Large Hadron Collider

Lecture 4

Physics Channels:

Jets, Z, W, Higgs, top, SUSY,extra-dimensions

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Taller de Altas Energías

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physics topics that will be studied

Standard Model:

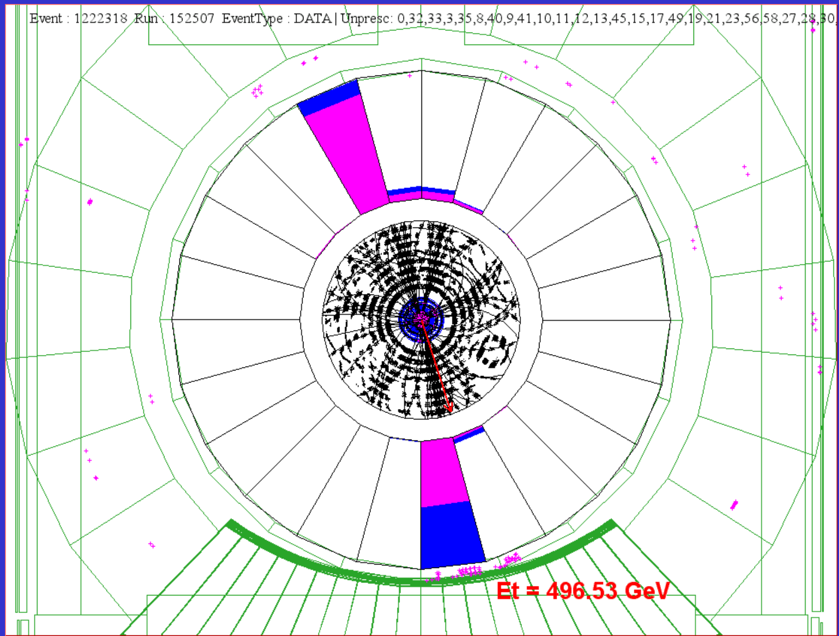
- Higgs search
- W, gauge couplings
- Top physics
- QCD
- CP violation

Beyond the Standard Model:

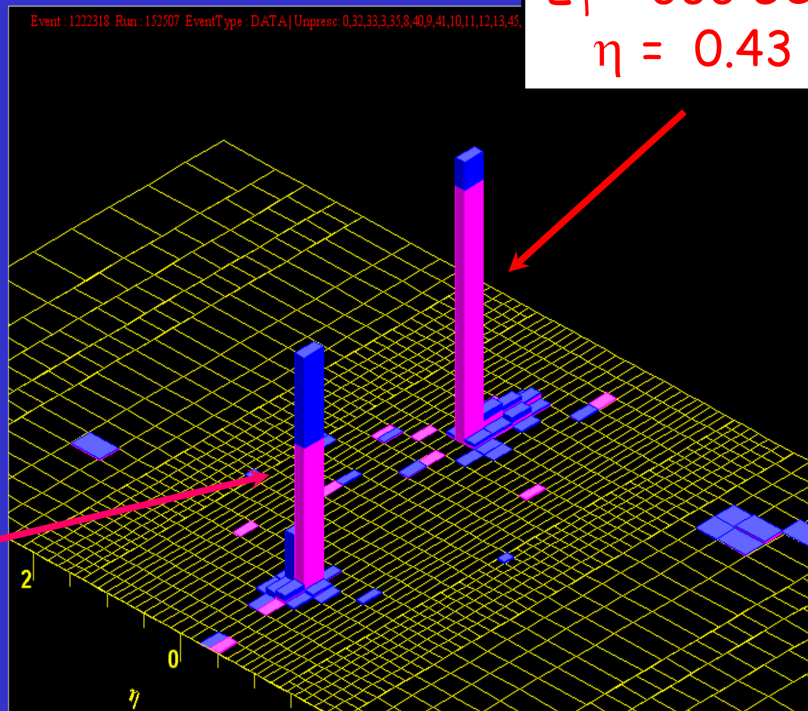
- Supersymmetry (s-quarks, gluinos, charginos, neutralinos, s-leptones).
- Extra dimensions (graviton, radion)
- Technicolor (tecnipions..)
- New particles: excited fermions, leptoquarks, little Higgs, leptones neutros pesados, new gauge bosons (z'…).

And the unexpected !!!!

A two jet event at the Tevatron (CDF)



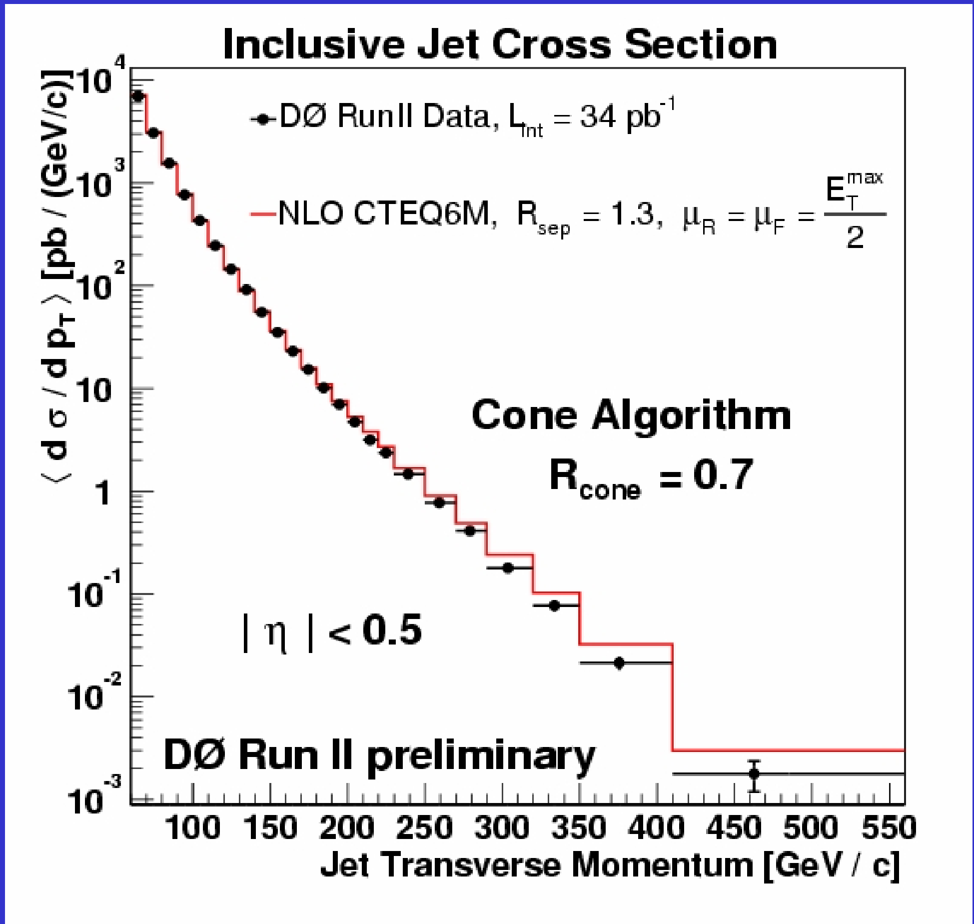
CDF (ϕ-r view)



E_T = 666 GeV
η = 0.43

E_T = 633 GeV
η = -0.19

Test of QCD Jet production



<u>Inclusive Jet spectrum as a function of Jet-PT</u>

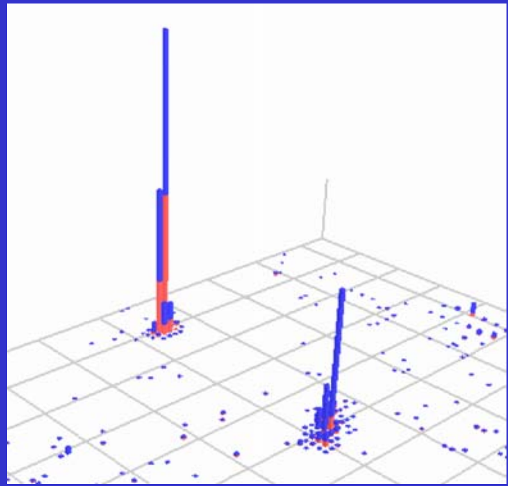
Data from the DØ experiment (Run II)

very good agreement over many orders of magnitude !

within the large theoretical and experimental uncertainties

Main experimental systematic uncertainties

- A Jet is NOT a well defined object (fragmentation, detector response)
  - one needs an algorithm to define a jet (e.g., a cone around a local energy maximum in the calorimeter)
  typical cone values: $\Delta R = \sqrt{\Delta\Phi^2 + \Delta\eta^2} = 0.5$

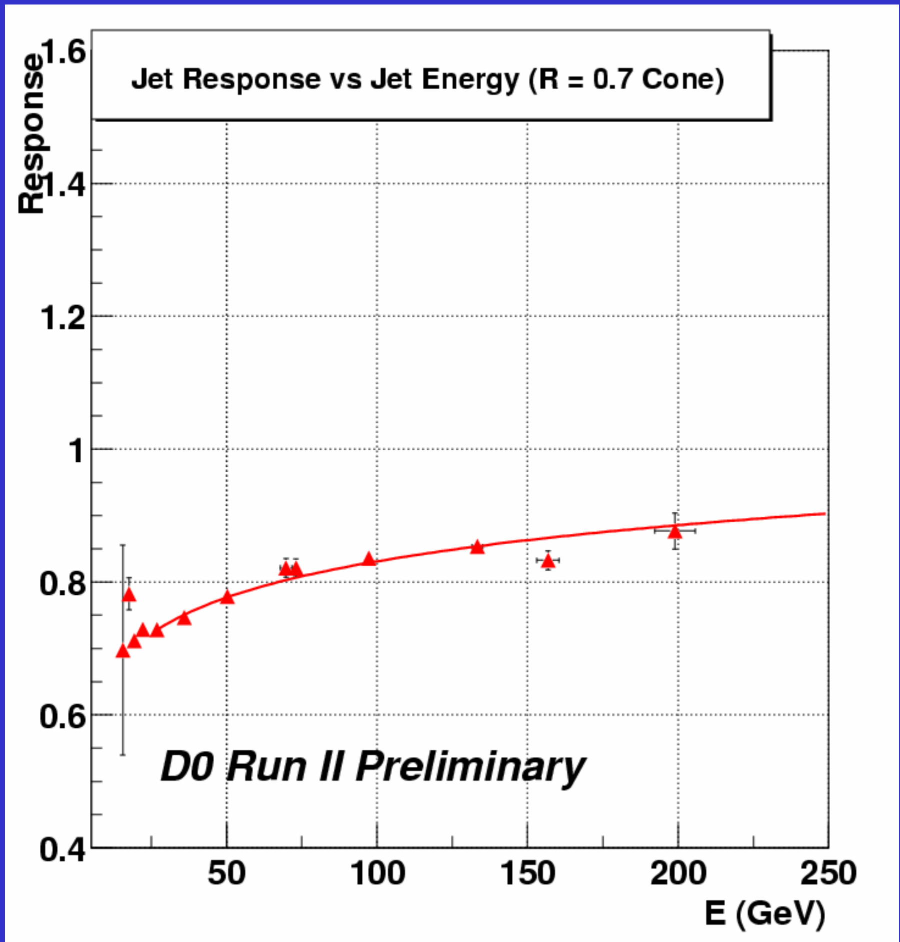


- Cone energy ≠ parton energy

Main corrections:

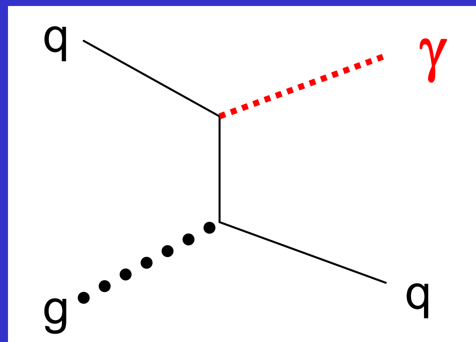
- Calorimeters show different response to e, γ and hadrons
- Subtraction of energy not originating from the hard scattering
- Correction for jet energy outside the cone

