Higgs Searches at Tevatron

- Motivation
- Experimental strategy (and detector)
- Higgs search status
- Prospects
- Conclusions

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for the CDF & DØ collaborations

Motivation

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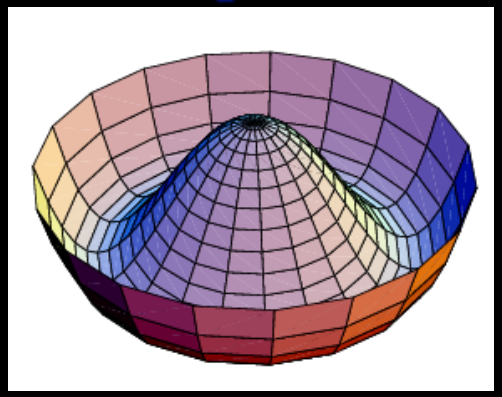
Electroweak Symmetry Breaking

- Gauge invariant → no mass term
- Higgs mechanism [with U(1) vector field]
  - $L = (D_\mu\phi)^*(D^\mu\phi) - V(\phi) - \frac{1}{4} F_{\mu\nu}F^{\mu\nu}$
    $\equiv \partial_\mu + ieA_\mu, \quad F_{\mu\nu} \equiv \partial_\nu A_\mu - \partial_\mu A_\nu$
    $V(\phi) = \mu^2\phi^*\phi + |\lambda|(\phi^*\phi)^2$
    - ϕ is complex scalar doublet: Higgs field
  - $e^2 A_\mu A^\mu \phi^*\phi$ in $(D_\mu\phi)^*(D^\mu\phi)$



$\langle\phi\rangle = v/\mathrm{sqrt}(2)$

Spontaneous symmetry breaking
$\mu^2>0$ (hot) potential minimum at $\phi=0$
$\mu^2<0$ (cold=present world) at $\phi\neq0$

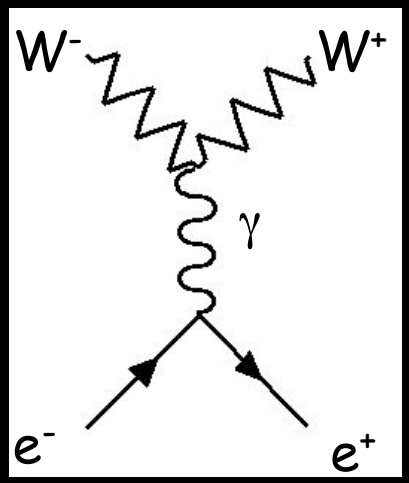
$(e^2v^2)/2\cdot A_\mu A^\mu$ ← mass term!!

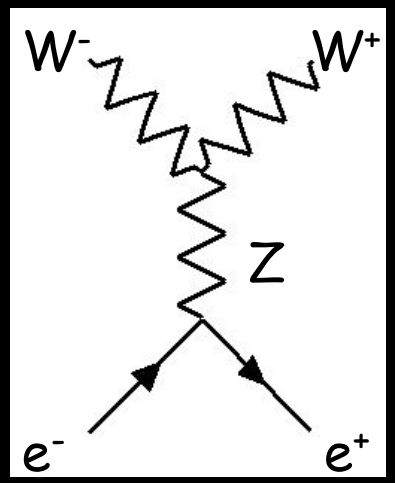
- One Higgs doublet in SM
  - 4 degree of freedom - 3 x (gauge boson) → one Higgs boson

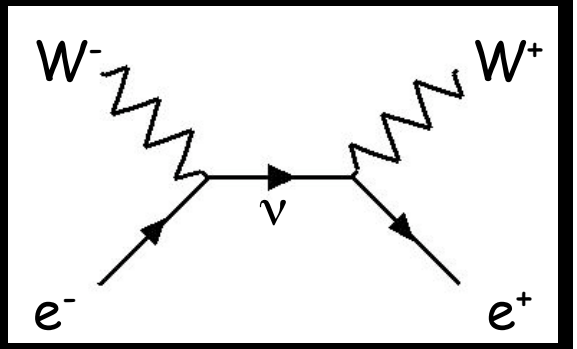
Why is Higgs Preferred?

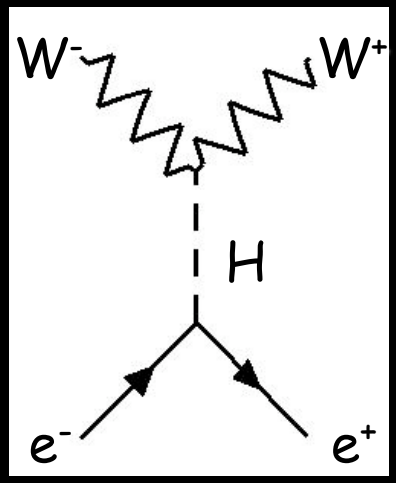
- Unitarity: individual diagram diverges with sqrt(s)
  - gauge cancellation
    - spin 1 intermediate state
  - <u>spin 0 component</u> due to wrong helicity state of e^+e^- ← must be canceled by spin 0 particle

proportional to mass → Higgs coupling!

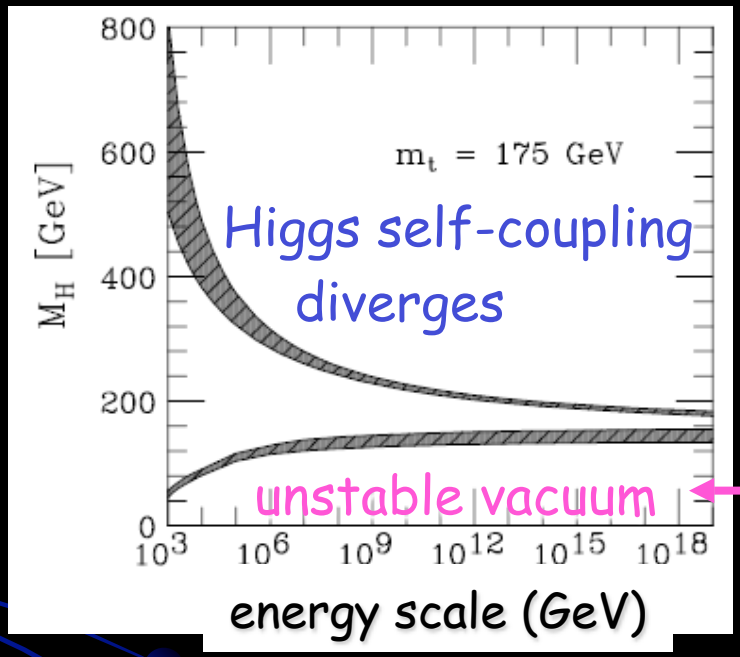




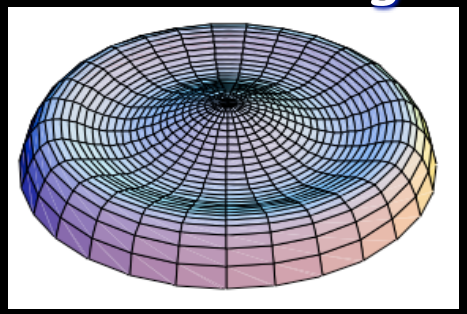




Higgs Mass



- M_H > 114.4 GeV @95% CL search by LEP2
- M_H < 175 (207) GeV @95% CL global EW fitting



- Needs to be light (160-180 GeV) for a theory valid up to Plank scale
- Finding a Higgs at M_H ~ 120 GeV would be an evidence of new physics

➔ 115-200 GeV is our target mass range

If the symmetry is not broken…?

- Fermion remains massless
- Nucleon mass almost unchanged, but proton would be heavier than neutron
- Spontaneous symmetry breaking by QCD → W/Z mass ~1/2500 (W,Z vs π) → very rapid inversed beta decay ($p \rightarrow n + e^{+} + \nu$)
- Unstable proton → no hydrogen atom

→ Completely different world !!

Mechanism of electroweak symmetry breaking is the mystery relevant for existence of ourselves

Experimental Strategy and Detector

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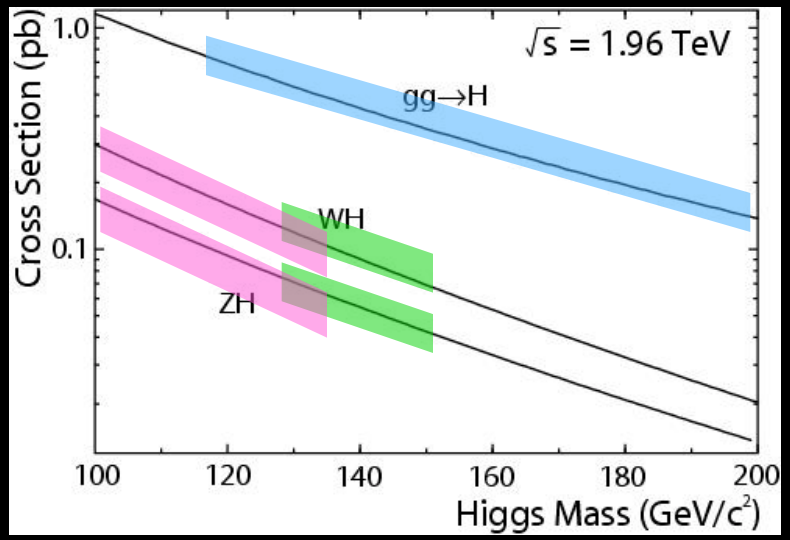
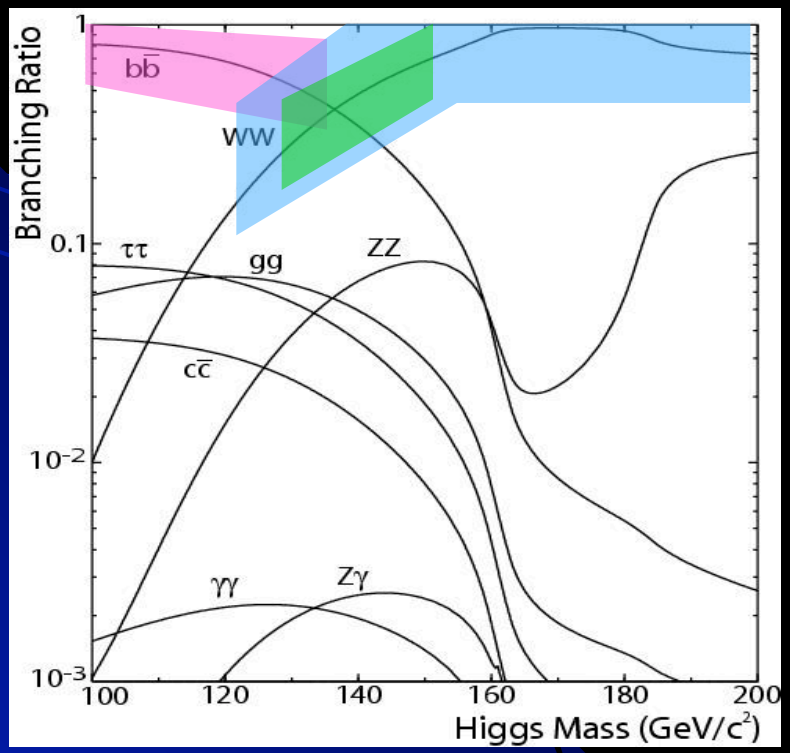
Search Strategy

