36th International Conference for High Energy Physics
Melbourne, 4-11 July, 2012

Search for neutral Higgs bosons in multi-b-jet final states

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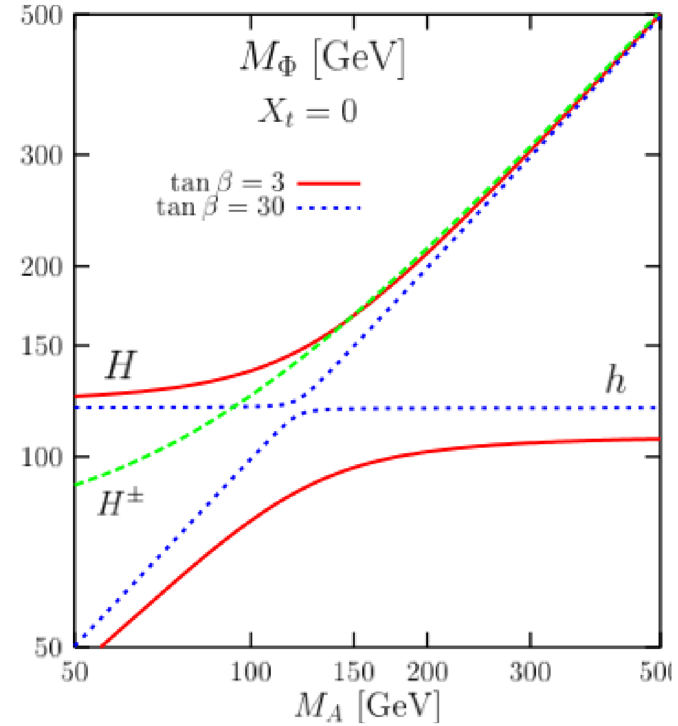
Outline

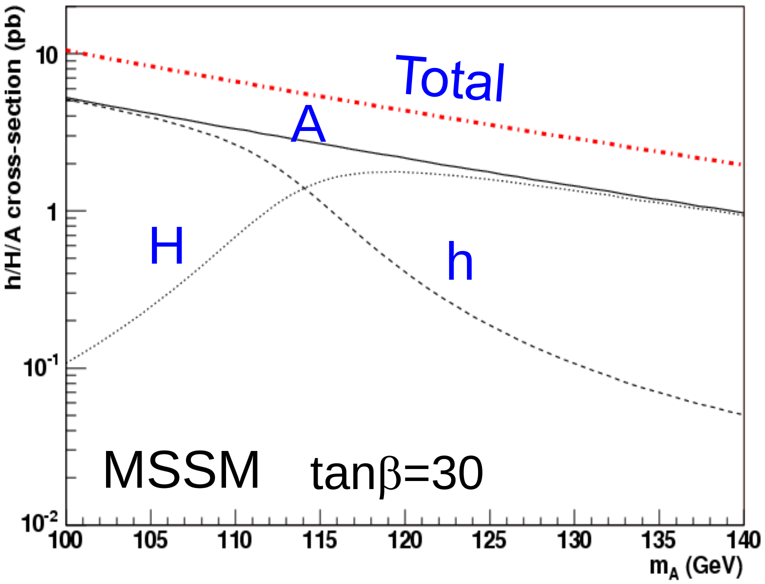
- Motivation
- MSSM framework
- Analysis overview
- Results
- Summary

Motivation

- Various extensions of the SM introduce additional Higgs field that can lead to multiple scalar bosons
- In MSSM, for instance, have two Higgs doublet fields
  - H_u (H_d) couple to up- (down-) type fermions
  - The ratio of their vacuum expectation values: $\tan\beta = \langle H_u \rangle / \langle H_d \rangle$
  - 5 Higgs particles after EWSB

    h, H, A, H^+, H^-
- At large tanβ, the masses of two Higgs bosons, A and either h or H, are approximately equal, effectively doubling the production cross section



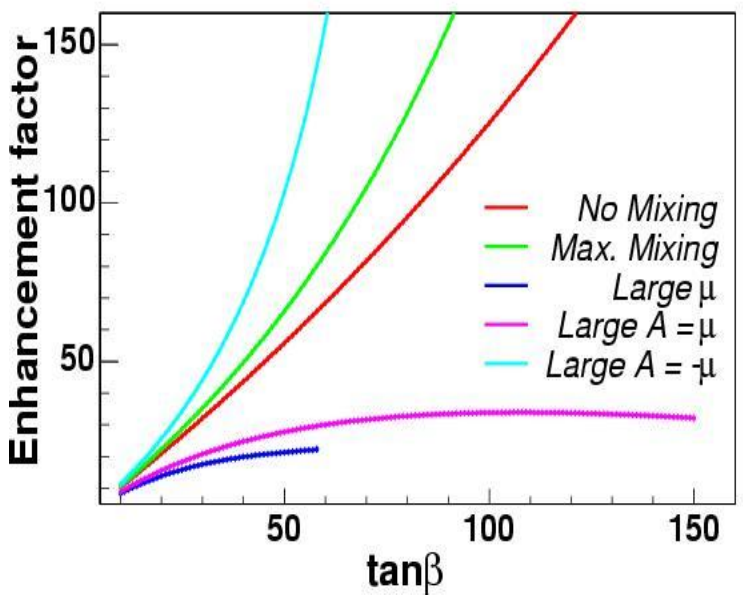


Motivation: MSSM scenarios

- At large tanβ, coupling to down-type quarks, i.e. b's, is enhanced wrt SM
  - At tree level the production cross section rise as tanβ^2
  - Modified by other SUSY parameters:

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

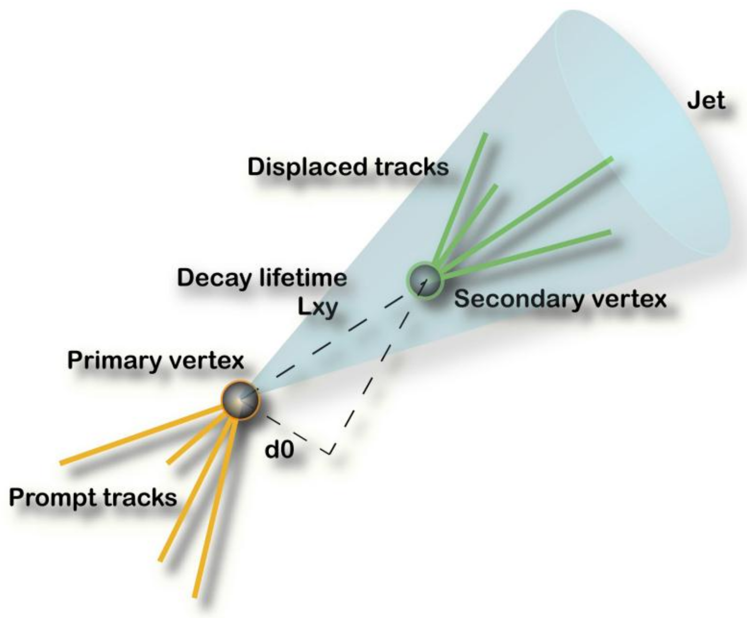
Δ_b – function of $X_t = A_t - \mu\cot\beta$, μ, M_g, M_q, etc.



- In general, the A/h/H decay branching ratio to b-quarks is ~90% with the reminder being mostly to τ-leptons
- LHC experiments, CMS in particular, have set strongest constraints so far on the MSSM parameter space using h → $\tau\tau$ decay mode
- However, MSSM is not the only option to explore at hadron colliders, e.g. scalar colour octet production could be one

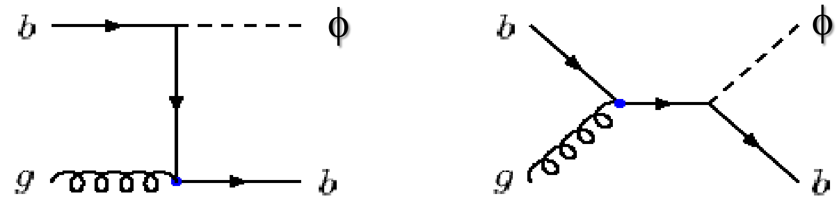
Analysis overview: event selection

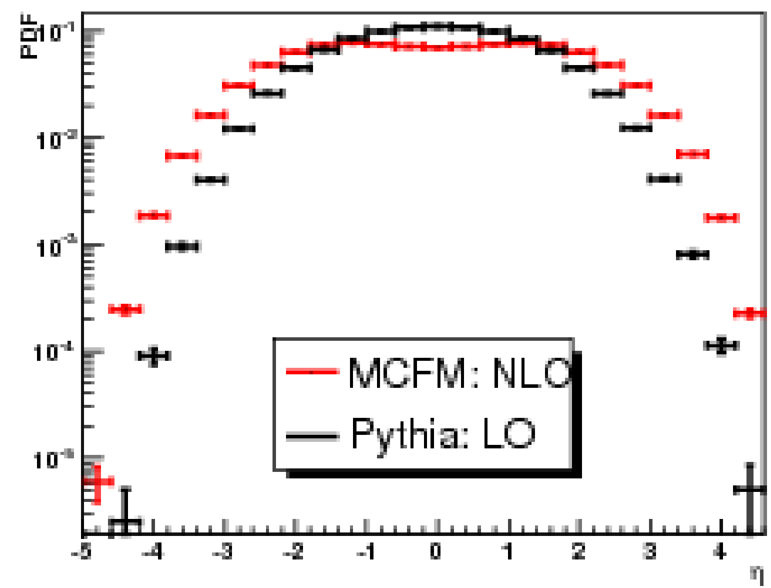
- Dedicated triggers that select at least 3 jets using b-tagging information
- Offline, require at least three jets with p_T > 20 GeV in $|\eta| < 2.5$ with at least two of them having p_T > 25 GeV
- Two leading jets and at least one of the third and fourth jets are required to be b-tagged
- In addition, a large sample with only two b-tagged jets is used to build models of multi-jet backgrounds
- To tag a b-jet, use a Neural Network event classifier that employs
  - Track impact parameter, jet "lifetime", decay vertex mass, etc.
  - Typical efficiencies of 50 – 70% with a mis-tagging rate of 0.5 – 4.5% depending on the operating point



