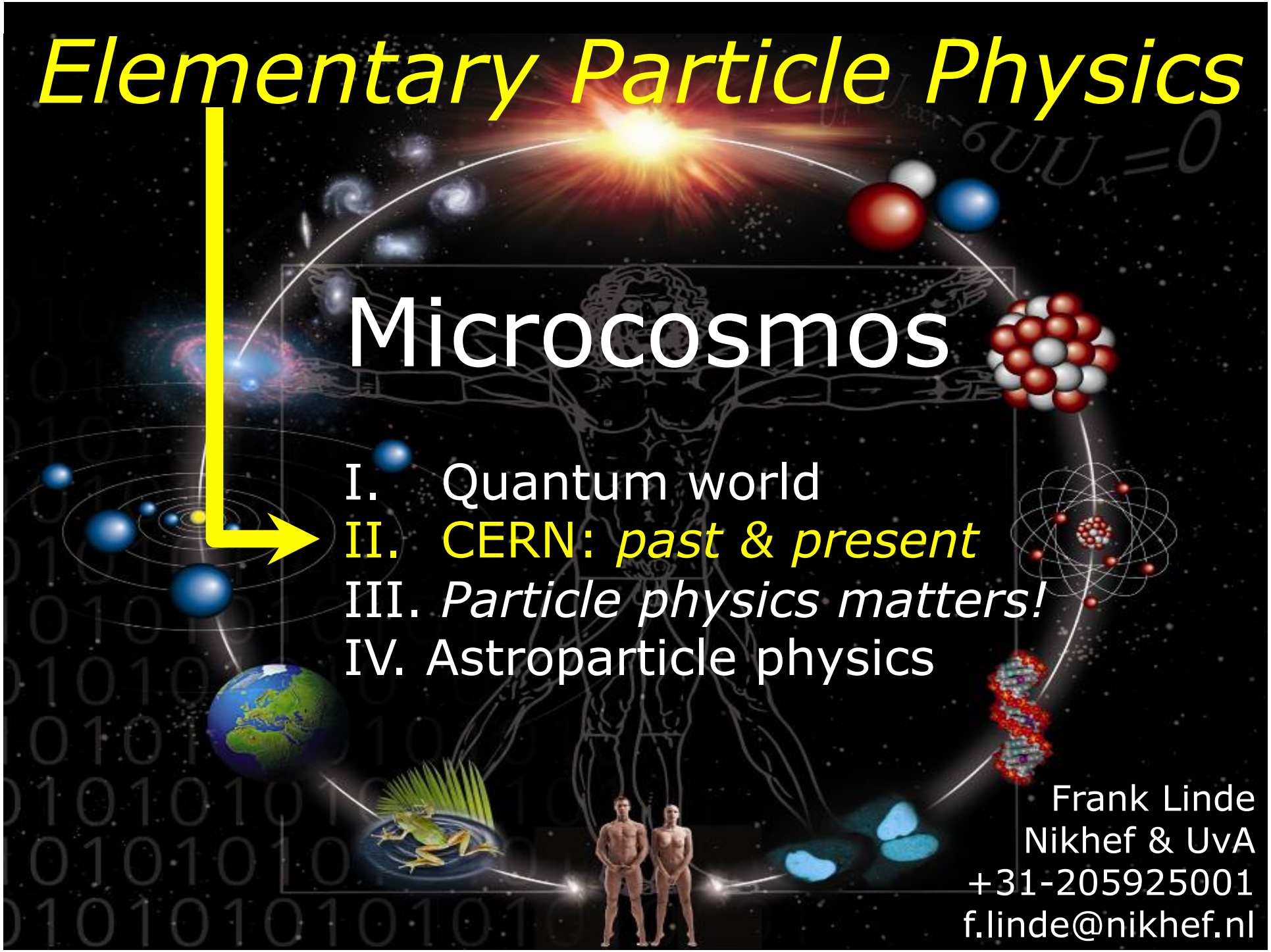
Elementary Particle Physics



Microcosmos

I. Quantum world
II. CERN: *past & present*
III. *Particle physics matters!*
IV. Astroparticle physics

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Quest: building blocks of matter

$$\mathcal{L}_{GWS} = \sum_f (\bar{\Psi}_f (i\gamma^\mu \partial\mu - m_f)\Psi_f - eQ_f \bar{\Psi}_f \gamma^\mu \Psi_f A_\mu) +$$

$$+\frac{g}{\sqrt{2}} \sum_i (\bar{a}^i_L \gamma^\mu b^i_L W^+_\mu + \bar{b}^i_L \gamma^\mu a^i_L W^-_\mu) + \frac{g}{2c_w} \sum_f \bar{\Psi}_f \gamma^\mu (I^3_f - 2s^2_w Q_f - I^3_f \gamma_5) \Psi_f Z_\mu +$$

$$-\frac{1}{4}|\partial_\mu A_\nu - \partial_\nu A_\mu - ie(W^-_\mu W^+_\nu - W^+_\mu W^-_\nu)|^2 - \frac{1}{2}|\partial_\mu W^+_\nu - \partial_\nu W^+_\mu +$$

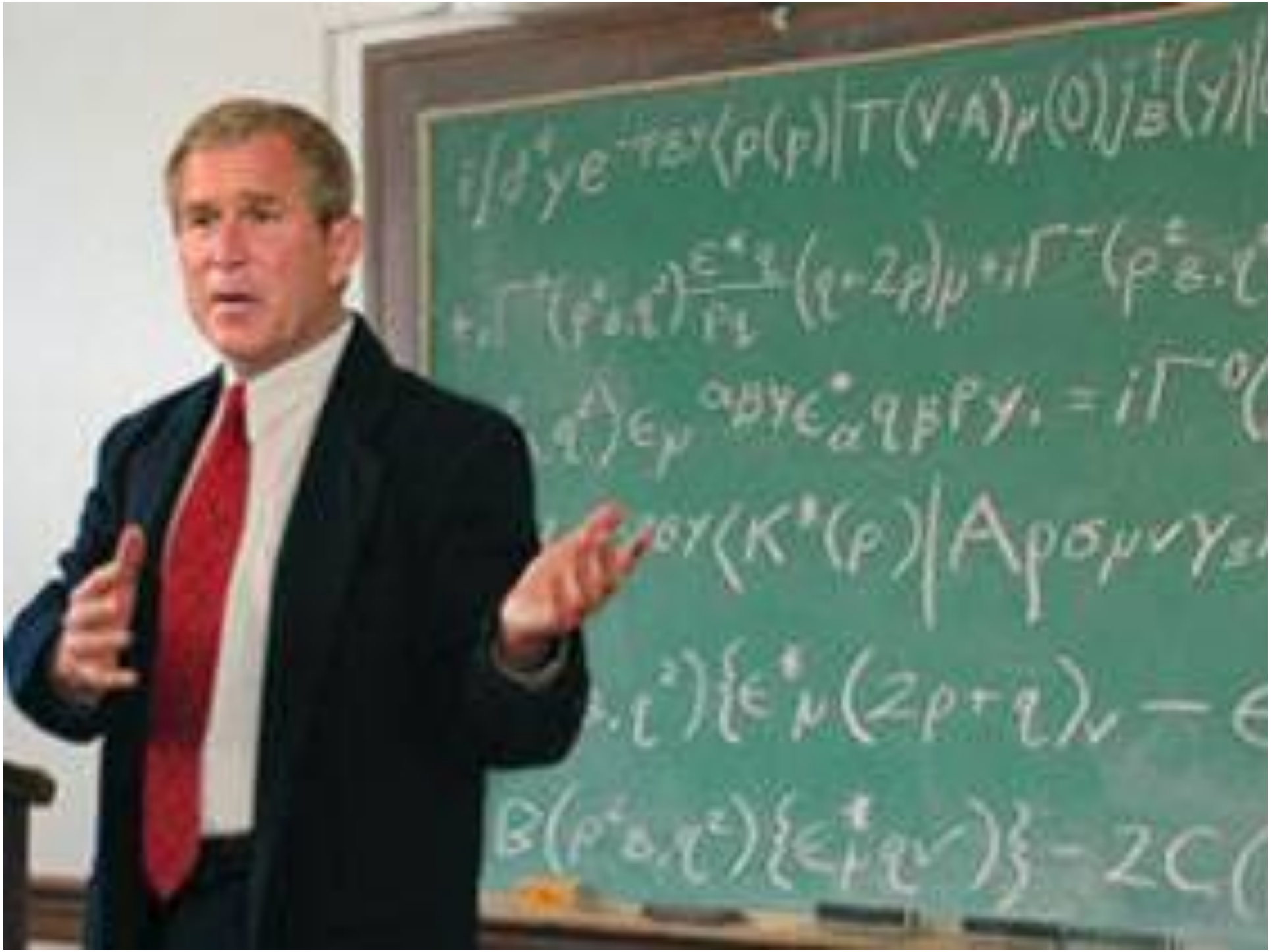
$$-ie(W^+_\mu A_\nu - W^+_\nu A_\mu) + ig' c_w (W^+_\mu Z_\nu - W^+_\nu Z_\mu|^2 +$$

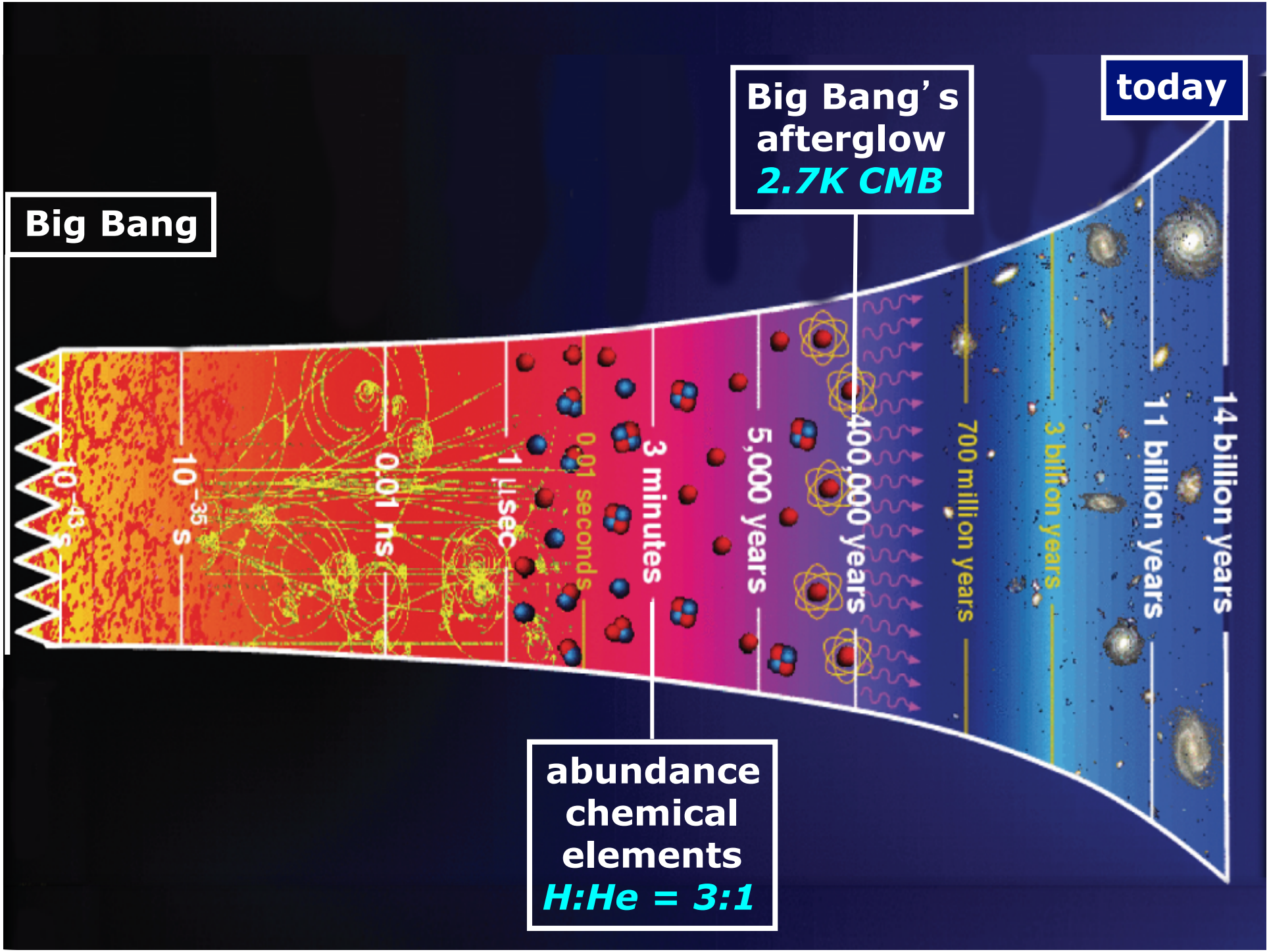
$$-\frac{1}{4}|\partial_\mu Z_\nu - \partial_\nu Z_\mu + ig' c_w (W^-_\mu W^+_\nu - W^+_\mu W^-_\nu)|^2 +$$

$$-\frac{1}{2} M^2_\eta \eta^2 - \frac{g M^2_\eta}{8 M_W} \eta^3 - \frac{g'^2 M^2_\eta}{32 M_W} \eta^4 + |M_W W^+_\mu + \frac{g}{2} \eta W^+_\mu|^2 +$$

$$+\frac{1}{2}|\partial_\mu \eta + i M_Z Z_\mu + \frac{ig}{2c_w} \eta Z_\mu|^2 - \sum_f \frac{g}{2} \frac{m_f}{M_W} \bar{\Psi}_f \Psi_f \eta$$

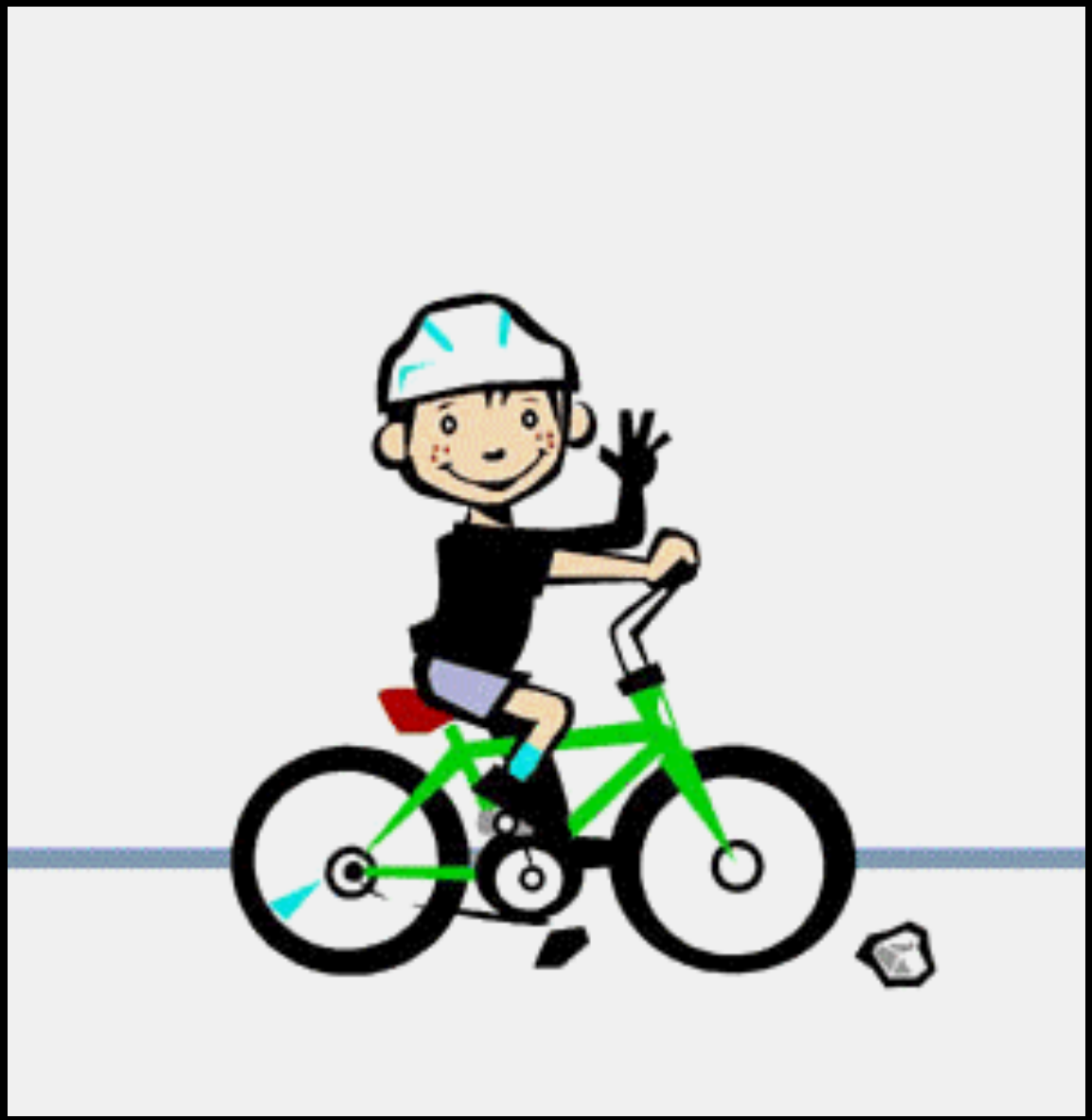
Standard Model



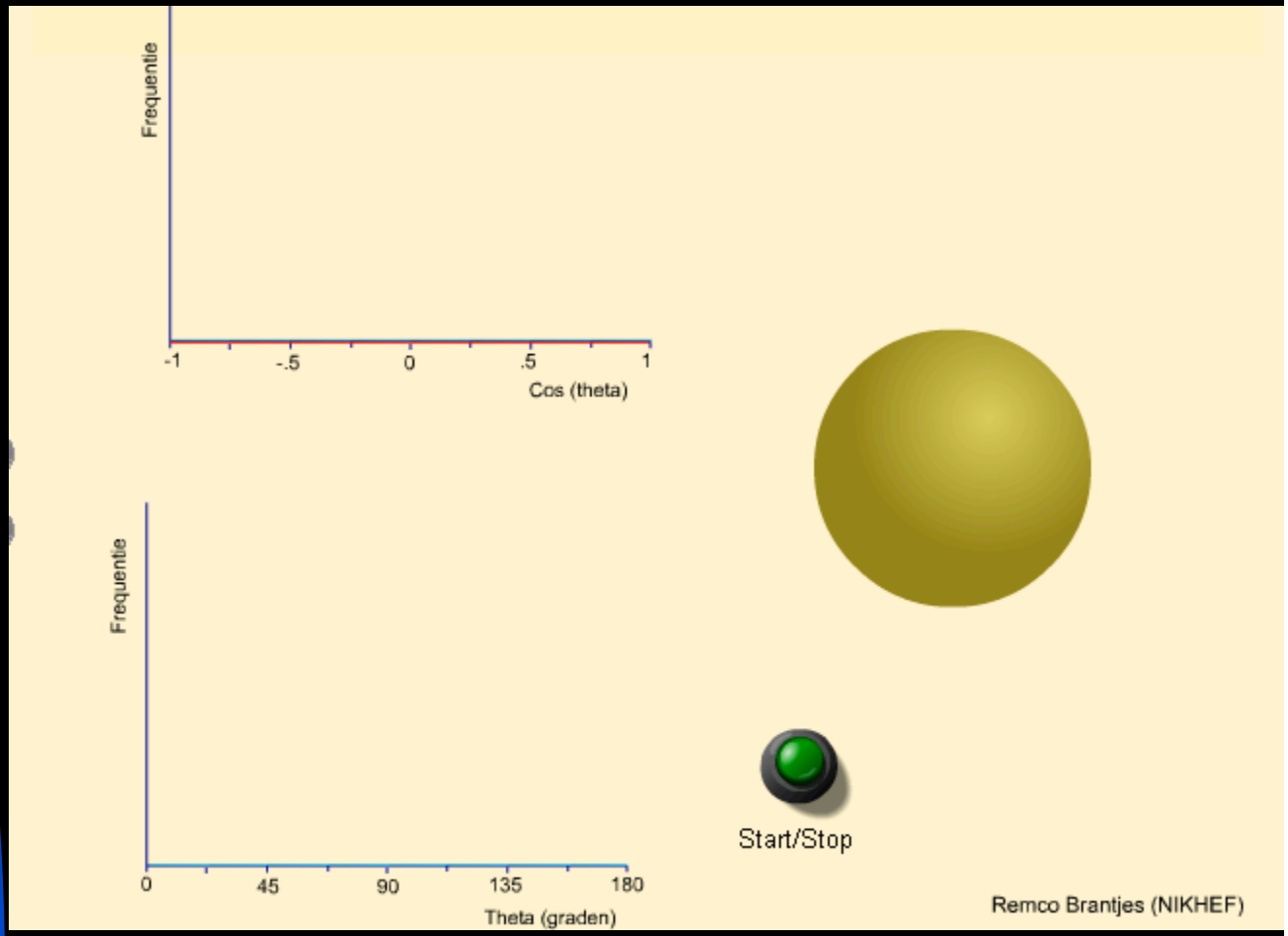

Big Bang
Big Bang's afterglow
2.7K CMB
today
abundance chemical elements
H:He = 3:1
14 billion years
11 billion years
3 billion years
700 million years
400,000 years
5,000 years
3 minutes
0.01 seconds
1 μsec
0.01 ns
10 −35 s
10 −43 s

Particle physics "*specials*"

