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Search for the Standard Model Higgs Boson at Low Mass at the Tevatron

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on behalf of the

CDF and DØ

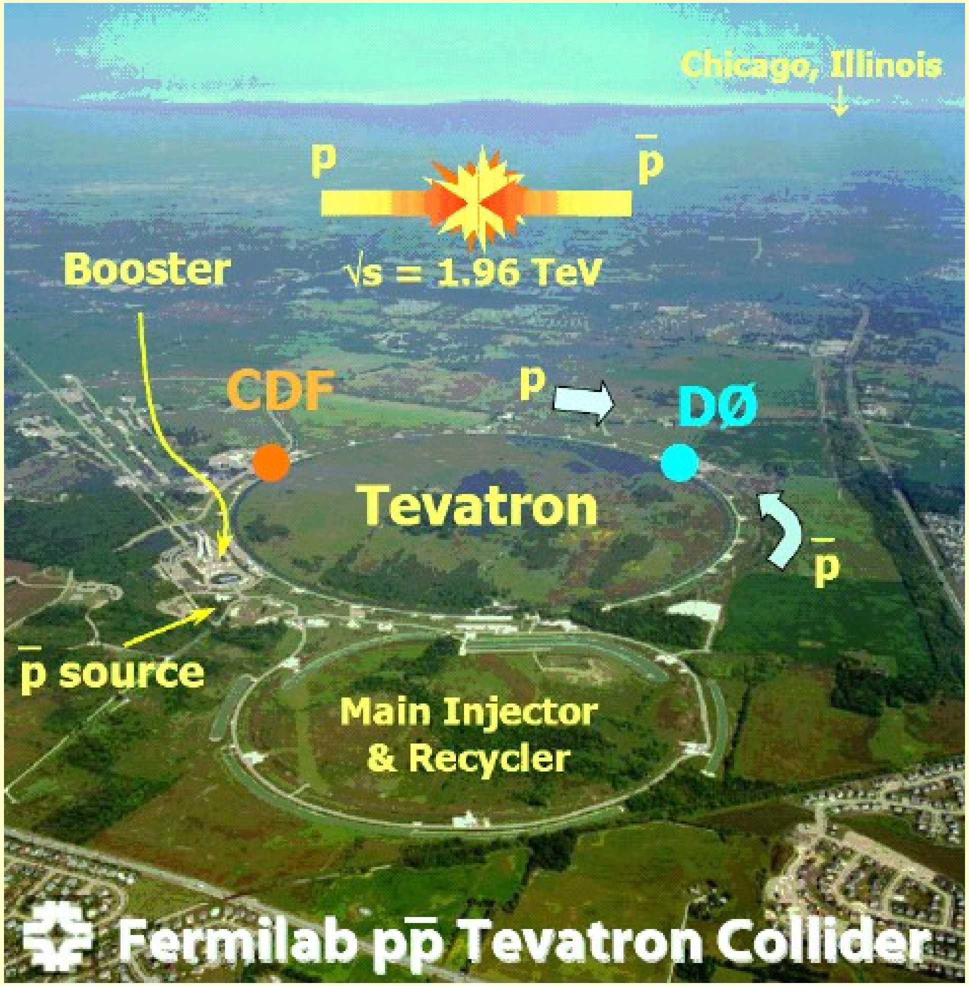
collaborations

Aspen Winter 2009
Workshop on Physics at the LHC era

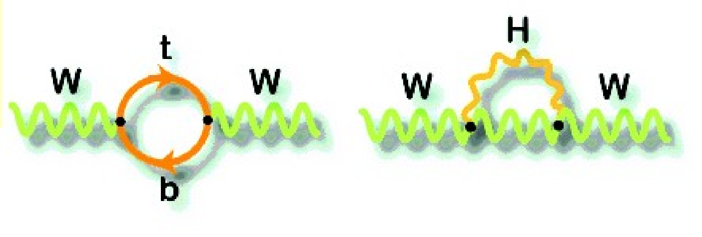
Outline

- Motivation
- Analyses overview
  - CDF
  - DØ

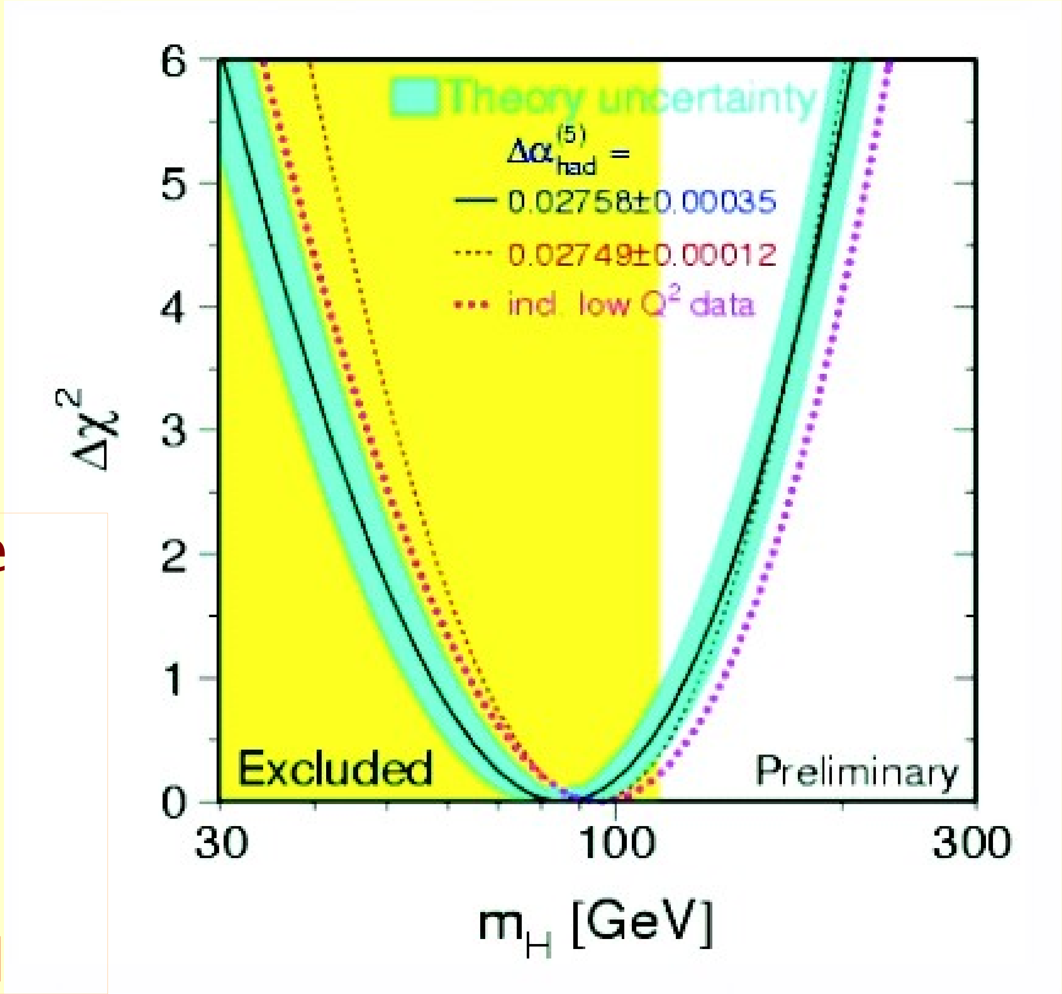
  } up to 2.7 fb^{-1}
- Combined limits
- Future perspectives



Bounds on Higgs mass

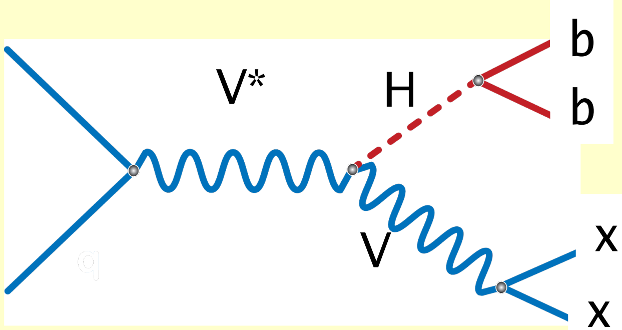


- Lower limits obtained from direct searches at LEP
  $m_H > 114.4$ GeV@95% CL
- And exclusion from Tevatron,
  $m_H \neq 170$ GeV@95% CL



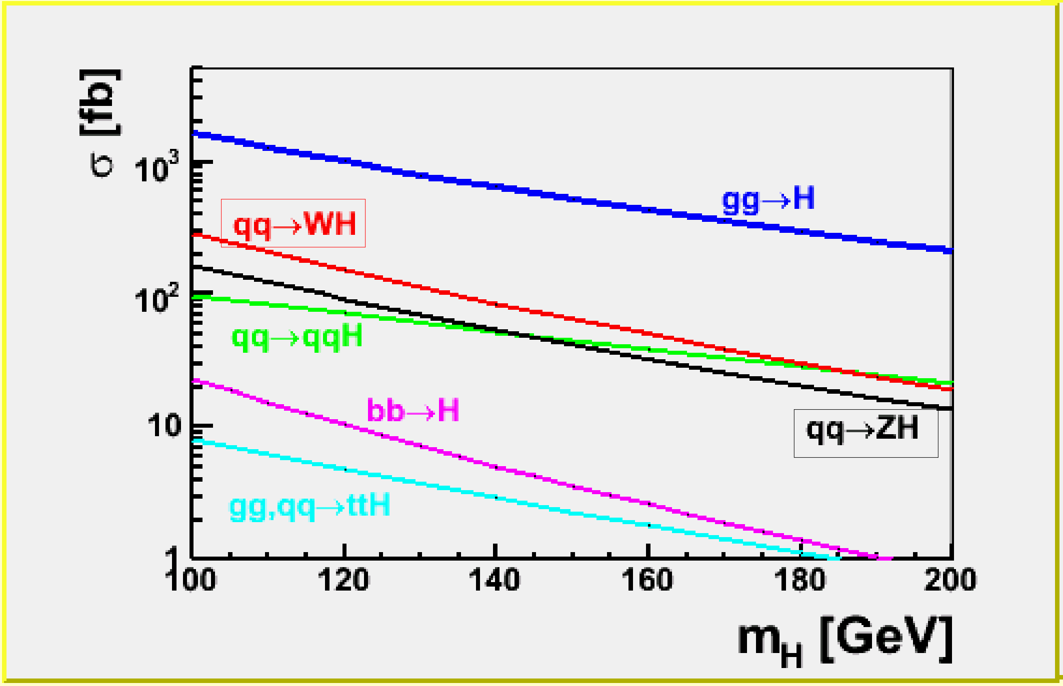
- Global SM electroweak fits provide upper limit
- The best fit gives $m_H = 84^{+34}_{-26}\, GeV$
- Limit from fit $m_H < 154$ GeV
- Lower Higgs masses are preferred

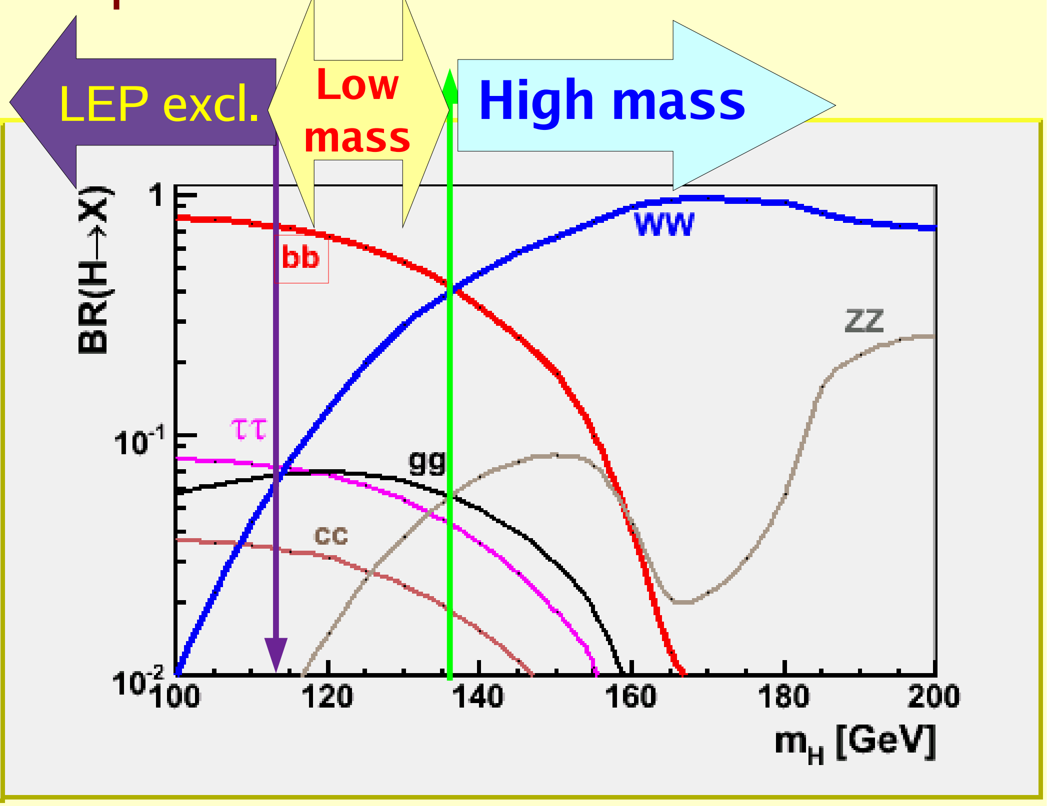
Production and Decay



- Main production process is gluon fusion
- Associated with vector boson, and vector boson fusion are significant
- use all contributions in analyses

- At lower masses dominant decay is to bb
- To suppress multijet backgrounds, we have to look into associated production





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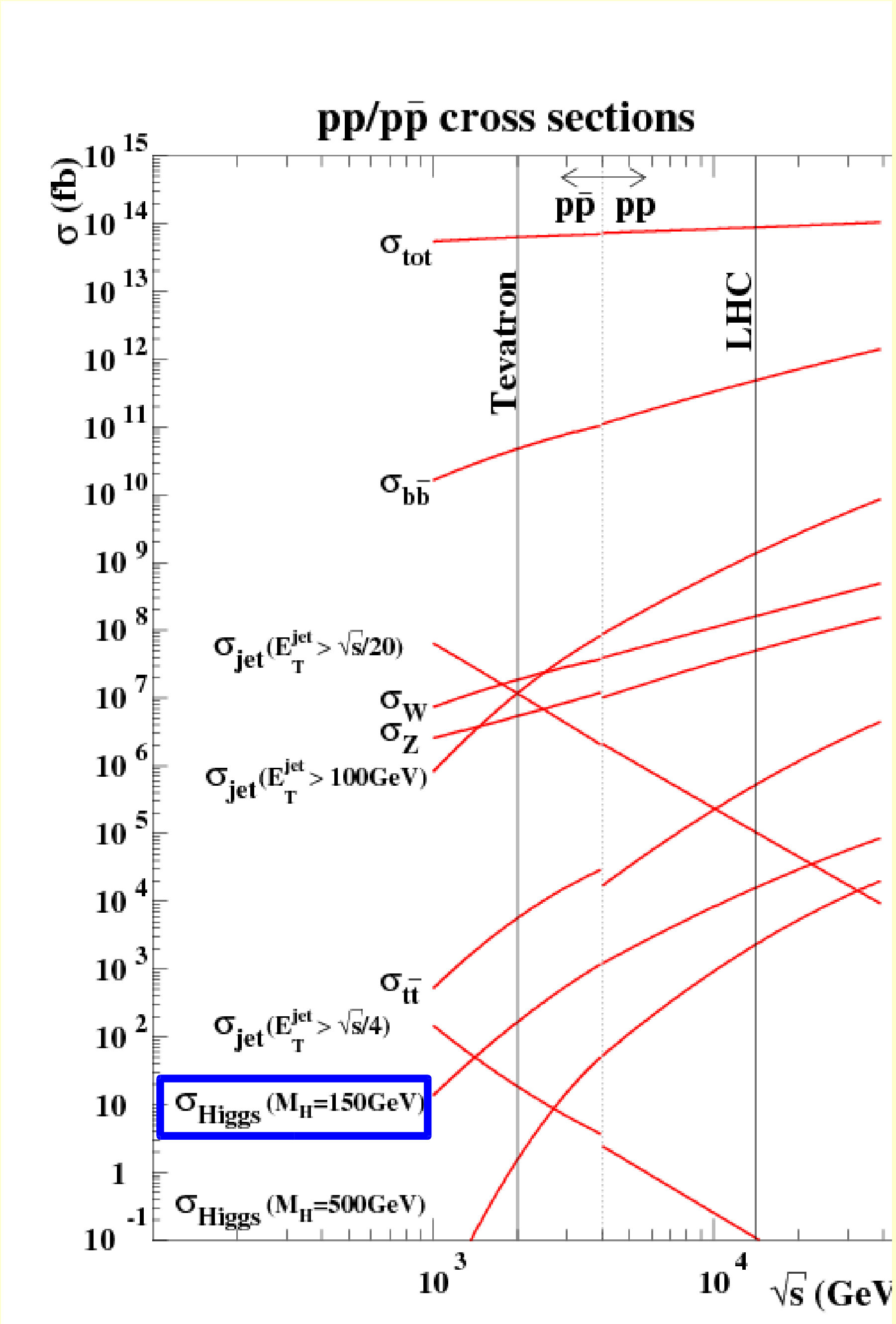
How do we search?



- We have to be able to measure known processes
  - Good background modeling
  - Good estimation of multijet production
  - Extensive application of advanced analysis techniques to find phase space regions with good signal and background separation
- Then we need to extract tiny signal from huge background
  - Measurement of low cross-section SM processes, like single top and VV, can help

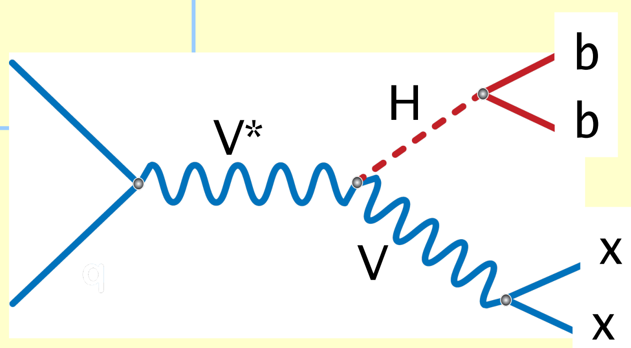
Overview of the Higgs search at Tevatron

- Low mass:
  - WH->lνbb (l=e,μ,τ)
  - ZH->llbb (l=e,μ,τ)
  - ZH->ννbb and WH->(l)νbb (the lepton is lost)
  - H->γγ
  - ttH->ttbb
  - VH->jjbb

We optimize lepton ID to improve sensitivity

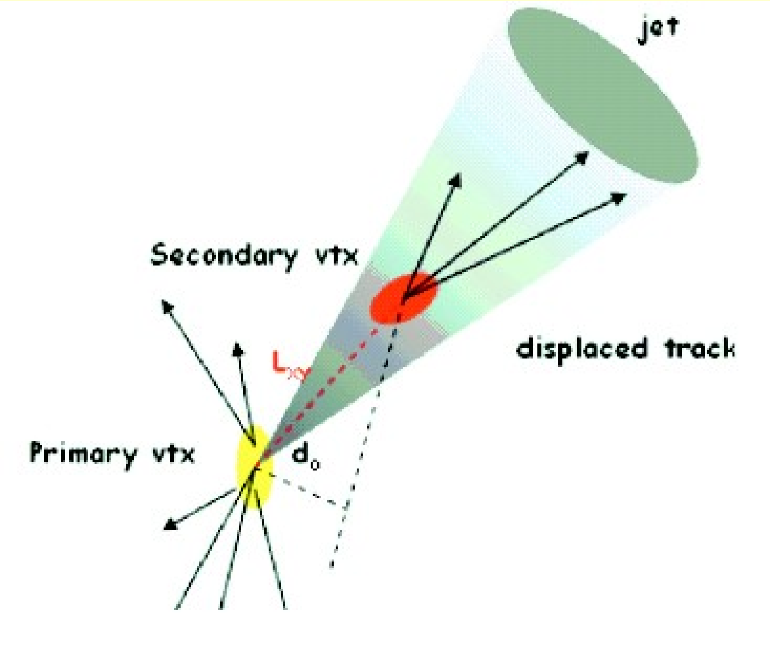
We select 1 or 2 b-jets to further suppress background

- Common challenges:
  - Lepton and jet id
  - MET reconstruction
  - b-tagging
  - multijet estimation
  - systematics
- Recent improvements:
  - Better trigger and b-tagging algorithms
  - Better lepton ID
  - Improved dijet mass resolution
  - precise measurements of some known SM processes



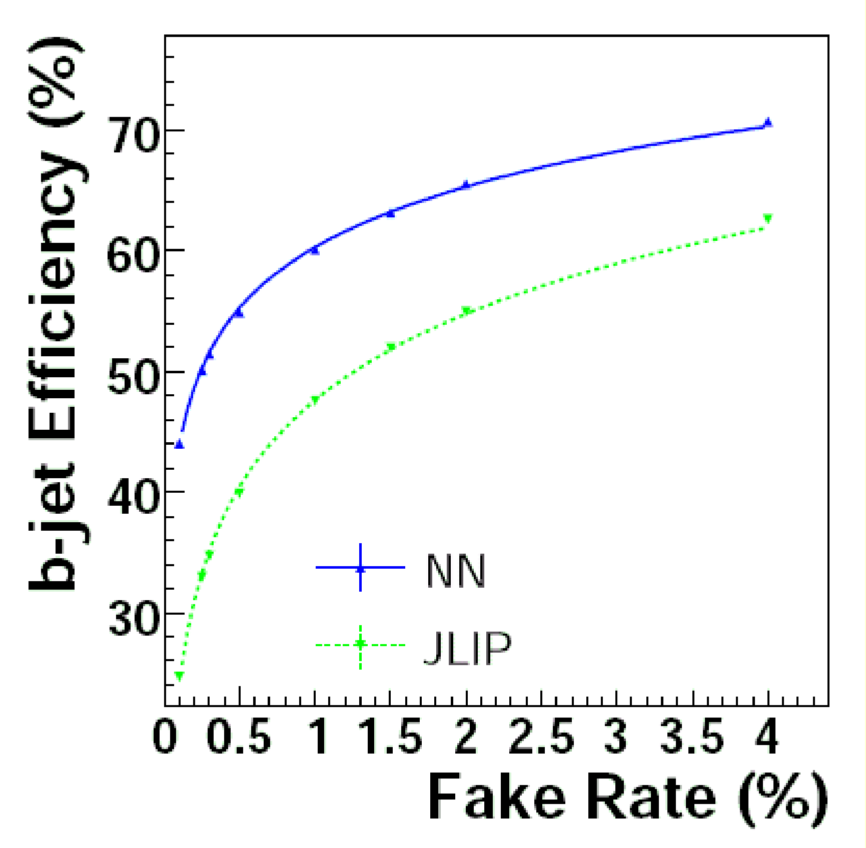
Tools – b tagging

- b-tagging is crucial for low mass Higgs searches
- Bottom quarks will hadronize, make bound states, b hadrons, immediately after they are produced
- Several b hadron properties can be exploited to tag the b-jets:
  - long B lifetime (1.57±0.01 ps)
    - Can travel few millimeters in detector
    - Displaced vertex from the hard-scatter interaction region on the order of ~ 3 mm
  - high mass (~5.2 GeV/c^2)
  - high charged decay multiplicity (4.97 ± 0.06) - more tracks
  - (Soft leptons are produced)

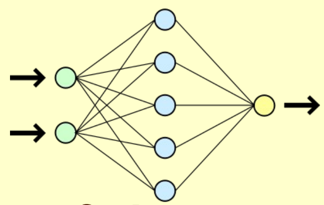
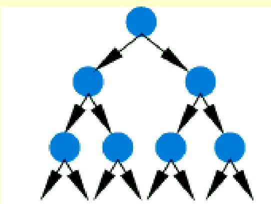


Tools – b tagging

- We develop b-taggers based on lifetime, or on their combination,
- D0:
  - Counting Signed Impact Parameter
  - Jet Lifetime Impact Parameter
  - Secondary Vertex Tagger
  - Neural network tagger – uses inputs from other taggers
- CDF:
  - SecVtx: secondary vertex finder.
  - JetProb: jet probability from track signed impact parameter.
  - Neural network tagger to better separate different flavors

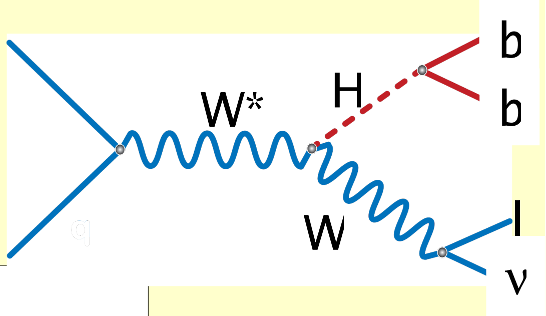


Multivariate techniques

- Once we understand data, we want to try to extract signal
- Multivariate techniques are more powerful than simple cut method
- One output, usually between 0 (background like) and 1 (signal like events)
- Neural networks 
  - trained on a set of discriminating variables for signal and background
- Decision trees 
  - simple "yes/no" answers for different cuts
- Matrix elements $\int \mathcal{M}$
  - uses LO matrix elements to calculate event probabilities

WH->lνbb, l=e,μ

$\int \mathcal{L}dt = 2.7\text{fb}^{-1}$

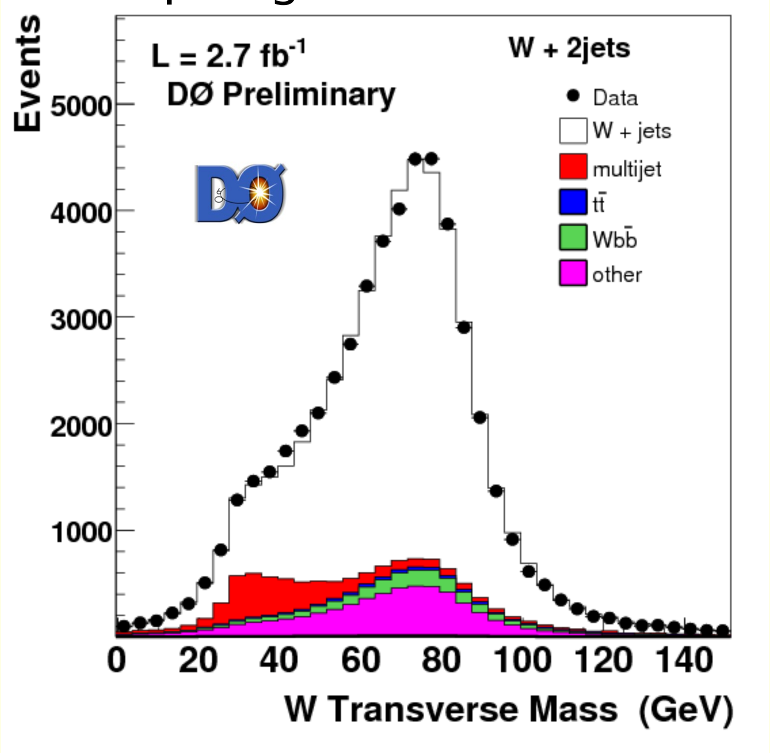


- Selection

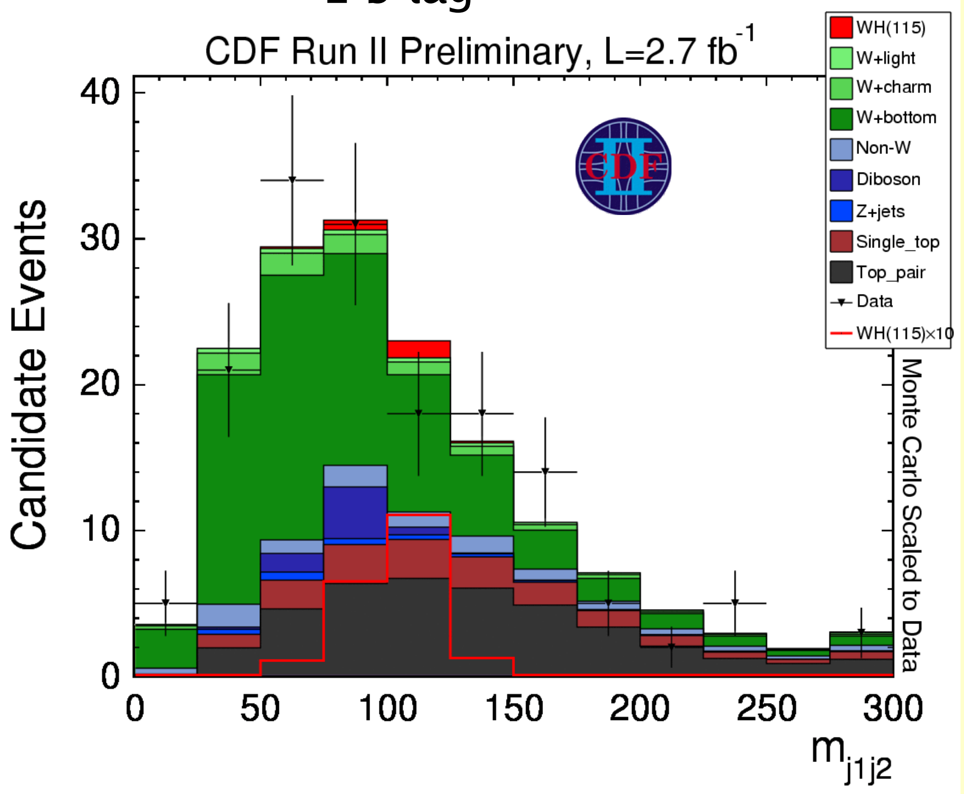
1 lepton	$p_T(l)>15,20$	MET > 20	
At least 2 jets	pT(j1)>25,20	pT(j)>20	One or 2 b-tagged jets

- Major issues: understanding multijet and W+jets productions
- D0: new result for this conference

pretag



2 b-tag



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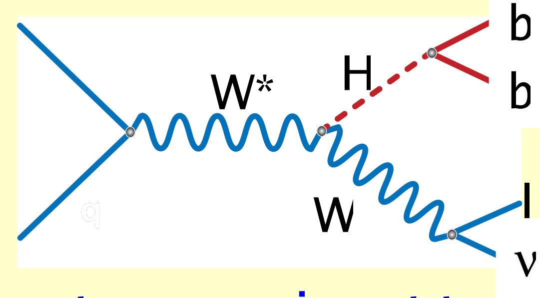
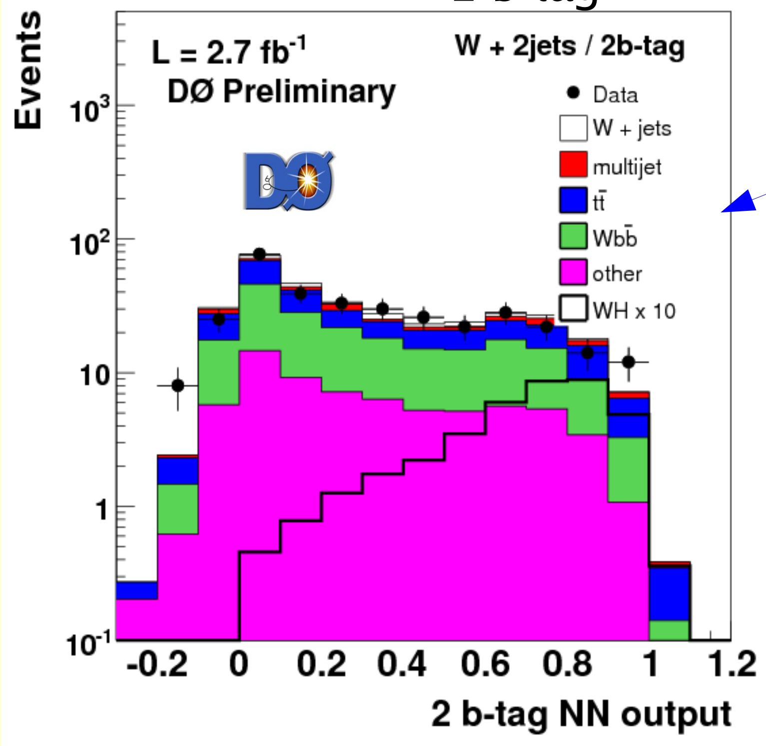
WH->lνbb, l=e,μ

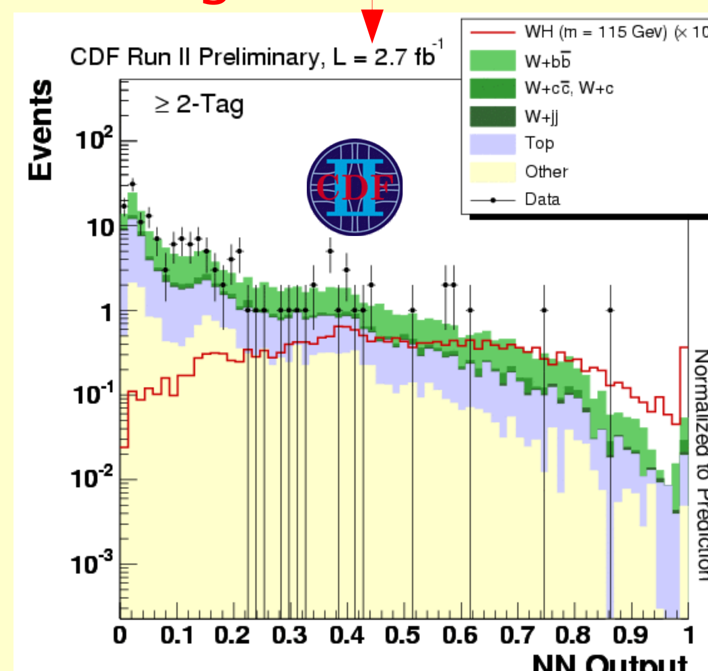
$\int \mathcal{L}dt = 2.7\text{fb}^{-1}$



2 b-tag



- D0: Uses Matrix Elements as an input to Neural Networks which is final discriminant
- CDF: Two separate analyses: Boosted Decision Tree with Matrix Elements as an input, and Neural networks. Results are combined using NN

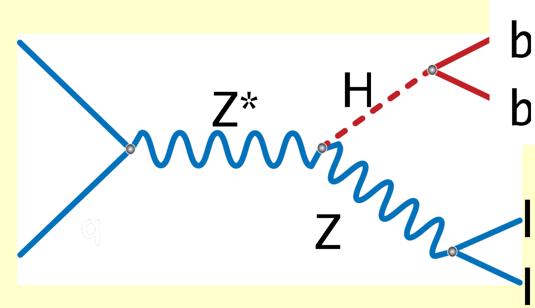


2 b-tag

- Systematics are similar, dominated by b-tagging
- Total ~15-30%

MH = 115	Exp.	Obs
CDF (2.7 fb^{-1})	4.8	5.6
D0 (2.7 fb^{-1})	6.4	6.7

ZH->llbb

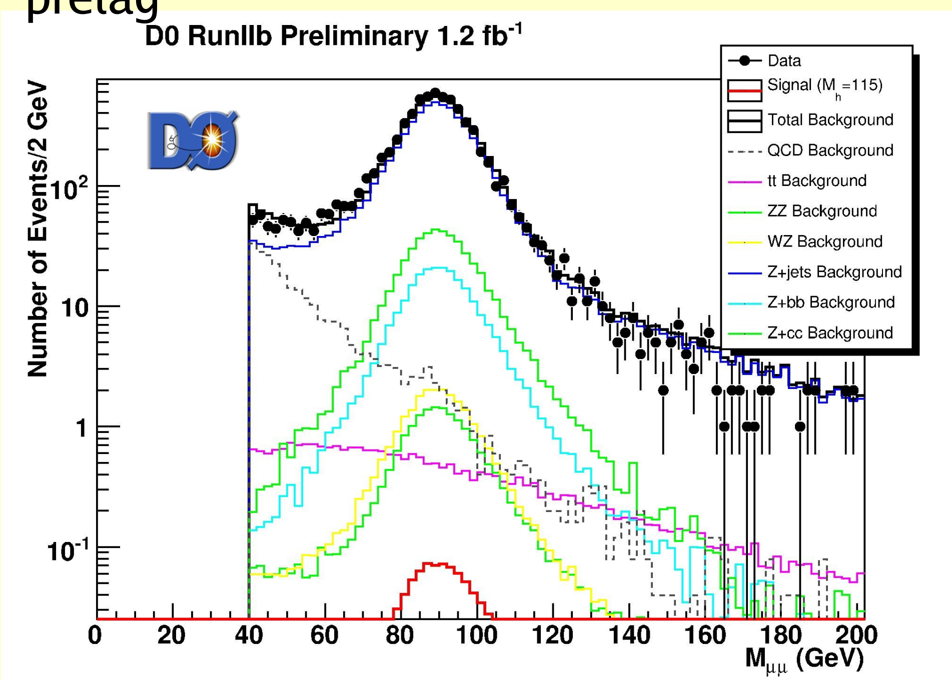


- Crucial: understanding of Z+jets processes
- Selection

	CDF		D0
2 leptons	pT(l1)>18	pT(l2) > 10	pT(e,m) > 15,10
At least 2 jets	pT(j1)>25	pT(j2)>15	pT(j)>15
One or 2 b-tagged jets	M_{ll} in Z mass window		

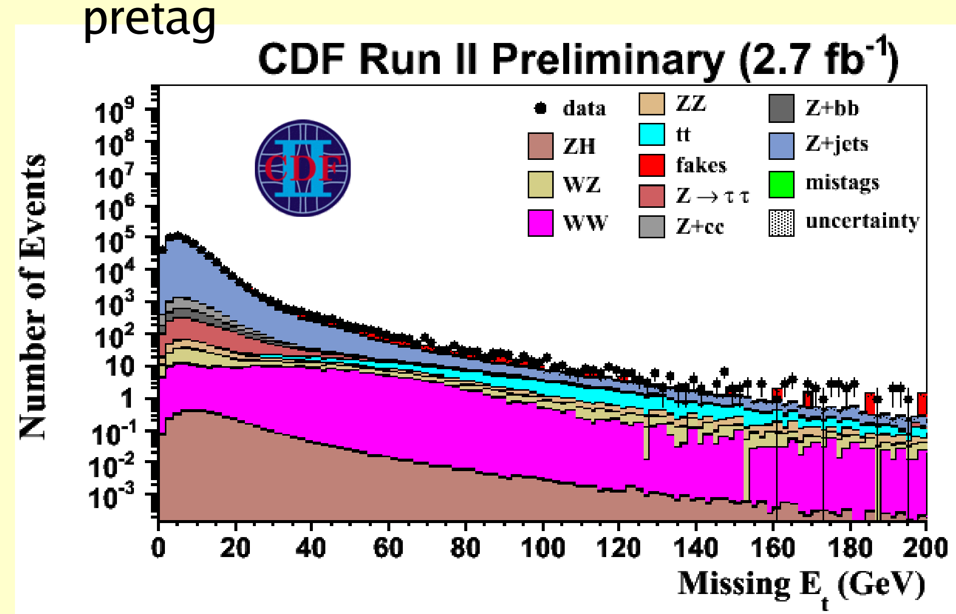
- To gain maximum sensitivity several lepton ID criteria are used

pretag



$\int \mathcal{L}dt = 2.3, 2.7\text{fb}^{-1}$

pretag



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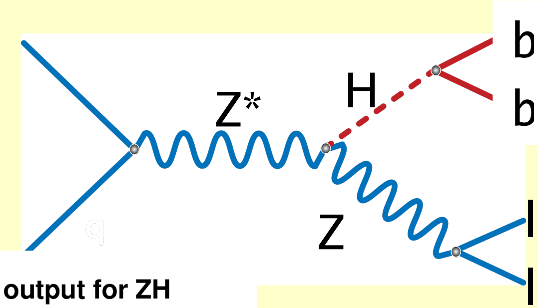
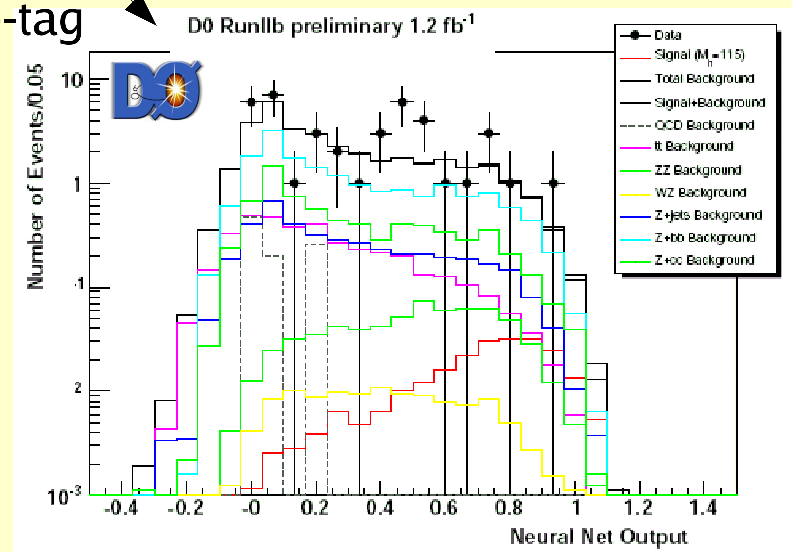
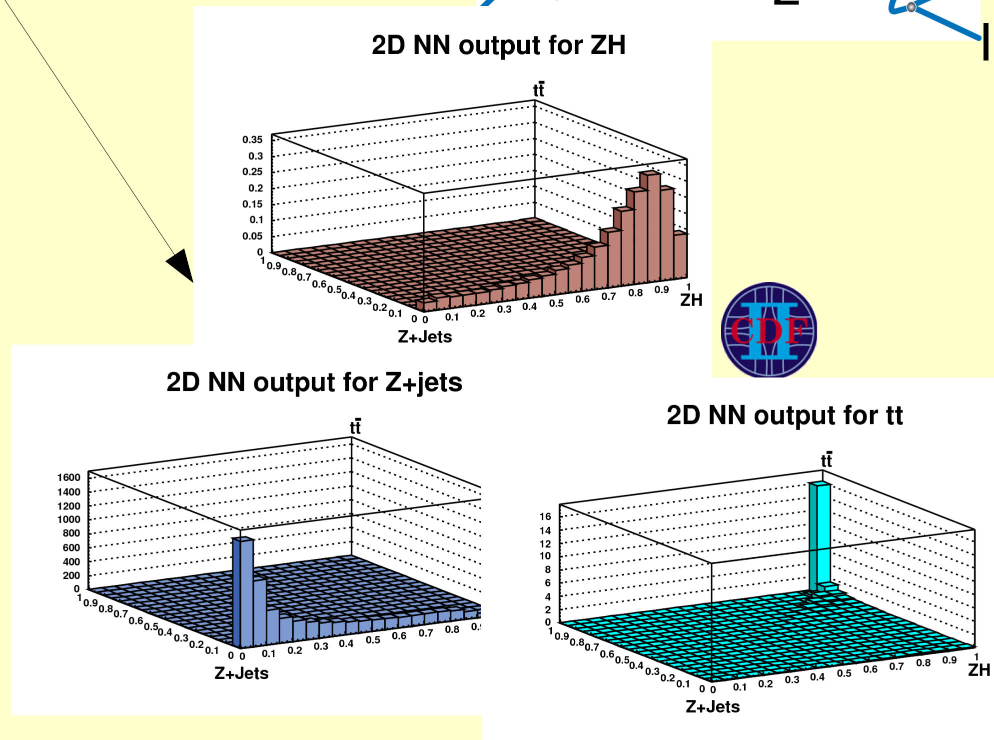
ZH->llbb



- CDF uses 2 dimensional NN as final discriminant
- D0 uses NN as final discriminant

2 b-tag

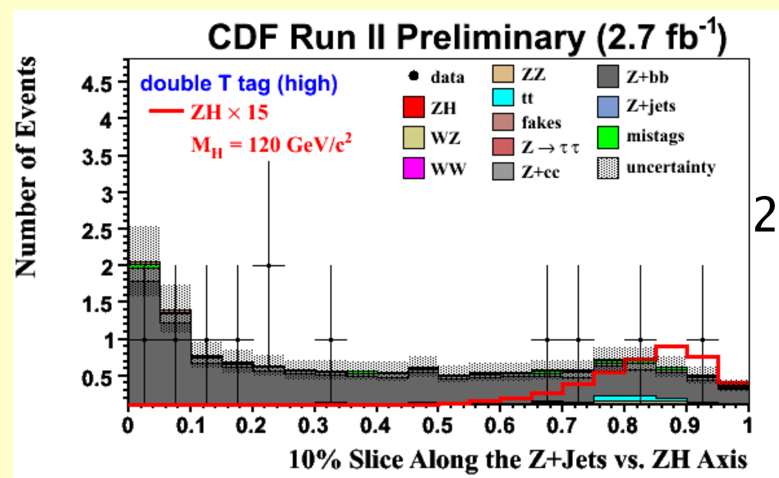




- Systematics dominated by b-tagging

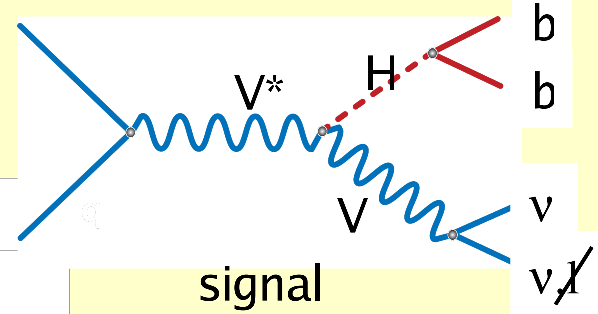
$\int \mathcal{L}dt = 2.3,\ 2.7\mathrm{fb}^{-1}$

MH = 115	Exp.	Obs
CDF (2.7 fb-1)	9.9	7.1
D0 (2.3 fb-1)	12.3	11

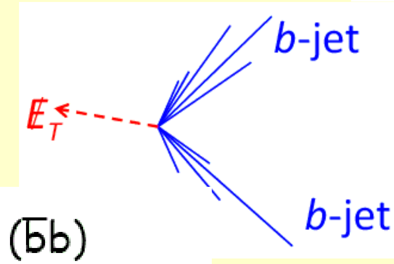


2 b-tag

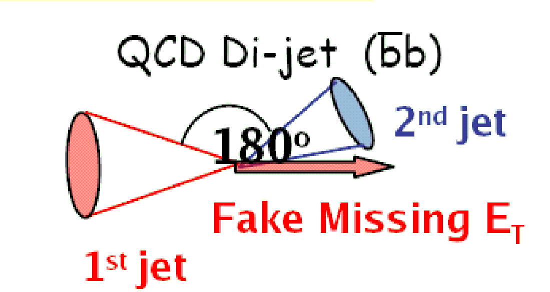
VH->$\not{E}_T$bb



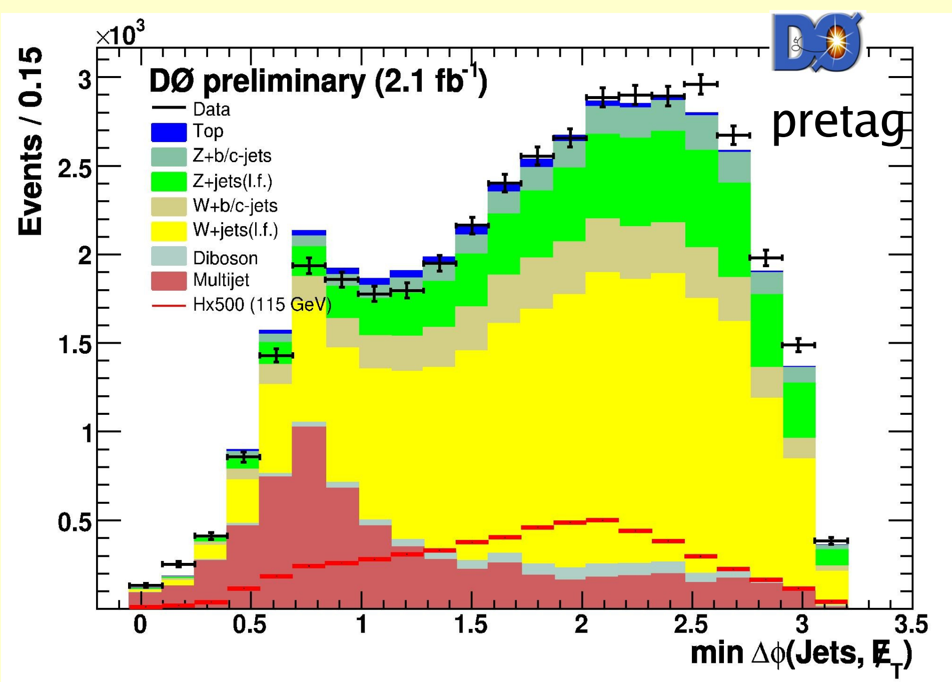
Selection:	CDF		D0
	MET > 50		MET > 40
At least 2 jets	pT(j1)>35	pT(j2)>25	pT(j)>20 Δφ(j,j) < 165°
One or 2 b-tagged jets			

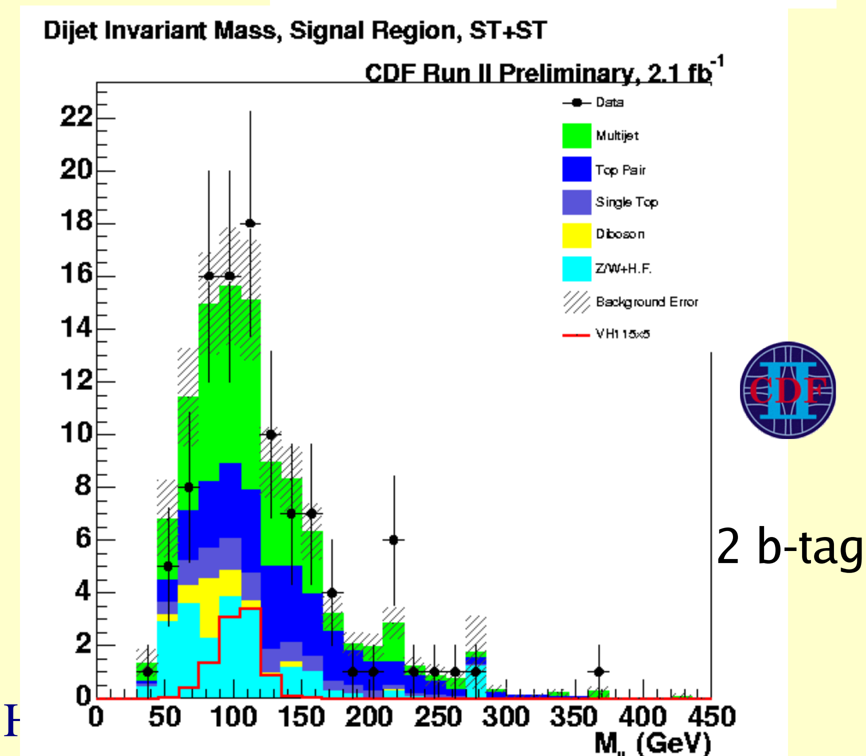


- Crucial issues trigger modeling and multijet estimation

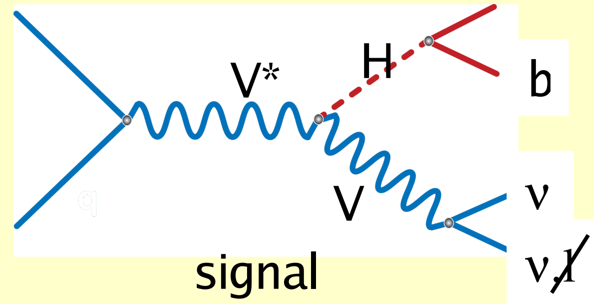


- CDF: Bulk of multijet is removed using dedicated NN $\int \mathcal{L}dt = 2.1\text{fb}^{-1}$



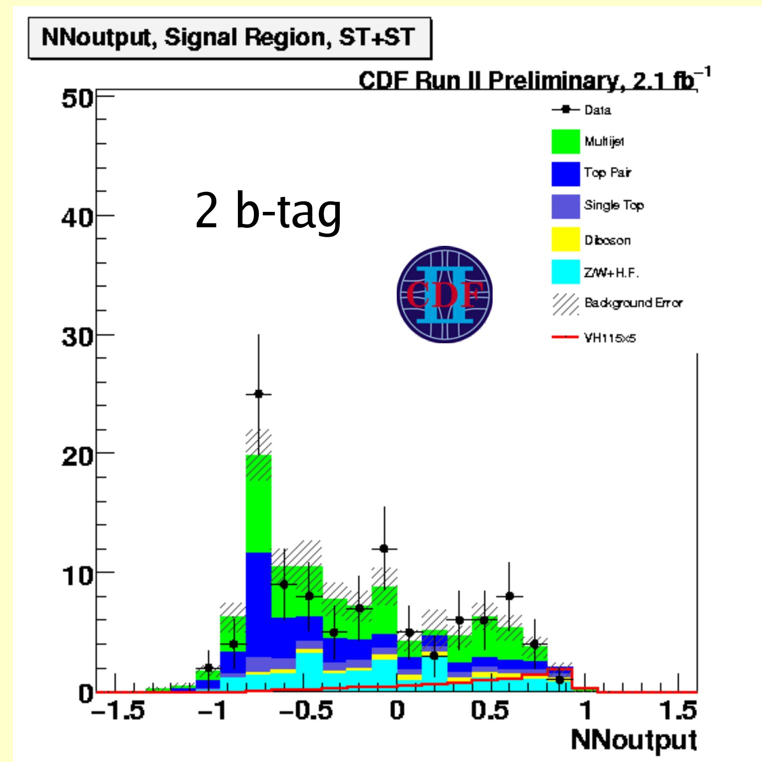


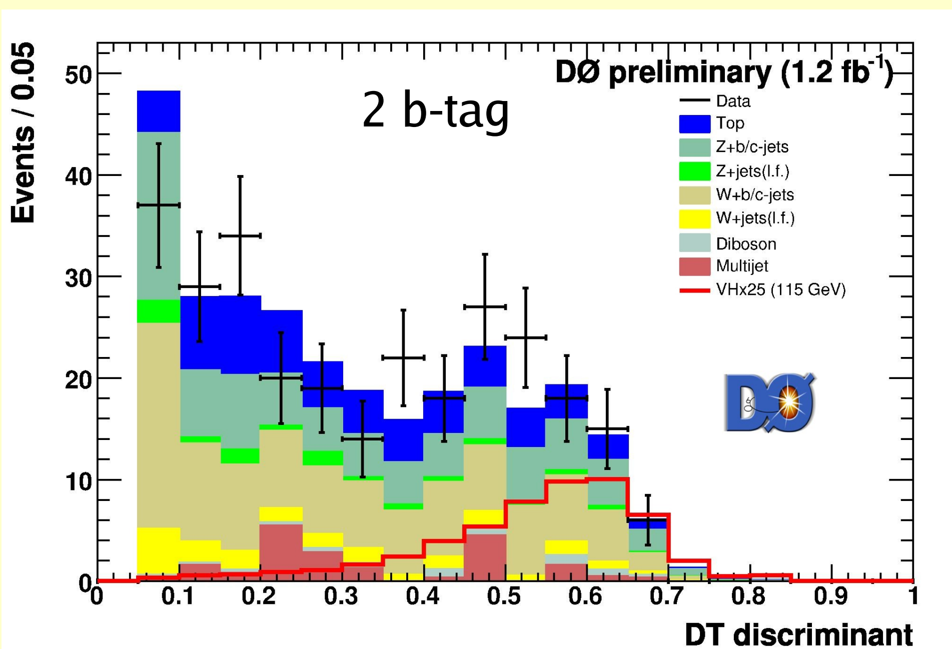
VH->$\not{E}_T$bb



- CDF: Final discrimination is done using NN
- D0: BDT is final discriminant
- Systematics dominated by multijet estimation, b-tagging...

$\int \mathcal{L}dt = 2.1\text{fb}^{-1}$



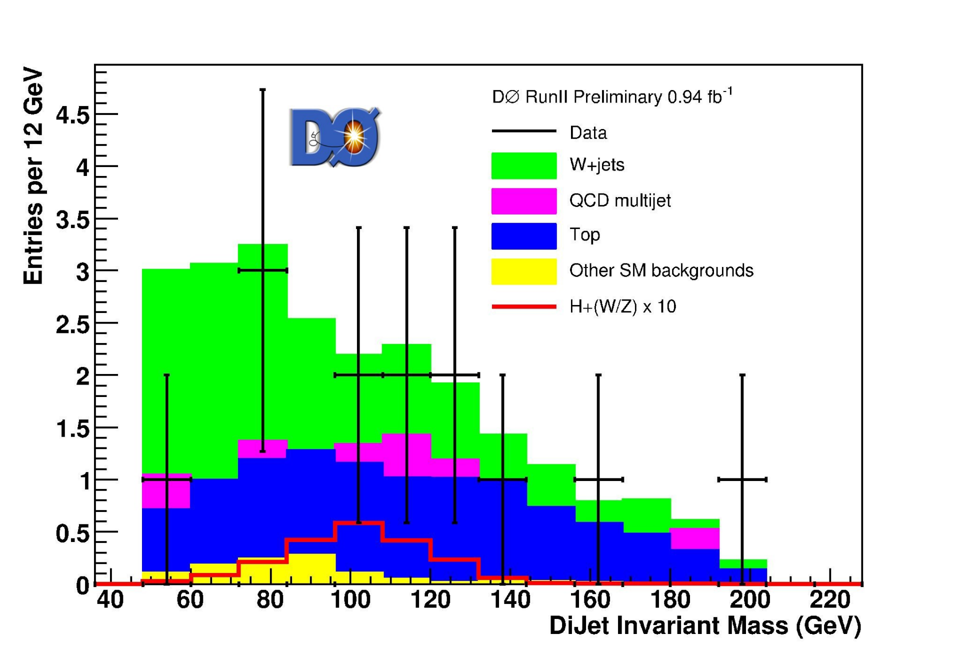


MH = 115	Exp.	Obs
CDF (2.1 fb^{-1})	5.6	6.9
D0 (2.1 fb^{-1})	8.4	7.5

(V)H->τ_{jet}+X

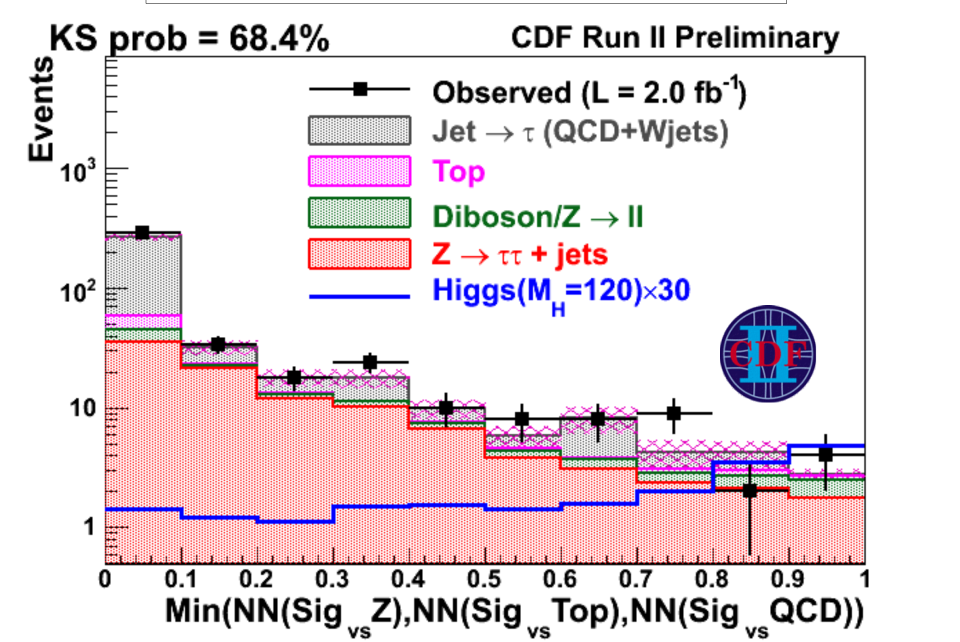
- D0: Search for WH->τνbb
- Complements WH->lνbb studies
- NN as final classifier

MH = 115	Exp.	Obs
D0 (0.94 fb^{-1})	42.1	35.4



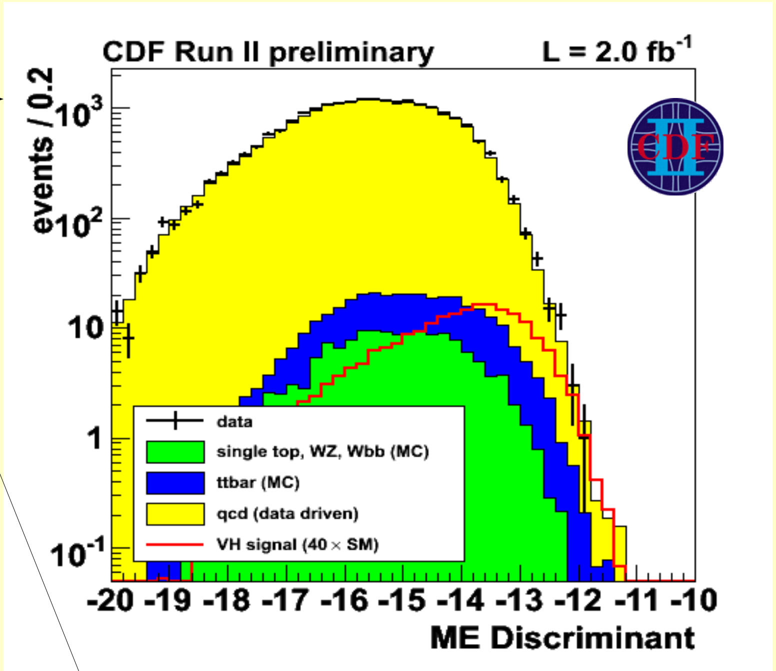
- CDF: Searches for all possible τ_{jet}+lepton(from τ decay)+2jets final states
- 3 separate NN against major backgrounds, minimum value is used as final discriminant

MH = 115	Exp.	Obs
CDF (2 fb^{-1})	30	24

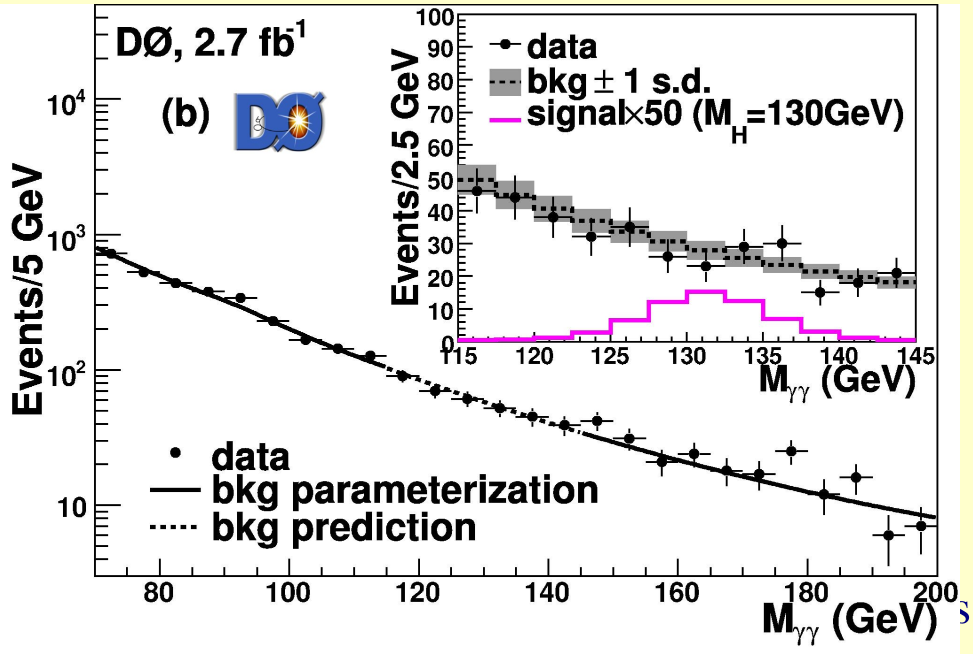


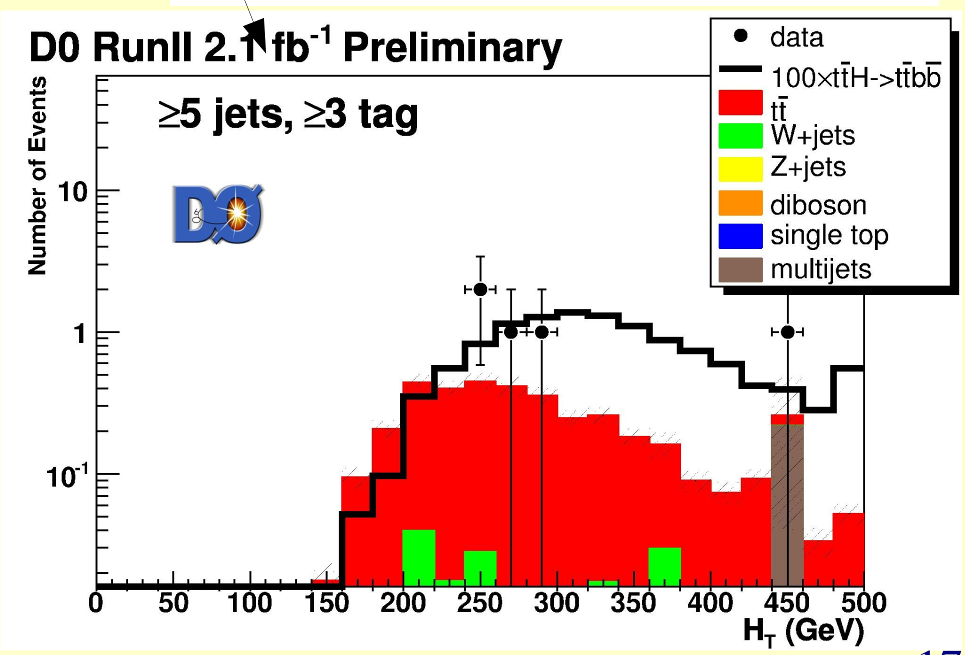
Benchmarks for LHC: H->γγ, ttH->ttbb and VH->jjbb

- VH->jjbb: ME based search, huge multijet background
- ttH->ttbb: at least 5 jets, at least 3 b-tags
- H->γγ: NN photon id, look for excess in di-photon mass spectrum



M^H = 115 GeV	Exp.	Obs
VH->jjbb (2 fb^{-1})	36.8	37.5
H->γγ (2.7 fb^{-1})	21.7	26
tth (2.1 fb^{-1})	45.3	63.9





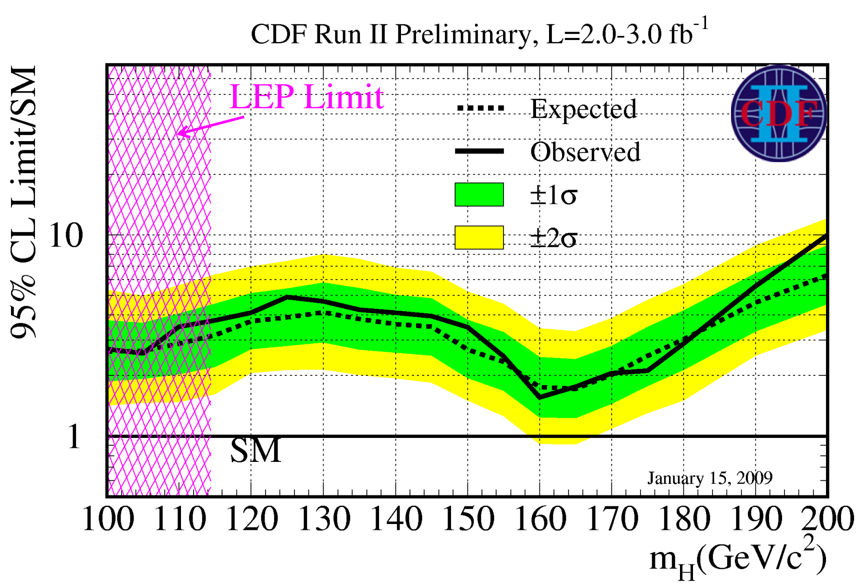
Limits – CDF and DØ

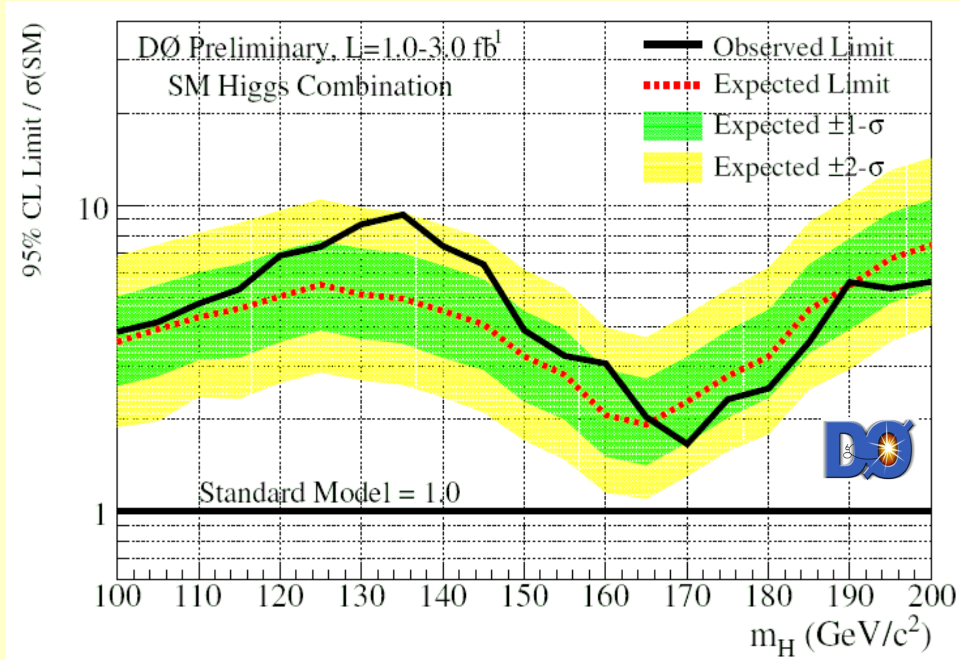
- Not all shown channels are used in combination, for instance D0 WH is for 1.7fb^{-1}, and l=e,μ

CDF		DØ	
Channel	Lumi	Channel	Lumi
WH->l ν bb	2.7	WH->l ν bb	1.7
VH->MET+bb	2.1	VH->MET+bb	2.1
ZH->ll bb	2.7	ZH->ll bb	2.3
H ->2jet+2 τ	2.0	H ->γγ	2.7

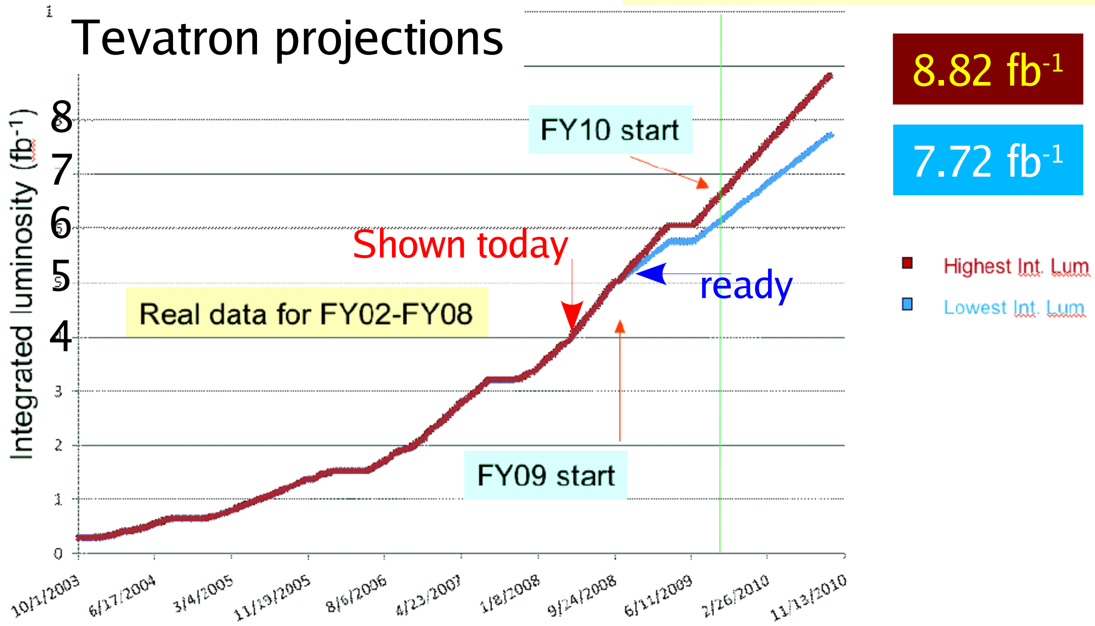
- Limits are ratios of excluded cross sections and SM cross sections

@95%CL	m_H [GeV]	CDF	DØ
expected	115	3.17	4.6
	130	4.12	5.1
observed	115	3.76	5.3
	130	4.67	8.7



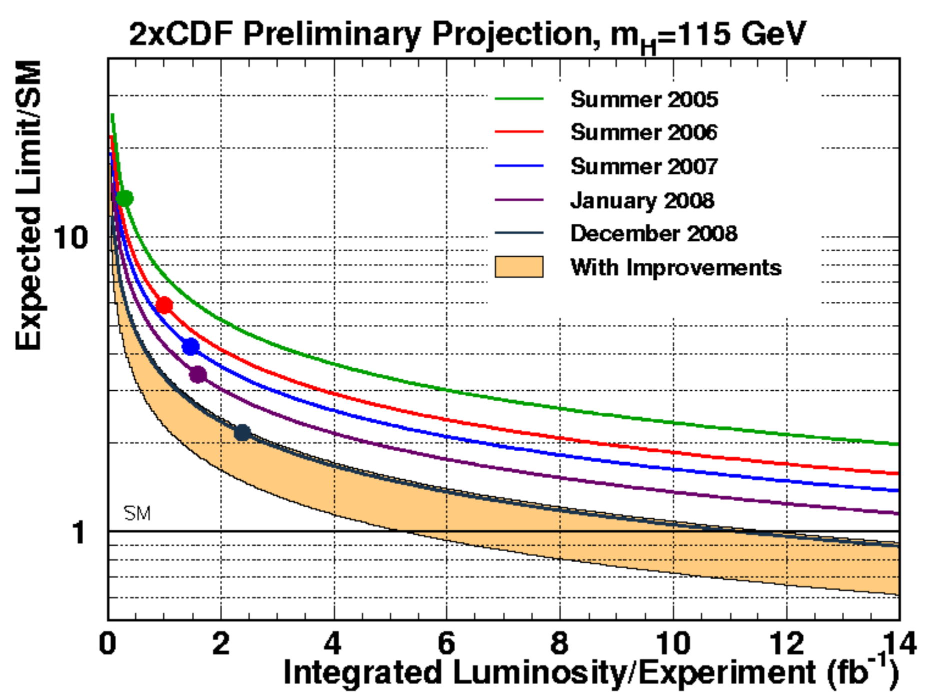


Future perspectives



- Data set has doubled every year
- Expect ~ 8 fb^{-1} by the end of 2010 from Tevatron
- We could have more than 6.5 fb^{-1} from each experiment

- 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.



Summary and Future Perspectives

- Tevatron is running well and its reliability has improved
- Two mature experiments, performing very well
  - The sensitivity continues to improve at a rate faster than the data accumulation.
- We expect further improvements from
  - more data (luminosity)
  - improvement of lepton identification
  - Improving b-tagging
  - Improving dijet mass resolution
  - optimization of multivariate techniques
  - including new channels
- Look for better limits in the next weeks

Backup

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The Higgs Mechanism

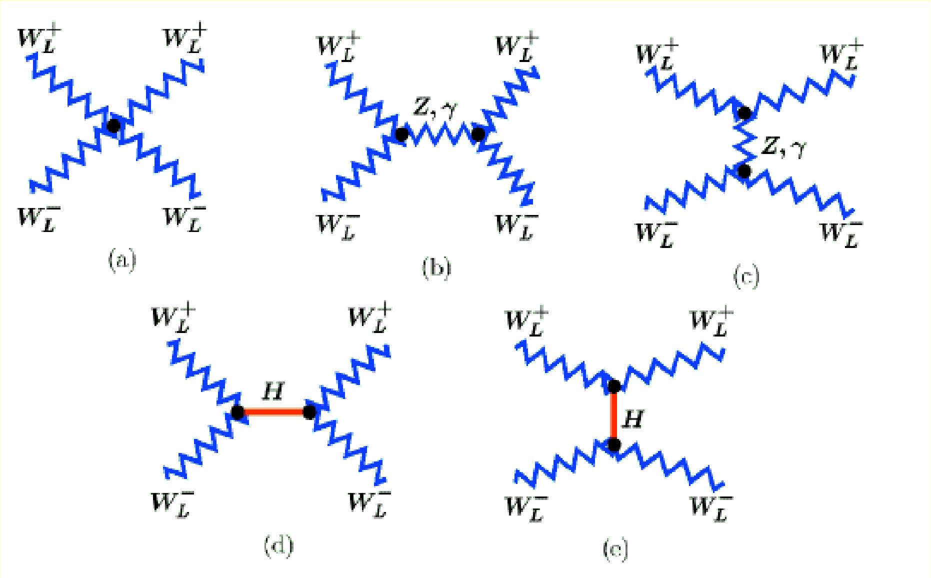
- Essential ingredient of the Standard Model
  - Complex scalar field with potential
- Used to break the electroweak symmetry......

$$M_{W^\pm} = \tfrac{1}{2} vg \qquad M_Z = \tfrac{1}{2} vg / \cos\theta_W = M_W / \cos\theta_W$$

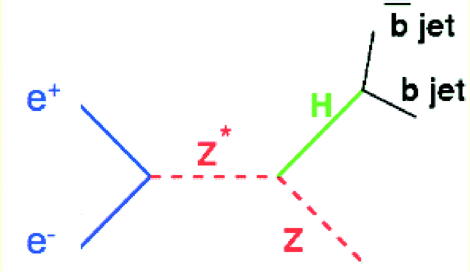
- ..... and to generate fermion masses:

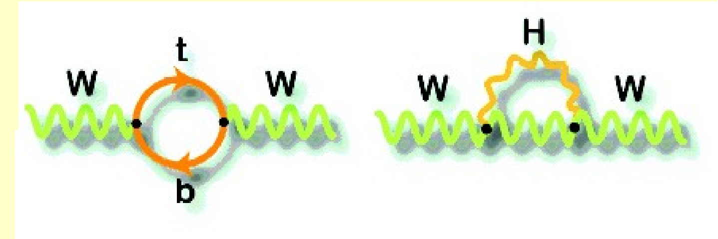
$$\mathbf{m_f = g_f v / \sqrt{2} \qquad \Rightarrow g_f = m_f \sqrt{2} / v}$$

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

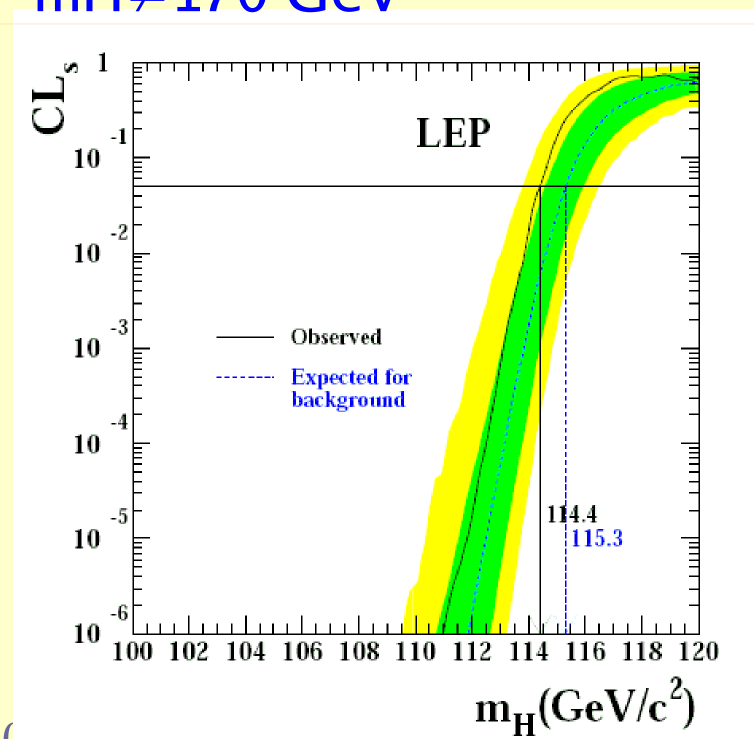


Bounds on Higgs mass

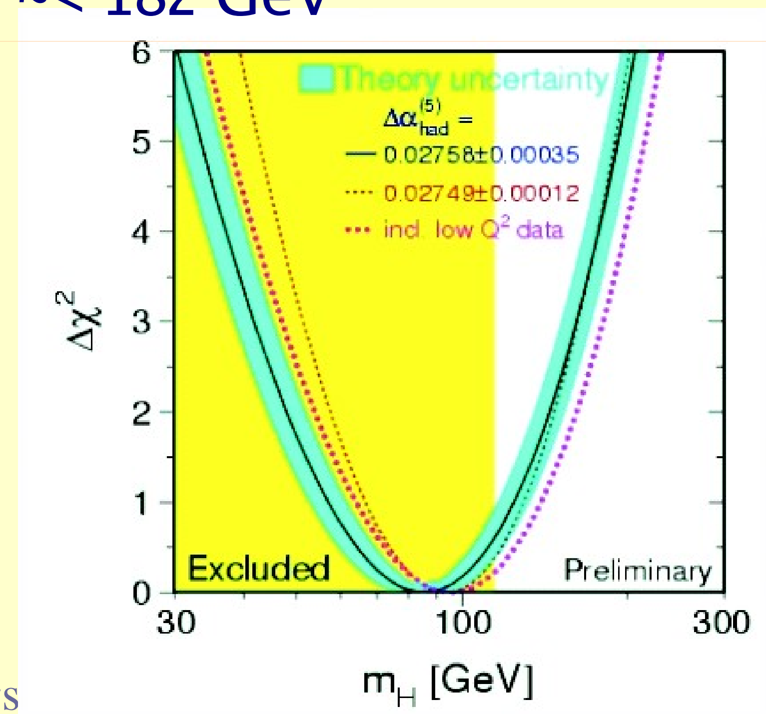




- Lower limits obtained from direct searches at LEP m_H > 114.4 GeV@95% CL
- And exclusion from Tevatron, mH≠170 GeV

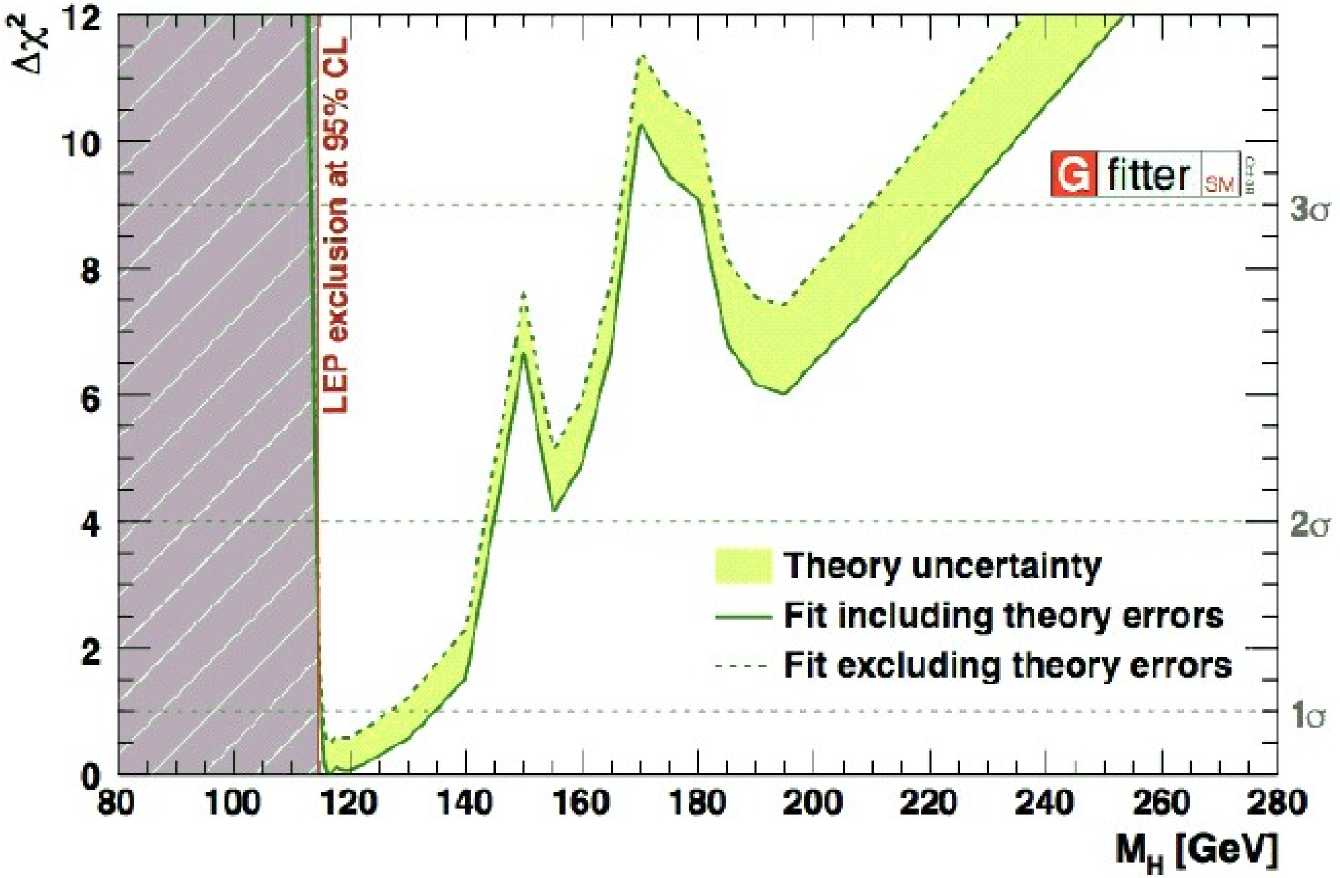


- global SM electroweak fits provide upper limit
- The best fit gives $m_H = 84^{+34}_{-26}$ GeV,
- Limit from fit m_H < 154 GeV
- Combined with direct searches: m_H ~< 182 GeV



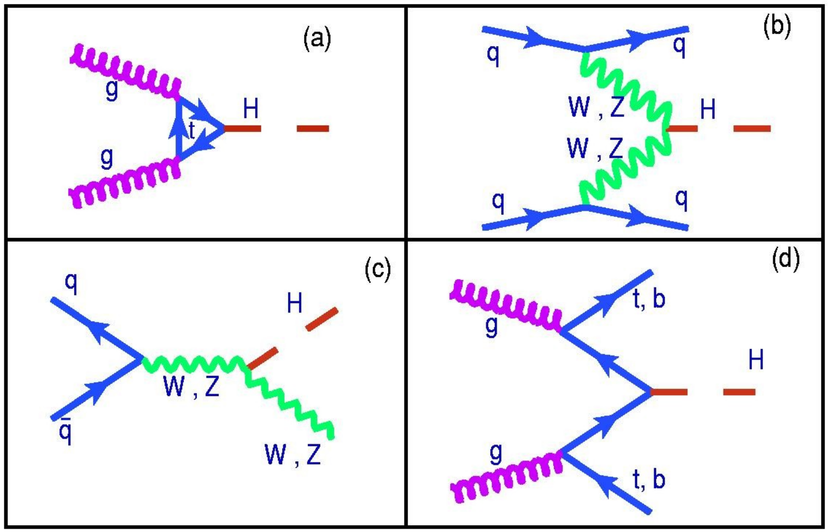
Impact on the global SM Higgs fit

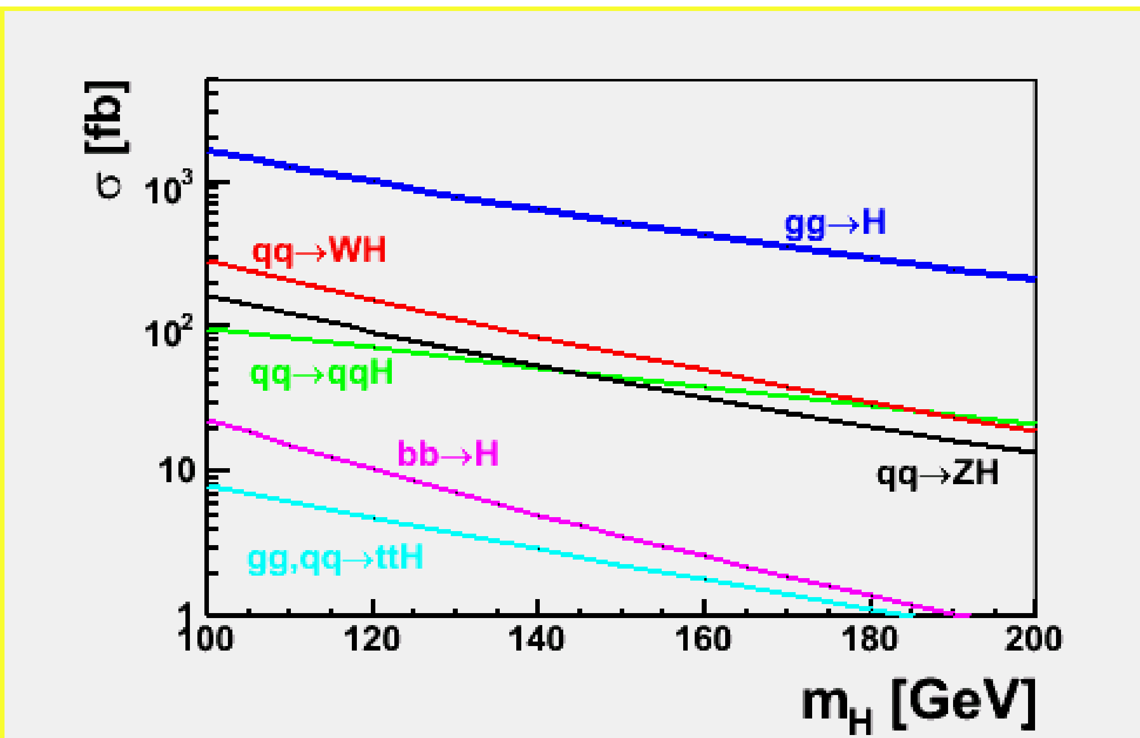
- Gfitter Group, arXiv:0810.3664 [hep-ph]
  - Includes constraints from LEP and Tevatron (Summer '08)



- Central value for the Higgs mass: $M_H = 116.4^{+18.3}_{-1.3}$ GeV

Production ...

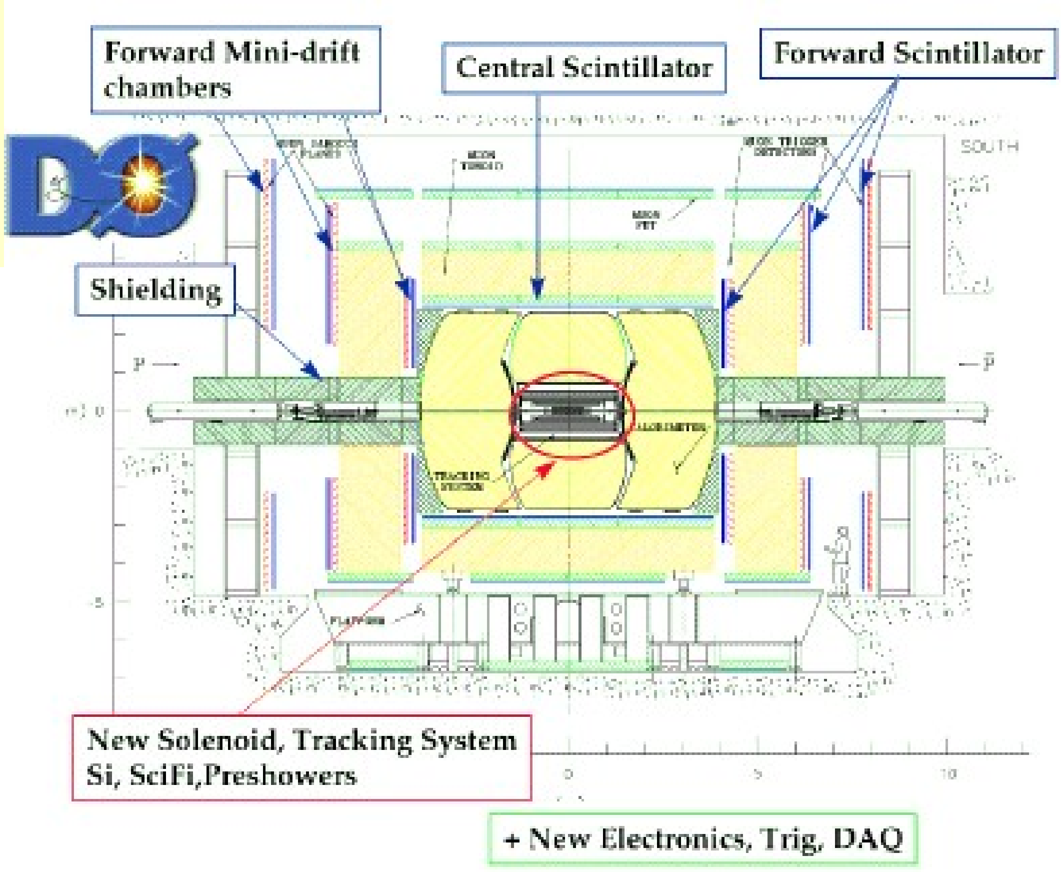


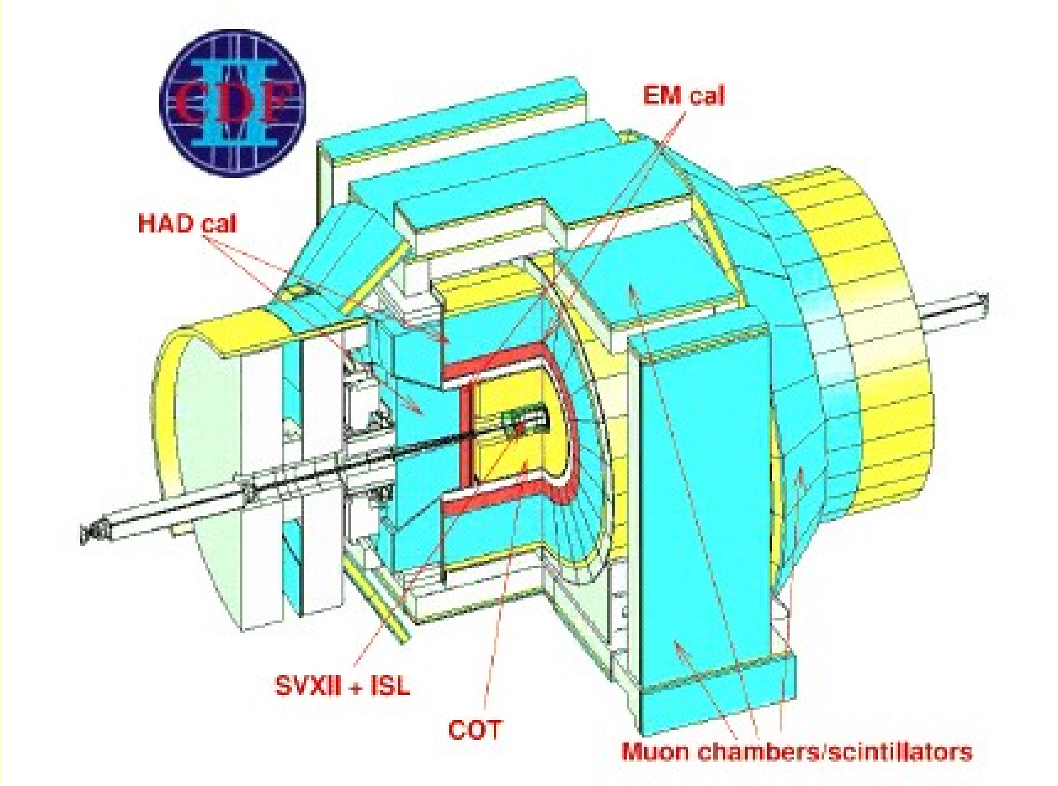


- Main production process is gluon fusion
- Associated with vector boson, and vector boson fusion are significant
- use all contributions in analyses

CDF and DØ experiments in Run II

- Both detectors are upgraded in Run II
  - New silicon micro-vertex trackers
  - New tracking systems
  - Upgraded muon chambers

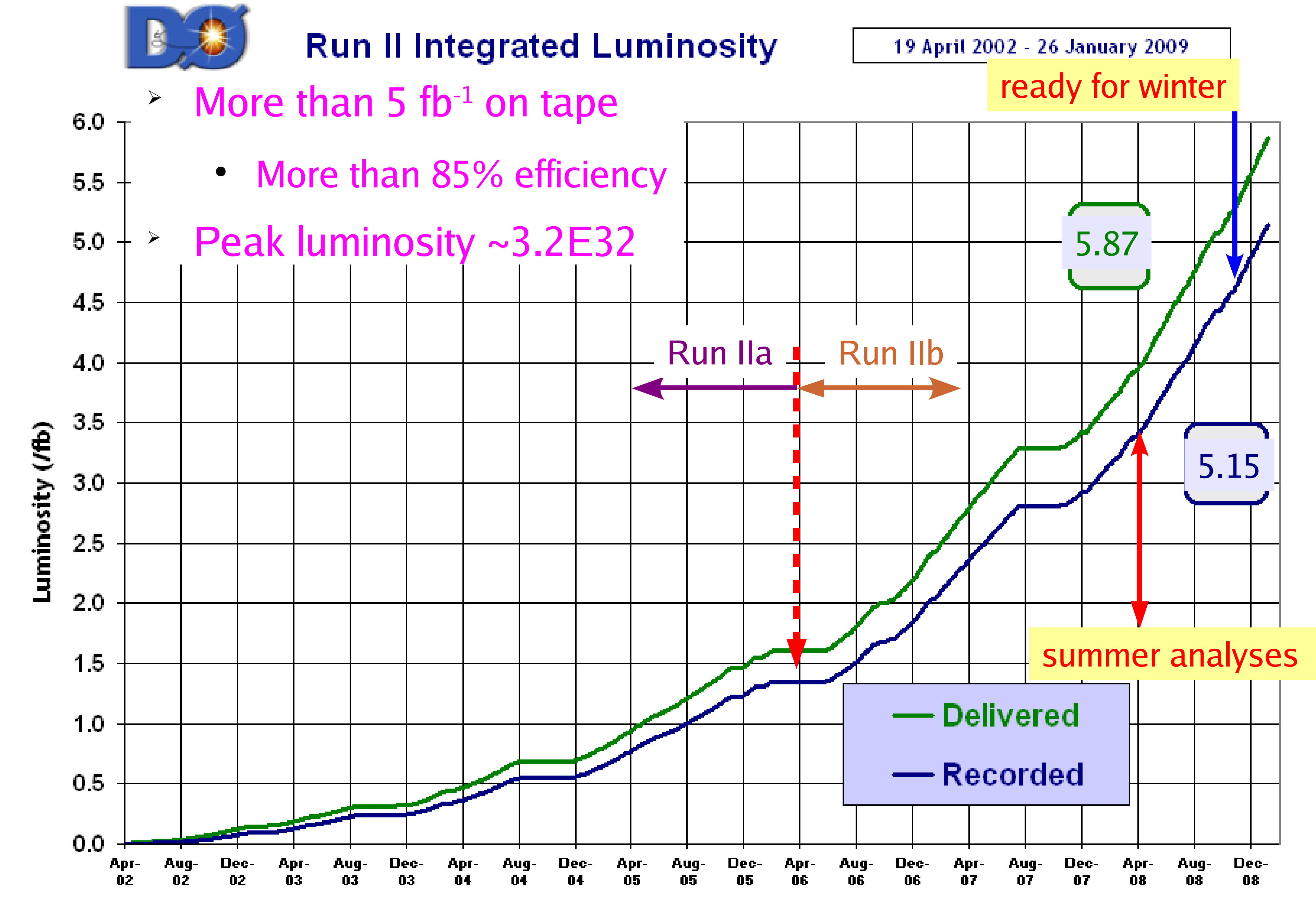




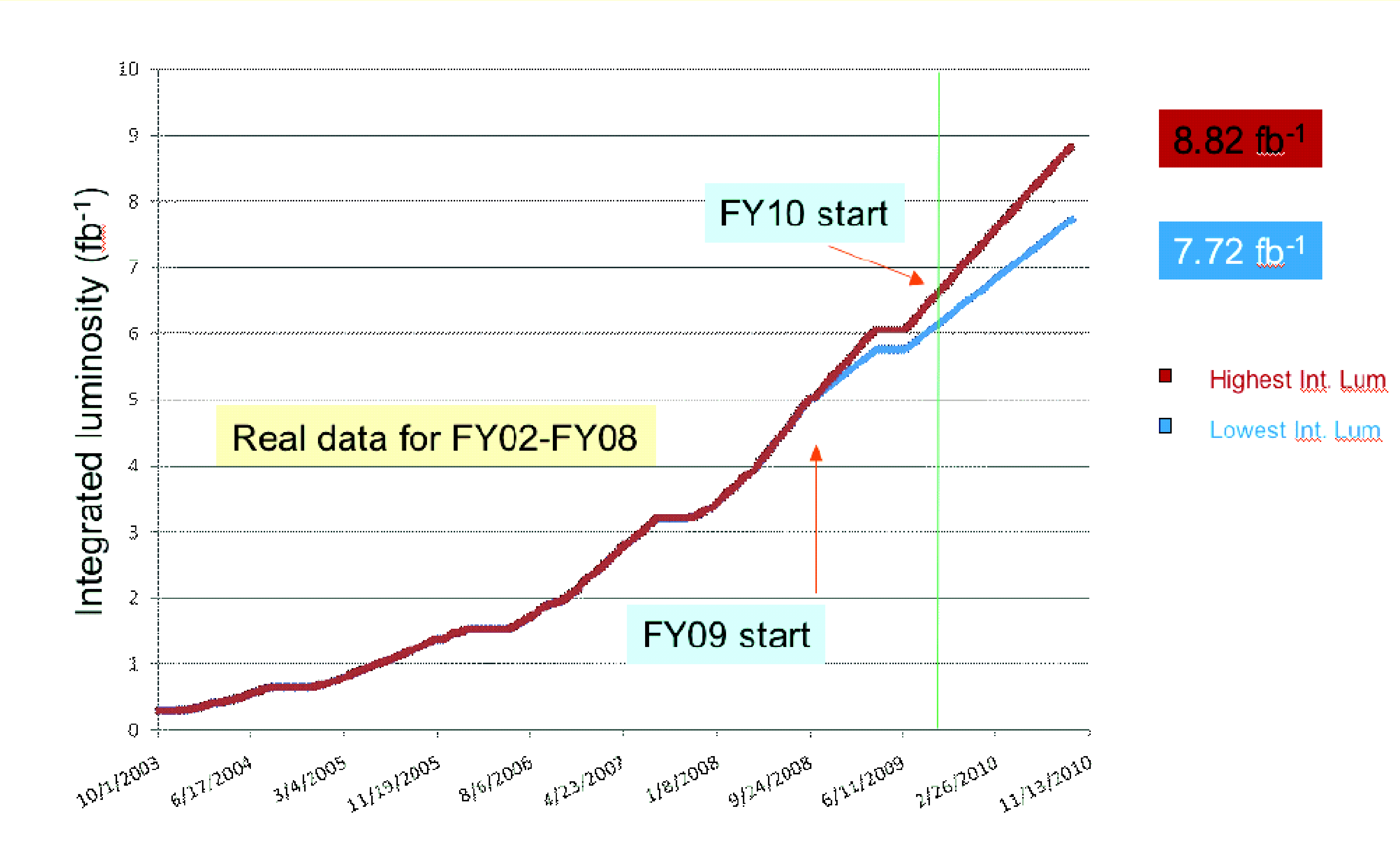
DØ: new solenoid, new pre-showers,
LØ for SMT in RunIIb, new L1Cal trigger

