Tevatron collider program

physics, results, future?

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STANDARD MODEL (~1975)

Current understanding of elementary particles and their strong and electro-weak interactions is given by Standard Model, a gauge theory based on the following "internal" symmetries:

$$SU(3)_c \times SU(2)_I \times U(1)_Y$$

The SU(3) is an unbroken symmetry, it gives Quantum Chromo-Dynamics (QCD), a quantum theory of strong interactions, whose carriers (gluons) are massless, couple to color (strong force charge)

SU(2)×U(1) (quantum theory of electroweak interactions) is spontaneously broken by the Brout-Englert-Higgs mechanism; which gives mass to electroweak bosons (W^+, W^-, Z^o and a massless photon) and all fermions

In the Minimal Standard Model, the Higgs sector is the simplest possible: contains two complex Higgs fields, which after giving masses to W^+, W^-, Z^o leaves a neutral scalar Higgs particle which should be observed - the ONLY particle not yet discovered in MSM

MINIMAL STANDARD MODEL

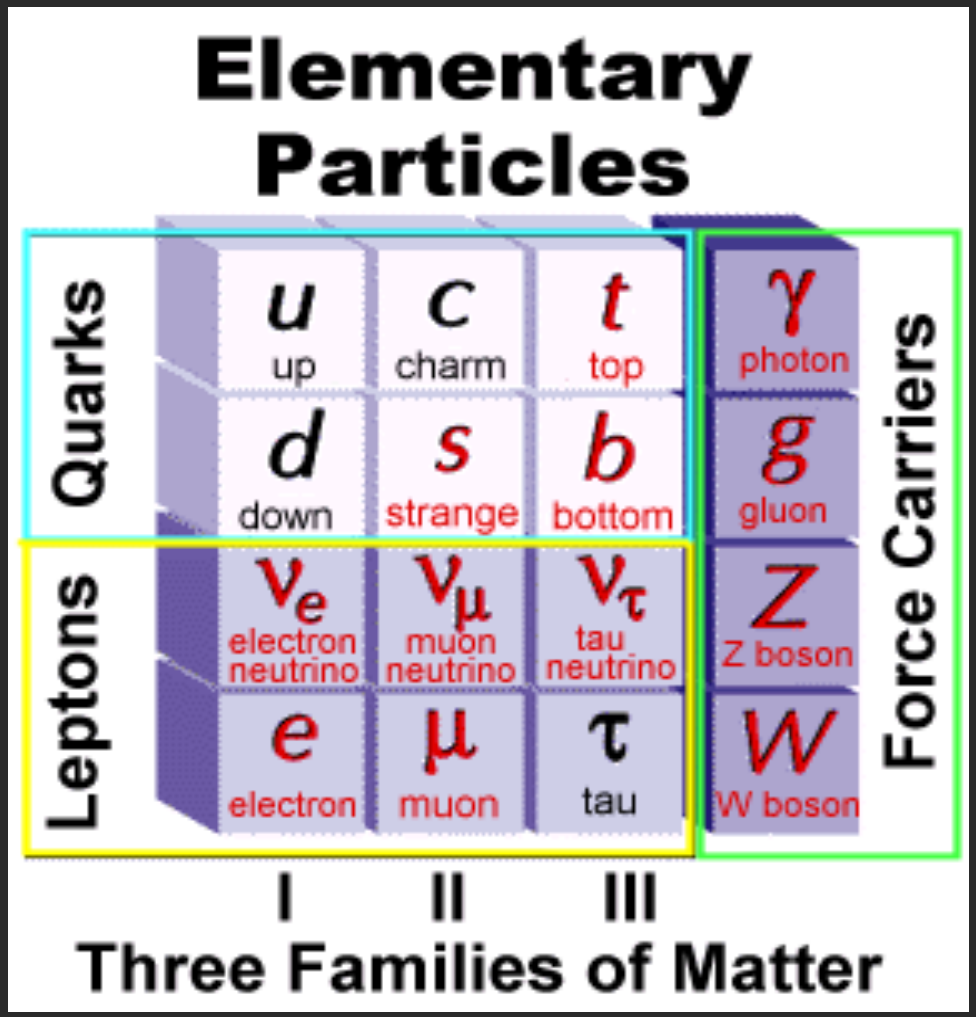
Matter is build of fermions - quarks and leptons, three families of each, with corresponding antiparticles; quarks come in three colors, leptons are color singlets, do not couple to gluons

Bosons are carriers of interactions: 8 massless gluons, 3 heavy weak bosons (W,Z) and 1 massless photon

A massive neutral scalar Higgs field permeates the Universe and is (in some way) responsible for masses of other particles (they originate from couplings to Higgs field)

HIGGS SCALAR IT IS THE ONLY PARTICLE NOT YET OBSERVED IN THE MINIMAL STANDARD MODEL

MINIMAL STANDARD MODEL



26 parameters NOT predicted by SM:

- masses of 6 quarks
- masses of 6 leptons
- coupling constants of SU(3), SU(2) and U(1)
- Higgs mass and vacuum expectation value
- Cabibbo-Kobayashi-Maskawa quark mixing angles and complex phase
- Maki-Nakagawa-Sakata lepton mixing matrix angles and complex phase
- QCD phase θ

ALL MUST BE MEASURED !!!

STANDARD MODEL – QUESTIONS ???

- why so many free parameters: all masses, all couplings, all mixing angles and CP-violating phases

- why 6 quarks and 6 leptons - is there an additional symmetry?

- why quarks and and leptons come in three pairs (generations)?

- why is CP not an exact symmetry (or why are laws of physics not symmetrical between matter and antimatter?) perhaps related $\Rightarrow$ why is our Universe matter-dominated?

- are quarks and leptons elementary or do they have structure at scale smaller than we can see ($<10^{-18}$ m)?

- muon and electron look identical, except for their masses, could muon be an "excitation" of what constitutes a "pointlike" electron??

STANDARD MODEL – QUESTIONS ???

- neutrinos - Dirac or Majorana ? why neutrino masses are so small?
- is proton stable?
- QCD - confinement of quarks and gluons was never proven; if we live in low temperatures where confinement works is there a phase transition at higher temperatures where quarks become free?
- what is the nature of spontaneous symmetry breaking of electroweak theory?
- do strong and electroweak interactions become one at very high energies ?

- HOW TO INCLUDE GRAVITY ???

BEYOND STARDARD MODEL??

- SUPERSYMMETRY
- TECHNICOLOR
- GRAND UNIFIED THEORIES based on larger symmetry groups, e.g. SU(5), SO(10), E_8, Monster group…
- STRING THEORY, SUPERSTRING THEORIES, BRANES, M-theory
- new models, extensions of Kaluza-Klein theory
- EXPERIMENTAL DATA NEEDED BADLY !!!!

ACCELERATORS = MICROSCOPES OF PARTICLE PHYSICS

- which particles to collide?

electrons+positrons : all kinematics known, all energy transformed into produced particles
difficult to accelerate, either very long, or large radius machines (large energy loss because of small mass) SLAC, LEP

proton machines: easy to built but "messy" collisions as protons can be viewed as bags filled with quarks and gluons
not all proton energy available in the collision
Tevatron at Fermilab, LHC at CERN

- beam energy (or, rather, energy available in collision)

- luminosity (related to beam intensity)

TEVATRON at Fermi National Accelerator Laboratory

TEVATRON at Fermi National Accelerator Laboratory

Superconducting proton – antiproton synchrotron accelerator

774 superconducting dipole magnets with 4.2 T magnetic field
240 superconducting quadrupole magnets

Run 0	1988-1989	10/pb	$\sqrt{s}$ = 1800 GeV
Run I	1992-1996	120/pb	$\sqrt{s}$ = 1800 GeV

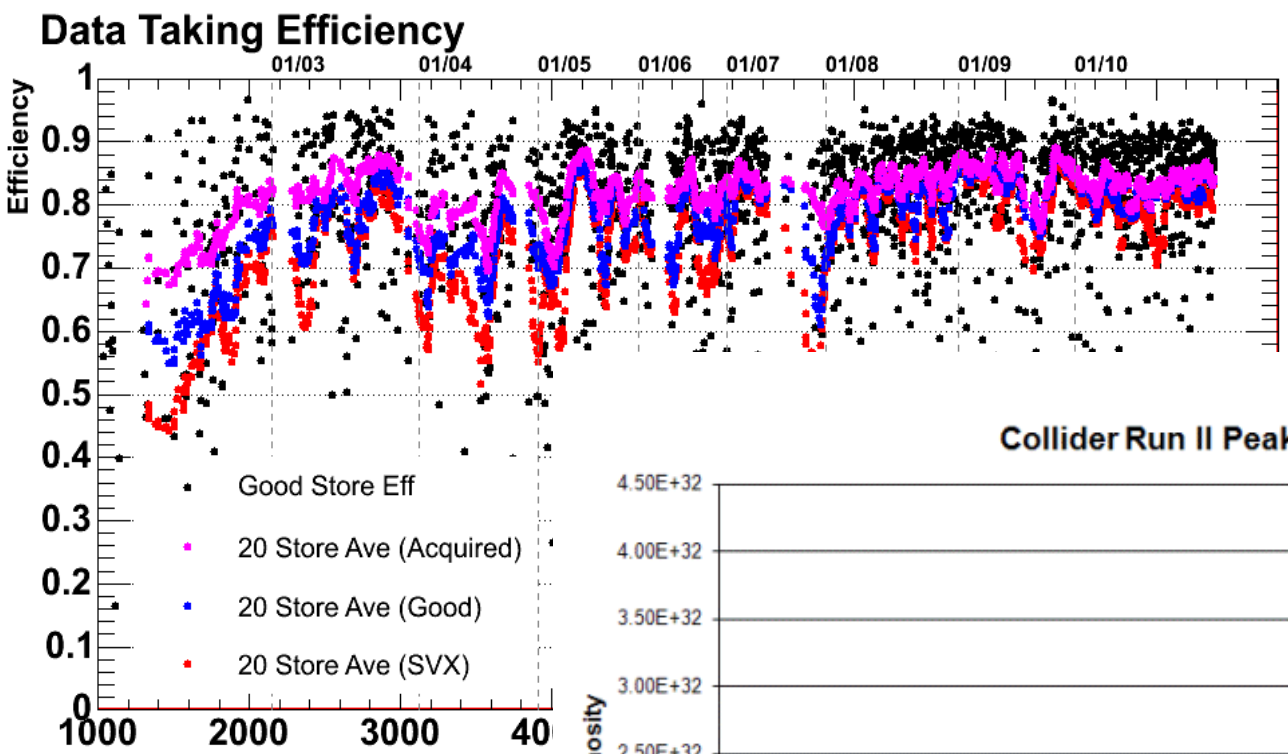
Significant upgrades for Run II:

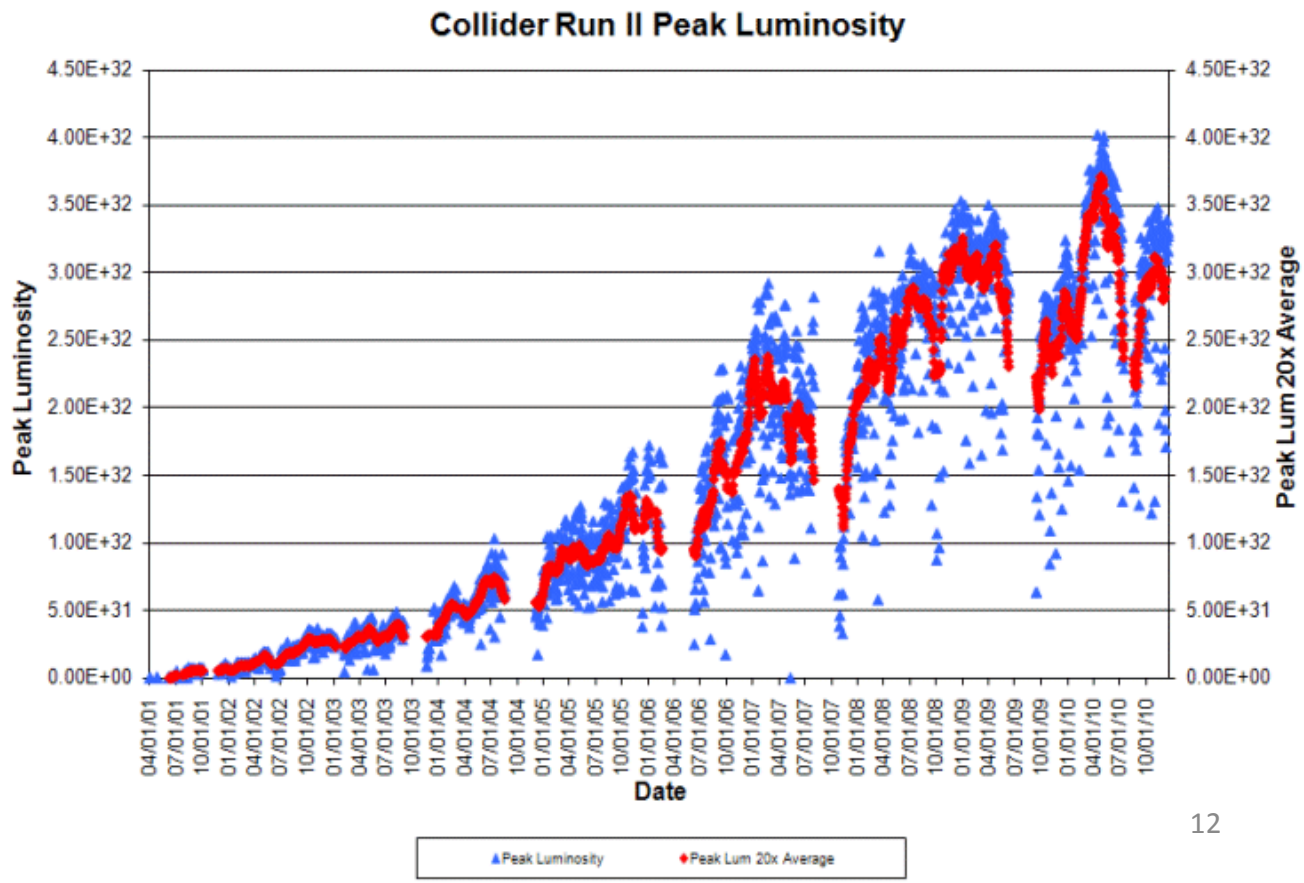
New Main Injector ⇒ CM energy ($\sqrt{s}$) increased from 1800 GeV to 1960 GeV (tt cross section increases by ~35%)

Different beam crossing time (396 ns and 132 ns later (?), instead of 3.5 μs in Run-I) –> fewer multiple interactions

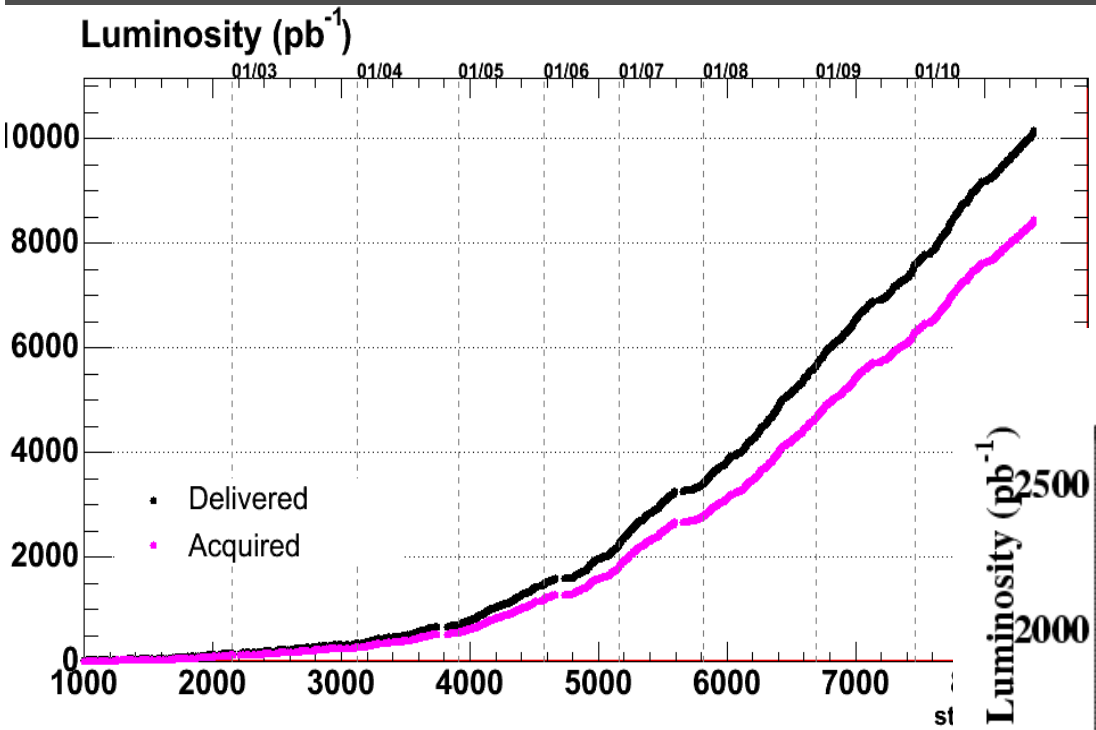
Run II	2001-	10/fb	$\sqrt{s}$ = 1960 GeV

TEVATRON at Fermi National Accelerator Laboratory



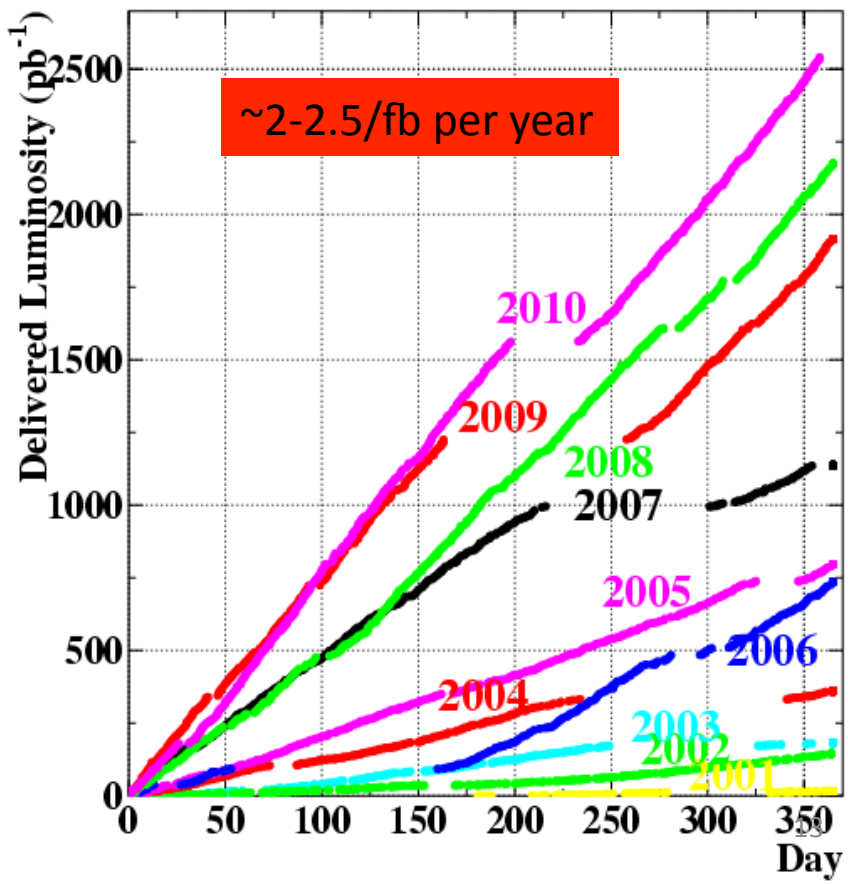


TEVATRON at Fermi National Accelerator Laboratory



the week of December 13, 2010, Tevatron integrated (delivered) luminosity exceeded 10/fb

Acquired luminosity > 8/fb



TEVATRON at Fermi National Accelerator Laboratory

Two large, multipurpose, detectors: CDF and D0

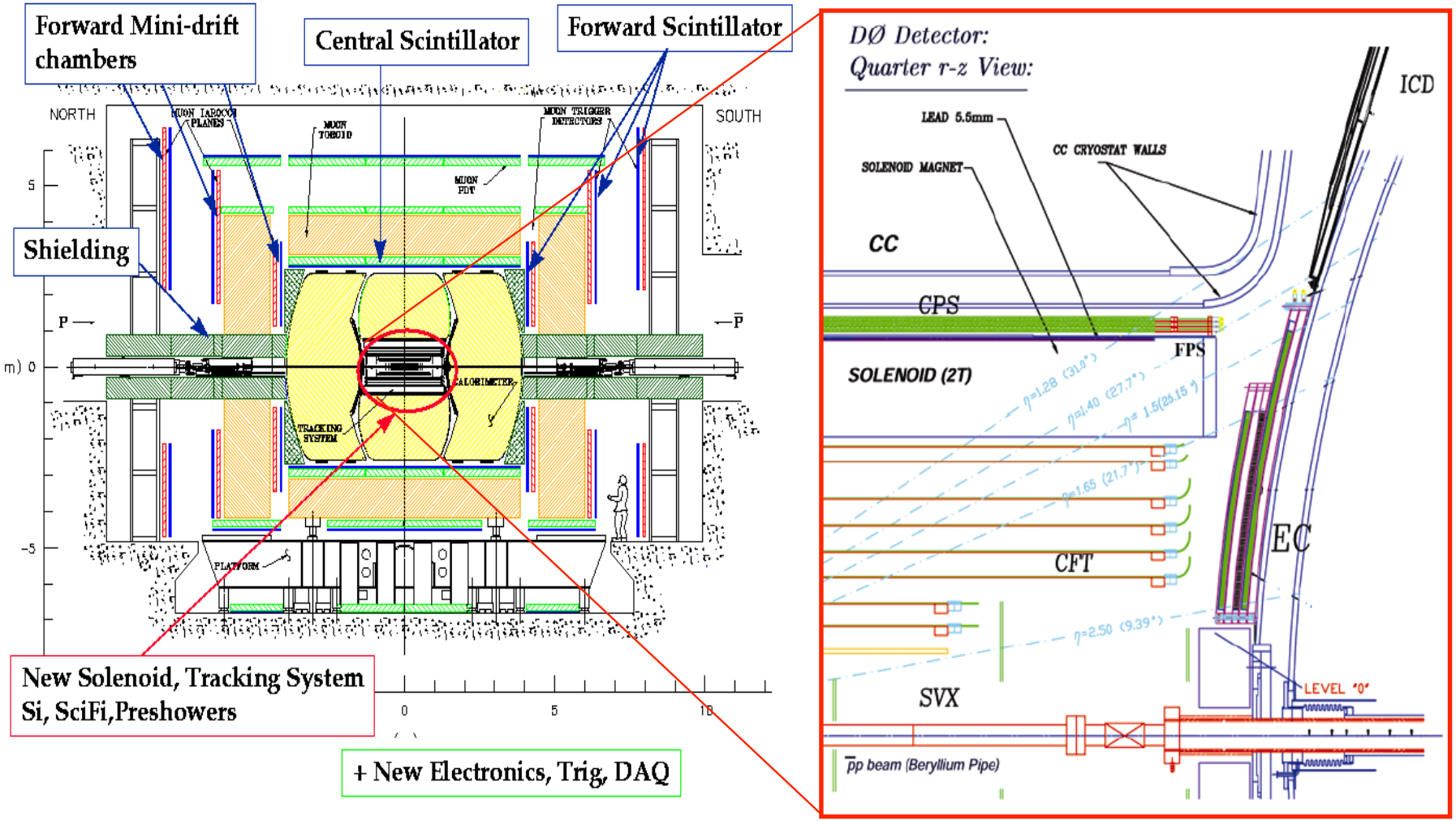
Significant upgrades to both detectors for Run II:

D0 : addition of SVX to allow better b-quark tagging
addition of a solenoid to allow track momentum reconstruction

D0 routinely reverses the orientation of its magnetic field – cancellation of many possible detector effects, important for any charge asymmetry measurement

CDF : new calorimeter for $1.1 < |\eta| < 3.5$ (much better energy resolution)
new (longer) SVX with double the Run-I tagging efficiency

D0 detector in Run II configuration



CDF detector in Run II configuration

*new calorimeter for 1.1< |η|<3.5
(much better energy resolution)
*new (longer) SVX with double the
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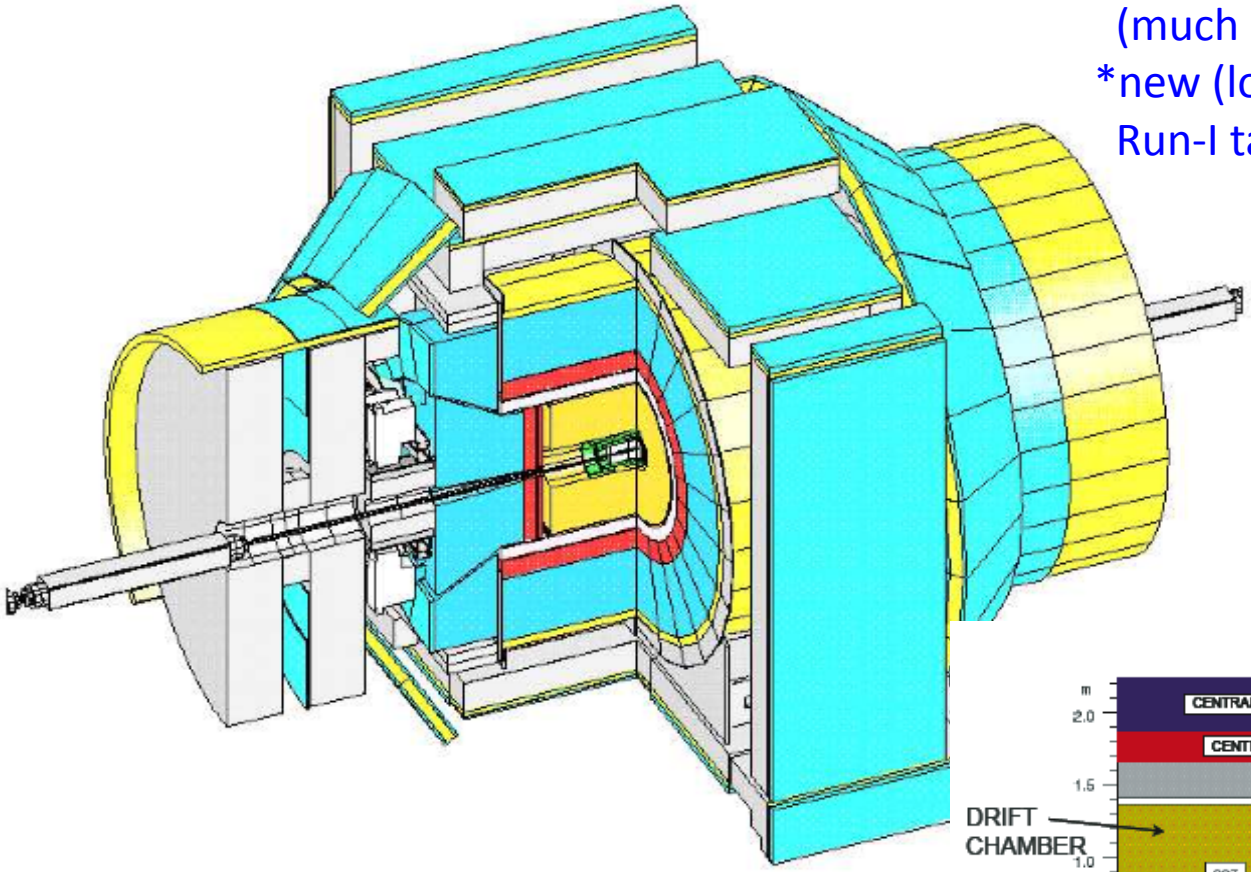
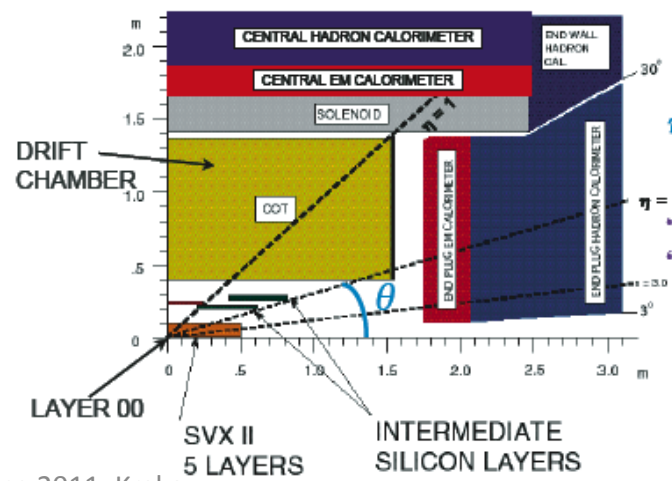




$\eta = -ln(tan(\theta/2))$

"central": $|\eta| < 1.1$

"forward": $|\eta| > 1.1$

TEVATRON PHYSICS

- I'll put emphasis on methodology at the expense of some analysis details, which can be found at:

D0: http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

CDF: http://www-cdf.fnal.gov/physics/physics.html

- Also, I'll show only a selection of results, as some became quickly obsolete with ~45/pb data collected at LHC in 2010

TEVATRON PHYSICS

- precision measurements/tests of Standard Model

  QCD studies

  W mass

  b-quark physics (lifetimes, spectroscopy, CP violation studies..)

