

Der Teilchenbeschleuniger

am CERN in Genf –

ein Blick ins frühe Universum

LHC

CERN

27 km

Frankreich



CERN 1954-2004



Conseil Européen pour la
Recherche Nucléaire

European Center for
Particle Physics



Sur le terrain du futur institut nucléaire



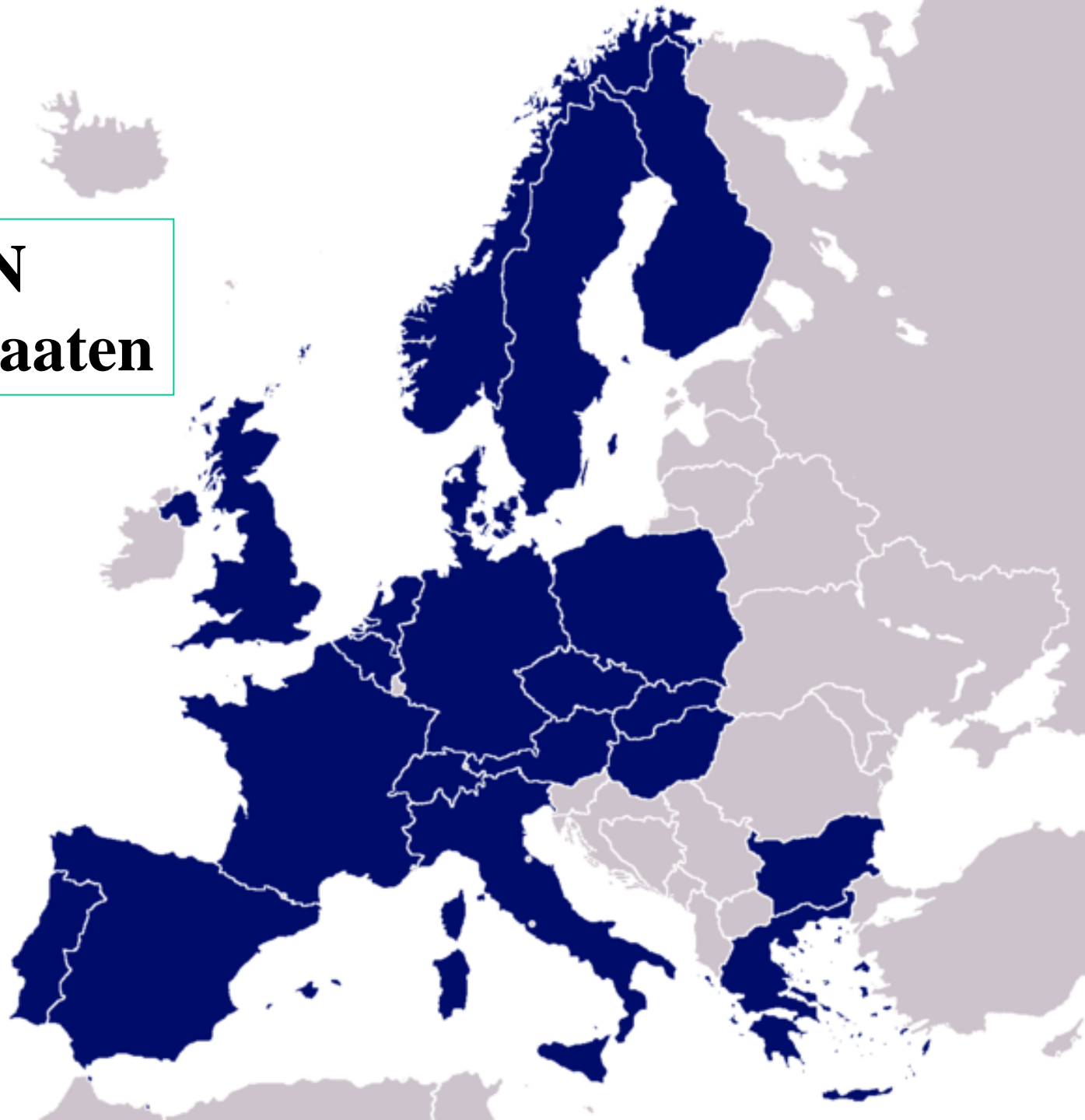
Sous la conduite de M. A. Picot, les membres du Conseil européen pour la recherche nucléaire se sont rendus hier à Meyrin pour reconnaître le terrain où s'élèvera le Centre nucléaire (voir en Dernière heure)

(Photo Freddy Bertrand, Genève)

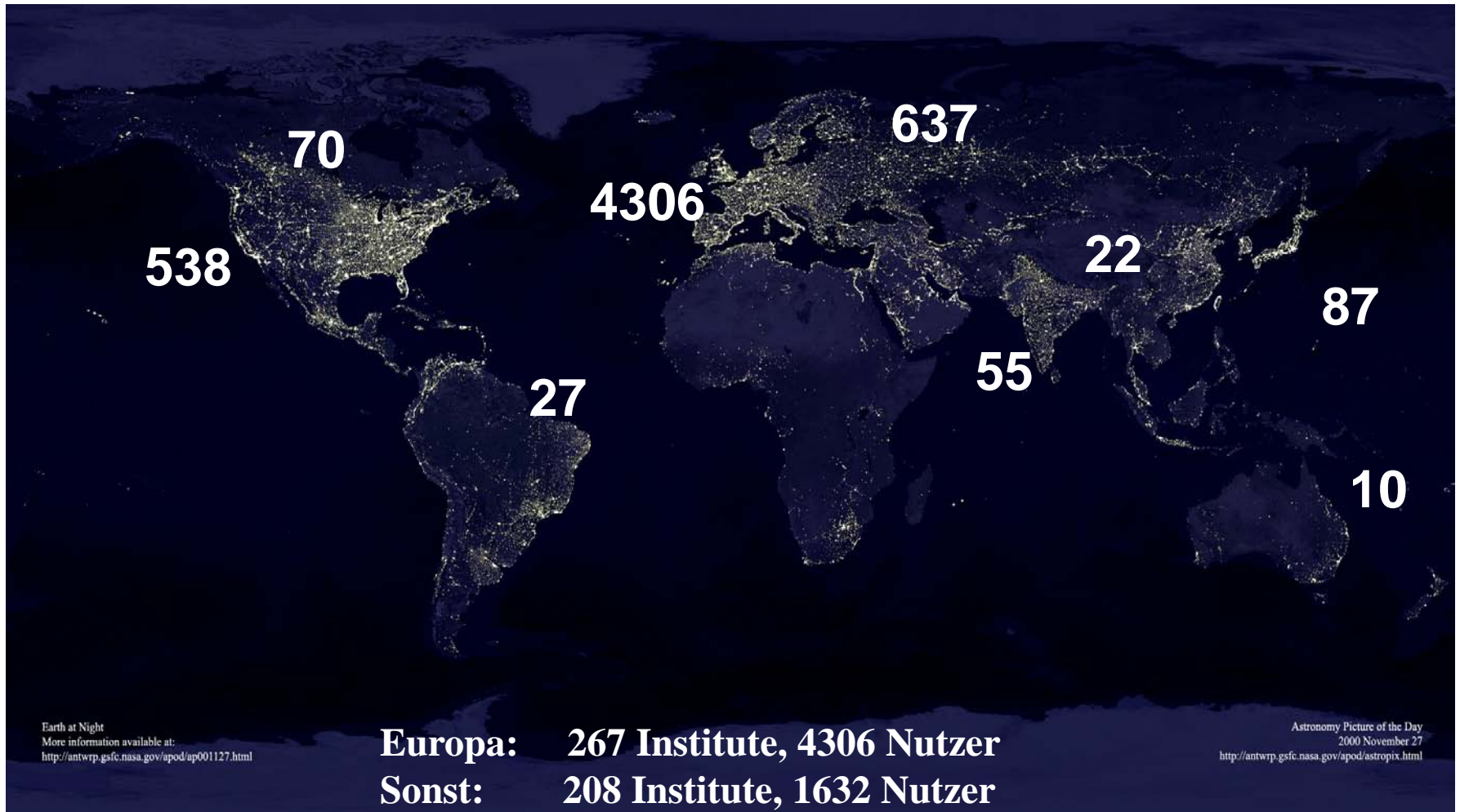
La Suisse du 30 octobre 1953



**CERN
Mitgliedstaaten**



CERN-Nutzer

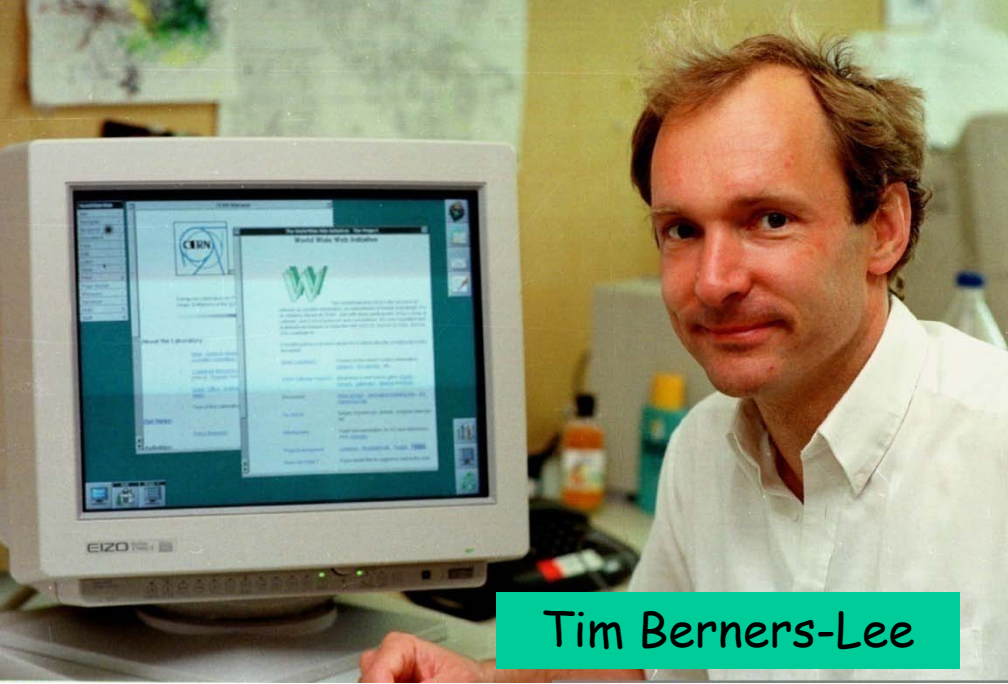




Weltgrößtes Labor für Elementarteilchenphysik

6000 Wissenschaftler

800 Millionen Euro / Jahr



Spin-Off

World Wide Web

- eine Erfindung bei CERN

Internet für alle!

Das WWW wurde 1990 am CERN erfunden, um den Daten- und Informationsaustausch innerhalb der Forschergruppen effektiver zu gestalten.

Rasch breitete es sich auf andere Wissenschaftszweige aus. Heute ist es ein wichtiger Bestandteil der globalen Infrastruktur (300 Millionen Nutzer).

Prominenz

Nobelpreisträger

C. Rubbia (1984),

S. Ting (1976),

G. Charpak (1992)



**Carlo Rubbia und Simon van der Meer
Nobelpreis 1984 (Entdeckung W und Z)**

Langjährige Zusammenarbeit CERN - RWTH

22. November 2004 - Aula I im Hauptgebäude, Templergraben 55, RWTH Aachen

Verleihung der Ehrendoktorwürde der RWTH an

Prof. C. Rubbia und Prof. S.C.C. Ting
anlässlich des 50-jährigen Bestehens von CERN



Carlo Rubbia
Nobelpreis 1984

16:15

**Prof. H. Schopper: 50 Jahre CERN -
Wissenschaftliche Erfolge und
Völkerverständigung**

17:00

Prof. G. Flügge: Laudatio

17:20

**Prof. B. Rauhut (Rektor der RWTH):
Honorary Doctorate to C. Rubbia and S.C.C. Ting**

17:30

Prof. C. Rubbia: The Future of Energy

18:00

Prof. S.C.C. Ting: The Anti Matter Universe

Kontakt: Prof. G. Flügge

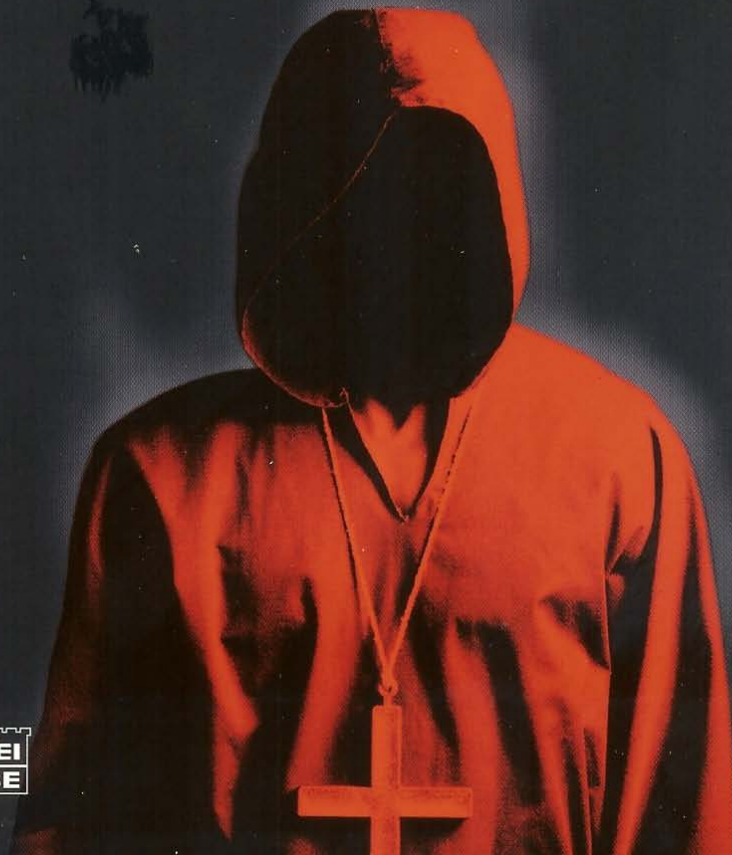


Samuel C.C. Ting
Nobelpreis 1976

DAN BROWN

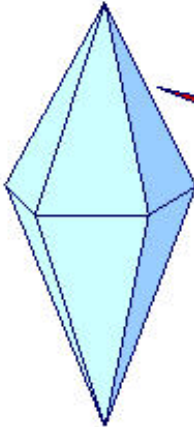
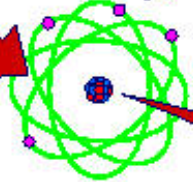


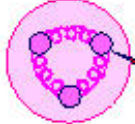


ILLUMINATI

THRILLER



BASTEI
LÜBBE

Die Struktur der Materie

Kristall Molekuel	Atom	Atom-Kem	Elementar- teilchen	
 	 Keme	 Mesonen  Baryonen Proton Neutron	 Leptonen $e, \mu, \tau, \nu_e, \nu_\mu, \nu_\tau$  Quarks u, c, d, s, b, t	
1 cm	10^{-8} cm	10^{-12} cm	10^{-13} cm = 1 fm	?

Elektromagnetische Wechselwirkung)

Kernkraft = starke Wechselwirkung

Die 4 Grundbausteine des Sonnensystems

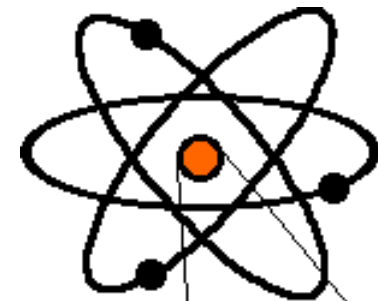
$\left(\begin{array}{c} \nu_e \\ e^- \end{array} \right)$ Neutrino
Elektron } Leptonen

$\left(\begin{array}{c} u \\ d \end{array} \right)$ up-Quark
down-Quark

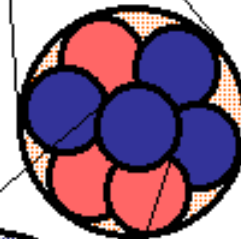
Kernbausteine = Nukleonen:

$p = \text{Proton} = u + u + d$

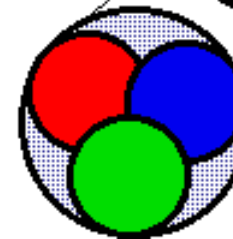
$n = \text{Neutron} = u + d + d$



Atom aus
Elektronen
und Kern



Kern aus
Nukleonen



Nukleon aus
Quarks

Grundbausteine sind punktförmig : “Elementarteilchen“

Standardmodell der Teilchenphysik

Materie:

viele Teilchen

Leptonen:

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$$

instabil!

Quarks:

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} t \\ b \end{pmatrix}$$

Wechselwirkungen: Austauschpartikel:

elektromagnetisch:

Photon	γ	masselos
Z-Boson	Z	91 GeV
W-Boson	$W^+ W^-$	80 GeV

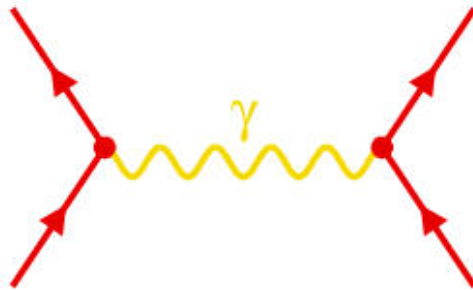
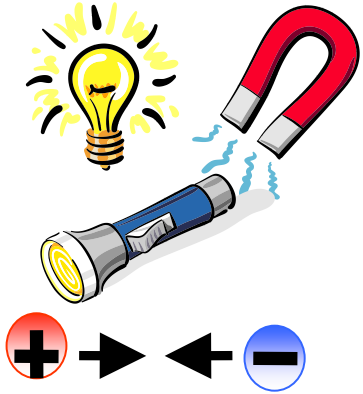
schwach:

stark:

Gluon	g	masselos
-------	---	----------

Experimentellen Daten werden akkurat beschrieben!

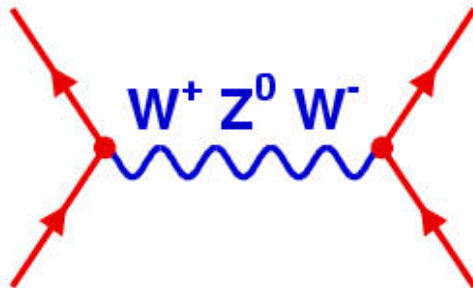
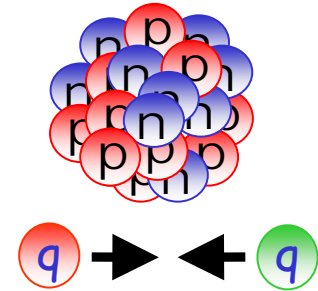
Fundamentale Wechselwirkungen



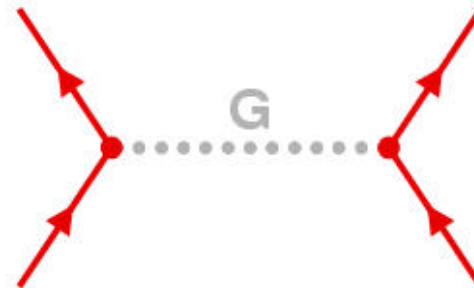
elektromagn. Kraft



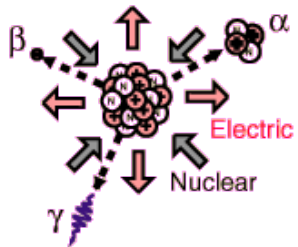
starke Kraft



schwache Kraft



Gravitation



schwächste 'Kraft'
im Mikrokosmos völlig
unbedeutend

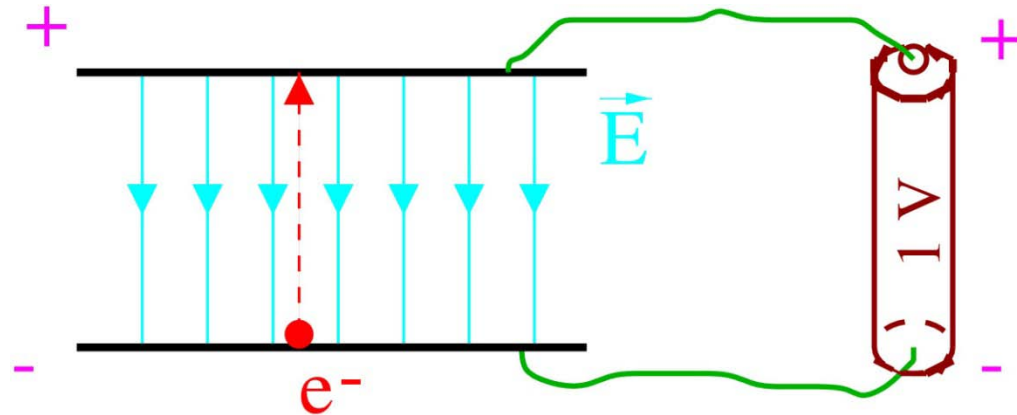


Energie und Masse

Energie-Einheit

eV = Elektronenvolt

$$1 GeV = 10^9 eV \approx 10^{-10} J$$



Energie und Masse



$$E = mc^2$$

$c = 300000 \text{ km/s}$

Energie kann in Masse umgewandelt werden und umgekehrt !

