Experimental verification of the Salaam-Weinberg model

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Experimental Particle Physics Student Seminar

Contents

- Theoretical considerations
- Discovery of W and Z bosons (and some properties of hadron colliders)
- Precision mesurements of Z
- Higgs production

Fermi theory

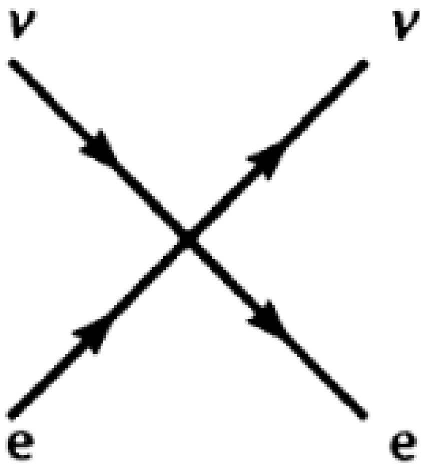
- Four fermion interaction
- Most effects can be included: GIM mechanism, neutral currents etc.
- With these included, it describes known decays quantitatively well at low energies
- But it’s high energy behaviour is flawed.

Renormalisability

- QED: infinities in amplitudes, but they can be absorbed into a redefinition of the bare quantities
- A theory is renormalisable, if at the cost of introducing a finite number of paramaters the predicted ampiltudes remain finite at high energies and all order of pertubation theory.
- Fermi's theory is nonrenormalisable

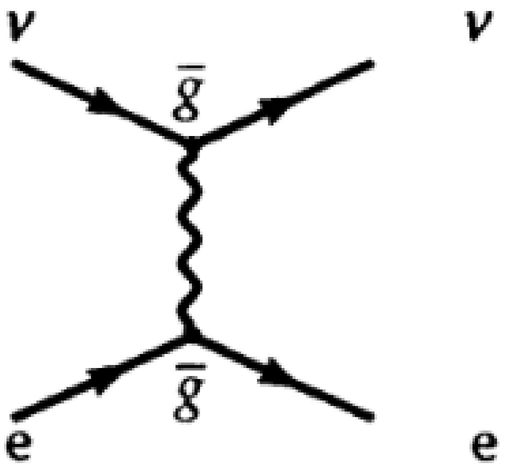
The solution

a)



$\Rightarrow$

b)



$G_F \sim 10^{-5}\mathrm{GeV}^{-2}$

g^2/M_W^2

The solution

- QED renormalisability needs a massless vector boson
- To get the Fermi theory as a low energy limit, we need massive vector bosons
- The solution to this is the Higgs-mechanism, in which the bosons gain a mass by coupling to a scalar field with nonzero vacuum expectation value

Discovery of Intermediate Bosons 1.

- 1977 Carlo Rubbia suggested converting the super proton synchrotron(SPS) into a proton-antiproton storage ring
- Total energy of colliding particles as 540GeV
- Approx. half of this momentum was carried by gluons
- The remaining half remaining to the 3 constituent quarks, so we can get 540/6=90GeV per $q\underline{q}$ collision

Parton Distribution Functions

Feynman -> Parton model

QCD -> Partons = quarks and gluons

Def.: $f_u(x)$: Probability of finding an u quark ith momentum fraction x

Valence and sea partons

For a proton: $\int (f_u(x)-f_{\underline{u}}(x))dx=2$

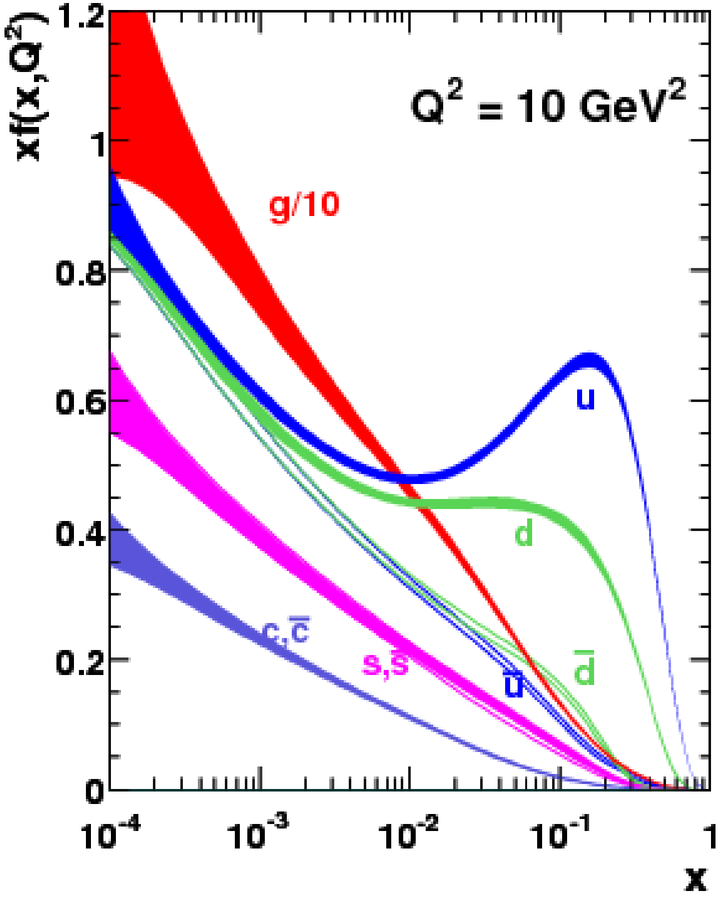
$\int \ (f_d(x)-f_{\underline{d}}(x))\ dx=1$

