TeV4LHC Higgs Section Summary

Aaron Dominguez

April 30, 2005 CERN

8 Talks from Theorists, D0, CDF, CMS & ATLAS Experiments

- Good list of goals for whole workshop
- This week showed some progress
- A call to action
- Outlook

Program of Work

www-clued0.fnal.gov/~iashvili/TeV4LHC_higgs/higgs.html

First draft of goals for Higgs working group

During the lifetime of the workshop we would like to perform dedicated studied that will allow us to answer the following questions:

- WH, ZH with H->bb: can we use what we have learned at the Tevatron to make these modes more easily accessible at the LHC?
- b-tagging: what have we learned at the Tevatron about tagging b's and rejecting charm and light-quarks and gluons?
- bb invariant mass resolution: how can we use our experience at the Tevatron to improve this at the LHC?
- Associated production of Higgs and ttbar: can we use our experience with top at the Tevatron to optimize this at the LHC?
- Associated production of SUSY Higgs and b's (at large tan beta): what have we learned from the Tevatron searches that can be applied to the LHC?
- Vector-boson fusion: what have we learned about forward jets that can help us tag vector-boson-fusion processes at the LHC?
- Higgs decay to two photons: what have we learned about photons at the Tevatron that can help us at the LHC?
- Higgs decay to WW-> leptons: can the Tevatron search help us optimize this at the LHC?
- Higgs decay to tau's: what have we learned about taus at the Tevatron?
- Advanced analysis techniques - how can our experience at the Tevatron be used for Higgs at the LHC?
- Theory: what calculations can we do to improve our predictions of signals and backgrounds at the Tevatron/LHC, as well as to improve our modeling?
- Are there signals for standard model and non-standard Higgs that we have overlooked?

Higgs Search Results from TeV + Outlook

- Gregorio Bernardi (reporting for both CDF & D0)
- Tevatron running very well now: better than design! D0 & CDF also running well.
- CDF & D0 have Higgs program under way
- Should have significant results by 2007

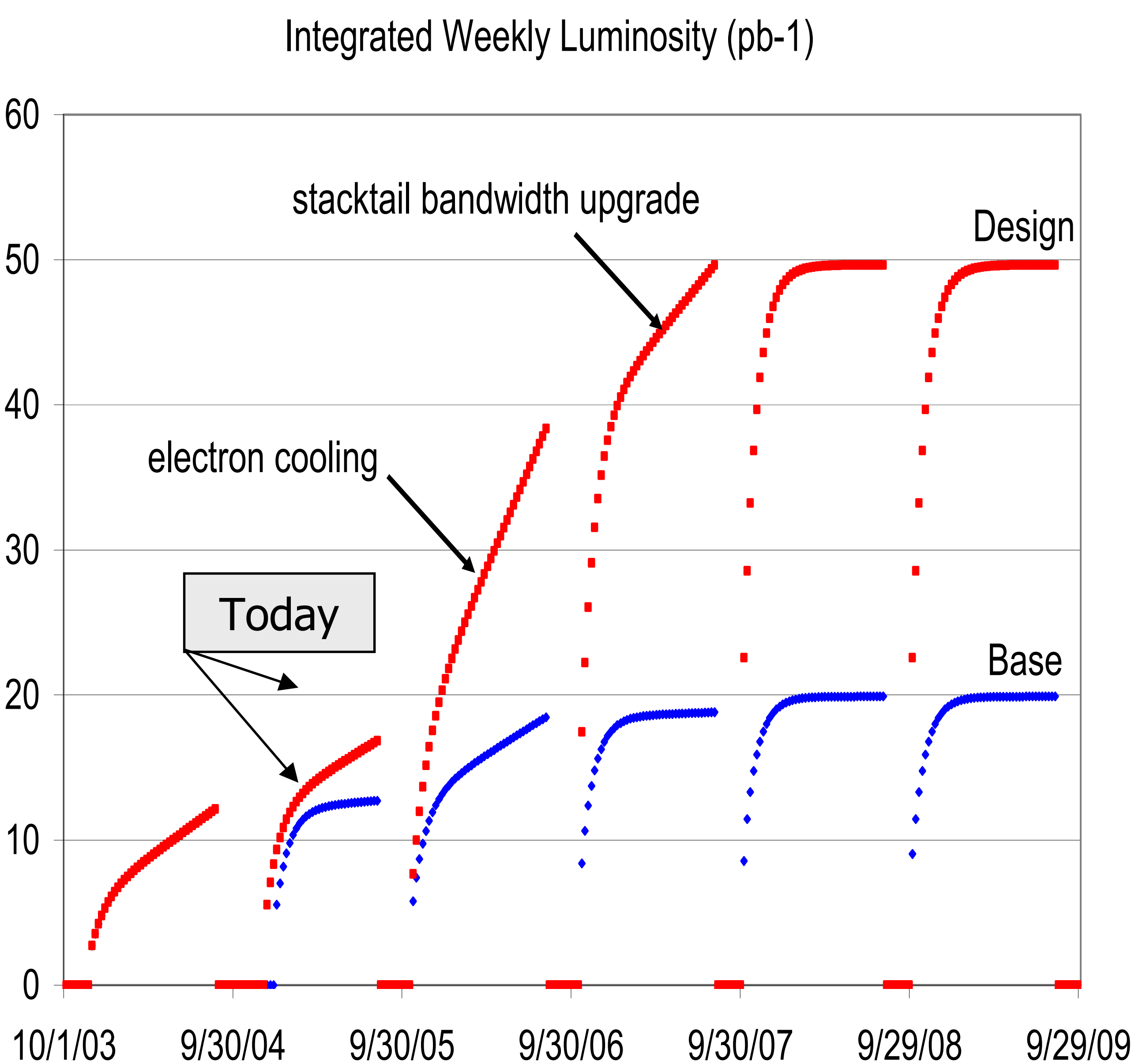
Tevatron Long Term Luminosity Plan

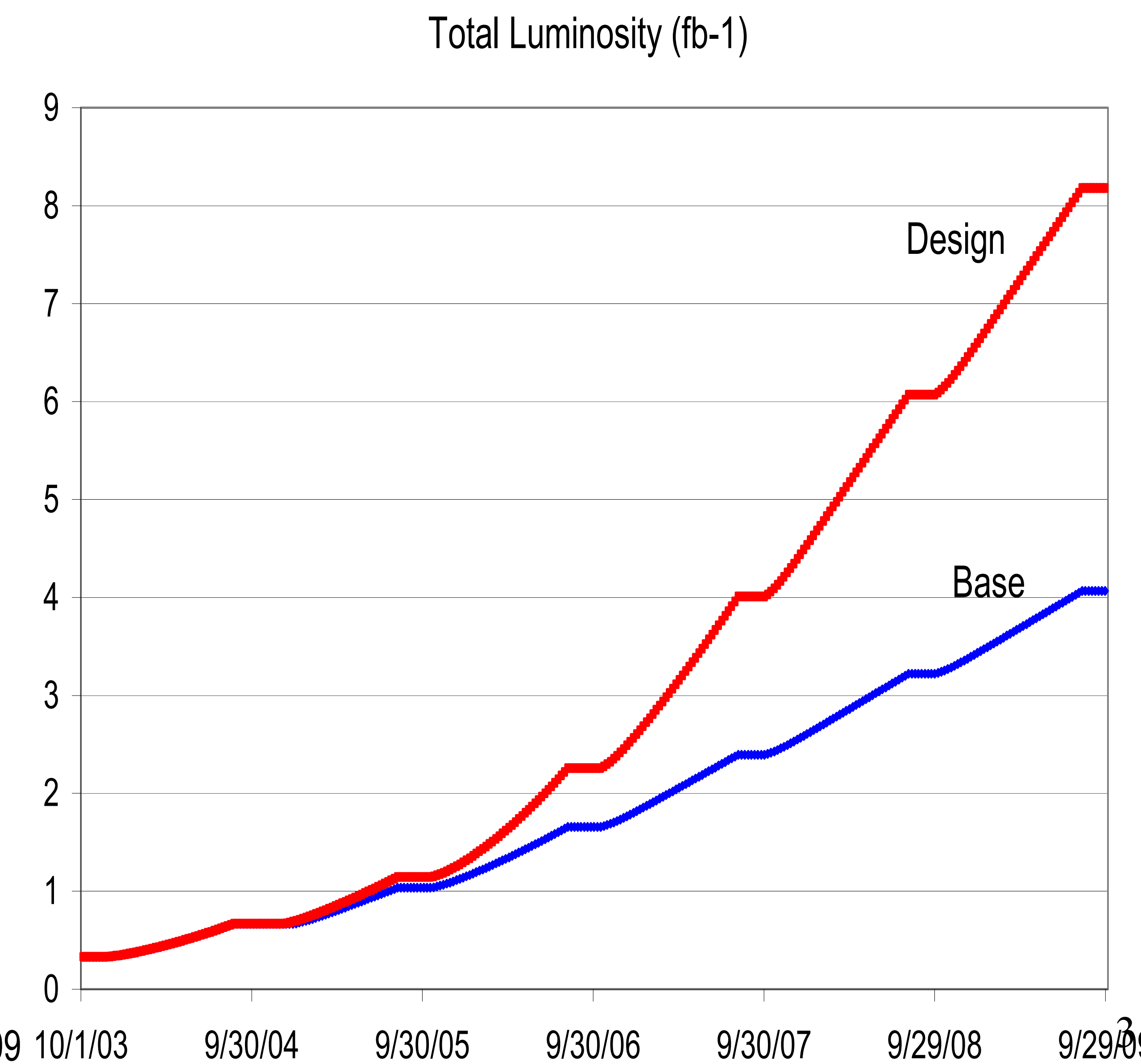
Increase in number of antiprotons
→ key for higher luminosity