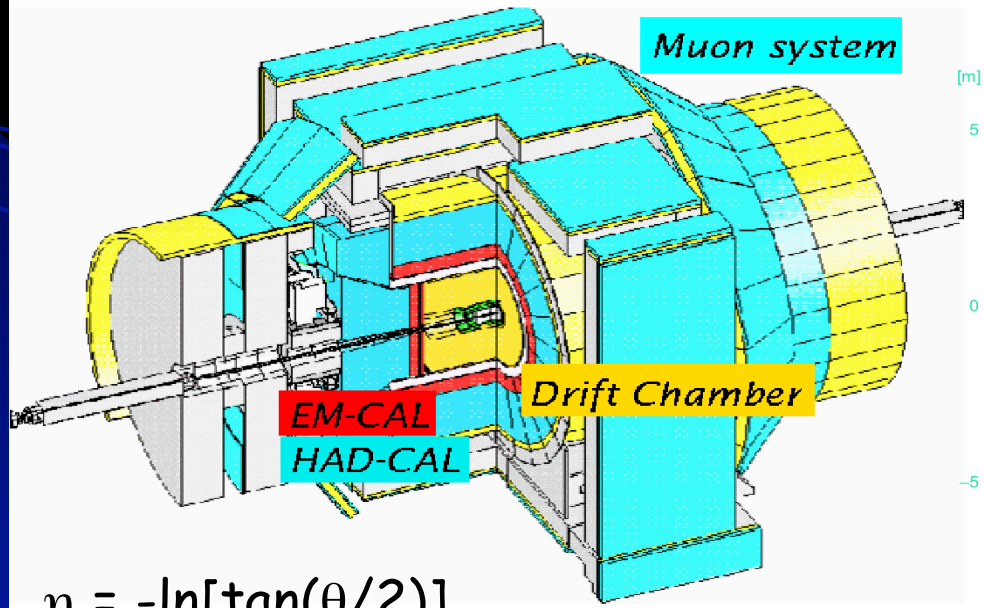


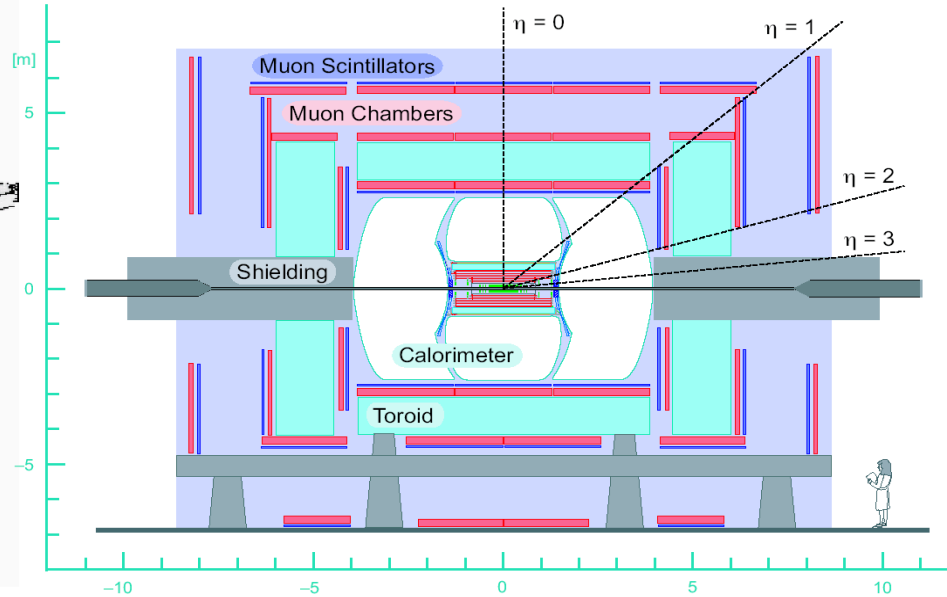


- M_H < 135 GeV
  - H → b b-bar dominant
  - too much BG in gg → H → b b-bar
  - → qq→W/Z+H(→bb)
- For high M_H range
  - H → WW dominant
  - → gg → H → WW
- For medium M_H range
  - W/Z+H(→WW) helps

The Detector

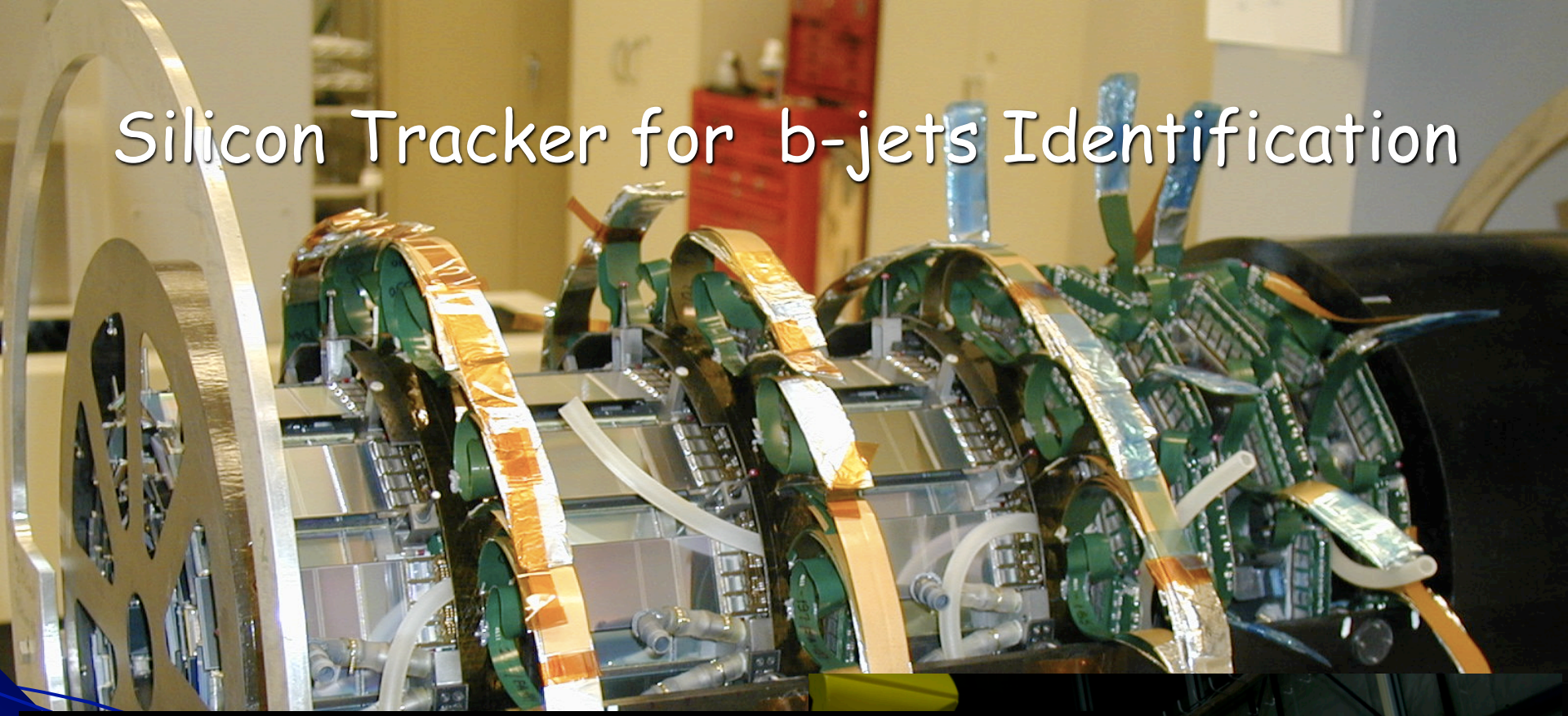
CDF acceptances (used)		DØ acceptances (used)	
tracking (Si-Vtx.)	$\lvert\eta\rvert \leq 2.0$	tracking (Silicon)	$\lvert\eta\rvert \leq 3.0$
Drift Chamber: high precision tracking	$\lvert\eta\rvert \leq 1.0$	Scintillating Fibers: tracking/triggering	$\lvert\eta\rvert \leq 1.6$
Em-Cal: e/γ	$\lvert\eta\rvert \leq 1.1$	Em-Cal: e/γ	$\lvert\eta\rvert \leq 3.0$
Had-Cal: jets/$\not{E}_T$	$\lvert\eta\rvert \leq 3.0$	Had-Cal: jets/$\not{E}_T$	$\lvert\eta\rvert \leq 4.0$
Em: scintillator/lead, Had: scintillator/steel ($e/\pi \approx 1.3$)		Compensating liquid Ar with Ur/Cu ($e/\pi \approx 1.06$)	
μ-acceptance	$\lvert\eta\rvert \leq 1.0$	wide muon coverage	$\lvert\eta\rvert \leq 2.0$





