Selected Results from DØ

- Tevatron Collider and DØ Experiment
- Highlights of Standard Model Physics
- Selected Topics of Physics Beyond SM

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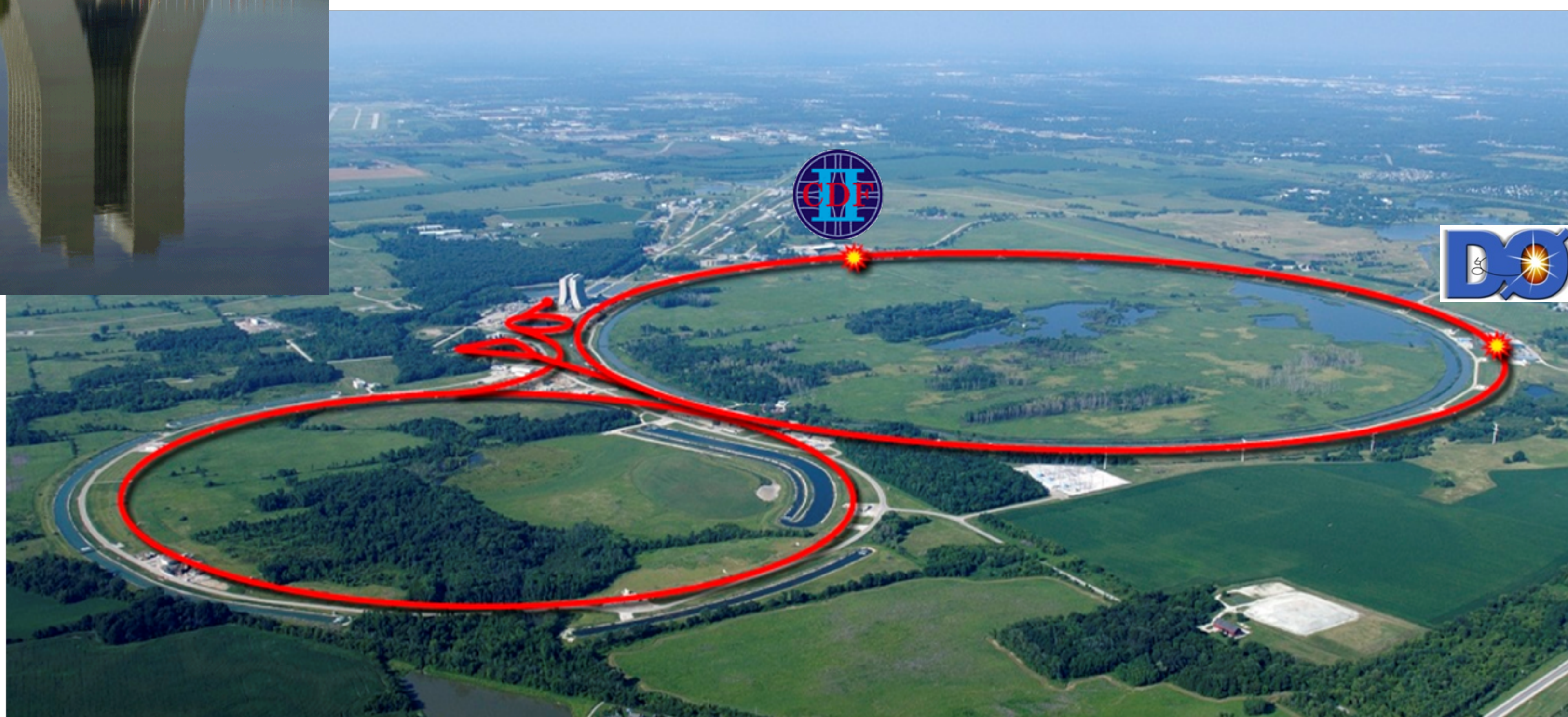
On behalf of the DØ Collaboration

Planck 2010
CERN, May 31 – June 4, 2010

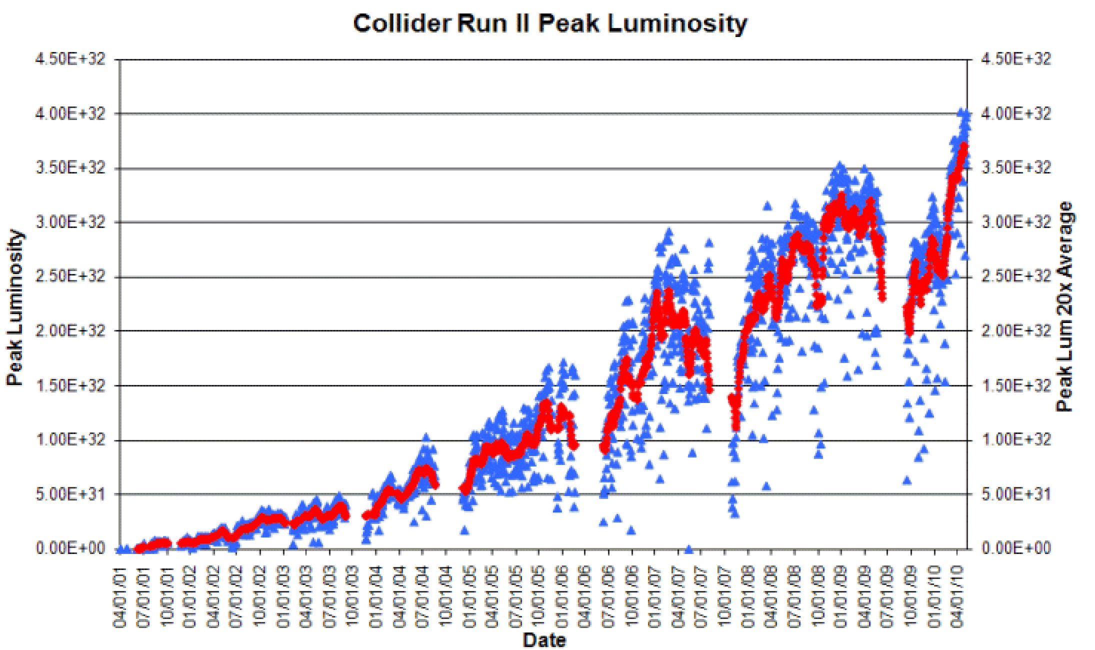
Tevatron Collider

$p\bar{p}$ collider with $\sqrt{s} = 1.96$ TeV

- Two experiments: CDF and DØ
- Two major running periods
  - Run I (1992 - 1995): ~120 pb^{-1} at 1.8 TeV;
  - Run II (2001 -) : 8.5 fb^{-1} and counting…



Record Luminosities



Peak inst. luminosity

~ 4×10^{32} cm^{-2} s^{-1}

Run II design:

2×10^{32} cm^{-2} s^{-1}

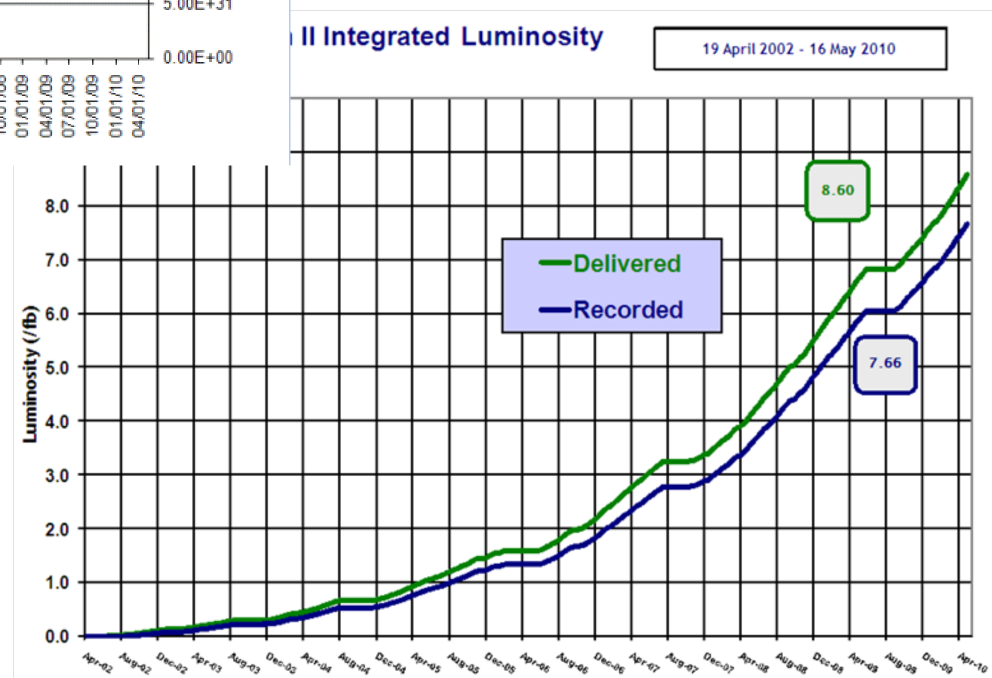
Run II bests (delivered):

~ 250 pb^{-1}/month

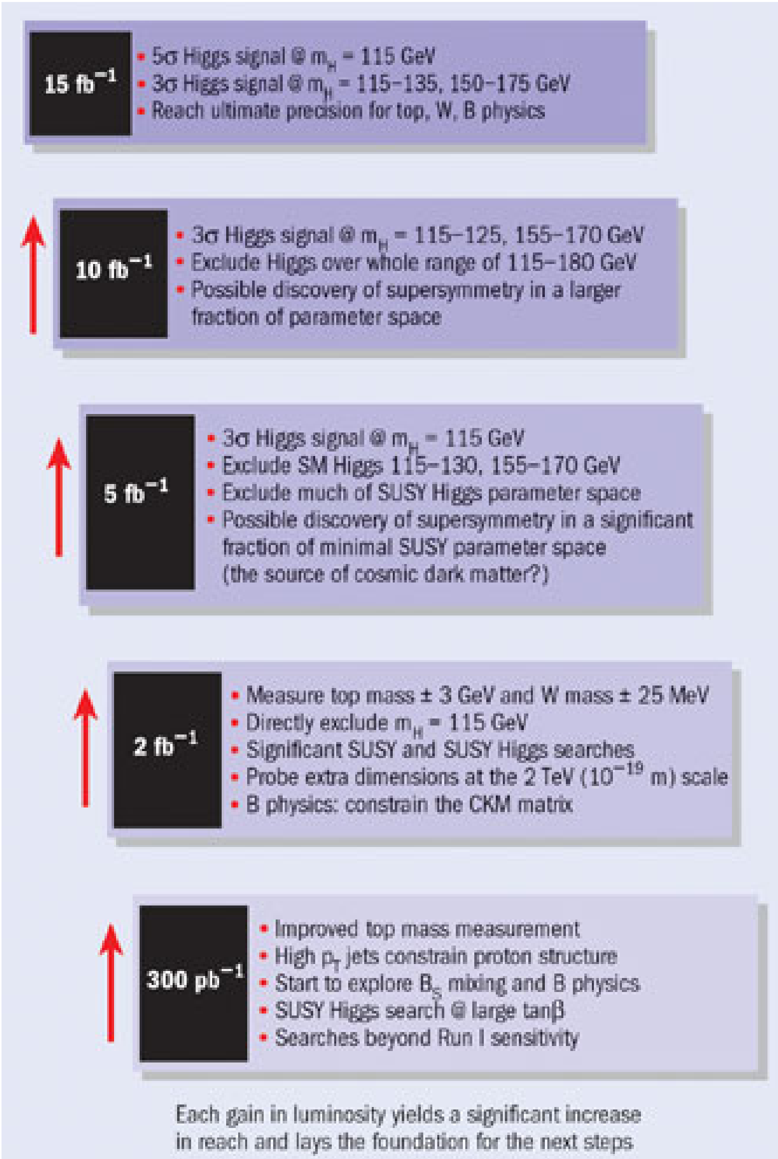
~ 14 pb^{-1}/day

~ 20 nb^{-1}/minute !

CDF/DØ collects more integrated luminosity in one minute than all ATLAS/CMS has recorded so far



Not Everything is Rosy…



CERN COURIER

Jan 1, 2003

Looking forward to physics at Tevatron Run II

Tevatron Run II is under way at Fermilab, with upgraded detectors addressing some of the most important questions in particle physics. What is the structure and what are

5 fb^{-1}

not there yet

- 3σ Higgs signal @ m_H=115 GeV;
- Exclude SM Higgs 115-130, 155-170 GeV
- Possible discovery of SUSY in a significant fraction of minimal SUSY parameter

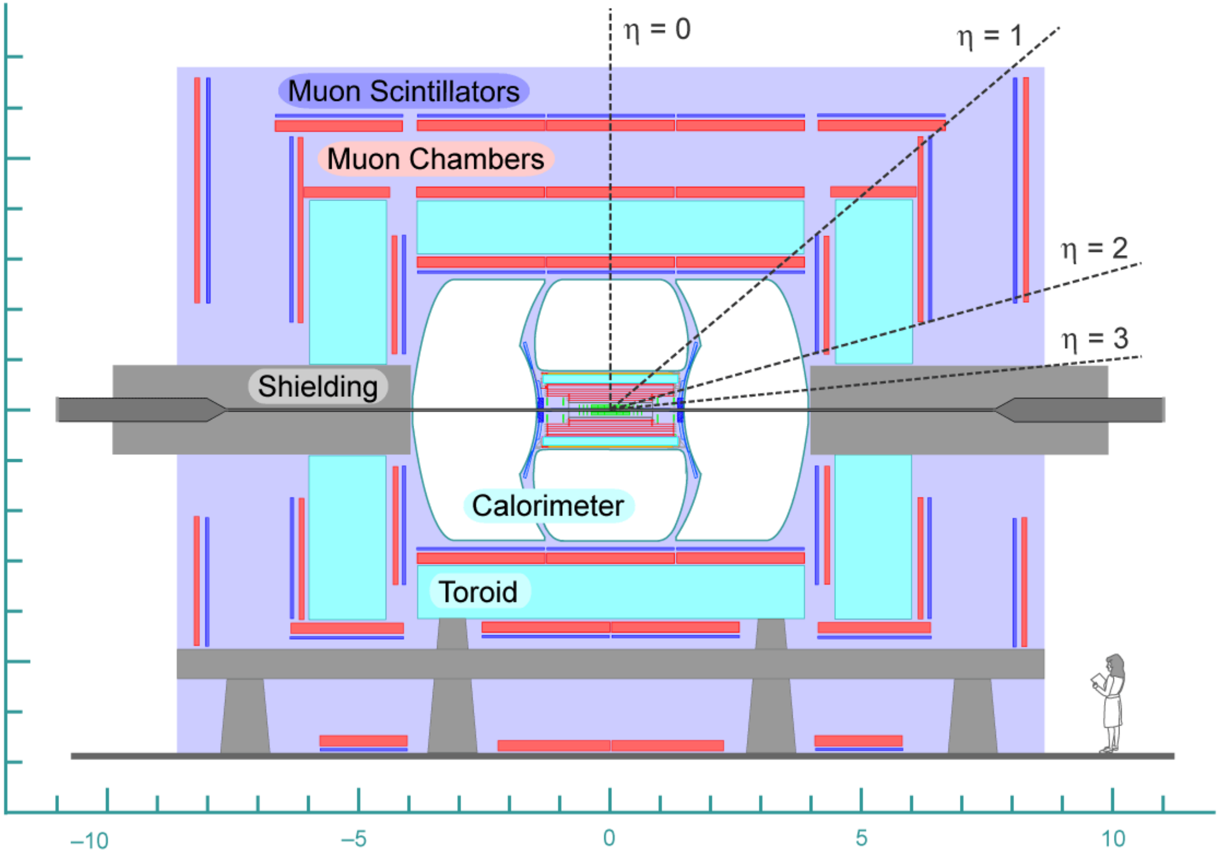
10 fb^{-1}

- 3σ Higgs signal @ m_H=115-125, 155-170 GeV
- Exclude Higgs over whole range 115-180 GeV
- Possible discovery of SUY in a large fraction of parameter space