Expected peak luminosity
→ $3 \cdot 10^{32}$ $cm^{-2}sec^{-1}$ by 2007

Currently expecting delivered luminosity to each experiment

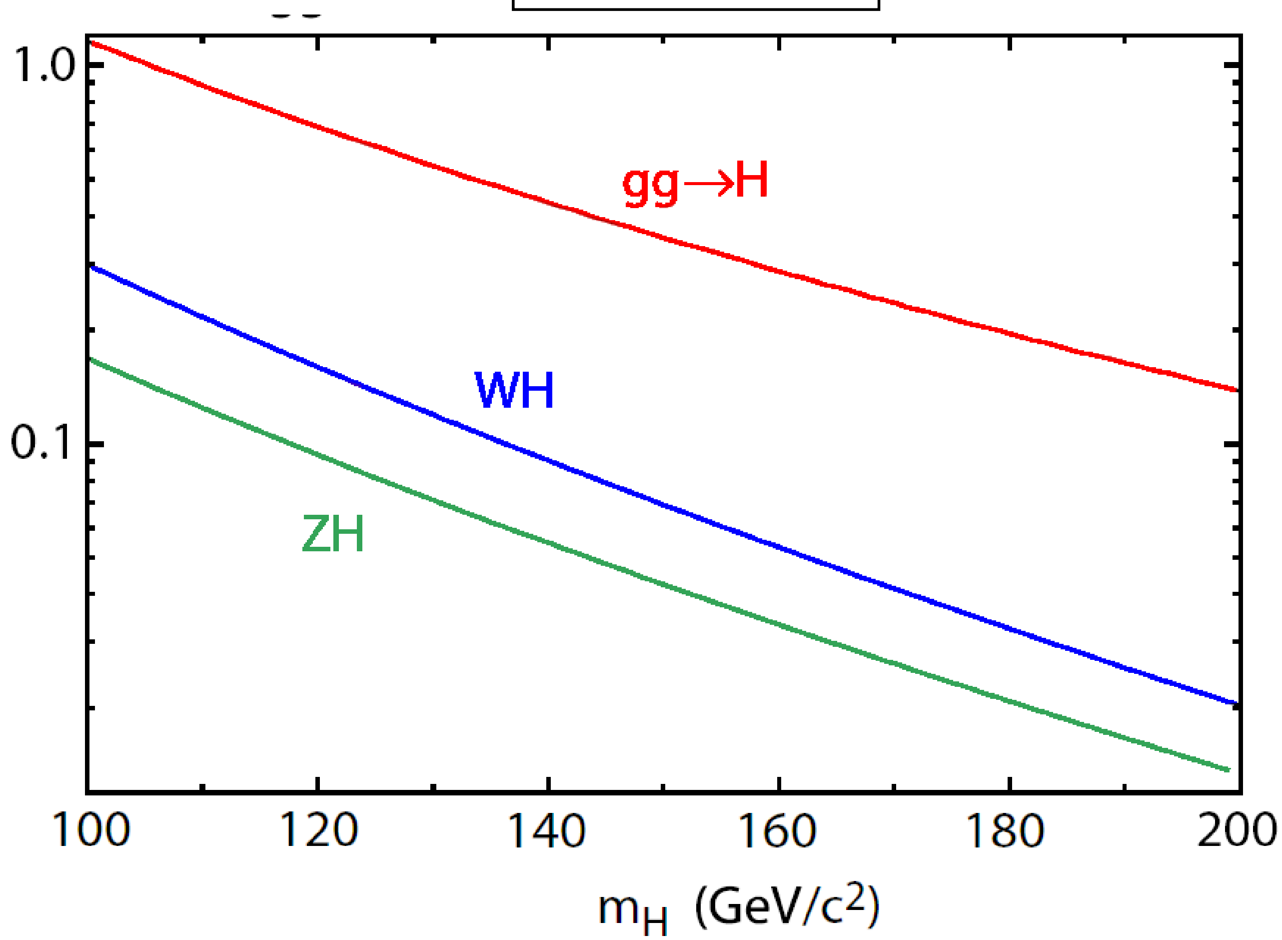
→ 4 - 8 fb^{-1}
by the end of 2009



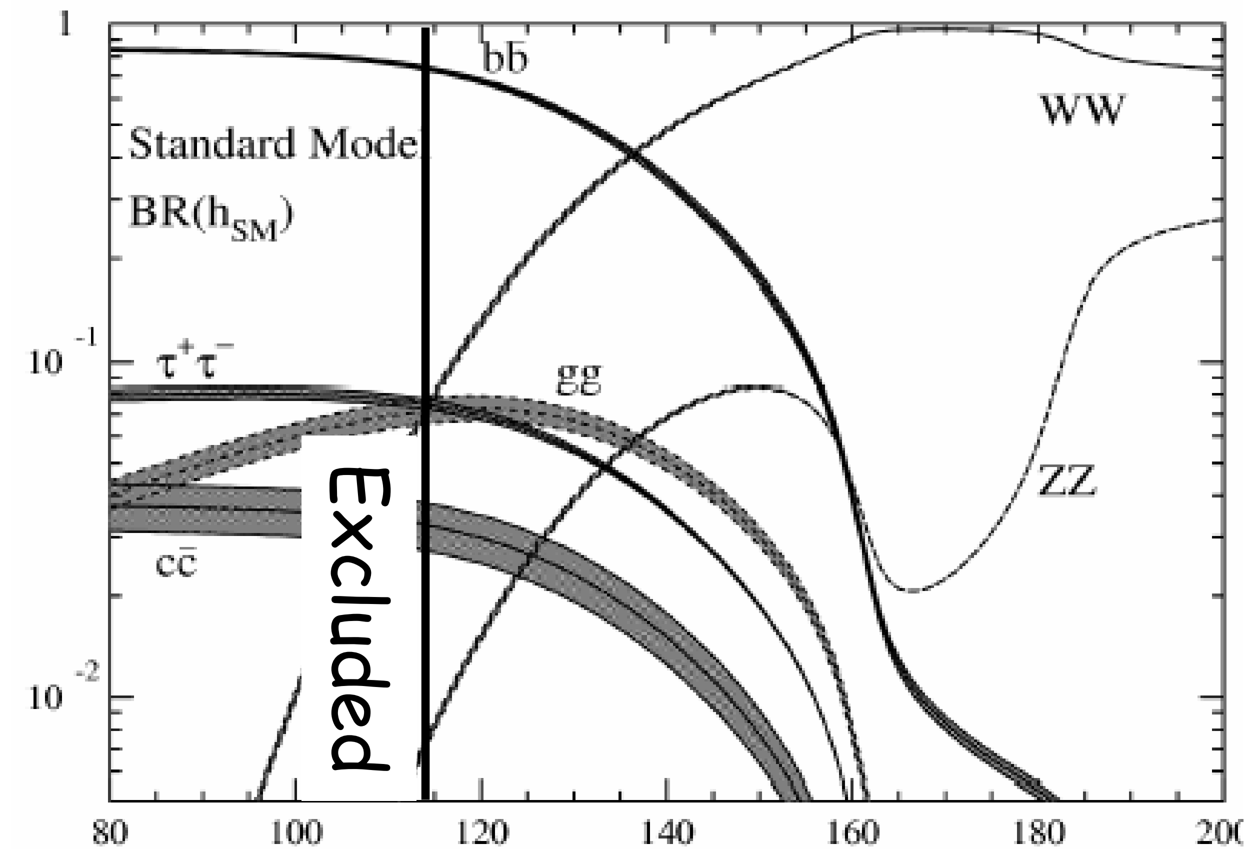


SM Higgs Production and Decays

Production



Decays



Production cross section

→ in the 1.0-0.2 pb range for gg → H

→ in the 0.2-0.03 pb range for associated vector boson production

Dominant Decays

→ $b\bar{b}$ for M_H < 135 GeV

→ WW^* for M_H > 135 GeV

Search strategy:

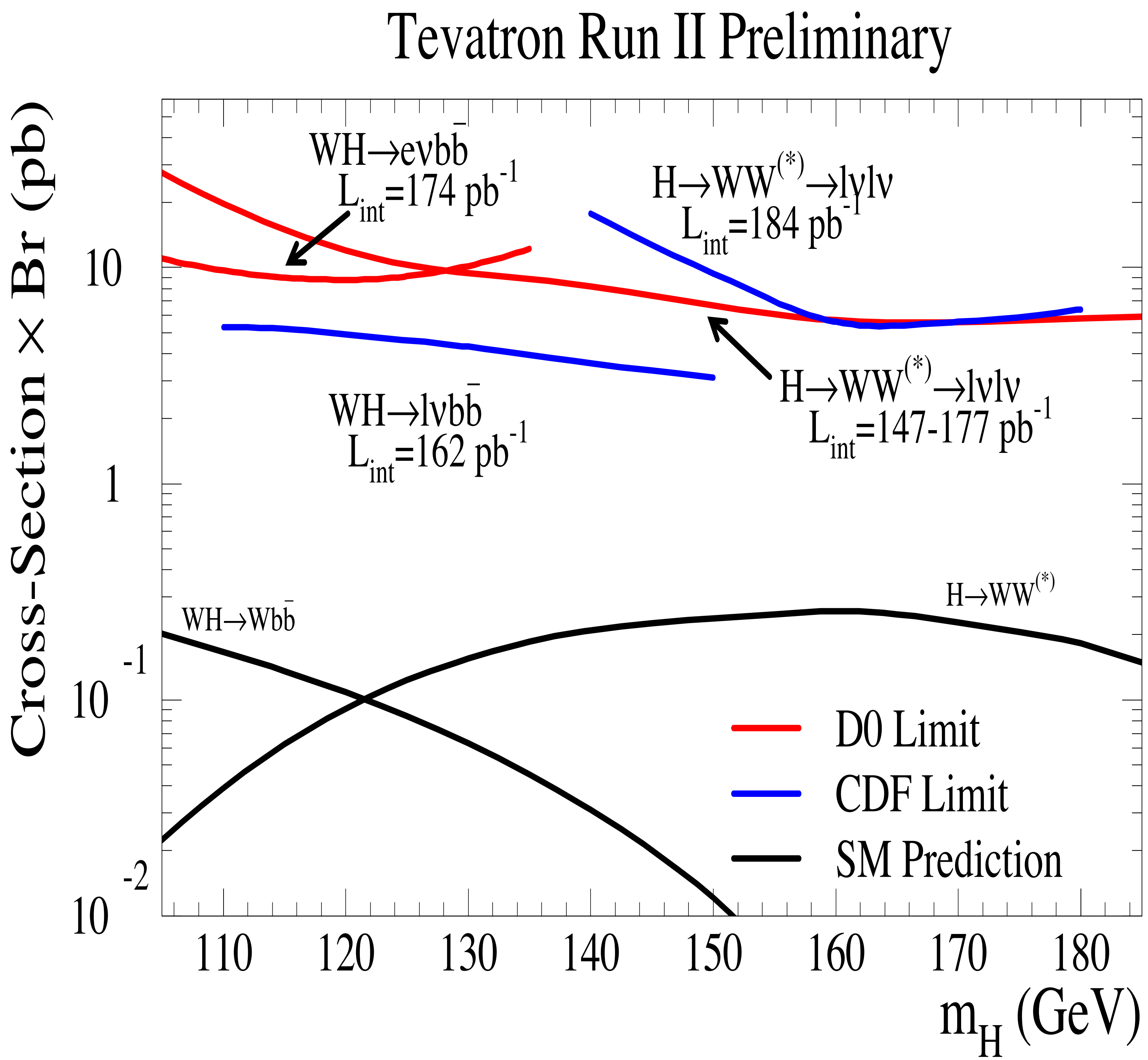
M_H <135 GeV associated production WH and ZH with H→bb decay

Backgrounds: top, Wbb, Zbb…

M_H >135 GeV gg →H production with decay to WW^*

Backgrounds: electroweak WW production…

SM Higgs Status/Prospects



Future improvements:

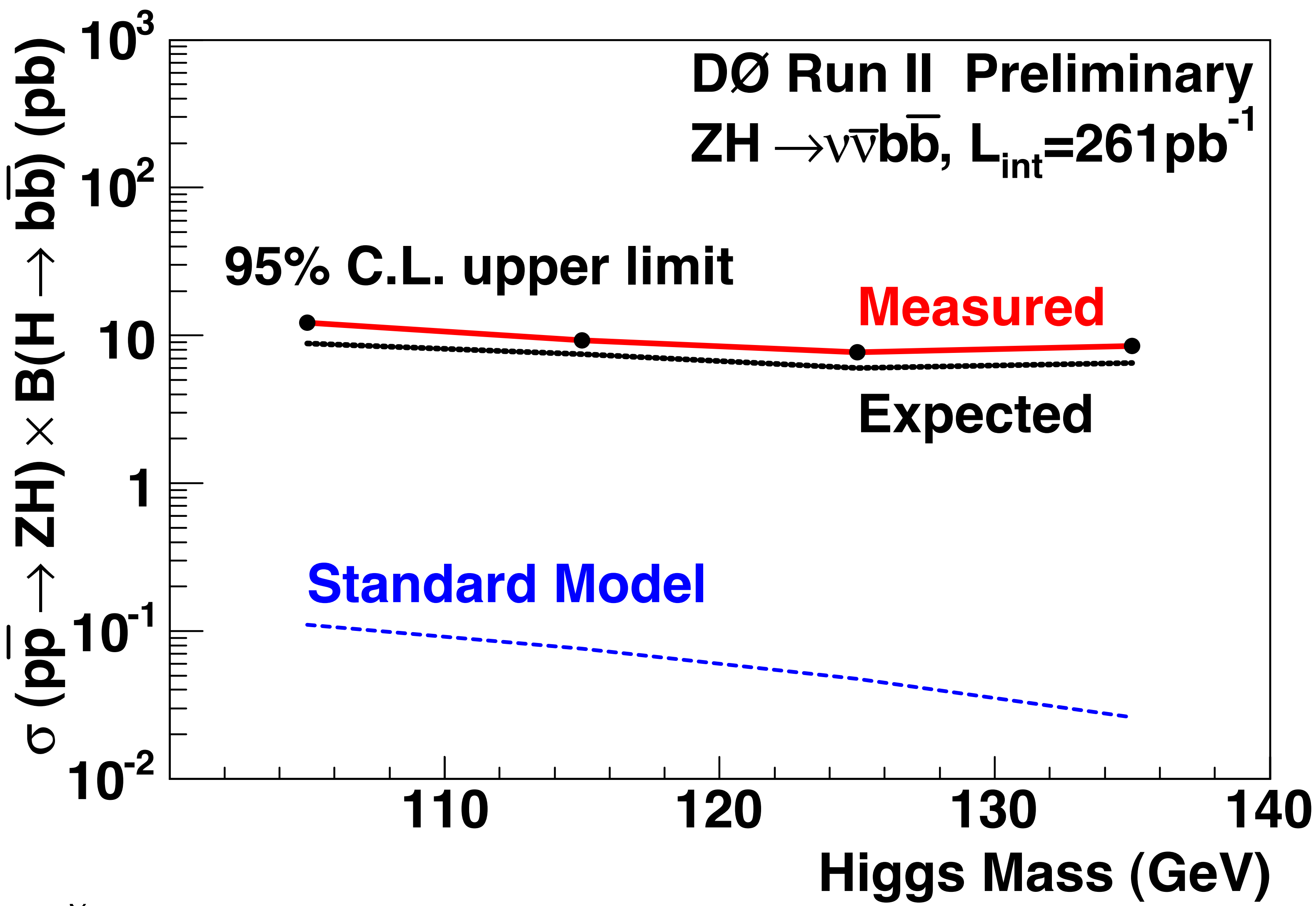
-Extend b-tagging acceptance
- Improve efficiencies
- Use Additional kinematic variables
-Better M_{bb} resolution

Add Zbb channels

First Run II Results for ZH → ννbb (261 pb^{-1})

Mass Window	105GeV [70,120]	115GeV [80,130]	125GeV [90,140]	135GeV [100,150]
Detected Data	4	3	2	2
Acceptance (%)	0.29 ± 0.07	0.33 ± 0.08	0.35 ± 0.09	0.34 ± 0.09
Total BKG	2.75 ± 0.88	2.19 ± 0.72	1.93 ± 0.66	1.71 ± 0.57
Limit @95% C.L.	12.2 pb	9.3pb	7.7 pb	8.5 pb
Expected Limit	8.8 pb	7.5 pb	6.0 pb	6.5 pb

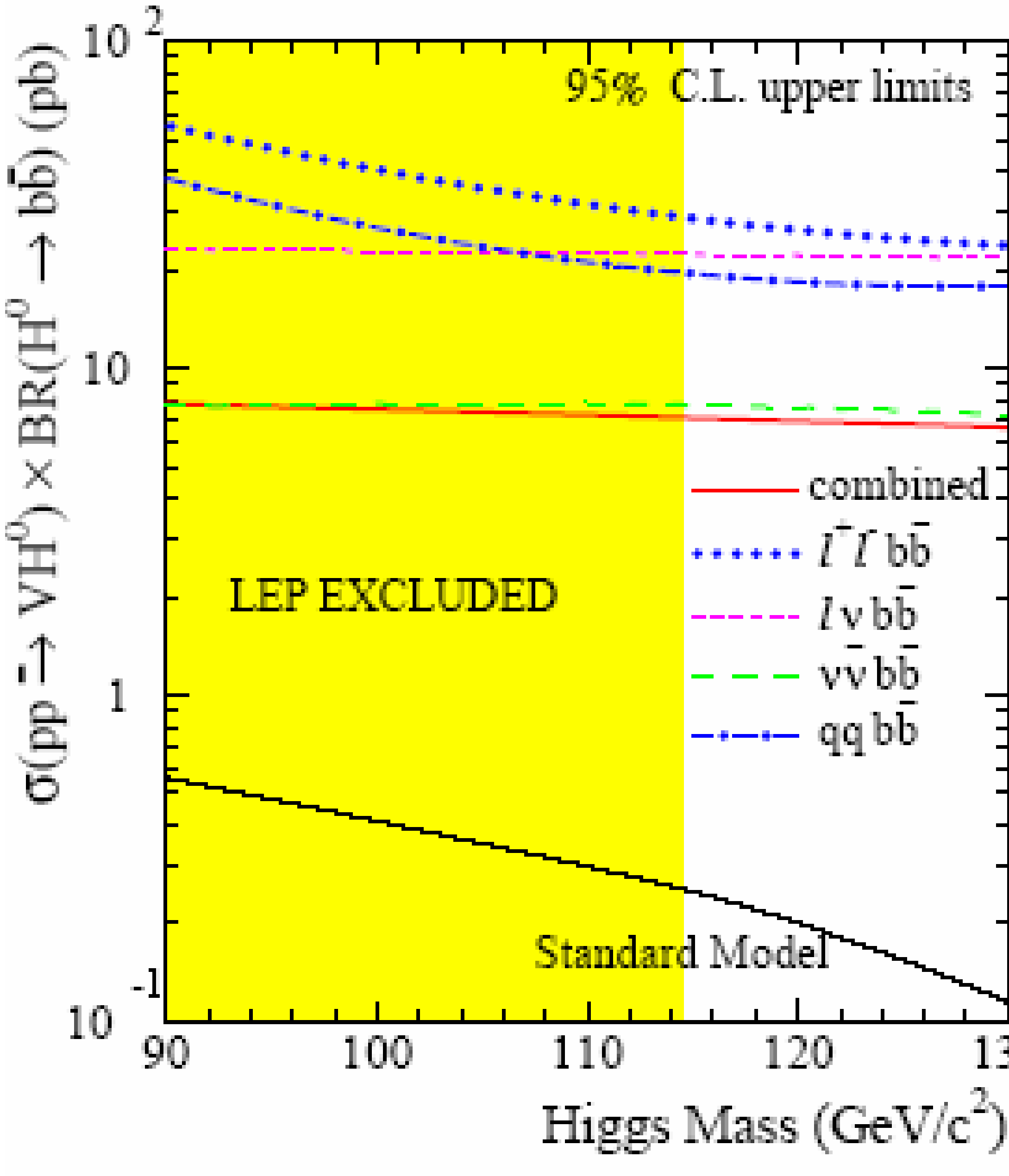
Wjj/Wbb	32%
Zjj/Zbb	31%
Instrumental	16%
Top	15%
WZ/ZZ	6%