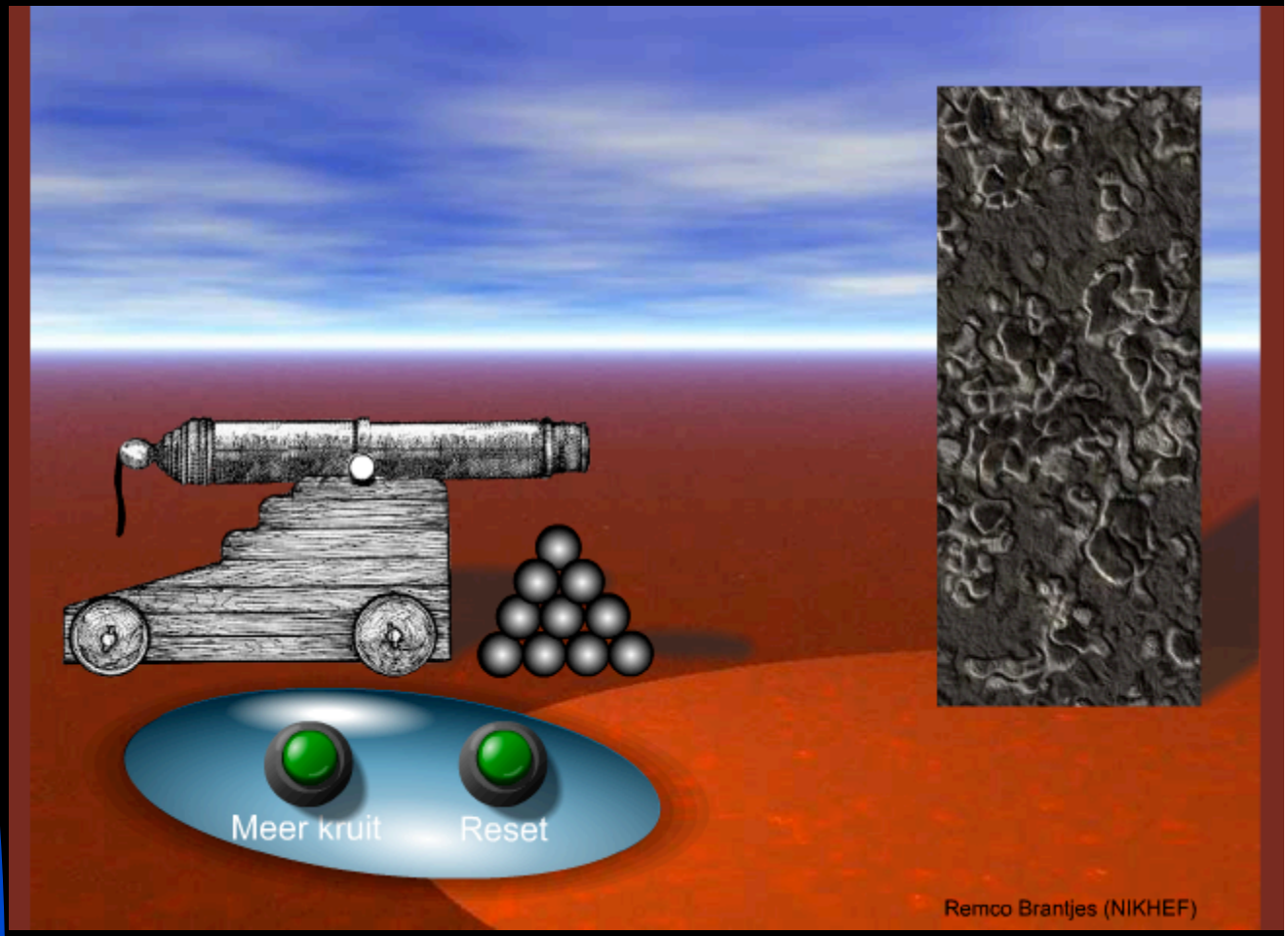
Particle collisions: *cross section*



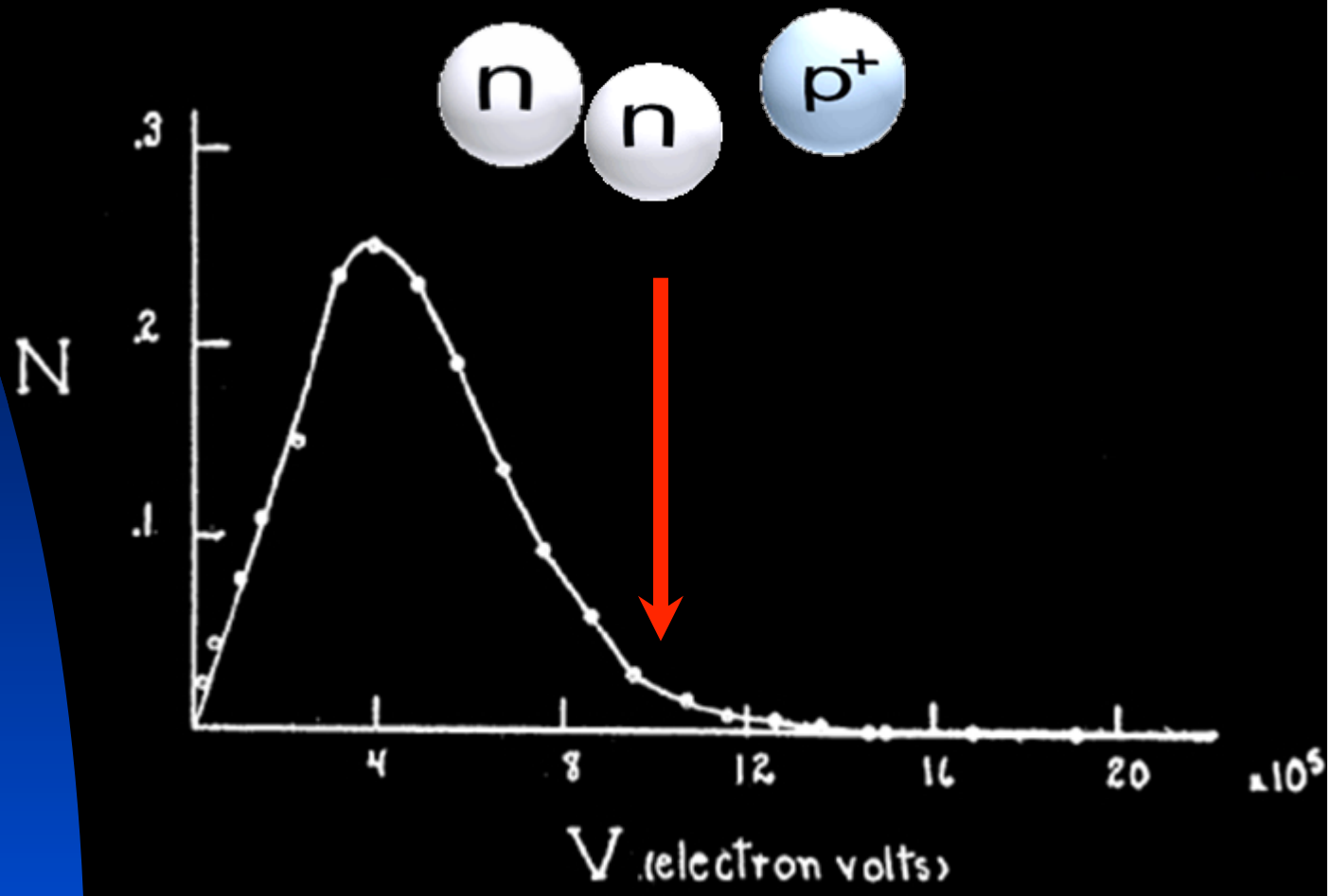
Cross section

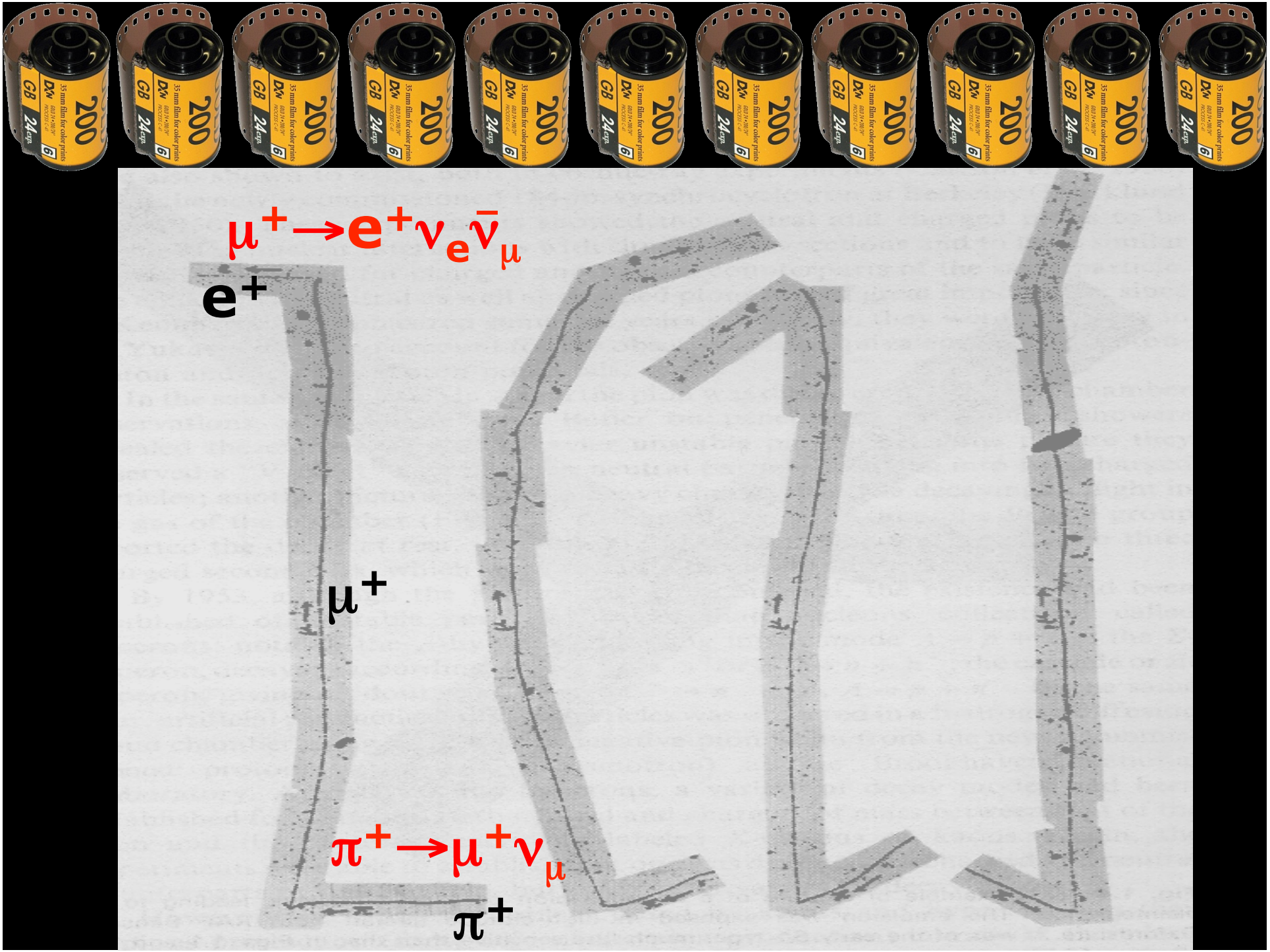


Particle instability: *decay*



Decay




$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$
e^+
μ^+
$\pi^+ \rightarrow \mu^+ \nu_\mu$
π^+

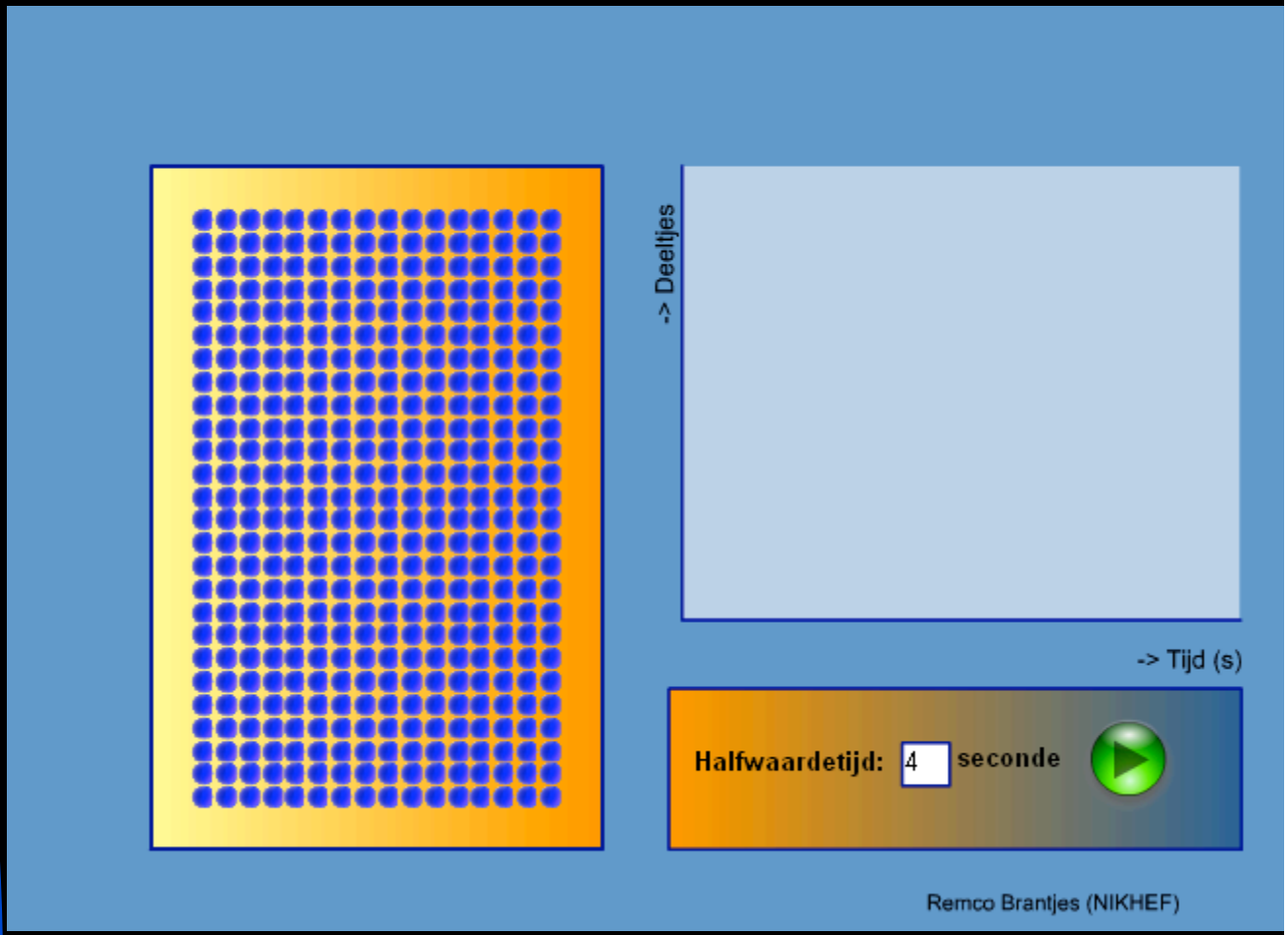
Lifetime ↔ life expectation

Unstable particles: *lifetime*

note:

As opposed to human beings, decay probability of an unstable particle does *not* depend on how long it lived already i.e. its past history!

simple!



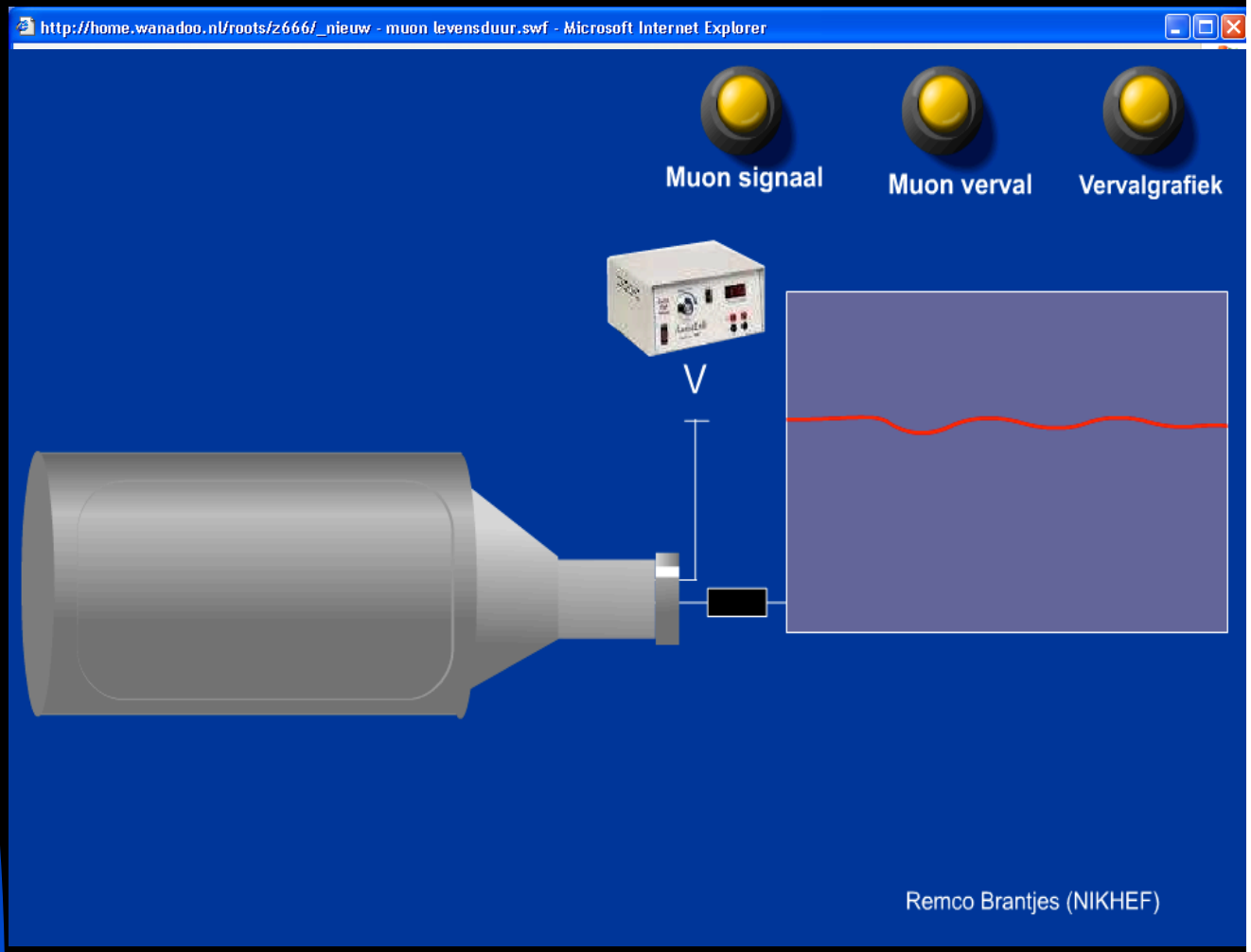
Actual experiment: *muon (μ) lifetime*

Start stopwatch:

Muon enters the detector.

Stop stopwatch:

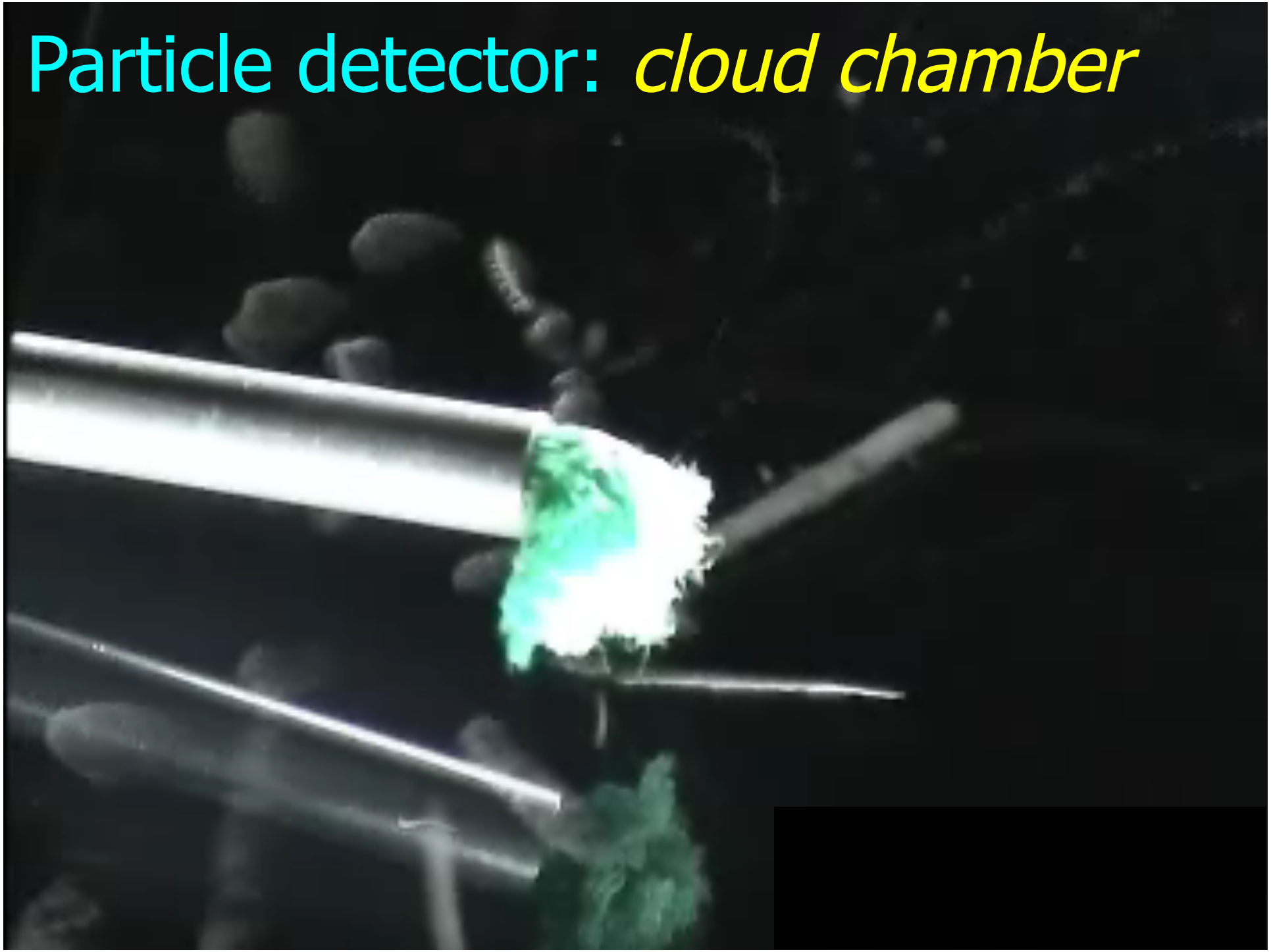
Muon decays: generated electron triggers detector.

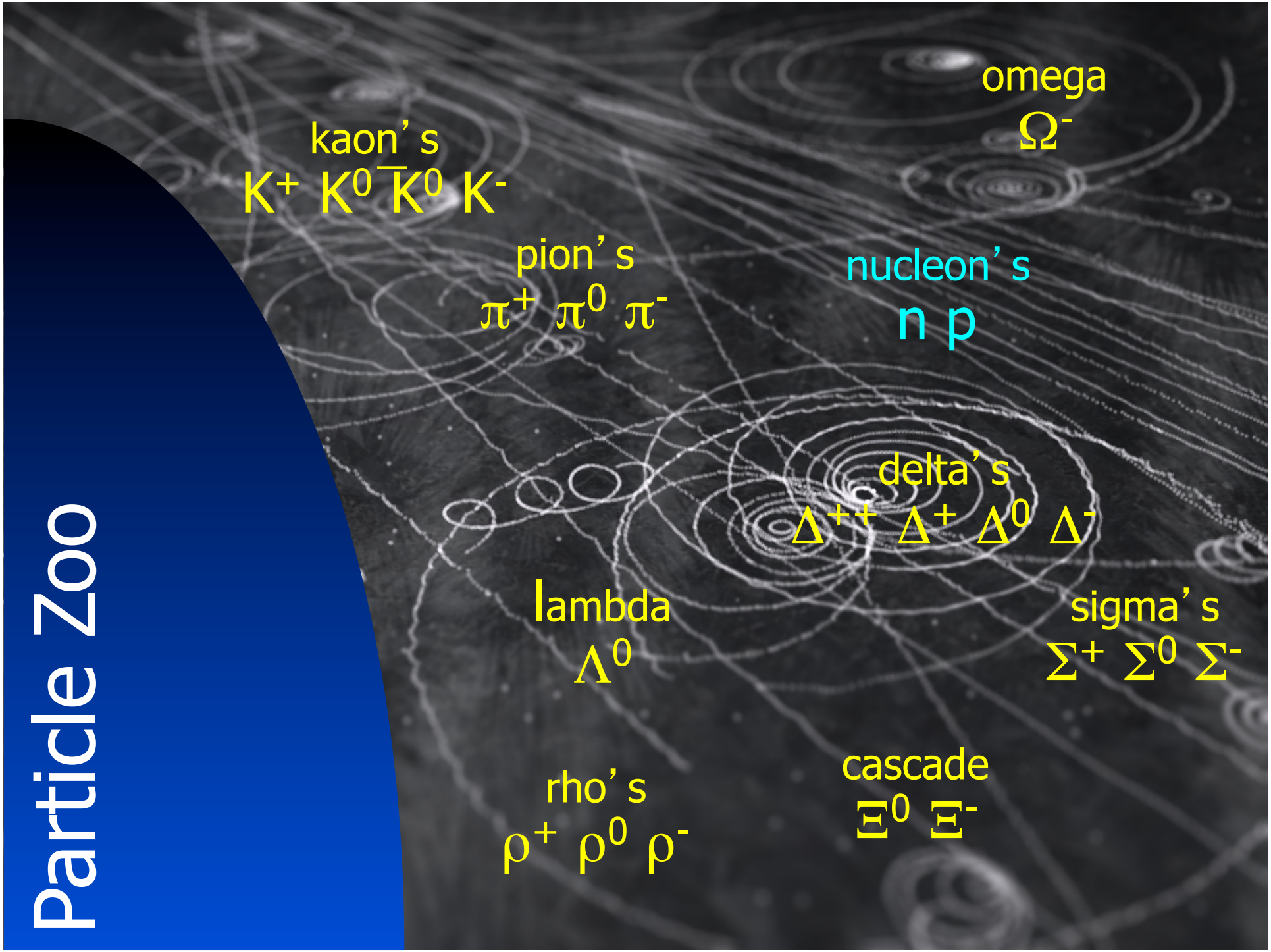


Particle physics

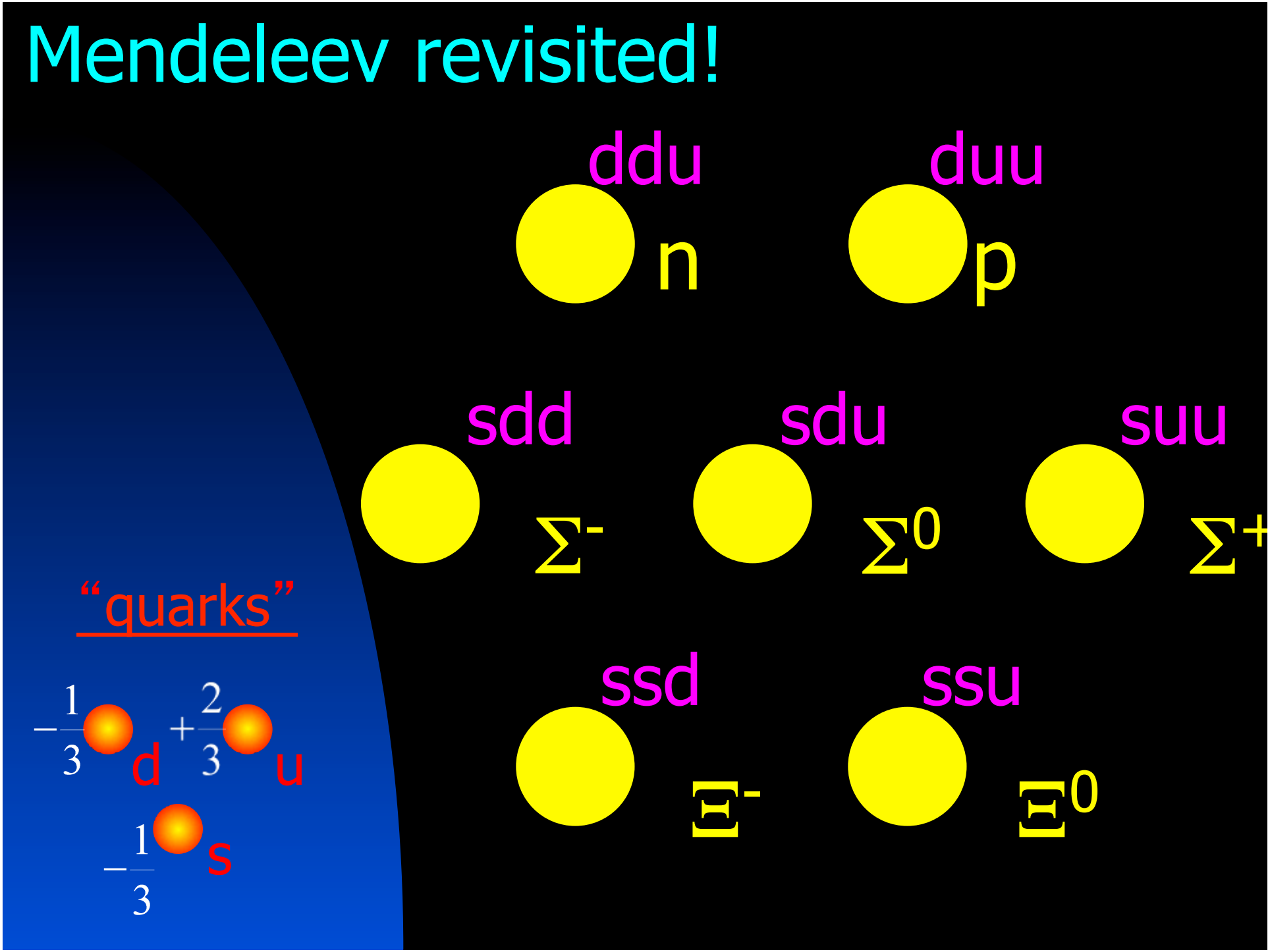
"old days"

Particle detector: *cloud chamber*




Particle Zoo
kaon's
K^+ K^0 $\bar{K}^0$ K^-
pion's
π^+ π^0 π^-
omega
Ω^-
nucleon's
n p
delta's
Δ^{++} Δ^+ Δ^0 Δ^-
lambda
Λ^0
sigma's
Σ^+ Σ^0 Σ^-
rho's
ρ^+ ρ^0 ρ^-
cascade
Ξ^0 Ξ^-

Mendeleev revisited!



