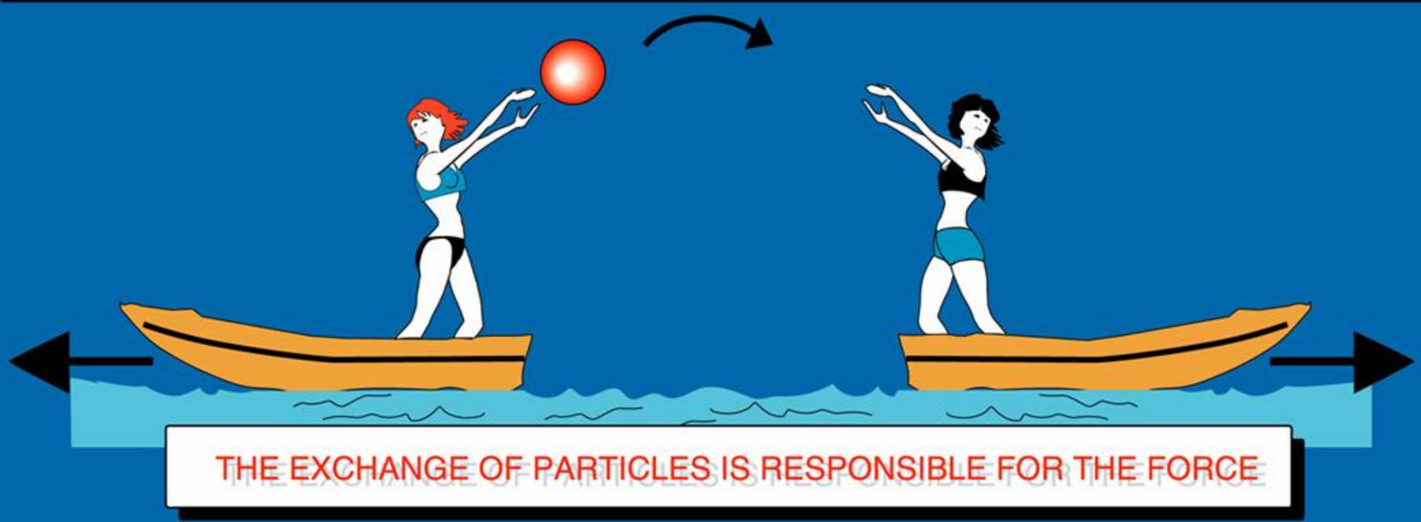
The forces in Nature

TYPE	INTENSITY OF FORCES (DECREASING ORDER)	BINDING PARTICLE (FIELD QUANTUM)	OCCURS IN :
STRONG NUCLEAR FORCE	~ 1	GLUONS (NO MASS)	ATOMIC NUCLEUS
ELECTRO -MAGNETIC FORCE	~ 10^{-3}	PHOTONS (NO MASS)	ATOMIC SHELL ELECTROTECHNIQUE
WEAK NUCLEAR FORCE	~ 10^{-5}	BOSONS Z^0 , W^+ , W^- (HEAVY)	RADIOACTIVE BETA DESINTEGRATION
GRAVITATION	~ 10^{-38}	GRAVITONS (?)	HEAVENLY BODIES

Elektro-
svak
Kraft



Fields

'Strong' interaction

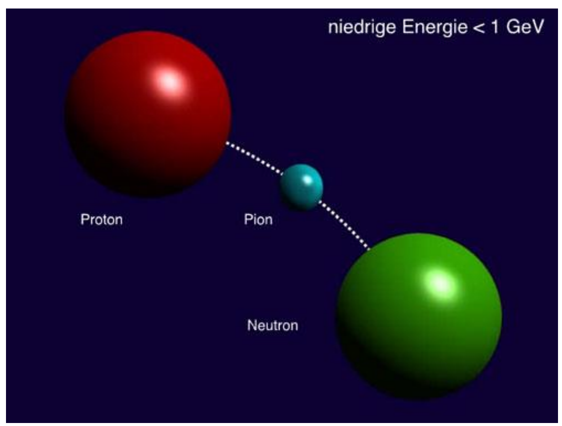
Back to the strong force: keeping protons and neutrons together

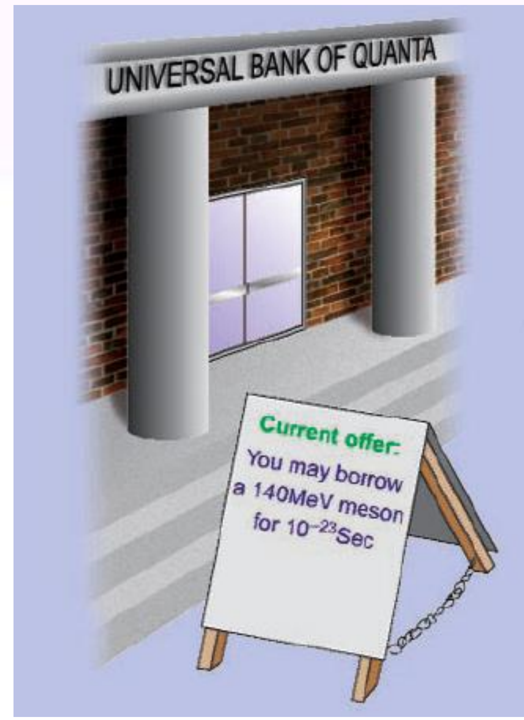
Yukawa (1934)

Exchange of massive particle
Pion

$$V(r) = -g^2 \frac{e^{-mr}}{r}$$

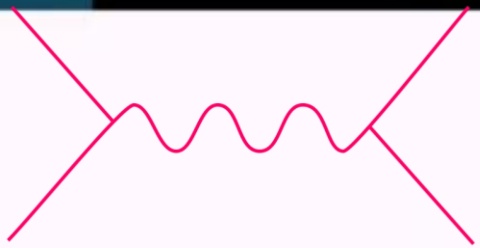
Modified Coulomb law





Allowed by uncertainty relation: 1.4 fm – 140 MeV

De fire kraftpotensialene



$$V_G = -G\frac{Mm}{r}$$

Newtons gravitasjon
(+korreksjoner p.g.a. Einstein)

$$V_C = -\alpha\frac{1}{r}$$

Coulombkraften

$$V_w = -g^2 \frac{1}{r} e^{-m_w r/(\hbar c)}$$

Svak kjernekraft

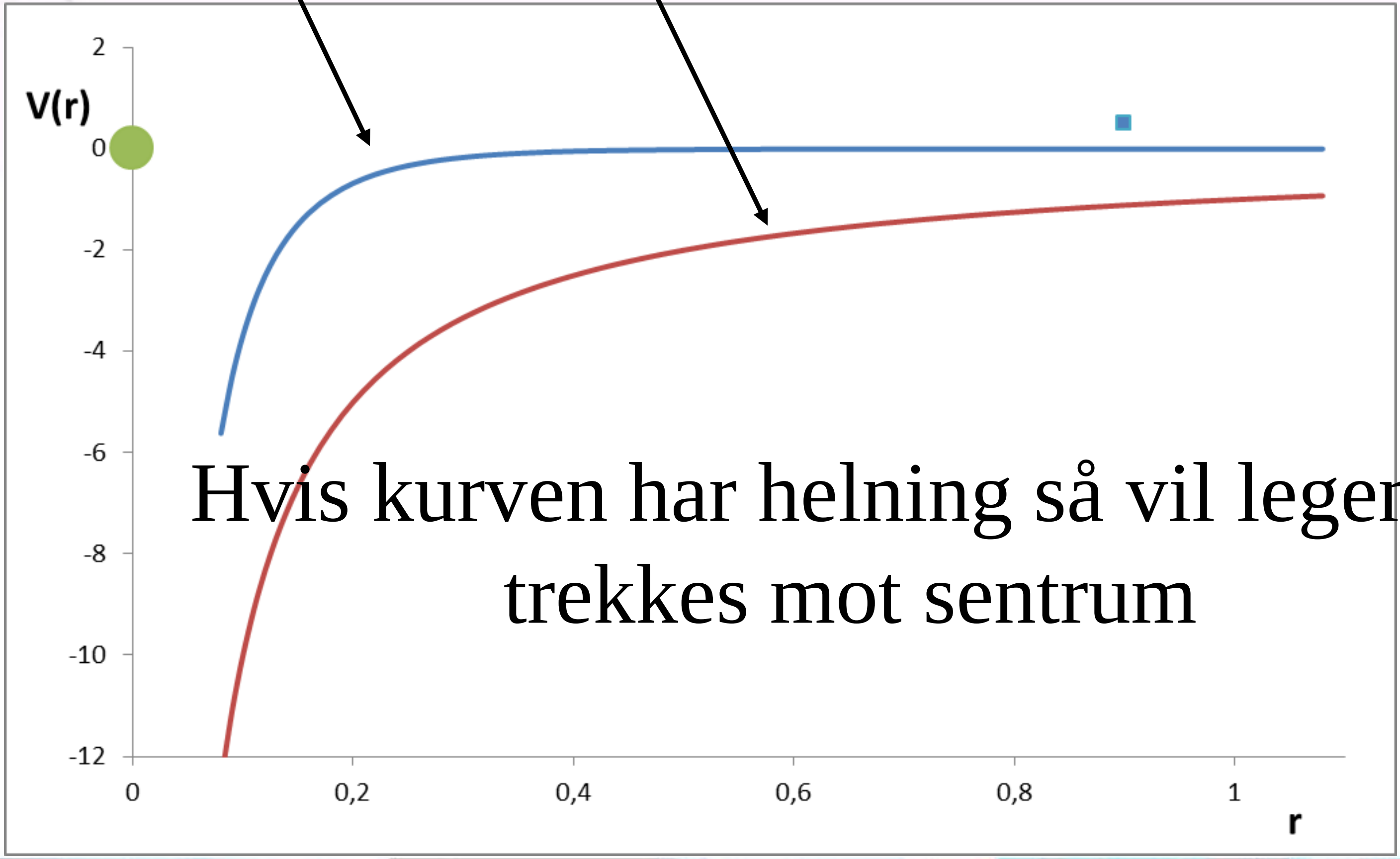
$$V_s = -\alpha_s \frac{4}{3}\frac{1}{r} + kr$$

