Top, Higgs, and searches at the Tevatron

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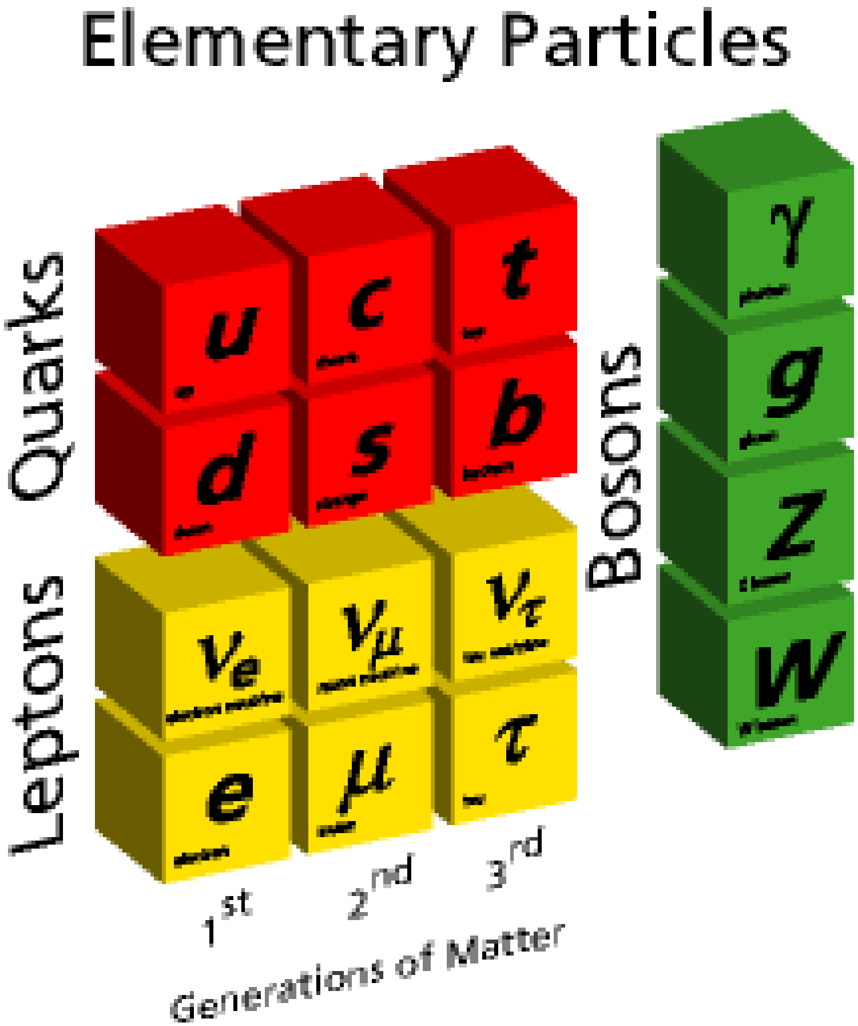
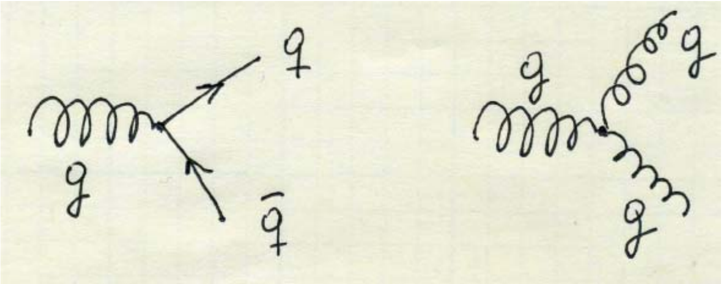
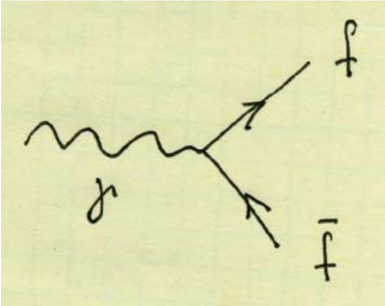
Fermilab

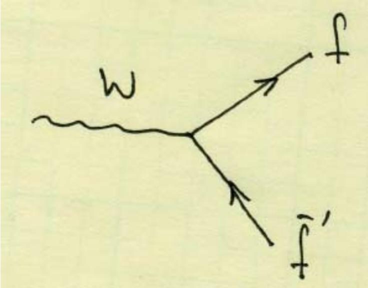
There are big and exciting questions today in physics. Like, what is the origin of dark energy?, what produces dark matter?, how do elementary particles get their masses? ... As an example on how to seek answers for the last two questions I will review three pieces of the Fermilab Tevatron Collider program. They are the top quark mass measurements, and the searches for the Higgs boson and the lightest supersymmetric particle.

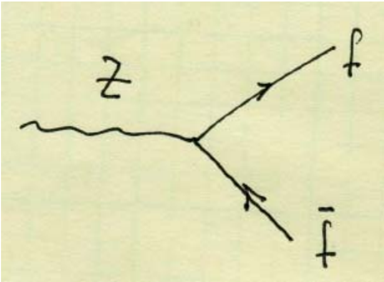
SM particles











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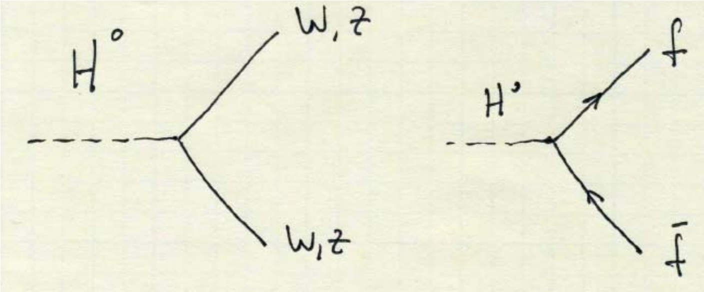
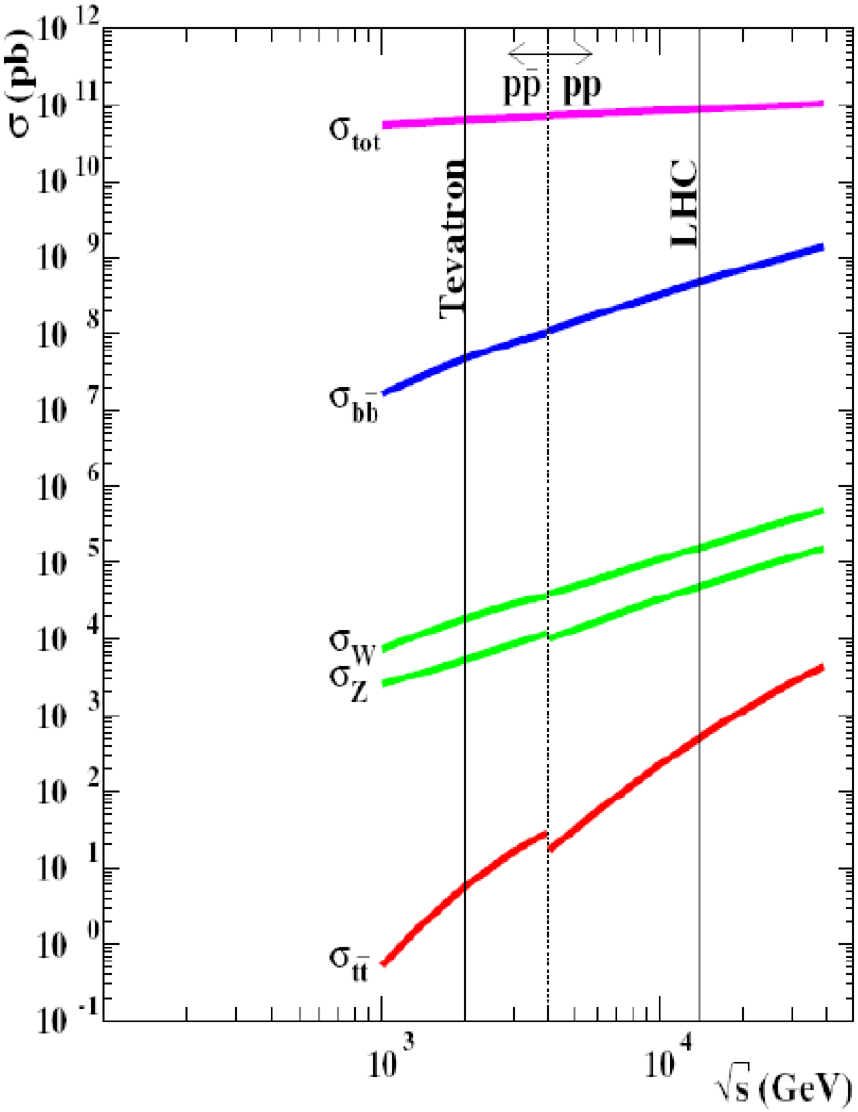
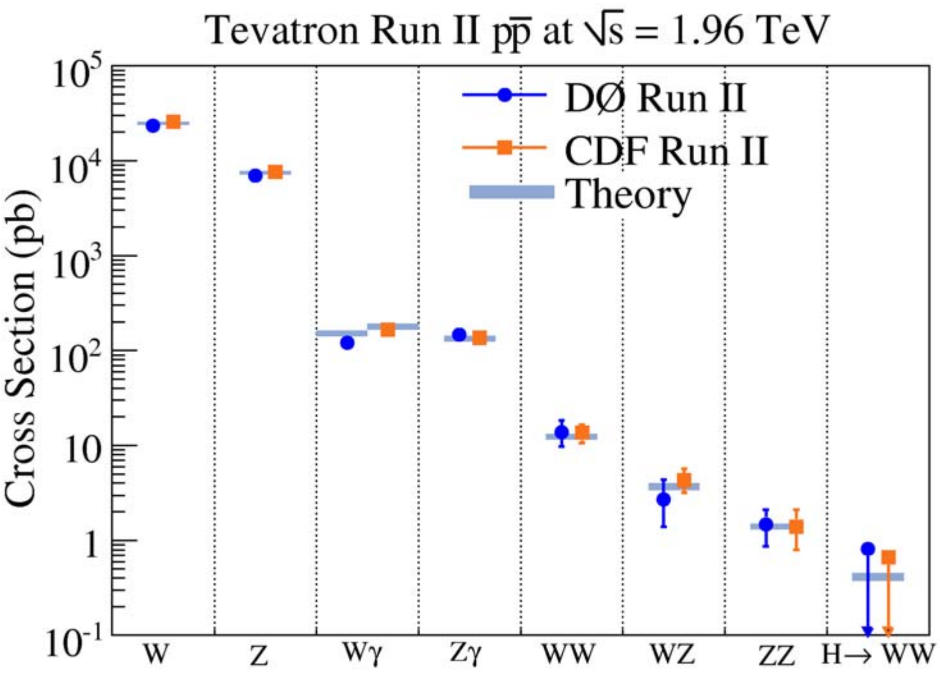


?

