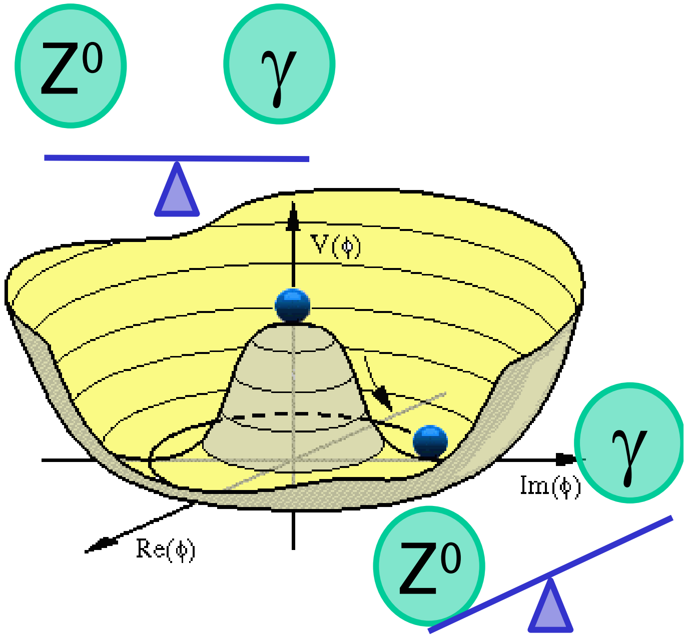
Search for Higgs Beyond the Standard Model at Tevatron Run II

Boris Tuchming
IRFU/SPP
CEA-Saclay

Overview:

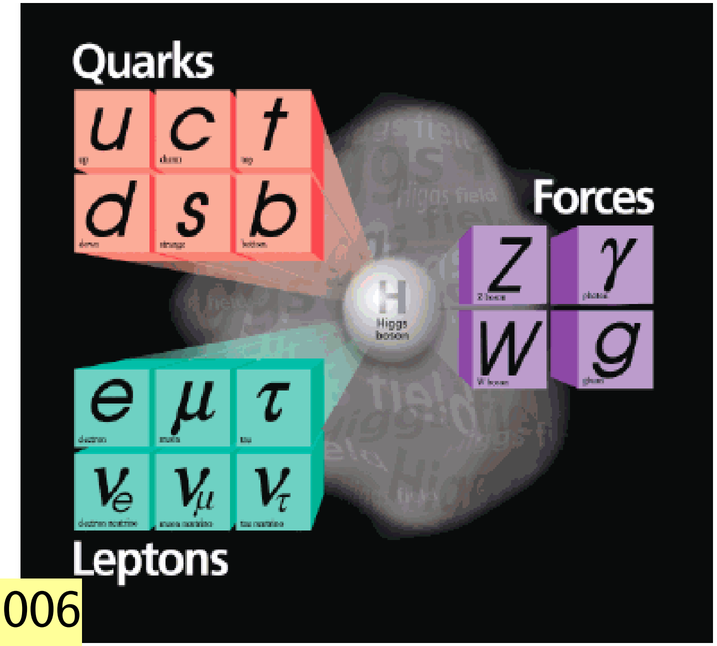
- -Introduction
- -Fermiophobic Higgs
- -SUSY Higgs

Searching Higgs beyond Standard Model



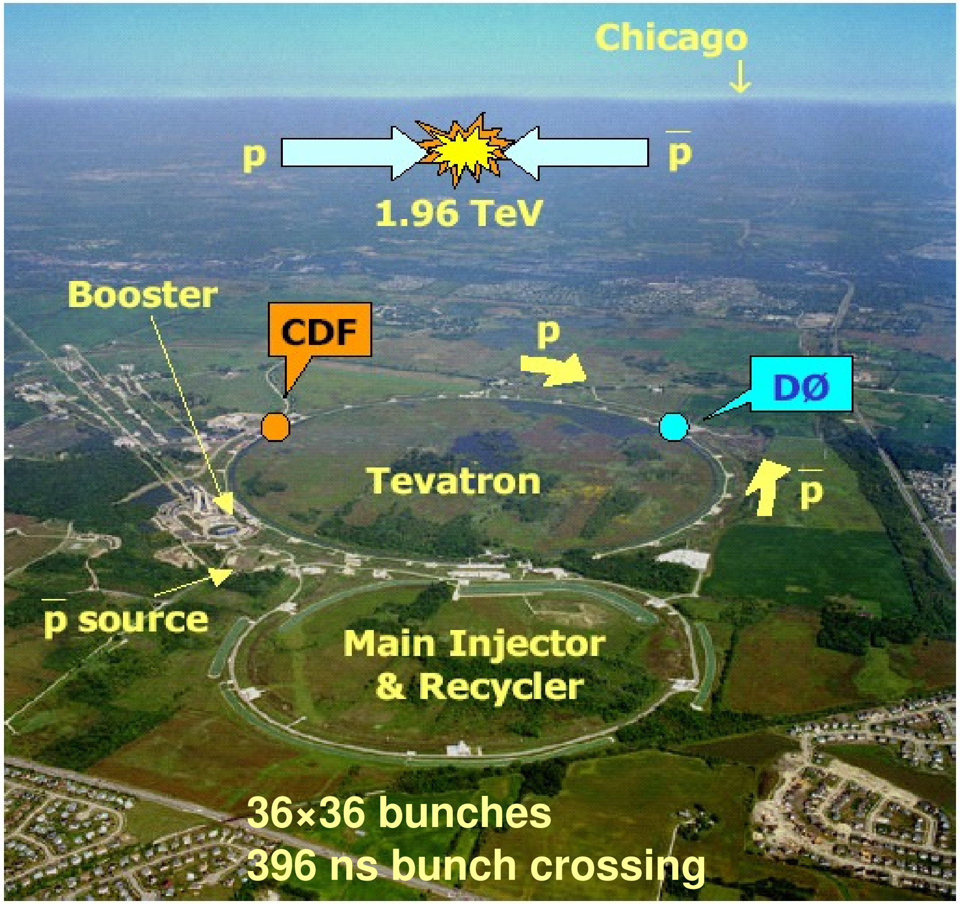
Standard Model
- simpliest explanation of EW symmetry breaking Standard Model Higgs mechanism with a $SU(2)_L \times U(1)_Y$ doublet
- But Higgs is still unobserved

- Standard Model is not the ultimate theory
  - lack of explanation: Choice of gauge group (GUT ?), flavour structure, mass hierarchy, neutrino masses, baryogenesis, dark matter, gravity……
  - Flaw: unstability of weak scale = naturalness
- We expect new physics at the TeV scale:
  - New physics likely means a different Higgs sector.
  - It is worth searching Higgs Beyond Standard Model: We could discover both Higgs and new Physics !!!
- In the following, search for neutral Higgs signatures
  - SUSY Higgs
  - Fermiophobic Higgs



h->bb : M. Michaut, Phd Thesis 2006
h->ττ : R. Madar, Phd Thesis 2011

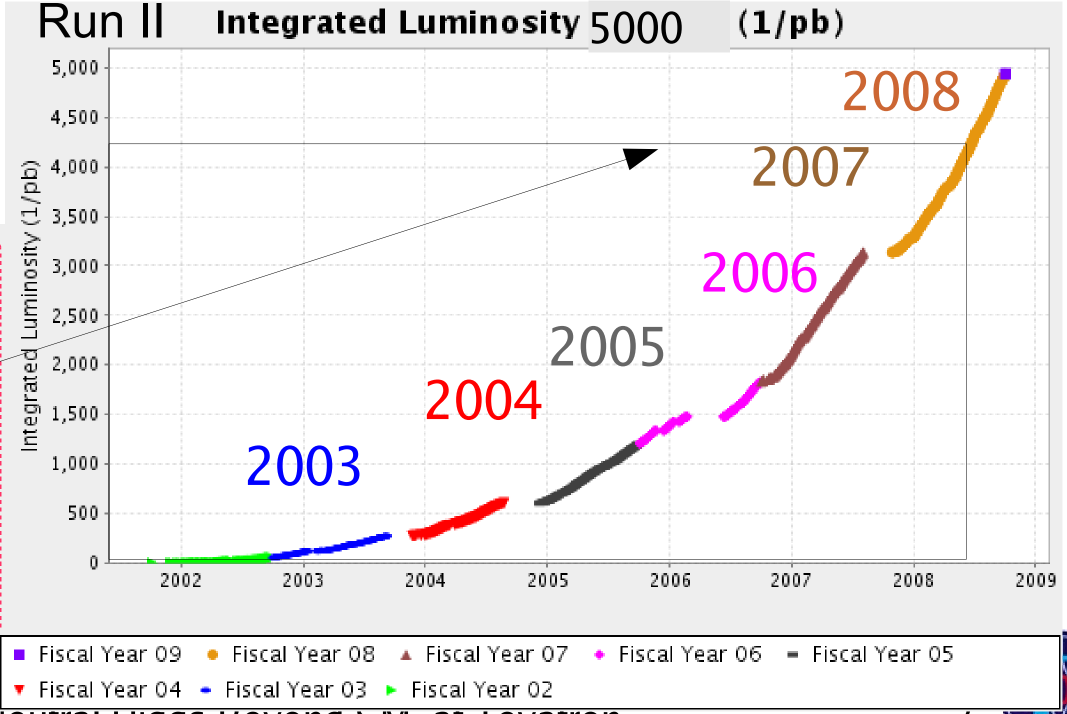
The Tevatron



Run IIa: (2002-2006)
~1.5 fb^{-1} delivered per experiment
Run IIb since june 2006
~3.5 fb^{-1} delivered per experiment

6 to 8 fb^{-1} by end of run (2009 or 2010)

~ 4 fb^{-1}/experiment on tape
The most recent results (summer 2008)
are based on 2 – 2.6 fb^{-1}
(data recorded up to spring 2008)



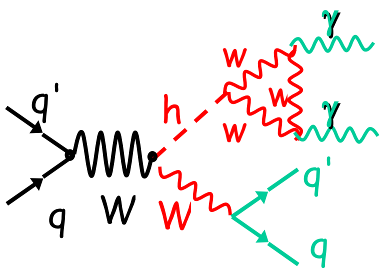
Fermiophobic Higgs.

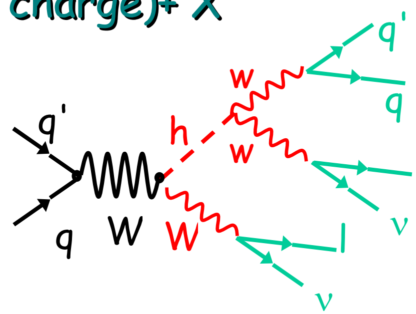
May arise for example from 2 Higgs doublet model type I

- one doublet couples to fermions, the other doublet couples to boson only.
- Decays: ZZ, WW*, $\gamma\gamma$

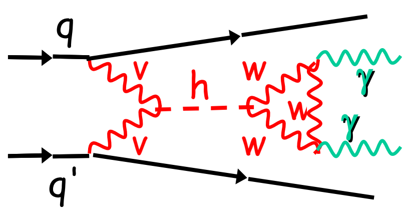
Production modes at Tevatron

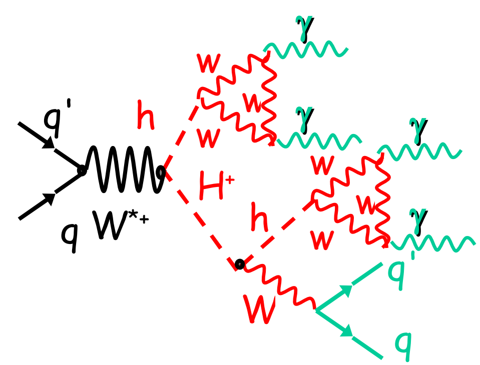
- usual gg fusion via top-loop is suppressed
- associated production with vector boson
  - $\gamma\gamma$+X,
  - WWW* -> 2 leptons (same charge)+ X





