Lehrerfortbildung 2009/2010

Große Beschleunigerexperimente (LHC, FAIR etc.)

Thomas Cowan
Direktor am Institut für Strahlenphysik
Forschungszentrum Dresden-Rossendorf

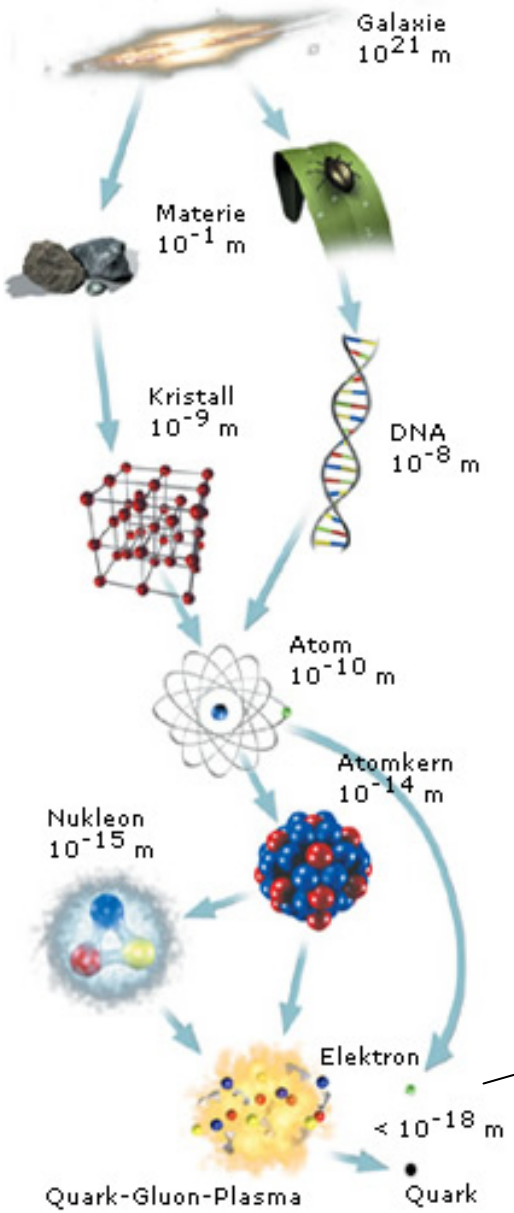
Einleitung
- Standardmodell und offene Fragen
- Ursache der Masse
- Entwicklung des Universums

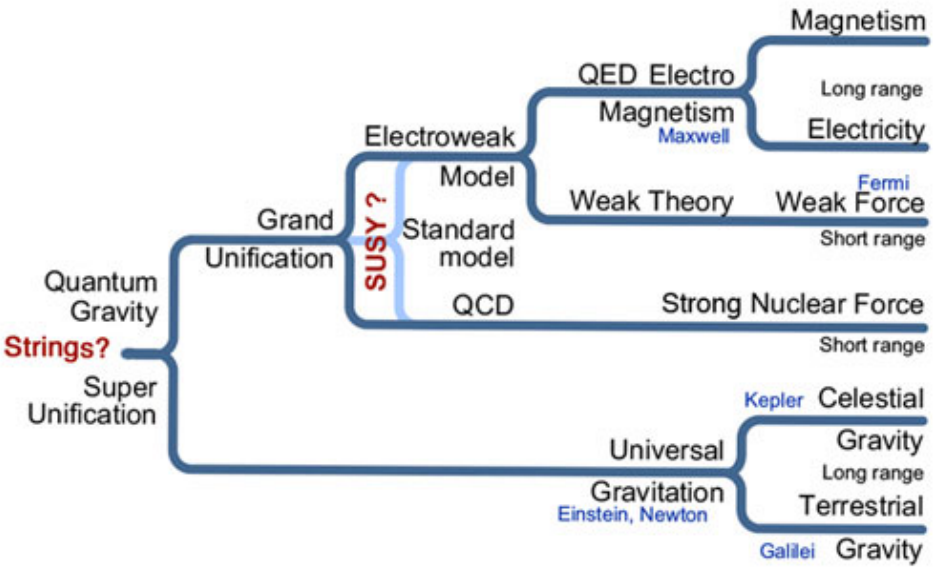
Wie kann man subnukleare Struktur messen?
- Das erste “Beschleunigerexperiment”
- Hochenergie Teilchenbeschleuniger
- Moderne Detektorsysteme

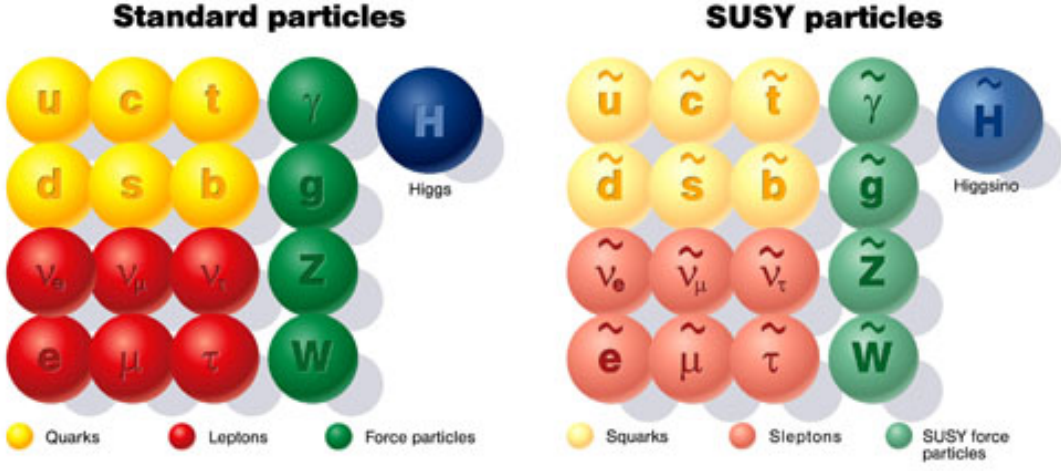
Suche nach der Ursache der Massen am LHC
- ATLAS-Experiment am Large Hadron Collider (CERN)
- Suche nach dem Higgs-Teilchen

stark wechselwirkende Materie
- Suche nach den Quark-Gluon-Plasmen an GSI/FAIR
- HADES @ GSI
- CBM @ FAIR

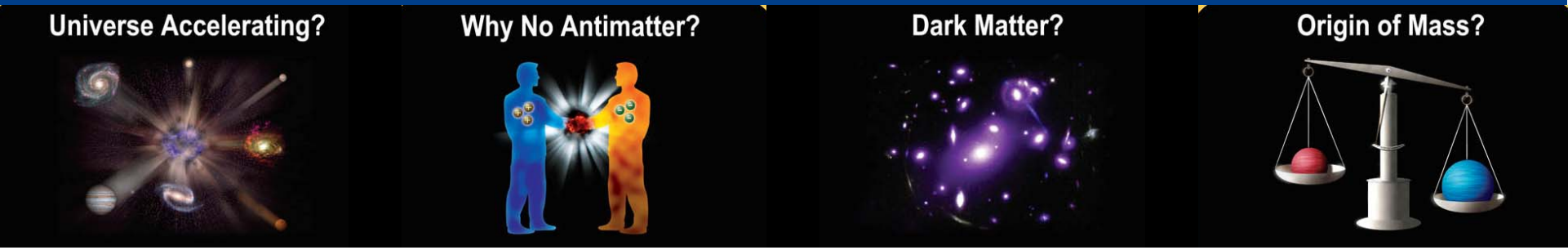
Teilchen- und Kernphysik: Standardmodell







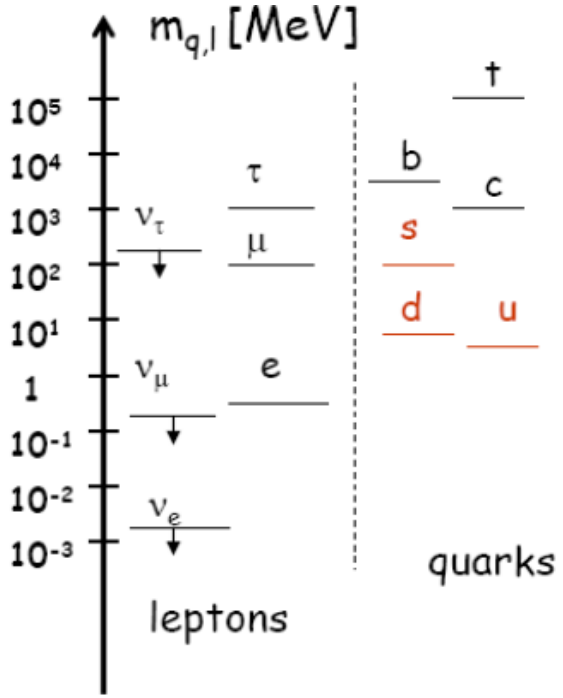
Teilchen- und Kernphysik: Offene Fragen



Standard model:

				Q
quarks	u	c	t	2/3
	d	s	b	-1/3
leptons	ν_e	ν_μ	ν_τ	0
	e	μ	τ	-1

3 particle families



- What is the origin of hadron masses?

$M_{proton} >> 3m_{u/d}$ (20 MeV) !

