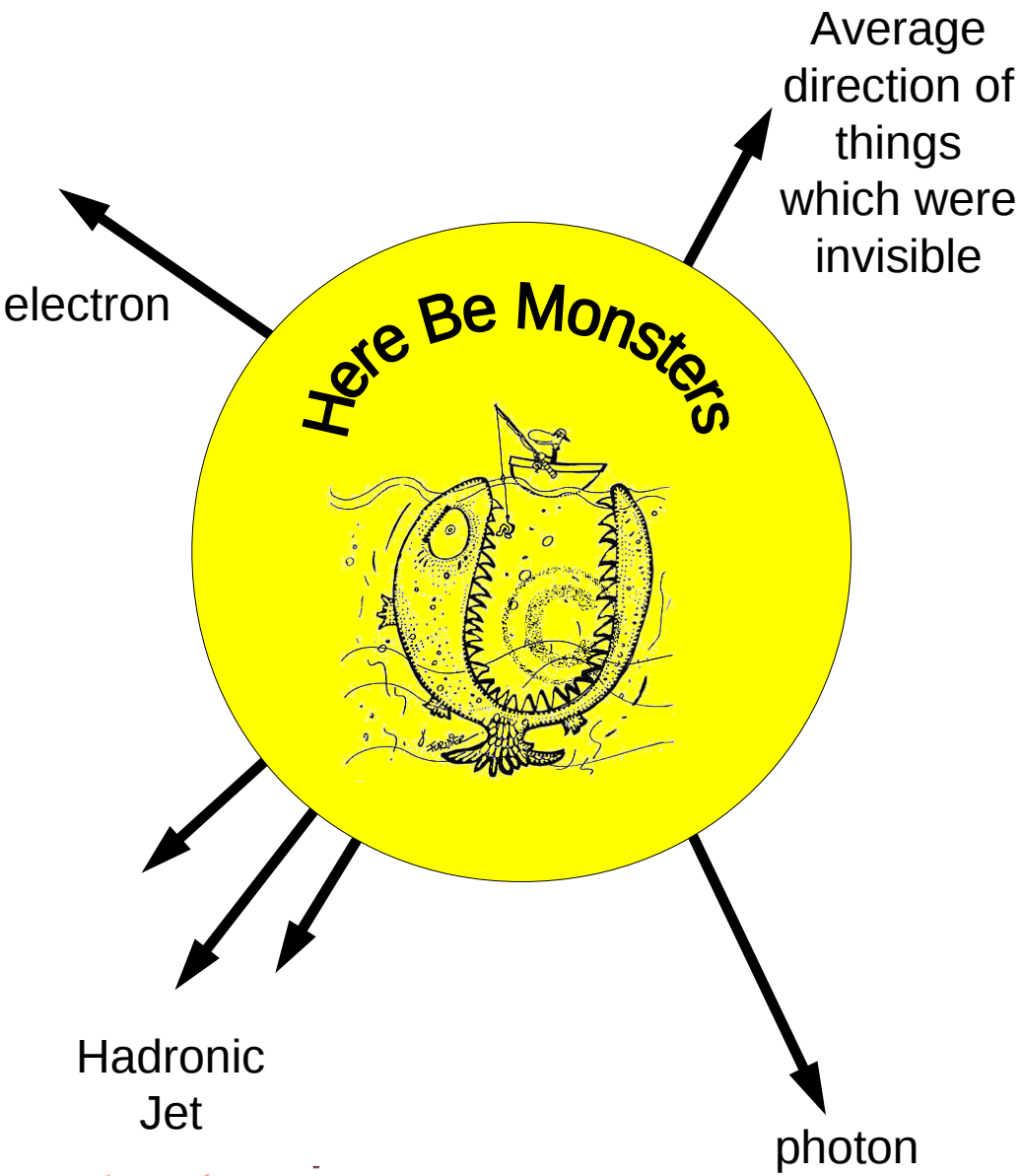
Common misconception:

- "Particle physics detectors take pictures of
  - Electrons
  - Quarks
  - Gluons
  - Photons
  - Gauge bosons
  - Supersymmetric particles
  - New Particles
  - if they are in our events."
- REALITY is quite some distance from this, which is why discoveries take time!

What is the problem?



Interesting things are hidden and we are blindfolded



Then March 2010, records broken: 3.5 TeV per beam!

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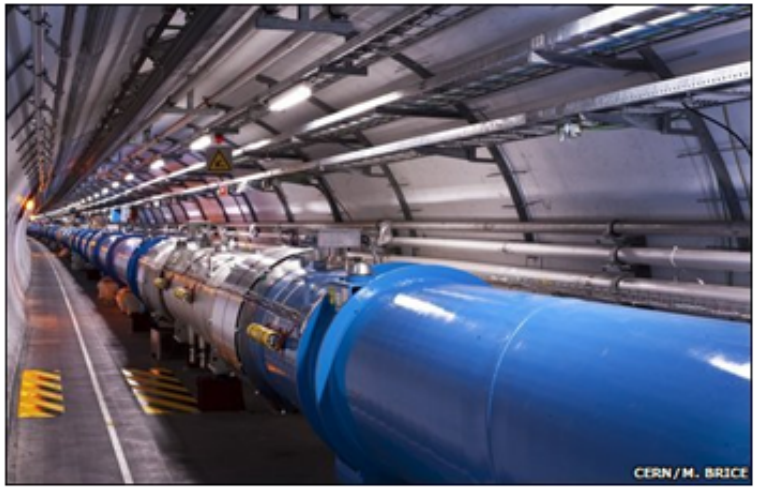
Large Hadron Collider smashes energy record again



The LHC's tunnel runs for 27km under the Franco-Swiss border

The Large Hadron Collider, the world's biggest physics experiment, has broken its own particle beam energy record.

On Friday morning, the machine created two beams of protons, each with an energy of 3.5 trillion electron volts.

The effort breaks the prior record, set by the LHC in December, of just over a trillion electron volts in each beam.

The LHC will now aim to smash those two beams together, hoping to create new particles that give insight into the most fundamental workings of physics.

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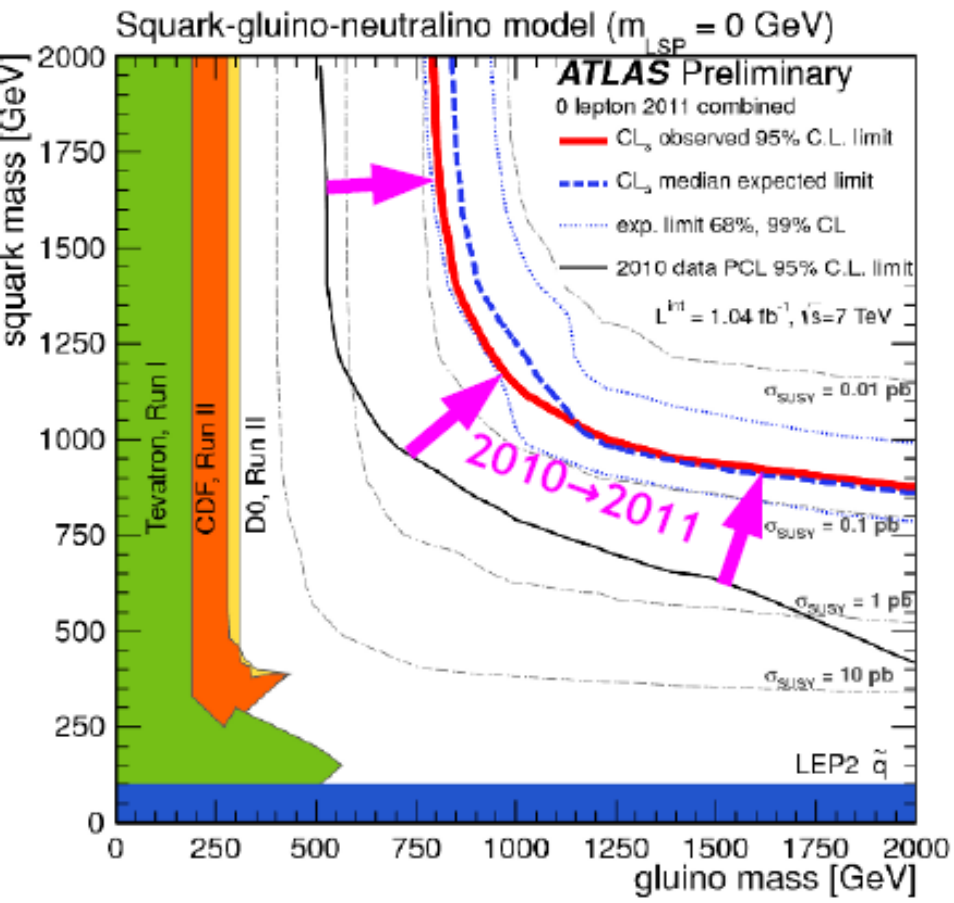
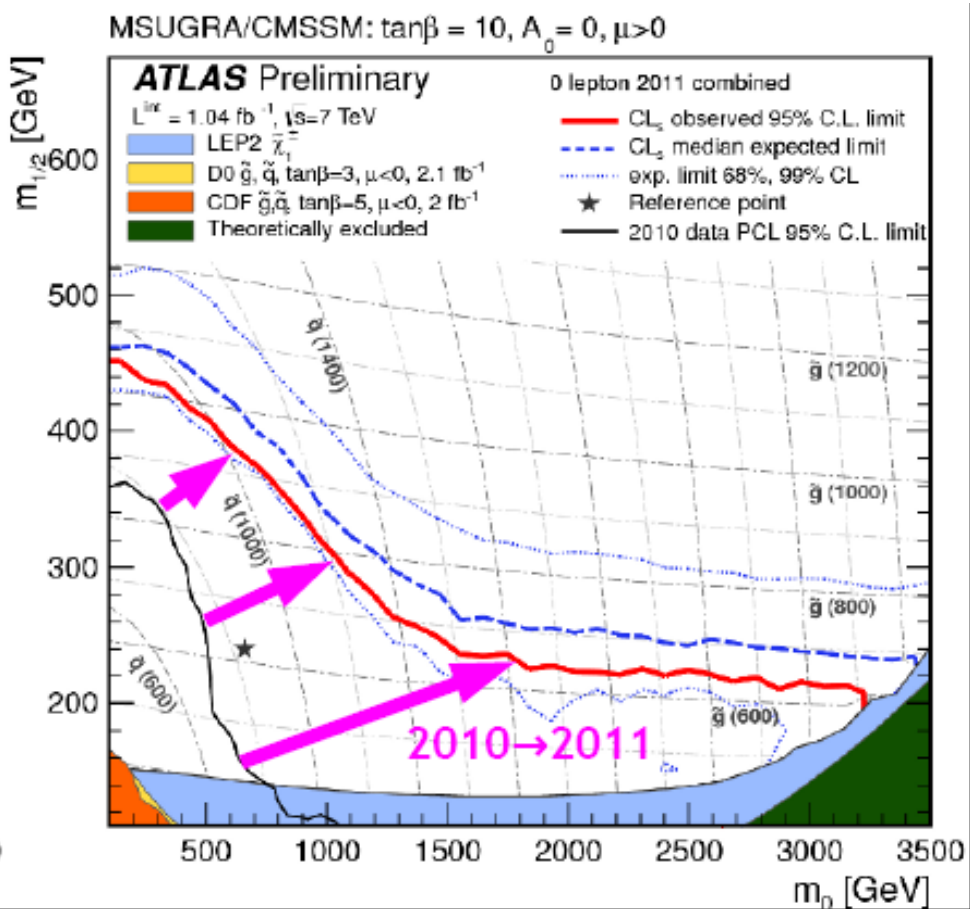
Latest results (yesterday!) …
… where is “Supersymmetry” ?