- Vector Boson Fusion qqH -> $\gamma\gamma$+X

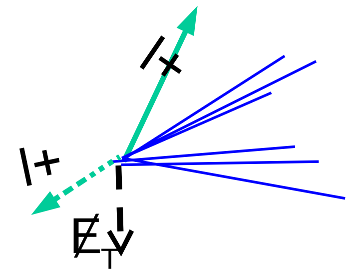




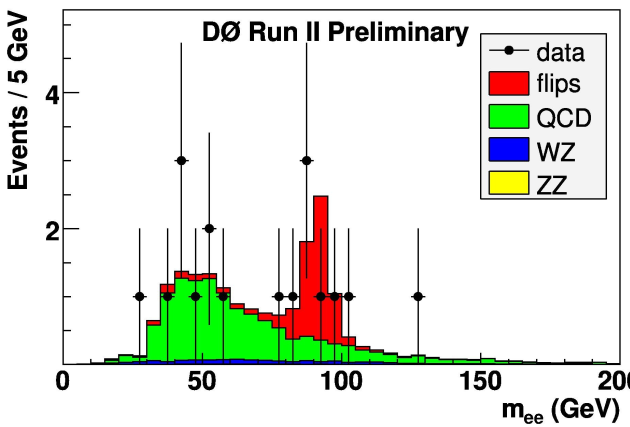
- via charged Higgs production
  - eg: qq-> hH+ -> hhW*+ -> $\gamma\gamma\gamma(\gamma)$ +X

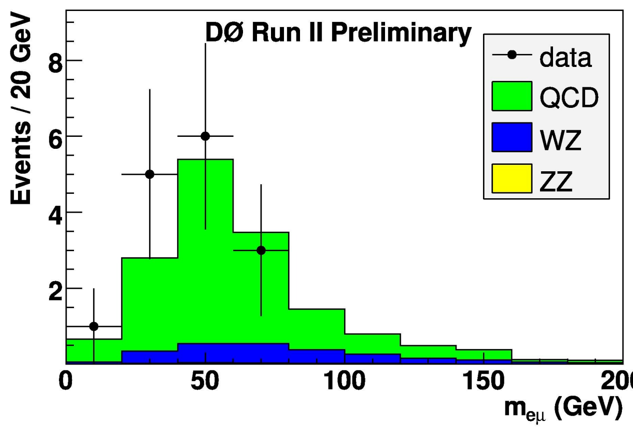
Fermiophobic Higgs: WWW* final state

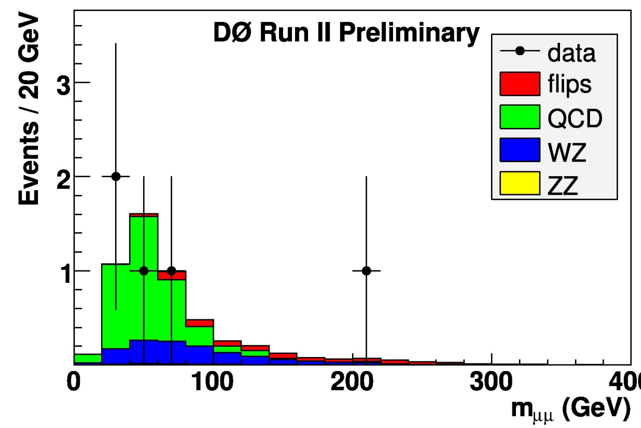
- Clear and clean signature
  - 2 like-charge isolated leptons p_T >15 GeV
  - Missing transverse energy, $\not{E}_T$ > 20 GeV



- Background arises from
  - WZ production — estimated from MC
  - Drell-Yan + mismeasured charge (~10^{-3}) — estimate from data
  - QCD, W+jets with fake leptons — estimate from data







DØ $\mathcal{L}$~1 fb^{-1}

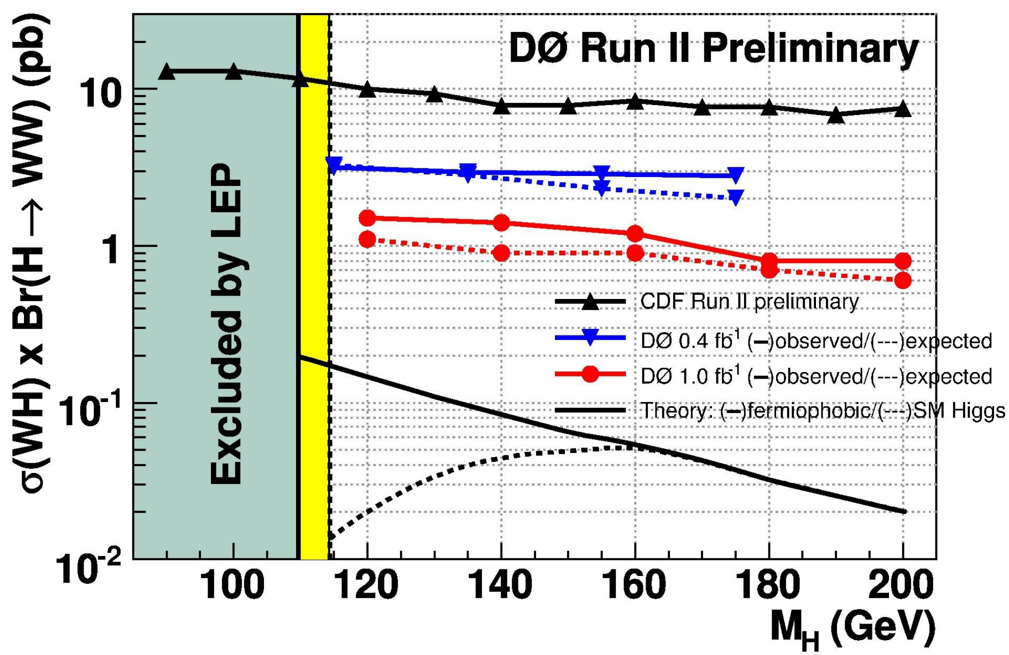
	ee	$e\mu$	$\mu\mu$
charge flips	11.9 ± 3.8	0.04 ± 0.02	$0.8^{+2.3}_{-0.8}$
W/QCD	7.4 ± 1.1	15.4 ± 2.8	2.8 ± 0.9
WZ	1.18 ± 0.17	2.46 ± 0.34	1.29 ± 0.18
ZZ	0.10 ± 0.01	0.16 ± 0.02	0.07 ± 0.01
total	20.6 ± 4.0	18.0 ± 2.8	$5.0^{+2.5}_{-1.2}$
data	19	15	5

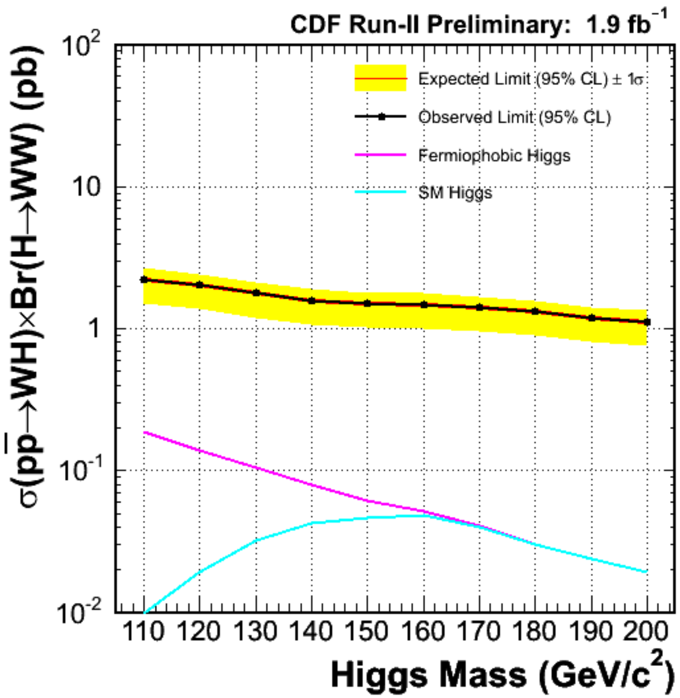
CDF $\mathcal{L}$~1.9 fb^{-1}

	events
bkg	141.7±9.2
sig(m_H=110)	0.938±0.050
sig(m_H=160)	0.272±0.016
data	134

WWW* limits

- Absence of deviation relative to background expectation can be interpreted in Fermiophobic model

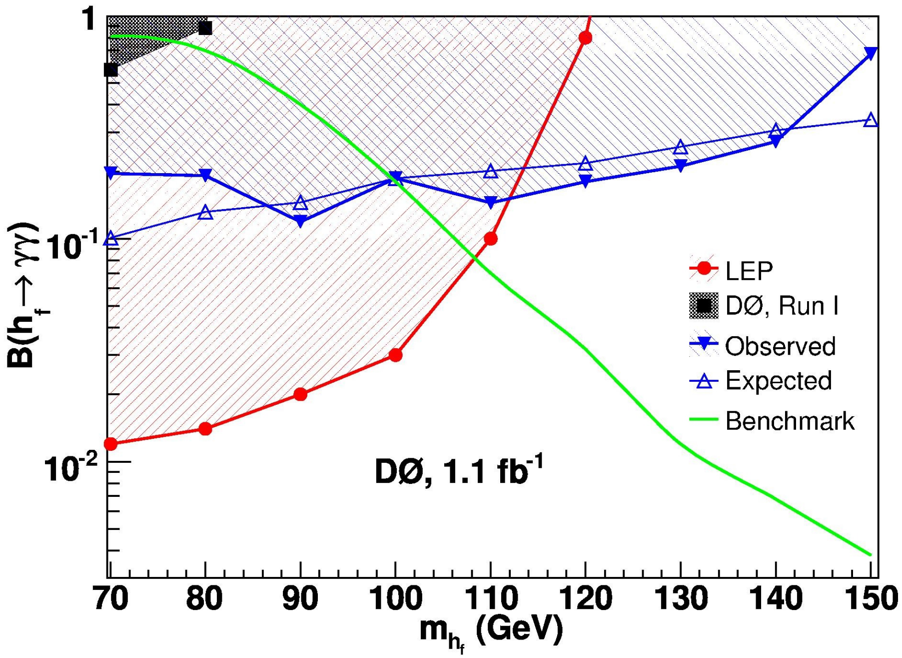


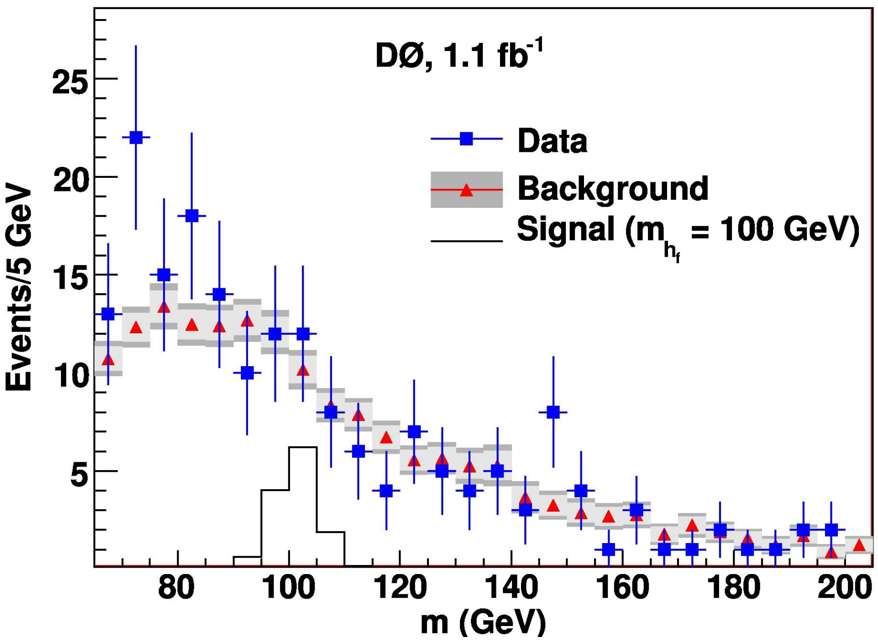


Results are one order of magnitude above benchmark Fermiophobic model.

