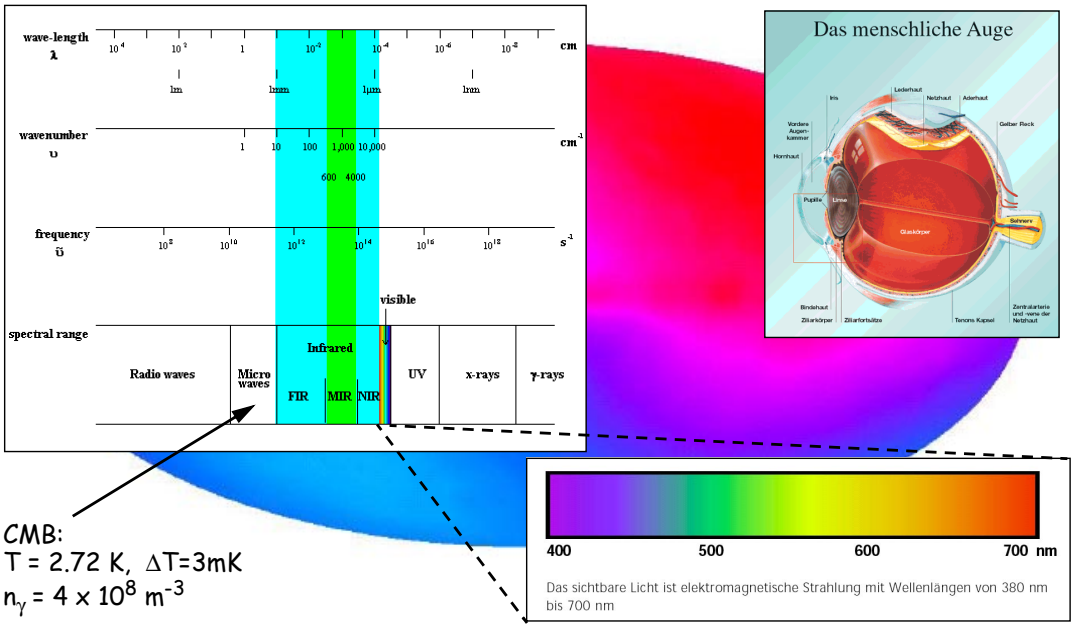
Detectors for Particle Physics

DESY Summer Student Lectures

2005

Carsten Niebuhr

Introduction



Literature

Textbooks:

K.Kleinknecht: *Detectors for Particle Radiation*
Cambridge University Press, 1998

W.R. Leo: *Techniques for Nuclear and Particle Physics Experiments*
Springer 1994

G.F.Knoll: *Radiation Detection and Measurement*
Wiley, 3rd edition

D.Green: *The Physics of Particle Detectors*
Cambridge University Press, 2000

C.Grupen: *Particle Detectors*
Cambridge University Press, 1996

W.Blum, L.Rolandi: *Particle Detection with Driftchambers*
Springer, 1994

Overview articles:

T.Ferbel: *Experimental Techniques in High Energy Physics*
Addison-Wesley 1987

Other sources:

Particle Data Group: *Review of Particle Physics*
Eur. Phys. J. C15, 1-878 (2000)

R.K.Bock, A.Vasilescu: *The Particle Detector BriefBook*
Springer, 1998 and //physics.web.cern.ch/Physics/ParticleDetector/BriefBook/

Further Sources on the Web

DETECTOR PHYSICS and APPLICATIONS CENTER - DePAC

http://besch2.physik.uni-siegen.de/~depac/DePAC/DePAC_main/DePAC_main_tutorials.html