DØ Experiment

A small experiment with only ~ 500 people from ~ 80 institutions in 17 countries

~50% US and ~50 non-US



Compact tracker (R~0.5m):
- Silicon, scintillating fiber

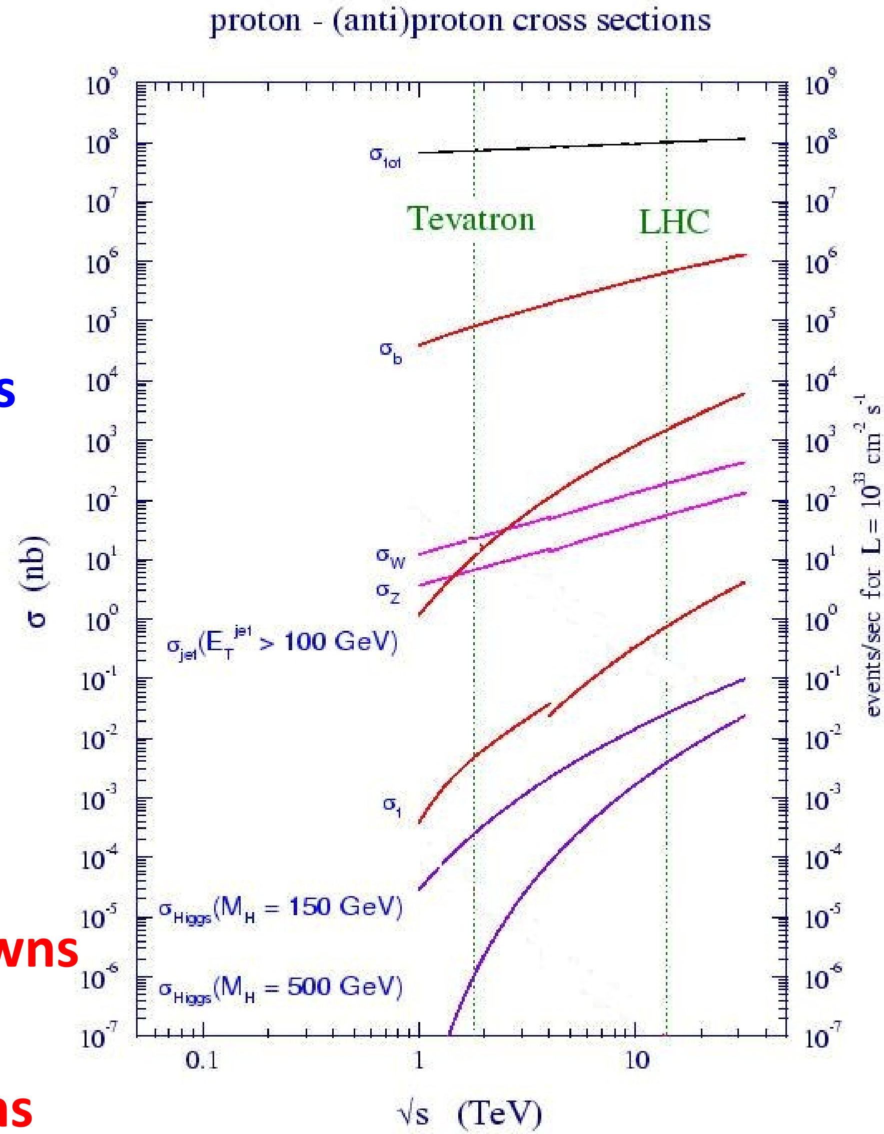
Calorimeter
- Liquid argon

Muon spectrometer
- Toriods + Drift tubes

Physics Program

decreasing production rate

- Cover known knowns
  - QCD;
  - W and Z bosons;
  - Top quark;
  - …
- Search for known unknowns
  - SM Higgs ?
  - …
- Expect unknown unknowns
  ???



Campbell, Huston & Stirling, Rept. Prog. Phys. 70, 89 (2007)

What about supersymmetry
or extra dimensions … ?

For many theorists: known unknowns

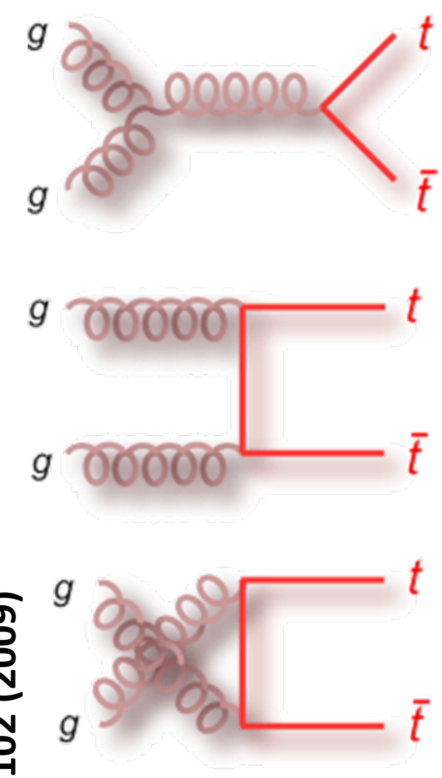
For some people: known knowns

For most of us: unknown unknowns

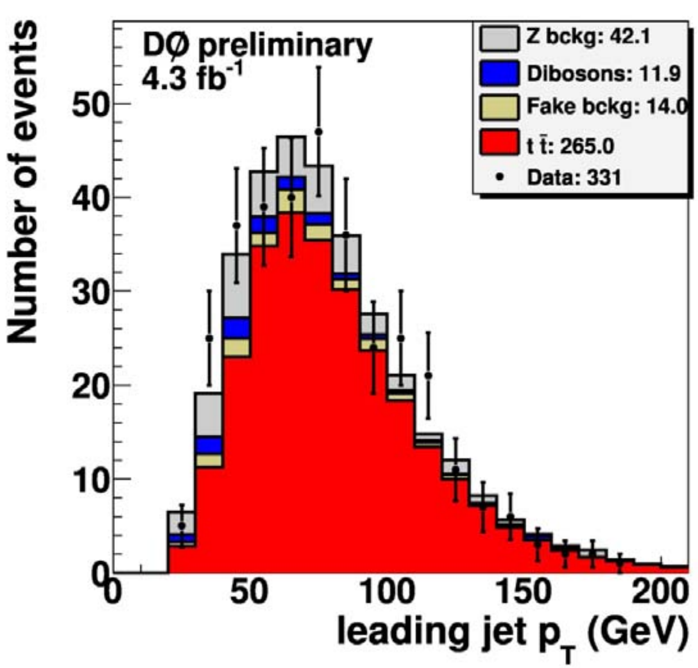
Top Quark

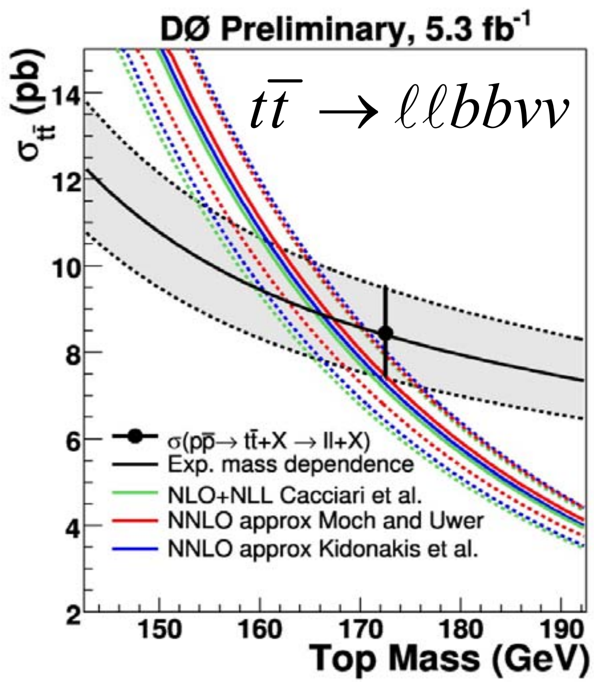
One of the most important discoveries at the Tevatron

- discovered with ~50 pb^{-1};
- extensive studies of its properties;
- potential sources of new physics:
  heaviest known elementary particle



Mostly pair produced through strong interaction, can be selected with high purity experimentally





Phys. Rev. D80, 071102 (2009)

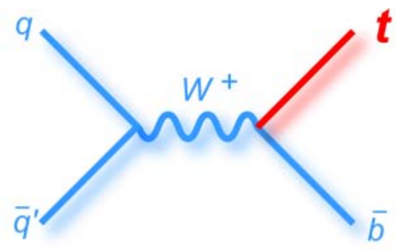
Single Top Quark

- Top quark can also be produced through Electroweak interaction (single top production)
  - $\Rightarrow$ polarized top quarks
  - $\Rightarrow$ σ proportional to CKM $|V_{tb}|^2$
- Its rate is about 50% that of pair production, but backgrounds are significantly higher
- Advanced techniques
  - Neural network;
  - Boosted decision tree;
  - Matrix element

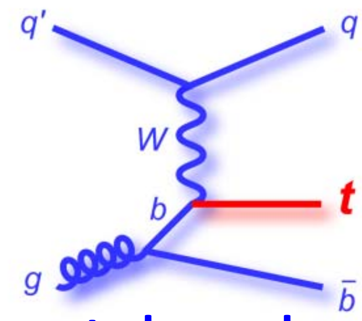
  for signal and background separation

Both CDF and DØ have observed a 5σ signal with a combined cross section

$$\sigma(s+t) = 2.8^{+0.6}_{-0.5} \text{ pb}$$

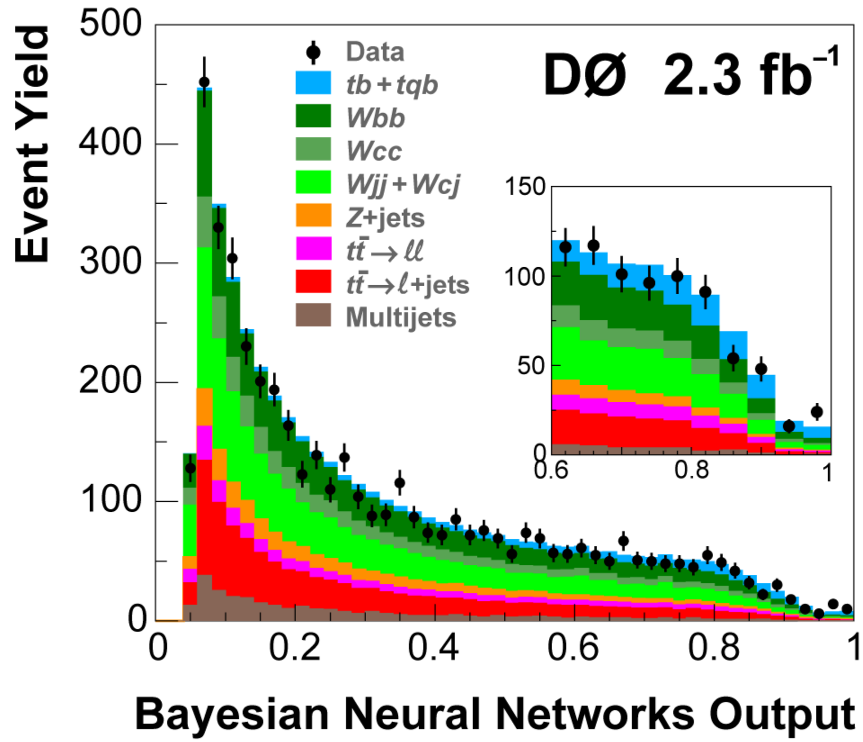


s-channel



t-channel

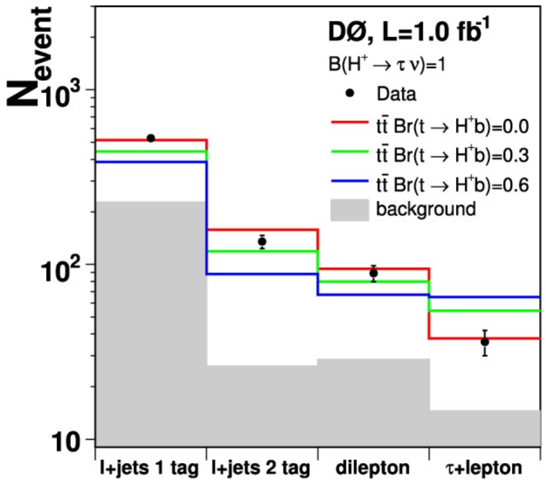
Phys. Rev. Lett. 103, 092001 (2009)



New Physics in Top Events ?