Fermiophobic Higgs: search for $\gamma\gamma$ at DØ

- Neural Network for γ/jet discrimination
  - Background from jj, γj, $\gamma\gamma$ mostly determined from data
  - no excess in $\gamma\gamma$ mass spectrum for $L\sim1.1\ fb^{-1}$
  - Event counting in 10 GeV sliding mass window: limit as a function of M_{hf} and $Br(h_F\to\gamma\gamma)$

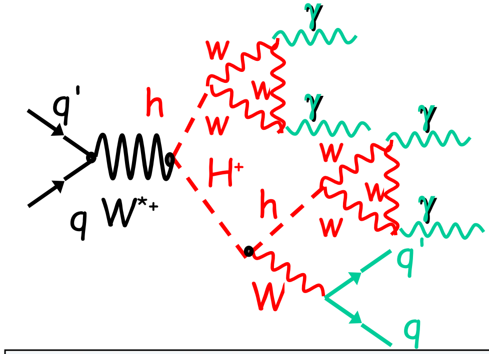


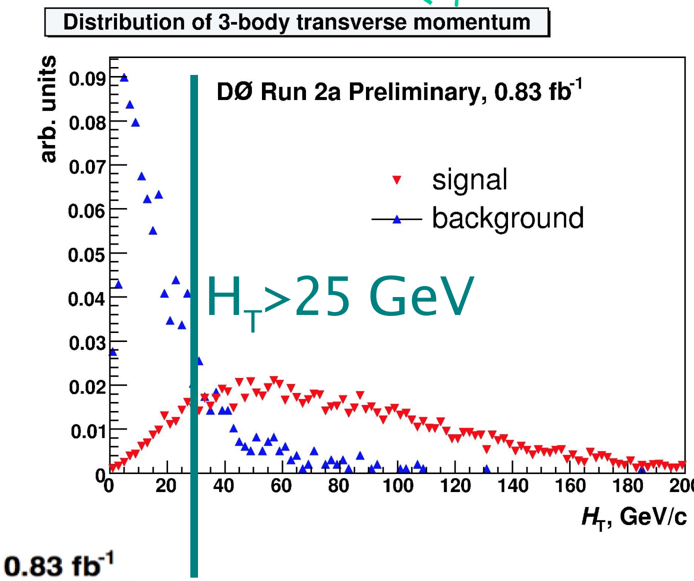


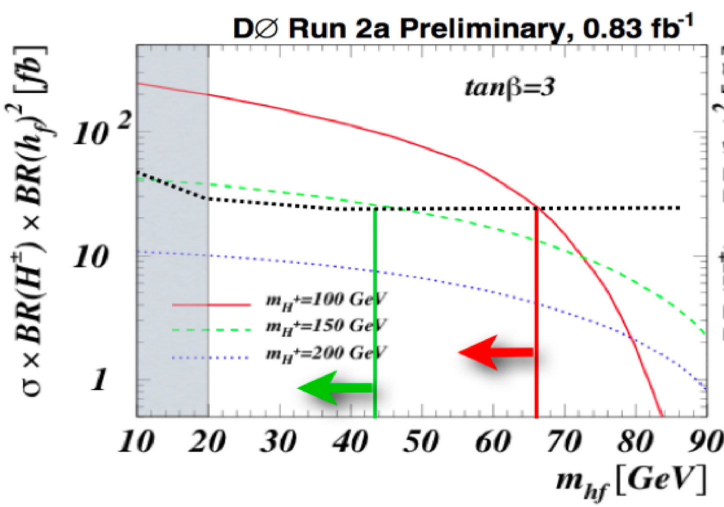
- Improve LEP limit by a factor of 4 for M_{hF}=120 GeV
- Need more data or analysis improvements to probe benchmark scenario
  - Can recycle more recent analysis searching for Standard Mode $H\to\gamma\gamma$ ($2.3\ fb^{-1}$)

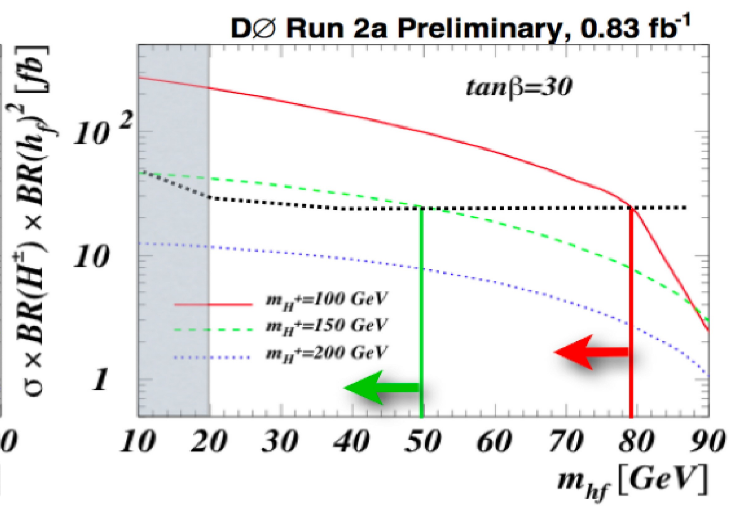
Fermiophobic Higgs: search for $\gamma\gamma(\gamma)$ at DØ

- 'Light' Higgs M_{hF}~40-80 GeV can escape search for $h_F \to \gamma\gamma$ at LEP if VVh coupling is suppprresed.
- 3γ signatures
  - Look for excess of high pt photons
  - small background arising from qq-> 3γ
  - H_T>25 GeV   bkg=1.1±0.2   DATA=0
- Production through charged Higgs is model dependent
  - limit as a function of M_{H^+}, M_{hF}, tan(β)=v2/v1 (ratio of vev's)



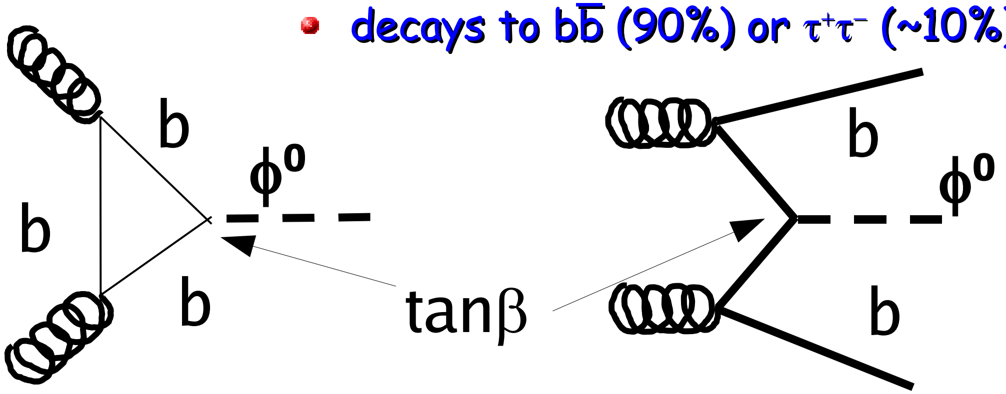






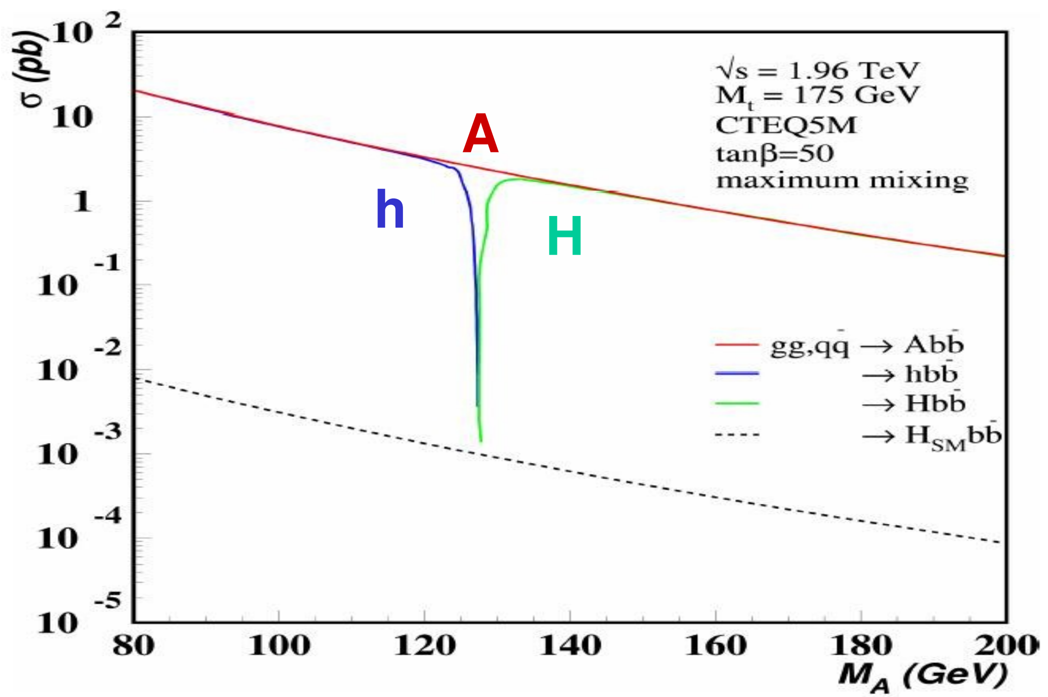
SUSY Higgs at large tan(β)

- In MSSM 2 Higgs doublets (type II)
  - tanβ= v2/v1 ratio of vev's
  - 5 Higgs : 3 neutral (h,H,A) and 2 charged (H^+,H^-)
  - 2 parameters at tree level : (M_A, tan(β))
- At large tan(β) : 2 neutral ~degenerated in mass with bbϕ coupling ~tan(β)
- cross-section enhanced by ~ 2 x $\tan^2\beta$ (at leading order) relative to SM
  - decays to $b\bar{b}$ (90%) or $\tau^+\tau^-$ (~10%)



channel:
$\tau^+\tau^-$

channels:
$b\bar{b}b(\bar{b})$
$b\bar{b}\tau^+\tau^-$

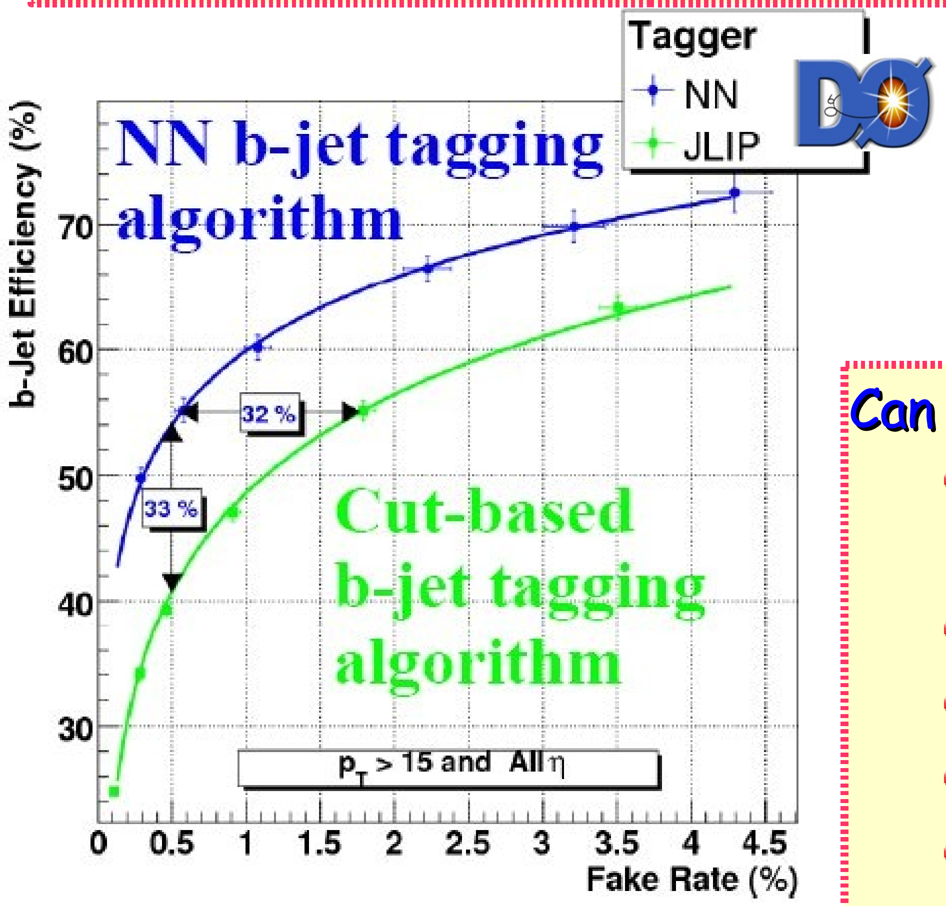


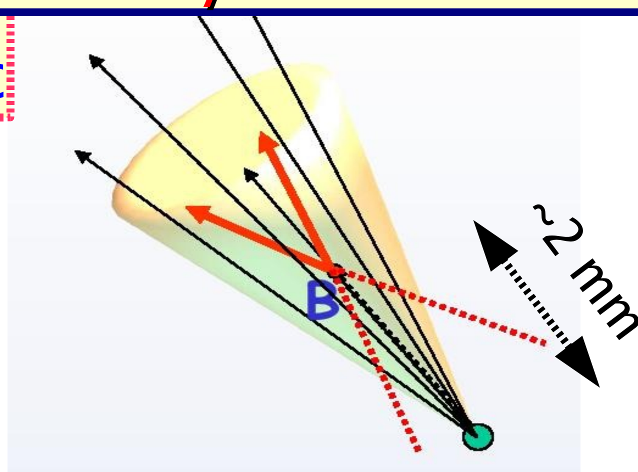
b jets tagging: essential to search Higgs in general

See talk by Sebastien Greder

B-hadrons are long lived particles: $c\tau$~0.5 mm.