CERN Summer Student Lecture Programme 2005

http://ph-dep-dt2.web.cern.ch/ph-dep-dt2/lectures_PD_2005.htm

Lecture Notes by Helmuth Spieler

http://www-physics.lbl.gov/~spieler/

Vorlesungsskripte D.Wegener Dortmund (in german)

http://www.physik.uni-dortmund.de/e5/

Transperancies of Detector Lecture C.N. (in german)

http://www.desy.de/~niebuhr/Vorlesung/Detektor/vorlesung.html

Transperancies of Detector Lecture Robert Klanner / Ralf Röhlsberger

http://adweb.desy.de/~klanner/Lehre/DetektorVorlesung/Overview.html

Topics of the Lecture

Part I

- Introduction
- Examples
- General Concepts
- Interaction of Charged Particles with Matter
  - Energy Loss: Bethe Bloch Formula
  - Multiple Scattering

Part II

- Use of Track Detectors for Momentum Measurement
- Gas Detectors
  - Proportional Chamber
  - Drift Chamber
  - TPC
  - MSGC, GEM
- Silicon Detectors
  - Strip Detectors
  - Pixel Detectors

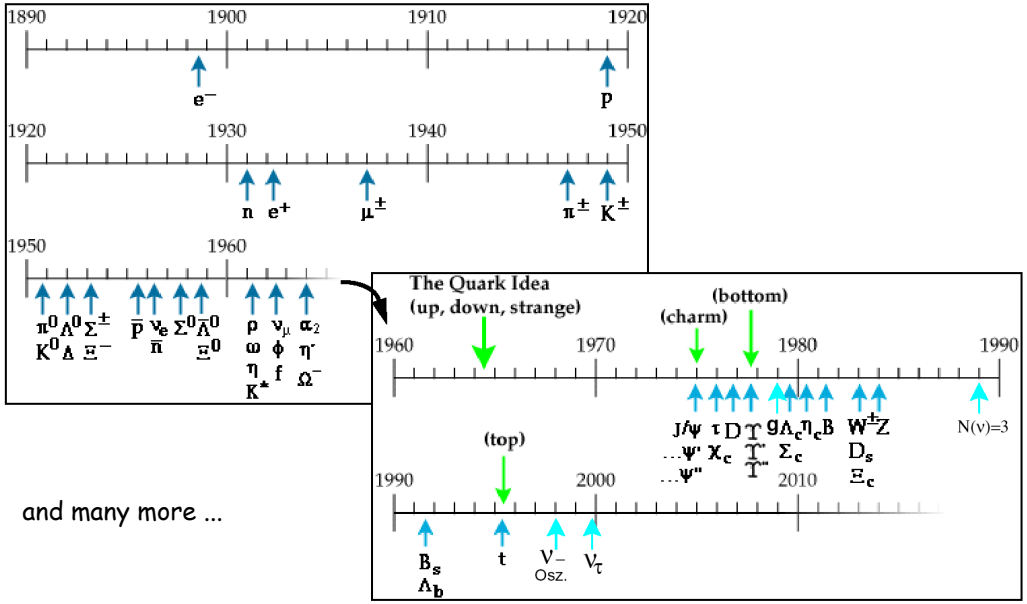
Part III

- Scintillation Counters
- Photodetectors
- Cherenkov Counters
- Transition Radiation
- Calorimeters
  - Shower Development
  - electromagnetic
  - hadronic

- not covered
  - Trigger
  - DAQ

Common Lecture by Robert Klanner
Friday, Aug 5th, Auditorium

What are the Objects ?

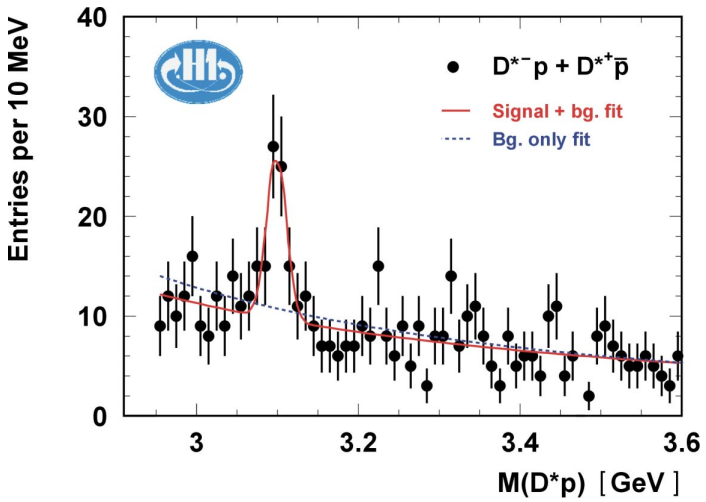


and many more ...