Signal and background modelling

- Generate gb → bh signal events with Pythia
- Reweight in p_T and η of spectator b-jet to match kinematic predicted by MCFM NLO calculations
- Build a kinematic likelihood discriminant (*D*) to select best jet pairing to suppress background



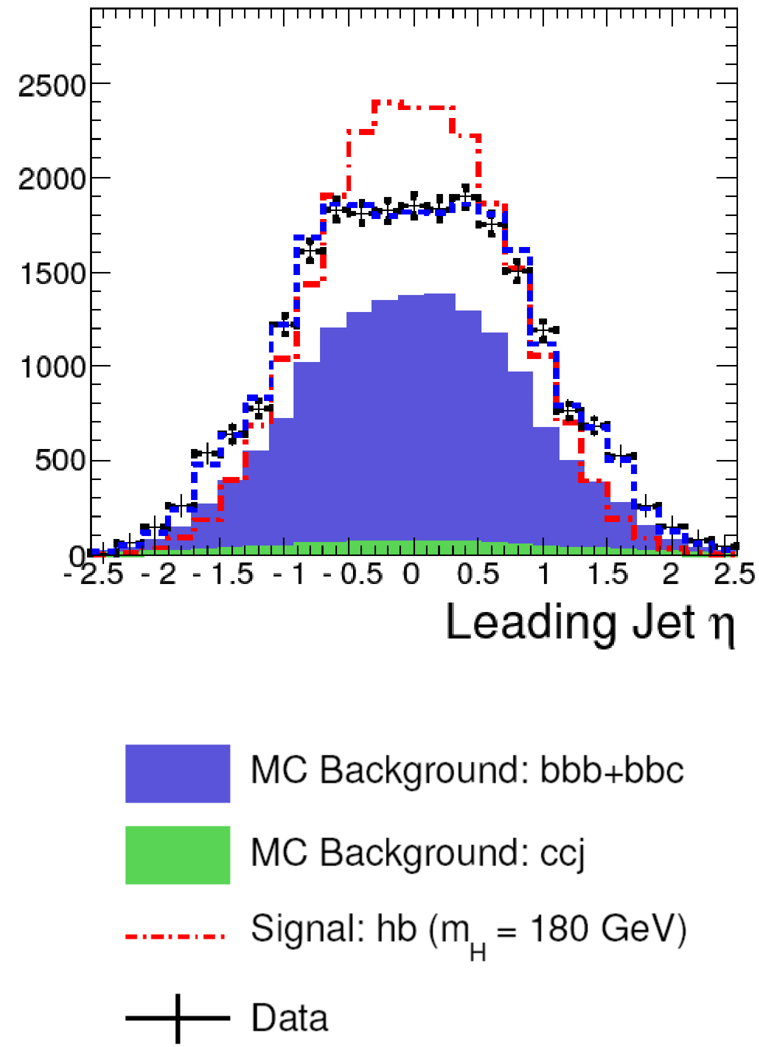


- Challenge to model multi-jet background due to
  - Large uncertainties on MC predictions, shapes and rates
  - Hard to find a control region

➢ Employ data driven method to predict shape, float normalization

Analysis overview: background model

- Predict background shape from 2-jet tagged data with correction from MC
- Use Alpgen+Pythia MC to simulate multi-jet background
- Prediction normalised to 3 (4) b-tag data



