

New Physics Searches at the Tevatron

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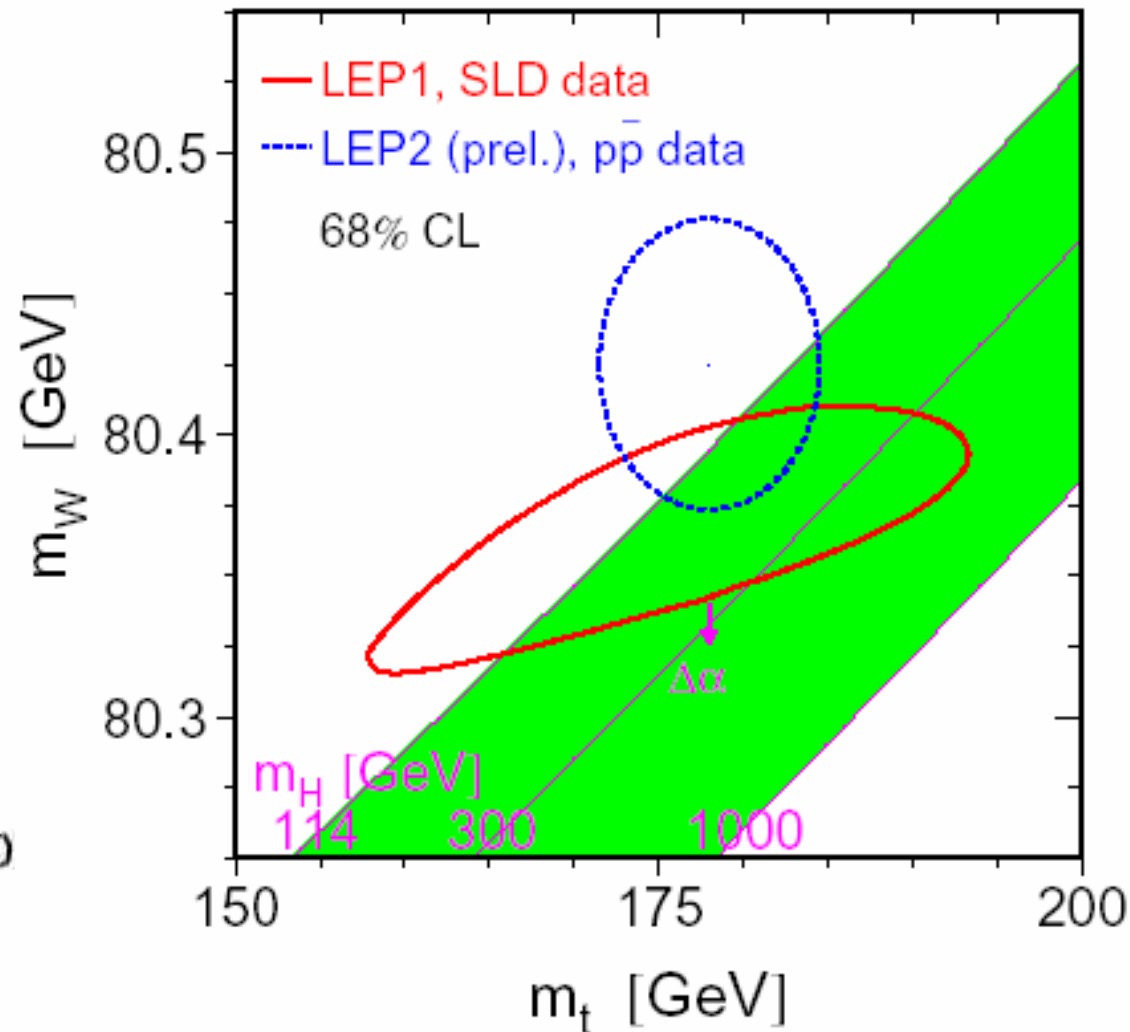
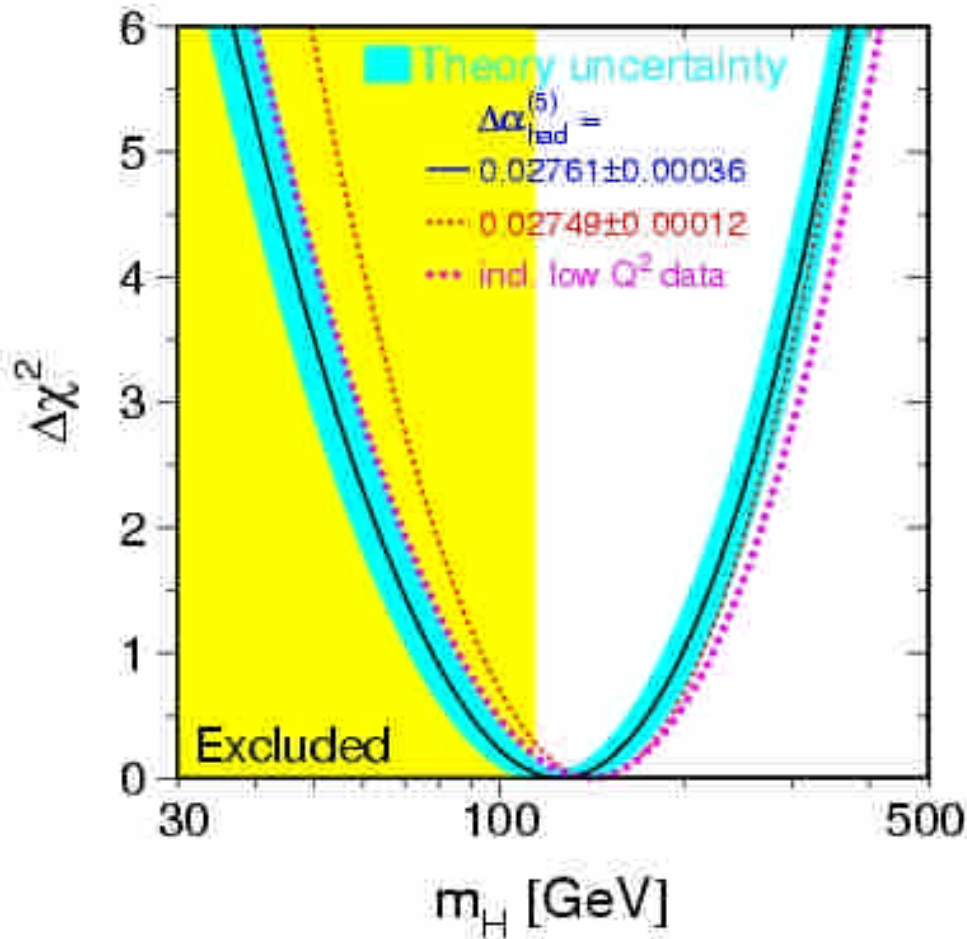
- Higgs: SM and Beyond
- Supersymmetry
- Conclusions

Recall LEP Results...

- SM Higgs boson candidates and mass limits
- Coupling limits
- MSSM: dedicated searches, three-neutral-Higgs boson hypothesis, benchmark and general scan mass limits
- CP-violating models
- Invisible Higgs boson decays
- Neutral Higgs bosons in the general two-doublet model
- Yukawa Higgs boson processes
- Singly-charged Higgs bosons
- Doubly-charged Higgs bosons
- Fermiophobic Higgs boson decays $h \rightarrow WW, ZZ, \gamma\gamma$
- Uniform and stealthy Higgs boson scenarios

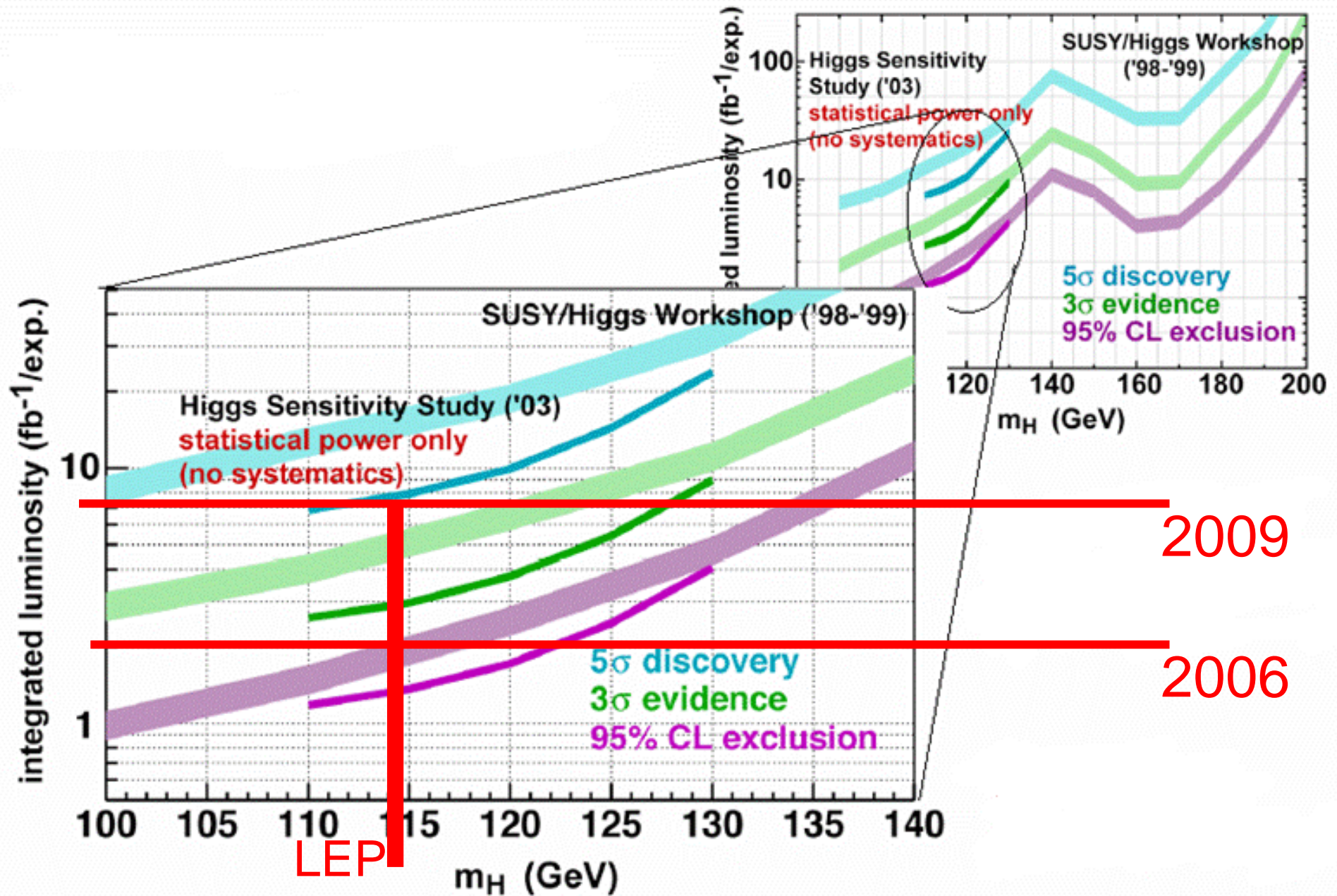
Search	Experiment	Limit
Standard Model Reduced rate and SM decay Reduced rate and $b\bar{b}$ decay Reduced rate and $\tau^+\tau^-$ decay Reduced rate and hadronic decay Anomalous couplings	LEP ALEPH L3	$m_H^{SM} > 114.4 \text{ GeV}$ $\xi^2 > 0.05: m_H > 85 \text{ GeV}$ $\xi^2 > 0.3: m_H > 110 \text{ GeV}$ $\xi^2 > 0.04: m_H > 80 \text{ GeV}$ $\xi^2 > 0.25: m_H > 110 \text{ GeV}$ $\xi^2 > 0.2: m_H > 113 \text{ GeV}$ $\xi^2 = 1: m_H > 112.9 \text{ GeV}$ $\xi^2 > 0.3: m_H > 97 \text{ GeV}$ $\xi^2 > 0.04: m_H \approx 90 \text{ GeV}$ $d, d_B, \Delta g_1^Z, \Delta \kappa_\gamma$ exclusions
MSSM (no scalar top mixing) General MSSM scan Larger top-quark mass	LEP DELPHI LEP	almost entirely excluded $m_h > 87 \text{ GeV}, m_A > 90 \text{ GeV}$ strongly reduced $\tan\beta$ limits
CP-violating models	LEP	strongly reduced mass limits
Visible/invisible Higgs decays Majoron model (max. mixing)	DELPHI	$m_H > 111.8 \text{ GeV}$ $m_{H,S} > 112.1 \text{ GeV}$
Two-doublet Higgs model (for σ_{\max})	DELPHI	$hA \rightarrow b\bar{b}b\bar{b}: m_h+m_A > 150 \text{ GeV}$ $\tau^+\tau^-\tau^+\tau^-: m_h+m_A > 160 \text{ GeV}$ $(AA)A \rightarrow 6b: m_h+m_A > 150 \text{ GeV}$ $(AA)Z \rightarrow 4b Z: m_h > 90 \text{ GeV}$ $hA \rightarrow q\bar{q}q\bar{q}: m_h+m_A > 110 \text{ GeV}$ $\tan\beta > 1: m_h \approx m_A > 85 \text{ GeV}$
Two-doublet model scan	OPAL	$\tan\beta > 1: m_h \approx m_A > 85 \text{ GeV}$
Yukawa process	DELPHI	$C > 40: m_{h,A} > 40 \text{ GeV}$
Singly-charged Higgs bosons $W^\pm A$ decay mode	LEP DELPHI	$m_{H^\pm} > 78.6 \text{ GeV}$ $m_{H^\pm} > 76.7 \text{ GeV}$
Doubly-charged Higgs bosons $e^+e^- \rightarrow e^+e^-$	DELPHI/OPAL L3	$m_{H^{++}} > 99 \text{ GeV}$ $h_{e^+e^-} > 0.5: m_{H^{++}} > 700 \text{ GeV}$
Fermiophobic $H \rightarrow WW, ZZ, \gamma\gamma$ $H \rightarrow \gamma\gamma$	L3 LEP	$m_H > 108.3 \text{ GeV}$ $m_H > 109.7 \text{ GeV}$
Uniform and stealthy scenarios	OPAL	depending on model parameters

SM Higgs Mass Indication

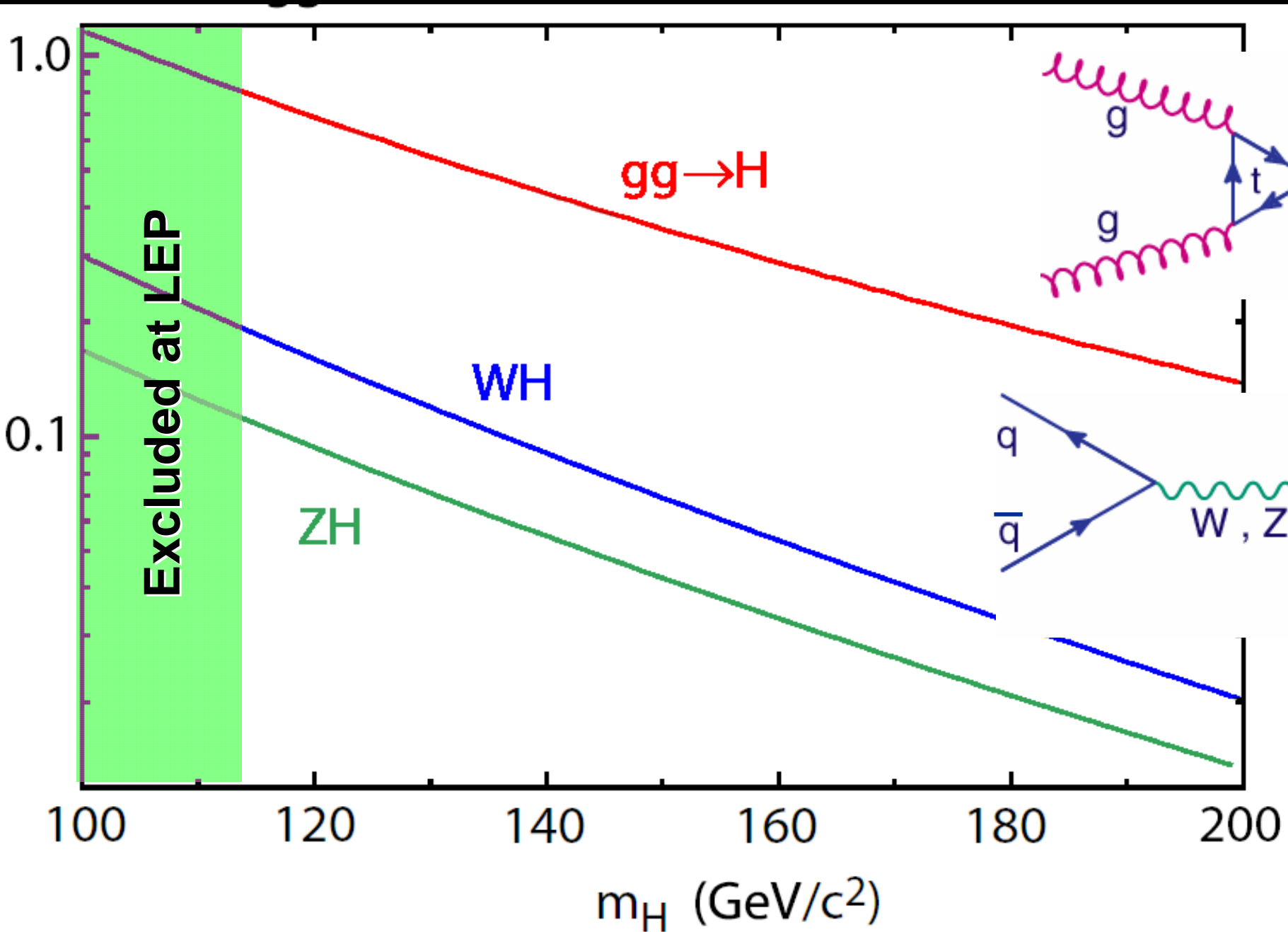


$$m_H = 126^{+73}_{-48} \text{ GeV}, m_H < 280 \text{ GeV} @ 95\% \text{ CL}$$

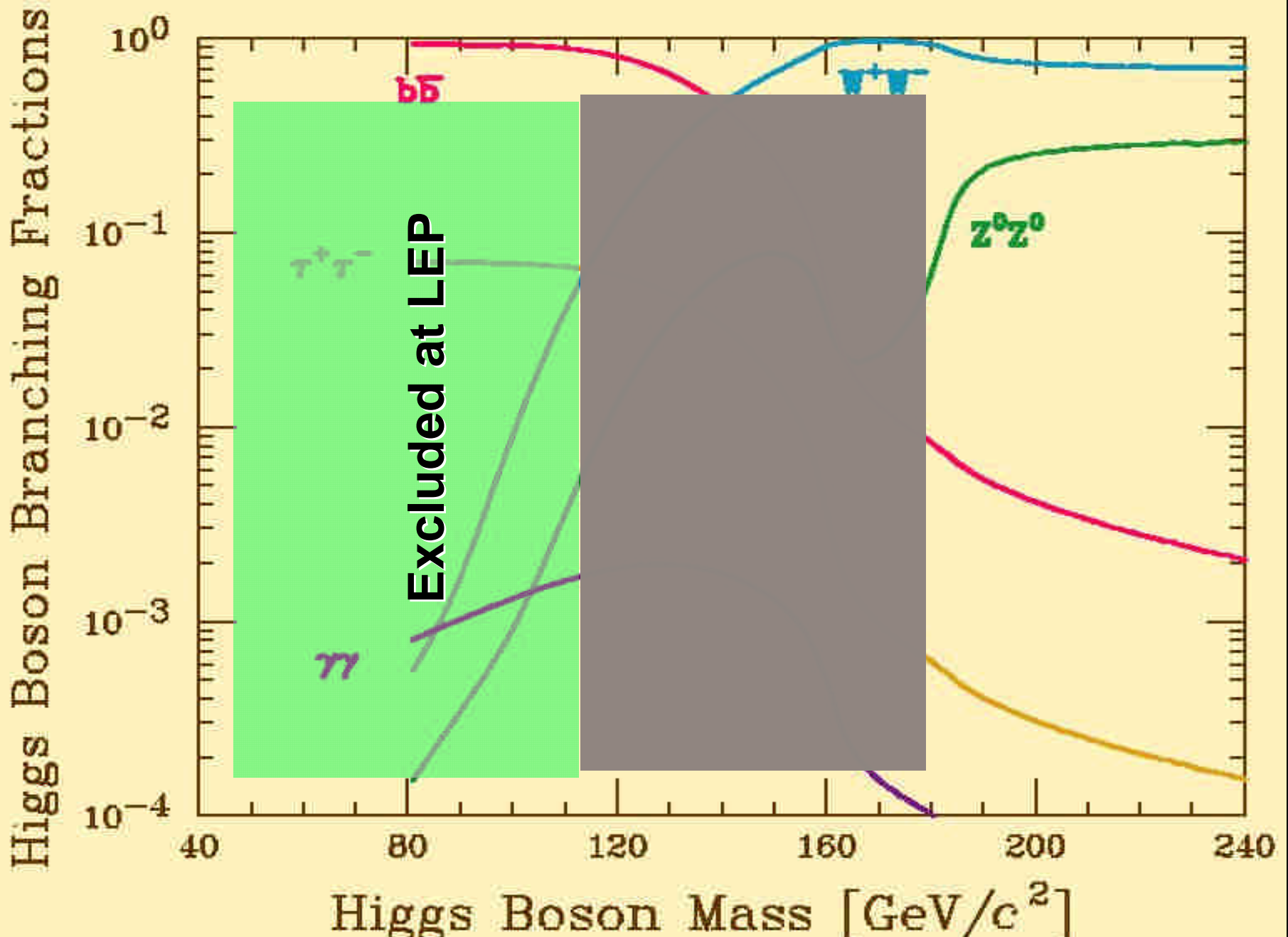
Tevatron SM Higgs Hunting



SM Higgs Production (pb)



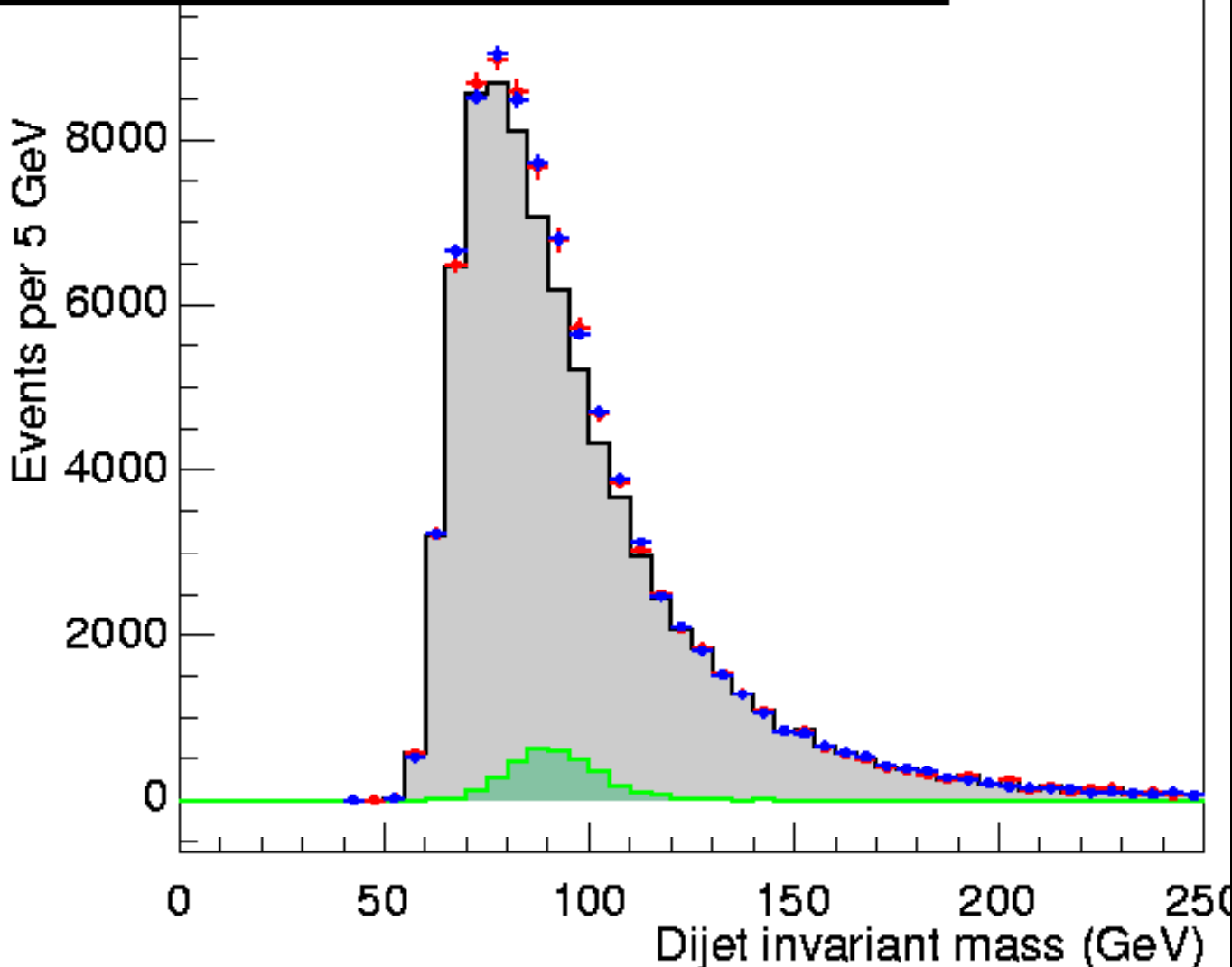
SM Higgs Decay: bb and WW



ggH ($H \rightarrow bb$): Low Mass < 135 GeV

CDF Run 2 preliminary - $L=333 \text{ pb}^{-1}$

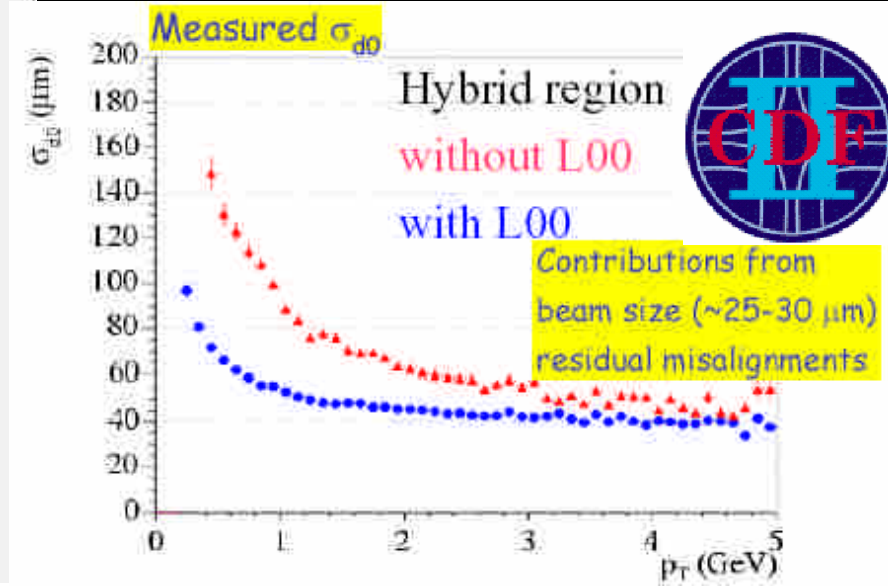
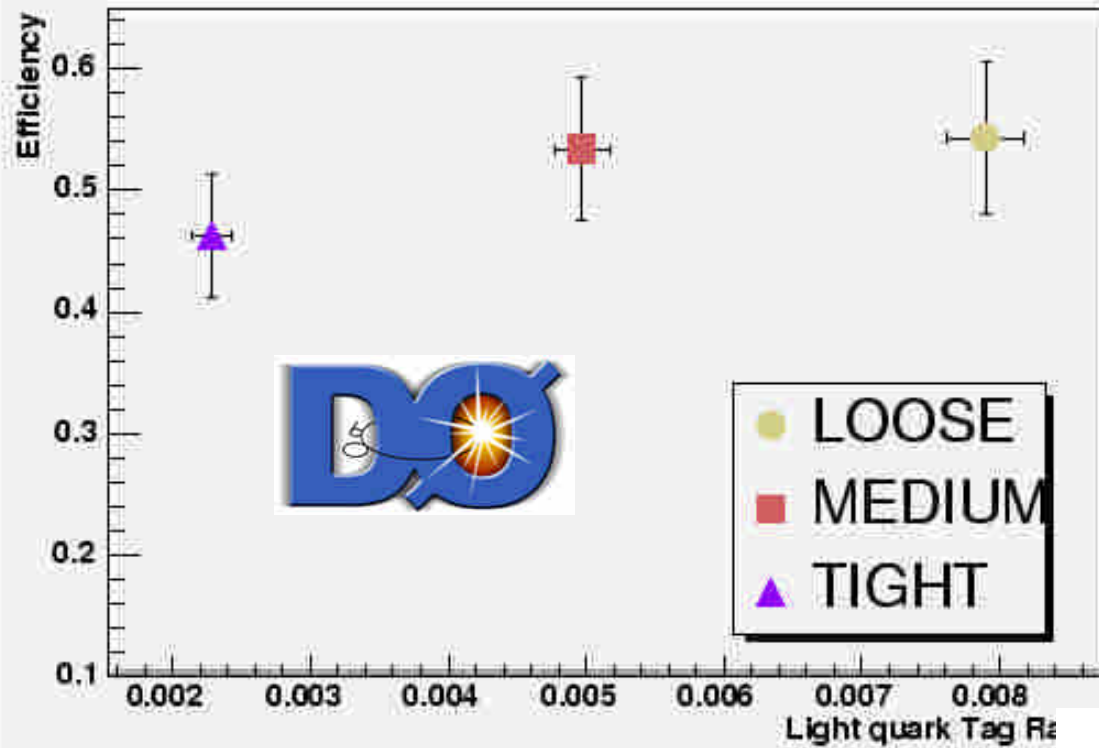
- Selected events
- Background
- Z signal: 3394 ± 515 events
- Fit result