Main experimental systematic uncertainty: Jet Energy Scale

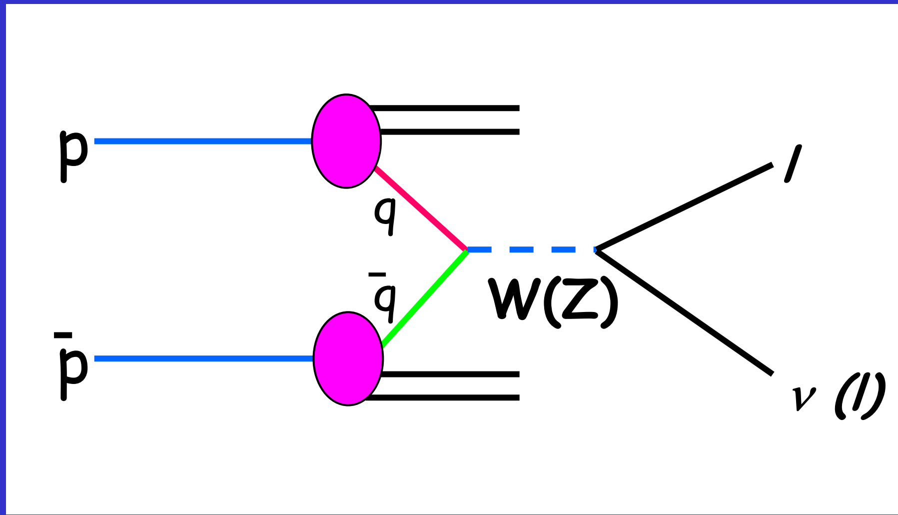


Jet response correction in DØ:

- measure response of particles making up the jet
- use photon + jet data - calibrate jets against the better calibrated photon energy



Test of W and Z production



Drell-Yan production process

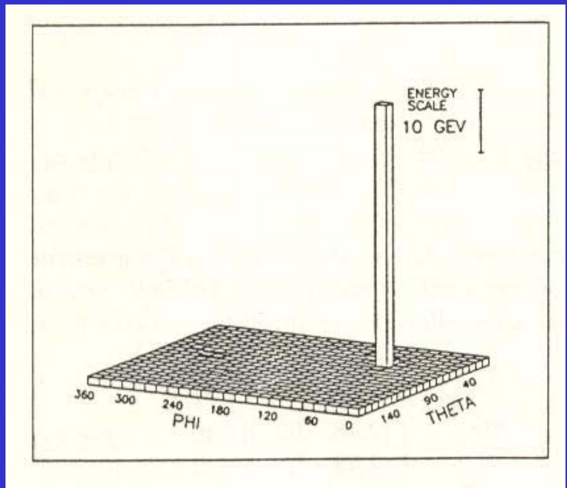
Tevatron:	expected rates for 2 fb^{-1}:	3 Mio W $\rightarrow$ ℓ n events
LHC:	expected rates for 10 fb^{-1}:	60 Mio W $\rightarrow$ ℓ n events
LEP II:	recorded events:	40 000 W $\rightarrow$ ℓ n events

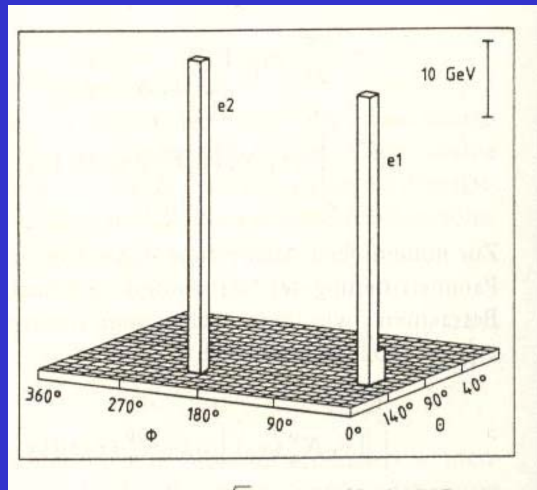
How do W and Z events look like ?

As explained, leptons, photons and missing transverse energy are key signatures at hadron colliders

→ Search for leptonic decays: $W \rightarrow \ell\ \nu$ large $P_T(\ell)$, large P_T^{miss}

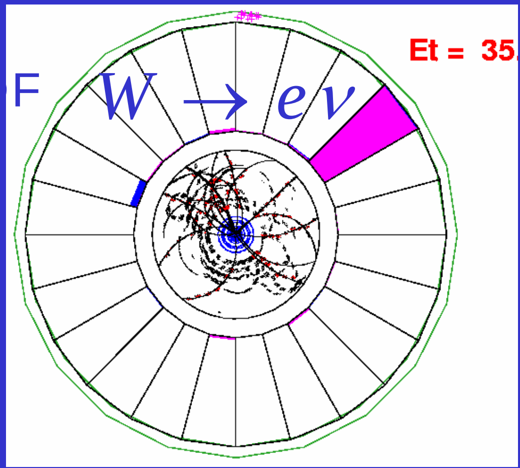
$Z \rightarrow \ell\ \ell$ 2 leptons with large $P_T(\ell)$

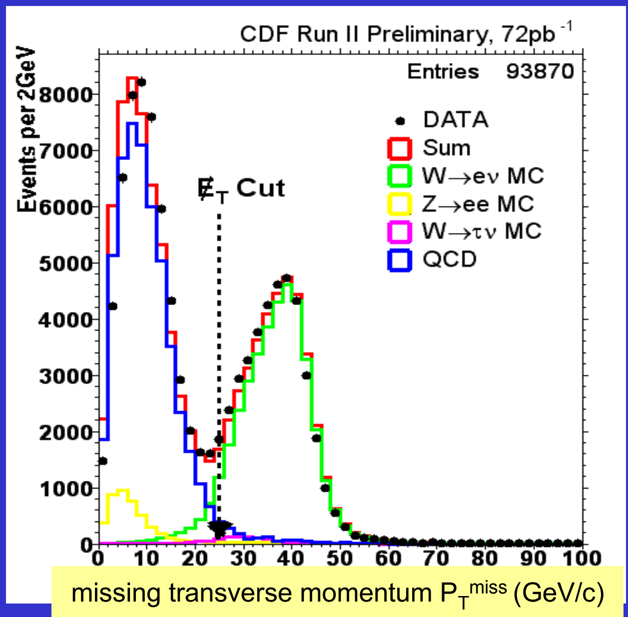




W/Z discovery by the UA1 and UA2 experiments at CERN (1983/84)

W / Z → eν / ee signals





Trigger:

- Electron candidate > 20 GeV/c

Electrons

- Isolated e.m. cluster in the calorimeter with P_T> 25 GeV/c
- Shower shape consistent with expectation for electrons
- Matched with tracks

