Higgs Searches at TeVatron

Status & prospects

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Outline

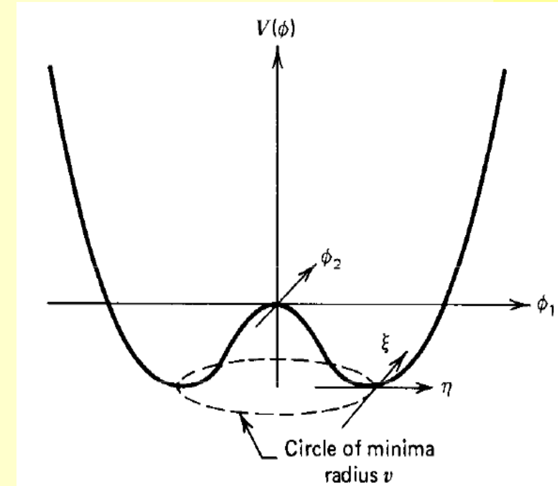
Introduction

Experimental context

Higgs searches at the TeVatron

Prospects

Introduction

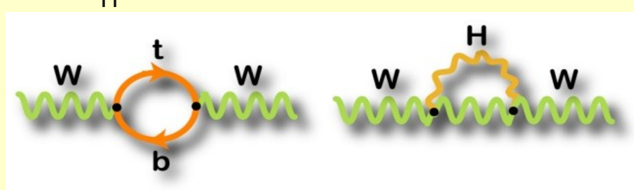


- Higgs mechanism allows to build a renormalisable theory with massive bosons and fermions
- Preserve gauge invariant dynamic
- Predicts a new boson: the Higgs

Available experimental limits

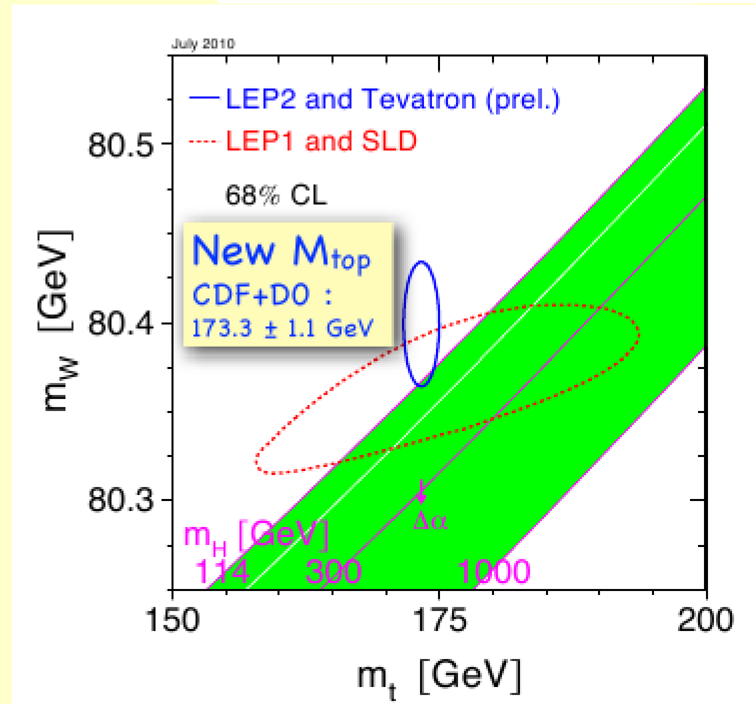
→ Direct searches at LEP: M_H >114 GeV at 95% C.L.

→ Precision theory fits



M_H< 158 GeV (95%) or <185 GeV with direct LEP limit

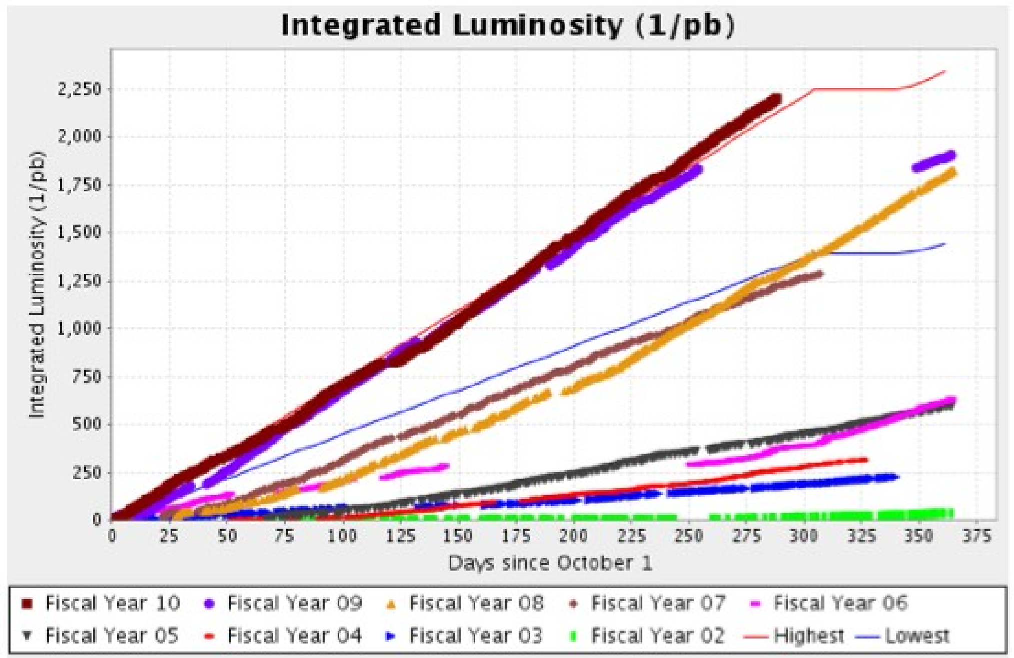
Light Higgs favoured –> in the Tevatron energy range!

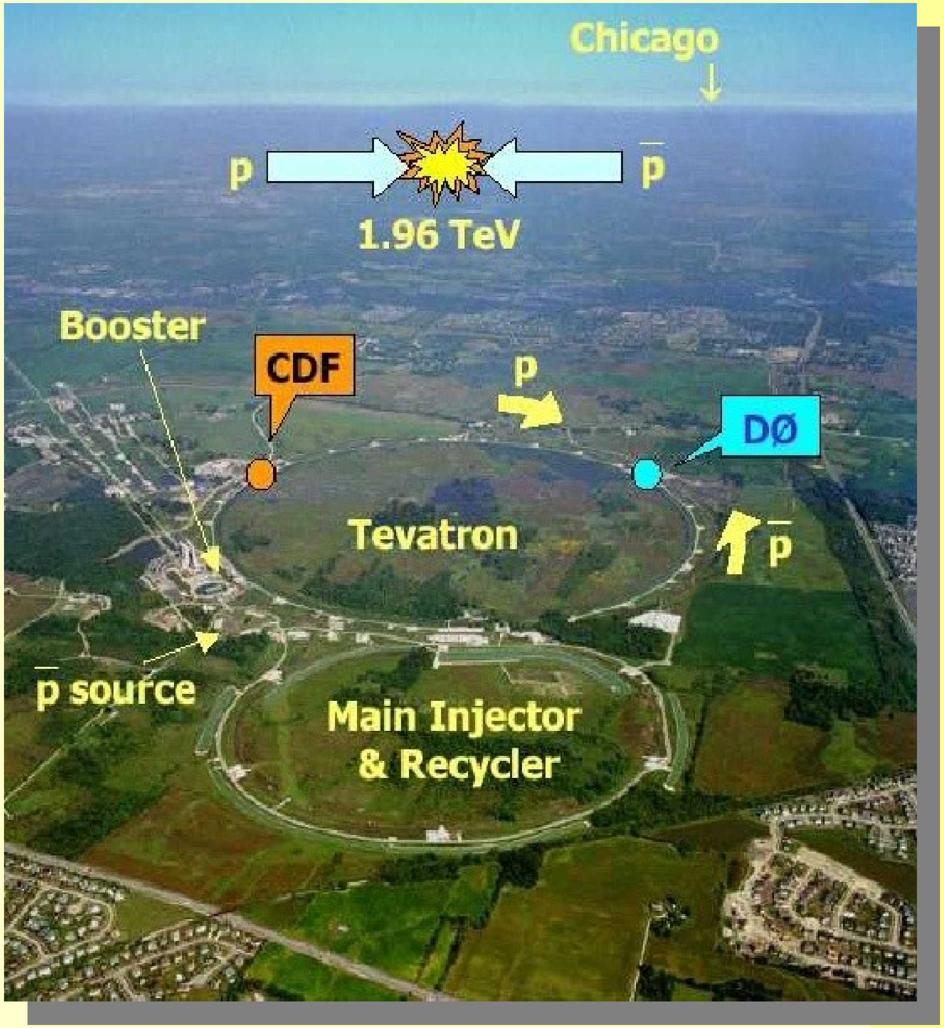


TeVatron accelerator

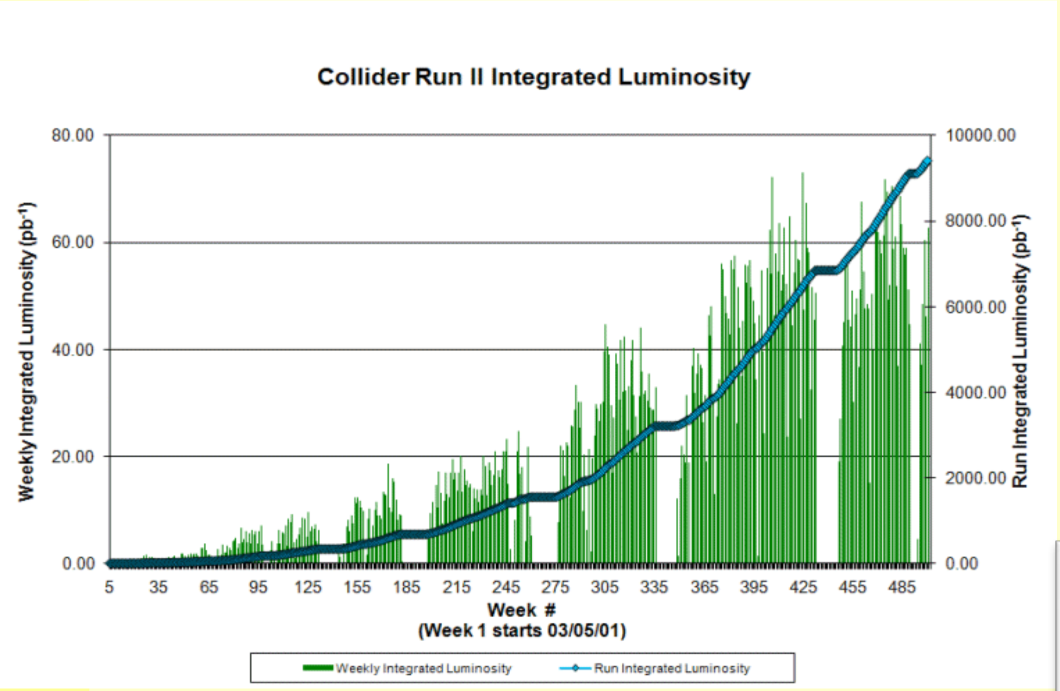
Excellent performance:

- Proton / anti-prorton collider @ 1.96 TeV
- Typical instantaneous luminosity:
  > 3×10^{32} cm^{-2}s^{-1}
- Integrated lum./week: ~58 pb^{-1}
  equivalent to Run I dataset every 2 weeks!





TeVatron

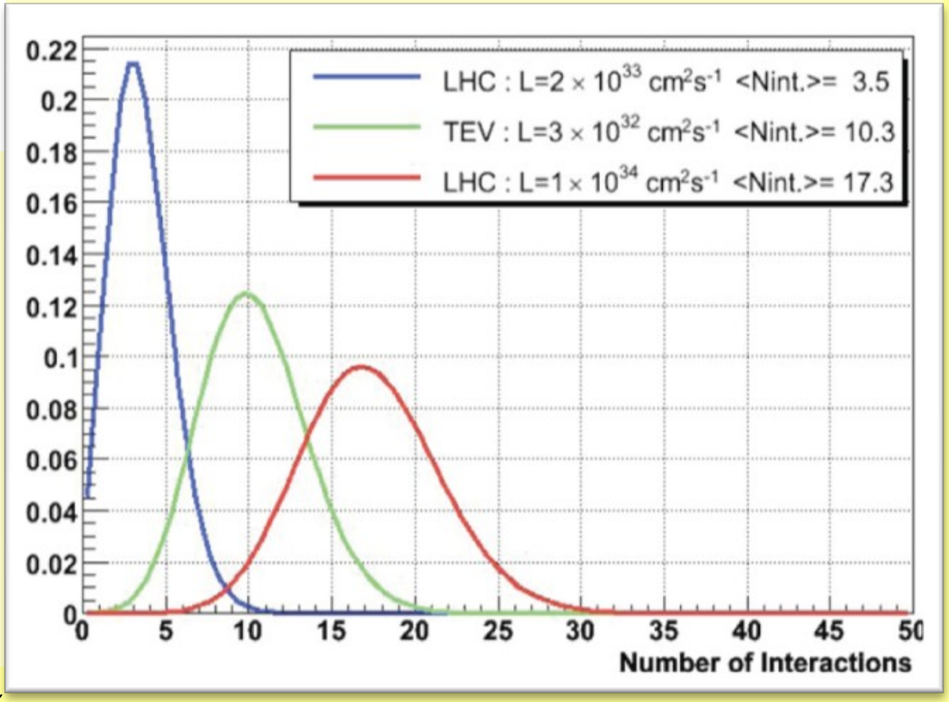


Delivered 9.4 fb^{-1} so far

- Expect: ~12 fb^{-1} by end of 2011

  ~18 fb^{-1} by end of 2014

  Not approved. Based on Run III proposal to run up to end of FY14.

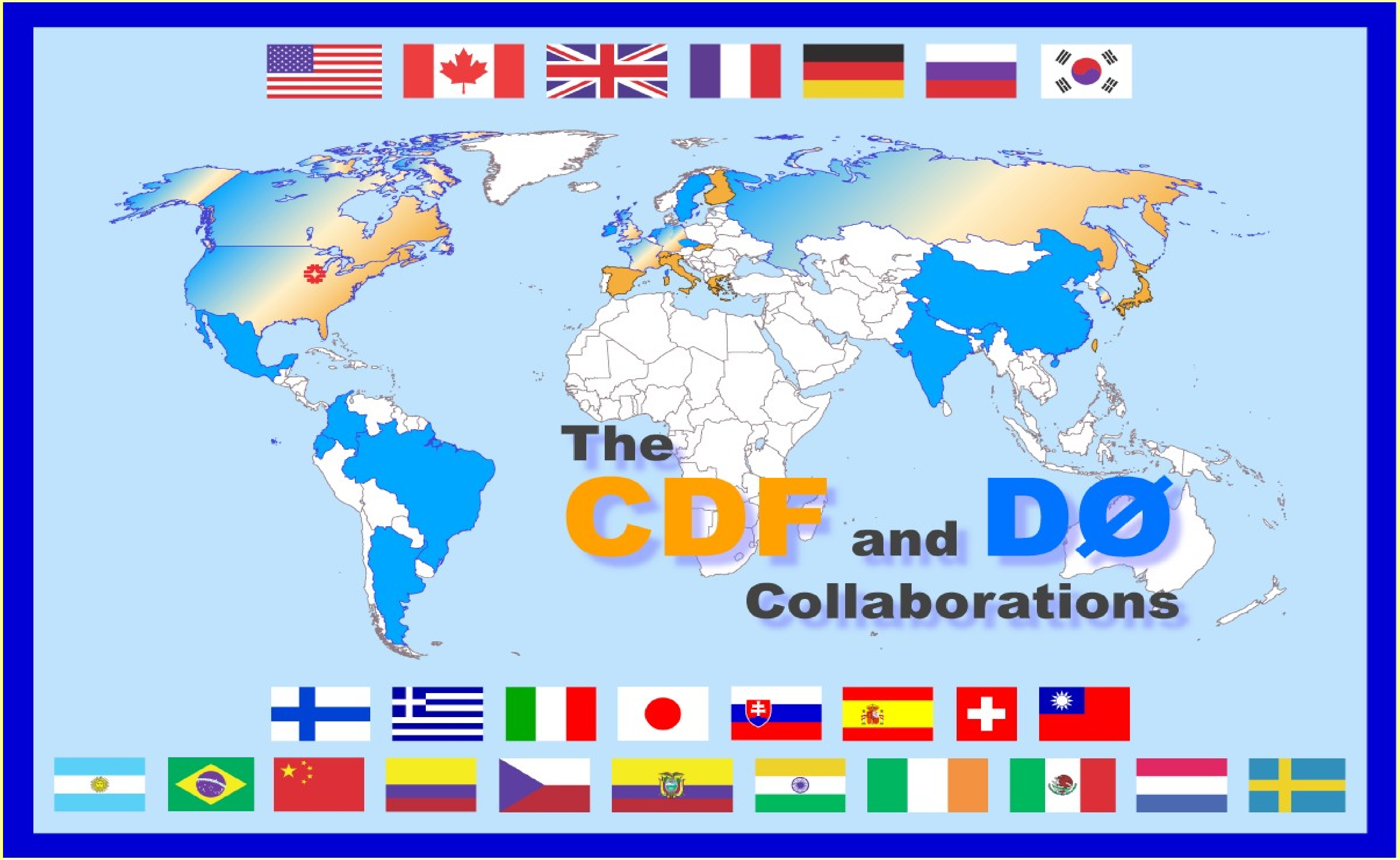


Average number of interactions:

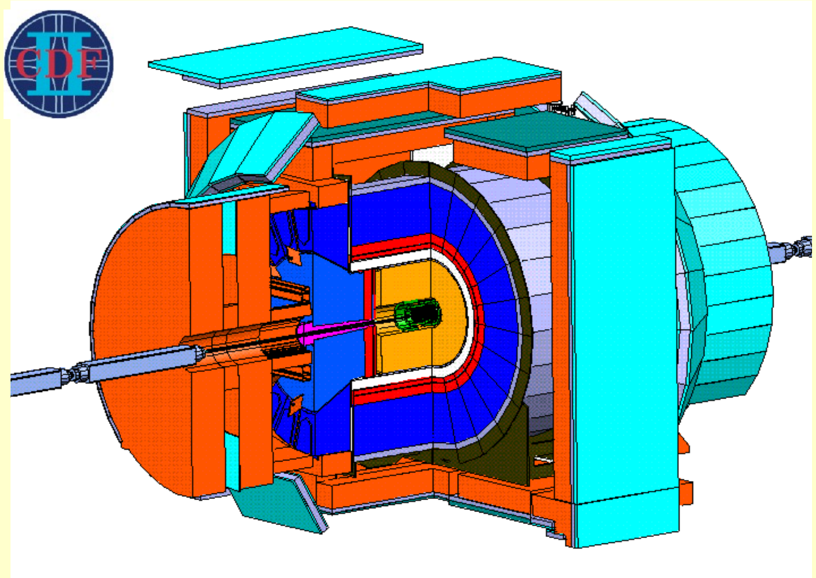
Tevatron (L=300x10^{30} $cm^{-2}s^{-1}$): <N>=10

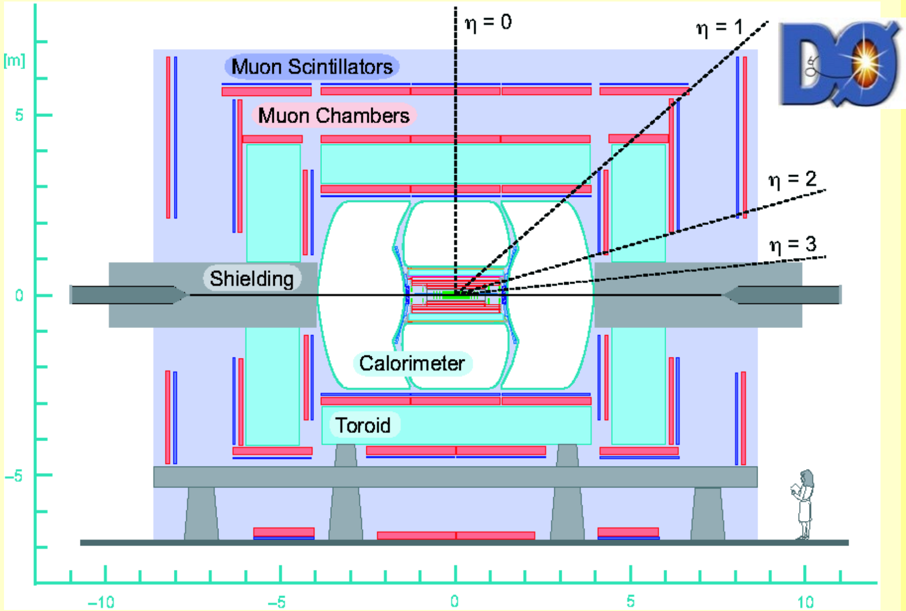
Significantly larger than for the initial running of the LHC

DØ & CDF



CDF & DØ detectors





Multipurpose detectors:

In a solenoidal magnetic field:

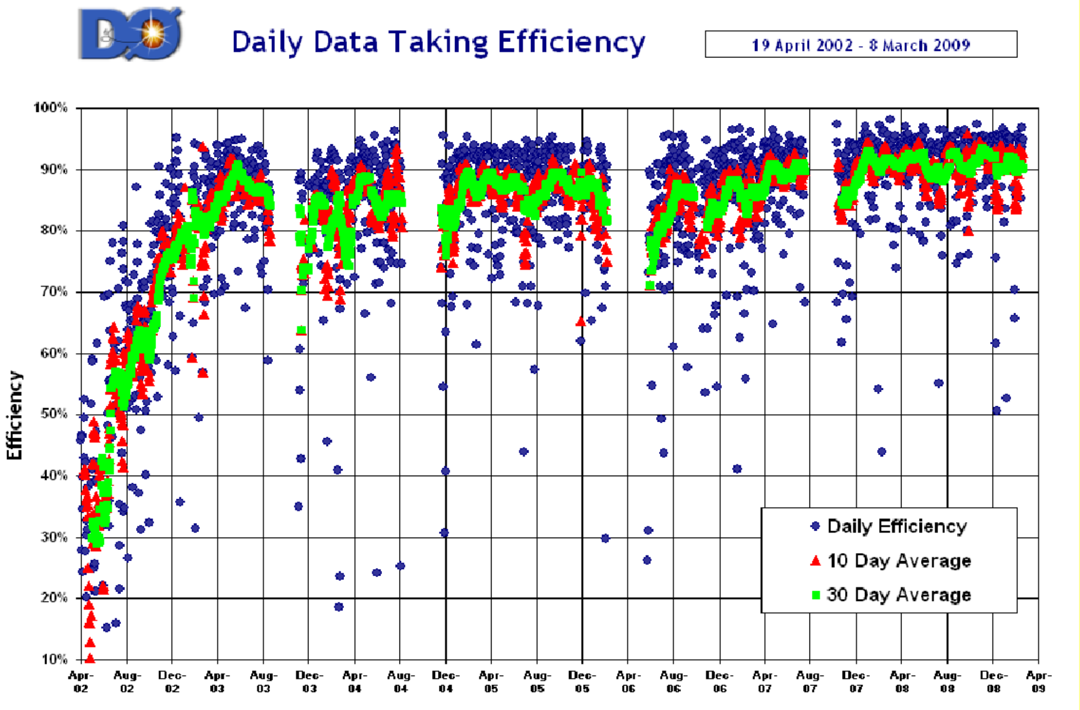
Silicon vertex detector

Tracking chamber (CDF), Fiber tracker (DØ

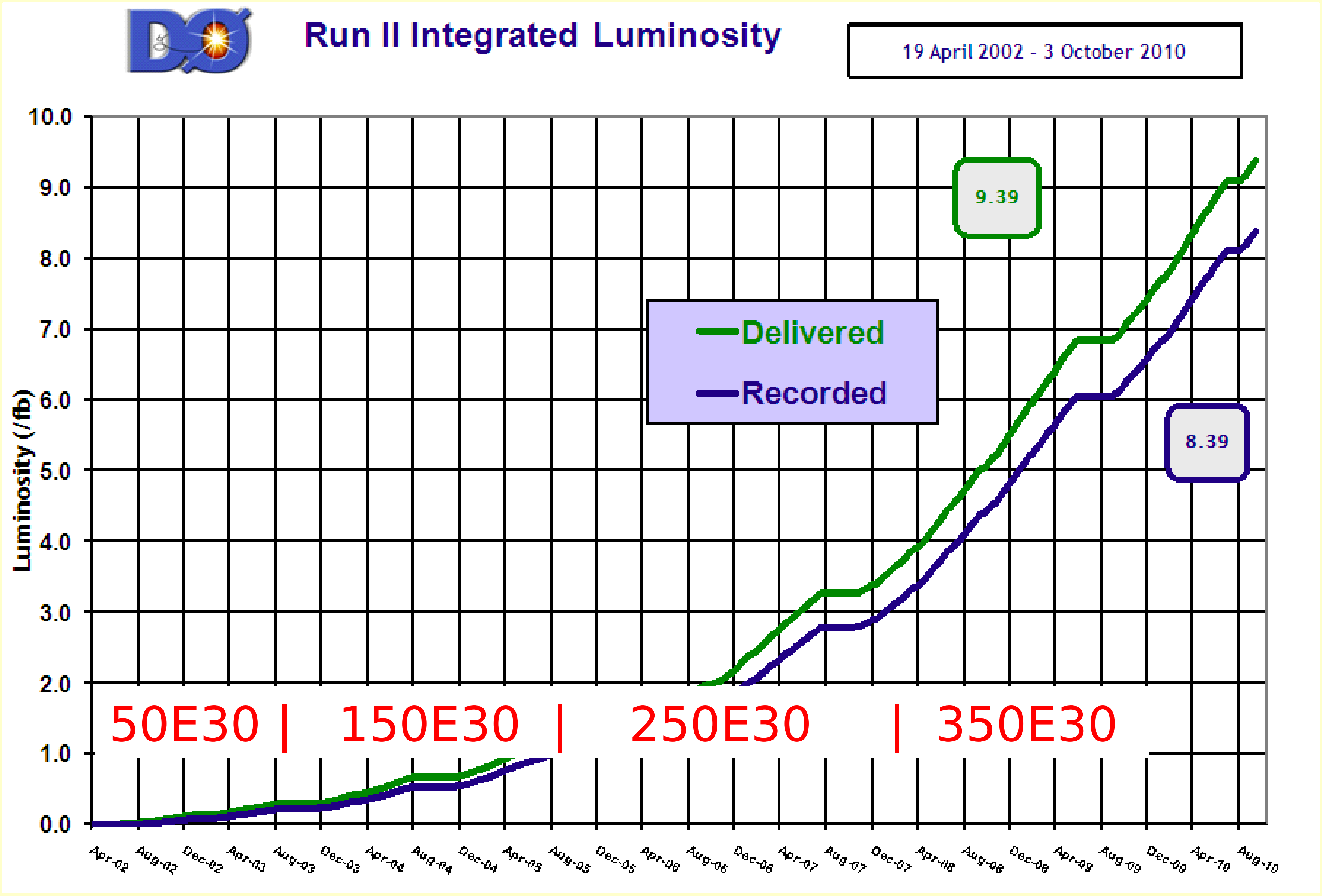
Preshowers

Electromagnetic and hadronic calorimeters

Muon system

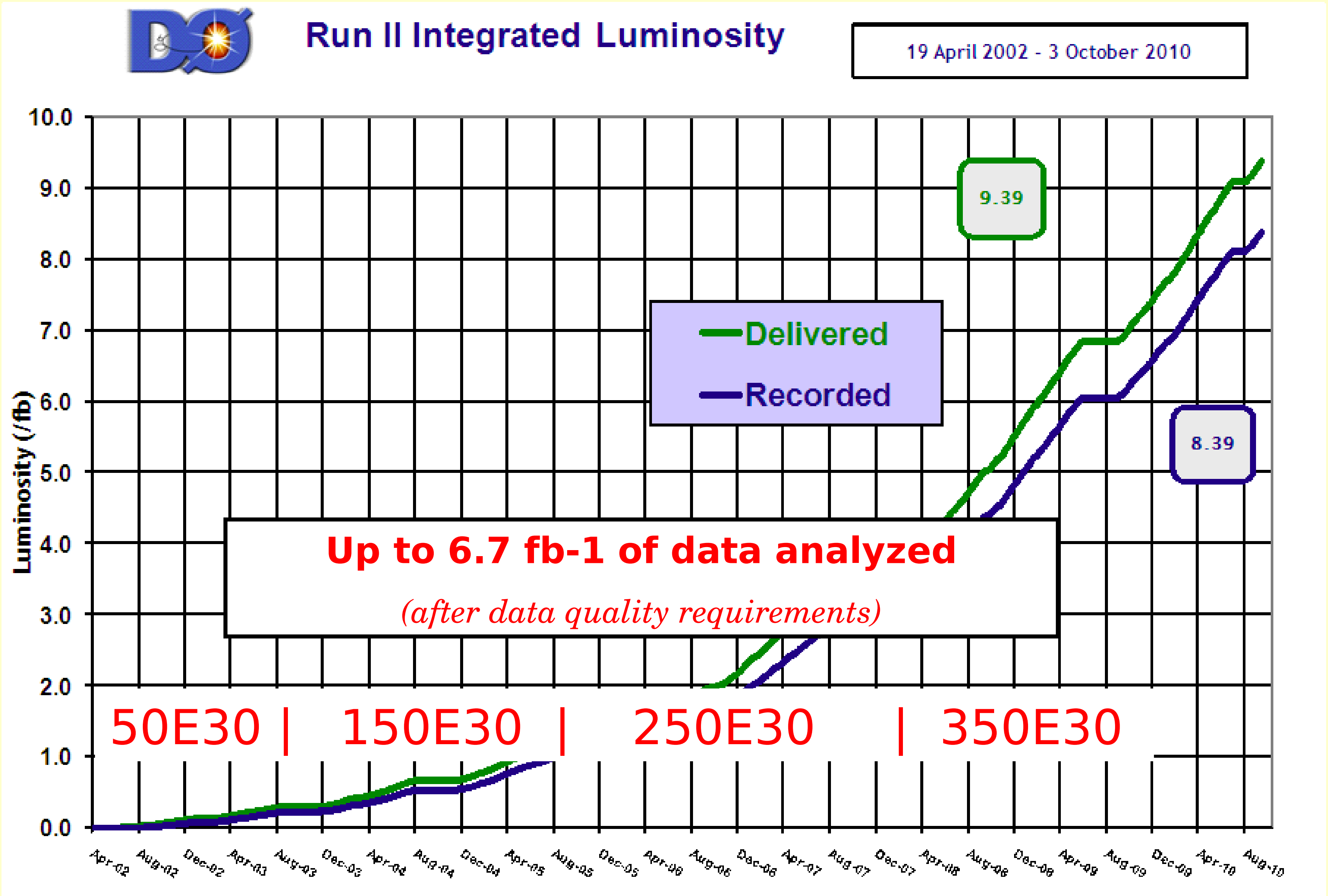


Data sets



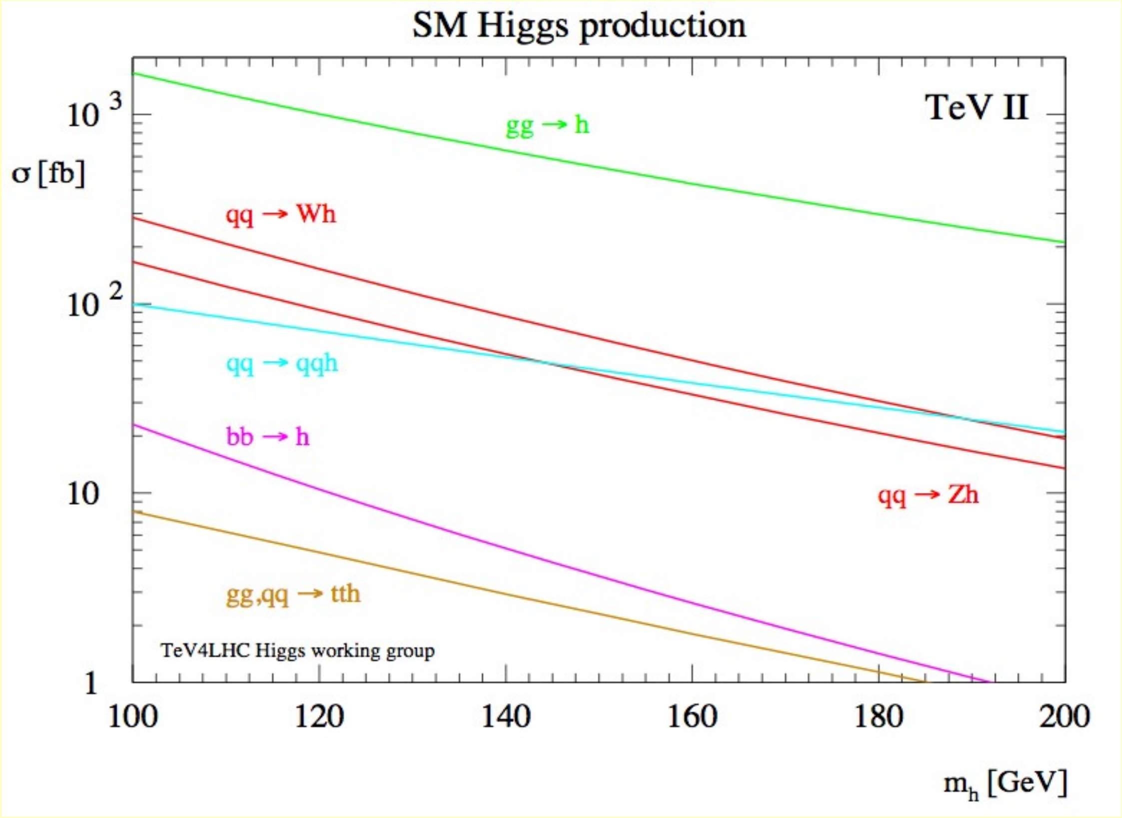
Run II Integrated Luminosity
19 April 2002 - 3 October 2010
Delivered
Recorded
9.39
8.39
Luminosity (/fb)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Apr-02
Aug-02
Dec-02
Apr-03
Aug-03
Dec-03
Apr-04
Aug-04
Dec-04
Apr-05
Aug-05
Dec-05
Apr-06
Aug-06
Dec-06
Apr-07
Aug-07
Dec-07
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10
Aug-10
50E30 | 150E30 | 250E30 | 350E30

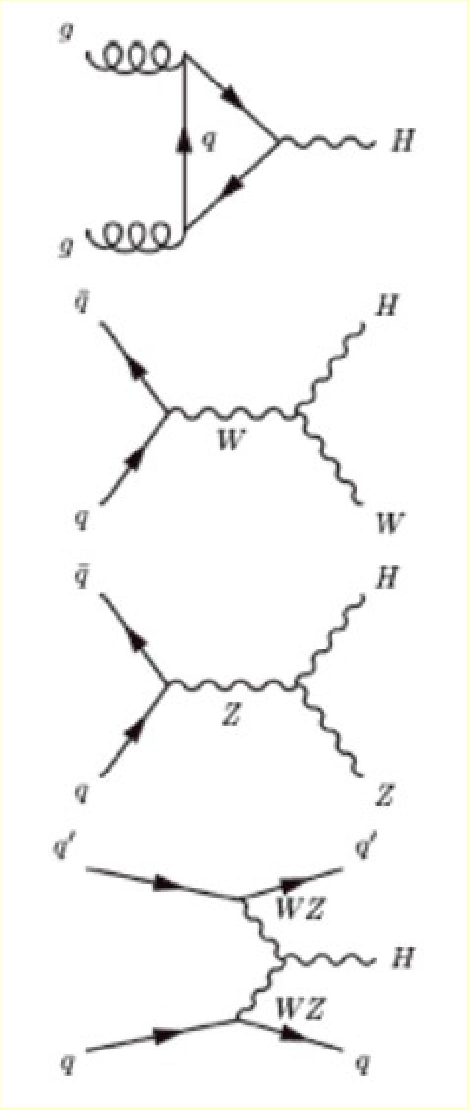
Data sets



Run II Integrated Luminosity
19 April 2002 - 3 October 2010
Luminosity (/fb)
Delivered
Recorded
9.39
8.39
Up to 6.7 fb-1 of data analyzed
(after data quality requirements)
50E30 | 150E30 | 250E30 | 350E30

Production modes





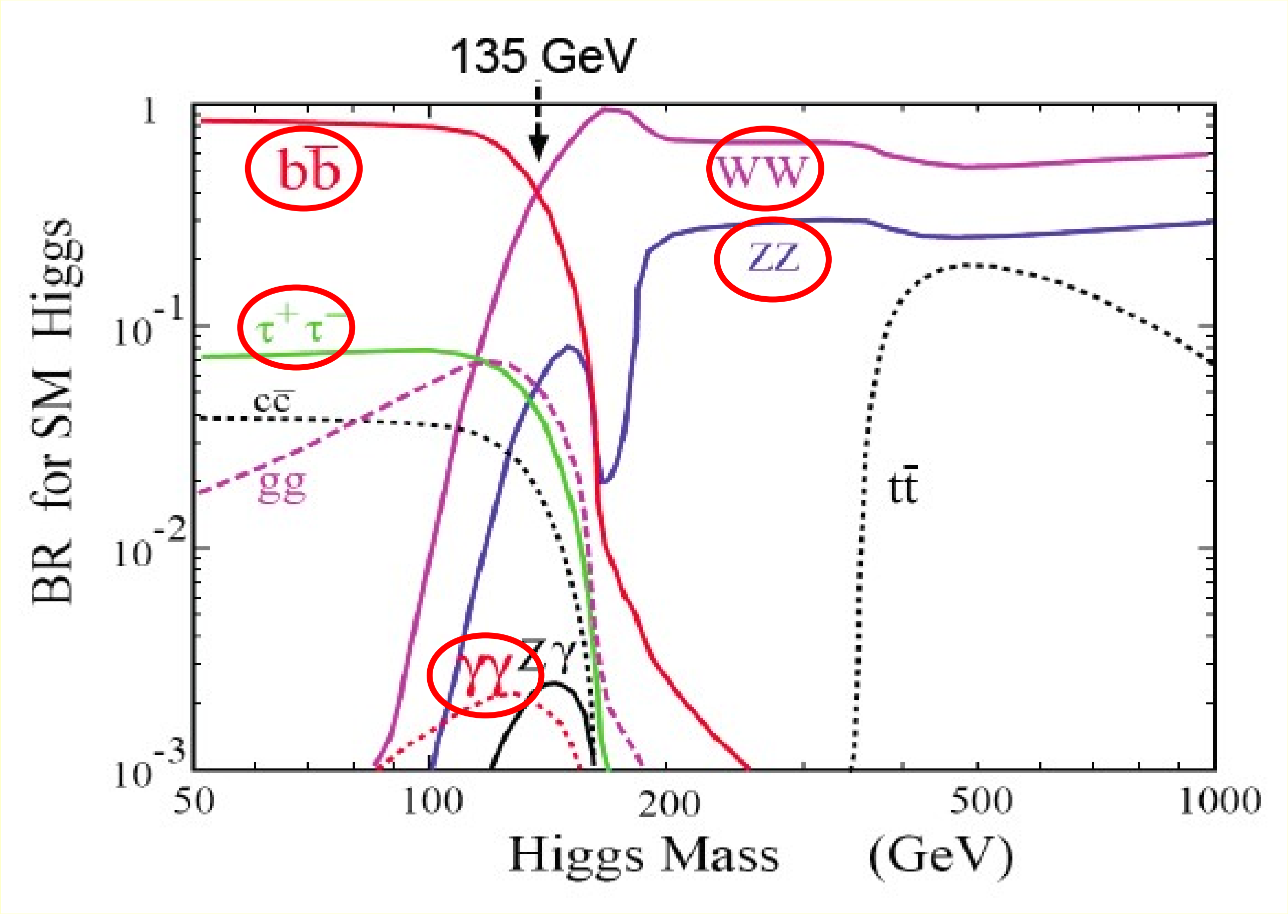
Main production mechanisms ***(115<m_H<180 GeV):***

Gluon fusion (gg→H): **σ ~0.8-0.2 pb**

Associated production (VH, V=W,Z): **σ ~0.2-0.02 pb**

Vector boson fusion (VBF): **σ ~0.1-0.02 pb**

Decays modes



Many decay modes being explored to increase the sensitivity of the search to the SM Higgs boson

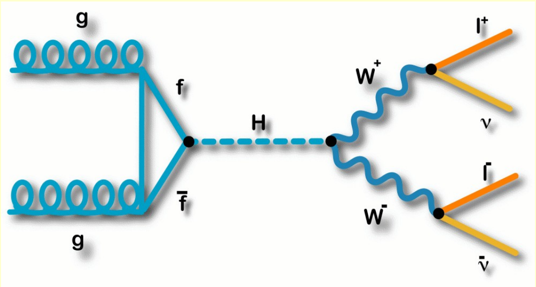
Search strategy

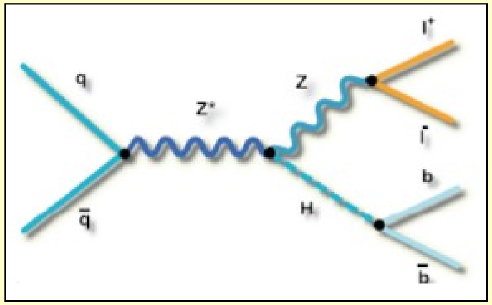
"Low-mass": m_H < 135 GeV:

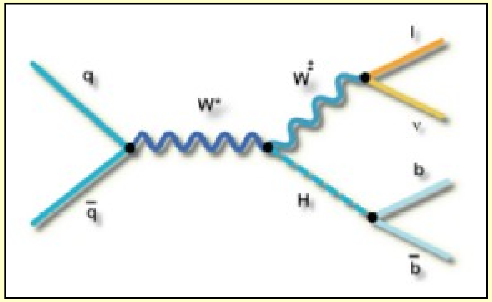
VH (V=W,Z) production with $H \rightarrow bb$ decay

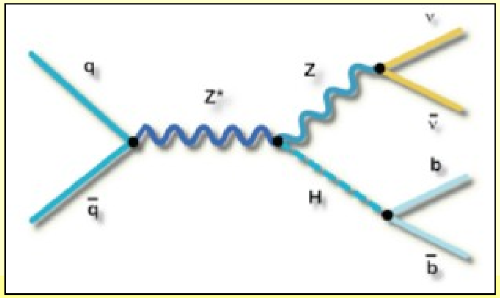
"High-mass": m_H > 135 GeV:

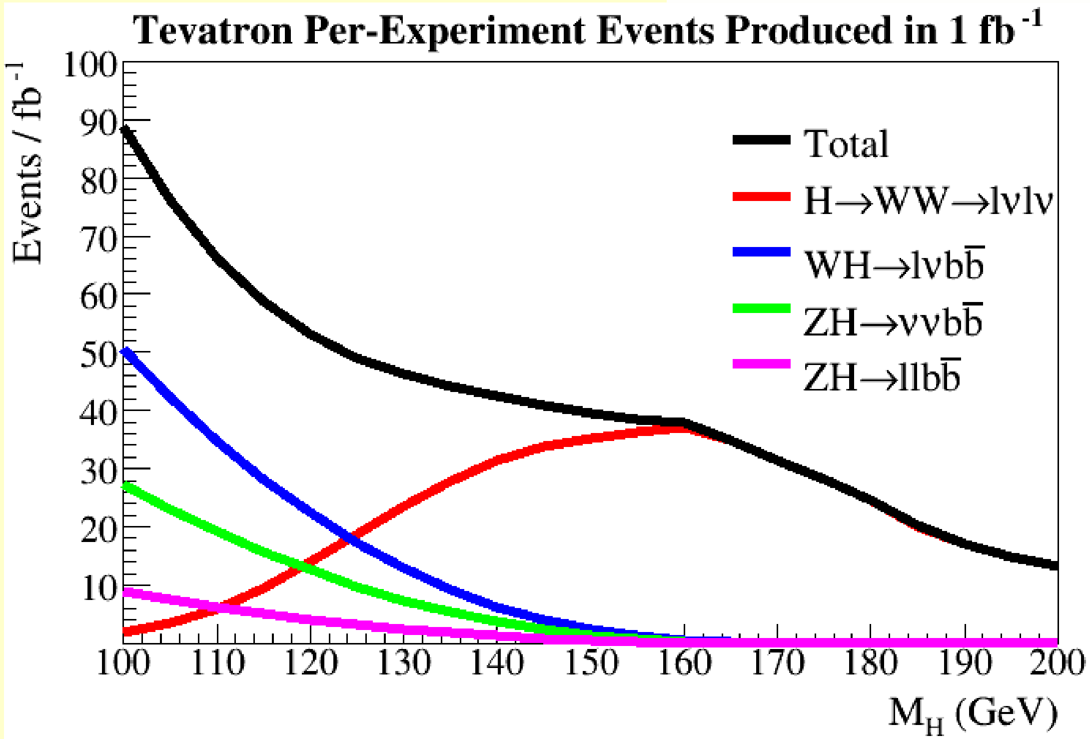
$gg \rightarrow H$ production with $H \rightarrow WW \rightarrow l\nu\ l\nu$ decay