Protonmasse $\hat{=} 1 GeV$

Teilchenbeschleuniger

Untersuchung **kleinster Materiestrukturen** oder **schwererer Teilchen**

verlangt

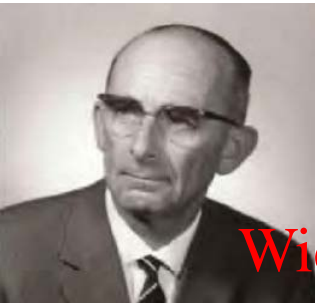
Beschleunigung von Teilchen auf **höchste Energien**

Heisenberg'sche Unschärferelation

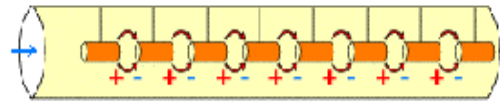
$$\Delta x \cdot \Delta p \geq h$$

$$E = m c^2 \quad \text{Einstein}$$

Linearbeschleuniger :

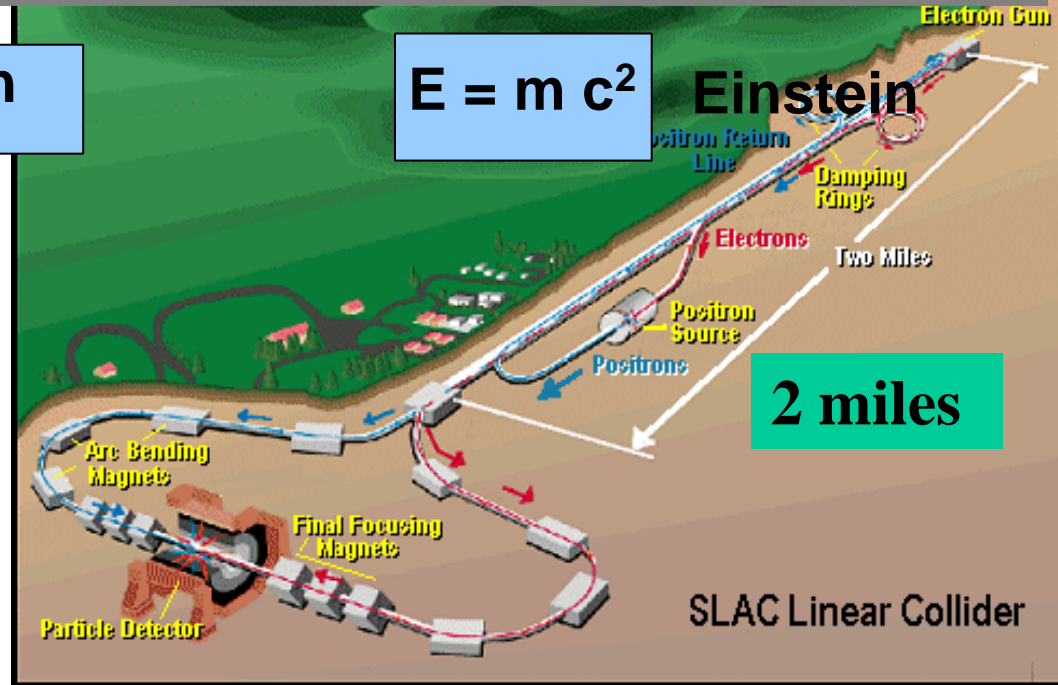


Wideröe, RWTHAachen



Wiederholtes Beschleunigen:

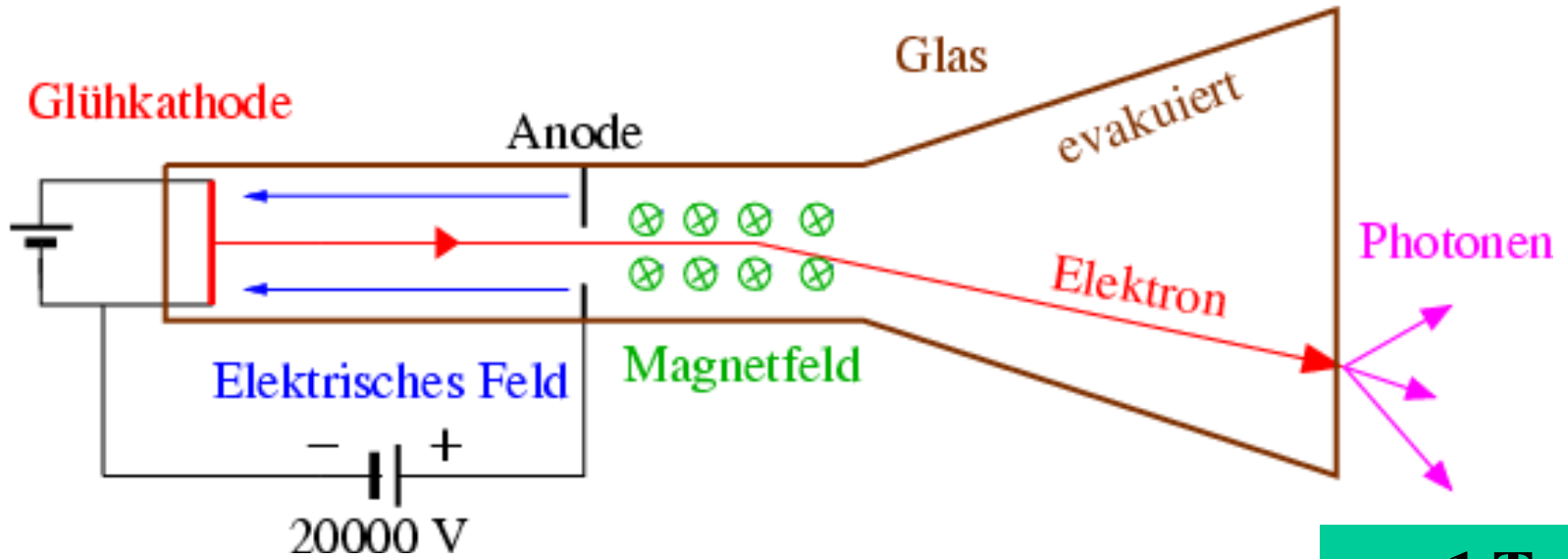
- 1 000 eV = 10^3 eV = 1 keV
- 1 000 000 eV = 10^6 eV = 1 MeV
- 1 000 000 000 eV = 10^9 eV = 1 GeV
- 1 000 000 000 000 eV = 10^{12} eV = 1 TeV



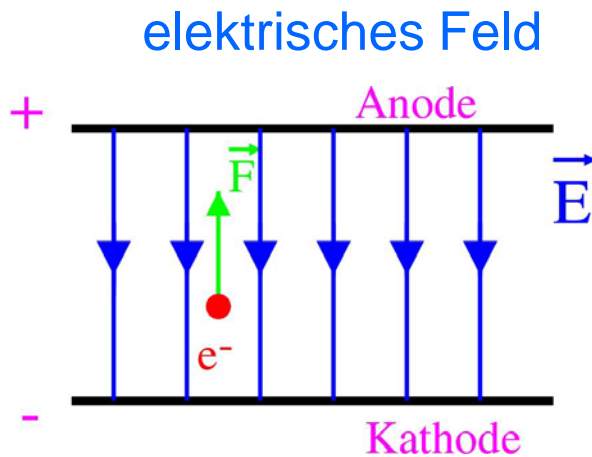
Stanford Linear Accelerator
ca. **50 GeV**

Teilchenbeschleuniger: Elektronen: 20 keV

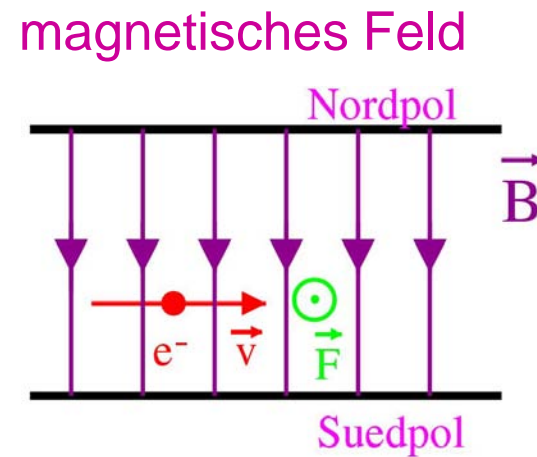
Erzeugung Beschleunigung Ablenkung Kollision



ca. 1 Tesla
= 1 T



beschleunigt oder lenkt ab

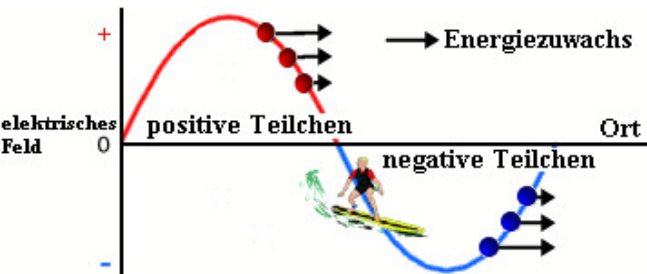
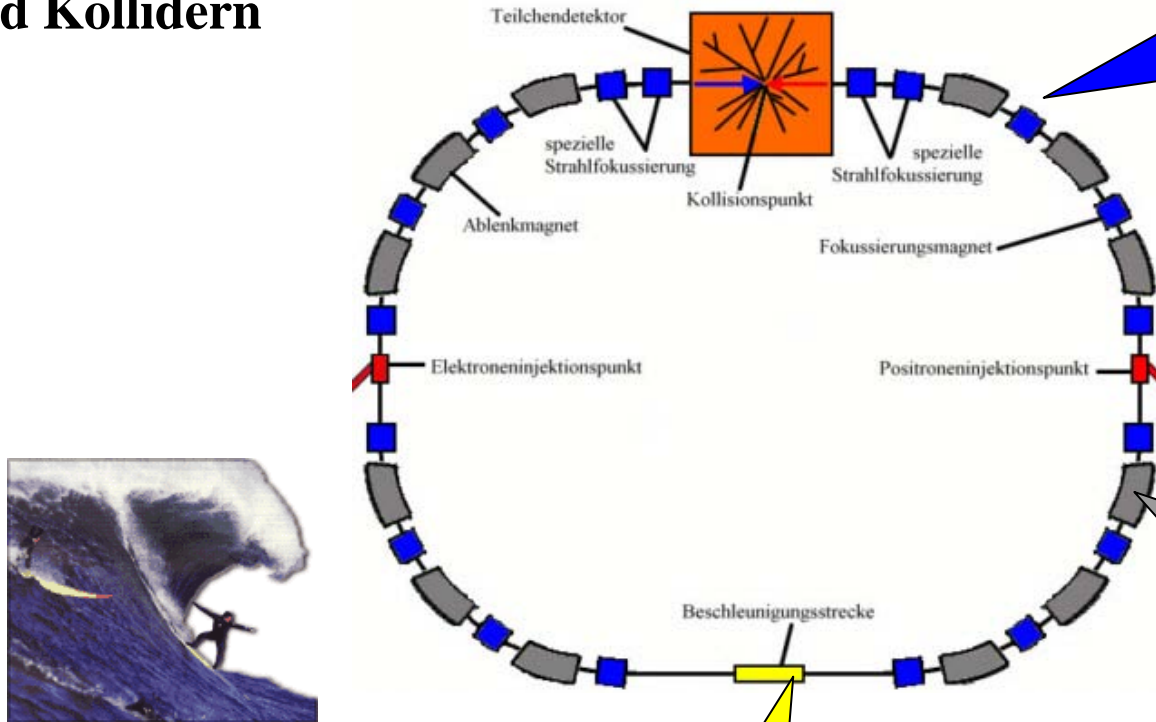


lenkt (stark) ab



Teilchenbeschleuniger

Weiterentwicklung zu Kreisbeschleunigern und Kollidern



Teilchenbeschleuniger

Grosse
Beschleuniger-
Zentren
weltweit:



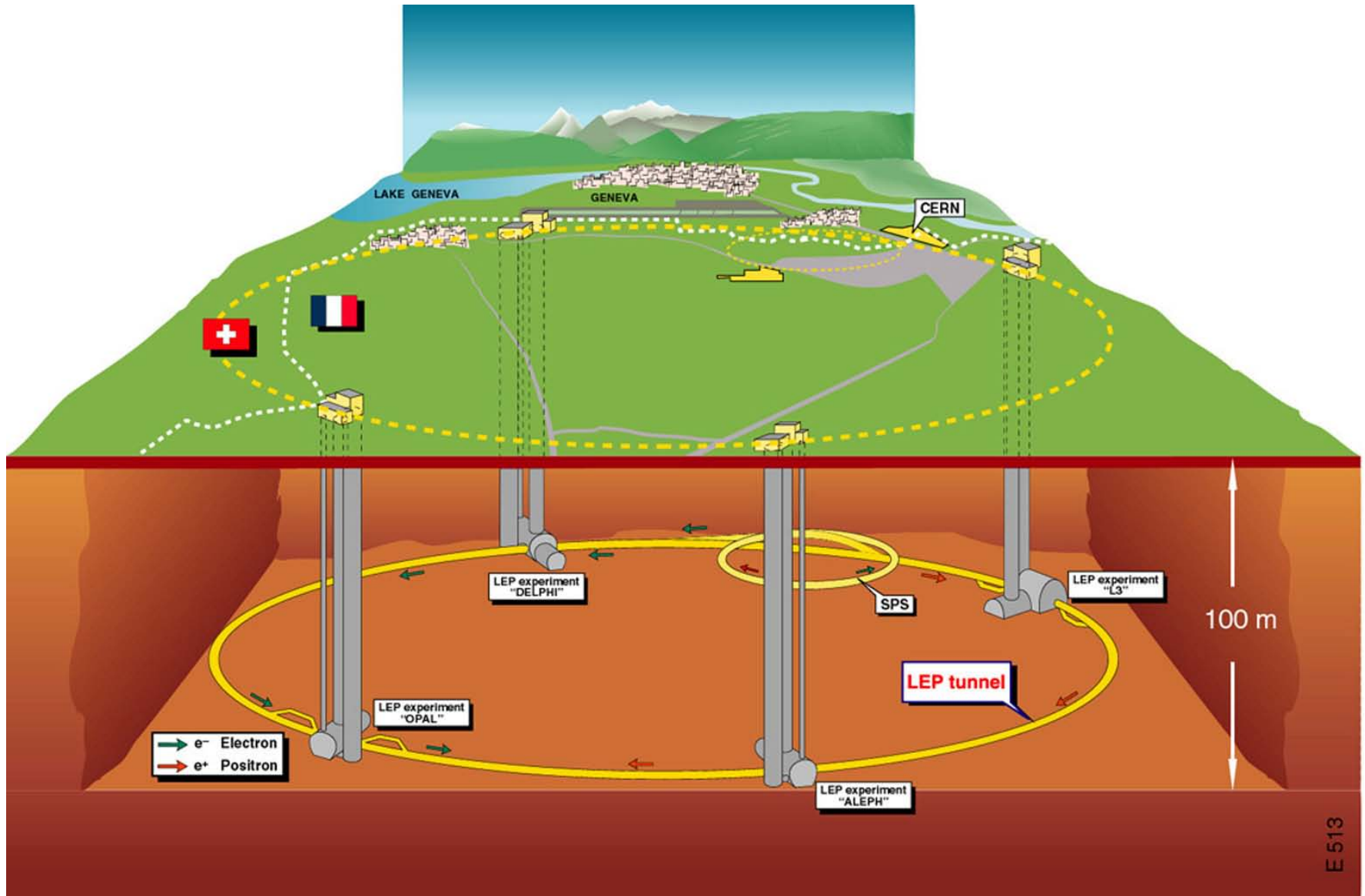
physikalische Entdeckungen/Verständnis



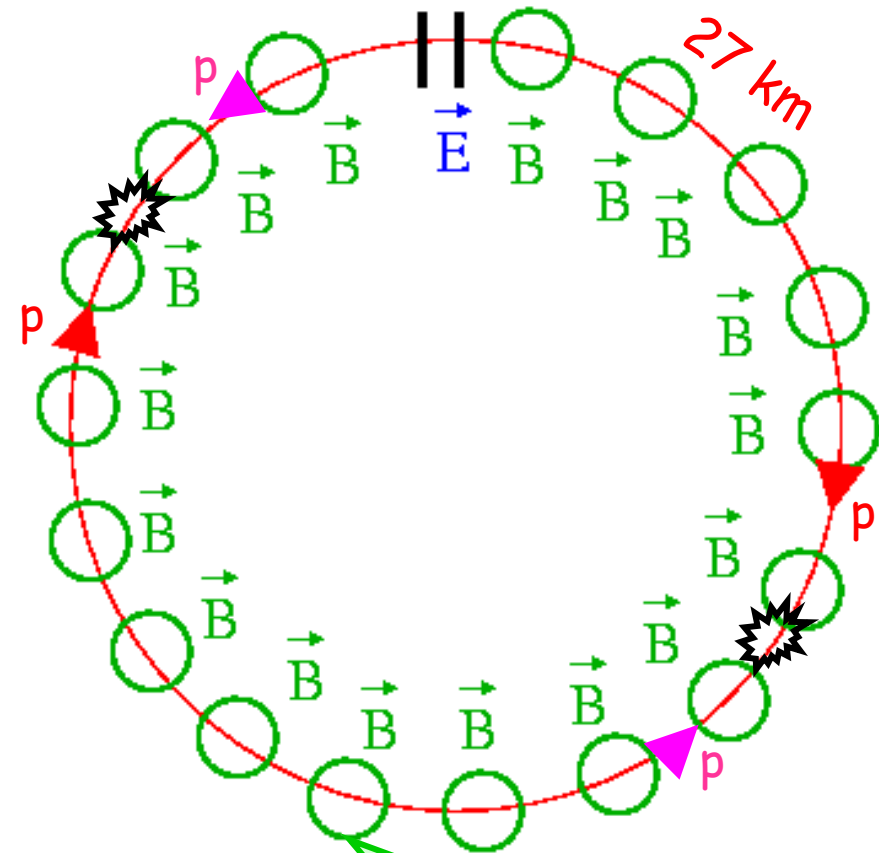
Durchbruch bei Detektor- und/oder Beschleunigertechnologie

Elektron-Positron-Kollider LEP am CERN

200 GeV



LHC = Large Hadron Collider



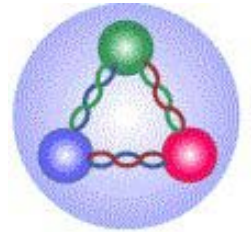
1200 Dipolmagnete,
supraleitend
je 14 m lang, $B = 8$ Tesla

Large

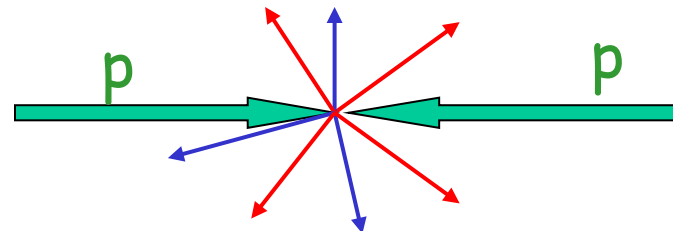
27 km,
14000 GeV
= 14 TeV

Hadron

Proton



Collider



Größe
wächst mit
Energie!

Cryogenic magnet test station



Der weltgrößte Teilchenbeschleuniger LHC

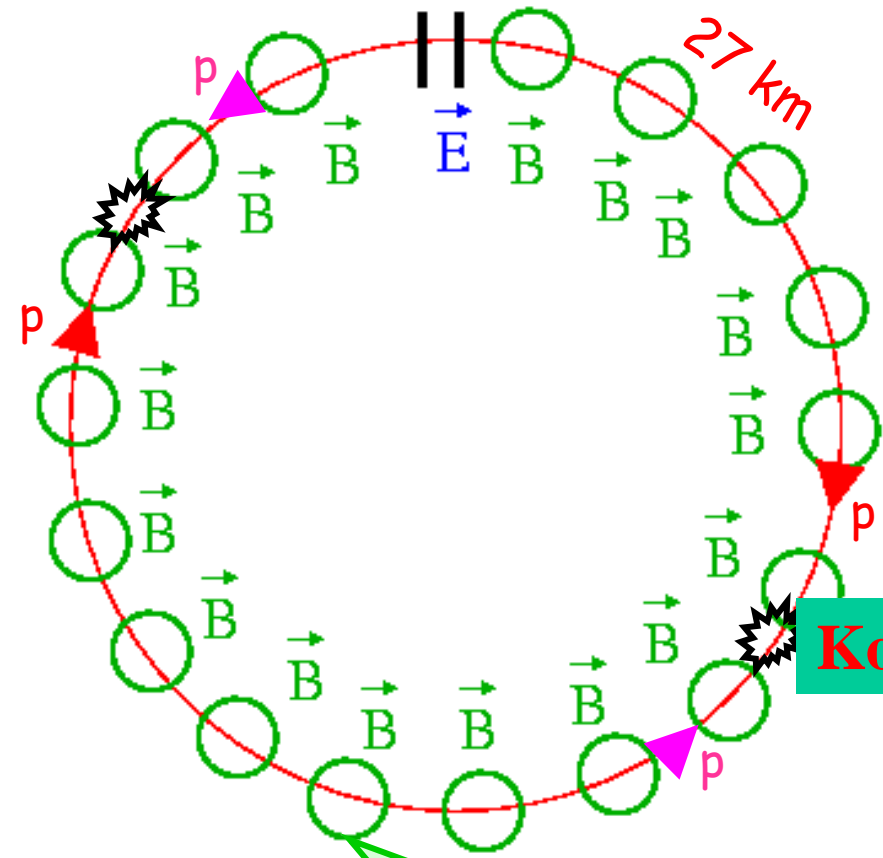
Eine „Zeitmaschine“ für die Reise zurück zum Urknall



LHC =

Large Hadron Collider

LHC = Large Hadron Collider

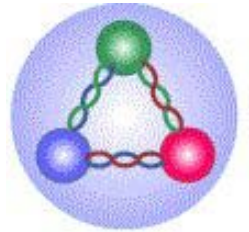


Large

27 km,
14000 GeV
= 14 TeV

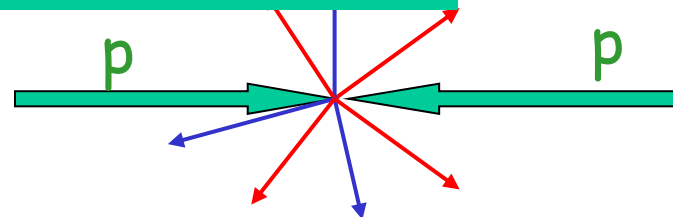
Hadron

Proton



Kollisionpunkte → Detektoren

Collider



1200 Dipolmagnete,
supraleitend
je 14 m lang, $B = 8$ Tesla

Größe
wächst mit
Energie!

