TECHNISCHE UNIVERSITÄT DRESDEN

iktp

Fakultät Mat/Nat Fachrichtung Physik Institut für Kern- und Teilchenphysik

Antimaterie

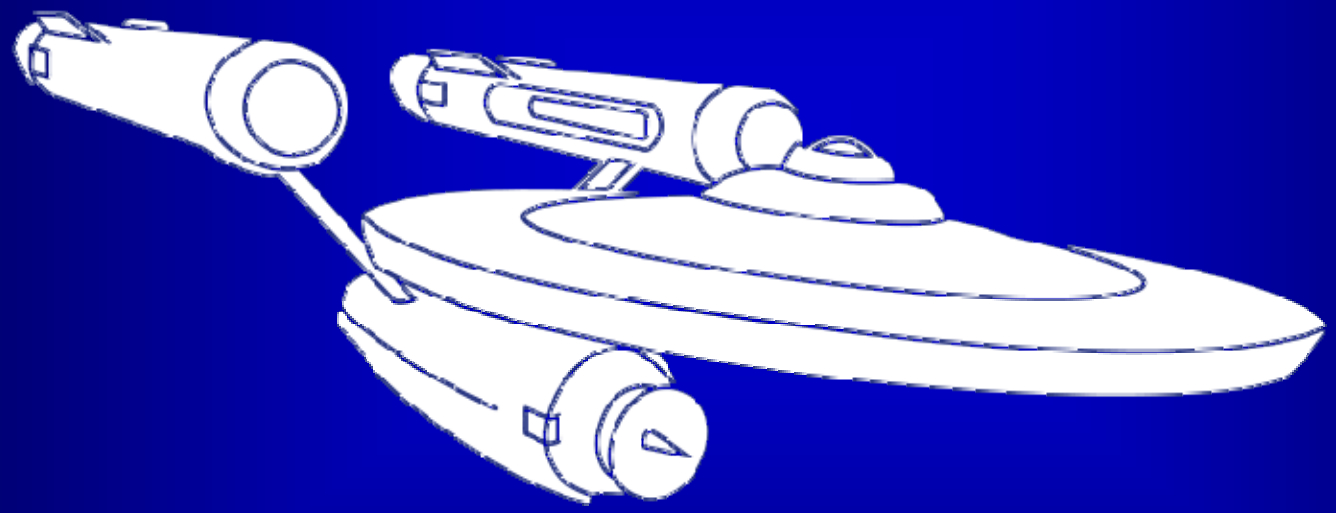
- Antimaterie populär
- Antimaterie wissenschaftlich betrachtet
  - Historisches
  - Antiteilchen
  - Eigenschaften von Antiteilchen
  - Vorkommen von Antimaterie
  - Antiteilchen als Forschungsgegenstand
  - Forschung mit Antimaterie

Kai-Thomas Brinkmann , 17. November 2007

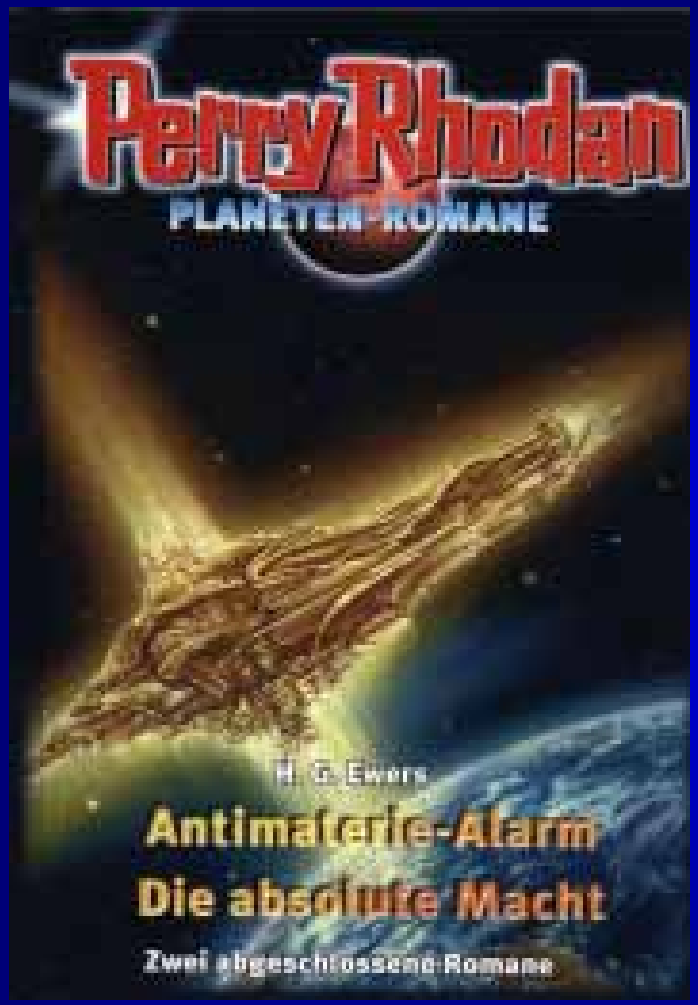
Antimaterie populär

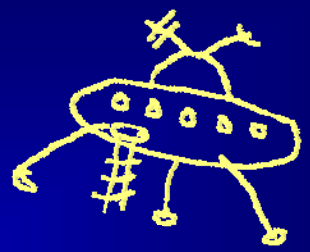
Antimaterie ist seit 50 Jahren unverzichtbar ...

IN DER SCIENCE FICTION



Antimaterie populär

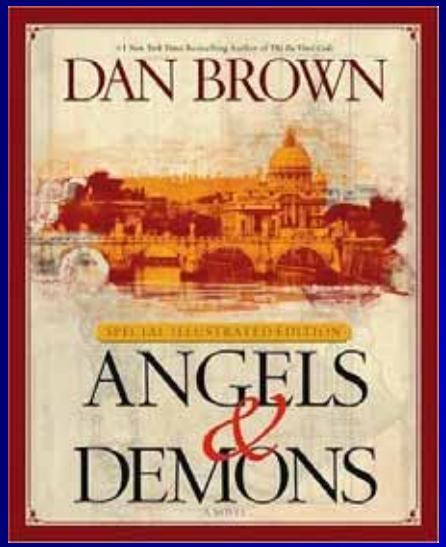


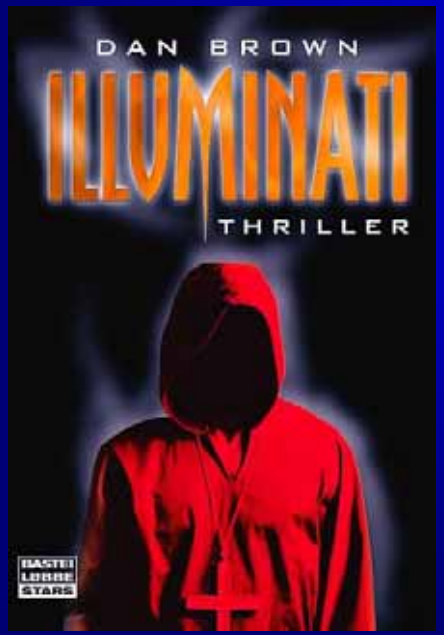


Antimaterie ergibt

- Raumschiffantriebe (oft FTL)
- Anti-Universen
- Waffen

Antimaterie populär





Antimaterie populär

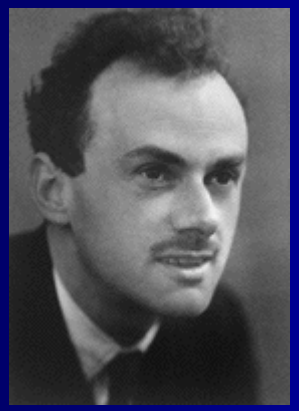
Antimaterie wissenschaftlich betrachtet

Antimaterie populär

Antimaterie wissenschaftlich betrachtet

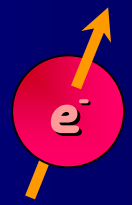
Antimaterie wissenschaftlich betrachtet

Dirac, 1928



Paul A.M. Dirac
(1902-1984)
Nobelpreis 1933

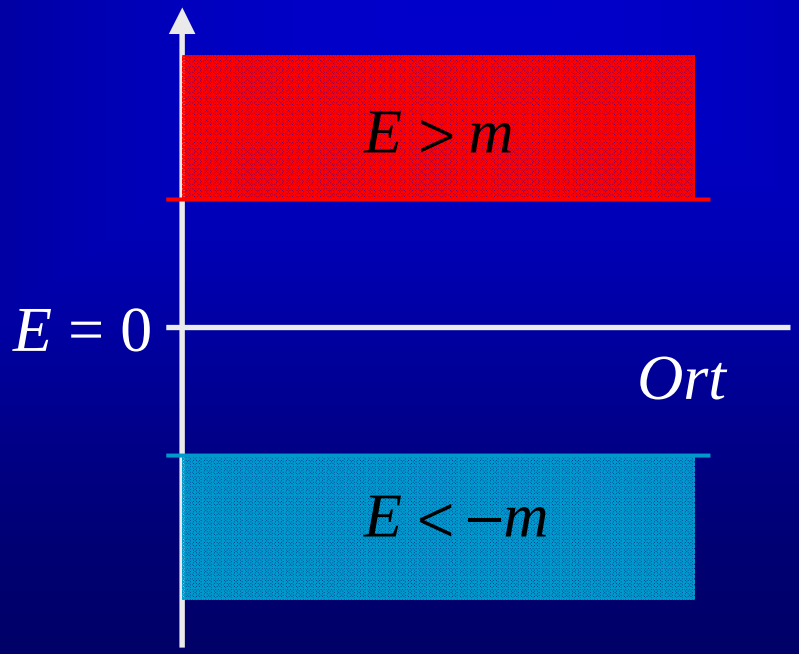
Erweiterung der Quantenmechanik von Fermionen auf relativistische Phänomene



⇨ Lösungen mit positiver und negativer Energie

$$E^2 = p^2 + m^2 \quad \Rightarrow \quad E = \pm\sqrt{p^2 + m^2}$$

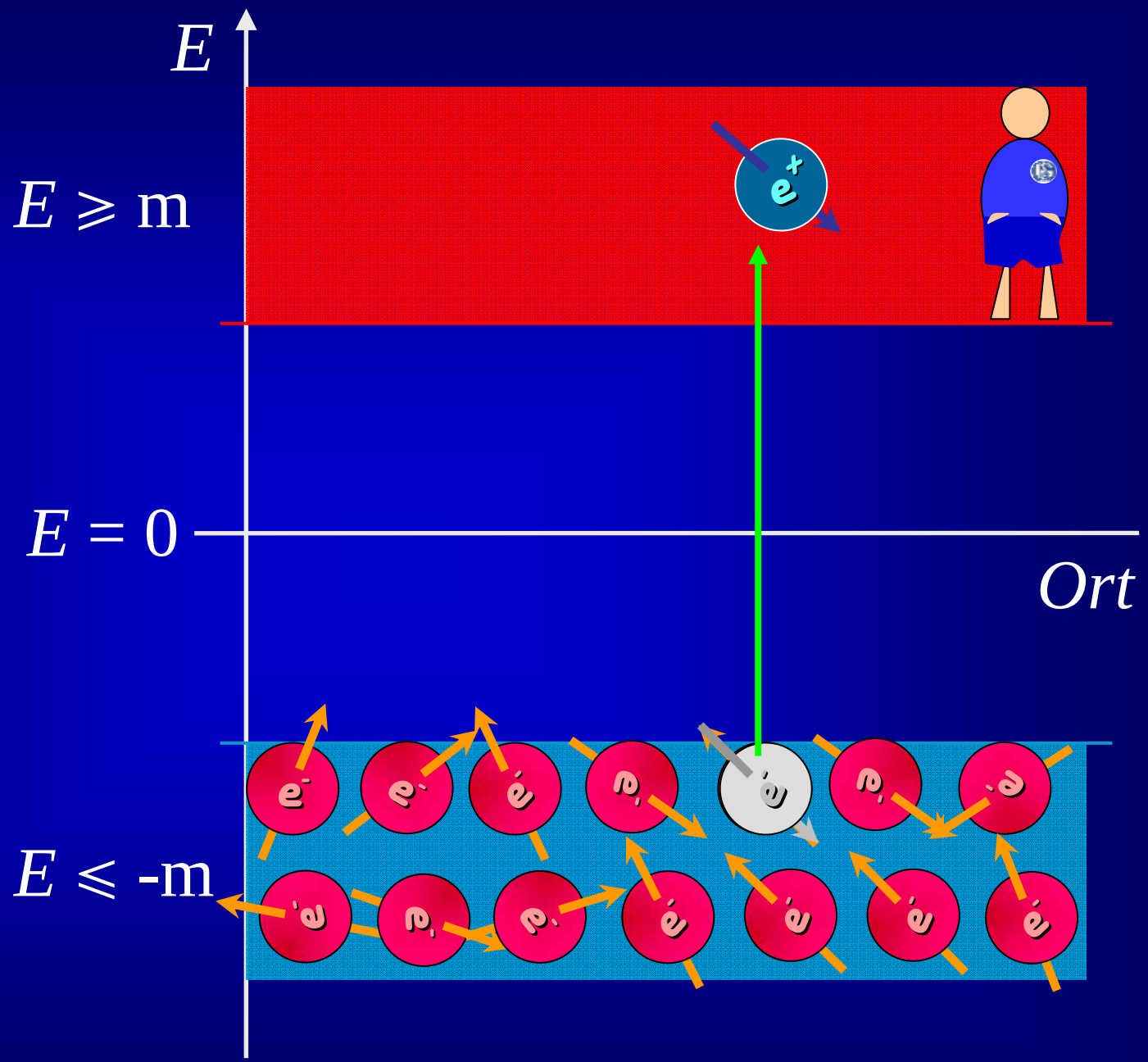
Deutung (1931):



theoretische Vorhersage eines Teilchens mit der Masse des Elektrons, aber positiver Ladung

Paul A.M. Dirac

Antimaterie physikalisch

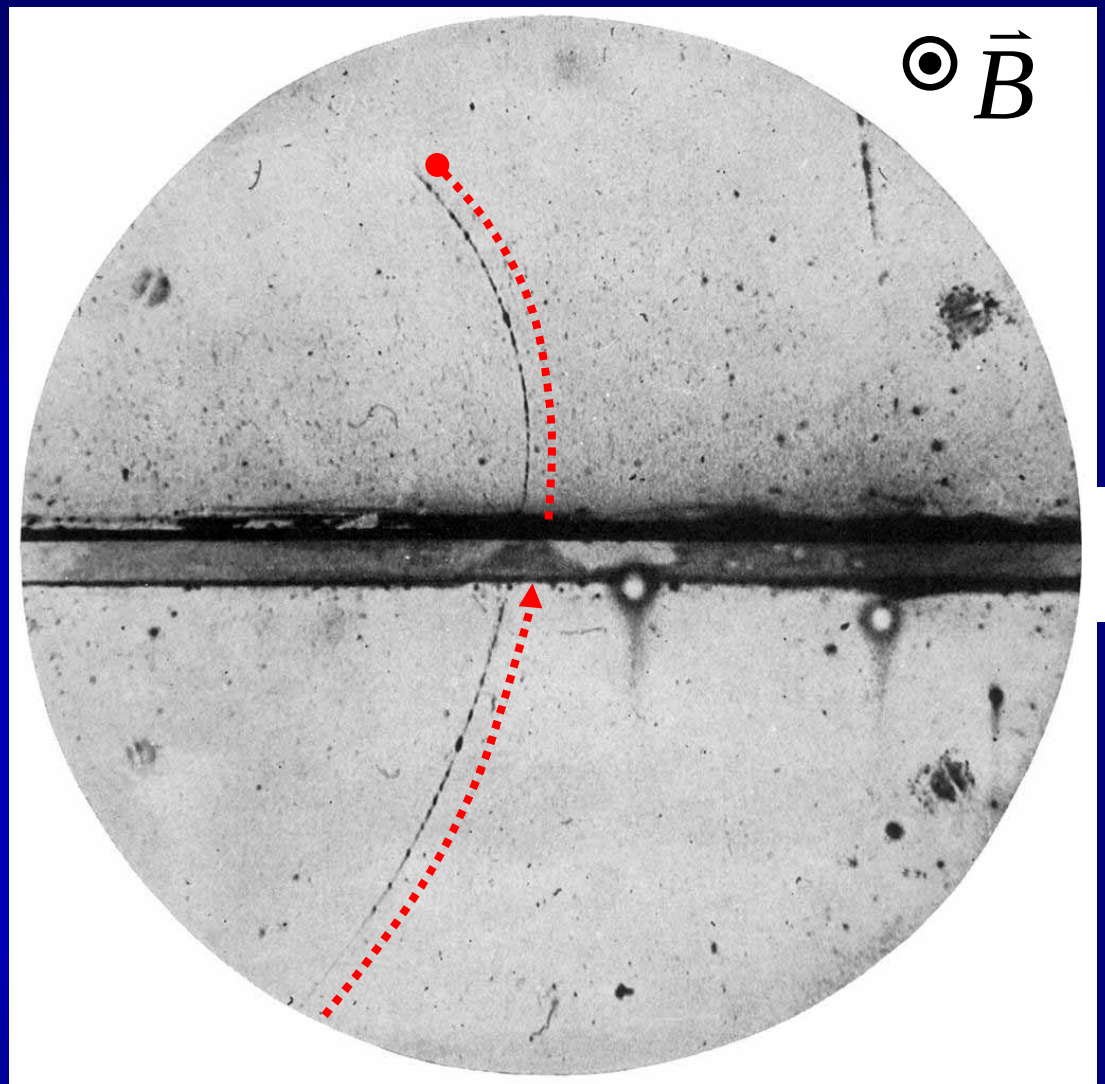


Anderson, 1932

Antimaterie physikalisch

Carl D. Anderson
(1905-1991)
Nobelpreis 1936

Victor F. Hess
(1883-1964)
Nobelpreis 1936



6 mm
Blei

FIG. 1. A 63 million volt positron ($H\rho = 2.1 \times 10^5$ gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ($H\rho = 7.5 \times 10^4$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.