$\int xf_g(x)dx \approx ½$ is what i said on the previous slide

This in nonpertubative info that we can’t compute, we know it from analysis of DIS data

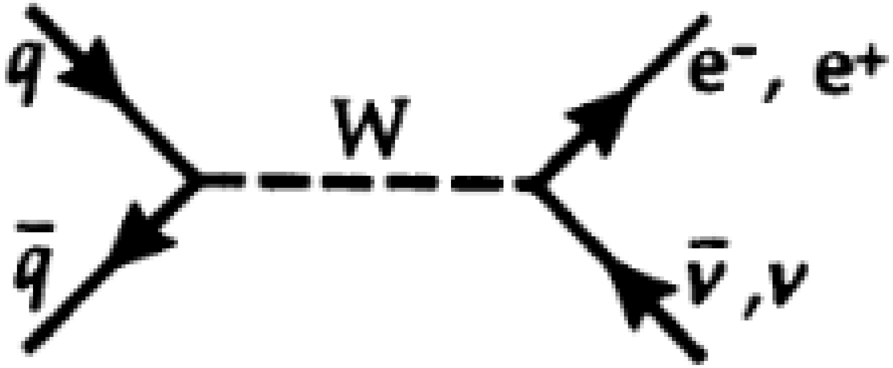
pQCD: phenomenology connecting diffetent observations (DIS, lepton colliders, hadron colliders) in a way consistent with QCD

MSTW2008


xf(x,Q²)
Q² = 10 GeV²
g/10
u
d
d̄
ū
s,s̄
c,c̄
1.2
1
0.8
0.6
0.4
0.2
0
10⁻⁴
10⁻³
10⁻²
10⁻¹
1
x

Discovery of Intermediate Bosons 2.

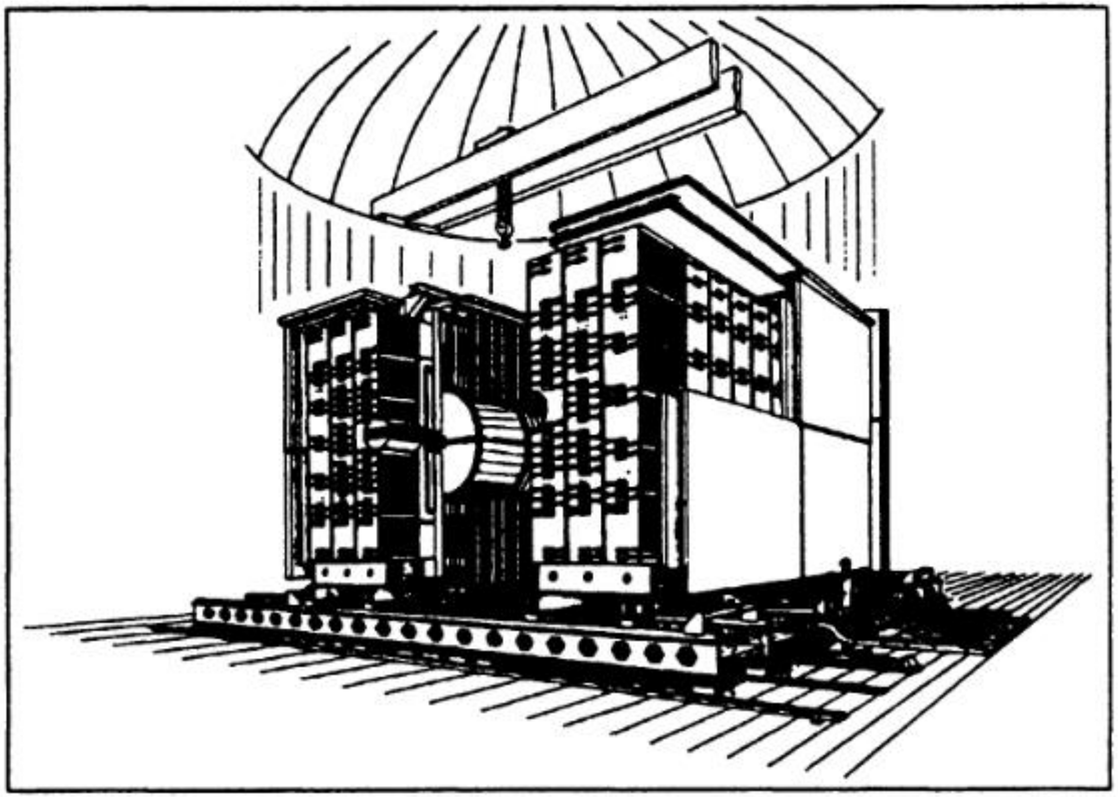
- About 90GeV per $q\underline{q}$ collision
- The mass of W and Z was predicted to be about 80-90GeV, so in theory it is possible to see a W decay:



Stochastic cooling

- The realisation of the pp storage ring was made possible by stochastic cooling(S. van der Meer)
- Stochastic cooling is used to reduce the transverse momentum spread within a bunch of charged particles in a storage ring by detecting fluctuations in the momentum of the bunches and applying a correction with and electro-magnet(negative feedback).
- Thermodynamic cooling

The UA1 detector



From center outwards: Collision point – Central detector, Drift chambers – EM calorimeter(alternate layers of heavy material and scintillators) – hadronic calorimater – drift chambers detecting muons

Discovery of Intermediate Boson 3.

- Since neutrinos cannot be detected, it is important to mesure electron and hadron energies accurately, so nearly full solid angle calirometer range is essential
- No calorimeters could be installed in a range of 0,2° from the beam direction, this could distort the momentum balance
- But, the only events of interest were events with high pT electrons, so they restricted the search to events where 2 adjacent cells of the EM calorimeter detected a particle at an angle larger then 5°.
- 3 weeks beam time -> 140 000 such events

Discovery of Intermediate Bosons 4.

- Further selection criteria were introduced
- pT>15GeV, angle to beam axis>25° in to adjacent EM calorimeter cells with the central detector showing a track of pT>7GeV in the direction of the hits in the calorimeter, 1106 events
- The momenta of other tracks pointing to the same cell in the calorimeter <2GeV, 276 events
- The direction of the transverse momentum in the calorimeter should match the direction of the trackin the central detector, 167 events left

Discovery of Intermediate Bosons 5.

- To exclude hadrons as a source of the track, energy mesured in the hadronic calorimeter <600MeV, 72 events left
- Energy mesured in calorimeter should agree with the momentum mesured in the central detector, 39 events left

Discovery of Intermediate Bosons 6.