- Breakdown of chiral symmetery

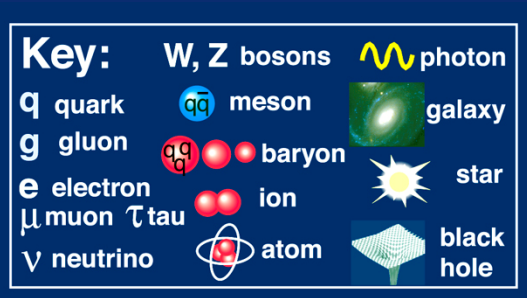
➢ Mass generation via Higgs mechanism

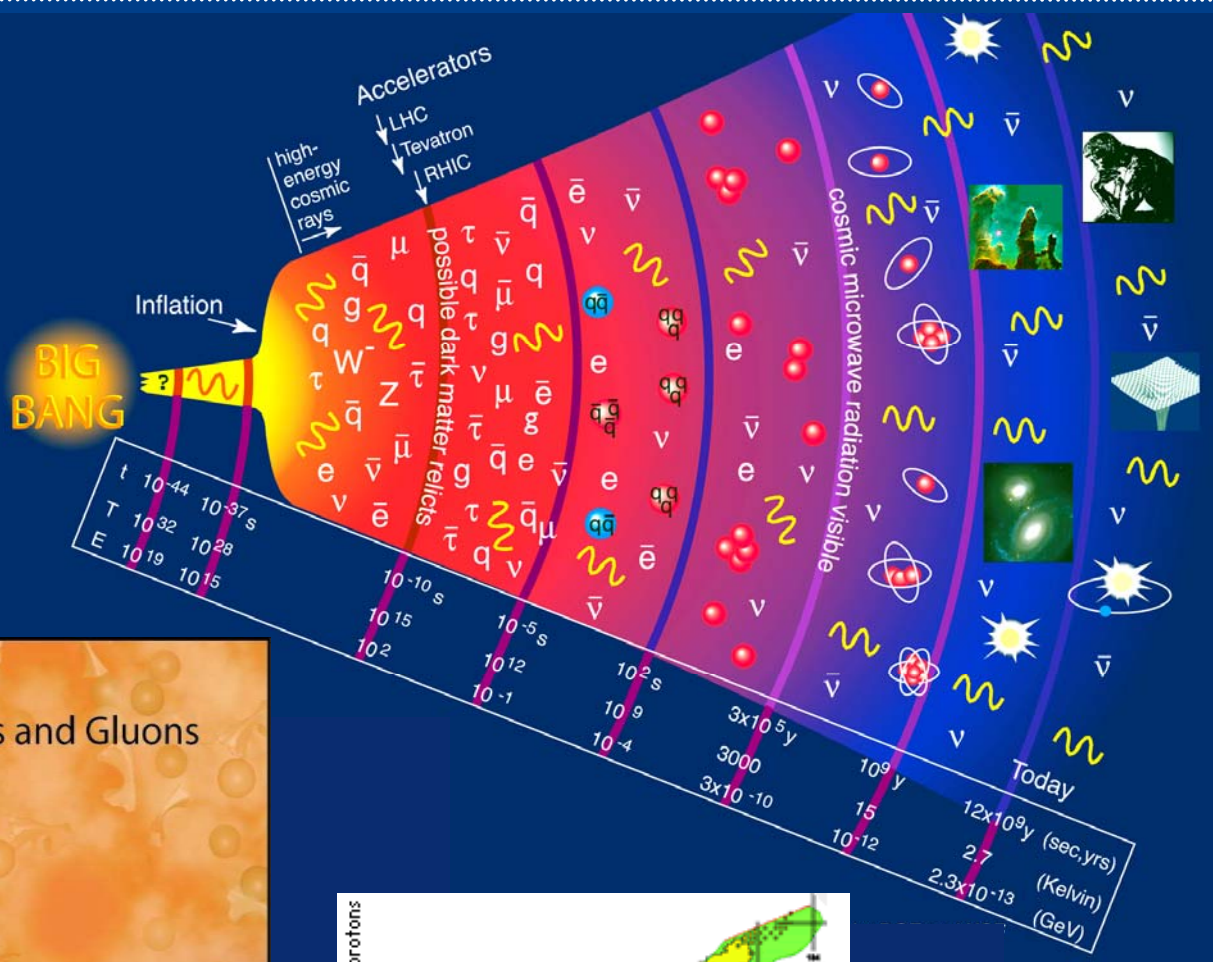
➢ „current quark masses"

Higgs Mechanismus:

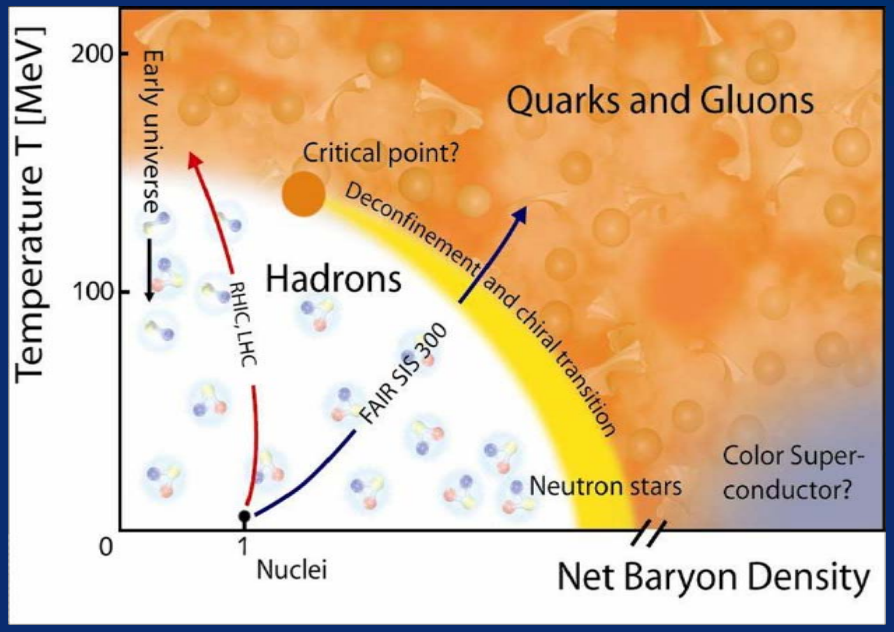
D. Stoeckinger, TU Dresden

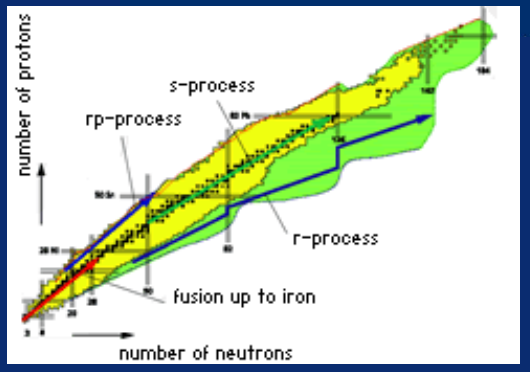
Teilchen- und Kernphysik: Entwicklung des Universums





Quark-Gluon-Plasma

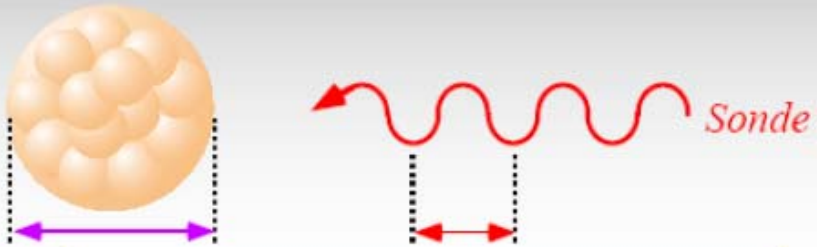




Entstehung der Elemente

Wie kann man subnukleare Struktur messen?

Auflösung subnuklearer Strukturen } → Hohe Energien (Kleine Wellenlängen) der 'Sonden'



$$\Delta s \geq \lambda \sim 1/E$$

Kleinster noch trennbarer Abstand zweier Objekte

Wellenlänge der 'Sonde': z.B. Licht, Elektronen, Protonen

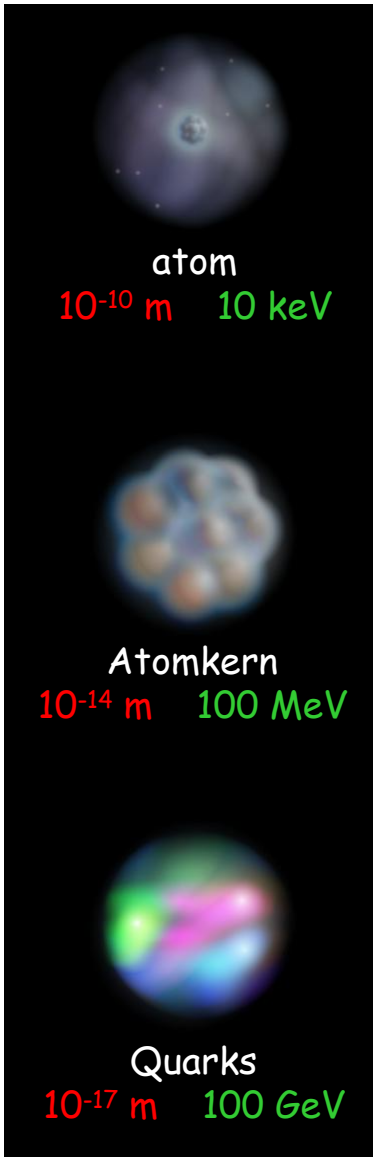
Energie der Sonden

$$E = h \cdot \nu = h \cdot \frac{c}{\lambda}$$

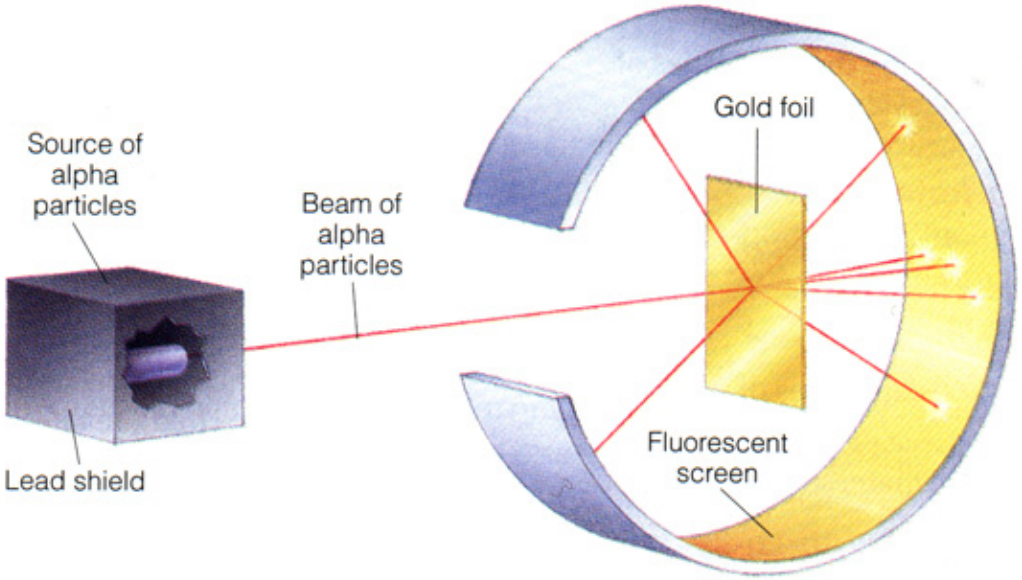
X-rays; Elektron-mikroskop

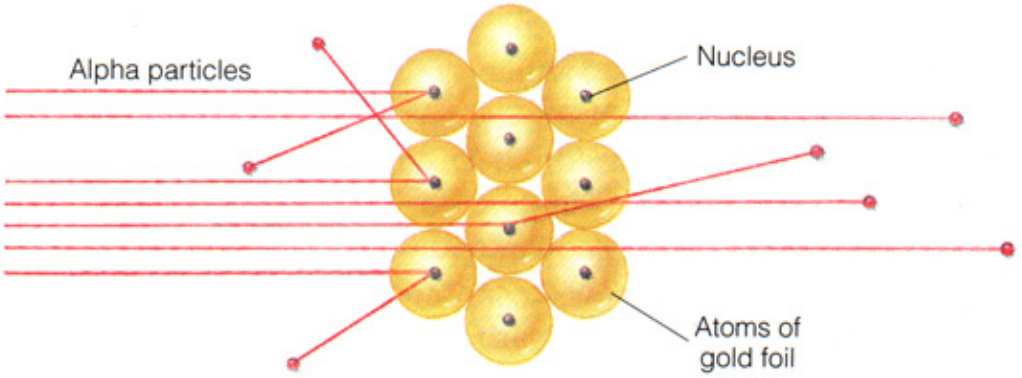
γ-rays; Niederenergie-beschleuniger (e.g., ELBE, GSI)

Hochenergie-beschleuniger (e.g., HERA, LHC, FAIR)



Ernst Rutherford (1911)





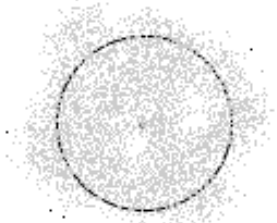
X

Indivisible Atom (hard sphere)