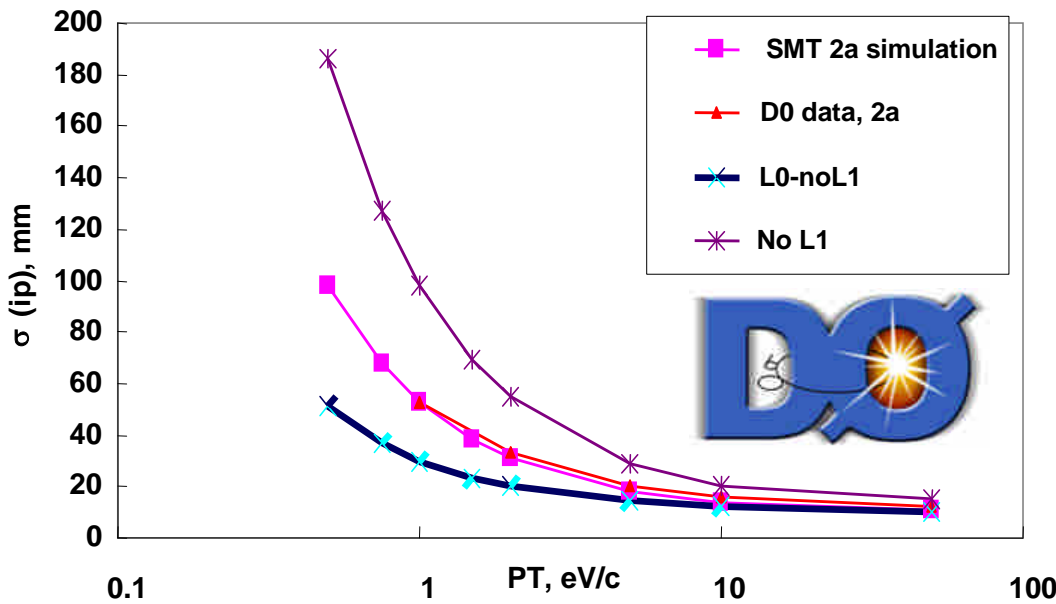
Most difficult,
first steps:
 $Z \rightarrow bb$

b-Tagging

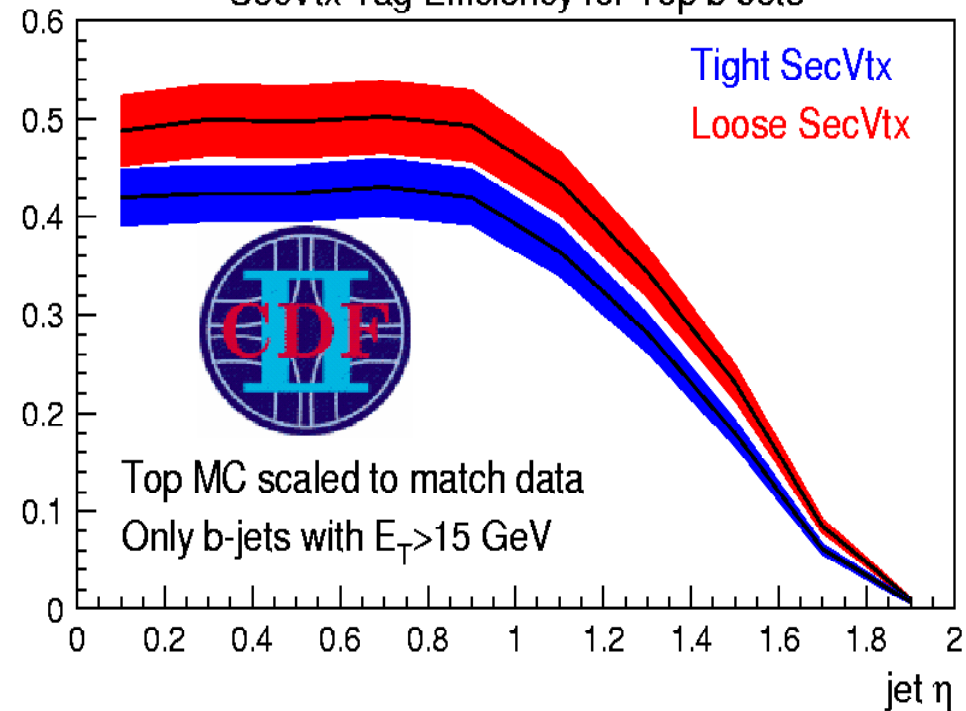
Central Region ($35 < p_T < 55$): b-tagging efficiency vs. light quark tagging efficiency



Impact parameter resolution

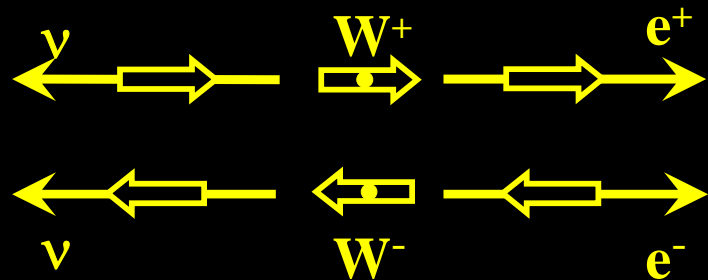
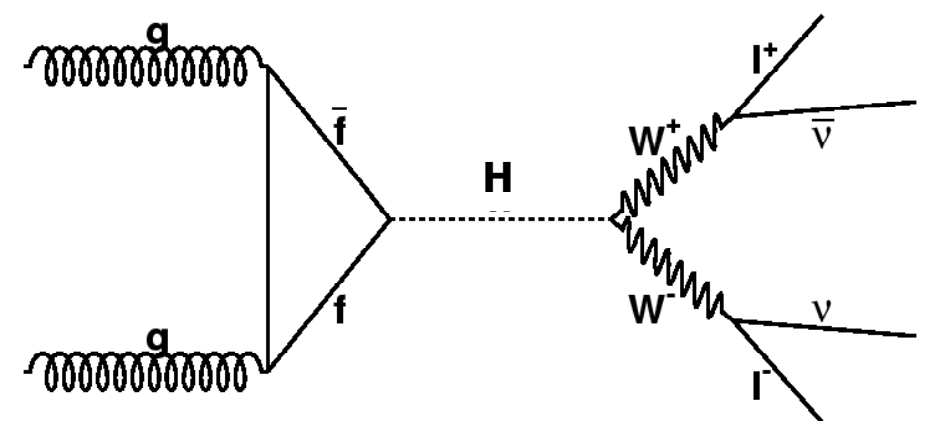
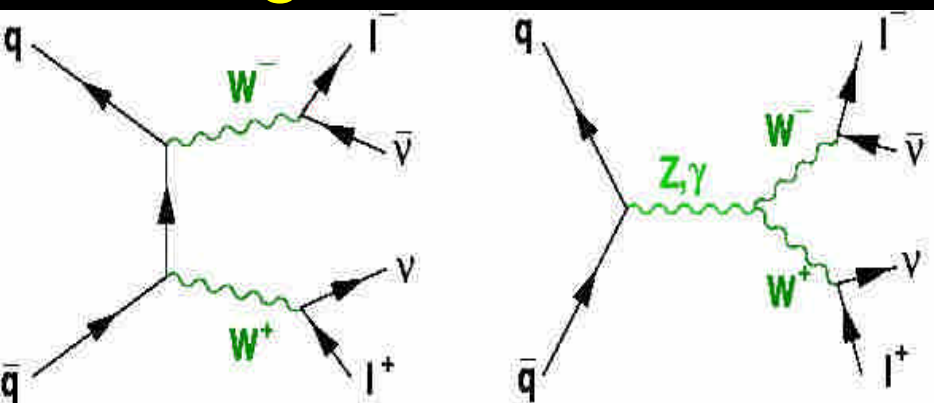


SecVtx Tag Efficiency for Top b-Jets

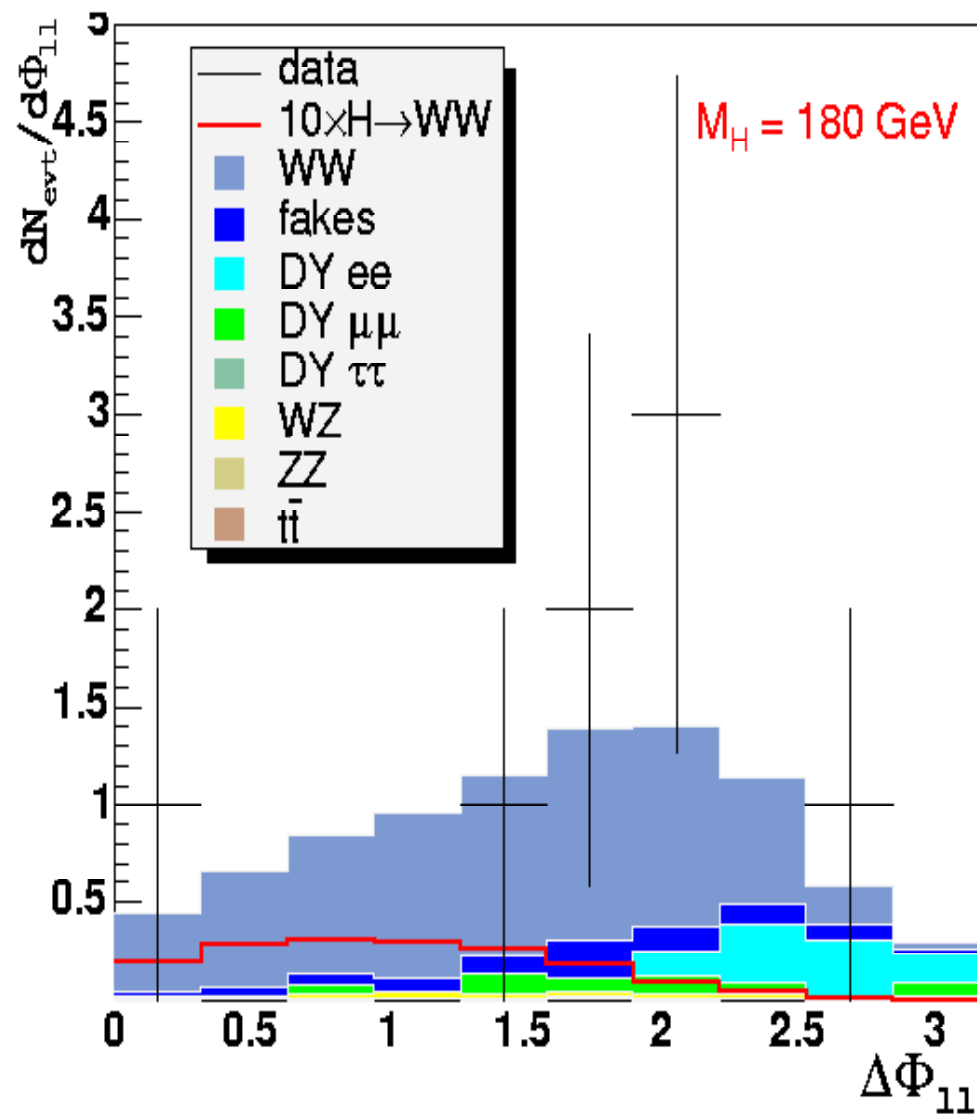


ggH ($H \rightarrow WW$): High Mass > 135 GeV

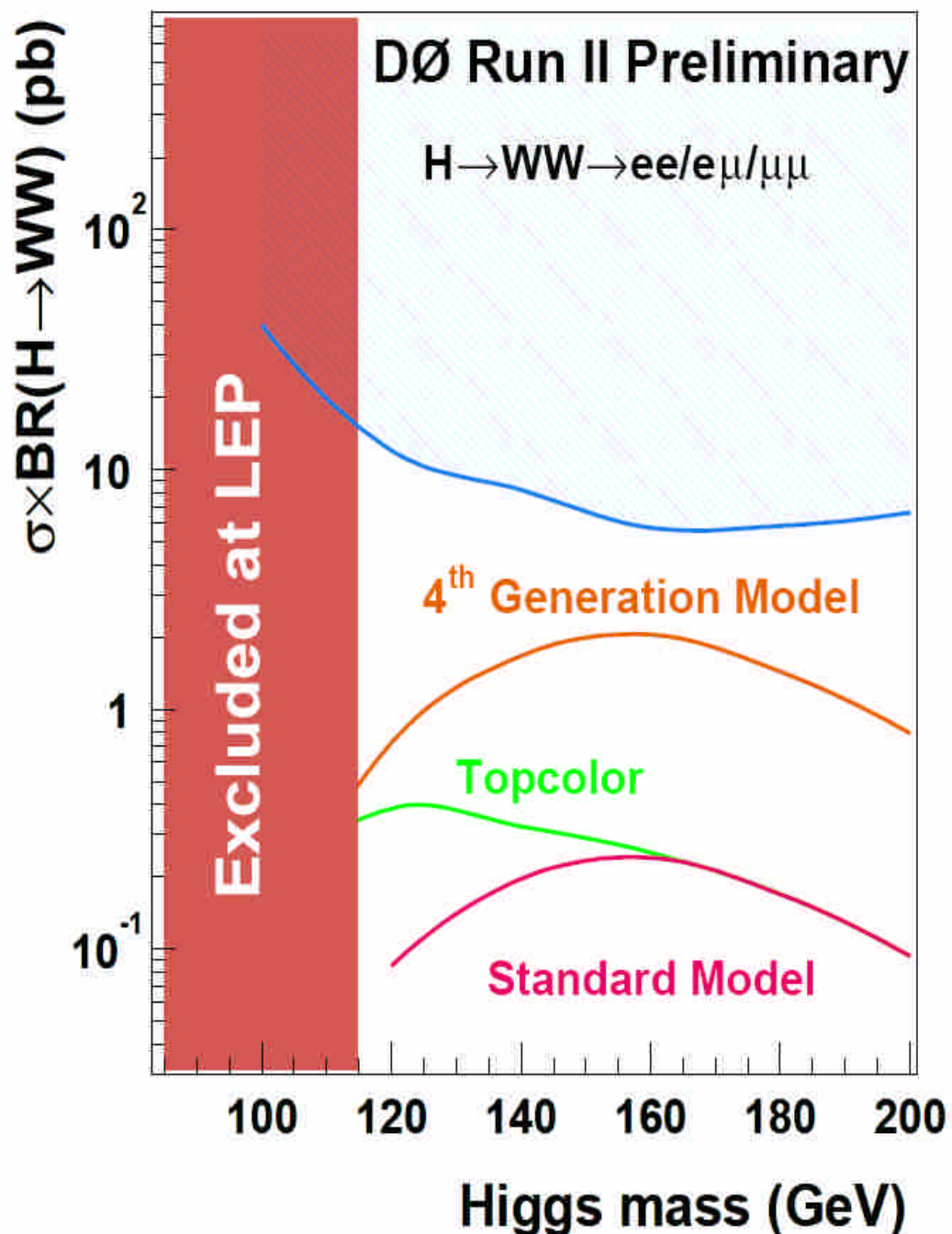
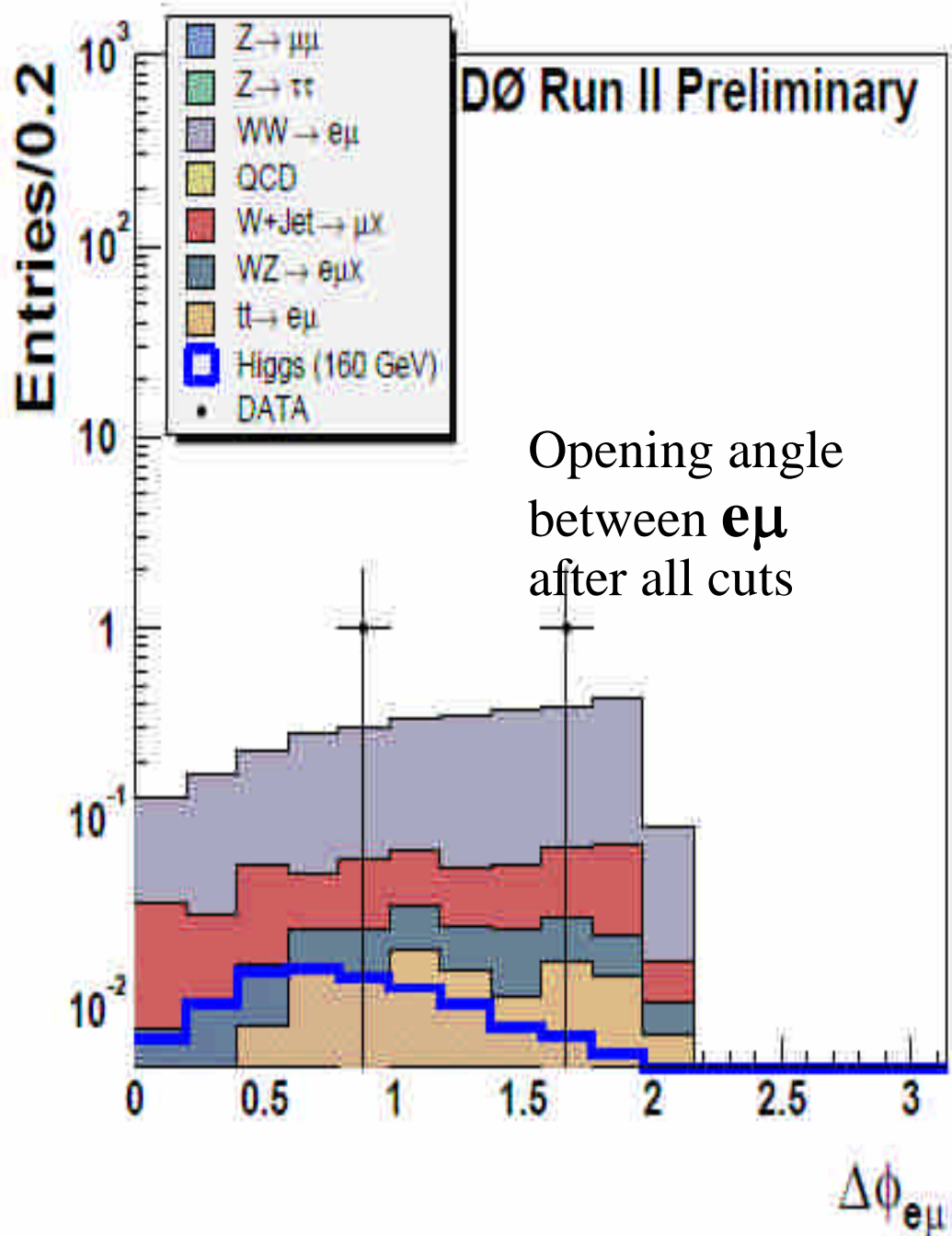
Background



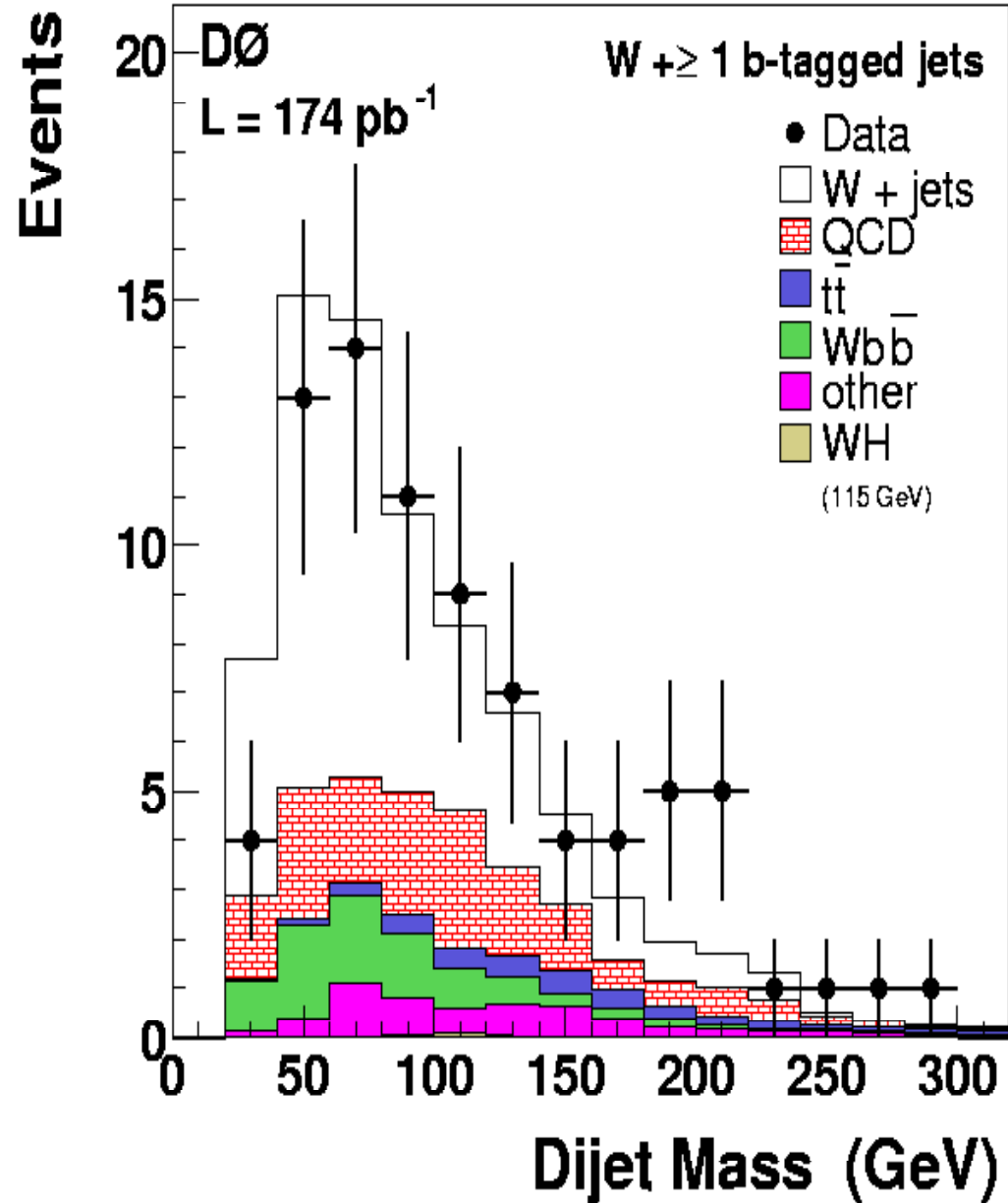
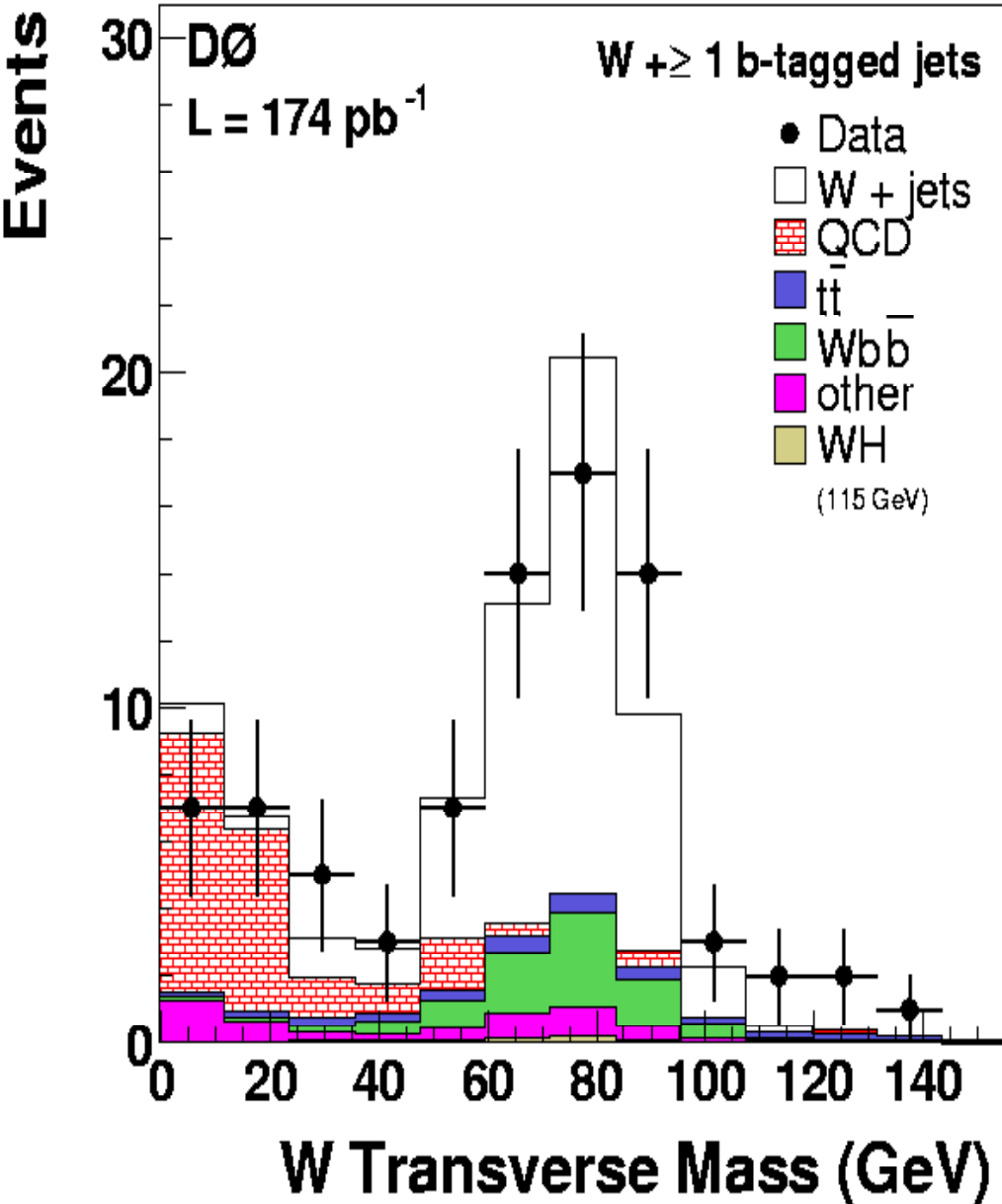
CDF Run II Preliminary, $L_{\text{int}} = 184 \text{ pb}^{-1}$



