SUSY Higgs Searches in the bbb Final State

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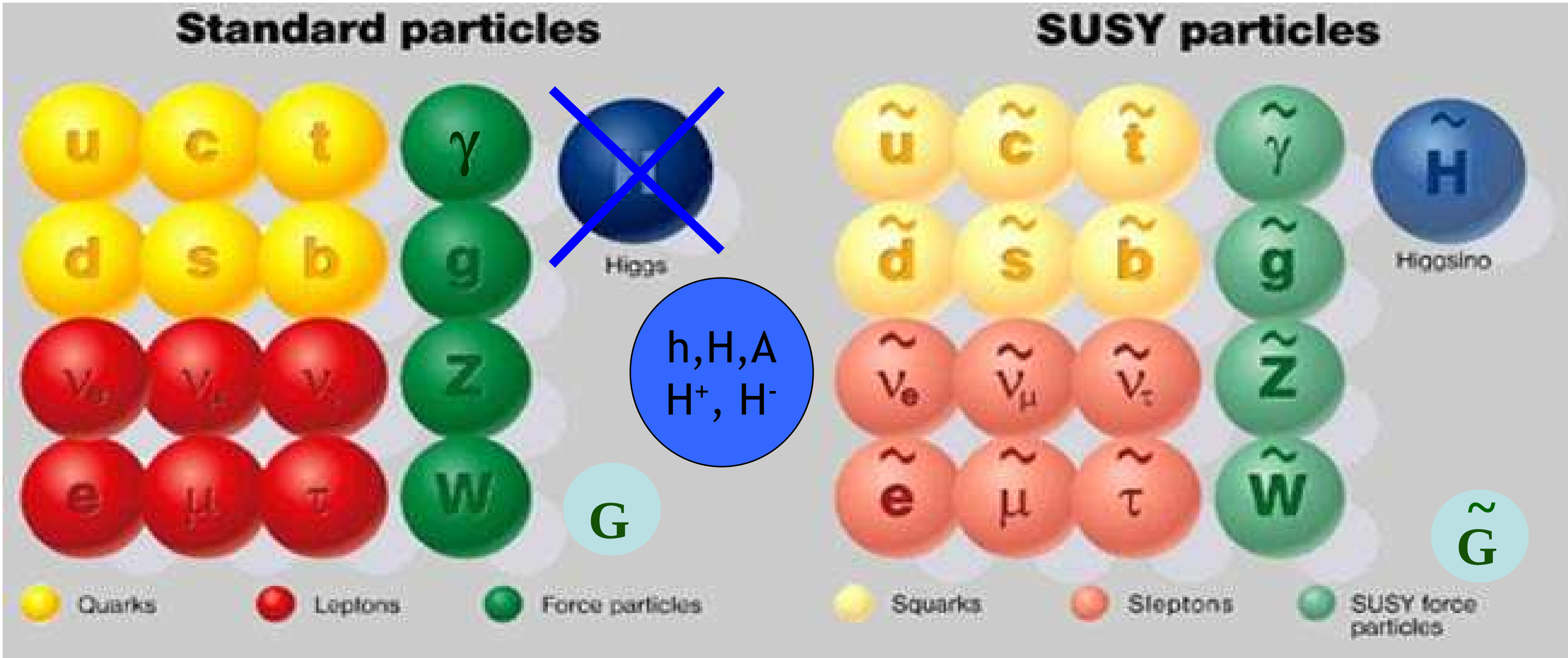
On behalf of the CDF and D0 Collaborations

The Higgs Boson

- Consider the Electromagnetic and the Weak Forces
- Coupling at low energy: EM: $\sim\alpha$, Weak: $\sim\alpha/(M_{W,Z})^2$
  - Coupling strength governed by the same dimensionless constant
  - Difference due to the mass of the W and Z bosons
    - Electroweak symmetry: $M_\gamma=M_Z=M_W$
    - But photons massless and W/Z are massive?
- May postulate the Higgs mechanism for the breaking of electroweak symmetry
  - Results in massive vector bosons and mass terms for the fermions
  - Theory predicts a massive new particle called the Higgs boson!

Supersymmetry



- SM particles have supersymmetric partners: differ by 1/2 unit in spin
- SUSY has many attractive properties
  - Cancellation of Higgs mass divergence, coupling unification, etc
  - Lightest neutralino is a dark matter candidate
- Requires larger Higgs sector than the single scalar of the SM
  - Simplest case: Minimal Supersymmetric Standard Model (MSSM)

Higgs in MSSM

- Instead of one scalar, get five:
  - Three neutral: h, H, A : (generically "ϕ")
  - Two charged: H^+, H^-
- Separate couplings for up-type and down-type fermions
- Properties of the Higgs sector largely determined by two parameters:
  - m_A : mass of pseudoscalar
  - $\tan\beta$: ratio of down-type to up-type couplings
- Typically, $m_h < m_A < m_H$, and $m_{H\pm} \sim m_A$
- For $\tan\beta$ near 1, h is SM-like and light - LEP-II limits apply
- Larger $\tan\beta$ shows more interesting behavior
  - A becomes degenerate with h or H (mass, couplings, etc)
  - Other decouples, SM-like, mass around 120 GeV
  - A + h/H production controlled by $\tan\beta$
- In the Standard Model, Higgs cross section is fixed – no free parameters
- In MSSM, production of A/h/H depends on $\tan\beta$ – range of possiblity
  - For the right value of $\tan\beta$, could already have discovery potential

