Search for Higgs-like particle produced in association with b quarks and measurement of $Z \to b\bar{b}$ cross section at CDF II

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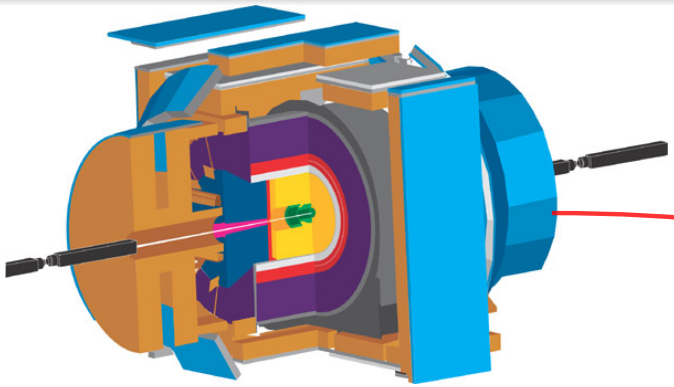
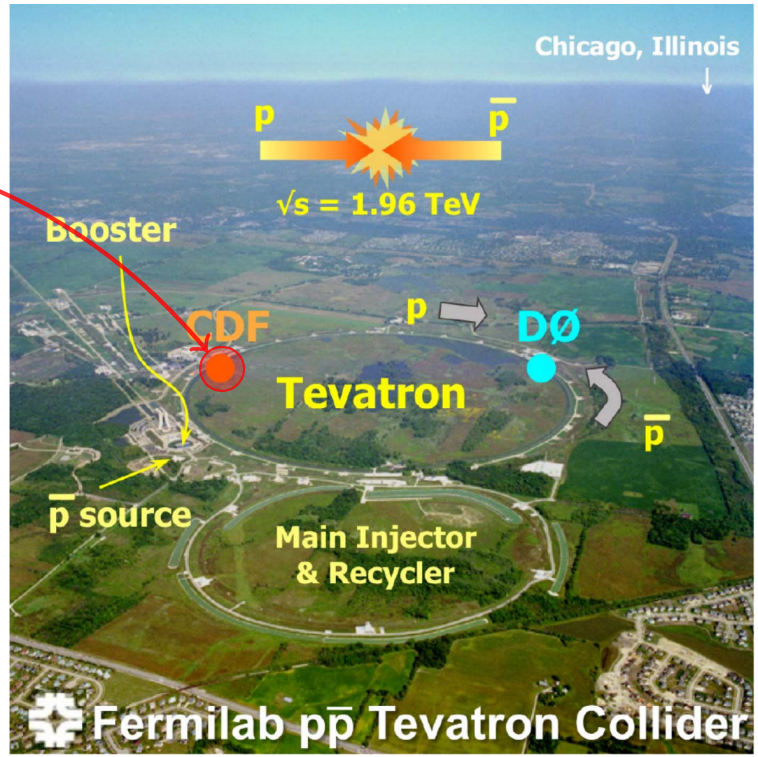
What if we missed something at low mass?

Di-jet searches at the LHC are pushing the limits for New Physics to really high masses. At low mass (100-300 GeV/c^2) they are limited by the possibility to trigger low energy b-jets

CDF II data can help to fill this gap



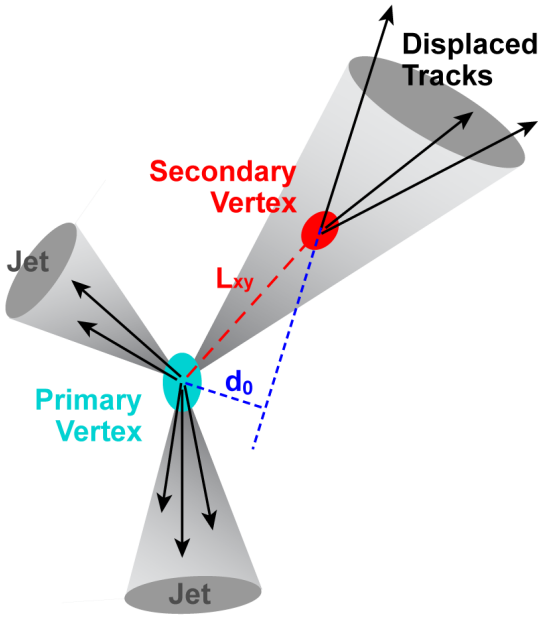


Outline

- The b-jet enriched data sample
- Inclusive $Z \to b\bar{b}$ measurement
- Inclusive $H \to b\bar{b}$ limit
- $b\phi \to b\bar{b}b$ limit, ϕ Higgs-like particle

b-jet enriched data sample

Overwhelming background from QCD multijet production



b-jet identification at CDF

- Displaced vertex
- L_{xy} cut
- Vertex mass separation

Performance:
40% efficiency on b-jets
1% fake rate (light jets)

