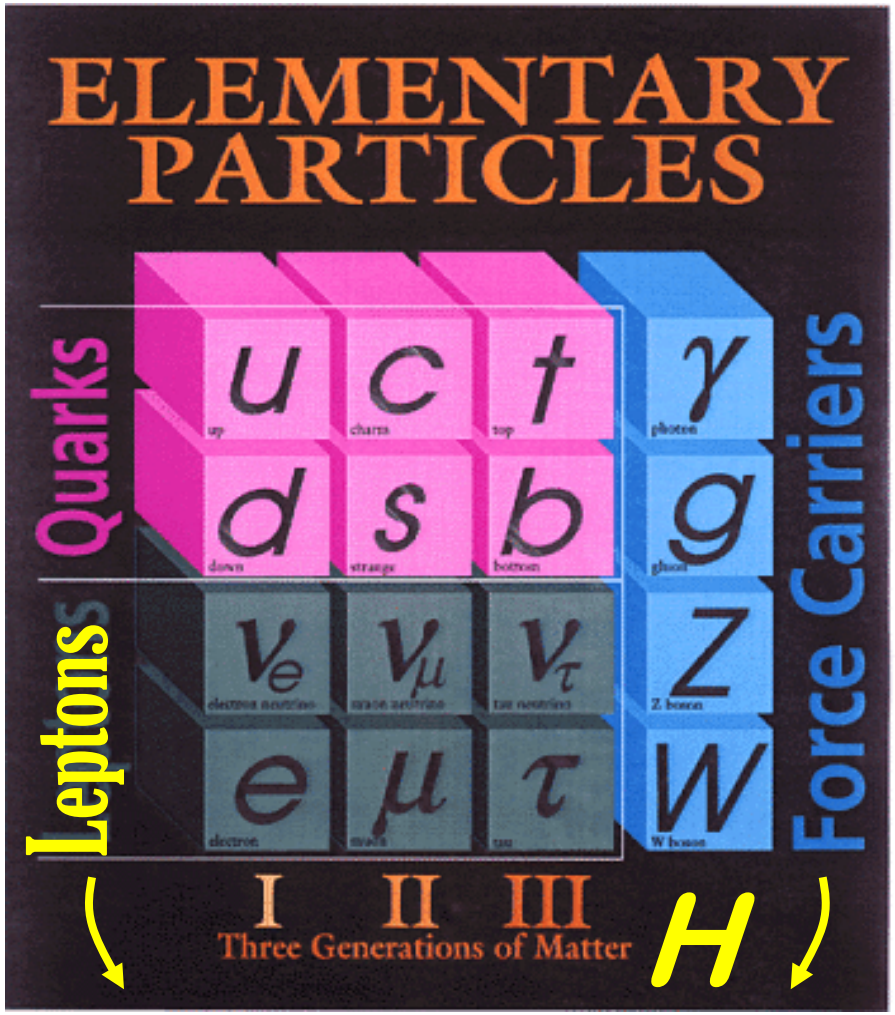
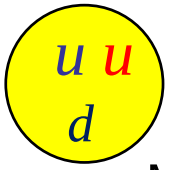
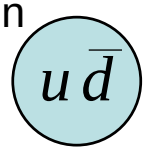
Experimental Physics at the MPP – A Historical Perspective

Particle Physics: What we know today ….





Baryon … , or Meson  …

electr. charge		Mass of particles (in GeV):			
+2/3	0	0.005	1.4	175	0
-1/3	0	0.006	0.3	4.5	0
0	0	>0	>0	>0	91
-1	±1	0.0005	0.1	1.8	80

“particles“: Spin 1/2 (fermions)

“fields“: Spin 1 (0) (bosons)

the „last missing“ particle is found

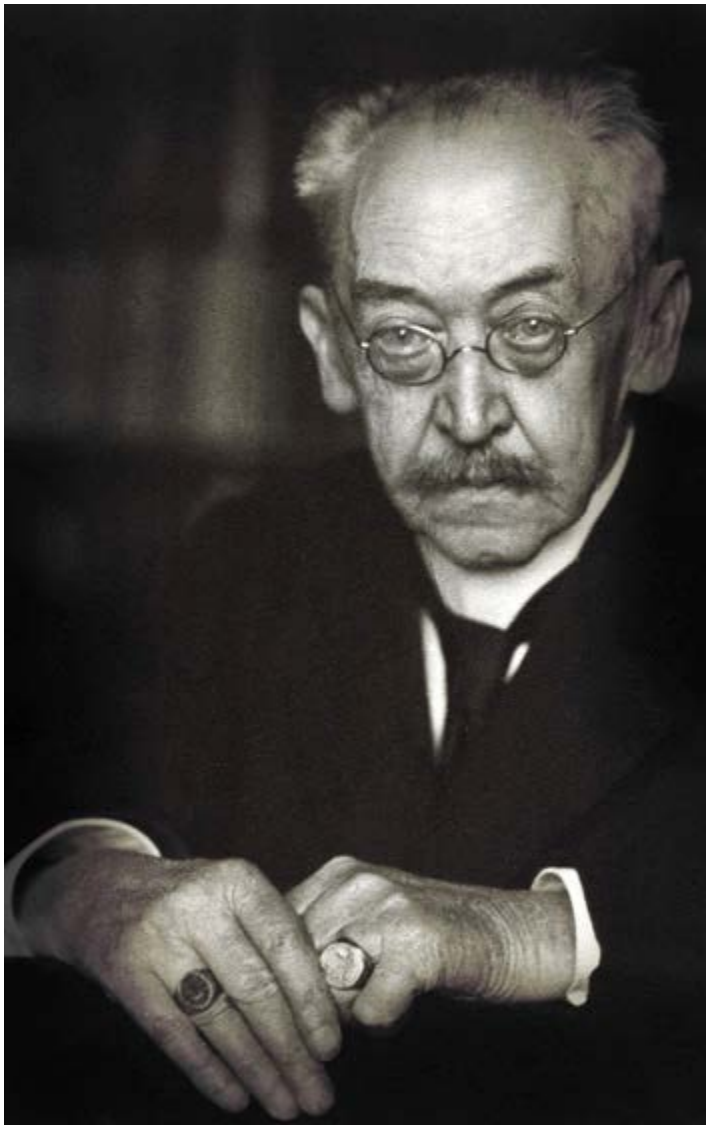
the Higgs *H* (2012 @CERN)

The Kaiser Wilhelm Society

1909: Adolf von Harnack (theology professor in Berlin)
memorandum to Kaiser Wilhelm II
on the reformation of German Science

".. to establish independent research institutes to coexist alongside the universities … they should conduct specialized basic research, predominantly in the natural sciences …"

He proposed the foundation of a brand new type of research association for the advancement of science:
The Kaiser Wilhelm Society.



The Kaiser Wilhelm Society

Jan 11, 1911: Foundation of the Kaiser-Wilhelm-Society in the Big Conference Hall of the Berlin Academy of Arts,
83 voting members from science, industry and arts.
Adolf von Harnack appointed as president

Logo of the KWS:

“Minerva”

Embodiment of wisdom, valor and endurance

Founding of the KWI for Physical Research

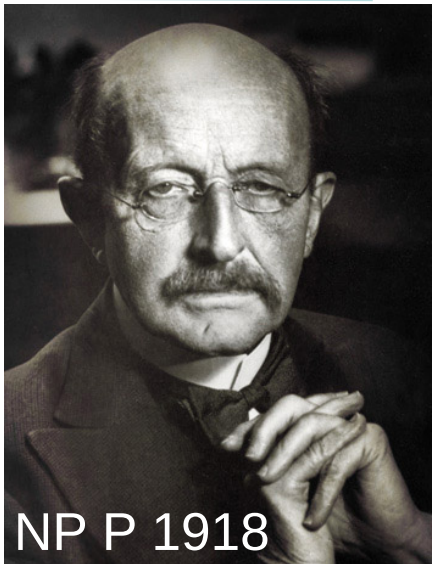
Jan. 1914: Application by Max Planck and others to the Prussian Government, the Industrial Koppel Foundation and the KWS to found a
“Kaiser-Wilhelm Institute for Physical Research”

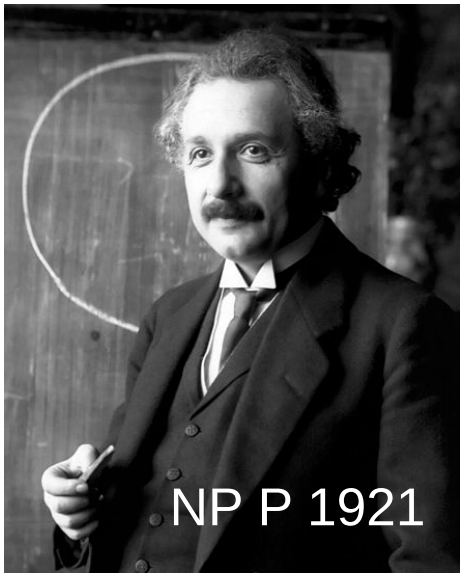
March 1914: Decision on foundation, Albert Einstein proposed as director

Intention to erect a building for the new institute on the “Berlin Dahlem Campus”, hosting the KWI for Chemistry (founded in 1912)

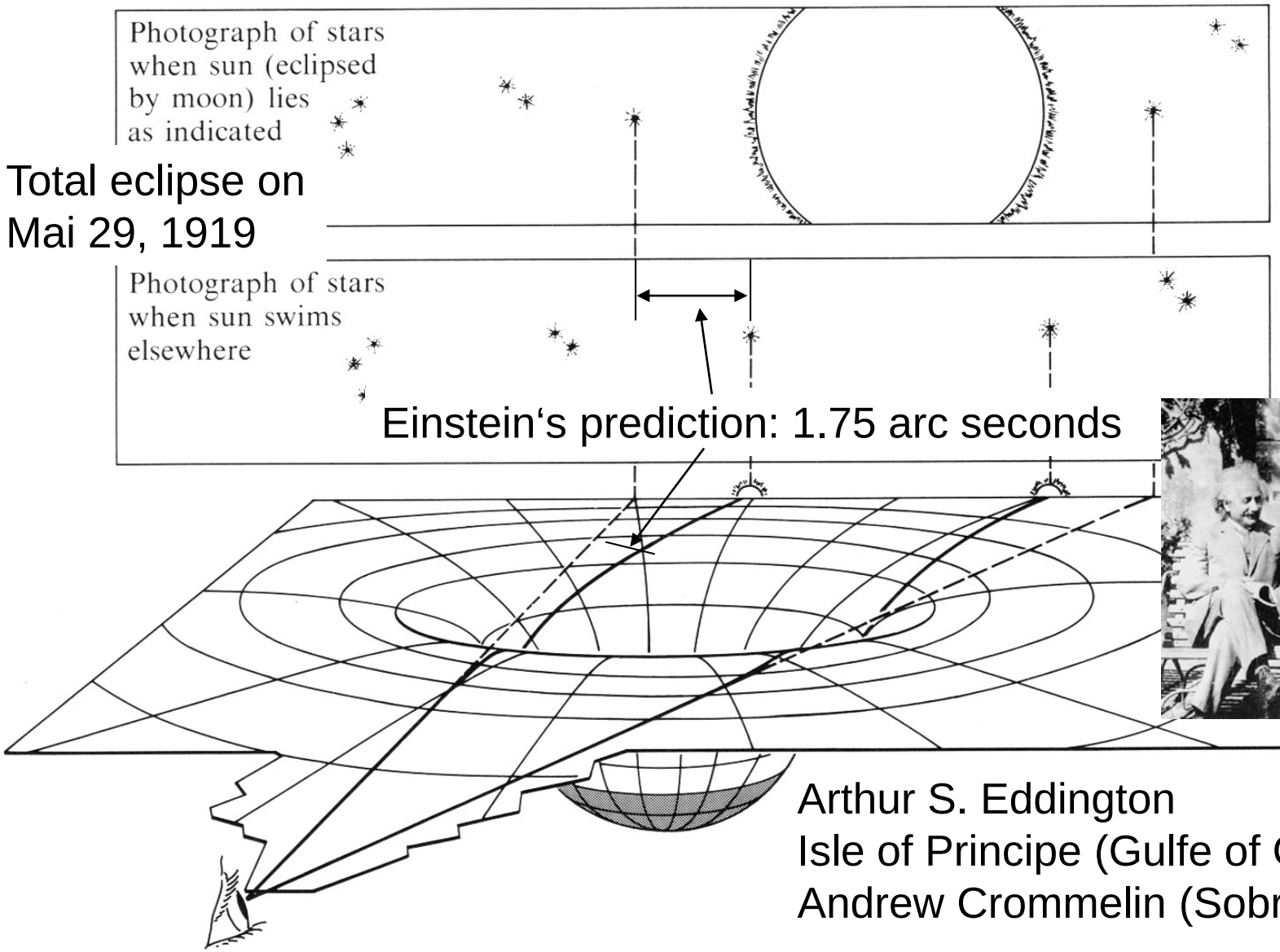
BUT: Outbreak of the 1st World War stopped planning

(Planck’s proposal to test Einstein’s prediction of the bending of light rays in a gravitational field with the solar eclipse of Aug. 24, 1914 on the Isle of Krim could not be realized)


NP P 1918


NP P 1921

Einstein‘s Famous Prediction



Total eclipse on
Mai 29, 1919

Arthur S. Eddington
Isle of Principe (Gulfe of Guinea)
Andrew Crommelin (Sobral, BR)

October 1st, 1917: Kaiser-Wilhelm-Institut für Physik

Institute located in the attic of the private home of Albert Einstein
Haberlandstraße 5, Berlin Schöneberg

Mission of the New Institute

„Das Kaiser-Wilhelm-Institut für Physik soll physikalische Forschungsarbeiten hauptsächlich durch Ankauf der jeweils nötigen Apparate nach dem freien Ermessen seines Direktoriums unterstützen. Dabei liegt die Absicht zugrunde, die verfügbaren Mittel möglichst ungeteilt bedeutenden Unternehmungen einzelner Forscher zuzuführen“

„The Kaiser-Wilhelm-Institute for Physics is aiming primarily to support physical research by purchasing the necessary equipment according to the free decision of its board of directors. With this it is intended to attribute the available resources in a preferentially undivided manner to extraordinary projects of individual researchers.“

Main activity: Evaluate applications of other institutions or individuals for financial support

Early History of the Institute

October 1922: Einstein proposes Max v. Laue as Deputy Director

(Einstein formally stayed as director until 1932, but delegated the daily activities more and more to Laue)

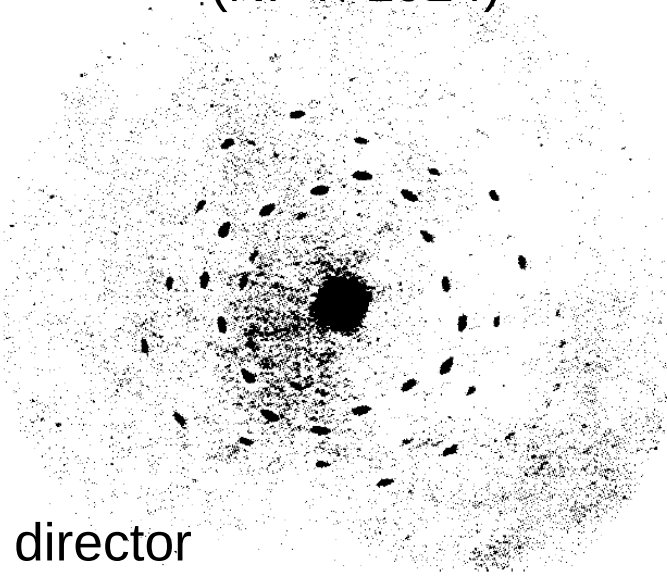
Decline during the 20'ies due to unfortunate overall financial boundary (-> inflation)

Laue was planning a fundamental reorganization, help offered (unexpectedly) by the Rockefeller Foundation

However, the "Machtergreifung" of the national socialists in 1933 made all plans obsolete,

Einstein emigrates, Laue declines offer to become director

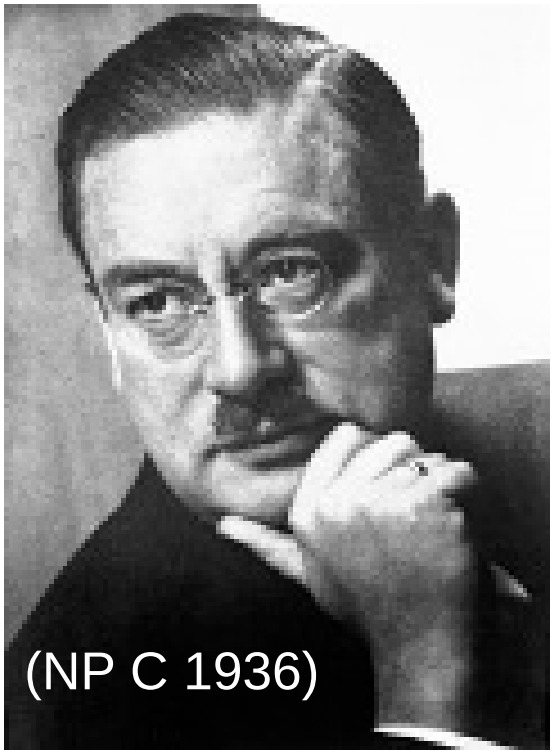
(NP P 1914)



Towards a Real Institute

October 1935: invited by Planck (president of the KWS since 1930), Peter Debye appointed as Director