Cross section in hadron machines





Fermilab's Tevatron complex

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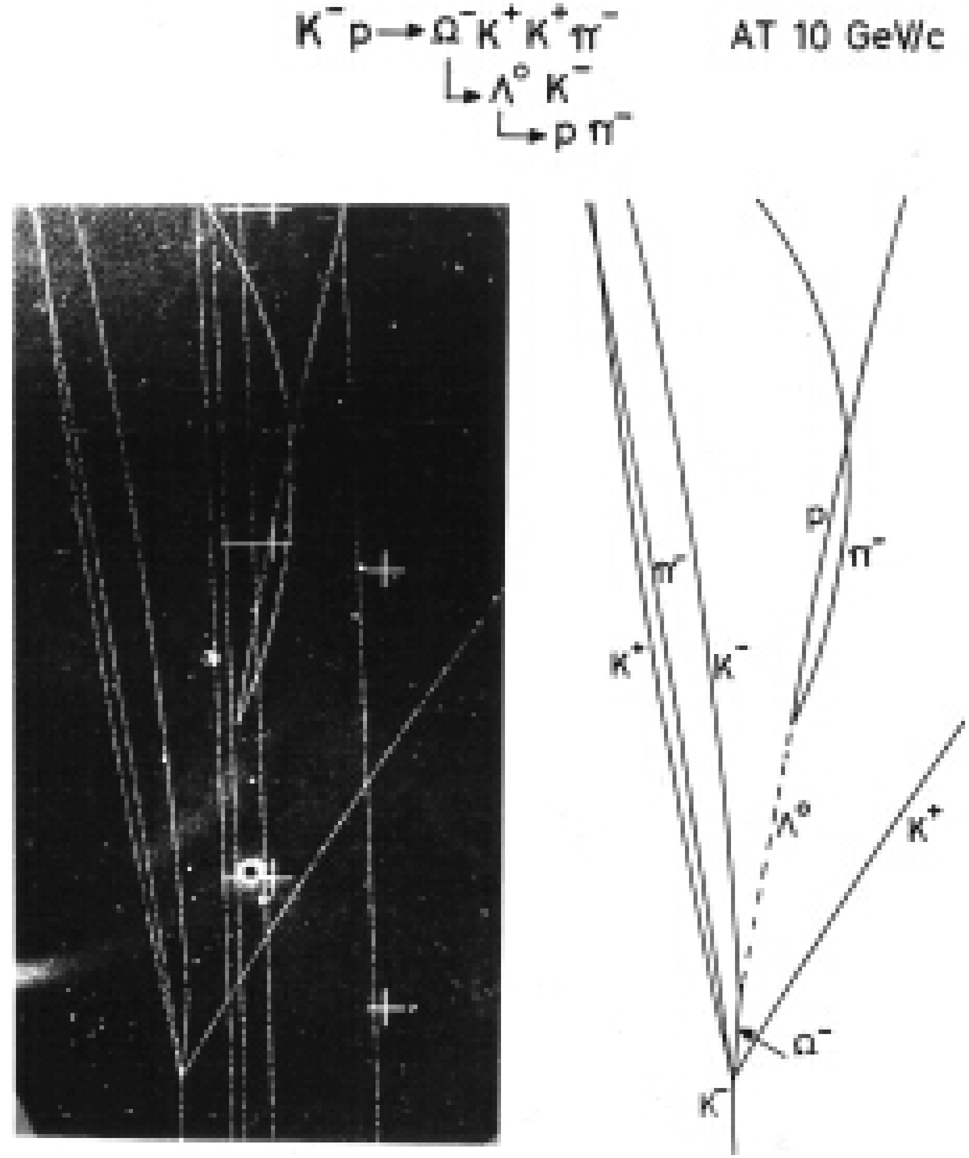
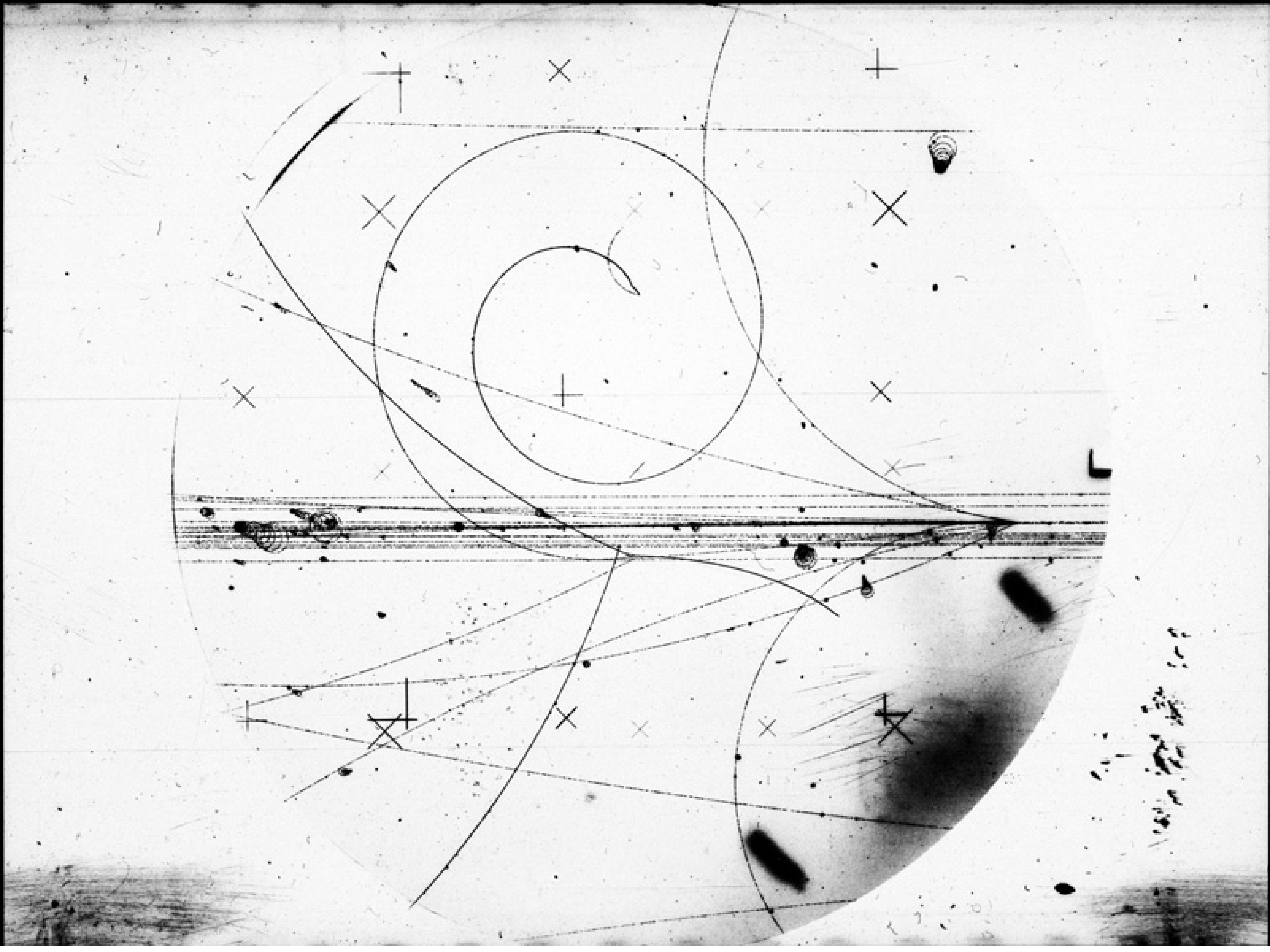
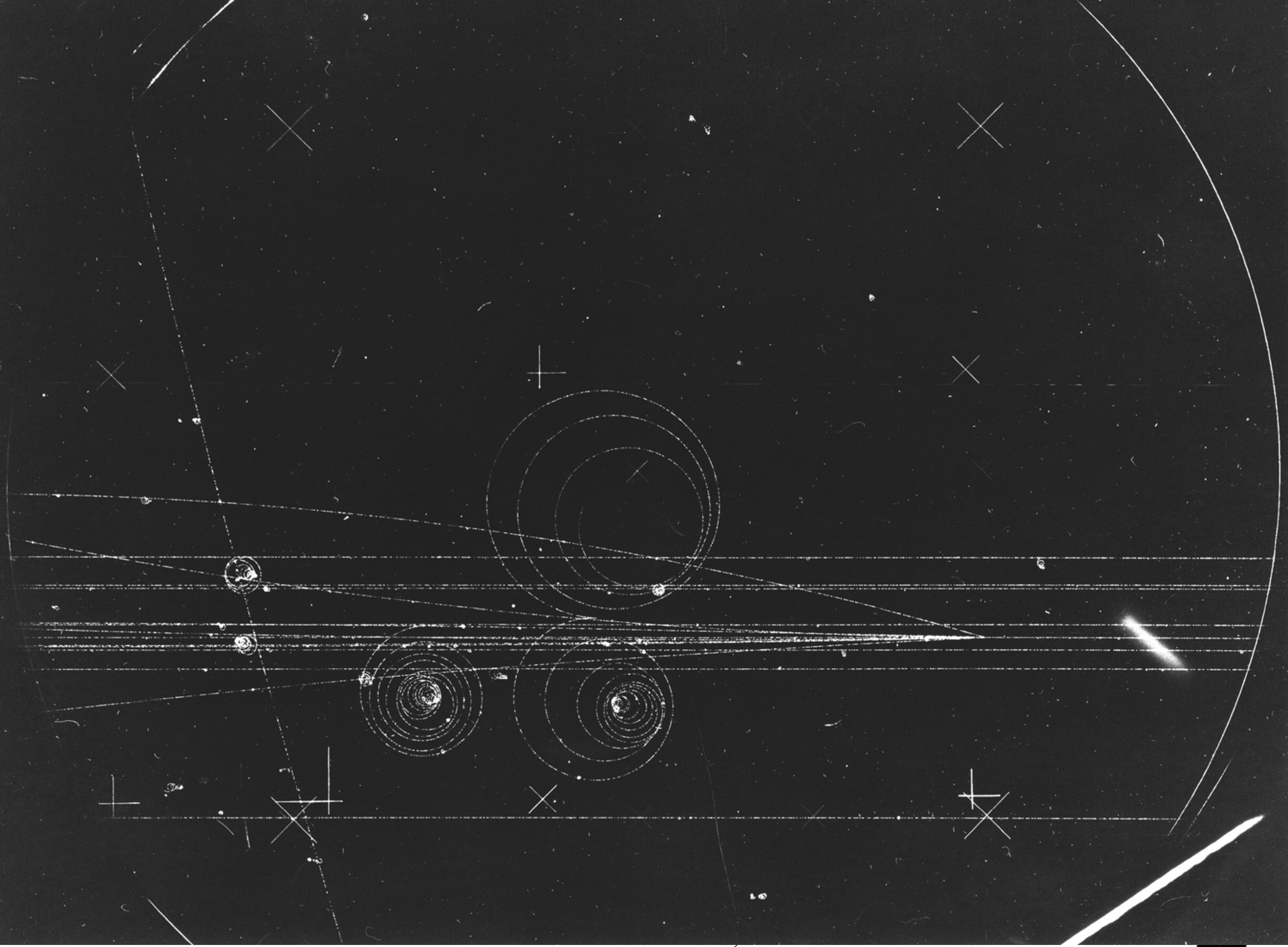
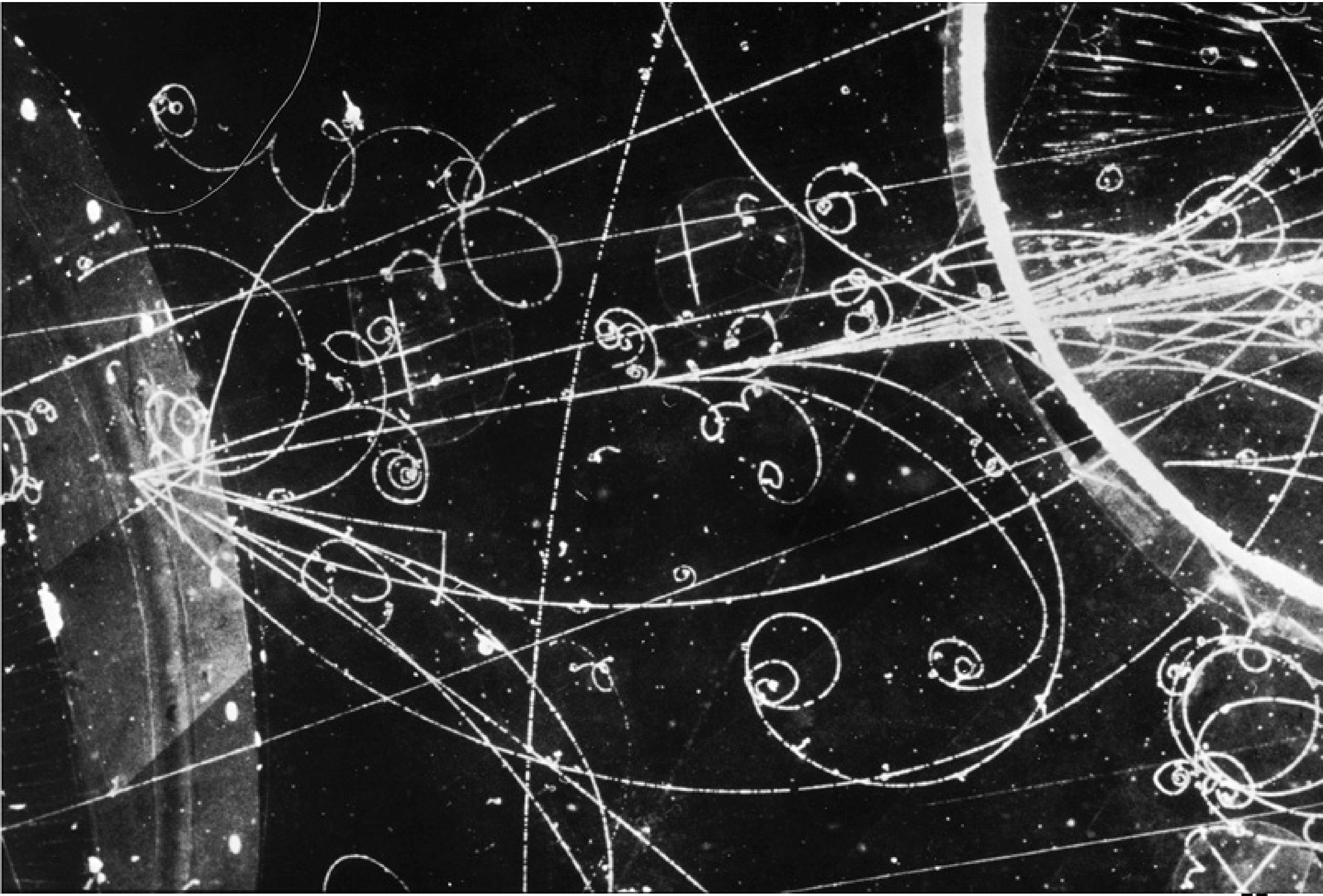
Fermilab’s Tevatron complex