Smart on-line selection is a key point for these searches

Triggering on b-jets

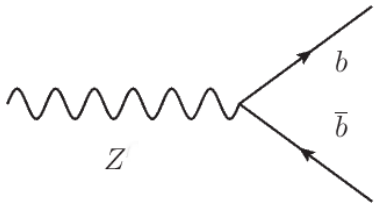
▸ TNS.2009.2020405

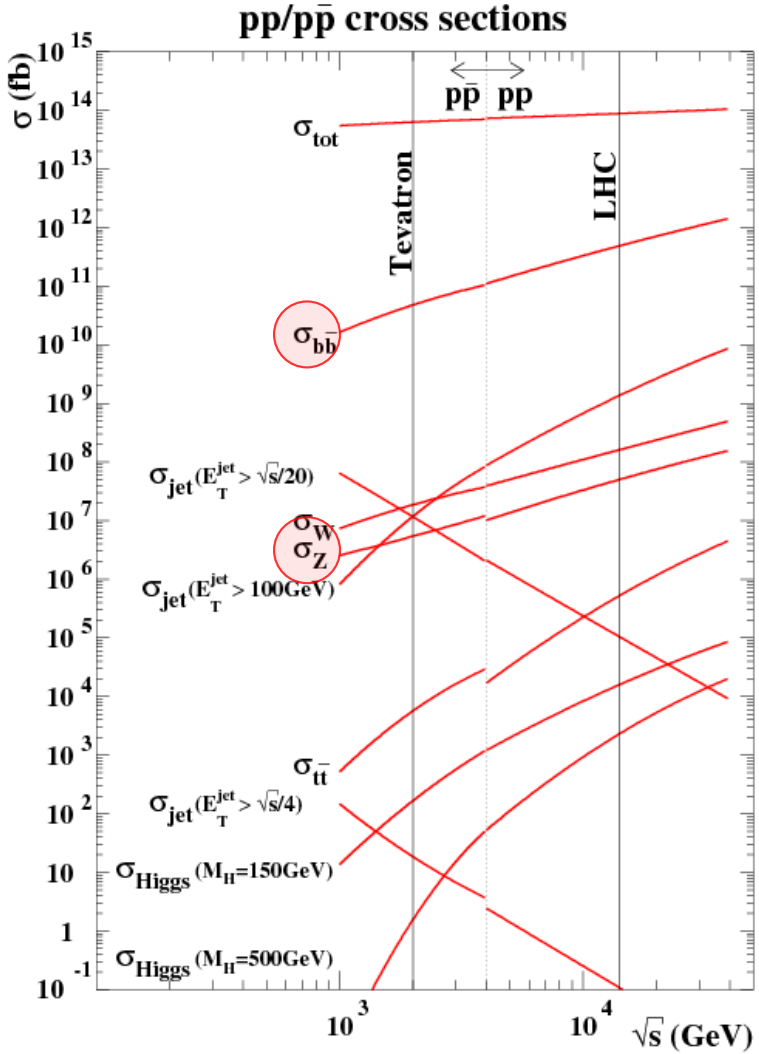
- Two jets with low energy thresholds ($15\ \mathrm{GeV/c^2}$)
- Fast $\mathcal{O}(10\mu s)$ and efficient (40%) on-line b-tagging on one jet

  5% efficiency for $Z \to b\bar{b}$
  10% efficiency for $H \to b\bar{b}$

- $5.4\ \mathrm{fb}^{-1}$ of integrated luminosity

Measurement of inclusive $Z \to b\bar{b}$ cross section





$Z \to b\bar{b}$ signal hidden among the overwhelming backgrounds:

- Irreducible QCD b-jets pairs
- c and light quarks initiated jets tagged as b-jet

Challenging search, but from high pain, high gain!

The $Z \to b\bar{b}$ as a standard candle to ..

- Determine the Jet Energy Scale (E_{data}/E_{MC}) for b-jets
- Confirm the correctness of all the tools
- Validate the background modeling for the other searches

Measurement of inclusive $Z \to b\bar{b}$ cross section

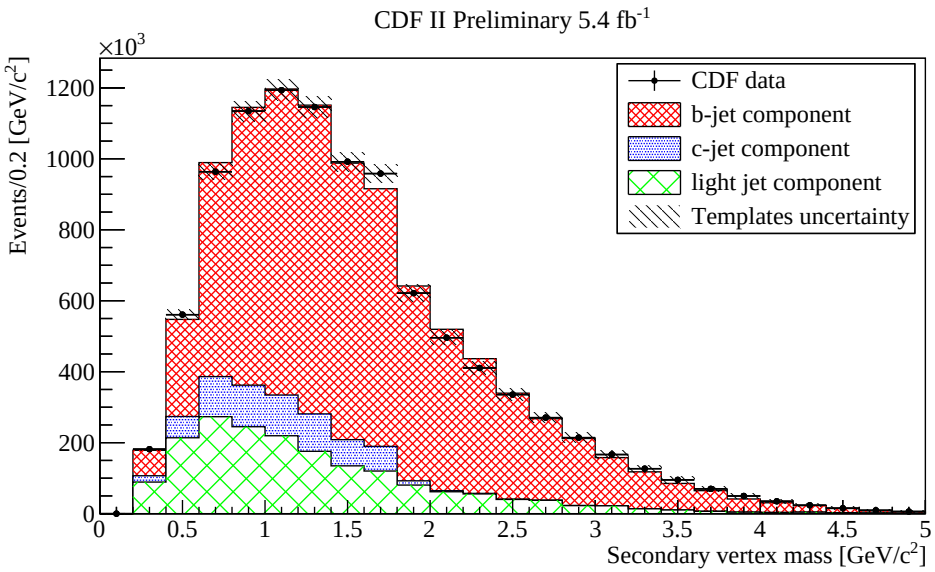
Analysis strategy ▸ CDF-PUB-11228

- Signal searched in a sample with two b-tagged jets
- Fit to the invariant mass of the two leading jets using:
  - QCD multijet background templates from data driven technique
  - $Z \to b\bar{b}$ signal template from Monte Carlo simulation

