Higgs boson searches in multi-b-jet final states

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For the DØ Collaboration

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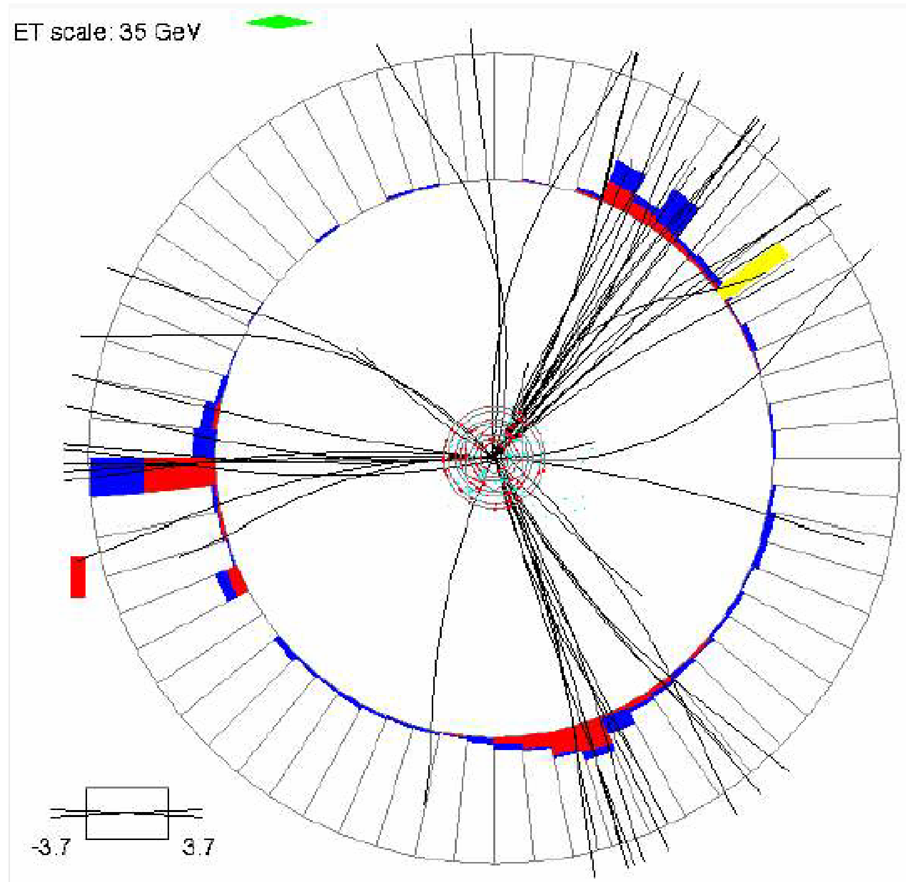
Event with 3-b-tagged jets



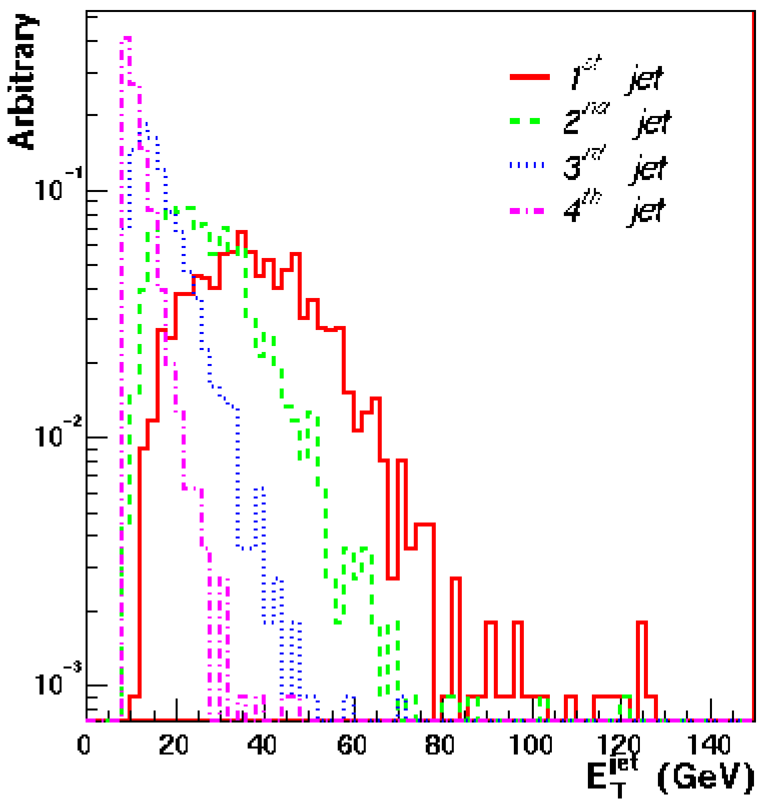
Introduction (1)

- Searches for Higgs boson(s) in bh/bbh(→bb) associated production is a challenge for both, theorists and experimentalists
- In theory
  - Only recently higher order calculations for bh/bbh production became available
    - Significant progress but still large uncertainties
  - (SUSY/MSSM) aspects of h/H/A phenomenology are complicated, and often no adequate tools are available for proper interpretation of experimental results
    - E.g. b-h/-H/-A couplings are not simple functions of tanβ, α, other SUSY parameters
- In experiment
  - It is a challenge to have efficient jet trigger (based on calorimetry) at level 1
    - Have more handles at higher trigger levels, but efficiency is still an issue
  - No MC tools to reliably estimate multi-(b)-jet bkgd. so analysis is (almost) entirely data driven
    - Little problem for the Tevatron, but hard to judge expectations at LHC
  - No signal MC event generator at NLO available
    - Resort on re-weighting of general purpose event generators

