Search for the Standard Model Higgs boson in final states with *b* quarks at the Tevatron

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PURDUE UNIVERSITY

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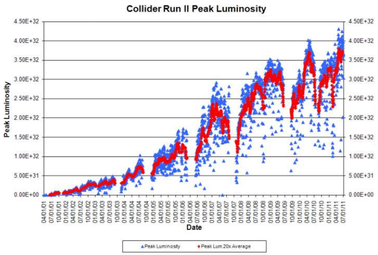
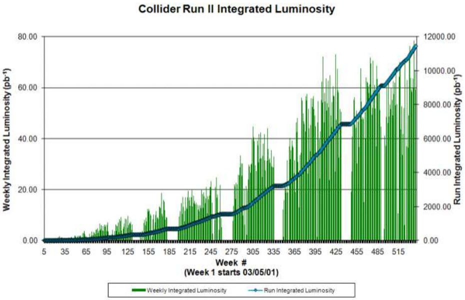
Outline

- The Tevatron collider;
- The CDF and DZero detectors;
- Higgs searches at the Tevatron;
- Low mass searches;
- Gaining acceptance and improving sensitivity;
- Latest results and future prospects;

Tevatron luminosity

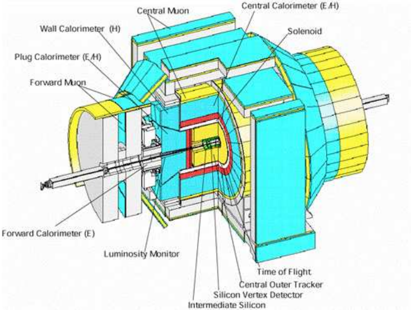
- Tevatron doing great in providing collisions to experiments.
- Today's talk: up to 7.8fb^{-1}(CDF), and 8.6fb^{-1}(DZero);

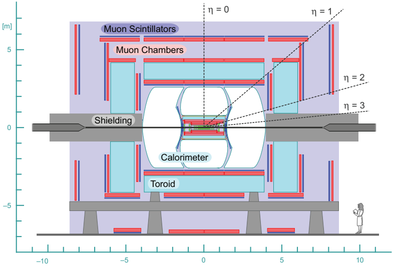




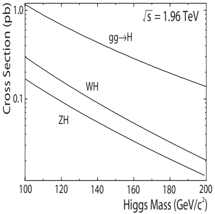
CDF and DZero, two general purpose detectors

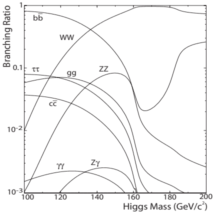
	CDF		DØ	
Tracking	Silicon	$\lvert\eta\rvert < 2 - 2.5$	Silicon	$\lvert\eta\rvert < 3$
	Drift cell	$\lvert\eta\rvert < 1.1$	Fiber	$\lvert\eta\rvert < 1.7$
Calorimetry	Scintillators	$\lvert\eta\rvert < 3.6$	LAr/DU	$\lvert\eta\rvert < 4$
Muon chambers	Drift Scintillators	$\lvert\eta\rvert < 1.5$	Drift Scintillators	$\lvert\eta\rvert < 2.0$





Higgs Searches at the Tevatron

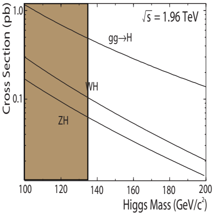


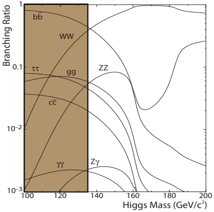


About the Higgs at the Tevatron:

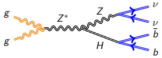
- **Direct production** dominates the mass spectrum.
- **Associated production** $\sim$ 5 times smaller.
- Two decay modes dominate: low / high mass
  - $m_H < 135$ GeV$/c^2$: $H \rightarrow b\bar{b}$
  - $m_H > 135$ GeV$/c^2$: $H \rightarrow WW$
- No single channel can do. **Must divide and conquer.**
- Analyzing all decay channel for best sensitivity.
  - Dedicated triggers to keep most of the Higgs events.
  - No single analysis with sufficient statistical significance.
- **Need** to **combine all** CDF Higgs searches and do the same also with DZero.
  - More information in other talks.