Die Geburt von CMS

Large Hadron Collider Workshop

Aachen, 4-9 October 1990

Compact Muon Solenoid

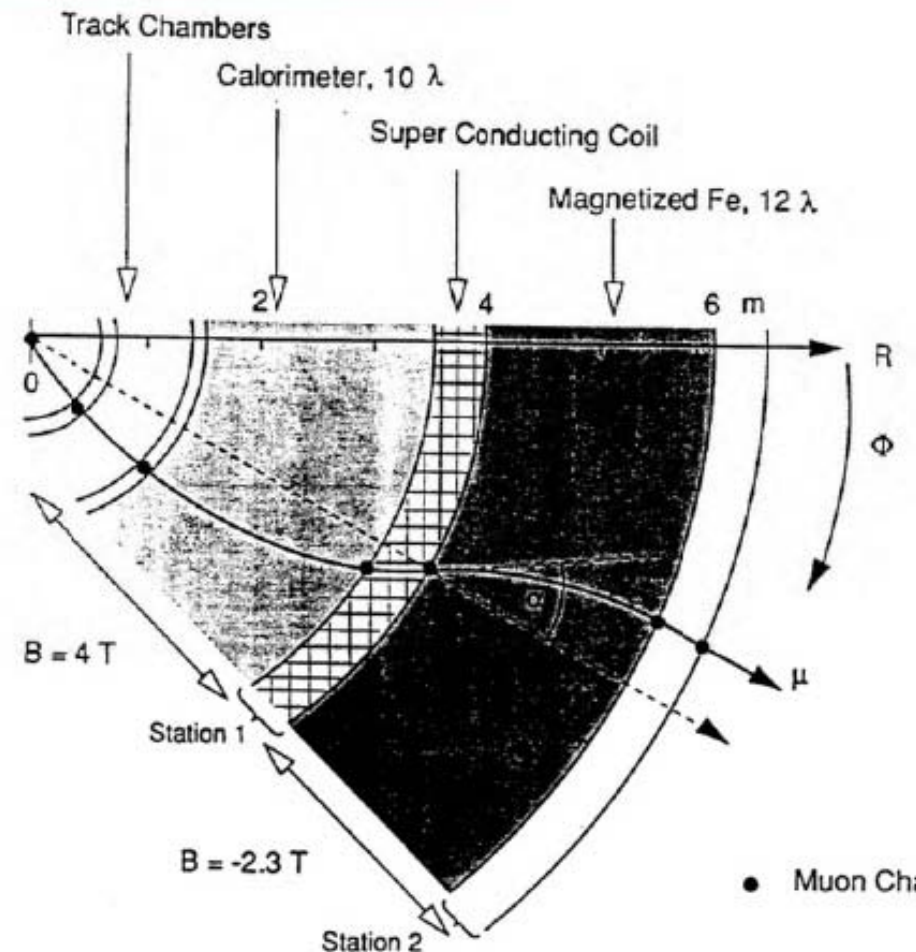
M. Della Negra, K. Eggert, M. Lanzagorta, M. Pimiä, F. Szoncsó

presented by M. Pimiä

SEFT, University of Helsinki, Finland

Abstract

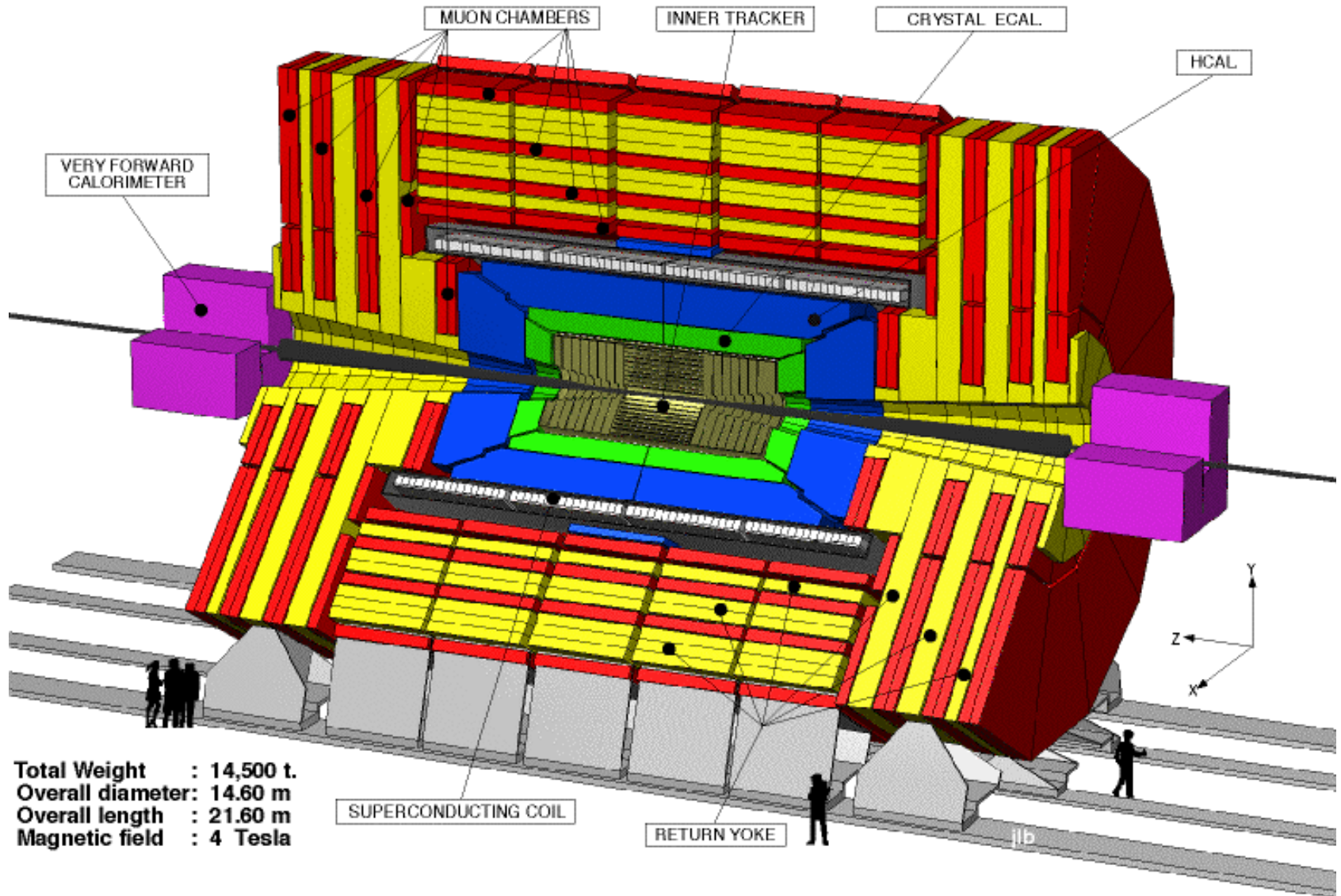
A compact detector for highest luminosities at LHC is discussed. Muon momentum resolution and muon triggering capability are studied by simulation. Good momentum resolution ($\Delta p/p = 4 \sim 10\%$) is achieved for $|\eta| < 3.5$ up to momenta $p = 1.6$ TeV. Flexible muon triggers providing reasonable trigger rates from a few Hz to a few hundred Hz are shown to be possible.



Compact Muon Solenoid CMS Detektor am LHC

Proton-Proton-Beschleuniger Schwerpunktsenergie 14 000 GeV

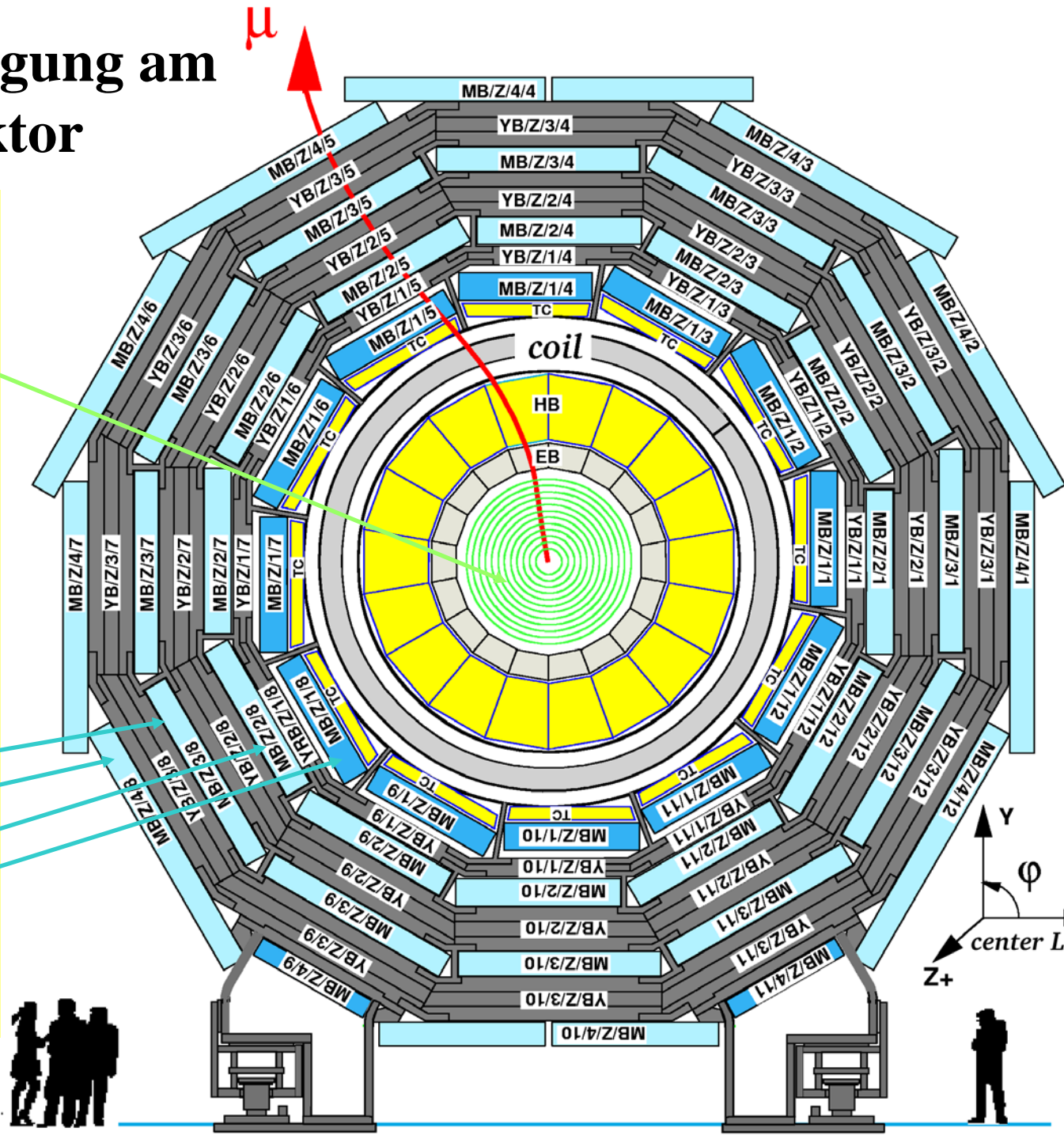
CMS-Detektor



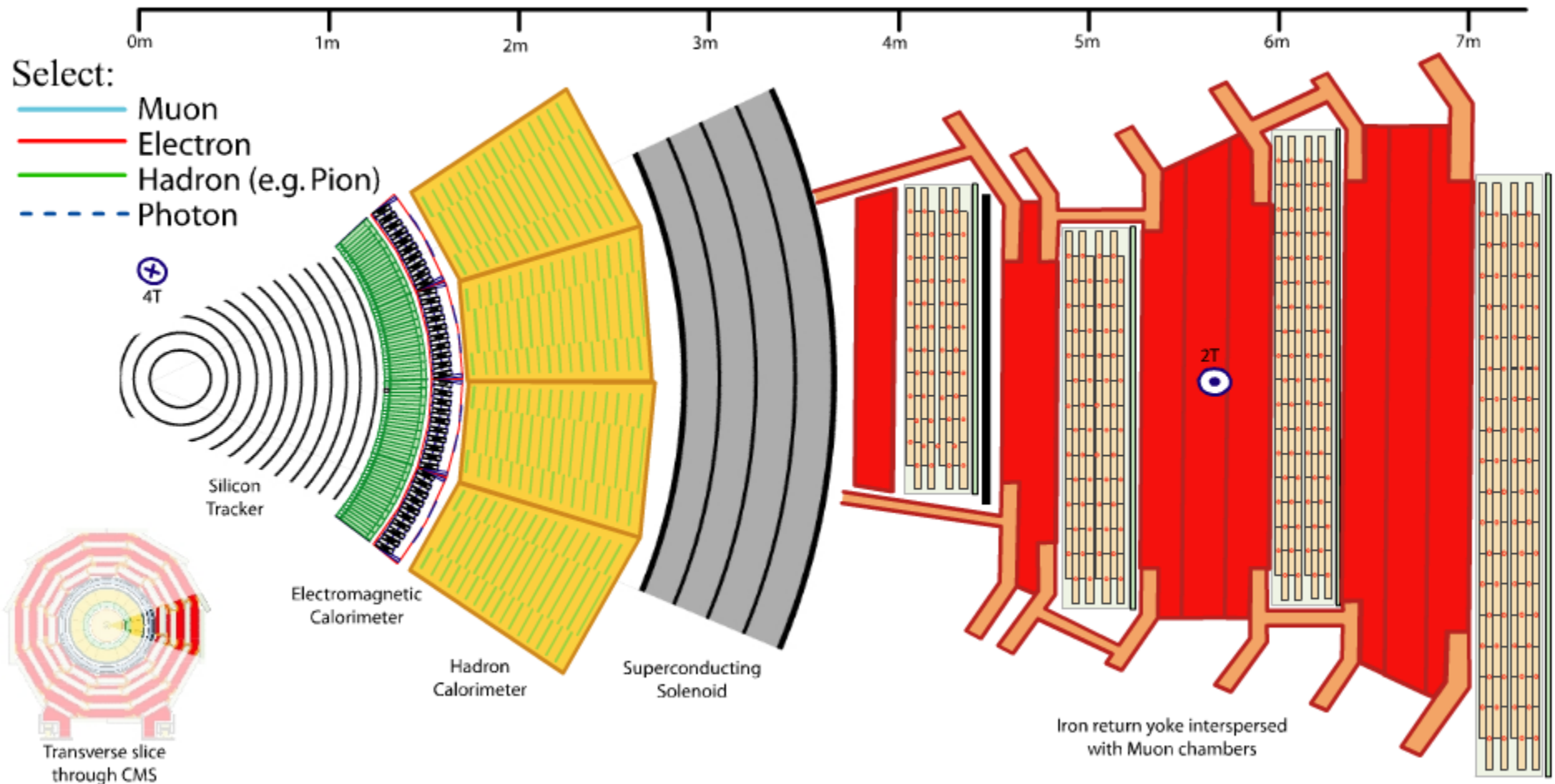
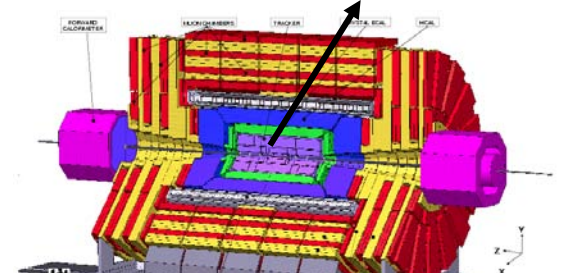
Aachener Beteiligung am CMS Detektor

- Innere Spur-kammern (Silizium)

- Myon-Detektor



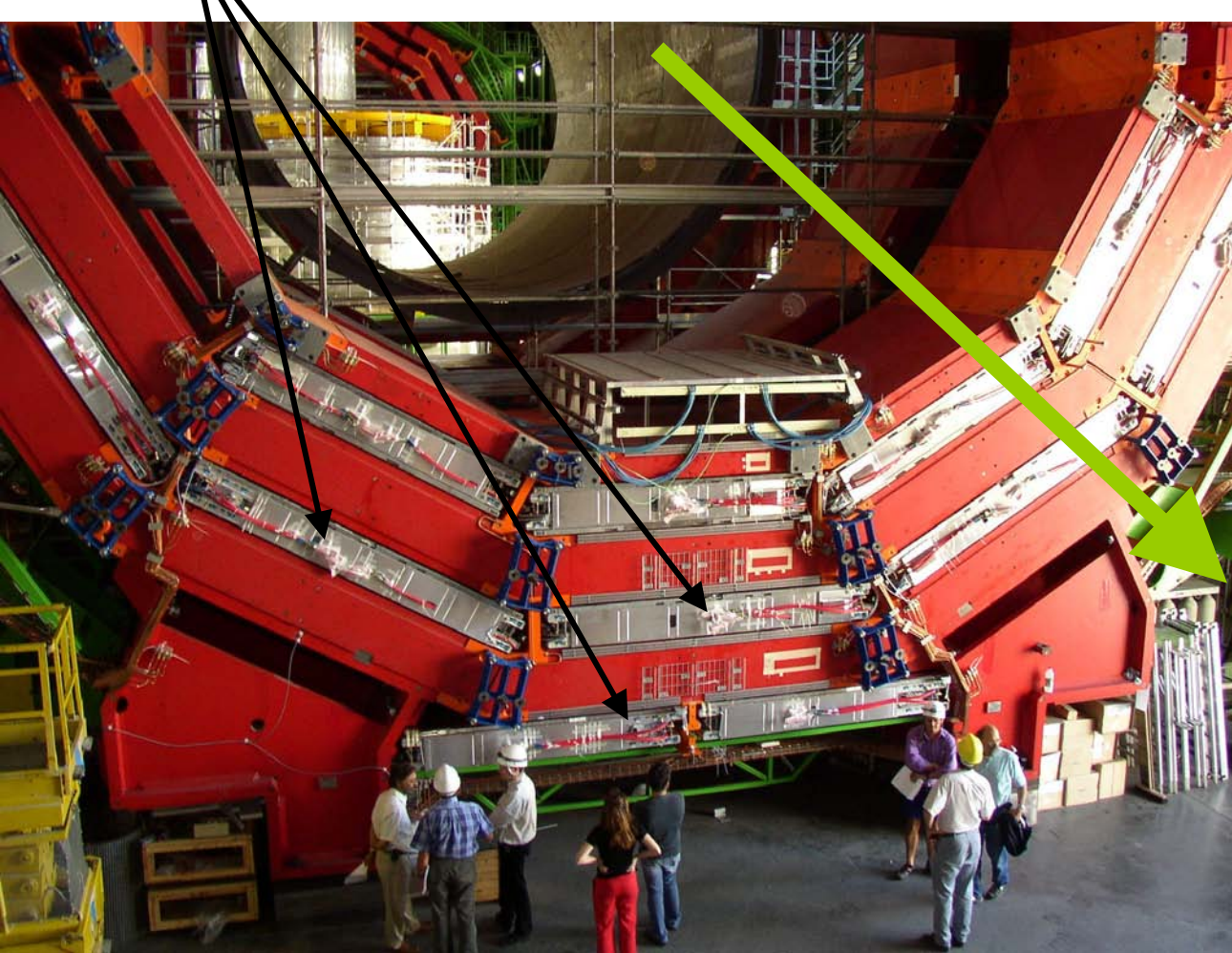
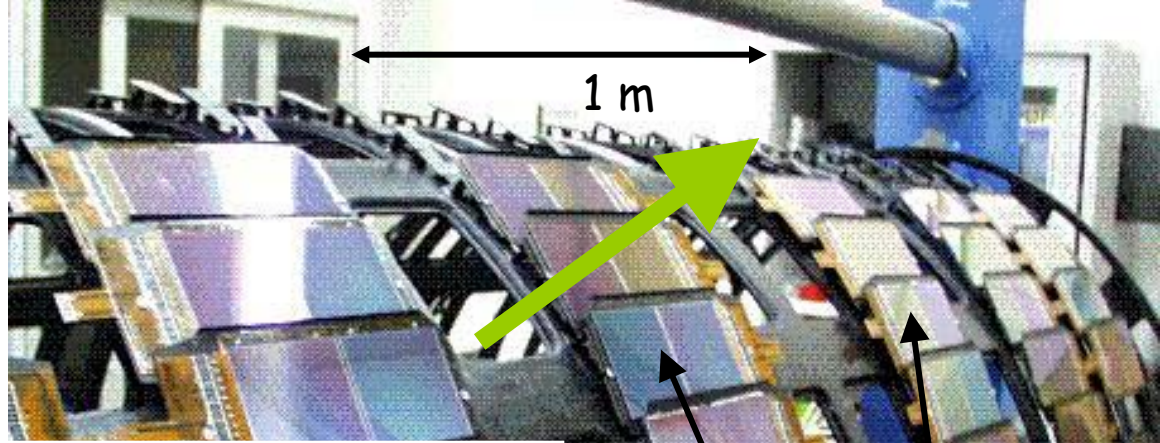
CMS-Detektor: Funktionsprinzip



Größe wächst mit Teilchenenergie!