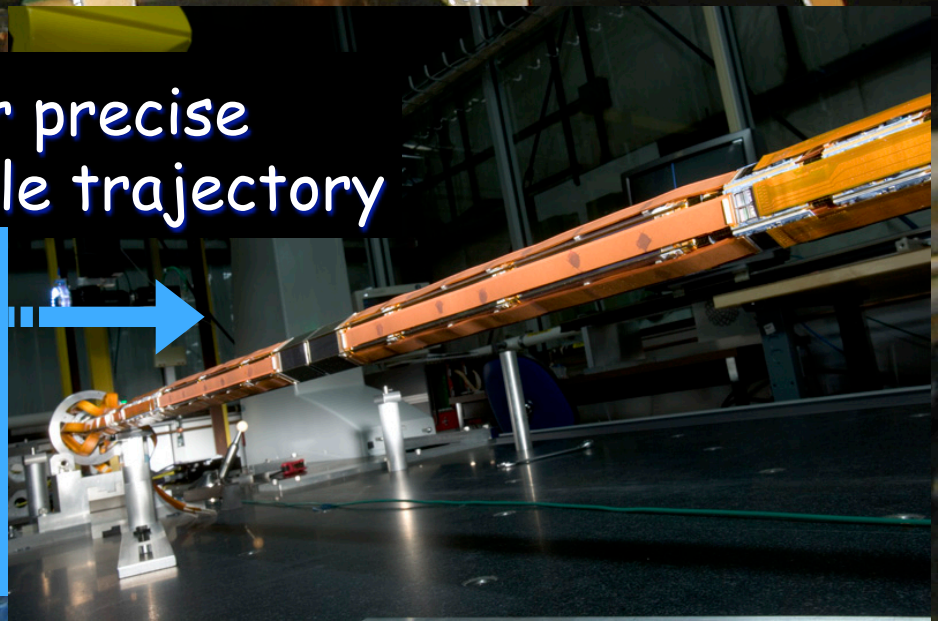
$\eta = -\ln[\tan(\theta/2)]$

Silicon Tracker for b-jets Identification

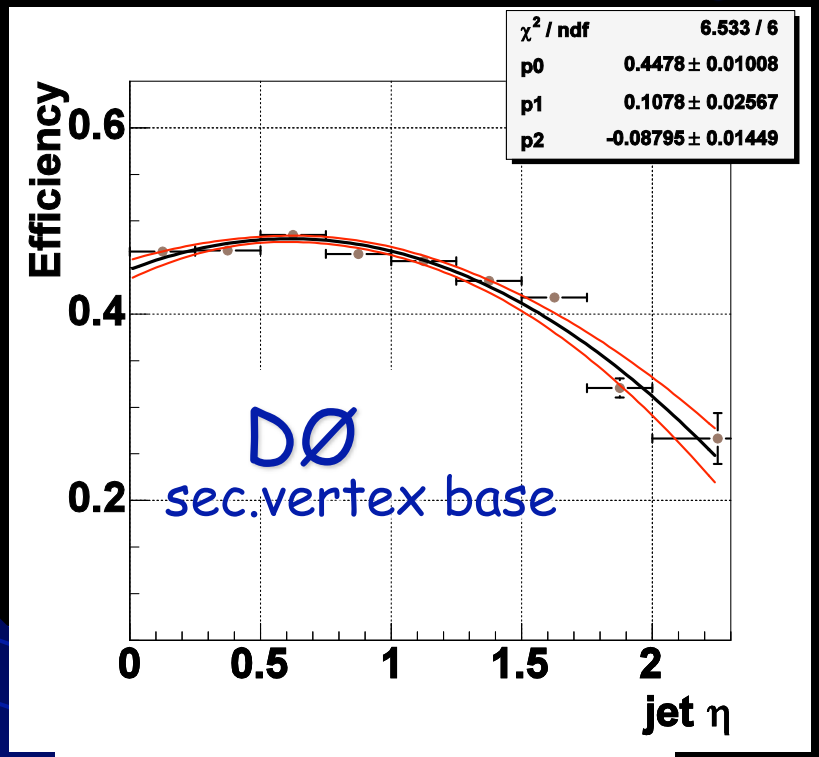


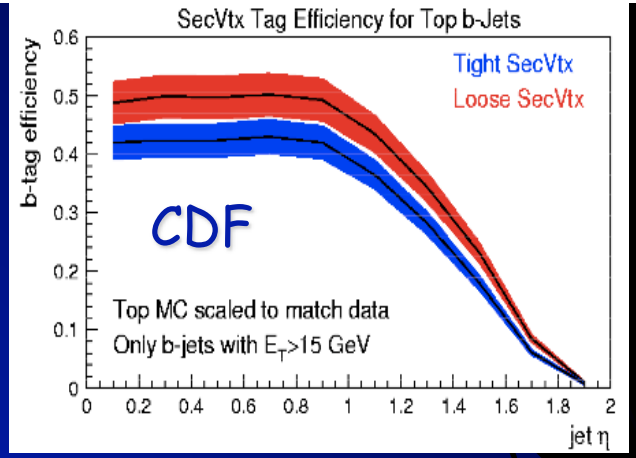
Silicon micro-strip detector for precise measurement of charged particle trajectory

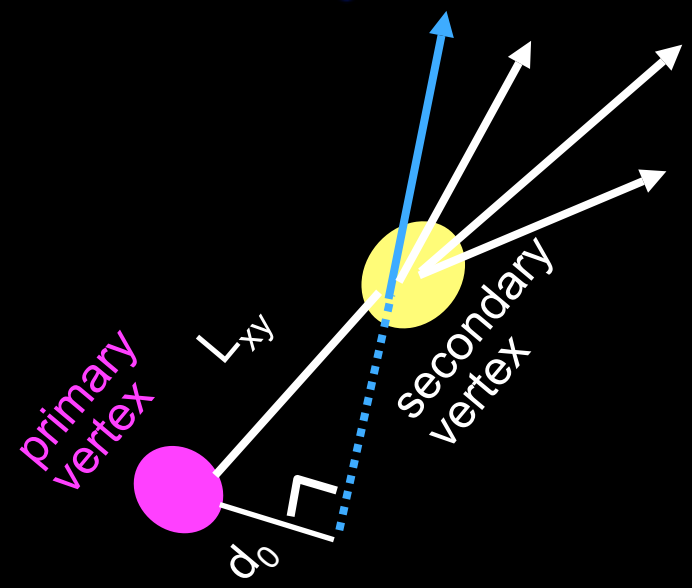
- New silicon detector in DØ for improvement of b-jet ID
  - installed and tested in this shutdown period



Identification of b-jets







- $c\tau_{b\text{-hadron}}$ ~ 400-500 μm → travel by a few mm from primary vertex
  - S(Lxy) = Lxy/σ(Lxy) or S(IP) = $d_0/\sigma d_0$ with V^0 (Ks etc.) removal

Higgs Search Status

- Standard Model
- MSSM

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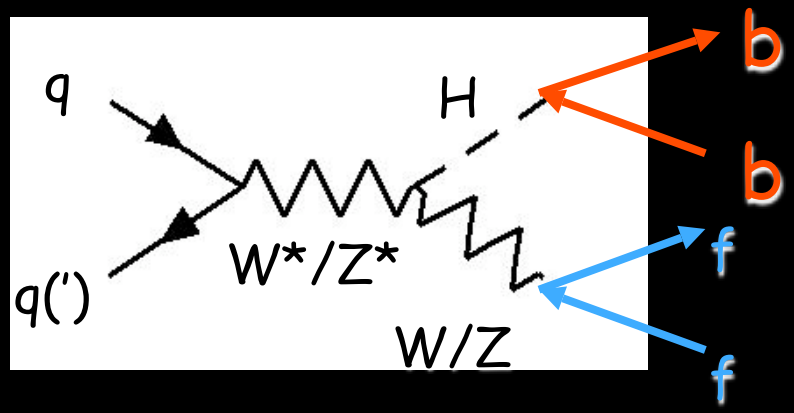
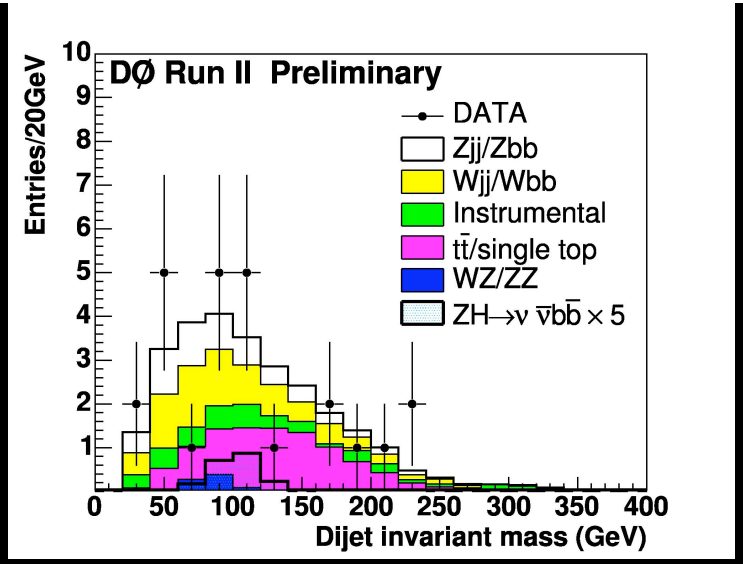
Standard Model – Low Mass Higgs



- $\sigma \times Br(W/Z \rightarrow ff)$ = 0.015-0.003 pb
- Backgrounds
  - W/Z+bb/cc/jj, top, W/Z +Z(→bb), QCD…
- b-jet ID, jet energy resolution are important

- W/Z identification
  - W→lν: high p_T isolated lepton + missing E_T → W mass
  - Z→νν: large missing E_T
  - Z→ll: high p_T isolated dilepton → Z mass
- High p_T dijets with b-ID → dijet mass