Mendeleev revisited!

ddd ddu duu uuu

Δ^- Δ^0 Δ^+ Δ^{++}

sdd sdu suu

Σ^{*-} Σ^{*0} Σ^{*+}

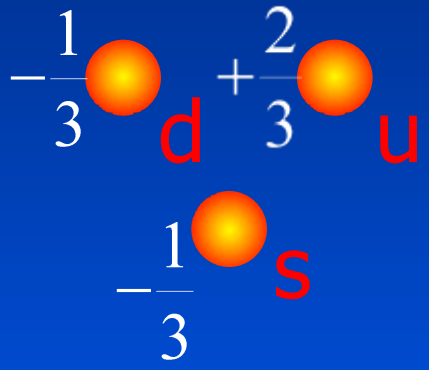
ssd ssu

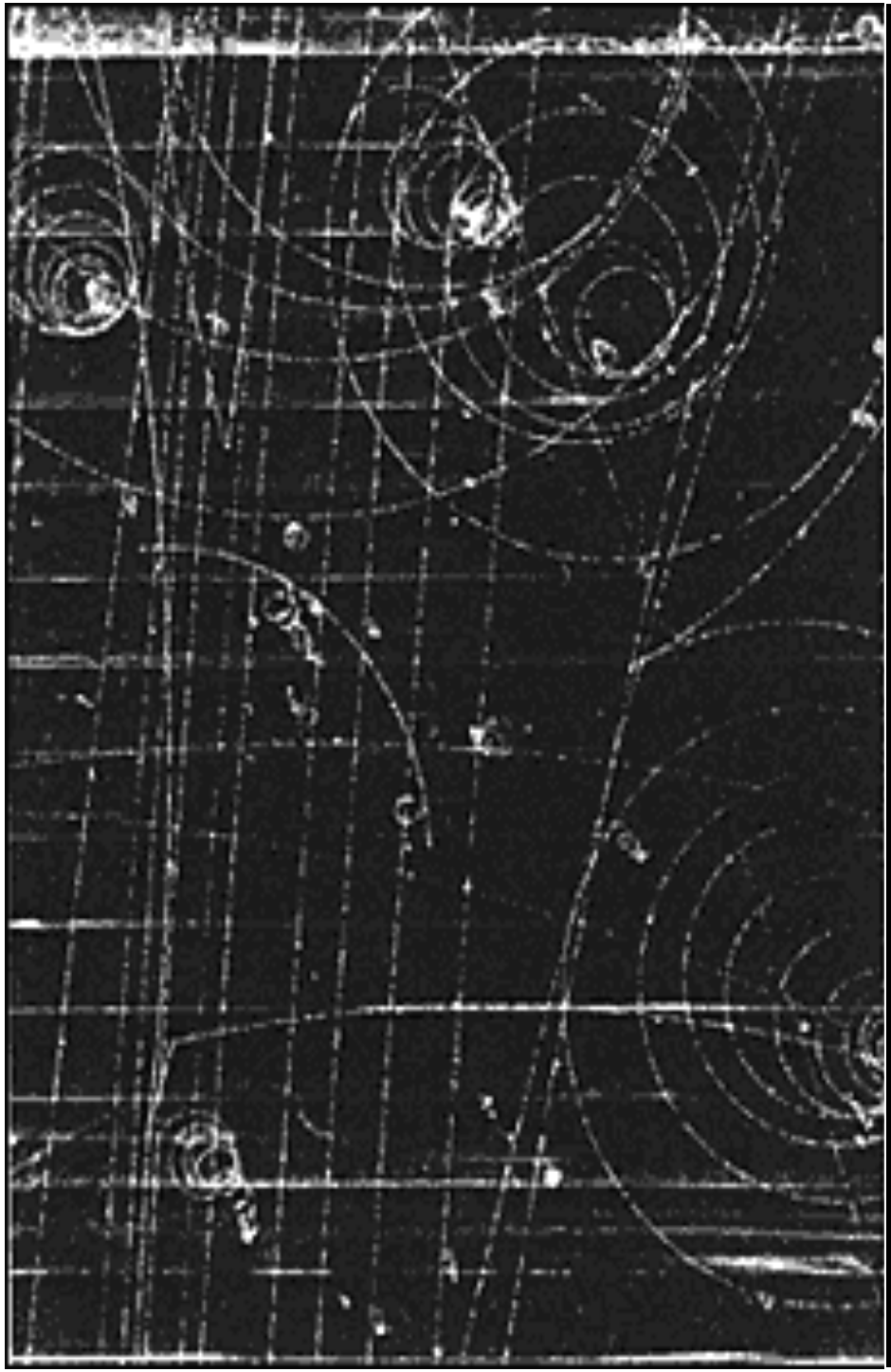
Ξ^{*-} Ξ^{*0}

sss

Ω^-

"quarks"





- $\Lambda^0 \rightarrow p\pi^-$
- $\Xi^0 \rightarrow \gamma\gamma\Lambda^0$
- $\Omega^- \rightarrow \pi^-\Xi^0$

Quark model: *Gell-mann (1964)*

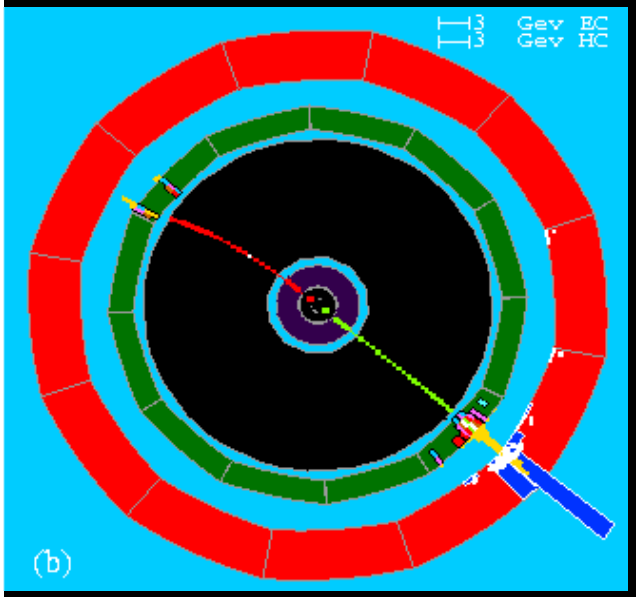
Show Instructions

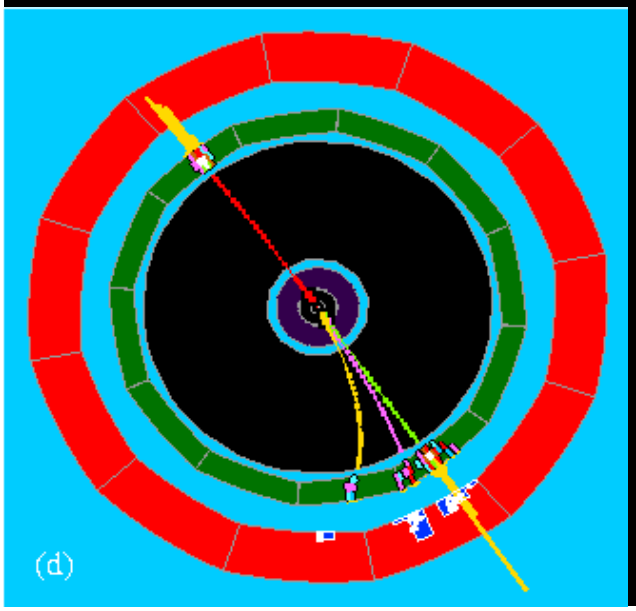
QUARK	CHARGE	QUARK	CHARGE	QUARK	CHARGE
u	+2/3	d	-1/3	s	-1/3
$\bar{u}$	-2/3	$\bar{d}$	+1/3	$\bar{s}$	+1/3

Done

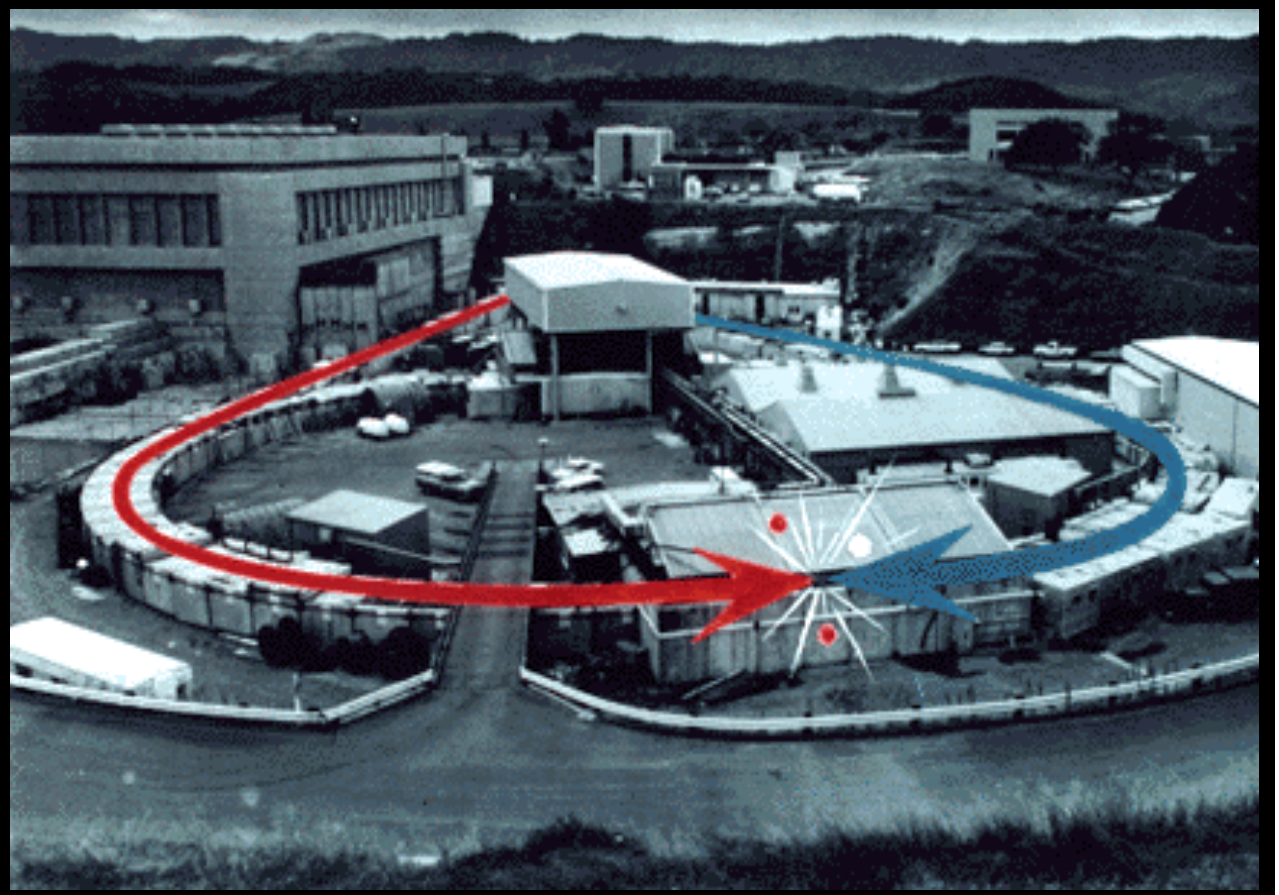
Reset

Tau (τ) discovery: *e^+e^- collider*





m_{tau} = 31553 $\times 10^{-28}$ gram

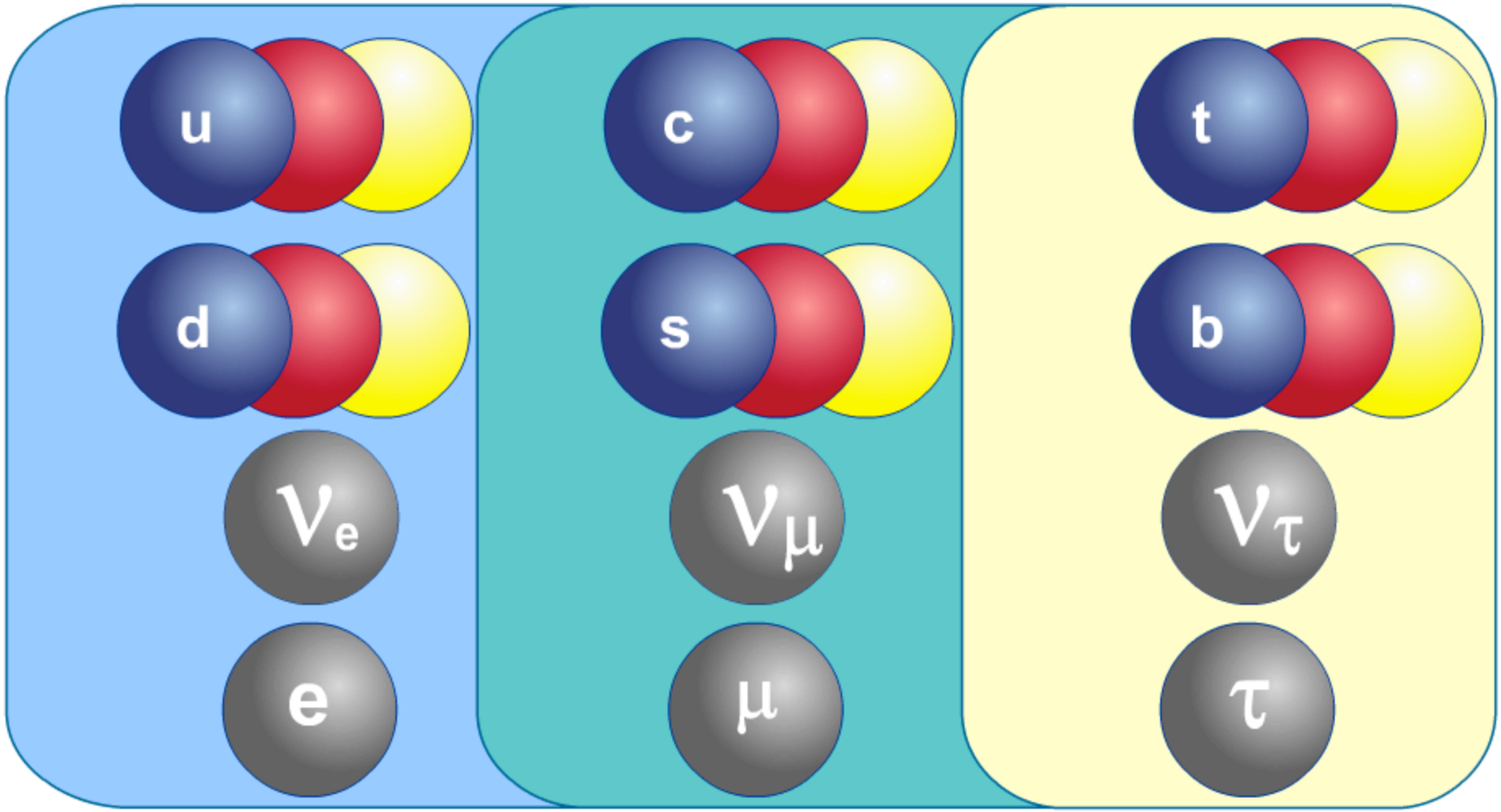


$e^+e^- \rightarrow \tau^+\tau^-$ $\tau^+ \rightarrow e^+\bar{\nu}_\tau\nu_e$

Massa
Lading

Gevoelig voor:

Elektromagnetische wisselwerking
Zwakke wisselwerking
Sterke wisselwerking
Gravitatie



Particle physics

Big questions

1. Quantization of electric charge?

The NIST Reference on
Constants, Units, and Uncertainty

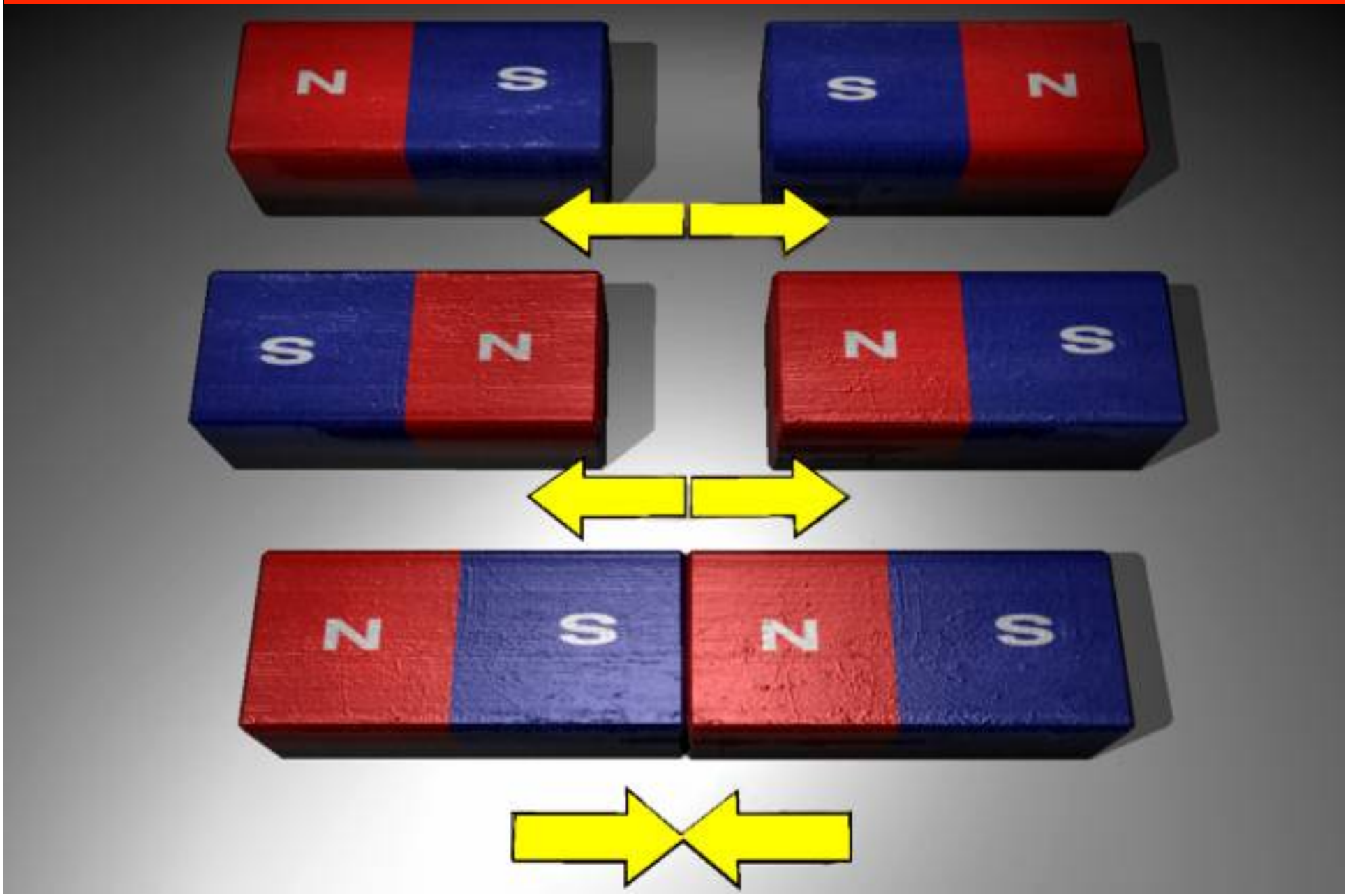
Constants Topics:

- Values
- Energy Equivalents
- Searchable Bibliography
- Background

Fundamental Physical Constants

elementary charge e	
Value	1.602 176 487 x 10^{-19} C
Standard uncertainty	0.000 000 040 x 10^{-19} C
Relative standard uncertainty	2.5 x 10^{-8}
Concise form	1.602 176 487(40) x 10^{-19} C

1. Quantization of electric charge?



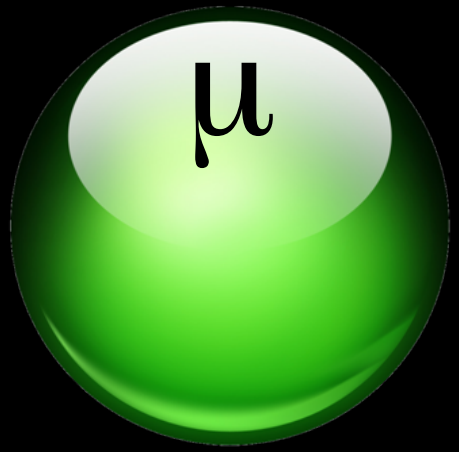
2. Origin of mass?

1897

Electron

Spin ½
Charge -1
Lifetime ∞
Mass 0.511 MeV

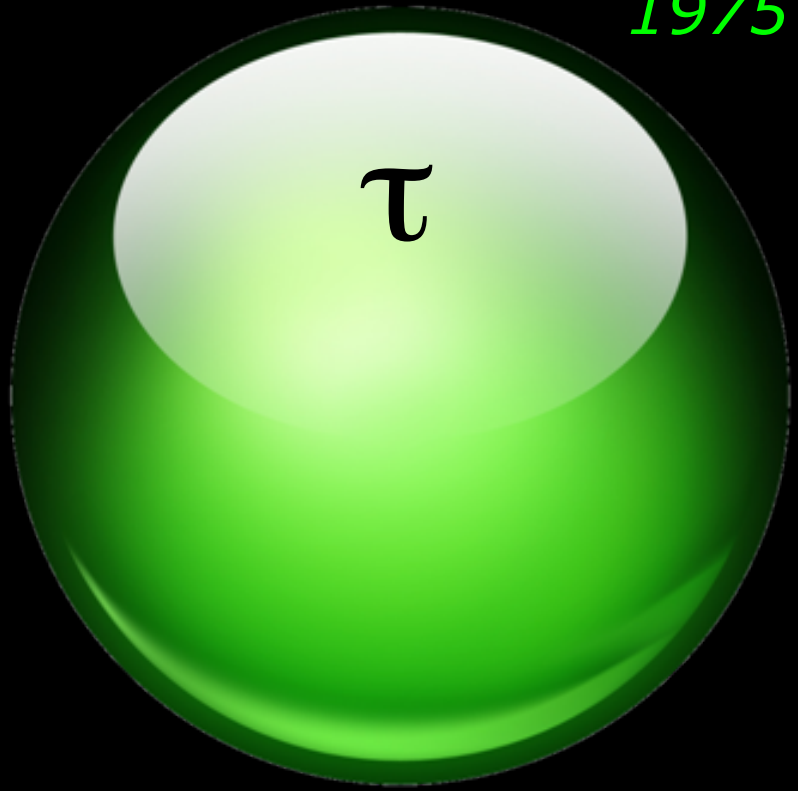
1937



Muon

Spin ½
Charge -1
Lifetime 2.2 μs
Mass 106 MeV

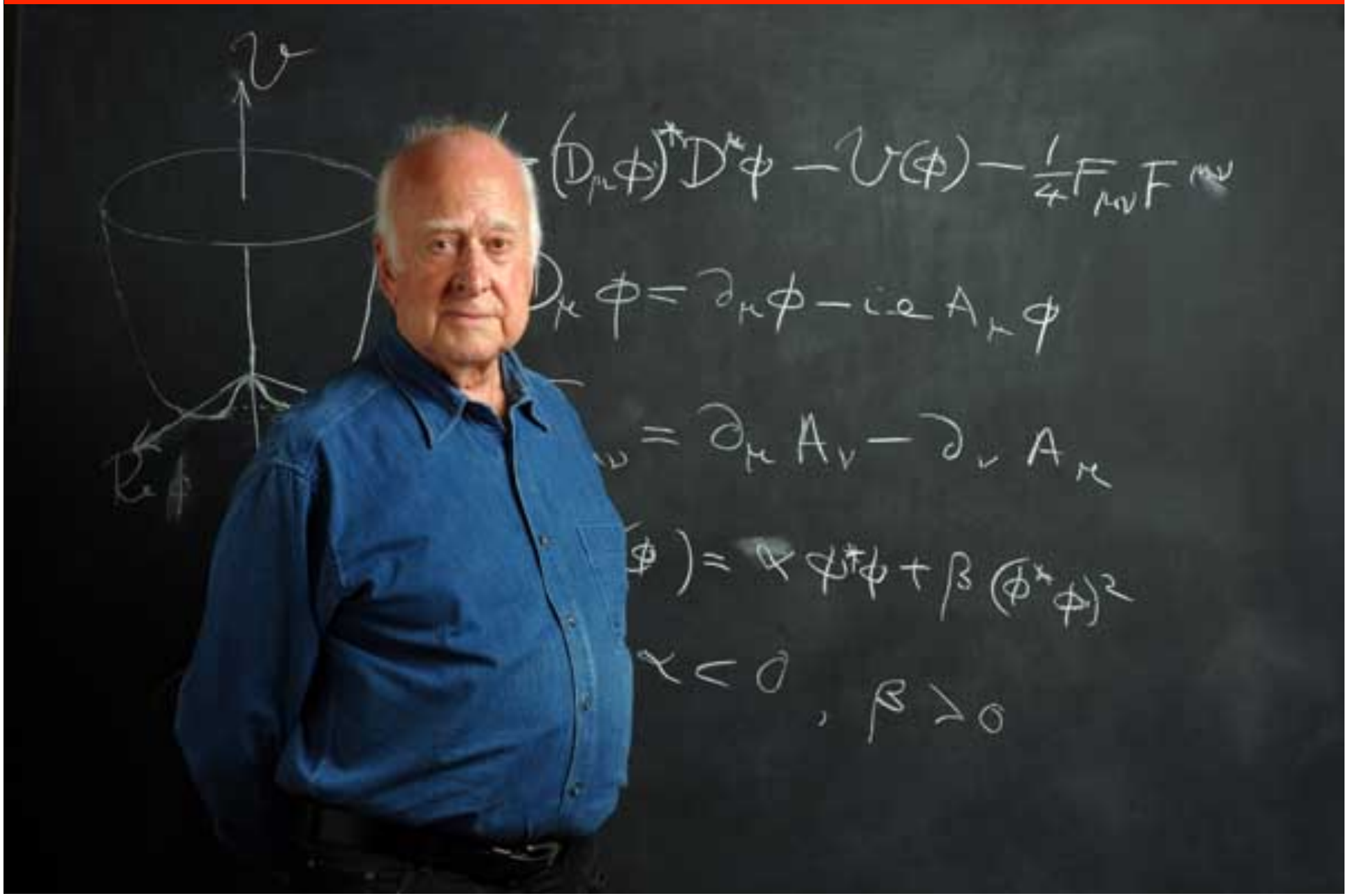
1975



Tau

Spin ½
Charge -1
Lifetime 290 fs
Mass 1770 MeV

2. Origin of mass?



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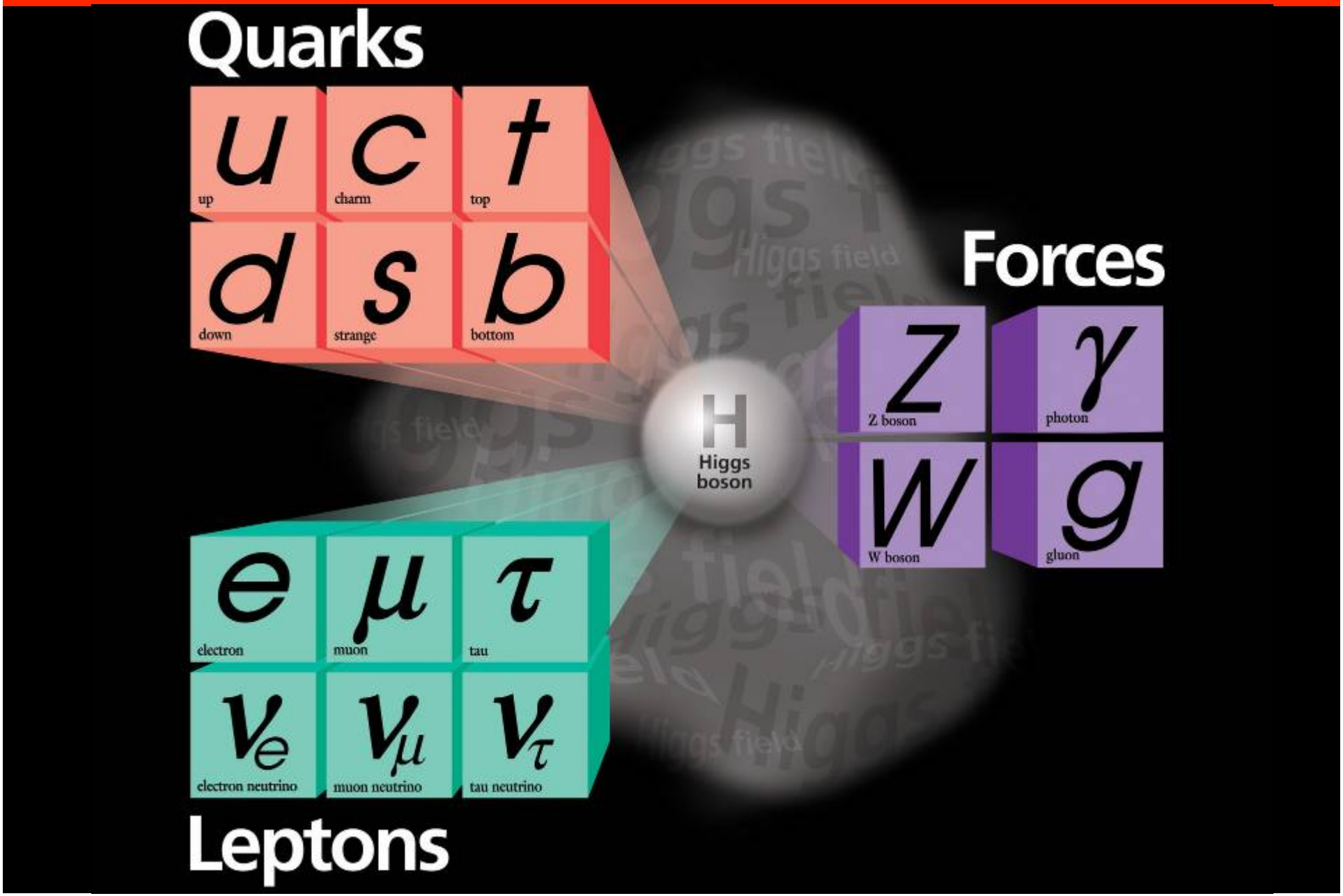