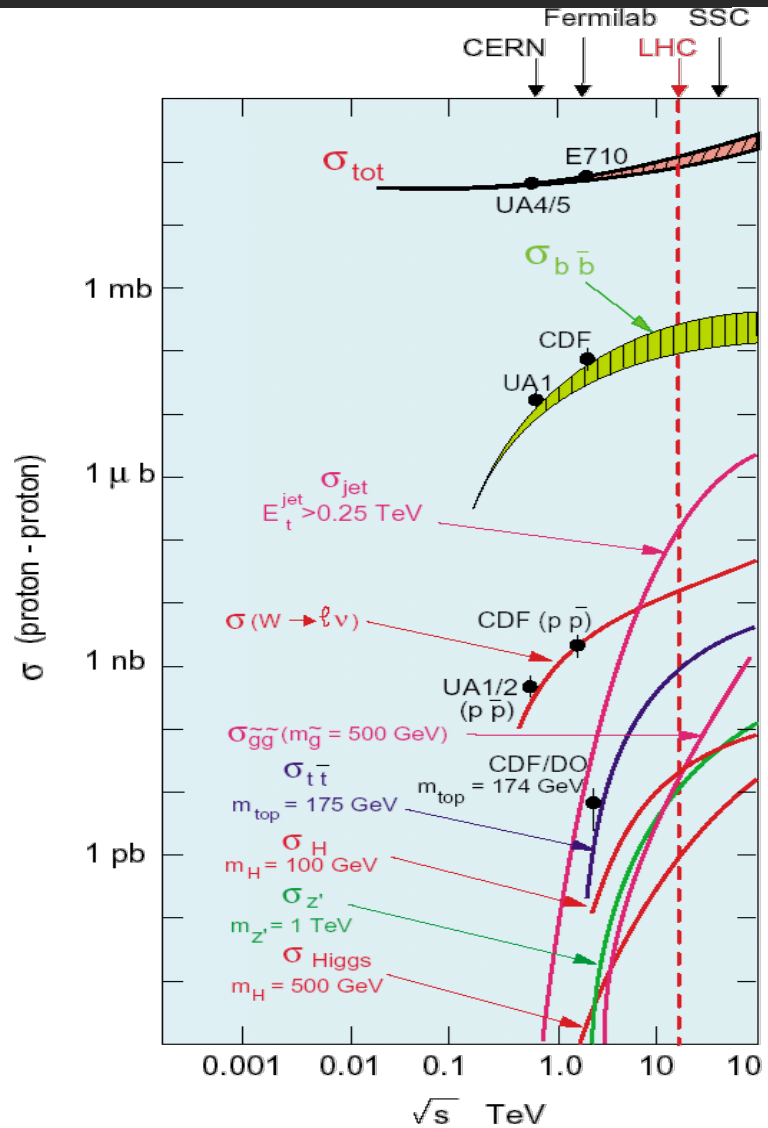
  WW, WZ, ZZ, Wγ, Zγ, γγ . . . . . .

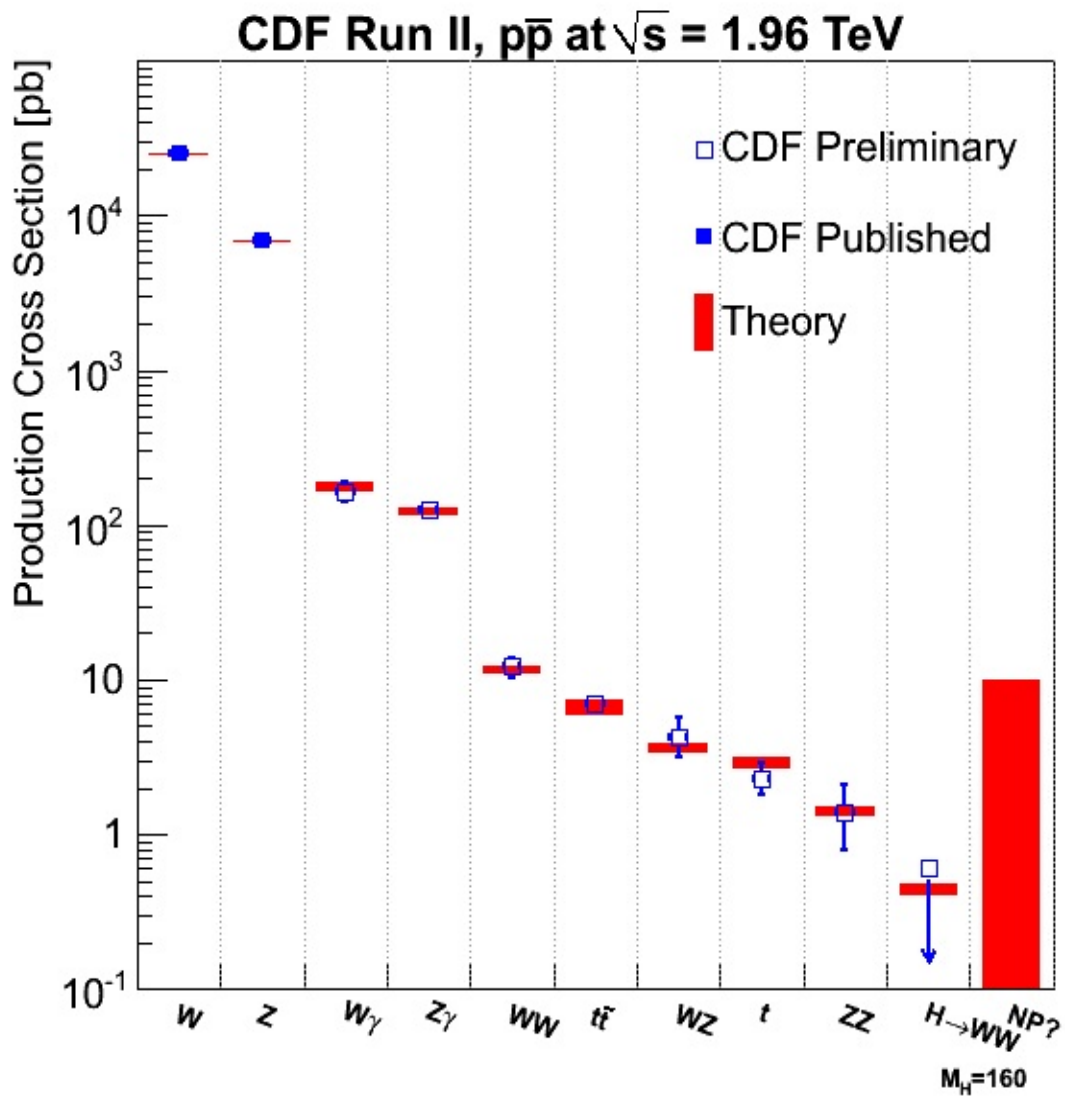
  top quark physics (top quark discovered 1993-1994)

  Higgs searches (MSM, MSSM)
  . . . . . .

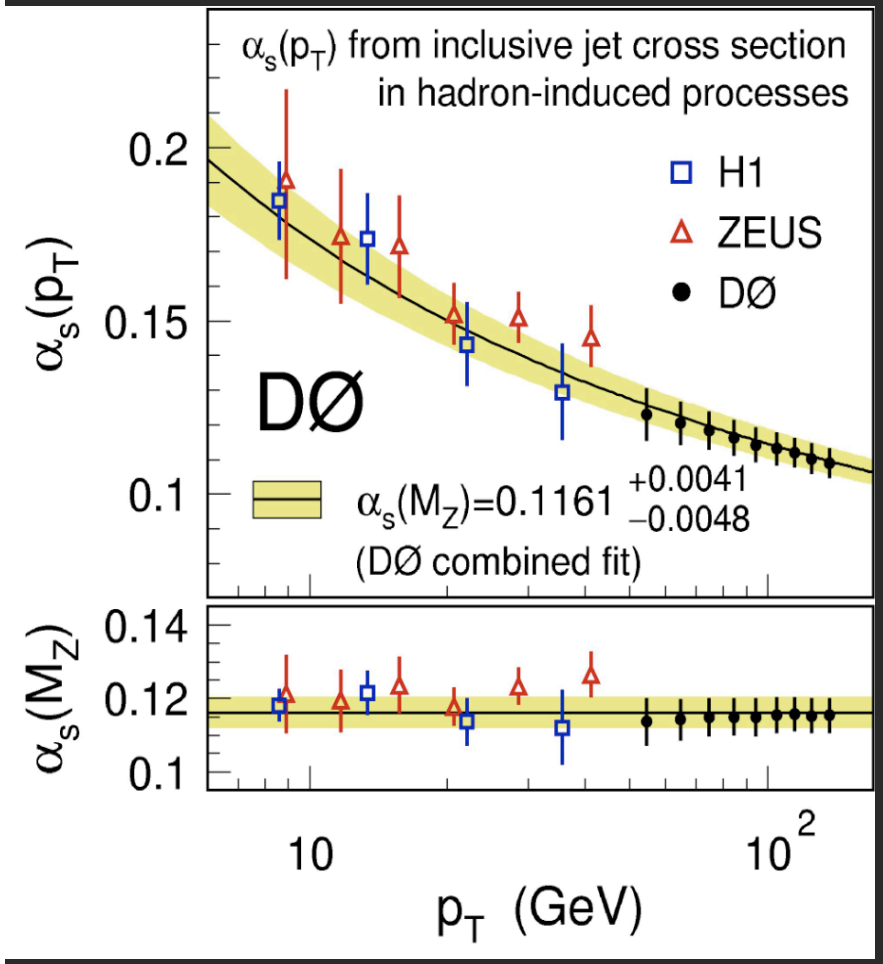
- searches for Physics "BEYOND the STANDARD MODEL"

TEVATRON PHYSICS





QCD STUDIES



Phys. Rev. D 80, 111107 (2009)

Measurement uses the p_T dependence of jet cross section

-χ^2 minimization of data/theory points

-22/110 points in the inclusive jet cross section used

-50 < p_T < 145 GeV/c,

- high points excluded to minimize PDF uncertainty correlations

- NLO+2 loop thresholds corrections

-MSTW2008NNLO PDF's

$\alpha_s(M_Z) = 0.1161^{+0.0041}_{-0.0048}$

CDF:

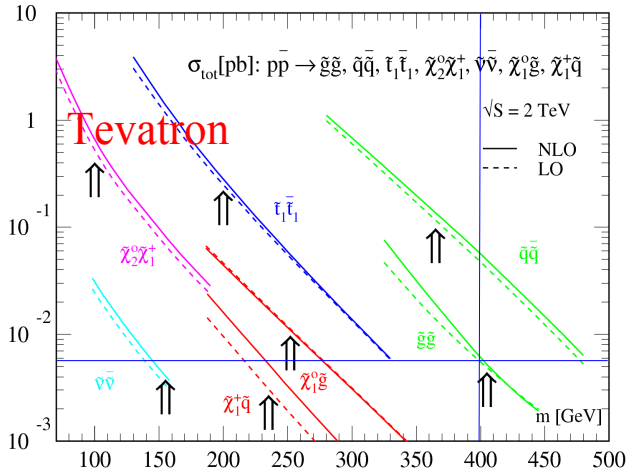
$\alpha_s(M_Z) = 0.1178^{+0.0081}_{-0.0095}$

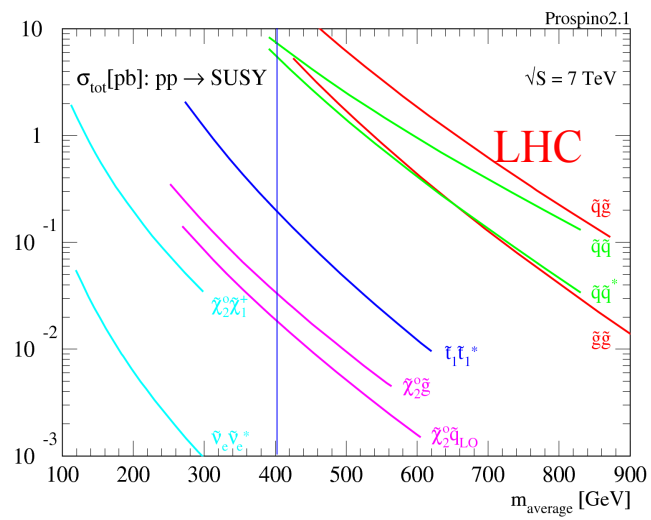
SEARCHES FOR NEW HEAVY PARTICLES

Most TEVATRON limits already obsolete with ~40/pb of LHC data

We already have produced more 400 GeV gluinos (if they exist) than the Tevatron

from Prospino



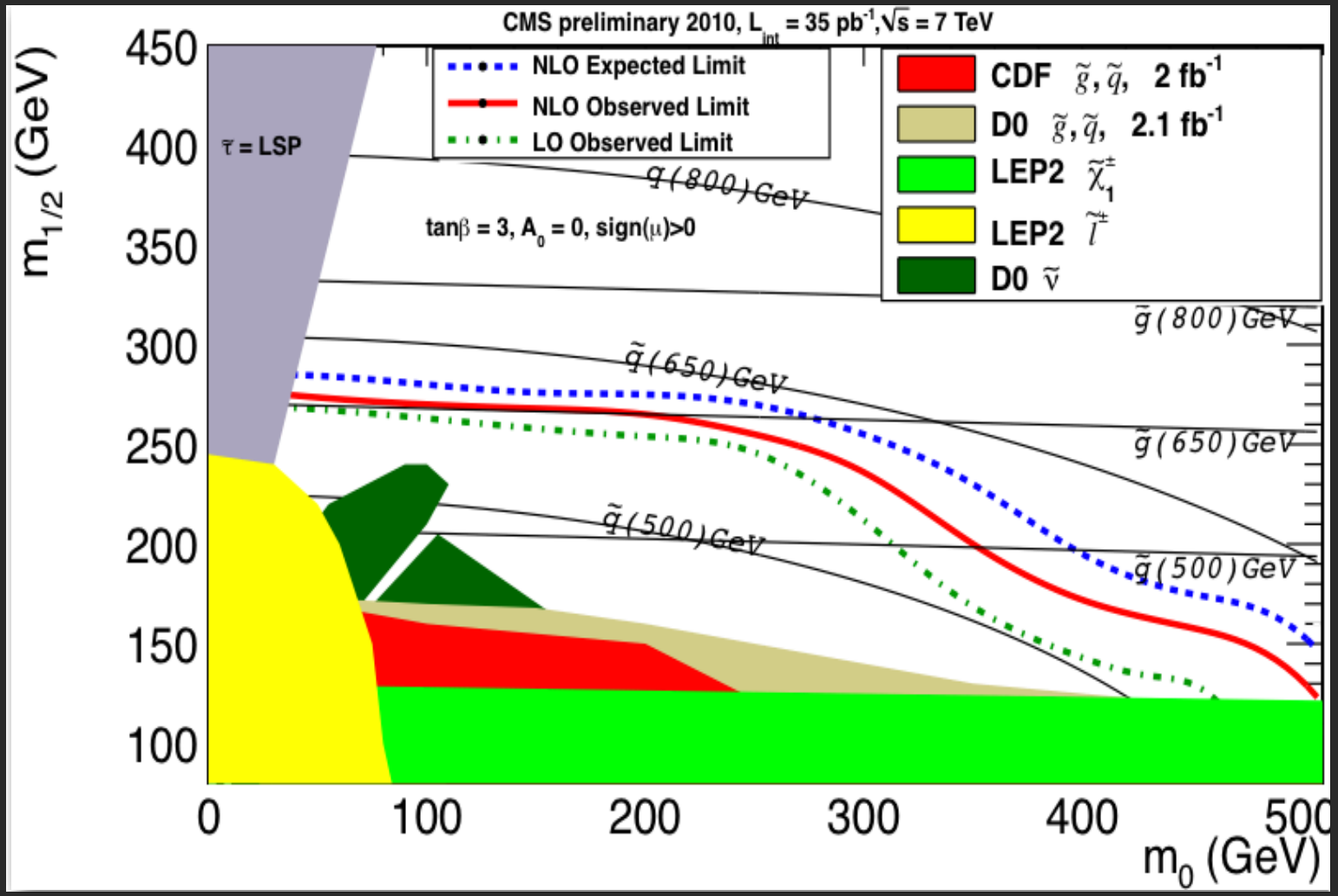


σ (400 GeV gluino) ~ 4 x 10^{-3} pb (Tevatron) → 32 gluinos in 8 fb^{-1}
~ 10 pb (LHC)

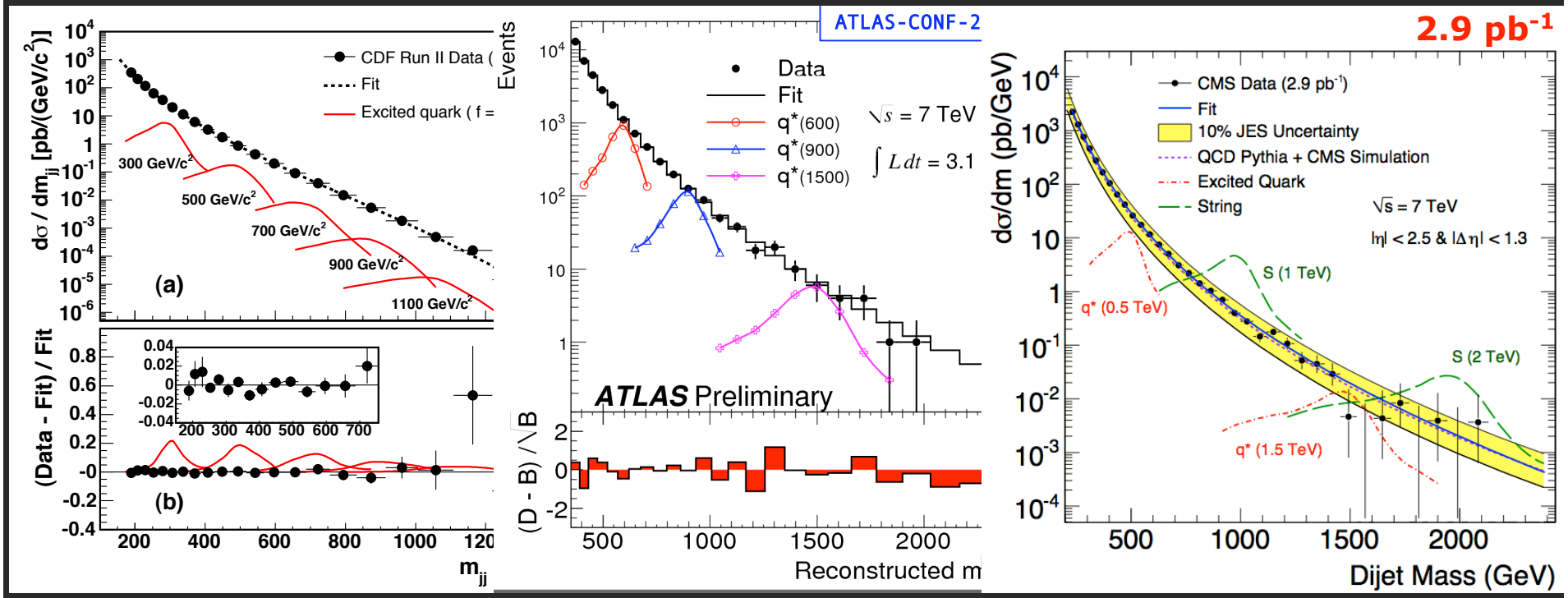
Exceed the Tevatron with ~ 3 pb^{-1}

SEARCH FOR Supersymmetry

Most TEVATRON limits already obsolete with ~40/pb of LHC data



SEARCHES FOR NEW MASSIVE PARTICLES IN M(jj)

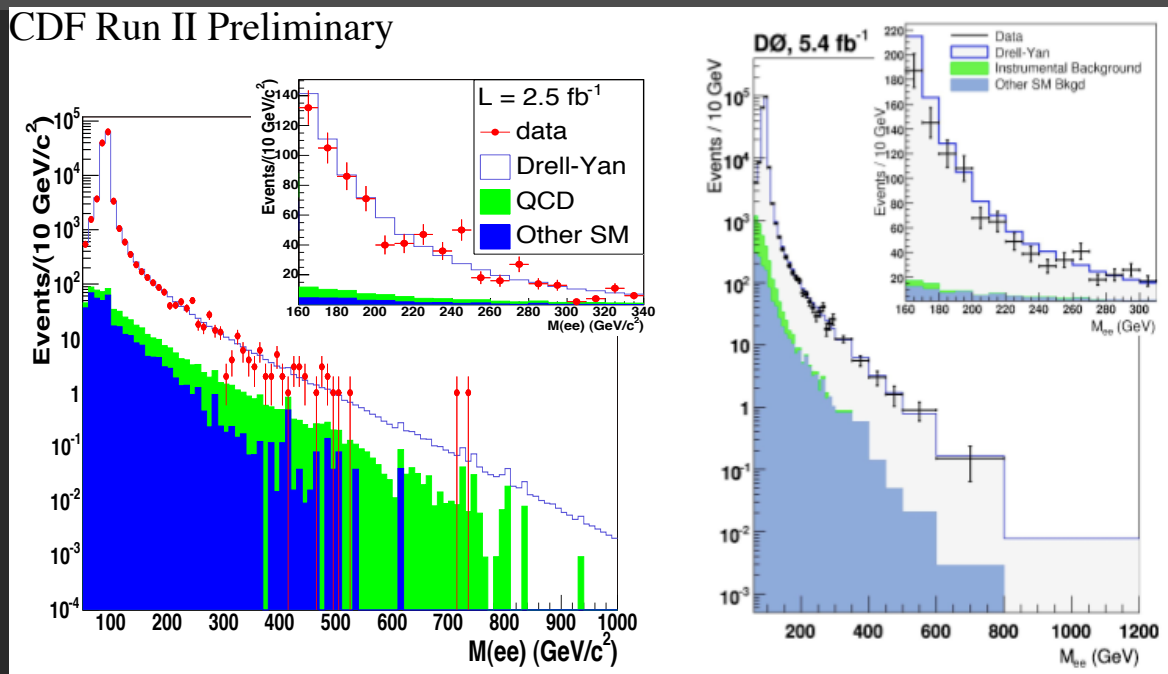


CDF LIMIT M(q*) > 870 GeV/c² ALREADY OBSOLETE WITH ~3/pb OF LHC DATA

M(q*) > 1.5 TeV/c² (ATLAS)

M(q*) > 1.58 TeV/c² (CMS)

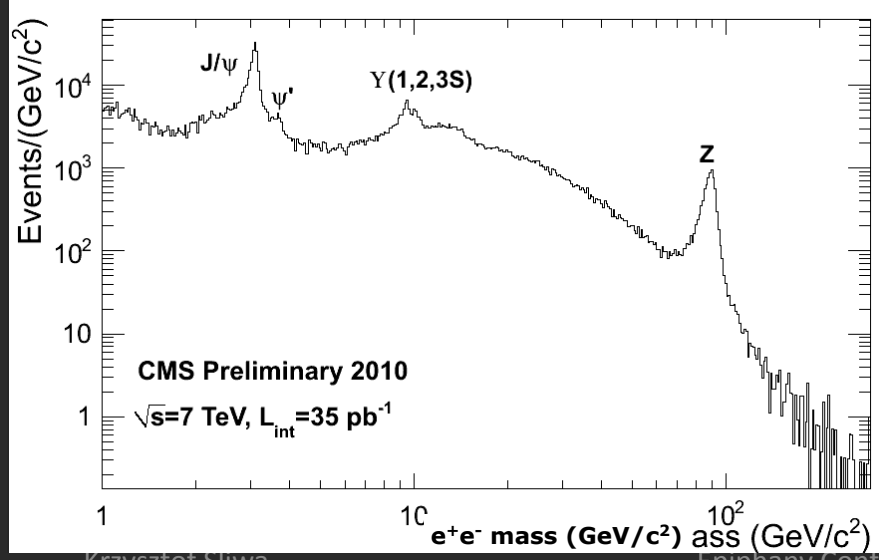
SEARCHES FOR NEW HEAVY PARTICLES IN M(ll)

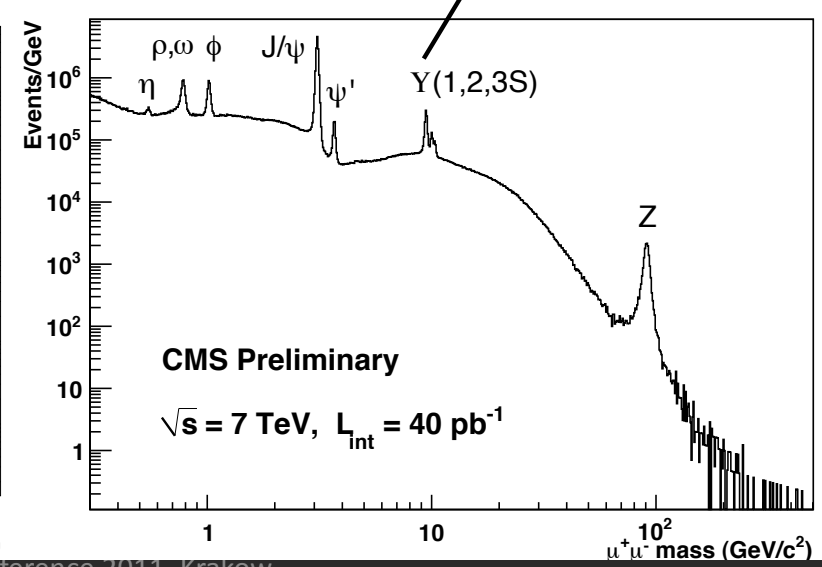


CDF observed a small excess (2.5 standard deviations) for an M(e+e-) around 240 GeV/c^2 above the SM prediction.

