Fundamental Discoveries at Accelerators

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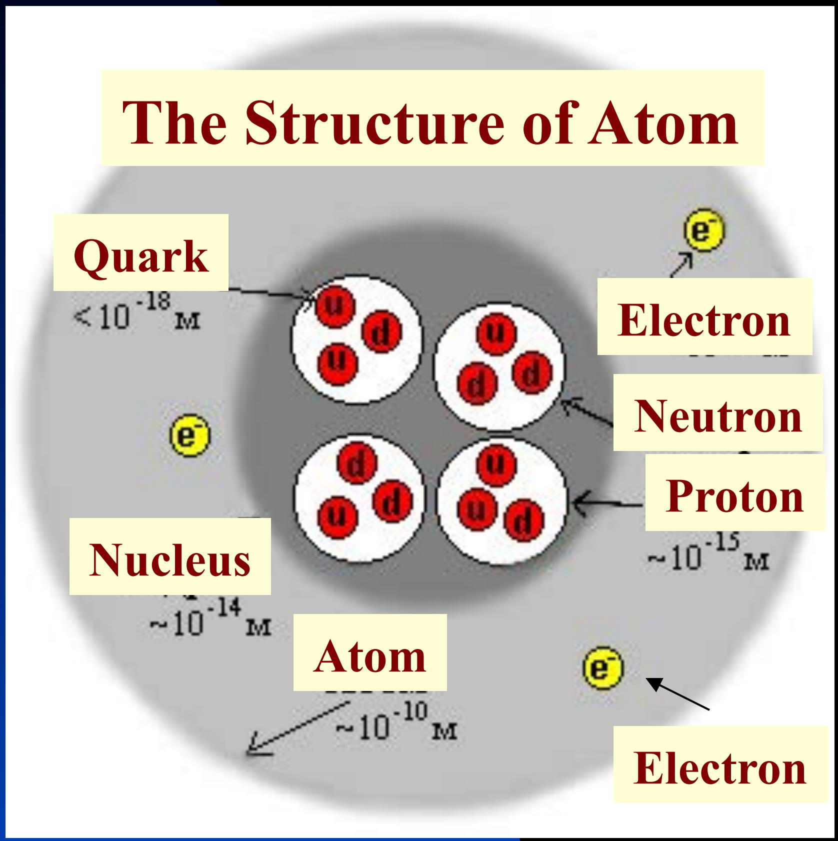
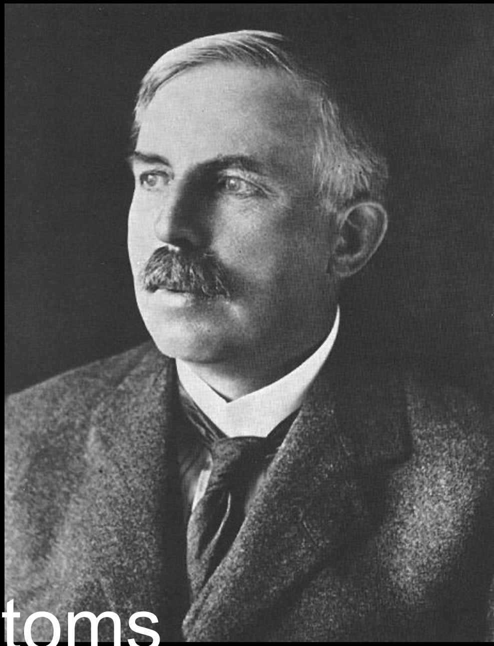
ISAPAN dedicated to V.I.Veksler
Dubna, 4-6 March 2002

Outline

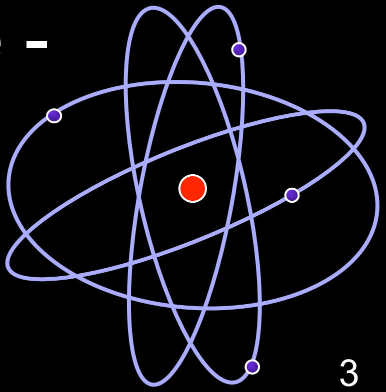
- Past Perfect (Далёкое прошедшее)
- Past (Славное прошлое)
- Present (Бурное настоящее)
- Future continuous (Светлое будущее)
- Future (Туманное грядущее)

The Structure of Atoms





- In 1912 E.Rutherford bombarded atoms with α-particles and discovered that atoms have small hard core - atomic nucleus ~ 10^{-14} m



Discovery of Elementary Particles

K

Ξ

Ω

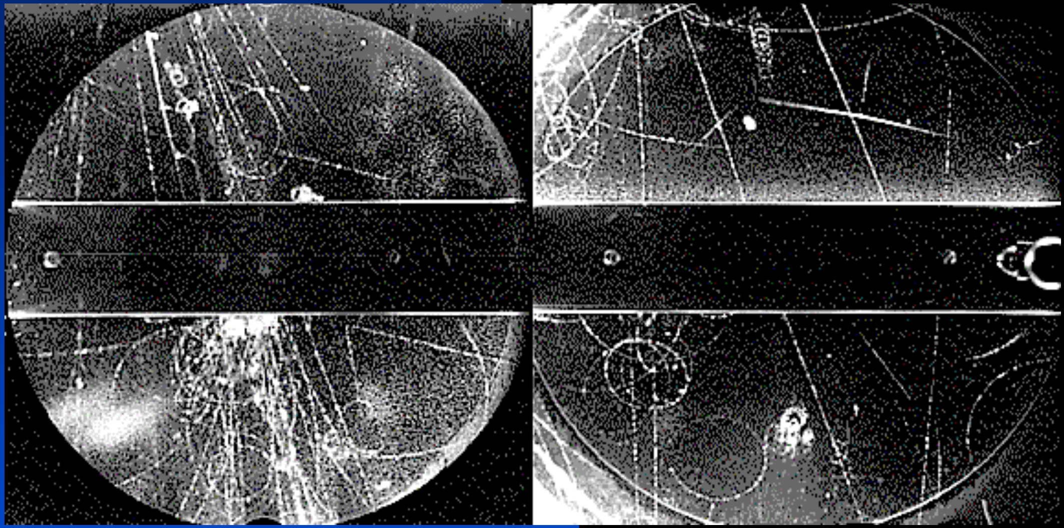
K

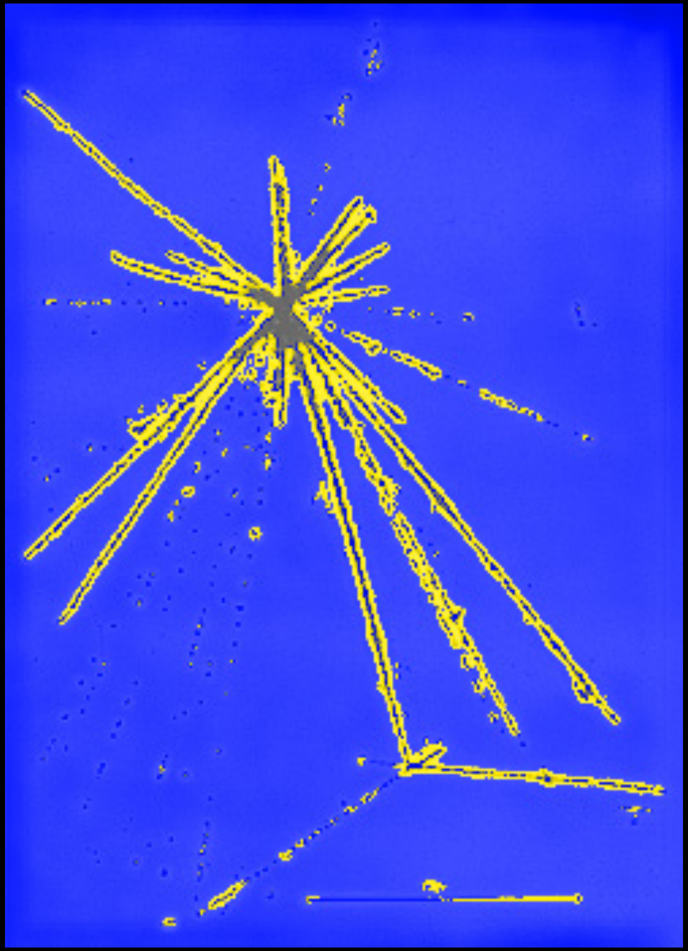
- The whole Zoo of elementary particles was discovered at accelerators
- Is was the window to the new micro world of Nature

Discovery of Strangeness

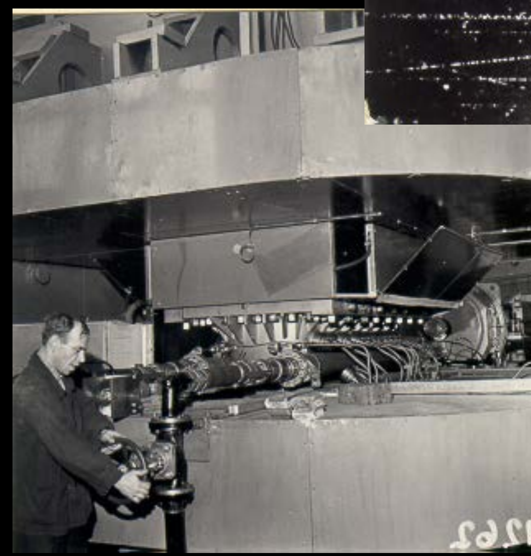
- Discovery of K-meson in 1947 and Λ-hyperon in 1952 were the first indications that the particles that we are made of are not the whole story.

  For some unknown reason Nature wanted something else!



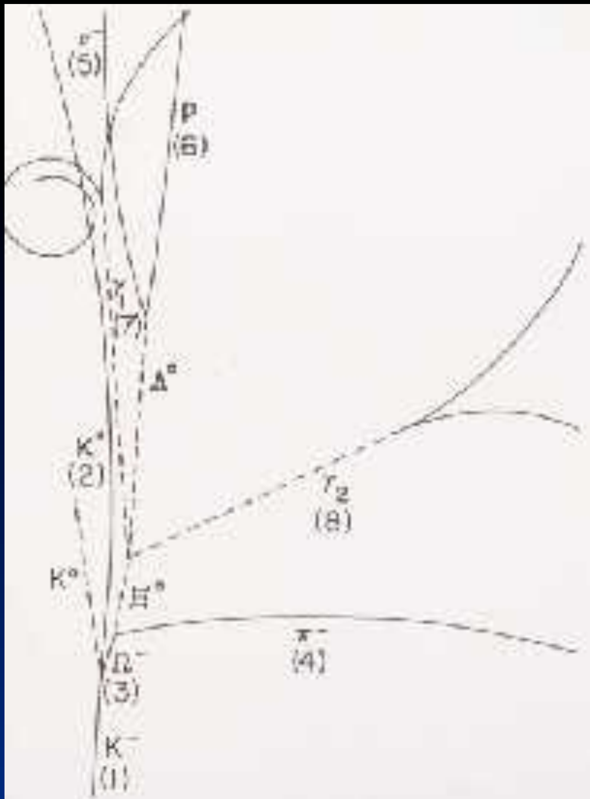


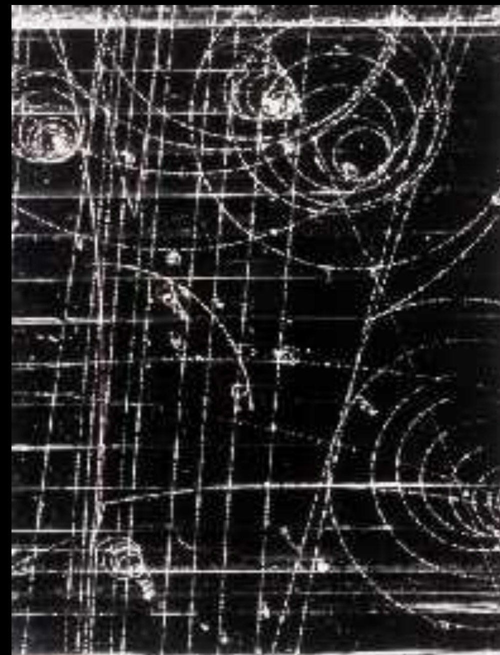
$\bar{\Sigma}^-$ - Hyperon in Dubna



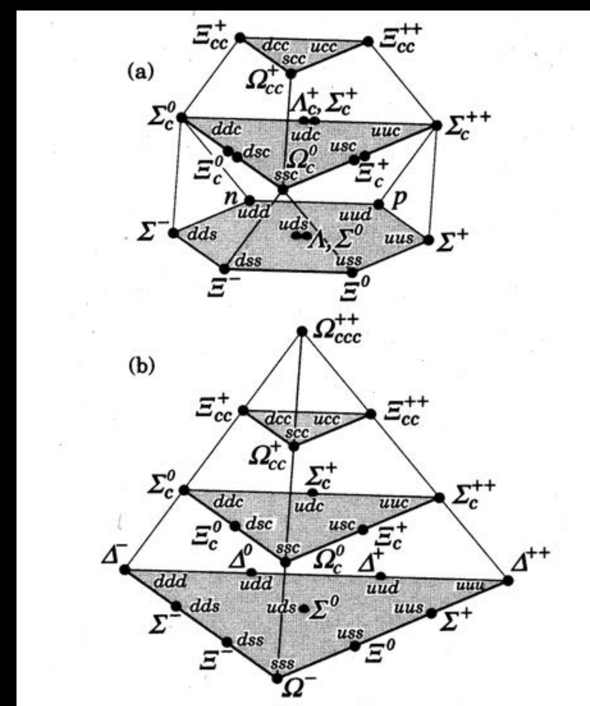
- $\bar{\Sigma}^-$ - hyperon has been discovered in 1960 at Dubna Synchrophasotron with the help of propane bubble chamber