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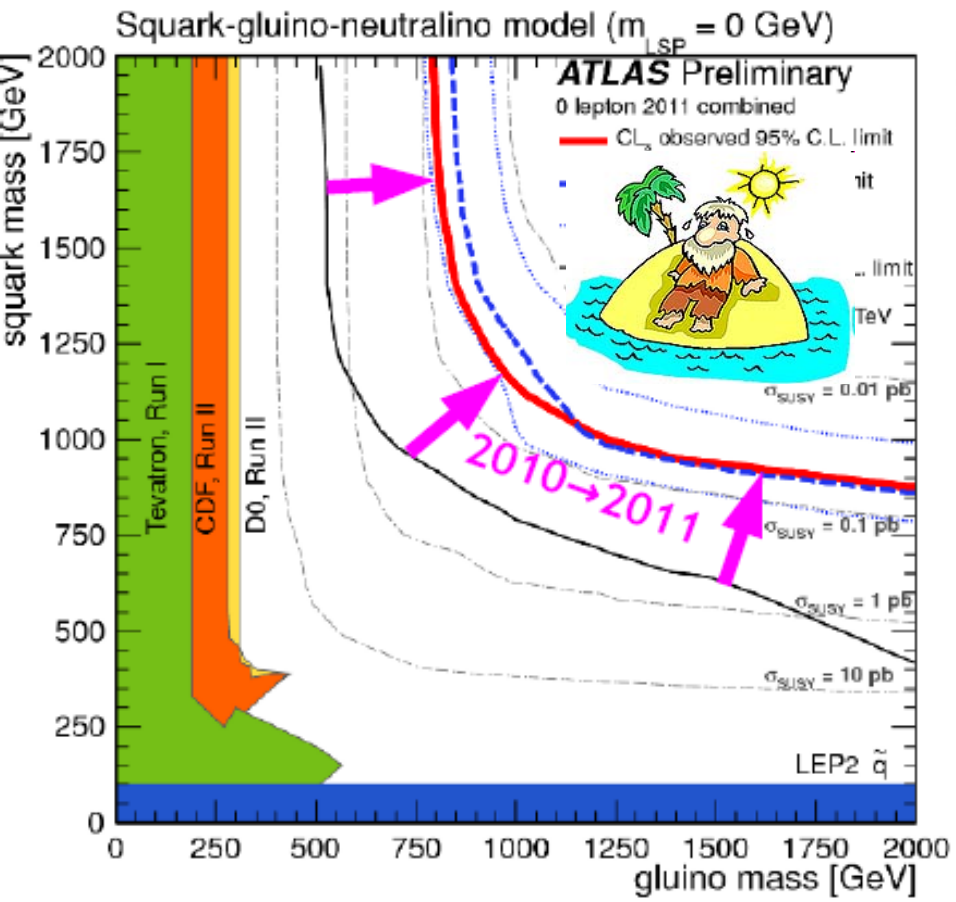
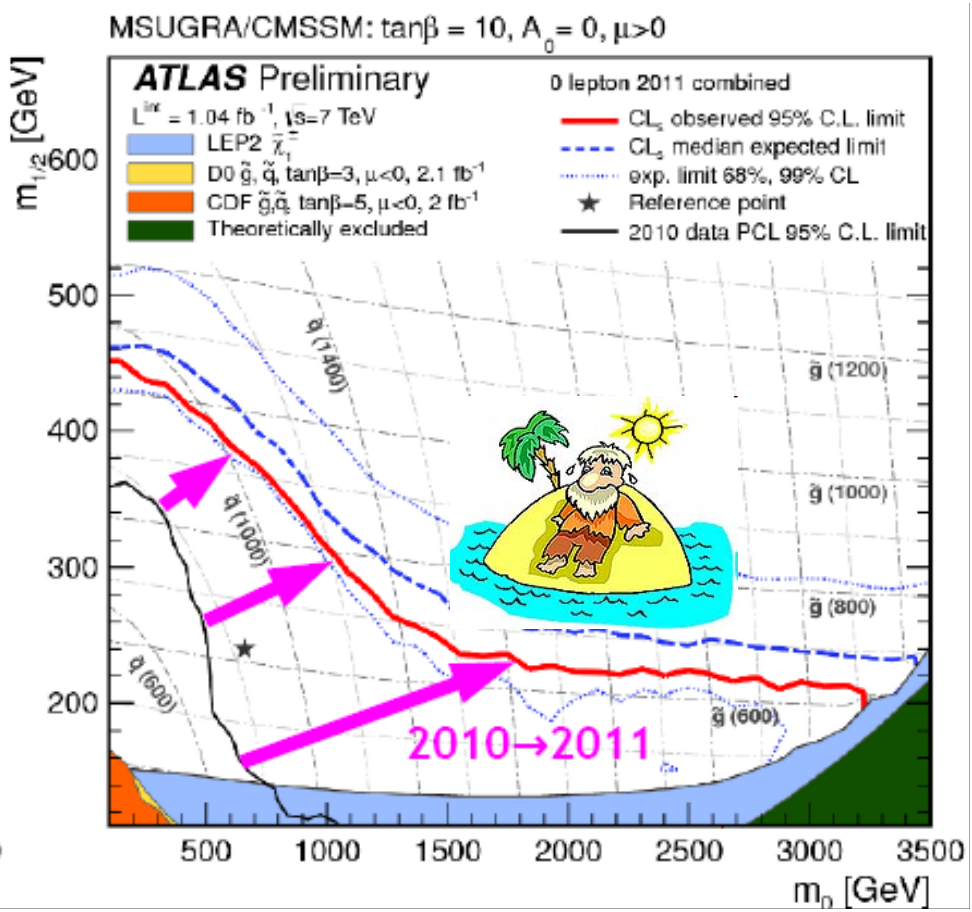
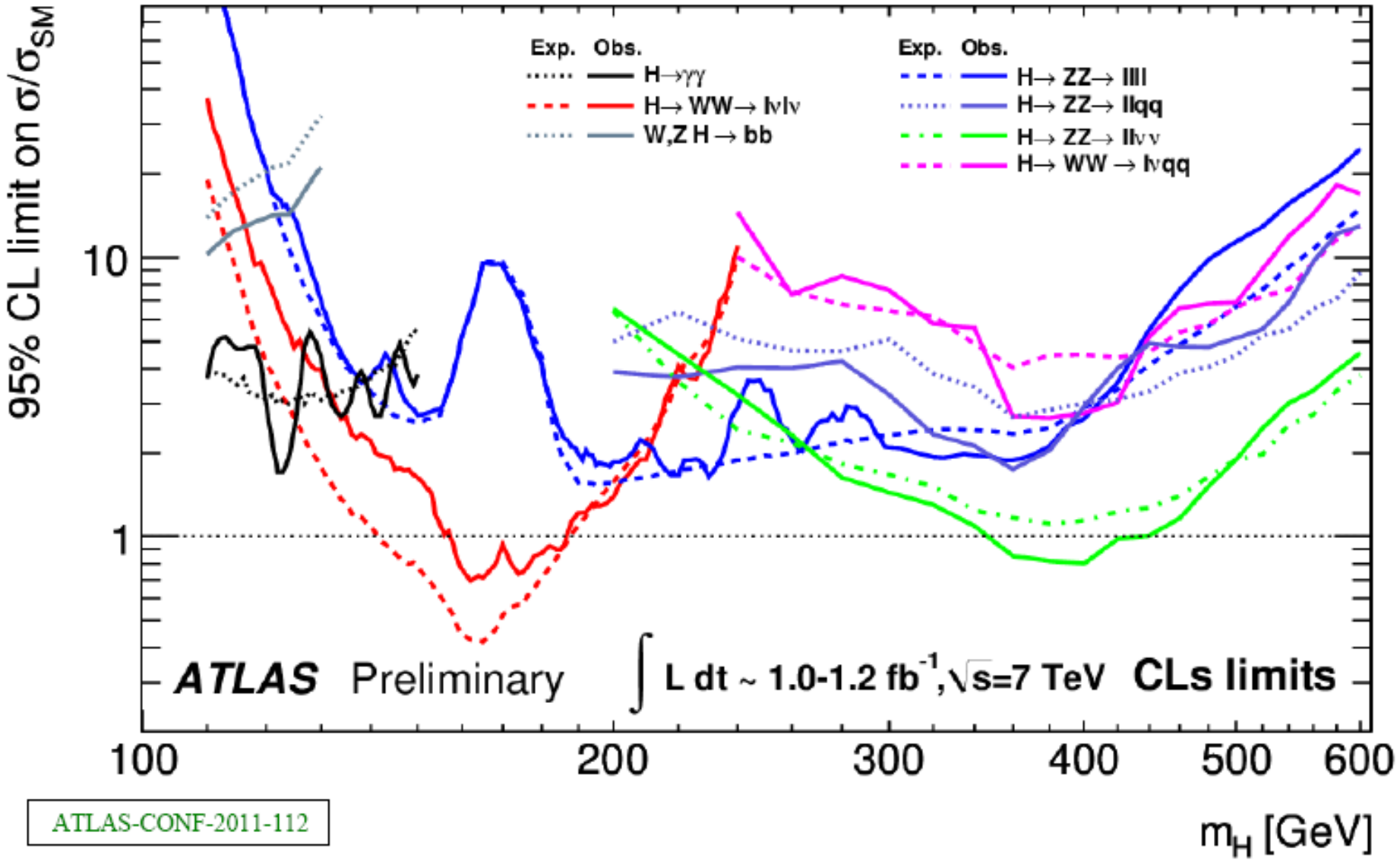


