Prospect for Higgs Discovery at the TeVatron Run II

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on behalf of the CDF & DØ collaborations

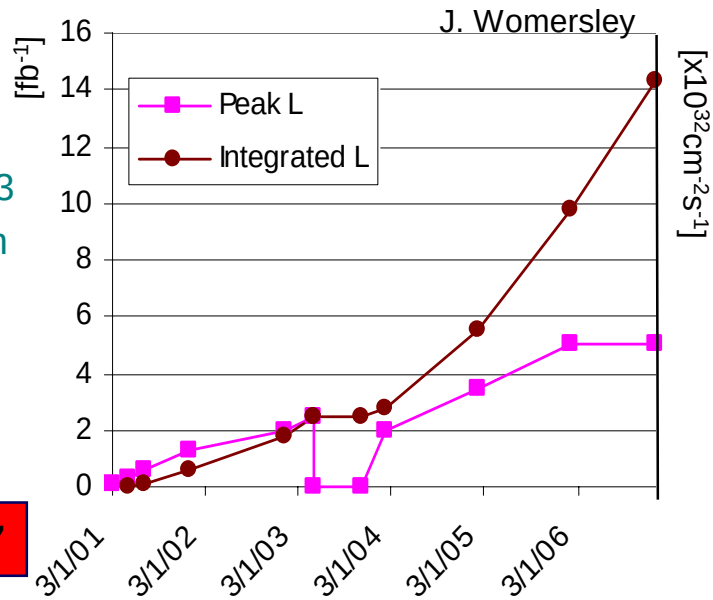
Collider Upgrade for run II

TeVatron at Run II

- Main Injector (MI)
  120-150 GeV/c p-pbar beams into TeVatron
- pbar Recycler (in MI)
  factor x 2 in luminosity
- Machine Parameters:

	Run Ib	Run IIa	Run IIa	Run IIb
Bunch Trains	6x6	36x36	140x108	140x108
Bunch Spacing (ns)	3,500	396	132	132
Luminosity $x10^{32}cm^{-2}s^{-1}$	0.16	0.8	2.1	5.2
Intgr. Luminosity (fb^{-1}/exp.)	0.1	1.1	2.1	14.8
CM Energy (GeV)	1,800	2,000	2,000	2,000
interactions/crossing	2.6	2.3	1.9	4.8

- Run II Program:
  - 132ns by late 2002
  - $2x10^{32}cm^{-2}s^{-1}$ by end of 2003
  - Shutdown for Run IIb silicon at the end of 2003/2004
  - $5x10^{32}cm^{-2}s^{-1}$ by 2005
  - $4fb^{-1}$ / year until 2007



15 fb^{-1} / experiment by 2007

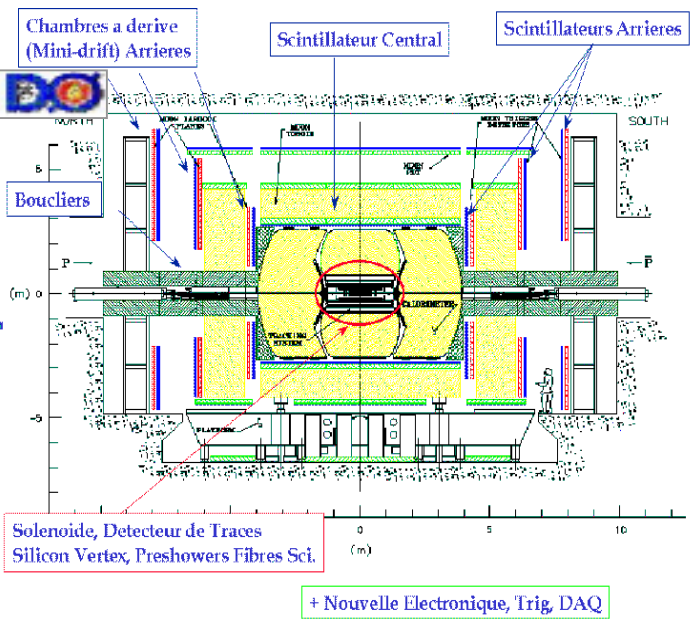
Detectors Upgrade for Run II

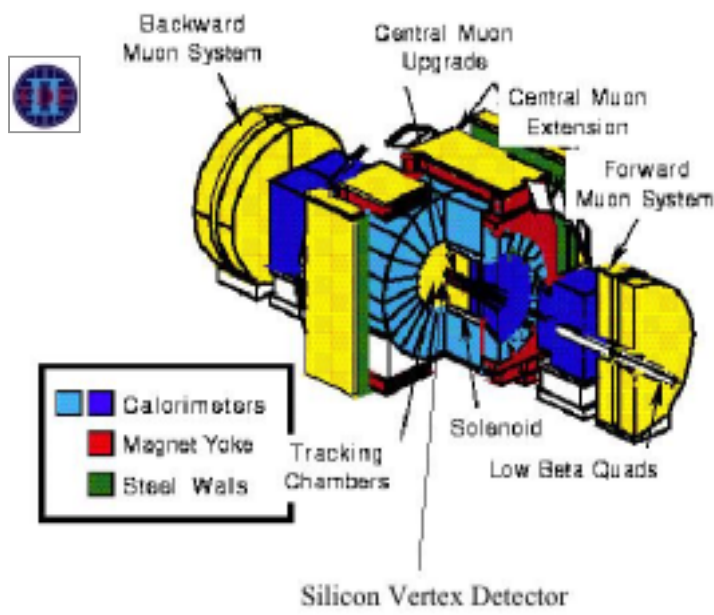
CDF:

- Replaced (wire) tracking system
- Improved Silicon Vertex detector for 3D vertexing
- Inhanced muon coverage in the forward region

DO:

- New Tracking system inside a 2T supra-conducting solenoid magnet
- New Silicon Detector for 3D vertexing
- New preshower detectors for electron/photon ID
- Enhanced muon coverage in central / forward region



