Electroweak and Top Physics at the Tevatron and the LHC

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Windows on the Universe

XXI Rencontres de Blois

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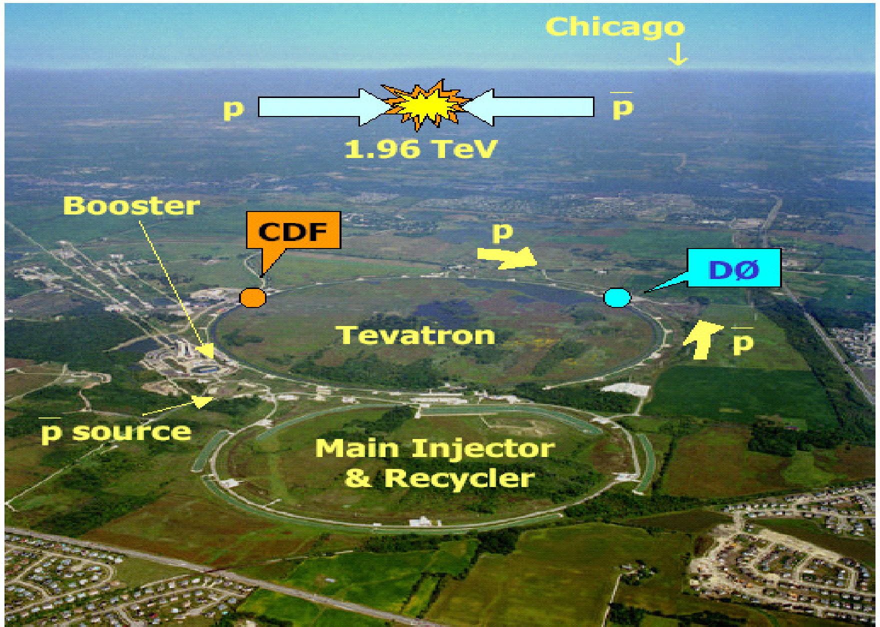
Tevatron and LHC



$\sqrt{s}$=1.96 TeV

- protons on antiprotons
  - ⇨ Bunch crossing every 396 ns
- 6.28 Km circumference
- 2 detectors (CDF and D0)

First p-pbar collision on October 13, 1985

- Run II started in 2001

Collider **D**etector at **F**ermilab
D0→collision point

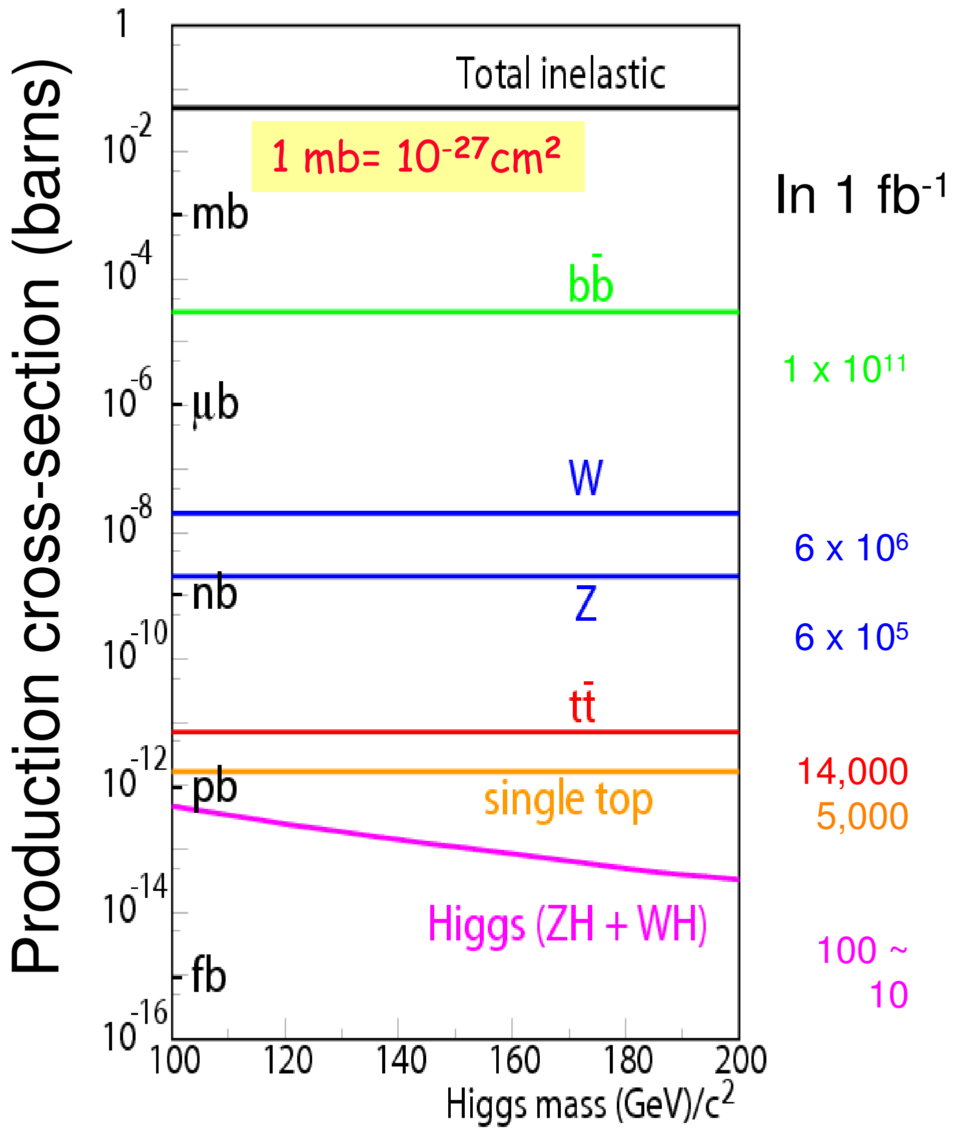
$\sqrt{s}$=14 TeV

- protons on protons
  - ⇨ Bunch crossing every 25 ns
- 27 Km circumference
- 5 detectors (two full purpose, ATLAS and CMS)
- First collisions:
  - ⇨ See S. Bertolucci's talk

A **T**oroidal **L**hc **A**pparatu**S**
Compact **M**uon **S**olenoid

The Tevatron Environment

Present (Tevatron)



typically today we run at $L=2x10^{32}cm^{-2}s^{-1}$...means

- several interactions per crossing
  - ⇨ Tough life
- ...we can go down in the ladder on the left and study rare processes $O(10^{-12})$ inelastic
  - ⇨ Provided that our triggers can select the needle in the haystack

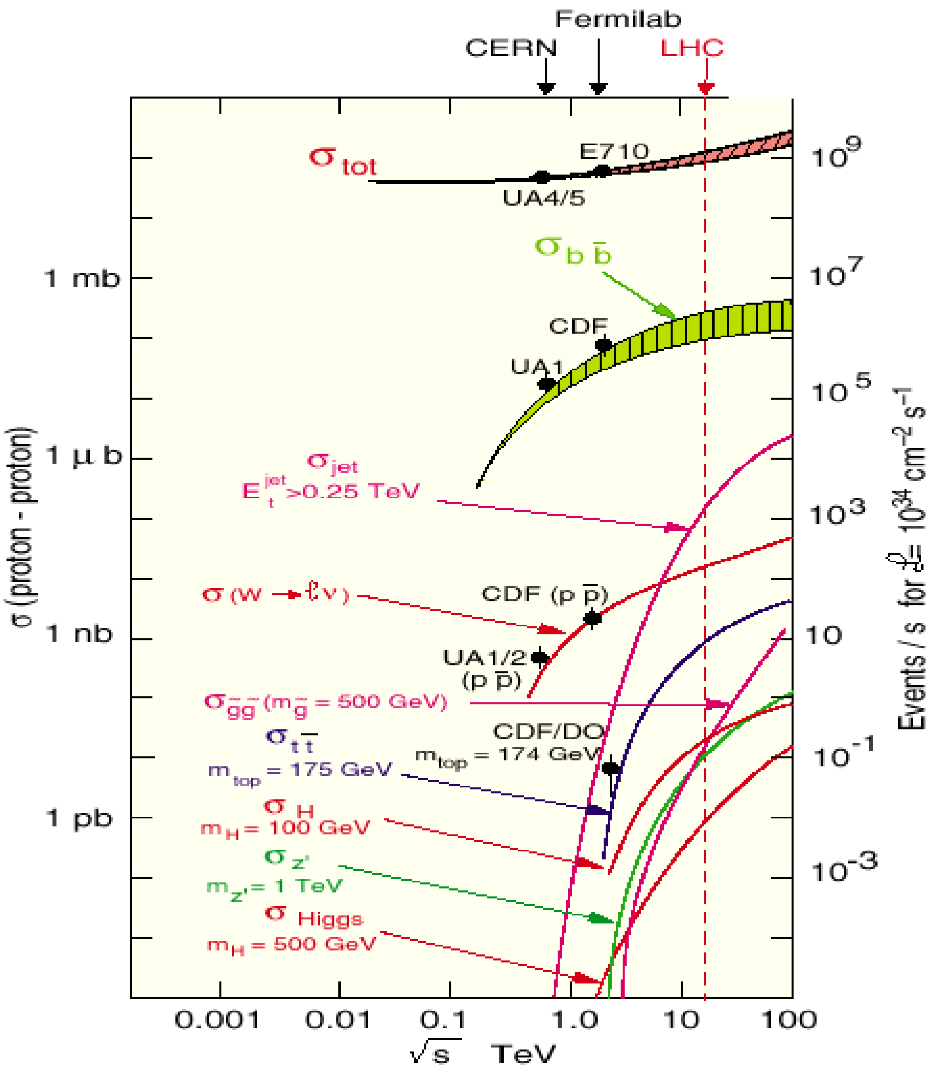
The LHC Environment

pp interacting at $\sqrt{s}$=14 TeV

- ☞ Increase in cross sections

crossing every 25 ns

- ☞ $L=10^{34}cm^{-2}s^{-1}$
- ☞ Life is even tougher
  - ⇨ Expected (on avg) ~14 interactions/crossing
- ☞ The large L, together with very large c.o.m. energy provides unique opportunities



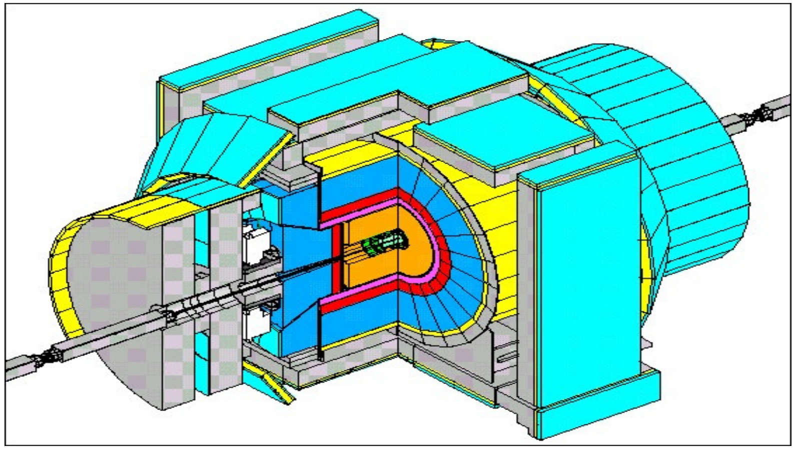
Again, triggering is the key

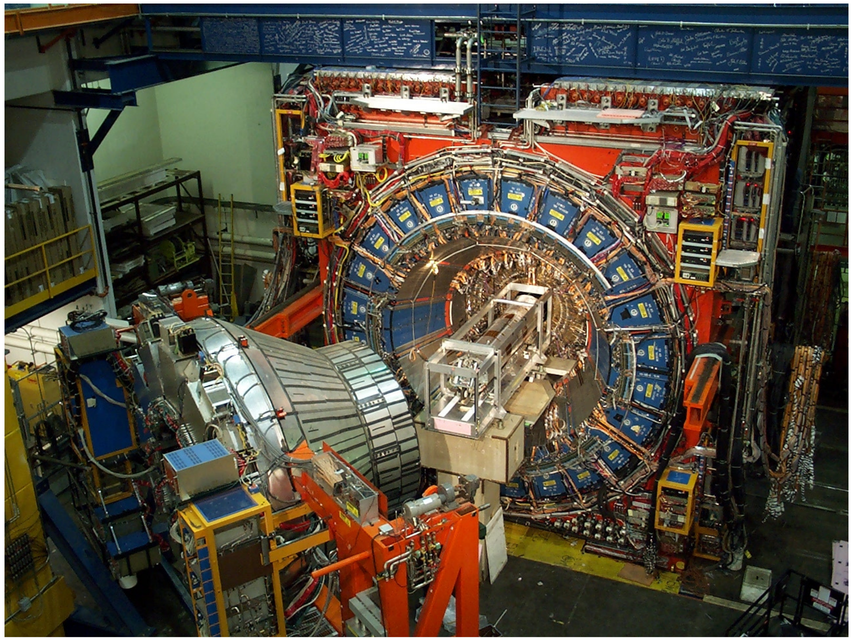
- ☞ Robust, redundant, well working detectors
  - ⇨ So far we know that the two detectors dedicated to high-pt physics (ATLAS and CMS) are working well