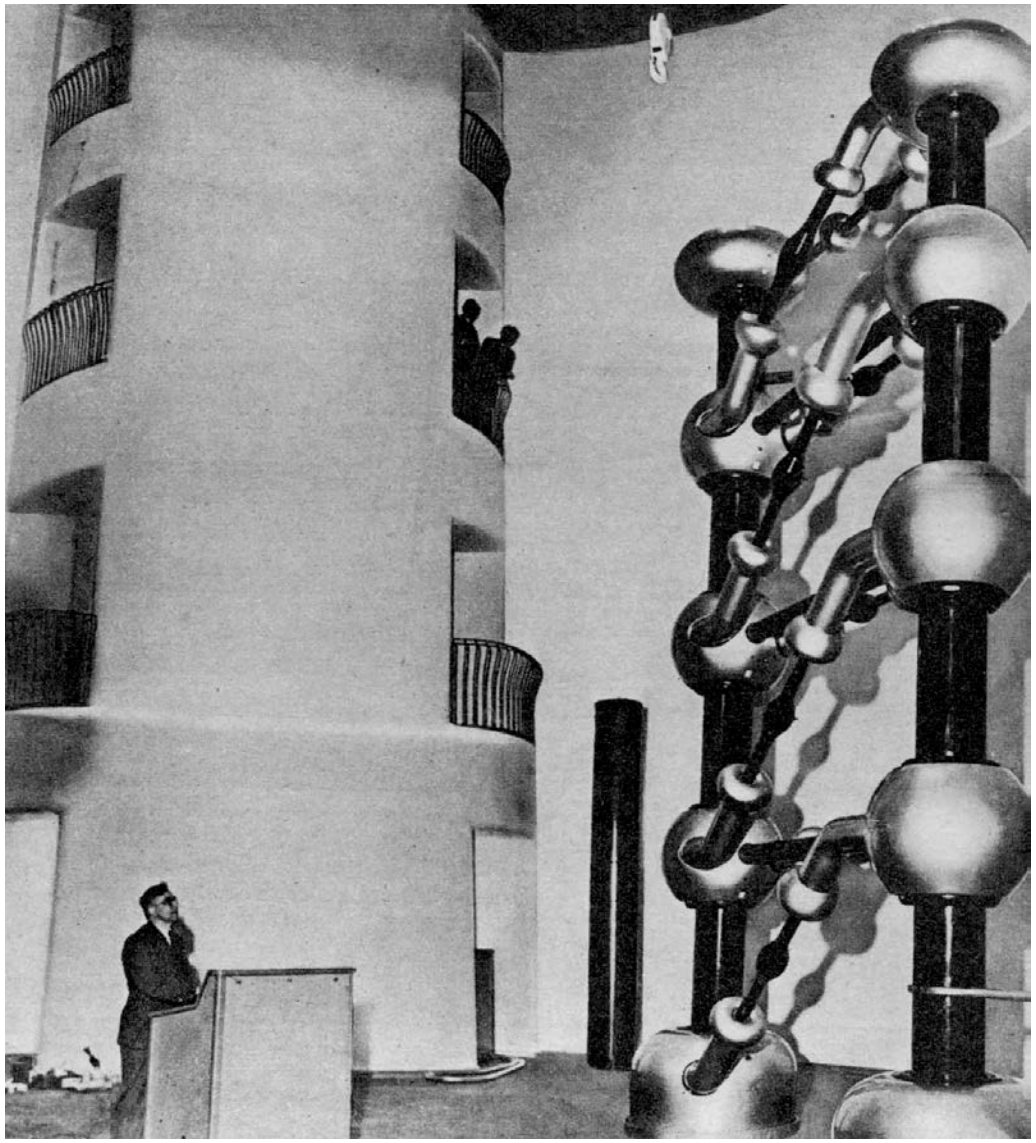
1937: own building in Berlin Dahlem



Debye recognized the change in development from atomic physics towards nuclear physics

KWI for Physics in Berlin-Dahlem

KWI for Physics: Experimental Facilities 1938



"Turm der Blitze"
(Tower of Lightnings)

High tension cascade generator
unique in Germany

(Greinacher principle)

1.4 (2.8) MV @ 5 mA

Experimental program:

Neutron source for the study of artificial nuclear transformation ("künstliche Atomumwandlung")

KWI for Physics: Experimental Facilities 1938

"Kältelaboratorium"
(Cryo laboratory)

Production of liquid
oxygen and hydrogen

also contained a
He liquefying plant,

Combined with
magnetic cooling,
mK temperatures
could be reached

Study of heat capacity vs temperature observed "freeze out" of phonon quantum states (the famous T^3 law of Debye up to Θ_D)

The KWI for Physics During WW II

After the discovery of nuclear fission (“Uranspaltung”) by Otto Hahn and Fritz Straßmann at the KWI of Chemistry in December 1938, interest shifted towards understanding the fission process and to study the possibilities for recovery of the released energy.

Early 1939: Foundation of the “Arbeitsgemeinschaft für Kernphysik”, inofficially: “Uranverein” (Uranium Club)

Purpose: construction of a “Uranbrenner”

Lead institution: KWI for Physics, (joined by C.F. v. Weizsäcker and K. Wirtz)

The KWI for Physics During WW II

In Sept. 1939 the “Uranverein” was put under the control of the “Heereswaffenamt” (armament research and development)

Debye was asked to give up his Dutch citizenship and to assume the German one in order to lead a secret weapon project.

Debye declined and left Germany for a guest professorship in Cornell.

Scientific leadership by
Otto Hahn (KWI for Chemistry)
and
Werner Heisenberg
(Director “am Institut” since 1942)

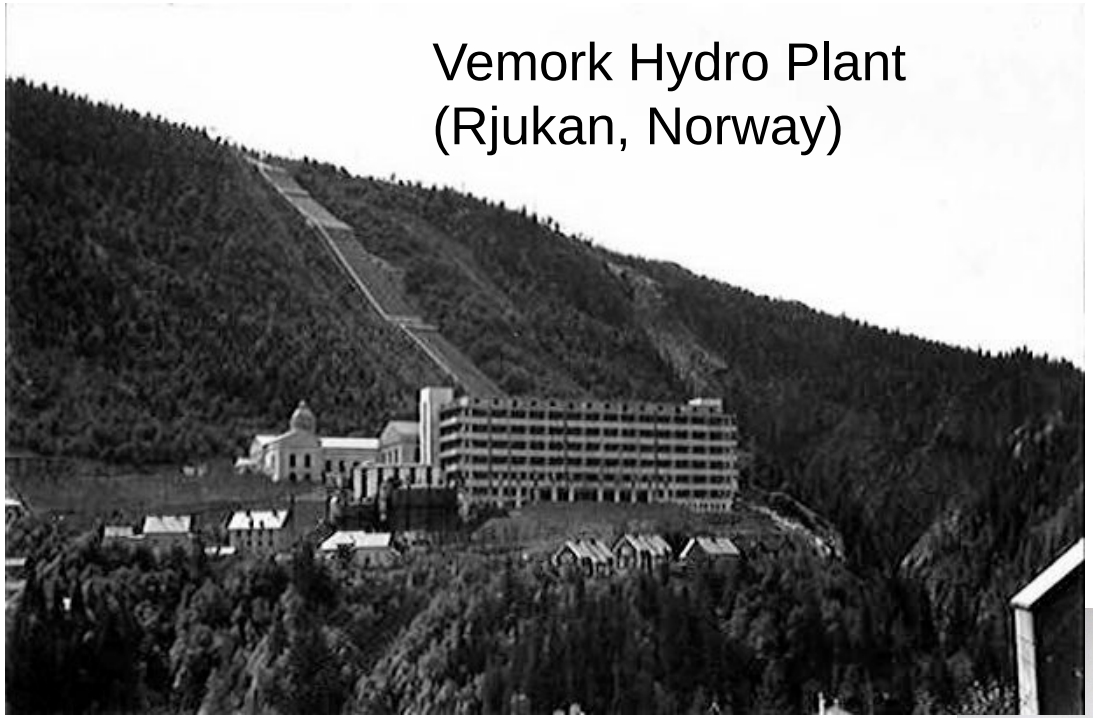
Project: The uranium burner, plans for a “bunker laboratory”, close to the “Turm der Blitze”

(NP C 1944)

(NP P 1932)

Scientist's Conscience

The Uranium Burner Project



Vemork Hydro Plant
(Rjukan, Norway)

Heisenberg proposed natural uranium as fission material, decided for heavy water as moderator

The problem: how to get sufficient quantities of D_2O

"Operation Gunnerside": Norwegian resistance fighters destroy the plant (Feb. 1943)

Allied bombing on Frankfurt and Leuna stops uranium production

The End of the Uranium Burner Project

1943: due to beginning allied bombing on Berlin relocation of project to Hechingen and Haigerloch (Hohenzollern, now Baden-Württemberg)

Early 1945:
last experiment in Haigerloch, reactor does not reach criticality due to lack of uranium (and D_2O)

← here: dismantling of the reactor pile by the Alsos-III-Mission

Heisenberg, Hahn, v. Weizsäcker, Wirtz and others brought to Farm Hill (GB)

The KWI for Physics After WW II

1946: Heisenberg, Wirtz and v. Weizsäcker return from detention to reorganize the work of the KWI for Physics in the premises of the “Aerodynamische Versuchsanstalt” in Göttingen

Fields of research:

elementary particles, cosmic ray research (Heisenberg, Wirtz)

first ideas towards nuclear fusion processes in stars (v. Weizsäcker)

The “Max Planck-Institute for Physics” is growing …

April 1947: association of the computational group of Heinz Billing
(construction of one of the first German “Elektronenrechner”,
invention of the magnetic drum storage).

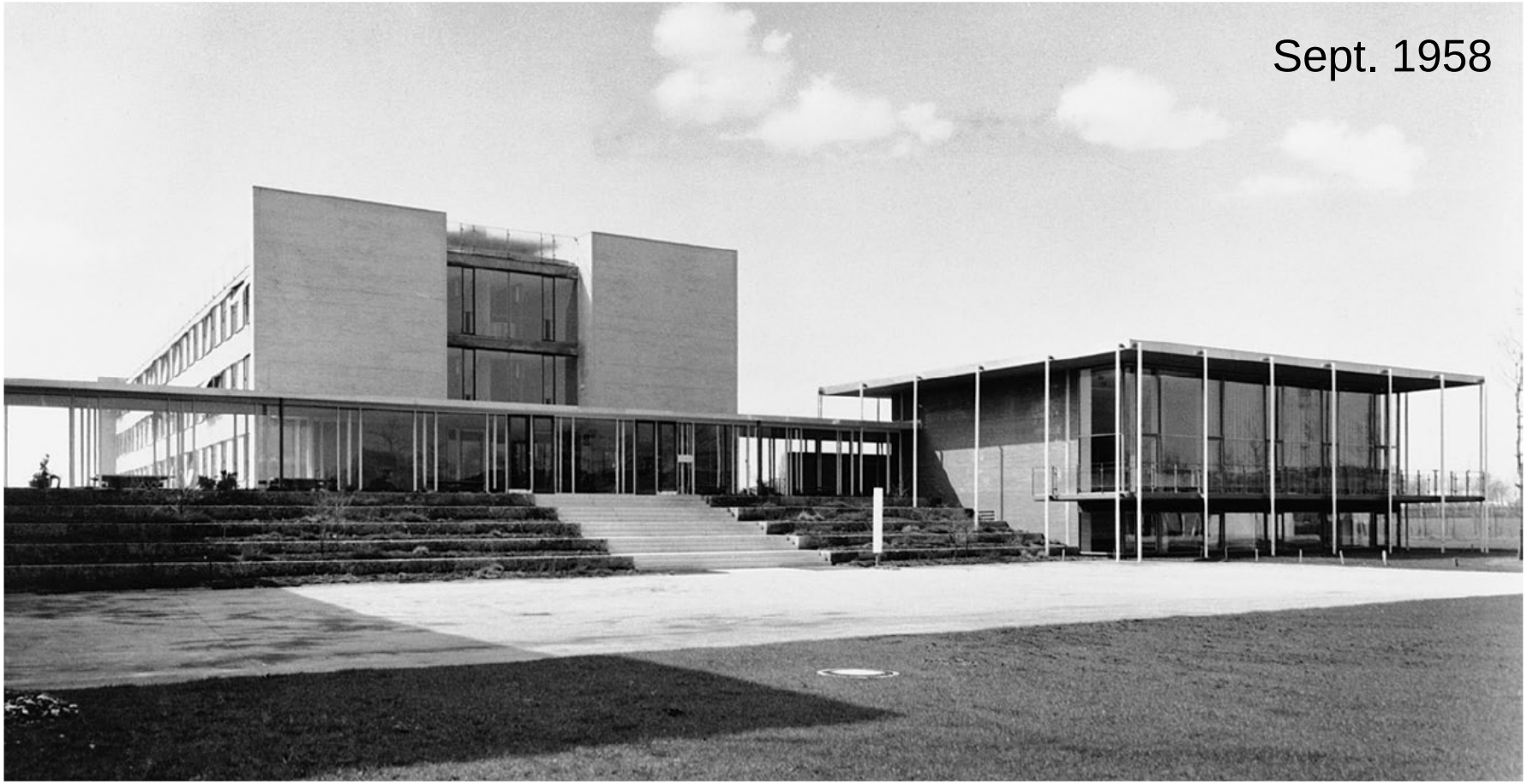
Juli 1947: Foundation of an astrophysical group led by Ludwig Biermann
(theoretical study of highly ionized gases -> “plasma”,
explanation of the “solar wind”).

Feb. 1948: “KWI für Physik” -> “Max-Planck-Institut für Physik”

Okt. 1955: Upon Heisenberg’s wish decision to move the growing institute
from Göttingen to Munich

emphasis on particle physics and astrophysical questions,
both theoretically and experimentally
(K. Wirtz went to Karlsruhe to continue reactor research)

“Max Planck-Institute for Physics and Astrophysics”

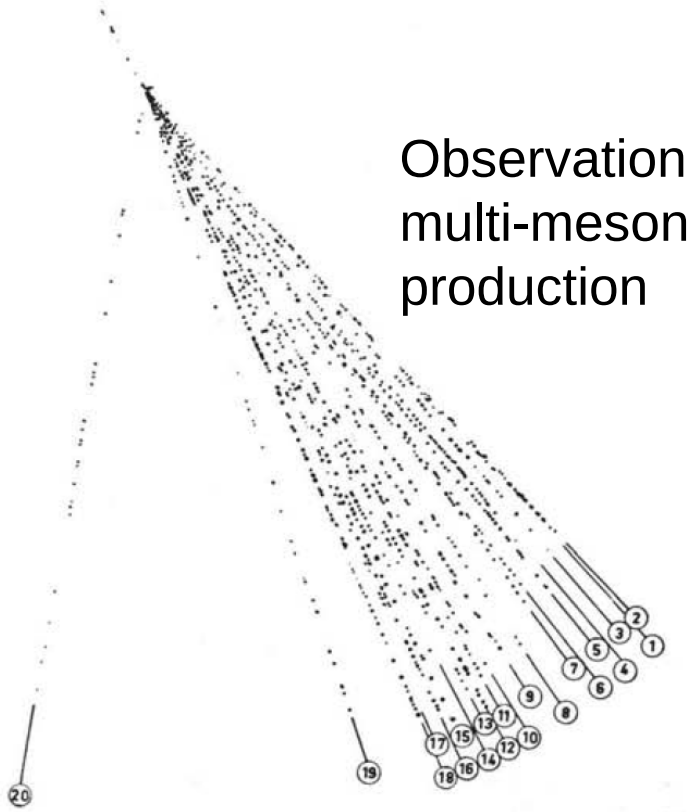


Departments for plasma physics, astrophysics and extraterrestrial physics later became independent MPI’s with new buildings in Garching

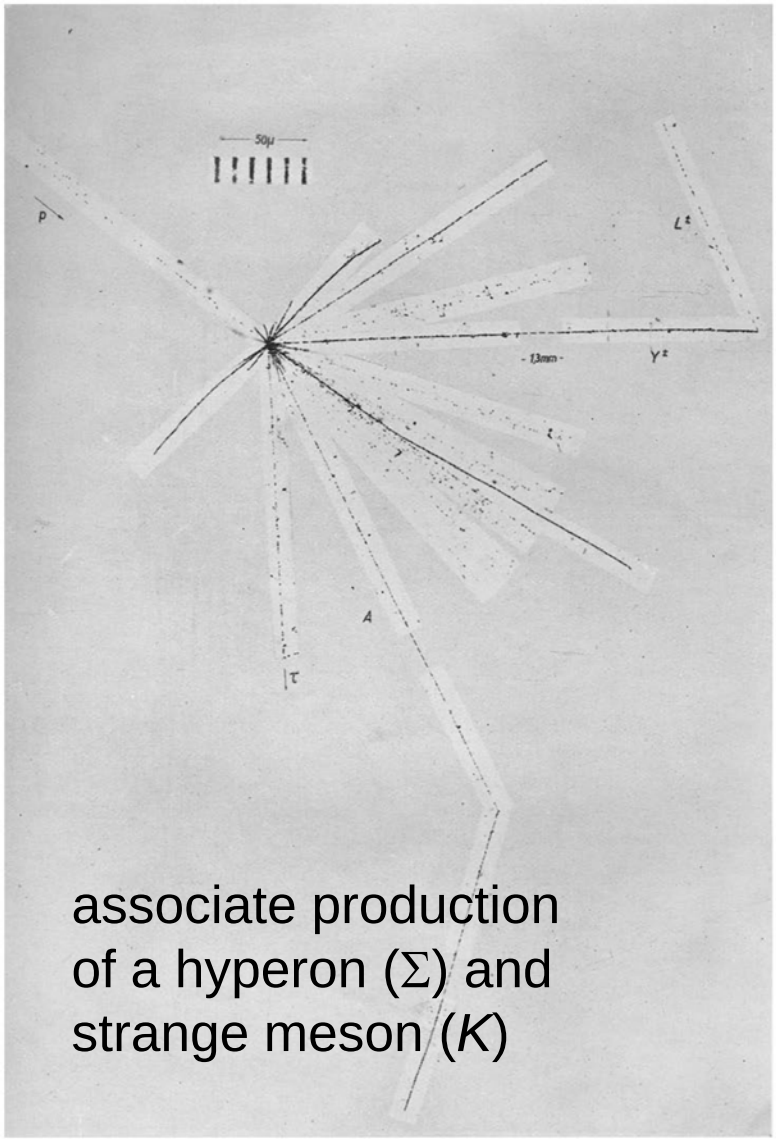
1991: renaming in “MPI für Physik (Werner-Heisenberg-Institut)”