Sterk kraft (mellom kvarker).
Nb: øker med avstand. Ikke mulig med enkle diagrammer

Hvilke sammenhenger finnes?

$$V(r) = -g^2 \frac{e^{-mr}}{r}$$

Yukawa og Coulomb potensialer



Hvis kurven har helning så vil legemer trekkes mot sentrum

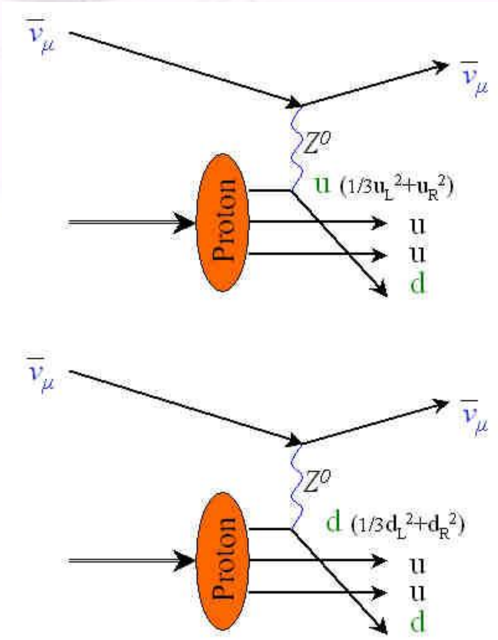
Mot Standardmodellen

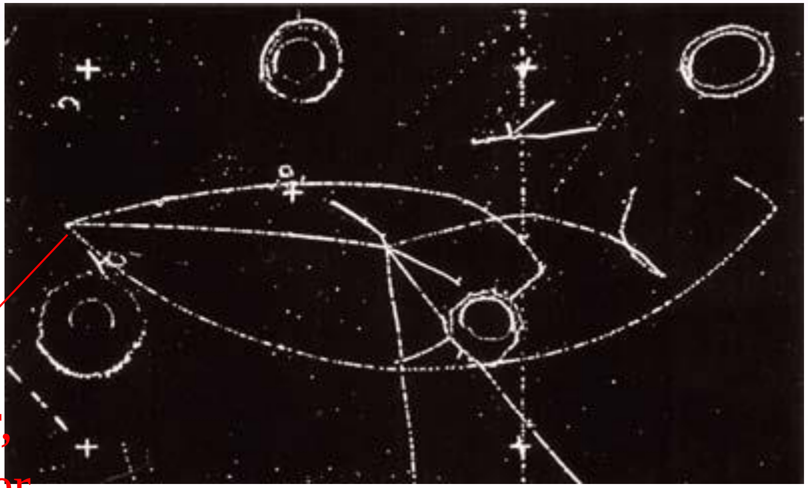
At the end of the 1950s V-A theory was the "standard model" of weak interactions. Its major drawback was its bad high-energy behaviour, which prompted various ideas to cure the problem of infinities. Guided by quantum electrodynamics, a gauge theory, attempts were made to construct a gauge theory of weak interactions, and in the mid-1960s the hypothesized charged intermediate vector boson (W±) was complemented with a neutral partner to achieve the required cancellations. **The invention of the Higgs mechanism solved the problem of having both a gauge theory and massive mediators of weak interactions. The progress made by Sheldon Glashow, Abdus Salam and Steven Weinberg was completed by the work of Martinus Veltman and Gerard 't Hooft,** which proved the renormalizability of the theory. **So, as 1971 turned to 1972, a viable theory of weak interactions that claimed weak neutral currents as a crucial ingredient was proposed, challenging the experimental groups to provide "yes" or "no"** as an answer to the question "do neutral currents exist?".

Sitat: CERN Courier 4 oktober 2004

= eksistens av Z-bosonet

Svak nøytral strøm
funnet i boblekammeret
"Gargamelle"





tre hadroner,
ingen leptoner

Cerns største triumf på 1970 tallet

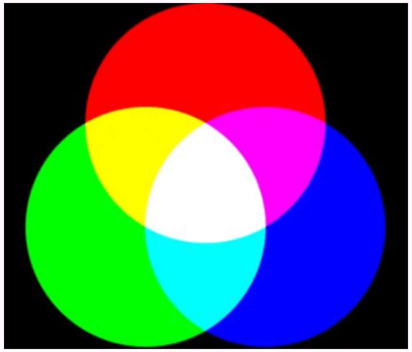
Kan alt beskrives med samme teori? Hva betyr ”samme teori”?

- Må ha en relasjon mellom ladningene i de forskjellige kreftene.
- Elektrosvak teori

$$g \sin\theta_W = e$$

g er svak ladning
e er elektrisk ladning
ofte brukes $\alpha = e^2/(2\varepsilon_0 hc)$
istedenfor ladning

1973



Colour charge

Δ^{++} three up-quarks with parallel spin, in a symmetric state

(u,u,u) *But: three fermions not allowed to be in identical states (Pauli exclusion principle)*

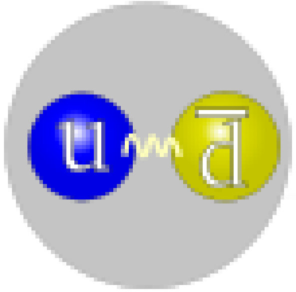
The three quarks must be different in one quantum number: "colour"

(Bardeen, Fritzsch, Gell-Mann)

Only colour-neutral bound states are allowed

MESONS = Quark-Antiquark

BARYONS = 3-Quark states



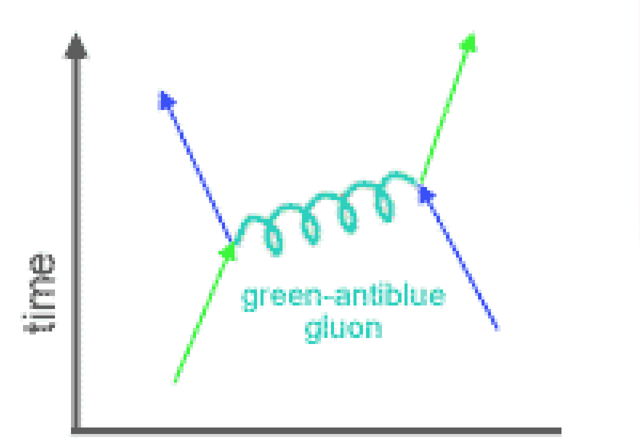
Positive pion

Colour-force transmitted by (eight) gluons

GLUONS CARRY COLOUR CHARGE - SELF-INTERACTION !