CMS-Detektor: Aachener Beteiligung

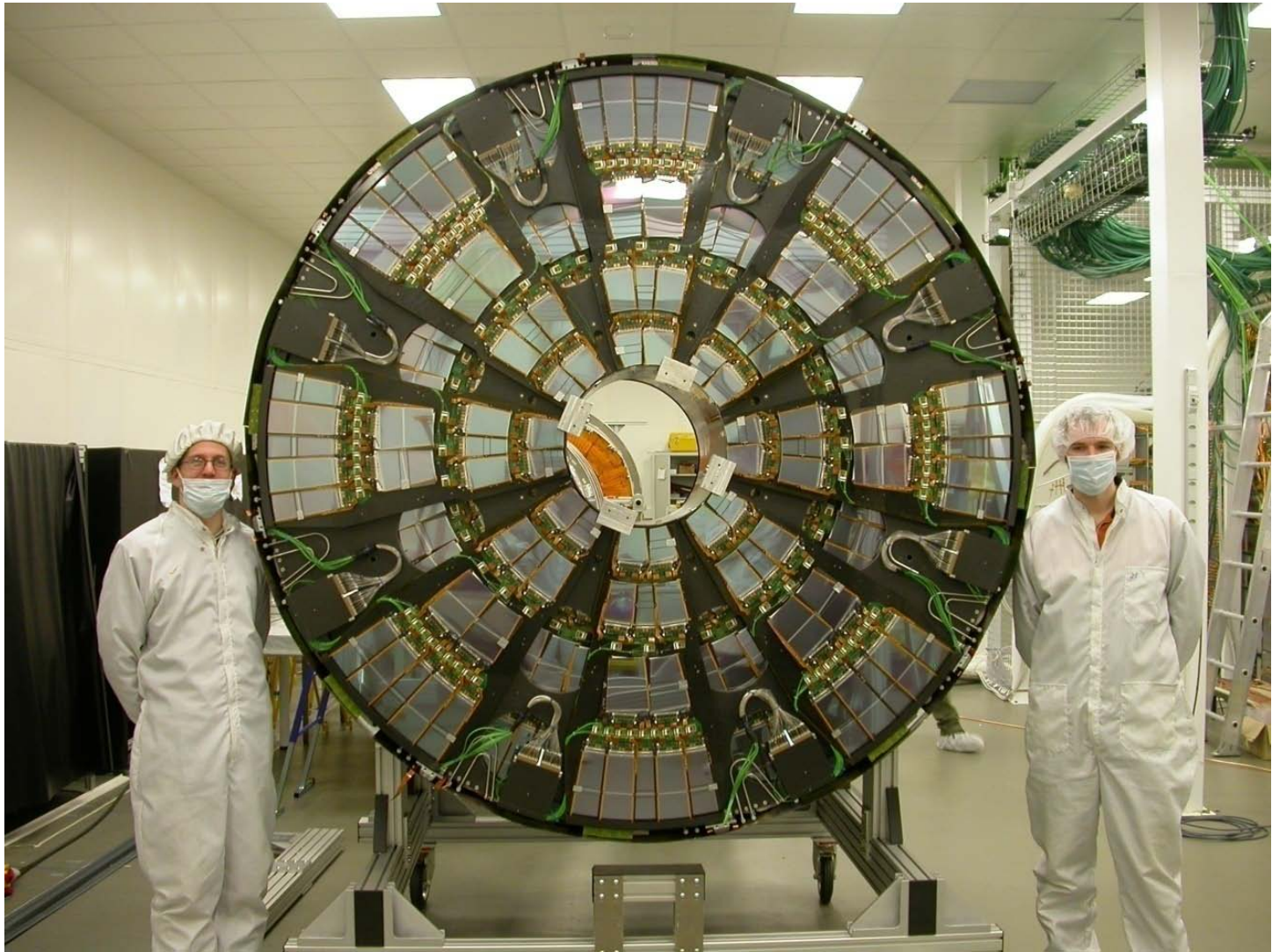
großflächige
Myondetektoren



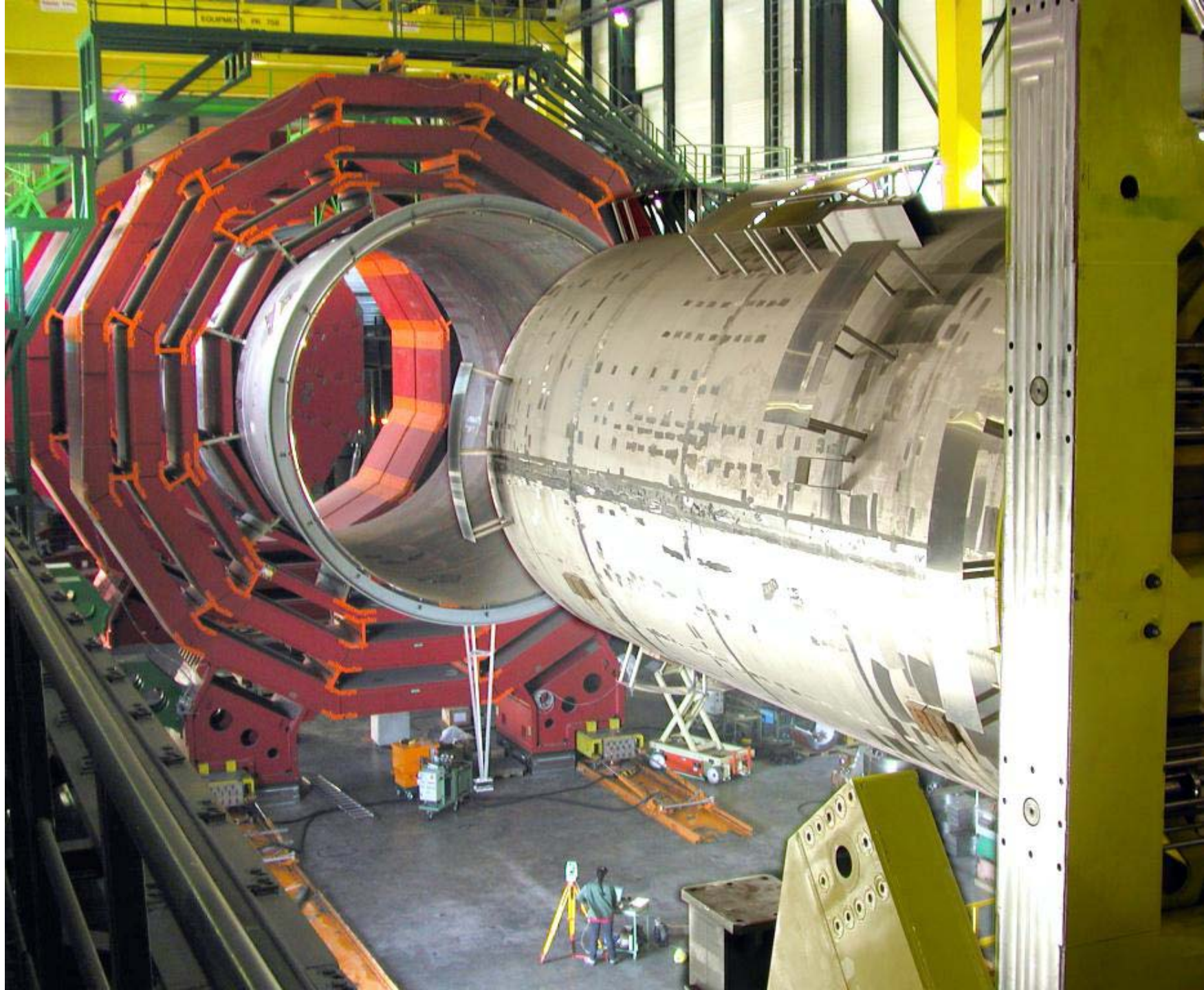
hochauflösende
Silizium-Detektoren



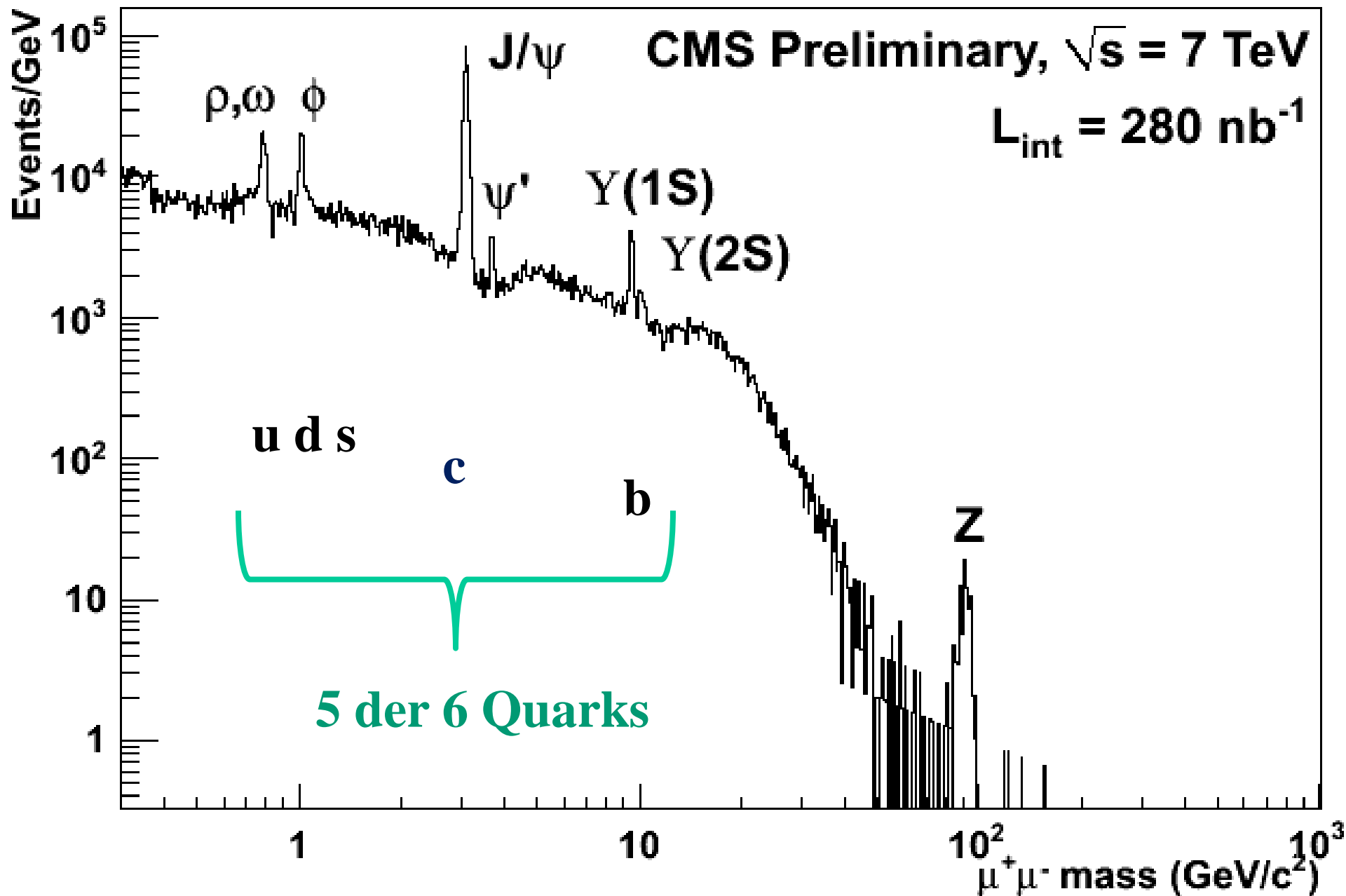
Endcap tracker built in Aachen ready for installation



CMS-Detektor am LHC



Here is the Compact **Muon** Solenoid



Das Standardmodell der Teilchenphysik

3 „Familien“

Materie-Teilchen:

Leptonen: $\begin{pmatrix} \nu_e \\ e \end{pmatrix}$ $\begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}$ $\begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$

Quarks: $\begin{pmatrix} u \\ d \end{pmatrix}$ $\begin{pmatrix} c \\ s \end{pmatrix}$ $\begin{pmatrix} t \\ b \end{pmatrix}$

leicht

schwer

sehr schwer

? Higgs ?

Kräfte = Wechselwirkungen:

- stark: **Gluon g** masselos
- elektromagn.: **Photon γ** masselos
- schwach: **W-,Z-Boson** sehr schwer

Offene Fragen:

- Teilchenmassen ??
- Gravitation ??
 - Higgs-Boson
 - Super-Symmetrie

Die Massen der Elementarteilchen

Beispiele:

EXPERIMENT

$$m_e = 510.9989 \text{ keV}$$

$$\frac{m_W}{m_Z} = \frac{80.451 \pm 0.033 \text{ GeV}}{91.188 \pm 0.002 \text{ GeV}}$$
$$= 0.8823 \pm 0.0004$$

Die Massen der Elementarteilchen

Beispiele:

EXPERIMENT

$$m_e = 510.9989 \text{ keV}$$

$$\frac{m_W}{m_Z} = \frac{80.451 \pm 0.033 \text{ GeV}}{91.188 \pm 0.002 \text{ GeV}} \\ = 0.8823 \pm 0.0004$$

THEORIE

$$m_e = 0$$

$$\frac{m_W}{m_Z} = \frac{0}{0}$$



Die Massen der Elementarteilchen

P.Higgs

Beispiele:

EXPERIMENT

$$m_e = 510.9989 \text{ keV}$$

$$\frac{m_W}{m_Z} = \frac{80.451 \pm 0.033 \text{ GeV}}{91.188 \pm 0.002 \text{ GeV}} \\ = 0.8823 \pm 0.0004$$

**ERWEITERTE
THEORIE**

$$m_e = \dots > 0$$

$$\frac{m_W}{m_Z} = \frac{\dots > 0}{\dots > 0} \\ = 0.8812 \pm 0.0014$$



Bisher nicht gefunden:

$$m_{\text{Higgs}} > 114 \text{ GeV}$$

⇒ Neues Teilchen: „Higgs“

LHC !



Der Higgs-Mechanismus - eine Analogie (I)



Higgs-Hintergrundfeld
erfüllt den Raum



Ein **Teilchen**
im Higgs-Feld...



... Widerstand gegen
Bewegung ...
Trägheit ↔ **Masse**

Der Higgs-Mechanismus - eine Analogie (II)

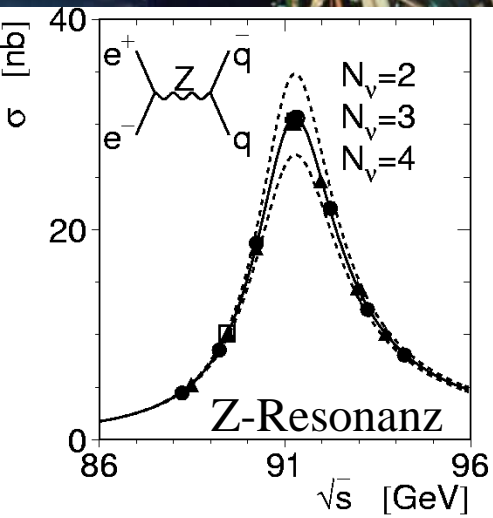
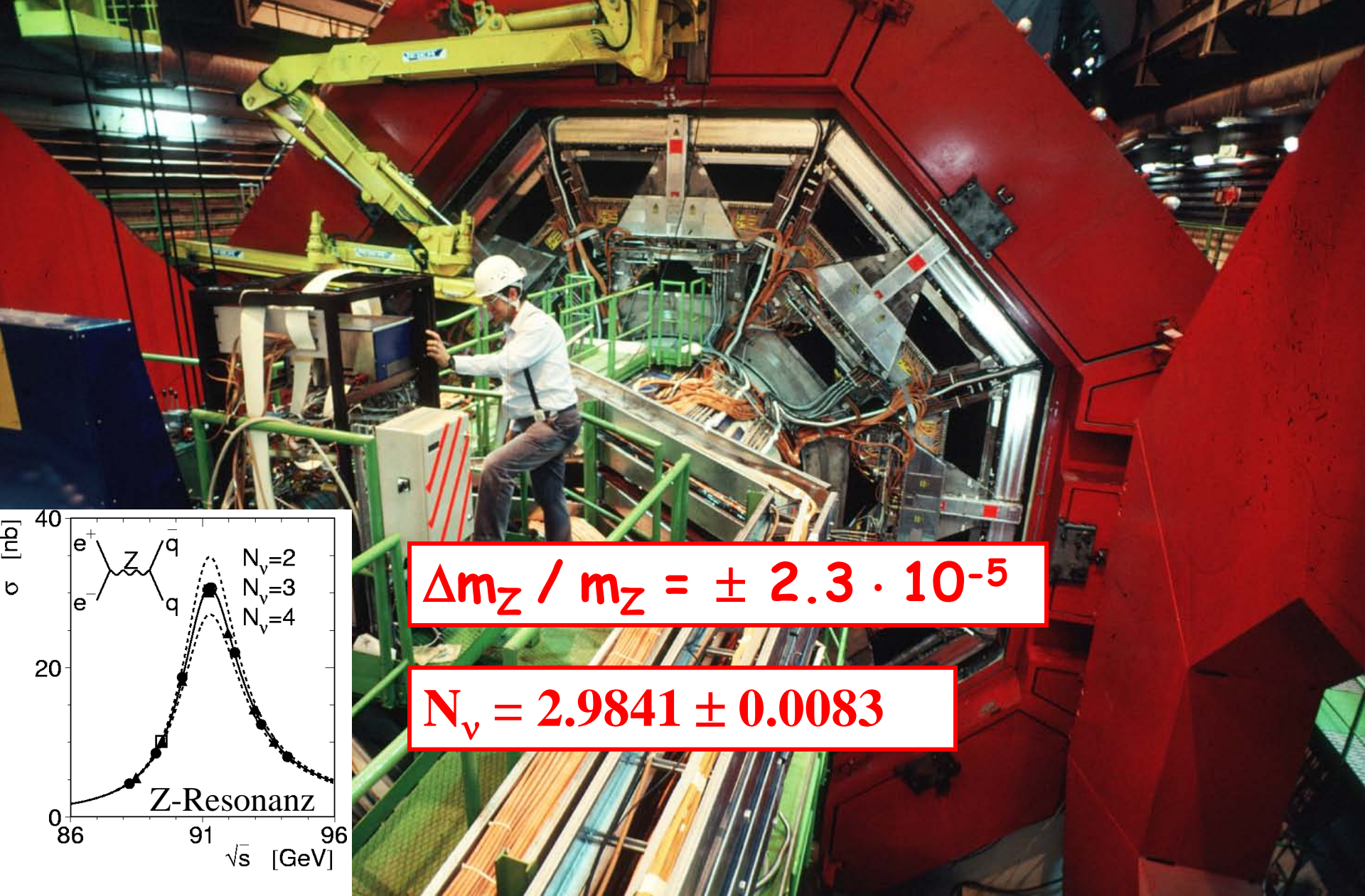


**Anregung des
Hintergrundfeldes**



**angeregtes Higgs-Hintergrundfeld
 \triangleq massives Higgs-Bosons**

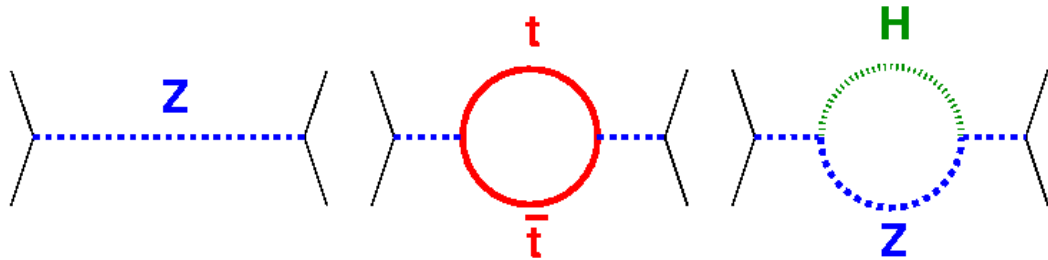
LEP-Detektor L3



$$\Delta m_Z / m_Z = \pm 2.3 \cdot 10^{-5}$$

$$N_V = 2.9841 \pm 0.0083$$

Vorhersage der Higgs-Masse

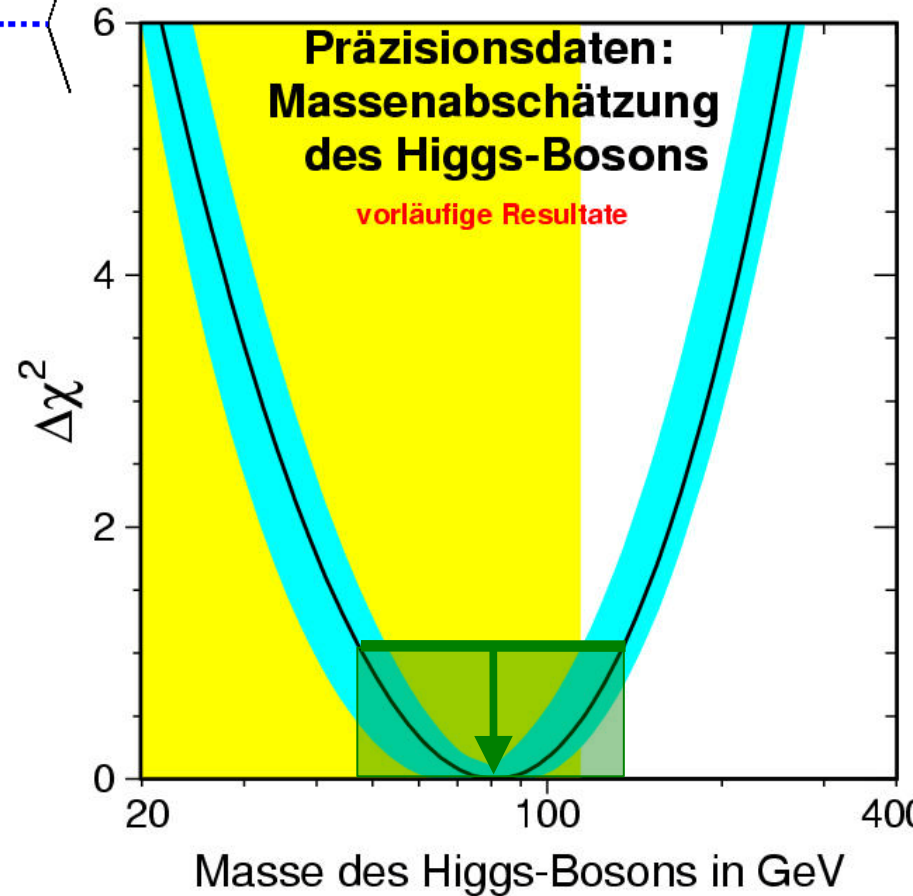


$$M_Z^2 = M_Z^2 \text{ 0.Ordnung} \cdot (1 + \Delta)$$

$$\Delta = \dots M_t^2 \dots + \dots \ln M_H \dots$$

inzwischen
gemessen

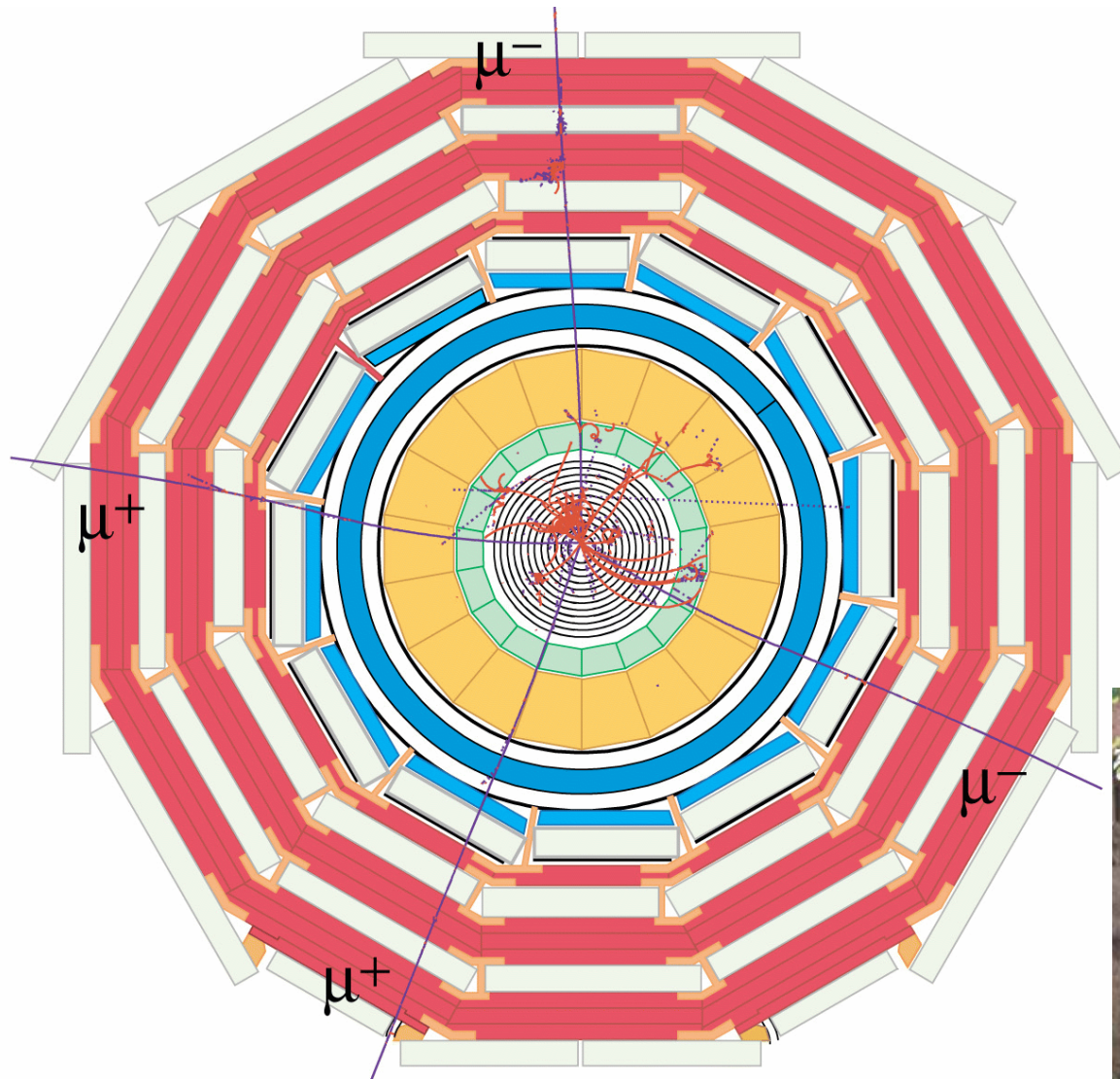
Vergleich Präzisionsmessung ↔ Korrektur
⇒ Vorhersage der Higgs-Masse