Background templates

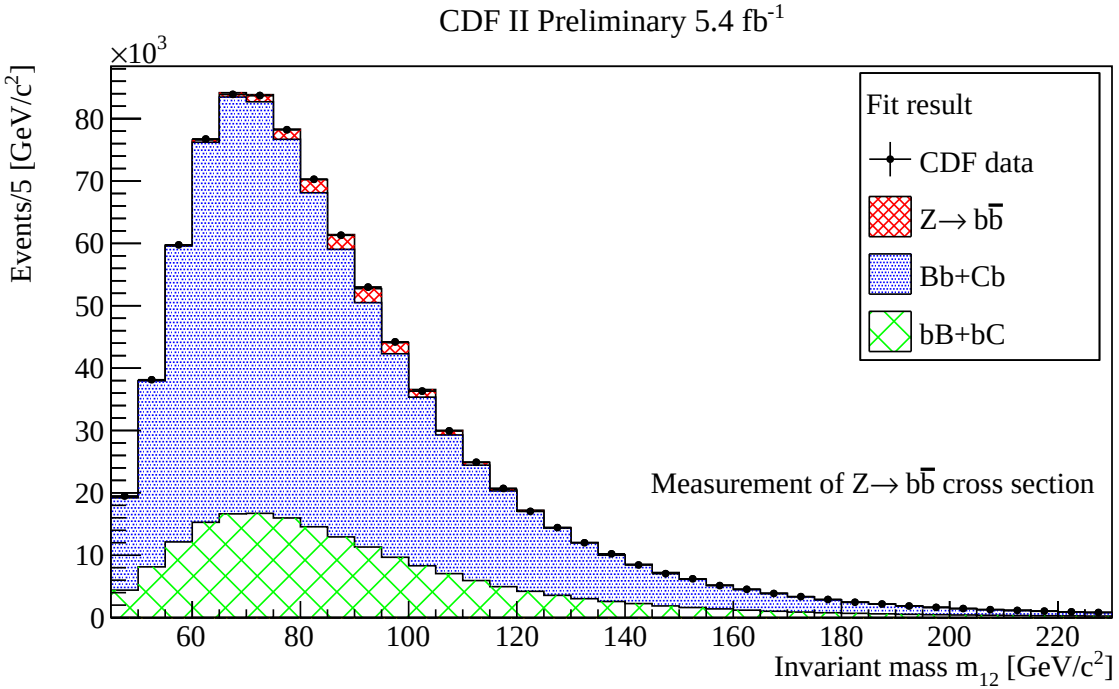
1. Sample with a single b-tagged jet and another untagged jet (Bx)
2. Non-b component removed from the single b-tagged sample with a cut on the Secondary Vertex mass
3. b-tagging parametrizations from simulations for the different jet flavors
4. b-tagging parametrizations to simulate the bias on the untagged jet

Templates for Bb, Bc and Bq backgrounds



Measurement of inclusive $Z \to b\bar{b}$ cross section

Fit to the double b-tagged sample



Binned maximum likelihood fit

CDF II Preliminary 5.4 fb^{-1}

Component	Fitted yield in events
$Z \to bb$	$(16.5 \pm 1.2) \times 10^3$
Bb+Cb	$(68.1 \pm 1.1) \times 10^4$
bB+bC	$(19.4 \pm 1.3) \times 10^4$
Bq	< 175 (1σ)
qB	< 61 (1σ)

No light quark initiated jets in the double b-tagged sample

More than 5σ significance including systematics

Measurement:

$$\sigma(p\bar{p} \to Z)\mathcal{B}(Z \to b\bar{b}) = 1.11 \pm 0.08(stat) \pm 0.13(sys) \text{ nb}$$

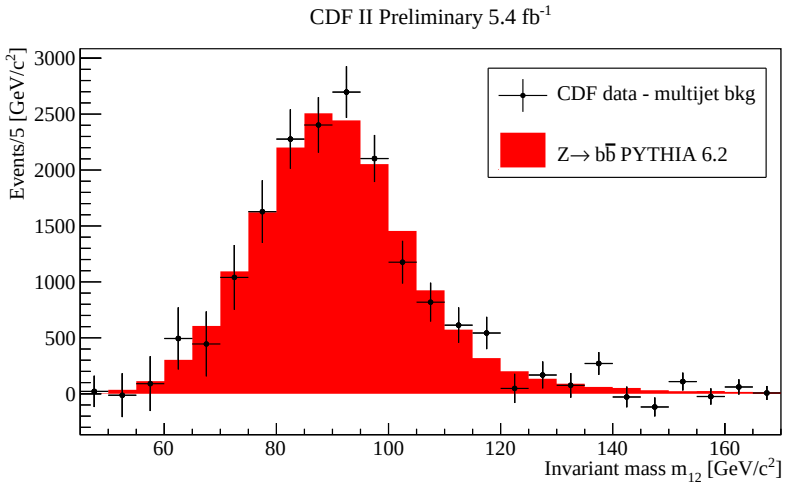
Theoretical NLO prediction:

$$\sigma(p\bar{p} \to Z)\mathcal{B}(Z \to b\bar{b}) = 1.13 \pm 0.02 \text{ nb}$$

Residual b-Jet Energy Scale:

$$\text{JES} = 0.993 \pm 0.022 \pm 0.015$$

Data-background



Limit on the inclusive Standard Model $H \to b\bar{b}$

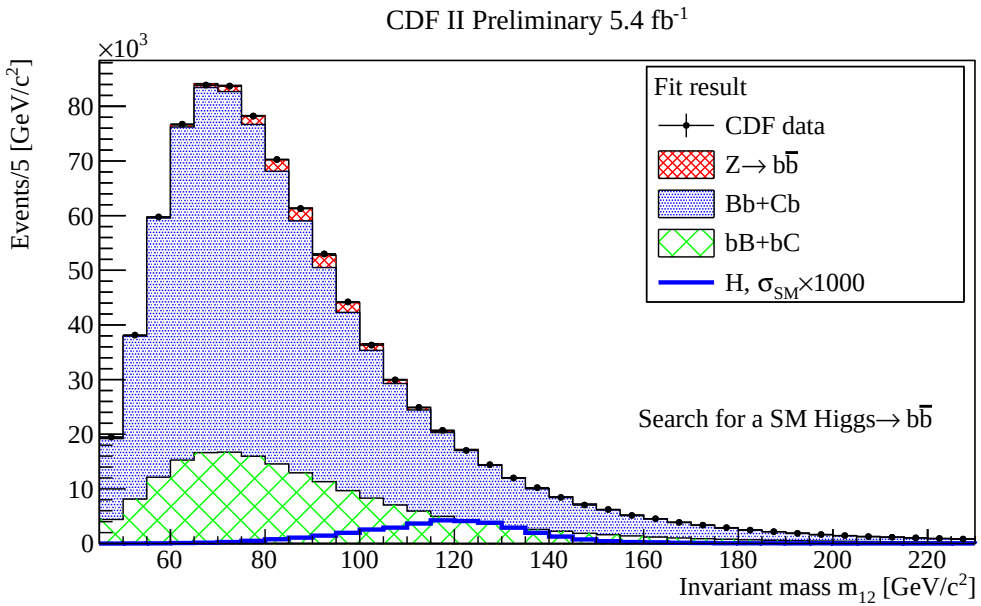
Testing a different production mechanism with respect to the one that led to the Tevatron $H \to b\bar{b}$ evidence

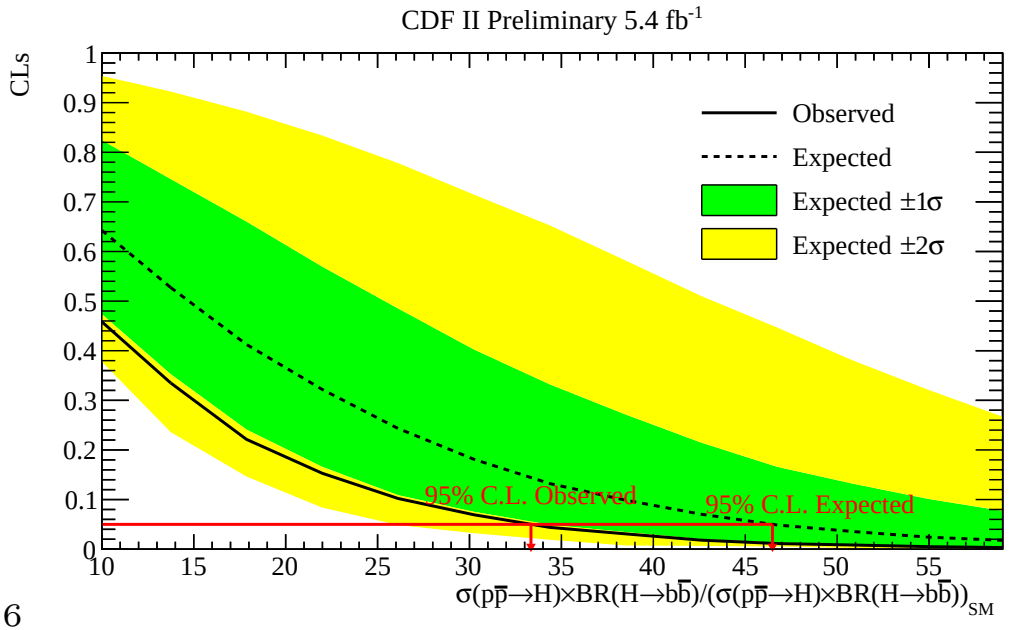
▸ CDF-PUB-11228

Search validated by the $Z \to b\bar{b}$ measurement:

- Same event selection
- Same background modeling

Very low $S/\sqrt{B} \sim 0.04$



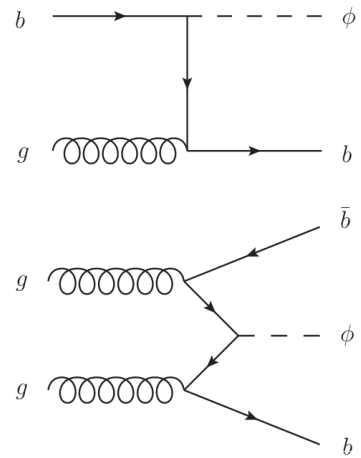


Upper limit set using CL_S method
Test statistic: χ^2 difference between fits in the B or S+B hypothesis