1973

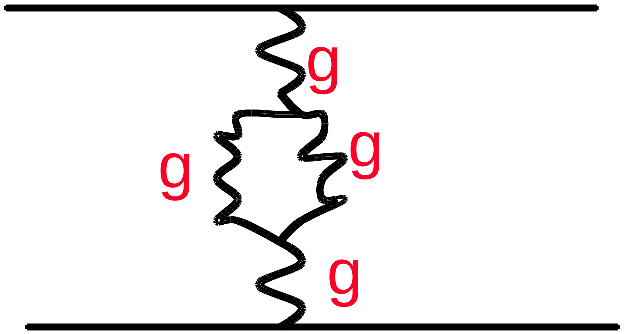
Gluons



Gluons are massless carriers of the strong force

There are 3 x 3 - 1 = 8 different gluons

Gluons carry colour charge -> self-interaction



Self-interaction of gluons

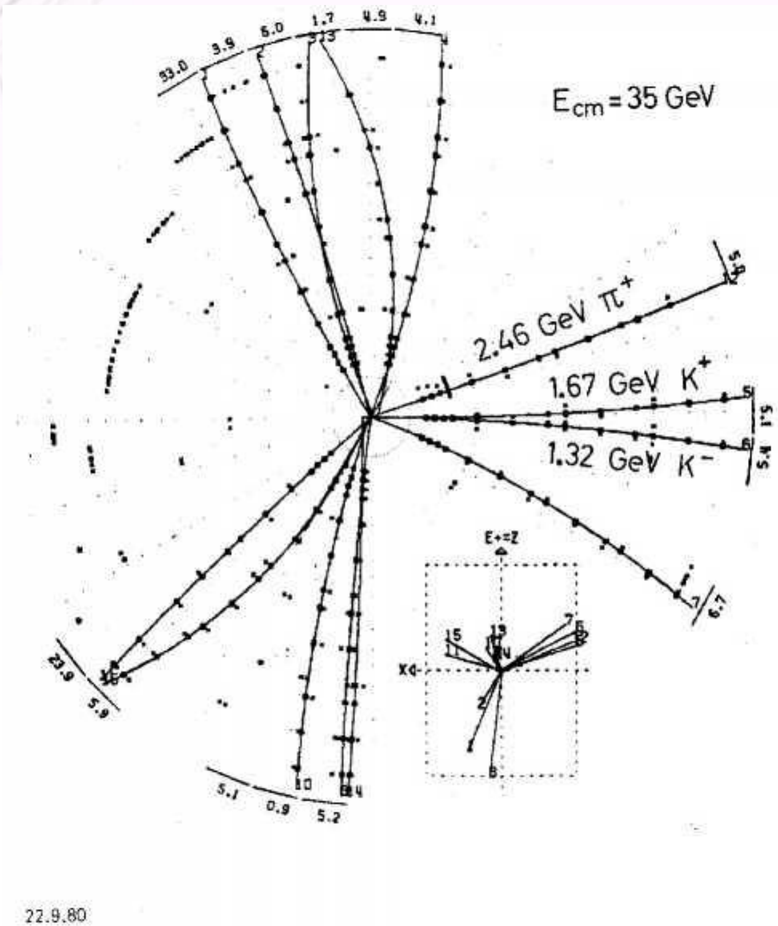
Potential rises linearly with distance (for large r)

$$V_{QCD} = -\tfrac{4}{3}\frac{\alpha_s}{r} + kr$$

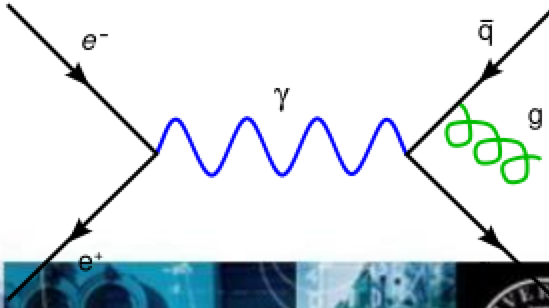
Small distances: asymptotic freedom

1973

Discovery of Gluons



Bjørn Wiik (1937-1999)



PETRA Storage Ring 1979 DESY (Hamburg)

Tre av kreftene beskrives godt som kvantefelt-teorier. Dette kalles 'Standardmodellen'.

- Forening av svake og elektromagnetiske vekselvirkninger
- Ingen relasjon mellom sterk og elektrosvak ladning.
- Hva med gravitasjon?
- Kvarker,leptoner,fotoner,gluoner….

Moderne partikkelfysikk

- Studier av materiens minste byggestener og av kreftene mellom dem
  - Eksperimentelt, ved å se på kollisjoner mellom partikler.
  - Teoretisk, ved å utvikle modeller og regne ut hva som skjer.

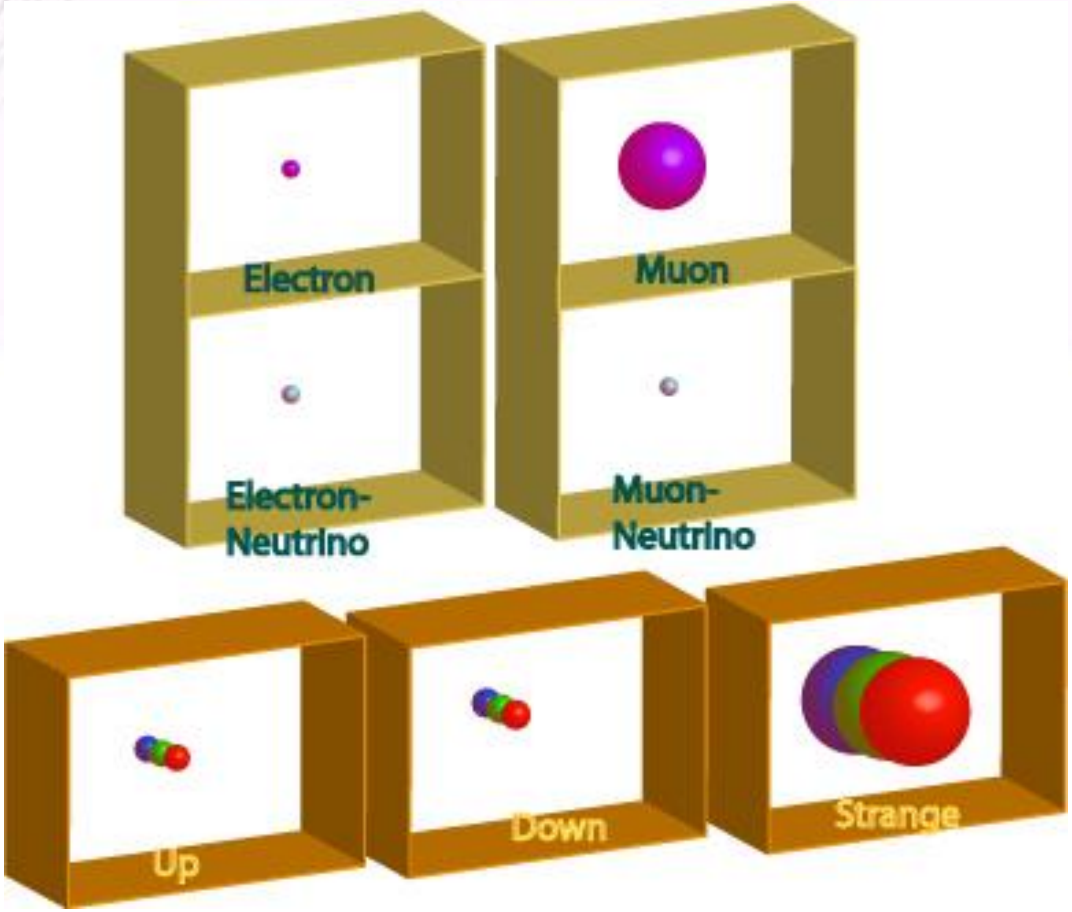
Ingredienser

- Kvarker
- Leptoner
- Vekselsvirkningspartikler
- Men hvor mange kvarker og leptoner?