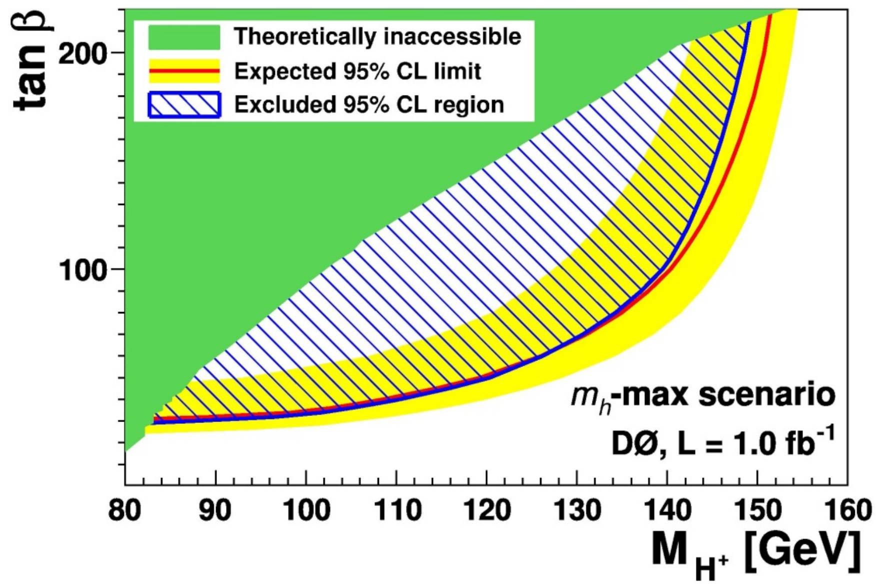
- **Charged Higgs boson can be potentially produced in top quark decays**

  $t \rightarrow H^{+}b$ competes with $t \rightarrow W^{+}b$



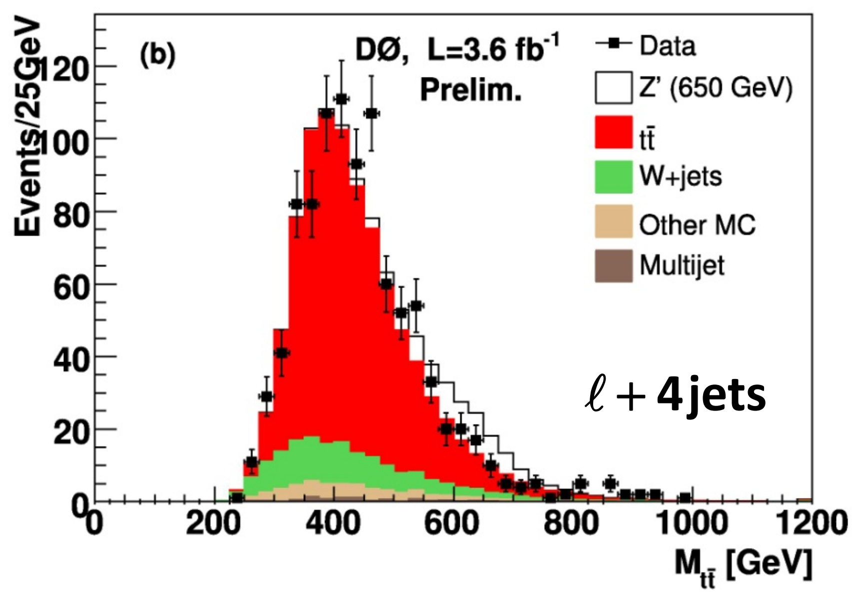
⇒ **modification in 1- and 2-lepton event ratios**

Phys. Lett. B682, 278 (2009)



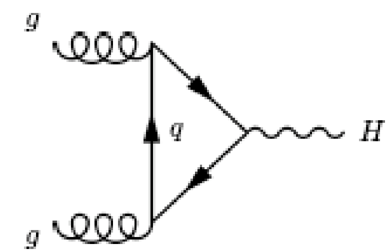
- **top quark events could be sources of potential new physics**

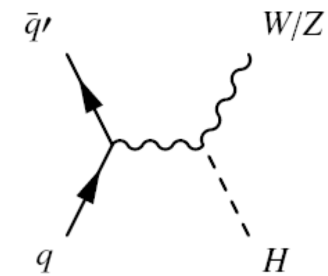
  eg topcolor-assisted technicolor model
  a tt condensate could generate large m_t:
  Z'→tt which will lead to a bump or distortion in m_{tt} mass distribution.
  Non observation of such effect
  ⇒ $M_{Z'}$ >820 GeV @ 95% CL



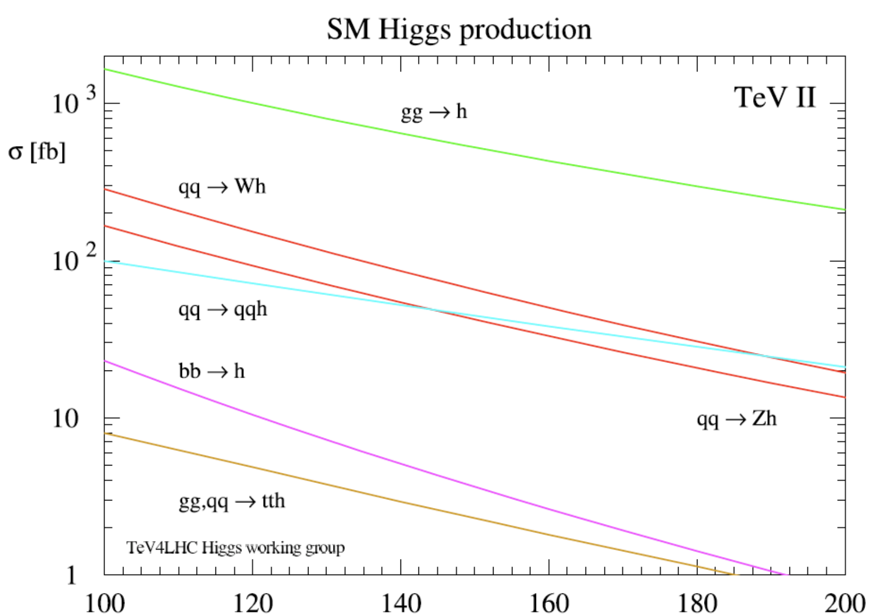
Standard Model Higgs Boson

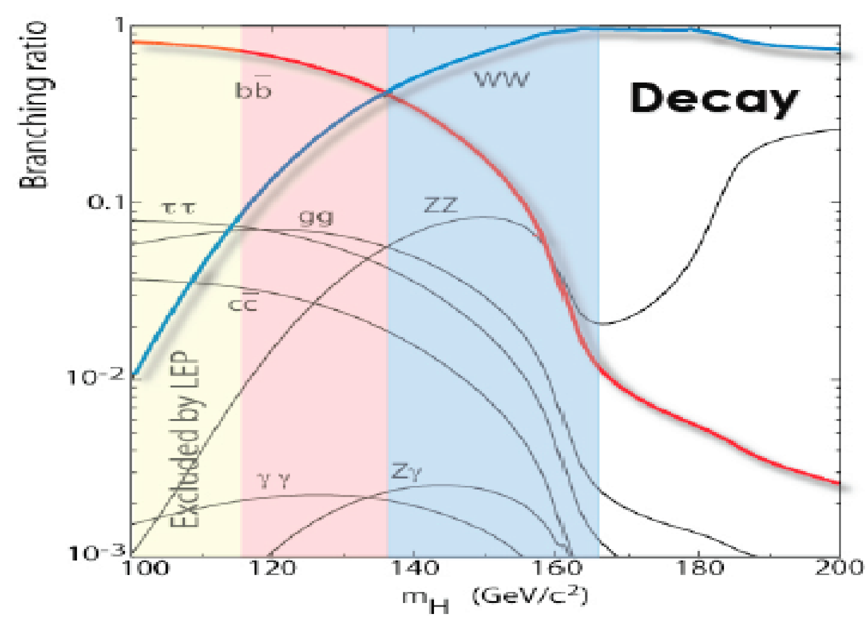
- **Production dominated by gg→H with a sizeable contribution from qq→VH: σ ~ 1 pb @ m_H=115 GeV**
- **Decay mostly to bb for m_H<130 GeV and to WW above that**
- **Trigger and background issues lead to main search channels**



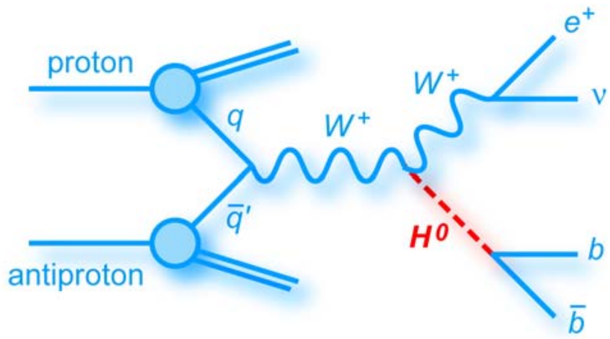


Low mass	$WH \to \ell\nu b\bar{b}$, $ZH \to (\ell\ell,\ \nu\nu) b\bar{b}$
High mass	$gg \to H \to WW^* \to \ell\ell\nu\nu$



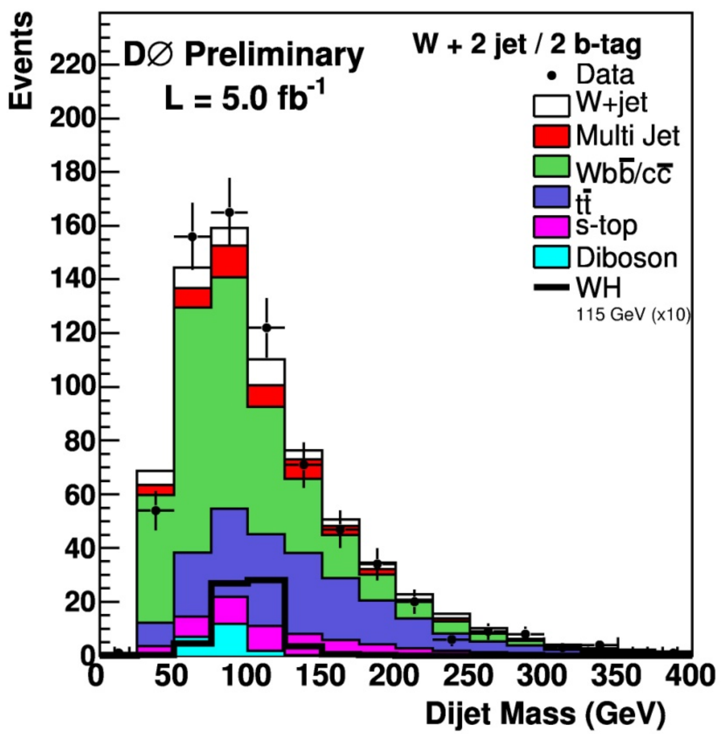


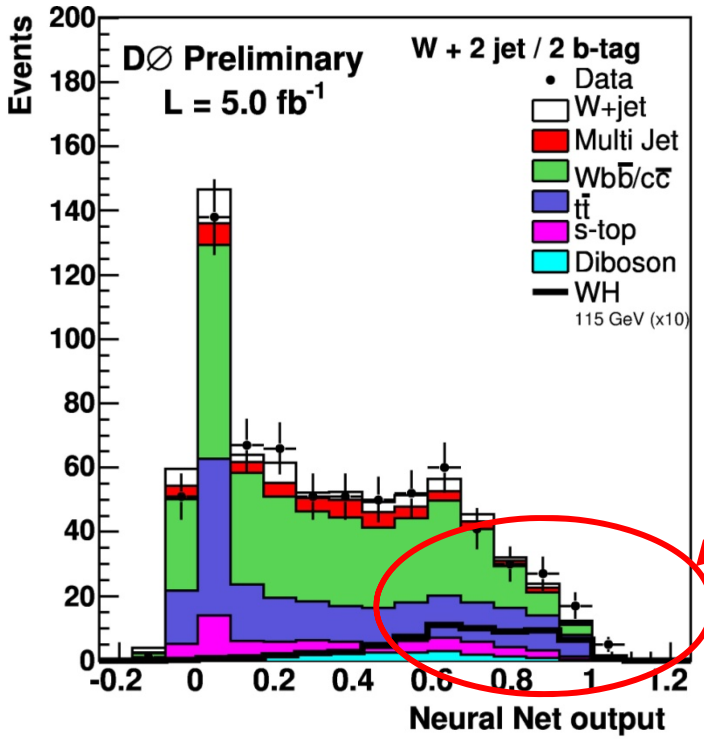
Low Mass Higgs Boson



- **Large Wqq and top backgrounds:**
  - b-jet tagging is essential
  - S/B ~ 1% even with 2 b-tag
- **Advanced technique a must for signal-background separation**
  - m_{bb} is still the best variable

$$\sigma\left(WH \to \ell \nu b\bar{b}\right) \approx 30 \text{ fb @ } m_H = 115 \text{ GeV}$$