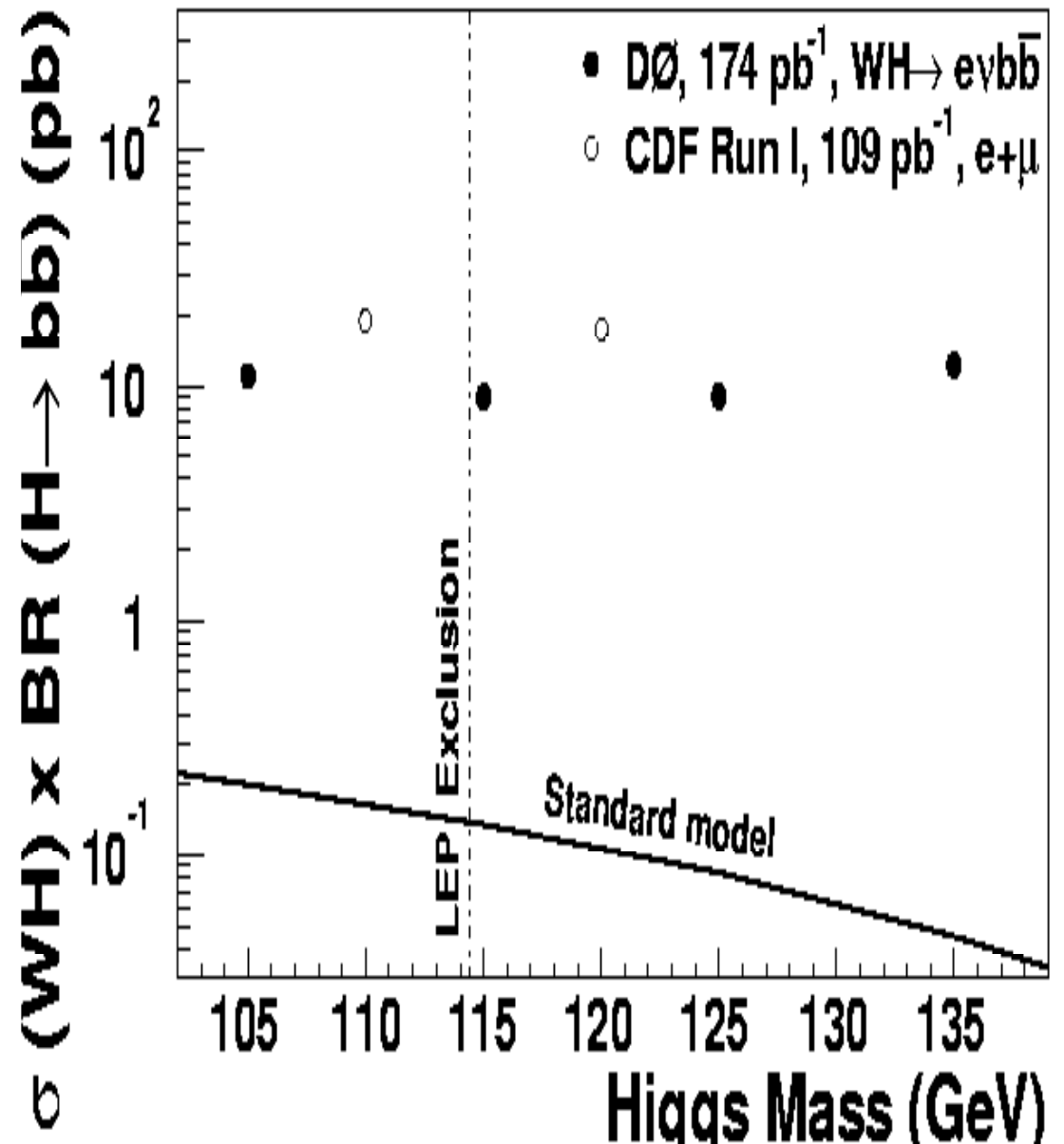
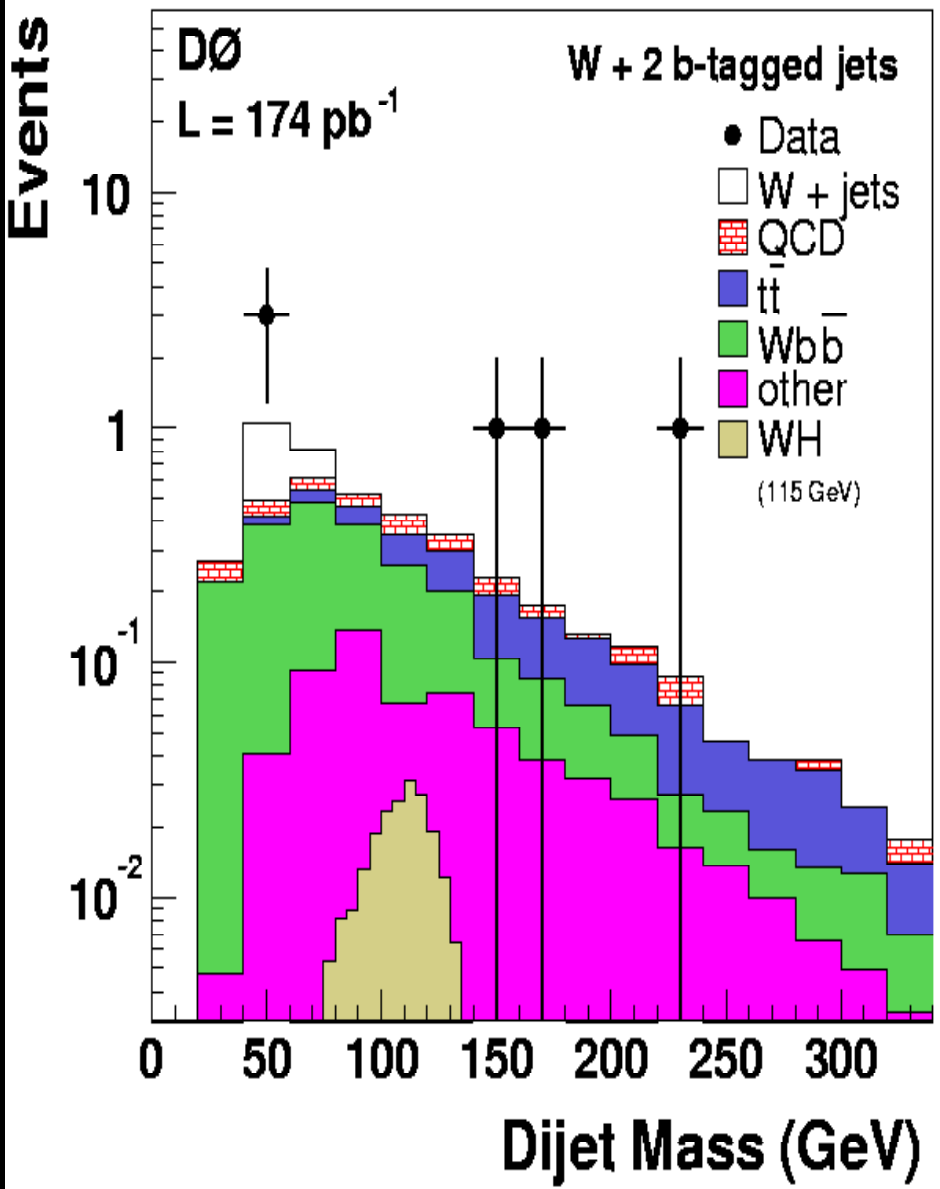
ggH ($H \rightarrow WW$): High Mass >135 GeV



Associated Production WH ($H \rightarrow bb$)

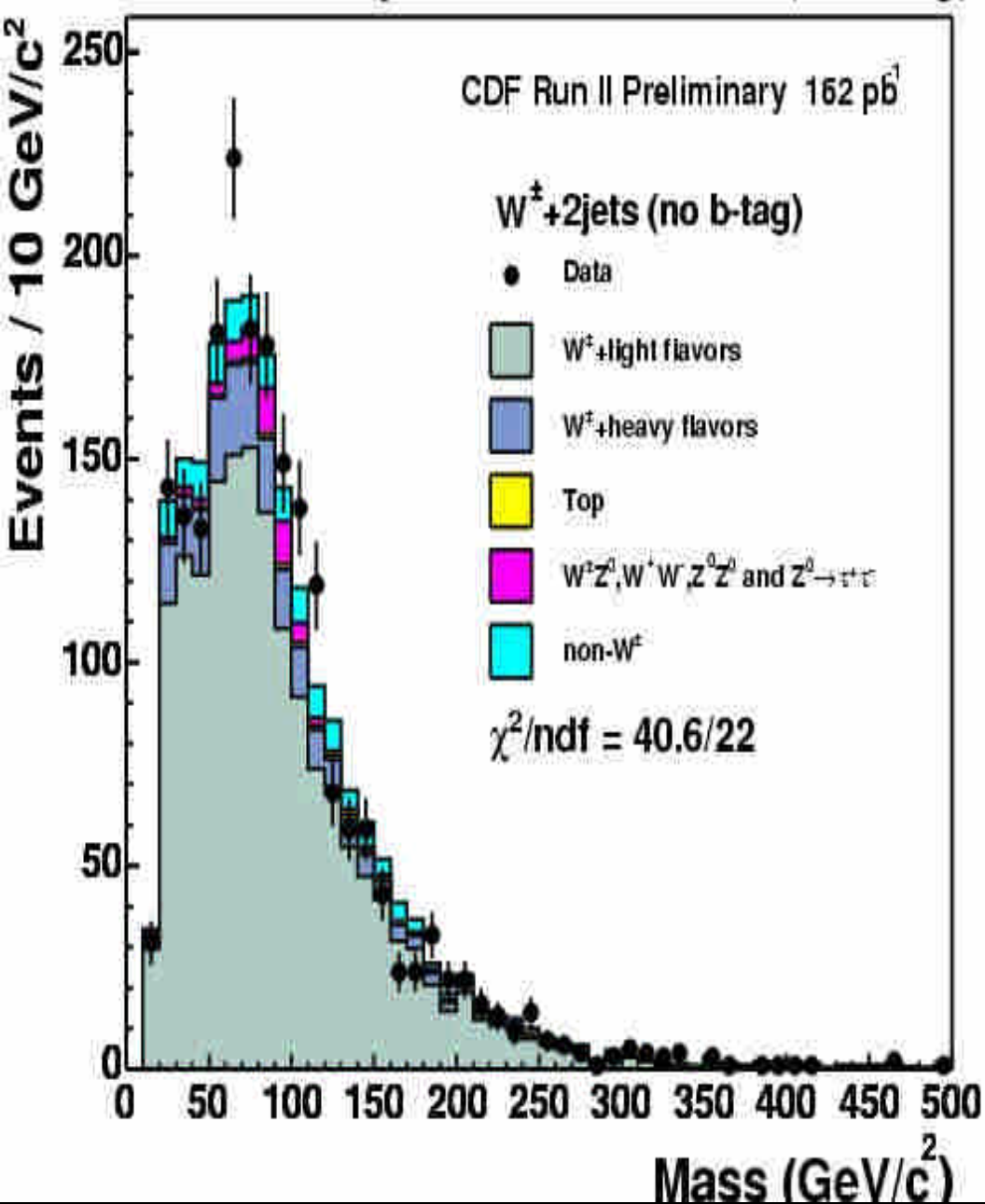


Associated Production WH ($H \rightarrow bb$)

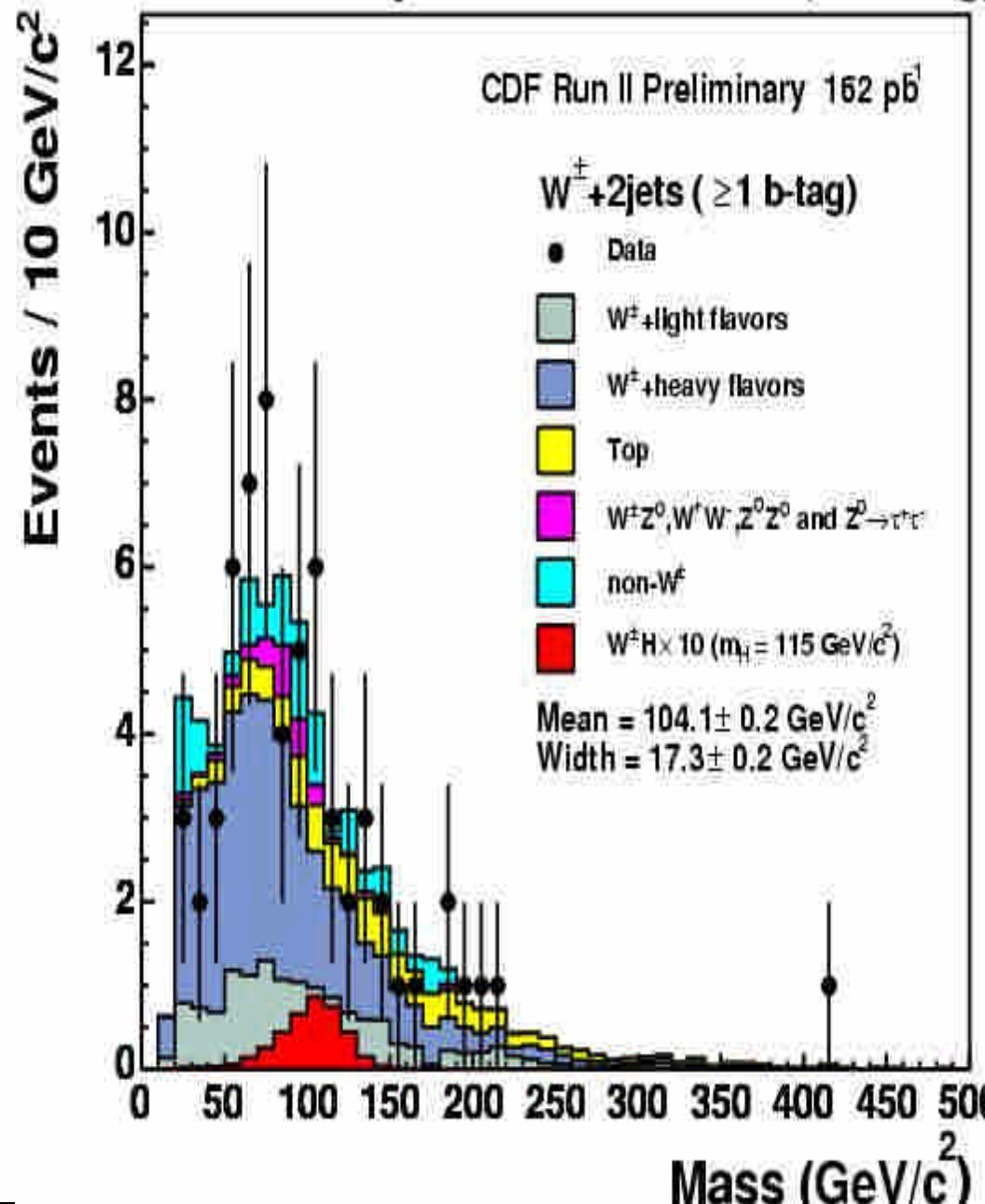


Associated Production WH ($H \rightarrow bb$)

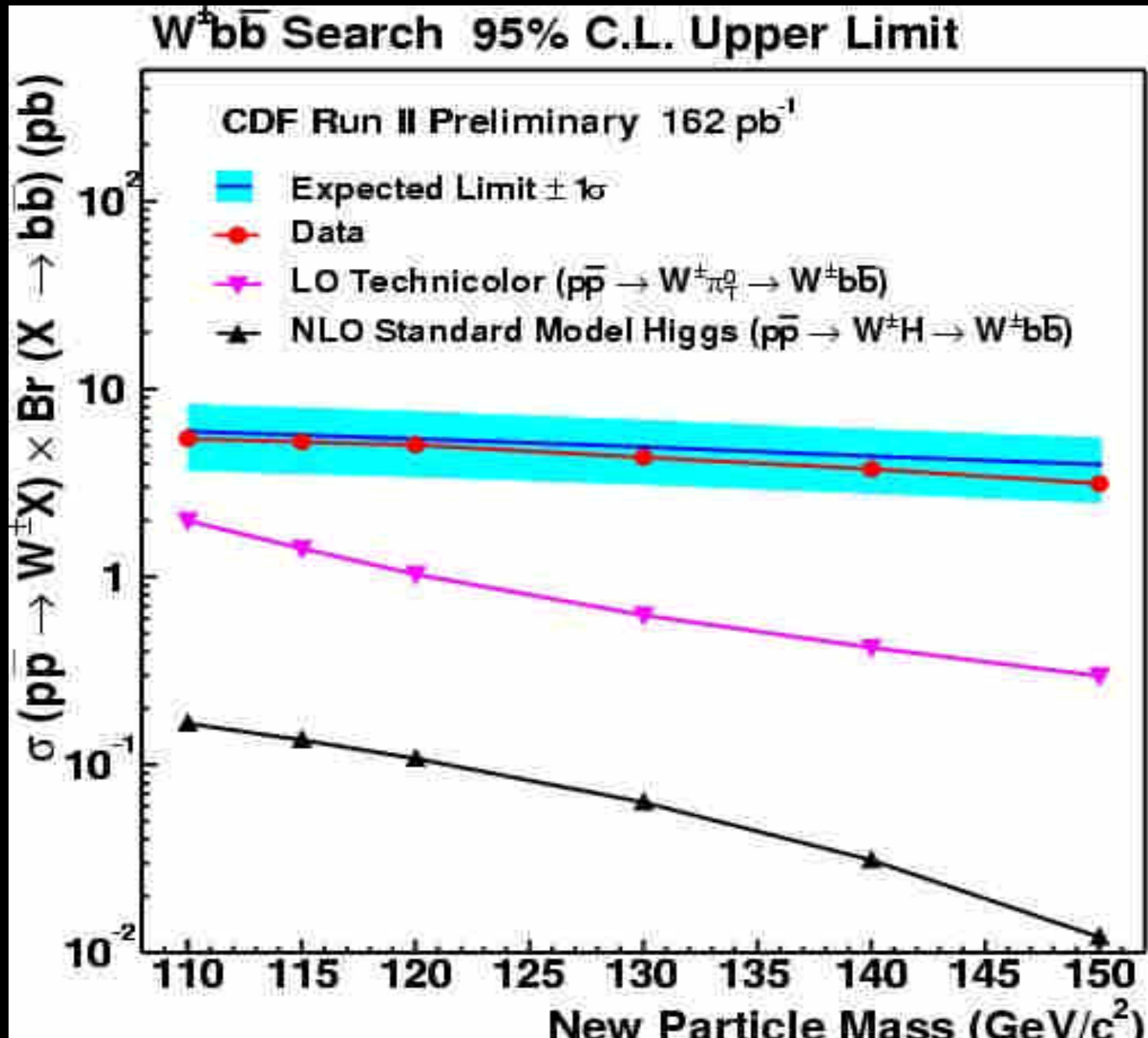
$W^{\pm}b\bar{b}$ Search Dijet Mass Distribution (no b-tag)



$W^{\pm}b\bar{b}$ Search Dijet Mass Distribution (≥ 1 b-tag)

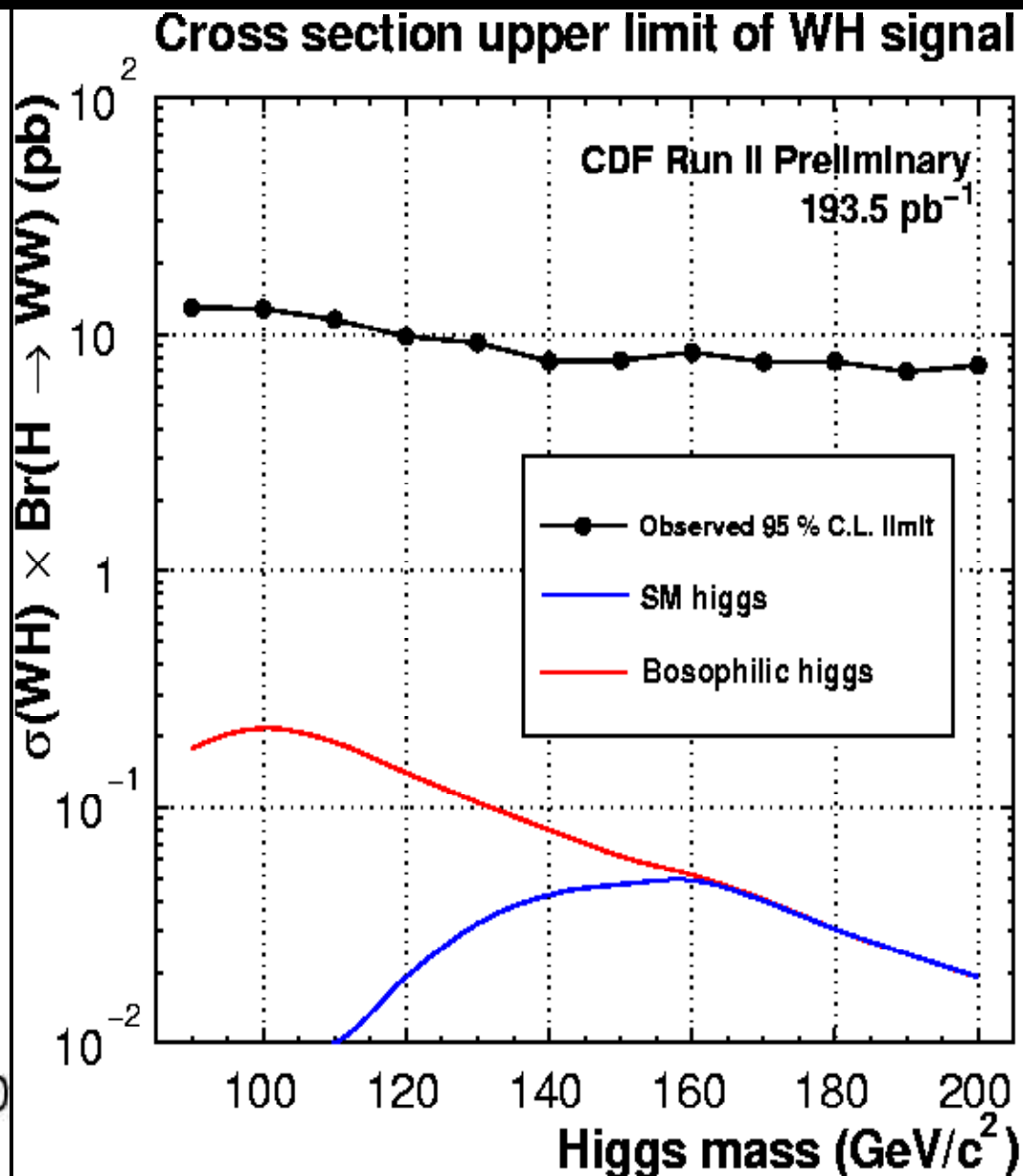
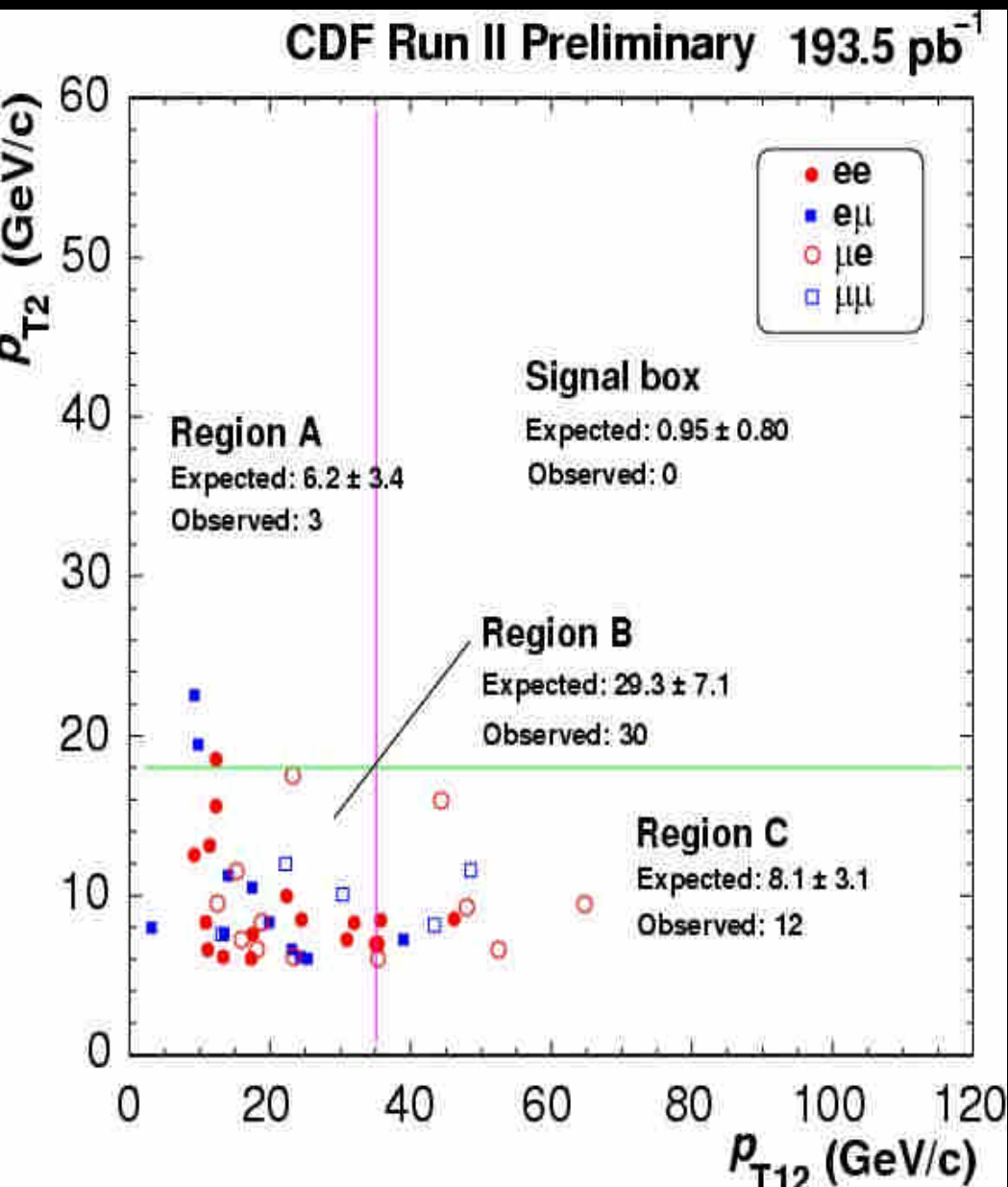


Associated Production WH ($H \rightarrow b\bar{b}$)

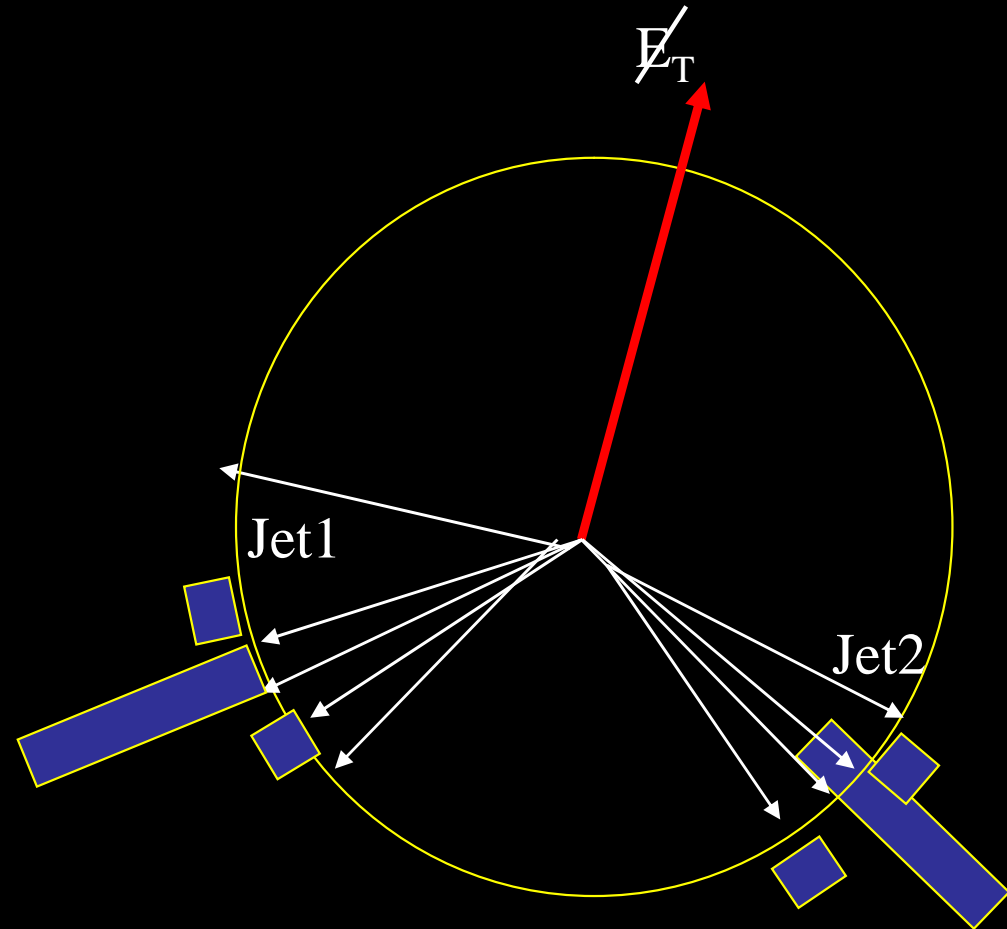
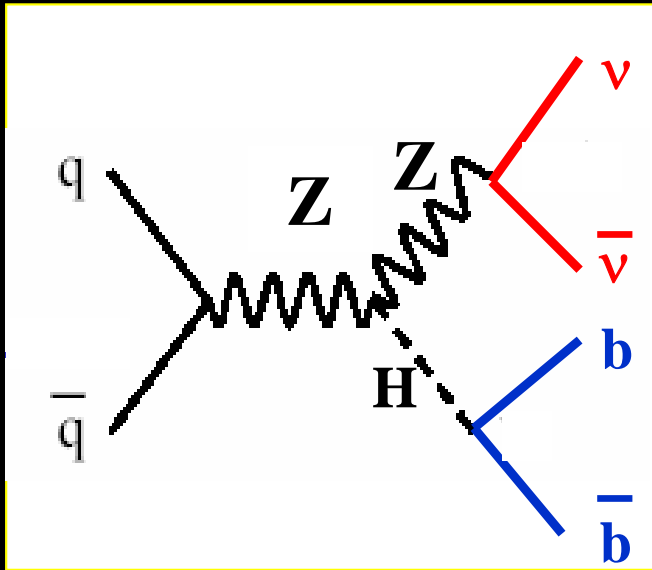