Startup com energy: 10 TeV
more on Thursday in S.Bertolucci's talk

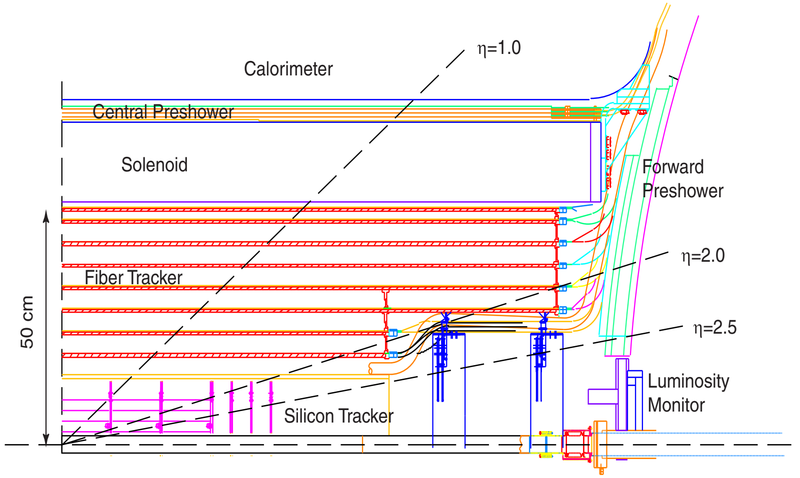
Our tools at the Tevatron

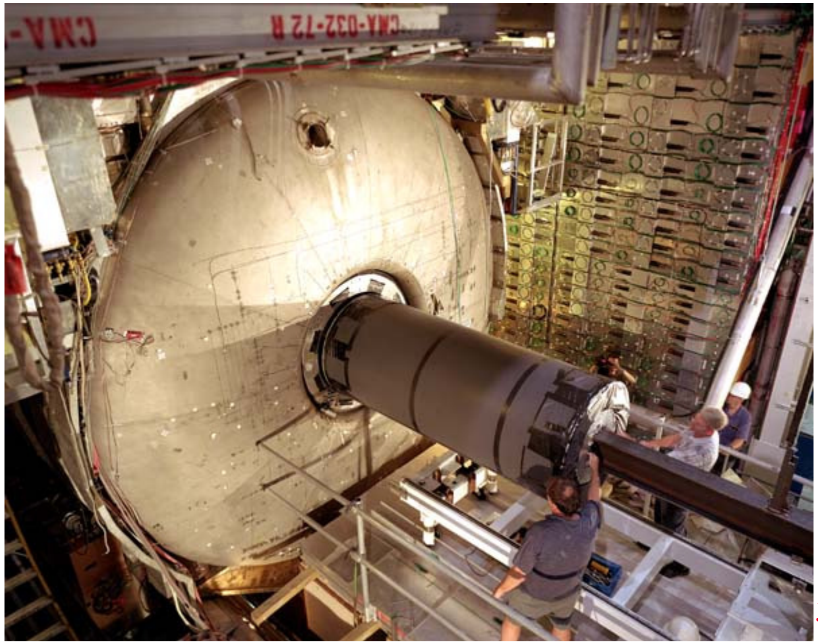
CDF





D0



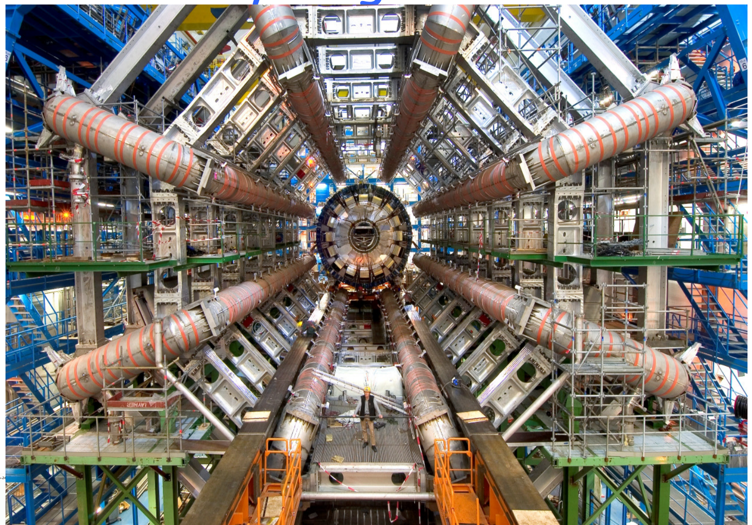


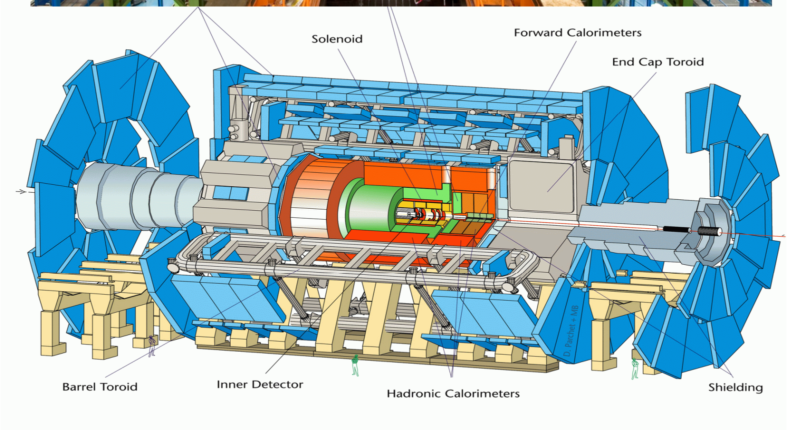
Our tools at the LHC

ATLAS

☞ Large magnetic spectrometer

⇨ Muons identified by using very large toroids in air

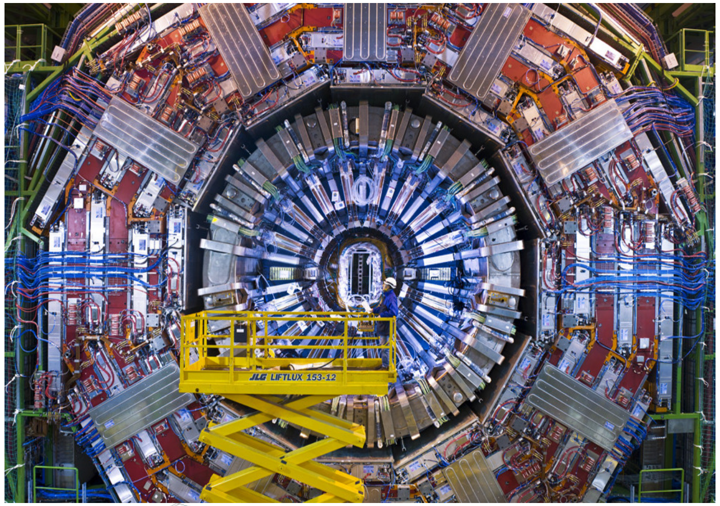


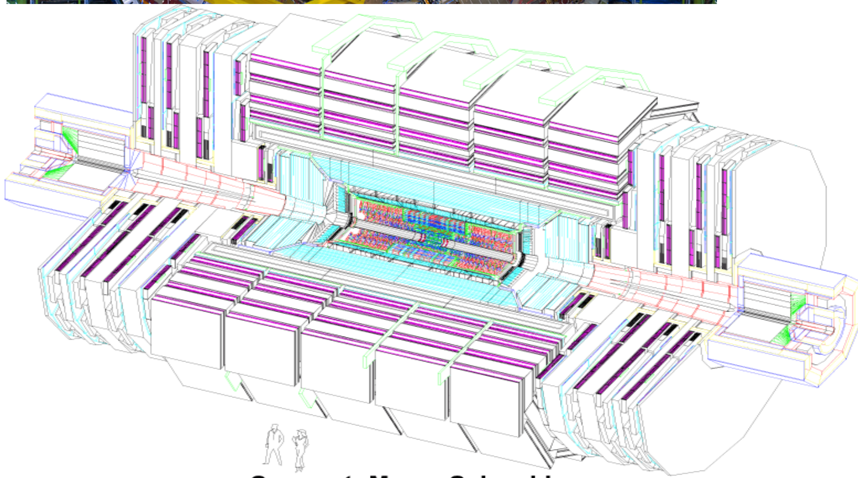


CMS

☞ Compact Muon Solenoid

⇨ Strong B field (4T)

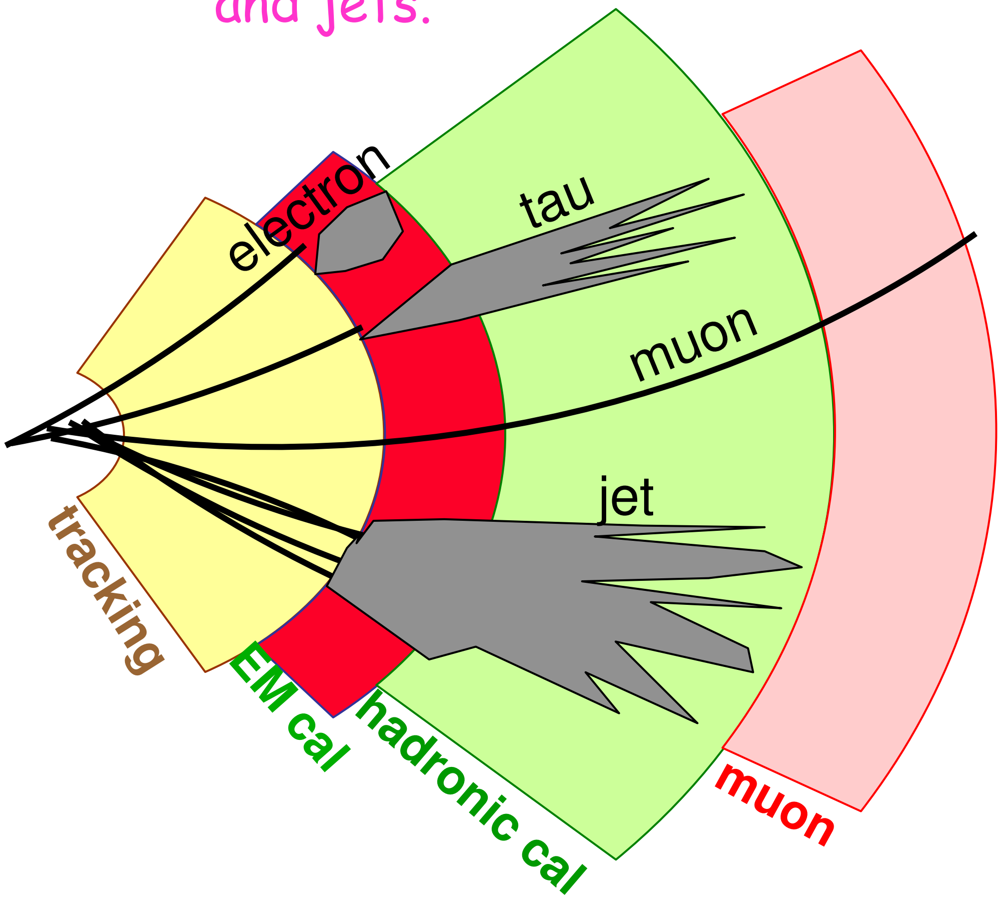


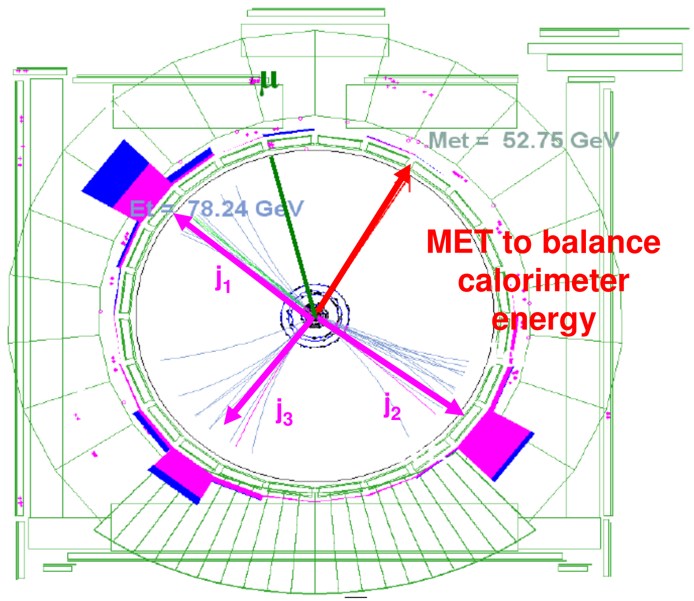


Experimental Signatures

EWK and Top Physics

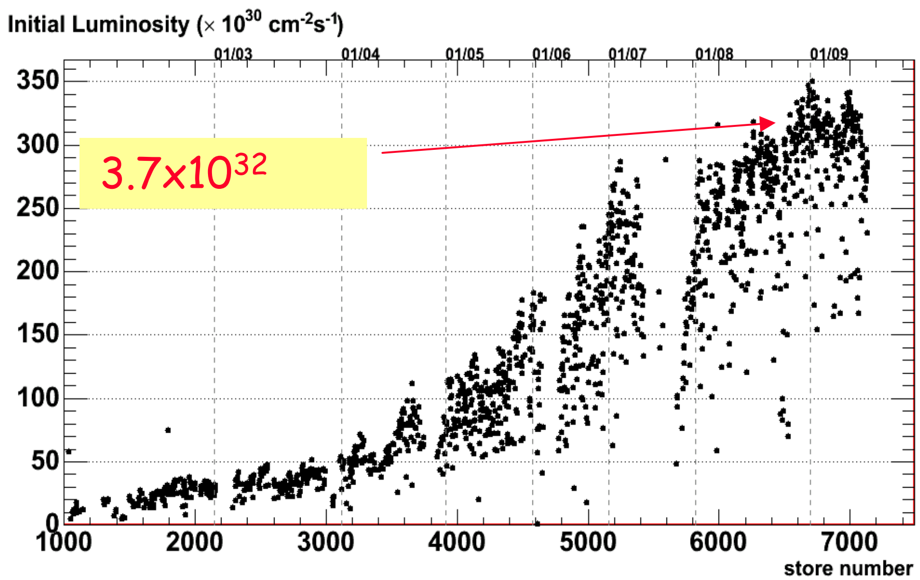
☞ mostly done with high p_T leptons (ν, e, μ and τ) and jets.