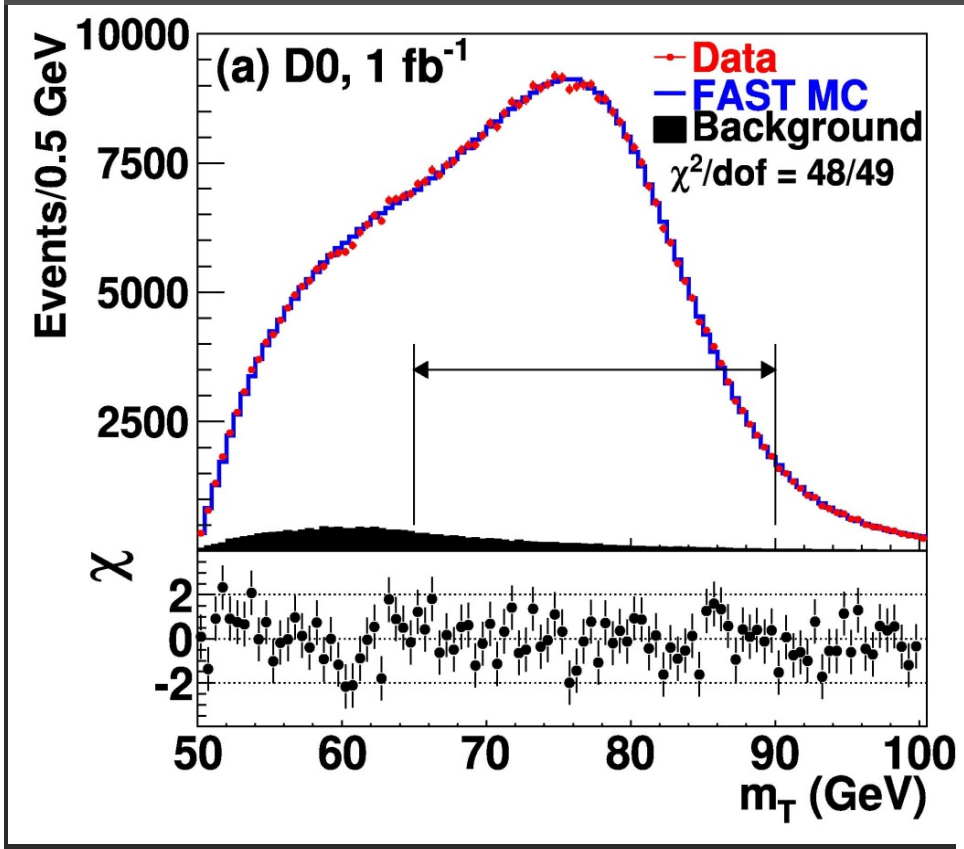
D0 did not see any deviation from SM with more data.

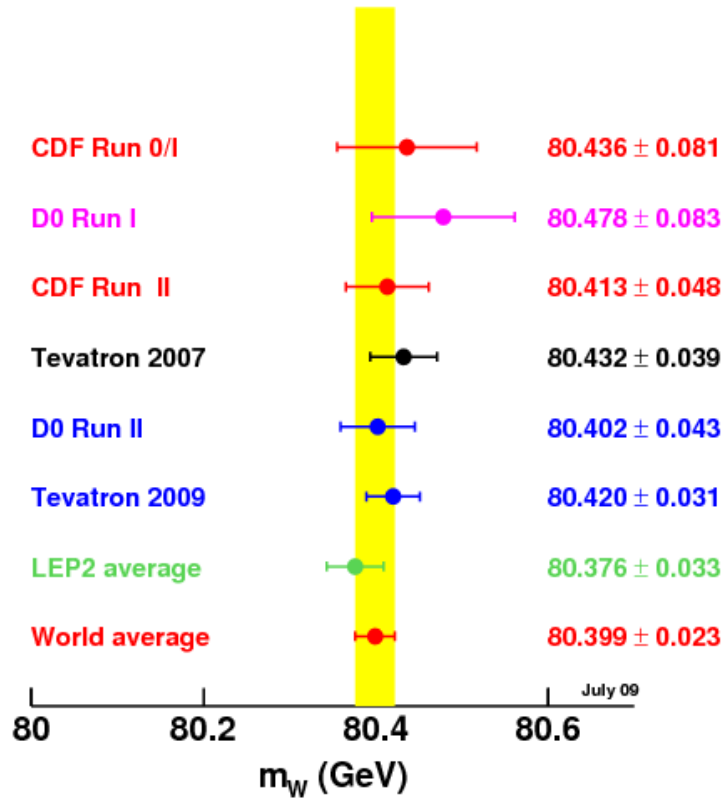
ATLAS and CMS see nothing





W boson mass

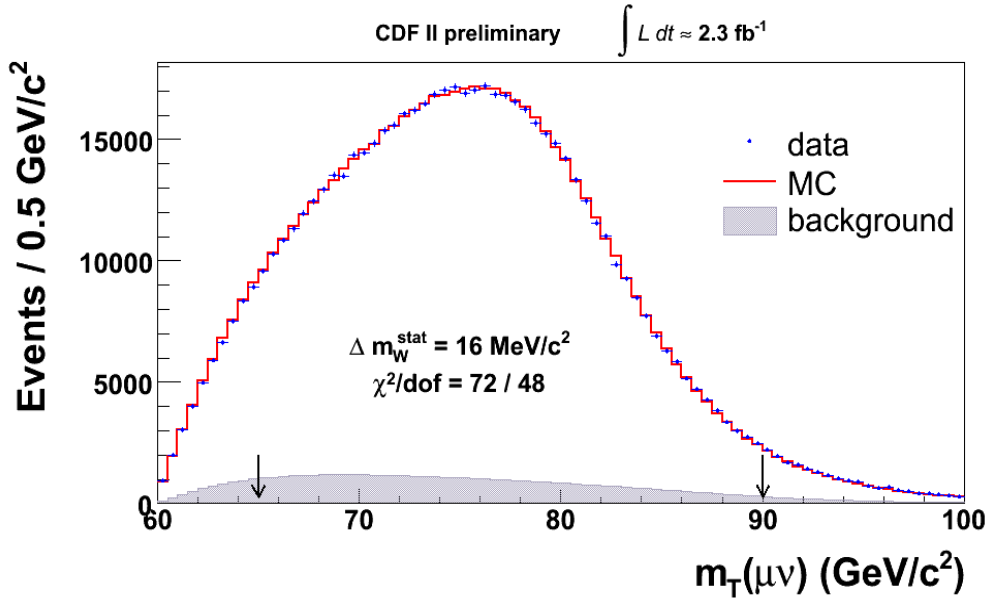


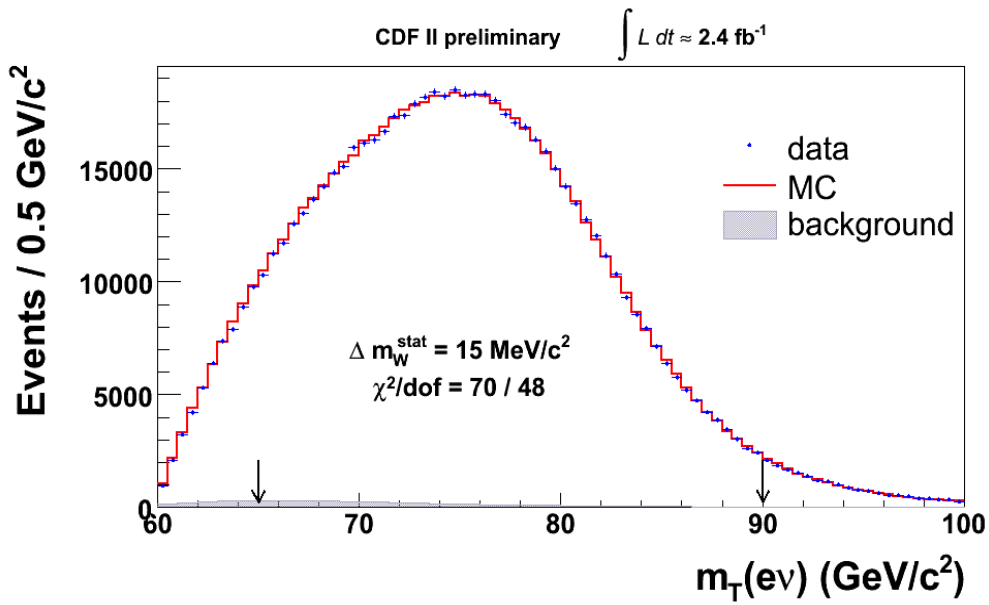


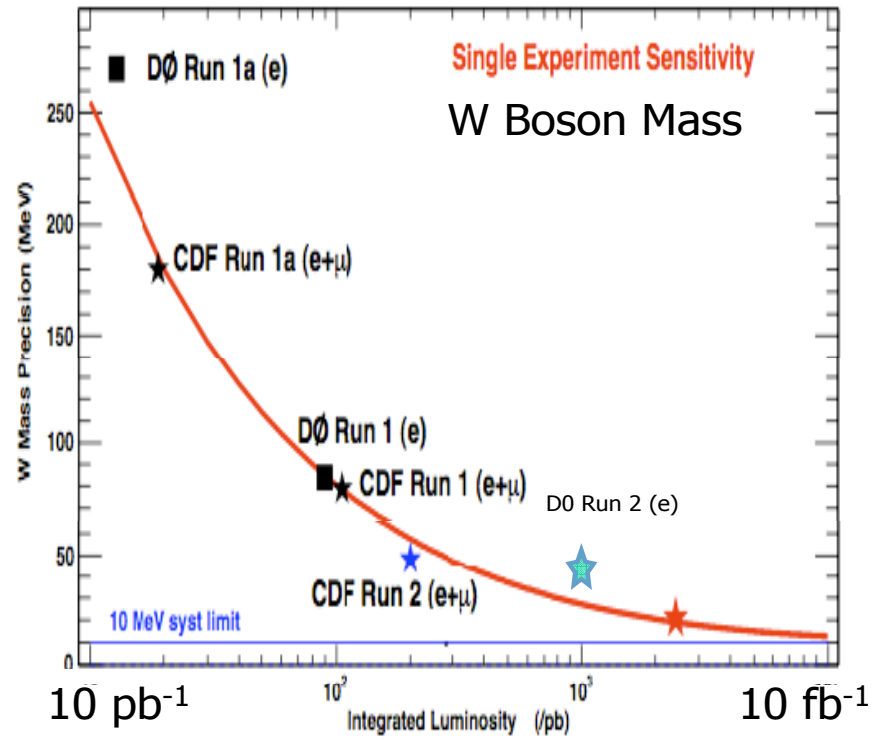
Tevatron: M_W = 80.420±0.031 GeV/c^2

World: M_W = 80.399±0.023 GeV/c^2

W boson mass



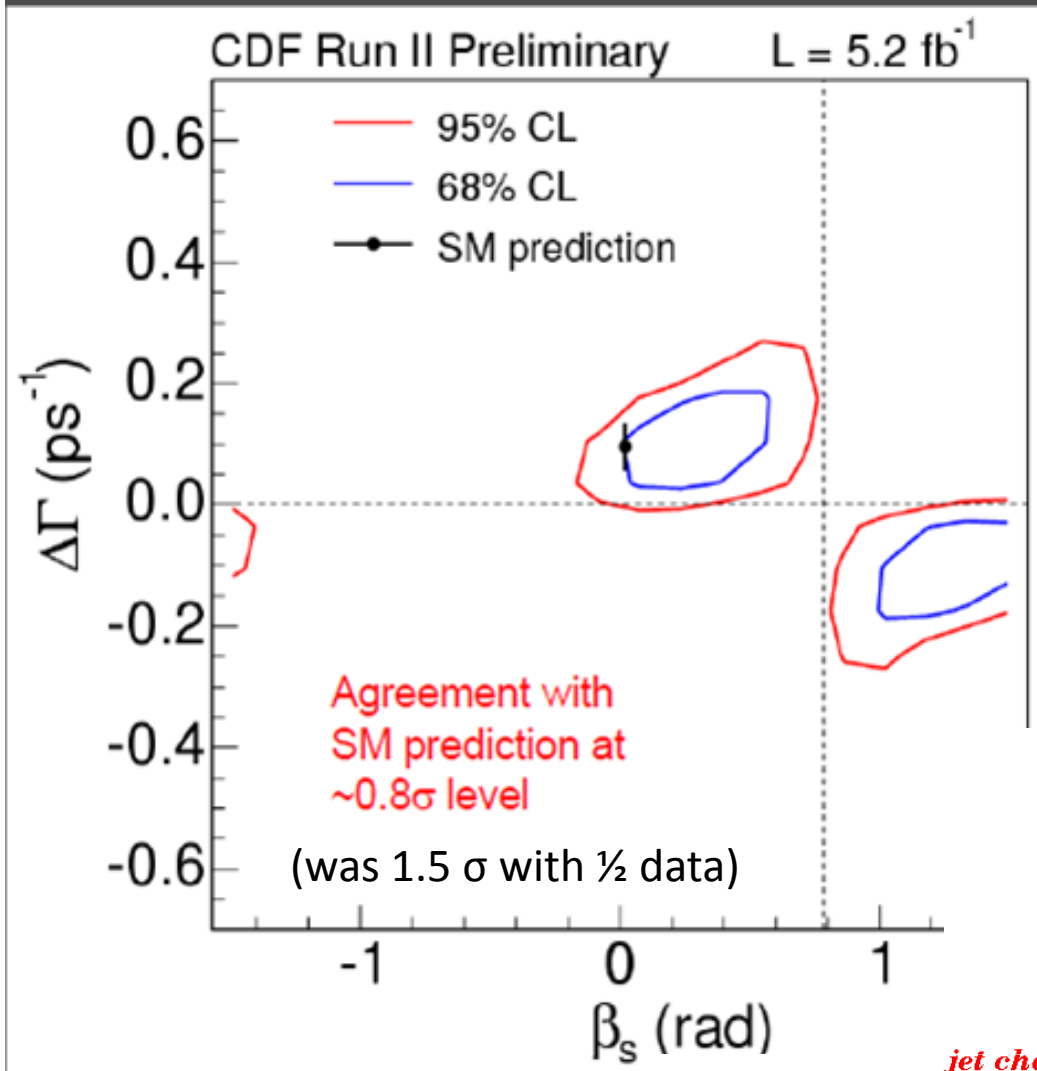


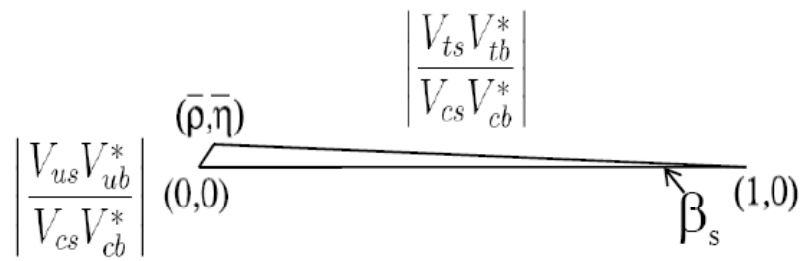


Tevatron plans to reach $\Delta M \sim 20\ MeV/c^2$

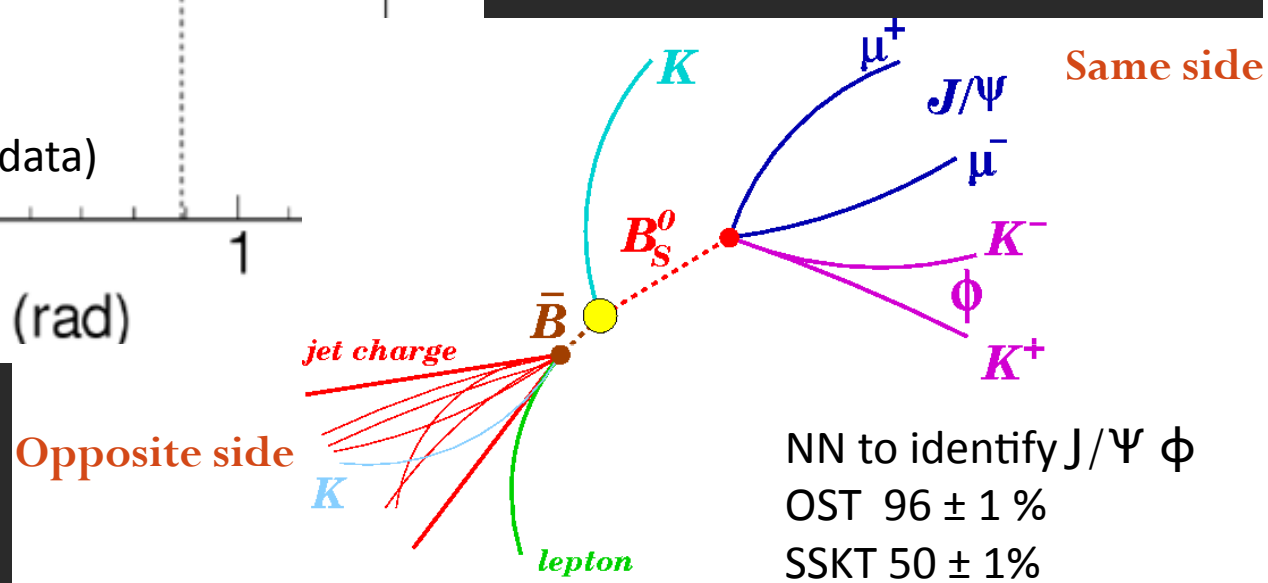
CAUTION: LHC experiments may find it VERY difficult to reach or exceed such precision - different machines: proton-proton (LHC) rather than proton-antiproton (Tevatron)

CP VIOLATION (B_s –> J/Ψ ϕ)



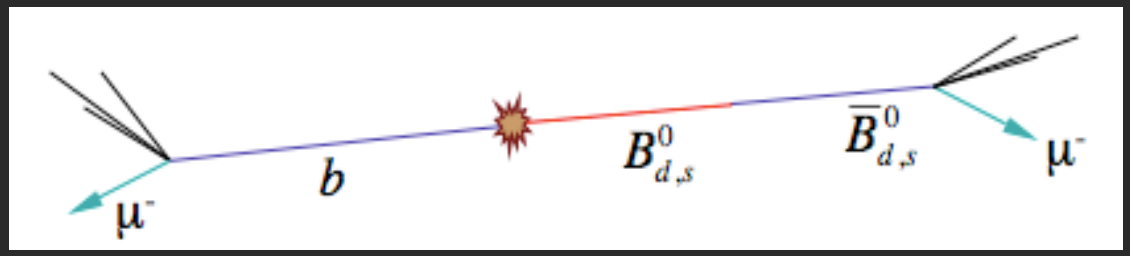


$\Delta\Gamma_s$ = 0.075 ± 0.035 (stat) ± 0.01 (syst) ps^{-1}



NN to identify J/Ψ ϕ
OST 96 ± 1 %
SSKT 50 ± 1%

CP VIOLATION IN B_s AND B_d (D0)

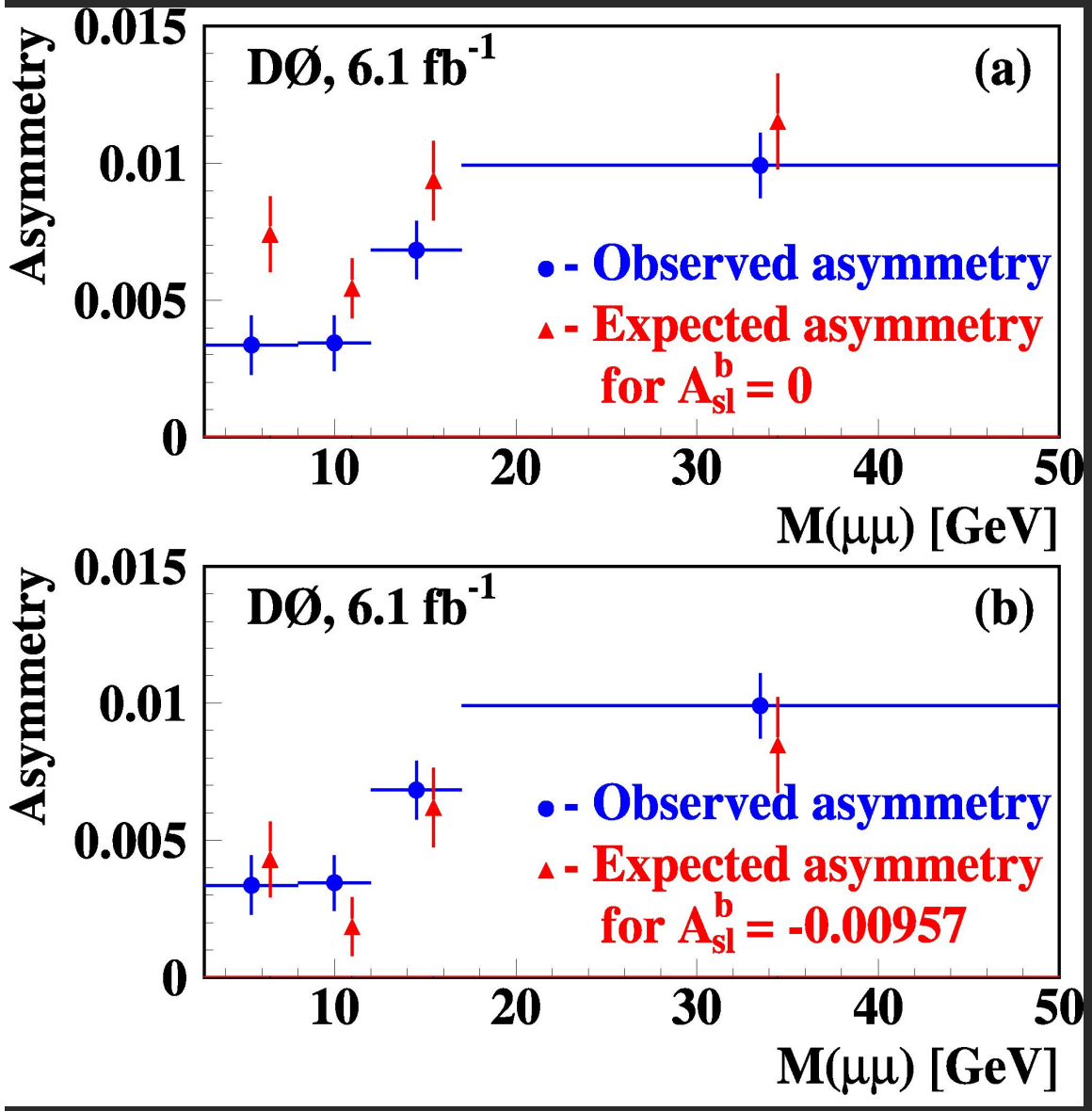


- Measure *CP* violation in mixing using the dimuon charge asymmetry of semileptonic *B* decays:

$$A^b_{sl} \equiv \frac{N^{++}_b - N^{--}_b}{N^{++}_b + N^{--}_b} \qquad a^b \equiv \frac{n^{++}_b - n^{-}_b}{n^{+}_b + n^{-}_b}$$

  - N_b^{++}, N_b^{--} : number of events with two *b* hadrons decaying semileptonically and producing two muons of same charge
  - One muon comes from direct semileptonic decay $b \rightarrow \mu^- X$
  - Second muon comes from direct semileptonic decay after neutral *B* meson mixing

same sign di-muon charge asymmetry (D0)