Associated Production $WH(H \rightarrow WW)$

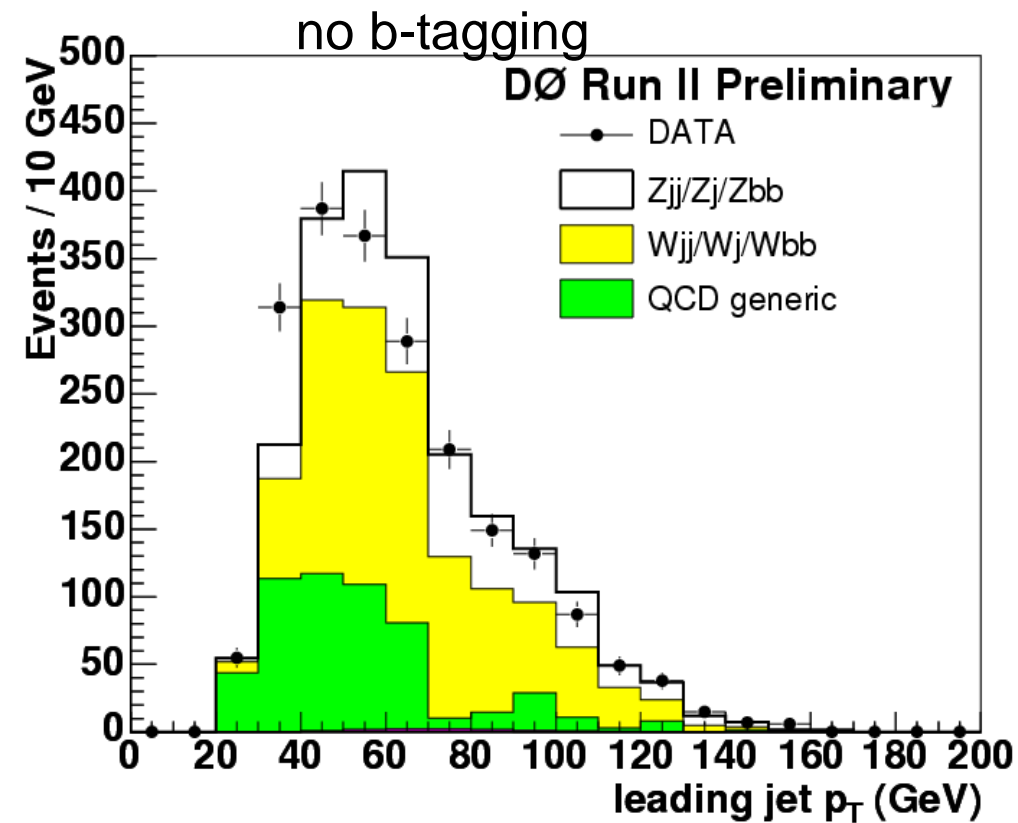
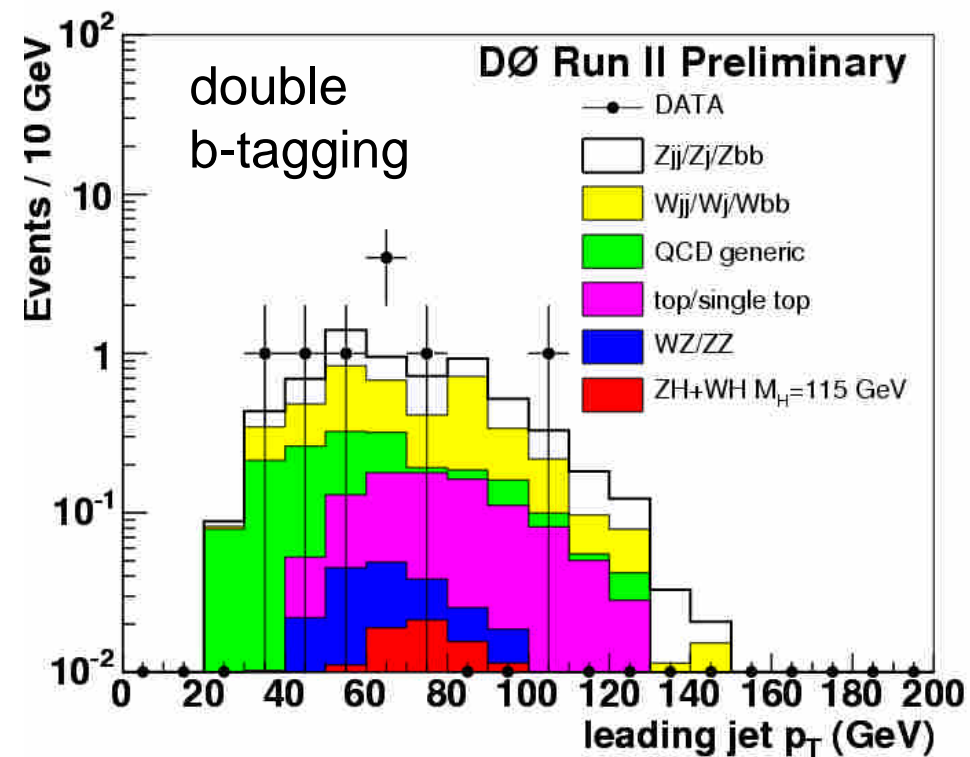
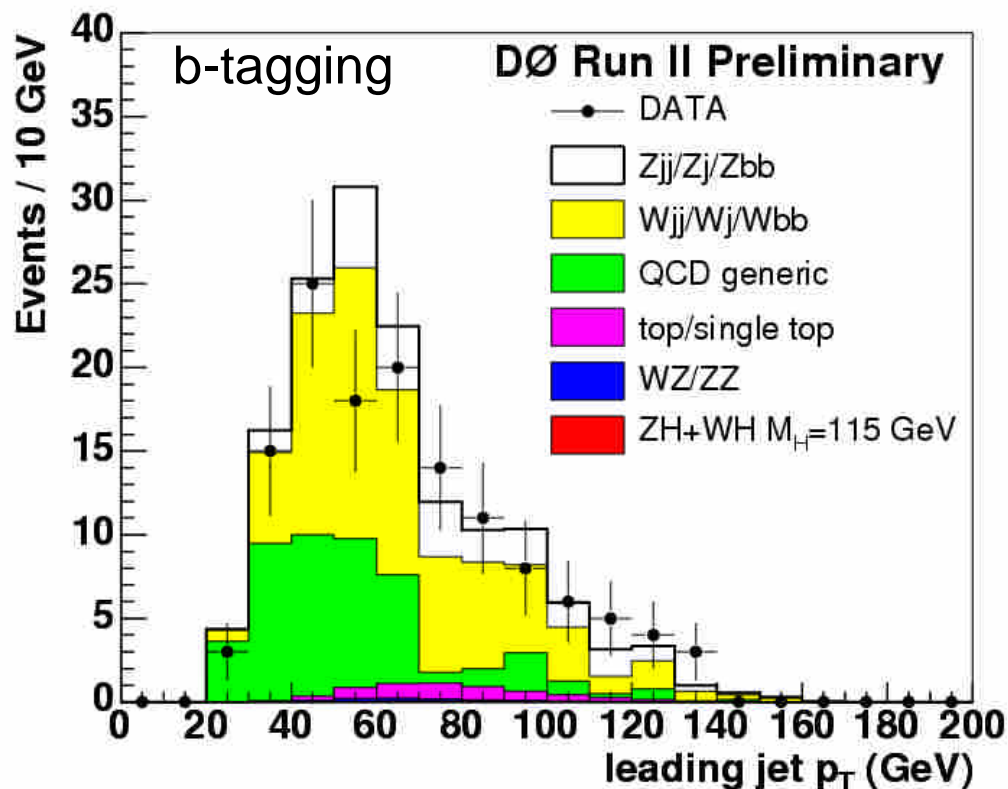
2nd leading lepton p_T vs di-lepton sum p_T



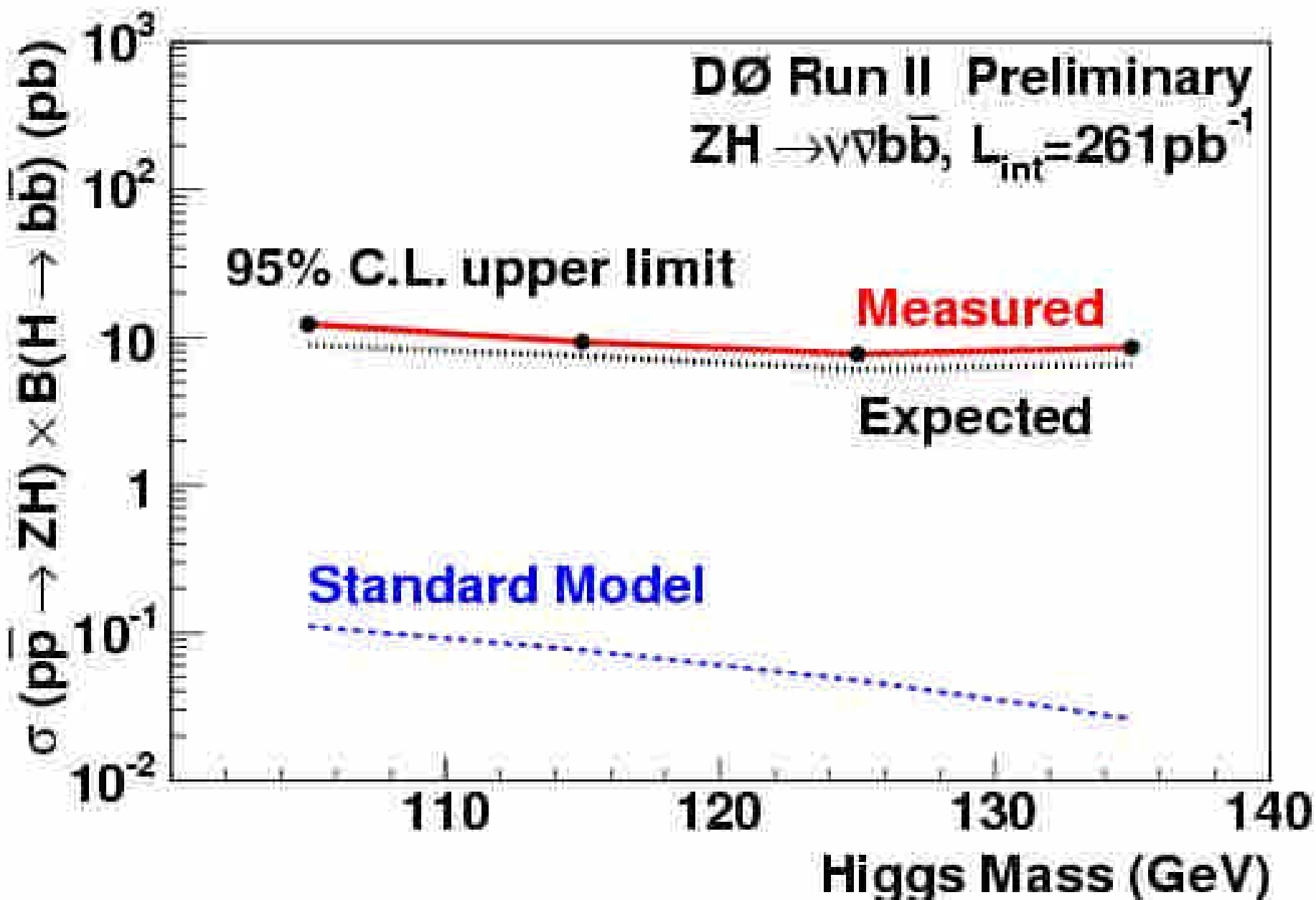
Associated Production $ZH \rightarrow \nu\nu b\bar{b}$



$ZH \rightarrow \nu\nu bb$

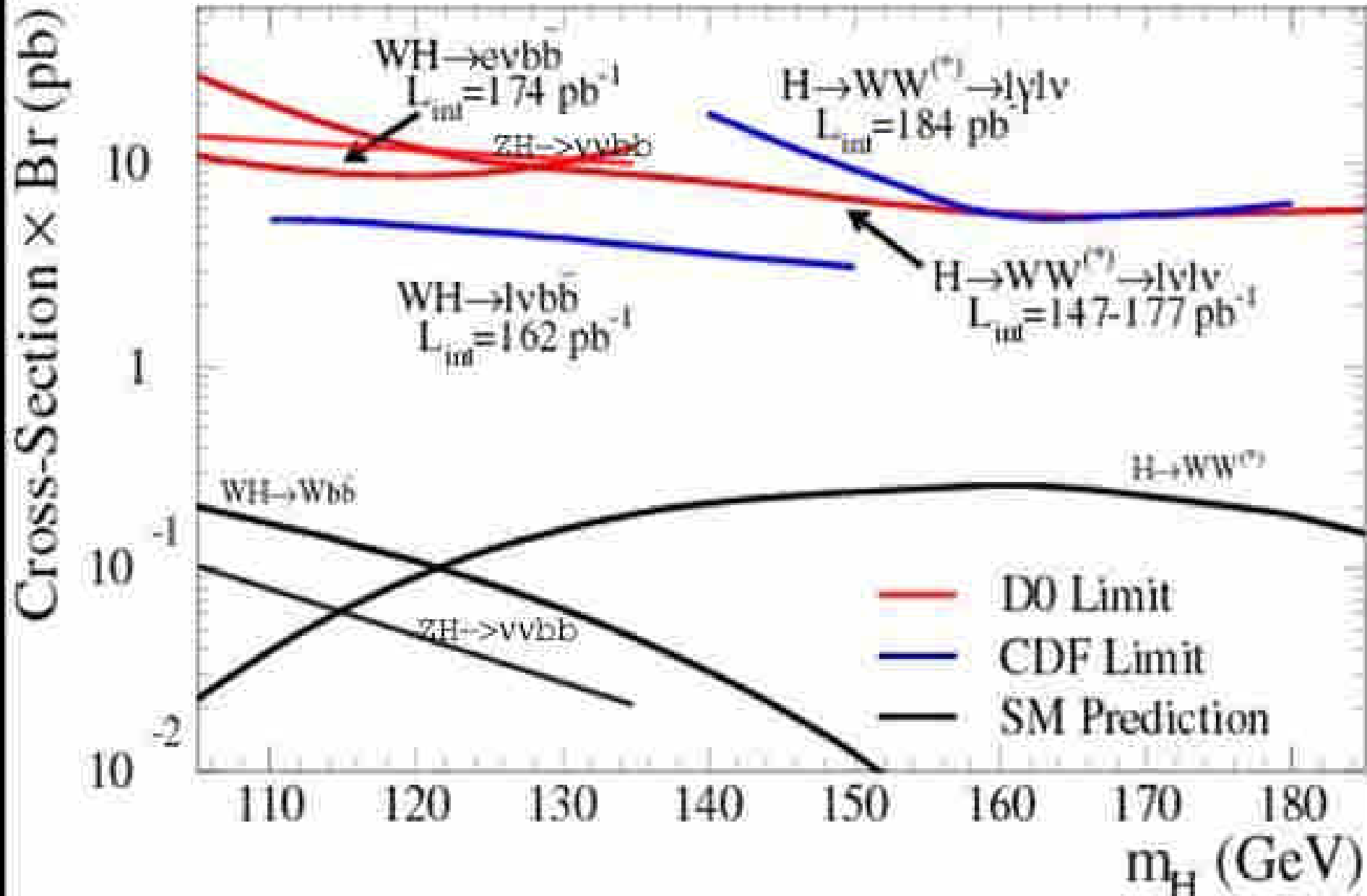


Associated Production $ZH \rightarrow \nu\nu b\bar{b}$



SM Higgs Boson Summary

Tevatron Run II Preliminary



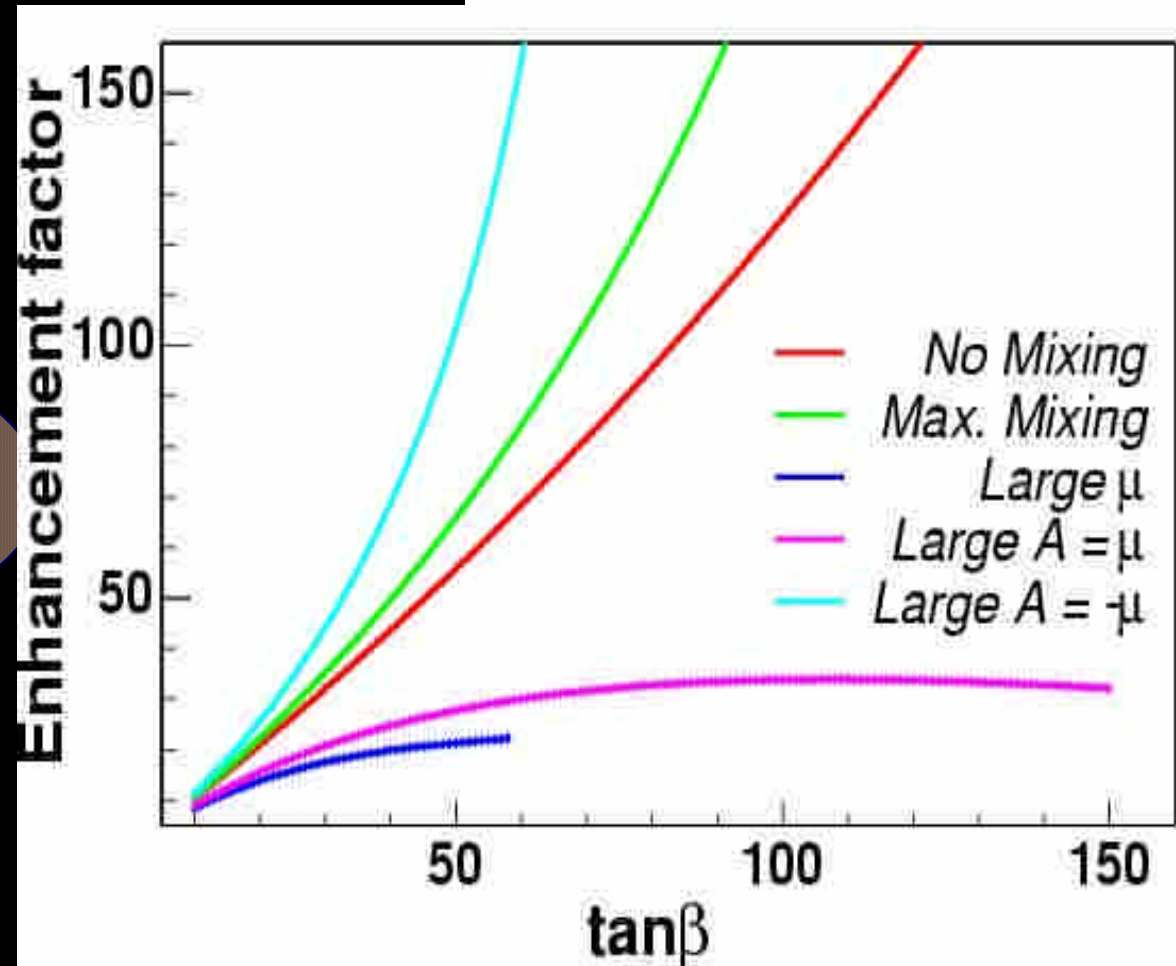
MSSM: bbA Cross Section

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

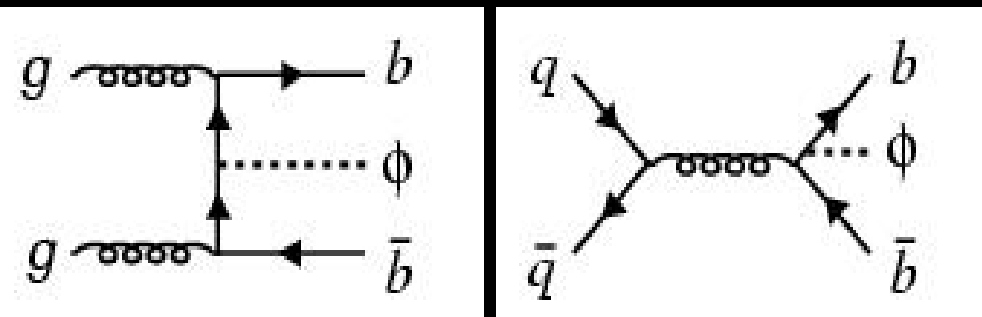
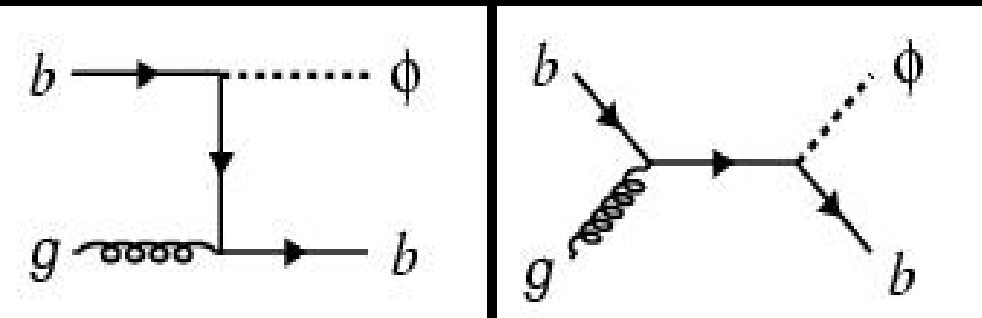
$$\Delta_b = \frac{\Delta h_b}{h_b} \times \tan \beta$$

depends on MSSM parameters: $X_t = A_t - \mu \cot \beta$, μ , M_g , M_q , etc.

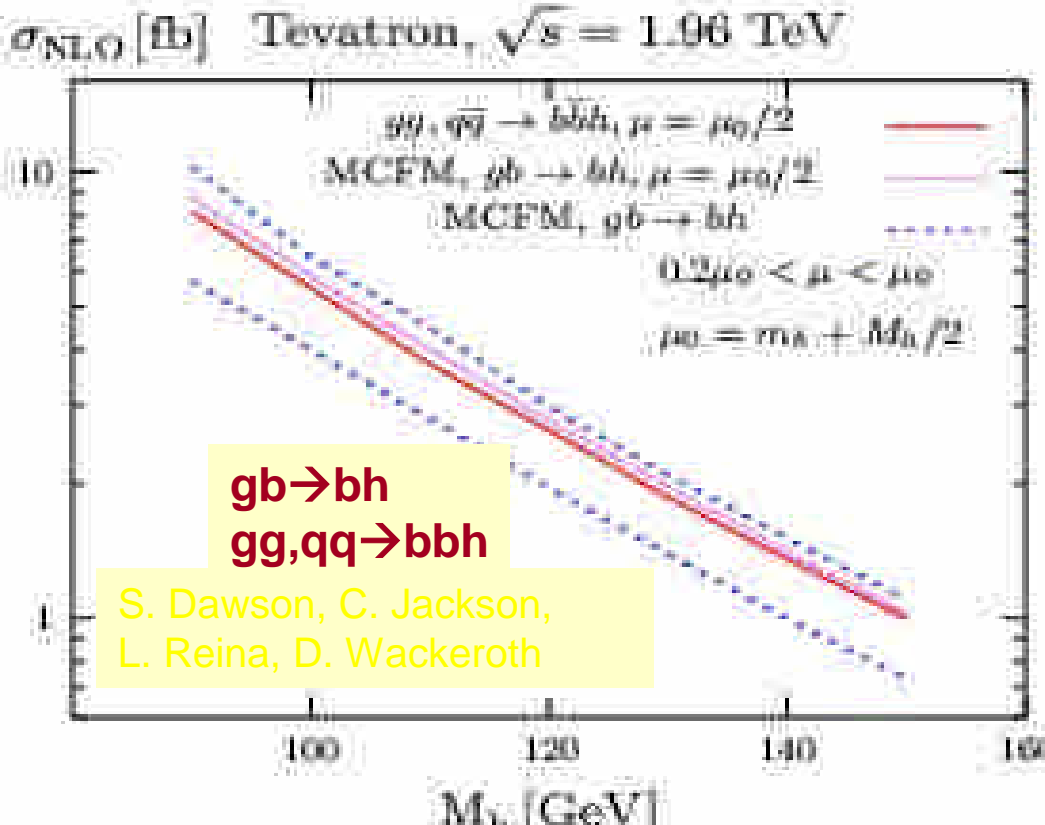
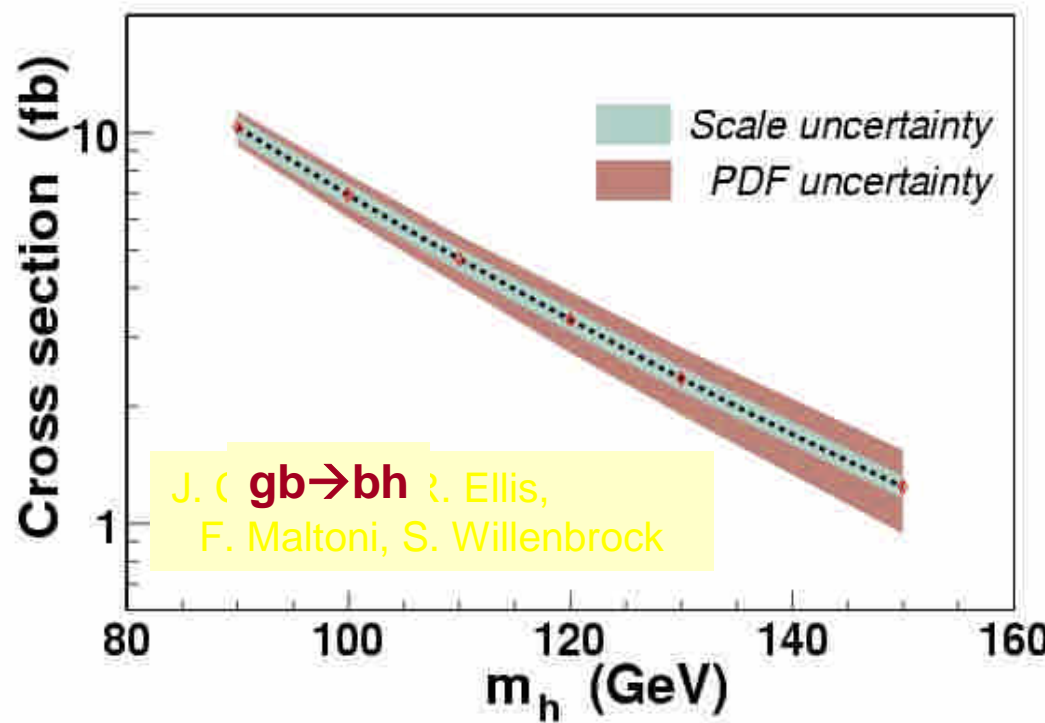
M. Carena, S. Mrenna, C. Wagner