B-hadrons can decay semi-leptonically: $b \to \mu\nu c$





Can make use of:

- High impact parameter of tracks
  ==> light quark Jet Probability
- Secondary vertex reconstruction (SVX)
- Lepton tag
- b-jet kinematics (large B-hadron mass)
- Combination of above with multivariate techniques (eg Neural Network)

Eg: CDF 2nd vertex tag: ε=50% for 2% mis-tag at η<1

Eg: DØ NN ε=60% for 1.5% mis-tag Pt=50 GeV (loose tag)

used for (b)bh->(b)bbb ε=50% for 0.5% mis-tag Pt=50 GeV (tight tag)

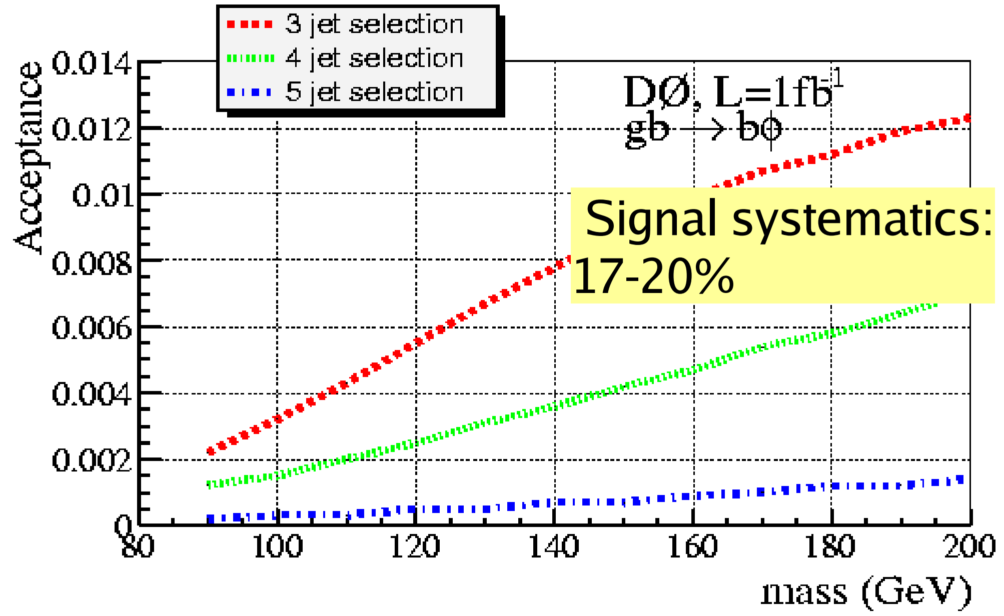
DØ: hb(b) -> bbb(b) (large impact from DØ France)

- Selection:
  - 3 to 5 jets with p_T>20 GeV $|\eta|$<2.5

    2 b-tag jet with p_T>25 GeV

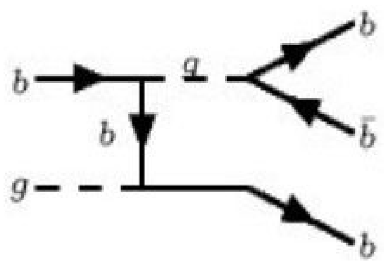
    3 b-tag in final selection
  - trigger ε~60-70%
    - multi-jet conditions
    - b-tagging conditions (challenging)
- In first 1 fb^{-1} of DATA

  3,224/2,503/704 events for 3/4/5 jets selection
- Signal simulated by Pyhia, reweight events to match MCFM NLO kinematics

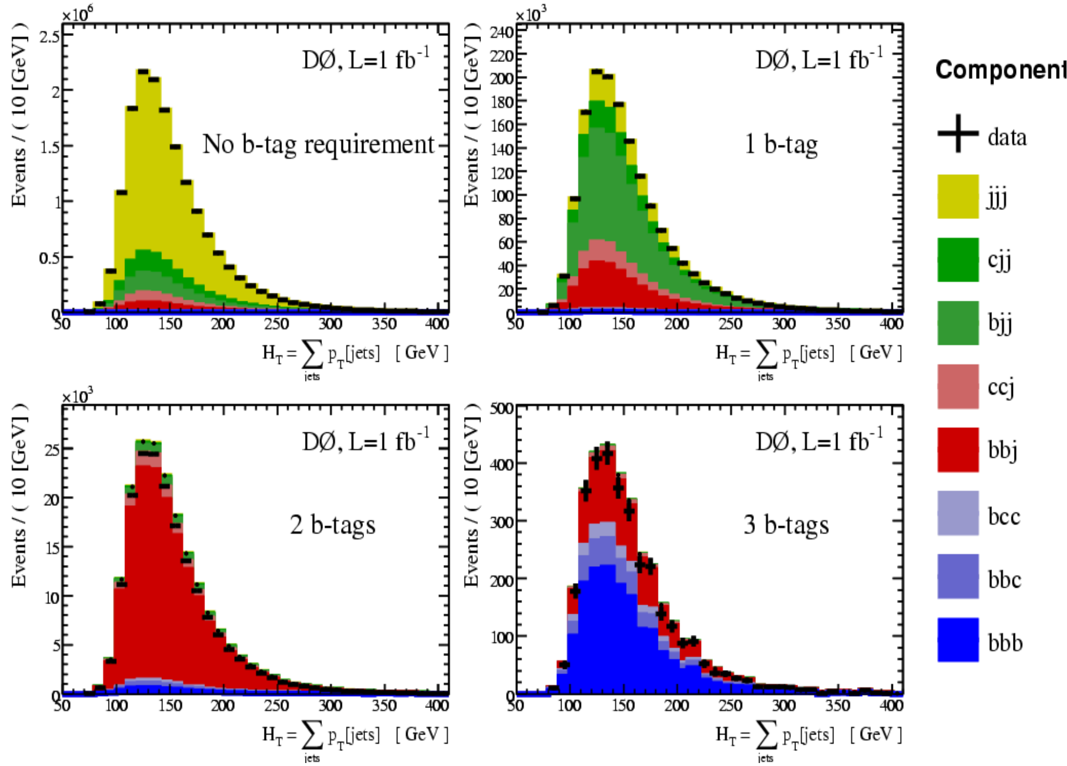


Challenge: modeling the background of hb(b) -> bbb(b)

- Large multi-jet background, hard to understand and model with data.
- backgrounds not only bbj, bbbb BUT ALSO odd number of visible heavy flavor (just like signal) bjj, bbc, bbb,....



- Main background for final selection is found to be bbb very similar to the signal final state.
- backgrounds are not predicted accurrately by MC
  - compute DATA/MC correction
  - large systematics



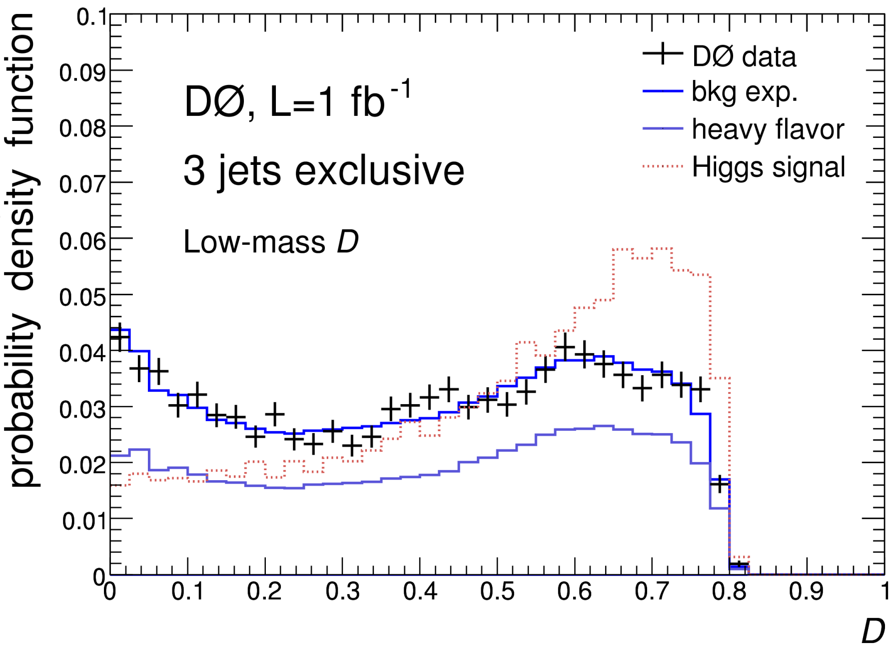
DØ $\mathcal{L}$~1 fb^{-1}

background analysis, obtained by fitting data to different tagging efficiency.

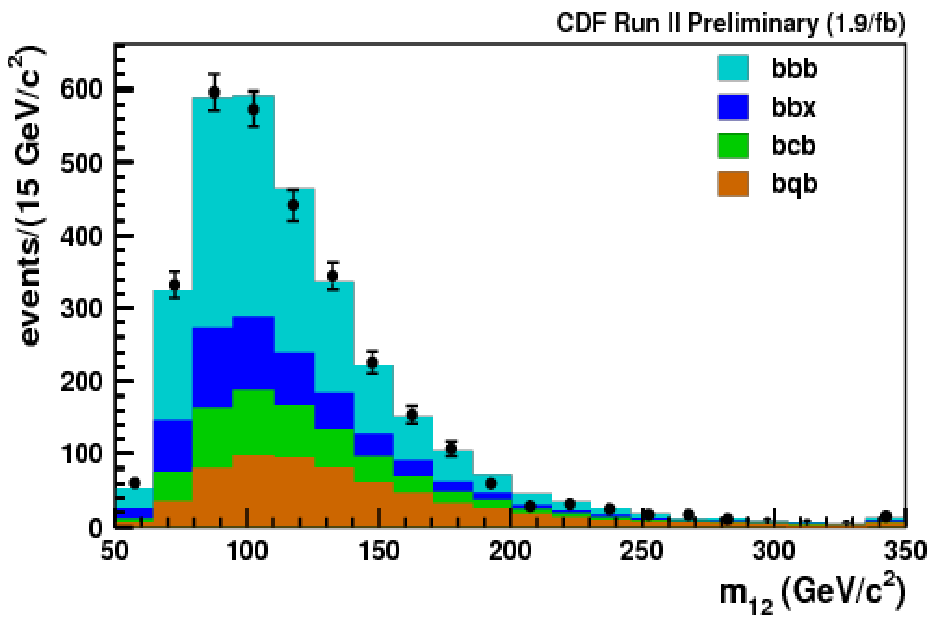
3 tag sample:	bbb	~50%
	bbj	~30%
	bbc+bcc	~17%
	ccj	~2%
	jjx	~1%