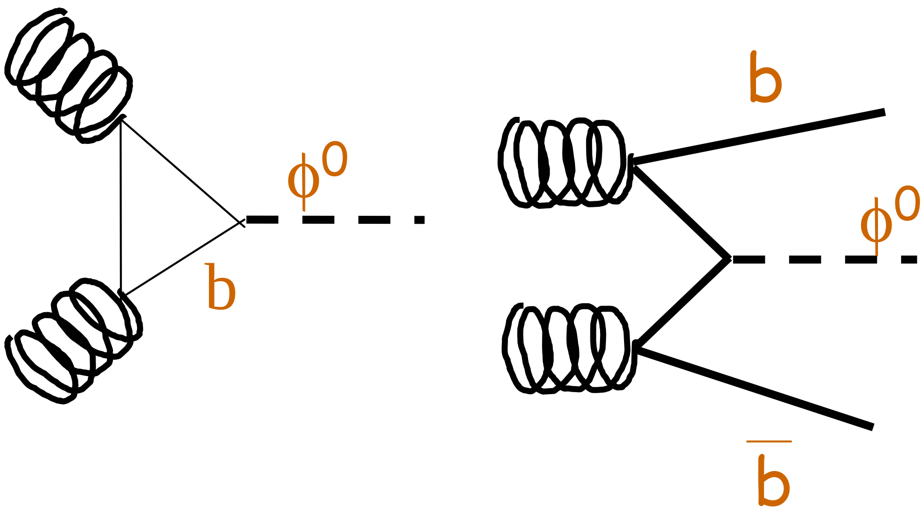
Higgs at High tanβ

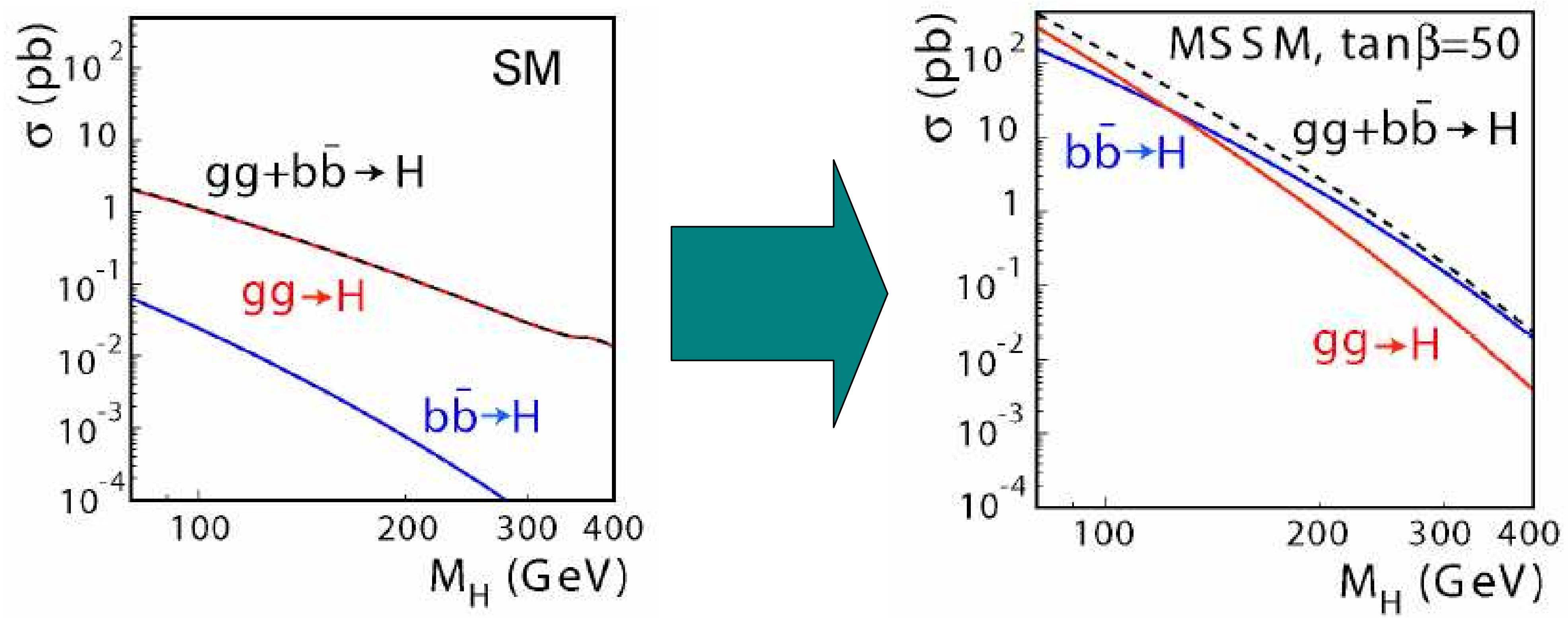
Processes involving bottom quarks (down-type) enhanced by $\tan^2\beta$

Boost from femtobarns to picobarns

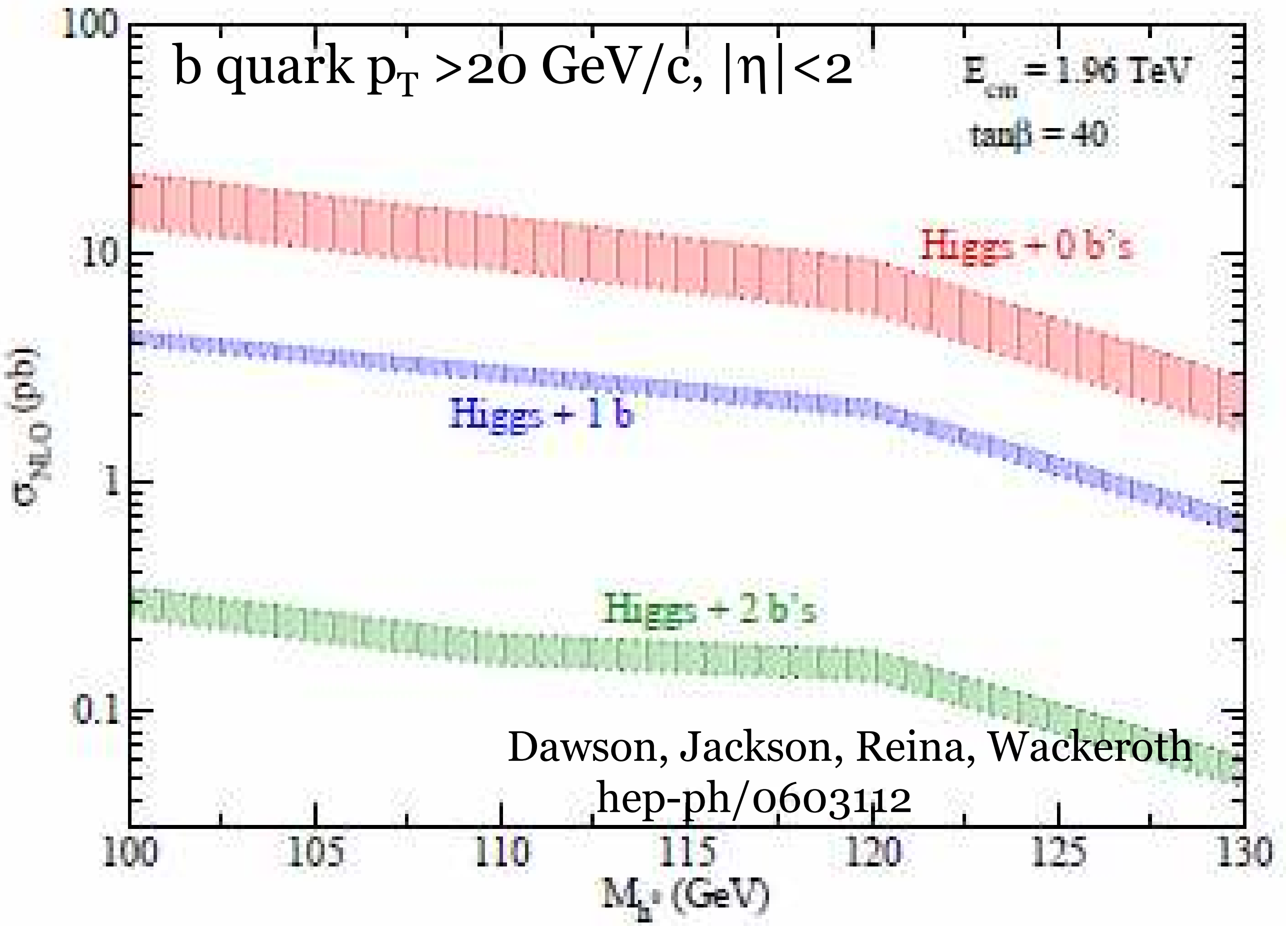
Could be observable at Tevatron!

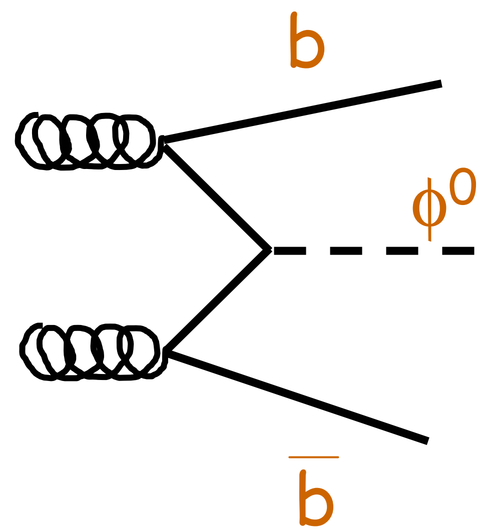
At large $\tan\beta$, decays into $b\underline{b}$ (90%) and $\tau\tau$ (10%) dominate