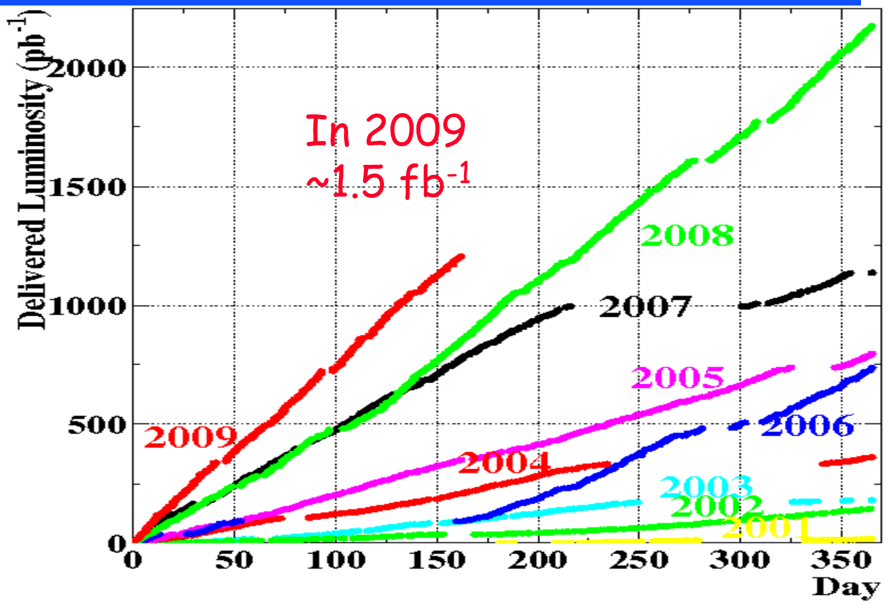


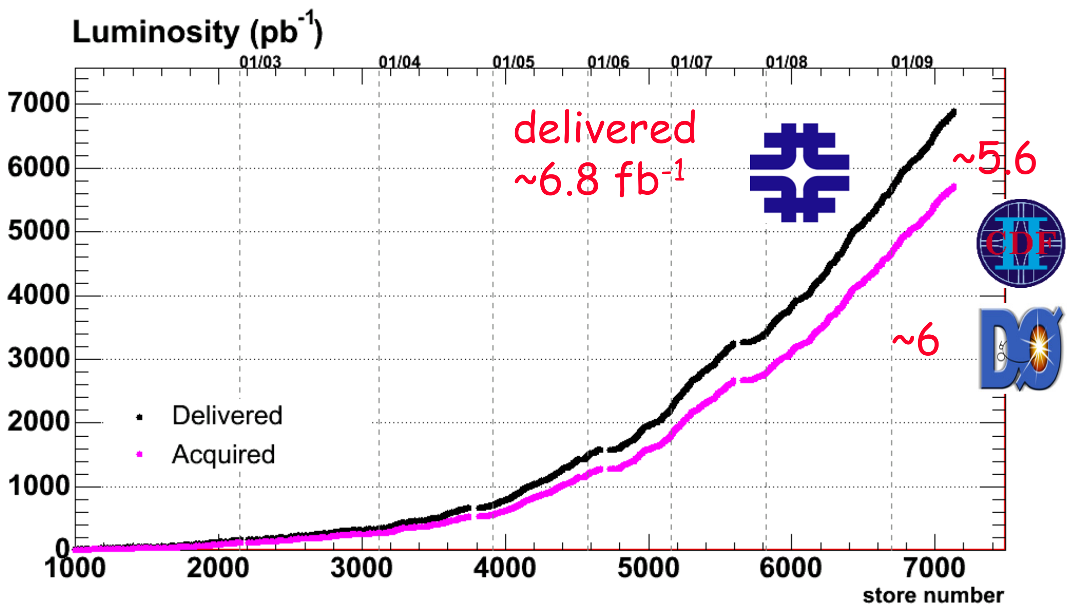


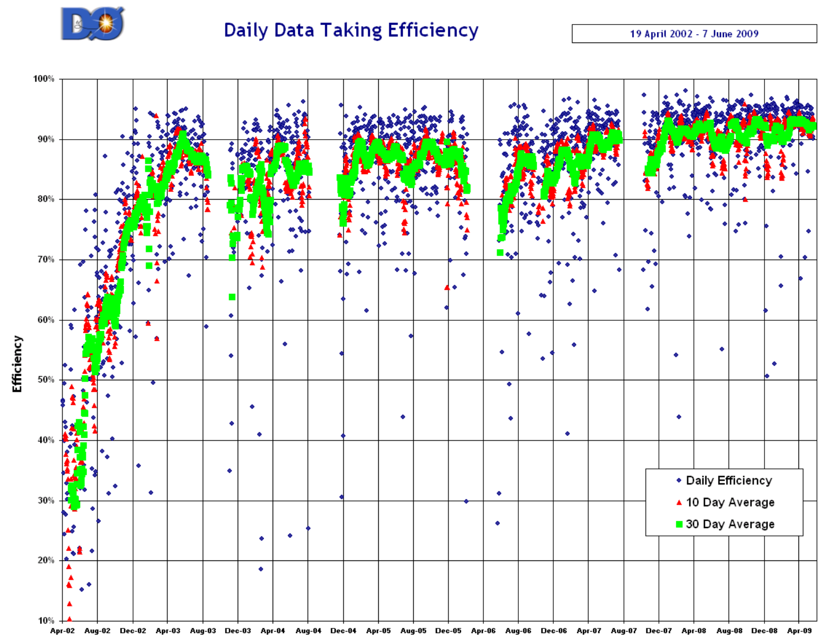
Presence of neutrinos is revealed via Missing Transverse Energy (MET) in the calorimeter.

Rare processes: luminosity is the key









Caveat on this talk

Electroweak and top physics represent a program rather than a set of analyses

- ☞ To put things in perspectives:
  - ⇨ ATLAS Physics Technical Design Report (2009): 316 pages
  - ⇨ CDF:
    79 published papers (D0 similar number)
- ☞ I decided to choose a few topics comparing Tevatron results/perspectives with results that should come from first years of LHC
  - ⇨ After W,Z discovery at SppS, Tevatron results show that hadron colliders can do precision measurements of ElectroWeaK observables
    - → Path for the future

W and Z Physics at hadron colliders

W,Z decay into fermion pairs:

→ $W^{\pm} \to l\nu, qq'$; $Z^{o} \to ll$, q-qbar

☞ Production

- ⇨ Test of N(N)LO calculations
- ⇨ Basic understanding of detectors and environment (p.d.f.)
- ⇨ Early measurements by CDF and D0 in Run II
  - → Expected to be the same for ATLAS and CMS

☞ Mass:

- ⇨ M_W sheds light on the Electroweak Symmetry Breaking (EWSB) mechanism

☞ Associated production of W,Z with:

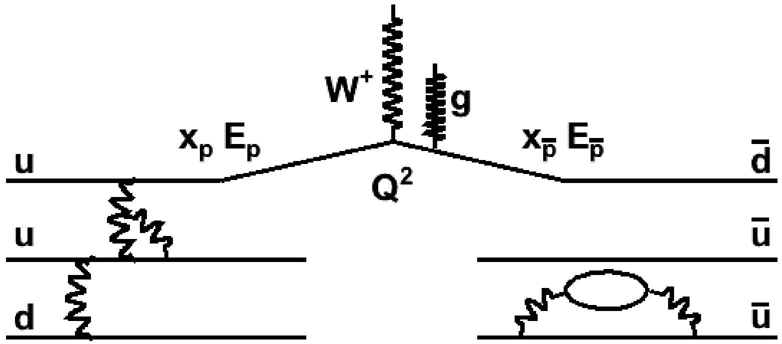
- ⇨ Bosons (γ,W,Z)
  - → Test of SM (gauge couplings)
  - → Processes are cornestone for Higgs searches, top physics
- ⇨ Jets
  - → Test of QCD and estimate of backgrounds for top, Higgs

W and Z boson production

Test of QCD

☞ Can be used to check calculations

- ⇨ Next to Leading Order (NLO) since long time
- ⇨ Next-NLO
  - → (recently with full spin correlations)



$$\sigma = \Sigma_{ab} \int dQ\, \delta(Q - 2E_p\sqrt{x_p x_p}) \int dx_p\, f_a(x_p, Q) \int dx_p\, f_b(x_p, Q)\, \hat{\sigma}(Q)$$

Sum over quarks, gluons

Kinematic constraint

Parton distribution functions

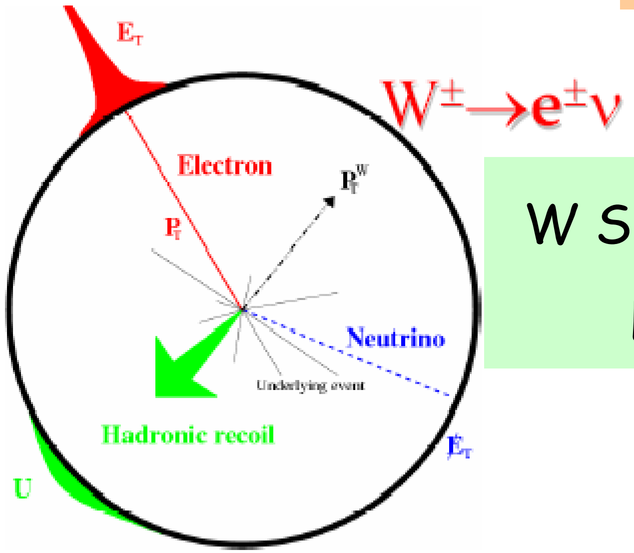
Calculable hard scattering cross section

Boson Signatures

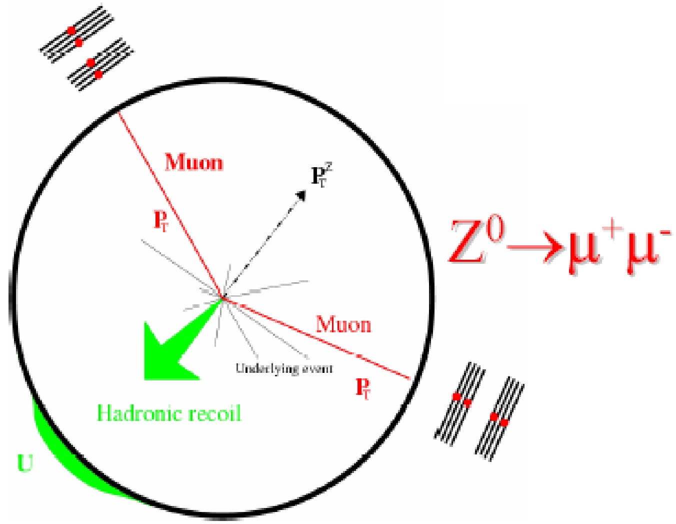
Electron:
EM Calorimeters
High Pt (Track)
Isolated

Muons:
Muon Detectors
High P_T
Isolated

Neutrinos:
Large Missing Energy
Only Transverse ($\not\!E_T$ or Met)

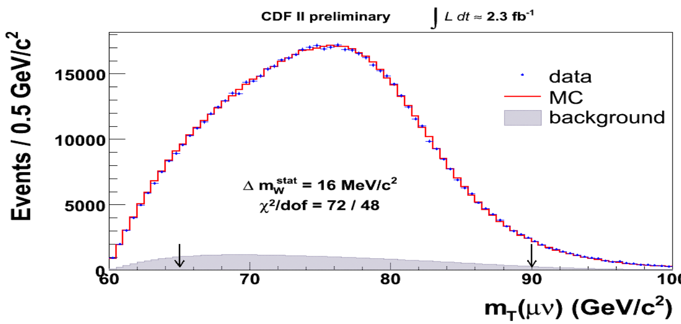


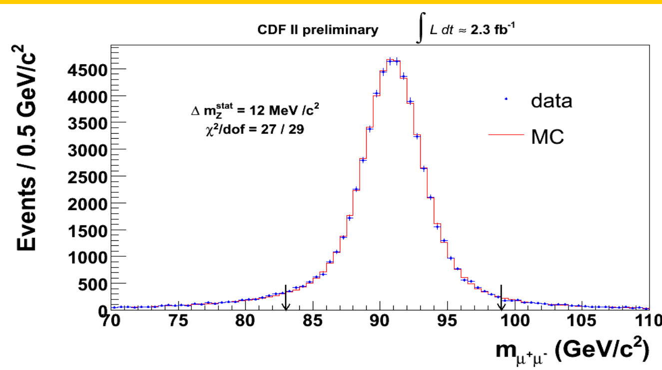
W Signature: Isolated Lepton and $\not\!E_T$



Z Signature: Two Isolated Leptons (diff charge)

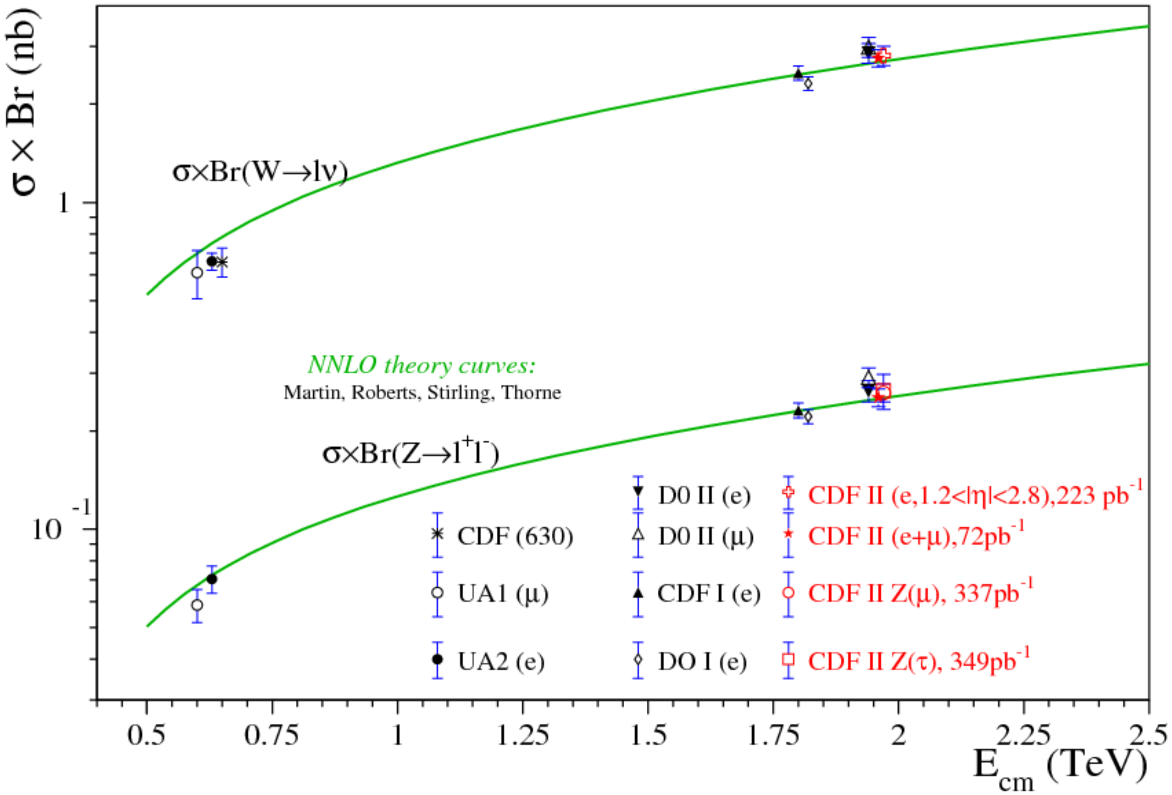
$$m_T = \sqrt{2p_T^e p_T^\nu(1 - \cos(\phi_e - \phi_\nu))}$$





25 years of σ(W,Z) at hadron colliders

In one slide..