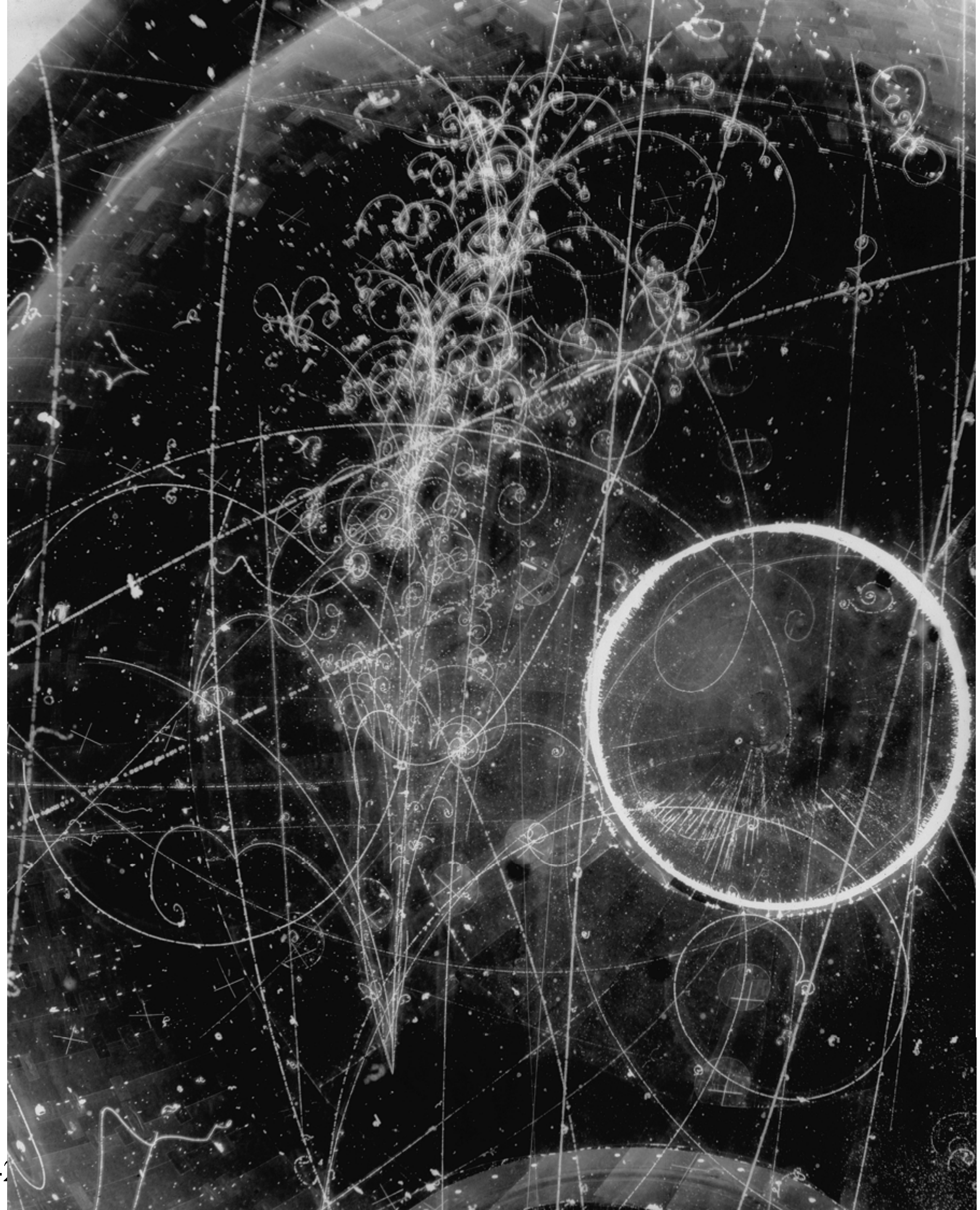
The Ω^- discovery











The detector onion

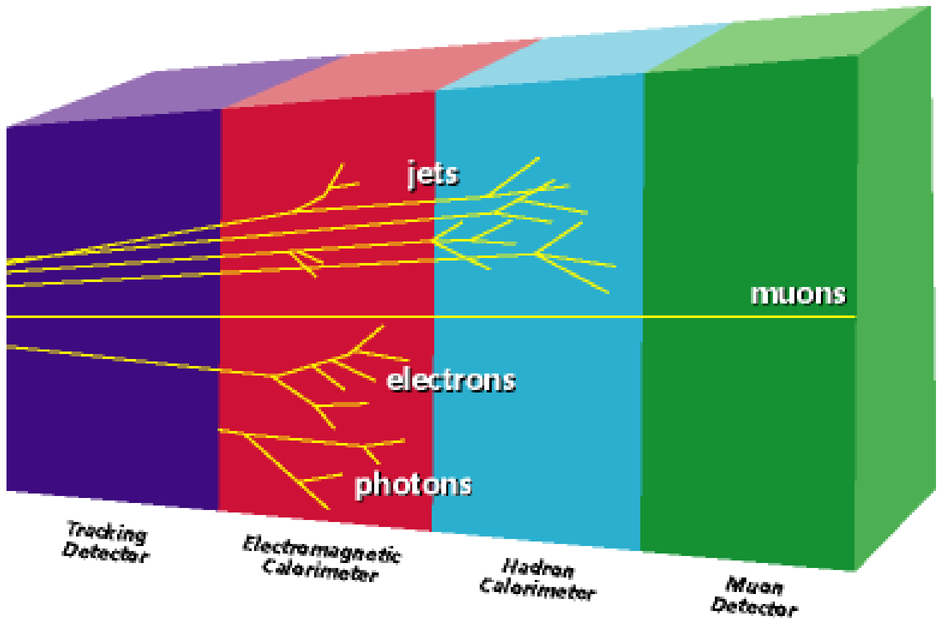
Muons

Convert more particles (energy)

Convert particles in Pb (energy)

Course tracking + field (momentum)

Fine tracking (vertices)