Fundamental Interactions

Forces	Strong force	Electro-magnetic force	Weak force	Gravity
Exchanged particles	Gluon	Photon	W,Z bosons	Graviton
Magnitude	1	0.01	10^{-5}	10^{-40}
	Nuclei Hadron Nuclear fusion Solar energy	Molecule, Atom Electronics Synchrotron rad. Aurora	Neutron decay Nuclei decay Neutrino Geothermy	Gravitation Galaxy Black Hole Stellar Pinwheel
Example	$\rho^0 \to \pi^+\pi^-$	$\pi^0 \to \gamma\gamma$	$K^0 \to \pi^+\pi^-$	
Lifetime [s]	$\approx 10^{-24}$	$\approx 10^{-16}$	$\approx 10^{-10}$	
$c\tau$ [mm]	$\approx 3\times10^{-13}$	$\approx 3\times10^{-5}$	≈ 30	

Recently observed Resonance at HERA



Pentaquark Candidate:

$\theta^0_c \to D^{*-} p \to K^- \pi^+ \pi^- p$

minimal quark content: $uudd\bar{c}$

sofar only seen by H1 ...

- real resonance ??
- statistically fluctuation ??
- detector effect ??
- need very good understanding of detector response
  - significance of signal S/B
  - resolution
  - efficiency / acceptance

Detection of Particles and Radiation

The goal of experimental particle physics: measurement of

- particle properties
- reaction probabilities (→ cross sections)

This requires determination of:

- particle type (mass, charge, spin etc)
- momentum / energy of particle
- emission angles

Elements contributing to such measurements :

- position sensitive detectors → position, direction
- deflection in magnetic field → $|\vec{p}|$
- calorimetry: total energy absorption and measurement → E_{tot}
- mass determination → m
- Cherenkov radiation or time of flight → β
- transition radiation → γ

Criteria for Ideal Detector

Because in general there can be very complex event topologies one often needs:

reconstruction of full event kinematics (background rejection)

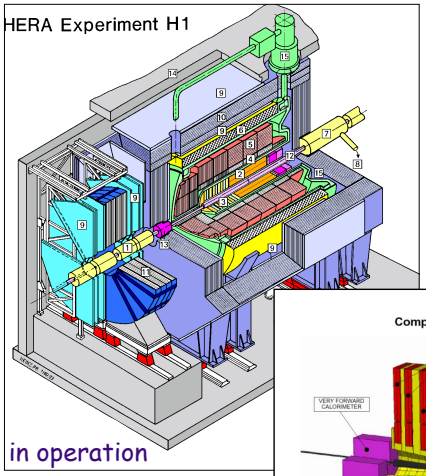
Most important:

- high efficiency
- high resolution
- high acceptance → try to cover full solid angle (4π)

also very important (partly conflicting demands):

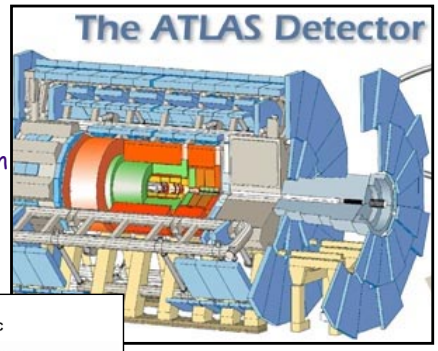
- particle identification capability
- fast response
- high rate capability
- very little dead time
- hermeticity
- no aging
- high reliability
- good accessibility
- low cost