Next points will be set by ATLAS and CMS at 14 (10) TeV

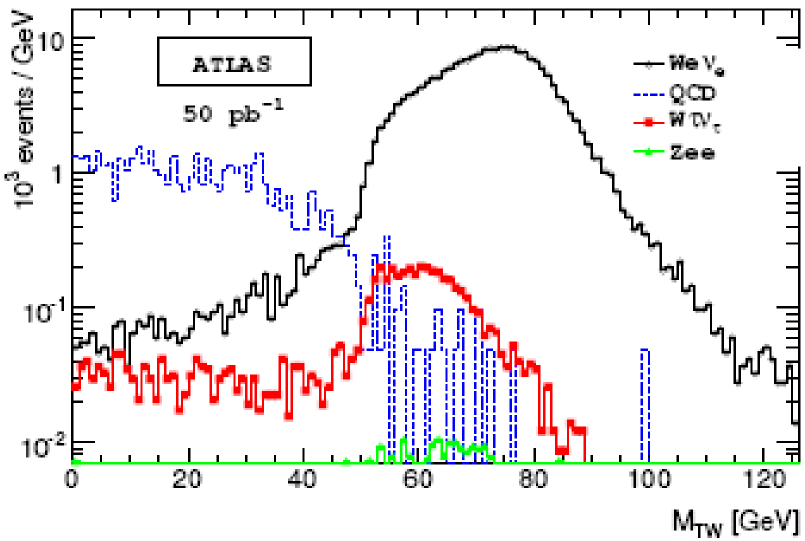
σ(W→eν)= 20 (12) nb

σ(Z→ll)= 2 (1.2) nb

LHC perspectives

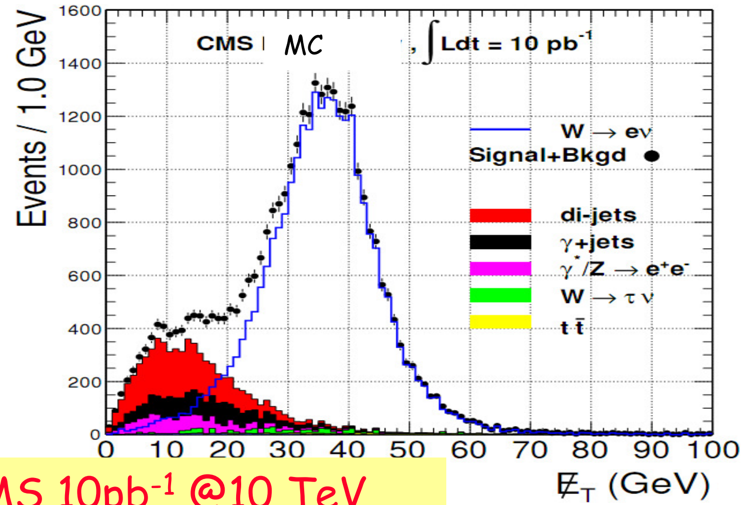
Both ATLAS and CMS plan on early days measurements of σ(pp→W,Z)

☞key to understand efficiencies, backgrounds

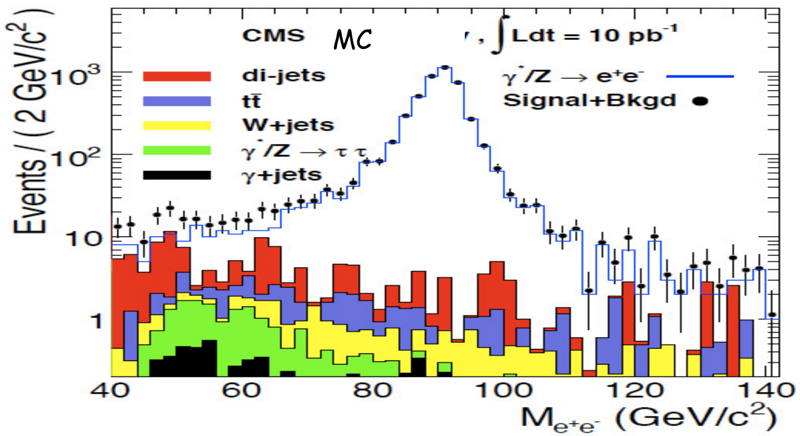


N. events(x10^4) in W→eν channel, after all selections, ATLAS in 50pb^{-1}, 14 TeV

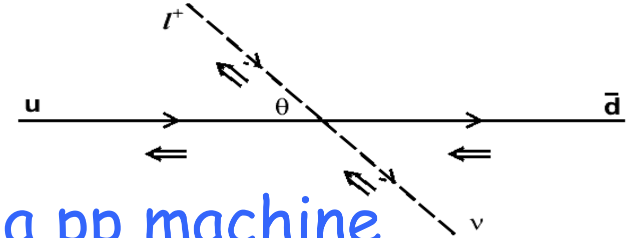
Selection	$W \to e\nu$	jets	$W \to \tau\nu$	$Z \to ee$
Trigger	37.01 ± 0.09	835 ± 18	1.73 ± 0.02	6.07 ± 0.01
$E_T > 25$ GeV, $\|\eta\| < 2.4$	30.84 ± 0.09	383 ± 12	1.03 ± 0.01	3.23 ± 0.01
Electron ID	26.77 ± 0.09	110 ± 6	0.91 ± 0.01	2.95 ± 0.01
$\not{E}_T > 25$ GeV	22.06 ± 0.09	4.6 ± 0.7	0.55 ± 0.01	0.06 ± 0.01
$M_T > 40$ GeV	21.71 ± 0.08	1.5 ± 0.4	0.43 ± 0.01	0.04 ± 0.01



CMS 10pb^{-1} @10 TeV



W Asymmetry

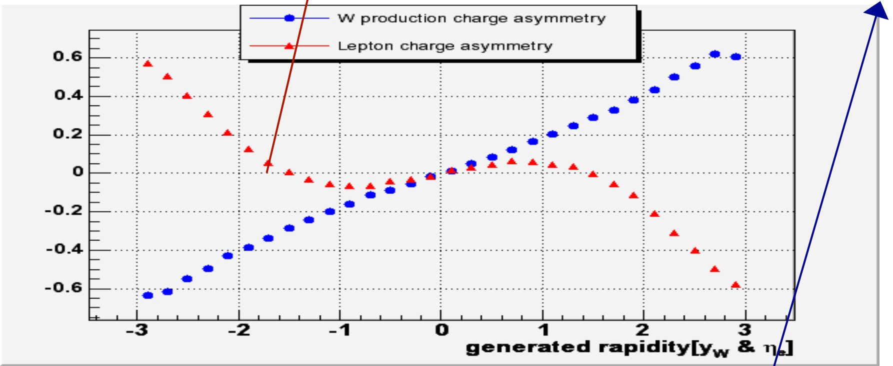


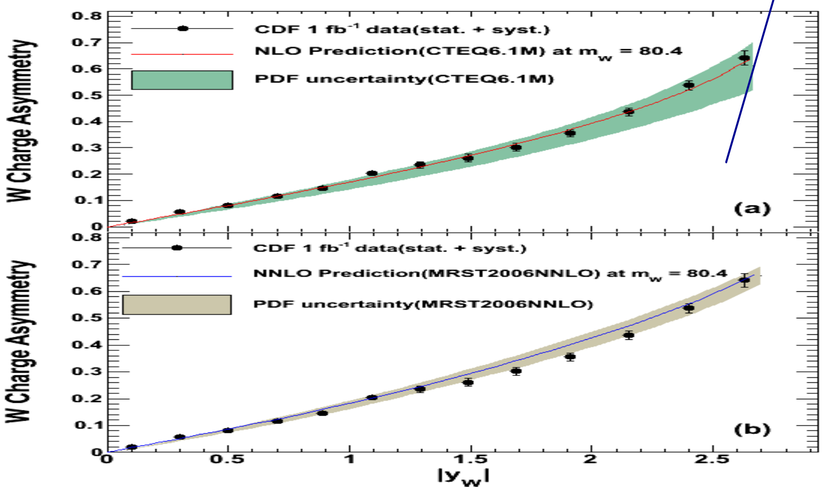
Traditional way to get some input on p.d.f.

- Largely exploited at Tev

$$A_l(\eta) = \frac{d\sigma(l^+)/d\eta - d\sigma(l^-)/d\eta}{d\sigma(l^+)/d\eta + d\sigma(l^-)/d\eta}$$

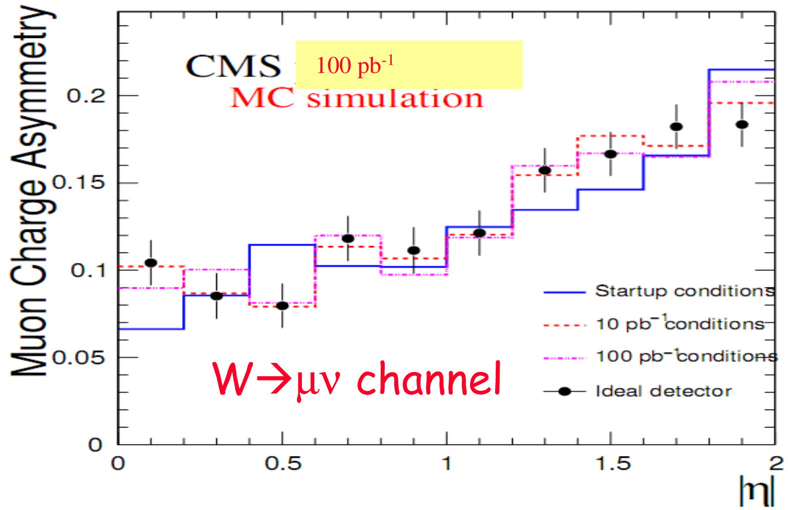
$$A(y_W) = \frac{d\sigma_+/dy_W - d\sigma_-/dy_W}{d\sigma_+/dy_W + d\sigma_-/dy_W}$$





LHC is a pp machine

- Intrinsic charge asymmetry of W production due to different contribution of valence quarks
  - ⇨ Systematics and bckg well understood



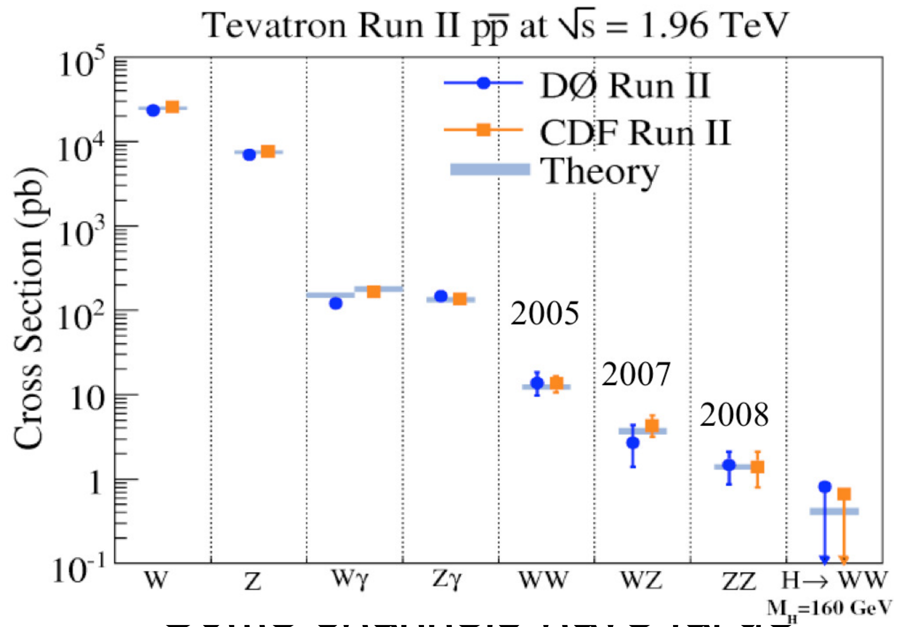
- Also:
  - ⇨ Ratio of central to forward σ(W) wrt NNLO calculations [CDF]

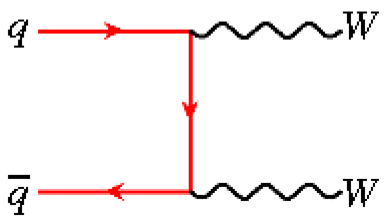
Dibosons

WZ,ZZ,WW,Wγ,Zγ

- x-sections at NLO
- Possibility NP: Trilinear Gauge Couplings
- Background for Higgs searches and for top physics

Tiny cross sections



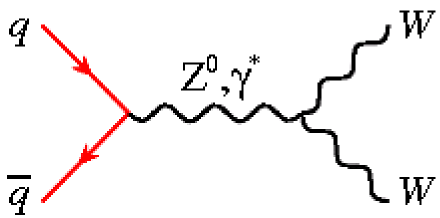


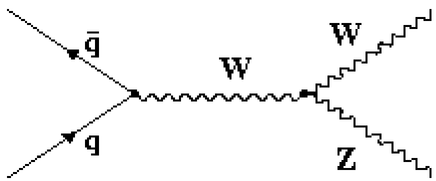
/ Z

B/S ratio

⇨ No counting experiment

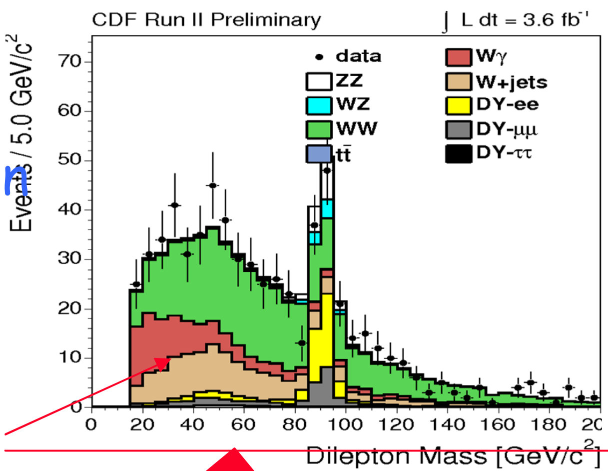
→ Need of "advanced techniques" to identify signal

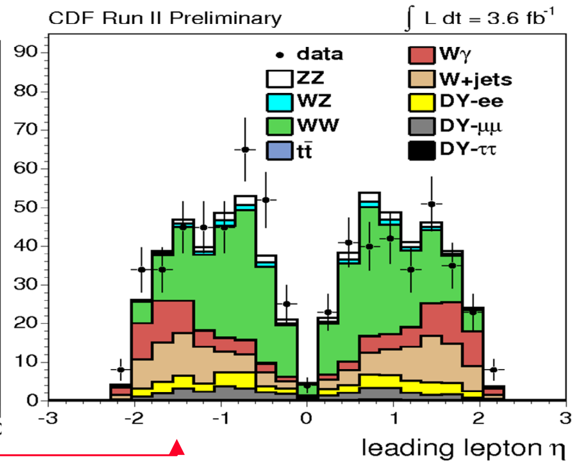


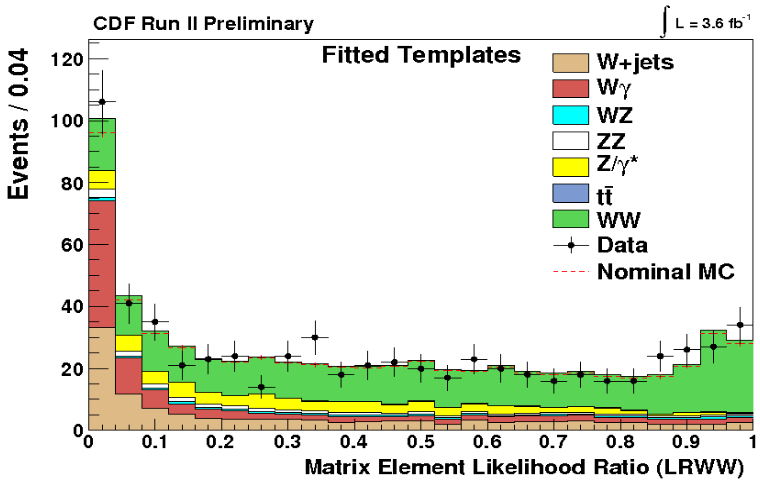


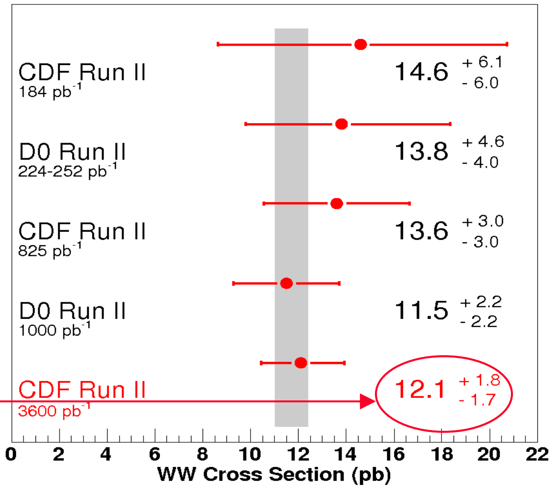
EWK- Diboson

- WW:
  - Recent CDF results with 3.6 fb^{-1}
  - Use of multivariate technique (ME LR) in WW→llνν channel