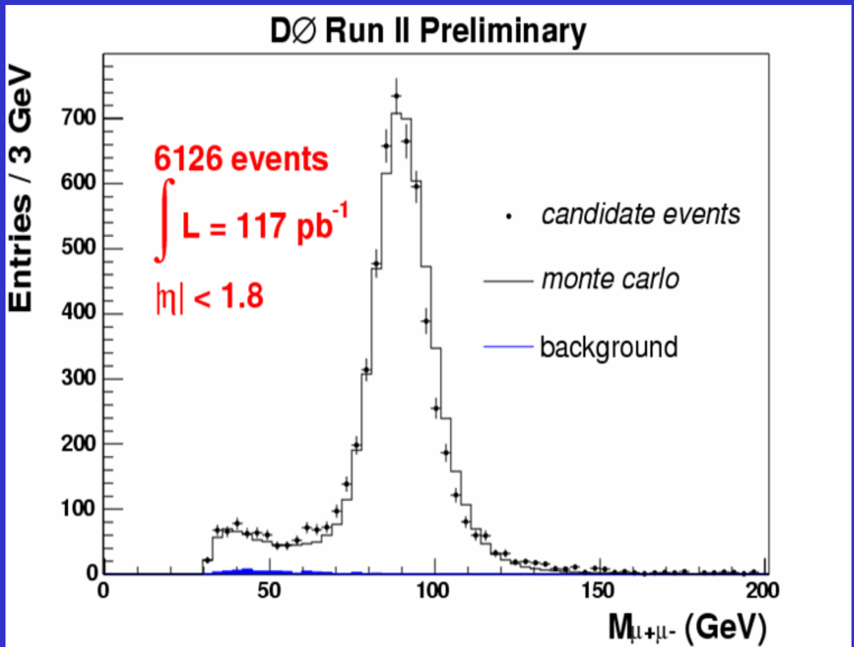
Z → ee

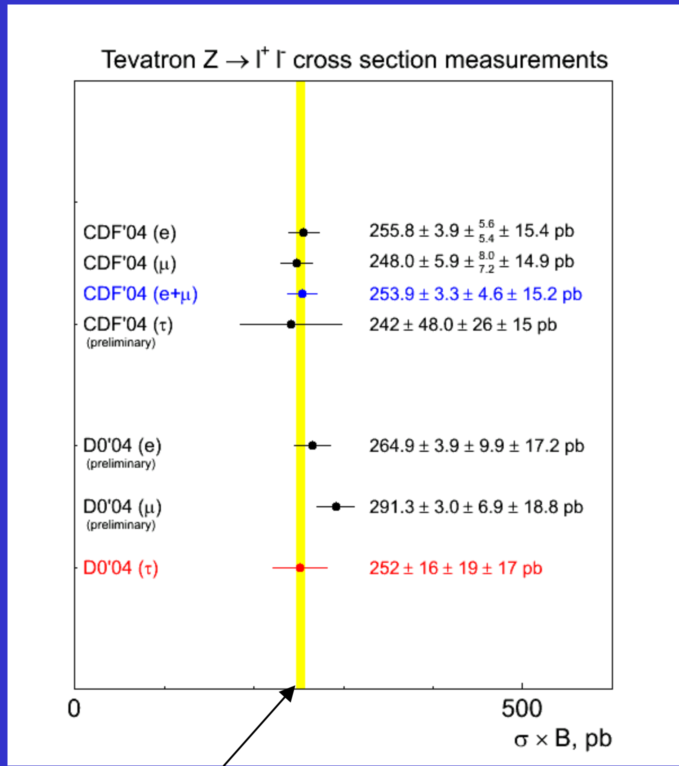
- 70 GeV/c^2 < m_{ee} < 110 GeV/c^2

W → eν

- Missing transverse momentum > 25 GeV/c

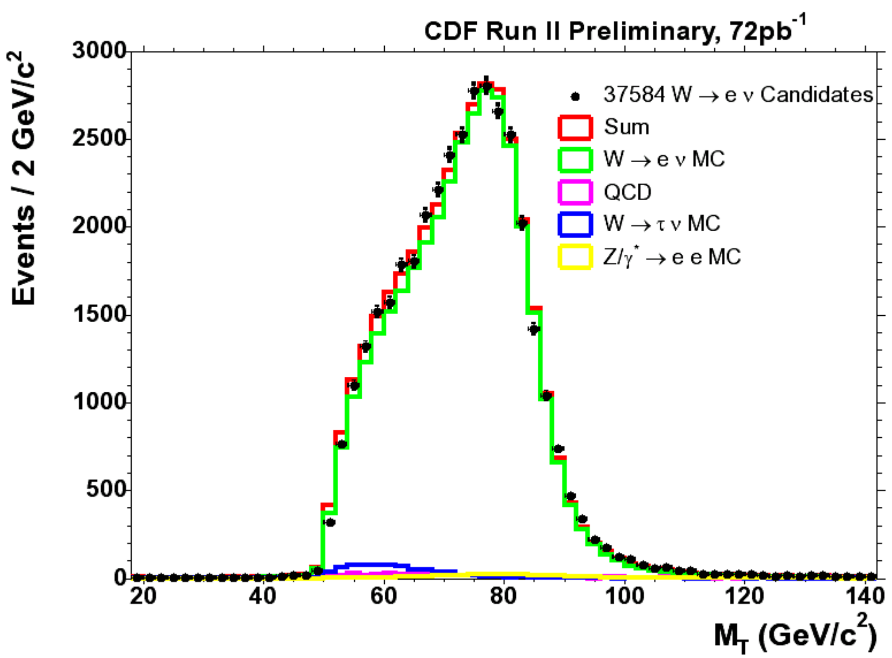
Z→ ℓℓ cross section

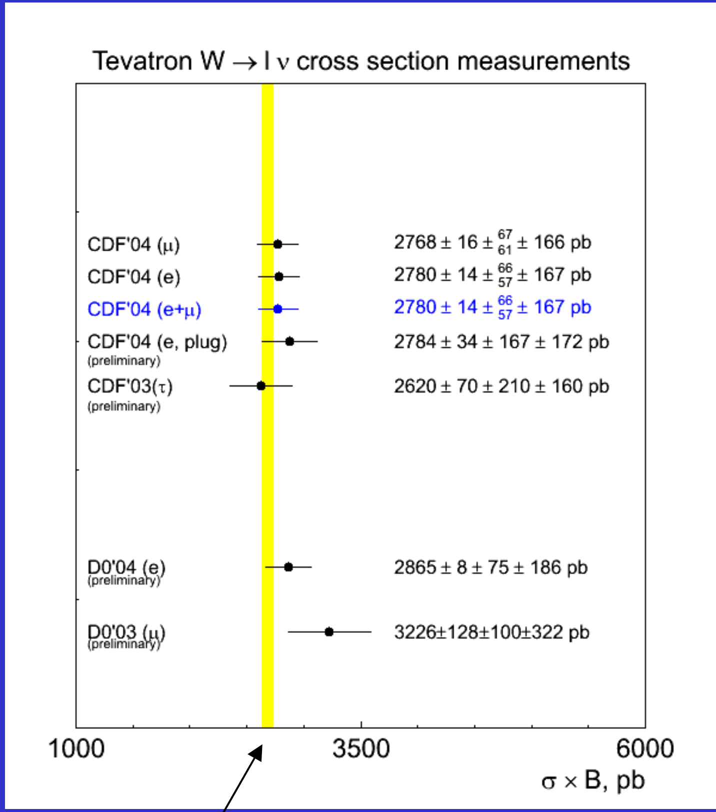




Good agreement with
NNLO QCD calculations
C.R.Hamberg et al, Nucl. Phys. B359 (1991) 343.

W → ℓν Cross Section



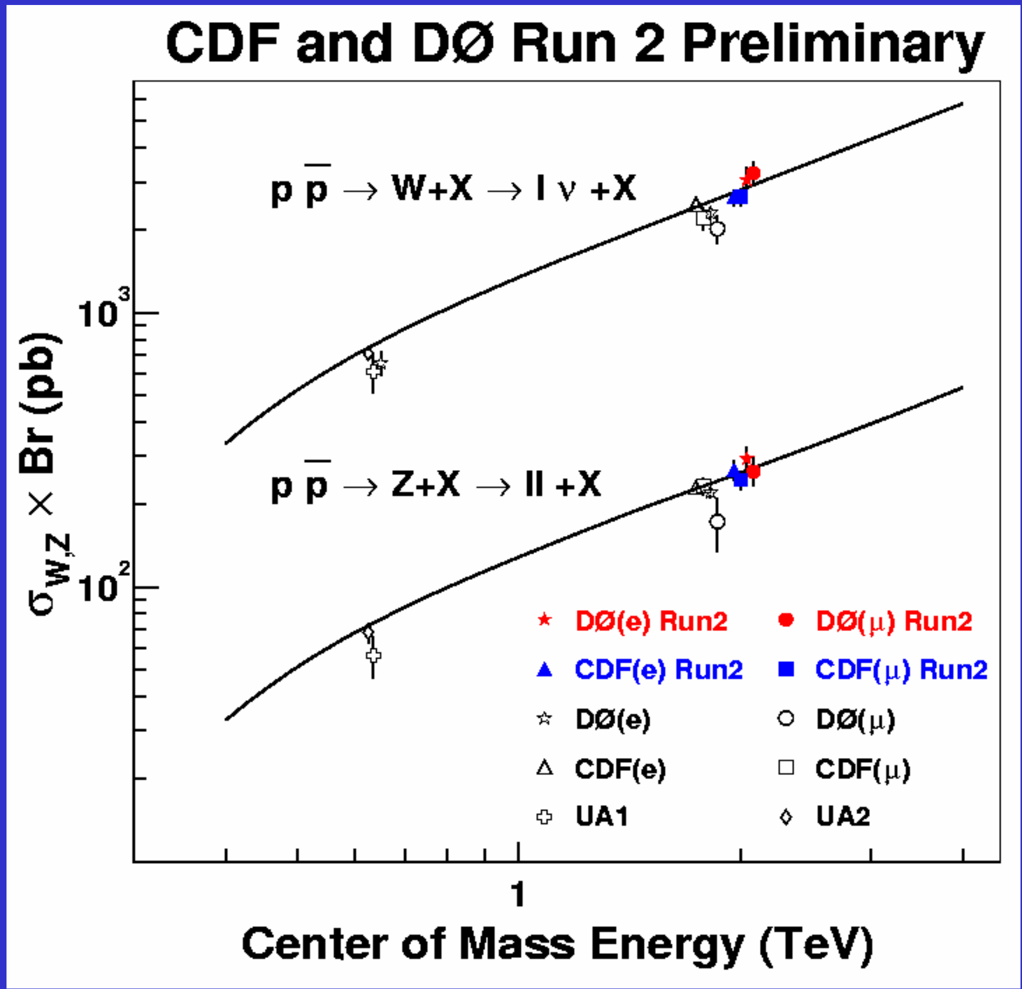


$$M_W^T = \sqrt{2 \cdot P_T^l \cdot P_T^\nu \cdot \left(1 - \cos \Delta\phi^{l,\nu}\right)}$$

Good agreement with NNLO QCD calculations

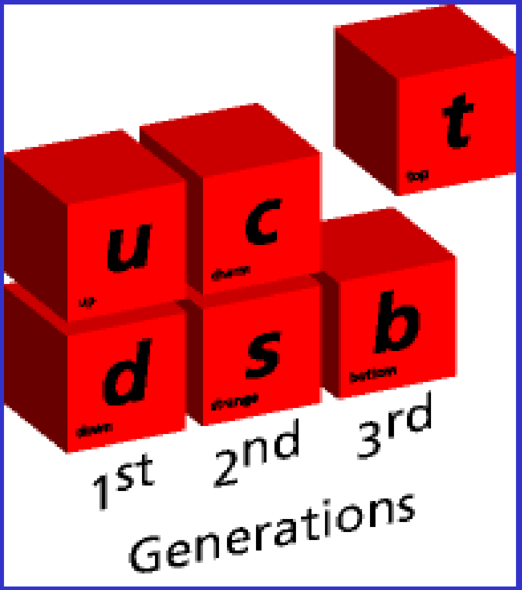
C.R.Hamberg et al, Nucl. Phys. B359 (1991) 343.

Comparison between measured W/Z cross sections and theoretical prediction (QCD)

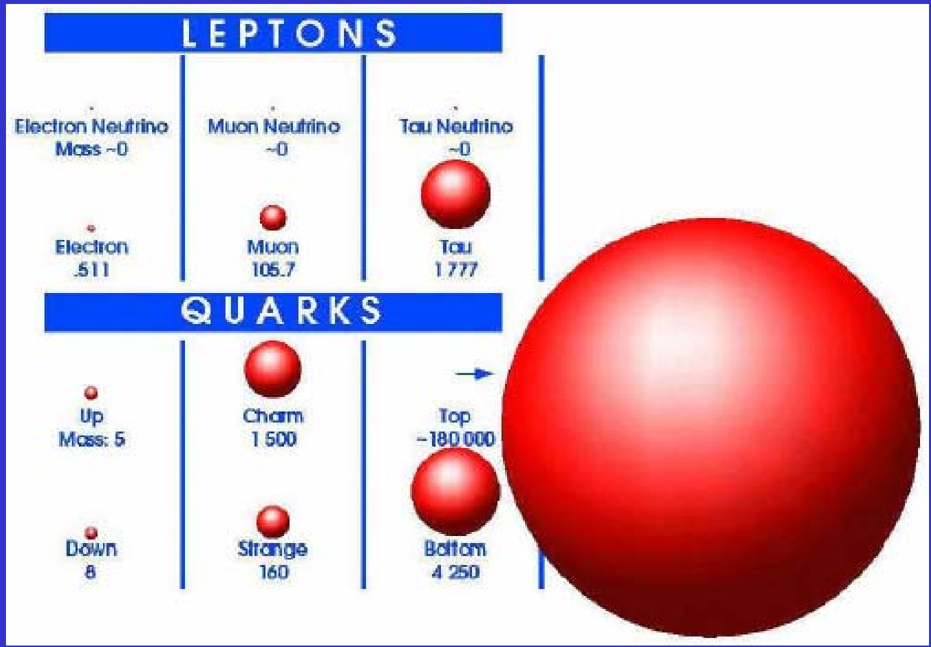


Top Quark Physics

- Discovered by CDF and DØ collaborations at the Tevatron in 1995
- Run I top physics results are consistent with the Standard Model
  (Errors dominated by statistics)
- Run II top physics program will take full advantage of higher statistics
  - Better precision
  - Search for deviations from Standard Model expectations



Why is Top-Quark so important ?

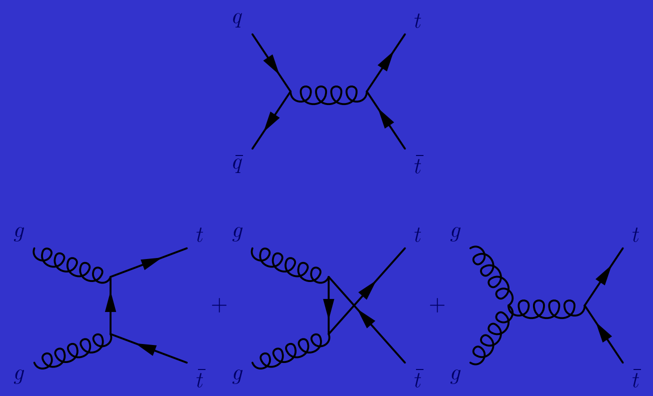


We still know experimentally very little about the properties of the top quark:

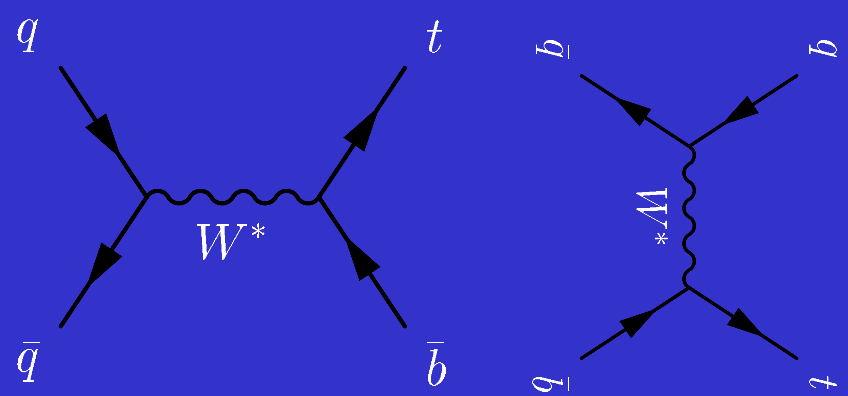
mass, spin, charge, lifetime, decay properties (rare decays), gauge couplings, Yukawa coupling,…

Top Quark Production

Pair production: qq and gg-fusion



single top-quarks qq, qb and gb-fusion



	Run I 1.8 TeV	Run II 1.96 TeV	LHC 14 TeV
qq gg	90% 10%	85% 15%	5% 95%
s (pb)	5 pb	7 pb	600 pb

	Run I 1.8 TeV	Run II 1.96 TeV	LHC 14 TeV
σ (qq) (pb)	0.7	0.9	10
σ (qb) (pb)	1.7	2.4	250
σ (gb) (pb)	0.07	0.1	60

