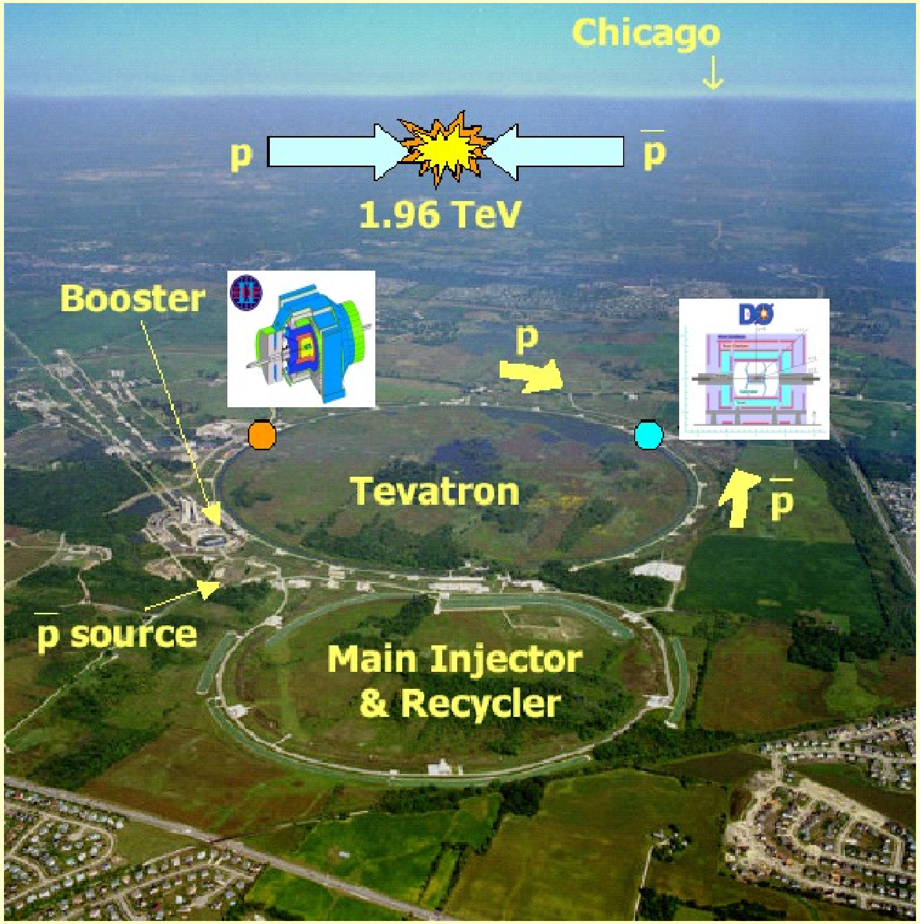
Higgs & SUSY Searches @ TeVatron

S. Greder,
On behalf of D0 and CDF collaborations

Outline

- Experimental status
- SM Higgs searches
- BSM Higgs searches
- SUSY searches
- Conclusion



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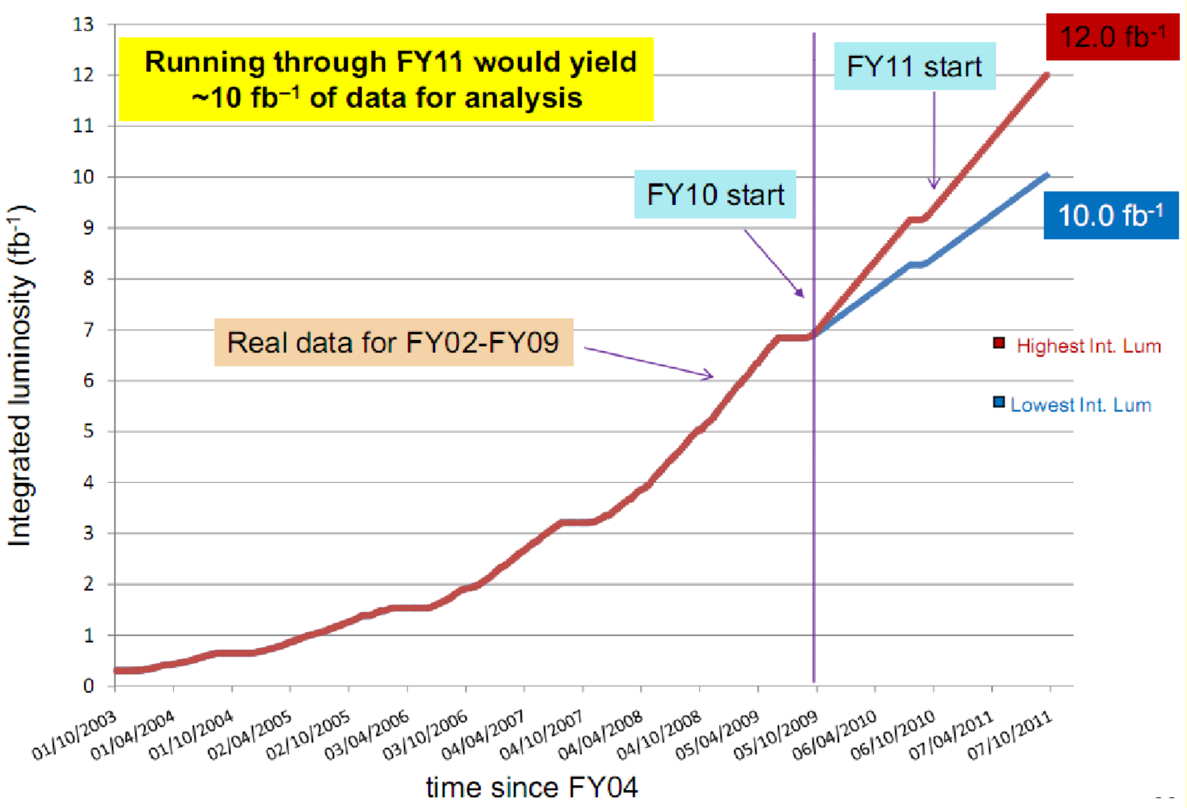
TeVatron

Tevatron and experiments perform well

- **~8fb^{-1}** delivered, **>7fb^{-1}** recorded by each experiment !
- Following design integrated luminosity
- Expect **>10fb^{-1}** by end of FY 2011



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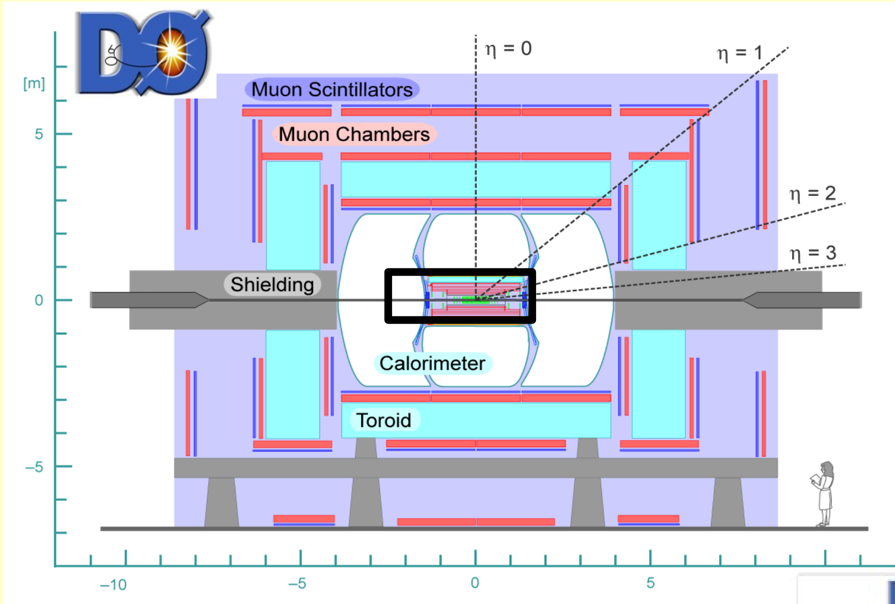
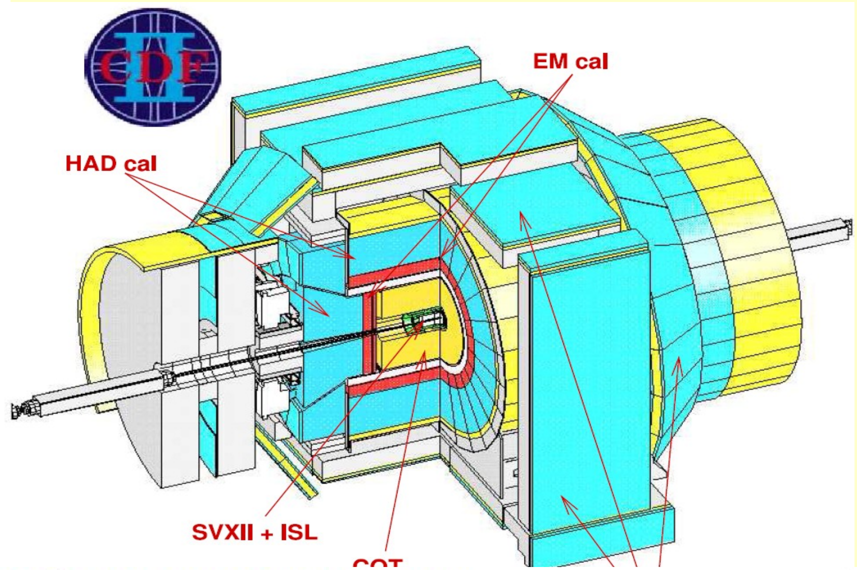
DØ & CDF





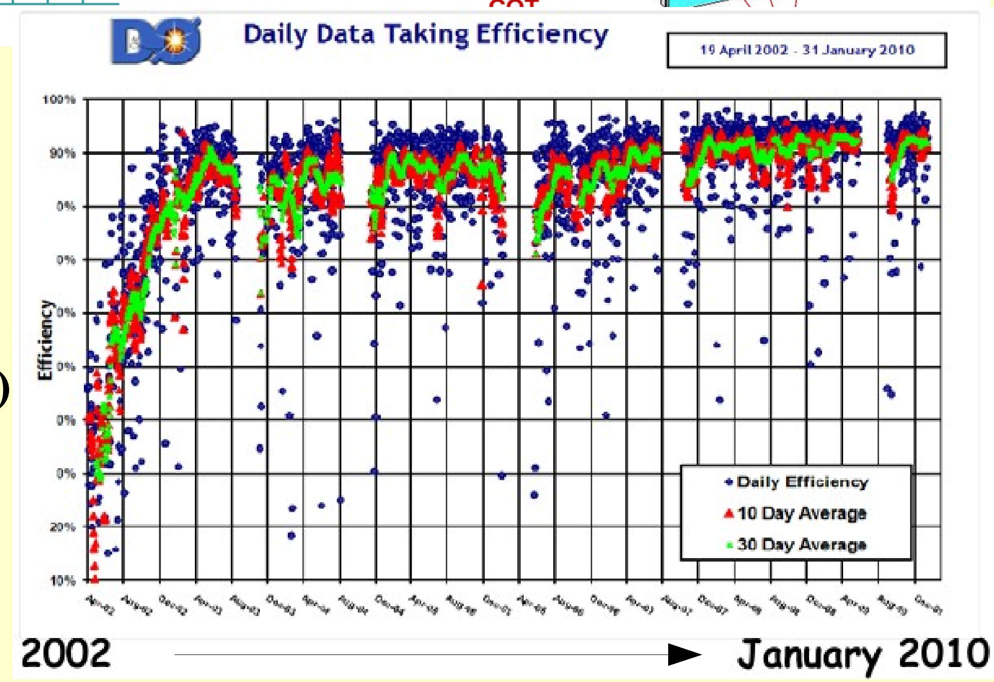
Silicon Tracker (SMT)

- 6 barrels, 4 layers, z ~1 m
- $|\eta| < 2.5$ *(CDF: 2)*
- New layer 0 @ r =1.6 cm

Scintillating Fiber Tracker (CFT)

- 8 layers (axial & stereo)
- 20 < r < 51 cm in 2T field

Muon system, $|\eta|<2$ *(CDF < 1)*



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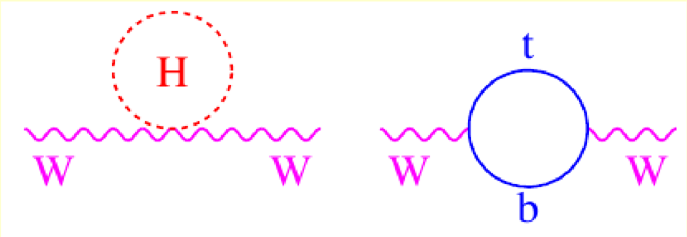
SM Higgs Searches

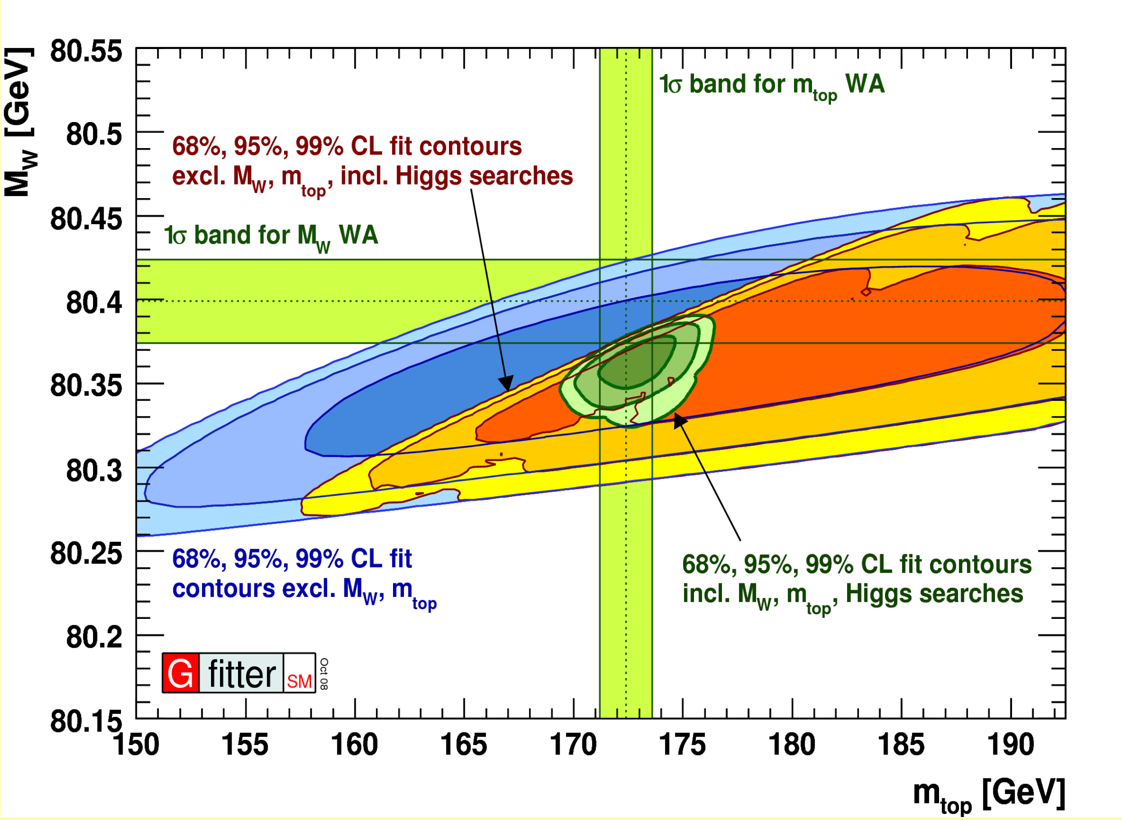
SM Higgs Constrains

Radiative corrections

$$\frac{G_F}{\sqrt{2}} = \frac{2\pi\alpha}{\sin^2 2\theta_W M_Z^2}[1 + \Delta r_\alpha + \Delta r_t + \Delta r_H]$$

$$\Delta r_H = \frac{G_F M_Z^2 (1 + 9\sin^2\theta_W)}{24\sqrt{2}\pi^2} \log\frac{M_H^2}{M_W^2} + \ldots$$





Electroweak precision measurements favour a light Higgs boson in the SM

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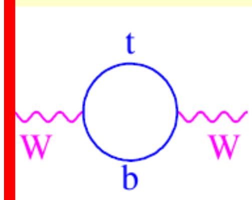
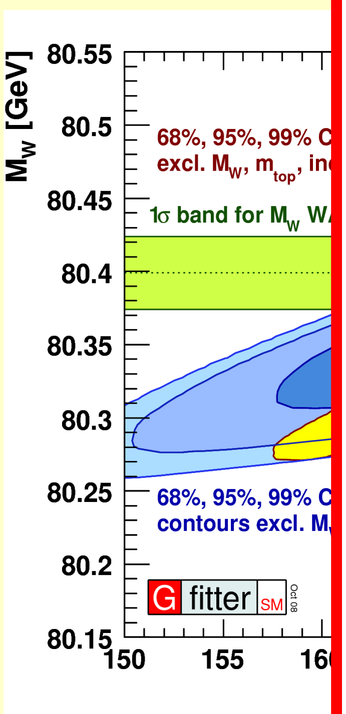
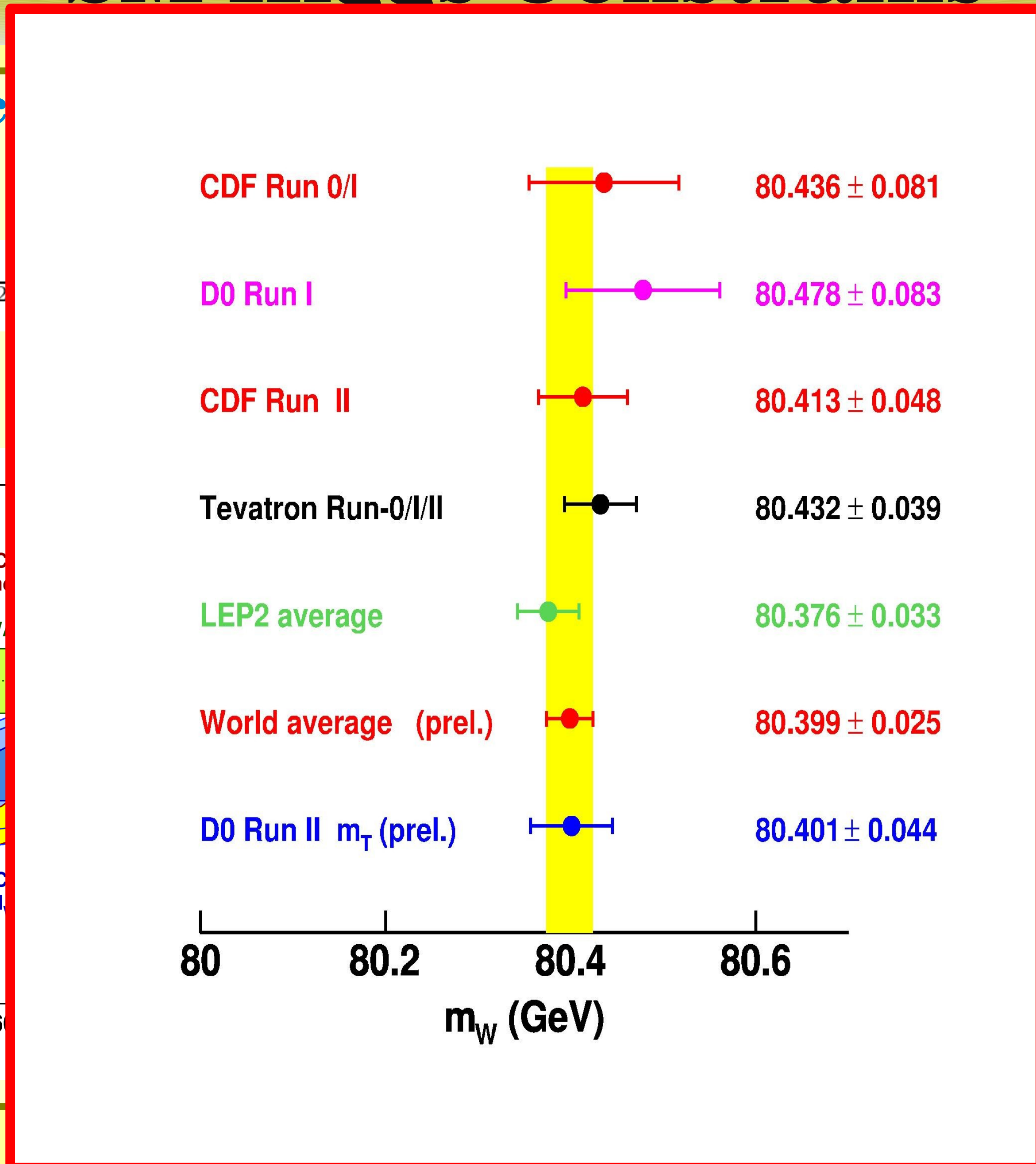
SM Higgs Constrains