Cosmic Ray Experiments (Group of K. Gottstein)

Balloon flights (typically 25 km high), emulsions as particle detectors (mid ’50s – early ’60s)



Observation of multi-meson production



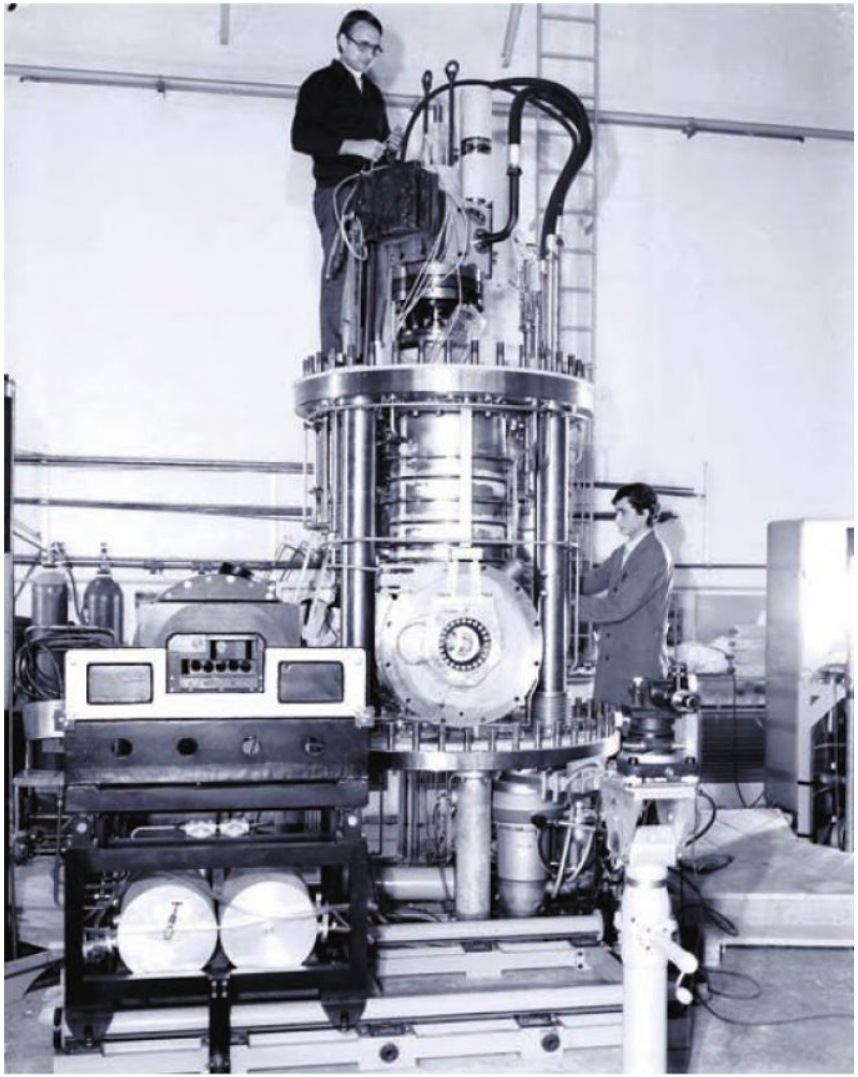
associate production of a hyperon (Σ) and strange meson (K)

Looking for Gravitational Waves in the early ’70ies

Heinz Billing (department of astrophysics) pioneered the field of gravitational wave detection

The Era of Bubble Chambers (Group of N. Schmitz)

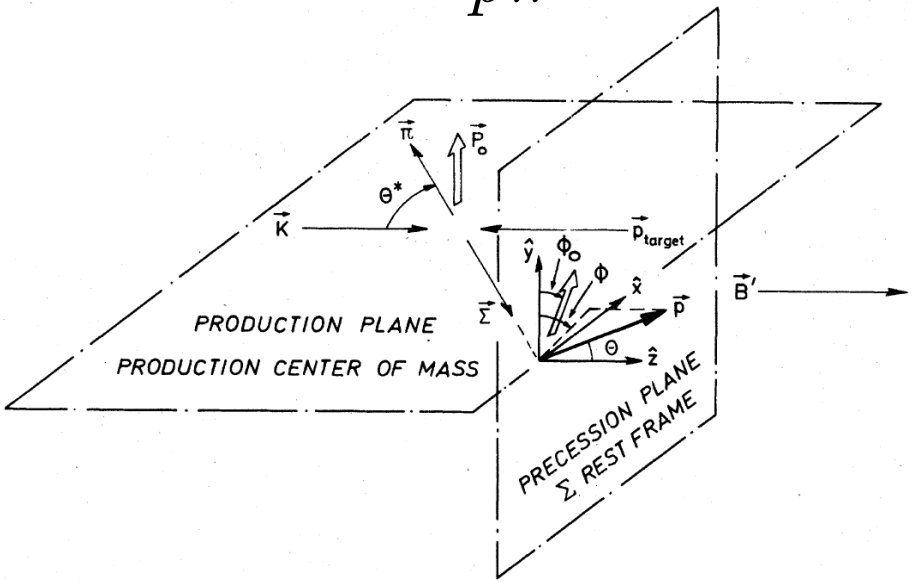
Rapid cycling Hydrogen Bubble Chamber (1971)



First precise measurement of the magnetic moment of the Σ^+

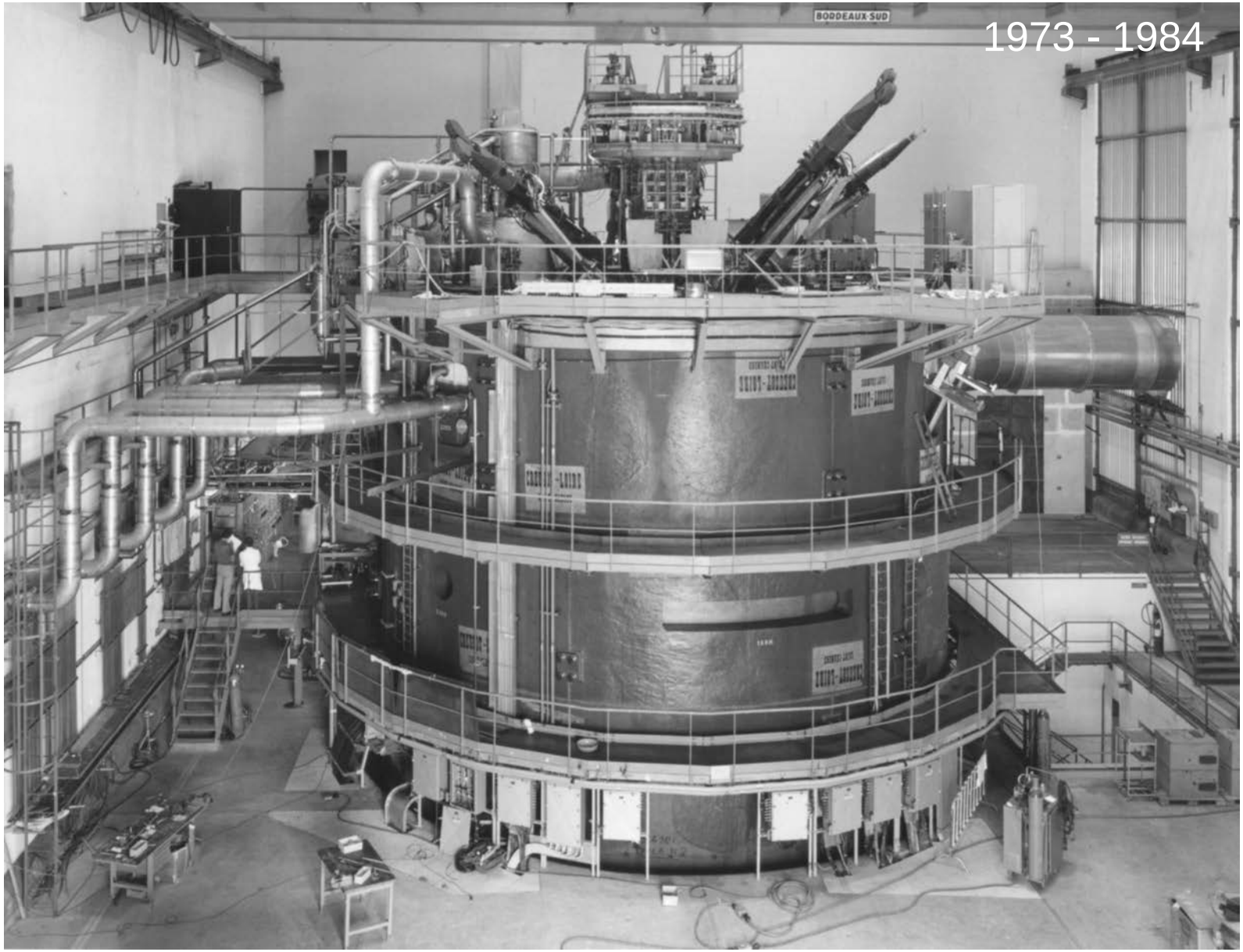
$$K^- p \to \Sigma^+ \pi^-$$

$$\hookrightarrow p\pi^0$$

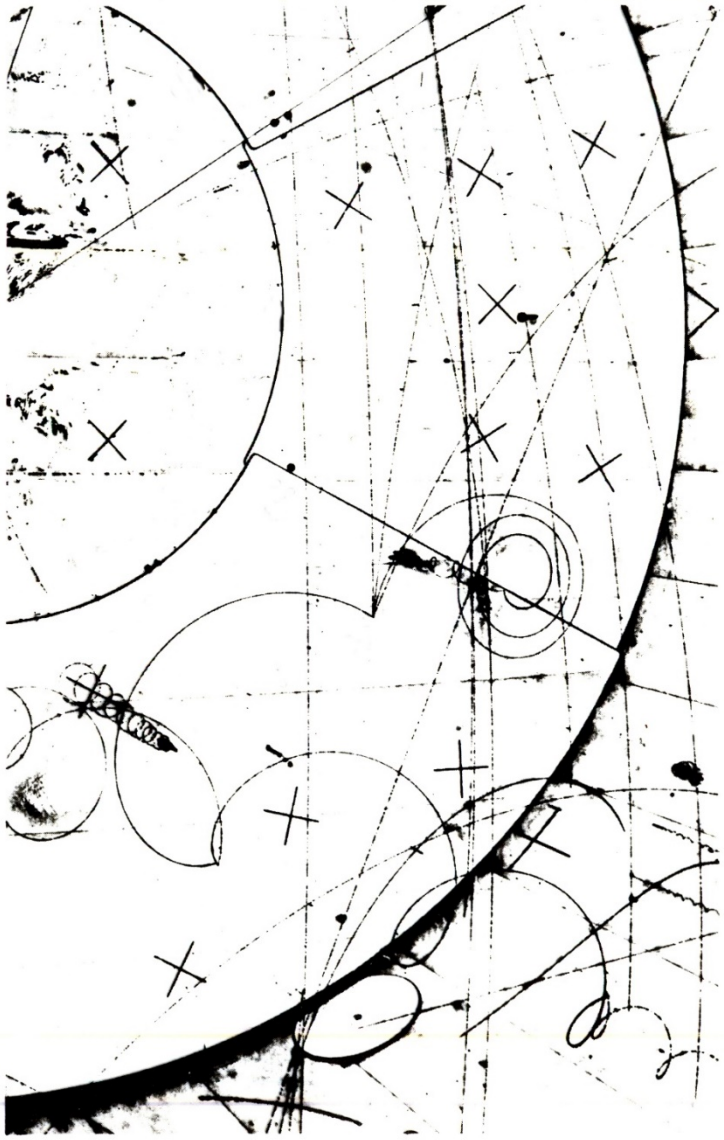


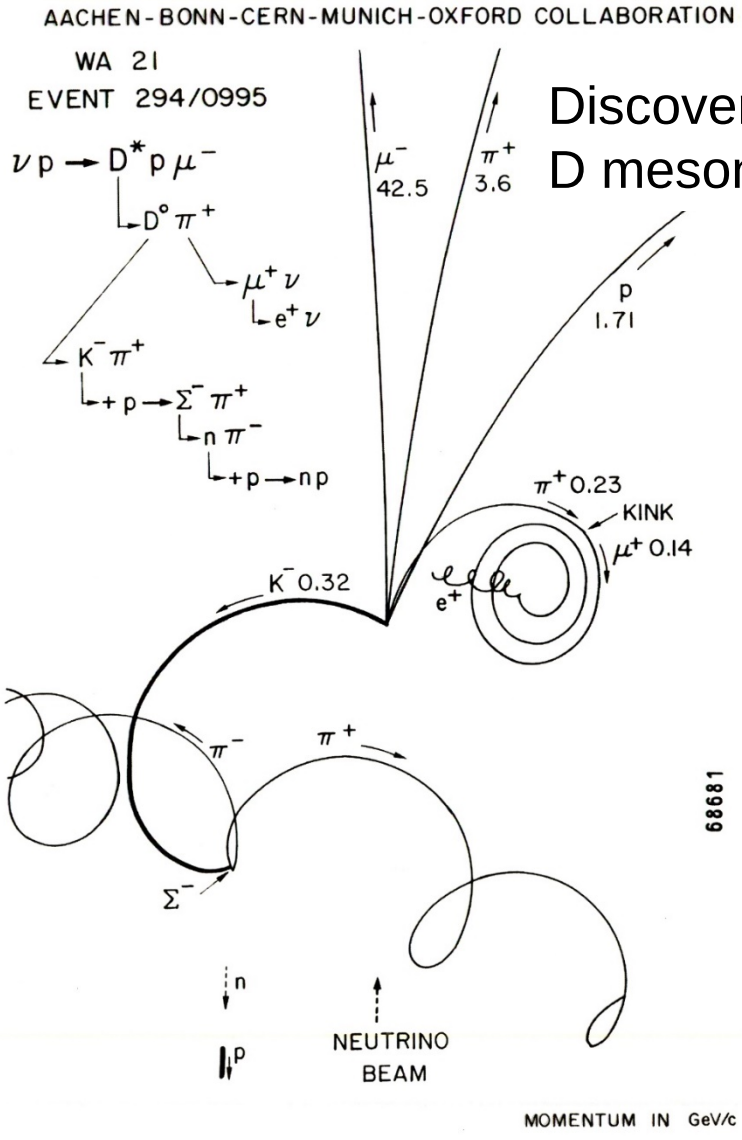
$$\mu_\Sigma = 2.30 \pm 0.14 \mu_N$$

The BEBC Facility („Big European Bubble Chamber“)



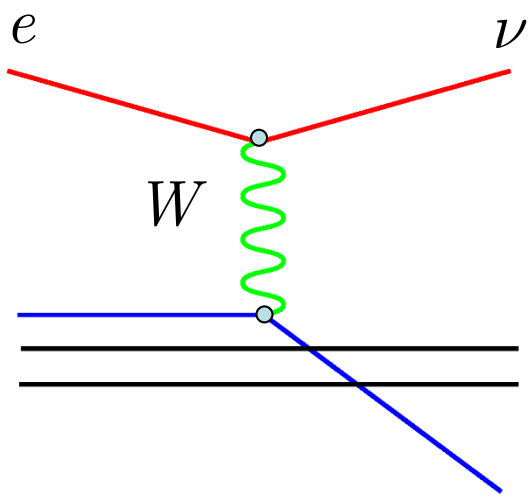
Charm Production with Neutrinos



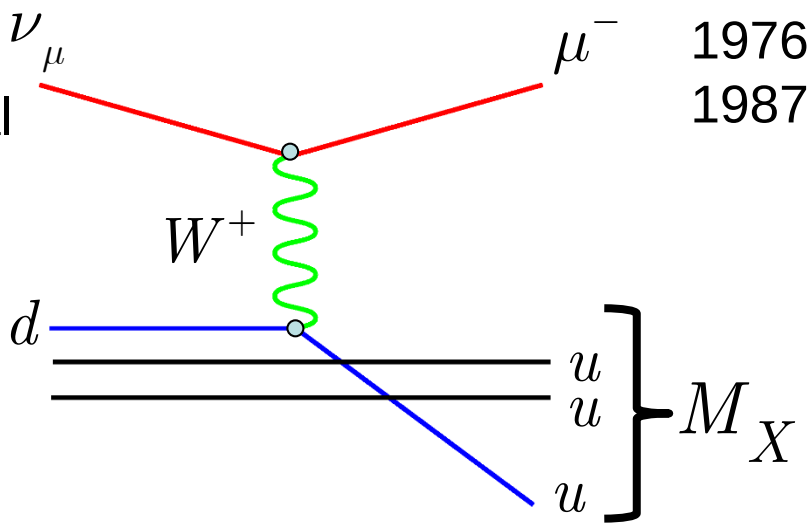


Discovery of the D meson

Deep Inelastic Scattering with Neutrinos

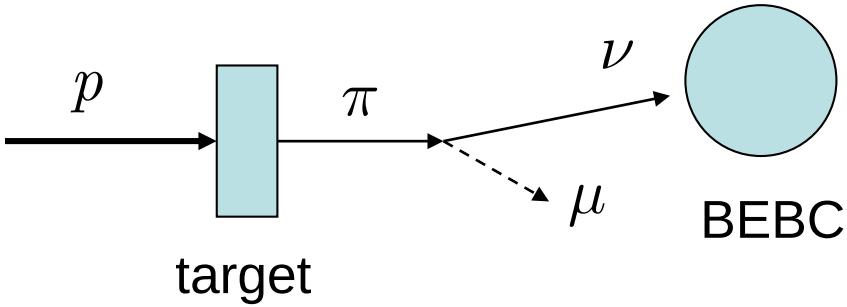


time reversal



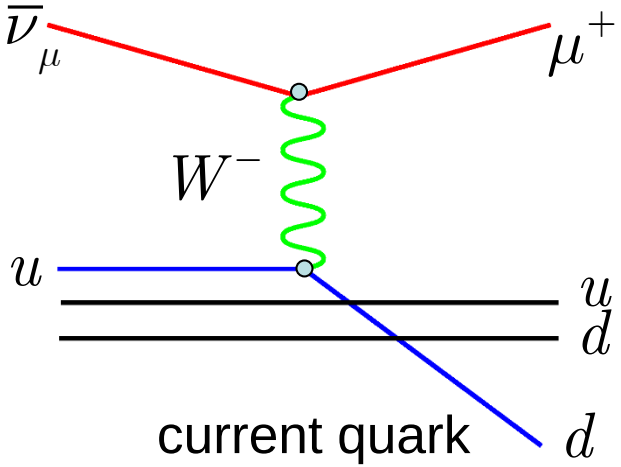
1976 - 1987

How to prepare a neutrino beam:



High energy needed: $\sigma \sim E_\nu$

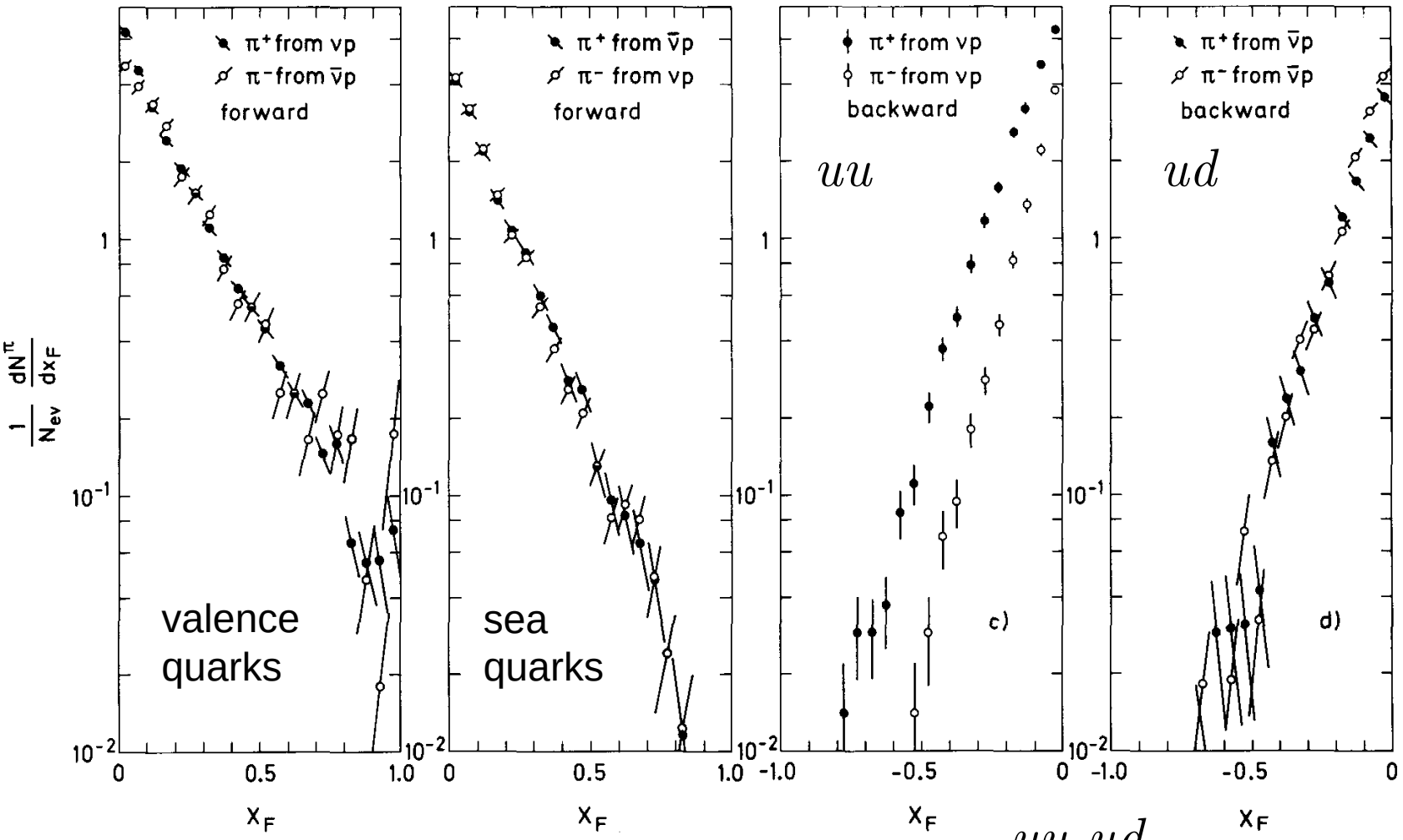
neutrinos select the quark flavor within the proton:



Flavor Tagging with Neutrinos: Quark "Fragmentation"

(Group of N. Schmitz)

$$x_F = 2p_q \,/\, M_X$$



„current" quark $\longrightarrow$ u, d

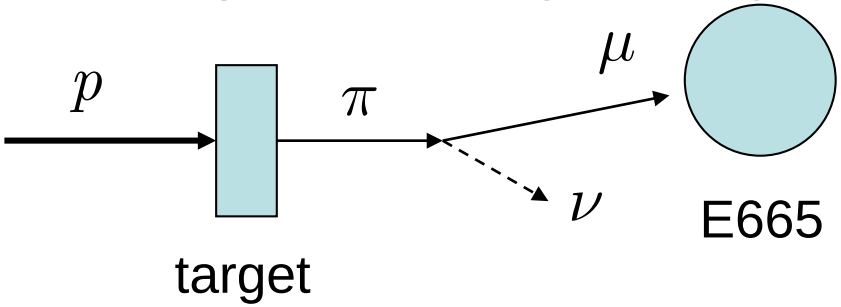
uu, ud $\longleftarrow$

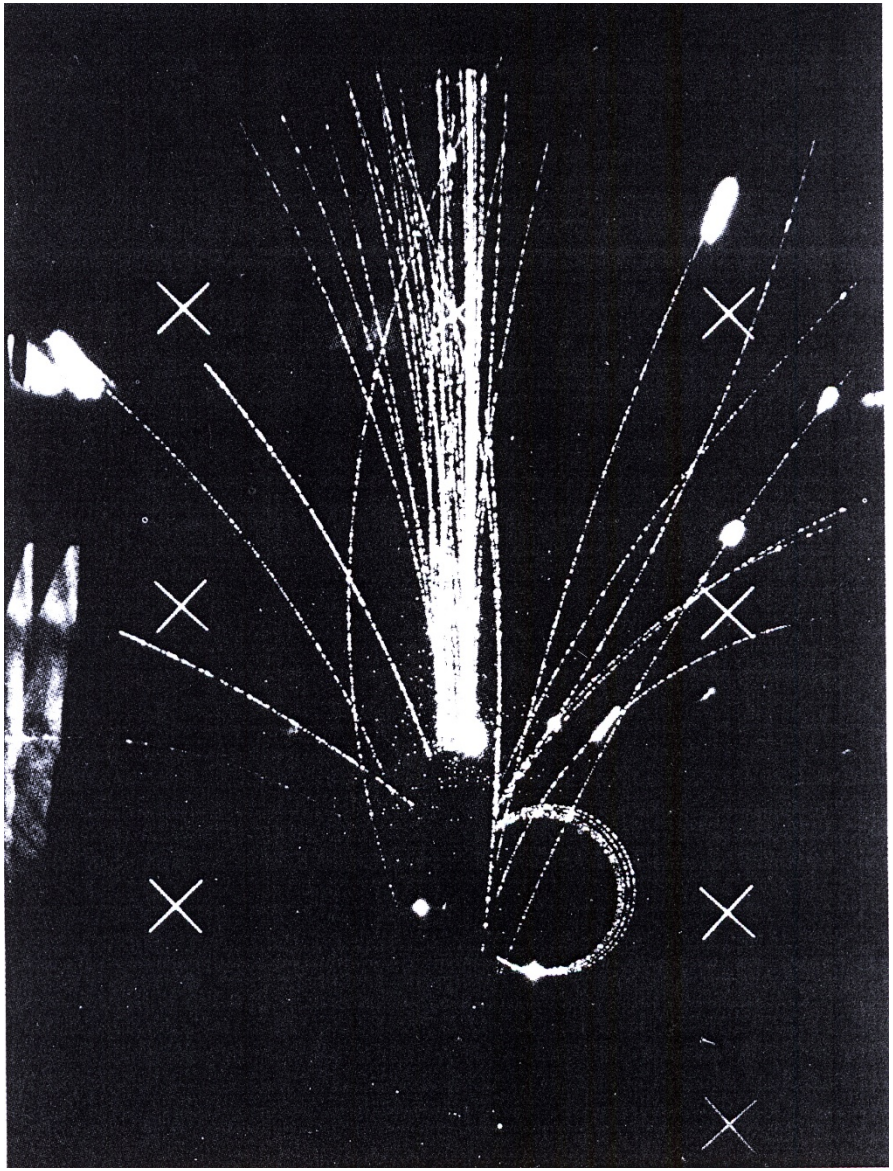
di-quarks (from target)

Scattering with Muons (1980 -> 1996)

E665 experiment at Fermilab

650 GeV proton beam (Tevatron)





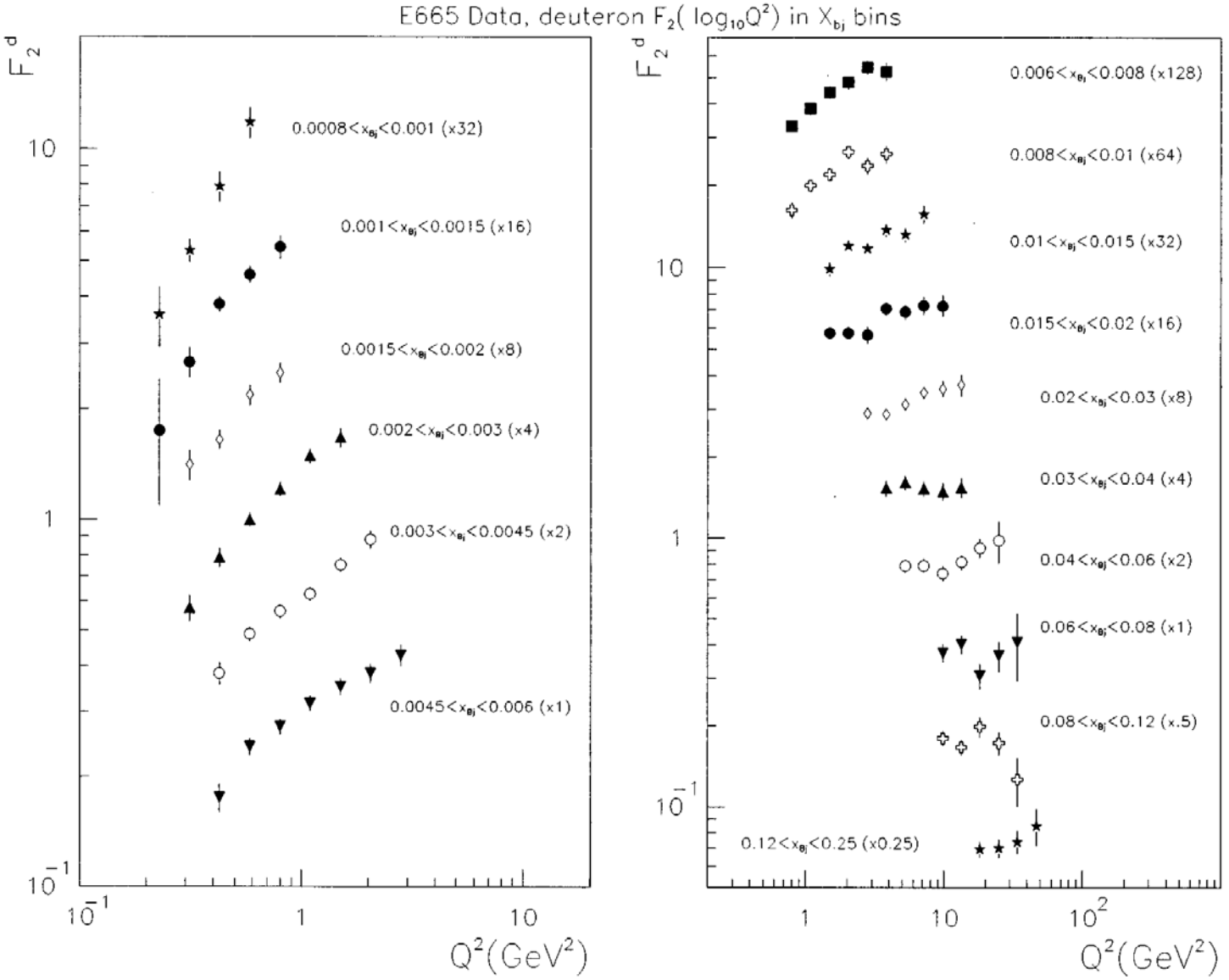
New detection technique:

Streamer Chamber
(V. Eckardt et al., MPI)

Big advantage over bubble chambers:

SC can be triggered!

Measurements of the Structure Function F_2

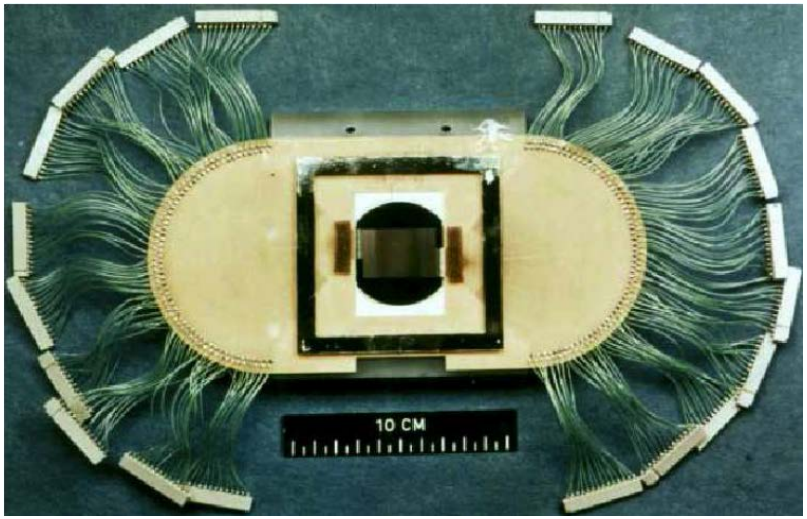


observation:

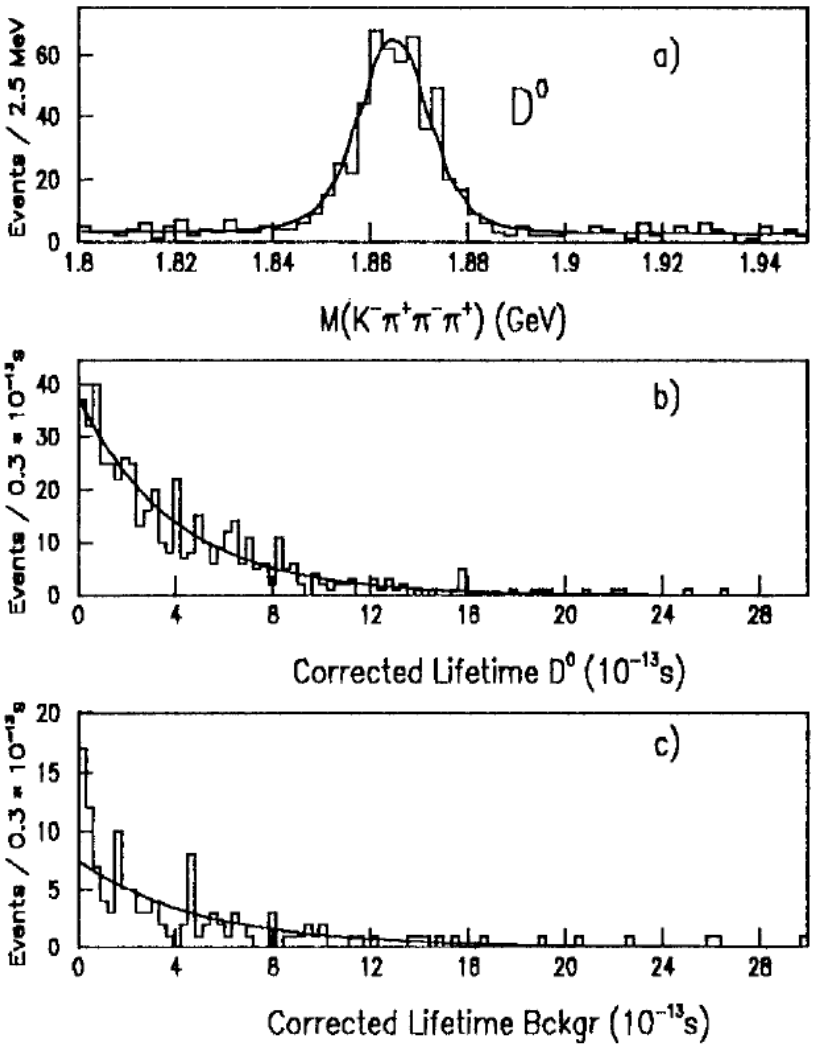
scaling violations at low x !