X

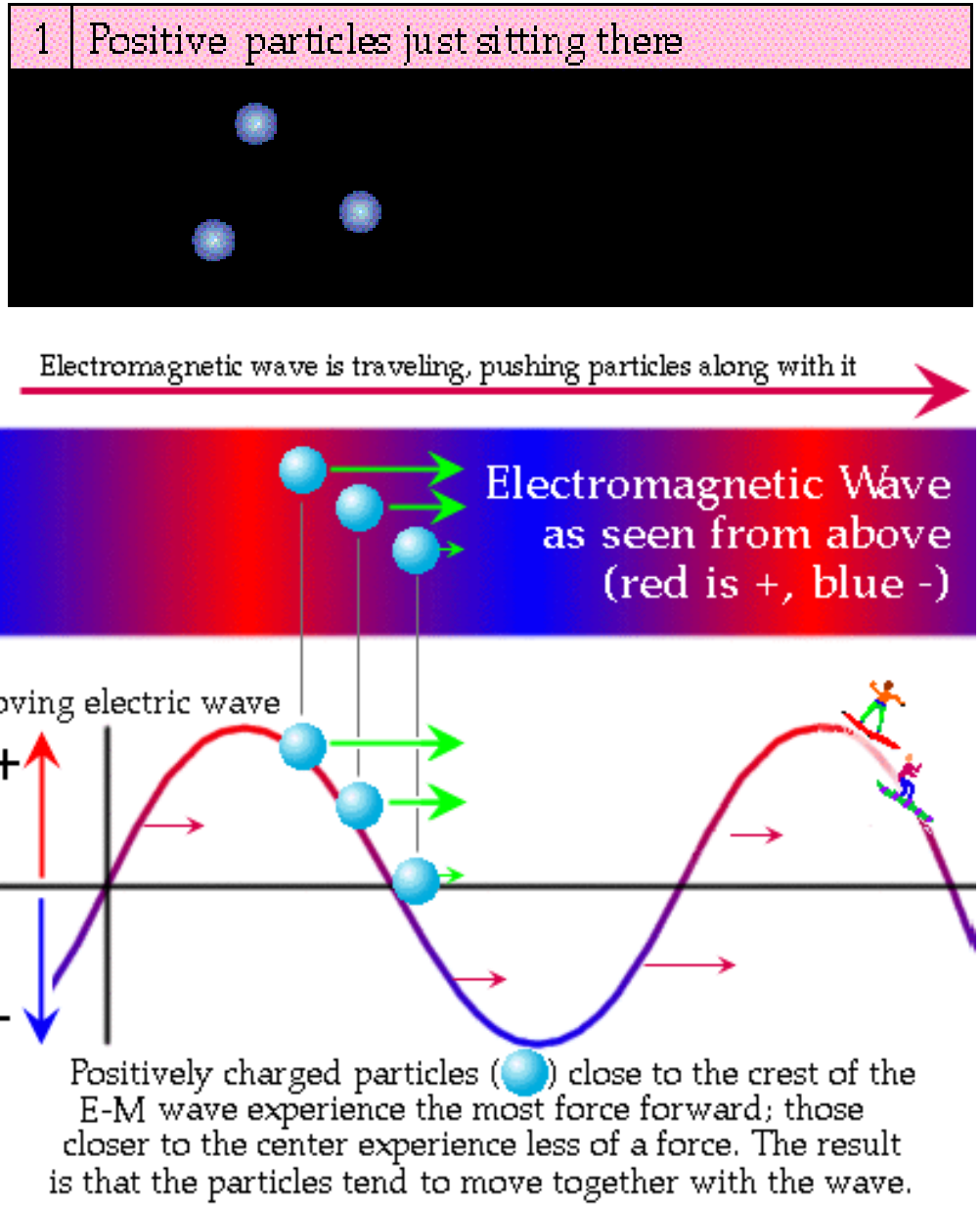
'Plum-pudding' Atom

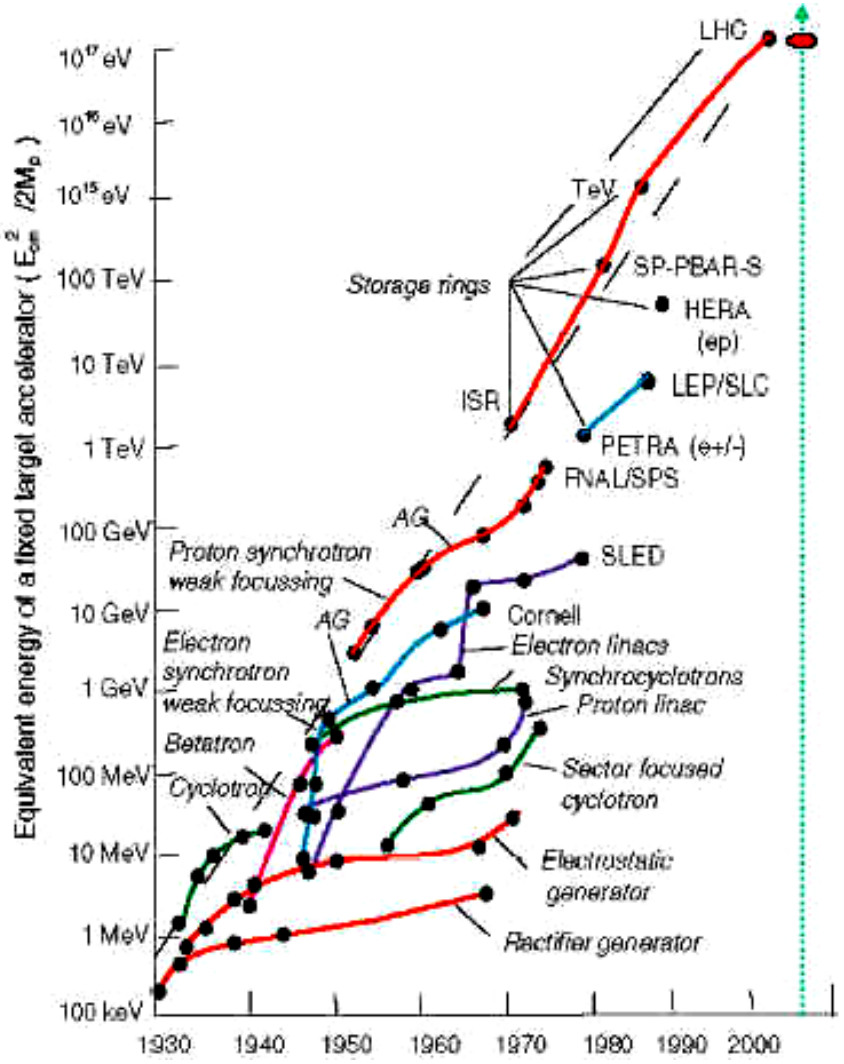
✓



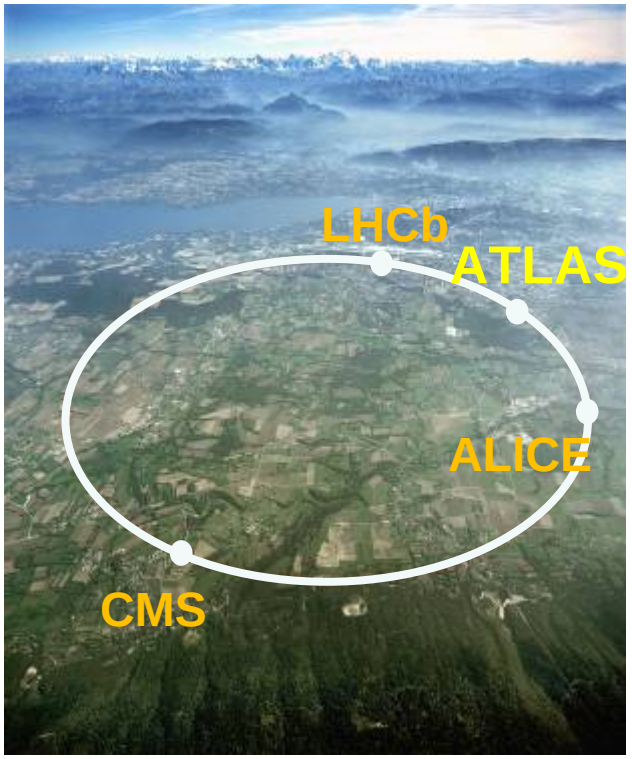
Rutherford Atom

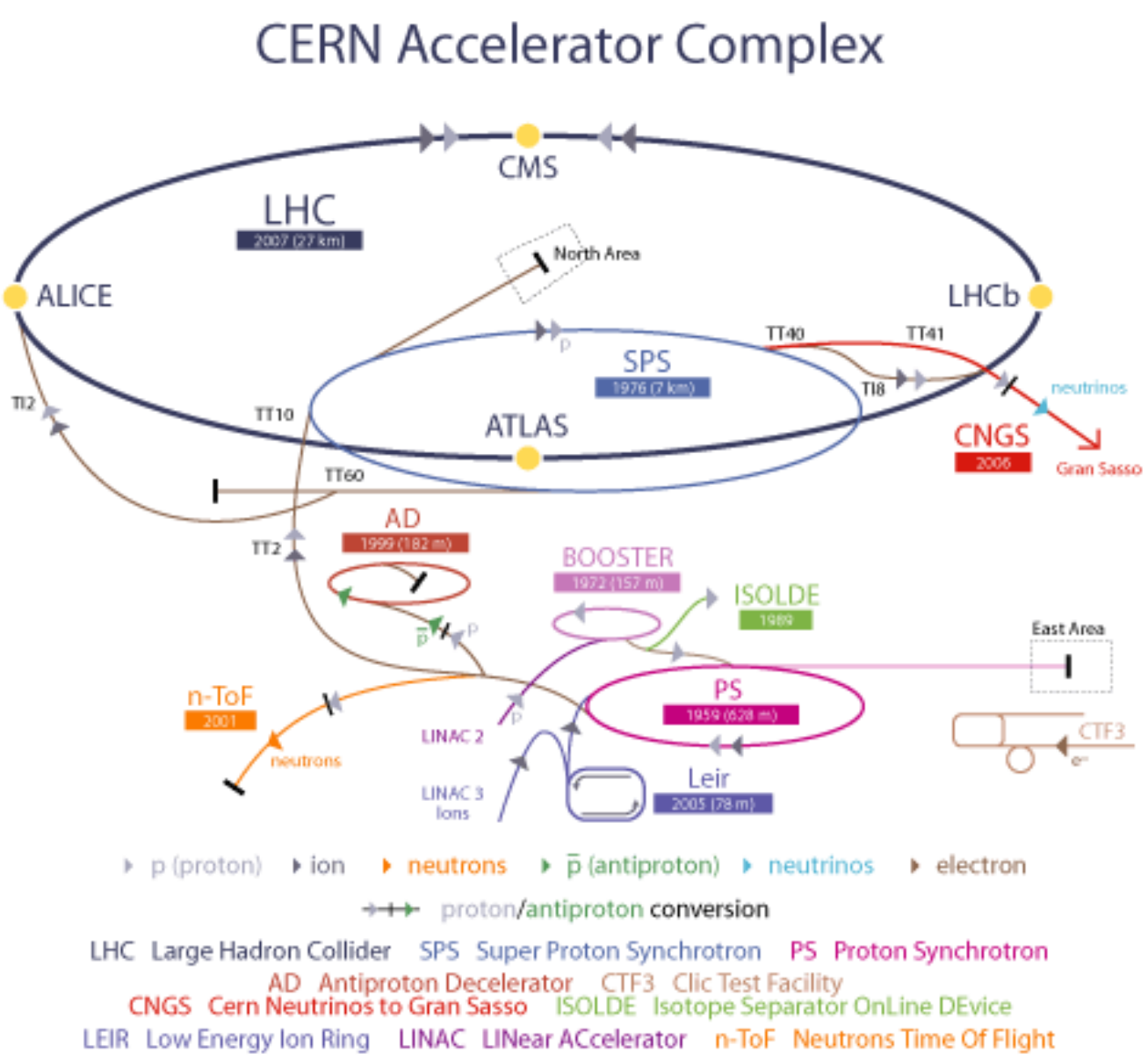
Teilchenbeschleunigung in elektromagnetischer Welle