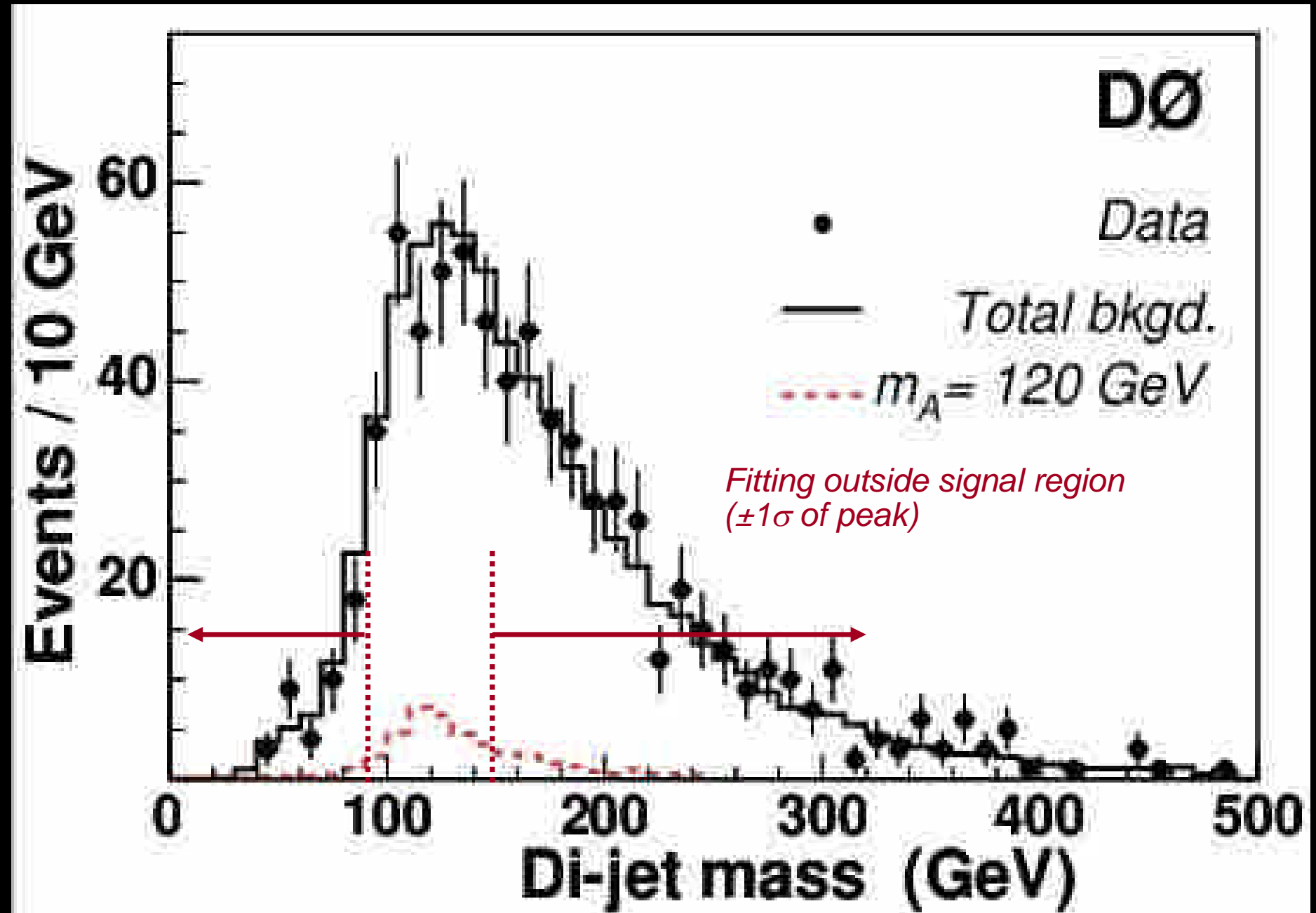
MSSM: bbA



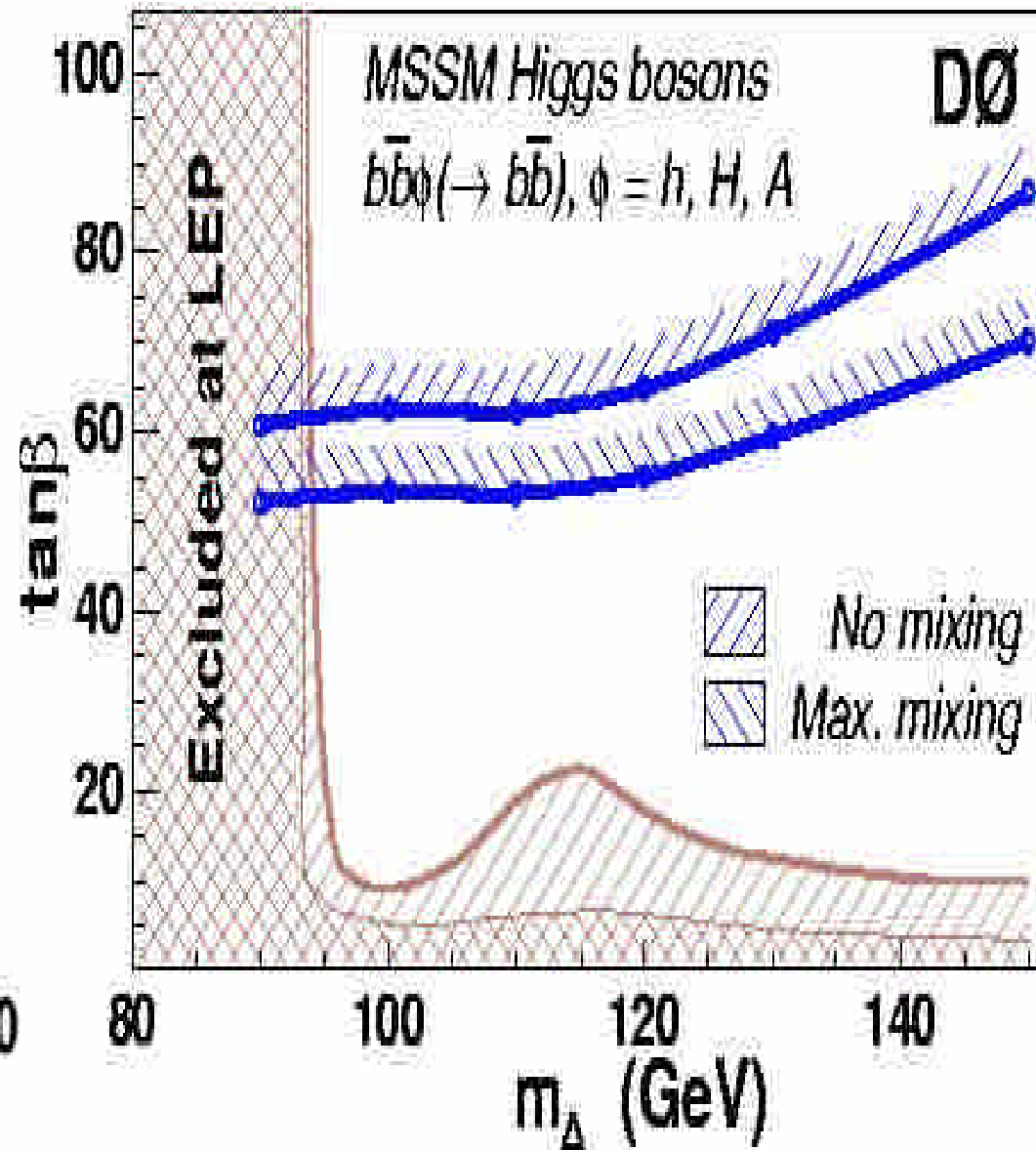
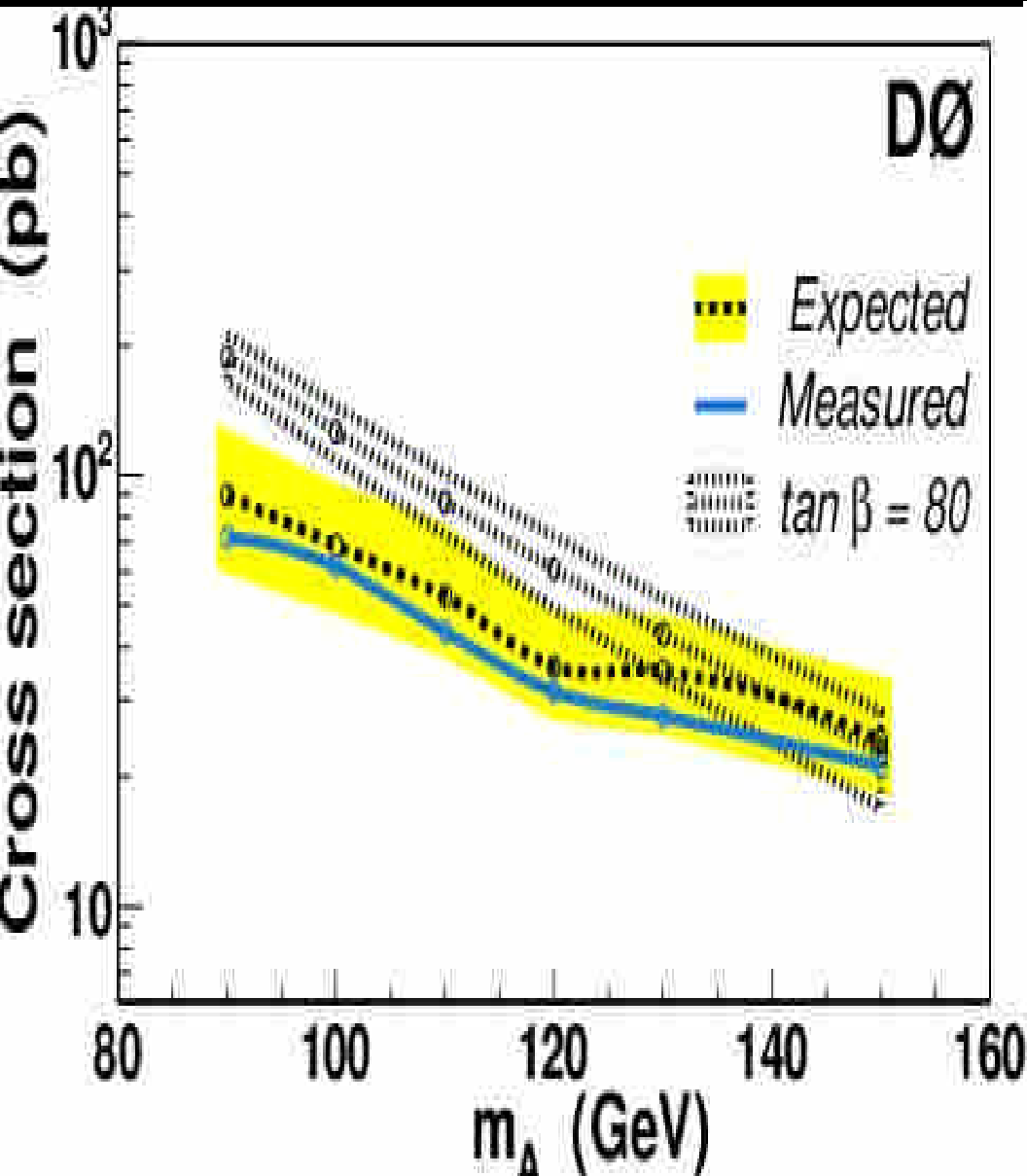
Both calculations at NLO agree within uncertainties



MSSM: $bbA \rightarrow bbbb$

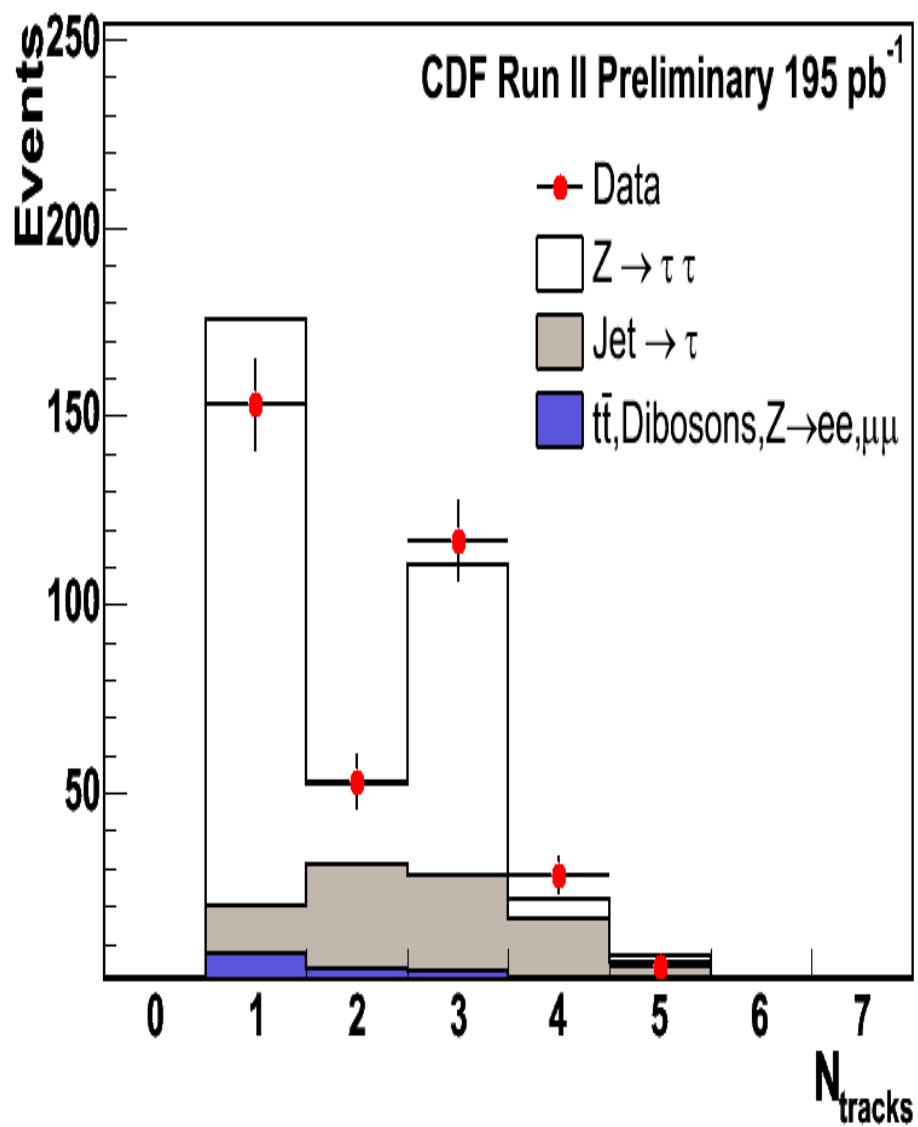


MSSM: $bbA \rightarrow bbb$

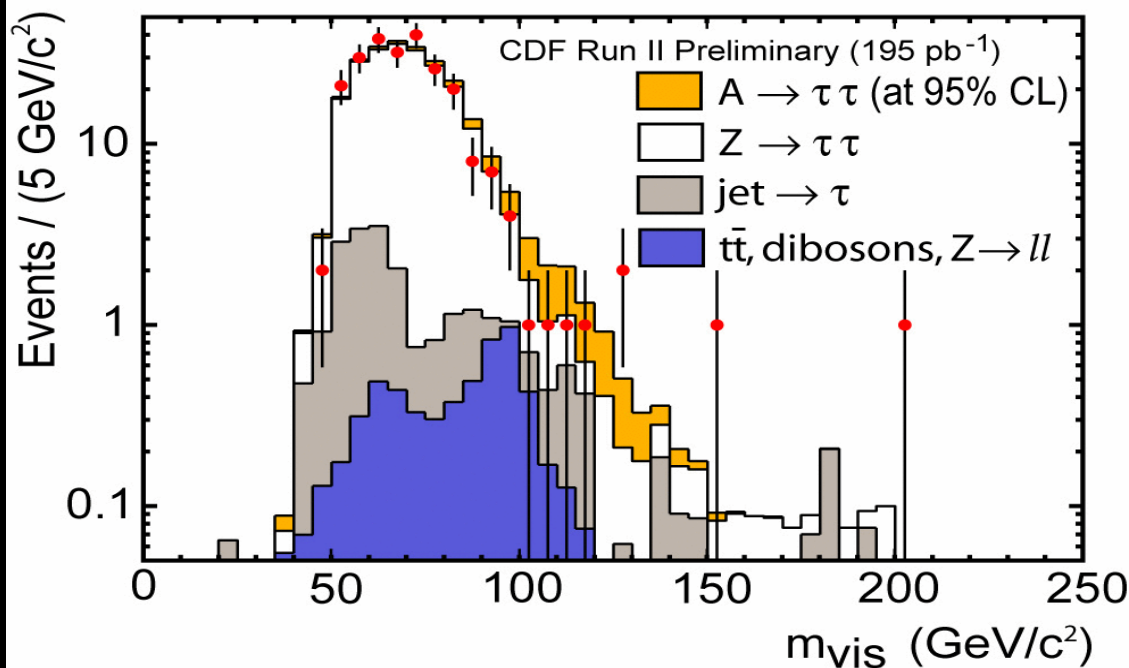


Higgs $\rightarrow \tau\tau$

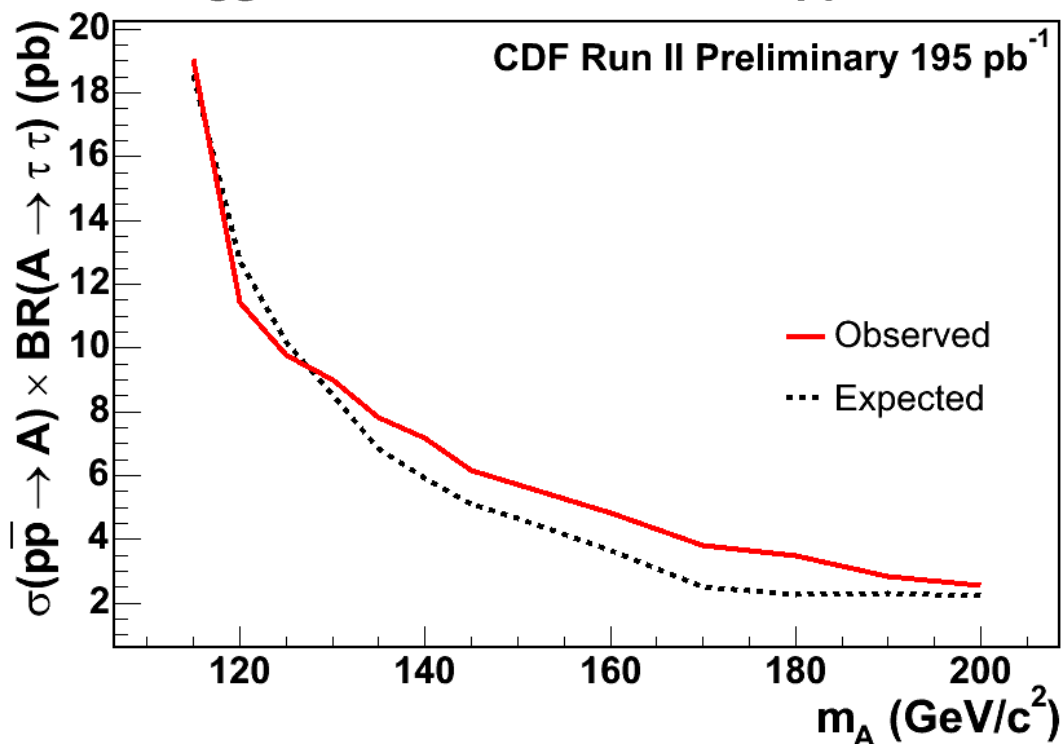
Higgs $\rightarrow \tau\tau$ Search, Track Multiplicity



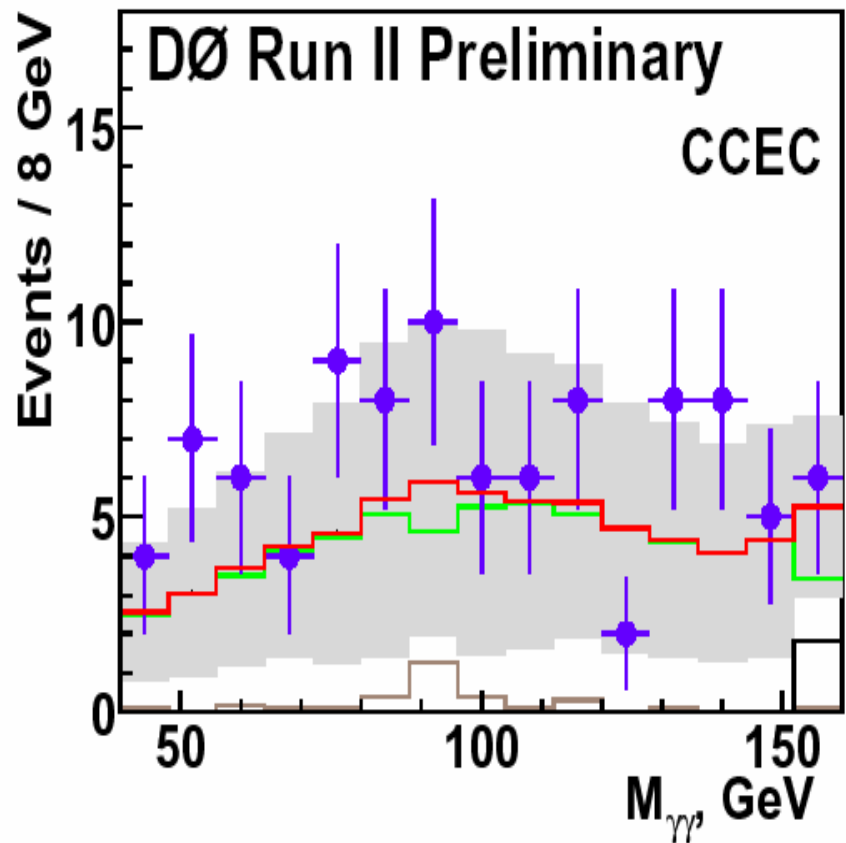
Higgs $\rightarrow \tau\tau$ Search, Example Fit for $m_A = 130 \text{ GeV}/c^2$



Higgs $\rightarrow \tau\tau$ Search, 95% CL Upper Limit



$H \rightarrow \gamma\gamma$



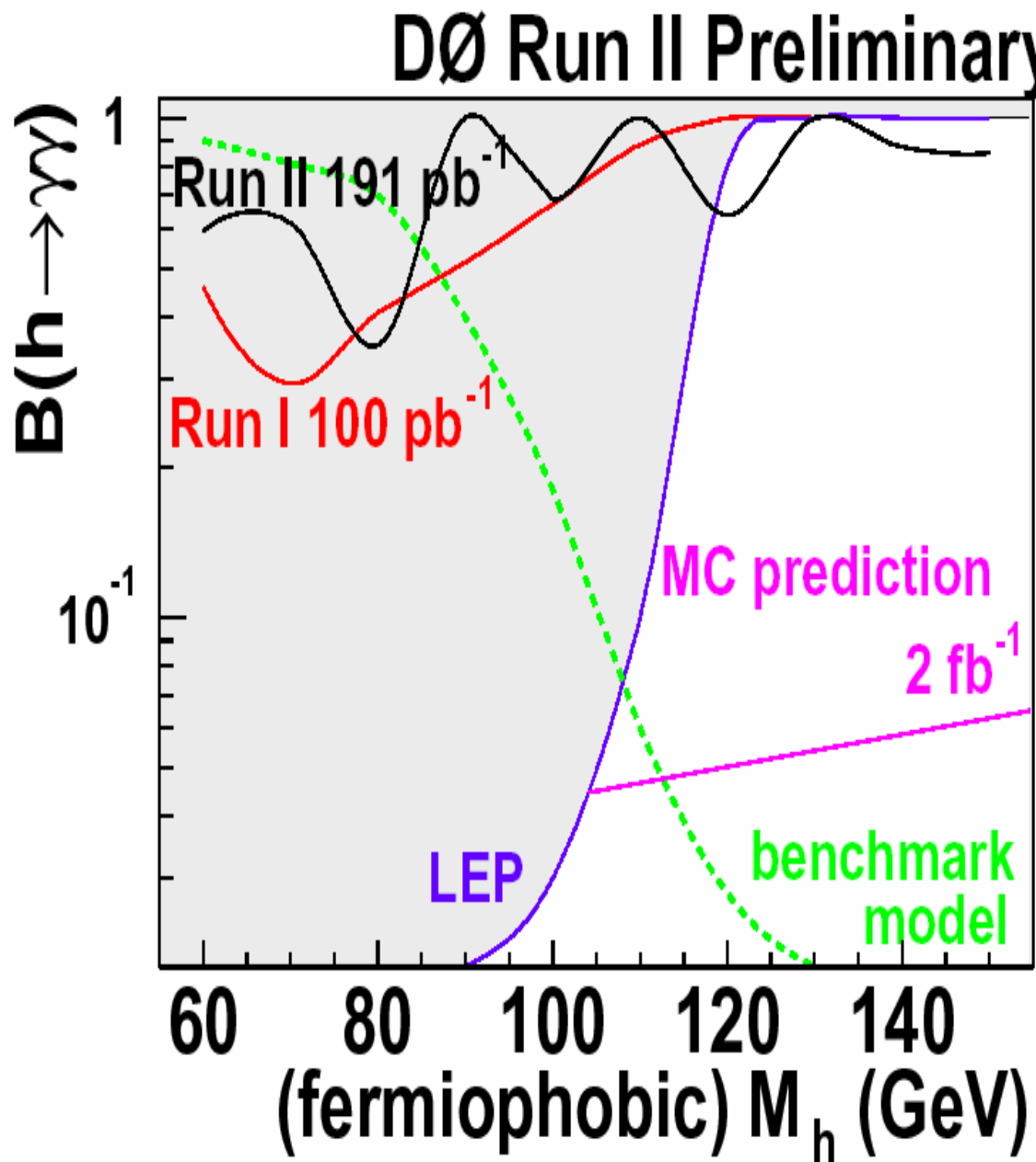
data = 97.0

bkgd = 68.8 \pm 45.8

QCD = 64.0 \pm 45.7

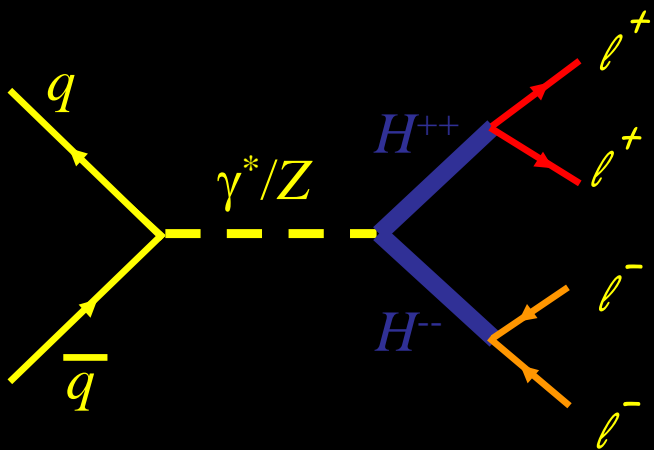
DY = 3.0 \pm 3.0

$\gamma\gamma$ = 1.8 \pm 0.1

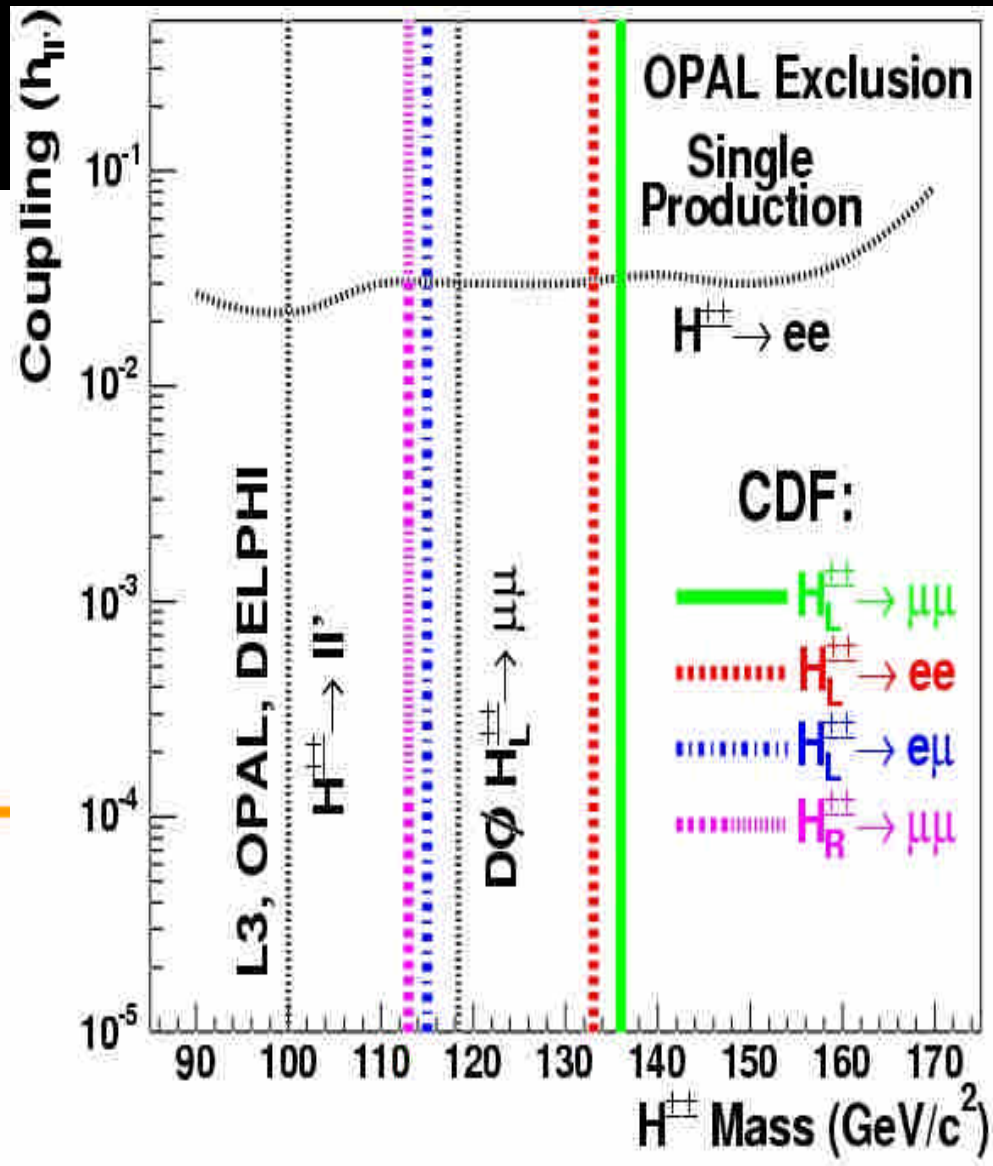
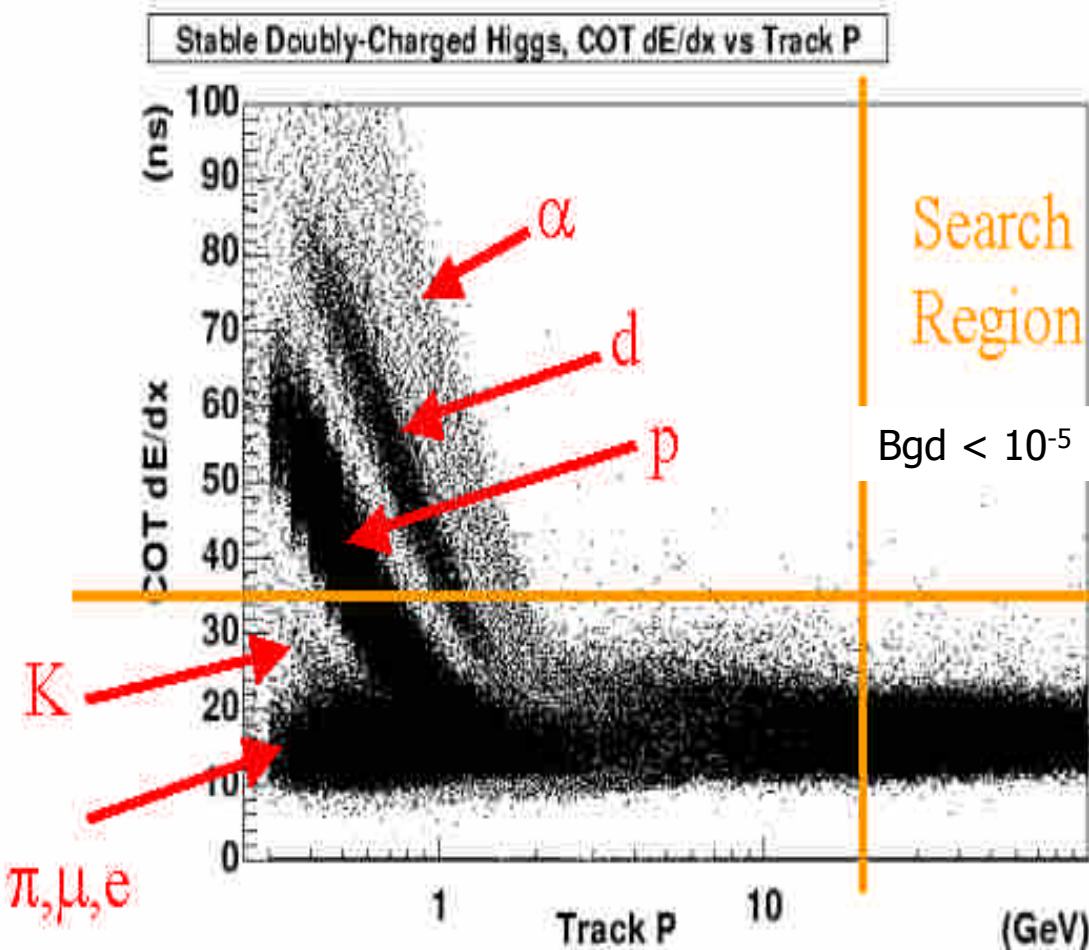