The Quark Model



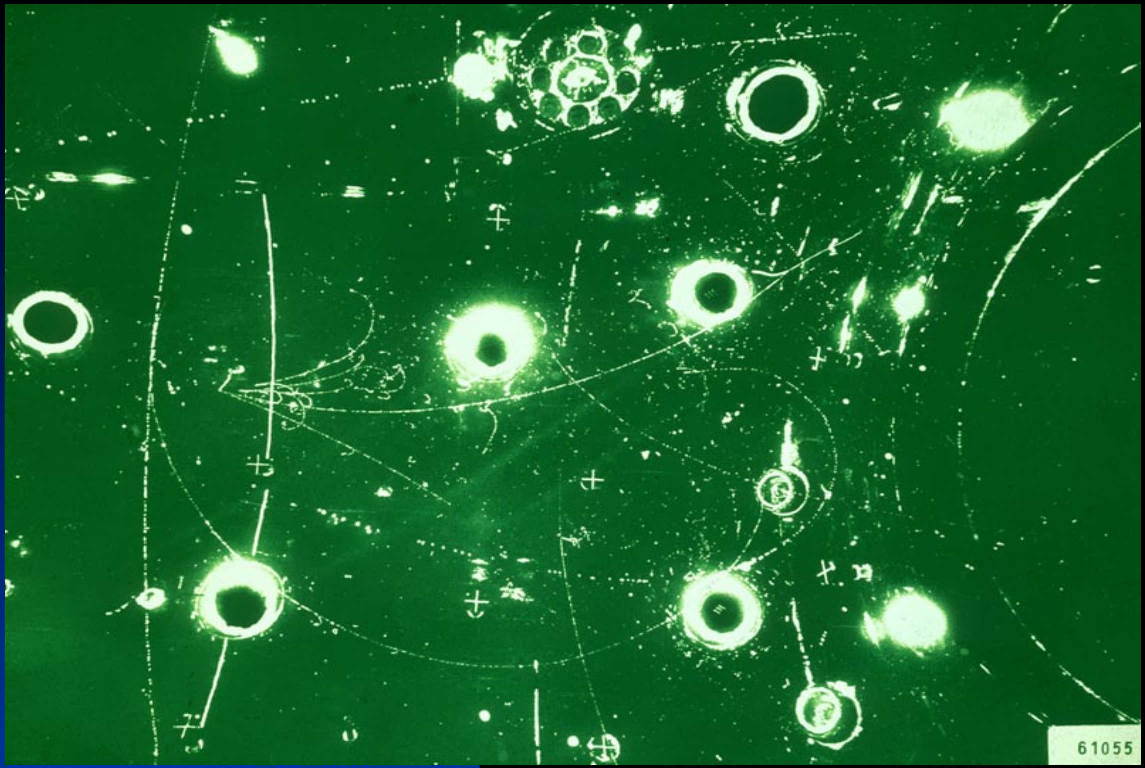


- The discovery of the "omega-minus“ at BNL in 1964 was the last piece in a subatomic puzzle.



- It confirmed the importance of the relationship between many particles, which was soon understood in terms of their underlying structure in the form of quarks.

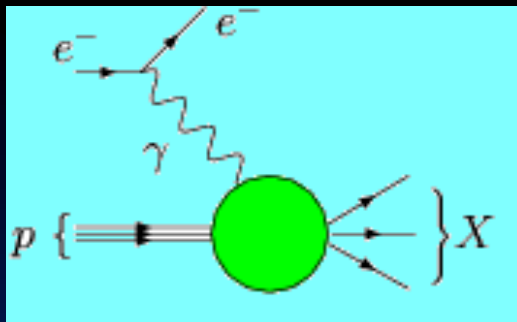
Discovery of Neutral Currents



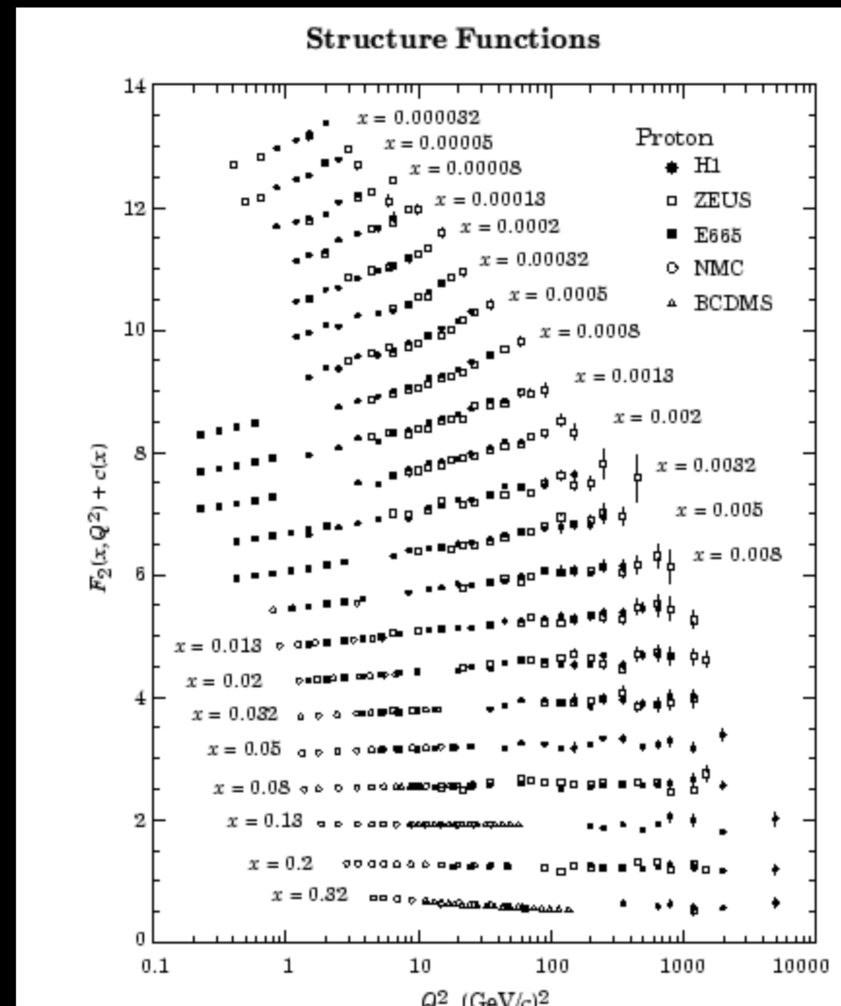
- This was a crucial test of the gauge model of weak interactions at CERN in 1973

- The heavy photon gives the neutral current without flavour violation

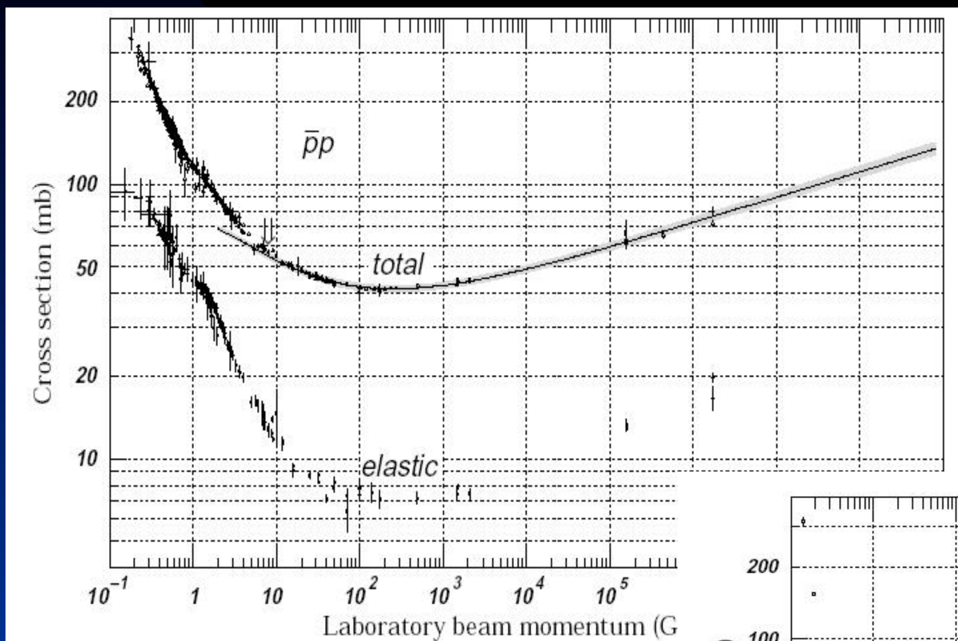
Discovery of Scaling in Strong Interactions



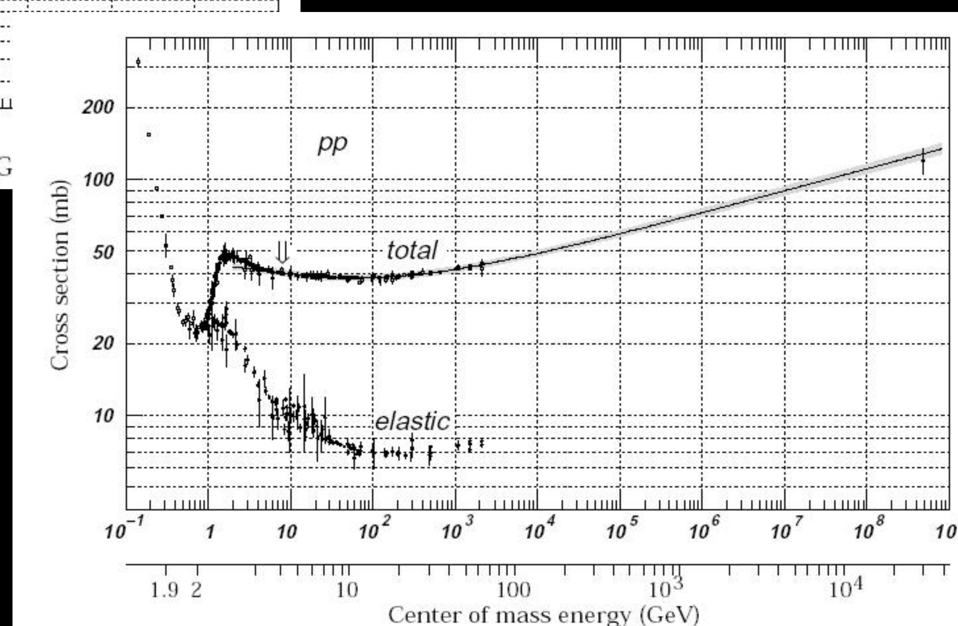
- Rutherford-like test of the proton structure
- Scaling behaviour of the structure functions of deep-inelastic scattering first observed at SLAC in 1968
- This was the first indication of existence of point-like partons inside proton