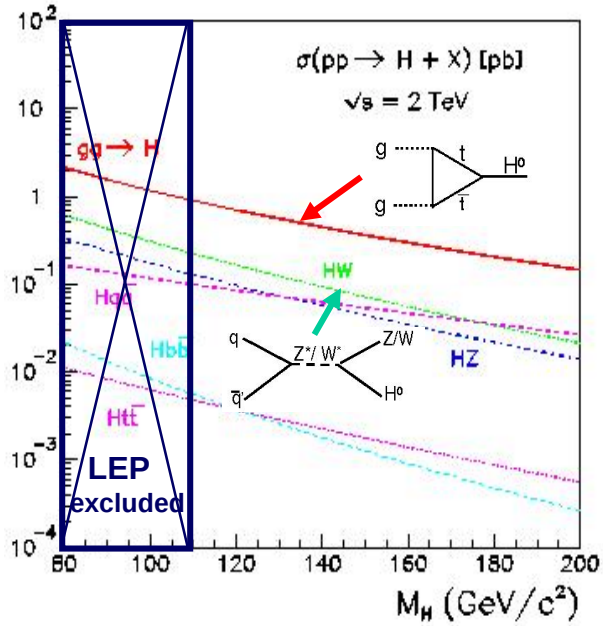


CDF & DØ ready for a high luminosity Run II

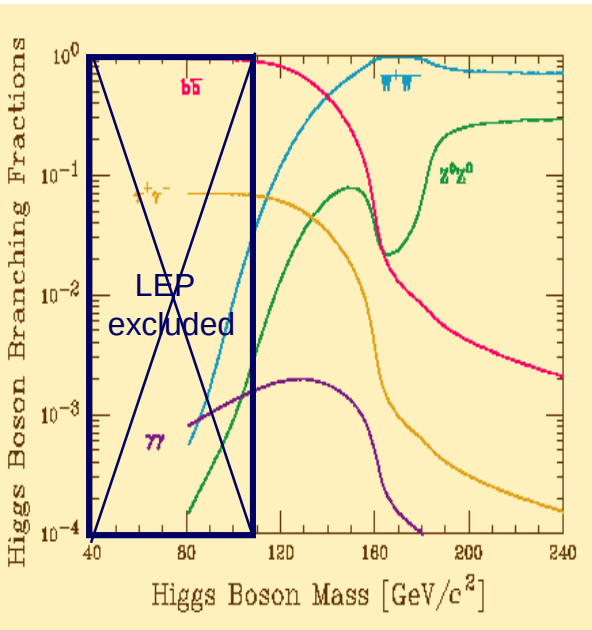
Higgs Discovery Channels

Higgs Production

- Inclusive Higgs cross-section high
  - ~1 pb = 1000 events / fb^{-1}
- But dominant decay H → bb
  swamped by background !
- Associate WH, ZH production
  - ~0.2 pb = 200 events / fb^{-1}
- Leptonic decays of W/Z help give the needed background rejection



Higgs Final States



m_H<130-140 GeV

- WH → lνbb bkgd: Wbb, WZ,tt, t
- ZH → l lbb bkgd: Zbb, ZZ,tt
- ZH → ννbb bkgd:QCD,Zbb,ZZ,tt

m_H>130-140 GeV

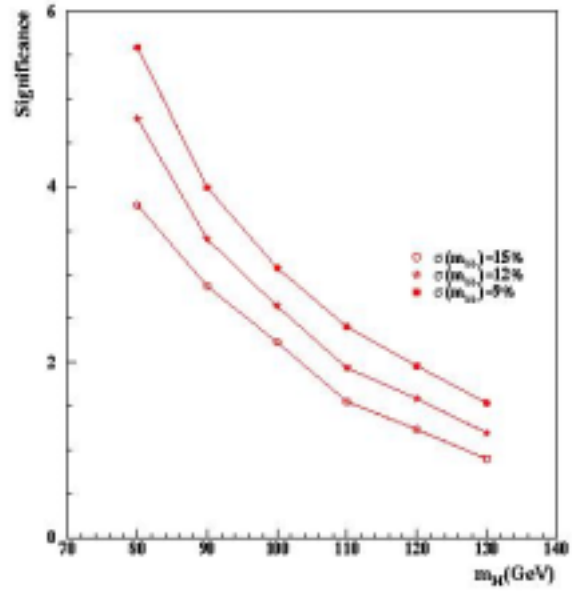
- gg → H →W*W* bkgd: Drell-Yann,
- WH →WW*W* WW, ZZ, tt, tW,ττ
- Initial Signal:background ratio: 7×10^{-3} !

The $WH \rightarrow l\nu b\bar{b}$ Channel

Selection:

"Most single powerful channel"

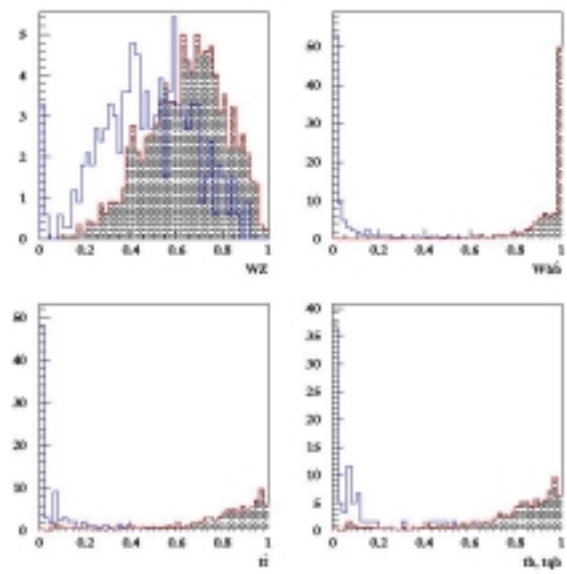
- key parameters:
  - b tagging: ε vs mistag
  - M($b\bar{b}$) resolution
- Discriminant variables:
  - high p_T lepton, high $\not{E}_T$
  - 2 b-tagged jets
- Dominant backgrounds:
  - $Wb\bar{b}$, $t\bar{t}$, single top, WZ



Expectations:

- S ~ 6 / fb^{-1}
- S/B ~ 10%

m_H(GeV)	110	120	130
σ_{WH} (pb)	0.22	0.16	0.12
$\varepsilon_{WH} \times BR$ (%)	~2.3	~2.3	~2.0
S/√B (1 fb^{-1})	**0.70**	**0.53**	**0.35**