Radiative c

$\frac{G_F}{\sqrt{2}} = \sin^2$







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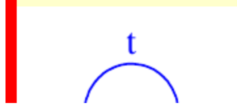
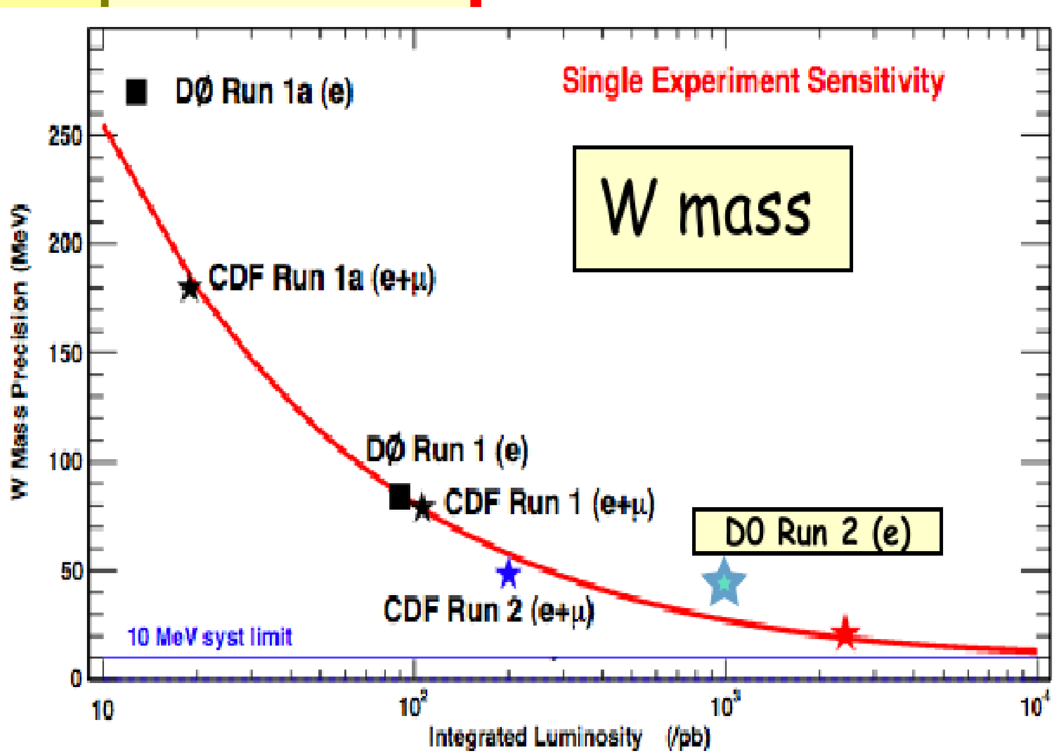
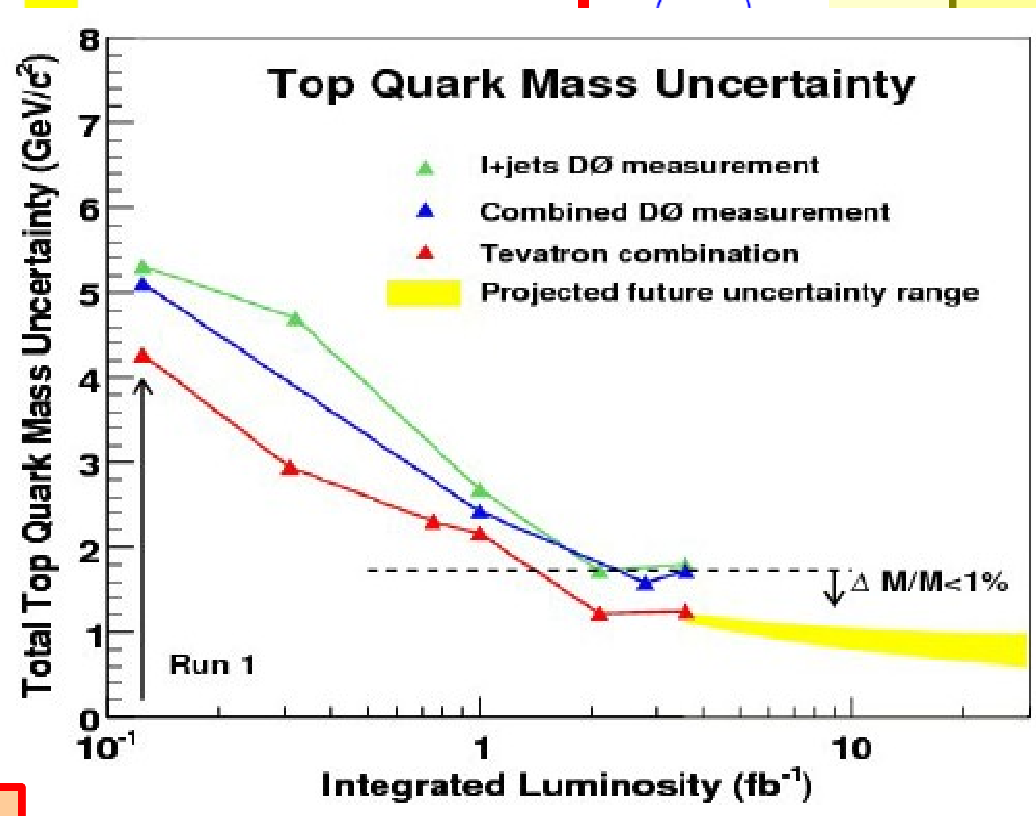
SM Higgs Constrains

Radiative c





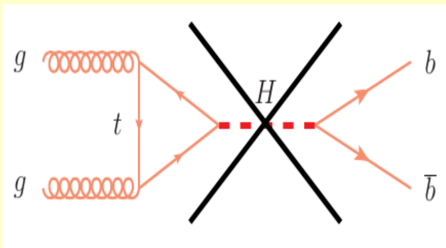


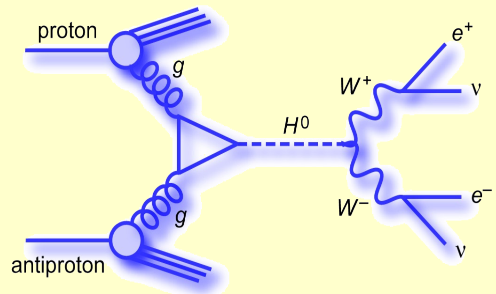
$\Delta M_{top} = \Delta M_W$ **~7 MeV necessary !**

SM Higgs: production & decay

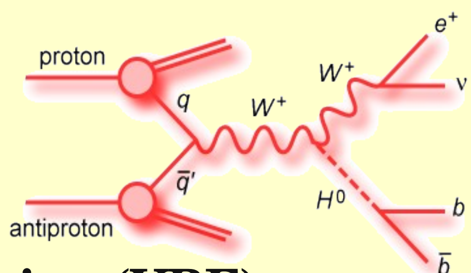
"Light" *(<135 GeV)*, "heavy" *(>135 GeV)* Higgs

- **gg fusion:** overwhelmed QCD bb (~$x10^6$);
  ↳ **H→WW**

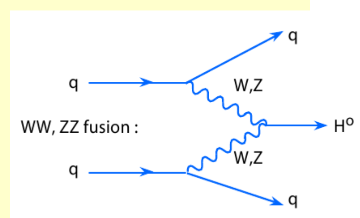


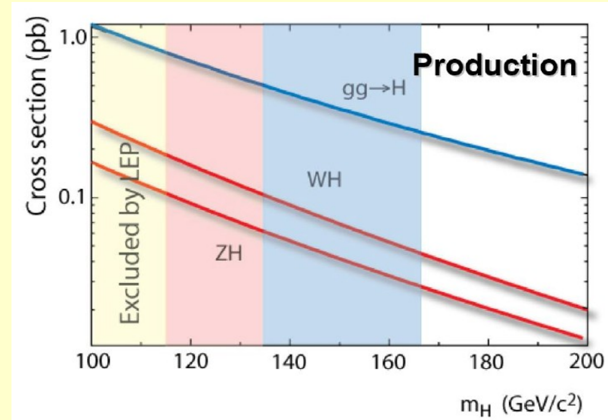


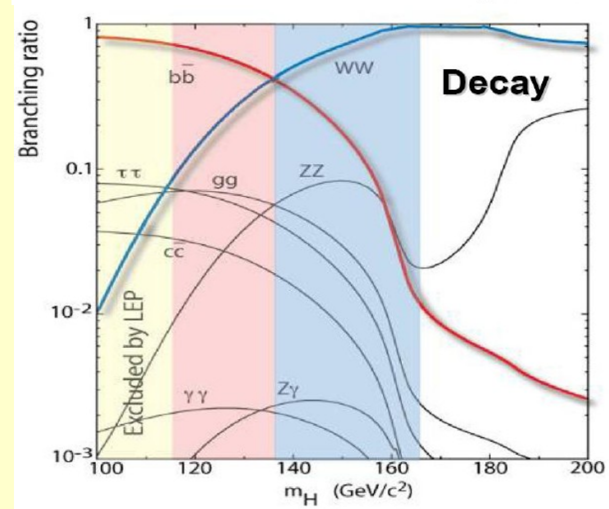
- **Associated production, (W/Z)H**
  - H→ **bb**, ττ



- **Vector boson fusion (VBF)**
  - Low yields *(but ok @ LHC)*







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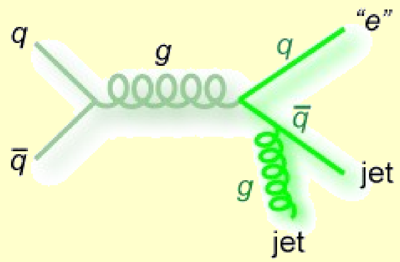
Backgrounds (I)

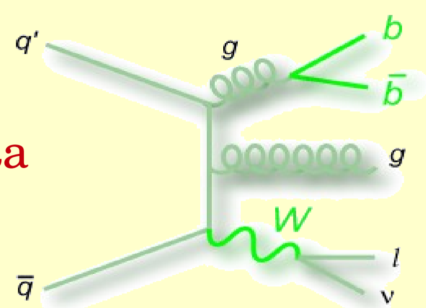
Instrumental

- **Multi-Jets :** *fake* leptons
- Evaluated in data

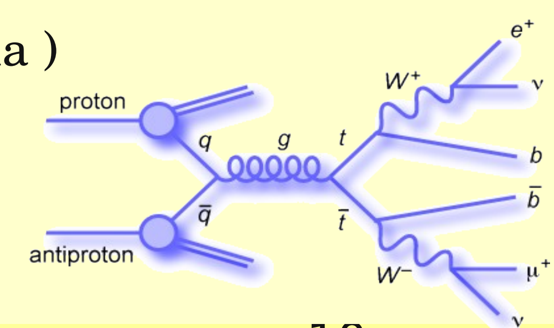


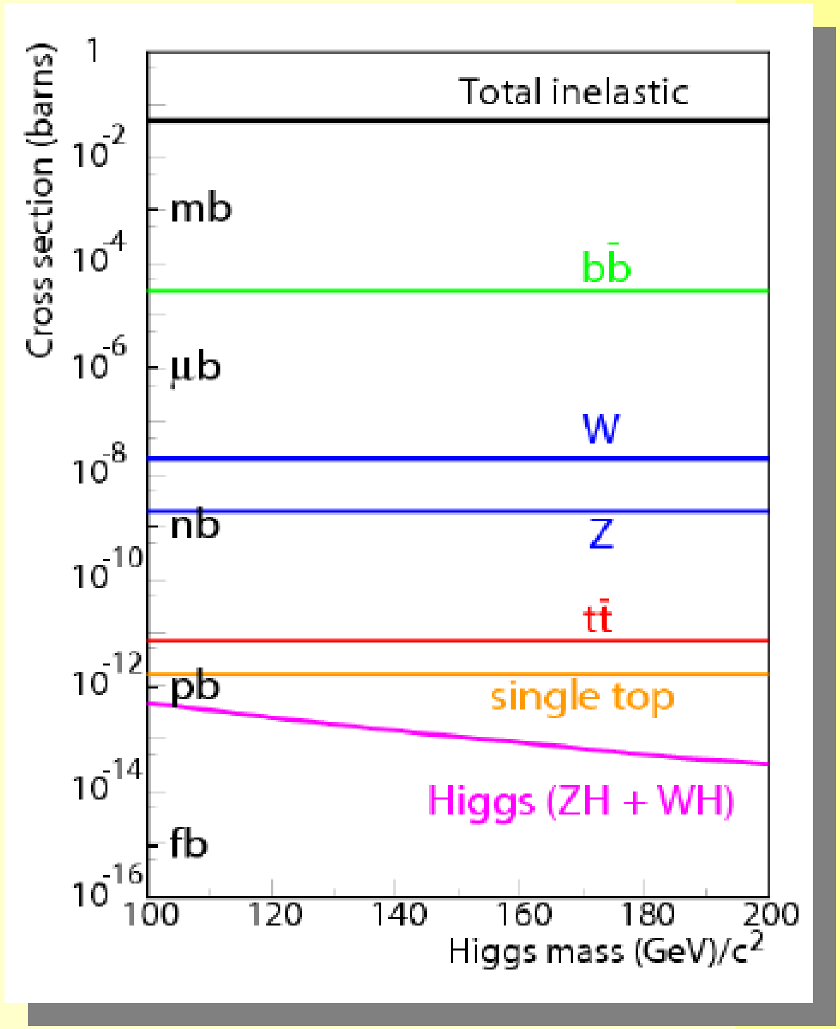
Physics

- **V+jets :** W/Z+jets *(fake b-jets),* W/Z+b(c)
- Alpgen+Pythia
- Normalised to data



- **Top :** single & pairs (CompHEP)
- **Di-bosons:** VV (Pythia)





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Backgrounds (II)

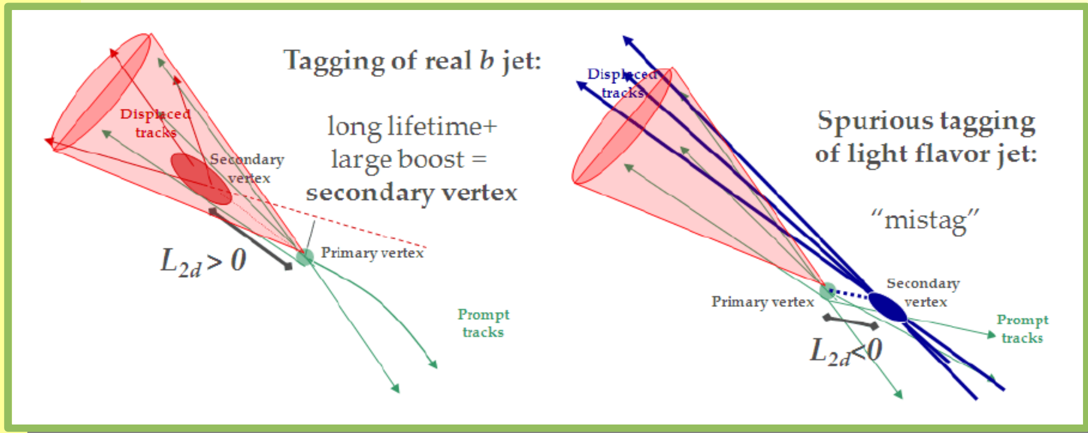
After QCD reduction

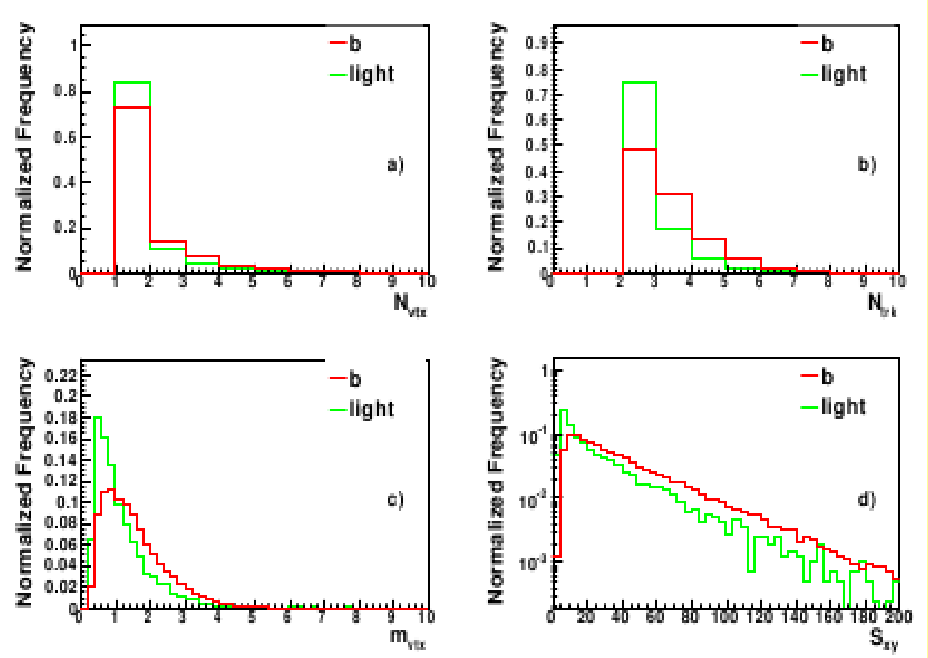
↳"V"+jets topology

- **B-identification**
  - Before identification: **S/B ~ 1/3000 !**
  - Reduces up-to 95% of light and c jets backgrounds
  - Increase sensitivity: split samples with **1 or 2** identified b-jets
- **Multivariate techniques**
  - Combine and improve individual discriminating observable
  - Output classifier used to set limits