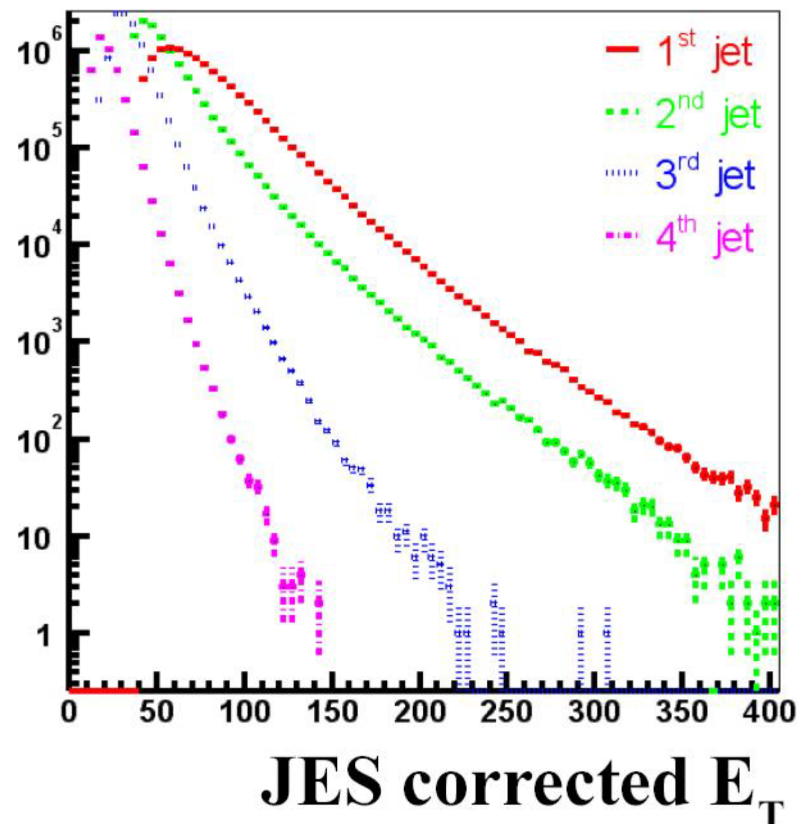
Introduction (2)

- Four leading jets E_T spectra in signal MC and preselected data
  - QCD multi-jet rate is large
  - Have to harden jet cuts to manage rate
  - Jets from (low mass) signal appear to be soft

MC: m_h = 120 GeV



Preselected data

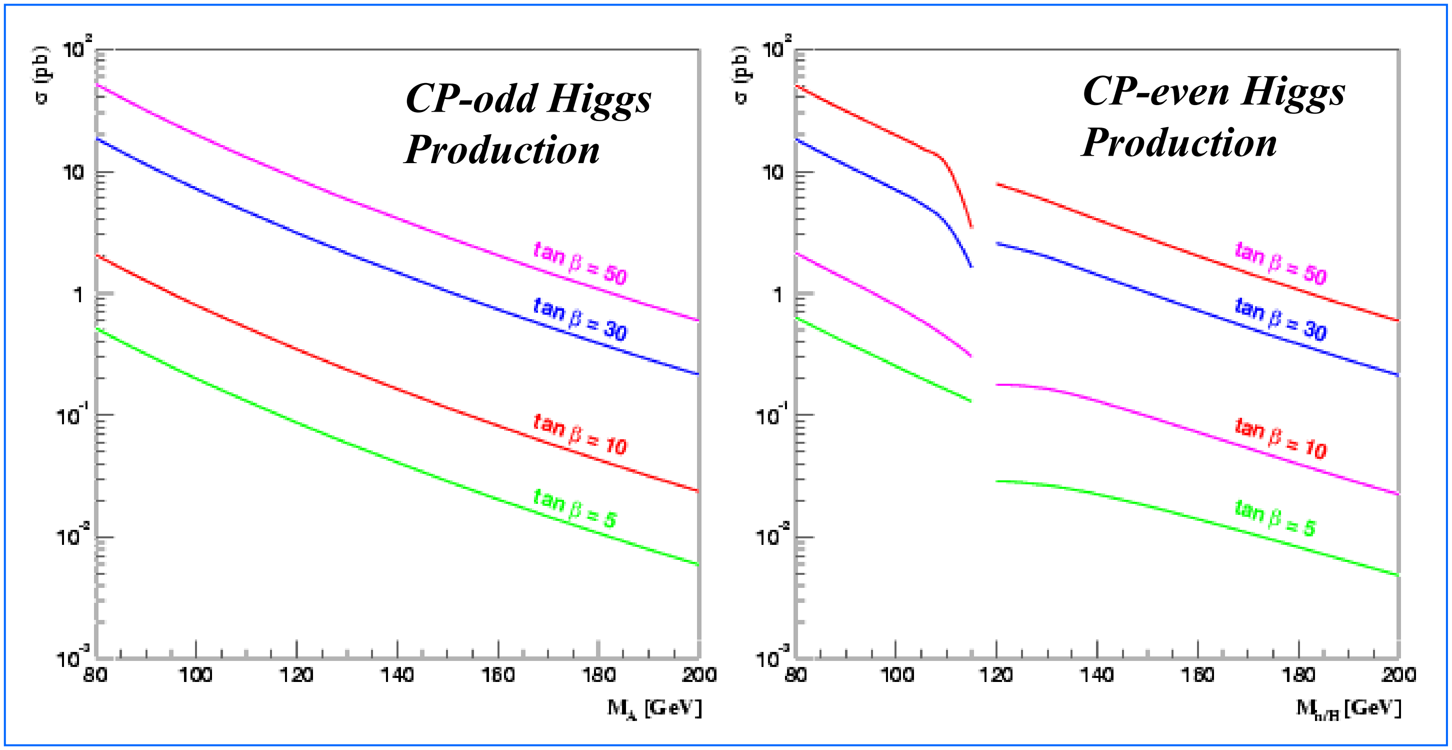


Monte Carlo tools

- Signal events generated with Pythia: **T. Sjostrand et al., Comp. Phys. Comm. 135 (2001) 238**
  - Cross-check with CompHEP: **A. Pukhov et al., hep-ph/9908288**
  - Cross sections normalized to NLO MCFM: **J. Campbell, K. Ellis, hep-ph/0204093**
  - Events are re-weighted to account for kinematics shape (Higgs p_T) difference
  - Details in the following slide
- Minimal use of MC in background shape evaluations
  - ALPGEN: **M.L. Mangano et al., JHEP 0307: 001, 2003**
  - MADEVENT: **F. Maltoni, T. Stelzer, JHEP 0302: 027, 2003**
- Masses, widths, decay branching fractions to bb
  - HDECAY v. 3.101: **M. Spira, hep-ph/9704448**
  - Two different models for cross-checks
    - **M. Carena, M. Quiros, C.E.M. Wagner, Nucl. Phys. B461 (1996) 407**
    - **S. Heinemeyer, W. Hollik, G. Weiglein, hep-ph/0002213 (FeynHiggsFast package)**
  - Yield somewhat different results, but the current experimental sensitivity to the region of MSSM parameter space doesn't allow to distinguish between the two