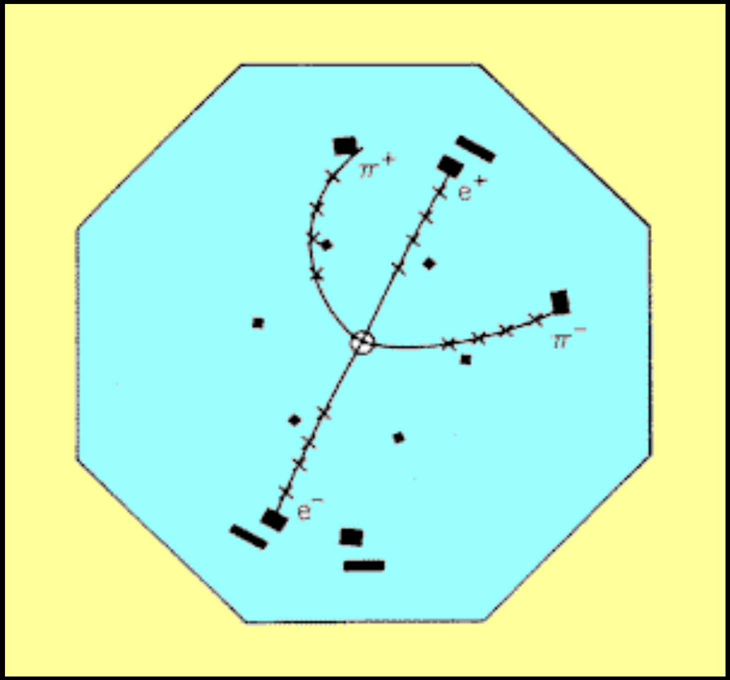
Total Cross-Sections (Serpukhov Effect)



- The increase of total cross-sections discovered at Serpukhov accelerator U-70 in 1971

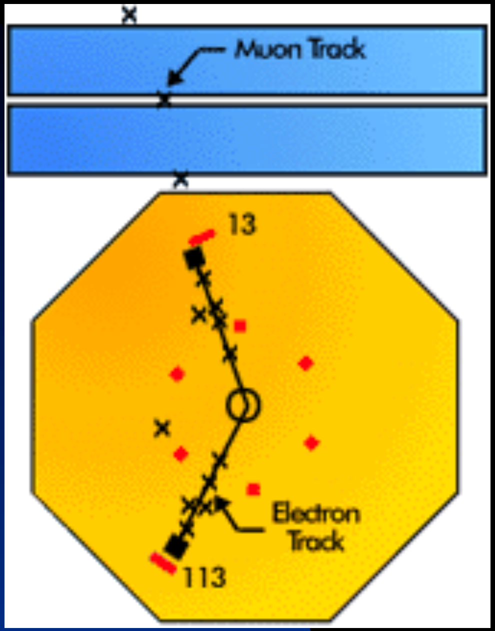


Discovery of Charm



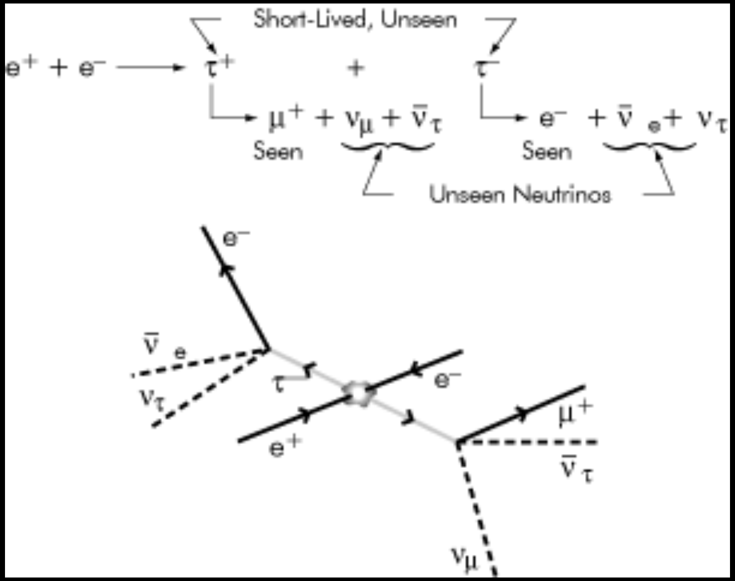
- Charm quark discovery at SLAC and Brookhaven in 1974 created much of excitement
- The second generation was completed, chiral anomaly was cancelled and the renormalizability of the SM was restored

Discovery of Tau-Lepton

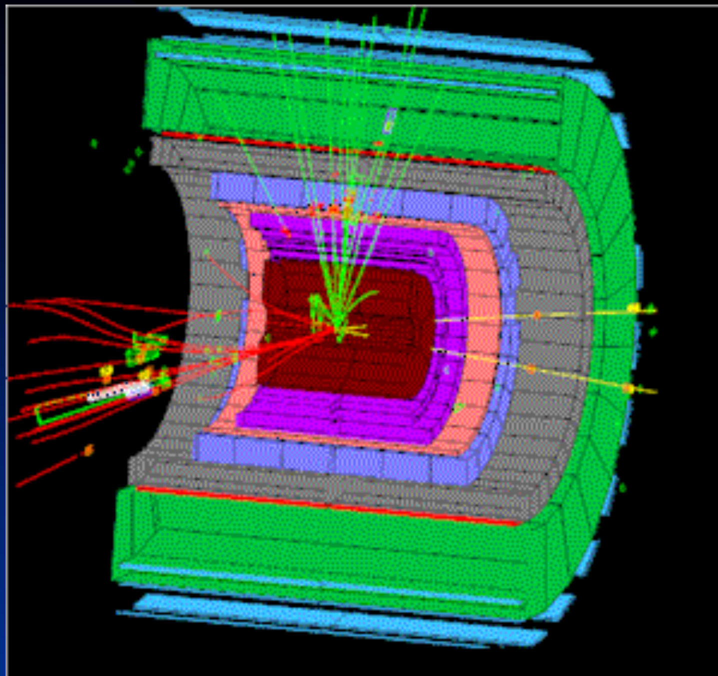


- Discovery of tau-lepton at SLAC in 1975 was expected and confirmed the quark-lepton unviversality

This heavy electron has a mass of 1.778 GeV and is heavier than a proton

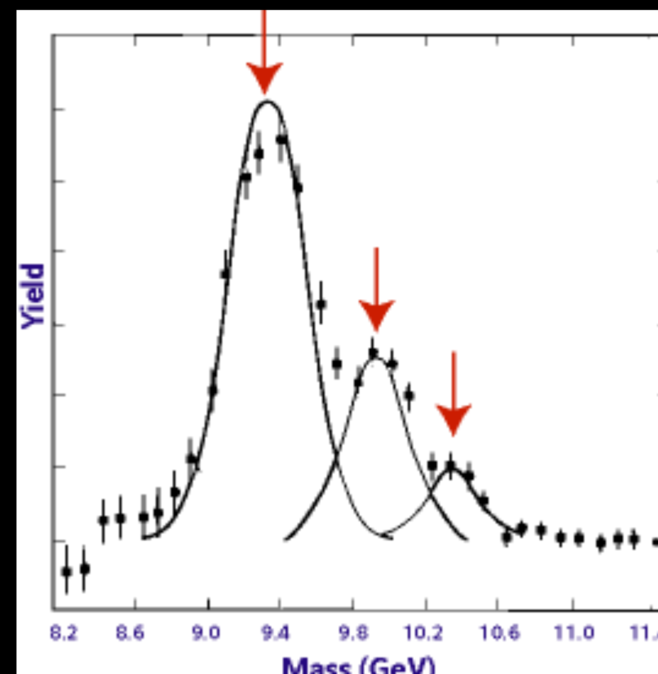


Discovery of Upsilon



- Together with the tau-lepton this was the beginning of the third generation discovered in 1977 at Fermilab

The reason why we need the 3-rd generation became clear only after discovery of CP-violation

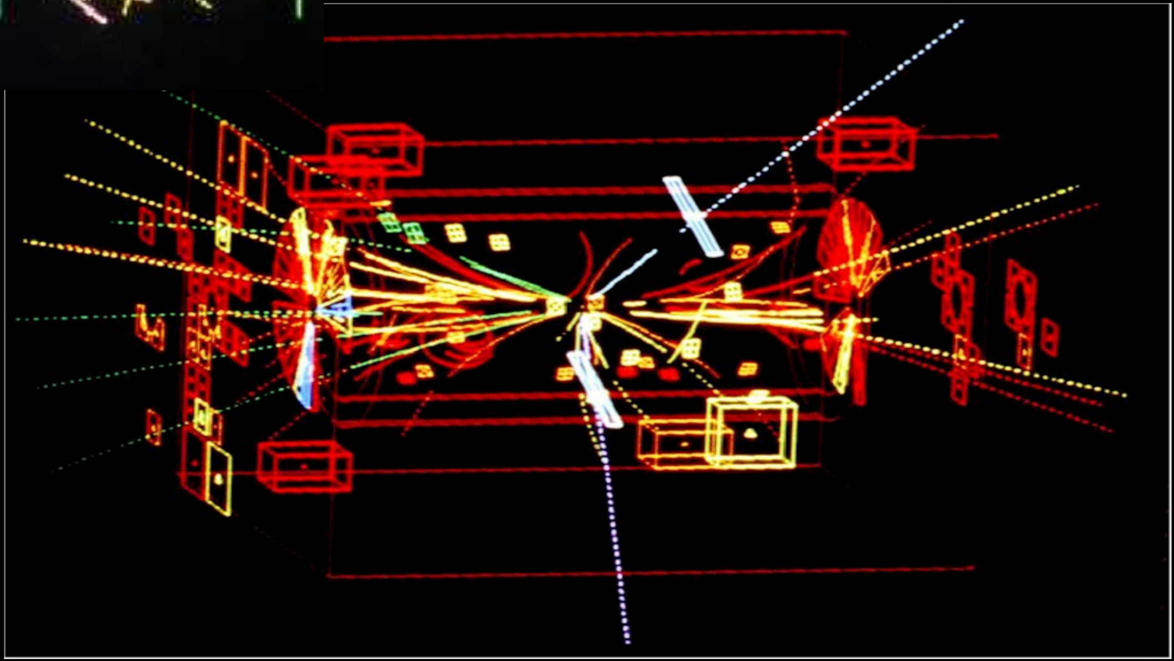


Discovery of the Gluon

- The gluon – the strong force carrier has been discovered at PETRA (DESY) accelerator in 1979 in three-jet events