Low Mass Searches – $m_H < 135$ GeV/c^2

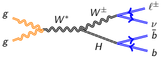




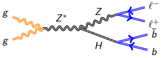
- $\sigma(H) \times B(H \to b\bar{b}) \approx 0.5$ pb
  - Final state overwhelmed by QCD
  - Other rare decay modes less sensitive
- $\sigma(VH) \times B(H \to b\bar{b}) \approx 0.1$ pb
  - Extra vector boson helps reducing backgrounds
- **Associated production**: main low mass channel



$VH \to \not{E}_T b\bar{b}$



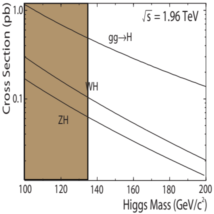
$WH \to \ell\nu b\bar{b}$

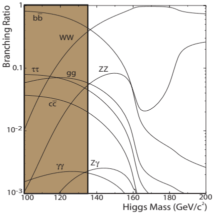


$ZH \to \ell\ell b\bar{b}$

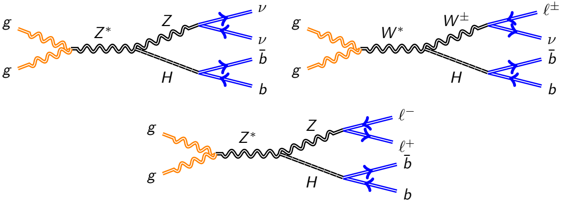
- **Direct production**: using other decay modes
  - $H \to \tau\tau$, $H \to \gamma\gamma$, $H \to WW$, $t\bar{t}H \to \ell\nu q\bar{q}b\bar{b}b\bar{b}$
  - Detailed talk by Azeddine KASMI [next talk];

Low Mass Searches – $m_H < 135$ GeV/c^2





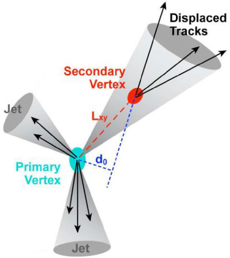
- **Associated production**: $W/ZH \to \ell\ell/\ell\nu/\nu\nu\ b\bar{b}$
  - $H \to b\bar{b}$ identified with 1 or 2 "b-tags".
  - W/Z identified from leptonic or hadronic decay

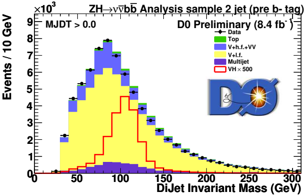


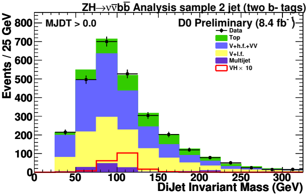
- Advanced analysis tools (NN,BDT) deployed to maximize sensitivity in each channel.

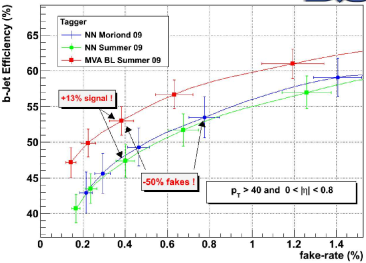
Reducing background with b quark ID

- Tagging b-jets from $H \to b\bar{b}$ removes reduces the backgrounds by two orders of magnitude;









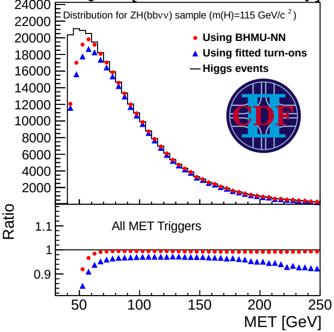
- Algorithms exploit the long lifetime of B-hadrons, yielding jets with displaced vertices;
- Using new tagging algorithms to maximize ID;
- Using MVA with **optimized operating points**, but also **using the actual output** for discrimination;

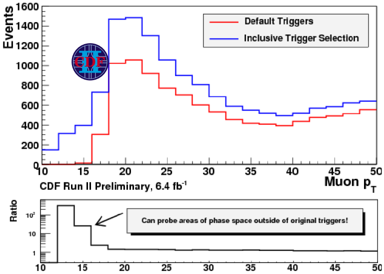
b-tagging is a key to improve sensitivity

Increasing acceptance by combining multiple trigger paths

- Dedicated triggers designed to meet specific physics goals;
- Combining several triggers, to maximize acceptance;
  - Either by defining an **new path**, namely an OR of the triggers;
  - Either by **a priori** partitioning the events into orthogonal samples, and check if the assigned trigger fired;
- Using *matrix-based* or *NN-based* (shown) parametrization to model the turn-on;
- A NN trigger parameterization allows to model the trigger turn-on, including the complex correlations between variables;