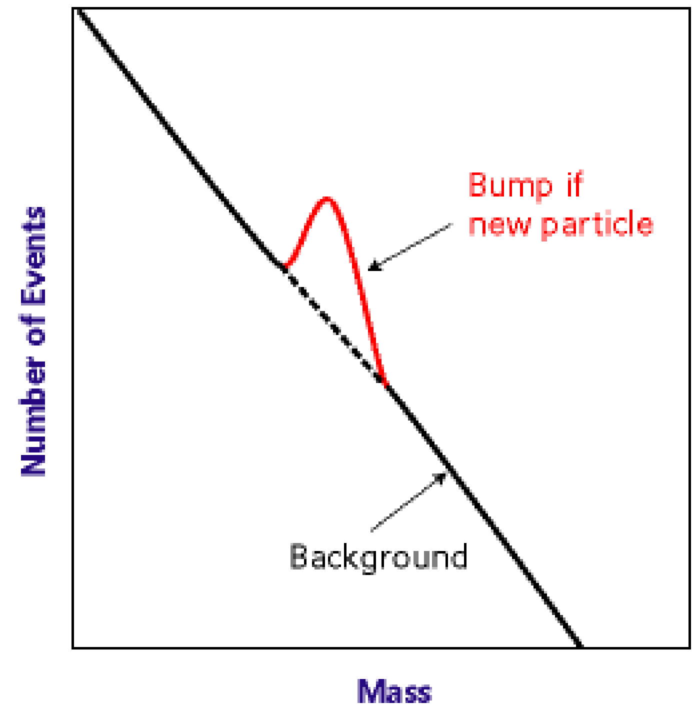


Combining particles

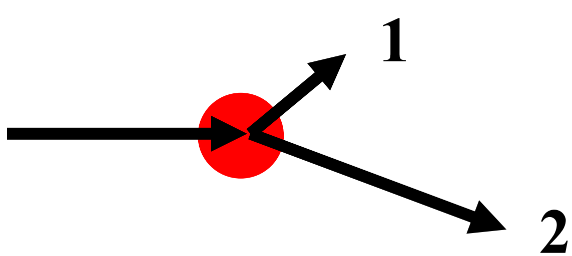
momentum $p = m\,\beta$

energy $E = m$

rest mass $m_0^2 = E^2 - p^2$

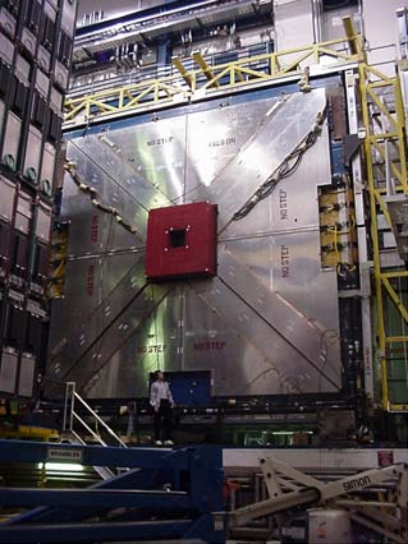


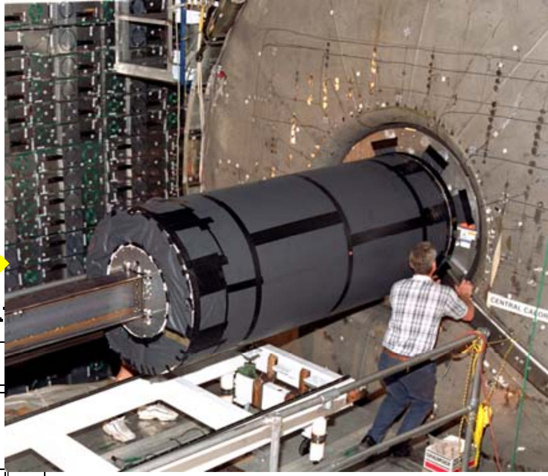
Particle decay



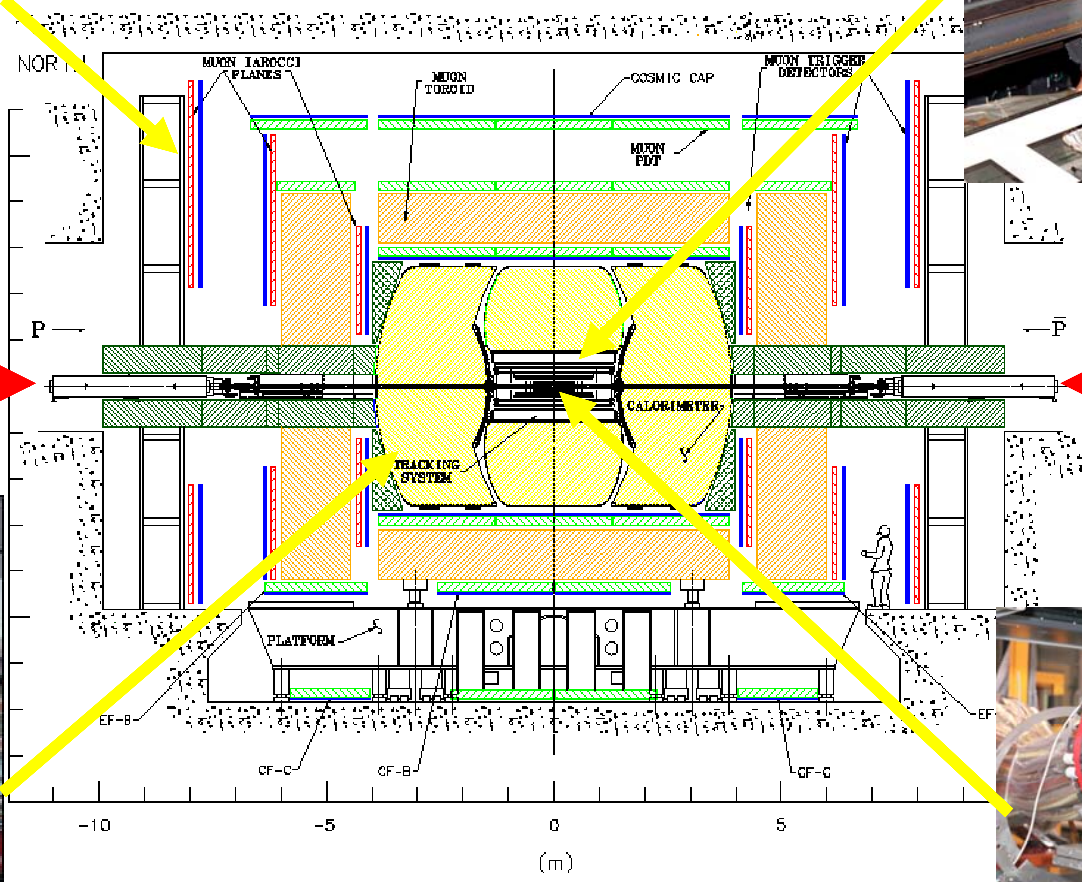
$$E = E_1 + E_2 \quad , \quad \vec{p} = \vec{p}_2 + \vec{p}_2 \quad , \quad M_0^2 = E^2 - \vec{p}^2$$

The D0 detector

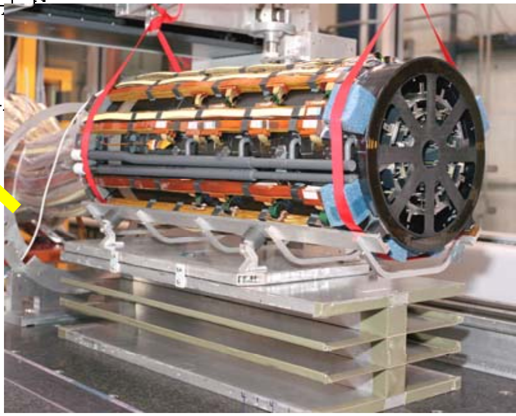




p

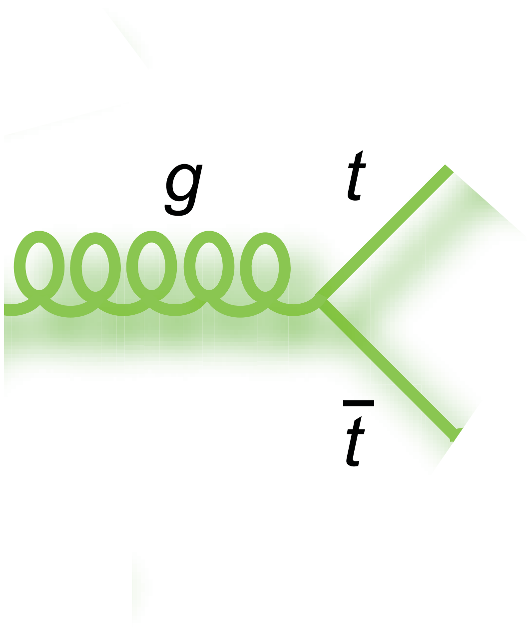


p-bar

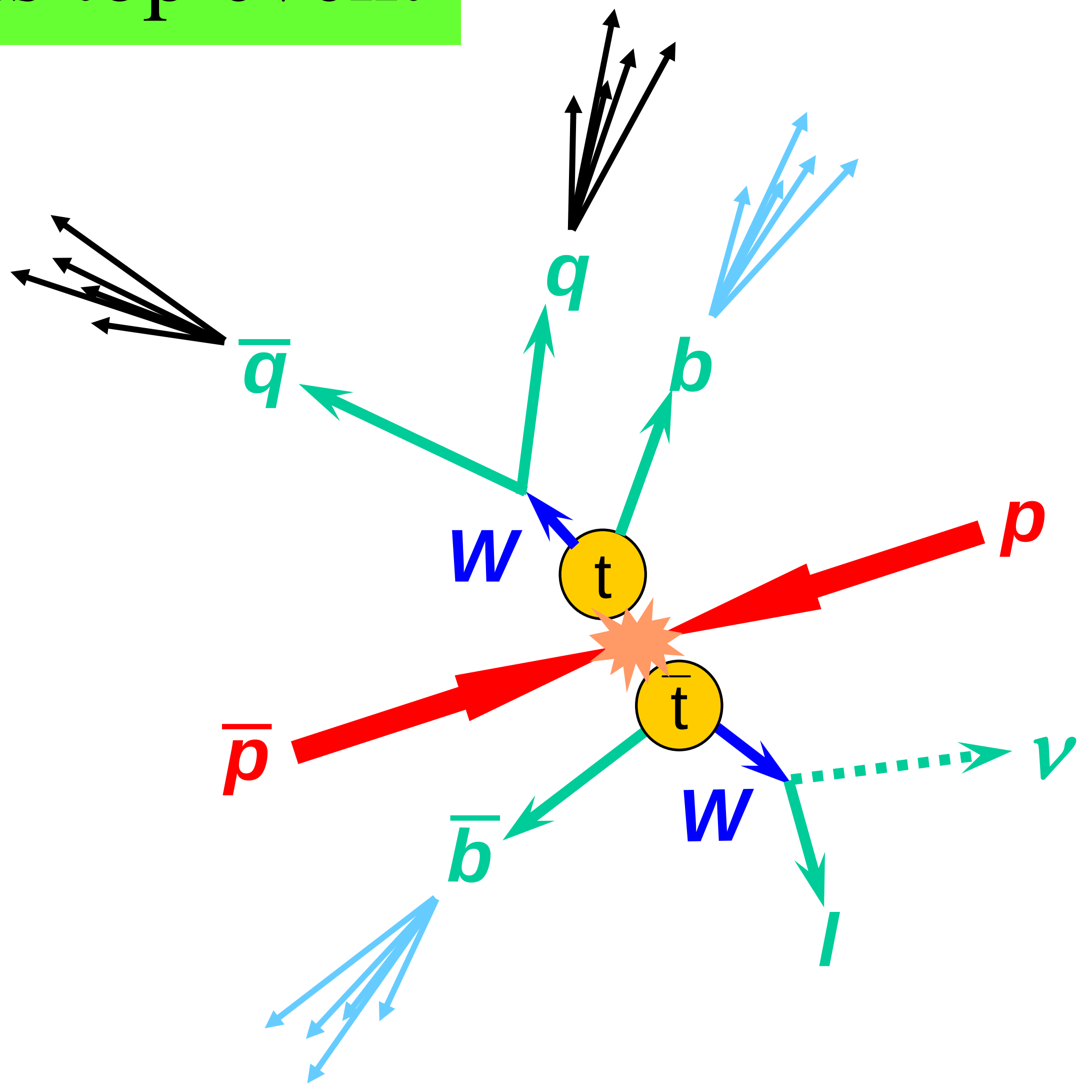


Measuring the top quark mass

Top pair production

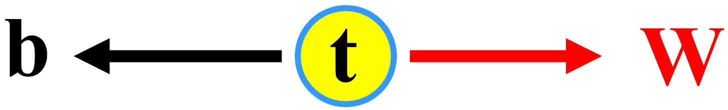


lepton+jets top event



Top and W decay

$M_t = 172\ GeV/c^2$



$p \sim 70\ GeV/c$

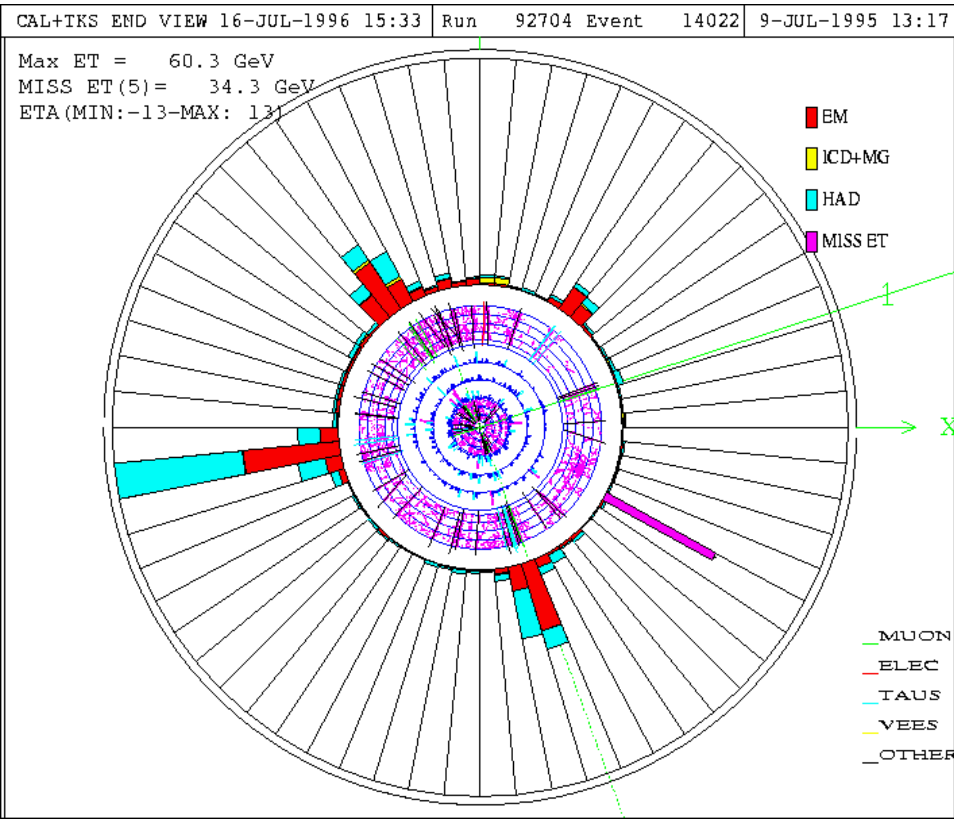
Top decays to W+b essentially 100 % of the time