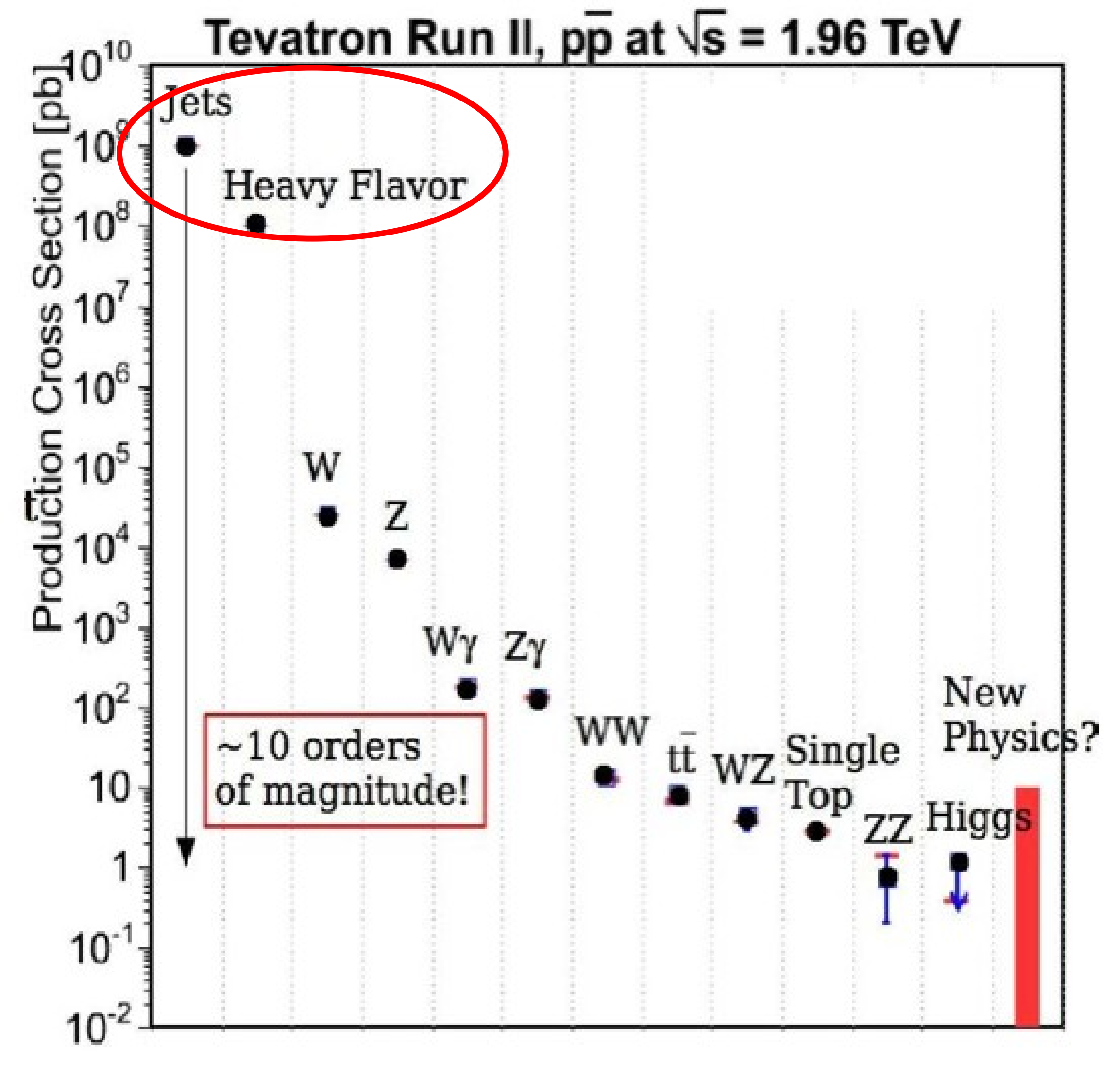






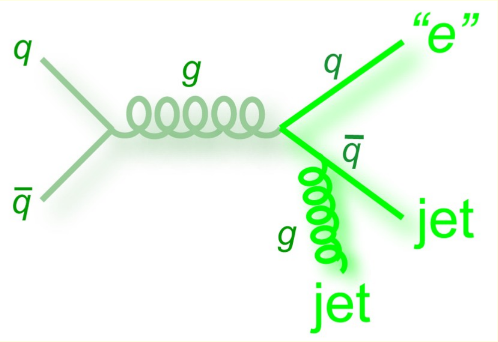
~600 Higgs events produced at the Tevatron in the main search channels with 10 fb^{-1}

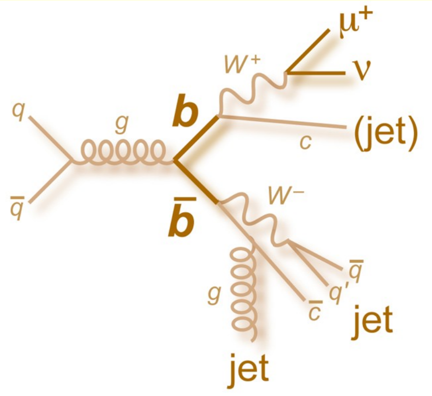
Backgrounds



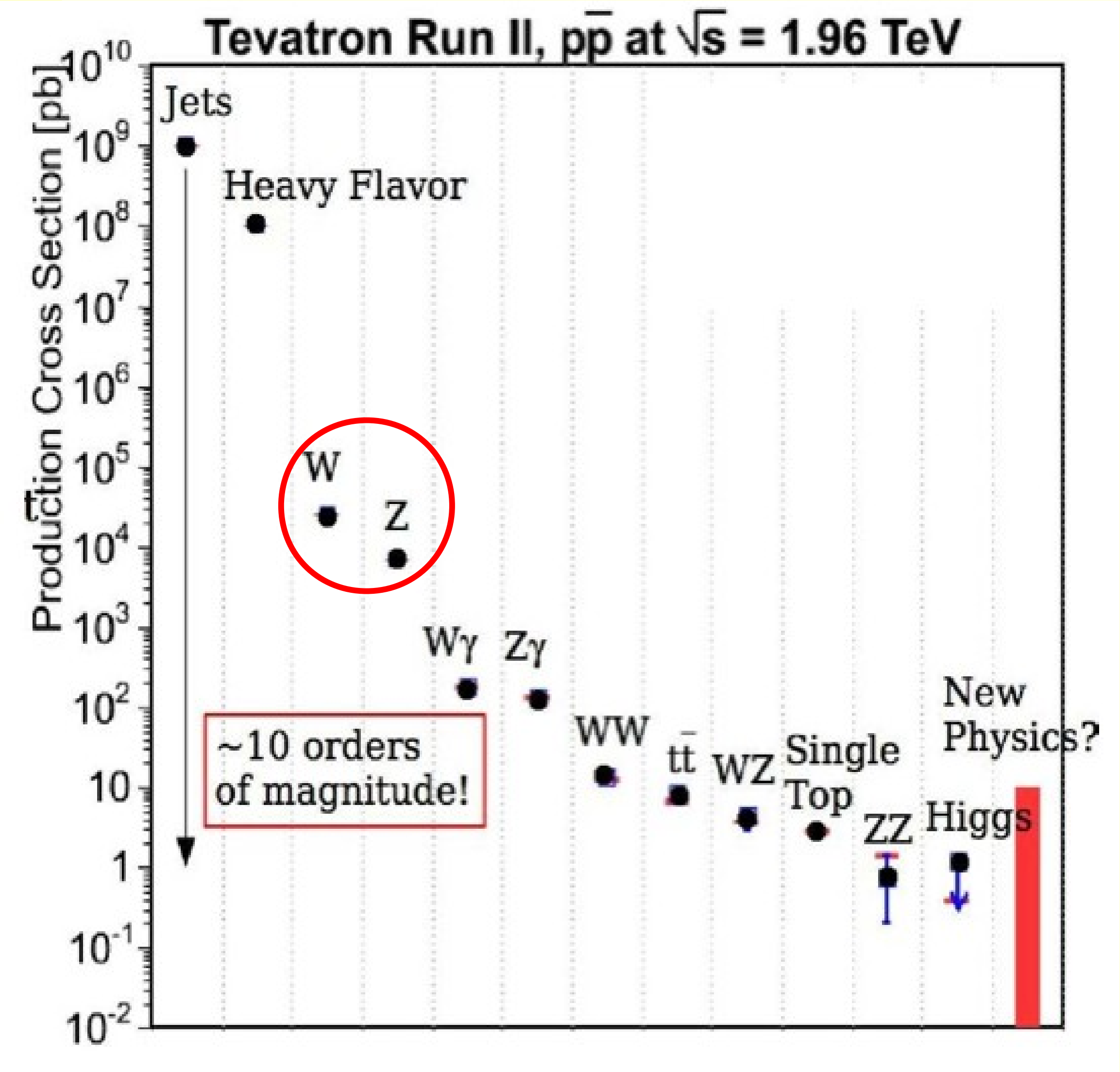
Instrumental backgrounds

- QCD multijet (e.g faking lepton)
- Derived from (sidebands) data





Backgrounds



Instrumental backgrounds

- QCD multijet (e.g faking lepton)
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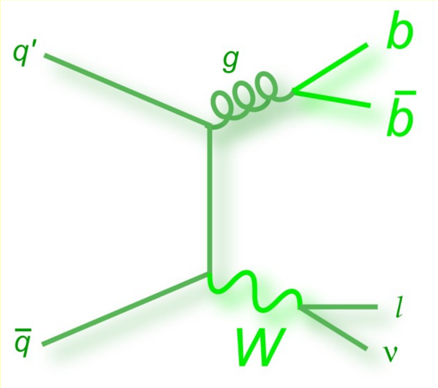
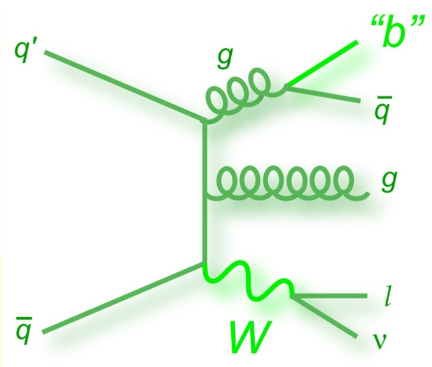
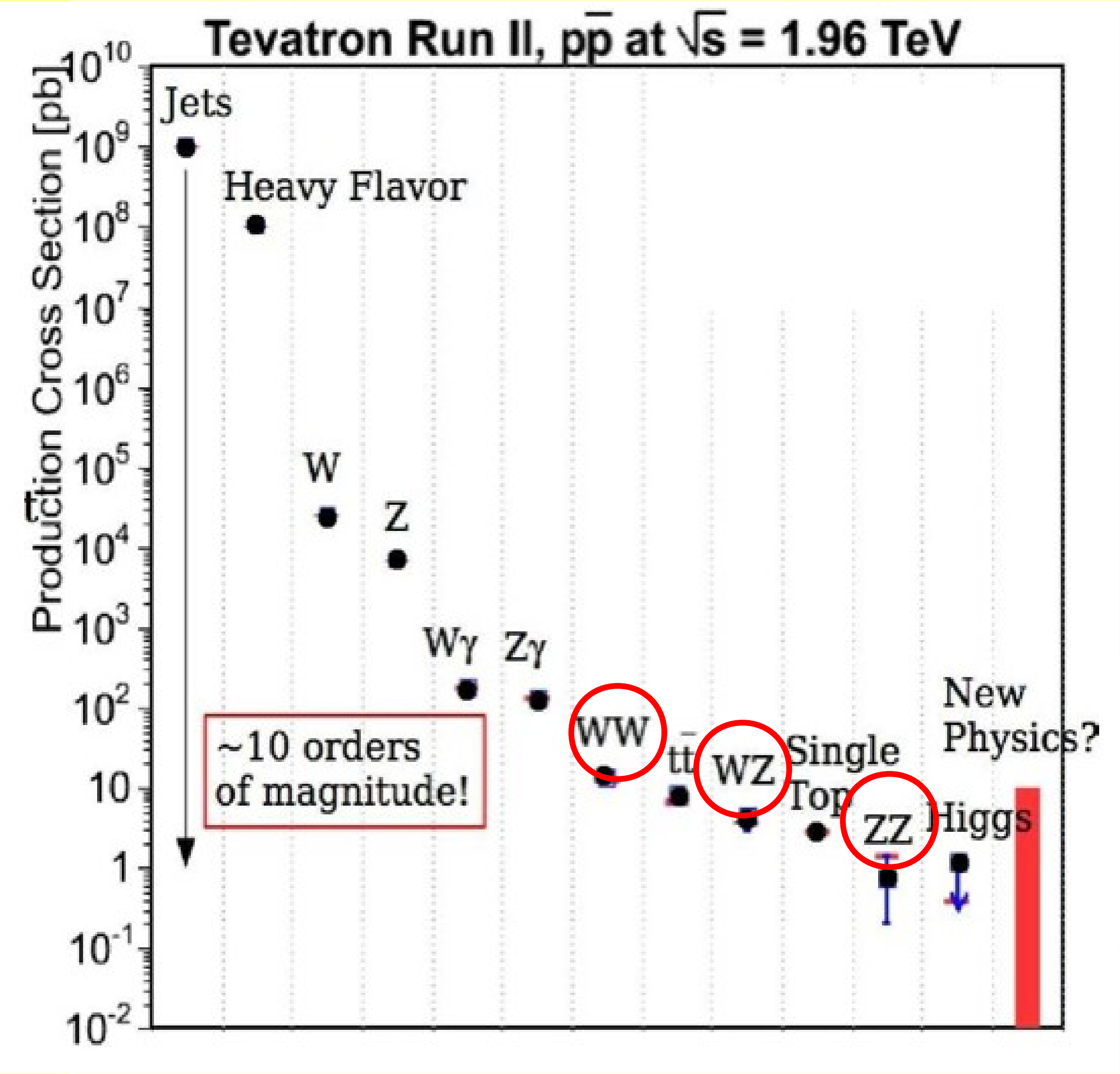
Physics backgrounds

- Simulation with latest theoretical calculations
- W/Z+jets with real / misidentified heavy flavour





Backgrounds

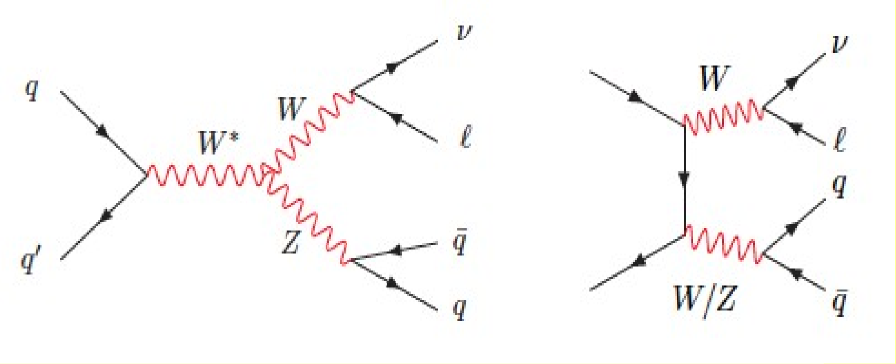


Instrumental backgrounds

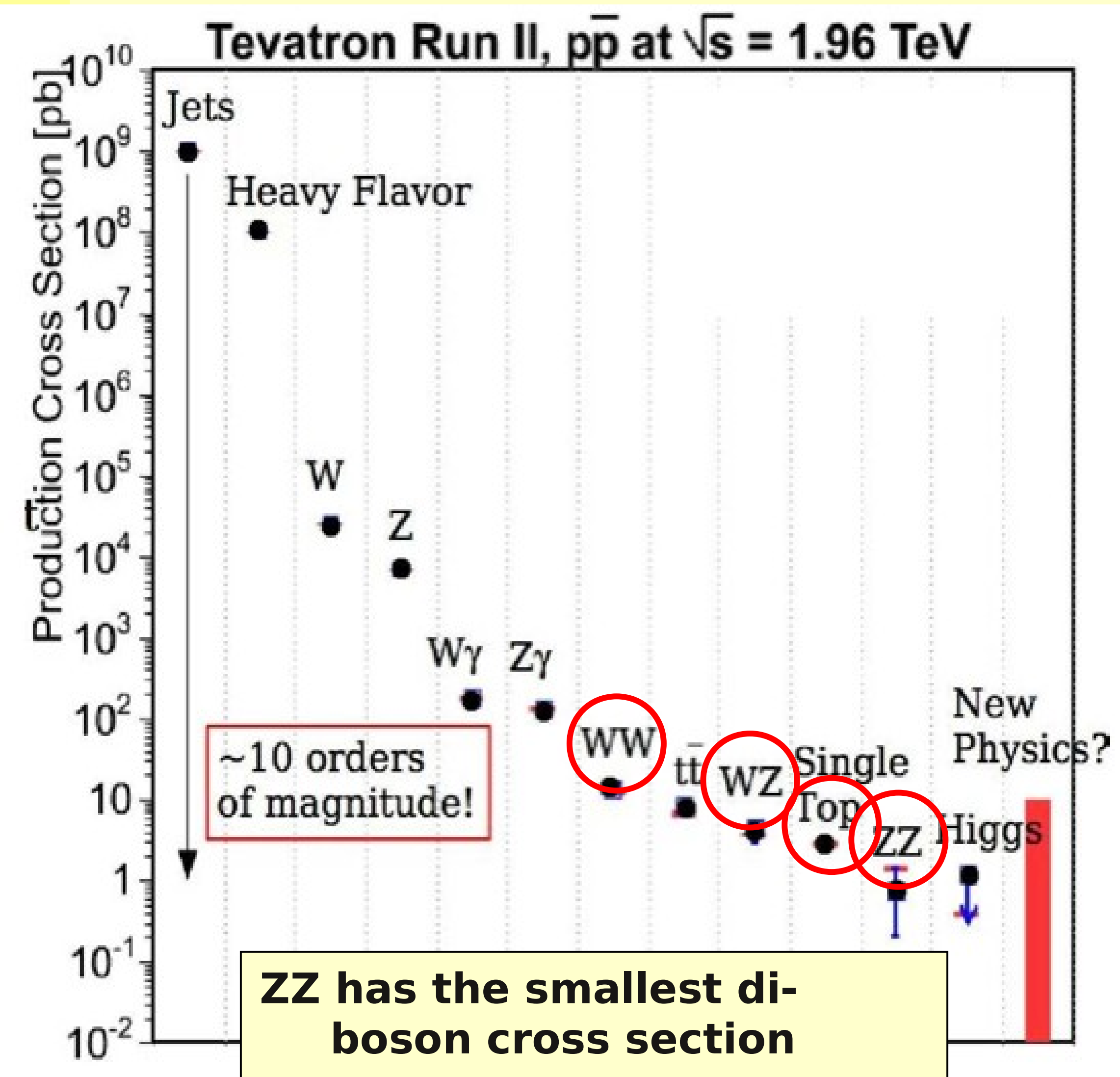
- QCD multijet (e.g faking lepton)
- Derived from (sidebands) data

Physics backgrounds

- Simulation with latest theoretical calculations
- W/Z+jets with real / misidentified heavy flavour
- Dibosons



Backgrounds



ZZ has the smallest di-boson cross section

σ (ZZ)=1.6 ± 0.1 pb

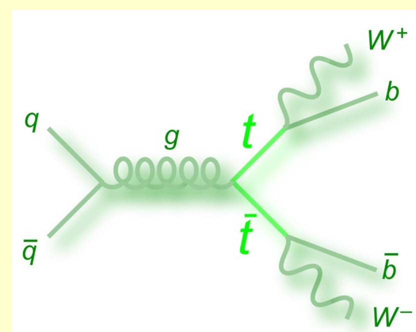
… next lower is the Higgs

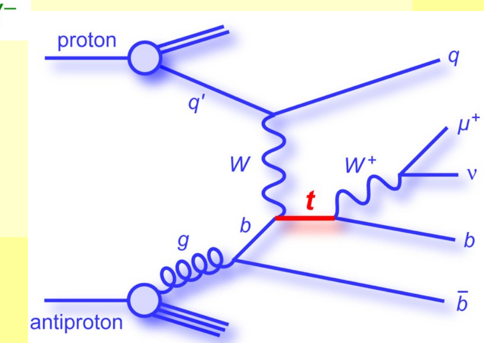
Instrumental backgrounds

- QCD multijet (e.g faking lepton)
- Derived from (sidebands) data

Physics backgrounds

- Simulation with latest theoretical calculations
- W/Z+jets with real / misidentified heavy flavour
- Dibosons
- Single / pairs of top productions





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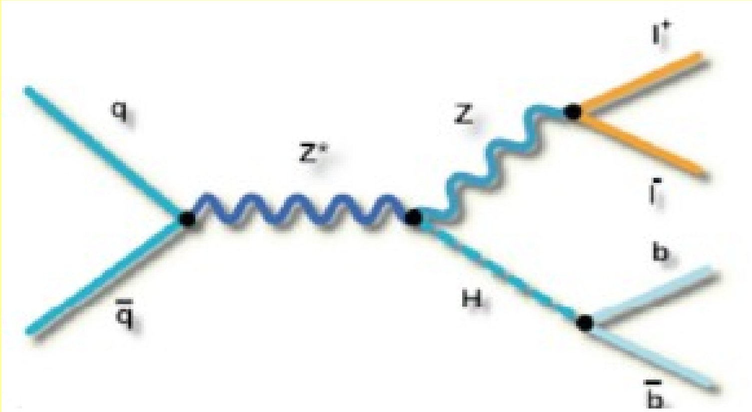
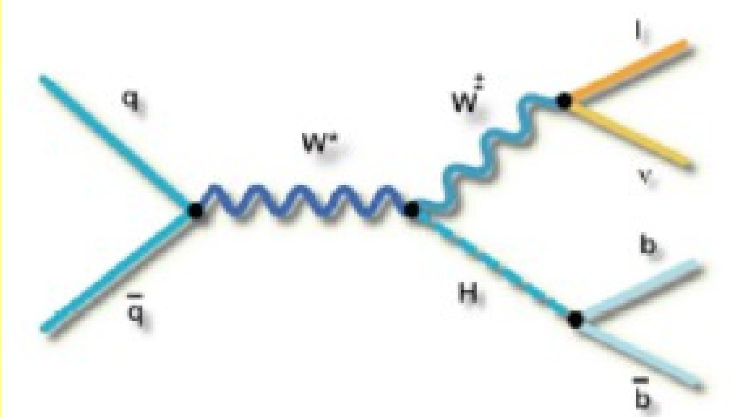
Low-mass searches



ZH→llbb: dilepton+2 b-jets

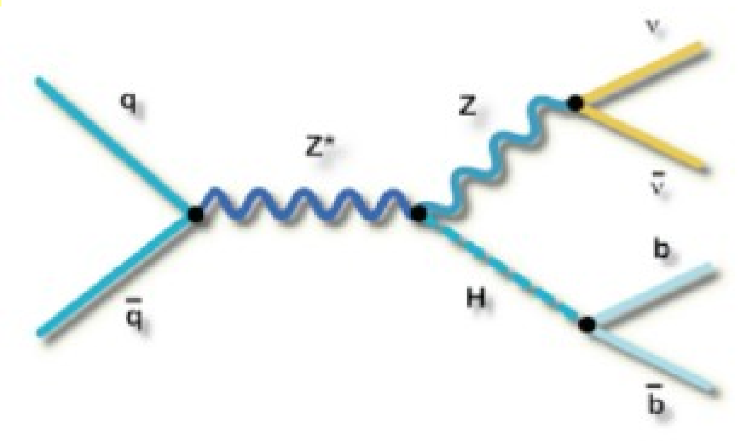
- Smallest signal rate but smallest background !
- Kinematically constrained