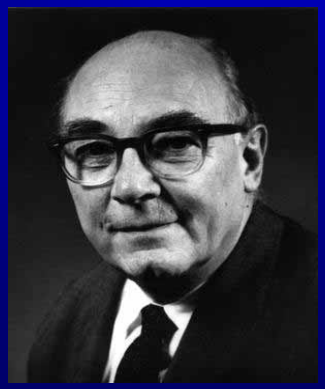
Experimenteller Nachweis von Antielektronen (≡Positronen) mit kosmischer Strahlung

Antimaterie physikalisch

Nachweis von

γ („Energie“) $\rightarrow e^+ e^-$

Carl D. Anderson



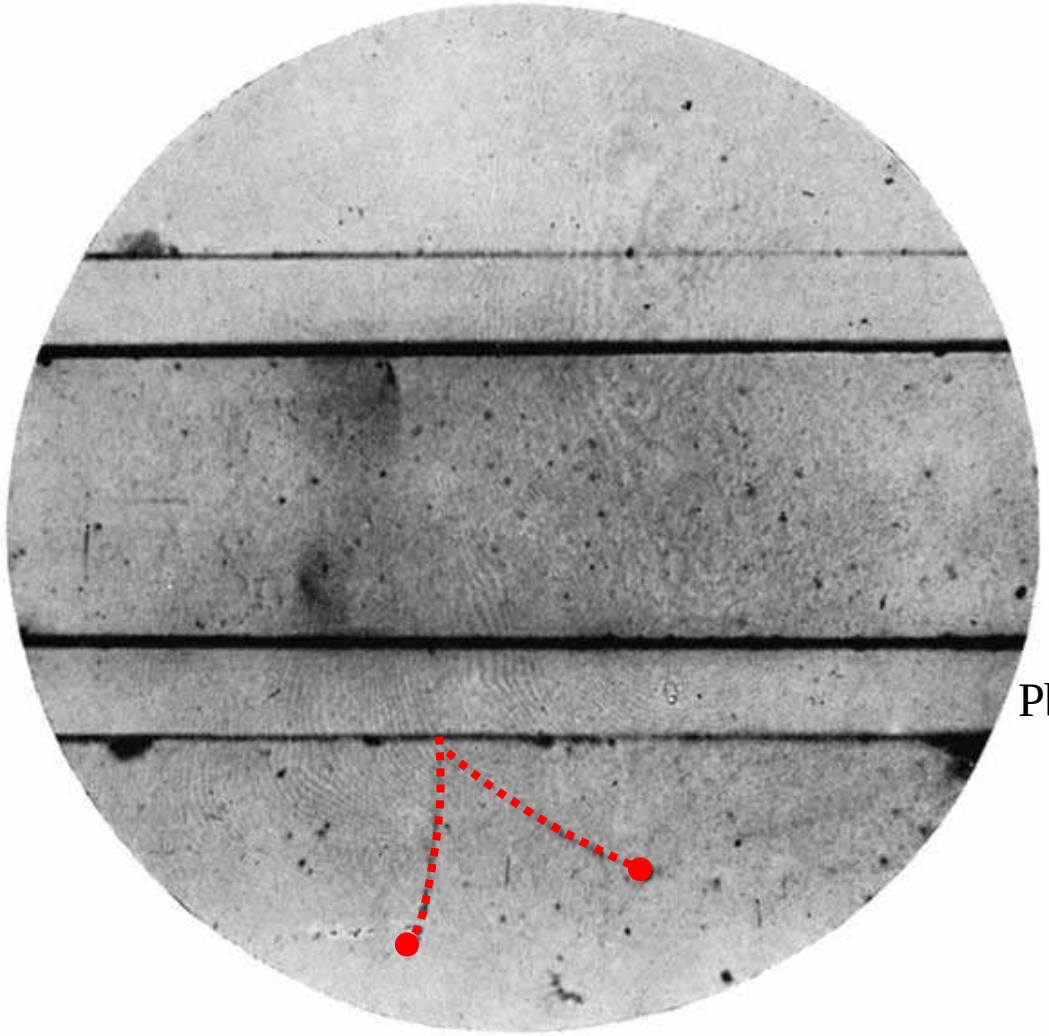


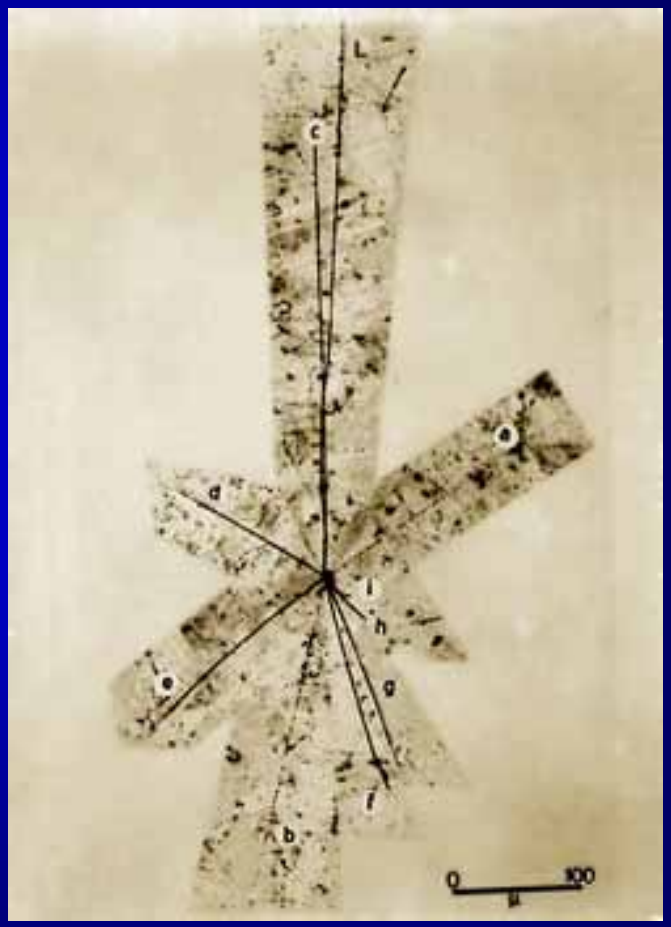
FIG. 2. A positron of 20 million volts energy ($H\rho = 7.1 \times 10^4$ gauss-cm) and a negatron of 30 million volts energy ($H\rho = 10.2 \times 10^4$ gauss-cm) projected from a plate of lead. The range of the positive particle precludes the possibility of ascribing it to a proton of the observed curvature.

Weitere Highlights in der Suche nach Antiteilchen

Erzeugung und Nachweis von Antiprotonen

Antimaterie physikalisch

1955 Nobelpreis 1959
O.Chamberlain,
E.Segrè,
C.Wiegand,
T.Ypsilantis



1956 Piccioni et al.: Antineutron

1965 Zichichi et al.: Antideuteron

Teilchen und Antiteilchen

Jedem Teilchen ist ein Antiteilchen zugeordnet.

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

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c^2	Electric charge	Flavor	Approx. Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0	u up	0.003	2/3
e electron	0.000511	−1	d down	0.006	−1/3
ν_μ muon neutrino	<0.0002	0	c charm	1.3	2/3
μ muon	0.106	−1	s strange	0.1	−1/3
ν_τ tau neutrino	<0.02	0	t top	175	2/3
τ tau	1.7771	−1	b bottom	4.3	−1/3

BOSONS force carriers spin = 0, 1, 2, ...

Unified Electroweak spin = 1			Strong (color) spin = 1		
Name	Mass GeV/c^2	Electric charge	Name	Mass GeV/c^2	Electric charge
γ photon	0	0	g gluon	0	0
W^-	80.4	−1			
W^+	80.4	+1			
Z^0	91.187	0			

Gravitation (?)

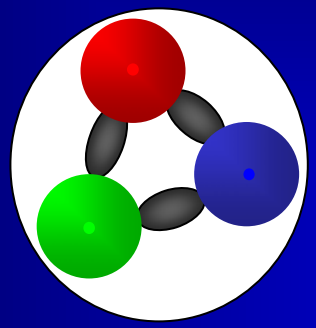
http://www.cpepweb.org/cpep_sm_large.html

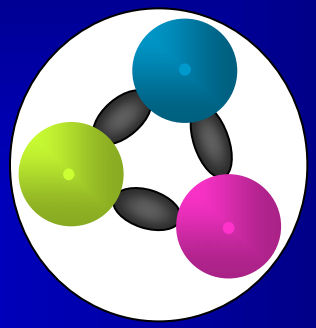
Fermionen (halbzahliger Spin) können nur zusammen mit ihren Antiteilchen erzeugt / vernichtet werden.

Für Bosonen (ganzzahliger Spin) gilt das nicht.

Alle (bekannten) Teilchen ergeben sich mit wenigen Konstruktionsregeln aus diesem Baukasten.

p
(uud)



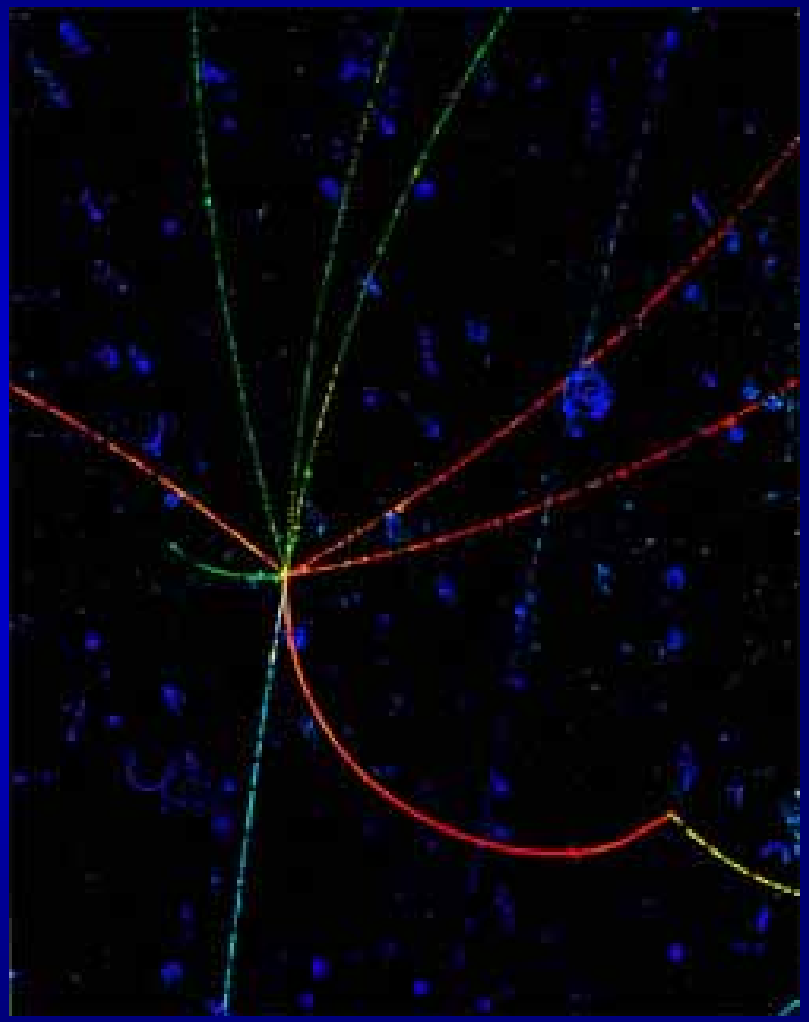


$\bar{p}$
($\bar{d}\bar{u}\bar{u}$)

1955 Nobelpreis 1959

O.Chamberlain,
E.Segrè,
C.Wiegand,
T.Ypsilantis

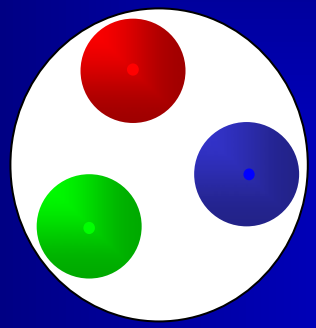
Erzeugung und Nachweis von Antiprotonen

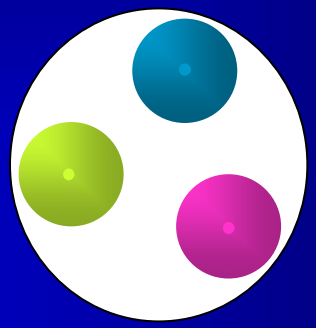


Nachweis von Antiprotonen

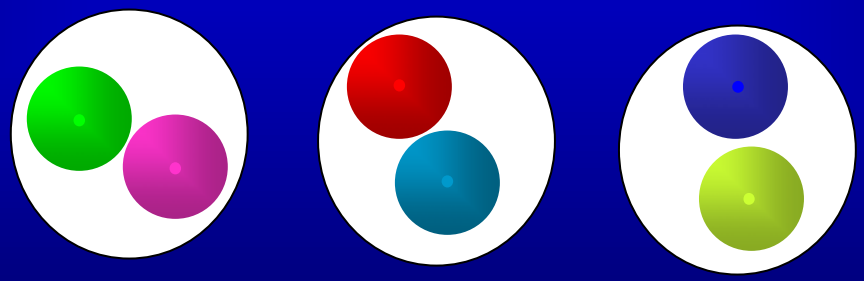
$$\bar{p}p \rightarrow \pi^+\pi^- \pi^+\pi^- \pi^+\pi^- \pi^+\pi^-$$

p
(uud)



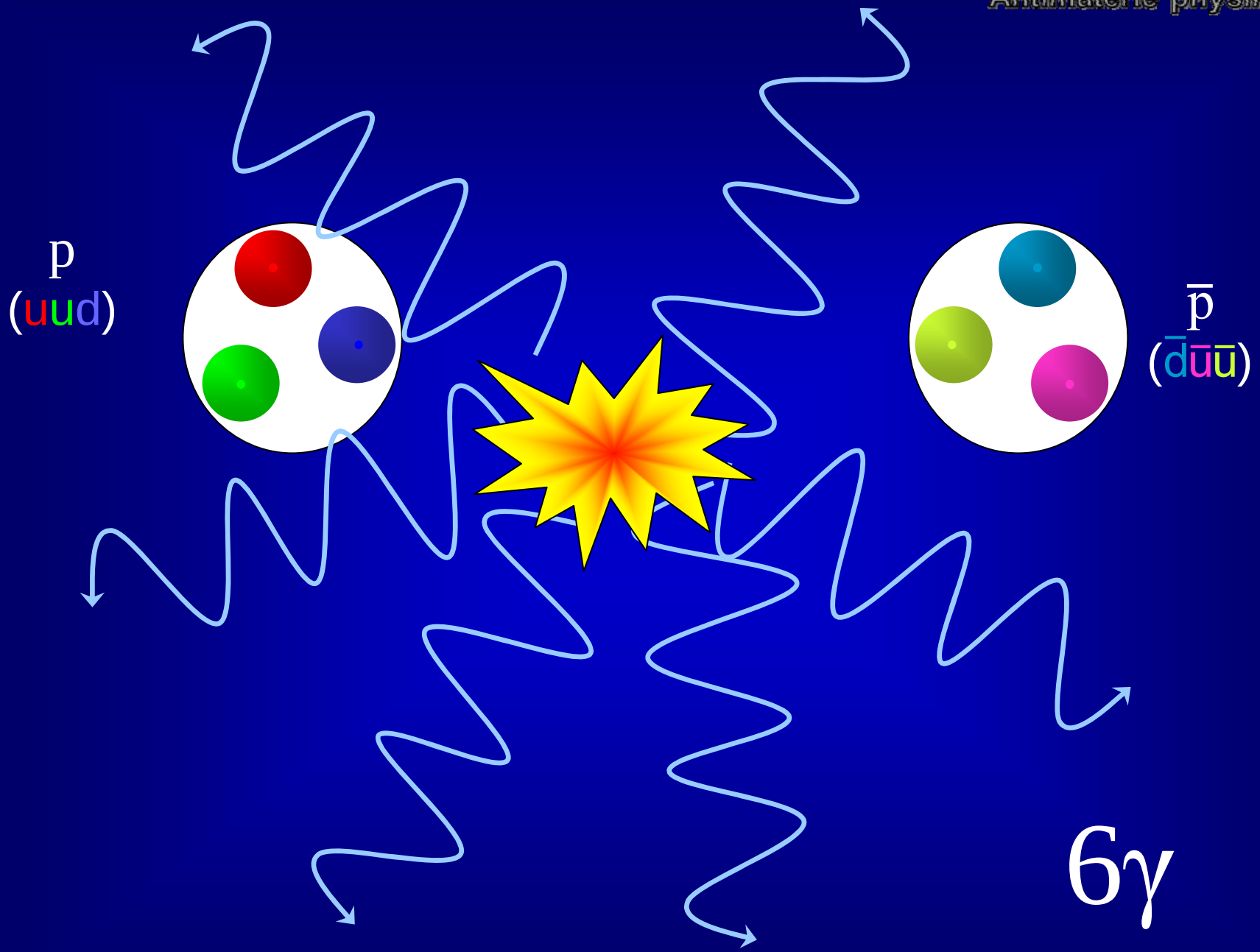


$\bar{p}$
($\bar{d}\bar{u}\bar{u}$)