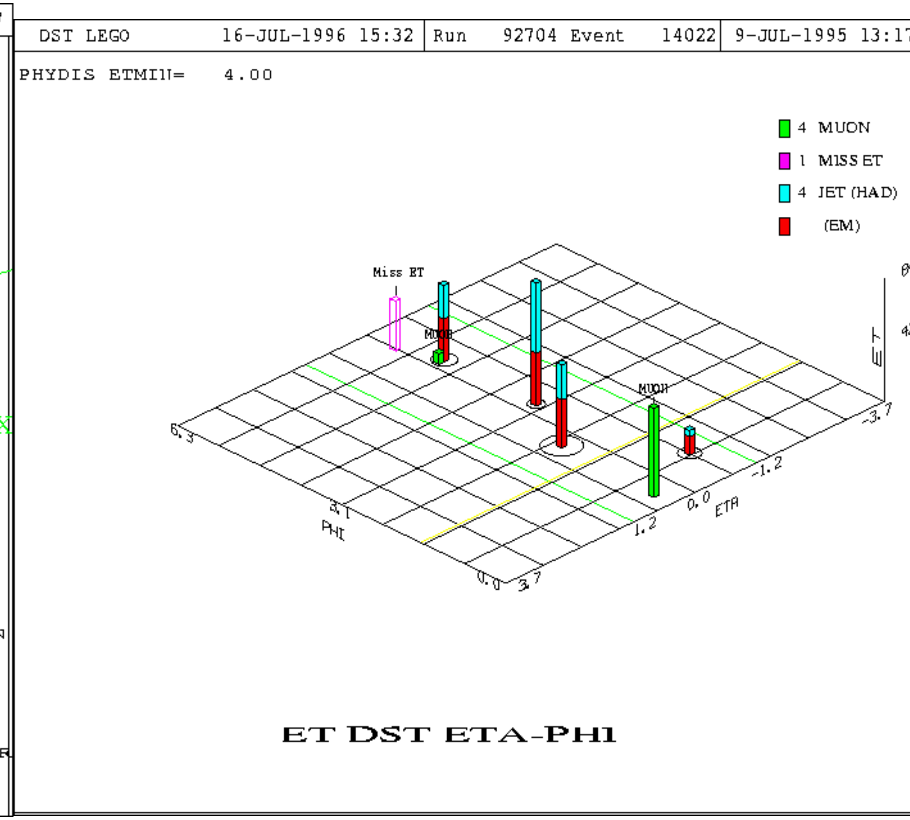
$M_W = 80\ GeV/c^2$

$p = 40\ GeV/c$

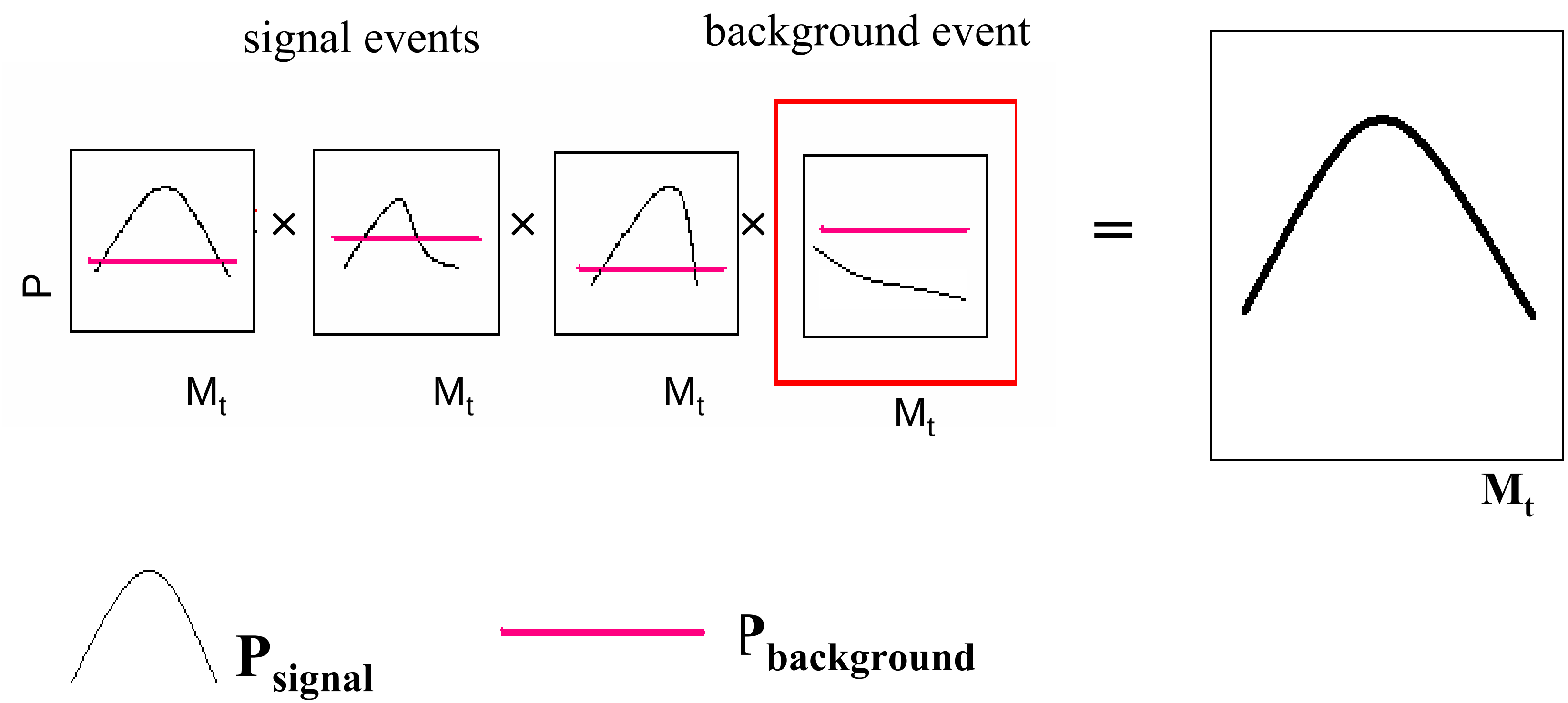
The decay to jets is 3 times more likely than to e and μ

Top discovery event (D0)

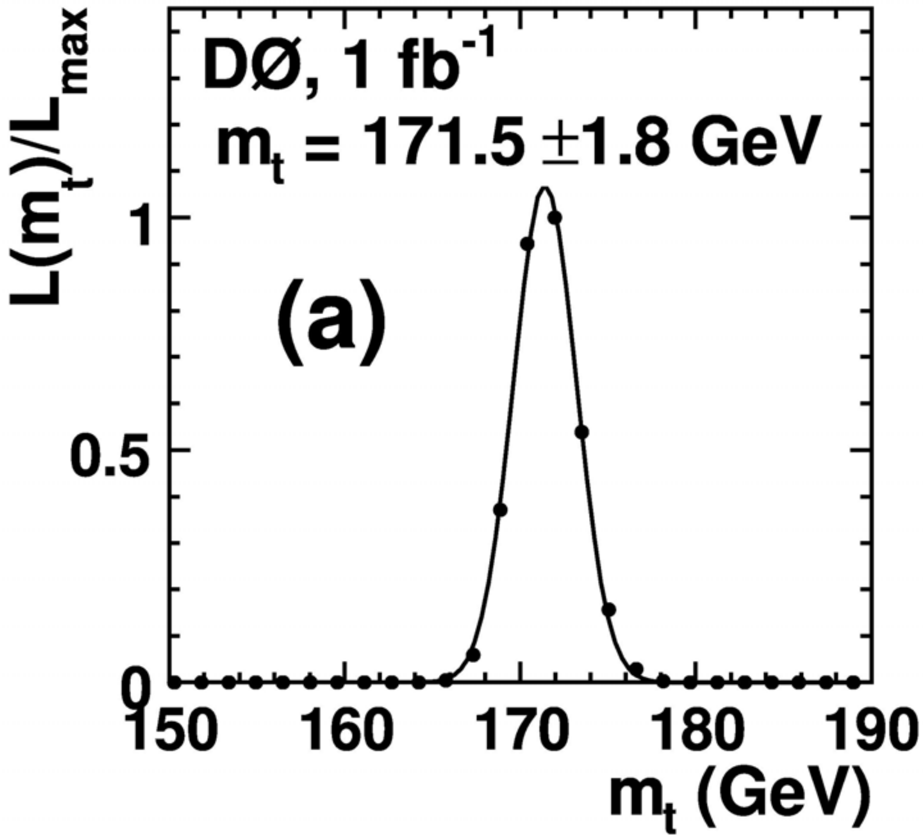




Using probabilities to measure the top mass



Top mass (D0)



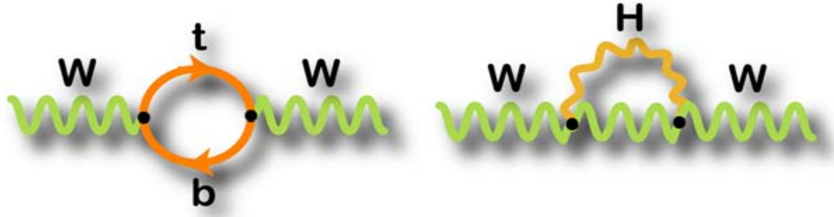
Why do we bother to measure the top mass to better than 1% ?