1973

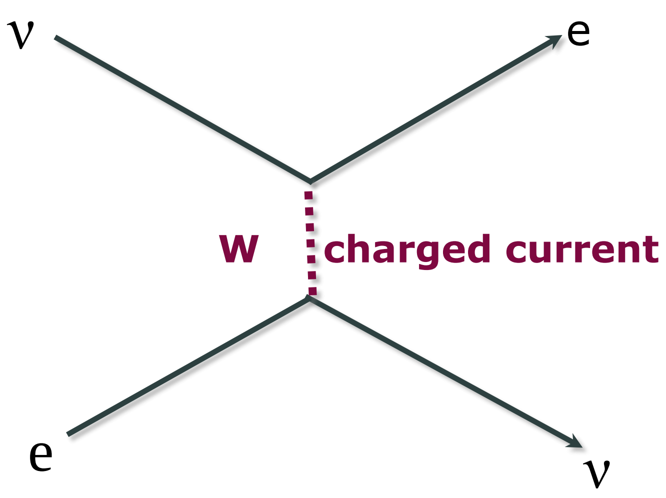
LEPTONS

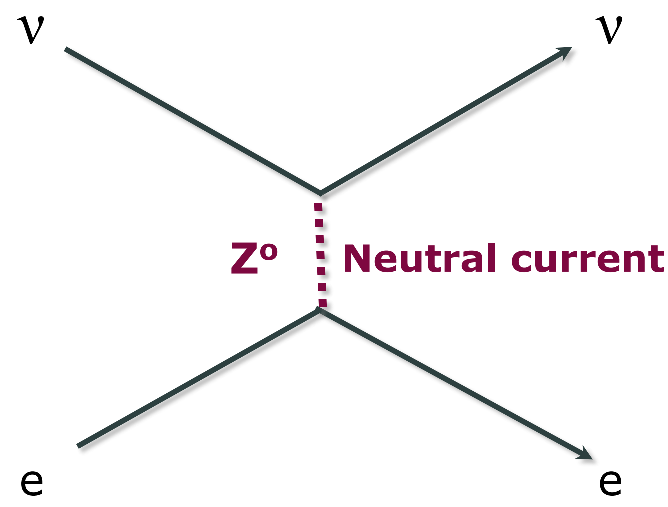
QUARKS



Fields

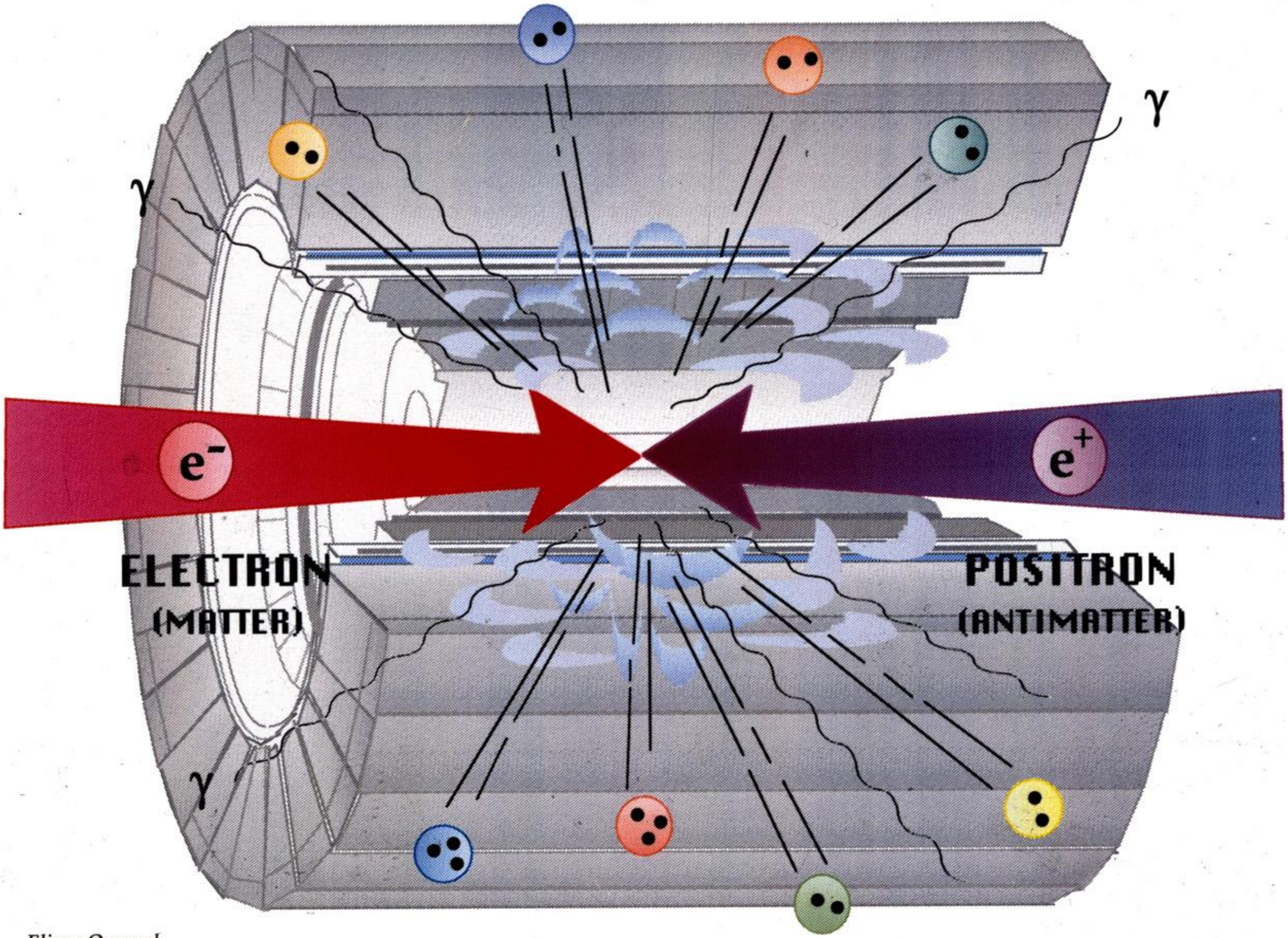
Electroweak Interaction 1968





Glashow, Salam, Weinberg (1968) - Electroweak Force

- The electromagnetic and weak interaction are different aspects of the same 'electroweak' force
- All quarks and leptons have a 'weak' charge
- There should be a 'heavy photon' (Z^o) and two charged vector boson ($W^{\pm}$) of mass ~ 50-100 GeV
- They acquire their mass by the interaction with the (new) "Higgs field" H.
- There are only 'left-handed' interactions



Eliane Onursal

Partiklers levetid

Heisenbergs usikkerhetsrelasjon

$$\Gamma\tau = \Delta E \Delta t \geq \hbar$$

Partikkel*vidde*

$$\Gamma = \frac{\hbar}{\tau} = \frac{6.5 \cdot 10^{-22} MeVs}{\tau}$$

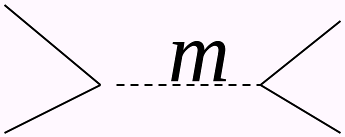
$$\Gamma = \Gamma_1 + \Gamma_2 + \Gamma_3$$

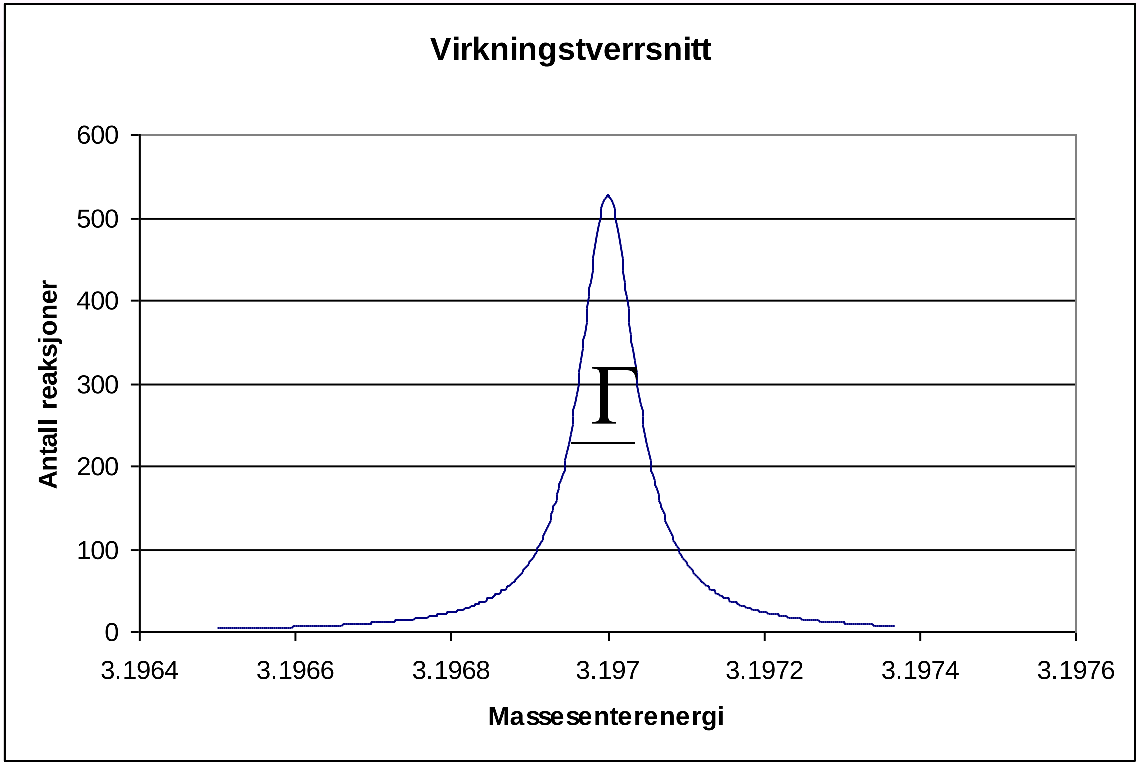
$$Br_i = \frac{\Gamma_i}{\Gamma}$$

Er en sum av *delvidder* som gir sannsynlighet til henfall til forskjellige slutt-tilstander

Resonans

$e^+ e^- \rightarrow$ (kvarker) $\rightarrow$ hadroner





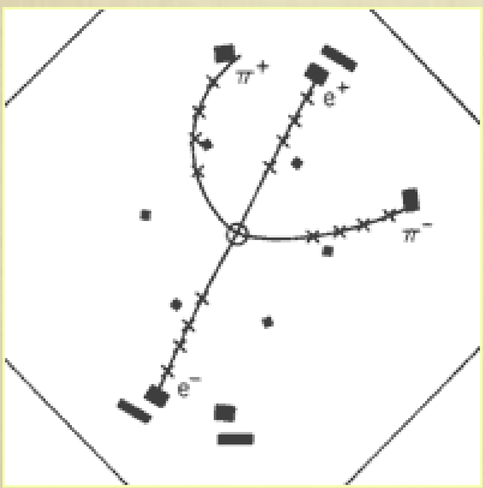
PARTICLE SPECTRUM

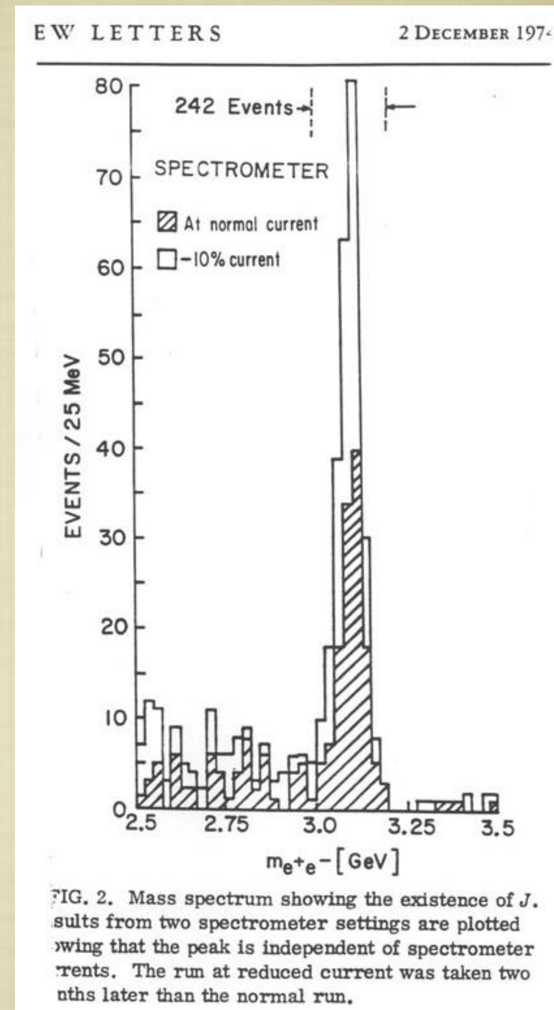
1974

And the charm quark was to be discovered soon afterwards :

The NOVEMBER REVOLUTION (11 November 1974)

Two groups discovered ~ simultaneously a new particle, which they called **'Psi'** at SLAC (Burt Richter) and '**J**' at Brookhaven (Sam Ting).