$\not{E}_T$ + *b*-jets [CDF II Preliminary]

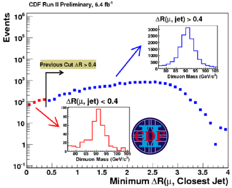


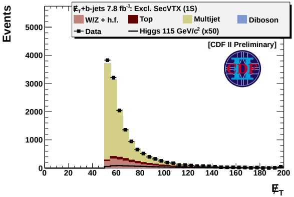


∼ 10% more data accepted

Relaxing kinematic cuts thanks to a better trigger model

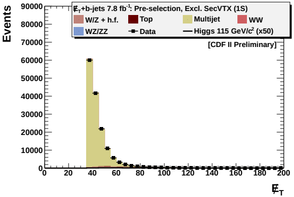
- NN turn-on allows to *relax* the kinematic requirements on the analysis, yielding **increased acceptance**;
- Relaxed cuts now accessible for the first time in $\not\!\!E_T$+b-jets;

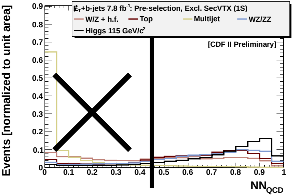




From $\not\!\!E_T > 50$ GeV$/c^2$ to $\not\!\!E_T > 35$ GeV$/c^2$ (+other relaxed cuts)

30-40% more Higgs
10x more background

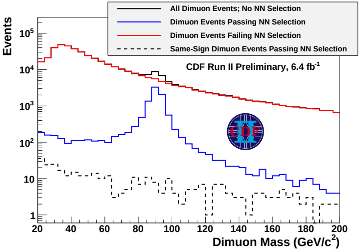




- Dedicated NN to remove QCD:
  - Rejects $\sim$ 90% of QCD, keeping $\sim$ 90% of Higgs;
  - Selection is as powerful as *lepton ID*;
- 2.5 better $S/\sqrt{B}$ in 2-tag sample;

Increasing acceptance to leptons

- $ZH \to \ell\ell b\bar{b}$: Multivariate lepton identification:
  - Leptons are required to pass a neural network selection (NN);
  - Inputs (μ-ID): p_T, η, ϕ, E_{EM}, E_{HAD}, $\Delta R(\mu, j)$, track χ^2, d_0, isolation, silicon hits; Similar inputs for electrons;
  - Separate networks for e,μ and each sub-dectector;
  - Improvement: 20% relative to cut-based analysis;

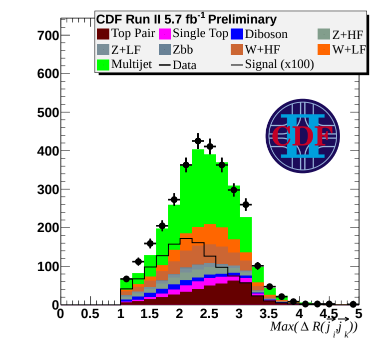


- $WH \to \ell\nu b\bar{b}$: Loose electron & isolated tracks form $W \to e\nu$ or $\tau\nu$:
  - Included as a separate lepton category: 5% increase in sensitivity;

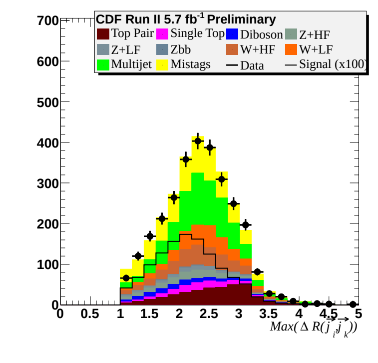
Much improved modeling

New data-driven model for multijet ($VH \to \not{E}_T + b$-jets)

- Using a new modeling, in which the mis-tags are modeled separately from QCD;
- Separating different processes with different uncertainties improves the sensitivity;