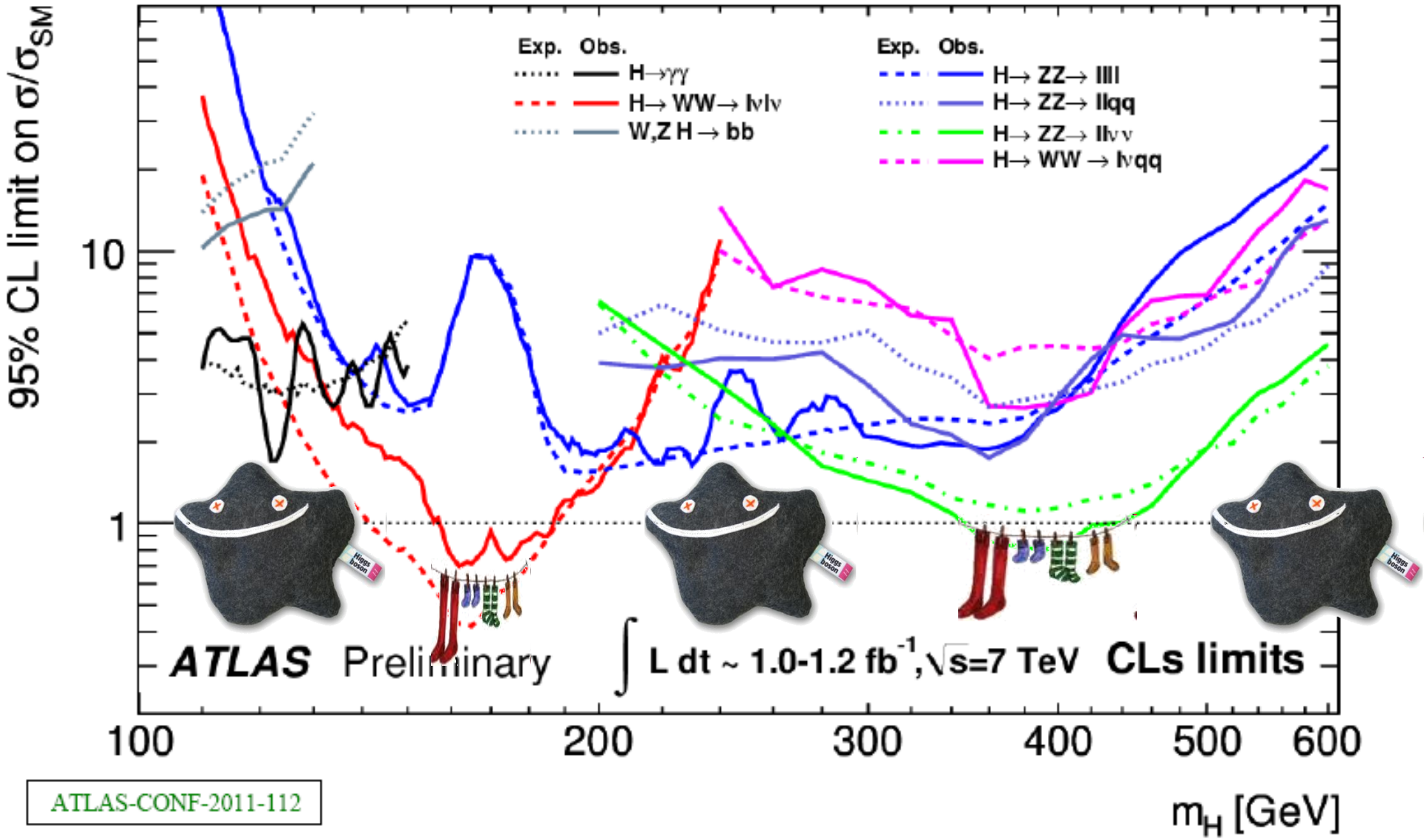


… where is the “Higgs Boson” ?



ATLAS-CONF-2011-112

Higgs "washing line" sagging under the weight of LHC data (=socks)



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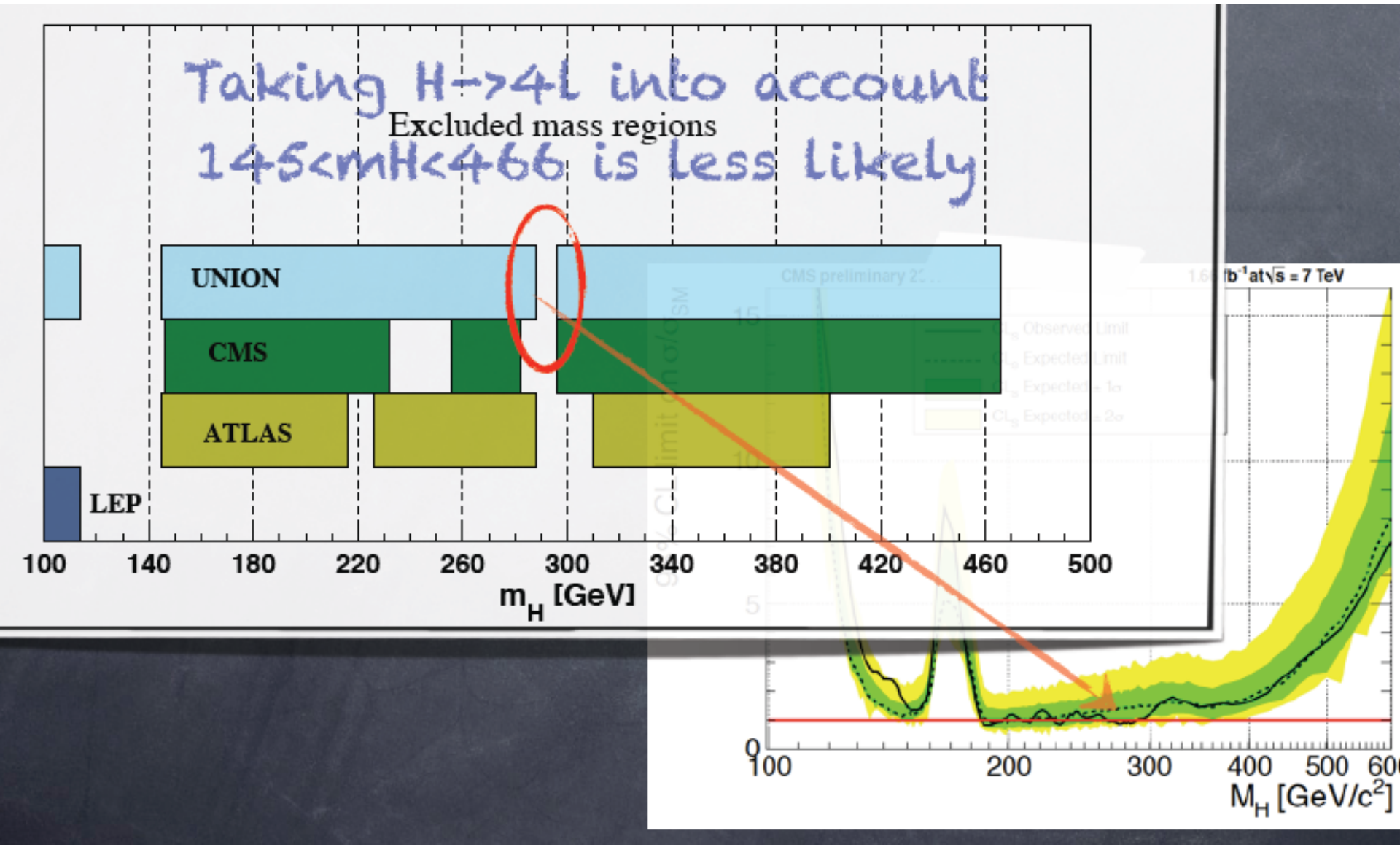
Higgs results as of Sept 2011



Get the results yourself!

https://twiki.cern.ch/twiki/bin/view/AtlasPublic

LHC and BEAM PARAMETERS

Beam Energy	3500	GeV	Inst.Luminosity	Probe Beam	
GMT Stable Beams	YES		LHC 0e+00	A 125	e8
Fill Number	1293		ATLAS 3e+00	B 125	e8
Num Colliding Bunches	16				

Accelerator Mode	Beam Mode
PROTON PHYSICS	STABLE BEAMS
Proton physics	Stable beam for physics