- Neural Net Analysis improves S/√B by ~30%

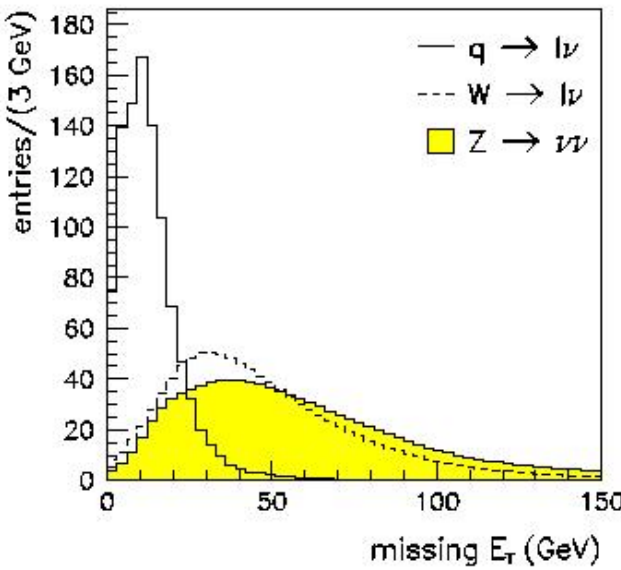
- needs M(bb) resolution ~ 10%
- needs good knowledge of Wbb

The ZH→νν̄bb̄ Channel

Selection:

σ × BR(ZH→ννbb) ~ σ × BR(WH→lνbb)

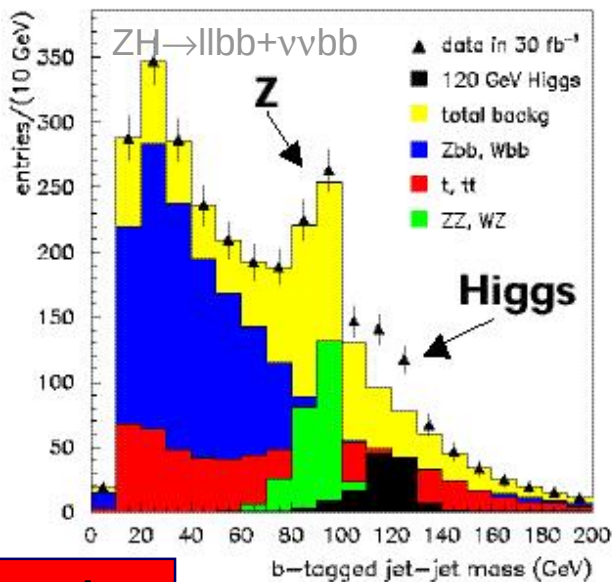
- Discriminant variables:
  - b tagging, M(bb) resolution
  - Jet Veto (rej. tt)
  - Missing E_T
  - $\Delta\Phi(\not\!\!E_T, \text{jet})$ (rej. QCD)
- Dominant backgrounds:
  - QCD bb̄ **No MC/data?**
  - Wbb̄, Zbb̄/cc̄



Expectations:

- S ~ 5 / fb^{-1}
- S/B ~ 15%
- M_H distribution

(QCD ~50% all bgd)



m_H(GeV)	110	120	130
BR xσ_{ZH} (pb)	0.022	0.010	0.013
S/√B (1 fb^{-1})	0.84	0.71	0.56

- needs QCD(bb) knowledge from data
- needs good knowledge of Zbb, Wbb

m_H = 120 GeV

The $H \rightarrow W^*W^* \rightarrow l^+ l^- \nu\bar{\nu}$ Channel

Selection:

- Discriminant Variables:
  - 2 high p_T lepton, high $\not\!\!E_T$
  - Jet Veto (rej. tt)
  - Spin correlation $\Phi(ll)$ (WW)
  - $M_T(ll\not\!\!E_T)$, $p_T(ll)$ (rej. $\tau^+\tau^-$)
  - Cluster Mass: (rej. WW)

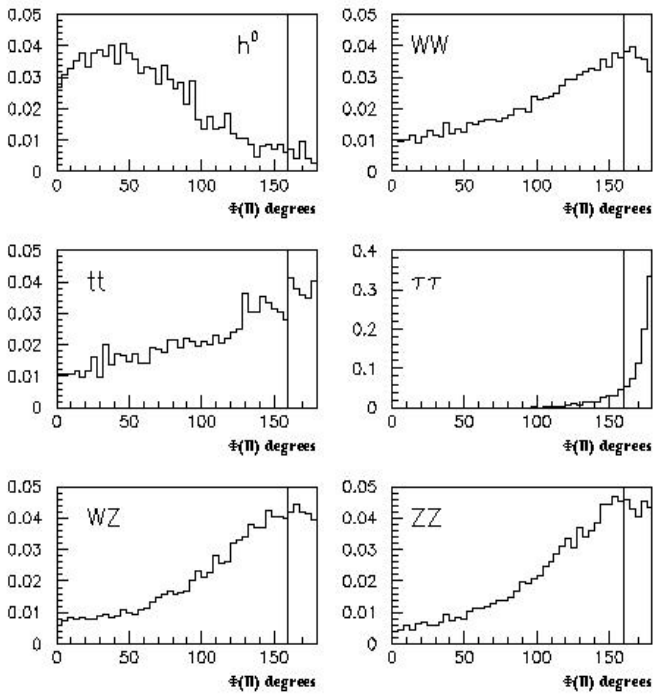
    $M_C=\sqrt{p_T^2(ll)+M_T^2(ll)} + \not\!\!E_T$

Likelihood function

- Dominant backgrounds:

  $W^+W^- \rightarrow l^+l^-\nu\nu$

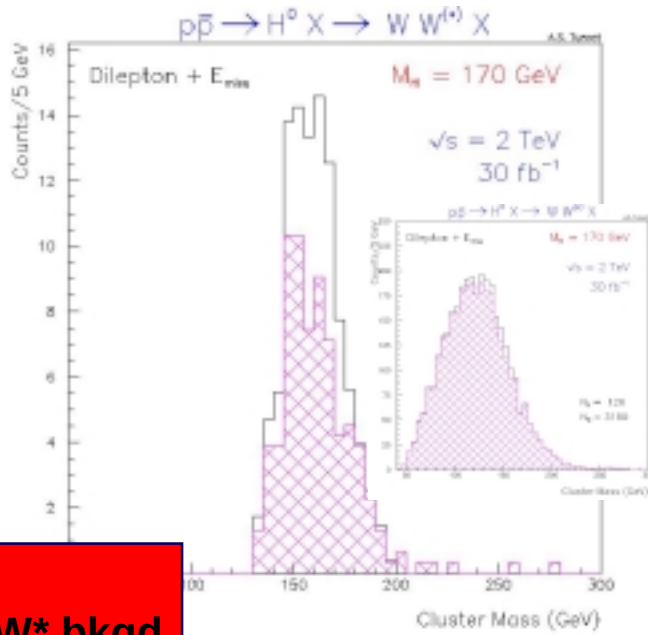
  W+fake, $t\bar{t} \rightarrow l^+l^-\nu\nu b\bar{b}$