Basic assumptions: Higgs boson production at large tanβ

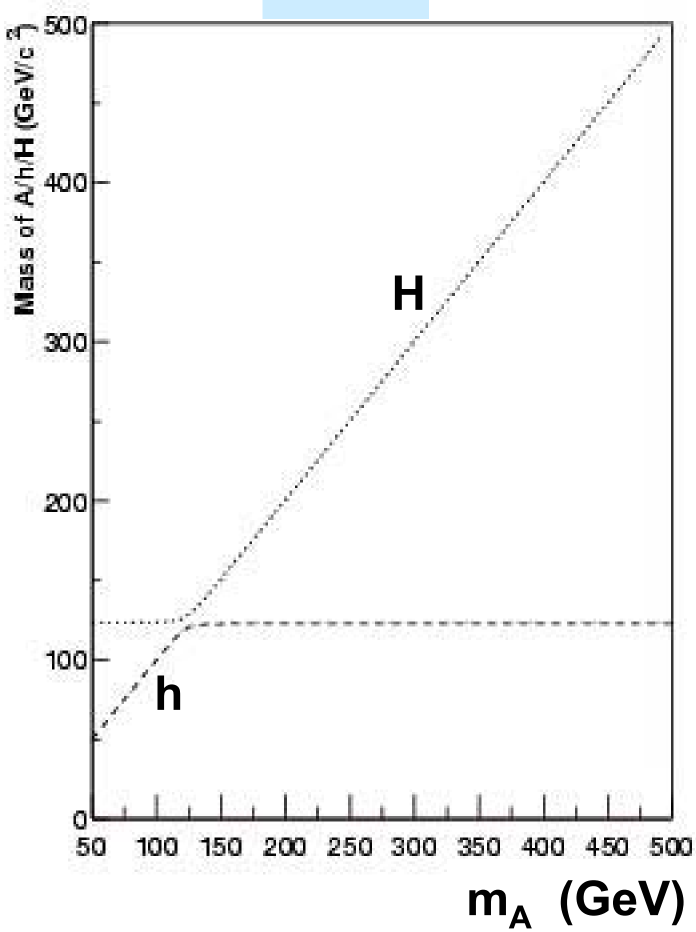
- Large tanβ → enhanced bbϕ (ϕ = h, H, A) coupling
  - Cross section rises like **$\tan^2\beta$**
- A and (h or H) are produced simultaneously
- A, h (or H) to bb decay branching fractions are ~ 0.9
- Except for a region m_A~110 – 130 GeV depending on tanβ and other MSSM pars.



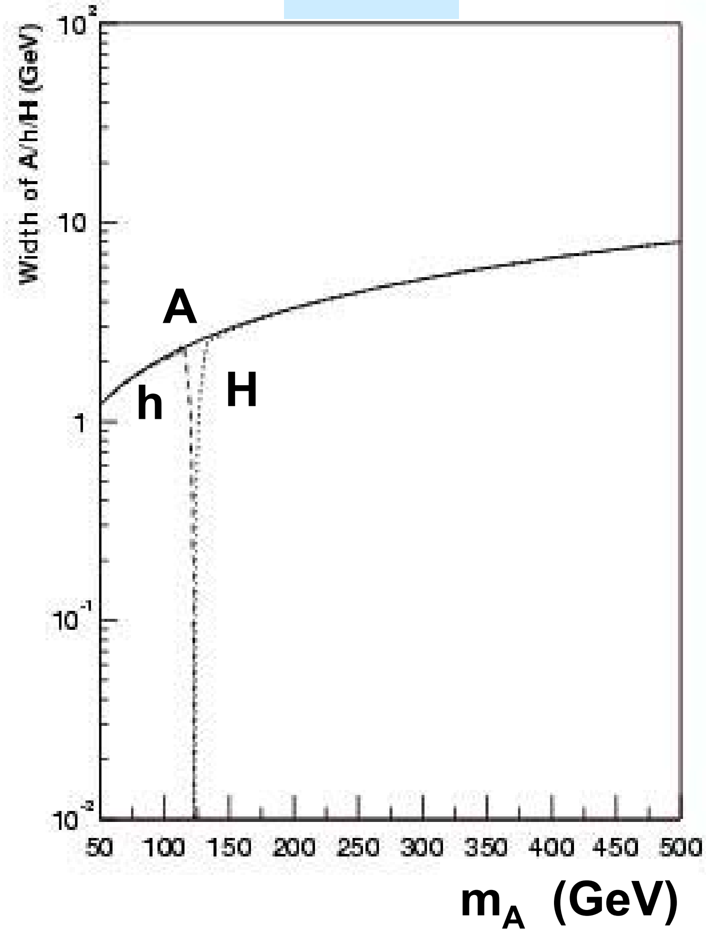
Basic assumptions: Higgs boson mass and width

- Results from HDECAY 3.101, tanβ = 30 (all other parameters set to default)