CDF: new Plug Calorimeters, new TOF

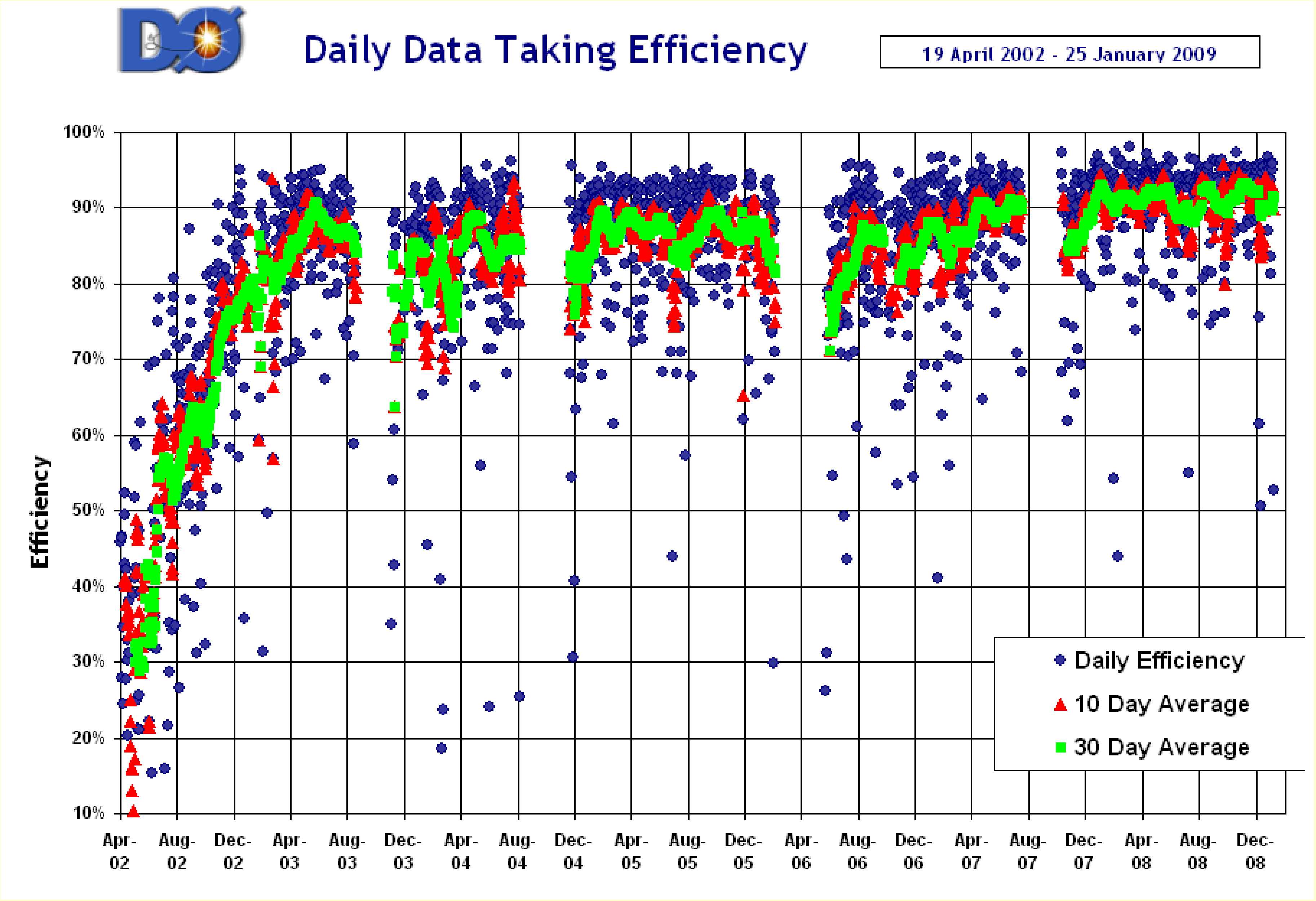
Data taking


Run II Integrated Luminosity
19 April 2002 - 26 January 2009
ready for winter
More than 5 fb^{-1} on tape
More than 85% efficiency
Peak luminosity ~3.2E32
5.87
Run IIa
Run IIb
5.15
summer analyses
Delivered
Recorded
Luminosity (/fb)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Apr-02
Aug-02
Dec-02
Apr-03
Aug-03
Dec-03
Apr-04
Aug-04
Dec-04
Apr-05
Aug-05
Dec-05
Apr-06
Aug-06
Dec-06
Apr-07
Aug-07
Dec-07
Apr-08
Aug-08
Dec-08

Tevatron projections

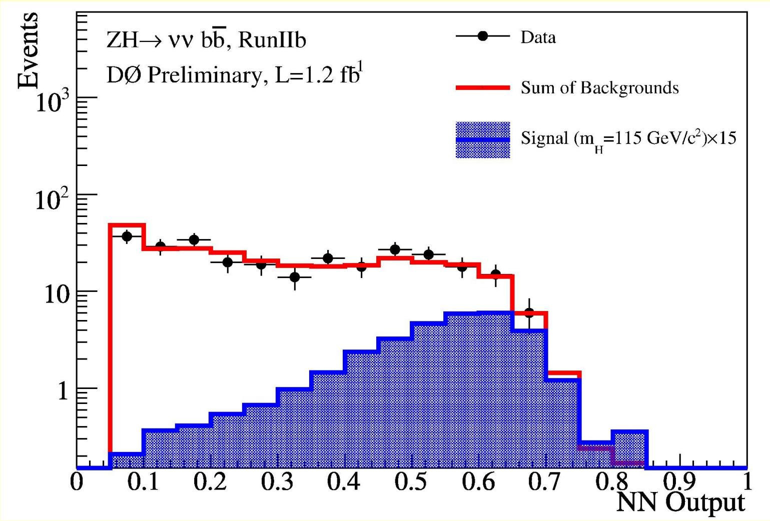


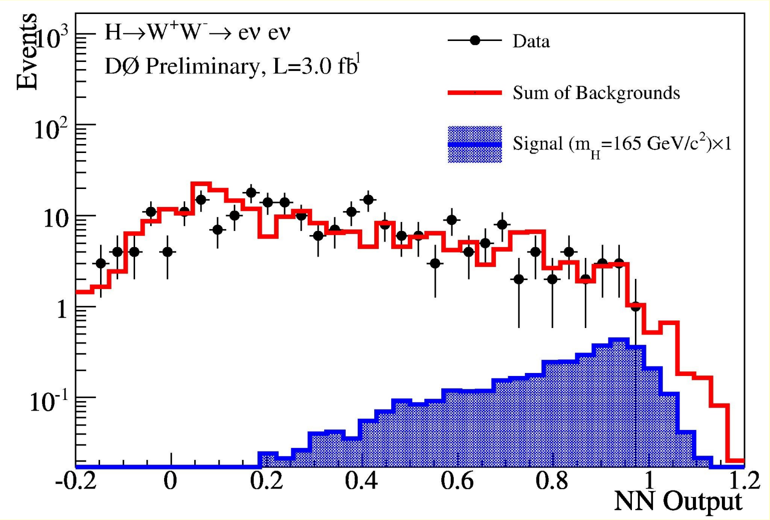
Data taking efficiencies



Combining channels

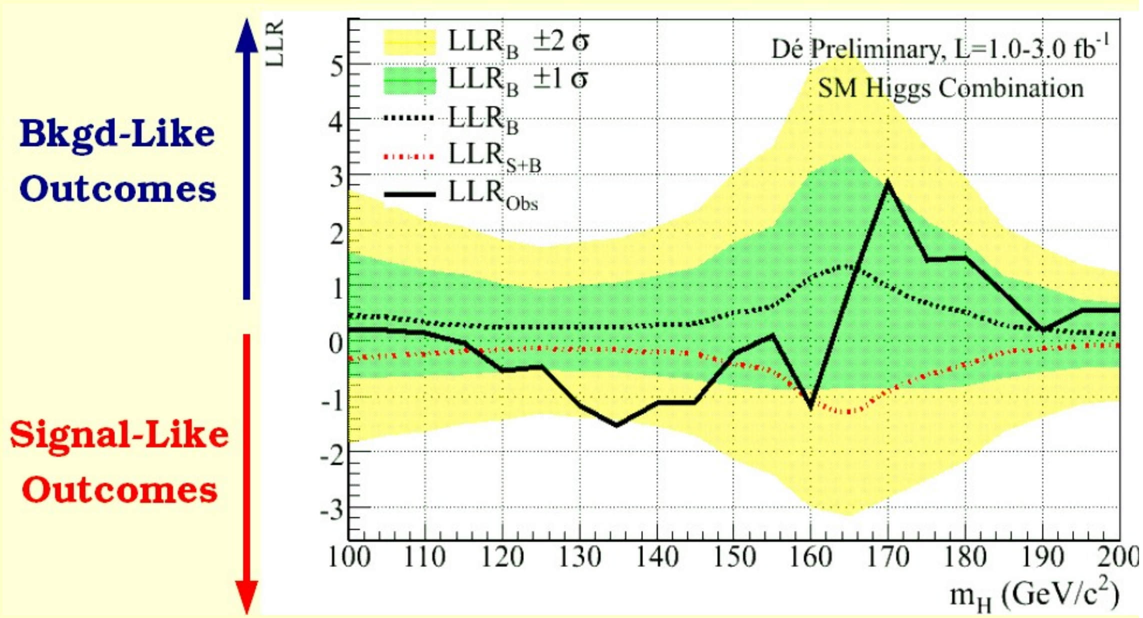
- Our goal is to understand the theory of the SM Higgs boson
  - The answer is either “The SM Higgs is there” or “It's not there”
- We test our data for compatibility with one of two hypotheses:
  - SM+Higgs or SM-Only
- We use a semi-Frequentist statistical model to perform this test

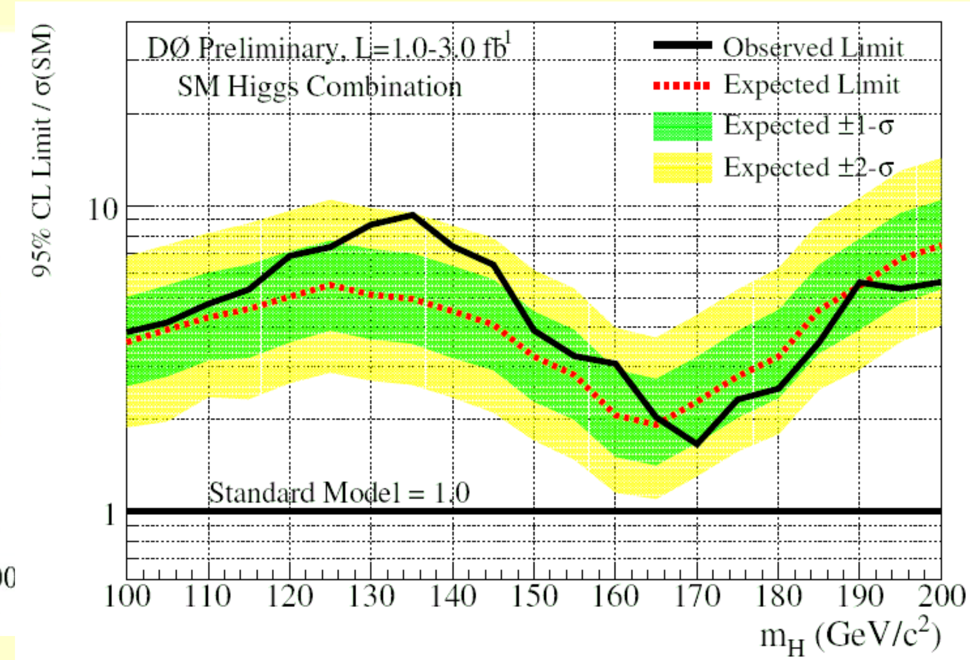




D0 limits

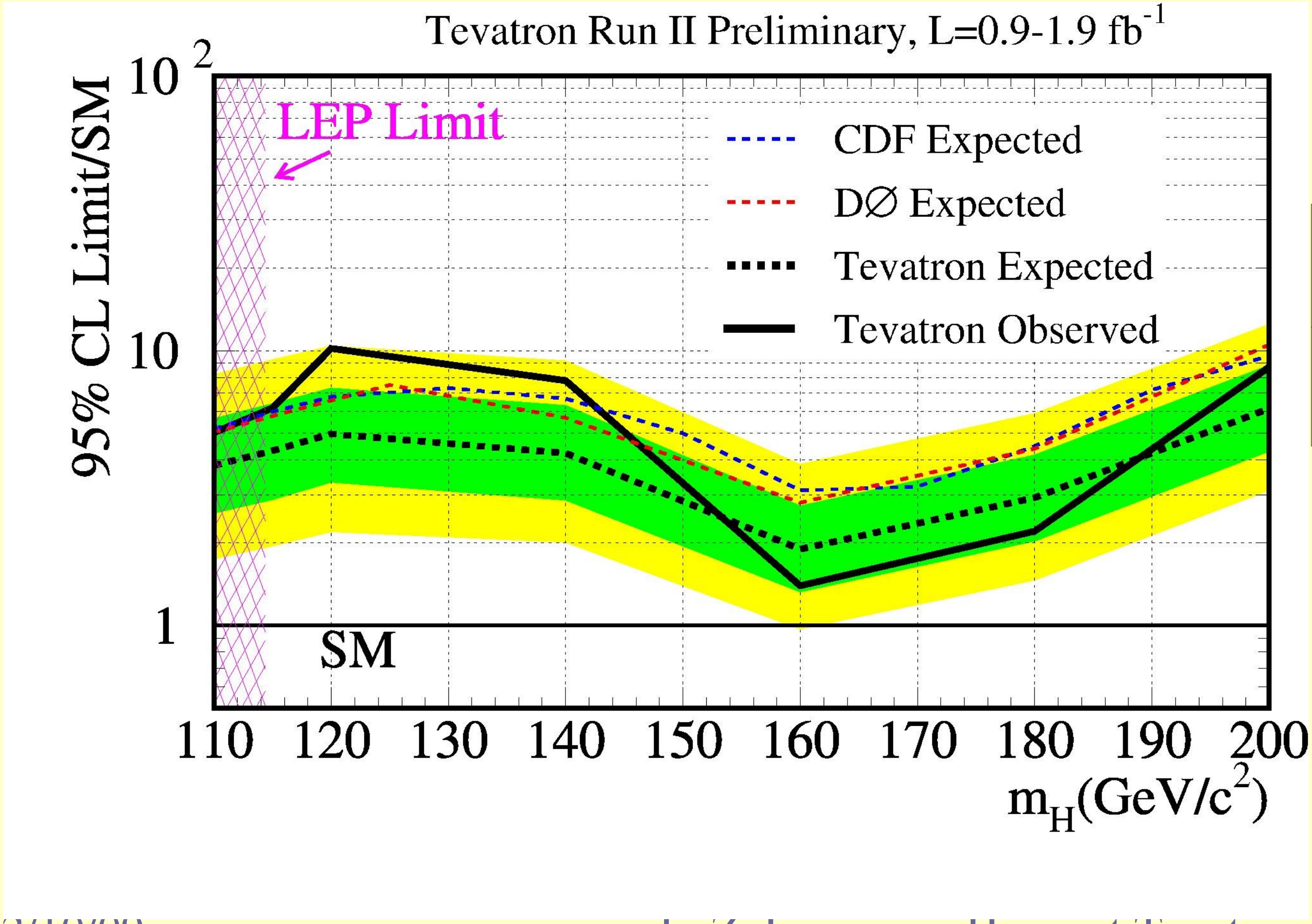
	expected		observed	
m_H [GeV]	115	165	115	165
Limit	4.6	1.9	5.3	2





- The width of the 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.

Combined limits – Tevatron



	m_H [GeV]	Tevatron
expected	115	4.3
	160	1.9
observed	115	6.2
	160	1.4

http://arxiv.org/abs/071