Systematic Uncertainty

Source	Sig	Bkg
Jet ID	7%	6%
JES	7%	8%
Jet resolution	5%	3%
b-tagging	22%	25%
Instrumental bkg	-	2%
Bkg Cross Section	-	17%
Total	26%	33%

Run I Combination / Sensitivities



Channel	Measured (expected) upper limits (pb) $M_H = 90$	$M_H = 110$	$M_H = 130$
$\ell^+\ell^- bb$	55.6 (36)	31.8 (24)	23.8 (25)
$\nu\bar{\nu} b\bar{b}$ (ST)	20.8 (30)	20.8 (21)	18.4 (17)
$\nu\bar{\nu} b\bar{b}$ (DT)	10.4 (17)	9.2 (14)	8.0 (12)
$\nu\bar{\nu} b\bar{b}$ (ST+DT)	7.6 (13)	7.8 (11)	7.4 (8.8)
$\ell\nu b\bar{b}$ (ST)	30.0 (18)	29.4 (15)	27.6 (12)
$\ell\nu b\bar{b}$ (DT)	31.0 (24)	26.6 (19)	24.2 (18)
$\ell\nu b\bar{b}$ (ST+DT)	23.2 (13)	22.6 (11)	21.6 (9.0)
$q\bar{q}' b\bar{b}$	38.2 (77)	21.2 (43)	17.8 (29)
All combined	7.8 (7.1)	7.2 (5.7)	6.6 (4.7)

PRL - hep-ex/0503039

Expected "sensitivity" similar for WH and ZH channels (@ m_H=110 GeV → limit of 11 pb for 106 pb^{-1} e+mu, SingleTag+DoubleTag)

Combination of all channels allows to go from 19 pb in a single channel (WH-DT) down to 6 pb

Run II vs Run I: expected limit 12 pb@ D0-RunII for WH-DT instead of 19 pb @CDF-Run I, with equivalent lumi (174 pb^{-1} e-chan. vs. 106 pb^{-1} e+mu-chan.)

- For WH-ST, expected limit 8 pb @ CDF-Run II vs. 15 pb @ CDF-Run I → PROGRESS

Summary

No deviations from SM observed (yet)

Higgs search is in progress:

For the SM Higgs

→Most of the channels (WH, ZH, single/double tag) have already been studied with Run II data → no showstoppers, but we have to keep improving efficiencies.

→ sensitivity (m_H >114 GeV) starts at ~2 fb^{-1} (2007)

→ Expect exclusion or evidence for a low mass Higgs when LHC produces its first results

For non SM Higgs sensitivity could be higher, see A. Haas talk

Expect soon substantial improvements in Higgs hunting with ~0.8 fb^{-1} already on tape

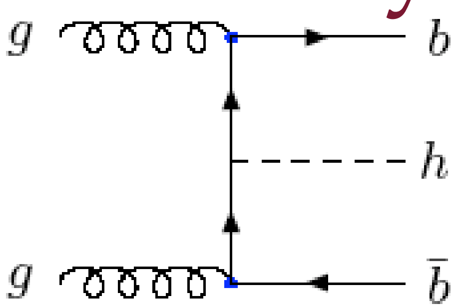
.....and with ~8 fb^{-1} expected in Run II

Inclusive Production of H or Z with bb

- Fabio Maltoni and friends (T. McElmurry and S. Willenbrock)
- Higgs production in association with heavy flavor is important production mode for TeV and LHC, especially in MSSM
- Replace H with Z and measure this to get handle on Higgs production & background

Higgs production with bottom quarks

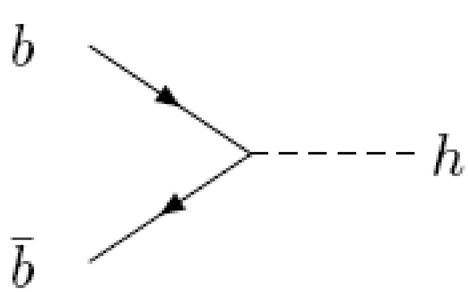
One way:



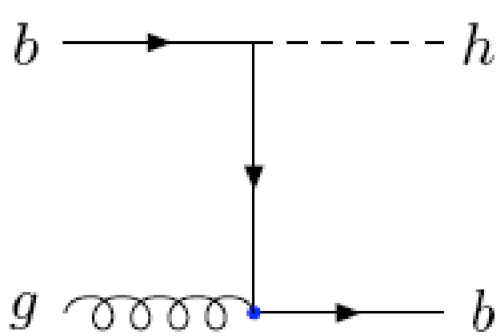
Keep the b massive and use the gg process for all three studies. The b mass acts as an infrared cutoff and there are no divergences. This is the 4 Flavor Scheme (4FS)

or the other:

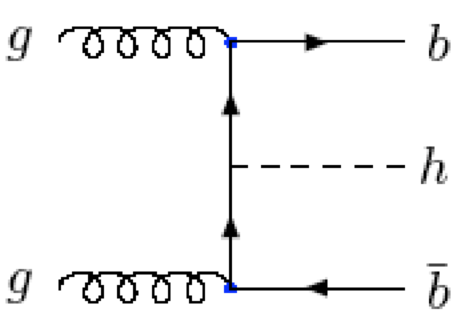
The "leading-order process" depends on how INCLUSIVE is the measurement to be performed:



FULLY INCLUSIVE



1 b at high p_T



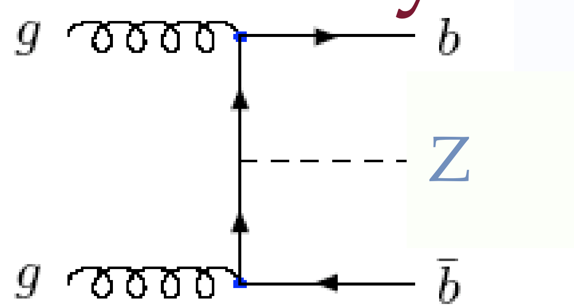
2 b's at high p_T

In so doing the large logs $\alpha_S \ln\left(\frac{m_h^2}{m_b^2}\right)$ are resummed into the b distribution function $b(x, m_h^2)$

This is the 5 flavor scheme.

Z production with bottom quarks

One way:



Keep the b massive and use the gg process for all three studies. The b mass acts as an infrared cutoff and there are no divergences. This is the 4 Flavor Scheme (4FS)

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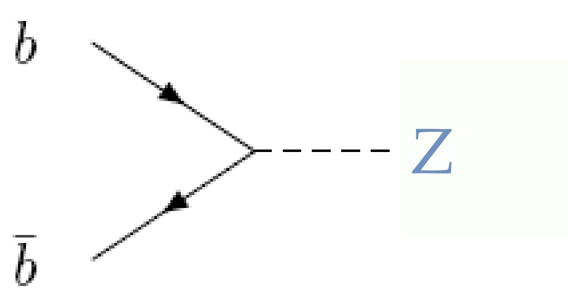

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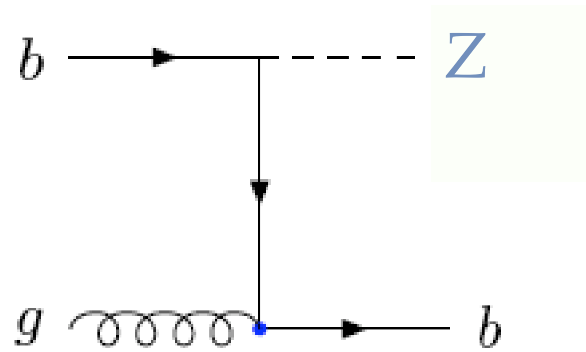
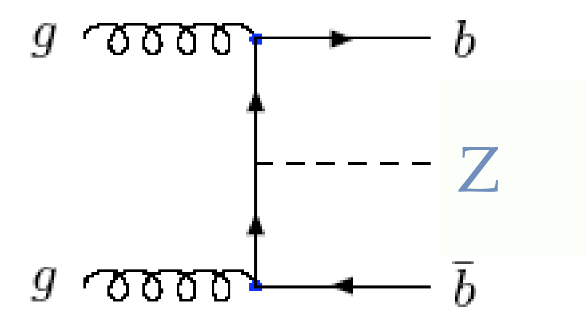
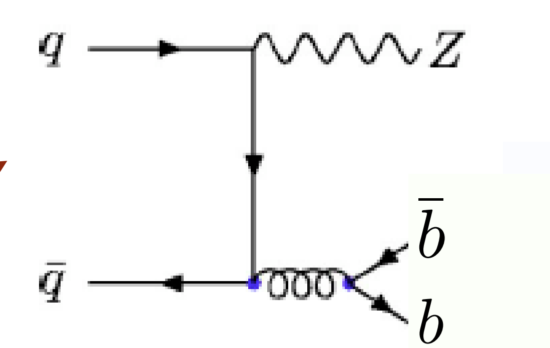


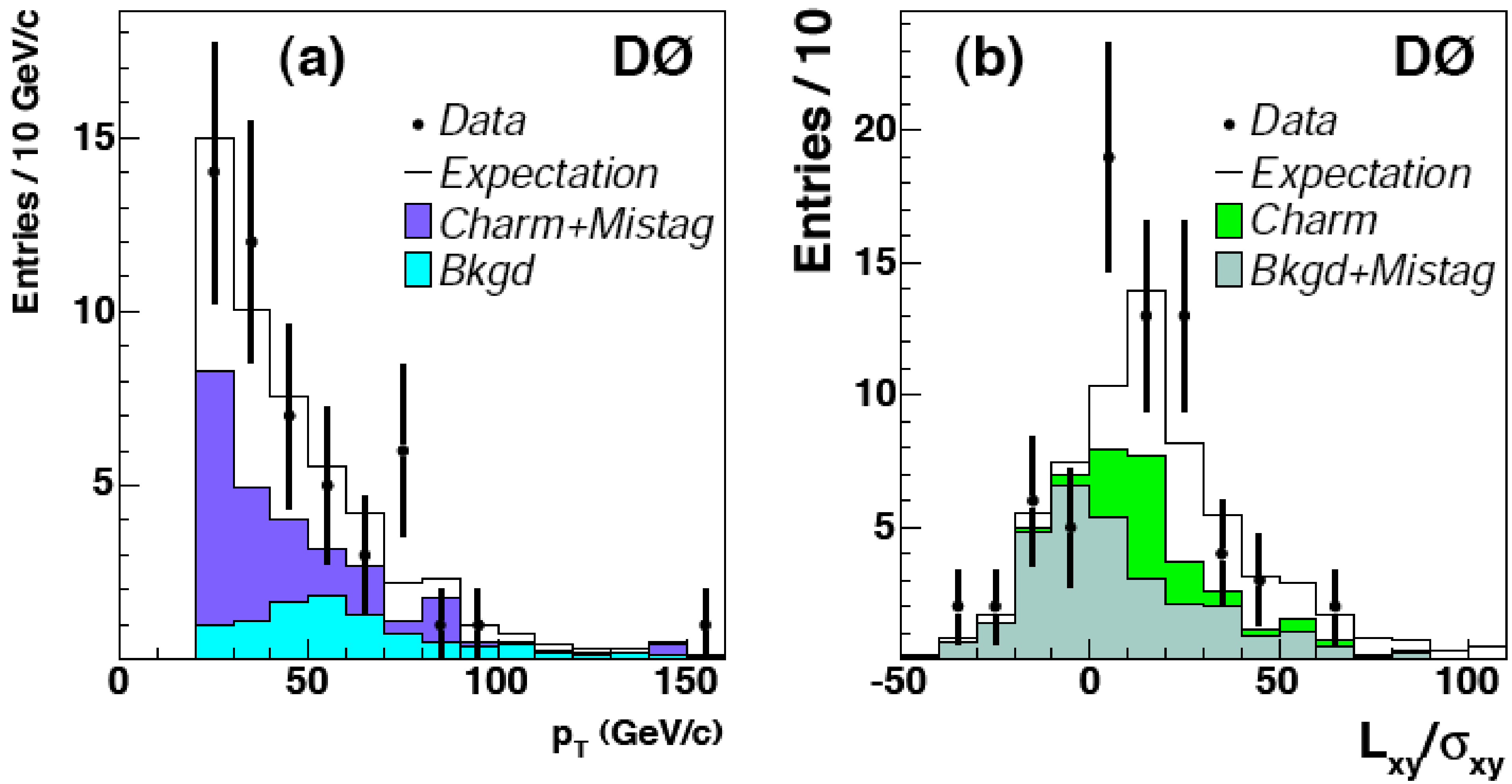
1 b at high p_T





further complication

Z+1 b-jet: Tevatron



(Dated: February 10, 2005)

Using the data collected with the DØ detector at $\sqrt{s} = 1.96$ TeV, for integrated luminosities of about 180 pb^{-1}, we have measured the ratio of inclusive cross sections for $p\bar{p} \to Z + b$ jet to $p\bar{p} \to Z$+jet production. The inclusive $Z + b$-jet reaction is an important background to searches for the Higgs boson in associated ZH production at the Fermilab Tevatron collider. Our measurement is the first of its kind, and relies on the $Z \to e^+e^-$ and $Z \to \mu^+\mu^-$ modes. The combined measurement of the ratio yields 0.021 ± 0.005 for hadronic jets with transverse momenta $p_T > 20$ GeV/c and pseudorapidities $|\eta| < 2.5$, consistent with next-to-leading order predictions of the standard model.

TEV4LHC PROJECT

Study heavy quark fractions in Z inclusive production

Why ?

theory: we can predict cross sections extremely well.

experiment: alternative approach, better sensitivity?