Expectations:

- S ~ 2-3 / fb^{-1}
- S/B ~ 10-45%

$m_H(GeV/c^2)$	150	160	170
$\varepsilon \times BR(hW^*W^*) \times \sigma_h(fb)$	2.8	1.5	1.1
$S/\sqrt{B}$ (30 fb^{-1})	2.8	3.9	3.8

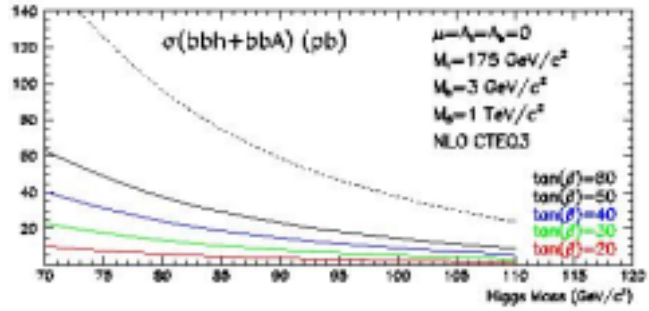


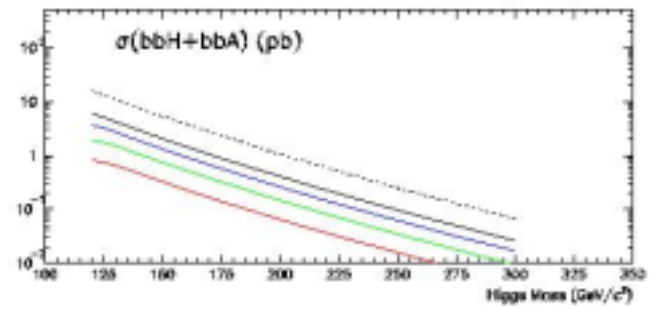
- requires high luminosity L
- needs good knowledge of WW* bkgd

MSSM Higgs Searches

MSSM Higgs production

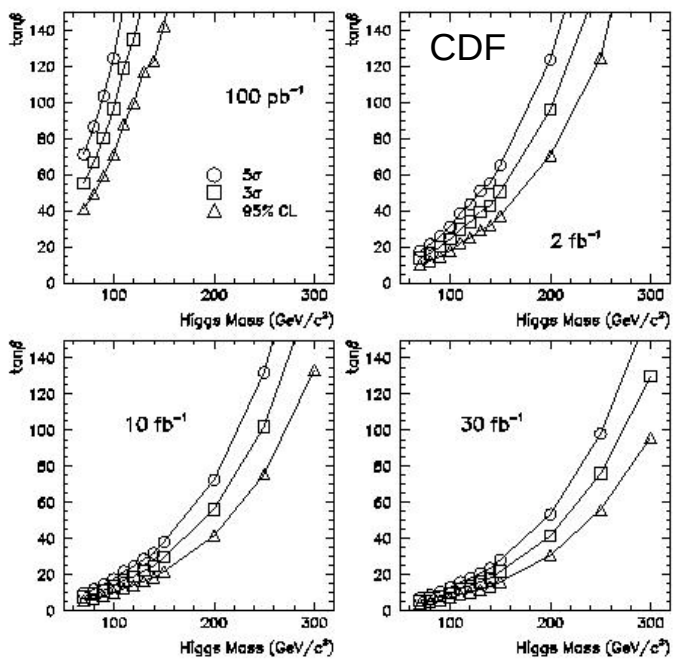
- Large tanβ:
  - Enhanced hbb/Hbb/Abb cross-sections ($\propto \tan^2\beta$)
  - High BR(h→bb)





Searches $p\bar{p} \to b\bar{b}\varphi \to b\bar{b}b\bar{b}$

- (φ = h,H,A)
- CDF run I analysis extended:
  - b-tag improvement
  - Displaced Vertex trigger
    80% improvement wrt run I
    lower multi-jet thresholds
- Analysis:
  - 4-b's jets final state
  - $E_T(j)$ cuts as $f(m_h)$
  - $\Delta\Phi(bb)$ (rej. g→bb)
- Background
  - QCD (bb/cc), Z/Wjj, tt



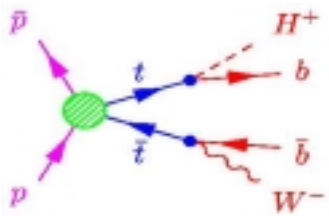
$\tan\beta = 40$:
S = 13-26
S/B ~ 21%- 34%
S/√B ~ 1.4-2.0

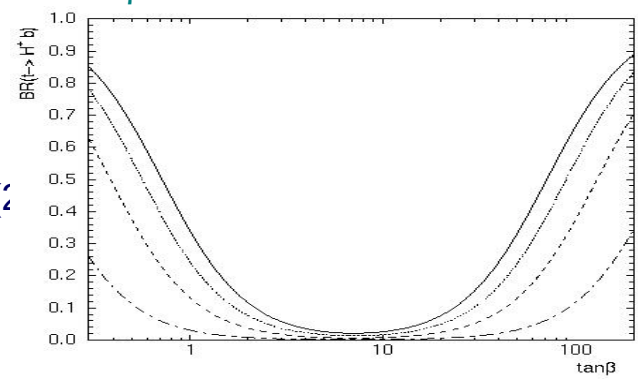
- requires high b-tag efficiency / trigger
- requires good knowledge of QCD bkgd

MSSM Charged Higgs Searches

Searches

- Searches for $t \to bH^{\pm}$ when $m_{H^{\pm}} < m_t - m_b$,
  - $t \to bH^{\pm}$ competes with SM $t \to Wb$
  - $BR(t \to bH^{\pm})$ significant for ∀high/low tanβ
- $H^{\pm}$ decays:
  - $H^{\pm} \to \tau\nu$, cs
  - $H^{\pm} \to t^*b \to Wbb$
- Expected $t\bar{t}$ statistics per experiment (2



