SM benchmark processes for the Higgs search at the Tevatron

Fabrizio Margaroli
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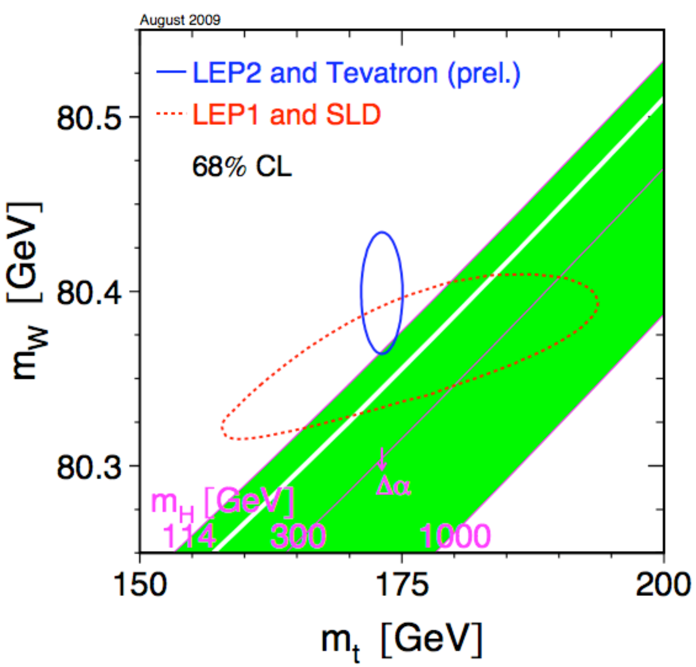
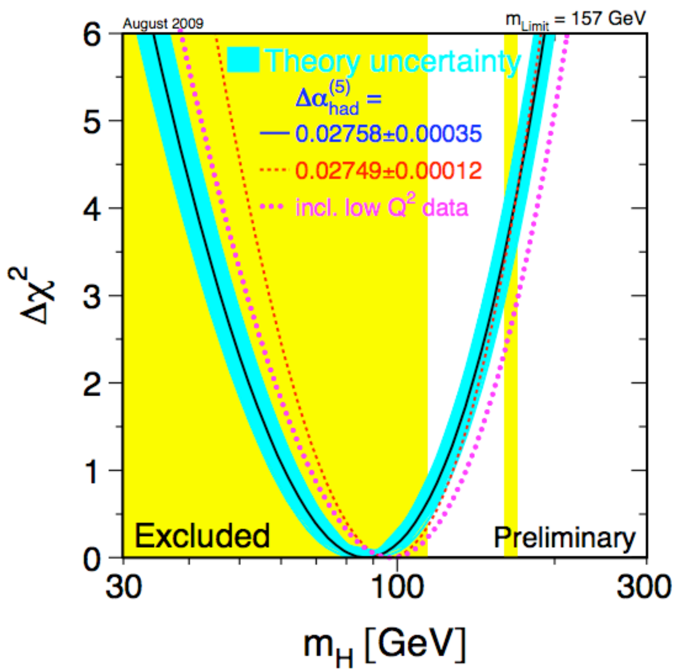
Where to look

Explaining the EW symmetry breaking is a major goal for particle physics
Finding the Higgs boson a good proof that this mechanism is the one that nature chose
Global fit with Tevatron's
m_{top} = **173.3 ± 1.3 GeV** and m_W = **80.399 ± 0.025 GeV**
gives expected

- m_H = **89+35-26 GeV** @ 68 % CL
- m_H **< 158 GeV** @ 95 % CL





Direct searches at LEP:
m_H > 114.4 GeV @ 95% CL

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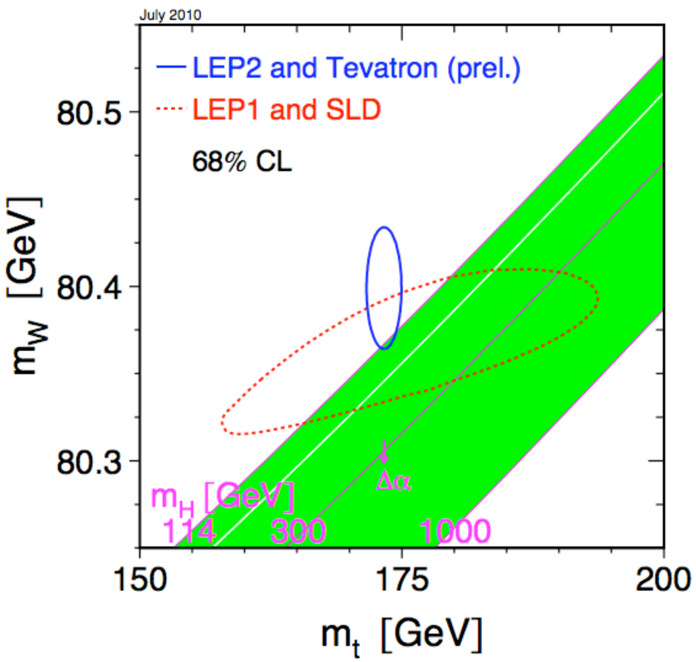

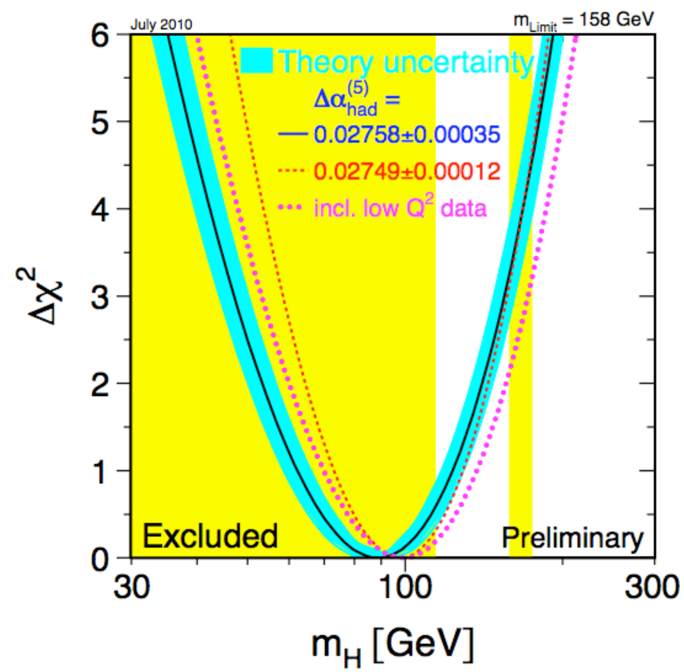

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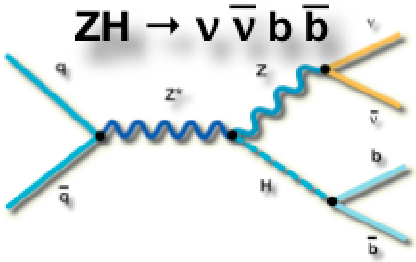
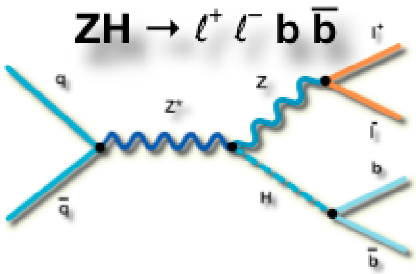
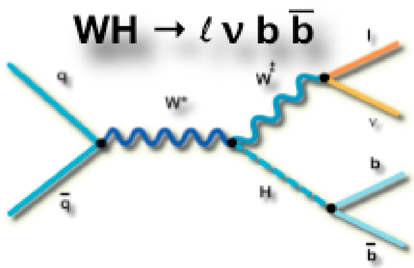
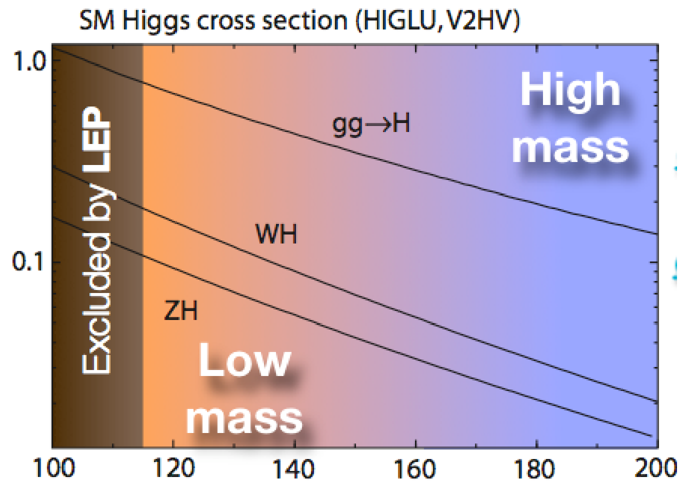
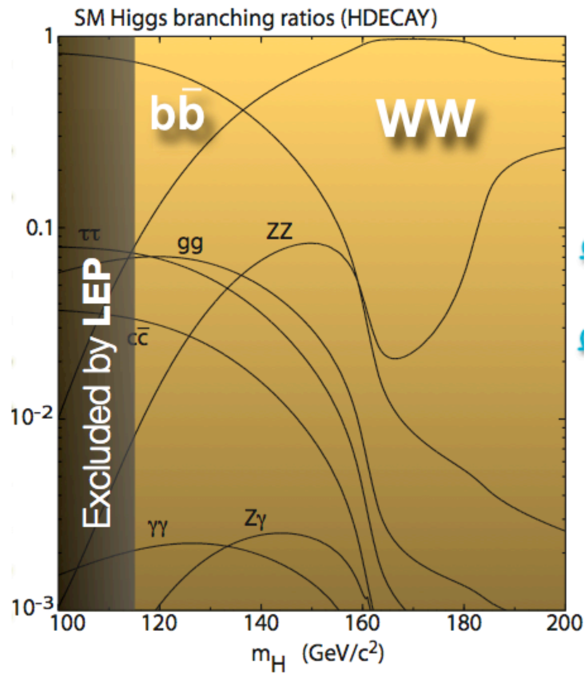




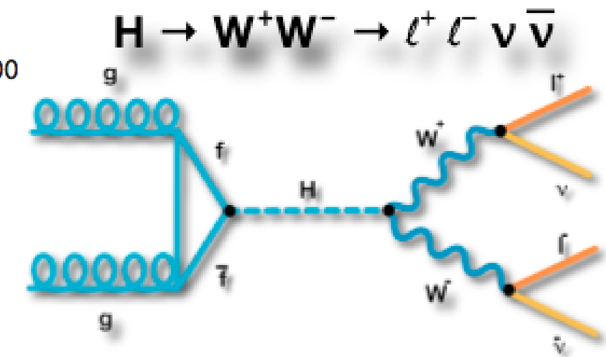


- σ(VH)xBR(H→bb)~0.1pb at low mass
- Presence of extra vector boson decays helps to reduce backgrounds





- σ(H)xBR(H→bb)~0.5pb at low mass
- But bbar final state overwhelmed by QCD



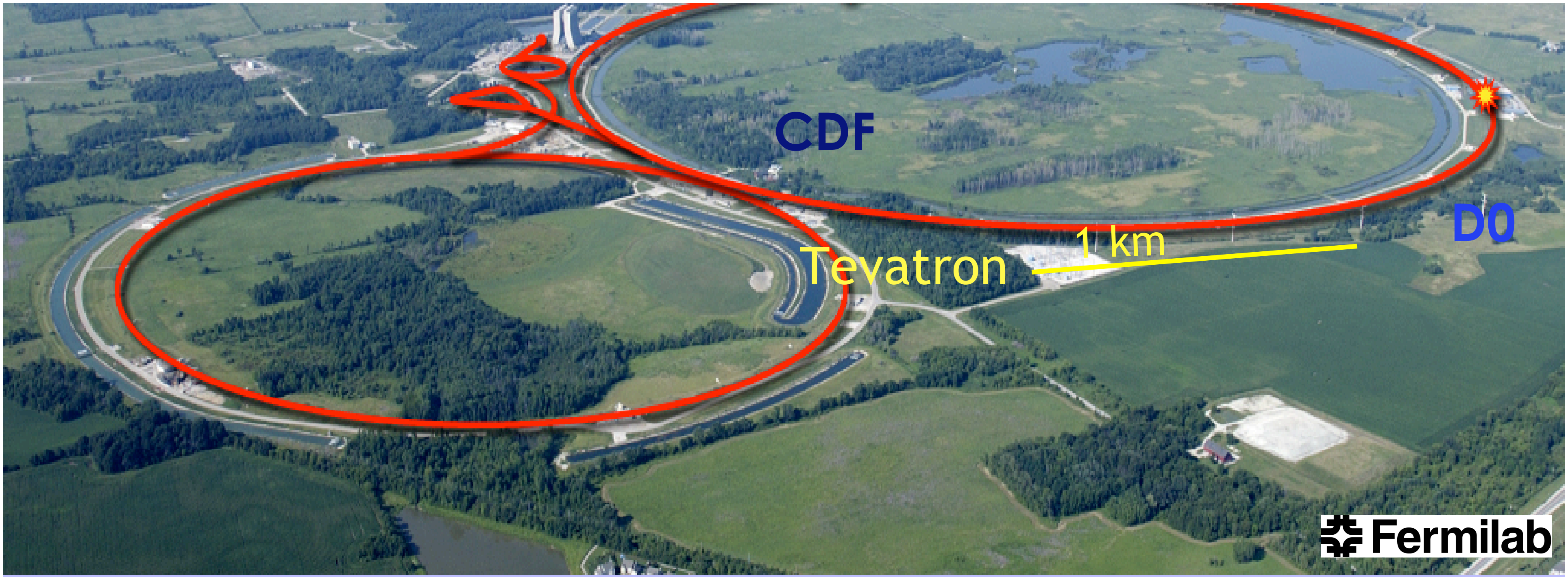
- σ(H)xBR(H→WW)~0.3pb at high mass
- But presence of charged and neutral leptons allows cleaner signature

Where?

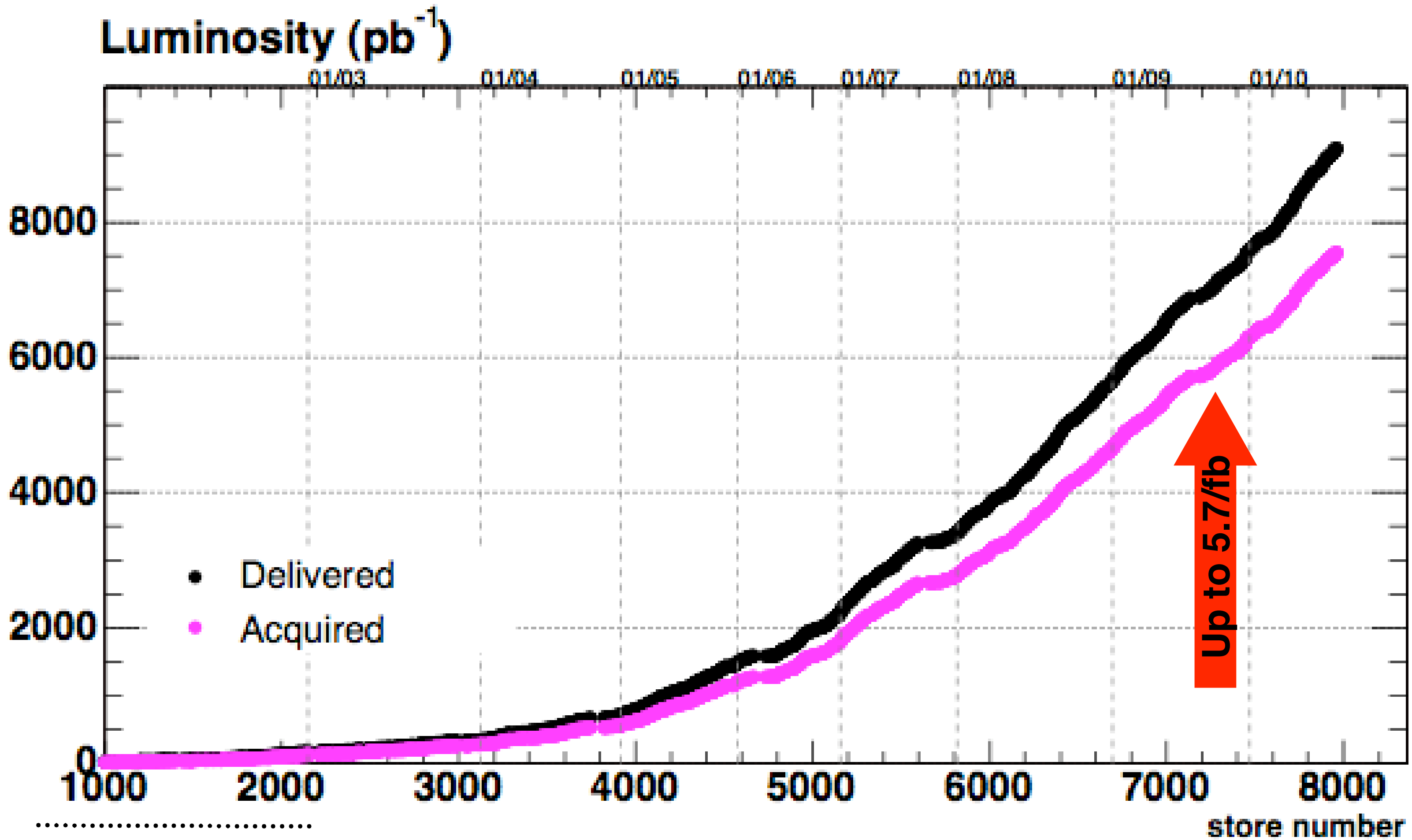
Fermilab's Tevatron Run II $p\bar{p}$ collider at 1.96 TeV, running since year '01. Currently performing very well:

- New record in instantaneous luminosity $4 \cdot 10^{32}$ cm^{-2} s^{-1}
- New record in delivered luminosity: >2fb^{-1} per year
- Two multi-purpose, well-understood detectors CDF and D0

Higgs created in 1 in $O(10^{11}/10^{12})$ collisions at the Tevatron



How many



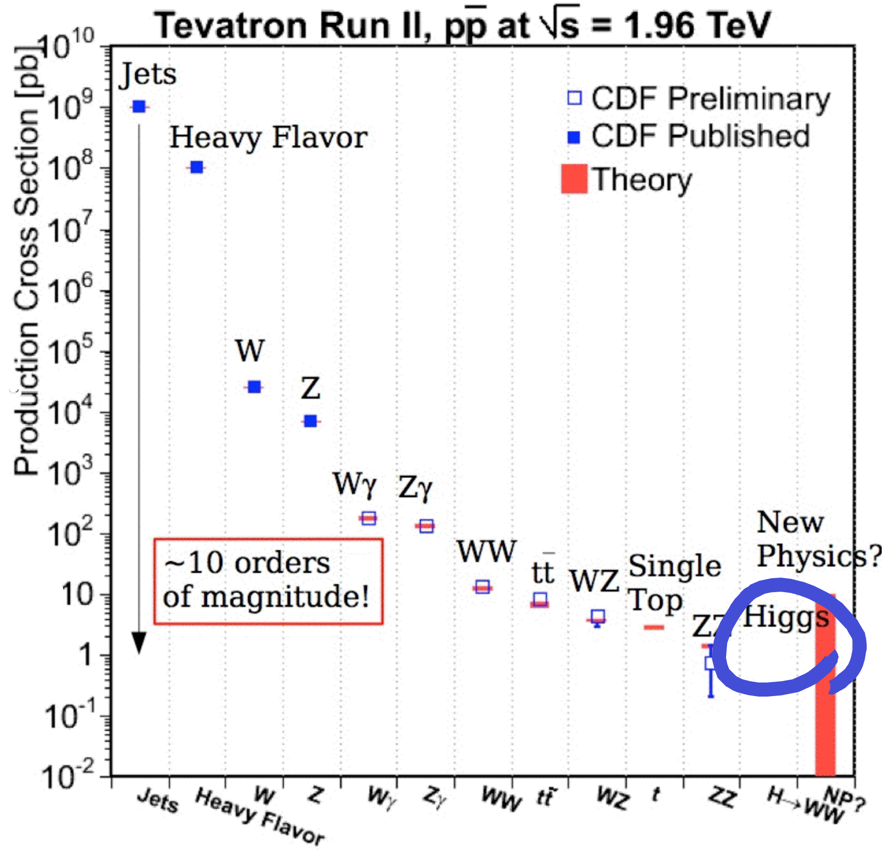
Delivered 9.0 fb^{-1}
Acquired 8 fb^{-1*} (slightly less w/ silicon)
Analyzed 6fb^{-1*}

*CDF shown here
Similar numbers for D0

The roadmap to Higgs

The Higgs search

Challenges	Low mass	High mass
Broad resonance	√	
No resonance!		√
Terribly low S/B	√	√
Need for MVA	√	√
Control QCD rate	√	
Control of W/Z+jets	√	
Control QCD kinematics	√	



Need to test all of the above in independent samples.
Even better if by doing so you produce

- a wealth of good physics
- and in several sectors of the SM!

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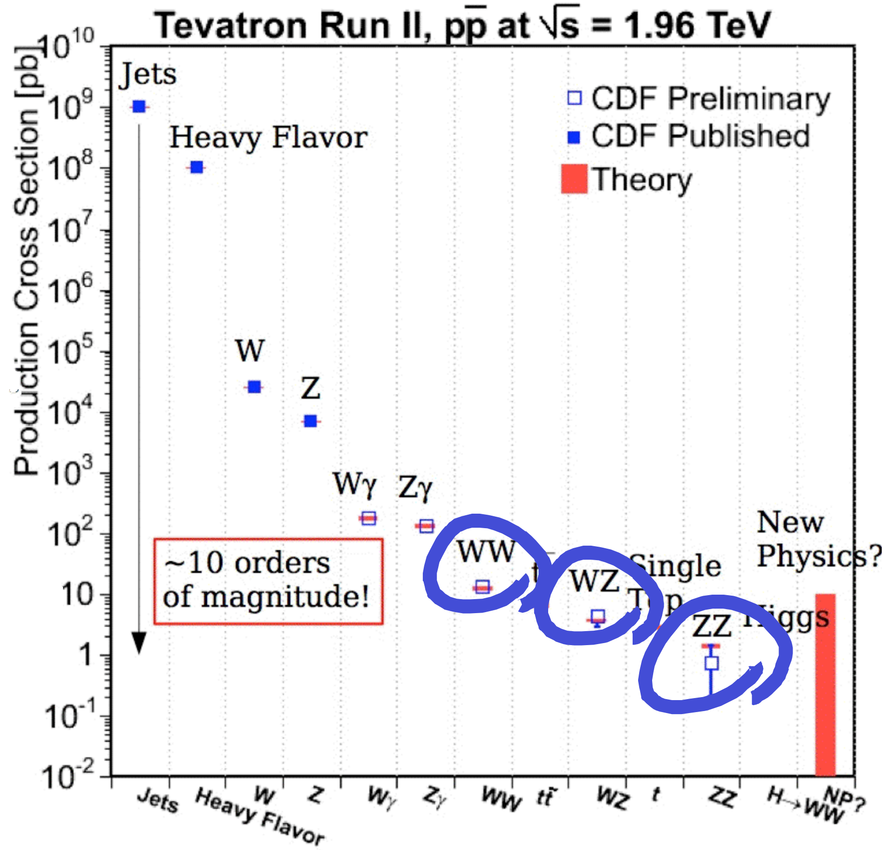

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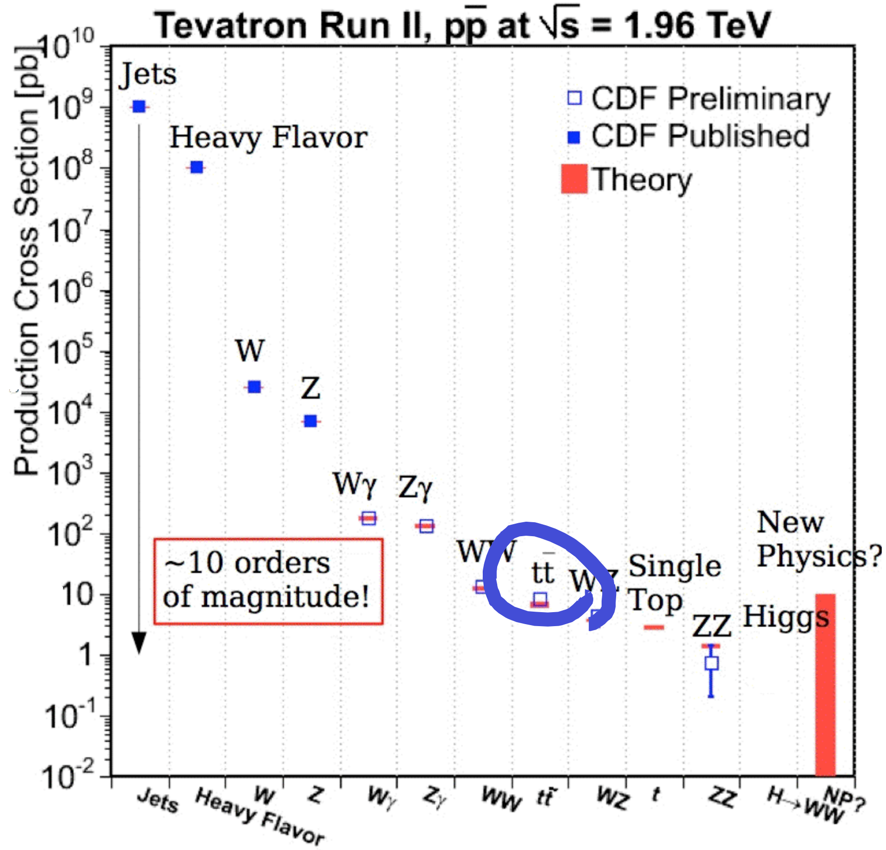

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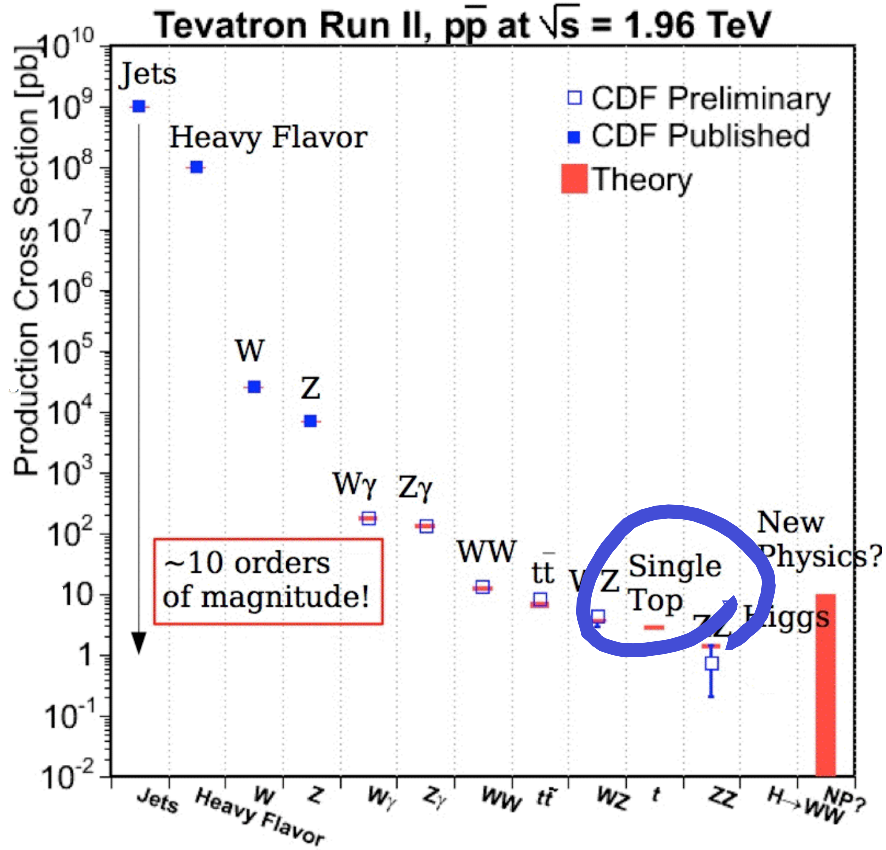

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Z→b$\bar{b}$

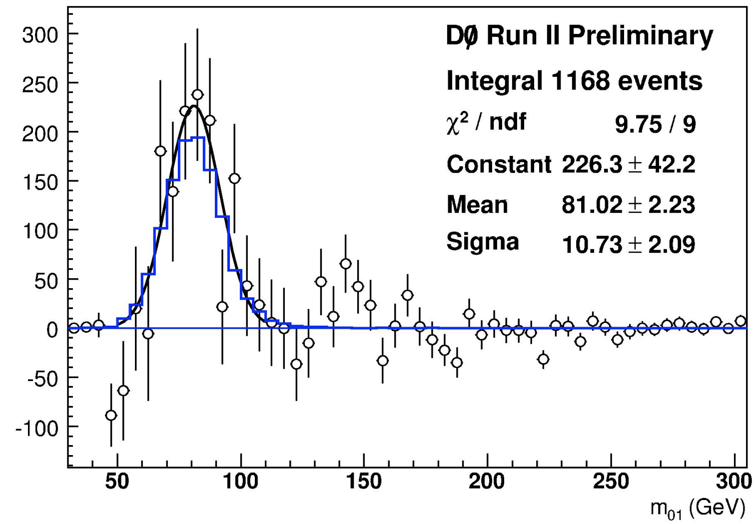
- Quark/gluons hadronize and produce particle jets.

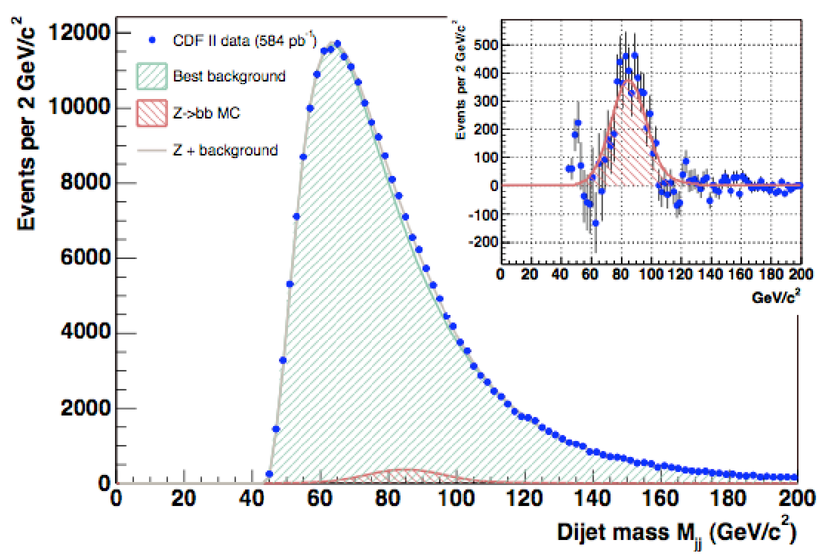
✓ Seconday vertex: B mesons have long lifetime: identification through search of a secondary vertex within a jet:
✓ b-tag eff: ~ 40%
✓ fake rate ~ 0.5%

✓ Neural Network for flavor separation

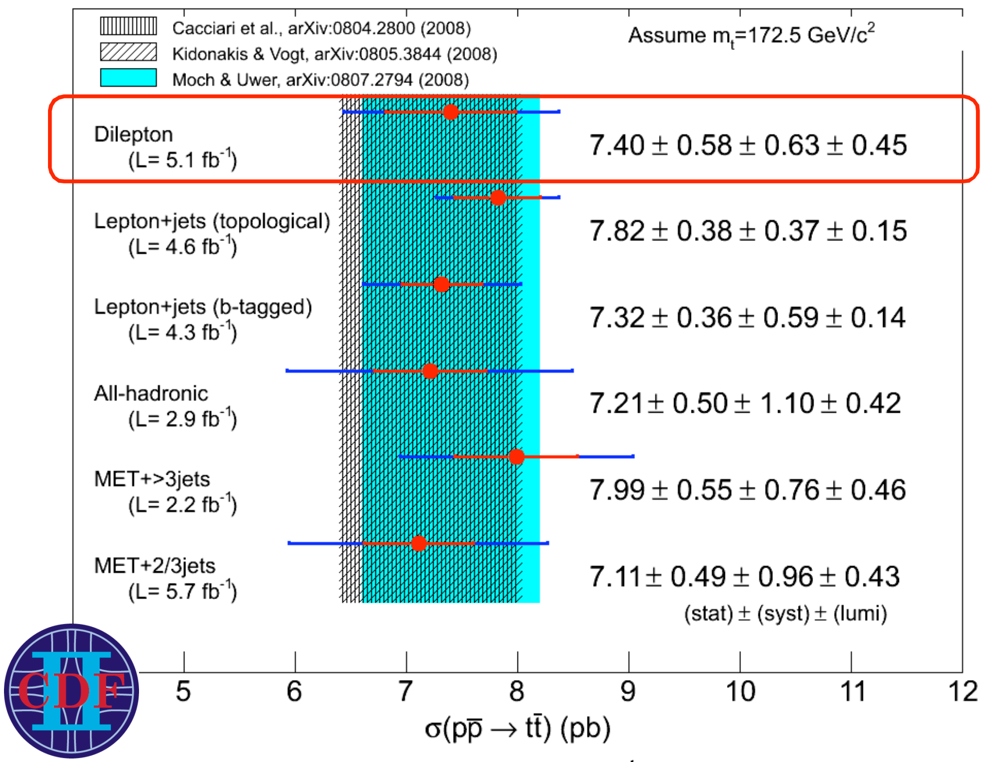
  - L_{xy}, vertex mass, track multiplicity, impact parameter, semi-leptonic decay information, etc...

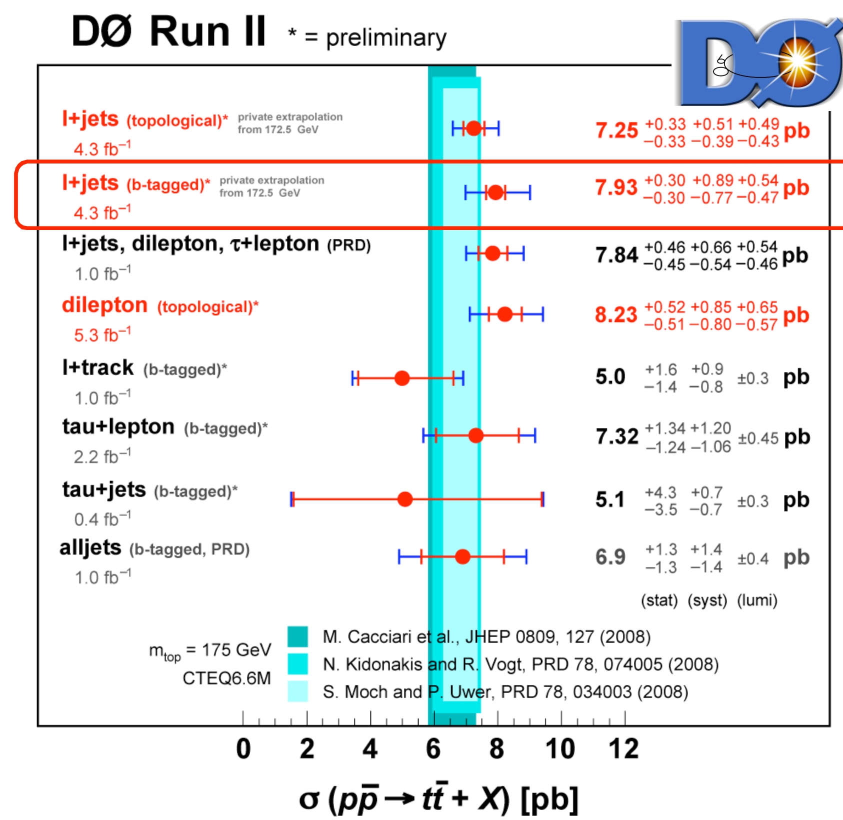
- Use b-jet trigger to control the rate
- S/B=1/30 for both CDF and D0
- QCD background modeled from data

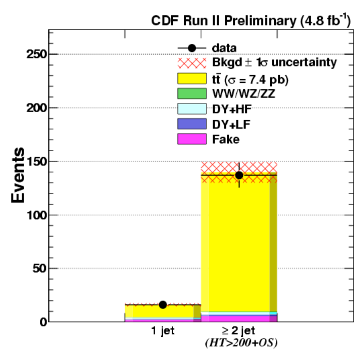


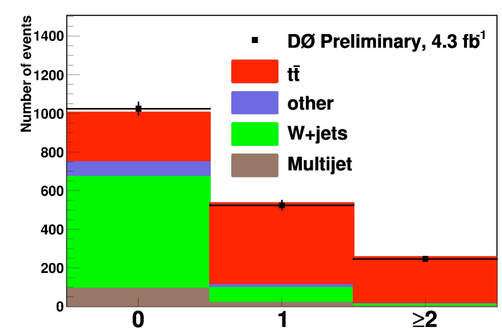


Total cross section:w/o multivariate









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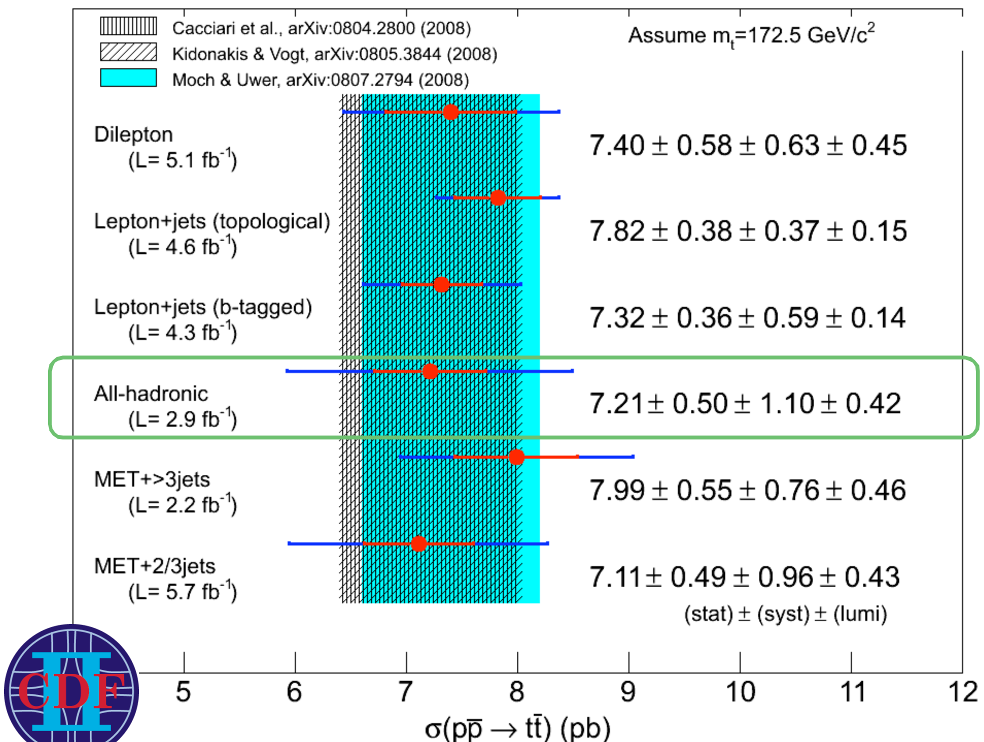
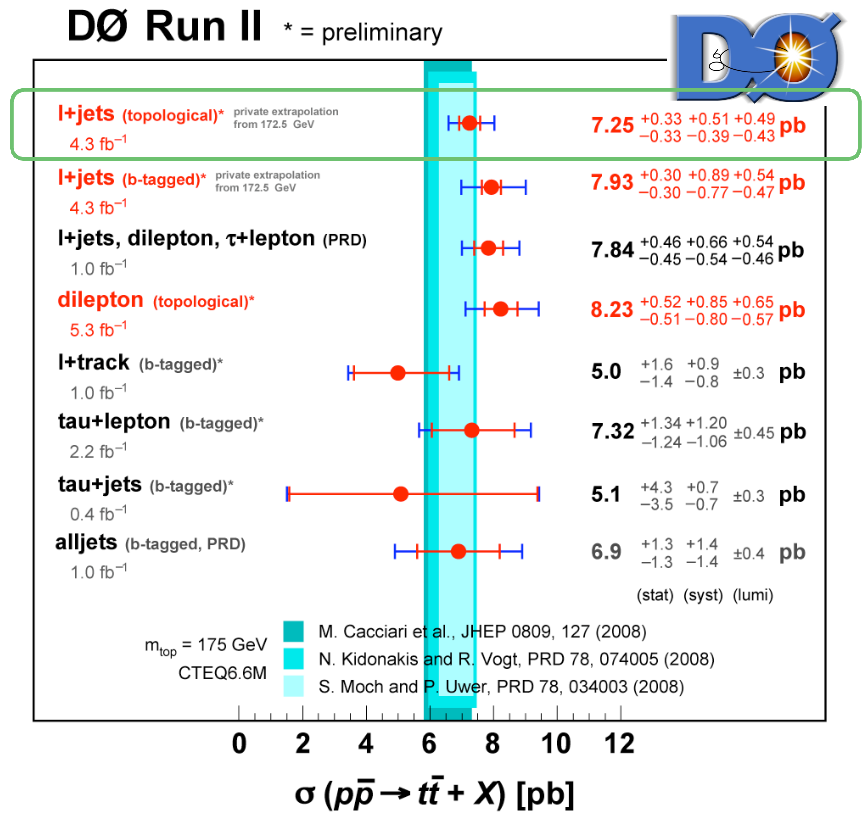
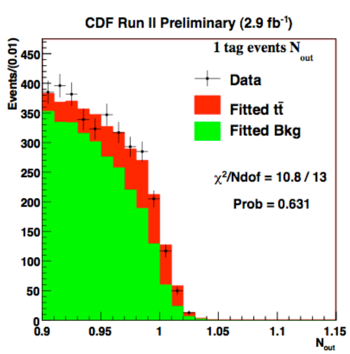
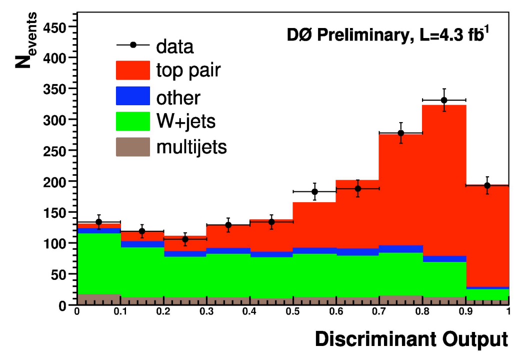
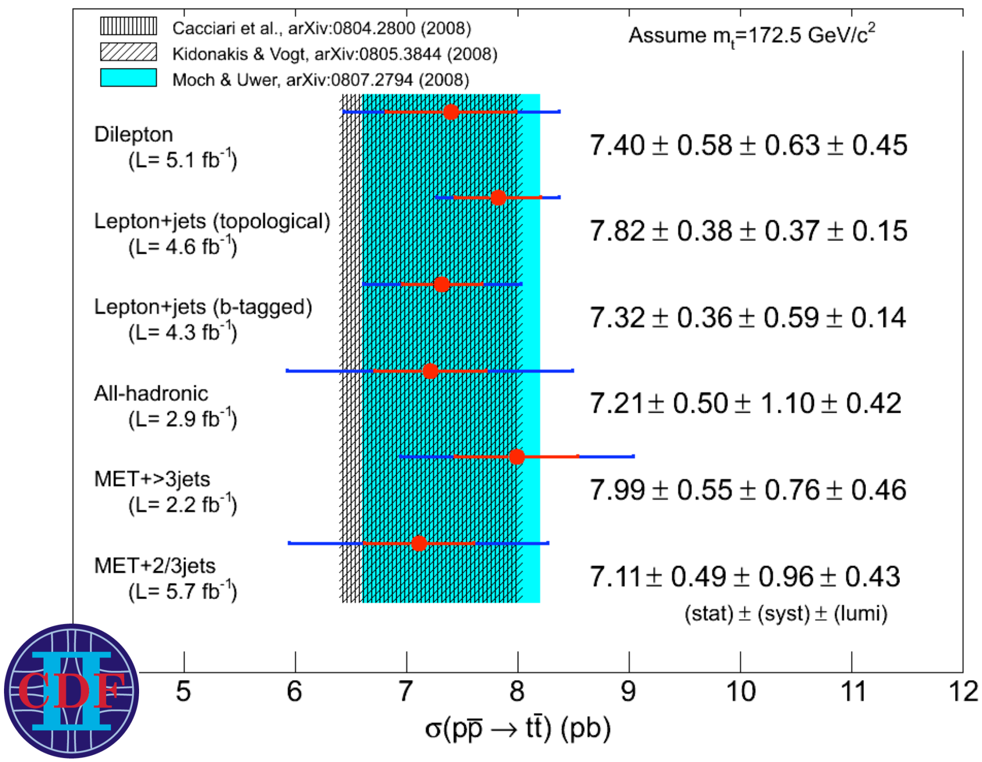


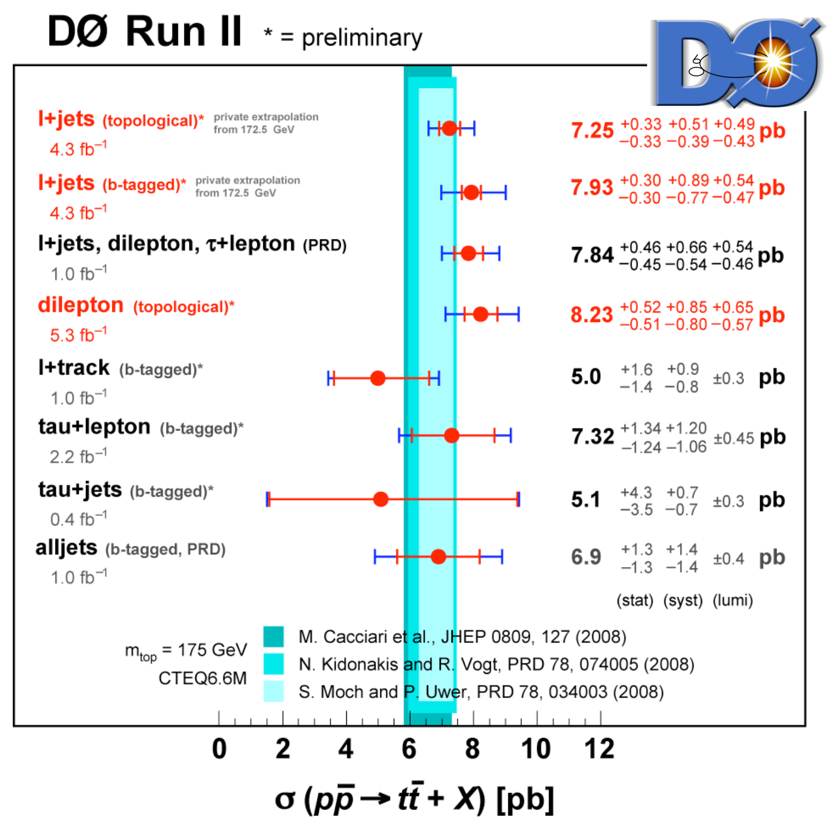






Total cross section: consistency

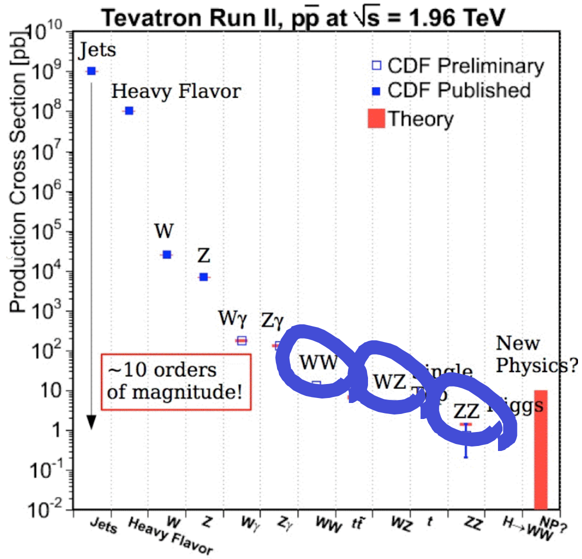




- Good consistency among channels/experiments → no apparent bias from usage of multivariate techniques
- *No reason to expect it!*: all systematic sources studied on independent samples, then propagated through the analyses

Benchmark processes to WH/ZH→MET+jets

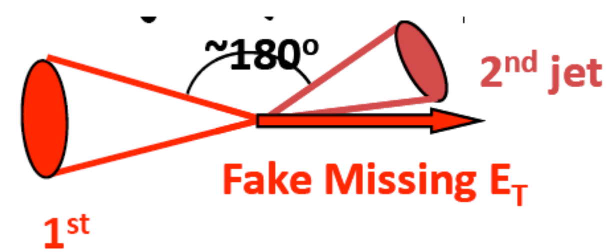
Diboson in MET+jets(+X)



Limited dijet mass resolution → overlap of the W and Z dijet mass peaks

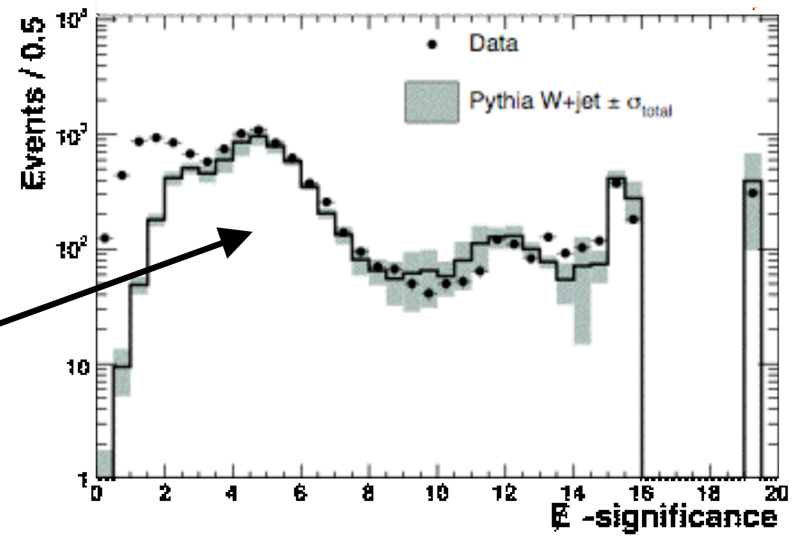
- require large MET and two jets
- no requirement on leptons

QCD here is dominant due to calorimeter energy resolution effects



Approach to QCD suppression:

- model the jet energy resolution as a function of jet Pt and eta to derive a probability for the event to be QCD like (CDF and D0)
- Test in events with identified leptons to check goodness



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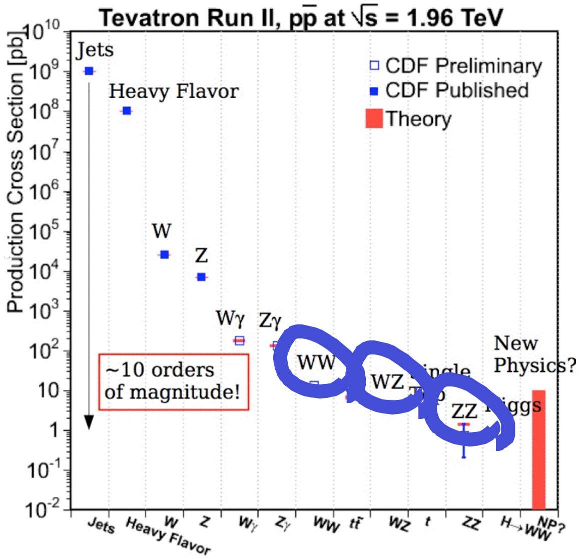

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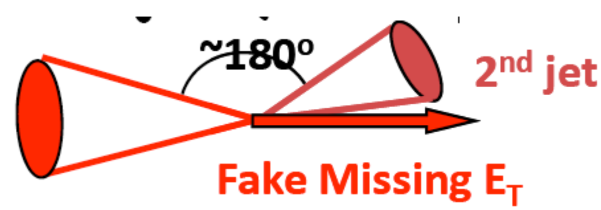

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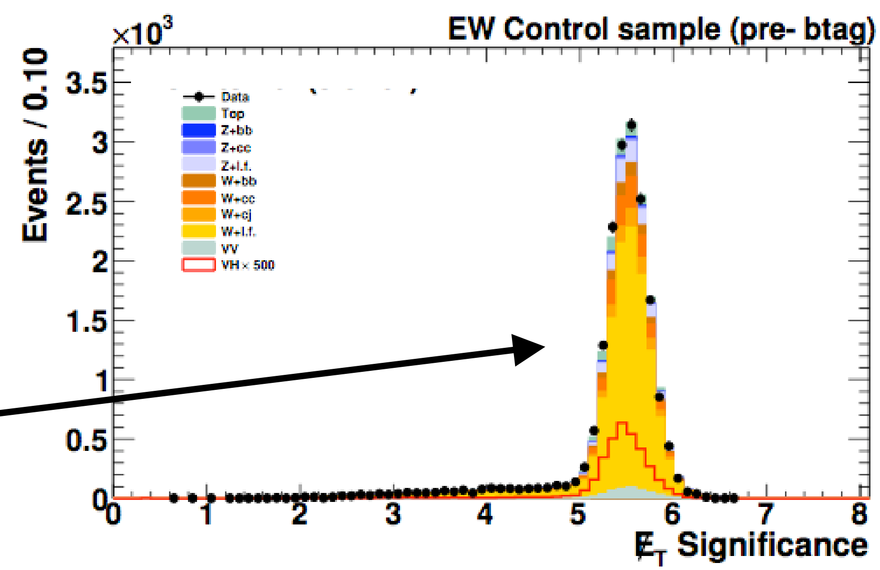


WW/WZ/ZZ→MET+jets

Goal: to measure WW/WZ/ZZ together in events where one boson decays to jets

After event selection cuts,

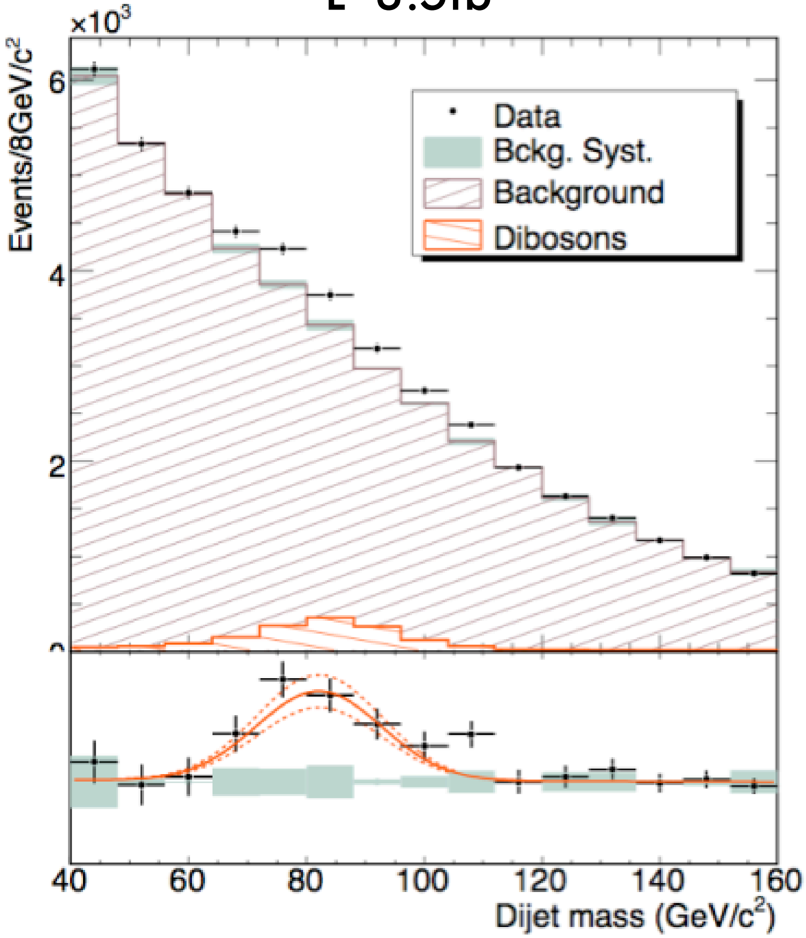
B=45000

S=1500 events (S/B=1/30)

Background model

- Use QCD events in the $\Delta\varphi(E_T,P_T)>1.0$ to model QCD in signal region
- MC for top, W/Z+jets
- W+jets: use γ+jj data to model it
  - Significantly reduces systematics associated to limited understanding of W+jets

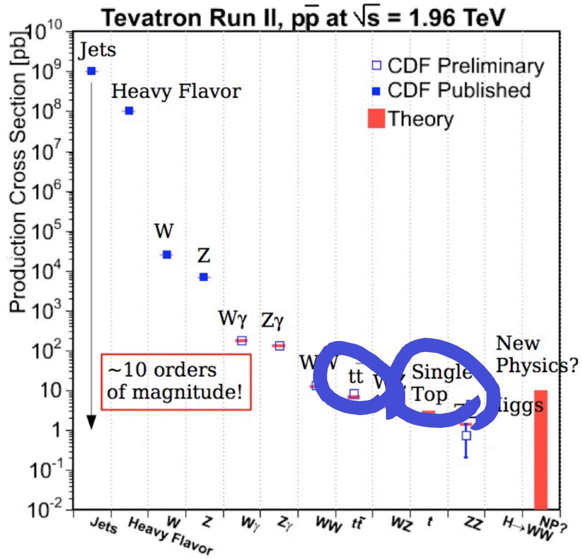
L=3.5fb^{-1}



Phys.Rev.Lett.103:091803,2009.

σ(WW+WZ+ZZ)=18.0 ± 2.8(stat) ± 2.4(syst) ± 1.1(lumi) pb

Going lower in cross sections



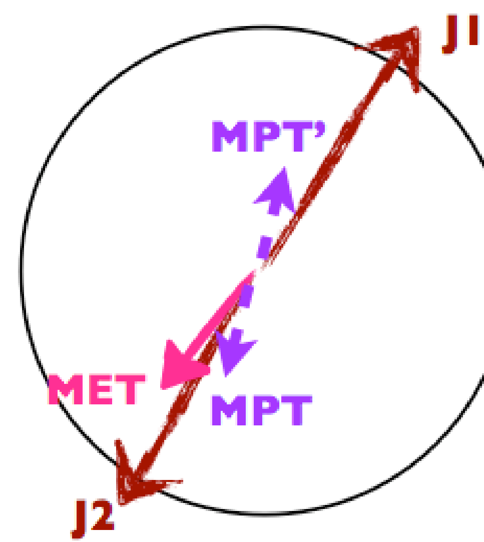
Idea: to measure a (smaller than WW/WZ/ZZ but) large and well-understood background with the same event selection as the HV search

- require large MET and two/three jets
- *At least one b-tagged jet*
- Explicit veto on charged leptons (e/mu)
- Accept tau decays without explicit ID

Top production sneaks in when leptons and/or jets are not reconstructed

- Utilize the different kinematical and topological properties of QCD events
- in particular the *missing Pt from the tracker* (MPT)
- develop a multivariate event selection (CDF and D0)

Typical QCD event



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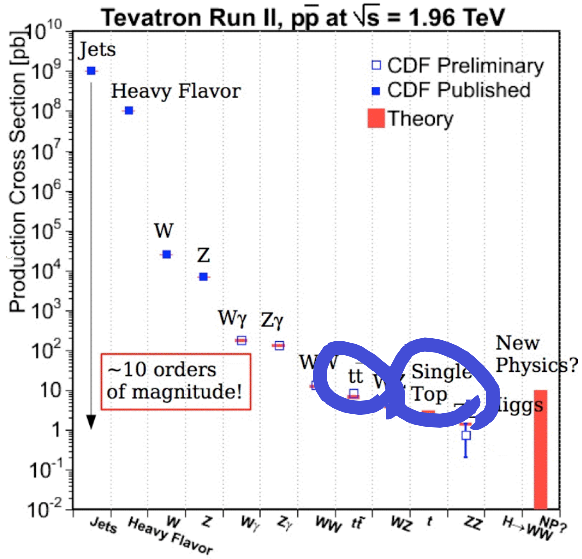

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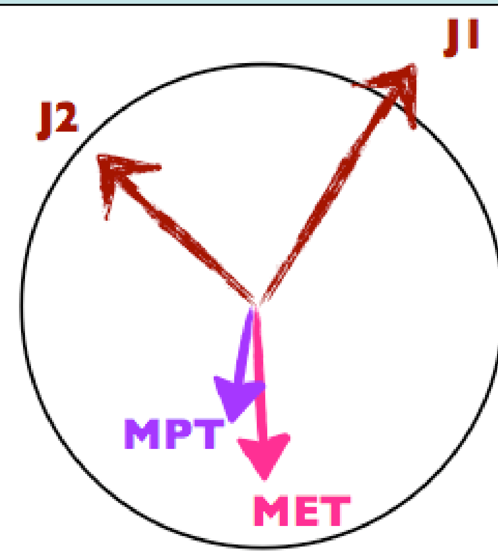
A sketch of ZH→ννbb event

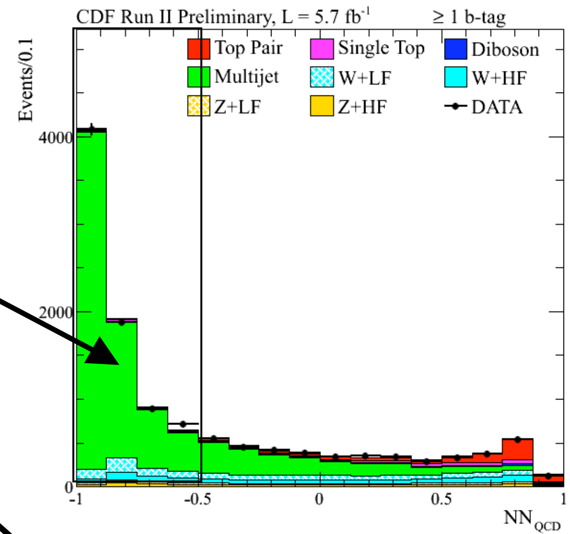


- Utilize the different kinematical and topological properties of QCD events
- in particular the *missing Pt from the tracker* (MPT)
- develop a multivariate event selection (CDF and D0)

$t\bar{t}$ in MET+(b)-jets

Using same two-step strategy as in search for $ZH \to \nu\nu bb$:

- One NN to suppress overwhelming QCD background and improve S/sqrt(S+B)
- Then one more NN to isolate the signal from the backgrounds that have large rate uncertainty (W+jets)

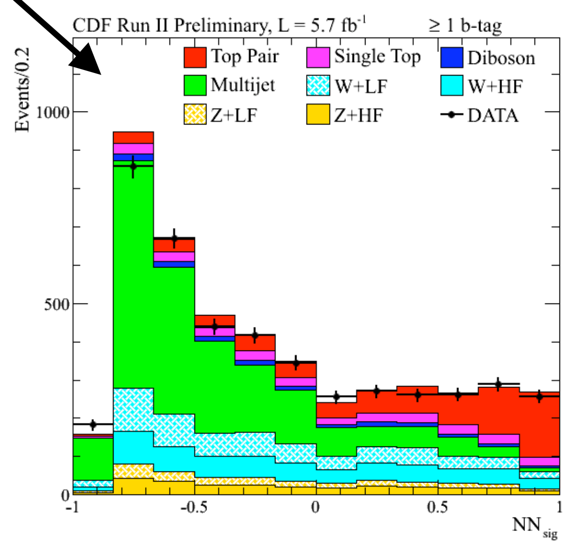


Many new particles can appear here in addition to Higgs

- $\tilde{b}\tilde{b} \to bb\chi^0\chi^0$
- 3rd gen leptoquarks
- technicolor etc.etc.

ttbar cross section measurement here is

- a test of the backgrounds/machinery
- independent from other $\sigma_{t\bar{t}}$ measurements $\to$ can be combined to increase precision

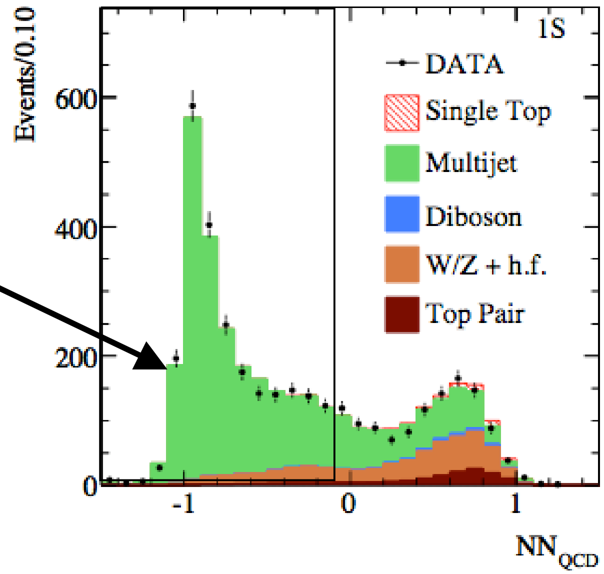


$\sigma_{t\bar{t}}(M_{top}=172.5)$= 7.1 ± 1.1 (stat+syst+lumi) pb

Single top in MET+(b)jets

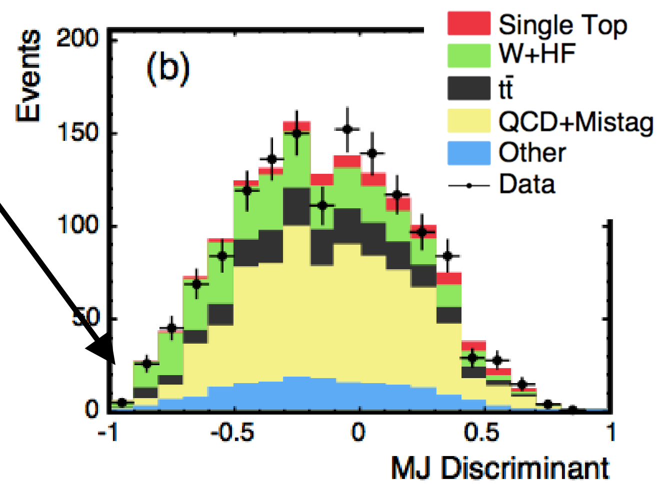
Using same two-step strategy as in search for $ZH \rightarrow \nu\nu bb$:

- One NN to suppress overwhelming QCD background and improve S/sqrt(S+B)
- Then one more NN to isolate the signal from the backgrounds that have large rate uncertainty (W+jets)



Phys.Rev.D81:072003,2010.

Signal here 10 times larger than Higgs in the same signature.



Phys.Rev.Lett.103:092002,2009.

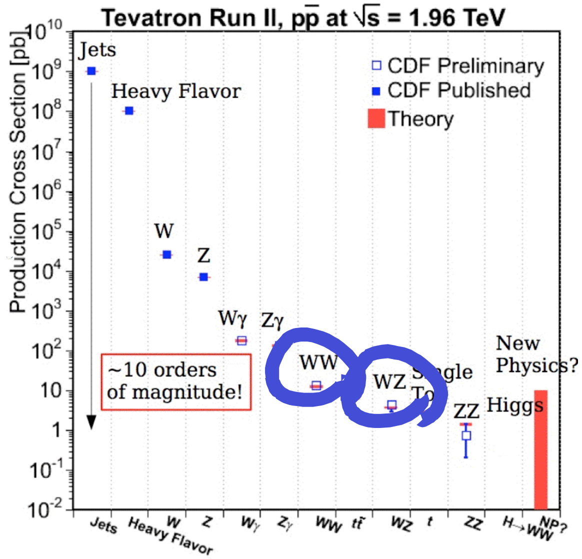
Single top cross section measurement here is

- a test of the backgrounds/machinery
- independent from other σ_t measurements → can be combined to increase precision

$\sigma_t(M_{top}=172.5) = 4.9 \pm 2.3$ (stat+syst+lumi) pb

Benchmark processes to WH→l+MET+jets

WW/WZ → l+MET+jets



Idea: to measure a background with the very similar topology and event selection as the HW search

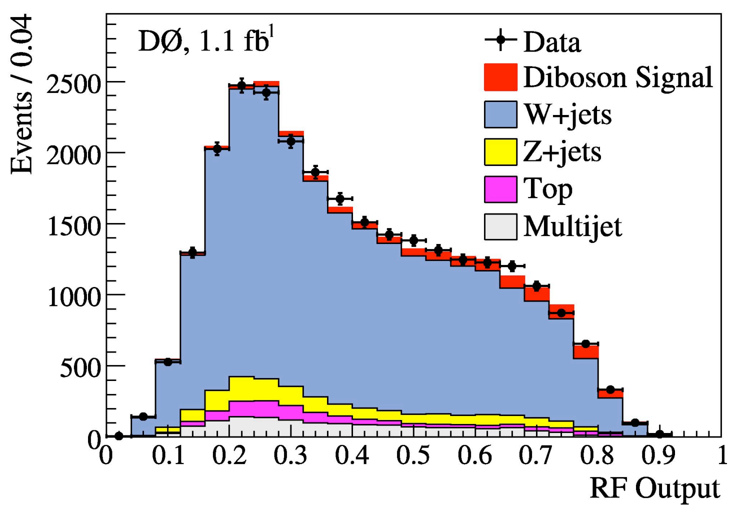
- require large MET and two jets
- one identified electron/muon
- Taus are especially challenging due to the large QCD background they carry with, and *are not considered here*

First evidence in this channel provided by D0 with L=1.1fb^{-1}

S=1000

B=27000

Multivariate technique provides some 30% improvement in sensitivity = 4.4sigma



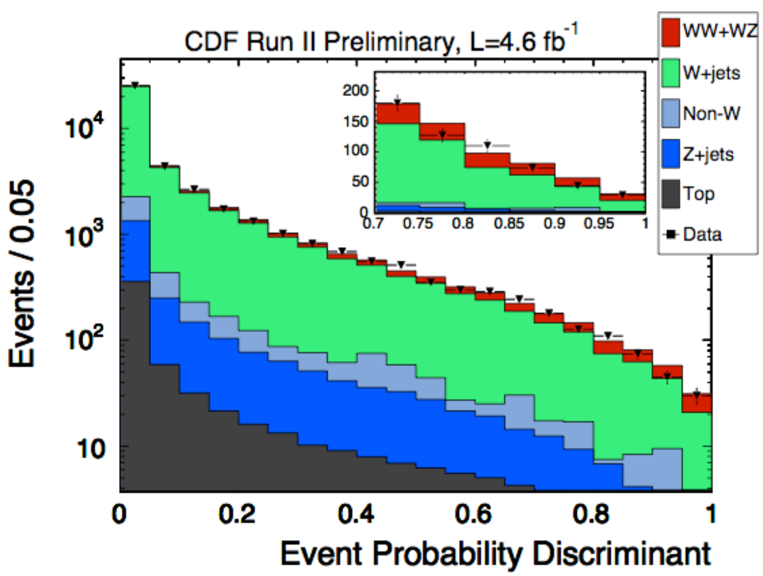
SM prediction of 16.1 +/- 0.9 pb.

σ(WW+WZ)= 20.2 + 4.5 pb

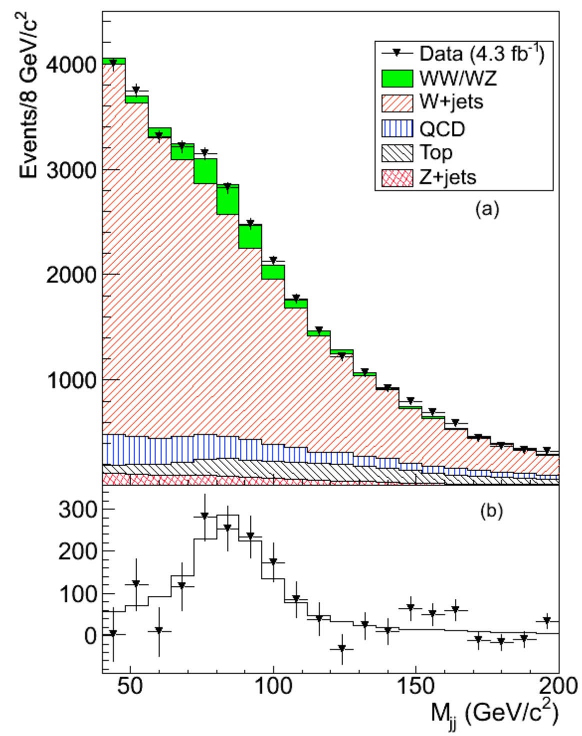
WW/WZ → l+MET+jets

Two different analysis
- one optimized for the dijet mass scan
- another uses Matrix Element technique.

Similar sensitivity, clear observations



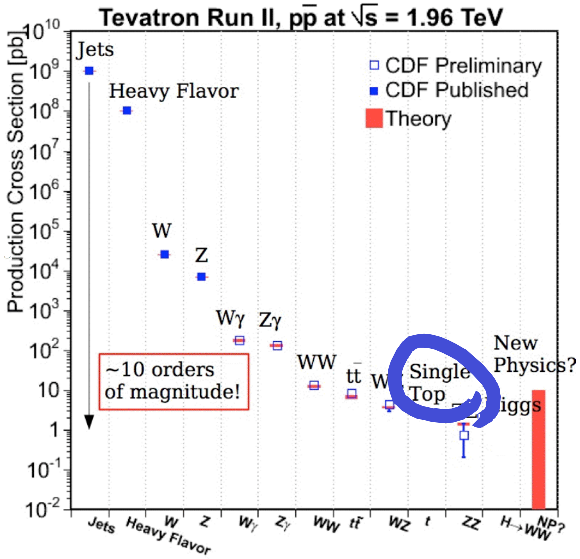
σ(WW+WZ)= 16.5 + 3.2 pb



σ(WW+WZ)= 18.1 + 4.1 pb

SM prediction of 16.1 +/- 0.9 pb.

Single top in l+MET+(b)jets



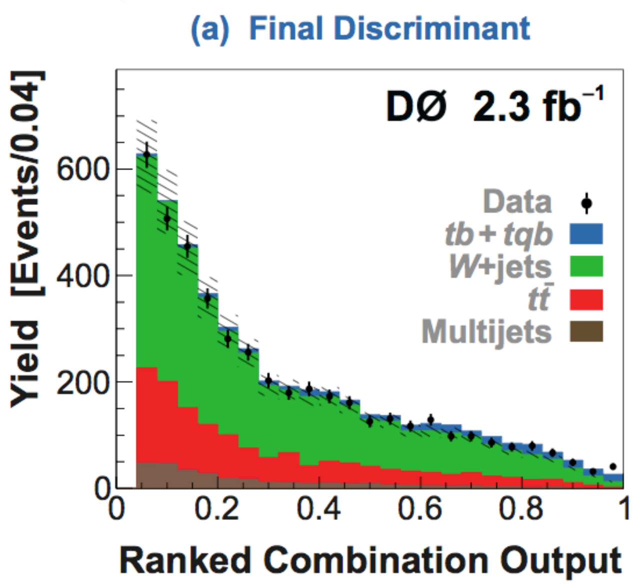
Now measure a signal smaller than WW/WZ but with (almost) the same event selection as the HW search

- require large MET and two/three(four) jets CDF(D0)
- At least one b-tagged jet
- One charged leptons (e/mu)

Simultaneous observations at CDF and D0

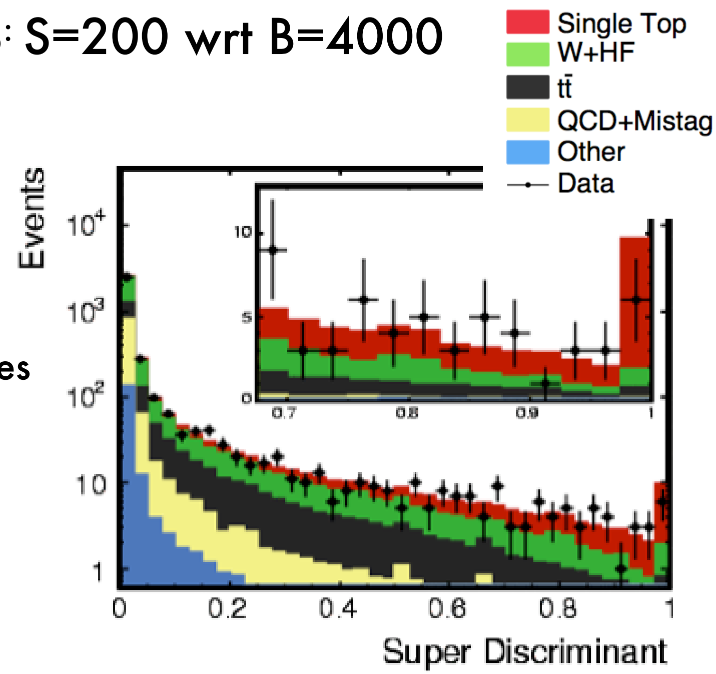
Similar S and B: S=200 wrt B=4000

Phys.Rev.Lett.103:092001,2009.



Likelihood
Neural networks
Bayesian NN
Evolutionary NN
Boosted decision trees
Matrix element

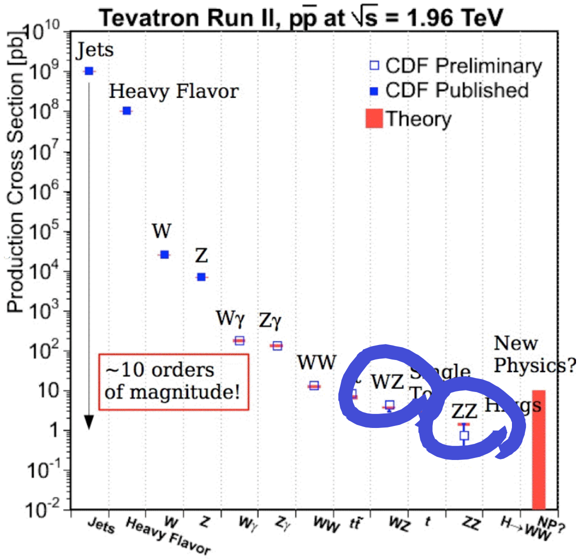
Good agreement!



Phys. Rev. Lett. 103, 092002 (2009).

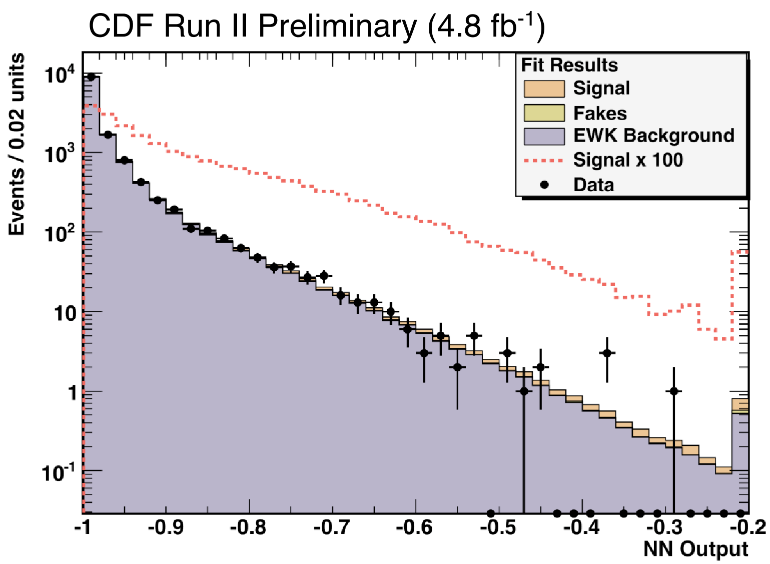
Benchmark processes to ZH→ll+jets

WZ/ZZ→llqq



Now measure WZ/ZZ but with similar event selection as the HZ→llbb search but withou b-tagging

- Opposite charge leptons(e/mu) in Z mass window
- Invariant mass of the dijet system close to Z
- Use quark/gluon jet discriminator



For signal extraction,

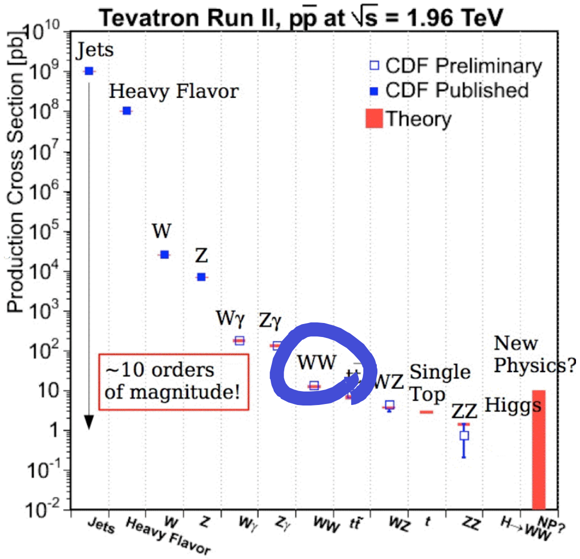
- Leave number of background and signal events unconstrained
- Treat systematic uncertainties as nuisance parameters in the fit

Result of Fit

- Background: 13603 ± 840
  - (Predicted 13541)
- Signal: 86.4 ± 107.7
  - (Predicted 201.9)
- Significance (p-value for background only hypothesis)
  - Observed: 0.167
  - Expected: 0.097

Benchmark processes to $H \rightarrow WW$

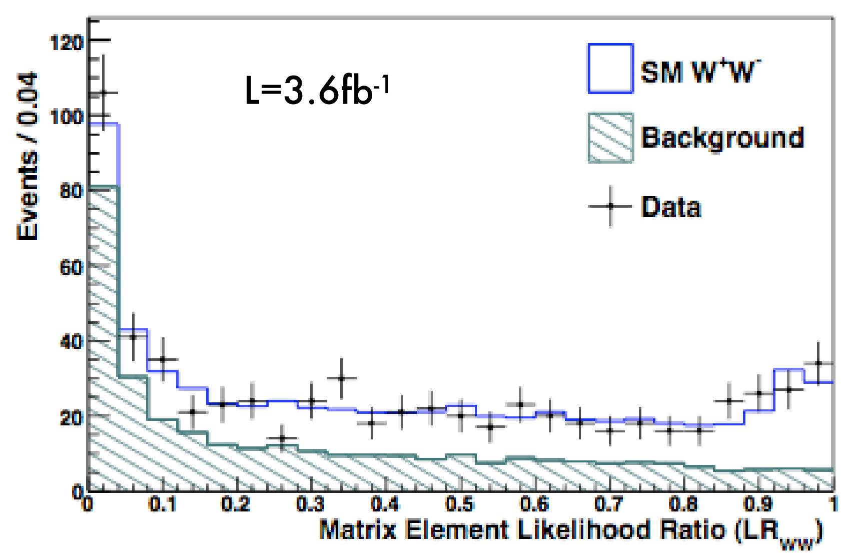
WW→llνν



WW largest physics background to H→WW

- require large MET and two opposite charge leptons(e/mu)
- Veto presence of jets to suppress ttbar
- Use Matrix Element to compute probability for event to be signal like
- Plug into a likelihood ratio to further discriminate S from B

SM predicts σ_{WW} = 11.7 ± 0.7 pb



Phys.Rev.Lett.104:201801,2010.

σ_{WW} = 12.1 ± 0.9 (stat) +1.6 (syst) pb

Mass extraction(1)

What if you really see a large excess over the background using multivariate techniques - how do you know if it's the Higgs?

Strategy *already implemented and tested!*

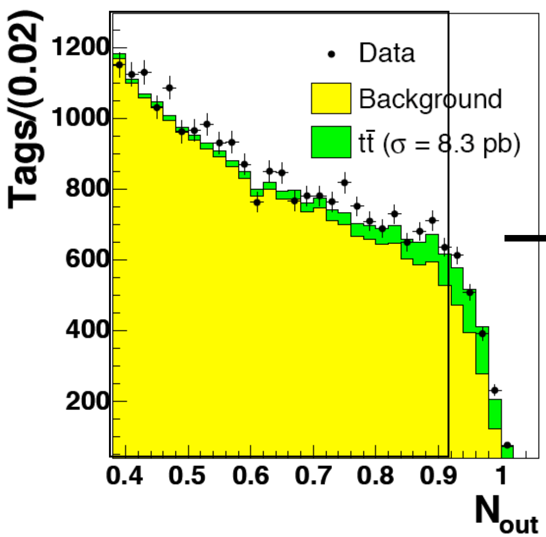
1) Remove the reconstructed resonance from your multivariate technique inputs

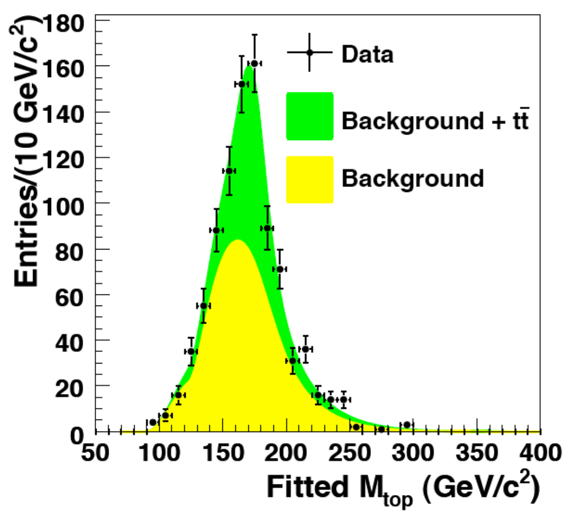
2) Cut on the MVA output and devise a method to measure its mass

Case example: σ_{tt} and M_{top} measurement in the all-hadronic channel with $1 fb^{-1}$

Don't use the reconstructed resonance as input so to leave it unbiased

S/B ratio ~1/100 before NN cut, 1/3 after





Phys.Rev.D76:072009,2007

σ_{tt} and M_{top} measurements in excellent agreement with orthogonal existing ones

Mass extraction(2)

What if you really see a large excess over the background using multivariate techniques - how do you know if it's the Higgs?

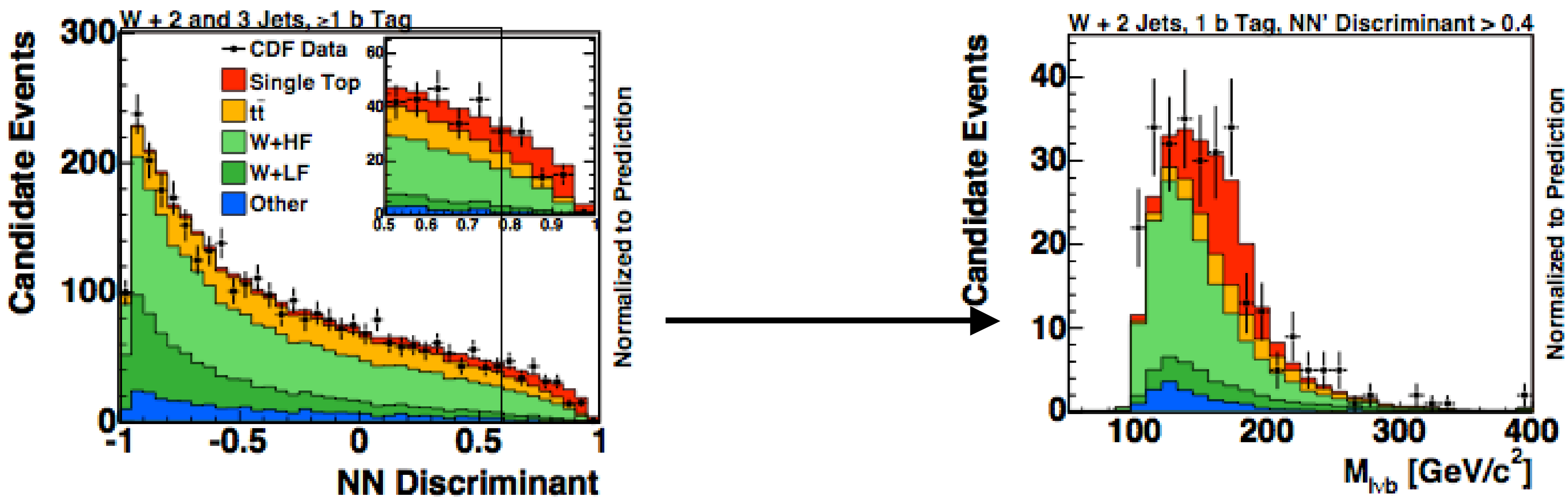
Strategy:

1) Remove the reconstructed resonance from your multivariate technique inputs

2) Cut on the MVA output and devise a method to measure its mass

Case example: σ_t measurement in the lepton+MET+(b)jets channel

Don't use the reconstructed resonance as input so to leave it unbiased



arXiv:1004.1181, submitted to PRD

No attempt at measuring the mass, but mass peak now visible

Mass extraction(3)

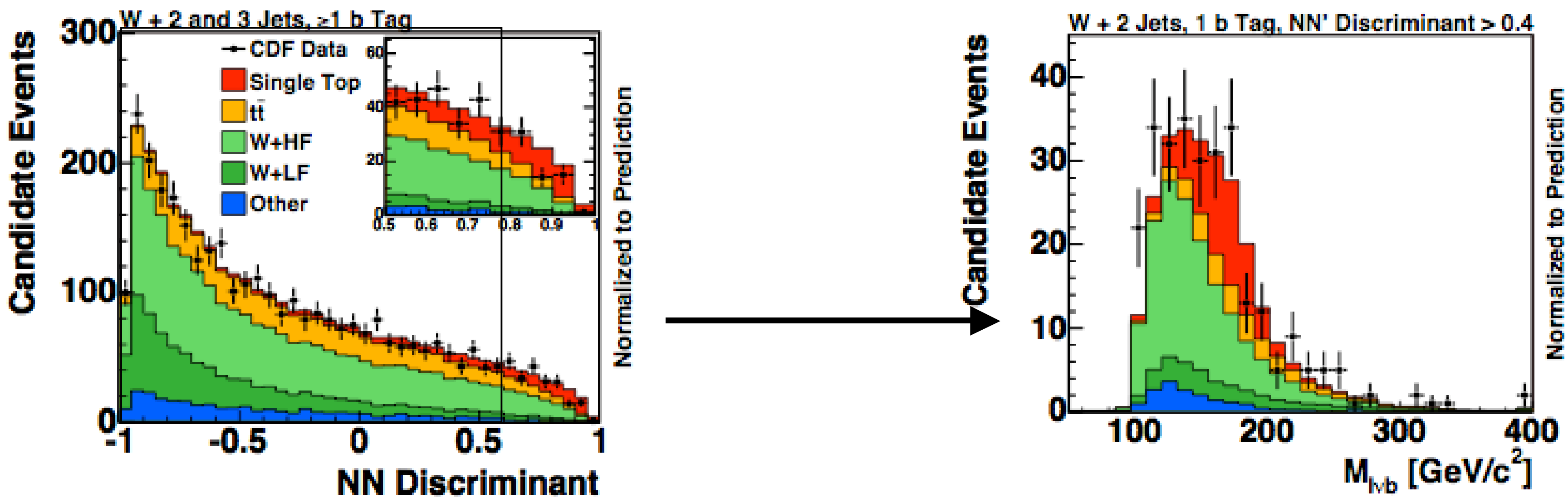
What if you really see a large excess over the background using multivariate techniques - how do you know if it's the Higgs?

Strategy:

1) Remove the reconstructed resonance from your multivariate technique inputs
2) Cut on the MVA output and devise a method to measure its mass

Case example: σ_t measurement in the lepton+MET+(b)jets channel

Don't use the reconstructed resonance as input so to leave it unbiased



arXiv:1004.1181, submitted to PRD

Yes ok but what about the high mass, H→WW→llνν? Good luck!

Conclusions

- Measured even the smallest standard model backgrounds to low mass Higgs production
- And in doing so, test all the tools needed for Higgs hunt!
  - Search/observation of dibosons in all decay modes that include V→jets
  - ttbar contribution
  - Single top observation

- At high mass backgrounds known better, still measured with high precision
  - Most sensitive measurement of WW production

- Next *crucial* step: observe diboson production with b-jets in the final state!

  Coming soon

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Thank you!