To measure the smallest particles

…

and beyond!

CERN teacher programme – Nederlandstalige editie!
(excuses, mijn slides zijn normaliter altijd in het Engels)

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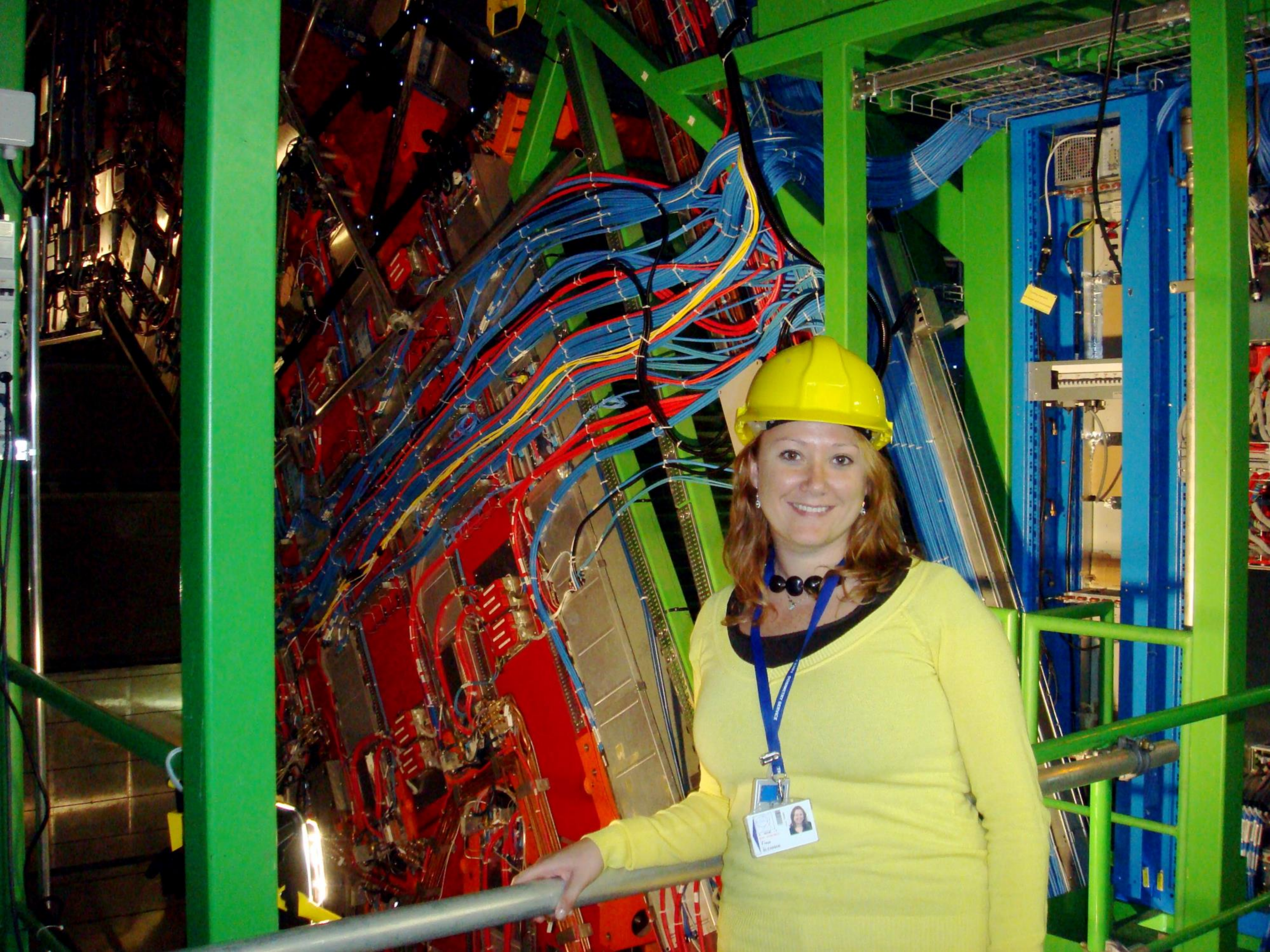
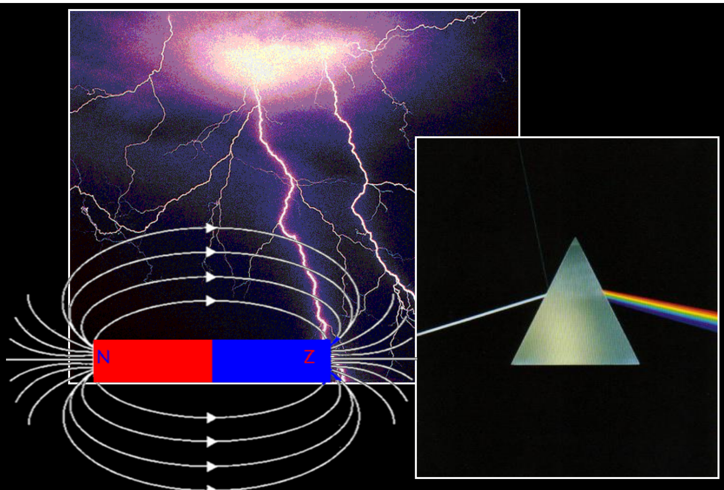


Introductievraag:

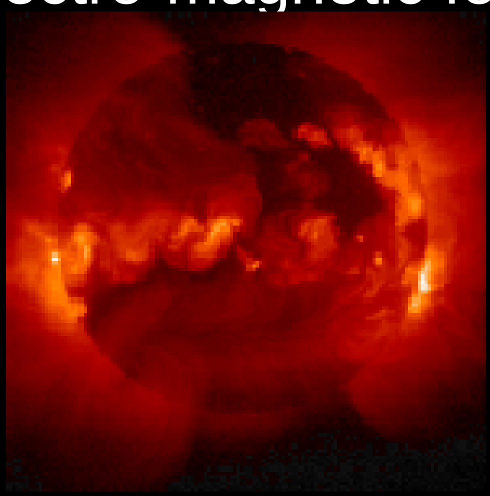
- Hoe denkt u dat wij deeltjes detecteren?

The four fundamental forces

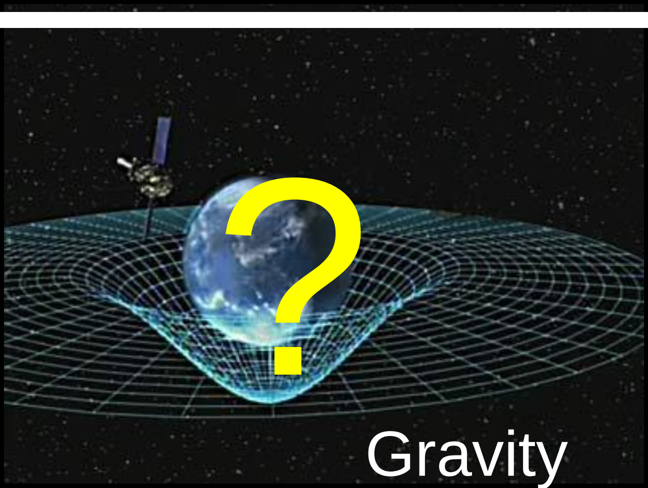


Electro-magnetic force

Strong force

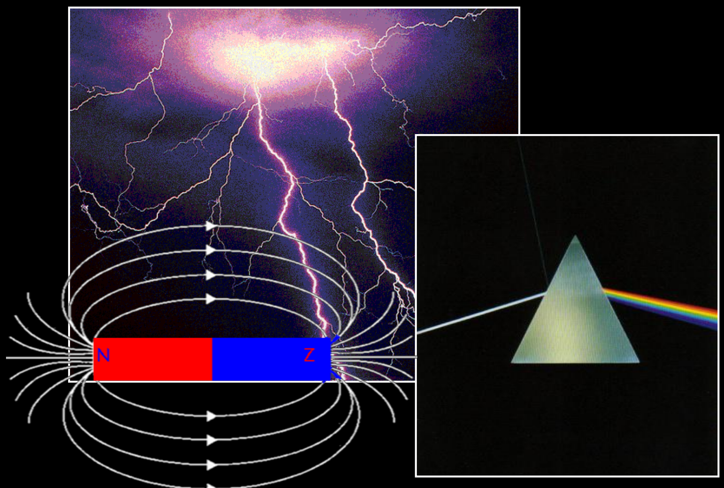


Weak force



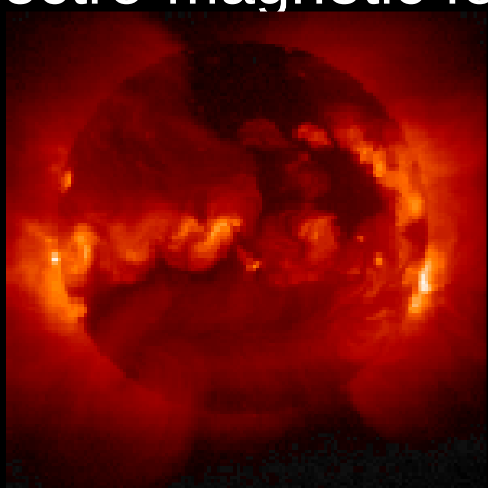
Gravity

Maar welke gebruiken we om deeltjes te zien?

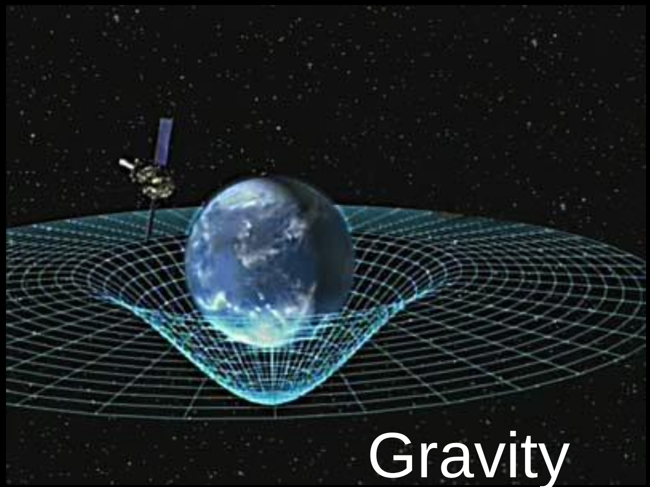


Electro-magnetic force

Strong force



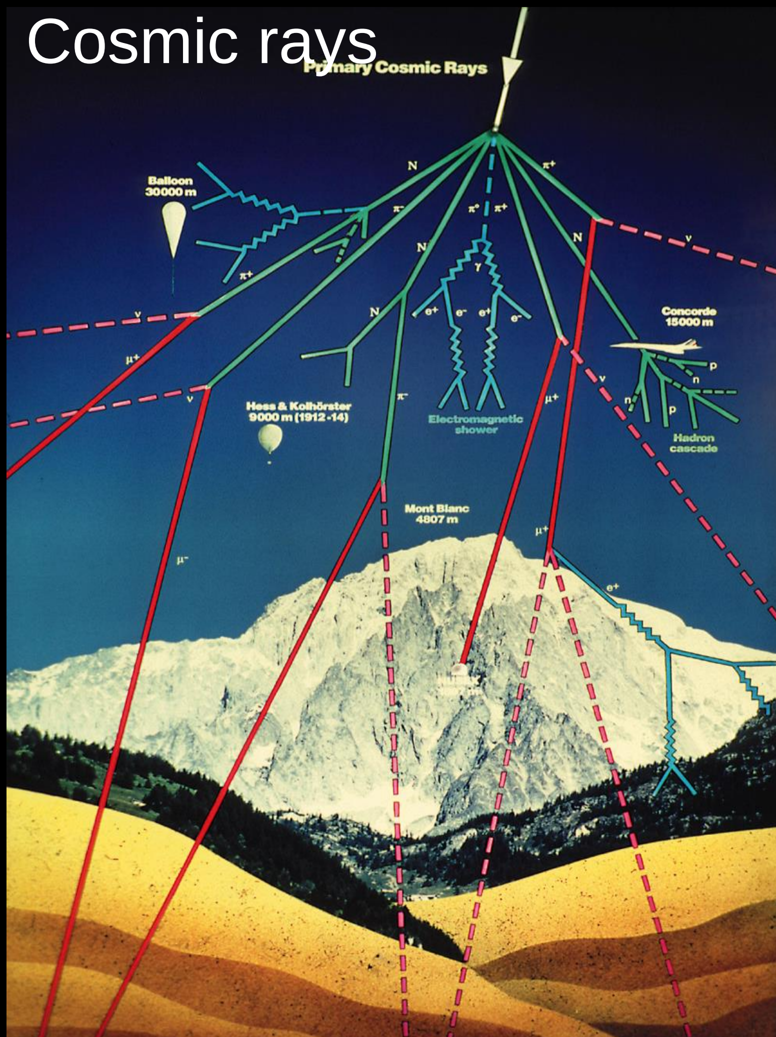
Weak force



Gravity

How do we know all this?

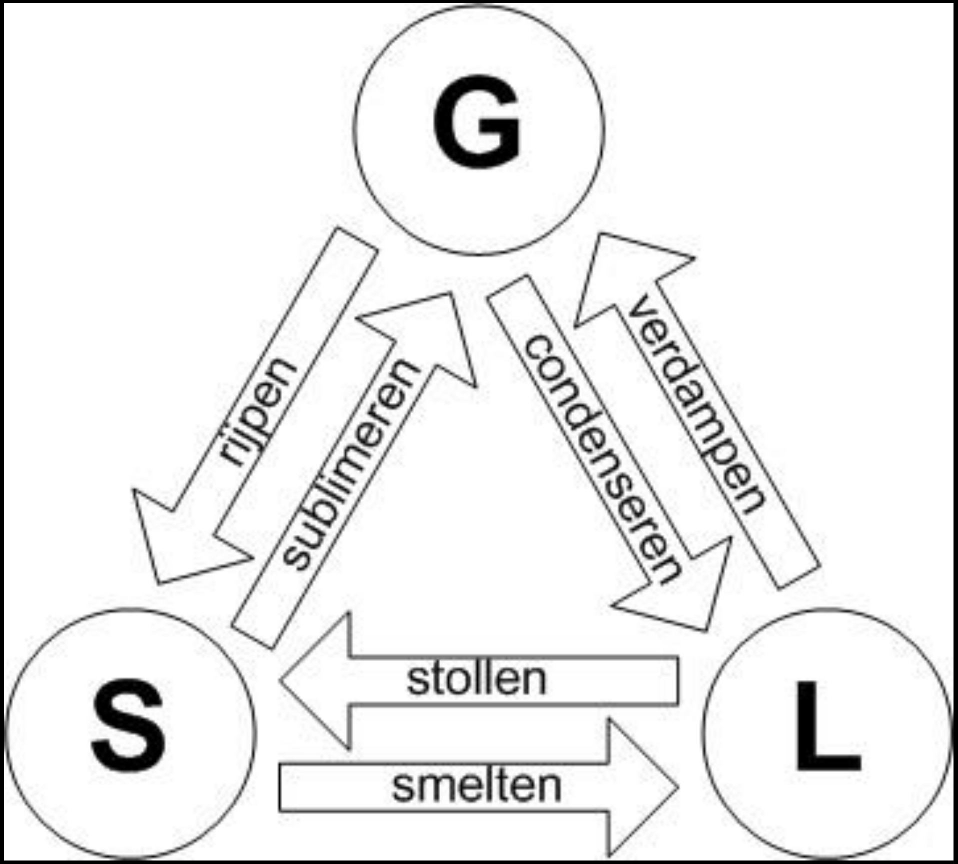
Cosmic rays



Accelerator experiments
Radioactivity experiments

And about 100 years of hard work by many people...