How ?

theory: NNLO calculation for Z(QQ) is now available.

experiment: look at what CMS has done, compare with MC's (Pythia, Herwig, SHERPA w/ CKKW), study feasibility at CDF and D0.

$\mathrm{Z} \rightarrow \mathrm{b\bar{b}}$ at CDF

- Julien Donini (CDF)
- We want to use dijets of b to measure Higgs mass, but jet energy is complicated with presence of heavy flavor
- Need dijets of b with known mass to calibrate, hence $\mathrm{Z} \rightarrow \mathrm{b\bar{b}}$
- But very difficult to measure at TeV/LHC

Z→bb Specific Trigger

SVT based Trigger

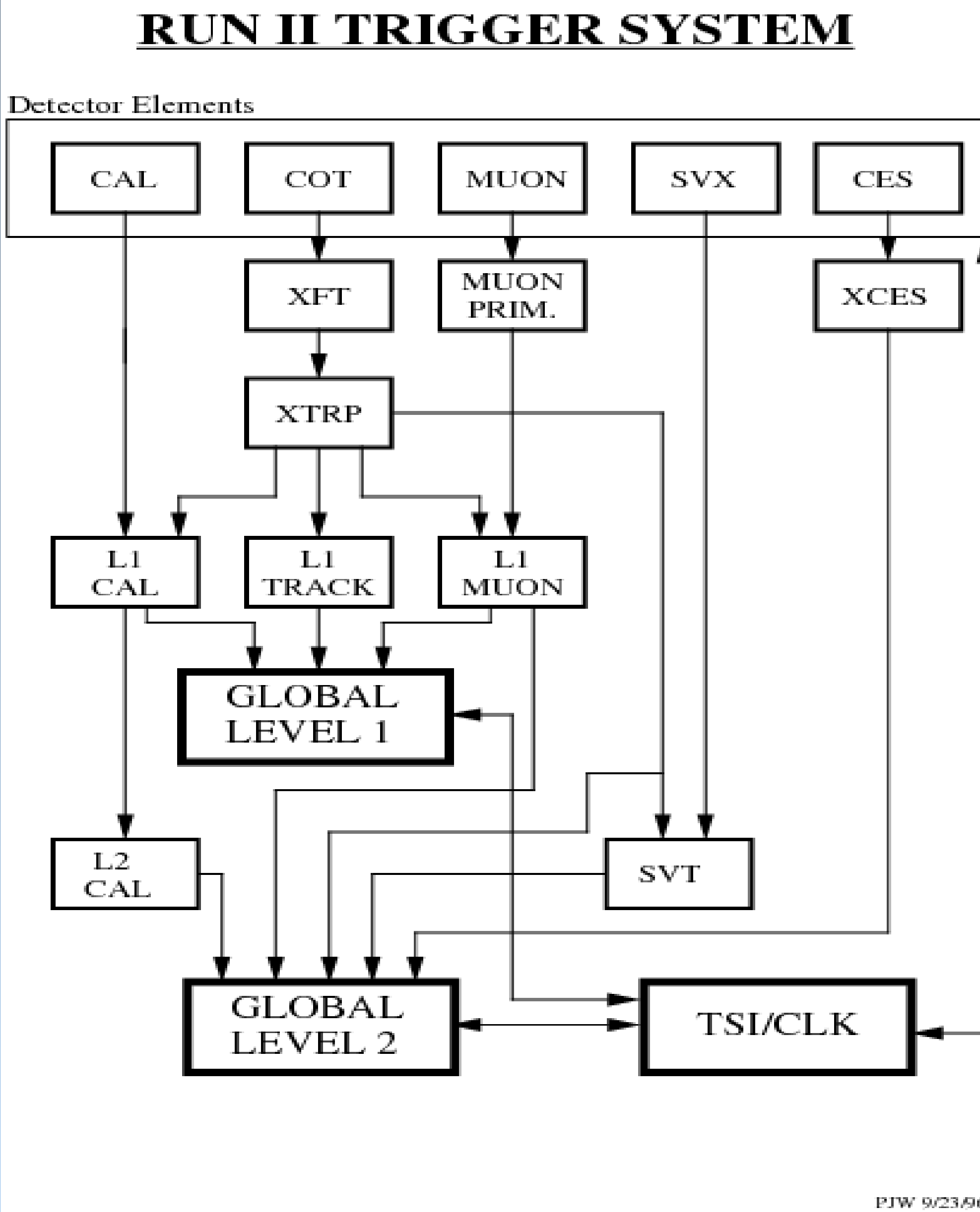
❑ Information given by the internal **trackers** (SVX and COT) are used at the **Level 2** of CDF trigger system to select events with **high impact parameter (d_0) tracks.**

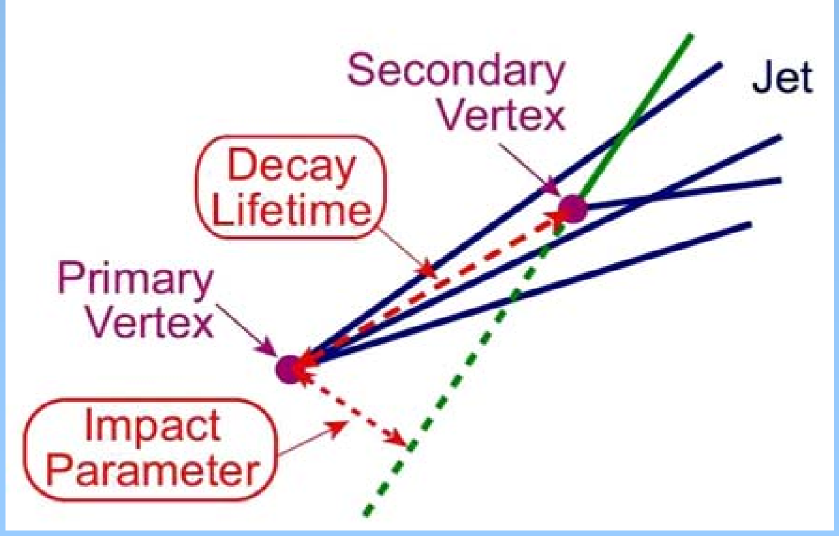
❑ This relies on the **SVT hardware** device which is able to measure P_t and impact parameter (to within 50 μm) of **charged tracks** in less than 20 μs. SVT has proven crucial for most of CDF II's B physics program

Z → bb trigger selects events with

- **Two displaced tracks:**
  - $d_0 > 160$ μm, $P_t > 2$ GeV
- **Two $E_t > 10$ GeV jets**

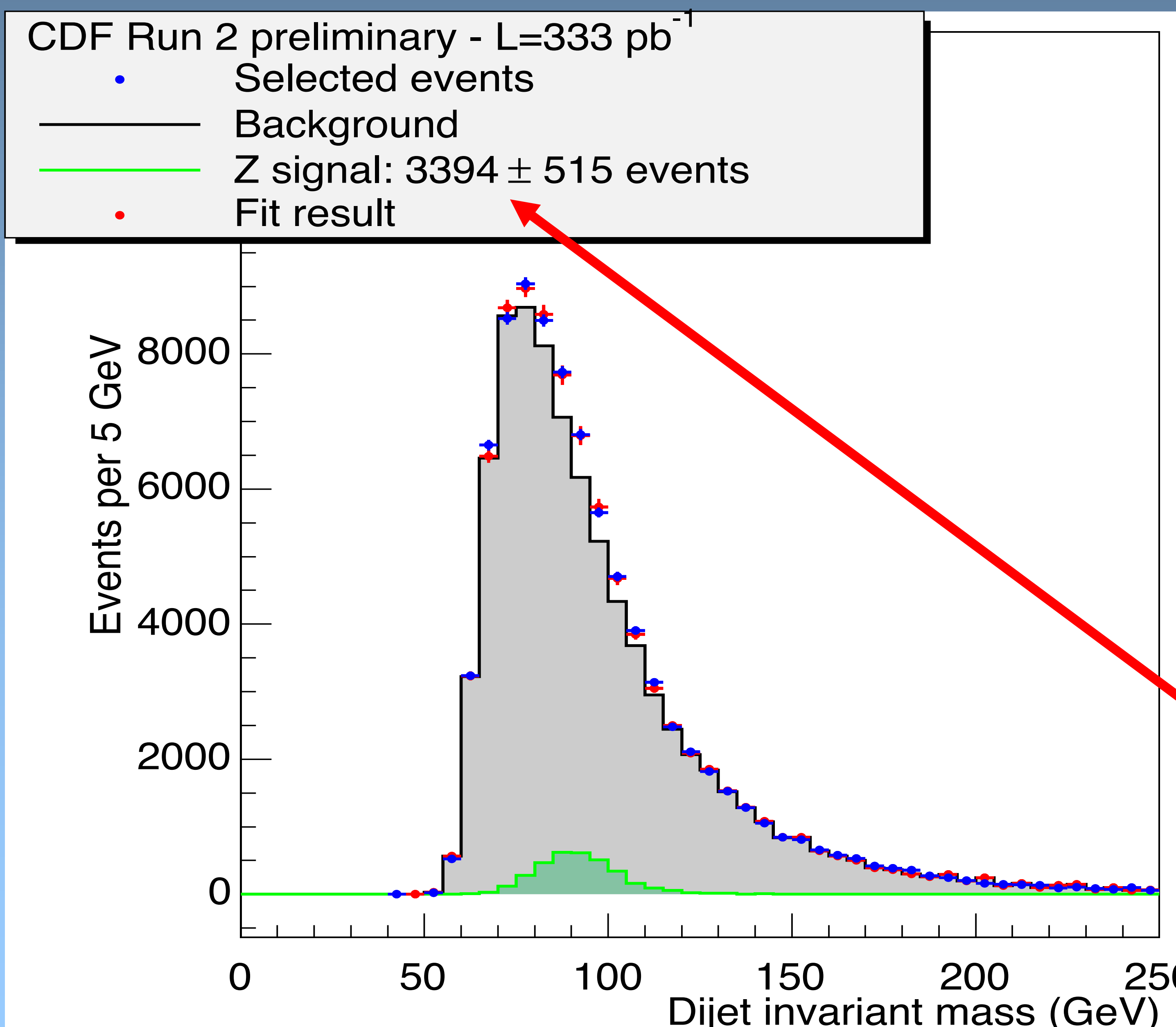
Efficiency on Z → bb is 4-5 %, but better than lepton trigger (<1%) which are biasing the jet E_t measurement.

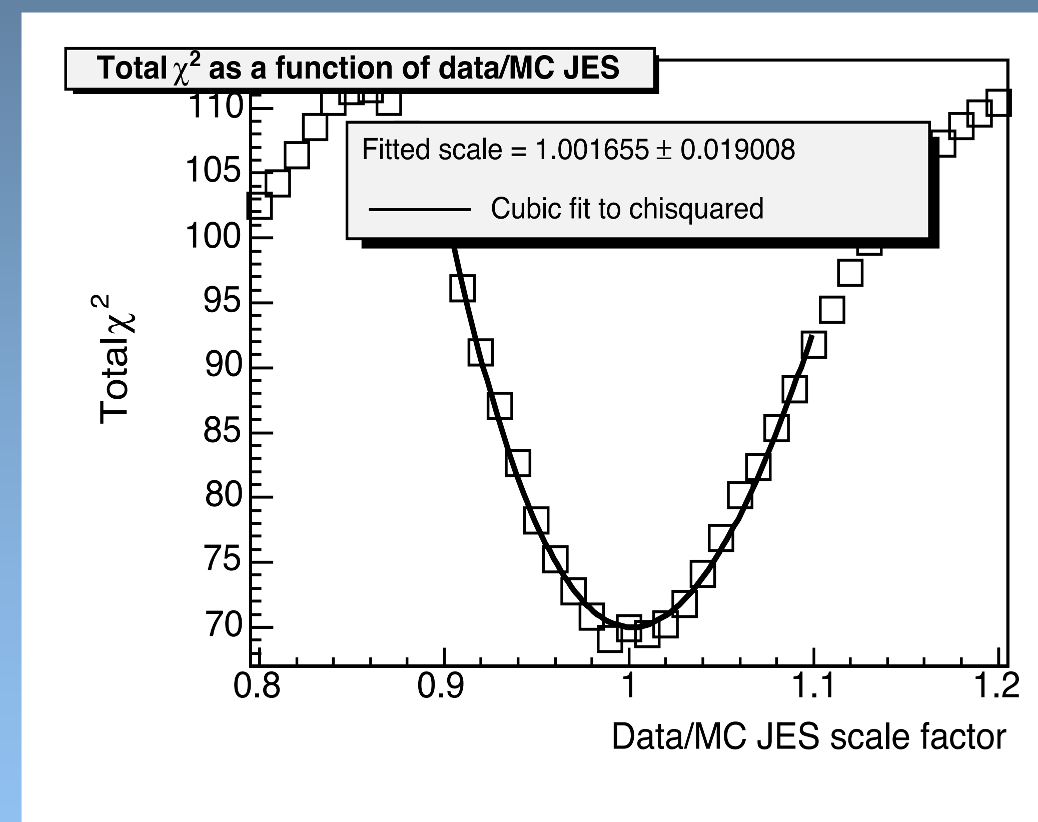




Fit and Data/MC Jet Energy Scale Factor

- We create **$Z \to bb$ signal templates with varying data/MC JES factors**
- We can then **fit the tagged data** to the sum of **background and signal templates**, for varying JES.
- The fit converges nicely and gives the JES and the **number of reconstructed Z's**





Among 85,720 events selected ($L=333pb^{-1}$) CDF finds

3400 ± 500 év. $Z \to bb$ decays

Conclusion

We showed that a significant Z signal could be extracted from CDF Run II data … and next ?

❖ **Improve the background shape model** to extract the best possible $Z \rightarrow bb$ signal.

❖ With enough statistics we will then be able to **constraint the b-jet energy scale**. With a 10 000 Z signal we should be able to determine the b-jet scale to within 1%.