The 3b channel



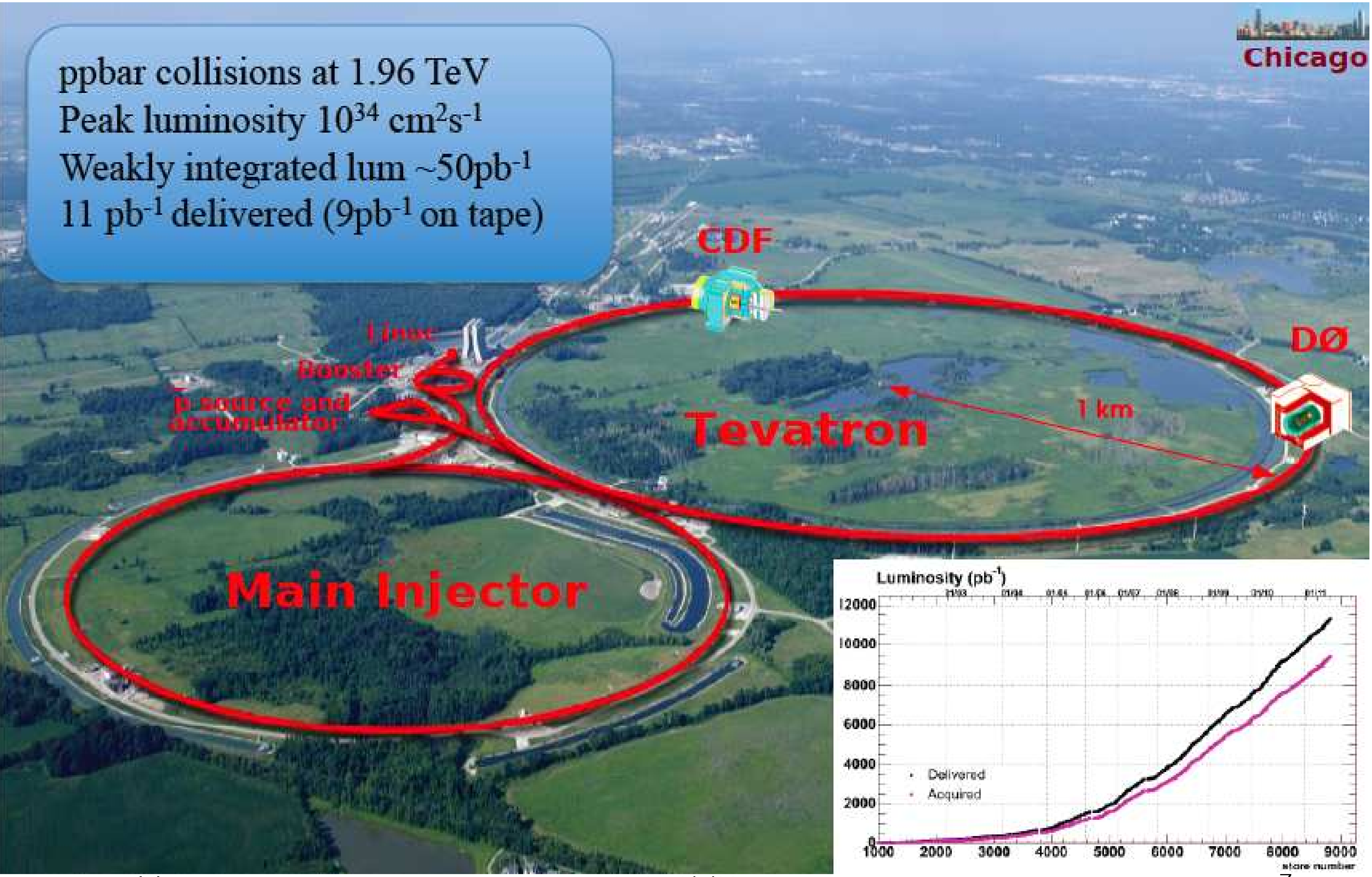


- Search for the bbφ→bbbb process
- Less cross section when requiring both b's to be high-p_T
- Look for the Higgs + 1b case

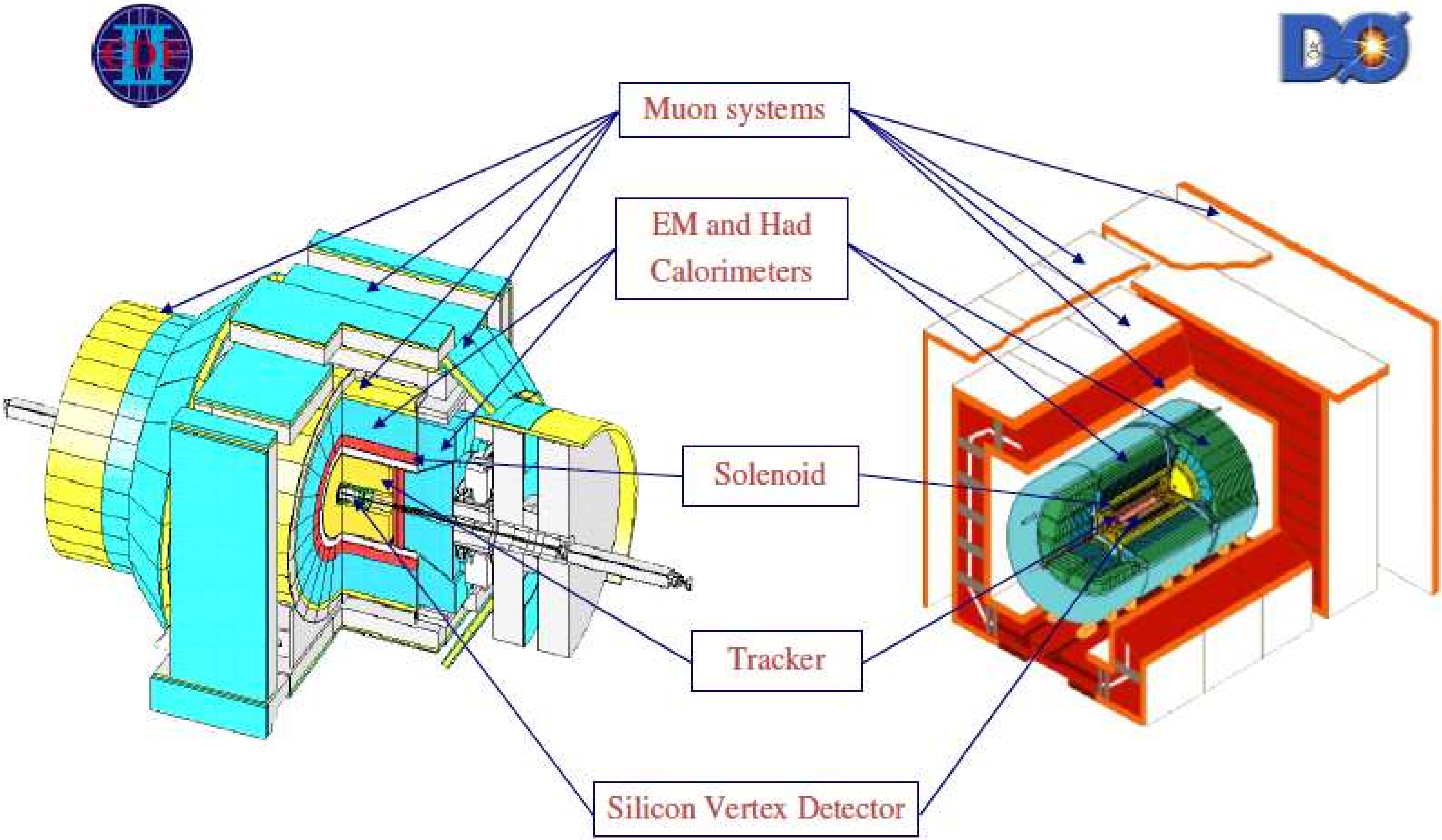
Signal: Three b-jets (two forming a mass peak from Higgs decay)

The Tevatron

ppbar collisions at 1.96 TeV
Peak luminosity 10^{34} $cm^2 s^{-1}$
Weakly integrated lum ~$50 pb^{-1}$
11 pb^{-1} delivered ($9 pb^{-1}$ on tape)