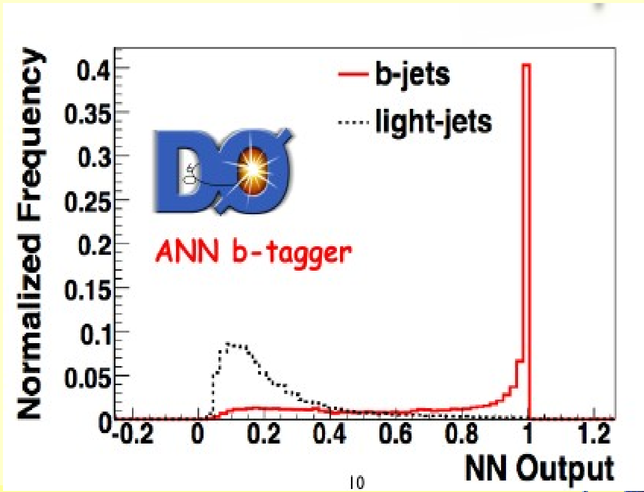
Heavy flavour identification (I)

Secondary vertices, Track Impact Parameter, Soft lepton





- Form Track-jets (simple-cone)
- Kalman filter to look for secondary vertices
  - Displaced
  - High track multiplicity
  - High mass, ...
  - **Efficiency:** ~50% b, ~0.5% mistags



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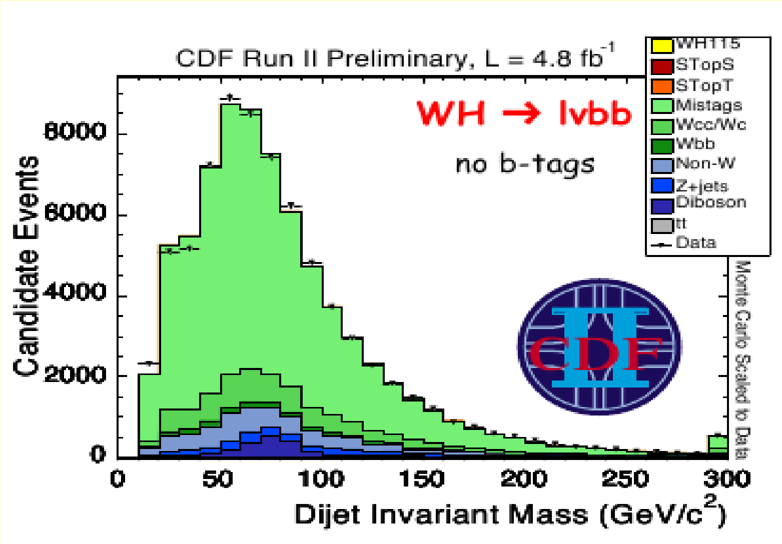
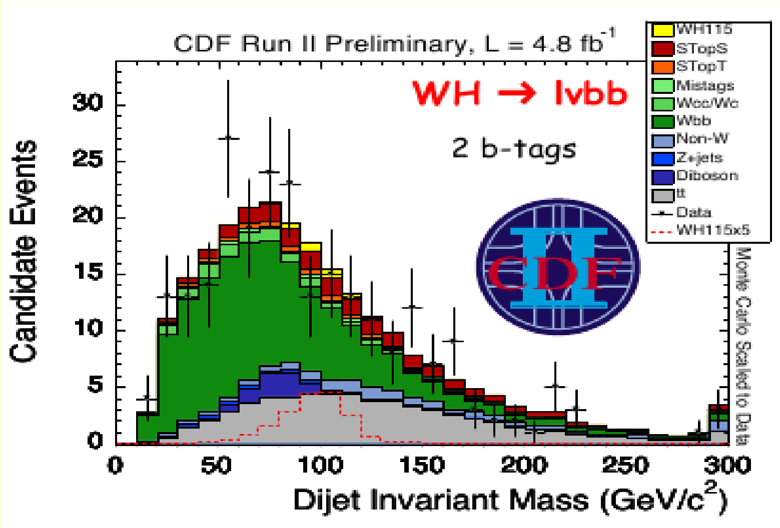
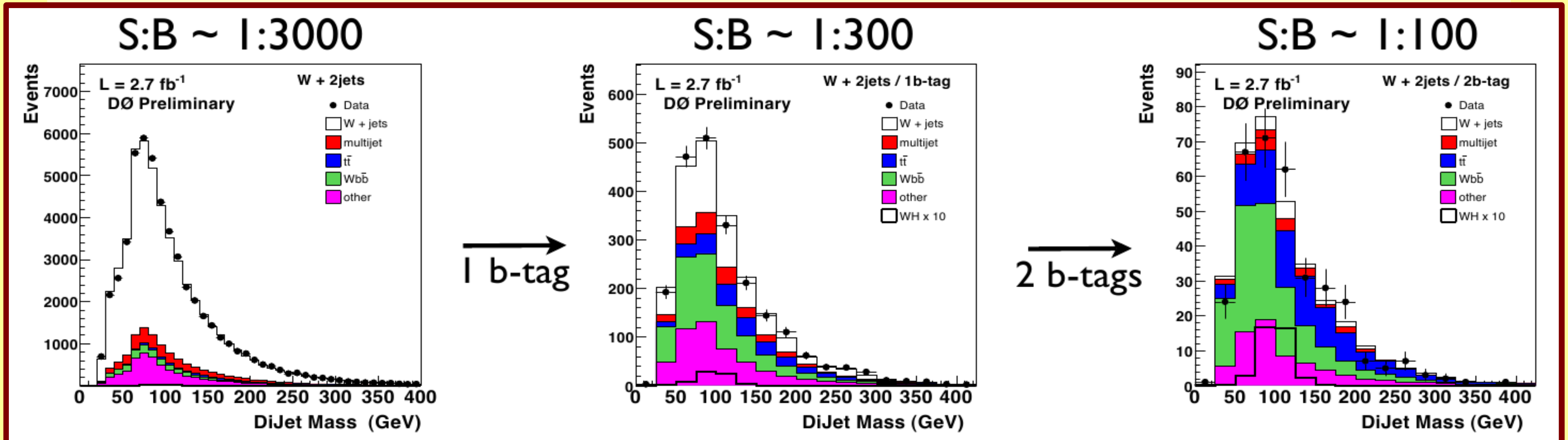
Heavy flavour identification (II)

Ex: WH-->lnubb







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Multivariate techniques

Most common methods

- Decision Trees (boosted, random forest, …)
- Matrix Element probabilities
- Artificial Neural Networks

$$P_{\mathrm{WH}}(x) = \frac{1}{\sigma} \underbrace{\sum_{i,j}}_{\text{Flavor}} \int_y \underbrace{f_i(q_1) f_j(q_2)}_{\text{PDF}} \times \underbrace{\frac{d\sigma_{\mathrm{WH}}}{dy}}_{\text{ME}} \times \underbrace{W(x,y)}_{\text{Detector Responce}}$$

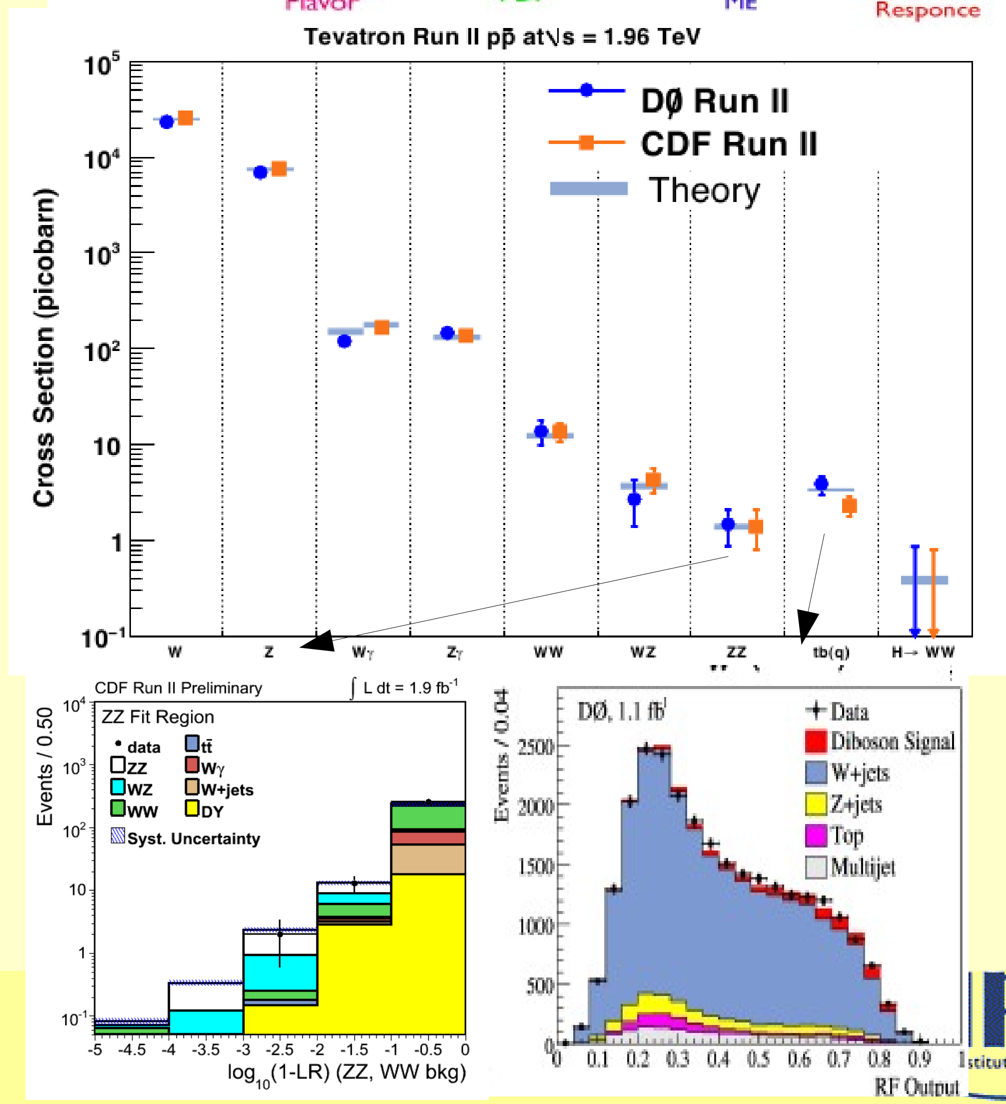
Proven utility

➥ **Single-top observation**

- Combined D0/CDF:

  http://arxiv.org/abs/0908.2171

➥ **VV → lνjj evidence/obs.**



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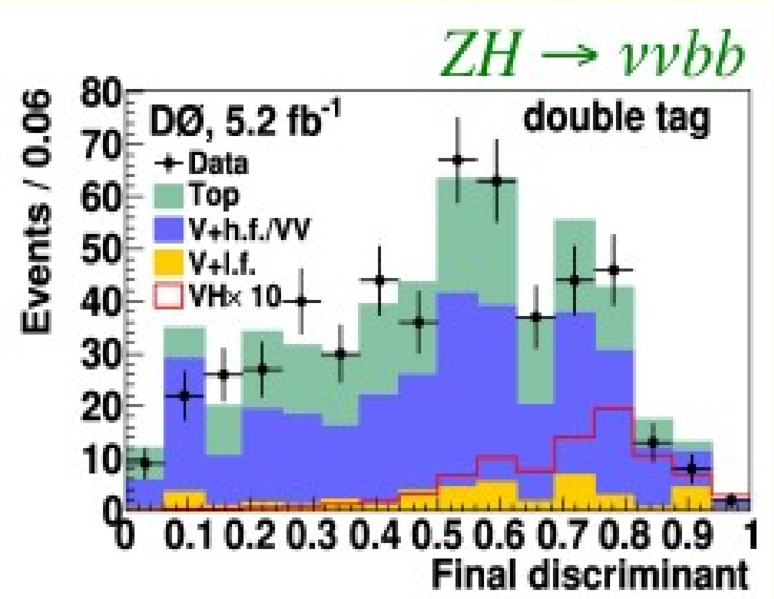
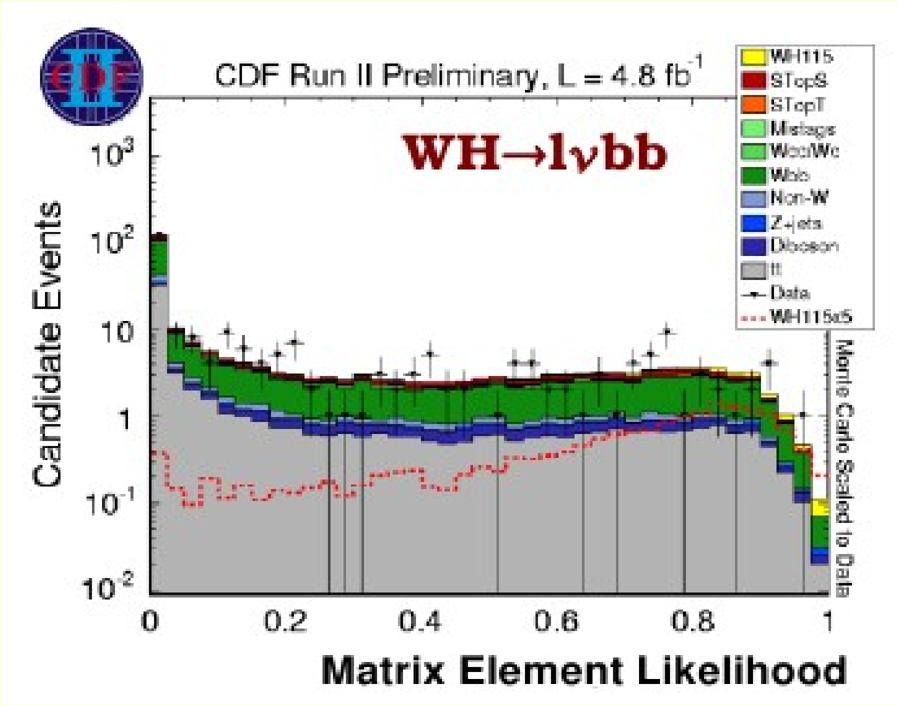
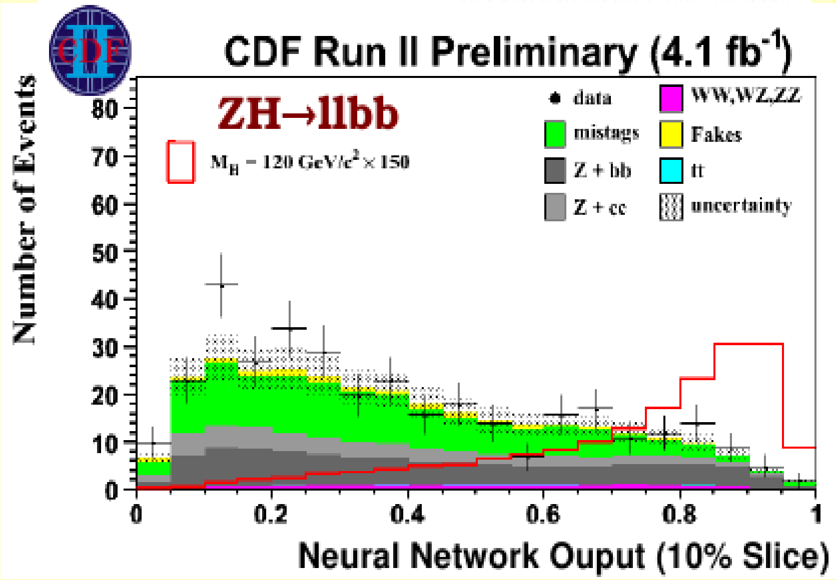
Multivariate techniques

Examples

- **Dijet mass:** S/B ~ 1/100
- **1/10 – 1/50** with MV techniques







Low-mass Higgs results

Limits expressed as ratio to SM cross section

Obs. (Exp) 95% CL upper limits / SM @ M_H = 115 GeV/c^2		
Channel	CDF II	DØ
$WH \to l^{\pm}\nu\, bb$	4.3 (3.8) in 4.3 fb^{-1}	6.9 (5.1) in 5.0 fb^{-1}
$VH \to \nu\nu\, bb$	6.1 (4.2) in 3.6 fb^{-1}	3.7 (4.6) in 5.2 fb^{-1}
$ZH \to l^+l^-\, bb$	5.9 (6.8) in 4.1 fb^{-1}	9.1 (8.0) in 4.2 fb^{-1}

Also using low-sensitivity channels

- diphoton, tau, ttH, ...
- Sensitivities **~ 40-60 SM**

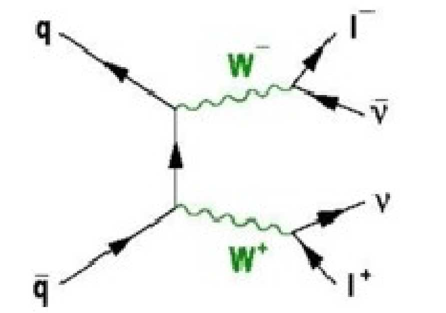
gg→H→WW

Cross section

- H --> WW --> lnulnu ~ **0.04pb** @ 160 GeV

  (6% of WW decays)