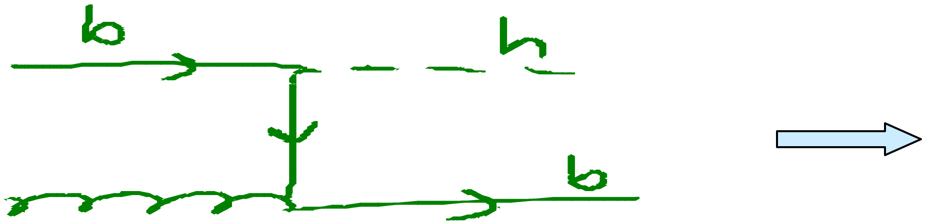
Mass

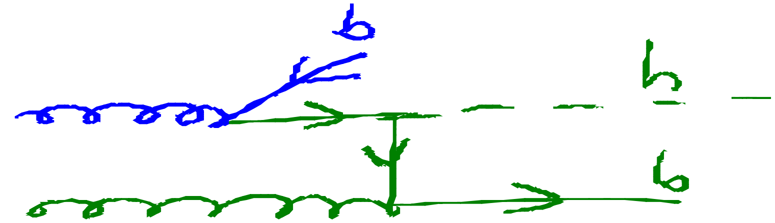


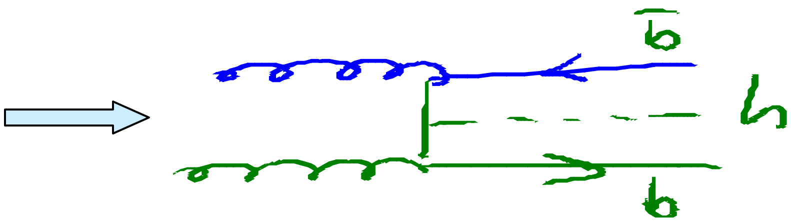
Width



bh vs bbh processes

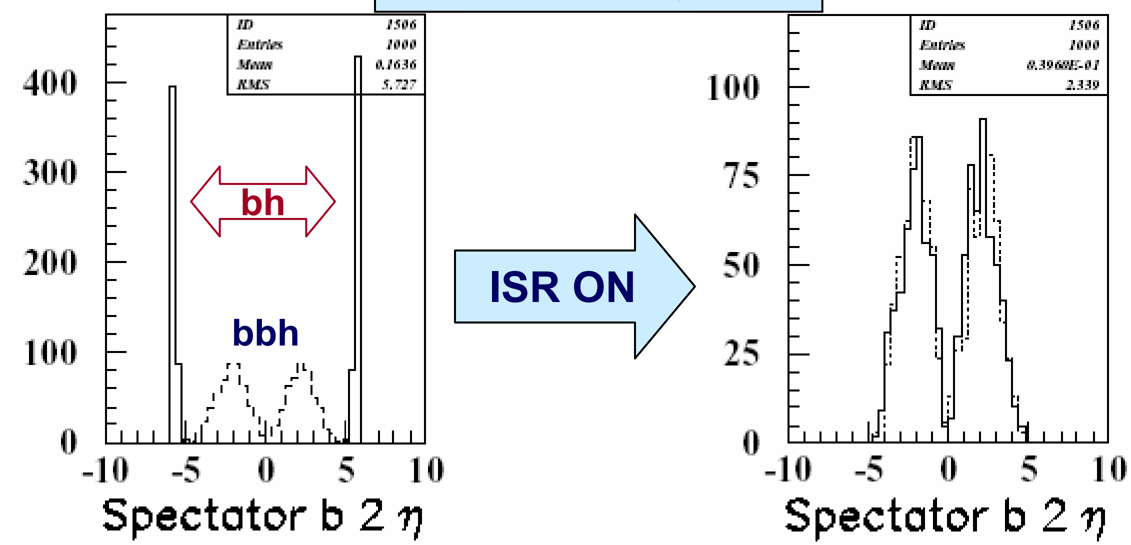






- Depending on kinematics, the 2nd spectator b might well be central

Let's ask Pythia



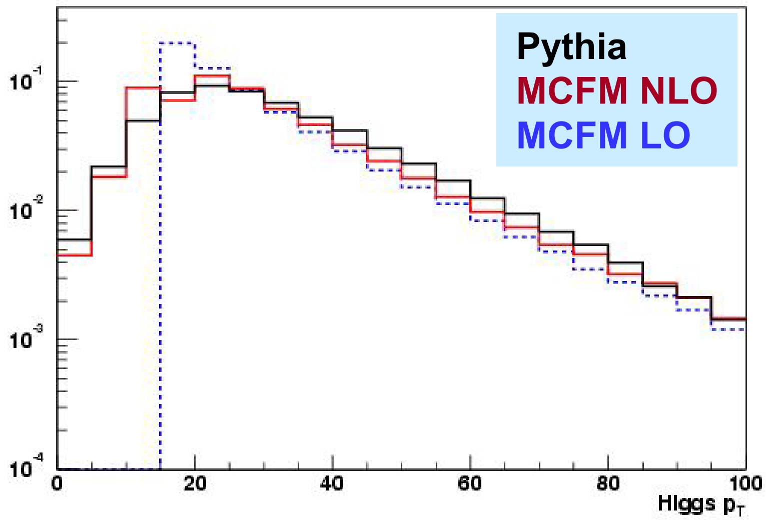
Almost exact overlap

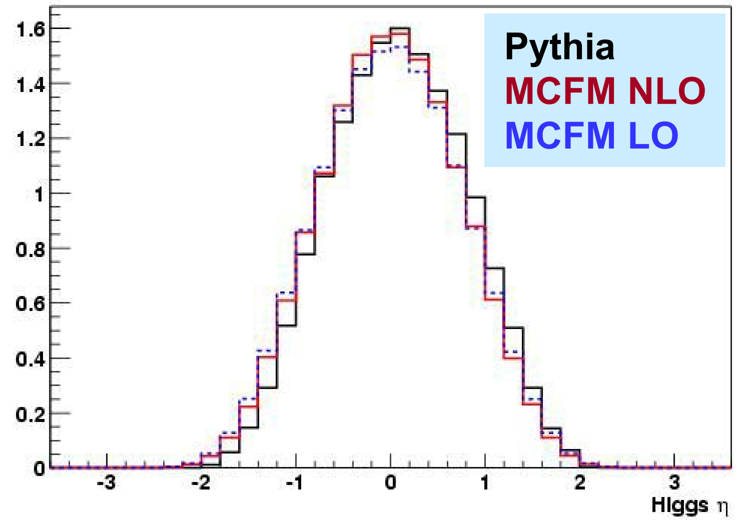
Can use bh or bbh

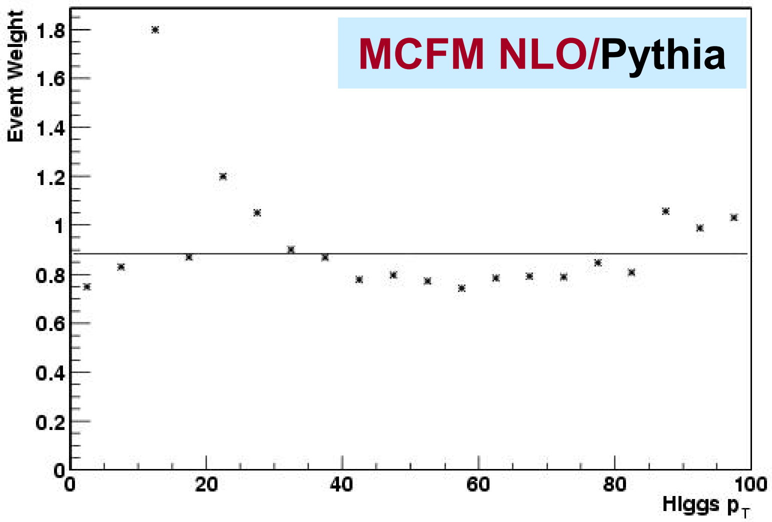
Use bh in the following

Signal simulation

- NLO x-sections: **J. Campbell, R.K. Ellis, F. Maltoni, S. Willenbrock, Phys. Rev. D67 (2003) 095002**
- Events are generated w/ Pythia, MSUB(32): bg → bH