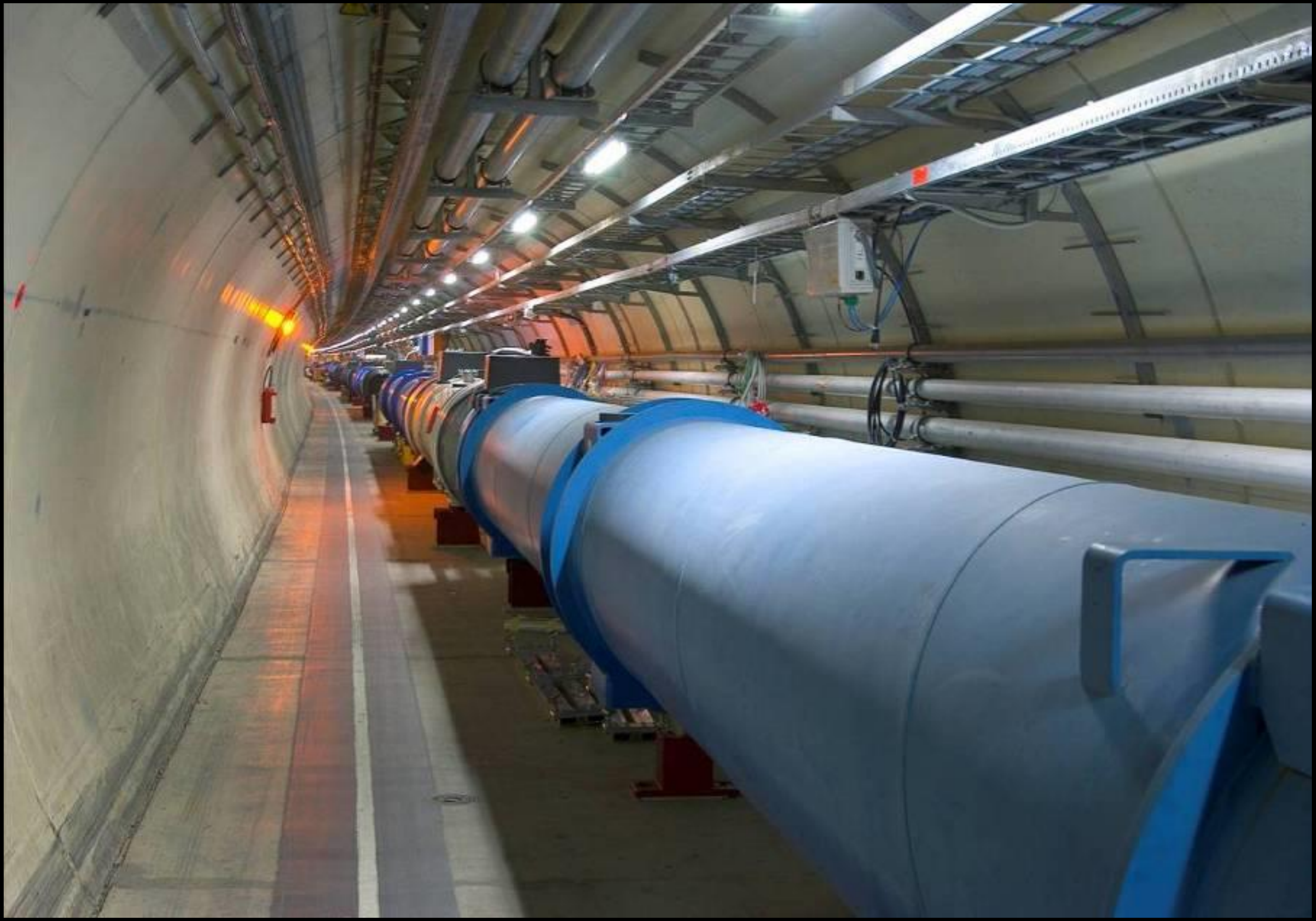
Faseovergangen



Waarom?

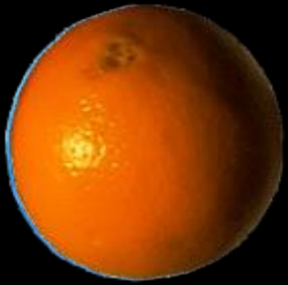
Needed: machine to make collisions

LHC in the tunnel



Example collisions

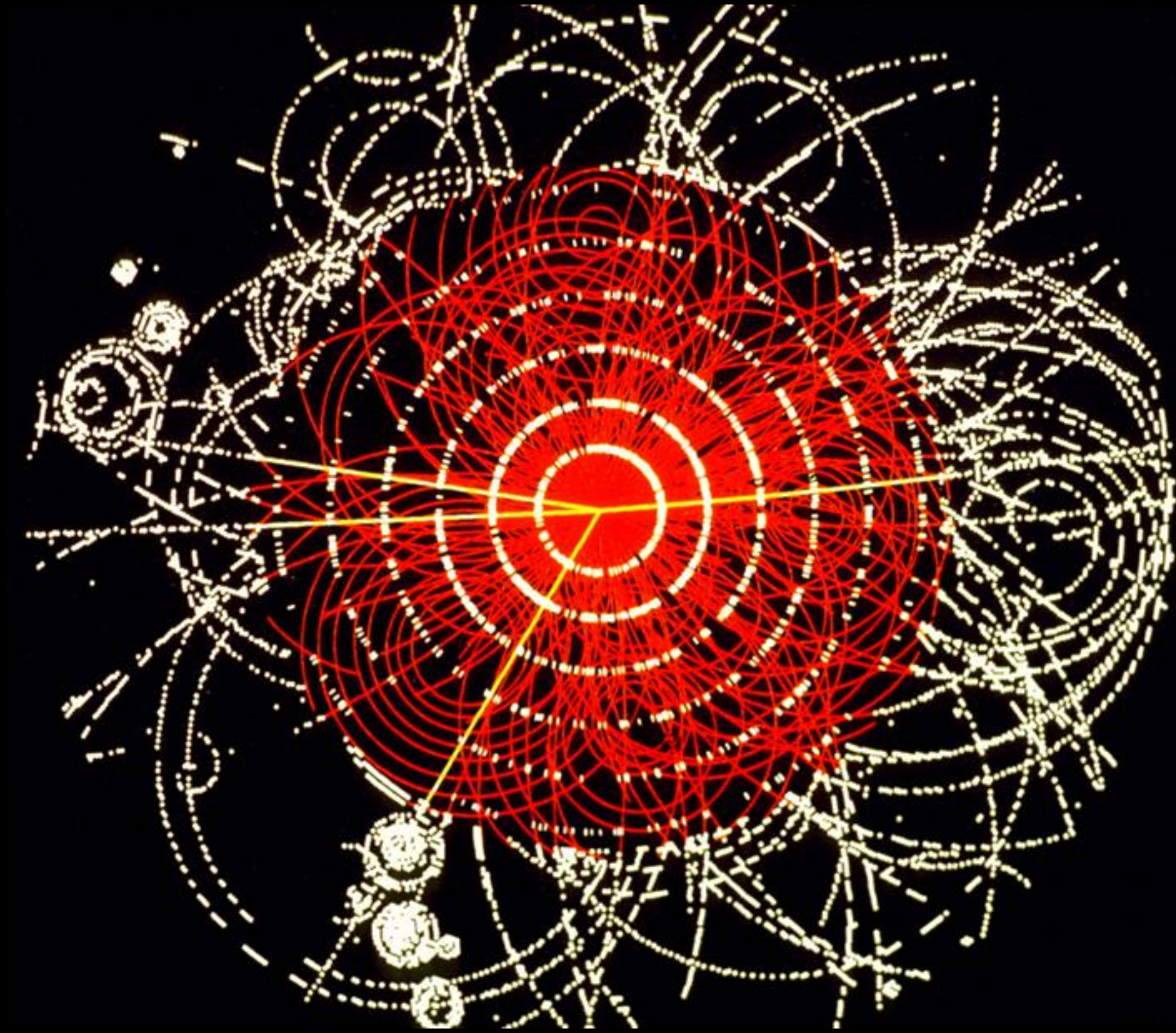
oranges!



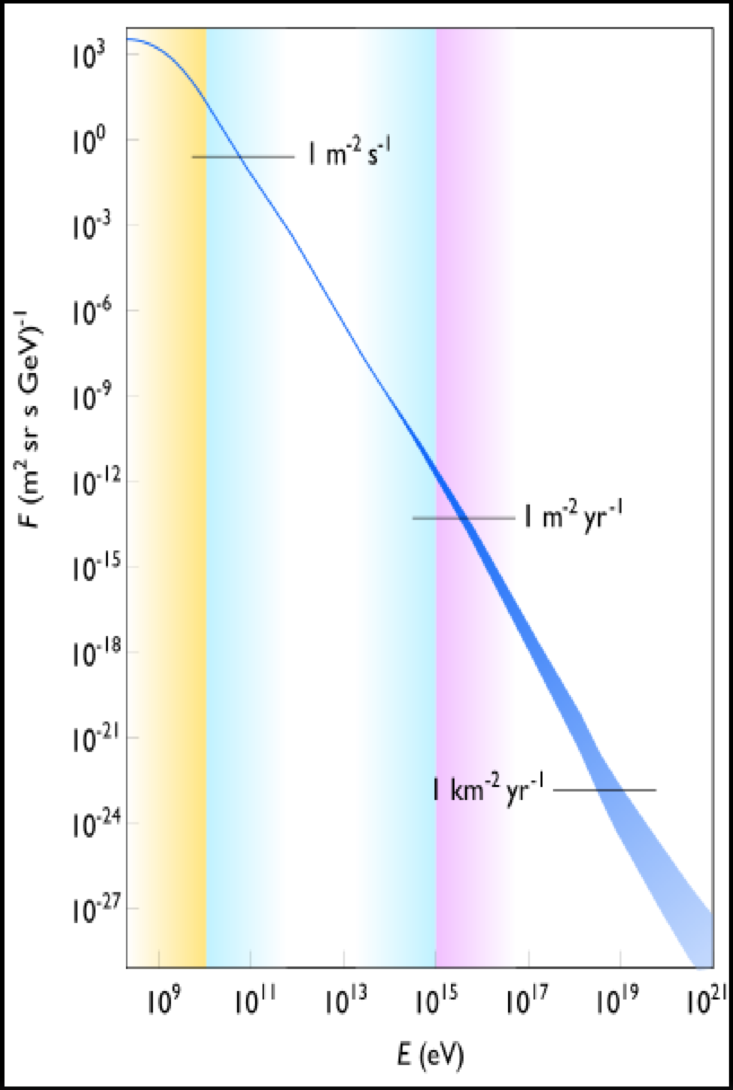
Example collisions

But other things can happen too!
And different every collision!

machine for detecting the collisions: particle detector



Deeltjes: waar en hoe?



- Energie deeltjes uit de cosmos
  - “kosmische straling”
  - Energie minstens 10^{20} eV
    - Dus 4×10^7 x LHC!
- Studies extreem hoog-energie straling:
  - hot topic
  - astrodeeltjesfysica

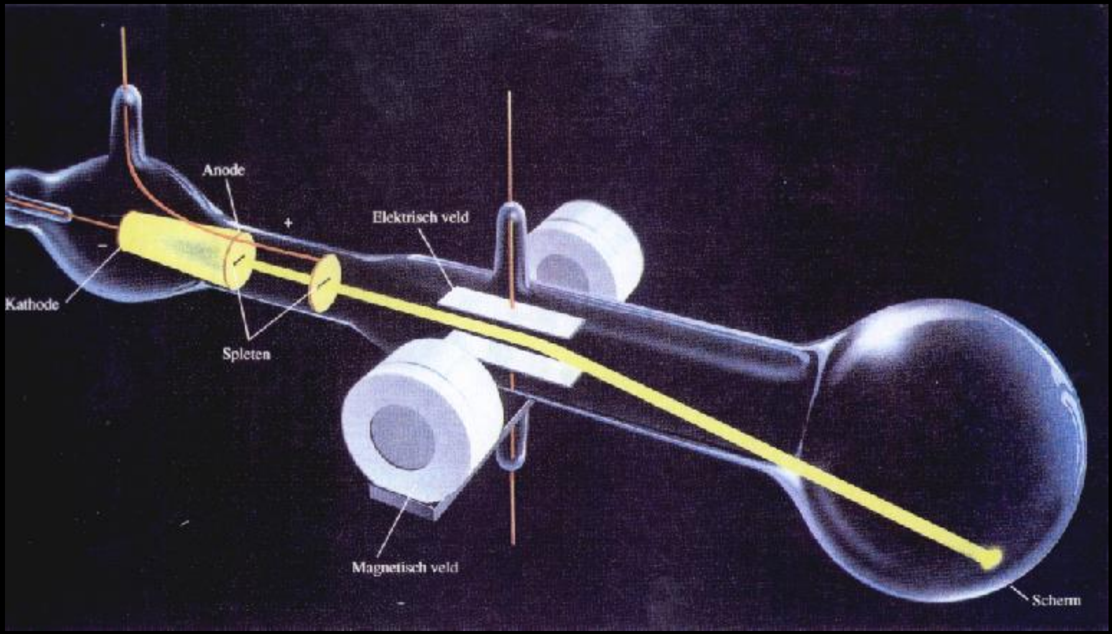
Begin bij het begin:

goed voorbeeld

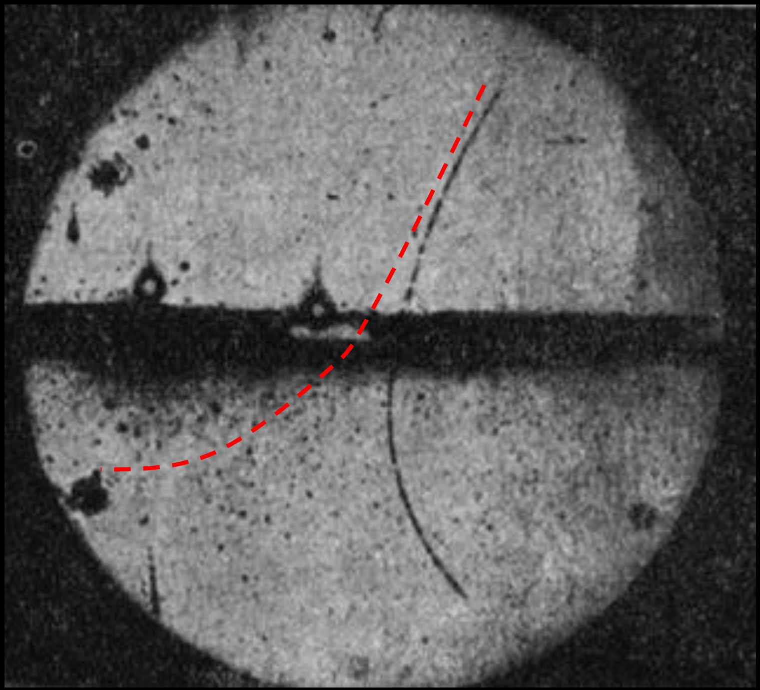
Deeltjes: een "jong" onderzoeksdomein

1897 J.J.Thomson

Ontdekking van het electron



Anti-matter



- Anti-matter: discovered in 1923
  - Predicted by theory
- *Almost* same as matter... But oppositely charged
- Problem: at big bang there was just as much matter as anti-matter... Where did it go?

Reminder: eenheden

Our scale	
Length	m
Mass	kg
Time	s
Energy	$kg\ m^2\ s^{-2}$

Particle Physics	
Length	fm
Mass	eV/c^2
Time	s
Energy	eV

Convert

$1\ eV = 1.6 \times 10^{-19}\ J$

$1\ GeV = 10^9\ eV$

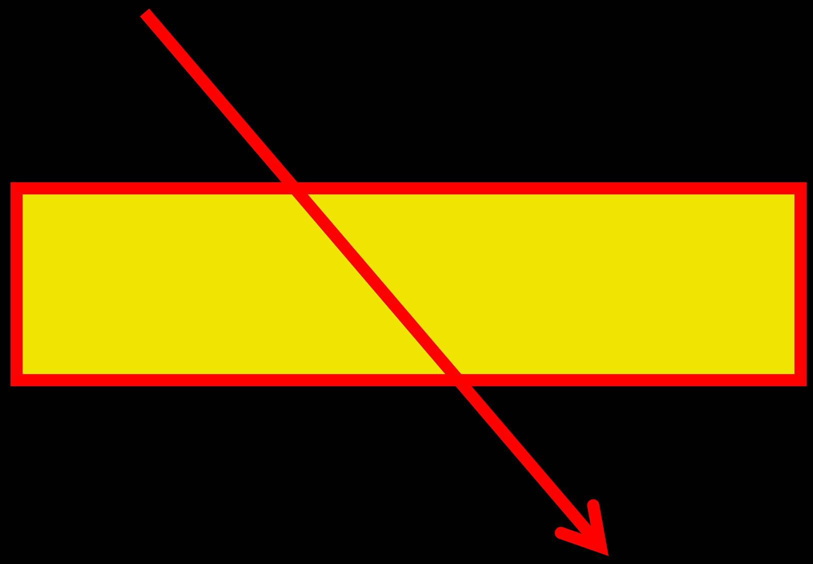
$1\ TeV = 10^3\ GeV$

$1\ fm = 10^{-15}\ m$

Note: often set $\hbar = c = 1$

Deeltjesbotsingen: en dan?