Top, W and Higgs masses are related

$$M_W^2(1 - M_W^2 / M_Z^2) = A^2/(1-\Delta r)$$

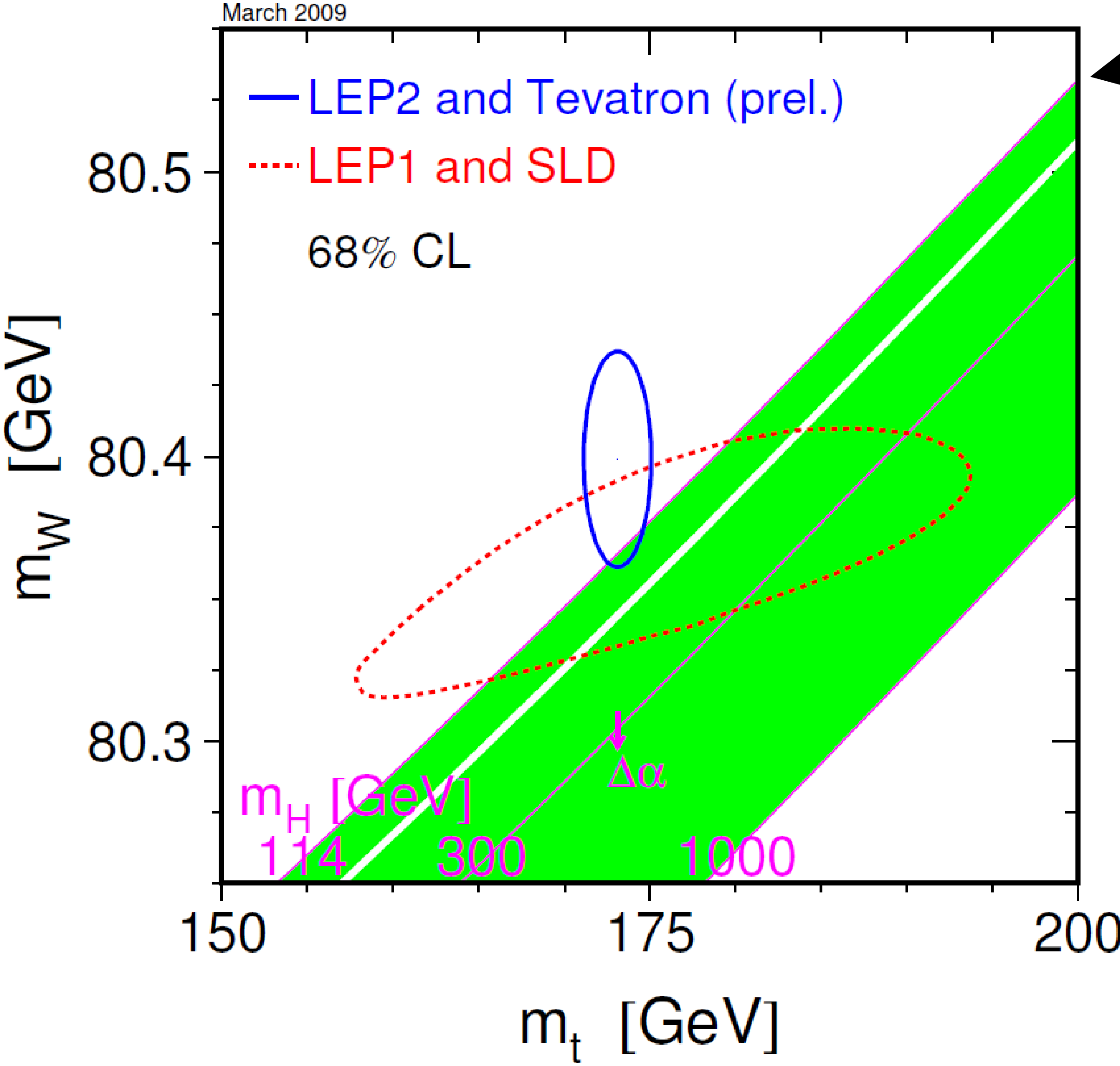
$$A = 37.2802\,GeV \quad \text{and}$$

$$\Delta r \approx a + b\ m_t^2 + c\ \ln(M_H^2 / M_W^2)$$



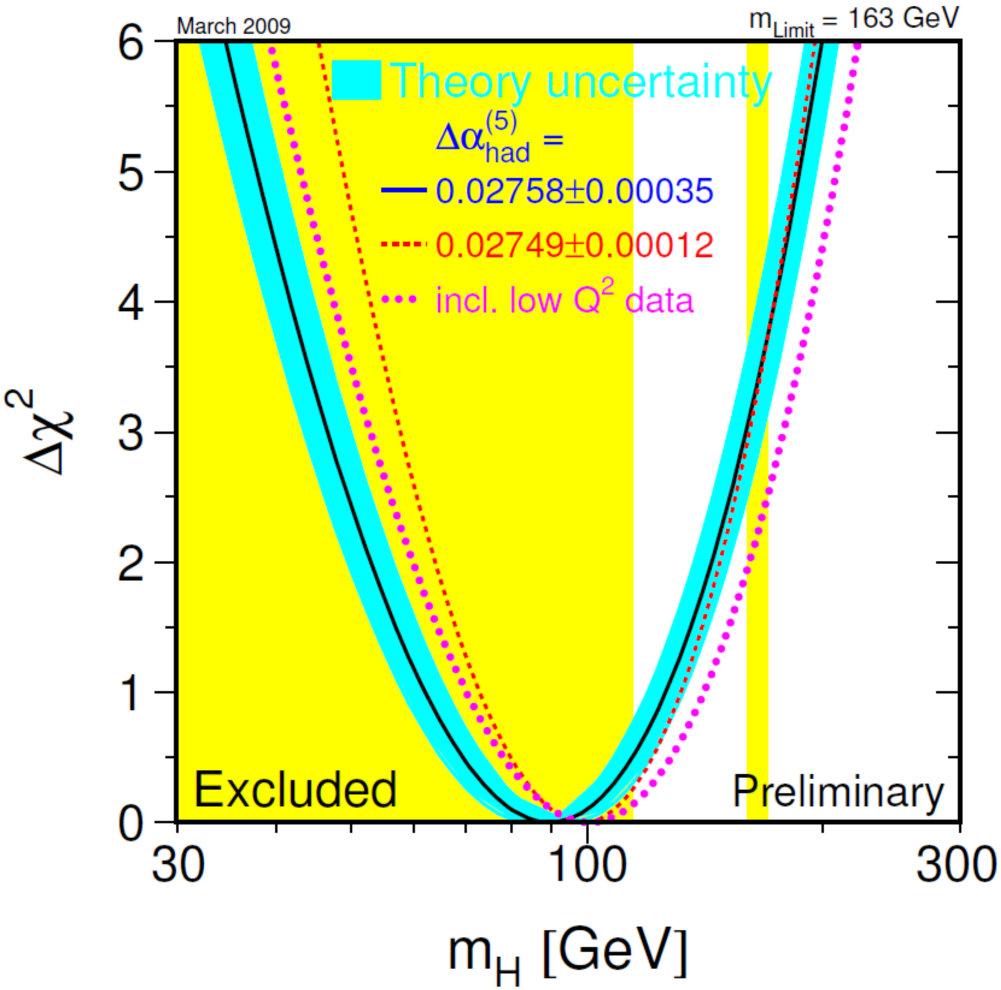
Accurate measurements of the top quark and W boson masses put constraints on the mass of the Higgs boson. Because of the log dependence to have meaningful constraints on the Higgs mass high precision measurement of the W and top quark masses are required.

LEP EWWG as of March 2009



These (almost) lines are the EW predictions.

Higgs limits

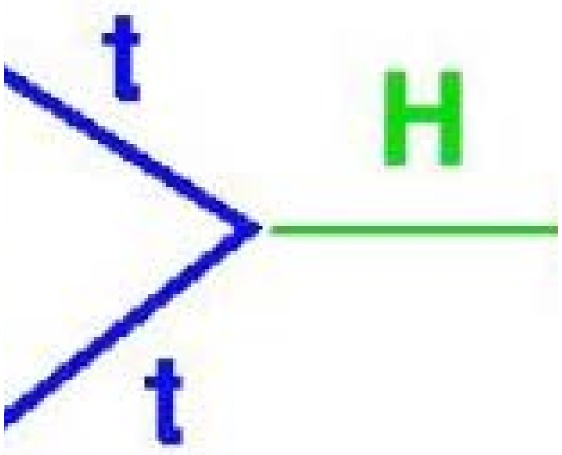


The SM Higgs mass limit from the EW fit is: m_H<163 GeV/c^2 at 95% CL.

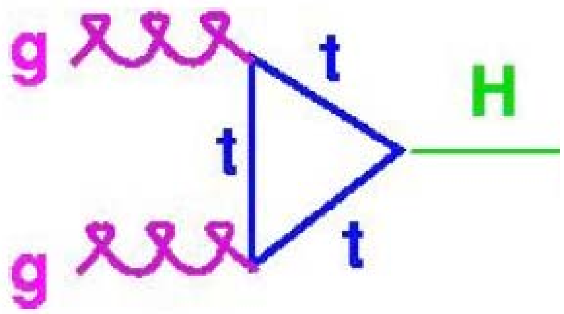
Footnote: There is a 3 σ discrepancy between the hadronic and leptonic F-B asymmetries. If any of this two are removed there are big changes in the Higgs mass limits (see M. Chanowitz, PRD 66:073002, 2002 and Fermilab W&C 2/23/2007)