ATLAS	ALICE	CMS	LHCb
PHYSICS	PHYSICS	PHYSICS	PHYSICS
Handshake	Handshake	Handshake	Handshake

This morning! (last year)

BEAM 1

Type: Proton

Intensity	22.596 10^{11}
Inj. Intensity	0.000e+00
Num Bunches	25
Lifetime	-0.200

Safe Machine Parameters

Setup-Beam	No
Stable Beam	Yes
Movable Dev. Allowed	Yes
Beam Present	Yes

BEAM 2

Type: Proton

Intensity	21.502 10^{11}
Inj. Intensity	0.000e+00
Num Bunches	25
Lifetime	0.332

Safe Machine Parameters

Setup-Beam	No
Stable Beam	Yes
Movable Dev. Allowed	Yes
Beam Present	Yes

COLLIMATORS

HORIZONTAL	BEAM 1 TH 4L1 B1	BEAM 2 TH 4R1 B2
GAP down	15.22	15.13
GAP up	15.22	15.21
TOP down	8.07	6.34
TOP up	8.04	6.35
BOTTOM down	-7.18	-8.88
BOTTOM up	-7.15	-8.87

VERTICAL	TVA 4L1 B1	TVA 4R1 B2
GAP down	9.82	9.69
GAP up	9.89	9.81
LEFT down	7.09	6.40
LEFT up	7.11	6.38
RIGHT down	-2.76	-3.51
RIGHT up	-2.75	-3.51

POST MORTEM

Counter: 217

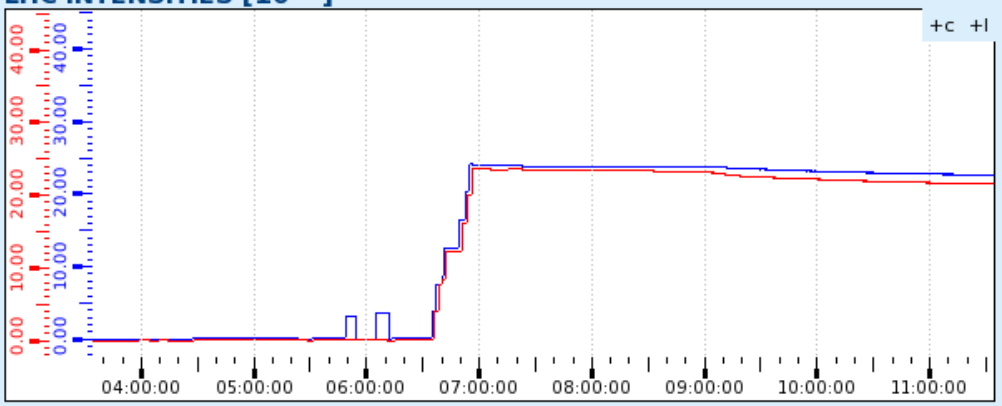
Last update: 18-08-2010 01:46:49

LHC OPERATOR MESSAGE

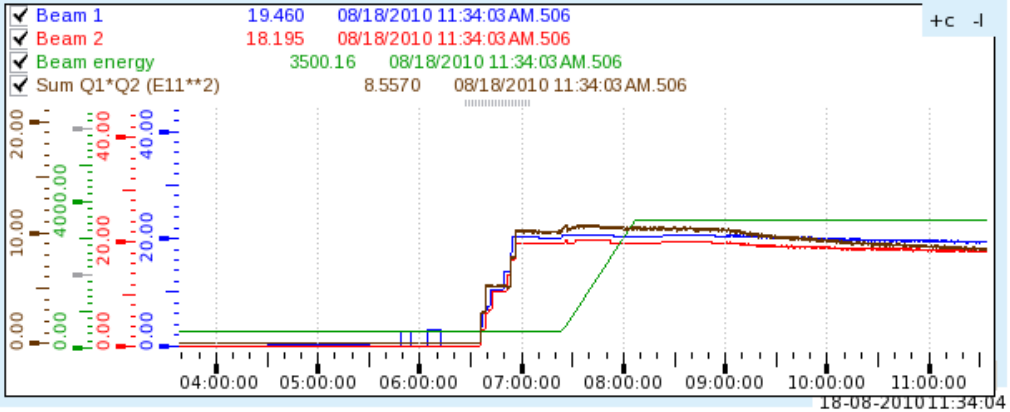
* * * STABLE BEAMS * * *

Fill for physics (25b_16_16_16)

LHC INTENSITIES [10^{11}]



ATLAS BPTX INTENSITIES [10^{11}]



18-08-2010 11:34:04

BBC News - Speed-of-light results under scrutiny at Cern - Mozilla Firefox

File Edit View History Bookmarks Tools Help

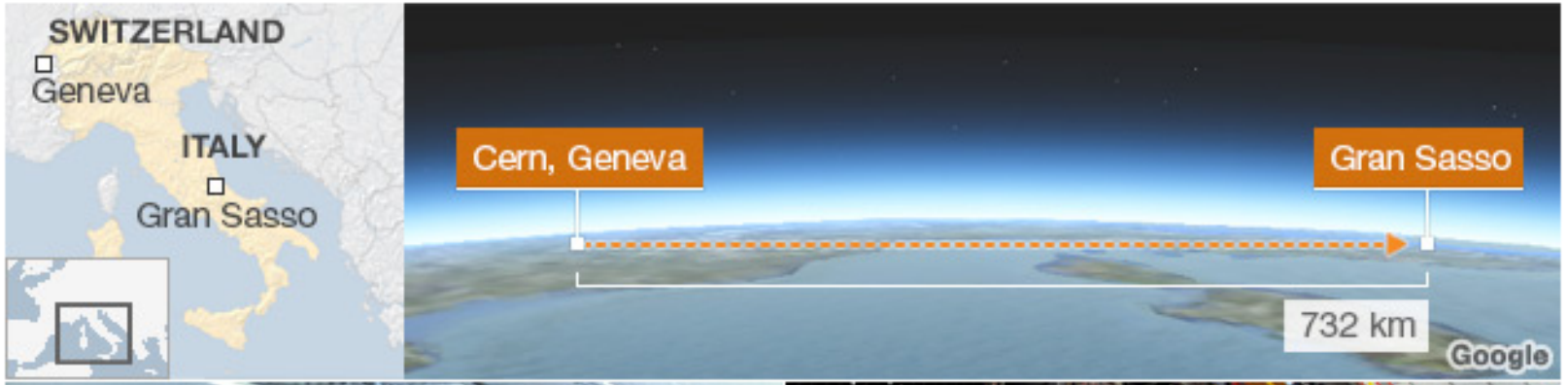
http://www.bbc.co.uk/news/science-environment-1501748

news neutrinos fa

0.0024 seconds
time taken by **neutrinos**

0.00000006 seconds
faster than the expected time

732 km
distance travelled through rock

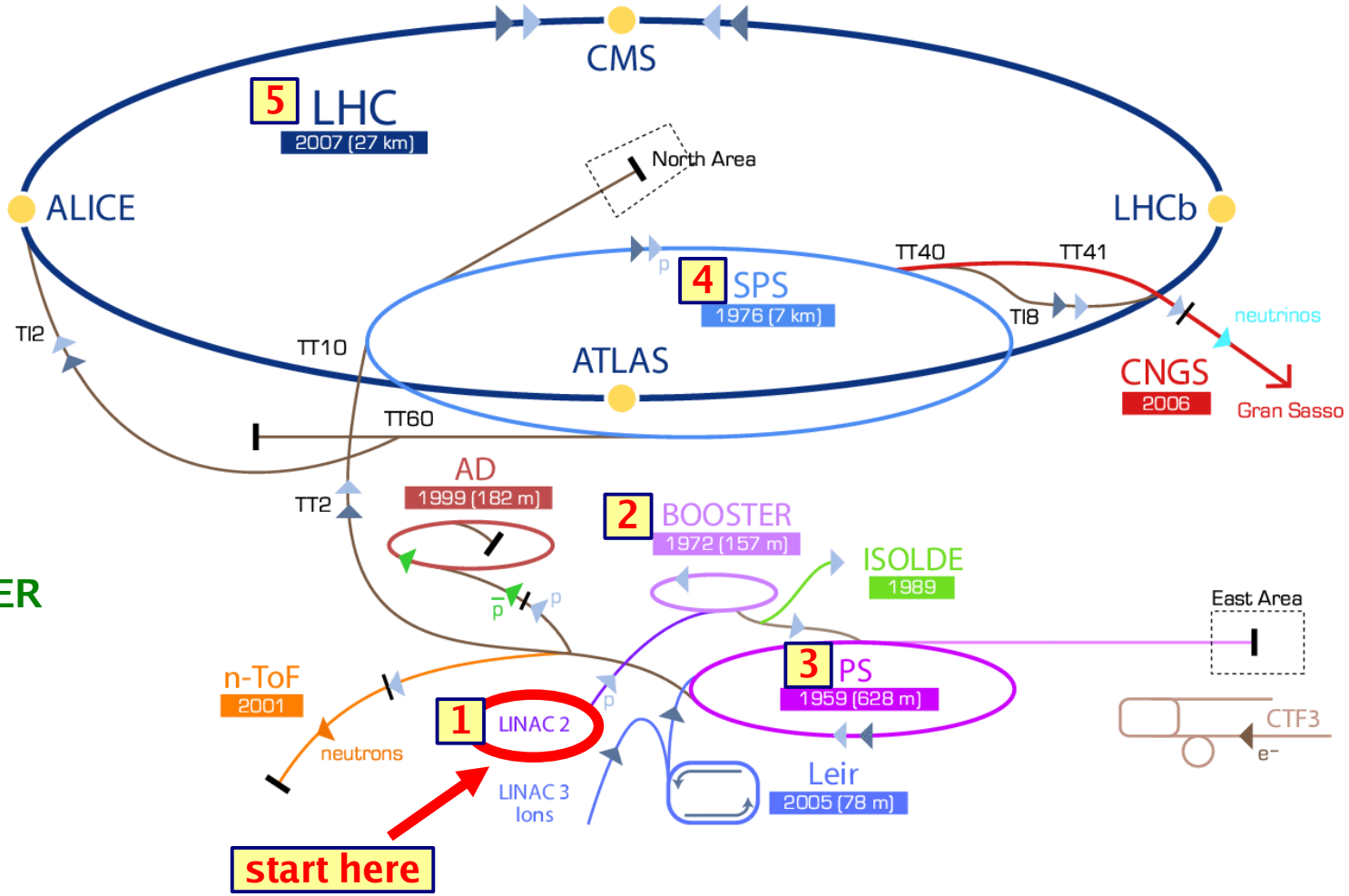


Cern, Switzerland: A beam of neutrino particles is sent through rock towards Italy