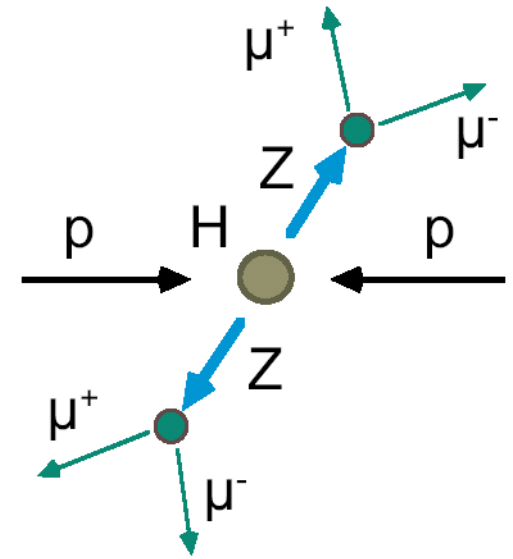
experimentell
ausgeschlossen

theoretische
Unsicherheit

Die Suche nach dem Higgs

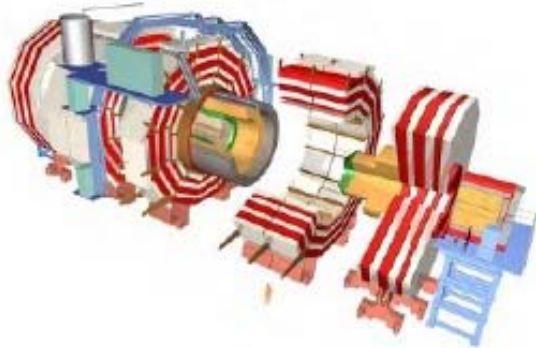


EXPERIMENTUM CRUCIS



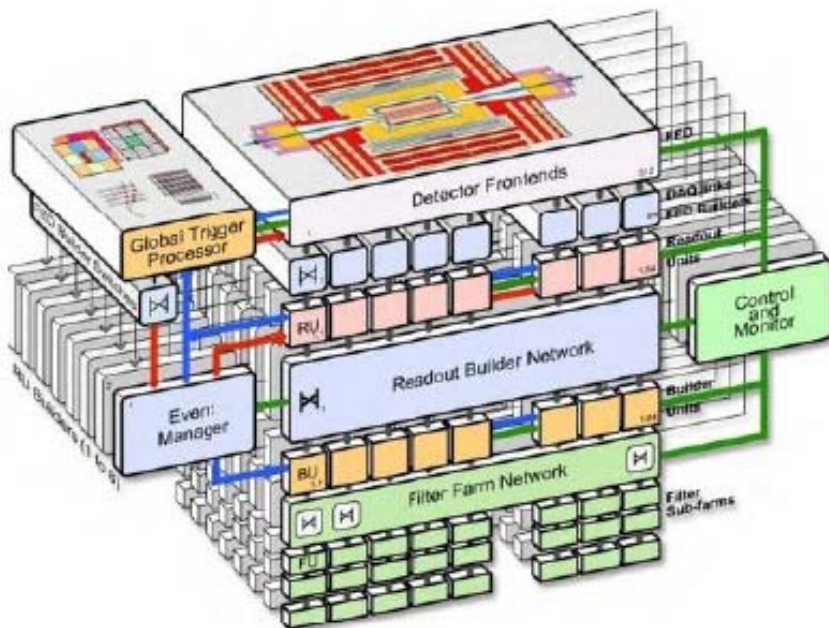
40 reconstructed vertices!
High PU run October 25, 2011

Datenverarbeitung



100 Mega-Pixel 3D-Kamera

40 Millionen Bilder pro Sekunde

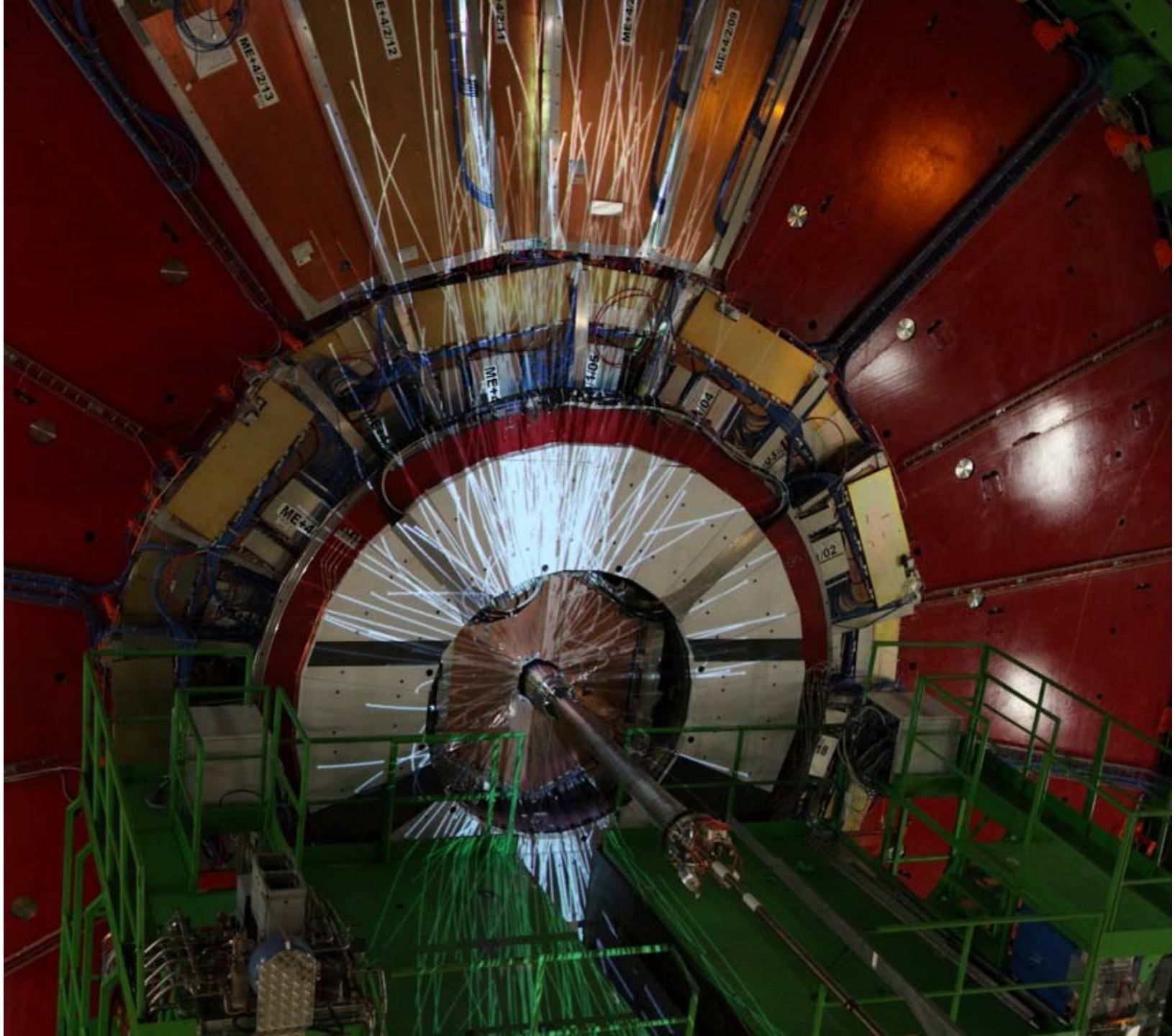


100 Bilder pro Sekunde werden ausgewählt

100 x 25 MByte pro Sekunde
= 1 Million Gbyte/Jahr

Millionen DVDs pro Jahr

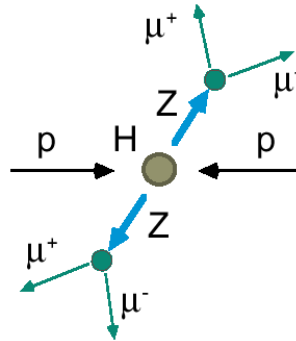




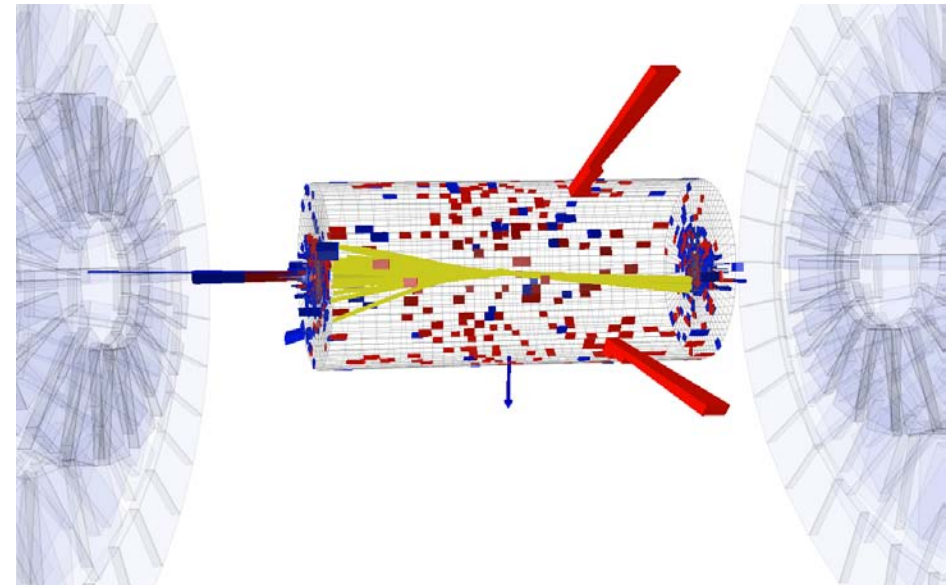
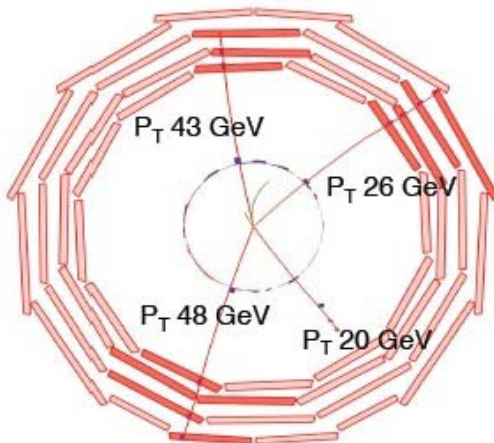
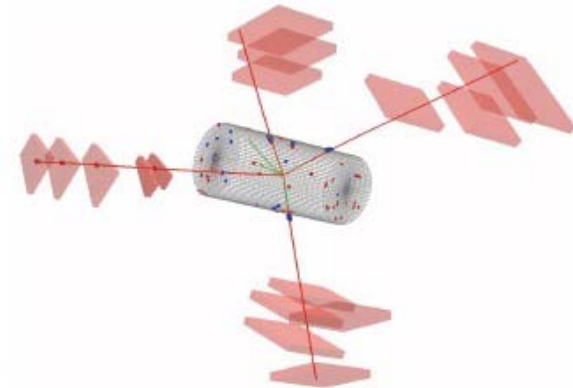
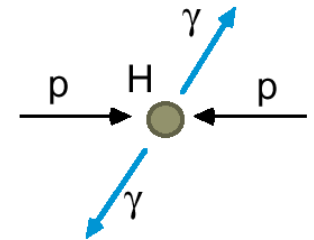
Die Suche nach dem Higgs Teilchen

Wichtige Zerfälle zum Nachweis am LHC:

- $H \rightarrow ZZ \rightarrow \mu\mu\mu\mu$
(der goldene Kanal)



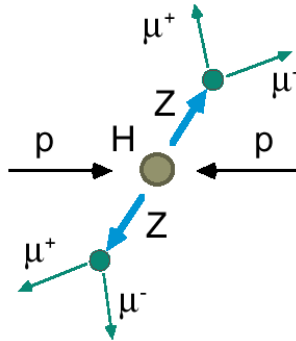
- $H \rightarrow \gamma\gamma$



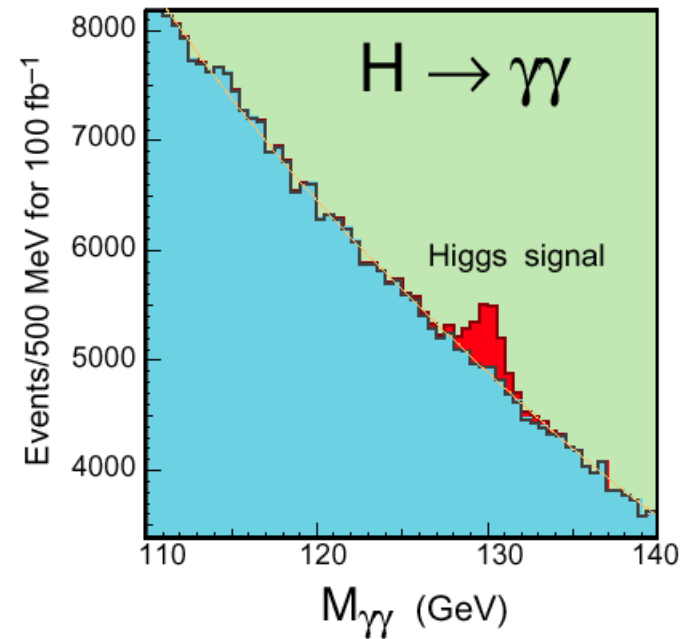
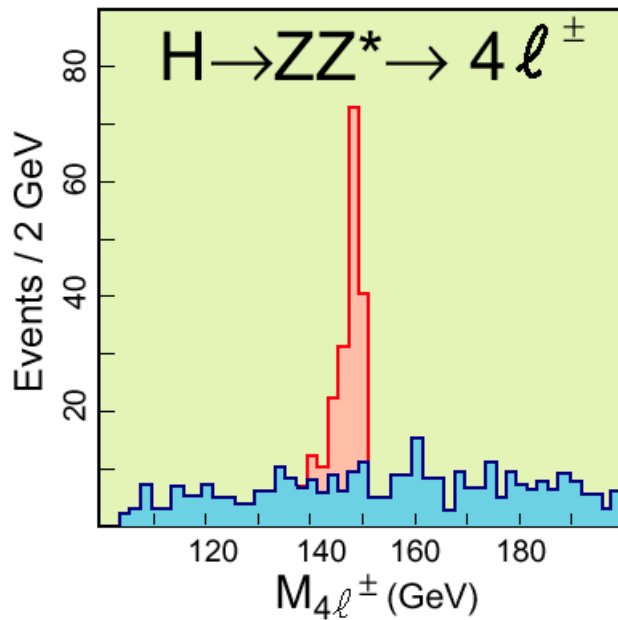
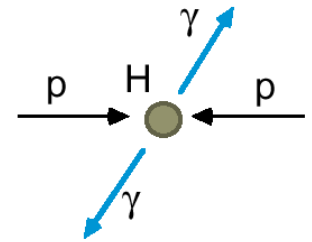
Die Suche nach dem Higgs Teilchen

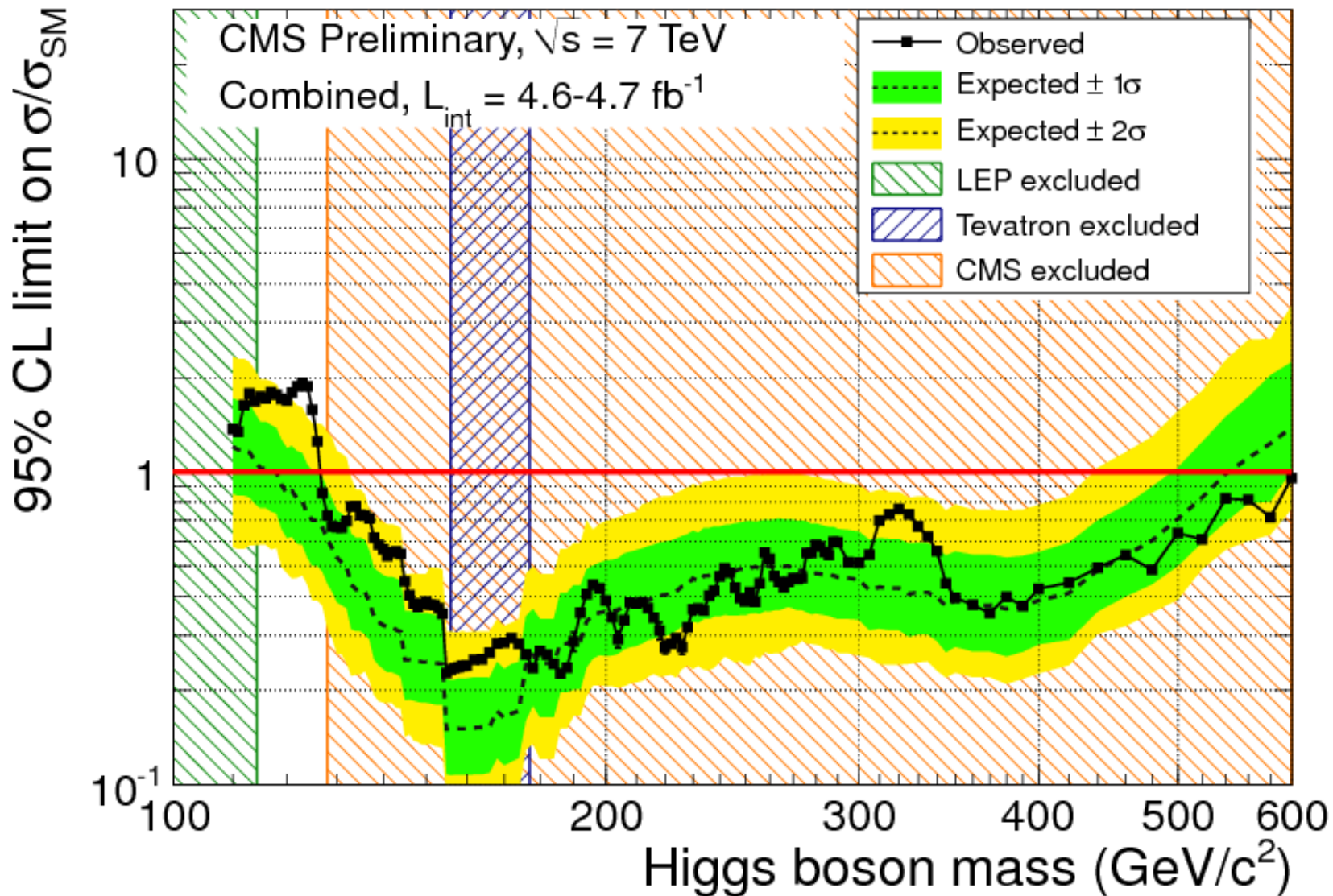
Wichtige Zerfälle zum Nachweis am LHC:

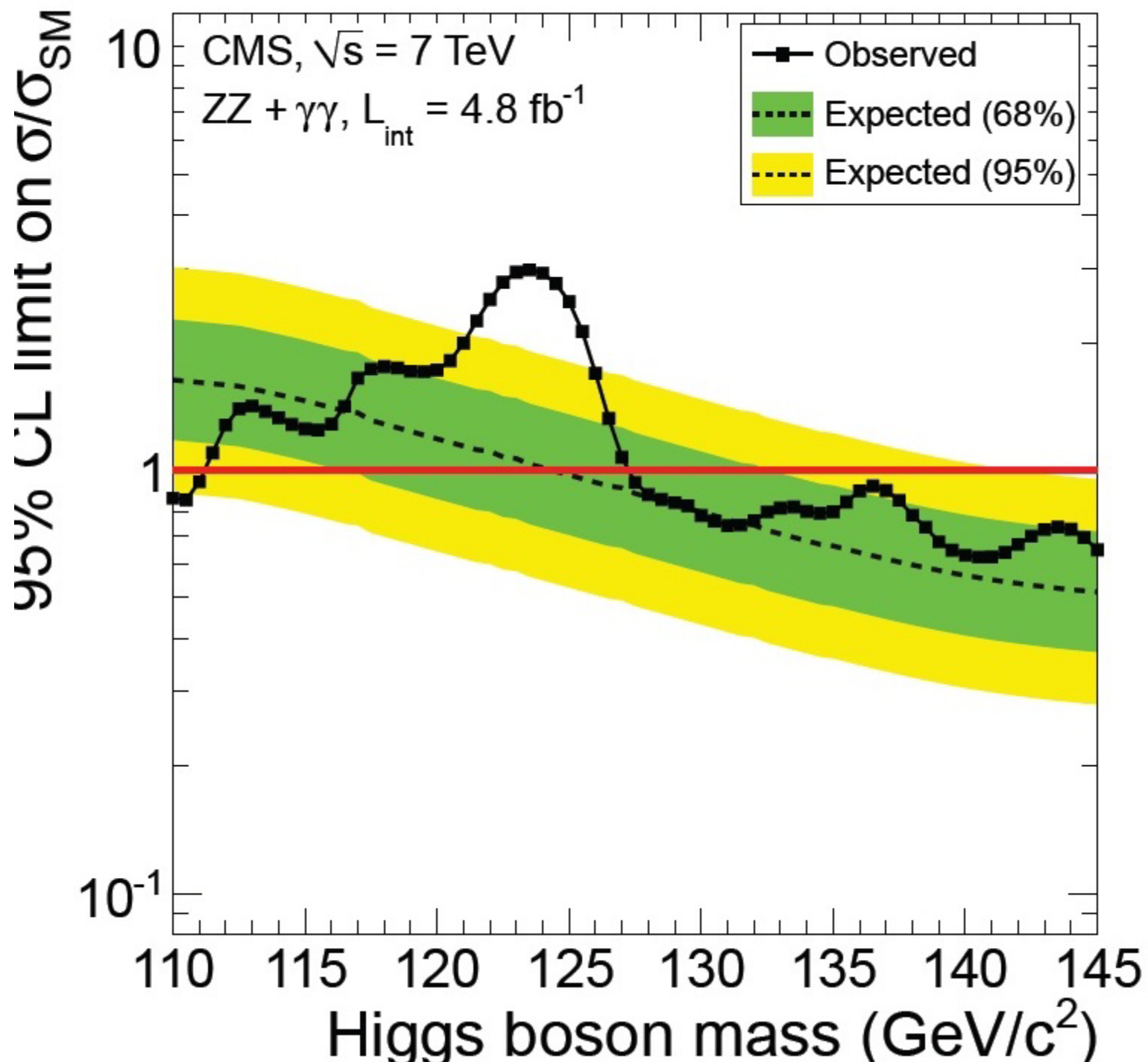
- $H \rightarrow ZZ \rightarrow \mu\mu\mu\mu$
(der goldene Kanal)