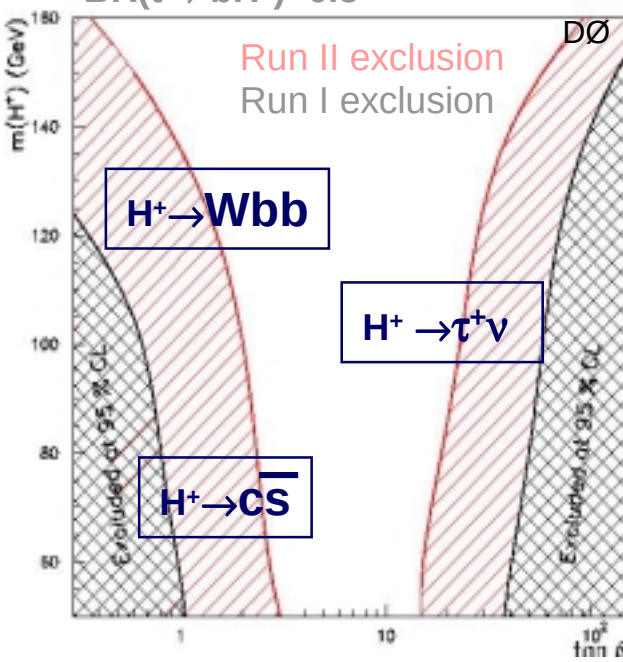


- ~3,800 $tt \to WbWb \to bl\nu bjj$
  ~200 $tt \to WbWb \to bl\nu bl\nu$

Direct Searches

- Extension of CDF run I analysis
- Look for $H^{\pm} \to \tau\nu$ in $t\bar{t}$
  Access to high tanβ
- Look for $H^{\pm} \to c\bar{s}$?
  Accessible if $m_{H^{\pm}} > m_W$

BR(t→ bH⁺)>0.5



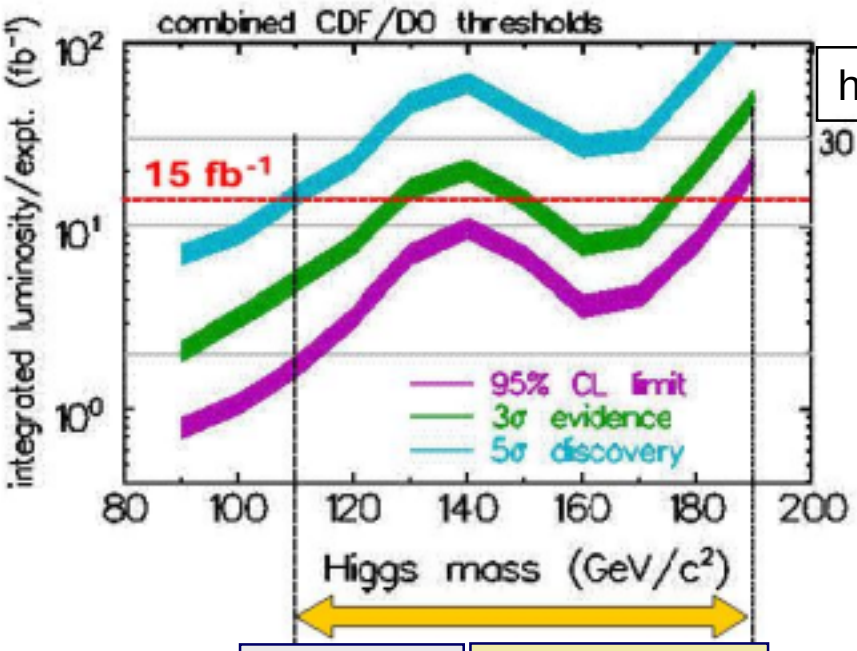
Indirect Searches

- Look for disappearance in $t\bar{t}$ events
  - deficit in di-lepton & lepton+jets σ_{tt}
- benefits from increase of $t\bar{t}$ statistics

Extend reach in ($m_{H^{\pm}}$, tanβ) plane

- appearance searches needs τ ID tools
- indirect searches based on acurate σ_{tt} measurements

Higgs Mass Reach: how to get there ...?



hep-ph/0010338

$m_H < 130\text{-}140\ GeV/c^2$

W/Z H → f f̄' b b̄

Key Parameters:

- Triggering
- b-tagging
- M_{bb} resolution
- Backgrounds & systematics

$m_H > 130\text{-}140\ GeV/c^2$

(W)H→ (W) W*W* →(ff̄')lνl'ν'

Key Parameters:

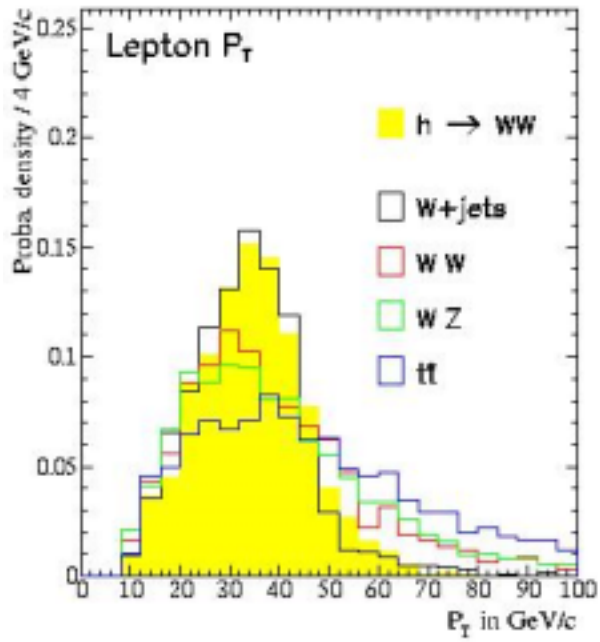
- Triggering
- Lepton ID & $\not\!\!E_T$ resolution
- Backgrounds & systematics

alot of work ahead of us...
But new tools are being developped...