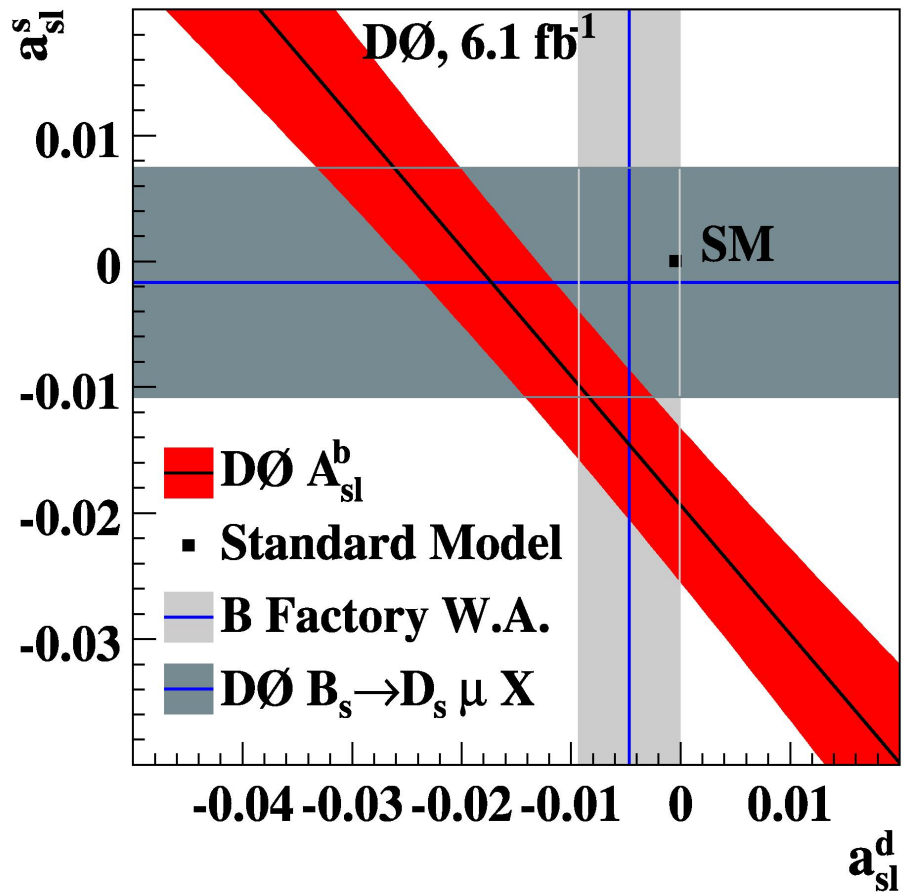


first evidence for Beyond the Standard Model CP Violation ?

evidence for anomalous like-sign dimuon charge asymmetry

A_{sl} is 3.2σ from Standard Model prediction

same sign di-muon charge asymmetry (D0)

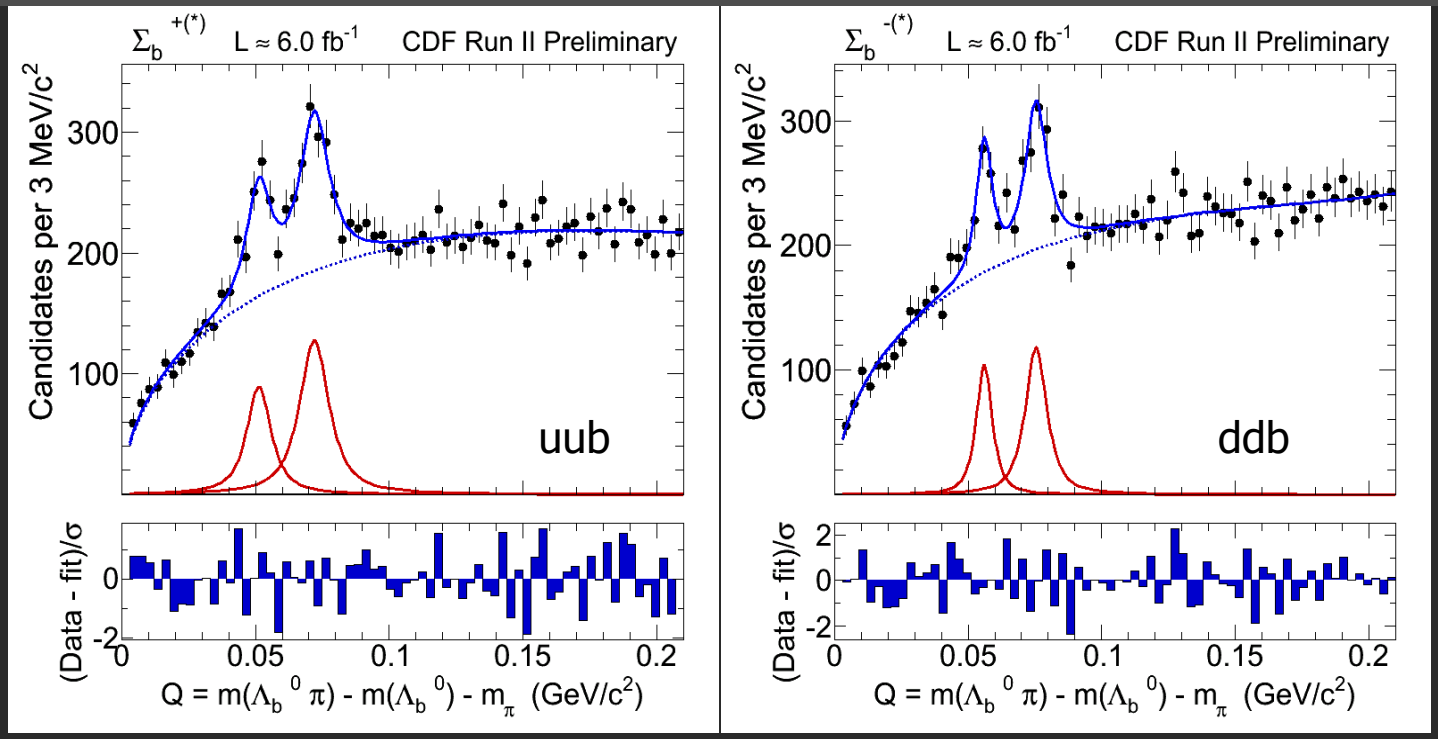


evidence for anomalous like-sign dimuon charge asymmetry

- A_{sl} is 3.2σ from Standard Model predictions : $A_{sl}^{theory} = (-2.3 \pm 0.6)\times10^{-4}$
- first evidence for Beyond the Standard Model CP Violation ?

$$A_{sl}^{b} = (-0.957 \pm 0.251(stat) \pm 0.146(syst))\times10^{-2}$$

Σ_b (2006)



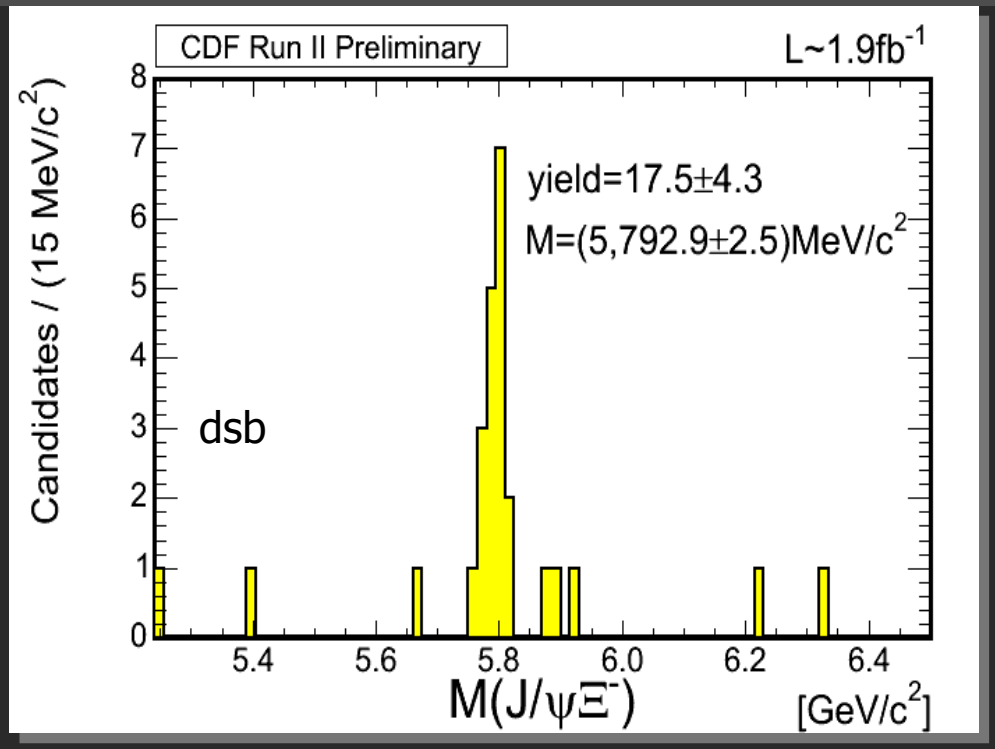
$m(\Sigma_b^+) = 5811.2^{+0.9}_{-0.8}(\text{stat.}) \pm 1.7(\text{syst.})\ \text{MeV}/c^2$

$m(\Sigma_b^-) = 5815.5^{+0.6}_{-0.5}(\text{stat.}) \pm 1.7(\text{syst.})\ \text{MeV}/c^2$

$m(\Sigma_b^{*+}) = 5832.0 \pm 0.7\ (\text{stat.}) \pm +1.8(\text{syst.})\ \text{MeV}/c^2$

$m(\Sigma_b^{*-}) = 5835.0 \pm 0.6(\text{stat.}) \pm +1.8(\text{syst.})\ \text{MeV}/c^2$

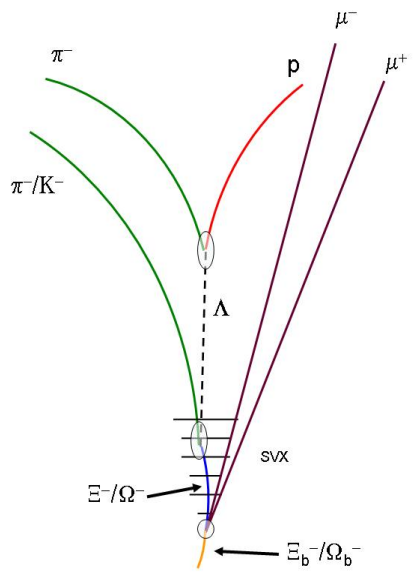
Ξ_b (2007)

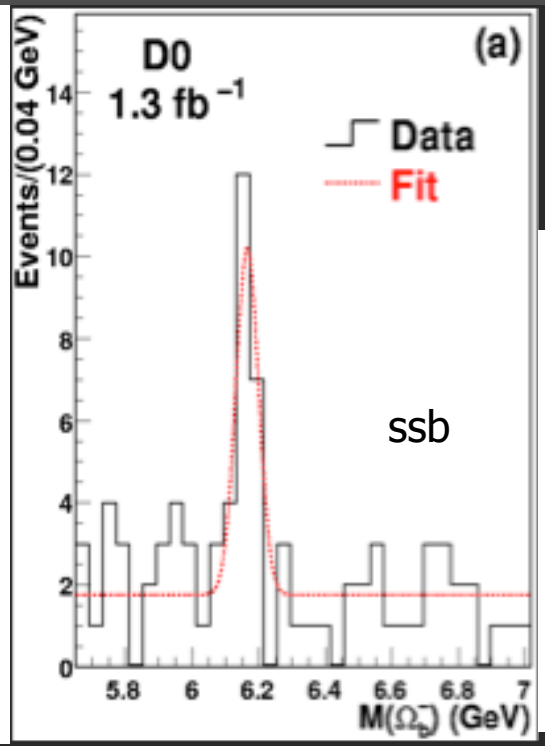


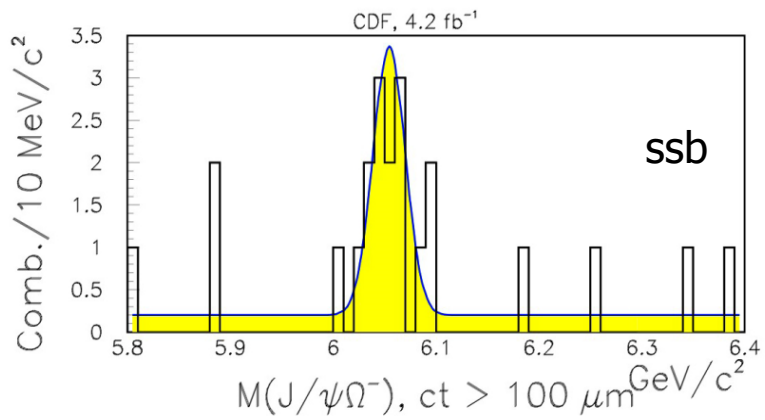
$m(\Xi_b) = 5790.9 \pm 2.6(\text{stat.}) \pm 0.8(\text{syst.})\ \text{MeV}/c^2$

$\tau(\Xi_b) = 1.56^{+0.27}_{-0.25}(\text{stat.}) \pm 0.02(\text{syst.})\ \text{ps}$

Ω_b (2008)





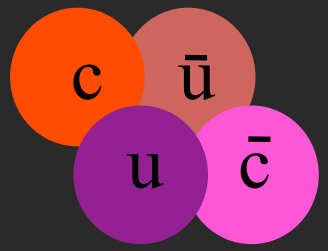


$m(\Omega_b^+) = 6054.4 \pm 6.8(\text{stat.}) \pm 0.9(\text{syst.})\ \text{MeV}/c^2$

$\tau(\Omega_b^+) = 1.13^{+0.53}_{-0.40}(\text{stat.}) \pm 0.02(\text{syst.})\ \text{ps}$

EXOTIC MESONS QCD ?

- Multi-quark mesons
  molecule, diquark-antidiquark

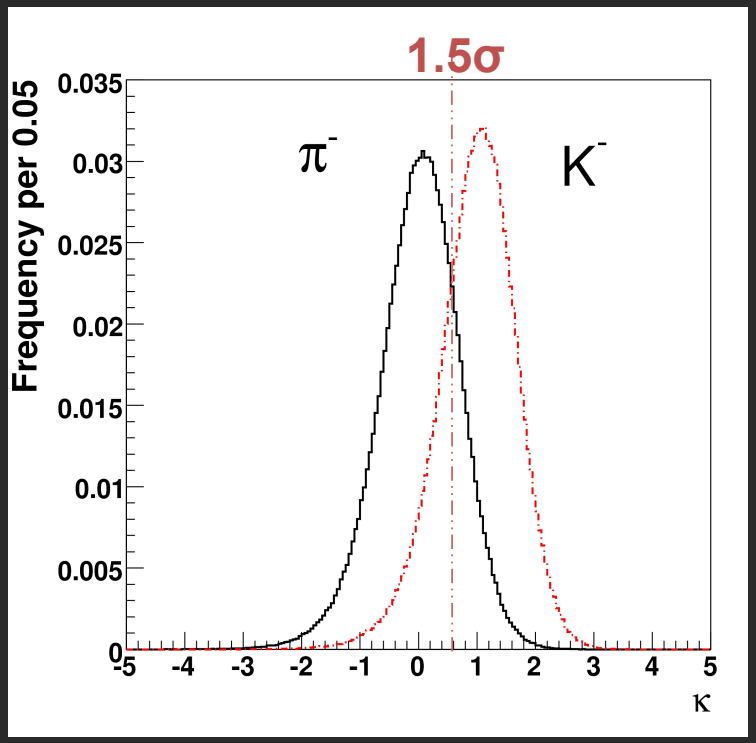


- Hybrid mesons
  quark-antiquark-gluon

- Glueball
  gluonic color singlet states

J/ψϕ? (threshold @4.116 GeV/c^2, VV, C=+)
(cc) with a mass above 4.116 GeV/c^2, expect tiny branching fraction

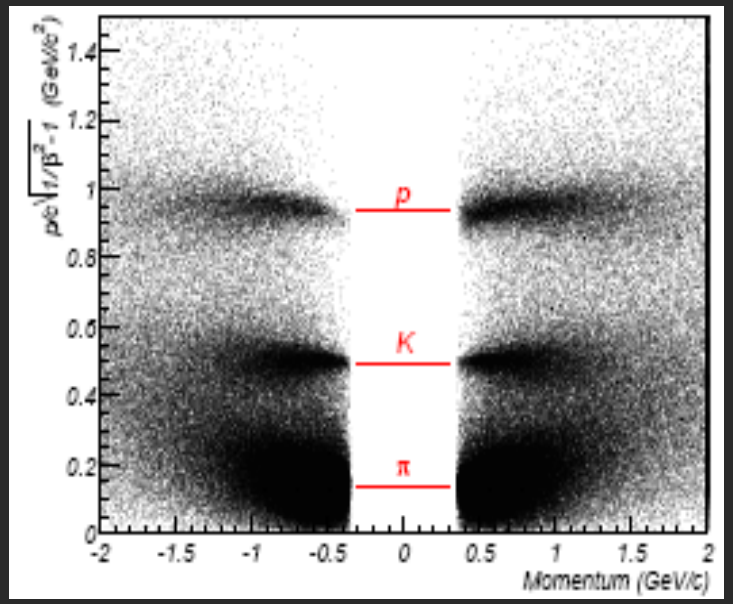
π/K/p identification (CDF)



dE/dx parameterized using $D^{*+(-)} \rightarrow D^0 \pi^{+(-)}$ sample

dE/dx efficiency ~100%

CDF Time-of-flight: Tevatron store 860-12/23/2001



Excellent resolution

Time-of-Flight acceptance+efficiency ~60%

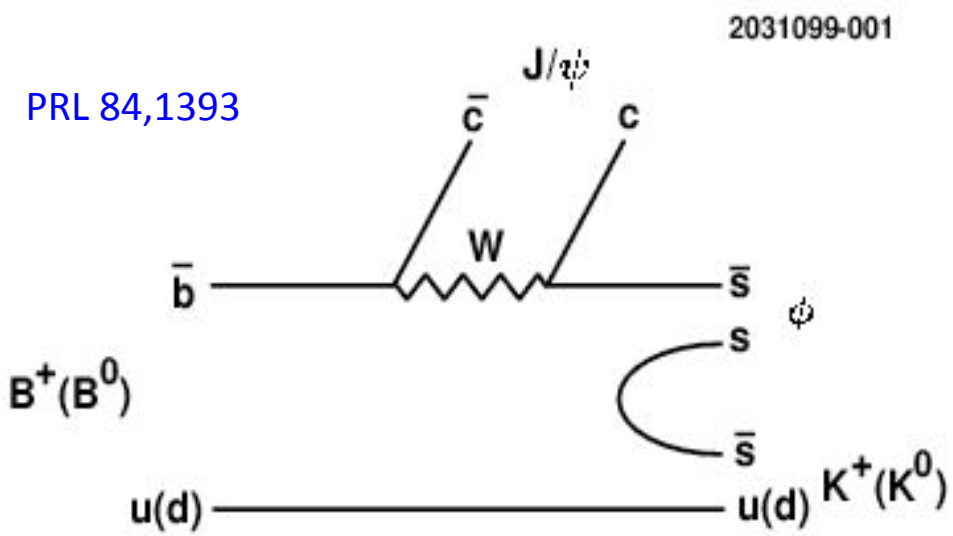
Make use of both dEdx and ToF for hadron PID summarizing dEdx and ToF into a log-likelihood ratio

Look for structures in B−>J/ψϕ

Experimentally easy to search through clean B→J/ψϕK channel taking advantage of B lifetime and narrow B mass window

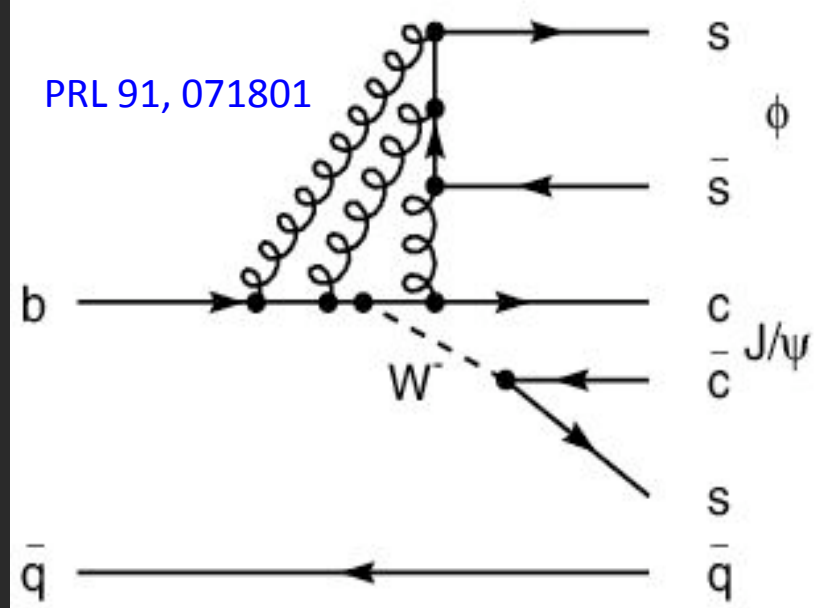
B→J/ψϕK is OZI suppressed, so low physics background

PRL 84,1393



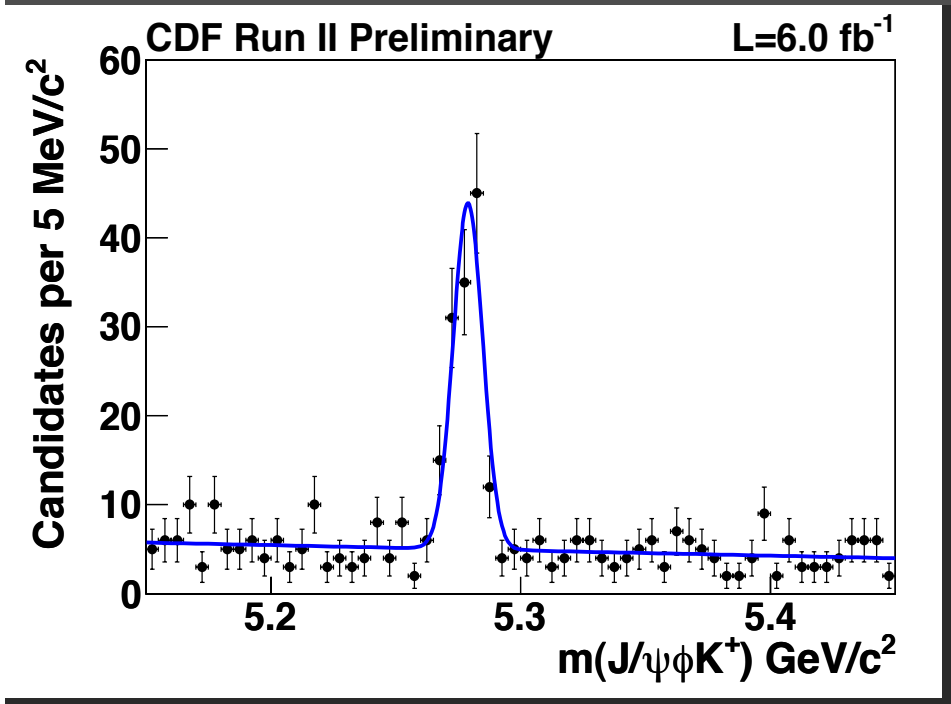
vacuum polarization

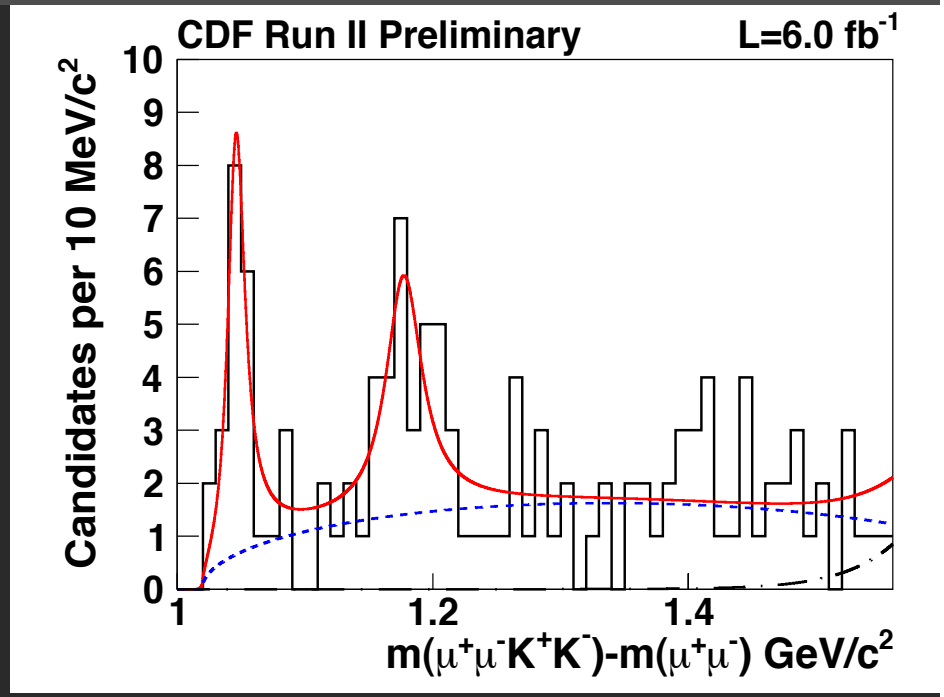
PRL 91, 071801



gluon coupling

Y(4140) ??