2D correction: likelihood vs invariant mass

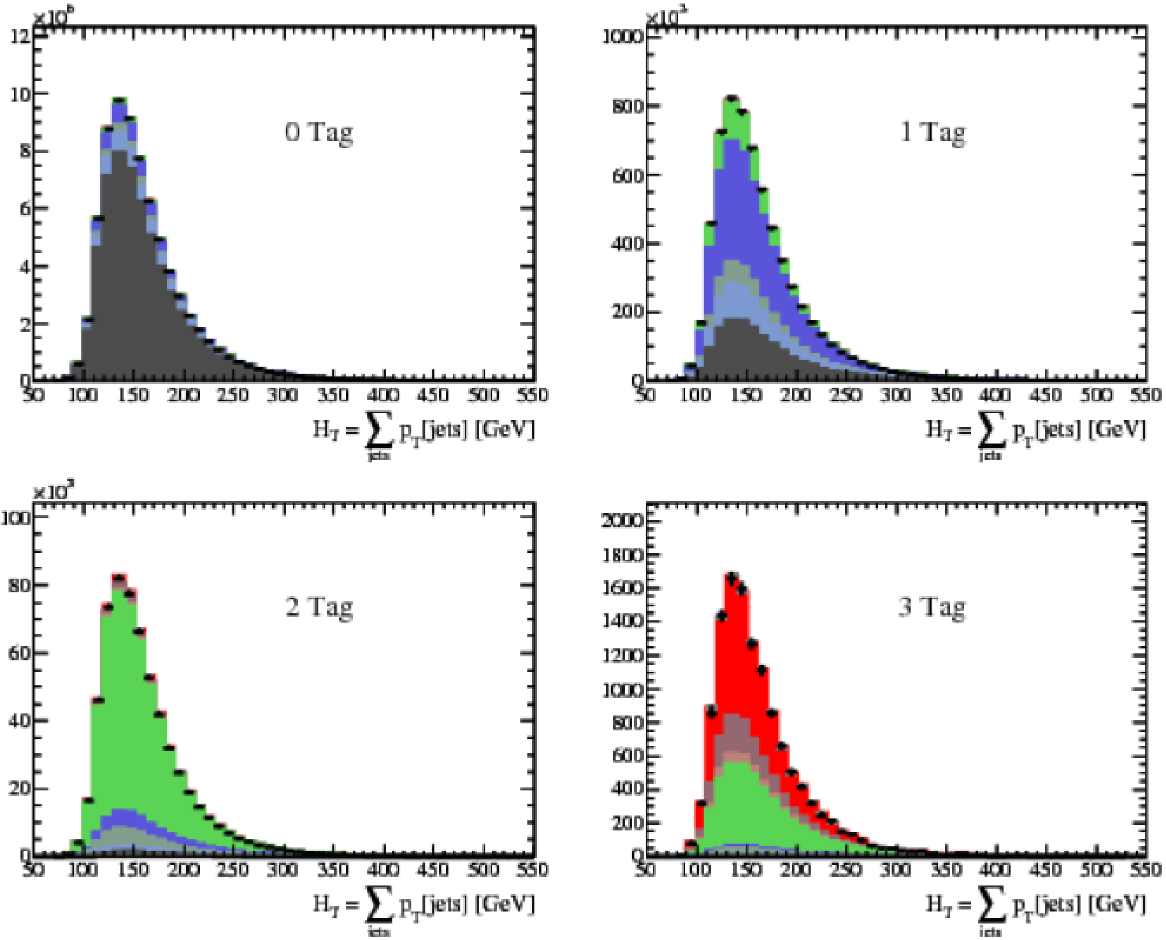
$$S^{exp}_{3\mathrm{Tag}}(\mathcal{D}, M_{bb}) = \frac{S^{MC}_{3\mathrm{Tag}}(\mathcal{D}, M_{bb})}{S^{MC}_{2\mathrm{Tag}}(\mathcal{D}, M_{bb})} S^{data}_{2\mathrm{Tag}}(\mathcal{D}, M_{bb}).$$