Result

Observed(expected) limit at 95% C.L. 33 (46) times the Standard Model cross section

Search for $\phi b \to b\bar{b}b$ process



Signal signature

Narrow neutral scalar ϕ into a b quark pair
Additional third b quark to reduce the background

- Bump in $m_{b\bar{b}}$, taken as 2 leading jets invariant mass

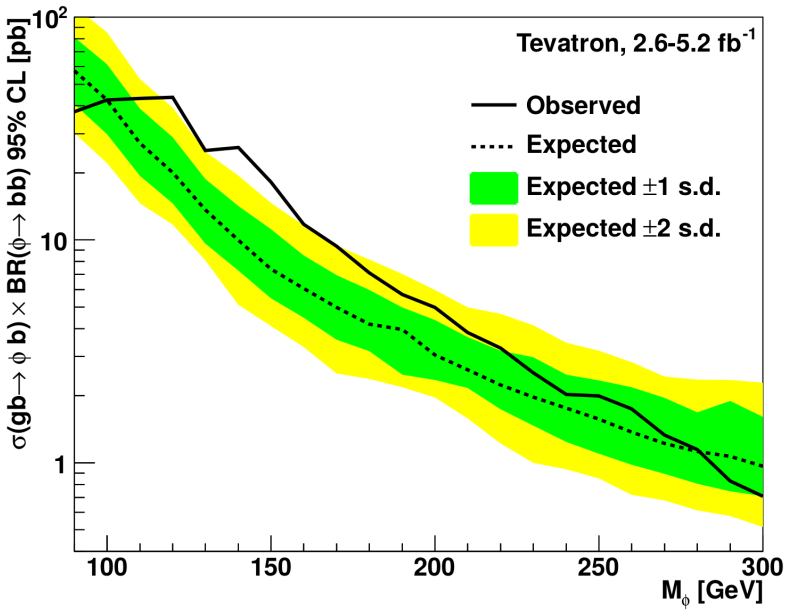
▸ PRD 86.091101

Motivation

This search can be included in various theoretical models:

- MSSM Higgs sector
- Dark-matter models with mediator particles with a large coupling to b quarks

The analysis is left in a general context of exotic resonance searches



Tevatron previous combined result (2012)
2σ excess

Search for $\phi b \to b\bar{b}b$ process

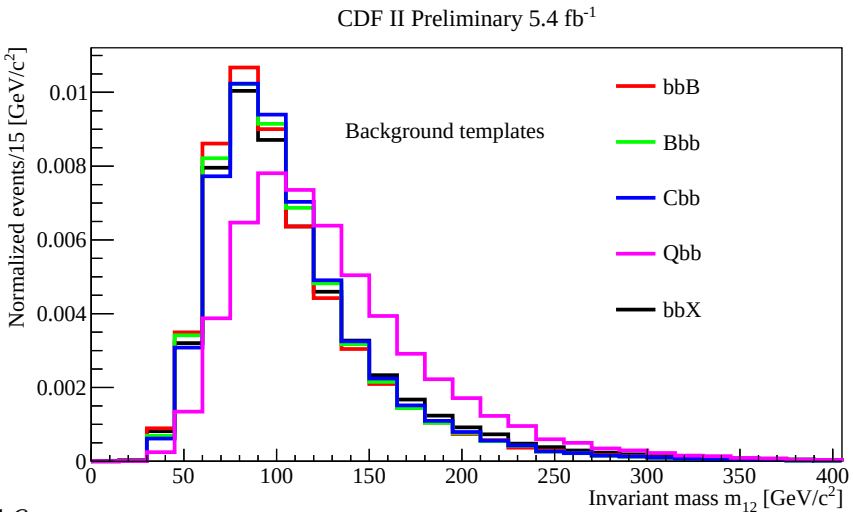
Analysis strategy

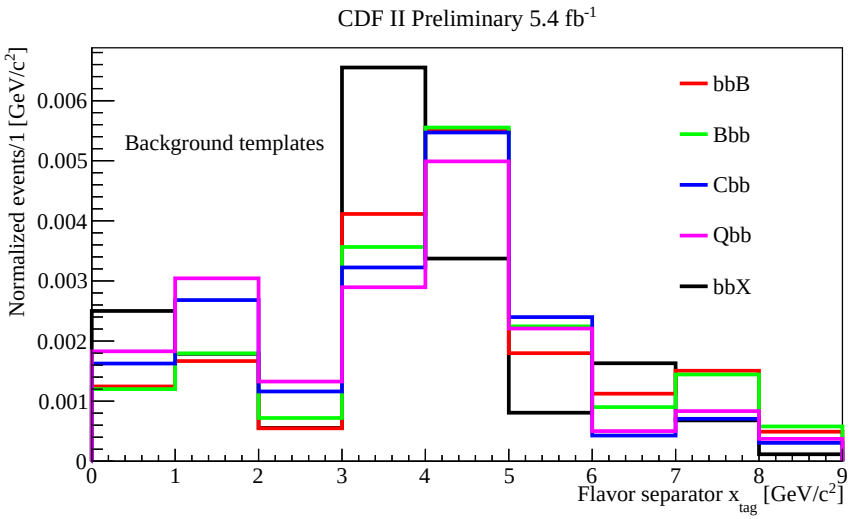
CDF-PUB-11229

- Signal searched in a sample with three b-tagged jets
- Signal and background modeling based on 2D templates: x_{tag} vs invariant mass m_{12}
- x_{tag} variable sensitive to the flavor of the jet, carries the information of the SV mass