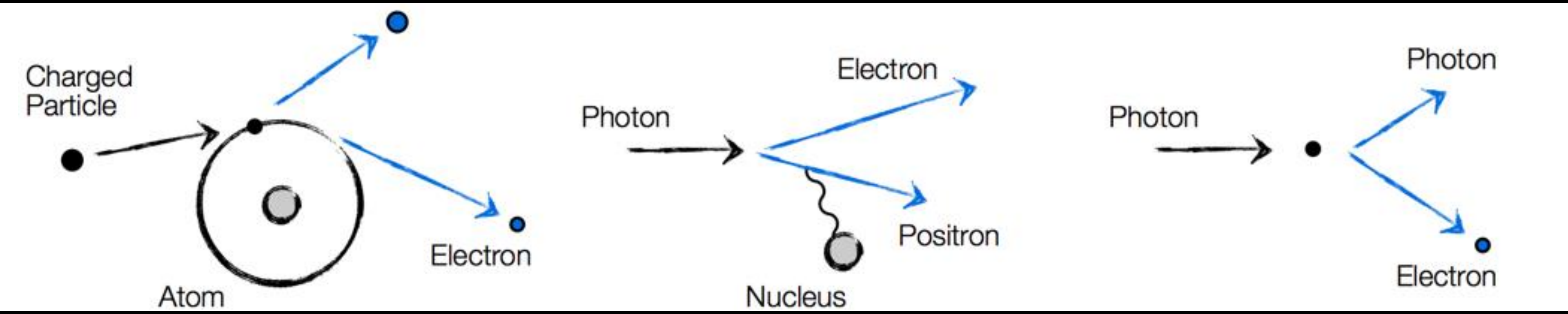
A high energy subatomic particle flies through matter, what happens?



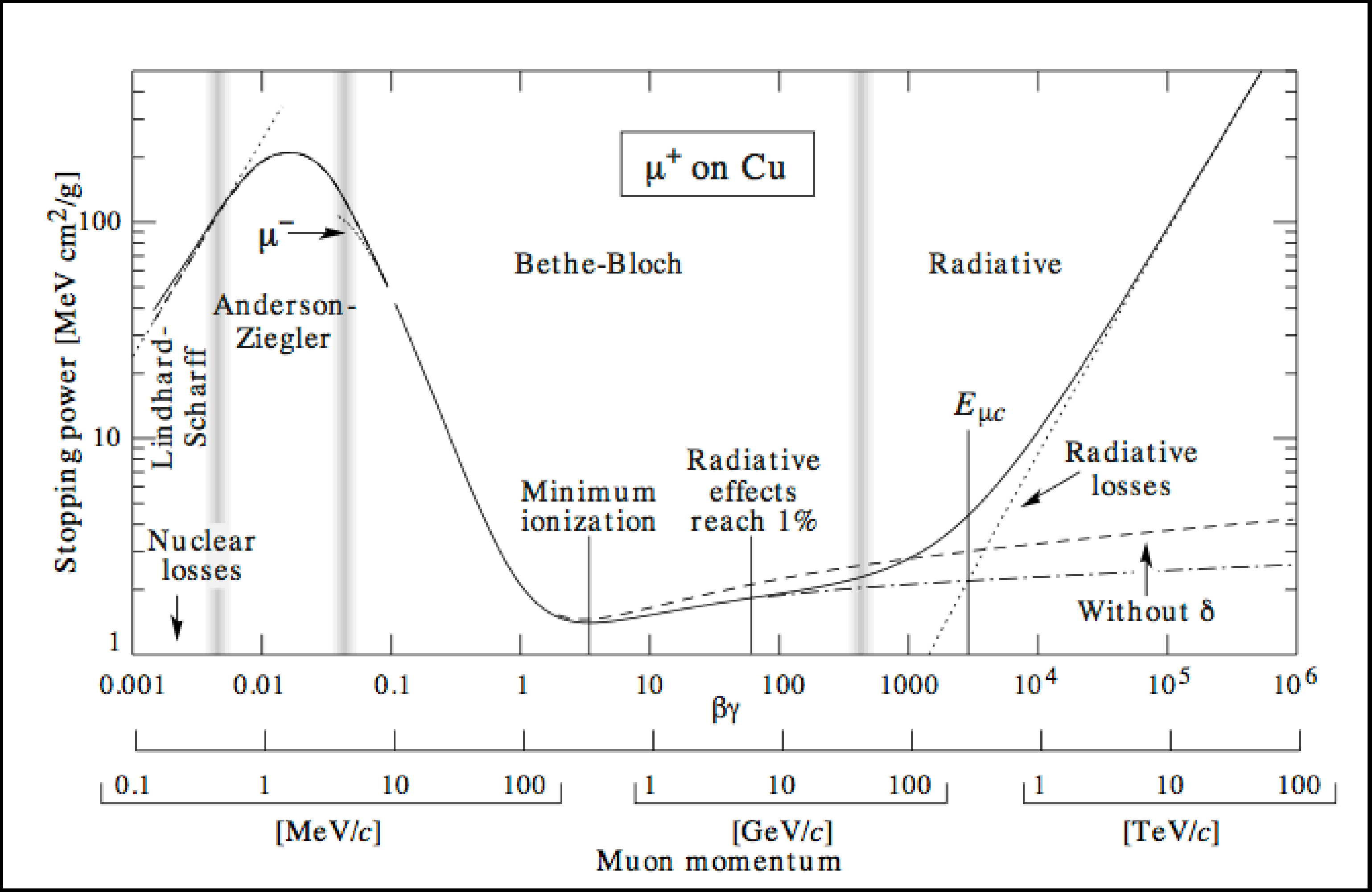
ionisation

Electron-positron pair production

Compton scattering

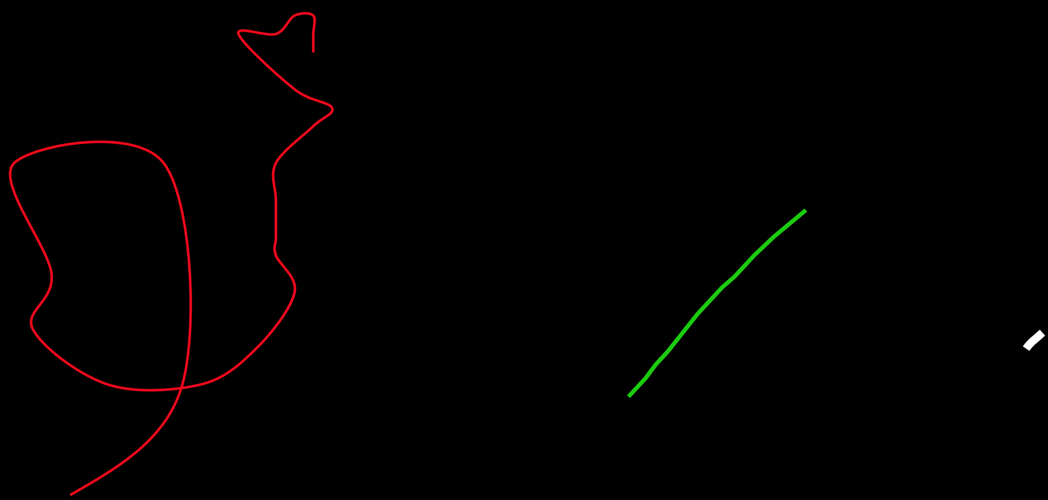


Muons in Copper



Example: a particle of 10 MeV in silicon

Electron | proton | alpha particle

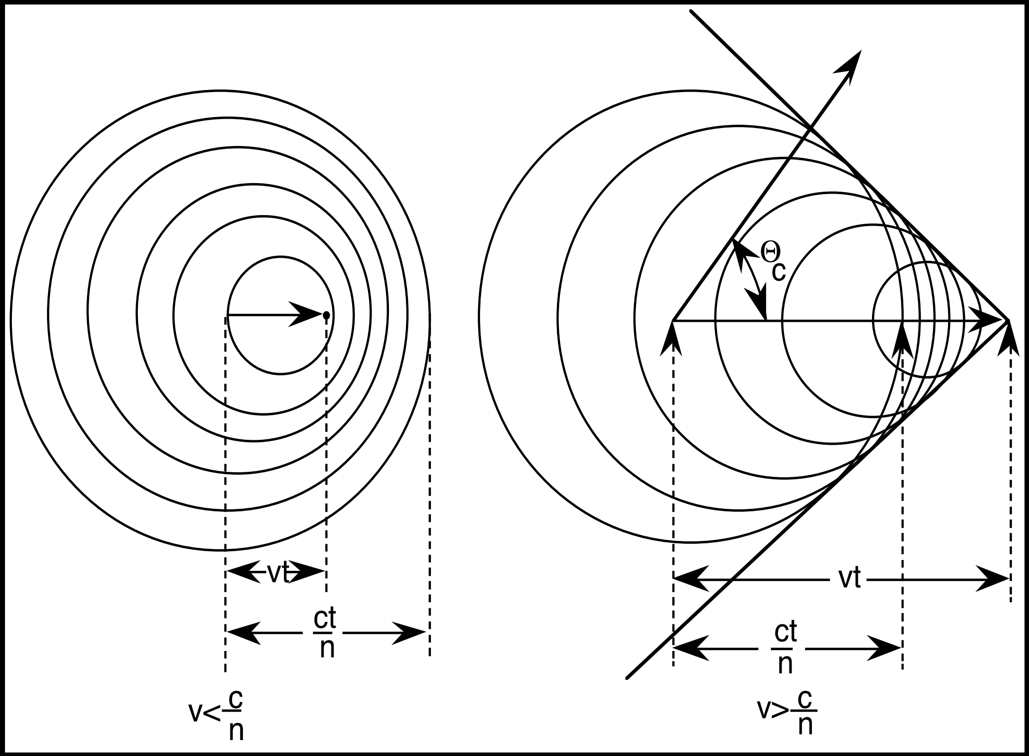


Curled[few cm] | 0.8mm | 70 µm

Cherenkov effect:

when v(particle) > v(light) in medium

v(light) = c/n

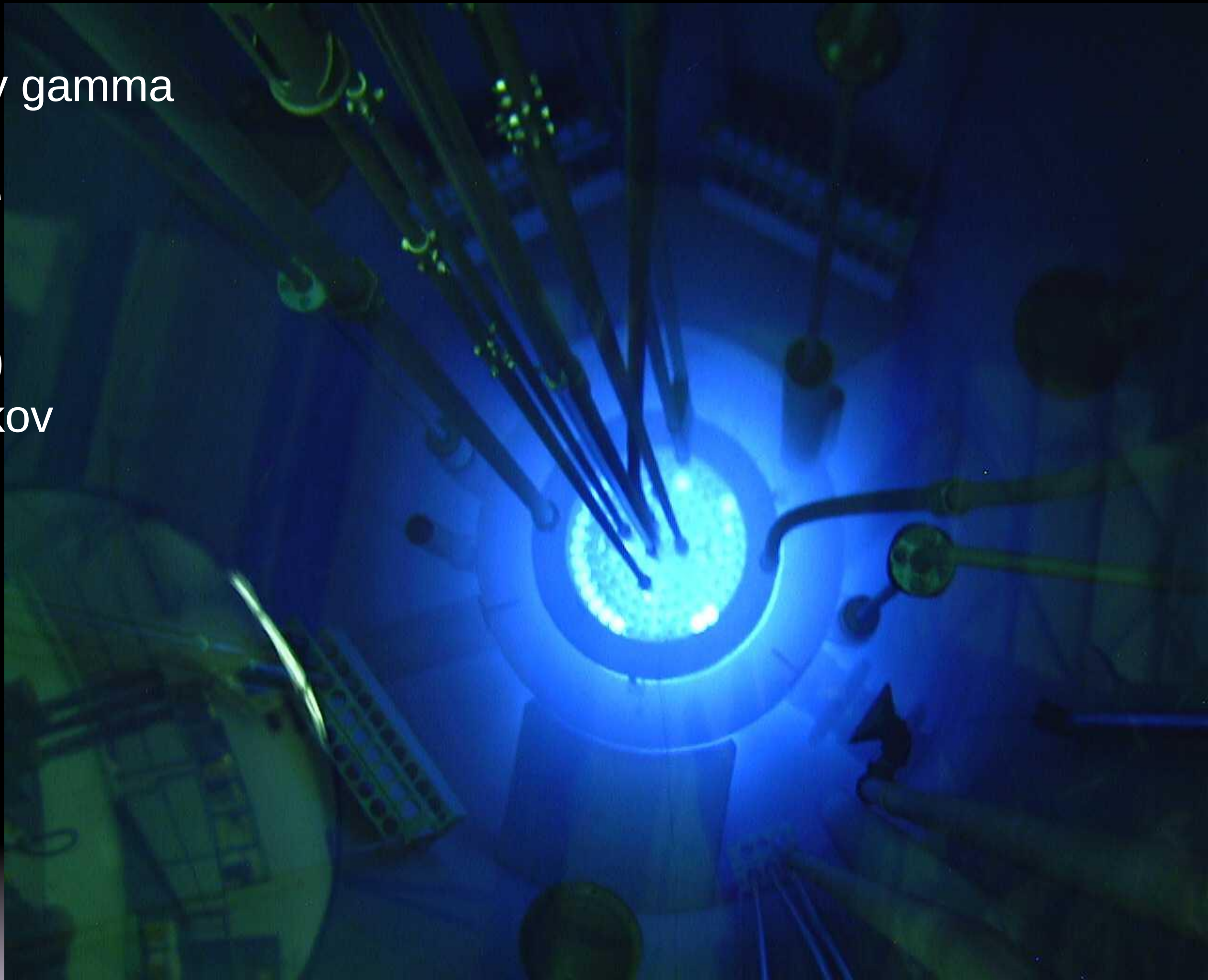


$\cos(\theta) = c/(vn)$

The effect is similar to the bow-wave of a fast boat in water,
or the supersonic bang of a plane going faster than the speed of sound.

Cherenkov radiation is responsible for the blue glow in the water surrounding the core of a water pool reactor (here the Reed college reactor, Portland, Oregon)

Electron and positrons pairs
are produced in the water by gamma
rays originating from the
Reactor core. Many of these
electrons or positrons travel
at speeds exceeding the
speed of light in water (=c/n)
and hence produce Cherenkov
radiation