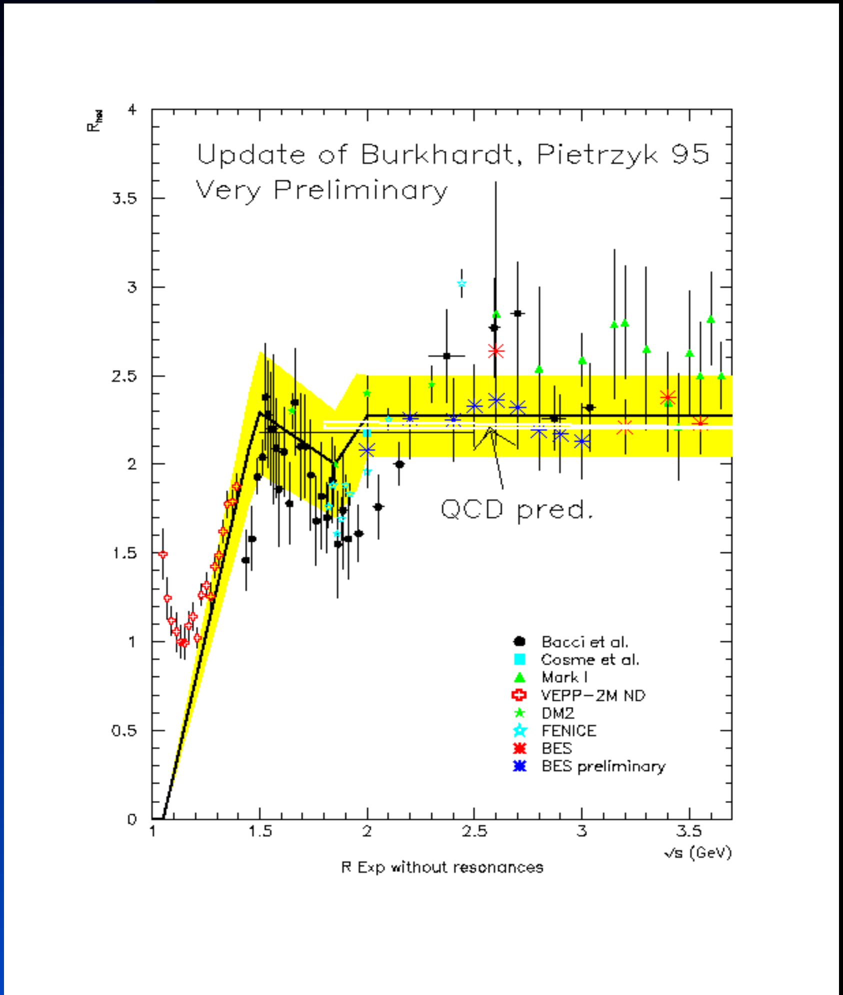
Discovery of W and Z bosons

- Discovery of W and Z bosons at CERN SPS collider in 1983



was a triumph of the SM and confirmation of its validity

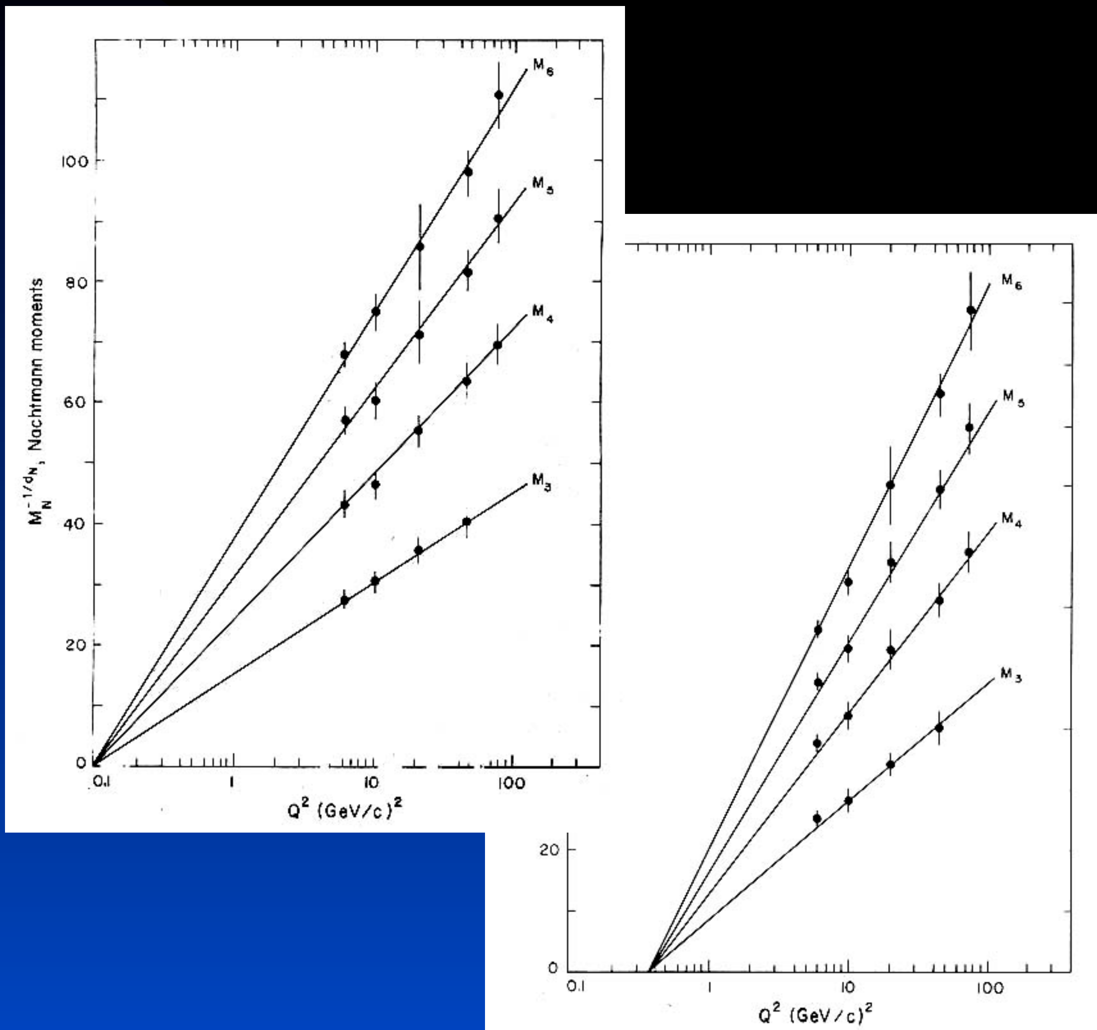
The Number of Colours



- The x-section of electron-positron annihilation into hadrons is proportional to the number of quark colours. The fit to experimental data at various colliders at different energies gives

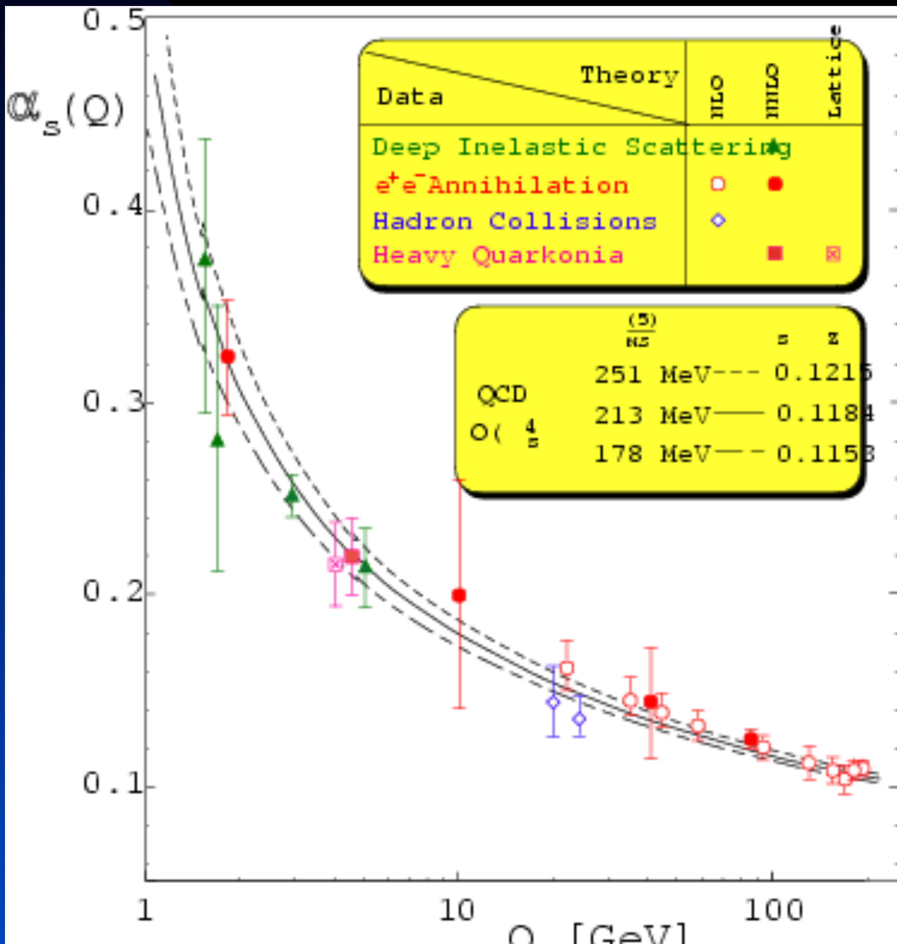
$$Nc = 3.06 \pm 0.10$$

Scaling Violations in DIS



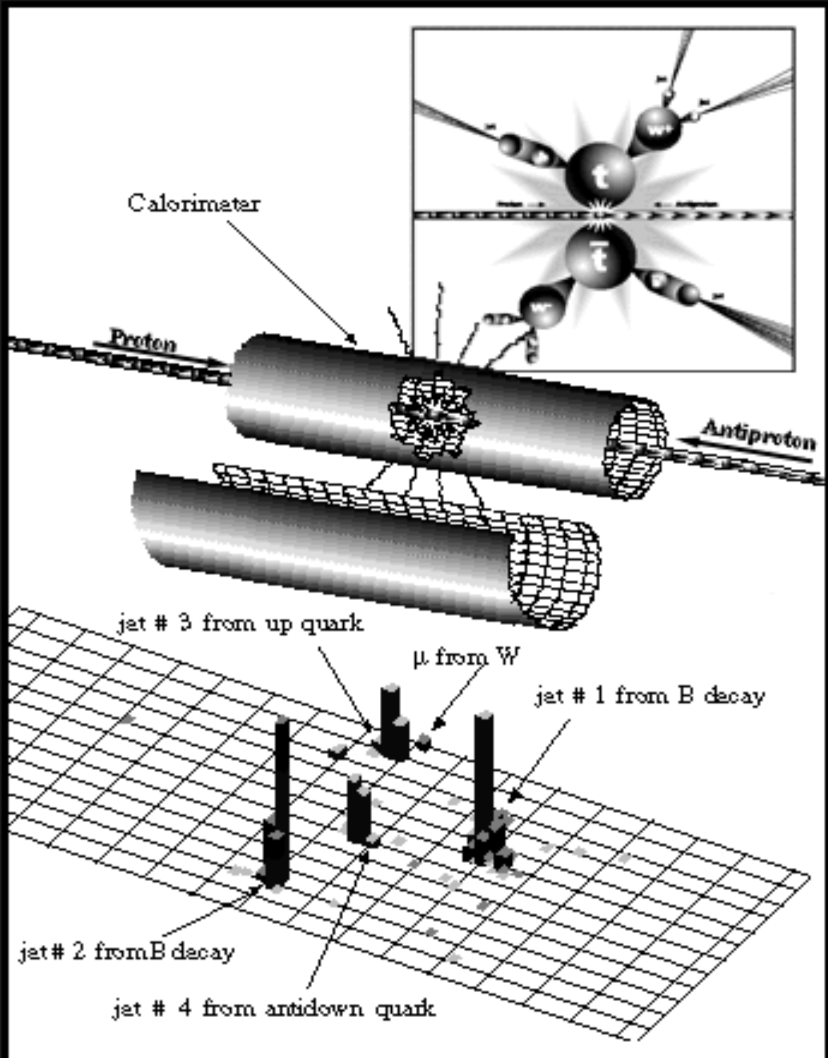
- This was the triumph of perturbative QCD
- Moments of the structure functions measured at CERN (SPS) and SLAC in 1977 fit precisely to QCD induced log corrections

Running of The Strong Coupling



- Asymptotic freedom of the strong interactions
- Remarkable test of QCD for different energies and various processes

Discovery of Top-quark



- Discovery of long waited top-quark at Tevatron in 1995 has marked the completeness of the 3-rd doublet of quarks