$B^+ \rightarrow Y(4140)K^+$; $Y(4140) \rightarrow J/\psi\, \phi$; $J/\Psi \rightarrow \mu^+\mu^-$; $\phi \rightarrow K^+ K^-$

$M = 4143.4 \pm 3.0$ (stat) ± 0.6 (syst) MeV/c^2

$\Gamma = 15.3 \pm {}^{10.4}_{6.1}$ (stat) ± 2.5 (syst) MeV/c^2

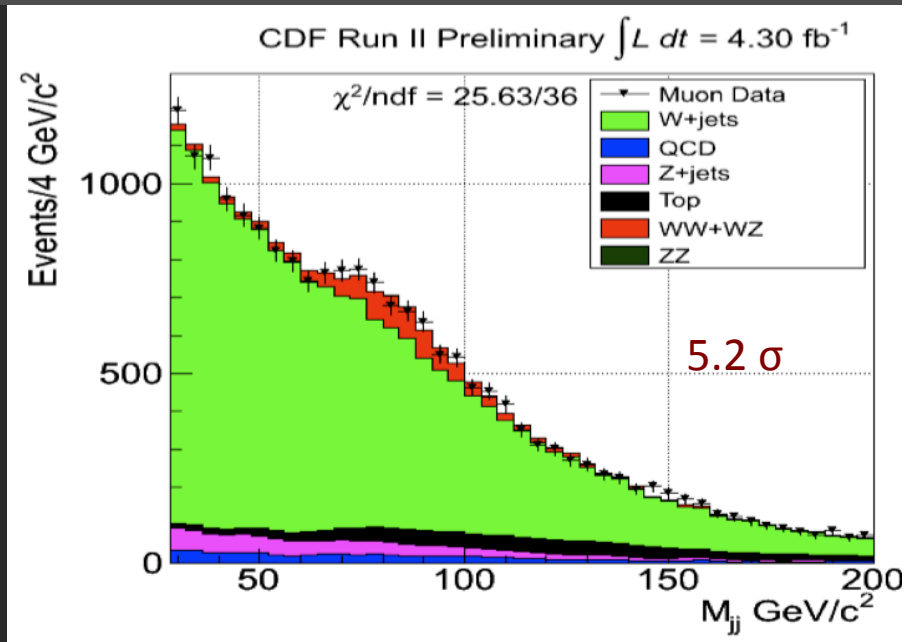
$M = 4274.4 \pm {}^{8.4}_{6.7}$ (stat) MeV/c^2 $> 5\ \sigma$

$\Gamma = 32.3 \pm {}^{21.9}_{15.3}$ (stat) MeV/c^2 $3.1\ \sigma$

WW, WZ

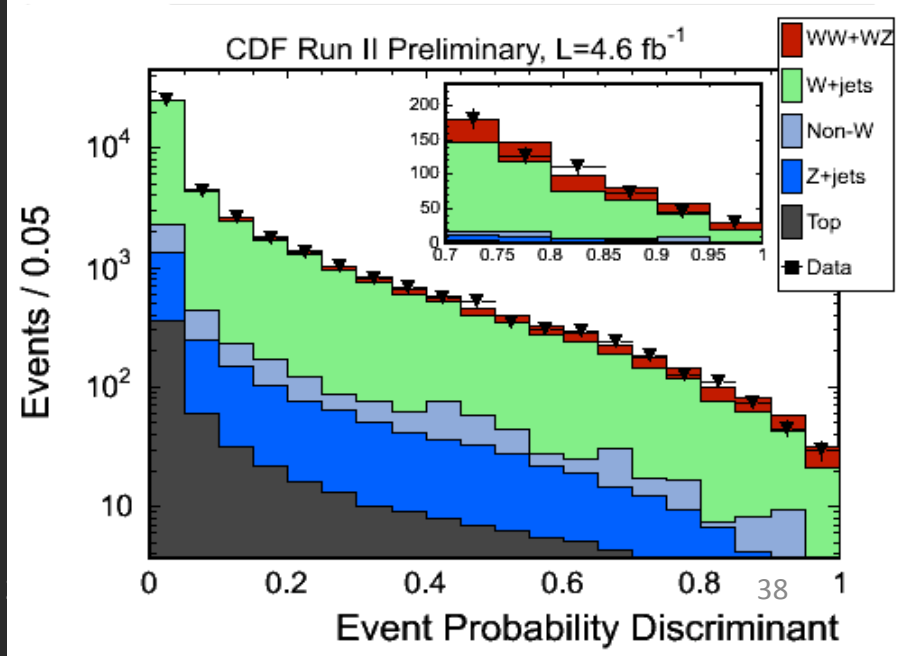
M(jj)

σ_{WW+WZ} = 18.1 ± 3.3 (stat) ± 2.5 (syst) pb



matrix element techniques

σ_{WW+WZ} = 16.5 ± 3.3 (stat) ± 3.5 (syst) pb



WW, WZ, ZZ, Zγ…

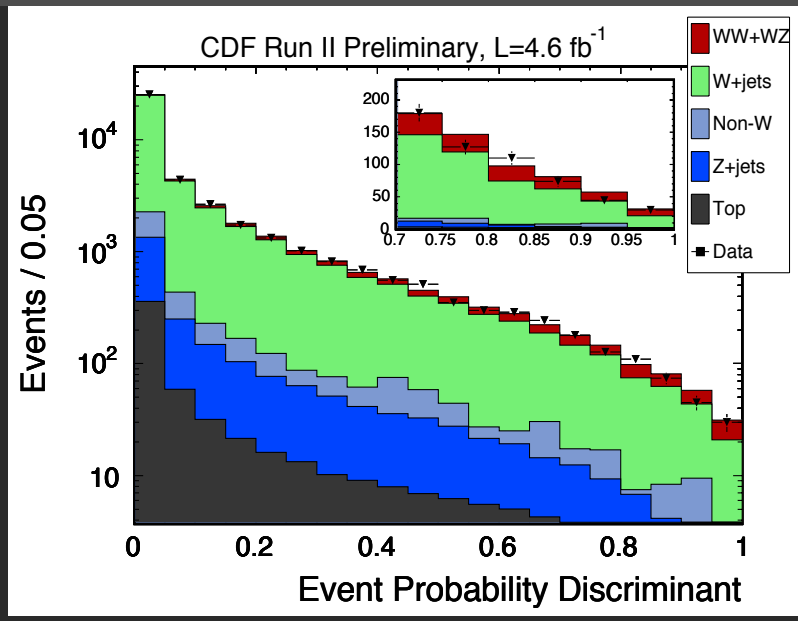
Neural nets and other multivariate techniques used in all these analyses.

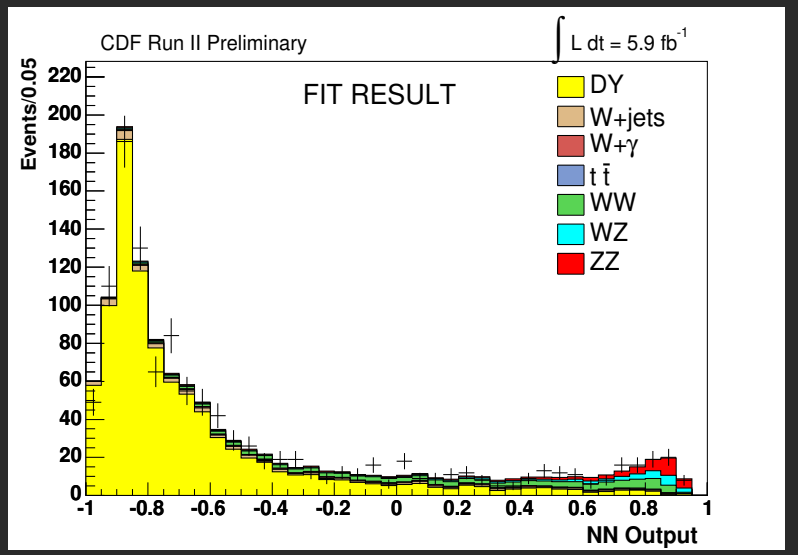
σ_{WW} = 12.1 ± 0.9 (stat) ± 1.6 (syst) pb

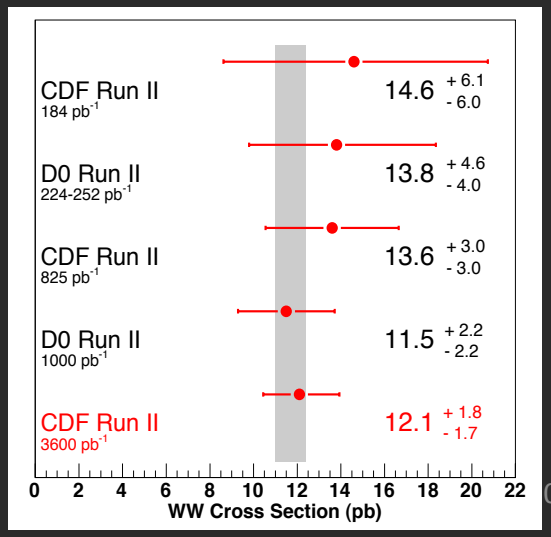
σ_{WZ} = 4.1 ± 0.7 pb

$\sigma_{Z\gamma}$ = 4.6 ± 0.2 (stat) ± 0.3 (syst) ± 0.3 (lum) pb

σ_{ZZ} = 1.45 ± 0.45 (stat) ± 0.41 (syst) pb







top mass and quark cross section

i. search for events with top signature

ii. calculate expected SM background

iii. count events above backgrounds

iv. apply corrections for acceptance and reconstruction inefficiencies and biases

–> tt pair-production cross section
–> single top production cross section

TOP QUARK WAS DISCOVERED AT TEVATRON IN !993-1994

top quark cross section

One should remember two important details:

It is *assumed* that the selected sample of events contains just the *$t\bar{t}$ events* and the *SM background*. This is the simplest and the most natural hypothesis since top quark is *expected* in the SM.

Some of the acceptance corrections are strongly varying functions of top quark mass, M_t. The measured cross section depend on the adopted value of M_t, which has to be determined independently.

top mass and cross section – methodology

DIRECT MEASUREMENT OF TOP MASS

All mass measurement techniques assume that each selected event contains a pair of massive objects of the same mass (top and anti-top quarks) which subsequently decay as predicted in SM.

It is *assumed* that the selected sample of events contains just the *$t\bar{t}$ events* and the *SM background*. This is the simplest and the most natural hypothesis since top quark is *expected* in the SM.

The combinatorics, i.e. the problem that only one out of a large number of jets-lepton(s) combinations is correct, adds to the complexity of the problem.

TOP MASS MEASUREMENT IN LEPTON+JETS CHANNEL

In the lepton+jets and all-jets final states there is enough kinematical constraints to perform a genuine fit

Leptons are measured best, jets not as well, while the missing transverse energy (MET) has the largest uncertainty

In the lepton+jets final state one may, or may not, use MET as the starting point for the transverse energy of the missing neutrino. In their published analyses CDF and D0 make use of MET.

CDF and D0 use template, multivariate template, DLM, Matrix Element, ideogram, and multivariant discriminant analyses to select their top enriched and background samples of events that are basis of their top mass and cross section analyses.

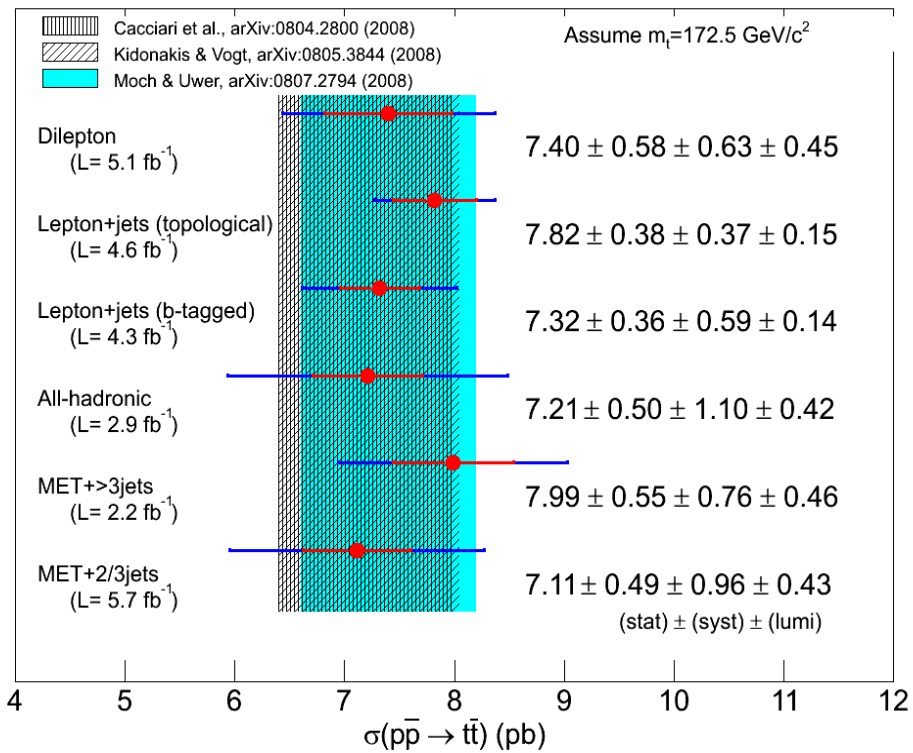
TOP MASS MEASUREMENT IN DI–LEPTON CHANNEL

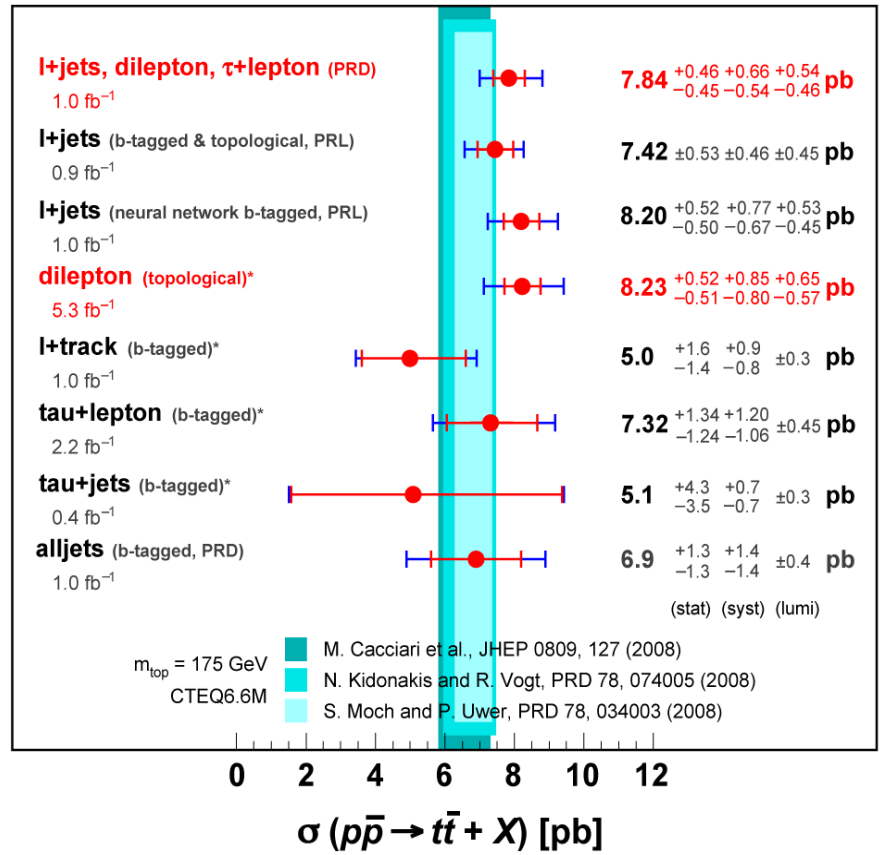
In the di-lepton mode situation is much more complicated, as the problem is under-constrained (two missing neutrinos). Several techniques were developed. All obtain a probability density distribution as a function of M_t whose shape allows identifying the most likely mass which satisfies the hypothesis that a pair of top quarks were produced in an event and that their decay products correspond to a given combination of leptons and jets.

MET may, or may not, be used.

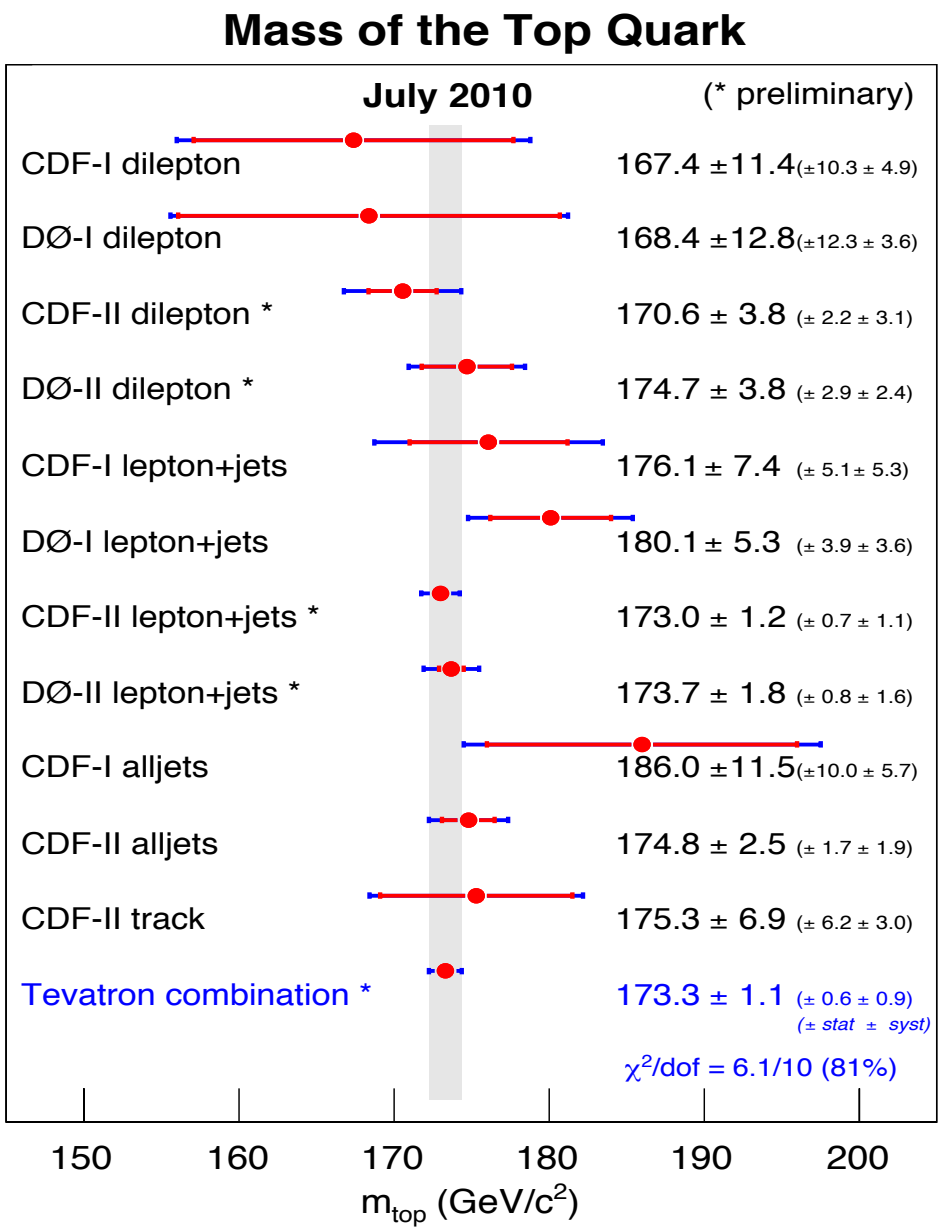
D0 and CDF developed several methods, the Neutrino Phase Space weighting technique (νWT) and the Average Matrix Element technique (MWT), a modified form of Dalitz-Goldstein, Dalitz-Goldstein-Sliwa and Kondo methods (I've been working in this field for many years …)

TOP CROSS SECTION





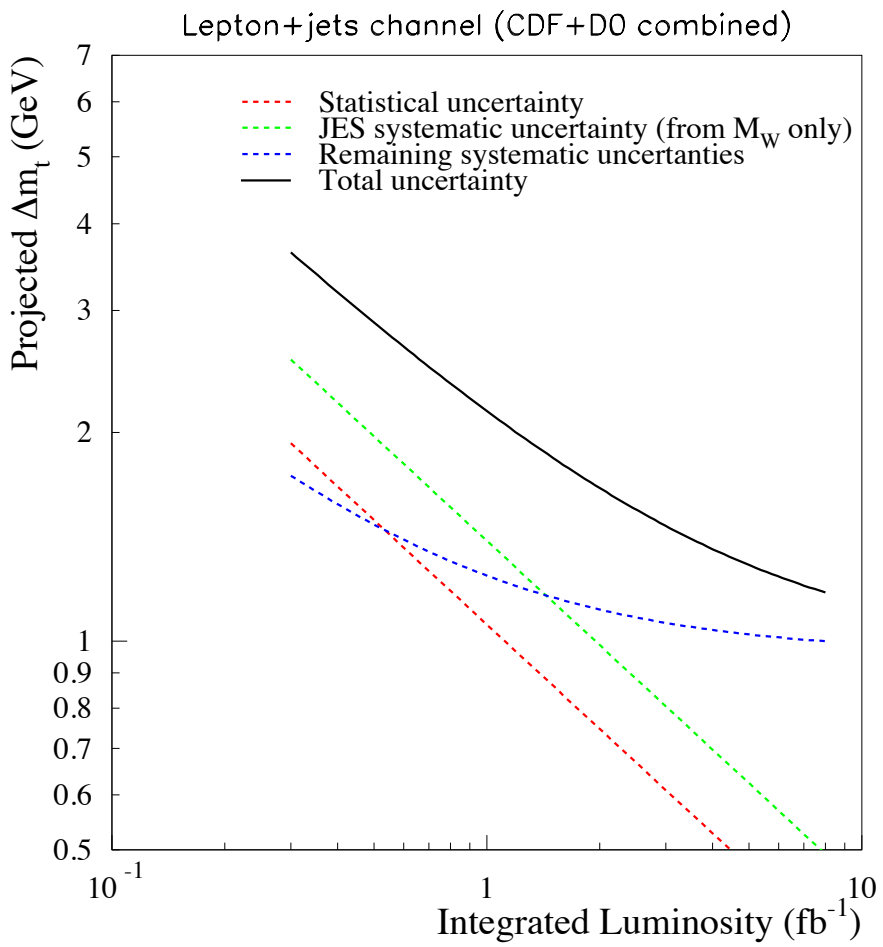
TOP MASS



D0 and CDF combined:

173.3 ± 0.6 (stat) ± 0.9 (syst)

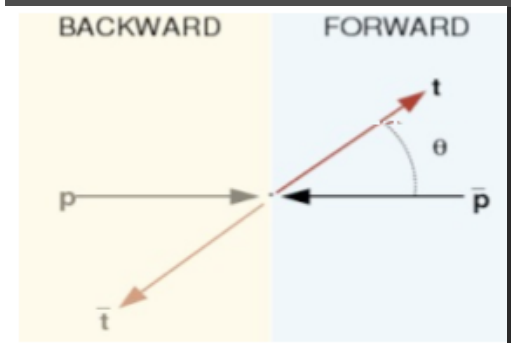
TOP MASS FUTURE?