F_2 is (also) a function of Q^2

Counter Experiments at CERN: Charmed Particles



(Group of U. Stierlin)



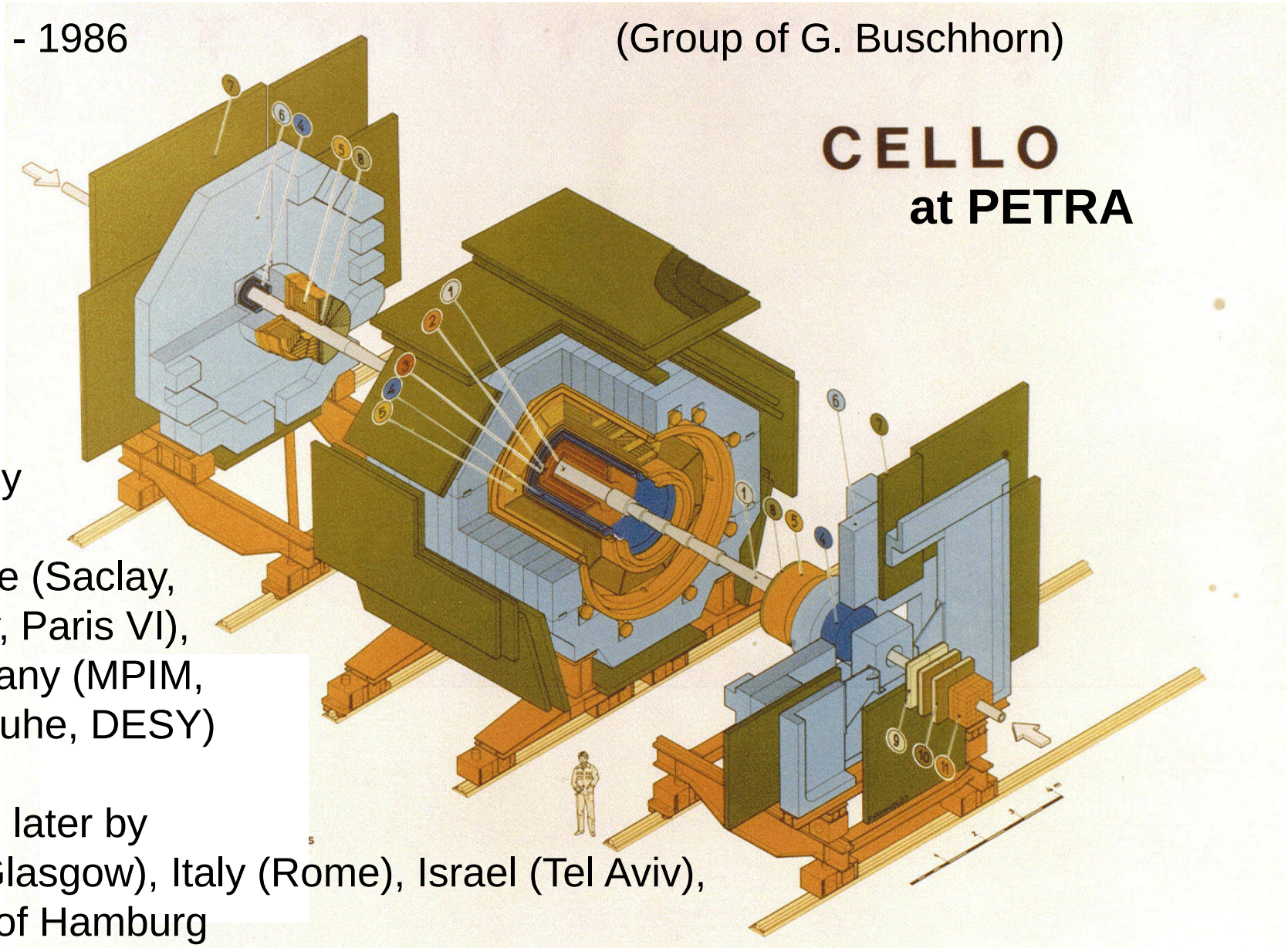
Strong Spectrometer Program at CERN PS and SPS (1970 – 1989)

NA32: Vertex determination via Silicon Microstrip Detector

Precise lifetime measurements of charmed mesons and baryons

Experiments at Electron – Positron Colliders

1980 - 1986 (Group of G. Buschhorn)



built by

France (Saclay, Orsay, Paris VI), Germany (MPIM, Karlsruhe, DESY)

joined later by
UK (Glasgow), Italy (Rome), Israel (Tel Aviv), Univ. of Hamburg

Standard Model: Electroweak Interference

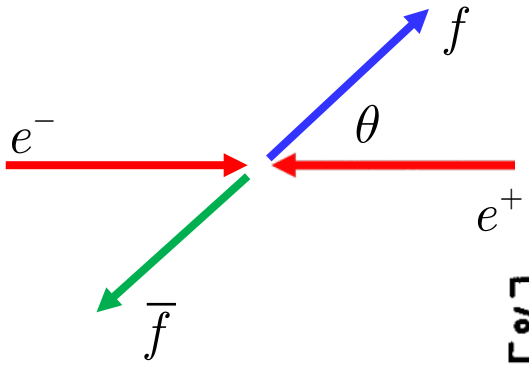
$$\frac{d\sigma}{d\Omega} = \left| \gamma + Z^0 \right|^2$$

$$e = g \sin\theta_W$$

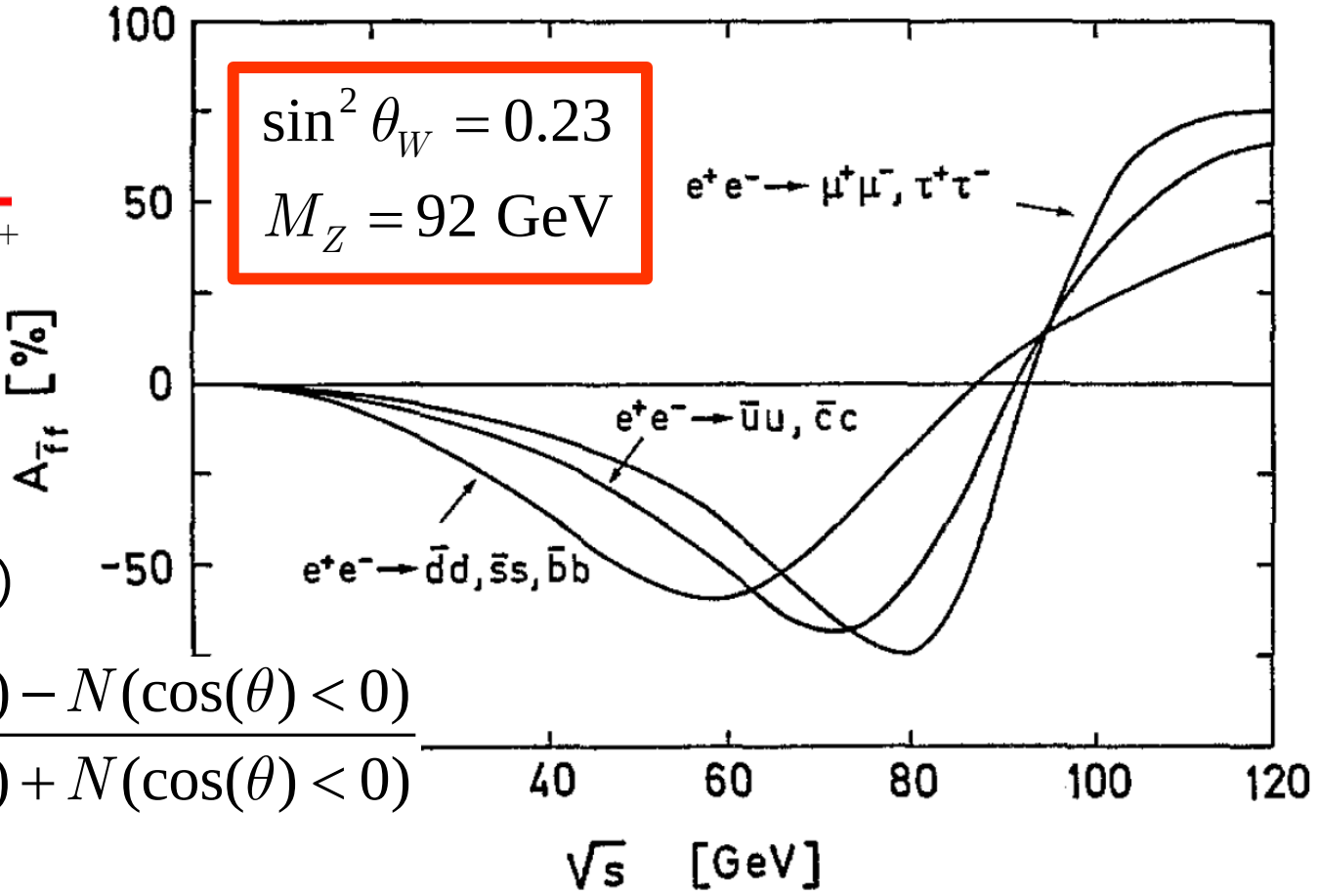
„SM“

$$\frac{G_F}{\sqrt{2}} = \frac{\pi\alpha}{2\sin^2\theta_W M_W^2}$$

$$M_W / M_Z = \cos\theta_W$$



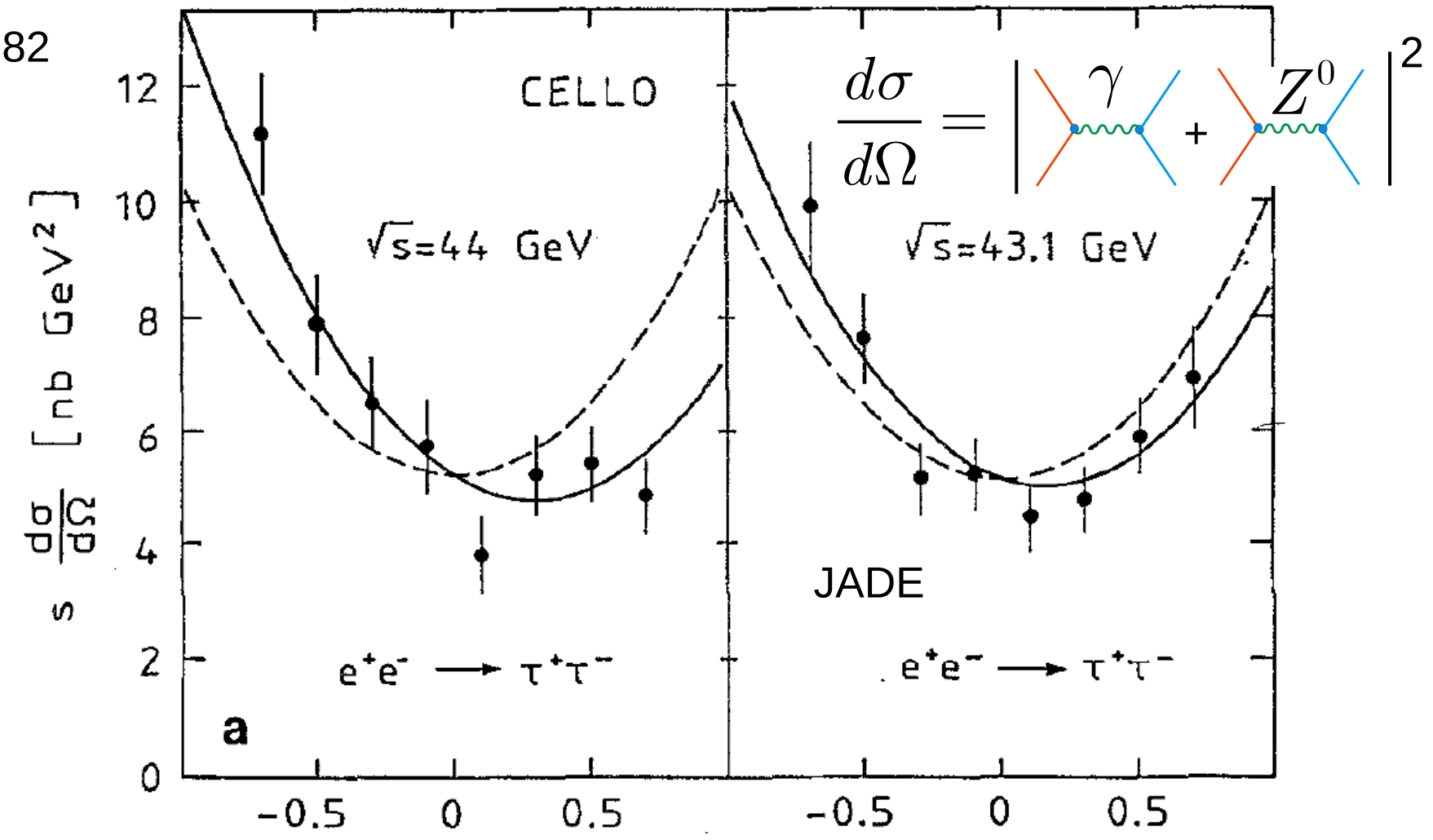
Forward-backward angular asymmetry („charge asymmetry“)



$$A_{\bar{f}f} = \frac{N(\cos\theta > 0) - N(\cos(\theta) < 0)}{N(\cos\theta > 0) + N(\cos(\theta) < 0)}$$

„Seeing“ the Z-Boson

1982



Measurements at PETRA
(highest energy at that time)

clear evidence for the Z^0

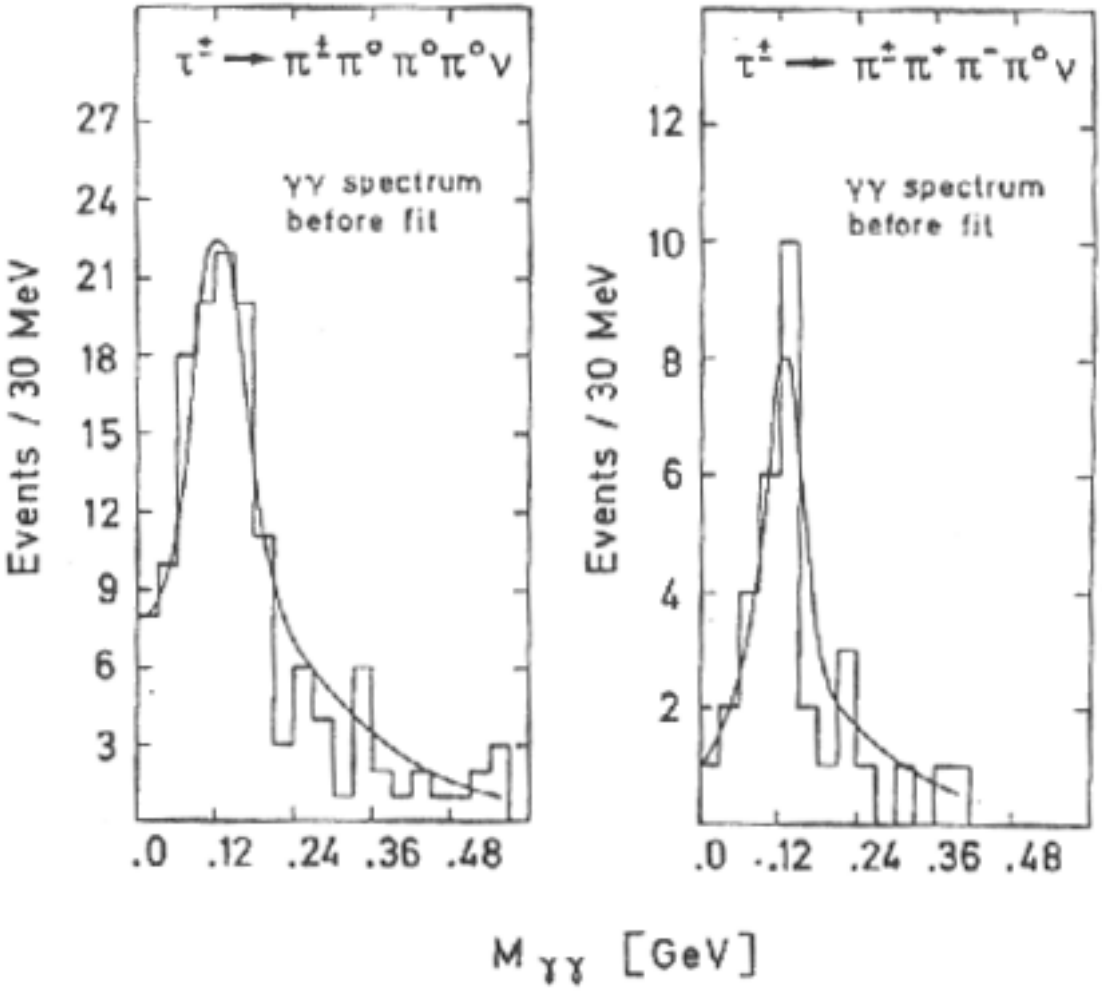
τ - Physics with the CELLO detector

First global analysis of all decay channels of the τ lepton, particularly multi-neutral final states

solves the so-called "1-prong" problem, i.e. the apparent lack of decays into 1 charged particle + neutrals.