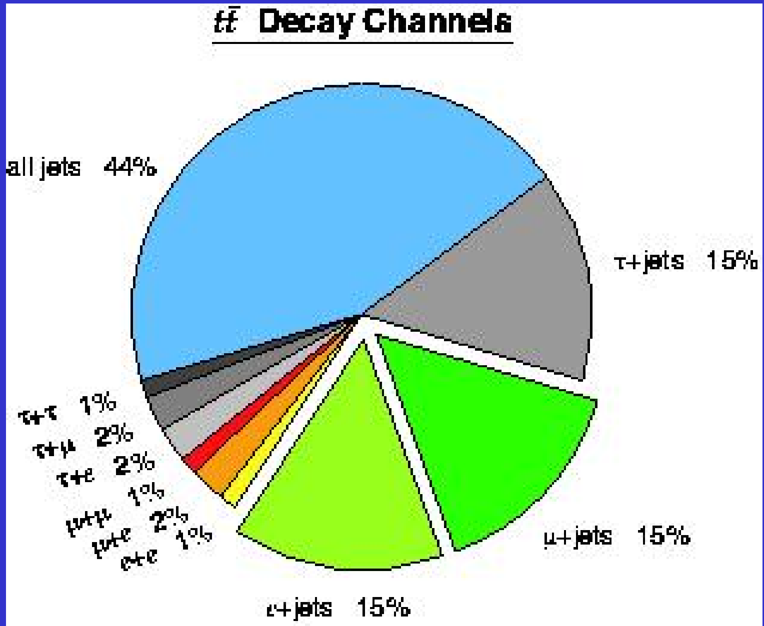
Top Quark Decays

BR ($t \to Wb$) ~ 100%

Both W's decay via $W \to \ell\nu$ (ℓ=e or μ; 5%)
dileptons

One W decays via $W \to \ell\nu$ (ℓ=e or μ; 30%)
lepton+jets

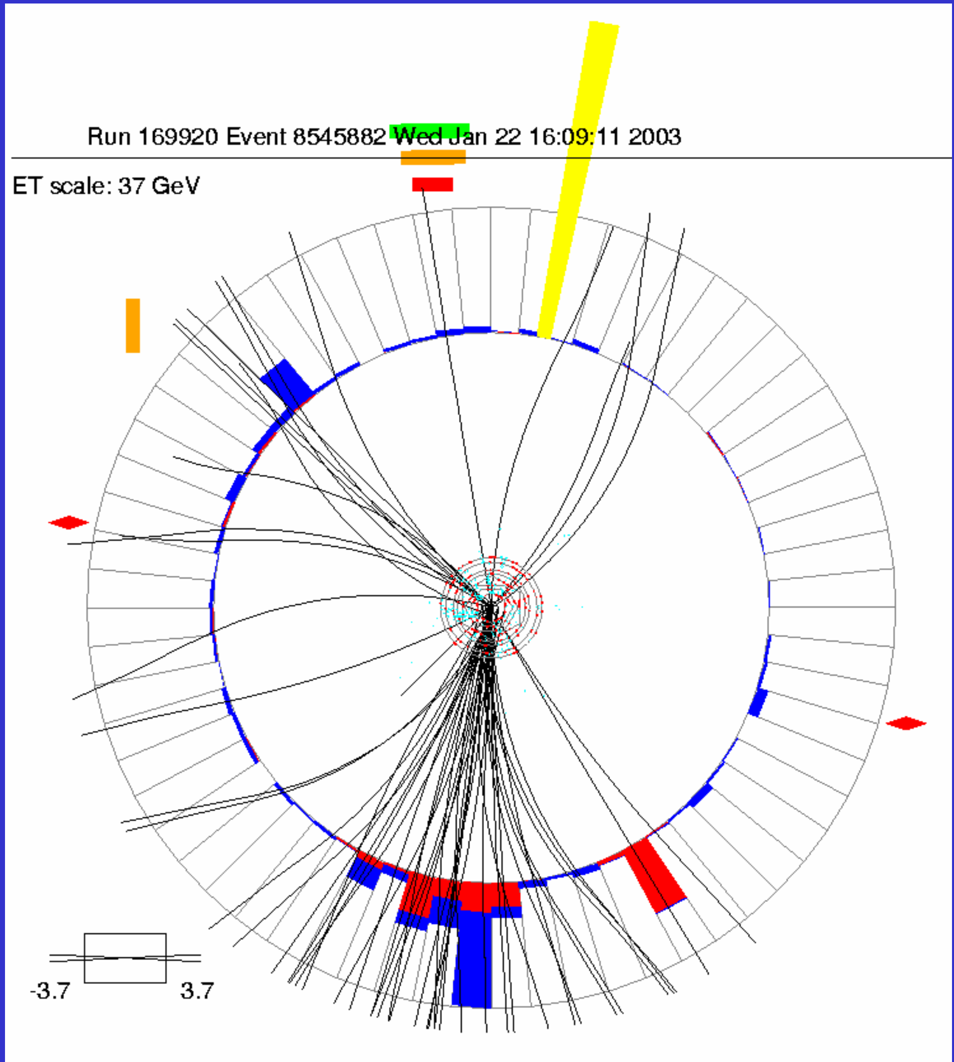
Both W's decay via $W \to qq$ (44%)
all hadronic, not very useful



Important experimental signatures: : - Lepton(s)

- Missing transverse momentum
- b-jet(s)

DØ top candidate event with two leptons



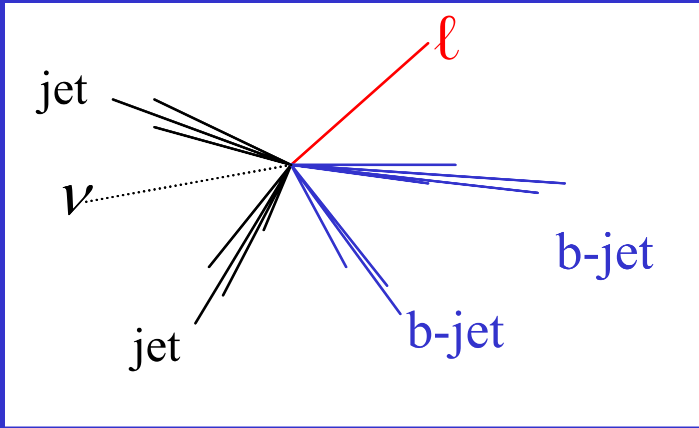
$p_T(e) = 20.3\ GeV/c^2$

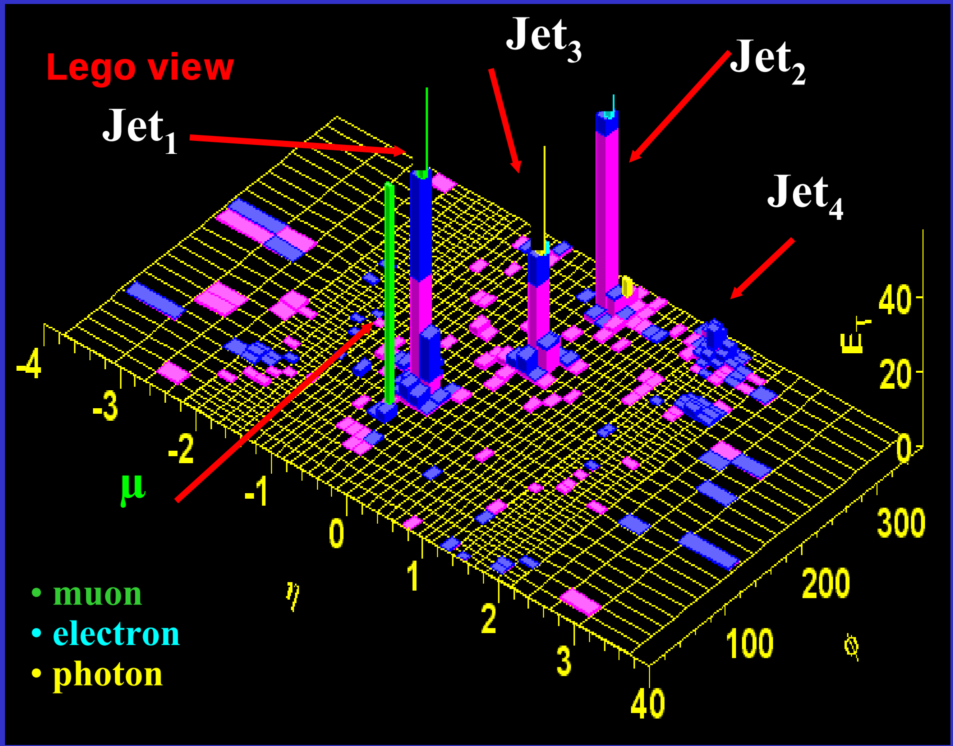
$p_T(\mu) = 58.1\ GeV/c^2$

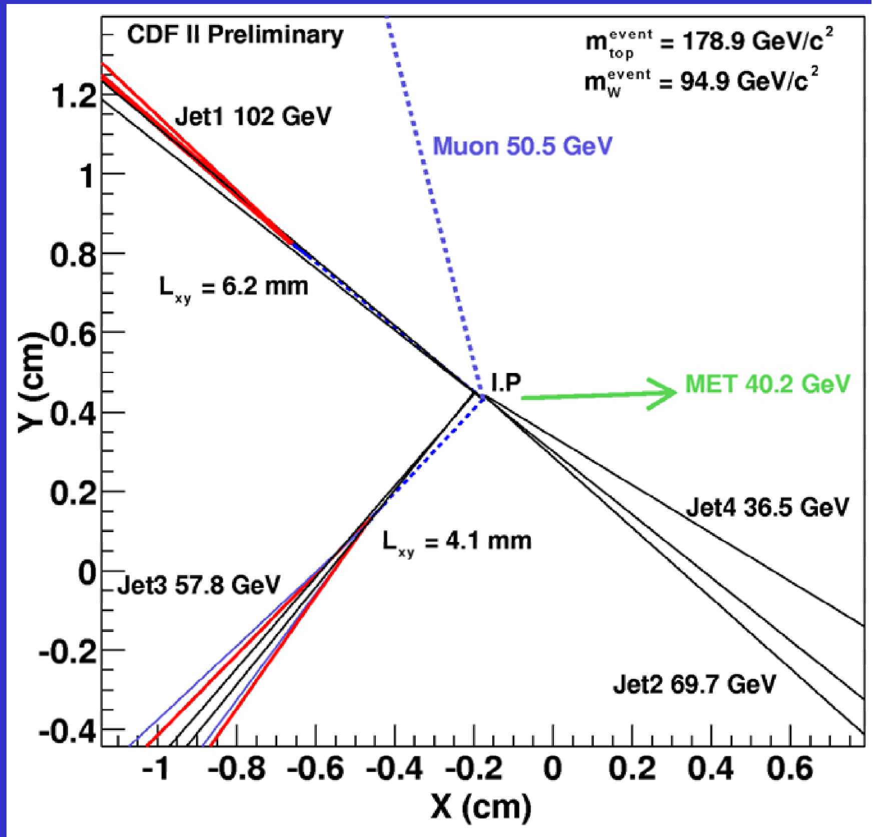
$E_T^j = 141.0, 55.2\ GeV$

E_T miss=91 GeV

A CDF Lepton + Jet event







$p_T(\mu)$ = 54.4 GeV
E_T^j = 96.7, 65,8, 54.8, 33.8 GeV
Missing E_T= 40.2 GeV

Precision measurements of m_W and m_{top}

Motivation:

W mass and top quark mass are fundamental parameters of the Standard Model;

The standard theory provides well defined relations between m_W, m_{top} and m_H

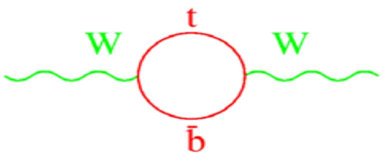
Electromagnetic constant
measured in atomic transitions

$$m_W = \left(\frac{\pi \alpha_{EM}}{\sqrt{2}\, G_F} \right)^{1/2} \frac{1}{\sin\theta_W \sqrt{1-\Delta r}}$$

Fermi constant
measured in muon decay

weak mixing angle
measured at LEP/SLC

radiative corrections
$\Delta r = f\,(m_{top}^2, \log m_H)$



G_F, α_{EM}, $\sin\theta_W$

are known with high precision

Precise measurements of the W mass and the top-quark mass constrain the Higgs-boson mass
(and/or the theory, radiative corrections)