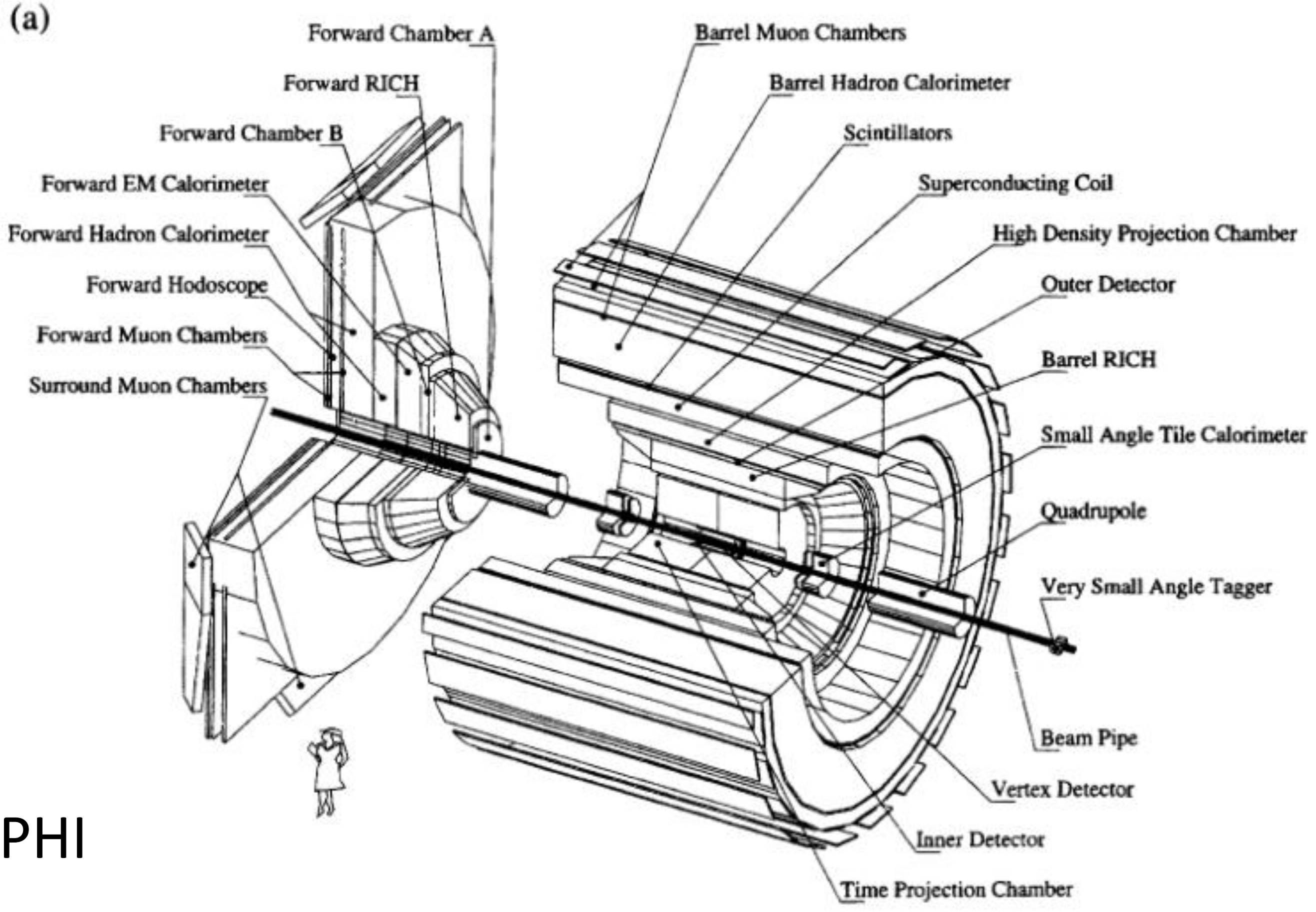
- Out of the 39 events
  - 11 looked like electron track + a hadronic jet in the opposite, no good, could be 2 jets
  - 23 events, two hadronic jets, electron was part of one, or events with Dalitz decay $\pi^0 \rightarrow \gamma + e^+ + e^-$
  - For these 34 events momentum balance was OK
  - 5 events, no hadronic jets, momentum balance not OK → neutrino, these were W→νe events, they fitted to

$$M_W = 81 +/- 5\text{GeV}$$

Discovery of Intermediate Bosons 7.

- The Z was dicovered with the same technique but now searching for a Z $\rightarrow e^+e^-$ decay, i.e. an opposite e^+ and e^- track, these are rare in $p\underline{p}$ collisions, but they found 1 event with an extracted M_Z=91GeV
- 1984 Nobel Prize: Carlo Rubbia, Simon van der Meer

Precision mesurements at LEP



DELPHI

$e^+e^- \rightarrow Z \rightarrow$ anything

$$\sigma = \frac{4\pi \lambda\!\!\!^{-2}(2J+1)}{(2s+1)^2} \frac{\Gamma_e \Gamma/4}{[(E-E_0)^2 + \Gamma^2/4]}$$

Relativistic Breit-Wigner formula, $E_0 = M_Z$
$e^+e^- \rightarrow$ virtual $\gamma \rightarrow$ anything neglected

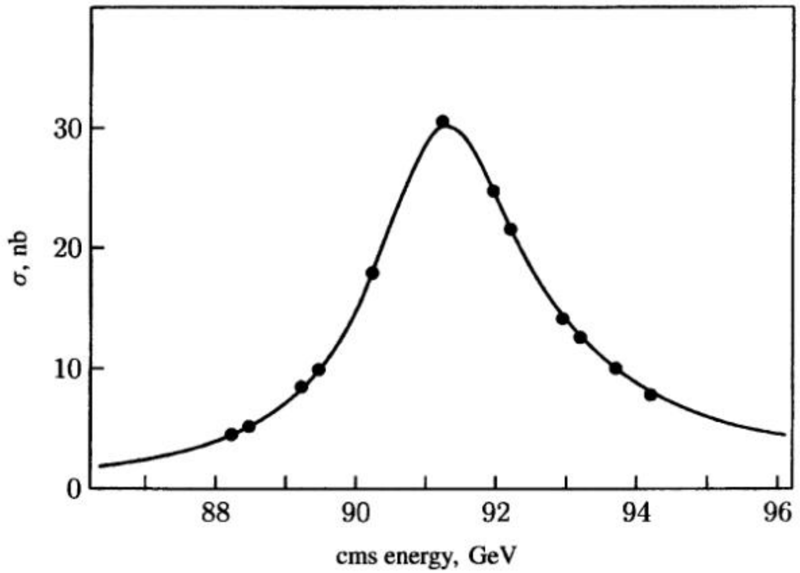


Fig. 7.15. The cross-section $\sigma(e^+e^- \rightarrow Z^0 \rightarrow \text{hadrons})$, as a function of the cms beam energy, compounded from CERN and SLAC data. The curve is the best-fit Breit–Wigner distribution and includes the effects of radiative corrections, which distort the otherwise symmetric distribution.