❖ Such a signal will also allow us to **perform detailed studies of resolution optimization algorithms**

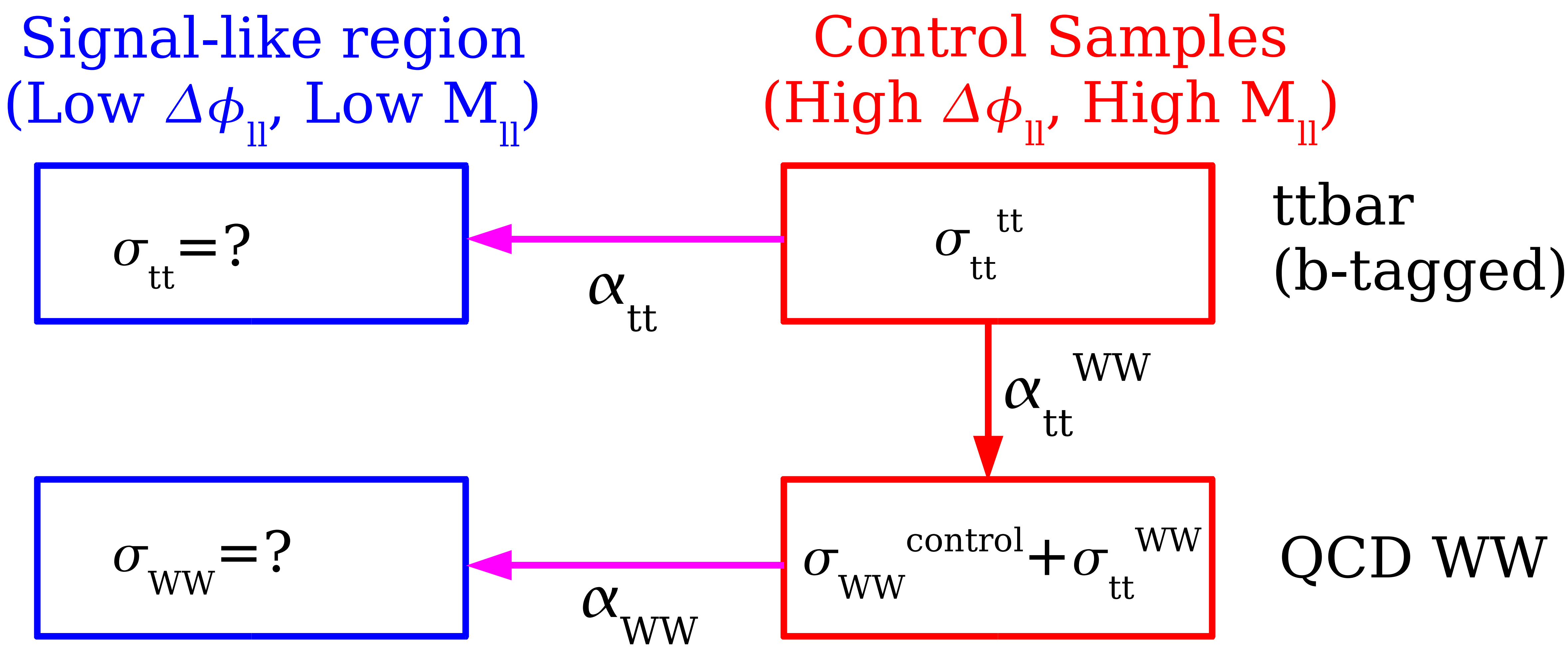
- for instance jet resolution algorithms, used for the $h \rightarrow bb$, that **combine tracks and calorimeter towers** *(H1 algorithm)* will be studied on the Z bbar dataset.

... More on this at the next TeV4LHC !

$\mathrm{H} \rightarrow \mathrm{W}^+\mathrm{W}^- \rightarrow \ell^+\ell^-\nu\bar{\nu}$ at ATLAS

- Bill Quayle (B. Mellado & Sau Lan Wu)
- Important channel for large range of m_{H}
- Introduced new discovery channel (+1j)
- Improved +0j channel
- Using TeV-style control regions
- Making good effort to be ready for ATLAS data coming from a real detector

Control Samples(2)



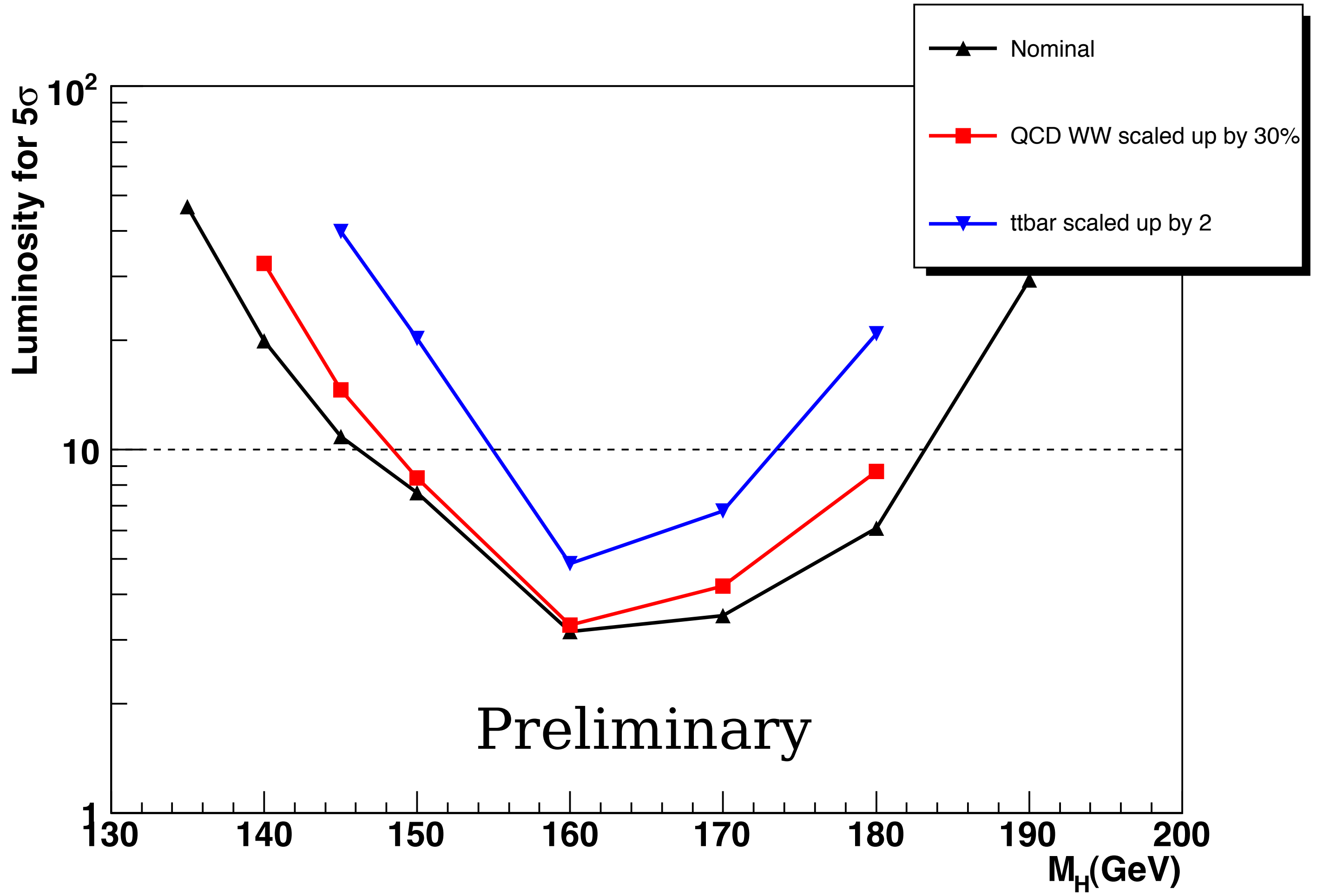
- **Define:**
  - α_{WW}=(QCD WW bg)/(QCD WW in control samp.)
  - α_{tt}=(tt bg)/(ttbar in tt control sample)
  - α_{tt}^{WW}=(tt in WW sample)/(tt in tt sample)

Results for WW+1j

Sample	ggH	VBF	ttbar	EW WW	QCD WW	Z+x
signal-like	26.91	3.82	8.97	0.24	24.57	9.51
WW control	1.52	0.09	51.1	1.49	51.8	17.55
tt control	0.63	0.08	70	0.03	1.91	9.09

Cross-sections (in fb) for M_H=160 GeV

Luminosity Plot for WW+1j



- WW+1j is a discovery channel, but off-shell effects in top backgrounds (which will lead to an increase in this background) may be important

Summary

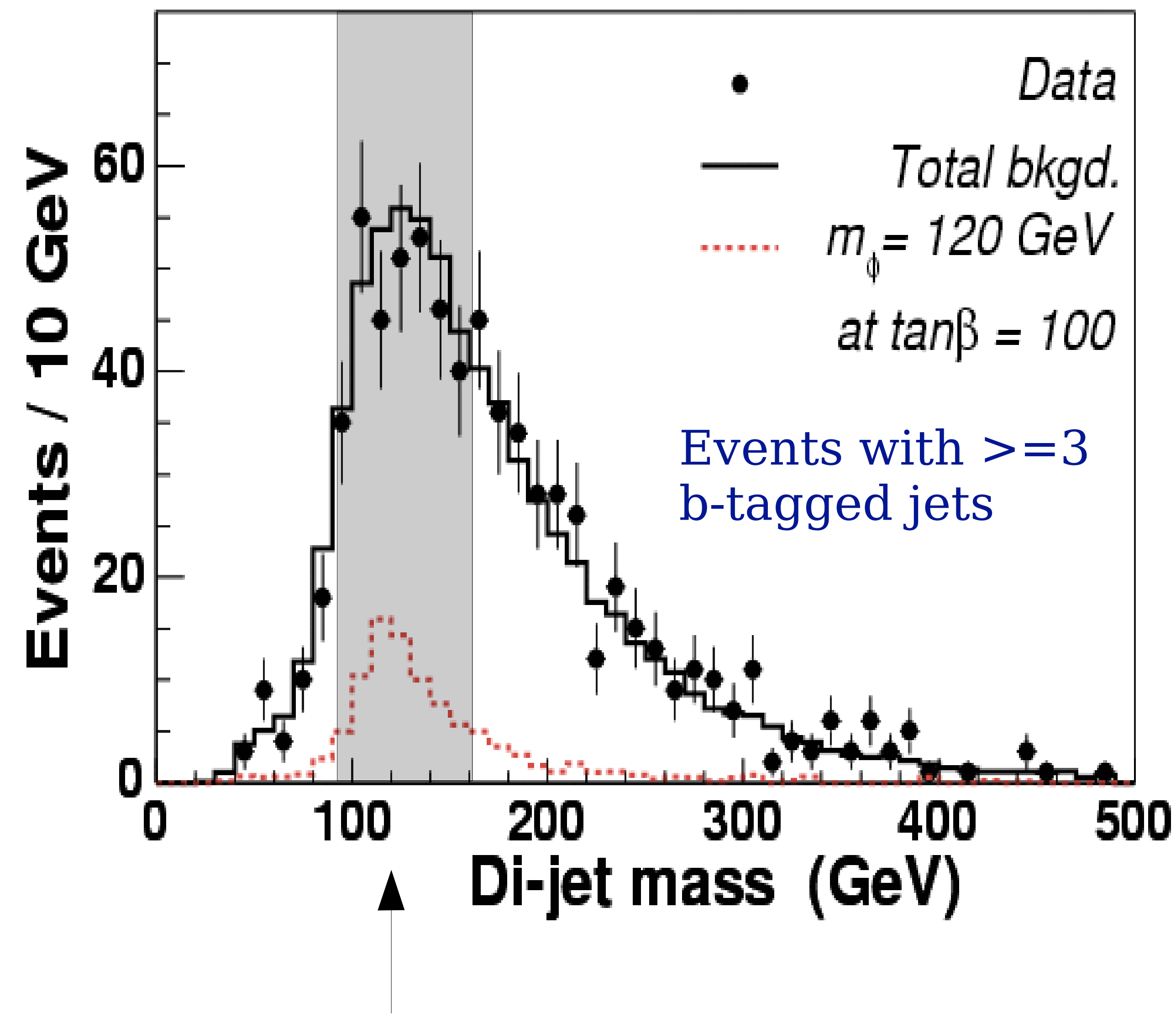
- We have introduced a new discovery channel: H+1j with H→WW→lνlν
  - s/b is close to 0.7 at M_H=160 GeV; compare to WW+0j (s/b~0.5) and WW+2j (s/b>~2)
- We have defined control samples and demonstrated signal extraction in the H+0j and H+1j with H→WW→lνlν channels
- Some important questions remain:
  - Higher order corrections to WW background
  - Off-shell effects in top background
  - Can we construct control samples to validate the extrapolation coefficients we're currently taking from Monte Carlo?
  - Experimental systematics (e.g. b-tagging uncert.)