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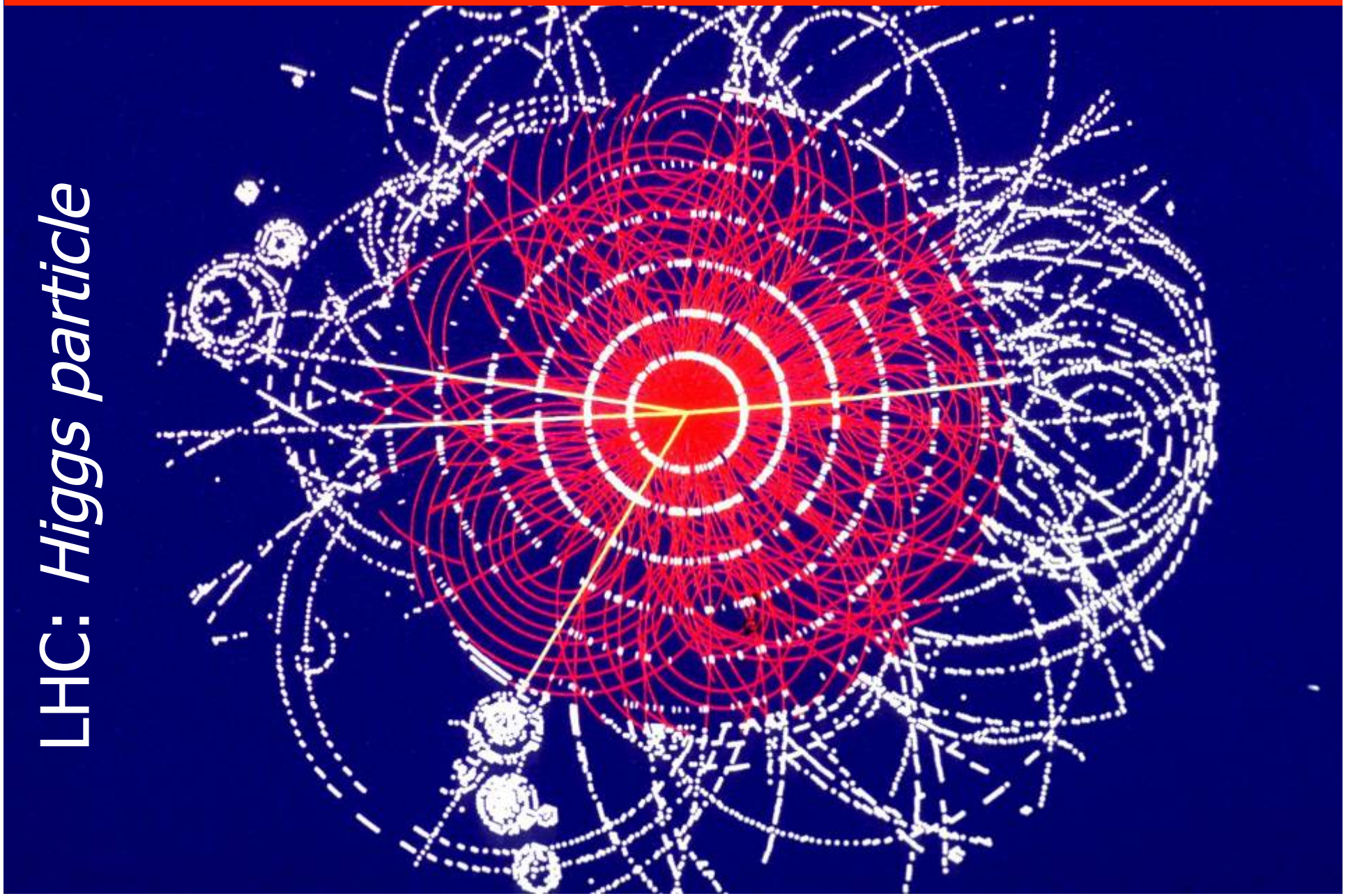


LHC: *Higgs particle*

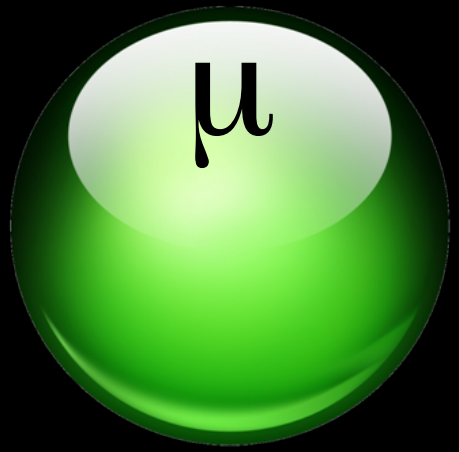
3. Three families?

1897

Electron

Spin ½
Charge -1
Lifetime ∞
Mass 0.511 MeV

1937



Muon

Spin ½
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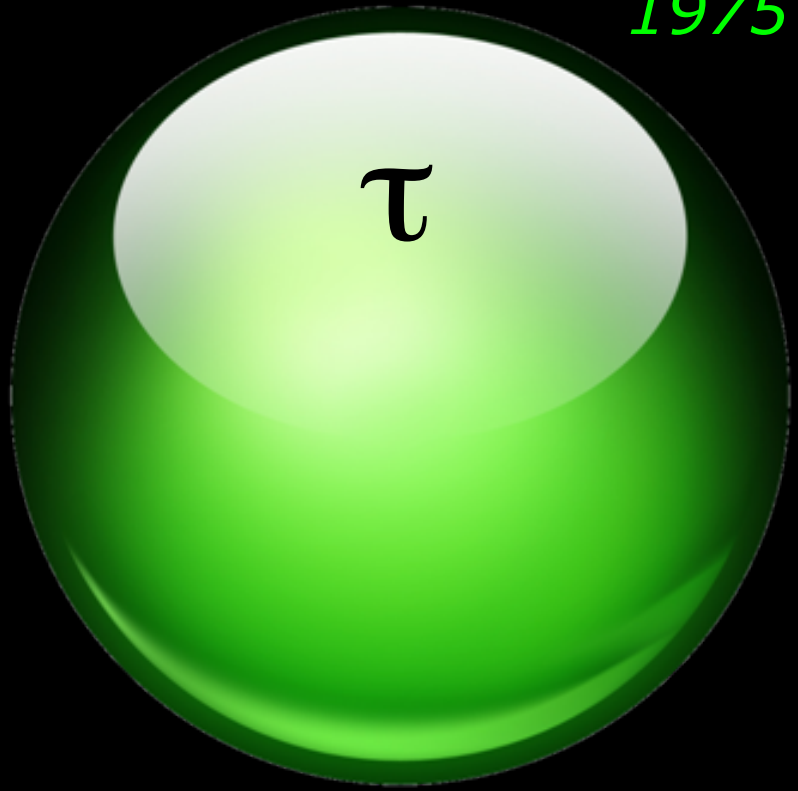
1975



Tau

Spin ½
Charge -1
Lifetime 290 fs
Mass 1770 MeV

4. What is the matter with antimatter?

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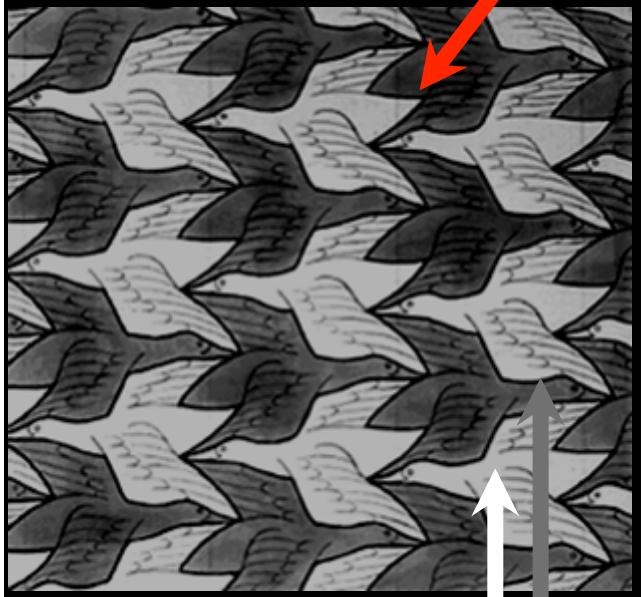
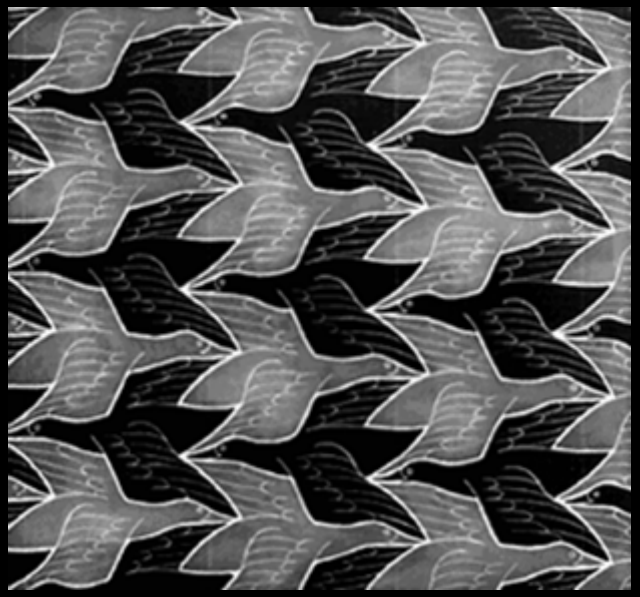
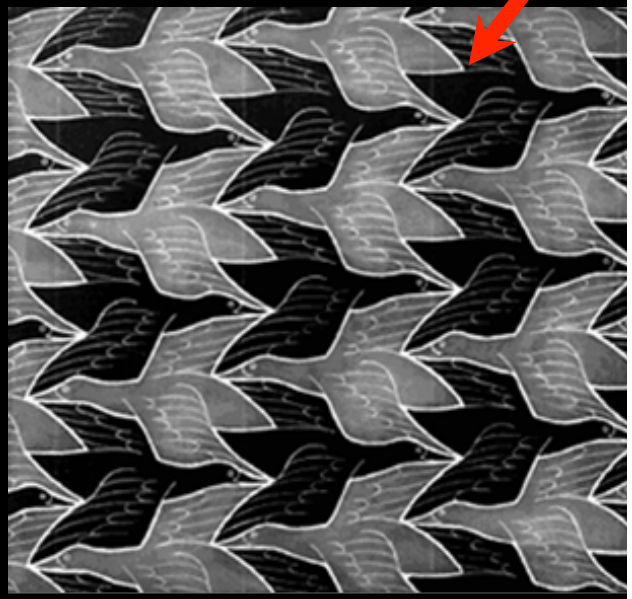
minute difference!







black ↔ white

black ↔ white mirror image

matter:	white	moving right i.o. left	ok i.e. unchanged
anti-matter:	black	moving left i.o. right	ok i.e. unchanged

5. Composition of the Universe?

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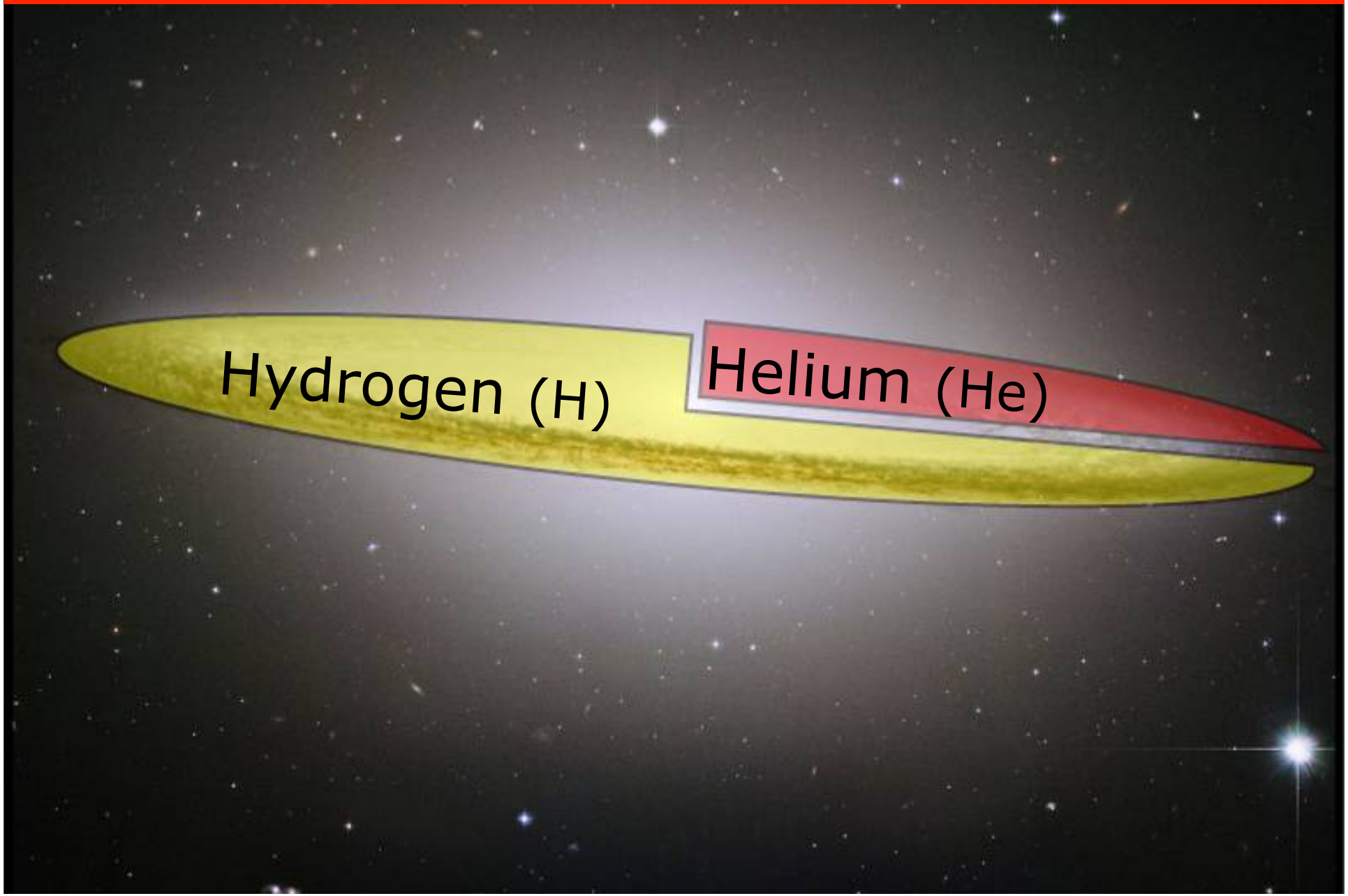

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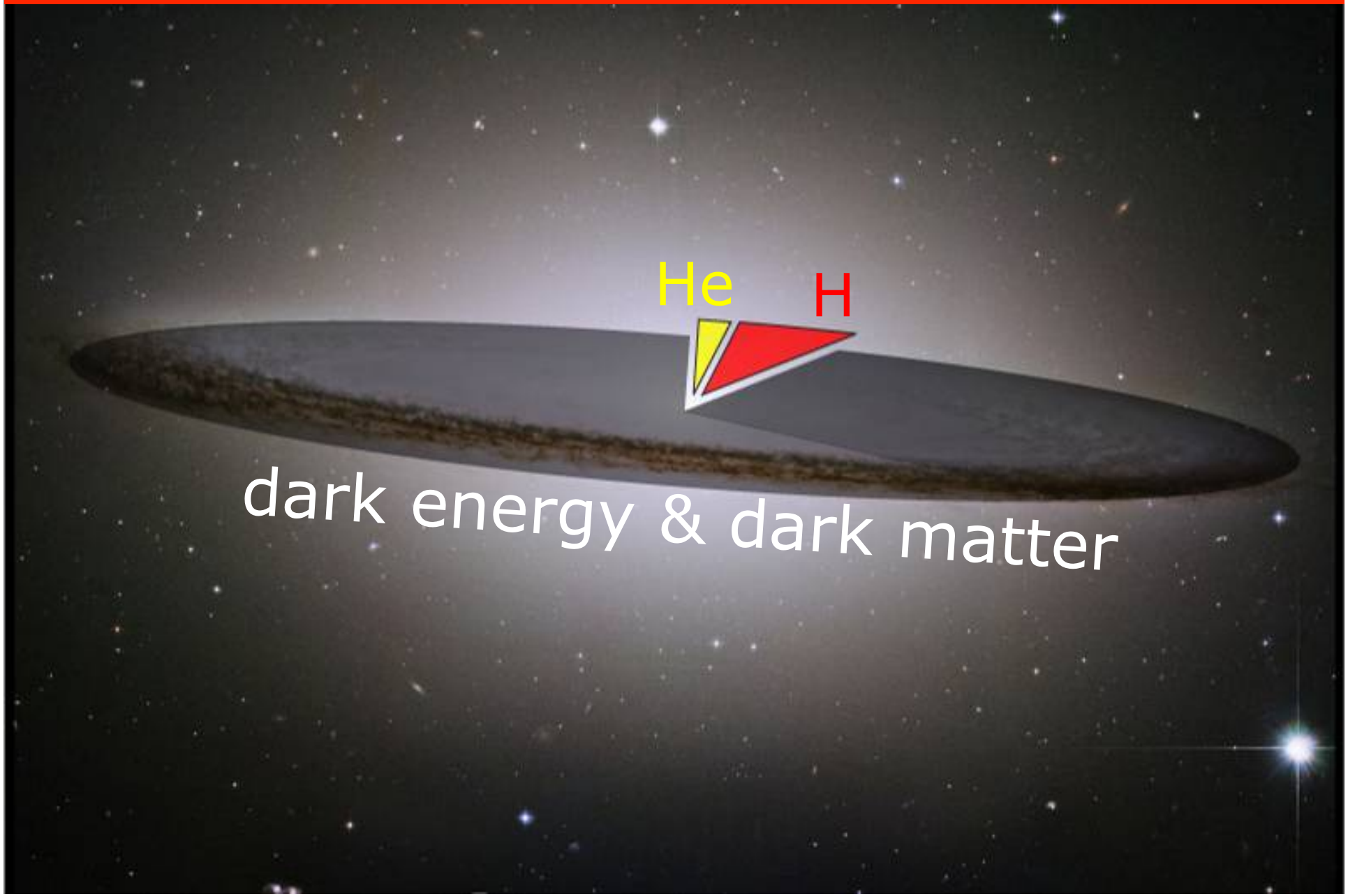

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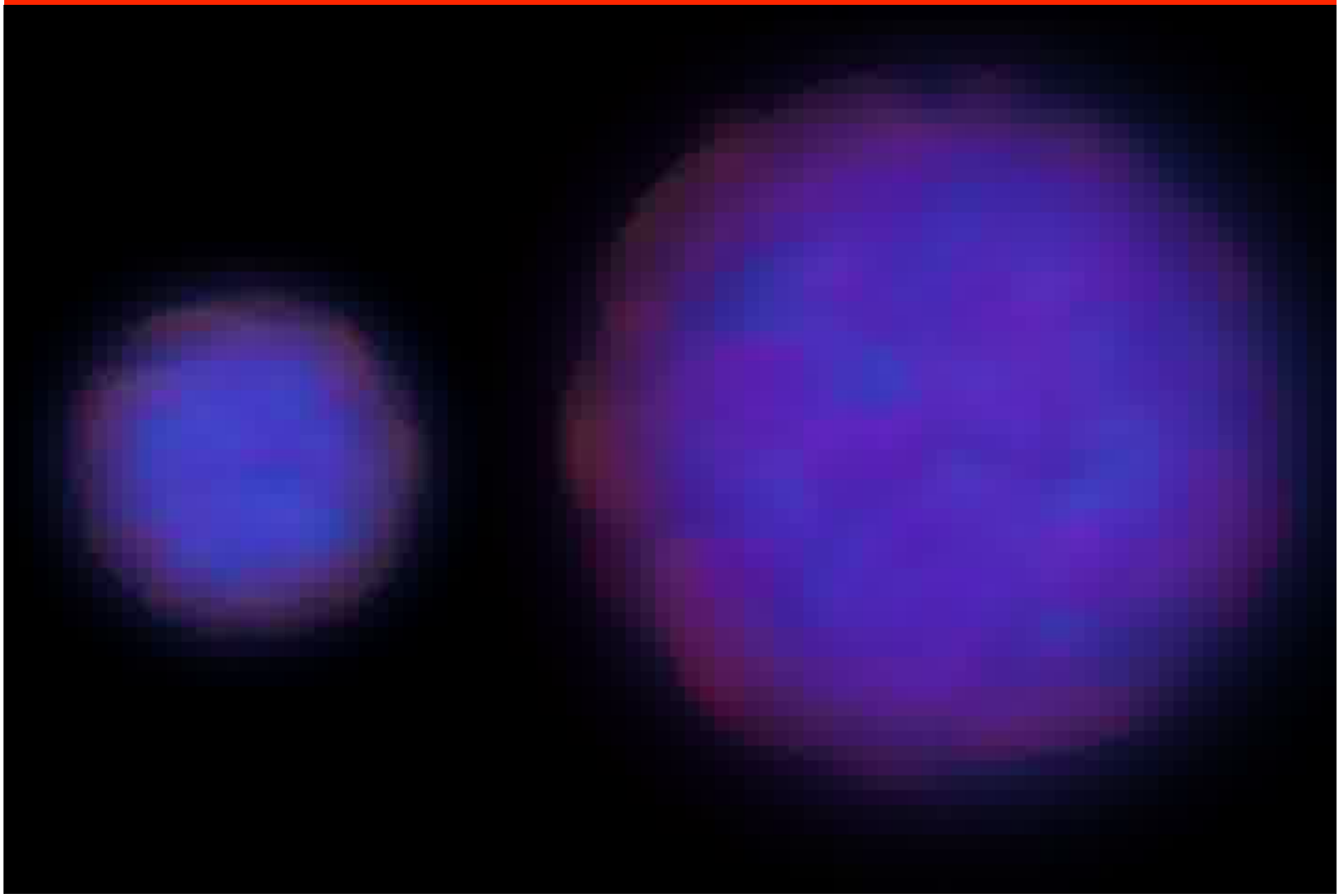

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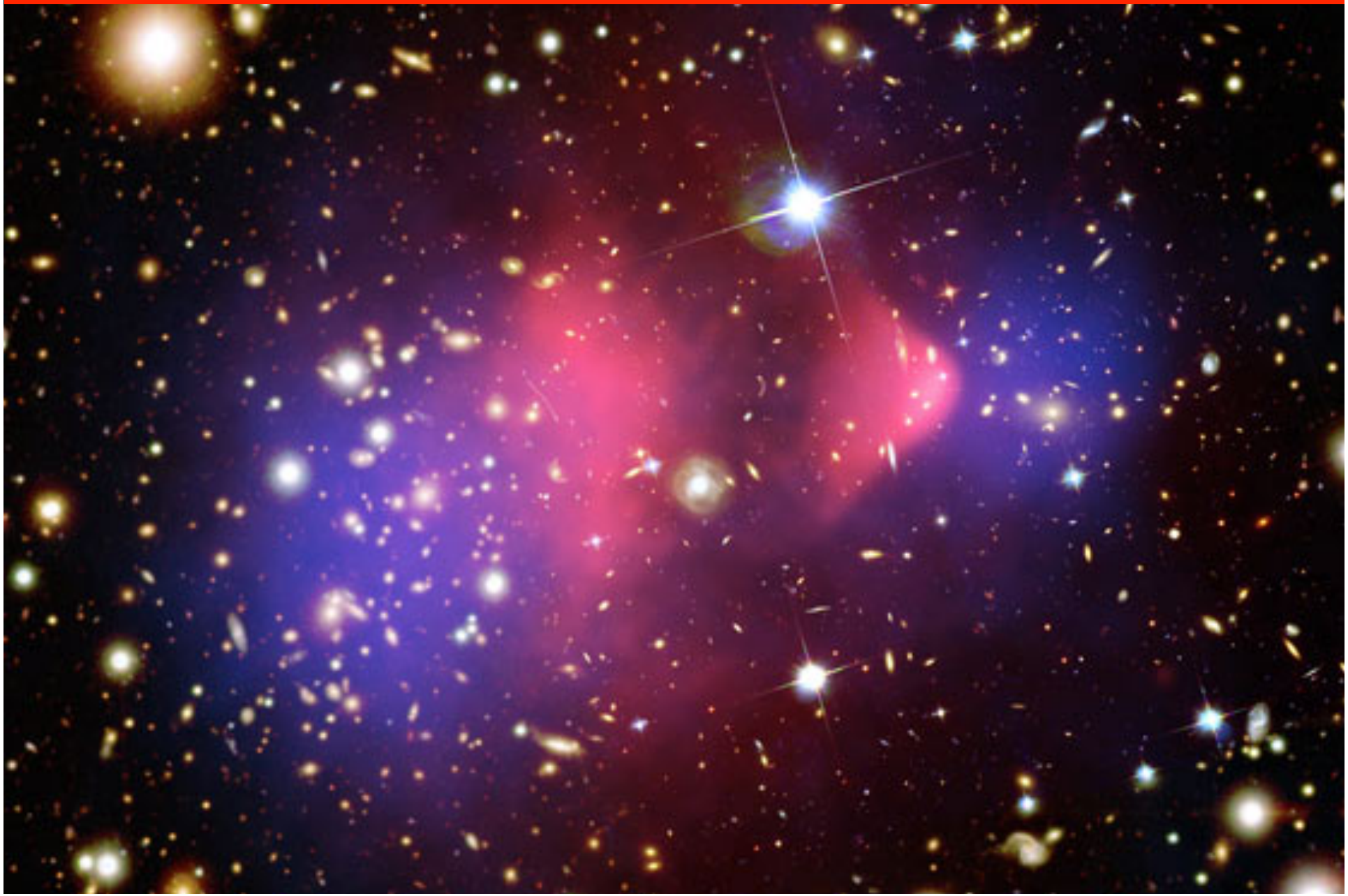