Total width

- The total width and the hadronic and leptonic partial widths can be determined from experiment
- The neutrino partial width was determined theoretically
- $(\Gamma_{total}- \Gamma_{hadronic}-3\Gamma_{e\underline{e}})/\Gamma_{\nu\underline{\nu}}$ = 3 light neutrino species

Data VS Theory

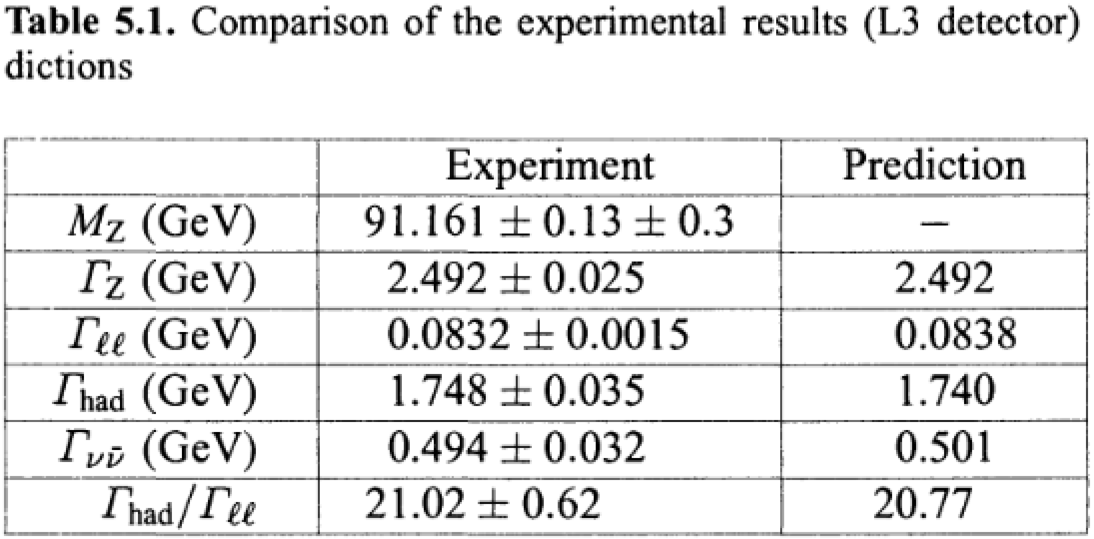
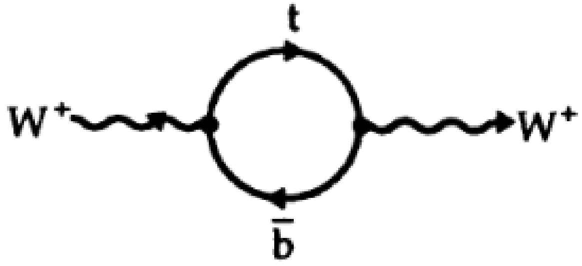
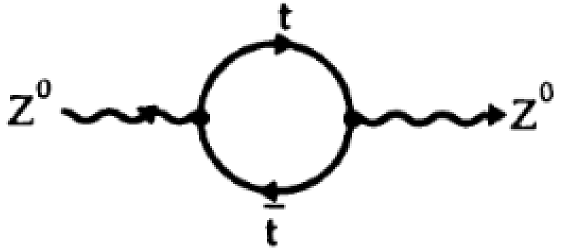


Table 5.1. Comparison of the experimental results (L3 detector) with standard model predictions

	Experiment	Prediction
M_Z (GeV)	$91.161 \pm 0.13 \pm 0.3$	–
Γ_Z (GeV)	2.492 ± 0.025	2.492
$\Gamma_{\ell\ell}$ (GeV)	0.0832 ± 0.0015	0.0838
Γ_{had} (GeV)	1.748 ± 0.035	1.740
$\Gamma_{\nu\bar{\nu}}$ (GeV)	0.494 ± 0.032	0.501
$\Gamma_{\text{had}}/\Gamma_{\ell\ell}$	21.02 ± 0.62	20.77