Summer 2010

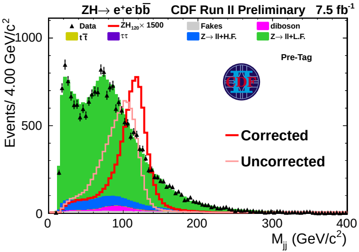


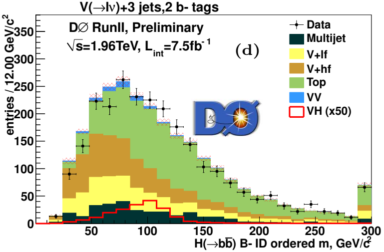
Summer 2011

Invariant mass (M_{jj}) resolution

- The invariant mass of the $b\bar{b}$ pair is the most sensitive variable to the Higgs;
- An improvement in resolution has a direct impact on the sensitivity of the search;

- Exploiting tracking and calorimeter information with a neural network;
- 15% resolution improvement;



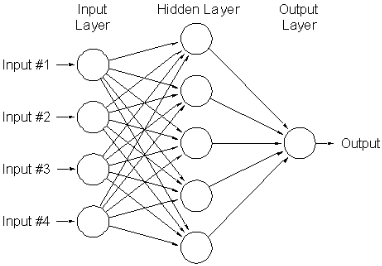


- Using b-ID output to derive M_{jj} from the highest b-ID jets;

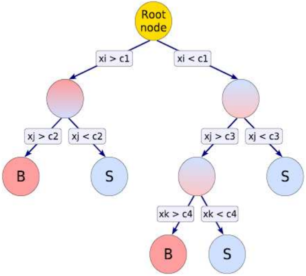
Multivariate techniques

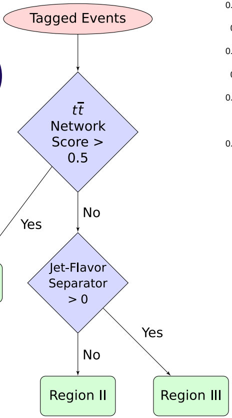
- All analysis presented use some sort of multivariate technique to exploit the correlations between multiple kinematic variables;
  - Improves sensitivity compared to cut-based analysis;
  - However, must be very careful with the choice of training sample;
  - Many checks performed in different kinematic regions to validate the modeling of the inputs to the MVA method and its output;
- Neural Networks, Boosted Decision Trees and Matrix Elements
  - Smearing to stabilize output: random forest, ensemble of networks;

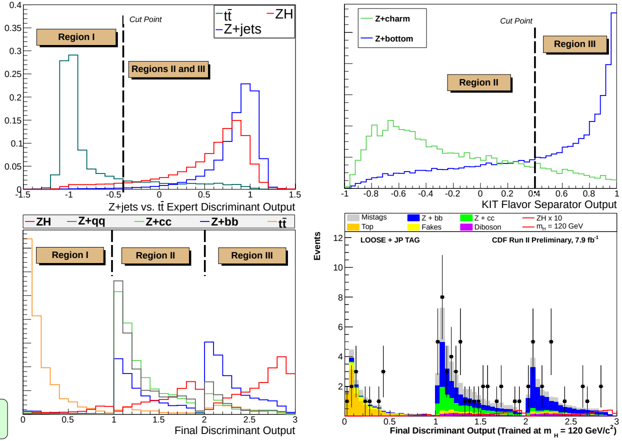
NEURAL NETWORKS



BOOSTED DECISION TREES

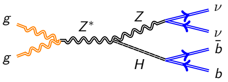


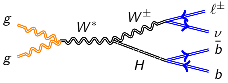


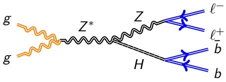


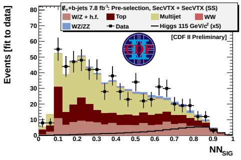
- Separating the *NN* output using $t\bar{t}$, light and heavy flavor score;
- Systematics on large backgrounds constrained by data in region I & II;
- 8% gain relative to the original discriminant network ($ZH \to \ell\ell b\bar{b}$);

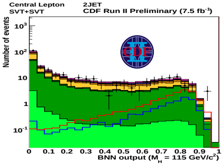
Discriminants, expected (observed) limits [115 GeV/c^2]