H^{++}/H^{--}

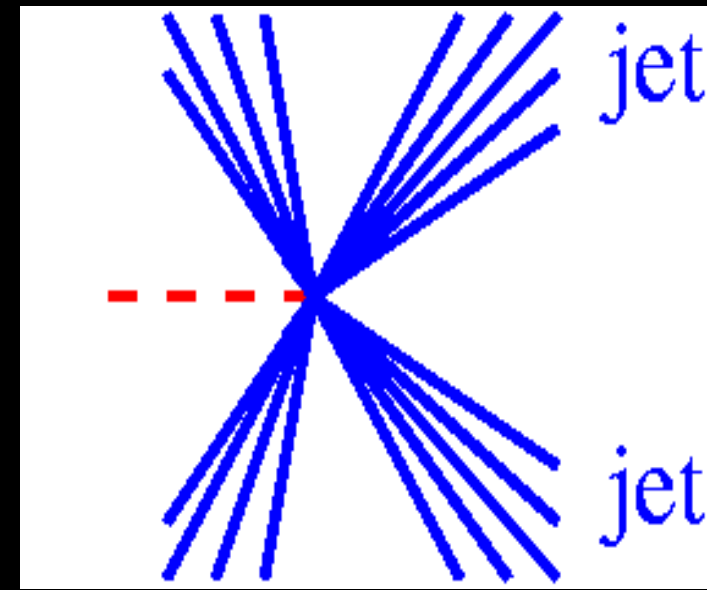
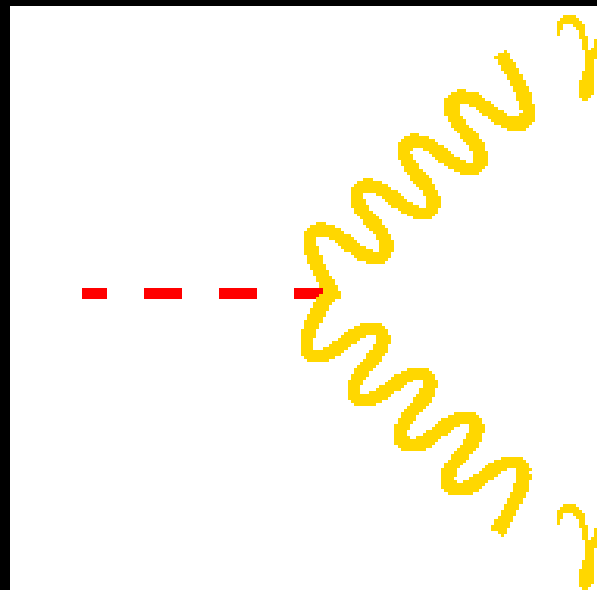
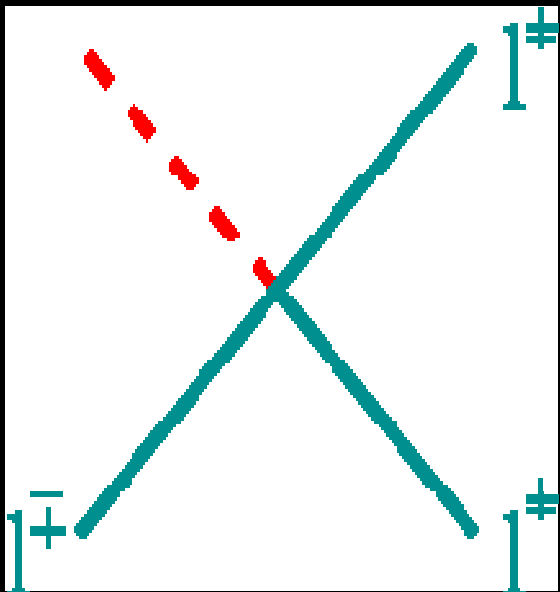
D0 (113 pb⁻¹) $M(H_L) > 118$ GeV ($\mu\mu$)
CDF (240 pb⁻¹) $M(H_L) > 136$ GeV ($\mu\mu$)
at 95% CL



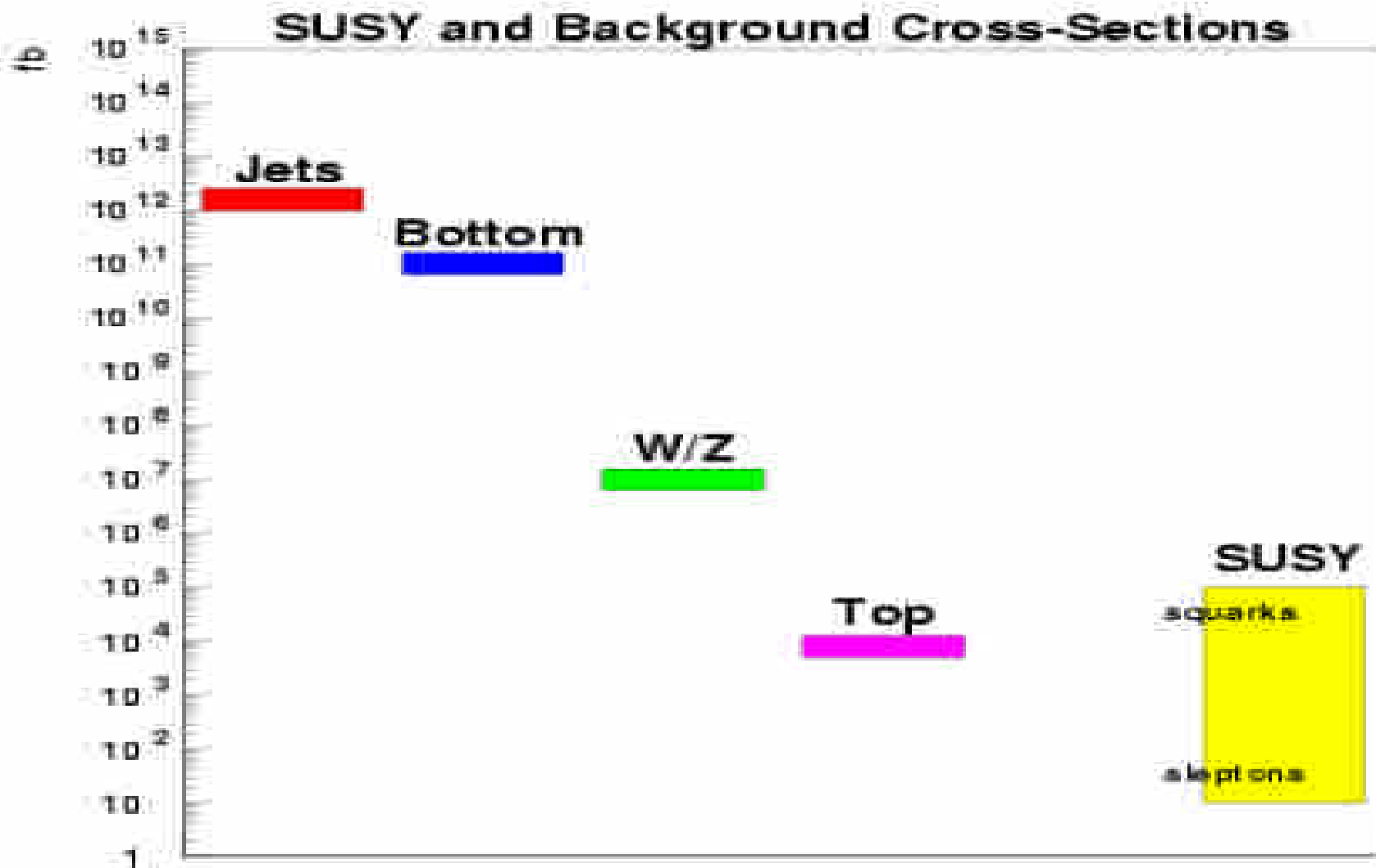
If long lived ($c\tau > 3$ m):
→ two high ionization tracks



SUSY Searches: Signatures



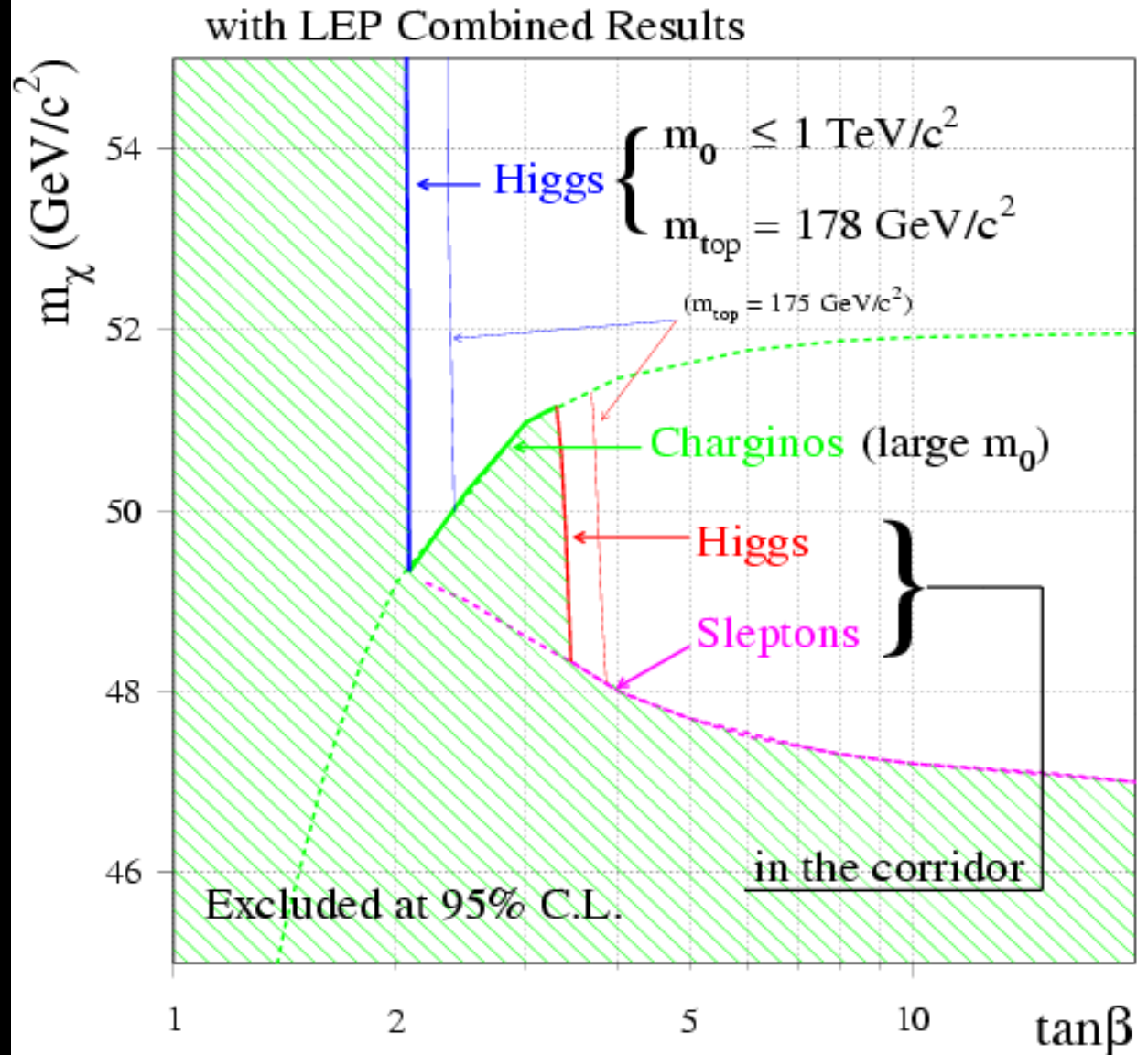
Small Expected Cross Section



LEP SUSY Limits

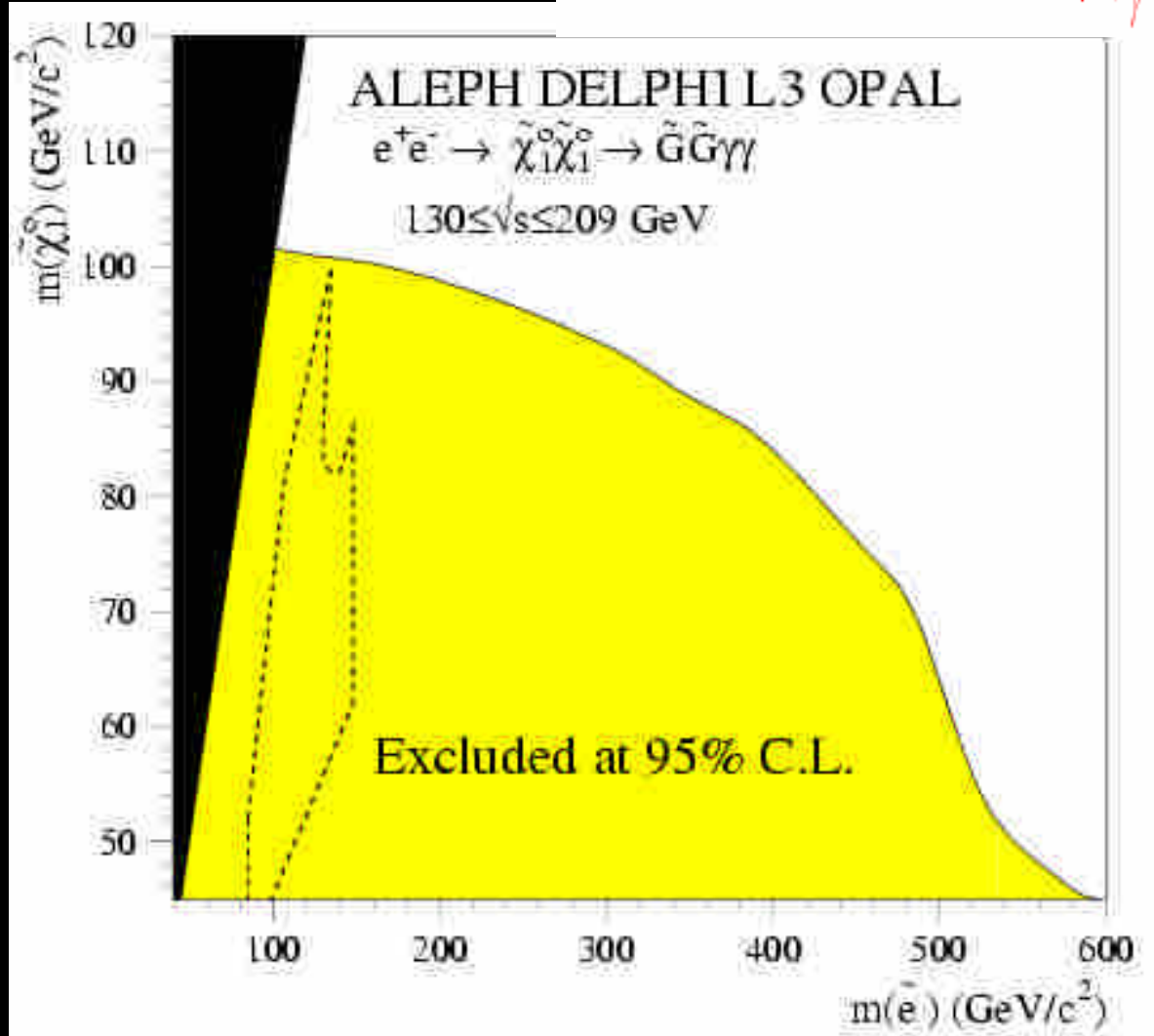
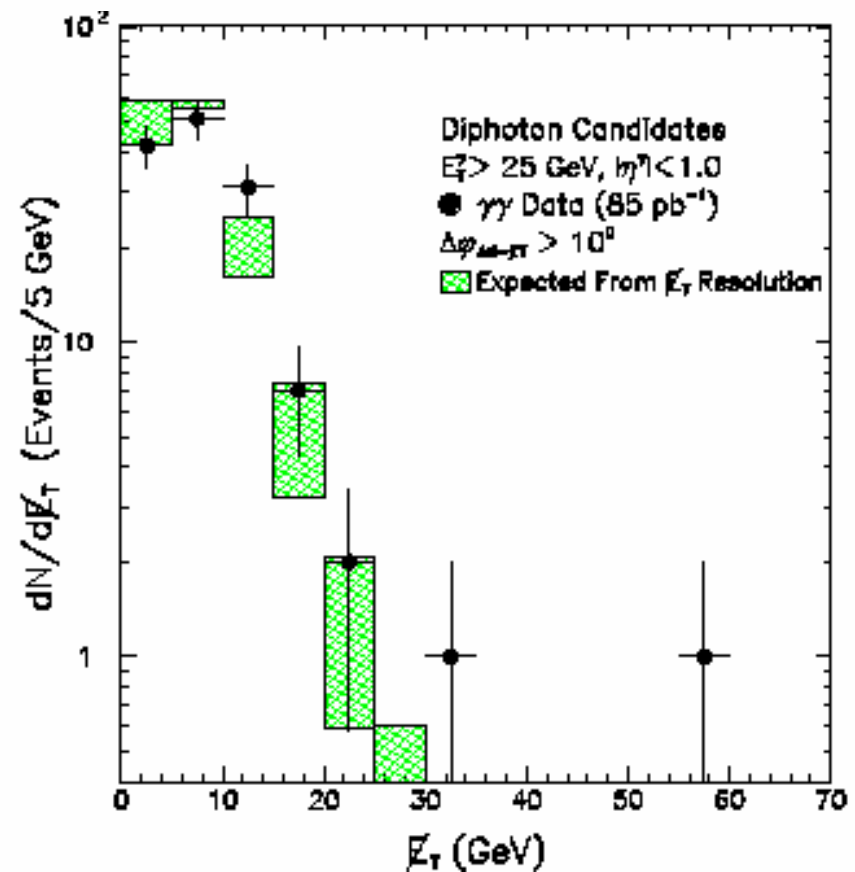
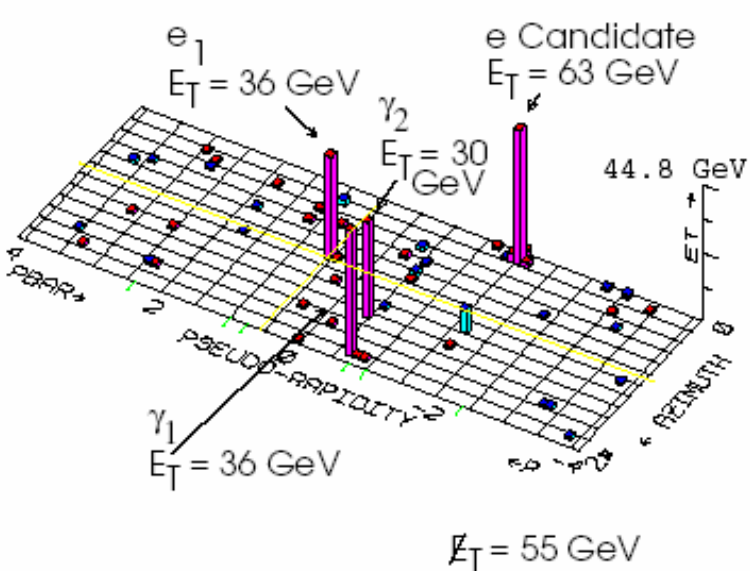
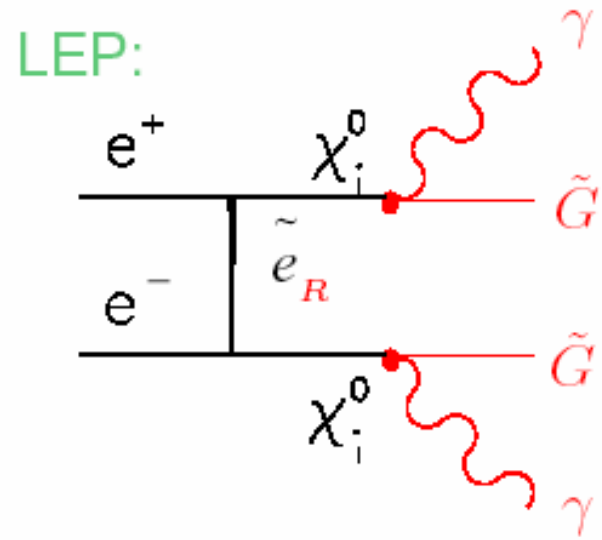
cMSSM

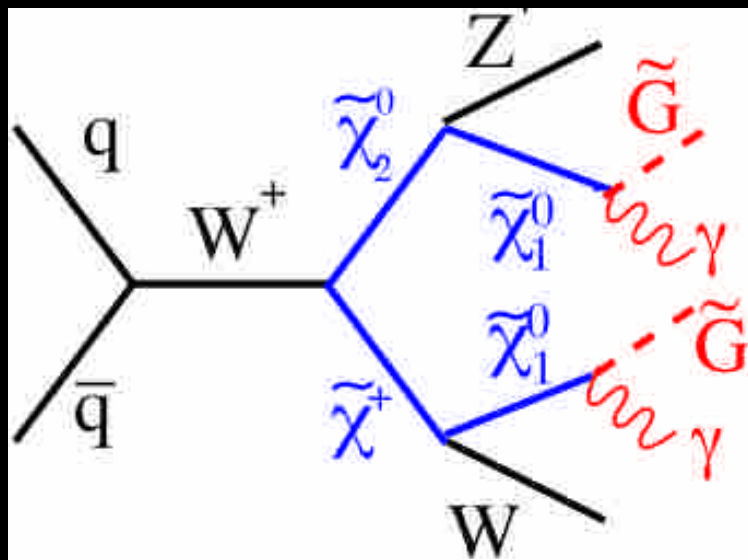
mSUGRA,
LSP
 $m_{\chi^0} > 50-60$ GeV



e^+e^- Candidate Event

GMSB History

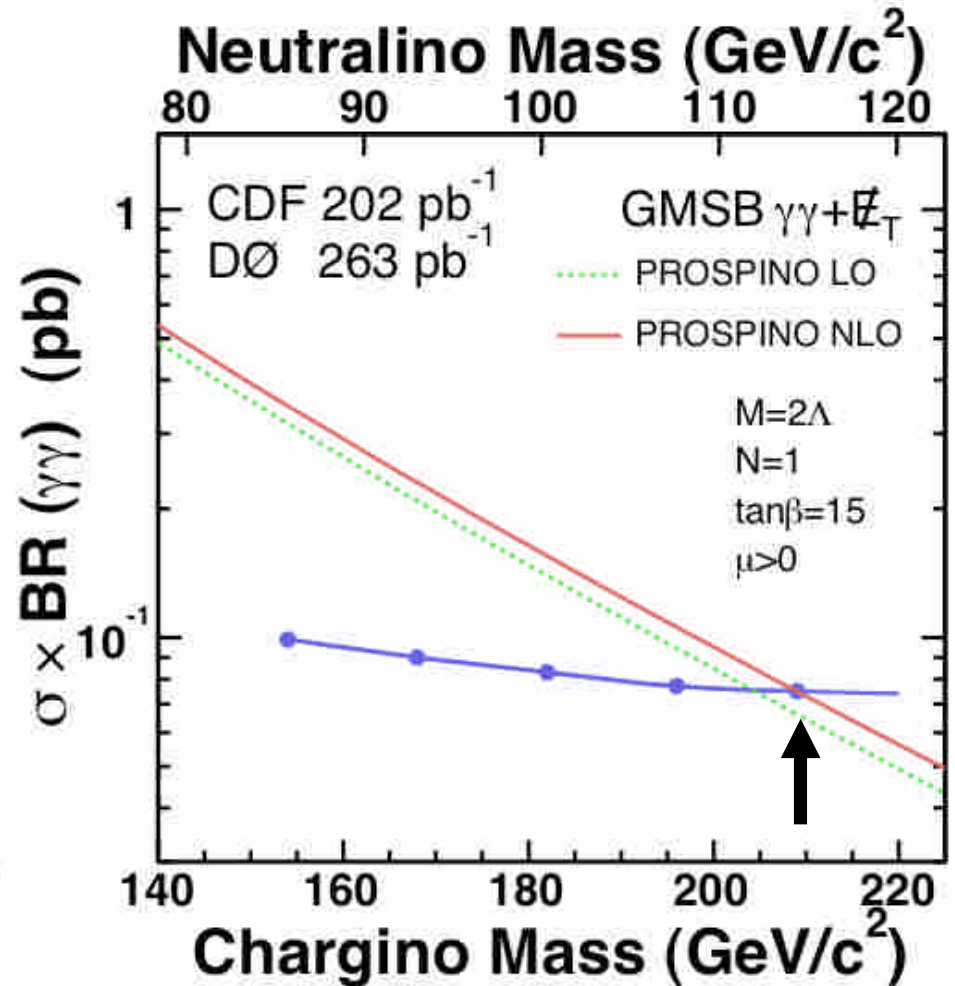
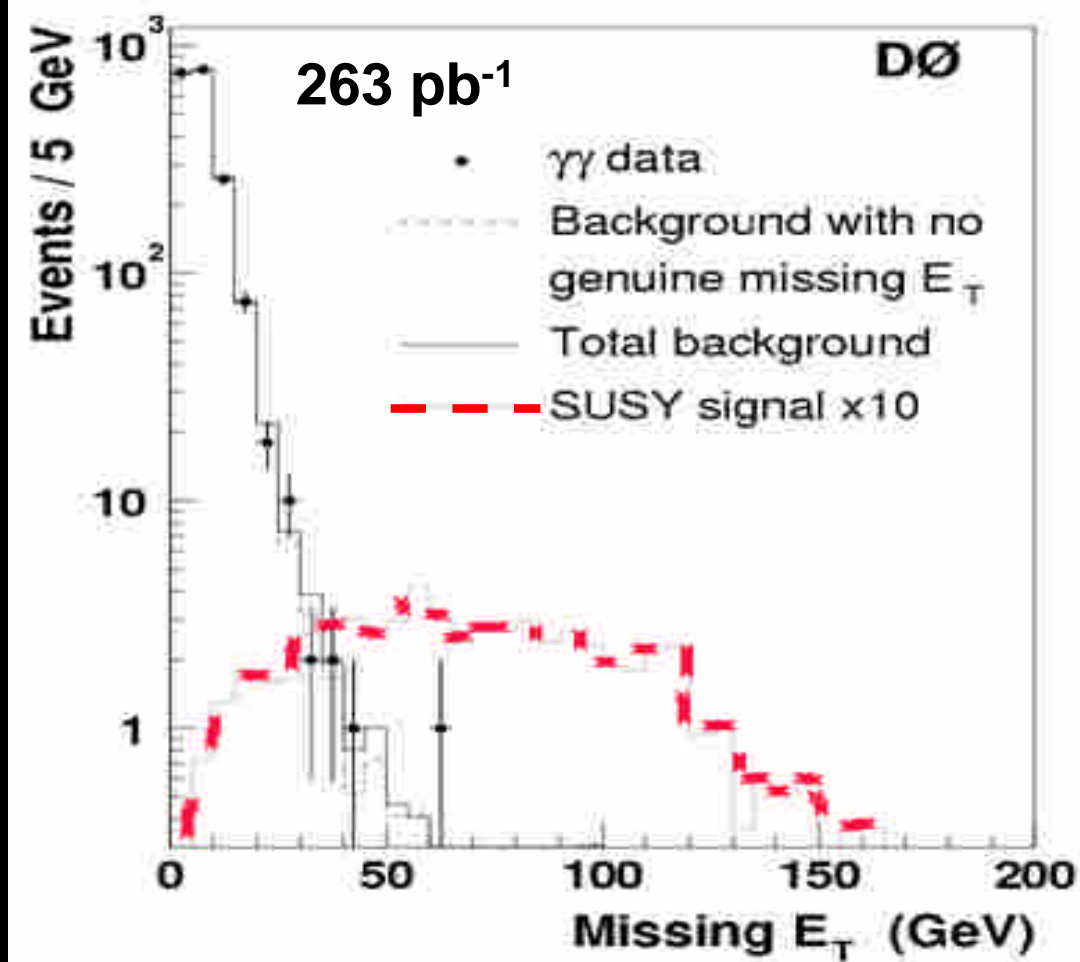