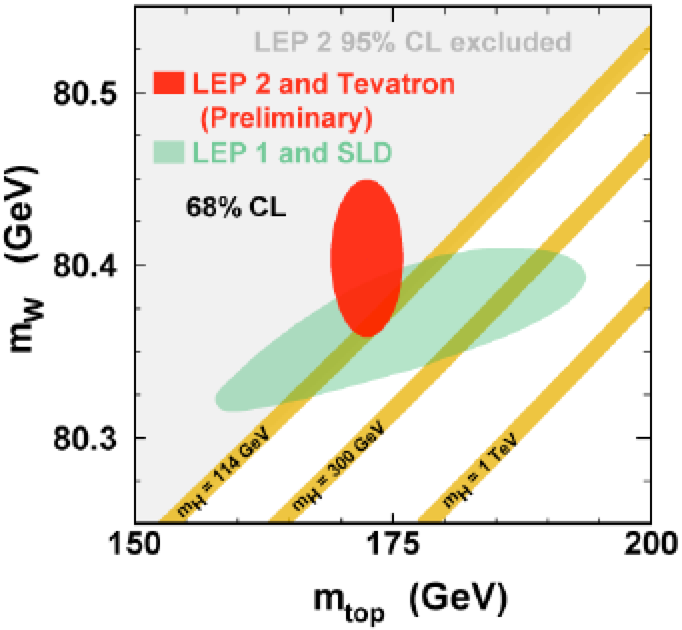
Top mass



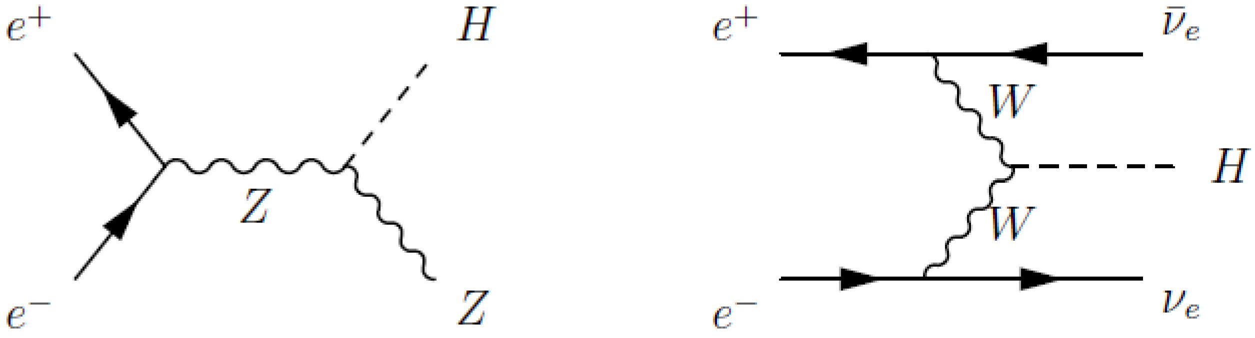
- The then undetected top quark gives higher order corrections to the W boson propagator (mass)
- The top quark mass enters the propagator in different ways, so M_W/M_Z is strongly dependepnt on it
- LEP: m_t<200GeV most likely about 150GeV
- TEVATRON: mesured m_t=172GeV

Higgs

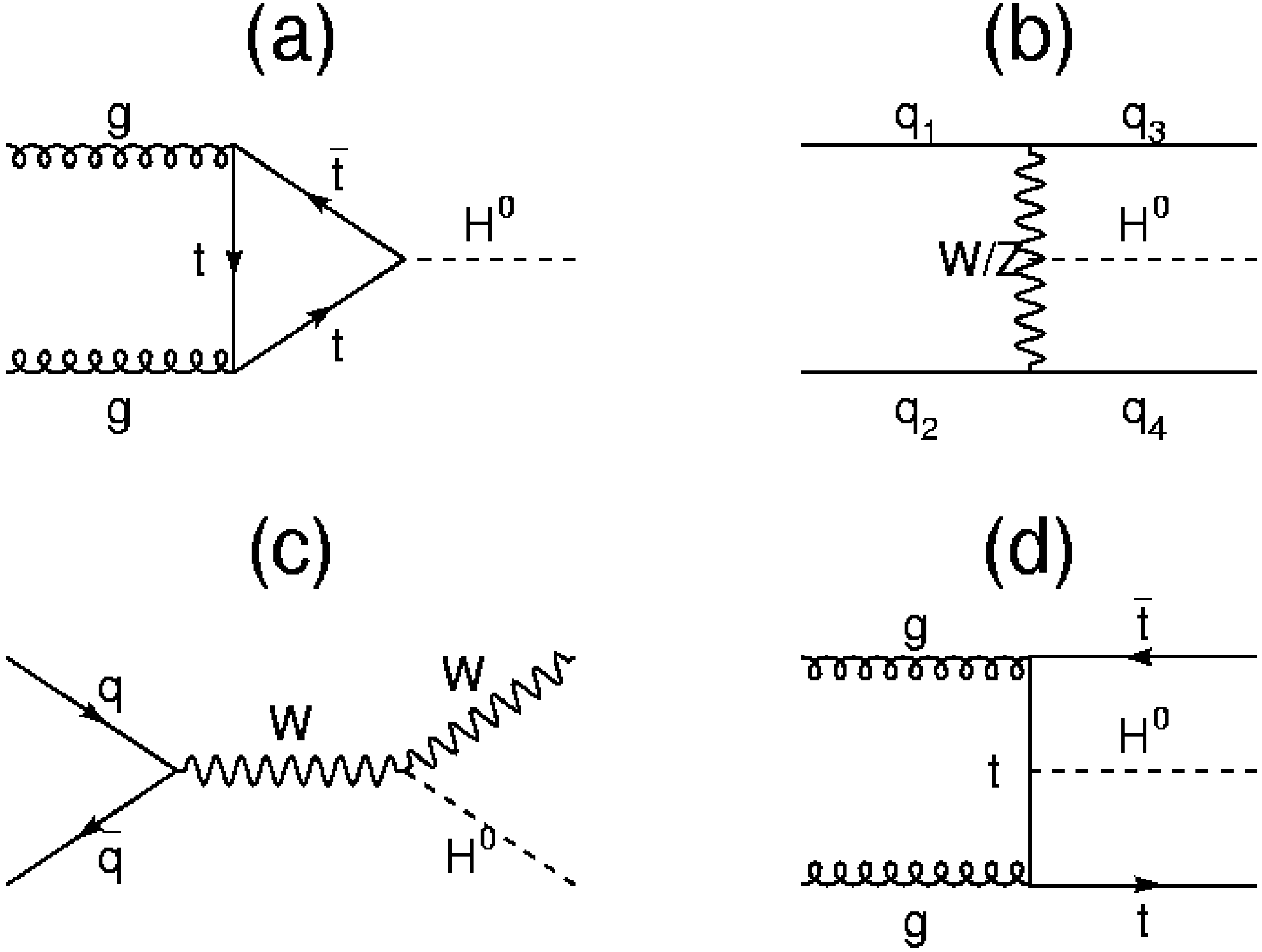
- Direct searches to be dicussed later
- Loop corrections vary as m_t^2 but $\log(m_H)$ so the limit for the Higgs mass is not that good