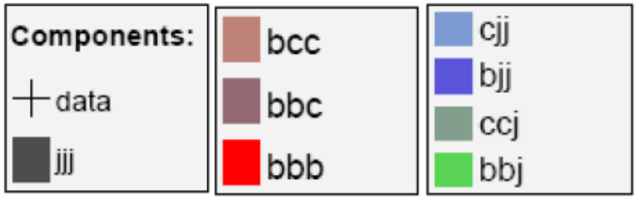
3 b-tag background

MC correction factor

2 b-tag data

Background validation



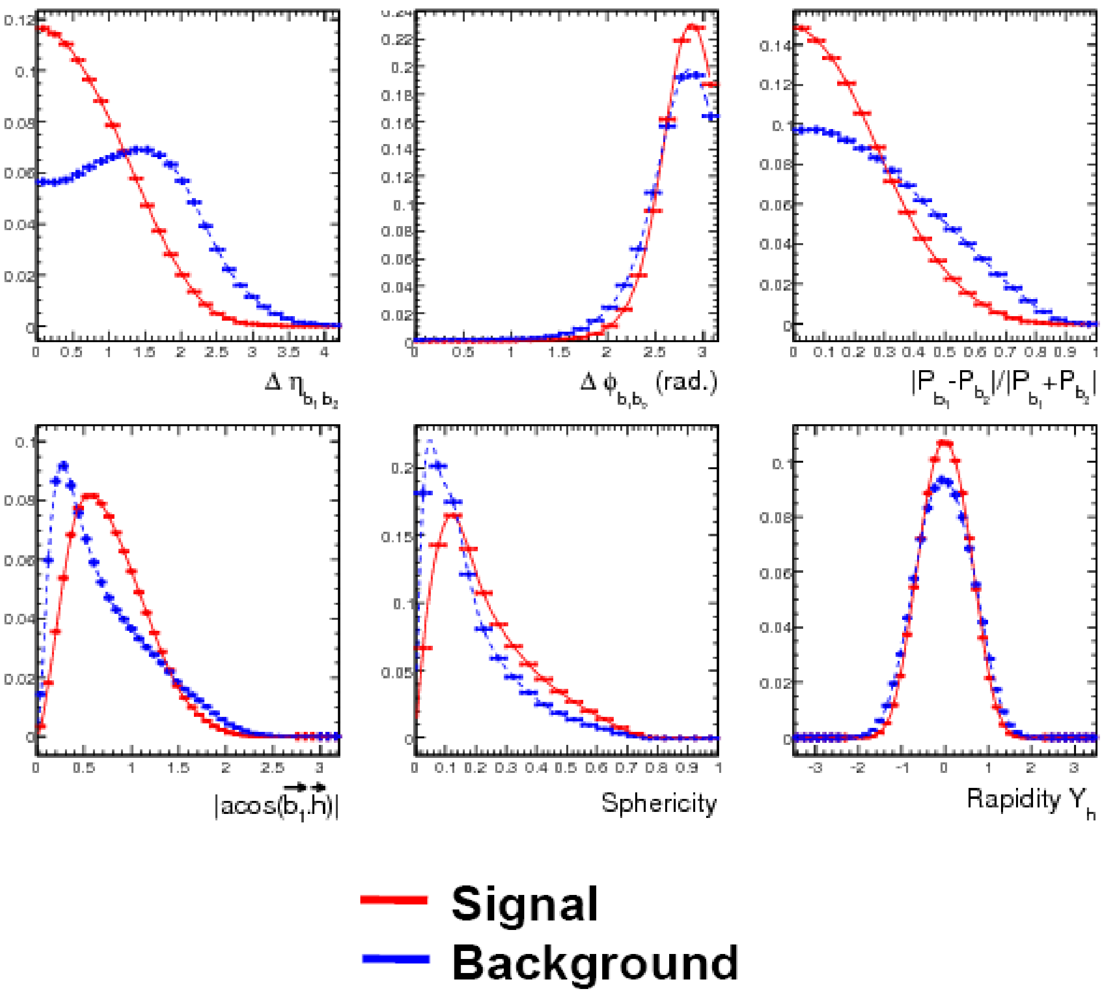


The sum of jets p_T, H_T, distributions in 0, 1, 2 and 3 b-tag events

- Flavour composition determined from simultaneous fit to data across samples with different number of tagged jets and b-tag operating points
- Bkgd. composition in 3 b-tag sample
  - bbb ~ 47%
  - bbj ~ 32%
  - bbc ~ 17%
  - ccj ~ 2%

Signal likelihood

Likelihood discriminant: $\mathcal{D}(x_1,\ldots,x_6) = \dfrac{\prod_{i=1}^{6} P_i^{\rm sig}(x_i)}{\prod_{i=1}^{6} P_i^{\rm sig}(x_i) + \prod_{i=1}^{6} P_i^{\rm bkg}(x_i)}$



where $P_i^{\rm sig}$ ($P_i^{\rm bkg}$) is the signal (bkgd.) PDF

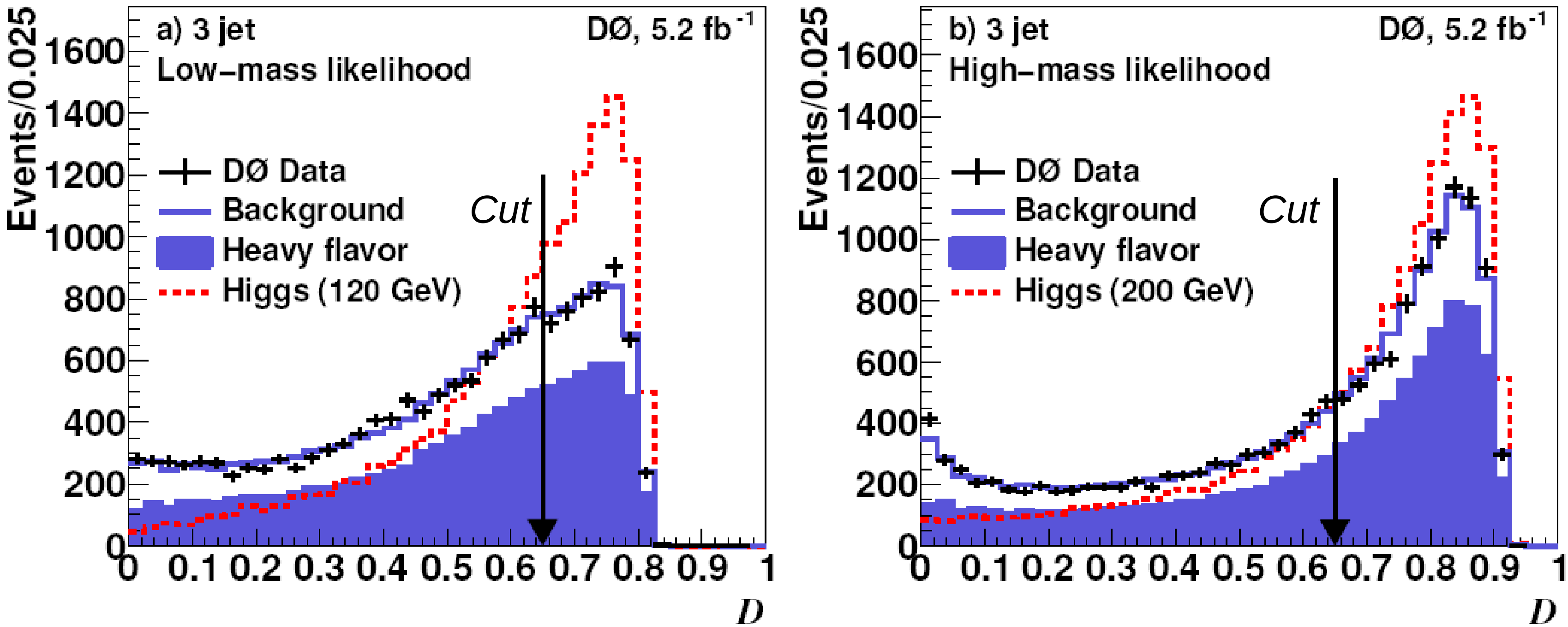
- Use six variables that are well modelled
- Trained on jet-pairings
  - In each event select pairing with highest LH value
- Build two likelihoods:

low mass M_A < 140 GeV

high mass $M_A \geq$ 140 GeV

Signal selection

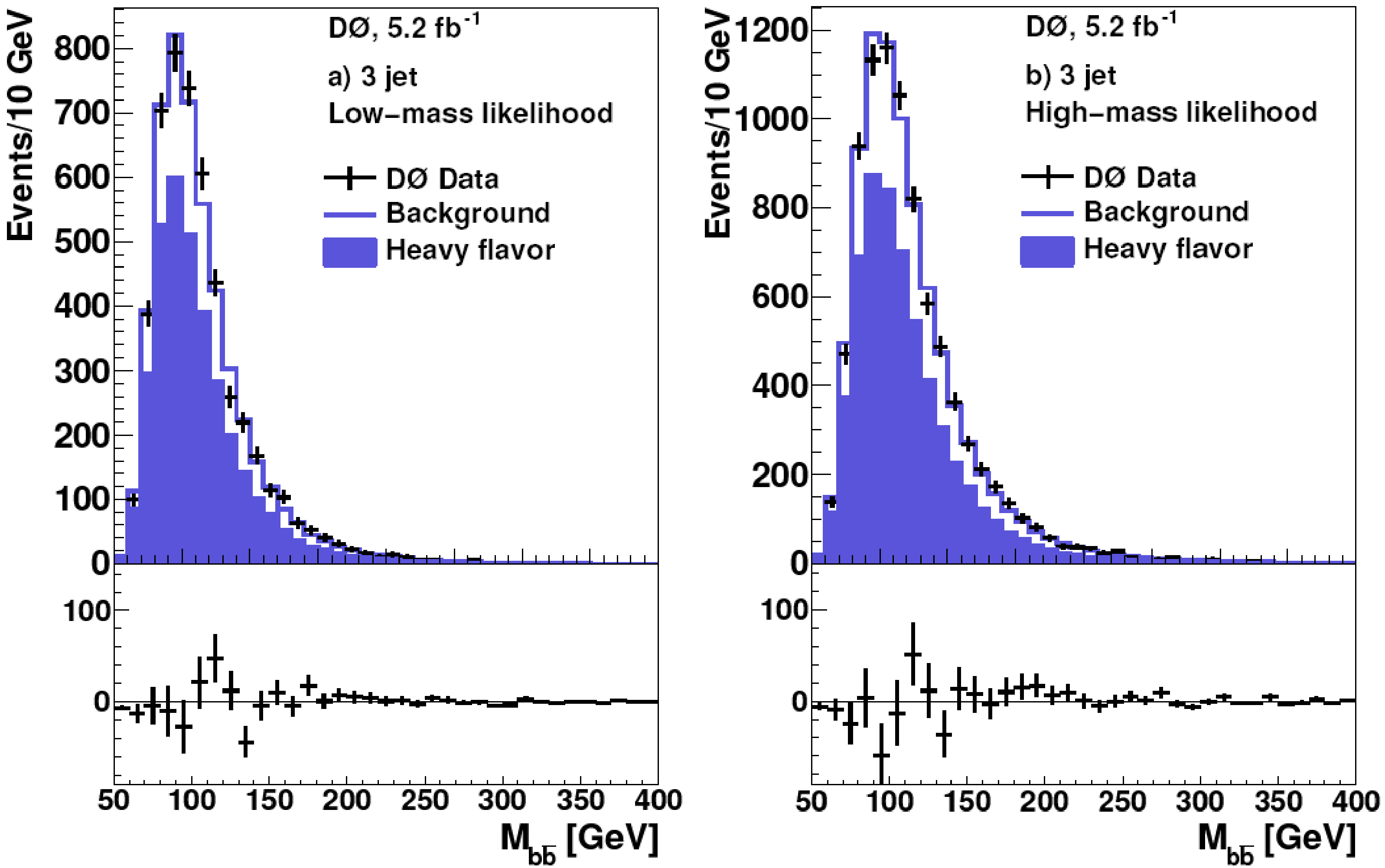
Projection of 2D distributions onto likelihood axis



- LH optimised considering expected sensitivity with full systematics
- Select events with LH *D* > 0.65 for all mass points