The Zoo Grows Larger

u	c 1974	t 1995
d	s 1947	b 1977

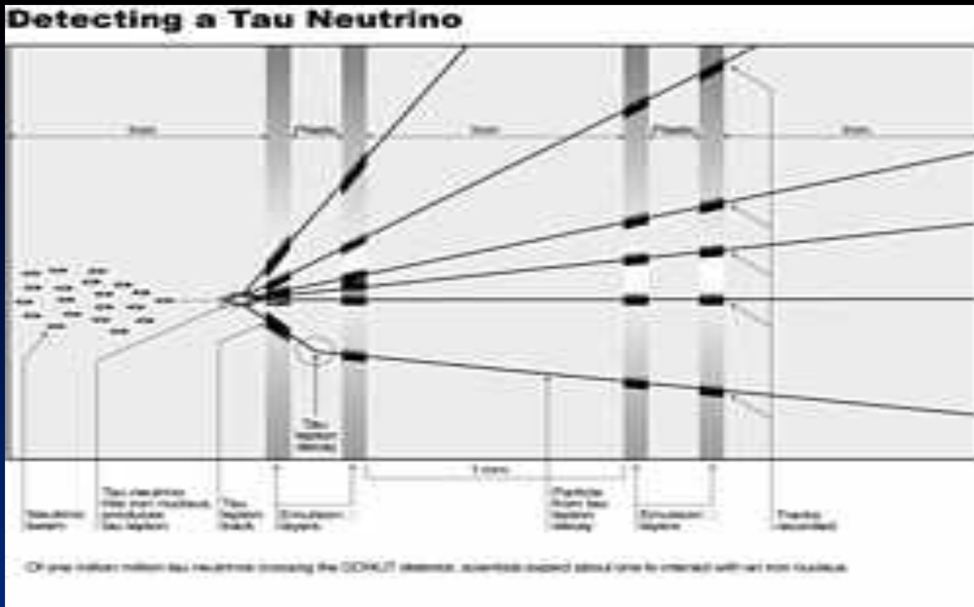
six quarks

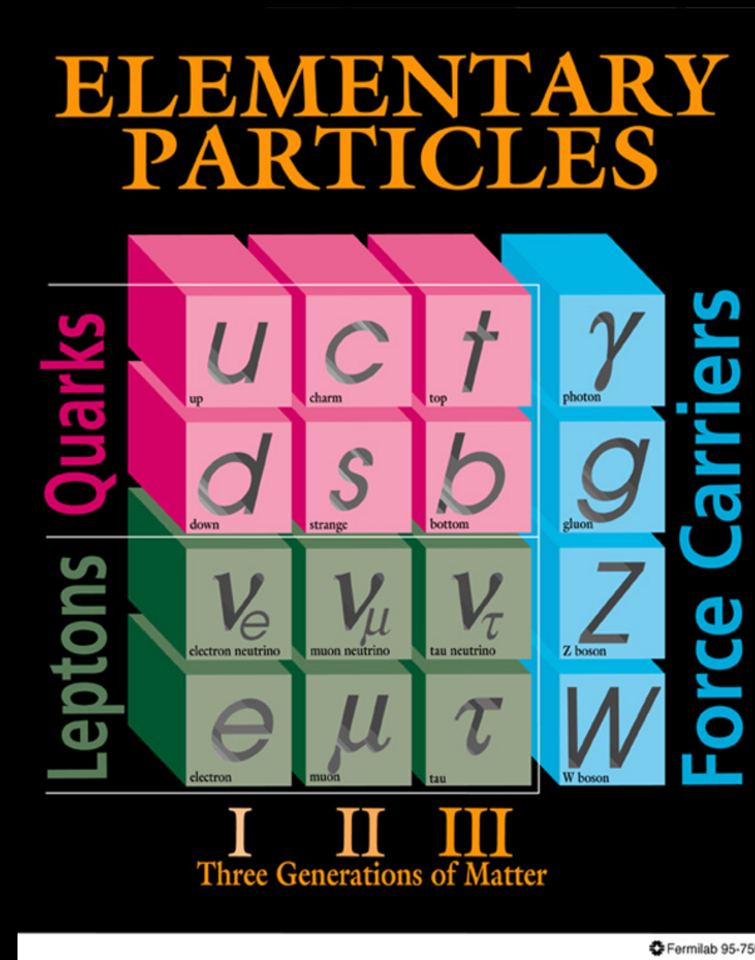
ν_e 1956	ν_μ 1963	ν_τ 2000
e 1895	μ 1936	τ 1975

six leptons

That was still not the end of the story. More fundamental objects have been discovered. Now we have a beautiful pattern of three pairs of quarks and three pairs of leptons. They are shown here with their year of discovery.

Discovery of tau-neutrino

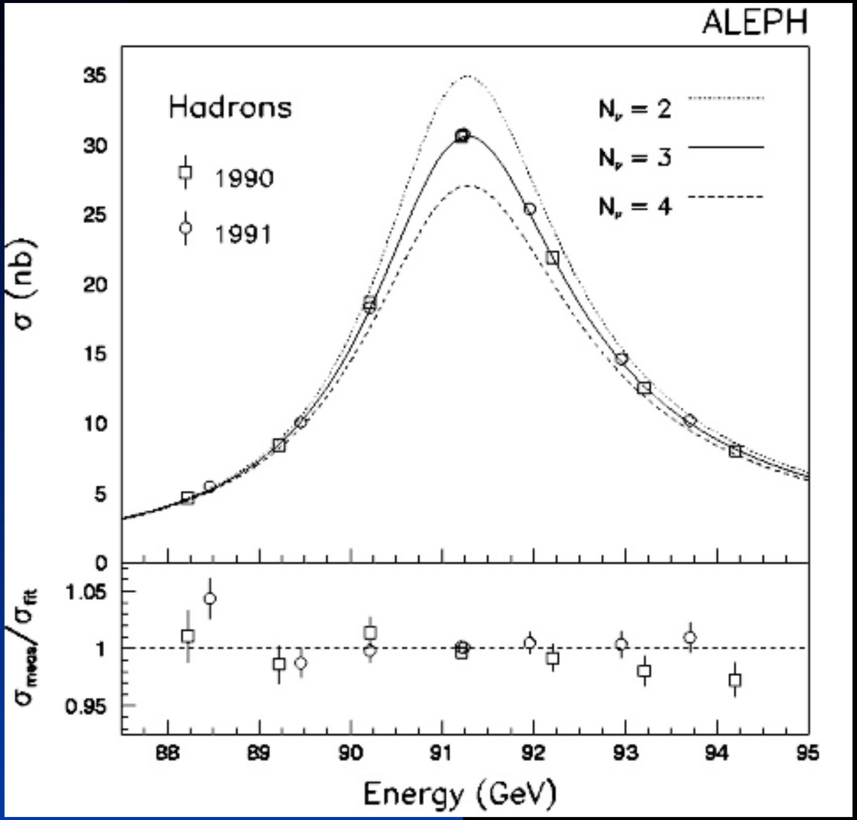




- Discovery of ν_τ at Fermilab in 2000 celebrated the completeness of the 3-rd generation of the SM particles.

Now only the Higgs is left !

The Number of Generations

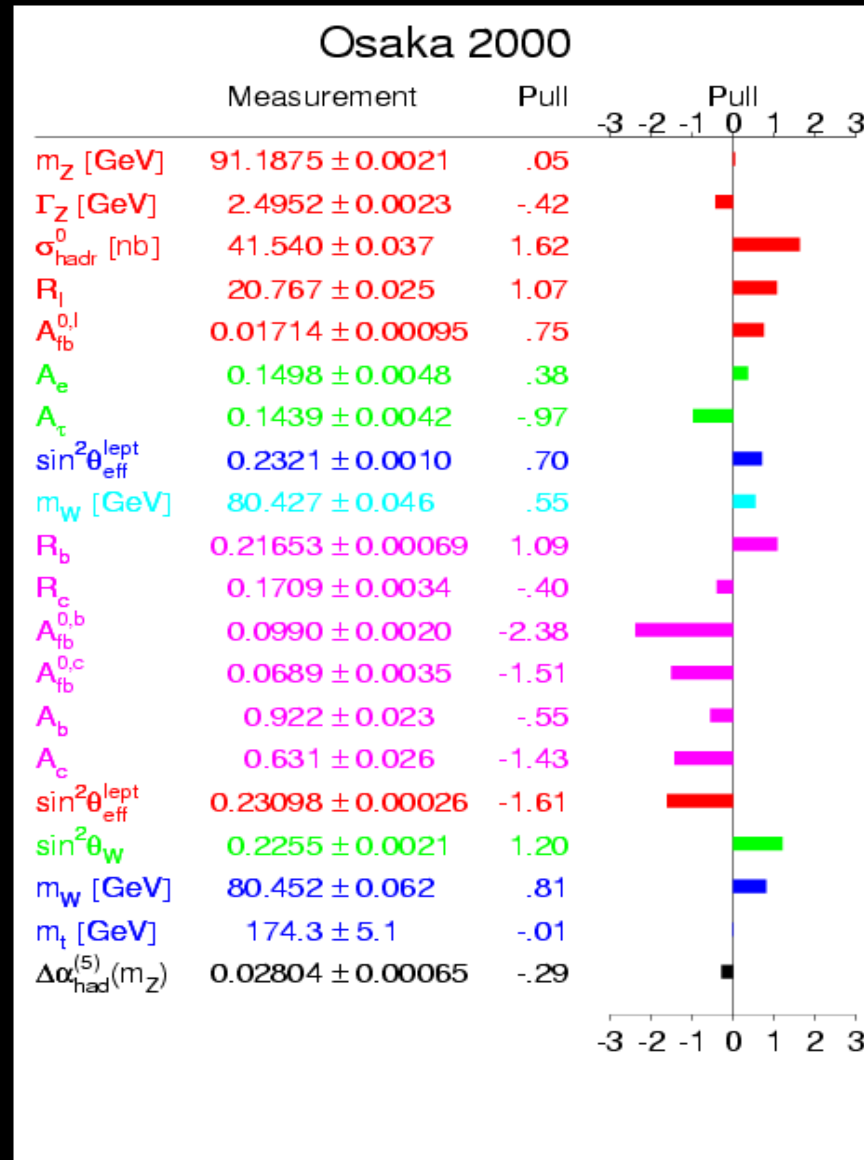


- Z-line shape obtained at LEP depends on the number of flavours and gives the number of (light) neutrinos or (generations) of the Standard Model

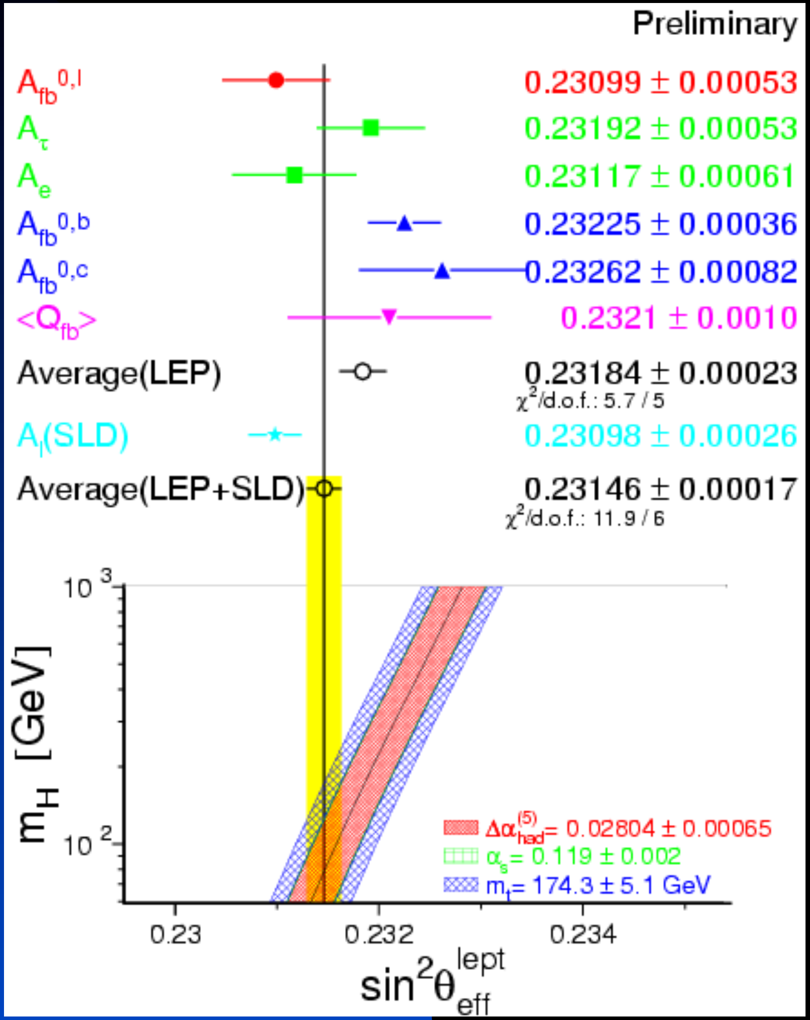
$$Ng = 2.982 \pm 0.013$$

The Triumph of the Standard Model

- Remarkable agreement of ALL the data with the SM predictions - precision tests of radiative corrections and the Standard Model