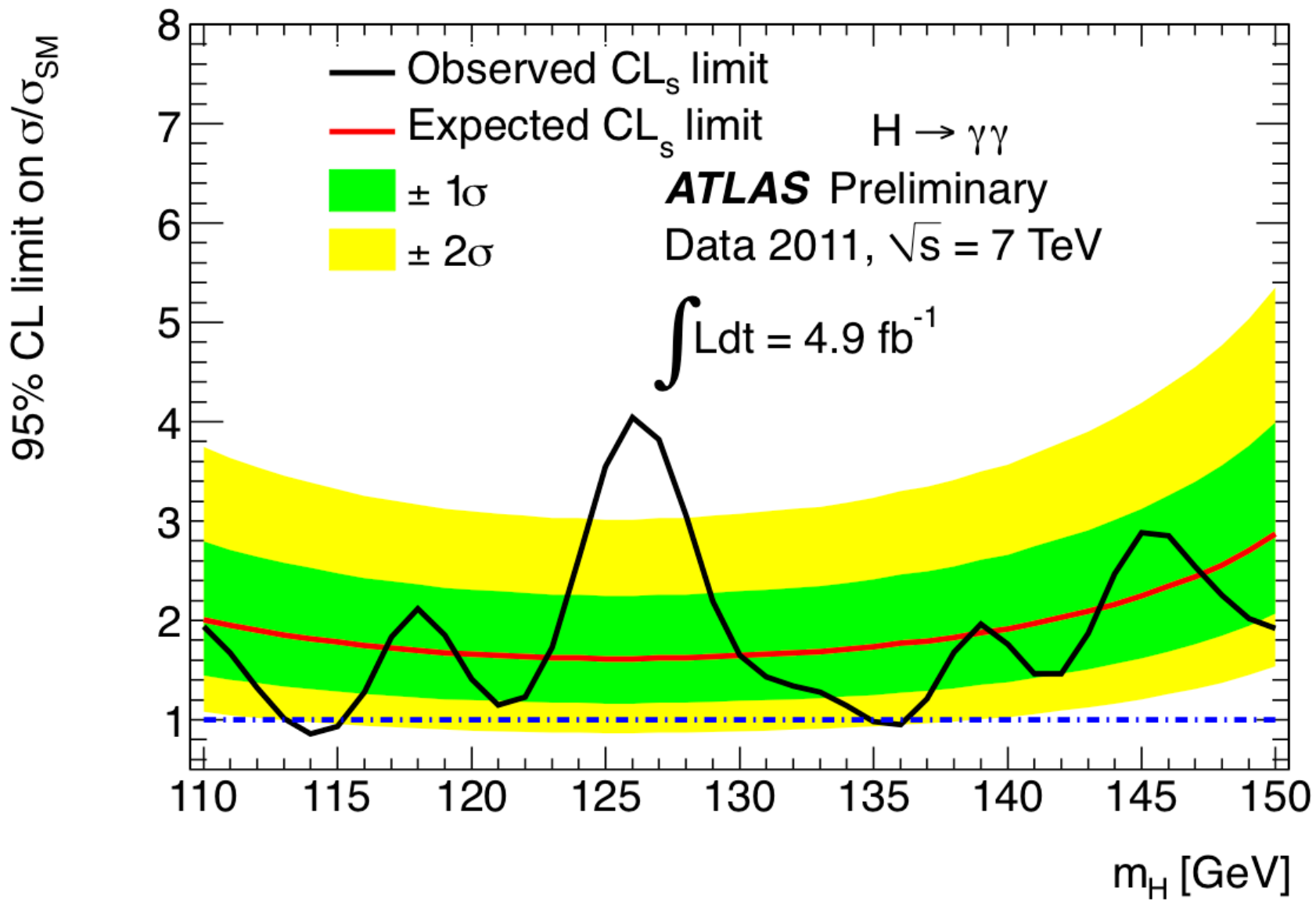


- $H \rightarrow \gamma\gamma$

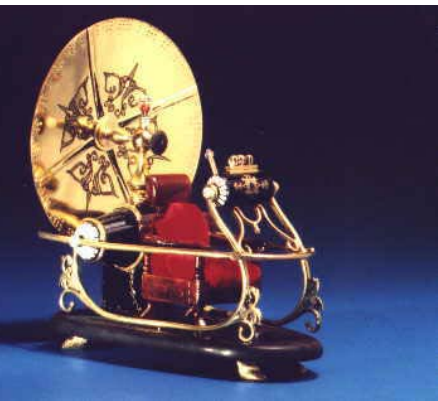








- **Elementarteilchen**
- **CERN**
- **Beschleuniger LHC**
- **Urknall**

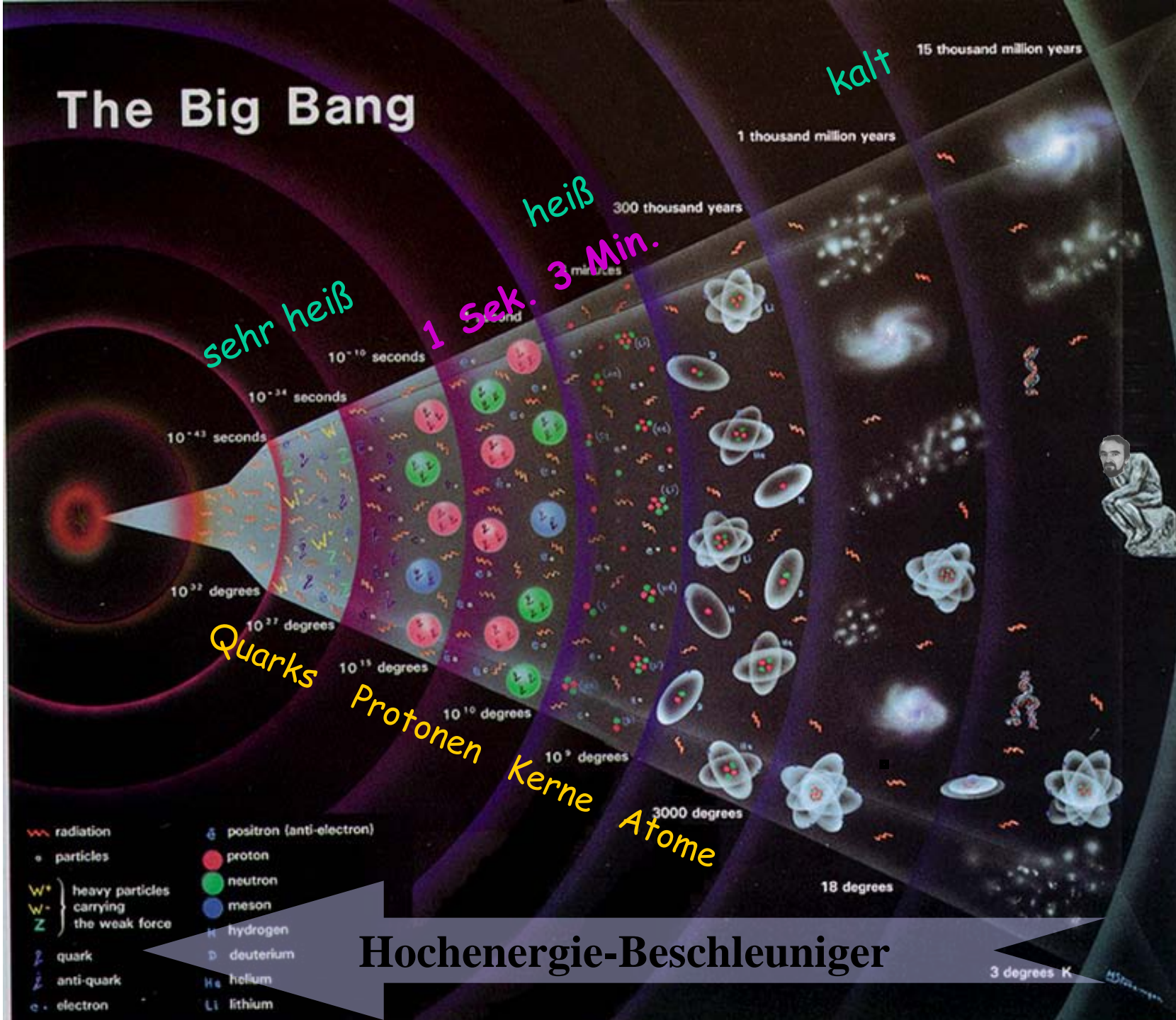


- **„Zeitmaschine“ ?**

Frühes Universum und Teilchenphysik
Dunkle Materie

D
E
R
U
R
K
N
A
L
L

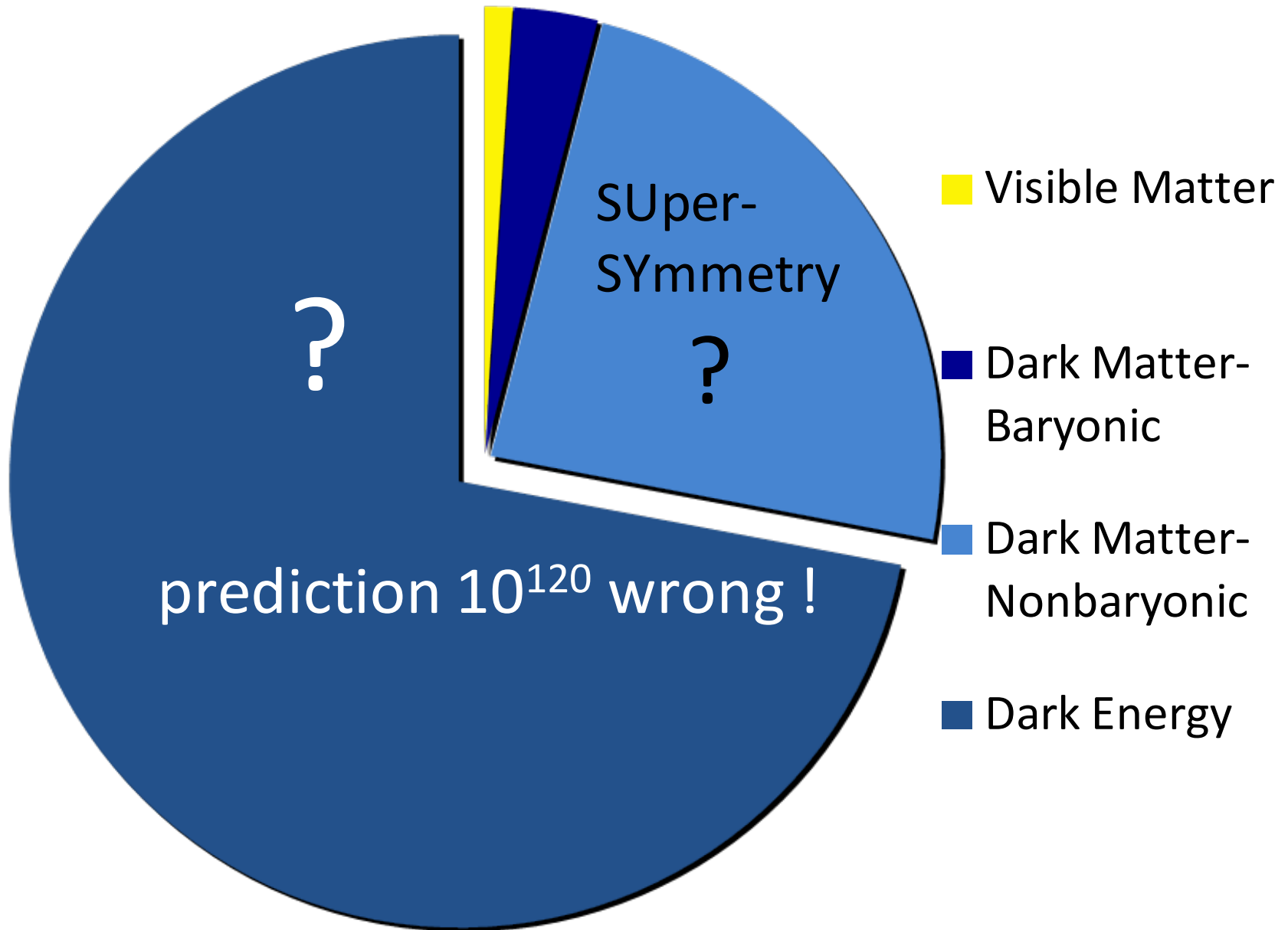
The Big Bang



Hochenergie-Beschleuniger



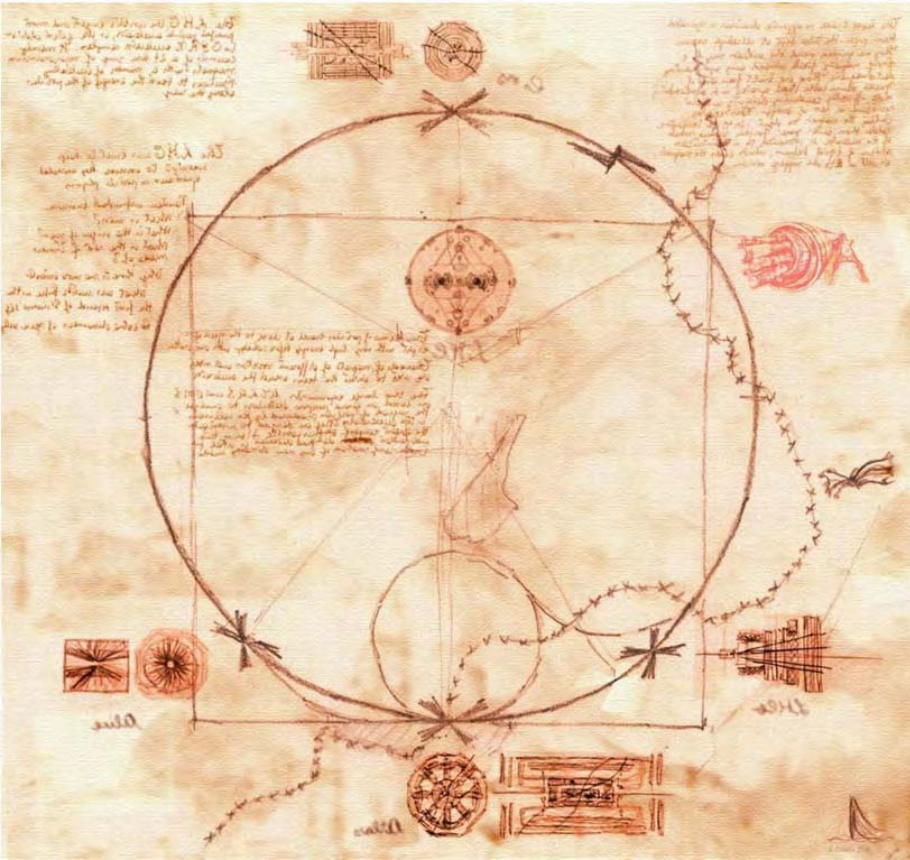
3 degrees K





Thank you!

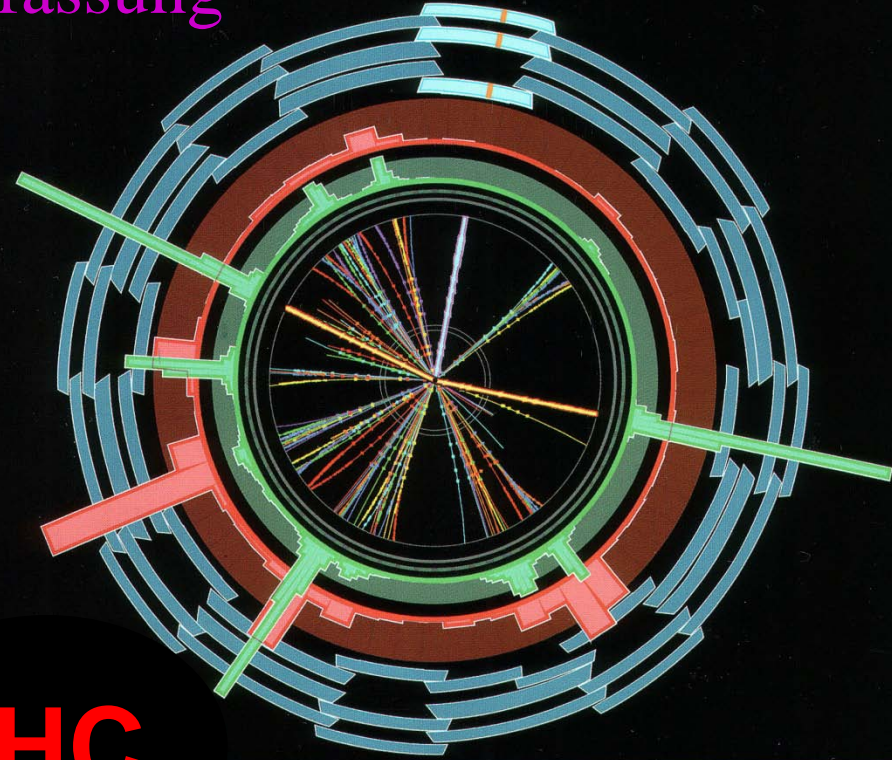
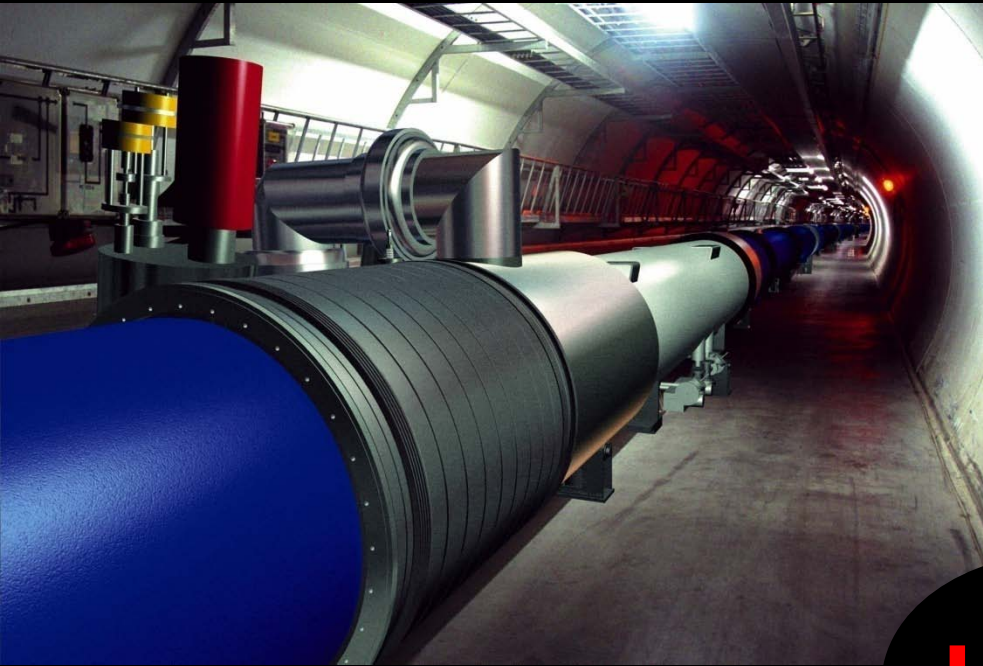
LHC



CMS tracker

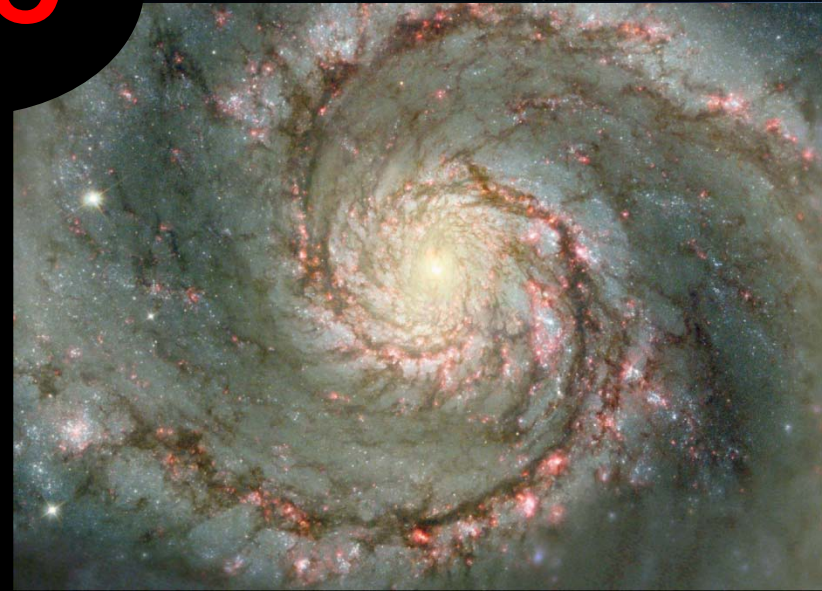


Zusammenfassung



LHC

- wir wollen verstehen,
- „was die Welt im Innersten zusammenhält“
 - wie das frühe Universum sich entwickelte



The God Particle ?

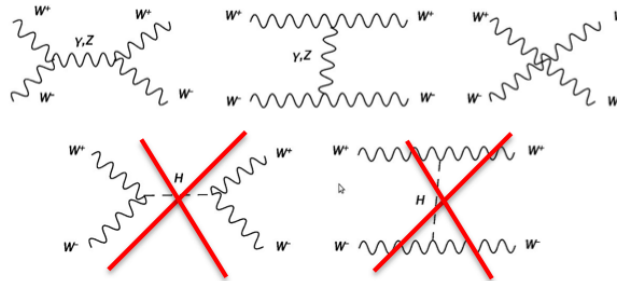
*As an atheist, Higgs is reported to be displeased that the particle is nicknamed the "God particle". Higgs is afraid the term "might offend people who are religious". This nickname for the Higgs boson is usually attributed to Leon Ledermann, but it is actually the result of Lederman's publisher's censoring. Originally Lederman intended to call it "the **goddamn particle**", because of its elusiveness.*



Higgs - for What?

