

# *The Search for $bb(h/H/A) \rightarrow bbbb$*

*Andy Haas – Columbia University*

*D0 Winter Physics Workshop*

*February 28, 2005*

*Presented on behalf of the “b bh p14” group:*

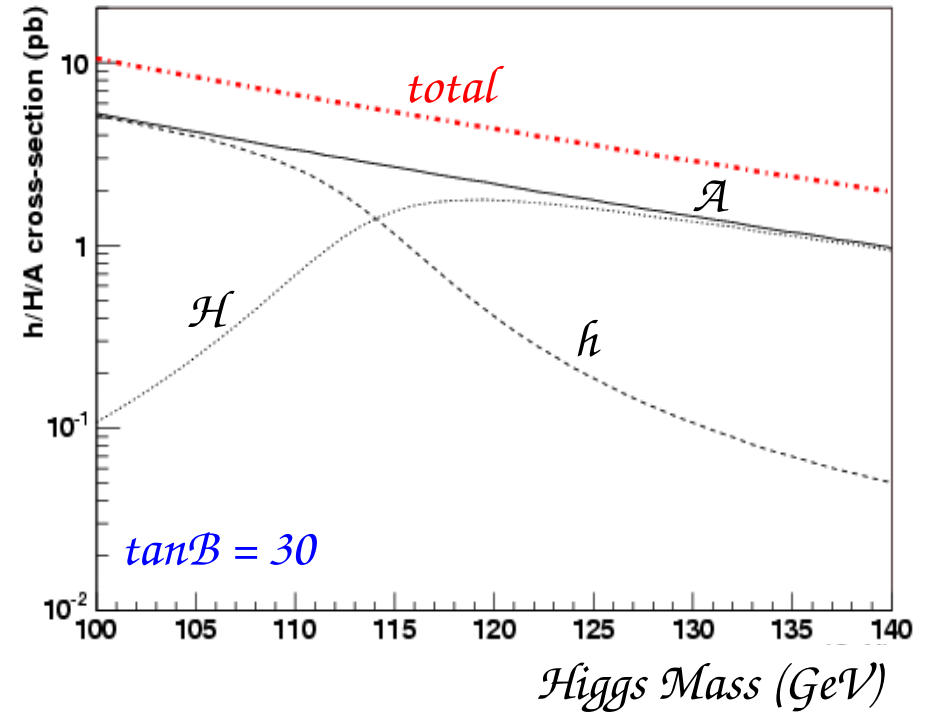
*Jyothsna Rani, Avto Kharchilava, and myself*

*with contributions from:*

*Marine Michaut, Boris Tuchming, and Tim Scanlon*

# Higgses in Supersymmetry

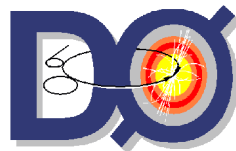
- Higgs fields come in pairs
  - Gotta cancel those quantum anomalies!
- 5 Higgs bosons :  $h, \mathcal{H}, \mathcal{A}, \mathcal{H}^+, \mathcal{H}^-$
- $\tan\mathcal{B} = \mathcal{H}_u / \mathcal{H}_d$ 
  - At  $\tan\mathcal{B} \sim 50$ , coupling of  $\mathcal{A}$  to  $b = \mathcal{A}$  to  $t$
  - Cross-sections for  $bbh$  grow like  $\tan^2\mathcal{B}$  !
- $h$  is predicted to be light,  $< \sim 135 \text{ GeV}$ 
  - LEP limits on Higgs mass -- 92 GeV (not the usual 114 GeV like in the SM...)
  - LEP limits are much looser ( $\sim 50 \text{ GeV}$ ) if CP-violation is allowed in the Higgs sector... this talk assumes CP-conserving Higgses !



At high  $\tan\mathcal{B}$  ( $> \sim 20$ ),

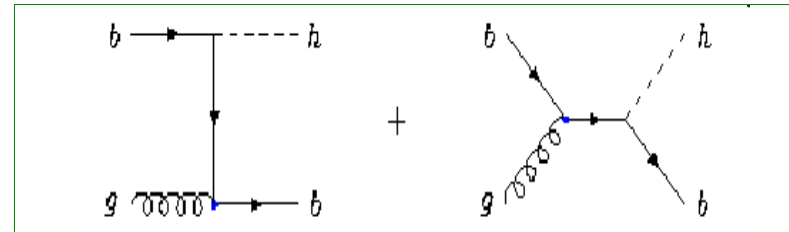
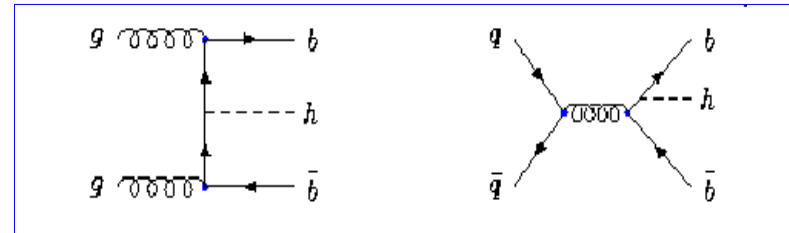
the  $\mathcal{A}$  is degenerate with the  $h, \mathcal{H}$ :

- $cs(\mathcal{A}) \sim cs(h/\mathcal{H})$
- $width(\mathcal{A}) \sim width(h/\mathcal{H})$
- $m(\mathcal{A}) \sim m(h/\mathcal{H})$
- $BR(\mathcal{A} \rightarrow bb) \sim BR(h/\mathcal{H} \rightarrow bb) \sim 90\%$