Gran Sasso, Italy: Bricks with ultrasensitive covering at underground laboratory detect arrival

CERN has many accelerators

7 GeV
5 LHC
450 GeV
4 SPS
26 GeV
3 PS
1.4 GeV
2 BOOSTER
50 MeV
1 LINAC2

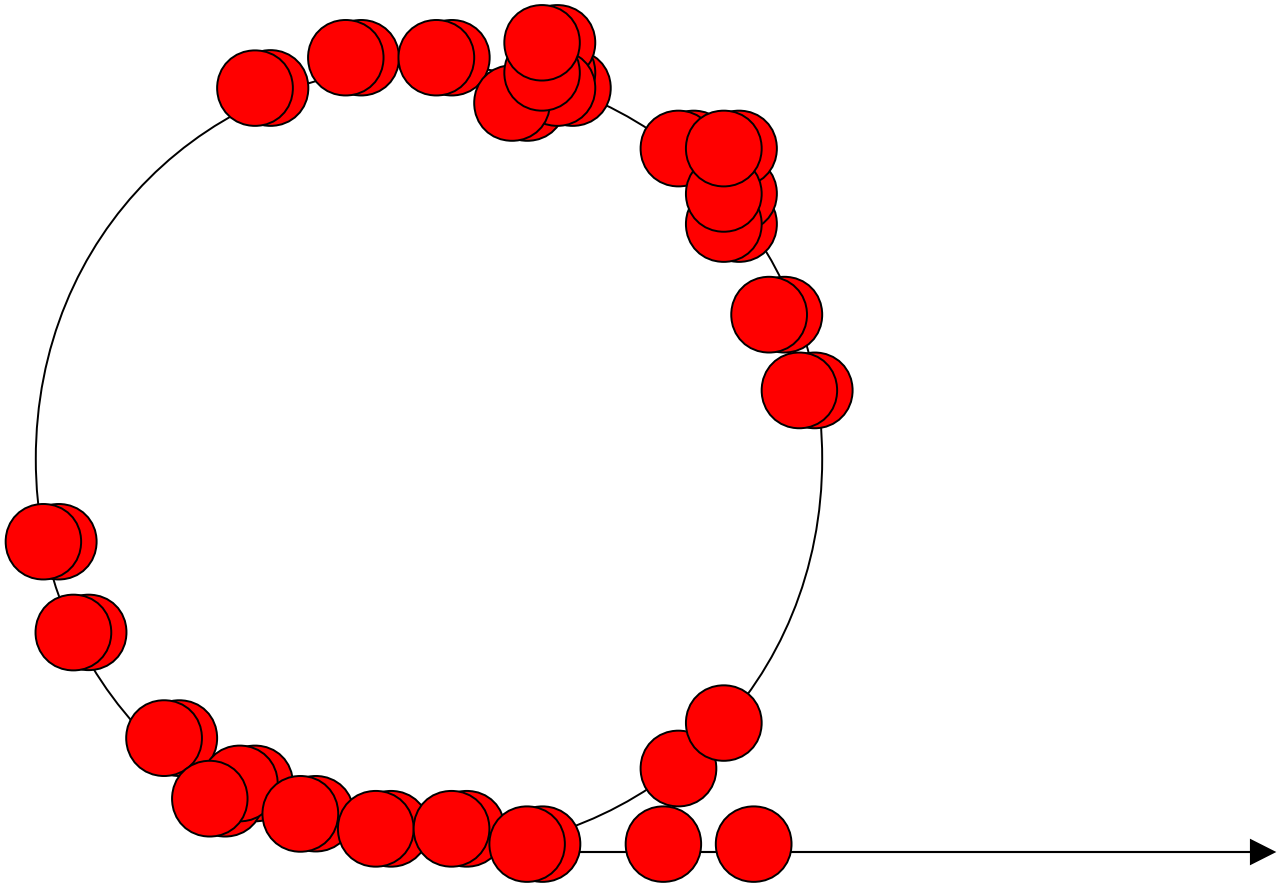


LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

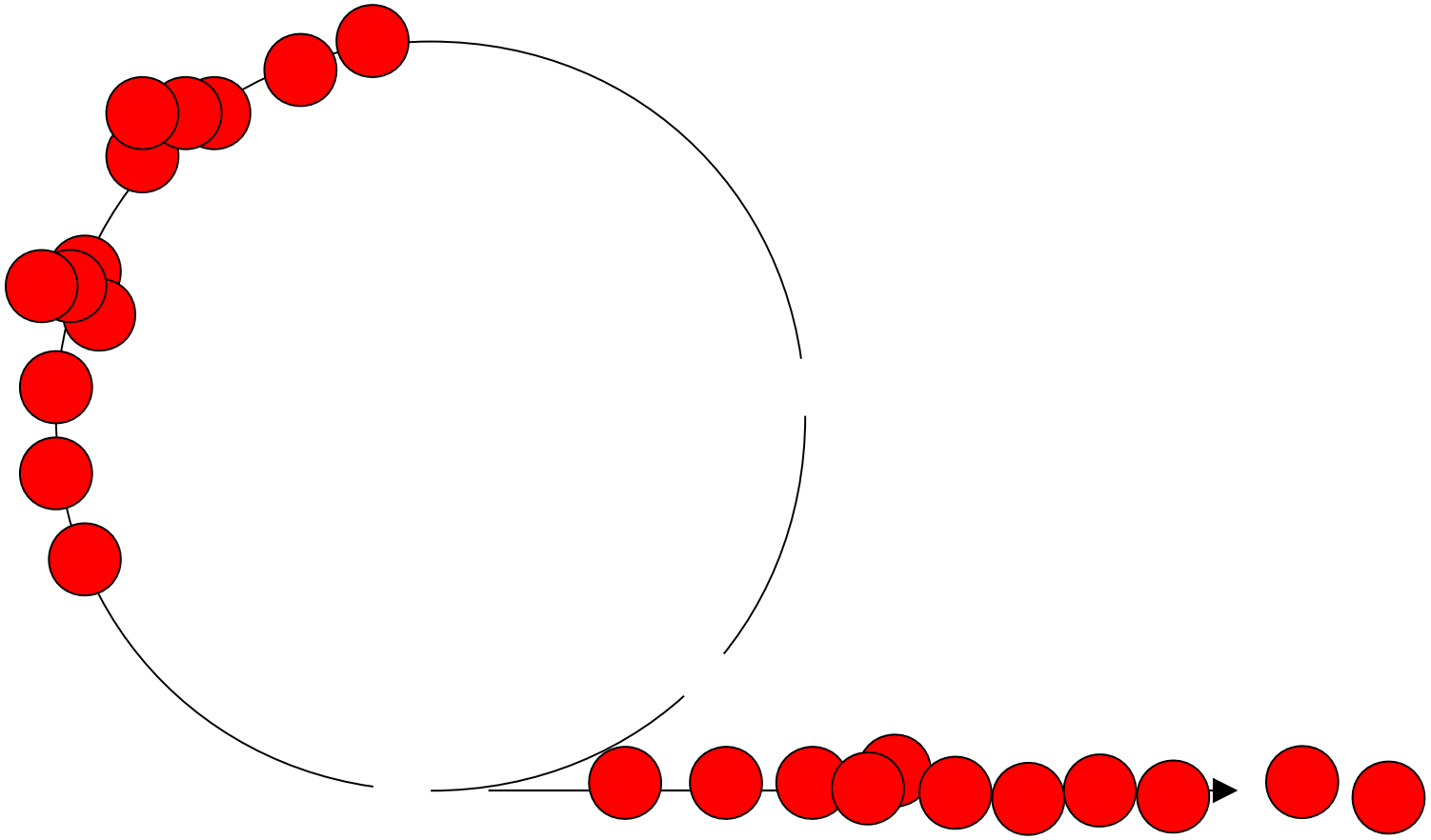
AD Antiproton Decelerator CTF3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice

LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight

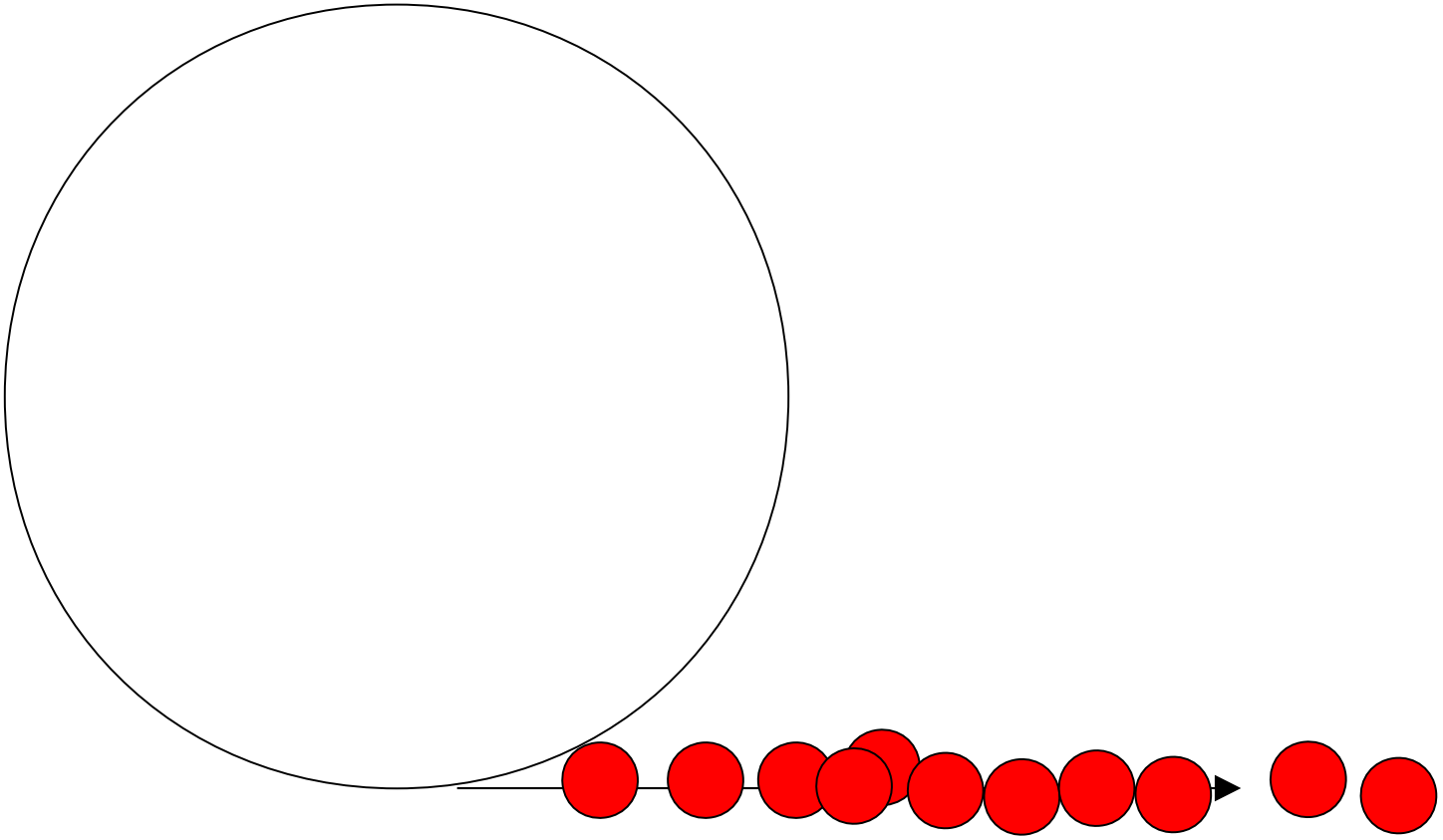
The two proton extractions



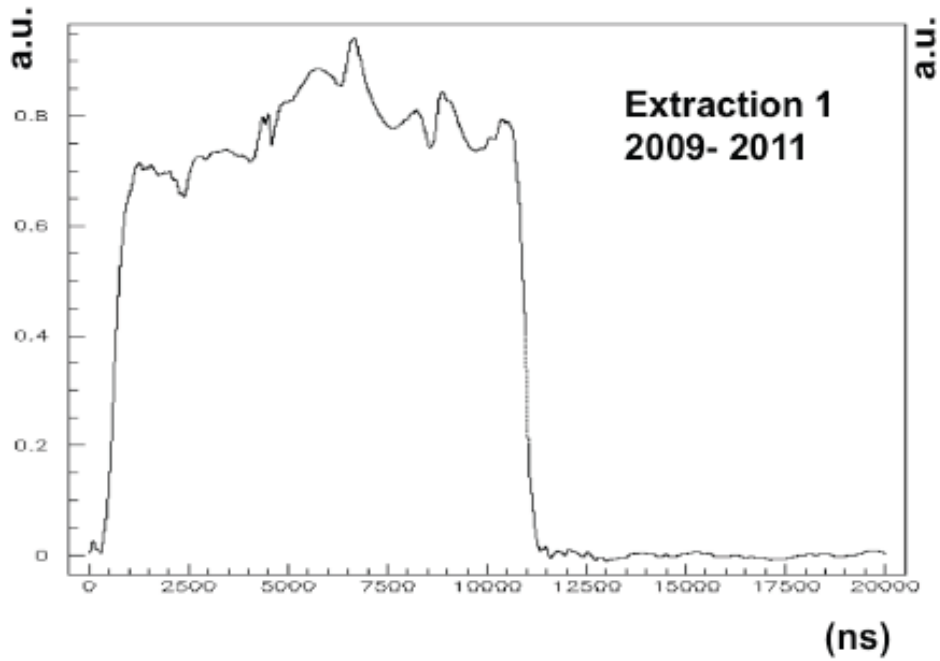
The two proton extractions



The two proton extractions



The proton extraction signatures for the “first” and “second” extractions.



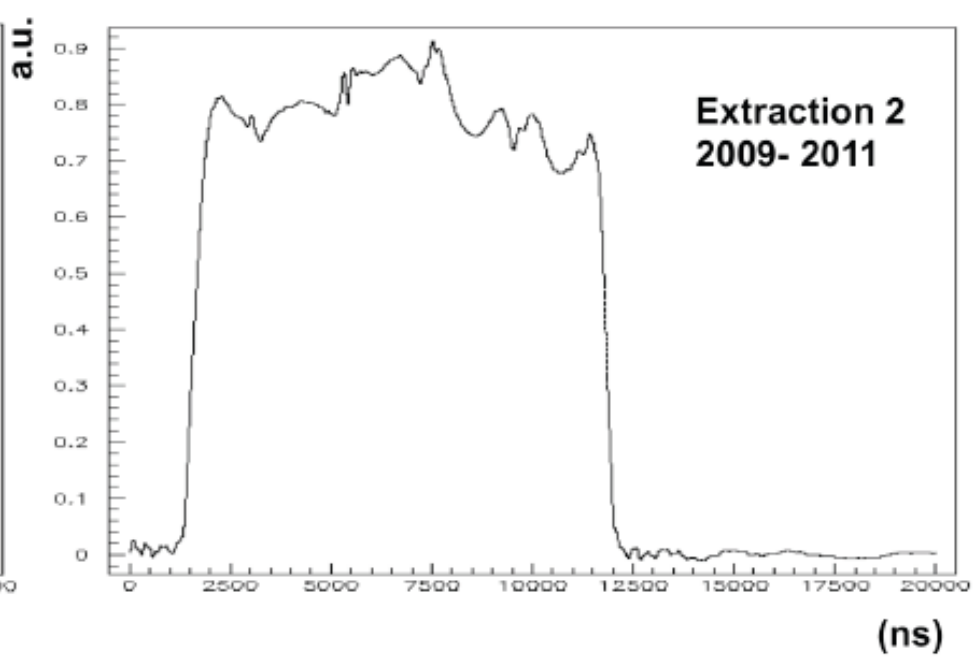
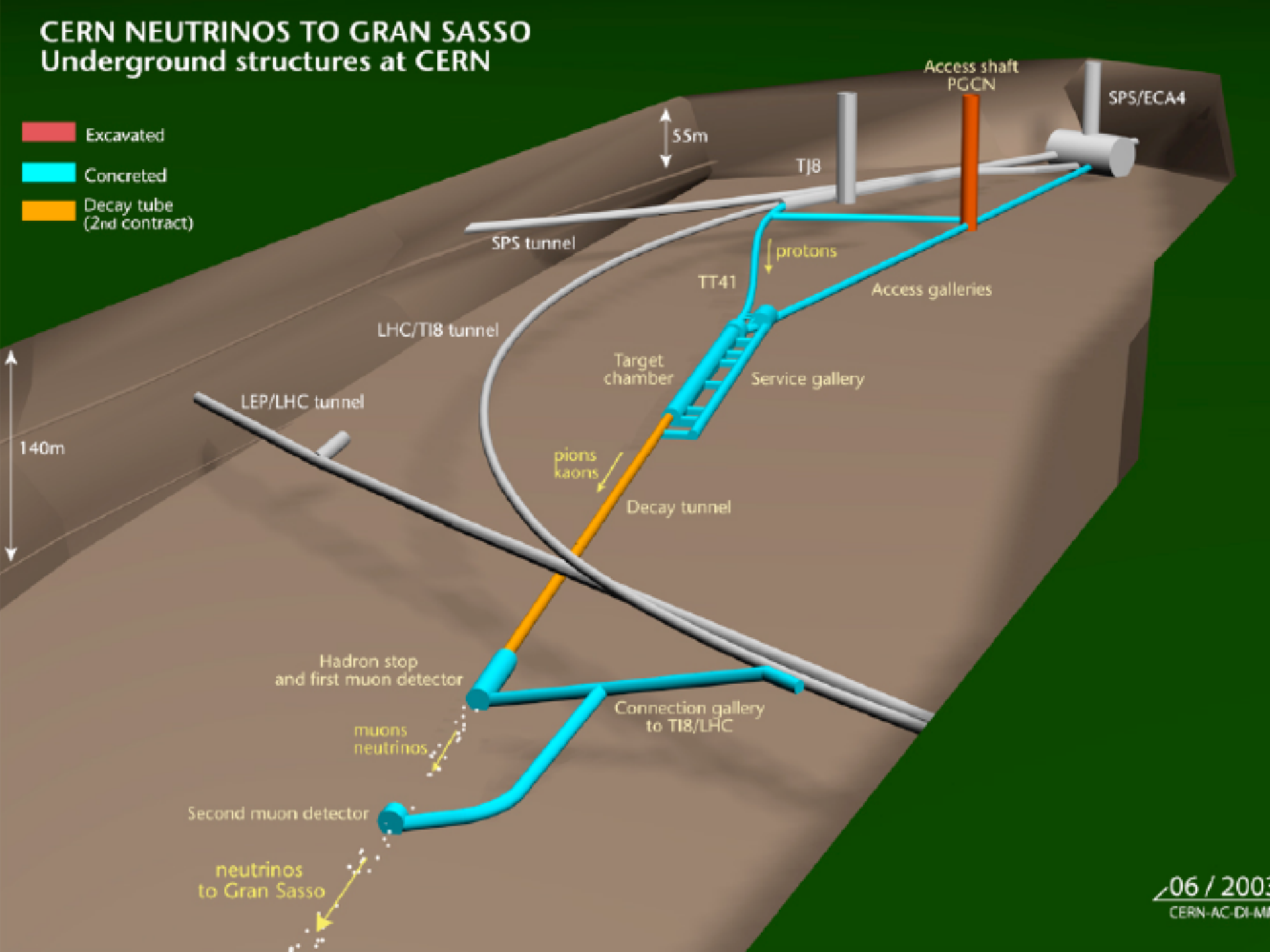


Fig. 9: Summed proton waveforms of the OPERA events corresponding to the two SPS extractions for the 2009, 2010 and 2011 data samples.


CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN
Excavated
Concreted
Decay tube
(2nd contract)
Access shaft
PGCN
SPS/ECA4
55m
TI8
SPS tunnel
protons
TT41
Access galleries
LHC/TI8 tunnel
Target
chamber
Service gallery
LEP/LHC tunnel
140m
pions
kaons
Decay tunnel
Hadron stop
and first muon detector
Connection gallery
to TI8/LHC
muons
neutrinos
Second muon detector
neutrinos
to Gran Sasso
06 / 2003
CERN-AC-DI-MI

Making neutrinos from the protons

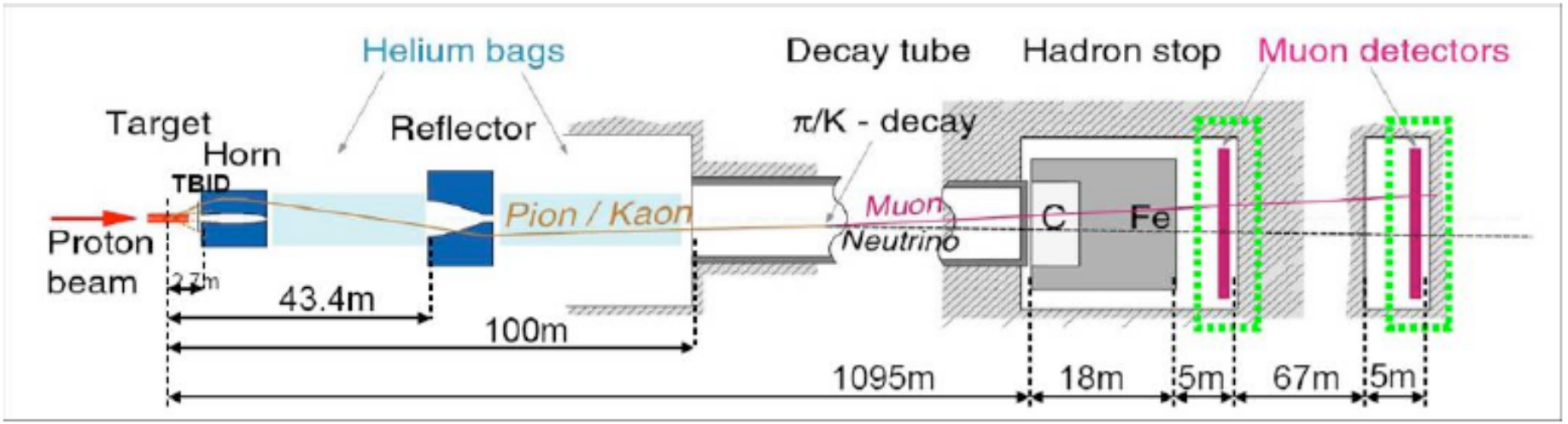
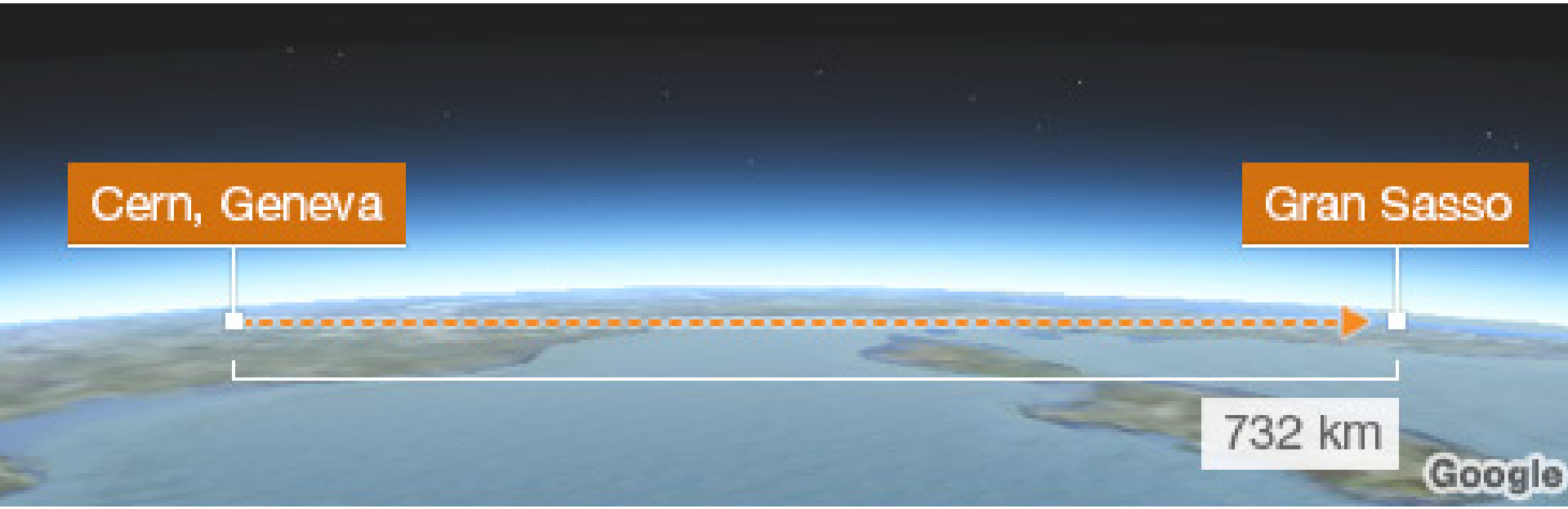


Fig.2: Layout of the CNGS beam line.

Neutrinos go through planet to Italy



What the neutrino distributions look like on arrival (data points) compared to protons at production (red curves)