The J/psi resonance was 'long-lived' (~10^{-20} sec). It could only decay by weak interactions, preferably into an s-quark. This explains the narrow peak.

Electro-weak Interaction

Fields

1970

Milestone paper (Glashow, Iliopoulos, Maiani)

PHYSICAL REVIEW D VOLUME 2, NUMBER 7 1 OCTOBER 1970

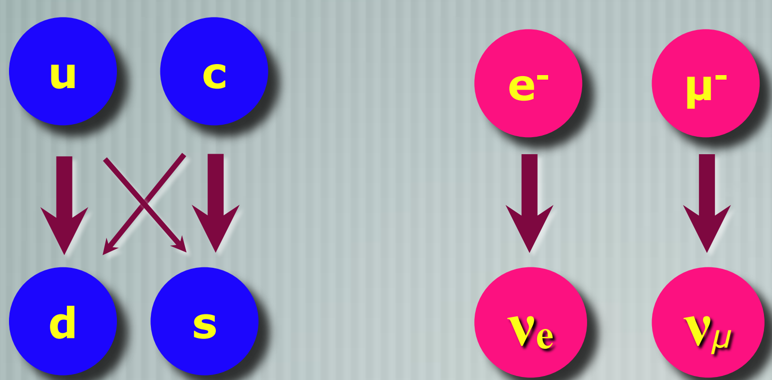
Weak Interactions with Lepton-Hadron Symmetry*

S. L. Glashow, J. Iliopoulos, and L. Maiani†
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02139

(Received 5 March 1970)

We propose a model of weak interactions in which the currents are constructed out of four basic quark fields and interact with a charged massive vector boson. We show, to all orders in perturbation theory, that the leading divergences do not violate any strong-interaction symmetry and the next to the leading divergences respect all observed weak-interaction selection rules. The model features a remarkable symmetry between leptons and quarks. The extension of our model to a complete Yang-Milis theory is discussed.

Quarks Leptons



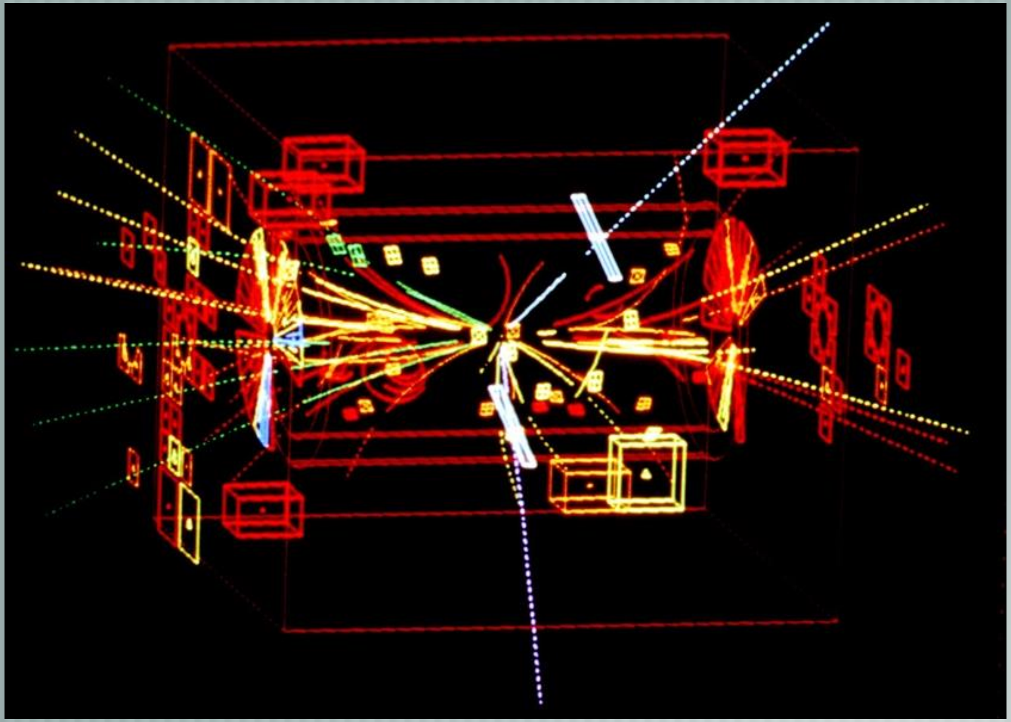
This was now called the 'Standard Model' (with two families)

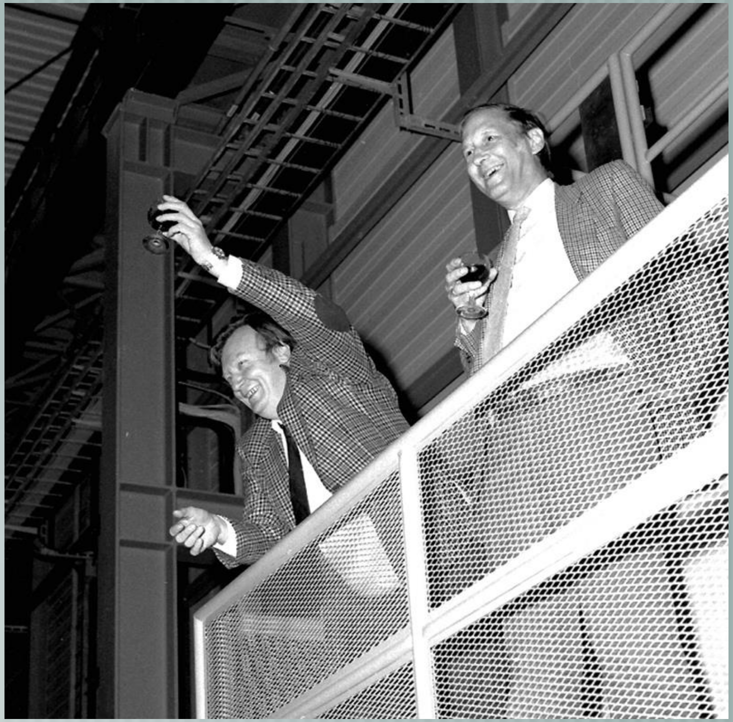
Fields

Electroweak Interaction 1983

Discovery of the W, Z bosons at CERN (1983)

(Carlo Rubbia - leader of UA1 collaboration, and proponent of proton-antiproton collider in SpS)
(Simon van der Meer - inventor of stochastic beam cooling)



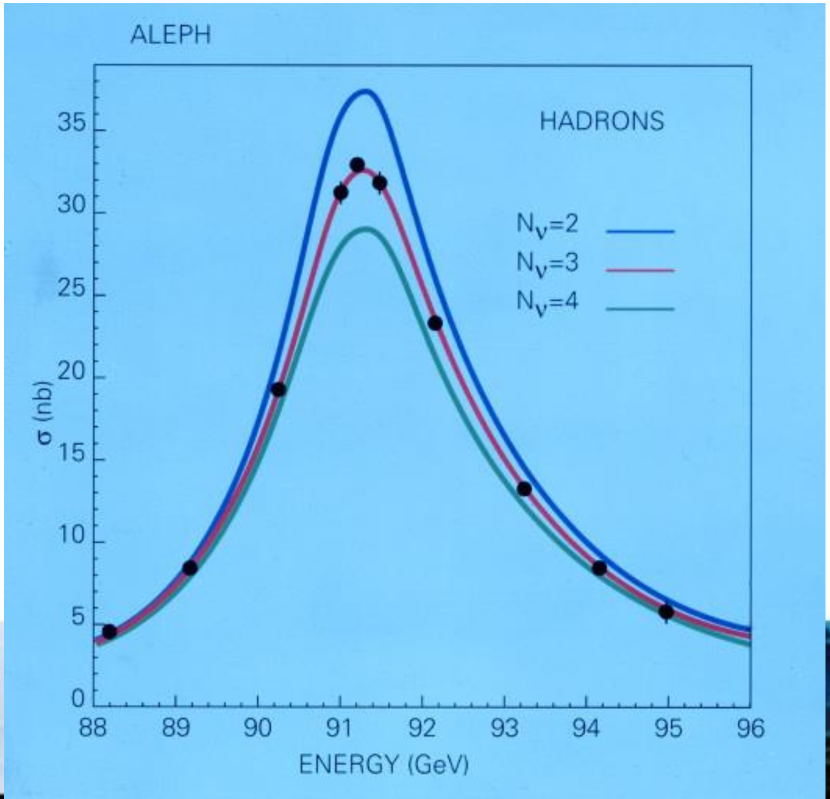


Hvor mange generasjoner av kvarker og leptoner?