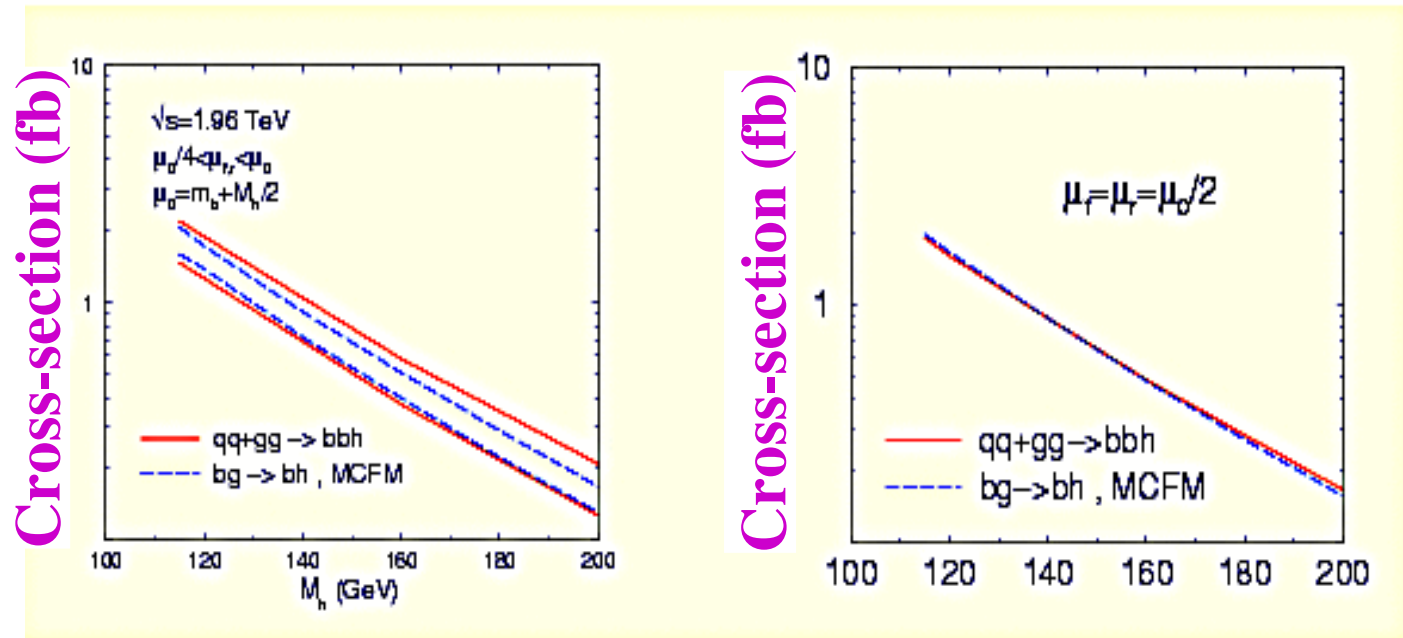


# Signal at $\mathcal{N}\mathcal{L}\mathcal{O}$

- There are two ways to calculate the signal production:
  - $bbh$  (4-flavor scheme)
  - $bh$  (5-flavor scheme) : use  $b$ -PDF
- Both methods now agree at  $\mathcal{N}\mathcal{L}\mathcal{O}$
- PDF errors are also in agreement

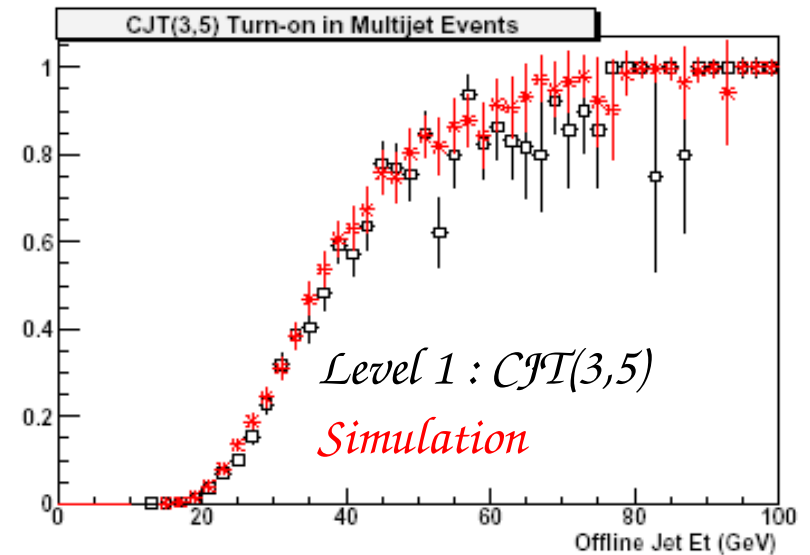


The central values  
and the uncertainties  
from renormalization  
and factorization scale  
both agree well !



# Data / Triggering

- Custom multi-jet triggers ( $v9-v12$ ) used from Nov. 2002 – June 2004
    - L1: CJT(3, 5 GeV)
    - L2: L2J(3, 8 GeV),  $H_T > 50$  GeV
  - Each triggerlist had new L3 criteria, as we tightened and improved them to remain within rate limits and retain efficiency
- $v12$ :  $\left\{ \begin{array}{l} \text{L3J}(3, 15 \text{ GeV})(2, 25 \text{ GeV}) \text{ in } |\eta| < 3.0 \\ \text{Jets use } 0.5 \text{ cone, L3Nada, CalCalib, and} \\ \text{PVZ to correct jet } E_T \text{ and } \eta \\ \text{Require good L3 PV with } |z| < 35 \text{ cm} \end{array} \right.$
- $260 \text{ pb}^{-1}$ , after bad runs/lumblocks
    - Skim (87.5 Million events):  
1 jet  $> 20$ , 3  $> 15$  GeV,  $|\eta| < 2.6$ , cone = 0.5



Trigger efficiencies measured using data:

- > mu-based unbiased trigger for L1/L2
- > special CJT(3,5) run for L3

68-80% efficient for  $m_{\Delta}$  of 90-150 GeV

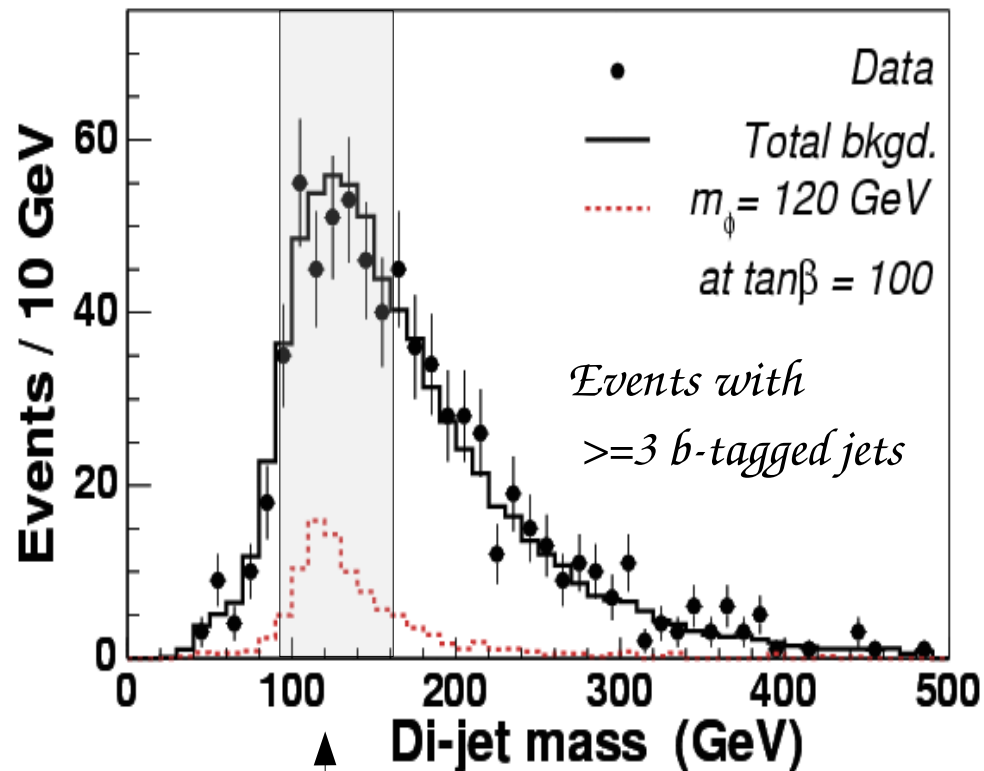
# Analysis Method

- *Signal:*

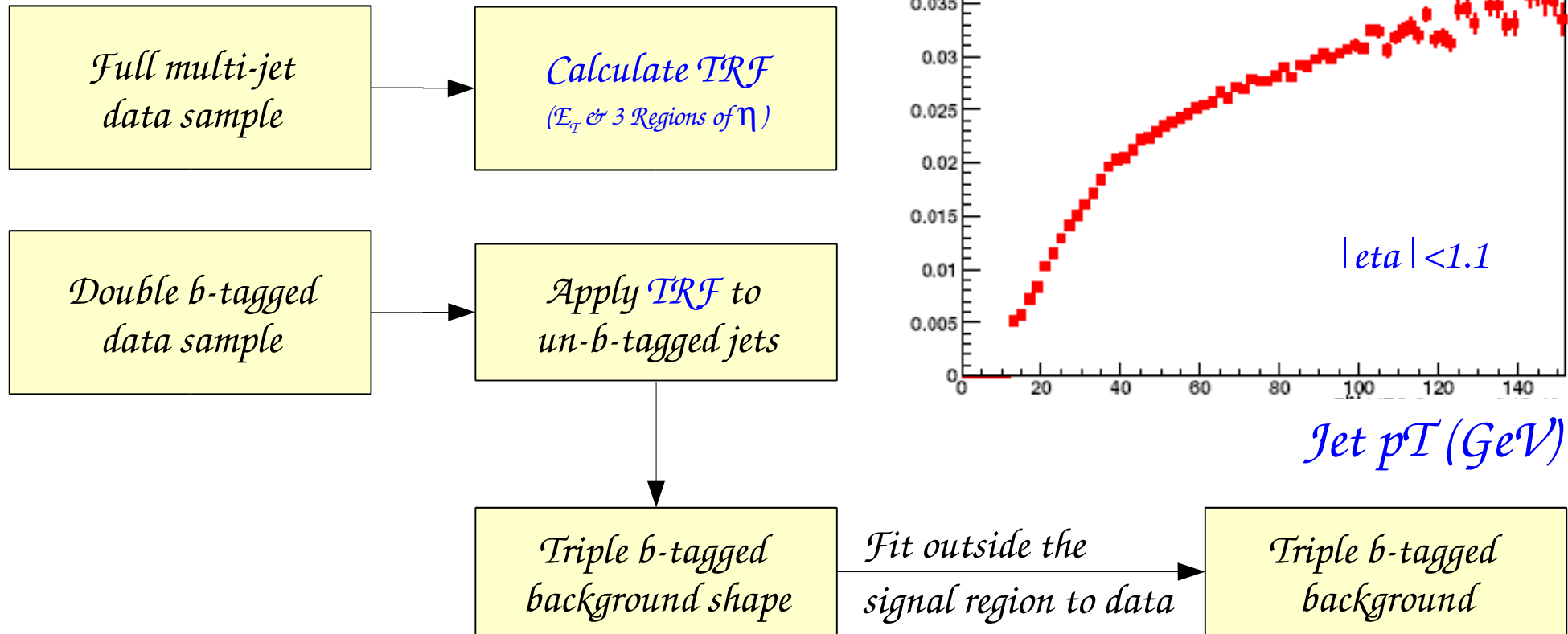
- 3 or more *b*-tagged jets
- Invariant mass of leading jets is peaked at  $m_A$

- *Backgrounds:*

- *Determined from data !*
  - *Shape estimated from the double b-tagged data sample*
  - *Normalized outside the “signal region”*
- *Also modeled in MC as a cross-check*
  - *“fakes”: all light-quark/gluons (data)*
  - *“heavy flavor”: (ALPGEN)  $bbj(j)$ ,  $ccj(j)$ ,  $bbcc$ ,  $cccc$ ,  $bbbb$*
  - *“other”:  $tt$ ,  $Z(\rightarrow bb)+jets$  (Pythia)*