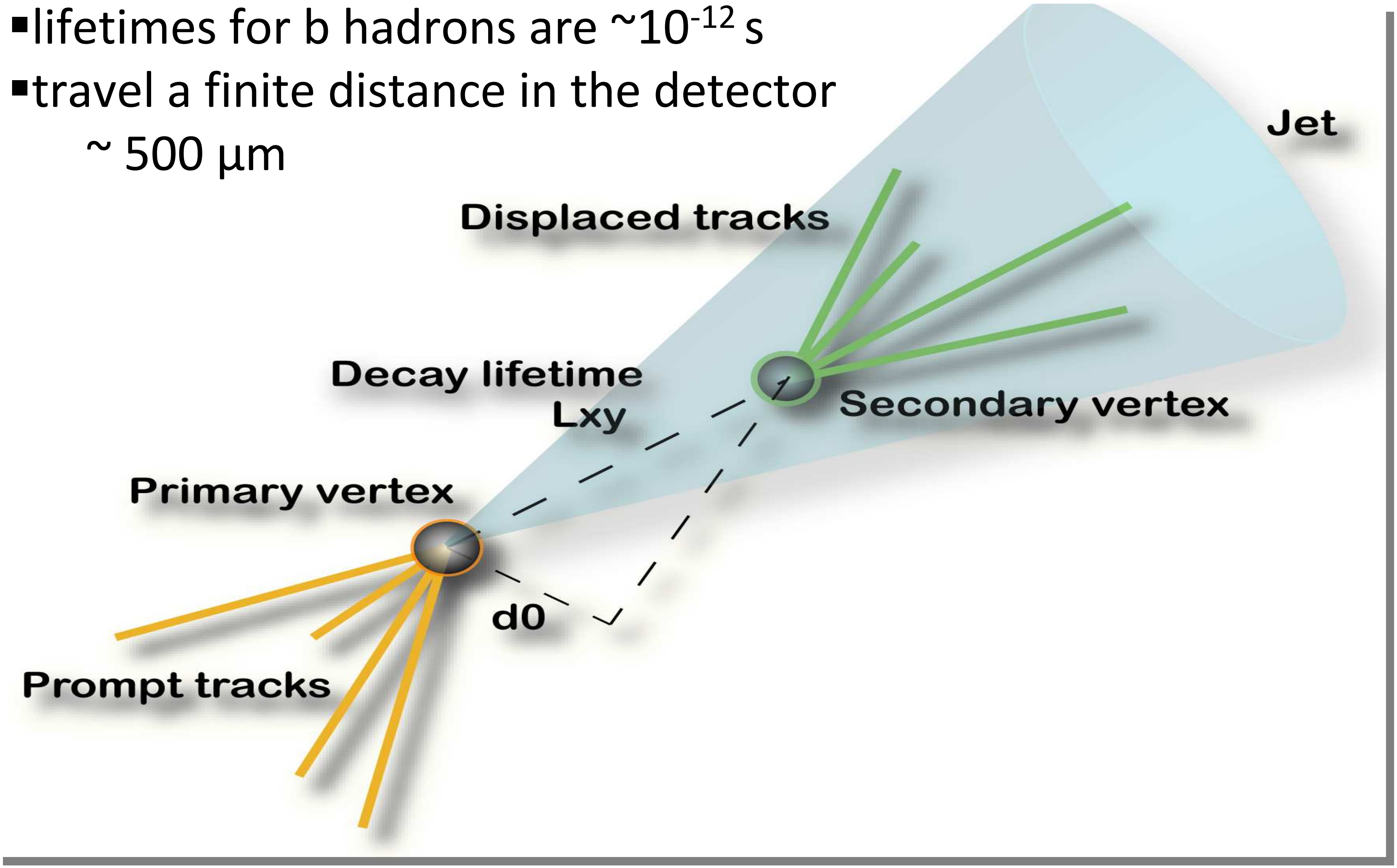


The CDF and D0 detectors



Identifying b jets

- lifetimes for b hadrons are ~10^{-12} s
- travel a finite distance in the detector
  - ~ 500 μm



3b Analysis Roadmap

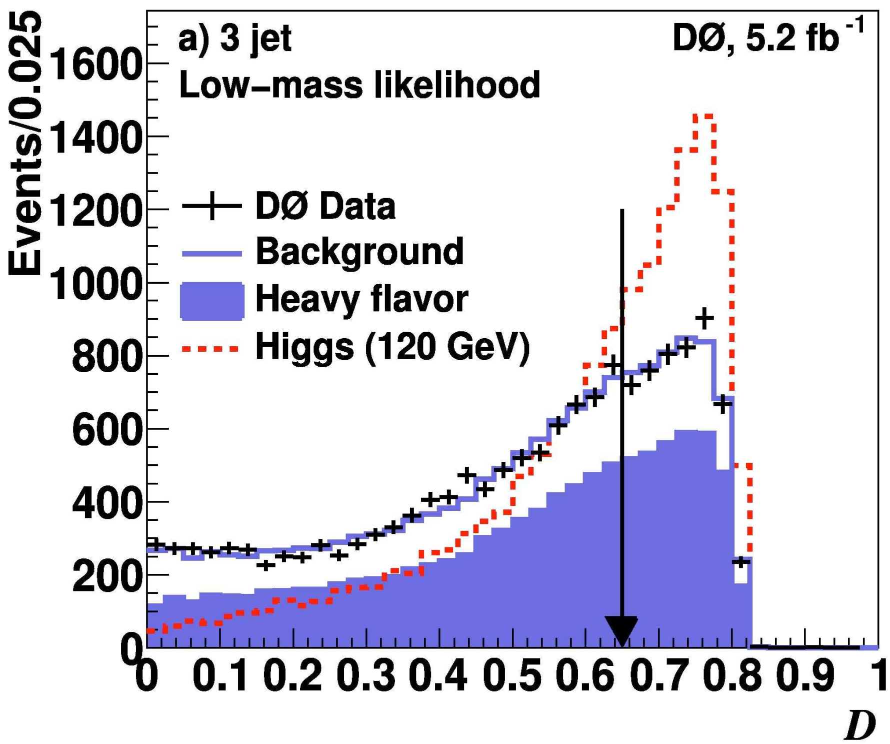
	CDF	DØ
Trigger	Based on two jets and two displaced tracks (no matching)	Multi-jet trigger with b-tagging.
Background	Derive estimates for each flavor combination from the data → Use Pythia to check for bias	Background shape modeled from a combination of data and Alpgen. → Rate obtained from fits to data
Discriminant	• Look for an excess in the mass of the two leading jets (m_{12}) • Use tag mass (m_{tag}) information to understand flavor composition • Perform a two-dimensional fit to the data using these estimates • Tag mass information determines background composition • Look for Higgs in m_{12} distribution	• Construct likelihood discriminant based on several angular and kinematic variables. • Cut on to improve s/b and highest likelihood value used to select jet pair for m_{jj} • Use low likelihood region as control region • Look for Higgs in m_{jj}