WH→lν bb: lepton+MET+2 b-jets

- Largest signal rate
- Larger V+jets background

Look for a dijet mass peak



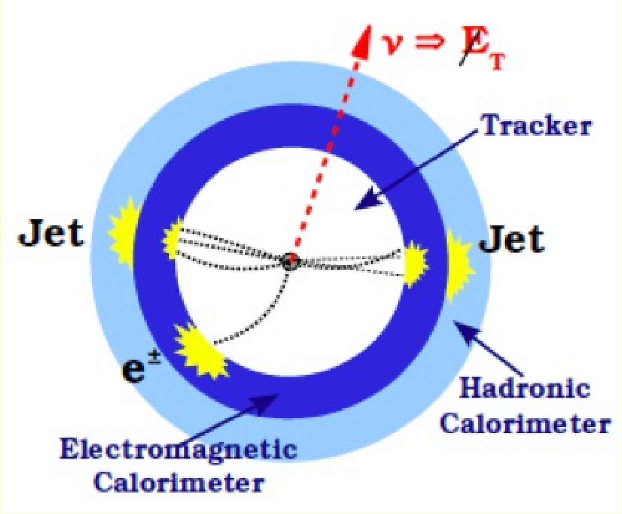
ZH→ν ν bb: MET+2 b-jets

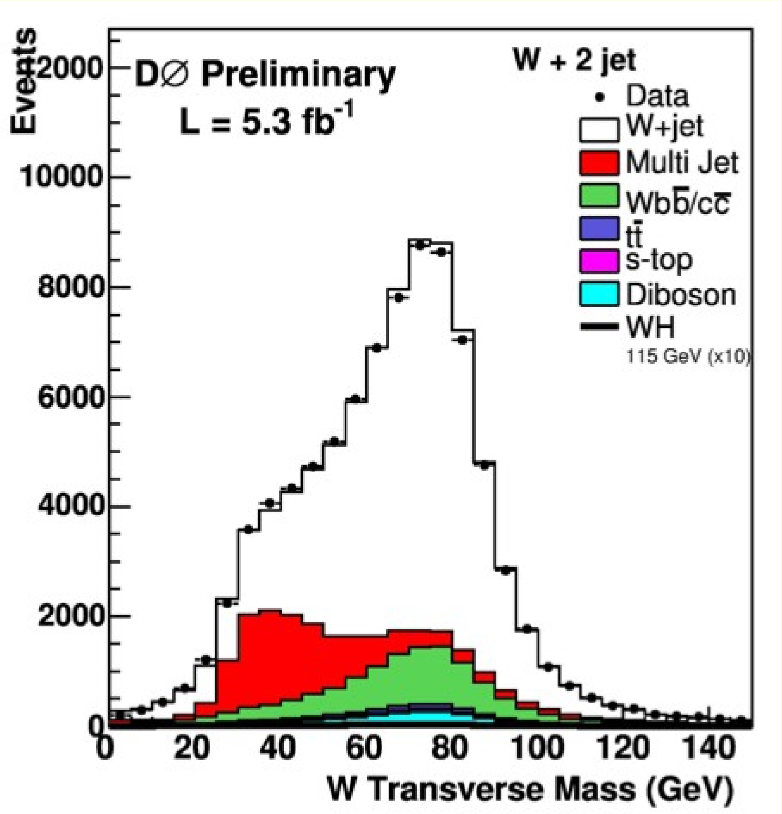
- Comparable signal rate to WH
- (significant contribution from
- WH→lν bb with missing lepton)
- Challenging instrumental background

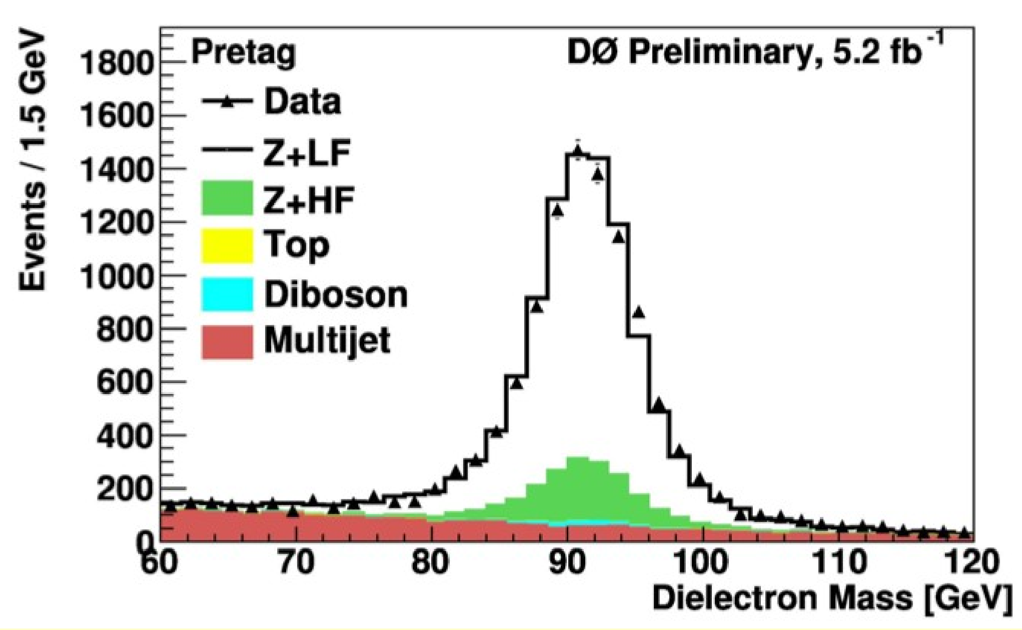
V+ 2(3) jets selection

Topologies

- Exploit W/Z leptonic decays for triggering
- Lepton pT > 10-15 GeV/c, MET > 20 GeV, jet pT > 15-20 GeV/c







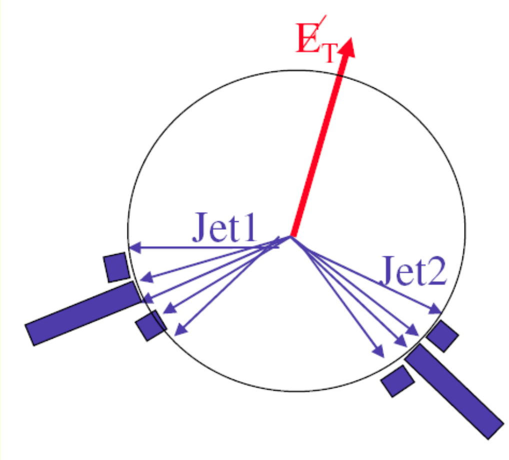
V+ 2(3) jets reconstruction

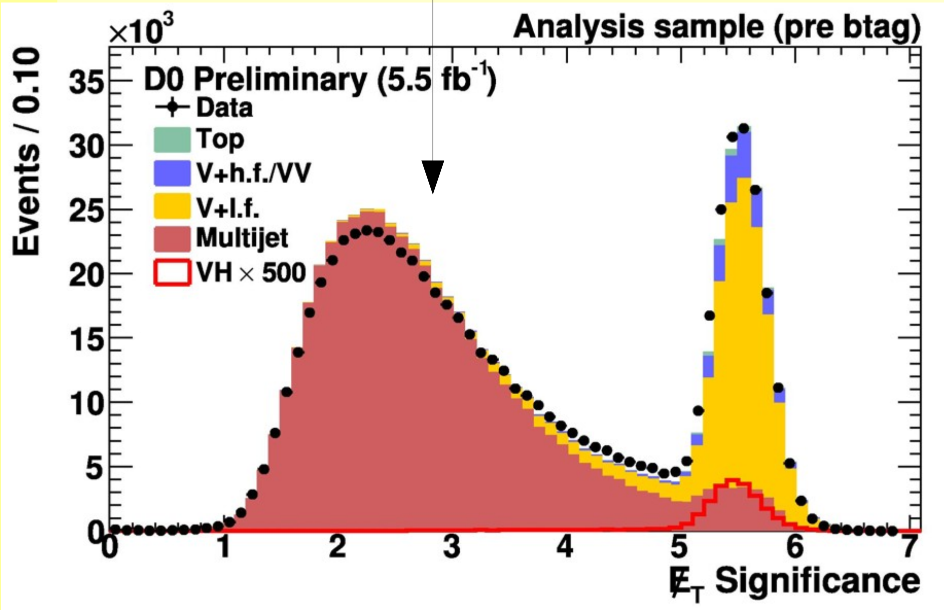
Topologies

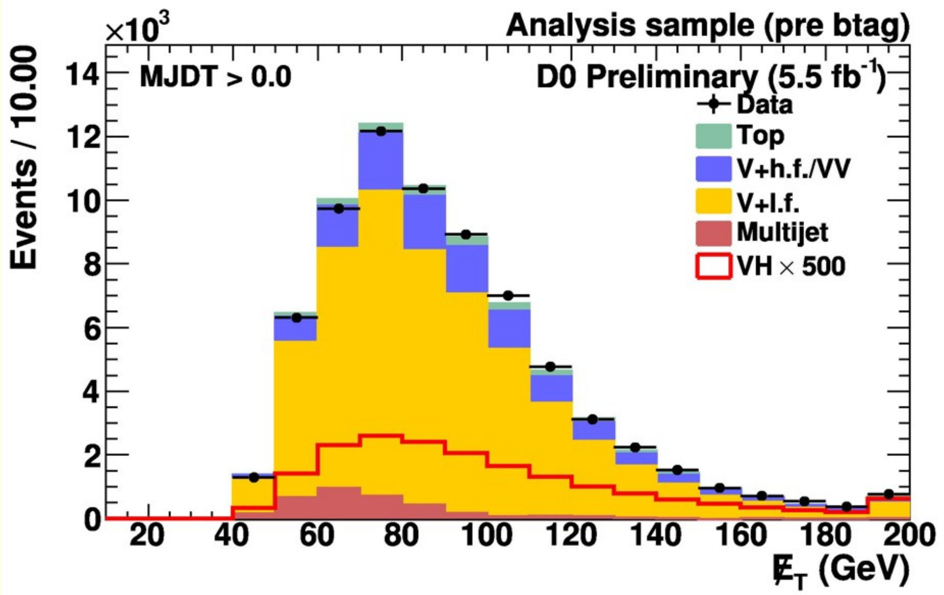
2 acoplanar jets and MET

- challenging to trigger on (MET+jets)
- large instrumental background from **QCD multijet**

Exploit significance of MET and correlation of calorimeter and tracker-based MET measurements

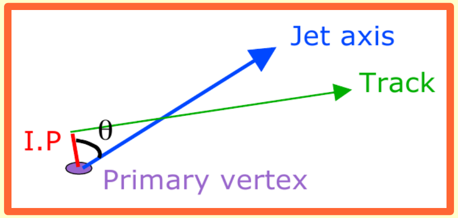






Heavy flavour identification

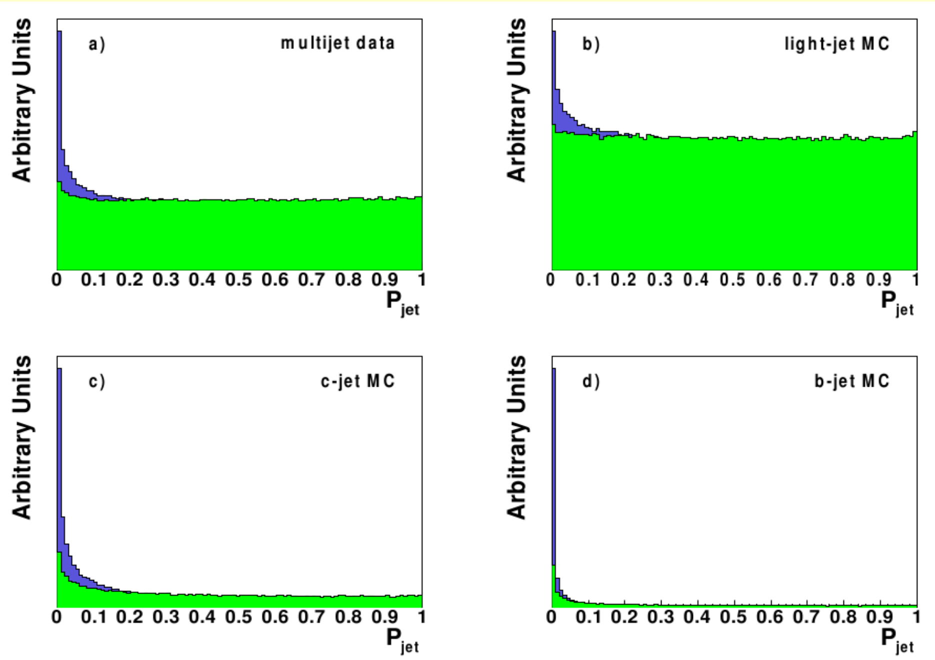
Track impact parameter based discriminant

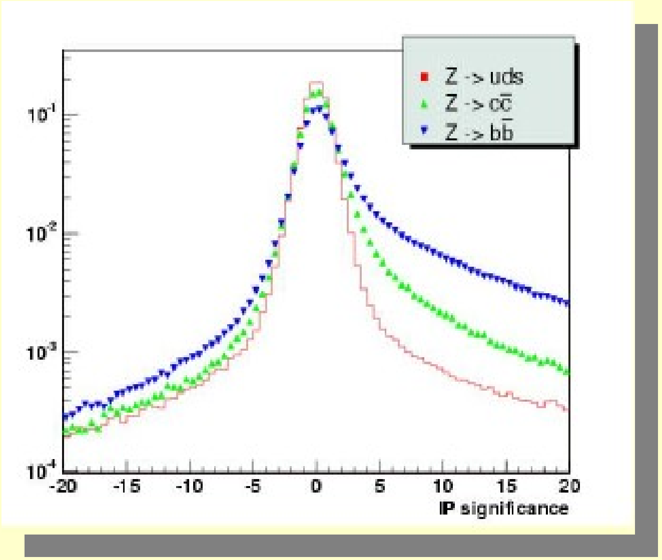


- **Discrete :** **CSIP**, count tracks $S_{IP} > S_0$ ($S_{IP} = IP/\sigma_{IP}$)
- **Continuous :** **JLIP**, IP resolutions, *R(s), with* $S_{IP} < 0$

$$\mathcal{P}_{trk}(\mathcal{S}_{IP}) = \frac{\int_{-50}^{-|\mathcal{S}_{IP}|} \mathcal{R}(s)ds}{\int_{-50}^{0} \mathcal{R}(s)ds}$$

$$\mathcal{P}_{jet}^{\pm} = \Pi^{\pm} \times \sum_{j=0}^{N_{trk}^{\pm}-1} \frac{(-\log \Pi^{\pm})^j}{j!} \quad \text{with} \quad \Pi^{\pm} = \prod_{i=1}^{N_{trk}^{\pm}} \mathcal{P}_{trk}(\mathcal{S}_{IP<0}^{IP>0})$$





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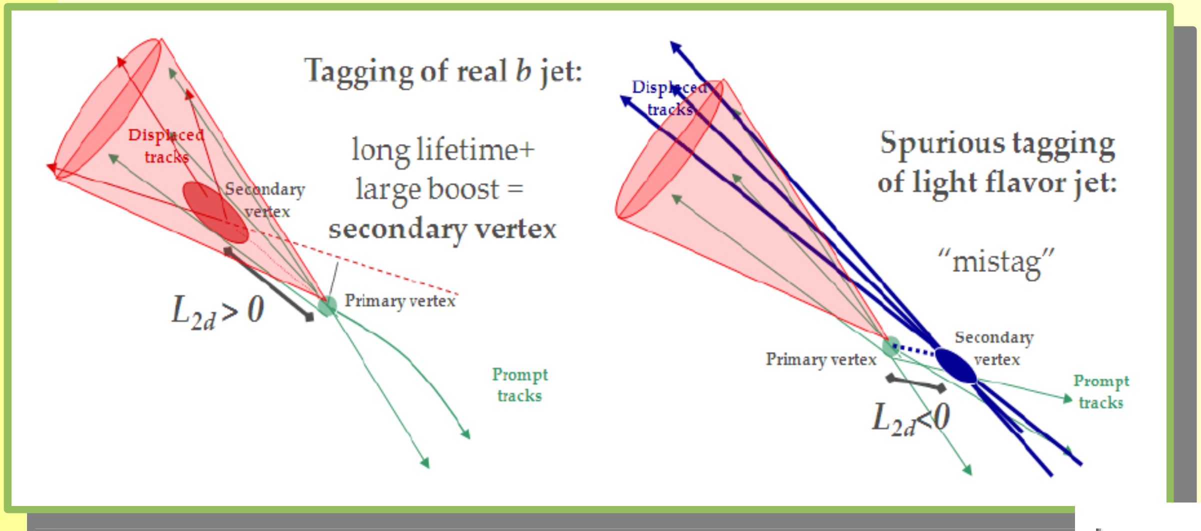
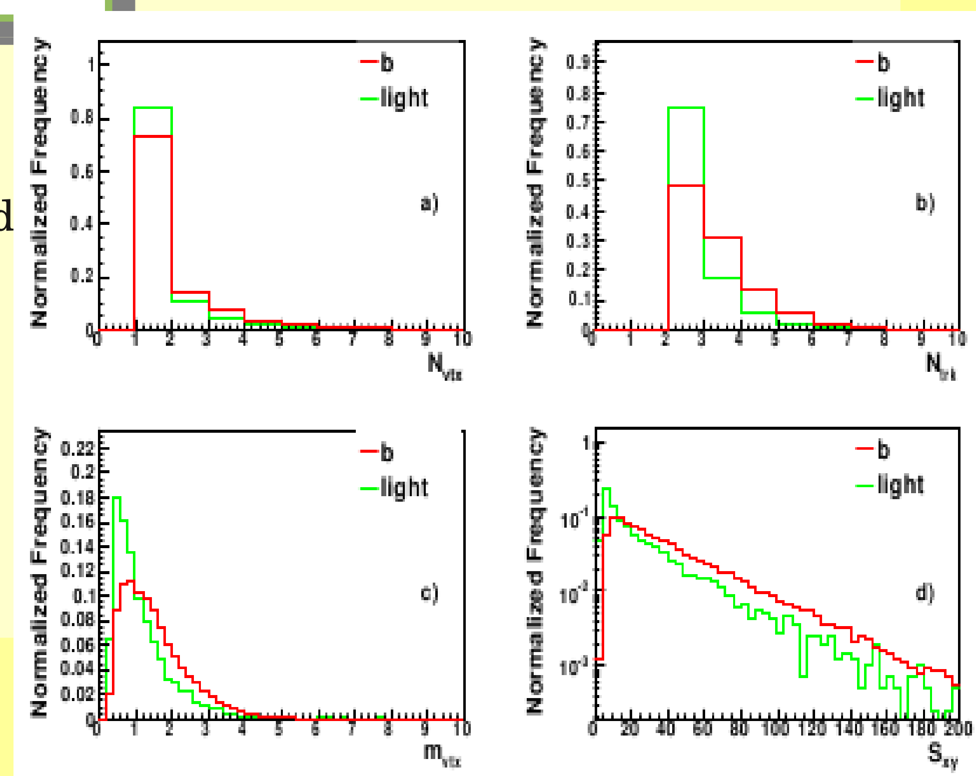
Heavy flavour identification

Secondary vertex, SVT



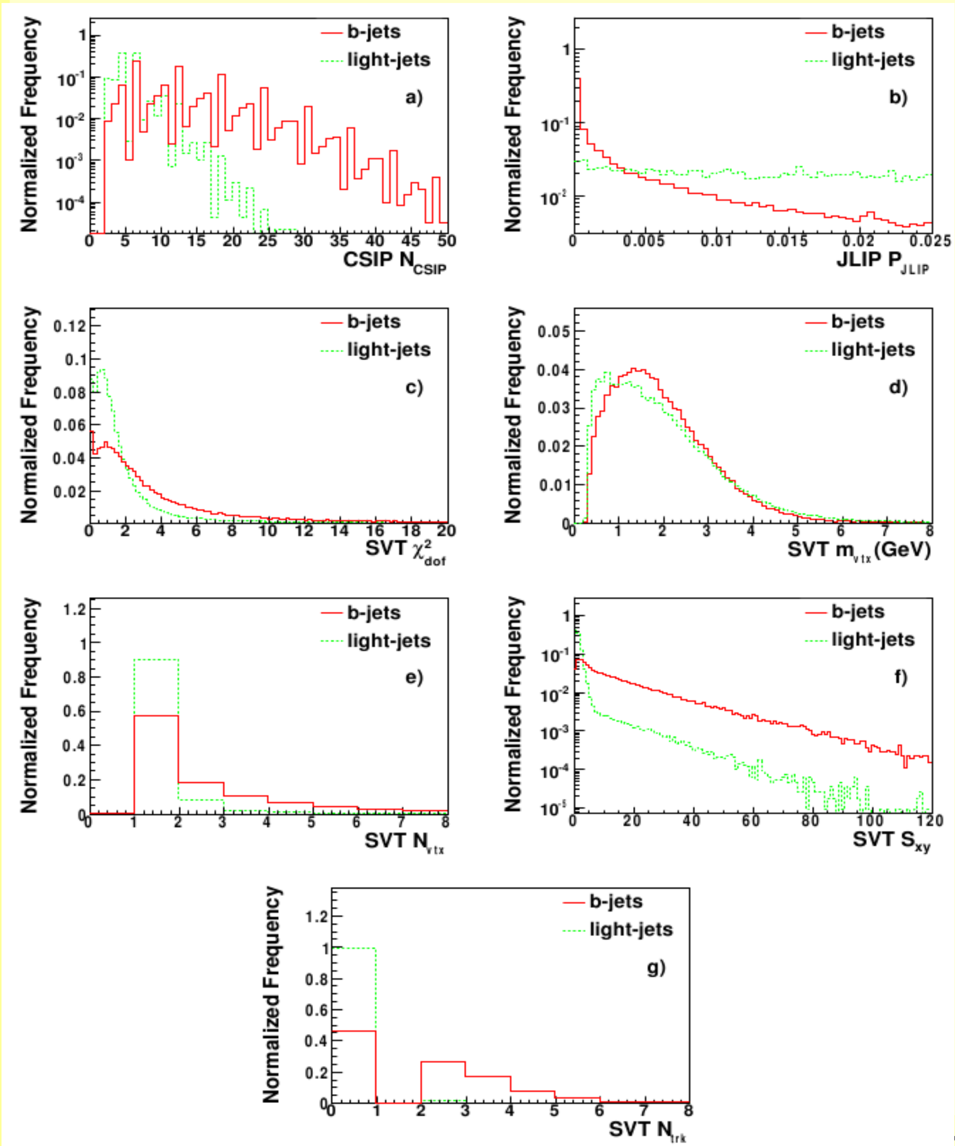


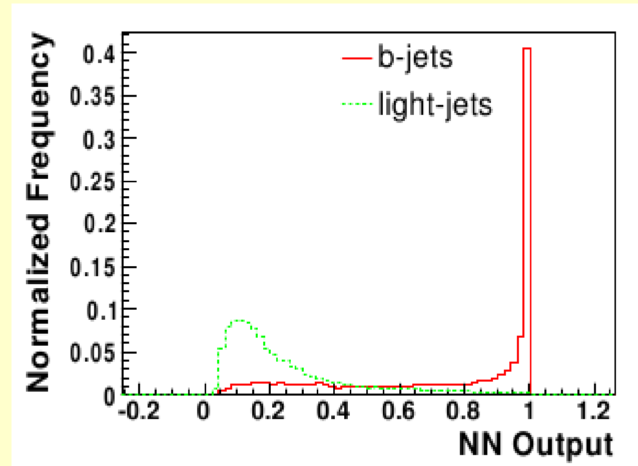
- Start from track-jet *("simple cone")*
- Search for displaced vertex with Kalman based filter
- **Jet tagged if :** ΔR(vertex,jet) < 0.5 & $S_{Lxy} > S_0$

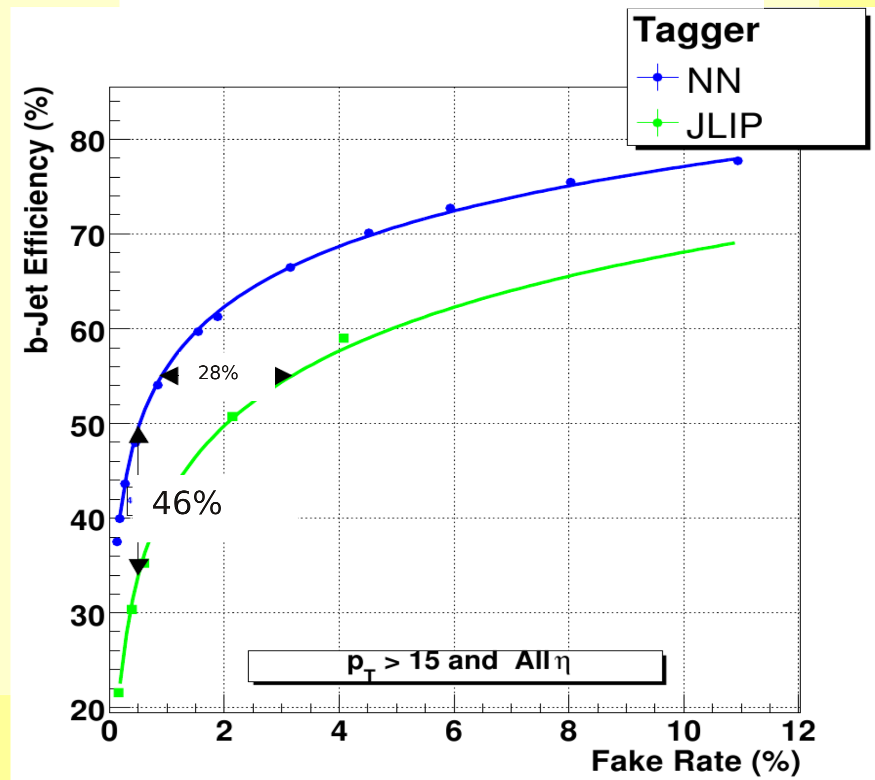
All in one !