@freyablekman

THE 13 PARTICLES A DETECTOR MUST BE ABLE TO MEASURE AND IDENTIFY

$e^{\pm}$ $m_e = 0.511$ MeV

$\mu^{\pm}$ $m_\mu = 105.7$ MeV $\sim 200\, m_e$

γ $m_\gamma = 0$, $Q = 0$

} EM

$\pi^{\pm}$ $m_\pi = 139.6$ MeV $\sim 270\, m_e$

$K^{\pm}$ $m_K = 493.7$ MeV $\sim 1000\, m_e$ $\sim 3.5\, m_\pi$

$p^{\pm}$ $m_p = 938.3$ MeV $\sim 2000\, m_e$

} EM, Strong

K^0 $m_{K^0} = 497.7$ MeV $Q = 0$

n $m_n = 939.6$ MeV $Q = 0$

} Strong

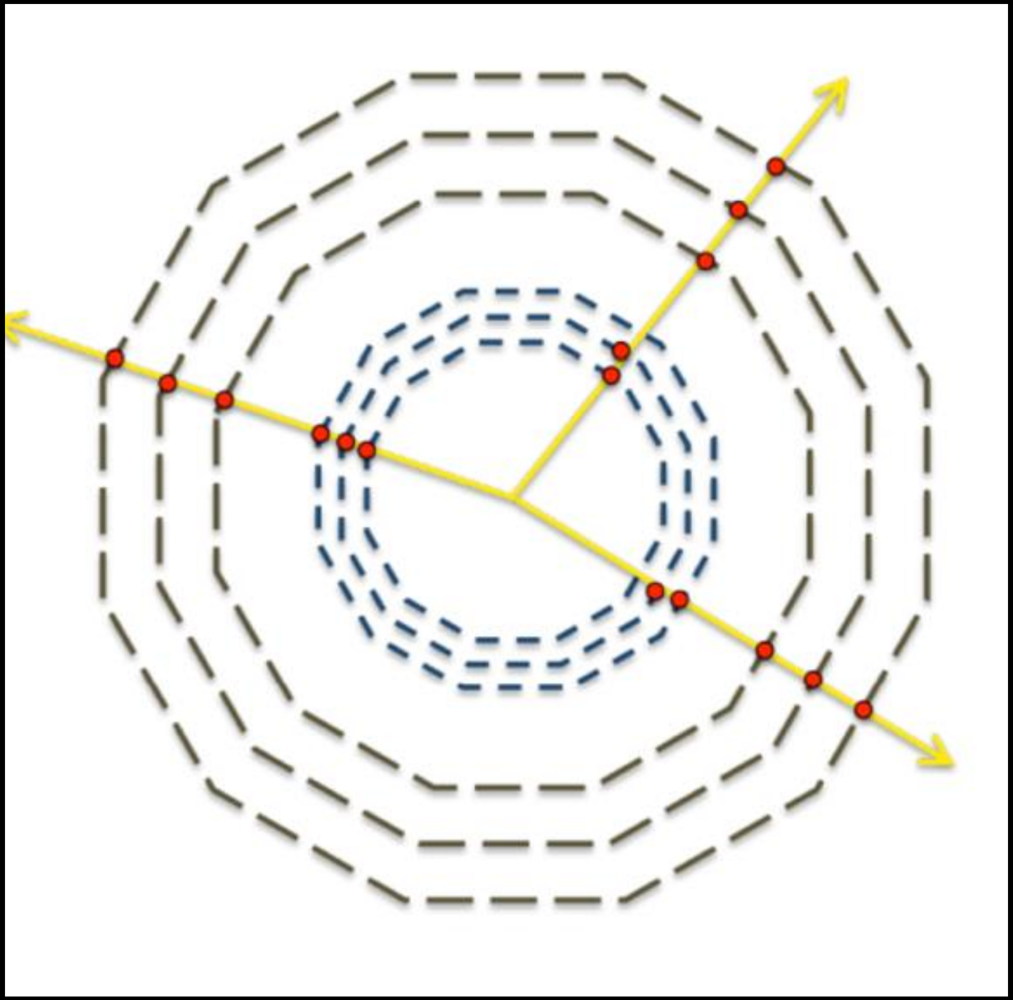
The Difference in

Mass, Charge, Interaction

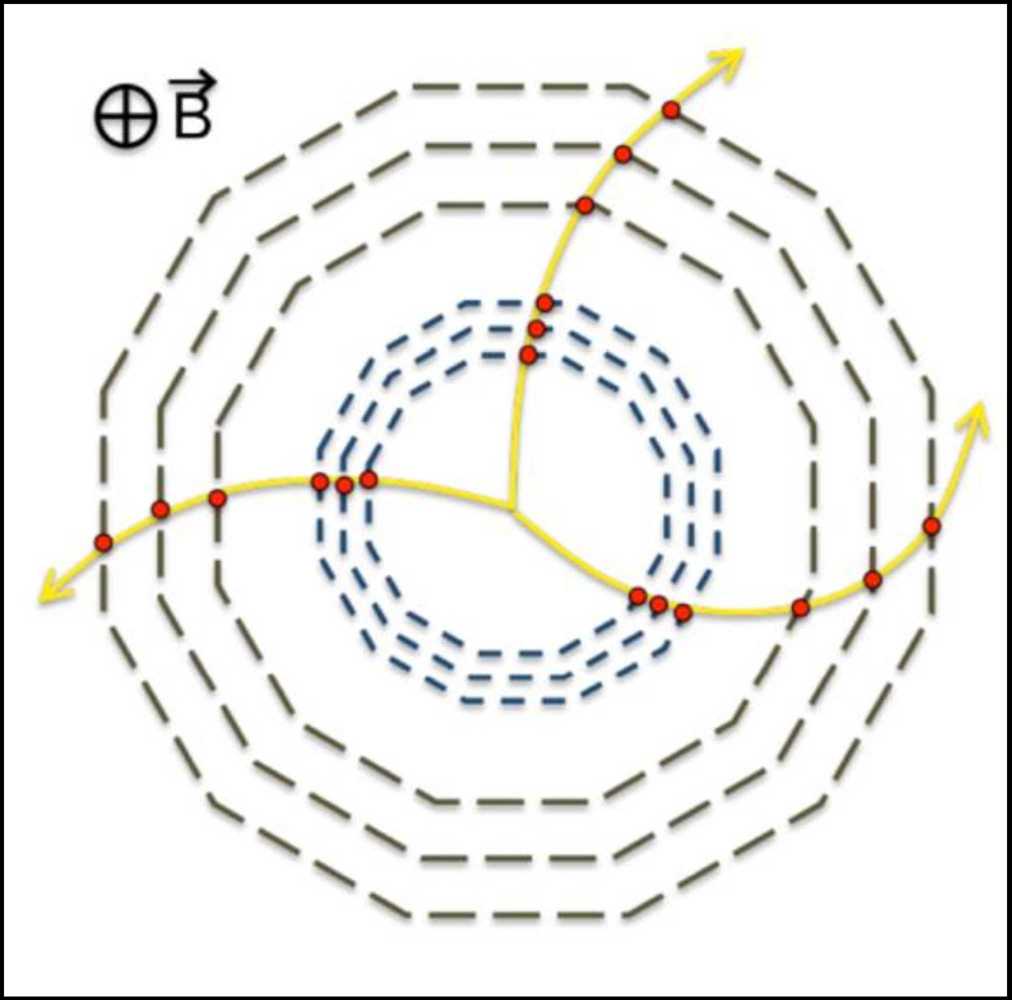
is the key to the Identification

W. Riegler/CERN

Magnetic fields: why?



Magnetic fields: why?



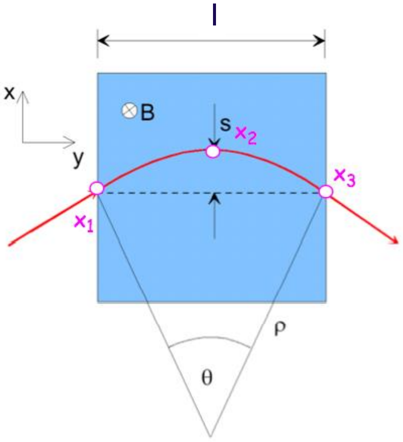
MAGNETIC ANALYSIS

Charged particle of momentum p in a magnetic field B

$$\frac{d\vec{p}}{dt} = q\vec{\beta} \times \vec{B}$$

If the field is constant and we neglect the presence of matter, the momentum is constant with time, the trajectory is helical.

$$p[\mathrm{GeV}] = 0.3B[\mathrm{T}]\rho[\mathrm{m}]$$



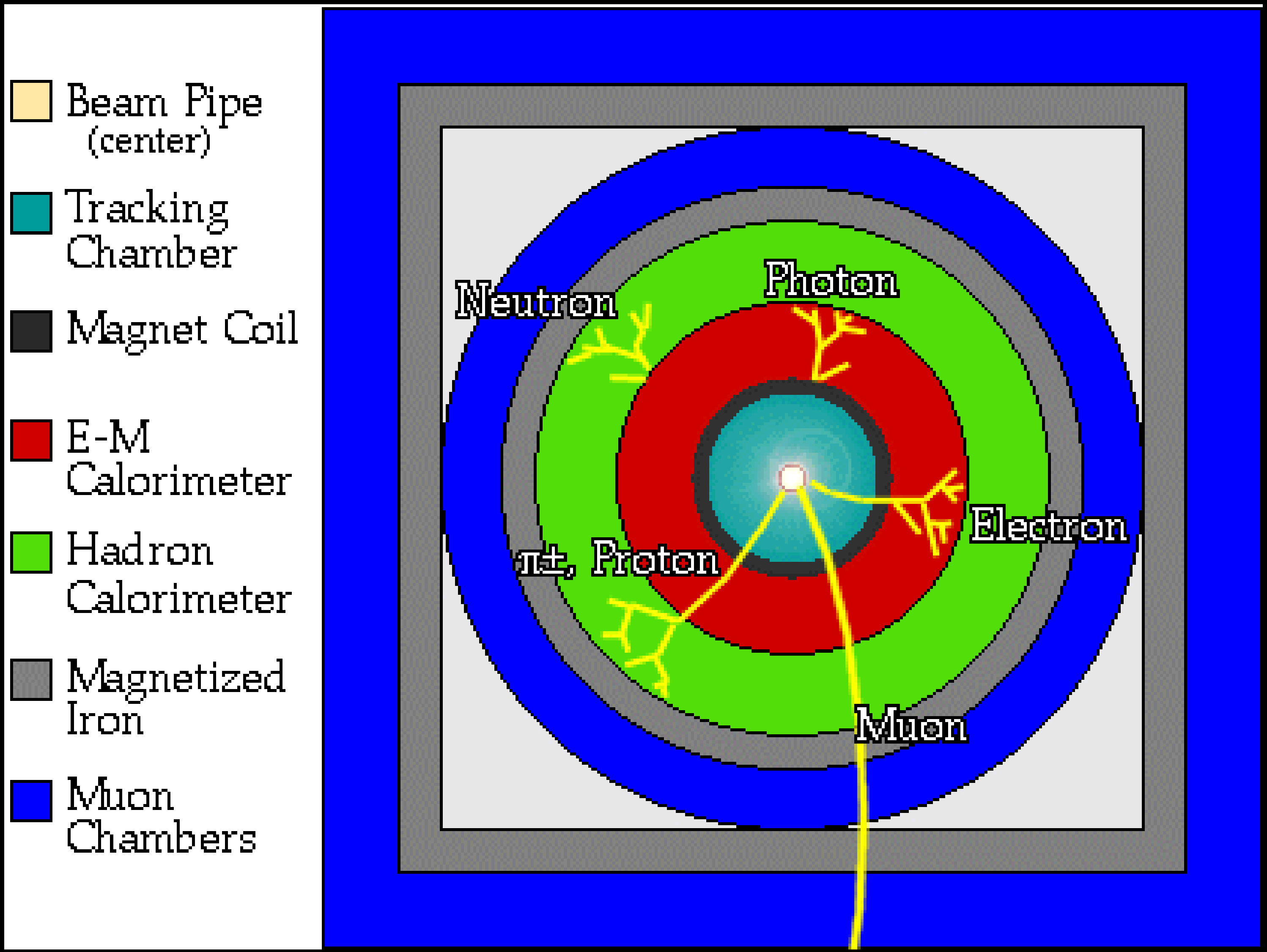
s = sagitta

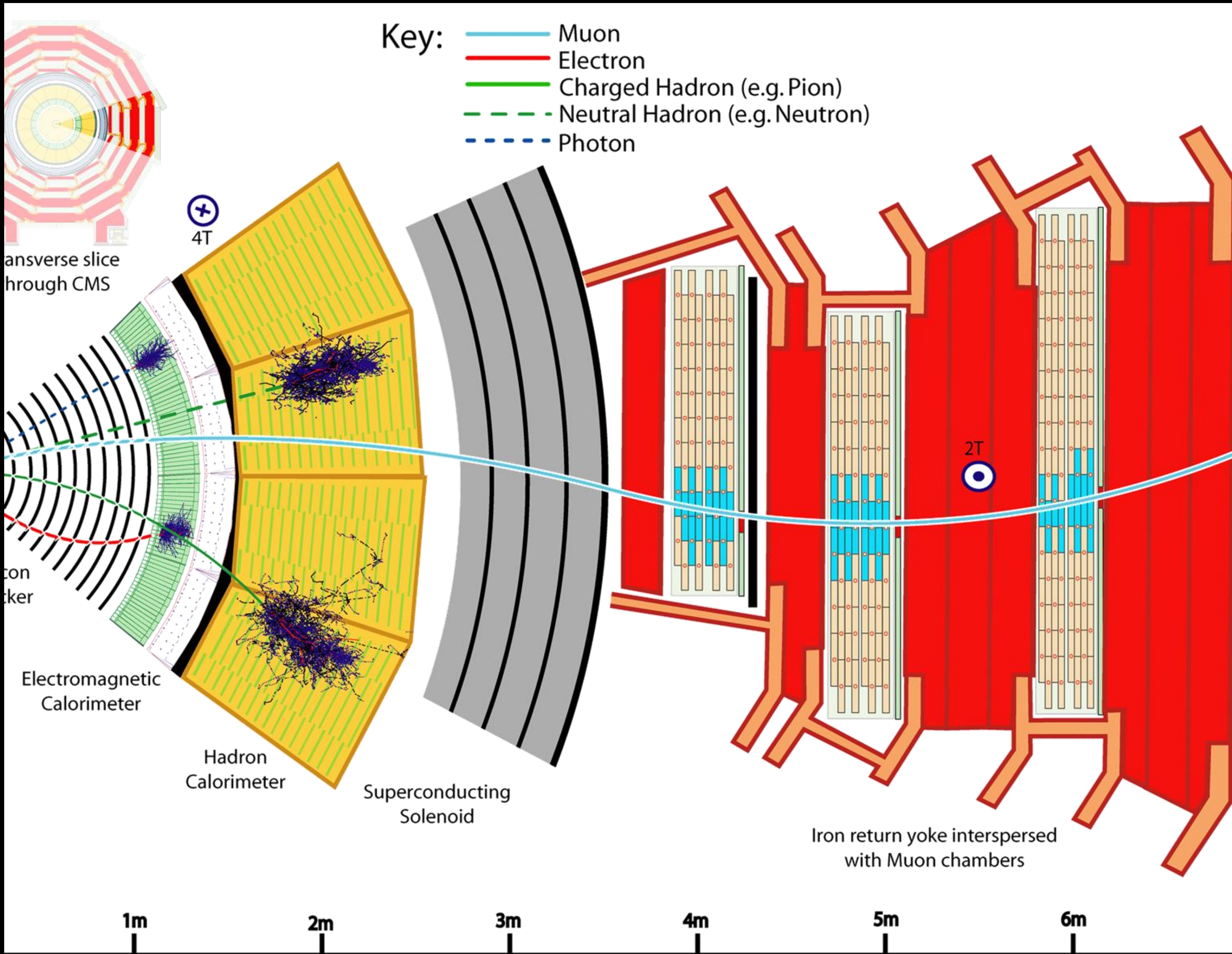
l = chord

ρ = radius

$$\rho \simeq \frac{l^2}{8s} \qquad p = 0.3\frac{Bl^2}{8s} \qquad \left|\frac{\delta p}{p}\right| = \left|\frac{\delta s}{s}\right|$$