LEP eksperimentene måler Z^0 bosonets totale vidde

$$\Gamma_Z = N_{\bar{u}u}\Gamma_{\bar{u}u} + N_{\bar{d}d}\Gamma_{\bar{d}d} + N_{\bar{l}l}\Gamma_{\bar{l}l} + N_{\bar{\nu}\nu}\Gamma_{\bar{\nu}\nu}$$

Tester også koblingenes *universalitet*



Standardmodellen (SM) oppsummert

- Tre *og bare tre* generasjoner kvarker og leptoner.
- Forening av elektromagnetisme og svake kjernekrefter.
- Litt asymmetri mellom materie og antimaterie (CP brudd) på en selvkonsistent måte
- Higgs-mekanisme for å gi partiklene masse
- Ingen jordiske observasjoner bryter med SM, Standardmodellen er en stor suksess!

Higgsmekanismen

- Mekanisme for å gi alle partikler *masse*
- *(men 95% av protonets masse forklares på andre måter (gluonfelt)*
- Forutsier en ny partikkel, higgspartikkelen, men sier ikke mye om dens egen masse.
- For gitt masse så kan produksjons og henfallsannsynligheter beregnes.

Søk etter Higgs-partikkelen

LEP

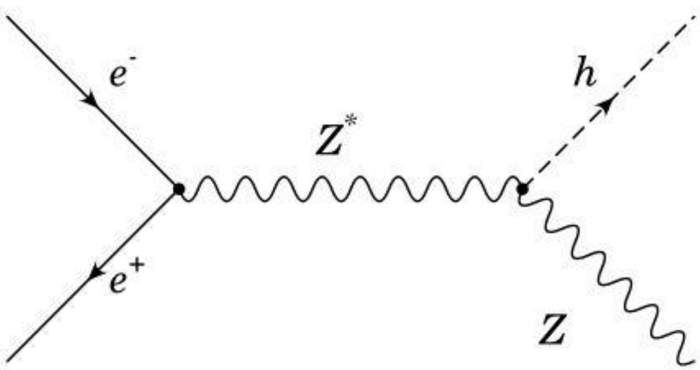
m(H) > 114 GeV

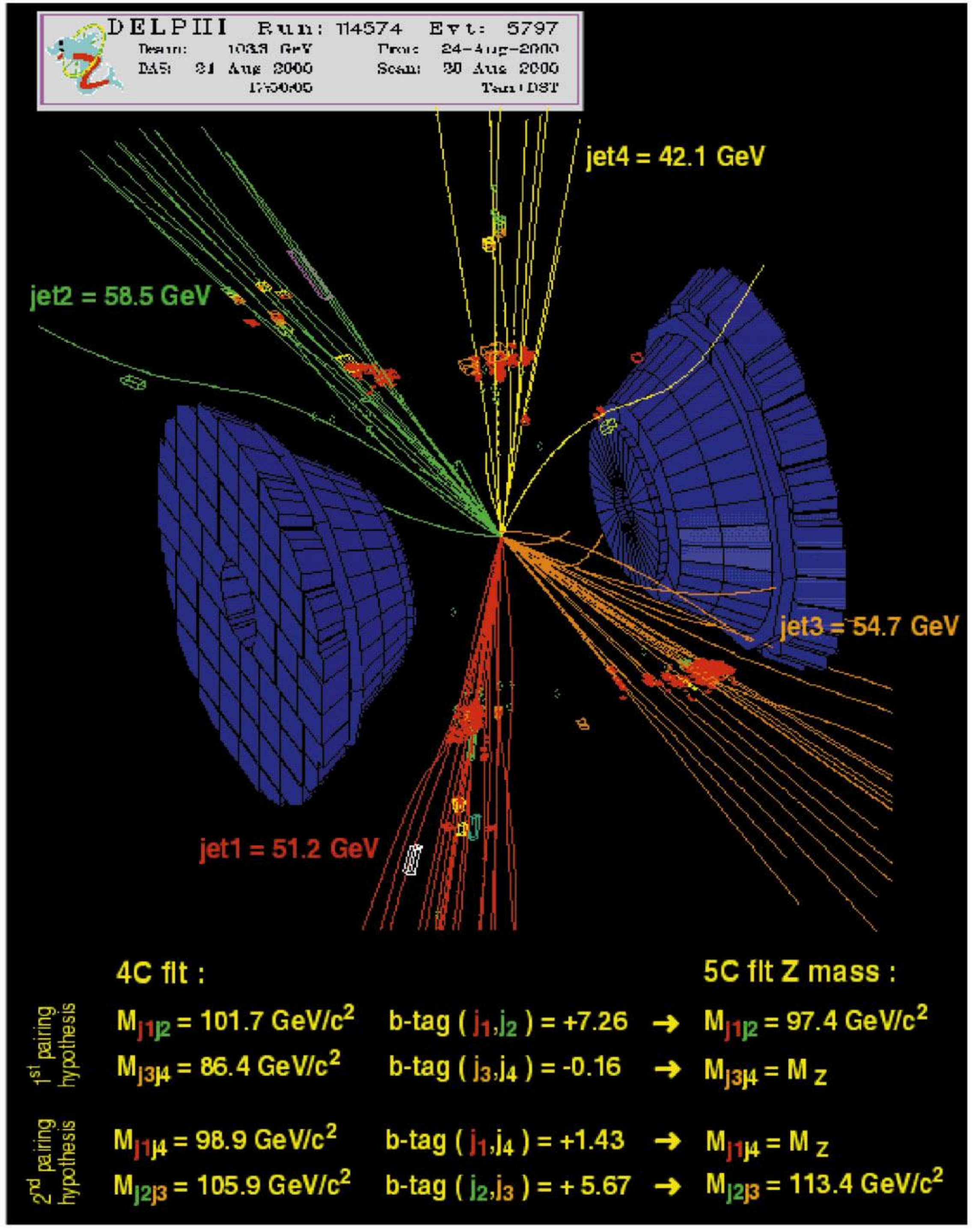
Tevatron (Fermilab)

Utelukker Higgsmasser rundt 140-160 GeV

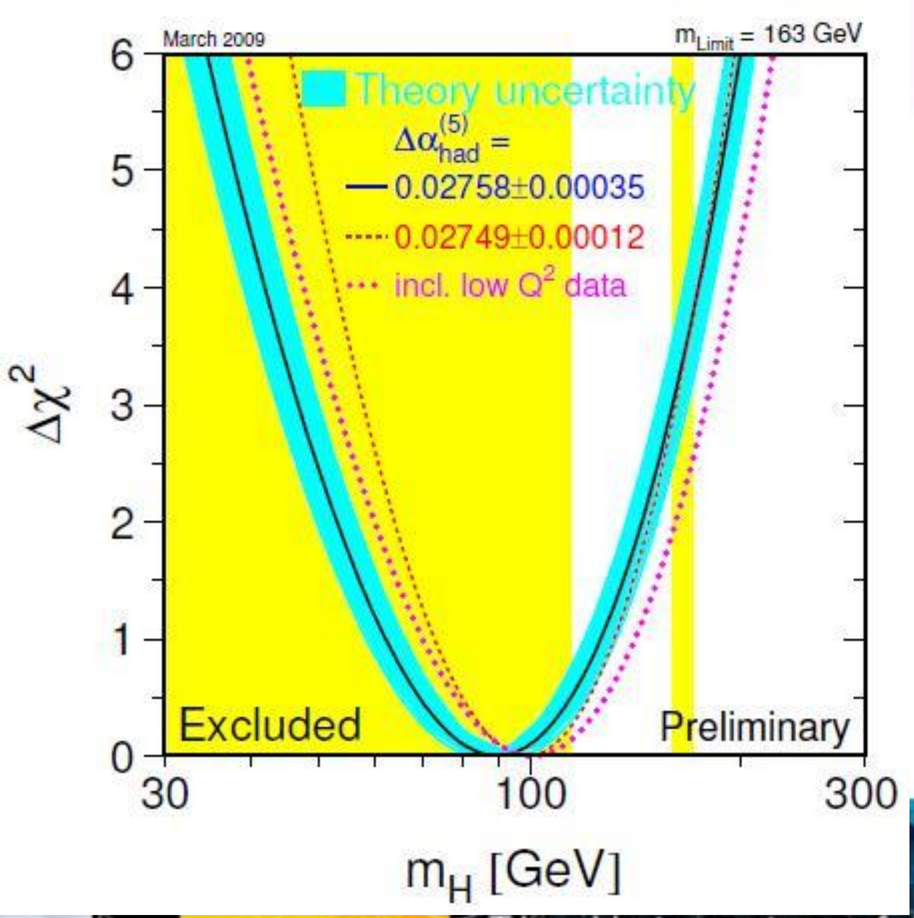
Det fins Higgs kandidater fra LEP-eksperimentene

Men ikke bevis: SM-Higgs massen må være over 114 GeV.