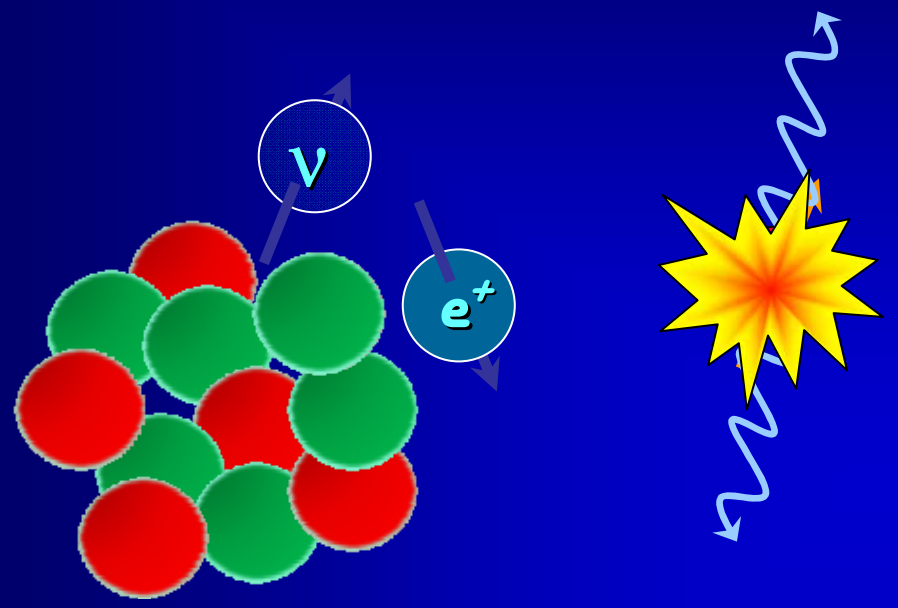


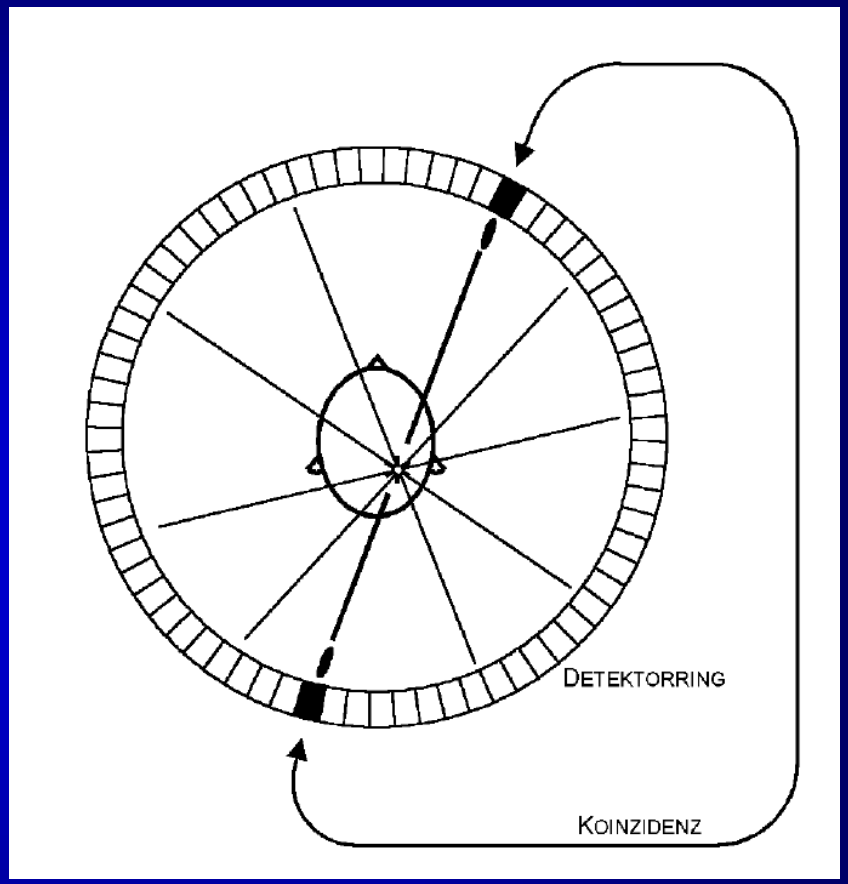
π^+ π^0 π^-
($u\bar{d}$ $u\bar{u}$ $d\bar{u}$)

Antimaterie physikalisch



Anwendung: PET (Positronenemissionstomografie)



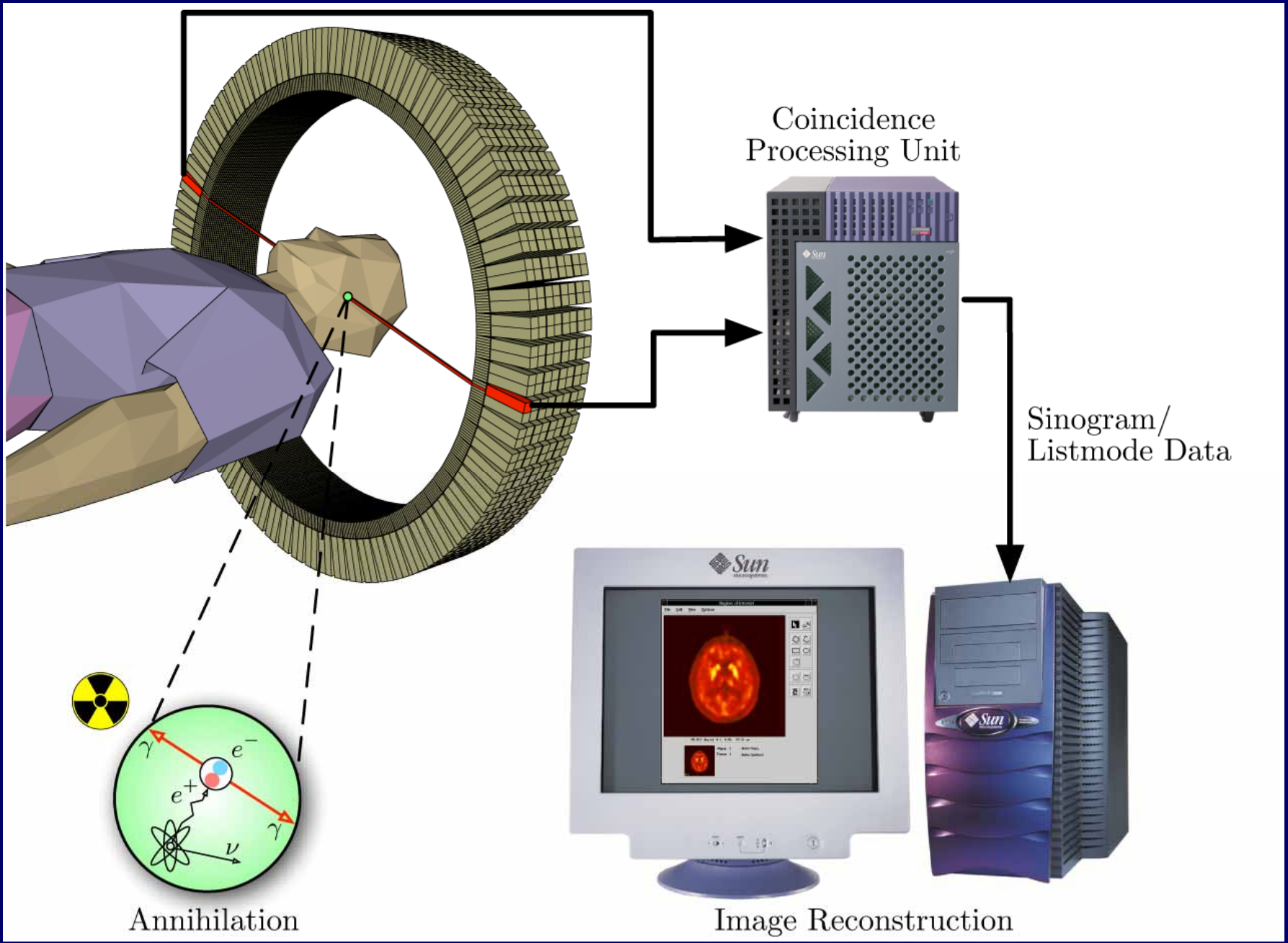


Positronen entstehen in

Zerfällen von Radioisotopen

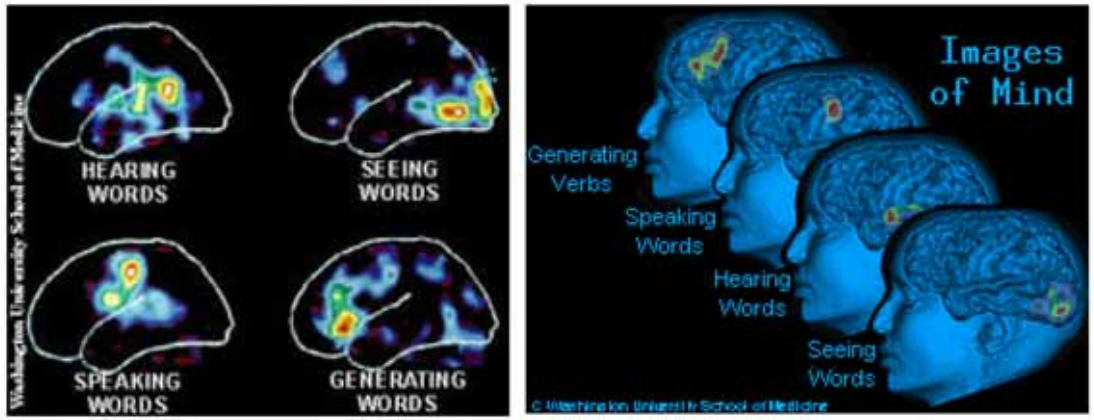
z.B. ^{11}C, ^{13}N, ^{15}O, ^{18}F geeignet zur Herstellung von Markern

Antimaterie - Anwendung



Antimaterie - Anwendung

Positronen-Emissions-Tomographie (PET)
funktionelle Bildgebung



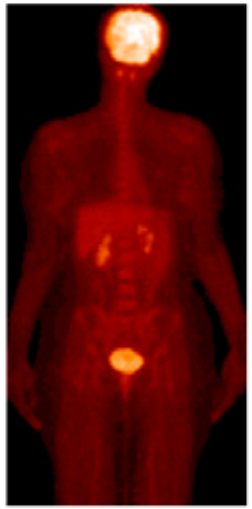
http://imbie.meb.uni-bonn.de/epileptologie/staff/lehnertz/NukMed5.pdf

Positronen-Emissions-Tomographie (PET)
Ganzkörper-Scan **gesunde Person**

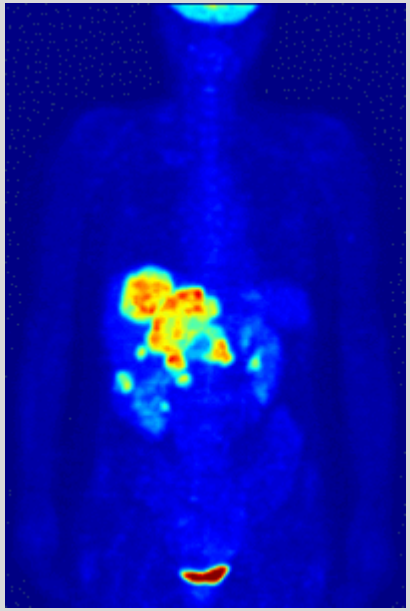
Gehirn →

Niere →

Blase →



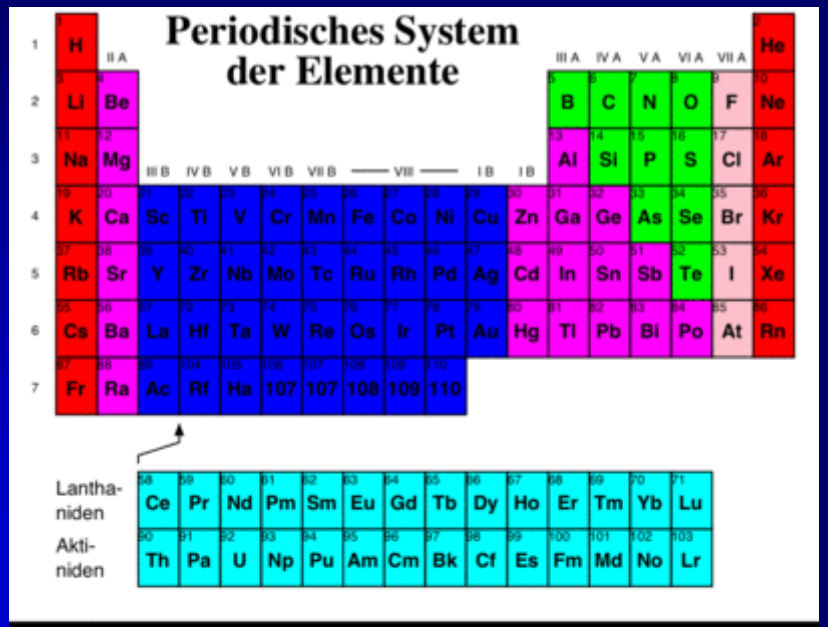
http://imbie.meb.uni-bonn.de/epileptologie/staff/lehnertz/NukMed5.pdf

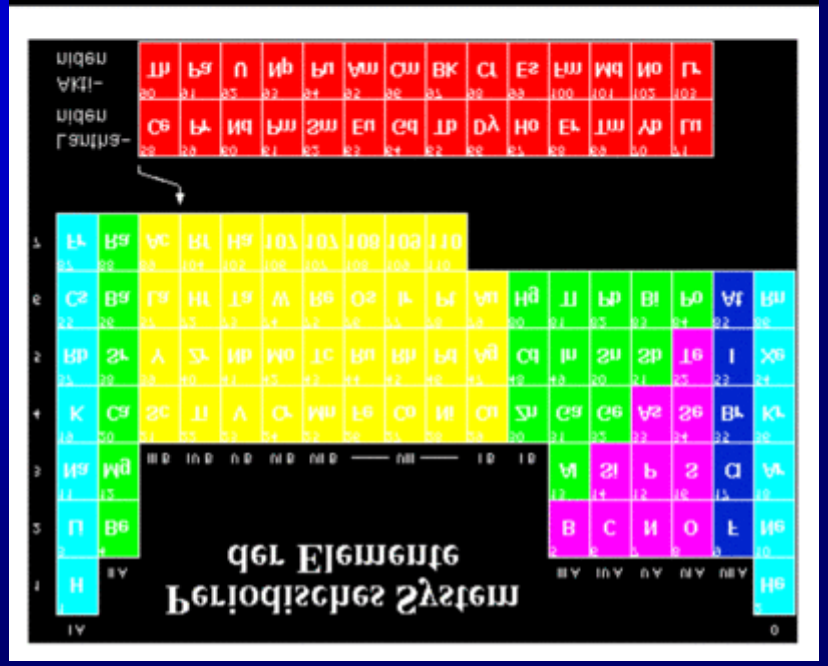


Antiteilchen und Antimaterie

Materie entsteht durch die (elektrisch neutrale) Bindung von Teilchen in Atomen.

Existiert dazu eine „Antiwelt“?