I remain a bit skeptical about the systematic errors, both experiments have developed a "procedure" to evaluate them, I worry that the error might be underestimated (because of some effects not yet taken into account)

LHC is a top factory - very large statistics - the challenge will be to reduce the systematic errors

FORWARD–BACKWARD ASYMMETRY IN TOP PRODUCTION

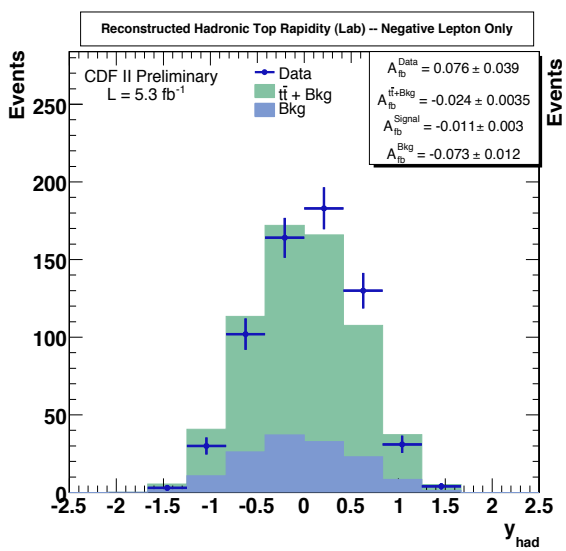


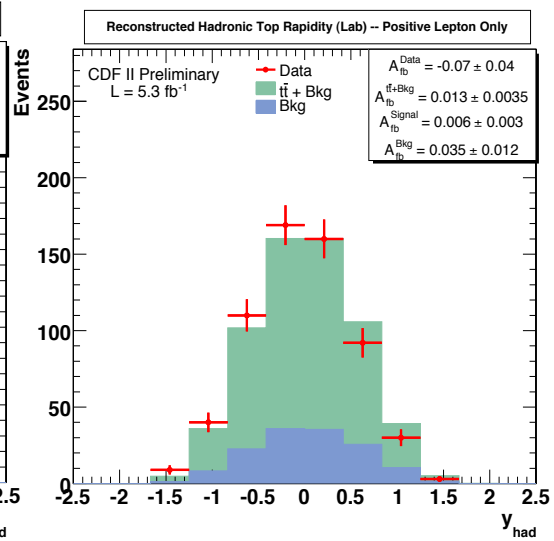
$$A_{fb} = \frac{F - B}{F + B}$$

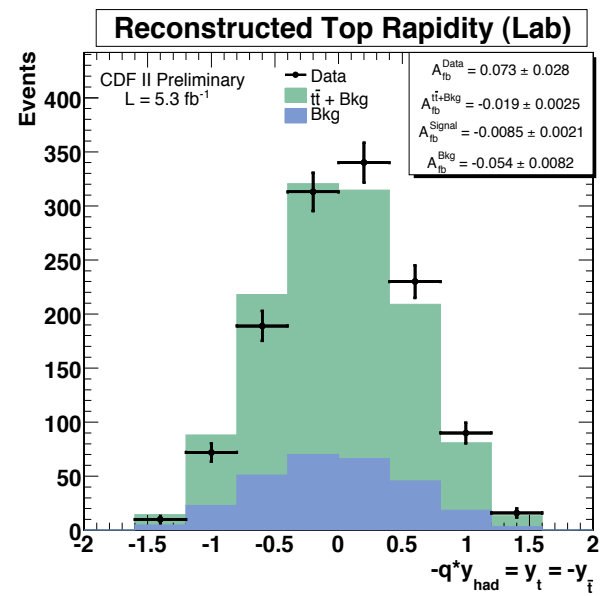
Standard Model predicts: A_{fb} = 0.05±0.015 (NLO QCD)
Recently there has been lots of activity to calculate A_{fb} more reliably

CDF(5.3/fb): A_{fb} = 0.158 ± 0.072 (stat) ± 0.017 (syst)

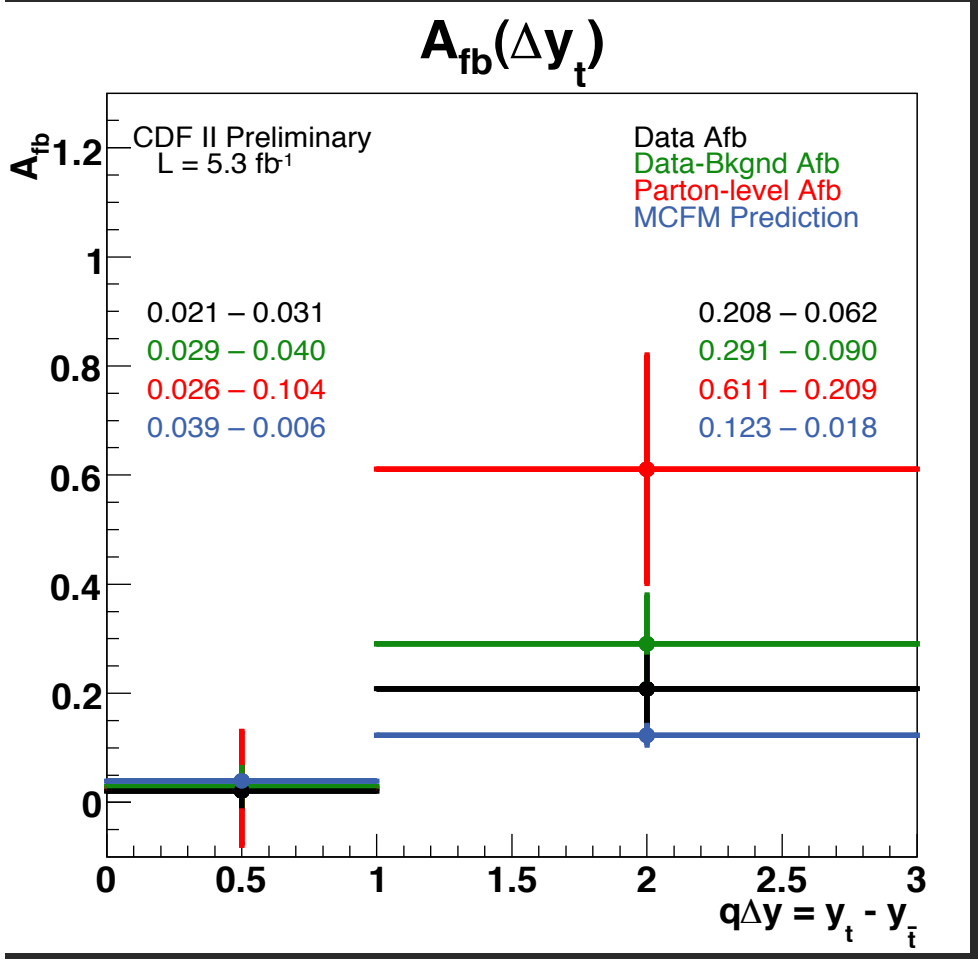
D0 (4.3/fb) : A_{fb} = 0.08 ± 0.04 (stat) ± 0.01 (syst)







FORWARD–BACKWARD ASYMMETRY IN TOP PRODUCTION



Standard Model predicts: $A_{fb} = 0.05 \pm 0.015$ (NLO QCD)

CDF (5.3/fb) :

$|\Delta y| < 1$

$A_{fb} = 0.026 \pm 0.104$ (stat) ± 0.055 (syst)

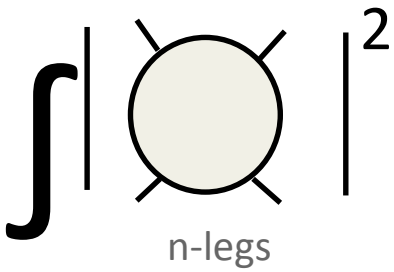
$|\Delta y| > 1$

$A_{fb} = 0.611 \pm 0.210$ (stat) ± 0.141 (syst)

Towards Top-Quark Pair Production @ NNLO

Recently there has been lots of activity to calculate A_{fb} more reliably

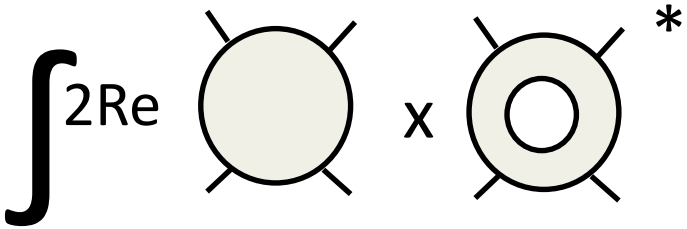
$\sigma_{ij} =$



n-legs

Leading-order, Born approximation

+



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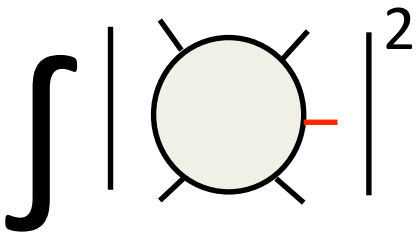
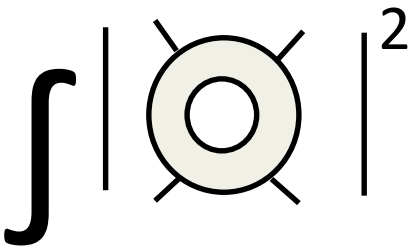


(n+1)-legs, real corrections

Next-to-leading order (NLO)

+



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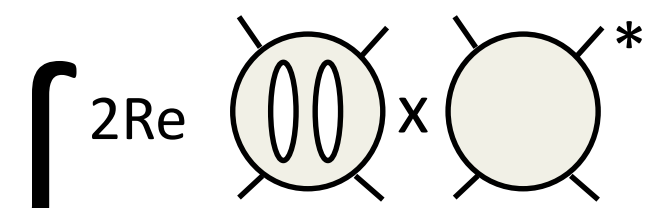

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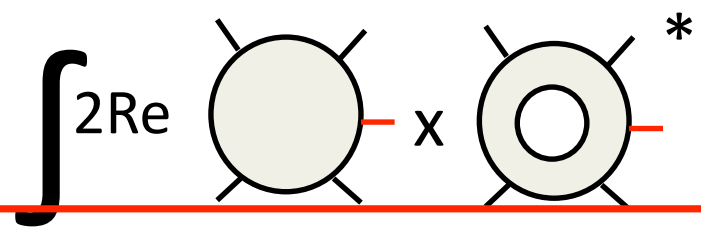

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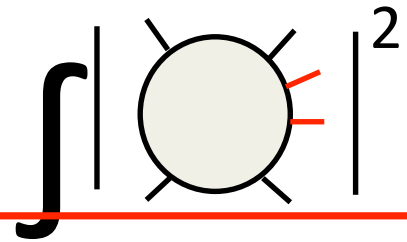
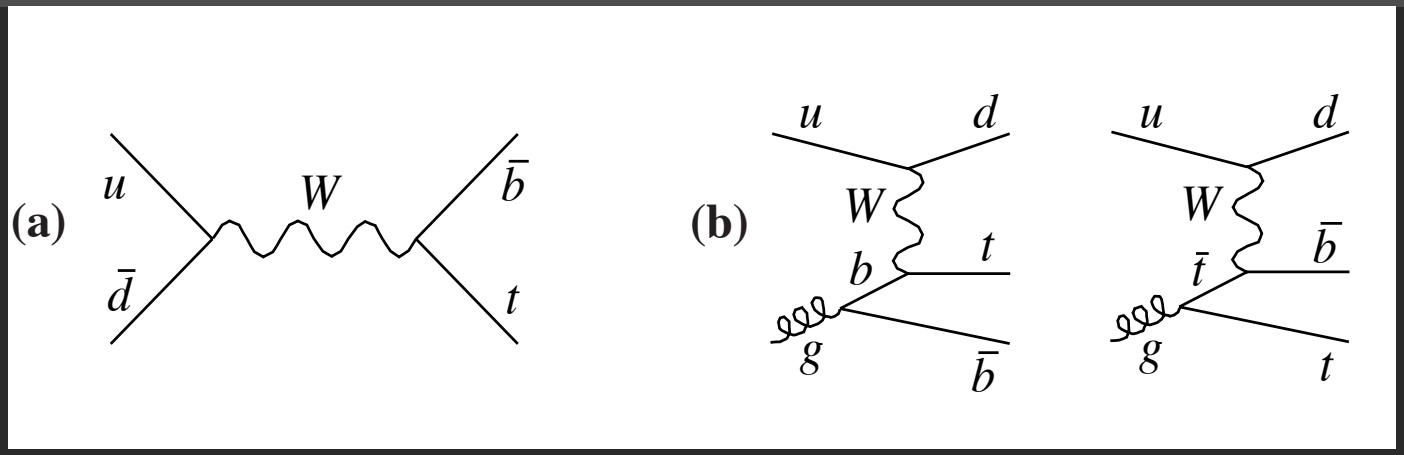


Next-to-next-to-leading order (NNLO)

$\delta\sigma^{NNLO}$

...

SINGLE TOP PRODUCTION



Electroweak process. Standard Model cross sections:

$\sigma(pp \to Wg \to t+X) = 1.70 \pm 0.20$ pb (Stelzer at al)

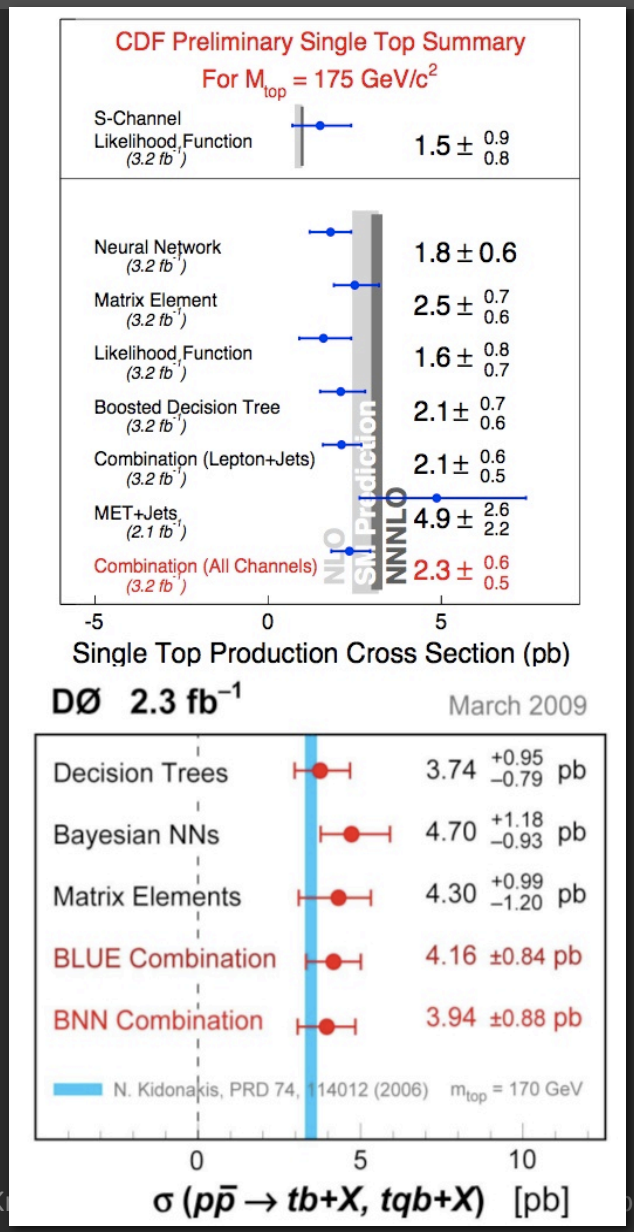
$\sigma(pp \to W^* \to t+X) = 0.72 \pm 0.04$ pb (Smith at al)

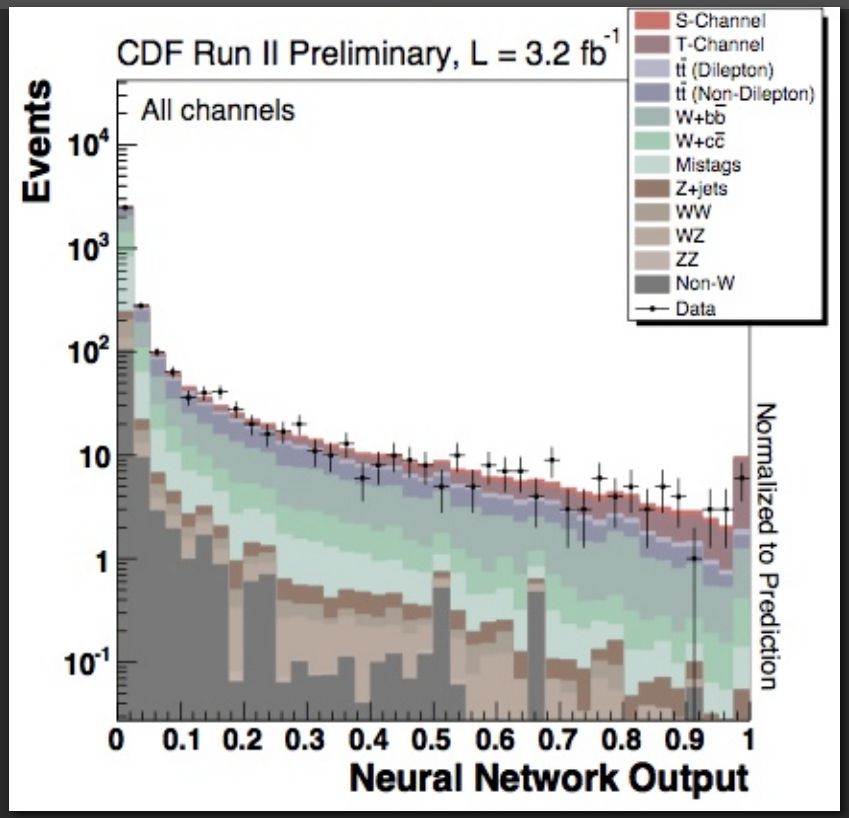
Direct access to Wtb vertex, one could determine the $|V_{tb}|$ element of Cabibbo-Kobayashi-Maskawa matrix

Search for anomalous couplings - large production rates or anomalous angular distributions

Also, demonstrate that ability to look for very small signals (Higgs?)

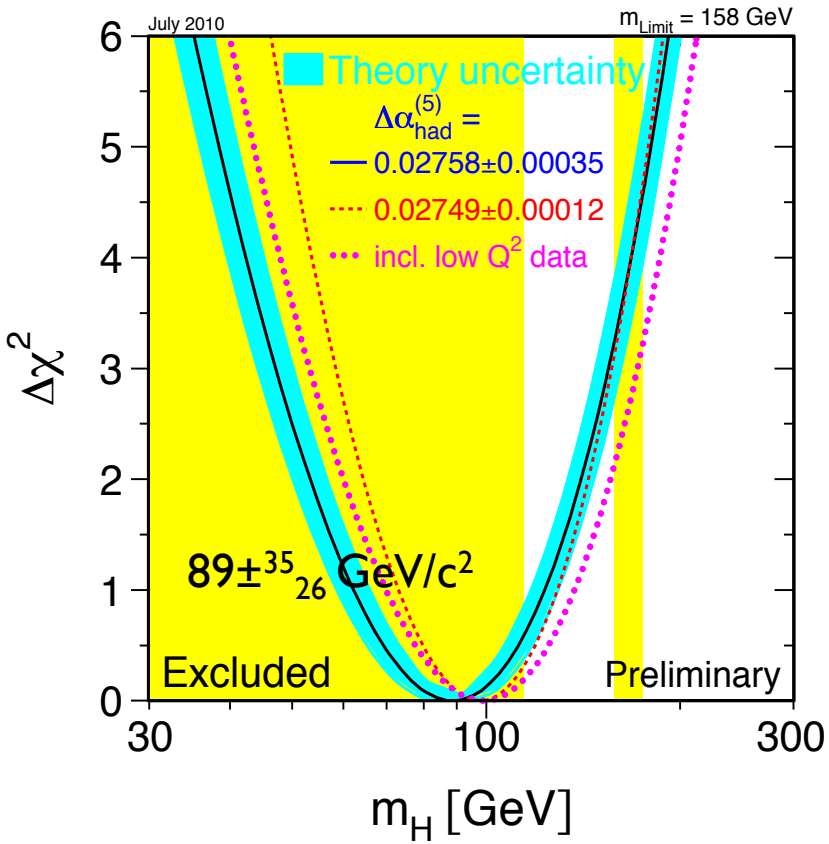
SINGLE TOP PRODUCTION

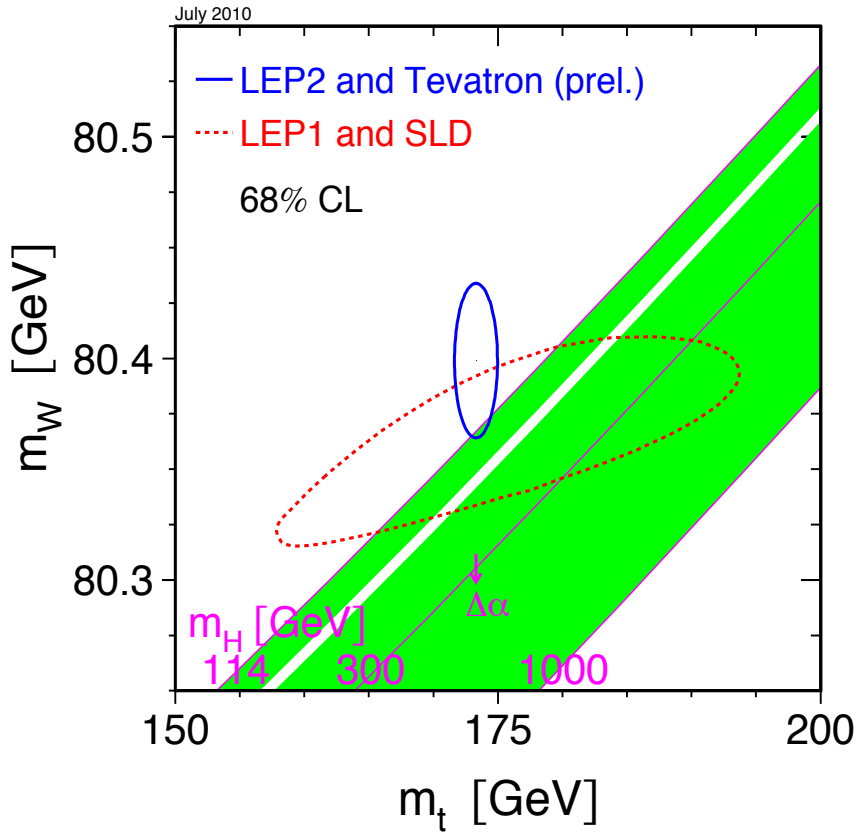




- Single Top Physics Program
  - test s vs t [new physics]
  - V_{tb} [precision]
  - lifetime [new physics]

MINIMAL STANDARD MODEL





It is possible to verify internal consistency of MSM through precise measurements: measurements of W and top mass constrain Higgs mass. Fundamental consistency tests of the Minimal Standard Model; sensitivity through radiative corrections (quadratic in m_t, logarithmic in m_H)

–> COMPARE WITH DIRECT LIMITS ON HIGGS MASS

Higgs production

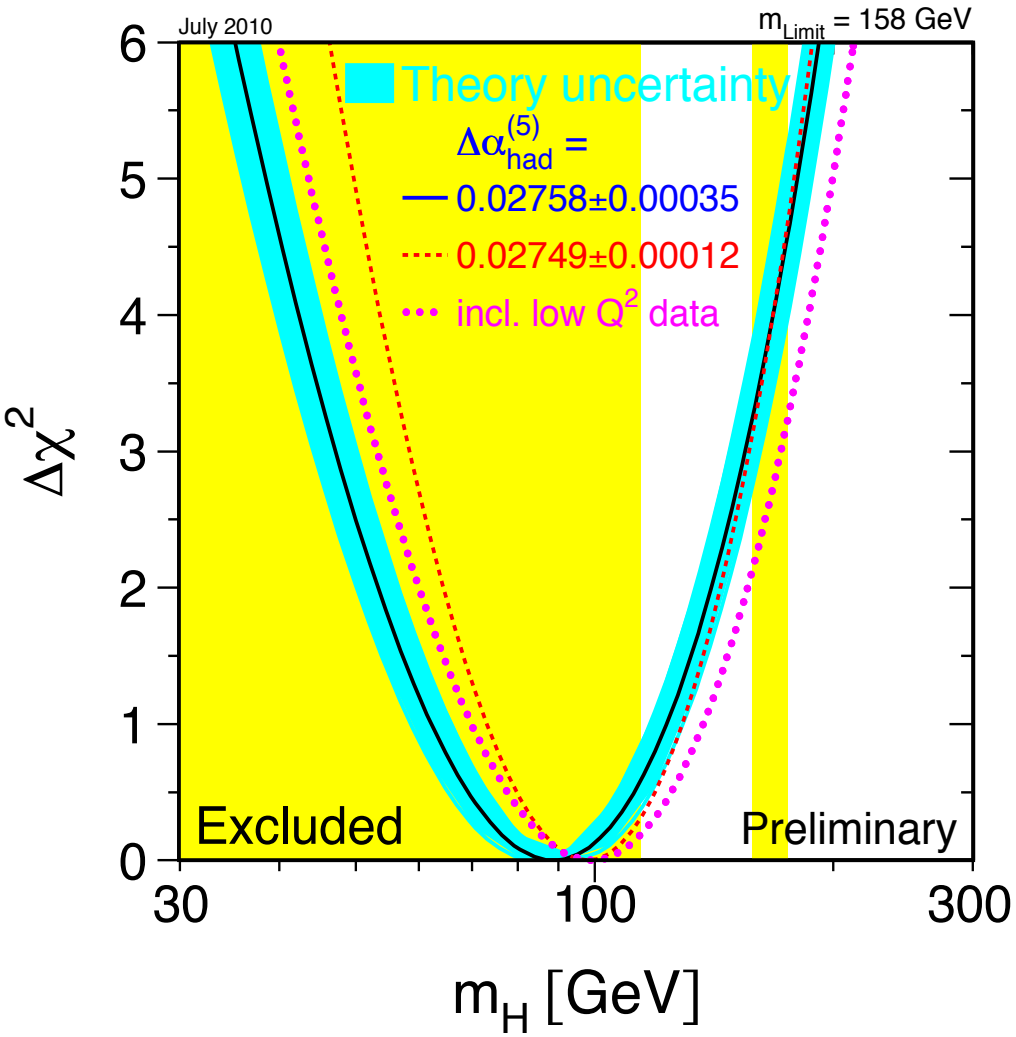
- Minimal Standard Model
  – one neutral Higgs

- LEP exclusion
  $M_H > 114$ GeV/c^2 @ 95% C.L.

- Indirect limits from consistency checks of SM
  $M_H < 158$ GeV/c^2 @ 95% C.L.
  ($M_H < 185$ GeV/c^2 @ 95% C.L.)