Background templates

- Starting point: double b-tagged sample
- b-tagging parametrizations applied to the third untagged jet

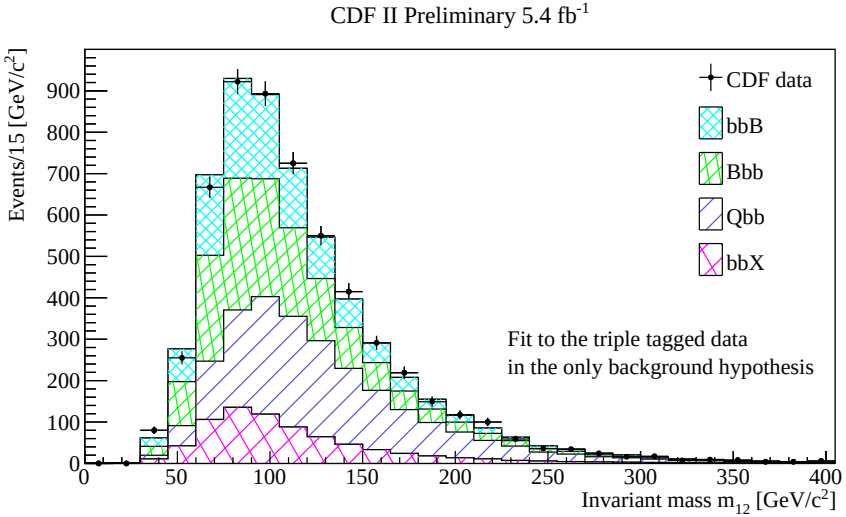




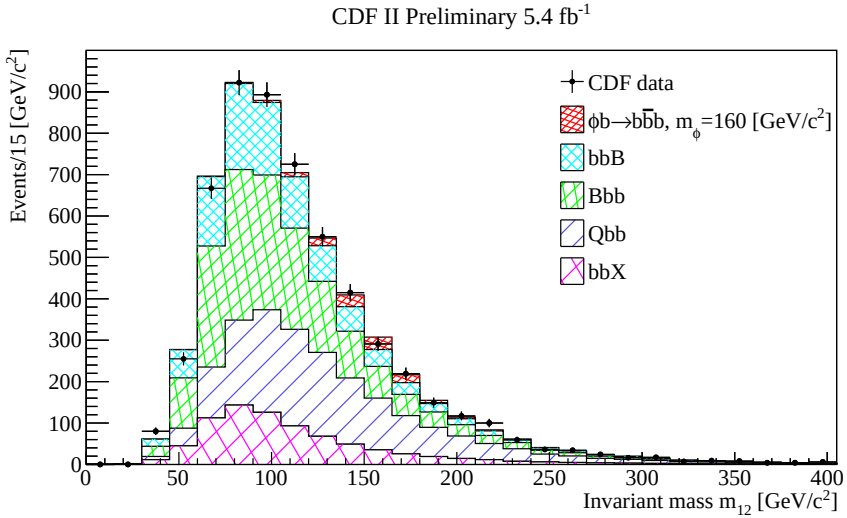
Search for $\phi b \to b\bar{b}b$ process