The W-mass measurement

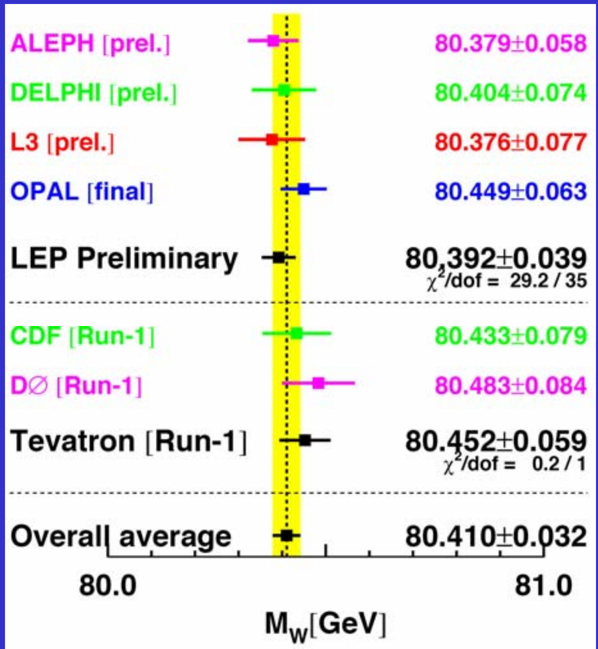
$$m_W = \left(\frac{\pi \, \alpha_{EM}}{\sqrt{2}\, G_F} \right)^{1/2} \frac{1}{\sin\theta_W \sqrt{1-\Delta r}}$$

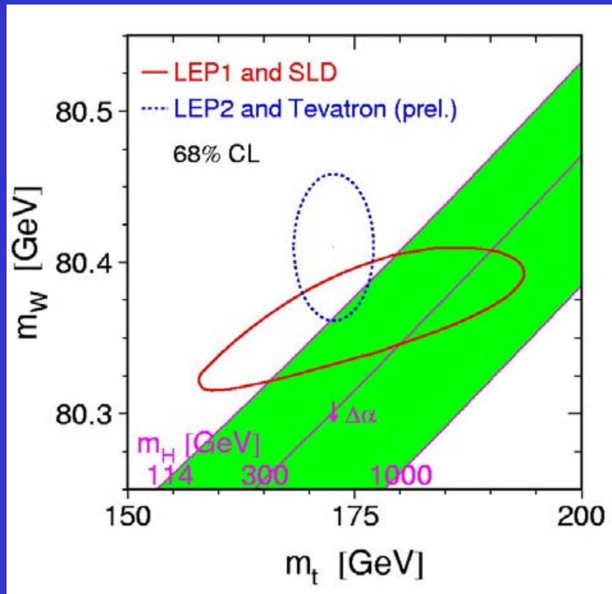
$4 \cdot 10^{-4}$

m_W (from LEP2 + Tevatron) = 80.410 ± 0.032 GeV

m_{top} (from Tevatron) = 172.5 ± 2.3 GeV

1.4%

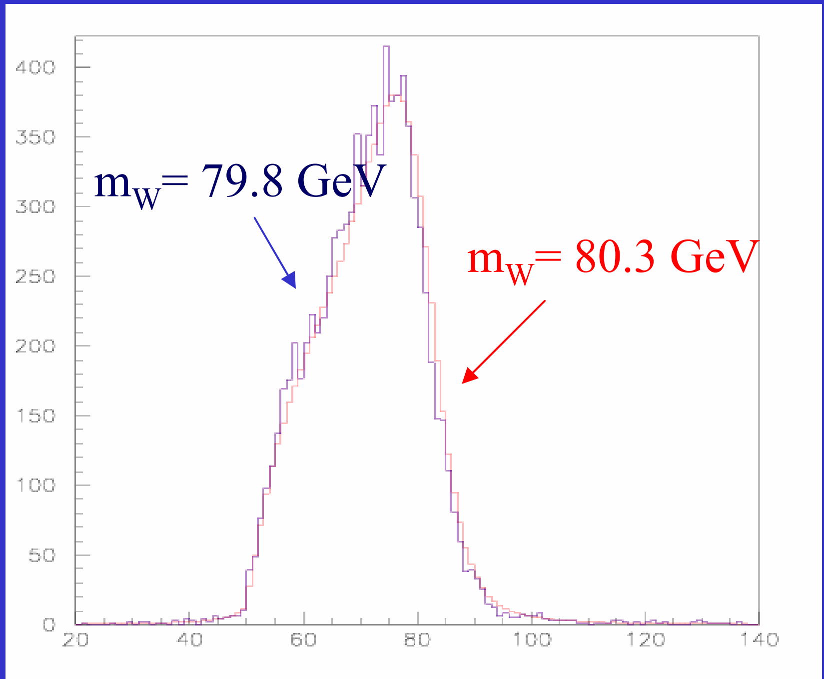




light Higgs boson is favoured by present measurements

Ultimate test of the Standard Model: comparison between the direct Higgs boson mass (from observation, hopefully) and predictions from rad. corrections….

The shape of the transverse mass distribution is sensitive to m_W



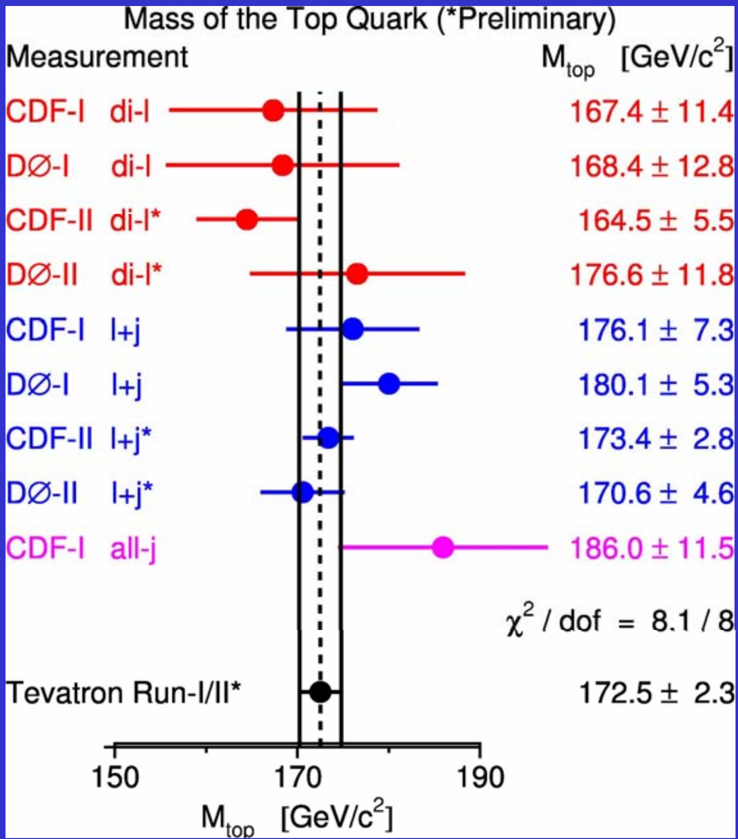
m_T^W (GeV)

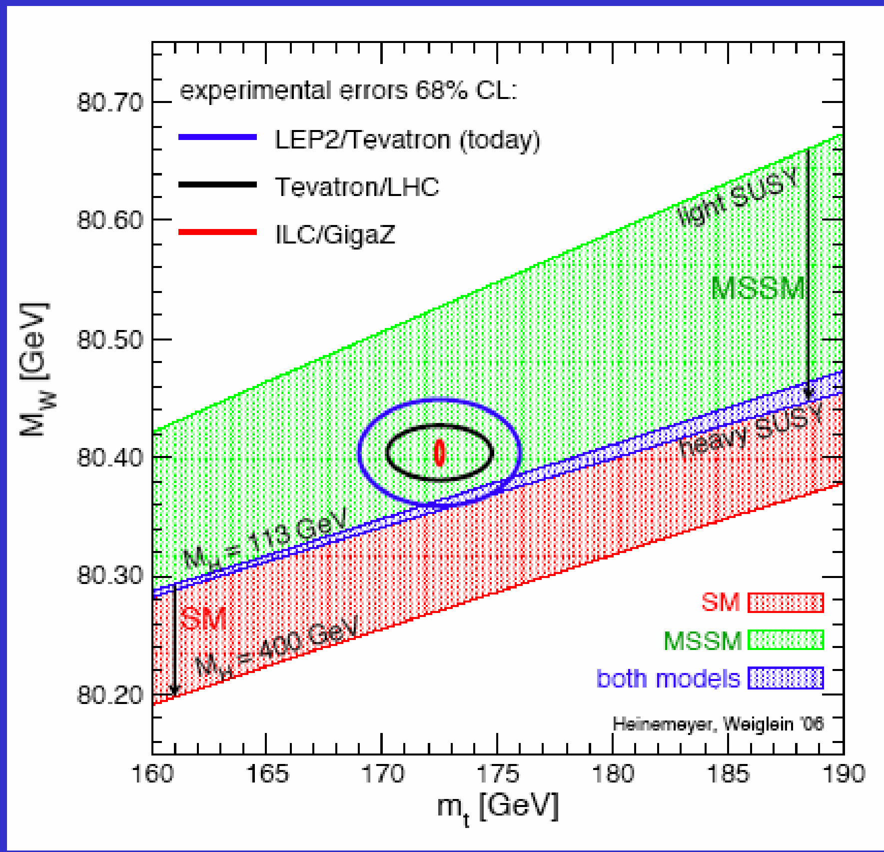
<u>Main uncertainties:</u>

- detector performance (energy resolution, energy scale, ….)
- theory: production model $p_T(W)$, G_W, …..
- backgrounds

Dominant error (today at theTevatron, and most likely also at the LHC) :
Knowledge of lepton energy scale of the detector !

Future Prospects for the top quark mass measurement

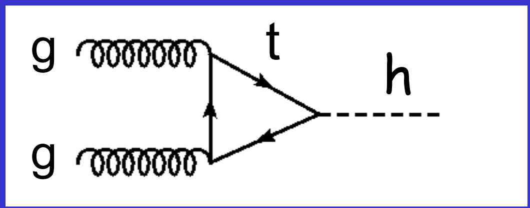




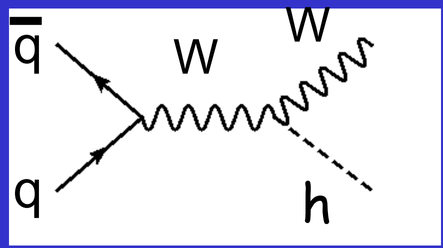
- Expected Tevatron precision : $\pm$ 1.5 GeV/c^2
- Expected LHC precision : ~ 1 GeV/c^2
- Expected ILC precision : ~ 0.1 GeV/c^2