- Associated production & VBF: +35% signal

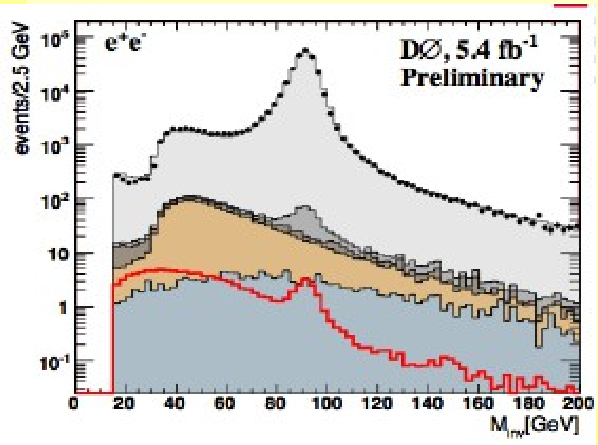


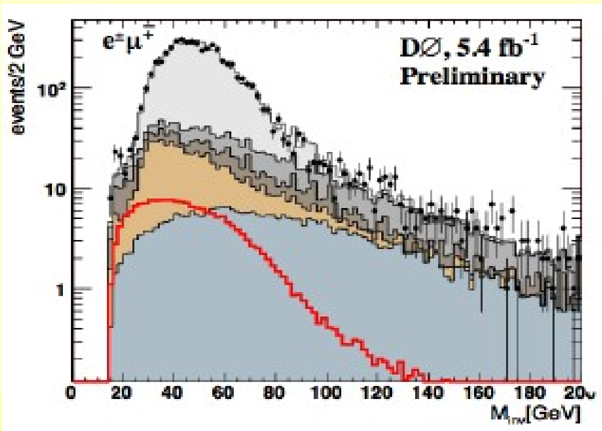
Di-Boson
WW: σ×BR = 13 pb
WZ: σ×BR = 4.0 pb
ZZ: σ×BR = 1.5 pb

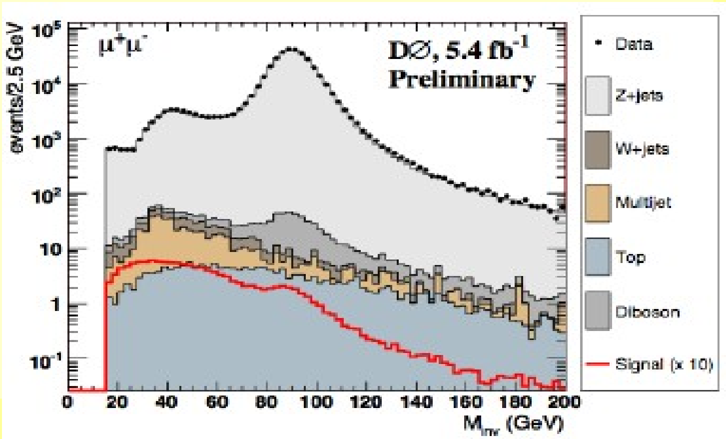
Other Backgrounds
ttbar: σ×BR =7 pb
single top: σ×BR = 3 pb

Topology

- 2 high pt isolated leptons and high missing Et
- Split in 3 channels: ee, mumu, emu



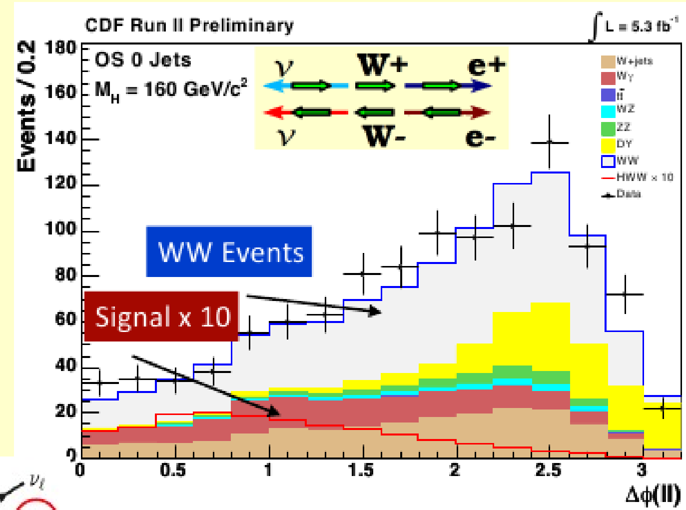


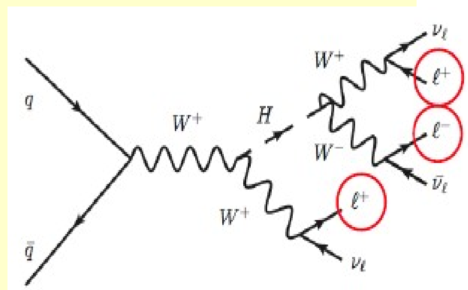


gg→H→WW

Spin correlations

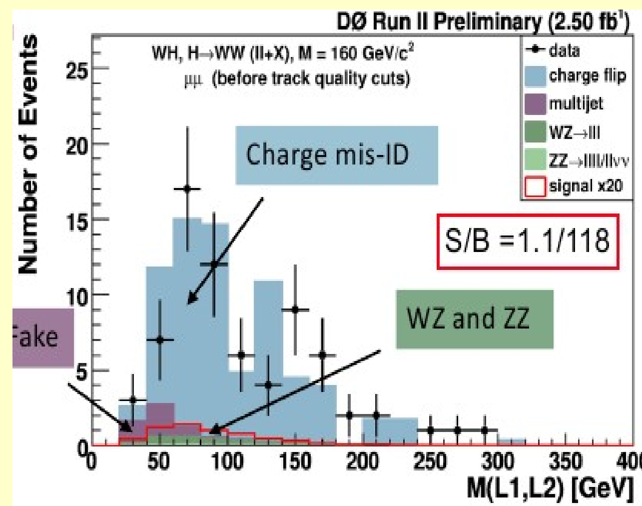
- Higgs is scalar !
- Correlations transmitted to decay products
  ↳ look at lepton angular correlations
- s/√b ~ 0.06 --> MV discriminant

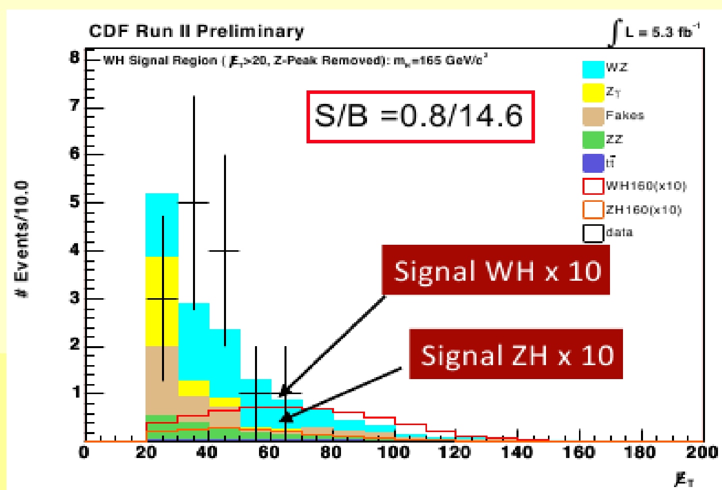




Additional acceptance

- **Same Sign** lepton from VH
- Low physics background but difficult instrumental one





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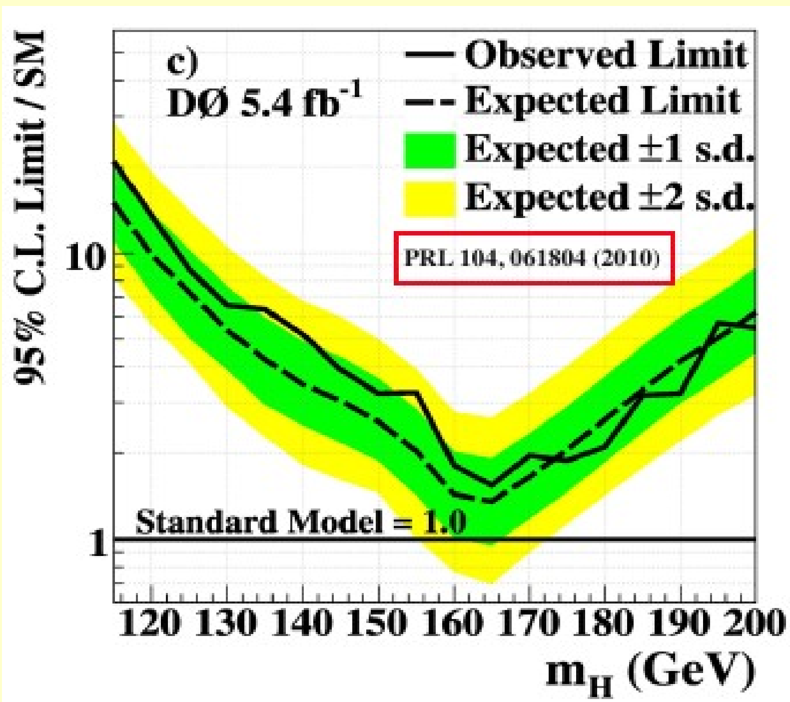
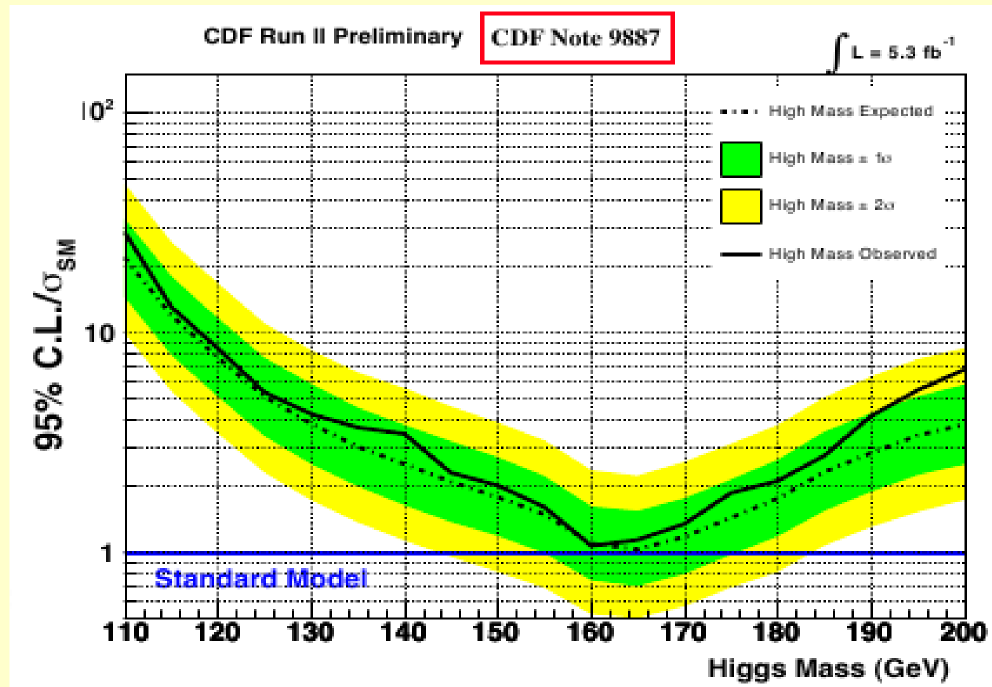
Results

Reaching SM sensitivity for each experiment independently !

$\sigma_{95} = 1.36 \cdot \sigma_{SM}(H)$ at $M_H = 165$ GeV (exp)
$\sigma_{95} = 1.55 \cdot \sigma_{SM}(H)$ at $M_H = 165$ GeV (obs)

$\sigma_{95} = 1.03 \cdot \sigma_{SM}(H)$ at $M_H = 165$ GeV (exp)
$\sigma_{95} = 1.13 \cdot \sigma_{SM}(H)$ at $M_H = 165$ GeV (obs)





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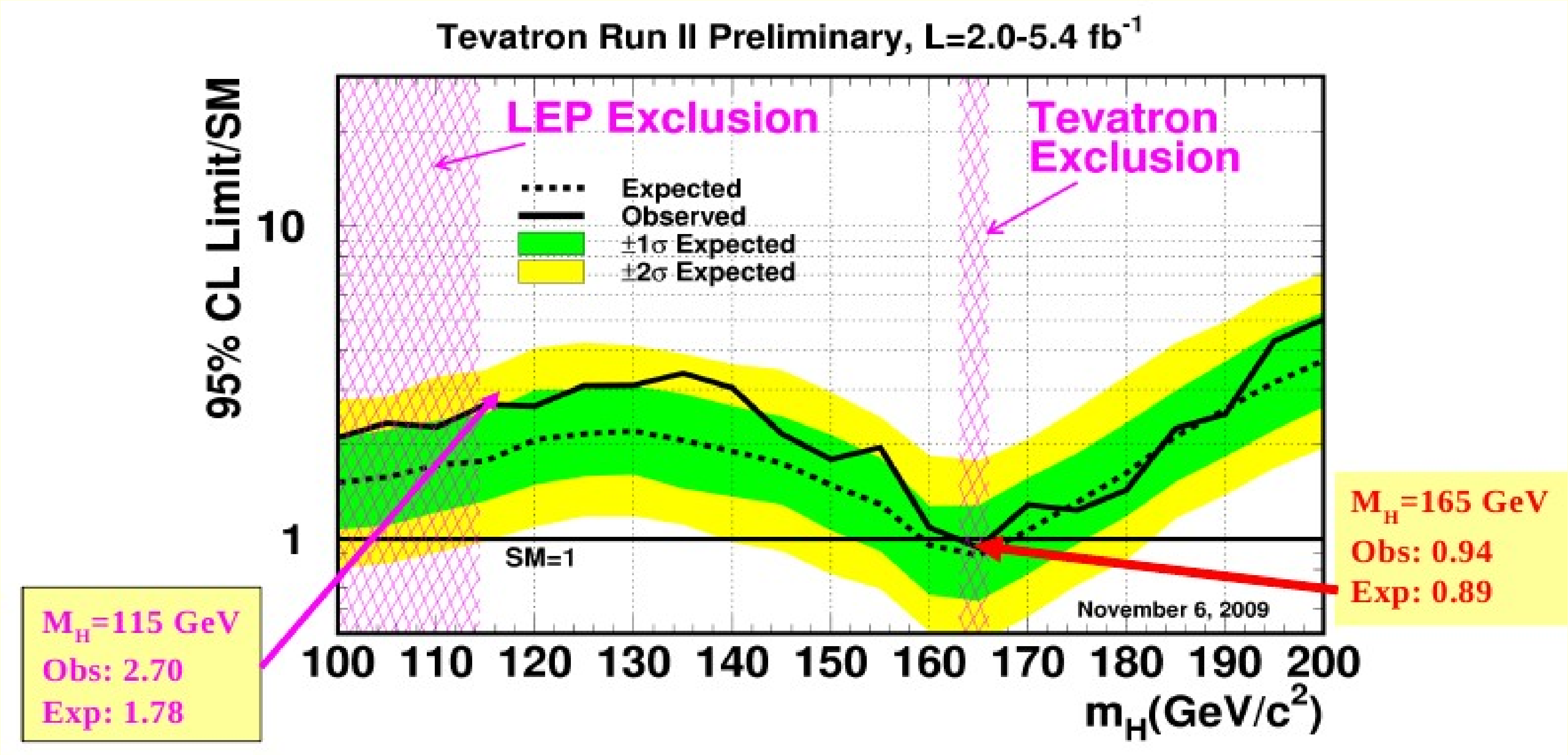
Tevatron Combination

Maximize sensitivity: combine experiments

- **H →WW:** first joint D0/CDF SM Higgs search paper, *PRL 104 061802 2010*
- **Exclusion:** $162 < m_H < 166$ GeV @ 95% C.L



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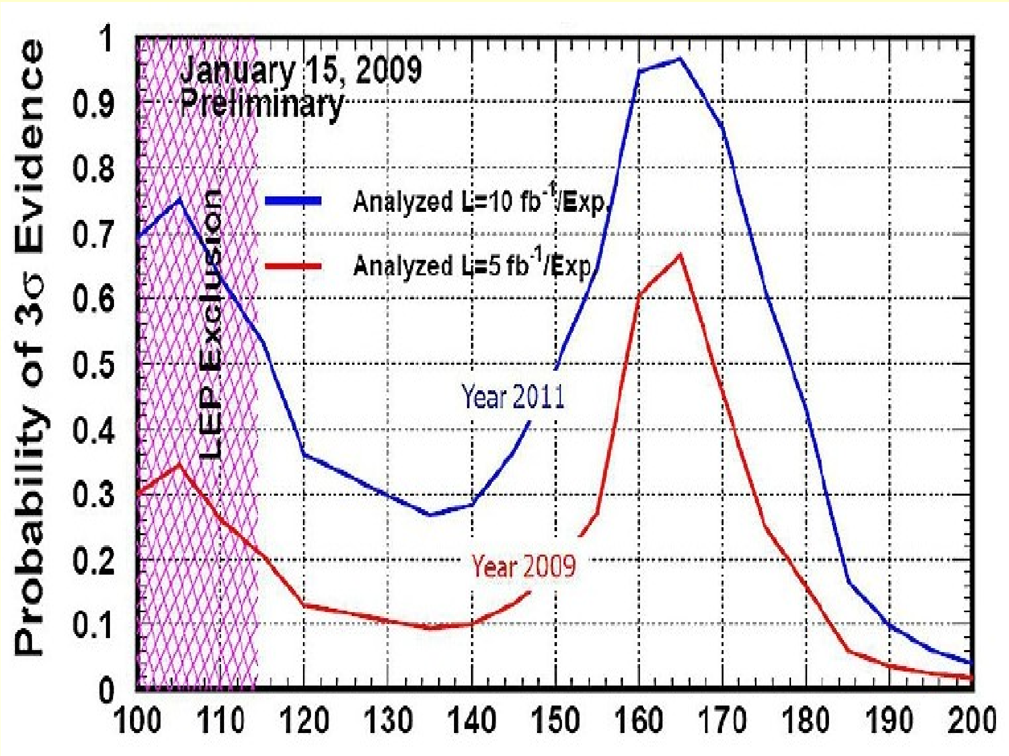
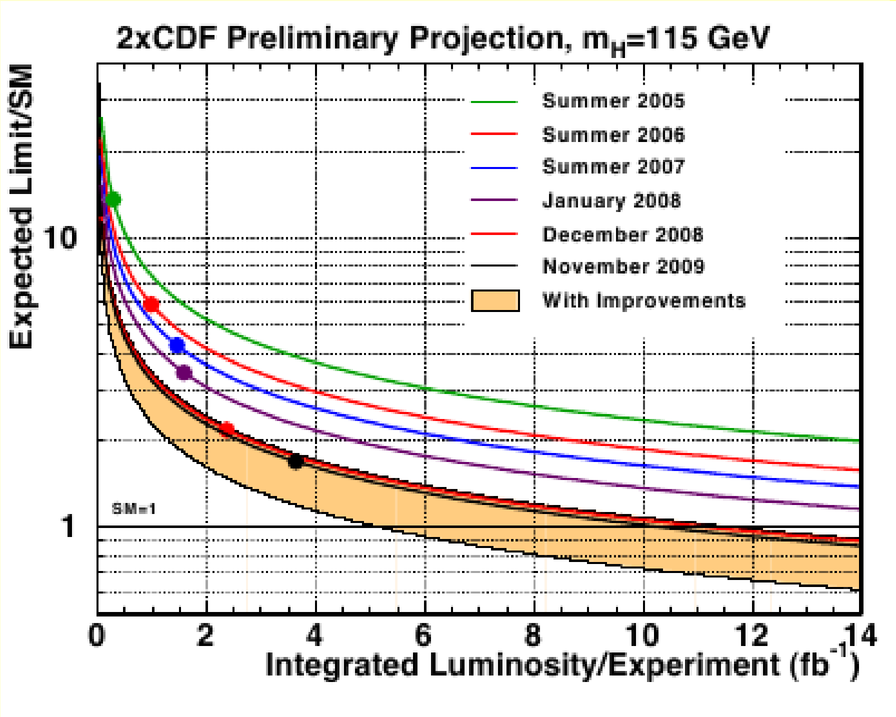
Prospects

Reminder: 10-12fb^{-1} expected !