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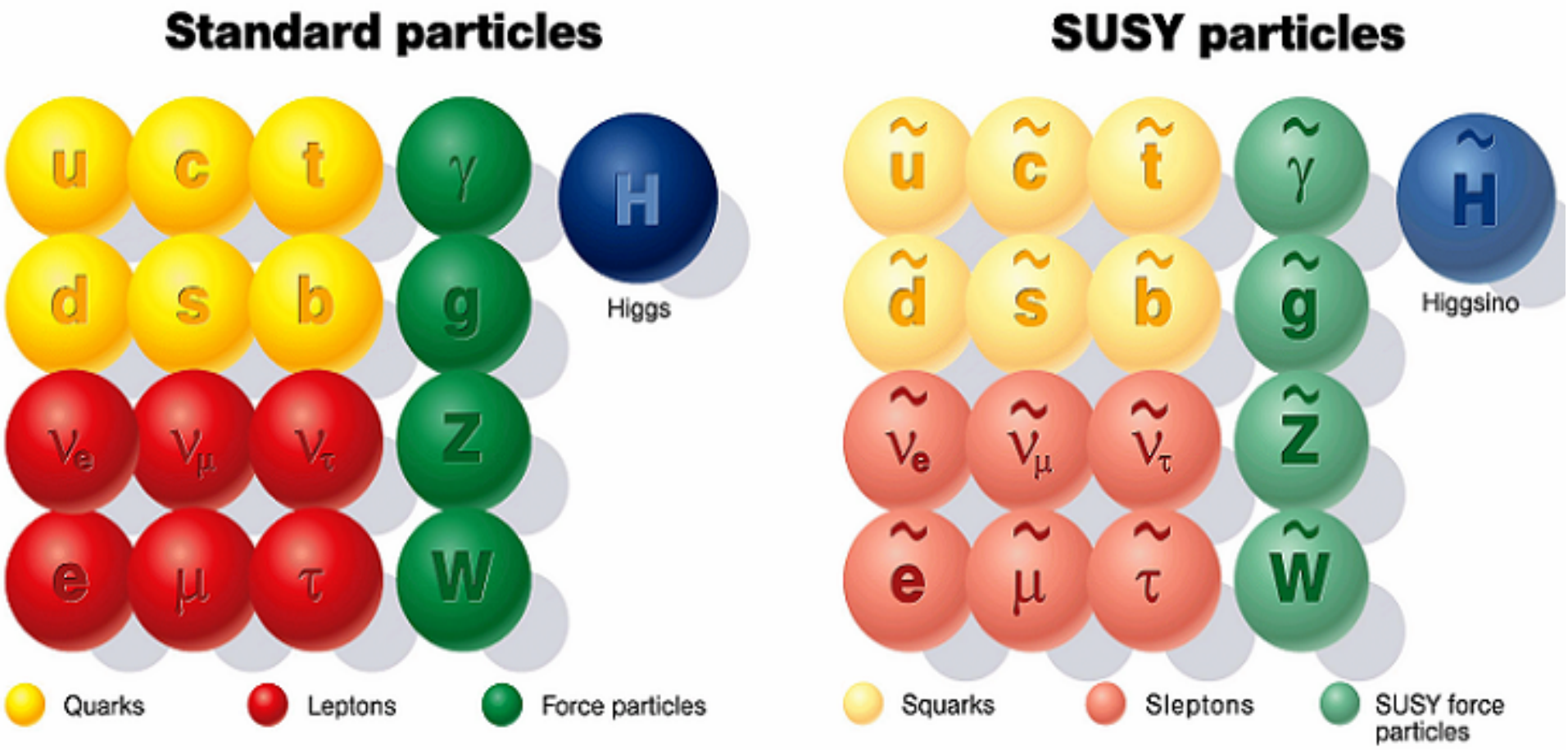
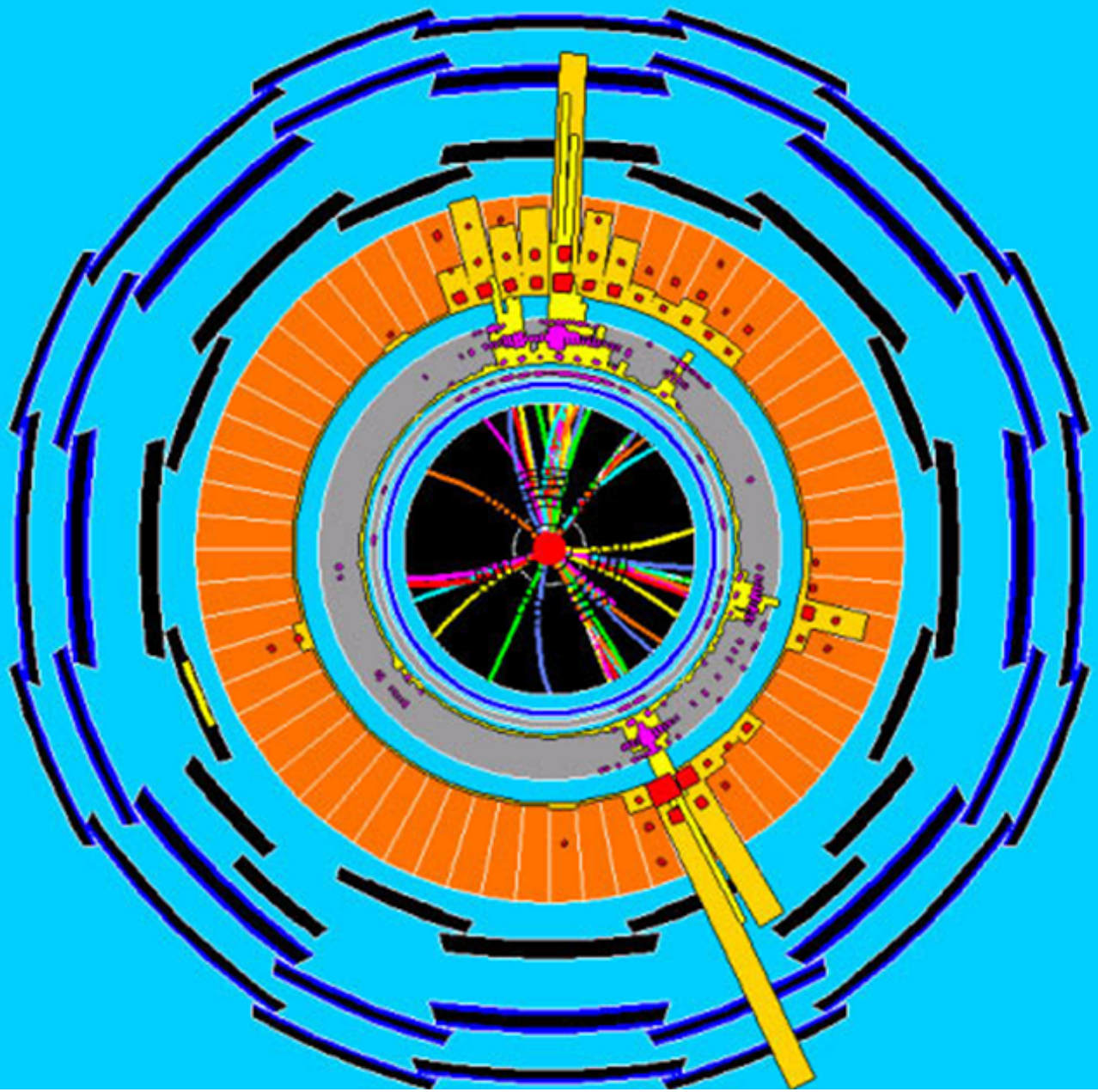


5. Composition of the Universe?

LHC: *supersymmetric particles*

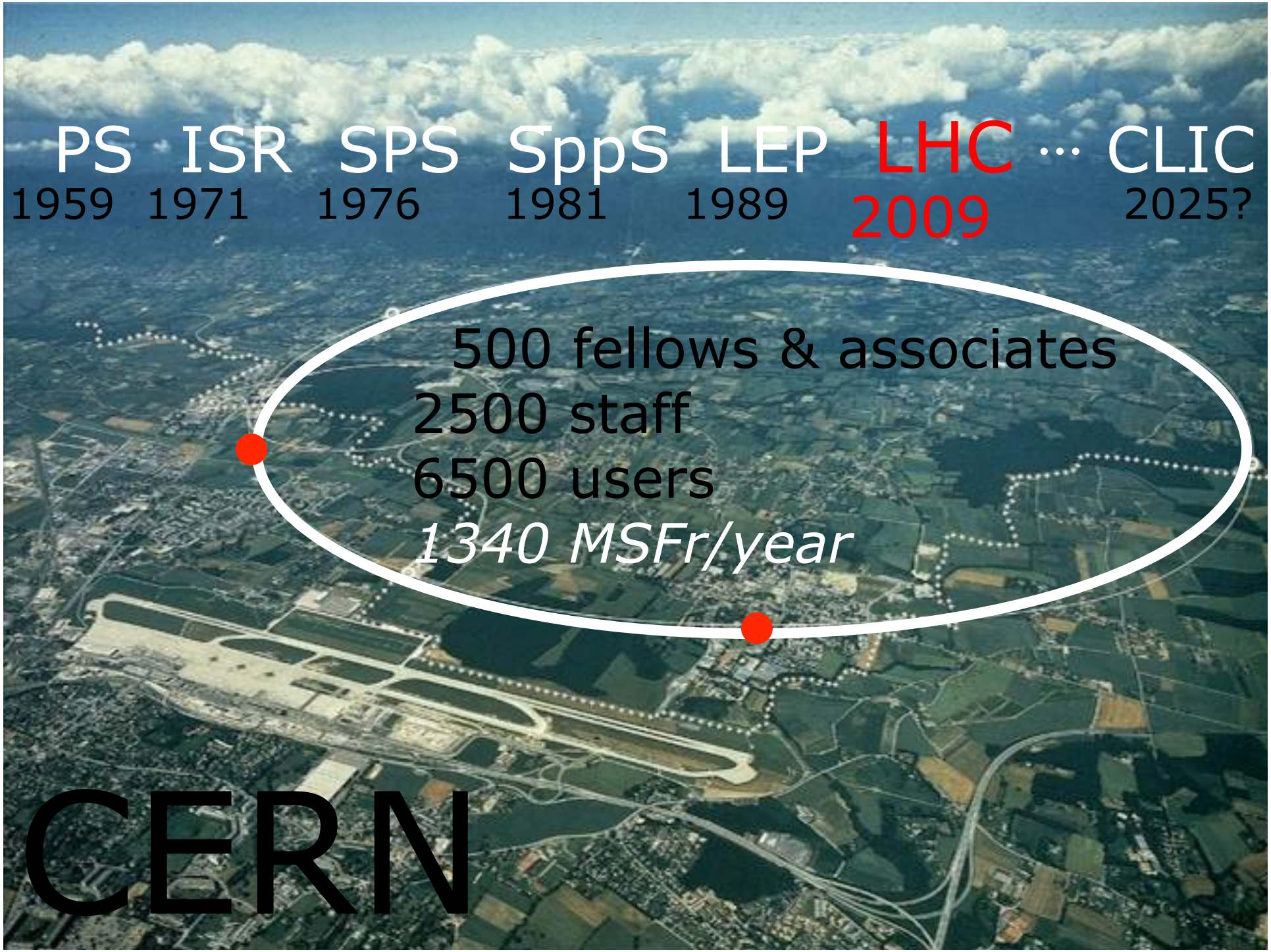


The PARTICLE ZOO
gluon
graviton

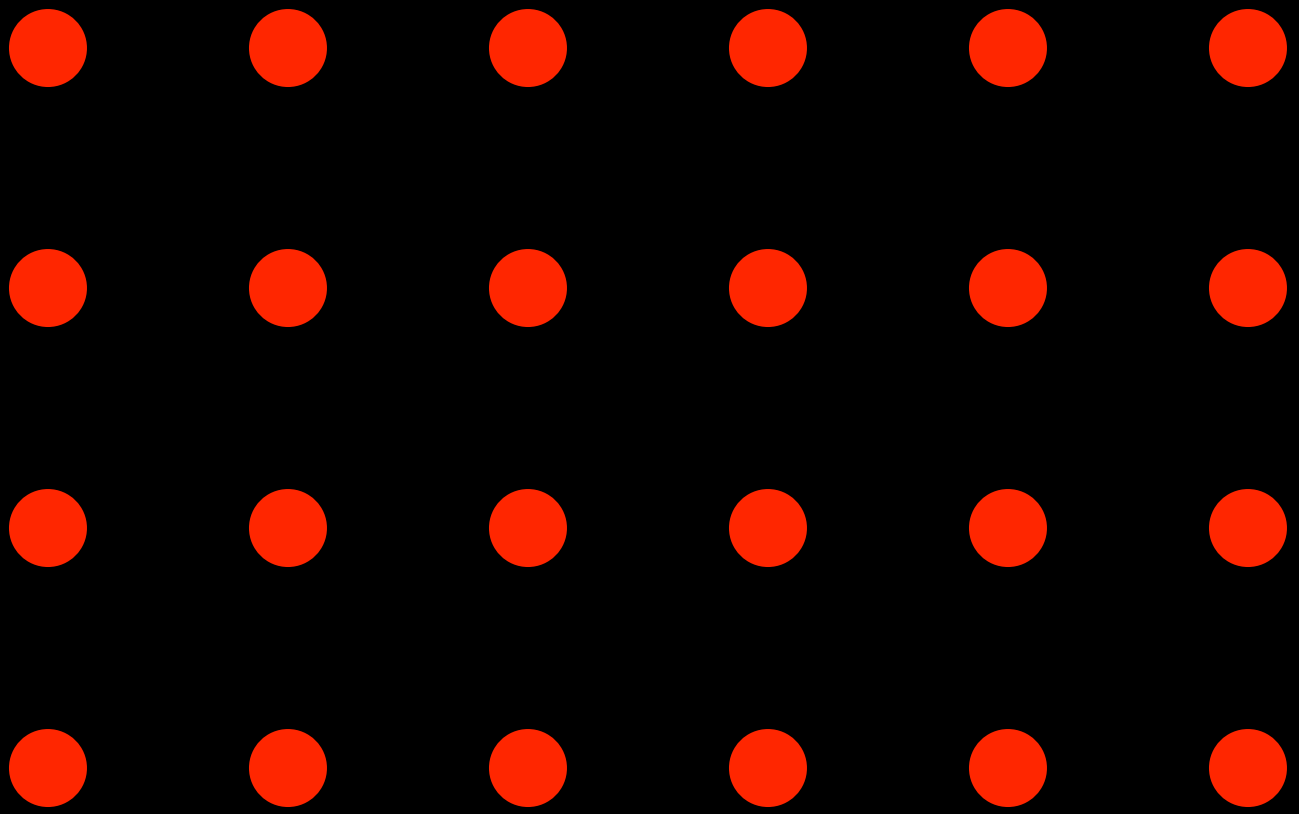
Particle physics

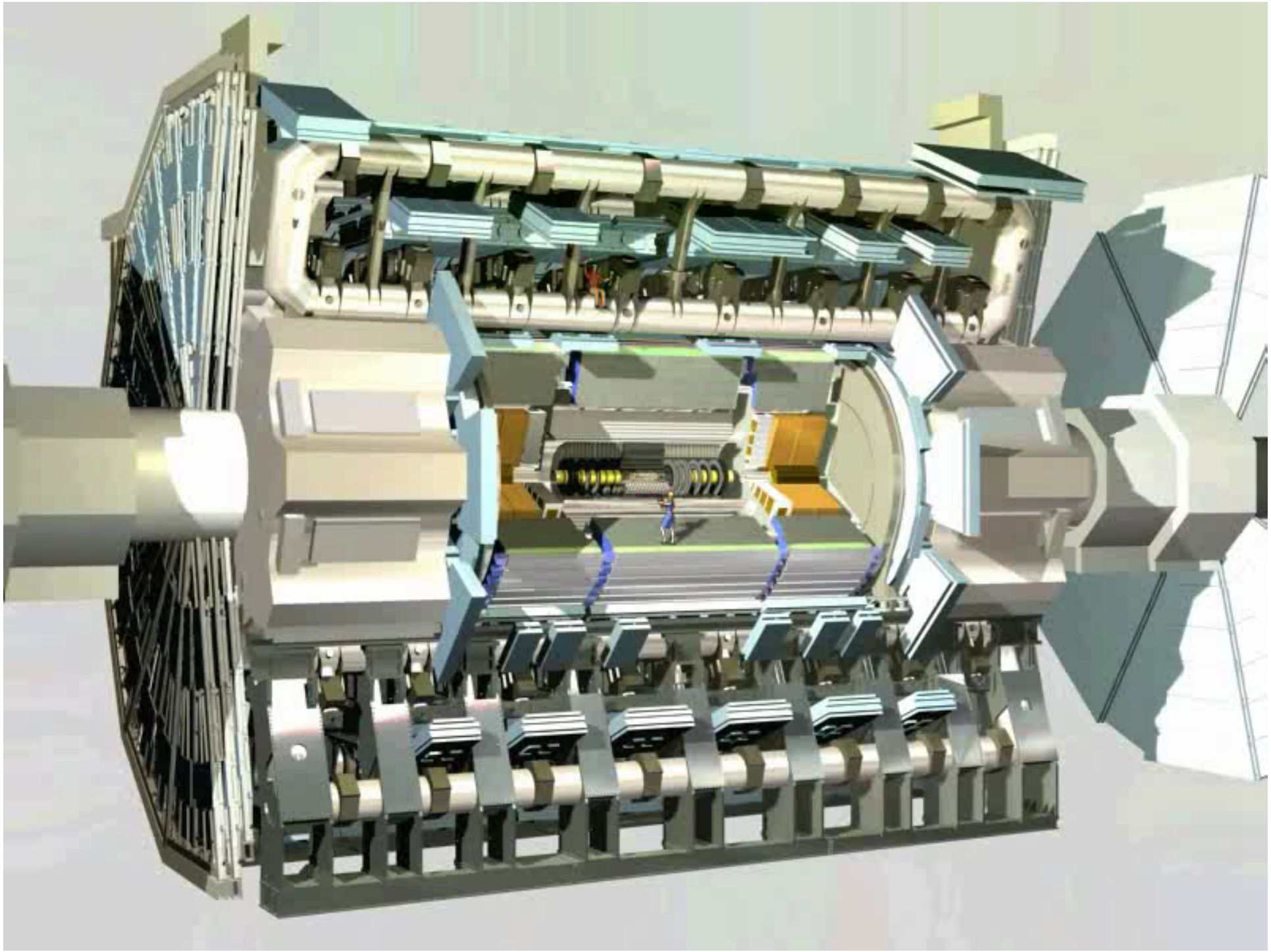
accelerators

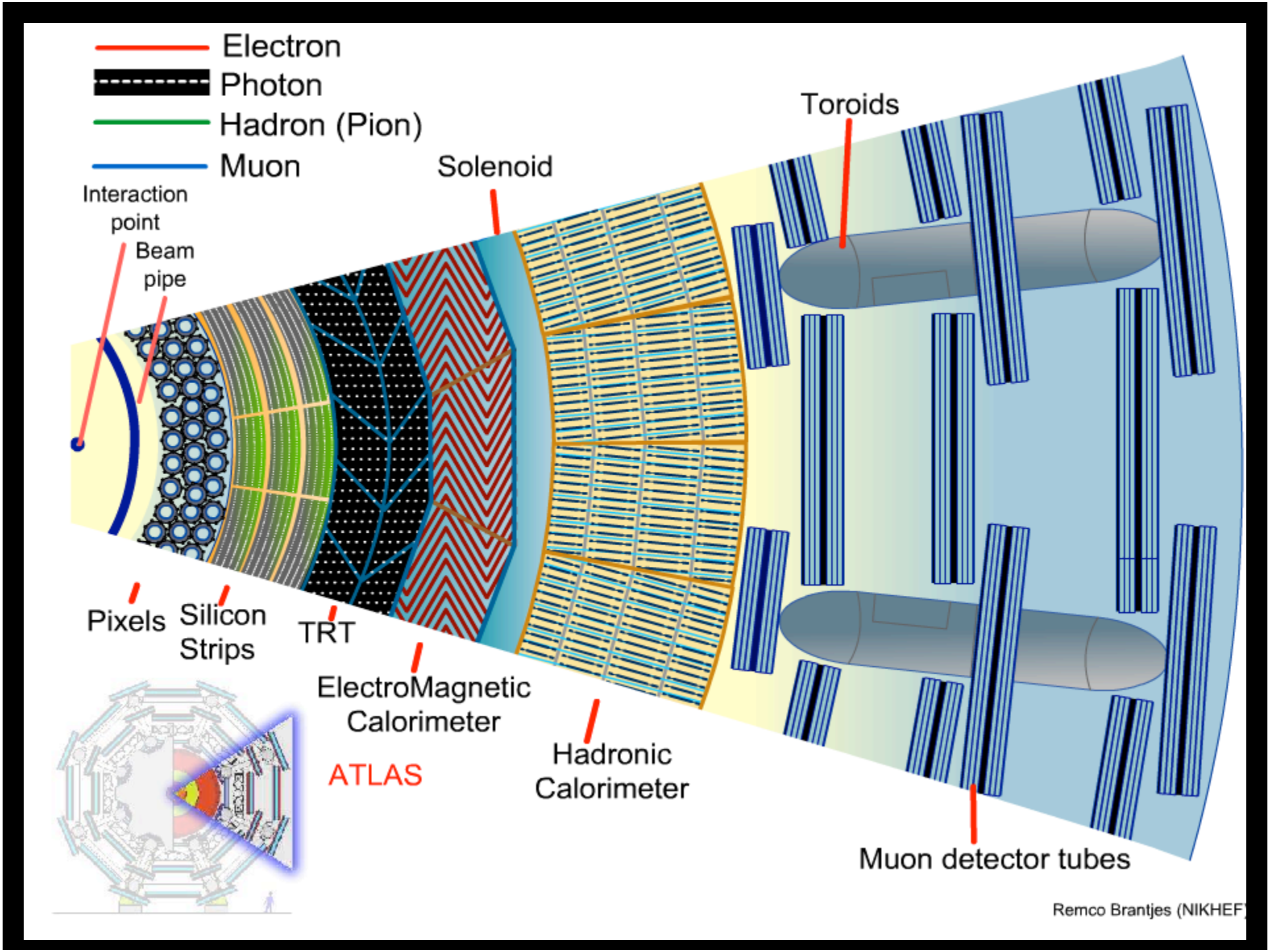
Post WW-II vision: creation of CERN


PS ISR SPS SppS LEP LHC … CLIC
1959 1971 1976 1981 1989 2009 2025?
500 fellows & associates
2500 staff
6500 users
1340 MSFr/year
CERN

Particle Detection






Electron
Photon
Hadron (Pion)
Muon
Interaction point
Beam pipe
Solenoid
Toroids
Pixels
Silicon Strips
TRT
ElectroMagnetic Calorimeter
Hadronic Calorimeter
Muon detector tubes
ATLAS
Remco Brantjes (NIKHEF)

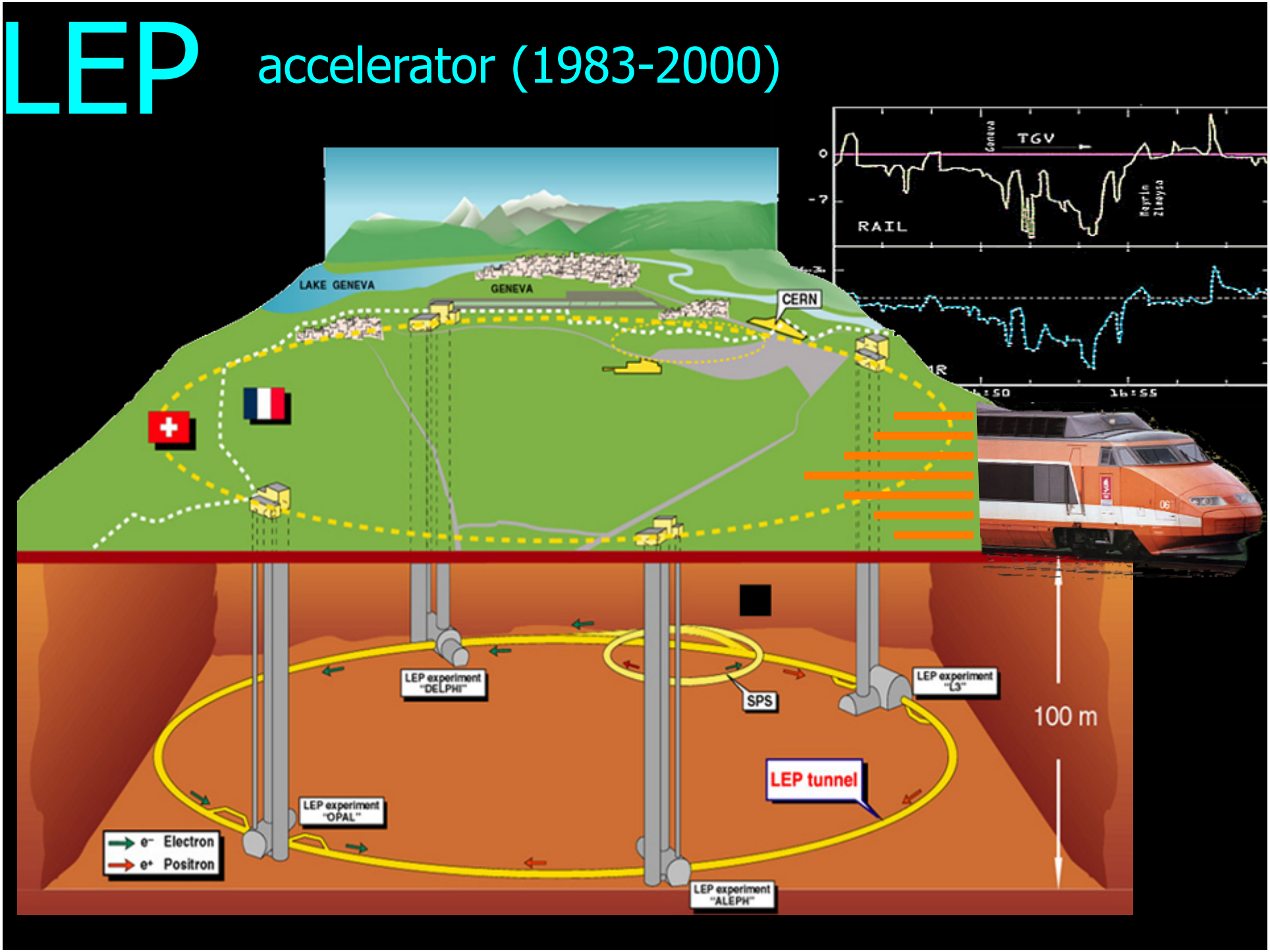
Artificial particle source: *accelerator*