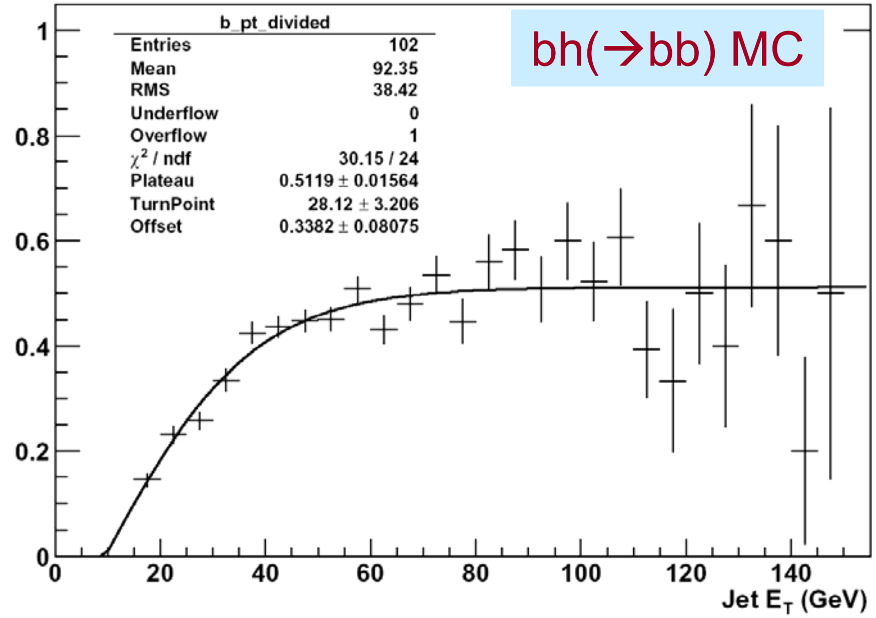


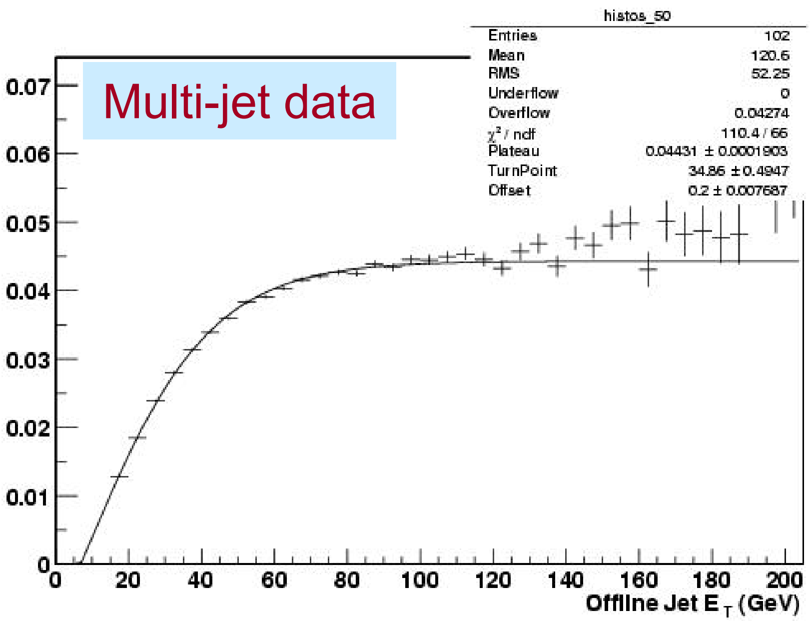


- Total rate normalized to MCFM NLO
- In the region of interest the NLO/Pythia corrections are at ~10% level
- Pythia MC events are assigned p_T(Higgs) dependent weights

b-tagging

- Tagging algorithm based on the measurement of secondary vertices
  - Cross-check w/ algorithms that employ impact parameter measurements
- Extra loose operating point:
  - b-tagging efficiency of ~ 40-50%
  - Light-quark mis-tag rate of ~ 3-4% depending on jet E_T

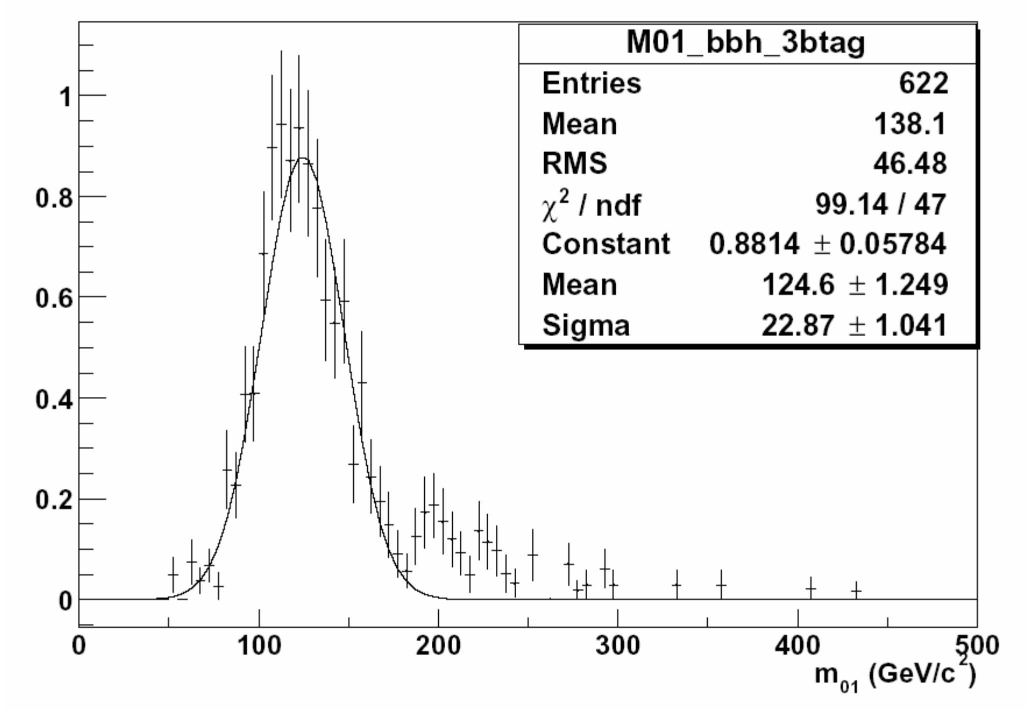




- Use η-dependent tag rate functions
- b-tagging as a function of jet multiplicity was observed flat within statistics