Final discriminant

Di-jet invariant mass distribution used as input for the limit setting

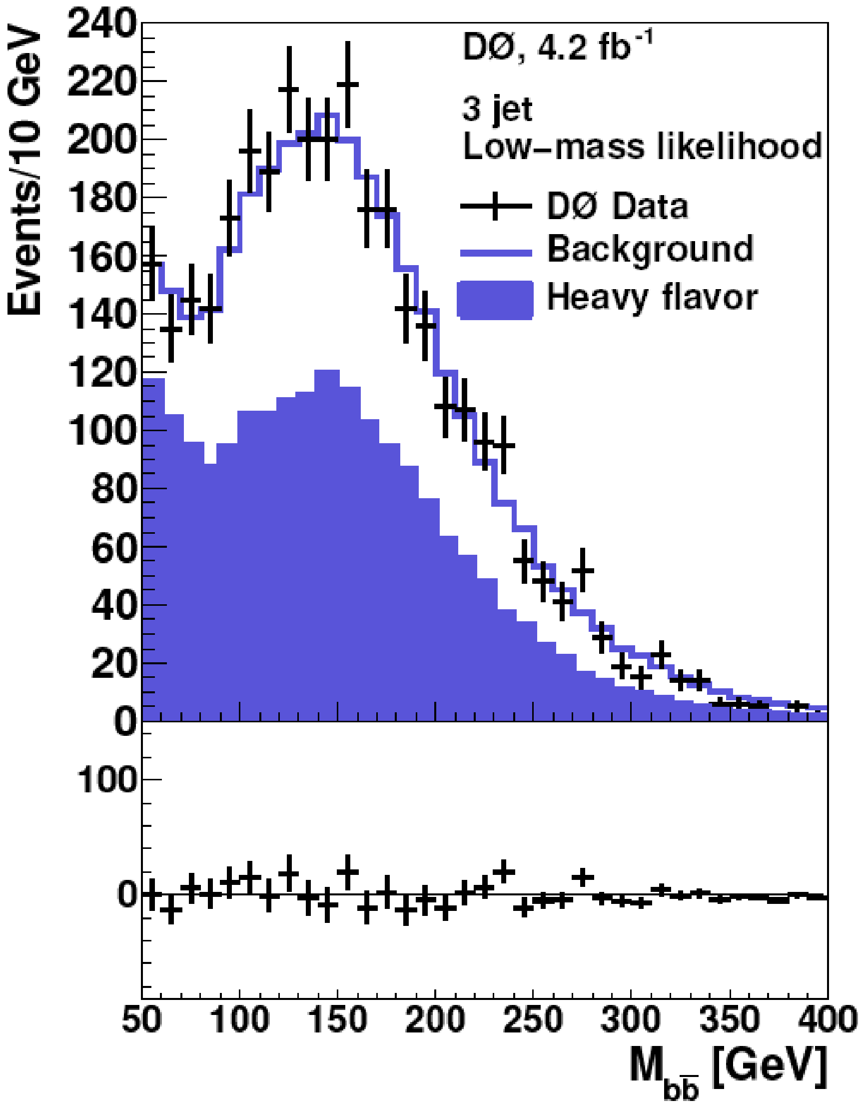


D > 0.65, background normalised to data

Discriminant validation

- Validate di-b-jet mass modelling in a kinematically similar but signal depleted region
  - "Wrong" jet pairs look like background
- Pick a pair with lowest likelihood in $D < 0.12$ region

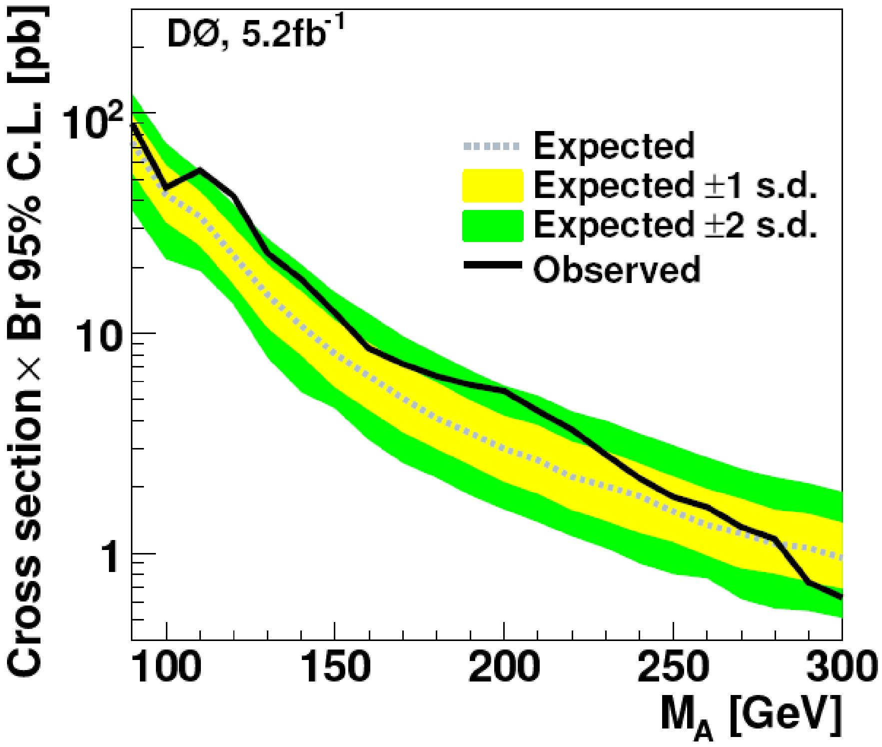
➢ Excellent agreement seen between the model and data