Higgs production at lepton colliders



Higgs production at hadron colliders



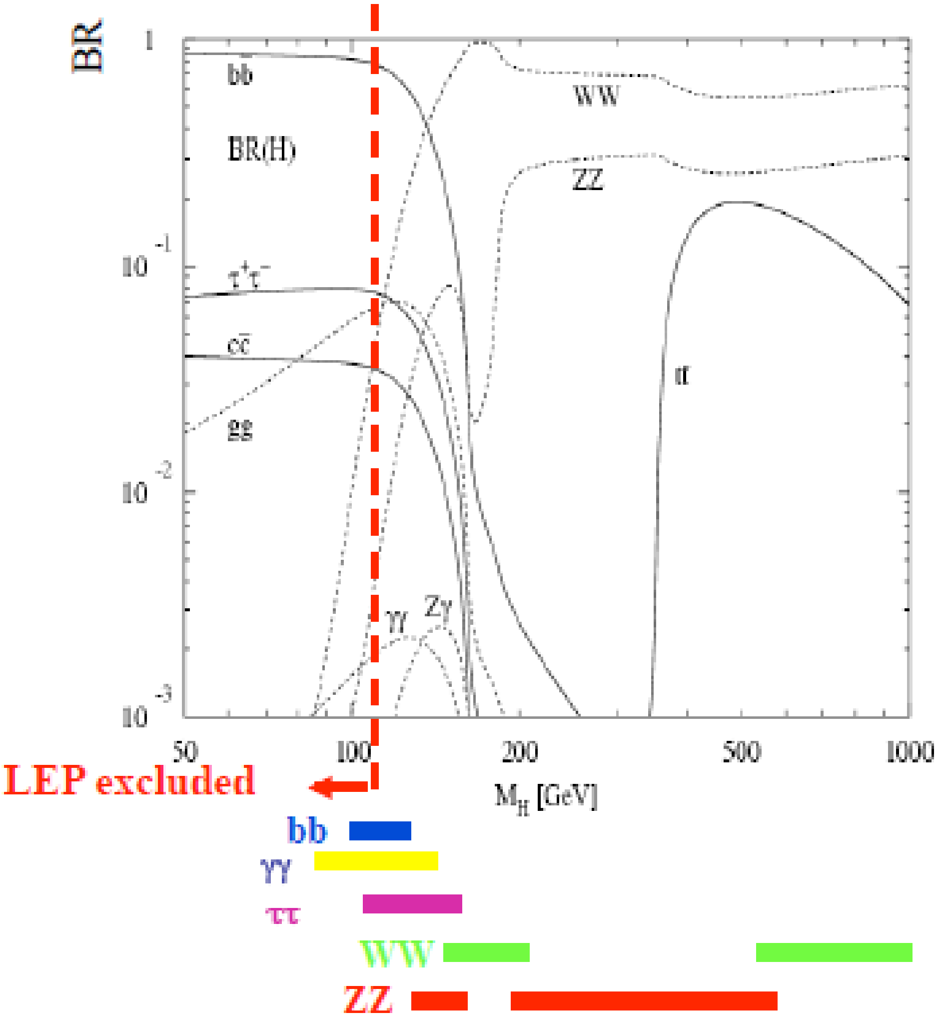
Strongly related program of hadron colliders (LHC)