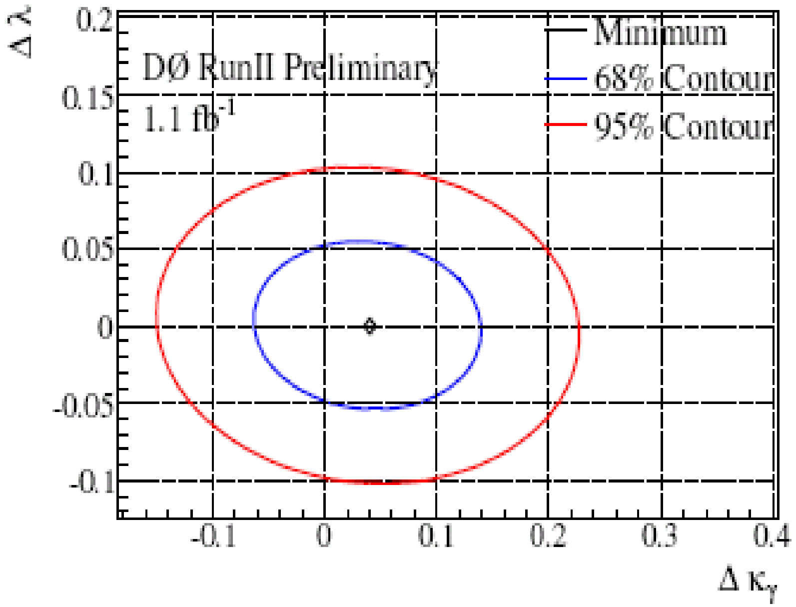




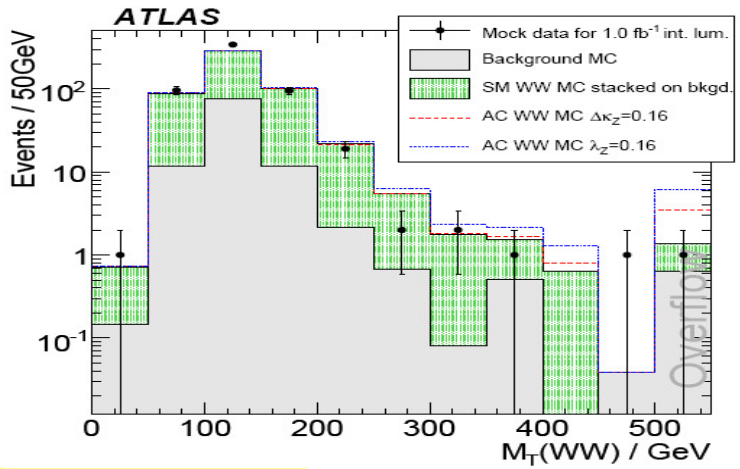
Window on the unknown

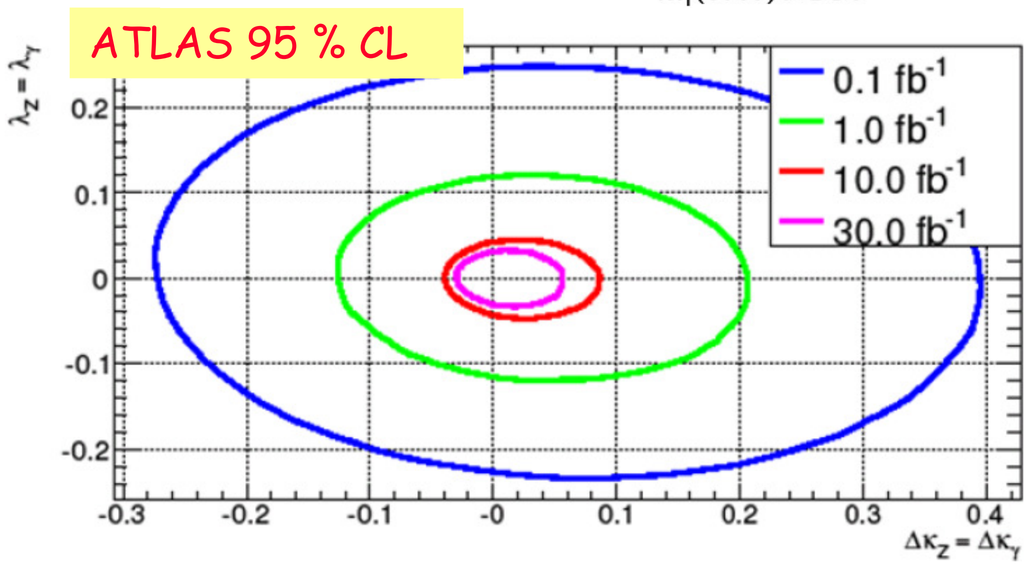
WW, WZ production through s-channel carries info on NP effects

- ☞ Scale larger than 1 TeV accessible
  - ⇨ Using its WW measurement, D0 recently updated TGC limits:



The large statistics available at LHC will allow to explore TGCs (and NP)

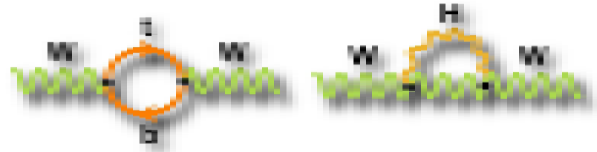




W mass at the Tevatron

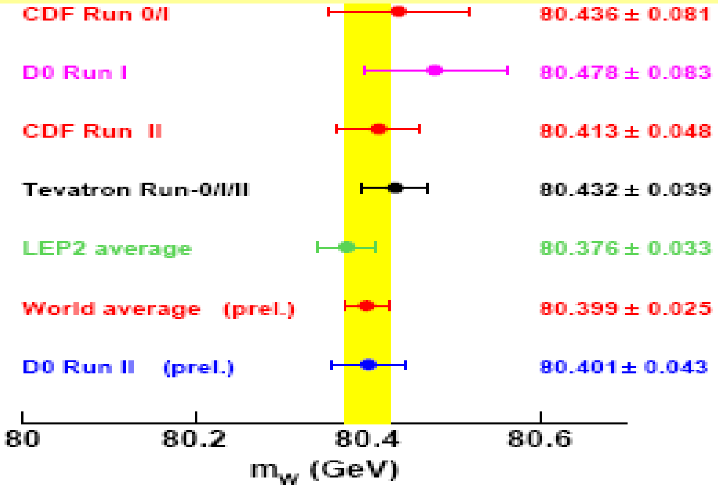
Together with M_{top} is connected to M_{Higgs}

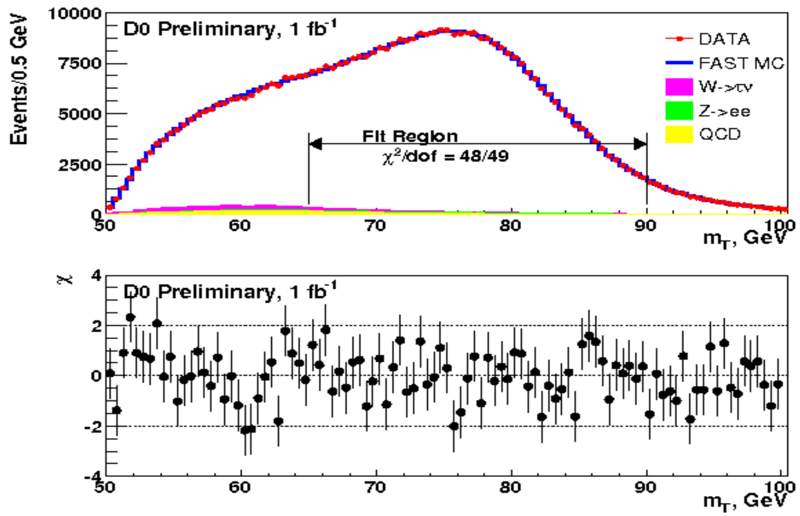
- ☞ Tevatron goal:
  - ⇨ break LEP record (33 MeV)
    - → Background under control
    - → Systematics reduced
- ☞ Can take longer than expected
  - ⇨ CDF only $0.2 fb^{-1}$, D0 new measurement $1 fb^{-1}$



D0 recent measurement with $1\ fb^{-1}$: $M_W = 80.401 \pm 0.021(stat) \pm 0.038(syst)$

Single best measurement!



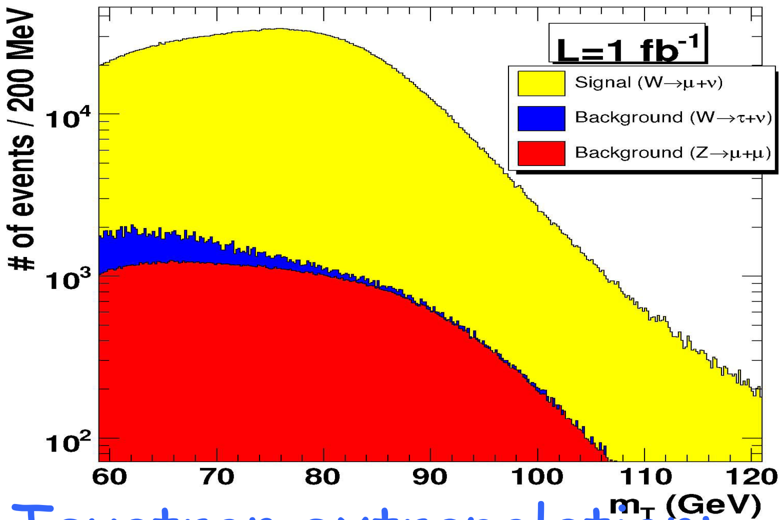


What else in the future?

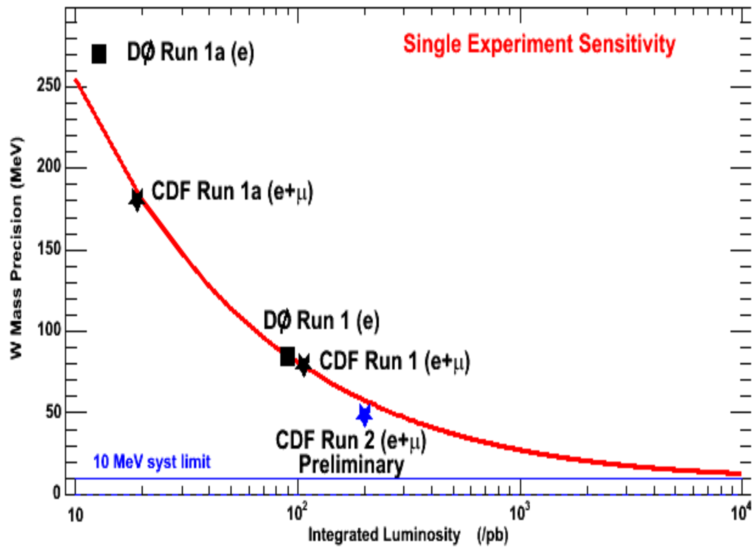
CMS and ATLAS will exploit

- ☞ Very large W statistics
  - ⇨ Sobering reminder: D0 result based on ~20%W→eν produced
- ☞ Large Z samples
  - ⇨ Key for energy scale systematic

CMS in 1 fb^{-1}



Tevatron extrapolation:



ATLAS: 15 pb^{-1} @14 TeV

Method	$p_T(e)$ [MeV]	$p_T(\mu)$ [MeV]	$M_T(e)$ [MeV]	$M_T(\mu)$ [MeV]
δm_W (stat)	120	106	61	57
δm_W (α_E)	110	110	110	110
δm_W (σ_E)	5	5	5	5
δm_W (tails)	28	< 28	28	< 28
δm_W (ε)	14	–	14	–
δm_W (recoil)	–	–	200	200
δm_W (bkg)	3	3	3	3
δm_W (exp)	114	114	230	230
δm_W (PDF)	25	25	25	25
Total	167	158	239	238

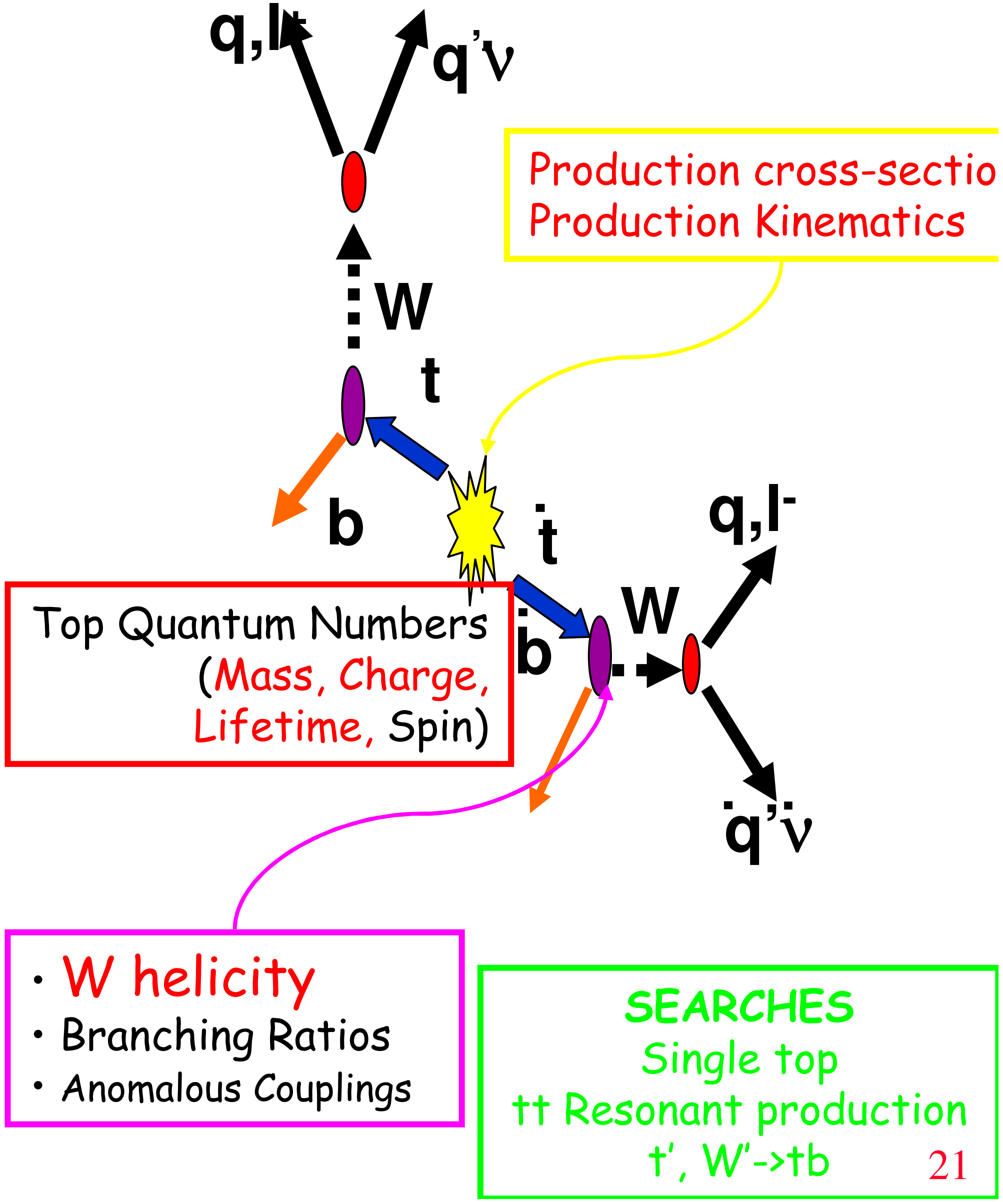
Top

Since its discovery in 1995 top physics is a real focus for the Tevatron

- ☞ Sheds light on the 3rd family
  - ⇨ Decays ~100% t→Wb
- ☞ Unique place to test QCD : "top fragments before hadronization"
  - ⇨ Provides a way to measure mass and cross section
    - → x-section: comparison wrt expectation
    - → Mass (unconstrained from SM): provides insight on the Higgs sector
      - Is anything special in a mass which is heavy as a gold Atom?