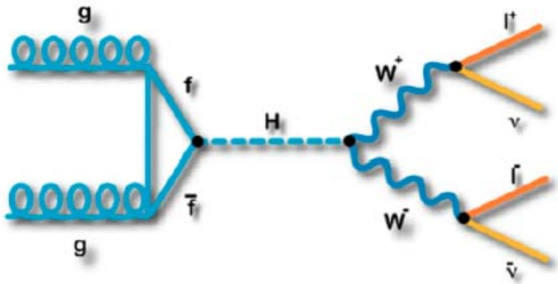




No sign of Higgs…

6 WH events expected

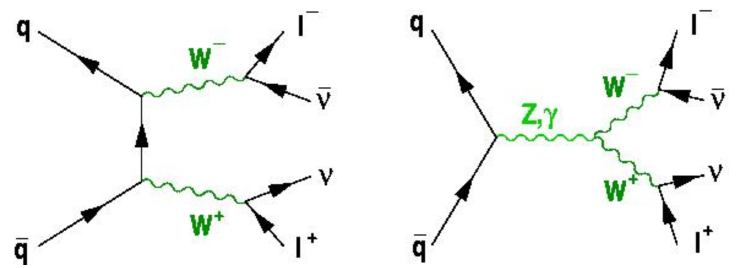
High Mass Higgs Boson



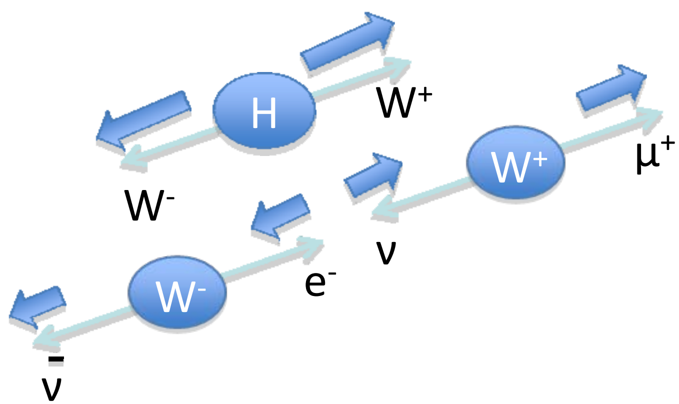
$$\sigma\left(H \to WW^* \to \ell\ell\nu\nu\right) \approx 20\ \text{fb}$$

$$@\ m_H = 160\ \text{GeV}$$

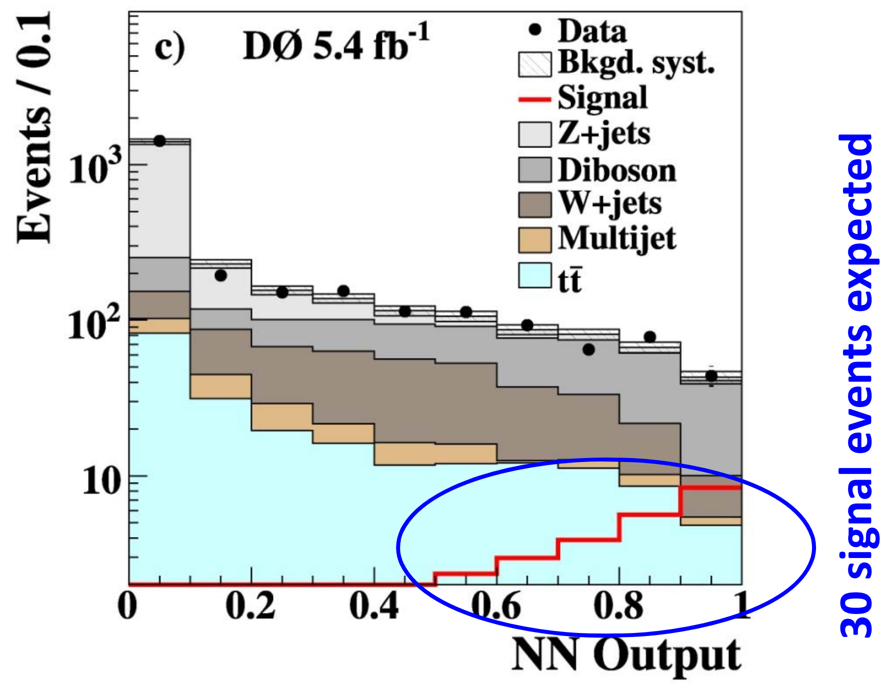
SM WW is the "irreducible" background



Signal and background events should have slightly different kinematics



The spin correlation leads to a smaller average opening angle between the two leptons



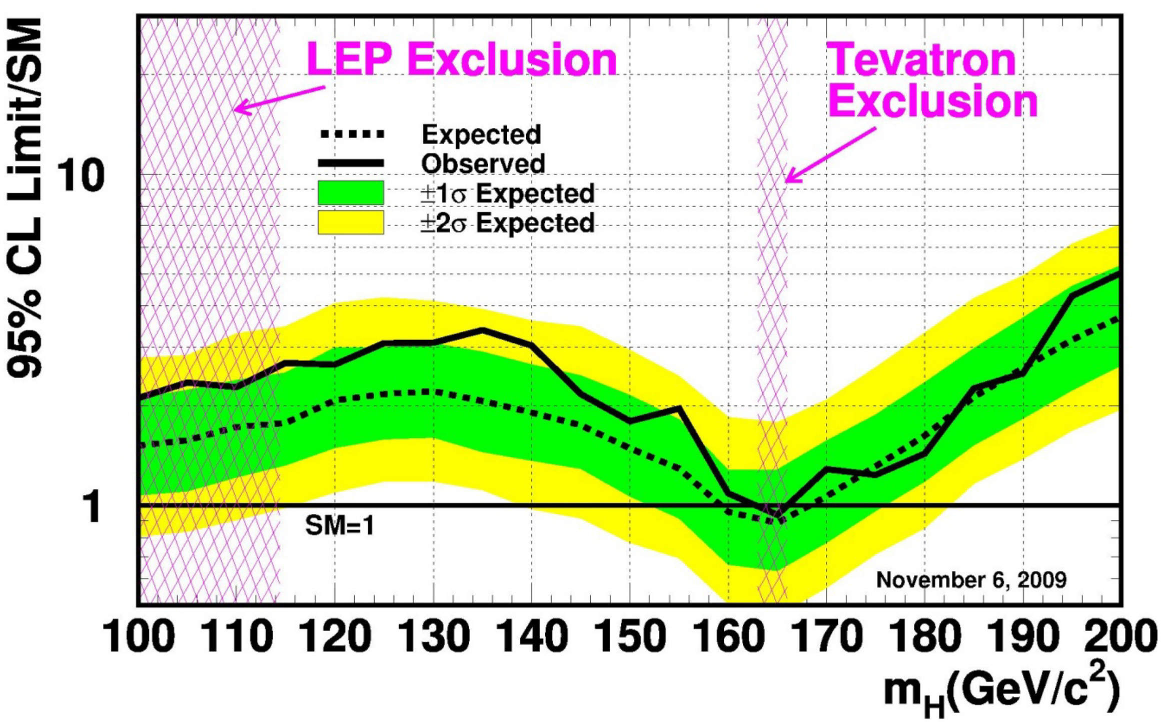
Phys. Rev. Lett. 104, 061804 (2010)

Tevatron Higgs Combination

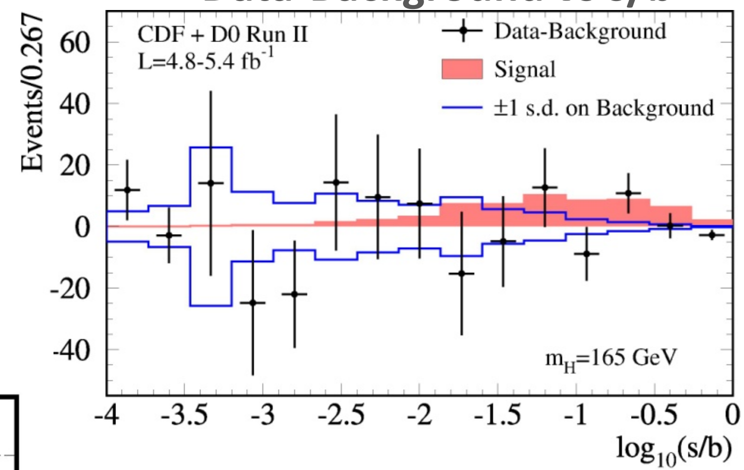
No evidence for a SM Higgs boson

Tevatron combination (@ 95% CL):
- low mass: σ×Br limit ~ (2-3)×SM
- high mass: excludes 162-166 GeV

Tevatron Run II Preliminary, L=2.0-5.4 fb^{-1}



Data-Background vs s/b



High mass combination published:
Phys. Rev. Lett. 104, 061802 (2010)

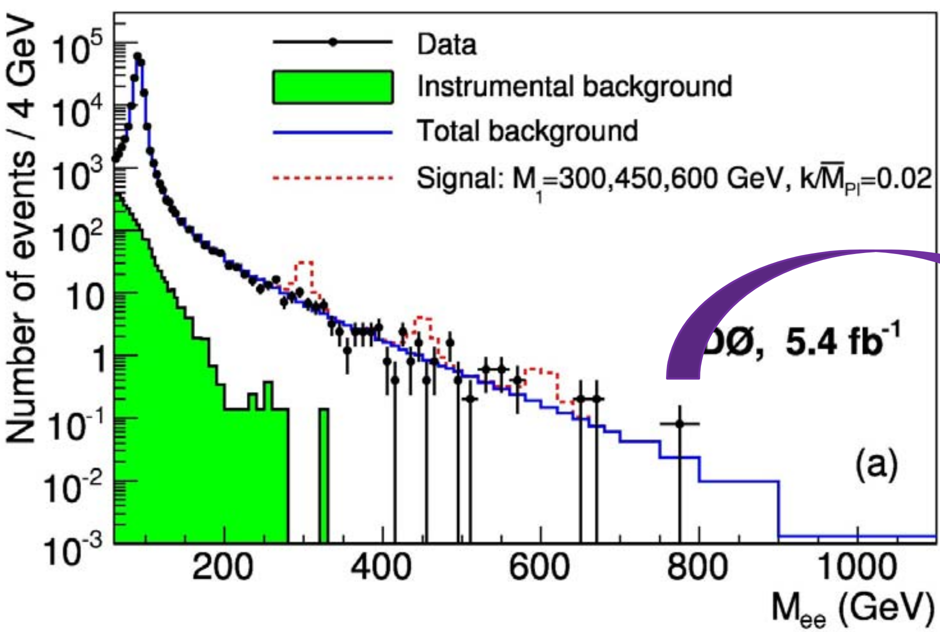
Dilepton Resonance

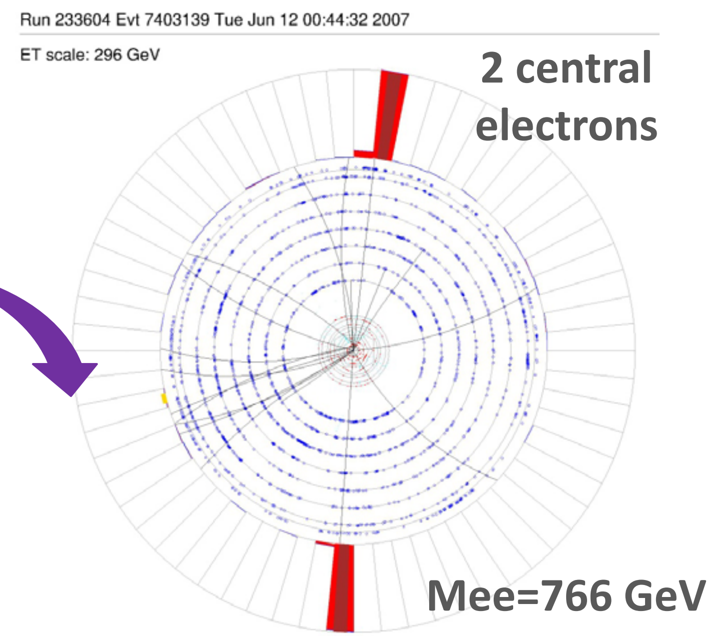
- **Lepton pair mass bump hunt has been fruitful historically**

$$J/\psi \to \mu^+\mu^-,\ \Upsilon \to \mu^+\mu^-,\ Z \to \ell^+\ell^-$$

- **No shortage of models predicting new high mass resonances**
  - **Z' model, Kaluza-Klein gravitons, Randall-Sundrum model, …**
- **No evidence either, depending on models**
  - **⇒ a lower mass limit of 700-900 GeV @ 95% CL**

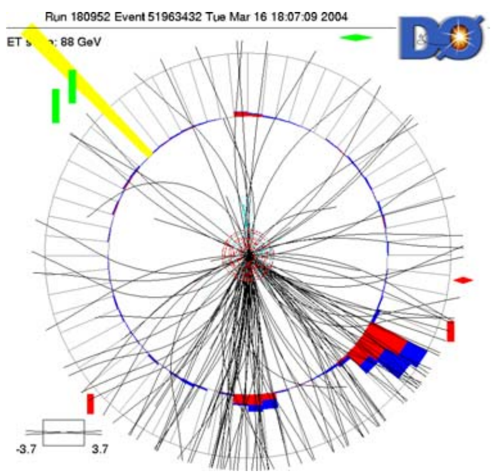
arXiv:1004.1826





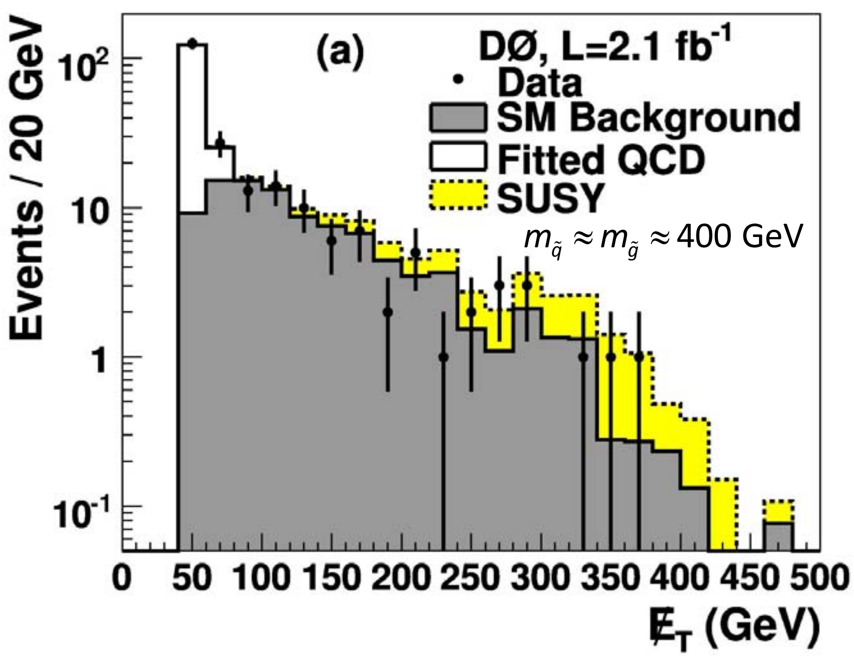
Supersymmetry – Jets+MET

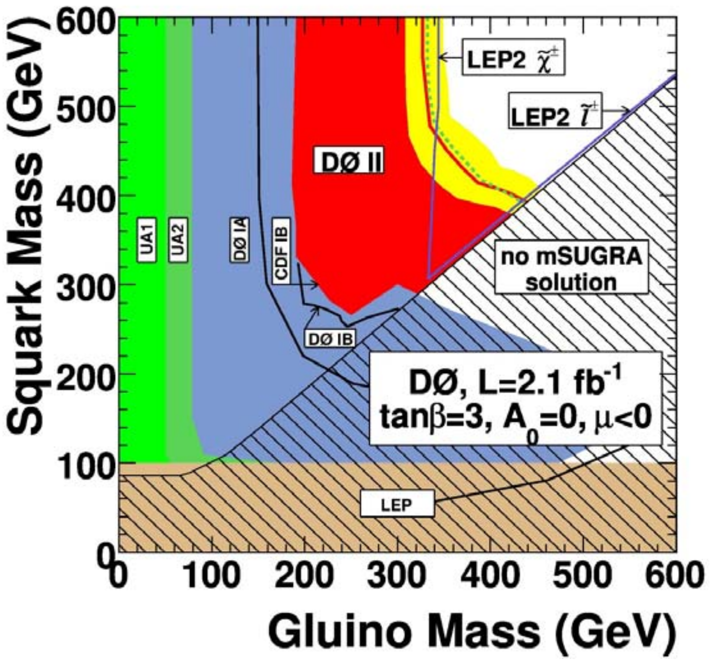
- **Squark and gluino production will likely lead the way**
  $\Rightarrow$ **jet+MET signature;**