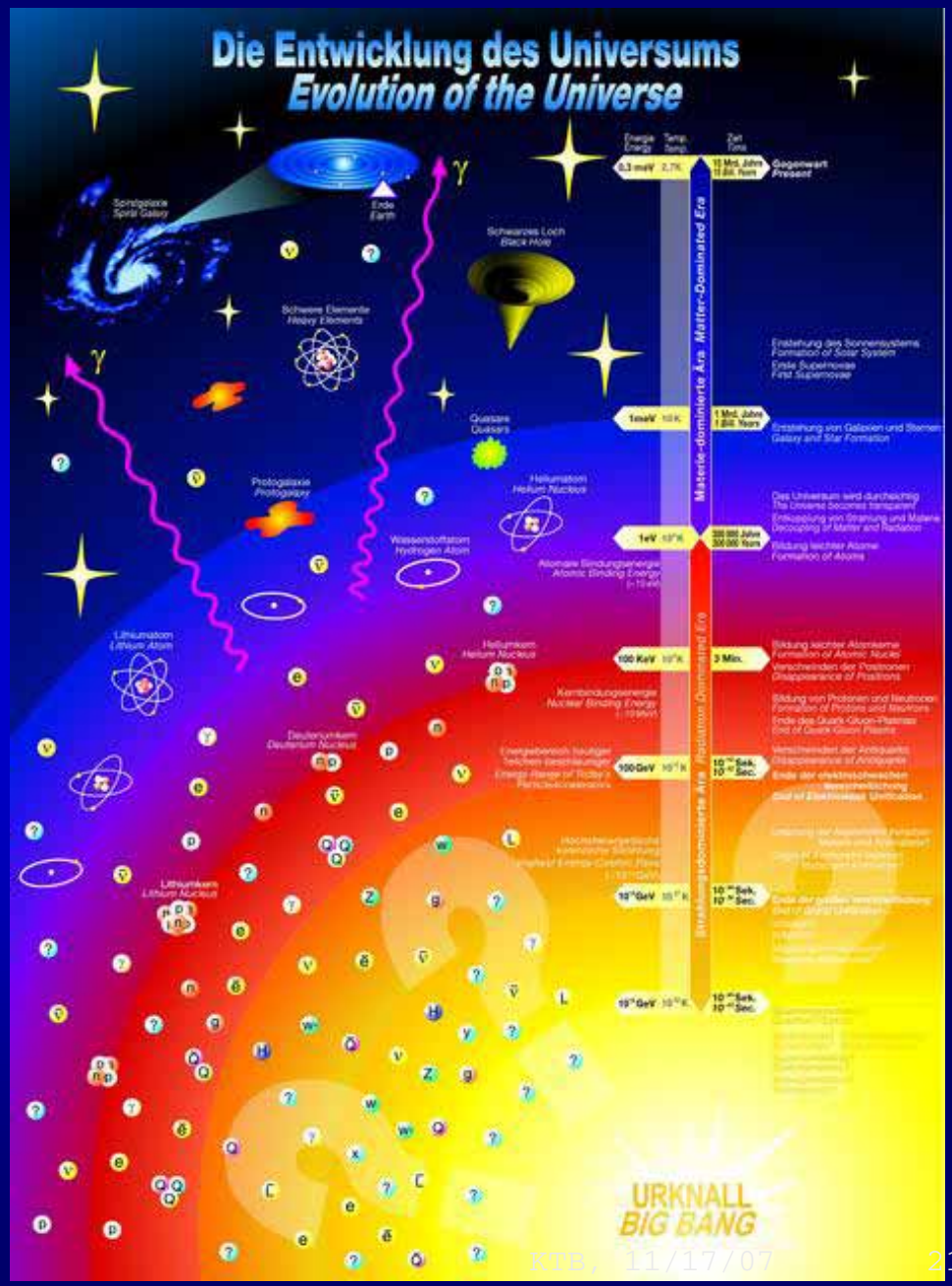




Suche im Kosmos

Im Urknall:

q/q̄ etc. im Gleichgewicht

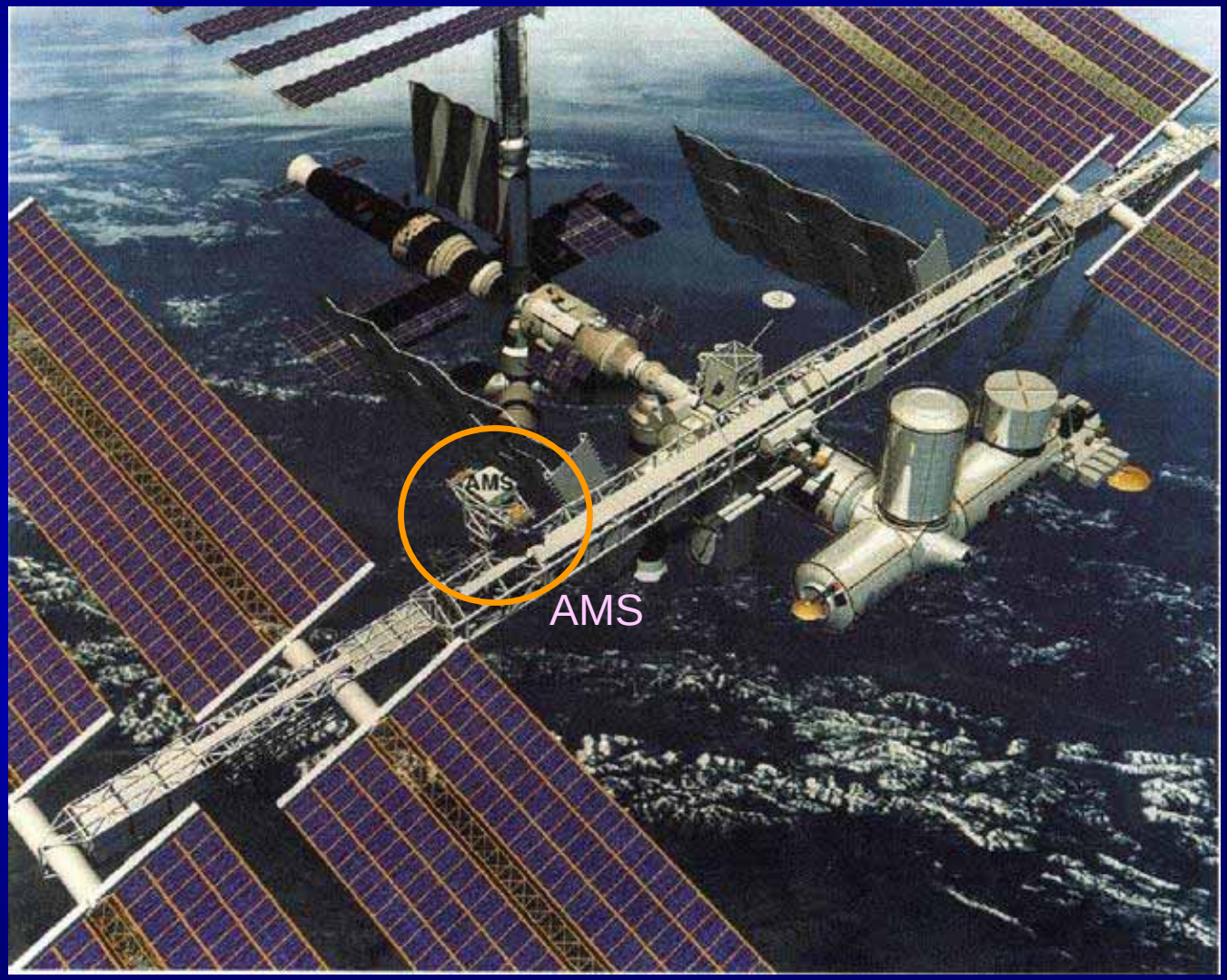


⇨ Materie und Antimaterie gleich häufig!

ODER?

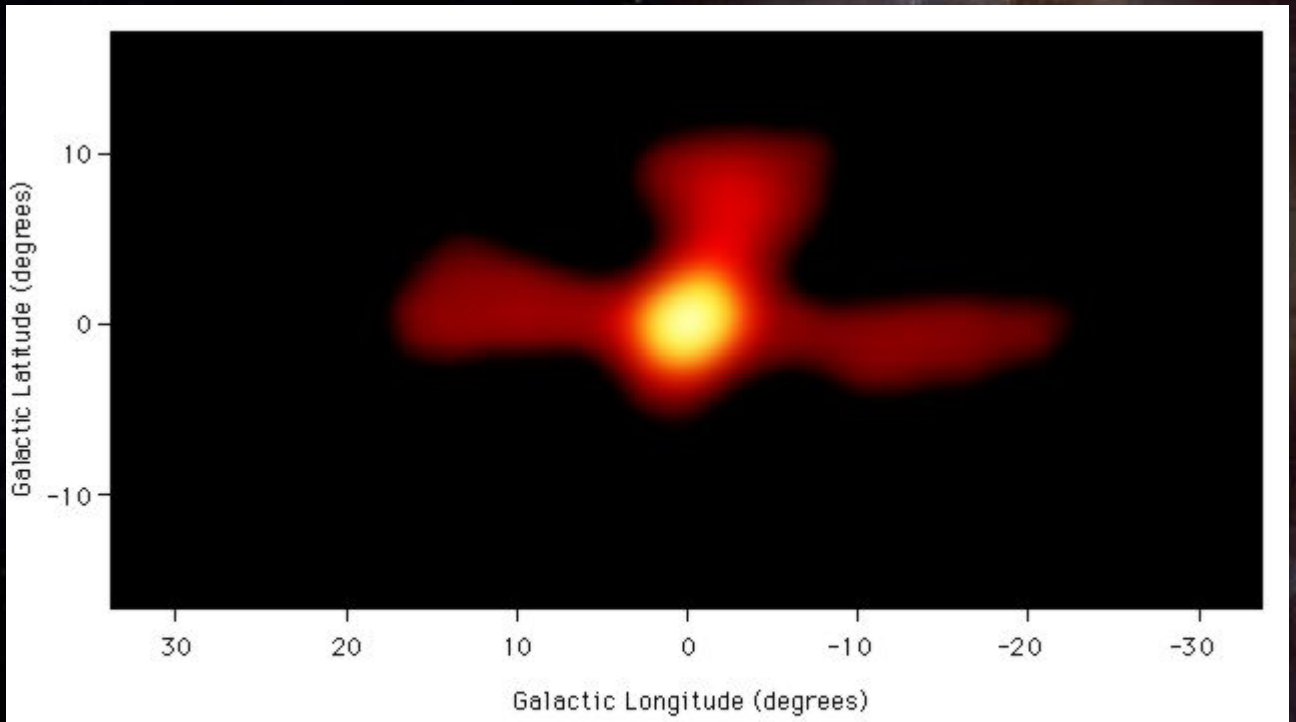
Suche in kosmischer Strahlung

Suche in kosmischer Strahlung



Suche im Universum

Materie, wo man hinsieht!



Caption: Map of the distribution of positrons towards the center of the Milky Way Galaxy, including the newly discovered antimatter "cloud". The brightest feature corresponds to the nucleus of the Galaxy. The horizontal structure lies along the plane of the Galaxy. The antimatter "cloud" is located above the Galactic center.

Courtesy of D. D. Dixon (University of California, Riverside) and W. R. Purcell (Northwestern University)

Suche im Kosmos

Im Urknall:

$q/\bar{q}$ etc. im Gleichgewicht

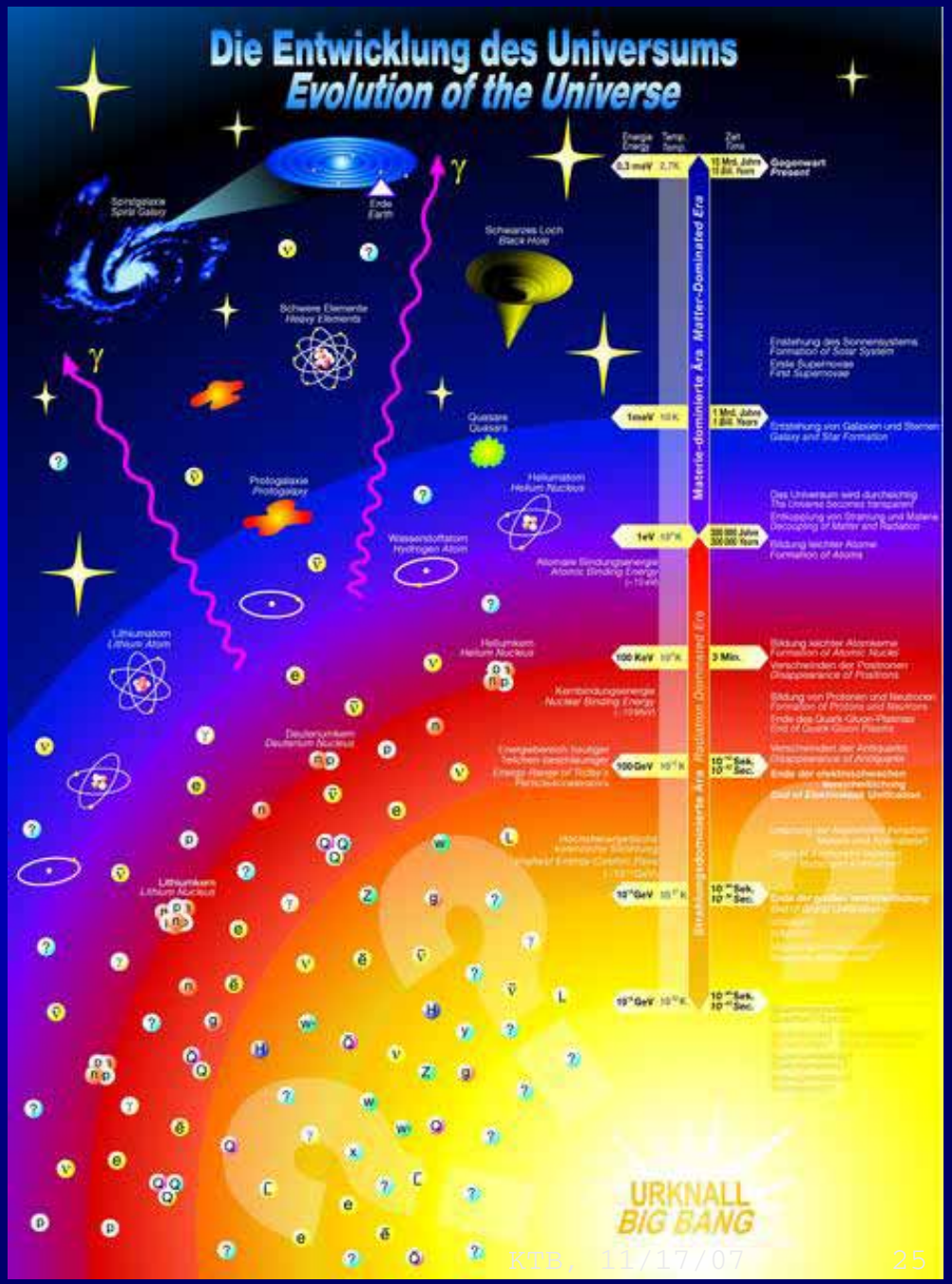
Heute:

q noch da, $\bar{q}$ nicht!

ÜBERRASCHUNG!

Wenn man genau guckt:

$$q/\bar{q} = 1 / (1-10^{-9})$$

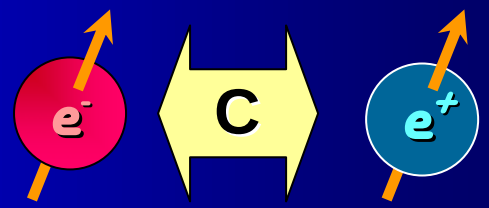


Antiteilchen als Forschungsgegenstand

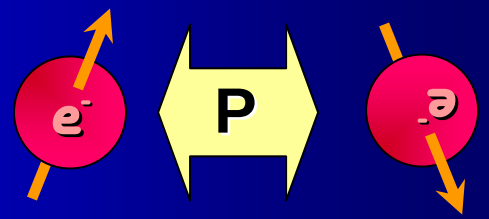
Es gibt experimentelle Hinweise auf eine Asymmetrie zwischen Teilchen und Antiteilchen aufgrund der Schwachen Wechselwirkung

Dieser Effekt wird **CP**-Verletzung genannt.

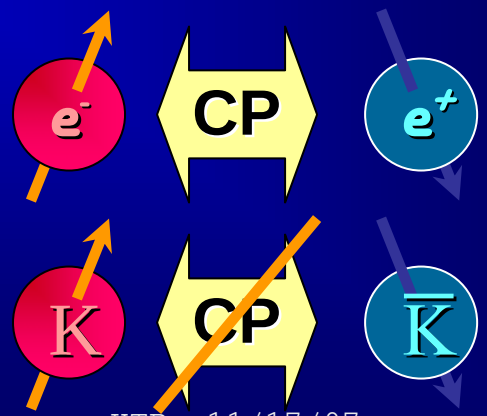
C macht aus einer Ladung eine Antiladung



P macht aus einem Teilchen sein Spiegelbild



Zusammen



(Das entspricht übrigens nach heutiger Vorstellung auch **T**, der Zeitumkehr!)