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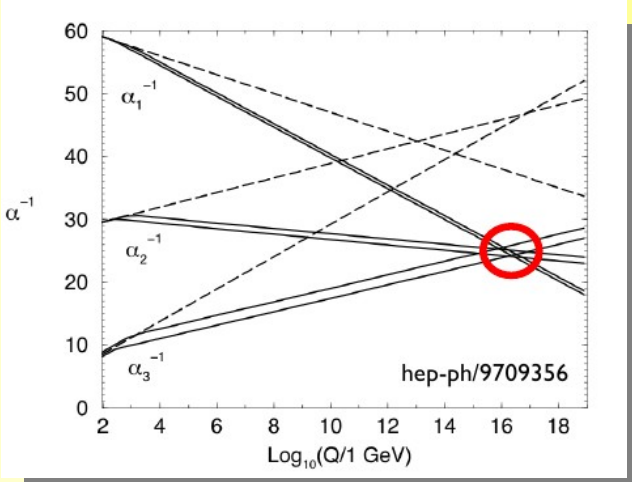
BSM Higgs Searches

Introduction

Despite of success, SM faces theoretical difficulties



SUSY

- Solves hierarchy, unification of gauge couplings, LSP ...

↳ **Enriched Higgs sector !**

  - At least 2 Higgs doublets
  - Large parameter space

    ↳ perform searches in more predictive models

Minimal Supersymmetric extension of SM (MSSM)

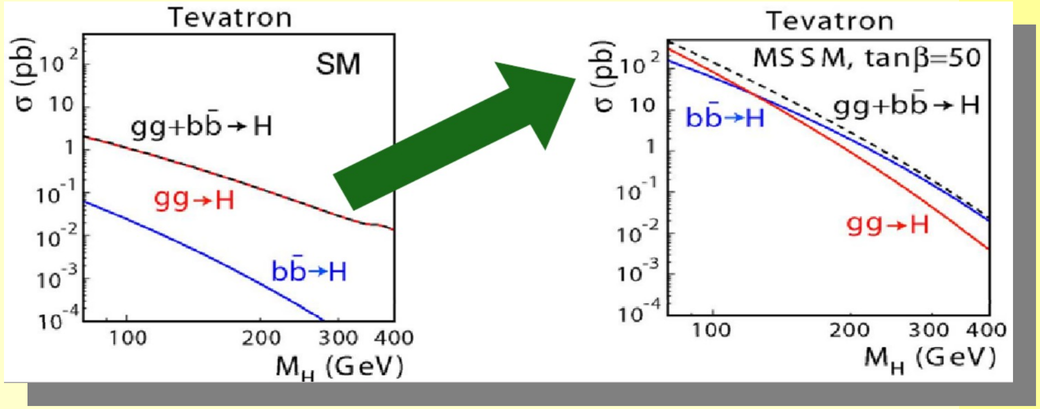
- **exactly 2 doublets** coupling to down-type and up-type fermions
- **After symmetry breaking, 5 physical states:**
  - 3 neutrals, **h** / **H** (both CP-even), **A** (CP-odd) → Φ
  - 2 charged Higgs **$H^{\pm}$**

MSSM Higgs

At tree level Higgs sector described by 2 parameters

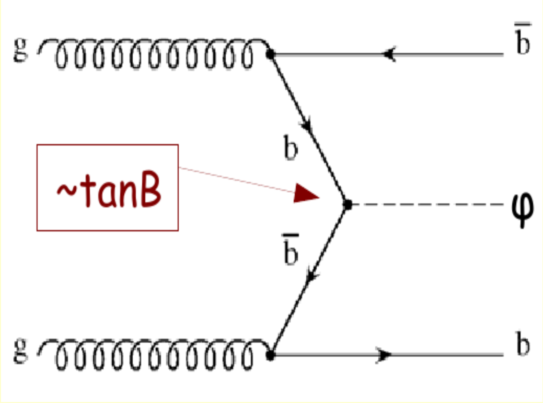
(other enter via loop corrections)

- m_A
- $\tan\beta$ = ratio of **vev** of each doublet

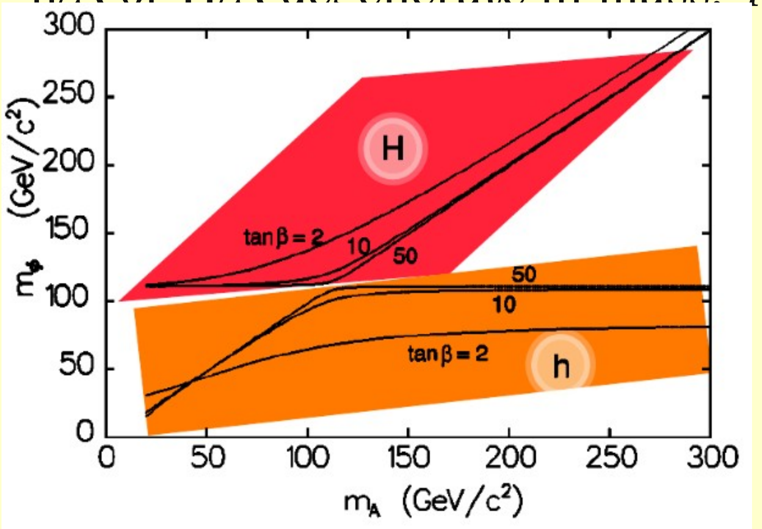


Large $\tan\beta$ regime:

- Coupling to b quarks **enhanced by $\tan\beta$** w.r.t SM *(production by $\tan^2\beta$)*



- h/A or H/A degenerate in mass, Φ



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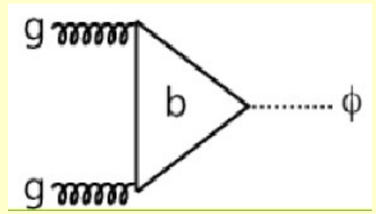
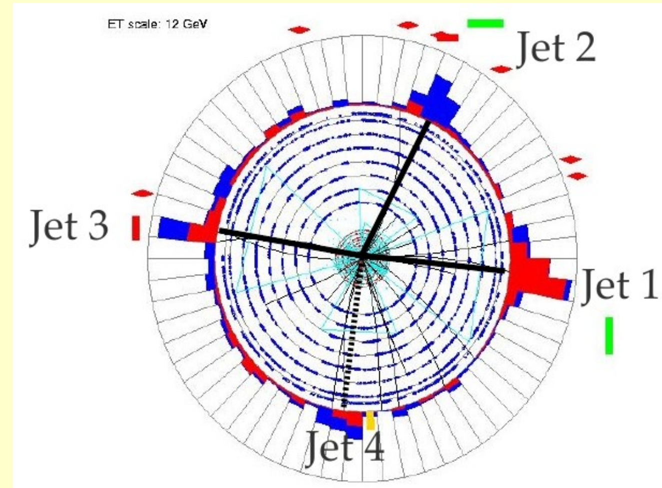
MSSM channels

Search channels

- BR($\Phi \rightarrow bb/\tau\tau$) ~ 90/10%





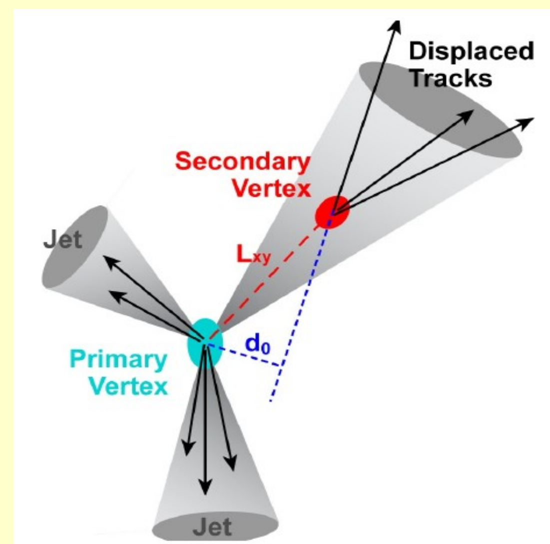
$\Phi \rightarrow \tau\tau$

- 2 production mechanism can be probed

$\Phi \rightarrow bb$

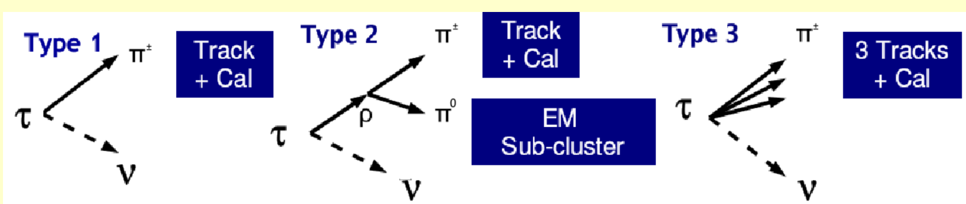
- Overwhelming multijet heavy flavour background

↳ **associated production bb → $\Phi \rightarrow$ bbb(b)**



Highly performance tau and b identification tools

- Tau are split in 3 types; efficiency ~60% tau, 1% jets



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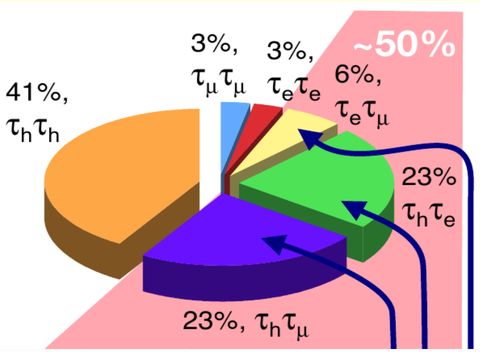
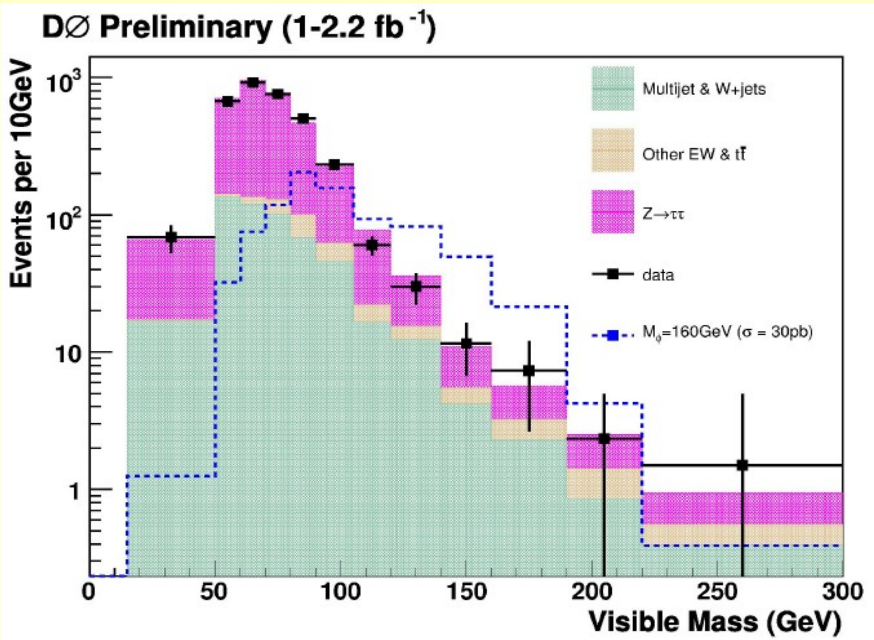
$\Phi \to \tau\tau$

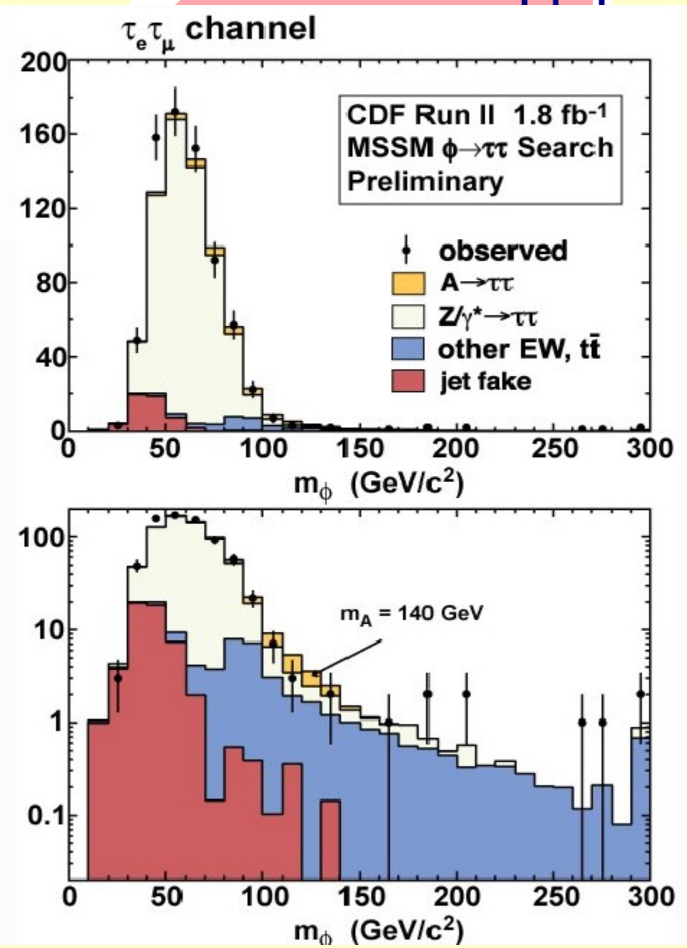
Low BR but clean signature

- **3 channels:** ee, mumu, emu
- **Signal:** 90-300 in 10 GeV bins
- **Main background:** Drell-Yann $\tau\tau$ (irreducible)
- **Final discriminant:** visible mass

$$m_{\rm vis} = \sqrt{(p^{\tau_1} + p^{\tau_2} + \not\!\!E_{\rm T})^2}$$







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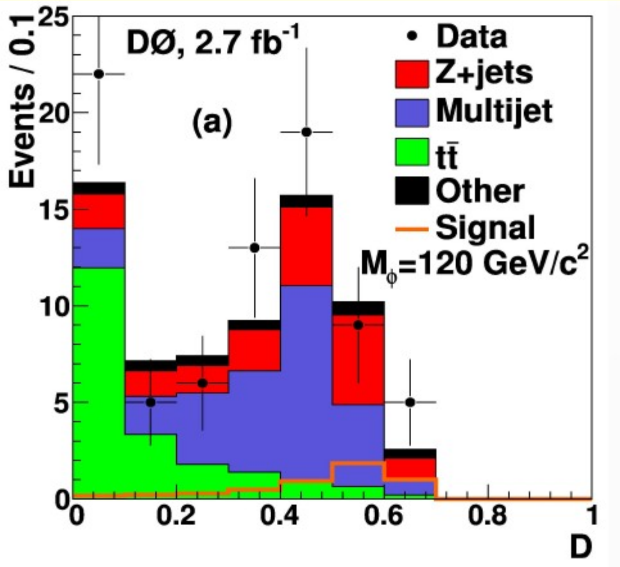
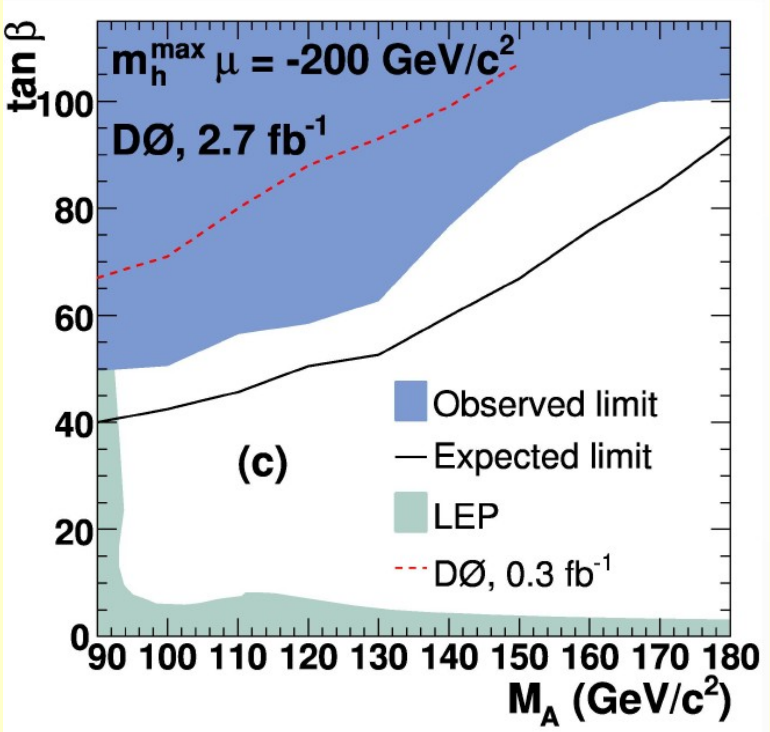
$\Phi \rightarrow \tau\tau + b$

Lower cross-section/branching ratio than bbb

- But <u>cleaner</u> signature, <u>orthogonal</u> to phi tautau
- Look for one isolated lepton + hadronic tau with opposite charge
  + 1 b-jet: high background suppression, increases signal sensitivity
- **Main backgrounds:** Z+jet, multijet and tt
- **Final discriminant:**
  Neural-Net against tt and LH against multijet: D = NN x LH





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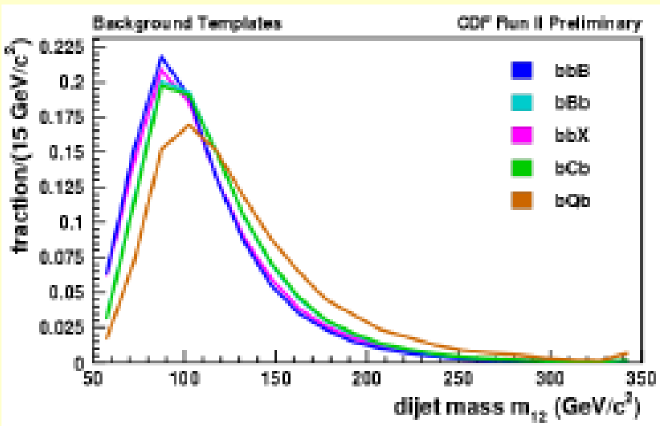
$\Phi \rightarrow$ bb + b