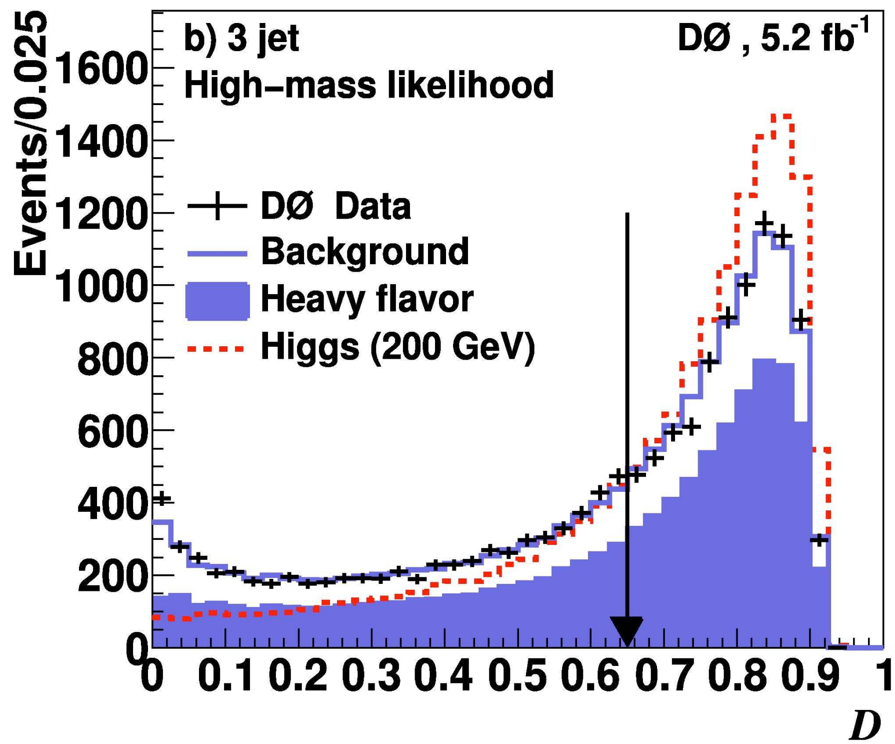
D0's Likelihood

Variables used to construct the likelihood:

- the angle between the leading jet in the pair and the total momentum of the pair
- $\Delta\eta$ and $\Delta\phi$ between the two jets in the pair
- the momentum balance in the pair
- the combined rapidity of the pair
- the event sphericity

$$\mathcal{D}(x_1, \ldots, x_6) = \frac{\prod_{i=1}^{6} P_i^{\text{sig}}(x_i)}{\prod_{i=1}^{6} P_i^{\text{sig}}(x_i) + \prod_{i=1}^{6} P_i^{\text{bkg}}(x_i)},$$

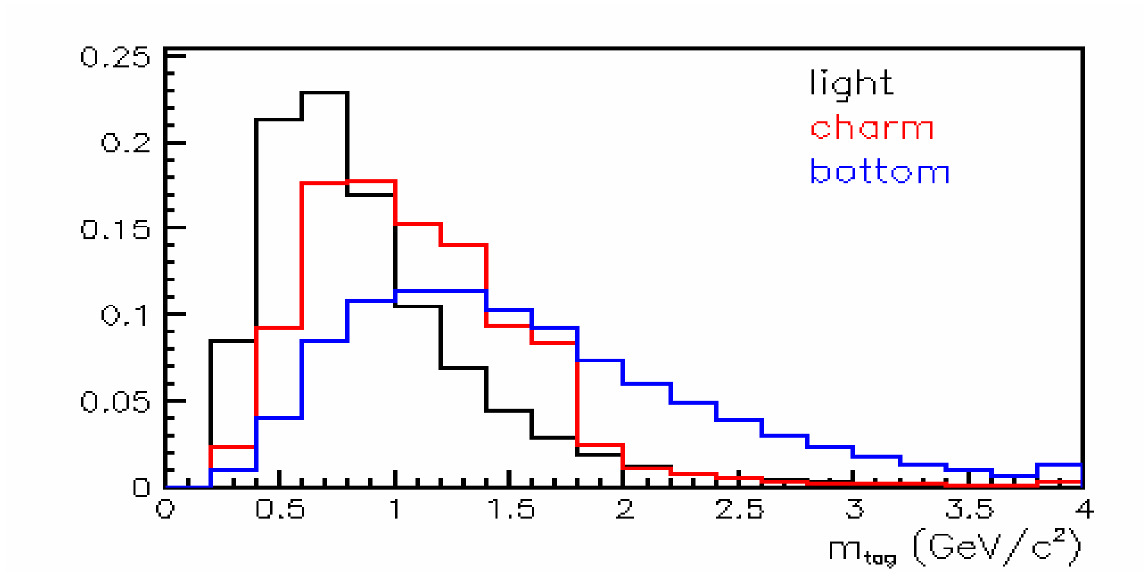


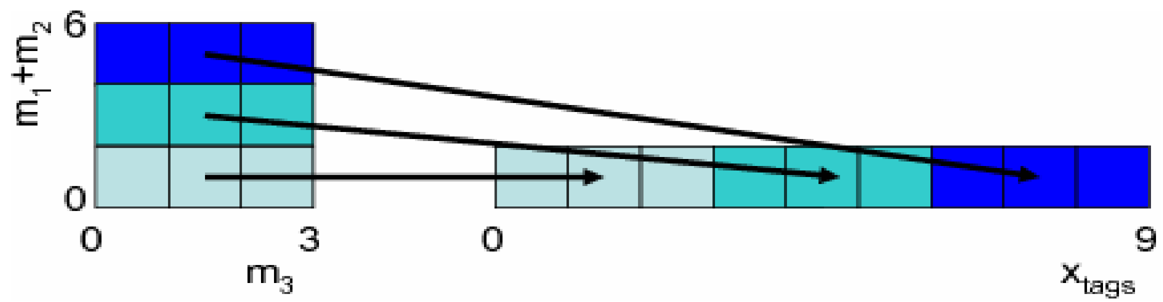


Cut on D improves s/b and highest D value is used to select jet pair to use for m_{jj}.

CDF's use of mass (x_{tags})

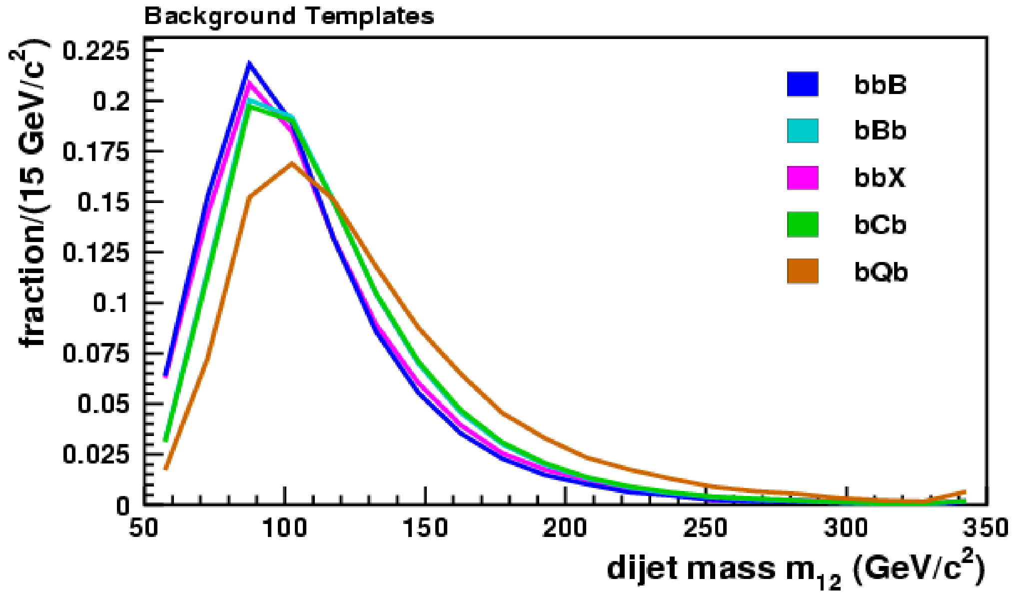
- Split events by flavor
- Characteristic m_{12} spectra
- Second variable to help separate backgrounds from each other, and Higgs+bbb from ones with c/q
- Important categories are:
  - bb + b : bbb, Higgs
  - bb + X : bbc, bbq
  - bX + b : bcb, bqb
  - Naturally breaks into m_1+m_2 and m_3
- Pack into 1D so overall templates are only 2D (technical reasons)
- Unstack 3x3 histogram into a 9-bin 1D histogram – "x_{tags}"