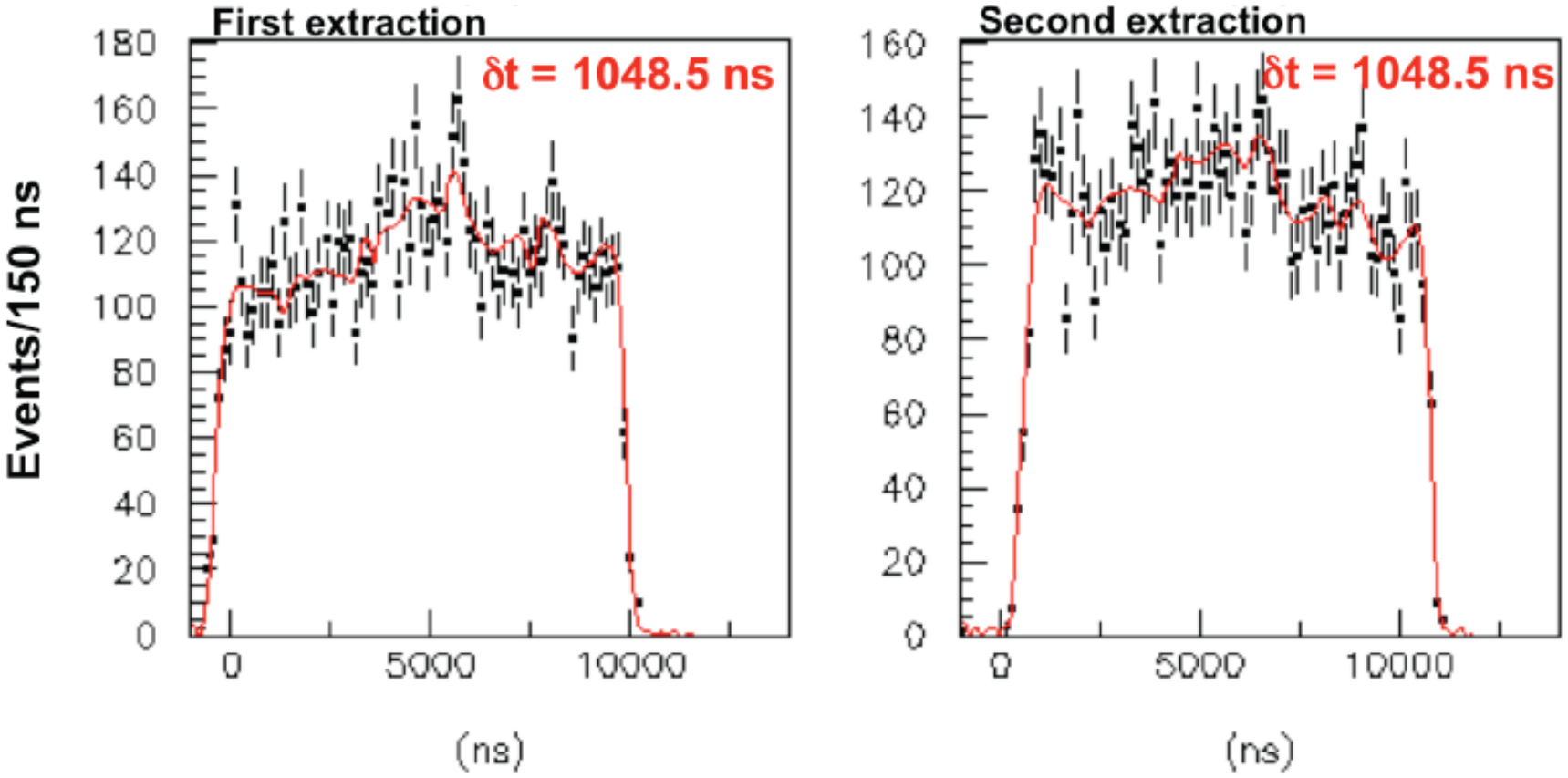
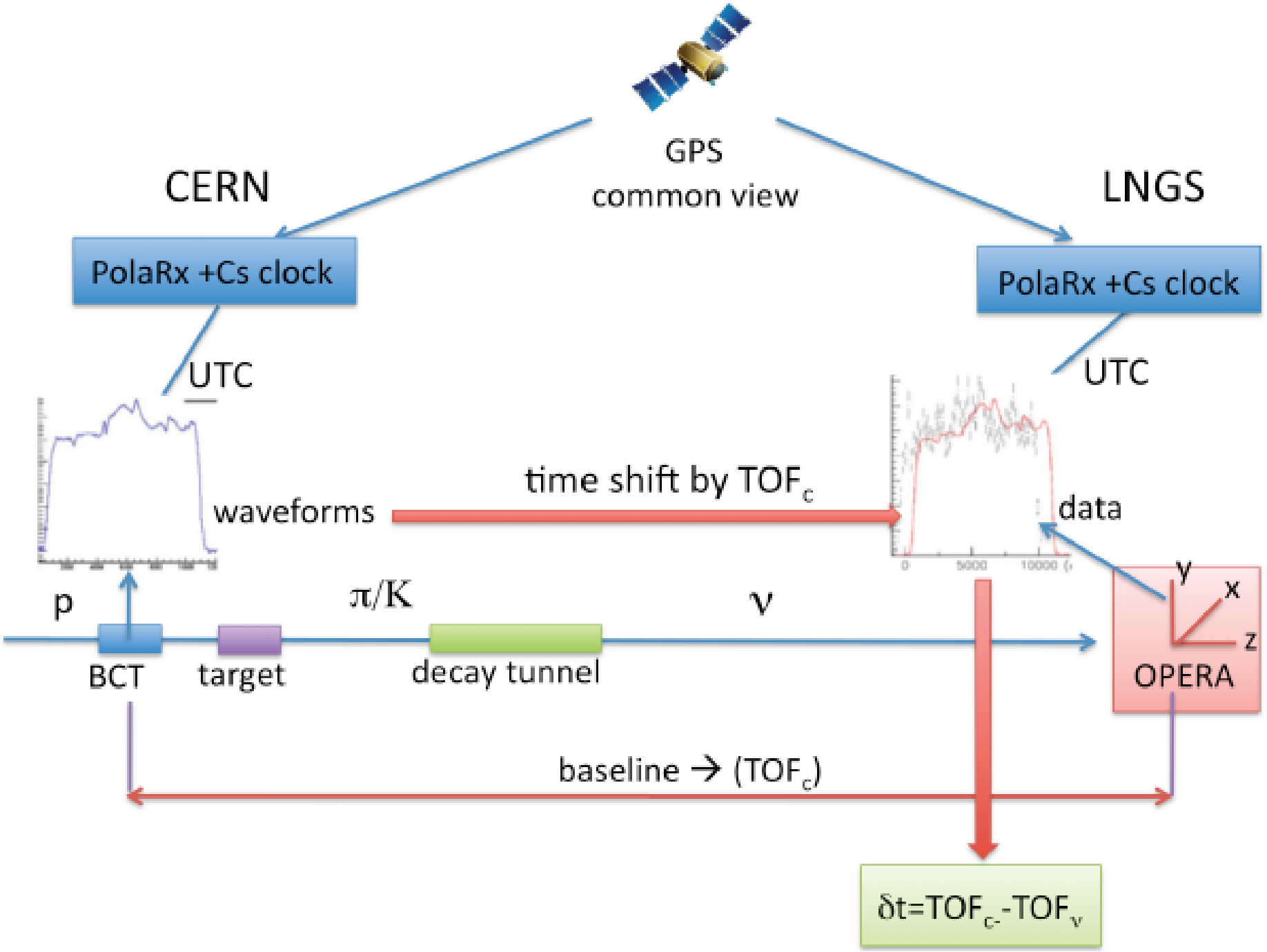


Fig. 11: Comparison of the measured neutrino interaction time distributions (data points) and the proton PDF (red line) for the two SPS extractions before (top) and after (bottom) correcting for δt (blind) resulting from the maximum likelihood analysis.

To measure a speed,
need distance and time


GPS
common view
CERN
LNGS
PolaRx +Cs clock
PolaRx +Cs clock
UTC
UTC
waveforms
time shift by TOF$_c$
data
p
π/K
ν
BCT
target
decay tunnel
OPERA
y
x
z
baseline → (TOF$_c$)
δt=TOF$_c$-TOF$_ν$

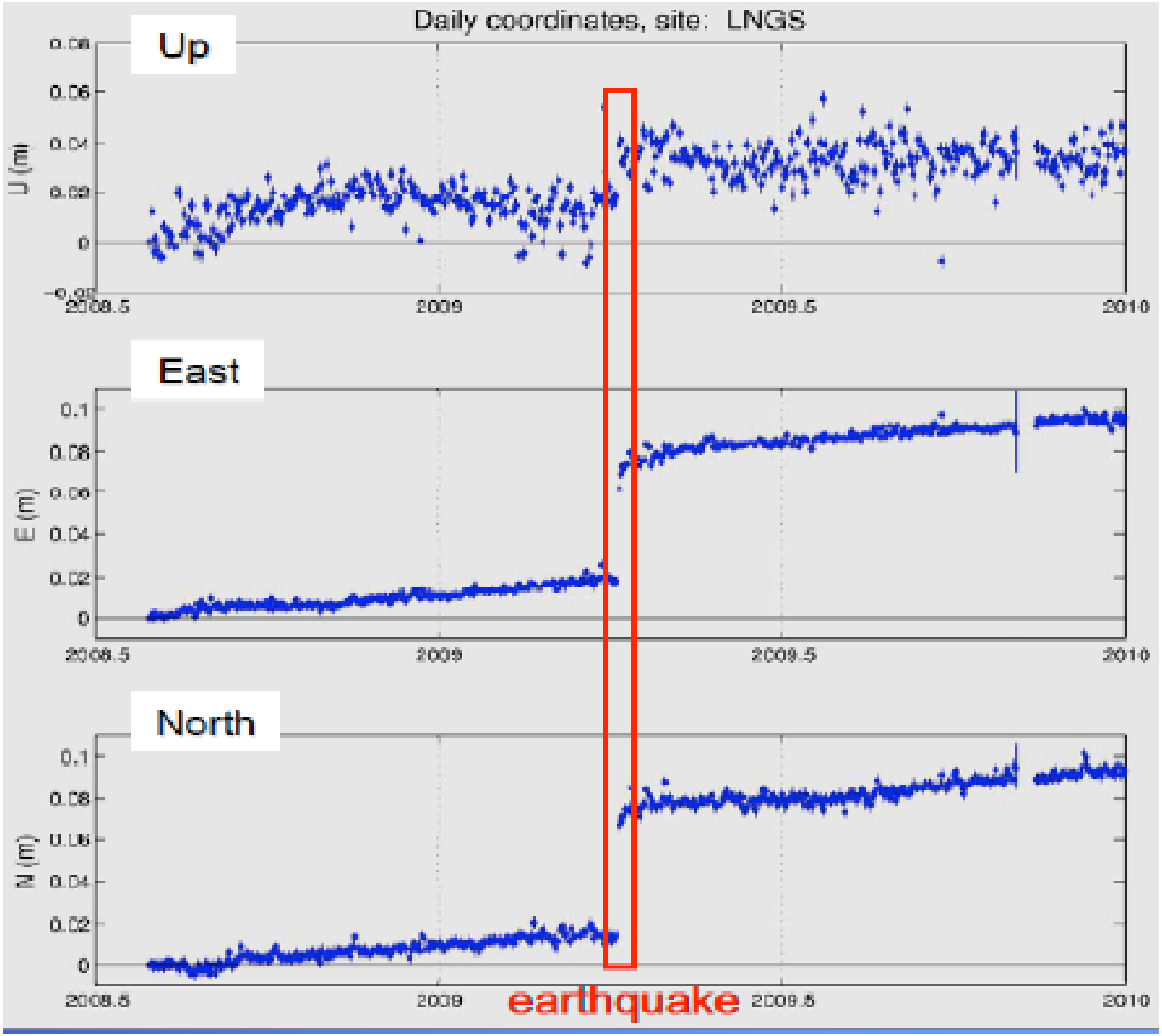


Fig. 7: Monitoring of the PolaRx2e GPS antenna position at LNGS, showing the slow earth crust drift and the fault displacement due to the 2009 earthquake in the L'Aquila region. Units for the horizontal (vertical) axis are years (meters).

Corrections for continental drift

The OPERA neutrino result

$$\delta t = TOF_c - TOF_\nu = (60.7 \pm 6.9\ (stat.) \pm 7.4\ (sys.))\ ns.$$

But this only includes the known unknowns.

The unknown unknowns could be of any size!

Where next?

- MINOS vows to refute/confirm within ~ 6 months
- Theorists have published scores of ambulance chasing papers, but most Lorentz-Violating “tachyon” theories don’t sit easily with existing MINOS and SN1987a result.
- In the mean time, my money is on a gross mistake:
  - Head of Department: “I’m too old for this”
  - “Oops-Lion” 1976
  - Double bump (forget name)
  - Endless stories at coffee
  - Internet makes things worse
- But amazing if it gets confirmed!

Let’s finish here!

Peterhouse Cambridge

Oldest and Smallest of the Cambridge Colleges