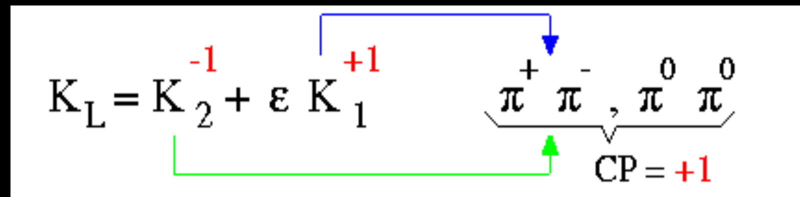


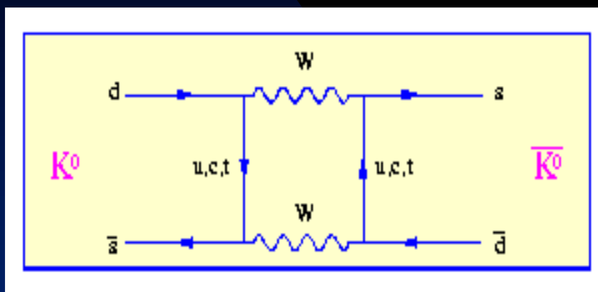
$\sin^2\theta_W$ and 3σ warning

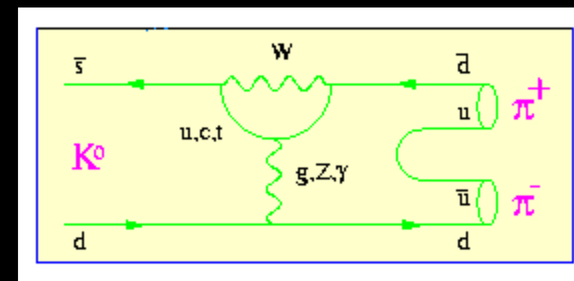


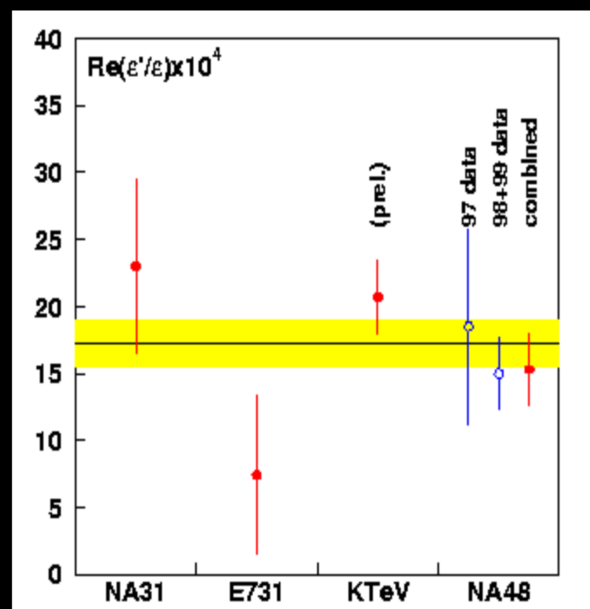
- Though the values of $\sin^2\theta_W$ extracted from different experiments are in good agreement, two most precise measurements from hadron and lepton asymmetries disagree by 3σ

Discovery CP Violation







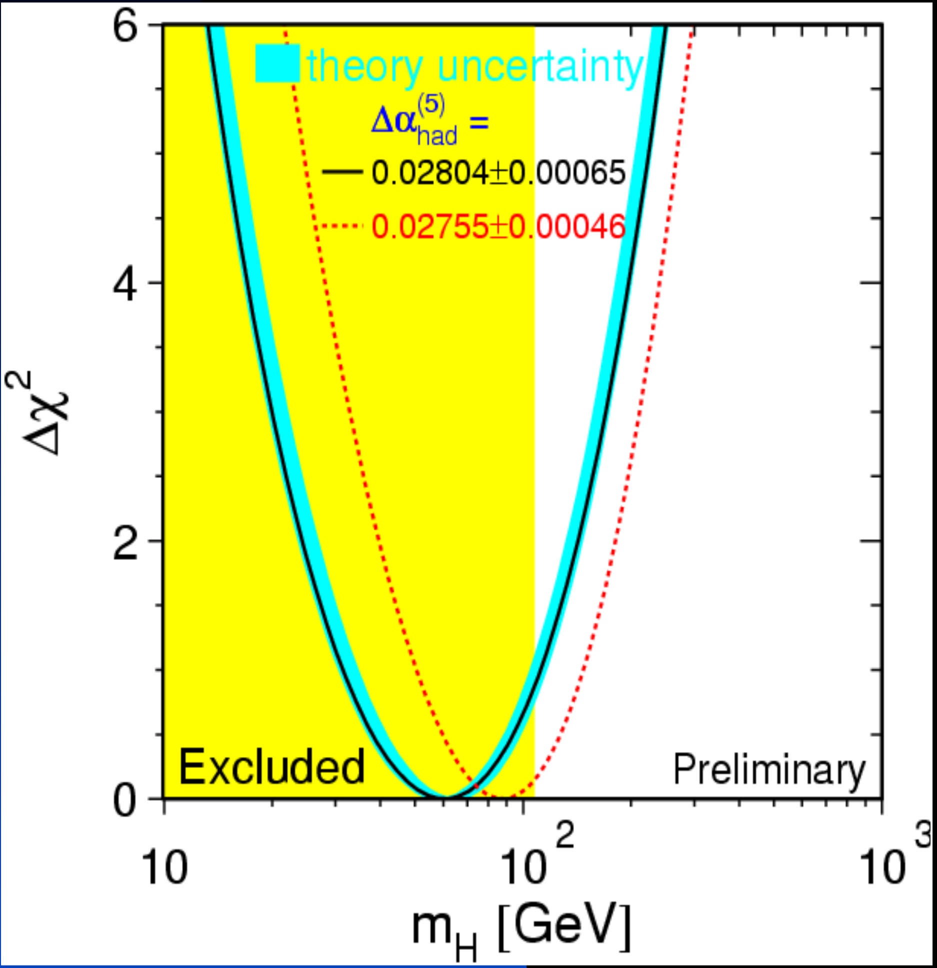


- Indirect CP violation in K-mesons and B-mesons
PEP II (BaBar)
KEKB (Belle)

- Direct CP violation in K-mesons
Fermilab (KTeV)
CERN (NA48)

$Re(\varepsilon'/\varepsilon) = (15.3 \pm 2.3)\ 10^{-4}$

The Higgs Mass Limit

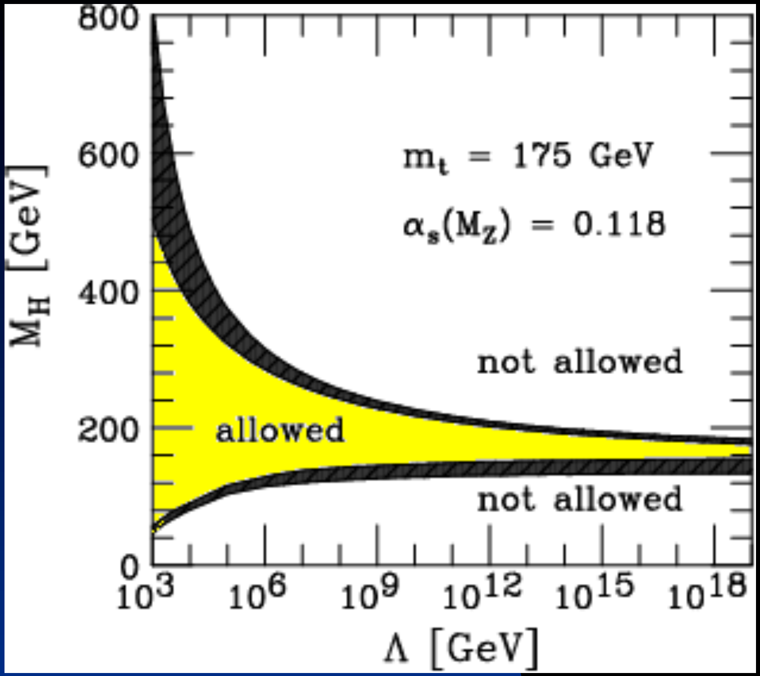


- Indirect limit from radiative corrections
- Direct limit from Higgs non-observation at LEP II (CERN)

$113 < m_H < 200$ GeV

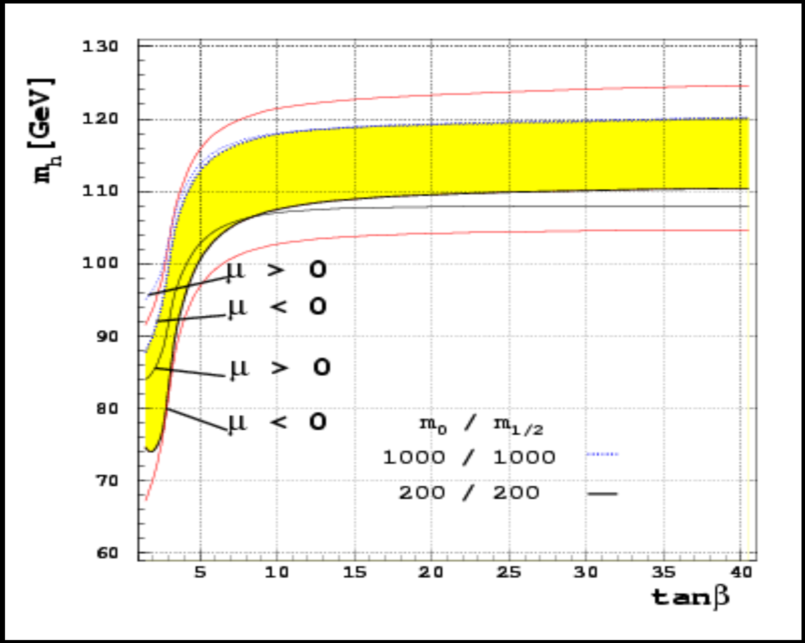
At 95 % C.L.

The Higgs Mass Limit (Theory)