$Z(\rightarrow \nu\nu)H(\rightarrow bb)$ L_{int} = 261 pb^{-1}



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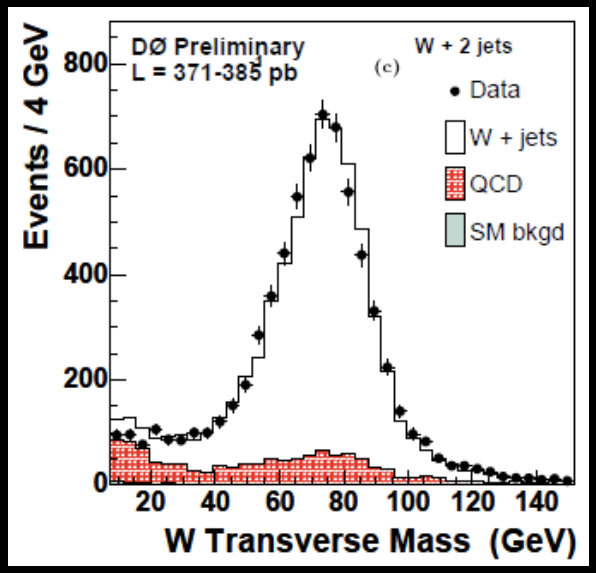
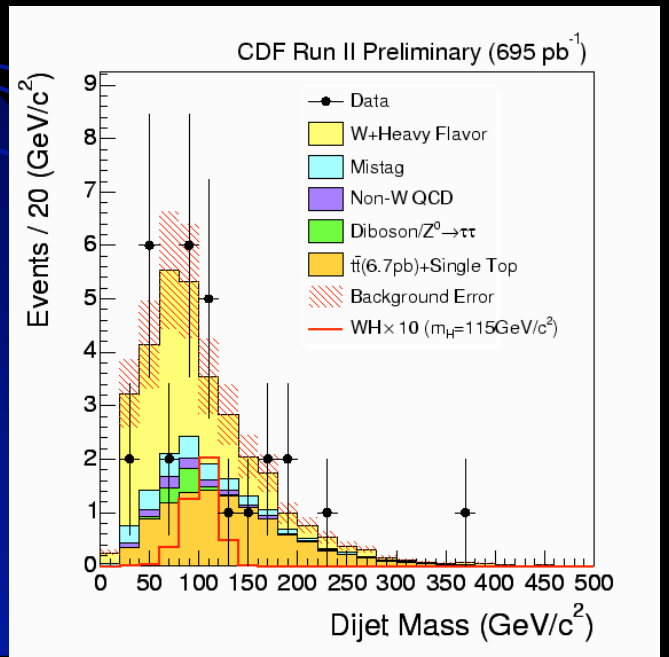
W(→lν)H(→bb)

- p_T(e or μ) > 20 GeV
- Missing E_T > 20 GeV (CDF)
  > 25 GeV (DØ)
- CDF: jet E_T>15 GeV, |η|<2
- DØ: jet E_T>20 GeV, |η|<2.5
- b-jet tagging





- Consistent with SM background expectations
  - backgrounds well understood

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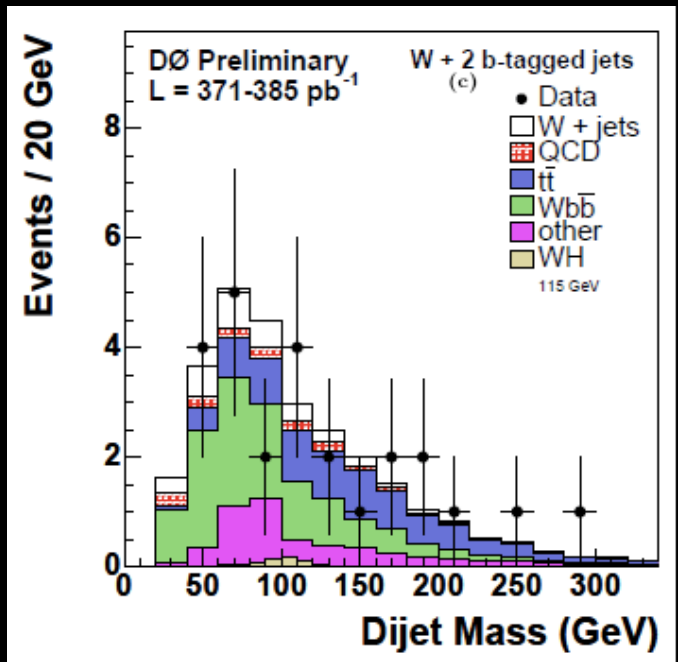
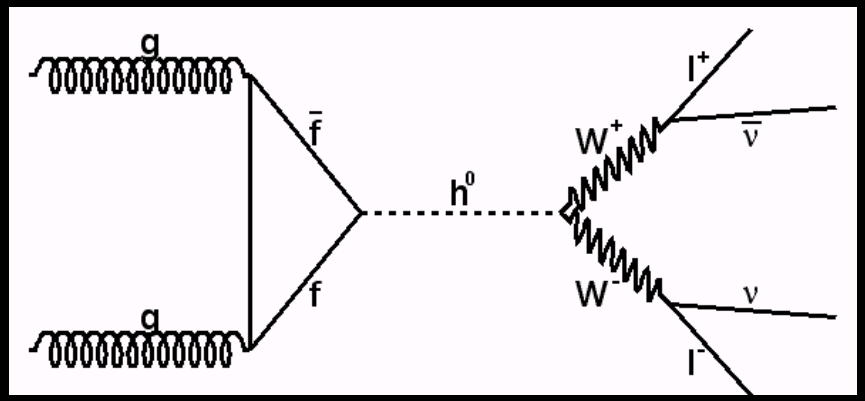
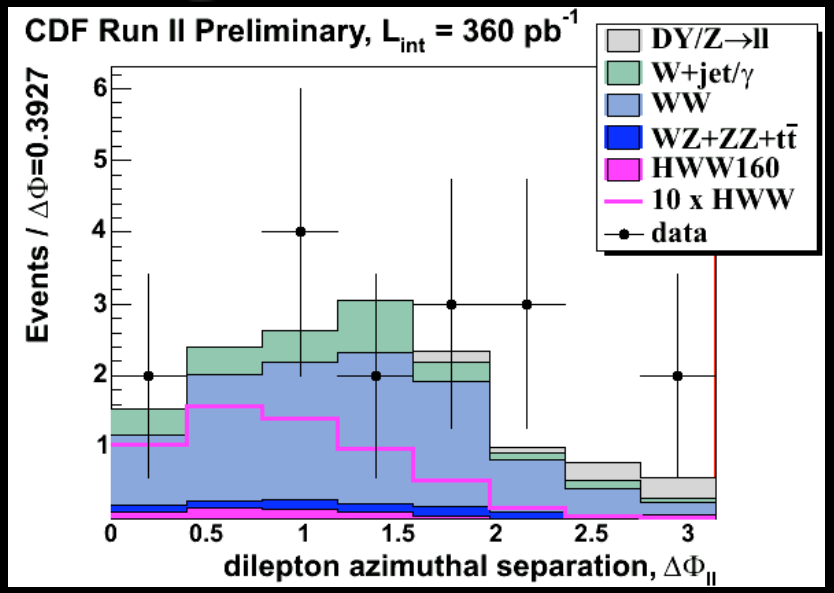
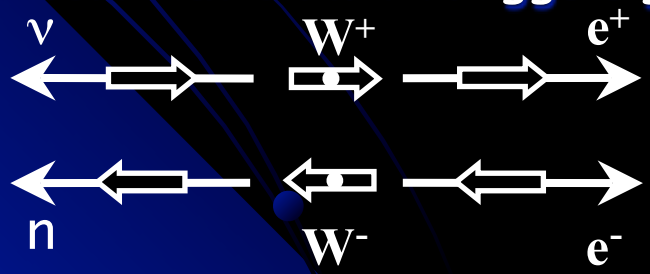


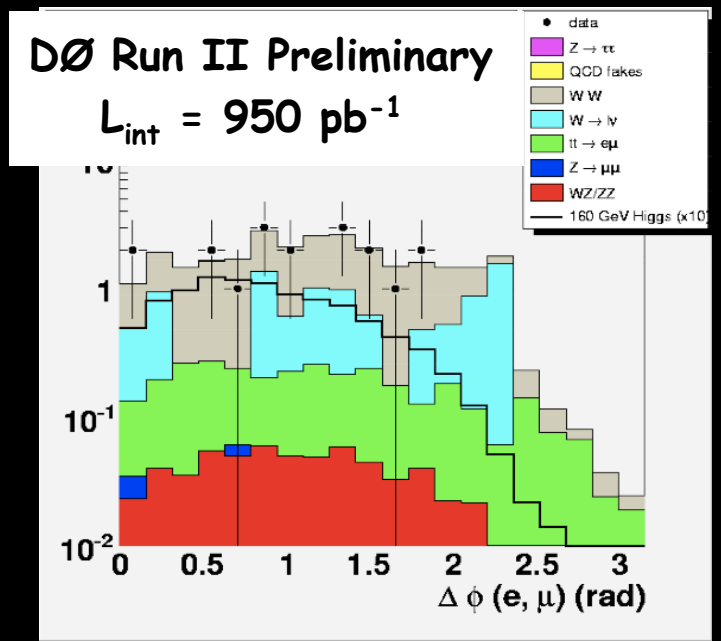
Standard Model – High Mass





- Two isolated high p_T leptons + missing E_T
- Dominant background is $qq \rightarrow WW$
  - different decay angular correlation with Higgs signal