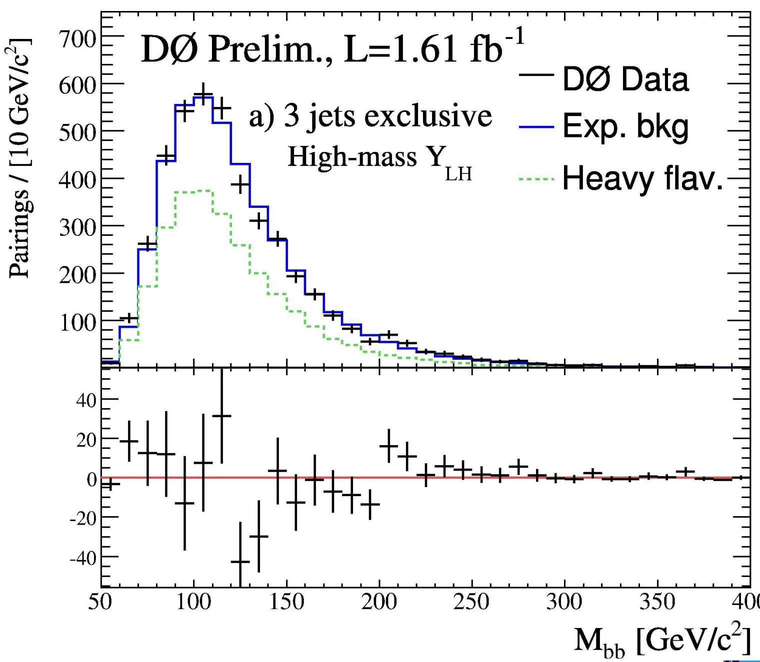
Searching for a hbb signal

- DØ: Likelihood based on kinematics to separate signal from background.
  - Verify data-background agreement in low-likelihood region
  - Then check the high-likelihood region.
  - Look for excess in di-jet mass spectrum



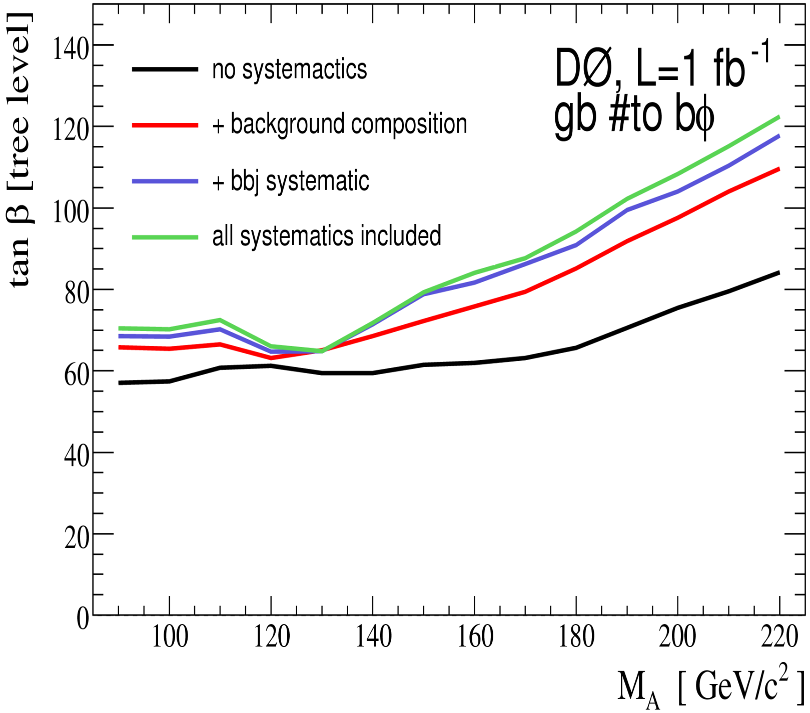
- CDF also perform bbb analysis in 2fb^{-1}
  - find similar background admixture





Background systematics

- Much larger impact than signal uncertainty
- The normalization is unknown, only the uncertainties on the background shape matters:
  - bbb vs bbj fraction
  - bbb vs. bbj kinematic
  - bbb vs. bbj b-tag shape
  - b jet energy scale resolution
  - b-tag trigger (different efficiency for 2tag and 3tag events)



eg for M_A= 160 GeV background systematics decreases sensitivity by ~50%

MSSM Benchmark

- 2 parameters, (M_A, tan(β)) to describe SUSY Higgs sector at Leading Order
- hbb vertex receive large corrections from sbottom-gluino and stop-higgsino loop

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

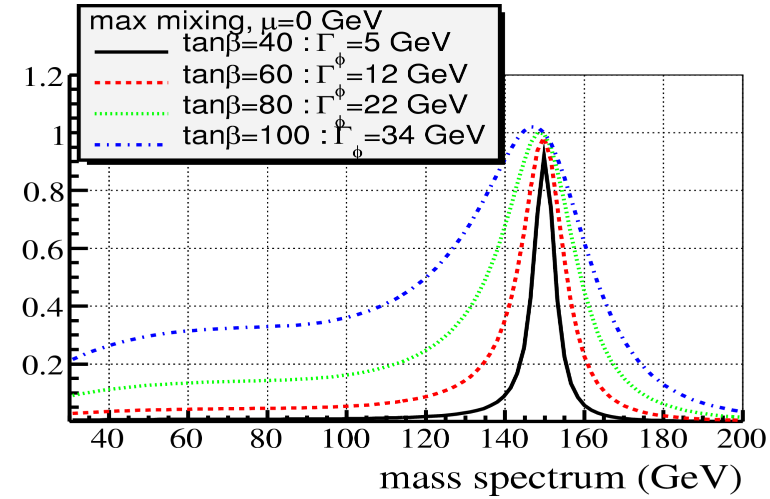
- Two common benchmarks
  - Max-mixing - Higgs boson mass m_h close to max possible value for a given tanβ
  - No-mixing - vanishing mixing in stop sector → small mass for h

	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

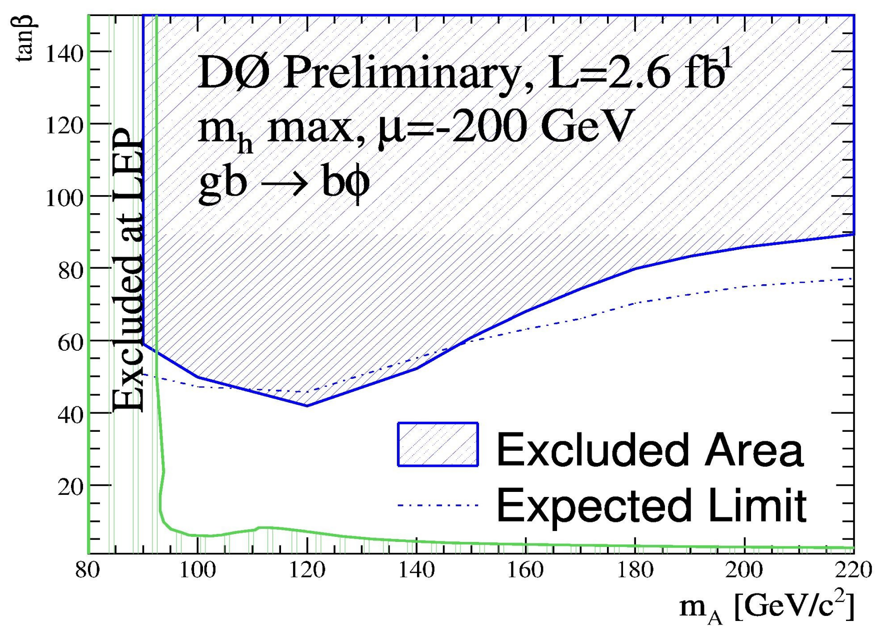
bbb(b) results

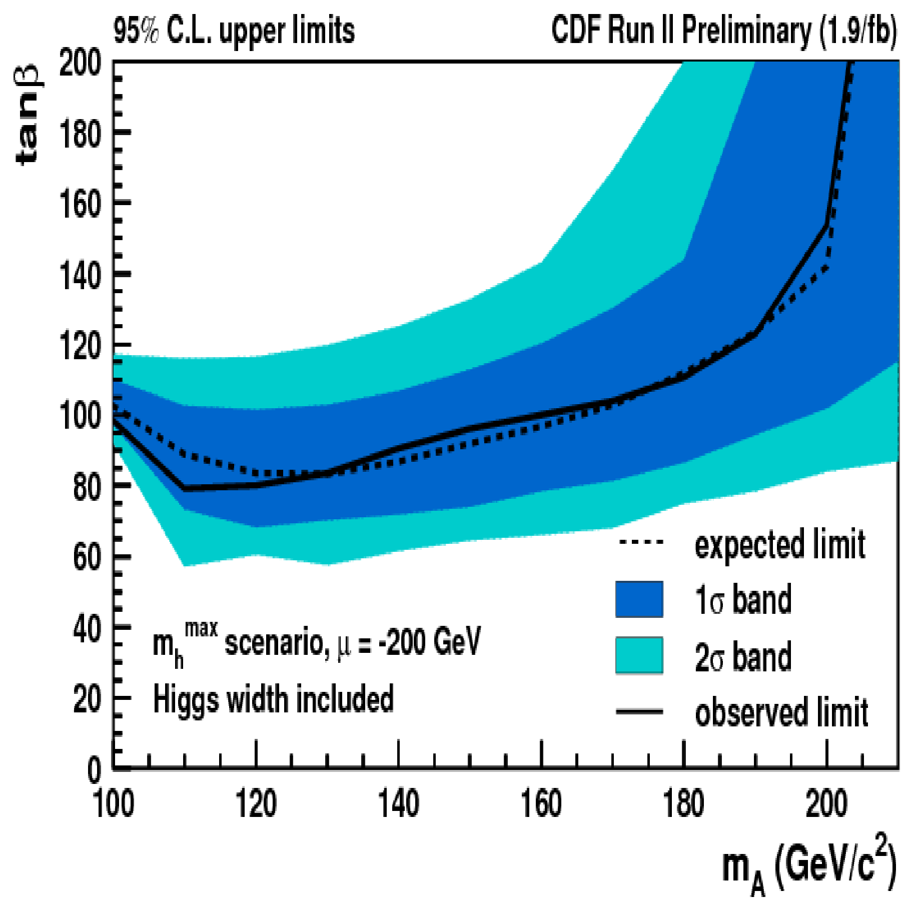
Interpret results in MSSM benchmark scenario:

- ϕbb coupling modified by SUSY loops
- also account for larger intrinsic width at large tan(β)



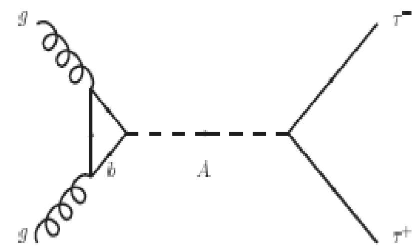
Results start to exclude interesting region tan(β) ~40 ~ M_{top}/M_b



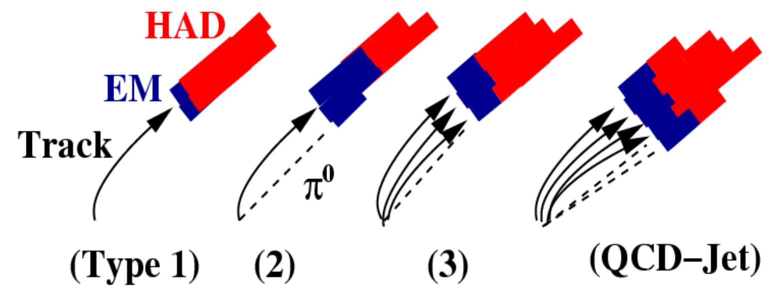


$\phi^0 \to \tau\tau$ at large tan(β)