these were identified as decays with several neutral pions

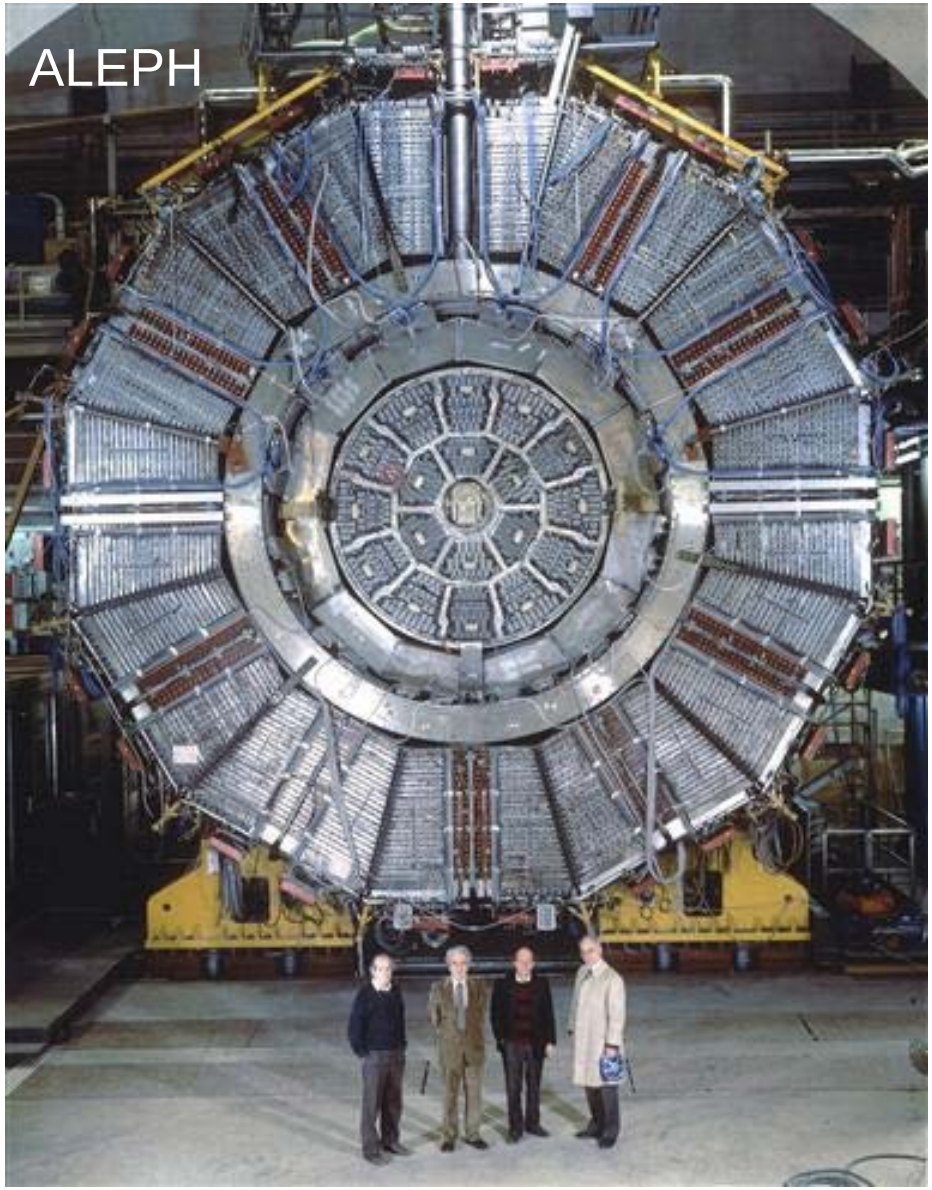
→ LAr calorimeter



invariant di-photon mass from the LAr calorimeter


The Big Step: LEP
1989 - 2000
OPAL
ALEPH
Large Electron Positron Collider
27 km circumference
DELPHI
L3
Collide electrons and positrons at the mass of the
Z Boson (~ 90 GeV) up to 206 GeV (W pair production)

Electron-Positron Experiments at CERN

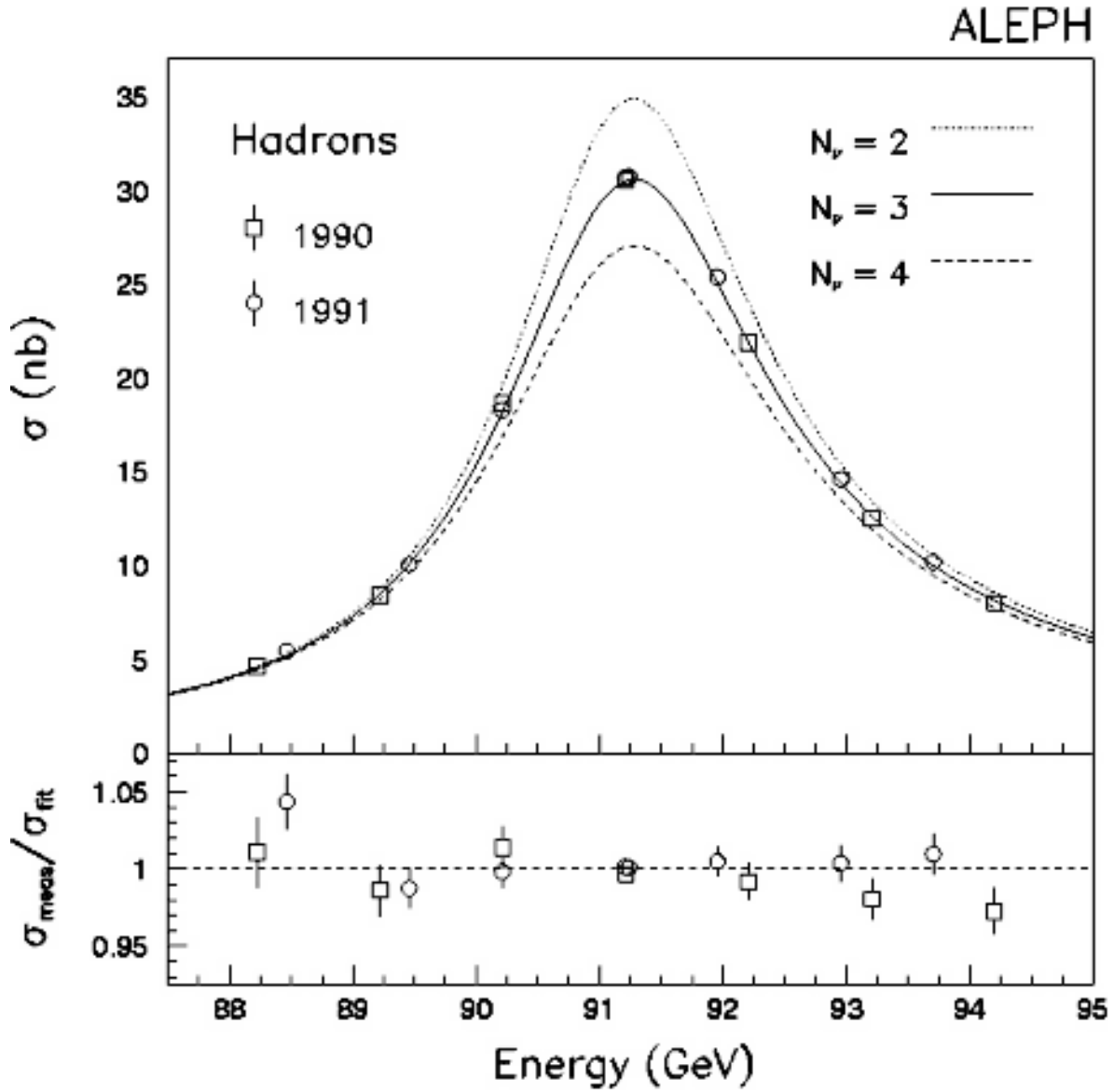


Group of U. Stierlin
-> S. Bethke

Precision measurements of the Standard Model

at the Z peak (LEP I) and beyond (LEP II)

LEP I : Rich Physics Harvest …



„Clean“ experimental environment (in contrast to hadronic machines)

High precision results

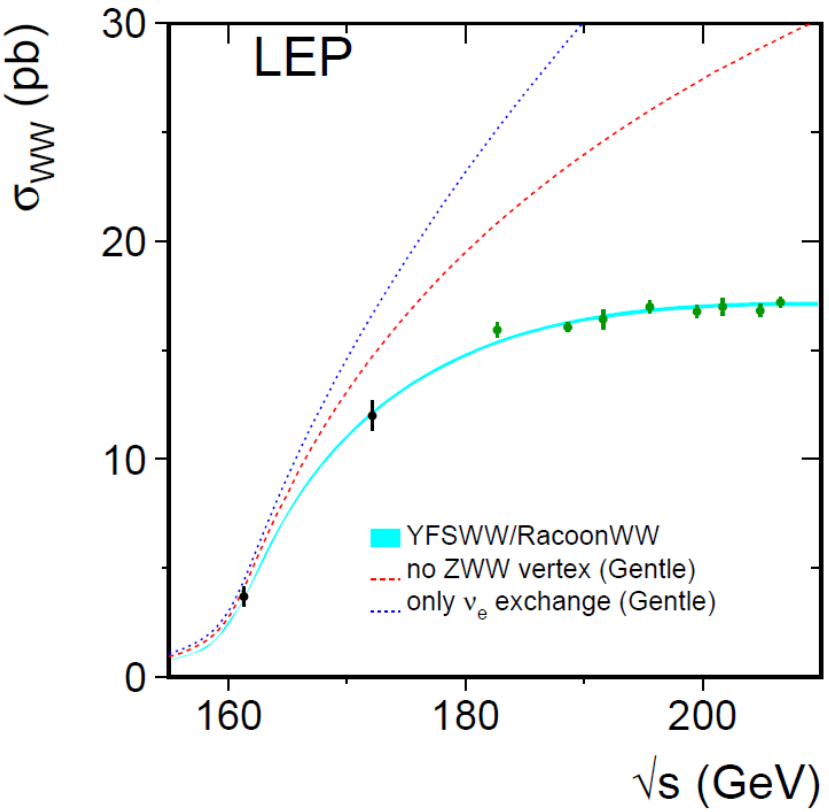
among them:

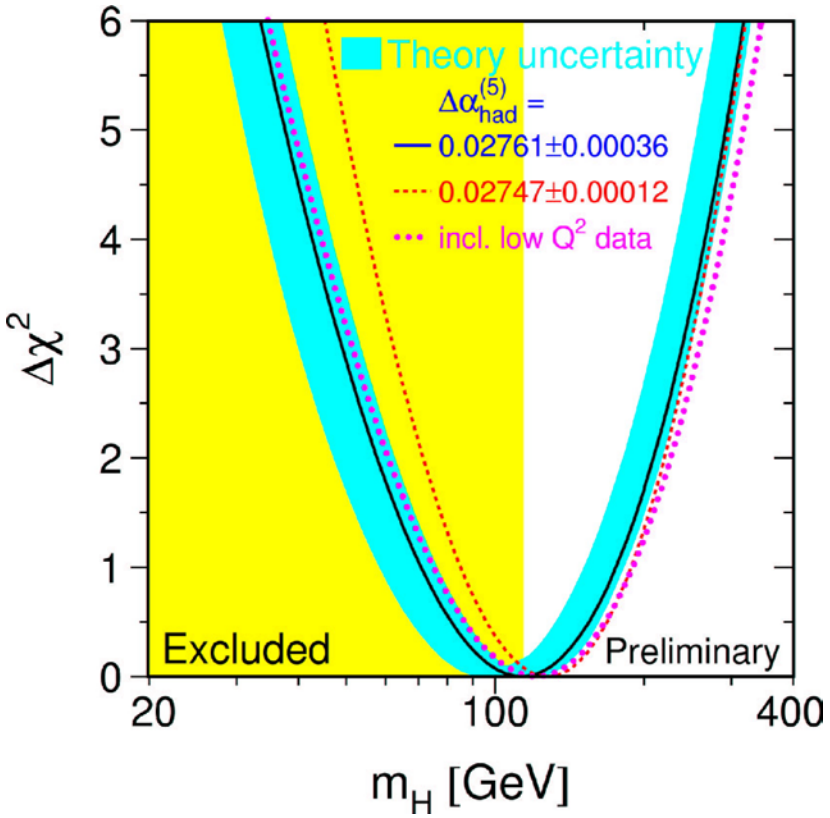
Number of light neutrinos is „3“

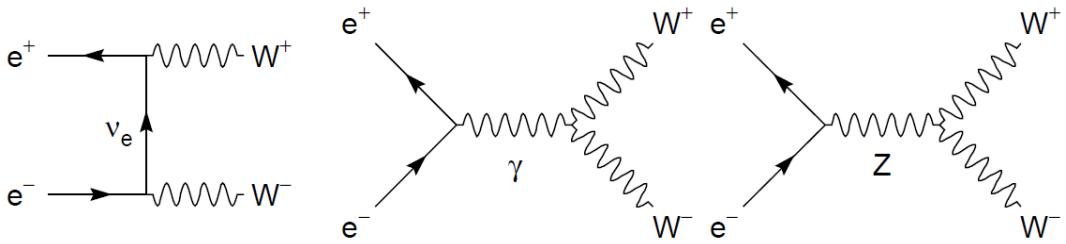
Standard Model proven to be correct (at low E),