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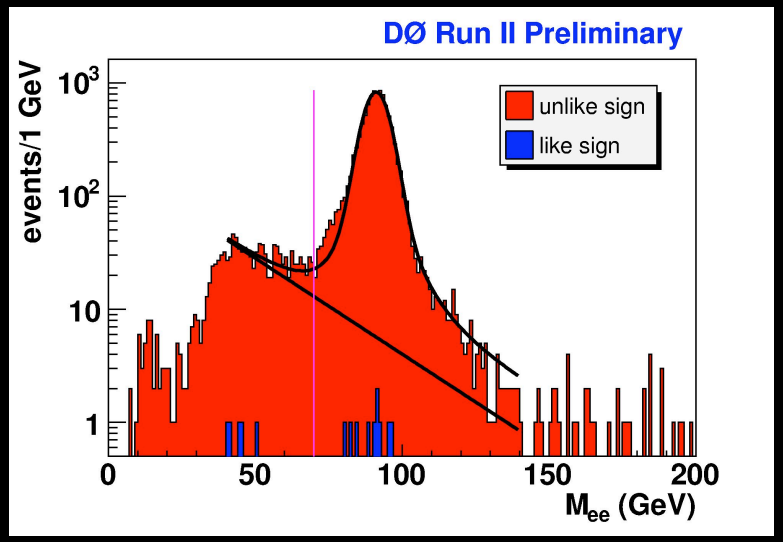
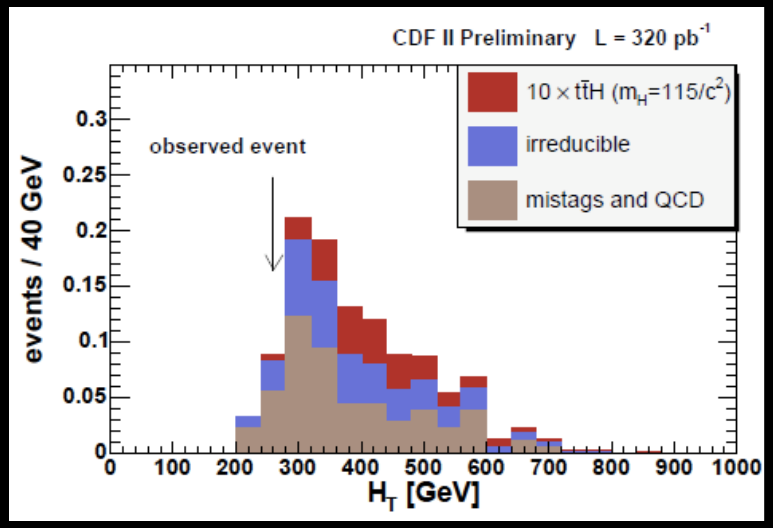
The Other Analyses

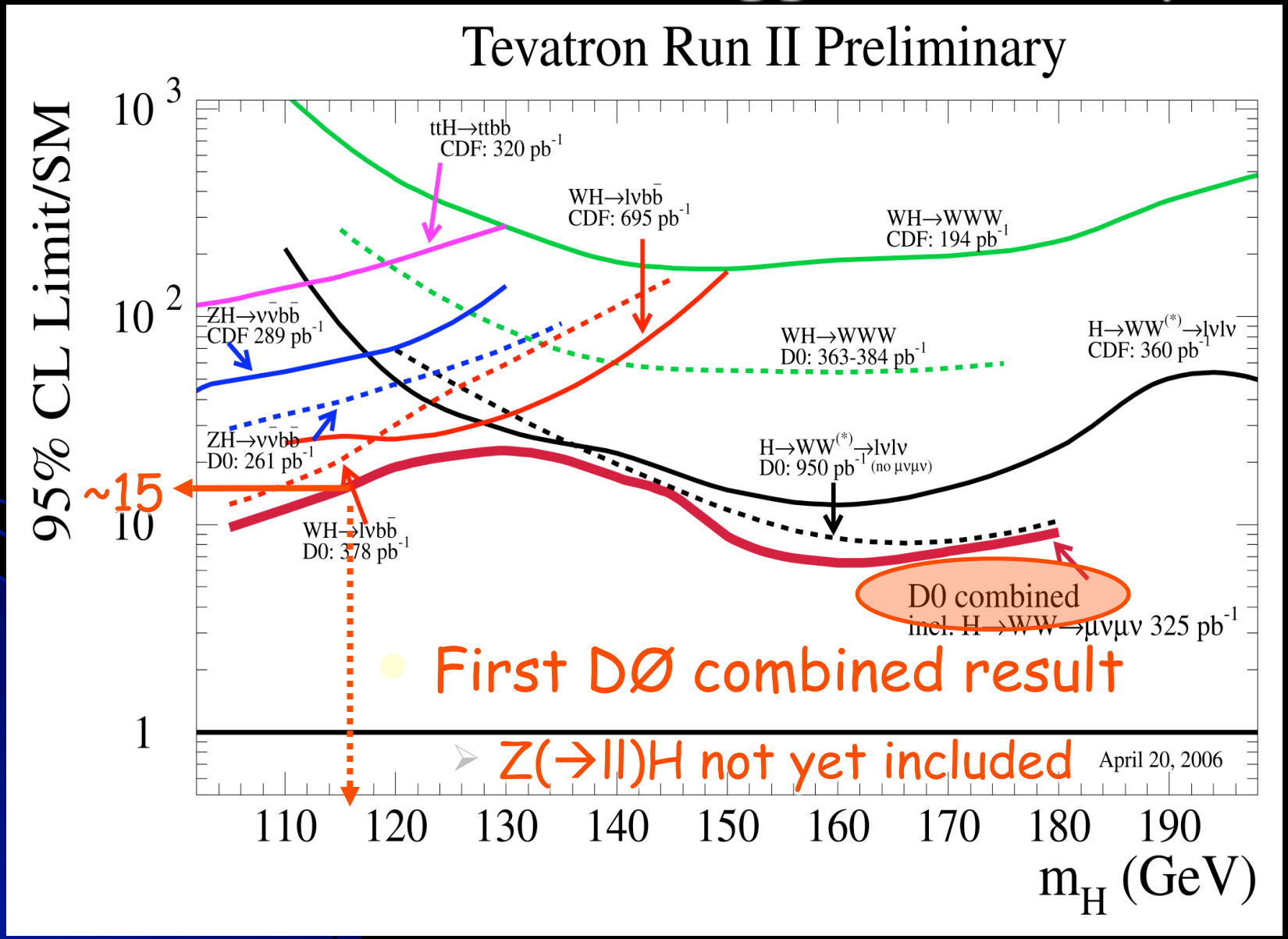
- $WH(\rightarrow WW) \rightarrow l^{\pm}\nu l^{\pm}\nu X$
  - high p_T isolated **like sign** dilepton ($ee, \mu\mu, e\mu$)
  - large missing E_T
  - diboson production is the main background due to charge mis-identification



- $t(\rightarrow bW)t(\rightarrow bW)H(\rightarrow bb)$
  - exactly one e or μ
  - missing E_T
  - 5 or more jets
  - 3 or more b-jets

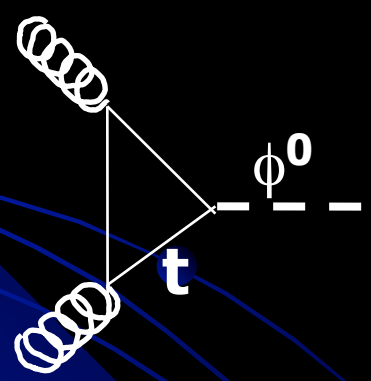


Standard Model Higgs Summary



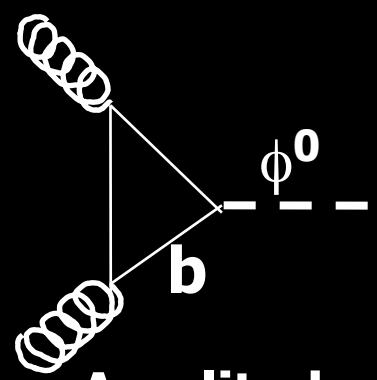
MSSM Higgs

- Two Higgs doublet in MSSM to avoid anomaly
  - 8 degrees of freedom – 3 x (longitudinal polarization of $W^{\pm}$ and Z) → 5 scalars ($\underbrace{h, H, A}_{\equiv\ \phi^0}$, $H^{\pm}$)
  - $\tan\beta = \langle H_u \rangle / \langle H_d \rangle$