All results, so far, obtained through events produced in strong interactions

- ⇨ Recent observation of single top (EWK) production

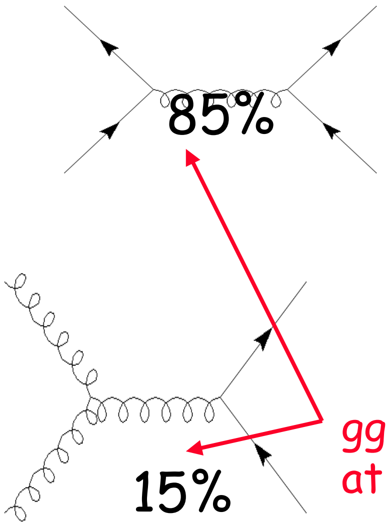


Production and decay

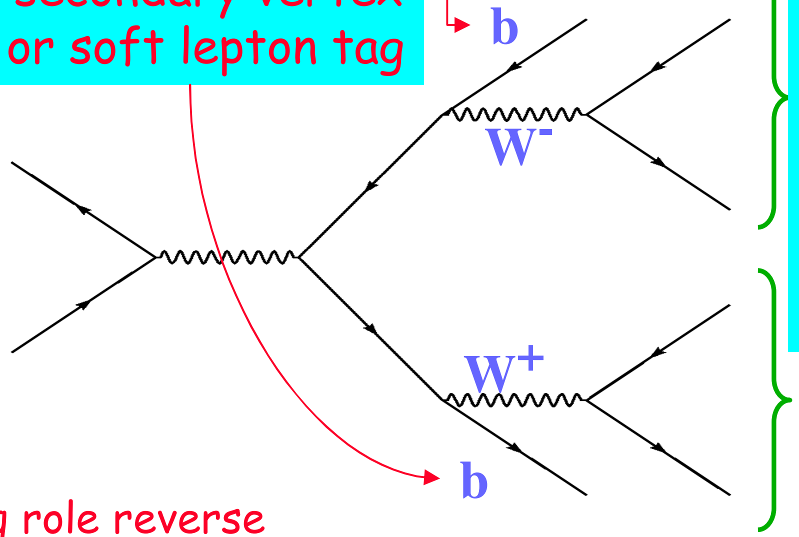
Recent results obtained with 2.8 -3.6 fb^{-1}

- ☞ l+jets
- ☞ Dileptons

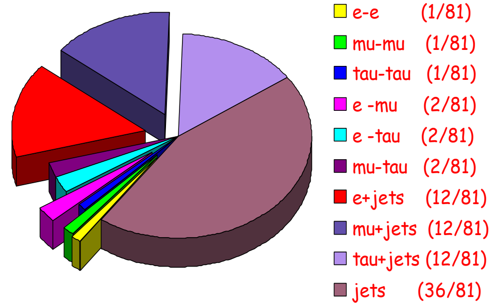
b-jet: identify via secondary vertex or soft lepton tag



gg and qq role reverse at the LHC



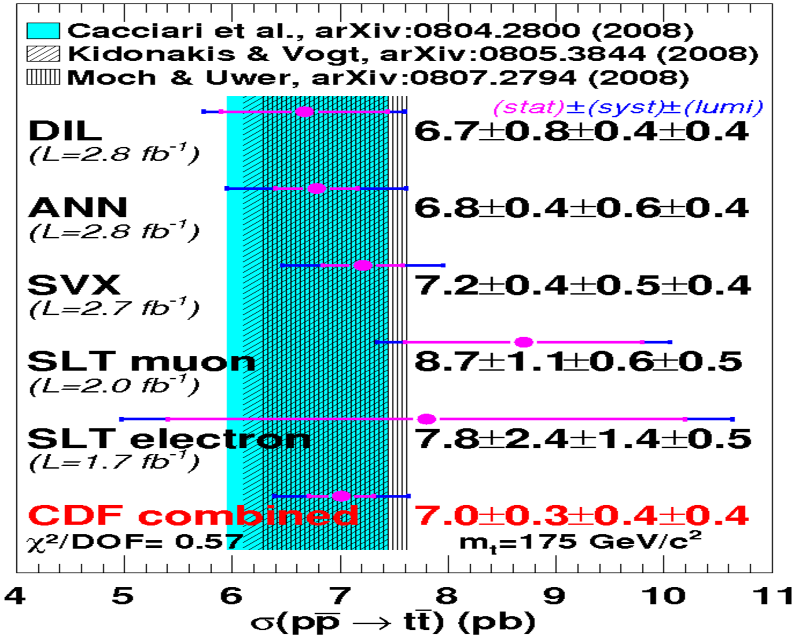
Event topology determined by the decay modes of the 2 W's (W^+W^-) in final state

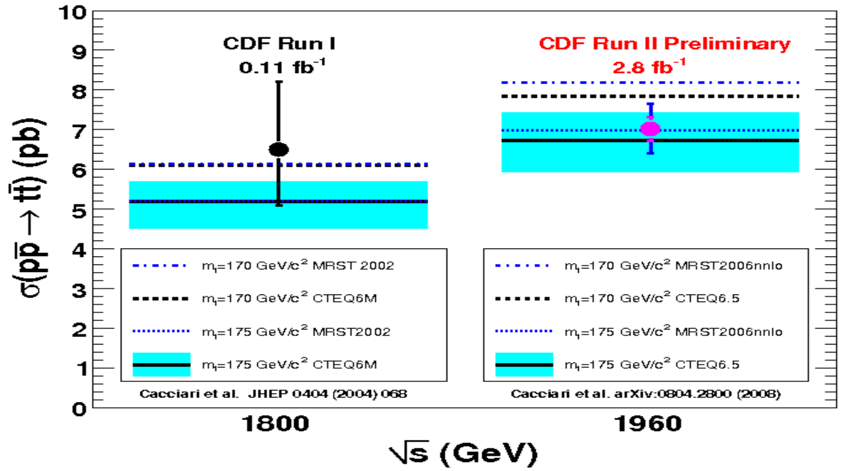


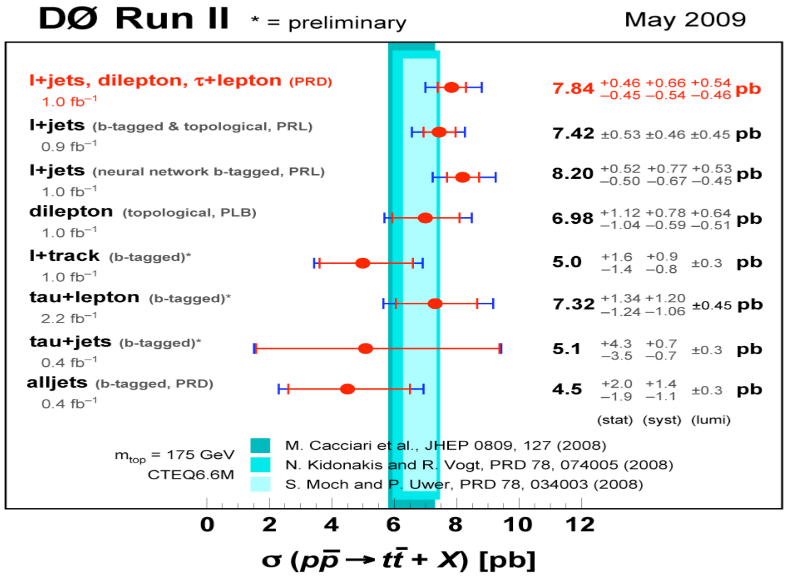
Most important decay channels:

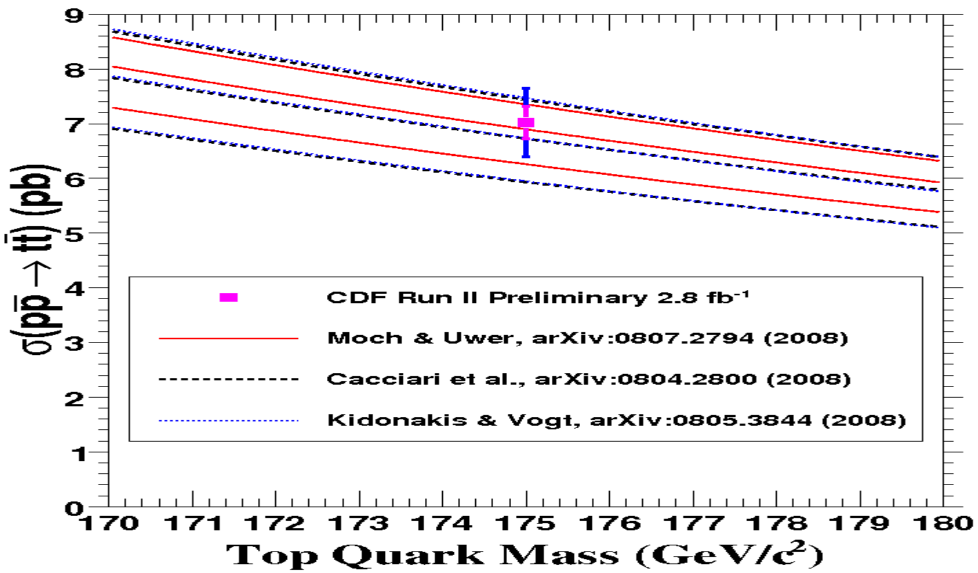
ttbar→llνν (dilepton) and ttbar→lνjj (semileptonic)

ttbar production-measurement









Challenge to NLO calculation accuracy

The LHC: top factory

The "top factory":

- ☞ σ_{ttbar}~800(500) pb @14(10) TeV
  - ⇨ Even in 100pb^{-1} @10 TeV O(50K) ttbar pairs
- ☞ Many studies project to use it as a "standard" candle to measure various effects in the detectors

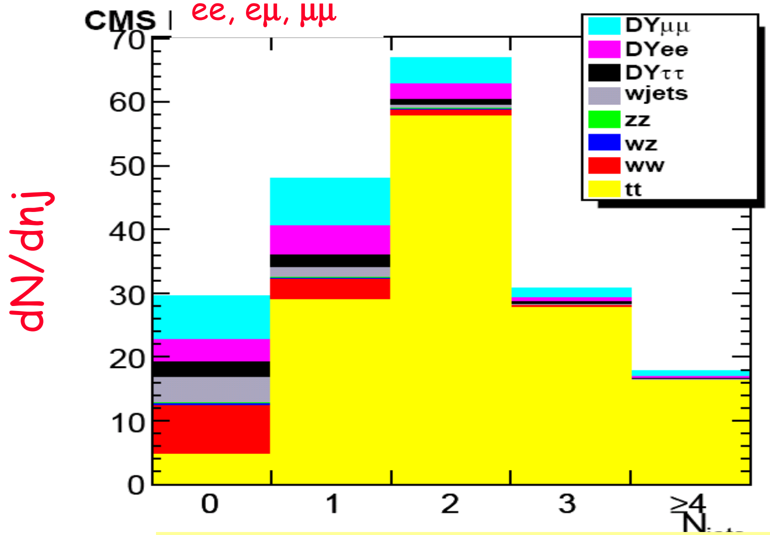
I favour physics, some measurements:

- ☞ ttbar production x-section
- ☞ Top properties
  - ⇨ Charge, mass, lifetime
  - ⇨ Rare (FCNC) decays
  - ⇨ W polarization in top decays
- ☞ Searches (t-tbar invariant mass)

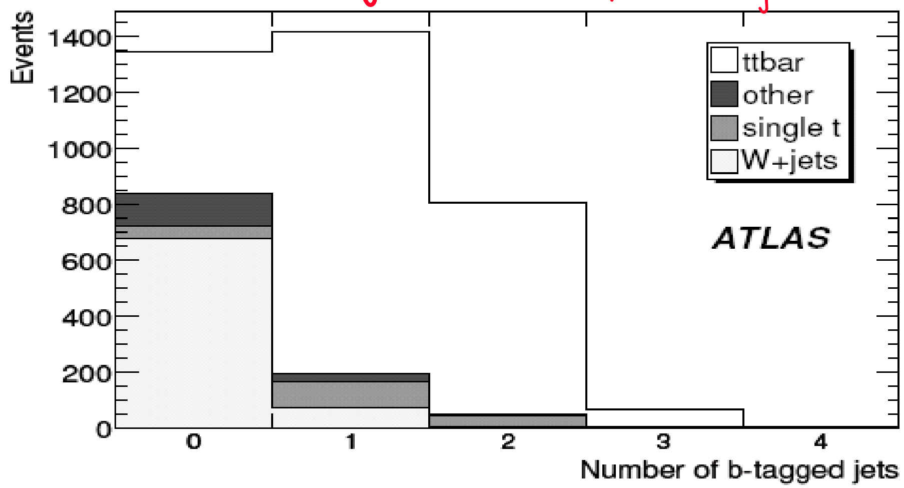
ttbar cross section at LHC

- dilepton channel
  - ⇨ no b-tagging, 14 TeV, 10 pb^{-1}, CMS: $\Delta\sigma/\sigma \sim 10\%$
- l+jets channel
  - ⇨ No b-tagging, 100pb^{-1} @14TeV, ATLAS: $\Delta\sigma/\sigma \sim 3(stat) \pm 16(syst)$
  - ⇨ b-tagging, 100pb^{-1} @14TeV, ATLAS: $\Delta\sigma/\sigma \sim 4.5(stat) \pm 8(syst)$