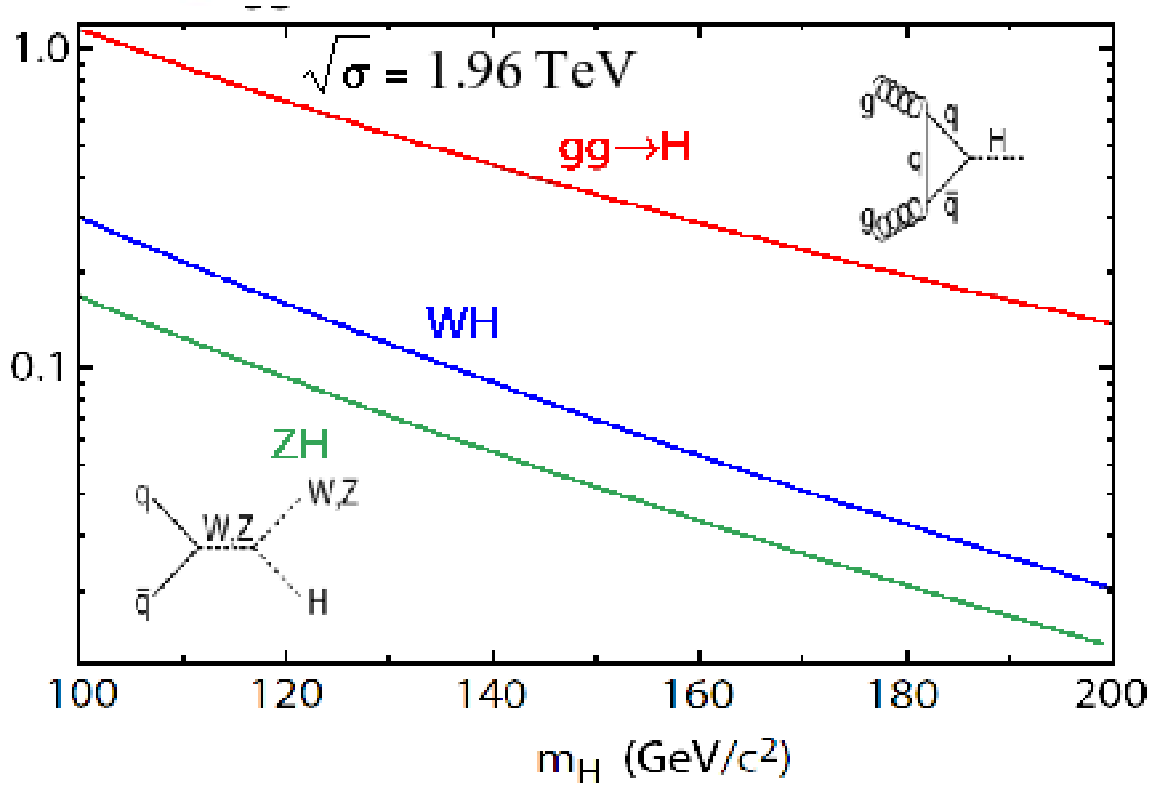
Looking for the Higgs

Higgs production

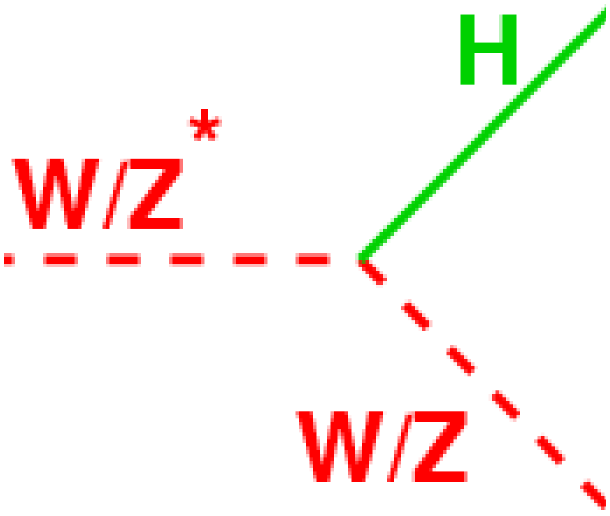


Higgs cross section



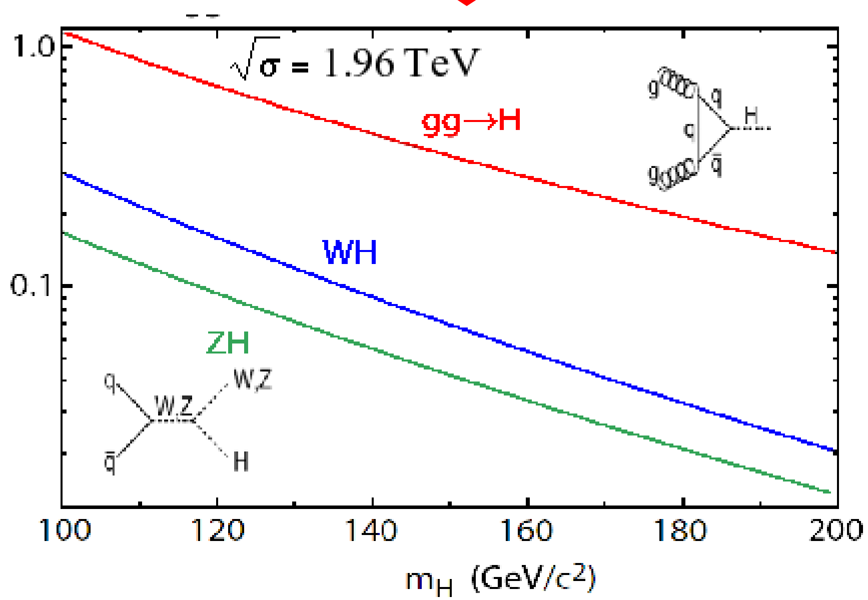


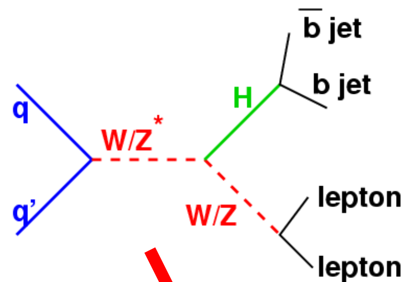
Higgs production

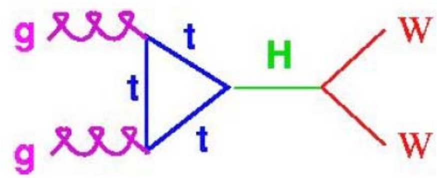


Cross section and branching ratios

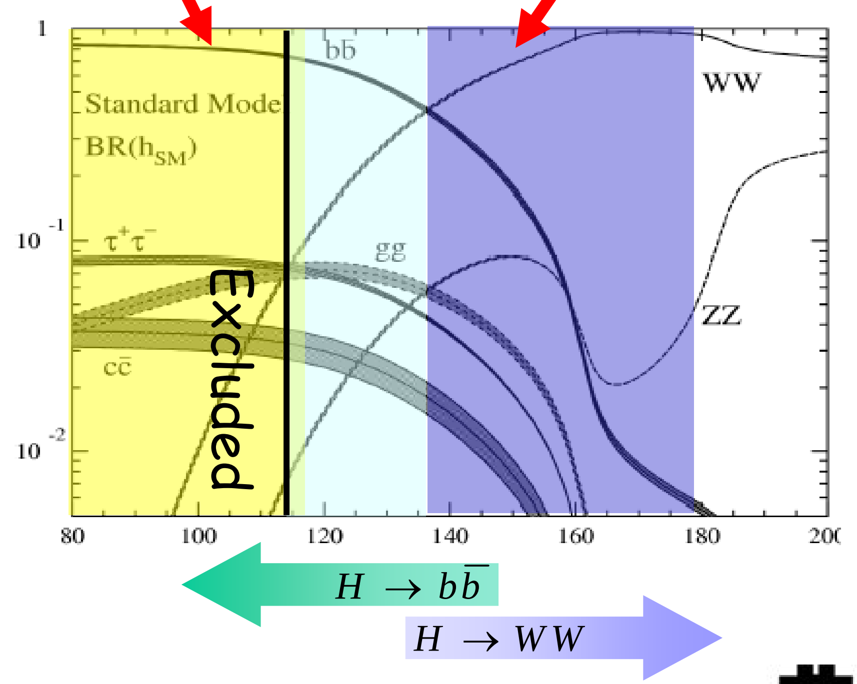
Production







Decay



Channels that enter in the combination

CDF

TABLE I: Luminosity, explored mass range and references for the CDF analyses. ℓ stands for either e or μ.

	$WH \to \ell\nu b\bar{b}$ 2 (TDT,LDT,STC)	$ZH \to \nu\bar{\nu}b\bar{b}$ TDT,LDT	$ZH \to \ell^+\ell^- b\bar{b}$ ST,DT	$H \to W^+W^-$ low,high S/B	$H + X \to \tau^+\tau^- + 2$ jets H+VBF+WH+ZH
Luminosity (fb^{-1})	1.9	1.7	1.0	2.4	2.0
m_H range (GeV/c^2)	110-150	100-150	110-150	110-200	110-150
Reference	[5]	[6]	[7]	[8]	[9]

D0

TABLE II: Luminosity, explored mass range and references for the DØ analyses. ℓ stands for either e or μ.

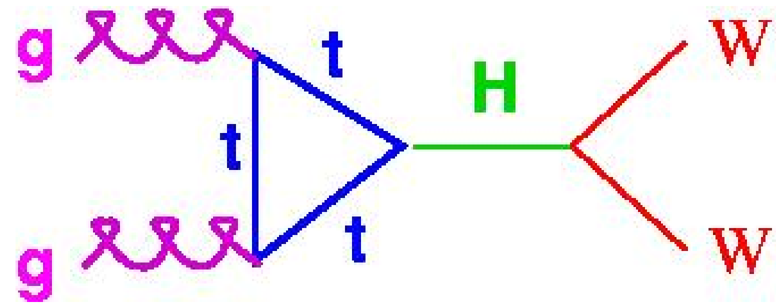
	$WH \to \ell\nu b\bar{b}$ 2 (ST,DT)	$ZH \to \nu\bar{\nu}b\bar{b}$ DT	$ZH \to \ell^+\ell^- b\bar{b}$ 2 (ST,DT)	$H \to W^+W^- \to \ell^\pm\nu\ell^\mp\nu$	$WH \to WW^+W^- \to \ell^\pm\nu\ell^\pm\nu$	$H \to \gamma\gamma$
Luminosity (fb^{-1})	1.7	2.1	1.1	2.3	1.1	2.3
m_H range (GeV/c^2)	105-145	105-145	105-145	110-200	120-200	105-145
Reference	[10]	[11]	[12]	[13],[14]	[15]	[16]

Due to lack of time I will only cover the highlighted channel

gg→ H→W$^+$W$^-$→l$^+$νl$^-$ν

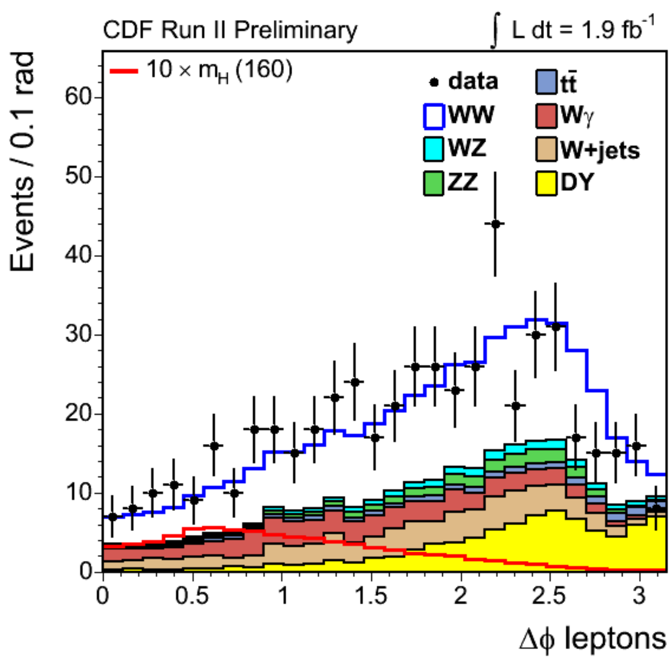
Basic selection:

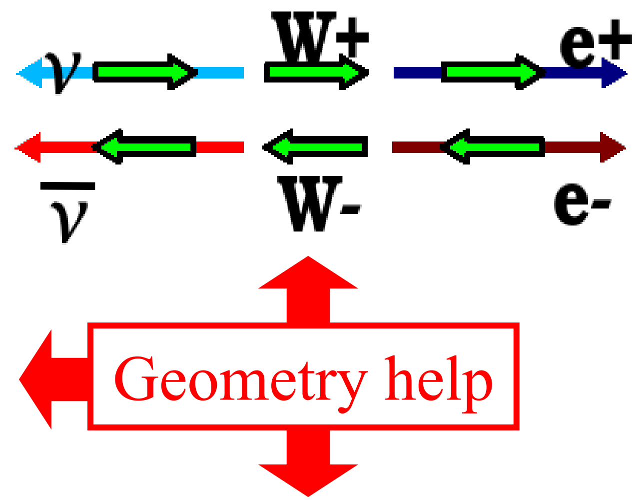
- Two opposite sign isolated leptons
- missing transverse momentum



Main backgrounds:

- WW, WZ, ZZ
- W+jets and Drell-Yang





Use full power of Matrix element

$H \rightarrow W^+W^-$ in CDF (1.9 fb^{-1})

Calculate probabilities

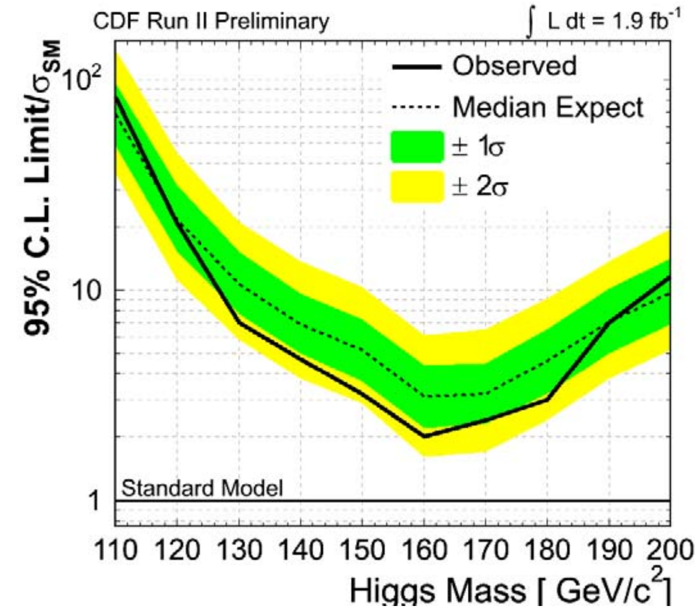
$$P_m(\vec{x}_{obs}) = \frac{1}{\langle \sigma_m \rangle} \int d^n \sigma_m^{theory}(y) \epsilon(y) G(\vec{x}_{obs}, y)$$