Di-jet mass resolution

- Apply all analysis cuts
- Two highest E_T jets found to give cleanest peak
- Di-jet mass resolution is ~ 15-20% depending on Higgs mass
  - Have room for improvements
  - Next round of analysis will enjoy improved jet energy resolution

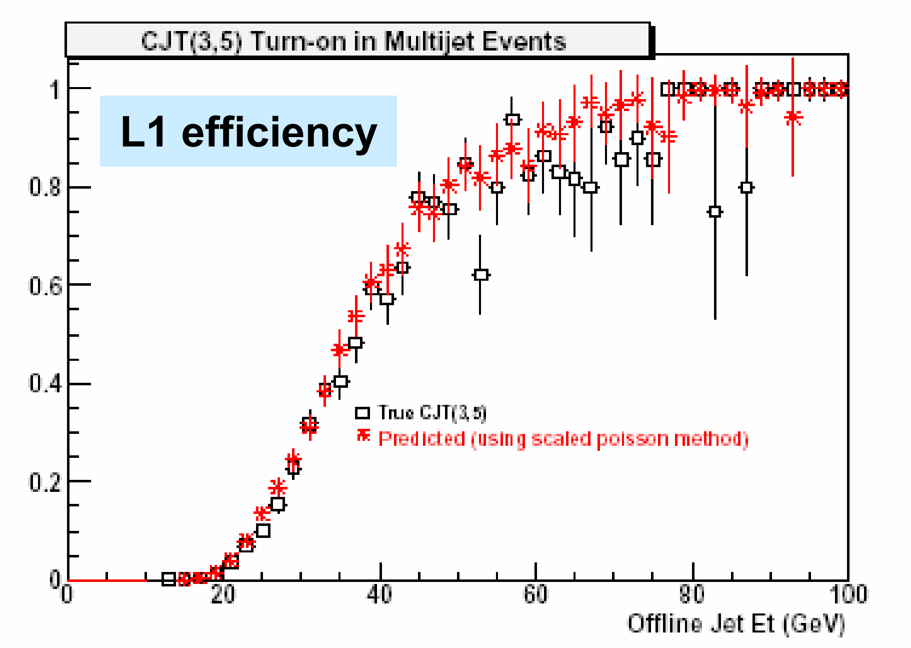


Event selection – triggering

- Typical trigger conditions: **CJT(3,5), L2(3,8)L2HT(50), L3(2,25)L3(3,15)**)

  L1: 3 jets of 5 GeV
  L2: 3 jets of 8 GeV & H_T > 50 GeV
  L3: 3 jets of 15 GeV & 2 jets of 25 GeV

- Current trigger employs impact parameter measurements at L2



- Overall trigger efficiency as measured in data agrees well with MC expectations
- Have signal efficiency of 65-80% relative to offline cuts depending on the Higgs boson mass

Event selection – offline

- Typical event selection criteria for various Higgs boson masses
  - Optimized for the best sensitivity
  - n_j^{min} = 3 data sample yields better results/limits

Analysis cuts on three leading jets E_T, η and its multiplicity

Signal (GeV/c^2)	E_T1(GeV)	E_T2(GeV)	E_T3(GeV)	$\|\eta\|_j$	n_j^{max}
$n_j^{min}=4,\ m_h=100$	40	35	15	2.5	4
$n_j^{min}=4,\ m_h=120$	45	35	15	2.5	5
$n_j^{min}=4,\ m_h=150$	60	40	15	2.0	5
$n_j^{min}=3,\ m_h=100$	45	35	15	2.5	4
$n_j^{min}=3,\ m_h=120$	45	35	15	2.5	4
$n_j^{min}=3,\ m_h=150$	60	40	15	2.0	4

Multi-b-jet background estimation

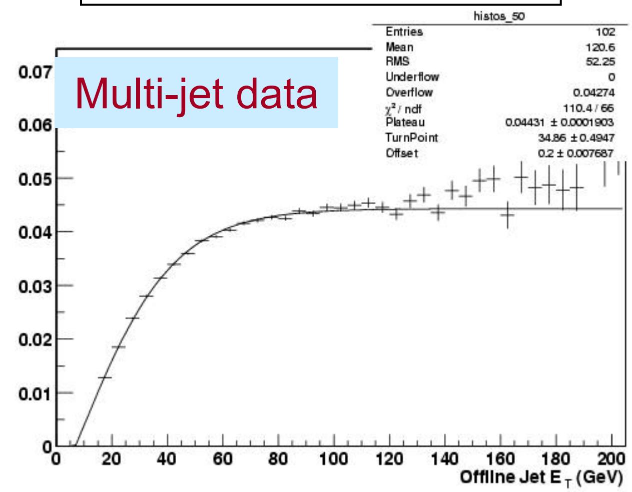
Full multi-jet data sample → Calculate TRF (E_T & 3 regions of η) ↔ Tag Rate Function

Full multi-jet data sample → Double b-tagged data sample

Double b-tagged data sample → Apply TRF

Calculate TRF → Apply TRF → Triple b-tagged background shape → Fit outside to real triple b-tagged distribution