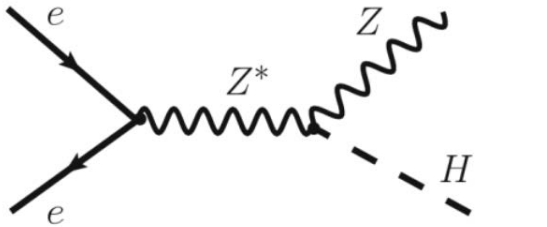
no significant deviations

LEP II : Predicting the Higgs mass



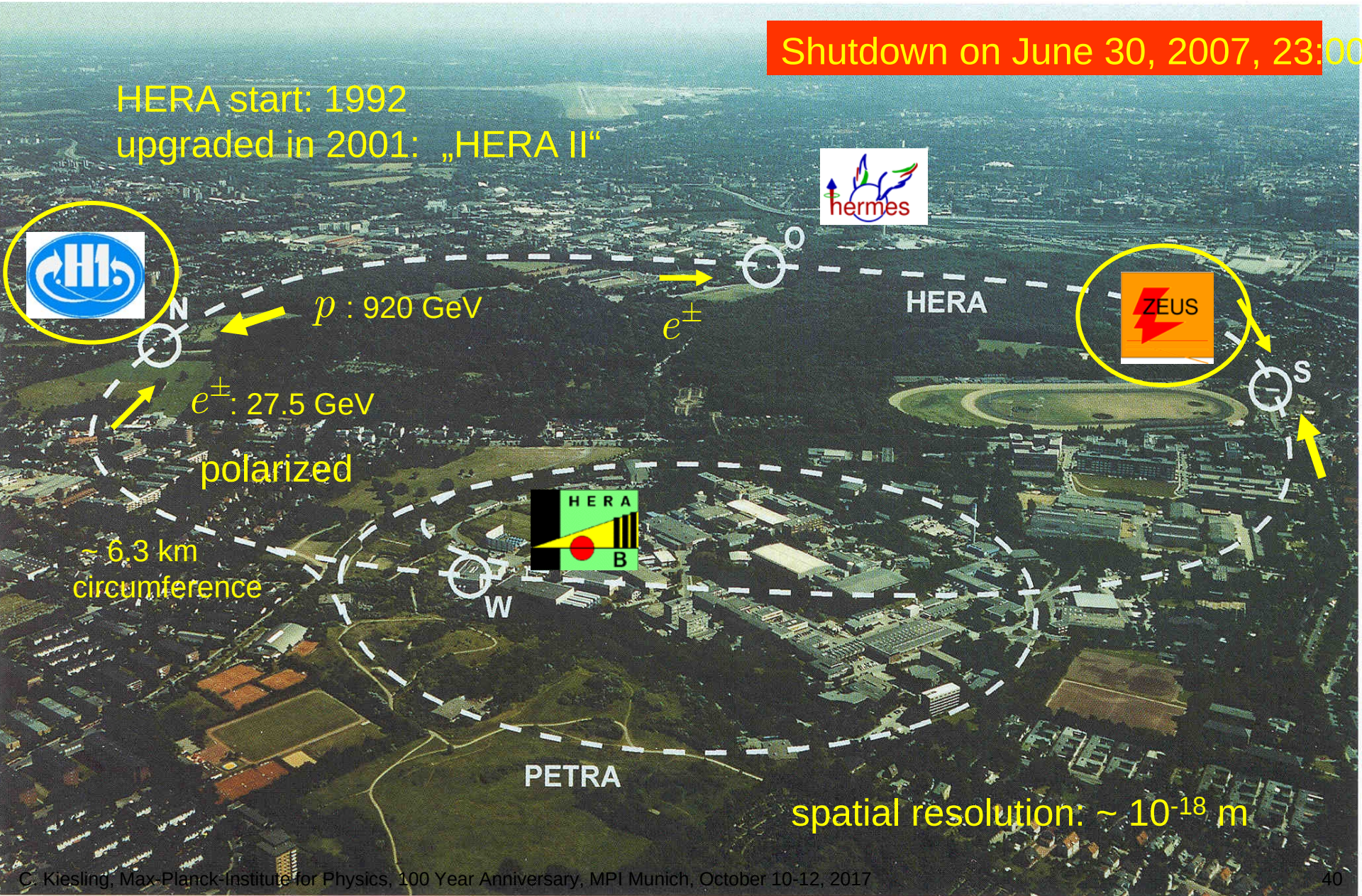




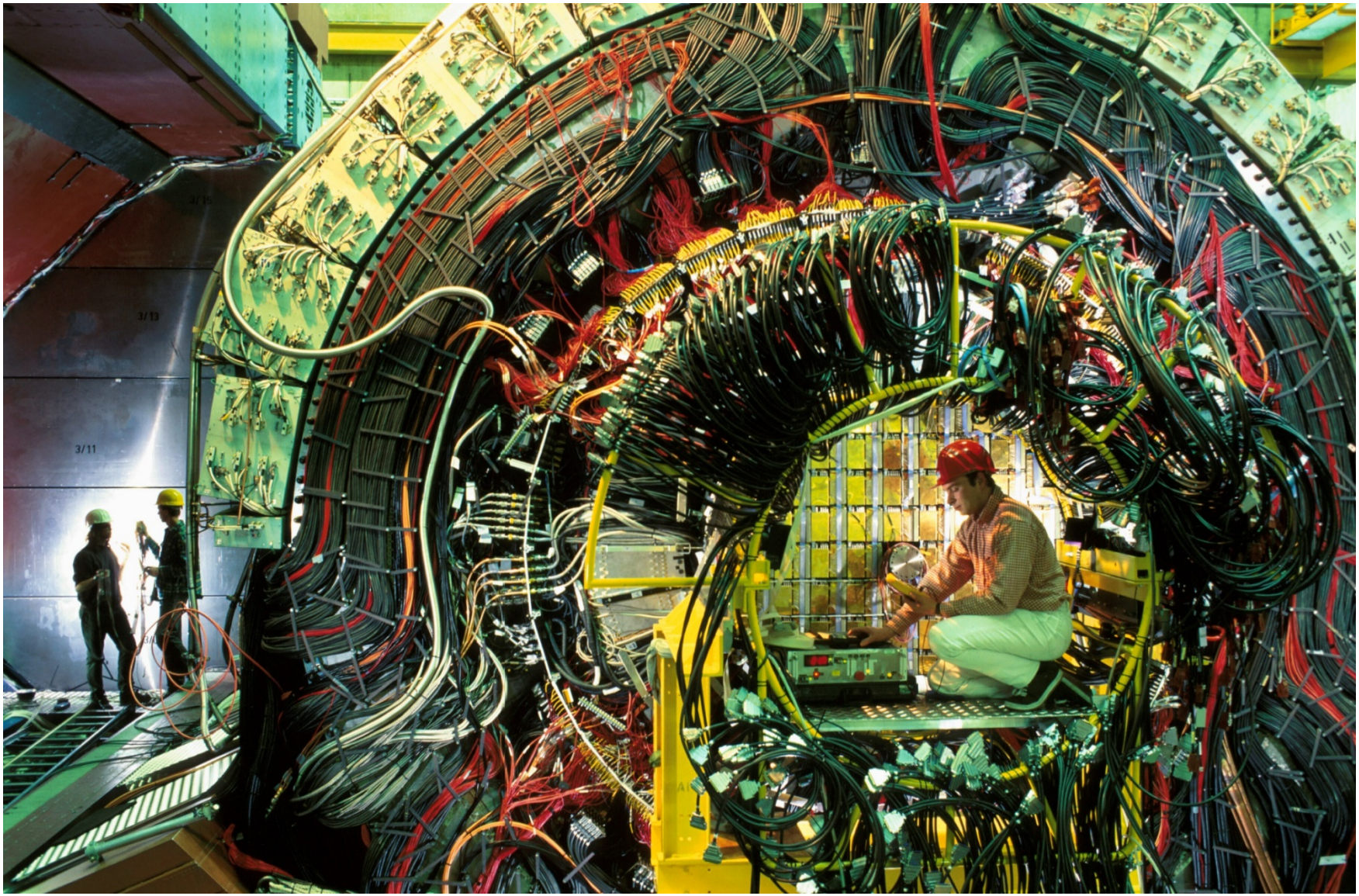


$$m_H > 113 \text{ GeV}$$

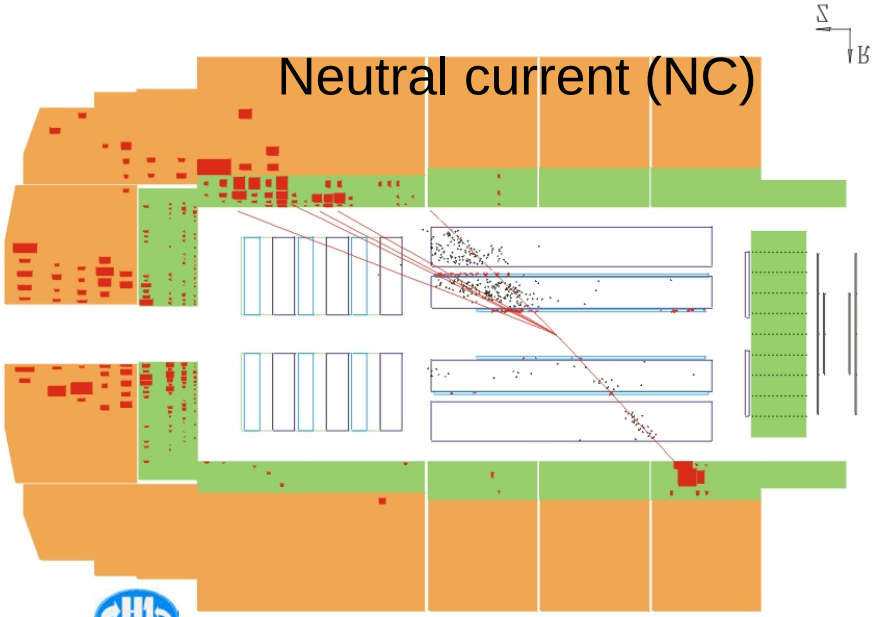
HERA – the world's largest electron microscope (Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany)

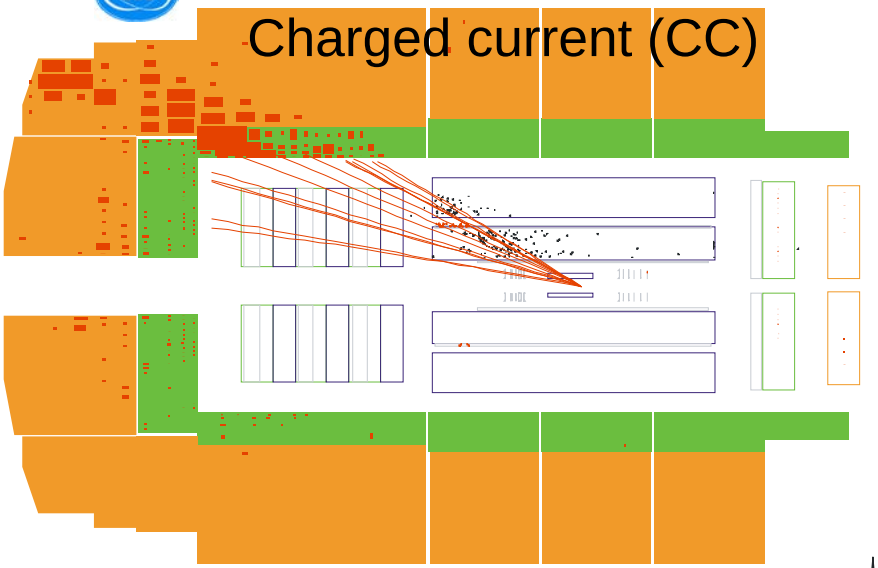


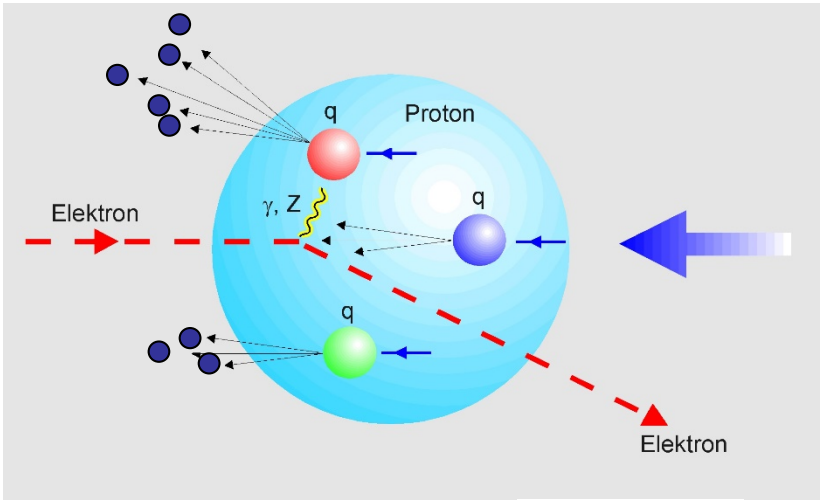
H1 Detector at HERA (Group of G. Buschhorn)

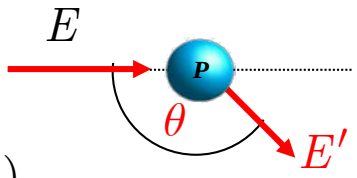


Electron Proton Scattering in a HERA Detector









$$Q^2 = 4EE'\cos^2\left(\frac{\theta}{2}\right)$$

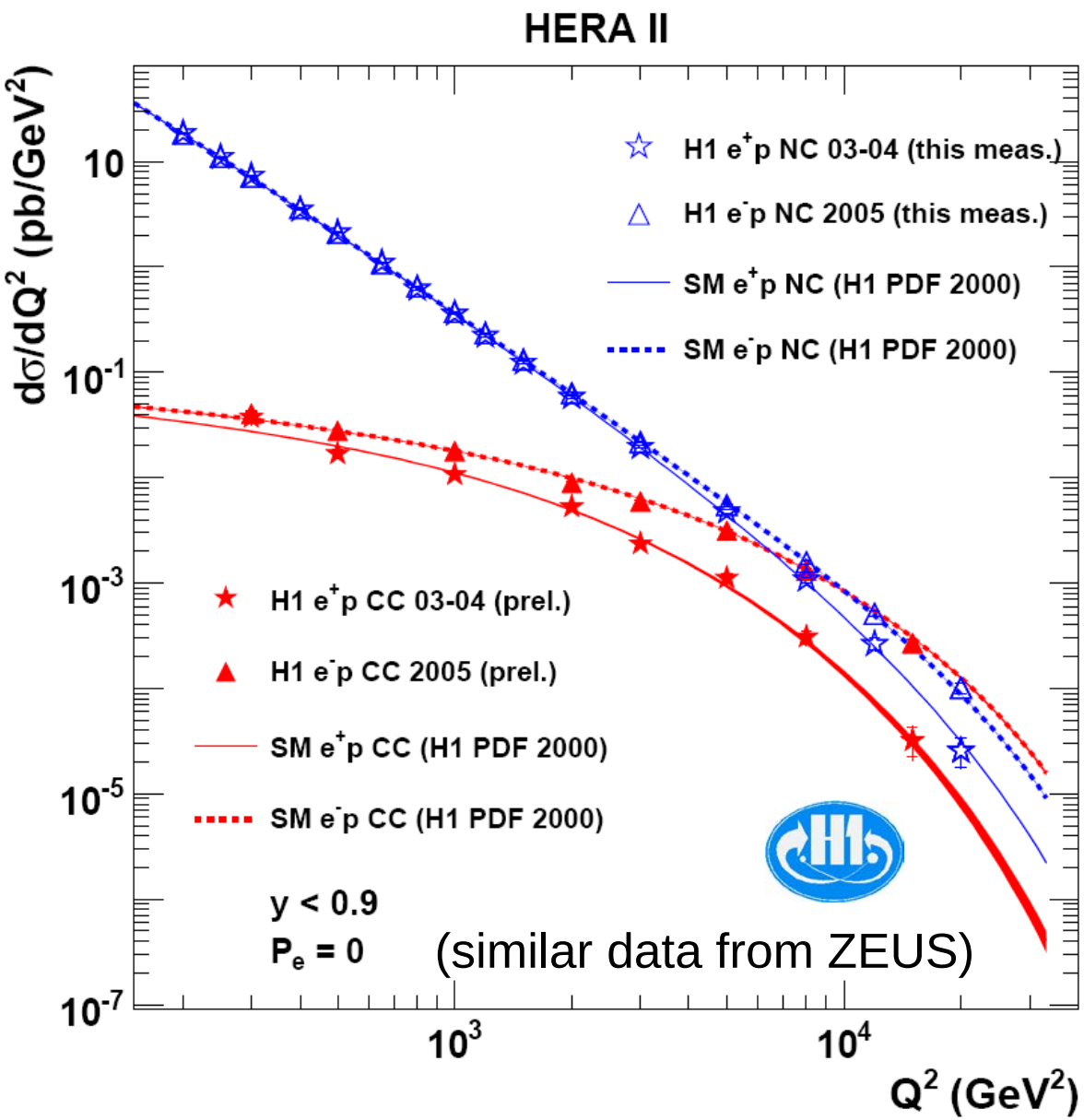
$$y = 1 - \frac{E'}{E}\sin^2\left(\frac{\theta}{2}\right)$$

$$x = \frac{Q^2}{sy}$$

Kinematics from $e^{\pm}$

(or from hadron jet)

Electroweak Unification at High Q^2 (NC & CC)



(Group of A. Caldwell)

$\sigma_{NC} >> \sigma_{CC}$

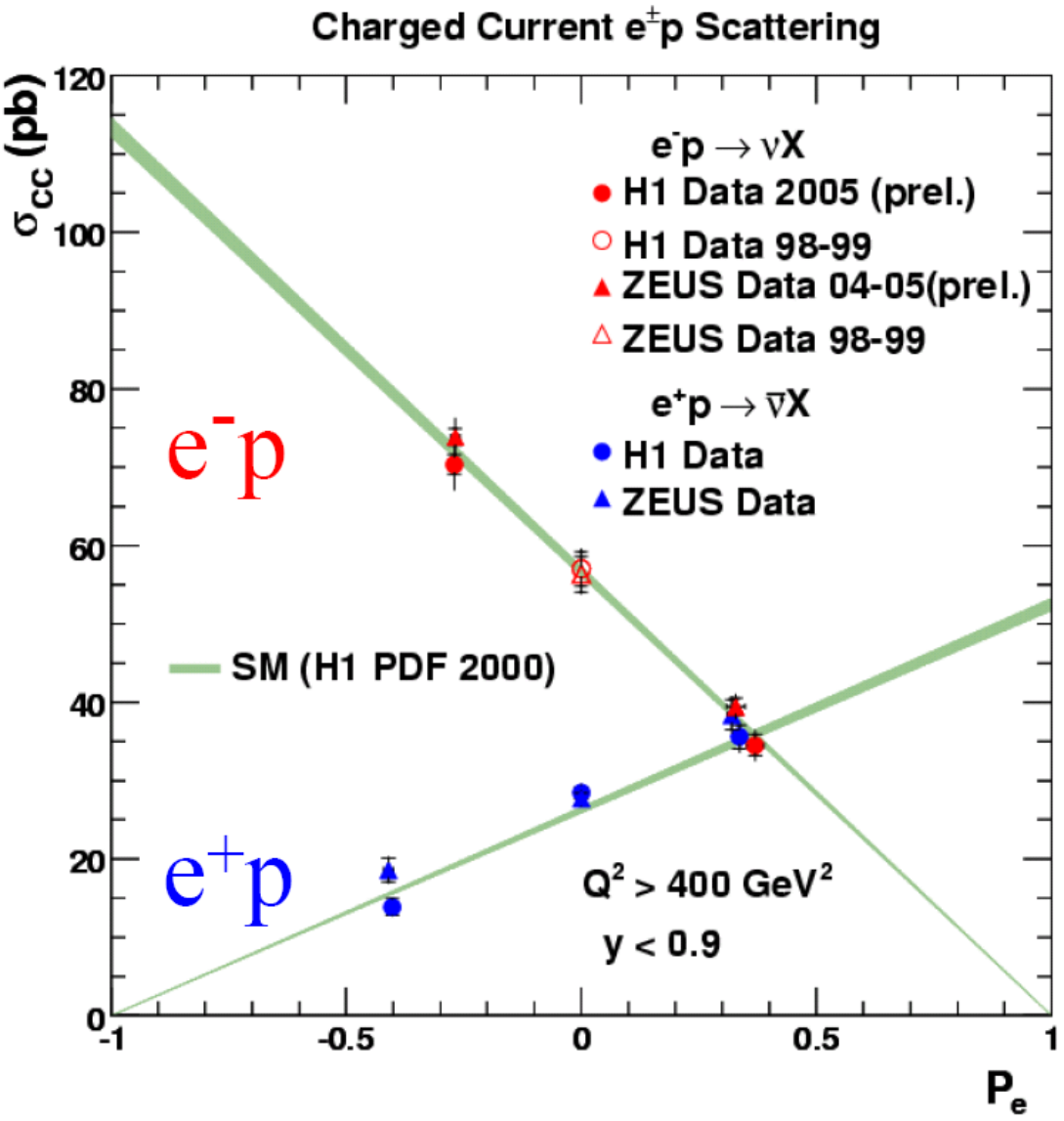
for $Q^2 << M_Z^2$

(photon exchange dominates)