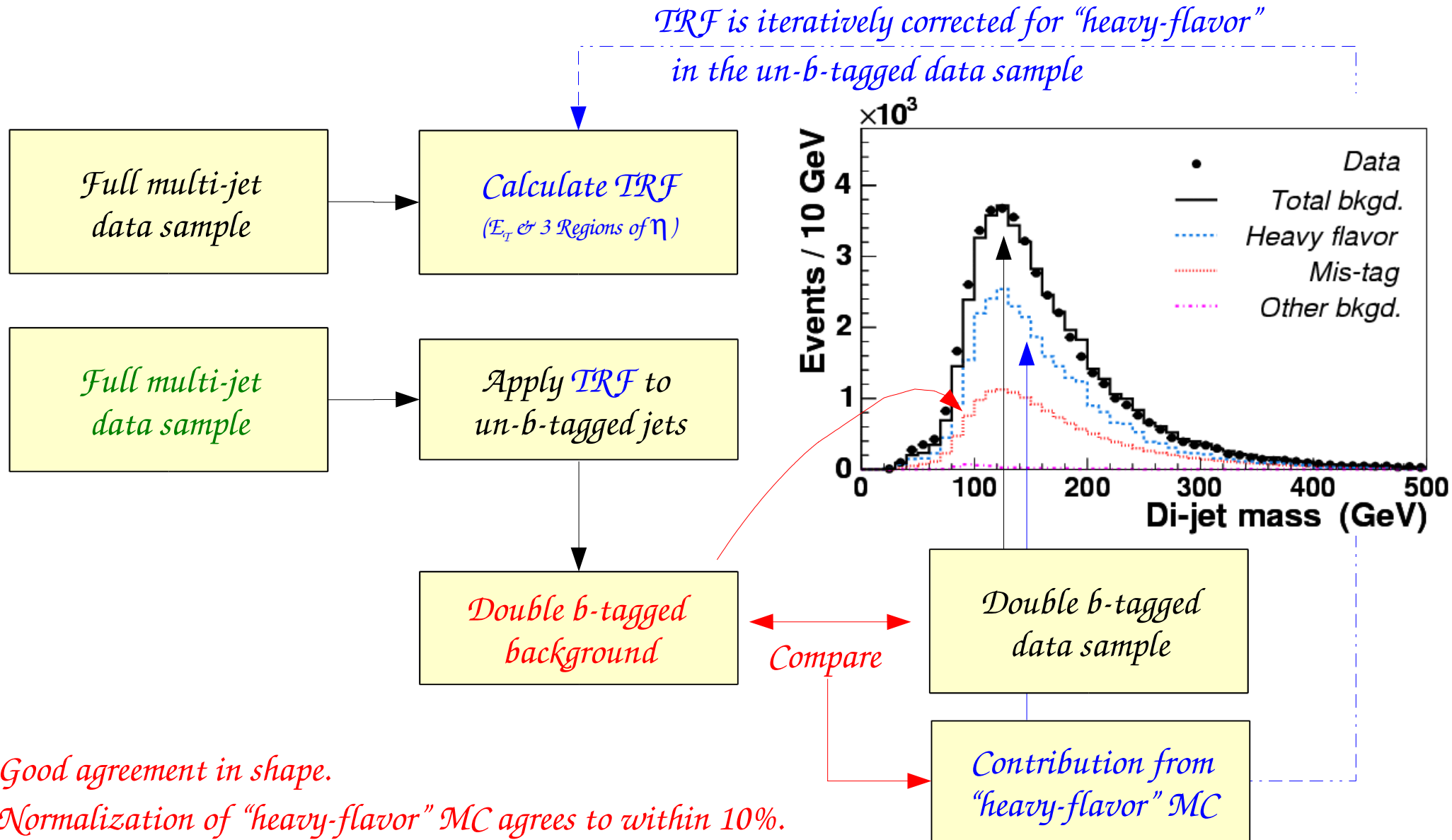


# Triple $b$ -tagged Background



*Background is completely determined from data !*

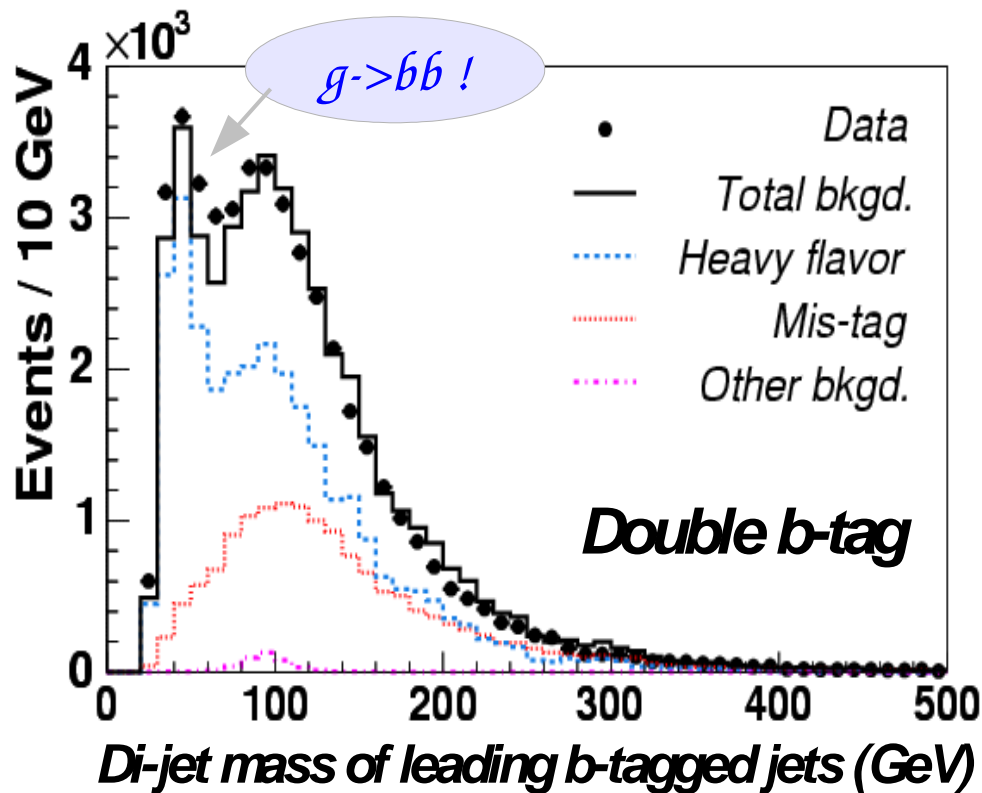
# Cross-check Using Double $b$ -tagged Data