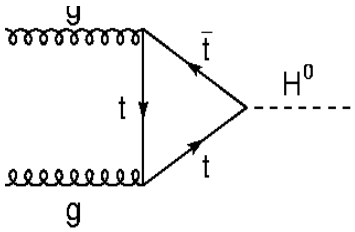
- In non-SM theories, many more Higgses, some charged (H^+,H^-), some neutral (h,A,H)

MOST OF RESULTS SHOWN HERE ARE INTEPRETED IN THE LANGUAGE OF MINIMAL SM HIGGS

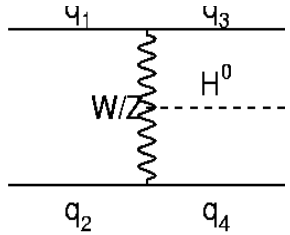


MSM Higgs production

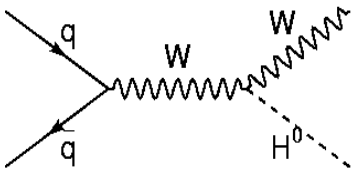
gluon fusion



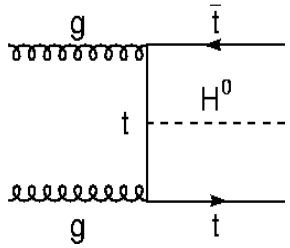
vector boson fusion (VBF)

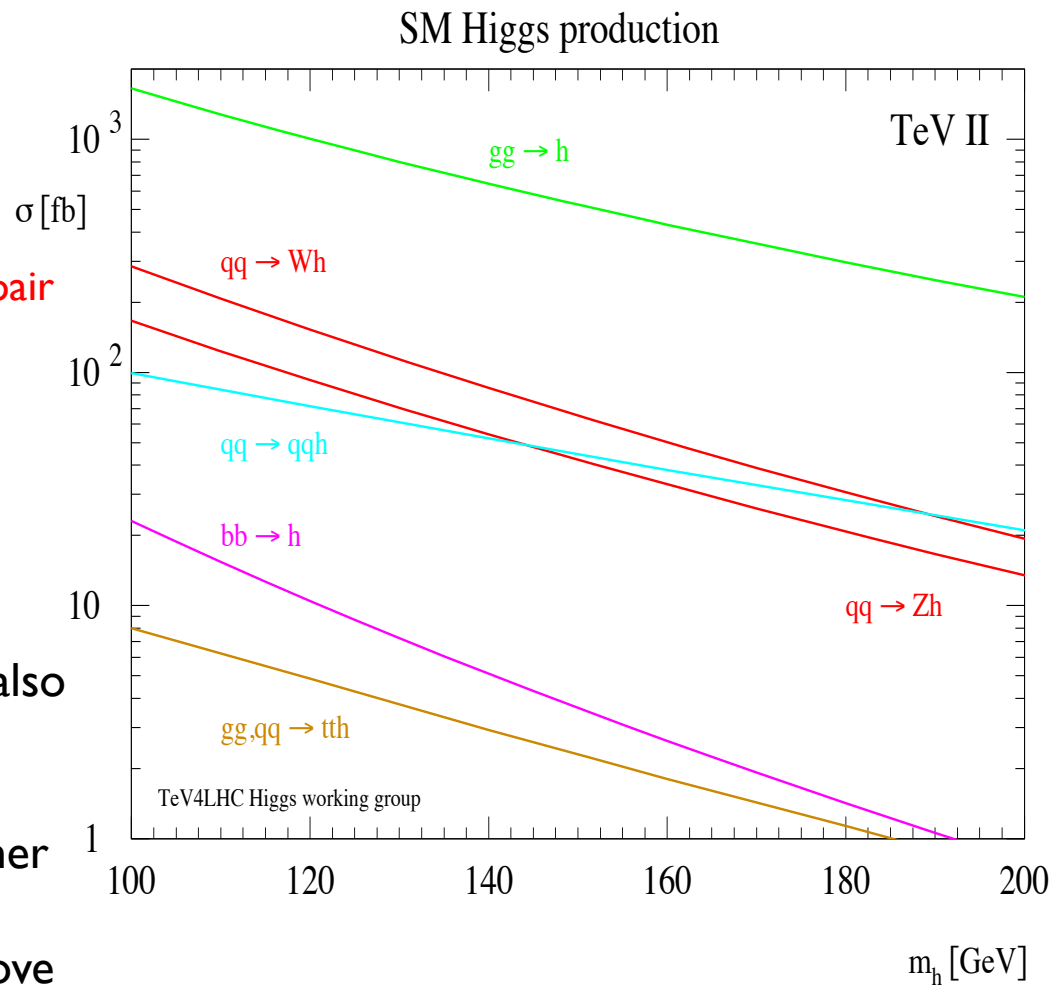


associated with W,Z



associative with top pair





gluon fusion – largest cross sections, but also large backgrounds

associative production – smaller but cleaner

VBF – even smaller but may help to improve sensitivity

MSM Higgs branching fractions

ANALYSIS STRATEGIES:

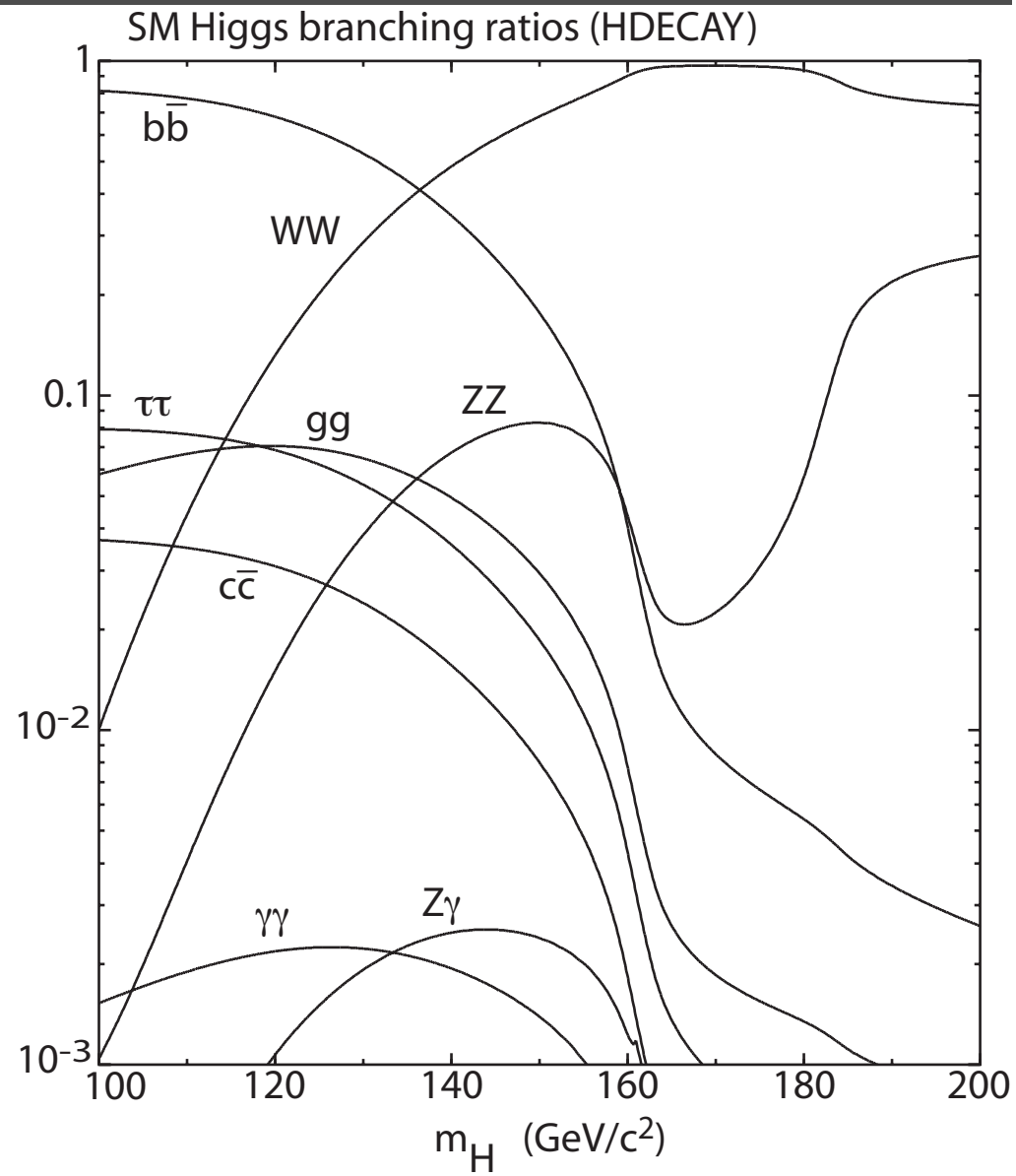
"low mass (< 135 GeV/c^2)

- -associated production: bb dominates have to rely on presence of leptons and neutrinos to reduce background
- -gluon fusion: bb dominated by background; ττ better, but small cross section

"high mass (> 135 GeV/c^2)

- -all production modes: WW and ZZ final states with leptons

use ALL accessible production modes and combine small signals from a large number of final states; take advantage of advanced analysis techniques



MSM Higgs high mass searches

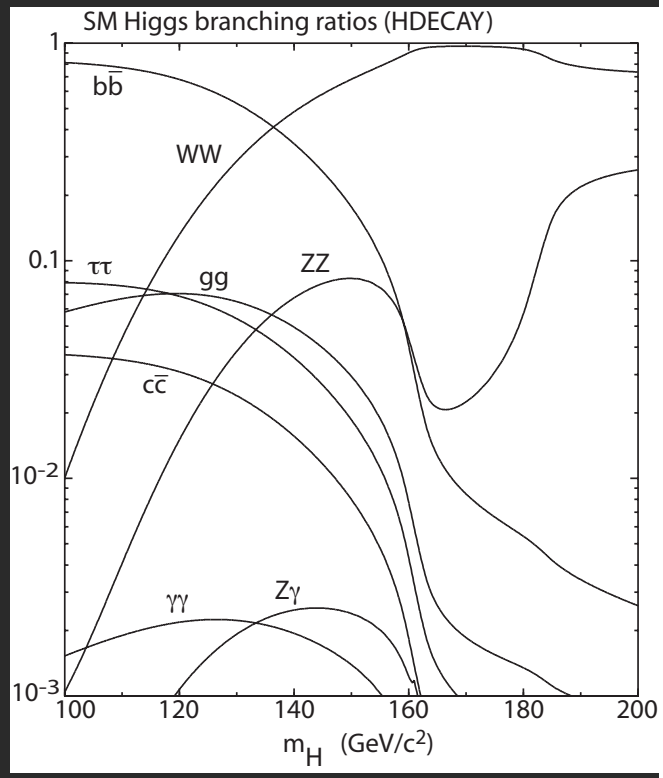
gluon fusion production mechanism
H −> WW final state is the most promising

signature
- two opposite sign leptons and MET (gg −> H −> WW)
- lep;tons and jets
- like-sign leptons (qq −> WH −> WWW)

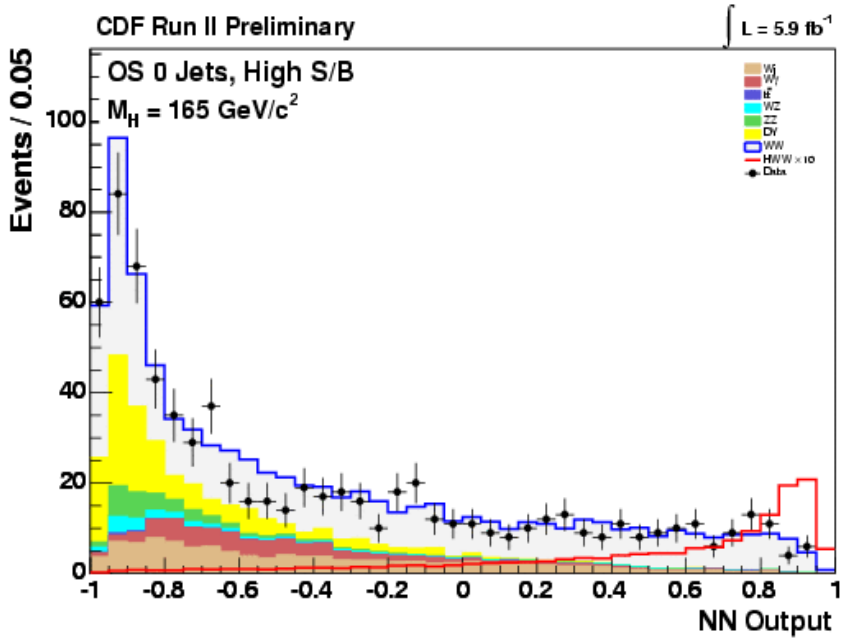
backgrounds: W+jets, Drell-Yan and di-boson production

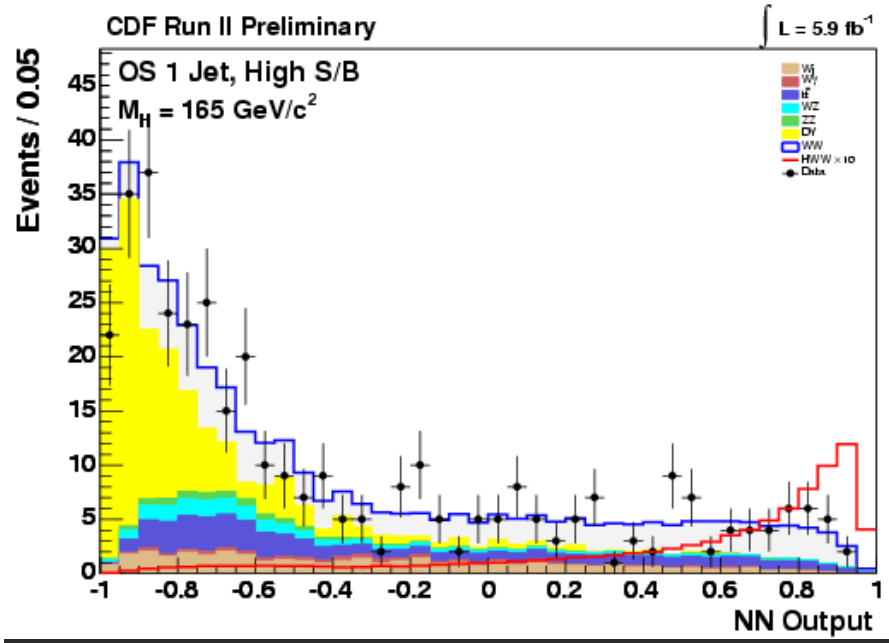
subdivide data according to number of jets, N=0,1,2; use the NN(CDF) or BDT(D0) for each category independently and then combine all results

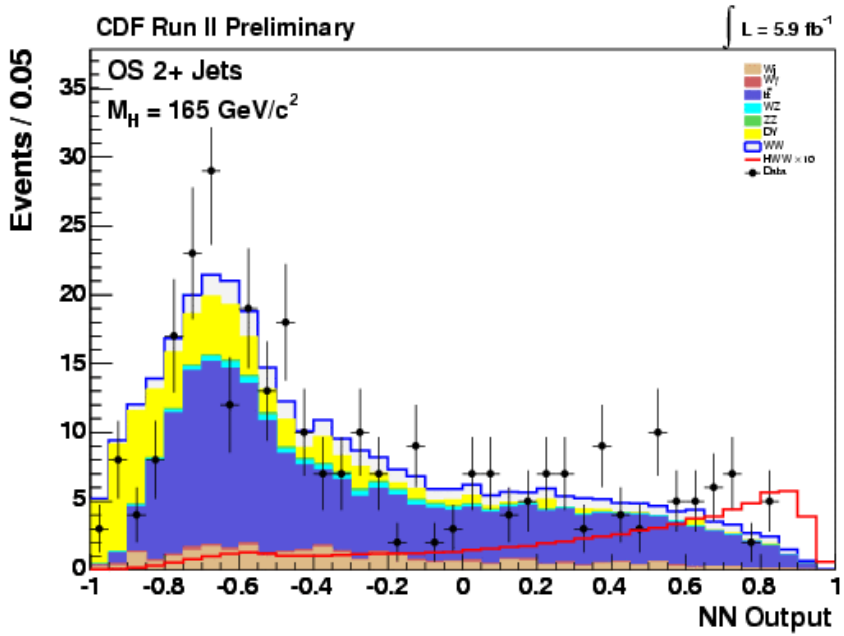
both CDF and D0 use multivariate techniques: neural nets (NN), matrix element (ME) and boosted decision tree (BDT)



MSM Higgs high mass searches







CDF analysis: NN templates for $M = 165\ GeV/c^2$

Inputs are lepton and jets kinematics, MET, lepton quality parameters

gluon fusion cross section:

D. de Florian and M. Grazzini, arXiv:0901.2427 [hep-ph]

C. Anastasiou, R. Boughezal, and F. Petriello, arXiv:0811.3458 [hep-ph]

MSM Higgs low mass searches

Associated production mechanism most important

signature

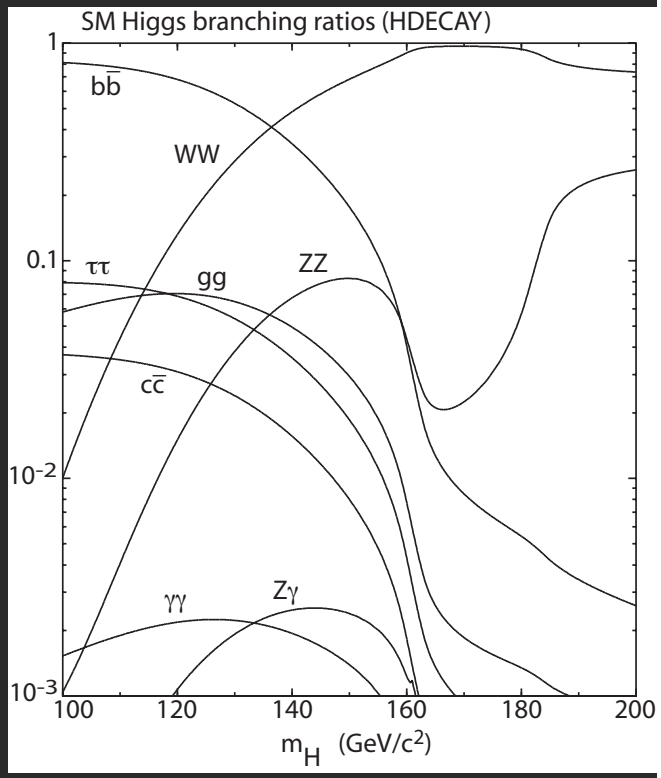
- pair of b quarks and MET or two leptons (qq –> ZH)
- pair of b quarks and lepton (qq –> WH)
- like-sign leptons (qq –> WH –> WWW)
- H –> γγ

- LOOK for a bump in M(bb) or M(γγ)

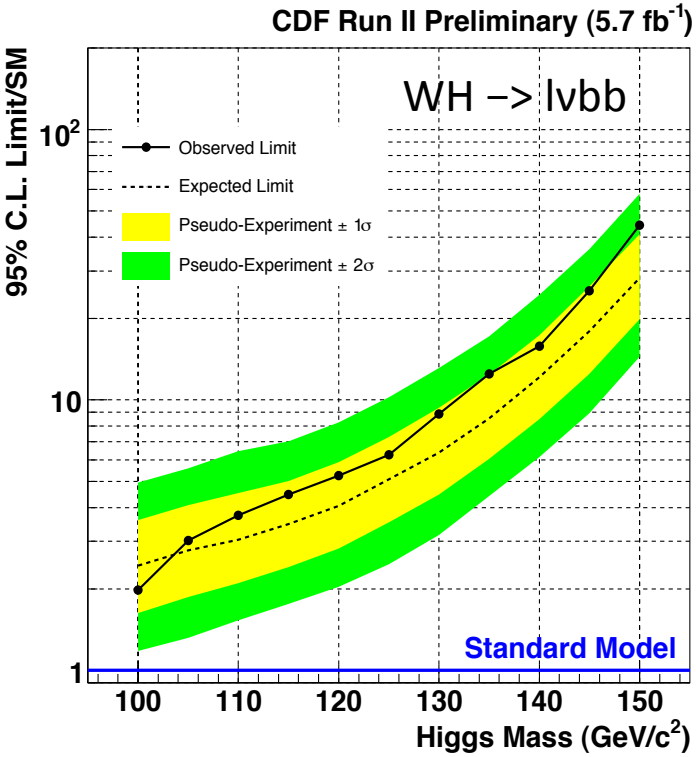
backgrounds: W+jets, Z+jets

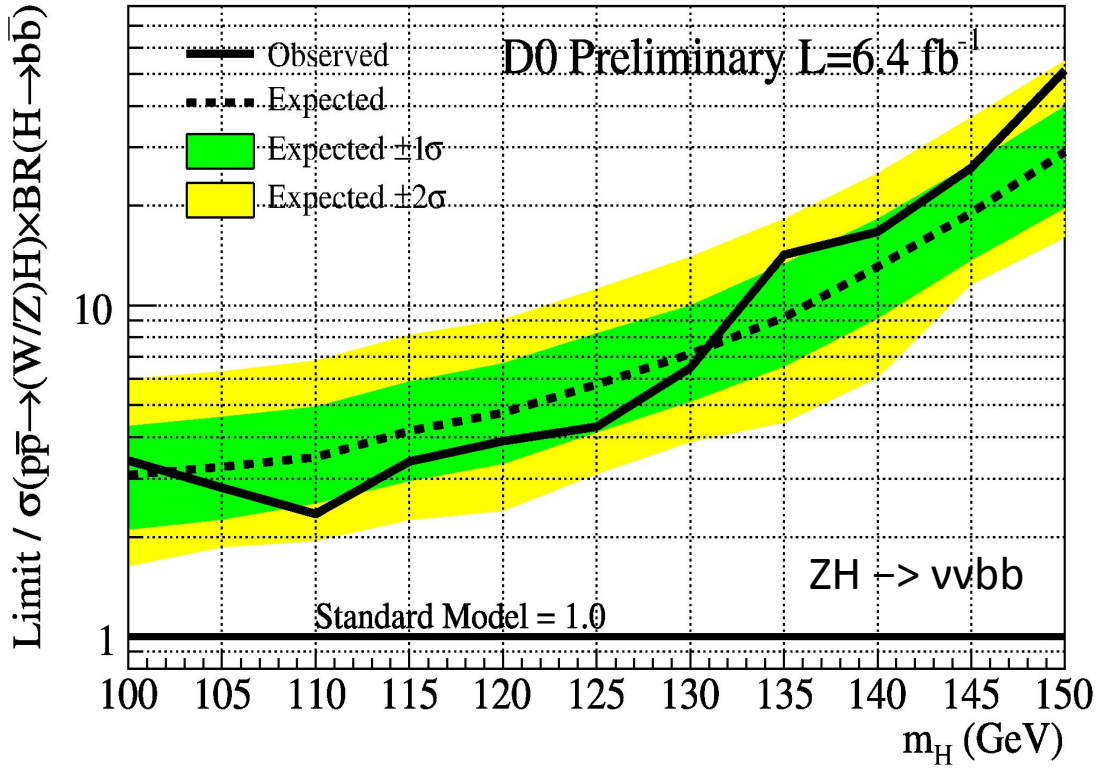
b-quark tagging essential to suppress background from W/Z+light quarks

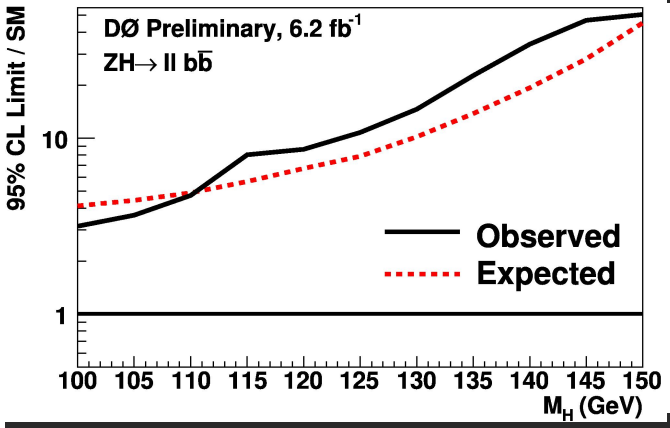
both CDF and D0 use multivariate techniques: neural nets (NN), matrix element (ME) and boosted decision tree (BDT)

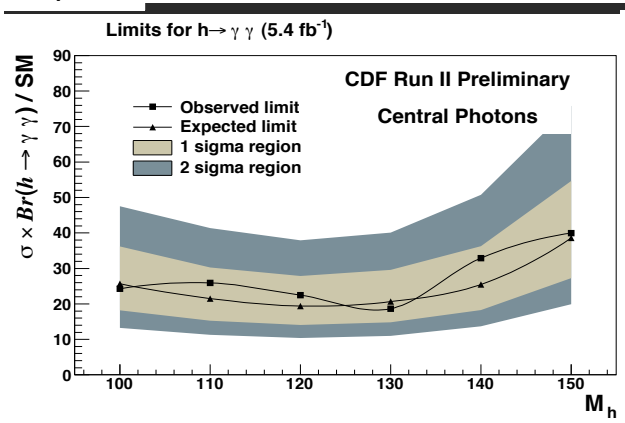


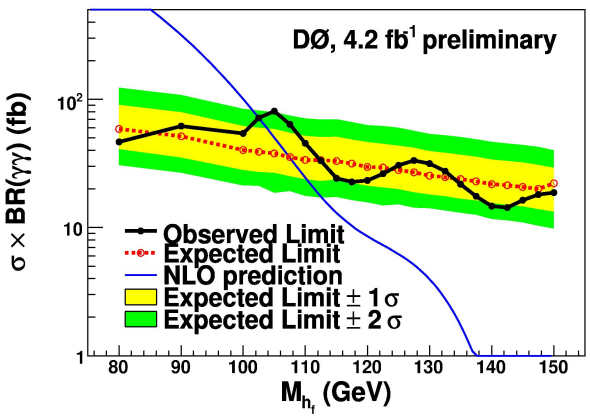
MSM Higgs low mass searches











combined CDF and D0 MSM Higgs searches

arXiv:1007.4587v1 [hep-ex]

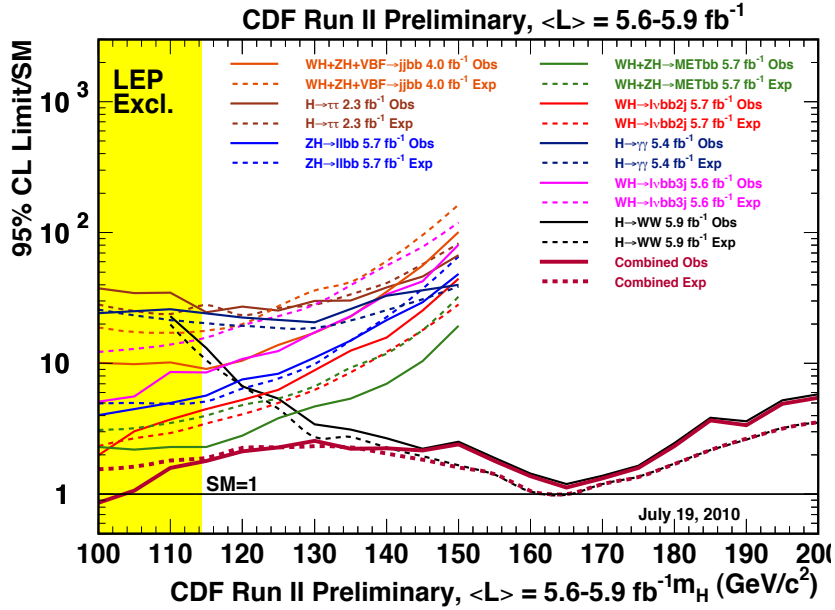
TABLE II: Luminosity, explored mass range and references for the different processes and final states ($\ell = e, \mu$) for the CDF analyses. The labels "2×" and "4×" refer to separation into different lepton categories.