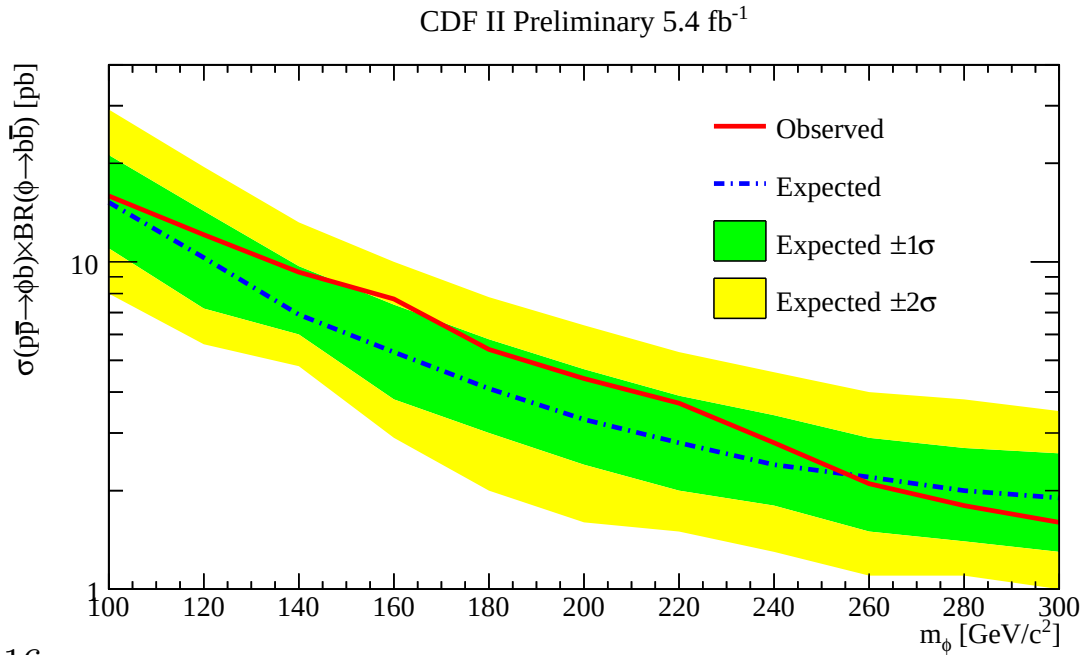
2D-fit to triple b-tagged data sample

Best fit w/o signal (projection in m_{12})



Best fit with signal (projection in m_{12})





Fit and background templates validated in a control sample

Upper limit set using CL_S method
Test statistic: χ^2 difference between fits in the B or S+B hypothesis
Systematics uncertainties included as nuisance parameters

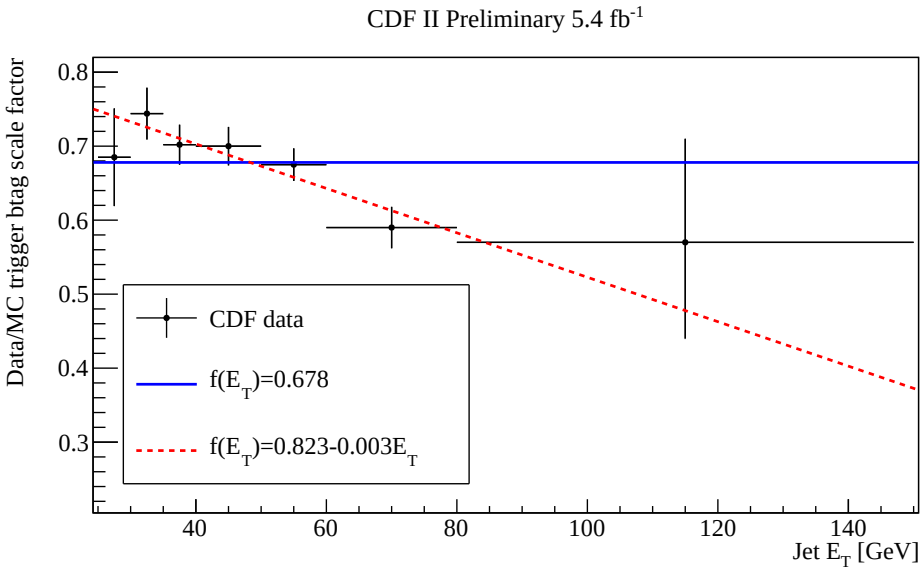
Summary and conclusion

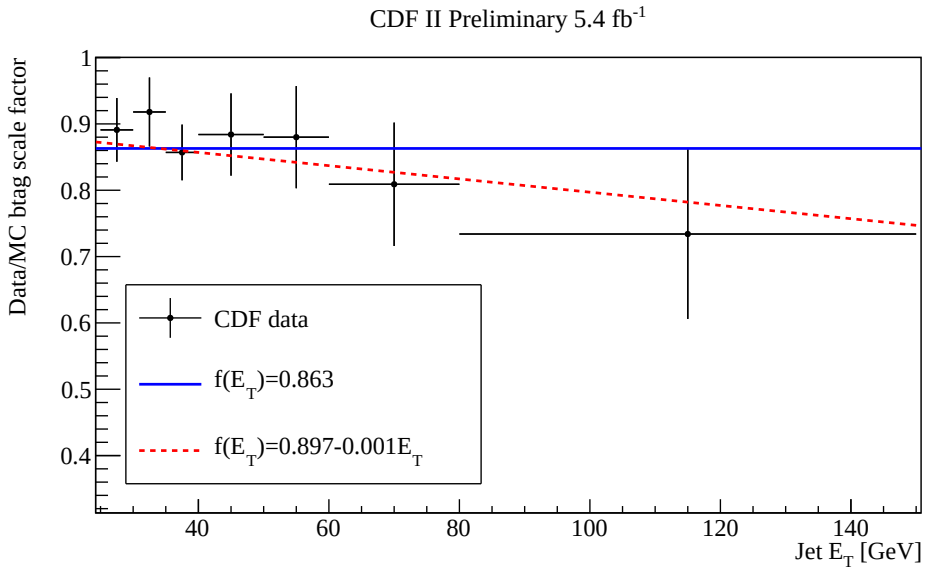
- Measurement of the $Z \to b\bar{b}$ cross section
  - More than 5σ significance
  - Validate the search for resonances in b-jets final states
  - Measurement of the b-Jet Energy Scale
- Limit on the inclusive Standard Model $H \to b\bar{b}$
  - First limit on the inclusive $H \to b\bar{b}$ process
- Limit on the $\phi b \to b\bar{b}b$ process
  - Best limit on the $\sigma \times \mathcal{B}$ in the low mass range
  - No excess in the "hot" region $100 - 150$ GeV/c^2 found

Tevatron datasets can still give important input to Physics, especially in region of the phace-space not well covered by LHC experiments