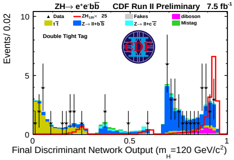




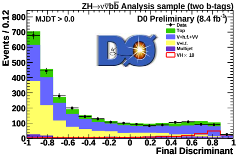


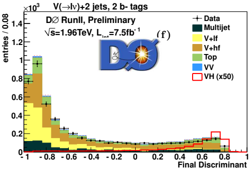


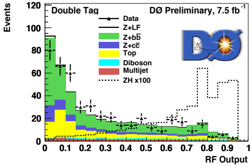




2.9 (2.3) xSM | 2.7 (2.6) xSM | 3.9 (4.8) xSM

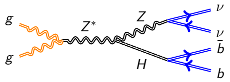


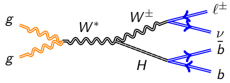


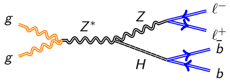


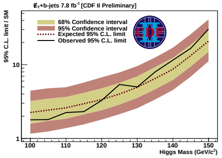
4.0 (3.2) xSM | 3.5 (4.6) xSM | 4.8 (4.9) xSM

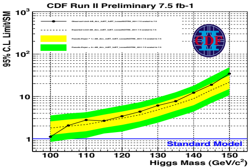
Limits throughout the mass range

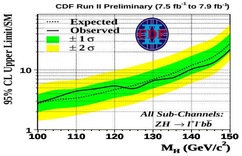


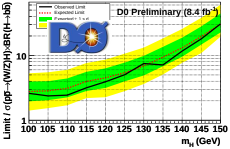


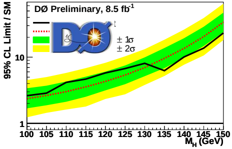


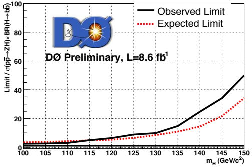






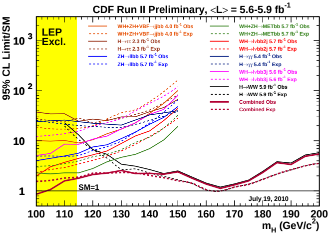


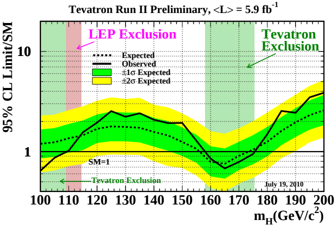




Combining the results from each channel

- Each individual analysis has improved over the 2010 results;
- Best individual analyses sensitive to $\sim 2.5\times$SM;
- They were only sensitive to about $\sim 3.5\times$SM last year;



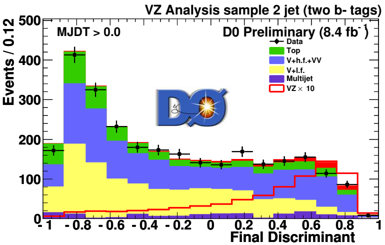


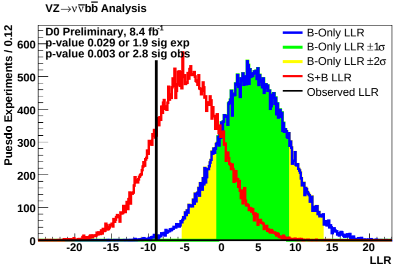
- Expecting sensible improvement in the low mass range;
- Limit @ 115 GeV/c^2should be $\sim 1.2\times$SM (using 4x $\mathcal{L}_{CDF}$);

Summer 2010 Results

Stay tuned for the new 2011 combinations !!!

Testing our sensitivity to WZ/ZZ production





Single-channel (here $ZH \to \nu\nu b\bar{b}$) expected sensitivity about 2σ.
Watch out for the combined result on diboson.

Conclusions

- Low mass Higgs is the hottest topic at the Tevatron;
  - $H \to b\bar{b}$ is the most sensitive decay mode for $m_H < 135$ GeV/c^2;
- We presented the latest results for the three main low mass channels;
  - This is only an overview: for more, go to the public webpages;
  - CDF: `http://www-cdf.fnal.gov/physics/new/hdg/hdg.html`;
  - DZero: `http://www-d0.fnal.gov/Run2Physics/higgs/`;
- Best channel now (last year) at $\sim 2.5(3.5)\times$SM @ 115 GeV/c^2;
- The combined result at low mass should be $\sim 1.2\times$SM;
  - Stay tuned for the actual result;

Other talks on Higgs @ Tevatron:

- High mass: TUCHMING, Boris & LIMOSANI, Antonio [earlier in this track];
- Other low mass channels: KASMI, Azeddine [next talk];
- CDF & DZero combinations: BUZATU, Adrian & GREDER, Sebastien [tomorrow];
- Tevatron combination: JAMES, Eric [Plenary Talk, July 27];

Thank You
Stay tuned for the combinations !!!