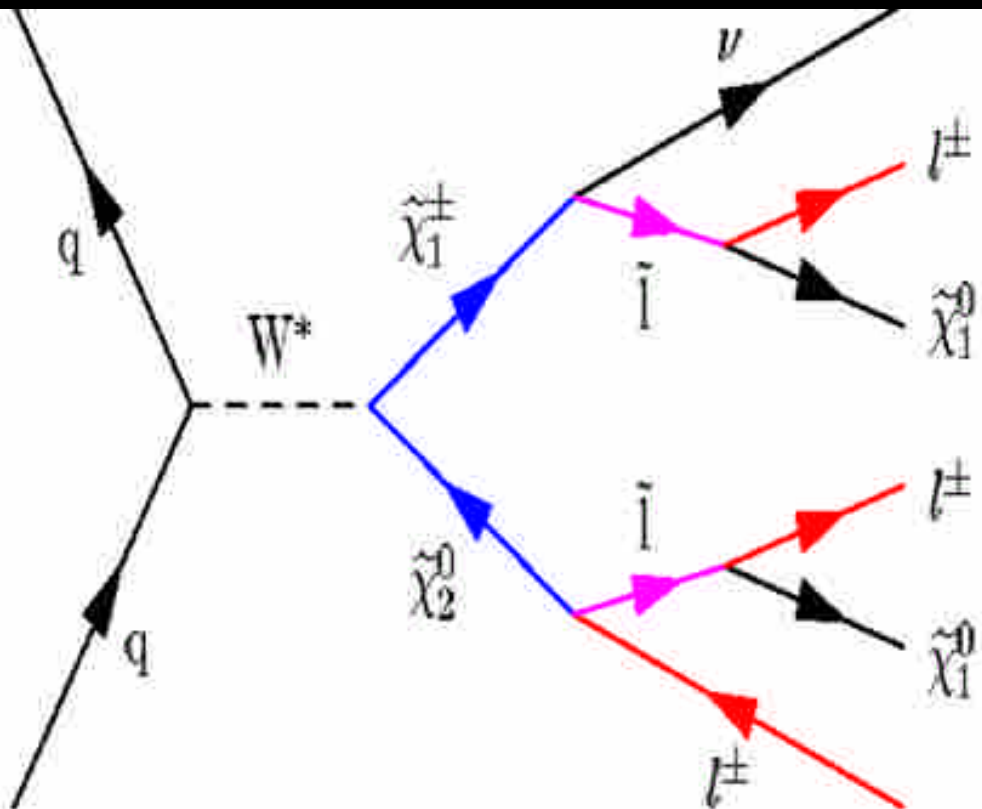
GMSB

	Exp bg	Obs	Limit m_{χ^+}
D0	3.7 ± 0.6	2	195 GeV
CDF	0.3 ± 0.1	0	167 GeV

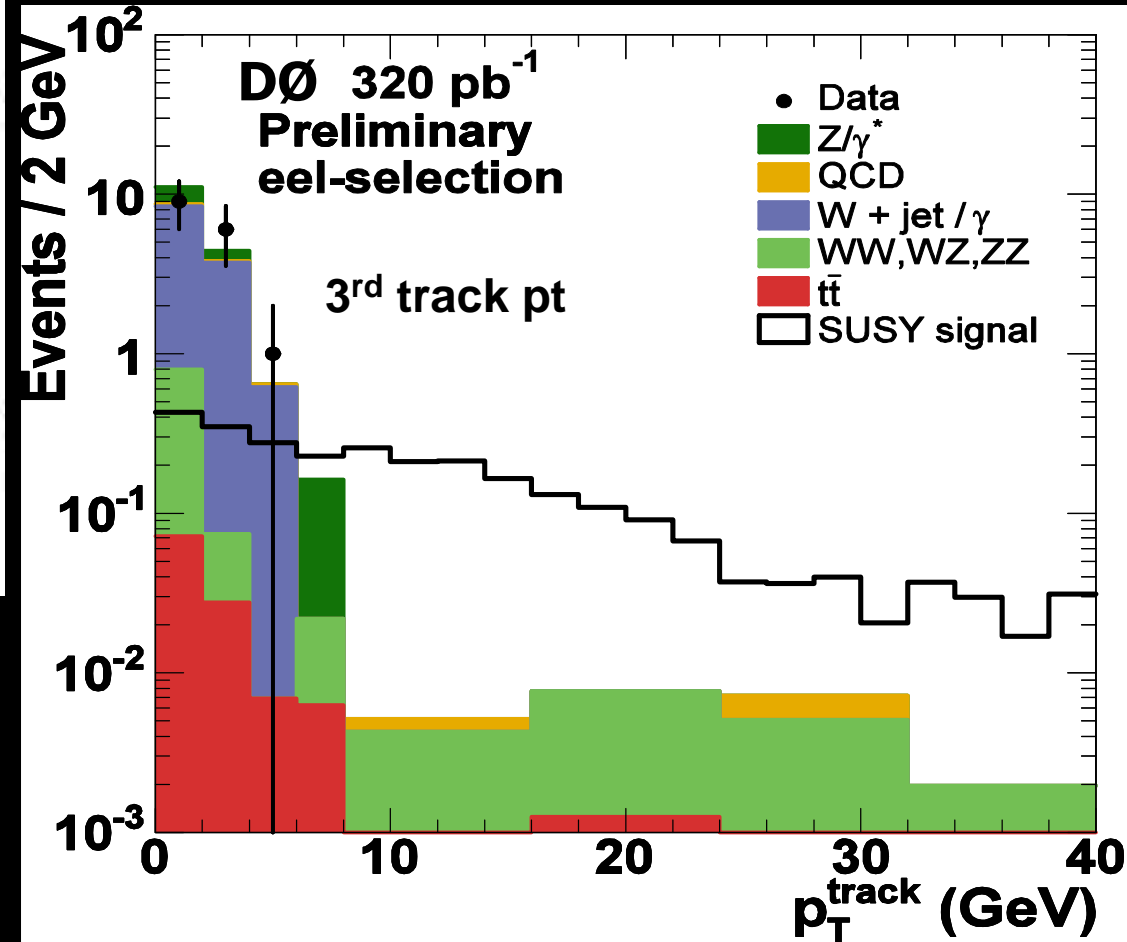
Combined CDF/D0:
 $m(\chi^\pm) > 209 \text{ GeV}$, $m(\chi^0) > 114 \text{ GeV}$



Tri-Lepton Searches



eel

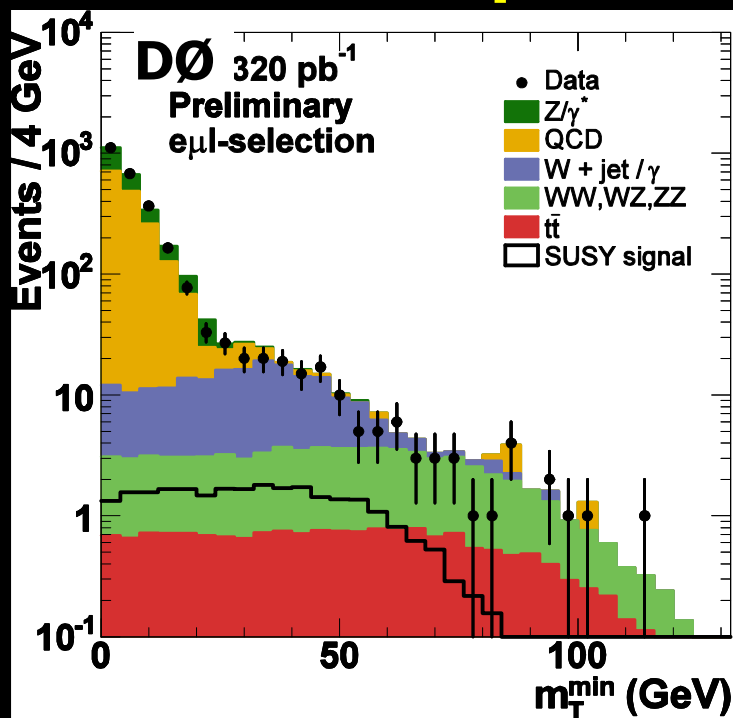


Expected bkg: 0.21 +/- 0.12

Observed: 0

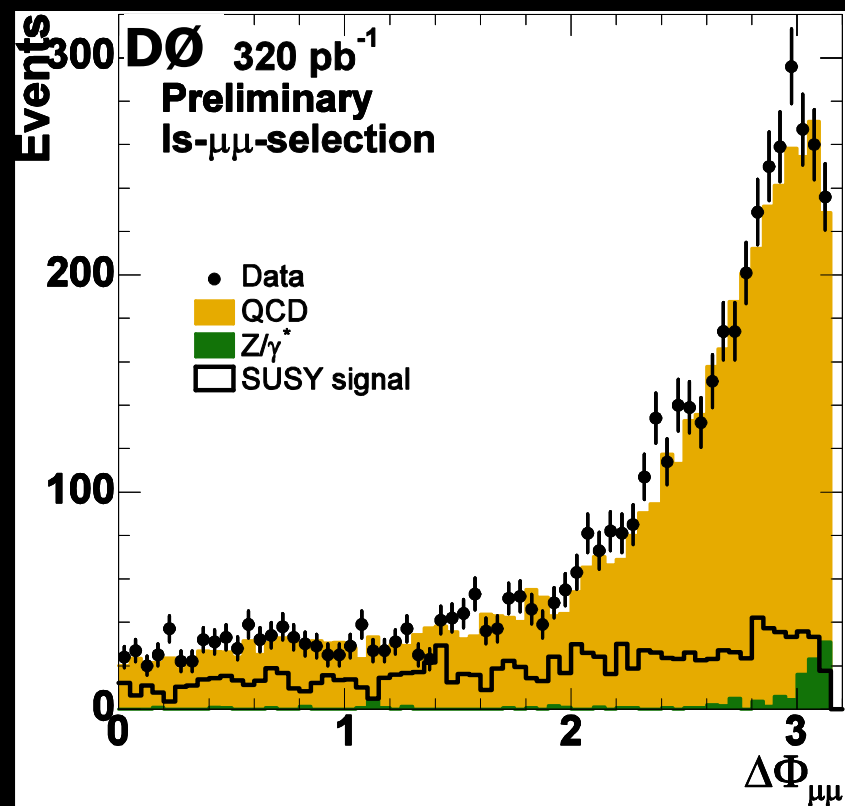
Tri-leptons with e and μ

$e\mu l$

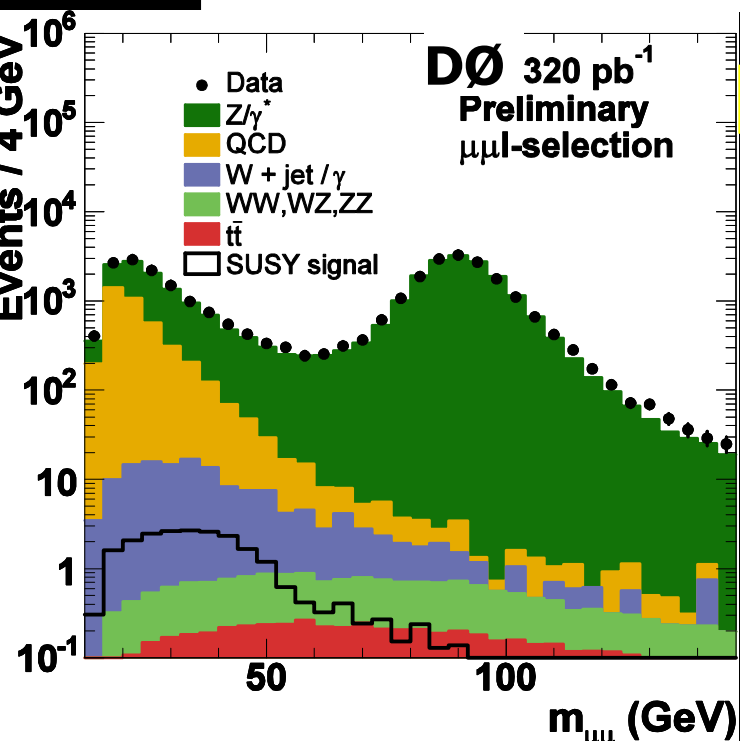


Expected bkg: $0.31^{+0.15}_{-0.12}$
 Observed: 0

like-sign $\mu\mu$



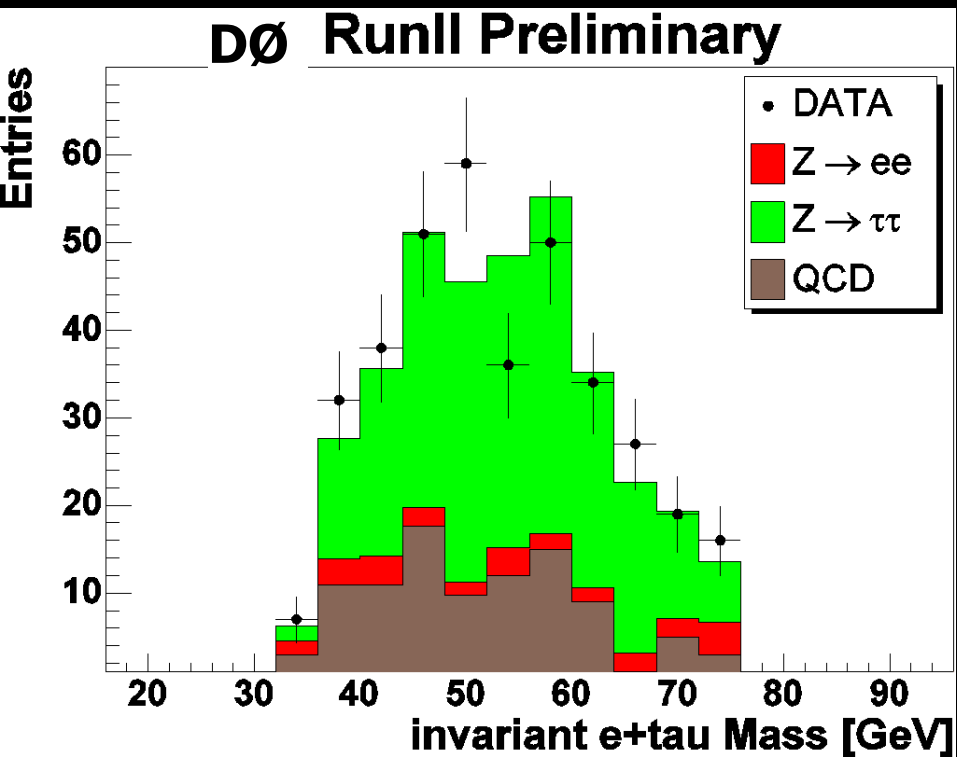
Expected bkg: 0.66 ± 0.37
 Observed: 1



$\mu\mu l$

Expected bkg: 1.75 ± 0.57
 Observed: 2

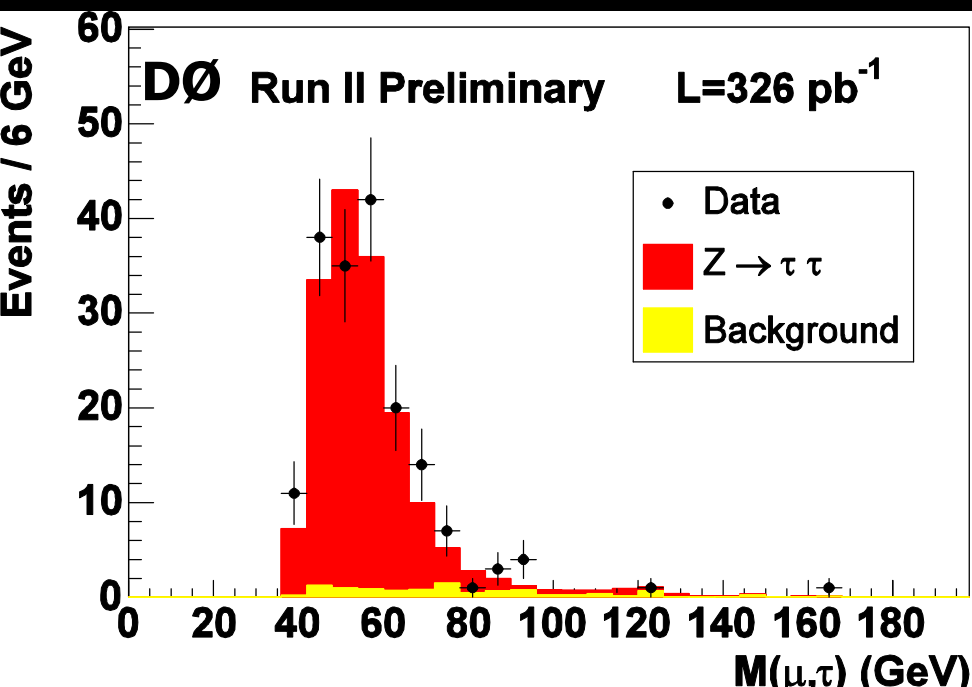
Tri-leptons with τ



$e\tau l$: $\tau \rightarrow$ hadrons

Expected bkg: 0.58 ± 0.11

Observed: 0

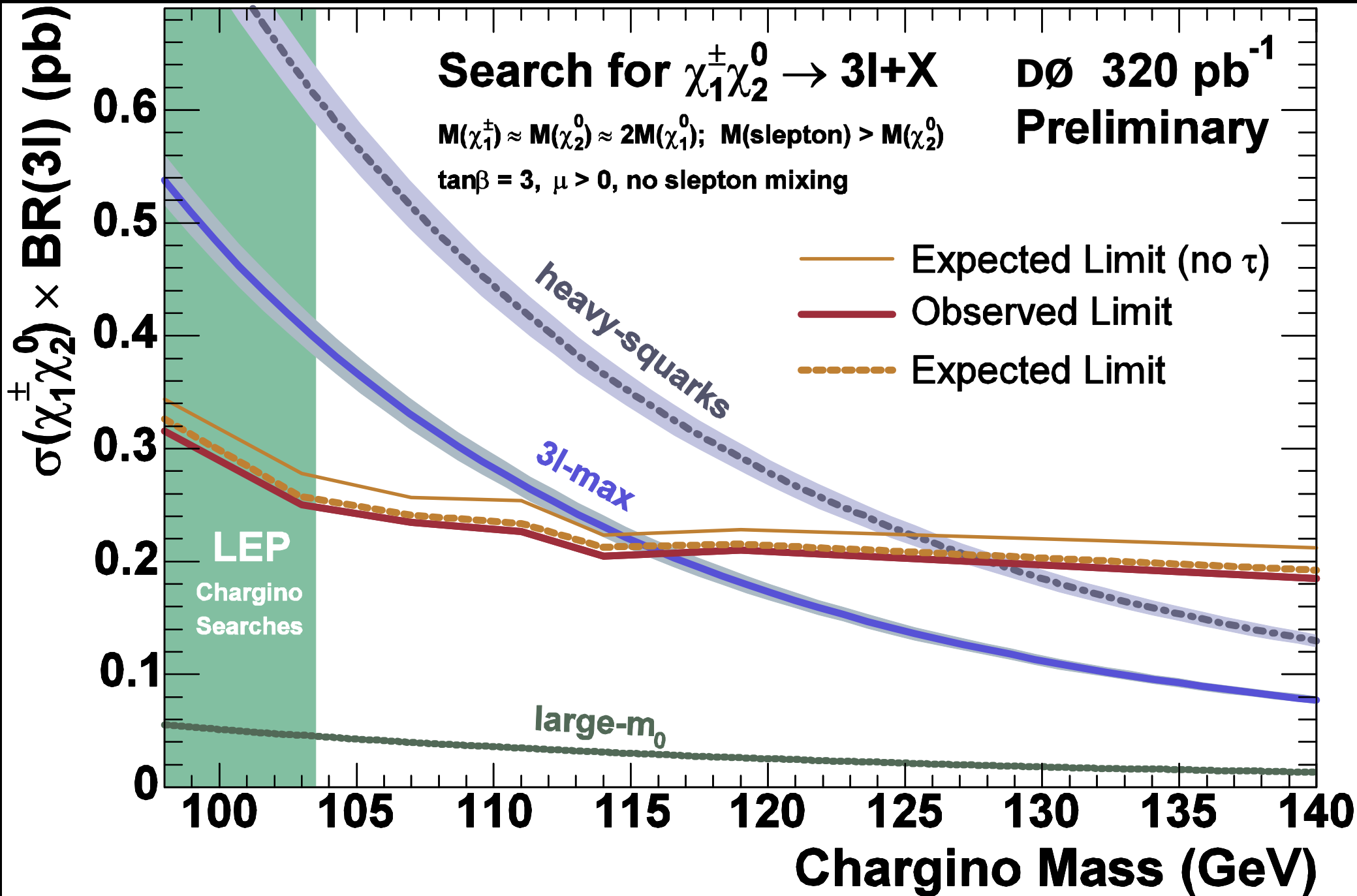


$\mu\tau l$: $\tau \rightarrow$ hadrons

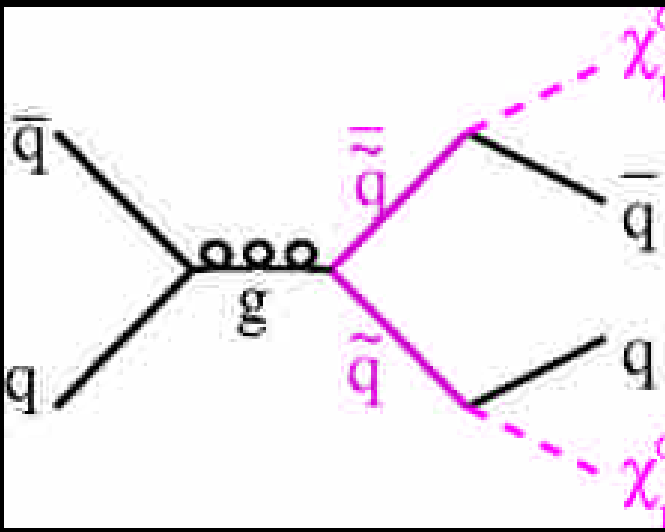
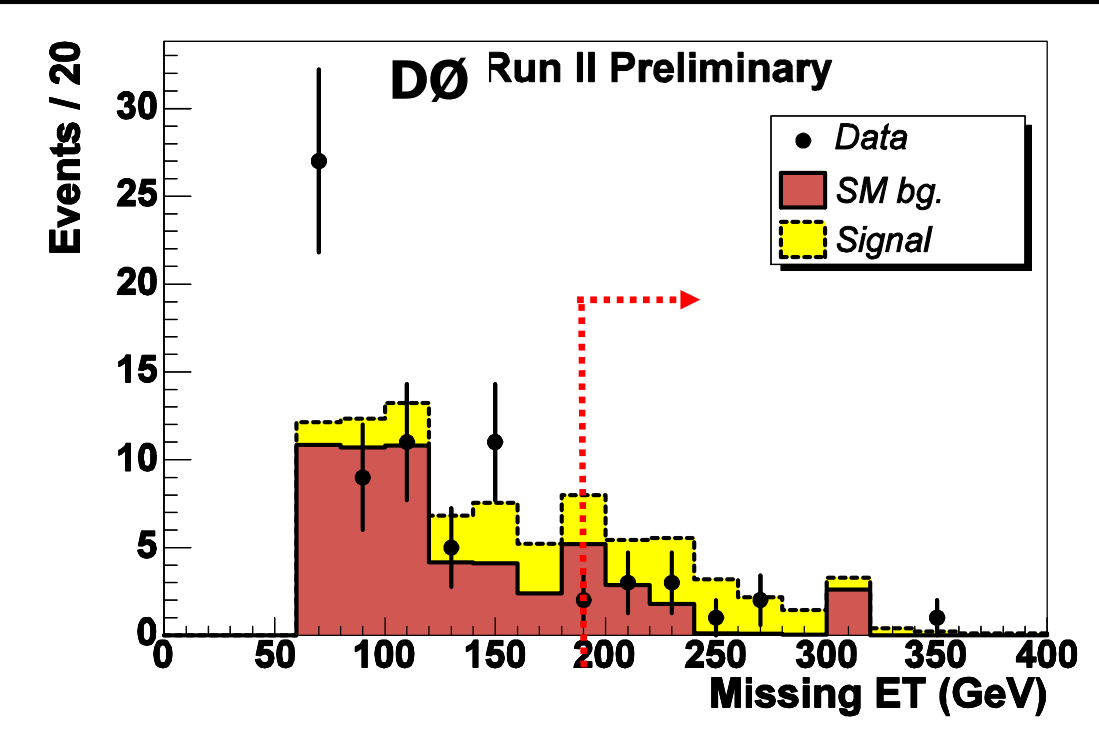
Expected bkg: 0.36 ± 0.12

Observed: 1

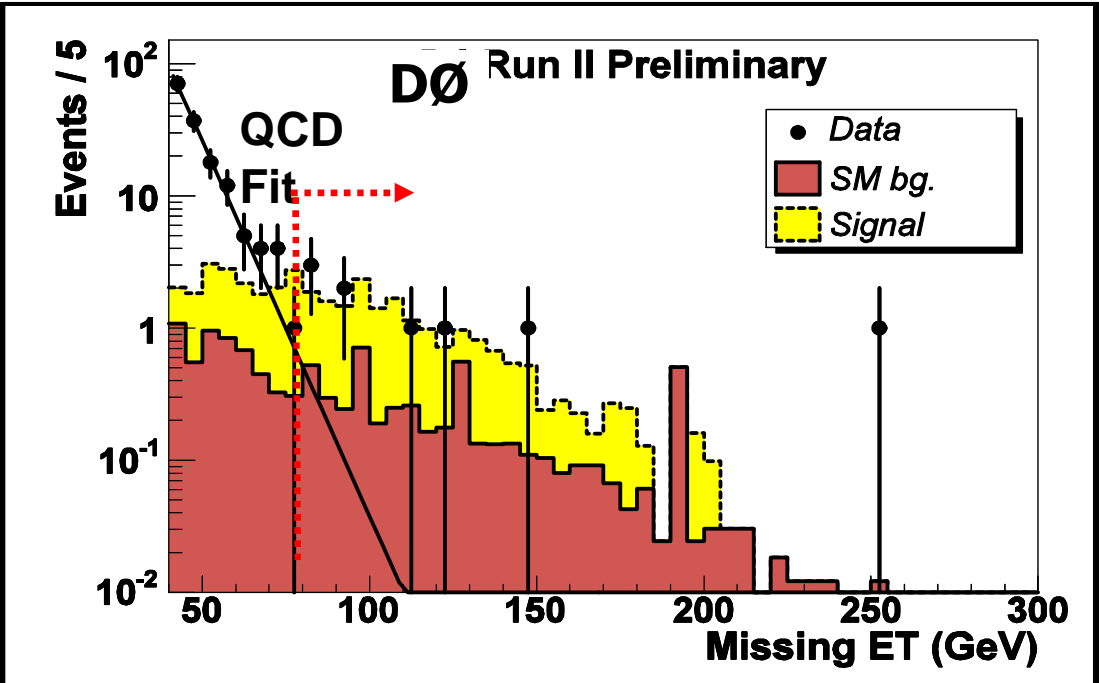
SUSY Tri-Lepton Limits



Squark-Gluino: $\tilde{q}\tilde{q}, \tilde{g}\tilde{g}, \tilde{g}\tilde{q}$

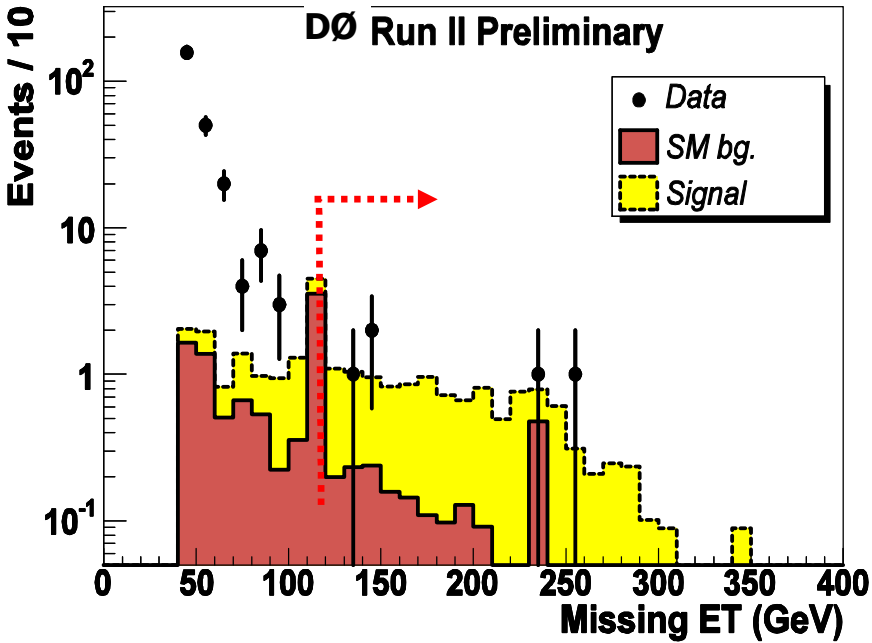


1) \tilde{g} heavier than \tilde{q} :
 $\tilde{q}\tilde{q}$ production dominates,
 acoplanar dijets



2) \tilde{q} heavier than \tilde{g} :
 $\tilde{g}\tilde{g}$ production dominates,
 multi (≥ 4) jets