MSSM Higgs Search at D0: Results & Outlook

- Andy Haas
- First RunII result of direct MSSM Higgs search. Sensitive to large tanβ due to enhanced bb-Higgs coupling
- Major progress on theoretical understanding of production mode this last year makes sensible experimental now results possible
- Still some 4f/5f concordance questions, but mostly solved

Analysis Method

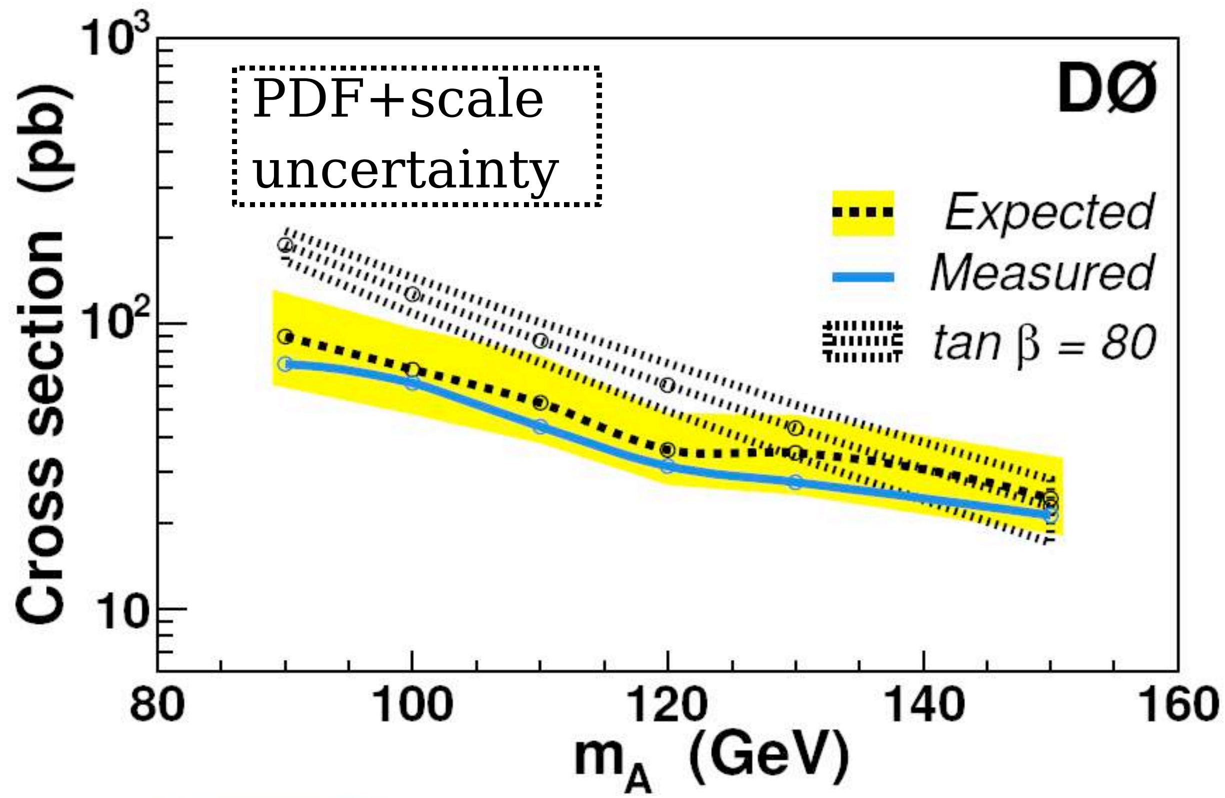
- Signal:
  - 3 or more b-tagged jets
  - Invariant mass of leading jets is peaked at m_A
- Backgrounds:
  - Determined from data!
    - Shape estimated from the double b-tagged data sample (taking into account the kinematic bias from requiring a 3rd b-tag)
    - Normalized outside the "signal region"
  - Also modeled in MC as a cross-check
    - "fakes": all light-quark/gluon jets (measured from data)
    - "heavy flavor": (ALPGEN) bbj(j), ccj(j), bbcc, cccc, bbbb
    - "other": tt, Z(→bb)+jets (Pythia)

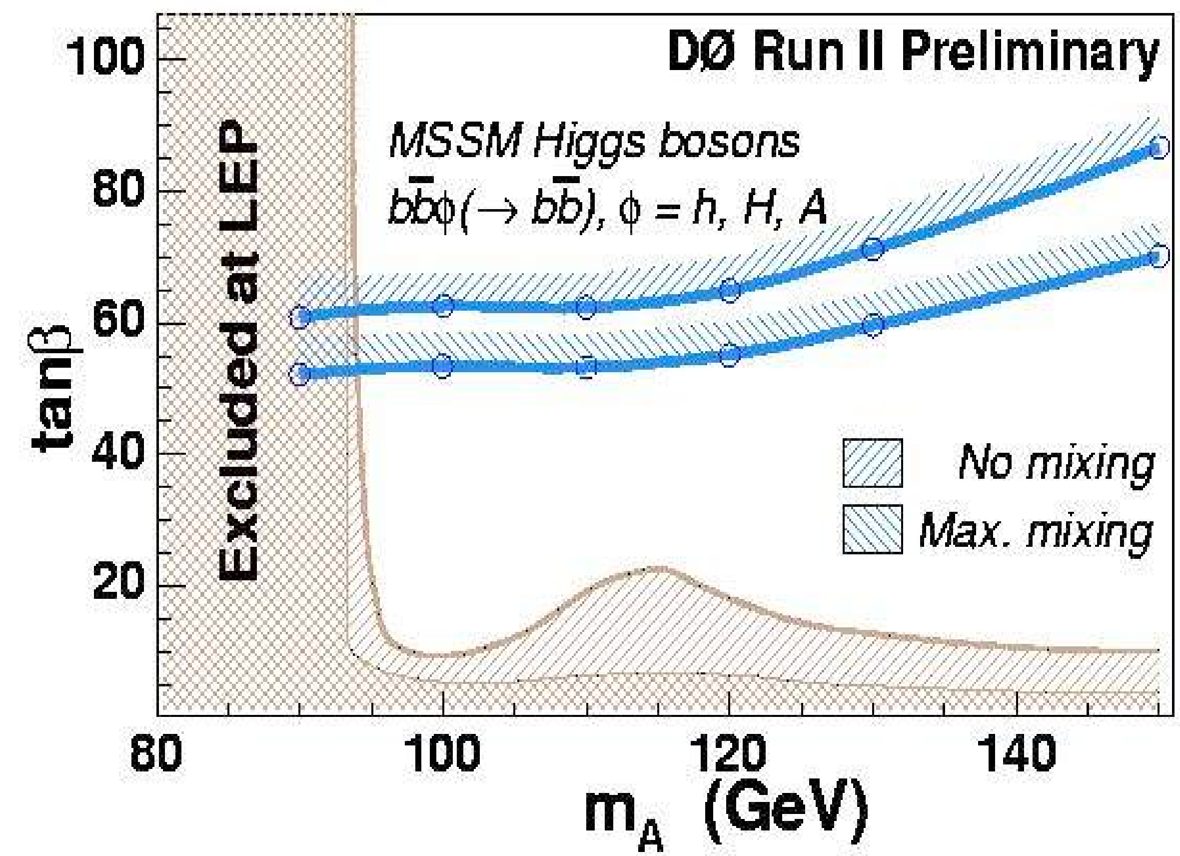


"Signal window"

MSSM Limits

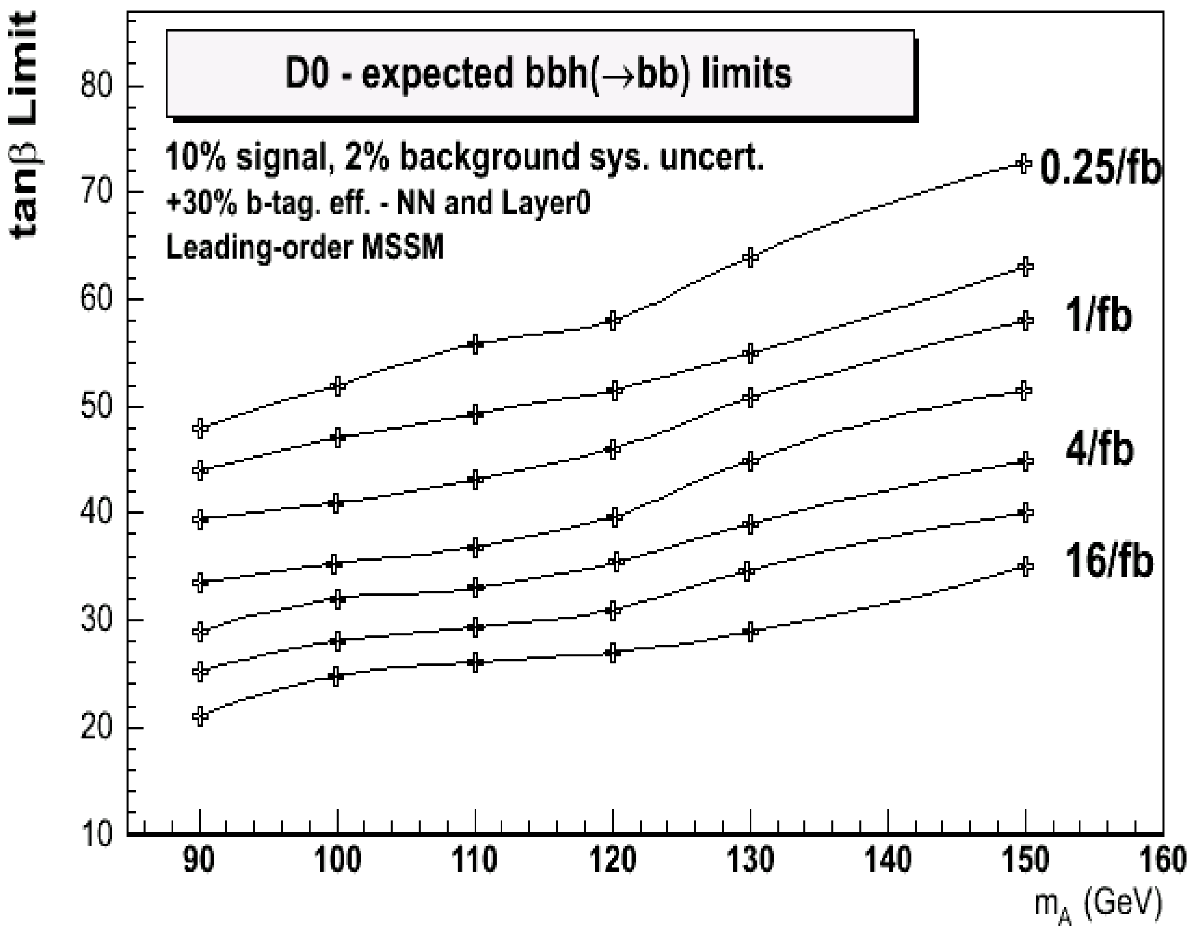
- Limits set using CL_S method (TLimit)
  - For each m_A, set a cross-section limit at 95% C.L.
  - We got a little lucky
- Cross-section uncertainties are calculated by varying the factorization / renormalization scales, and the PDF sets (CTEQ6)
- The current result excludes much more parameter space than our preliminary result from last year
  - Similar analysis, with more data
  - But, much more carefully done! And:
    - better reconstruction
    - vastly improved theoretical understanding





Improved Expectations

- Use of a NN for b-tagging and addition of silicon “Layer 0” for Run IIb (this fall!)
  - About a 30% improvement in b-tagging efficiency at the same background rate
- Can also decrease the systematic uncertainties by a factor of ~2
  - More statistics for measuring b-tagging efficiency, and better studies
  - Smaller jet energy scale uncertainty
  - More trigger studies



Exclude down to tanB~25 for low m_A

Exclude up to m_A~200 GeV for tanB>~50

Some sensitivity up to m_A~300 GeV for very large tanB

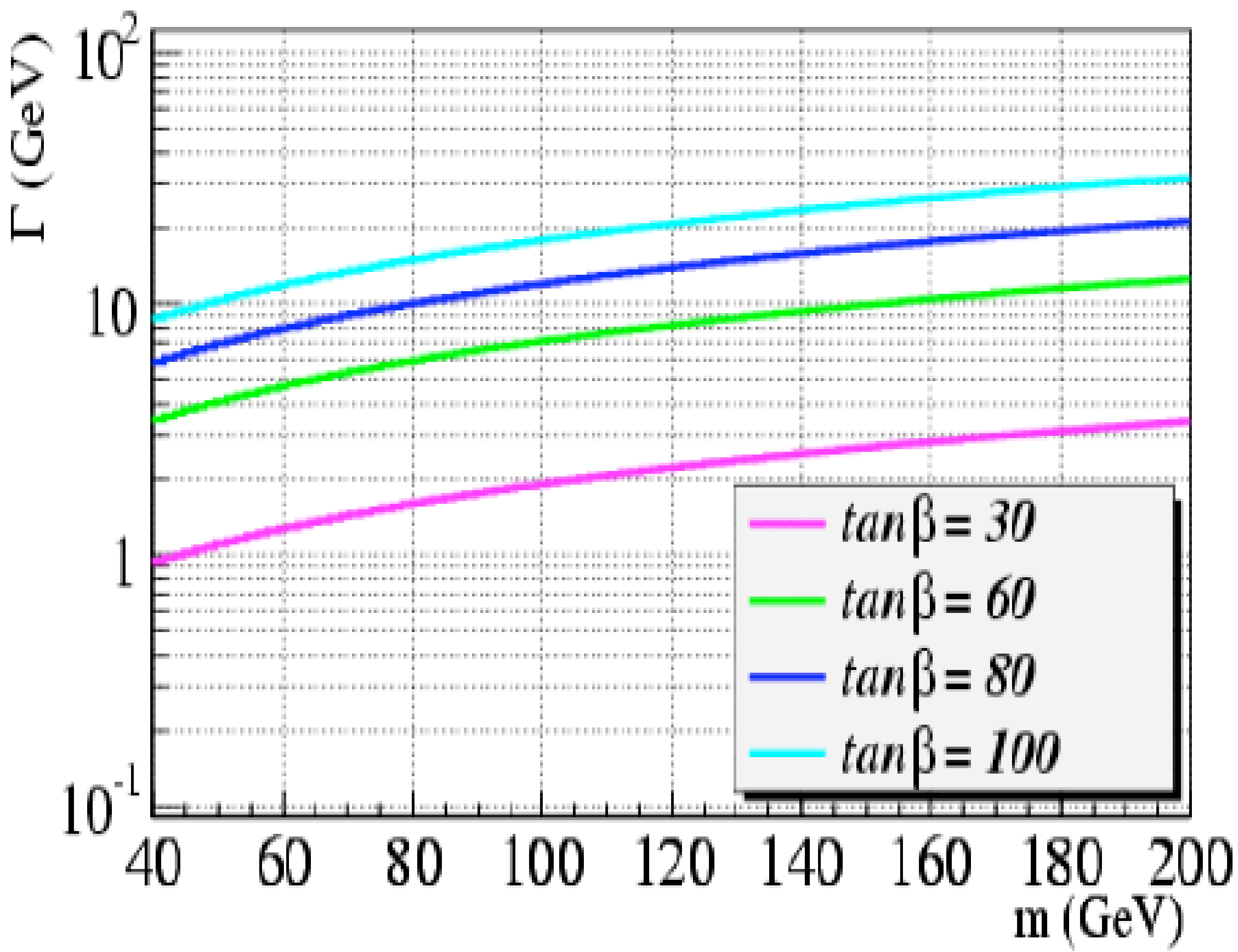
Impact of Higgs width at high $\tan\beta$

- Marine Michaud (D0)
- Part of a very nice D0 MSSM Higgs search which is most sensitive at large values of $\tan\beta$
- The worry is that a wide Higgs at high $\tan\beta$ will be more difficult to see at D0

Problem I looked at

- Given the integrated luminosity used in DØ bbH analysis, it is sensitive to the production of Higgs boson only at high tan β : for a Higgs mass of 150 GeV, the tan β excluded at 95% CL are above 93

Higgs Width from HDECAY



- The Higgs width, which goes like tan β^2, is sizable and its influence has to be studied :