Experiment at particle accelerator: schematic





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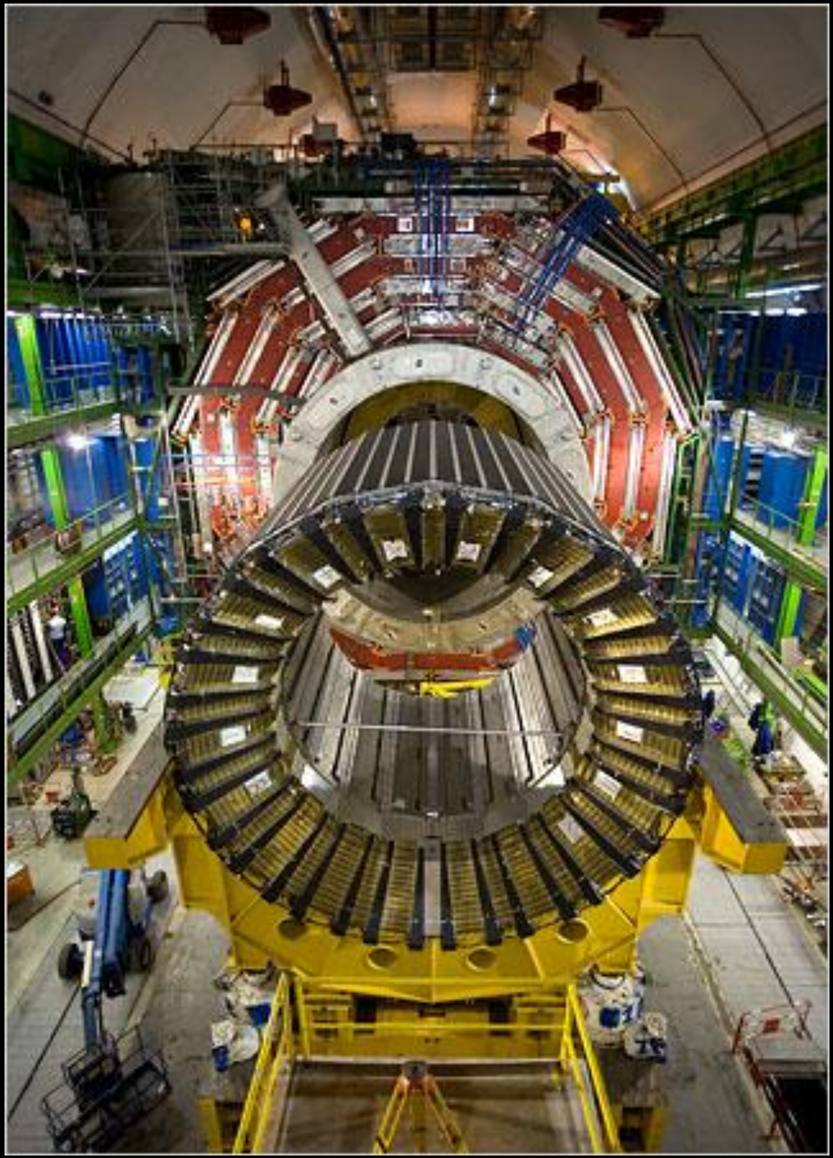
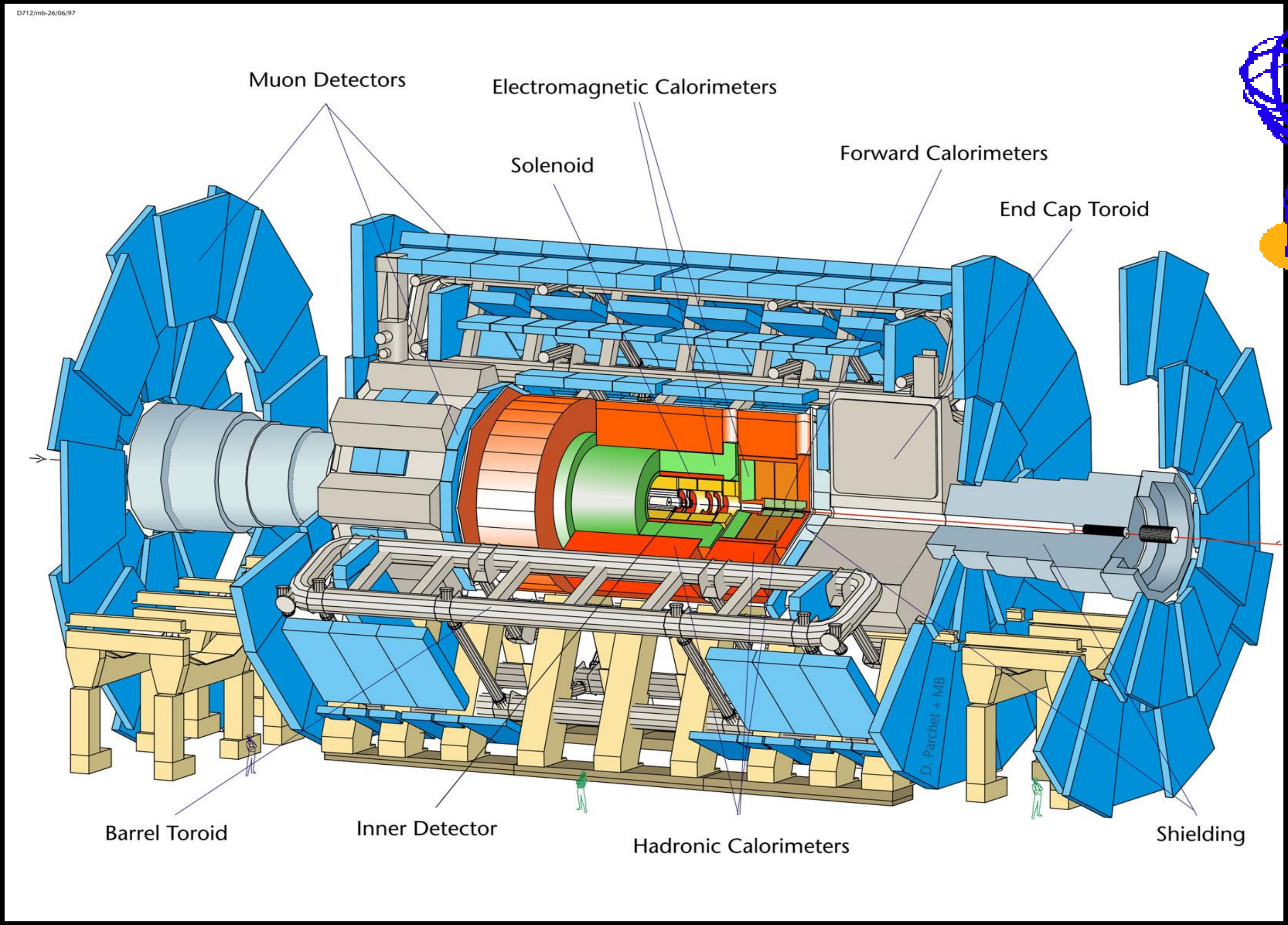


CMS

- Compact
- Muon
- Solenoid

- “Compact” is relative...

De ATLAS detector: Toroidaal veld



Diameter : 25m   Length : 46m   Weight : 7000 Tons □ 0.3 g/cm^3

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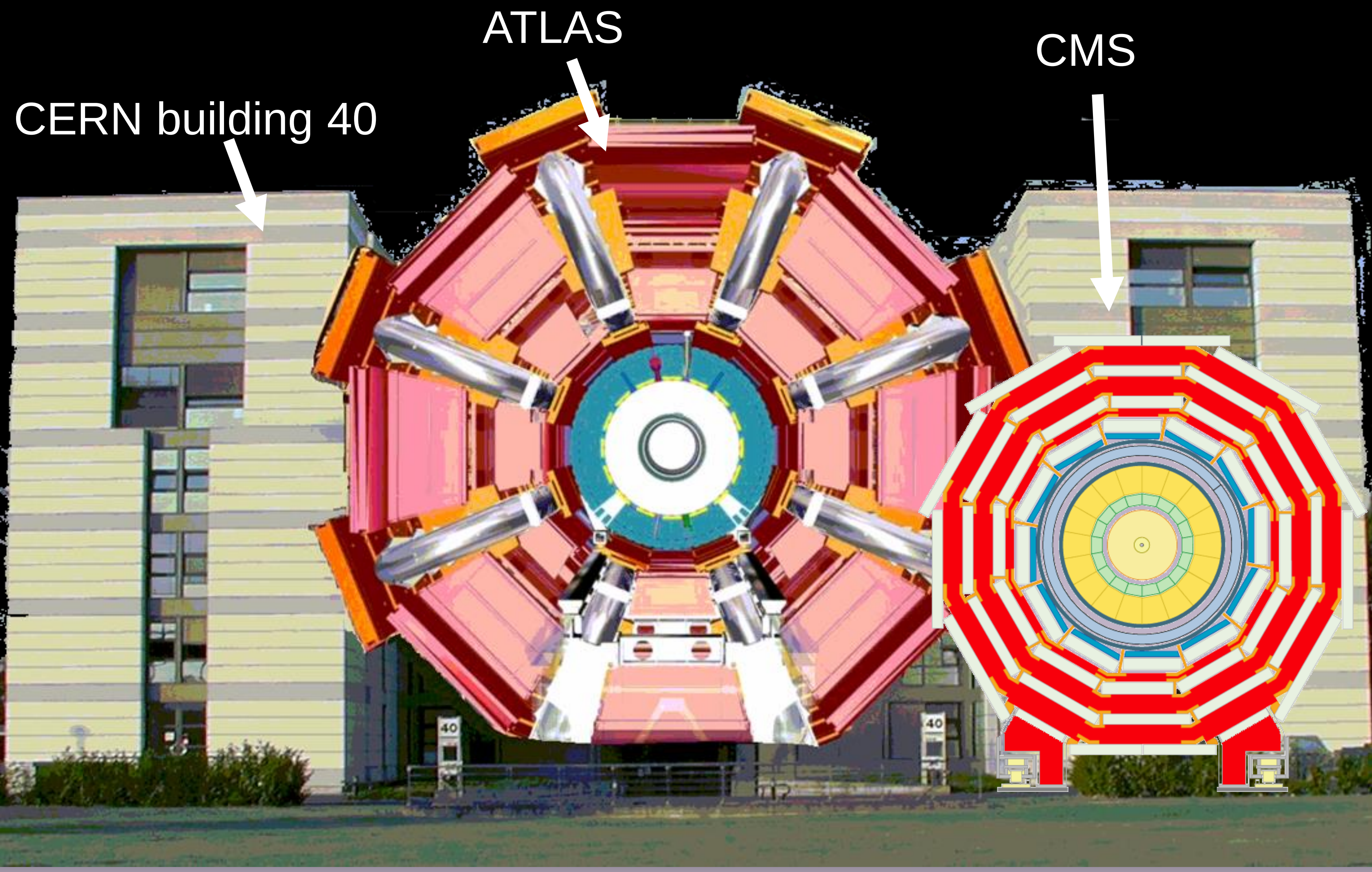
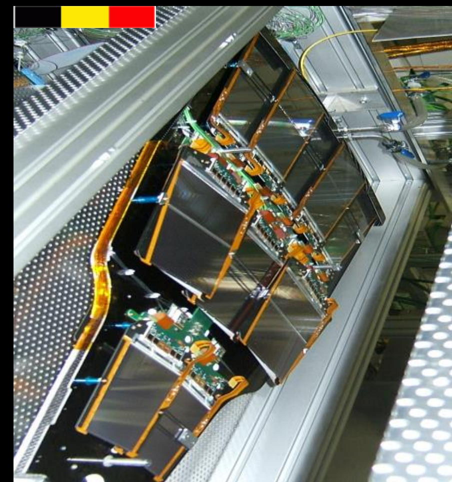
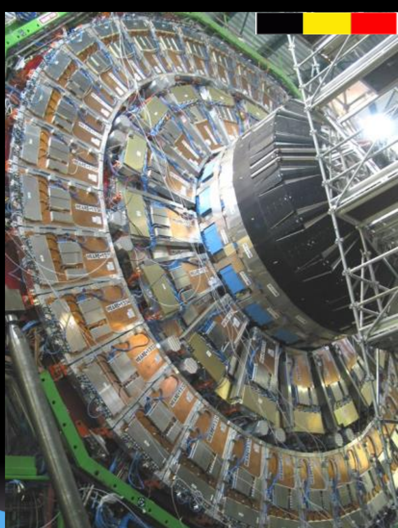
ATLAS is twice as big!

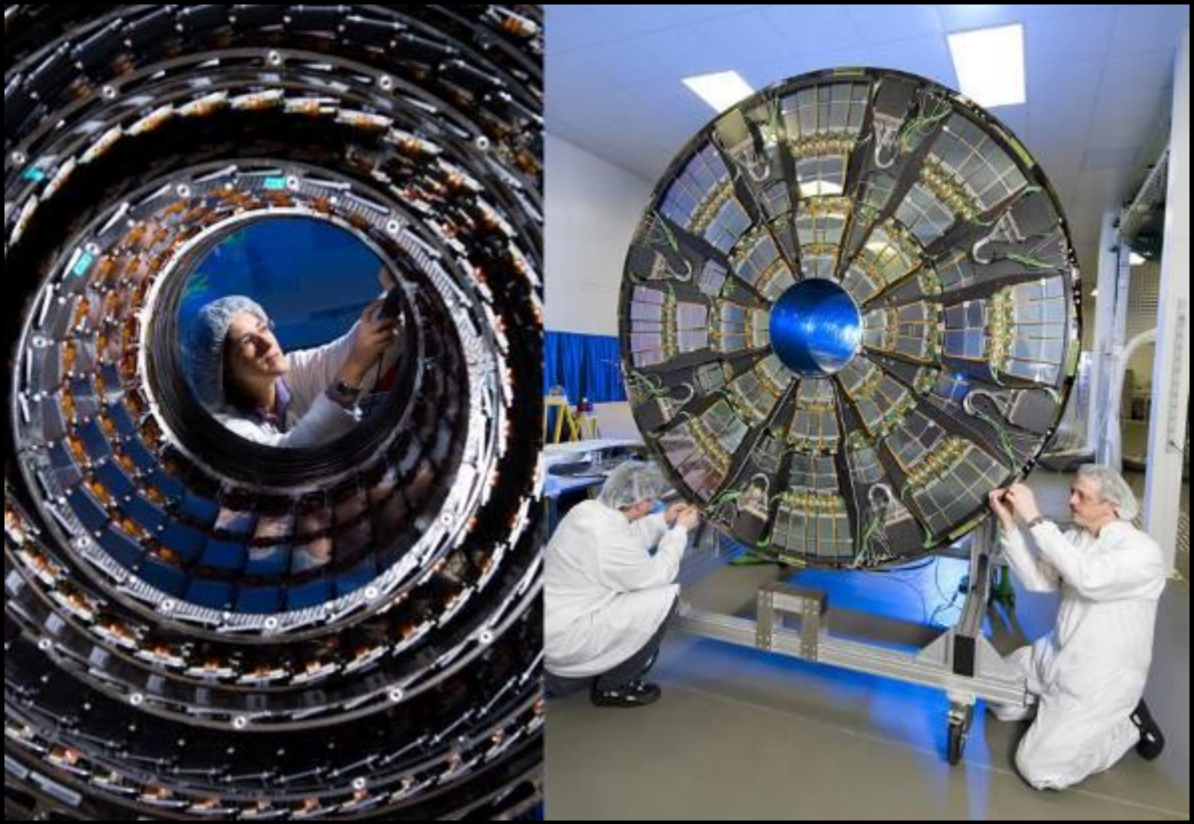


CMS in opbouw





Silicium spoordetector



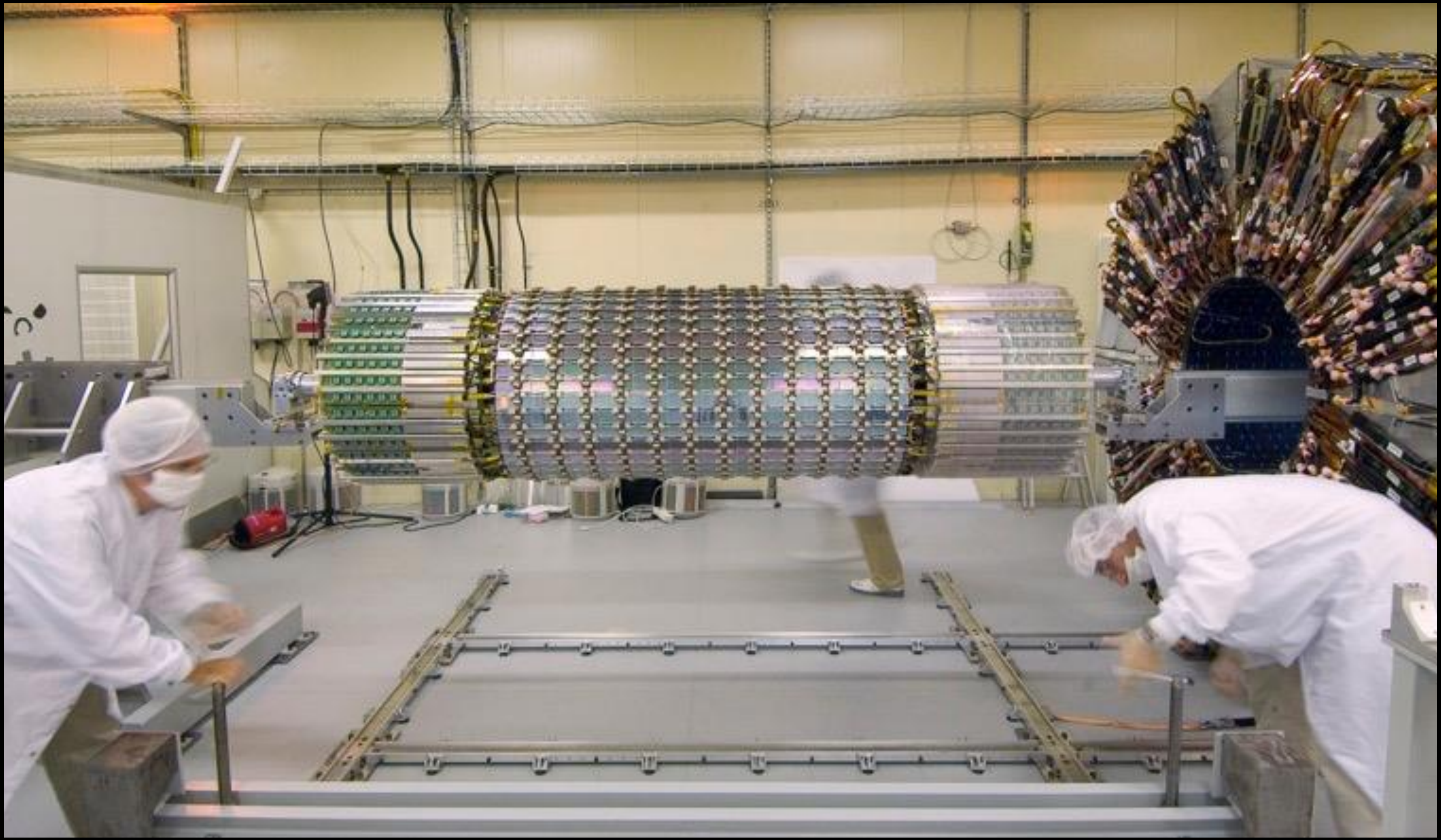
Silicium sensoren met fijne onderverdeling (baantjes en pixels) laten toe de deeltjessporen te meten in het magneetveld en aldus hun impuls te bepalen.