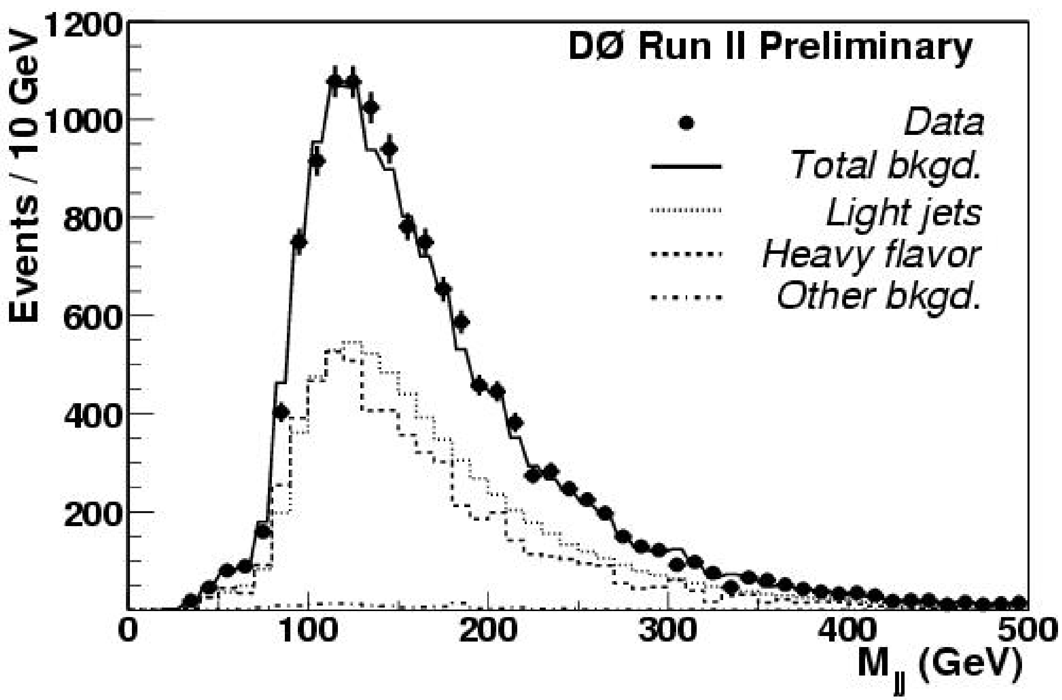
Double b-tagged data sample ↔ Cross-check of bkgd. estimation method



Correct TRF for HF contamination (< 8%)

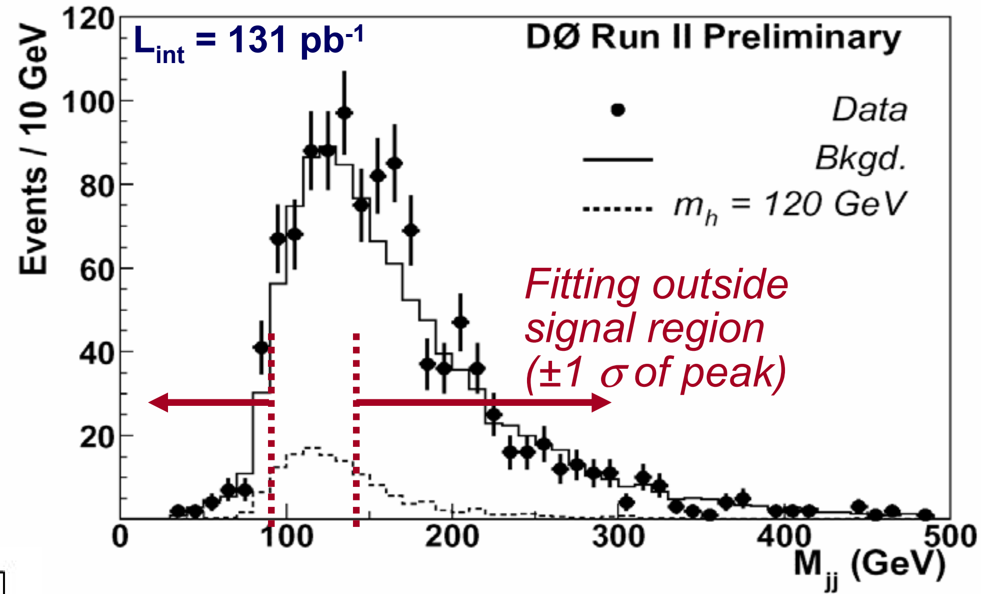
Double b-tag sample

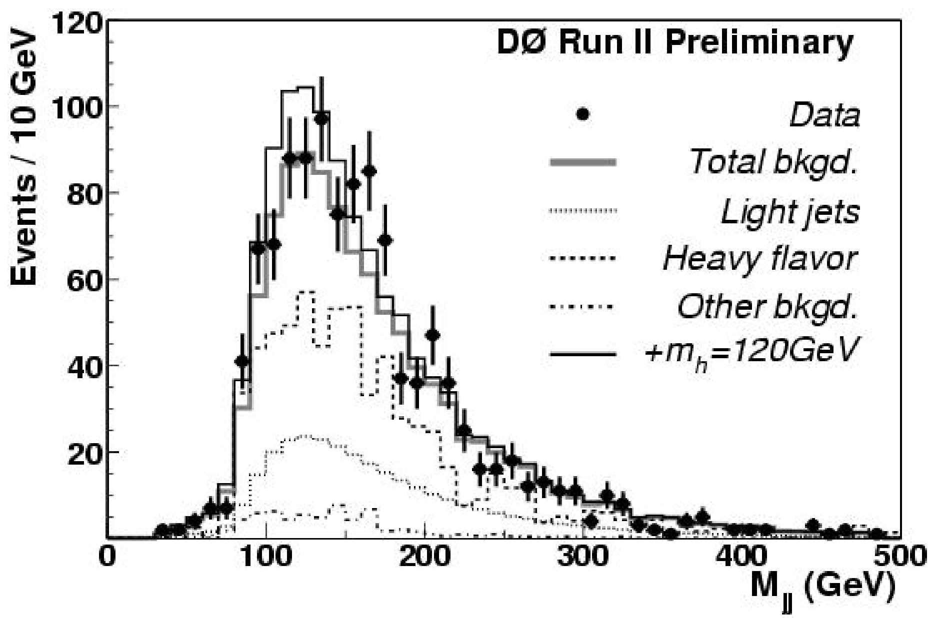
- Multi-jet fakes are estimated from data
- Normalization of HF multi-jet processes (mainly bbjj + some bbbb) is left as a free parameter in the fit
  – After correction for ccjj events, the HF bkgd. is by a factor of ~1.2 higher in data then predicted by ALPGEN (!)
  – Light quark/gluon jet rate comparable to HF contribution