Antiteilchen und Antimaterie

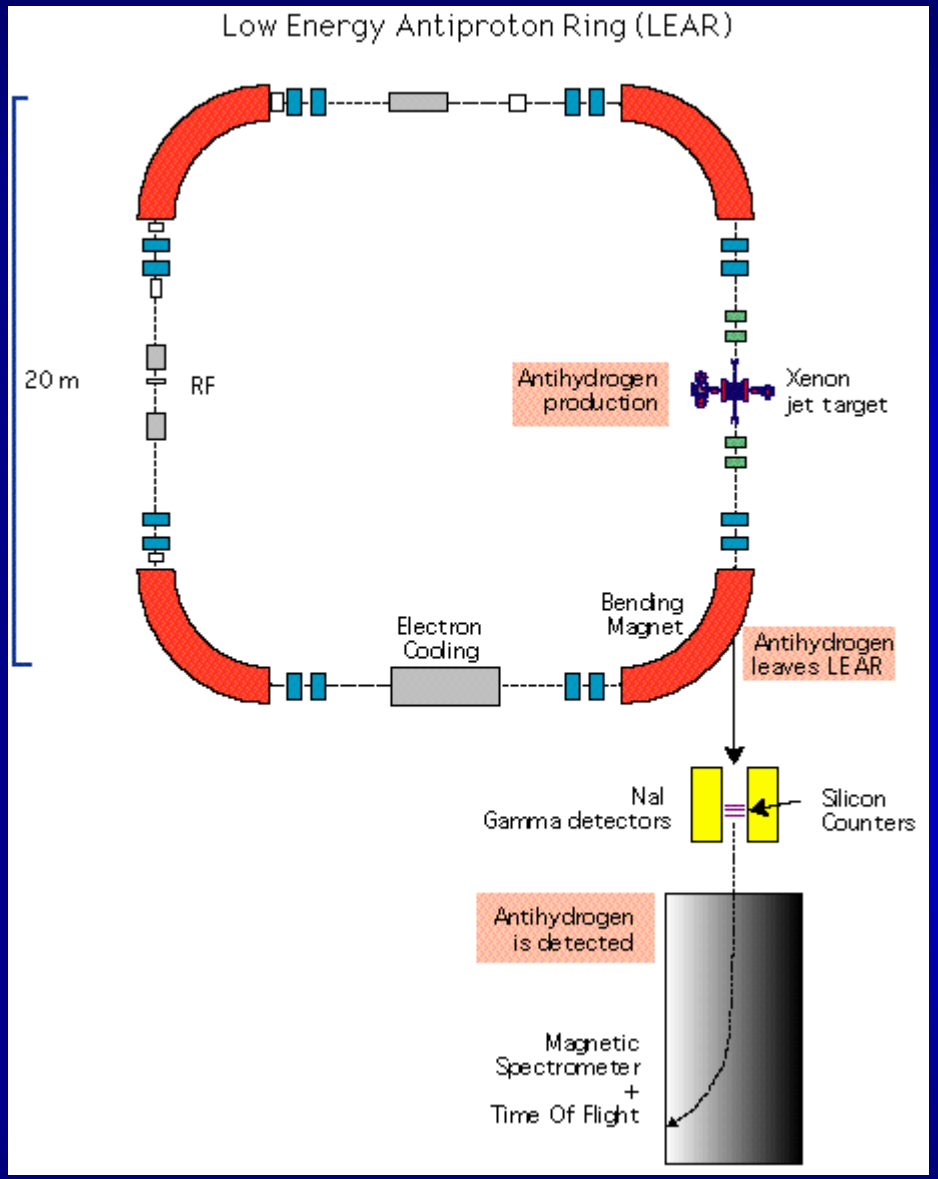
Materie entsteht durch die Bindung von Teilchen zu (elektrisch neutralen) Atomen.

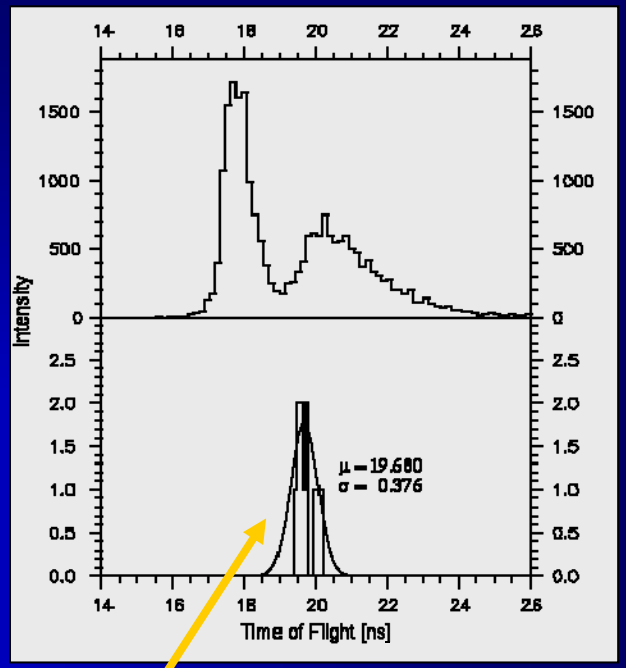
Antimaterie: Erstmal Antiwasserstoff!

Dazu muss man Antiprotonen mit Antielektronen zusammenbringen.

Dies gelang erstmals 1996 am CERN.

Oelert et al., 1995

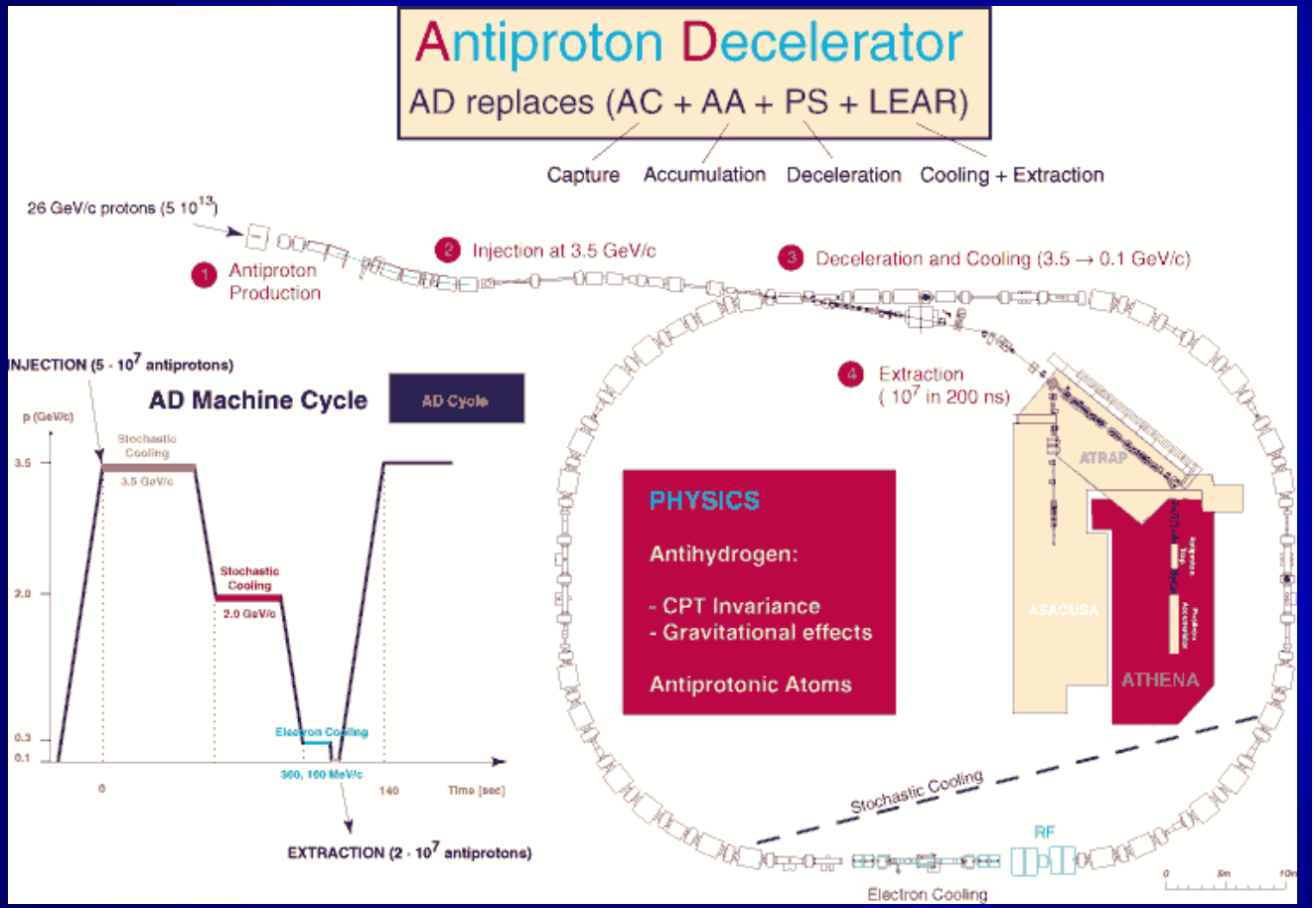


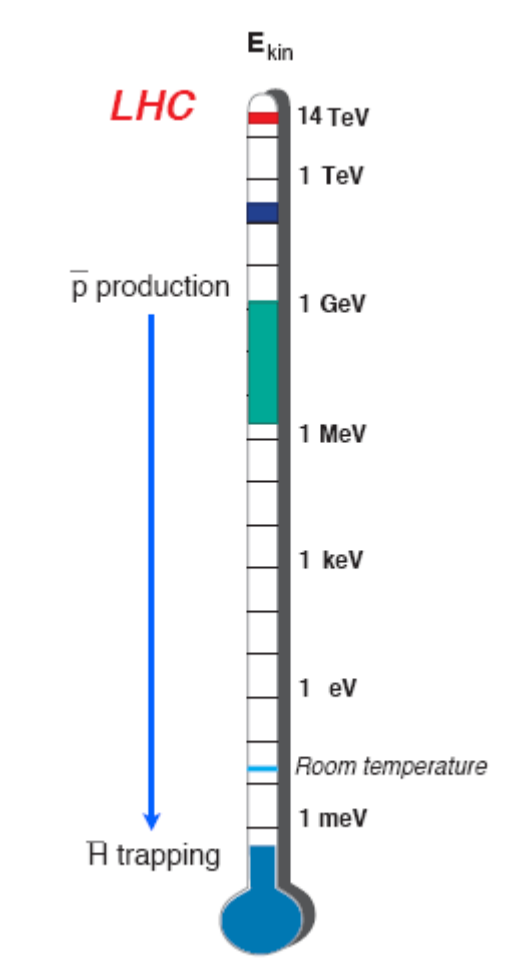


PS 210

Produktion von (11±2) $\bar{H}$ in vielen Wochen am Beschleuniger

Quelle der Antiprotonen sind dabei leistungsfähige Beschleuniger, z.B. der CERN-Komplex.

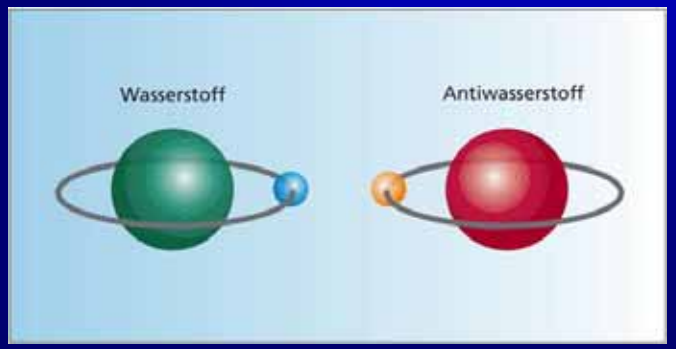




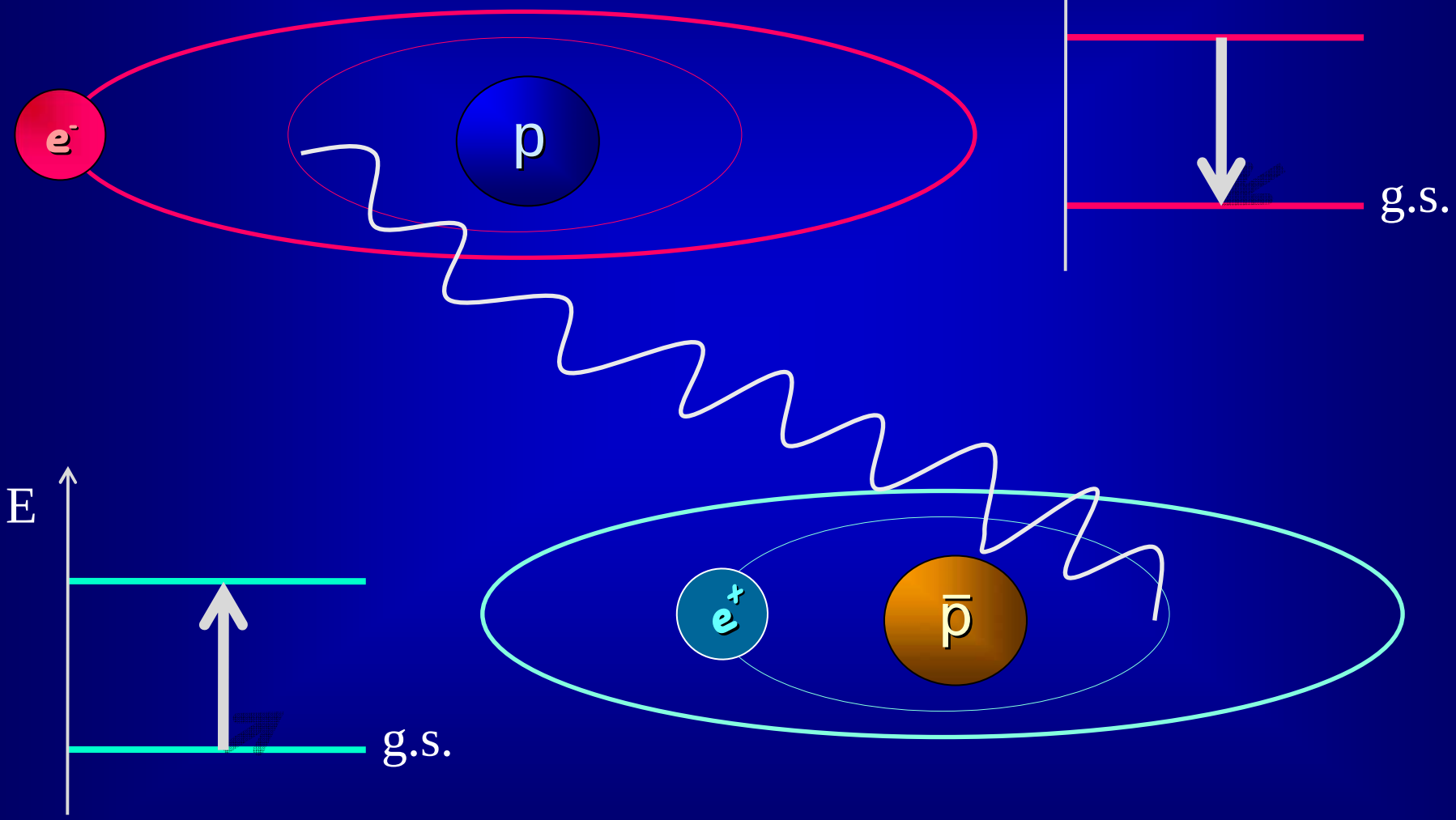
Moderne Experimente erzielen erheblich höhere Wirkungsgrade.