$Q^2 \geq M_Z^2 : \ \sigma_{CC} \sim \sigma_{NC}$

manifest electroweak unification

Results on Polarized CC Reactions at High Q^2



Total CC cross section with longitudinally polarized electrons and positrons

$$\sigma_{cc}^{e^{\pm}p}(P_e) =$$

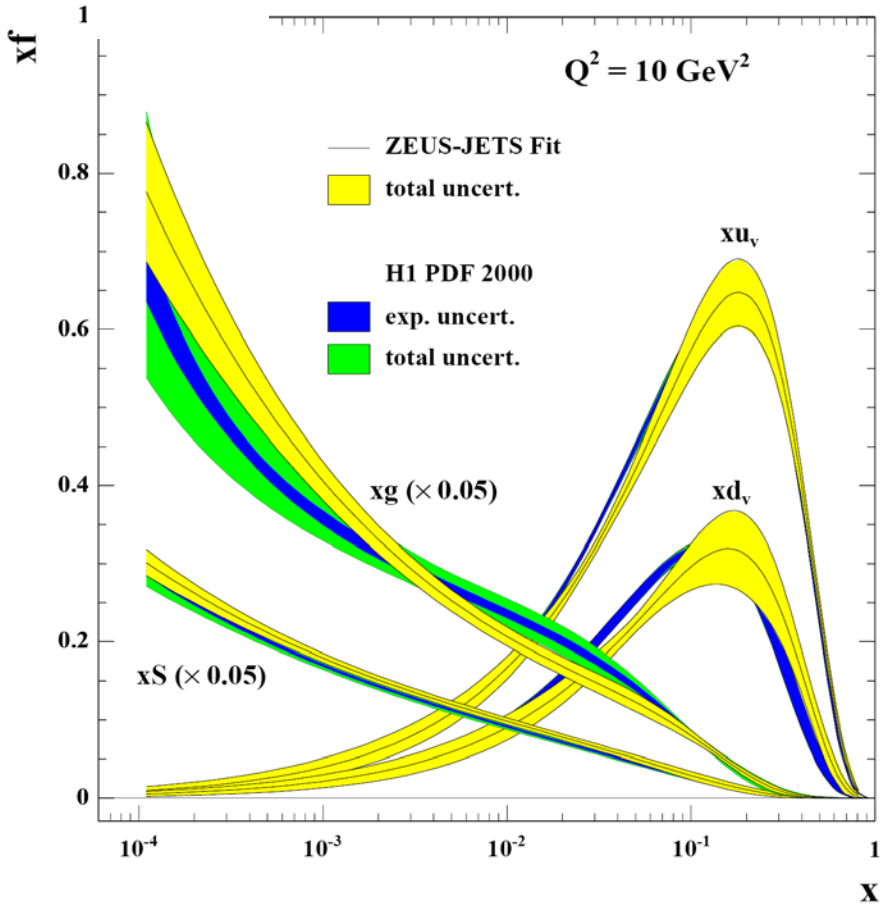
$$(1 \pm P_e)\sigma_{cc}^{e^{\pm}p}(P_e = 0)$$

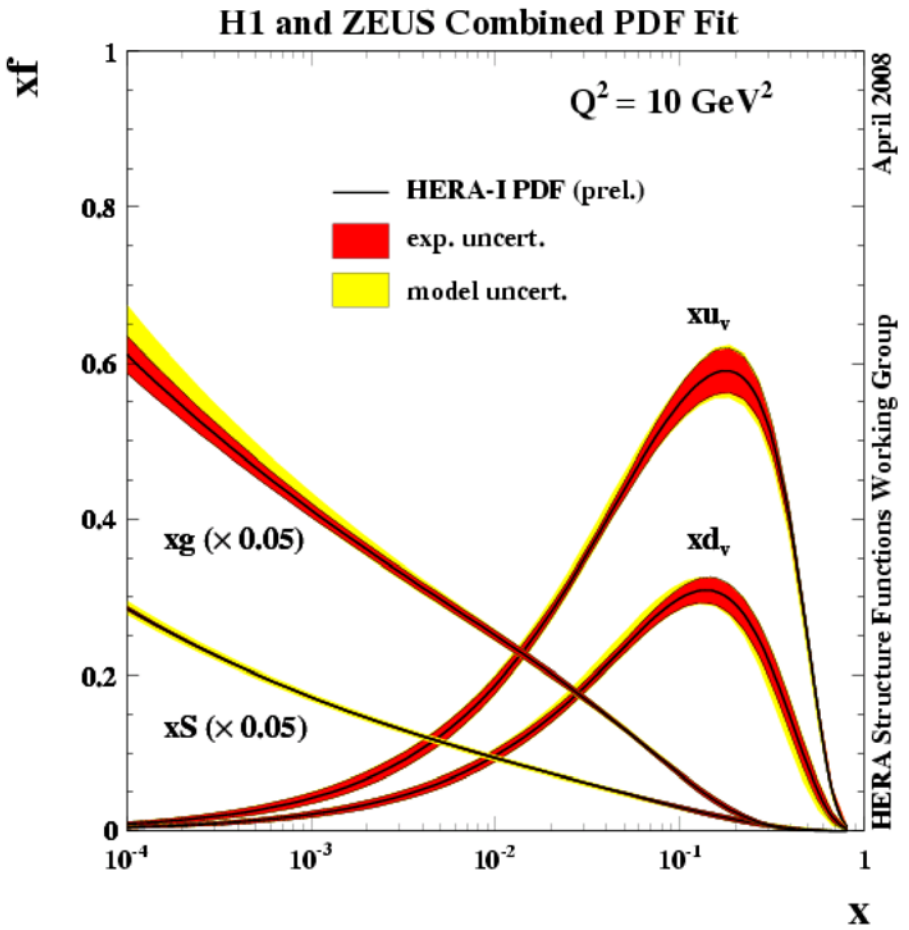
- linear dependence on P_e firmly established
- extrapolations to $P_e = \mp 1$ consistent with zero
  → no right-handed weak currents
- e^- : $M_{W_R} > 208\,\mathrm{GeV}$

  e^+ : $M_{W_R} > 186\,\mathrm{GeV}$

  $95\%\,C.L.$

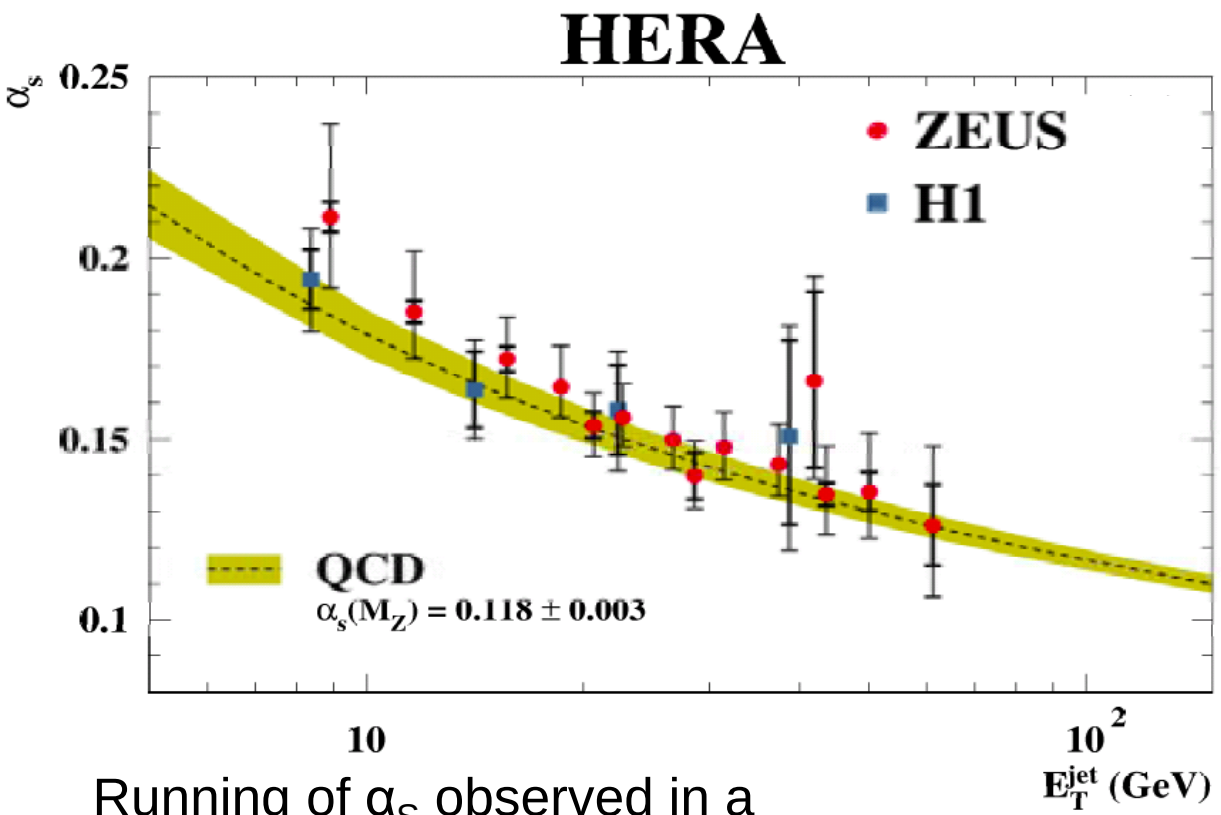
Parton densities: Combined Fit of H1 and ZEUS data

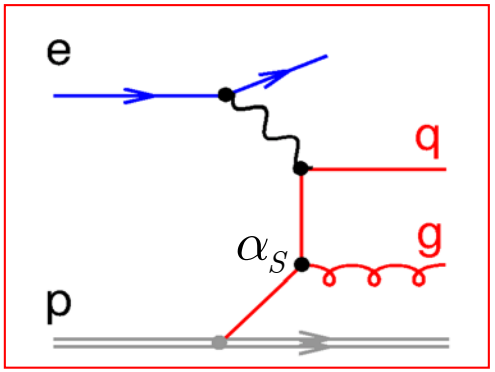




- Precise determination of pdf's down to x ~ 10^{-4}
- ~50% of proton momentum carried by the gluons!

Running of the Strong Coupling "Constant" α_S

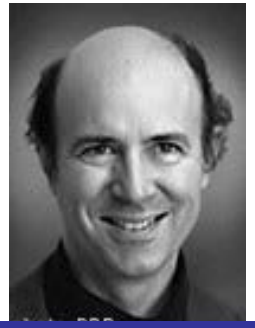




Running of α_S observed in a single experiment!

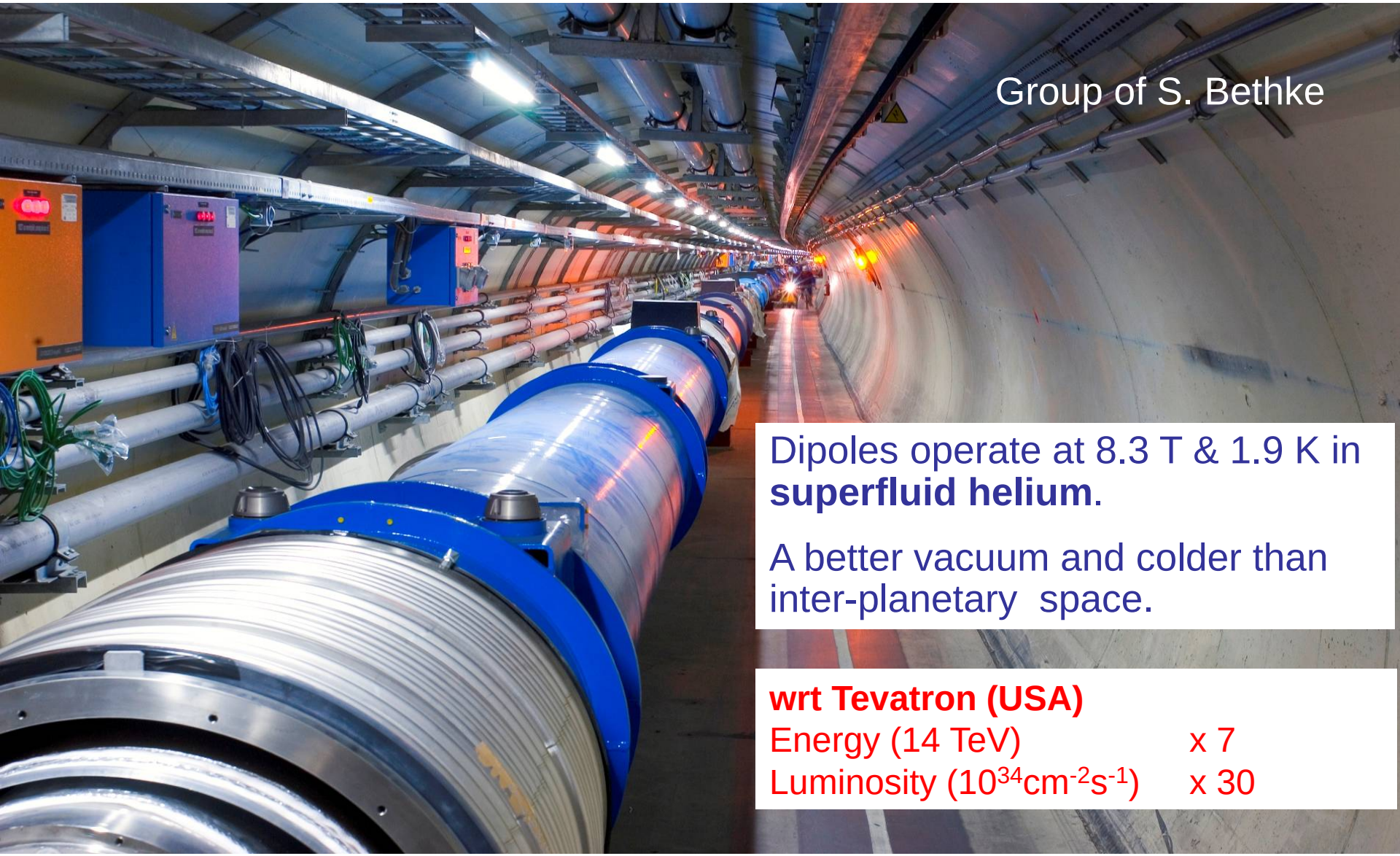
NP 2004


D. Gross


F. Wilczek


D. Politzer

LHC – The Ultimate Machine



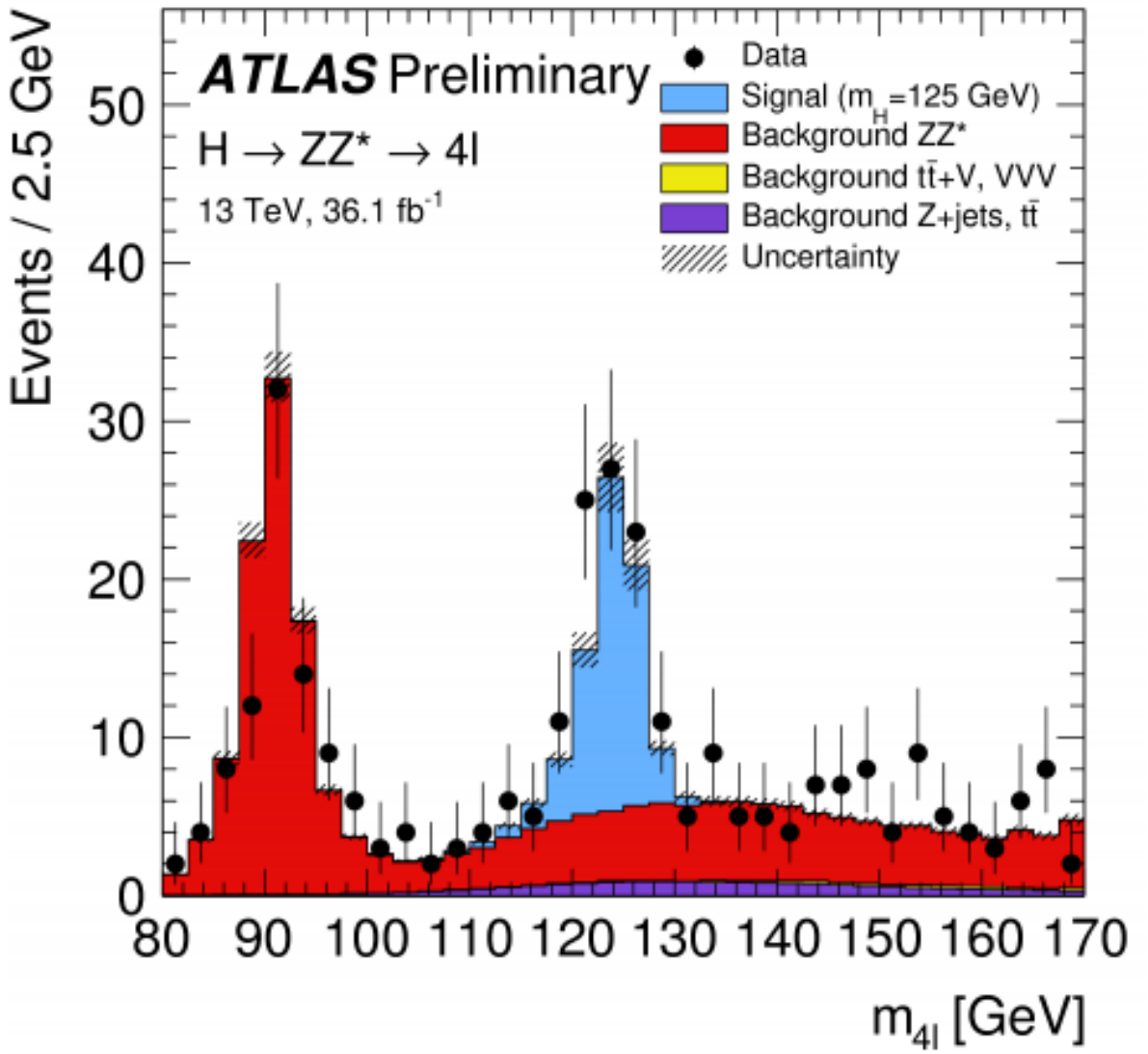
Dipoles operate at 8.3 T & 1.9 K in **superfluid helium**.

A better vacuum and colder than inter-planetary space.

wrt Tevatron (USA)

Energy (14 TeV)	x 7
Luminosity ($10^{34}cm^{-2}s^{-1}$)	x 30

Finally – The Higgs is Found ….



The Standard Model is complete !

[announced on July 4, 2012]

see presentation by Sandra Kortner on Thursday

Conclusions: