# Higgs combination at the Tevatron

*(a personal view)*

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**CERN**

**LHC-HCG Meeting,**

**6th December 2010**

# Tevatron New Phenomena & Higgs Working Group



Members: representatives from both experiments and Higgs group conveners (*ex-officio)*

Weekly meetings (or bi-weekly during quieter times) with minutes sent to a mailing list

Introduced second mailing list restricted basically to the members only (mainly to discuss technical details and initial results without confusing others)

Occasionally special meetings with invited speakers

Maintained webpage http://tevnphwg.fnal.gov/ with link to results, discussions on systematics, etc.

# Responsibilities of the combination group

Agree on what to combine, when, and how

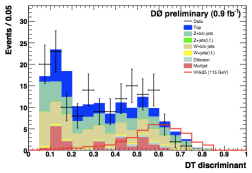
- Understand theory input for Higgs signals and dominant backgrounds
- Discuss and agree on the treatment of systematic uncertainties which are common to both experiments. For this also consult or invite experts to the meetings
- Agree on the form of input needed from analysers (histogram naming etc.)
- Agree on the schedule and tentative inputs
- Do the combination ;)
- Interpretation and approval of the combination such that it can be forwarded to the collaborations. Write the conference notes/publication drafts
- Respond to collaboration comments/review
- Respond to questions/comments/criticism from outside the collaborations

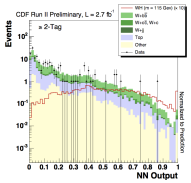
It is mainly the responsibility of the analysers and Higgs conveners that the recommendations of the combination group are followed and the inputs are sound. Combo group does its checks and requests fixes to inputs that are problematic

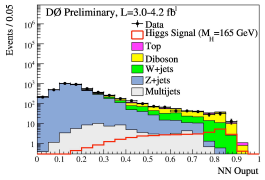
# Main goal

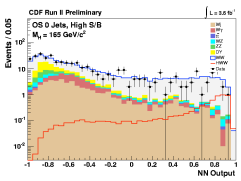
## Combine all channels from CDF and DØ for best Higgs sensitivity

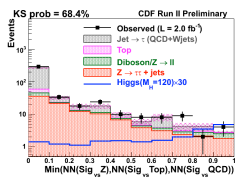
- Combining more than 70 different channels per experiment

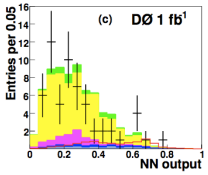


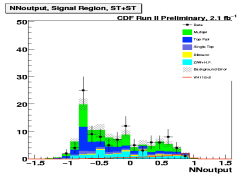



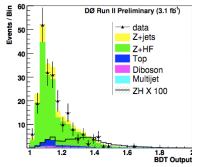



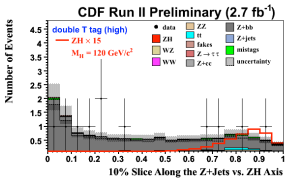



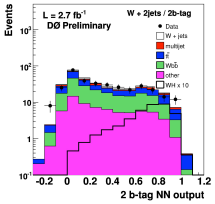



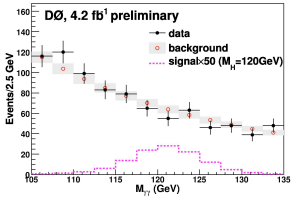




TABLE II: Luminosity, explored mass range and references for the different processes and final states ($\ell = e, \mu$) for the CDF analyses. The labels "2×" and "4×" refer to separation into different lepton categories.

| Channel | Luminosity (fb$^{-1}$) | $m_H$ range (GeV/$c^2$) | Reference |
|---|---|---|---|
| $WH \to \ell\nu b\bar{b}$ 2-jet channels 4×(TDT,LDT,ST,LDTX) | 5.7 | 100-150 | [5] |
| $WH \to \ell\nu b\bar{b}$ 3-jet channels 2×(TDT,LDT,ST) | 5.6 | 100-150 | [6] |
| $ZH \to \nu\bar{\nu}b\bar{b}$ (TDT,LDT,ST) | 5.7 | 100-150 | [7] |
| $ZH \to \ell^+\ell^- b\bar{b}$ 4×(TDT,LDT,ST) | 5.7 | 100-150 | [8, 9] |
| $H \to W^+W^-$ 2×(0,1 jets)+(2+ jets)+(low-$m_{\ell\ell}$)+(e-$\tau_{had}$)+($\mu$-$\tau_{had}$) | 5.9 | 110-200 | [10] |
| $WH \to WW^+W^-$ (same-sign leptons 1+ jets)+(tri-leptons) | 5.9 | 110-200 | [10] |
| $ZH \to ZW^+W^-$ (tri-leptons 1 jet)+(tri-leptons 2+ jets) | 5.9 | 110-200 | [10] |
| $H + X \to \tau^+\tau^-$ (1 jet)+(2 jets) | 2.3 | 100-150 | [11] |
| $WH + ZH \to jjb\bar{b}$ 2×(TDT,LDT) | 4.0 | 100-150 | [12] |
| $H \to \gamma\gamma$ | 5.4 | 100-150 | [13] |