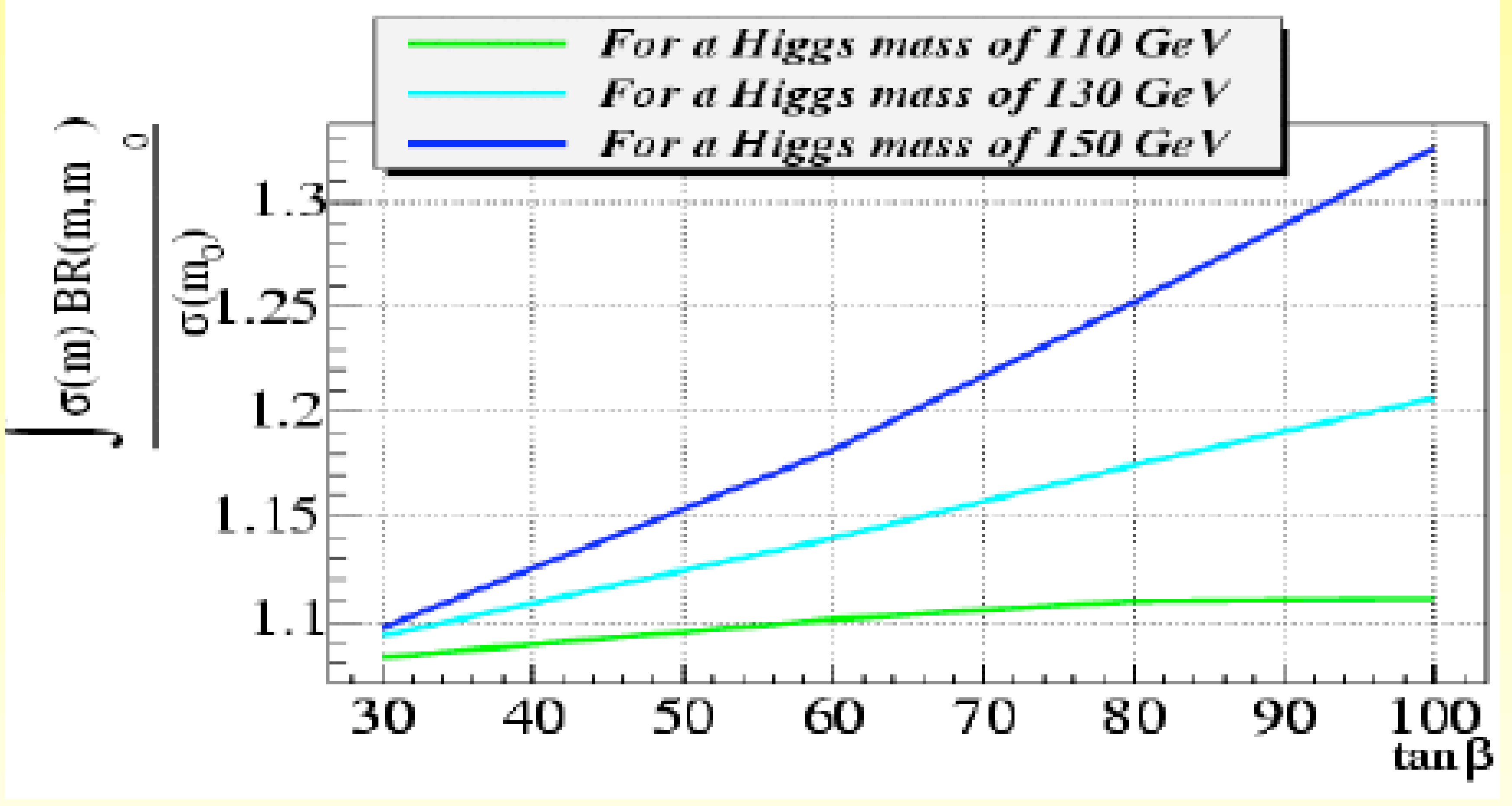
  m_H = 150 GeV
  expected tan β limit = 93
  Γ(150 GeV, 93) = 22 GeV

Cross section if Higgs width is taken into account

- The cross section if we don't neglect the Higgs width is given by :

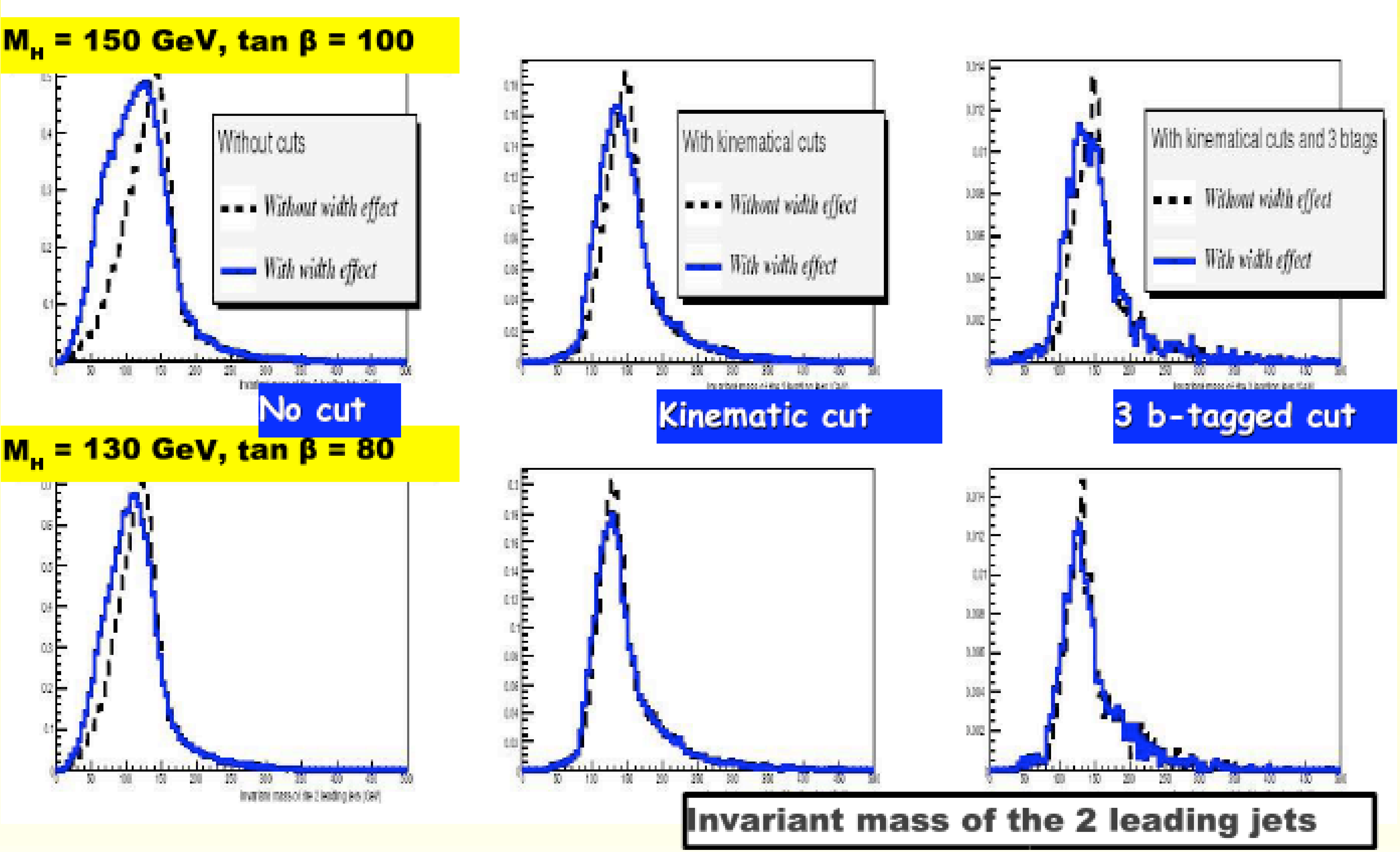
$$\int \mathrm{BW}(\mathrm{m}, \mathrm{m_H})\sigma(\Gamma = 0, \mathrm{m})\,\mathrm{dm}$$

- The ratio between the cross section with a non 0 Higgs width and the one with a 0 Higgs width (versus tan β):



Cross section is always increased if taking Higgs width into account. The possible loss in signal acceptance is then soften by this larger cross section.

Effect on the analysis (2): Invariant mass peak for m_H = 150 and 130 GeV



Conclusion

3 effects are seen :

- the event spectrum tail at low mass due to the large variation of the bH cross section at law mass

=> can lead to loss in signal acceptance due to Higgs fluctuating low in mass

- the variation of the cross section with the 3rd b jet P_T : the cross section at high P_{Tb} varies less

=> the event spectrum tail is smaller for high P_{Tb} that is for high Higgs mass

- the bH cross section taking the Higgs width into account is always higher than the one for a 0 width Higgs boson

=> the possible loss in efficiency is compensated with a higher cross section

With our analysis cuts, the events that are added through the Higgs width effect are cut.

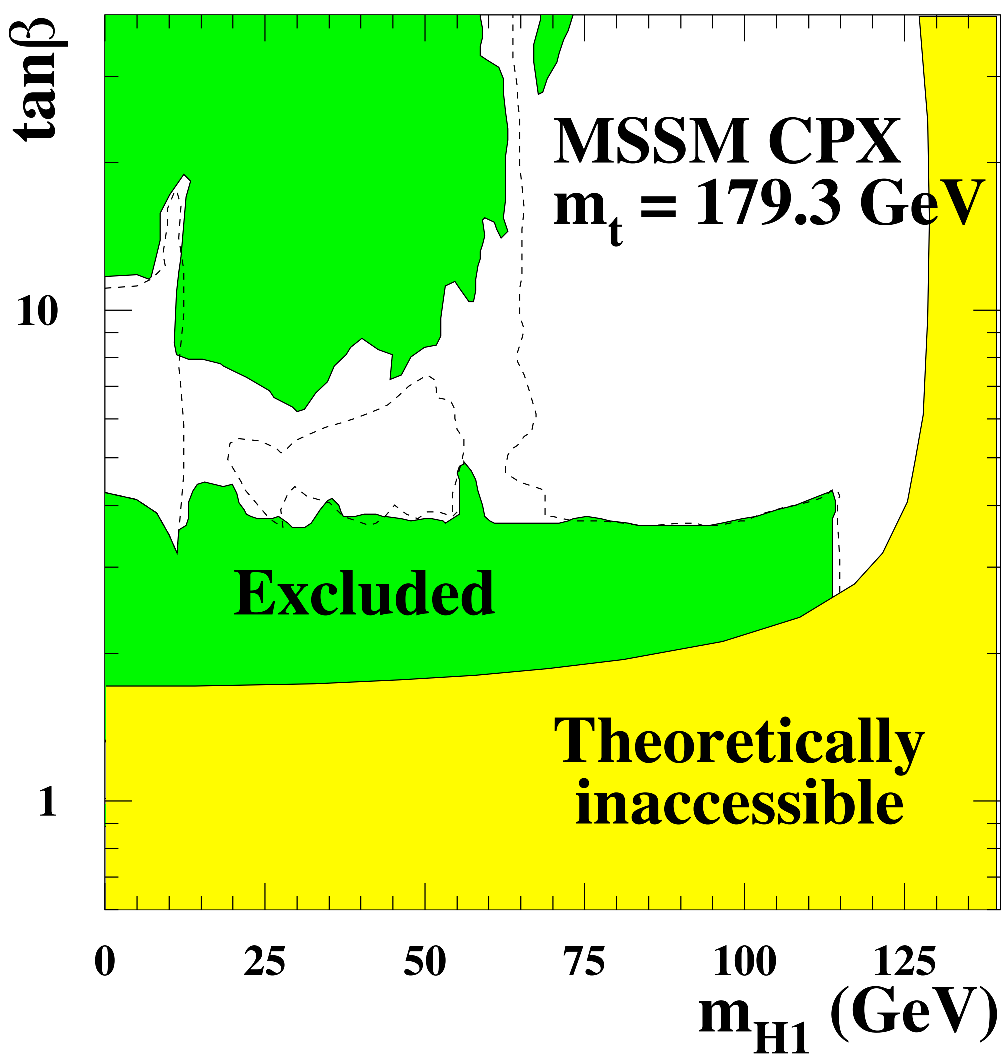
The Higgs width can be neglected with the current analysis cuts, until at least a Higgs mass of 150 GeV and tan β = 100.

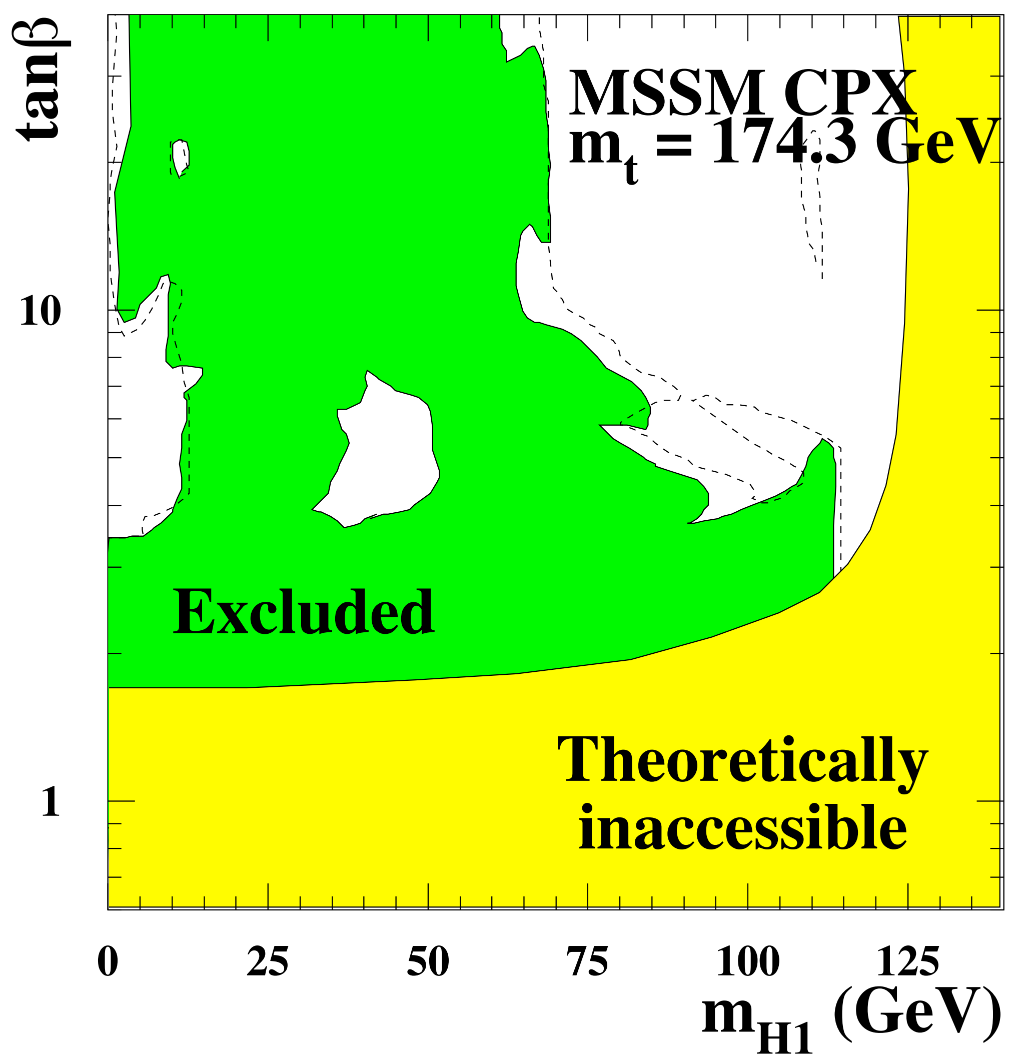
SUSY Higgs: TeV4LHC?