- **But it suffers large backgrounds**
  - **QCD jet production: MET from mismeasurement;**
  - **W/Z+jets, WW/WZ/ZZ: genuine MET**

- **No evidence so far**
  $\Rightarrow$ **300-400 GeV lower mass limits on squarks/gluinos**



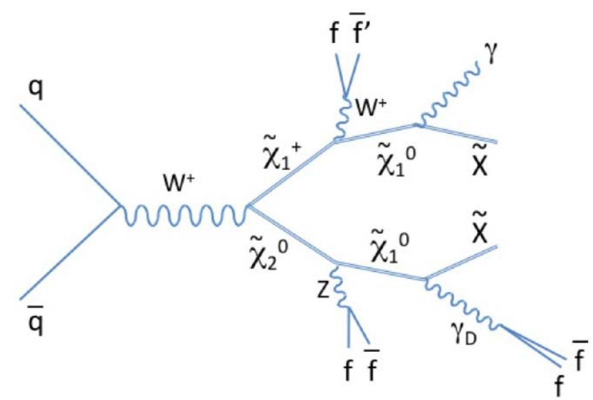


Phys. Lett. B660, 449 (2008)

Supersymmetric Hidden Valley

Productions and decays are largely the same as the standard supersymmetry except

- **NLSP = lightest neutralino**
- **LSP = hidden-valley state X**

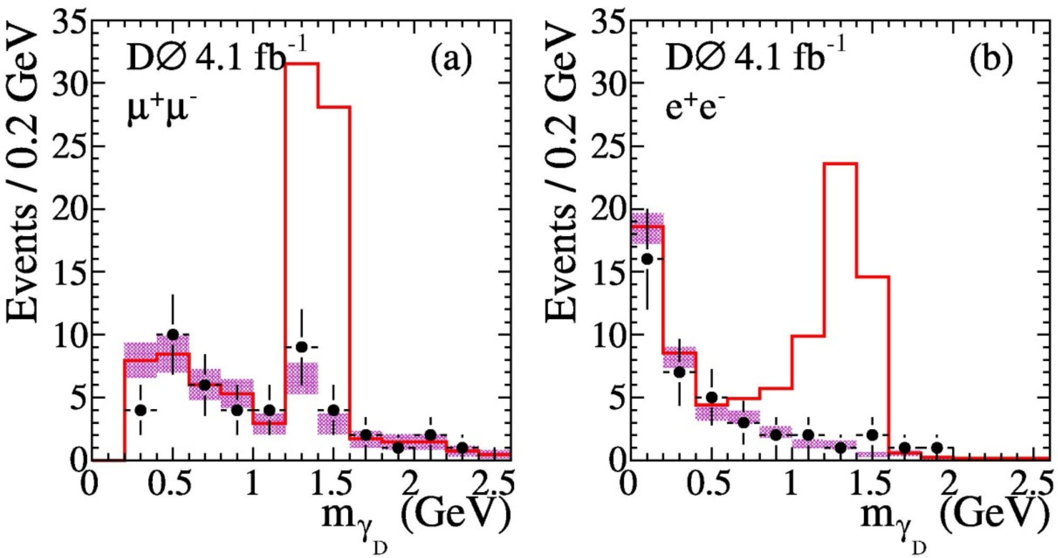


$$\tilde{\chi}_1^0 \to \gamma\tilde{X},\ \gamma_D\tilde{X} \text{ and } \gamma_D \to f\,\bar{f}$$

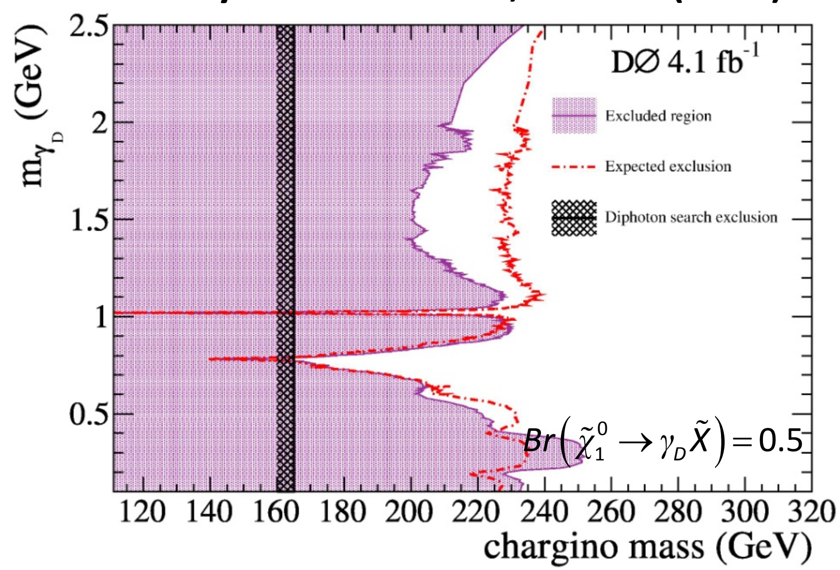
Motivated to explain recent results of some astrophysical experiments (DAMA, Fermi/LAT,…)

We search for dark photon decay

$$\gamma_D \to e^+e^-,\ \mu^+\mu^-$$



Phys. Rev. Lett. 103, 081802 (2009)



Higgs Boson in nMSSM

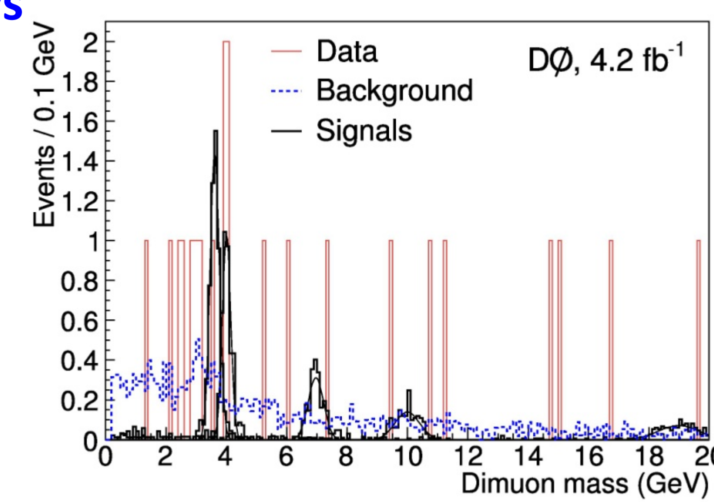
CP even neutral Higgs (h) predominantly decays to a pair of lighter pseudoscalar Higgs bosons

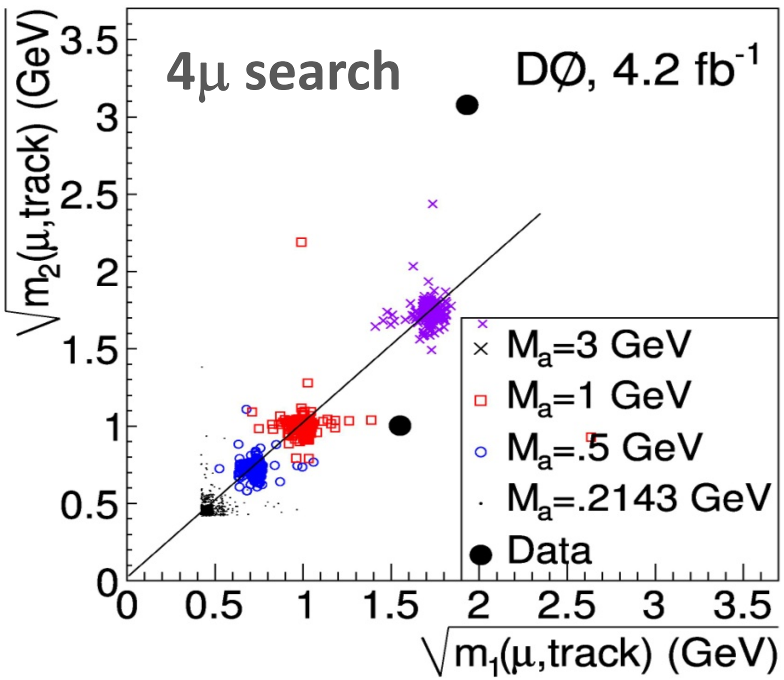
$$h \to aa,\ a \to \mu^+\mu^-, \tau^+\tau^-$$

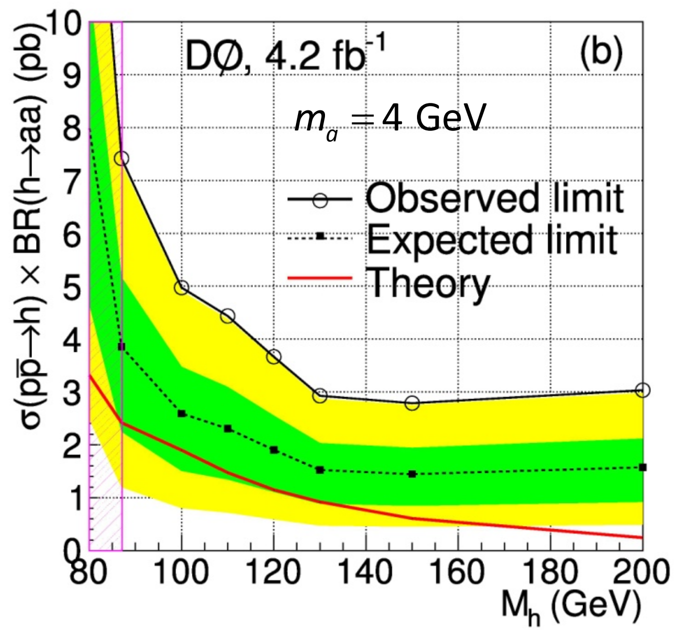
Search for 4μ and $2\mu 2\tau$ events

for small m_a, hard to reconstruct two close μ's
$\Rightarrow \mu$+track (better granularity in tracking)

No credible candidate observed

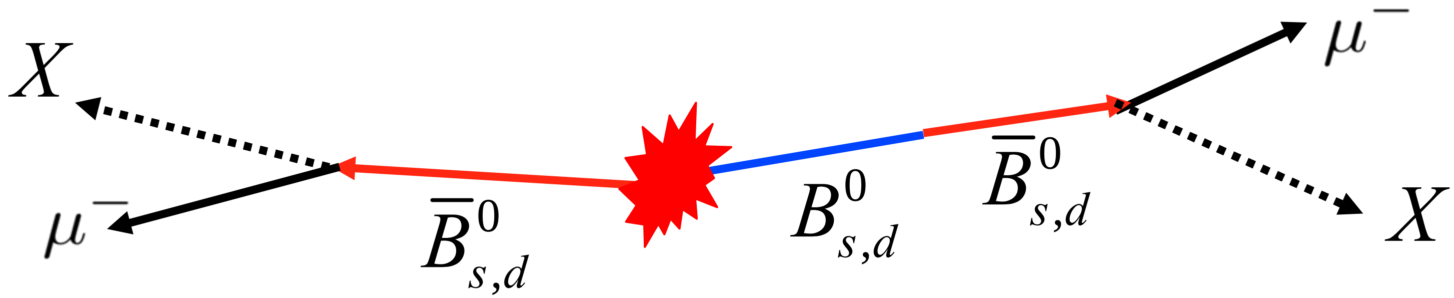






Phys. Rev. Lett. 103, 061801 (2009)

A_{sl}^{b} Measurement



Like-sign dimuon events are expected from B meson oscillation. Dimuon charge asymmetry from semileptonic B decays is expected to be small in the standard model

$$A_{sl}^{b} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} = \left(-2.3^{+0.5}_{-0.6}\right) \times 10^{-4}$$

(Lenz & Nierste: hep-ph/0612167)

New sources can significantly modify the asymmetry. Unlike B factories, the Tevatron is sensitive to asymmetries in both B_s and B_d system.

Measurement Issues

Many sources of hard-to-simulate backgrounds:

- **Kaon and pion decay in flight;**
- **Hadron punch throughs;**
- **Wrong charge measurement (e.g. wrong track association);**
- **Charge dependent reconstruction efficiency**

All background contributions are measured from data with minimum input from Monte Carlo simulations.