Look for peak in invariant di-jet mass spectrum

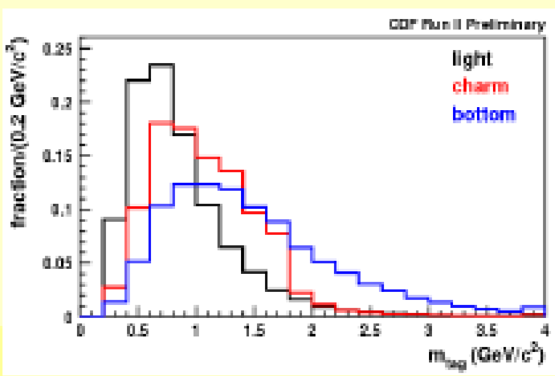
- **Challenging backgrounds:** heavy-flavour multijet *(bbb, bbc, …)*
  ➥ use *data-driven* methods

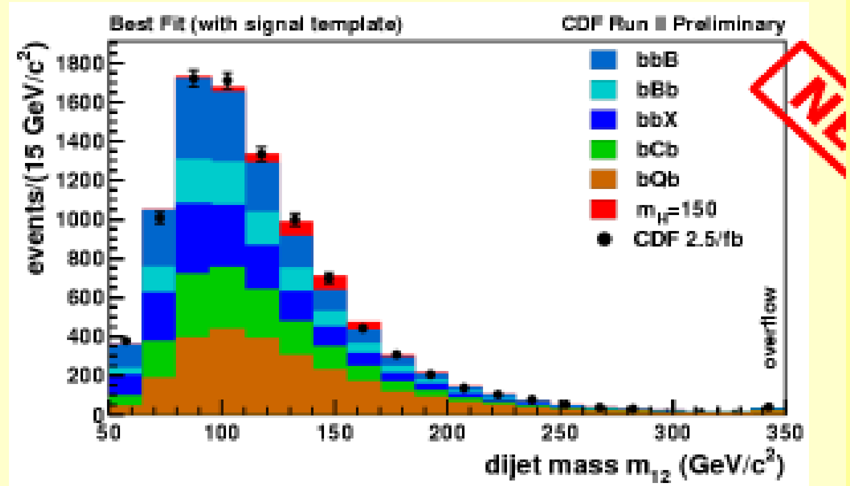
- Updated analysis from CDF:

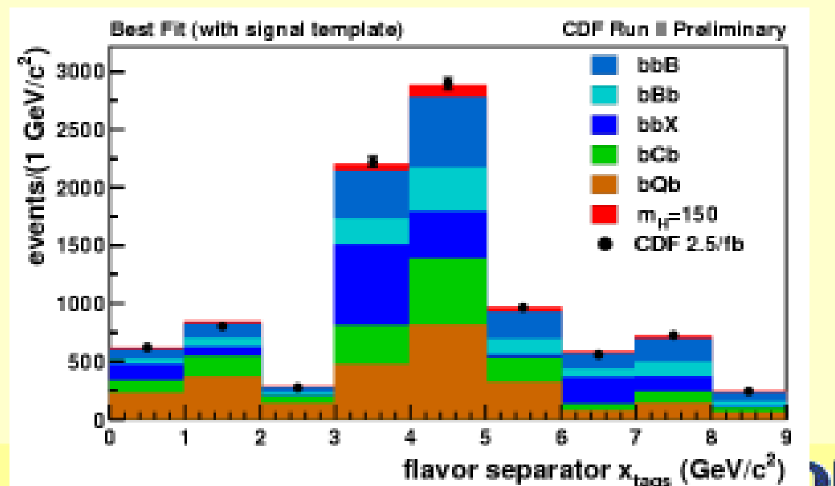
Di-jet mass



+ tag information





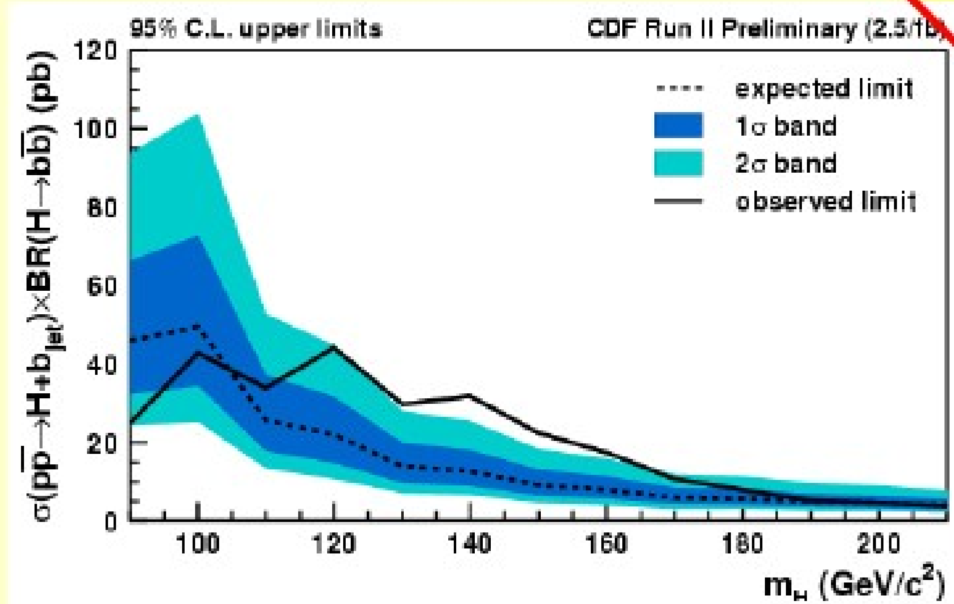


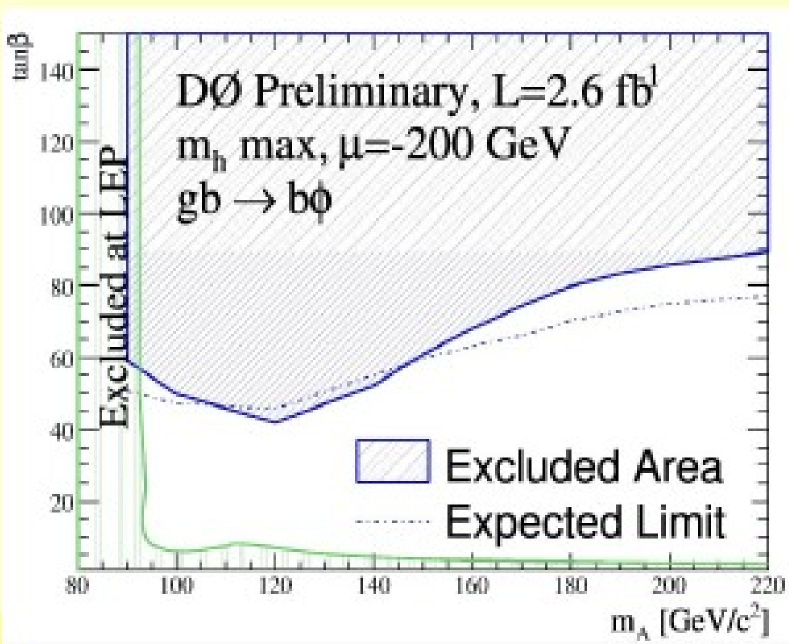
bΦ → bb + b

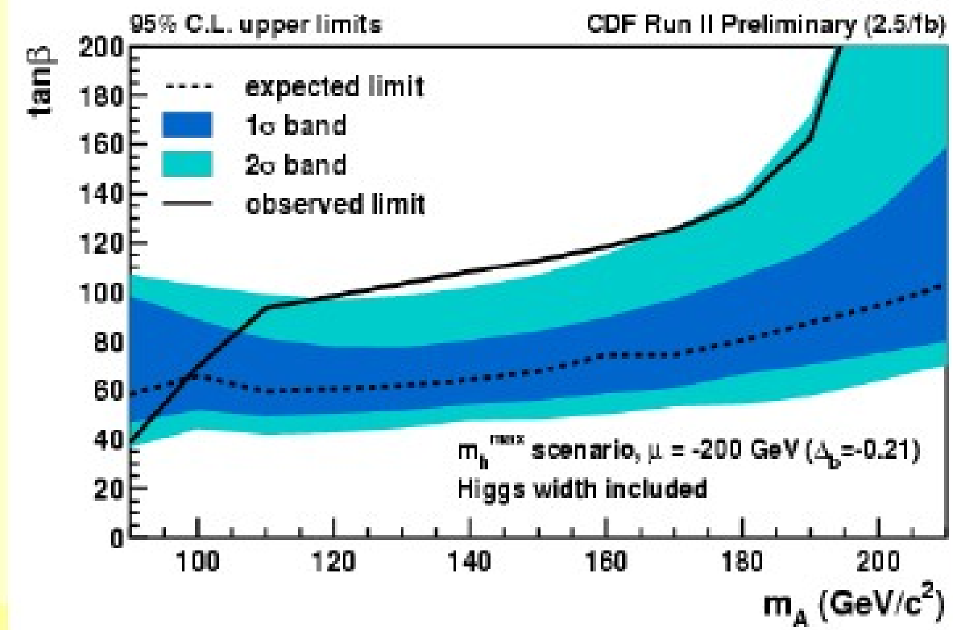
NEW

Exclusion limits at 95% C.L

- **Cross section:** exclude any *(narrow)* resonance + b
- In MSSM parameter space, increased width at high tan beta
  (see back-up slides for other scenarios)







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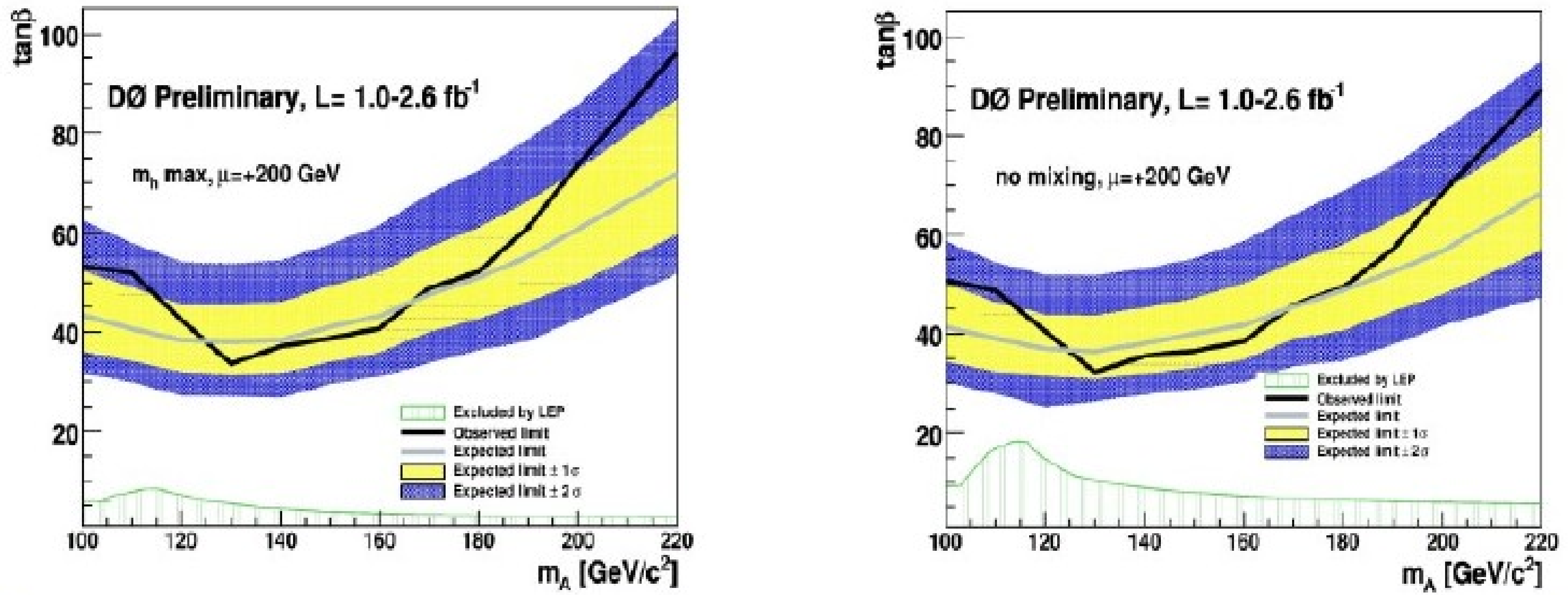
Tevatron MSSM Combination

D0 combination across channels

- $\Phi \rightarrow \tau\tau$ *(2.2fb^{-1})*, b$\Phi \rightarrow$ b$\tau\tau$ *(1.2fb^{-1})*, b$\Phi \rightarrow$bbb *(2.6fb^{-1})*
- Same toolbox as SM combination
- Expect new Tevatron all channels combination *by this summer*



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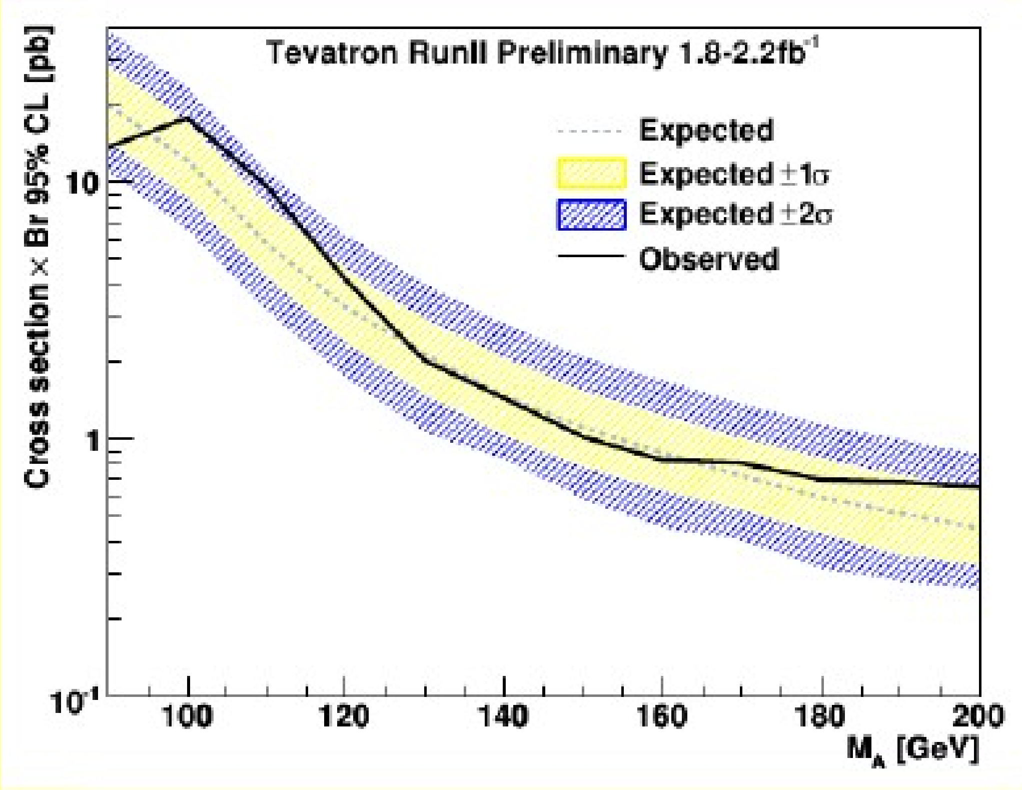
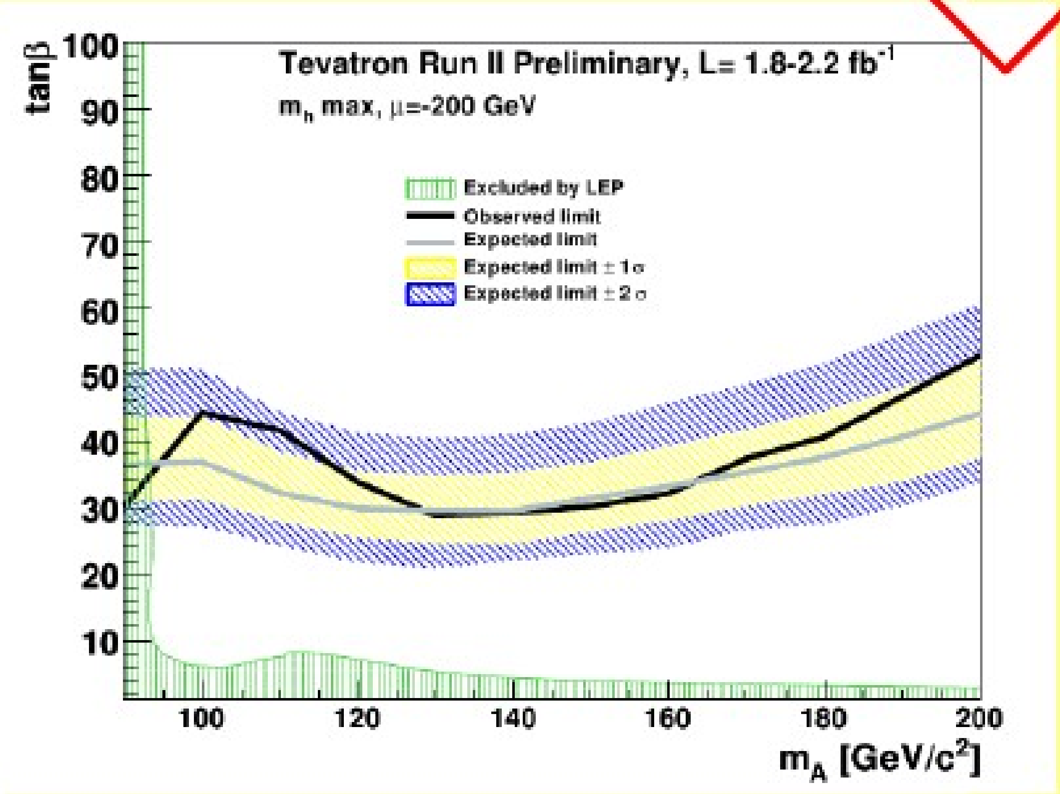
Tevatron MSSM Combination

$\Phi \rightarrow \tau\tau$ update

- Improved theory interpretation
- Similar sensitivity to D0 all channels
- **tanβ > 30-50** excluded for m_A up-to 200 GeV/c^2

NEW





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Exploring low tanβ: charged Higgs, $H^{\pm}$

If and $m_H < m_{top}$: search for H in top decays

Two models:

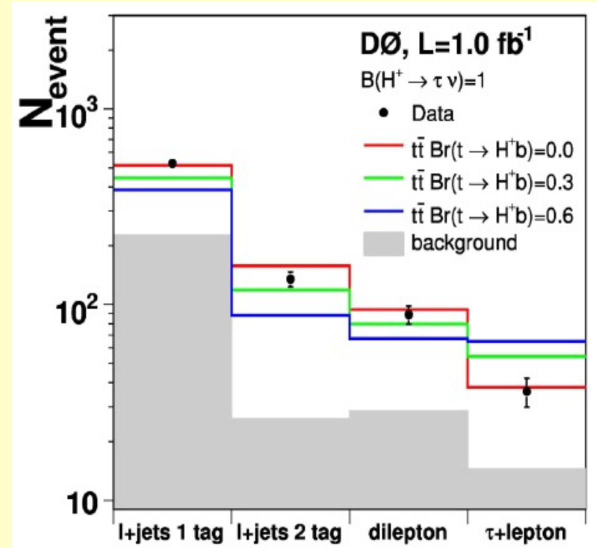
- **Tauonic:** H → taunu & **Leptophobic:** H → cs

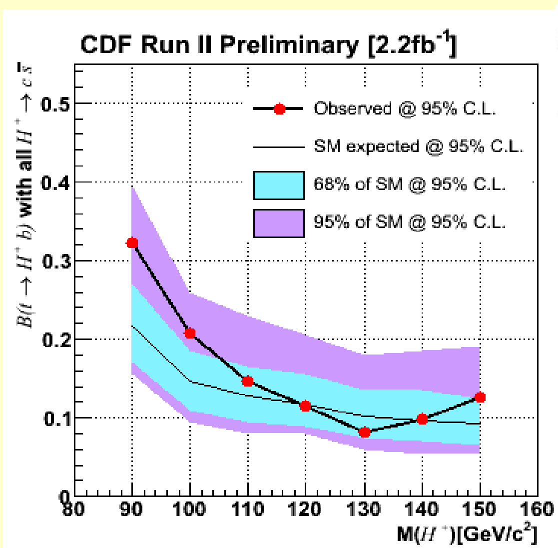
Search dilepton, lepton+jets, lepton+tau top channels

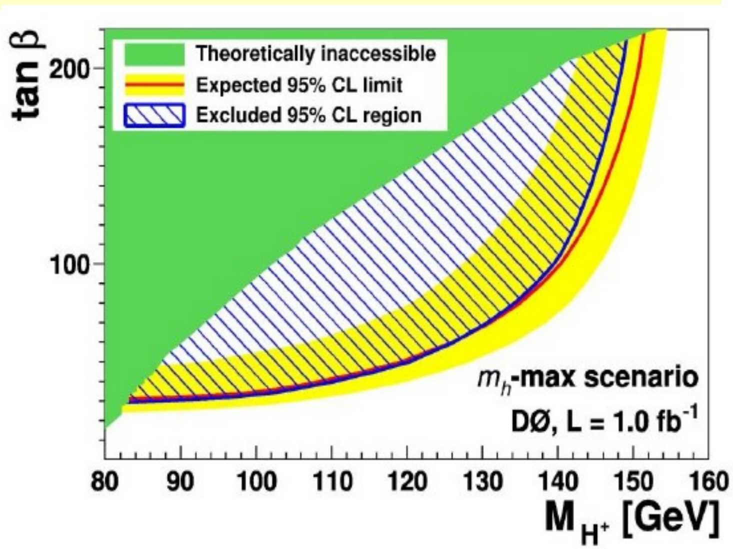
95% CL Limits on BR(t→H+b)

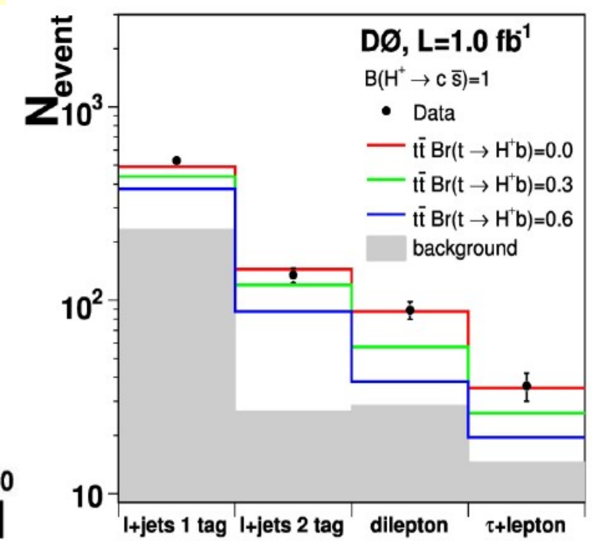
Phys. Lett. B 682, 278 (2009)

- Leptophobic > 0.22, Tauonic > 0.15-0.19









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Beyond MSSM: NMSSM Searches

MSSM m_h < 135 GeV & EW fits: < 154 GeV @ 95% C.L

- But LEP $m_{h\to bb}$ > 114.4 GeV ... *(> 82 GeV for any Higgs decay)*

NSSM: altered Higgs sector

- Two additional pseudo-scalar Higgs bosons (s and a)
  - $h \to aa$ dominates

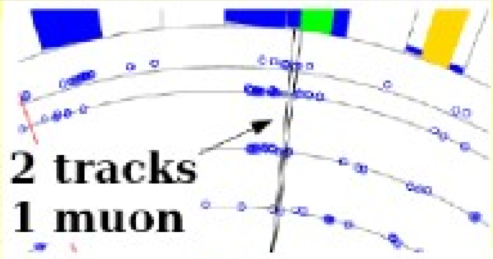
If $m_a < 2m_\tau$, dominant decay **$aa \to \mu\mu\mu\mu$**

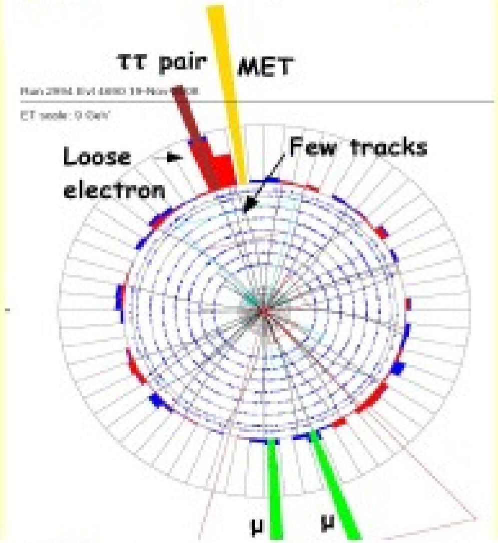
- **Backgrounds:** multijet, $Z\to\mu\mu$
- **Limits:** σ x BR < 5 -10 fb
- BR($a\to\mu\mu$) < 7% Limit m_h > 82 GeV

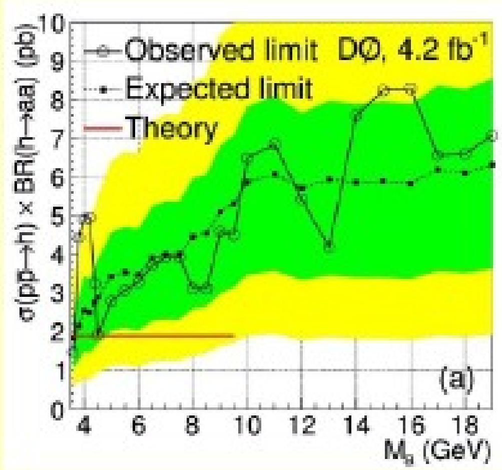
If $2m_\tau < m_a < 2m_b$, look for: **$aa \to \mu\mu\tau\tau$**

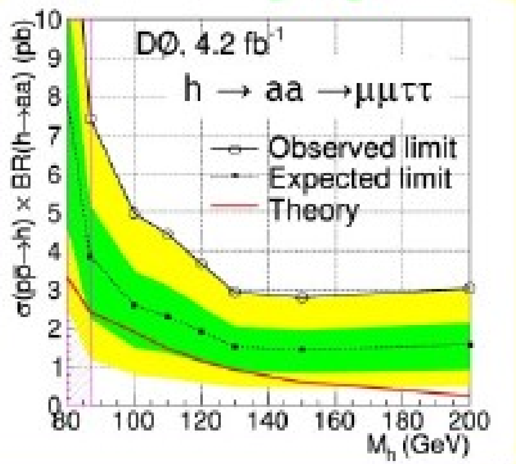
- **Backgrounds:** multijet, Z+jets, ...
- **Limits:** m_h > 86 GeV

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









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Susy Searches

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Introduction

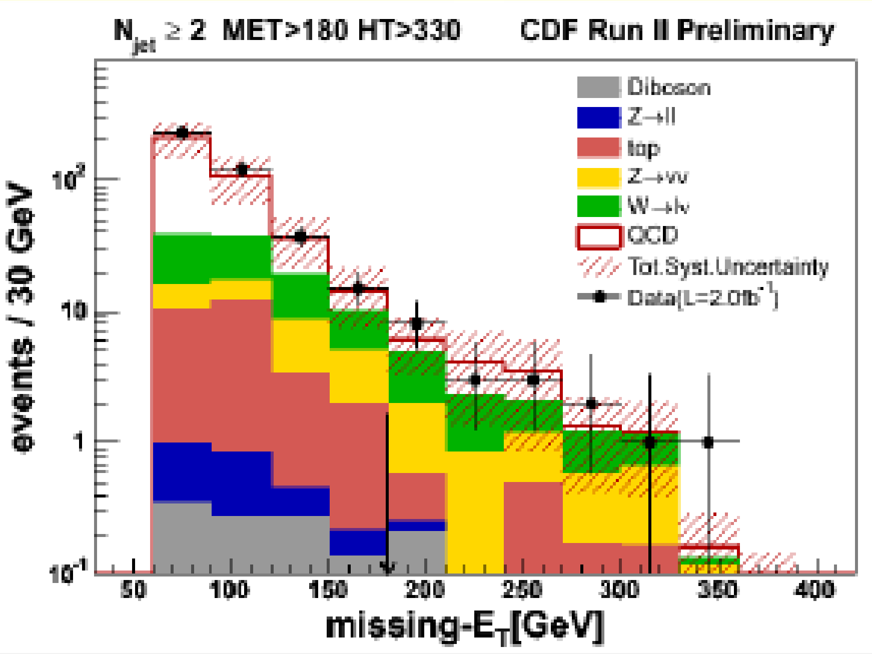
Searches at Tevatron assuming different breaking scenarios

- MSSM, mSUGRA, GMSB, ...

Typical signatures

- Jets and/or leptons + MET due to escaping lightest supersymmetric particle (LSP)
- e.g sgluinos/squarks in mSUGRA

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



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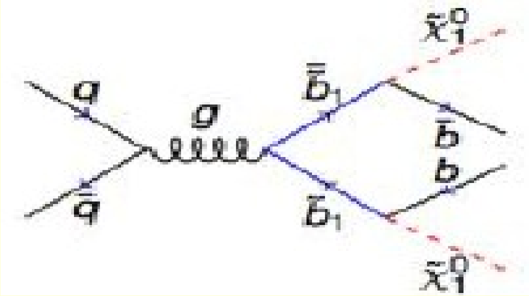
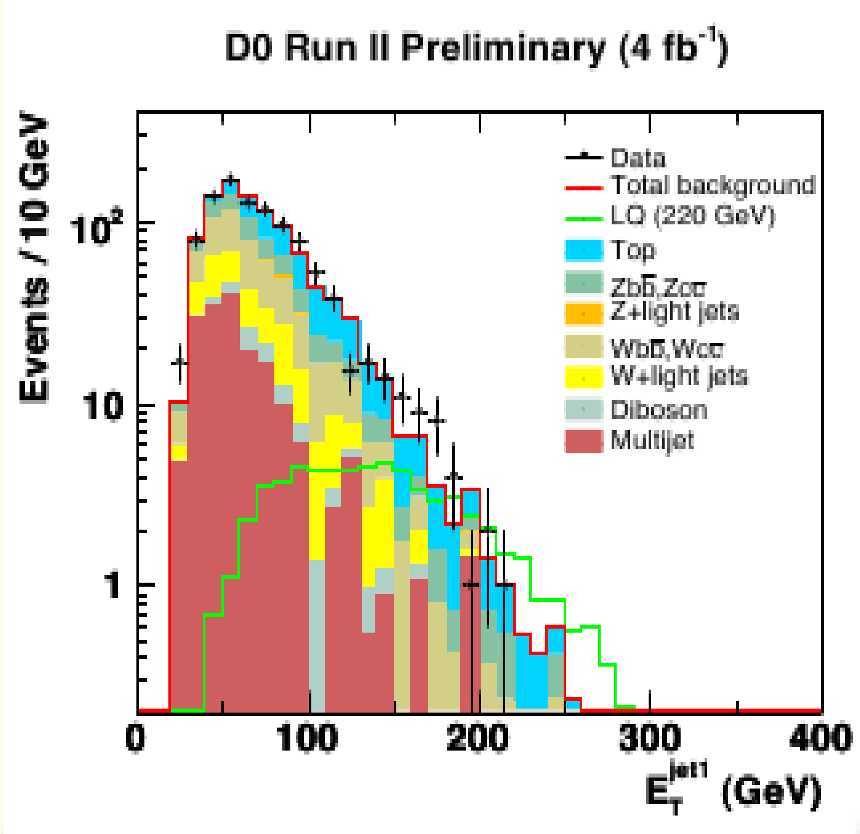
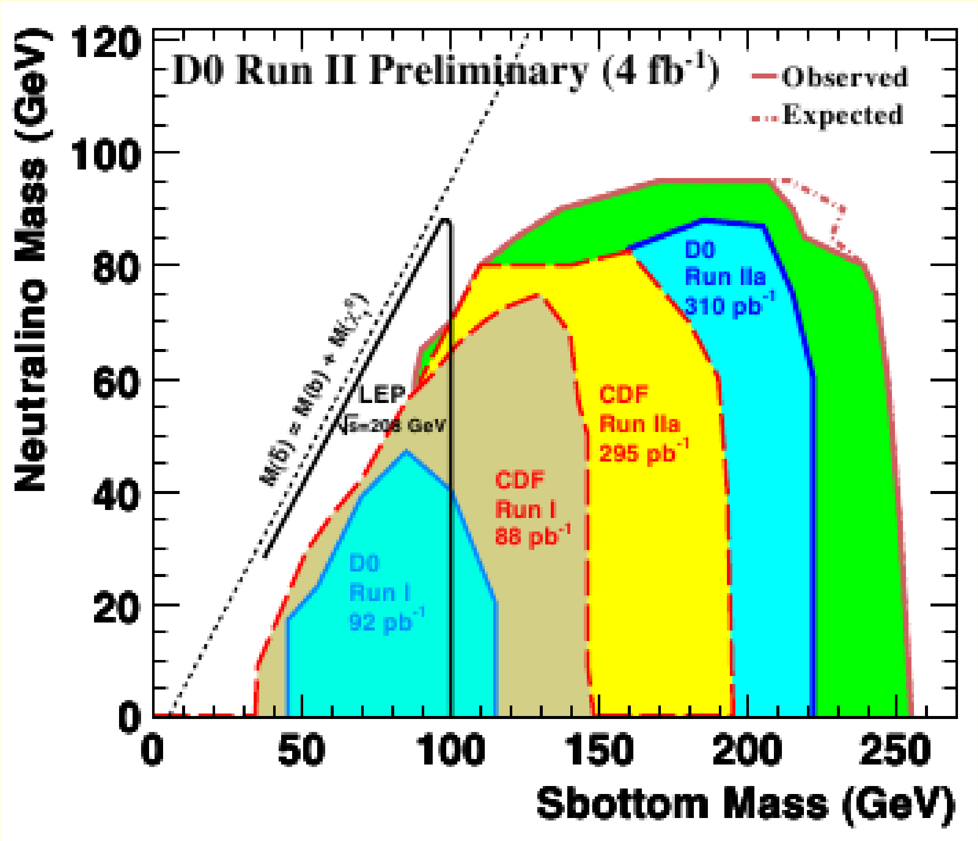
Sbottom pair production

MSSM

- BR(b1 -->$\tilde{\chi}_1$ $\tilde{b}$) = 100%
- Require at least 1 b-tagged jet







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Stop pair production

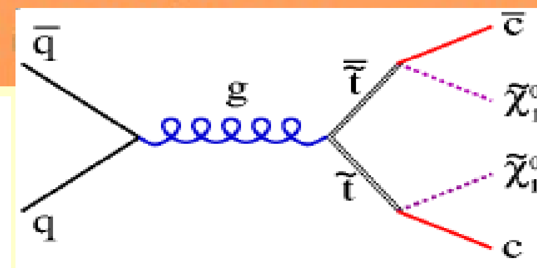
MSSM

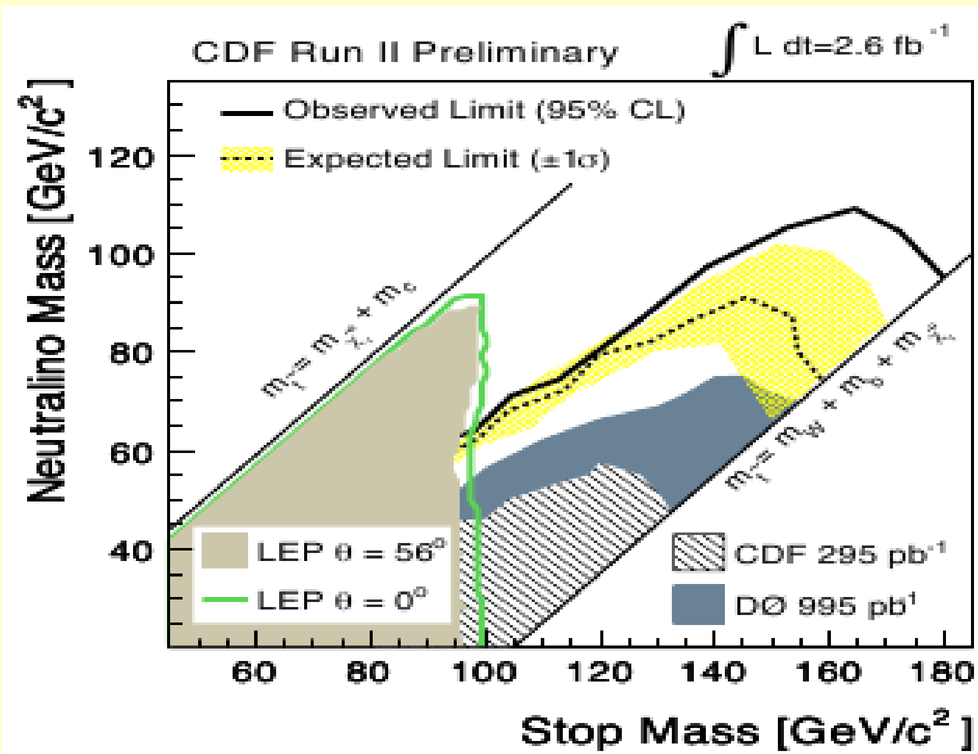
- QCD extracted from data
- Sensitivity optimised with NN