Squark-Gluino

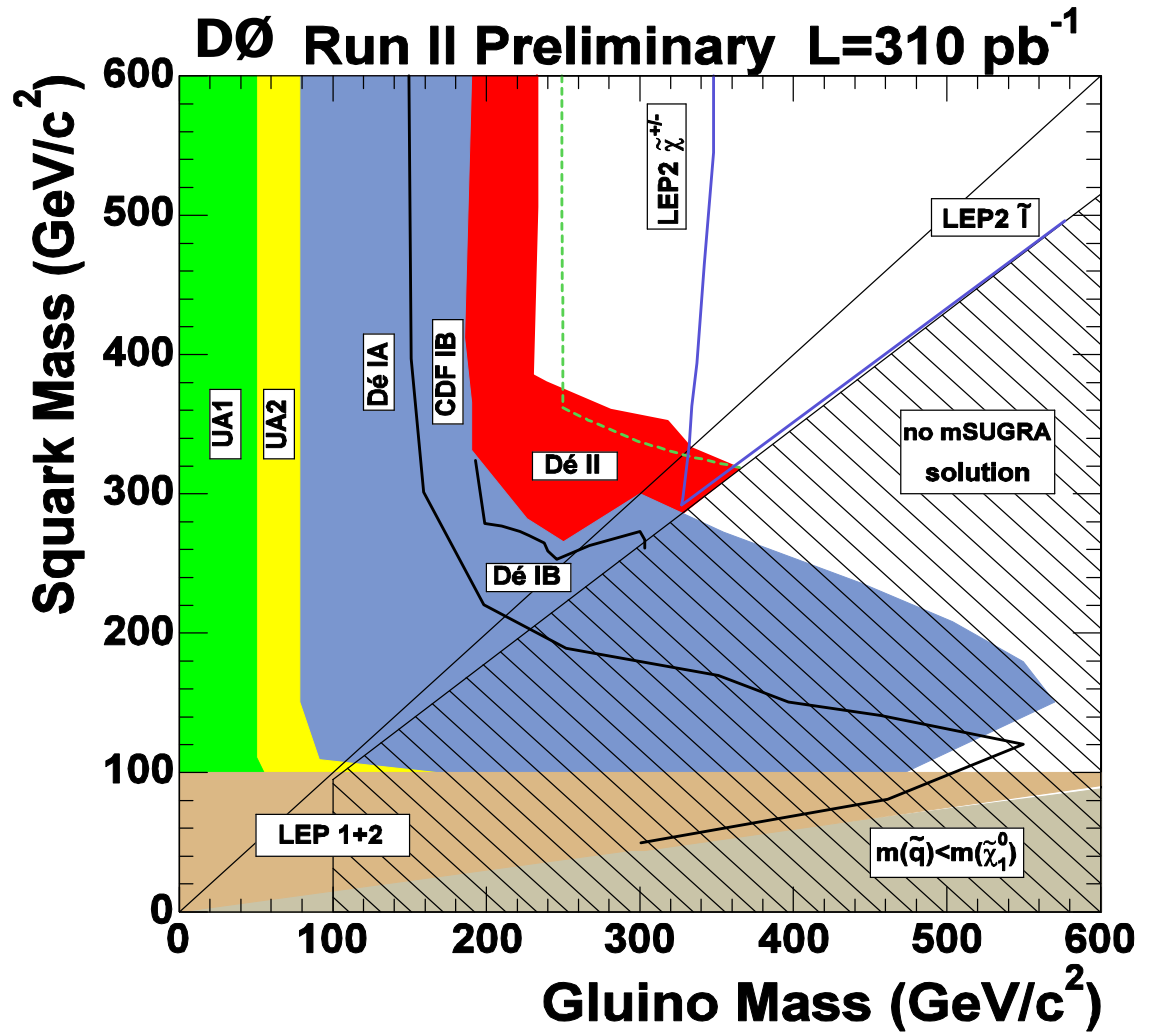


3) $\tilde{q}\tilde{g}$ similar masses:
 $\tilde{g}\tilde{q}$ production important,
 3 jet events

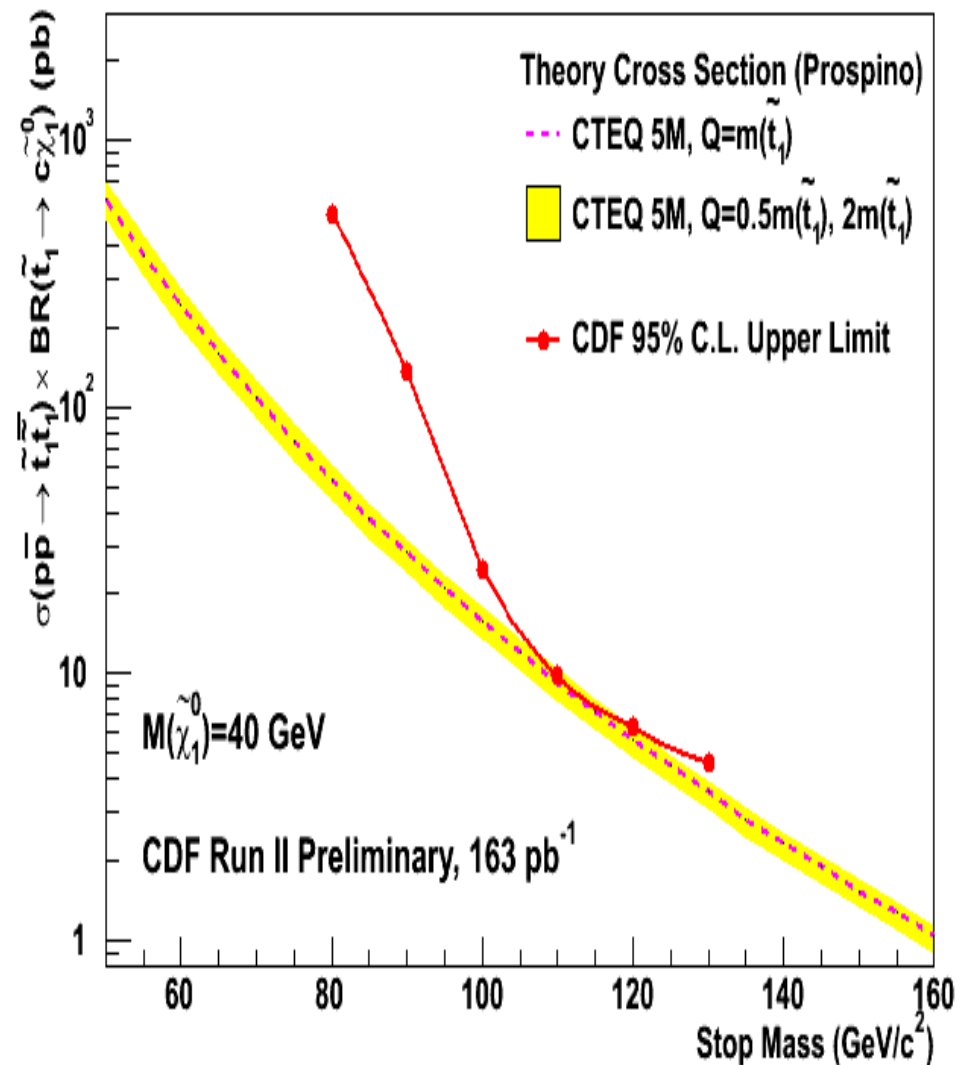
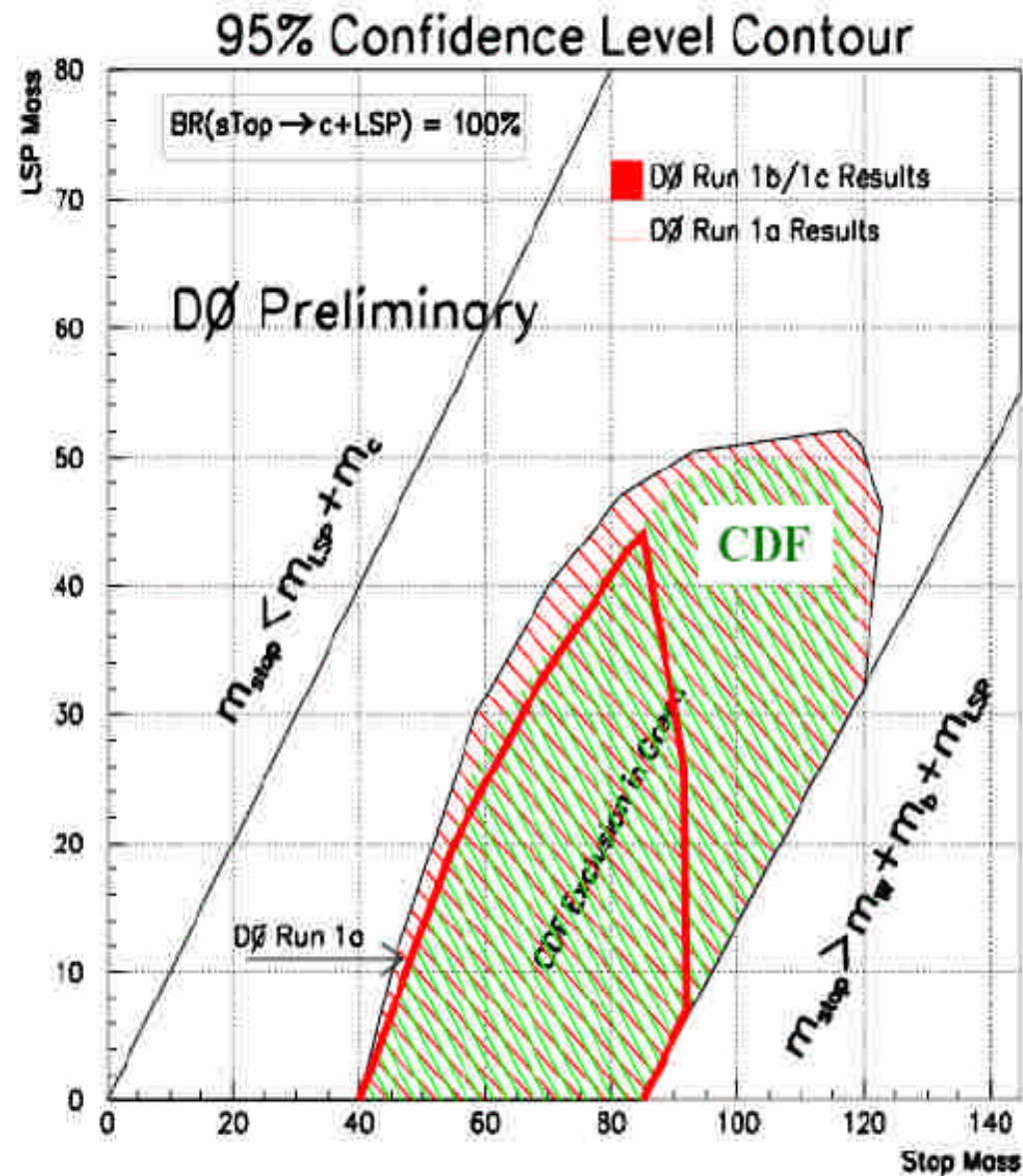
1) $\tilde{q}\tilde{q}$ production (dijets)
 Expected 12.8 +/- 5.4
 Observed 12

2) $\tilde{g}\tilde{g}$ production (≥ 4 jets)
 Expected 7.1 +/- 0.9
 Observed 10

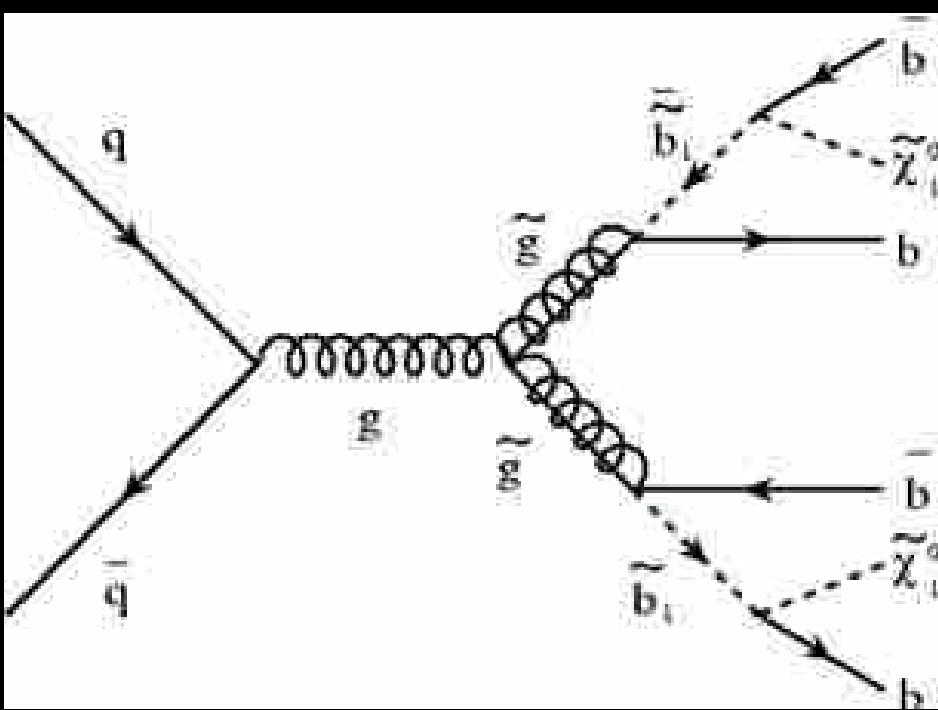
3) $\tilde{q}\tilde{g}$ production (3 jets)
 Expected 6.1 +/- 3.1
 Observed 5



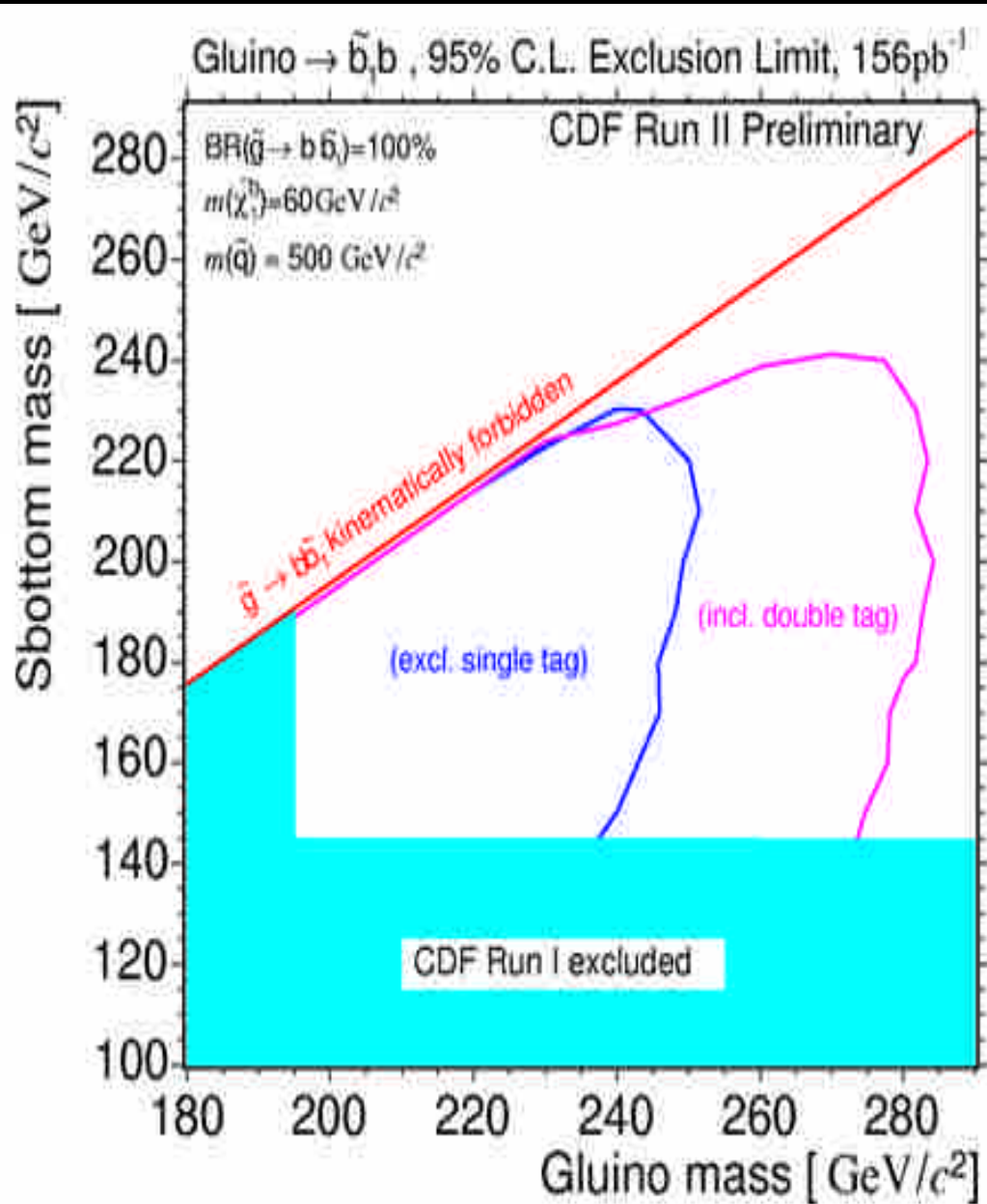
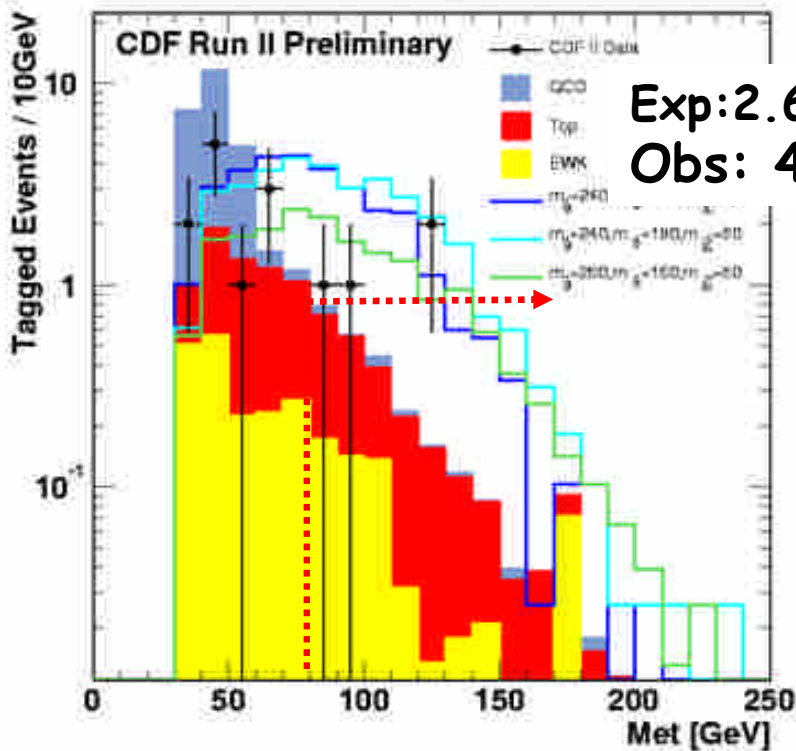
Light Scalar Top ($\tilde{t} \rightarrow c\tilde{\chi}^0$)



Glauino \rightarrow Sbottom

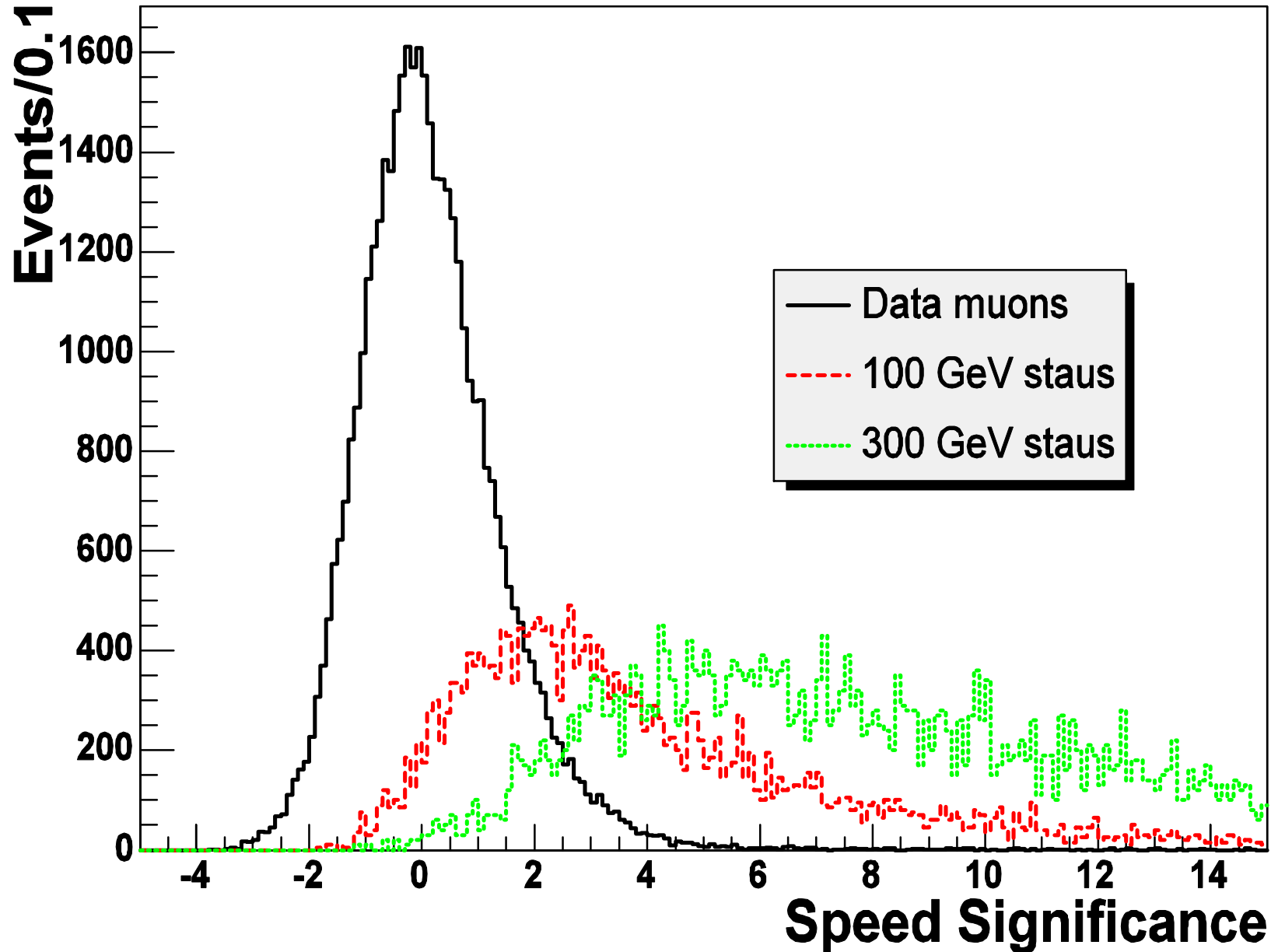


Inclusive double tagged events



CHAMP (Charged Massive Particle)

DØ Run II Preliminary



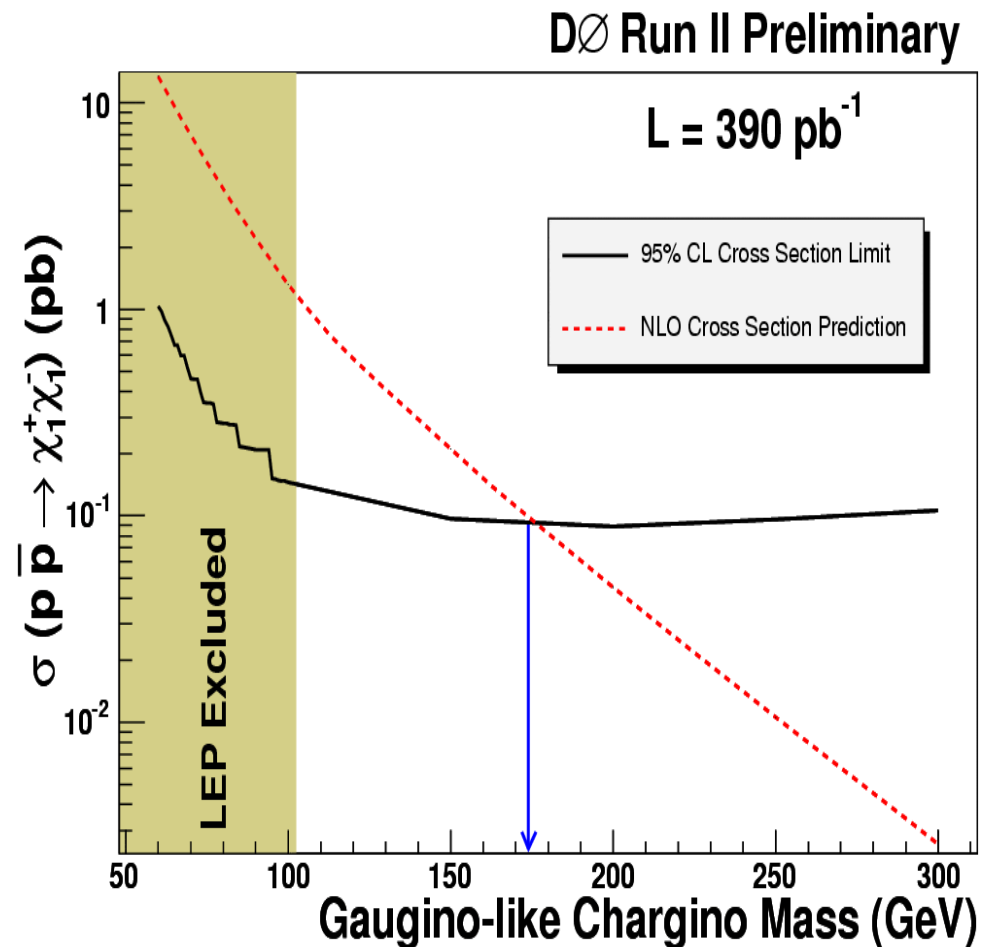
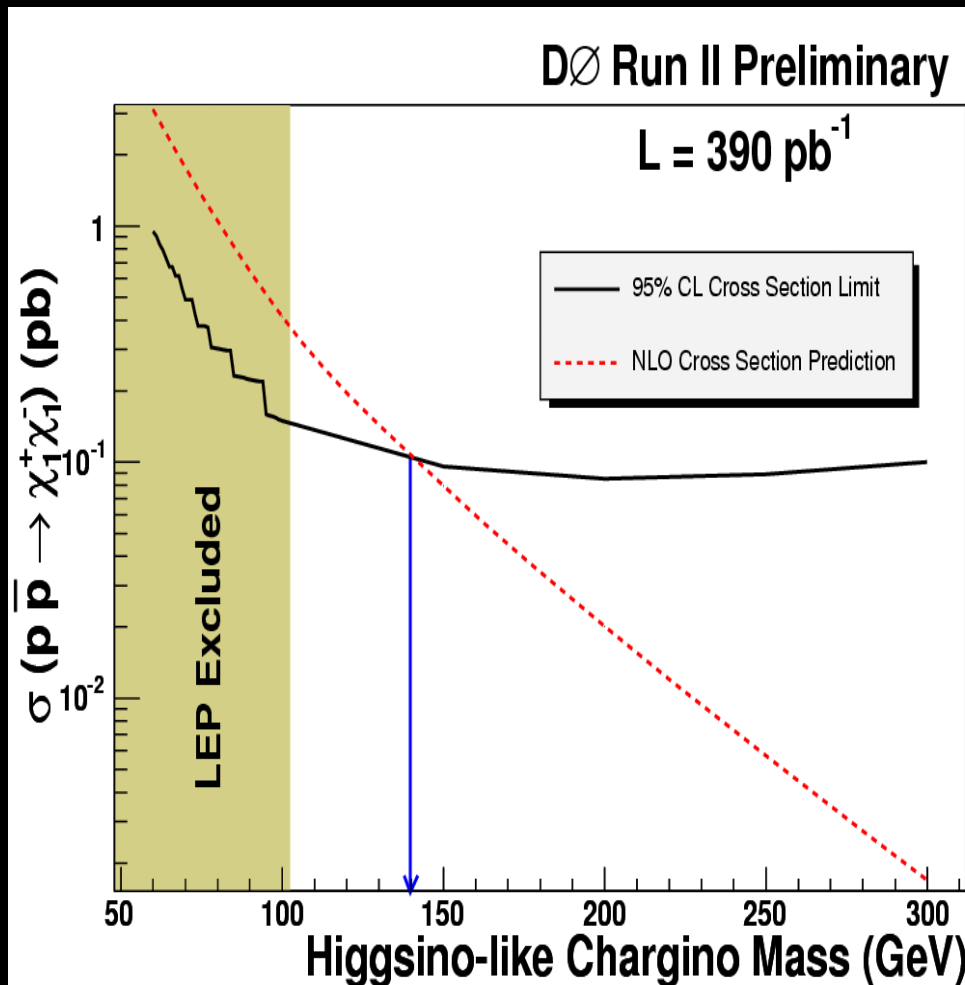
CHAMP: AMSB Interpretation

Limits in AMSB: CHAMP: $\tilde{\chi}^{\pm}_1$

Expected bgd	Obs
0.66 ± 0.06	0

Higgsino-like: $m(\chi^{\pm}_1) > 140$ GeV

Gaugino-like: $m(\tilde{\chi}^{\pm}_1) > 174$ GeV



Conclusions

- Much learned from LEP Searches
- Tevatron Searches started (some limits beyond LEP)
- Higgs bosons:
 - gg fusion (bb, WW decay)
 - ZH, WH (bb, WW decay)
 - bbA, H⁺⁺, h → $\gamma\gamma, \tau\tau$
- Supersymmetry:
 - Neutralino/Chargino (GMSB, mSUGRA)
 - Squark/Gluino
 - Stop, Sbottom, Staus
- Further Searches (parallel sessions):
 - Z' (**Gregory Veramendi**)
 - Compositeness (**Xuan Nguyen**)
 - Rare charm decays (**Brendan Casey**)
- Exciting time for new discoveries!