If there is a good detector for charge asymmetry measurement, it's DØ:
the polarities of the central solenoid and muon toriod are reversed on a regular basis:

$\Rightarrow$ **Trajectories of μ^+ are exactly the same as those of μ^- with the reversed magnet polarity;**

$\Rightarrow$ **Almost equal sizes for the four polarity combinations, events are reweighted according to integrated luminosities to minimize instrumental effect;**

$\Rightarrow$ **Significant systematic uncertainty reduction in charge asymmetry measurements.**

Raw Asymmetries

Muon selection

- $1.5 < P_T < 25$ GeV and $|\eta|<2.2$;
- muons with $P_T < 4.2$ GeV must also have $|P_Z| > 6.4$ GeV;
- consistent from the primary vertex

1.50×10^9 muons are selected (inclusive sample)

Like-sign dimuon selection

- Two muons with the same charge;
- $M(\mu\mu) > 2.8$ GeV to suppress events from the same B decay

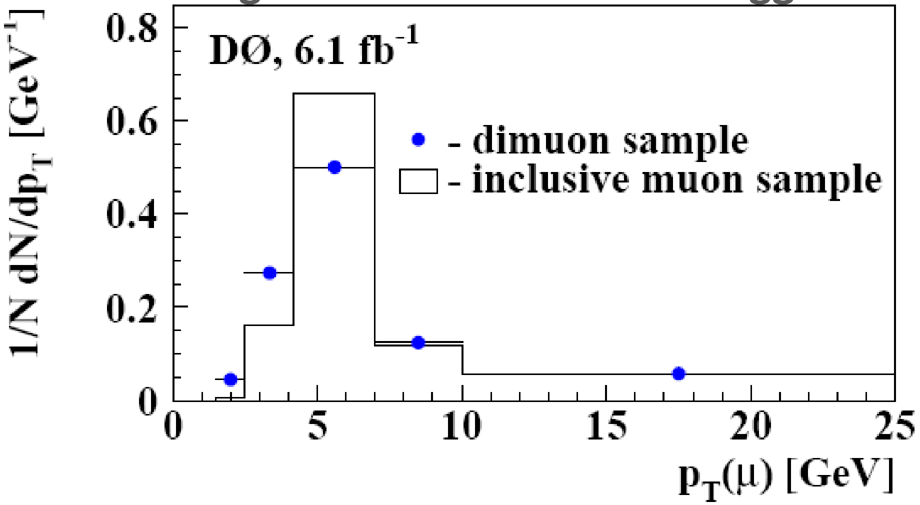
3.7×10^6 like-sign dimuons are selected

Raw asymmetries:

$$a = \frac{n^+ - n^-}{n^+ + n^-} = (+0.955 \pm 0.003)\%$$

$$A = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = (+0.564 \pm 0.053)\%$$

Single-muon and di-muon triggers



Backgrounds & Dilutions

- The raw asymmetries are affected by non-muon backgrounds

dilution factors →

$$a = k A_{sl}^{b} + a_{bkg}$$
$$A = K A_{sl}^{b} + A_{bkg}$$

← background contributions

- They are diluted by semileptonic b or c decays without oscillations

- "Background" contributions can be broken down as

$$a_{bkg} = f_k a_k + f_\pi a_\pi + f_p a_p + (1 - f_{bkg})\,\delta$$
$$A_{bkg} = F_k A_k + F_\pi A_\pi + F_p A_p + (2 - F_{bkg})\,\Delta$$

  - all are measured from data, validated with MC simulation
  - backgrounds to **a** and **A** are correlated

  $a_{bkg} \approx A_{bkg} \Rightarrow$ cancellation of systematic uncertainties

- Dilution factors k and K are determined from MC simulations:

  B and c quark decays are well modeled in MC

$$k = 0.041 \pm 0.003, \quad K = 0.342 \pm 0.023$$

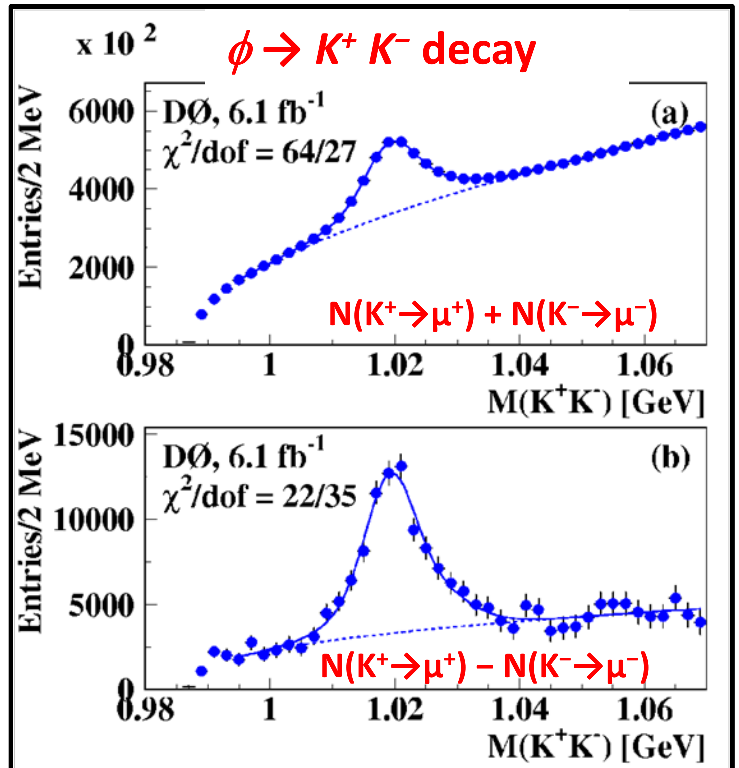
Kaon Background

The largest background charge asymmetry is from Kaons

- K^+ and K^- interact with the detector differently

$$\sigma(K^- d) \approx 80 \text{ mb}, \ \sigma(K^+ d) \approx 33 \text{ mb}$$

- The mean free path is longer for K^+ than K^-, more chance for decay in flight and punch through (should lead to more ++ than - -)



Its contribution is measured from data using Kaons from resonance decays

$$K^{*0} \to K^+\pi^-, \ \varphi(1020) \to K^+K^-$$

- Require Kaon to be identified as a muon;
- Separate mass distributions for "μ^+" and "μ^-";
- Computing the charge asymmetry

$$a_K = (5.5 \pm 0.11)\% \quad f_K = (15.5 \pm 0.2)\%$$

Summary of Background

$$a_{bkg} = f_k a_k + f_\pi a_\pi + f_p a_p + (1 - f_{bkg})\,\delta$$

$$A_{bkg} = F_k A_k + F_\pi A_\pi + F_p A_p + (2 - F_{bkg})\,\Delta$$

	$f_K a_K$ (%) or $F_K A_K$ (%)	$f_\pi a_\pi$ (%) or $F_\pi A_\pi$ (%)	$f_p a_p$ (%) or $F_p A_p$ (%)	$(1-f_{bkg})\delta$ (%) or $(2-F_{bkg})\Delta$ (%)	a_{bkg} or A_{bkg}
Inclusive	0.854±0.018	0.095±0.027	0.012±0.022	−0.044±0.016	0.917±0.045
Dimuon	0.828±0.035	0.095±0.025	0.000±0.021	−0.108±0.037	0.815±0.070

Uncertainties are statistical only

Putting pieces together

$$A_{sl}^{b} = (+0.94 \pm 1.12\ \text{(stat)} \pm 2.14\ \text{(syst)})\% \quad \text{(from inclusive)}$$

$$A_{sl}^{b} = (-0.736 \pm 0.266\ \text{(stat)} \pm 0.305\ \text{(syst)})\% \quad \text{(from dimuon)}$$

Instead of measuring A_{sl} separately from the two raw asymmetries, systematic uncertainties can be significantly reduced by taking the difference

$$A' \equiv A - \alpha a = (K - \alpha k) A_{sl}^{b} + (A_{bkg} - \alpha a_{bkg})$$

Here $\alpha \approx 0.959$ is chosen to minimize systematic uncertainties

A_{sl}^{b} Final Result

$$A_{sl}^{b} = \left[-0.957 \pm 0.251\ (\text{stat}) \pm 0.146\ (\text{syst})\right]\ \%$$

$$A_{sl}^{b}(SM) = \left[-0.023^{+0.005}_{-0.006}\right]\%$$

The result is validated by many consistency and closure tests

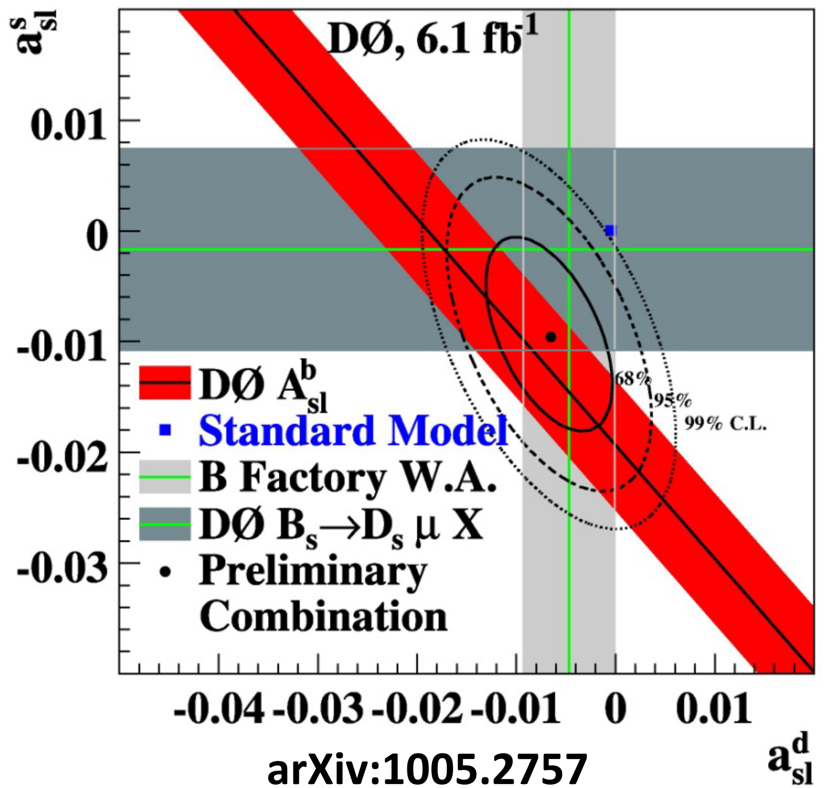
Both B_d^0 and B_s^0 are produced at the Tevatron

$$A_{sl}^{b} = 0.506 a_{sl}^{d} + 0.494 a_{sl}^{s}$$

$$\left(a_{sl}^{b} \equiv \frac{\Gamma(\bar{B} \to \mu^+ X) - \Gamma(B \to \mu^- X)}{\Gamma(\bar{B} \to \mu^+ X) + \Gamma(B \to \mu^- X)} \right)$$

based on their relative production fractions

The result differs from the SM by 3.2σ. Time will tell...



arXiv:1005.2757

Prospects

- **Most of the results shown are from 5 fb^{-1} or less, expect improvement from increased statistics**

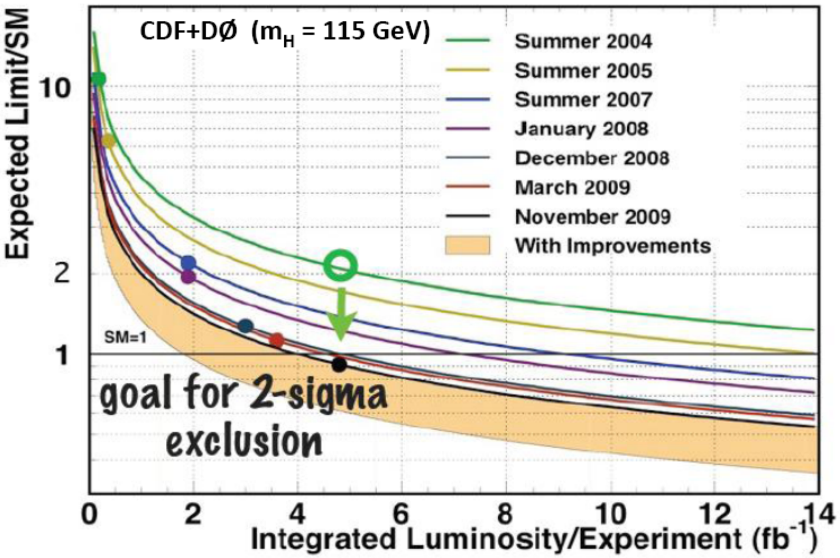
  but only for high profile or interesting analyses,
  no people to repeat some of the analyses

- **Improvements being worked on**
  - **Find leptons in detector gaps, track only leptons;**
  - **Improved b-tagging: better flavor separation,…;**
  - **Jet energy resolution: separate treatment of heavy-flavor and light jets;**

  ….

- **Tevatron will run in 2011 (~10 fb^{-1} recorded), unclear beyond that**

  With 10 fb^{-1} analyzed per experiment, it is *possible* that Tevatron will exclude the entire Higgs boson mass range favored by the EW fits *if it is not there*



Summary

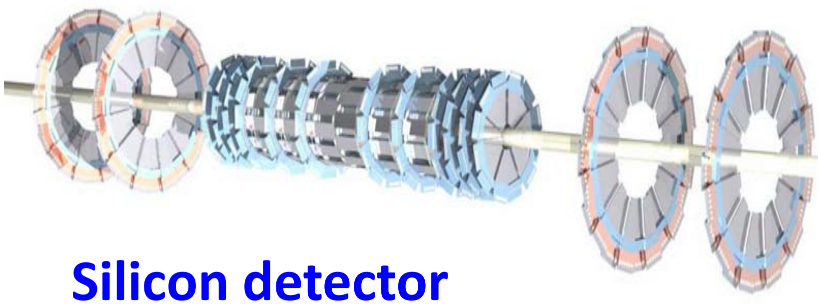
- DØ has been remarkably productive. This short presentation cannot do justice to all the results we have produced over the years. We have had many discoveries and surprises. There might be a few more surprises in store. For a complete list of results, please see
  http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

- Both CDF and DØ have also perfected reconstruction algorithms and analysis techniques. All of these will benefit the LHC experiments which many of us are part of.

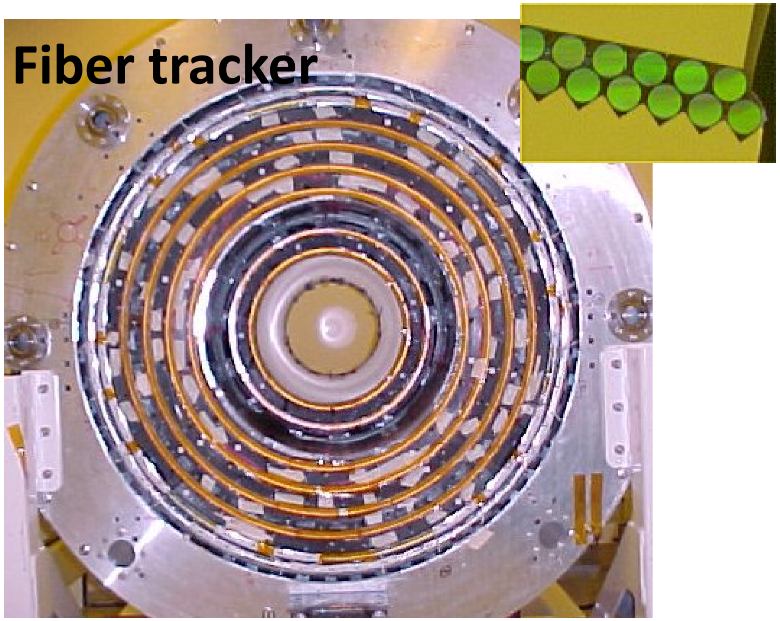
- Tevatron has answered many questions and yet is leaving many unanswered. Welcome LHC… don't dismiss Tevatron yet, it still has a few years to quack!