- W,Z bosons
  - Focus on leptonic decays because of the hadronic background, this is a calibration method
- More precise mesurements m_W vs $m_t$as mentioned before
- Higgs searches

Higgs searches at hadron colliders

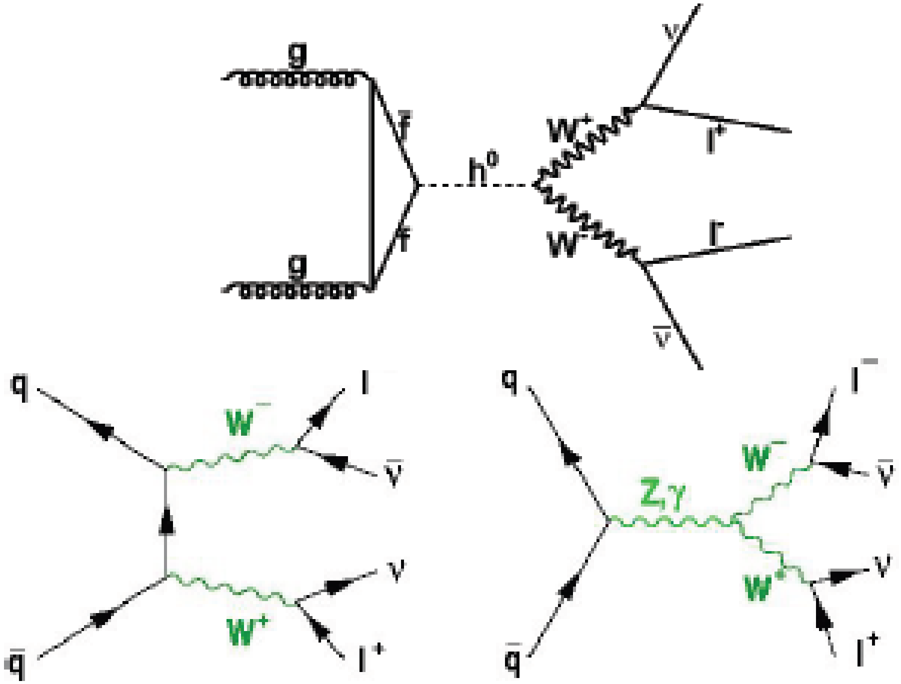
- Either Higgs will be found at LHC or something new happens, since the Higgs prevents unitarity violation of $WW \rightarrow WW$
- To make a discovery one has to show a signal of some decay mode of the Higgs and show that it is inconsistent with being a background, I will show to examples of such decays and their background

Calculated decay branching ratios



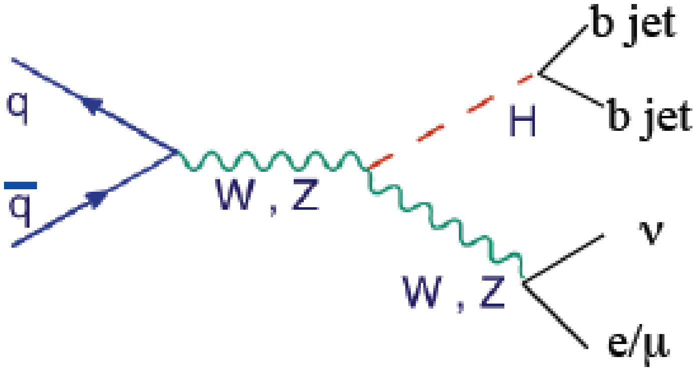
High m_H, $H \rightarrow l^+ l^- \nu \bar{\nu}$

- Impossible to reconstruct Higgs mass because of the neutrinos.
- Use spin correlations to supress background(Higgs is scalar so leptons from Higgs decay are collinear).
- There is a similar decay with $ZZ \rightarrow llll$



Low m_H, Higgs strahlung, $b\underline{b}$ decay

bottom jets, missing energy, high pT electron



High backgrounds (expected signal ~ 1.6, background ~ 110)

Closing remarks

- The SM is consistent with all current data, with the Higgs remaining to be detected
- In case the Higgs doesn’t exist, some other mechanism has to kick in to conserve unitarity
- LHC can mesure in an energy range where something has to happen
- Discovery harder at low mass, because more channels contribute