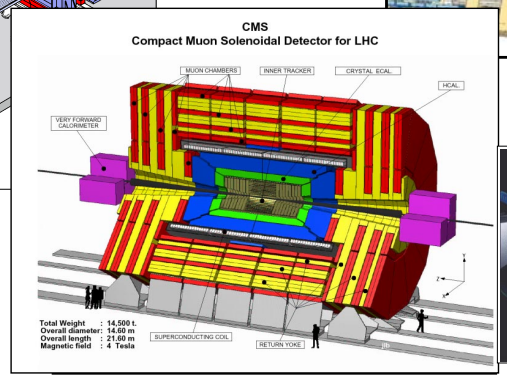
Modern Collider Detectors



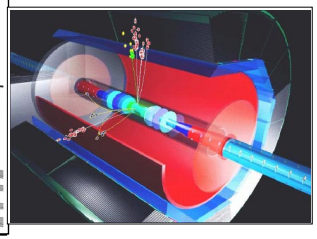
in operation

LHC Detectors:
under construction





TESLA detector:
under R&D



Some Particle Physics Experiments

Besides the large collider detectors there are many other expts: www.hep.net/experiments/all_sites.html

Bates Linear Accelerator (MIT)
BLAST , OOPS , SAMPLE

Beijing IHEP
ARGO-YBJ , BES , Tibet ASgamma

Brookhaven
BRAHMS , Crystal Ball (E913/914) , E787 , E821/muon g-2 , E850 , E852 , E863/ EMU01 , E864 , E865 , E869 , E877 , E881 , E885 , E890 , E891 , E895 , E905 , E906 , E907 , E909 , E910 , E913/914 (Crystal Ball) , E917 , E923 , E926 , E927 , E949, E953 , EIC , EMU01/E863 , High Gain Harmonic Generation FEL , ICAE , IFEL , IMB , LEGS , MECO , Microundulator FEL , NuMass/E952 , PHENIX , PHOBOS , pp2pp , Smith-Purcell , STAR , Zero Degree Calorimeter

CERN
ALEPH , ALICE , AMS , ANTARES , ASACUSA , ATHENA , Atlas (European) , ATRAP , CDHS neutrino experiment/WA1 , CERES/NA45 , CHORUS , CMS , CosmoLEP , CPLEAR/PS195 , Crystal Barrel/PS 197 , Crystal Clear/RD18 , DELPHI , EMU01 , FELIX , HARP , ICANOE , ISOLDE , L3 , LHC-B , MISTRAL , NTOF1, NTOF2, NTOF3 , NA45.2/IONS/EL.PAR , NA47/SMC , NA48, NA48.1, NA48.2 , NA49 , NA50 , NA51 , NA52/ Newmass , NA56/SPY , NA57 , NA58/COMPASS , NA59 , NA60 , NOMAD , OBELIX/PS201 , OPAL , OPERA , PAMELA , PS185 , PS205/HELIUMTRAP , PS210 , PS212/DIRAC , PS214/HARP , RD8 , RD11 , RD12/TTC , RD13 , RD27 , RD39/SMSD , RD41/ MOOSE , RD42 , RD44/Geant 4 , RD45 , RD46 , RD48/ ROSE , RD49/RADTOL , TOSCA , TOTEM , WA85 , WA92 (Beatrice) , WA94 , WA97 , WA98 , WA102