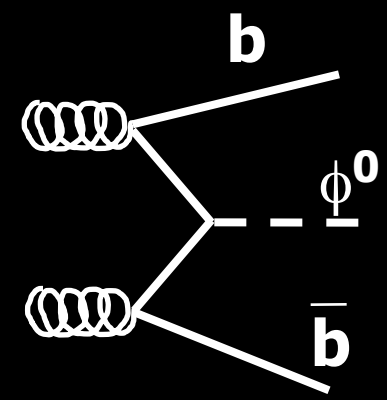


Amplitude ∝ 1/tanβ

+



Amplitude ∝ tanβ

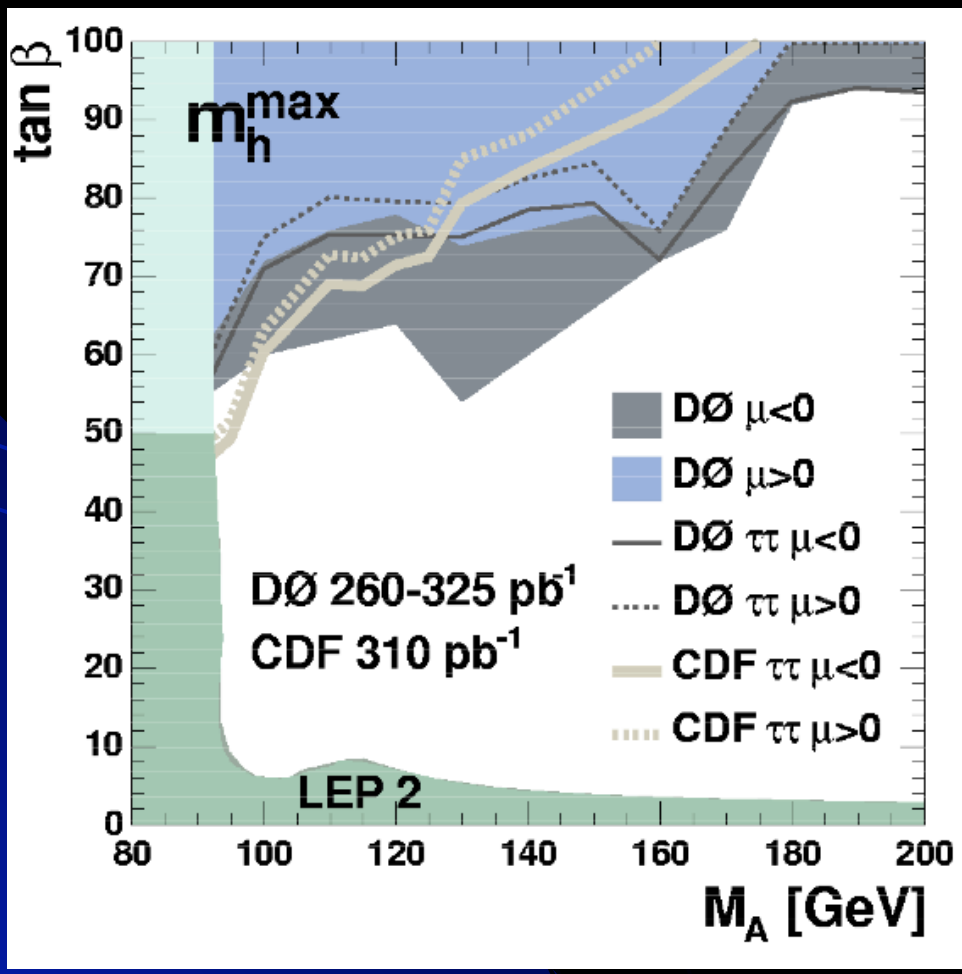


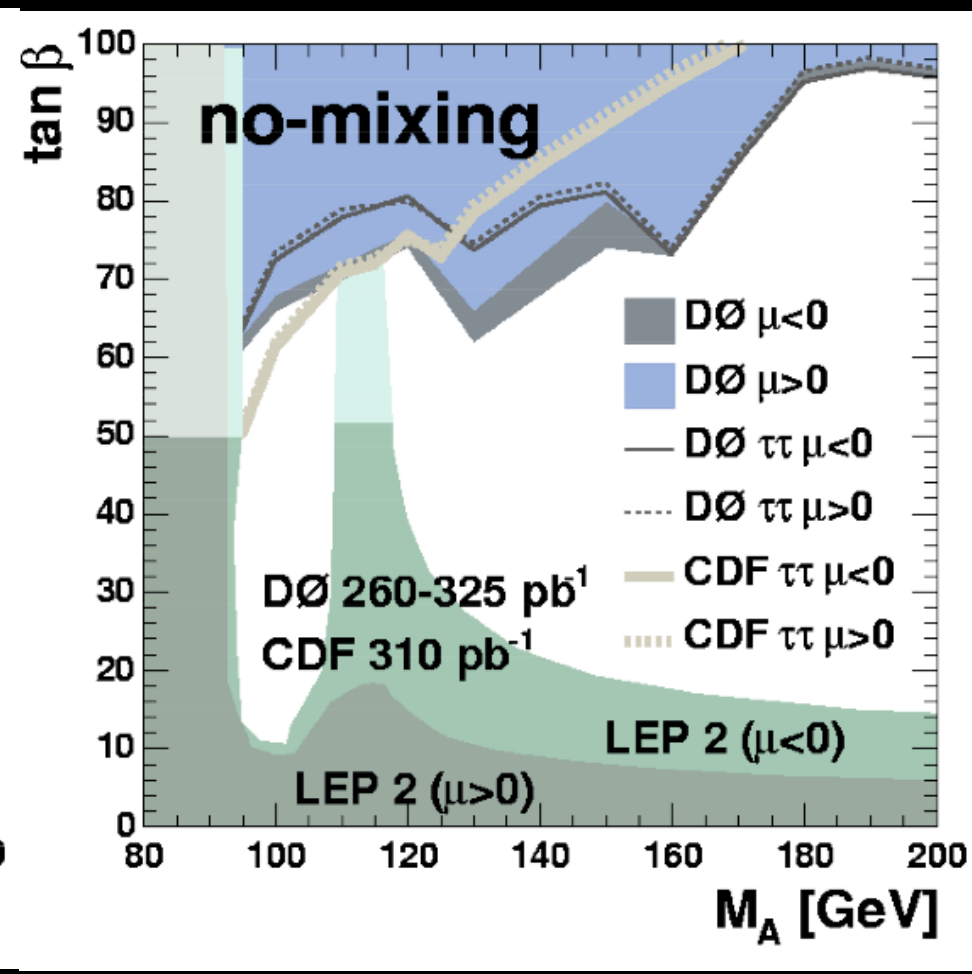
Amplitude ∝ tanβ

  - At high tanβ, σ(h or H, A) is enhanced
  - Br(A→bb)~90%, Br(A→ττ)~10%

MSSM Higgs Search Status

- CDF: $\phi^0 \rightarrow \tau\tau$; DØ: $b(b)\phi^0 \rightarrow b(b)bb$, $\phi^0 \rightarrow \tau\tau$





Prospects

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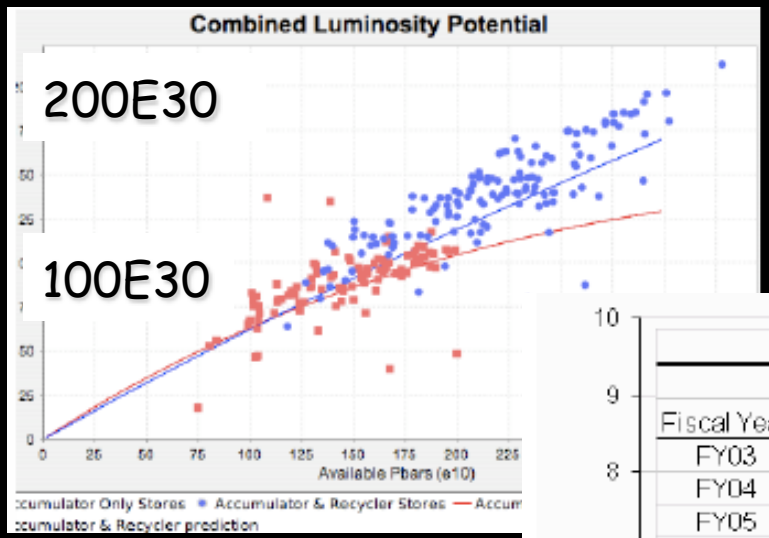
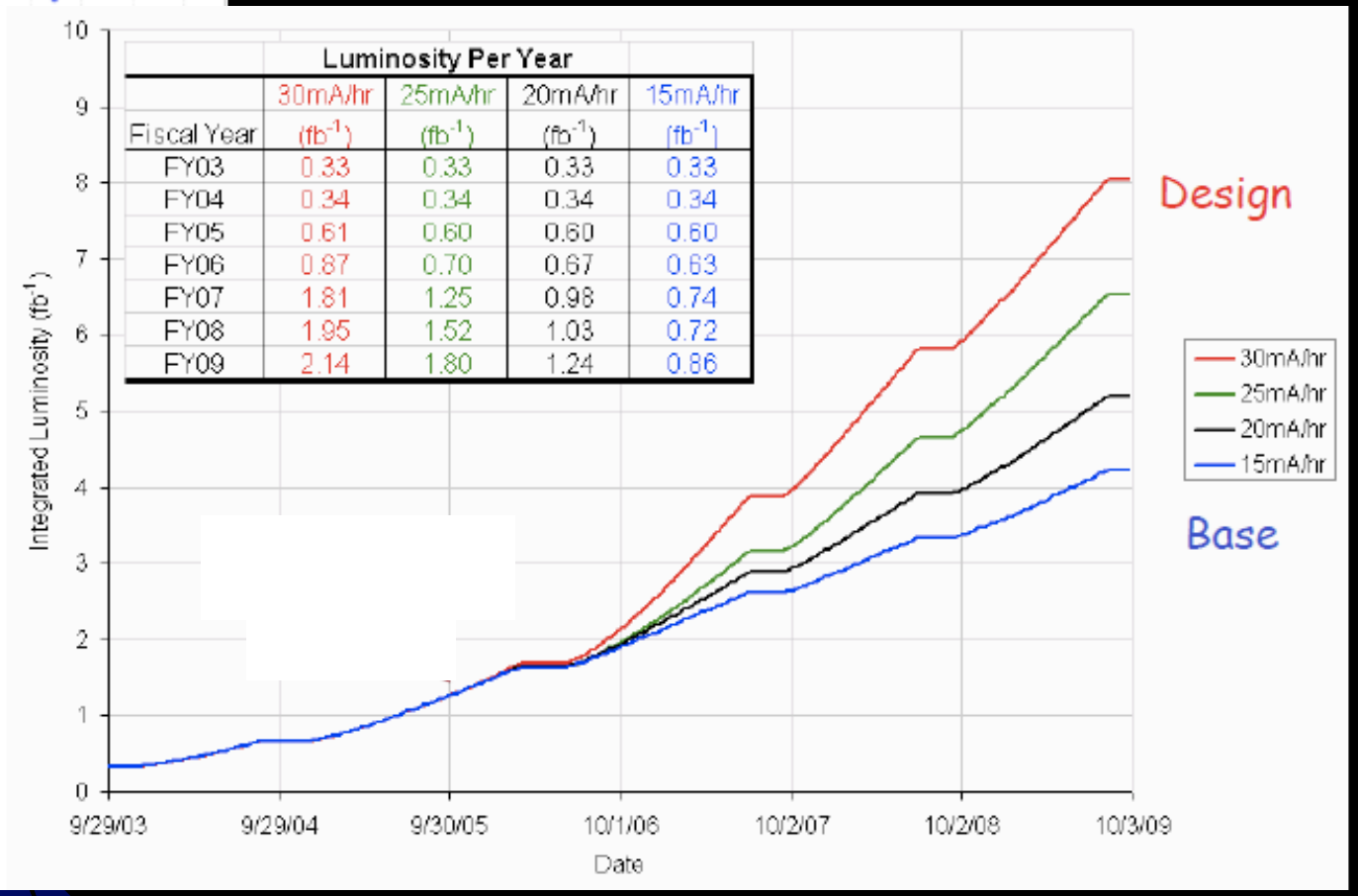
Luminosity



- Improvement by the recycler as a storage ring of p-bar
- Electron cooling at the recycler