Large Hadron Collider @ CERN



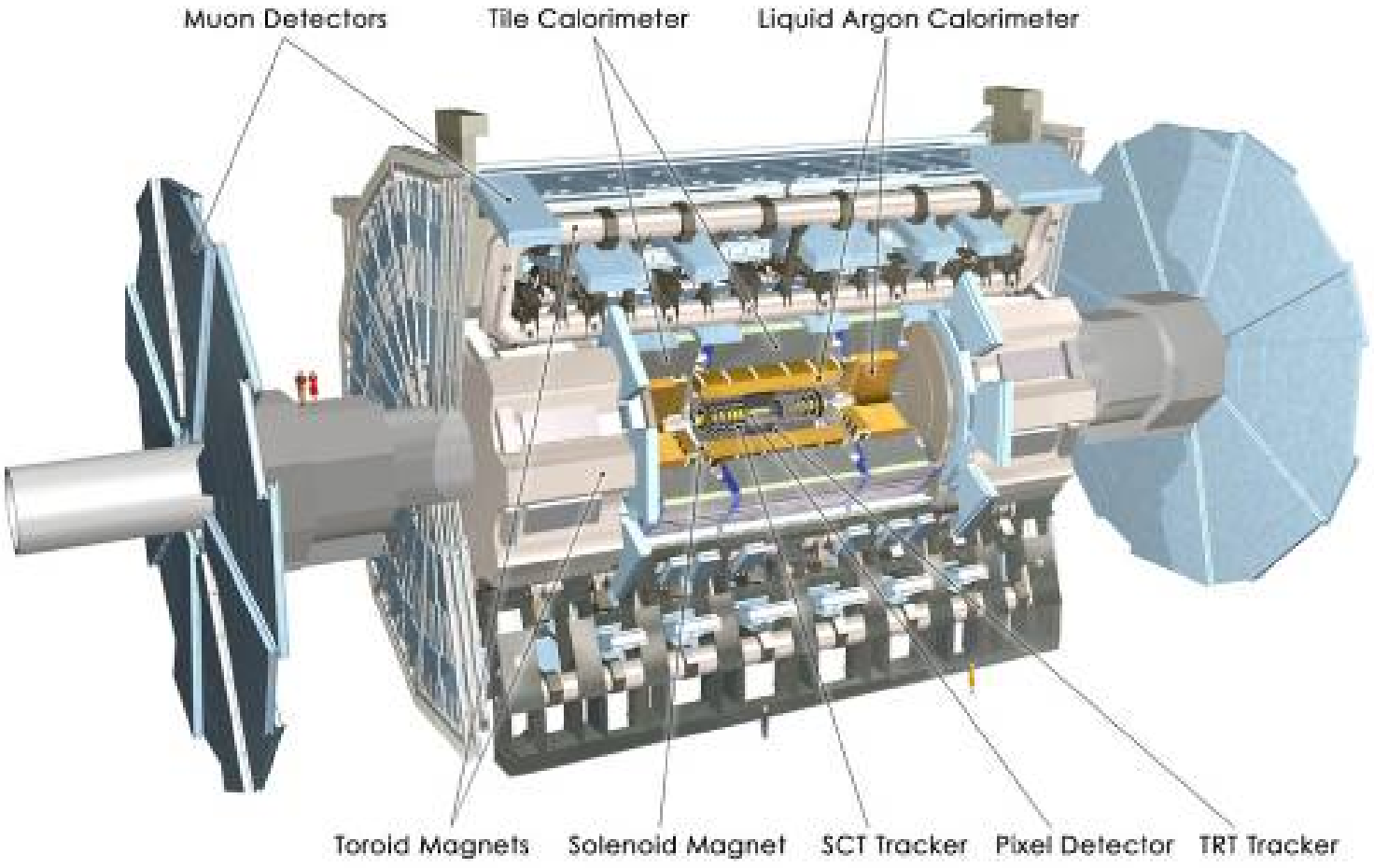

CERN Accelerator Complex
CMS
LHC
2007 (27 km)
North Area
ALICE
LHCb
SPS
1976 (7 km)
TT40
TT41
TI8
neutrinos
CNGS
2006
Gran Sasso
TI2
TT10
ATLAS
TT60
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1989
East Area
n-ToF
2001
neutrons
LINAC 2
PS
1959 (628 m)
CTF3
LINAC 3
Ions
Leir
2005 (78 m)
p (proton)
ion
neutrons
p̄ (antiproton)
neutrinos
electron
proton/antiproton conversion
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

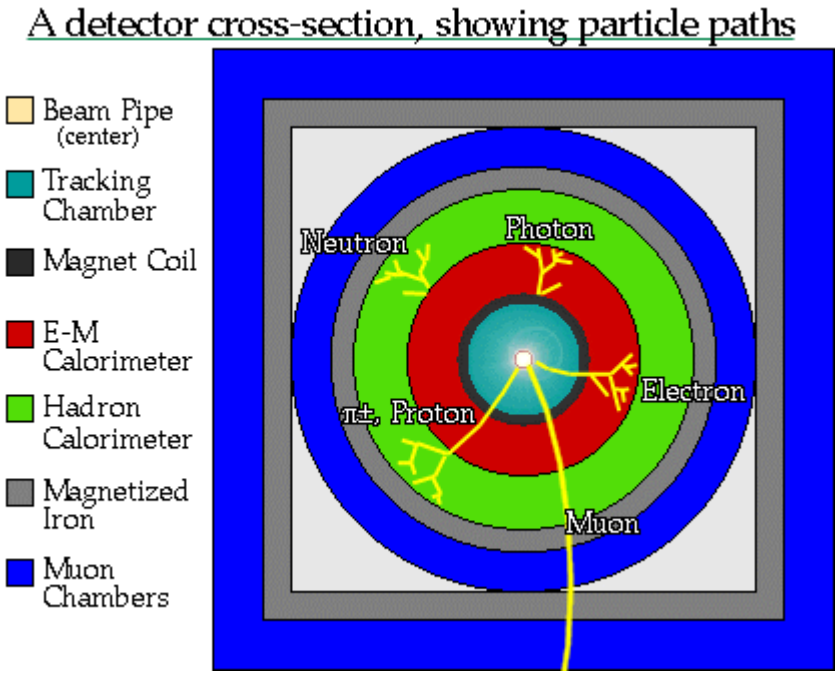
Physik mit dem ATLAS-Experiment am LHC

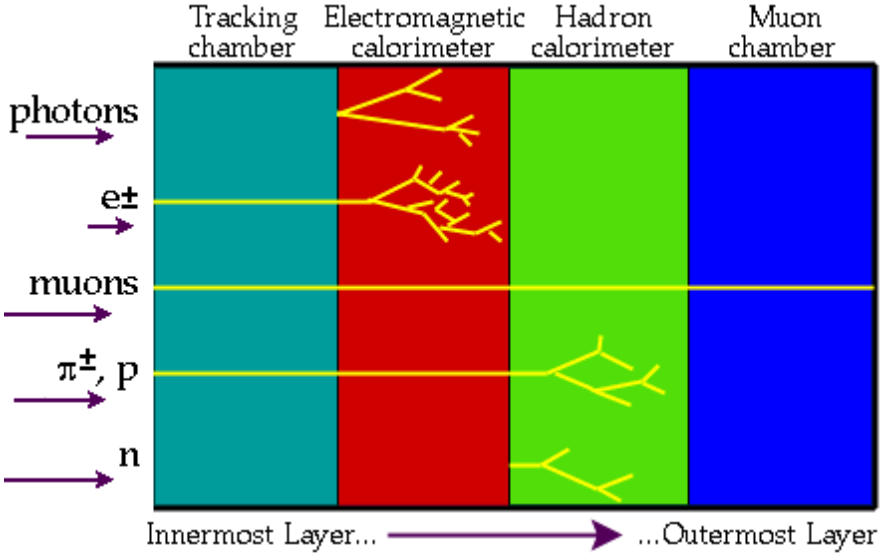
- 1850 Wissenschaftler in 161 Instituten aus 37 Ländern
- M. Kobel, A. Straessner (TU Dresden)

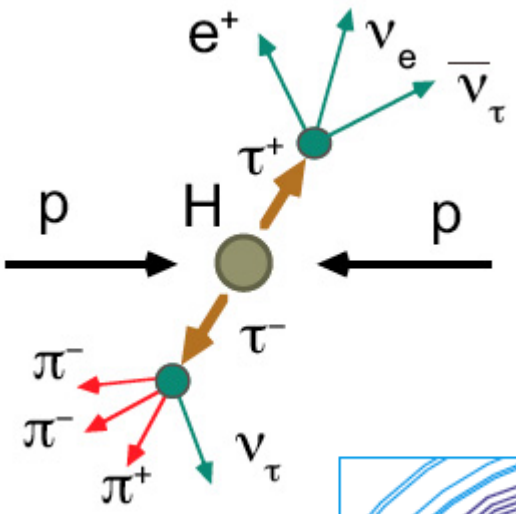
p p

- Proton-Proton-Kollisionen bei 14 TeV
- 1 Billionen Wechselwirkungen pro Sekunde



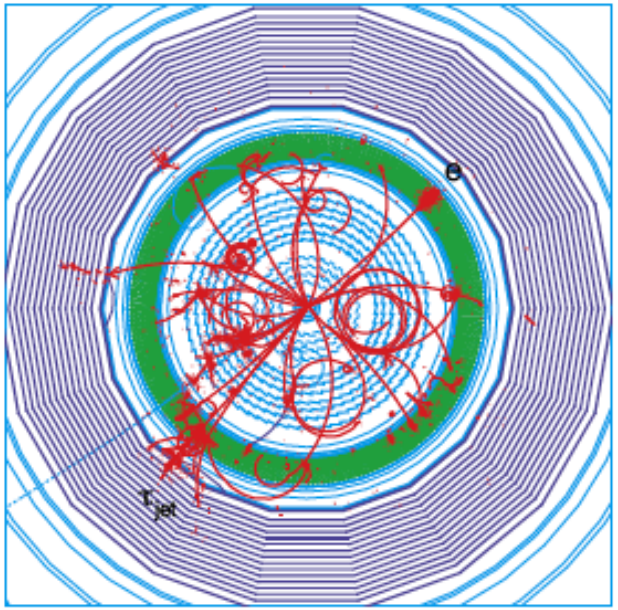

A detector cross-section, showing particle paths
Beam Pipe (center)
Tracking Chamber
Magnet Coil
E-M Calorimeter
Hadron Calorimeter
Magnetized Iron
Muon Chambers
Neutron
Photon
Electron
π±, Proton
Muon