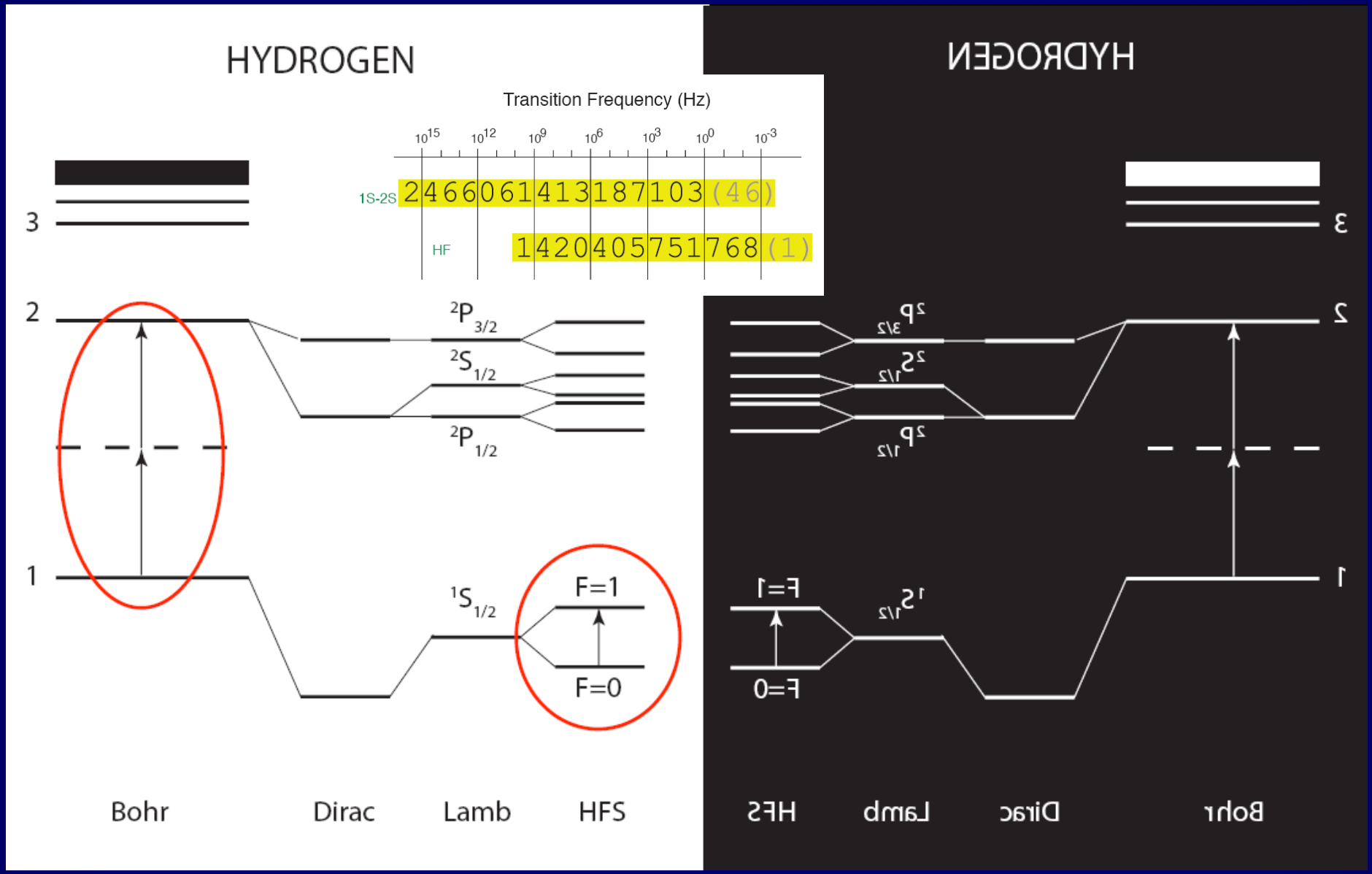
Herstellung und Speicherung vieler Tausend $\bar{H}$ in Experimenten mit „Fallen“.

Damit lassen sich viele Fragen zur Symmetrie von Materie und Antimaterie untersuchen.

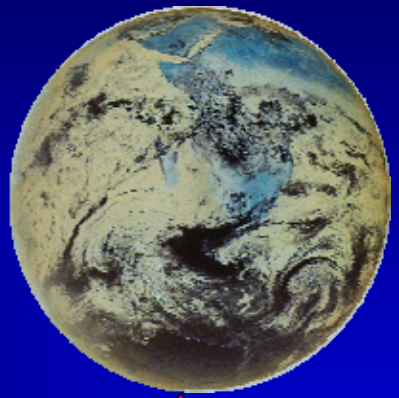


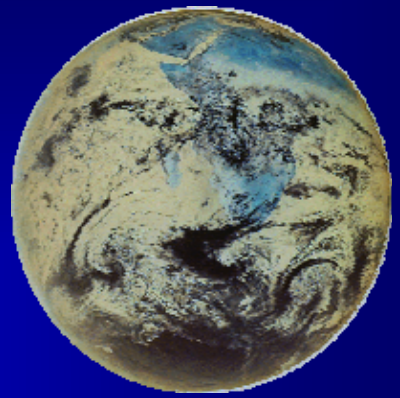
Materie-Antimaterie-Symmetrie der Naturgesetze?

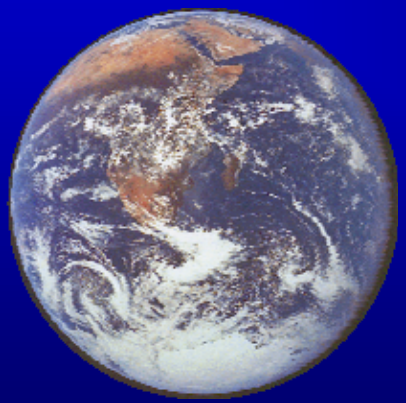


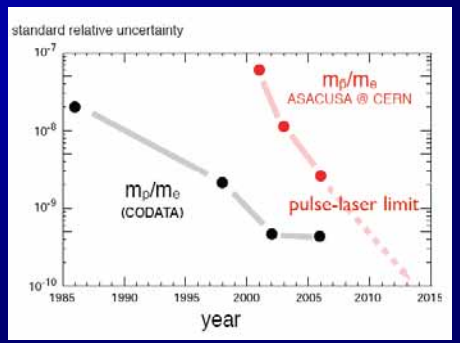

HYDROGEN
Transition Frequency (Hz)
10^{15} 10^{12} 10^{9} 10^{6} 10^{3} 10^{0} 10^{-3}
1S-2S 2466061413187103(46)
HF 1420405751768(1)
3
2
1
$^2P_{3/2}$
$^2S_{1/2}$
$^2P_{1/2}$
$^1S_{1/2}$
F=1
F=0
Bohr
Dirac
Lamb
HFS

Antimaterie

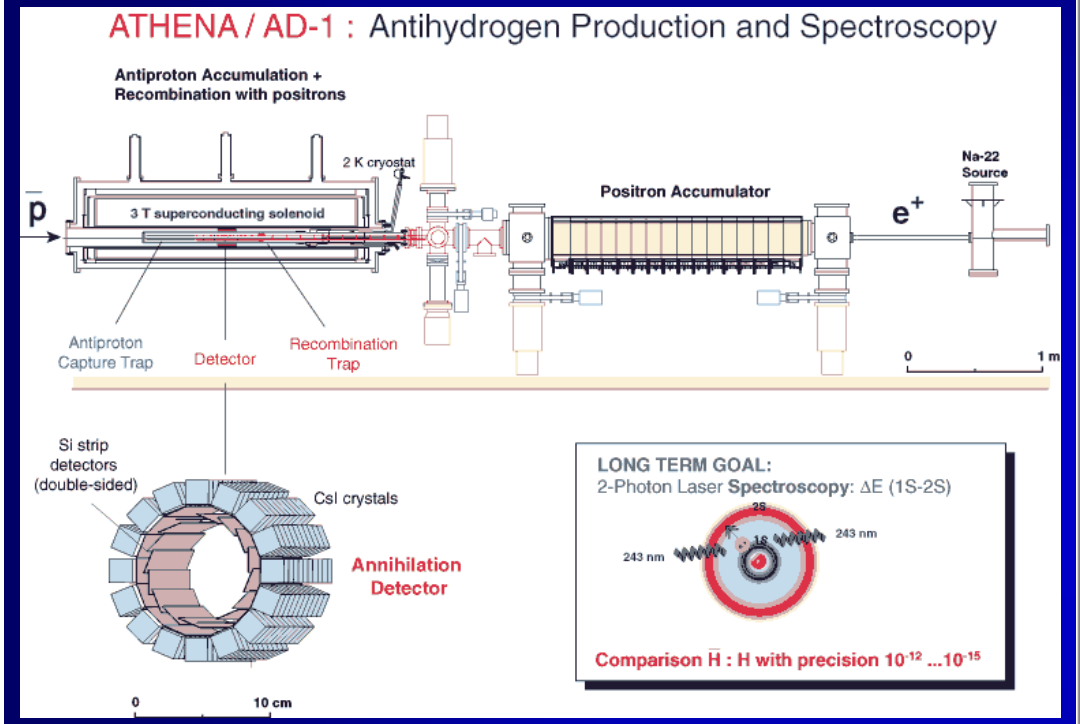


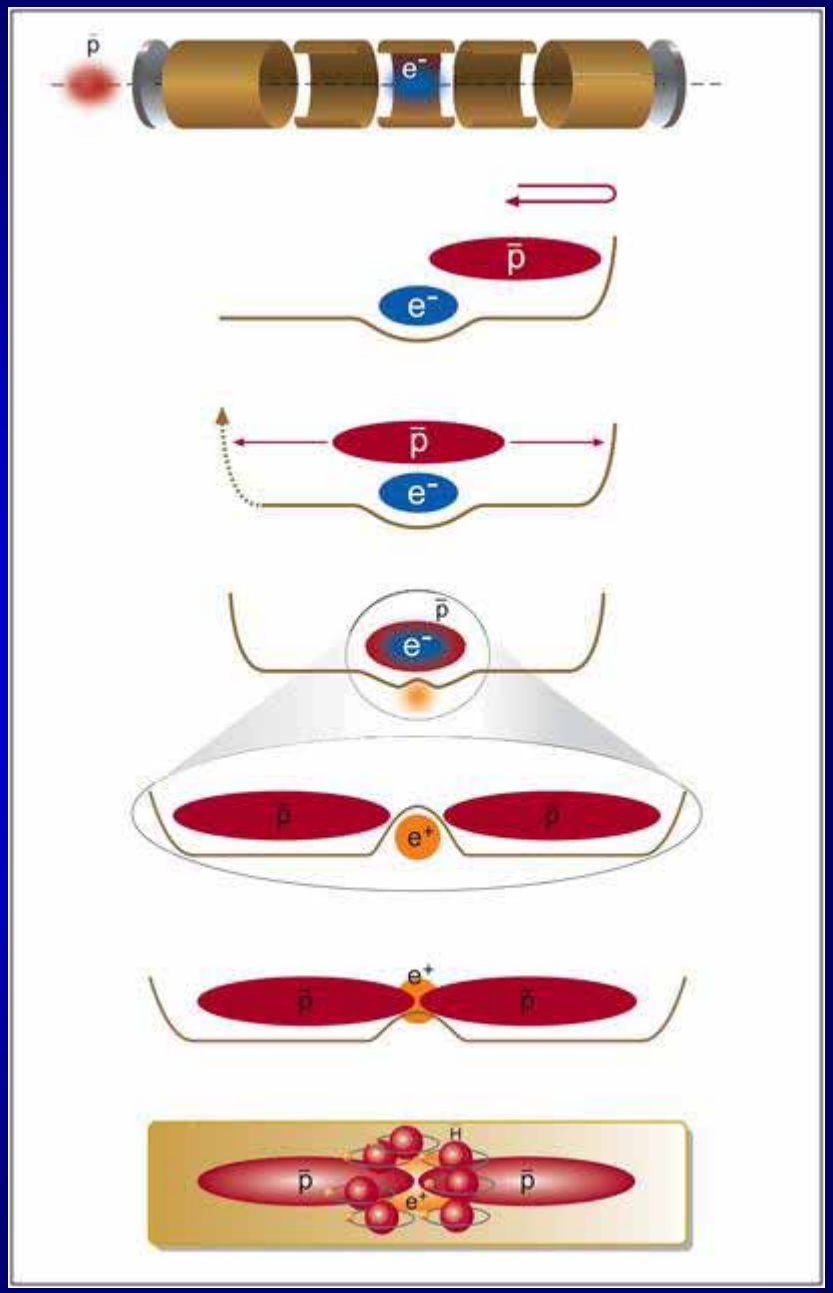






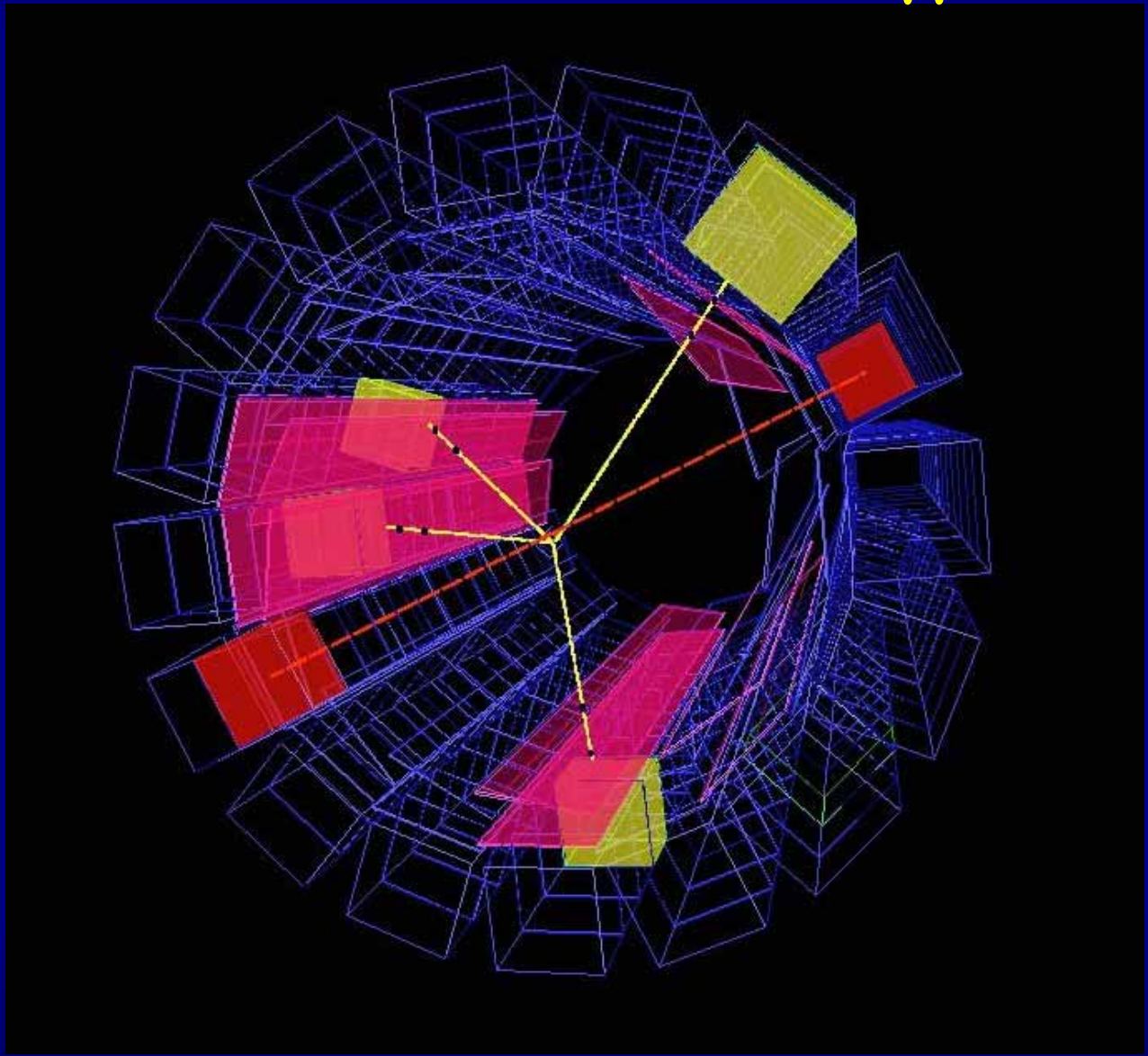
ATHENA


ATHENA / AD-1 : Antihydrogen Production and Spectroscopy
Antiproton Accumulation + Recombination with positrons
p̄
3 T superconducting solenoid
2 K cryostat
Positron Accumulator
e+
Na-22 Source
Antiproton Capture Trap
Detector
Recombination Trap
0
1 m
Si strip detectors (double-sided)
CsI crystals
Annihilation Detector
0
10 cm
LONG TERM GOAL:
2-Photon Laser Spectroscopy: ΔE (1S-2S)
2S
1S
243 nm
243 nm
Comparison H̄ : H with precision 10-12 ...10-15


p̄
e-
e+
H

ATHENA

$$H\bar{H} \rightarrow \pi^+\pi^- \pi^+\pi^- \gamma\gamma$$



Nächste Schritte mit Antimaterie

Speicherung und Untersuchung kalter „Gase“ von $\bar{H}$ in Experimenten mit „Fallen“.