Higgs production at LHC

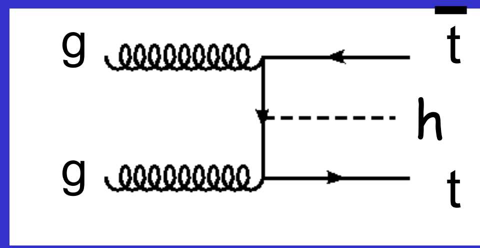
gluon-gluon fussion



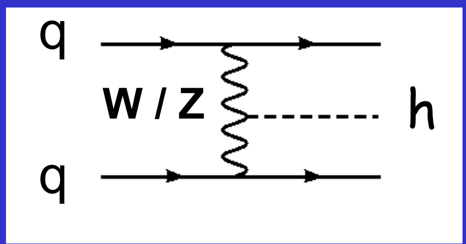
Associated to W



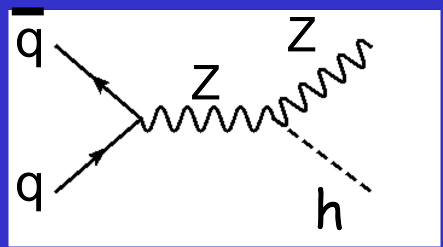
Associated to t



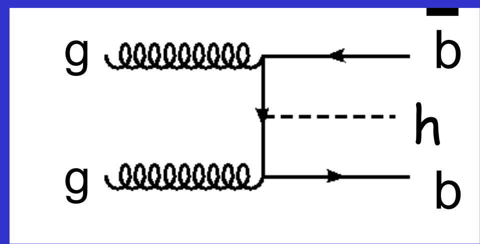
W/Z fussion



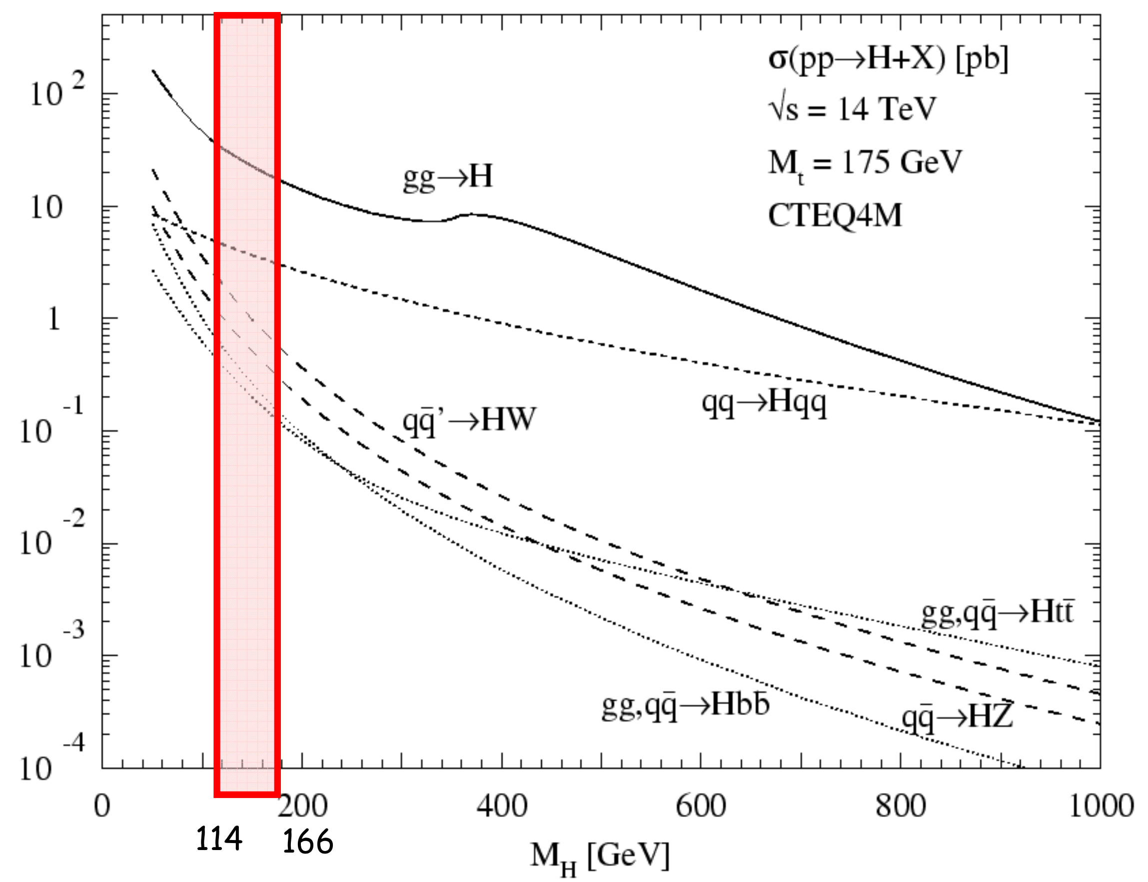
Associated to Z



Associated to b



Cross section production at LHC



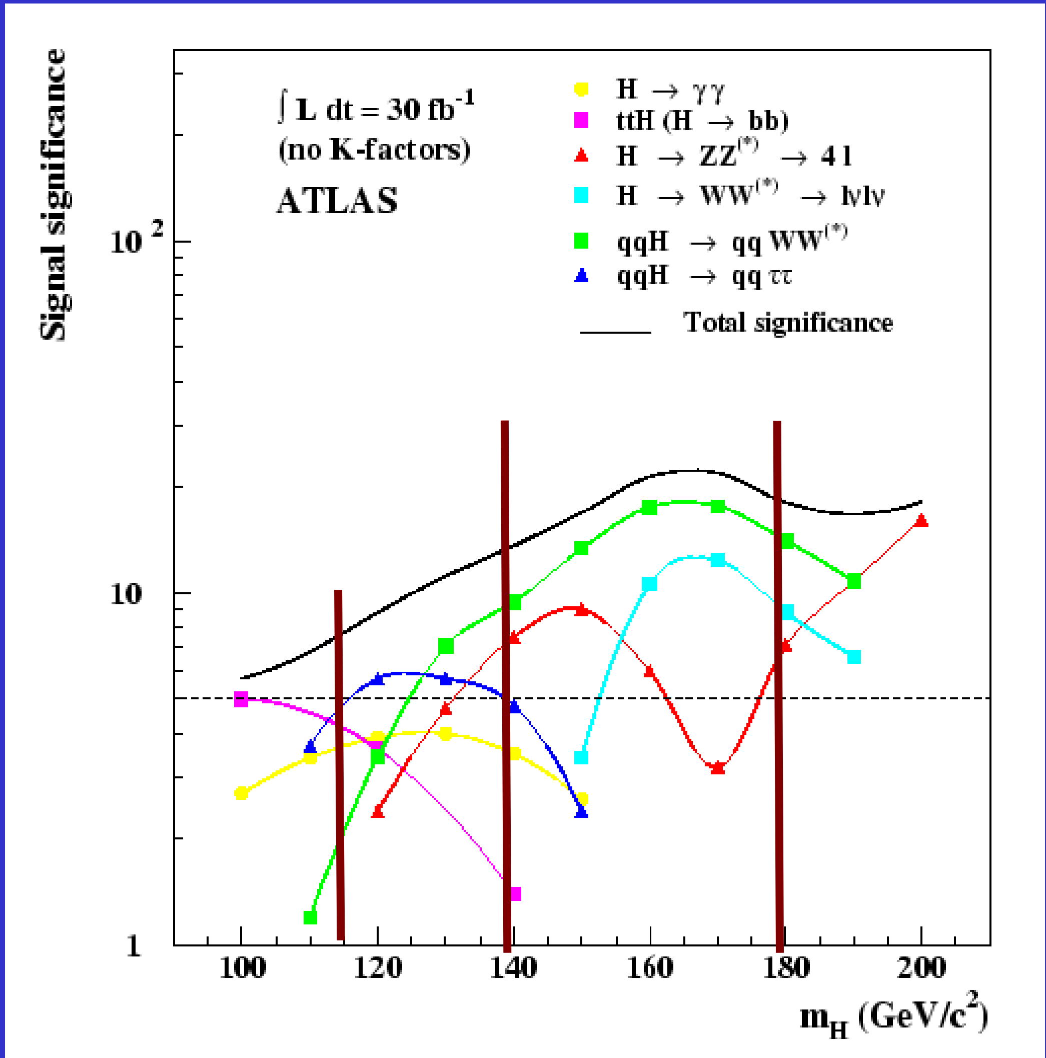
Region allowed

Example
m_h = 140 GeV

prod.	σ(pb)	Events/Y.
$g\,g \to h$	25	250 000
$W\,W \to h$	4.0	40 000
h W	1.2	12 000
h Z	0.6	6 000
h t t	0.2	2 000
h b b	0.3	3 000

Low luminosity

Significance at LHC



Significance $S = \dfrac{N\ (\text{siganl})}{\sqrt{N\ (\text{background})}}$

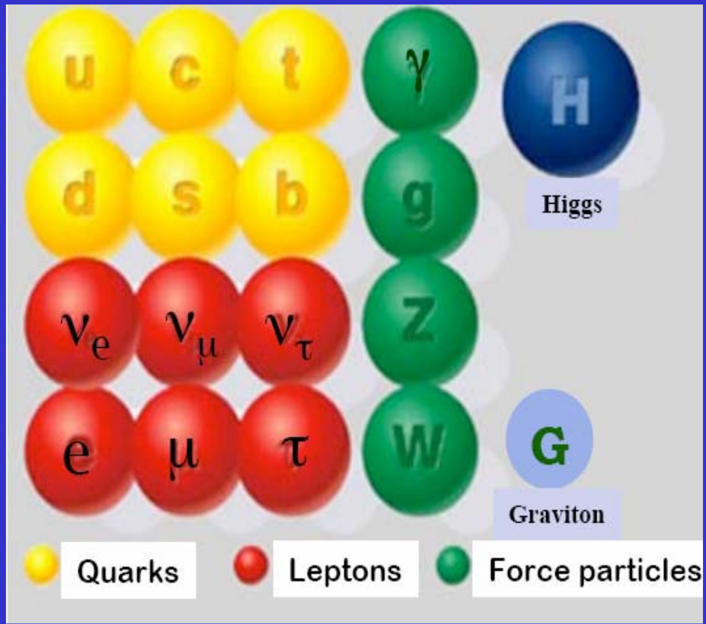
$L = 30\ fb^{-1}$ = 3 years@LowLum

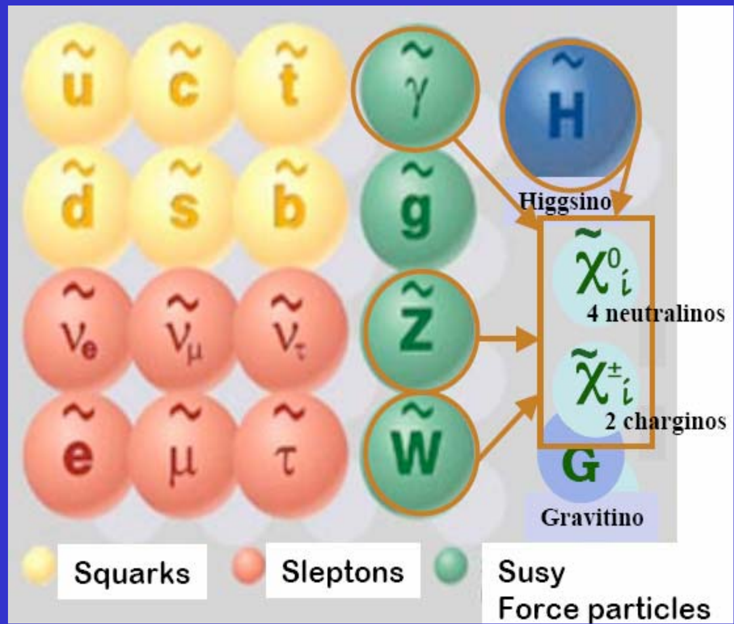
Discovery ⇒ S > 5

m_H=140 GeV		m_H=180 GeV	
$\gamma\gamma$	3	WW*	9
tt bb	1	ZZ*	7
ZZ*	7		
qq WW*	9	qq WW*	13
qq $\tau\tau$	5		
total S	13	total S	17

Supersymmetry

Extends the Standard Model by predicting a new symmetry
Spin ½ matter particles (fermions) ⇔ Spin 1 force carriers (bosons)





New Quantum number: R-parity: $R_p = (-1)^{B+L+2s}$ = +1 SM particles
- 1 SUSY particles

Experimental consequences of R-parity conservation:

- SUSY particles are produced in pairs
- Lightest Supersymmetric Particle (LSP) is stable.
  In most models LSP is also weakly interacting:
  LSP ≡ χ^0_1 (lightest neutralino)

  → LSP is a good candidate for cold dark matter

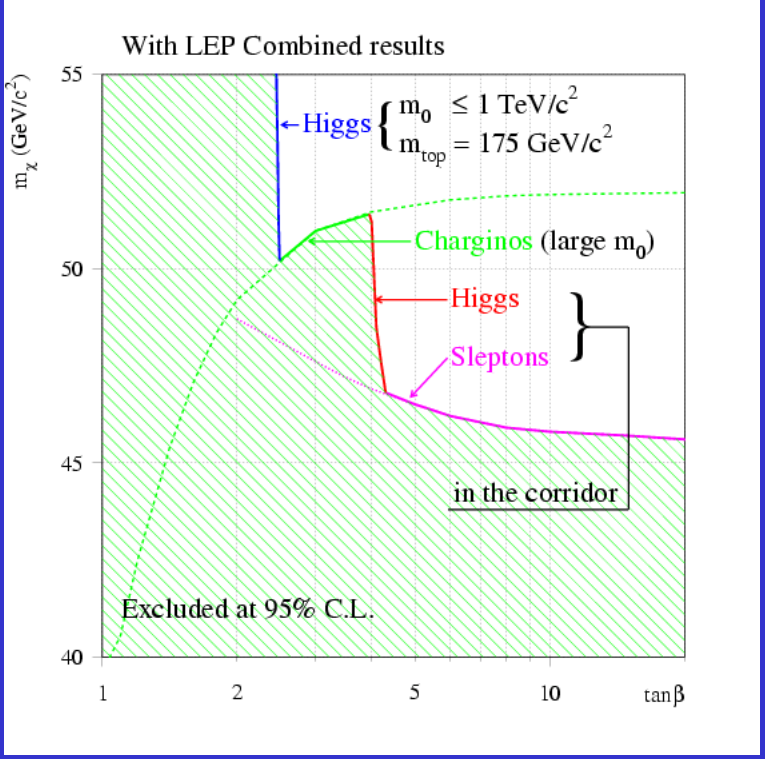
  → LSP behaves like a ν → it escapes detection

  → E_T^{miss} (typical SUSY signature)

The **masses of the SUSY particles** are not predicted;
Theory has many additional new parameters (on which the masses depend)

However, charginos/neutralinos are usually lighter than squarks/sleptons/gluinos.