- Both experiments show the same sensitivity
  - ⇨ Time will tell…
- Very encouraging:
  - ⇨ precision measurements can be performed
    - → Top mass from x-section dependence?



electron+jets channel, dN/dn_j



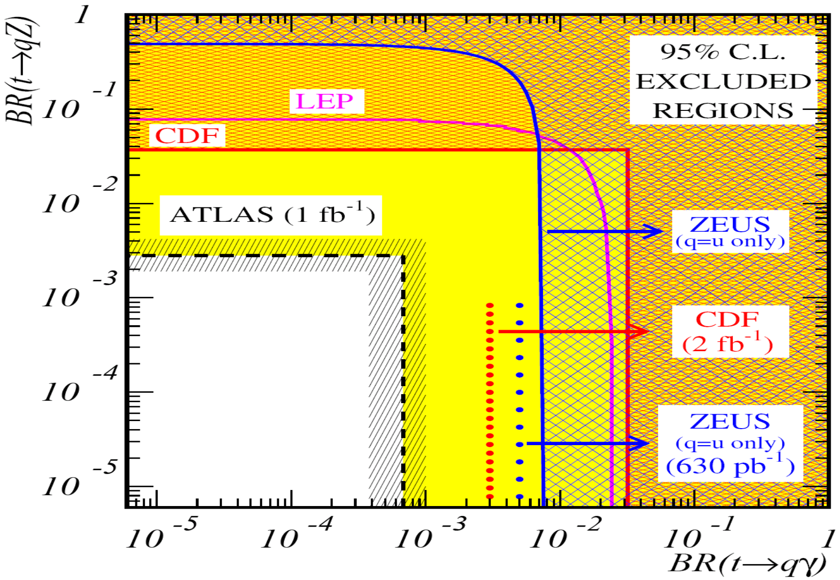
Tau channels of limited use at the Tevatron. Will LHC do better?

Top: window on new physics

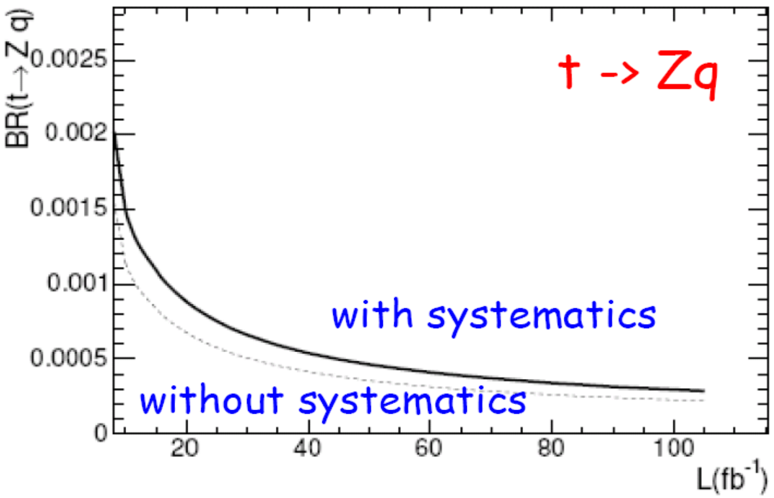
FCNC decays

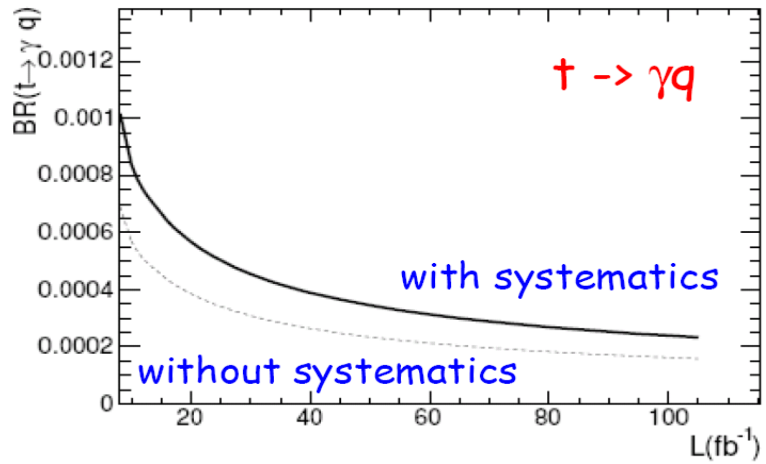
- ☞ Suppressed at tree level in Standard Model
  - ⇨ In some theories enhanced to $O(10^{-4})$
- ☞ Pioneered by CDF
  - ⇨ FCNC: BF($t \to Zq$, $t \to q\gamma$): <~3÷4% (CDF)

ATLAS studied its capability in 1fb-1



CMS studied how a large data set help in the search of rare top decays



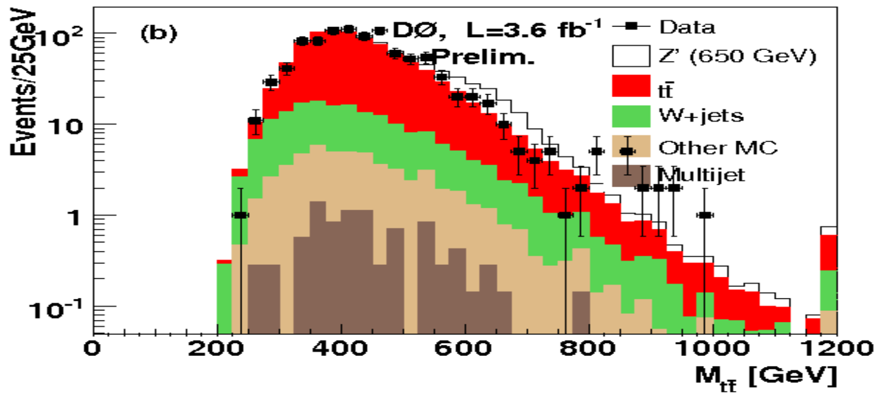


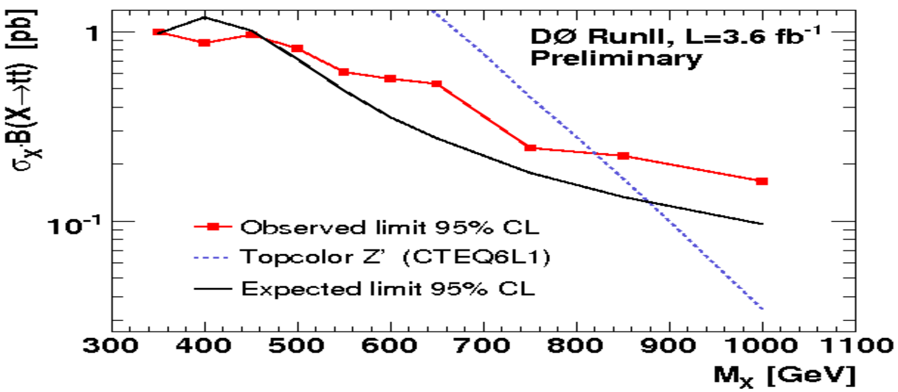
Window on New Physics

ttbar resonances

- Predicted in non-SM ElectroWeak Symmetry Breaking:
  - ⇨ Top quark condensate
- Z'-like states

Tevatron result: D0



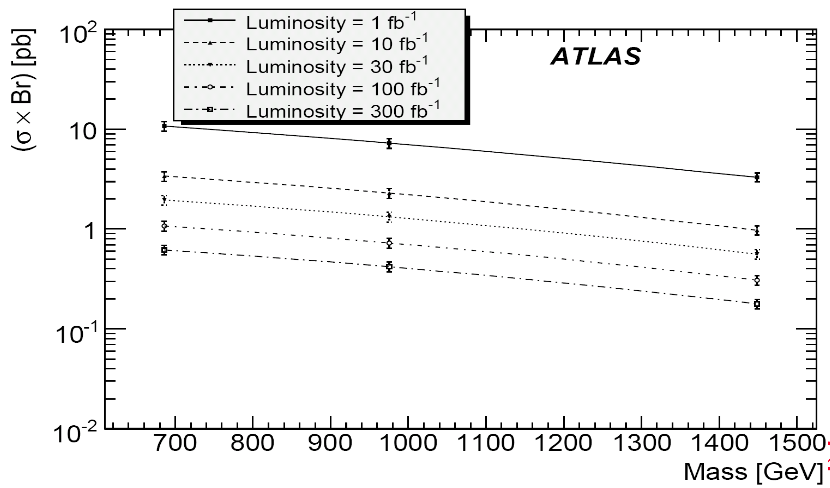


LHC will have an extra gear thanks to:

- Larger c.o.m. energy
  - ⇨ More phase space
  - ⇨ Larger cross sections
- High luminosity

5 σ observation at ATLAS, 14 TeV

or what luminosity can buy!



Top mass. How do we measure it?

Different techniques

- ☞ Comparison of mass-sensitive observables in data and MC templates ("template method")
- ☞ Insertion of kinematics (and dynamics) of top-processes

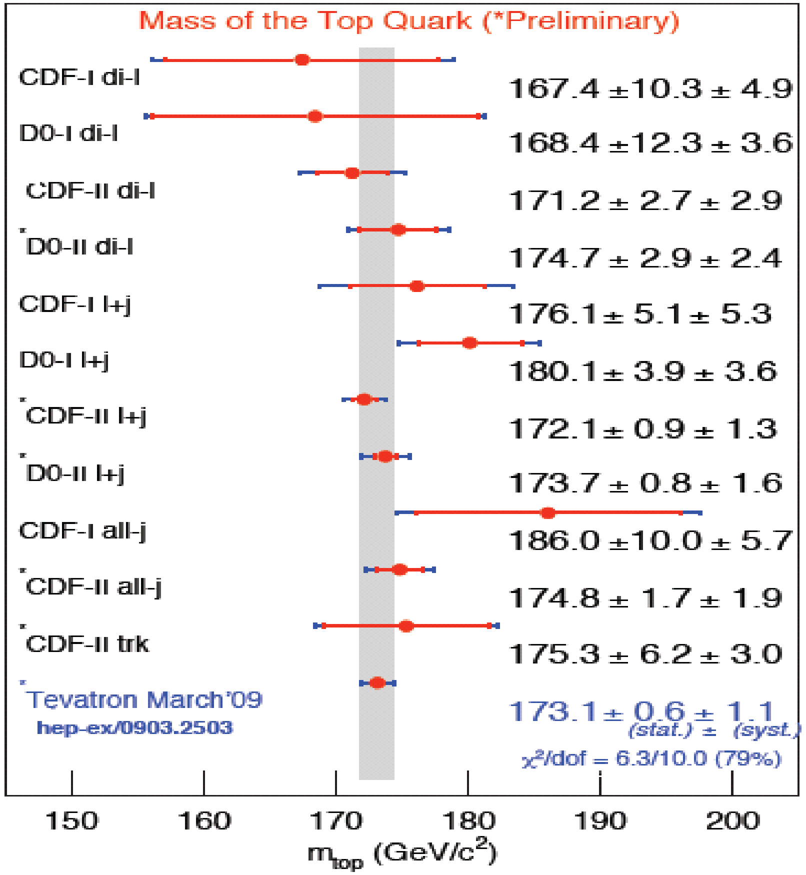
Pioneered by D0 in Run I, now widely used

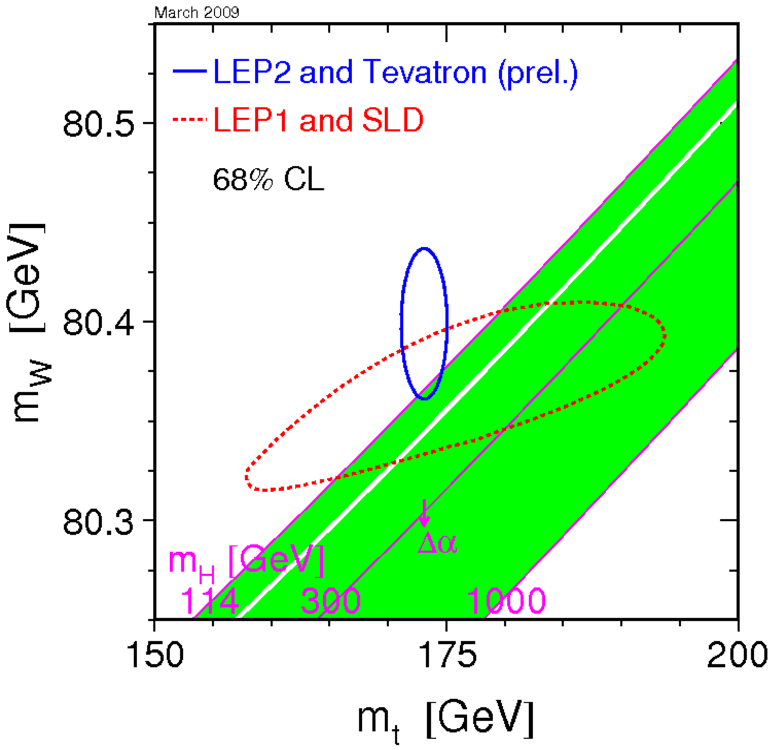
- ☞ We became smarter over time
  - ⇨ Most of the uncertainties due to jet-energy scale
    - → In-situ calibration using W→jj decays
      - Useful in events ttbar→WWbb→lνjj
    - → Ongoing efforts to understand the subtleties of jet fragmentation
      - Large statistics helps in both cases
  - ⇨ Use different channels (all-had, dilepton, l+jets)
    - → Different S/B
    - → Different systematics
  - ⇨ Different observables (eg: decay length of B hadrons)
  - ⇨ For l+jets and dilepton also combined measurement

Disclaimer: I am not discussing what the M_{top} we measure is!

What is at stake?