Een digitale camera met meer dan 70 miljoen pixels die 40 miljoen fotos per seconde trekt !

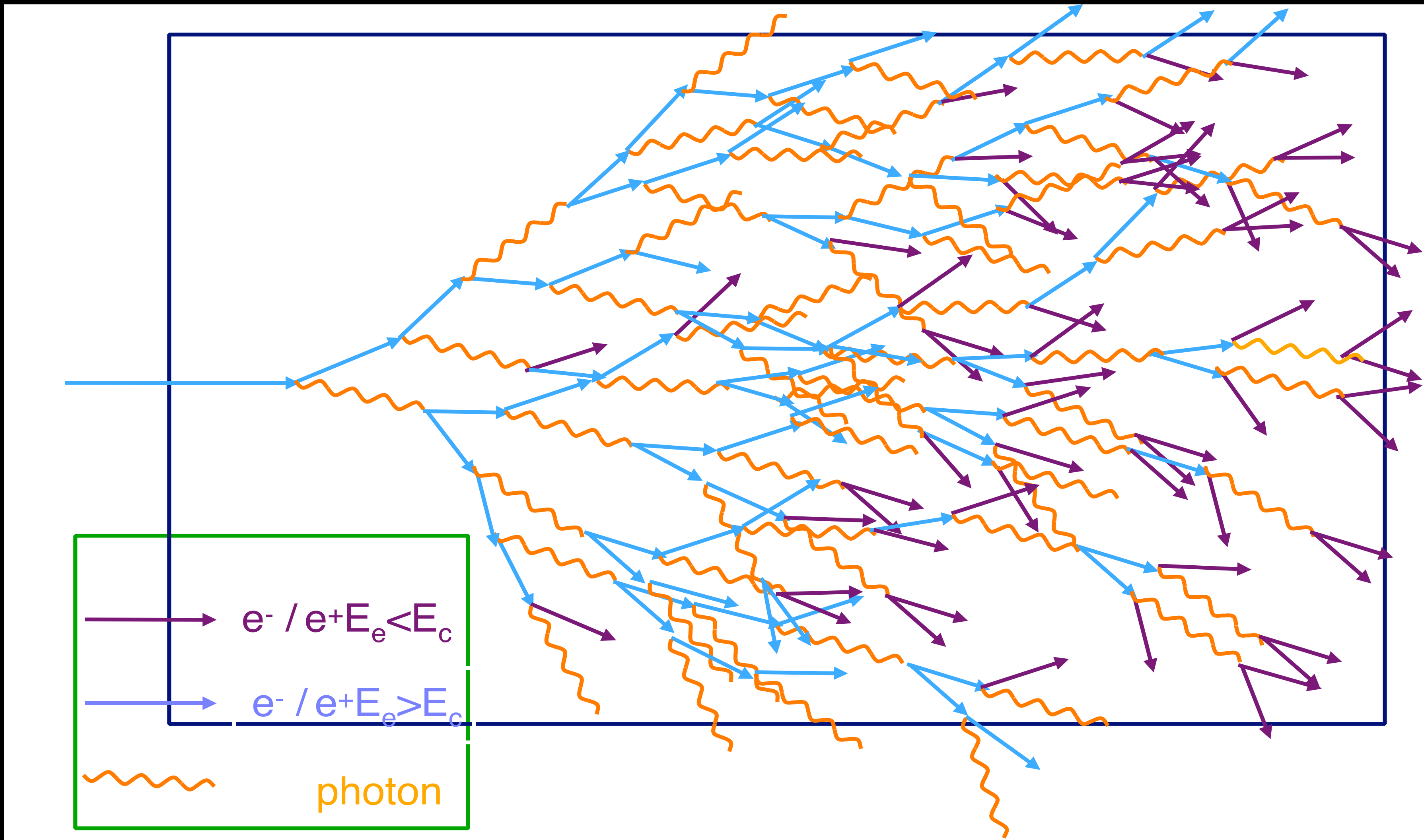
Deel van de upgrade (= nieuwe versie detector) zal op VUB worden gemaakt!

Doel: Meten van de trajecten van geladen deeltjes

‘small’ silicon detectors



Energiemetingen/Calorimetrie



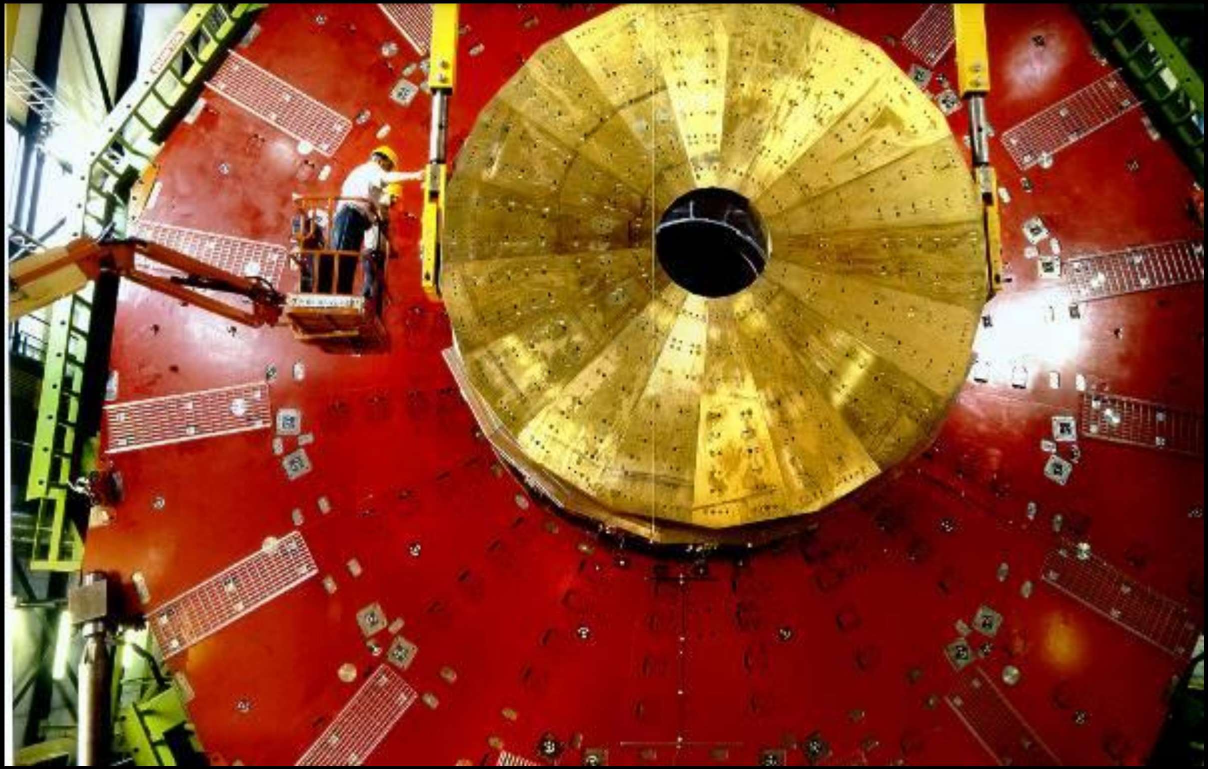
Electromagnetische calorimeter

80000 kristallen van $PbWO_4$ (loodtungstaat) geven scintillatielicht waarvan de intensiteit evenredig met de energie van het invallend deeltje (e of γ)

~80% metaal – volledig doorschijnend !

Doel: meting energie van electronen, positronen en fotons

Hadron calorimeter



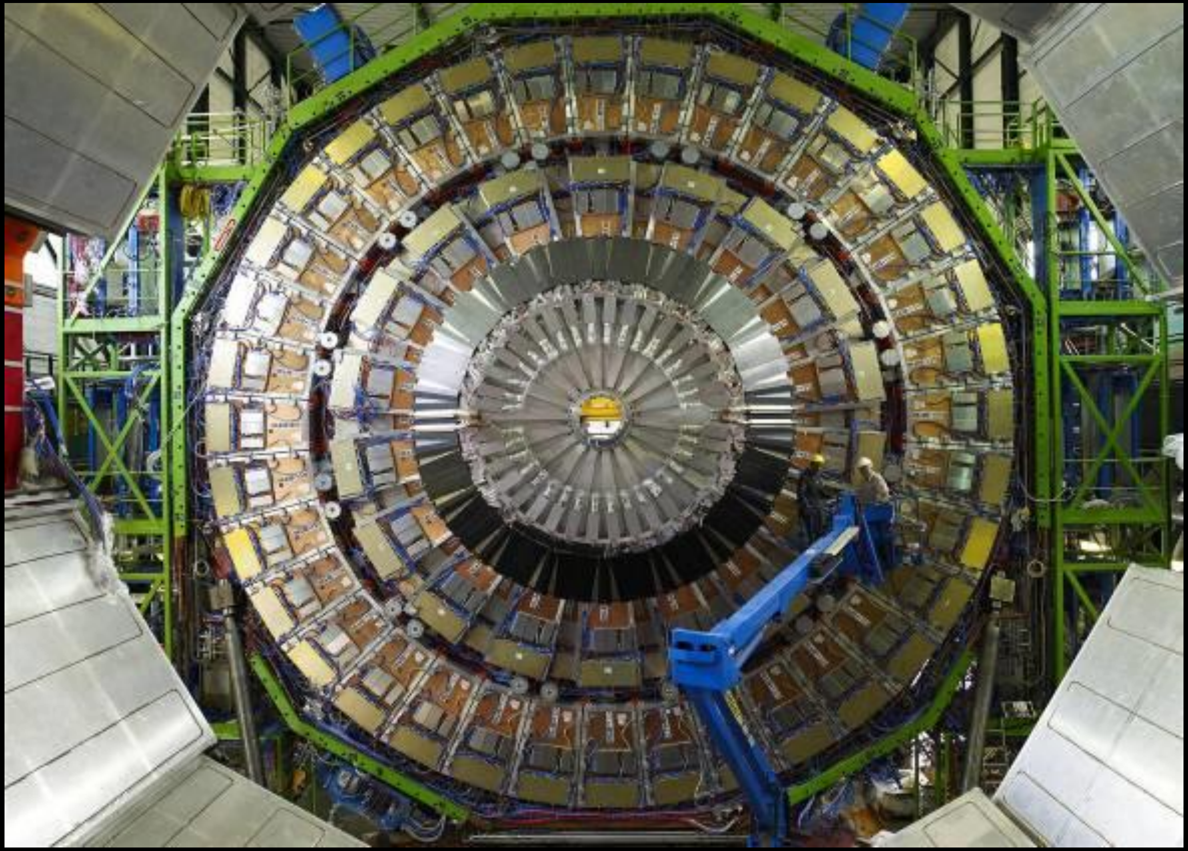
Opgebouwd uit alternerende lagen van messing en plastieken scintillator tegels.

Bomhozen van de Russische marine werden hiervoor gerecycleerd !

Doel: meting van de energie van hadronen (bv. proton, neutron)

Recyclage

Muon detectoren

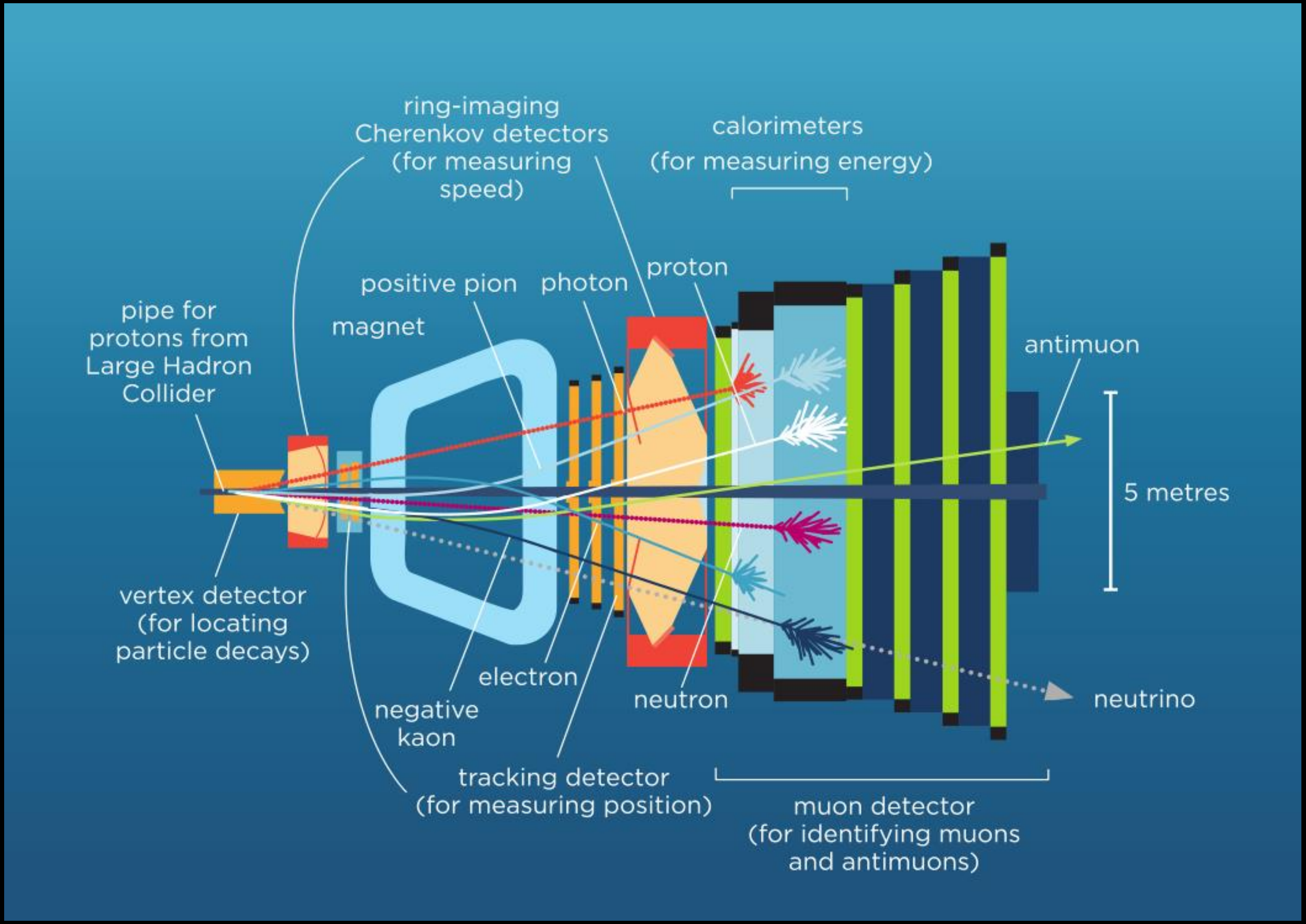


CMS gebruikt 3 soorten muon detectors: drift kamers (DT), cathode strip kamers (CSC) en resistieve platen kamers (RPC).

De totale oppervlakte beslaat ongeveer die van een voetbalveld… 6000 m^2 !