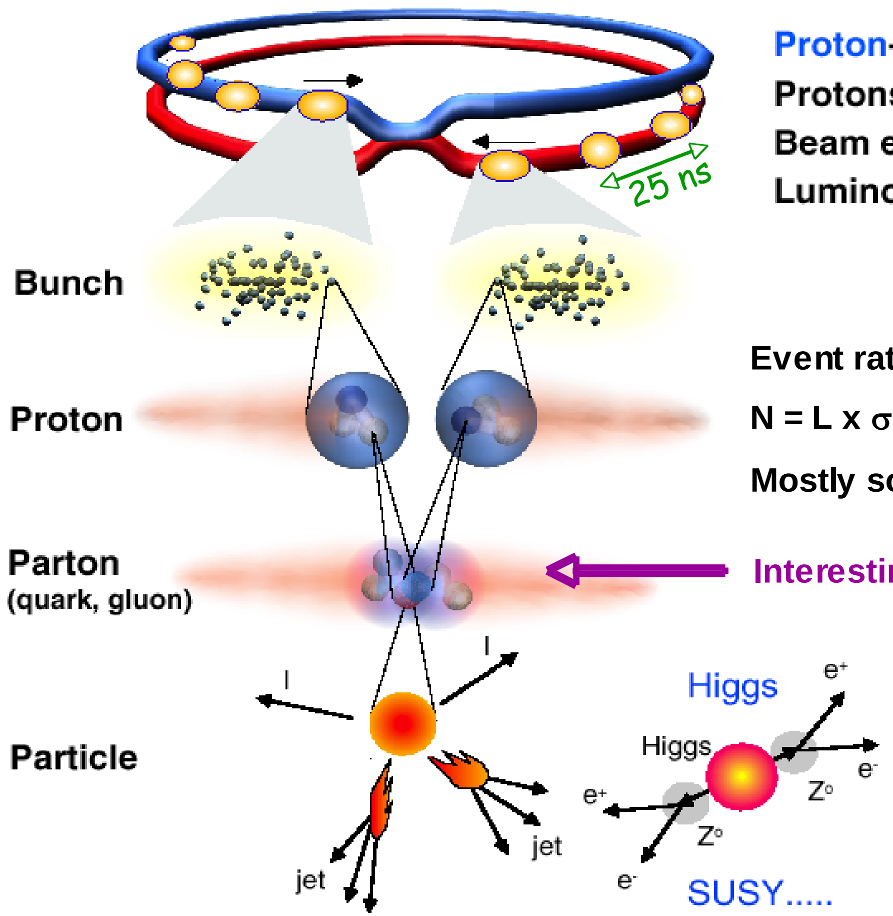




Pre-LHC situasjon



Collisions at LHC



Proton-Proton

Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	10^{34} cm^{-2} s^{-1}

Event rate in ATLAS :

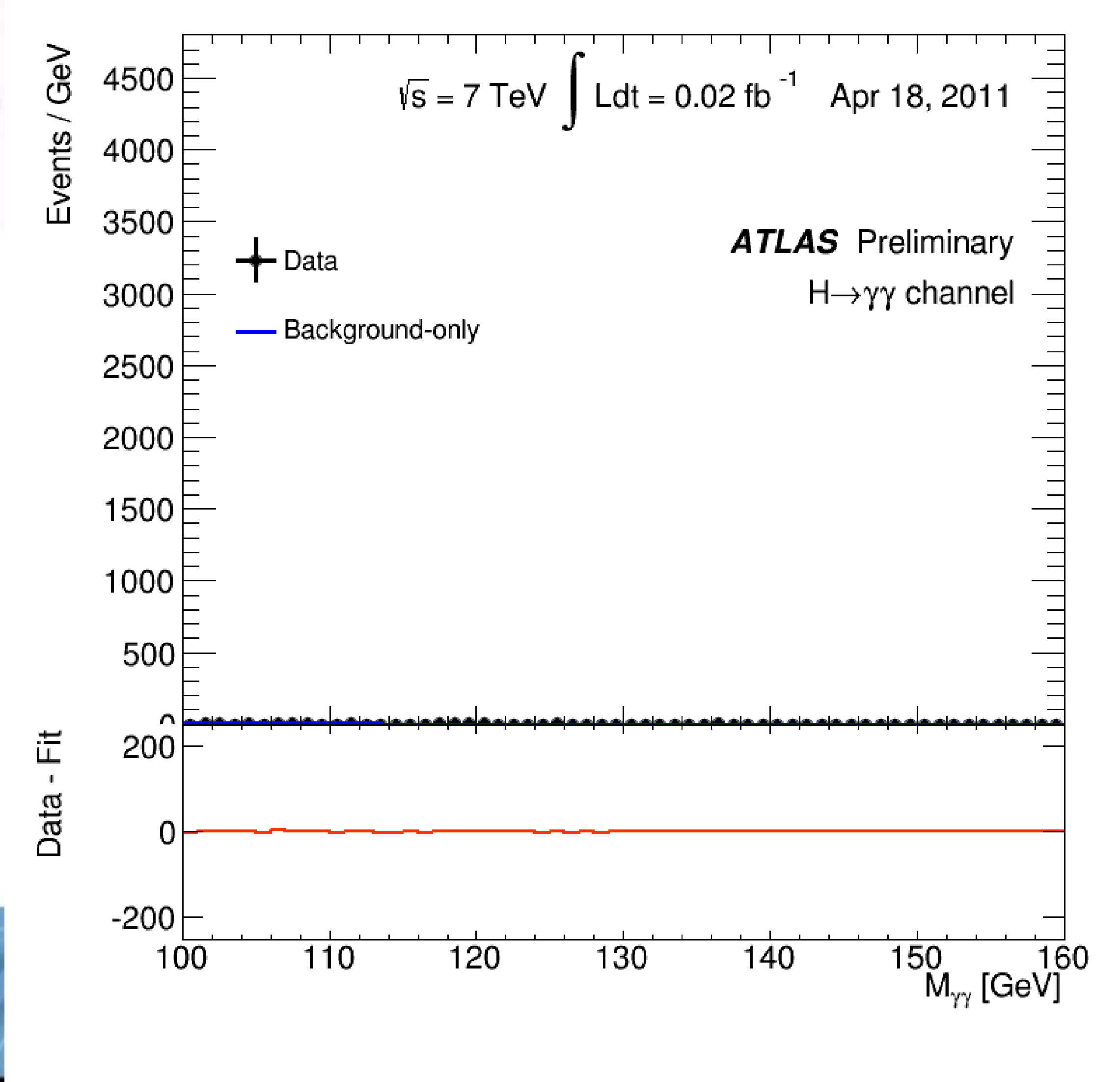
$N = L \times \sigma$ (pp) $\approx$ 10^9 interactions/s

Mostly soft (low p_T) events

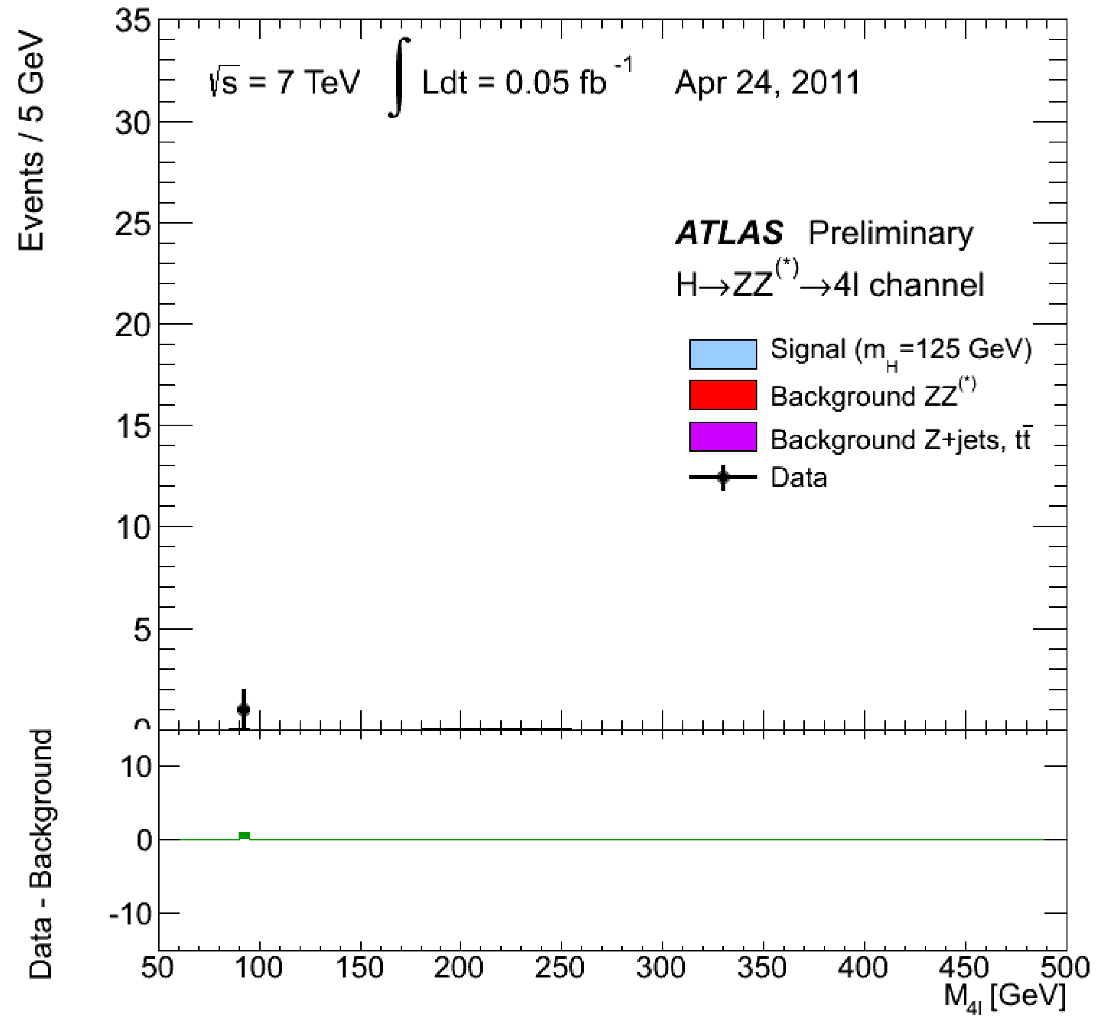
Interesting hard (high-p_T) events are rare