TABLE III: Luminosity, explored mass range and references for the different processes and final states ($\ell = e, \mu$) for the D0 analyses. Most analyses are in addition analyzed separately for RunIIa and IIb. In some cases, not every sub-channel uses the same dataset, and a range of integrated luminosities is given.

| Channel | Luminosity (fb$^{-1}$) | $m_H$ range (GeV/$c^2$) | Reference |
|---|---|---|---|
| $WH \to \ell\nu b\bar{b}$ (ST,DT,2,3 jet) | 5.3 | 100-150 | [14] |
| $VH \to \tau^+\tau^- b\bar{b}/q\bar{q}\tau^+\tau^-$ | 4.9 | 105-145 | [15, 16] |
| $ZH \to \nu\bar{\nu}b\bar{b}$ (ST,TLDT) | 5.2-6.4 | 100-150 | [17, 18] |
| $ZH \to \ell^+\ell^- b\bar{b}$ (ST,DT,$ee$,$\mu\mu$,$ee_{ICR}$,$\mu\mu_{trk}$) | 4.2-6.2 | 100-150 | [19] |
| $VH \to \ell^\pm\ell^\pm + X$ | 5.3 | 115-200 | [20] |
| $H \to W^+W^- \to e^\pm\nu e^\mp\nu, \mu^\pm\nu\mu^\mp\nu$ | 5.4 | 115-200 | [21] |
| $H \to W^+W^- \to e^\pm\nu\mu^\mp\nu$ (0,1,2+ jet) | 6.7 | 115-200 | [22] |
| $H \to W^+W^- \to \ell\bar{\nu}jj$ ×2 | 5.4 | 130-200 | [23] |
| $H \to \gamma\gamma$ | 4.2 | 100-150 | [24] |
| $t\bar{t}H \to t\bar{t}b\bar{b}$ (ST,DT,TT,4,5+ jets) | 2.1 | 105-155 | [25] |

## More than 200 different sources of systematic uncertainties are considered, and constrained in sidebands

# Doing the combination

CDF and DØ used mainly two different techniques and completely separate programs to do the combination

CDF mainly Bayesian limits, DØ $CL_s$ limit

As a cross check, both experiments compute individual CDF, DØ and Tevatron combinations. All results have to agree within 5-10%!

Note: the final statistical analysis of individual searches (and combinations therein) are done with the same programs as the 'big combinations'

The two collaborations review the combined result in form of a conference note and internal presentation, where both collaborations follow their own review process

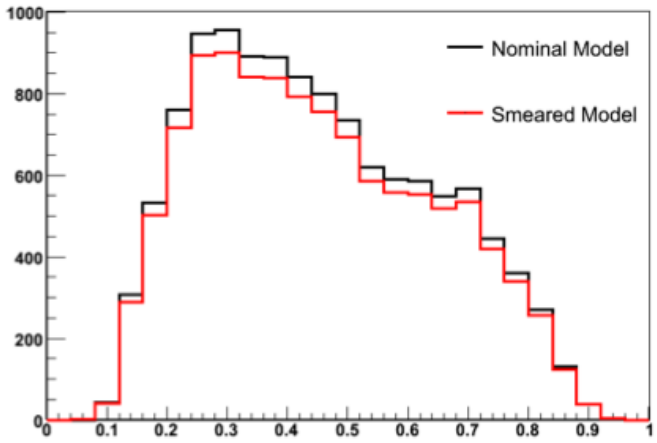
The collaborations do not review the individual results (analyses) of the other collaboration

(Within the combination group and among the conveners individual results of the other collaboration are discussed)

# Practicalities

Exchange of histograms

- Can do a variety of statistical treatments and compare
- Cross check analyzers work
- Scaling of histograms if needed
- Etc.




Shape errors supplied as alternate shape histograms

- Typically ±1σ shape variations are explored one source at a time by analyzers

Histogram names used to categorize correlations in a way easy to understand

Treatment of common systematics and histogram naming to be decided by the combination group in advance (though some limited adjustment at the combination stage still possible). Conveners need to follow up with analyzers

Same treatment of individual results which appear in addition in separate conference notes or papers

# Timelines and approval procedure I.

Usually twice a year individual CDF and DØ combinations, once or twice per year Tevatron combination

Start combination procedure approx. 4 weeks before the conference to have time to understand and validate the result (combo group and collaborations)

Usually set a ‘cut-off’ and a ‘drop’ date for results entering the combination

- Cut-off date is usually 2-3 weeks before the combination needs to be ready. This date determines which analysis is mature to enter the combination
- Drop date is usually one week later. After this time individual inputs cannot be changed, only dropped from the combination (if not approved by the collaboration for example)

Combination result has to be final and documented in a conference note a week before the conference. Note be reviewed by the two collaborations before final approval

# Timelines and approval procedure II.

All these deadlines interfere with the approval of the individual results of the experiments which have their own review processes

Individual analyses and issues surrounding systematics become more complex

- As the data sample grows (ie, statistical uncertainty falls)
- As we get closer to SM sensitivity (ie, when resolving a signal matters more)

Due to this, the typical reasons why analyzers do not make it with their result in time (my experience from DØ):

- Underestimation of the time and difficulties to estimate systematic uncertainties and the final statistical evaluation of the result
- Underestimation of the time needed for the internal review

Simply having earlier deadlines does not help

- Not easy to fool the analyzers about the real deadlines ;)
- Constant reminder of the deadlines
- Workshops to discuss intermediate results with certain goals

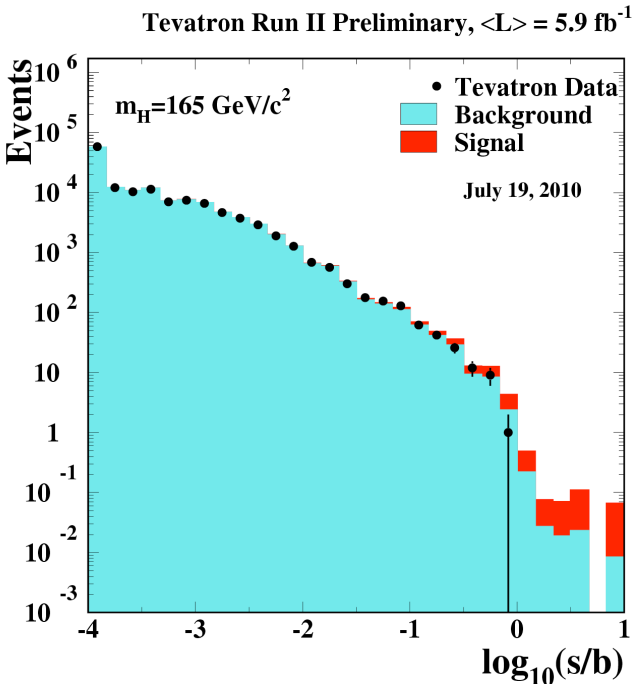
# Timelines and approval procedure III.

It takes usually almost a week and a lot of computer resources to run and make checks of the full Tevatron combination

This is certainly a limiting factor if any problems (e.g. differences between the two limit setting procedures) need to be tracked down

- Start combination procedure early enough (difficult of course if individual results are not ready)
- Discuss and investigate everything well before the rush time (changes in systematics treatment, code improvement, etc.)
- Ongoing work to speed up the calculation (e.g. combine bins with same s/b of different channels, not straight forward due to profiling/integration)

Important to have many experts per experiment who can work together



# Joint publications

**Combination of Tevatron searches for the standard model Higgs boson in the $W^+W^-$ decay mode**

T. Aaltonen[†],[15] V.M. Abazov[‡],[53] B. Abbott[‡],[121] M. Abolins[‡],[106] B.S. Acharya[‡],[35] M. Adams[‡],[84] T. Adams[‡],[80] J. Adelman[†],[83] E. Aguilo[‡],[7] G.D. Alexeev[‡],[53] G. Alkhazov[‡],[57] A. Alton[mm‡],[104] B. Álvarez González[x†],[61] G. Alverson[‡],[99] G.A. Alves[‡],[2] S. Amerio[ff†],[39] D. Amidei[†],[104] A. Anastassov[†],[86] L.S. Ancu[‡],[52] A. Annovi[†],[38] J. Antos[†],[58] M. Aoki[‡],[82] G. Apollinari[†],[82] J. Appel[†],[82] A. Apresyan[†],[91] T. Arisawa[†],[46] Y. Arnoud[‡],[17] M. Arov[‡],[95]