Maximizing performances with multivariate technics

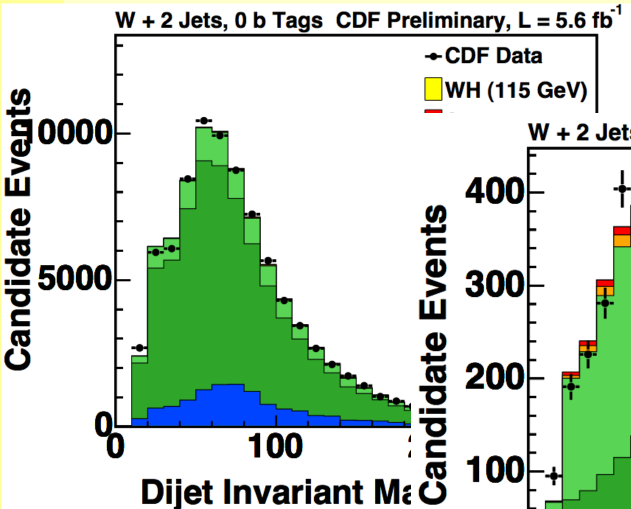
- CSIP, JLIP & 5 SVT properties

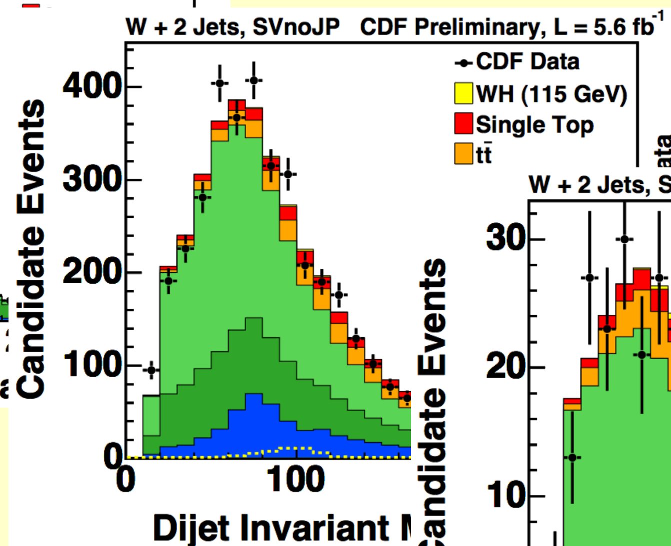


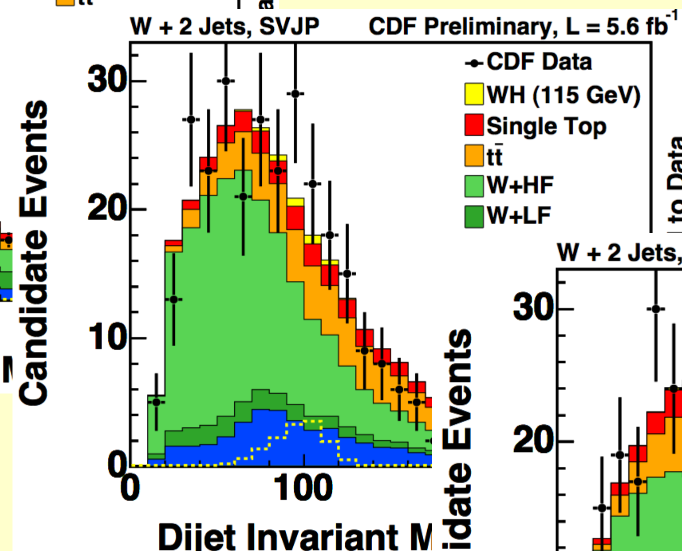


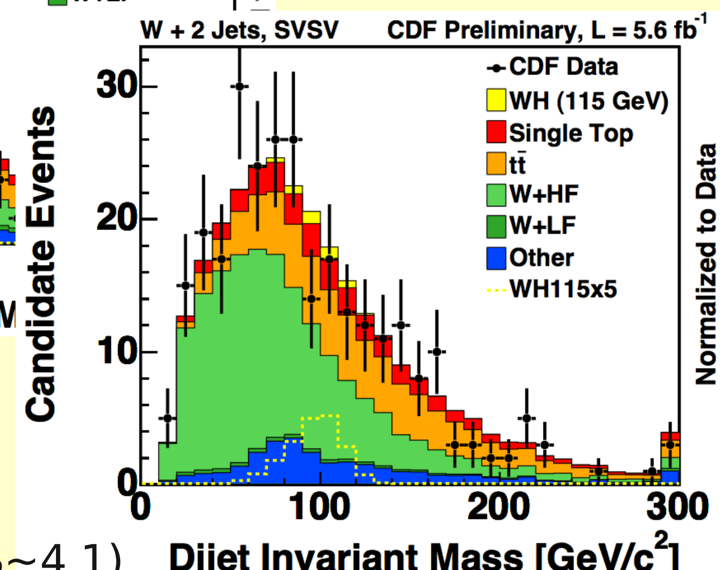


Heavy flavour identification









WH→lν bb

Dijet invariant mass is the single most discriminant variable

S:B ~ 1:4000

S:B ~ 1:400 (S~10.3)

S:B ~ 1:100 (S~2.8)

Search channels

S:B ~ 1:75 (S~4.1)

Improving sensitivity

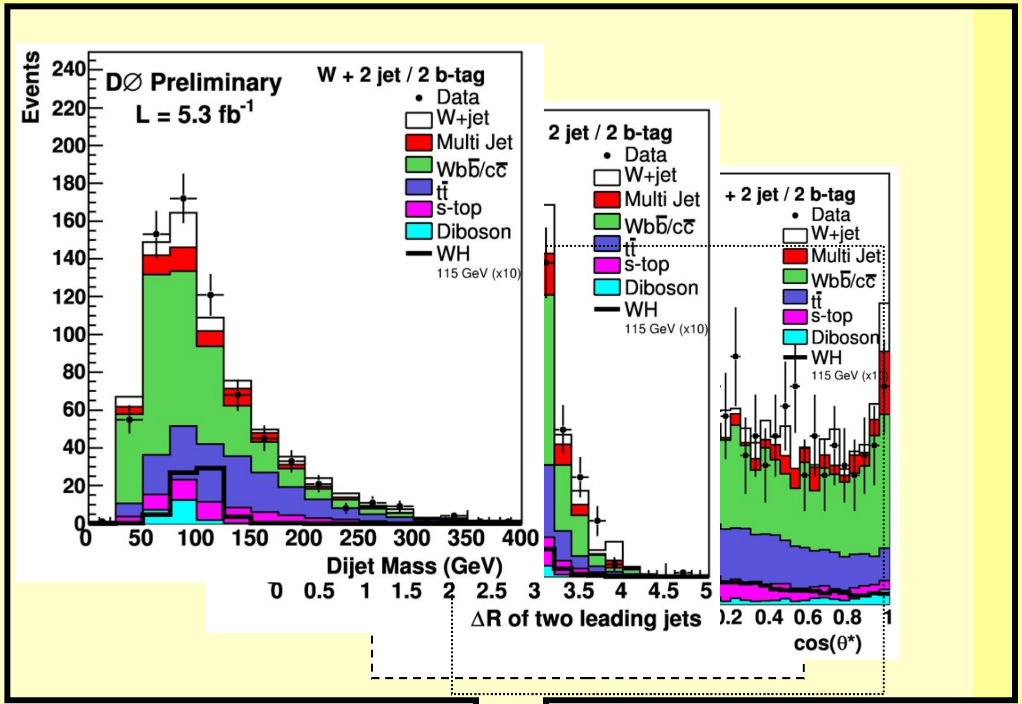
Multivariate techniques

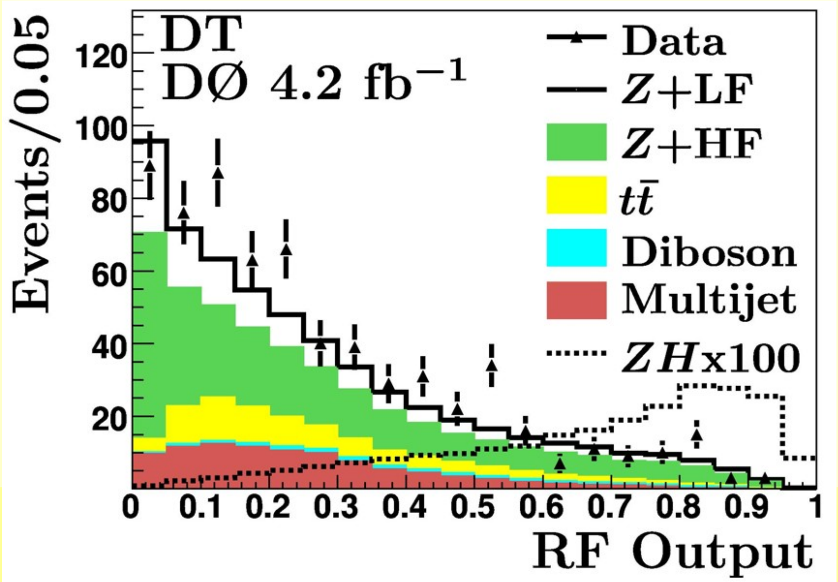
Used in all analyses

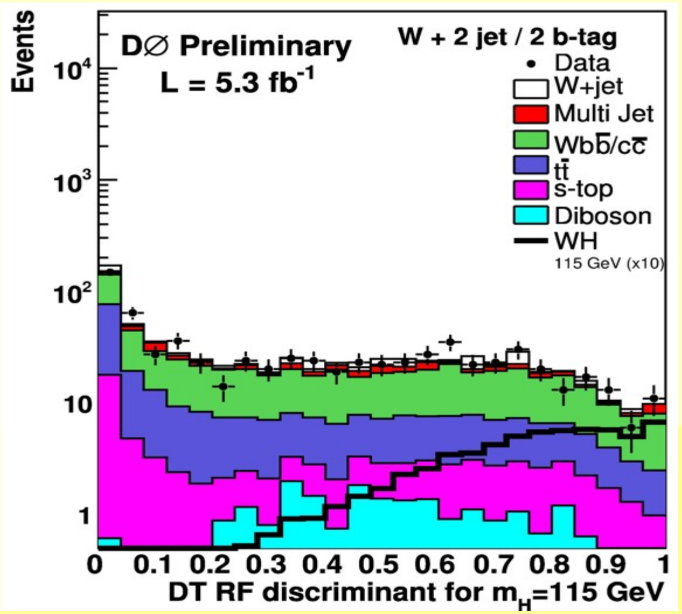
Neural Net, Decision Trees

Exploit correlations of many weakly disriminating variables

~15-20% improvements w.r.t dijet mass





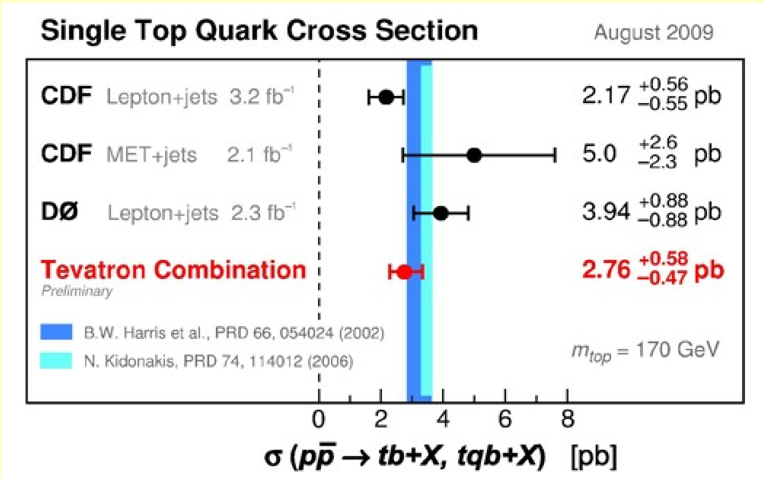


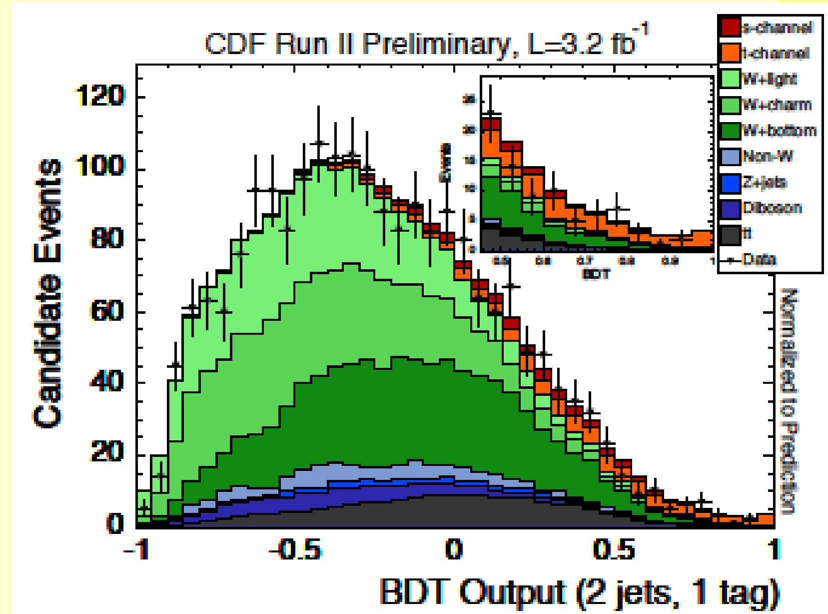
Benchmark measurements

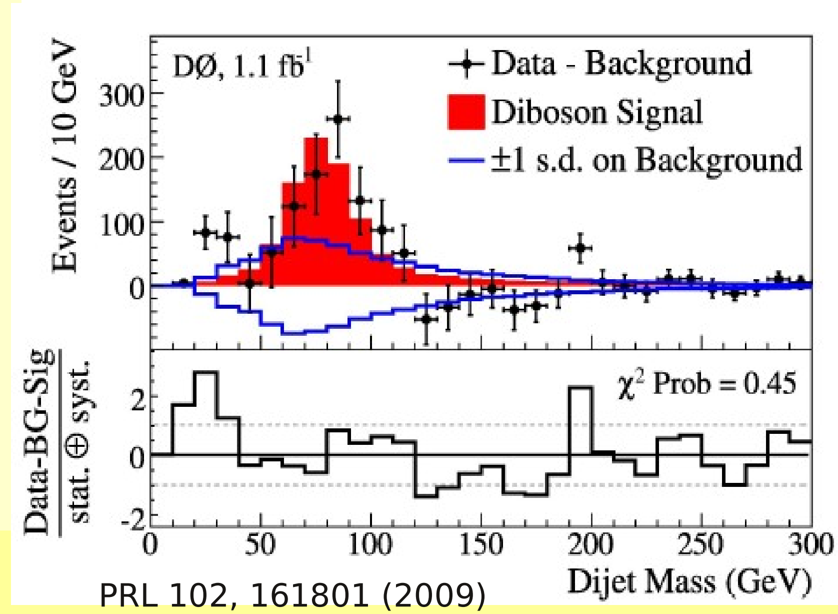
Strategy validation

Phys. Rev. Lett. 103, 092001, 092002 (2009)

- Single-top observation
- Diboson production







PRL 102, 161801 (2009)

- Fighting same backgrounds
- Similar techniques & optimizations
- Measured x-sections consistent with SM predictions

Systematic uncertainties

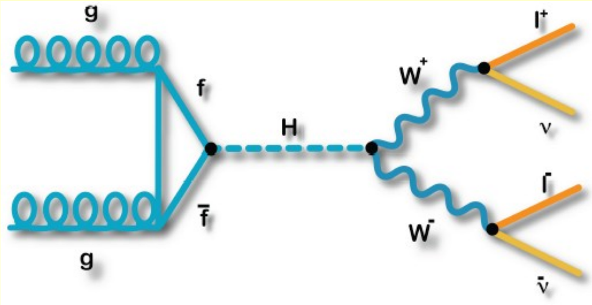
Example: D0 ZH--> nunubb search

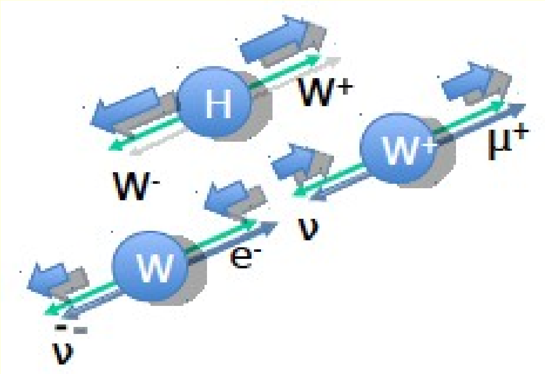
Systematic Uncertainty	Type	Signal	Background
Jet Energy Scale	Shape & Norm	2.7	3.5
Jet Reco*ID	Shape & Norm	0.4	0.8
Jet Resolution	Shape & Norm	0.9	0.8
Cross Sections	Flat Norm	6.0	7.5
Mulit-jet Normalization	Flat Norm	–	1.5
Heavy Flavor Fraction	Flat Norm	–	9.8
Parton Distribution Function	Shape only	–	–
Vertex Confirmation	Shape & Norm	2.5	1.5
Taggability	Shape & Norm	3.6	3.3
b-Tagging	Shape & Norm	8.7	7.9
Trigger Efficiency	Shape & Norm	3.5	3.4
μ ID	Shape & Norm	1.1	1.5
EM ID	Shape & Norm	0.2	0.3
Alpgen MLM	Shape only	–	–
Alpgen Event Scale	Shape only	–	–
Alpgen Underlying Event	Shape only	–	–
Luminosity	Flat Norm	6.1	6.1

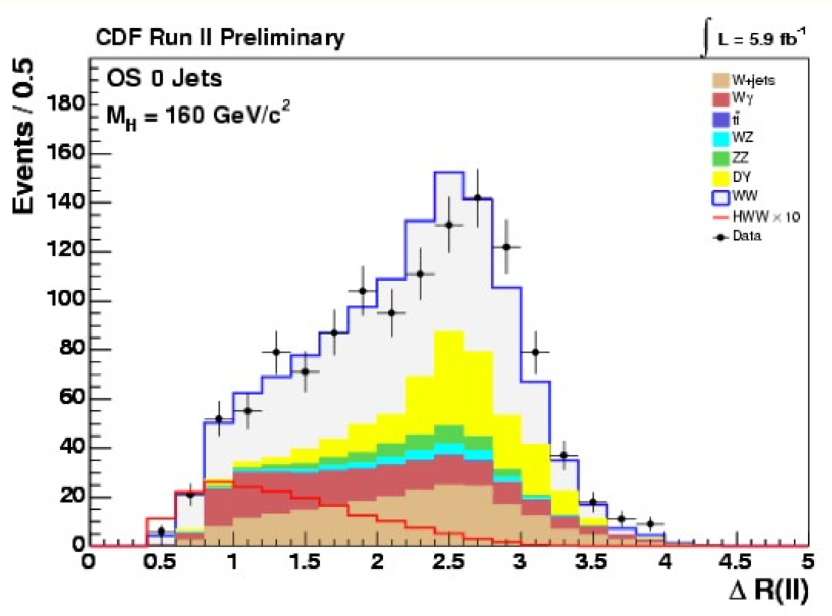
Total: ~15% ~ 20-25%

High mass searches

- Highest sensitivity channel for m_H>125 GeV.
- Dominant contribution from gg→H→WW, but consider also VH and VBF production (~35% more signal).
- Clean signature of two opposite-sign leptons (ee, μ μ , eμ) plus MET.
- Dominant backgrounds: top paris, diboson
- Theory: gg-->H NNLL+NNLO







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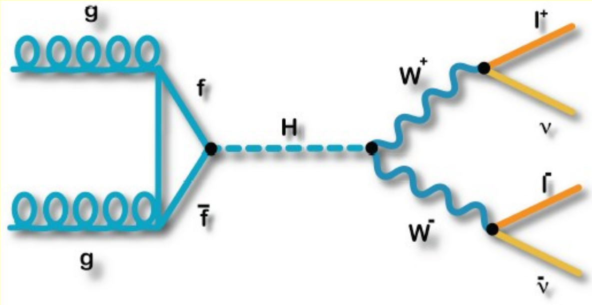
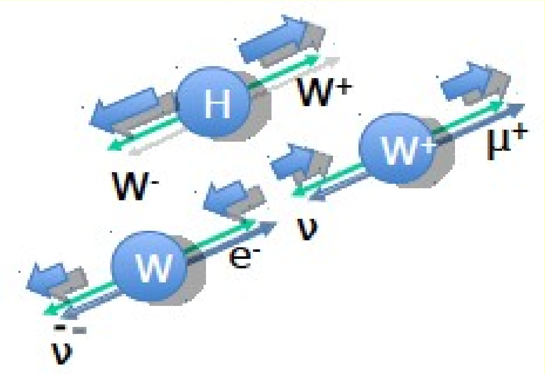
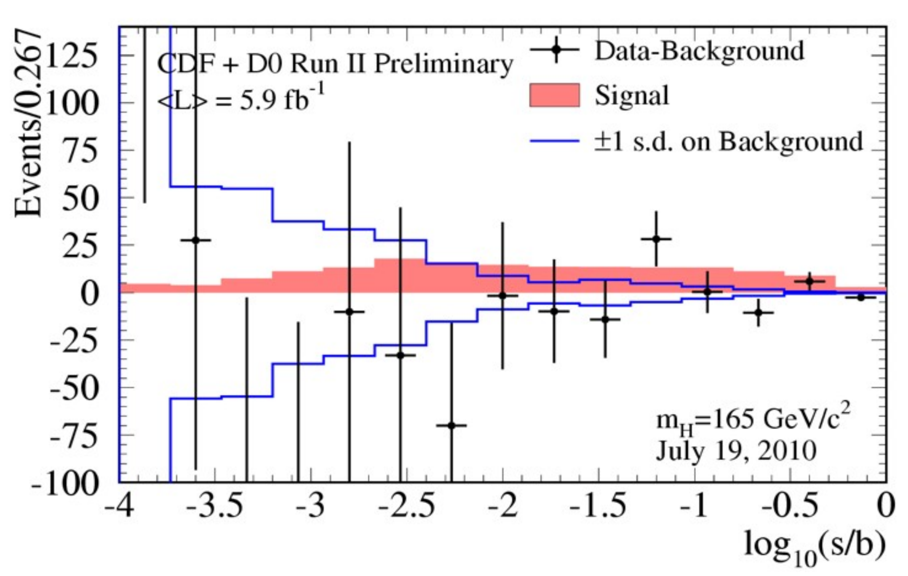


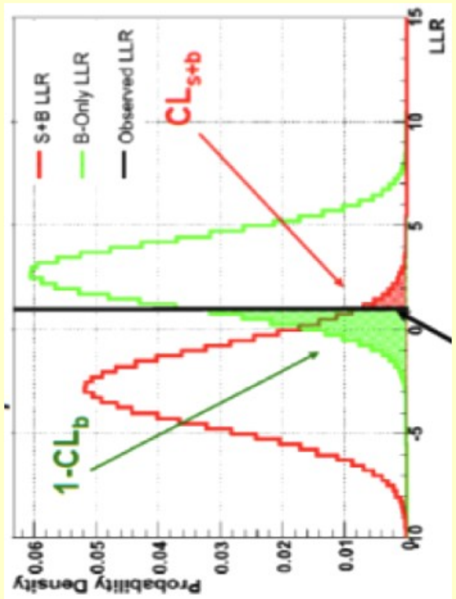


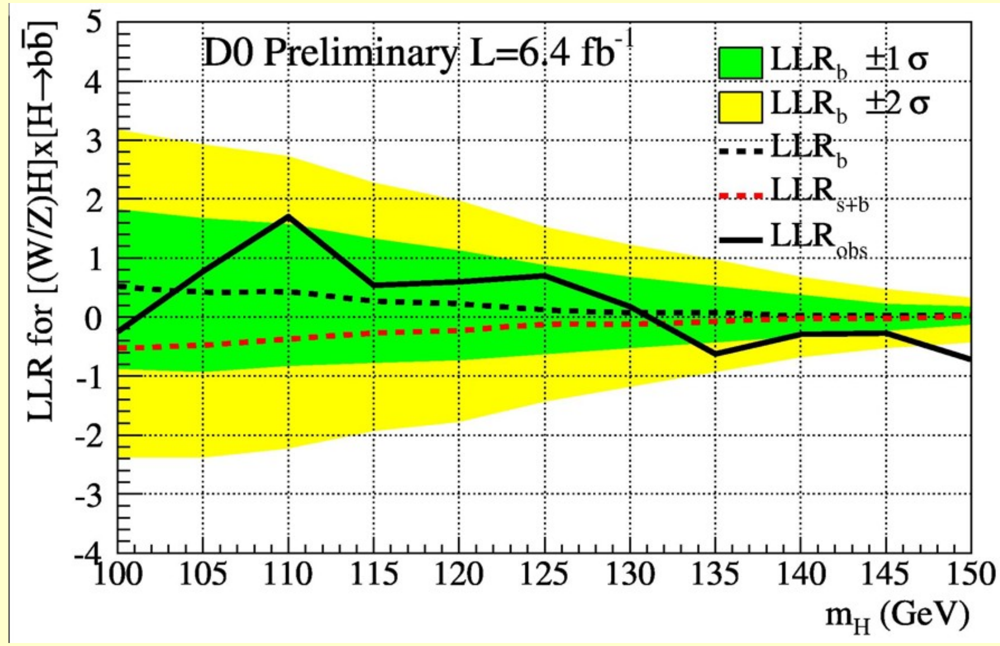


No excess in data: setting limits

Data deficit

Data excess





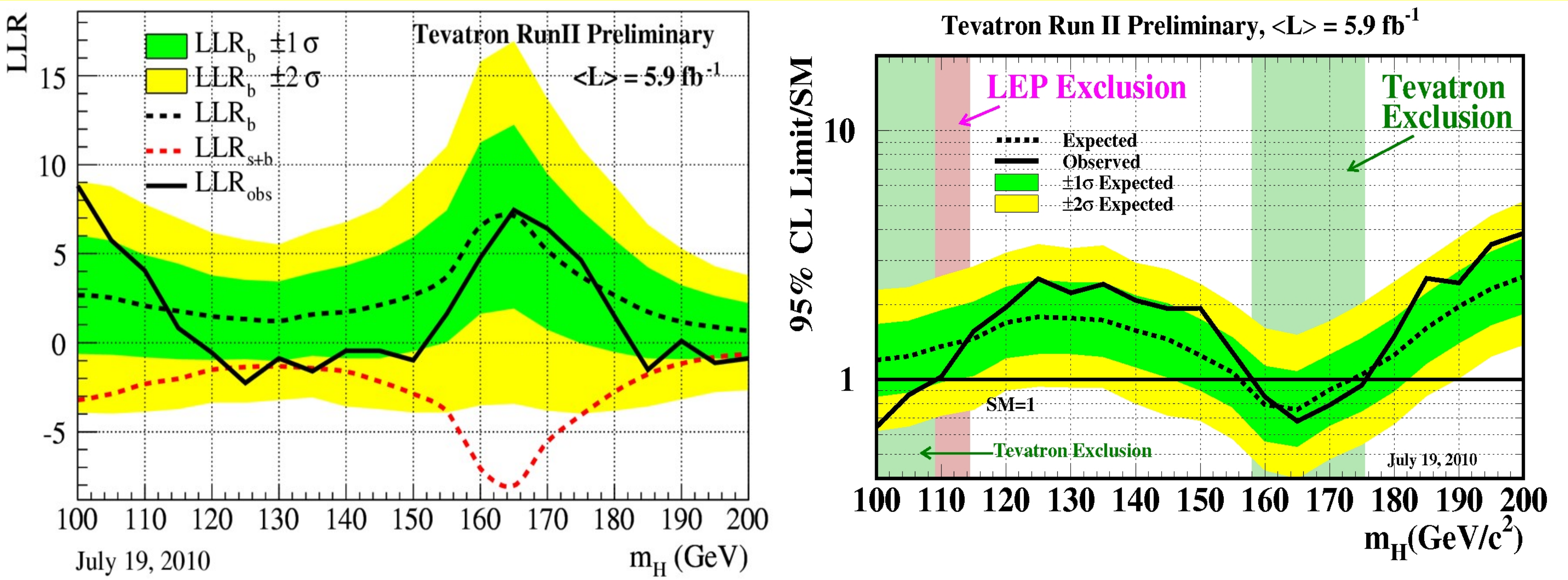
Modified Frequentist / Bayesian methods used to extract limits

Define: $CL_s = \dfrac{CL_{s+b}}{CL_b}$

Signal cross sections for which $CL_s < 0.05$ are excluded at the ≥95% CL.

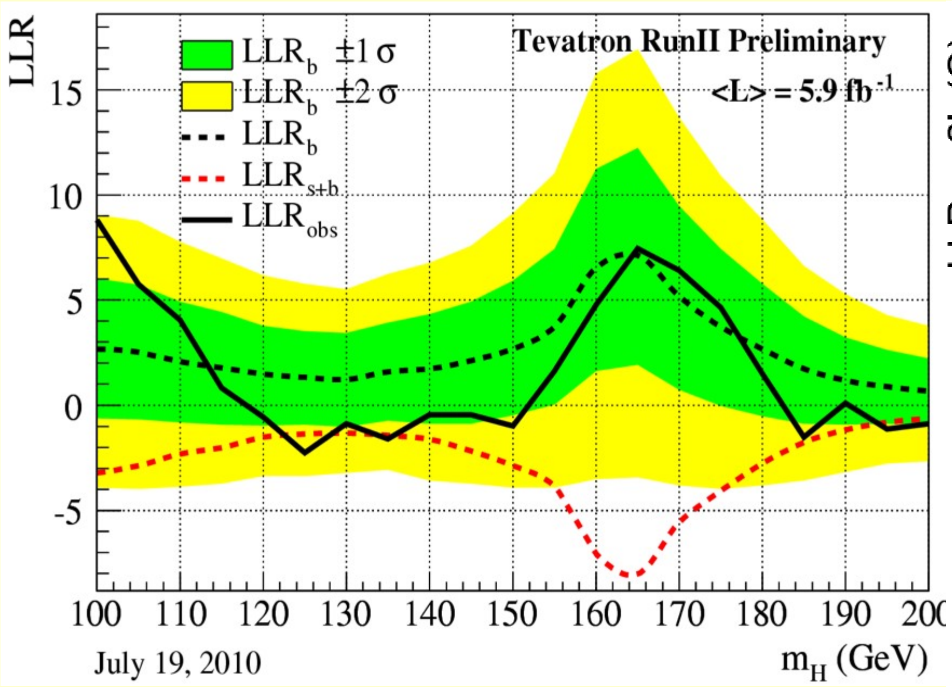
- Dashed lines show S+B and B-only mean value.
- Shaded bands indicate 1 and 2 sigma variations of B-only distribution
- Solid black line indicates **data observation**

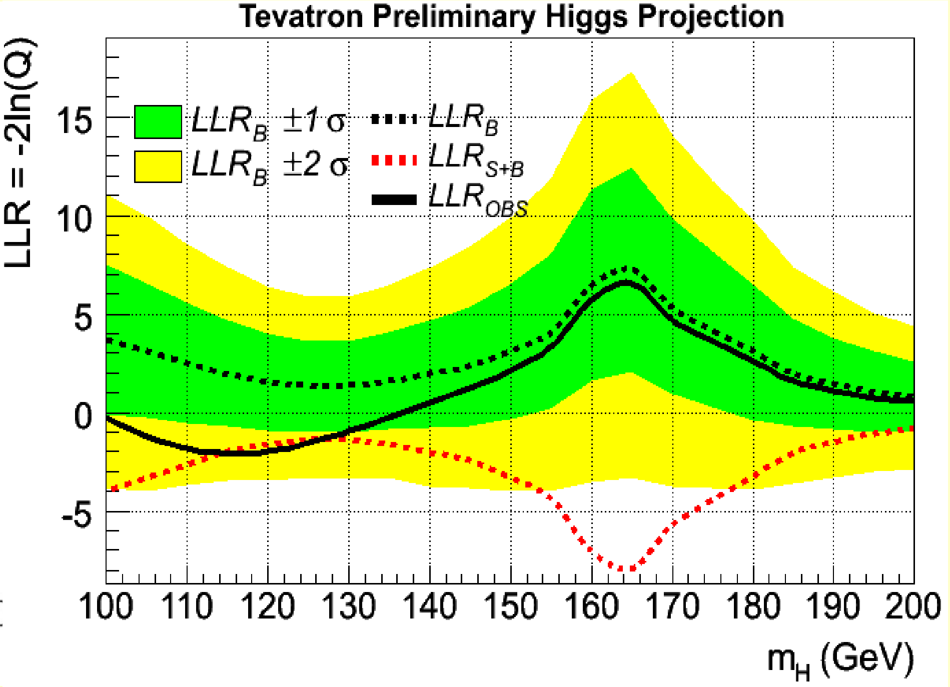
TeVatron combination



- A-priori sensitivity >1-1.5σ in the m_H=100-150 GeV range.
- Expected exclusion range from 156 to 173 GeV
- “Signal-like” excess at low mass but also consistent with background-only hypothesis.
- @ 115 GeV, 1.45x SM

Perspectives



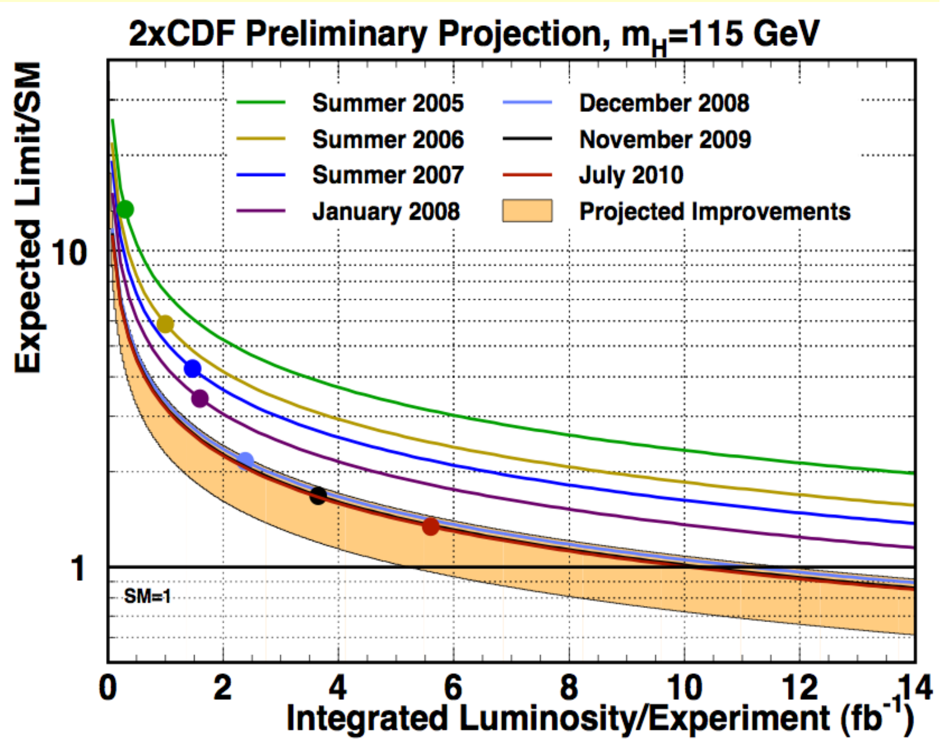


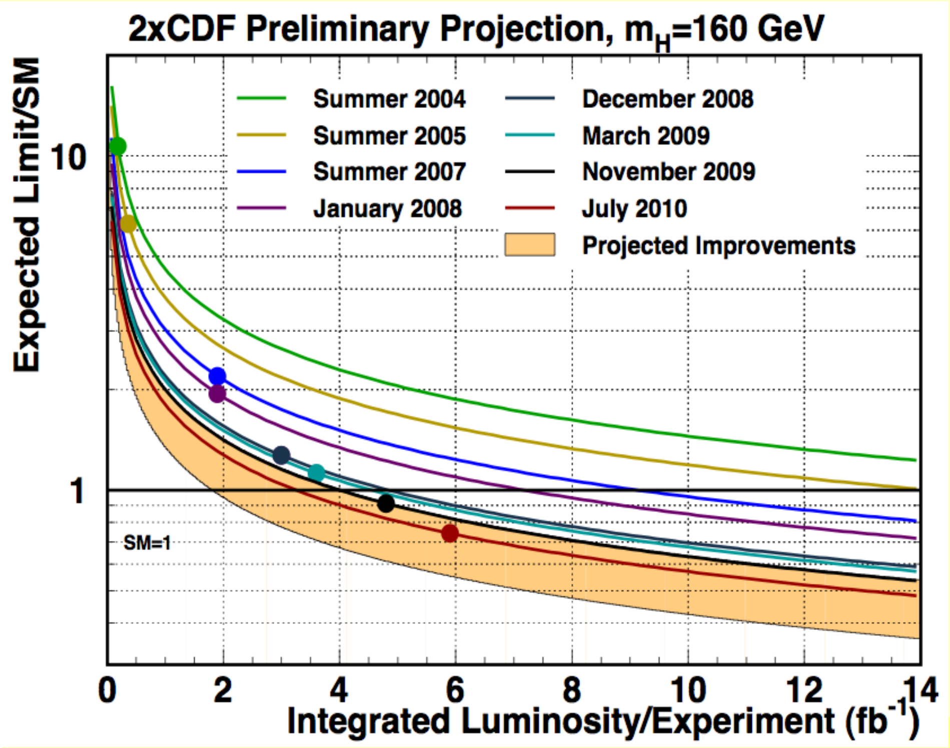
Injecting a SM-like signal with m_H=115 GeV at 6 fb^{-1} and evaluate expected LLR

➔ observed limit consistent with a what would be expected from signal+background (but also consistent with background-only :))

Perspectives

- Try to keep smart ! Limits have improved faster than 1/√L due to analysis improvements.
- Major effort underway to continue to improve intrinsic sensitivity:
  - Optimized object identification/resolution
  - Optimized selections and signal-to-bckg discrimination
  - Reduced systematic uncertainties
  - Adding new channels …





D0 Higgs sensitivity improvements

Type	Projected Improvement	WH→lvbb	ZH→llbb	ZH→vvbb	H→WW	Other Channels
Lepton ID	MVA Electron ID	1%	5%	-1%	3%	3%
	Improved MuonID/tracking	4%	3%	-2%	0%	3%
	Add Isolated Tracks	2%	0%	-1%	3%	2%
	Add ICR Electrons	2%	0%	-1%	3%	2%
	Add EC Electrons	0%	0%	0%	0%	2%
	Improved energy scale	1%	2%	0%	2%	5%
Trigger/Reco	Trigger/Reconstruction Efficiency	5%	3%	0%	0%	5%
Jet Selection	Dijet Mass Resolution	10%	10%	10%	0%	0%
	MVA B-ID	5%	5%	5%	0%	0%
	MVA Bottom vs Charm	4%	4%	4%	0%	0%
MVA Analysis	Enhanced Techniques	10%	10%	10%	10%	10%
	New signal separation variables	5%	5%	5%	5%	5%
	MVA QCD Rejection	3%	1%	0%	3%	3%
	Matrix Element Discriminants	5%	5%	5%	5%	3%
	Kinematic Fitting	5%	0%	0%	0%	3%
Optimization	Track Variables	5%	3%	0%	5%	5%
	Optimized B-ID Usage	3%	3%	3%	0%	0%
	Optimized Jet Treatment	3%	8%	0%	0%	0%
New Channels	HWWetau	0%	0%	0%	0%	5%
	Vhetaujj	0%	0%	0%	0%	3%
	HZZ	0%	0%	0%	0%	3%
	VH->trileptons	0%	0%	0%	0%	3%
	Additional Decay Modes	5%	5%	0%	5%	5%
	Existing Improvements:	57%	70%	29%	41%	
	Planned Improvements:	36%	27%	23%	12%	
	Total:	113%	116%	59%	58%	

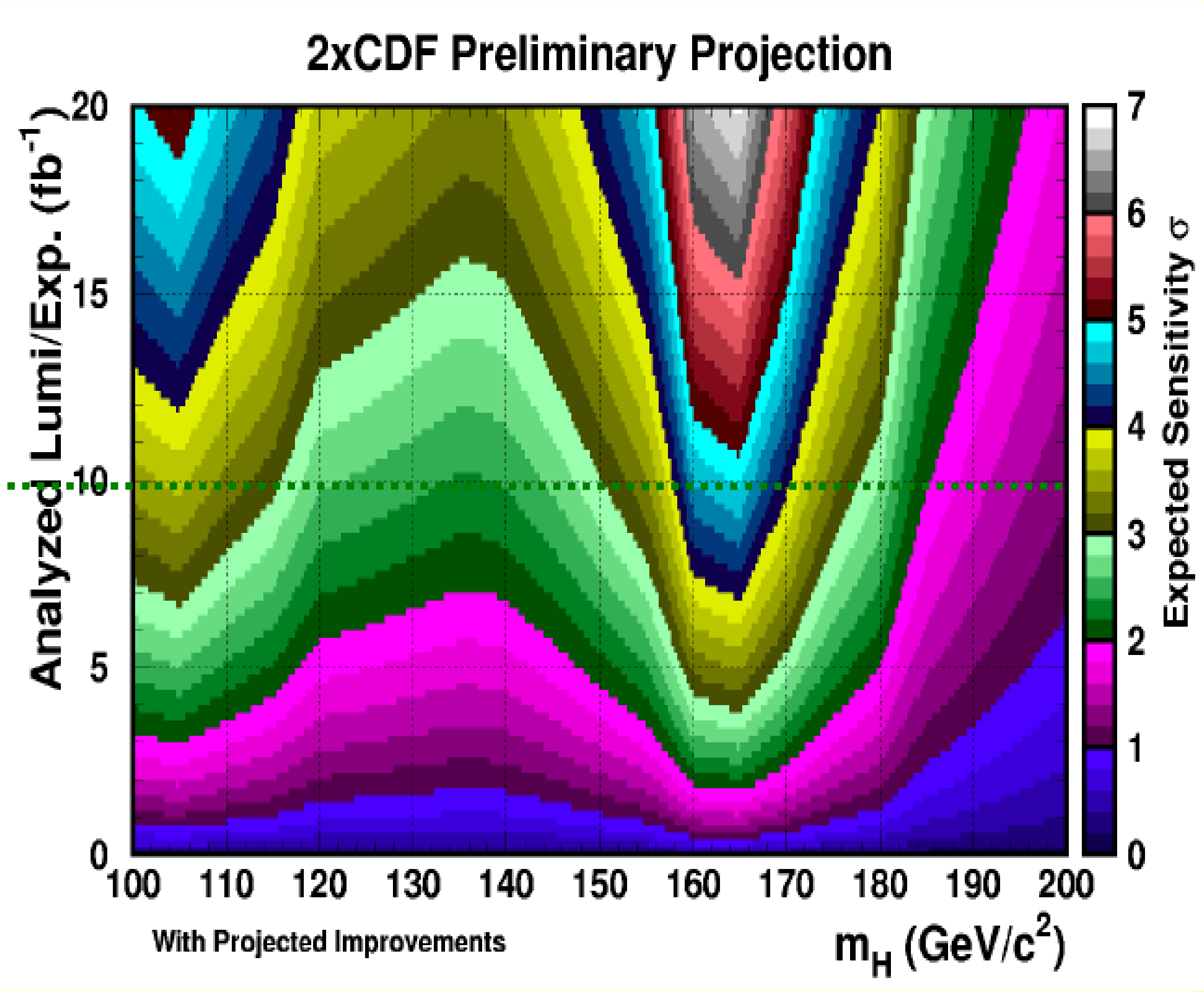
Yellow are existing improvements, white are (on-going) expected