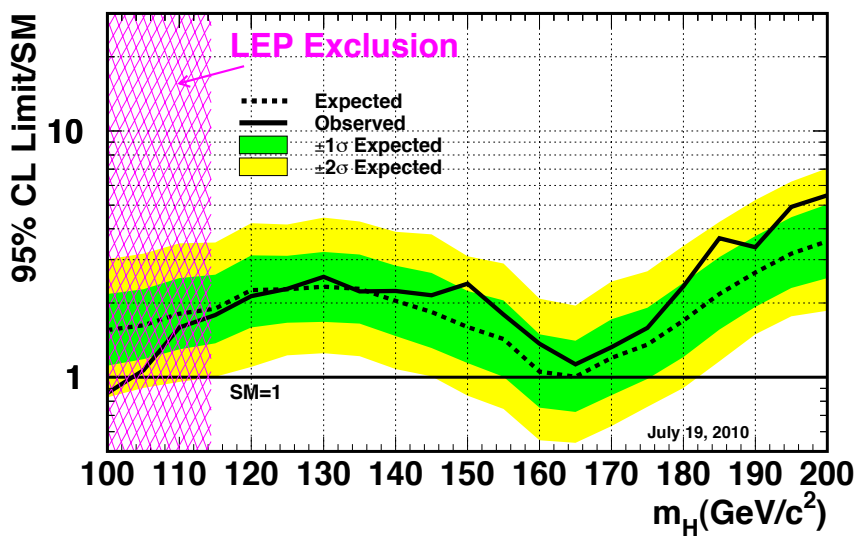
Channel	Luminosity (fb^{-1})	m_H range (GeV/c^2)	Reference
$WH \to \ell\nu b\bar{b}$ 2-jet channels 4×(TDT,LDT,ST,LDTX)	5.7	100-150	[5]
$WH \to \ell\nu b\bar{b}$ 3-jet channels 2×(TDT,LDT,ST)	5.6	100-150	[6]
$ZH \to \nu\bar{\nu}b\bar{b}$ (TDT,LDT,ST)	5.7	100-150	[7]
$ZH \to \ell^+\ell^- b\bar{b}$ 4×(TDT,LDT,ST)	5.7	100-150	[8, 9]
$H \to W^+W^-$ 2×(0,1 jets)+(2+ jets)+(low-$m_{\ell\ell}$)+(e-τ_{had})+(μ-τ_{had})	5.9	110-200	[10]
$WH \to WW^+W^-$ (same-sign leptons 1+ jets)+(tri-leptons)	5.9	110-200	[10]
$ZH \to ZW^+W^-$ (tri-leptons 1 jet)+(tri-leptons 2+ jets)	5.9	110-200	[10]
$H + X \to \tau^+\tau^-$ (1 jet)+(2 jets)	2.3	100-150	[11]
$WH + ZH \to jjb\bar{b}$ 2×(TDT,LDT)	4.0	100-150	[12]
$H \to \gamma\gamma$	5.4	100-150	[13]

TABLE III: Luminosity, explored mass range and references for the different processes and final states ($\ell = e, \mu$) for the D0 analyses. Most analyses are in addition analyzed separately for RunIIa and IIb. In some cases, not every sub-channel uses the same dataset, and a range of integrated luminosities is given.

Channel	Luminosity (fb^{-1})	m_H range (GeV/c^2)	Reference
$WH \to \ell\nu b\bar{b}$ (ST,DT,2,3 jet)	5.3	100-150	[14]
$VH \to \tau^+\tau^- b\bar{b}/q\bar{q}\tau^+\tau^-$	4.9	105-145	[15, 16]
$ZH \to \nu\bar{\nu}b\bar{b}$ (ST,TLDT)	5.2-6.4	100-150	[17, 18]
$ZH \to \ell^+\ell^- b\bar{b}$ (ST,DT,ee,$\mu\mu$,ee_{ICR},$\mu\mu_{trk}$)	4.2-6.2	100-150	[19]
$VH \to \ell^\pm\ell^\pm + X$	5.3	115-200	[20]
$H \to W^+W^- \to e^\pm\nu e^\mp\nu, \mu^\pm\nu\mu^\mp\nu$	5.4	115-200	[21]
$H \to W^+W^- \to e^\pm\nu\mu^\mp\nu$ (0,1,2+ jet)	6.7	115-200	[22]
$H \to W^+W^- \to \ell\bar{\nu}jj$	5.4	130-200	[23]
$H \to \gamma\gamma$	4.2	100-150	[24]
$t\bar{t}H \to t\bar{t}b\bar{b}$ (ST,DT,TT,4,5+ jets)	2.1	105-155	[25]

combined CDF and D0 MSM Higgs searches





Bayesian Posterior Probability

$$p(R|\vec{n}) = \frac{\int\int d\vec{s}d\vec{b}L(R,\vec{s},\vec{b}|\vec{n})\pi(R,\vec{s},\vec{b})}{\int\int\int dRd\vec{s}d\vec{b}L(R,\vec{s},\vec{b}|\vec{n})\pi(R,\vec{s},\vec{b})} \Rightarrow \int_0^{R_{0.95}} p(R|\vec{n})dR = 0.95$$

$R = (\sigma \times BR)/(\sigma_{SM} \times BR_{SM})$, $R_{0.95}$: 95% Credible Level Upper Limit

$\vec{s},\vec{b},\vec{n} = s_{ij}, b_{ij}, n_{ij}$ (# of signal, background and observed events in j-th bin for i-th channel)

π : Bayes' prior density

Combined Binned Poisson Likelihood

$$L(R,\vec{s},\vec{b}|\vec{n}) = \prod_{i=1}^{N_{\text{channel}}} \prod_{j=1}^{N_{\text{bin}}} \frac{\mu_{ij}^{n_{ij}} e^{-\mu_{ij}}}{n_{ij}!}$$

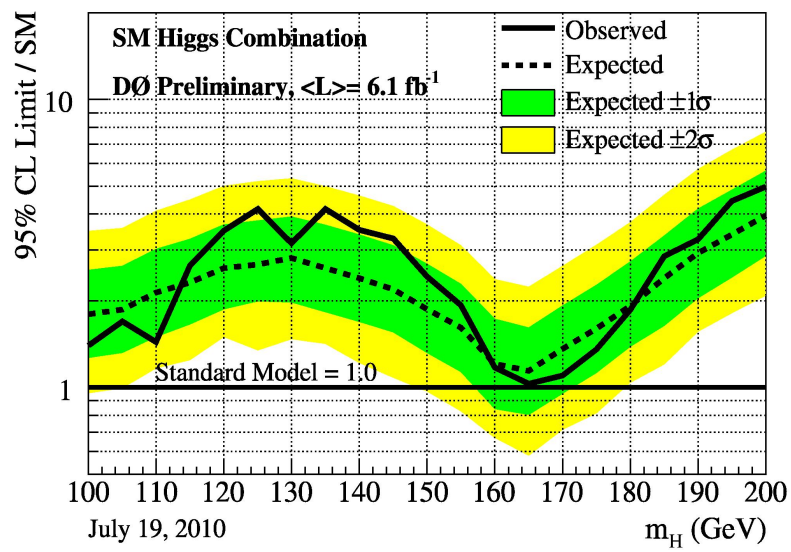
Principle of ignorance

- for the number of higgs events (instead of higgs Xsec)

$$\pi(R,\vec{s},\vec{b}) = \pi(R)\pi(\vec{s})\pi(\vec{b}) = s_{tot}\theta(Rs_{tot})\pi(\vec{s})\pi(\vec{b})$$

$s_{tot} = \Sigma_{i,j} s_{ij}$: Total number of signal prediction

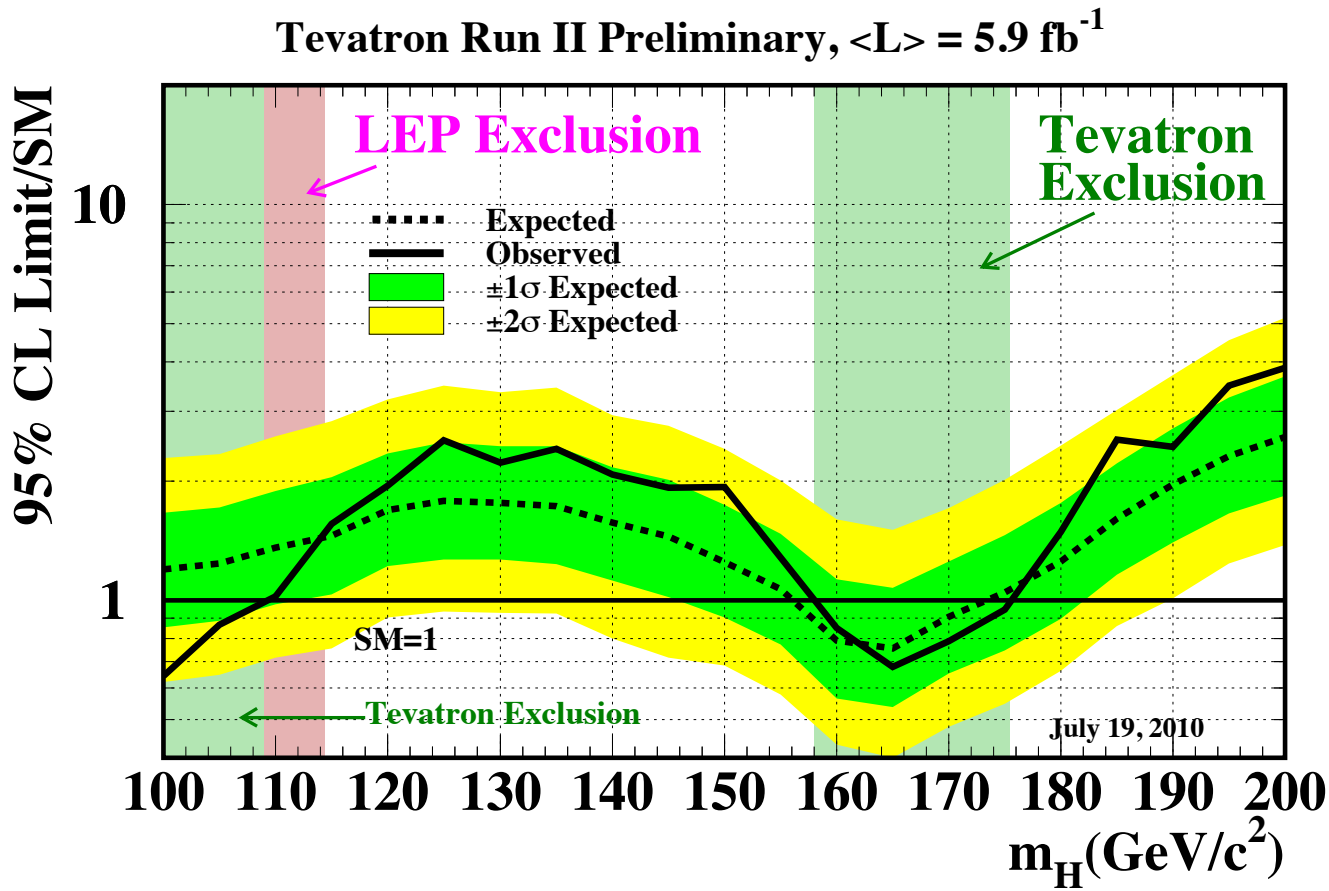
$\pi(x) = G(x|\hat{x},\sigma_x) \quad (x = s, b)$ $\quad \hat{x}$: expected mean, σ_x: total uncertainty



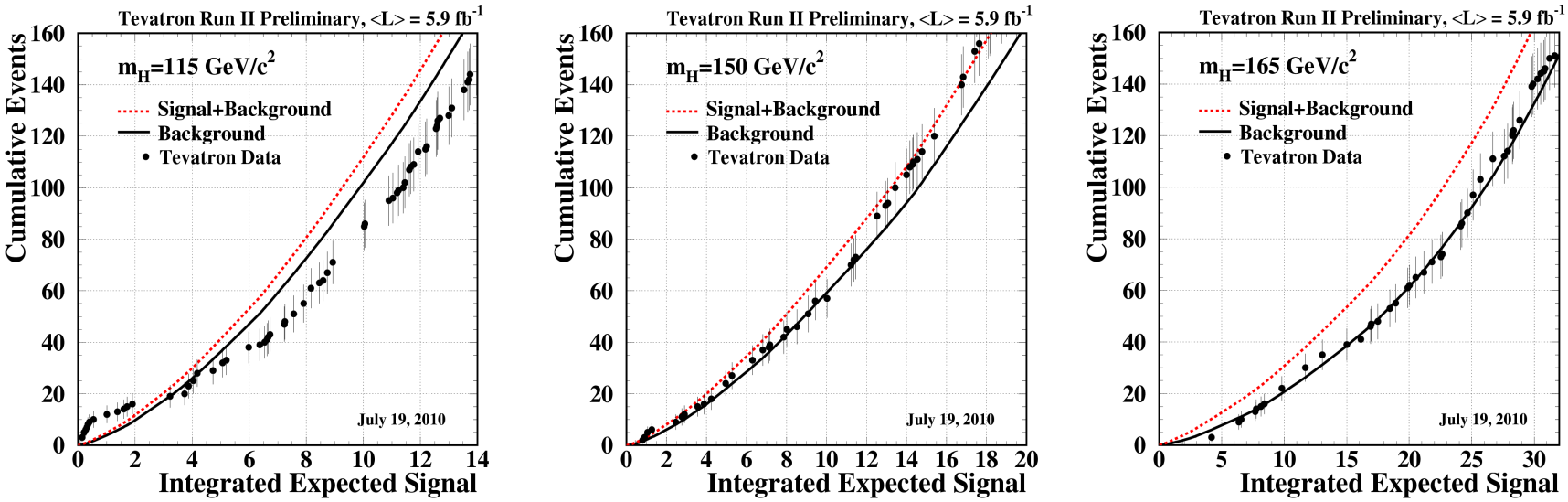
combined CDF and D0 MSM Higgs searches

EXCLUDED @ 95% confidence level (July 19, 2010)

158 GeV/c^2 < M_H < 175 GeV/c^2 (and 100 GeV/c^2 < M_H < 109 GeV/c^2)

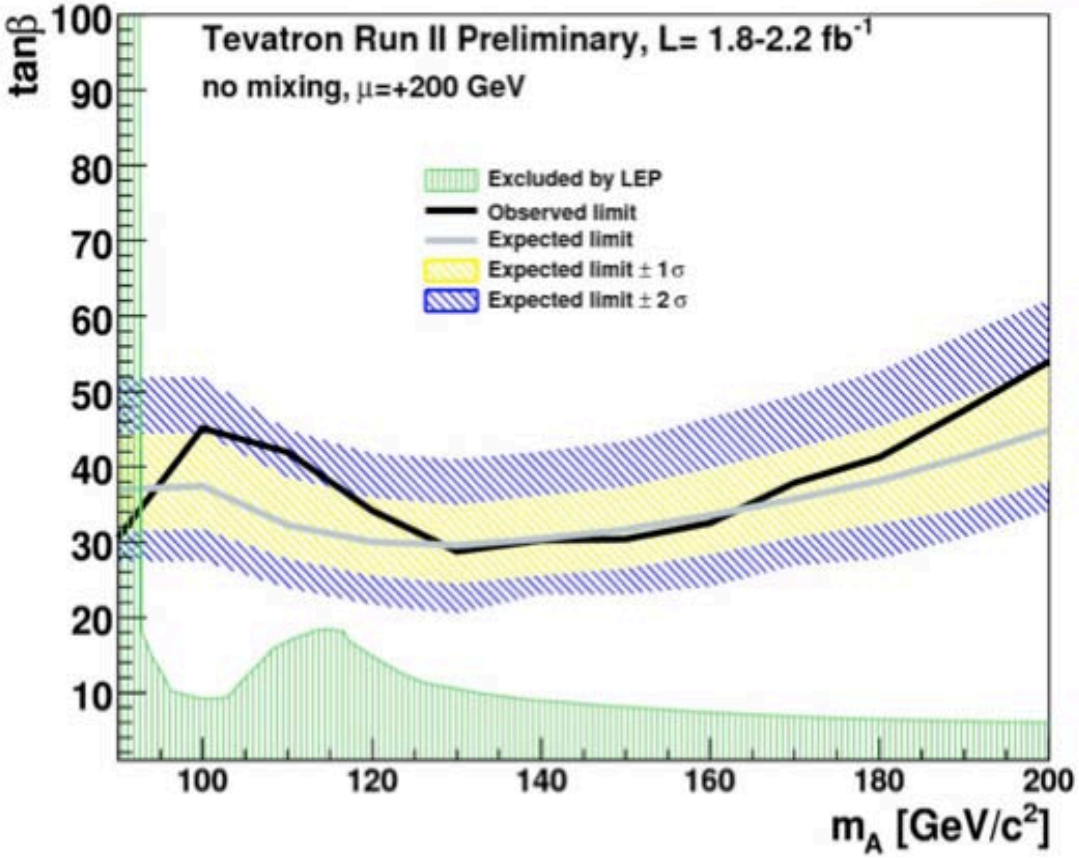


combined CDF and D0 MSM Higgs searches



There seem to be some excess of events at 140-150 GeV/c^2 (??)

MSSM Higgs searches



In MSSM gg −> h/A/H, gb −> bA cross section is enhanced at large tanβ compared to SM gg −> H.

In addition h −> bb, which is still difficult to detect, new modes become accessible: h −> ττ, hb −> bbb, bττ, Hbb −> bbbb, bbττ

h −> ττ

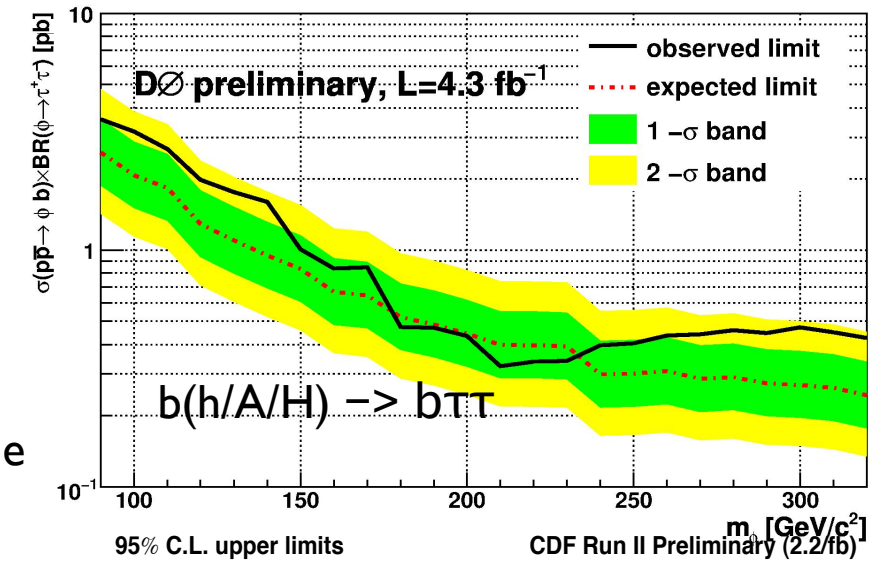
MSSM Higgs searches

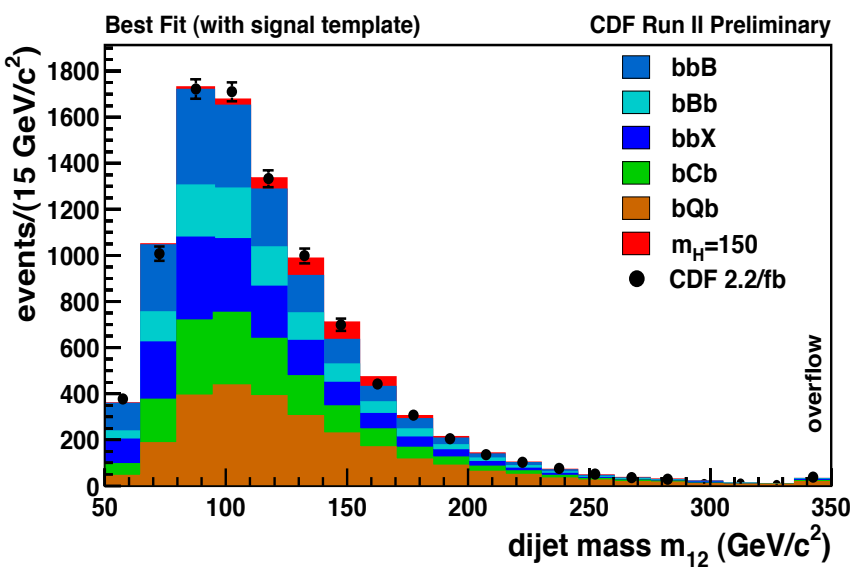
New searches:

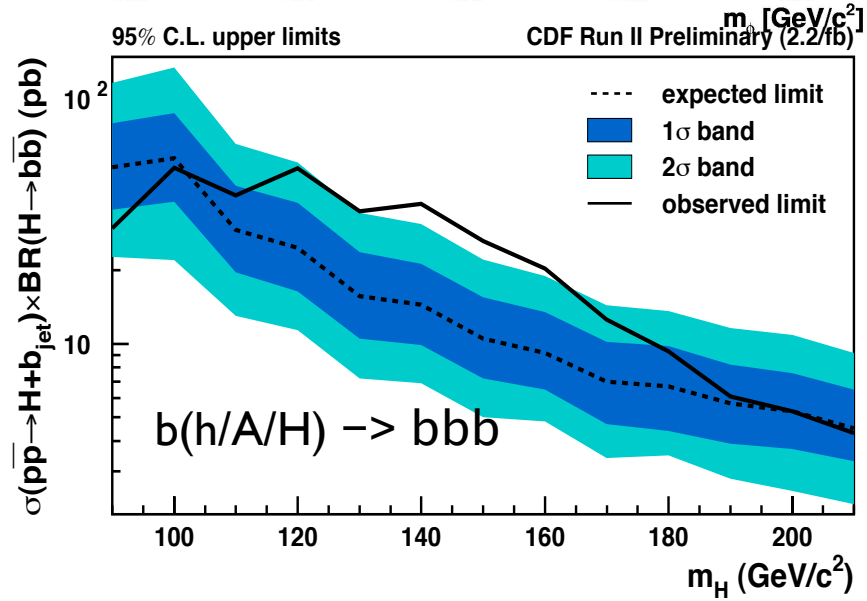
D0 : b(h/A/H) −> bττ

CDF: b(h/A/H) −> b+bb
(2-σ excess at ~140 GeV/c^2)

Enhanced production cross sections and cleaner final states with a signature of multiple b-quarks (b tagging) or multiple τ.



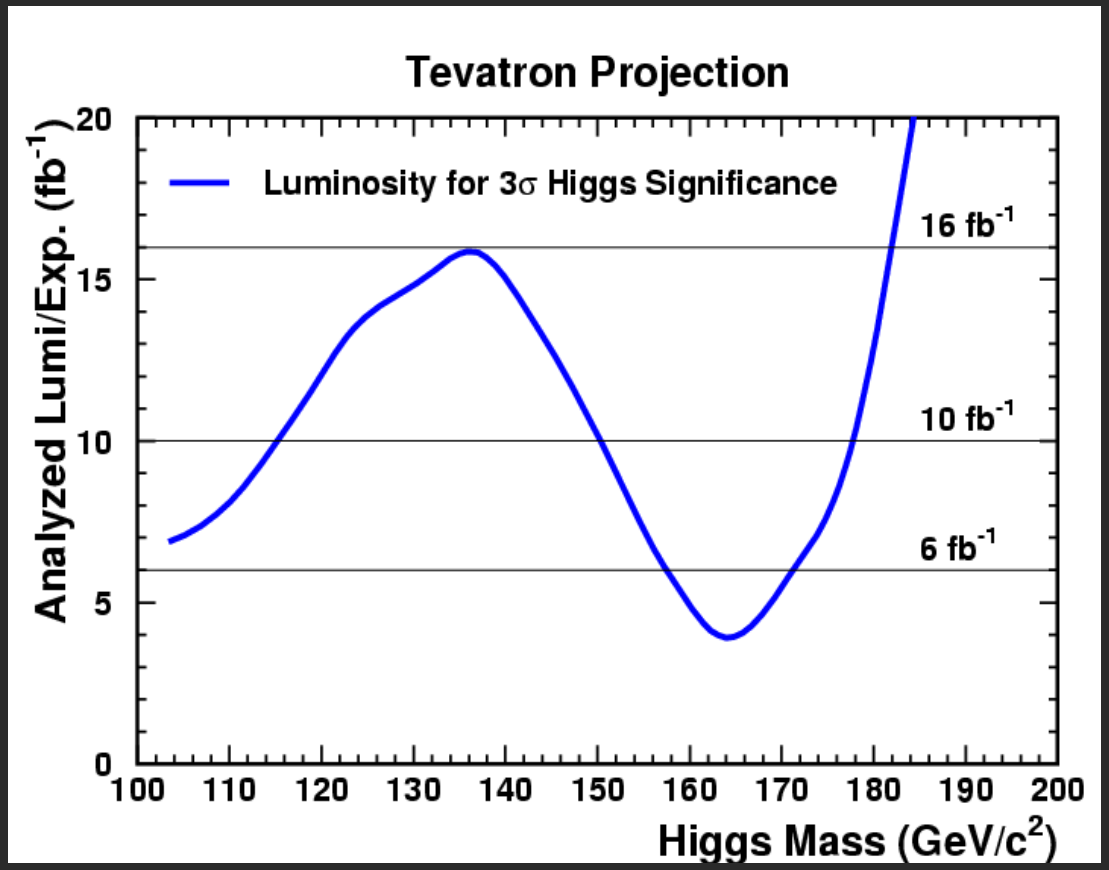




Standard Model Higgs searches: projections

At the end of 2011 (10/fb analysed data) sensitivity > 2.4 σ in the range 100 – 185 GeV/c^2 (3σ at 115 GeV/c^2)

With 16/fb (by the end of 2014) sensitivity of 3 σ in the range 100 – 185 GeV/c^2 (4σ at 115 GeV/c^2)



CERN "OLD" SCENARIO

Following the technical discussions in Chamonix (January 2010) the CERN management and the LHC experiments decided

- Run at 3.5 TeV/beam up to a integrated luminosity of around $1 fb^{-1}$ – end of 2011
- Then consolidate (fix) the LHC machine for 7 TeV/beam (during a shutdown in 2012)
- From 2013 onwards LHC will be capable of maximum energies and luminosities

FERMILAB extension proposal

In April 2010 D0 and CDF experiments at Tevatron presented a proposal to extend the current run by 3 years

In 4 years (by 2014) this would increase the current integrated luminosity at 2 TeV from 8/fb to 16/fb per experiment and could compete with LHC with light Higgs searches (as LHC in the January 2010 scenario would only have ~ 1/fb at 7 TeV by 2013)

CERN NEW SCENARIO

Run for 2 years and collect 5-10/fb at ~8 TeV

If the decision is taken soon (another Chamonix meeting in January 2011) then, in my mind, it does NOT make sense to run Tevatron Collider any longer,
as even for the light Higgs it is not (and will not be) competitive with LHC and its superior detectors

CLOSING TEVATRON COLLIDER ?

P5 committee met on October 26, 2010.
It gave support to the Fermilab extension proposal under the condition that NEW FUNDS (~35 M$/y) are found. This might be difficult in the current economy.

Proposal will be re-evaluated in Fall 2011.

If LHC runs smoothly and also in 2012, then Tevatron will most likely stop its program at the end of 2011.

2011 could be the last year of Tevatron Collider.

SUSY: the "golden" candidate for "new physics"

- CDF- the famous ee$\gamma\gamma$MET event: recorded April 28, 1995 in Run-I. Its "a posteriori" probability according to Standard Model is ~10^{-6}