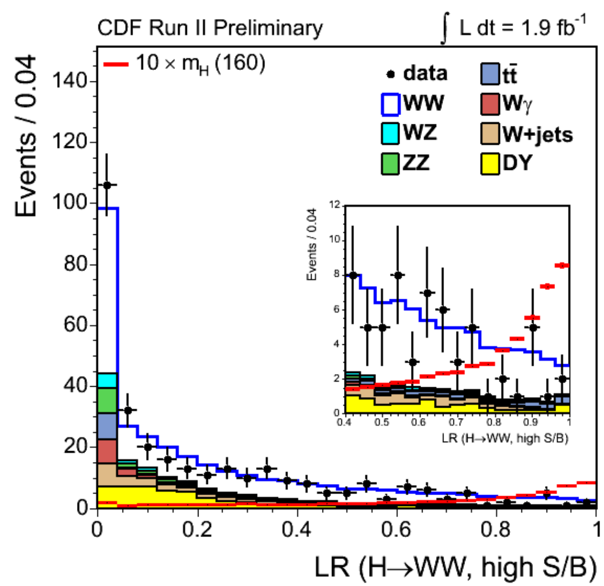
P_m : Event-by-event probability for process m
y : true lepton kinematics, incl. neutrinos
$\vec{x}_{obs}$: observed kinematics
ϵ : lepton efficiencies
G : detector resolution function

Calculate discriminant

$$LR(m_H) = \frac{P_{Higgs}(m_H)}{P_{Higgs}(m_H) + \sum_{bg=WW,WZ,tt,..} f_{bg} P_{bg}}$$

Check for observation

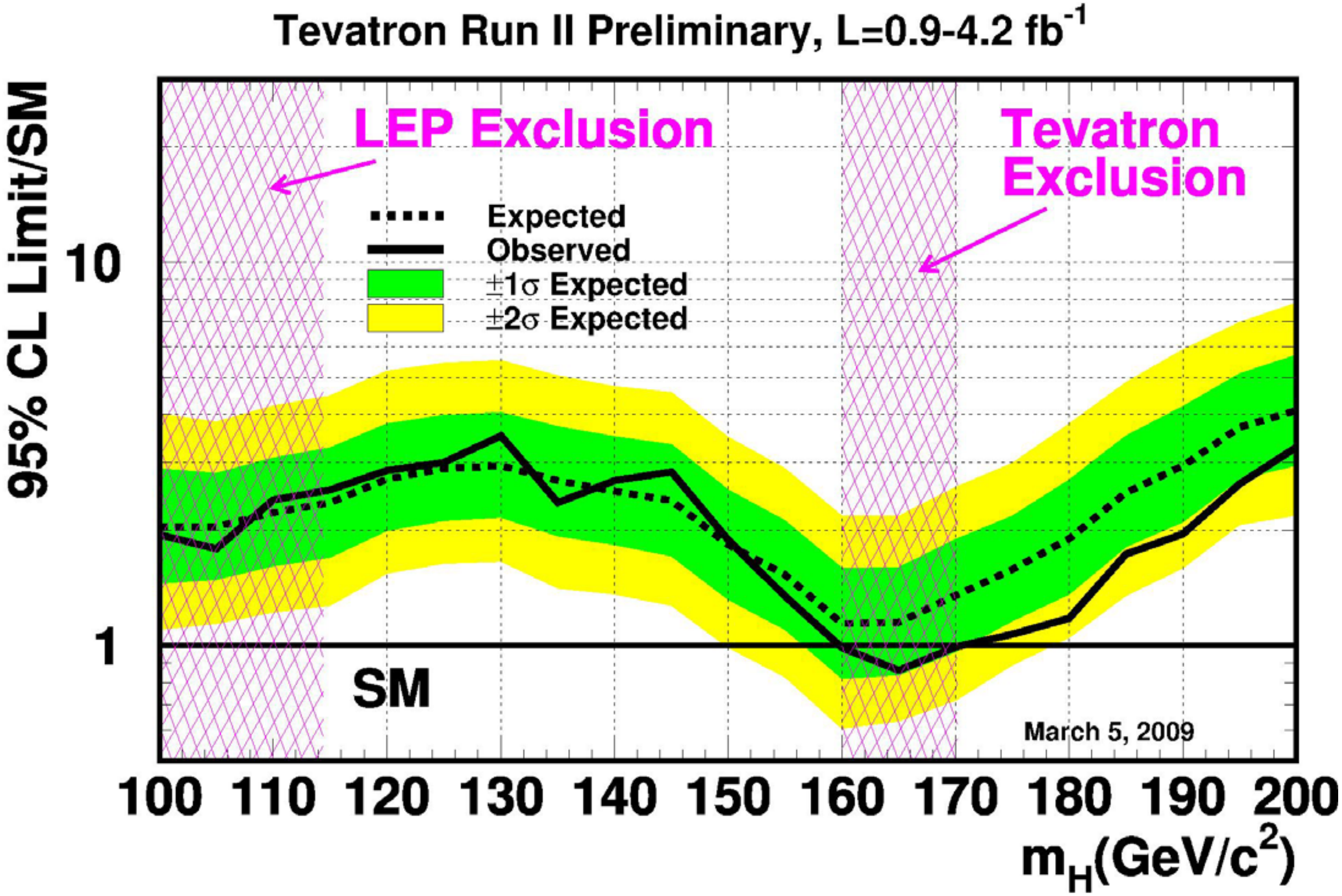




If no observation set limit

Winter 2009 Higgs limits

D0 + CDF all channels combined



Direct searches

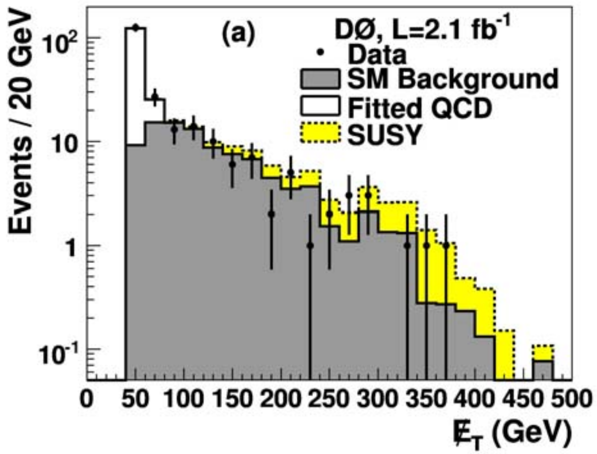
Searches for squarks and neutralinos

$$p\bar{p} \rightarrow \tilde{q}\bar{\tilde{q}} \rightarrow q\tilde{\chi}_1^0\bar{q}\tilde{\chi}_1^0$$

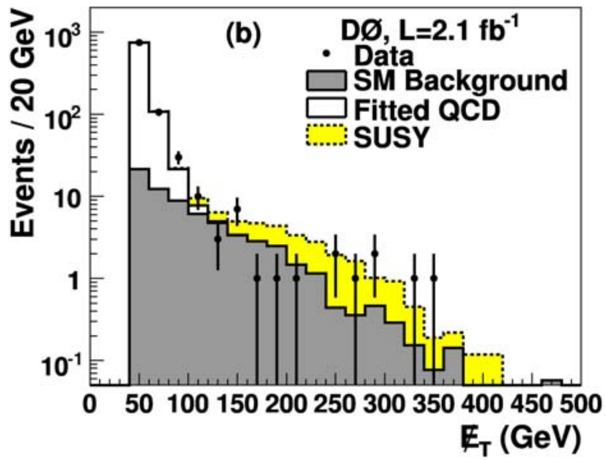
$$p\bar{p} \rightarrow \tilde{q}\tilde{q} \rightarrow q\tilde{\chi}_1^0 q\tilde{\chi}_1^0$$

$$p\bar{p} \rightarrow \tilde{q}\tilde{g} \rightarrow q\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$$

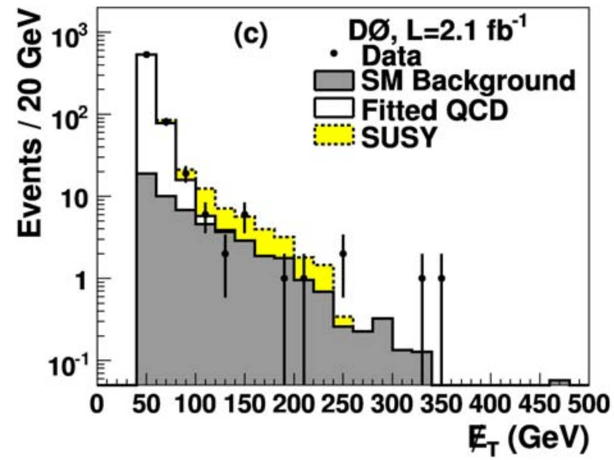
$$p\bar{p} \rightarrow \tilde{g}\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$$



di-jet events

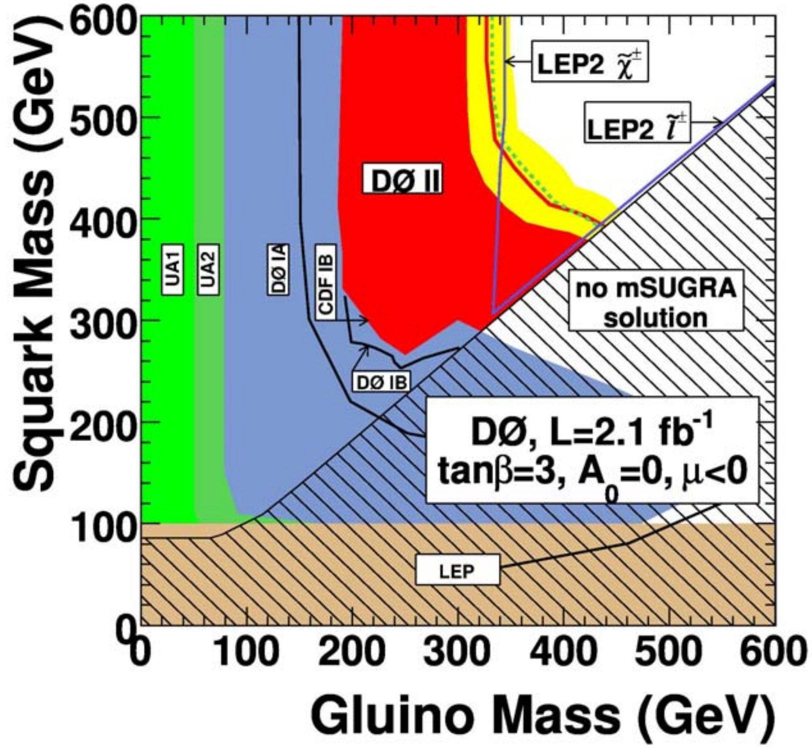


3-jet events



4-jet events

Squark-gluino searches



CDF and D0 have already publish ~100 papers on searches of all kind of particles. No particles beyond the SM have been found. We are all waiting for the LHC.

Bouchet challenge

Edward Bouchet obtained his PhD in physics from Yale in 1876.

He was the first African American to obtain a PhD in physics in an American university and the sixth American to earn a PhD in physics period.

Edward Bouchet 1852-1918