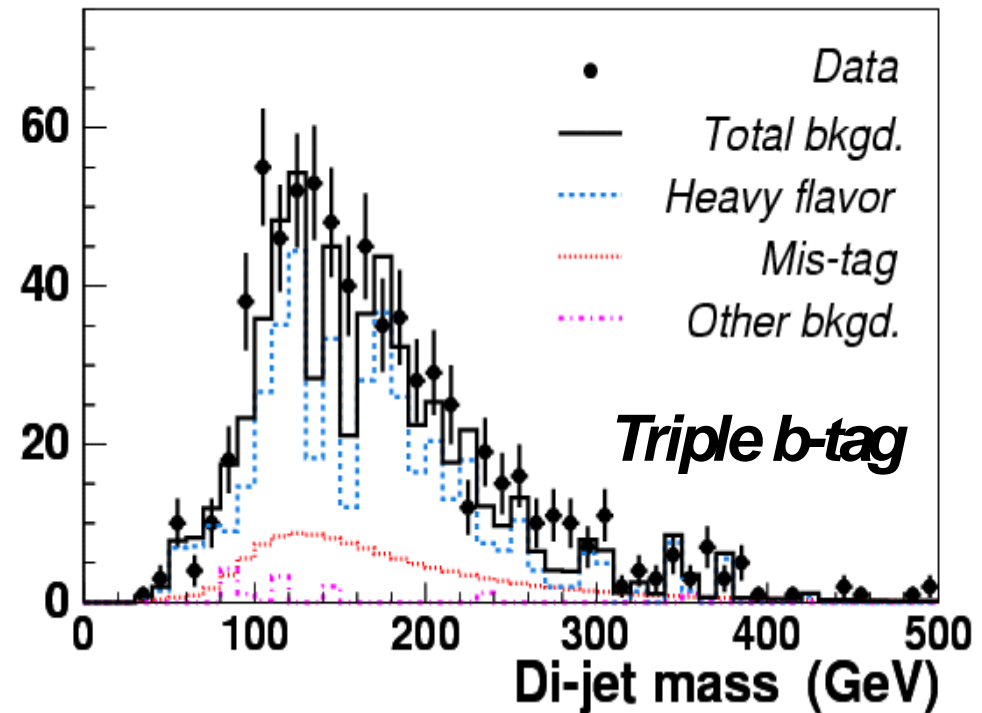
*Good agreement in shape.*

*Normalization of "heavy-flavor" MC agrees to within 10%.*

# MC Cross-checks



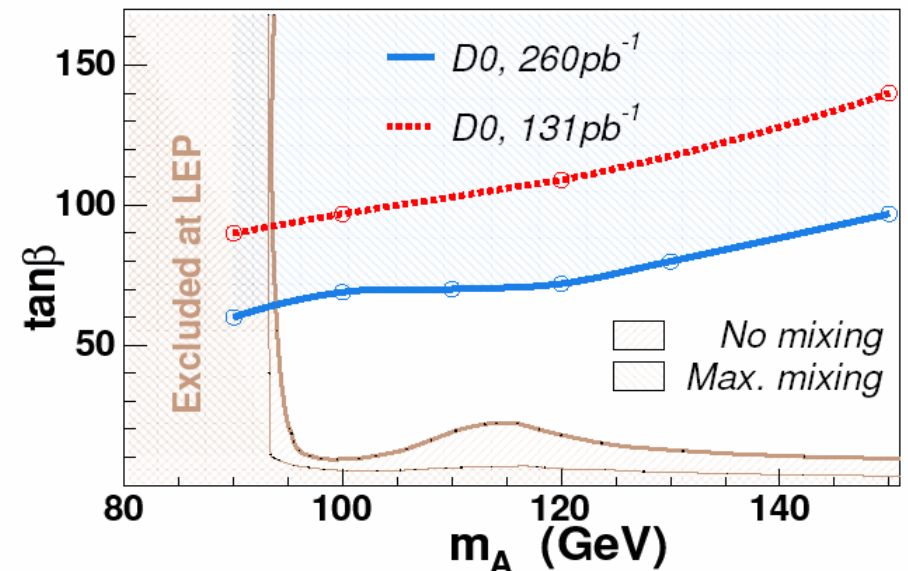
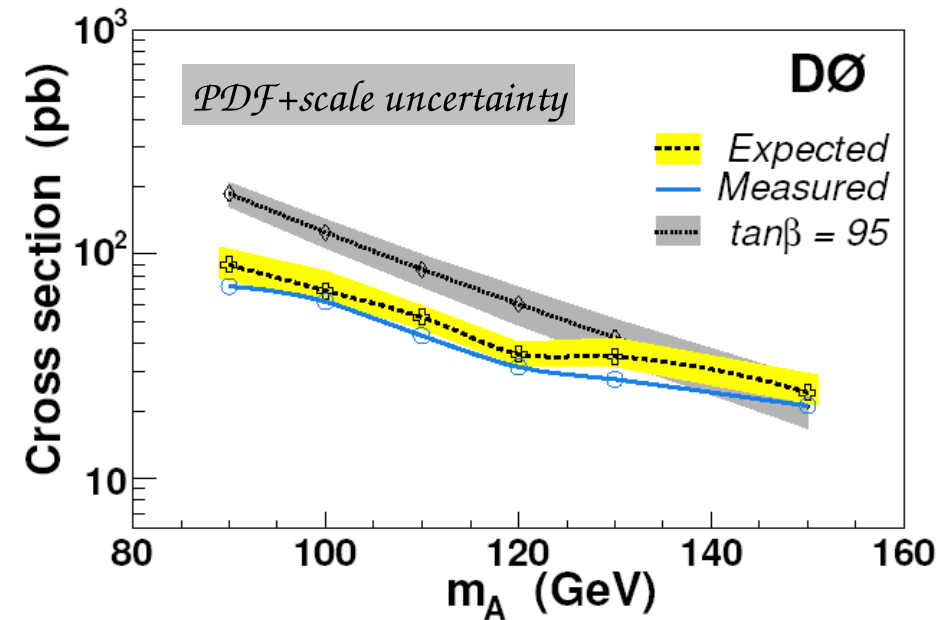
*Monte Carlo accurately predicts many other distributions in the double b-tagged data as well.*