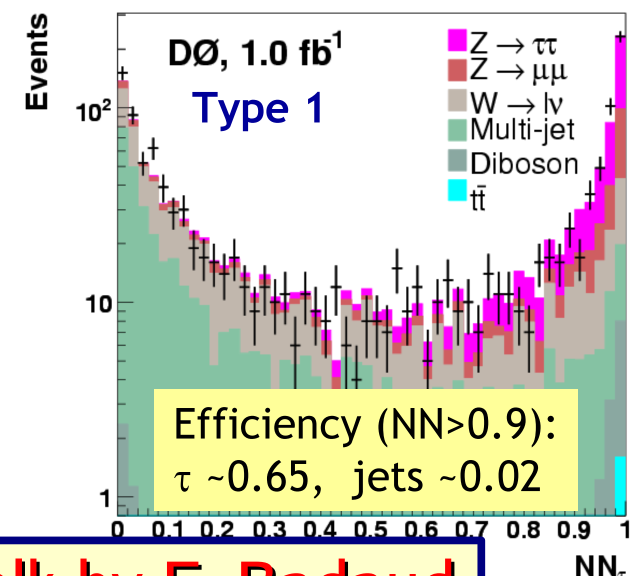
- Taus decay within the inner detector, ~17% to e, μ, ~65% to hadrons. Three channels used:
  - $\tau \to \mu\ \nu\nu + \tau \to$ hadrons ν — $\tau_\mu\tau_h$ channel
  - $\tau \to e\ \nu\nu + \tau \to$ hadrons ν, — $\tau_e\ \tau_h$ channel
  - $\tau \to e\ \nu\nu + \tau \to \mu\ \nu\nu$ — $\tau_e\ \tau_\mu$ channel



- At DØ, hadronic tau candidates are divided into 3 types:
  - Type 1: one track, calorimeter cluster without EM subcluster
  - Type 2: one track, calorimeter cluster with EM subclusters
  - Type 3: 2 or 3 tracks consistent with tau mass, calorimeter cluster



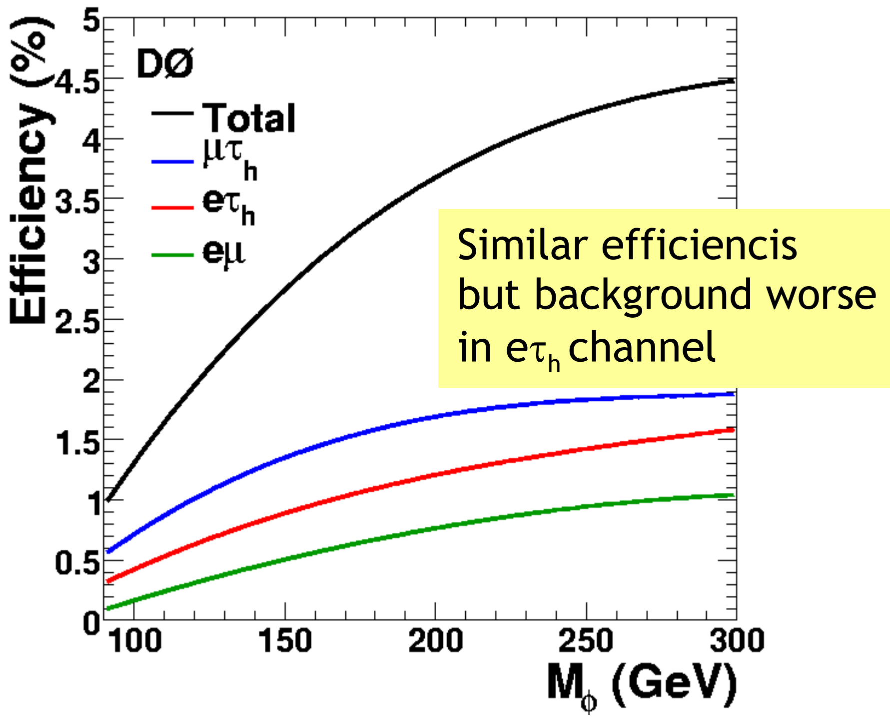
- Tau identification is based on Neural Network: Non-linear correlations between variables are taken into account Discriminating variables: Profile, Isolation, ...
- Dedicated energy correction: τ–energy scale

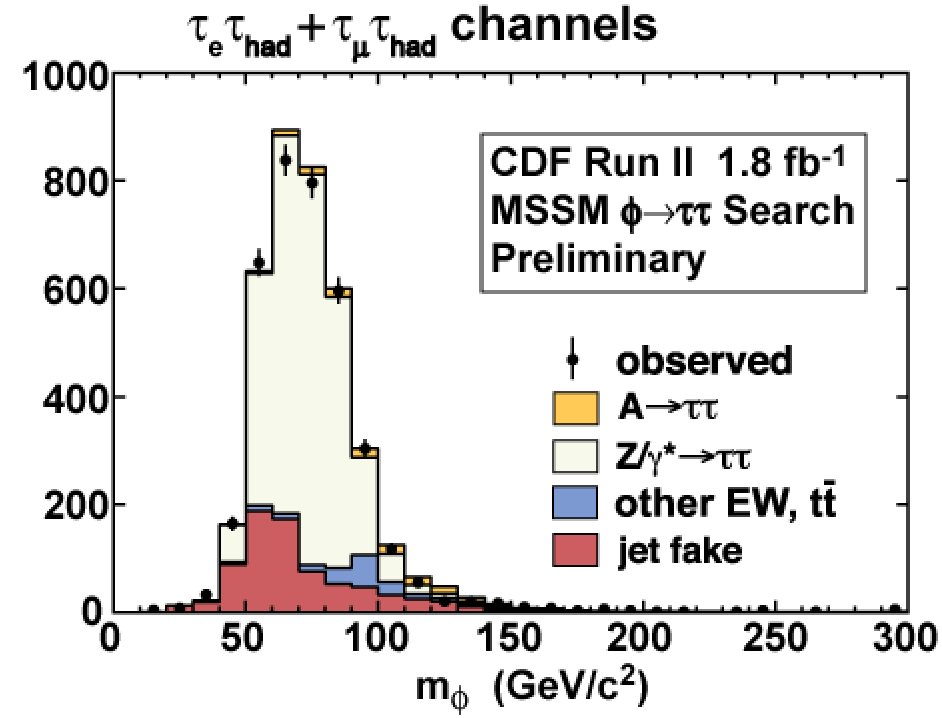


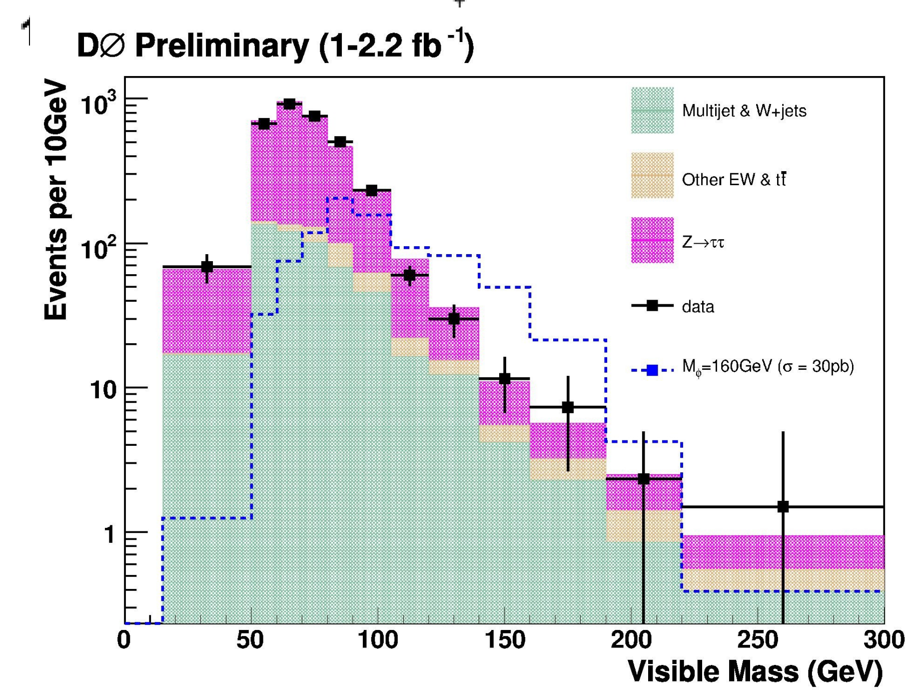
See talk by F. Badaud

$\phi^0 \to \tau\tau$ at large tan(β)

- Main backgrounds arise from Z->ττ , W+jets and multi-jets events







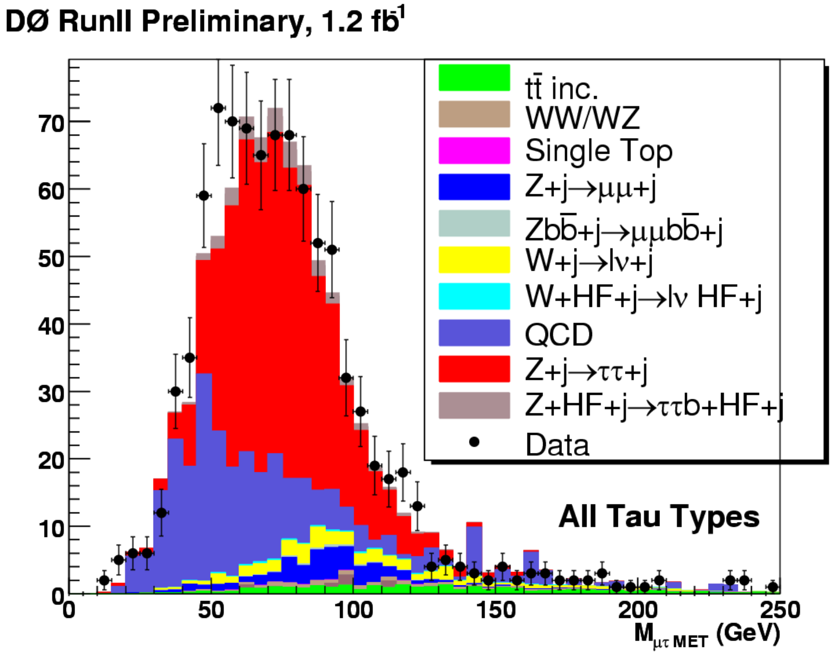
- Discrimination against background based on visible mass:

$$m_{\text{vis}} = \sqrt{(p^{\tau_1} + p^{\tau_2} + \not{E}_T)^2}$$

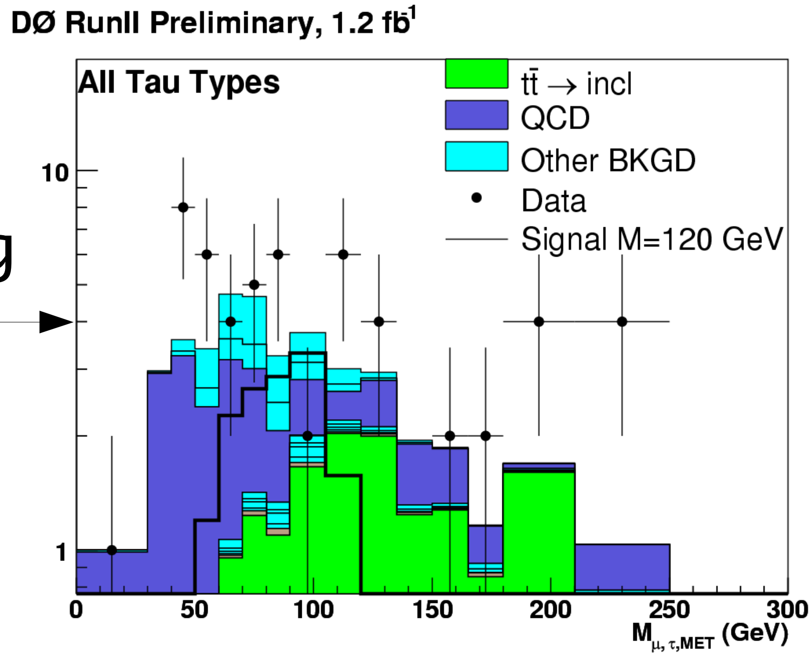
- No sizeable excess wrt background expectation

DØ: (b)bϕ^0->(b)b$\tau\tau$ at large tan(β)