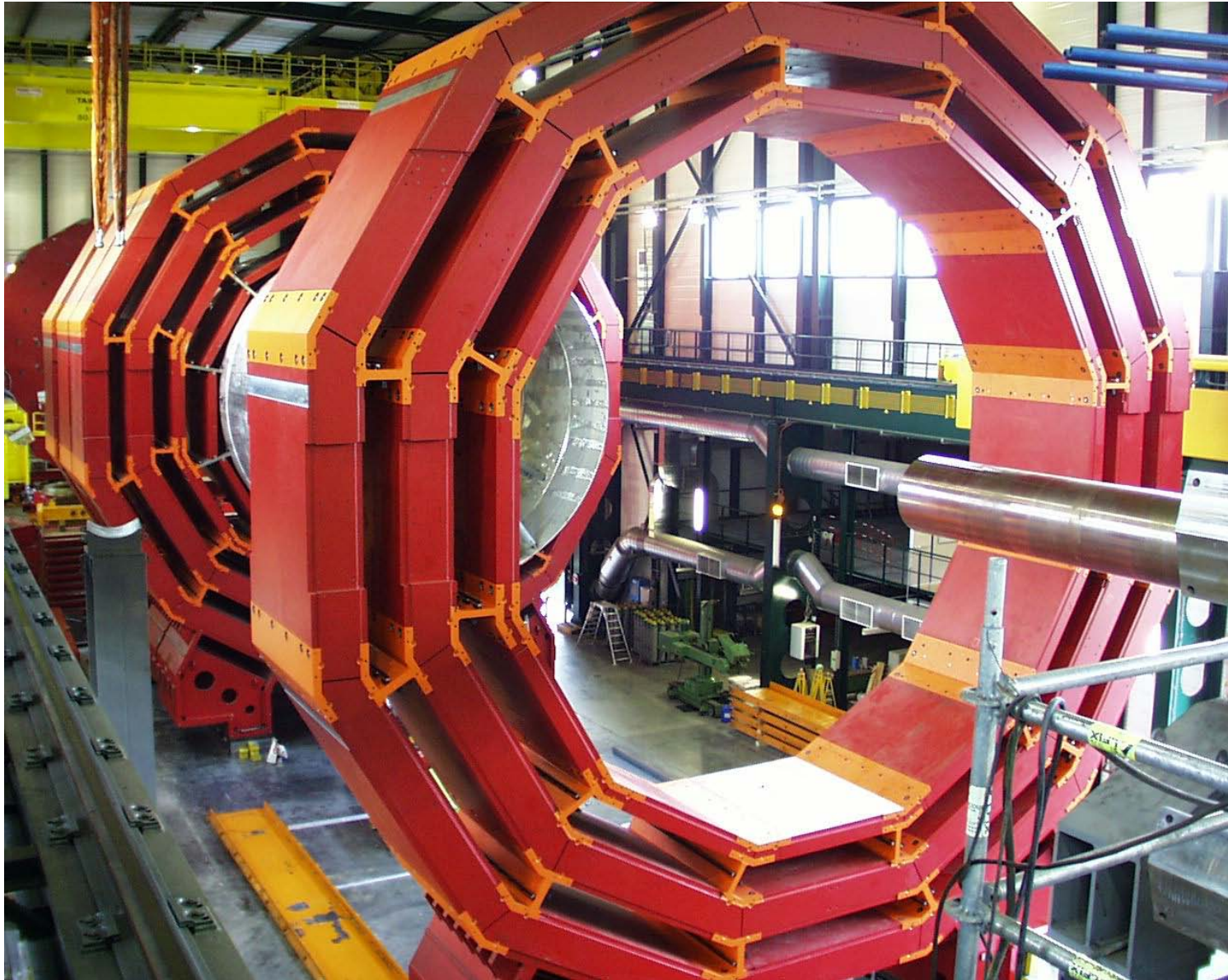
- Control over WW scattering by a scalar is the major reason !

Without Higgs below 1 TeV, we expect WW scattering starting to diverge at high $\sqrt{\hat{s}}$.



nion

Complete the missing parts ...



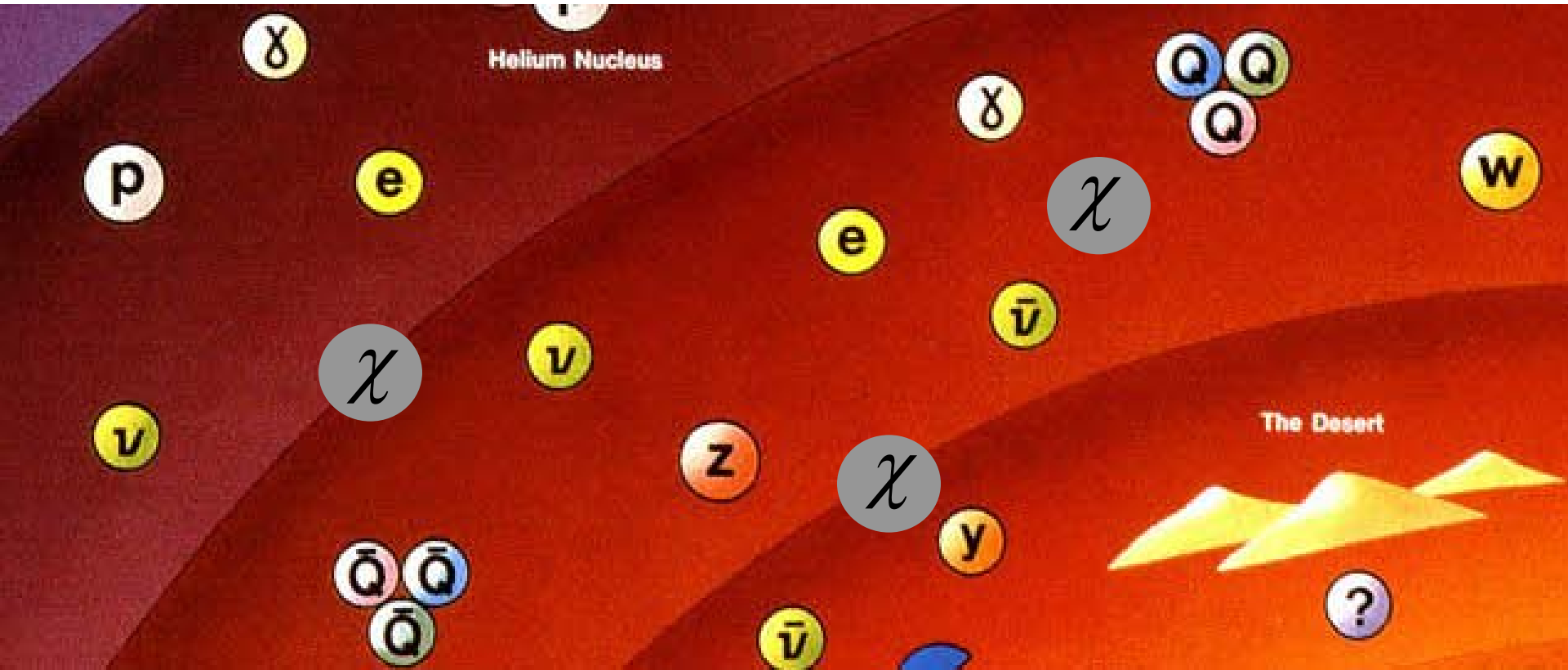
... to make very interesting (SM) physics at the LHC

Elementarteilchen im frühen Universum

$t = 10^{-10}$ s

$E = 100$ GeV

Teilchenbeschleuniger!



Heiße Elementarteilchen-Suppe !

Welche Teilchen gibt es ? Wie wechselwirken sie ?

Dunkle Materie = Neutralinos χ ???

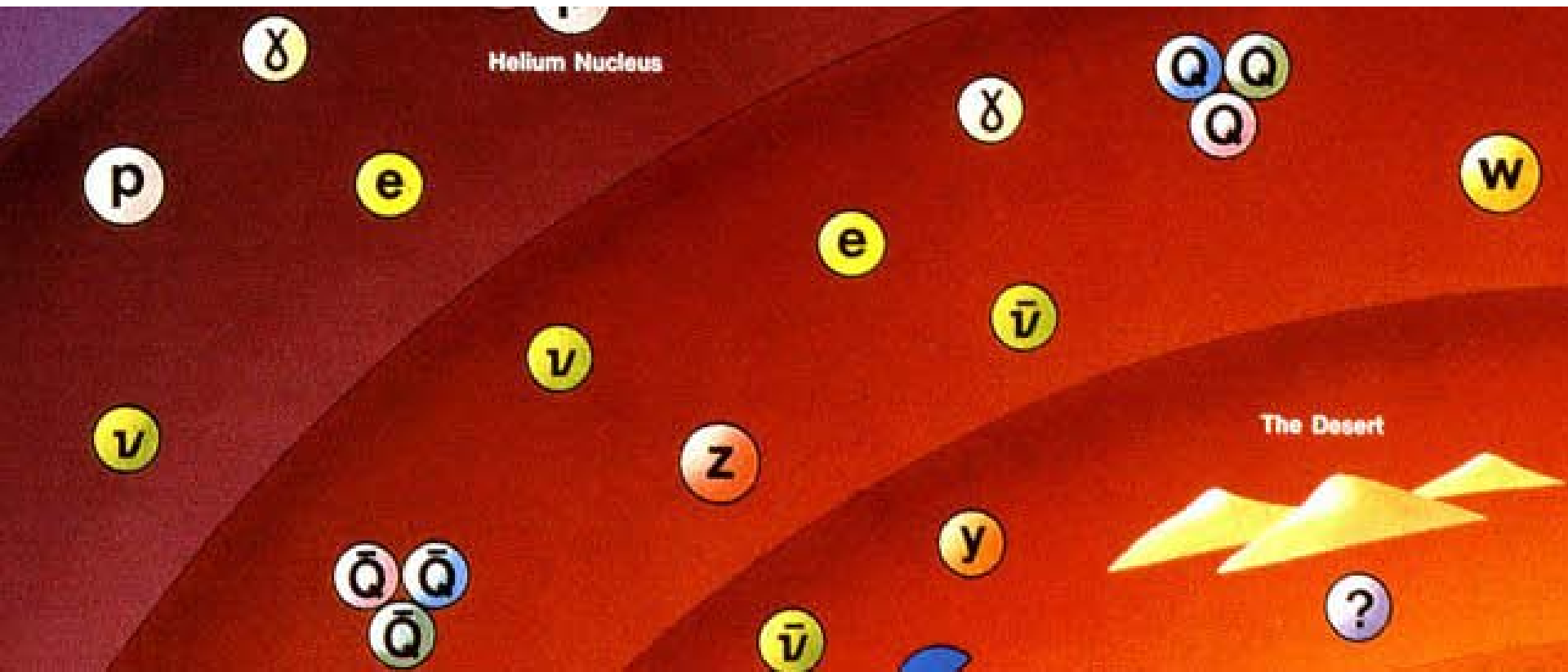
LHC !

Elementarteilchen im frühen Universum

$t = 10^{-10}$ s

$E = 100$ GeV

Teilchenbeschleuniger!



Heiße Elementarteilchen-Suppe !

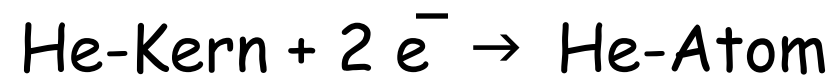
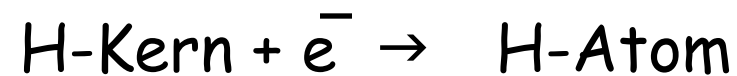
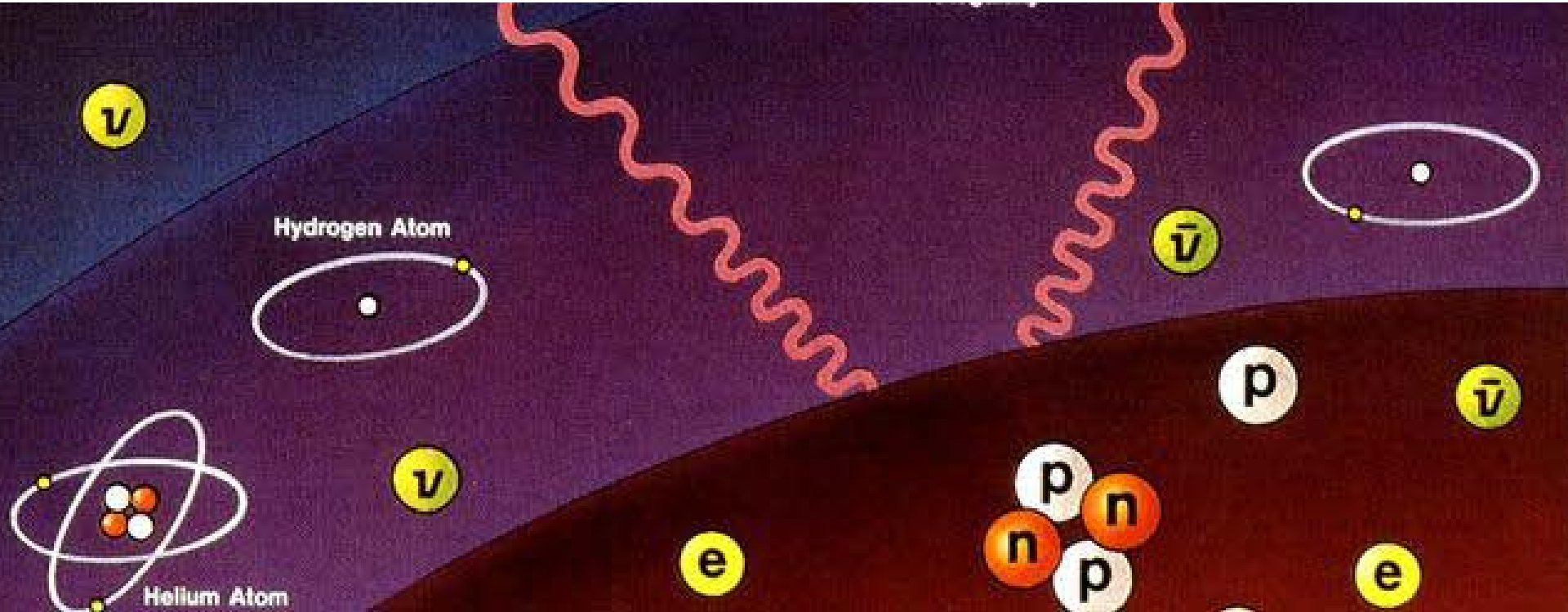
Welche Teilchen gibt es ? Wie wechselwirken sie ?

Bildung von Atomen

$t = 300\,000$ Jahre

$T = 3000\text{ °C}$

$E = 0.3\text{ eV}$



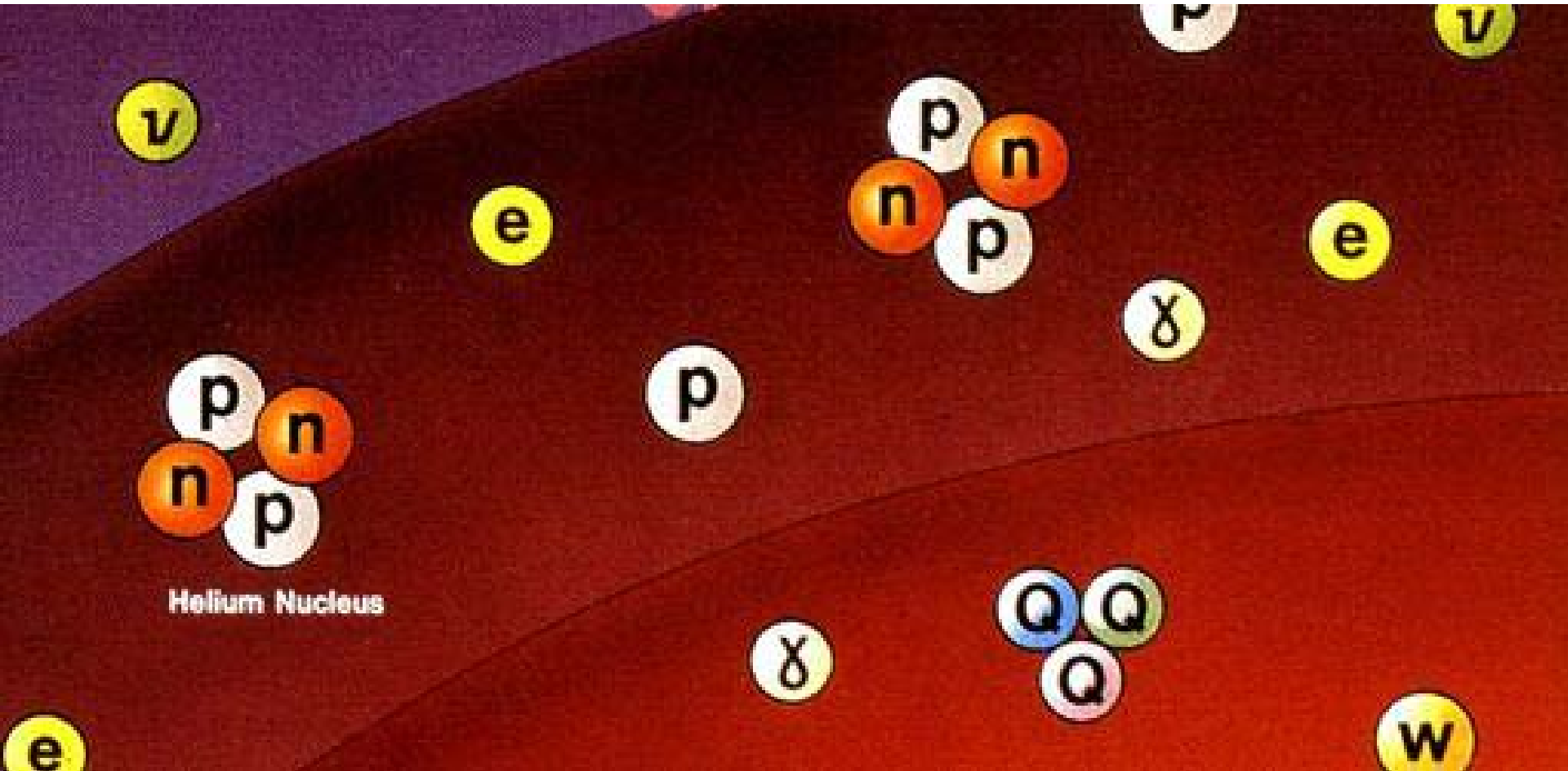
Licht = kosmische Hintergrundstrahlung!

Entstehung von Helium-Kernen

$t = 3 \text{ min}$

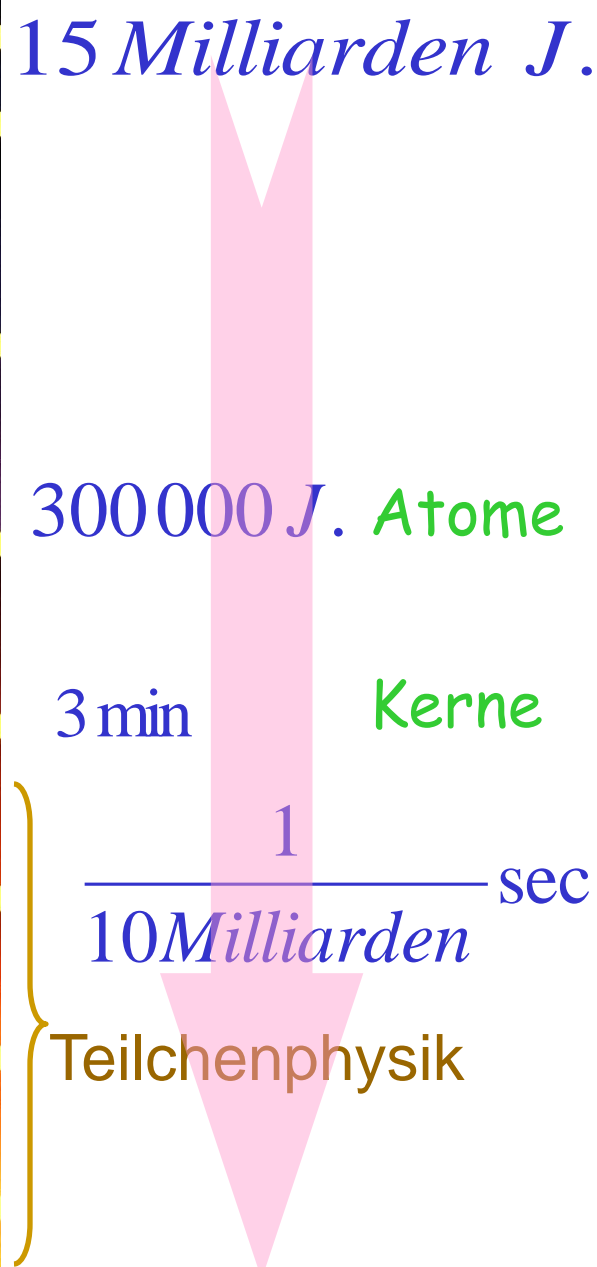
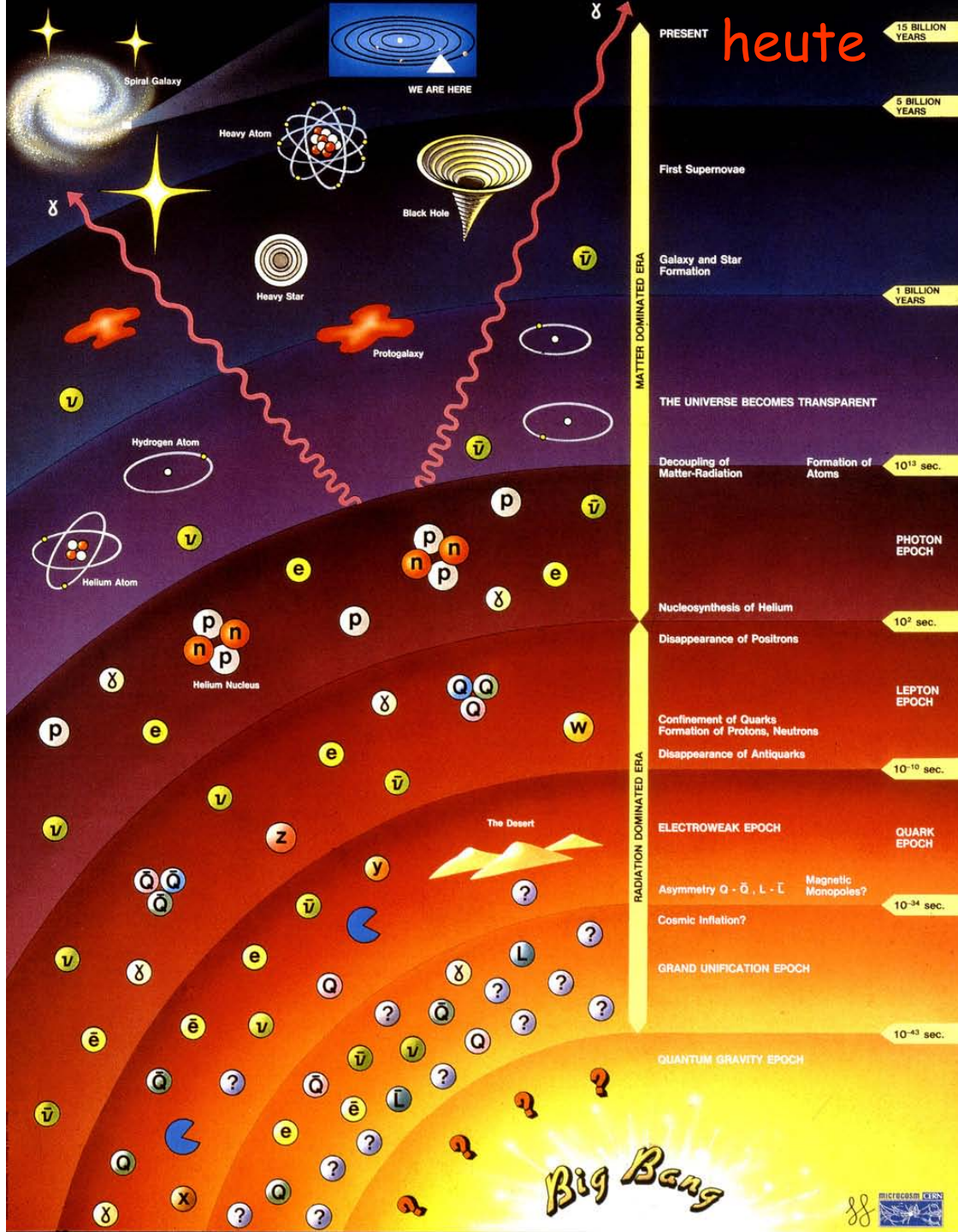
$T = 1\,000\,000\,000 \text{ }^\circ\text{C}$