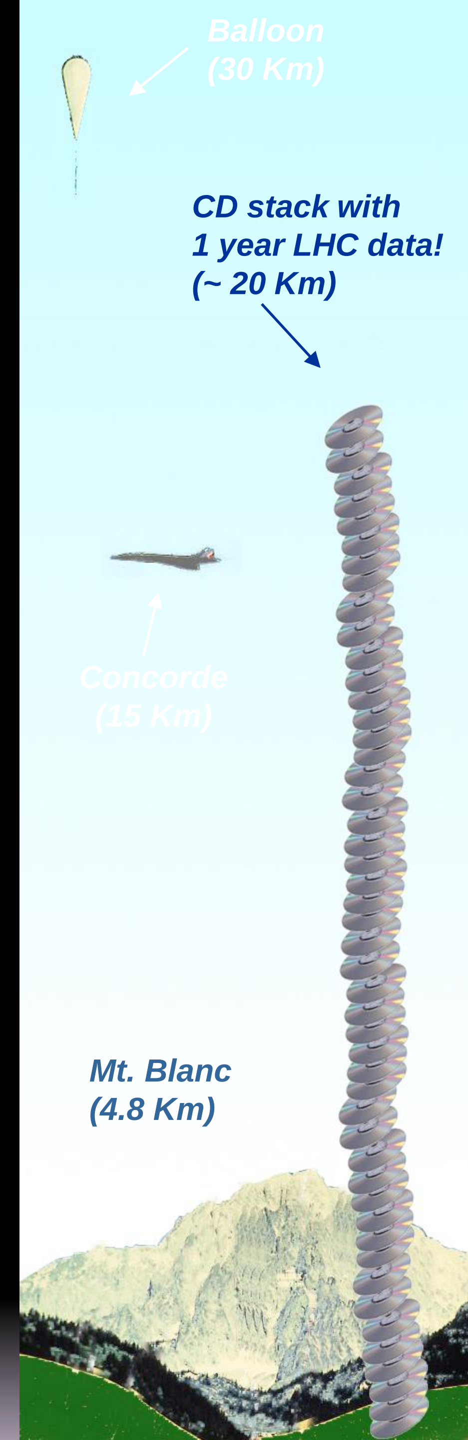
Doel: muonen identifieren en hun impuls meten

Cherenkov detectors in LHCb

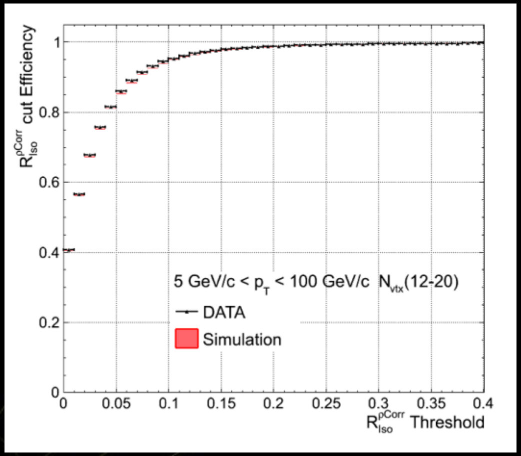


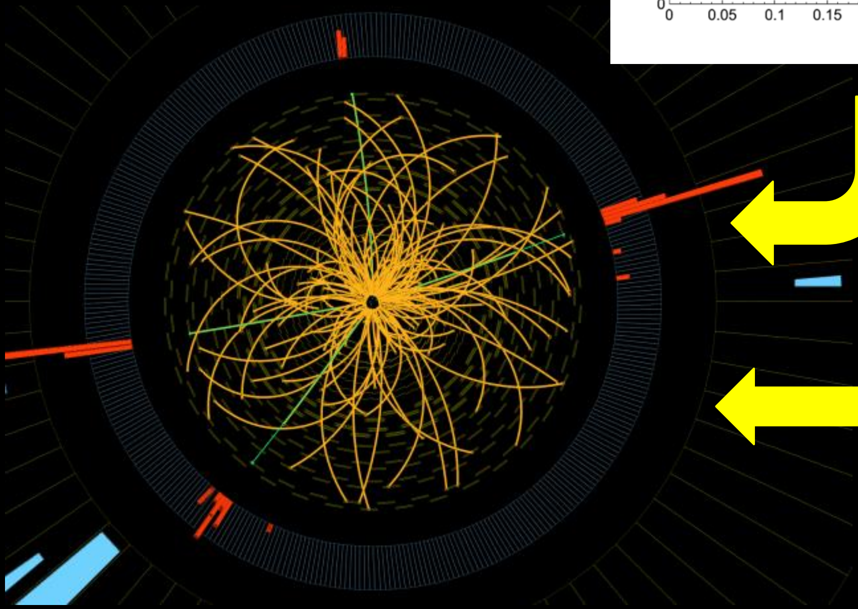
LHC experiments will produce **10-15 million GB** of data each year (about 20 million CDs!)

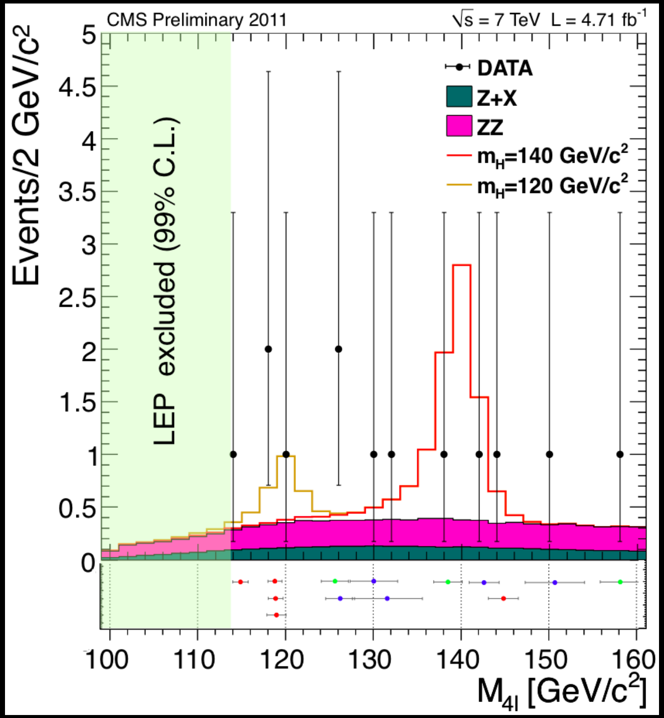
LHC data analysis requires a computing power equivalent to **~100,000 of today's fastest PC processors**.



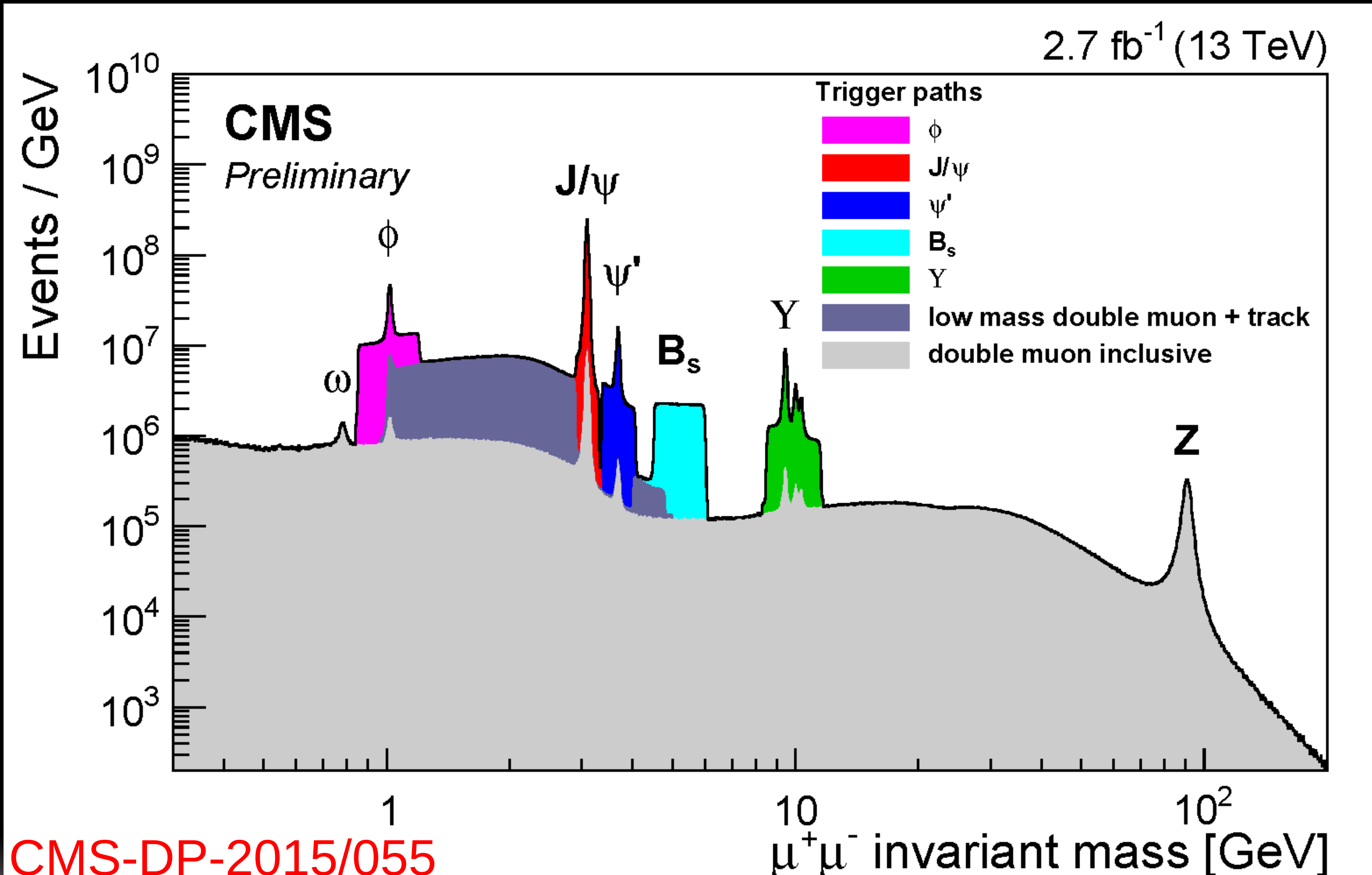
What do we actually do?