Nächste Generation von Quellen für Antiprotonen

mit noch höheren Produktionsraten

für fundamentale Experimente mit kalten Antiprotonen

für Experimente mit Antiprotonen bei sehr hohen Energien als Sonde für die Herstellung bisher unbekannter Teilchen in $\bar{p}p$ bei hohen Energien

FAIR Facility for Antiproton and Ion Research

Kick-Off Event
and
Symposium on the Physics at FAIR

7 - 8 November 2007
GSI, Darmstadt, Germany

Advisory Committee
Horst Stöcker (Chair)
Ingo Augustin
Roland Garoby
Bill Gelletly
Hans Gutbrod
Zbigniew Majka
Thomas Stöhlker
Ulrich Wiedner

Local Organizing Committee
Ingo Augustin
Bruno Becker-de Mos
Hans Gutbrod
Alexander Kurz
Ingo Peter
Horst Stöcker

Registration and information:
www.fair-center.org/registration

Registration deadline:
15 October 2007

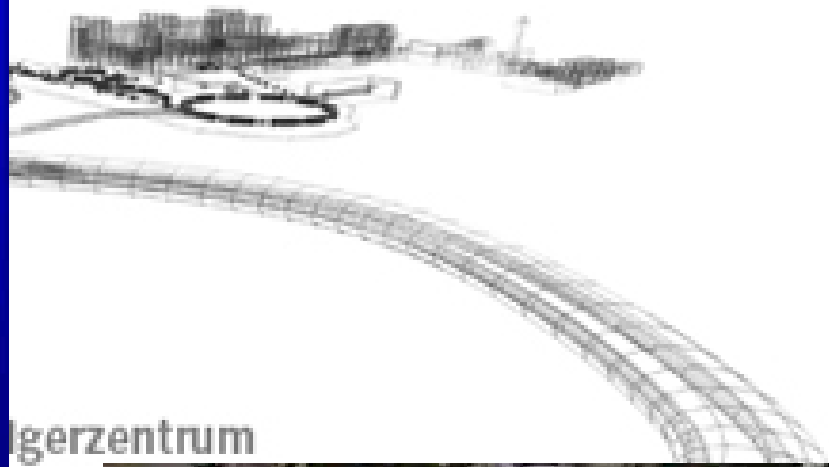
Contact:
fair-event@gsi.de
phone: +49 6159 71 2916
fax: +49 6159 71 3916

HELMHOLTZ GEMEINSCHAFT

GSI

Photo from http://antwrp.gsfc.nasa.gov

GSI



lgerzentrum
und

FAIR Facility for Antiproton and Ion Research

Ausbau der GSI-Anlagen mit Blick auf:

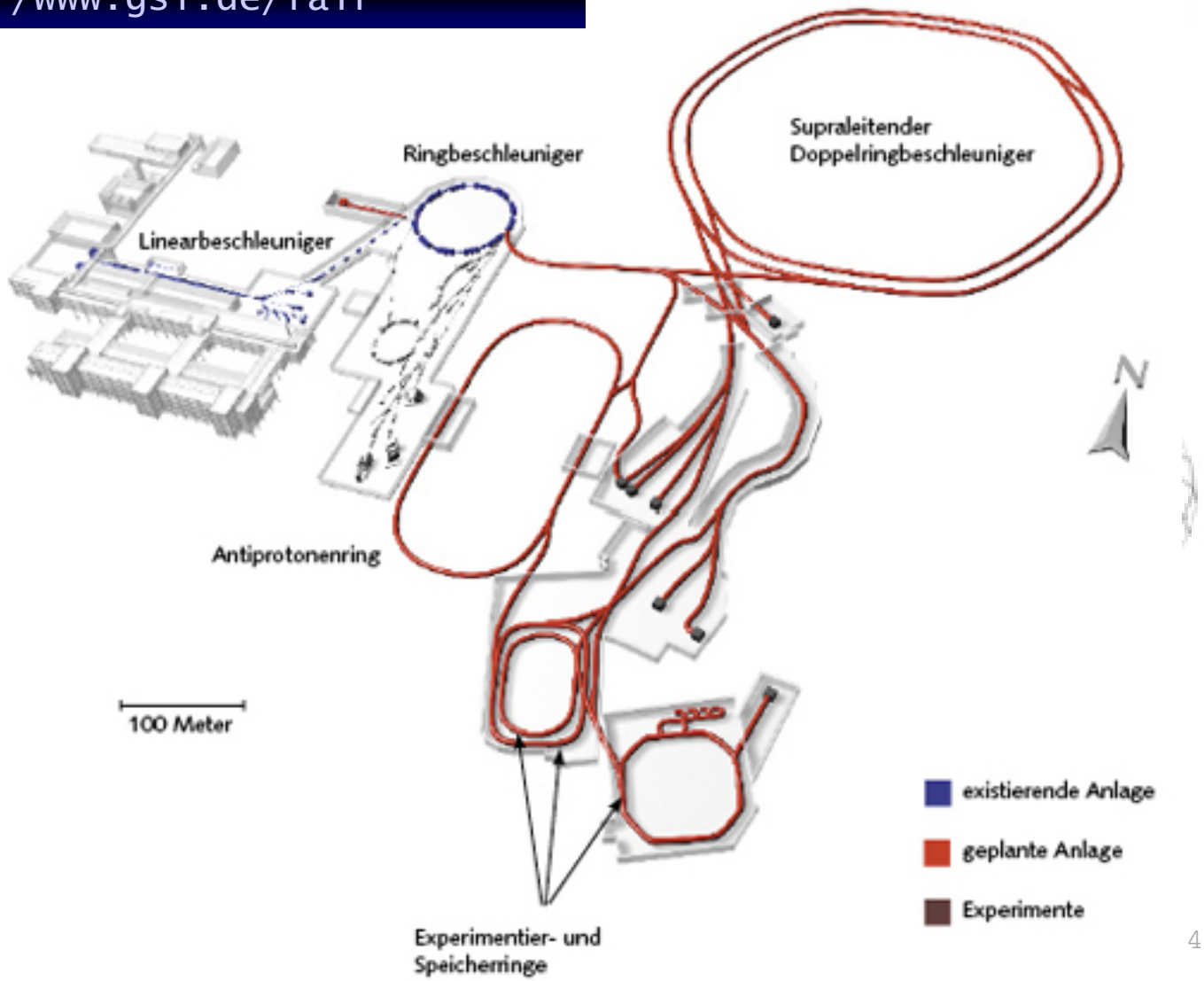
- **höchste Intensitäten**
- **höchste Brillanz**
- **höhere Strahlenergien**
- **höchste Strahlleistung**
- **parallelen Betrieb für verschiedene Experimente**
- **Produktion sekundärer Strahlen hoher Qualität**

FAIR Facility for Antiproton and Ion Research

http://www.gsi.de/fair/

FAIR Facility for Antiproton and Ion Research

http://www.gsi.de/fair

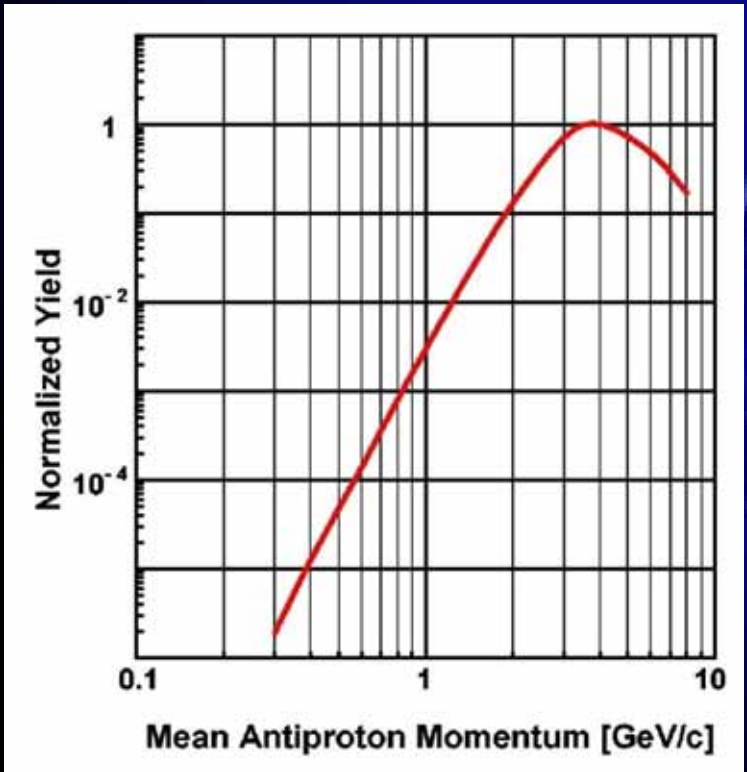


GSI Future Project

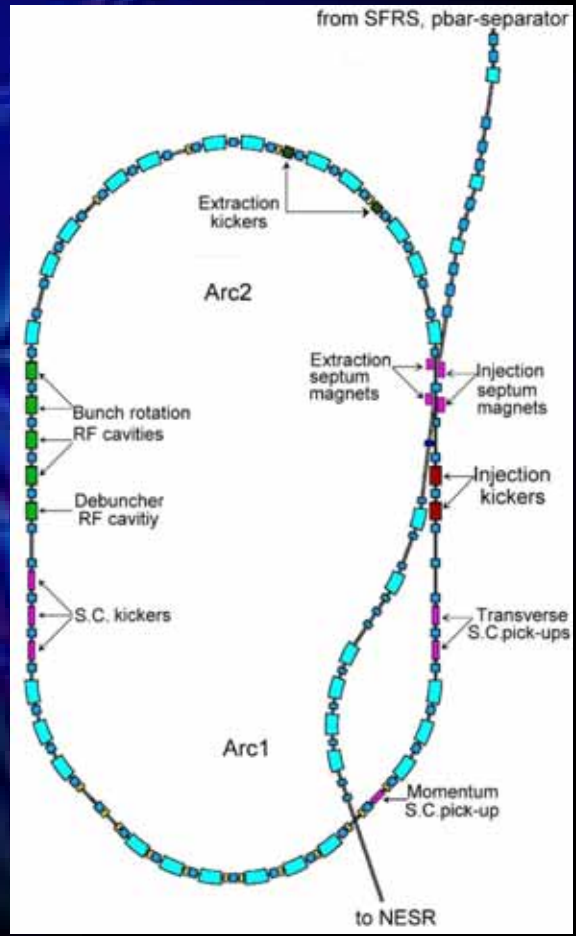
Sekundäre Strahlen - Antiprotonen

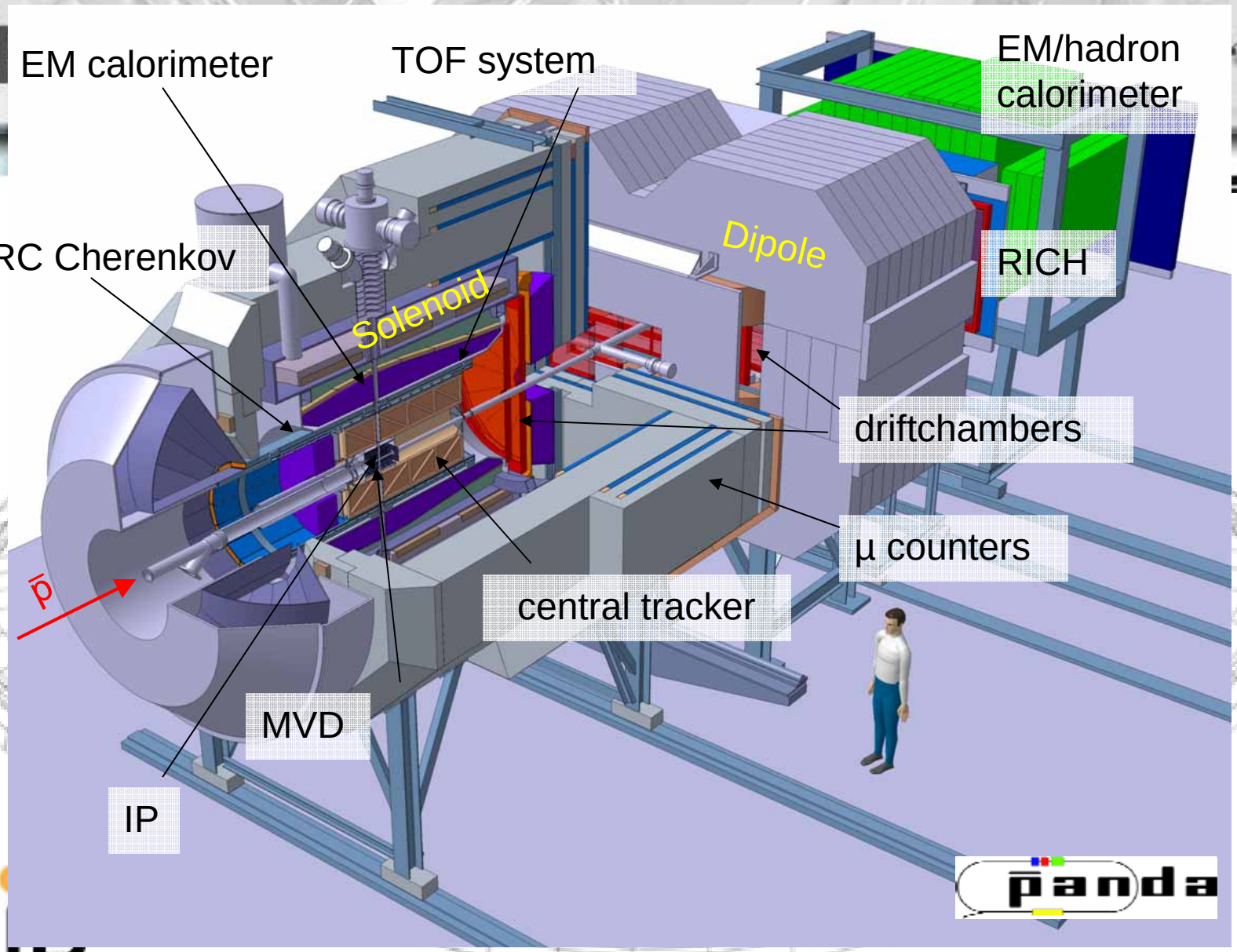
29 GeV Protonen auf Cu (oder Ir)

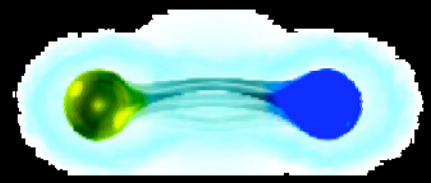
Ausbeute: $3{,}5 \cdot 10^{-6}$ Antiprotonen bei 3,5 GeV/c

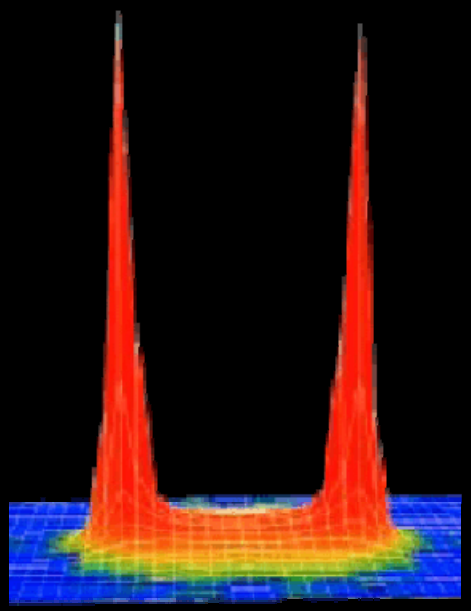


($8 \cdot 10^{7}$ pro Puls von $2 \cdot 10^{13}$ p)

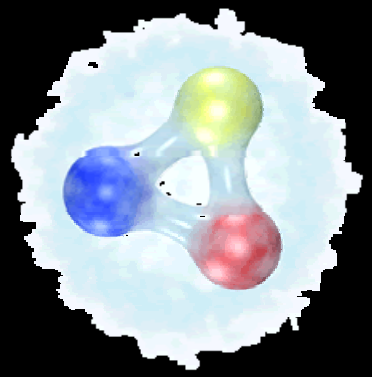


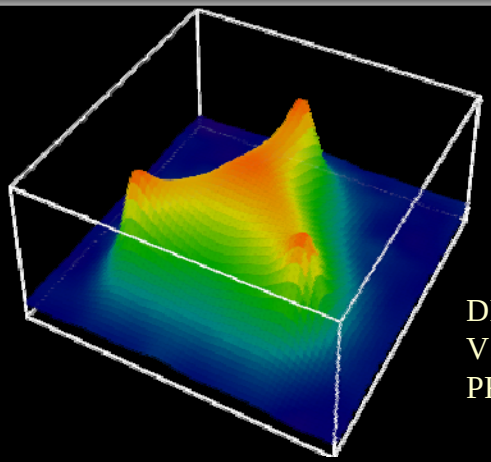

EM calorimeter
TOF system
EM/hadron calorimeter
DIRC Cherenkov
Solenoid
Dipole
RICH
driftchambers
μ counters
central tracker
p̄
MVD
IP
panda



