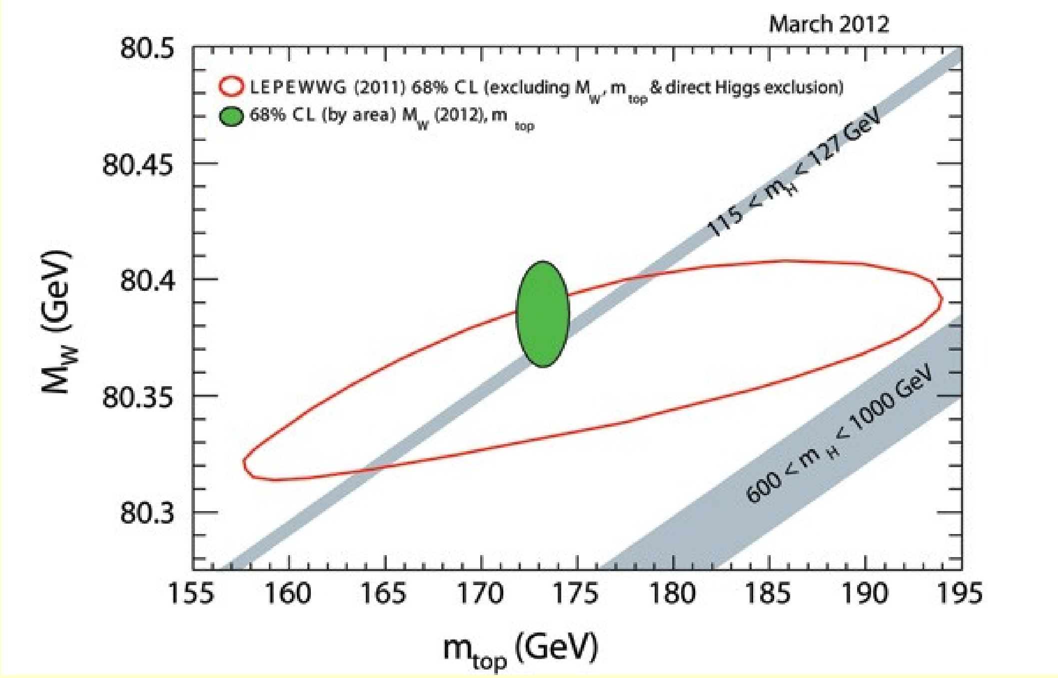
Closing in on the Higgs boson

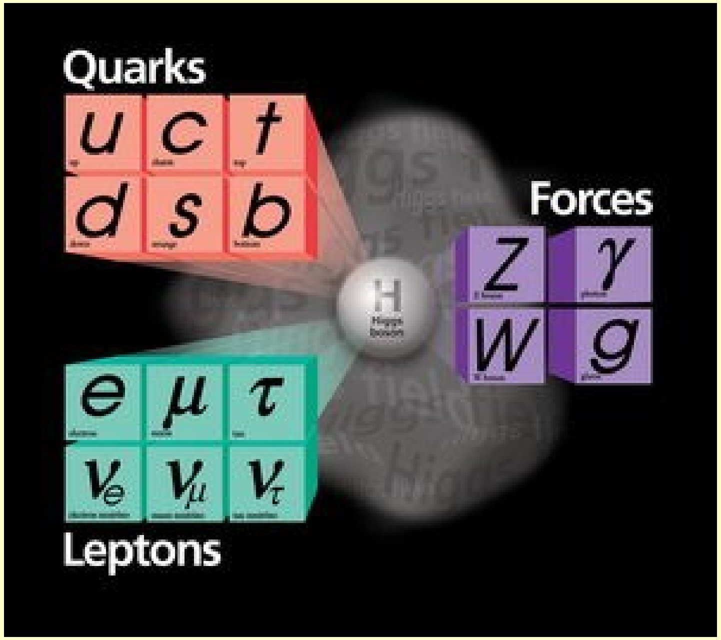


Lidija Živković

INN Vinca, Belgrade

Seminar @LPNHE

September 6th, 2012



- Outline
  - Motivation
  - Higgs search at Tevatron
  - Current limits
  - Future

Introduction

Standard Model

- The Standard Model is defined by the symmetries of the Lagrangian:
  - $G_{SM} = SU(3)_C \times SU(2)_L \times U(1)_Y$
  - Interactions: strong, weak, and electromagnetic
  - carriers: gluons – g, weak bosons $W^{\pm}$, Z, and photon
- matter particles:
  - leptons and quarks
- and the pattern of spontaneous symmetry breaking
  - complex scalar field
  - breaks $G_{SM} = SU(3)_C \times SU(2)_L \times U(1)_Y \rightarrow SU(3)_C \times U(1)_{EM}$

The Higgs Mechanism

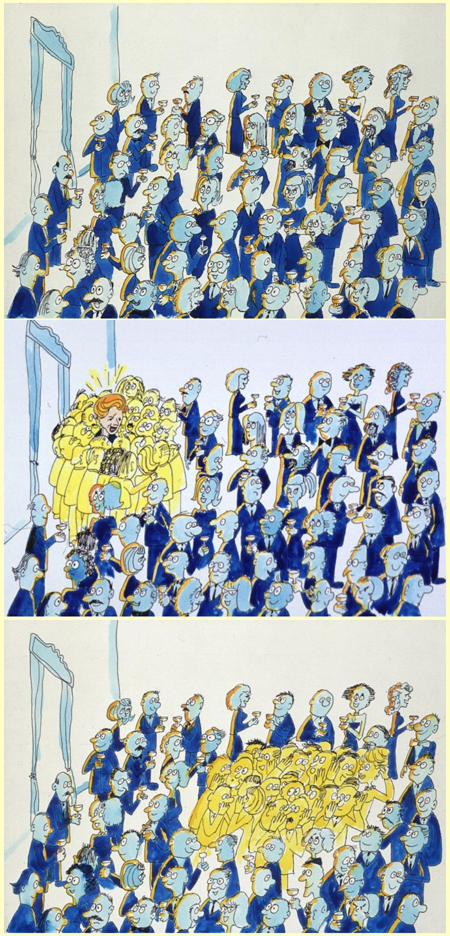
- Essential ingredient of the Standard Model
  - Complex scalar field with potential
- Used to break the el. weak symmetry...

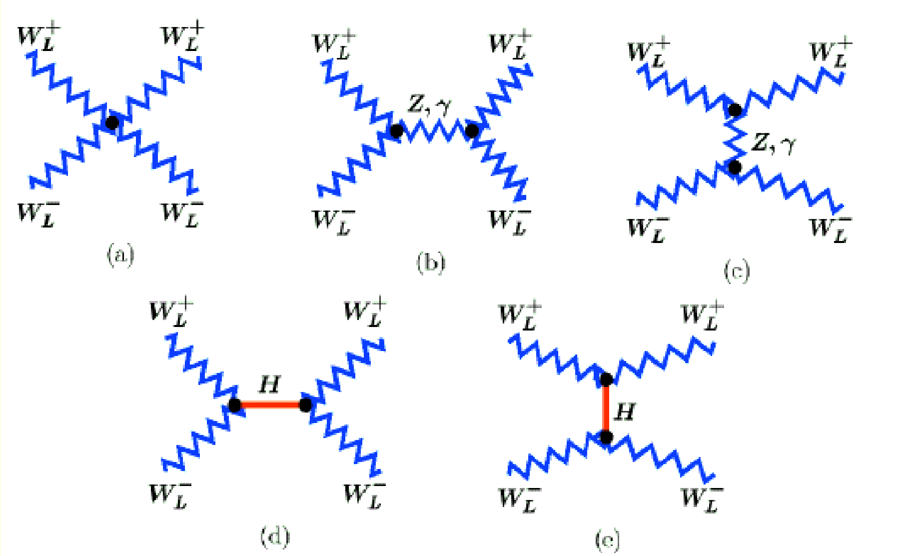
$$M_W = \frac{1}{2} vg \qquad M_Z = \frac{1}{2} vg / \cos\theta_W = M_W / \cos\theta_W$$

- ... and to generate fermion masses:

$$m_f = g_f v / \sqrt{2} \;\Rightarrow g_f = m_f \sqrt{2} / v$$

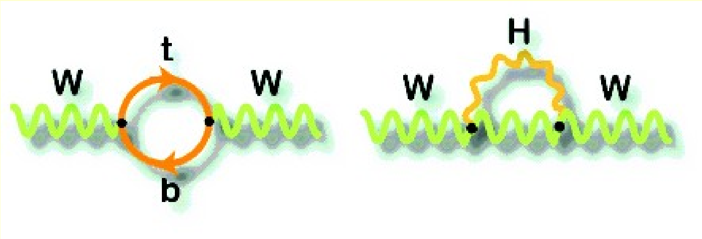
- Unitarity requires a Higgs boson or similar
  - cross section for WW scattering diverges like s/M_W^2
  - scalar Higgs boson cancels divergences

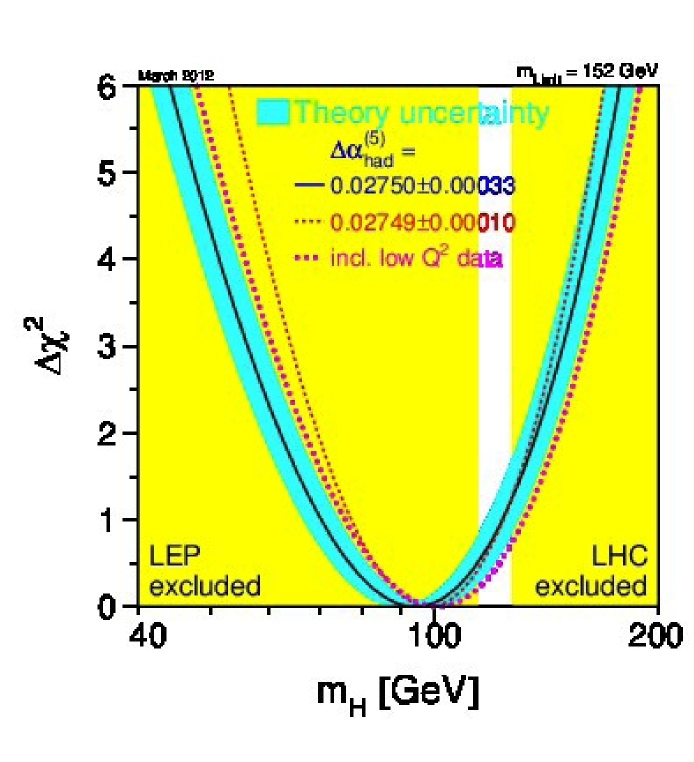




Bounds on Higgs mass

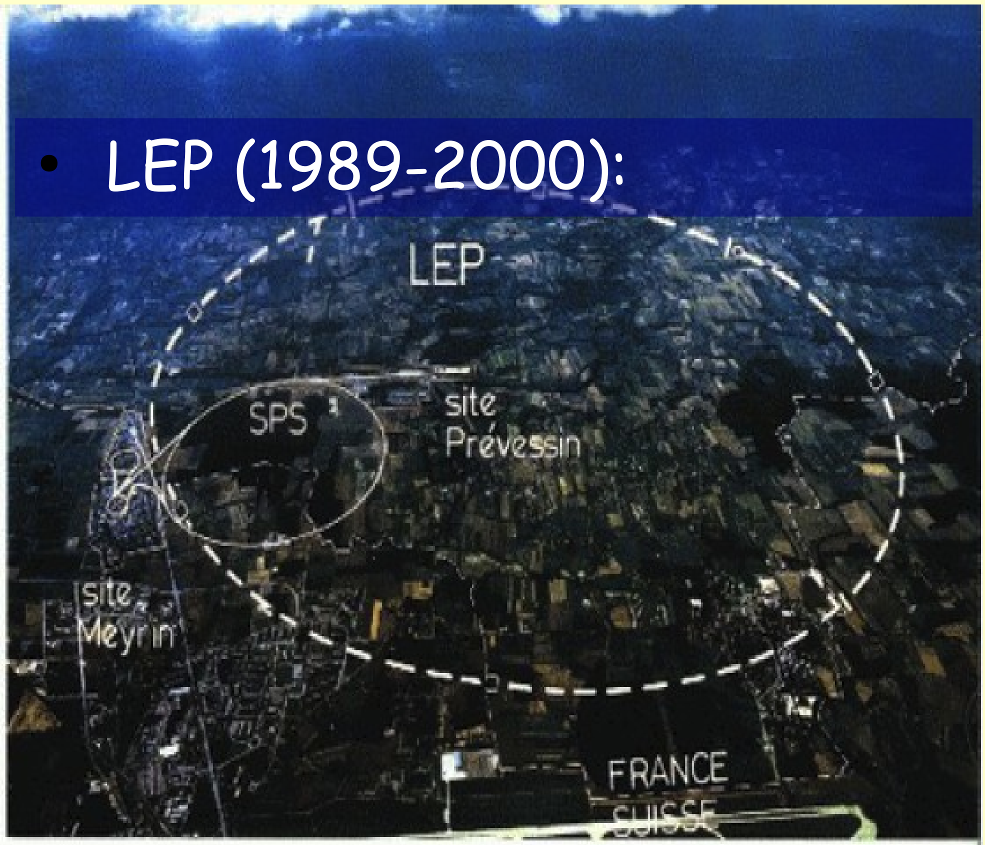
- Global SM electroweak fits provide upper limit
- The best fit gives $m_H = 94^{+29}_{-24} GeV$
- Limit from fit m_H < 152 GeV



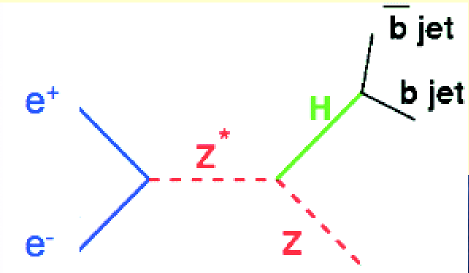


Bounds on Higgs mass

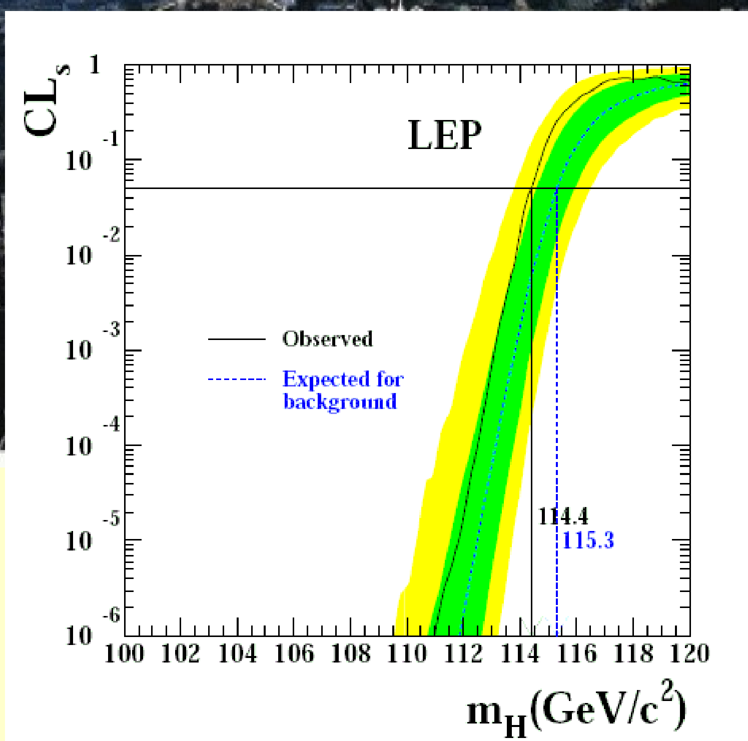
- LEP (1989-2000):



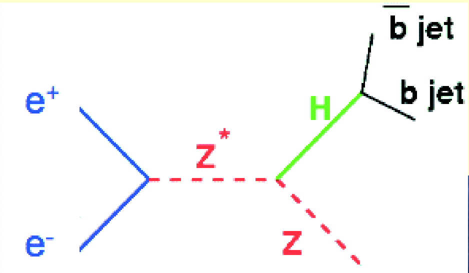
Bounds on Higgs mass



- LEP (1989-2000):
  m_H > 114.4 GeV@95% CL



Bounds on Higgs mass



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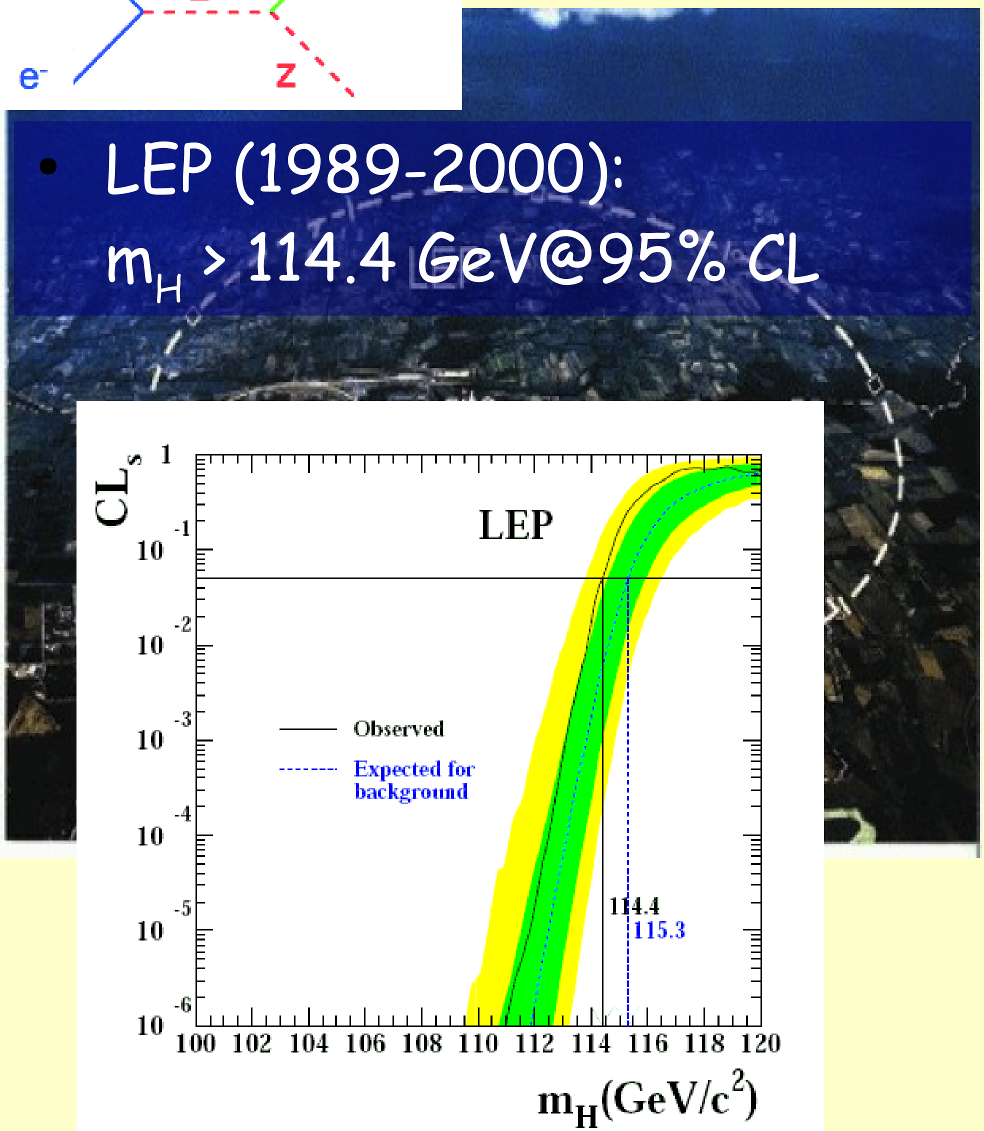
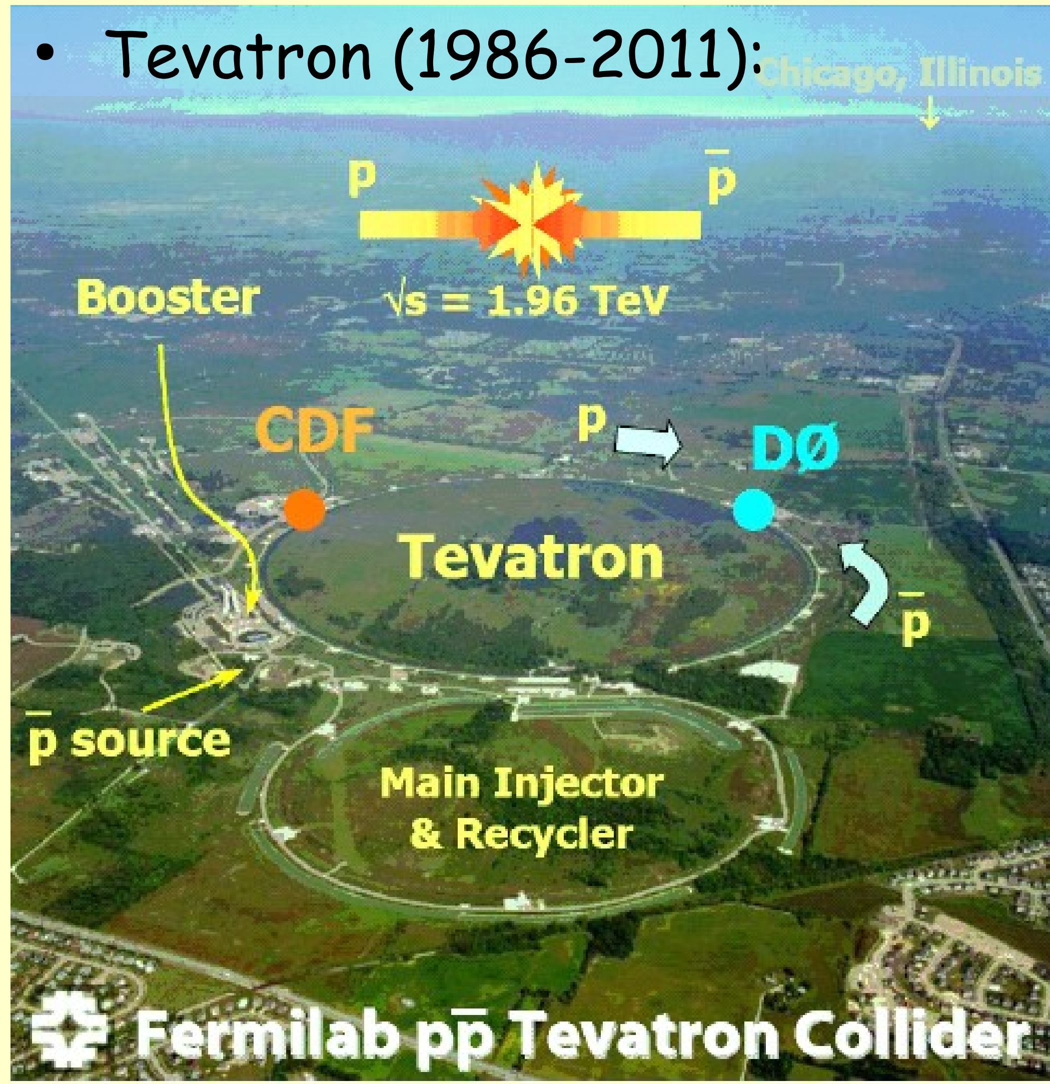
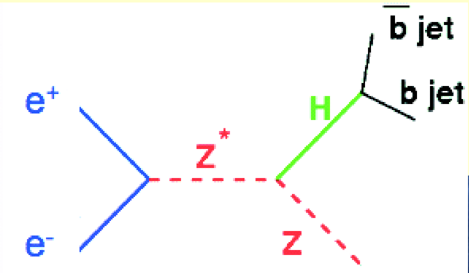


- Tevatron (1986-2011):



Bounds on Higgs mass



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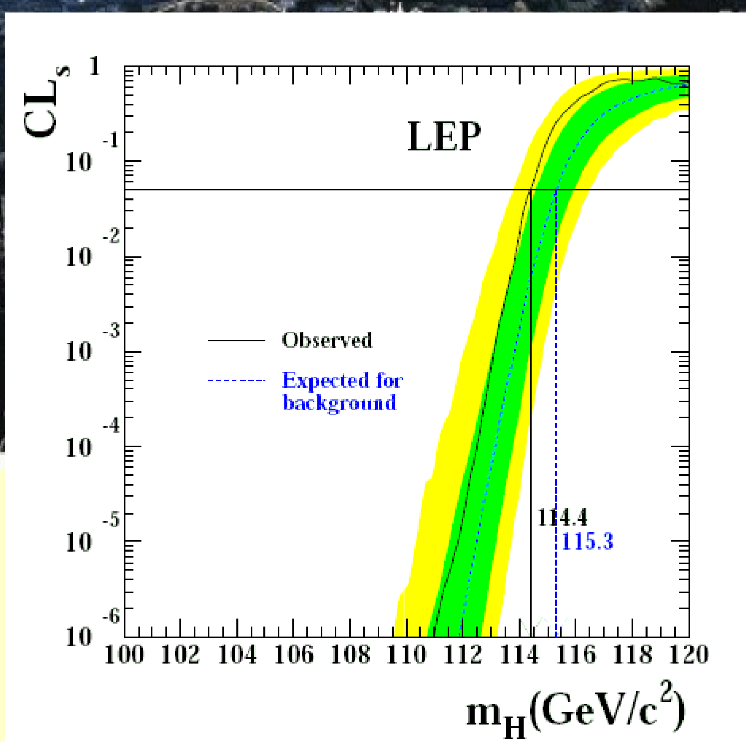
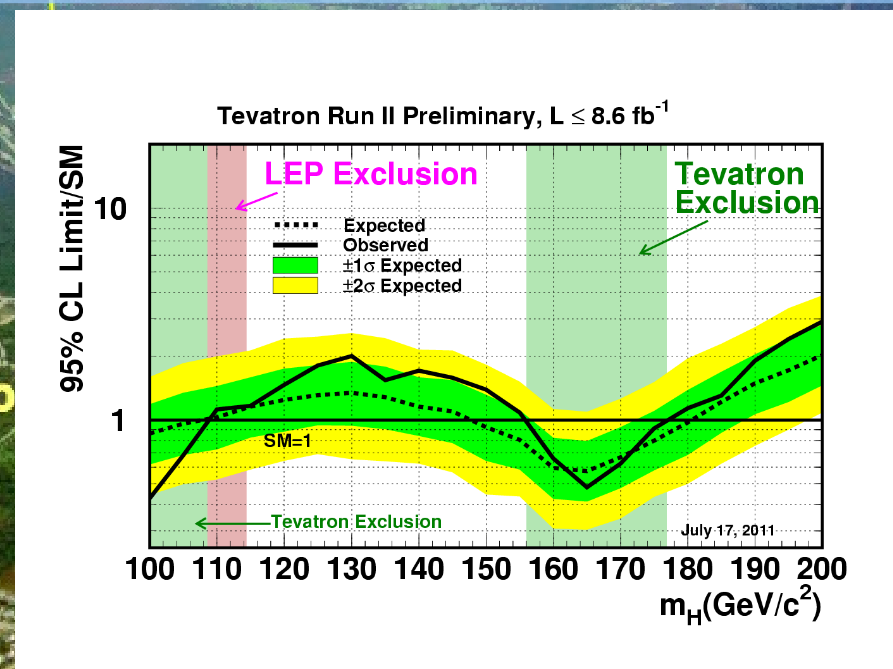
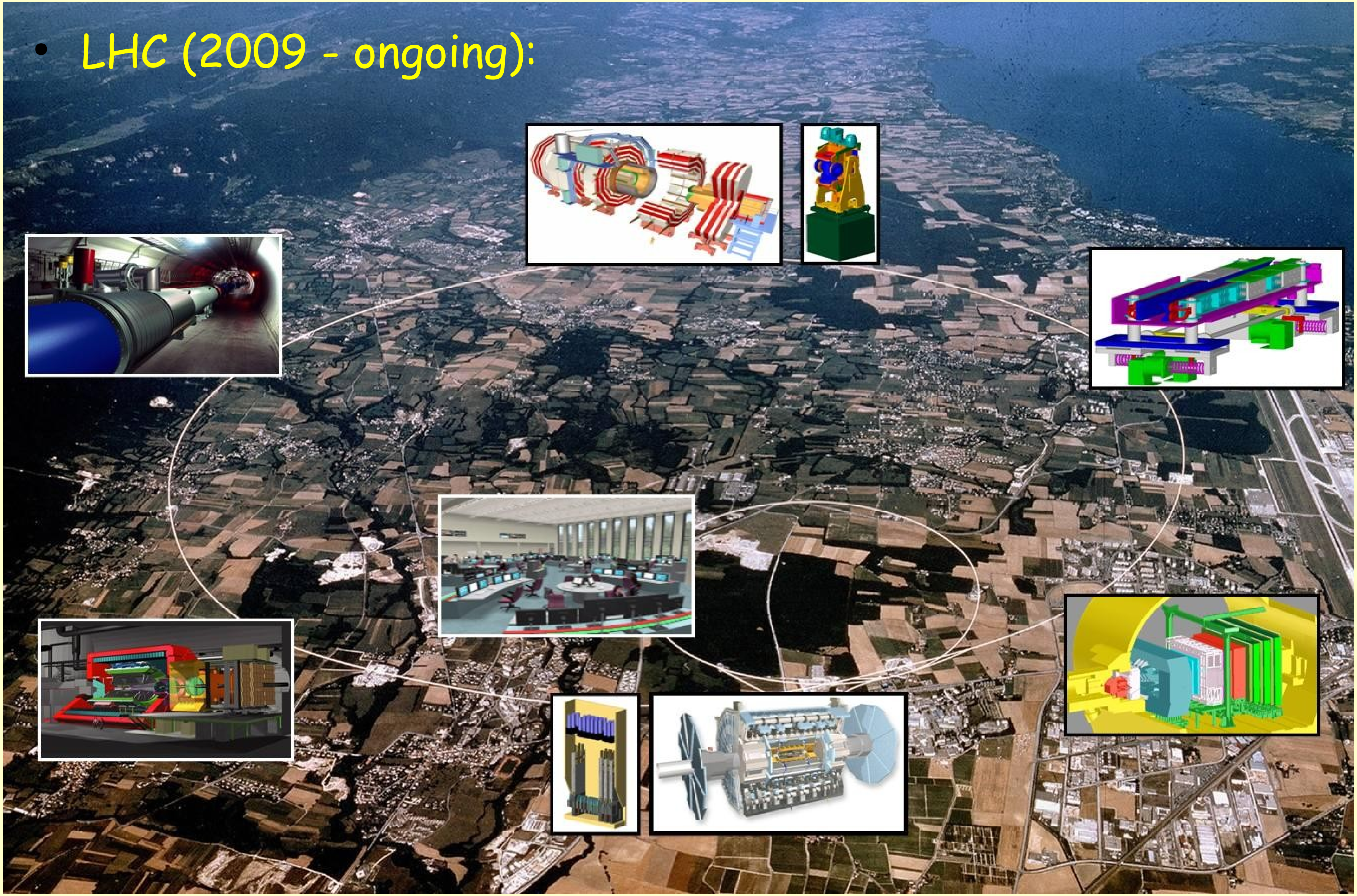


- Tevatron (1986-2011):
  Summer 2011:
  Exclude: 156 – 177 GeV and
  100 – 108 GeV



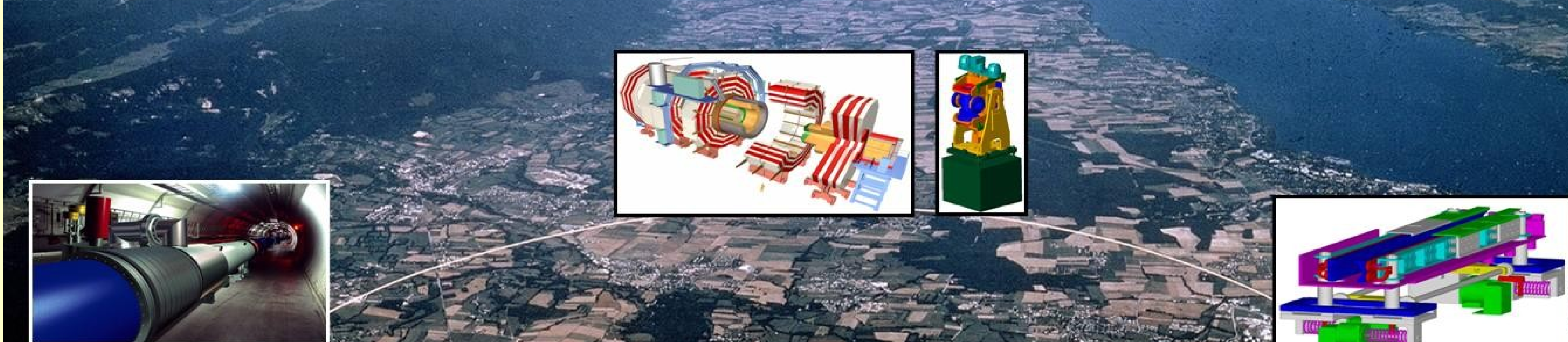
Bounds on Higgs mass

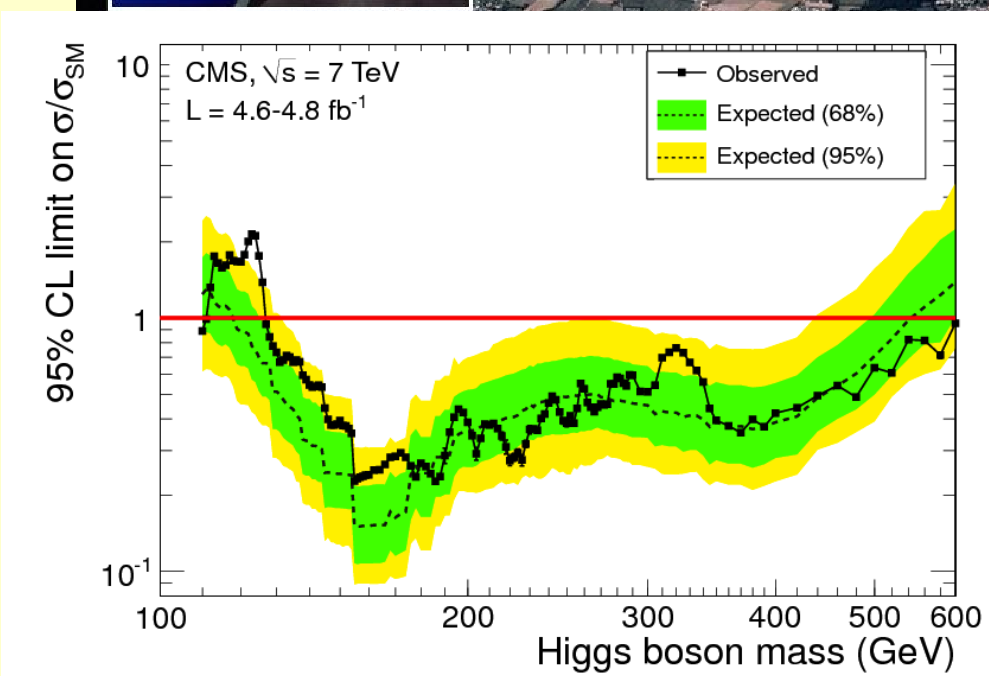
- LHC (2009 - ongoing):

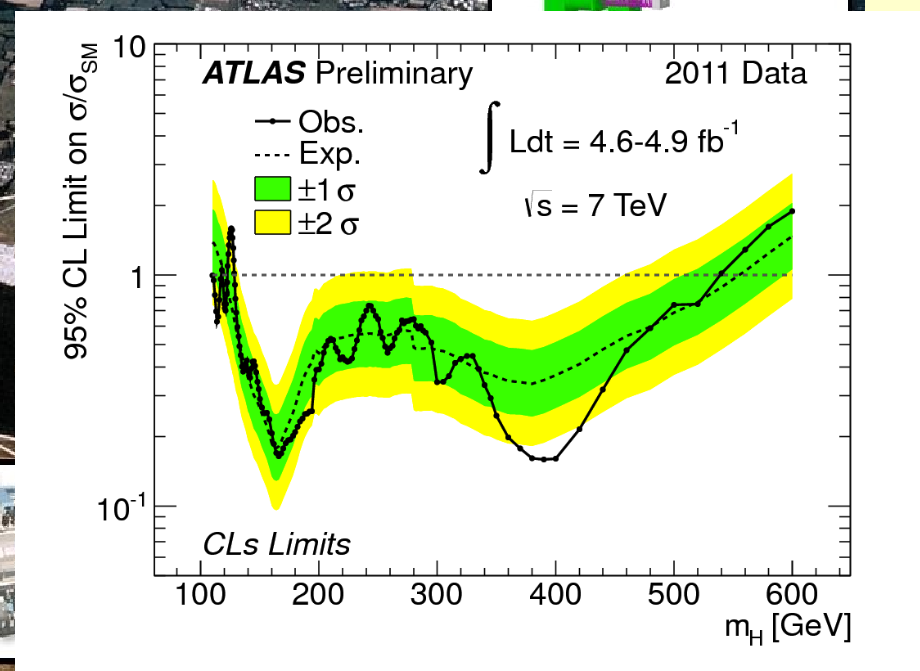


Bounds on Higgs mass

- LHC (2009 – spring 2012): only 122.5-127 GeV is allowed

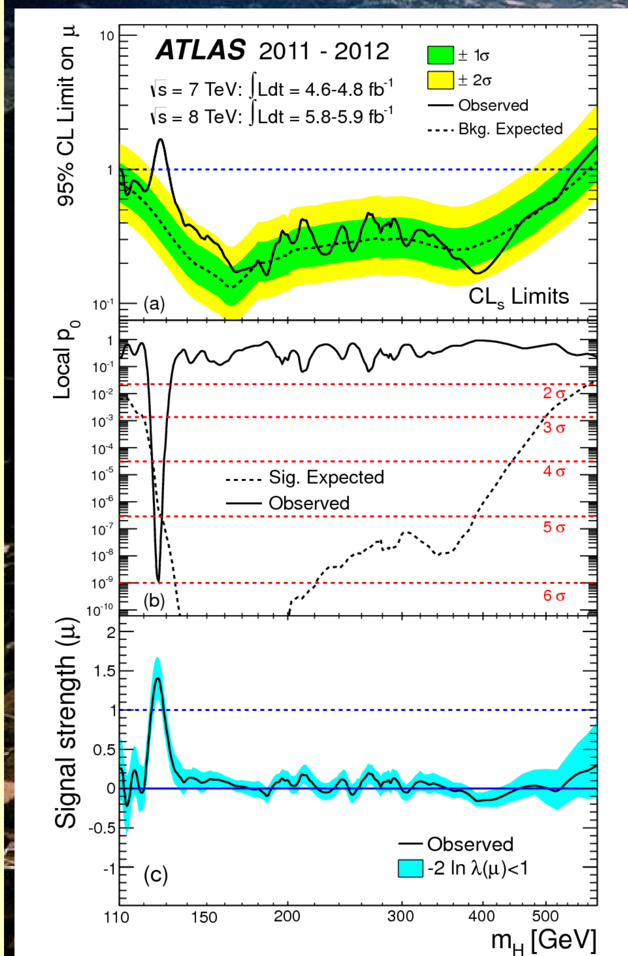






New particle!

- LHC (July 2012): observation of the new particle!



NAUKA

Saznanje o Higsovom bozonu pred vratima

lidiaz / 03.07.2012. u 13:23

KOMENTARI: 84 / POŠALJITE KOMENTAR / ČITANOST: 1540 / PREPORUKE: 17

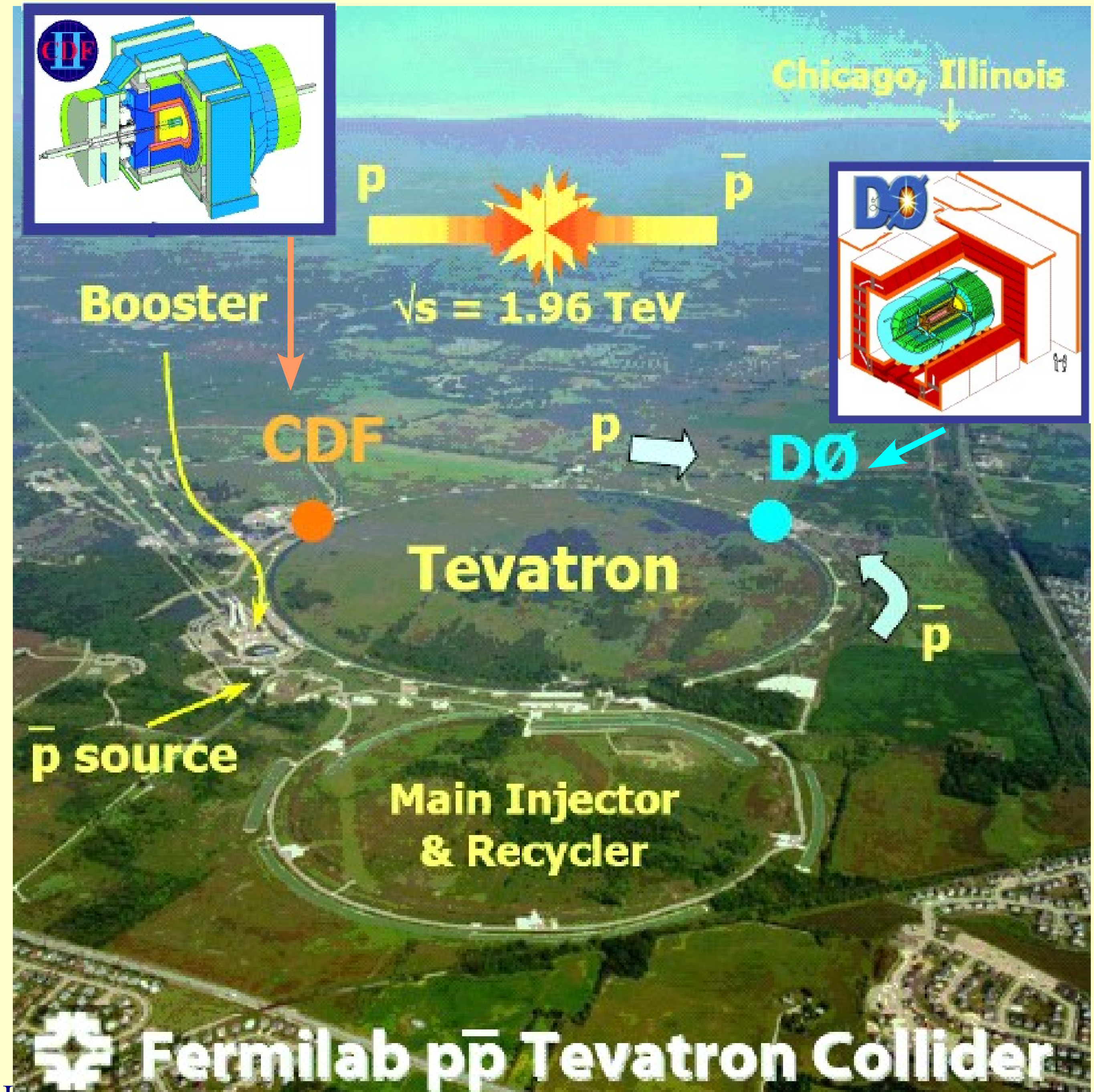
Sutra u 9 ujutro u Cernu ce zapoceti seminari sa najnovijim rezultatima o Higsovom bozonu. Seminare ce drzati Joseph Incandela sa Univerziteta Kalifornije iz Santa Barbare i Fabiola Gianoti iz Cerna. Joe je spokesperson CMS-a, Fabiola Atlasa. Spokesperson je prakticno glavni menadzer eksperimenta.

Experiments

The Tevatron

$p\bar{p}$ collisions

- Ran for 25 years
  - 9 in Run II
- Center of mass energy $\sqrt{s}$ = 1.96 TeV
- Discovered top quark
- Excluded high mass range of the Higgs boson
- The most precise measurement of the W and top mass
- It stopped running on September 30th, 2011



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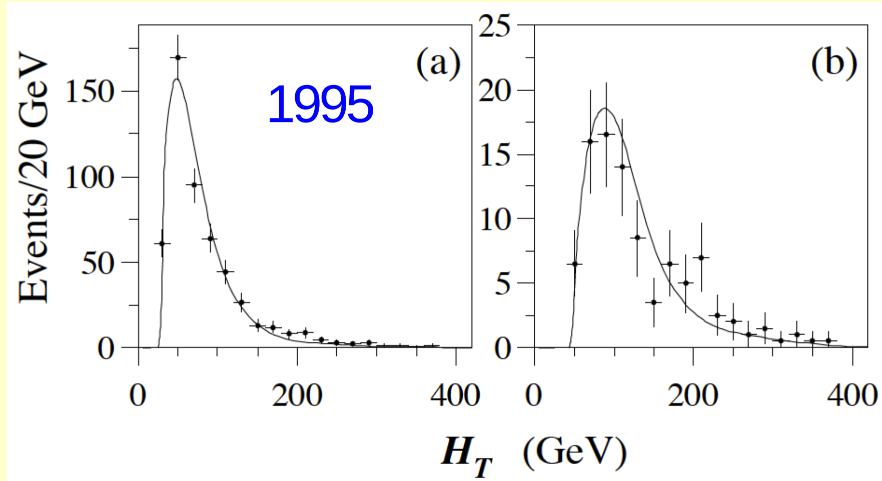
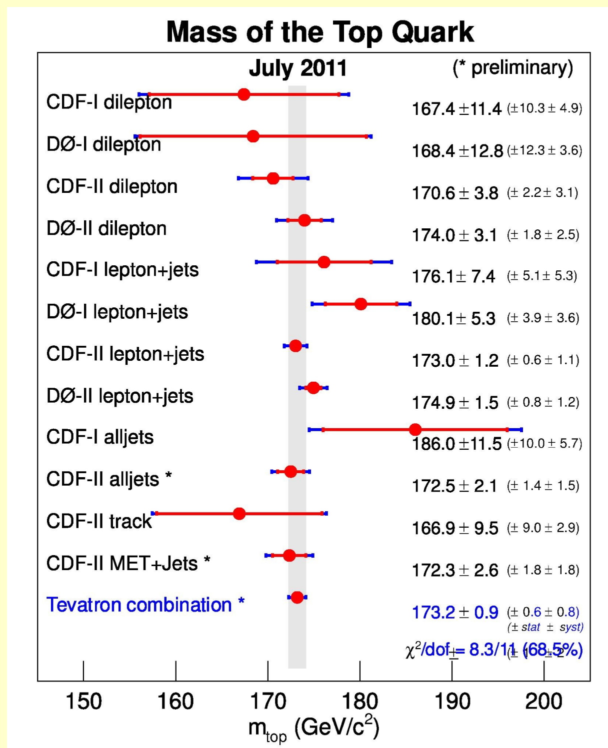
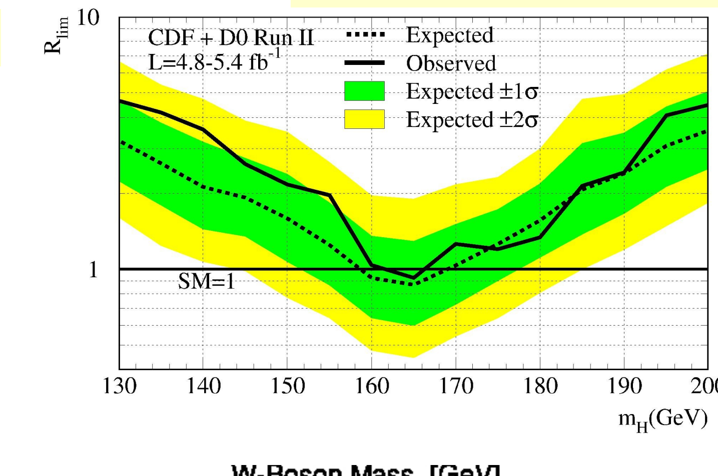
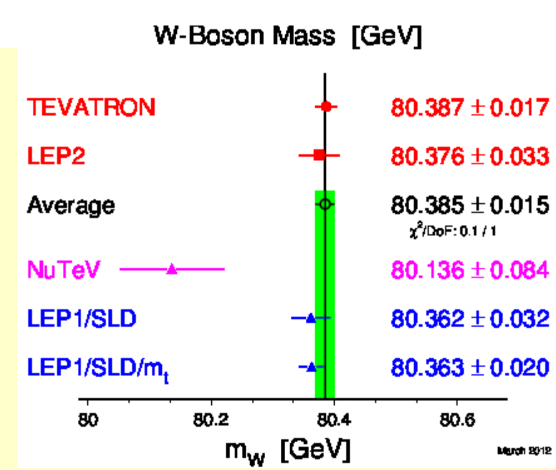




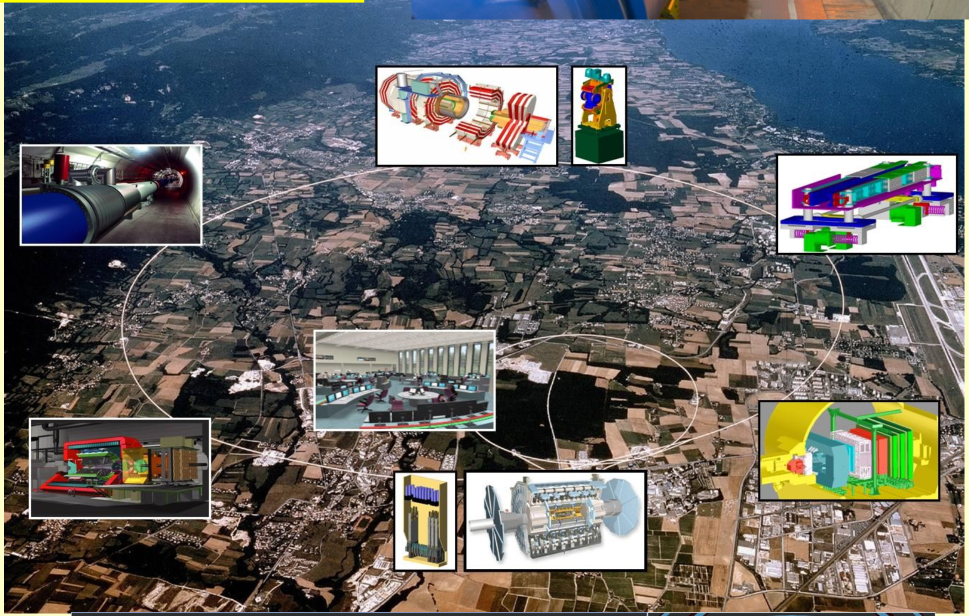


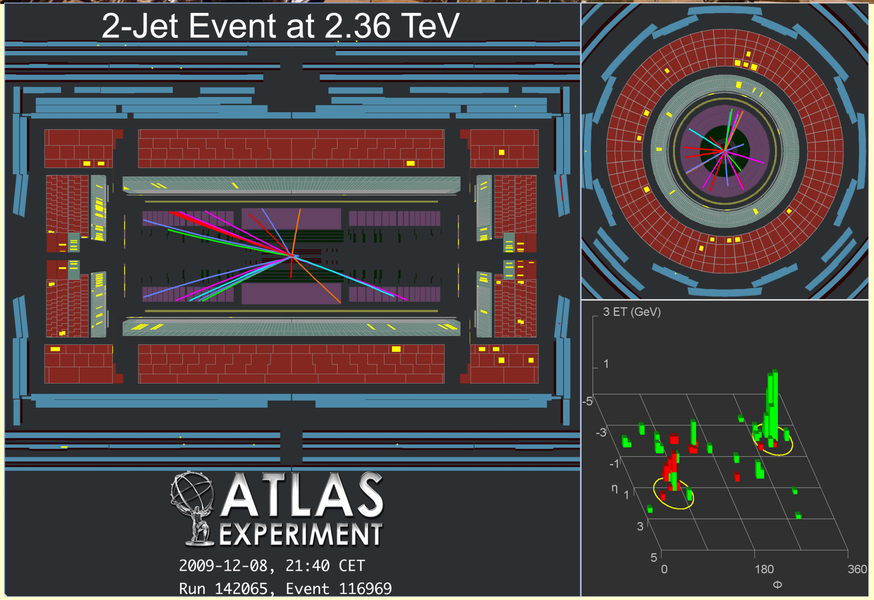


The LHC

- First beam on September 10^{th} 2008
- First collisions end of 2009
- Goal is $\sqrt{s}$ = 14 TeV (exp. 2014)
  - Collisions at $\sqrt{s}$ = 2.36 TeV in December 2009
  - It was running at $\sqrt{s}$ = 7 TeV through 2010 and 2011
  - It is running at $\sqrt{s}$ = 8 TeV in 2012
- Goal is to collect 10 fb^{-1}/yr and later 50 fb^{-1}/yr
  - It collected ~40 pb^{-1} by the end of 2010, 5 fb^{-1} in 2011, expected about four times that much in 2012 (14 fb^{-1} already)
  - 100 fb^{-1} possible in 2016
- Discovered Higgs boson like particle

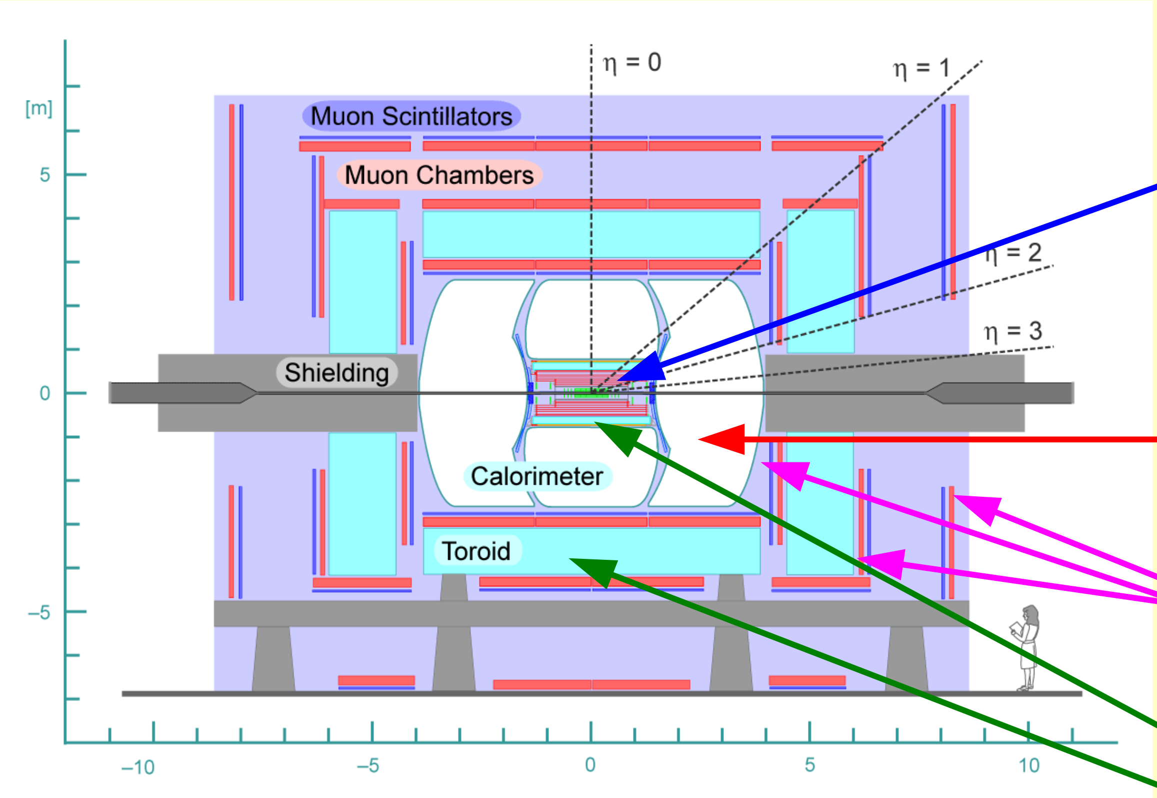
pp collisions





DØ experiment

500 scientists
85 institutions
19 countries

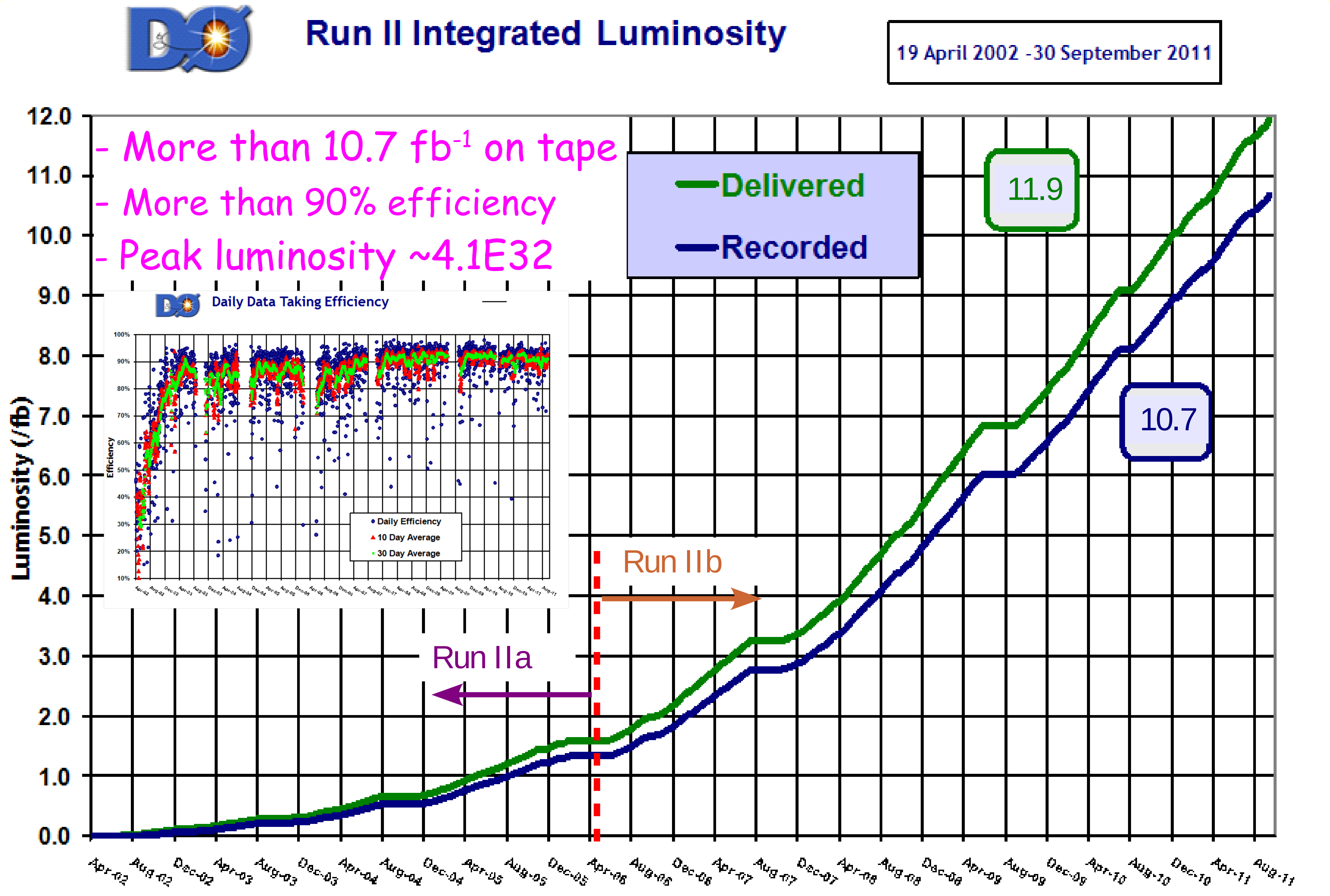


- Silicon microstrip vertex detector
- Scintillating fiber tracker
- Uranium/liquid argon calorimeter
- Wire chamber + scintillation counter muon detector system
- 2T solenoid magnet & 1.8 T toroid magnet

3-Level trigger system:
Collision rate 1.7 MHz
Level 1 (hardware): 2.5 kHz
Level 2 (software): 1 kHz
Level 3 (software): 100 Hz
We save ~25MB/s

Angular coverage	|η|
Muon ID	~2
Tracking	~2.5
EM / Jet ID	~4

Data taking

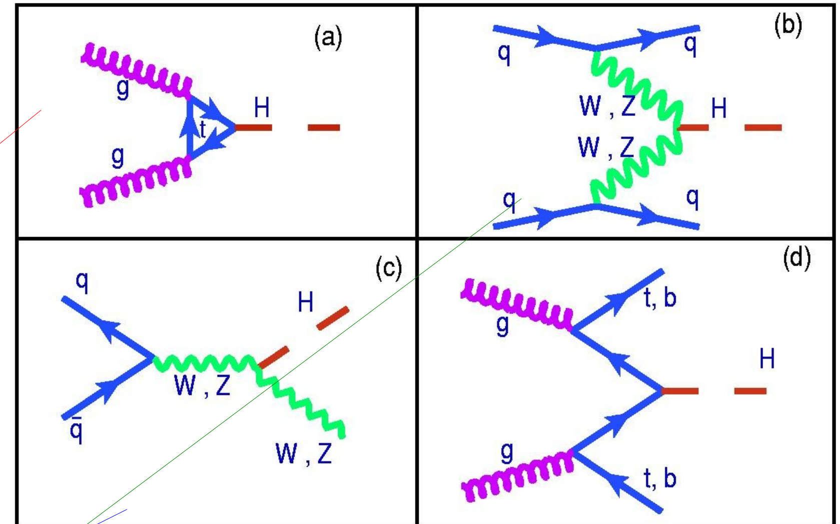


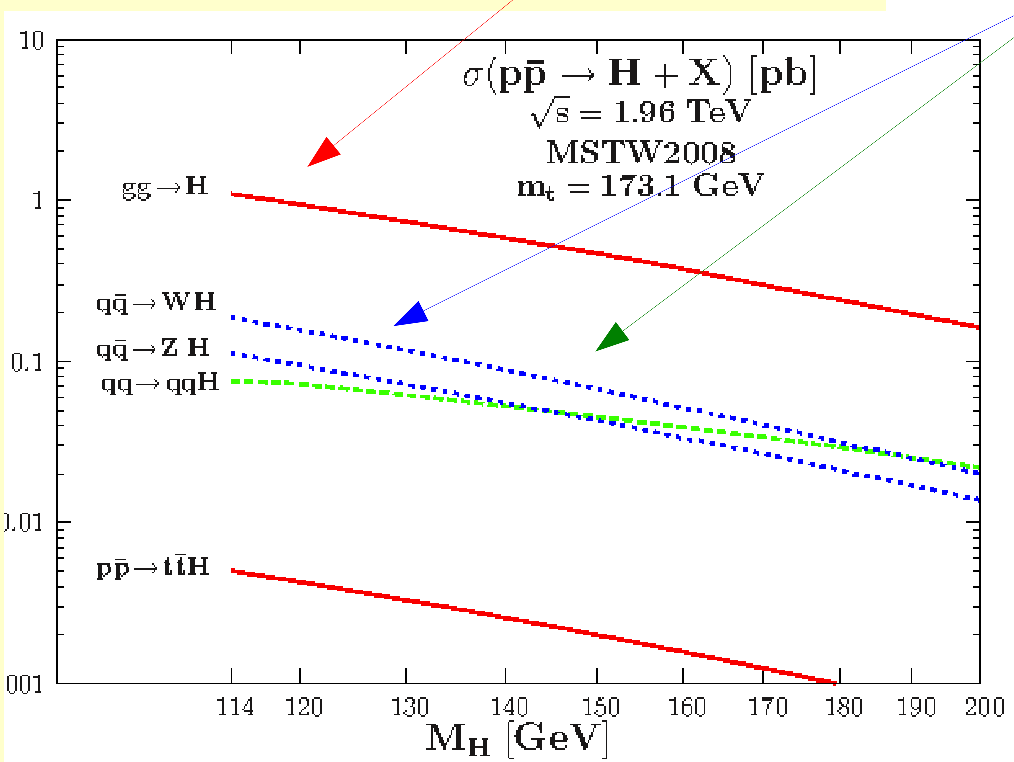
Run II Integrated Luminosity
19 April 2002 -30 September 2011
- More than 10.7 fb-1 on tape
- More than 90% efficiency
- Peak luminosity ~4.1E32
Delivered
Recorded
11.9
10.7
Run IIb
Run IIa
Luminosity (/fb)
Daily Data Taking Efficiency
Daily Efficiency
10 Day Average
30 Day Average

Higgs searches at Tevatron

Production …

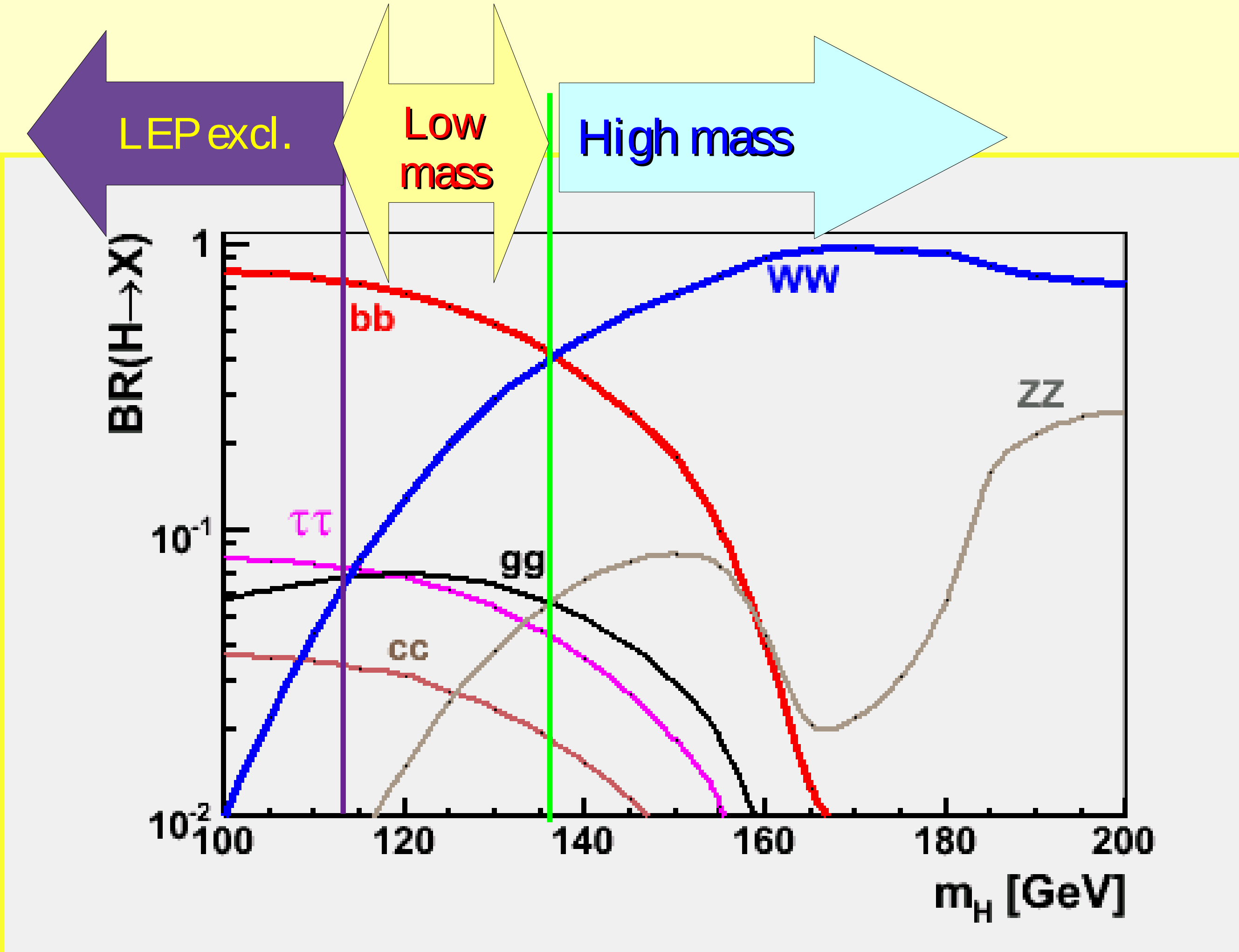
- Main production process is gluon fusion





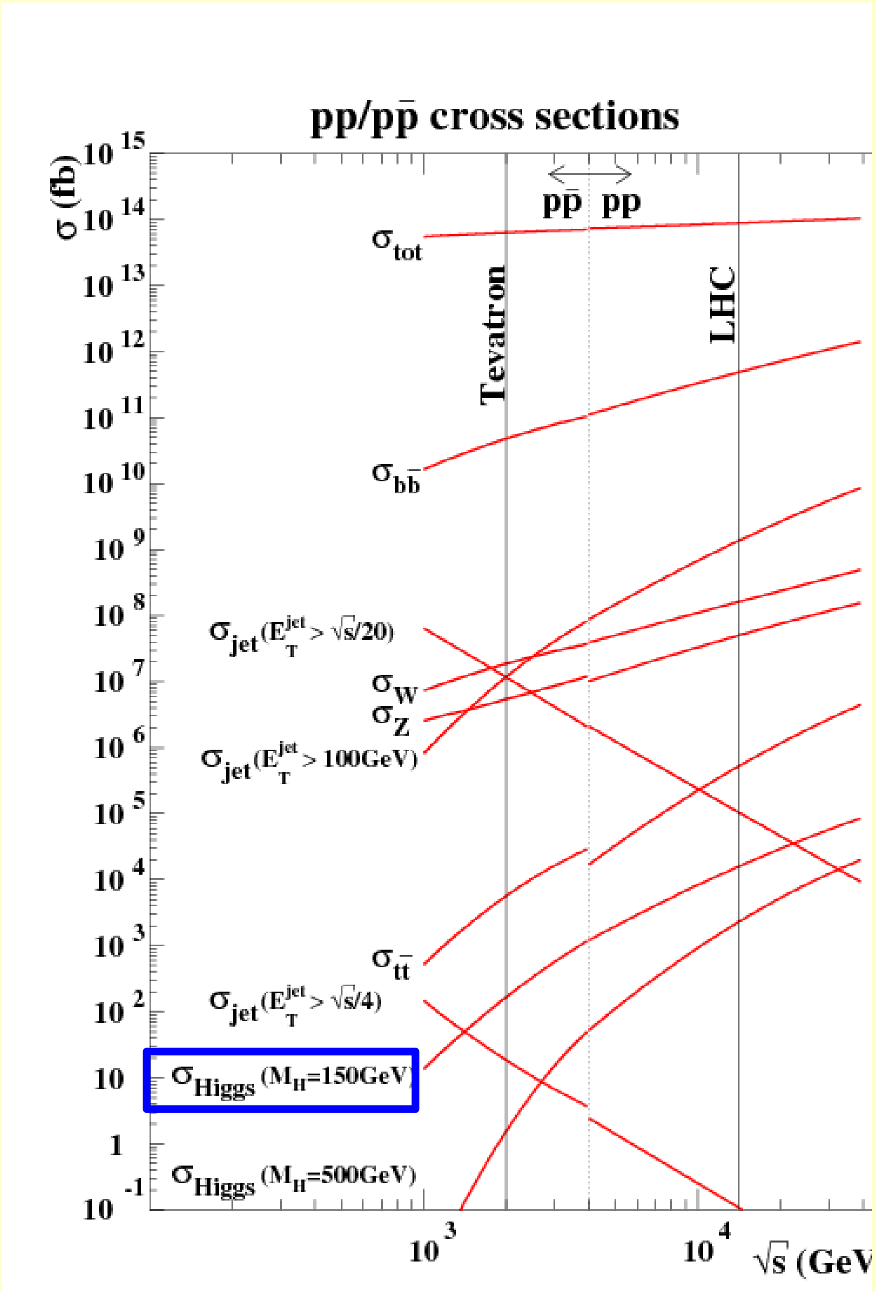
- Associated with vector boson, and vector boson fusion are significant

… and Decay



- At lower masses dominant decays to bb
- At higher masses dominant decays to WW
- Due to the small σ×BR other processes are less usable at Tevatron

How do we search?



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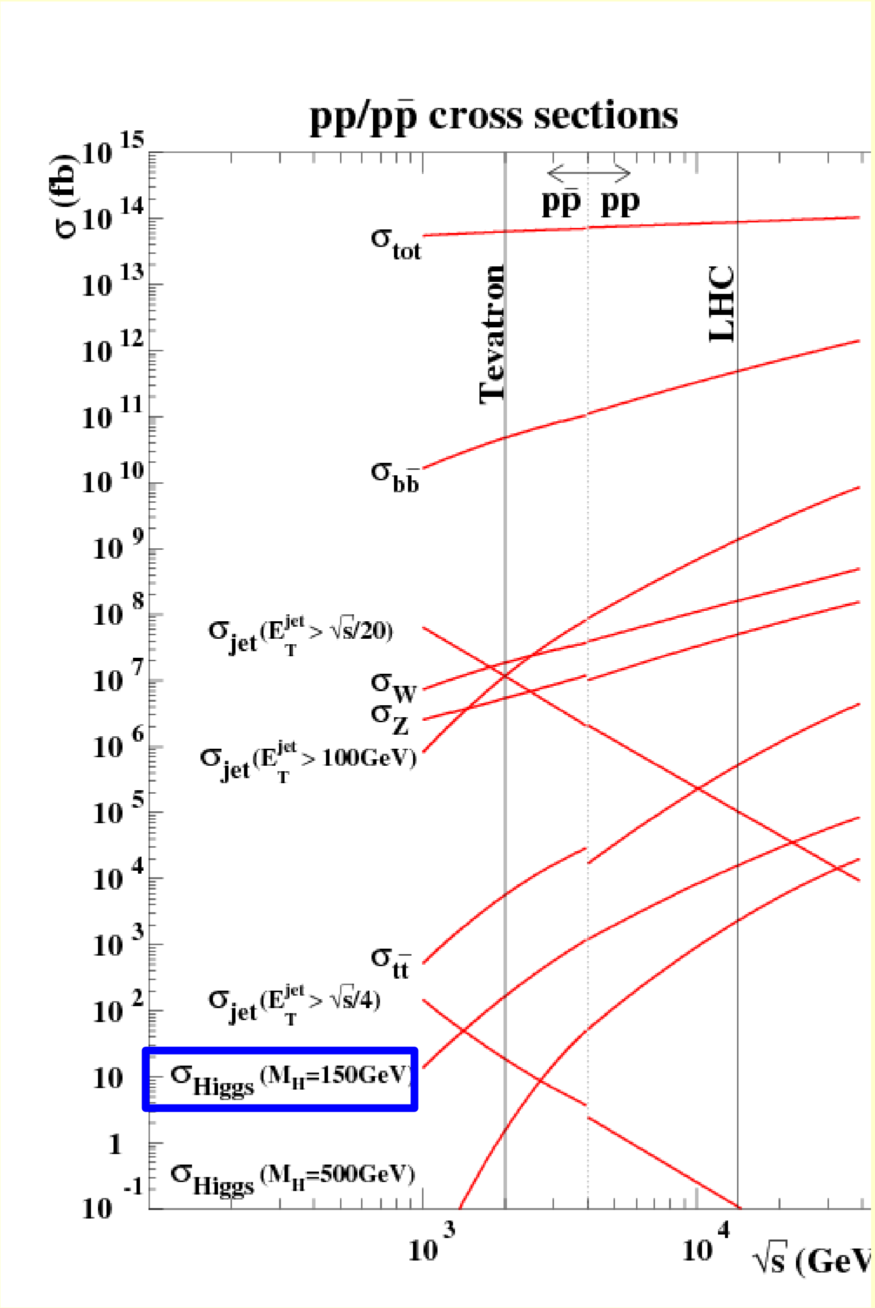
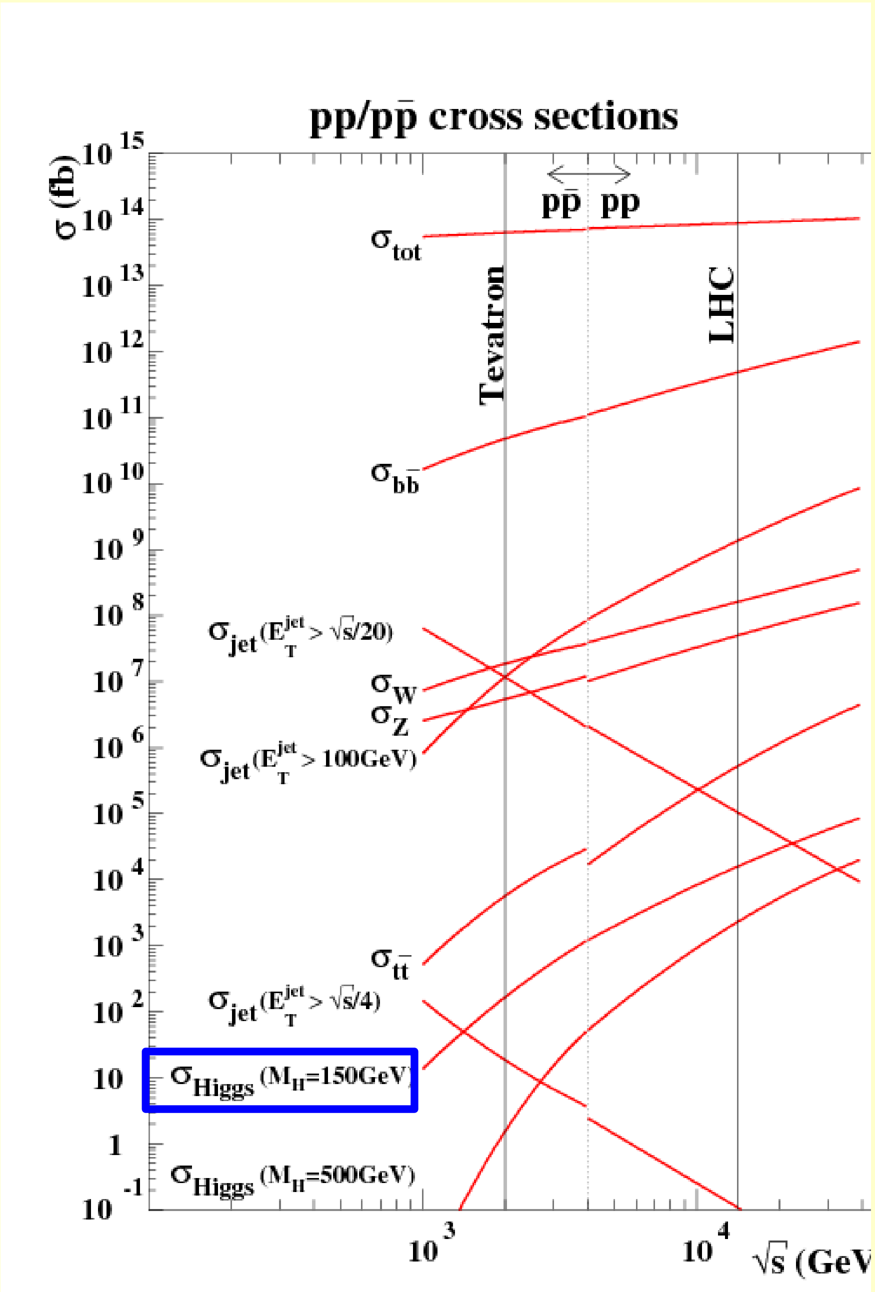
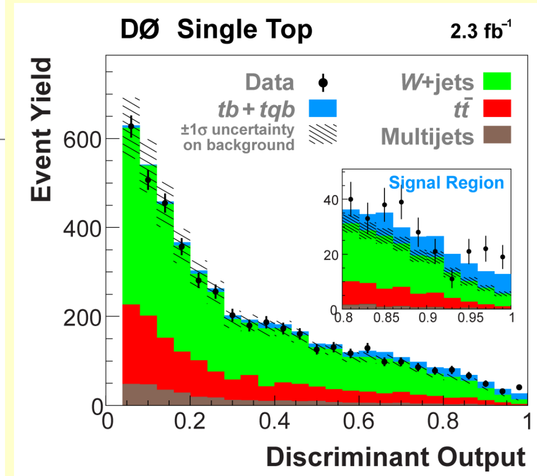
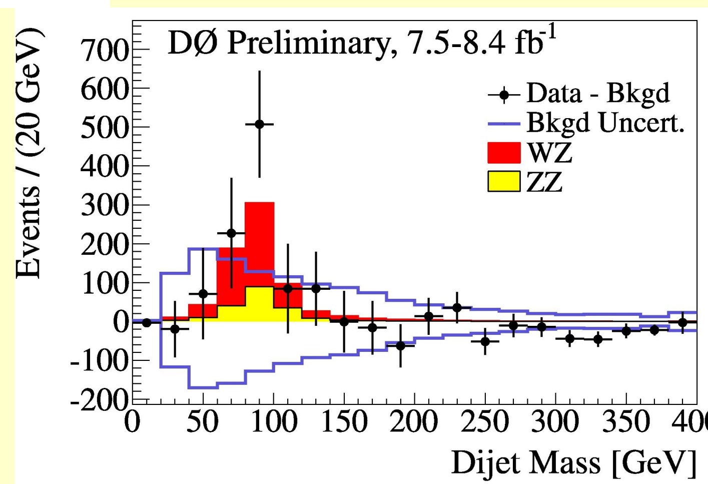


- We need to extract tiny signal from huge background
  - We have to be able to measure known processes
    - Good background modeling
  - Extensive application of advanced analysis techniques to find phase space regions with good signal and background separation
  - Measurements of low cross-section SM processes like single top, WW, WZ and ZZ, are a proof of principle.

How do we search?







- Measurements of low cross-section SM processes like single top, WW, WZ and ZZ, are a proof of principle.

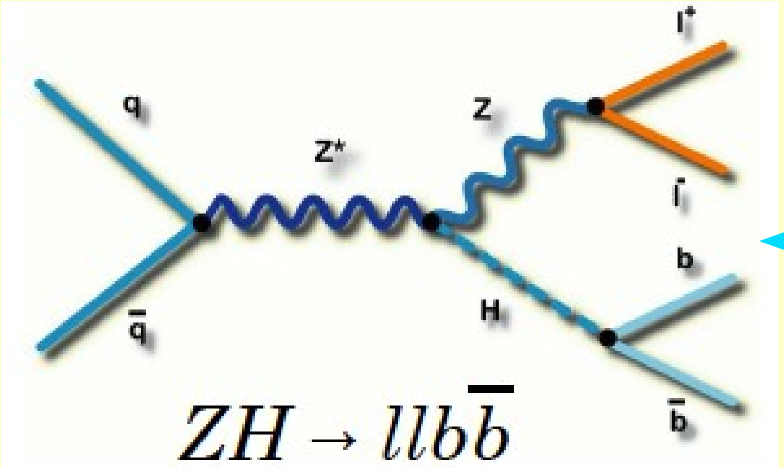
Overview of the Higgs search at DØ

Overwhelmed by multijet production if searched for in gg→H

	Gluon fusion	VH
H→bb		V=W→lν, low mass
H→bb		V=Z→ll, low mass
H→bb		V=Z→νν, W→~~l~~ν, low mass
H→γγ	Low mass	Low mass
H→ττ		Low mass
H→WW→lν+X		V=W→lν, High mass
H→WW→lνlν	High mass	
H→WW→lνjj	High mass	

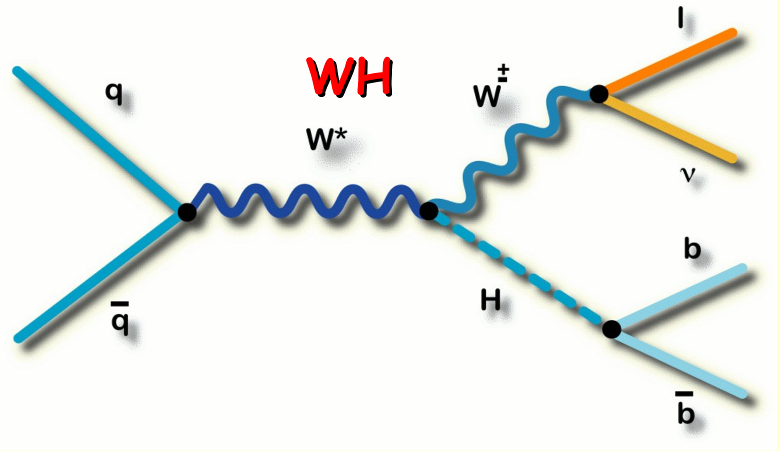
- Common challenges:
  - lepton and jet id, missing transverse energy (MET) reconstruction, b tagging, QCD estimation, systematics
- Recent improvements:
  - Better trigger and b-tagging algorithms, better lepton ID, improved dijet mass resolution

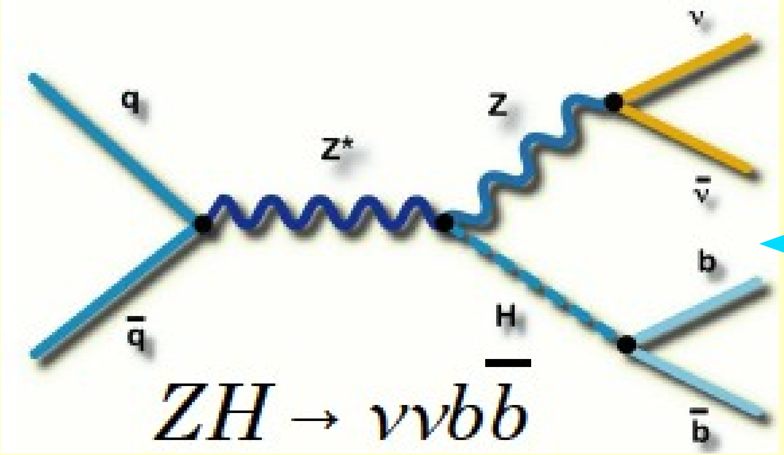
Search for the Low Mass Higgs Boson



- ZH → llbb – 2 leptons + 2 b-jets
- Low background, small signal
- Modeling of the Z+jets background; rejection of the tt background

- WH → lνbb – 1 lepton + MET + 2 b-jets
- Modeling of the W+jets backgrounds
- Modeling and rejection of the multijet backgrounds





- ZH → ννbb – MET + 2 b-jets
- Significant contribution from WH where a lepton is not reconstructed
- Background modeling and rejection

Search for the Low Mass Higgs Boson

Preselection	Zero or one or two leptons, MET, two or three jets
Modeling	Multijet model, W and Z-boson pT, jet angles
Background Rejection	Multijet suppression, tt rejection
b-tagging	Further signal optimization, several b-tagging categories
Final Result	Final multivariate analysis, systematics statistical analysis

Event Selection

$$m_{TR} = \sqrt{E^2 - p_x^2 - p_y^2}$$

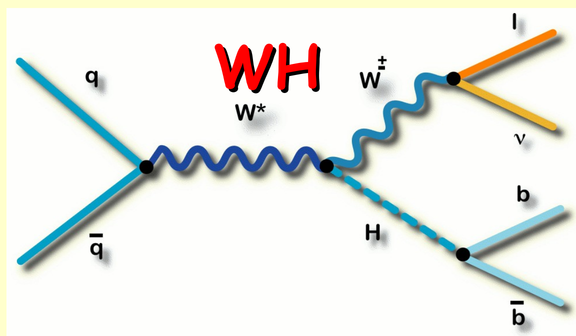
— WH

— H → WW

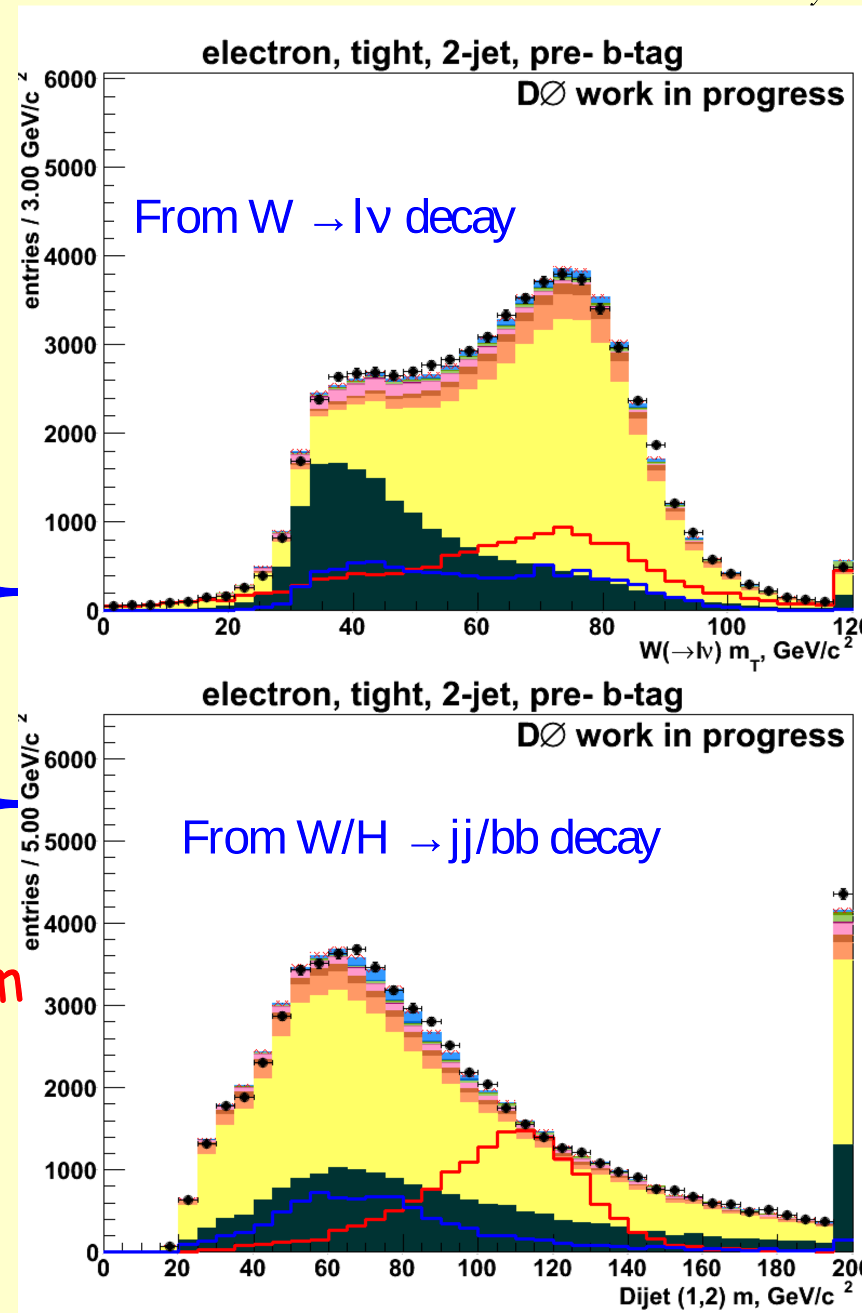
m_H=125 GeV

(s*2000)

- Two high p_T leptons, or one high p_T lepton and high MET, or high MET from vector boson



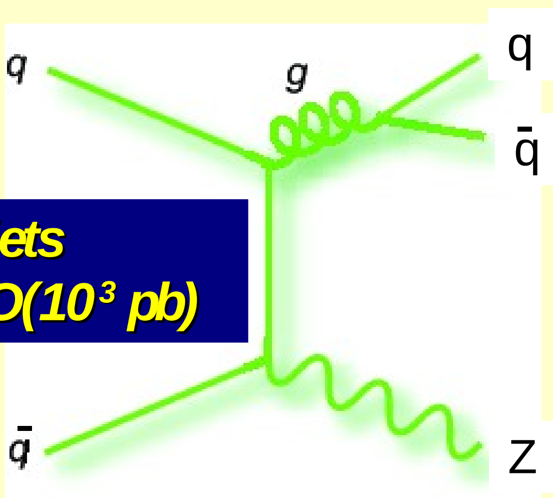
- At least two high p_T jets from Higgs boson



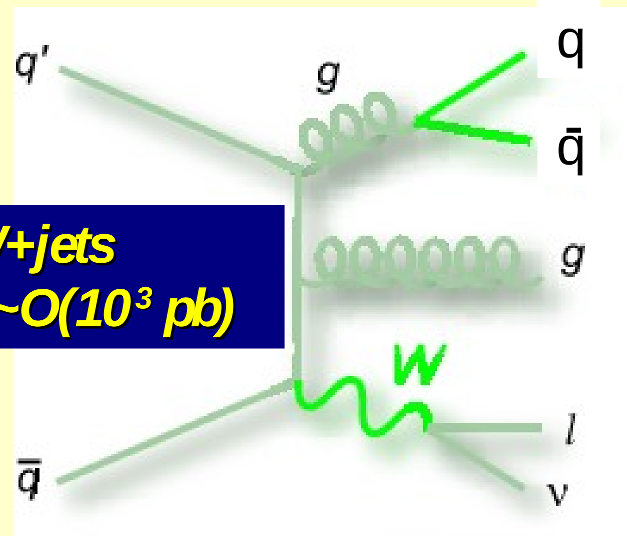
Modeling of the background

- We model background processes with Alpgen+Pythia, Pythia and CompHEP
- Normalized with the highest order cross section available (NLO or better)

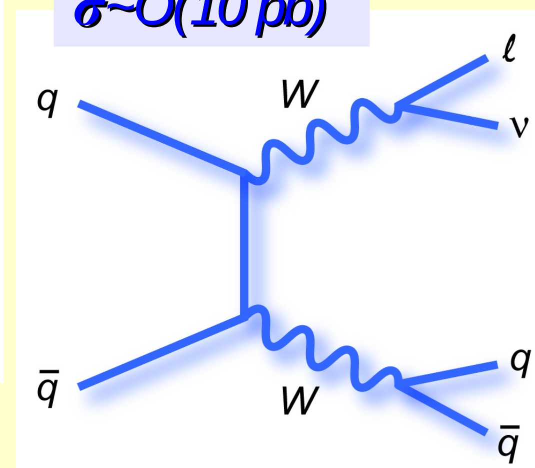
Z+jets
$\sigma \sim O(10^3\ pb)$



W+jets
$\sigma \sim O(10^3\ pb)$

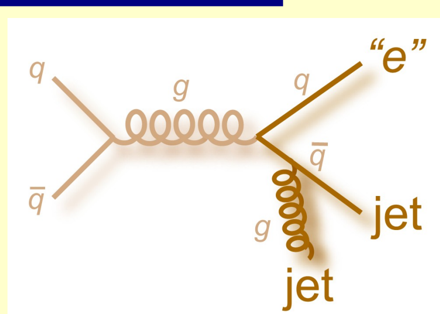


diBoson
$\sigma \sim O(10\ pb)$

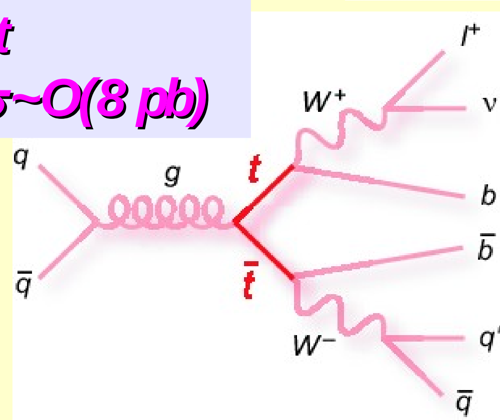


Higgs signal
$\sigma \sim O(0.1\ pb)$

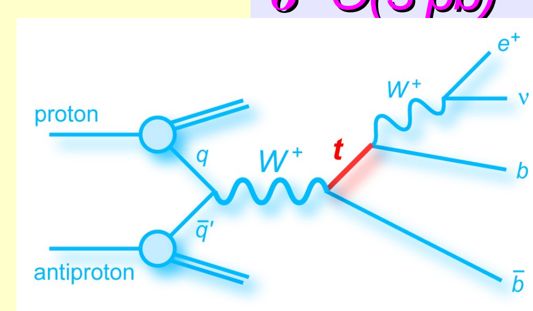
Multijet (QCD) from data



tt
$\sigma \sim O(8\ pb)$

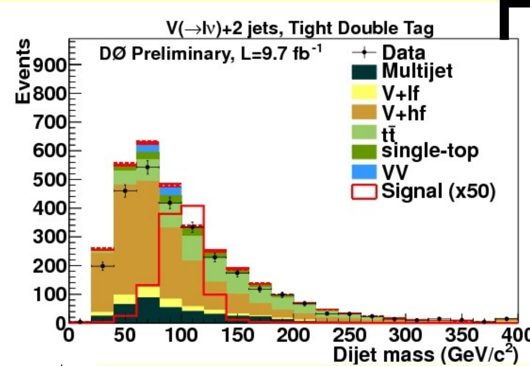


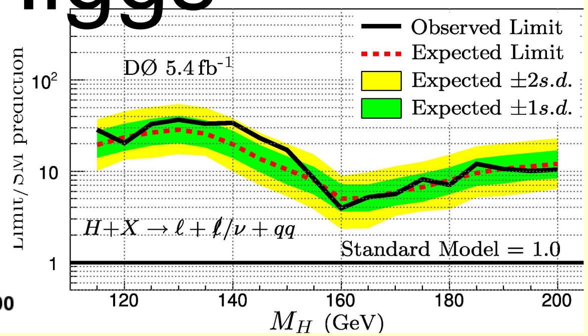
Single top
$\sigma \sim O(3\ pb)$



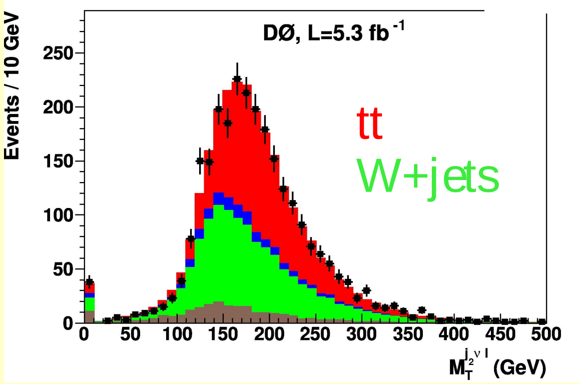
Modeling of the W+jets

Higgs



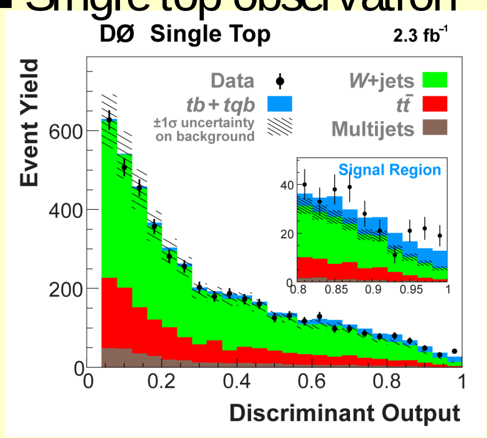


Cross section, mass, properties

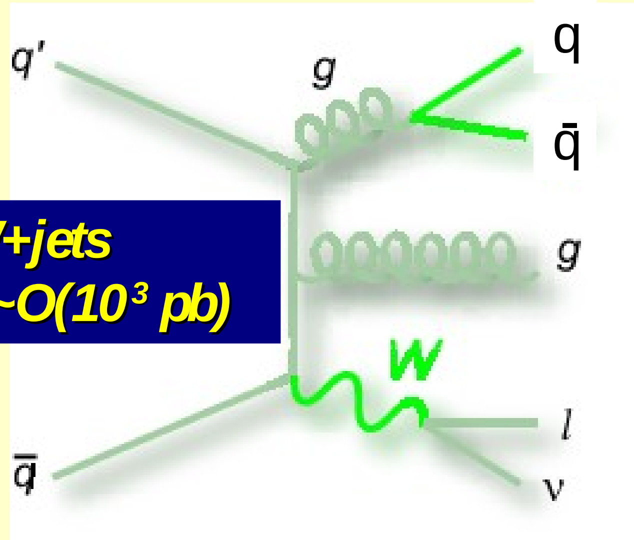


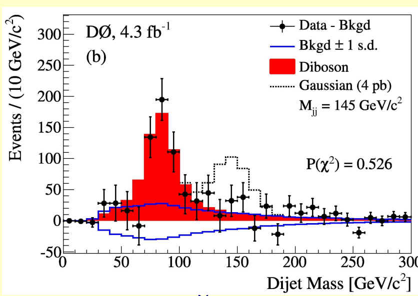
Top quark

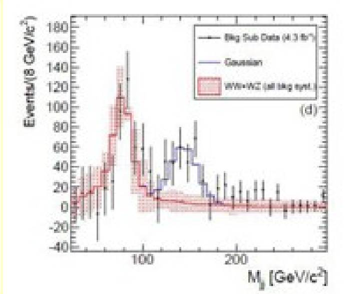
Single top observation



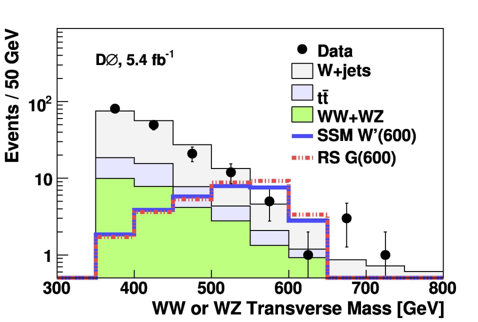
W+jets
σ~O(10³ pb)

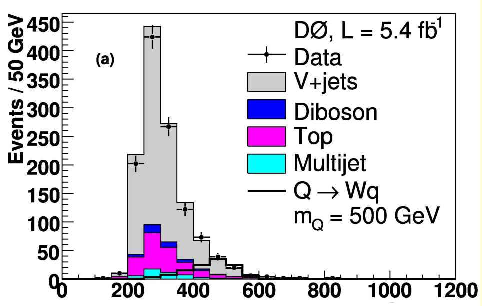


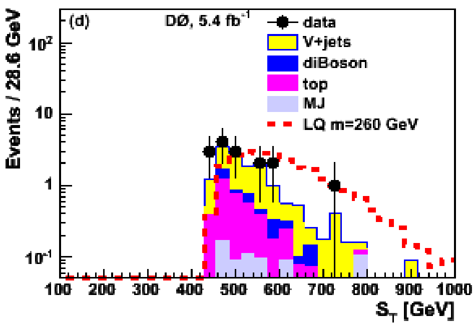




New physics

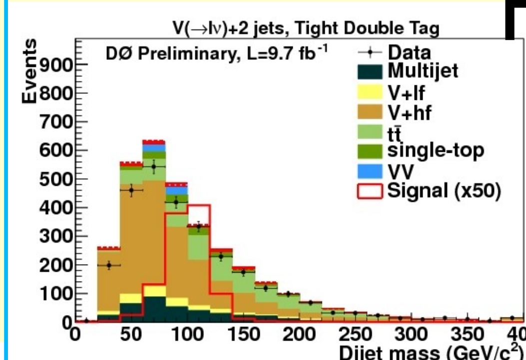


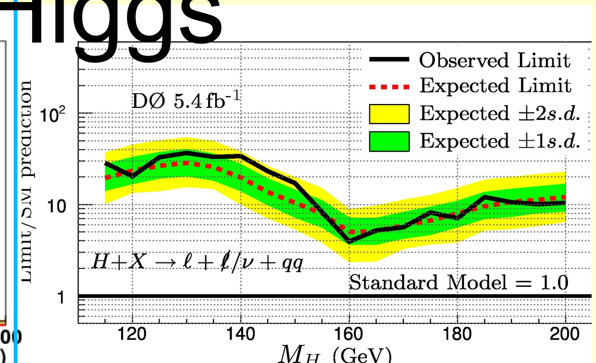




Modeling of the W+jets

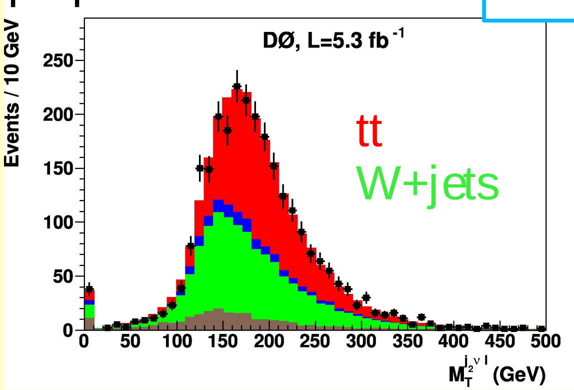
Higgs



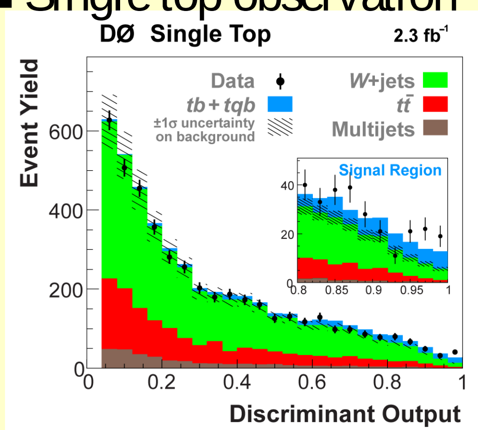


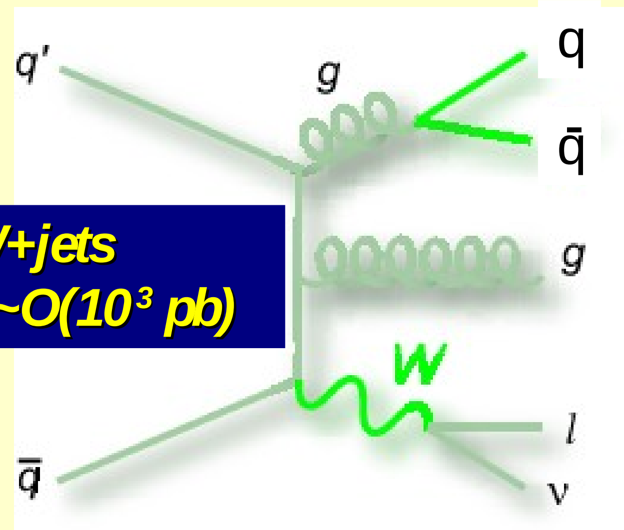
Top quark

Cross section, mass, properties



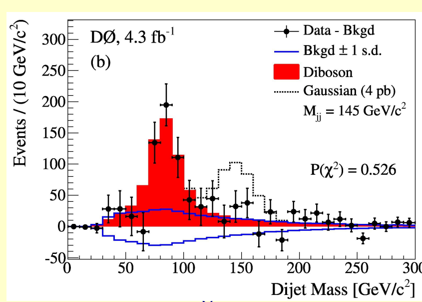
Single top observation

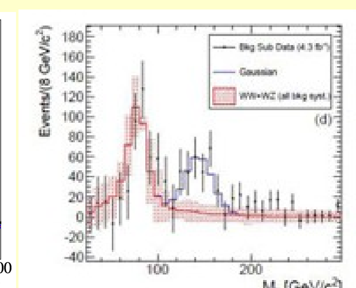




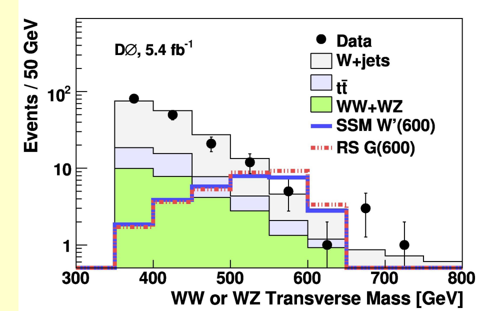
W+jets

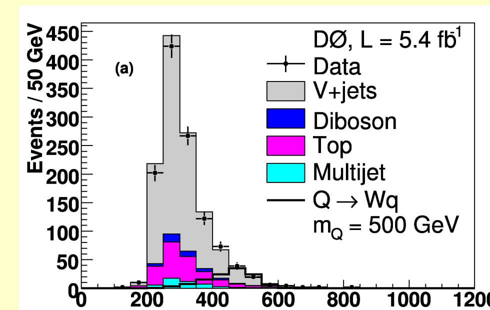
σ~O(10³ pb)

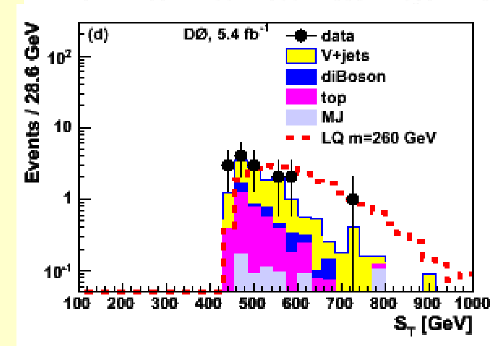




New physics

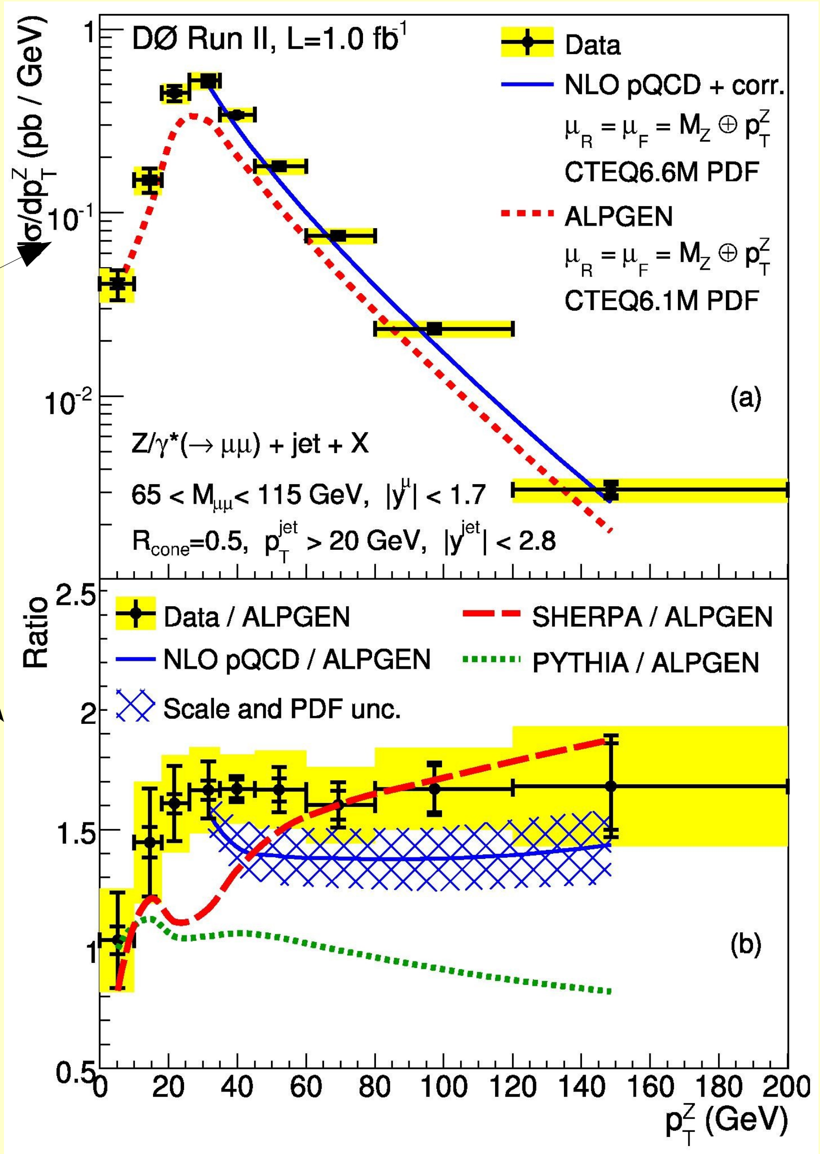






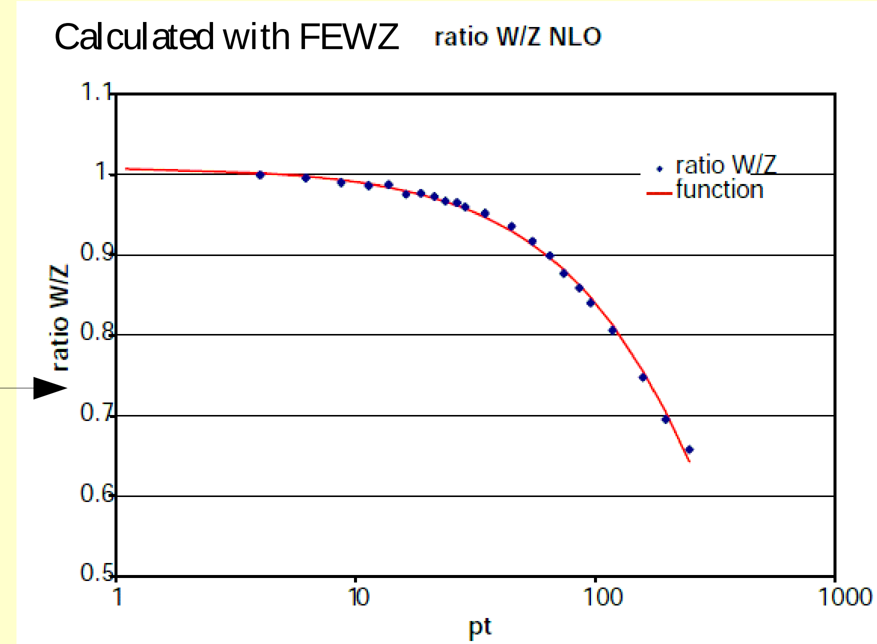
Modeling of the background - Z p_T

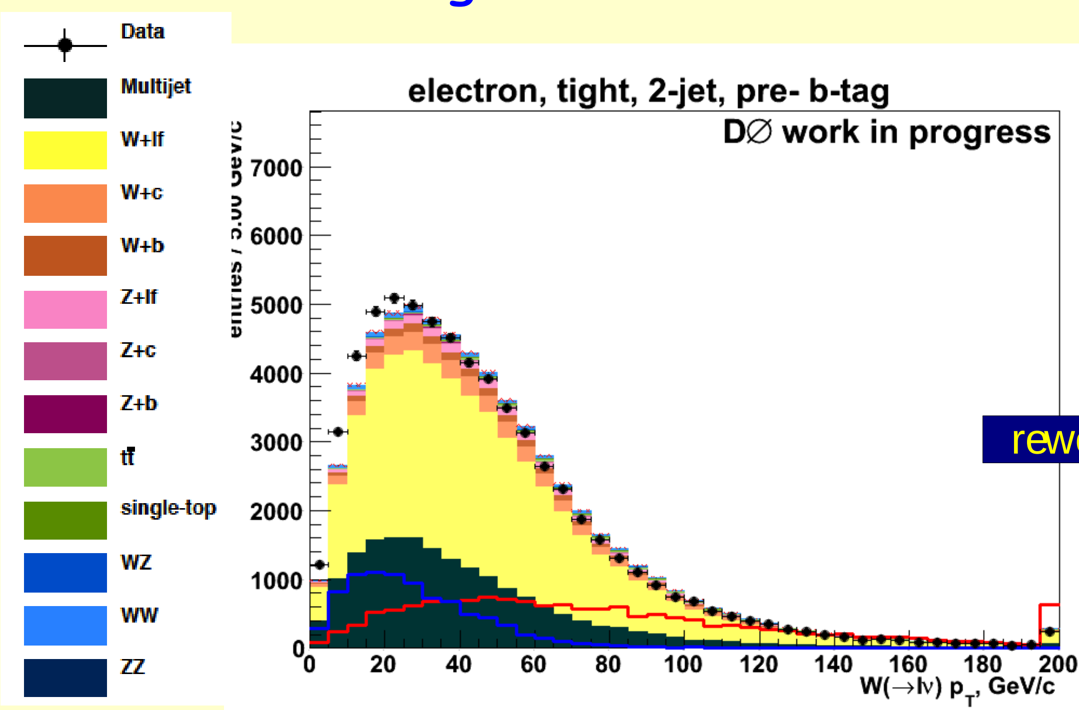
- Our generators do not describe vector boson (W or Z) p_T correctly
- We measured differential cross section $d\sigma/dp_T^Z$ and used that measurement to correct the Monte Carlo



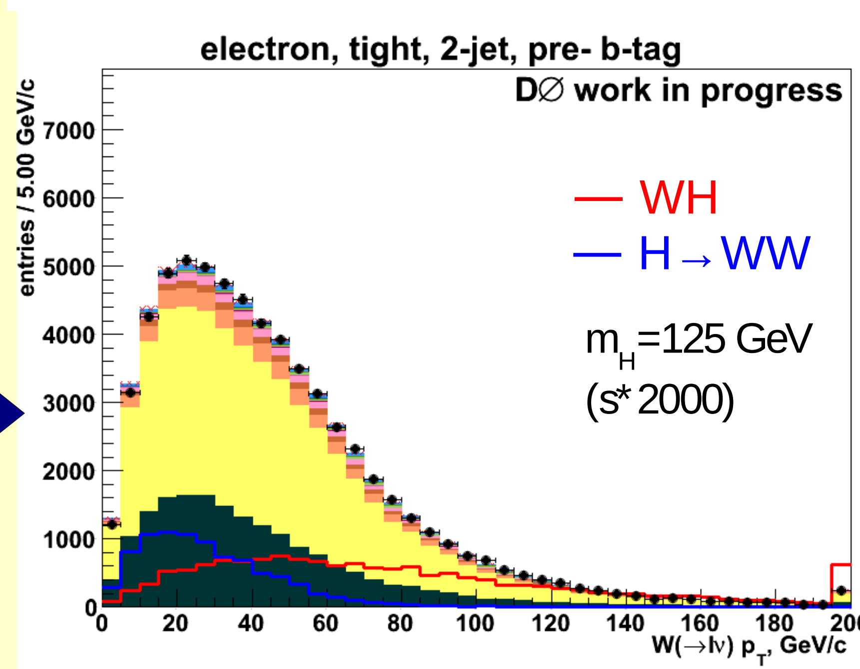
Modeling of the background - W p_T

- To determine the correct shape of W p_T we compared it to the measurement of the Z p_T corrected to the predicted NLO ratio between W and Z p_T
  - Compare to data to correct the remaining difference





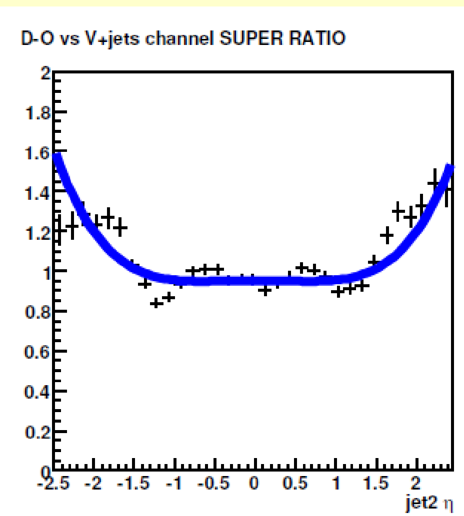
reweight

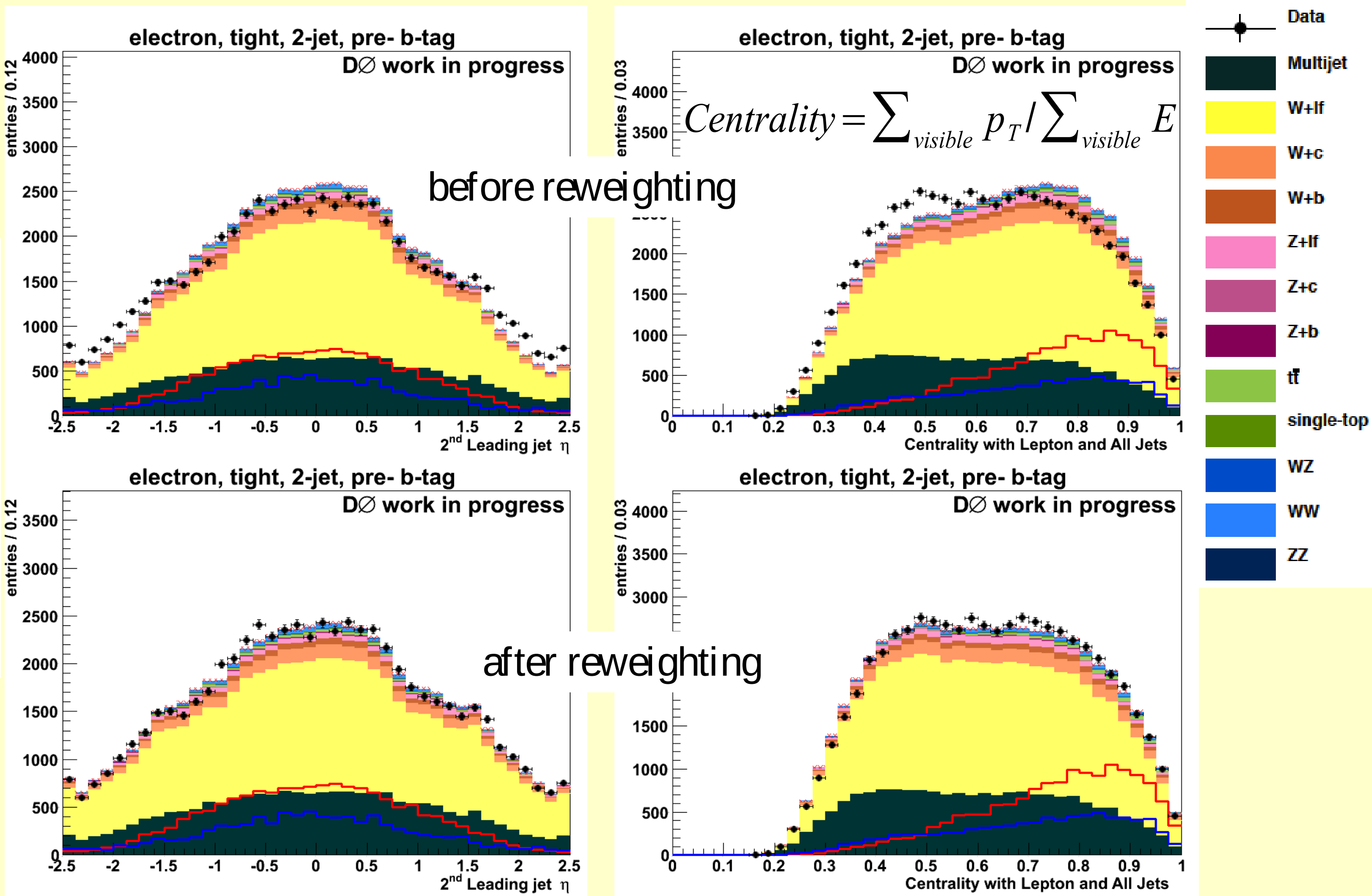


Modeling of the backgrounds – jet angles

- MC generators that we use do not describe jet angles correctly
- Correct distributions based on data, inclusive Z+jets and other generators

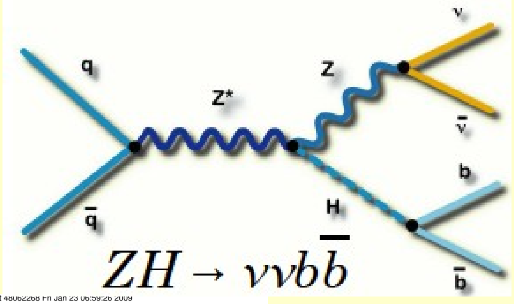
$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$



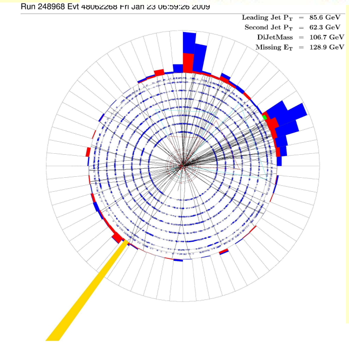


— WH
— H→WW
m_H=125 GeV
(s* 2000)

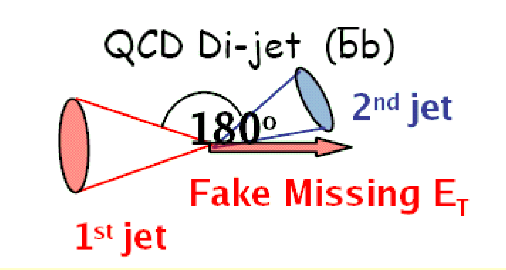
Multijet modeling -VH→$\not\!\!E_T$bb



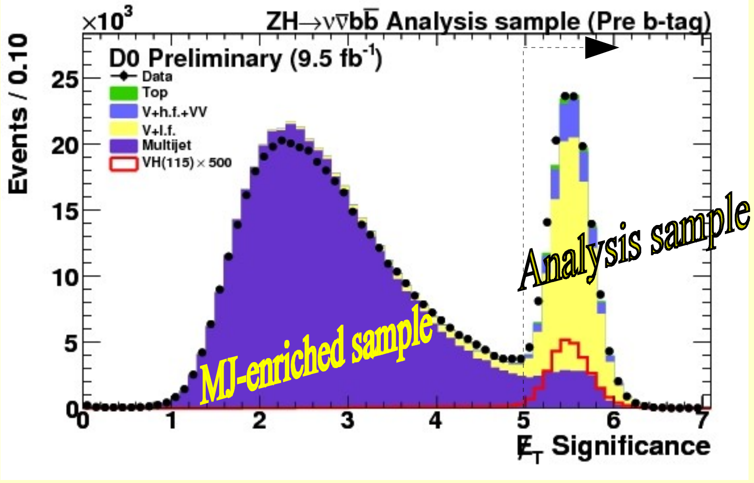
- Multijet mostly from the mismeasurement of jets



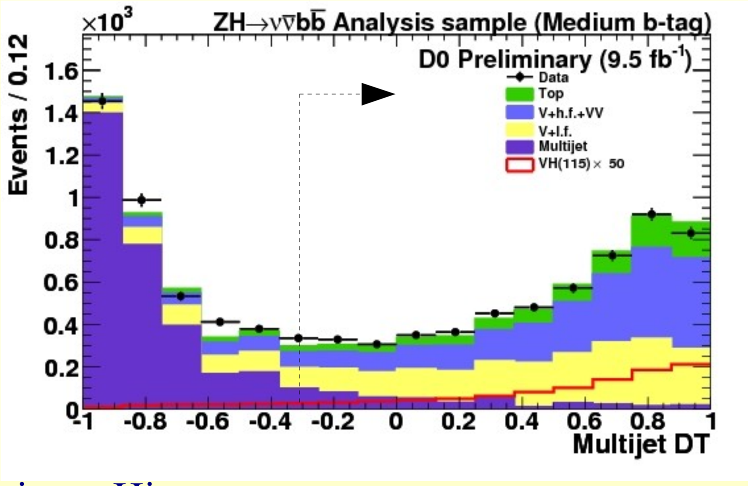
- Define four different regions:
  - Analysis sample – used for final result
  - EW control sample – to model V+jets backgrounds
  - MJ model - to model the MJ background in the analysis sample
  - MJ-enriched sample, used to validate the MJ-modeling procedure



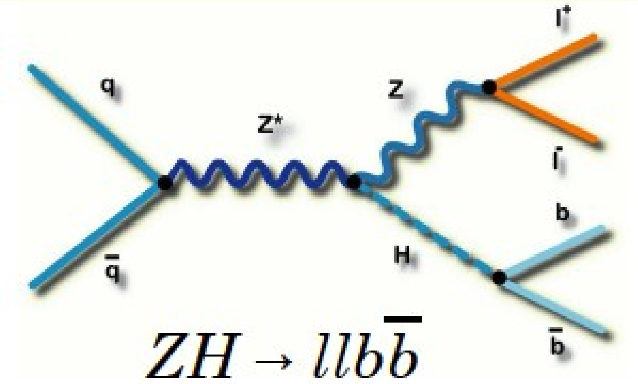
Remove events with low $\not\!\!E_T$ significance ($\approx \not\!\!E_T/\sigma_{\not E_T}$)



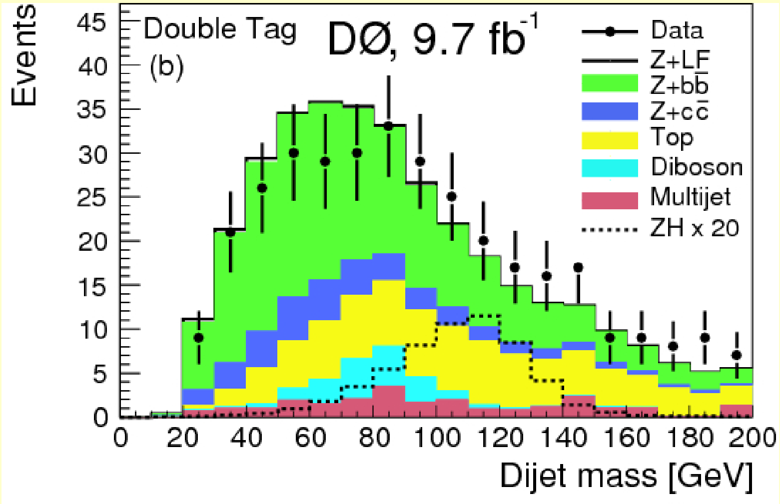
Dedicated MVA against multijet events + medium b-tag



Better dijet mass resolution - ZH→llbb



- To exploit the fully constrained kinematics energies of the leptons and jets are adjusted within their experimental resolutions, using a likelihood fit that constrains m_{ll} to the mass and width of the Z boson, and constrains the p_T of the llbb system to zero with an expected width determined from ZH MC events.



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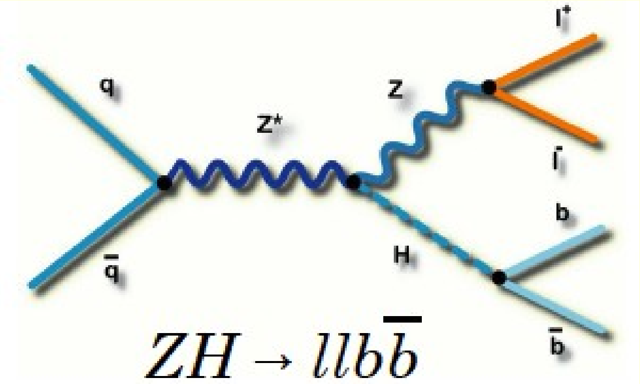

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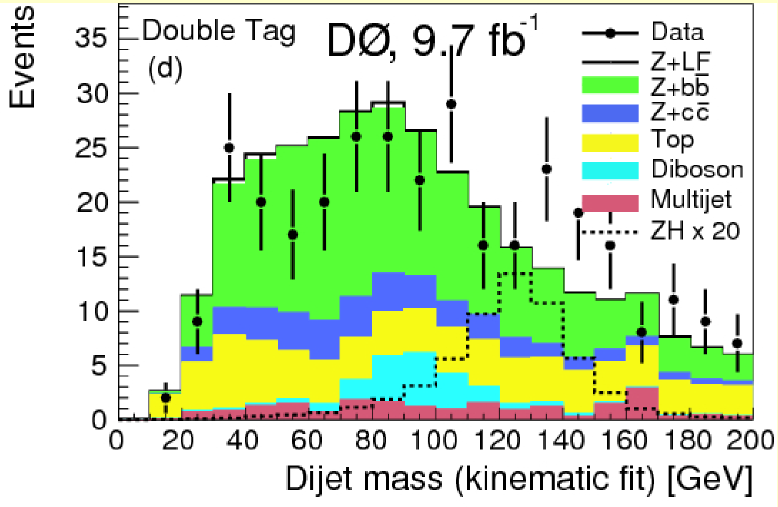
- Kinematic fit improves the dijet mass resolution by 10–15%, depending
- The dijet mass resolution for M_H = 125 GeV is 15 GeV with the kinematic fit



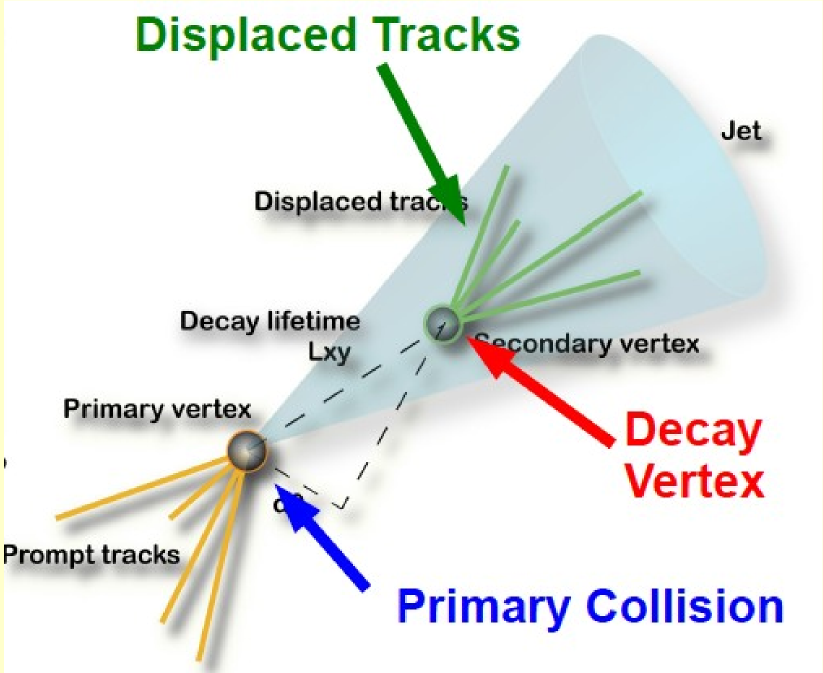
Yields after selection

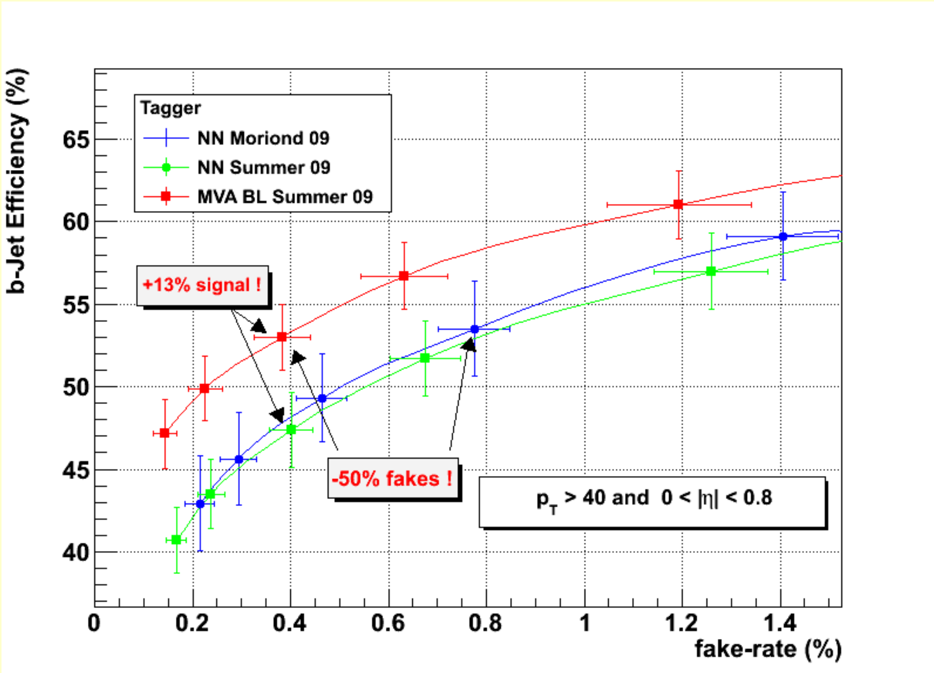
M=125 GeV	0 lepton search ZH → vvbb	1 lepton search WH → lvbb	2 leptons search ZH → llbb
Signal	35	46	9.2
V+jets	92480	240426	23558
MJ	1977	68366	1284
Top	1934	7222	285
Diboson	3144	6824	530
Total background	99535±12542	322838±24756	25658
Data	98980	322836	25849

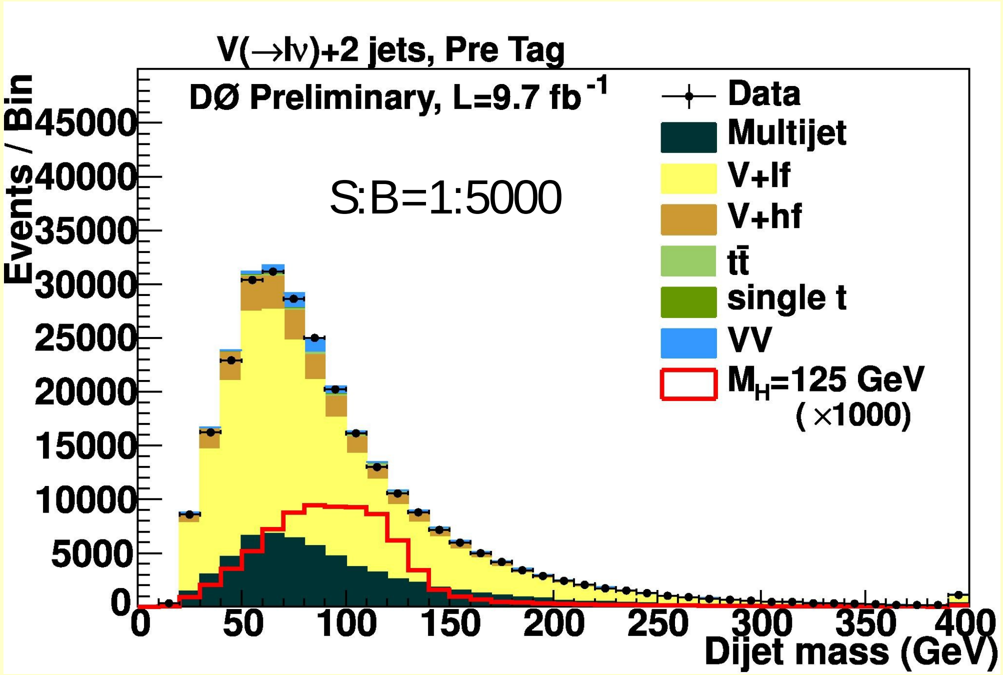
- Dominant backgrounds are V+jets, dominant component V+light flavors – more than 80%
  => Introduce b-tagging

b-tagging

- Several b hadron properties can be exploited to tag the b-jets:
  - long B lifetime (1.57±0.01 ps)
  - high mass (~5.2 GeV/c2)
  - high charged decay multiplicity – more tracks
- Combined information used in multivariate tagger







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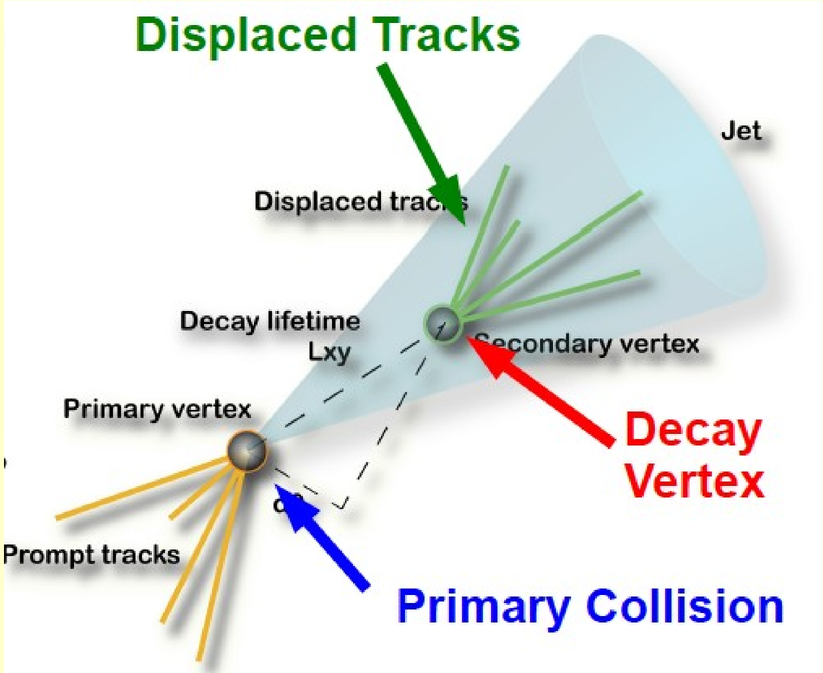
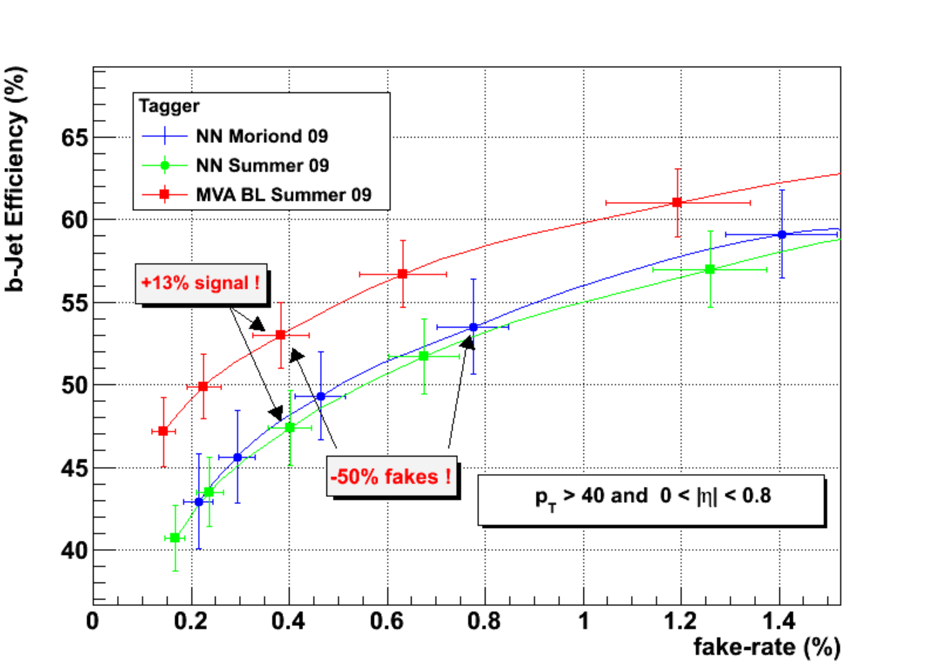
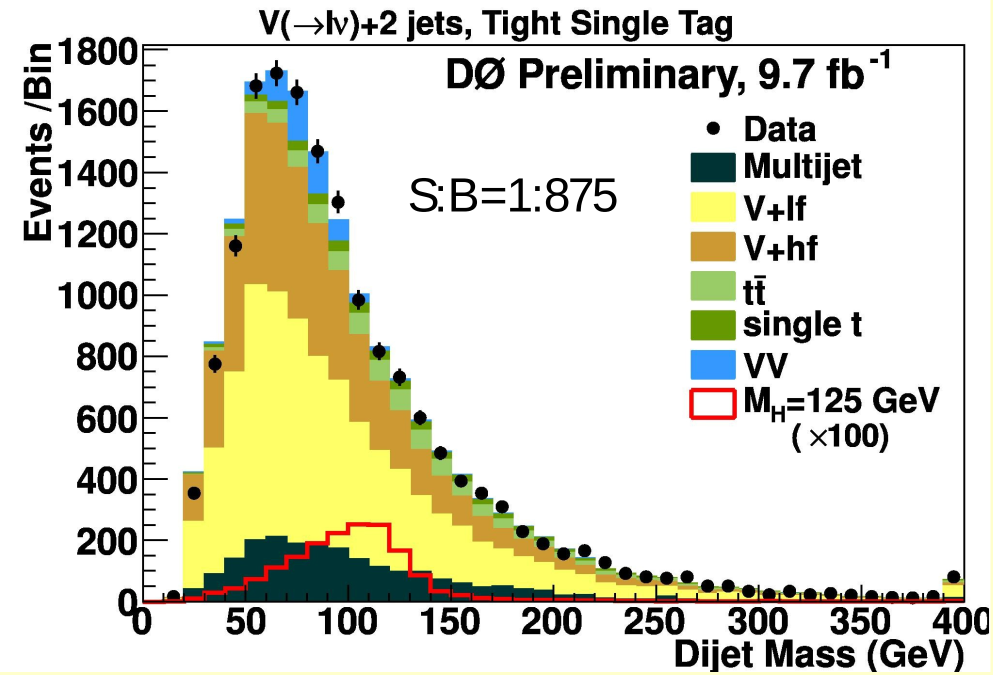


- Combined information used in multivariate tagger





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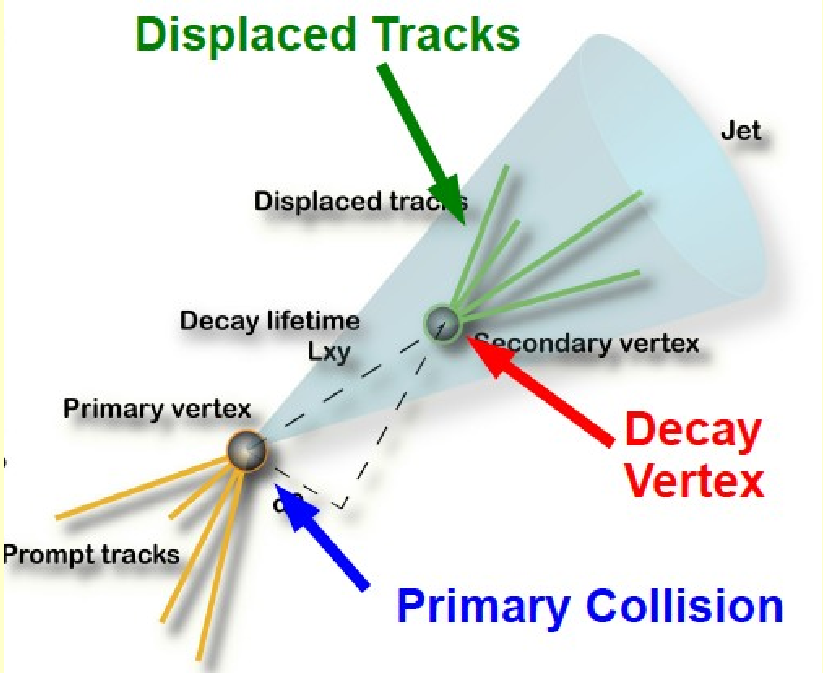
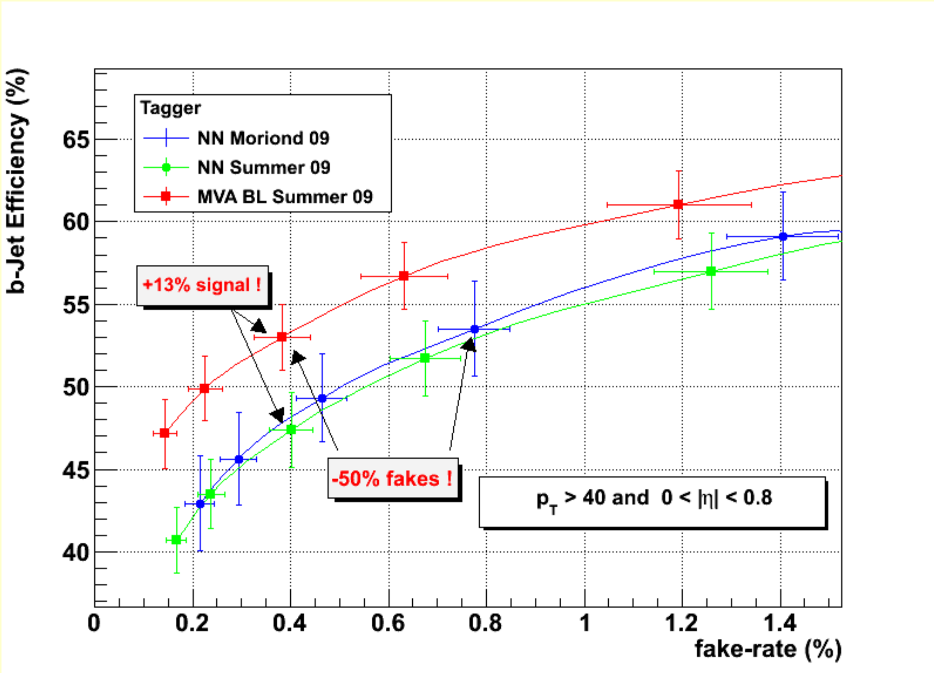
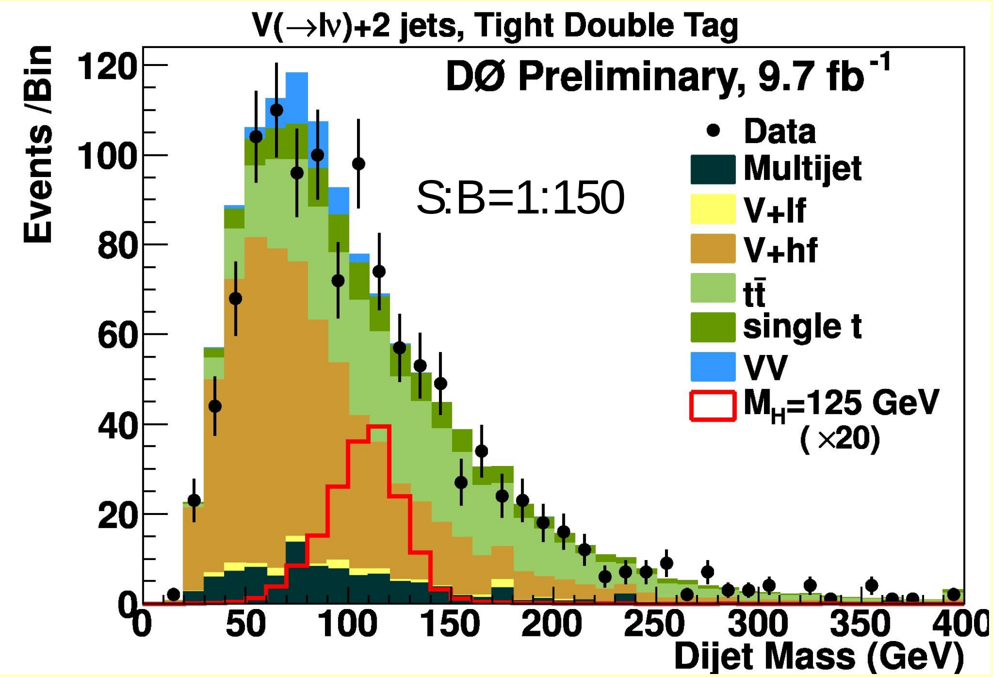


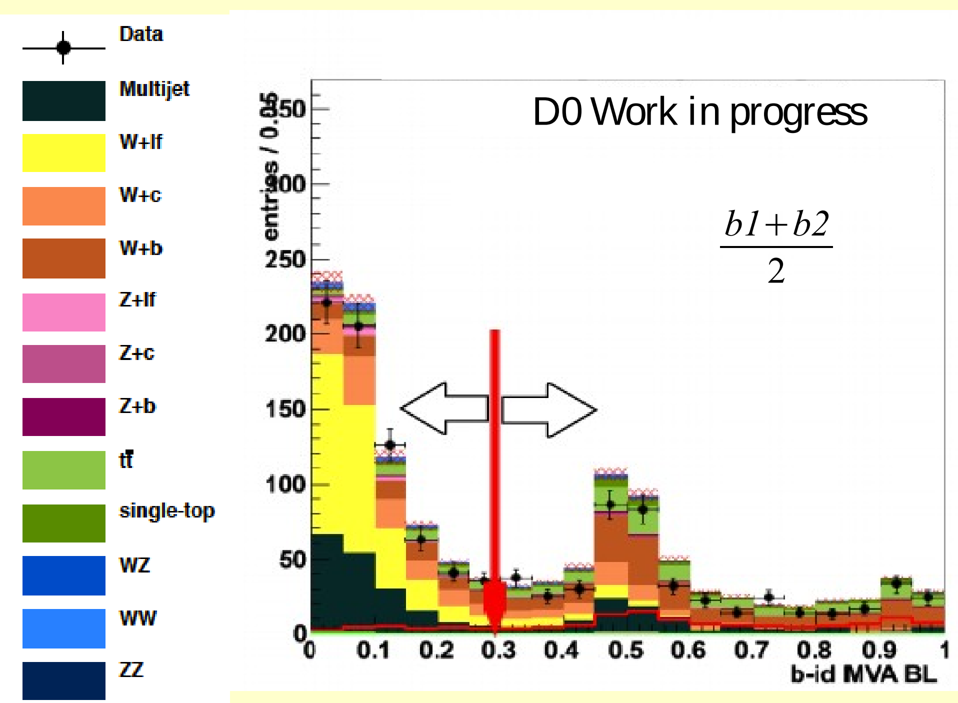




Further optimization with b-tagging

- Multivariate tagger allows for different configurations
  => Increase sensitivity of the search

	2 jets excl.	3 jets excl.	4 jets incl.
0 tag	H → WW → lνjj		WH → WWW vbf H → WW
1 loose tag			
1 tight tag	WH → lνbb		ttH
2 loose tags			
2 tight tags			



— WH
— H → WW

2 jets excl. Tag	~ 4 fb^{-1} Data	H → WW	125 WH	WWW
pretag	42102	2.9	5.6	2.2
0 tag	31656	2.2	0.8	1.5
1 loose tag	6711	0.5	0.6	0.4
1 tight tag	2724	0.2	1.8	0.2
2 loose tags	597	0.0	0.5	0.1
2 tight tags	414	0.0	2.0	0.0

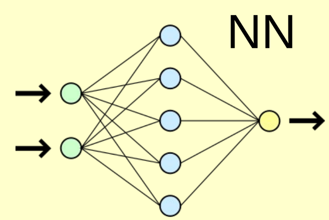
Yields after b-tagging - promeni

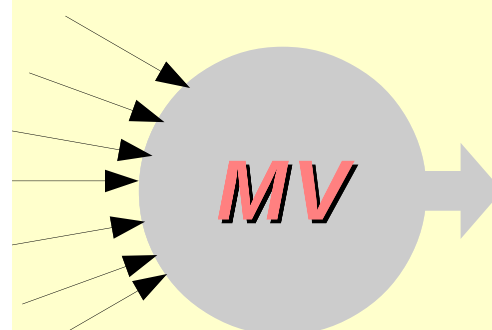
M=125 GeV	0 lepton search ZH → nunubb		1 lepton search WH → lnubb		2 leptons search ZH → llbb	
Signal	12.8	11.3	13.9	19.2	2.5	2.9
V+jets	4186	695	13635	5691	660	222
MJ	278	6	4634	2020	54	26
Top	761	377	2413	2437	77	99
Diboson	237	56	648	256	33	19
Total background	5462±776	1134±192	21330±2190	10404±1059	824±102	366±39
Data	5453	1039	20684	10071	886	373

- For instance in WH double tag, expected 19.2 signal events for the Higgs mass of 125 GeV, and 10404 background events - s:b~1:540
- But
  - Uncertainties on the background are larger than expected signal
  - Simple counting experiment will not work.

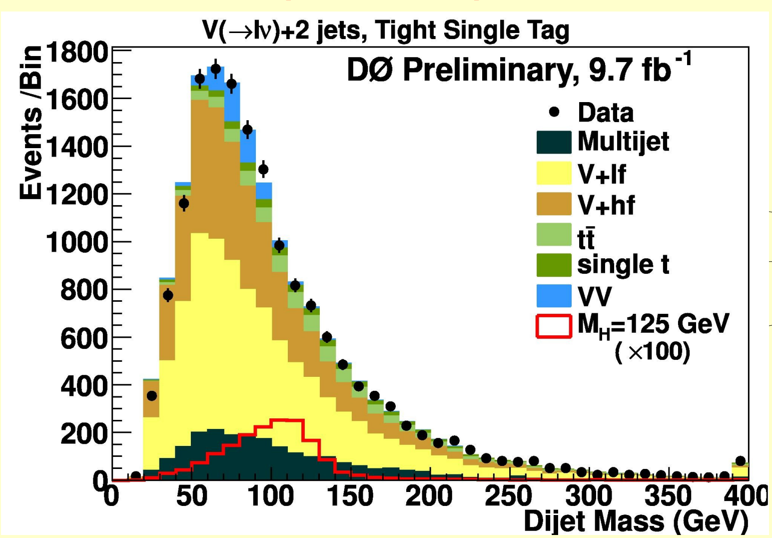
Multivariate techniques

- Multivariate techniques are more powerful than simple cut method
  - They exploit correlations between different observables
- One output, usually between 0 (background like) and 1 (signal like events)

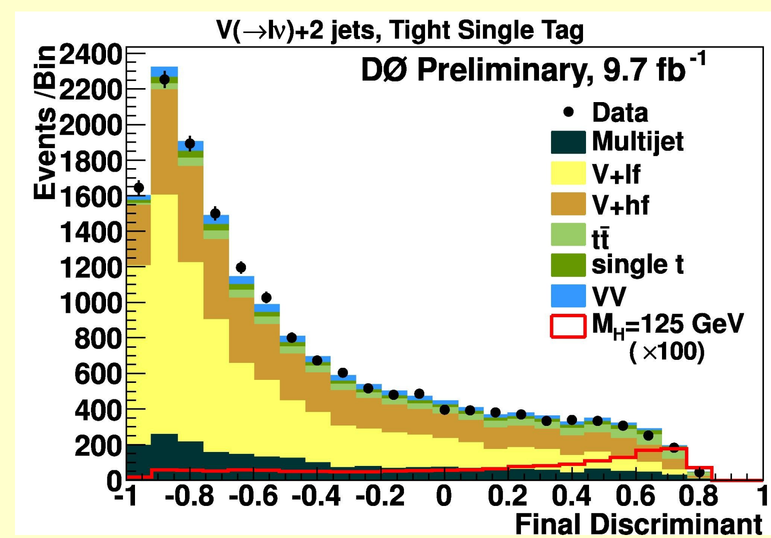


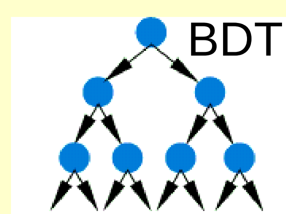


Good separation power



Well modeled



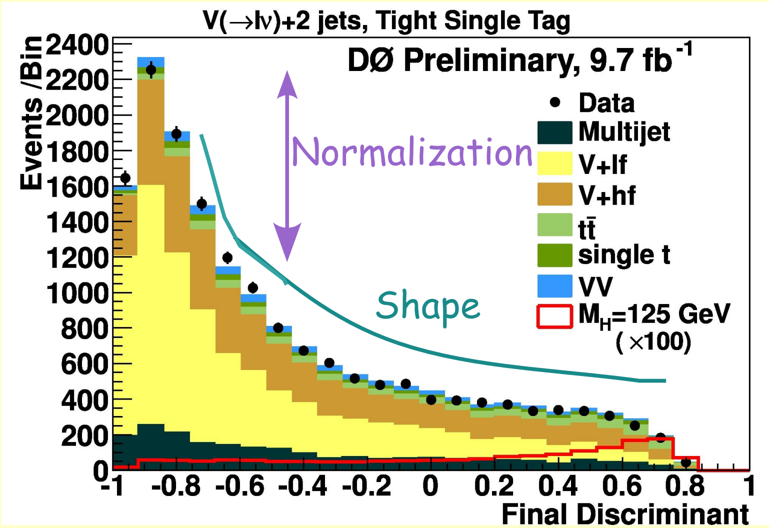


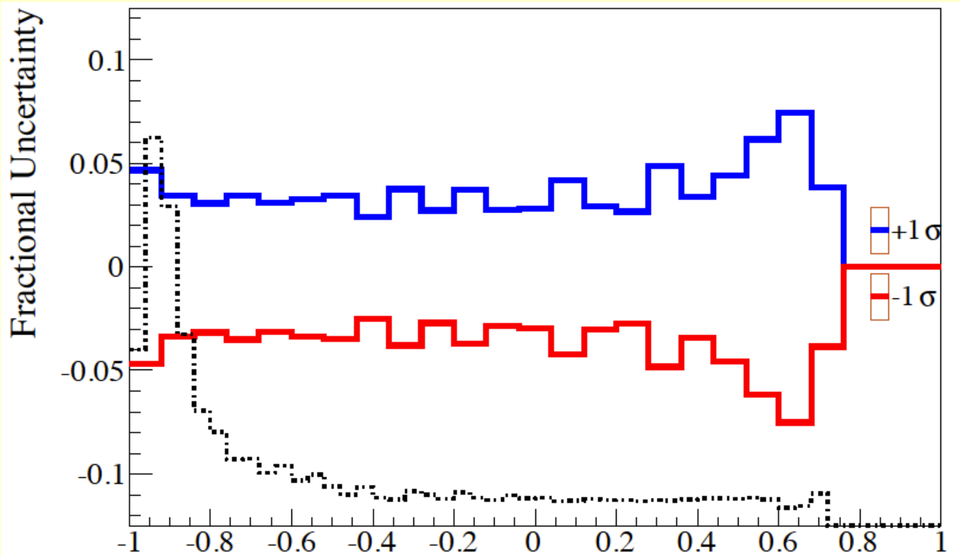
Systematics

- Uncertainties affect both the normalization (luminosity, cross section,...)

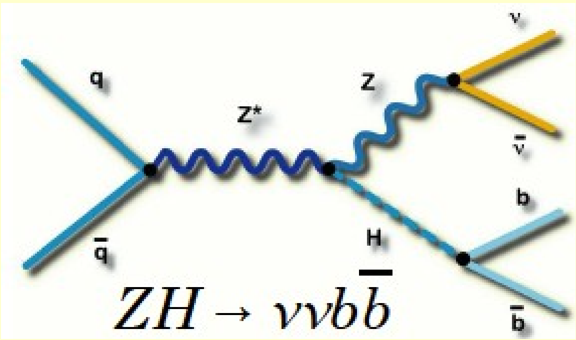
	Background	Signal
Luminosity	6.10%	6.10%
Cross section	3-10%	10.00%
QCD nomalization	20.00%	x
lepton ID	3.00%	3.00%

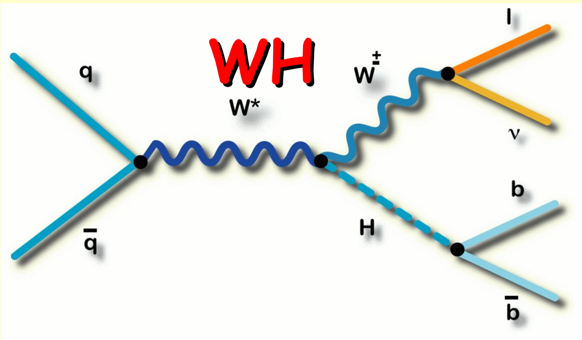
- and the differential distributions (Jet Energy Scale, ID and resolution, QCD shape, reweighting, b-tagging, HF content...)

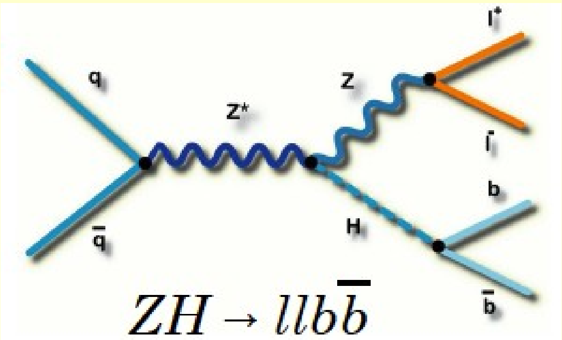


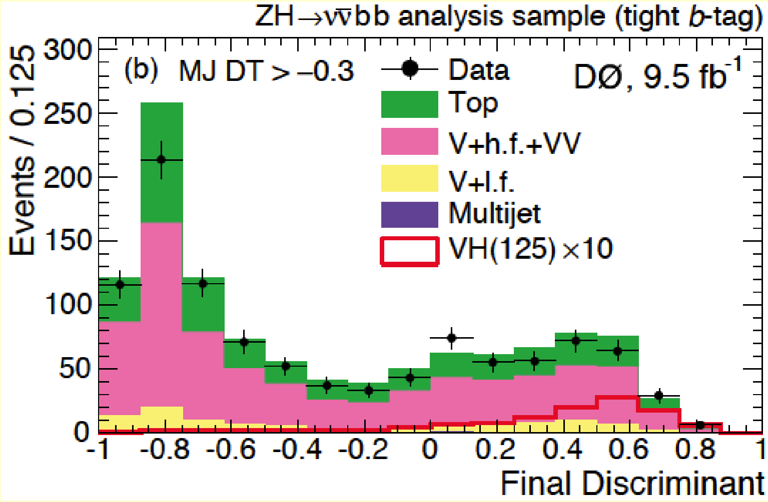


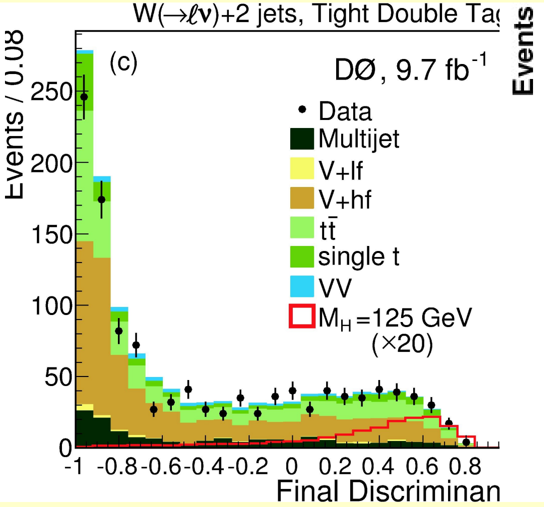
Results

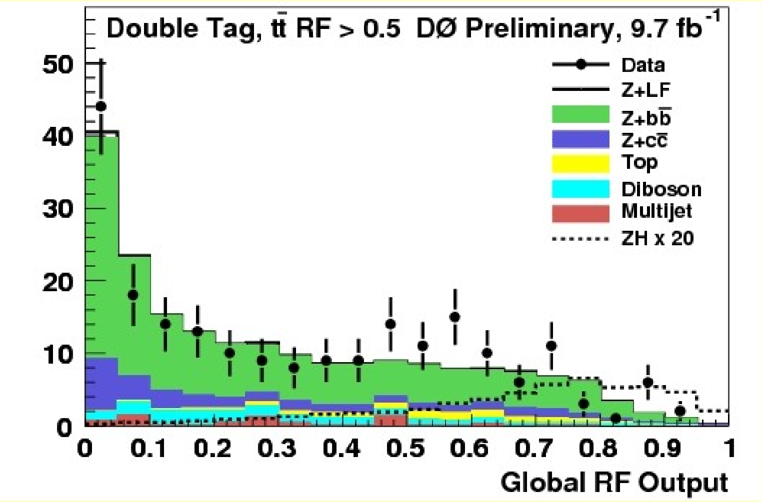








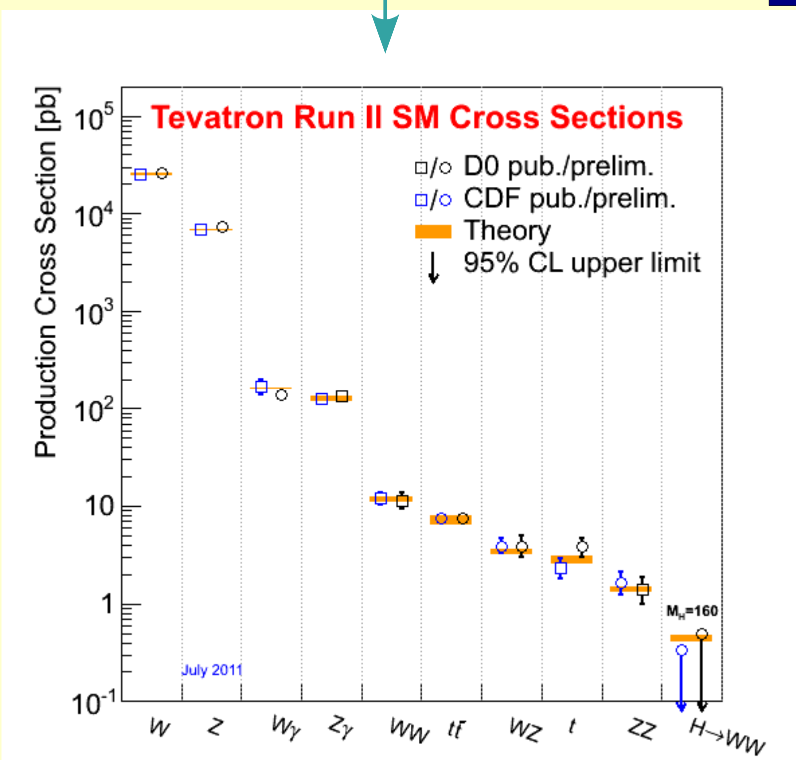




DØ (9.5 fb^{-1})	Exp.	Obs	DØ (9.7 fb^{-1})	Exp.	Obs	DØ (9.7 fb^{-1})	Exp.	Obs
M_H = 115 GeV	2.7	3.0	M_H = 115 GeV	3.2	3.7	M_H = 115 GeV	3.7	4.3
M_H = 125 GeV	3.9	4.3	M_H = 125 GeV	4.7	5.2	M_H = 125 GeV	5.1	7.1

Validation of the search

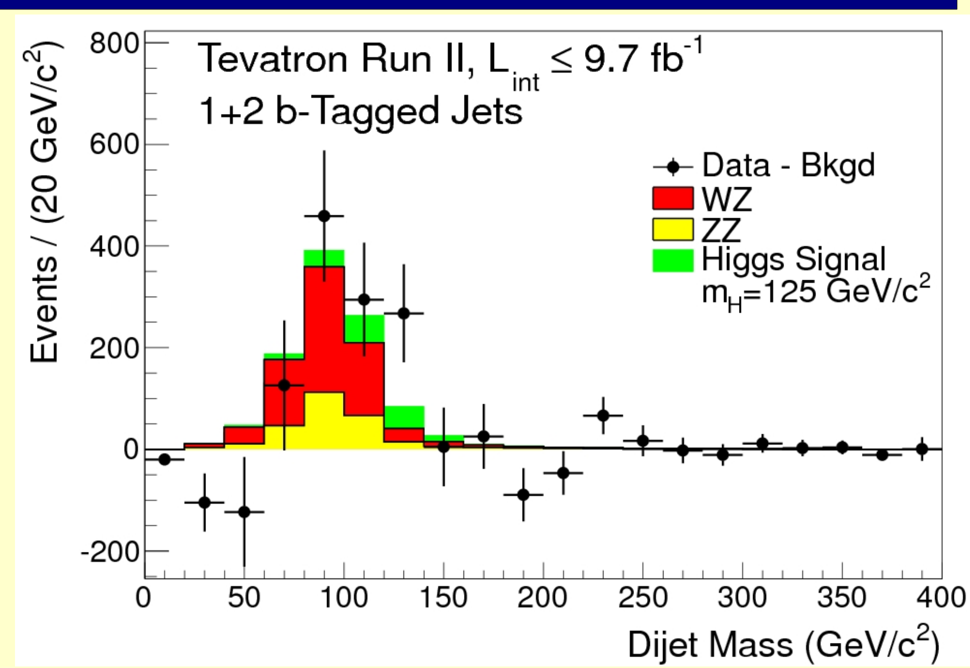
- Tevatron has measured many SM processes
- Some of them with very low cross sections



- The latest is the W/Z+Z → bb
  - ~6 higher cross section than the Higgs signal with m_H = 125 GeV
  - Exactly the same analysis

$$measured\ W/Z+Z \rightarrow bb: 3.9 \pm 0.6(stat) \pm 0.7(syst)$$

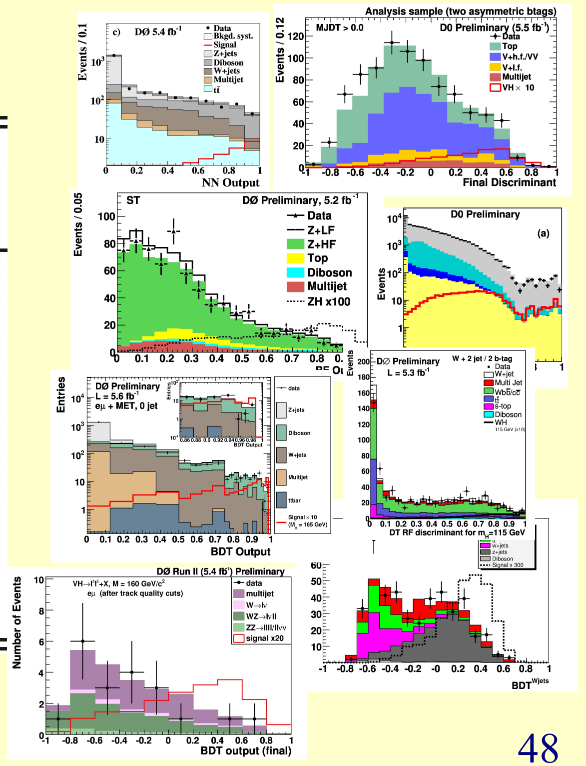
$$SM\ prediction\ W/Z+Z \rightarrow bb: 4.4 \pm 0.3\ pb$$



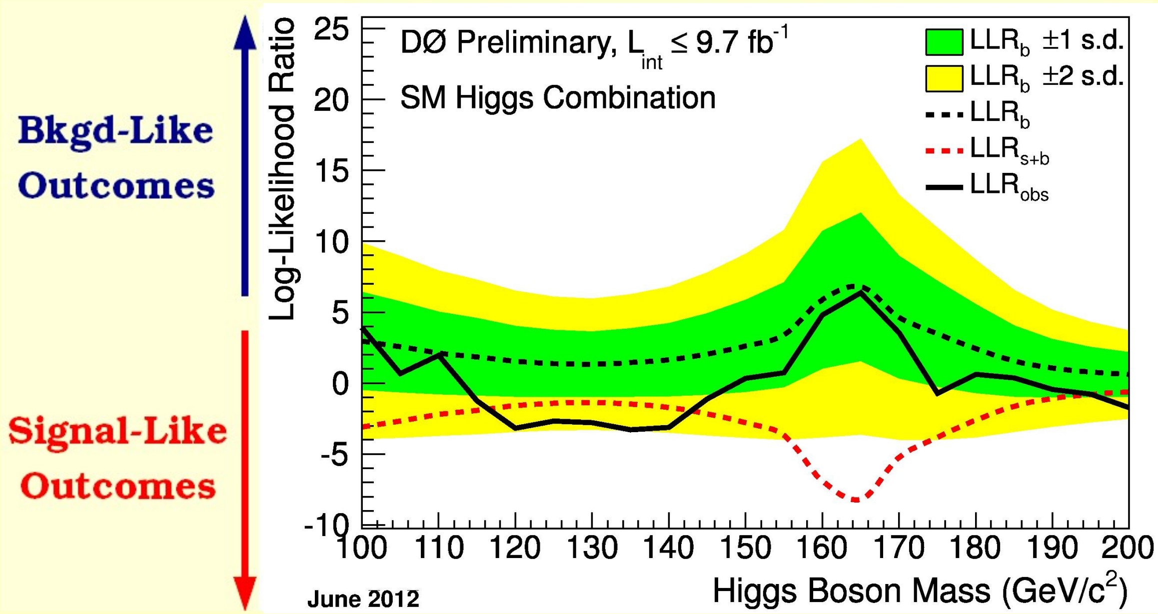
Combining channels

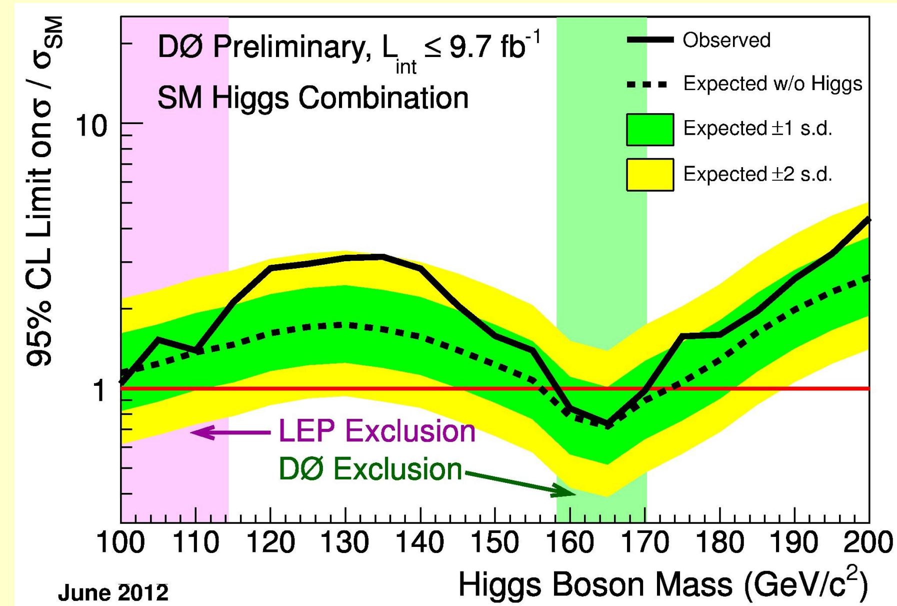
- Our goal is to understand the theory of the SM Higgs boson
  - The answer is either "The SM Higgs is there" or "It's not there"
- We test our data for compatibility with one of two hypotheses:
  - SM+Higgs or SM-Only
- Combine many channels: DØ + CDF

Channel	Luminosity (fb^{-1})	m_H range (GeV/c^2)
$H+(X)\to \ell\nu+\geq jj$ (0,1,$\geq$2b tags)×(2,3,4+ jet)	9.7	100-200
$ZH\to \nu\bar{\nu}b\bar{b}$ (MS,TS)	9.5	100-150
$ZH\to \ell^+\ell^-b\bar{b}$ (TST,TLDT)×(ee,$\mu\mu$,ee_{ICR},$\mu\mu_{trk}$)	9.7	100-150
$VH\to e^\pm\mu^\pm+X$	9.7	115-200
$H\to W^+W^-\to \ell^\pm\nu\ell^\mp\nu$ (0,1,2+ jet)	9.7	115-200
$H\to W^+W^-\to \mu\nu\tau_{\rm had}\nu$	7.3	115-200
$H\to W^+W^-\to \ell\bar{\nu}jj$	5.4	130-200
$VH\to \ell\ell\ell+X$	9.7	100-200
$VH\to \tau\tau\mu+X$	7.0	115-200
$H\to\gamma\gamma$	9.7	100-150



Understanding limit plots

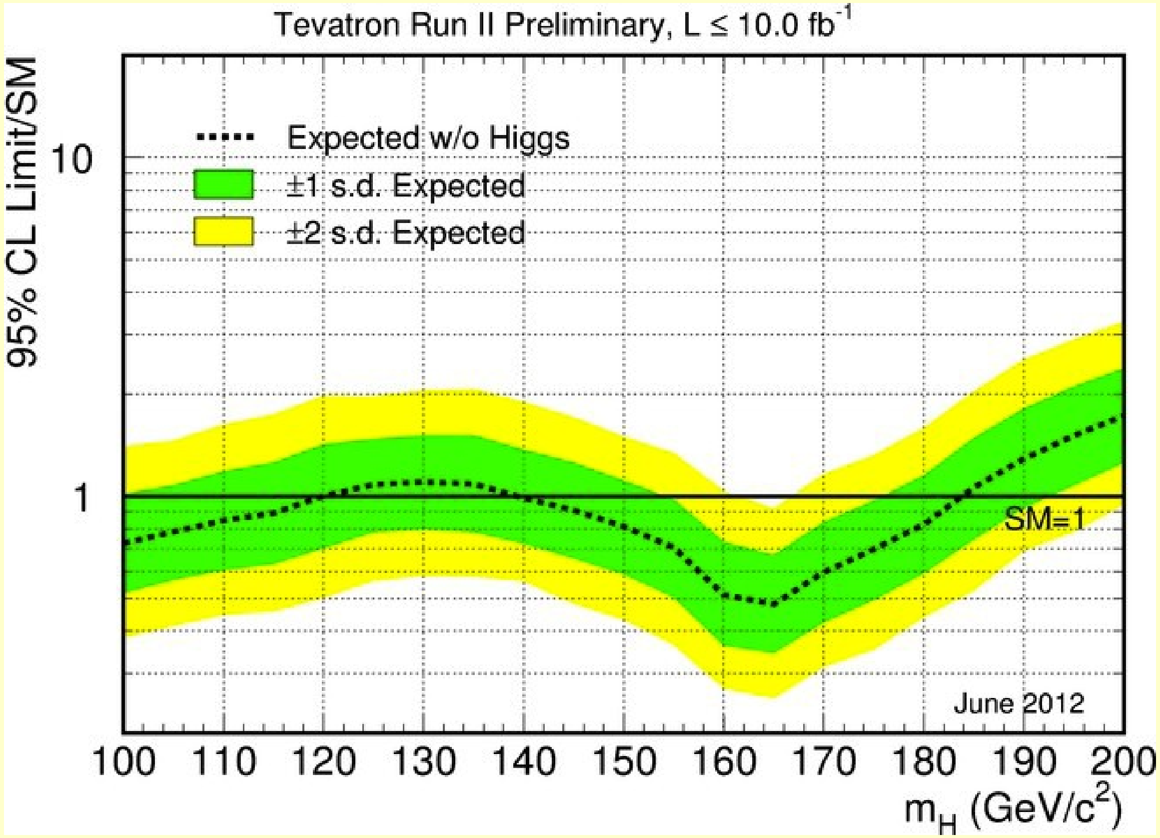




- The width of the Log Likelihood Ratio, LLR_b, distribution (1σ and 2σ bands) provides an estimate of how sensitive the analysis is to a signal-like background fluctuation in the data, taking account of the presence of systematic uncertainties
  - For example, when a 1σ background fluctuation is large compared to the signal expectation, the analysis sensitivity is thereby limited.
- The value of LLR_{obs} relative to LLR_{s+b} and LLR_b indicates whether the data distribution appears to be more like signal-plus-background or background-only.

The new Tevatron limit

- The new Tevatron exclusion
  - It is expected to exclude Higgs mass in regions 100 - 120 GeV and 141 - 184 GeV
  - Actual exclusion: 100-103 GeV and 147 - 180 GeV @95% CL



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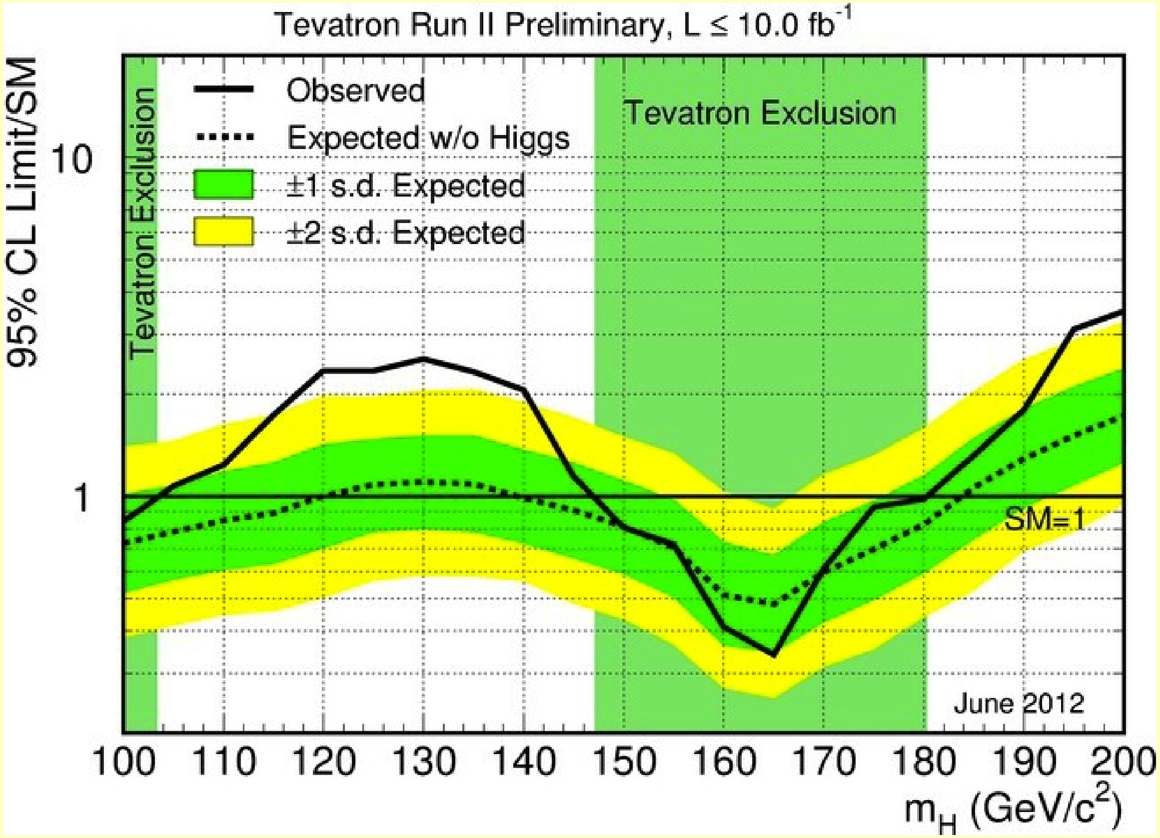

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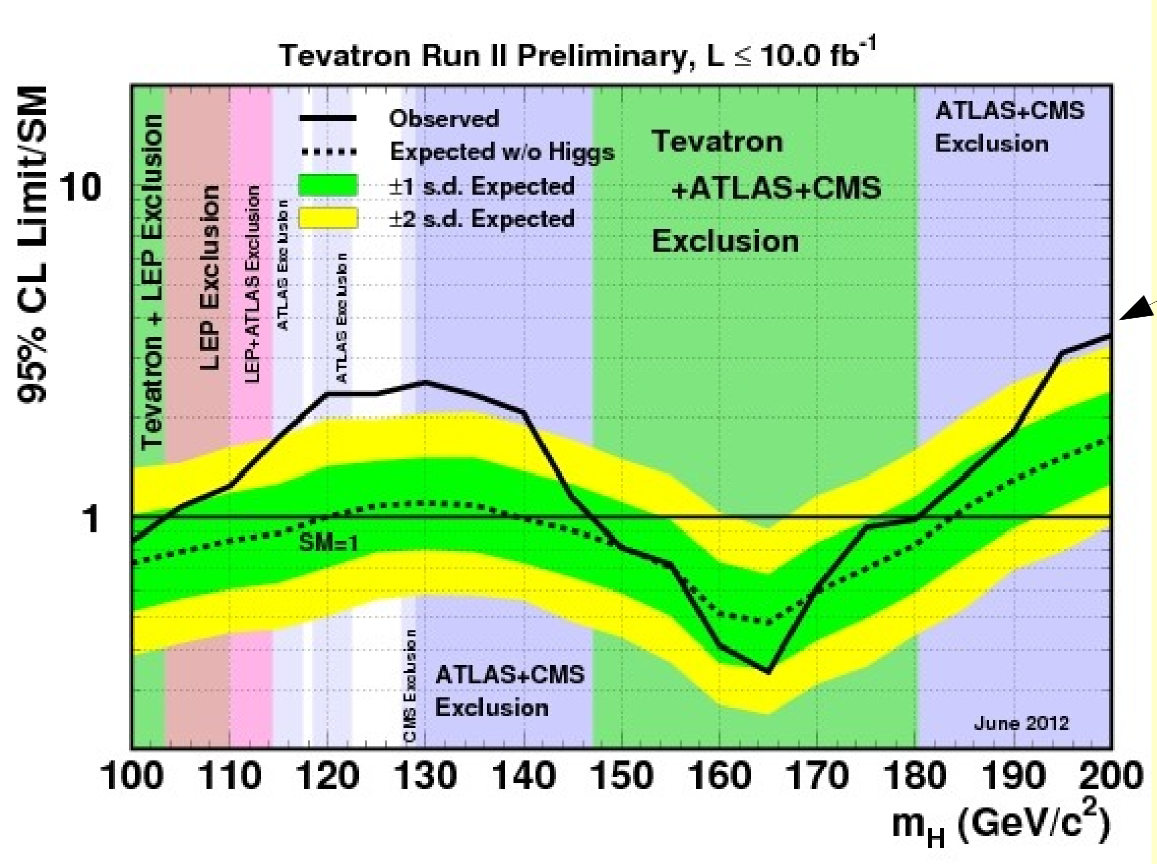
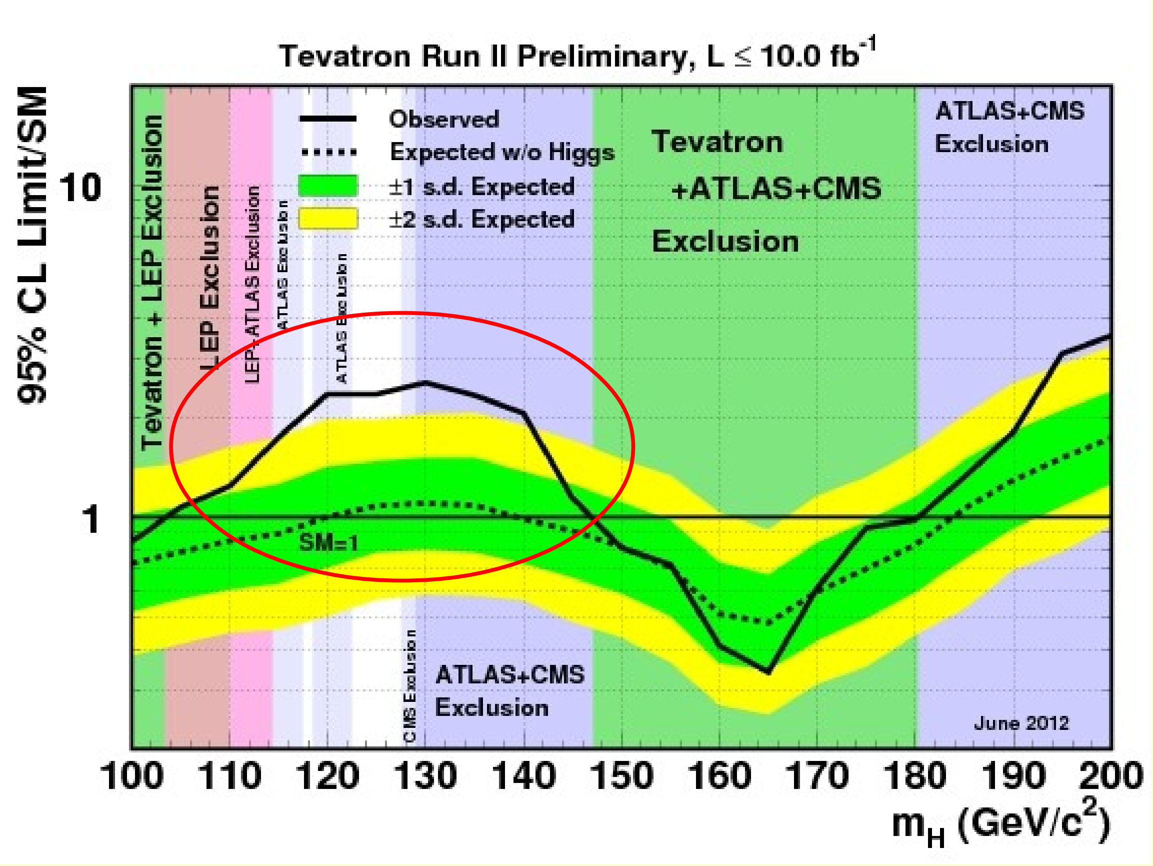


July 2nd; ATLAS and CMS changed in a meantime

The new Tevatron limit

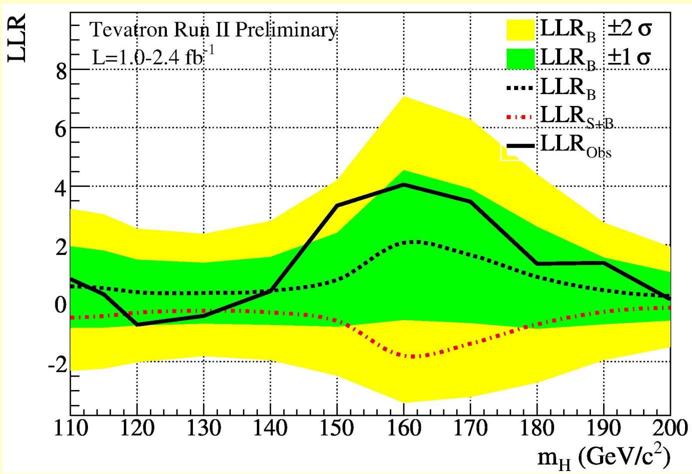
- Look at the low mass

TeV (≤10 fb^{-1})	Exp.	Obs
M_H = 120 GeV	1.00	2.35
M_H = 125 GeV	1.08	2.35
M_H = 130 GeV	1.10	2.55

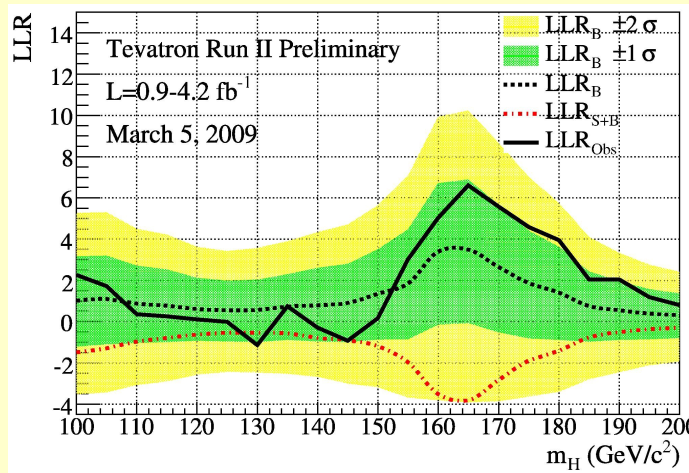


Little history of Tevatron results

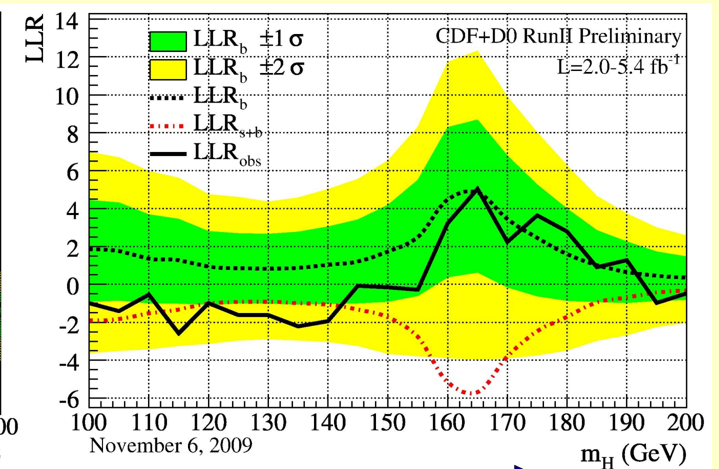
Data of 2007; up to 2.4 fb^{-1}



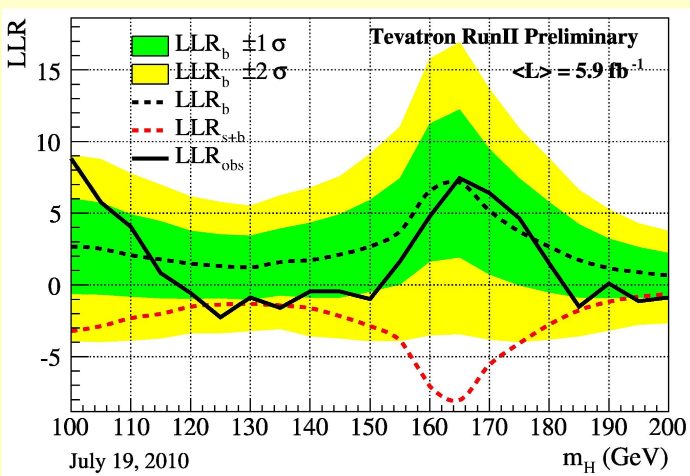
Data of 2008; up to 4.2 fb^{-1}



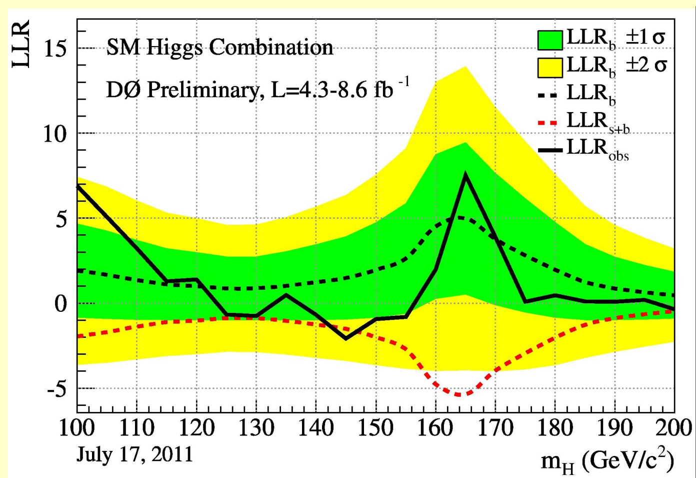
Data of mid 2009; up to 5.4 fb^{-1}



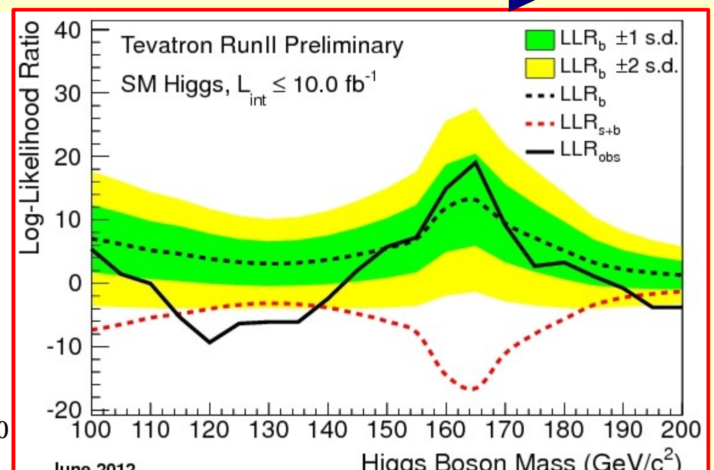
Time



Data of mid 2010; up to 5.9 fb^{-1}

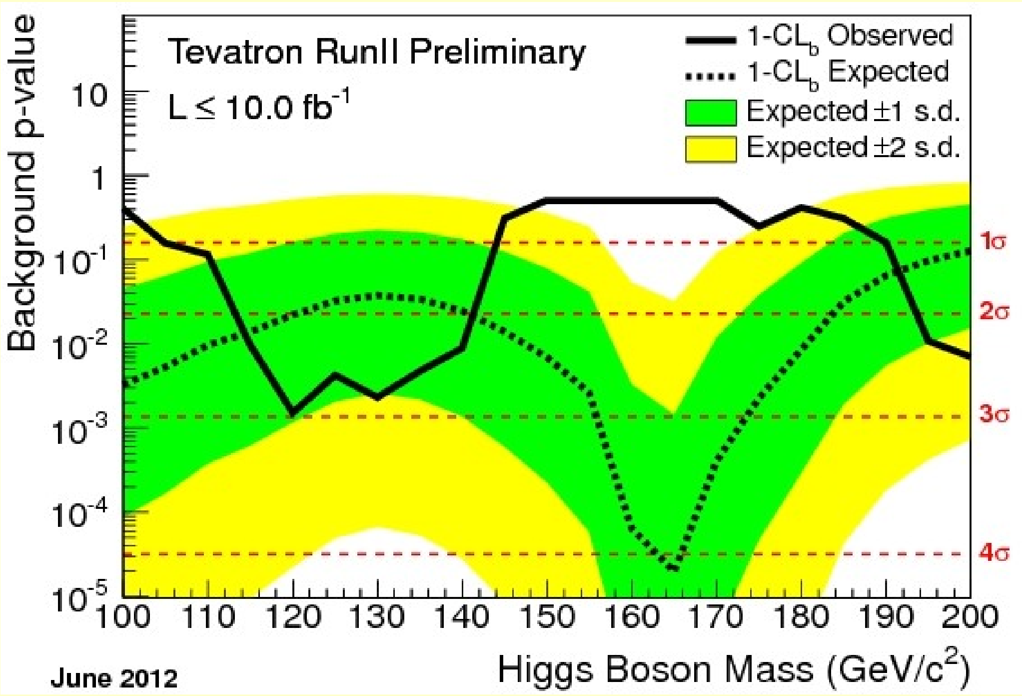


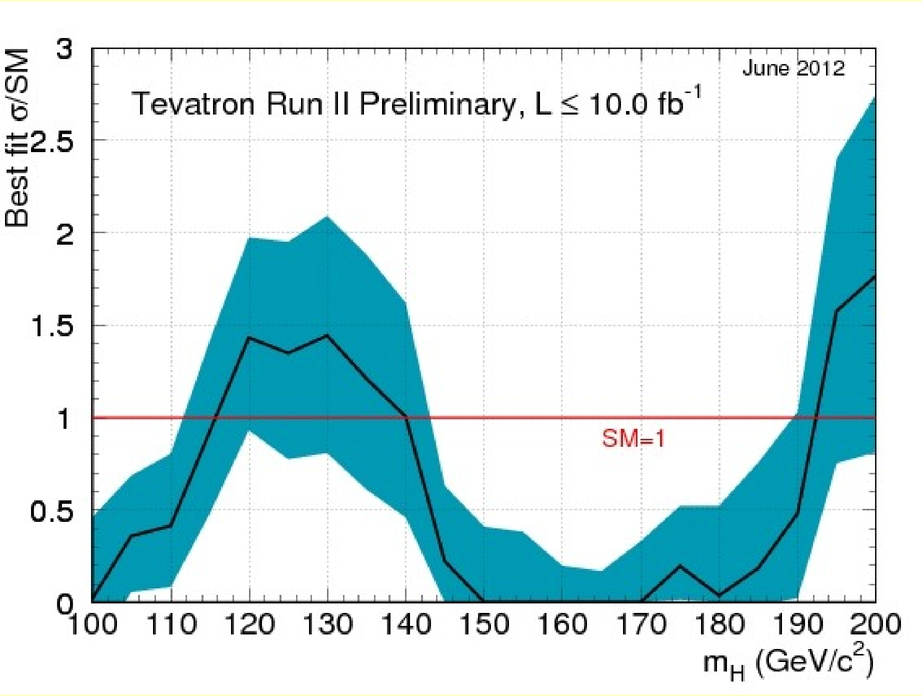
Data of mid 2011; up to 8.6 fb^{-1}



Full data set; up to 10 fb^{-1}

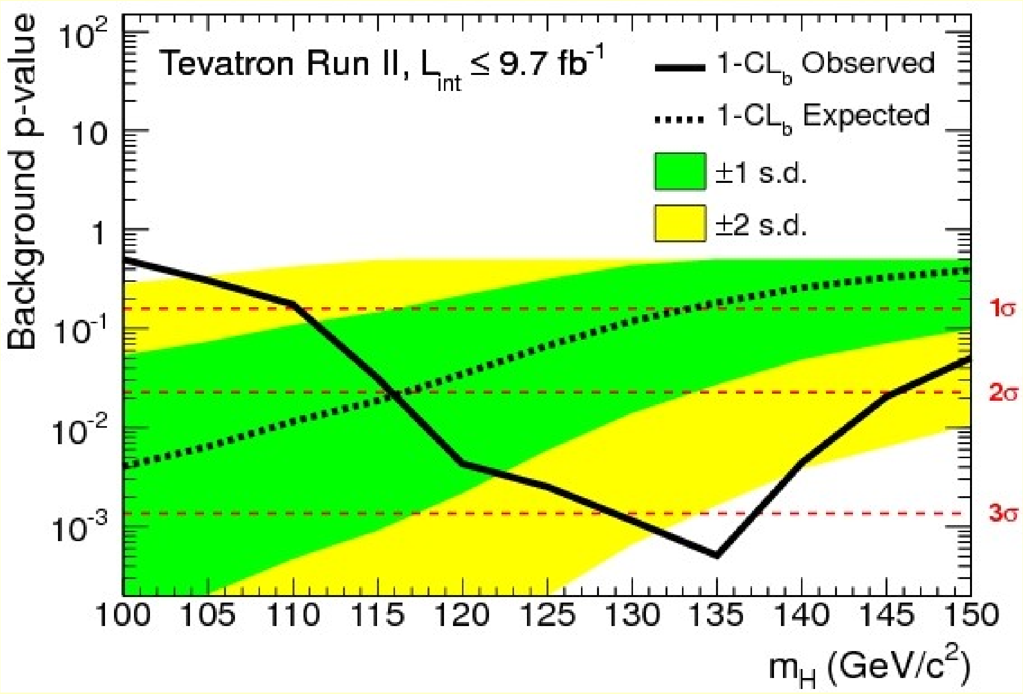
Quantifying the excess

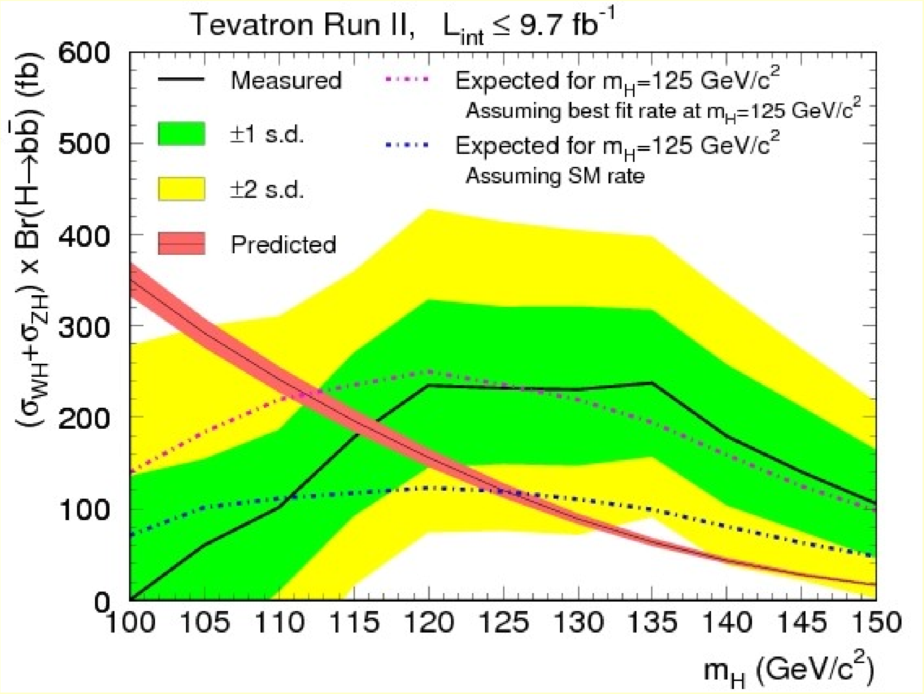




- Local p-value distribution for background only expectation.
  - Minimum local p value: 3 standard deviation (@120 GeV)
  - Global p value with Look Elsewhere Effect: 2.5 standard deviations
- Best fit for the signal, signal strength, consistent with SM within 1σ

Quantifying the excess - H → bb





- Local p-value distribution for background only expectation.
  - Minimum local p value: 3.3 standard deviation, @125 GeV is 2.8
  - Global p value with Look Elsewhere Effect: 3.1 standard deviations

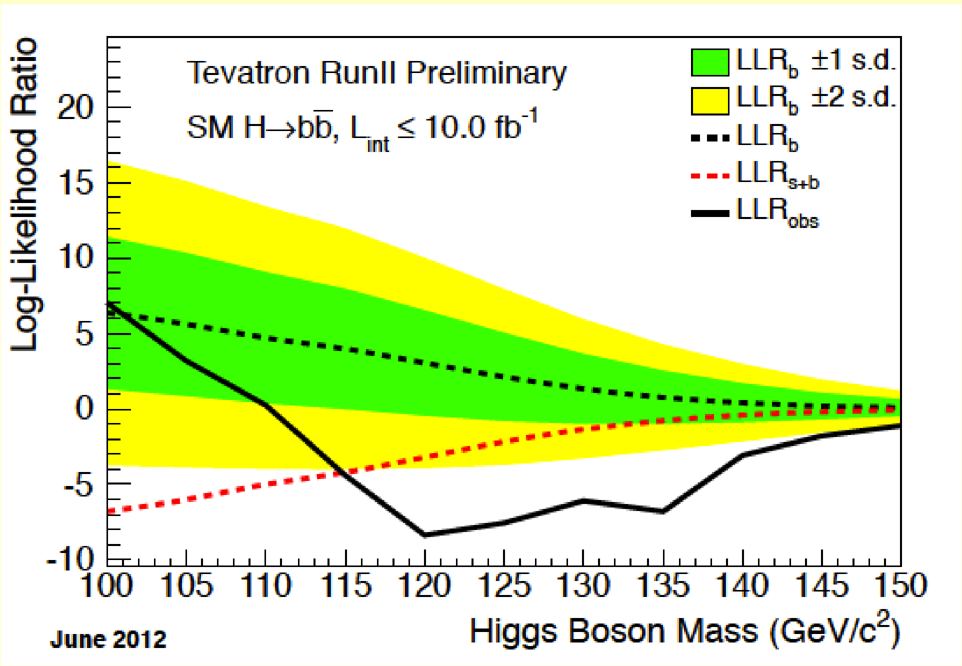
- Cross section measurement:

$$(\sigma_{WH}+\sigma_{ZH})\times B(H\rightarrow b\bar{b})=0.23^{+0.09}_{-0.08}(stat+syst)\,pb$$

SM @125 GeV: 0.12±0.01 pb

How the signal would look like

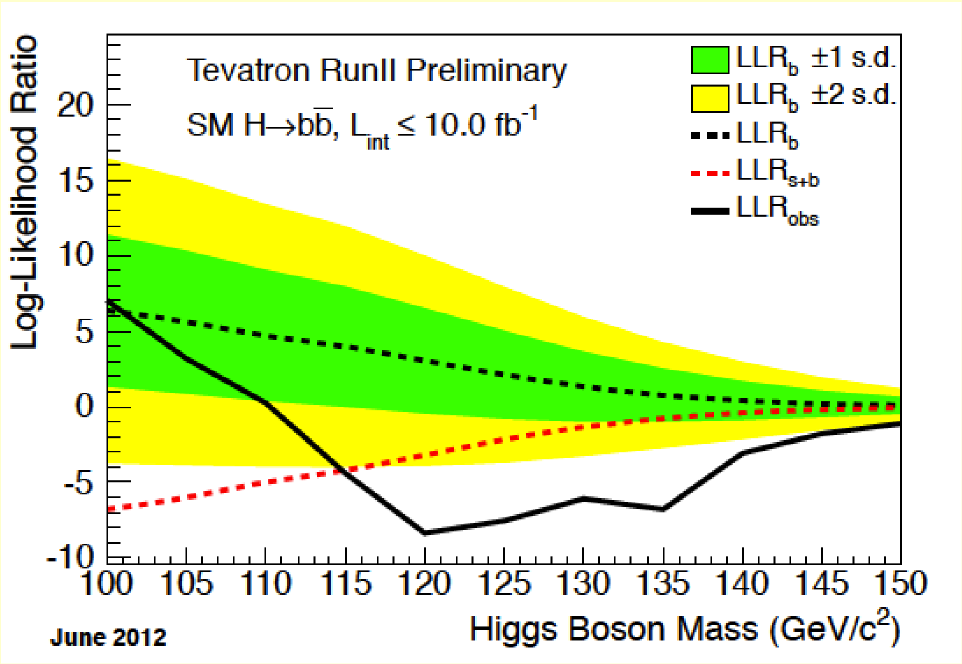
- Look at H → bb only

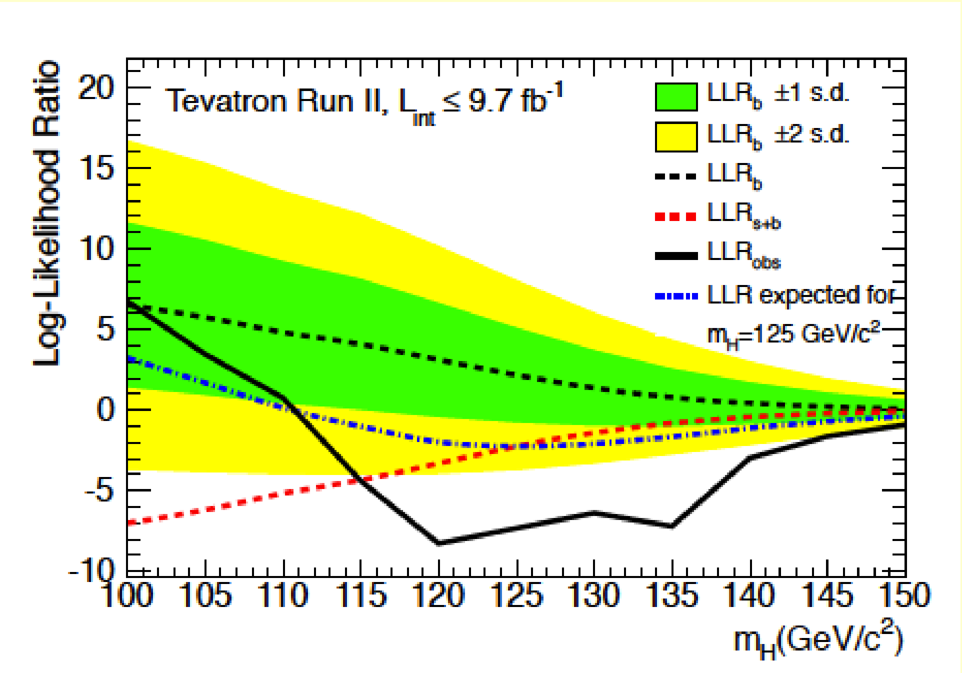


- If there is a signal, how would it look like?

How the signal would look like

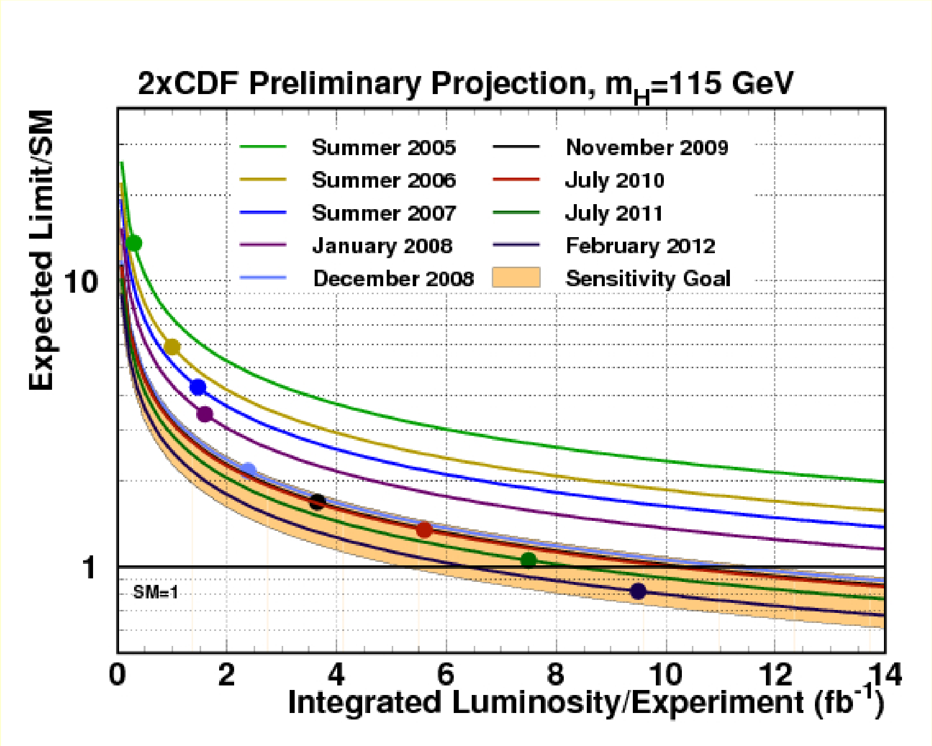
- Look at $H \rightarrow bb$ only





- If there is a signal, how would it look like?
- We injected a signal with m_H=125 GeV
  - Expect broad excess over a whole mass range
- We have an evidence of a particle decaying to bb – 3.1 s.d.

Tevatron progress

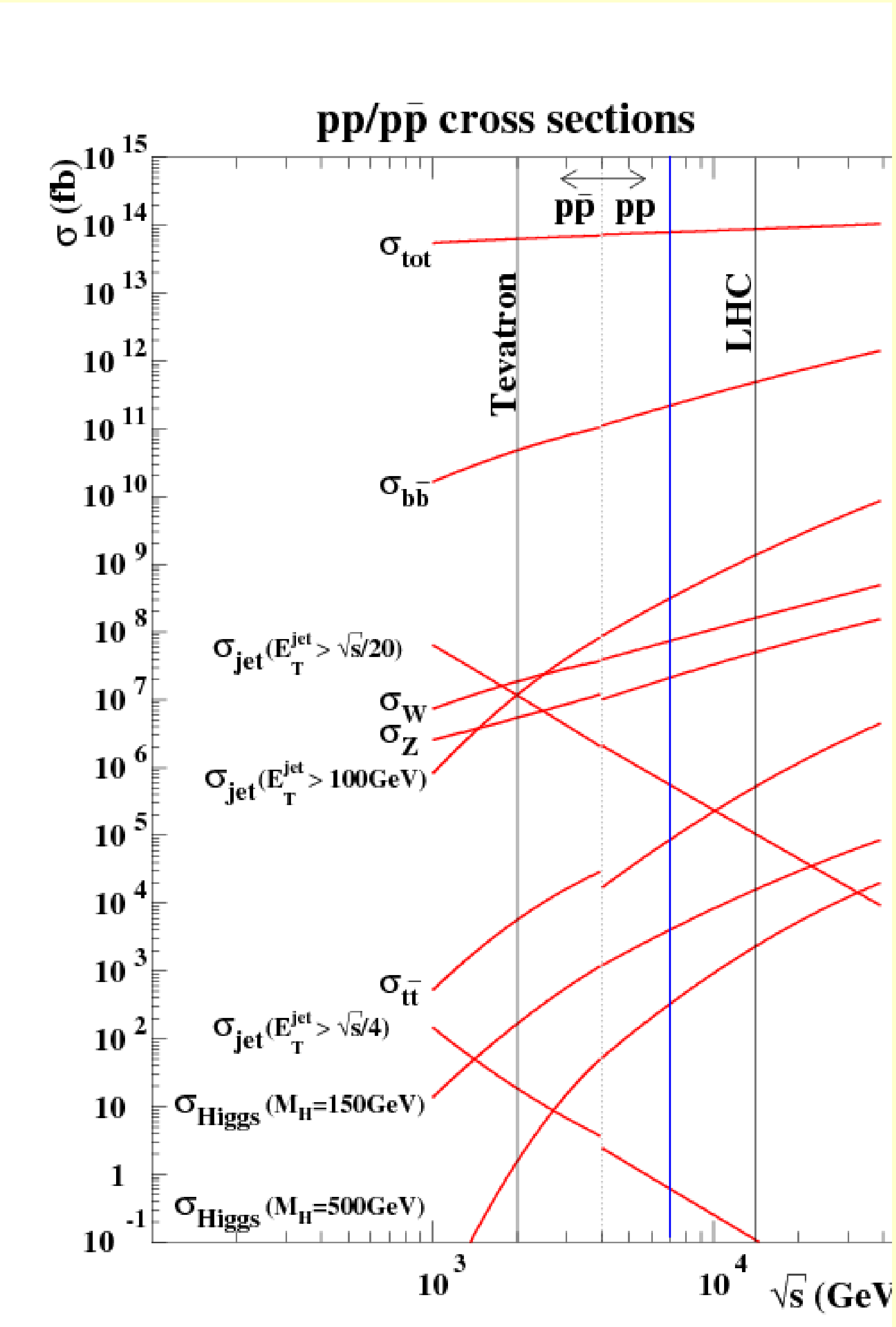


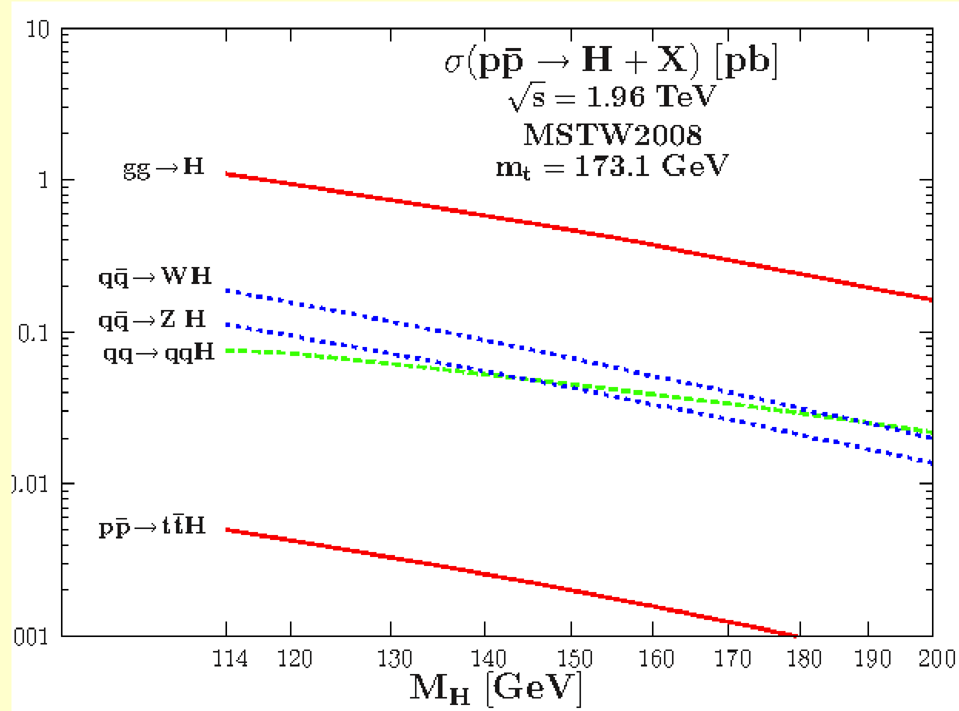
- Recent improvements include MVA for EM id and b-tagging, improved trigger, improved muon smearing, improved jet energy scale and resolution, improved dijet mass resolution, improved background modeling…

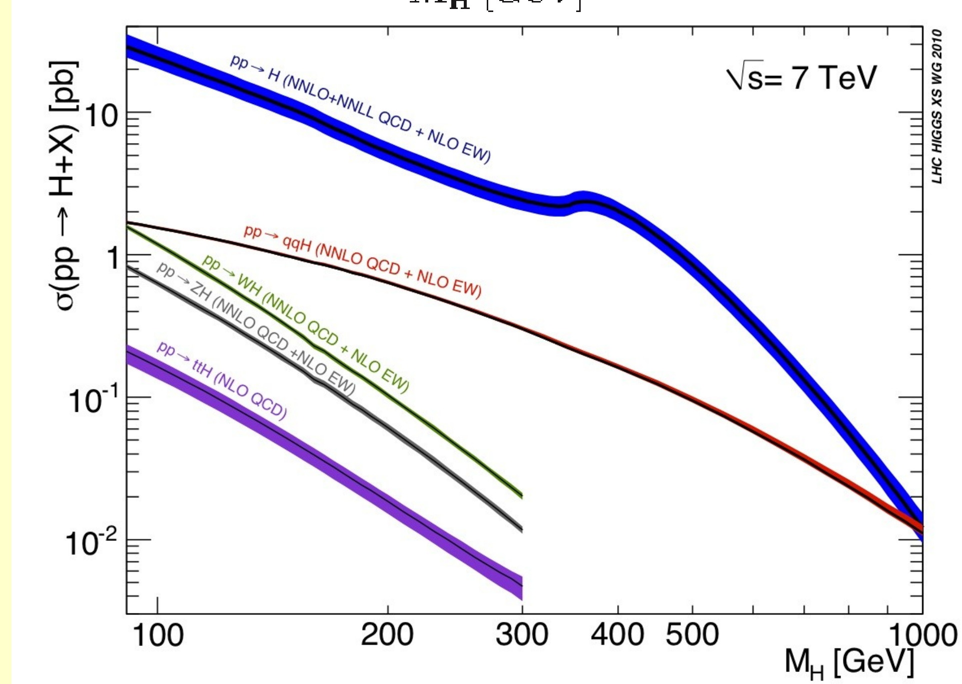
- Projected median expected upper limits on the SM Higgs boson cross section, scaling CDF performance to twice the luminosity.
- The solid lines are $1/\sqrt{L}$ projections, as functions of integrated luminosity per experiment.
- Improvements better than expected from $1/\sqrt{L}$

Higgs future

Tevatron vs. LHC



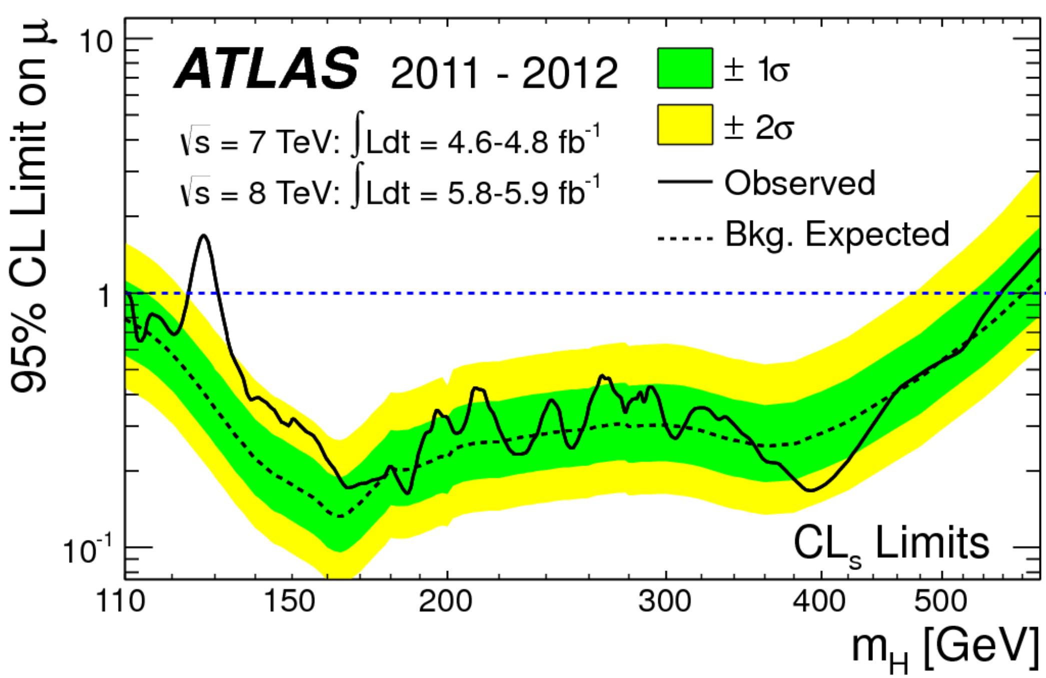


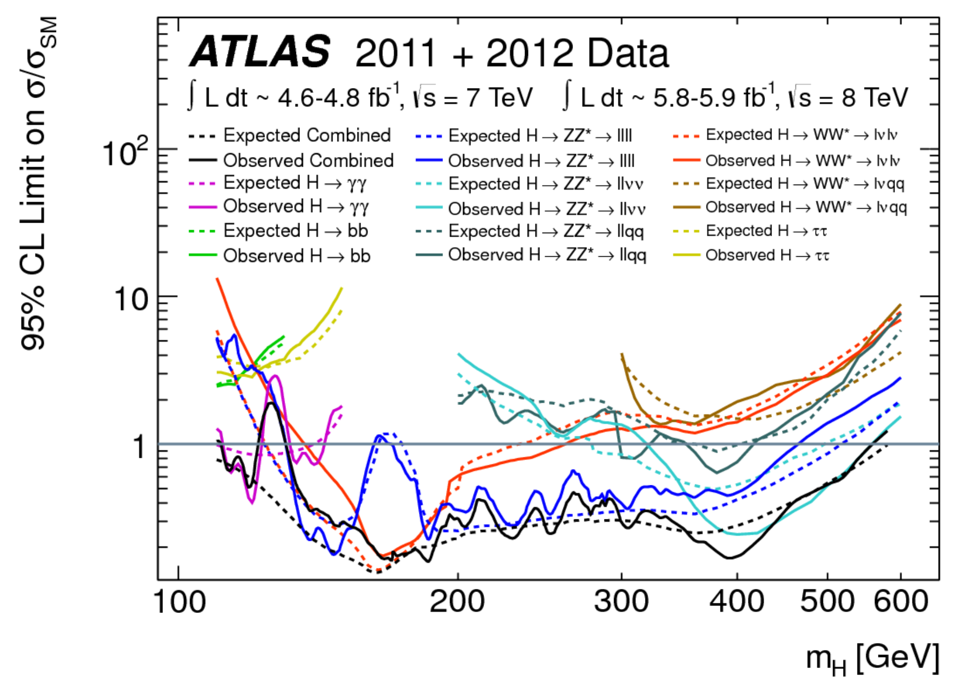


Higgs at LHC

- Some years ago I had in my talk the following sentence:
  "The SM Higgs boson will be discovered or excluded in the first year of physics running"
  - This was with expectation of 14 TeV run and with 10 fb^{-1} collected in that first year

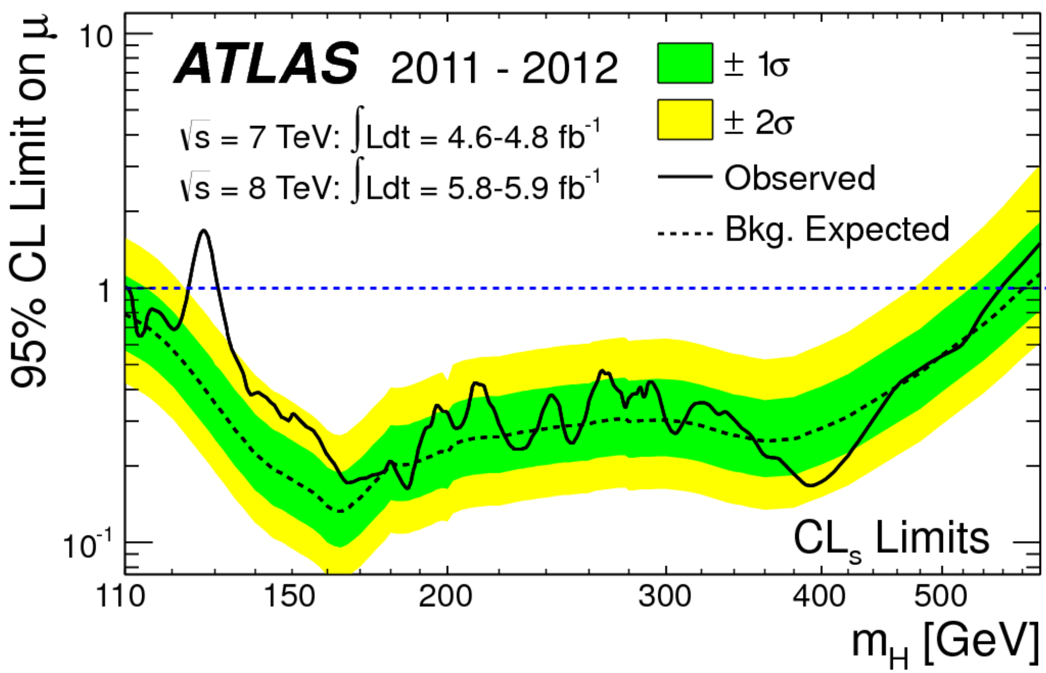
- Today, with 7/8 TeV and ~10 fb^{-1} altogether SM Higgs boson like particle is observed

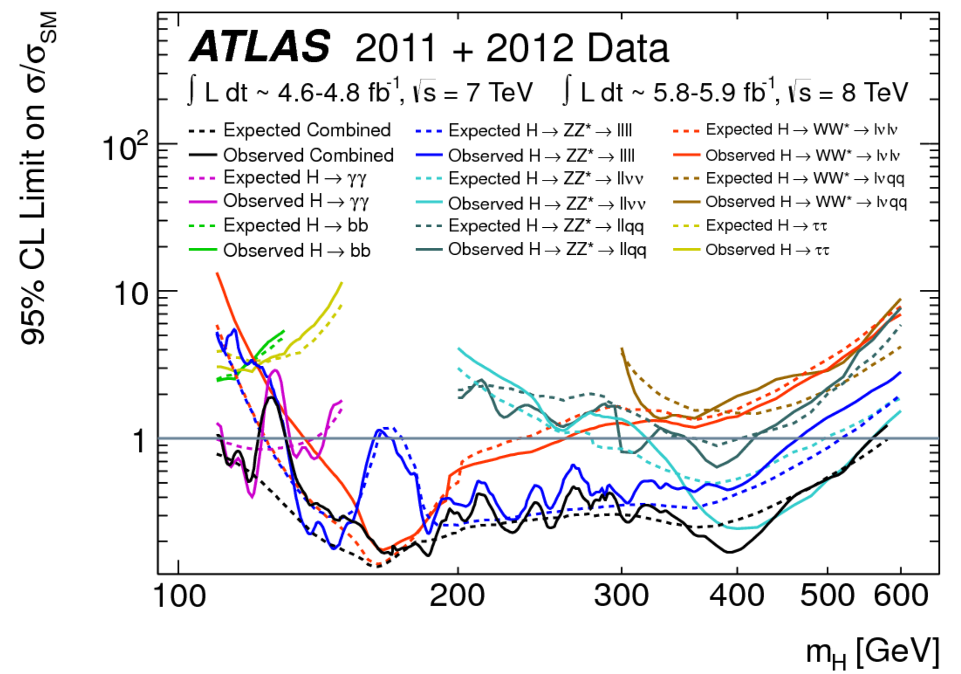




Higgs at LHC

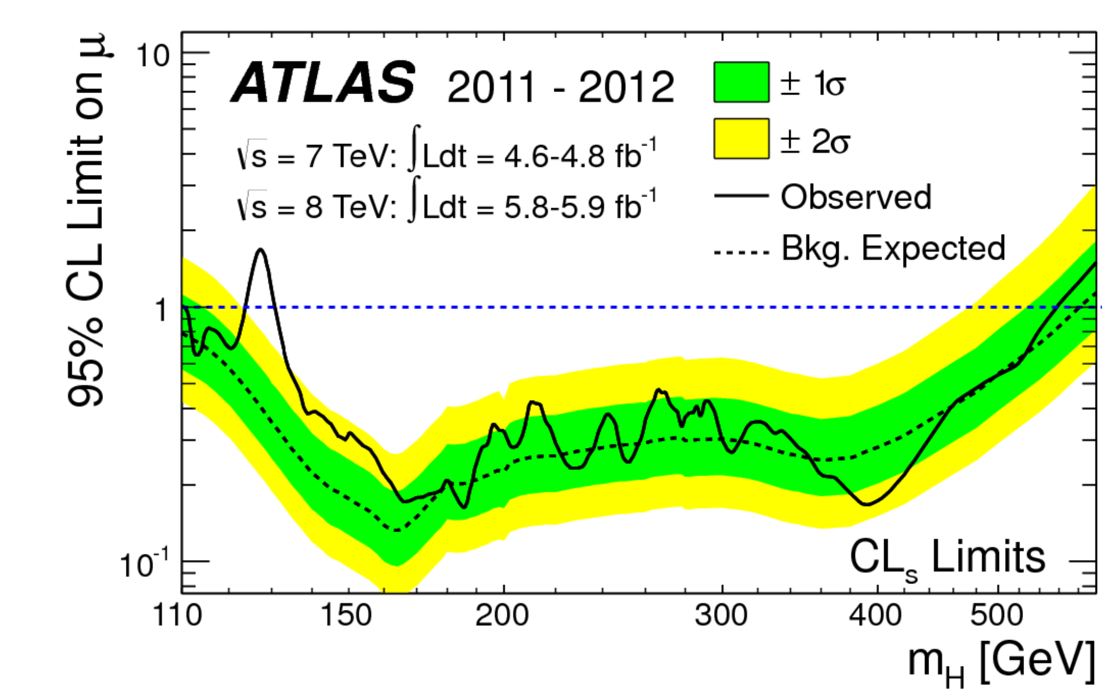
- Both experiments observed a Higgs like particle with a mass around 125 GeV in γγ and ZZ channels

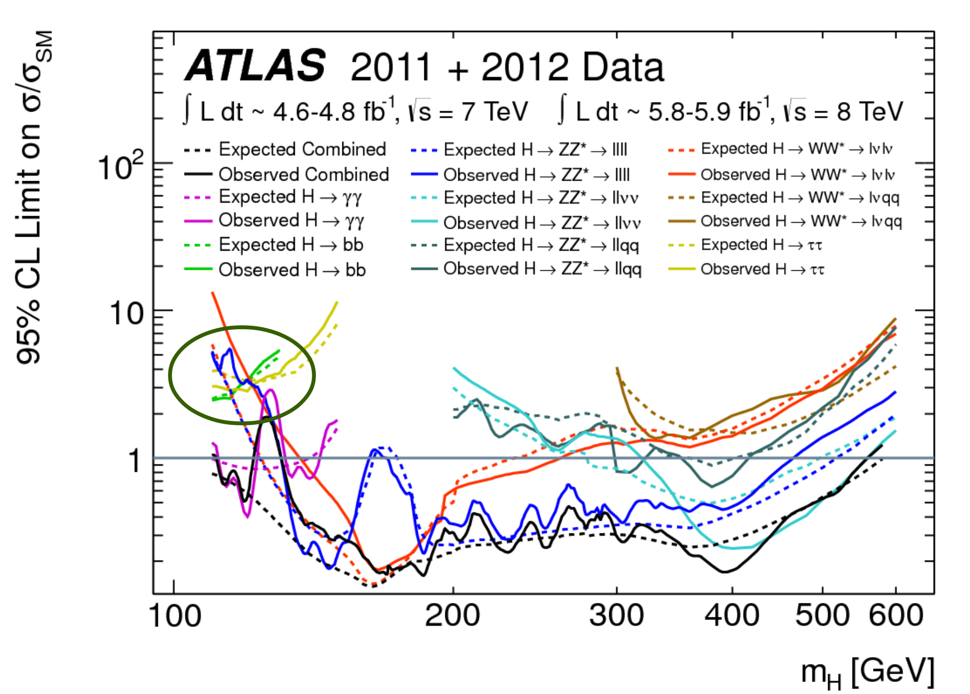




Higgs at LHC

- Both experiments observed a Higgs like particle with a mass around 125 GeV in γγ and ZZ channels
- H → bb is not the most sensitive channel





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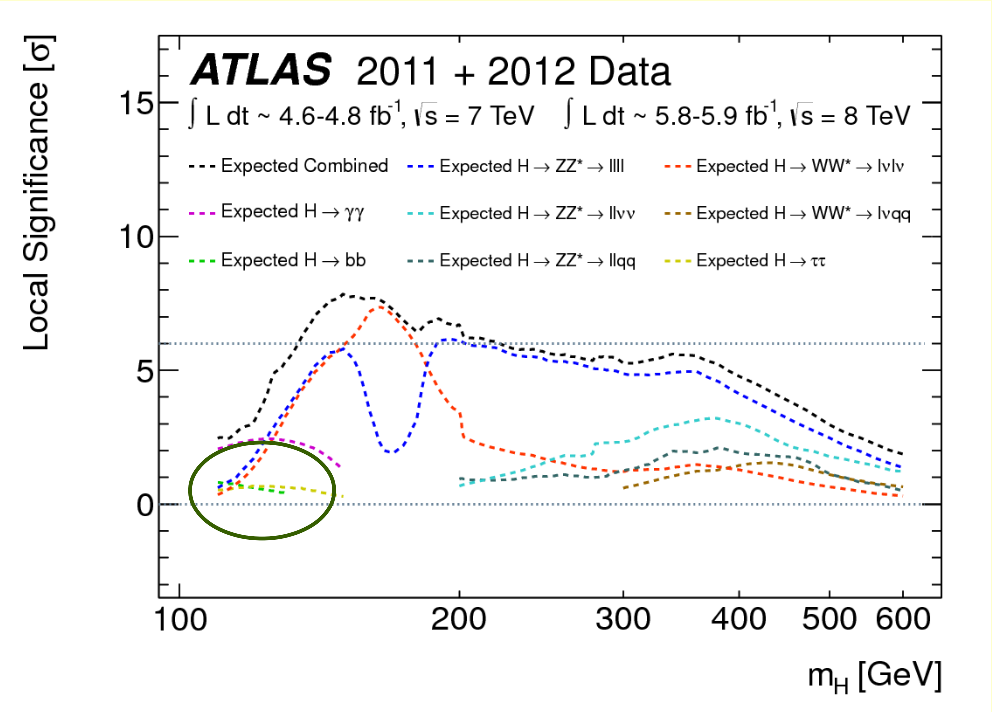
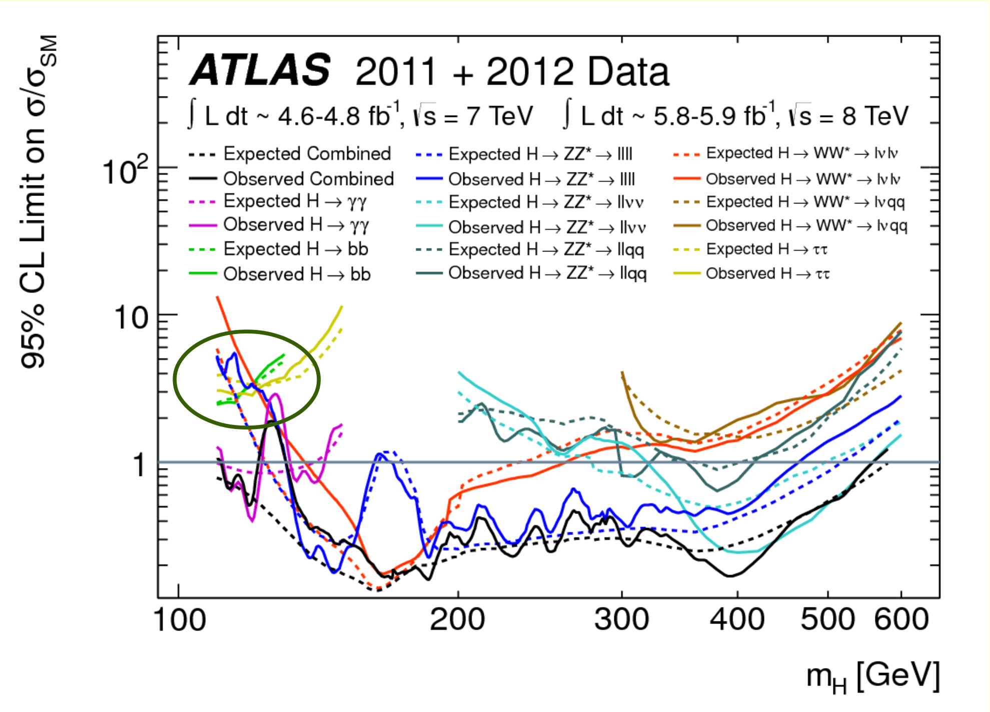
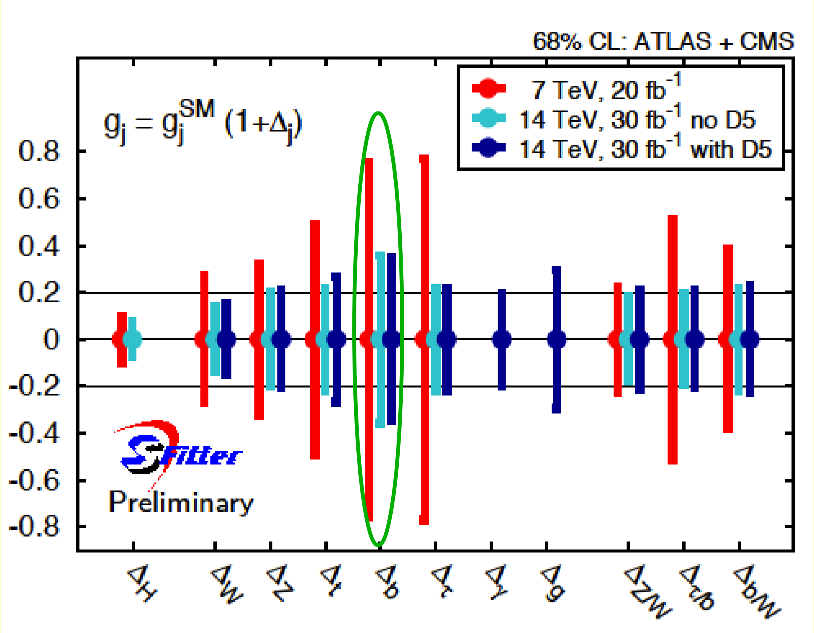




Finding the Higgs boson

- Higgs boson is observed in $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow llll$
  - Afterward we need to verify the nature of the new particle
    - Measure its mass, width and spin
    - Measure its couplings

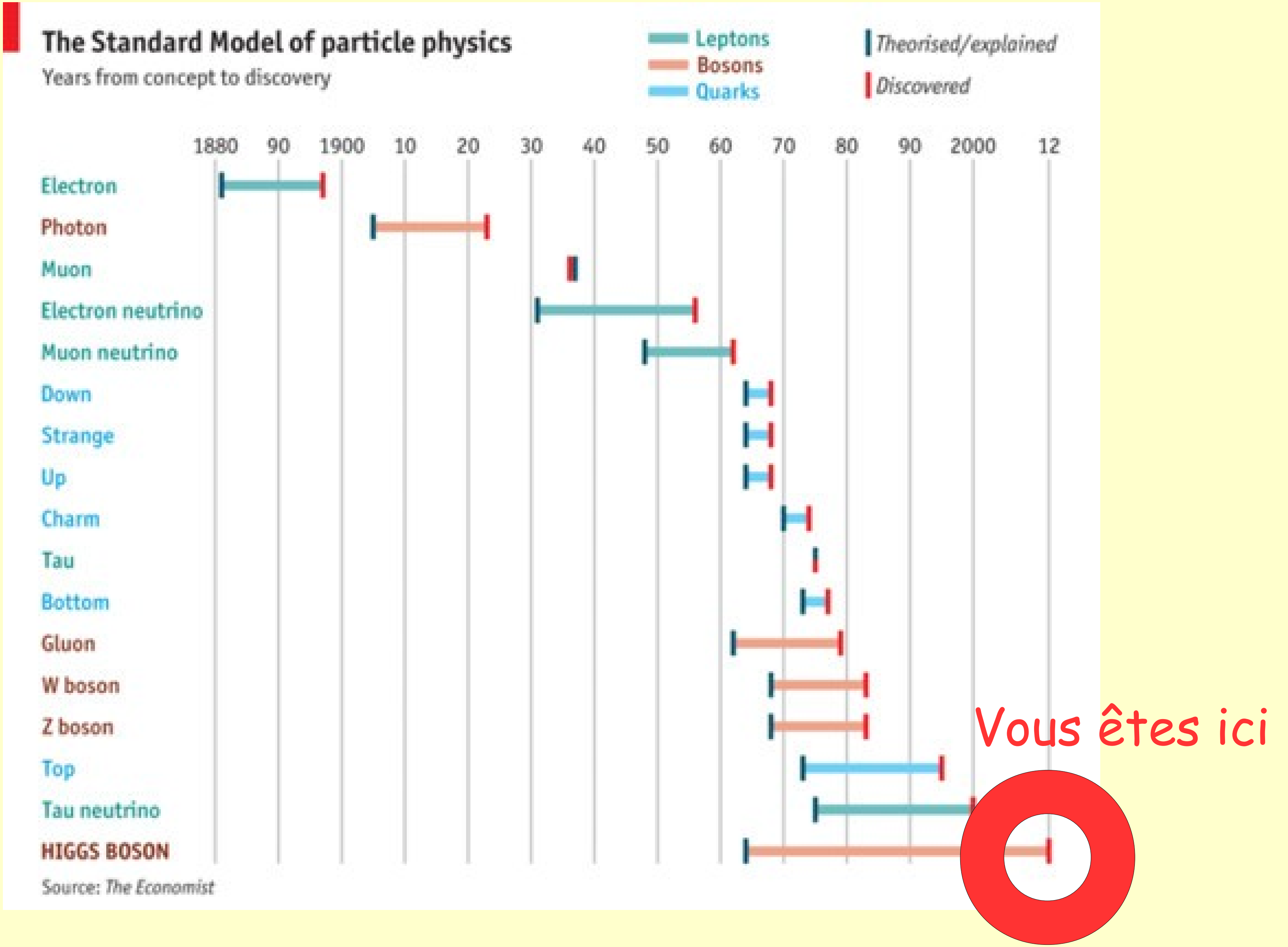


- Recent study shows that it would be possible to measure coupling to a b-quark with a precision of ~80% if mass is 125 GeV, with 7 TeV and 20 fb^{-1}
  - It would be ~30% with 14 TeV and 30 fb^{-1}
- $H \rightarrow bb$ will be very important channel in the next few years of the LHC Higgs program
  - Final Tevatron data set can help in the first measurements

Summary

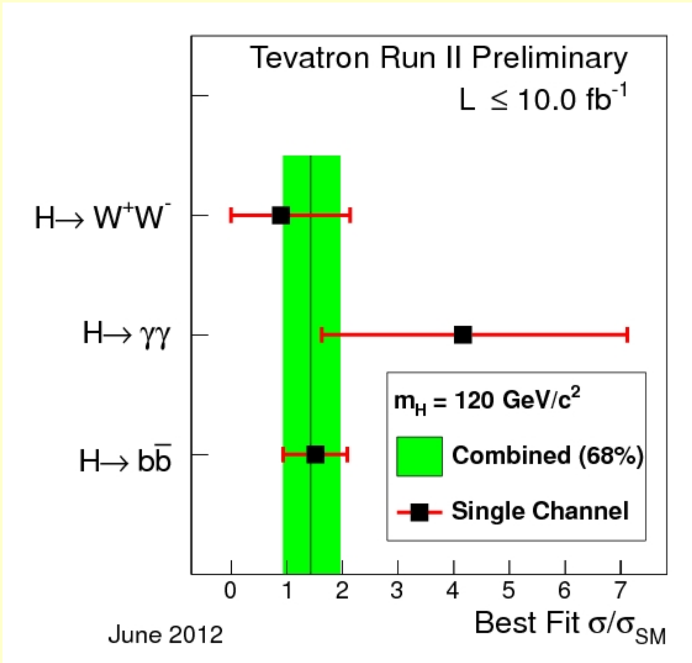
- The year 2012 is already very exciting
  - Tevatron experiments reported an evidence of a Higgs boson like particle which decays to bb final state
  - LHC experiments observed a Higgs boson like particle in $\gamma\gamma$ and ZZ final state with a mass around 125 GeV
- The next step may be even more difficult – to verify the nature of the new particle
  - Every possible channel will play a role
  - Tevatron experiences will help these efforts

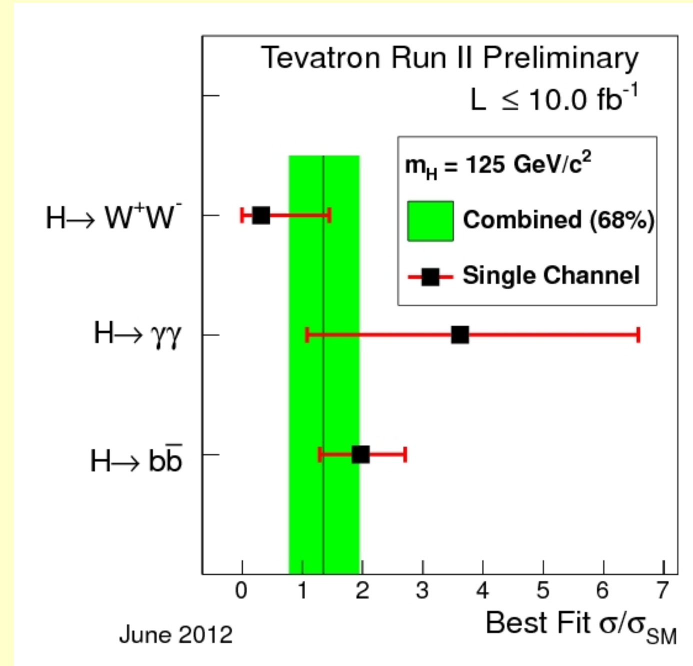
Summary


The Standard Model of particle physics
Years from concept to discovery
Leptons
Bosons
Quarks
Theorised/explained
Discovered
1880
90
1900
10
20
30
40
50
60
70
80
90
2000
12
Electron
Photon
Muon
Electron neutrino
Muon neutrino
Down
Strange
Up
Charm
Tau
Bottom
Gluon
W boson
Z boson
Top
Tau neutrino
HIGGS BOSON
Source: The Economist
Vous êtes ici

Backup

Higgs xs


Tevatron Run II Preliminary
L ≤ 10.0 fb^{-1}
H→ W$^+$W$^-$
H→ γγ
H→ b$\bar{b}$
m$_H$ = 120 GeV/c^2
Combined (68%)
Single Channel
0 1 2 3 4 5 6 7
June 2012
Best Fit σ/σ$_{SM}$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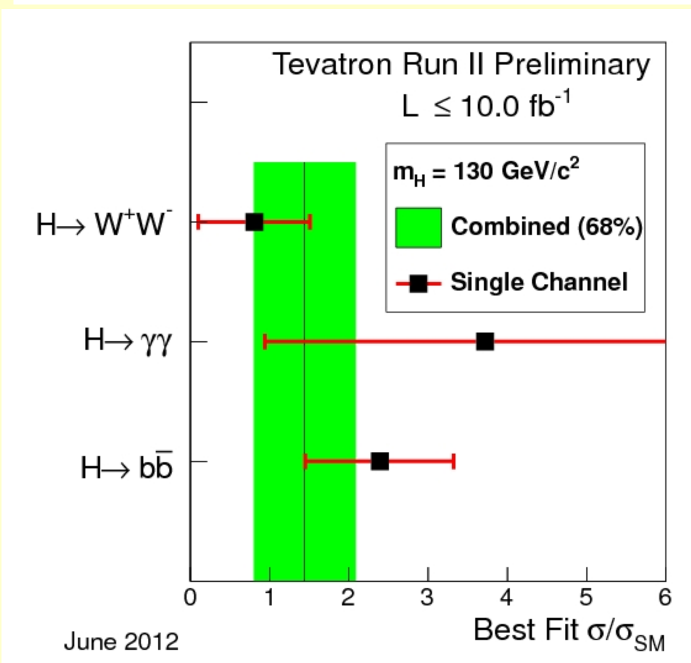
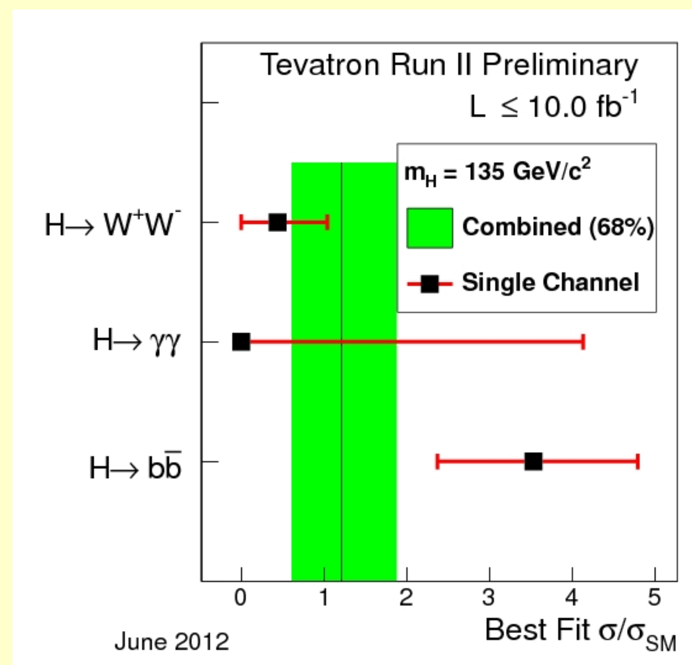
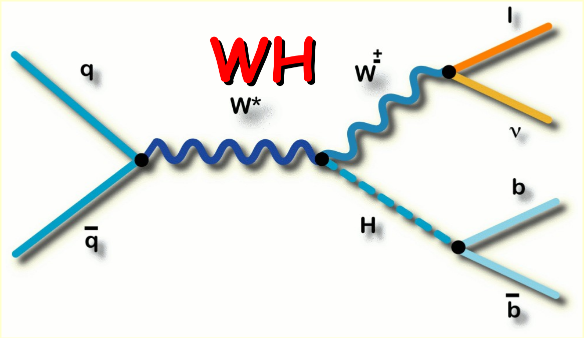
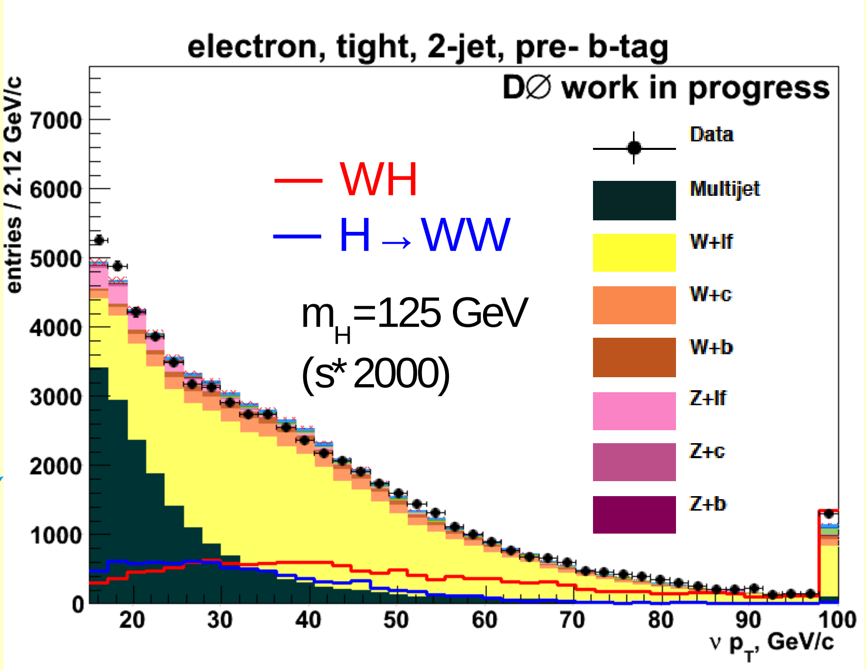

Tevatron Run II Preliminary
L ≤ 10.0 fb^{-1}
m$_H$ = 130 GeV/c^2
Combined (68%)
Single Channel
H→ W$^+$W$^-$
H→ γγ
H→ b$\bar{b}$
0 1 2 3 4 5 6
June 2012
Best Fit σ/σ$_{SM}$

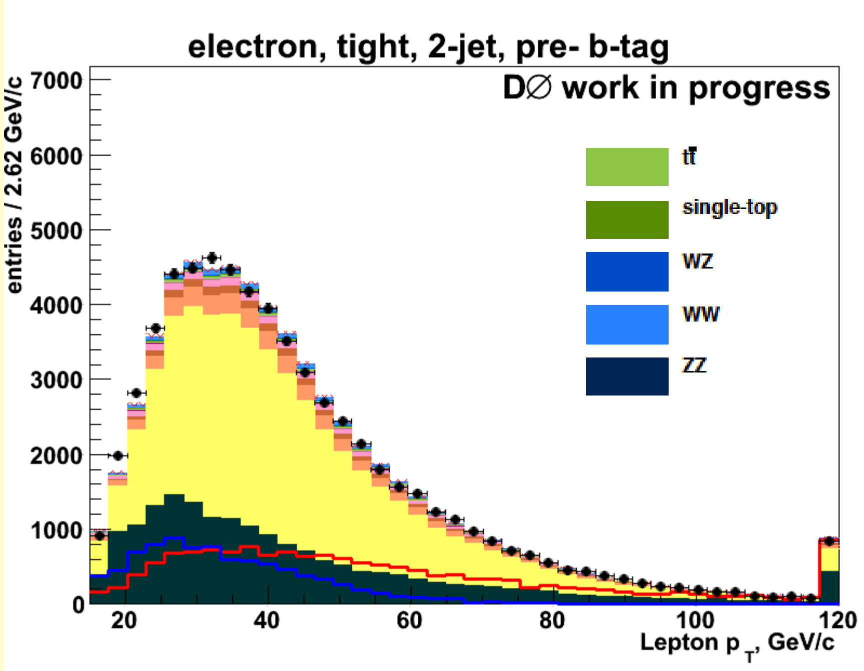

Tevatron Run II Preliminary
L ≤ 10.0 fb^{-1}
m$_H$ = 135 GeV/c^2
Combined (68%)
Single Channel
H→ W$^+$W$^-$
H→ γγ
H→ b$\bar{b}$
0 1 2 3 4 5
June 2012
Best Fit σ/σ$_{SM}$

Event Selection

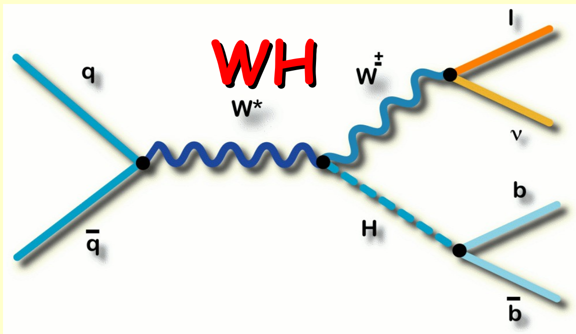




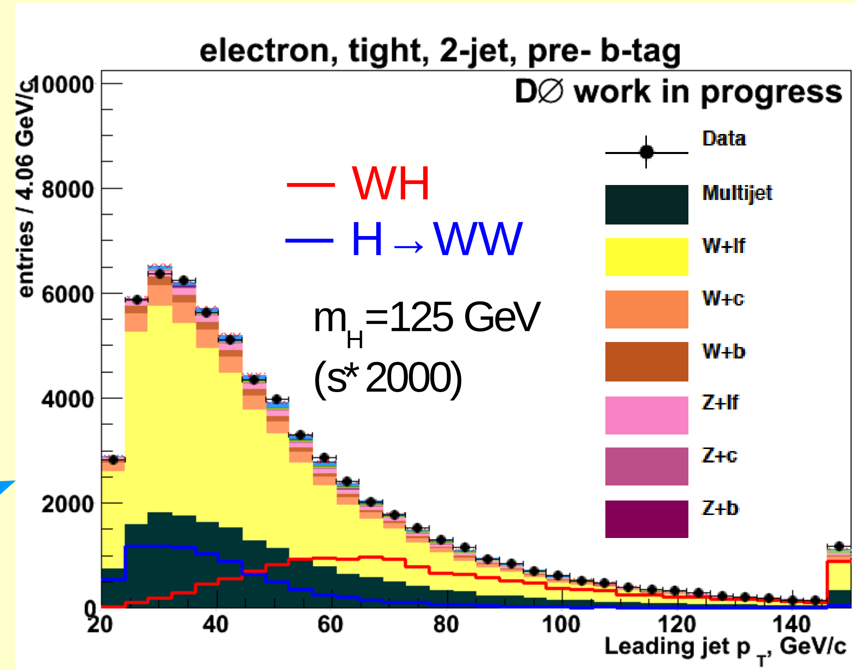
- Missing E_T - MET > 15 GeV
  - calculated from calorimeter cells
- Electron (lepton)
  - combine track and calorimeter information
  - p_T > 15 GeV

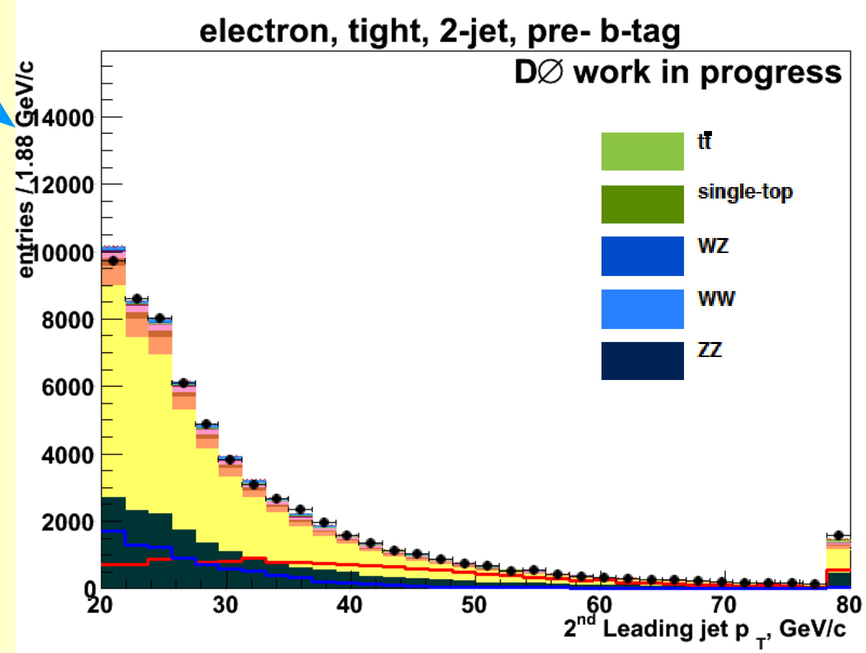


Event Selection

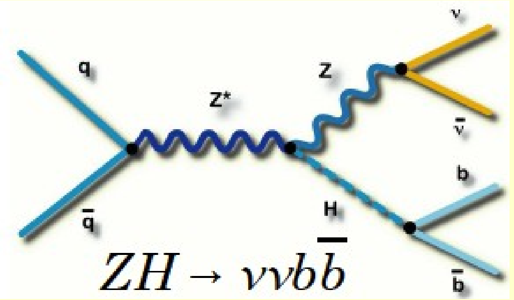


- At least 2 jets:
  - jet p_T > 20 GeV
- QCD reduction
  - electron faking jet
  - missmeasured jet energies give MET
- Triangle cut between transverse mass and MET

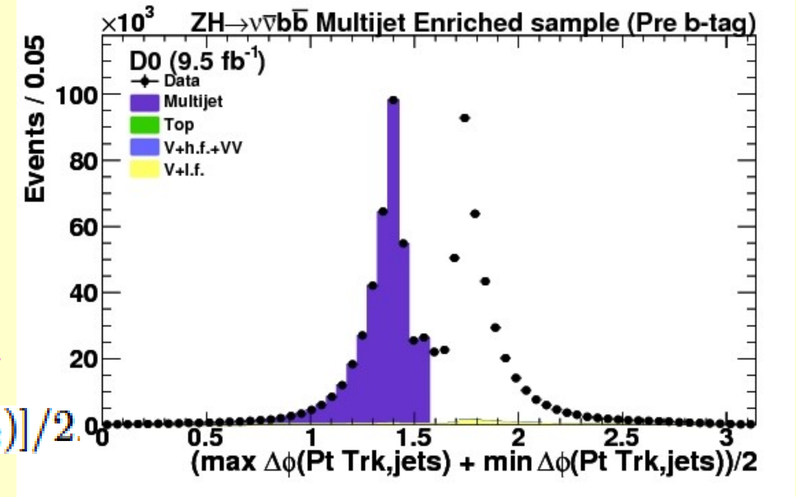


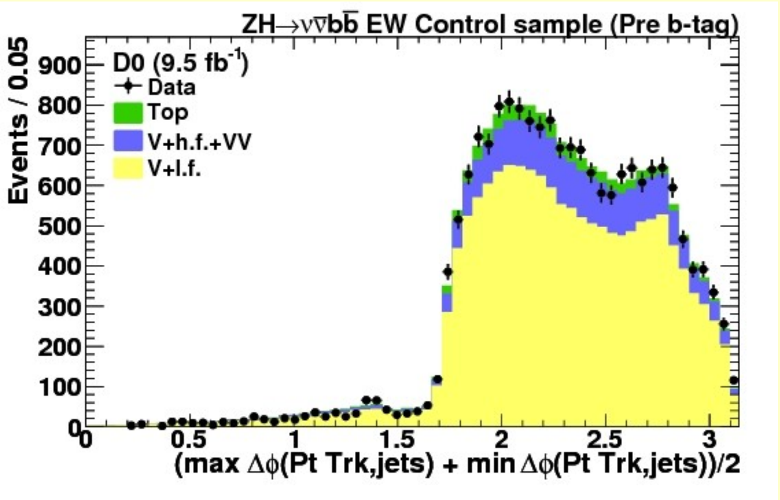


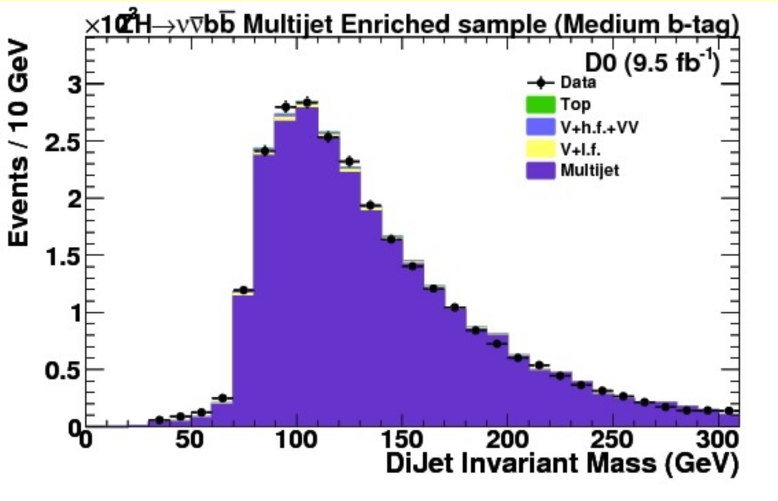
Multijet modeling -VH→$\not\!E_T$bb



- Multijet mostly from the mismeasurement of jets
- Define four different regions:
  - Analysis sample – used for final result
  - EW control sample – to model V+jets backgrounds
  - MJ model - to model the MJ background in the analysis sample based on $\mathcal{D} = [\Delta\phi(\not\!p_T, \mathrm{jet}_1) + \Delta\phi(\not\!p_T, \mathrm{jet}_2)]/2$.
  - MJ-enriched sample, used to validate the MJ-modeling procedure

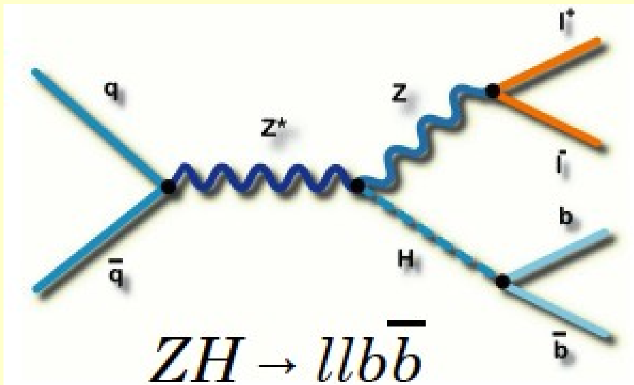


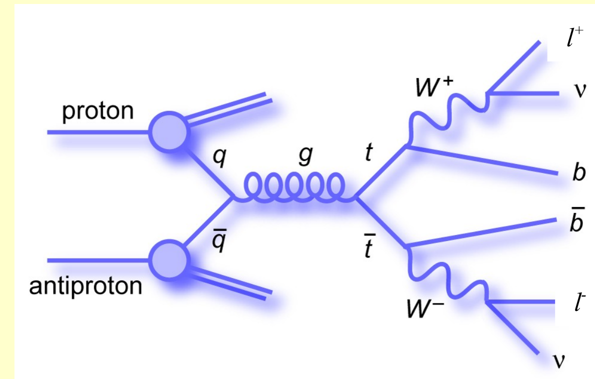




Further background rejection - ZH→llbb

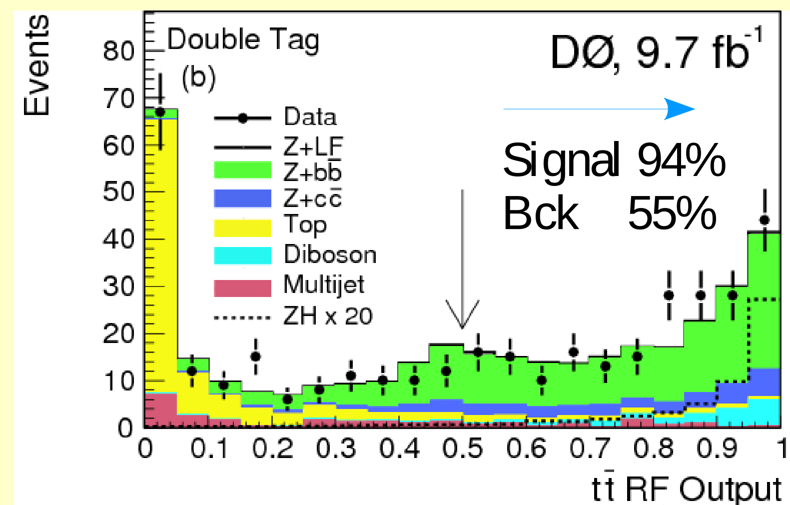
- Separate different topology of the ZH → llbb and tt → llbb+MET - more than 25% of the total background





- Train separate MVA with tt as the only background => more than 10% improvement in sensitivity

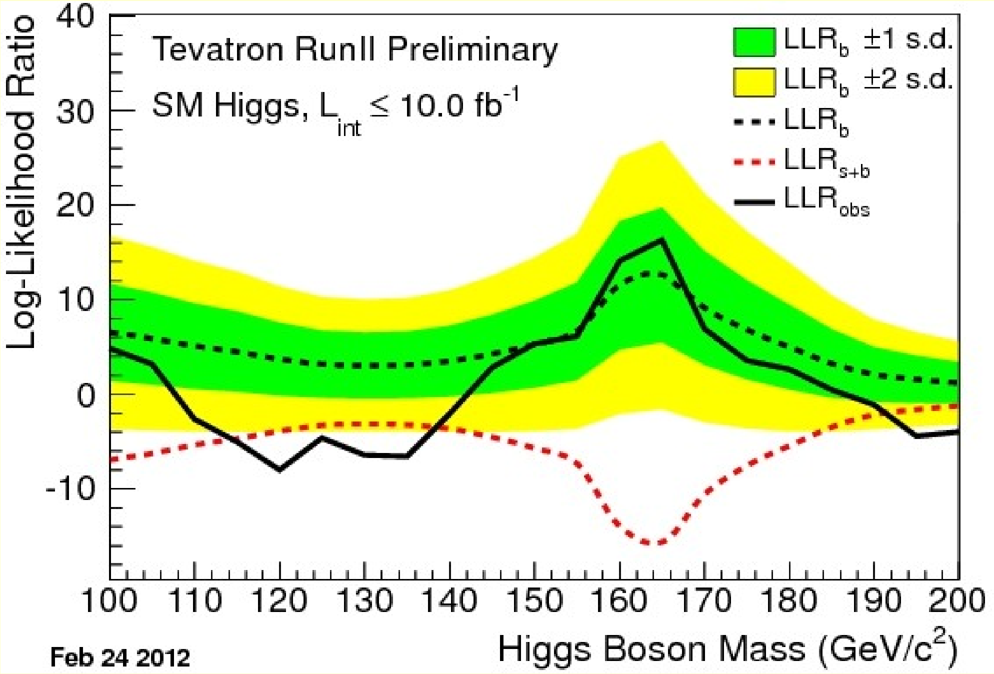
M=125 GeV	2 leptons search ZH → llbb	
Signal	2.5	2.9
V+jets	660	222
MJ	54	26
Top	77	99
Diboson	33	19
Total background	824±102	366±39
Data	886	373



tt enriched | tt depleted

How the signal would look like

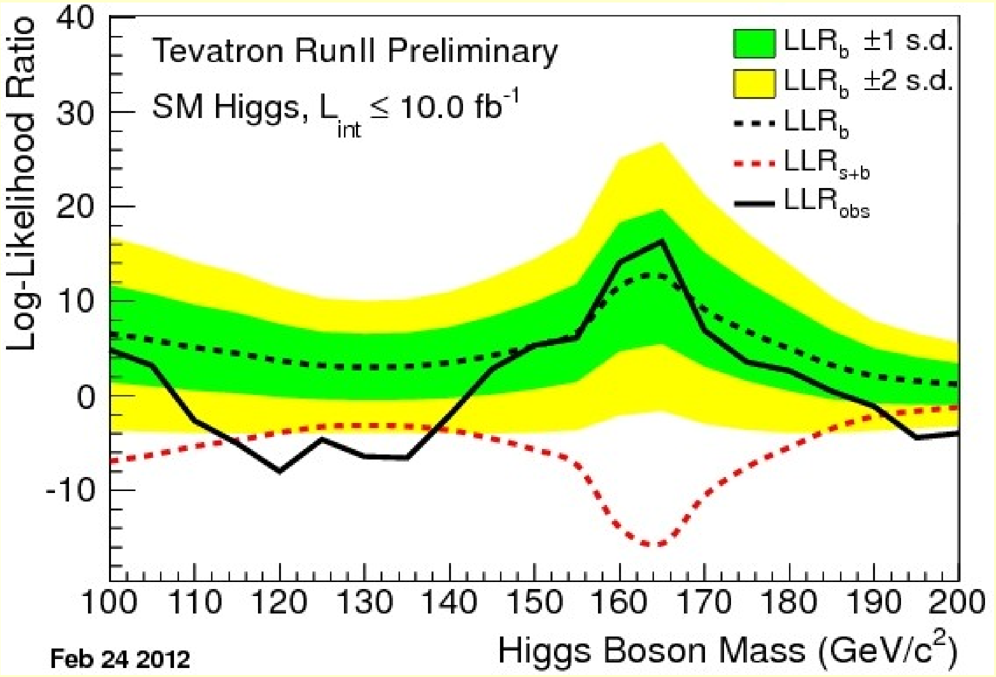
Real data



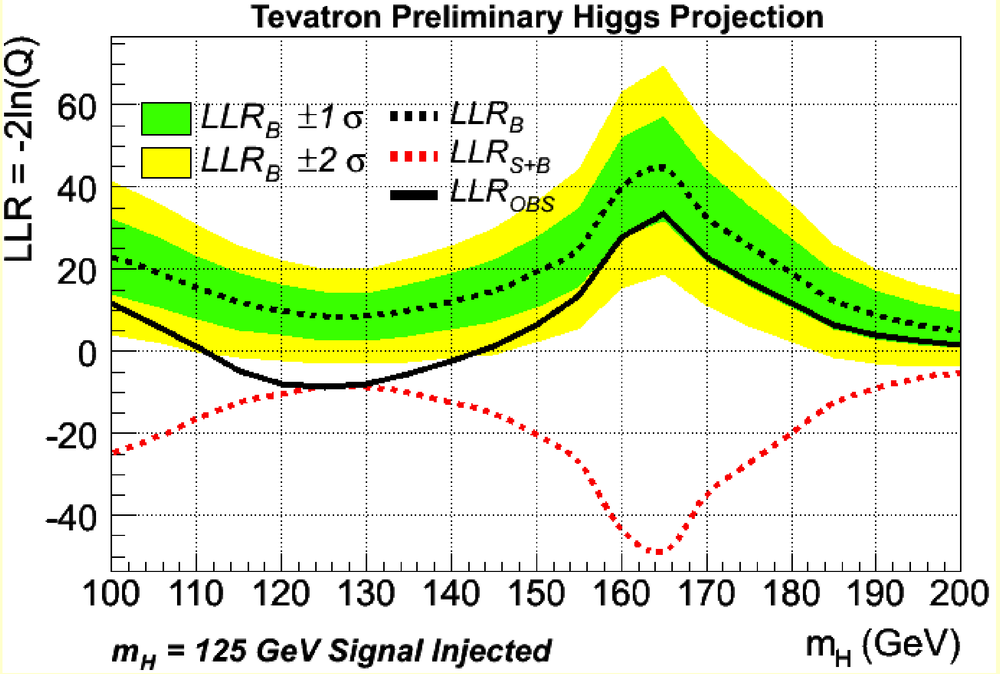
- If there is a signal, how would it look like?

How the signal would look like

Real data



3σ signal injection

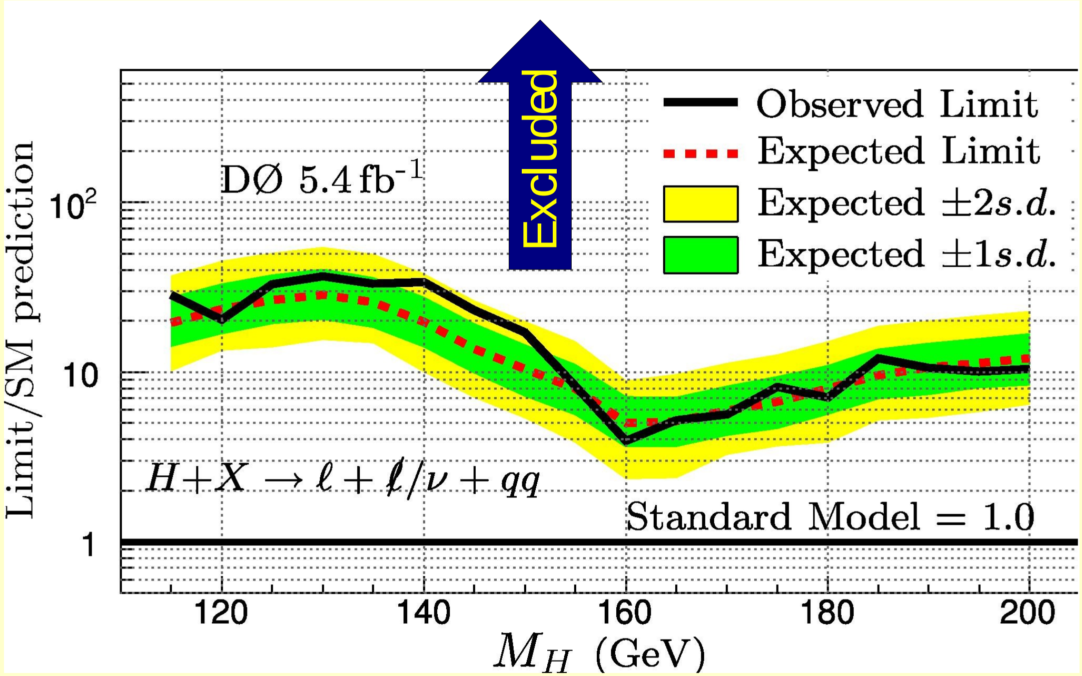


- If there is a signal, how would it look like?
- We injected a signal with m_H=125 GeV and scaled a luminosity so excess would be 3σ
  - Expect broad excess over a whole mass range

Limits on H→WW→lνjj

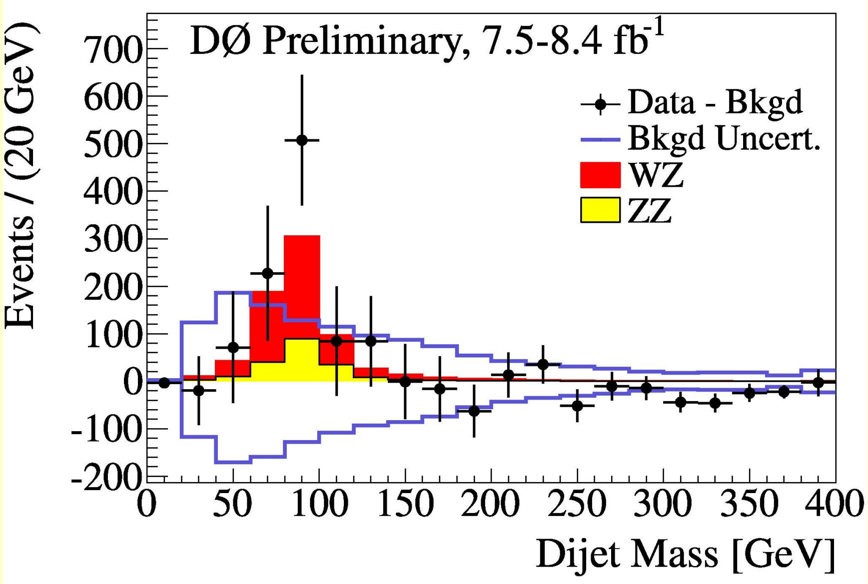
- When we don't observe any excess in data we set limits on production
- Use RF output distributions as discriminant to set upper limits
- Combine electron and muon final states
- The first result on the search for the Higgs boson in this final state

D0 (5.4 fb^{-1})	Exp.	Obs
M_H = 165 GeV	5.09	4.01



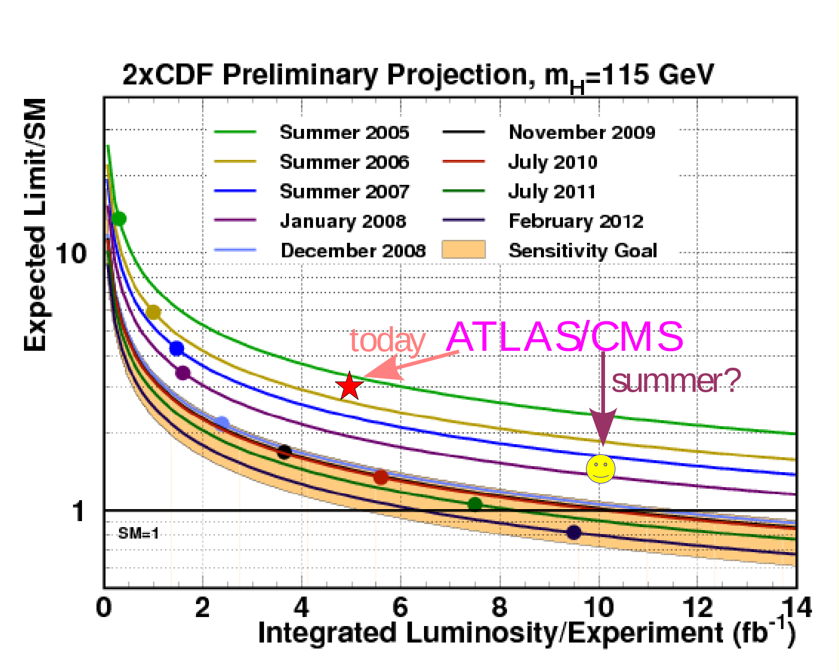
Current status of VH → Vbb searches

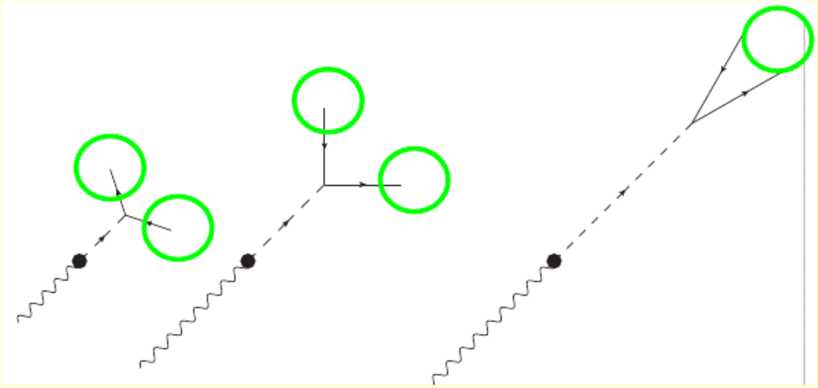
- Both Atlas and CMS presented results with a full dataset
- Atlas and CMS: select leptons and jets with higher p_T, higher MET, introduce cuts on V p_T, more cleaning cuts, only one b-tagging category (limit between 2 and 3 times σ_{SM})
- CDF and D0: lower lepton and jets p_T, less cleaning cuts, multiple lepton and b-tagging categories, excessive use of multivariate techniques
  - Many precise measurements performed, some still on their way
  - The latest is the evidence of the diboson production with b-jets in final state

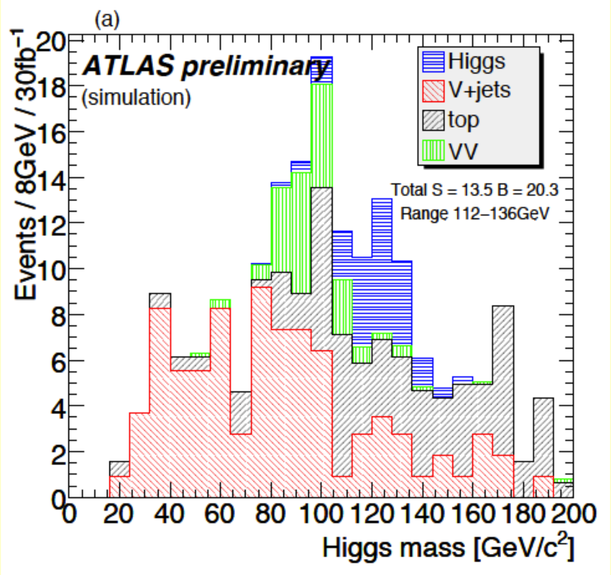


Prospects for the VH → Vbb searches

- Great potential for improvements
  - Understanding of the SM processes is crucial
- Recent development with jet substructure techniques can further increase sensitivity
  - Monte Carlo study shows potential of 3.7σ evidence for Higgs with mass of 120 GeV with 30 fb^{-1} and 14 TeV



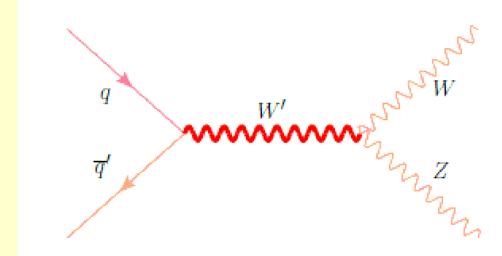




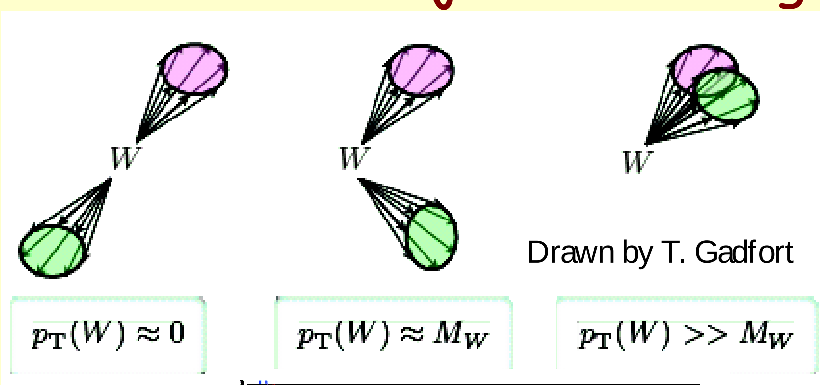
If no Higgs boson

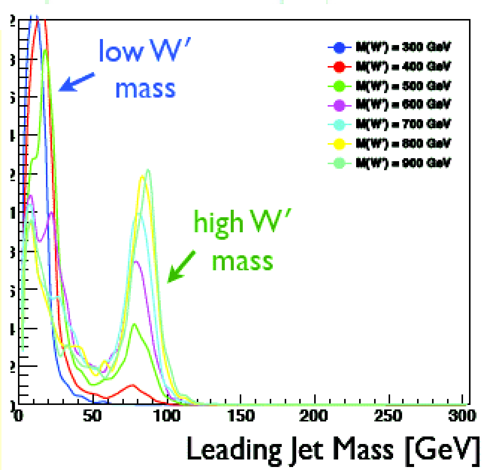
- Still need something to unitarize WW scattering
  - Final states will often contain pair of gauge bosons
  - W + 2 jets will play a crucial role in investigations of these processes
  - Since W/Z bosons will be boosted, jet substructure techniques will be powerful tools

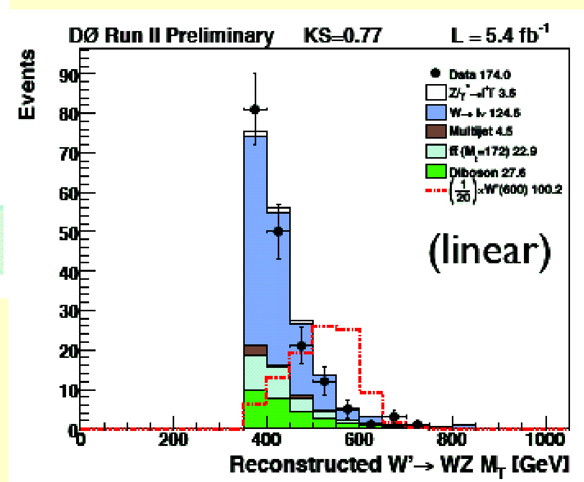
Diboson resonances

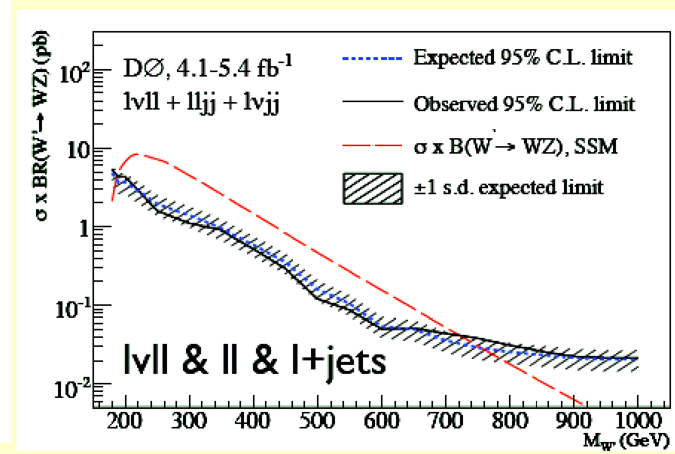


- Many extensions of the Standard Model predict new gauge groups with associated spin-1 gauge bosons
  - They can decay to two bosons
  - For high masses W(Z) is boosted, decay products are close
    - Two jets are merged into one single heavy jet



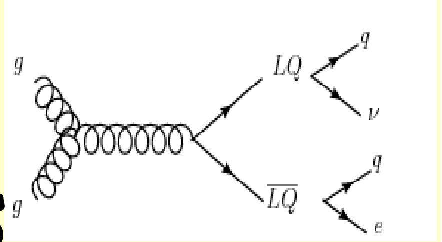






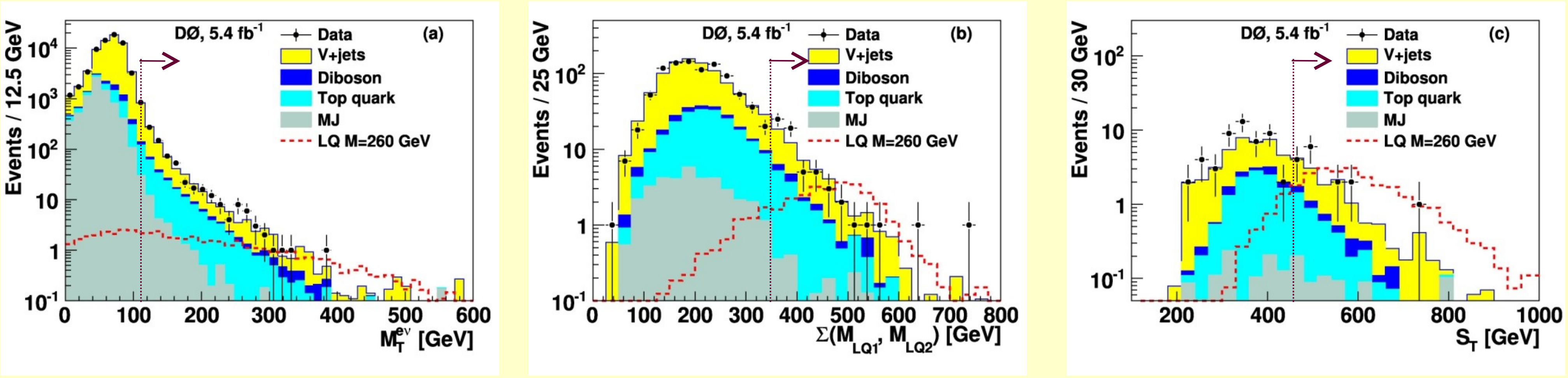
At high resonance mass l+jets is dominant

Leptoquark or what a summer student can do in eight weeks

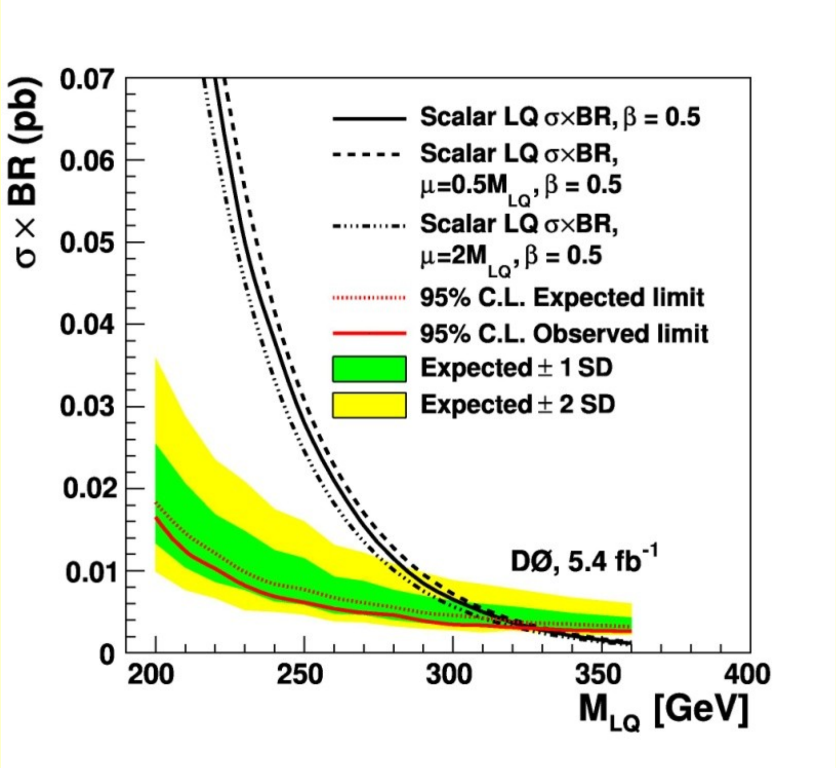


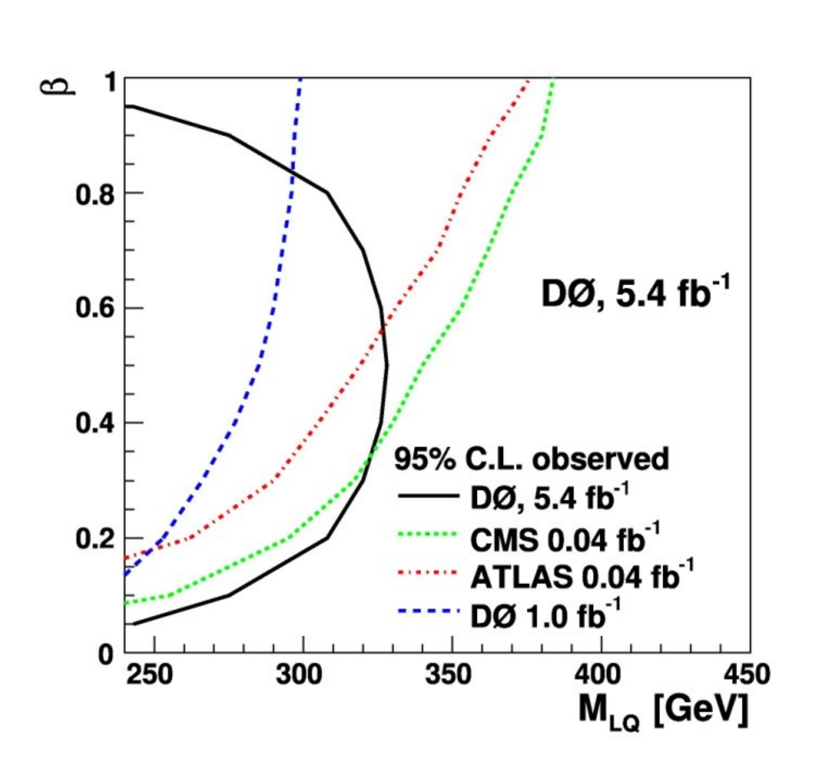
- Leptoquarks are predicted by many extensions of the Standard Model (SUSY, GUT, technicolor, etc.)
  - Composite, short-lived and decays to a lepton and a quark
- Developed an algorithm to correctly assign pairs of lepton (e,ν) and jets to parent LQ
- Simple cuts

Signal	50 → 25
Background	69000 → 15



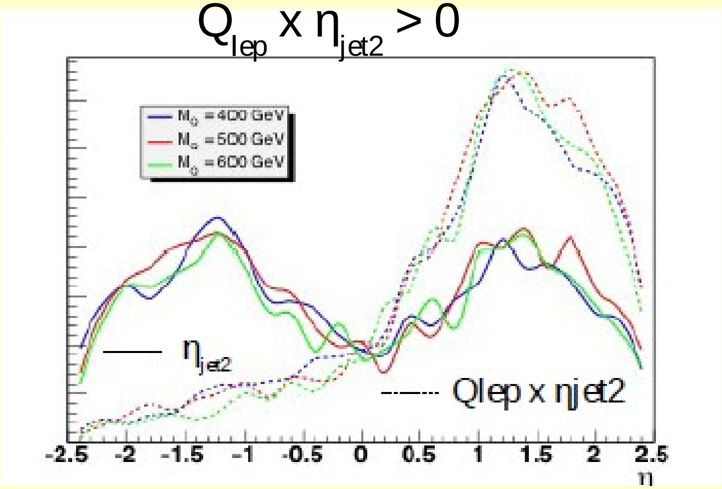
Leptoquark - result





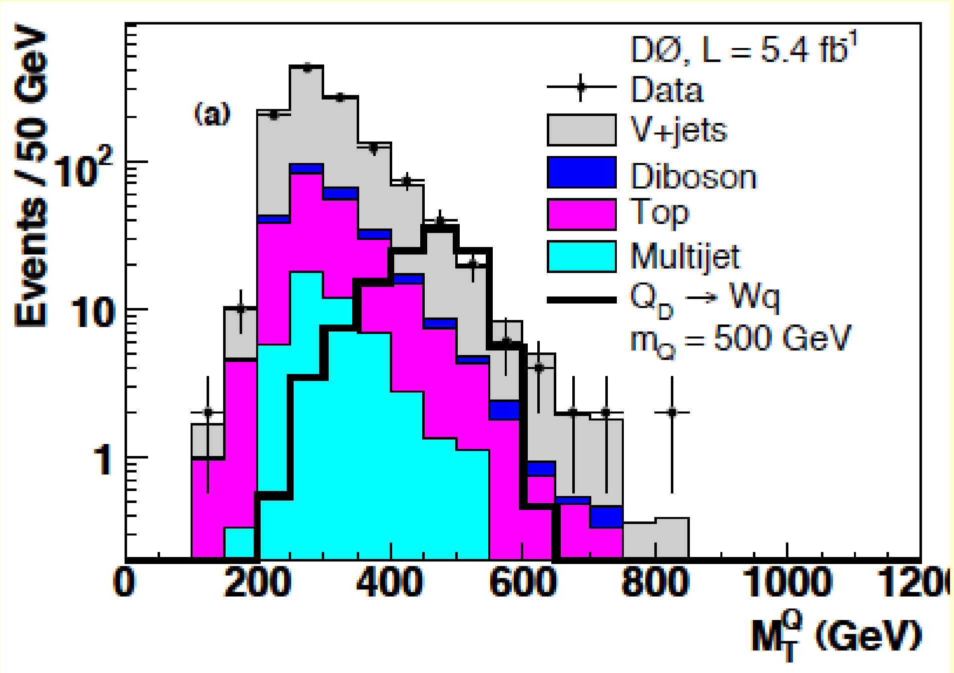
Vector quark

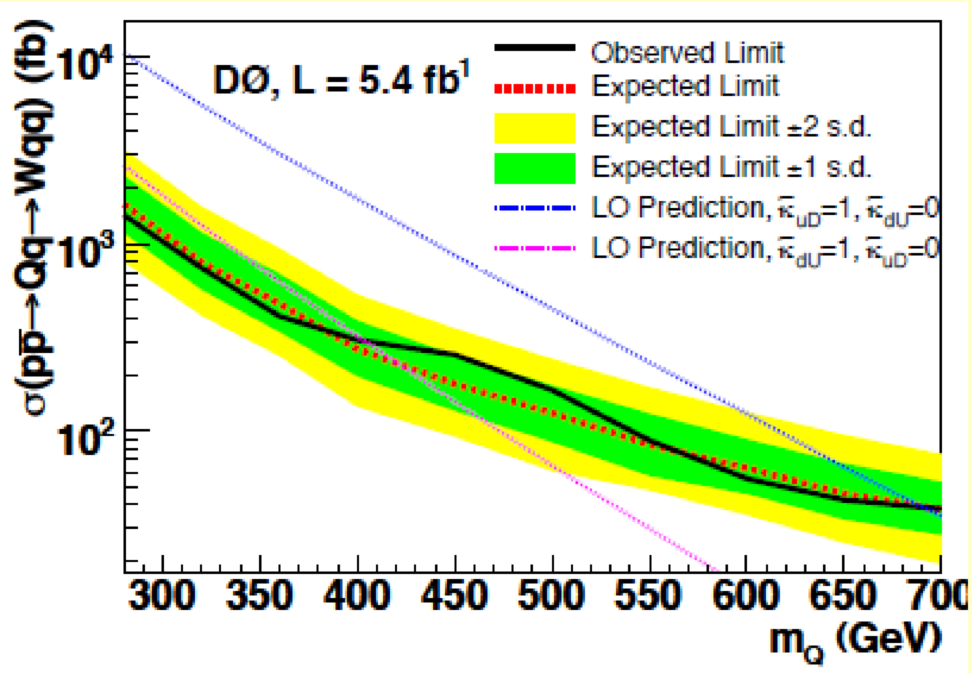
- Many new theories predict vector-like quarks:
  - Little Higgs
  - Warped extra dimensions
  - Universal extra dimensions => lowest KK excitation of SM fermions comprises a vector-like 4th generation
- Vector-like quarks are:
  - Fermions despite the name
  - Their left- and right-handed components transform in the same way under $SU(3) \times SU(2)_L \times U(1)$
- 2nd jet in Qq->Wqq signal comes from SM quark produced in association with vector quark
  => forward, relatively soft
- Direction of 2nd jet is correlated with production of VQ/anti-VQ, and therefore correlated with the sign of the lepton in W decay mode



Vector quark

- W+q
- m_T(l+ν+lead jet) used to search for a signal
- In the absence of the significant excess, limits are set





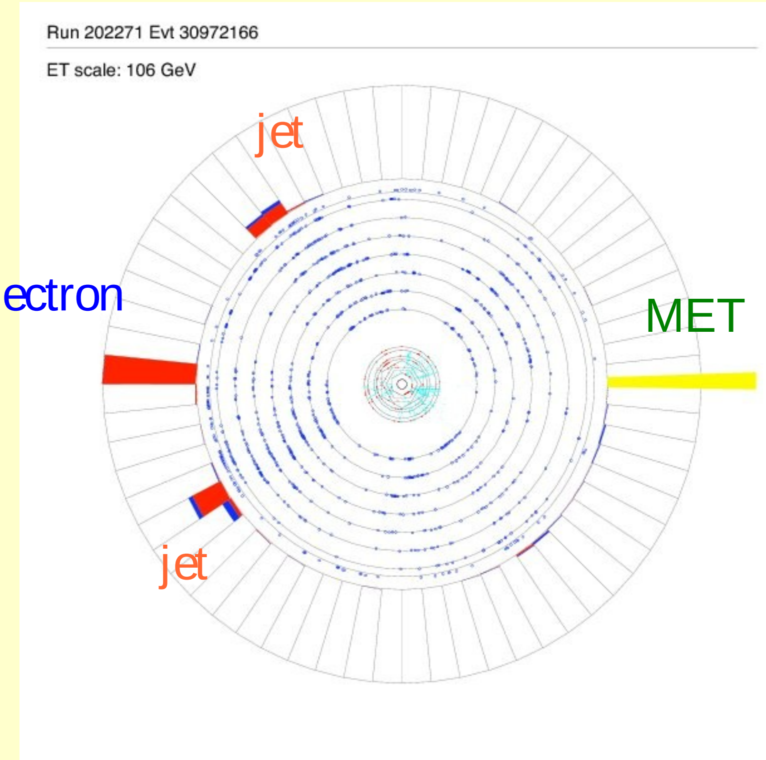
Reconstructing the event

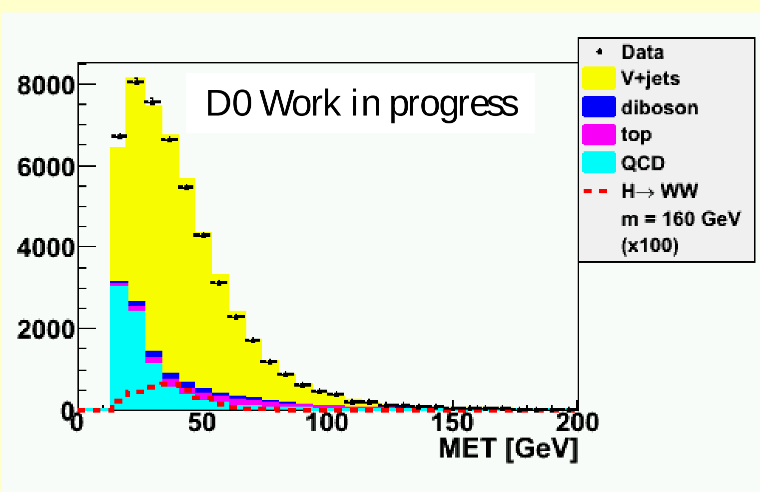
- Neutrinos interact weakly
  - Escape detection
- Ascertain presence by absence
  - Conservation of momentum

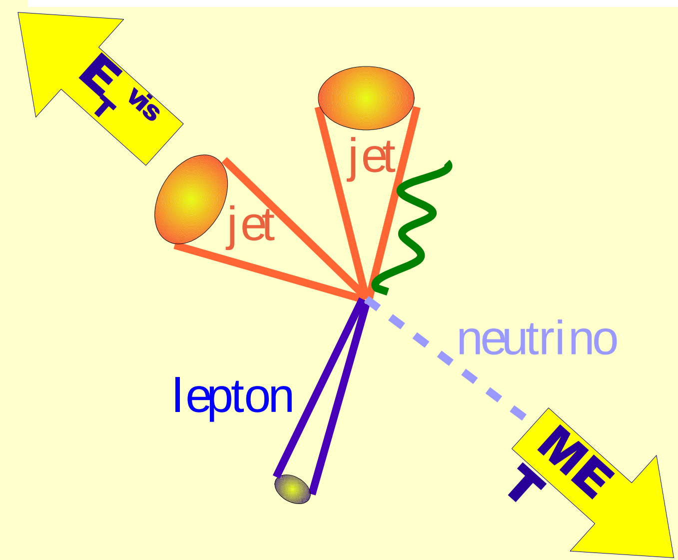
$$E_T^{initial} = 0 \Leftrightarrow E_T^{final} = 0$$

- Missing transverse energy (MET)

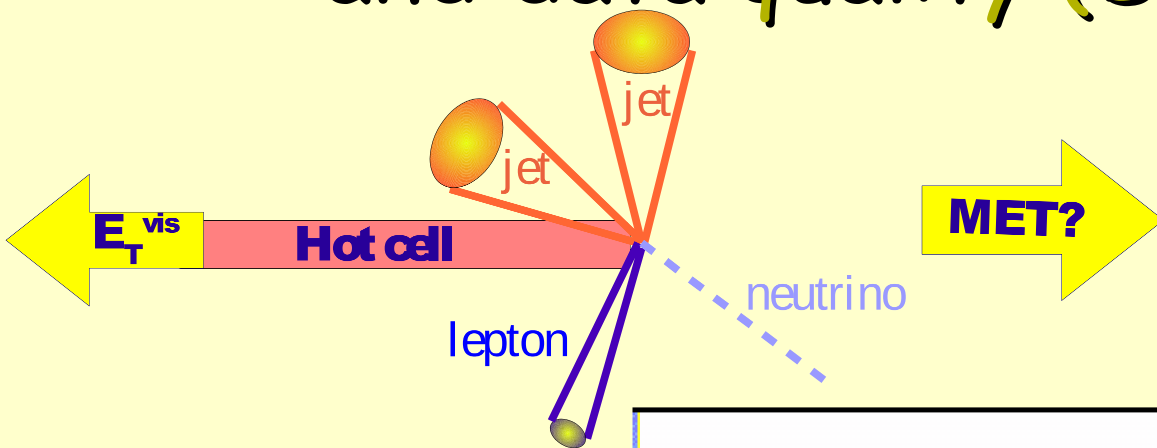
$$MET = E_T^{visible}$$



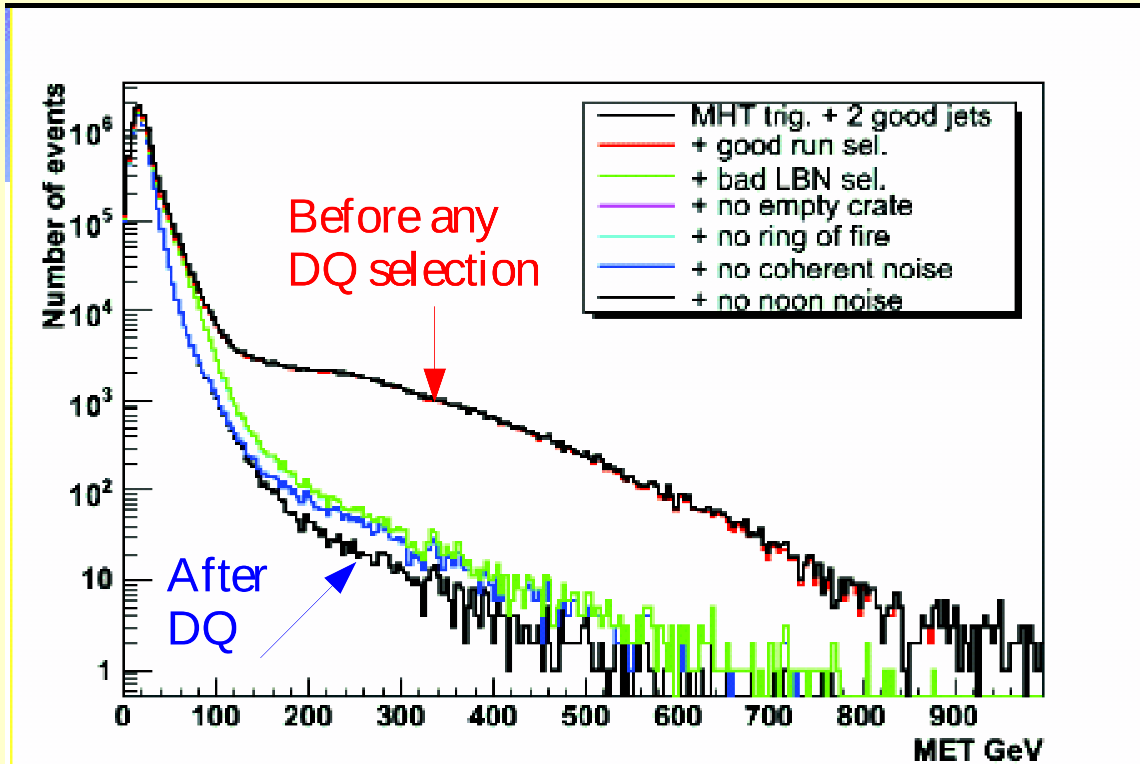




Missing transverse energy (MET) and data quality (DQ)

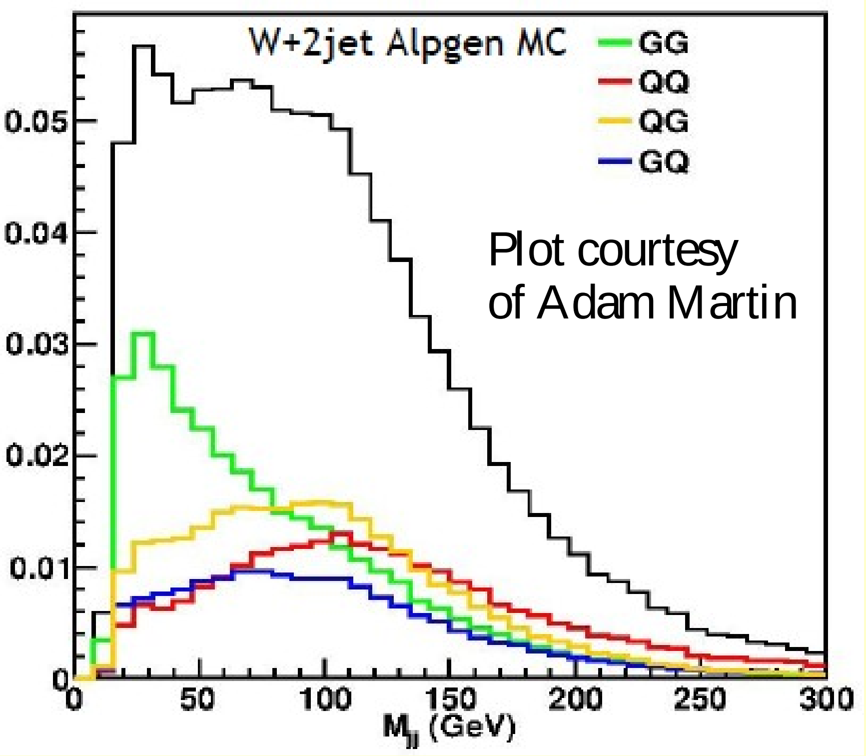


- Any calorimeter problem can appear as an event with large MET
  - Lot of "new physics"



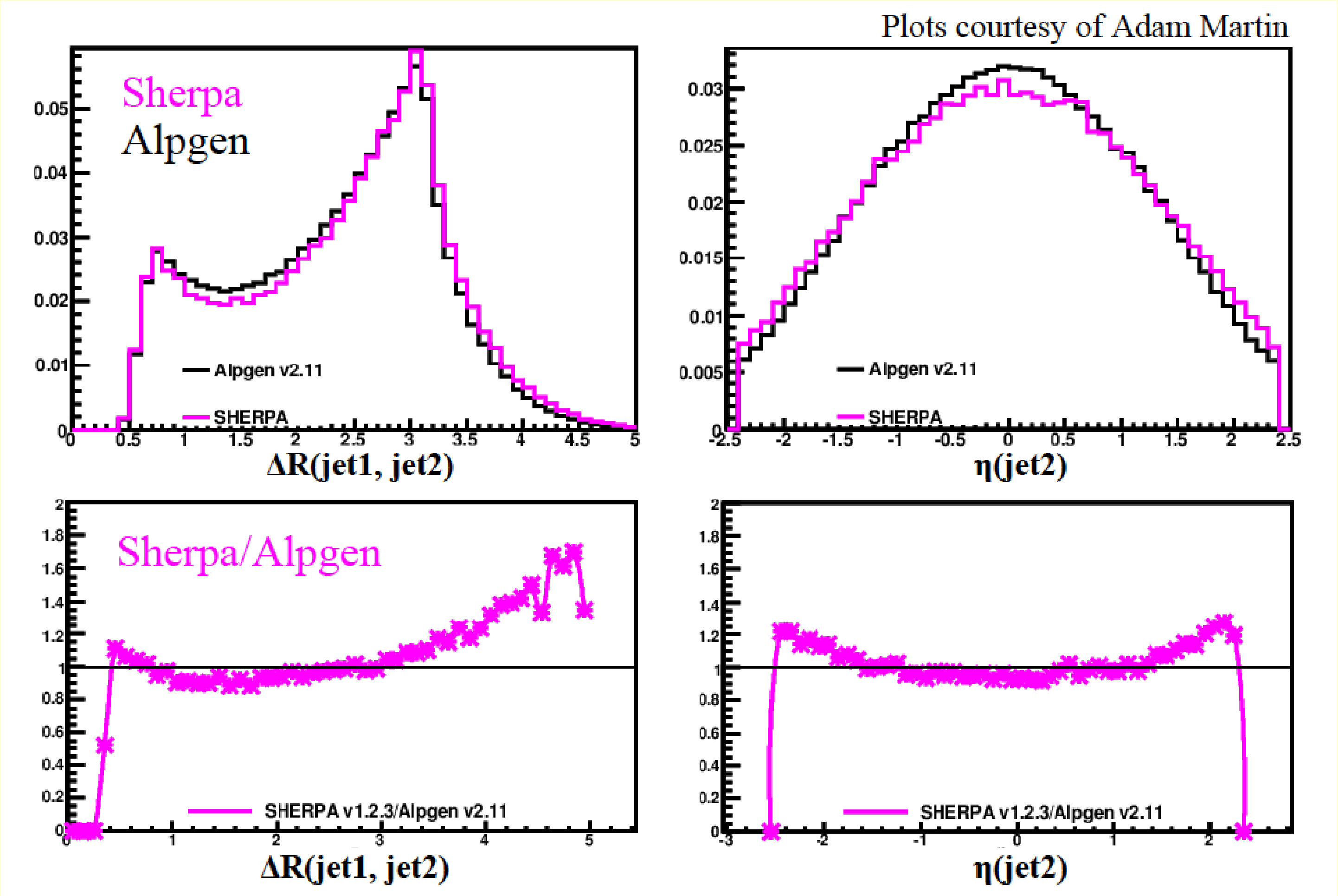
Jet reconstruction

- Reconstruction:
  - D0 iterative mid-point cone algorithm with radius R=0.5
  - Must be a hadronic shower and does not contain noisy calorimeter cells
  - At least two tracks fro primary vertex
- Jet Energy Scale
  - Measured in γ+jets events
  - Correct energy to particle level
    - For detector response, out of cone showering, overlap with pileup energy
- Relative data/MC correction
  - Measured in Z+jets events
  - Different correction depending on quark vs gluon content



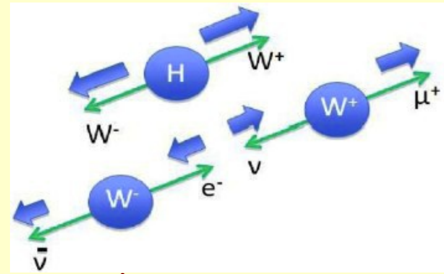
W+jets modeling

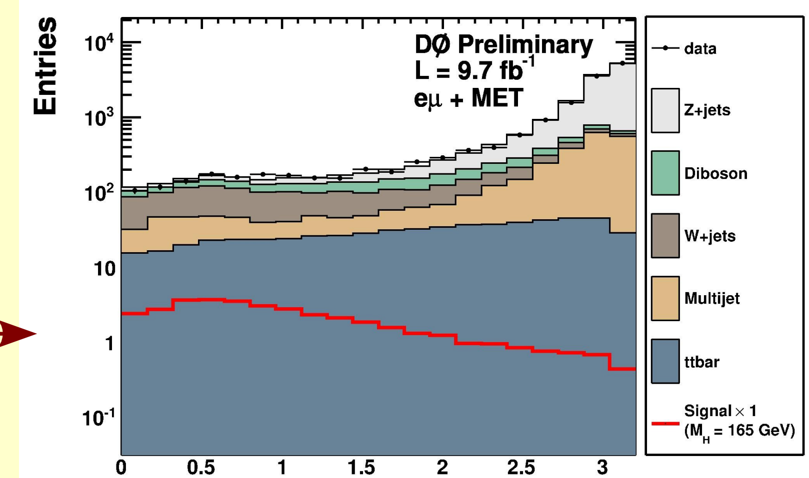
- Alpgen does not describe data properly
  - We know it from measurements
  - And from comparison with other generators

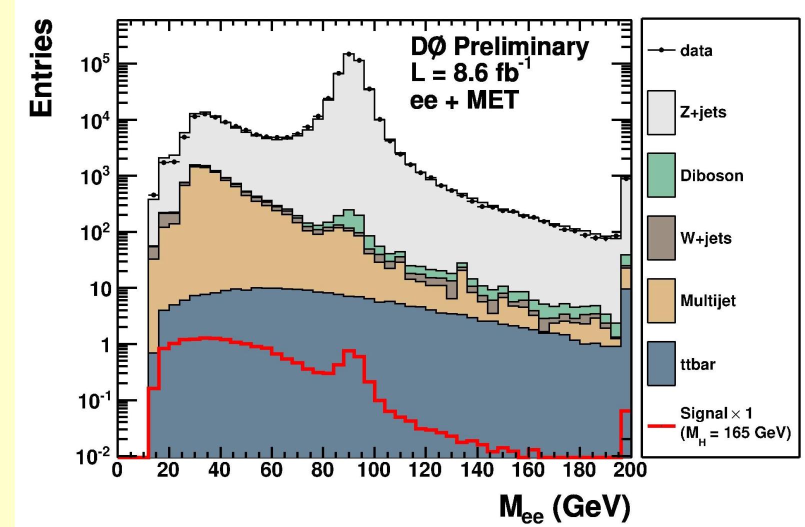


High mass Higgs - H → WW → lνlν

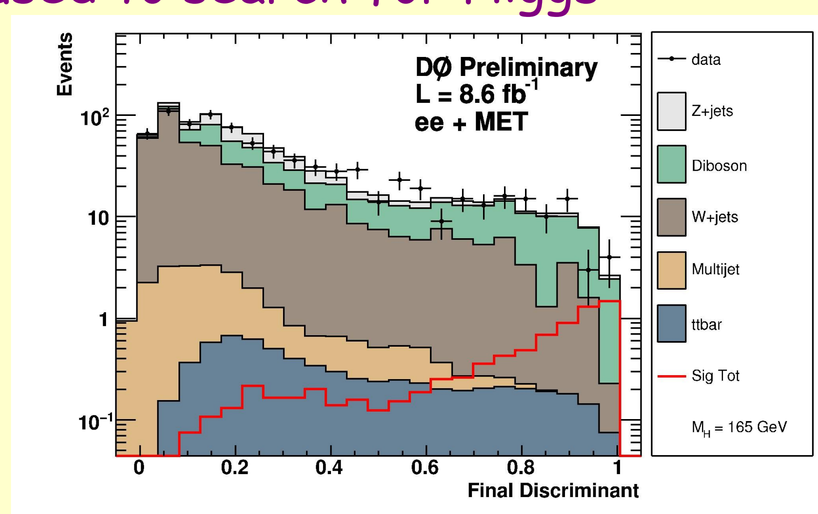
- Characteristics:
  - In signal WW pair is coming from spin 0 Higgs boson
  - Leptons prefer to point in same direction
  => Di-lepton opening angle $\Delta\varphi_{ll}$ discriminates again irreducible WW background.
  - Dilepton mass is small and broad
  => Discriminates against Drell-Yan







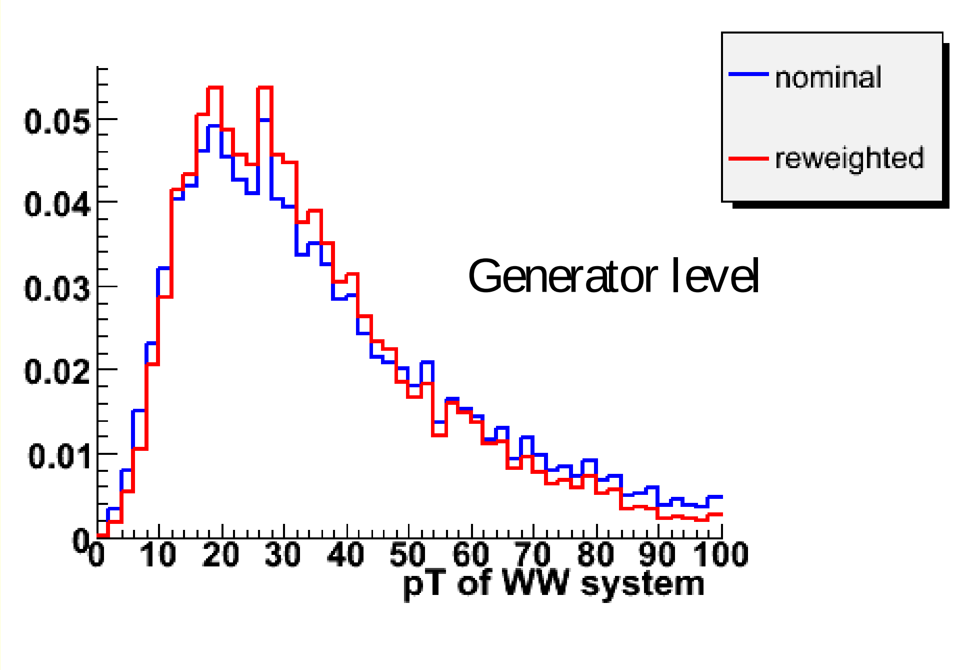
- Dedicated MVA rejects Z+jets events
- Another MVA used to search for Higgs
- This search contributed to the first Tevatron exclusion

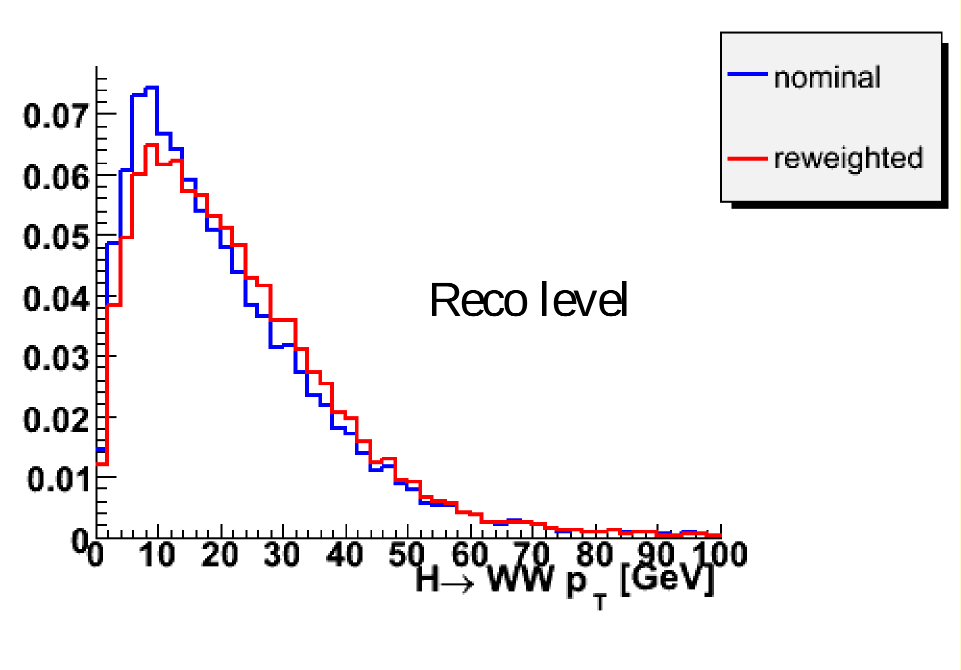


DØ (9.7 fb^{-1})	Exp.	Obs
M_H = 165 GeV	0.82	1.16
M_H = 125 GeV	3.77	4.23

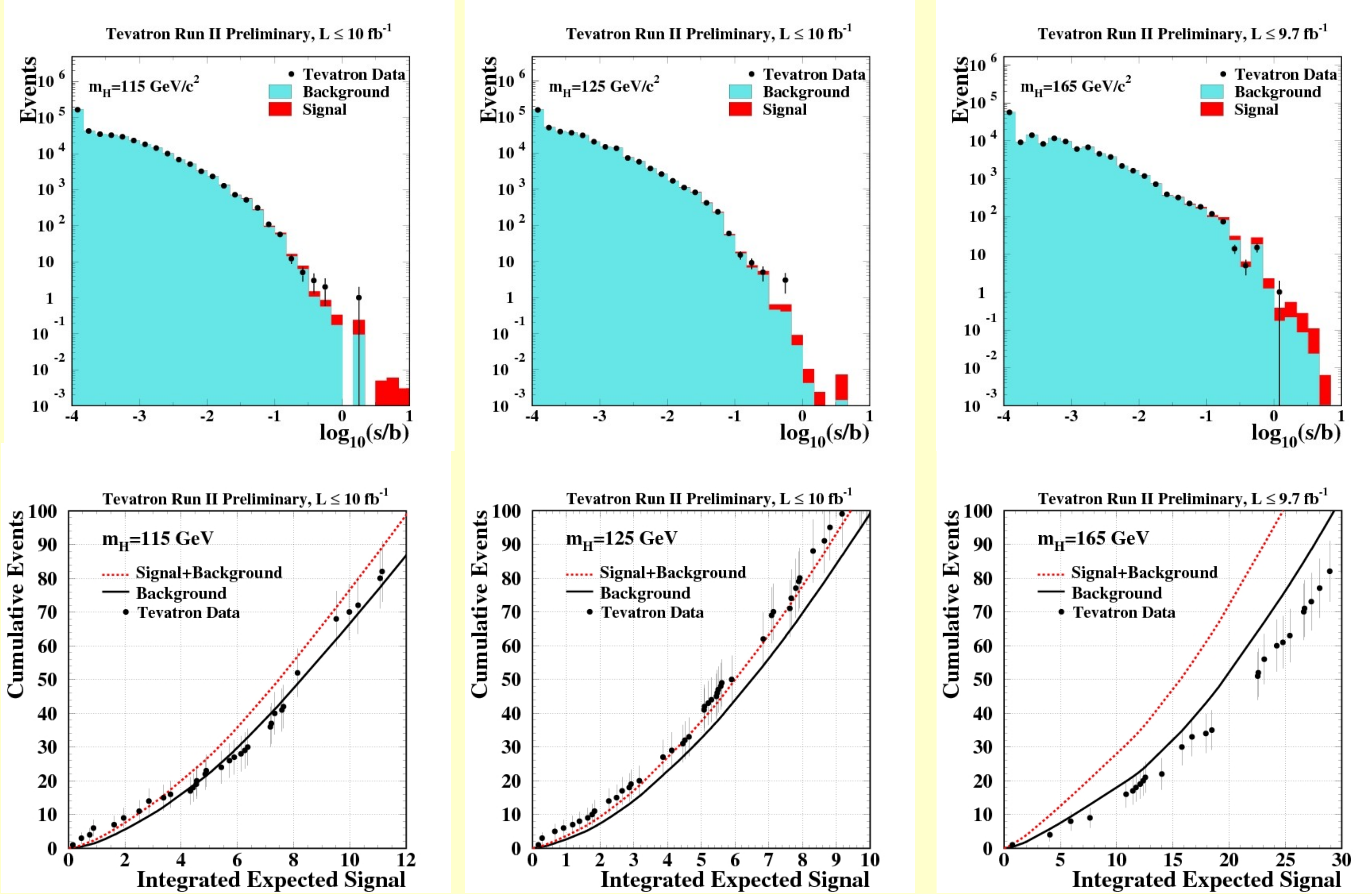
Modeling of the signal

- We model our signal with PYTHIA
  - But we know that PYTHIA has some issues
  - We use other generators for comparison, MC@NLO with Herwig, Sherpa or recently the HqT program, for the signal modeling
    - provides Higgs p_T distributions up to NNLL+NNLO

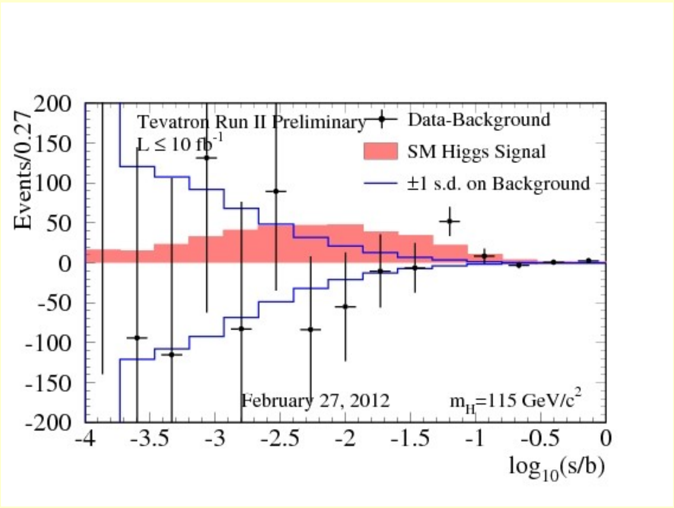


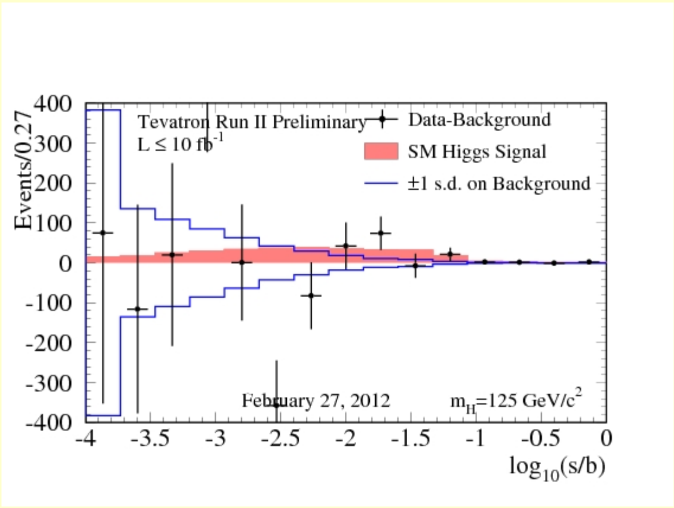


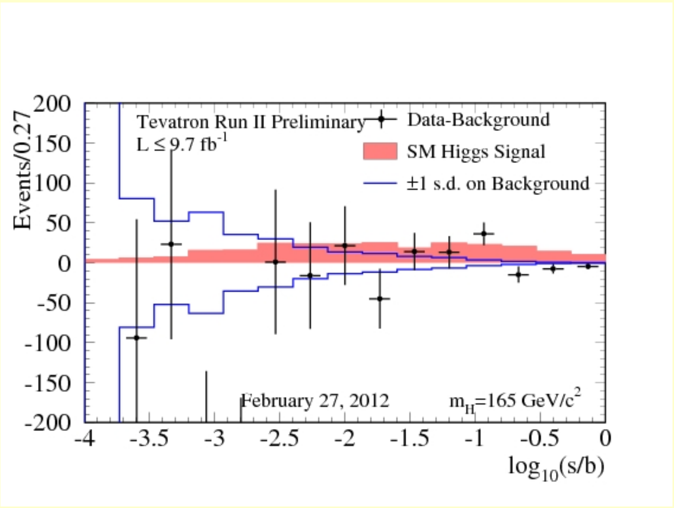
Cumulative distributions



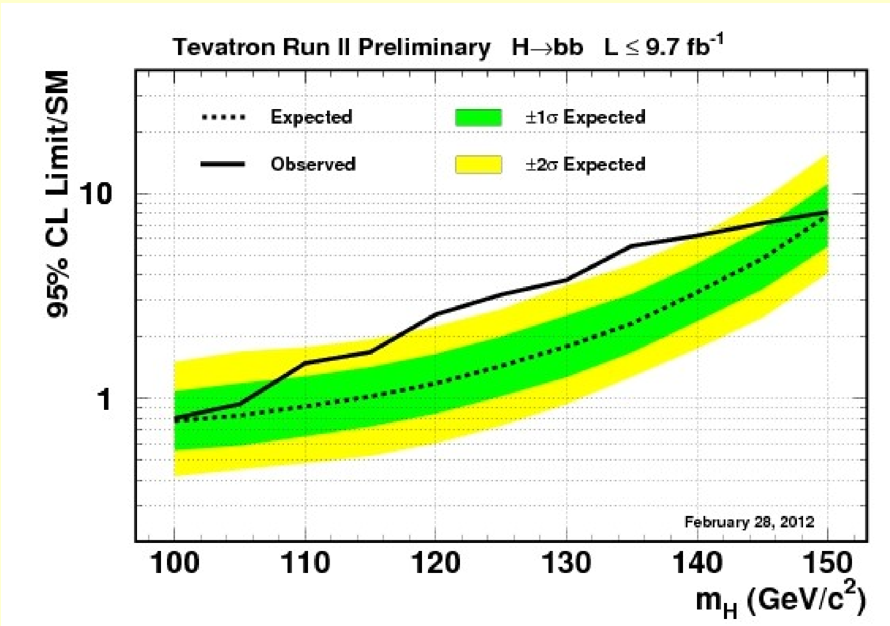
Data - Background

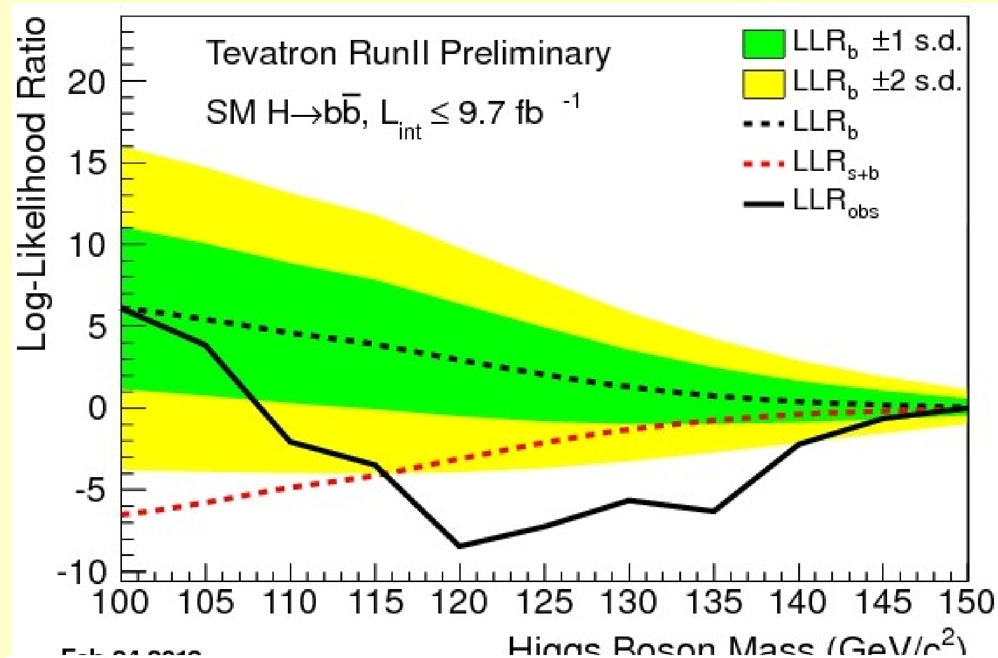


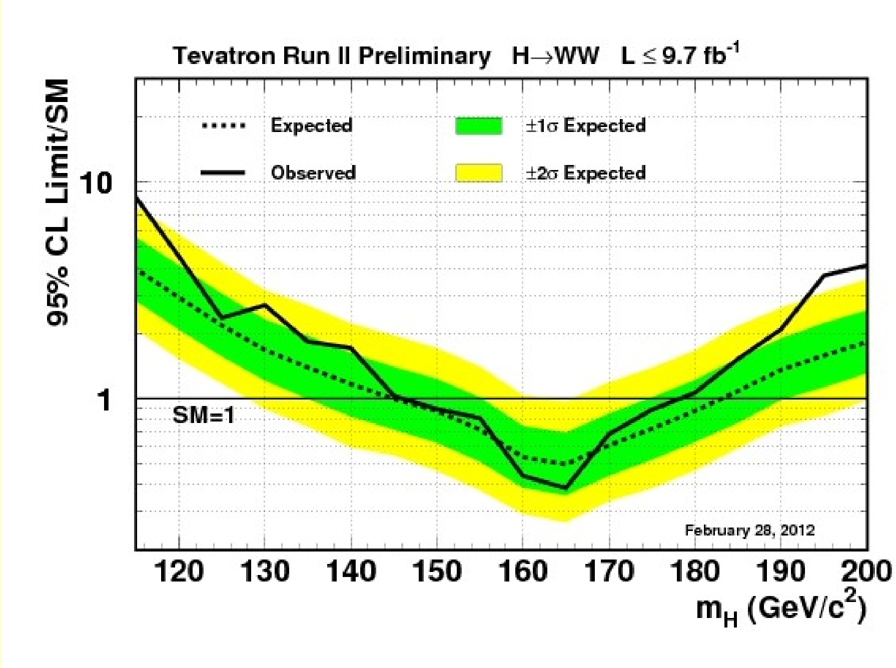


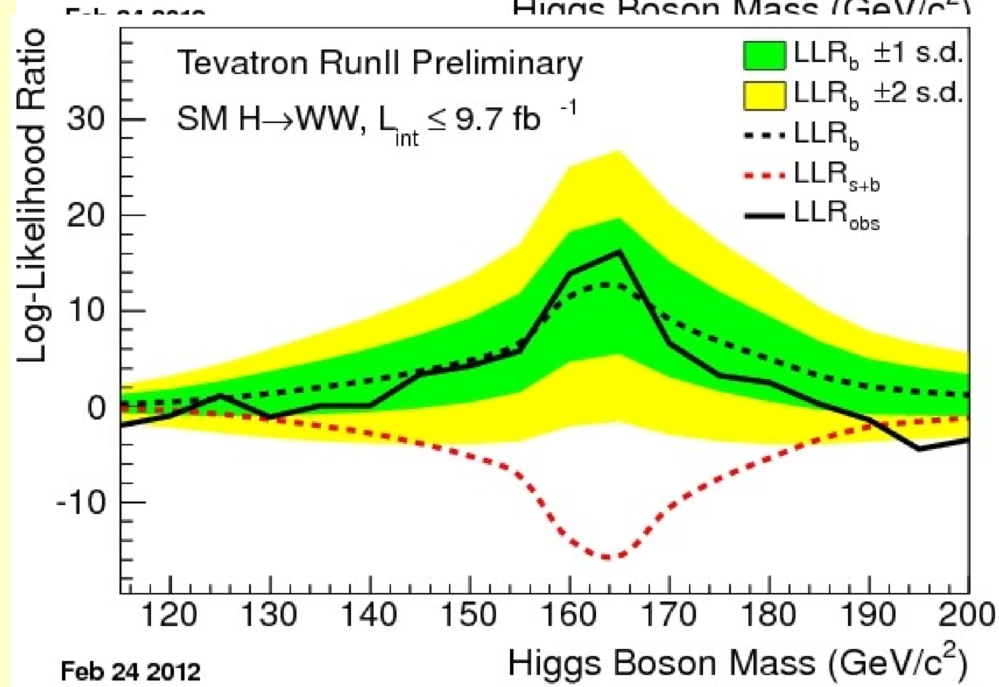


Separate limits

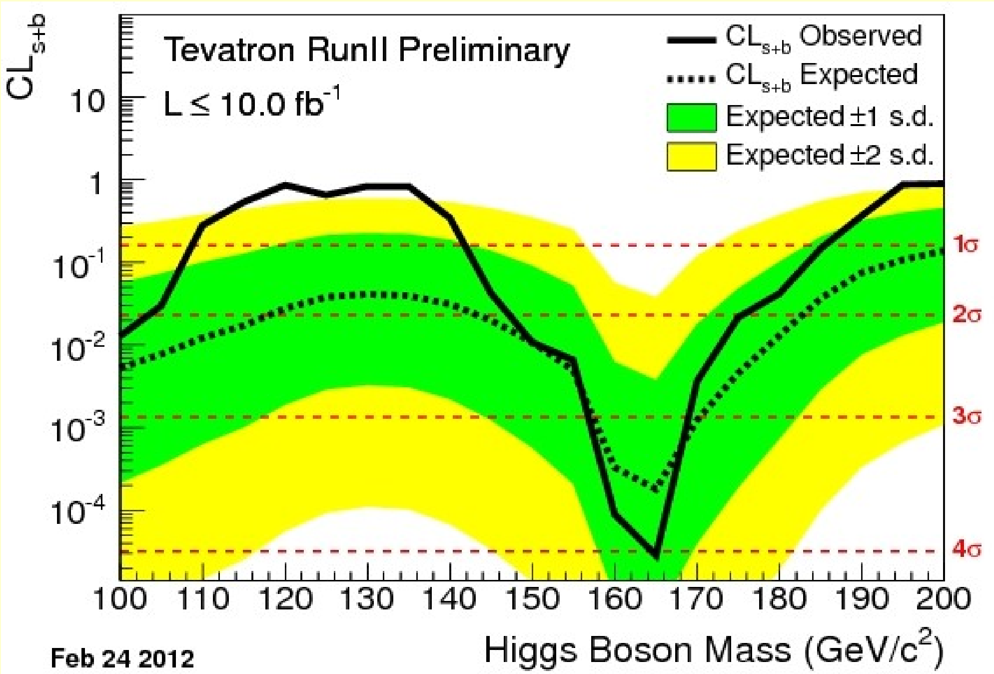


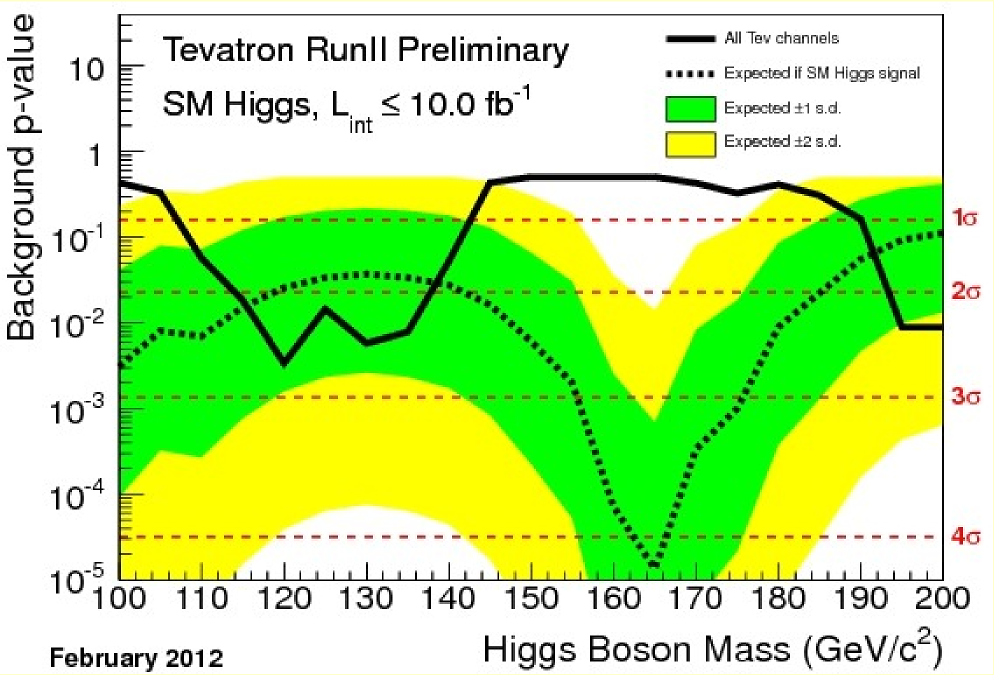






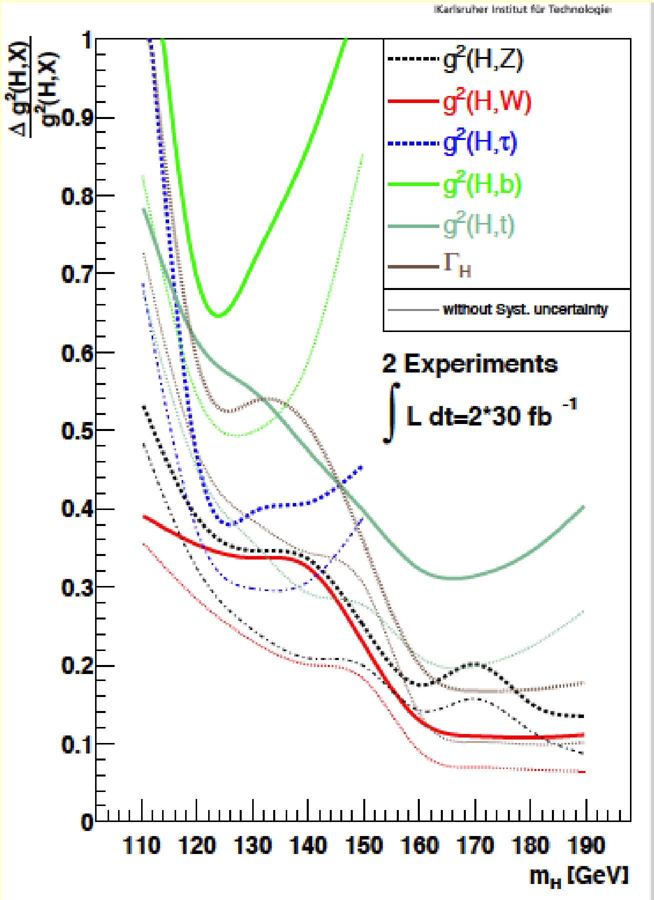
Quantifying excess





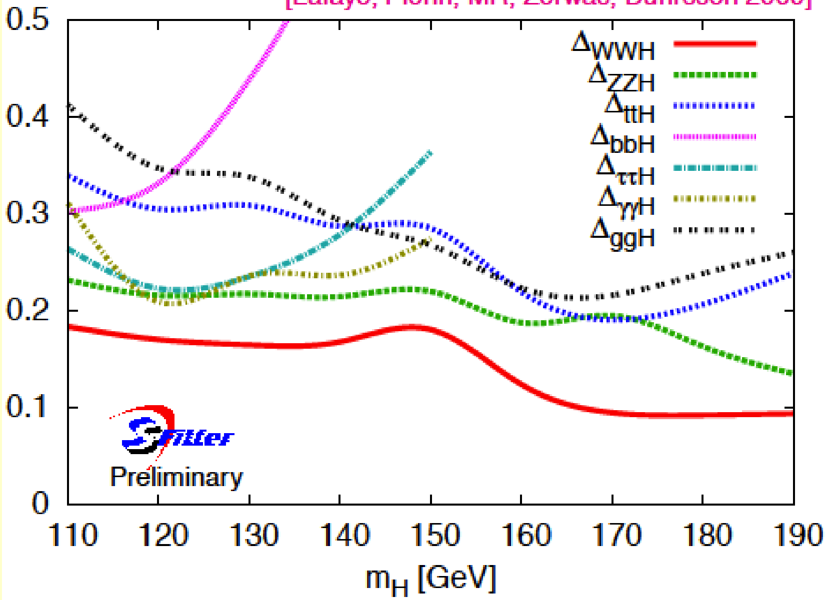
- Small value disfavors hypothesis, while value close to 1 favors it
  - Left: S+B hypothesis disfavored for mH=165 GeV and favored for mH~130 GeV
  - Right: the opposite; it can translate to an excess of 2.7s over the background prediction

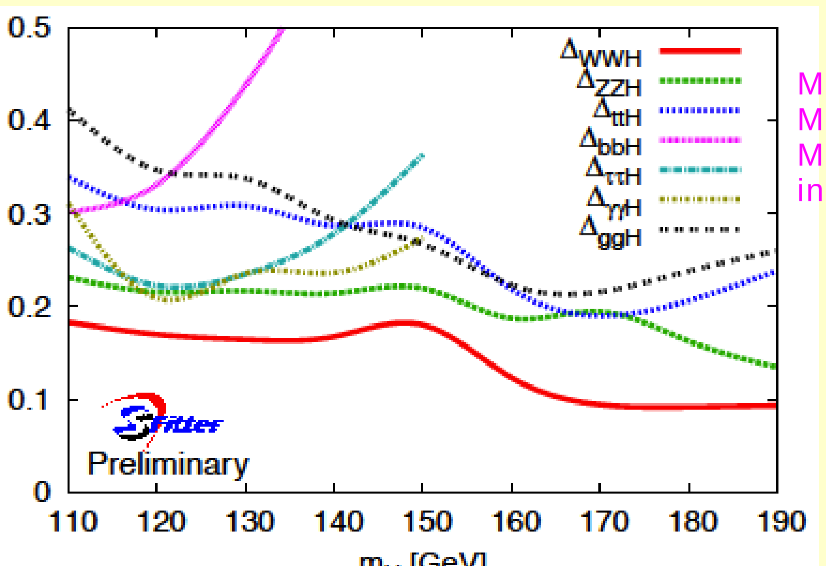
Measurements



[Zeppenfeld, Kinnunen, Nikitenko, Richter-Was; Dührssen et al.]

[Lafaye, Plehn, MR, Zerwas, Dührssen 2009]



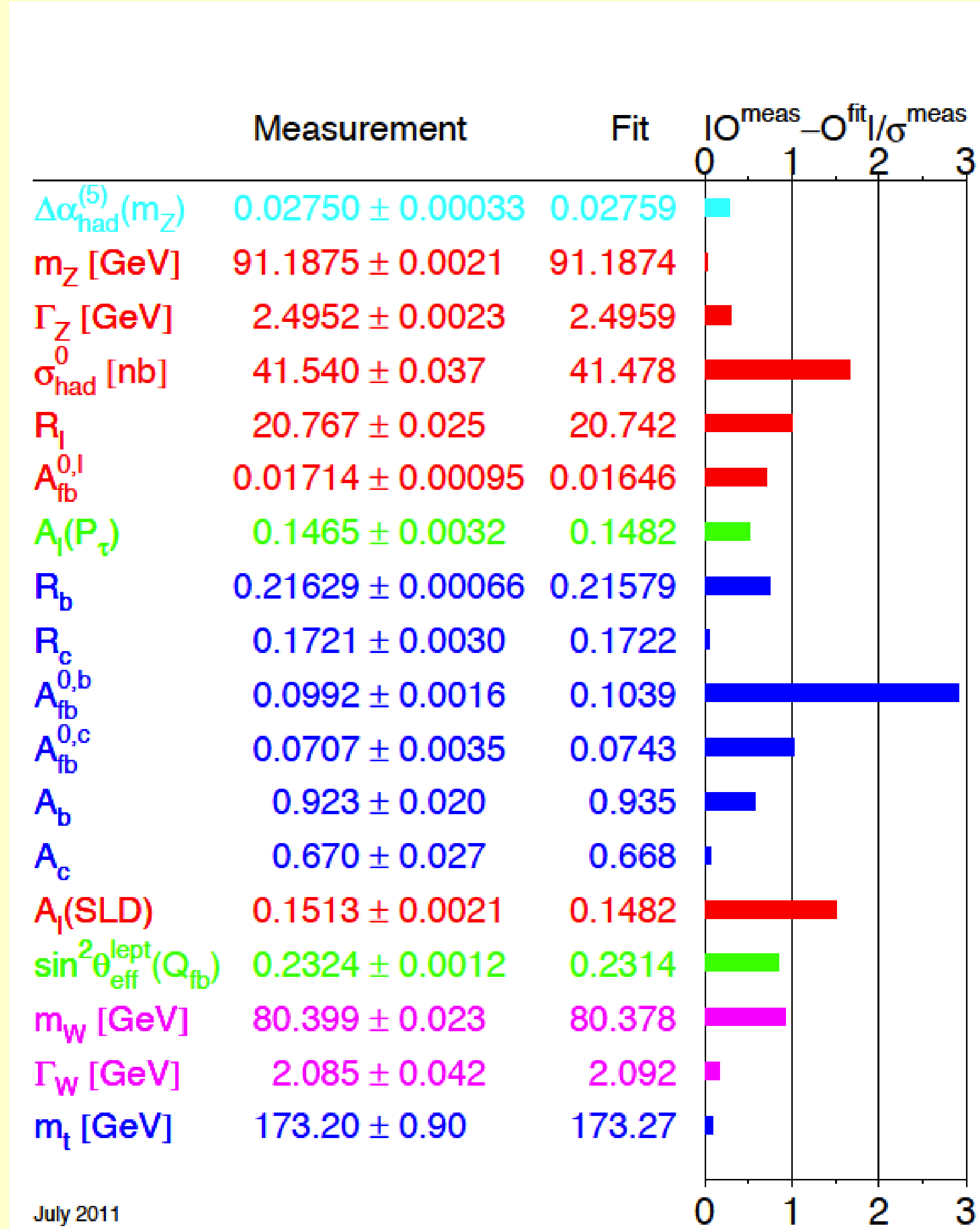


M. Rauch, talk at Moriond EW 2012;
M. Klute, R. Lafaye, T. Plehn,
M. Rauch, D. Zerwas, M. D¨uhrssen,
in preparation

Look Elsewhere Effect

- We estimate the LEE effect in a simplified manner. In the mass range 100–125 GeV/c2, where the low-mass H→bb searches dominate, the reconstructed mass resolution is approximately 10-15%, or about 15 GeV/c2. We therefore estimate a trials factor of ~ 2 for the low-mass region. For the high-mass searches, the H→W+W– searches dominate the sensitivity. There is little-to-no resolution in reconstructing mH in these channels due to the presence of two neutrinos in the final state of the most sensitive analyses. We expect a trials factor of approximately two for the high-mass searches. In total, we expect that there are roughly four possible independent locations for uncorrelated excesses to appear in our analysis. The global p-value is therefore 1–(1–pmin)4, using the Dunn-Sidak correction [56]. The global significance for such an excess anywhere in the full mass range is estimated to be 1.52σ.

SM fits


Measurement
Fit
$|O^{meas}-O^{fit}|/\sigma^{meas}$
0 1 2 3
$\Delta\alpha_{had}^{(5)}(m_Z)$ 0.02750 ± 0.00033 0.02759
m_Z [GeV] 91.1875 ± 0.0021 91.1874
Γ_Z [GeV] 2.4952 ± 0.0023 2.4959
σ_{had}^0 [nb] 41.540 ± 0.037 41.478
R_l 20.767 ± 0.025 20.742
$A_{fb}^{0,l}$ 0.01714 ± 0.00095 0.01646
$A_l(P_\tau)$ 0.1465 ± 0.0032 0.1482
R_b 0.21629 ± 0.00066 0.21579
R_c 0.1721 ± 0.0030 0.1722
$A_{fb}^{0,b}$ 0.0992 ± 0.0016 0.1039
$A_{fb}^{0,c}$ 0.0707 ± 0.0035 0.0743
A_b 0.923 ± 0.020 0.935
A_c 0.670 ± 0.027 0.668
A_l(SLD) 0.1513 ± 0.0021 0.1482
$\sin^2\theta_{eff}^{lept}(Q_{fb})$ 0.2324 ± 0.0012 0.2314
m_W [GeV] 80.399 ± 0.023 80.378
Γ_W [GeV] 2.085 ± 0.042 2.092
m_t [GeV] 173.20 ± 0.90 173.27
July 2011
0 1 2 3

Lessons from Tevatron

- Efficient data taking
  - Lower downtime to fix problems in control room, providing data of the best quality
- Object reconstruction and identification
  - High efficiency and purity
- Excellent modeling of known processes
  - Understanding the problems
- Powerful multivariate techniques
  - They are not an answer, but valuable tool
- Systematic uncertainties
- Superb statistical tools

D0 llbb with 4.2 fb^{-1}

M_H (GeV)	100	105	110	115	120	125	130
Expected/SM:	5.1	5.6	6.2	7.1	8.4	10.0	12.7
Observed/SM:	3.0	3.8	4.6	5.9	7.9	9.2	12.1
Observed (fb):	41	44	44	47	50	45	45

D0 ννbb with 5.3 fb^{-1}

m_H (GeV)	100	105	110	115	120	125	130
Observed	3.6	3.9	3.4	3.7	4.9	5.5	7.4
Expected	3.4	3.8	4.2	4.6	5.5	6.7	7.8

D0 WH with 5.4 fb^{-1}

	Combined 95% C.L. Limit $/\sigma_{SM}$	
Higgs Mass [GeV]	Expected	Observed
100	3.3	2.7
105	3.6	4.0
110	4.2	4.3
115	4.8	4.5
120	5.6	5.8
125	6.8	6.6
130	8.5	7.0
135	11.5	7.6
140	16.5	12.2
145	23.6	15.0
150	36.8	30.4

ATLAS VH with 4.7 fb^{-1}

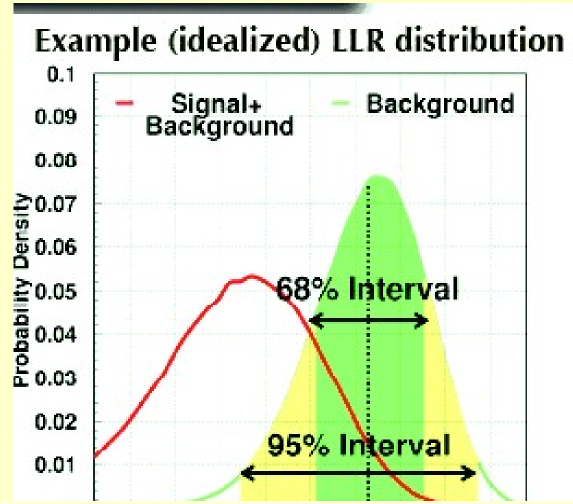
mass	$ZH \to \ell^+\ell^- b\bar{b}$		$WH \to \ell\nu b\bar{b}$		$ZH \to \nu\bar{\nu}b\bar{b}$		Combined	
[GeV]	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
110	7.5	5.5	3.8	4.4	4.0	4.5	2.7	2.6
115	7.8	5.8	5.5	5.6	4.8	5.1	3.9	3.0
120	10.1	7.4	4.9	5.9	5.4	5.1	3.1	3.2
125	10.4	8.2	8.0	7.5	5.9	5.6	3.5	3.8
130	13.1	10.6	8.5	9.1	12.2	8.9	5.3	5.1

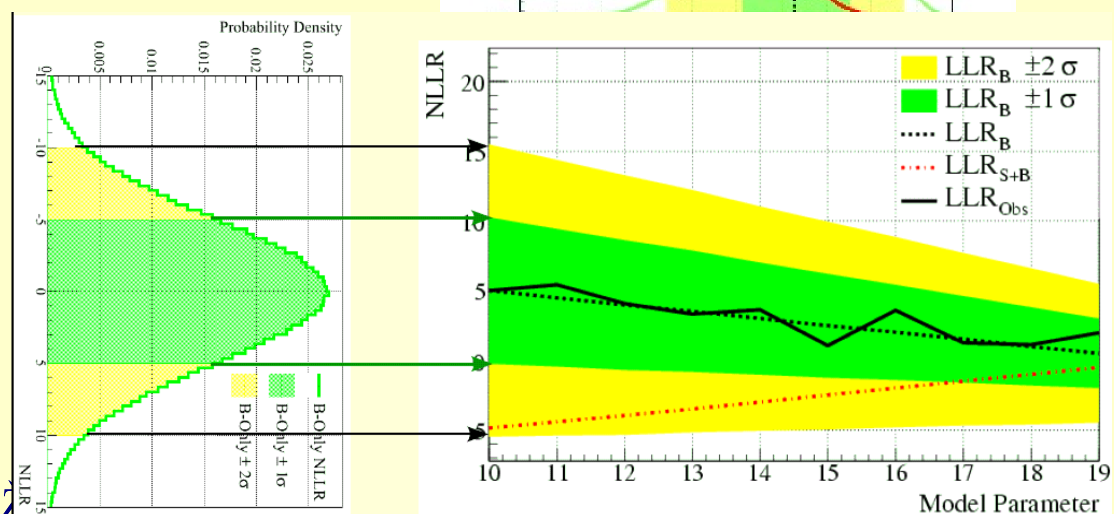
Cross sections

- Higgs
  ggH: D. de Florian and M. Grazzini, Phys. Lett. B 674, 291 (2009)
  C. Anastasiou, R. Boughezal and F. Petriello, JHEP 0904, 003 (2009)
  W/ZH: J. Baglio and A. Djouadi, arXiv:1003.4266v2
  VBF: P. Bolzoni, F. Maltoni, S. -O. Moch and M. Zaro, arXiv:1109.3717.
  (Signal is generated with Pythia with CTEQ6L1 LO parton distribution functions, normalized with MSTW 2008 NNLO PDF (ggh))
- Diboson: J. M. Campbell and R. K. Ellis, Phys. Rev. D 60, 113006
- tt: U. Langenfeld, S. Moch and P. Uwer, Phys. Rev. D 80, 054009 (2009)
- Single top: N. Kidonakis, Phys. Rev. D 74, 114012 (2006)
- W/Z+jets: ultimately from data but in agreement with (FEWZ):R. Gavin, Y. Li, F. Petriello and S. Quackenbush, Comput. Phys. Commun. 182, 2388 (2011).
  h.f. fraction from(MCFM) J. M. Campbell and R. K. Ellis, Phys. Rev. D 65, 113007 (2002).

Limit settings

- Limits derived using semi-frequentist CLs method where test statistic is
  LLR = -2LogQ
  = -2Log[P(s+b)/P(b)]
  - P are probability distribution functions for the signal+background and background only hypotheses
  - P are populated via random Poisson trials with mean values given by the expected number of events in each hypothesis
- Systematic uncertainties are incorporated by varying the expected number of events in each hypothesis according to the size and correlations of the uncertainties





- In the case of the Higgs search, we seek to set limits on potential signal rates
  - ⇒ Similar test, comparing signal+background and background-only hypotheses
  - ⇒ Signal rate is now a fixed parameter to be tested

$$Q = \frac{L(D|S+B)}{L^{\dagger}(D|B)}$$

← Two independent likelihood maximizations are performed over nuisance parameters: one for each hypothesis (S+B & B-Only)

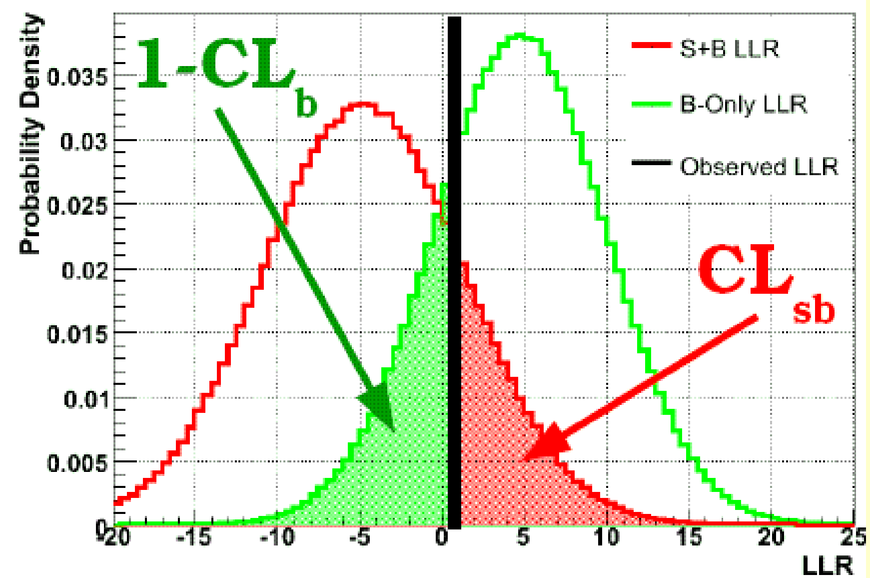
$$LLR \; = \; -2 \ln Q \; = \; \chi^2(D|S+B) \; - \; \chi^2(D|B)$$

- The relative frequency of outcomes from S+B and B-Only pseudo-experiments allows us to test the signal rate

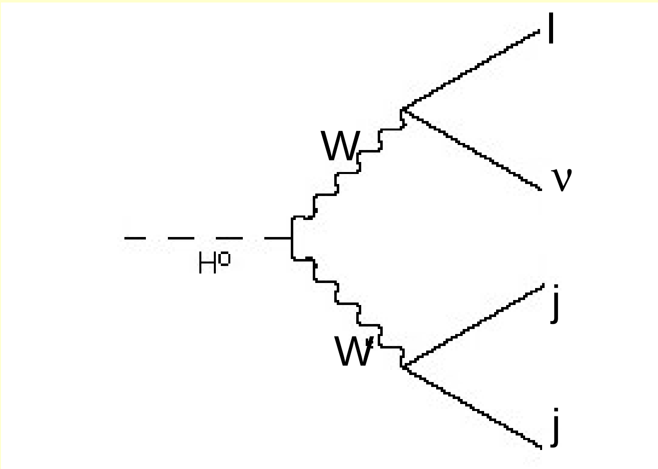
  CLsb: fraction of S+B pseudo-experiments more background-like than data

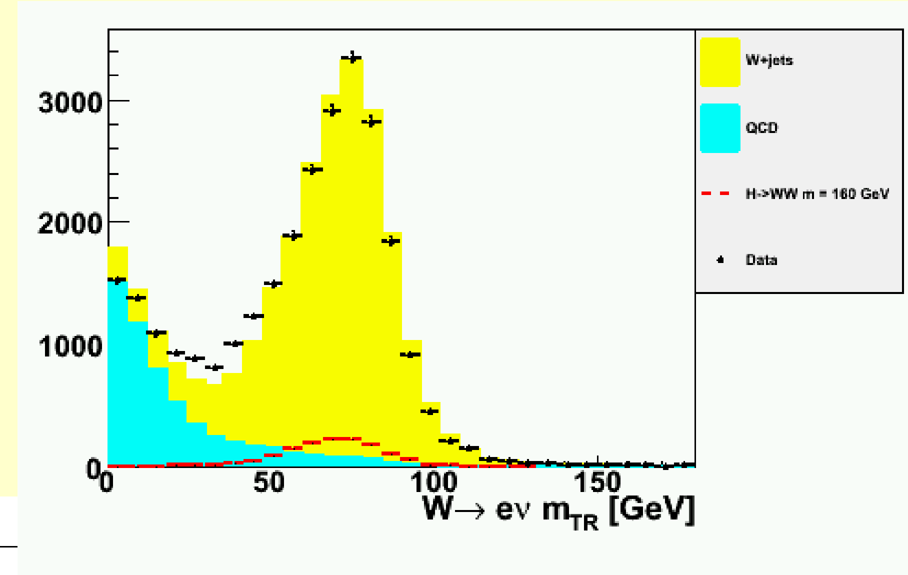
  CLb: fraction of B-Only pseudo-experiments more background-like than data

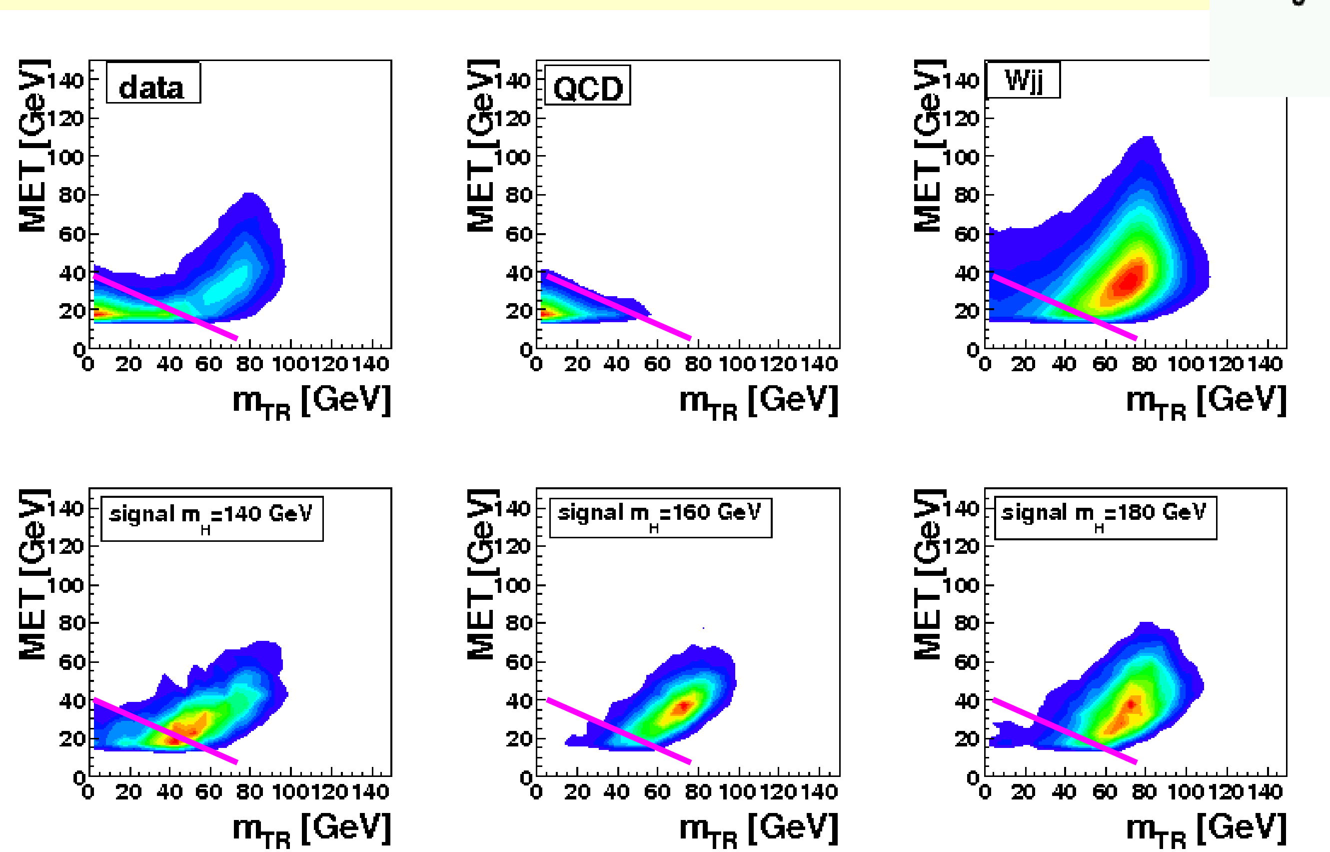
  1-CLb: fraction of B-Only pseudo-experiments more signal-like than data



Event Selection

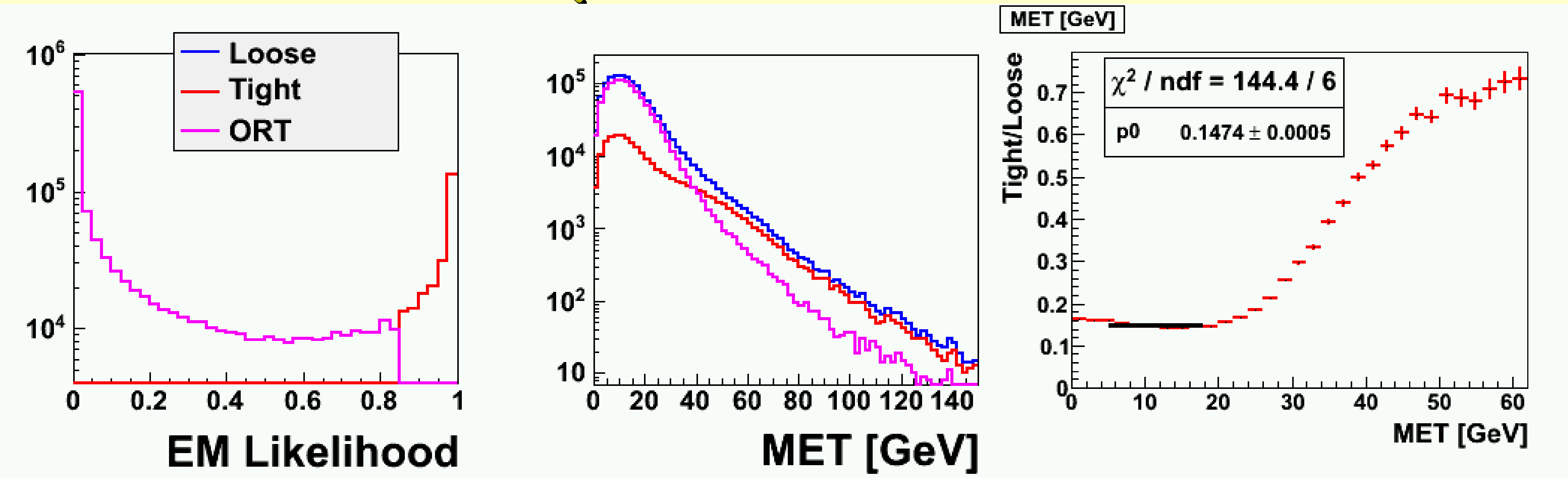




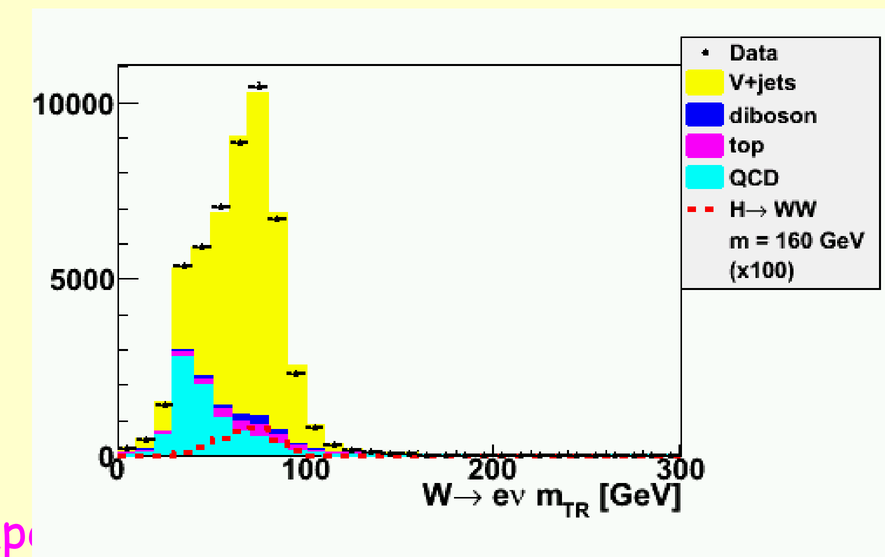


- QCD reduction
  - electron faking jet
  - missmeasured jet energies give MET
- Triangle cut between transverse mass and MET

QCD estimation



- We use so called matrix method
  - Define 3 different sample: Loose, Tight and Orthogonal:
    - Loose and Tight are used to measure efficiency of QCD and "signal" events in data, ε_{QCD} and ε_{Sig}, and to obtain normalization
    - Orthogonal is used to get the correct shap



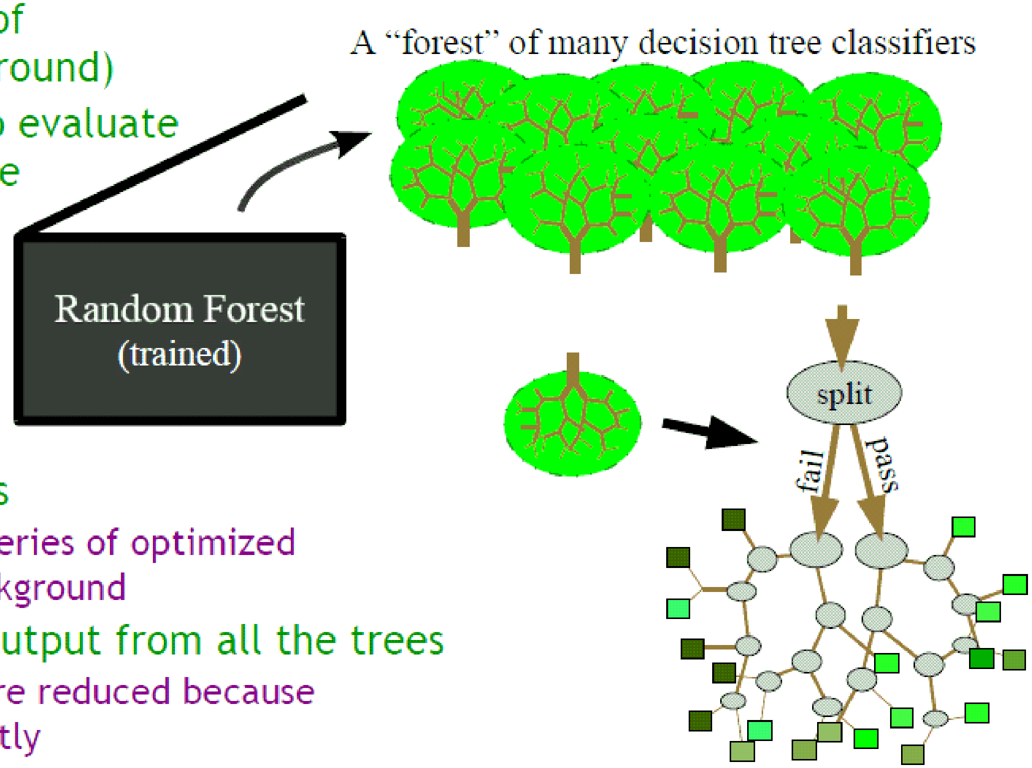
  - It may depend on the p_T of lepton

NLO pQCD calculations & MC Models

- pQCD predictions calculated with MCFM, JetPhoX
- Many LO MC programs on the market:
  - MEPS: Alpgen, Sherpa, Madgraph, Helac, Madevent, ...
  - PS: Pythia, Herwig, Ariadne, ...
- CKKW
  - the separation of ME and PS for different multijet processes is achieved through a kT-measure
  - undesirable jet configurations are rejected through reweighting of the matrix elements with analytical Sudakov form factors and factors due to different scales in alpha_s
- MLM
  - matching parameters chosen, ME and PS jets matched in each n-parton multiplicity, events vetoed which do not have complete set of matched jets
  - further suppression required to prevent double counting of n and n+1 samples (replaces Sudakov reweighting in CKKW)

Multivariate Classification

- Improve signal and background separation w/ a multivariate classifier
  - Found Random Forest (RF) classifier to be the most powerful and robust
- From outside (black box), RF works similar to other classifiers (e.g. NN)
  - Trained by feeding it events of known origin (signal or background)
  - Use trained Random Forest to evaluate new events and determine the likelihood of being signal



- Inside the RF
  - Many different tree classifiers
    - Each tree classifier performs a series of optimized cuts to separate signal from background
  - The RF output averages the output from all the trees
    - Fluctuations and over-training are reduced because each tree will fluctuate differently

An example of limits settings

- Our goal is to understand the theory of the SM Higgs boson
  - The answer is either "The SM Higgs is there" or "It's not there"
- We test our data for compatibility with one of two hypotheses:
  - SM+Higgs = signal-like or SM-Only = b-only
- DØ uses a frequentest approach to setting limits:
  - If this experiment is repeated many times, how often would we obtain a result which is as signal-like as what we have observed?
- A 95% CL observed exclusion means:
  - If the excluded signal exists in nature, then only 5% of the time would we obtain a result as background-like as observed in this case.

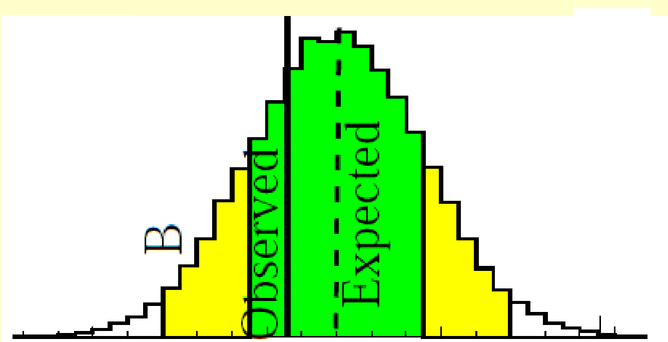
An example of limits settings

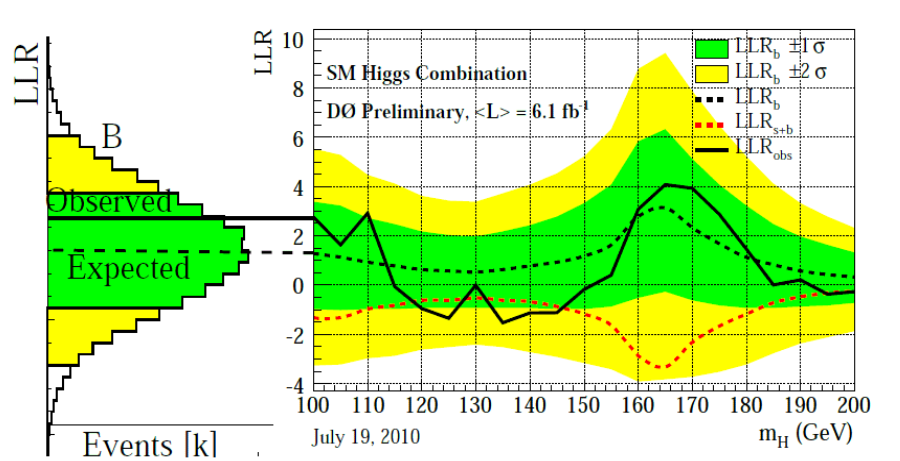
- Compare Poisson likelihood of B hypothesis to S+B hypothesis, and calculate their negative log likelihood ratio (LLR):

$L(B)$	$L(S+B)$	LLR
$\prod_i \frac{b_i^{d_i}\exp(b_i)}{d_i!}$	$\prod_i \frac{(s_i+b_i)^{d_i}\exp(s_i+b_i)}{d_i!}$	$2\cdot\sum_i s_i - d_i\cdot\log(1+s_i/b_i)$

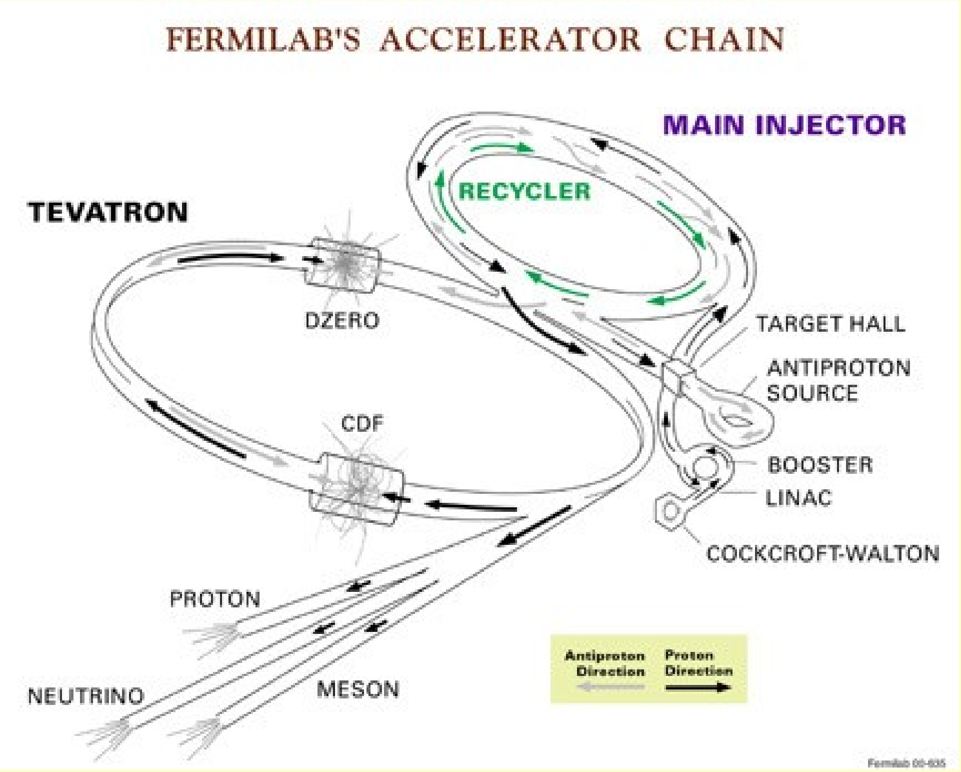
where d_i events observed in bin i with S and B expectations s_i and b_i.

- Sum over all bins gives observed LLR
- Repeat calculation but with pseudo-data obtained by a Poisson fluctuation of b_i in each bin (B) or s_i+b_i in each bin (S+B)
- Repeat many times to obtain LLR distribution: median is Expected LLR





Tevatron accelerator



- The Cockcroft Walton accelerates negative hydrogen ions to 740 KeV. The negative ions are then accelerated down the LINAC to 400 MeV. The particles enter the booster where the electrons are stripped off, leaving the protons. In the Booster, the protons are then accelerated to 8 GeV. Once the protons enter the Main Injector, they are accelerated to 150 GeV. From here, the protons are injected into the Tevatron. The Tevatron accelerates protons and antiprotons to nearly 1 TeV.
- Fermilab makes antiprotons by smashing protons against a nickel target. The Antiproton Source in Fermilab's accelerator complex makes about 20 antiprotons for every 100 million protons they smash on the target. Fermilab then collects the antiprotons in the accumulator, one of the complex's 10 accelerators. The antiprotons are transferred over to the Recycler ring and then cooled. Cooling the antiprotons makes them easier to manipulate and accelerate and increase the rate of collisions.