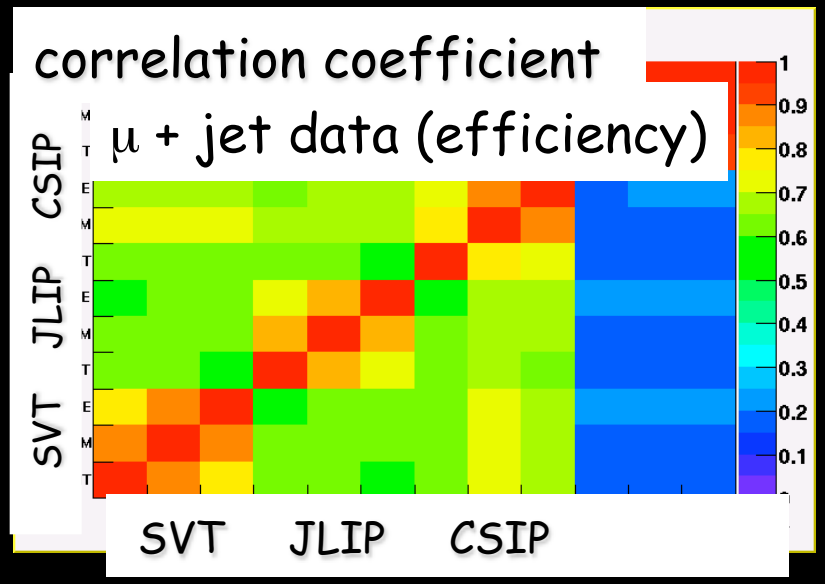


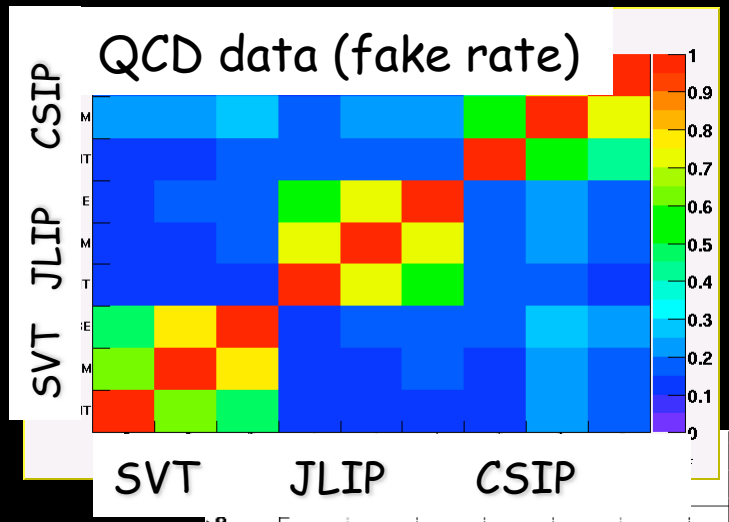
Luminosity Per Year

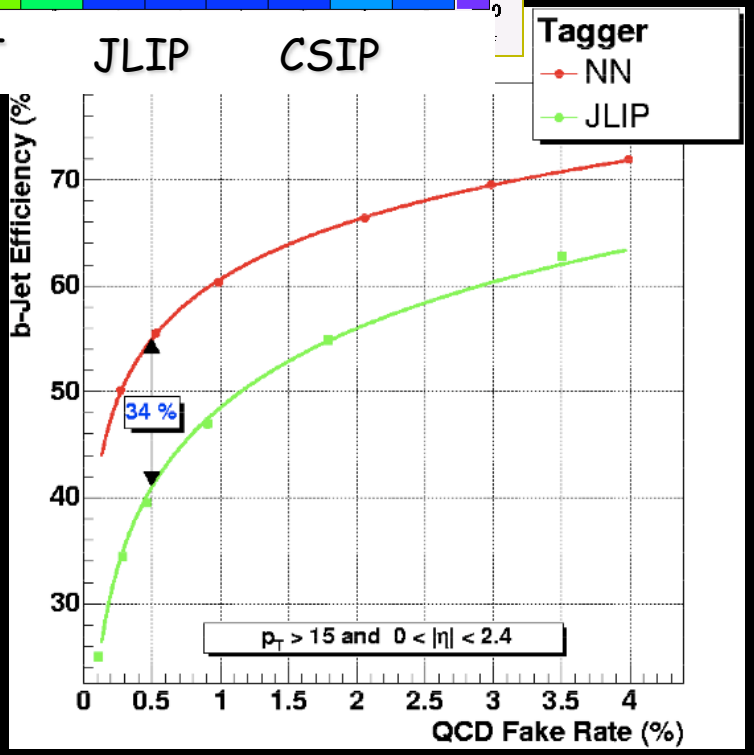
Fiscal Year	30mA/hr (fb^{-1})	25mA/hr (fb^{-1})	20mA/hr (fb^{-1})	15mA/hr (fb^{-1})
FY03	0.33	0.33	0.33	0.33
FY04	0.34	0.34	0.34	0.34
FY05	0.61	0.60	0.60	0.60
FY06	0.87	0.70	0.67	0.63
FY07	1.81	1.25	0.98	0.74
FY08	1.95	1.52	1.03	0.72
FY09	2.14	1.80	1.24	0.86

- 4-8 fb^{-1} by 2009

Improvement of b-tag at DØ







- Three b-tag algorithms in DØ; SVT, JLIP, and CSIP
  - correlated in efficiency
  - small correlation for fake
  - ➔ significant improvement by combination by Neural Network (~30% per jet)

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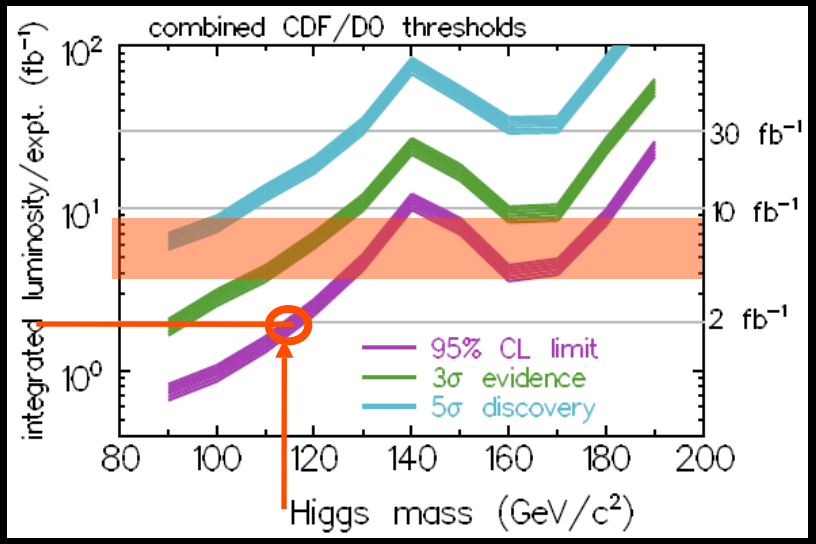
The Future of SM Higgs Search

- Comparison w.r.t. old sensitivity study
  - For M_H=115GeV: Limit/σ =15 @~330pb^{-1} by DØ alone vs 95% CL exclusion @2fb^{-1}



item	gain		
		cross efficiency	1.1
lum(2/0.33)	2.4	L0/L1cal	1.1
NN b-tag	1.4	multivariate selection	1.5
jet resolution	1.2	reduced syst.	1.1
new channels	1.1	combine with CDF	1.4
increased acceptance	1.1	grand total	14

- We can reach very close to the sensitivity study

Conclusions

Conclusions

- Mechanism of electroweak symmetry breaking is a profound mystery
- Searches have been carried out with 194-950 pb^{-1} of data
  - Remaining events consistent with SM backgrounds
- If the (SM) Higgs exists and is light, there is a great potential to find the Higgs