Lepton trigger for Higgs Searches

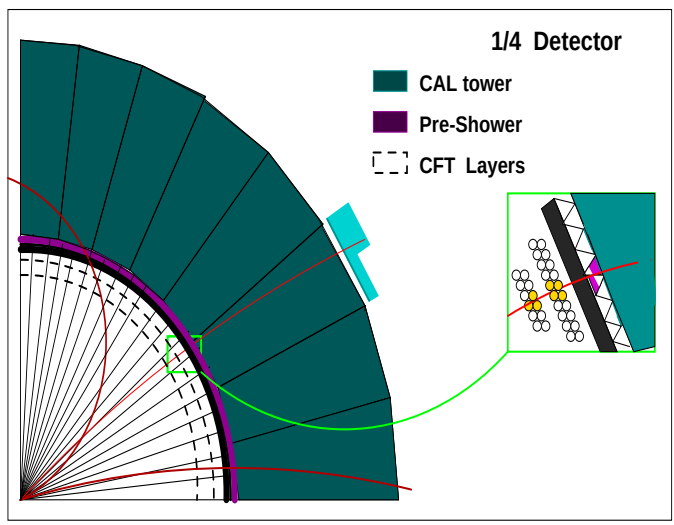
Lepton & $\not\!\!E_T$ Triggers

- mbias cross-section of 75 mbarn !
  - Require specific trigger against QCD jet / fake
  - Specifically for soft leptons
- Soft Lepton for b-tagging (H $\rightarrow$bb)
  - b$\rightarrow$lν+X and b$\rightarrow$J/ψ($\rightarrow$ ll)+X
- High p_T lepton (H $\rightarrow$ W*W*,Z*Z*)
  - W$\rightarrow$lν, Z$\rightarrow$ll
- Missing E_T (W $\rightarrow$lν)



Performances

- Re-design of lepton triggers:
  - increased trigger band width
    eg: L1= 10-50 kHz
  - Use correlation between
  - detectors
- Lepton triggers:
  - [ee] $p_T(e) > 2.5$ GeV/c
  - [$\mu\mu$] $p_T(\mu) > 1.5$ GeV/c
  - [μ] $p_T(\mu) > 4.0$ GeV/c
- Missing E_T triggers:
  - missing E_T resolution ~7-10GeV

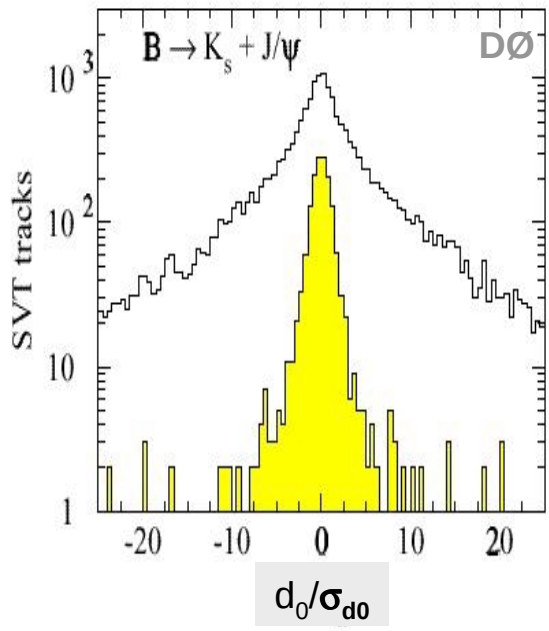


- Triggers to be tested with 1st data
- effects of mbias, pile-up, to be studied

b trigger for Higgs Searches

b-Triggering using shifted vertex

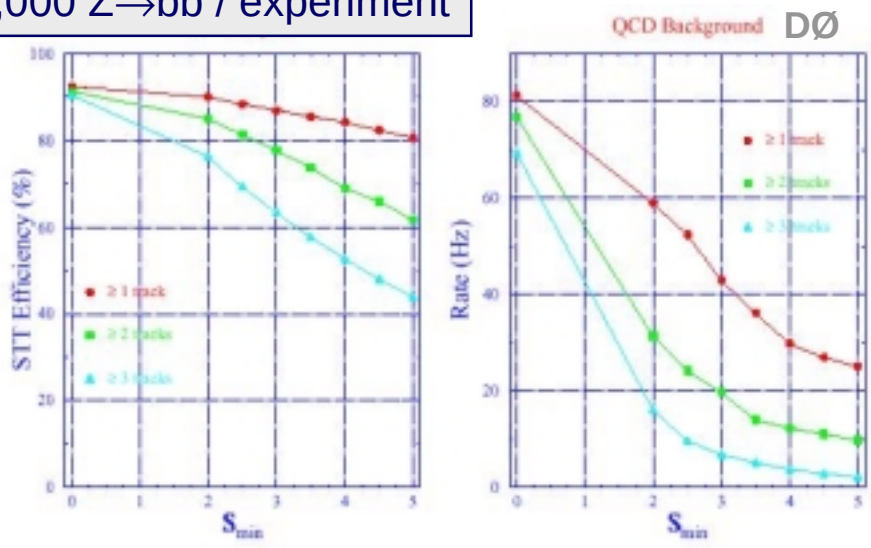
- b decays within few ~mm
  - tracks w/ high Impact parameter d_0
- Specific Triggers developped for run II:
  - Selection using tracks with high $S = d_0/\sigma_{d0}$



Performances

- Trigger on ZH→ννbb:
  - efficiency ε ~ 80%
- Trigger on Z→bb
  - efficiency ε ~ 20% vs rates ~20 Hz

50,000 Z→bb / experiment

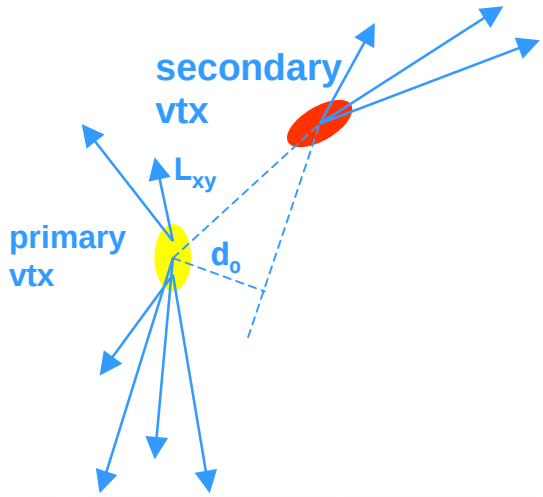


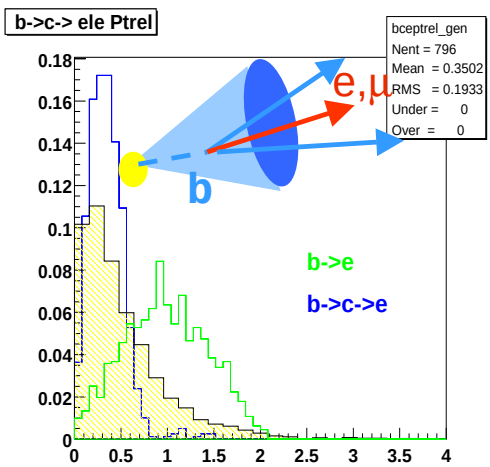
- b-triggers will be tested with 1st data
- crucial for Z →bb calibration, M(bb) resolution, b-tag efficiency studies