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

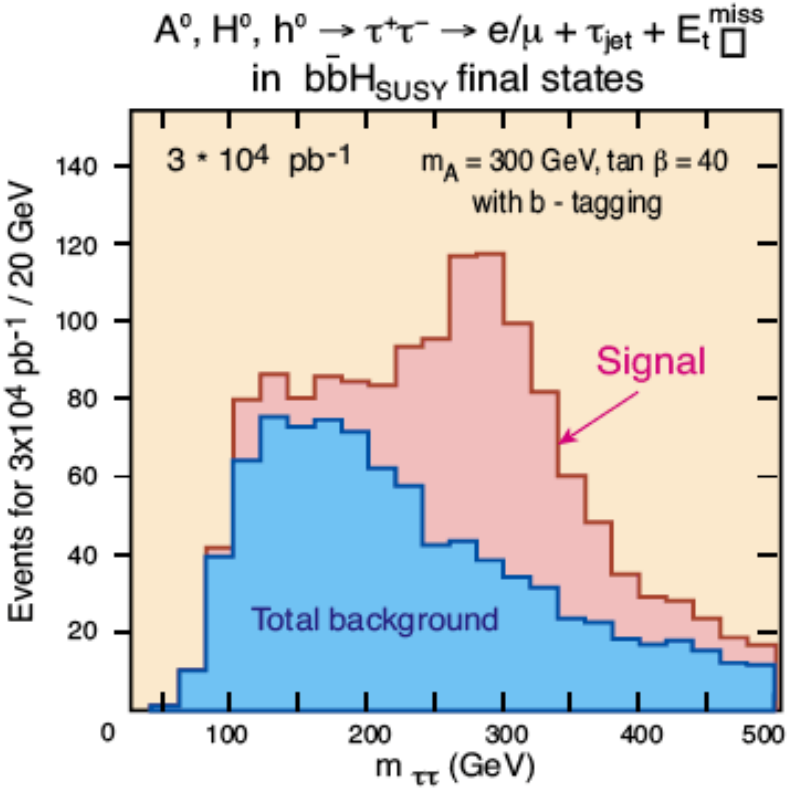


Suche nach dem Higgs-Boson

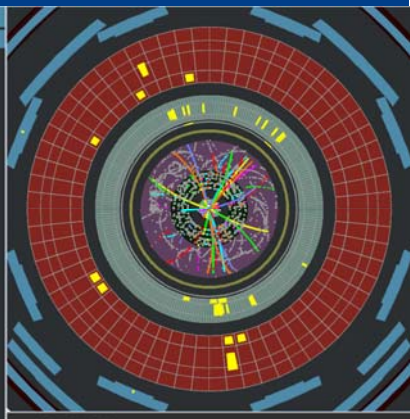
- Das Higgs-Boson verleiht den Elementarteilchen Masse
- Es ist der letzte Baustein des Standardmodells
- Gesucht anhand seiner Zerfallsprodukte

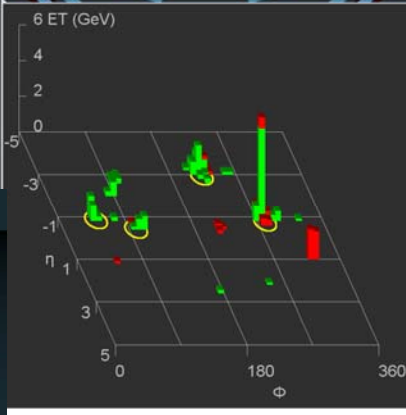


$H \rightarrow \tau\tau \rightarrow e + \tau_{jet}$("3-prong")



ATLAS: erste Ereignisse



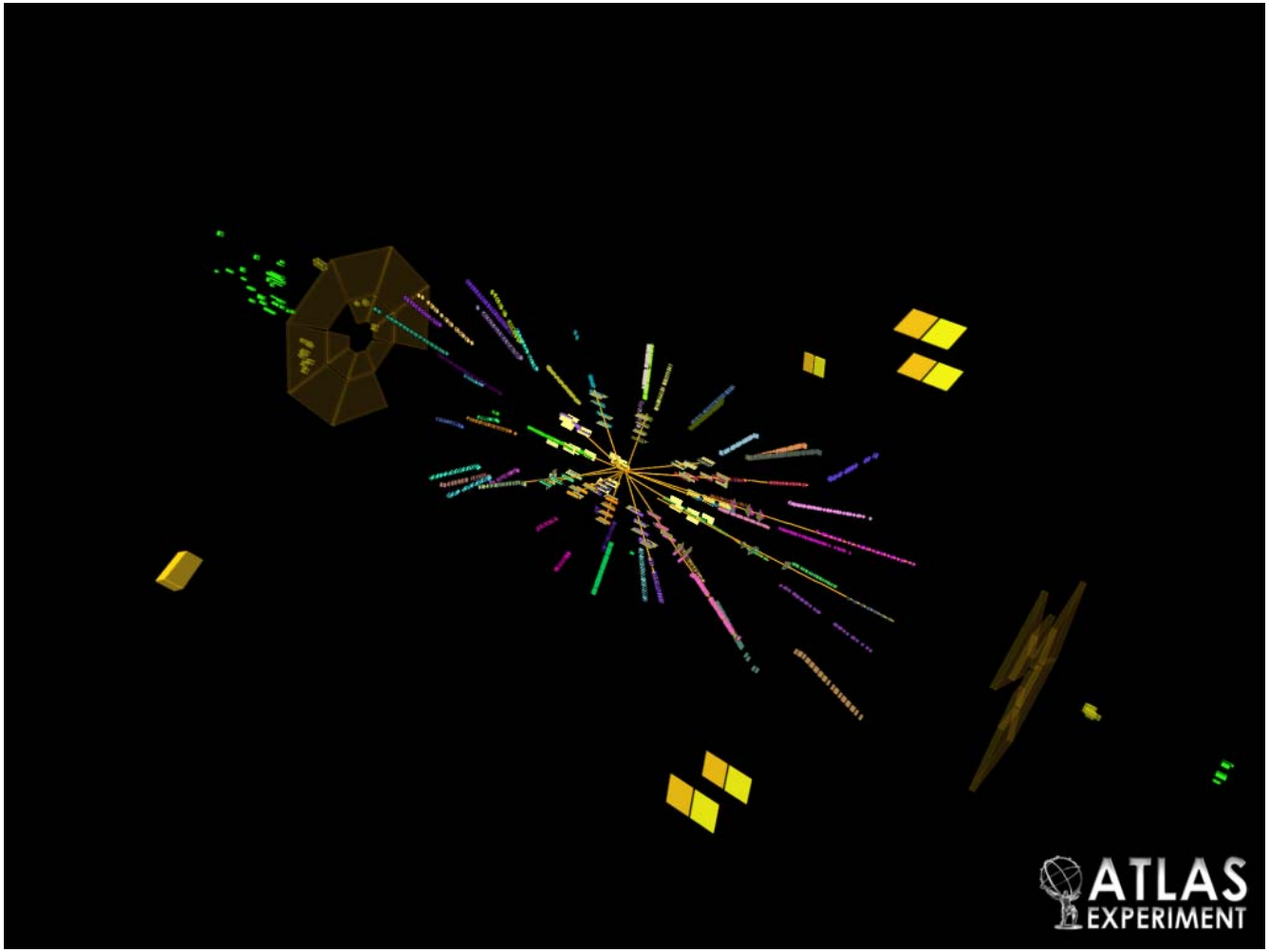


- Excitement in ATLAS Control Room as first high energy collision events are recorded

- Jetzt geht's auf zu neuen Entdeckungen!

- Stay tuned…

Latest events:

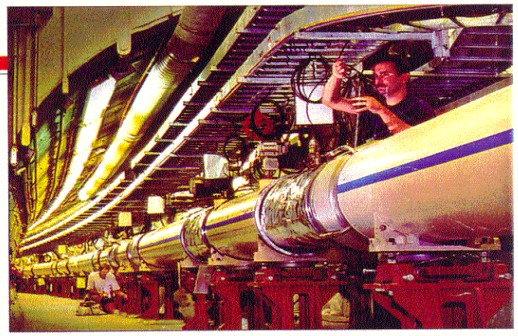


FORSCHUNG & TECHNIK

TEILCHENPHYSIK

Angst vor dem großen Knall

Physiker wollen bei New York den Anfang des Universums erforschen und lösen Endzeitstimmung aus



VOR DEM ERSTEN STOSS Seit Juli flitzen Goldatome durch den unterirdischen Ringtunnel. Ab Herbst gehen sie auf Kollisionskurs

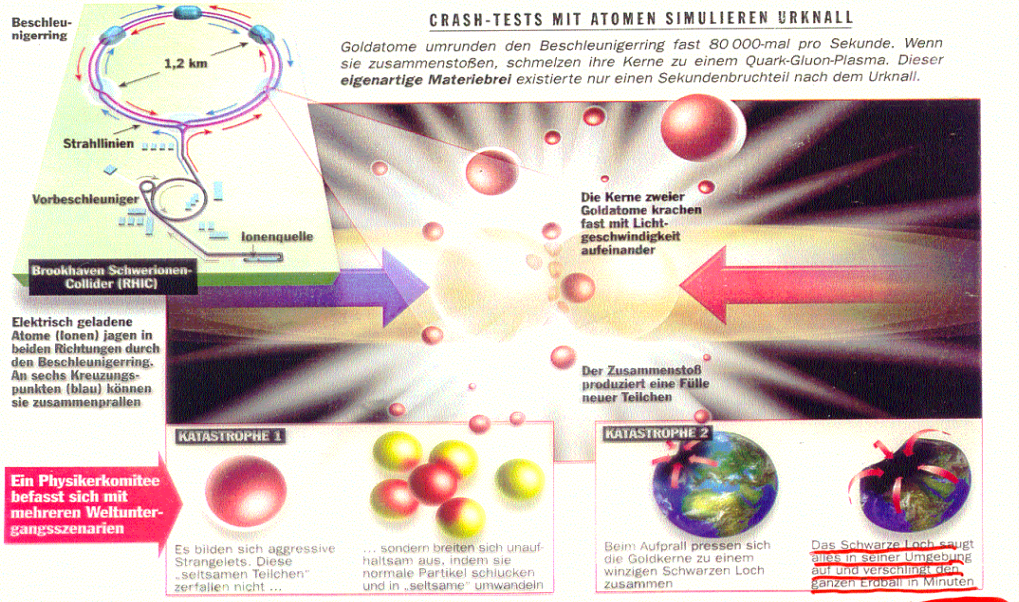
In der „Unendlichen Geschichte" von Michael Ende breitet sich das Nichts unaufhaltsam aus. Es reißt Tiere und Pflanzen fort, verschlingt Berge und Seen – und lässt von ganz Phantásien nicht mehr als ein Sandkorn übrig.

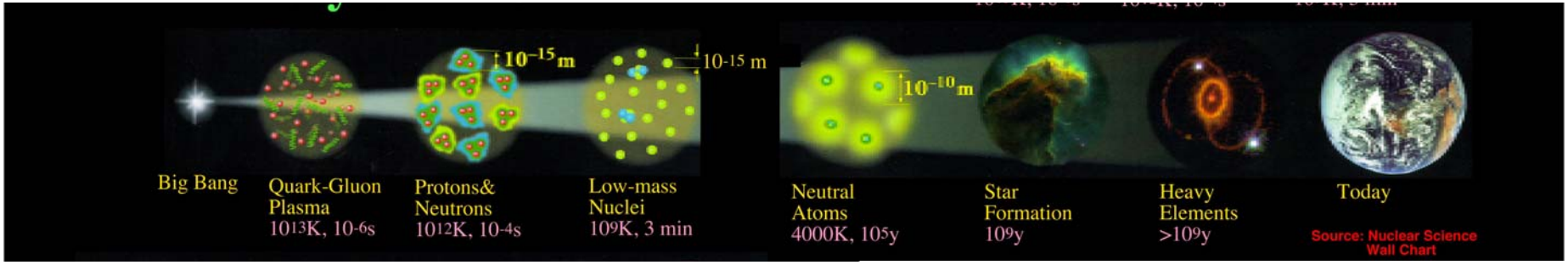
Solch ein Schicksal steht vielleicht der Erde bevor, fürchten jetzt viele Amerikaner, wenn ein neuer Teilchenbeschleuniger bei New York ab Herbst schwere Atome aufeinander hetzt. Der Relativistische Schwerionen-Collider (RHIC) in Brookhaven lässt die Teilchen so heftig zusammenkrachen, dass sie 10 000-mal heißer als die Sonne werden. Damit wollen die Physiker Bedingungen schaffen, wie sie direkt nach dem Urknall herrschten.