<u>Present mass limits</u> :	m (sleptons, charginos)	>	90-103 GeV	LEP II
	m (squarks, gluinos)	>	~ 250 GeV	Tevatron
Run 1	m (LSP, lightest neutralino)	>	~ 45 GeV	LEP II



LEP-II limit on the mass of the Lightest SUSY particle

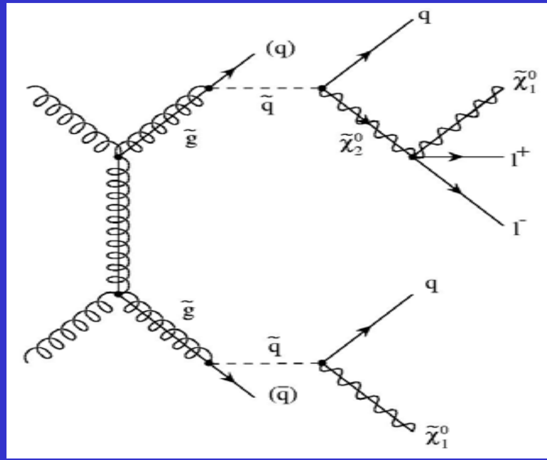
assumption:
lightest neutralino = LSP

Search for Supersymmetry at the LHC

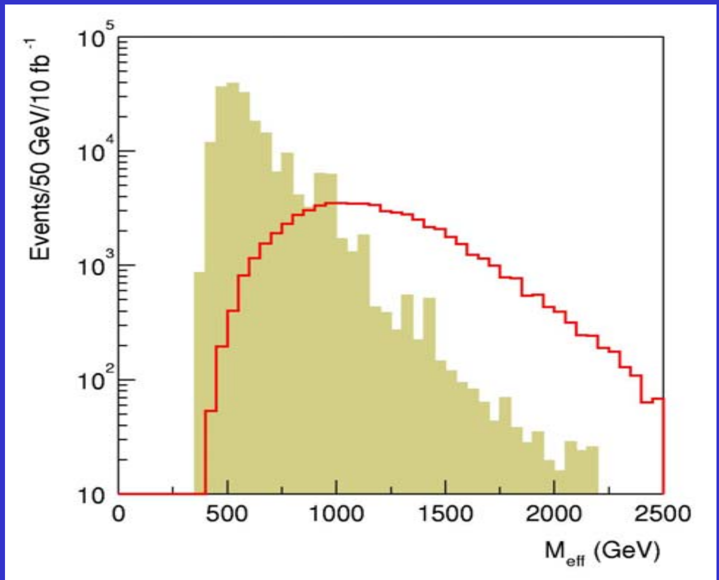
- If SUSY exists at the electroweak scale, a discovery at the LHC should be easy

- Squarks and Gluinos are strongly produced

  They decay through cascades to the lightest SUSY particle (LSP)



⇒ combination of Jets, Leptons, E_T^{miss}



LHC reach for Squark- and Gluino masses:

1 fb^{-1}	⇒	M ~ 1500 GeV
10 fb^{-1}	⇒	M ~ 1900 GeV
100 fb^{-1}	⇒	M ~ 2500 GeV

TeV-scale SUSY can be found quickly !

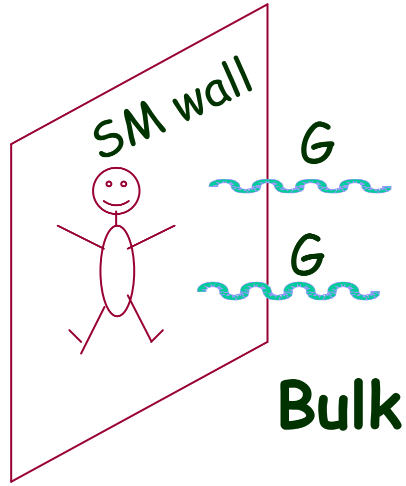
Extra dimensions at the LHC

- Much recent theoretical interest in models with extra dimensions
  Explain the weakness of gravity (or hierarchy problem) by extra dimensions
- New physics can appear at the TeV-mass scale
  i.e. accessible at the LHC

Example: **Search for direct Graviton production**

$$gg \rightarrow gG\,,\; qg \rightarrow qG\,,\; q\bar{q} \rightarrow Gg$$

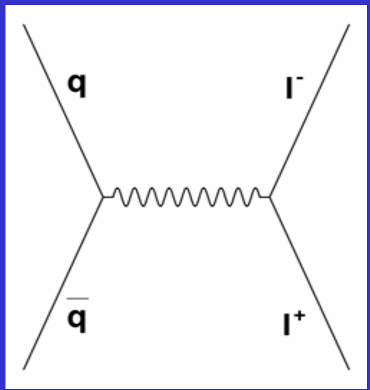
$$q\bar{q} \rightarrow G\gamma$$



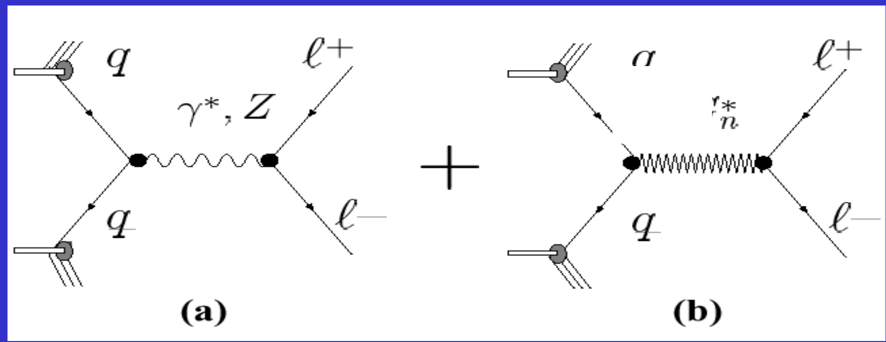
$\Rightarrow$ **Jets or Photons with E_T^{miss}**

Search for New Resonances in High Mass Di-leptons

Neutral Gauge Boson Z



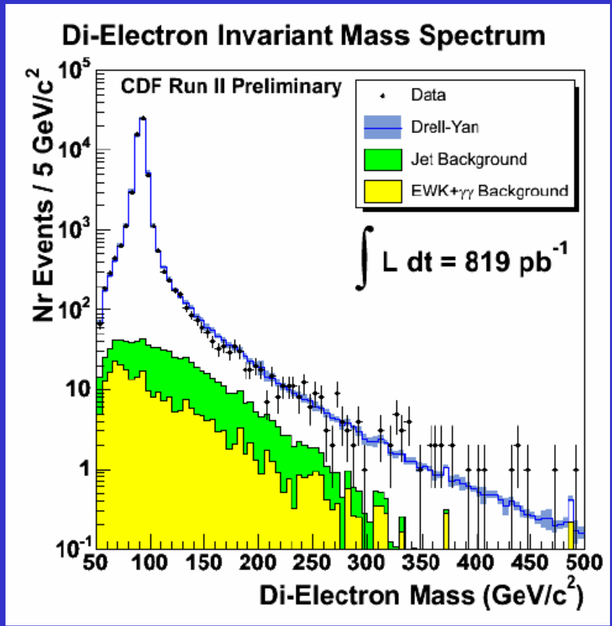
Neutral Gauge Boson Z'



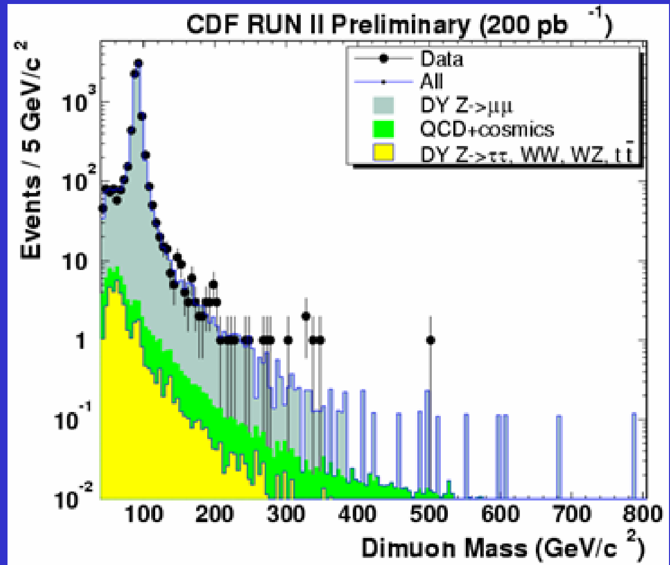
Main background from Drell-Yan pairs

Tevatron data and mass limits

Di-electron Invariant Mass



Di-muon Invariant Mass

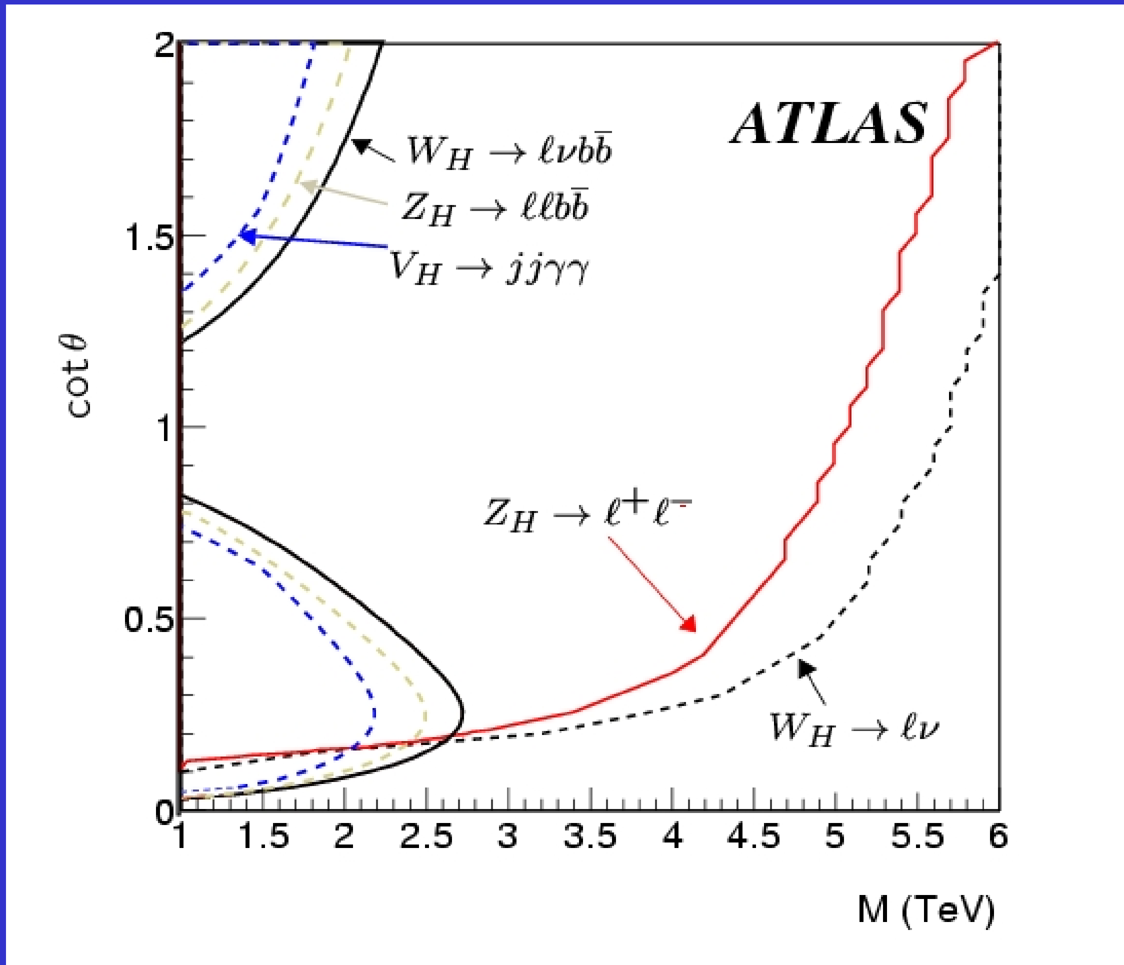


Data are consistent with SM background → No excess observed.