DESY
H1 , HERA-B , Hermes , TESLA , ZEUS

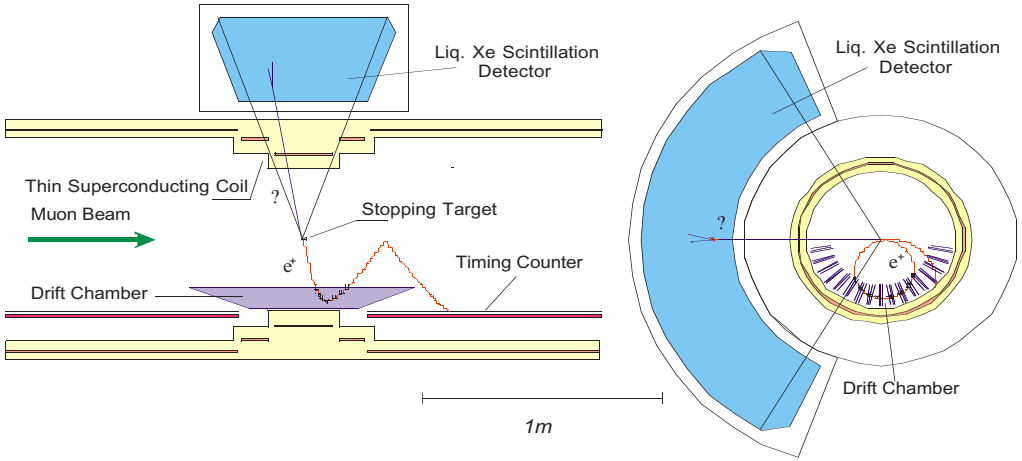
Fermilab
Antihydrogen/E862 , APEX/E868 , Auger Project , BooNE/E898 , BTEV/C0 , CDF/E830 , CDMS/E981 , CEX/E853 , Charmonium/E835 , CMS (US Server) , COSMOS/E803 , D0 (DZero)/E823 , Donut/E872 , E665 , E771 , E789 , Fermi III Project , FOCUS/E831 , HyperCP/E871 , KTEV/E799/E832 , MINOS/E875 , NuMI , NUSEA/E866 , NuTeV/E815 , SDSS , SELEX/ E781 , Zero Degrees/C0

Gran Sasso
BOREXino , CRESST , CUORICINO , DAMA , EASTOP, GALLEX(finished) , GENIUS , GNO , Heidelberg Dark Matter Search (HDMS) , Heidelberg-Moscow Experiment , ICARUS , LUNA , LVD , MACRO , MONOLITH , NOE , OPERA , USA

Search for Rare/Forbidden Decays

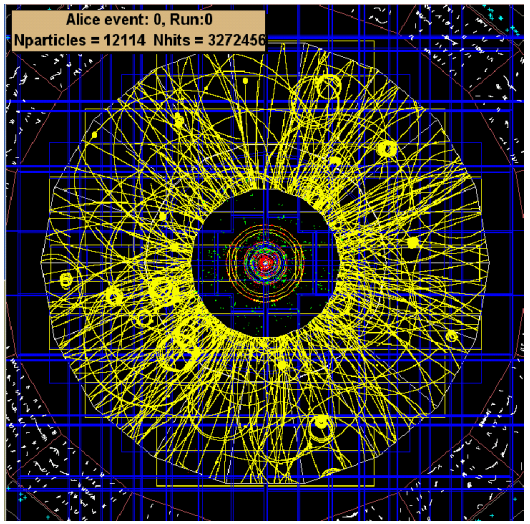
Expermiment in preparation at Paul Scherrer Institut (Switzerland):

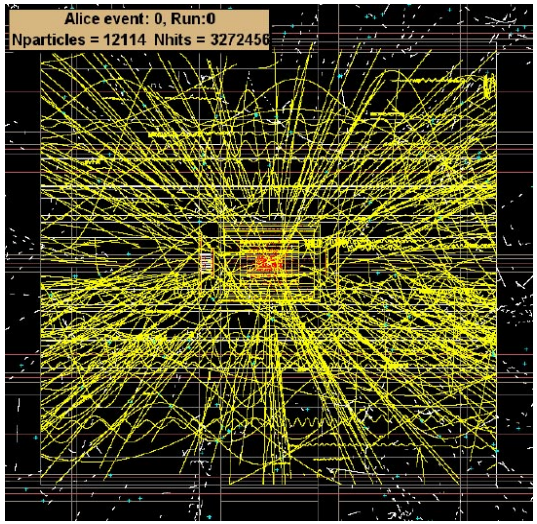
- search for lepton-number violating process: $\mu \rightarrow e\,\gamma$
- needs excellent energy resolution, high event rate but small track multiplicity per event
- start data taking in 2006



