Intricately Searching for Simplicity
An Introduction to Experimental Particle Physics

Nature's basic pieces and their interactions

Anything understood seems simple enough...

Reductionism

Understanding =

Identifying fundamental constituents and

delineating the rules of their interactions

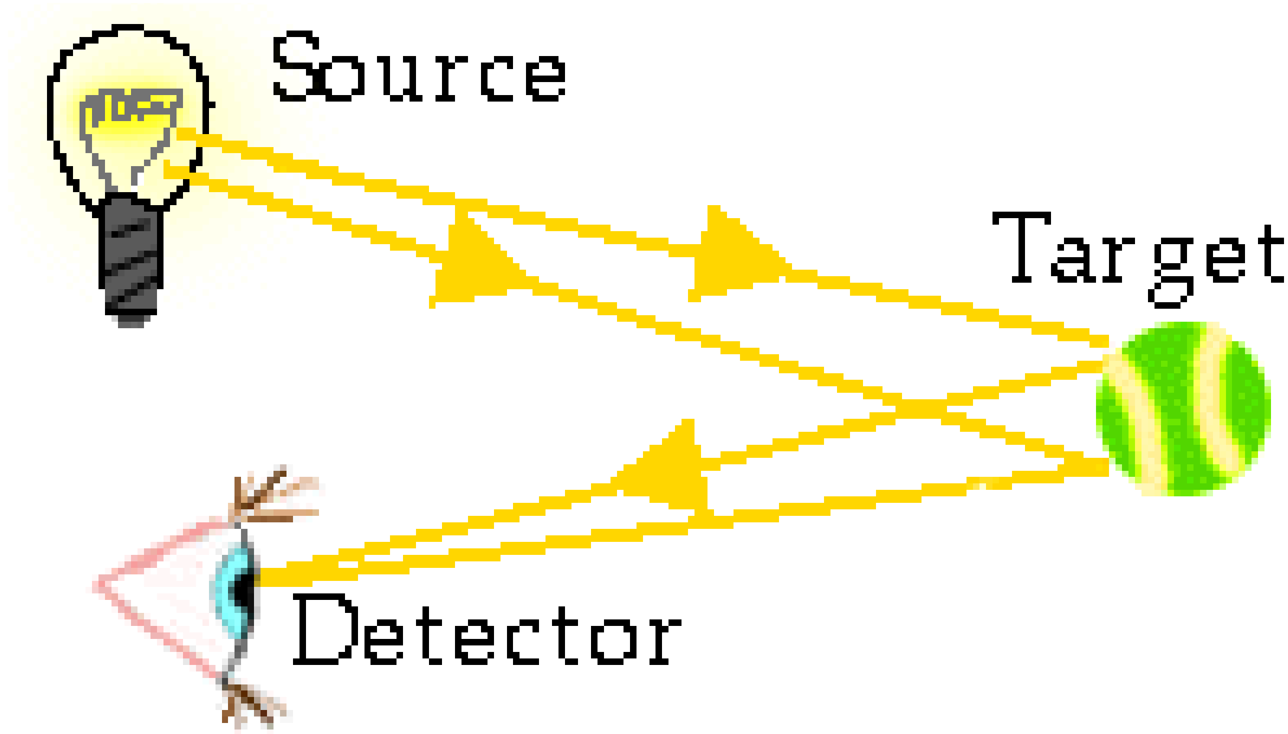
Two Frontiers

- Energy
- Precision

Bigger Bang ⇒ More Muck

$$E = mc^2$$

Seeing

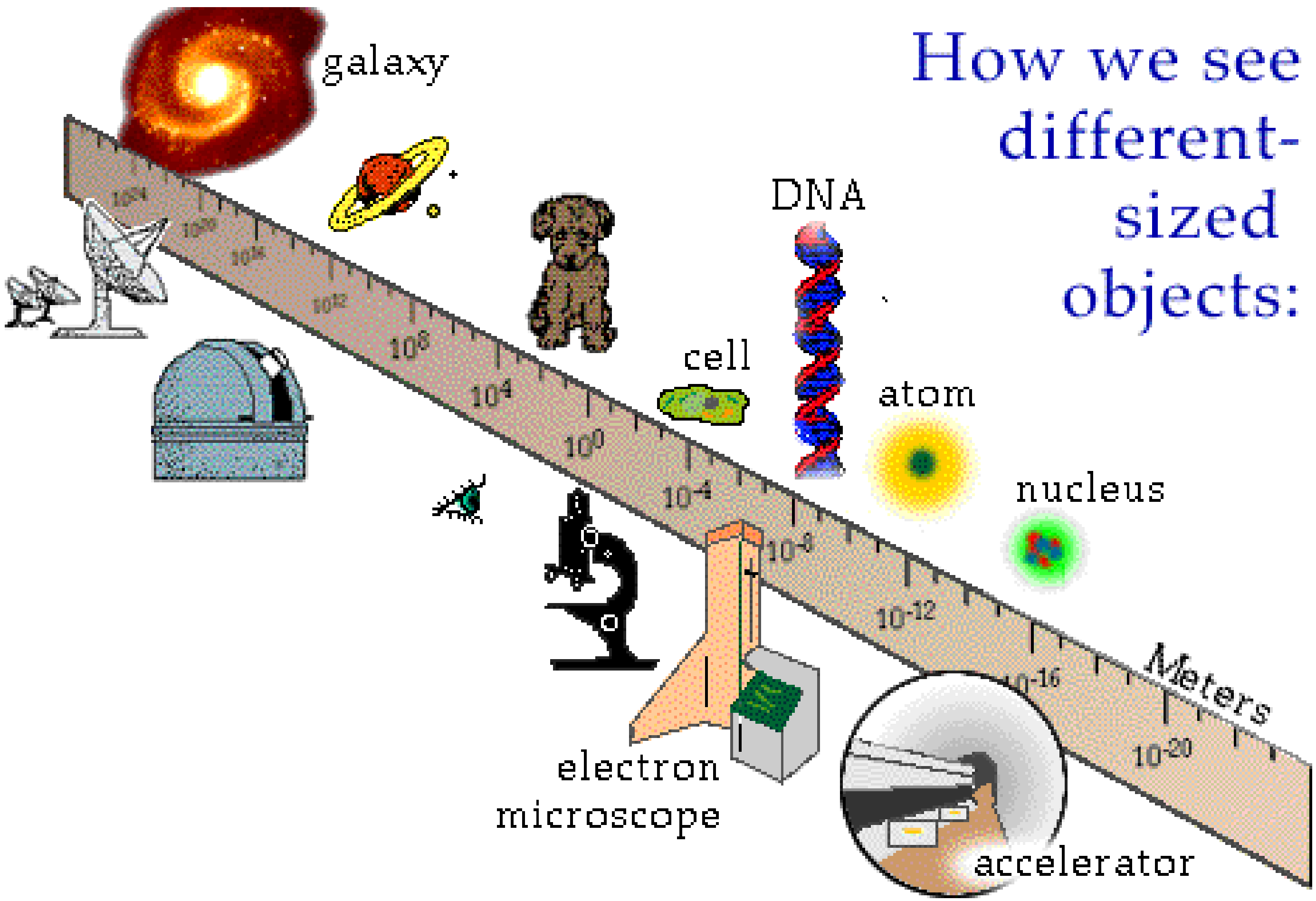


Imaging quality limited by probe's wavelength and detector's sensitivity (resolution)