- The SM Higgs

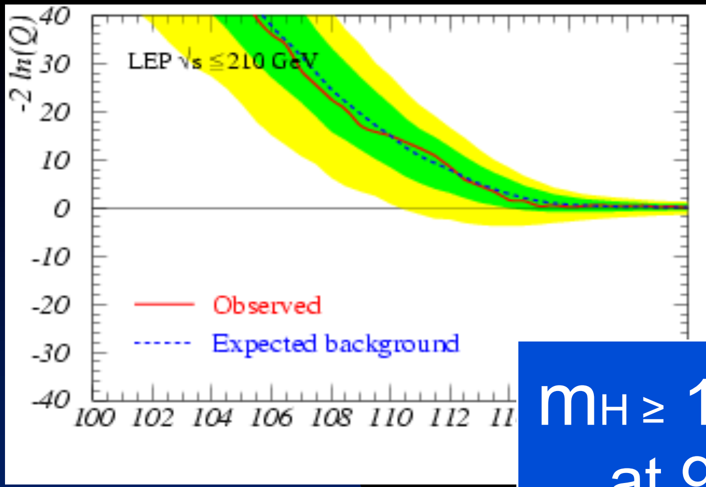
$m_H \geq$ 134 GeV

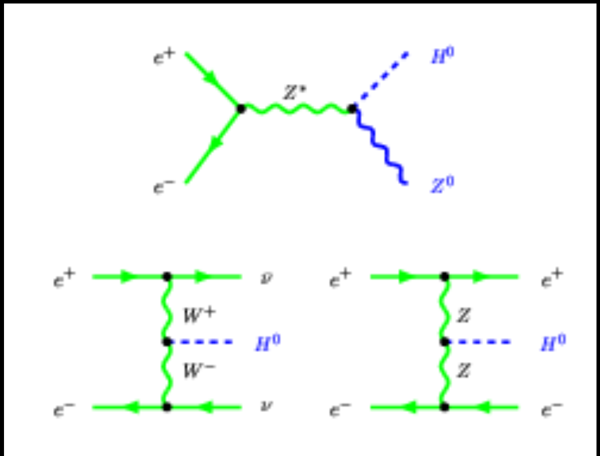


SUSY Higgs

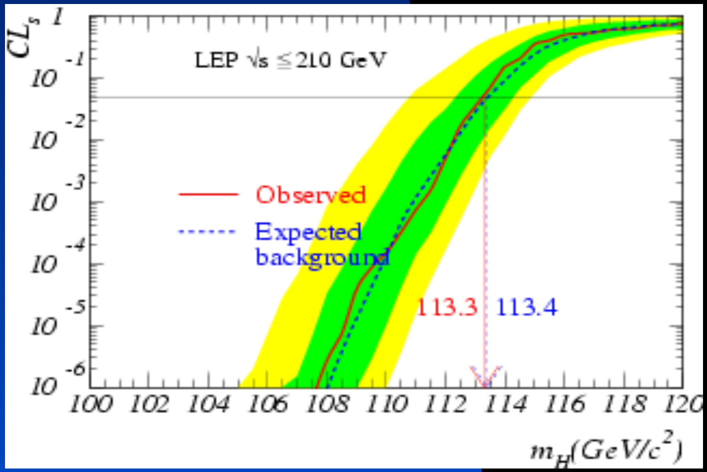
$m_H \leq$ 130 GeV

Higgs Searches

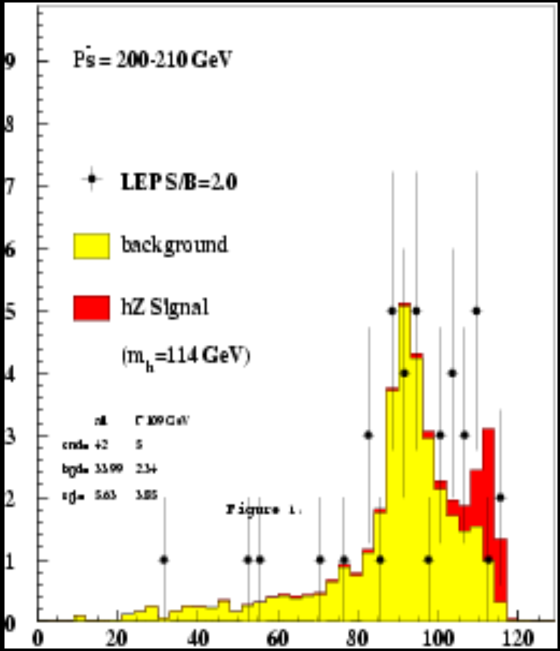




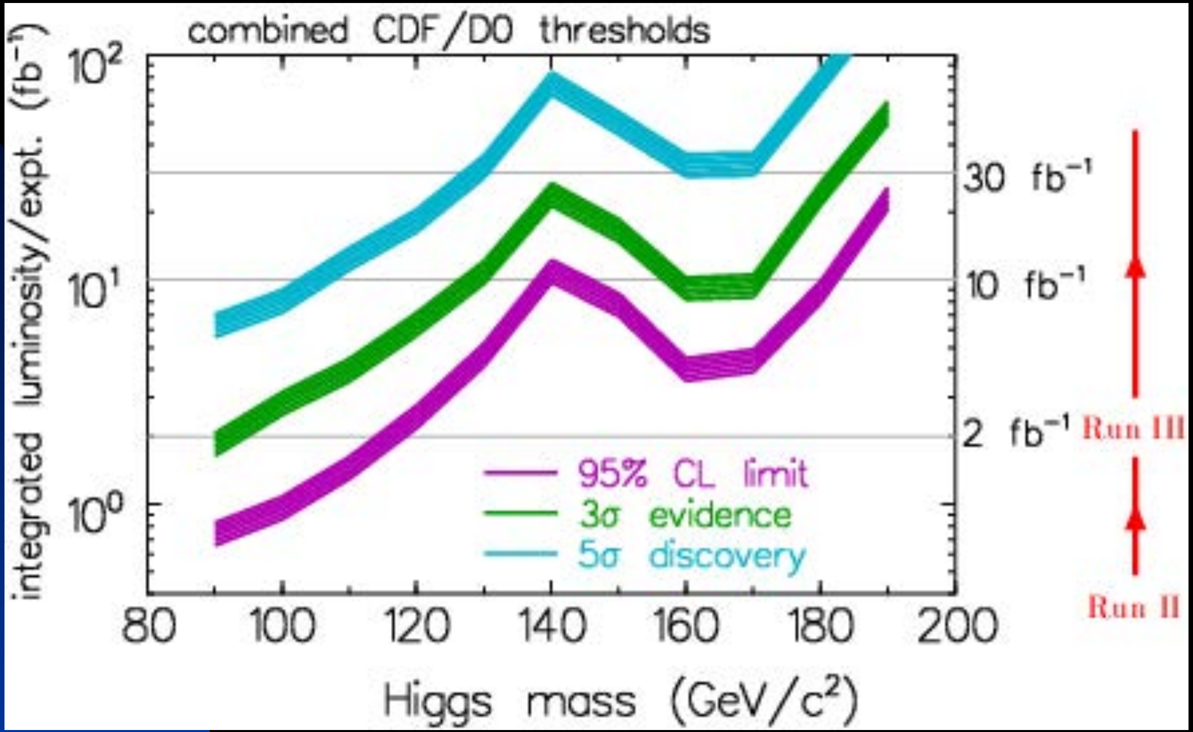
$m_H \geq 113.4$ GeV
at 95 % C.L.



114 -115 GeV
Event

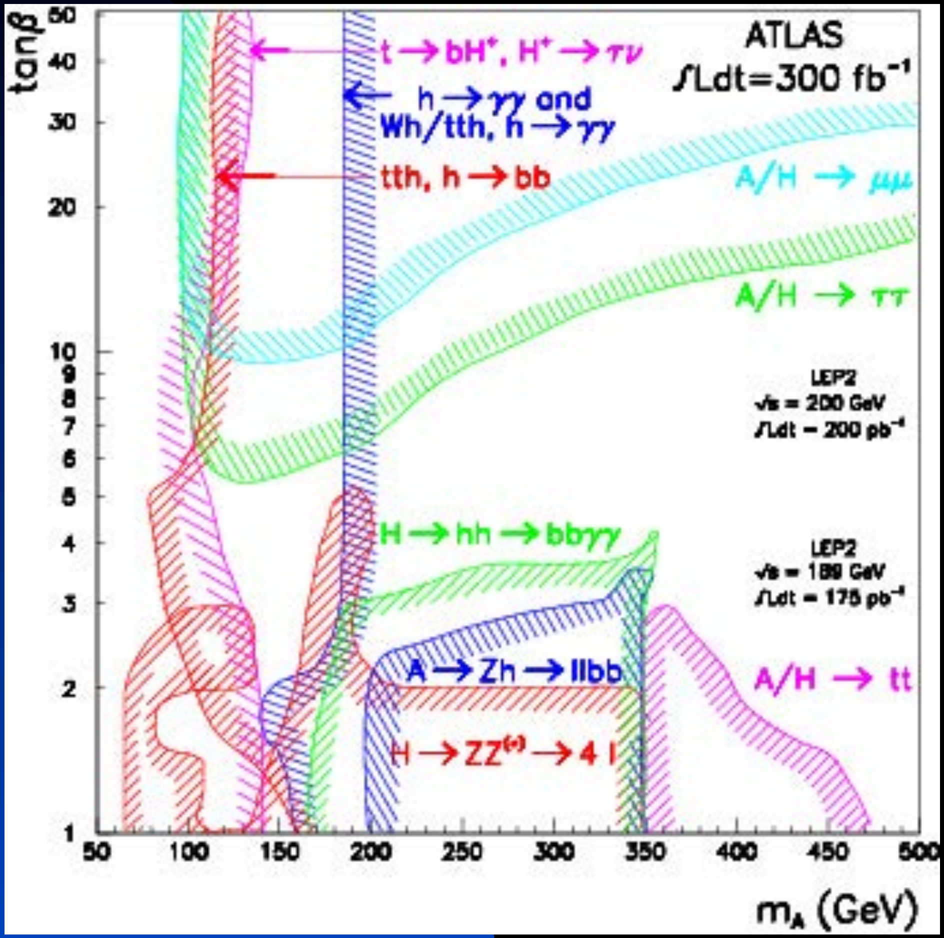


Looking for Higgs at Tevatron



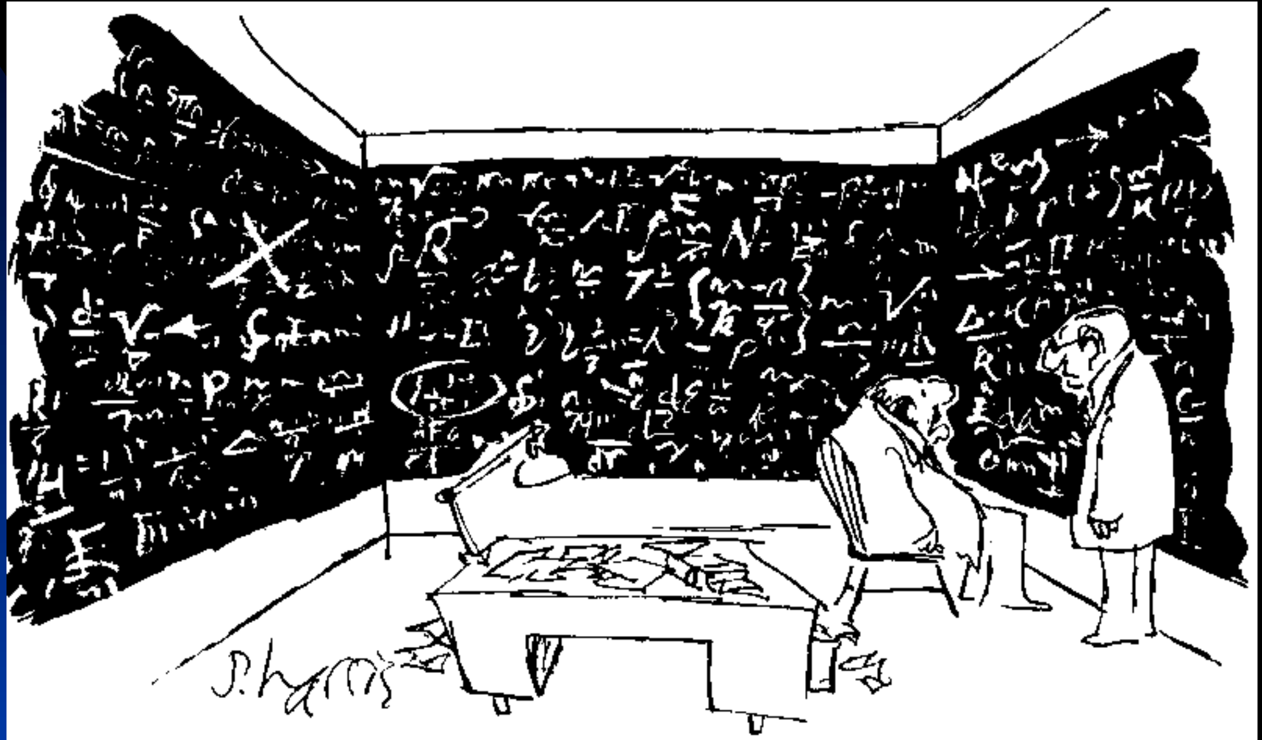
- Tevatron will reach 120 GeV limit before LHC and 180 GeV in future

Looking For Higgs at LHC



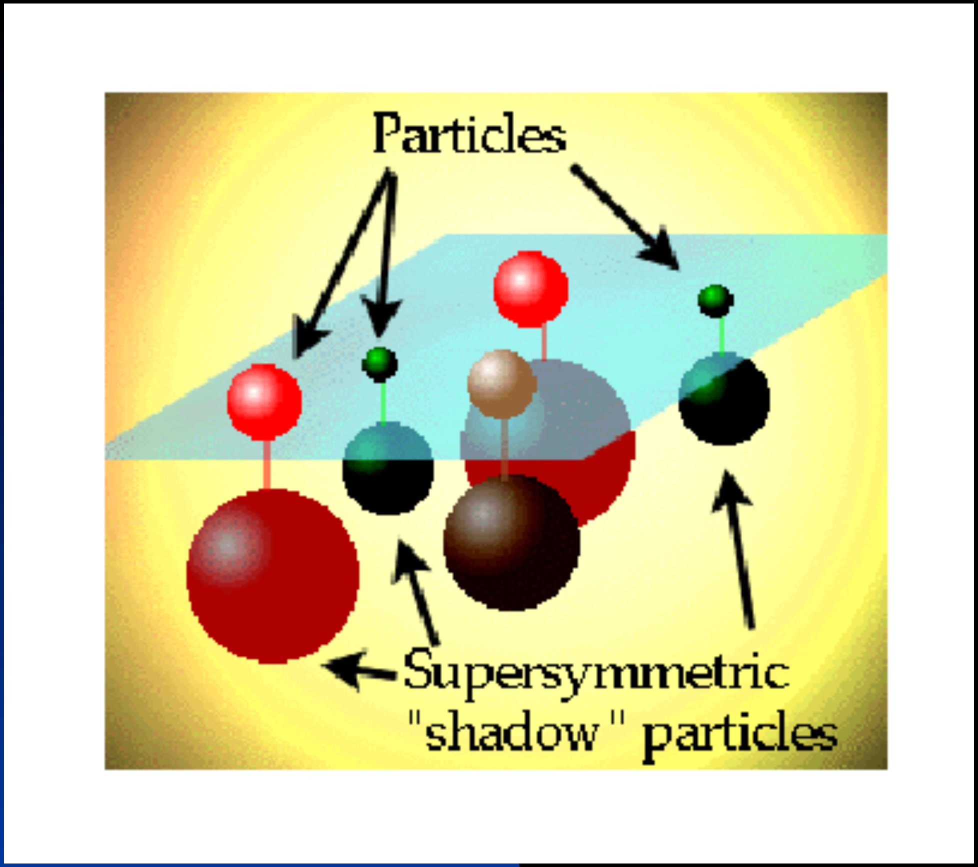
- Various channels for the Higgs search at LHC
- LHC will cover the whole parameter space and will find Higgs (or?)