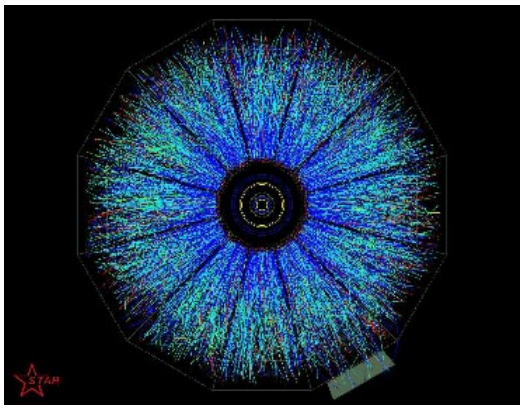
ALICE at LHC

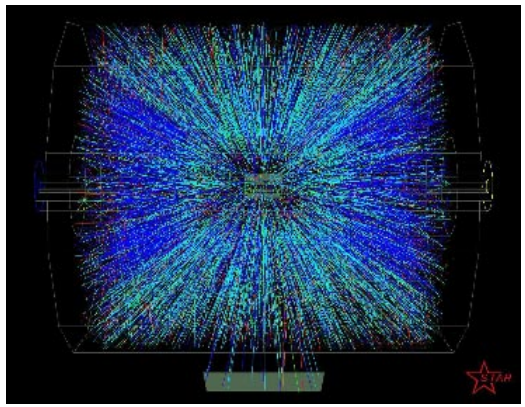
Heavy Ion Physics: this simulation shows 1/10 of all 10000-20000 expected tracks in a typical event. The separation of all these tracks puts high demands on the position resolution of the device





Real Event in STAR at RHIC



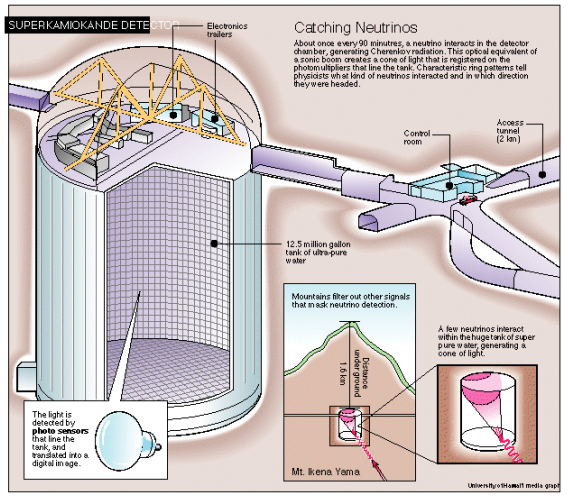


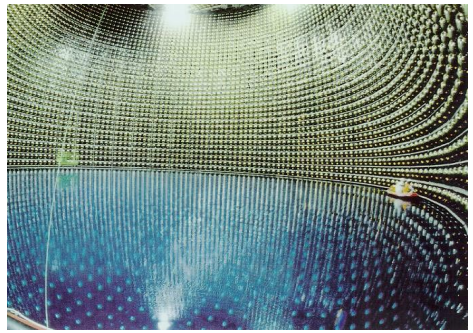
≈ 2000 tracks per event

Super-Kamiokande (Japan)

Search for proton-decay and for neutrino oszillations

- 50000 tons of water
- 12000 photo tubes





Reactions :

- $\nu_\mu N \rightarrow \mu N$ → Cherenkov
- $\nu_e N \rightarrow eN$ → shower