Similar procedure compared to combinations for conferences. But more formalized. Spokes authored a written document

Results to be combined should be submitted to a journal by each collaboration prior to joint paper submission

Each collaboration follows its own rules in the review process (again, details of the ‘submitted-for-publication’ results are not subject of the review)

Final approval by the Spokes and Physics coordinators of both experiments

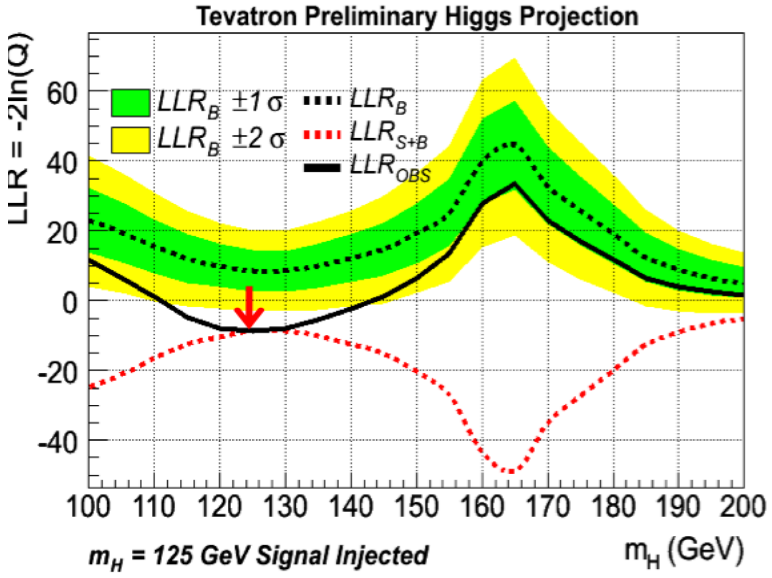
In answering the referees’ questions the combination group is playing role of the primary authors

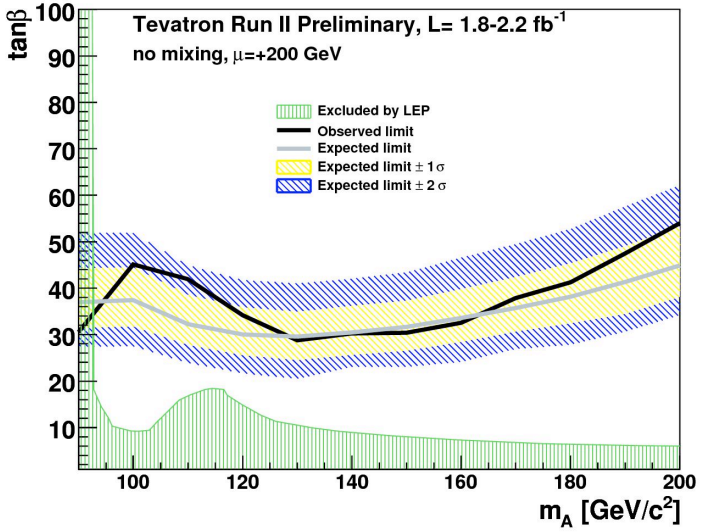
Combining the authorship list of the two collaborations turned out to be nearly as complex as combining the Higgs results ;)

# A lot to do even without conference deadlines

Many other tasks belong to the combination group and new challenges emerge with time

- Projections (including detailed estimates on improvements)
- How would a signal look like?
- How well could we measure the mass?
- Other combinations (e.g. MSSM, in future include SM searches)
- Etc.



# Conclusions

Most things happen and get decided with common sense

The roles and challenges of the combo group evolve with time

The best is to set up everything and practice already in advance, not just when the combination needs to be done. Get used to work with each other

- At times naturally can be prickly and so good to build up trust and understanding. Tensions, when they do arise, are virtually always a result of misunderstanding
- There are times when one does need the input of PCs and Spokes, to set the milestones, etc. (They are anyway involved, mailing list etc.)

There is a healthy competition between CDF & DØ, but at the end the dominant sentiment is solidarity (no discovery with only one Tevatron experiment!)