- Look for high p_T $\tau_\mu \tau_h$ +jet
- First channel to use dedicated tau triggers
- Before b-tagging : background Z+jets and QCD



b-tagging



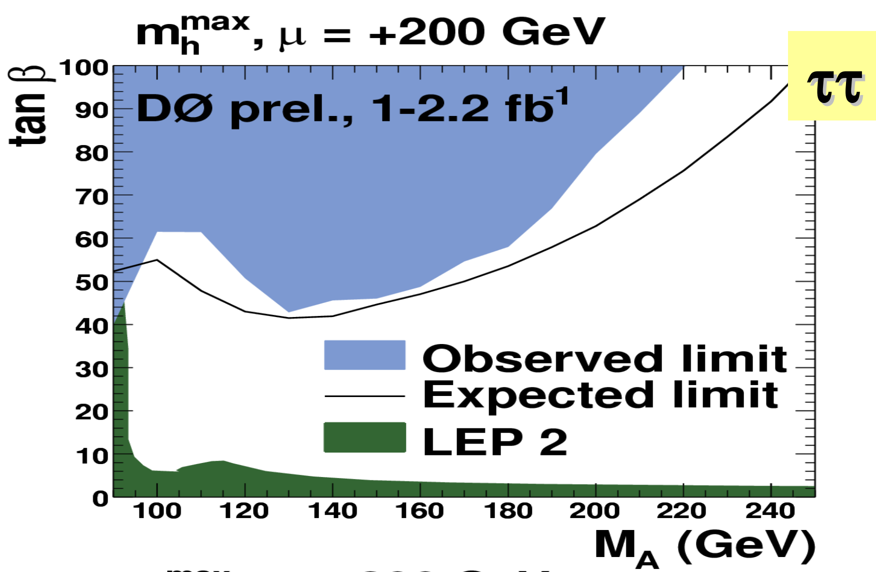
- Main background is top pair production and QCD after b-tagging
- Multivariate technique enhance S/B
- No significant excess above background expectation

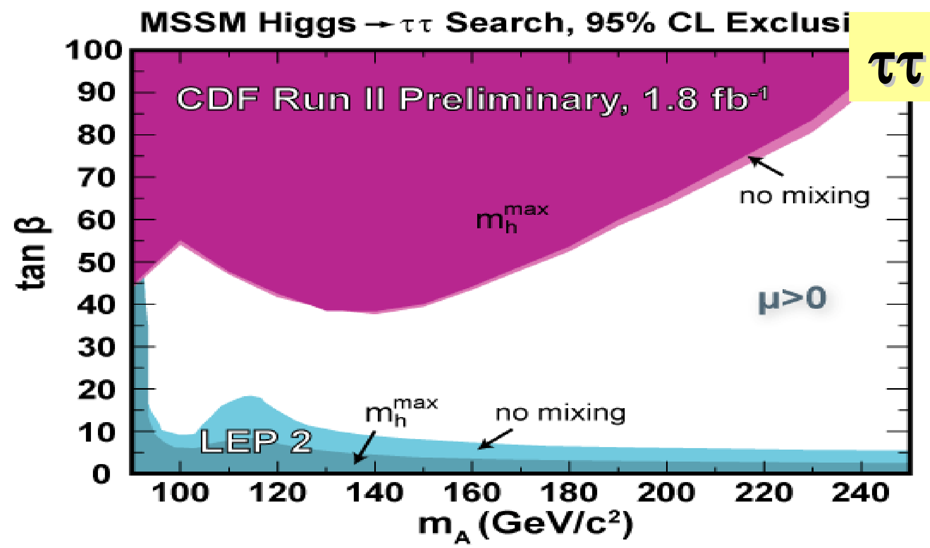
MSSM results: tau channels

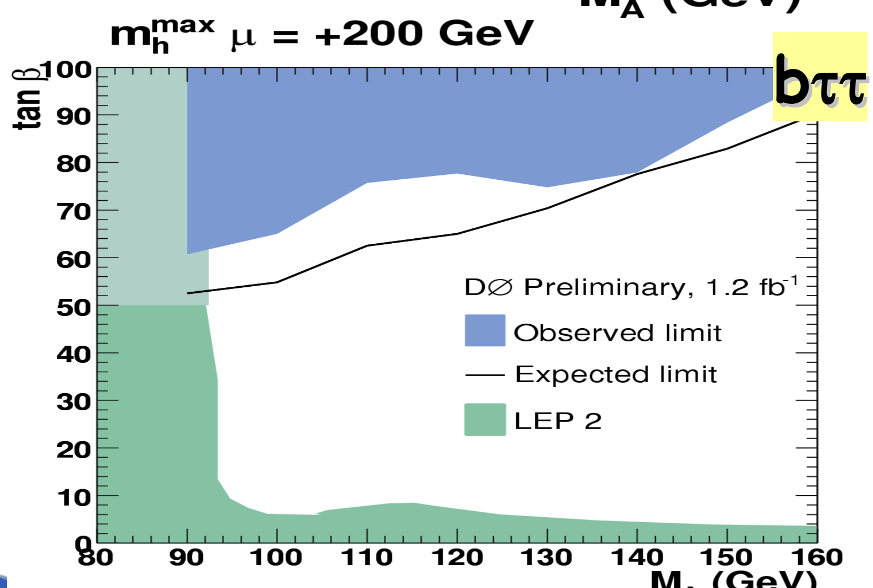
Interpret results in MSSM benchmark scenarios

- tau channels less sensitive to difference between scenarios than bbb channels:

$$\text{yield} \simeq \frac{\cancel{\Gamma(\phi \to b\bar{b})} \times \Gamma(\phi \to \tau^+\tau^-)}{\cancel{\Gamma_{total} \sim \Gamma(\phi \to b\bar{b})}}$$







- Note complementarity: bττ can cover « hole » due to large Z background in ττ channel.

- Results start to exclude interesting region tan(β) ~40 ~ M_{top}/M_b

Conclusion

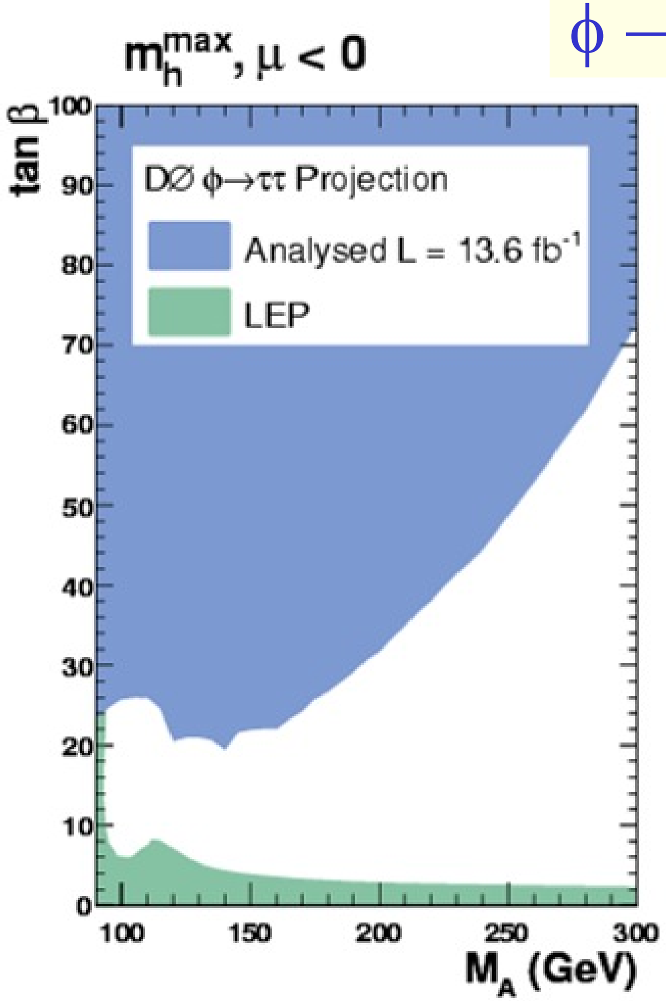
- Tevatron experiments are able to search for Higgs beyond Standard Model.
- Constraints have been obtained in the last years for Fermiophobic and MSSM Higgs production:
  - Improvement relative to LEP limit for Fermiophobic Higgs
  - Starting to probe region of interest $\tan(\beta) < 40$ for MSSM Higgs
- More results are expected to come with
  - more data, thanks to Tevatron performance
  - combinations between channels and experiments
    - Latest news says that eg in SUSY, some phase space at $\tan(\beta) < 30$ could be excluded when combining, bbb, $\tau\tau$, $b\tau\tau$ channels from DØ and CDF.
  - Forseen analysis improvements at DØ:
    - better b-tagging
    - better jet momentum resolution
    - better tau-id and Electromagnetic identification
    - better trigger efficiency (oring of existing conditions)

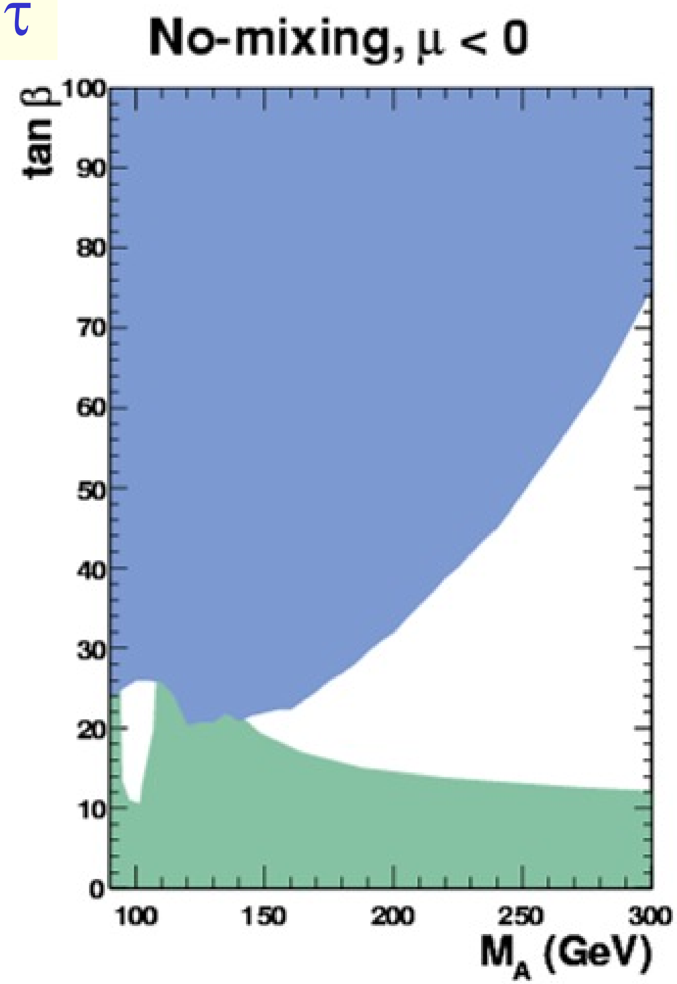
Support slides

Projections

Projections for full 2010 dataset (2 experiments)

$\phi \longrightarrow \tau\tau$





MSSM interpretation $b\phi \to bbb$

- Strongest limits for the m_h^{max} scenario with $\mu<0$
  - Large sensitivity to μ and its sign through loop corrections:
    - Negative μ gives enhanced production
    - No exclusion below for m_h^{max} , $\mu>0$.