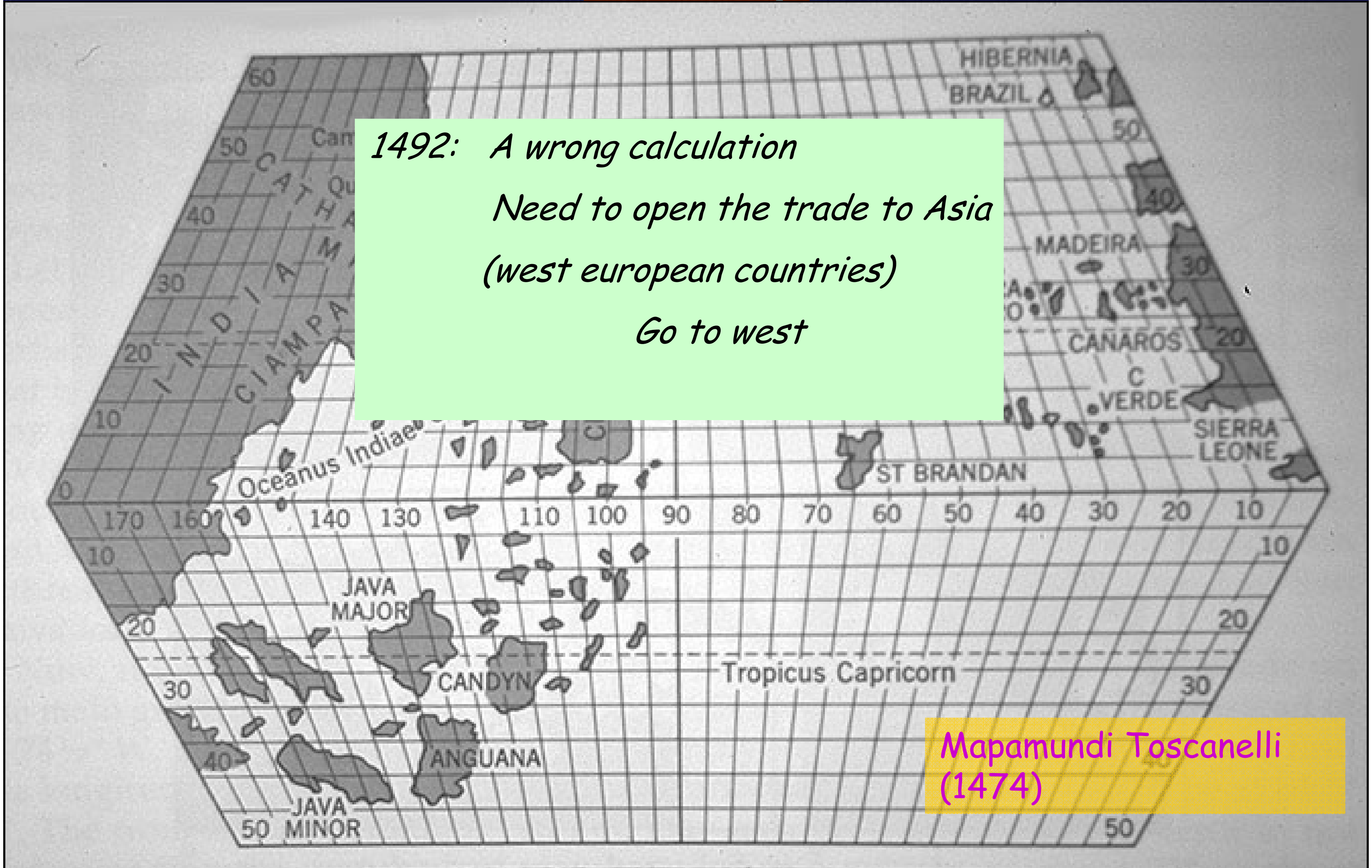
		ee	μμ	ττ	
Z´ mass limits (SM couplings)					
95% C.L.	**CDF /D0:**	**850**	**835**	**394**	**GeV/c^2**

Potential mass limits at the LHC

ATLAS discovery potential for Z_H and W_H assuming L=300 pb^{-1}



Summary



1492: A wrong calculation

Need to open the trade to Asia

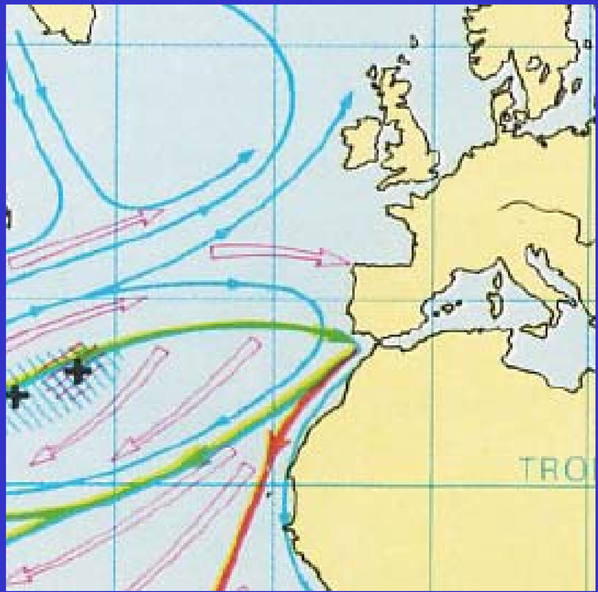
(west european countries)

Go to west

Mapamundi Toscanelli (1474)

One good idea

Before C. Columbus many attemps to go west were tried by Portuguese and English (even Vikings who seemed to have reached Greenland) but ….



The “alize winds” + see currents

always made these expeditions to

fail as they were opposite to the direction

if tried from the european cost

C. Columbus was a good sailor, who worked for the English and Portuguese navy companies for several years. He knew and learned about that…

He had the idea that before going west he should first go south to the Canary Islands, this time taking the “alize winds” in his favour..

Another good idea

Used of the most advanced technology: The Portuguese Carabelle

The portuguese carabelle combined the knowledge of the Hanseatic and Mediterranean sailing. They represented by that time the “state-of-the-art” in sailing.

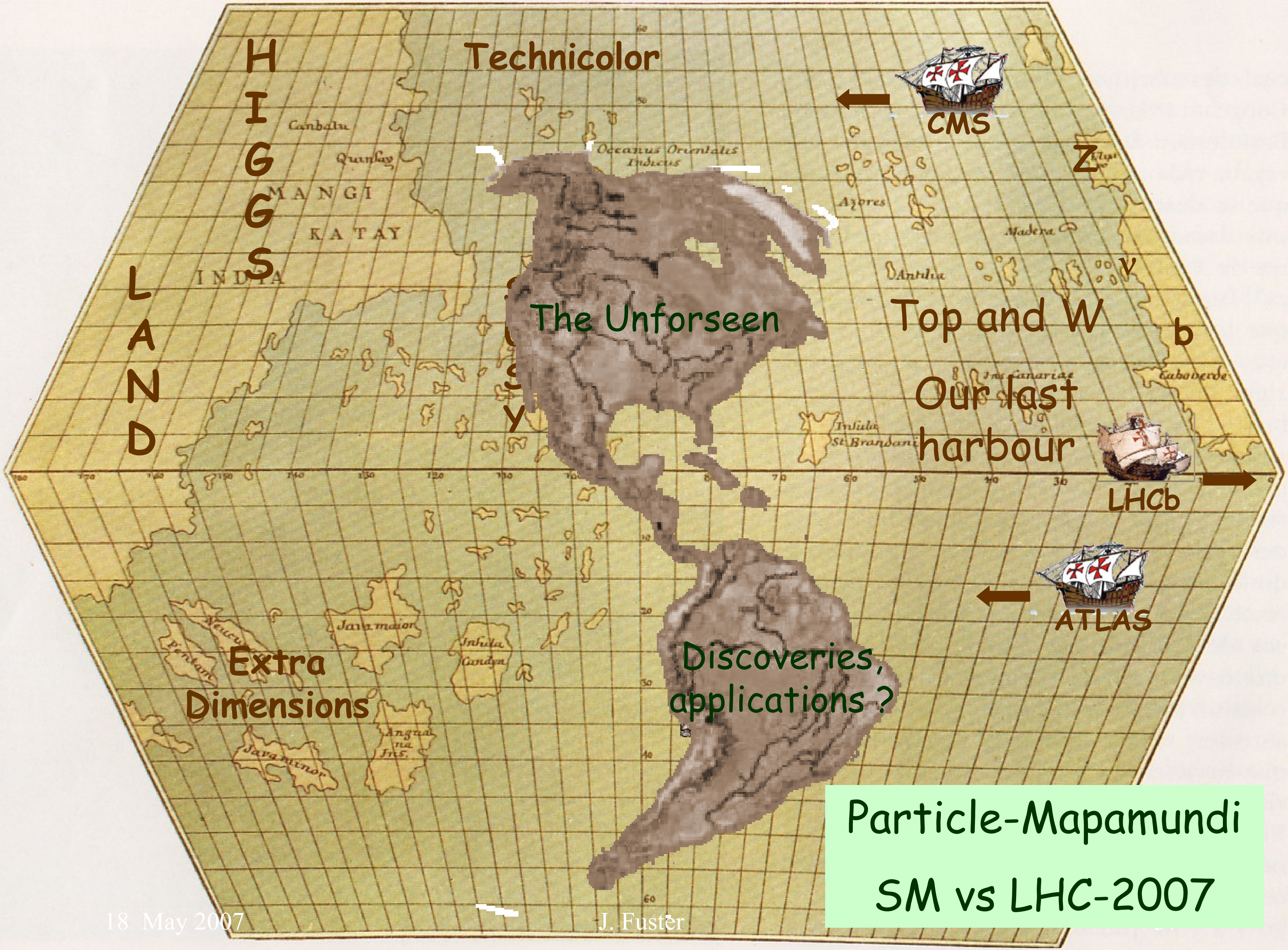
It was very fast, could sail for many different wind configurations, was small and optimized ratio crew/maintenance, etc…

In summary, thanks to:

- a wrong model of the earth
- high level of expertise in sailing
- use of the most performant technolgies of the time

The travel could succeed

(after being rejected by two scientific committees, Portuguese and Spanish)


HIGGS
LAND
Technicolor
CMS
Z
ν
Top and W
b
Our last harbour
LHCb
ATLAS
The Unforseen
Discoveries, applications ?
Extra Dimensions
Particle-Mapamundi
SM vs LHC-2007
Canbalu
MANGI
KATAY
INDIA
Oceanus Orientalis Indicus
Azores
Madera
Antilia
Ins Canarias
Caboverde
Insula St. Brandani
Java maior
Insula Candyn
Java minor