$E = 0.1 \text{ MeV}$



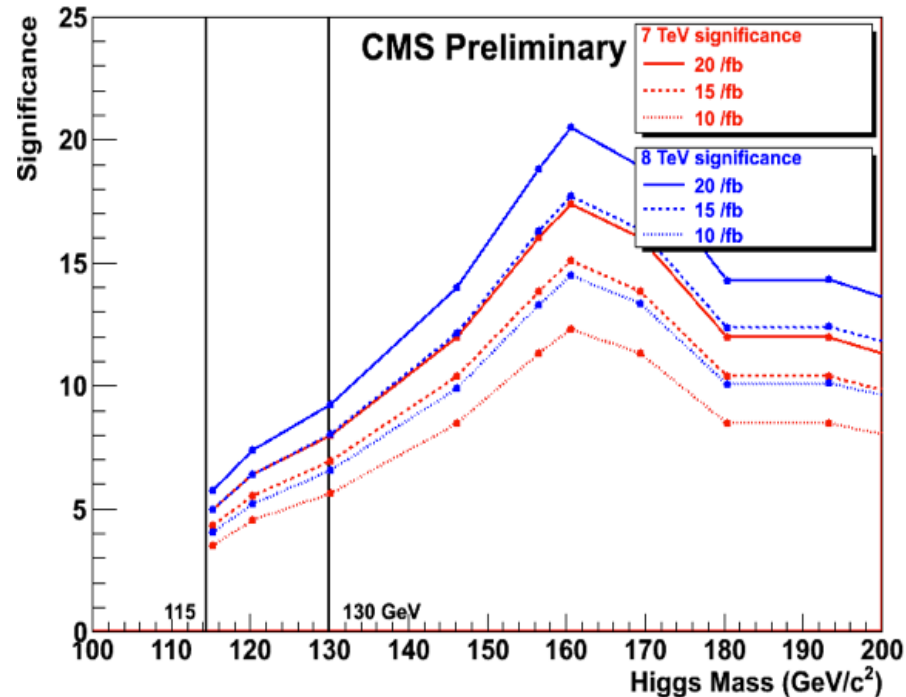
Schwere Kerne (C, O, U...) entstanden erst in Supernovae !

Prozesse im frühen Universum



The search for the Higgs

- Integrated luminosity the key
 - Need $>20 \text{ fb}^{-1}/\text{expt}$ going into LS1
 - Could use 2 experiments as they are ideally intended, to corroborate conclusively rather than combine.
- Can reach same $\int L dt$ with lower pile-up at 8 TeV
 - Important for low-masses, particularly $\gamma\gamma$ channel
- Luminosity leveling
 - May be an attractive option provided sufficiently long fills
- Enhanced discovery reach in the full mass range



Discovery potential
(non-optimised
analysis)

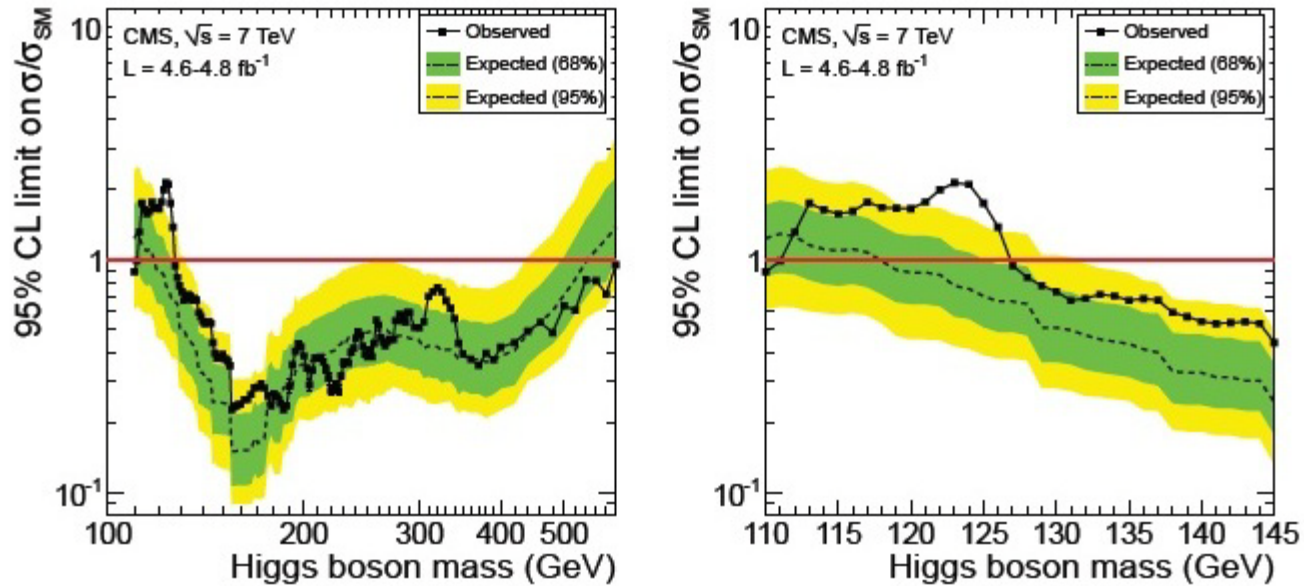


Figure 3: The 95% CL upper limits on the signal strength parameter $\mu = \sigma/\sigma_{SM}$ for the SM Higgs boson hypothesis as a function of the Higgs boson mass in the range 110–600 GeV (left) and 110–145 GeV (right). The observed values as a function of mass are shown by the solid line. The dashed line indicates the expected median of results for the background-only hypothesis, while the green (dark) and yellow (light) bands indicate the ranges that are expected to contain 68% and 95% of all observed excursions from the median, respectively.

Arbeiten am Teststrahl



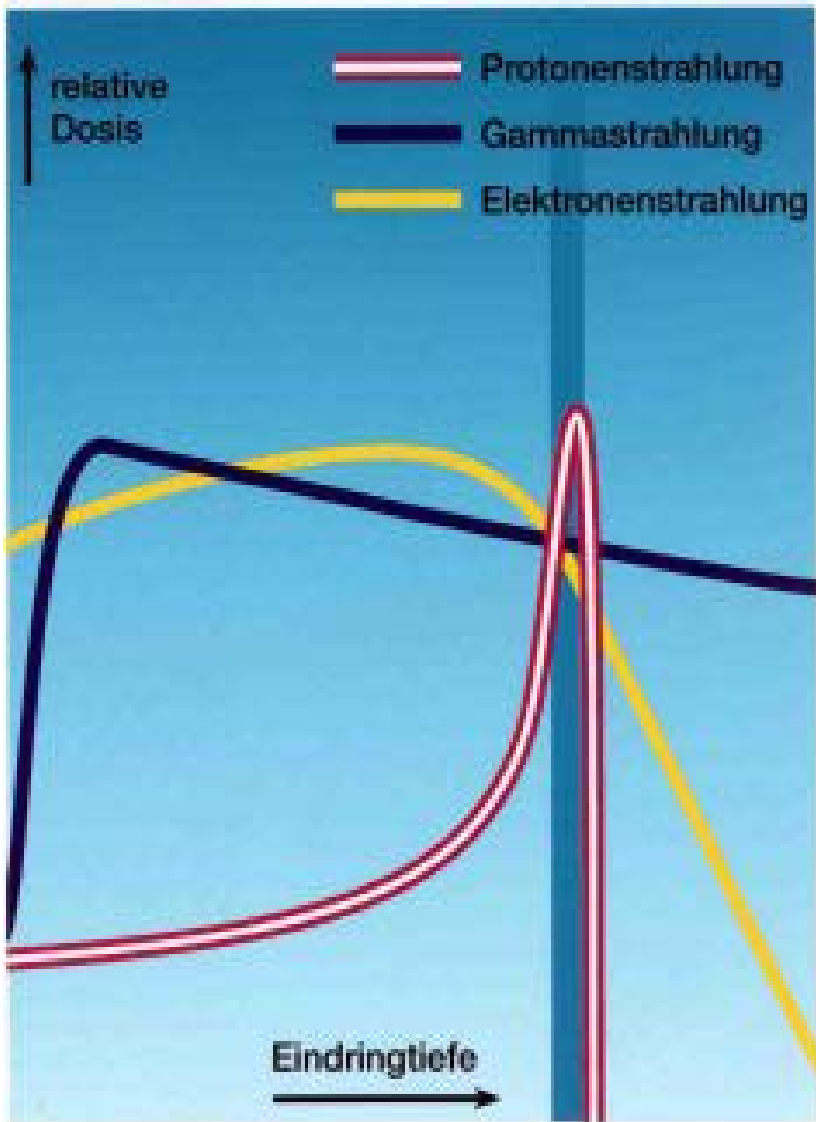
Besuch von
Ministerin Bulmahn

19 September 2008

- Malfunctioning of a magnet after few days of operation
- Repair of 53 magnets necessary
- First collisions scheduled for summer 2009



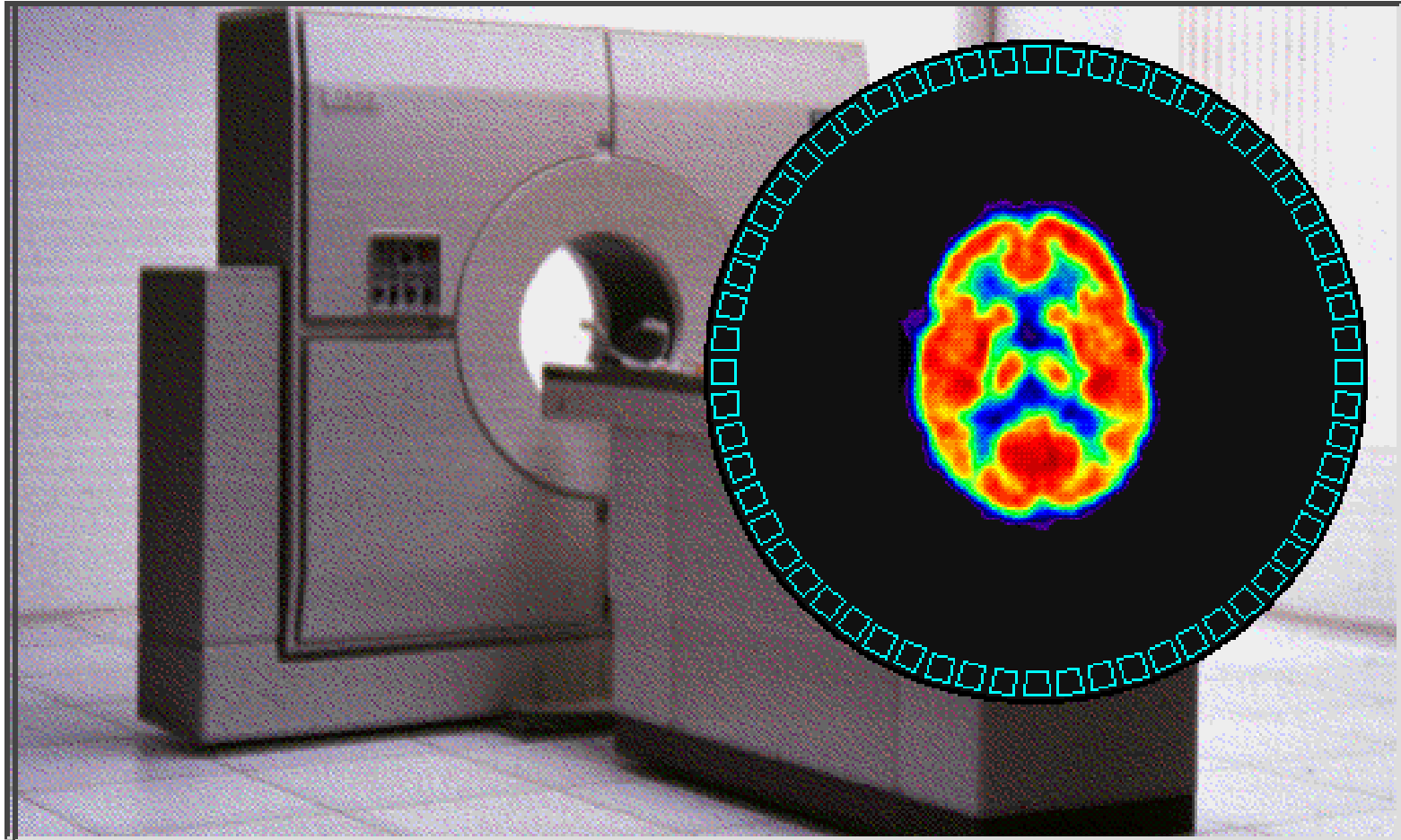
Tumor-Bestrahlung mit leichten Ionen



Mit leichten Ionen lässt sich die Bestrahlung so dosieren, dass der Tumor zerstört wird, ohne das gesunde Gewebe zu schädigen.



PET Funktionsweise



**CMS
Caverne
80 m
unter
der
Erde**

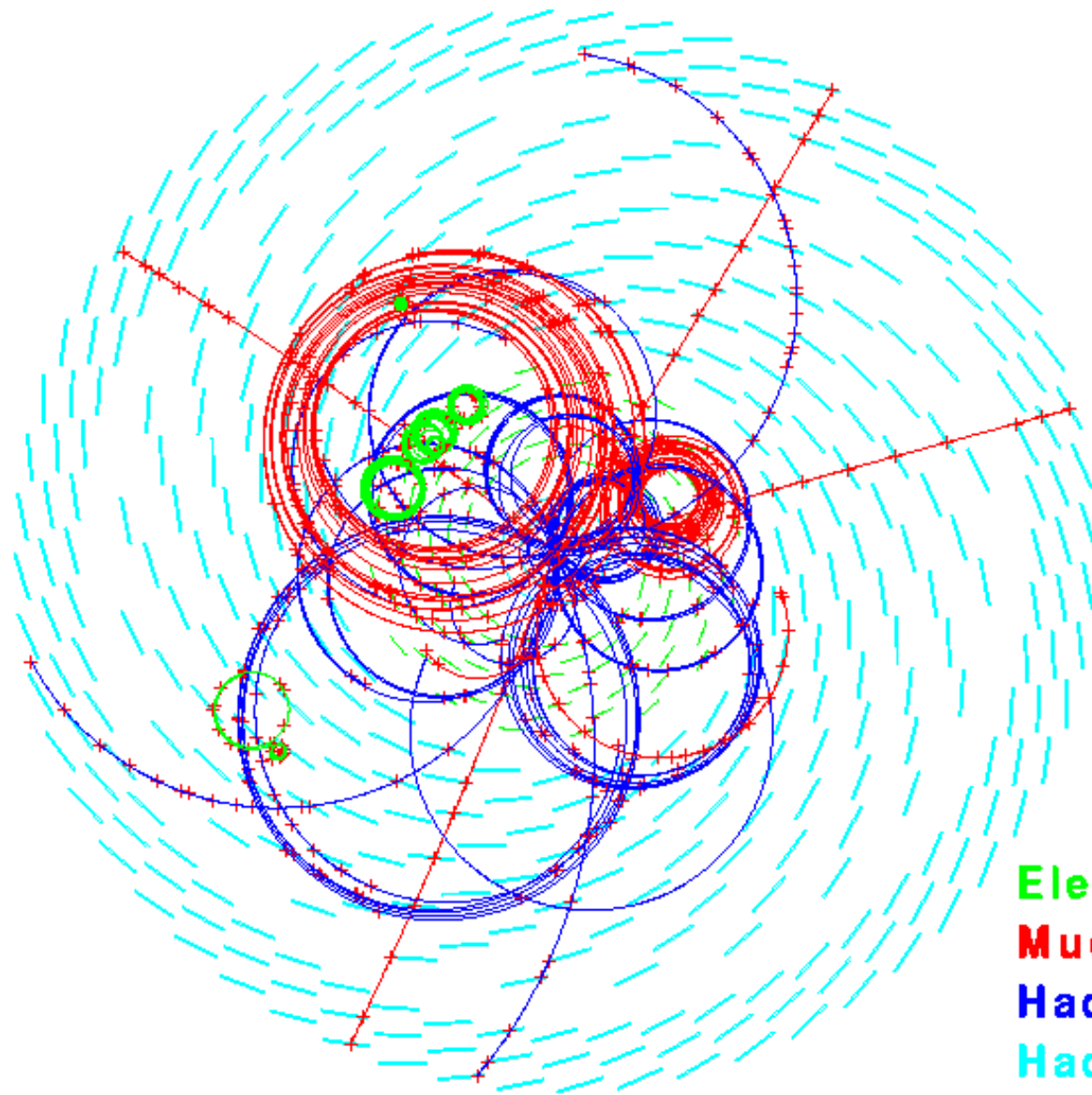
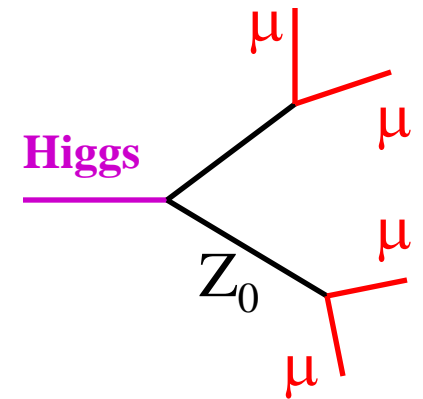


Fertiges Beschleunigersegment



CMS

$H \rightarrow \mu\mu\mu\mu$
 $m(H) = 150 \text{ GeV}$



Electrons

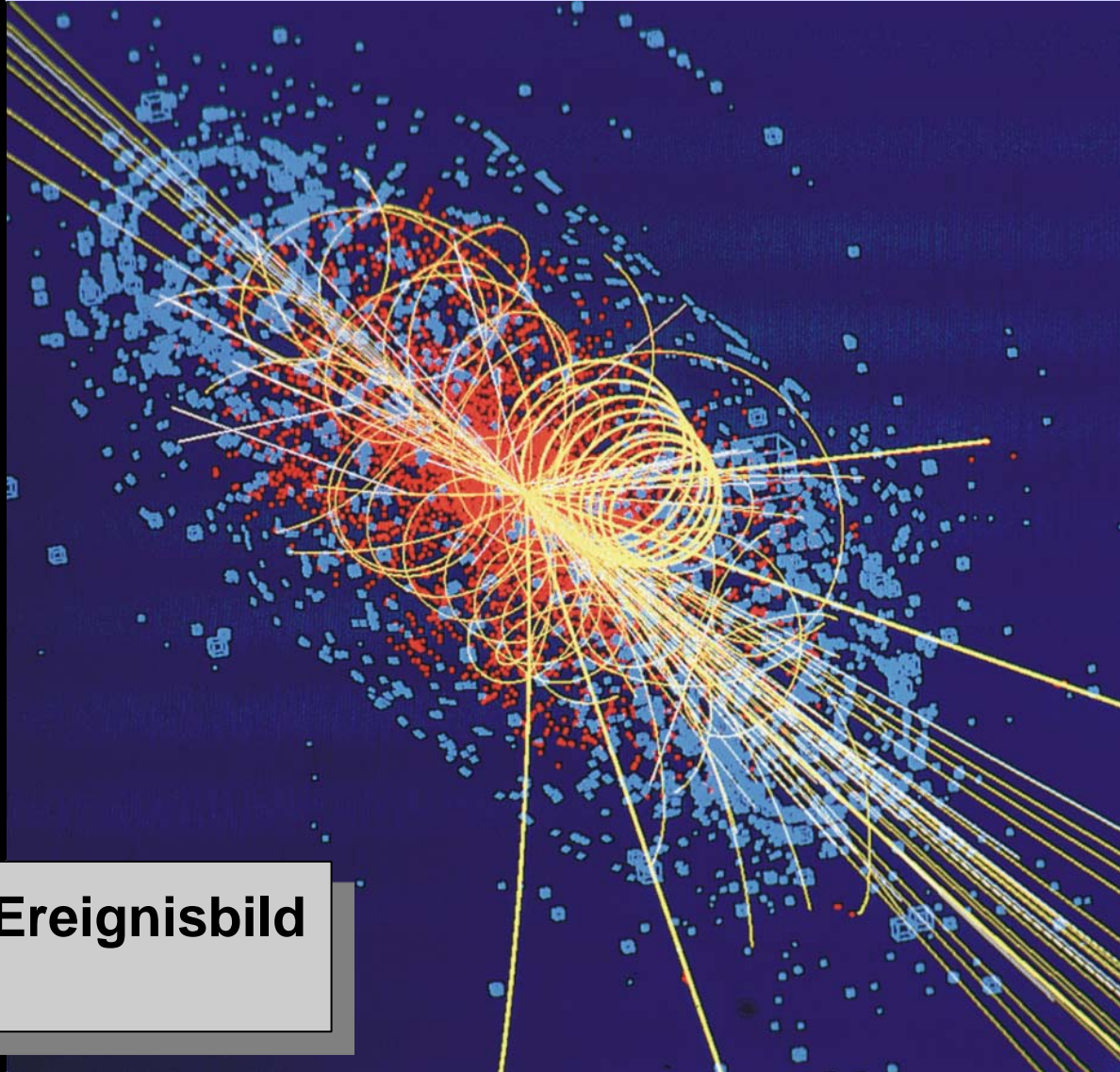
Muons

Hadrons $p_t < 2 \text{ GeV}$

Hadrons $p_t > 2 \text{ GeV}$



"Bilder" der Teilchenkollisionen



typisches Ereignisbild
in 2007 ...