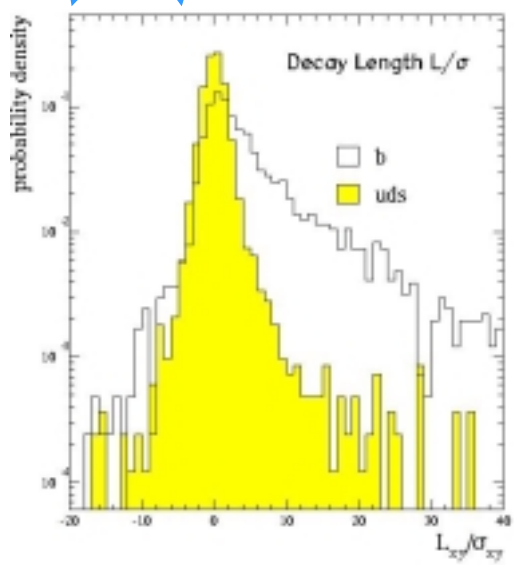
b-tagging for Higgs Search

b tagging at Run II

- Mandatory for Low Higgs Mass analysis
- "Multi-tag" approach being developped:
  - Soft Lepton from b $\rightarrow$ lν X
  - High Impact parameter tracks
  - Displaced Vertex:
    2-tracks vertex, Vertex fit χ^2
    M(vertex), L_{xy} $/\sigma_{xy}$
  - Multi-variate likelihood







Performances

- b-tagging studies still progressing as software evolves:

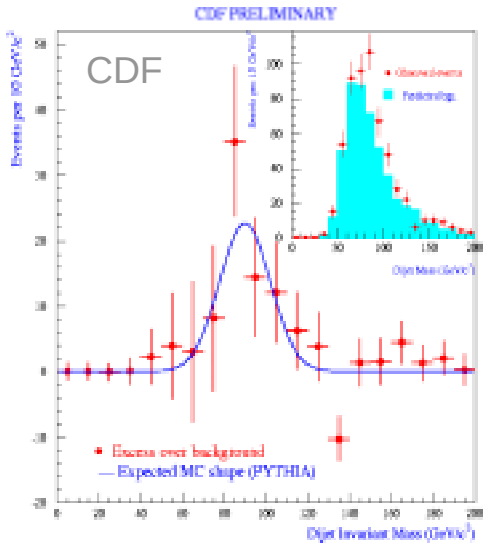
ε_b ~ 40% /Jet w/ <1% fake
ε_b ~ 10% / lepton (acceptance, electron ID
ε_b ~ 60% (soft lepton+vertex) achievable

Z $\rightarrow$bb calibration, M(bb) resolution, b-tag efficiency

$Z \rightarrow b\bar{b}$ decays at the TeVatron

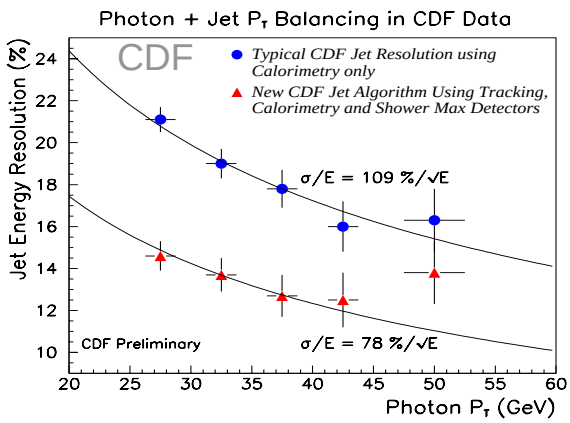
$Z \rightarrow bb$ Selection

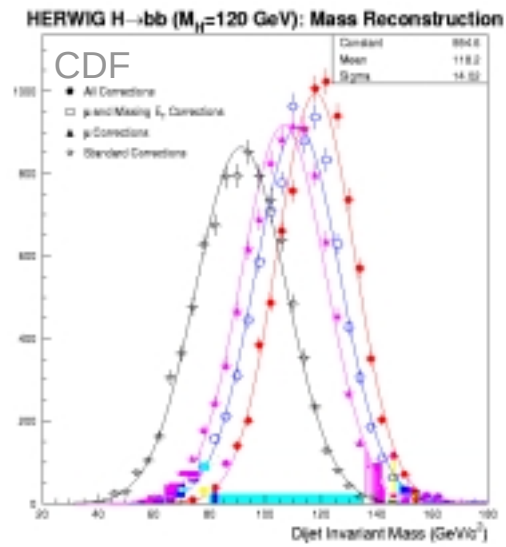
- (Higgs) Mass resolution is critical
- $Z \rightarrow bb$ sample (CDF run I):
  - 1-μ trigger
  - 2 b-tags w/ ε_{2b} ~ 27.8%
  - Kinematical cuts: $\Sigma_3^n E_T$, $\Delta\Phi_{jj}$
- M_{bb} Resolution (CDF run I)
  - Minimize $\Delta P = (p^{jet} - p^b)$
    - correction with p^μ
    - correction for missing E_T
    - correction for charged fraction



Run II M_{bb} Resolution Studies

- CDF expects 30% improvement
  - use track+calorimeter for Jet calibration
- DØ defined a Z(bb) trigger





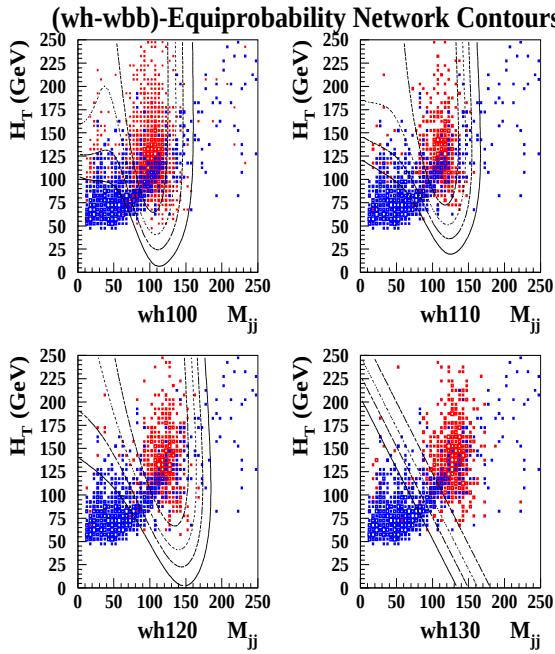
-"The" crucial point for H→bb analysis
- Improvement still to be established for DØ