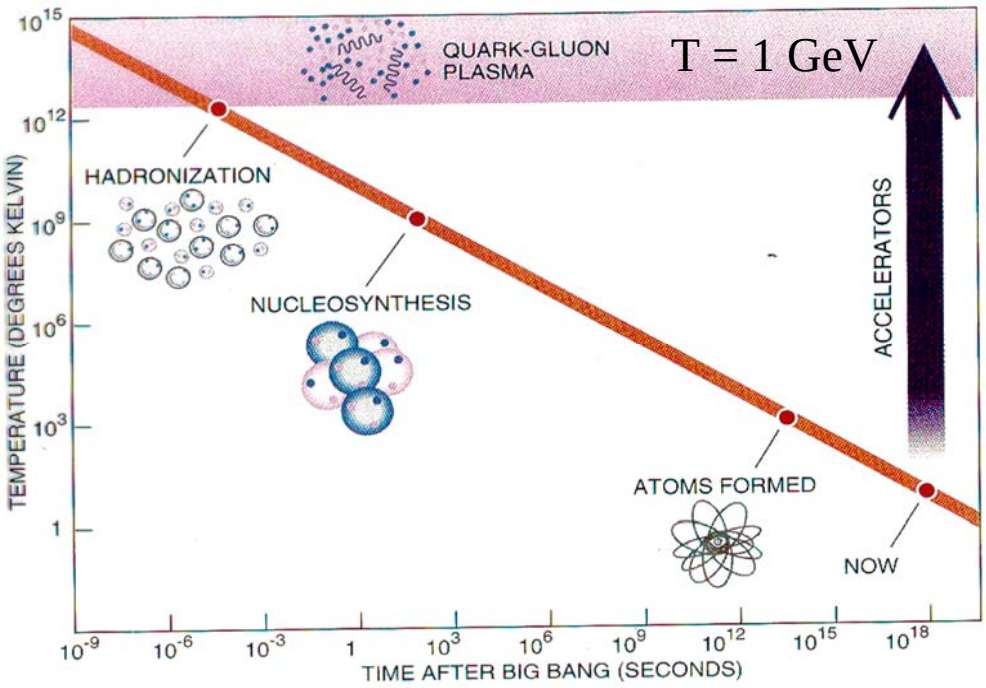
„Eine Kettenreaktion könnte den Planeten verschlingen", warnte im Juli Walter Wagner, ein weithin unbekannter Physiker auf Hawaii. Die angesehene „Sunday Times" meldete daraufhin: „Urknall-Maschine könnte Erde zerstören." Seitdem versuchen die RHIC-Forscher verzweifelt, besorgte Bürger zu beruhigen. Forschungsleiter John Marburger hat sogar ein Physikerkomitee einberufen, das diesen Monat zu den Katastrophenszenarien Stellung nimmt.

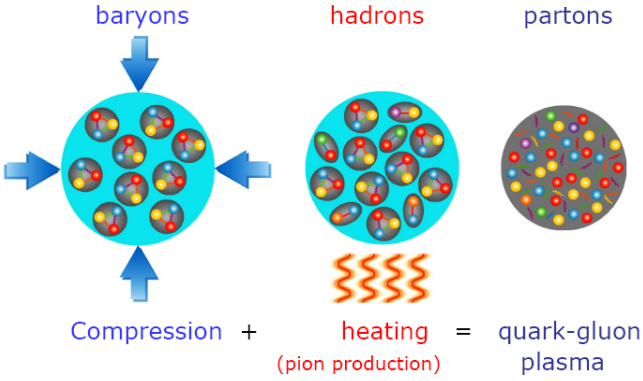
CRASH-TESTS MIT ATOMEN SIMULIEREN URKNALL

Goldatome umrunden den Beschleunigerring fast 80 000-mal pro Sekunde. Wenn sie zusammenstoßen, schmelzen ihre Kerne zu einem Quark-Gluon-Plasma. Dieser ***eigenartige Materiebrei*** *existierte nur einen Sekundenbruchteil nach dem Urknall.*









Big Bang expansion cools matter, particles freeze out and decay…
Relativistic Heavy Ion Collisions are analogous!

Facility for Anti-Proton and Ion Research — At GSI, Darmstadt

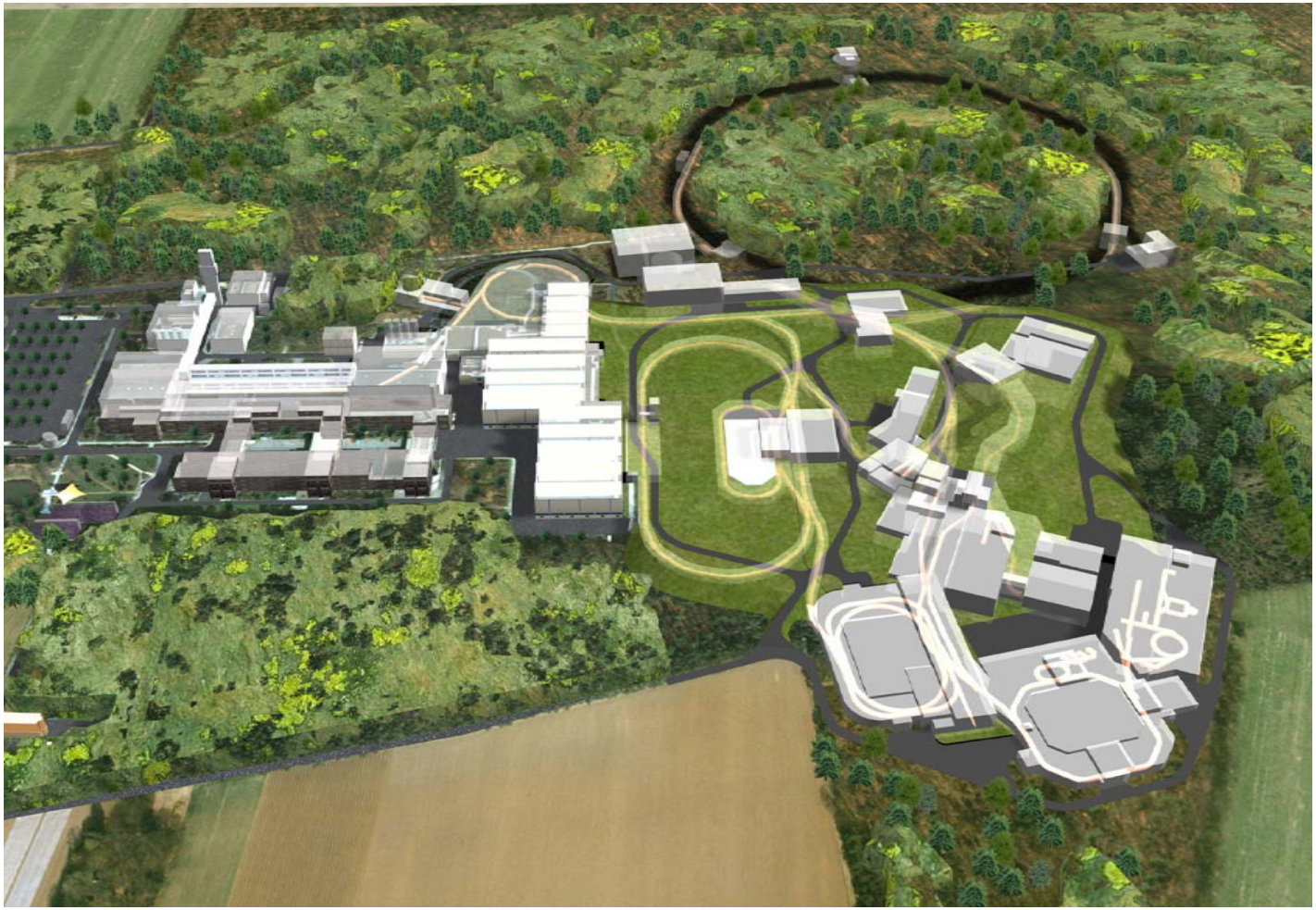
Hadron physics with anti-proton beams

Nuclear structure physics with rare isotope beams

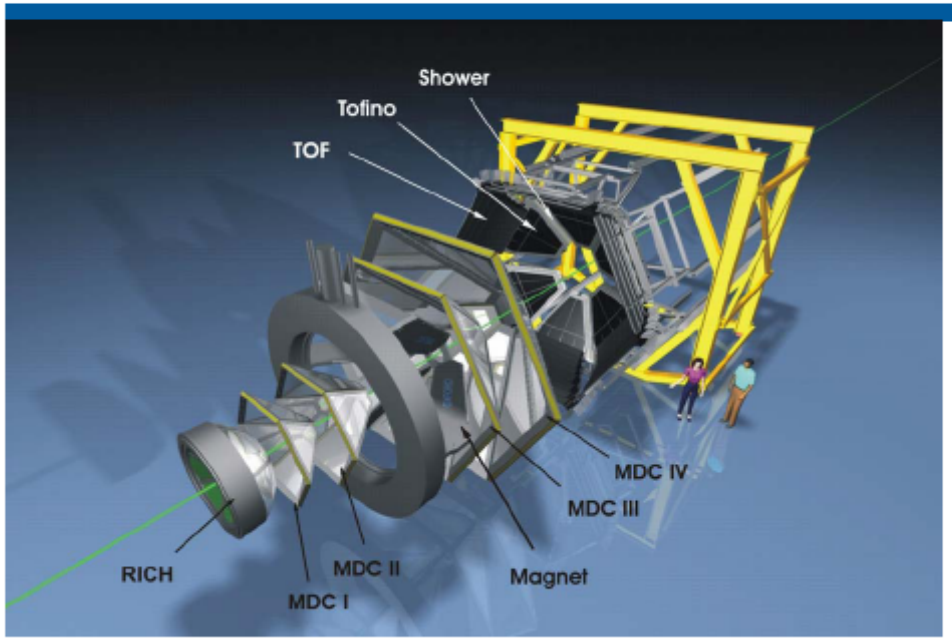
Plasma physics with short-pulsed heavy-ion beams