MSSM scenario with conserved R_p:

➠ $\tilde{t}_1$ is pair produced

➠ $BR(\tilde{t}_1 \to b\tilde{\nu}\ell^{\pm}) = 100\ \%$





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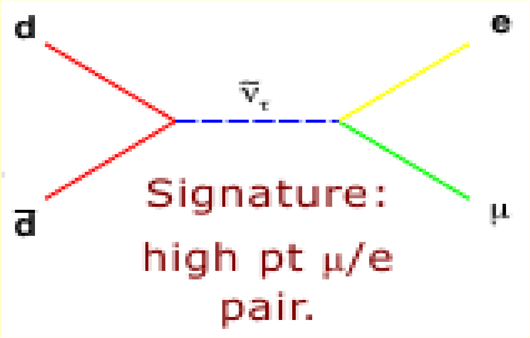
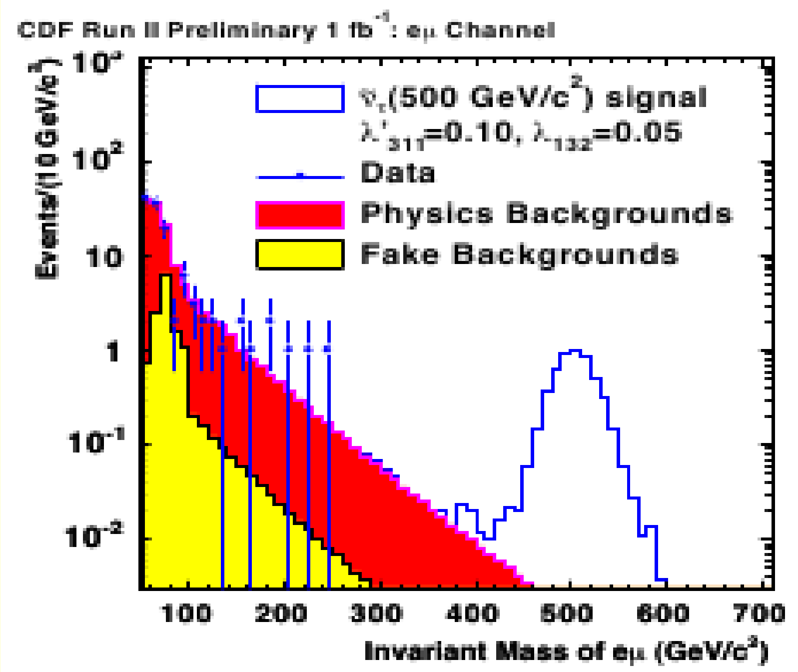
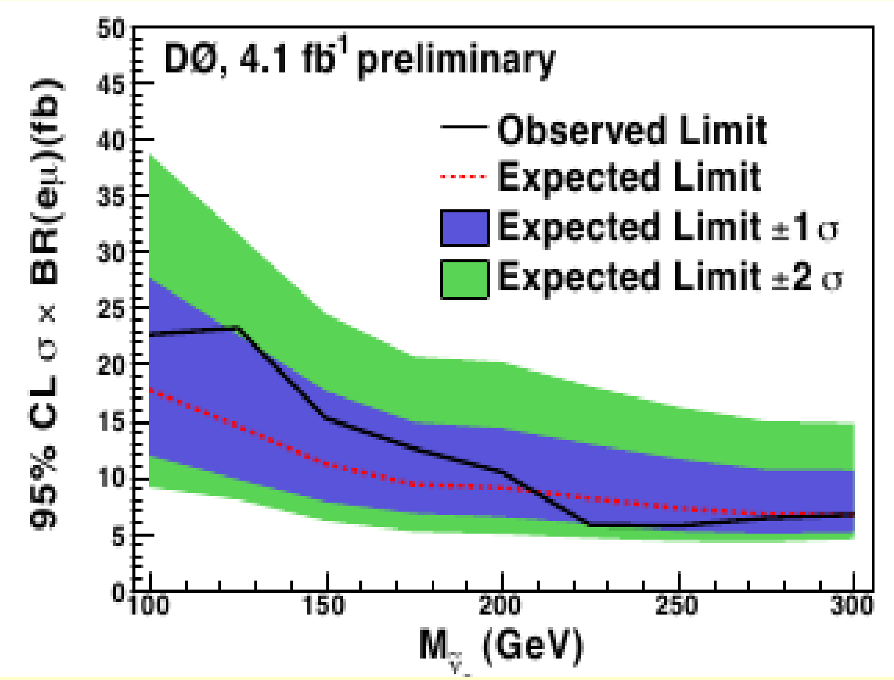
RPV Tau sneutrino

RPV violated scenario

- Tau sneutrino is LSP
- Lepton flavour violating channel
- Very clean signature







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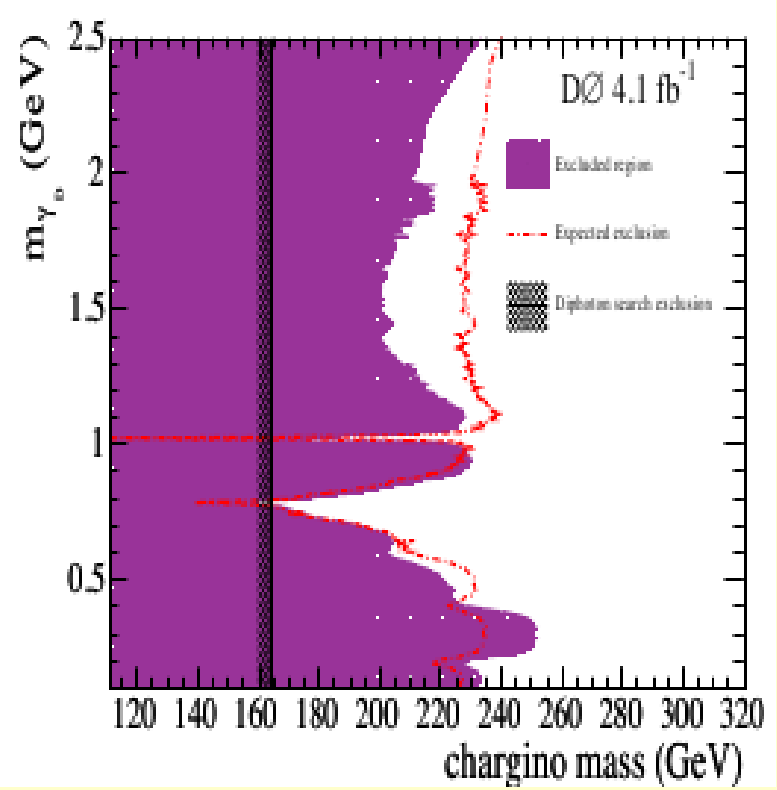
And …

Many other searches

- GMSB, diphoton
- Hidden Valley dark photon
- Chargino/neutralino (trilepton)
- …



Sparticles exclusions

- gluino/squark up to 390 GeV
- Light sbottom / stop up to 250 / 200 GeV
- Chargino / neutralino up to 150 GeV

~

Prospects & Conclusion

No evidence of (B)SM Higgs ... yet, but:

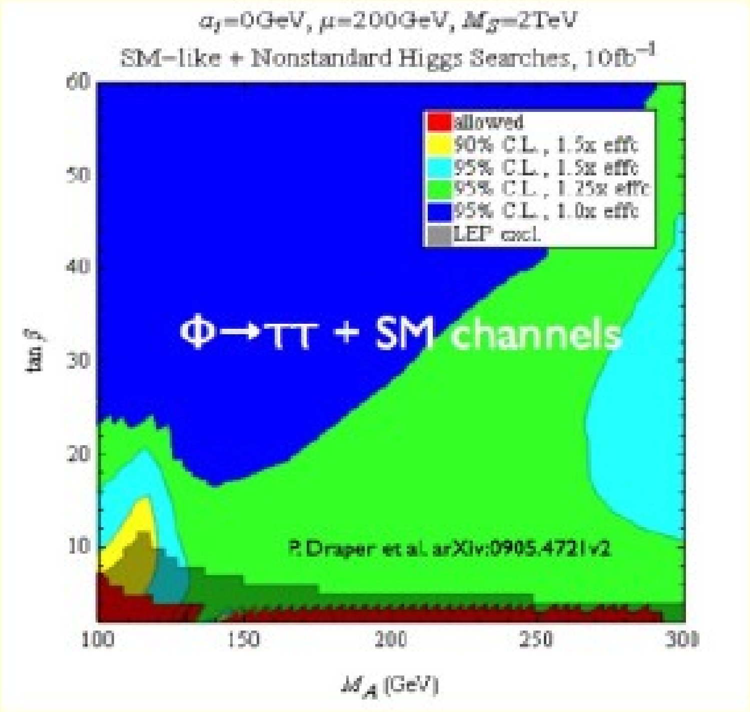
- Tevatron and experiments are performing very well
- Expect to deliver up to 10-12fb^{-1} by 2011 !

+ On-going tools and analyses improvements

- **tanβ ~ 20** for low m_A in reach

+ SM Higgs exclusions → MSSM constraints

- SM-like / MSSM-like Higgs searches interplay
- See P. Draper et al., arxiv: 0905.4721v2
- **Potential to probe @ 95% C.L large MSSM parameter space**



Exciting ahead, keep tuned !

Back-up

MSSM benchmarks

- Five additional parameters due to radiative correction
  - M_{SUSY} (parameterizes squark, gaugino masses)
  - X_t (related to the trilinear coupling $A_t \rightarrow$ stop mixing)
  - M_2 (gaugino mass term)
  - μ (Higgs mass parameter)
  - M_{gluino} (comes in via loops)

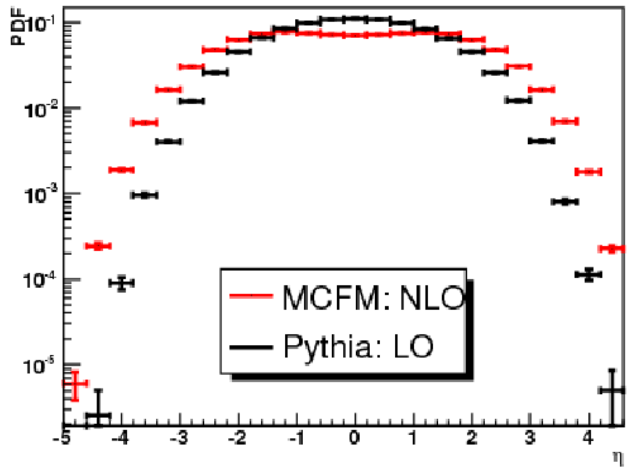
	m_h-max	no-mixing
M_{SUSY}	1 TeV	2 TeV
X_t	2 TeV	0
M_2	200 GeV	200 GeV
μ	±200 GeV	±200 GeV
m_g	800 GeV	1600 GeV

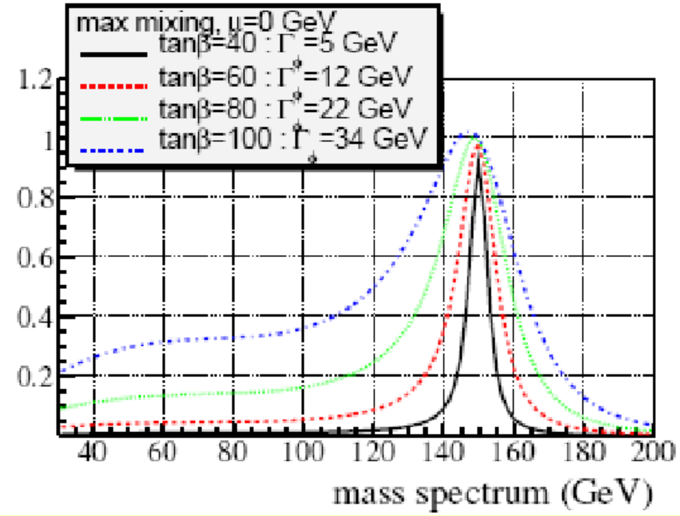
- Two common benchmarks
  - Max-mixing - Higgs boson mass m_h close to max possible value for a given $\tan\beta$
  - No-mixing - vanishing mixing in stop sector $\rightarrow$ small mass for h

Conclusion

Neutral MSSM Higgs → bb + b[b]

- Signal prediction
  - Pythia hb MC
  - Weighted to match NLO MCFM
    - Kinematics of spectator b-quark
- Final limits corrected for:
  - Width not negligible at high tanβ
  - MSSM NLO Corrections
    - FeynHiggs





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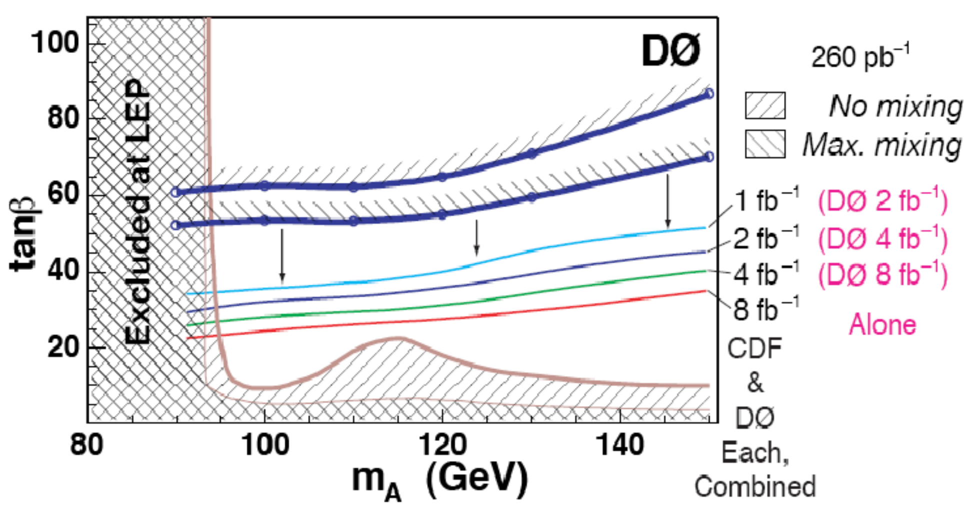
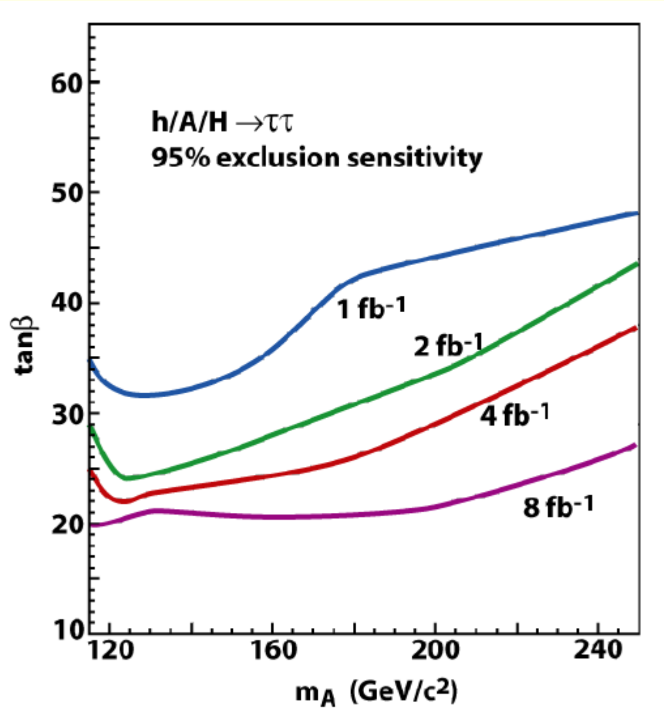
MSSM evolution





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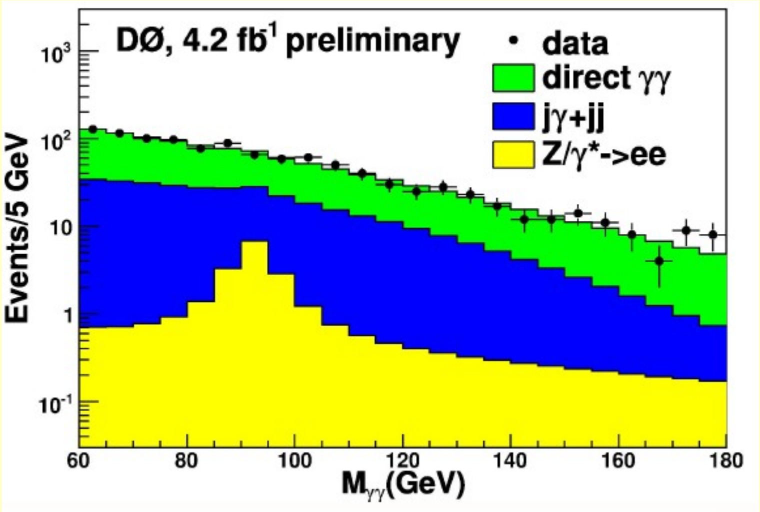
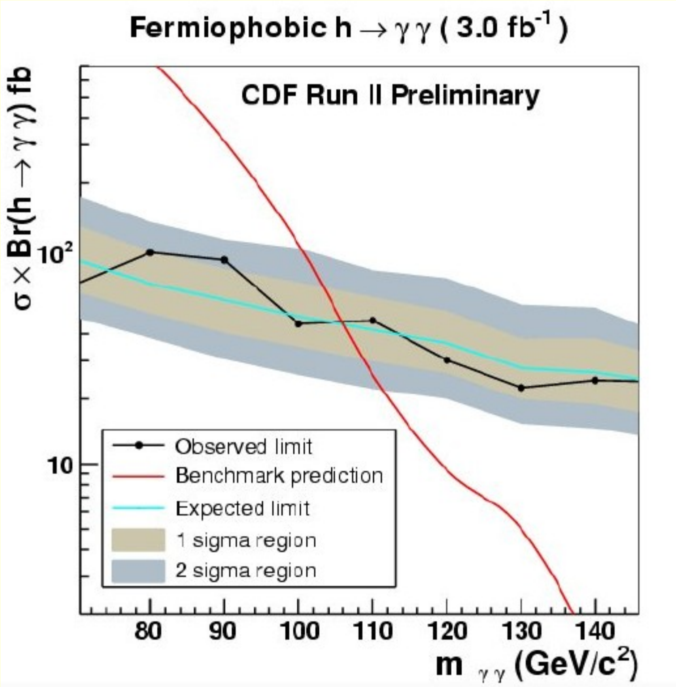
Fermiofobic Higgs





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