New Analysis Techniques

Discriminant Analyses

- Principles:
  - Combine variables w/ S/B resolution power into discriminants
  - Use all tological differences Signal vs Backgrounds

  $\Rightarrow$ Likelihood and Neural Network



- 30% improvement vs classic approach
  - Important gain in effective luminosity
  - Crucial for low m_H search

  $\rightarrow$ Multi-jets final states
  - Important for high m_H search:

  $\rightarrow$ Discrimination $h \rightarrow W^*W^*$ vs WW^*

- Neural Net Approach for b-tagging

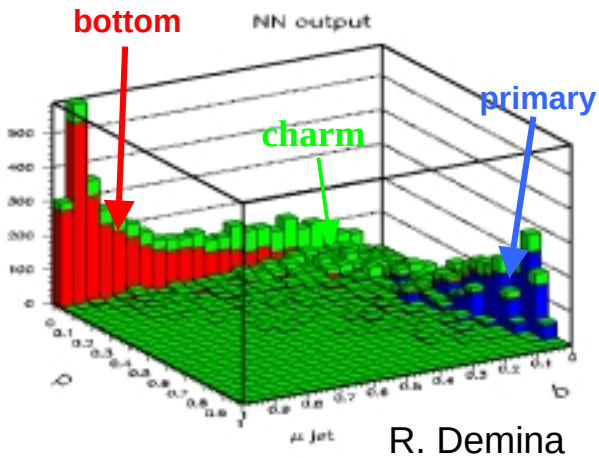
  Used in LEP experiments:
  - Combine lifetime & kinematics
  - Output 3 continous variables:

    "bottmness"

    "charmness"

    "primaryness"

  $\Rightarrow$ preliminary studies show +60% improvement in double-tagging vs Run I algo



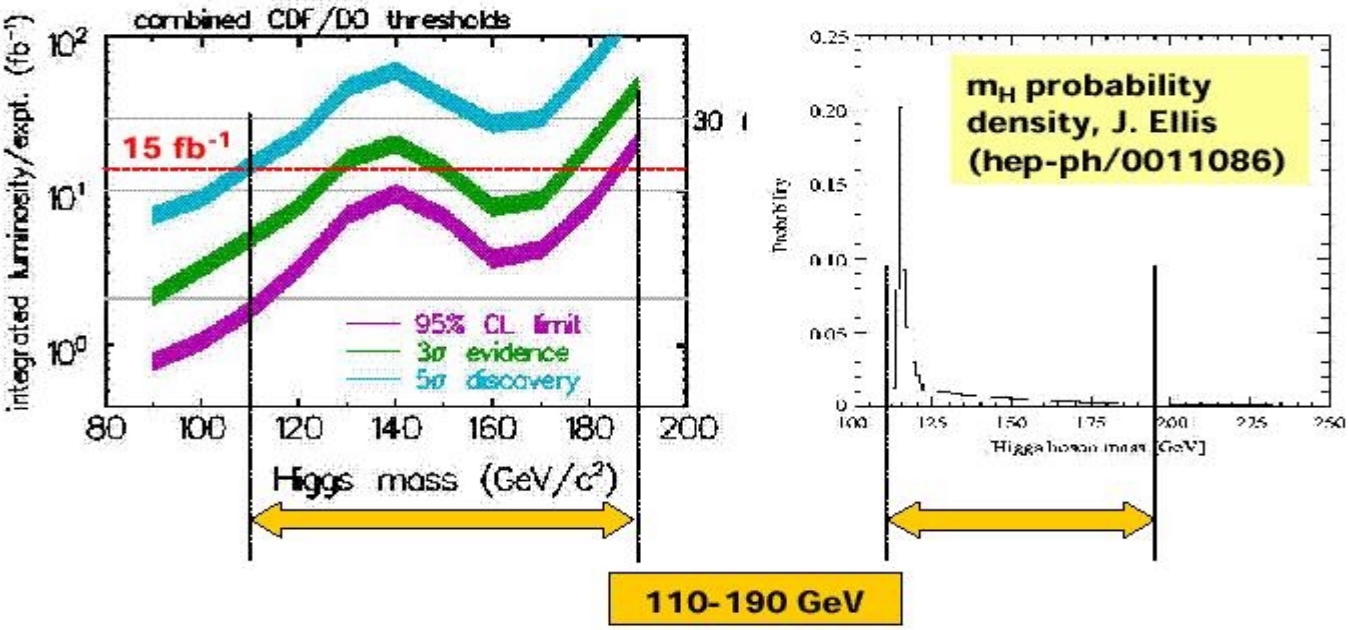
R. Demina

being implemented in full simulation software

Conclusion.....

A very exciting time ahead of us...

- Light Higgs 3-sigma evidence needs 15 fb^{-1} /exp.
- High Mass higgs requires 20 fb^{-1} /exp.



..and a very busy time...

Full simulations studies are being developped to increase sensitivity

- b-tagging tools
- Backgrounds studies
- new Analysis techniques

... Data will bring us the truth

Machine schedule is to deliver:

~ 2 fb^{-1} by 2003

~15 fb^{-1} by 2007

....What about m_H = 115 GeV ?

- **If Higgs is indeed here:**
  - Signal Evidence requires
    - ~5 fb^{-1} with 3 standard evidence (2004-5)
  - Expected number of events
    - per experiment with 15 fb^{-1} (2007)

Mode	Signal	Background	$S/\sqrt{B}$
$l\nu bb$	92	450	4.3
$\nu\nu bb$	90	880	3.0
$llbb$	10	44	1.5

  - If we do see something, we need to measure:
    - its Mass
    - Its production cross-section
    - Can we see $H \rightarrow \tau\tau$ (BR ~ 8%) ?
    - Can we see $H \rightarrow W^*W^*$ (BR ~ 5%) ?

- **If Higgs is not here:**
  - we can exclude a m_H = 115 GeV Higgs
    - at 95% CL with 2 fb^{-1} (2003)