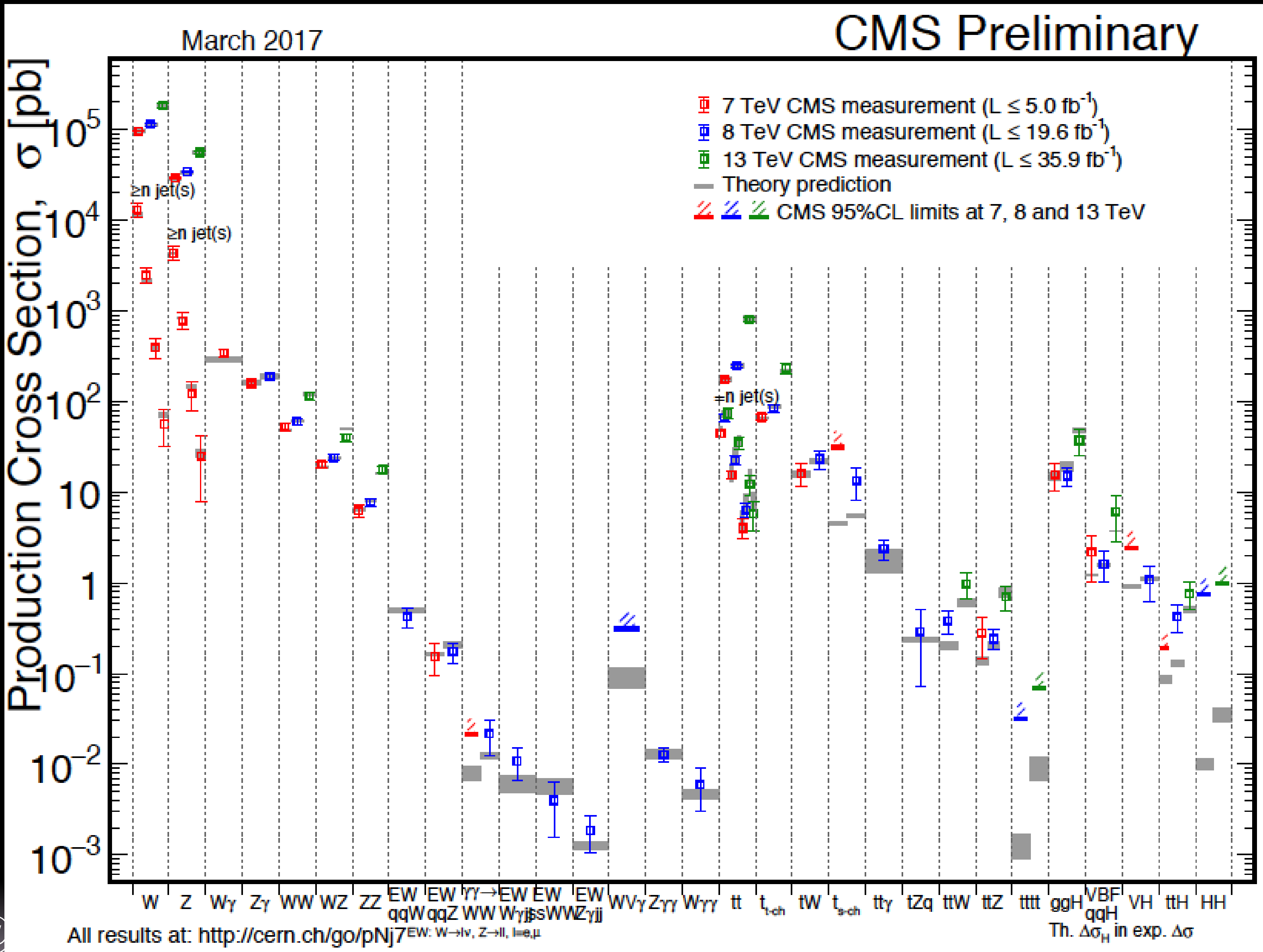


The Compact Muon Solenoid

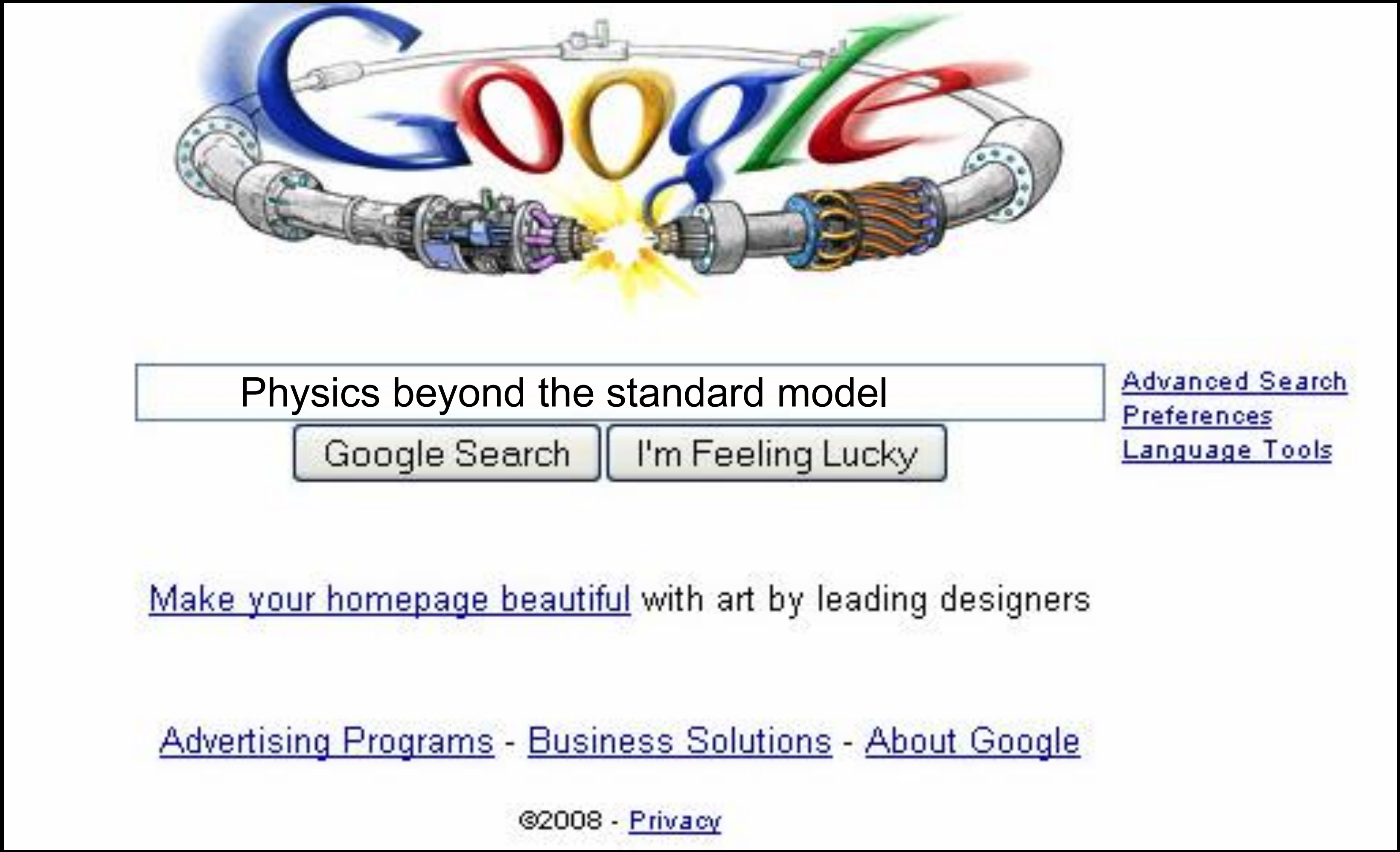


CMS-DP-2015/055

Standard Model: still going strong

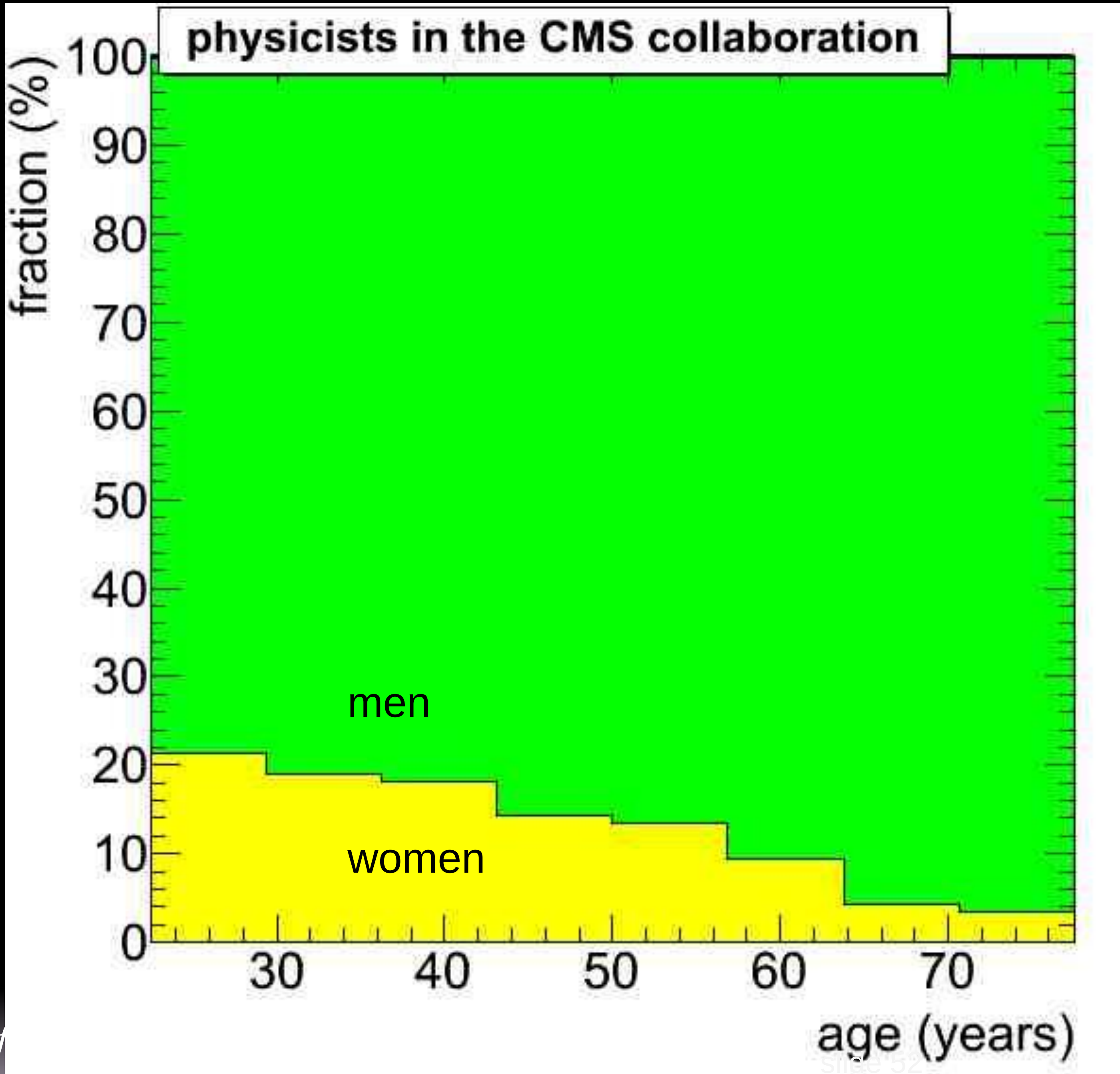


LHC: search engine



Questions?

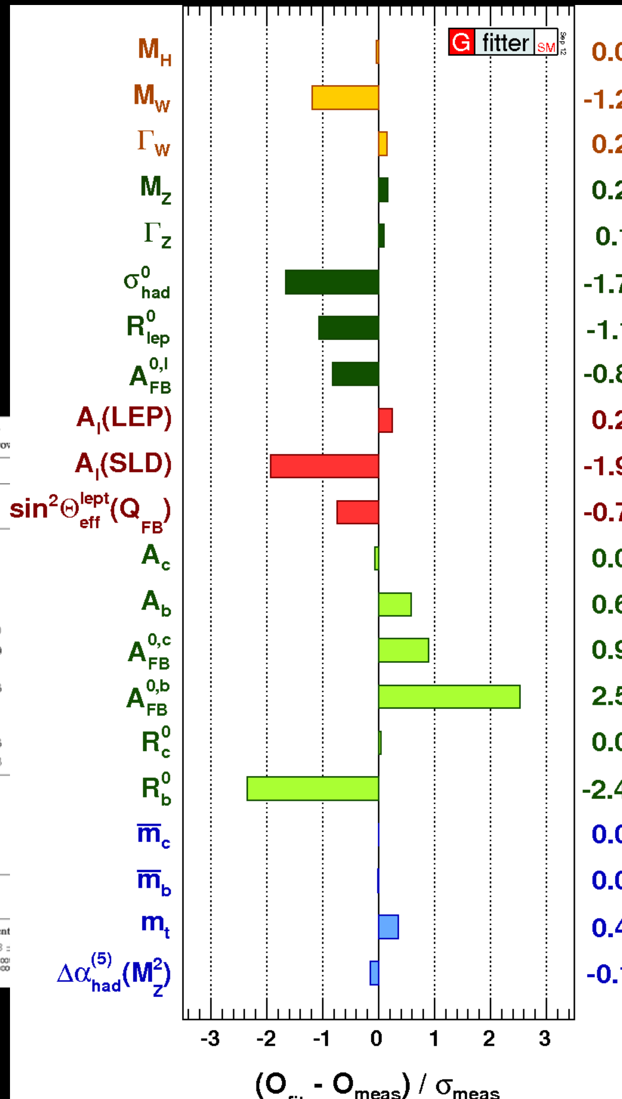
Backup slides

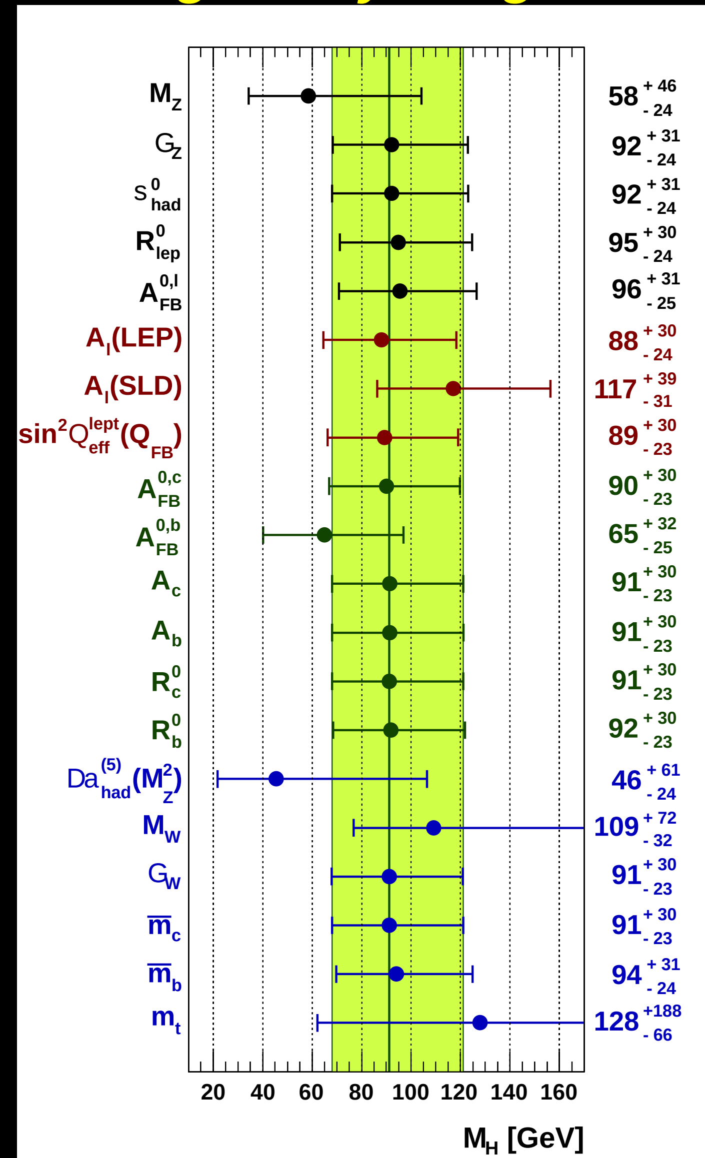

physicists in the CMS collaboration
fraction (%)
100
90
80
70
60
50
40
30
20
10
0
men
women
30
40
50
60
70
age (years)

Standard Model (pretty) good at describing everything

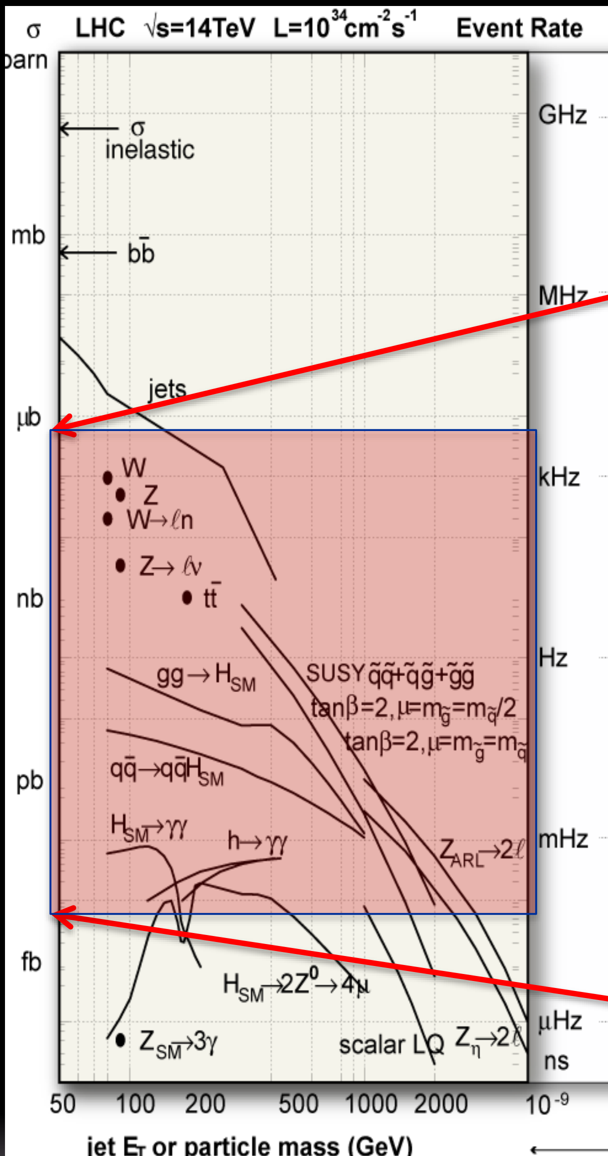
Parameter	Input value	Free in fit	Fit result incl. M_H	Fit result not incl. M_H	Fit result incl. M_H but not exp. input in rov
M_H [GeV]$^{(\circ)}$	125.7 ± 0.4	yes	125.7 ± 0.4	94^{+25}_{-22}	94^{+25}_{-22}
M_W [GeV]	80.385 ± 0.015	–	80.367 ± 0.007	80.380 ± 0.012	80.359 ± 0.011
Γ_W [GeV]	2.085 ± 0.042	–	2.091 ± 0.001	2.092 ± 0.001	2.091 ± 0.001
M_Z [GeV]	91.1875 ± 0.0021	yes	91.1878 ± 0.0021	91.1874 ± 0.0021	91.1983 ± 0.0116
Γ_Z [GeV]	2.4952 ± 0.0023	–	2.4954 ± 0.0014	2.4958 ± 0.0015	2.4951 ± 0.0017
σ^0_{had} [nb]	41.540 ± 0.037	–	41.479 ± 0.014	41.478 ± 0.014	41.470 ± 0.015
R^0_ℓ	20.767 ± 0.025	–	20.740 ± 0.017	20.743 ± 0.018	20.716 ± 0.026
$A^{0,\ell}_{FB}$	0.0171 ± 0.0010	–	0.01627 ± 0.0002	0.01637 ± 0.0002	0.01624 ± 0.0002
A_ℓ $^{(\star)}$	0.1499 ± 0.0018	–	$0.1473^{+0.0006}_{-0.0008}$	0.1477 ± 0.0009	$0.1468 \pm 0.0005^{(\dagger)}$
$\sin^2\theta^\ell_{eff}(Q_{FB})$	0.2324 ± 0.0012	–	$0.23148^{+0.00011}_{-0.00007}$	$0.23143^{+0.00010}_{-0.00012}$	0.23150 ± 0.00009
A_c	0.670 ± 0.027	–	$0.6680^{+0.00025}_{-0.00038}$	$0.6682^{+0.00042}_{-0.00035}$	0.6680 ± 0.00031
A_b	0.923 ± 0.020	–	$0.93464^{+0.00004}_{-0.00007}$	0.93468 ± 0.00008	0.93463 ± 0.00006
$A^{0,c}_{FB}$	0.0707 ± 0.0035	–	$0.0739^{+0.0003}_{-0.0005}$	0.0740 ± 0.0005	0.0738 ± 0.0004
$A^{0,b}_{FB}$	0.0992 ± 0.0016	–	$0.1032^{+0.0004}_{-0.0006}$	0.1036 ± 0.0007	0.1034 ± 0.0004
R^0_c	0.1721 ± 0.0030	–	0.17223 ± 0.00006	0.17223 ± 0.00006	0.17223 ± 0.00006
R^0_b	0.21629 ± 0.00066	–	0.21474 ± 0.00003	0.21475 ± 0.00003	0.21473 ± 0.00003
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	yes	$1.27^{+0.07}_{-0.11}$	$1.27^{+0.07}_{-0.11}$	–
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	yes	$4.20^{+0.17}_{-0.07}$	$4.20^{+0.17}_{-0.07}$	–
m_t [GeV]	173.18 ± 0.94	yes	173.52 ± 0.88	173.14 ± 0.93	$175.8^{+2.7}_{-2.4}$
$\Delta\alpha^{(5)}_{had}(M^2_Z)$ $^{(\triangle\nabla)}$	2757 ± 10	yes	2755 ± 11	2757 ± 11	2716^{+49}_{-43}
$\alpha_s(M^2_Z)$	–	yes	0.1191 ± 0.0028	0.1192 ± 0.0028	0.1191 ± 0.0028
$\delta_{th} M_W$ [MeV]	$[-4, 4]_{theo}$	yes	4	4	–
$\delta_{th} \sin^2\theta^\ell_{eff}$ $^{(\triangle)}$	$[-4.7, 4.7]_{theo}$	yes	-1.4	4.7	–

$^{(\circ)}$Average of ATLAS ($M_H = 126.0 \pm 0.4$ (stat) ± 0.4 (sys)) and CMS ($M_H = 125.3 \pm 0.4$ (stat) ± 0.5 (sys)) measurement assuming no correlation of the systematic uncertainties. $^{(\star)}$Average of LEP ($A_\ell = 0.1465 \pm 0.0033$) and SLD ($A_\ell = 0.1513$ ± 0.0021) measurements, used as two measurements in the fit. $^{(\dagger)}$The fit w/o the LEP (SLD) measurement gives $A_\ell = 0.1474$ ($A_\ell = 0.1467^{+0.0006}_{-0.0004}$). $^{(\triangle)}$In units of 10^{-5}. $^{(\nabla)}$Rescaled due to α_s dependency.





Standard model success



Shaded area: goal of measurements from the CMS proposal (25 years ago)