Triple b-tag sample

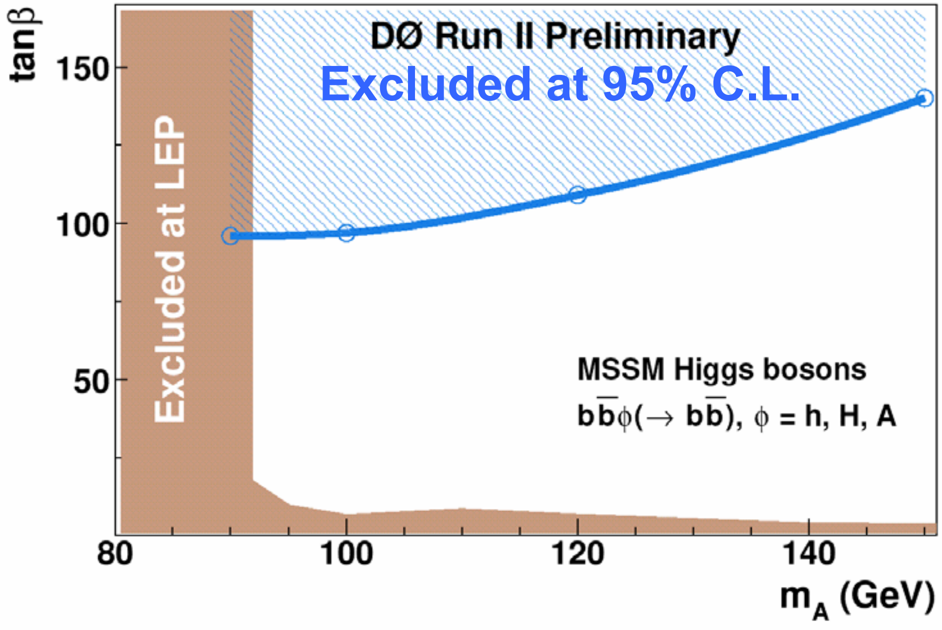
- At least 3 jets; p_T and η cuts optimized for Higgs mass and # of required jets
- Look for excess in di-jet mass
- Background shape determined from double b-tagged data by applying fake tag function to non-b-tagged jets



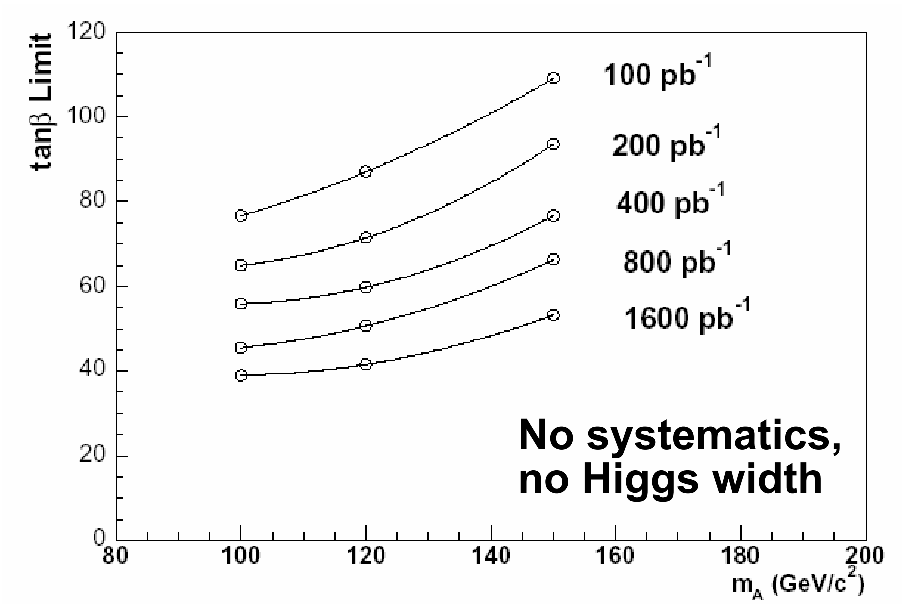


- HF production is dominant
- No additional tuning for HF fraction is required once its rate is fixed in double b-tag sample

bϕ/bbϕ(→bb): preliminary results



- Signal acceptance is ~ 0.2–1.5% depending on m_h and final state
- Systematics (22-28%) taken into account
  - JES, b-tagging, resolution, trigger …
  - Decay width approximated by Gaussian



- Sensitivity to tanβ down to ~ 40 for m_A = 100 GeV is expected with 1.6 fb^{-1} of data and with the current assumptions and performances

Systematics

- Systematic uncertainties on signal acceptance (%)

Signal (GeV/c^2)	NLO/LO	Trig	Resolution	JES	Jet ID	B–tag	Total
n_j^{min}=4, m_h=100	5	9	8.0	20	3.8	13.5	27.7
n_j^{min}=4, m_h=120	5	9	12.0	16	3.4	13.5	26.5
n_j^{min}=4, m_h=150	5	9	11.9	13	3.5	13.8	24.9
n_j^{min}=3, m_h=100	5	9	7.5	12	3.7	13.5	22.4
n_j^{min}=3, m_h=120	5	9	12.5	7.5	3.5	13.2	22.5
n_j^{min}=3, m_h=150	5	9	12.8	3.4	3.6	13.4	21.8

- Systematic uncertainties for backgrounds ~ 8-10% depending on n_j^{min}, m_h; mostly b-tagging or statistic related
- Expect improvements in next round of analysis

Signal and background: Tevatron vs LHC ?

- bh/bbh production cross section from: **S. Dawson, C.B. Jackson, L. Reina, D. Wackeroth, hep-ph/0408077**
- Take bbjj rates as given by ALPGEN
  - Selections
    - $p_T^b > 30$ GeV, $|\eta| < 2.5$, ΔR_{min}(j-j, j-b) > 0.4
    - $p_T^j > 15$ GeV, $|\eta| < 2.5$, ΔR_{min}(j-j, j-b) > 0.4
  - The dominant bkgd. at the Tevatron
  - In reasonable agreement with data ?
    - Need more studies to claim this

Signal, m_H = 150 GeV, vs bkgd. rates

Process	Tevatron	LHC	Ratio
b(b)h, σ [fb]	0.8	90	110
bbjj, σ [nb]	1.6	120	75

- S/B ratio is more advantageous at LHC ?
  - Interesting but need more solid ground

Summary

- Preliminary results have been obtained for MSSM Higgs boson searches
- Although limits set on ($\tan\beta$, m_A) plane are not general or competitive yet, the current analysis demonstrates high potential of the Tevatron/DØ for searches in multi-b-jet final states
- Many challenges have been addressed and better understanding acquired of
  - Triggering, jet tagging, MC issues
- Next round of analysis with better object IDs and more data look very promising