Now is the Time to Search for Higgs at Tevatron

Backup

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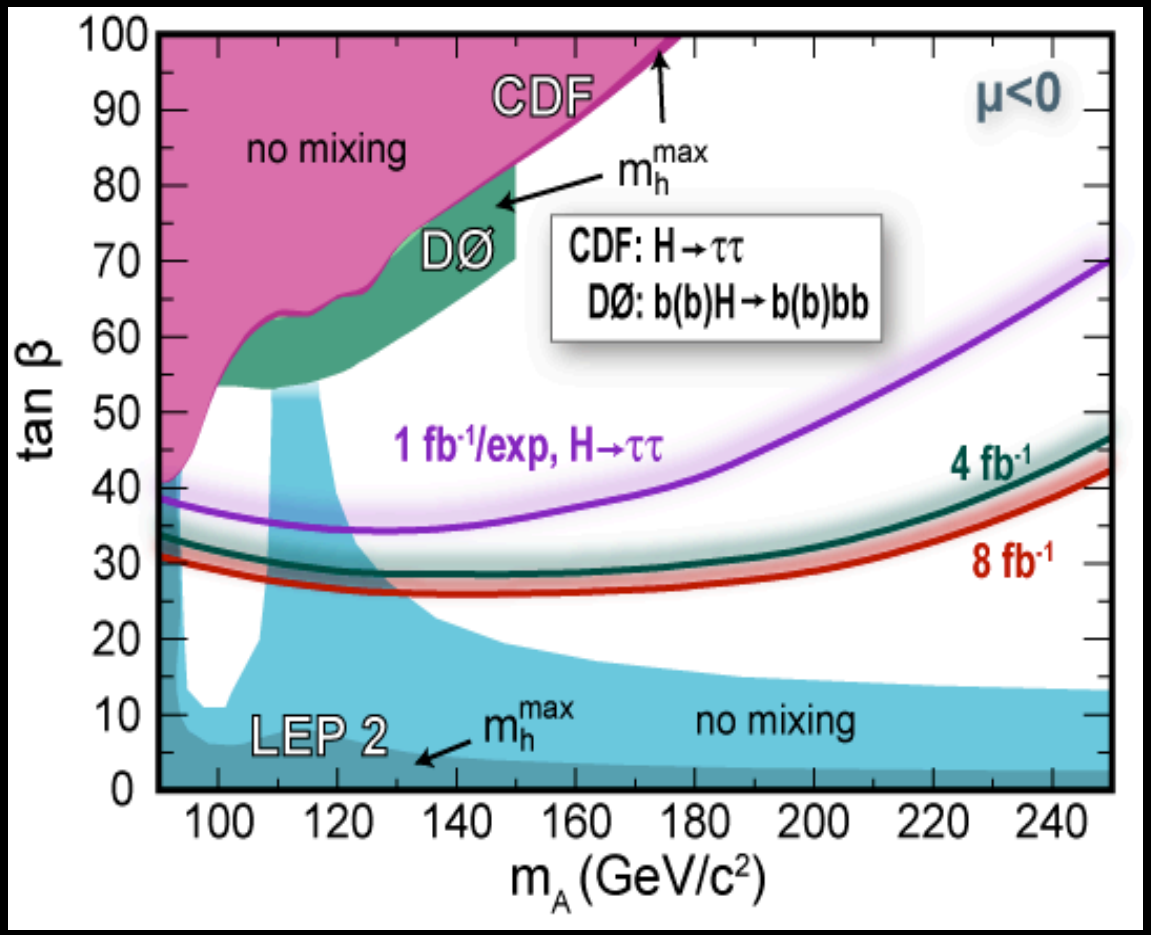
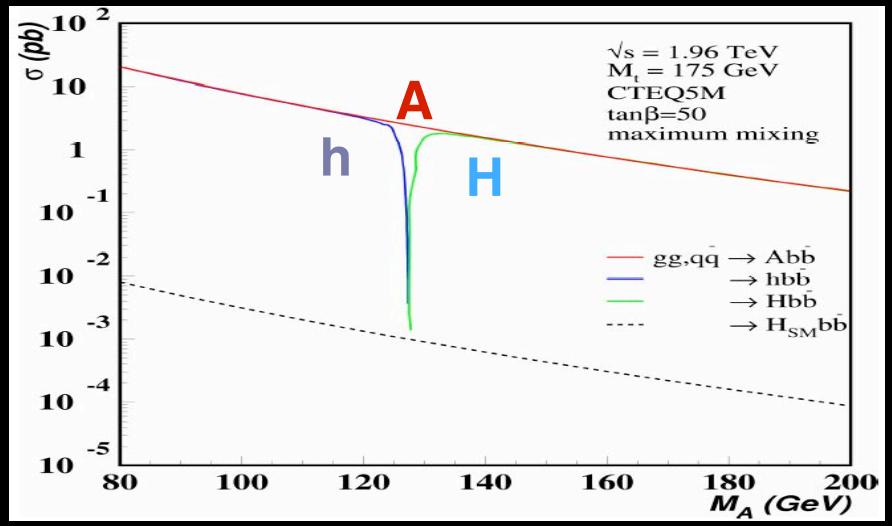
Projection of MSSM Higgs Search

- Tevatron will probe below $\tan\beta = \frac{m_t}{m_b}$



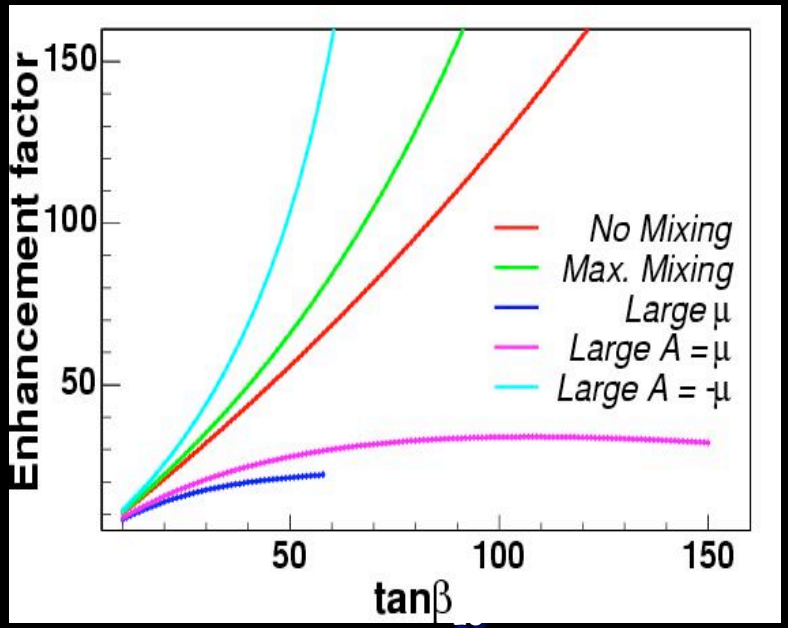
MSSM Parameters

	$m_h - \max$	$no - mixing$
M_{SUSY}	$1\,TeV$	$2\,TeV$
X_t	$2\,TeV$	0
M_2	$200\,GeV$	$200\,GeV$
μ	$\pm 200\,GeV$	$\pm 200\,GeV$
$m_{\tilde{g}}$	$800\,GeV$	$1600\,GeV$



$$\sigma \times BR_{SUSY} = 2 \times \sigma_{SM} \times \frac{\tan^2\beta}{(1+\Delta_b)^2} \times \frac{9}{9+(1+\Delta_b)^2}$$

radiative correction depending on many parameters

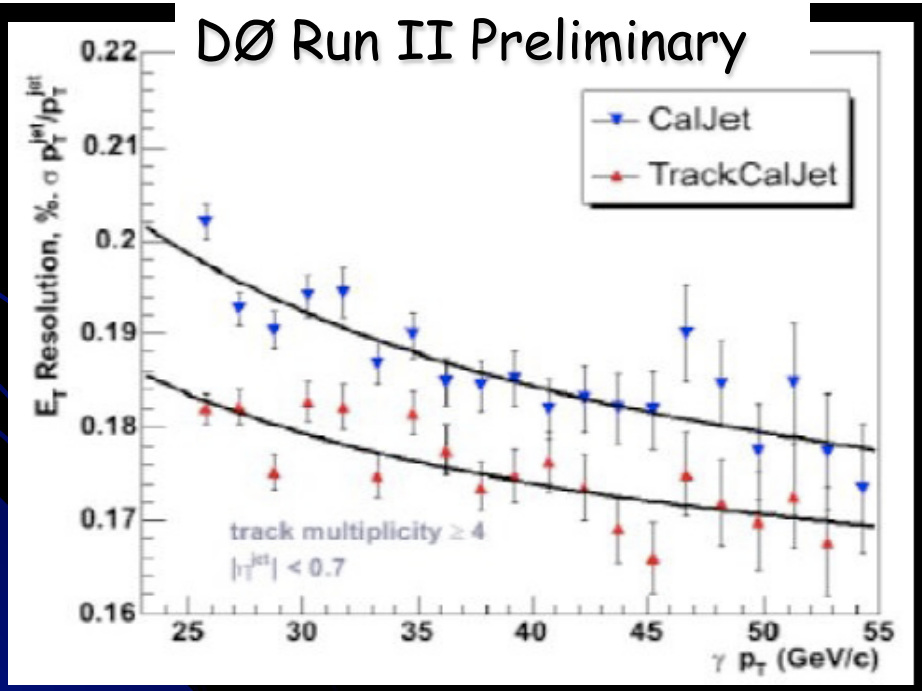


Kazu Hanagaki

New Technique of Jet Reconstruction

- Charged track information in jet reconstruction
  - $E_{cal} = E(e/\gamma) + E(\text{neutral hadron}) + E(\text{chrgd had})$
  - $E_{trkcal} = E_{cal} - E^{expect}(\text{chrgd had}) + E_{trk}(\text{chrgd had})$

resolution measured in γ+jet data



similar improvement at CDF as well

b-tag efficiency measurement at DØ

- Solve 8 equations for 8 unknowns

example to measure JLIP efficiency with the combination of muon tag

before b-tag

$$n = n_b + n_{cl}$$ μ+jet

$$p = p_b + p_{cl}$$ μ+jet && opposite tag

b-tag by muon

$$n^{\mu} = \varepsilon_b^{\mu} n_b + \varepsilon_{cl}^{\mu} n_{cl}$$

$$p^{\mu} = \varepsilon_b^{\mu} p_b + \varepsilon_{cl}^{\mu} p_{cl}$$

unknowns

b-tag by tagger under testing

$$n^{JLIP} = \varepsilon_b^{JLIP} n_b + \varepsilon_{cl}^{JLIP} n_{cl}$$

$$p^{JLIP} = \beta\, \varepsilon_b^{JLIP} p_b + \alpha\, \varepsilon_{cl}^{JLIP} p_{cl}$$

b-tag by both tagger

$$n^{\mu,JLIP} = \kappa_b\, \varepsilon_b^{\mu} \varepsilon_b^{JLIP} n_b + \kappa_{cl}\, \varepsilon_{cl}^{\mu} \varepsilon_{cl}^{JLIP} n_{cl}$$

$$p^{\mu,JLIP} = \kappa_b\, \beta\, \varepsilon_b^{\mu} \varepsilon_b^{JLIP} p_b + \kappa_{cl}\, \alpha\, \varepsilon_{cl}^{\mu} \varepsilon_{cl}^{JLIP} p_{cl}$$

number of events

Low Mass Higgs Search at DØ

- $W(\rightarrow e/\mu+\nu)H(\rightarrow bb)$: σxBR = 0.015 pb
- $Z(\rightarrow ee/\mu\mu)H(\rightarrow bb)$: σxBR = 0.003 pb
- $Z(\rightarrow \nu\nu)H(\rightarrow bb)$: σxBR = 0.015 pb

for 261-389 pb^{-1}	eff	S	B	S/sqrt(B)
$W(\rightarrow e\nu)H$	3.4%	0.18	4.7	0.08
$W(\rightarrow \mu\nu)H$	1.7%	0.10	4.0	0.05
$Z(\rightarrow ee)H$	4.5%	0.05	1.4	0.04
$Z(\rightarrow \mu\mu)H$	5.9%	0.05	3.1	0.03
$Z(\rightarrow \nu\nu)H$	5.2%	0.21	9.0	0.07
$W(\rightarrow \nu)H$ miss lep.	4.2%	0.15	9.0	0.05