Tevatron has a striking measurement < 1%





Together with EWK fits:

M_H< 163 GeV/c² at 95 % CL

Tevatron combined:

173.1±0.6(stat)±1.1(syst) GeV/c² (3.6 fb⁻¹)

Top Mass...present and future

Measurement of M_{top}: at Tevatron, LHC:

- ☞ kinematic reconstruction, fit to invariant mass distribution
- ☞ Best measurement from lepton +jets

Experimental accuracy of M_{top}:

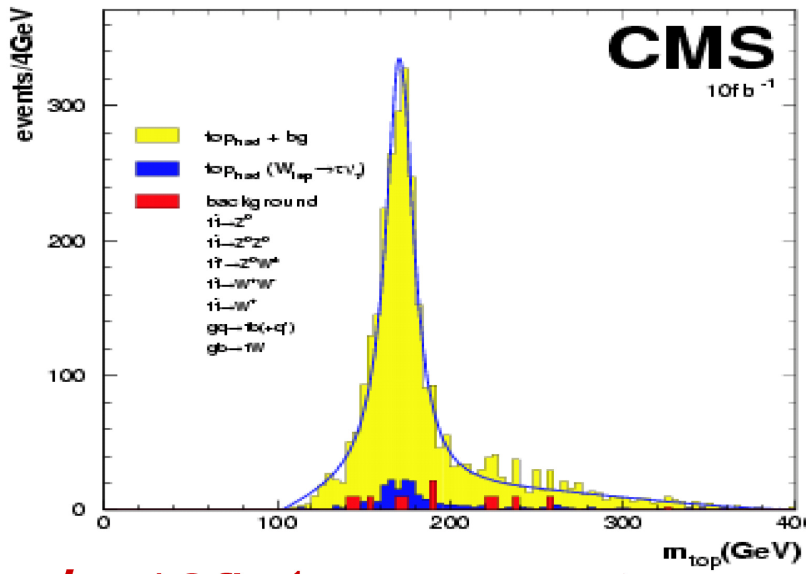
- ☞ you measure the mass that is implemented in your MC

Situation at the Tevatron:

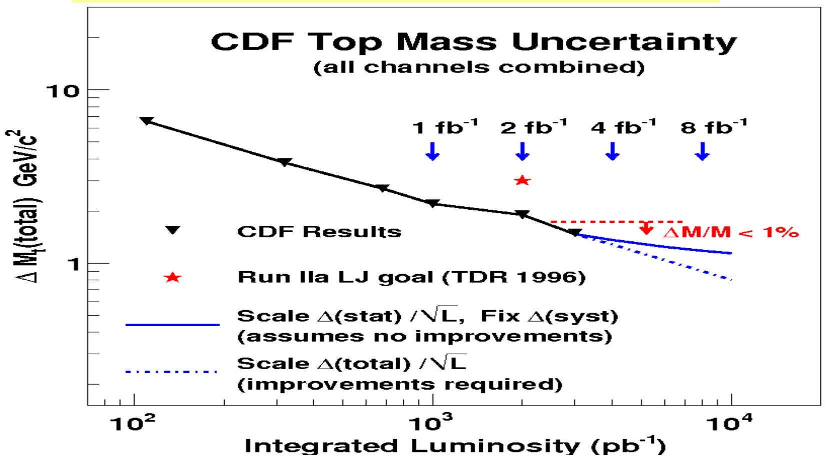
- ☞ δM_{top} = 1.2 GeV (Tevatron today, was 2.3 two years ago)

Projections at the LHC:

- ☞ δM_{top} ≈ 5 GeV with 1 fb^{-1}
- ☞ δM_{top} < 1 GeV with 10 fb^{-1}



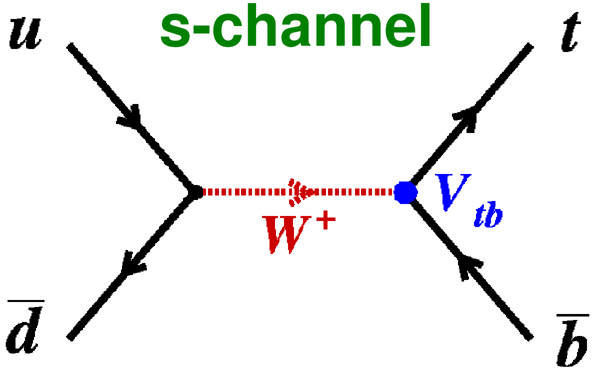
Will Tevatron get there first?



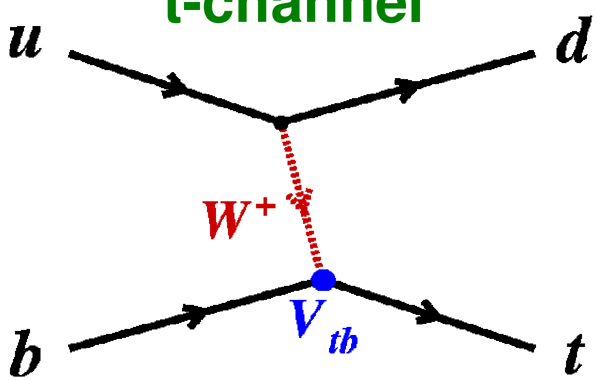
My prediction: top mass will be a lasting Tevatron heritage

Single Top Quark – Why look for it?

s-channel



t-channel



LHC:

$\sigma_s = (11 \pm 1)$ pb

$\sigma_t = (247 \pm 10)$ pb

$\sigma_a = (56 \pm 6)$ pb

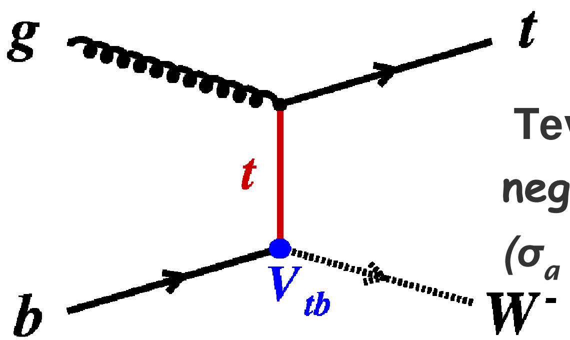
SM NLO predictions (Tevatron):

$\sigma_s = (0.88 \pm 0.11)$ pb

$\sigma_t = (1.98 \pm 0.25)$ pb

B.W. Harris et al., Phys. Rev. D 66, 054024 (2002),
Z. Sullivan, Phys. Rev. D 70, 114012 (2004),
N. Kidonakis, Phys. Rev. D74, 114012 (2006)

associated production



Tevatron:
negligible
(σ_a ~ 0.3 pb)

- EWK production
- topology similar to WH
- tiny cross section
- $\sigma_{single\ top}$ ~ $|Vtb|^2$
→ measurement of **Vtb**

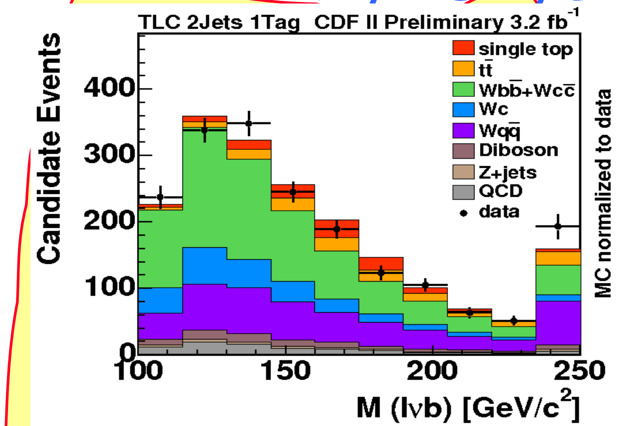
Evidence in 2008 (D0),
observation in 2009 (CDF&D0)

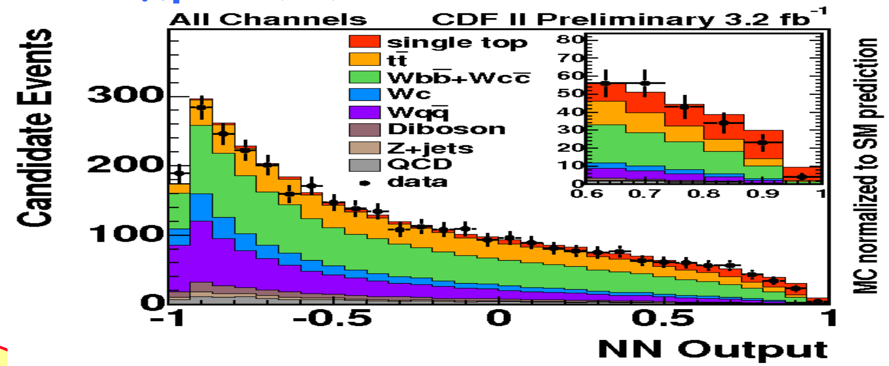
It took 14 years from ttbar to s-top

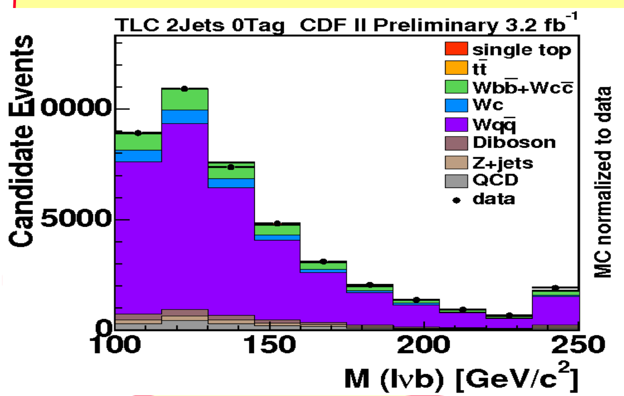
Tiny cross section
Large background } Counting exp. not possible, use MV techniques

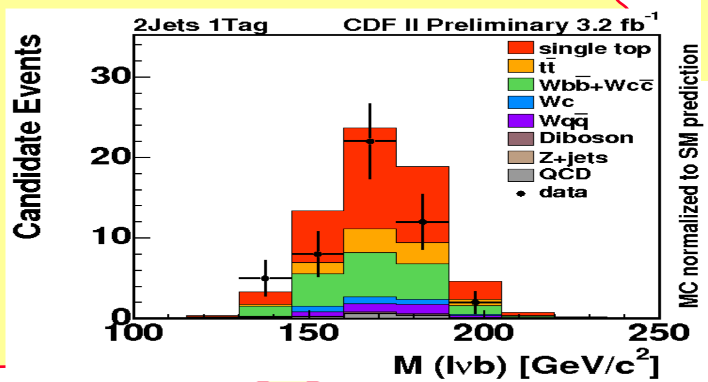
☞ imply a very good knowledge of the detetor response in order to combine many variables with separating powers

⇨ NN, BDT, Likelihood.., as example NN:









CDF: $\sigma = 2.3^{+0.6}_{-0.5}$ pb

$V_{TB} = 0.91 \pm 0.11 \pm 0.07$(th)

DØ: $\sigma = 3.94 \pm 0.88$ pb

$\Delta\sigma/\sigma = \pm 22\%$

Single top at LHC

LHC x-sections:

- ⇨t-channel: ≅250 pb
- ⇨s-channel: ≅11 pb
- ⇨associated ≅ 66 pb

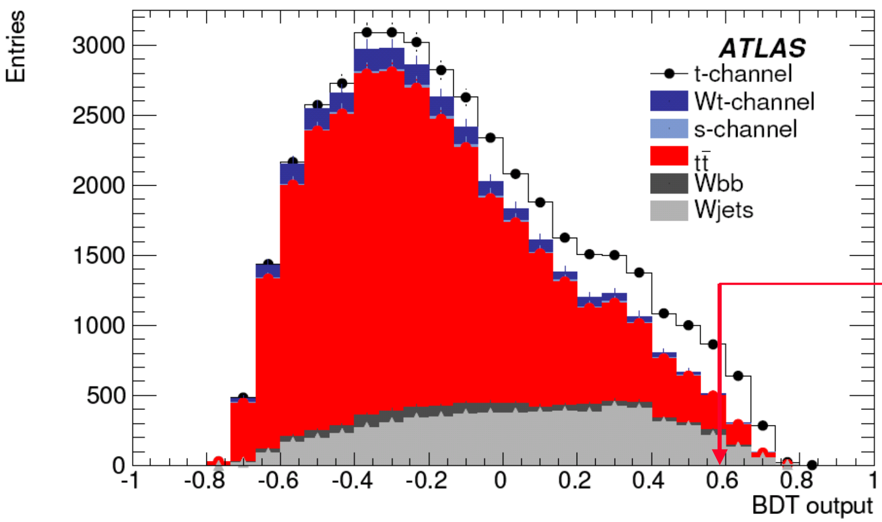
t-channel best candidate for observation

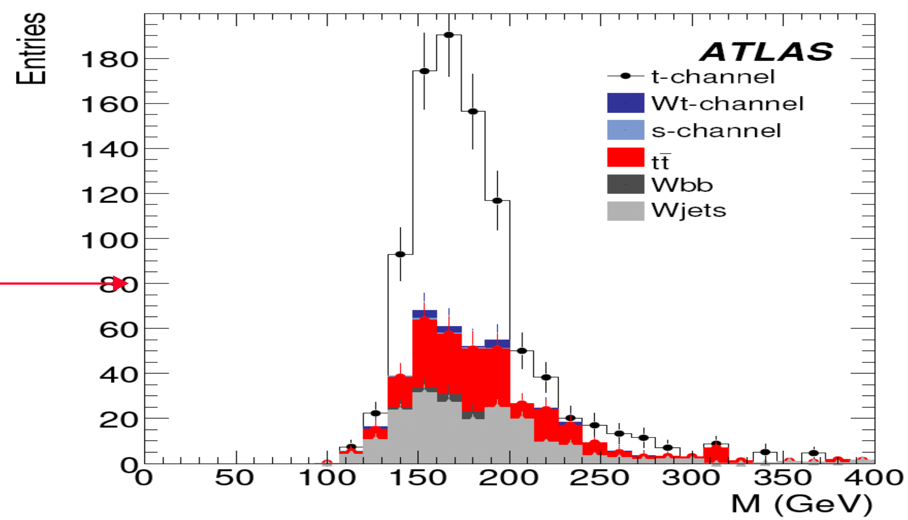
- ☞ Large background due to ttbar, W+jet events, multijet events
  - ⇨B tagging needed

ATLAS study (1 fb^{-1})

- ☞ Improved wrt TDR (found to be too optimistic)
- ☞ Cuts based selection
  - →S/B~1/3
  - ⇨"Advanced method" (a la D0/CDF) to reduce remaining bckg (mostly ttbar)
  - →S/B~1.3

$\Delta\sigma/\sigma$=±5.7%(stat)±22(syst)=23% (t-channel)





Conclusion

Precision ElectroWeak measurements and top Physics are

- ☞ Bread and butter for hadron colliders
  - ⇨ Tevatron accuracy on M_W, M_{top} can still improve
    - → CDF M_W measurement with 0.2 fb^{-1} stat. limited
    - → LHC will need time to compete
- ☞ Many measurements are statistics limited
  - ⇨ This is where we expect significant LHC contribution "soon"
    - → At the border of the SM
- ☞ We are now testing fundamental aspects of the theory
  - ⇨ Be ready for surprises as we move from
    - → DC (D0/CDF) to AC(Atlas/CMS)

Acknowledgments

Thanks to my colleagues:

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☞Mistakes are, of course, mine

My personal thanks to the Organizers for inviting me to give this talk in such a beautiful place in front of such a distinguished audience

Thank you!