*Monte Carlo predicts a background shape and normalization in good agreement with the triple b-tagged data.*

# Limits

- *Signal efficiency uncertainty (21%):*
  - b-tagging (15%)*
  - Trigger (9%)*
  - JES (8%)*
  - Luminosity (6.5%)*
  - NLO kinematics (5%)*
  - Jet reco/ID (4%)*
  - Jet energy resolution (1%)*
- *Background shape/norm. uncertainty (3%):*
  - TRF shape (2%)*
  - Statistics outside signal region (1%)*
  - Width of signal region (1%)*
- *Limits set using  $CL_s$  method (TLimit)*
  - *For each  $m_A$ , set a cross-section limit*
  - *Interpret in MSSM at tree-level, assuming  $\tan^2\beta$  cross-section enhancement*



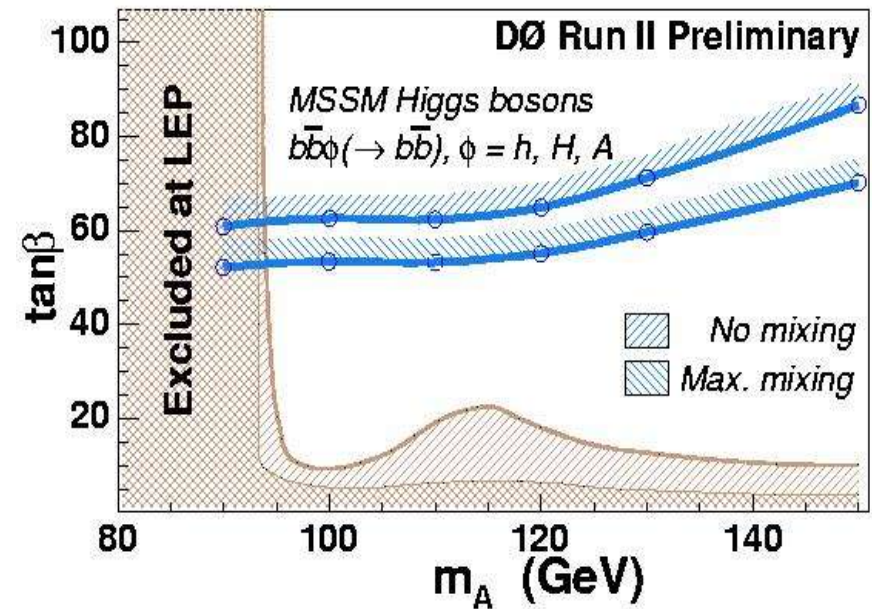
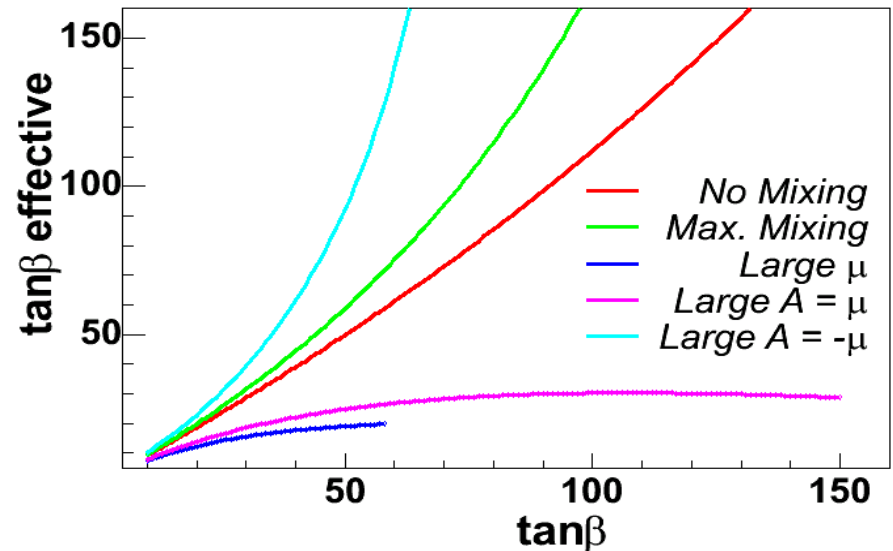
# MSSM Beyond Tree-Level

- Supersymmetric loop corrections are calculated using "CPSuperH"
  - Production doesn't scale like  $\tan^2\beta$ ... can be faster or slower depending on the supersymmetric model and its parameters
- We set limits on  $\tan\beta$  vs.  $m_A$  in two of the "benchmark scenarios":
  - no mixing and maximal mixing in the stop-quark sector