We like elegant solutions



"Whatever happened to *elegant* solutions?"

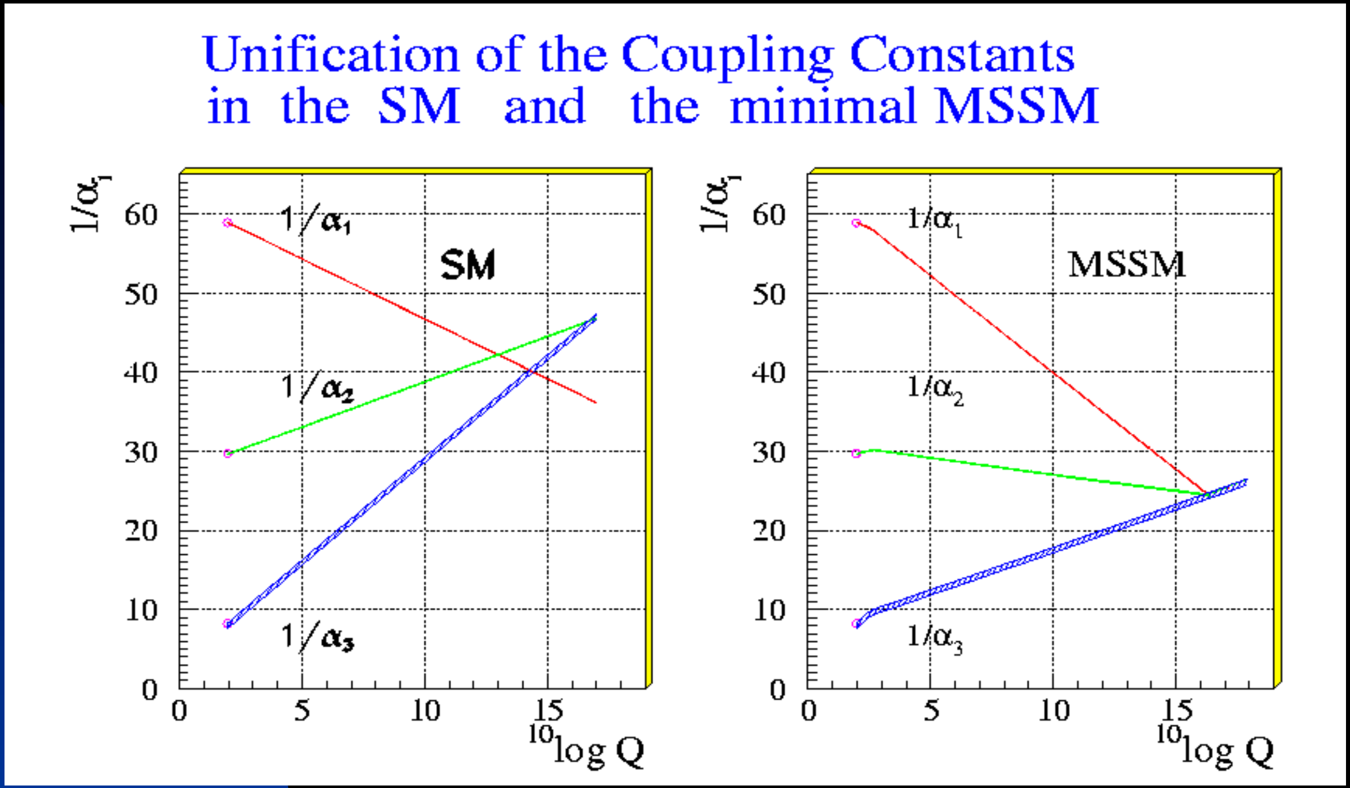
SuperSymmetry



- After 30 years since theoretical invention SUSY is still the matter of speculations. Supported mainly due to mathematical beauty and unification with gravity.

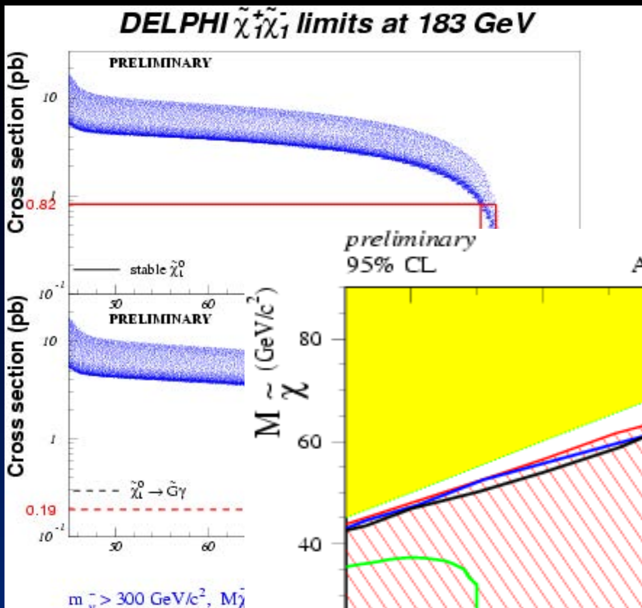
Every particle has a heavy partner of the same type but with the spin different by ½.

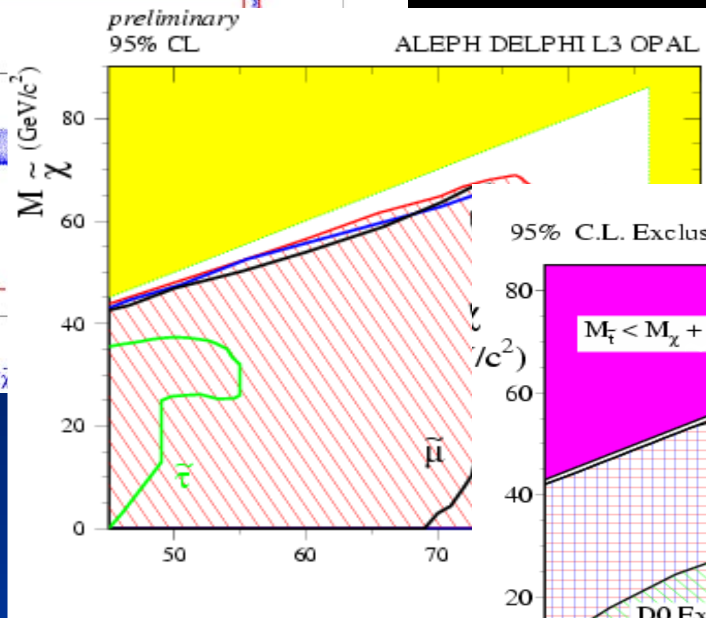
Unification Of Interactions

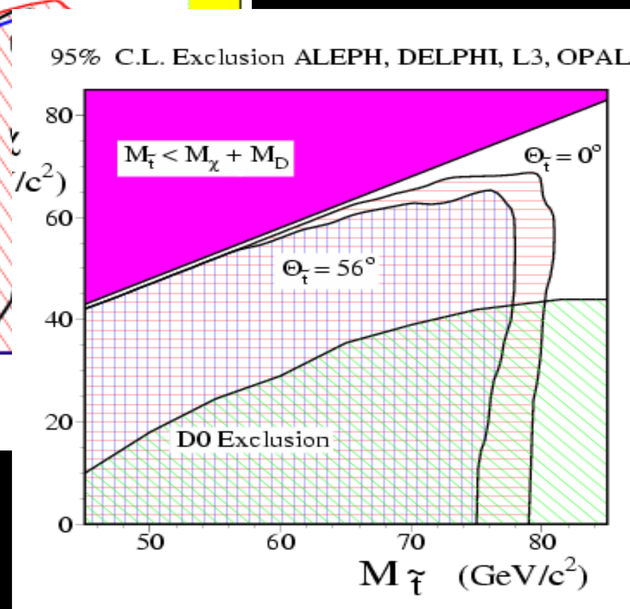


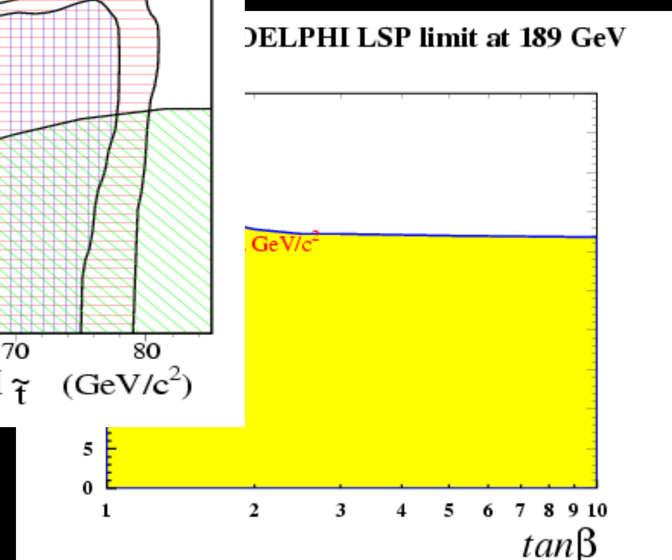
- Precise measurement of the couplings at LEP allowed us to check the unification ideas and to get the first indication of Supersymmetry

SUSY Searches









$m_{\chi^+} \geq$ 100 GeV

$m_{\chi^0} \geq$ 40 GeV

$m_{\tilde{g}} \geq$ 300 GeV

$M_{\tilde{q}} \geq$ 300 GeV

$m_{\tilde{l}} \geq$ 100 GeV

Superparticles

SParticle Data Group

The SPDG is an international collaboration that reviews Sparticle Physics and related areas of Astrophysics, and compiles/analyzes data on particle properties. SPDG products are distributed to 130,000 physicists, teachers, and other interested people. The Review of Sparticle Physics is the most cited publication in particle physics during the last twenty years. Plots of SPDG statistics are available.

Mirror sites: USA (LBNL) Brazil CERN Italy (Genova) Japan (KEK) Russia (Novosibirsk) Russia (Protvino) UK (Durham)

Review of Sparticle Physics Charts, Educational materials, Sparticle Adventure Information and Databases
US-HEPFOLK Sparticle Physics: Twenty Years of Discoveries Home Pages of major HEP labs

The Review of Sparticle Physics

C. Caso *et al.*, The European Physical Journal C103 (2018) 1 (2018 Authors)

- 2019 — 2019 Web update of Reviews, Tables, Plots — New November 2, 2019
- 2019 — 2019 Web update of Sparticle Listings — New July 6, 2019
- 2018 — 2018 Summary Tables and Conservation Laws
- 2018 Reviews, Tables, Plots (incl. Intro. Text) — Superseded by 2019 Web Version
- 2018 Sparticle Listings (published version) — Superseded by 2019 Web Version

- Errata (last changed January 18, 2020)
- Archived WWW editions: 2017 2016 2015
- Descriptions of the Summary Tables, Reviews, Listings, etc.
- Ordering information and list of products
- 2018 Authors and Directory of Sparticle Data Group Authors, Associates, and Advisors
- Computer-readable files — masses, widths, cross-sections, etc., including Palm Pilot XXII files.
- Encoder tools (for SPDG collaborators)

Discovery of the new world of Supersymmetry

Back to 60’s

New discoveries every year