Higher Energy ⇒ Shorter Wavelength

$$E = \frac{hc}{\lambda}$$

The Apposite Eye and the Appropriate Wavelength



Consequently, Accelerators

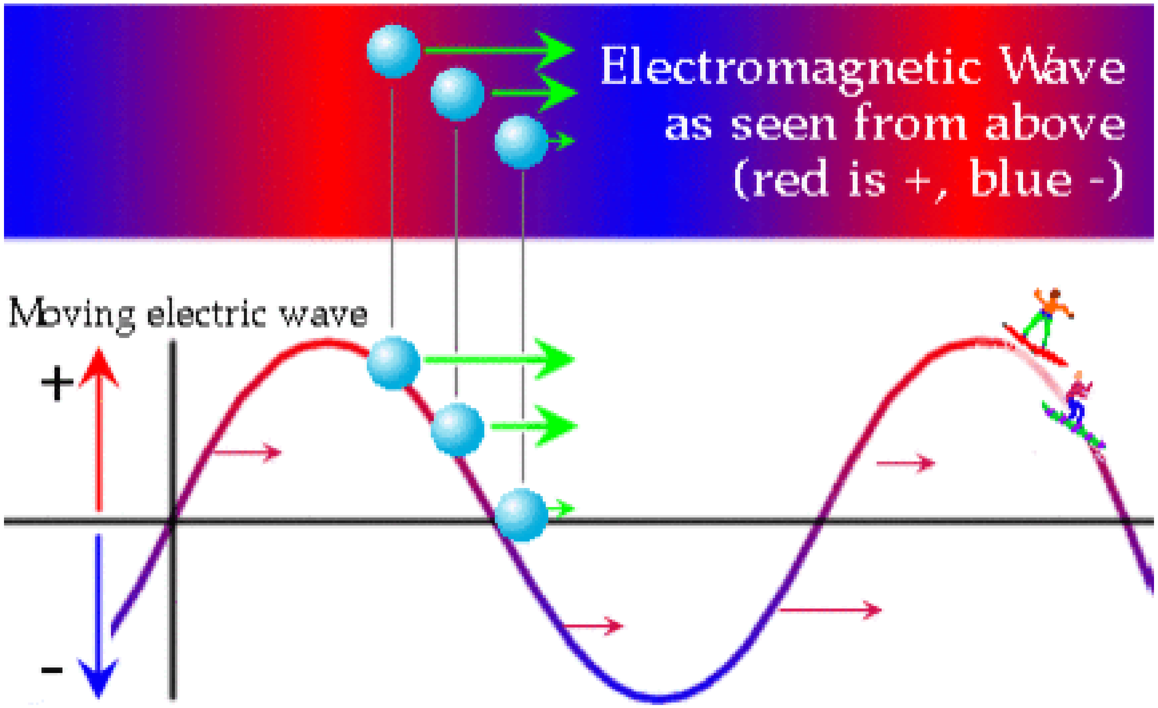
- To increase $E = mc^2$
- To increase $E = \frac{hc}{\lambda}$

$hc \approx 12345$ ev • Å

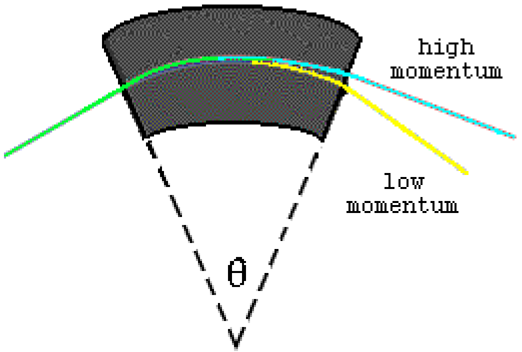
So, to “see” objects of 10^{-20} m dimensions,

$E \approx 10^{14}$ eV = 100 TeV

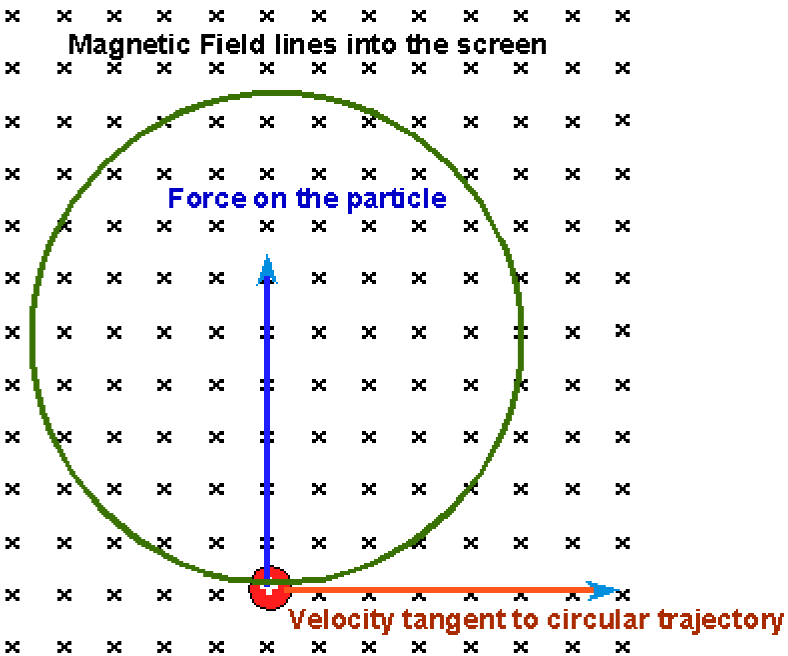
Accelerator Physics (short course)



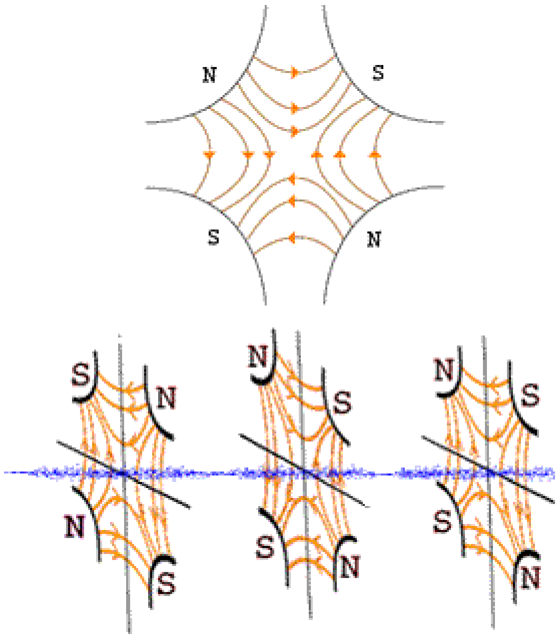
Electromagnetic waves push



Magnets steer



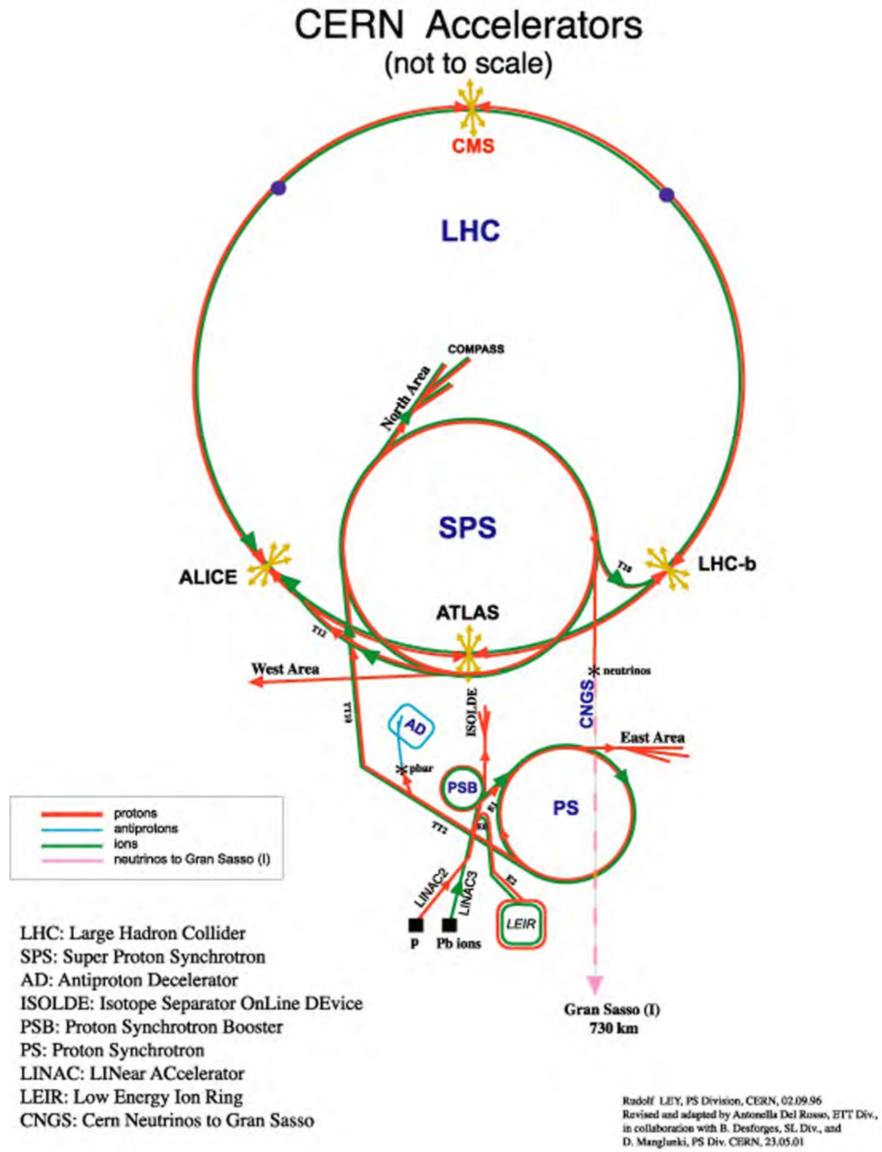
turn



and squeeze

CERN

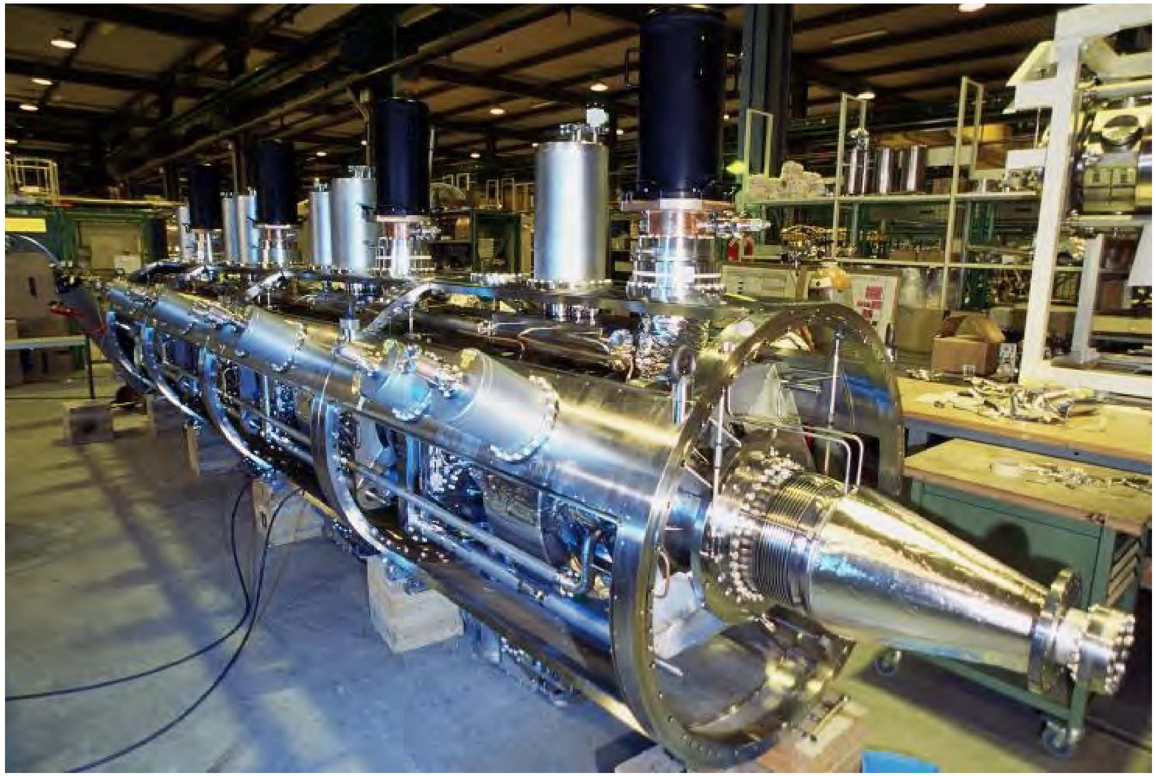
CERN Accelerator Complex



CERN Large Hadron Collider (LHC)

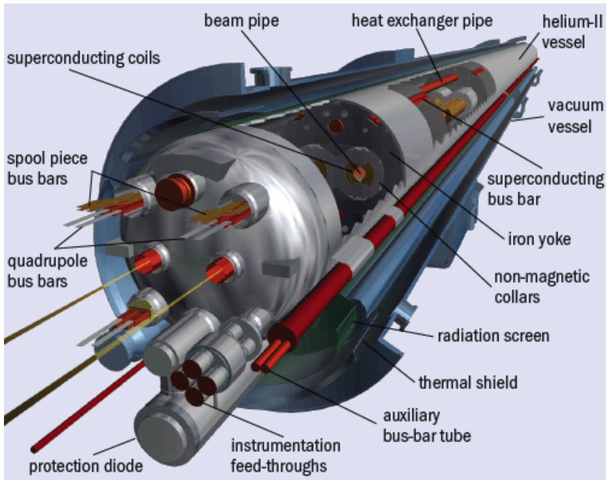
- Circumference 27 kilometers
- Revolution frequency 11.2455 kHz
- Power consumption ~120 MW

Radio-Frequency Cavities (16)



- Accelerating field 5 MV/m
- Forward coupler power, peak 176 kW
- RF frequency 400.8 MHz

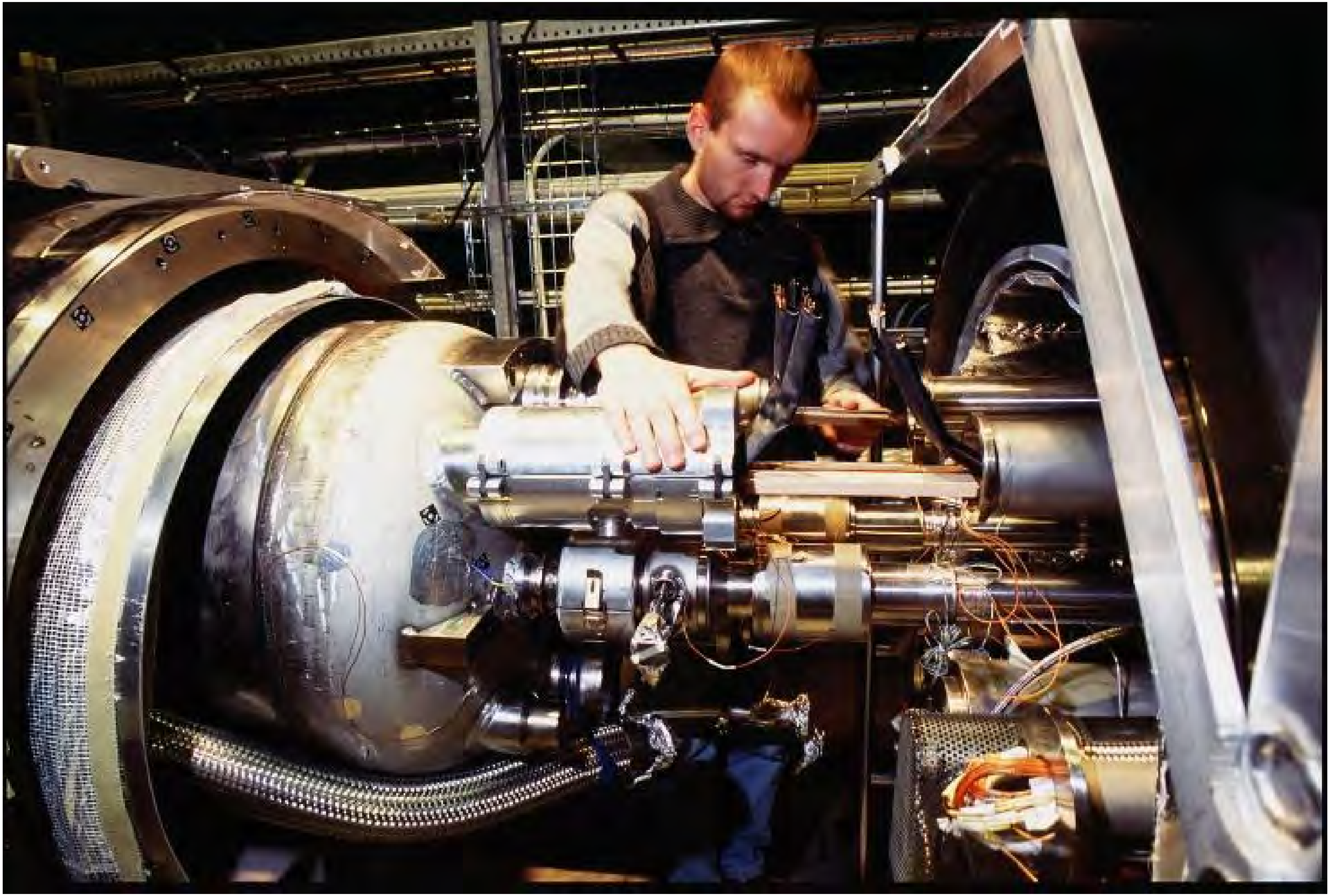
Dipole Magnet (1232)

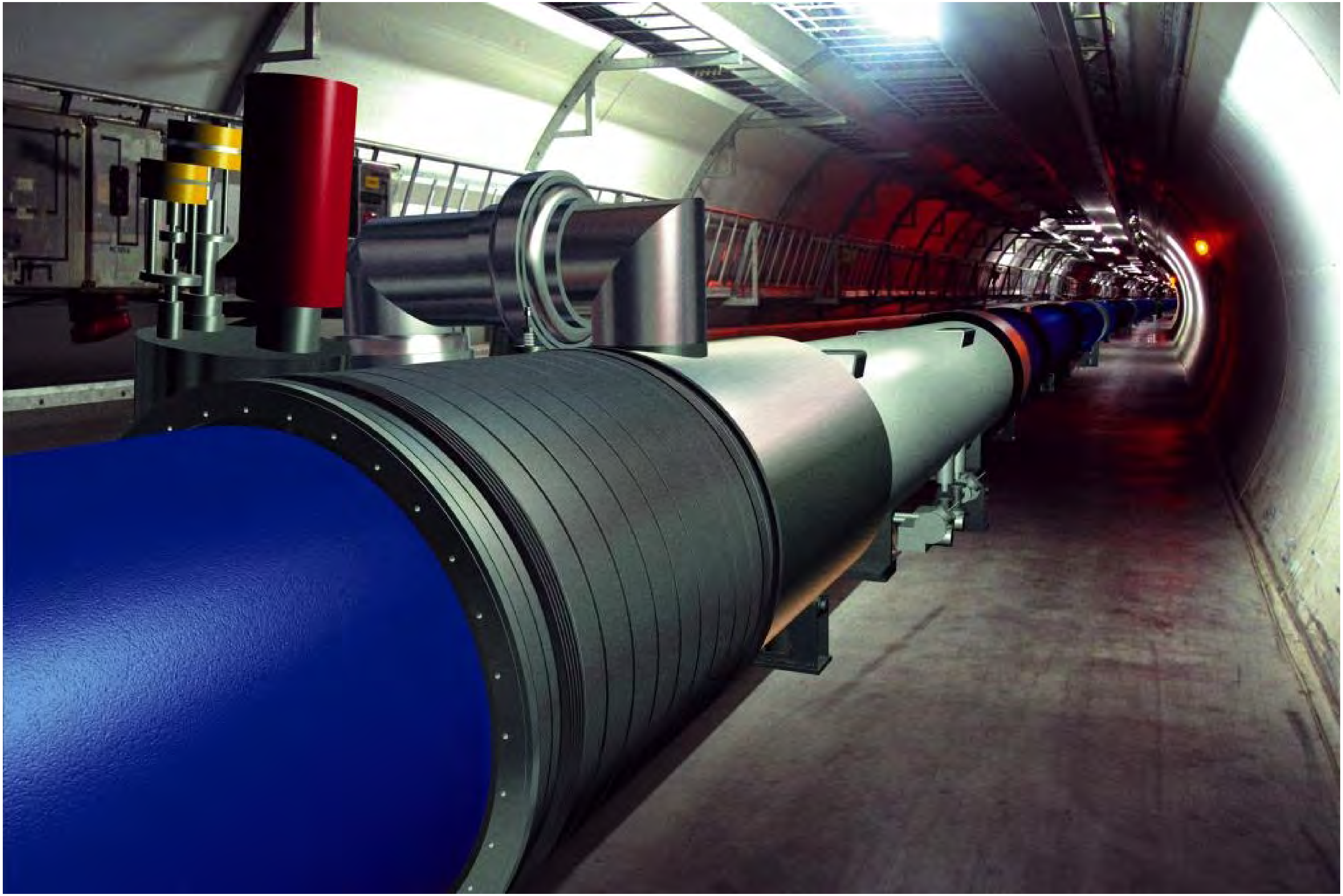


- Magnetic Length 14.3 m; Cold-mass weight 23800 kg
- Nominal Operating Temperature 1.9 K
- Operational Current (at 7 TeV) 11850 A
- Stored Energy per Magnet (Nom Current) 7513.9 kJ
- Operational Field (at 7 TeV) 8.3296 T
- Bending Radius 2807.456 m

Quadrupole Magnet (392)

- Length 3.1 m
- Weight 3600 kg
- Operating Temp 1.6 K
- Current 11870 A
- Stored Energy 394.5 kJ
- Field 3.791 T





Then, Slam Accelerated Particles into Each Other or a Target

- Scatter for structural analyses

- Matter for production and evolution analyses

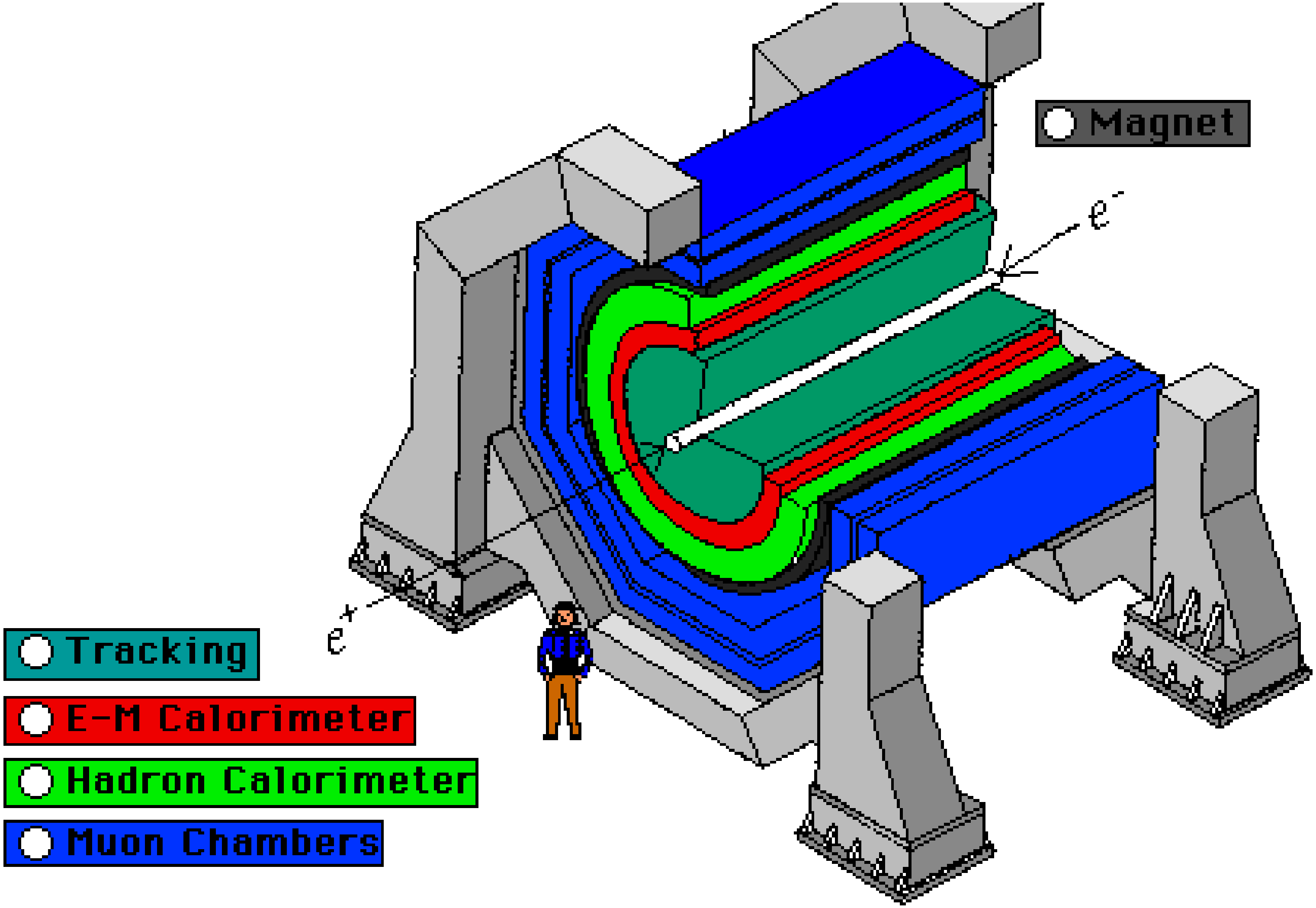
Detectors: Seeing the Outcome

Event Reconstruction

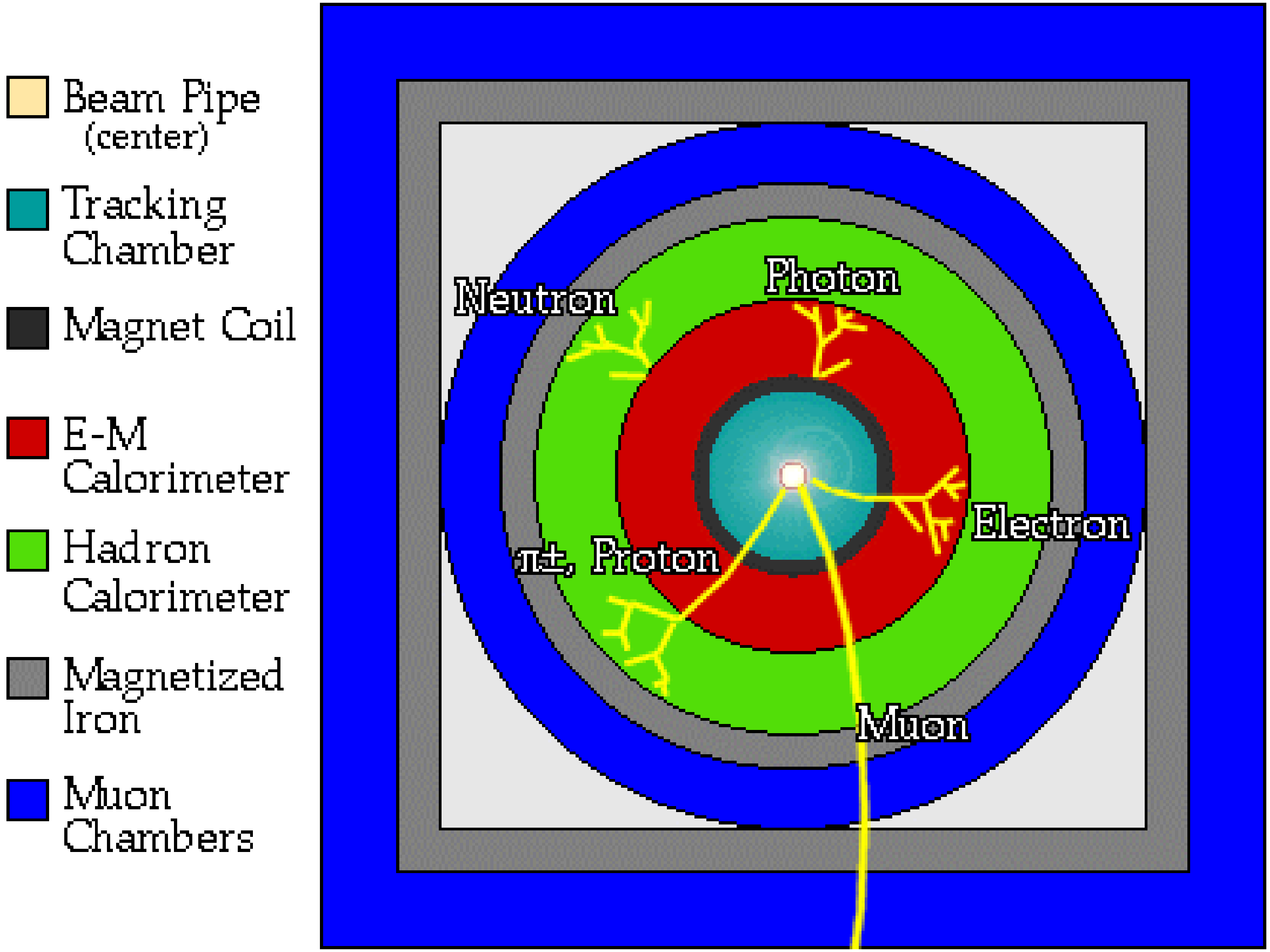
$$M^2 = E^2 - P^2$$

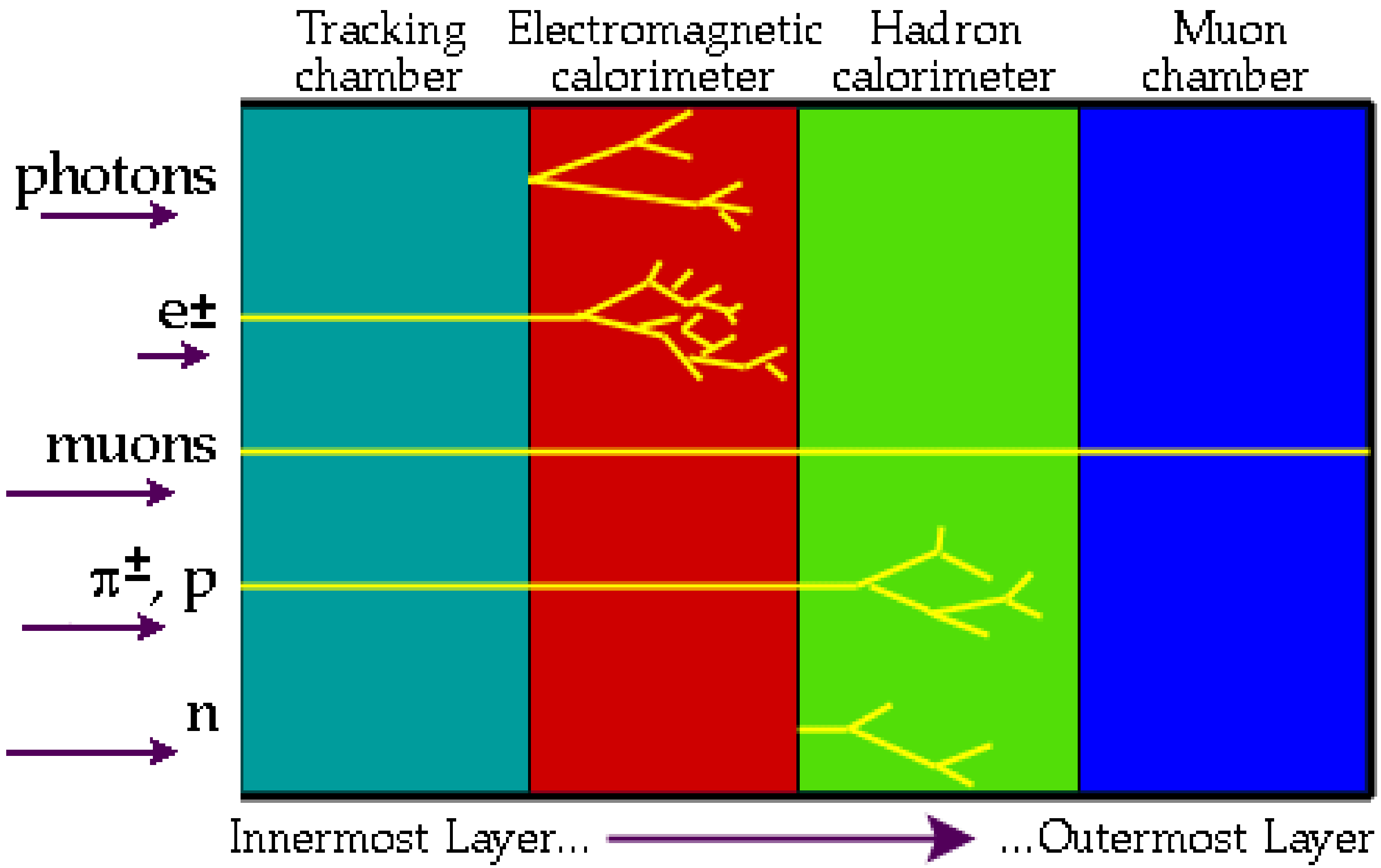
- Must determine
  - speed / momentum / energy
  - identity

Standard (Collider) Detector

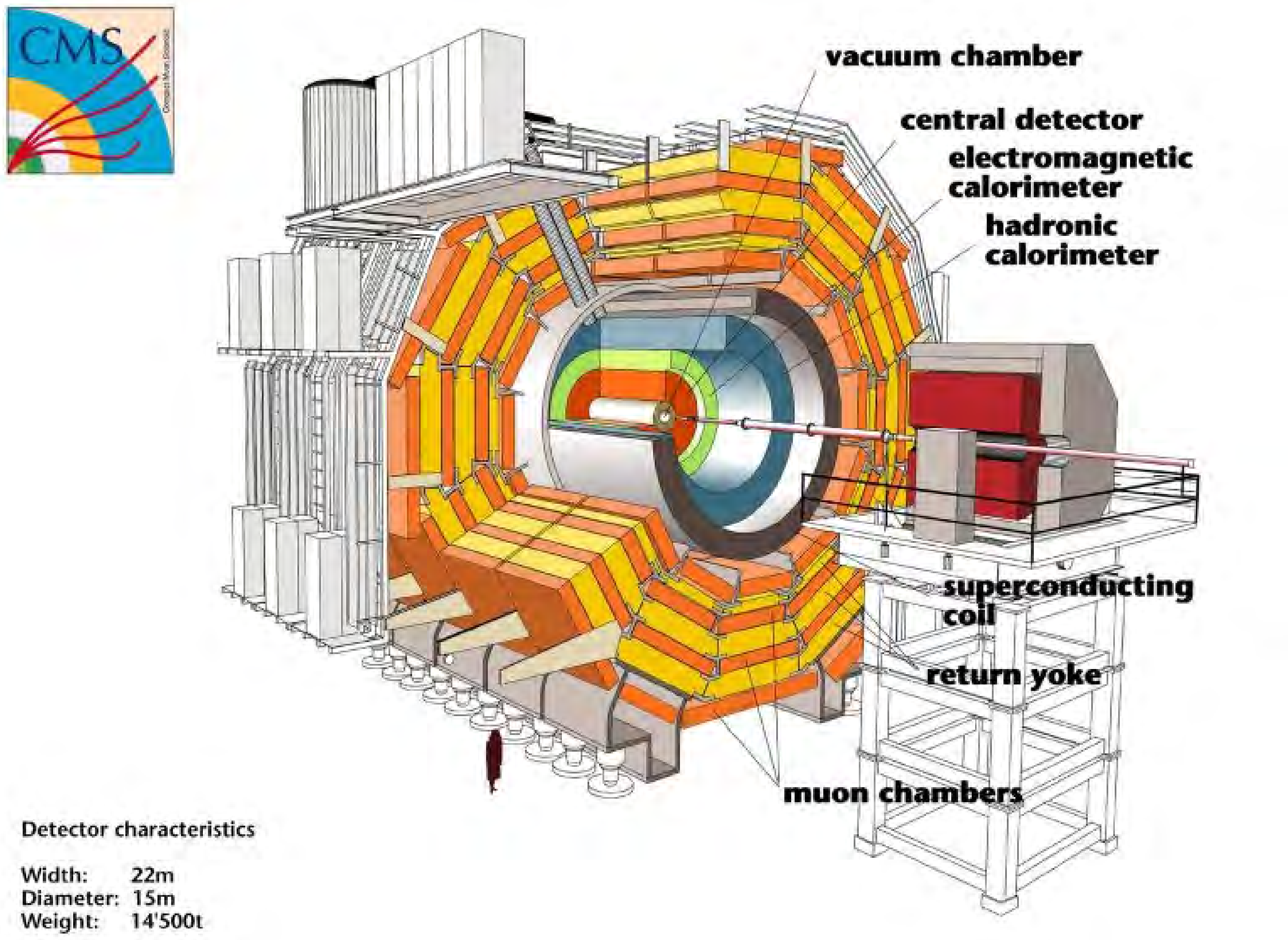


A detector cross-section, showing particle paths

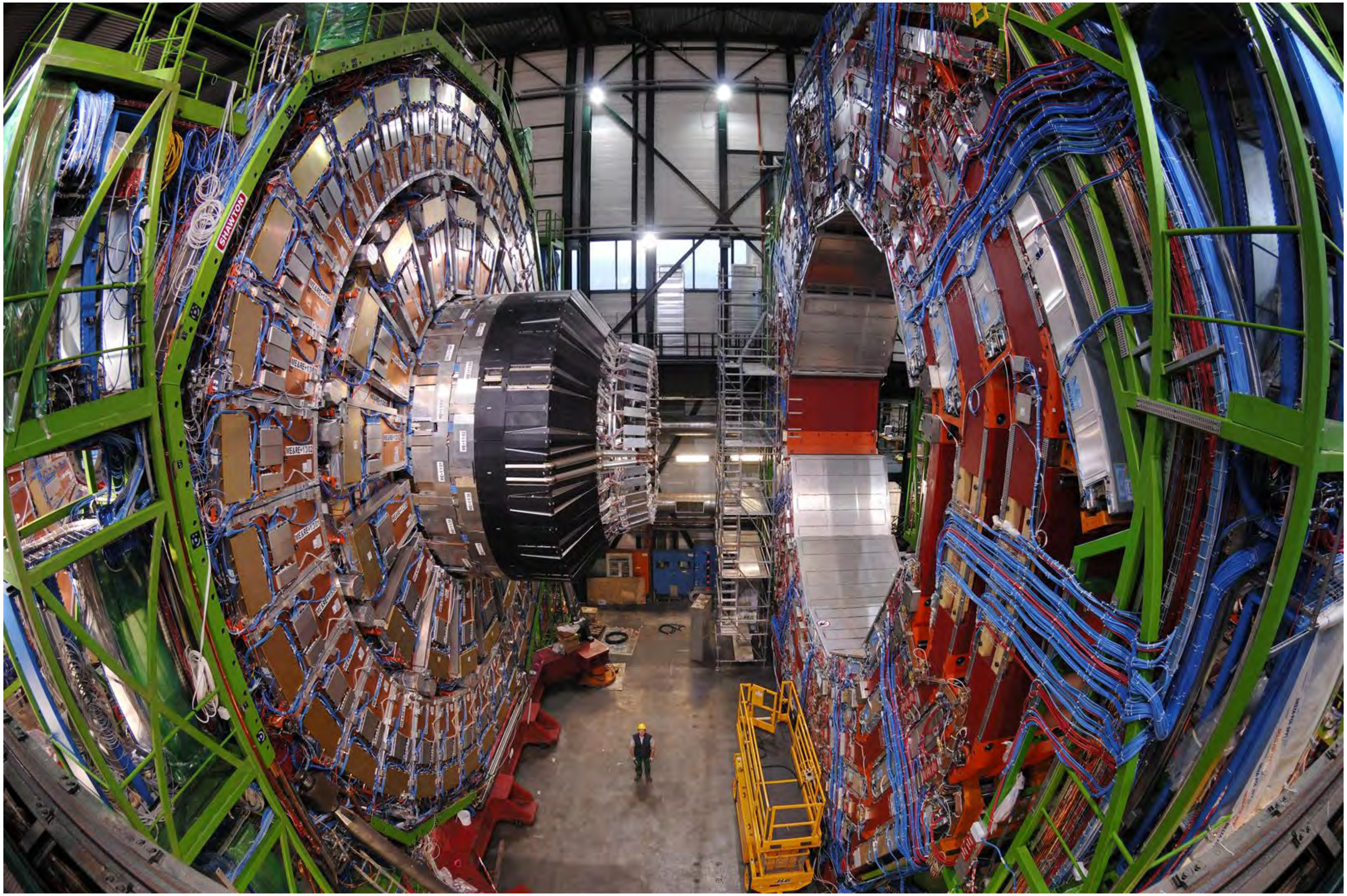



Tracking chamber
Electromagnetic calorimeter
Hadron calorimeter
Muon chamber
photons
e±
muons
π±, p
n
Innermost Layer...
...Outermost Layer

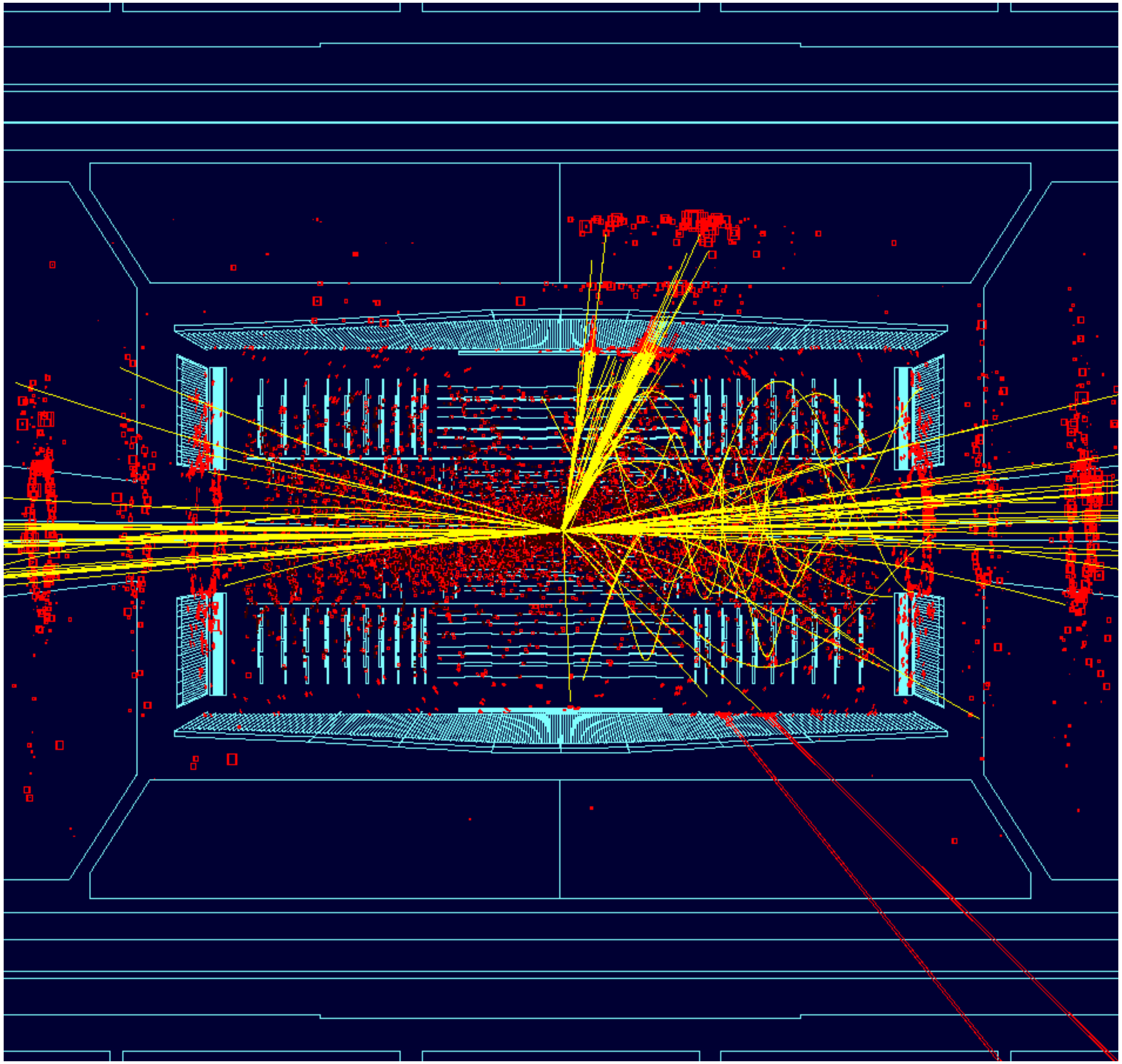
Compact Muon Solenoid (CMS)



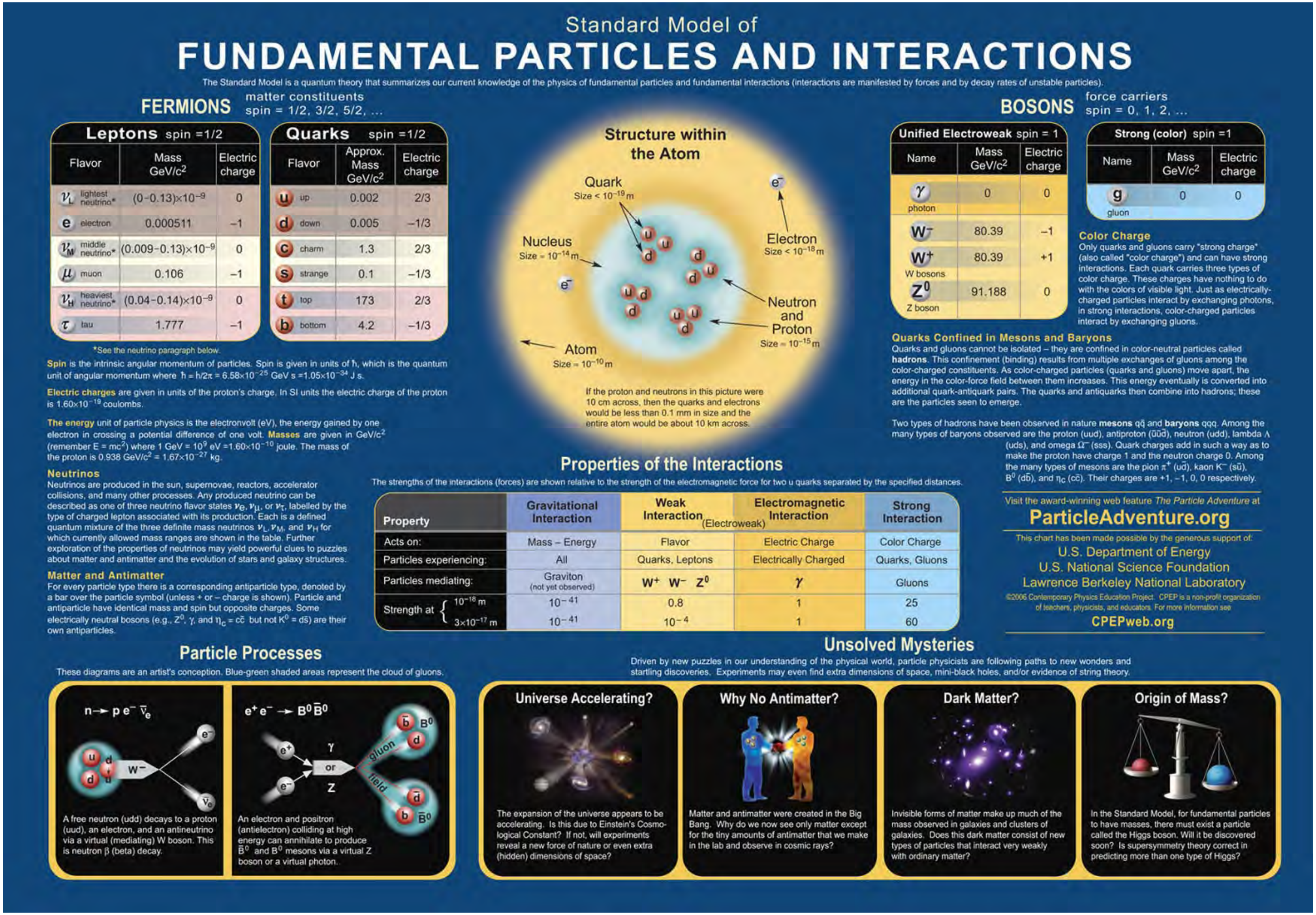
Just Before Closing



How an Interesting Event Appears



The Standard Model



Fundamental Constituents

FERMIONS matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin =1/2

Flavor		Mass GeV/c^2	Electric charge
ν_L	lightest neutrino*	$(0-0.13)\times10^{-9}$	0
e	electron	0.000511	–1
ν_M	middle neutrino*	$(0.009-0.13)\times10^{-9}$	0
μ	muon	0.106	–1
ν_H	heaviest neutrino*	$(0.04-0.14)\times10^{-9}$	0
τ	tau	1.777	–1

Quarks spin =1/2

Flavor		Approx. Mass GeV/c^2	Electric charge
u	up	0.002	2/3
d	down	0.005	–1/3
c	charm	1.3	2/3
s	strange	0.1	–1/3
t	top	173	2/3
b	bottom	4.2	–1/3

Observed Particles

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$ Baryons are fermionic hadrons. These are a few of the many types of baryons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	**uud**	1	0.938	1/2
$\bar{\mathbf{p}}$	antiproton	$\bar{u}\bar{u}\bar{d}$	–1	0.938	1/2
n	neutron	**udd**	0	0.940	1/2
Λ	lambda	**uds**	0	1.116	1/2
Ω^-	omega	**sss**	–1	1.672	3/2

Mesons $q\bar{q}$ Mesons are bosonic hadrons These are a few of the many types of mesons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	–1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.776	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2.980	0

The Interactions

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60

BOSONS

force carriers
spin = 0, 1, 2, …

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^- W bosons	80.39	–1
W^+ W bosons	80.39	+1
Z^0 Z boson	91.188	0

Strong (color) spin =1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Rules (Symmetries)

- Continuous
  - Energy
  - Momentum
- Discrete
  - Charge
  - Isospin (I)
  - **Strange-ness**
  - Charm-ness
  - Bottom-ness
  - Top-ness
  - *Baryon Number (B)*
  - **Lepton Number (L/LF)**
  - Parity (P)
  - Charge Parity (C)
  - **Time Parity (T) or CP**
  - CPT

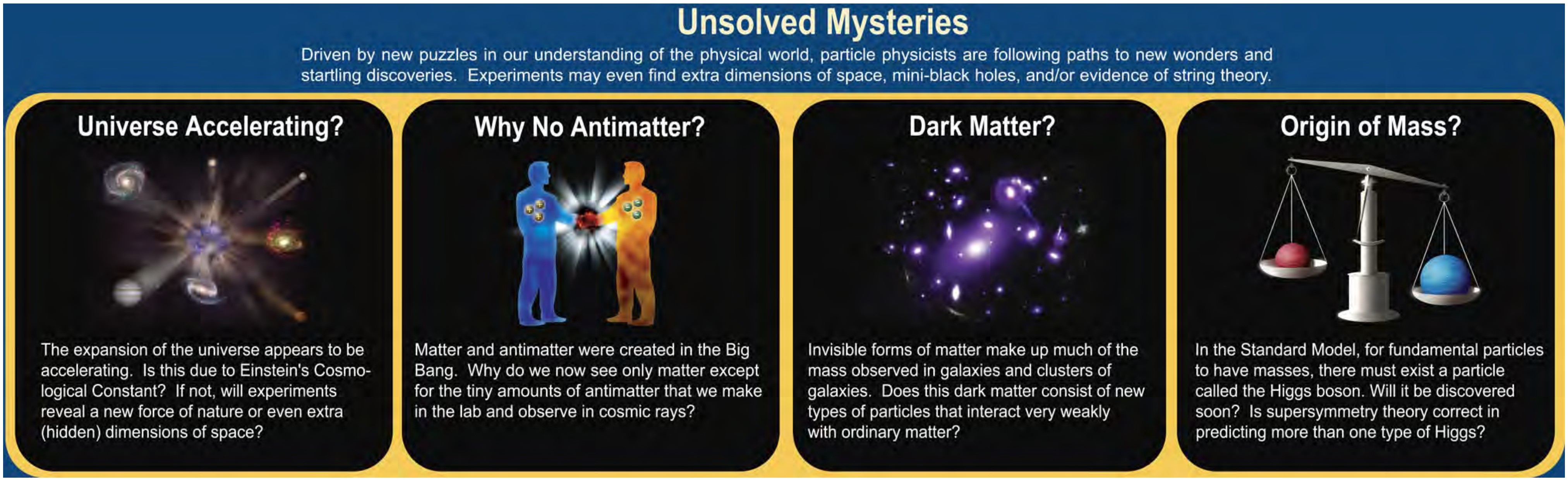
The Nutshell

- Strong interactions create almost everything but change nothing

- Electromagnetic interactions create most of the rest and change very little (isospin)

- Weak interactions do most of the "damage"

Yet, Big Questions Remain



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