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

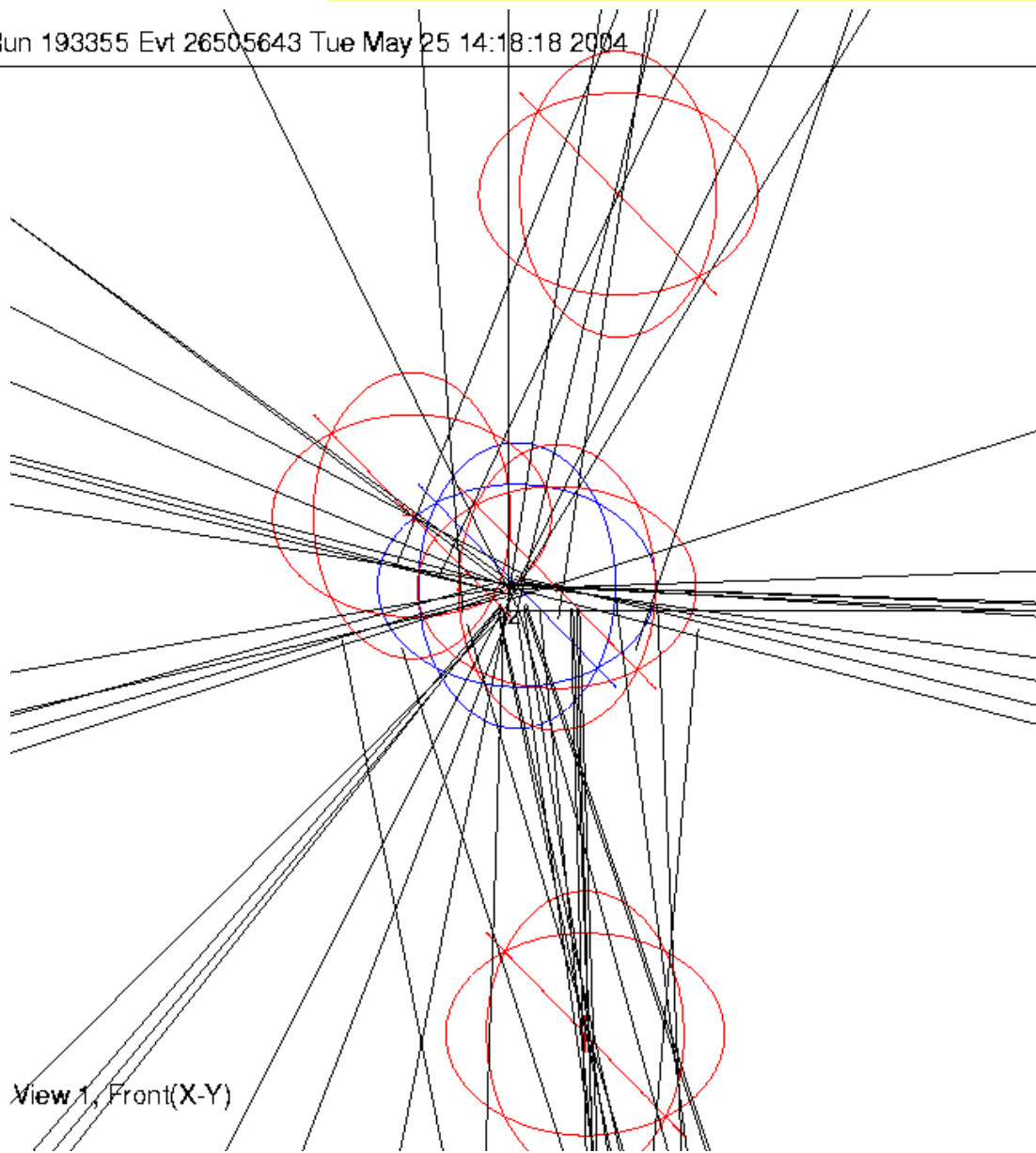
$\Delta_b$  is a function of various SM/SUSY parameters:

$X_t = A_t - \mu \cot\beta, \mu, M_g, M_q, \text{ etc.}$

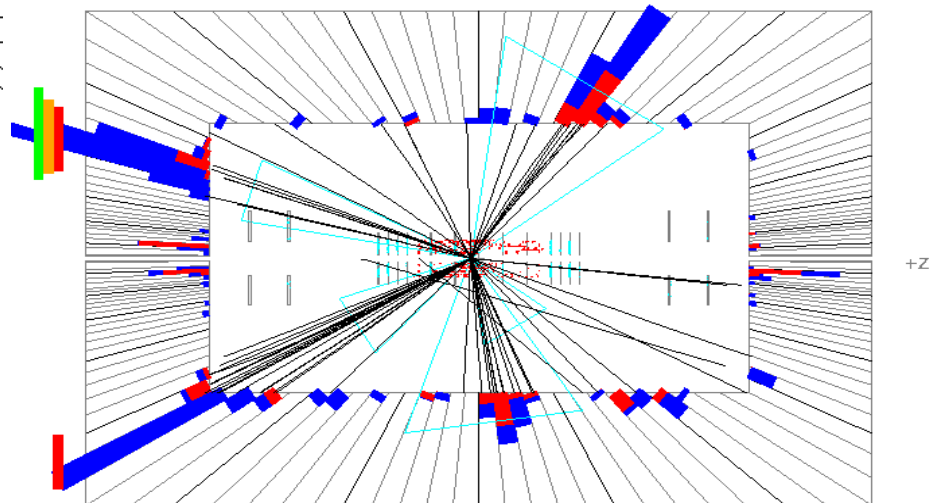
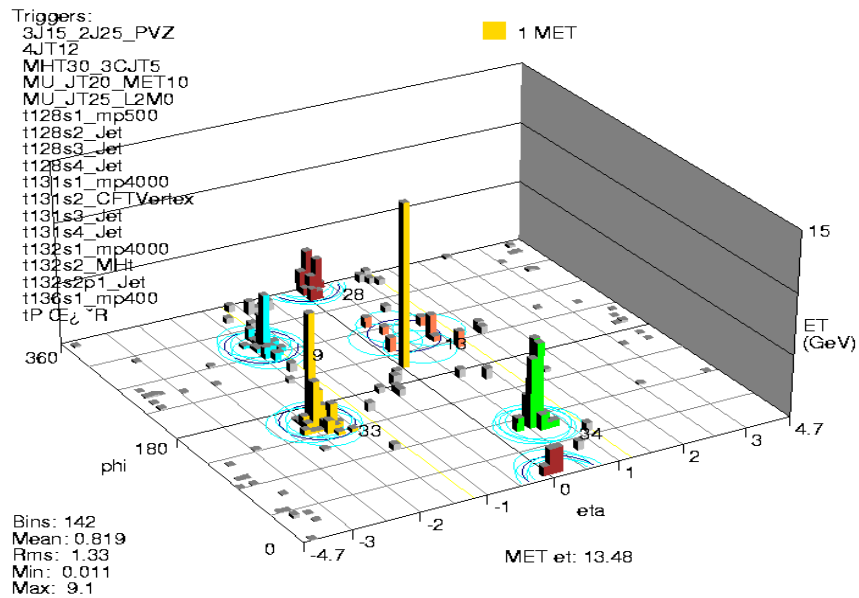