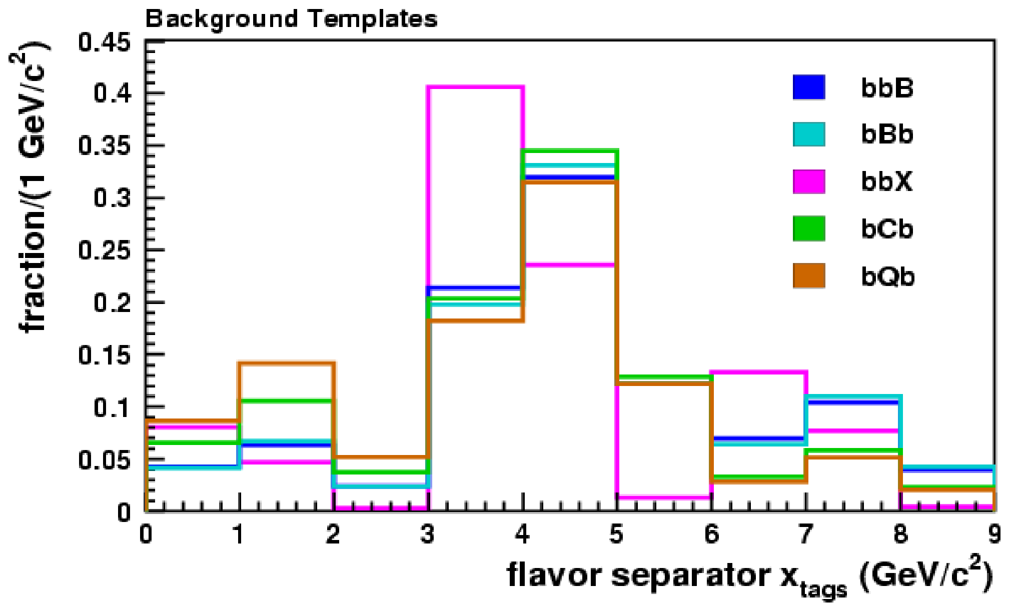




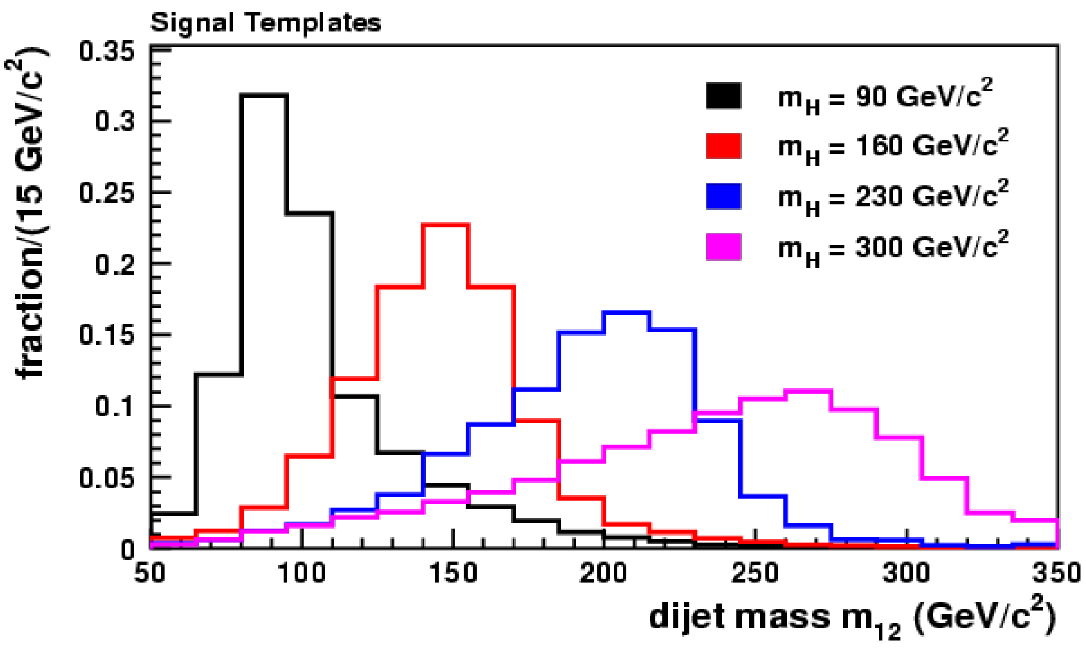
CDF uses 2D fit (m_{12} and x_{tags})

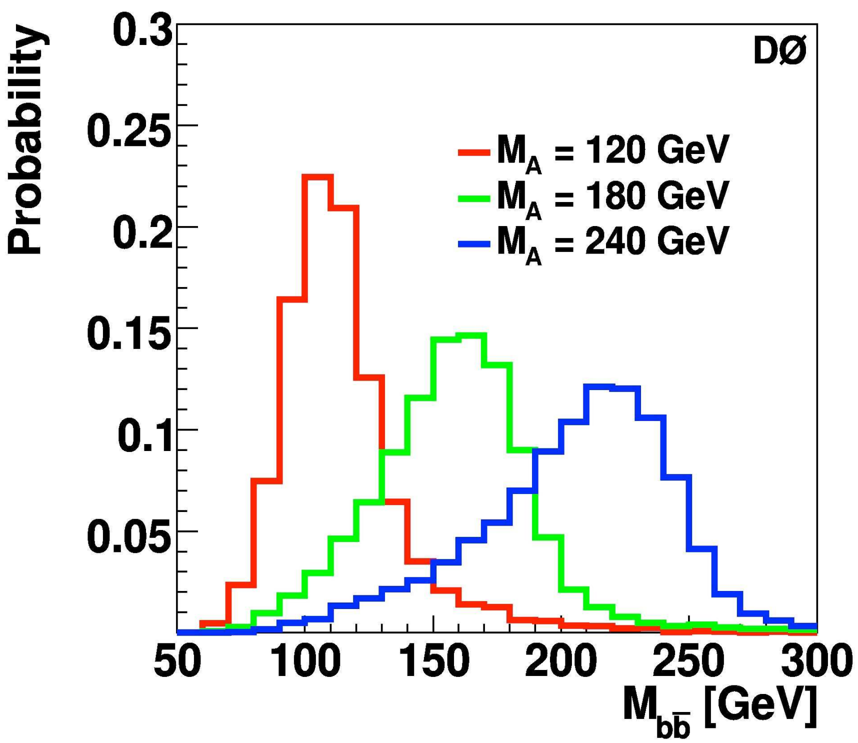
- The bbX events can be separated by third tag mass in x_{tags}
- Two lead jet tag masses separate bbB, bBb from bCb, bQb
- Separation out bbc and bbq by using m_3
- Templates are actually 2D histograms in both m_{12} and x_{tags}
  - Fit itself is also 2D
  - Only show projections for clarity