See the presentation by Daniel Whiteson tomorrow for CDF results!

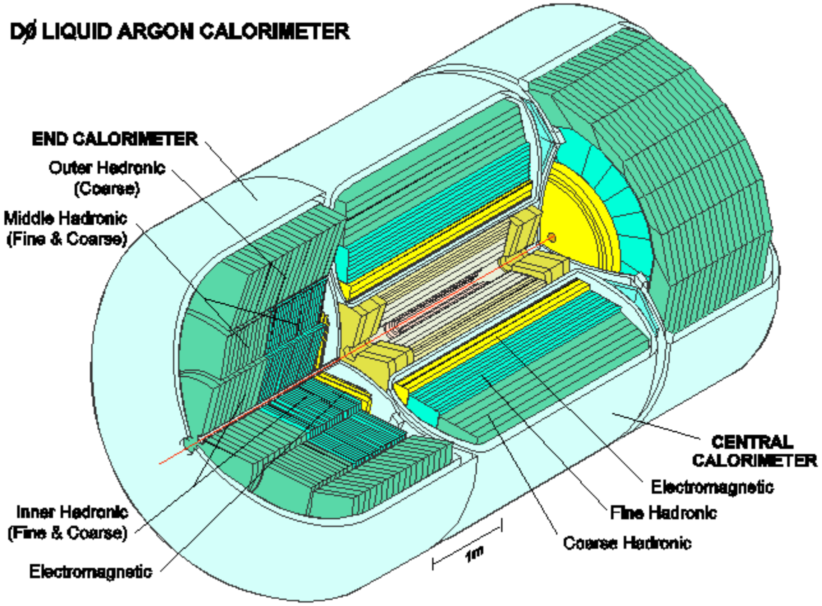
DØ Detector Subsystems

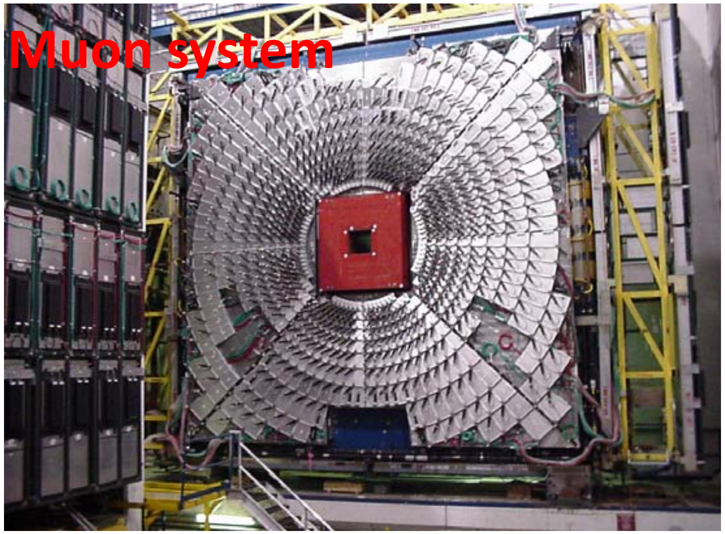


Silicon detector



Fiber tracker

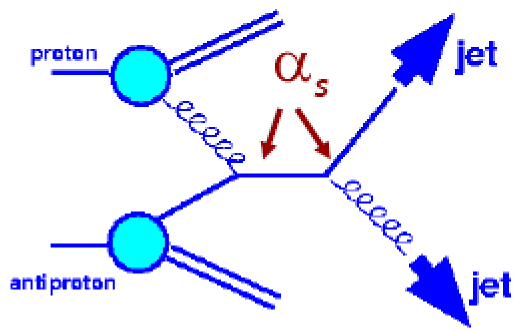




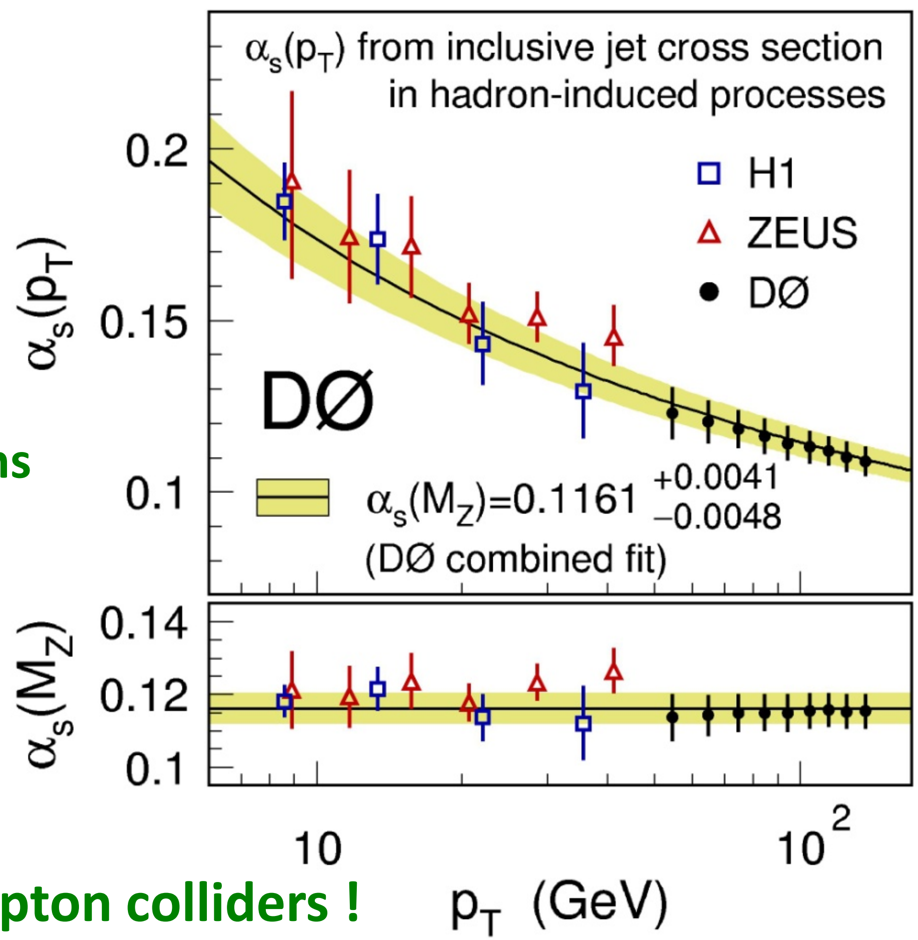
Muon system

Strong Coupling Constant

- Jets are copiously produced at hadron colliders, their rates are sensitive to α_s;



Phys. Rev. D 80, 111107 (2009)



- Recent advances in the inclusive jet cross section calculation

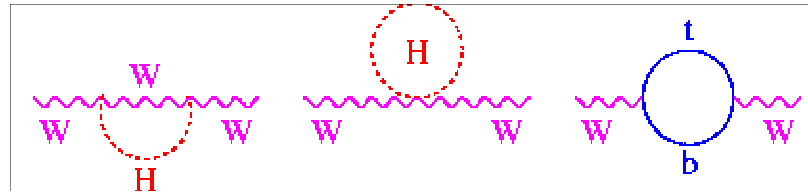
  NLO + 2-loop threshold corrections

- DØ inclusive jet cross section

$$\alpha_S(M_Z) = 0.1173^{+0.0041}_{-0.0049}$$

comparable to measurements at lepton colliders !

W Boson Mass

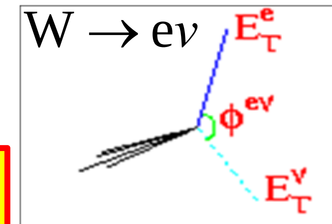


A key standard model input parameter

indirect information for unknown physics

A tour de force of detector understanding

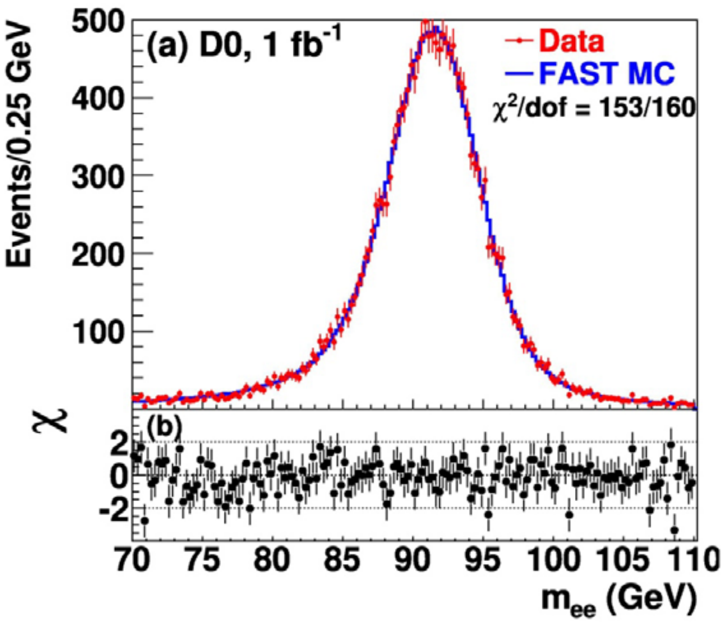
lepton momentum and hadronic recoil calibration at ~0.05% driven by Z→ll statistics

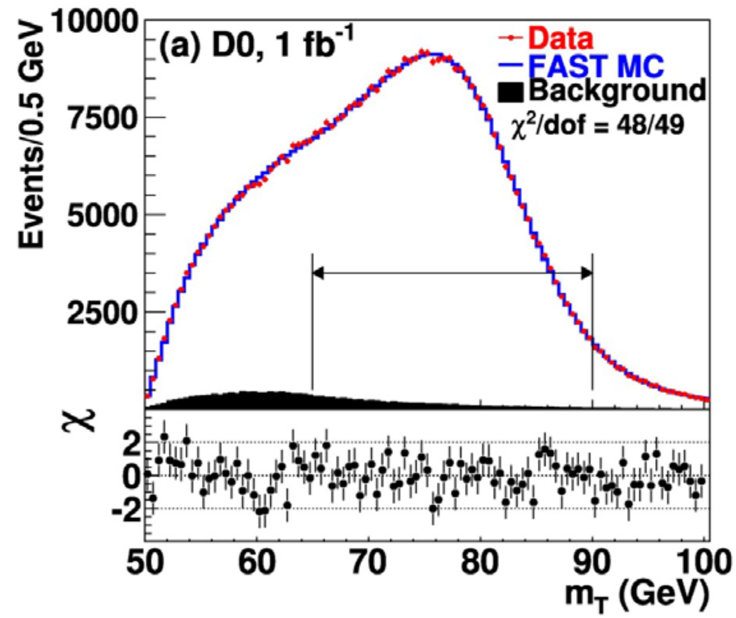


Single best measurement
M_W = 80.401 ± 0.043 GeV

⇒

New world average
M_W = 80.399 ± 0.023 GeV

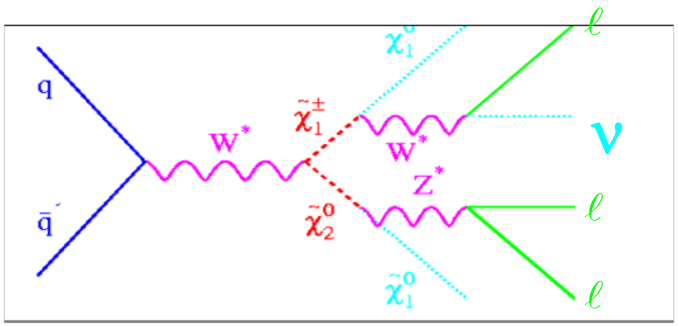




Phys. Rev. Lett. 103, 141801 (2009)

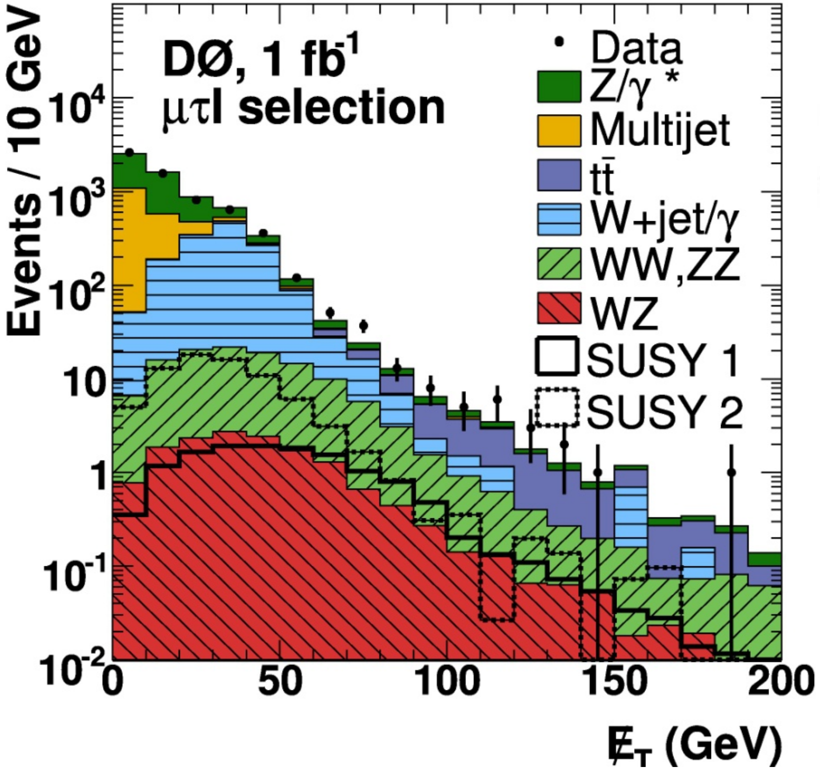
Supersymmetry - Trilepton

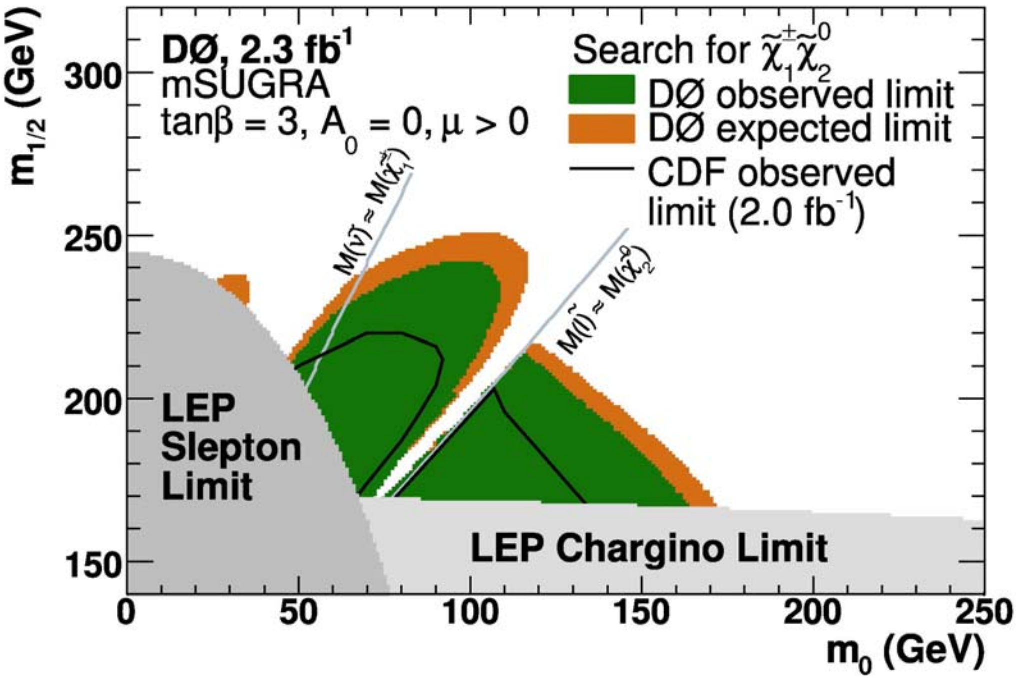
- **Perhaps the most clean signature from supersymmetry;**
- **Experimental challenges:**
  Low event rate, soft 3rd lepton, backgrounds are still large, …