Atomic physics with highly charged ions and low-energy anti-protons

Nuclear collisions:
CBM
Ion beams 10^9/s
10 – 45 AGeV



HADES: the structure of resonance matter

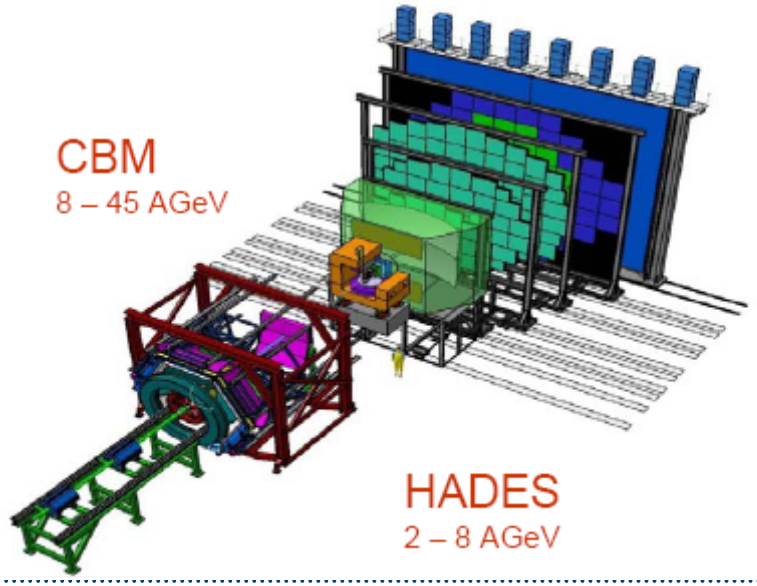


HADES

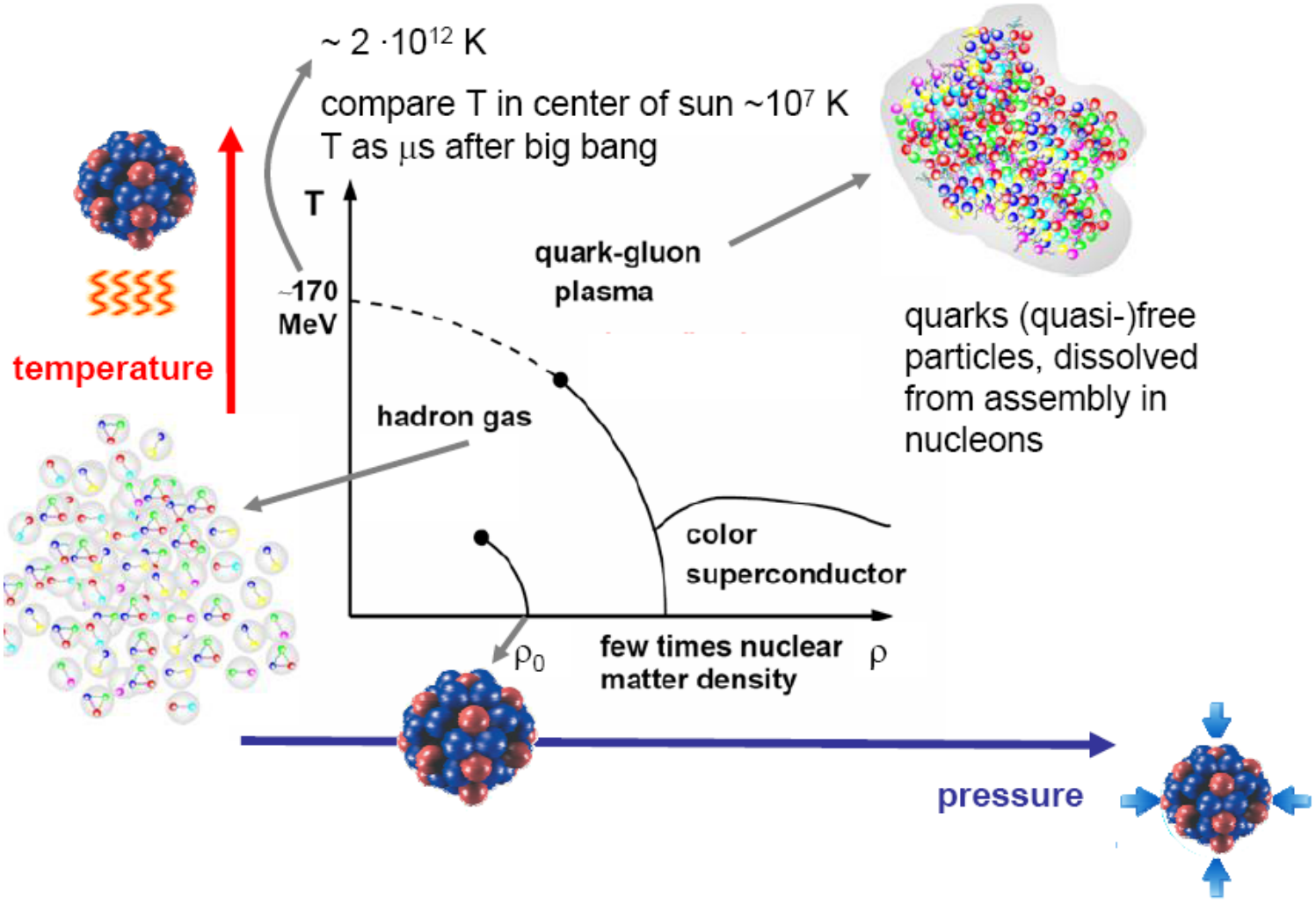
- in-medium modifications of hadrons
- 2010-14:
  heavy collision systems (Ni, Au)
  and π-induced reactions
- @ SIS-100/FAIR:
  Dielectron excitation function
  up to 8 AGeV

CBM

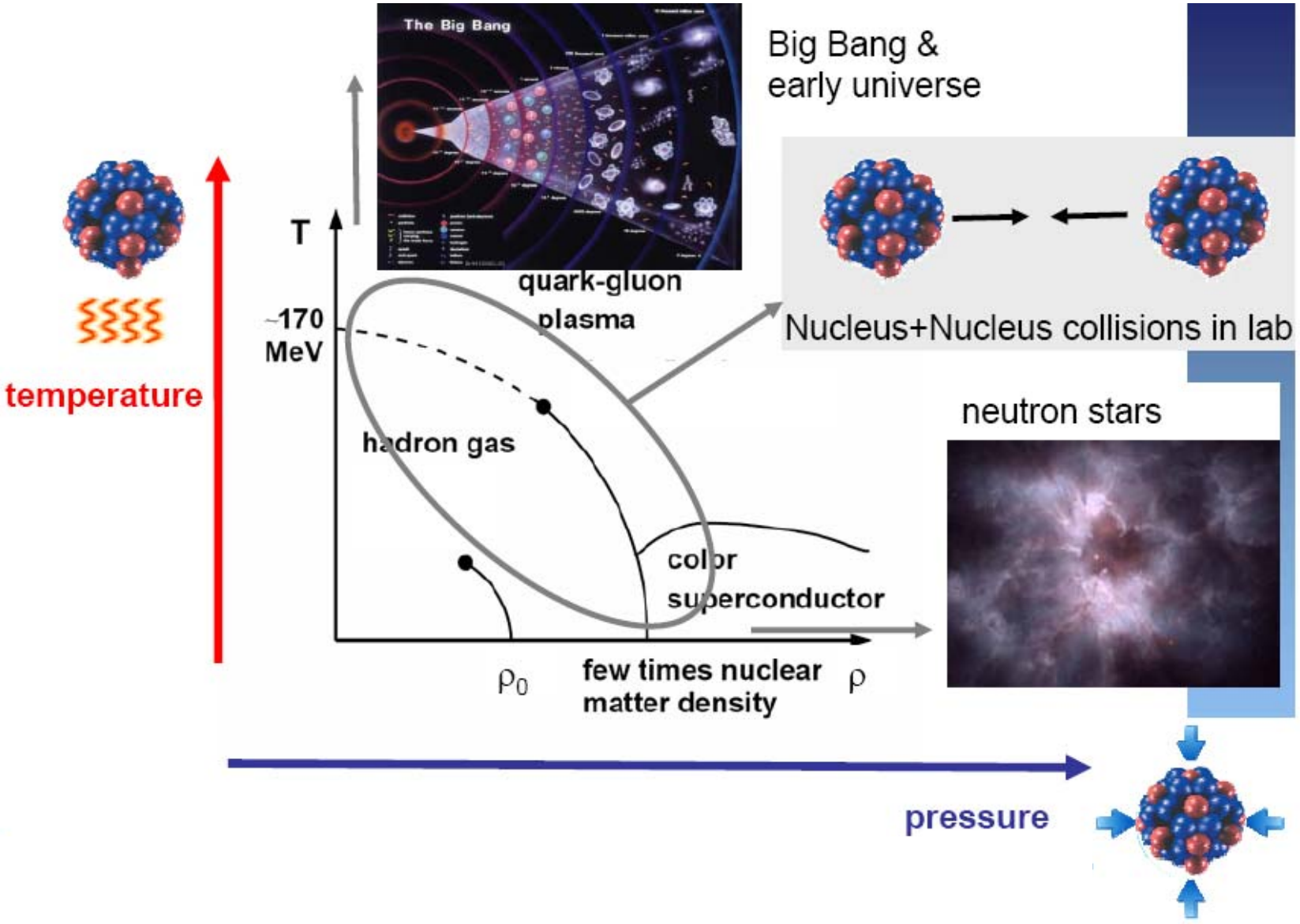
- Exploration of the QCD phase diagram at highest baryon densities
- Experimental focus on rare diagnostic probes
- High-rate detectors with free-streaming readout and online event selection



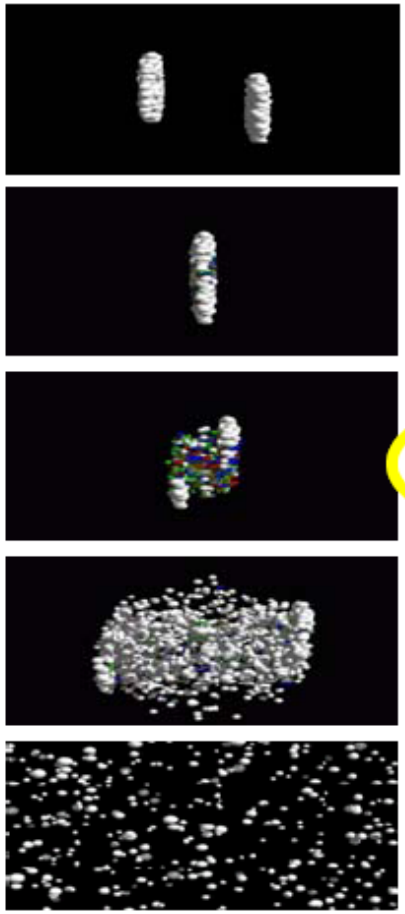
Phasediagram: stark wechselwirkende Materie



Phasediagram: stark wechselwirkende Materie



UrQMD 160 GeV Au+Au



before collision

compression and heating ($T >> T_{chem} \sim 160$ MeV)