Signal Shape

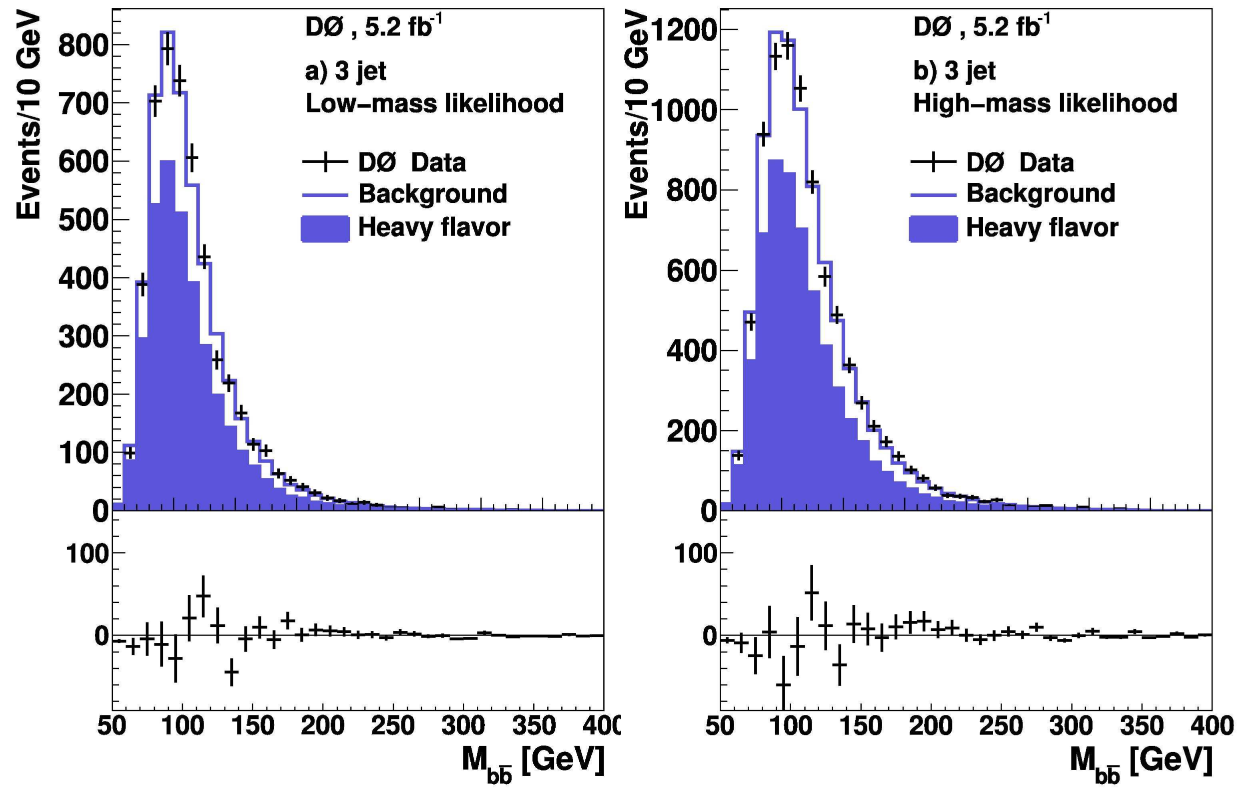


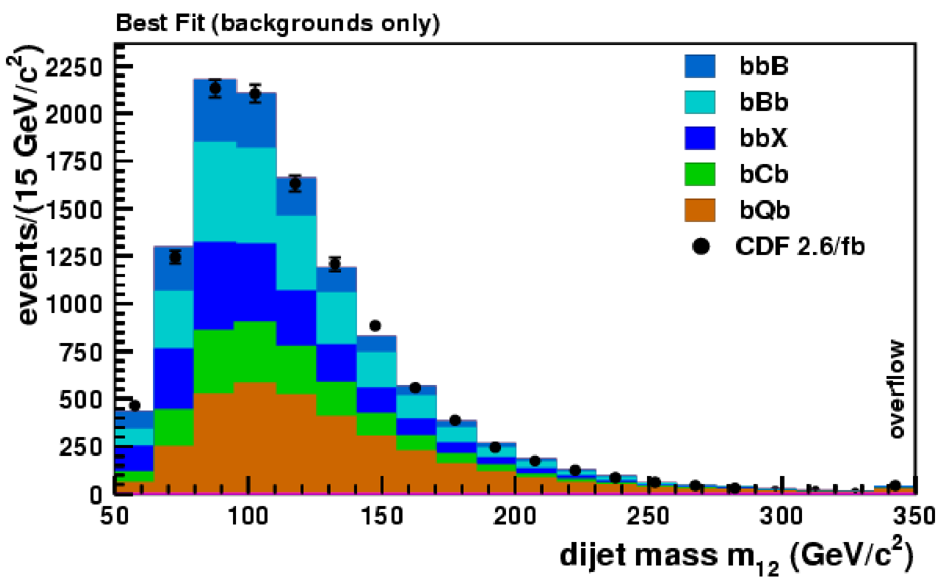


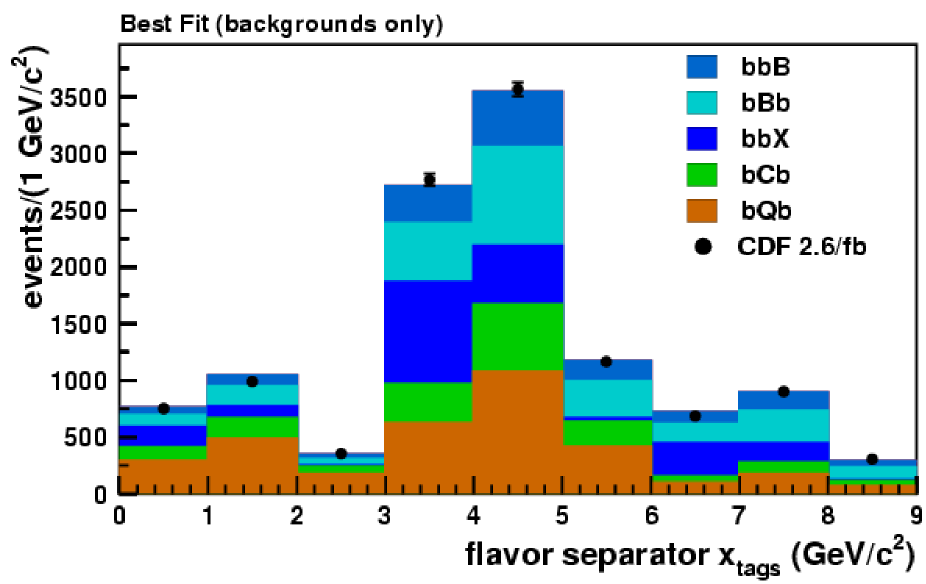
Combined detector acceptance and ID efficiency is about 1 % for both experiments.

The Data

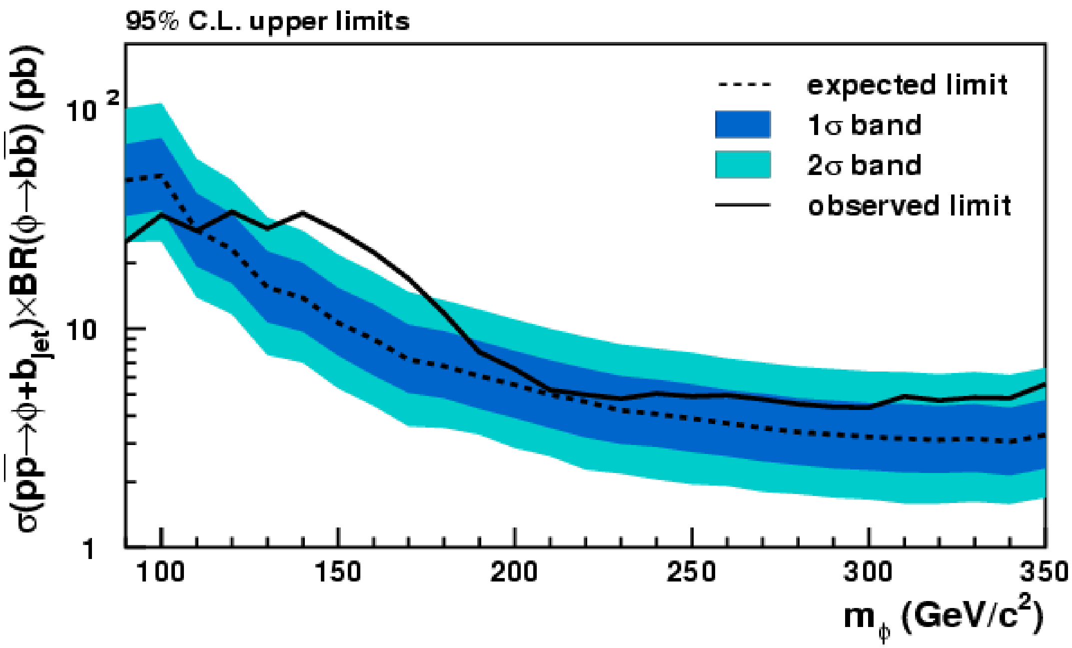
- Generally good agreement between data and background models
- Quantify agreement and set limits using pseudoexperiments