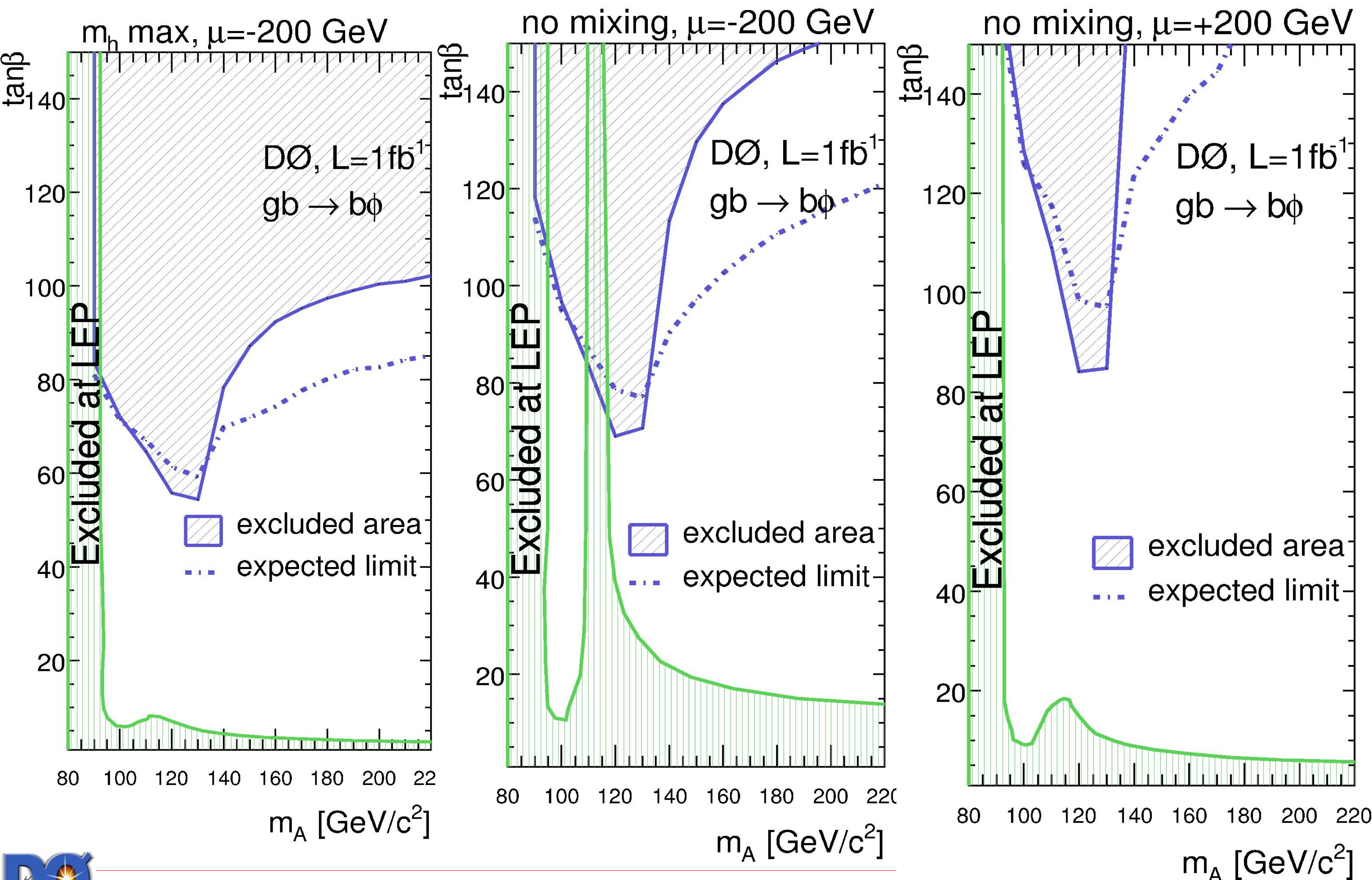
Tau channel more sensitive and less dependent on MSSM scenario

$$\sigma(b\phi \to bb\bar{b}) = 2 \times \sigma(b\phi)_{SM} \times \frac{\tan^2\beta}{(1+\Delta_b)^2} \times \frac{9}{(1+\Delta_b)^2+9}$$

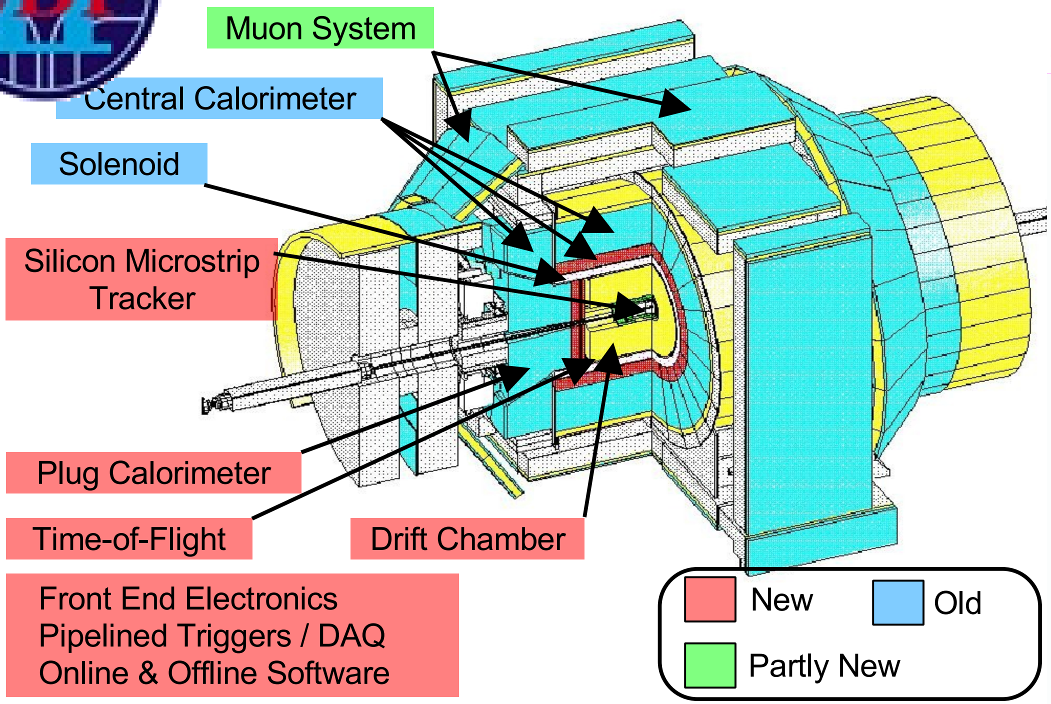
$$\sigma(\phi \to \tau^+\tau^-) = 2 \times \sigma(\phi)_{SM} \times \frac{\tan^2\beta}{(1+\Delta_b)^2} \times \frac{(1+\Delta_b)^2}{(1+\Delta_b)^2+9}$$

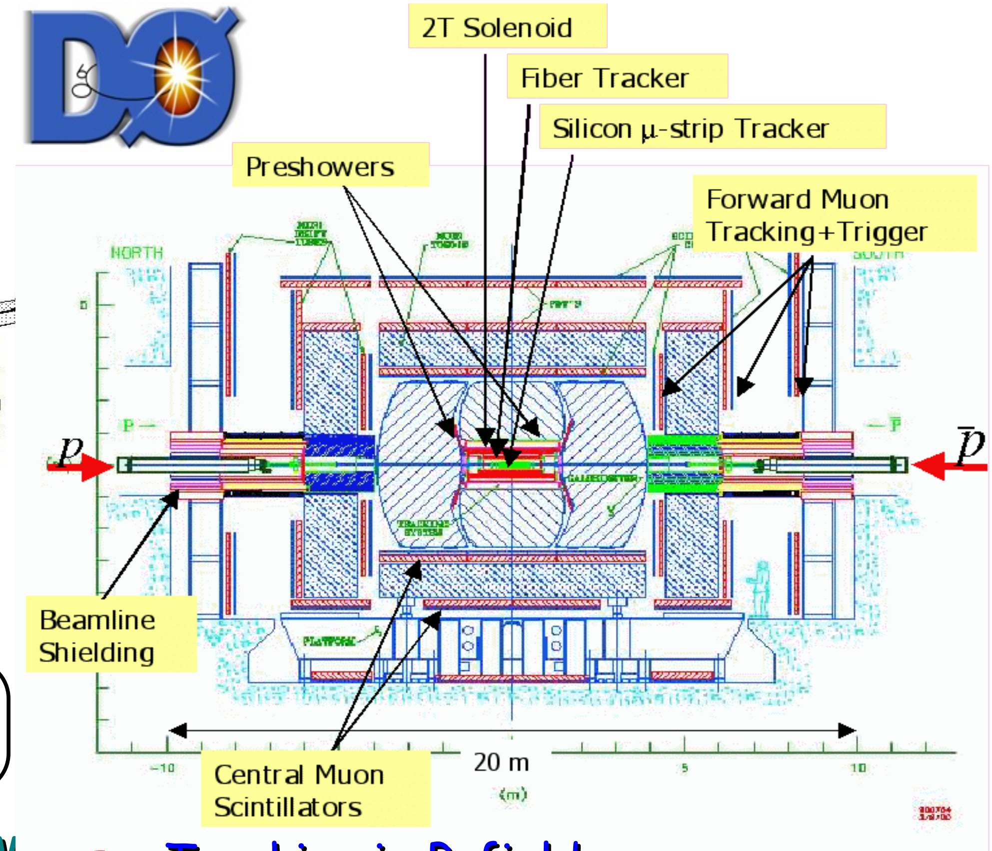
$$\Delta_b = \frac{2\alpha_s}{3\,\pi}\, m_{\tilde{g}}\, \mu\, \tan\beta \times I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}}) + \frac{\alpha_t}{4\,\pi}\, A_t\, \mu\, \tan\beta \times I(m_{\tilde{t}_1}, m_{\tilde{t}_2}, \mu)\,.$$

MSSM interpretation $b\phi \rightarrow bbb$



Tevatron Experiments at RunII





New
- silicon detector
- Drift chamber
- TOF PID system

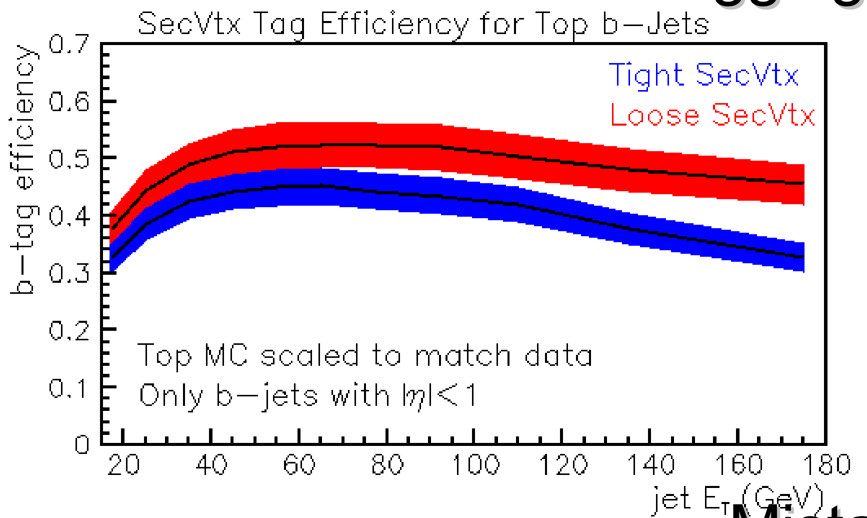
Upgraded
- Calorimeter
- DAQ/trigger
- displaced-vertex trigger

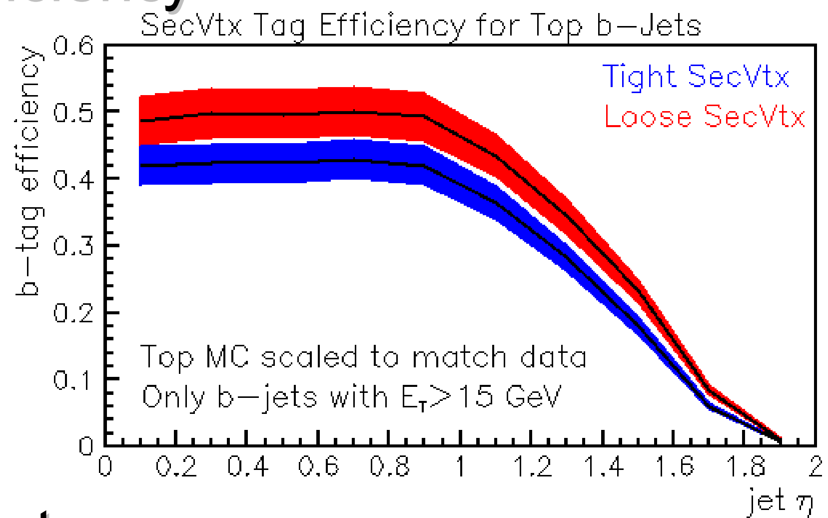
New
- Tracking in B-field
- Silicon detector
- fiber tracker

Upgraded
- Calorimeter, muon system
- DAQ/trigger
- RunIIb: Silicon layer 0, Cal Trigger

backup CDF b-tag plots

Tagging efficiency





Mistag rate