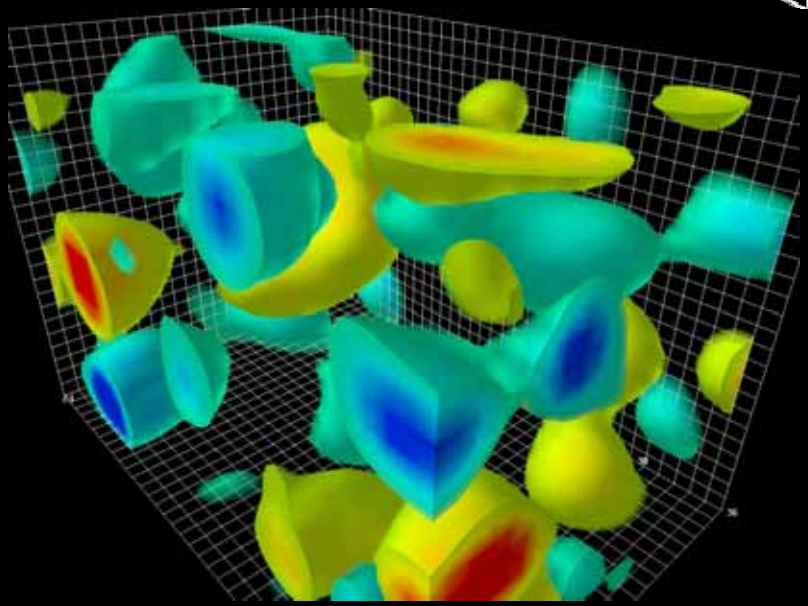


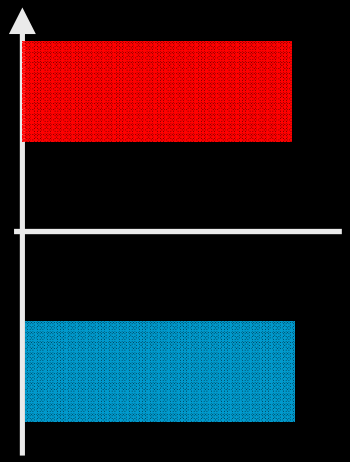
Bali et al.,
NP Proc.Suppl. 63(97)209



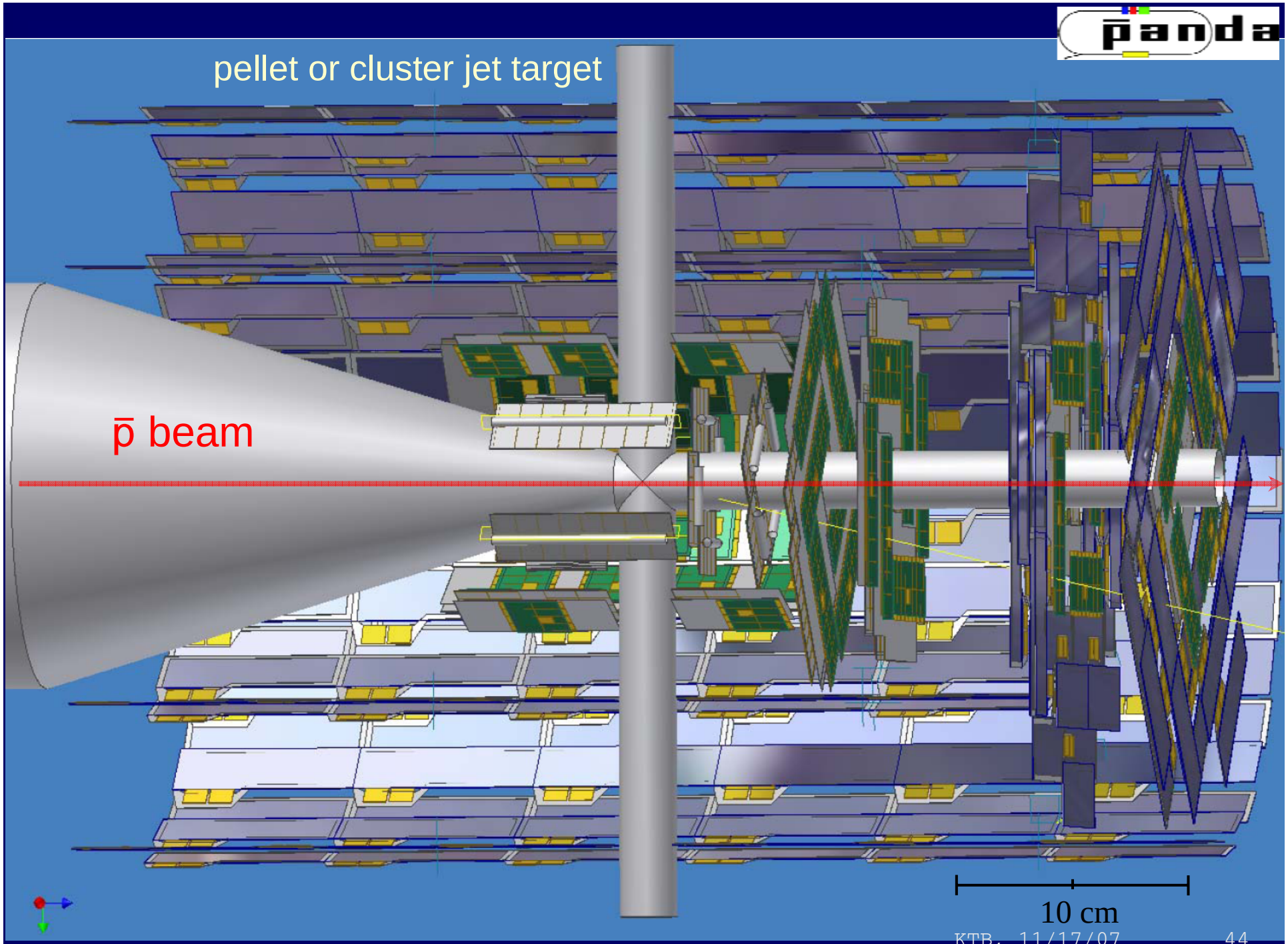


DIK collaboration,
V.G. Bornyakov et al.,
PR**D 70**, 054506 (2004)

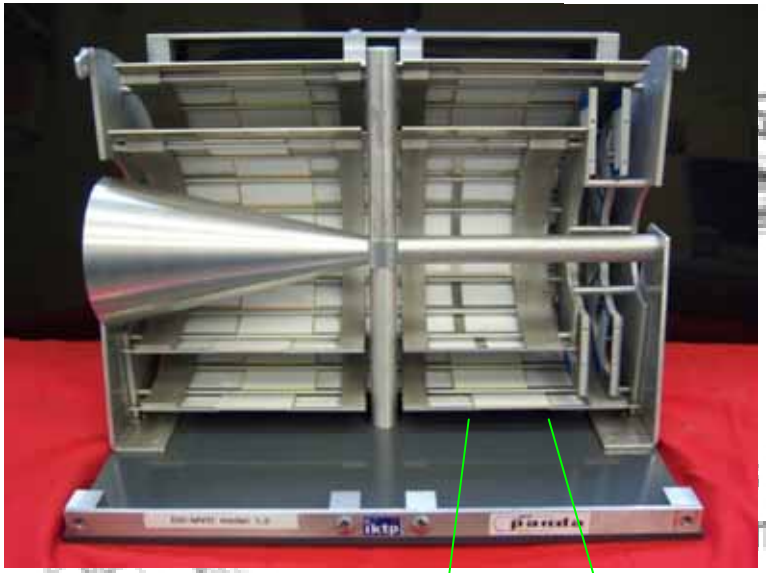




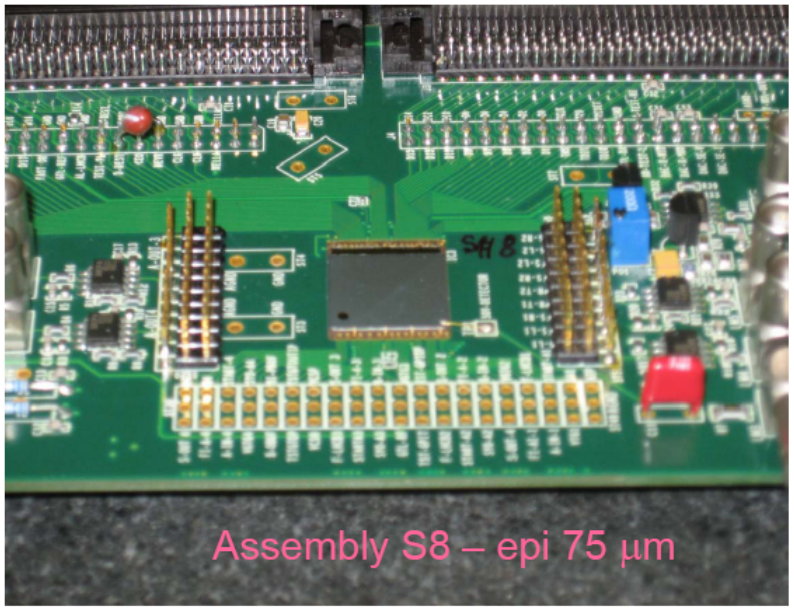
Derek B. Leinweber
http://www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/Nobel/


pellet or cluster jet target
p̄ beam
10 cm

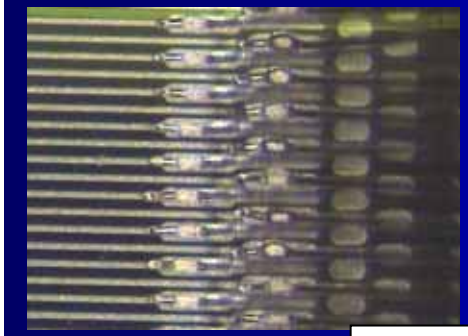
FAIR Facility for Antiproton and Ion Research

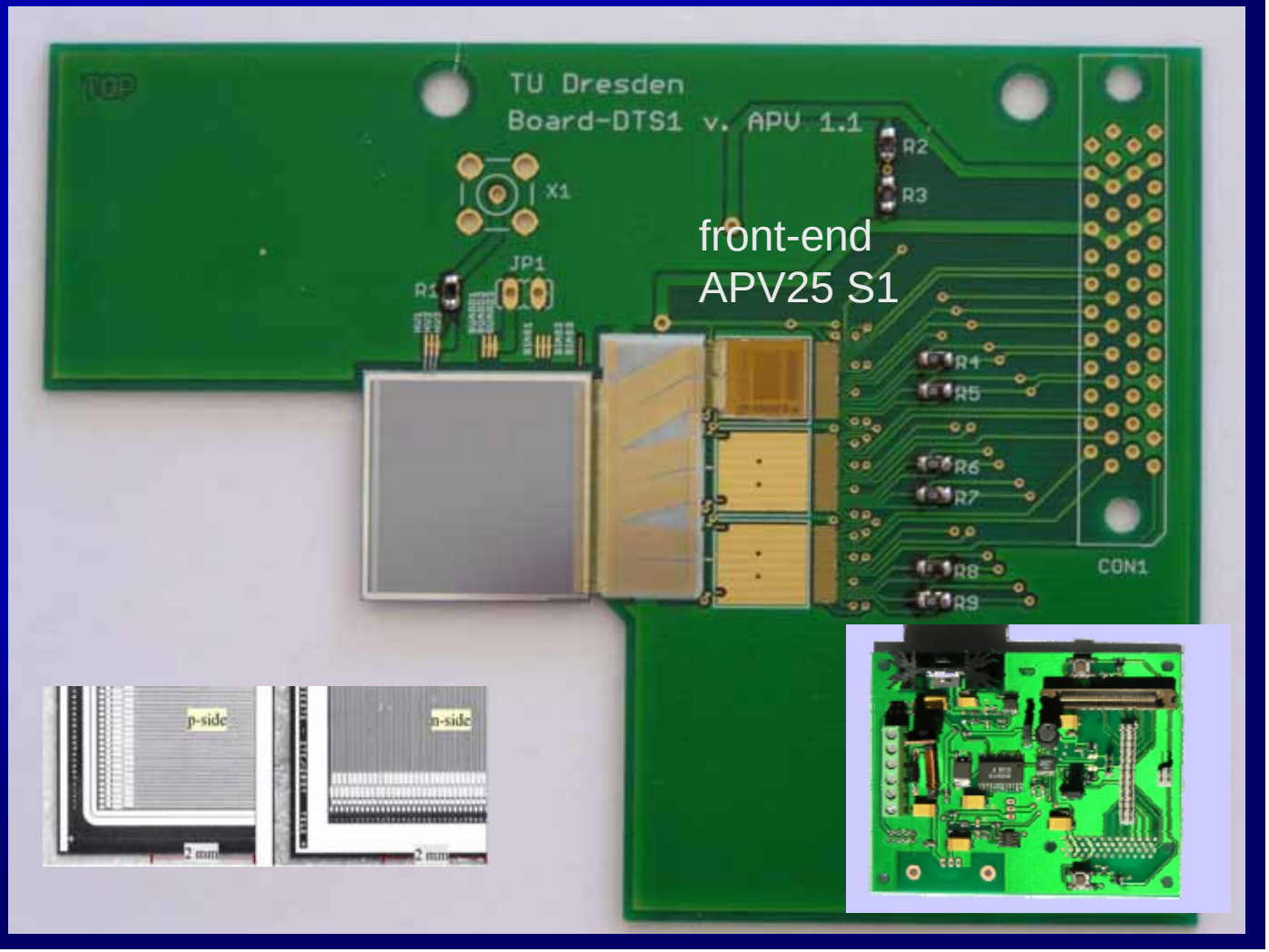


Test with laser-diode



Strip Sensors – Test Station



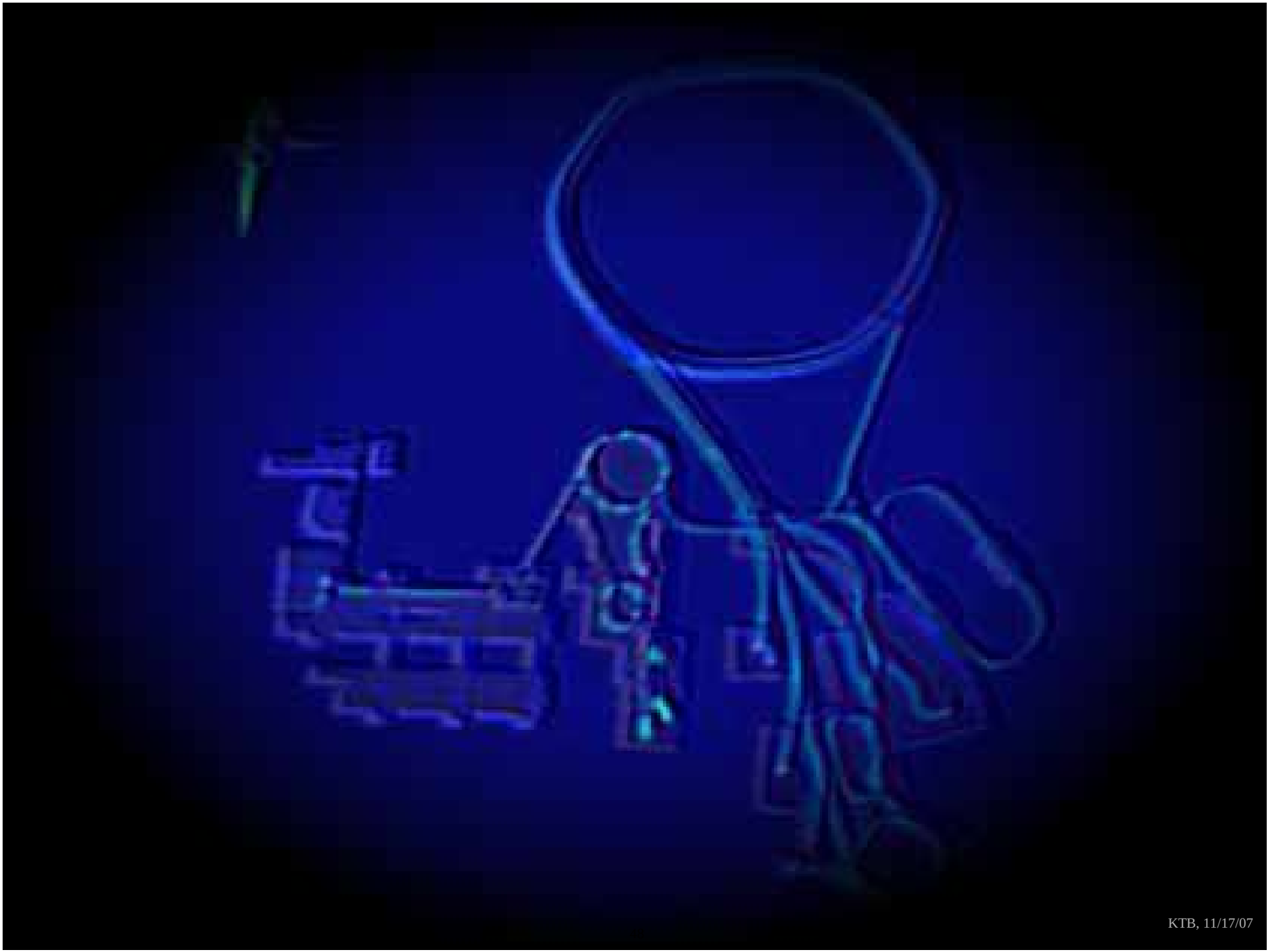


front-end
APV25 S1

double-sided sensor
“telescope” ITCirst,
m^2 50

Die P̄ANDA-Kollaboration

~350 Physiker aus 47 Instituten in 16 Ländern

Austria – Belaruz - China - Finland - France - Germany – Holland - Italy – Poland – Romania - Russia – Spain - Sweden – Switzerland – U.K. – U.S.A.

Basel, Beijing, Bochum, Bonn, IFIN Bucharest, Catania, Cracow, Dresden, Edinburg, Erlangen, Ferrara, Frankfurt, Genova, Giessen, Glasgow, KVI Groningen, GSI, Inst. of Physics Helsinki, FZ Jülich, JINR, Katowice, Lanzhou, LNF, Mainz, Milano, Minsk, TU München, Münster, Northwestern, BINP Novosibirsk, Pavia, Piemonte Orientale, IPN Orsay, IHEP Protvino, PNPI St. Petersburg, Stockholm, Dep. A. Avogadro Torino, Dep. Fis. Sperimentale Torino, Torino Politecnico,Trieste, TSL Uppsala, Tübingen, Uppsala, Valencia, SINS Warsaw, TU Warsaw, AAS Wien