LEP

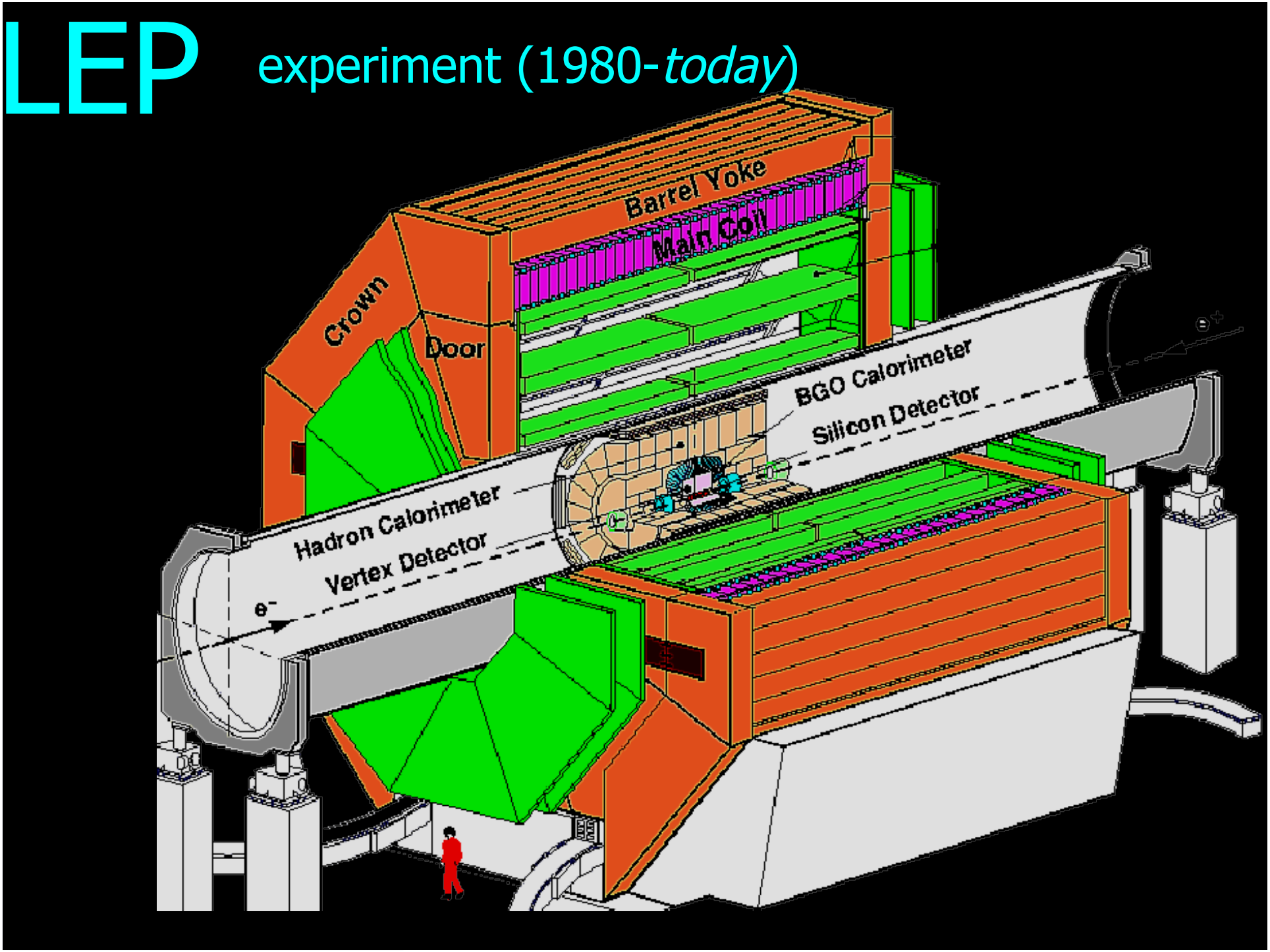
Large Electron Positron project

1989-2000

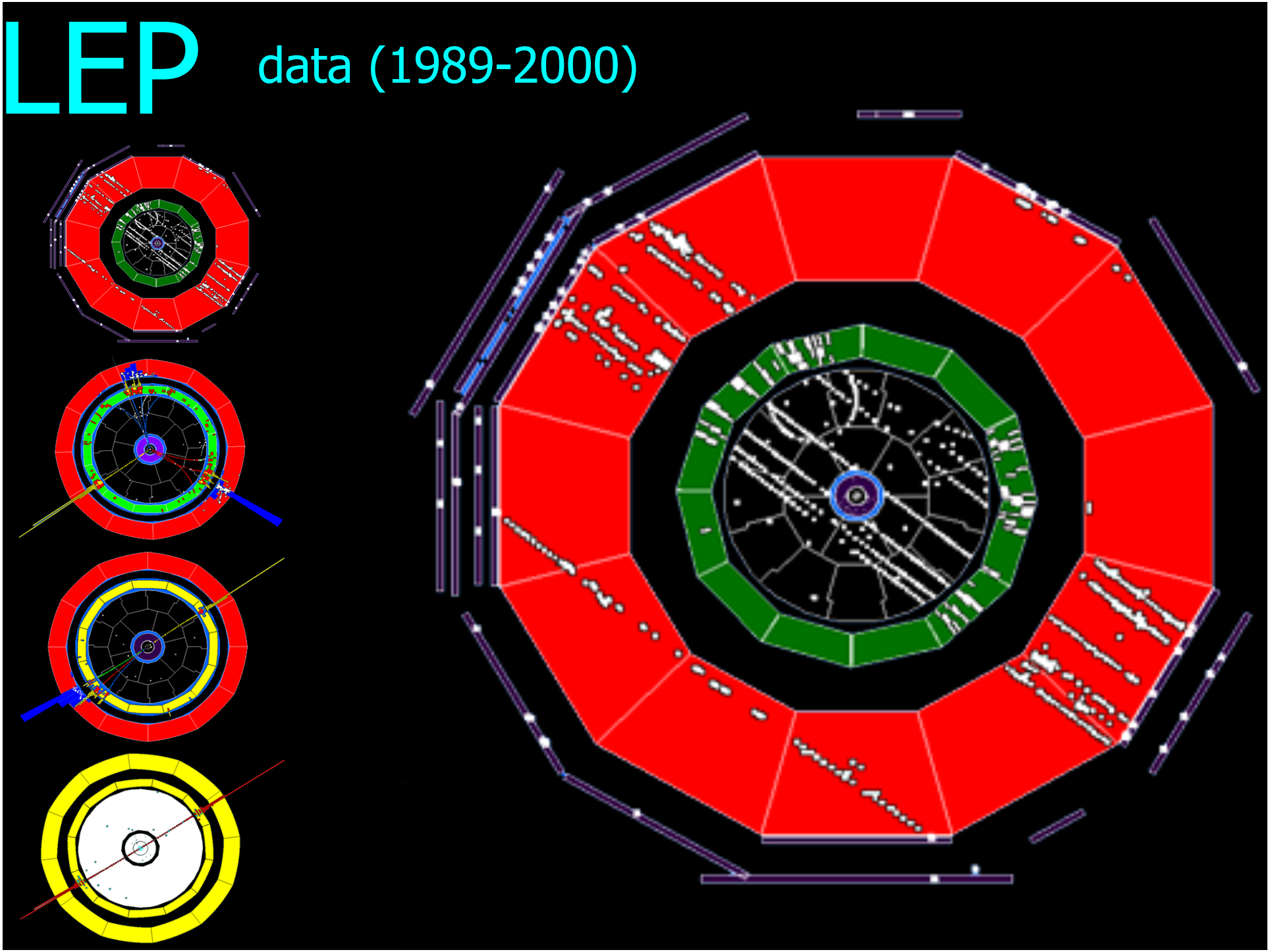
LEP accelerator (1983-2000)



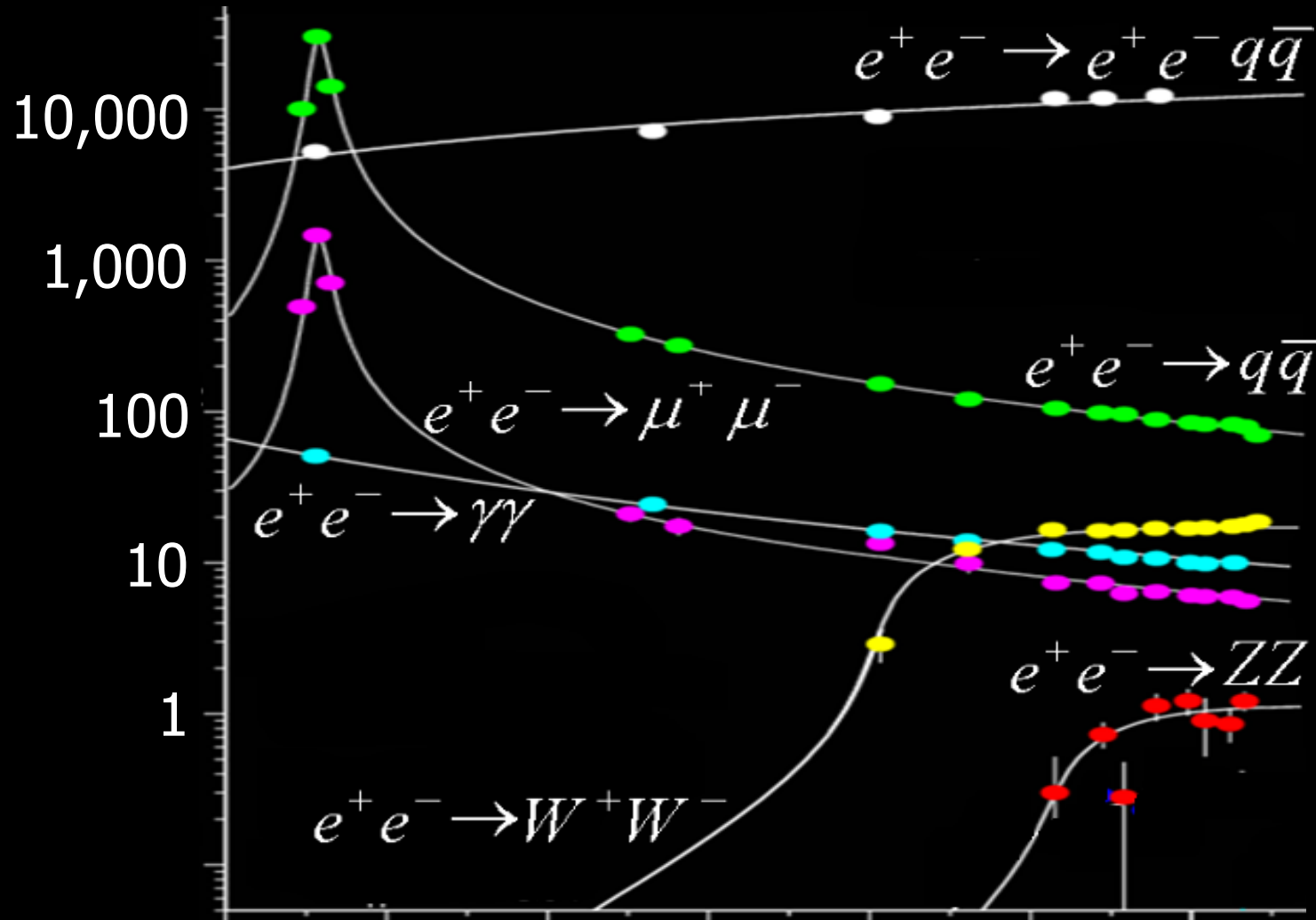
LEP experiment (1980-*today*)



LEP data (1989-2000)



LEP results (1989-*today*)



LHC

Large Hadron Collider

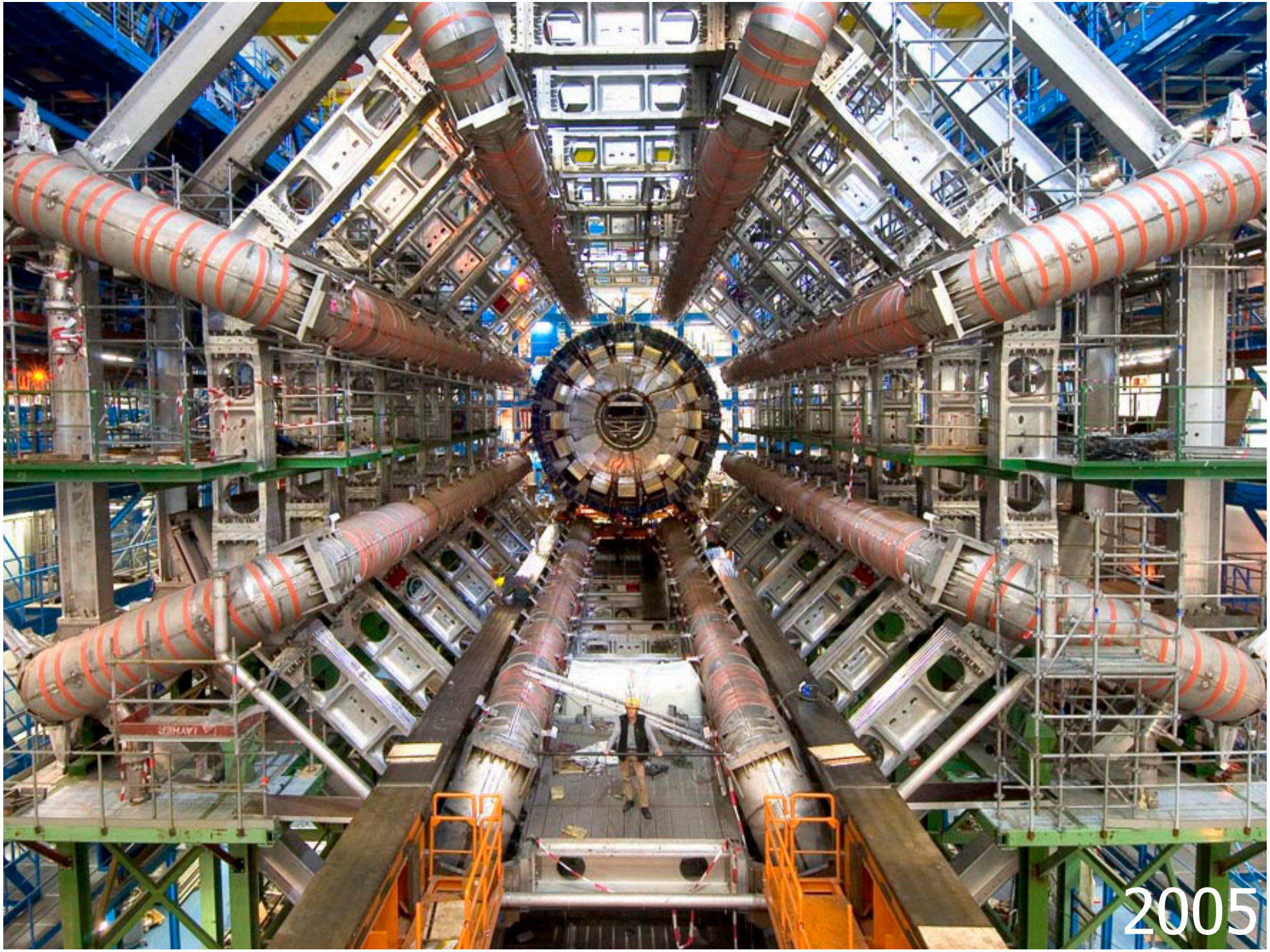
2009-2030?

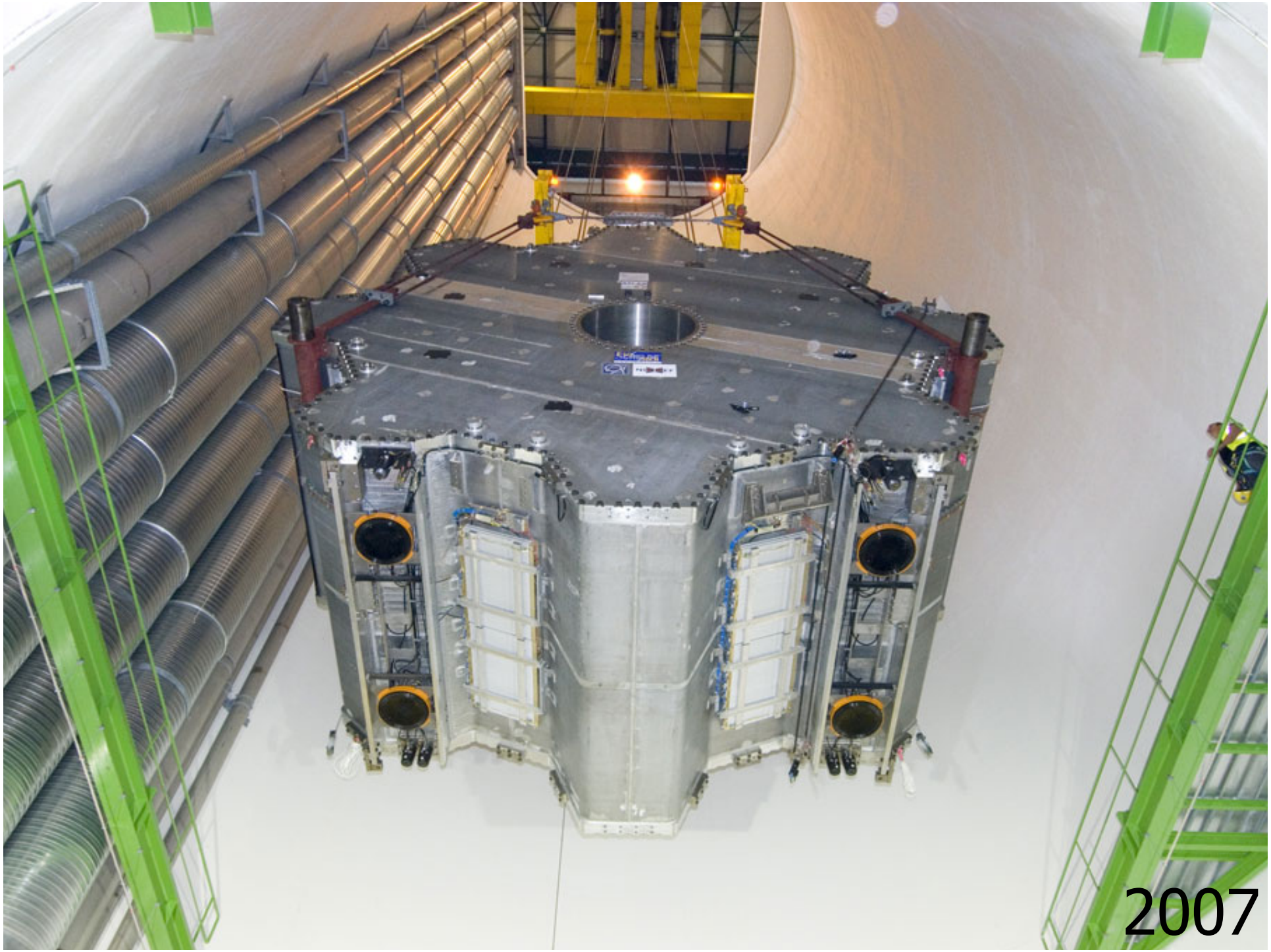
Large Hadron Collider

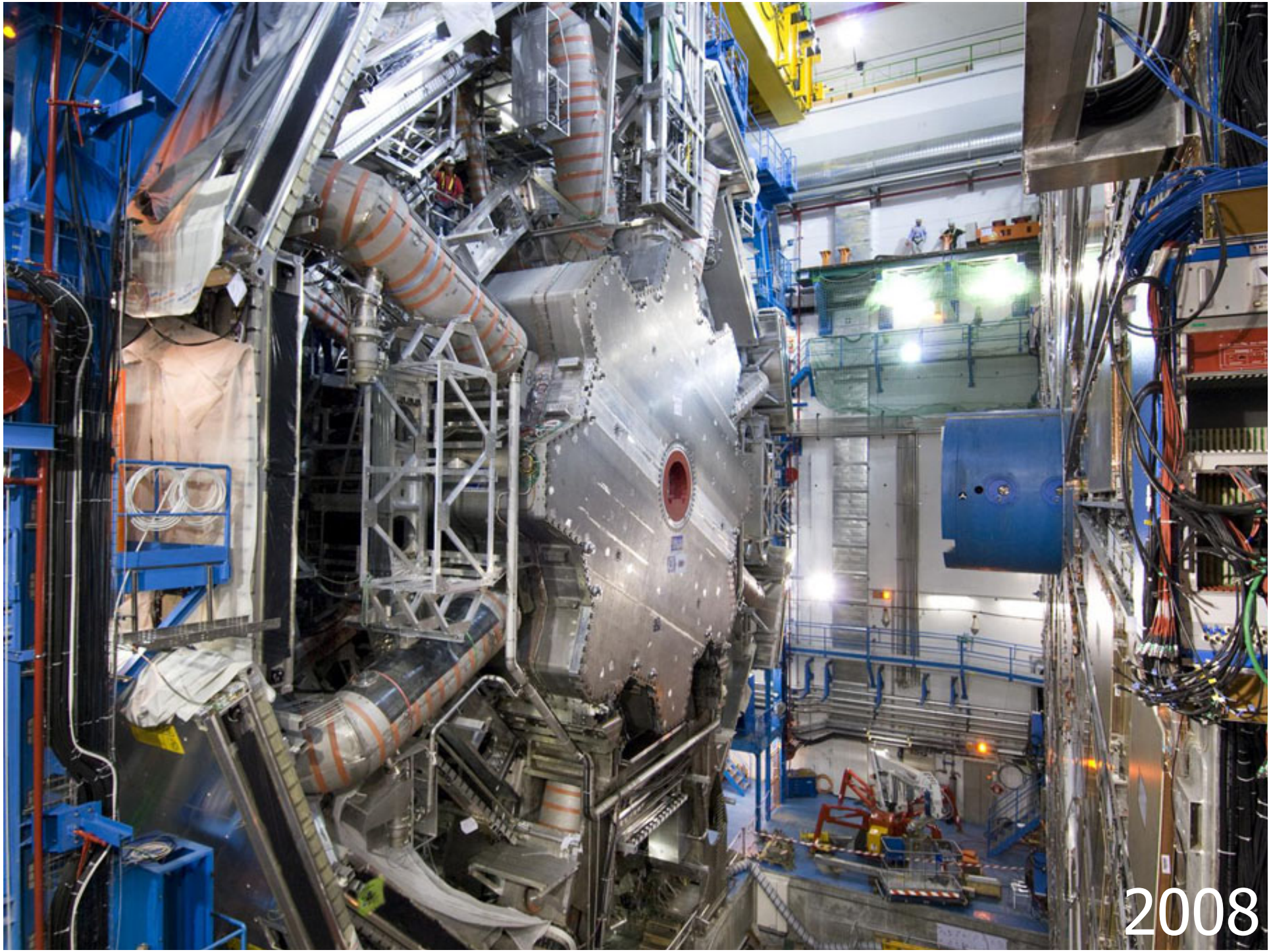
2009 → 2030?

2001

2003


2005


2007

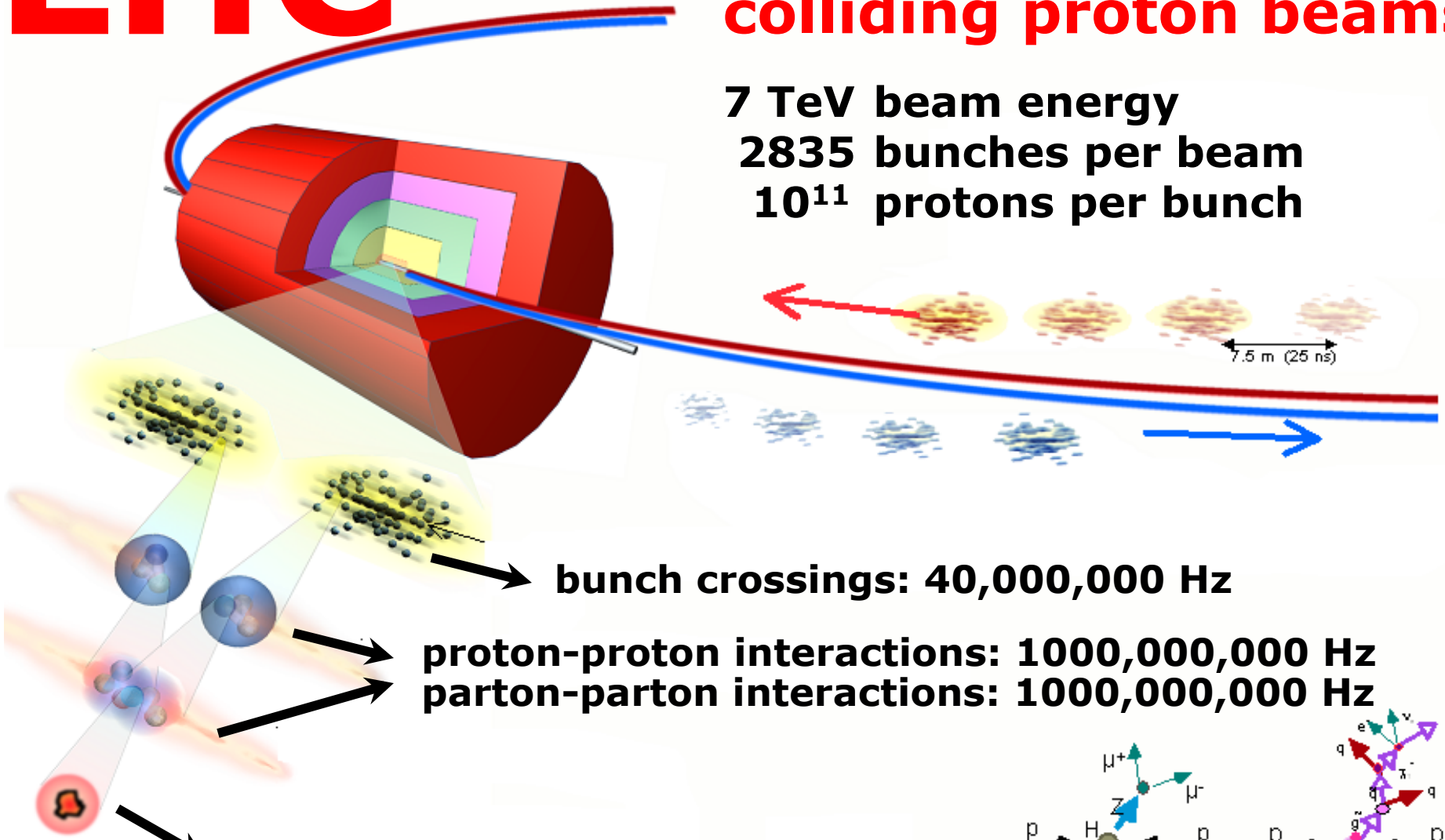

2008

ATLAS
detector
2010

LHC

colliding proton beams

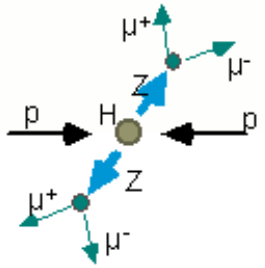
7 TeV beam energy
2835 bunches per beam
10^{11} protons per bunch

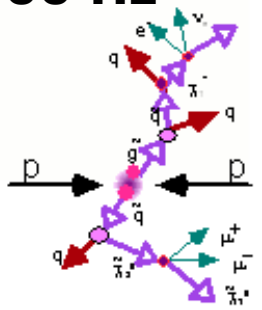


bunch crossings: 40,000,000 Hz

proton-proton interactions: 1000,000,000 Hz
parton-parton interactions: 1000,000,000 Hz

new physics (Higgs, …): 0.00001 Hz

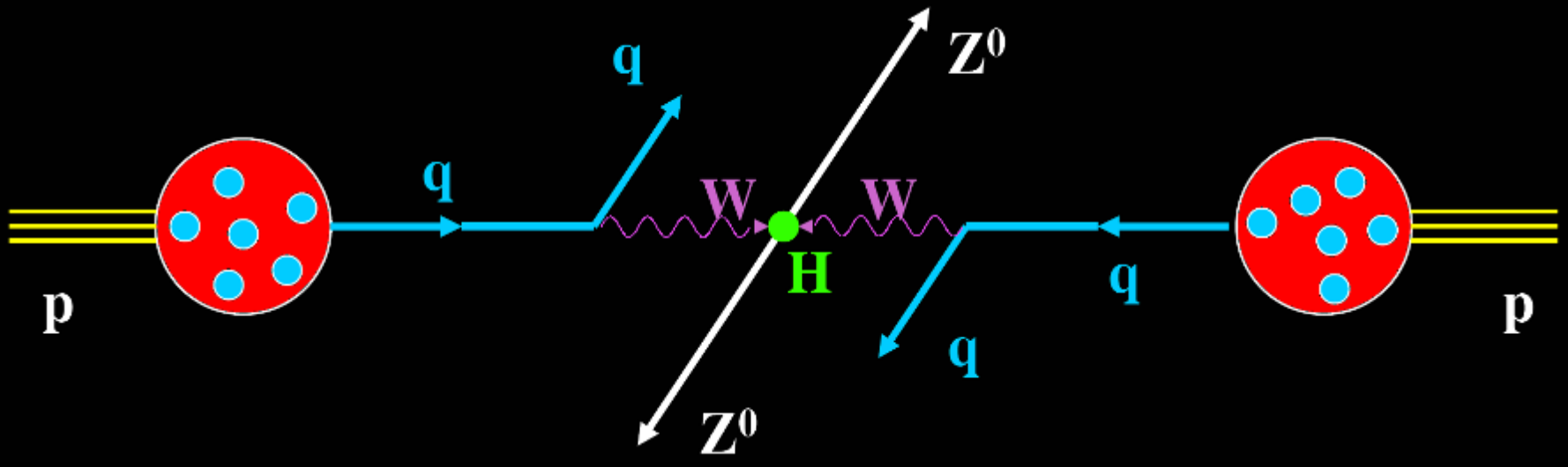




selection of 1 event in 10,000,000,000,000,000 events!

LHC ***beam energy*** & the Higgs

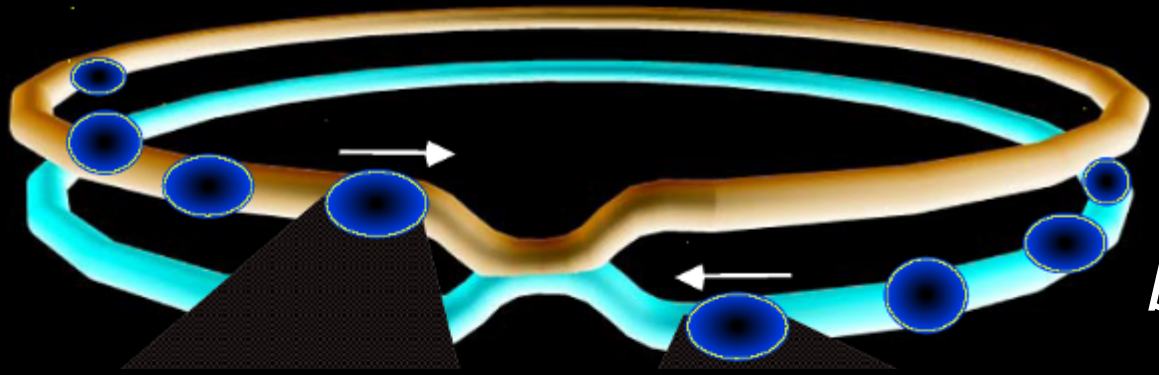
115 GeV < M_{Higgs} < 1000 GeV



M_{Higgs}=1000 GeV=1 TeV
→ W-energy ~ ½ TeV
→ q-energy ~ 1 TeV
→ p-energy ~ 6 TeV

LHC:
7 TeV
proton beams

LHC ***beam intensity*** & the Higgs



2804
bunches/beam

new physics:
few events/day

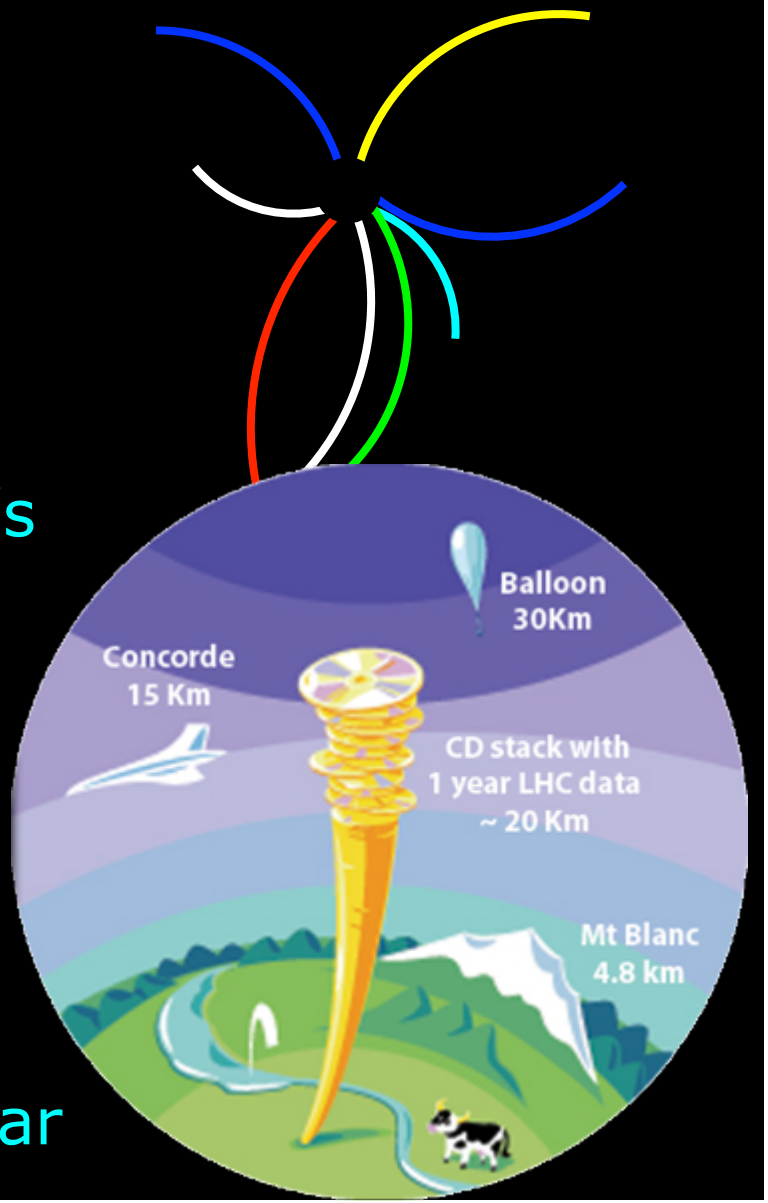
ATLAS events

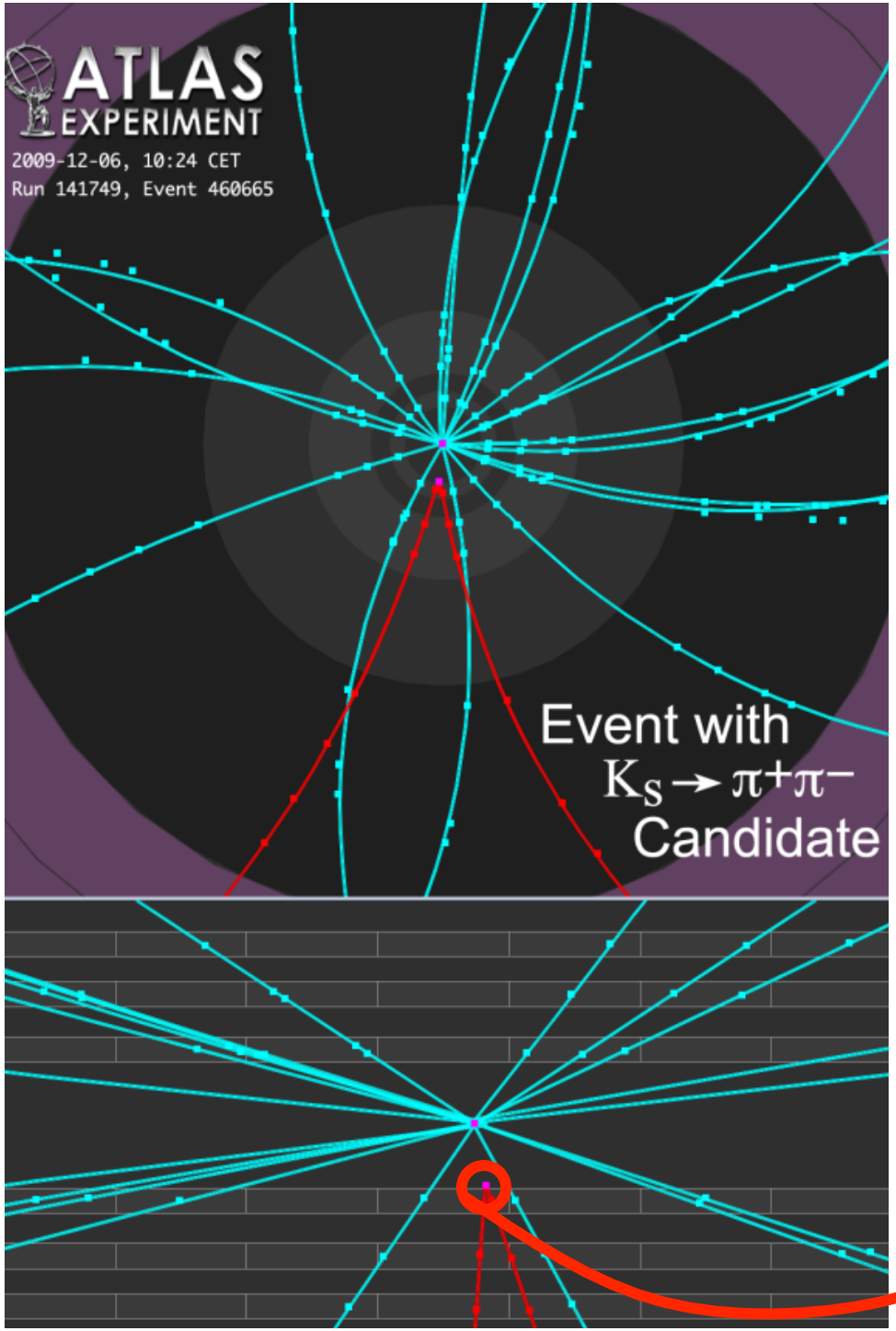
LHC bunch-bunch crossings:
40.000.000/s

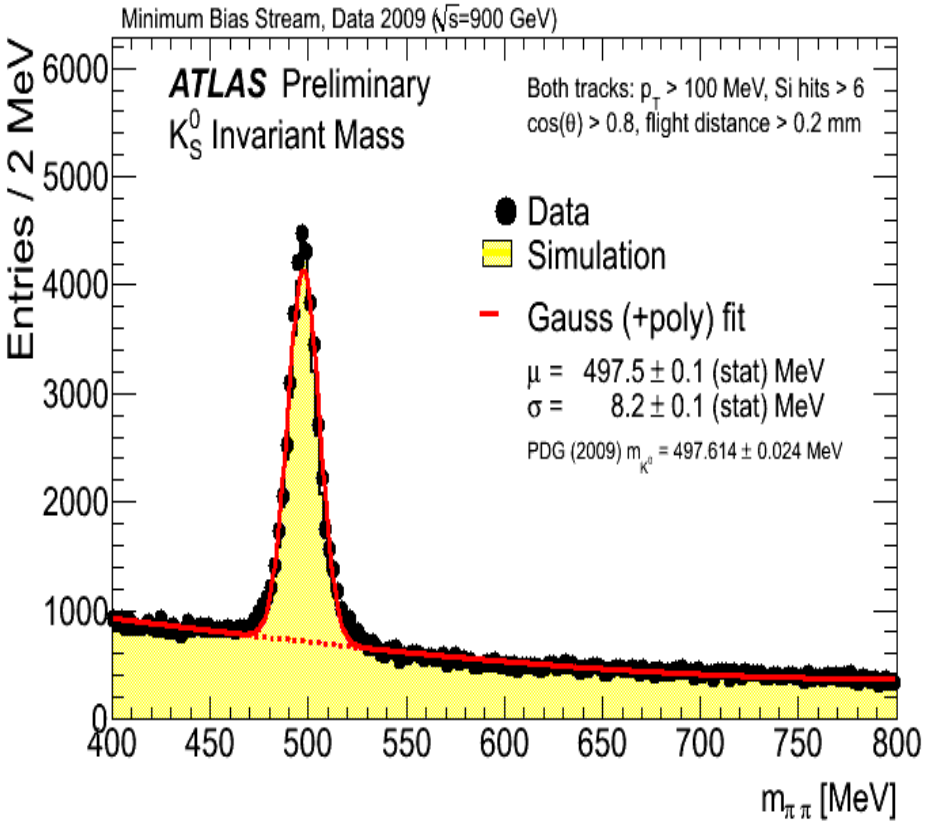
pp interactions:
20/bunch-bunch crossing
⇒ 800.000.000 pp interactions/s

selection:
100 pp interactions/s
⇒ ongeveer 1 per 10 miljoen

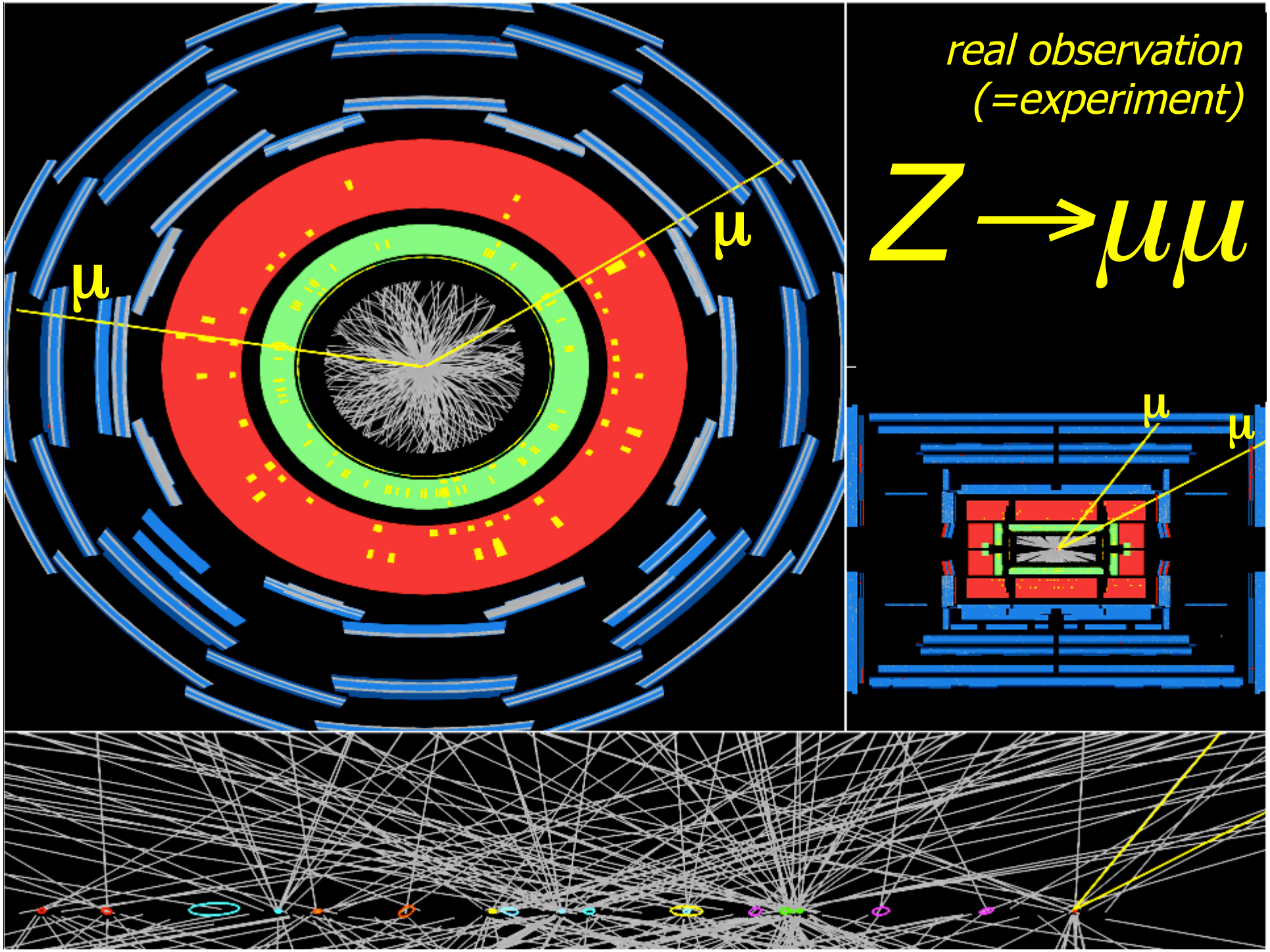
data volume:
200 MB/s
⇒ 2 miljoen GB/year = 2 pB/year

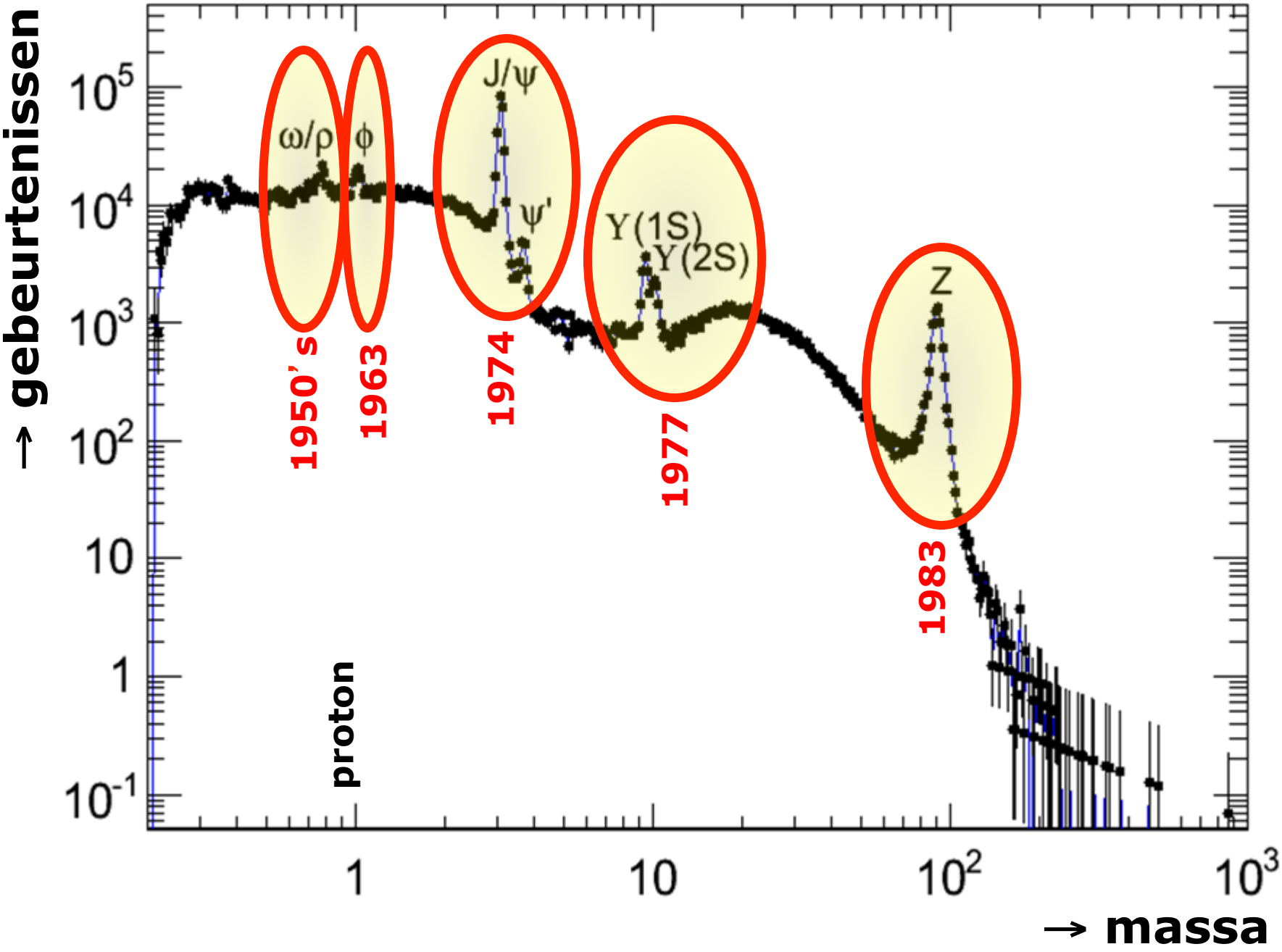






$K^0_S \rightarrow \pi^+\pi^-$


real observation
(=experiment)
$Z \rightarrow \mu\mu$
μ
μ
μ
μ


→ gebeurtenissen
10^5
10^4
10^3
10^2
10
1
10^{-1}
ω/ρ
φ
J/ψ
ψ'
Υ(1S)
Υ(2S)
Z
1950's
1963
1974
1977
1983
proton
1
10
10^2
10^3
→ massa

Higgs

HIGGS BOSON

H

The **HIGGS BOSON** is the theoretical particle of the Higgs mechanism, which physicists believe will reveal how all matter in the universe get its mass. Many scientists hope that the Large Hadron Collider in Geneva, Switzerland will detect the elusive Higgs Boson when it begins colliding particles at 99.99% the speed of light.

Wool felt with gravel fill for maximum mass.

LIGHT ●●●●●●●●●●●● HEAVY

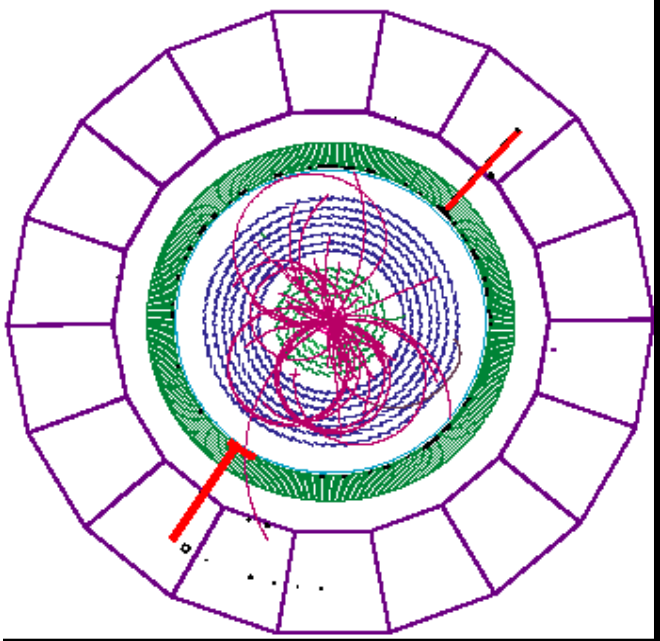
$9.75 PLUS SHIPPING

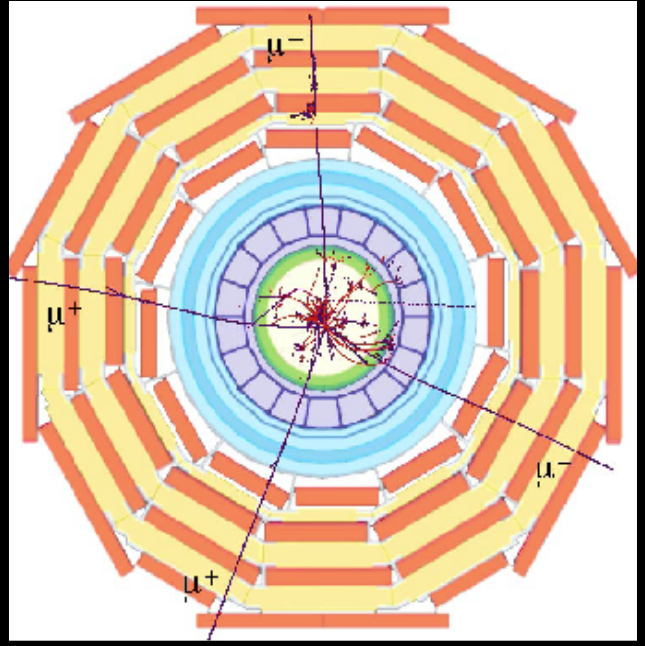
GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU NEUTRINO MUON UP QUARK
NEUTRON DOWN QUARK TAU GLUON **HIGGS BOSON** NEUTRINO TACHYON ELECTRON UP QUARK DOWN
NEUTRINO MUON UP QUARK PROTON NEUTRON DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHY
UP QUARK PROTON NEUTRON DOWN QUARK TAU GLU
N TACHYON ELECTRON UP QUARK TAU NEUTRINO MUON UP QUARK PROTON N
DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU NEU
UP QUARK PROTON NEUTRON DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON ELECTRON UP

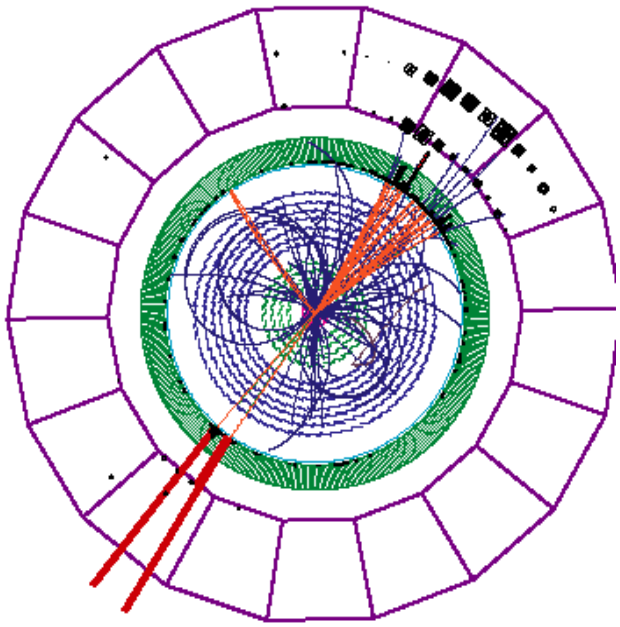
The PARTICLE ZOO

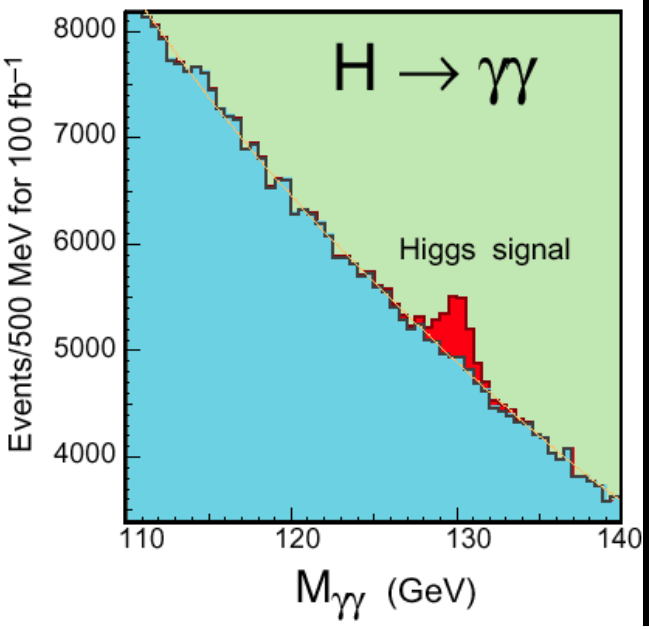
theoretical prediction (=simulation)

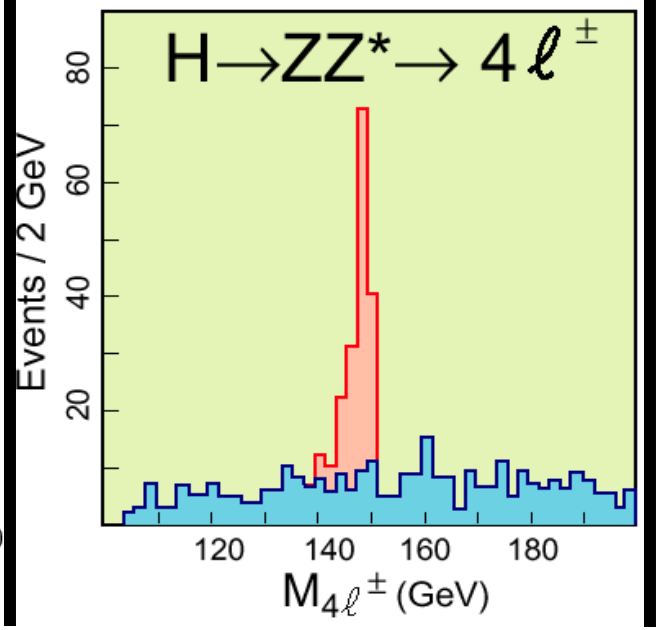
Higgs signature in LHC experiments

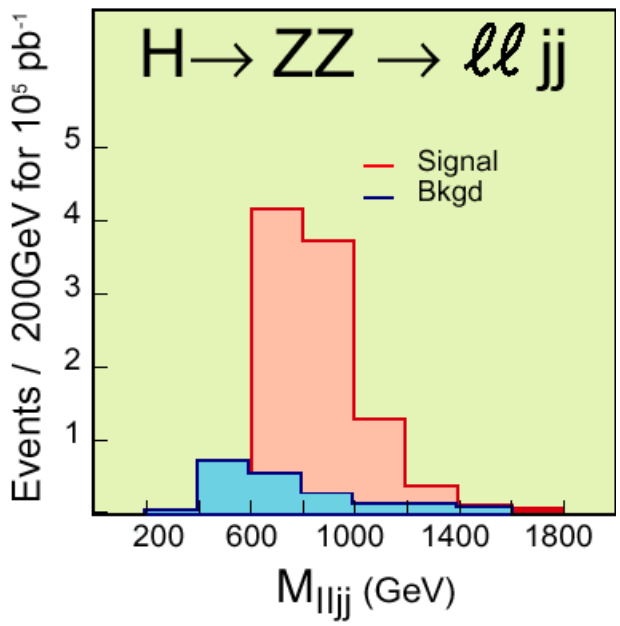


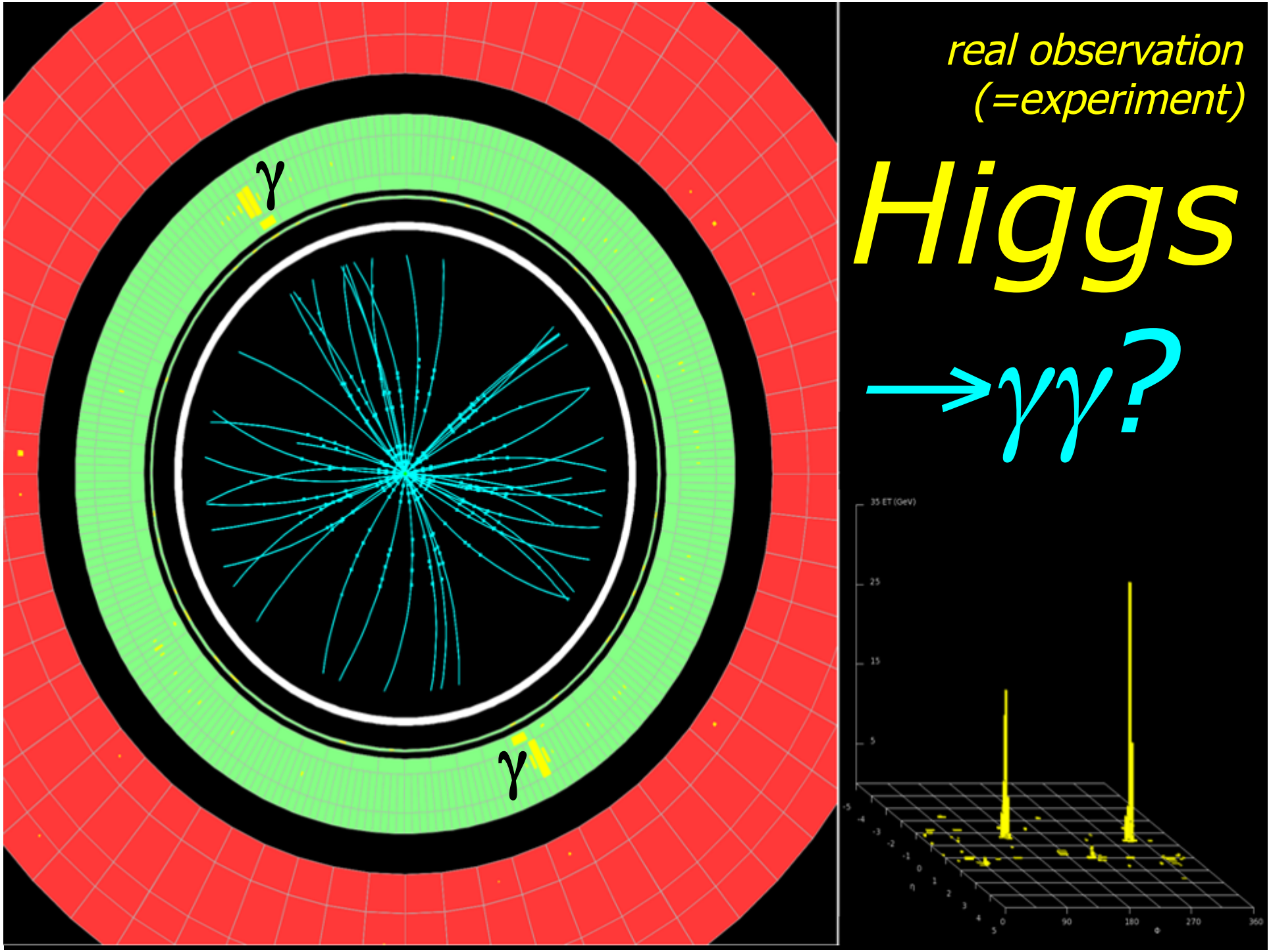




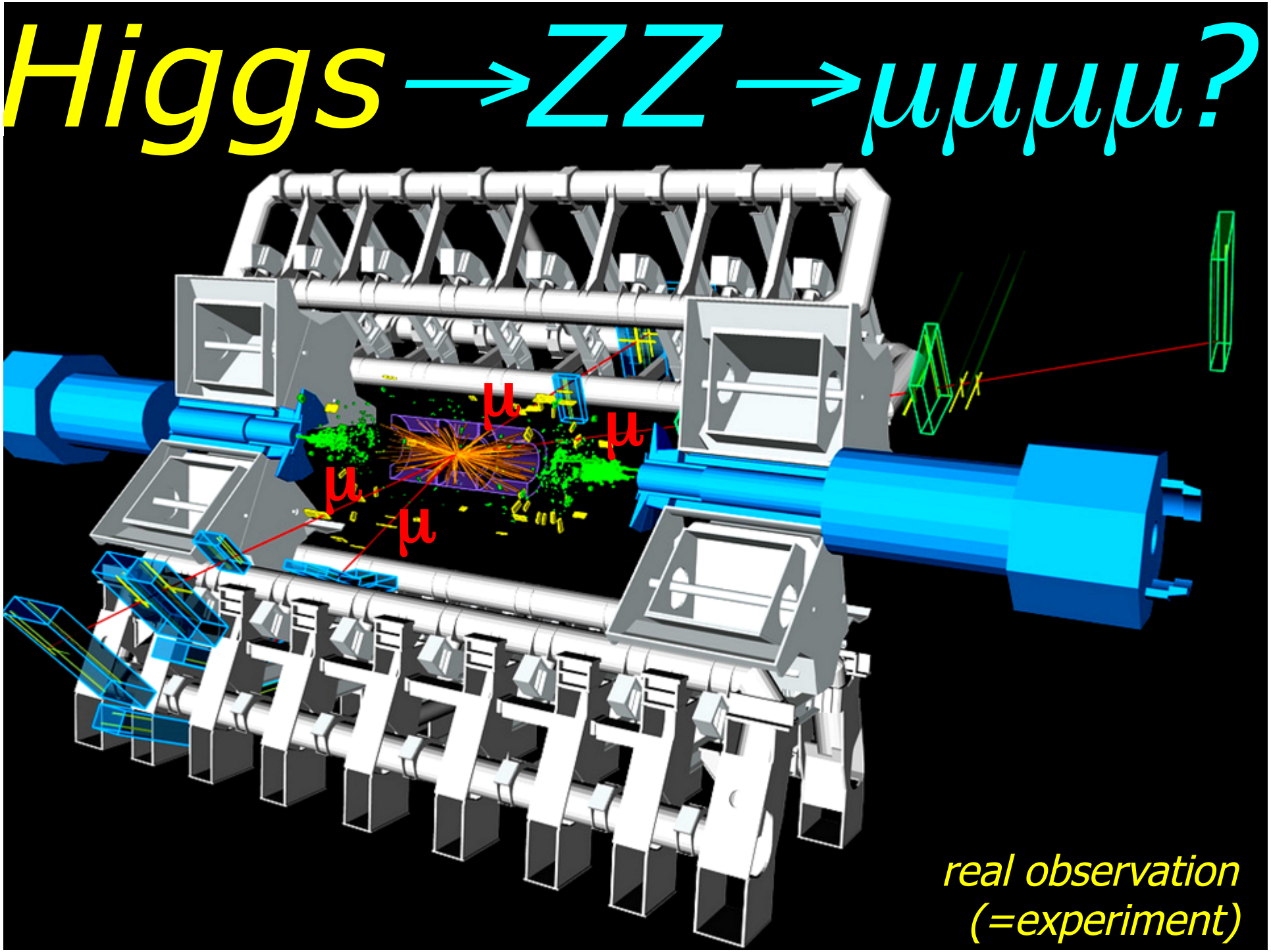




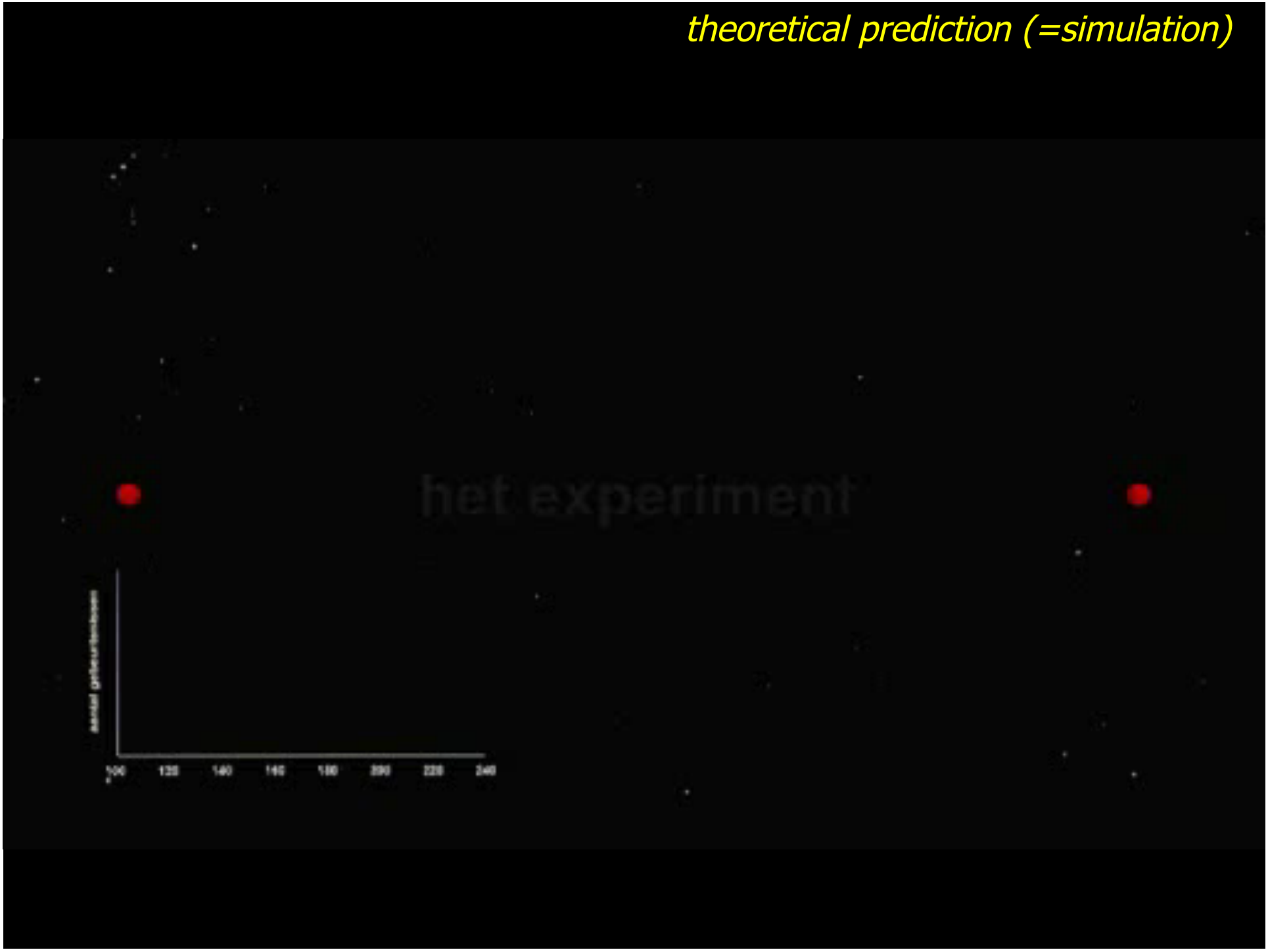


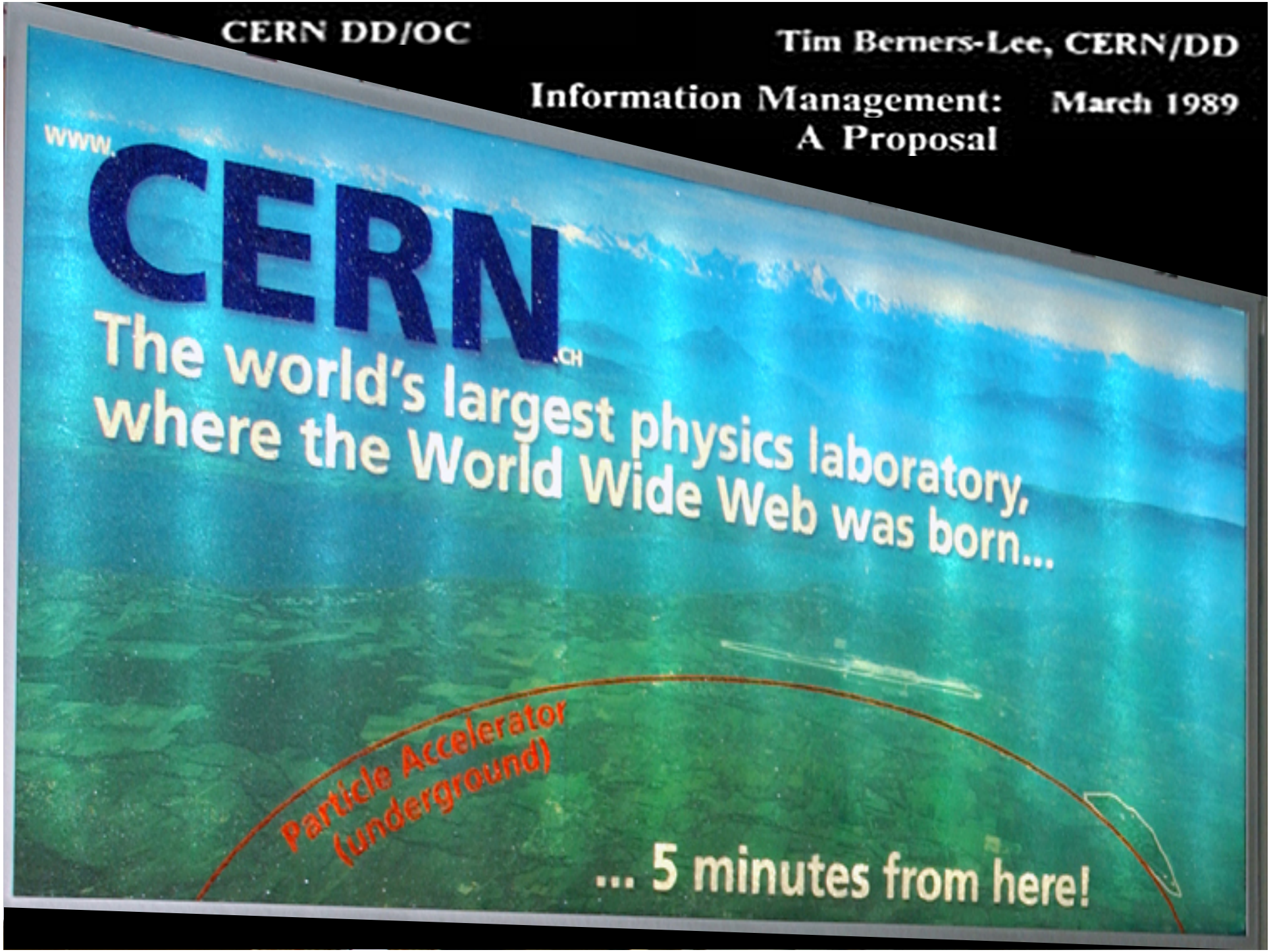

γ
γ
real observation
(=experiment)
Higgs
→γγ?
35 ET (GeV)
25
15
5
-5
-4
-3
-2
-1
0
1
2
3
4
5
η
0
90
180
270
360
φ

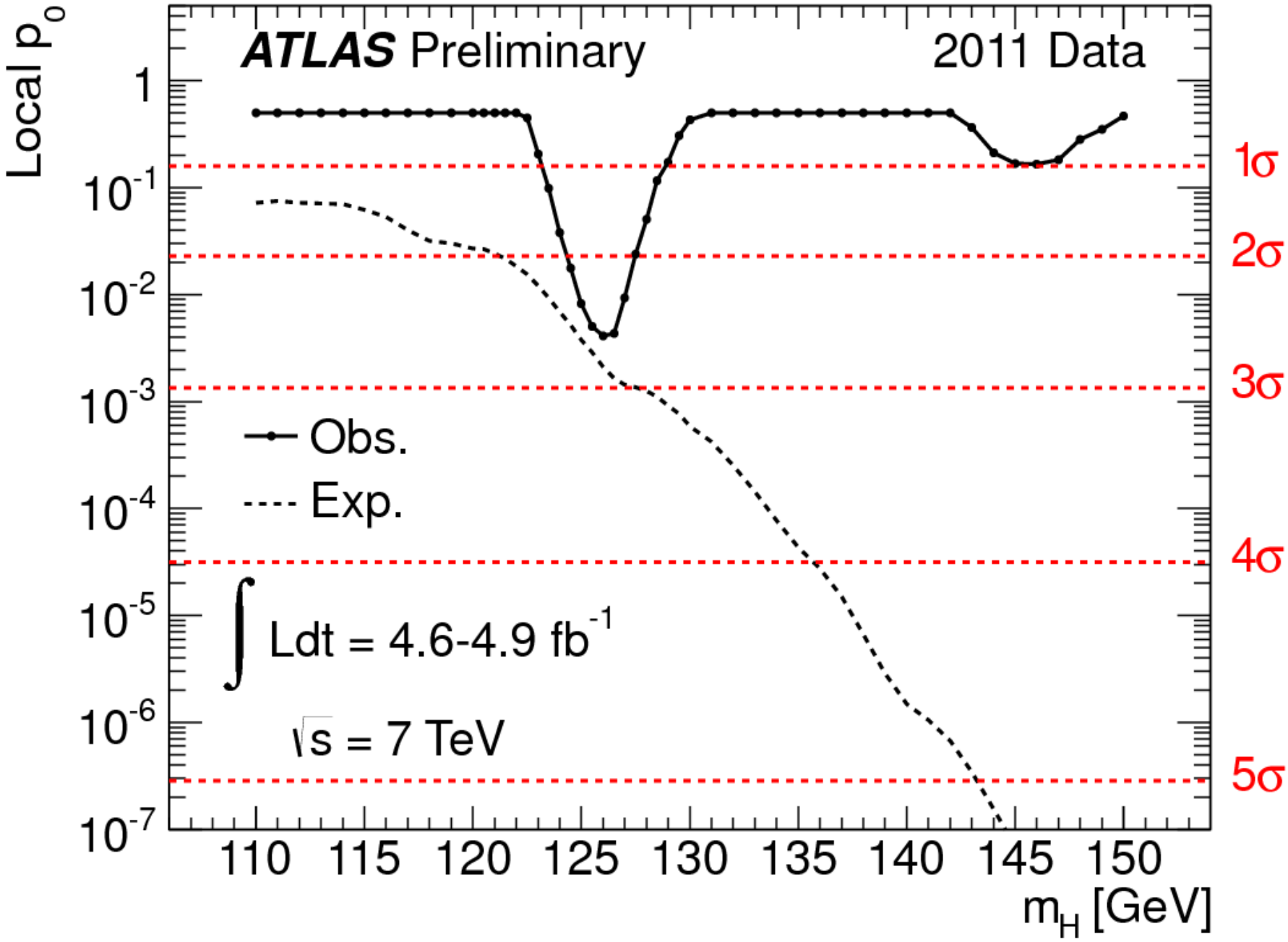
Higgs→ZZ→μμμμ?



theoretical prediction (=simulation)




CERN DD/OC
Tim Berners-Lee, CERN/DD
Information Management: March 1989
A Proposal
www.
CERN
.CH
The world's largest physics laboratory,
where the World Wide Web was born...
Particle Accelerator
(underground)
... 5 minutes from here!

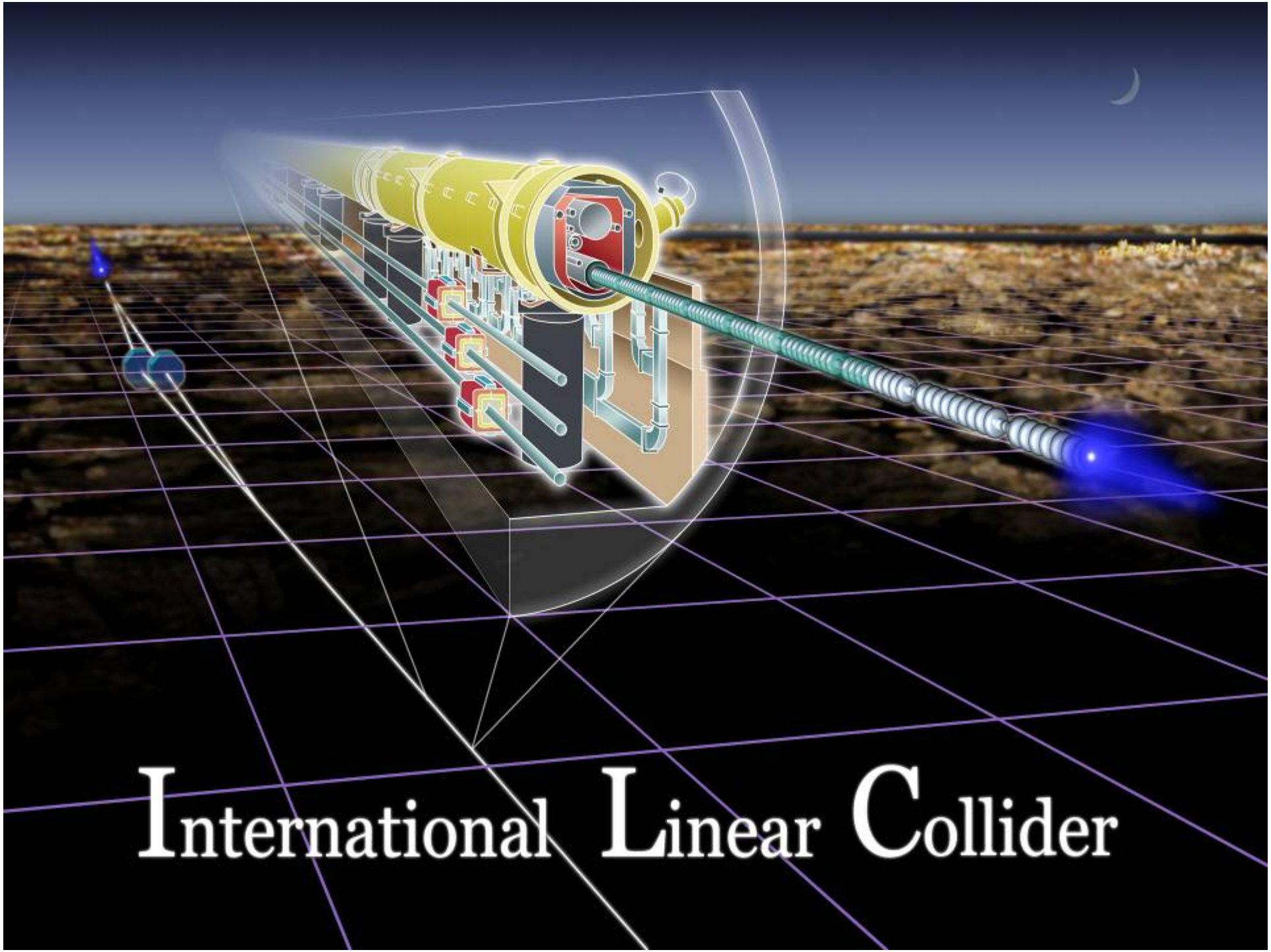

ATLAS Preliminary
2011 Data
Local p0
1
10-1
10-2
10-3
10-4
10-5
10-6
10-7
1σ
2σ
3σ
4σ
5σ
Obs.
Exp.
∫ Ldt = 4.6-4.9 fb-1
√s = 7 TeV
110
115
120
125
130
135
140
145
150
mH [GeV]

Peter Higgs
visits ATLAS

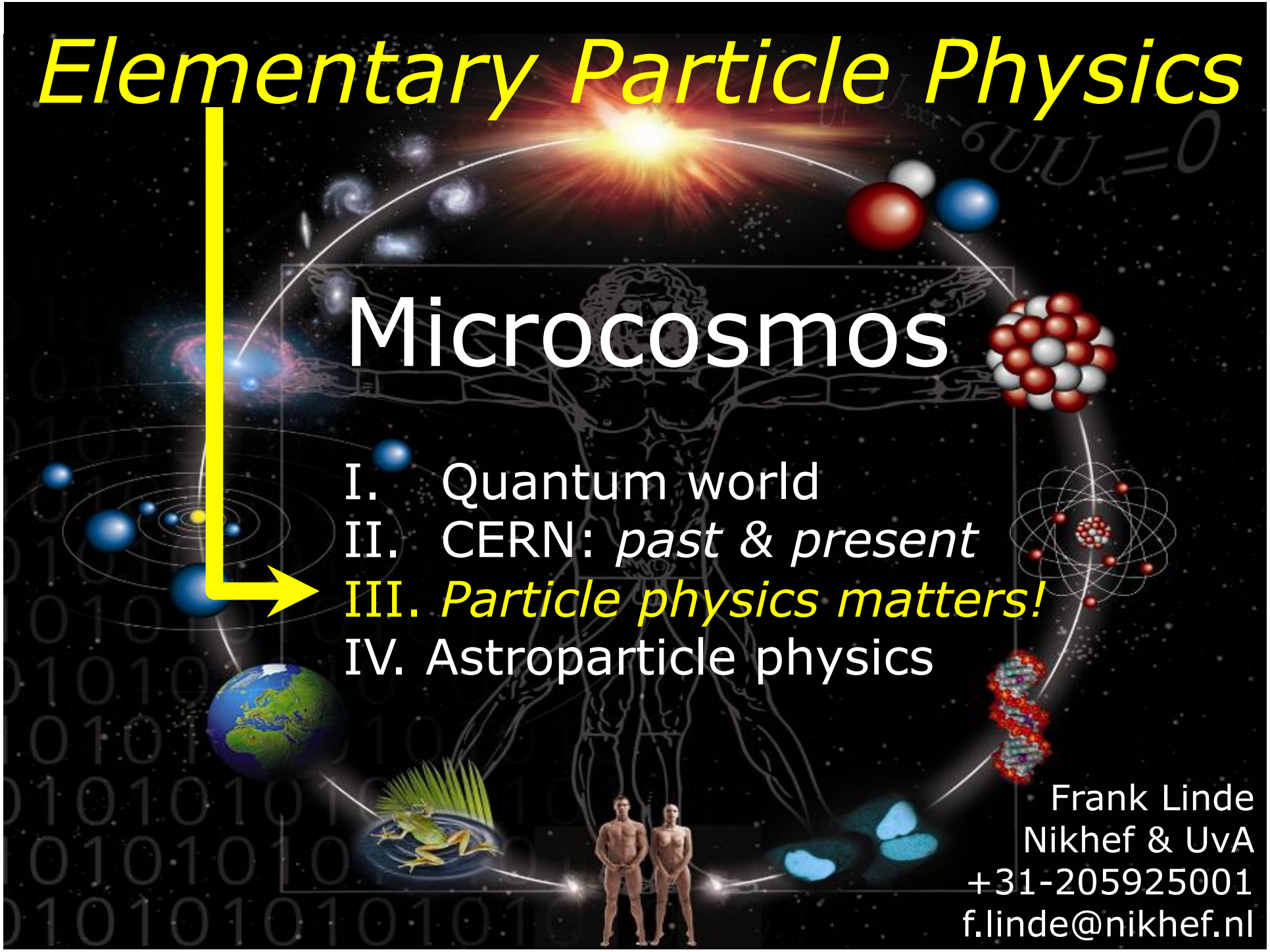
CLIC

Compact LInear Collider

≥2025?


International Linear Collider

Elementary Particle Physics



Microcosmos

I. Quantum world
II. CERN: *past & present*
III. *Particle physics matters!*
IV. Astroparticle physics

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