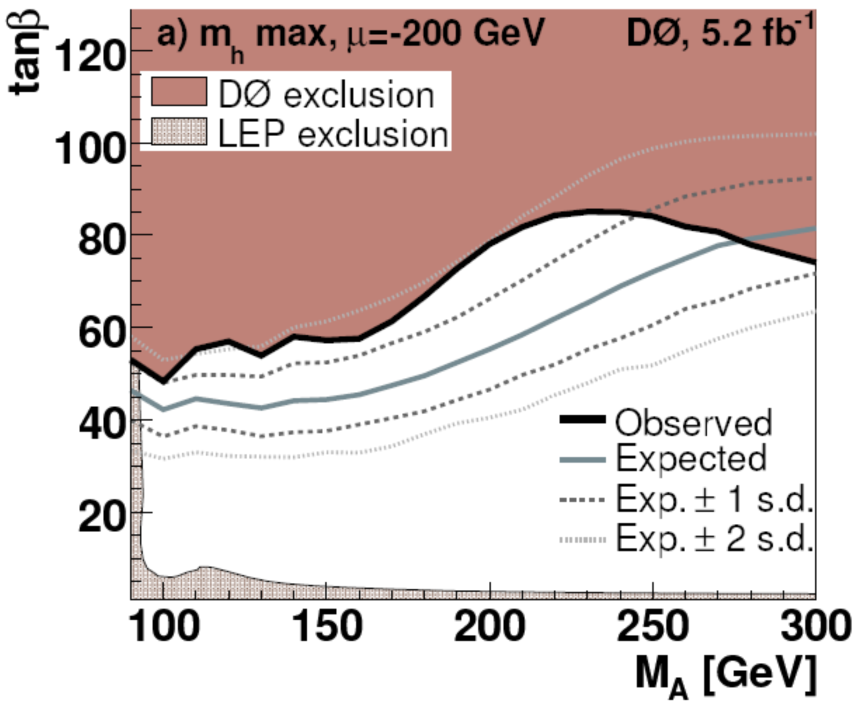


Systematics

- Signal
  - b-quark jet identification efficiency, energy calibration, resolution, trigger modelling, luminosity (6.1%)
  - Theoretical uncertainty on the signal cross section: choice of factorization scale (10%) and PDF (5-13%) depending on the Higgs boson mass
- Background
  - Many uncertainties affecting the simulation, like jet energy scale and resolution, cancel when the data driven bkgd. prediction is employed with correction factors estimated from MC
  - Remaining uncertainties are due to b-tagging, heavy vs light flavor jet energy resolution
- Overall, experimental systematic uncertainties are dominated by b-tagging (15 – 20%) and jet energy scale (2 – 14%), depending on the mass hypotesis

Limits





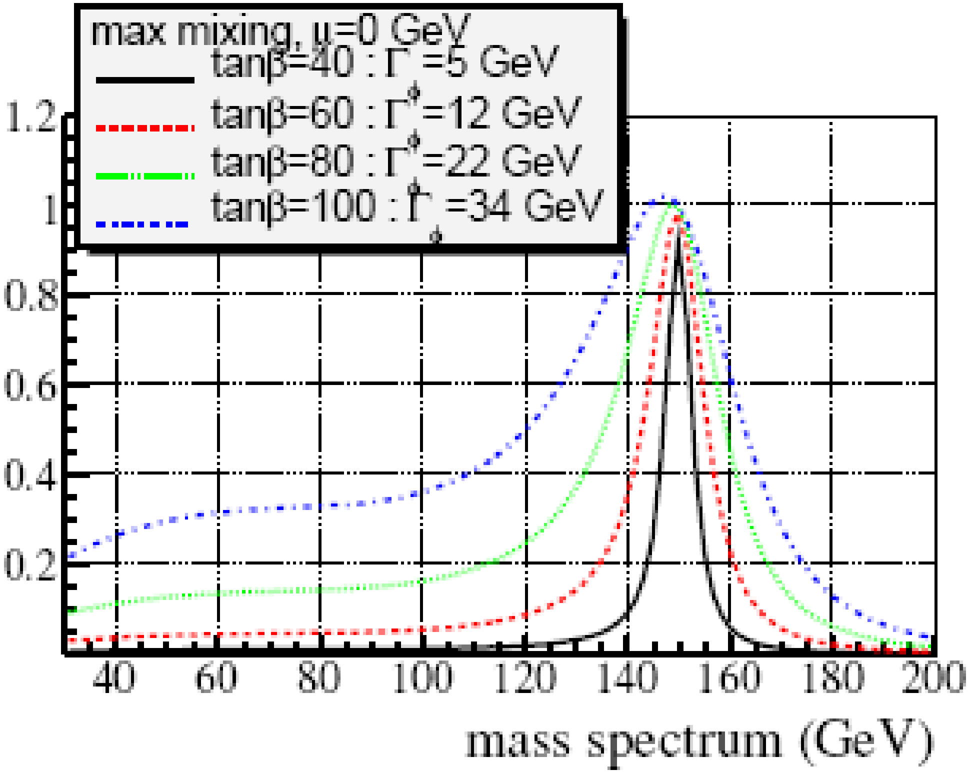
Published in Phys. Lett. B689 (2011) 97

Summary

- Substantial region in the MSSM parameter space up to Higgs boson masses of 300 GeV has been excluded in final states with b-quarks using 5.2 fb^{-1} of data
- Full data collected in Run II of the Tevatron is being analysed
- Combination of results from CDF and D0 are in the works

Backups

Signal width effect



Radiative corrections have significant effect

Larger effect for bbb channels
Less significant for bττ

- Large enhancements to the couplings give large widths

Simulate widths using “narrow” samples and convoluting with Breit-Wigner

Systematics