Backup

b-tagging data/MC scale factors





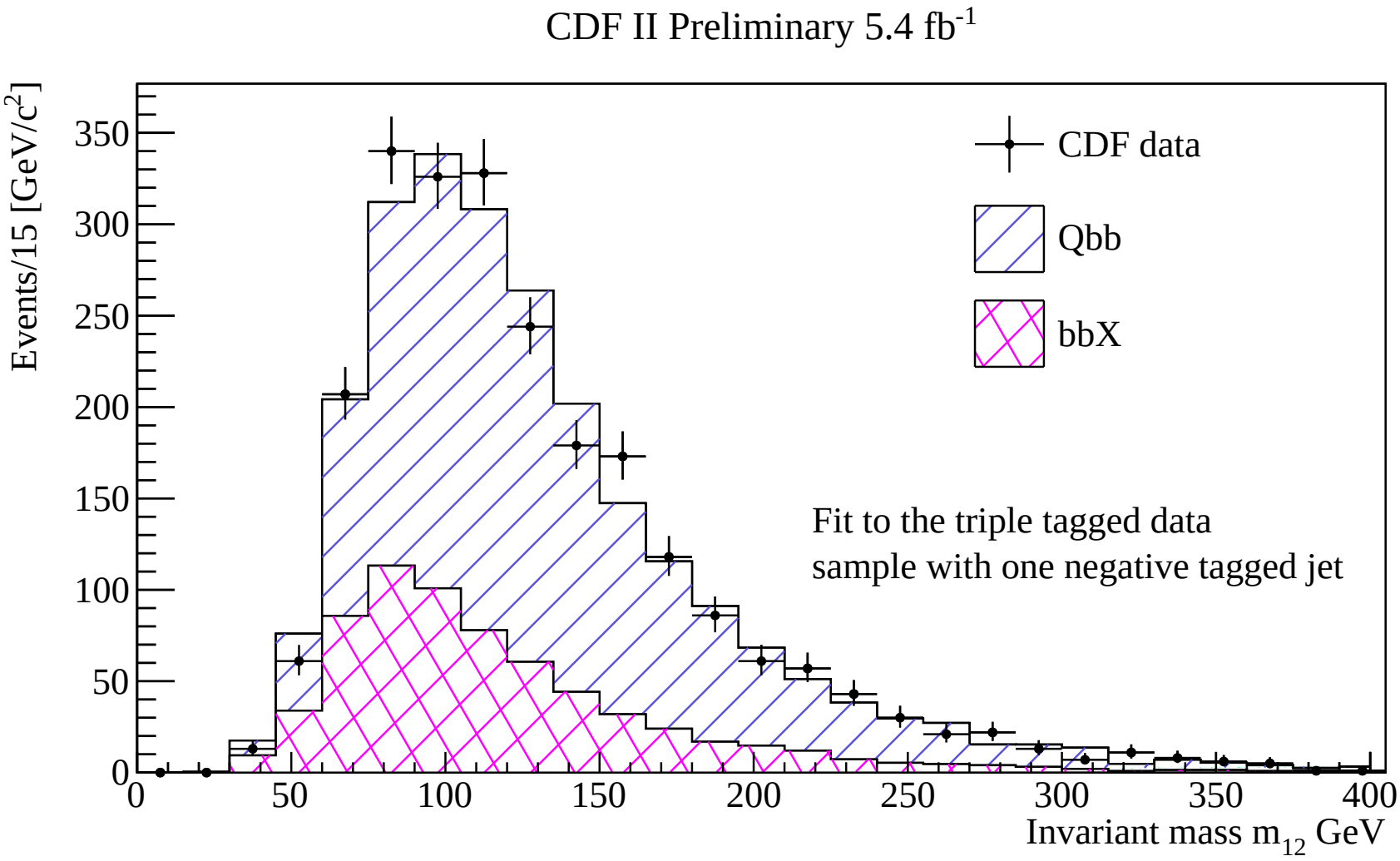
$Z \to b\bar{b}$ systematic uncertainties

CDF II Preliminary 5.4 fb^{-1}

Source	Systematic uncertainty b-Jet Energy Scale	$Z \to b\bar{b}$ cross section
Luminosity		5.9%
Background template statistics	0.004	2.3%
c-quark component in $b\bar{b}$ templates	0.005	2%
Signal Monte Carlo statistics	0.002	3%
b-tag energy dependence	0.004	5%
b-tag scale factor		5%
Trigger and b-tag combined scale factor		4%
Jet Energy Correction		1.4%
Final State Radiation		2.6%
Parton Distribution Functions		1.1%
Total	0.008	11.4%

$\phi b \rightarrow b\bar{b}b$ control sample

Fit to the triple tagged sample, with one of the jet negative tagged (mistag)



$\phi b \to b\bar{b}b$ systematic uncertainties

CDF II Preliminary 5.4 fb^{-1}

Systematic uncertainties on the $\phi b \to b\bar{b}b$ search

Source	Variation	Applies to	Type
Luminosity	5.9%	signal	rate
Offline b-tag	5% per jet	signal	rate
Online and offline b-tag combined	4%	signal	rate
JES	$7-4$%	signal	rate/shape
x_{tag}	3%	signal	shape
PDFs	2%	signal	rate
Template stat. uncertainty	-	background	shape
Heavy flavor normalization	5%	background	rate