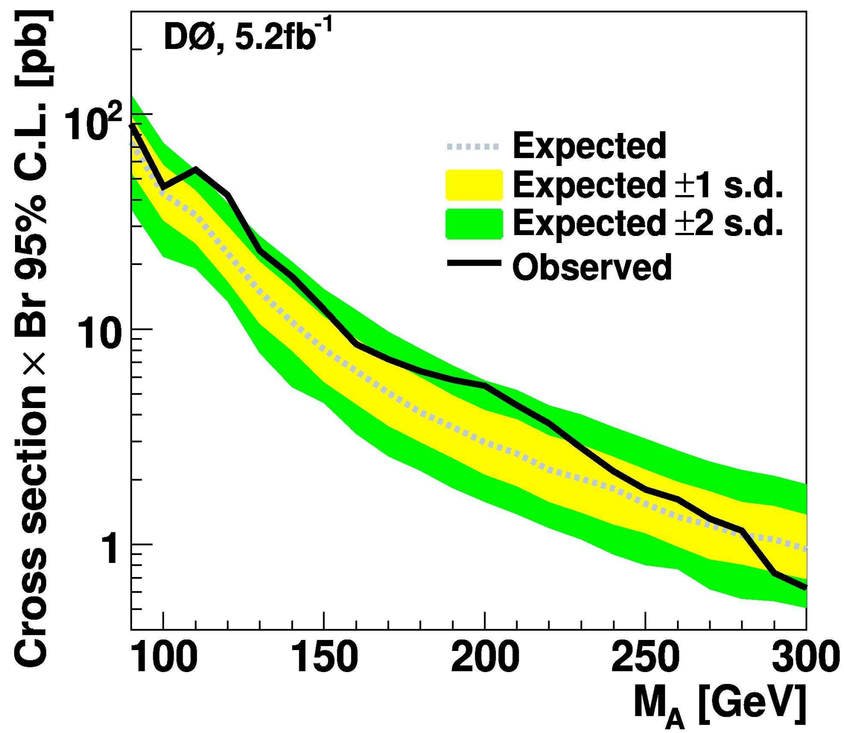






Results





Max deviation from expected at 150 GeV/c^2
Including the trials factor, 1-CL_b = 2.5% (1.9σ)
Corresponds to σ x BR ~ 15 pb

Max deviation from expected at 120 GeV/c^2
Including the trials factor about 2.0σ

Analyses are similar and work is ongoing to combine!

Interpretation

- Previous limits for a resonance much narrower than the experimental resolution!
  - SM Higgs, new scalars, etc

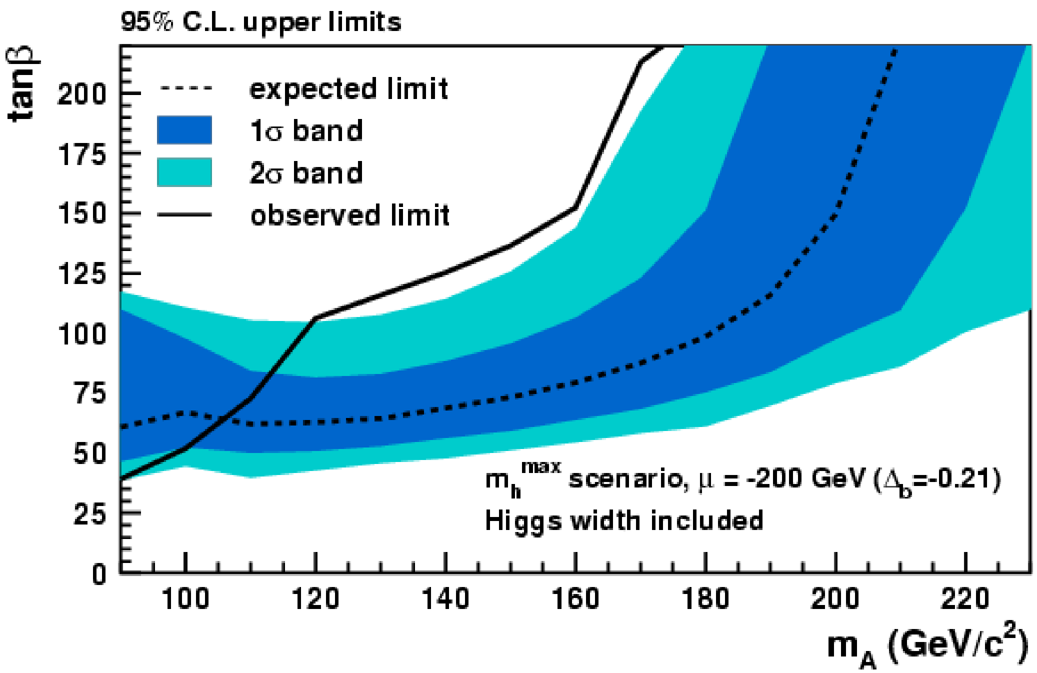
- At tree level,
  σ x BR = $2\sigma_{SM}\tan^2\beta$ x 90%

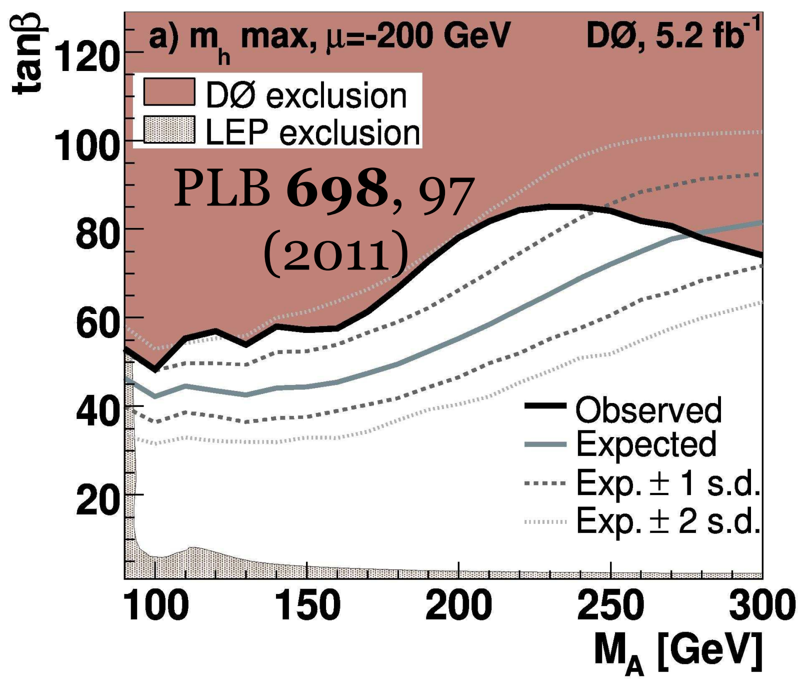
- MSSM Higgs in high-tanβ scenarios not generally narrow

- Higgs properties are largely, but not completely, determined by m_A and tanβ

- Loop corrections introduce dependence on other SUSY parameters
  - M. Carena *et al.*, Eur.Phys.J. C45 (2006) 797-814 (hep-ph/0511023)

MSSM Constraints





High values of tanβ also excluded by di-tau analyses and recent LHC results.

Summary

- CDF updated MSSM Higgs results in the 3b channel
  - Submitted for publication in PRD (arXiv:1106:4782)
- D0 published 3b search in PLB with 5.2 fb^{-1}

  → Effort to combine results in progress.
- No significant excess observed, but some excess evident in both experiments
- Analysis is adaptable to other signal models besides MSSM Higgs

For more information

http://arxiv.org/abs/1106.4782
(Submitted to PRD)

http://arxiv.org/abs/1011.1931
Phys.Lett.B698:97-104,2011