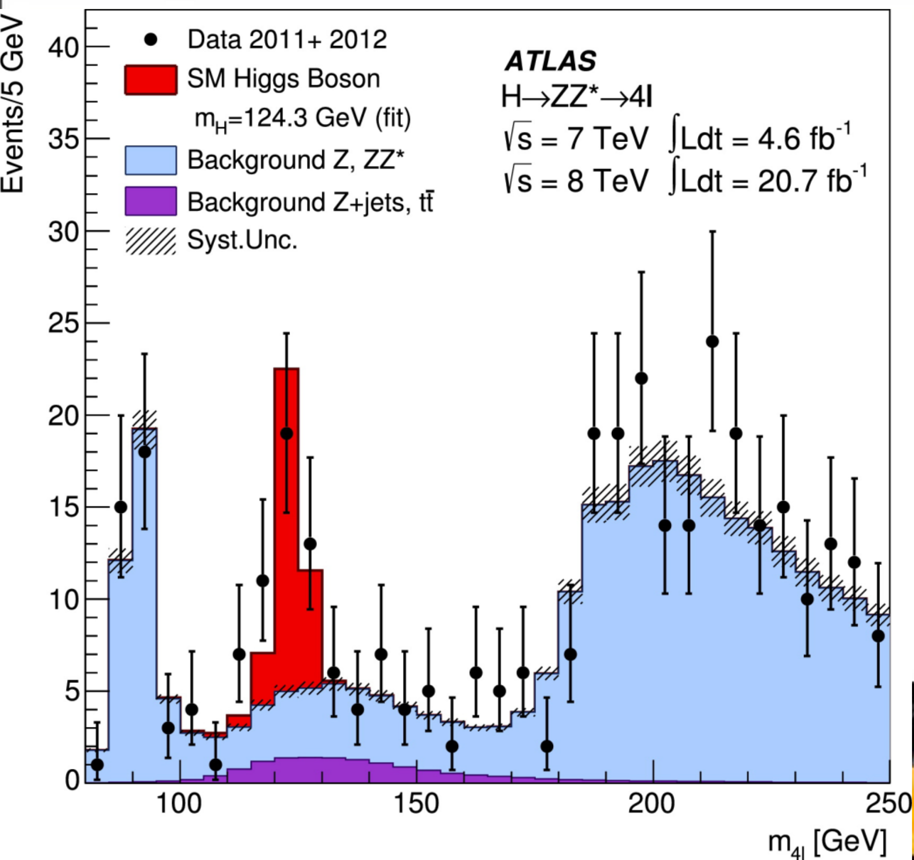
Selection of 1 in 10,000,000,000,000

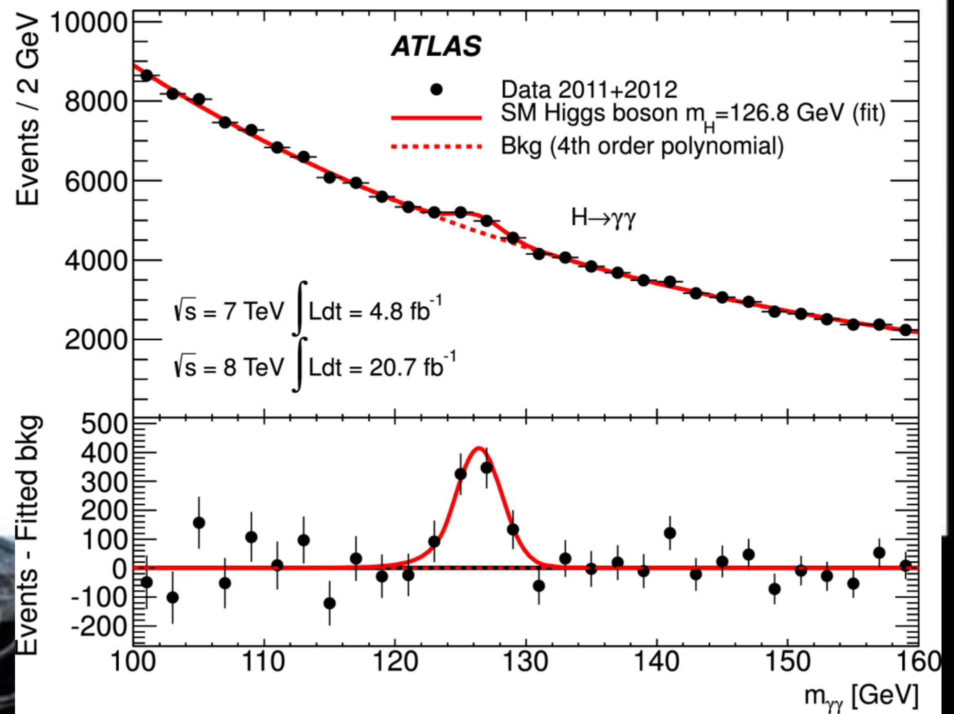
Utvikling av $m_{\gamma\gamma}$ spekter



Tilsvarende for masse til fire leptoner




Events/5 GeV
Data 2011+ 2012
SM Higgs Boson
m_H=124.3 GeV (fit)
Background Z, ZZ*
Background Z+jets, tt̄
Syst.Unc.
ATLAS
H→ZZ*→4l
√s = 7 TeV ∫Ldt = 4.6 fb⁻¹
√s = 8 TeV ∫Ldt = 20.7 fb⁻¹
m_4l [GeV]


Events / 2 GeV
ATLAS
Data 2011+2012
SM Higgs boson m_H=126.8 GeV (fit)
Bkg (4th order polynomial)
H→γγ
√s = 7 TeV ∫Ldt = 4.8 fb⁻¹
√s = 8 TeV ∫Ldt = 20.7 fb⁻¹
Events - Fitted bkg
m_γγ [GeV]


En stor suksess!!!
Matter
Atom
Electron
Proton
Quarks
Nucleus
Neutron
Matter particles
All ordinary particles belong to this group
These particles existed just after the Big Bang. Now they are found only in cosmic rays and accelerators
LEPTONS
QUARKS
FIRST FAMILY
SECOND FAMILY
THIRD FAMILY
Electron
Responsible for electricity and chemical reactions; it has a charge of -1
Electron neutrino
Particle with no electric charge, and possibly no mass; billions fly through your body every second
Up
Has an electric charge of plus two-thirds; protons contain two, neutrons contain one
Down
Has an electric charge of minus one-third; protons contain one, neutrons contain two
Muon
A heavier relative of the electron; it lives for two-millionths of a second
Muon neutrino
Created along with muons when some particles decay
Charm
A heavier relative of the up; found in 1974
Strange
A heavier relative of the down; found in 1964
Tau
Heavier still; it is extremely unstable. It was discovered in 1975
Tau neutrino
not yet discovered but believed to exist
Top
Heavier still
Bottom
Heavier still; measuring bottom quarks is an important test of electroweak theory
Force particles
These particles transmit the four fundamental forces of nature although gravitons have so far not been discovered
Gluons
Carriers of the strong force between quarks
Felt by: quarks
The explosive release of nuclear energy is the result of the strong force
Photons
Particles that make up light; they carry the electromagnetic force
Felt by: quarks and charged leptons
Electricity, magnetism and chemistry are all the results of electro-magnetic force
Intermediate vector bosons
Carriers of the weak force
W⁻
W⁺
Z⁰
Felt by: quarks and leptons
Some forms of radio-activity are the result of the weak force
Gravitons
Carriers of gravity
Felt by: all particles with mass
All the weight we experience is the result of the gravitational force

Ubesvarte spørsmål

- Mekanismen for å gi partiklene masse er bekreftet, men vi må studere higgspartikkelen.
- S.M. kan ikke forutsi verdier av massene.
- Hvorfor er elektron og protonladningene like?
- Hvorfor ingen antipartikler i universet? (CP-bruddet vi observerer er for lite til å forklare)
- Kan vi få med gravitasjon i en enhetlig teori?
- Hva består den mørk materien i universet av?
- Hvordan kan vi forklare universets ekspansjonshastighet?