# Pictures

Run 193355 Evt 26505643 Tue May 25 14:18:18 2004

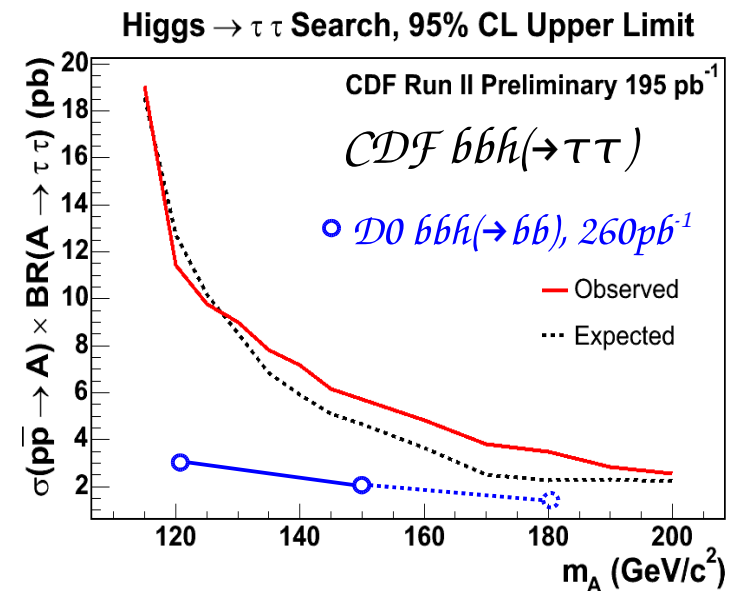
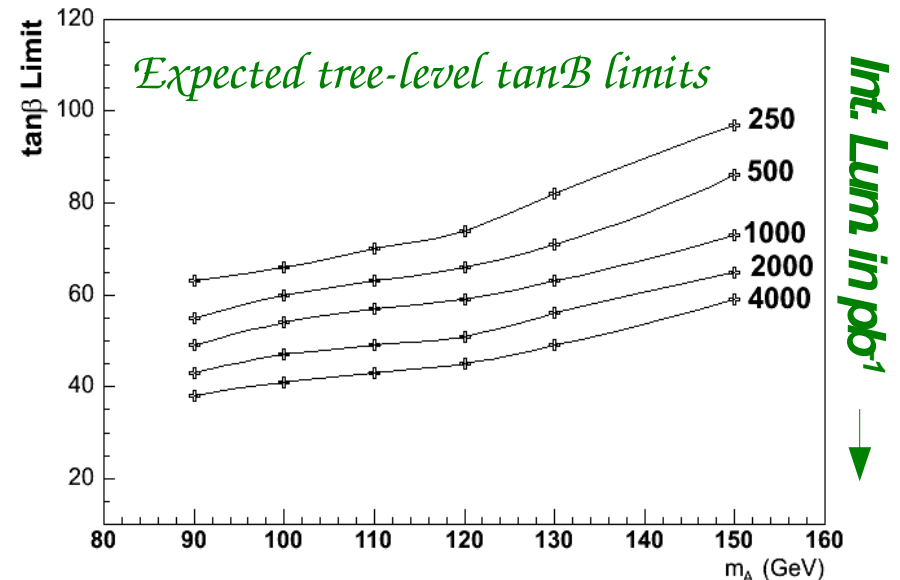


Run 193355 Evt 26505643 Tue May 25 14:18:18 2004

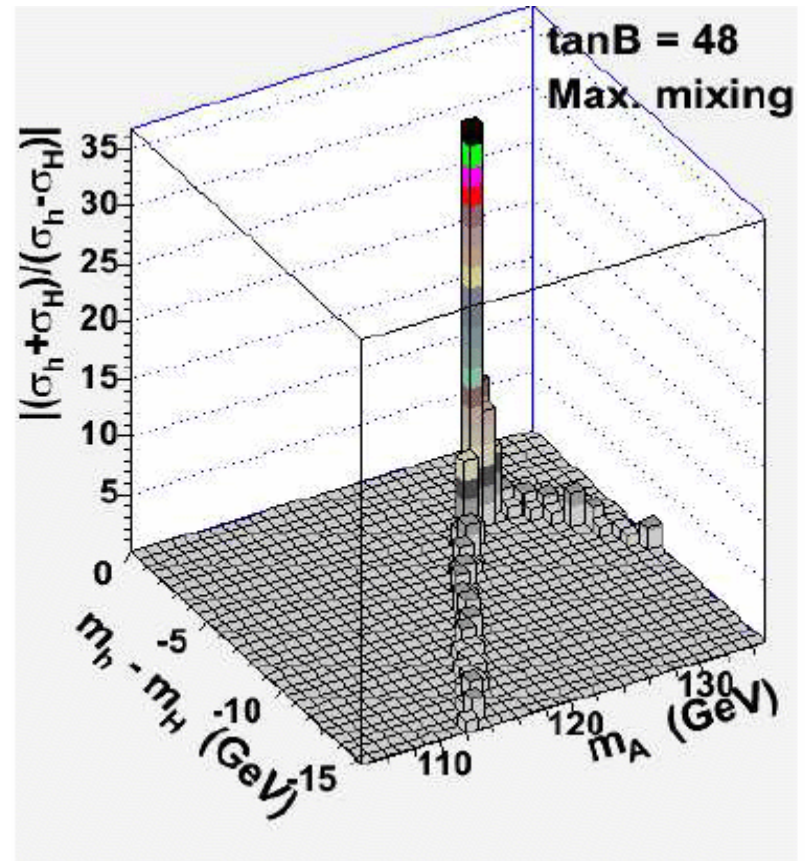


# Conclusions / Future

- You have approved these preliminary results to be shown at conferences
- Our PRL is in EB review
- With no analysis improvements, can exclude down to  $\tan\beta=40$  with  $4\text{fb}^{-1}$
- We look forward to a much improved p17 analysis
  - Inclusion of more data and triggers
  - A new focus on  $b$ -tagging
  - Neural network?
- We're keeping an eye on our competitors...



# Backup Slides



*Mass splitting, weighted by cross-section*