No indication so far

Phys. Lett. B680, 34 (2009)





Higgs Boson in Supersymmetry

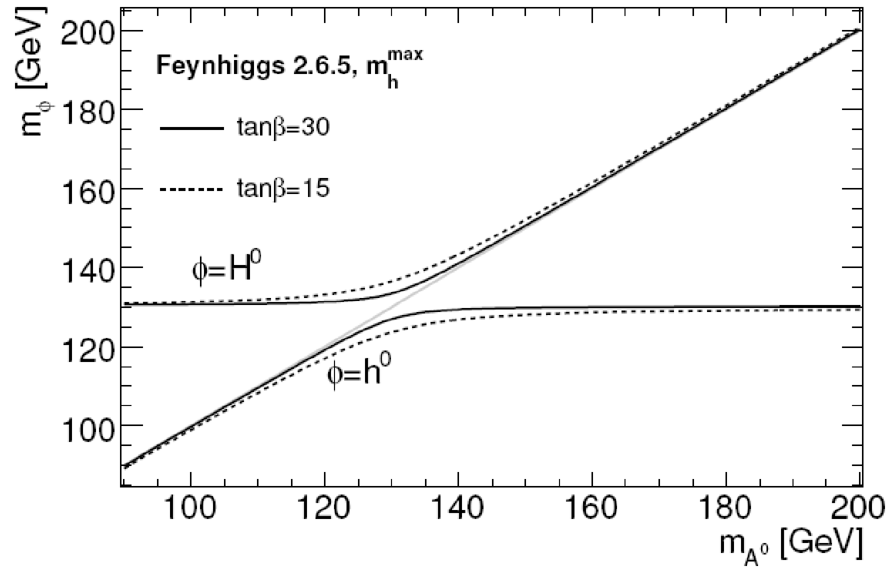
Minimal Supersymmetric Standard Model (MSSM)

- predicts five Higgs bosons: h, H, A, H^+, H^-
- two of the three neutral Higgs are generally degenerate in mass ⇒ φ
- φ production cross is proportional to $\tan^2\beta$

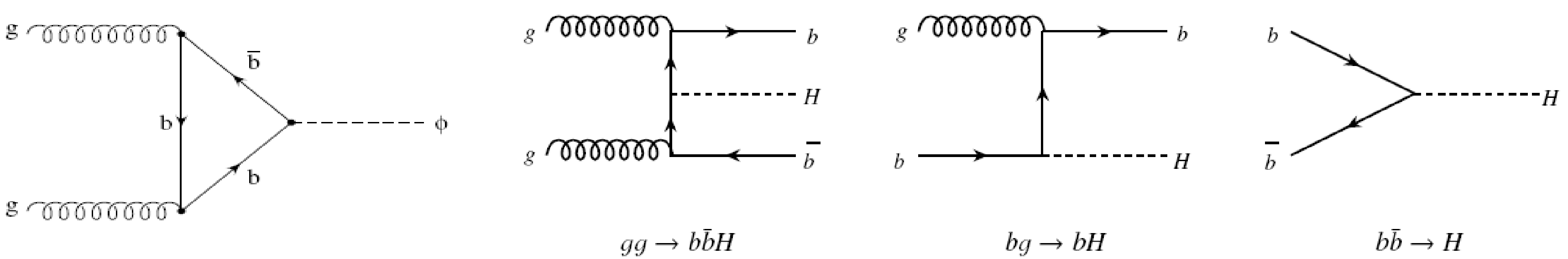
$$g_{hbb}^2 + g_{Hbb}^2 + g_{Abb}^2 \approx 2 \times \tan^2\beta \times g_{SM}^2$$

- φ decays predominantly to bb and ττ pair

$$\text{For } \tan\beta \sim 40 \; (\approx m_t / m_b)$$
$$Br(\phi \to b\bar{b}) \sim 90\%,$$
$$Br(\phi \to \tau\tau) \sim 10\%$$



- Two production types: direct (a la SM) and associated

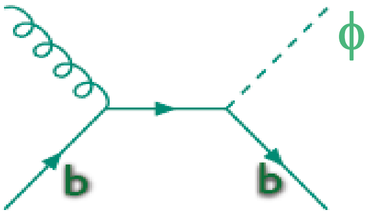


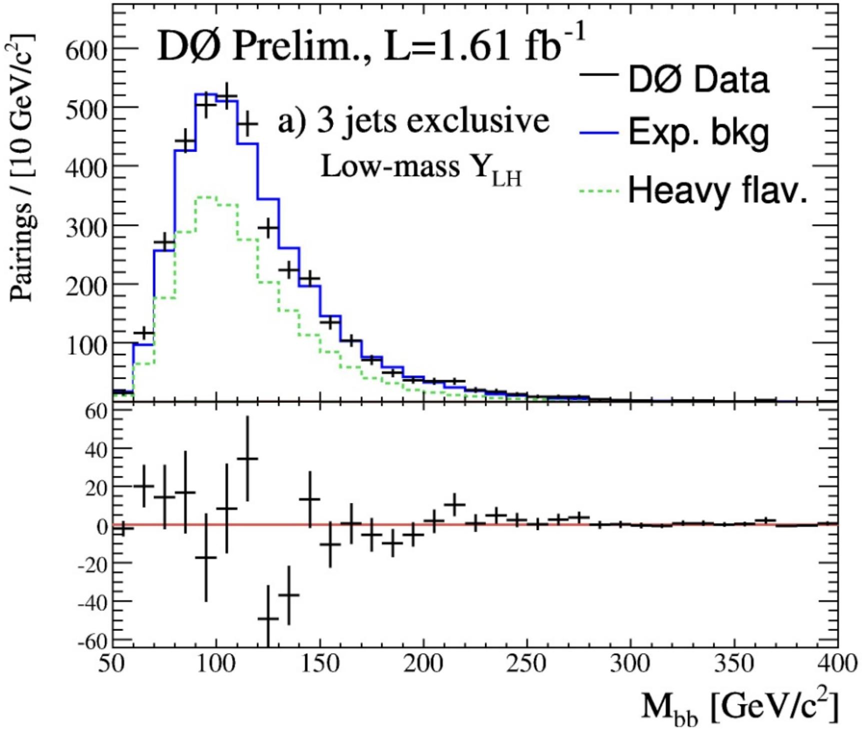
direct production

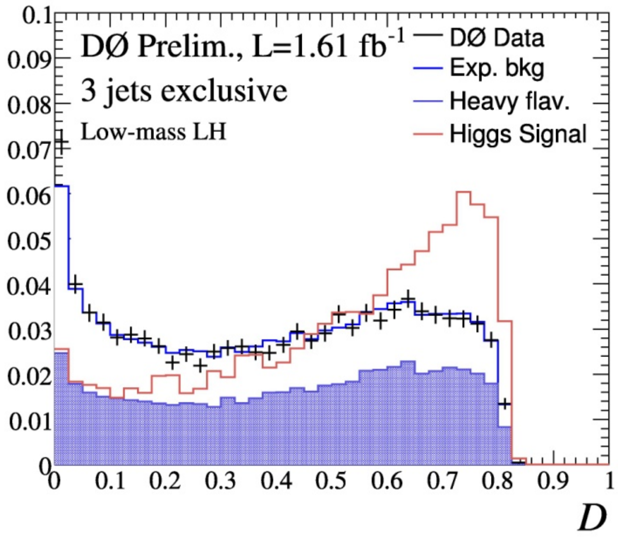
associated production

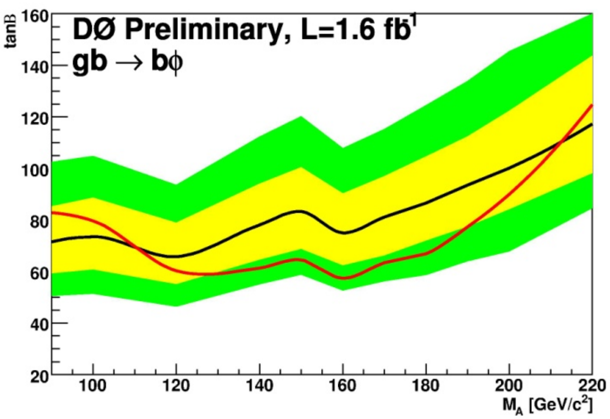
SUSY $\phi \to bb$

- Search for $gb \to \phi b \to bbb$: an extra b important for background reduction;
- select events with 3 b-tagged jets, look for mass bump of 2 b-tagged jets;
- Likelihood discriminant to improve S/B, data-driven background determinations



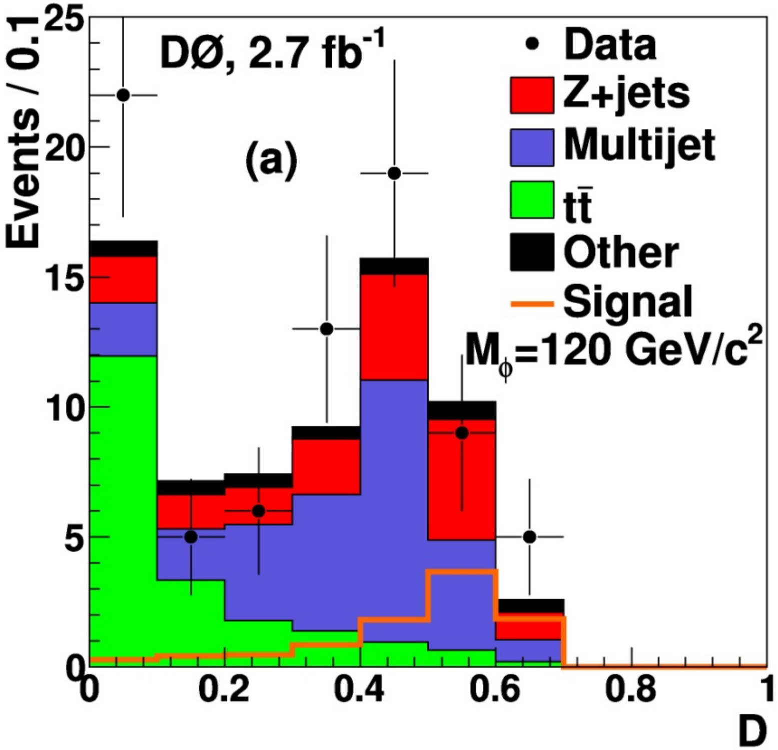


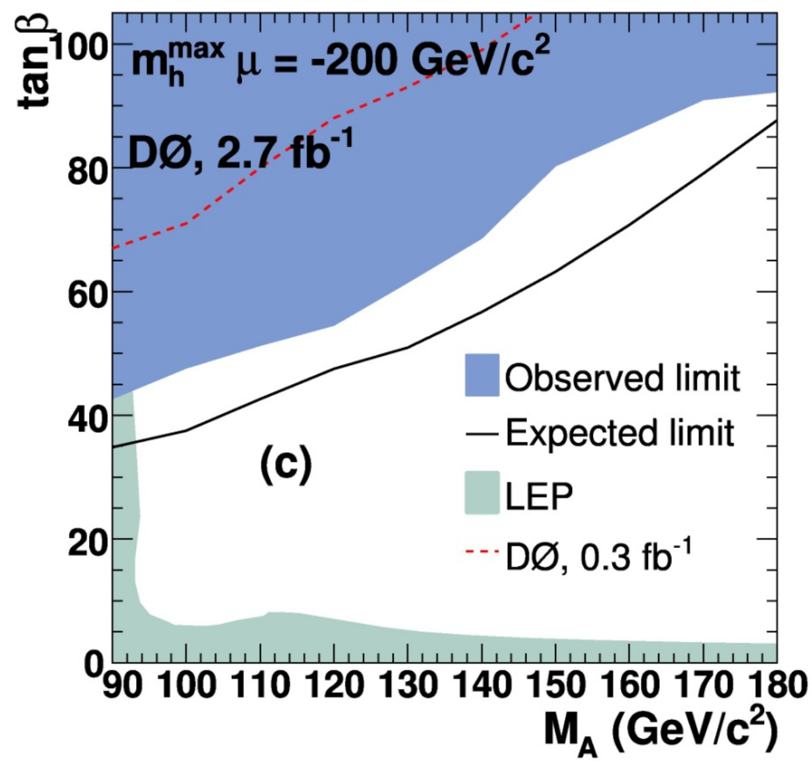




SUSY $\phi\to\tau\tau$

- Search for $gb\to\phi b\to\tau\tau b\to\mu\tau_h b$
  μ as the trigger, b-jet reduces $Z\to\tau\tau$ background
- improve S/B separation using two (tt, multijets) multivariate discriminants, estimate remaining multijet backgrounds using like-sign events;
- sensitivities are similar to the $gb\to\phi b\to bbb$ search





Phys. Rev. Lett. 104, 151801 (2010)