- Sven Heinemeyer with friends (M Carena, C Wagner, G Weiglein)
- How can the TeV *really* help us with SUSY Higgs searches at the LHC?
- 1) Keep on truckin' 2) Build on existing searches 3) Define new benchmarks 4) Combine LEP+TEV SUSY Higgs limits

CPX Harder at TeV

Compare m_t dependence:

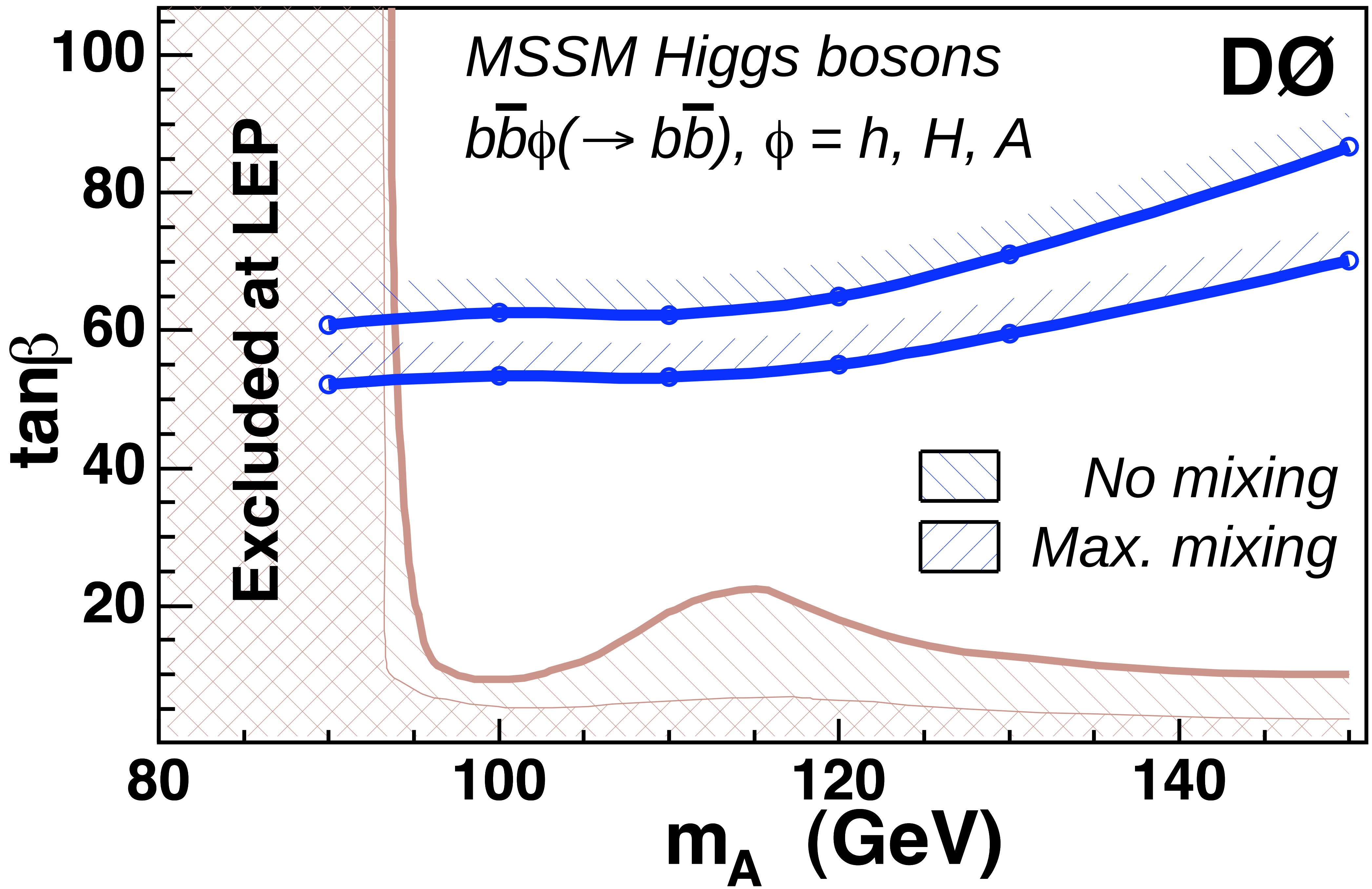




What the Tevatron can possibly do:

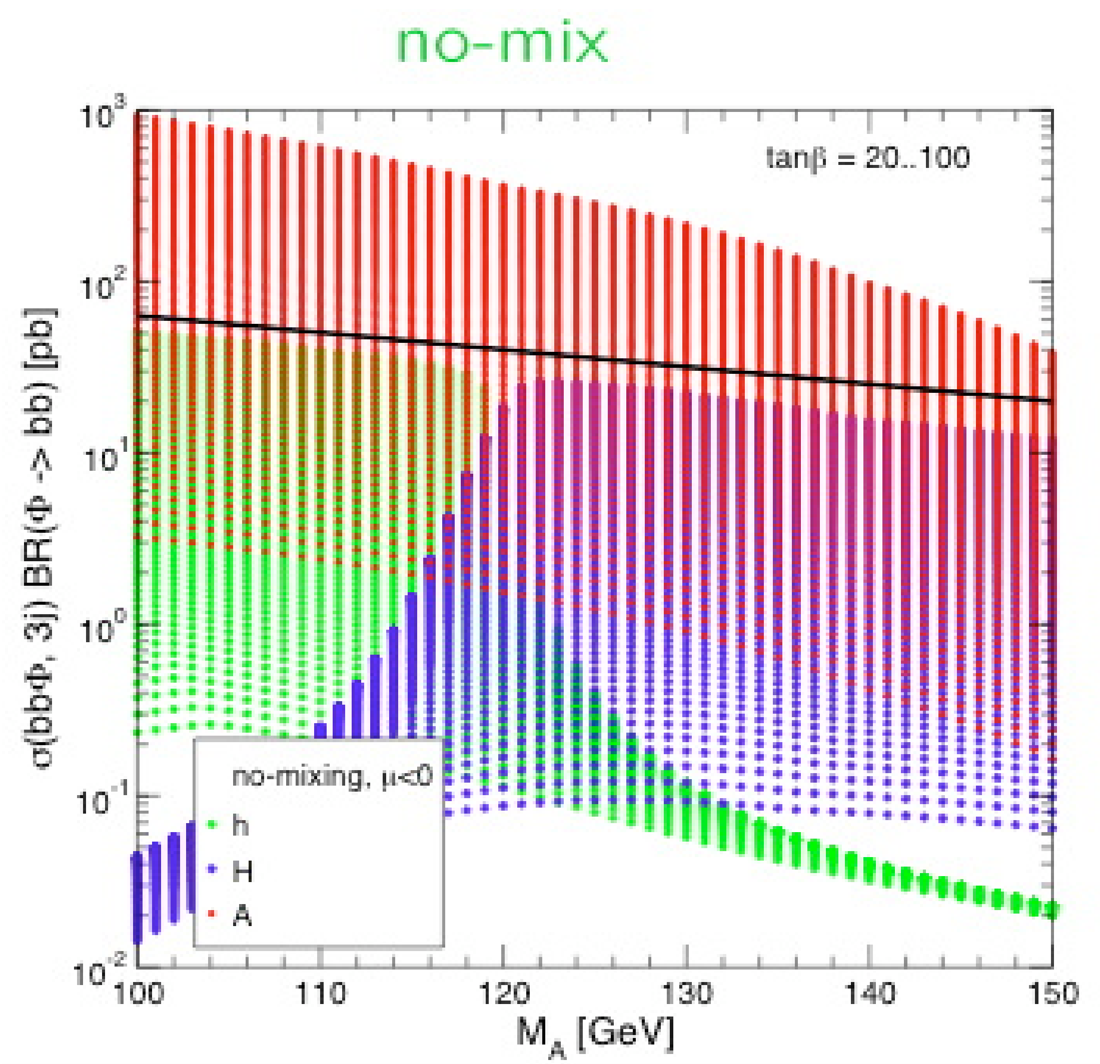
$\Rightarrow$ measure a **small** and **accurate** m_t value

Latest result from D0 [*hep-ex/0504018*]

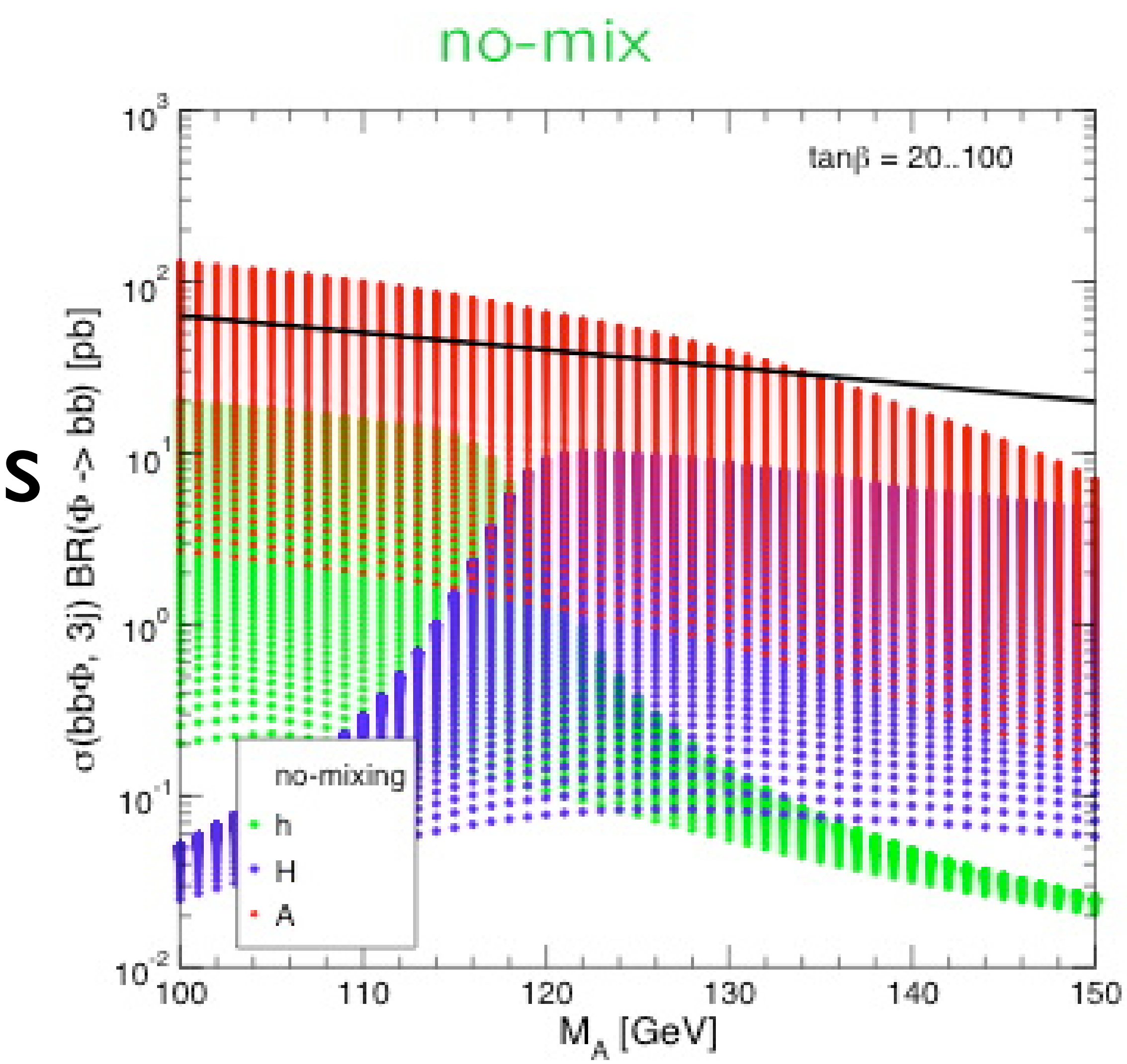


Where do the large differences in the "no mixing" and "max mixing" scenario come from?

Previous benchmarks had -μ which makes difference b/w “max” “min” at TeV Change sign of μ in new benchmarks



Becomes



$$y_b \sim \frac{m_b}{1+\Delta m_b}, \qquad \Delta m_b \sim \alpha_s \tan\beta\, \mu\, m_{\tilde{g}}\, I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}})$$

4. Conclusinos

- Idea I: Tevatron can cover "complicated" MSSM parameters

  $\rightarrow$ holes in CPX scenario with very light Higgs

  $\Rightarrow$ very difficult for the Tevatron . . . $W^* \rightarrow H^\pm h_1$??

  (other issues: m_t dependence, higher-order uncertainties, LEP/Tevatron analysis . . .)

- Idea II: Define benchmarks $\Rightarrow$ continuous Tevatron/LHC search

  $\rightarrow$ "optimistic" /" pessimistic" scenarios to show possible variation in exclusion bounds

  $\rightarrow$ focus on Tevatron search channels

  $\Rightarrow$ largest variation via $\Delta m_b \sim \alpha_s \, \mu \tan\beta$

  $\Rightarrow$ large variation in exclusion bounds

  $\rightarrow b\bar{b}\phi \rightarrow b\bar{b}\, b\bar{b}$ (also: $t \rightarrow H^+ b$, $gg \rightarrow h$, . . .)

Call to Action

- Manpower/transition issues from TeV to LHC mean we can't do *everything* we want
- Making good progress on (hopefully) most important issues, both theory & expt
- One more meeting, and then that's the end of TeV4LHC workshop
- Start thinking about documented results now and start writing in Fall