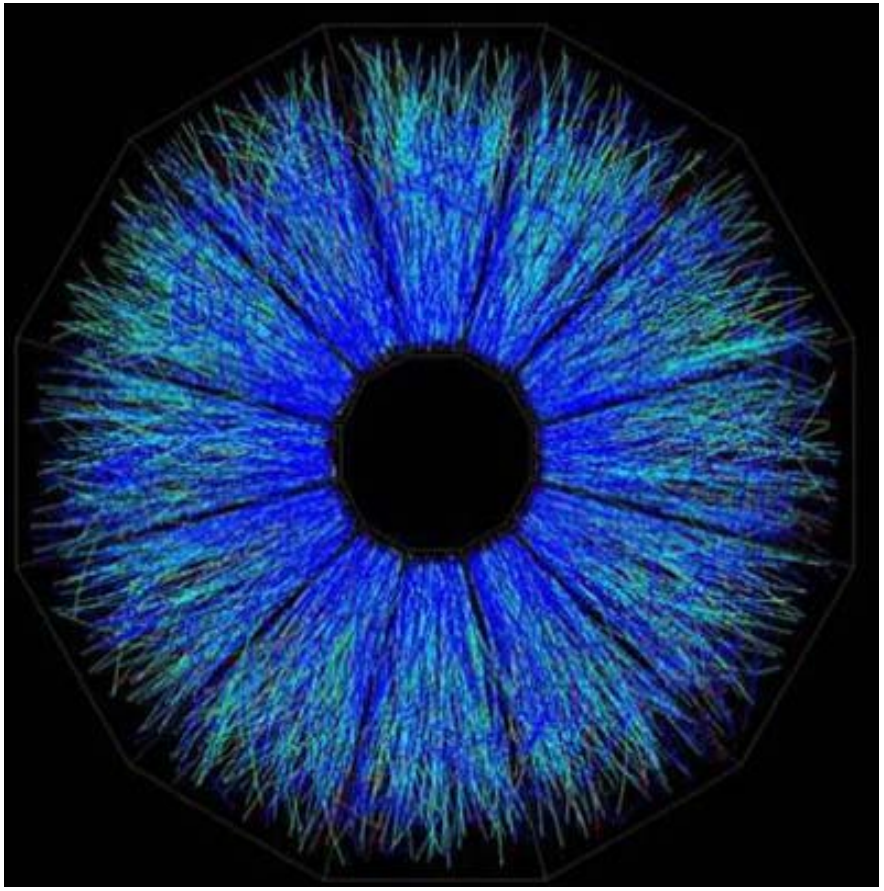
thermalization of the "fireball"
(high T and ρ reached for ~10fm/c = 3.3 10^{-23} s)

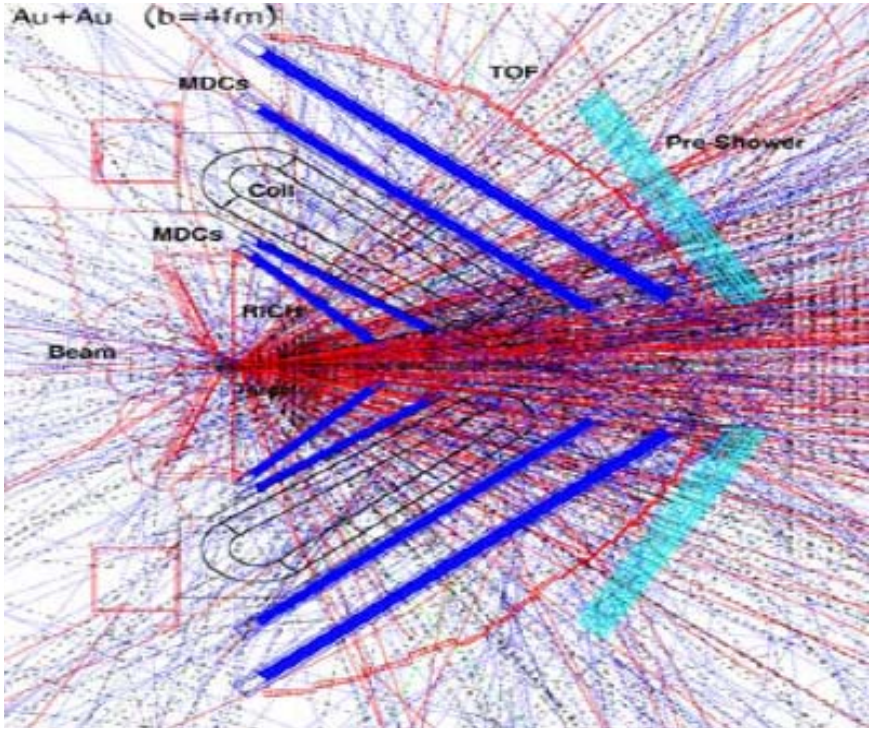
expansion

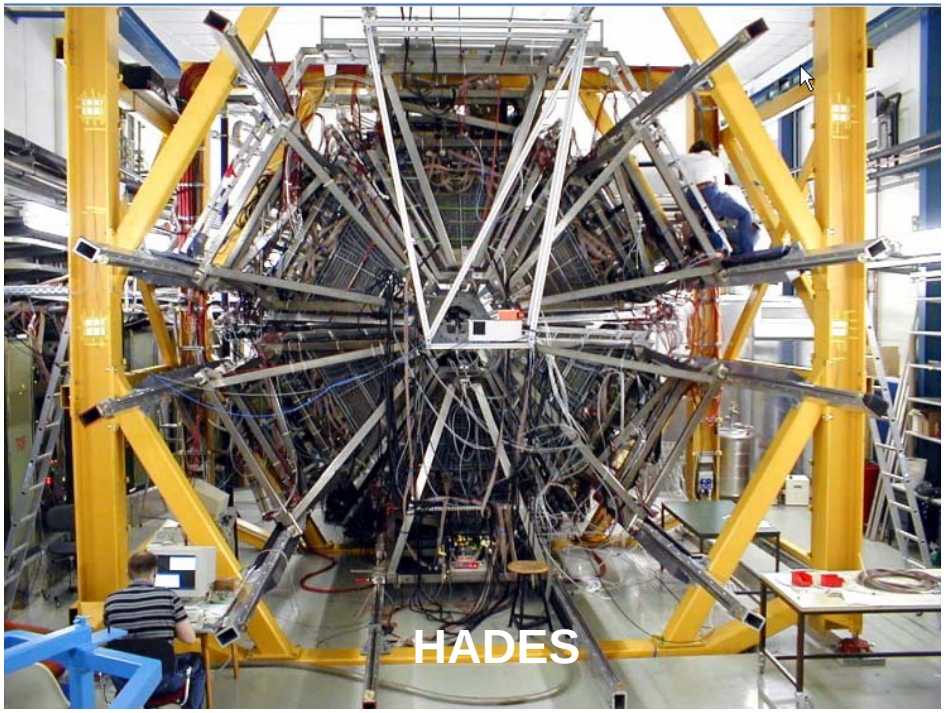
chemical freezeout (number and type of particles frozen)
kinetic freezeout (particle momenta frozen)
$T_{chem} \sim 160$ MeV ~ $2 \cdot 10^{12}$ K)

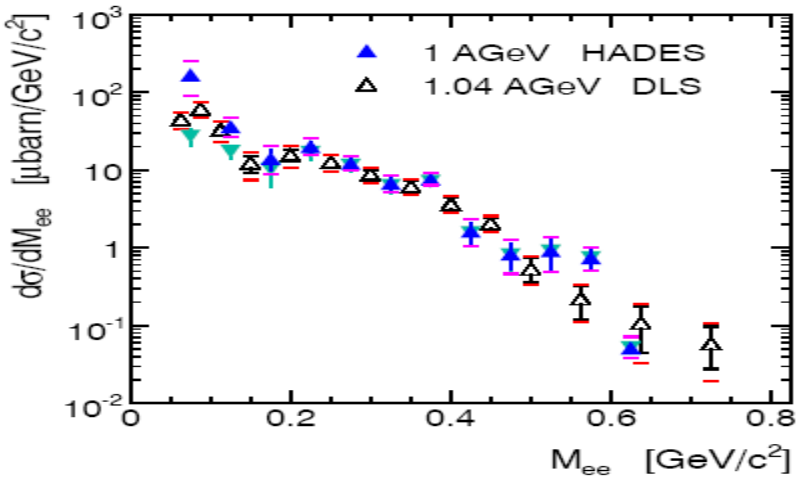
Relativistische Schwerionenstöße

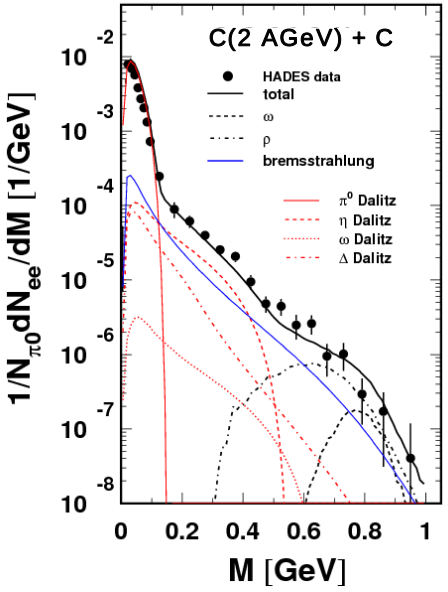
- measure as many produced particles as possible: reconstruct the properties of the produced hot and dense matter
- A+A collisions studied at various energies
  → investigate different regions of the phase diagram









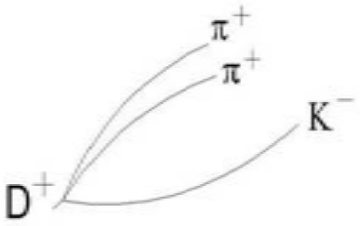


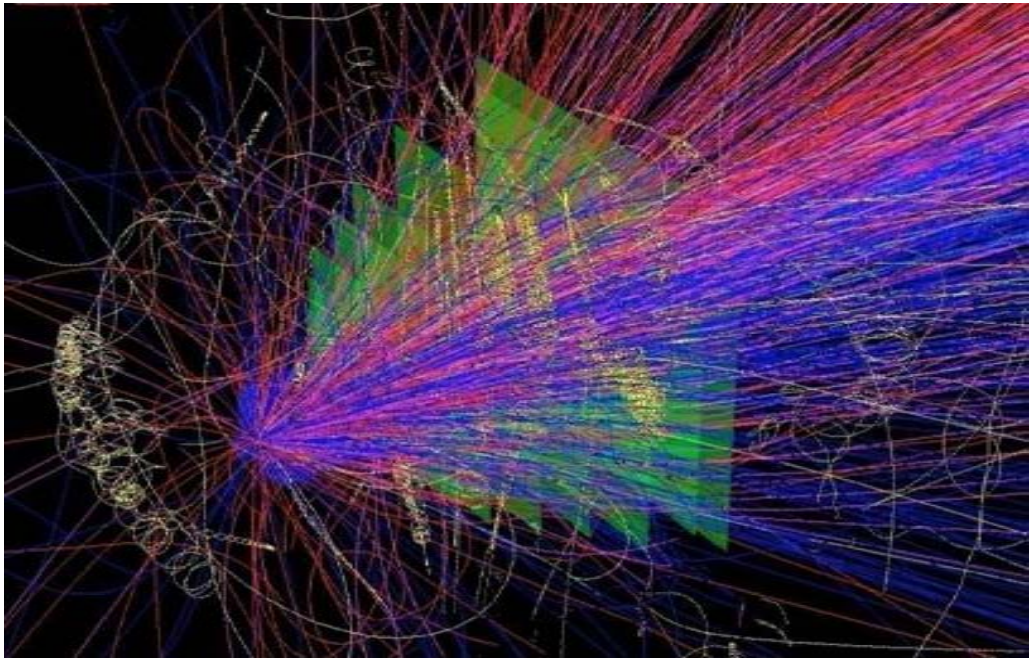
Massen der Hadronen

Challenge: high track density: ≈ 600 charged particles in ± 25° @ 10MHz

Task

- track reconstruction: 0.1 GeV/c < p ≤ 10-12 GeV/c $\Delta p/p \sim 1\%$ (p=1 GeV/c)
- primary and secondary vertex reconstruction (resolution ≤ 50 μm)
- V_0 track pattern recognition





Zusammenfassung

- Große Beschleunigerexperimente liefern neues Verständnis der Struktur der Materie

- LHC-Experimente sind jetzt dabei, die Ursache der Masse zu untersuchen

- Stark wechselwirkende Materie wird am GSI-Darmstadt mit Schwerionenstößen untersucht

- Neue Experimente, wie CBM @ FAIR, werden die Entwicklung des Universums genauer erläutern