Perspectives

End of 2011: 10 fb^{-1}/exp

$>2.4\sigma$ for $m_H<185$ GeV

3σ for $m_H\sim115$ GeV



Perspectives

End of 2014: 16 fb^{-1}/exp

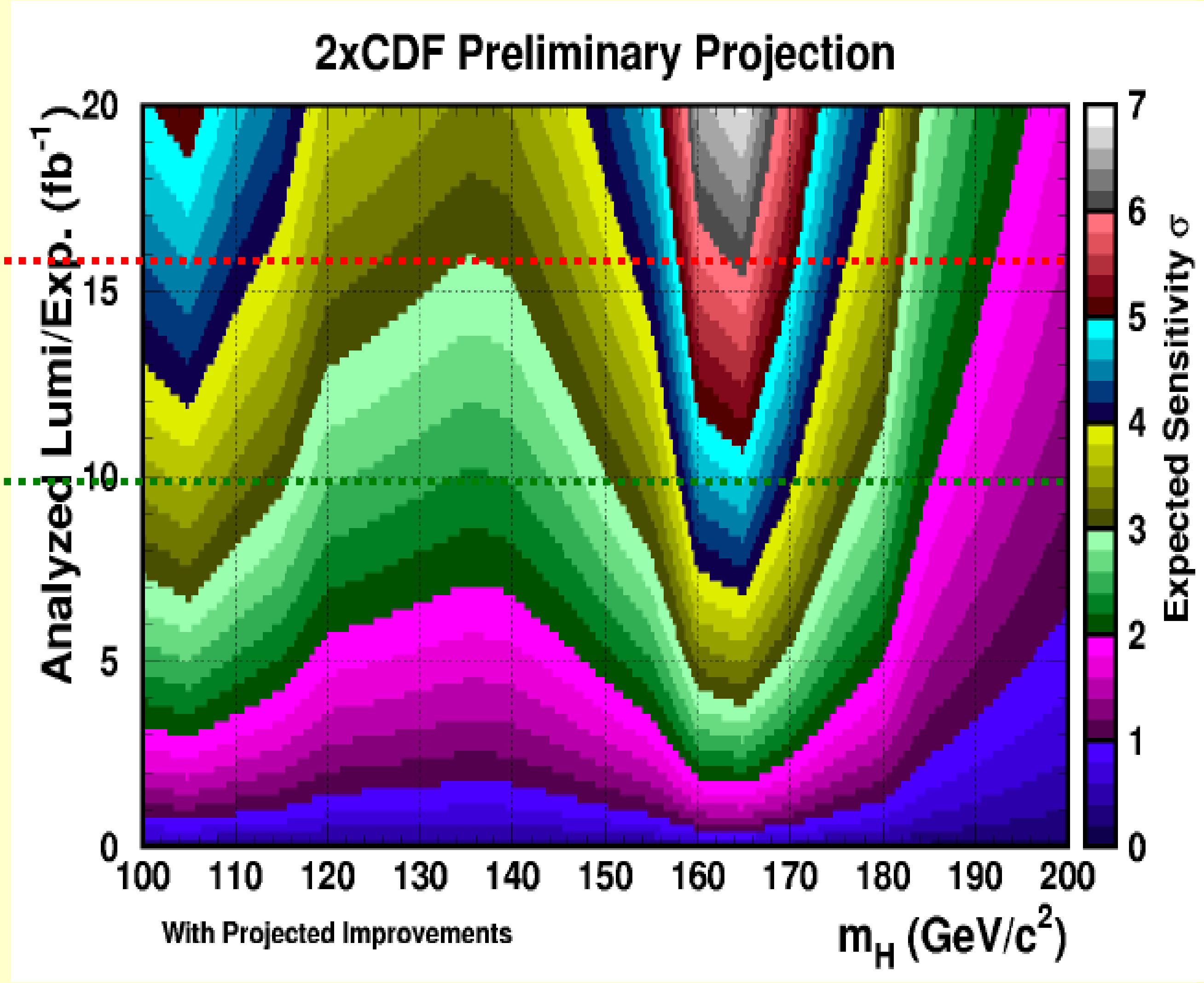
>3σ for m_H<180 GeV

4σ for m_H~115 GeV

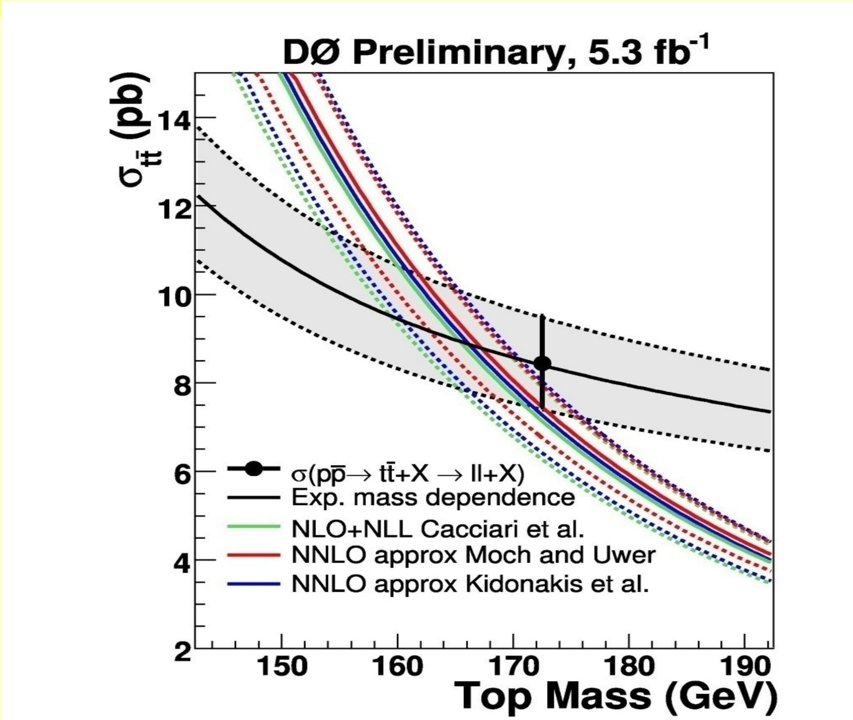
End of 2011: 10 fb^{-1}/exp

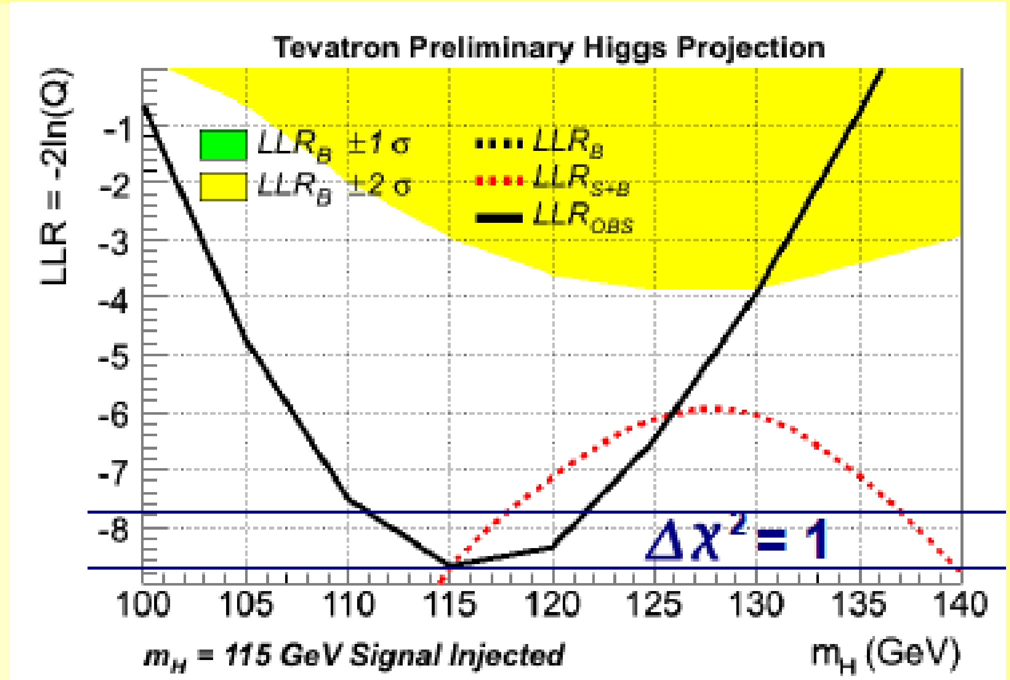
>2.4σ for m_H<185 GeV

3σ for m_H~115 GeV

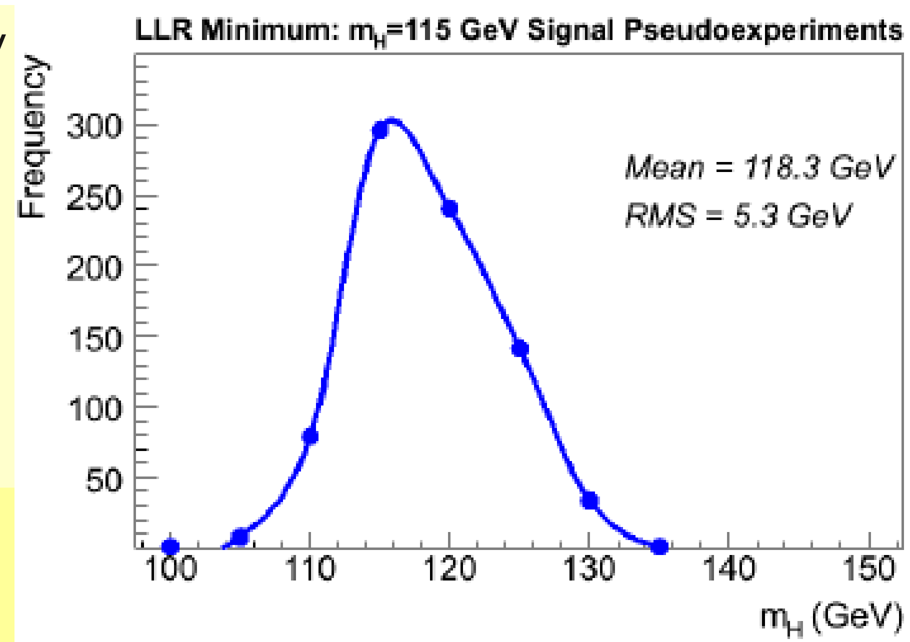


Perspectives

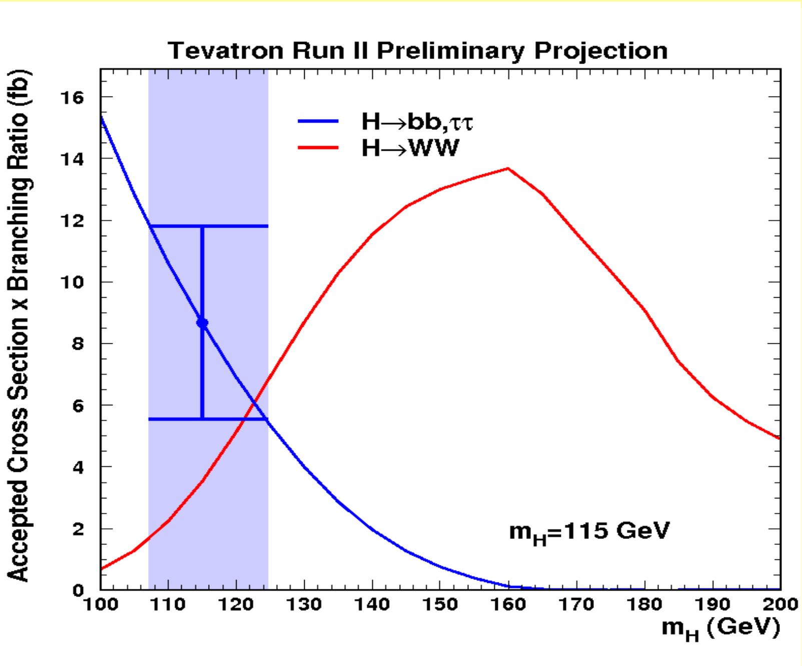


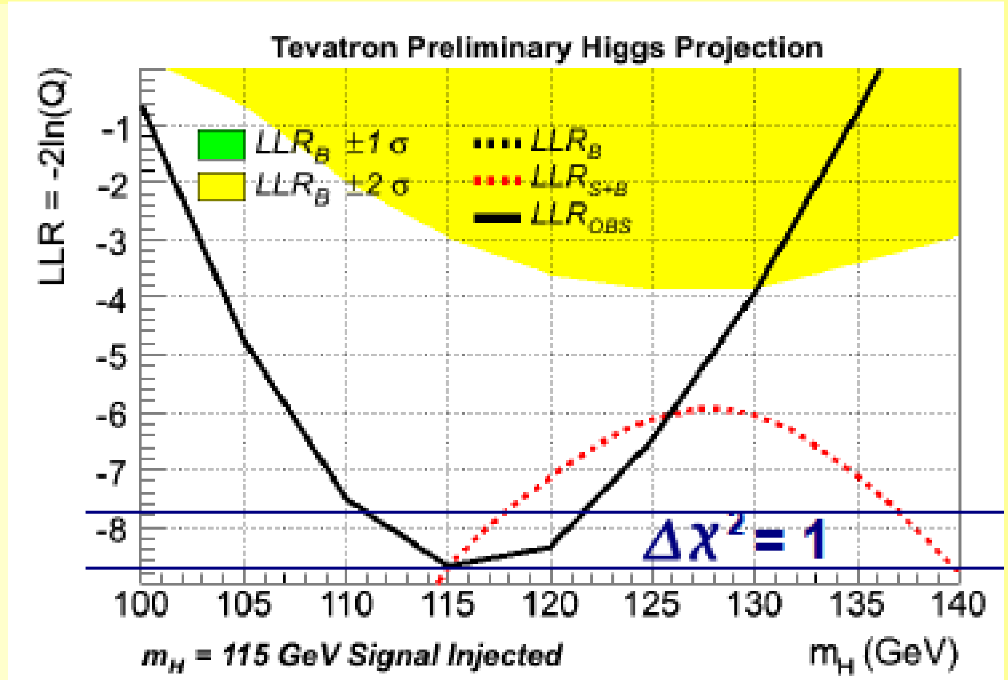


- Steeply falling cross section provides opportunity to determine mass with good resolution.
- Curvature of the observed LLR vs m_H is the most accurate estimate of such resolution.
- Ensemble testing assuming signal at 3σ level yields a mass resolution of **~5-6 GeV** below m_H~135 GeV. Resolution degrades at higher masses.



Perspectives





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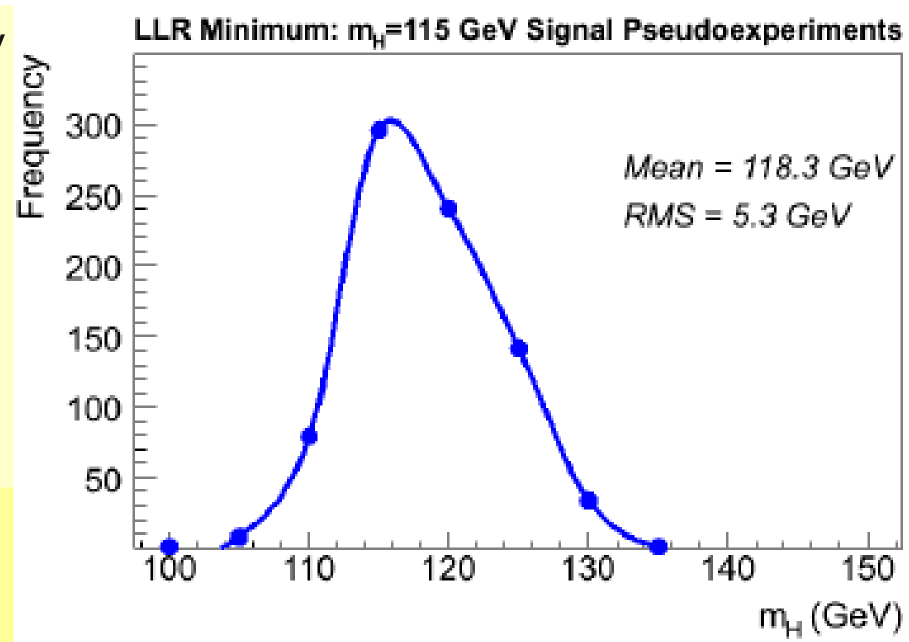
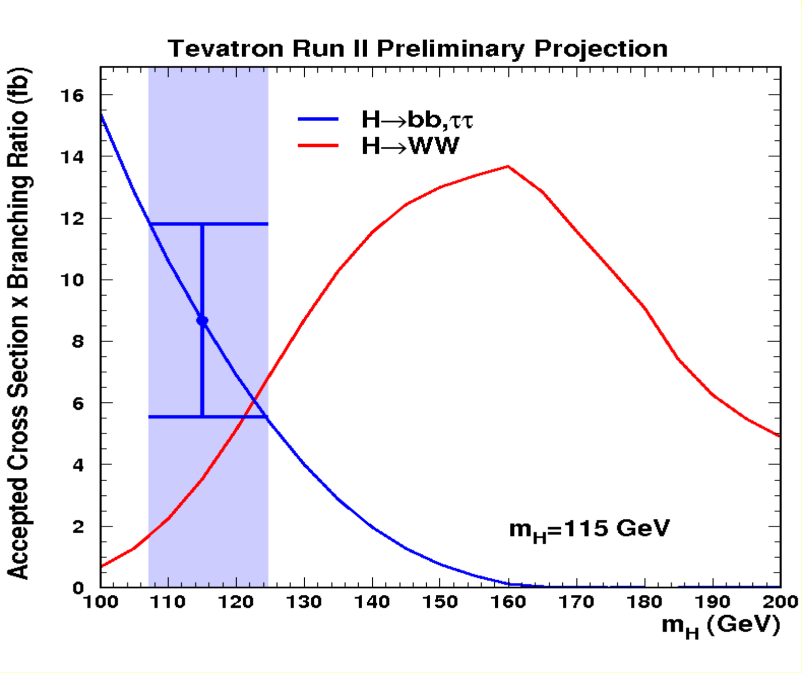
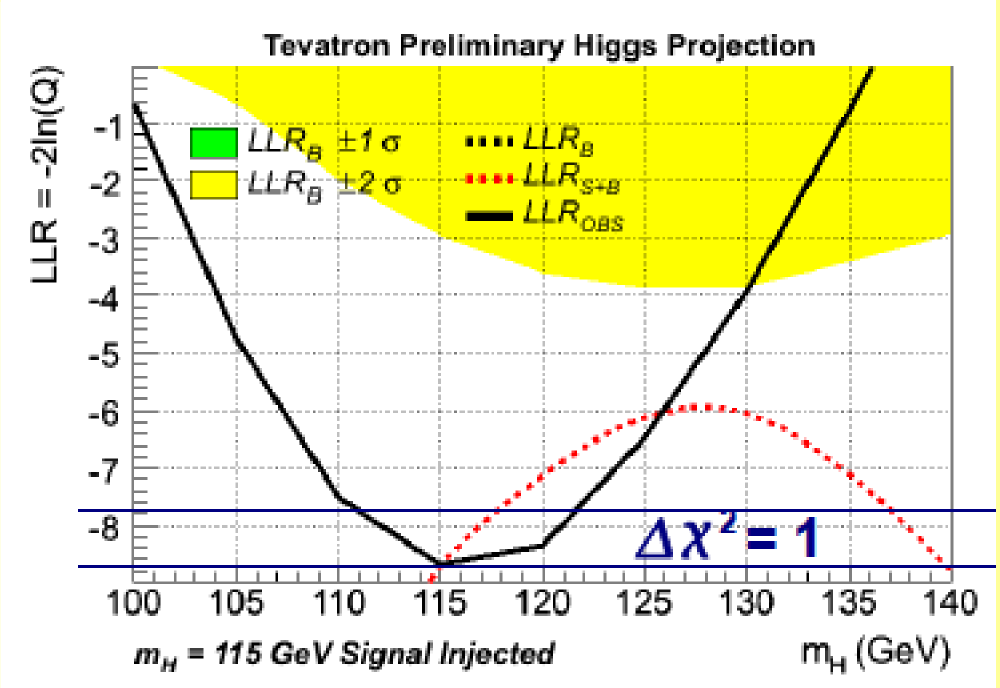


Perspectives





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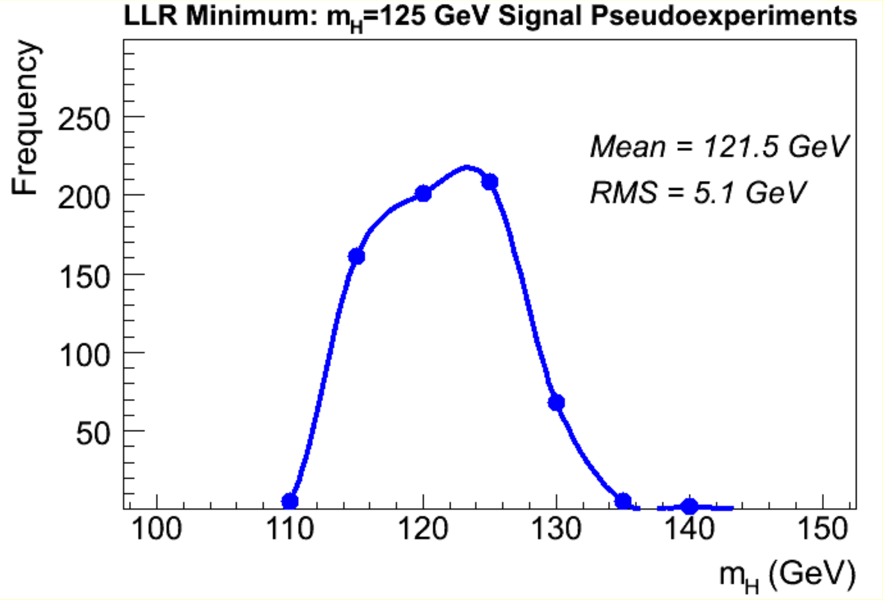
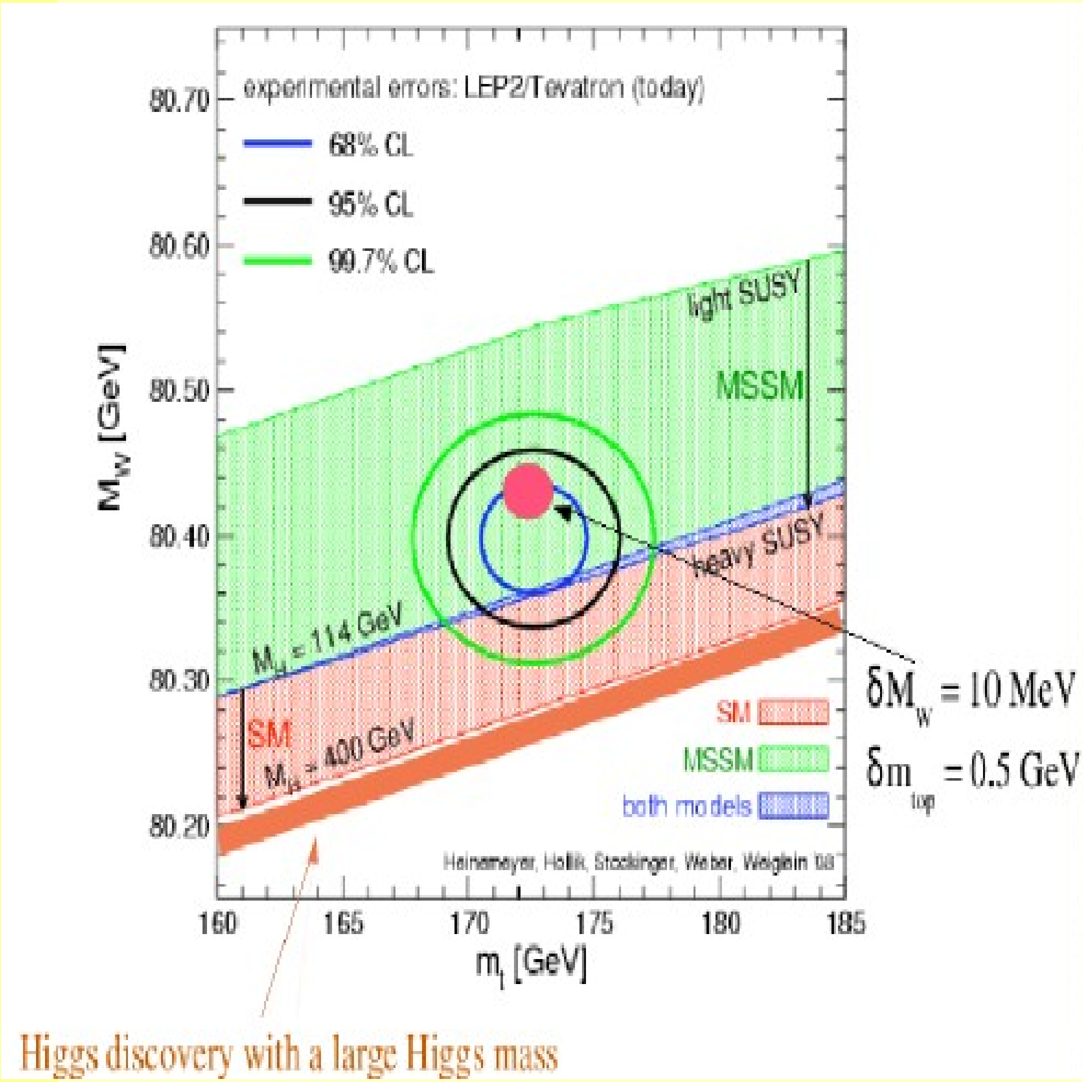


Indirect constrains



For equal contribution to the Higgs mass uncertainty need:

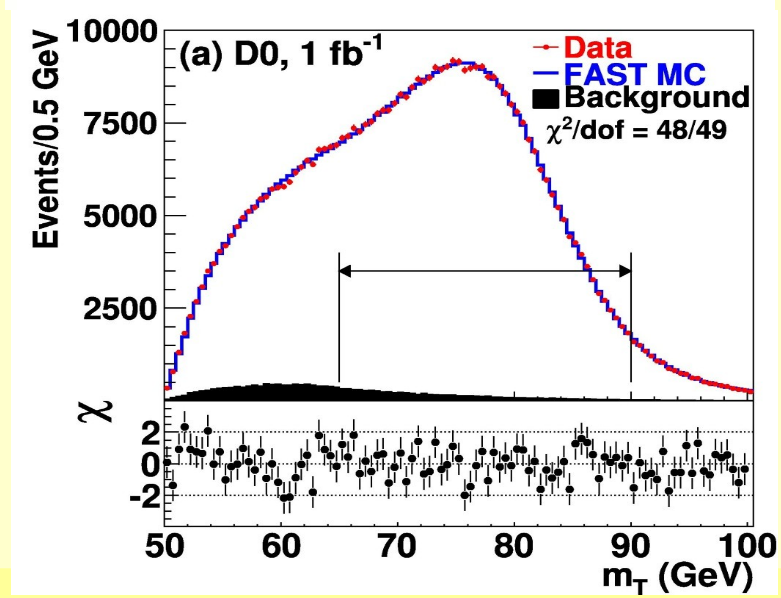
$$\Delta M_W \approx 0.006 \; \Delta M_t \, .$$

Current Tevatron average:

$$\Delta M_t = 1.3 \text{ GeV}$$

$\Rightarrow$ would need: $\Delta M_W = 8$ MeV

Currently have: $\Delta M_W = 25$ MeV



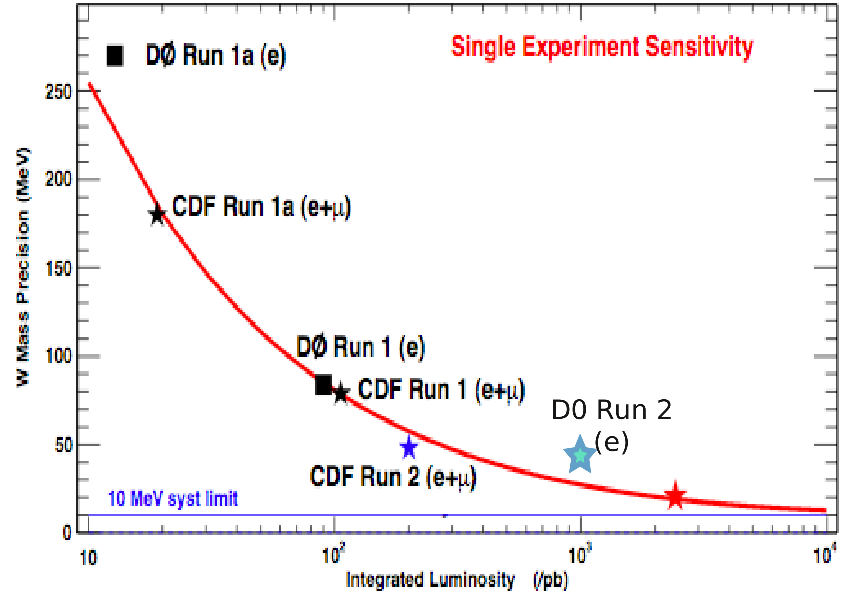
Indirect constrains

source of uncertainties	1 fb-1	6 fb-1	10 fb-1
Statistics	23	10	8
Systematics			
Electron energy scale	34	14	11
Electron resolution	2	2	2
Electron energy offset	4	3	2
Electron energy loss	4	3	2
Recoil model	6	3	2
Electron efficiencies	5	3	3
Backgrounds	2	2	2
Total Exp. systematics	35	16	13
Theory			
PDF	9	6	4
QED (ISR-FSR)	7	4	3
Boson Pt	2	2	2
Total Theory	12	8	5
Total syst+theory	37	18	14
(if theory unchanged)		20	17
Grand total	44	21	16

At end of Run II, expect total uncertainty on W mass of 16 MeV from DØ alone.

Expect similar performance from CDF, and combined error of 12 MeV.

This legacy measurement will be in the textbooks for decades to come.



with $\delta m_W = 15$ MeV, $\delta m_t = 1$ GeV
and $m_W = 80.400$ GeV :

$$m_H = 71^{+24}_{-19}\ \mathrm{GeV} \quad < 117\ \mathrm{GeV} @ 95\%\ \mathrm{cl}$$

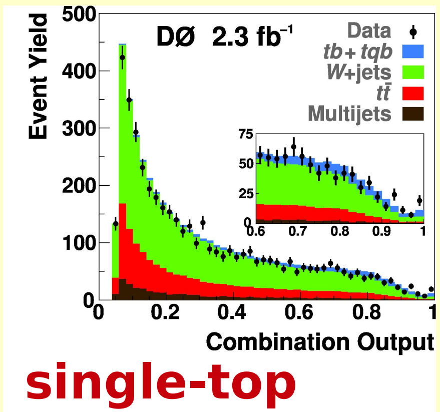
(P. Renton, ICHEP 2008)

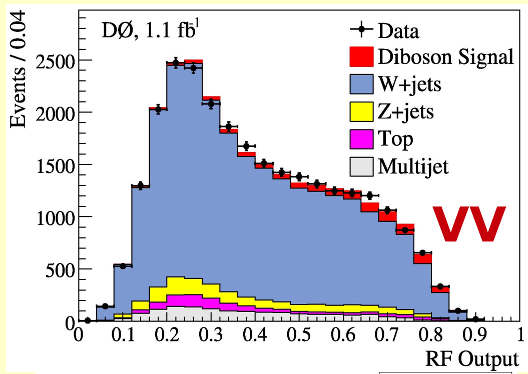
Conclusion

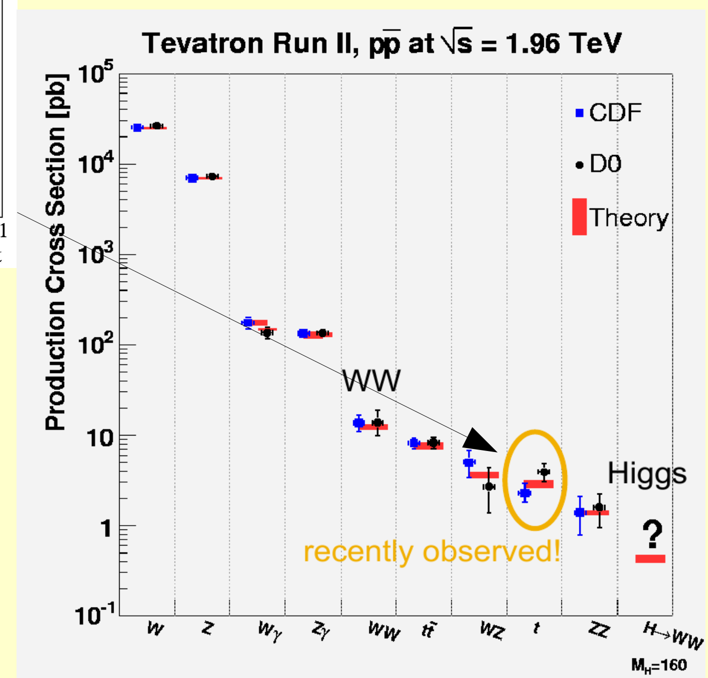
Excellent performances of accelarators and detectors

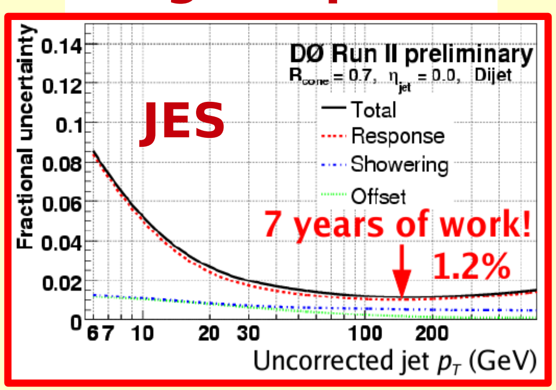
Very mature analyses allow us to do better than only increasing statistics

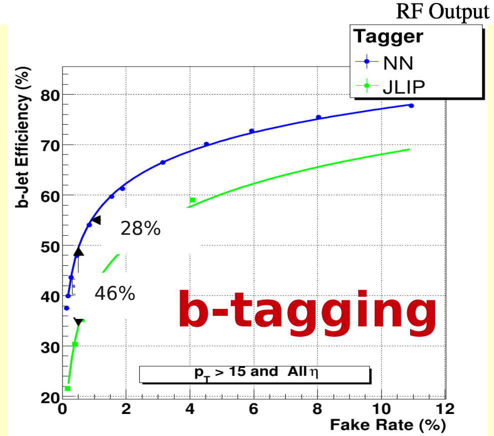
Exciting prospects: exclusion $120 < M_H < 200$ GeV ~2012 !





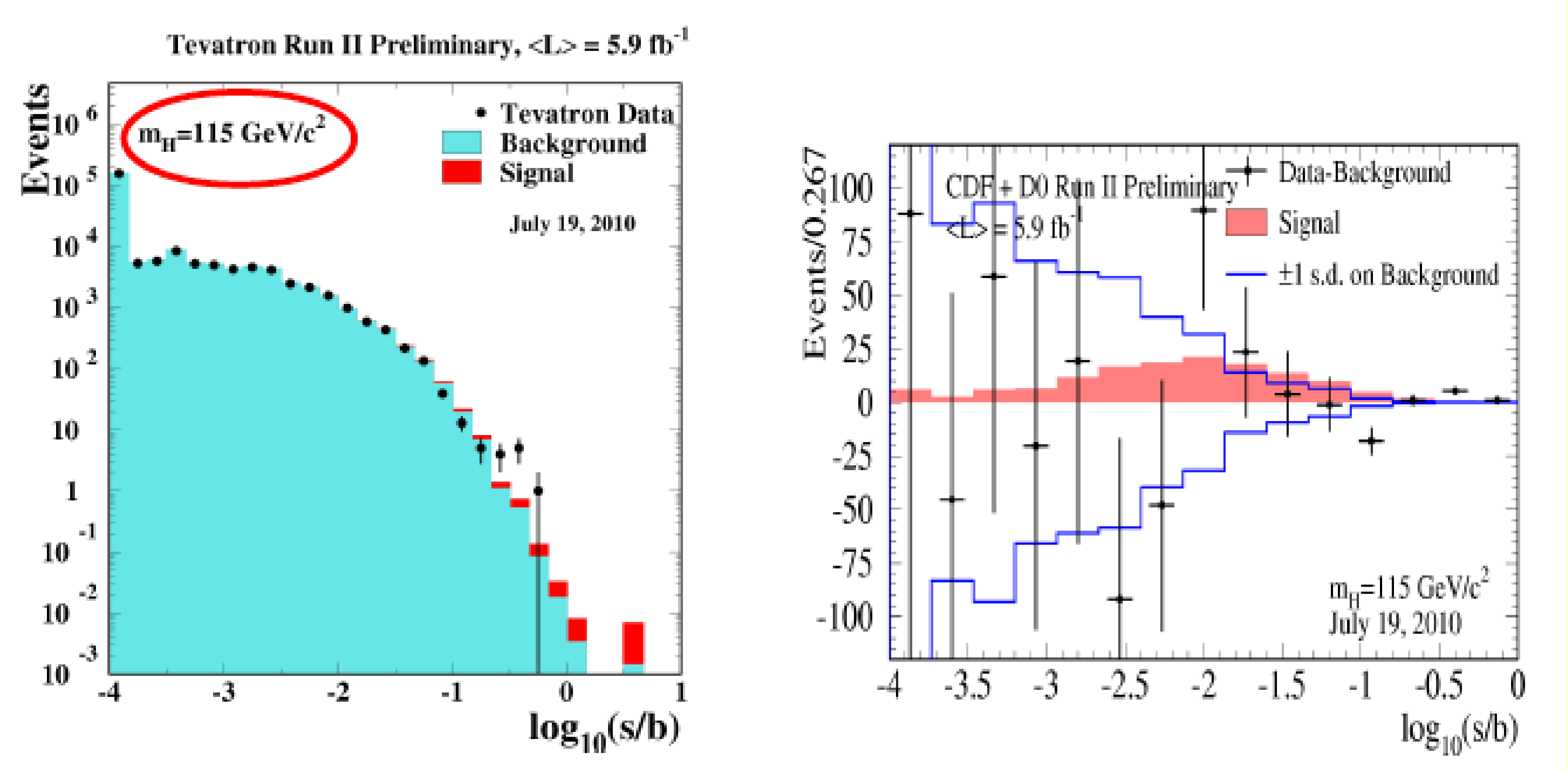






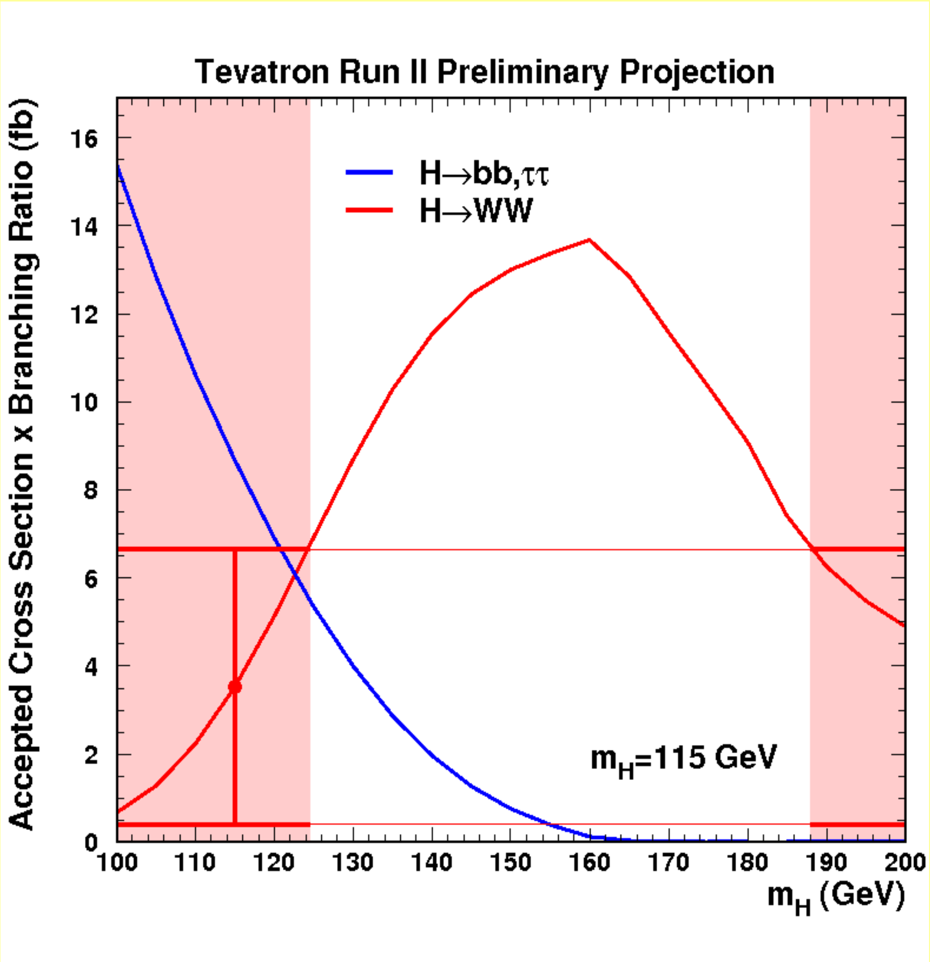
BACK-UP

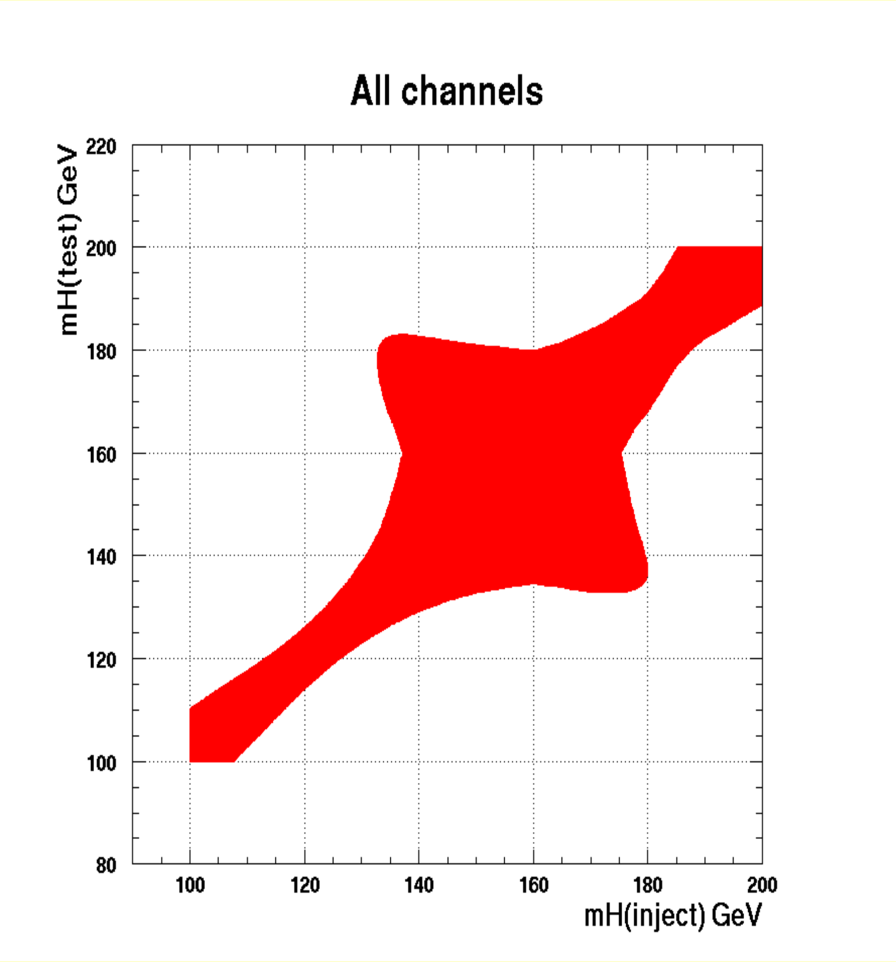
Reading TeVatron data



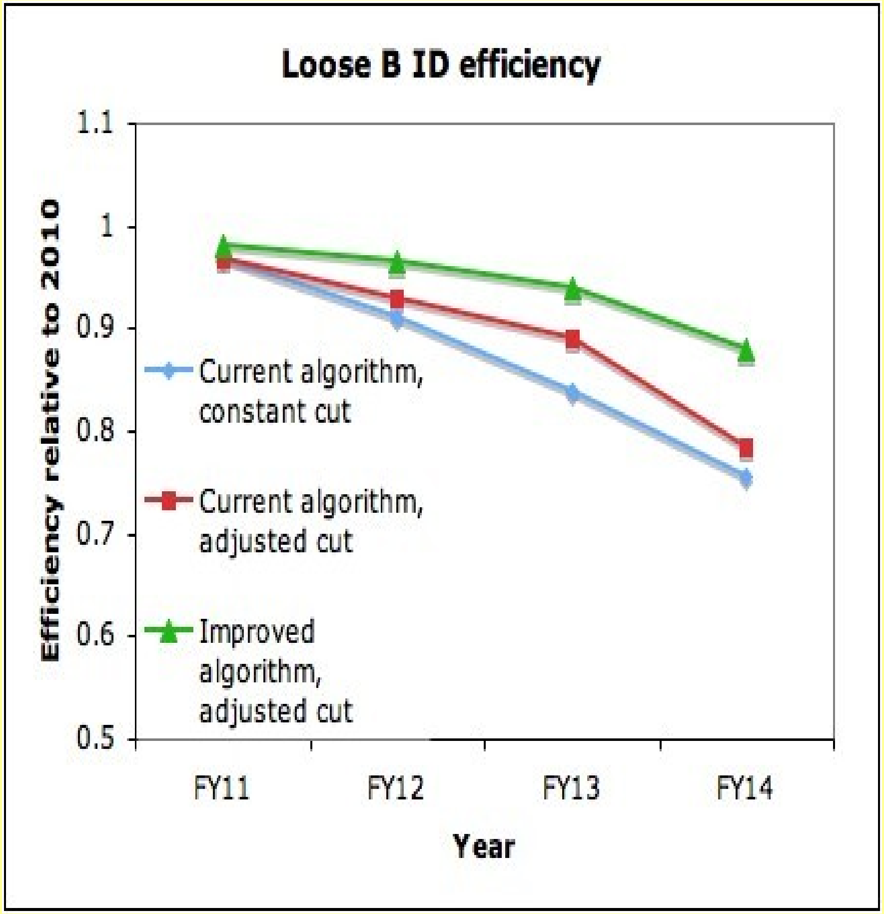
- Display all input histogram bins ordered according to S/B in one plot.
- The background model has been constrained by the data.
- Data consistent with the background-only hypothesis within the systematic uncertainties.

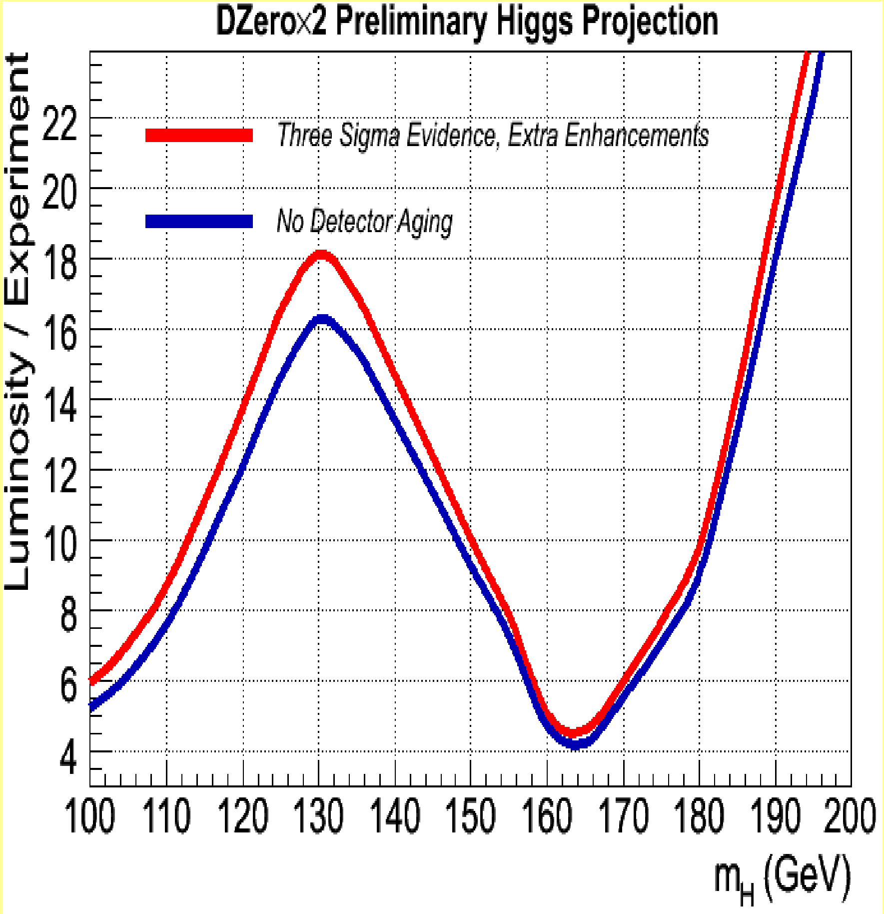
Reading TeVatron data





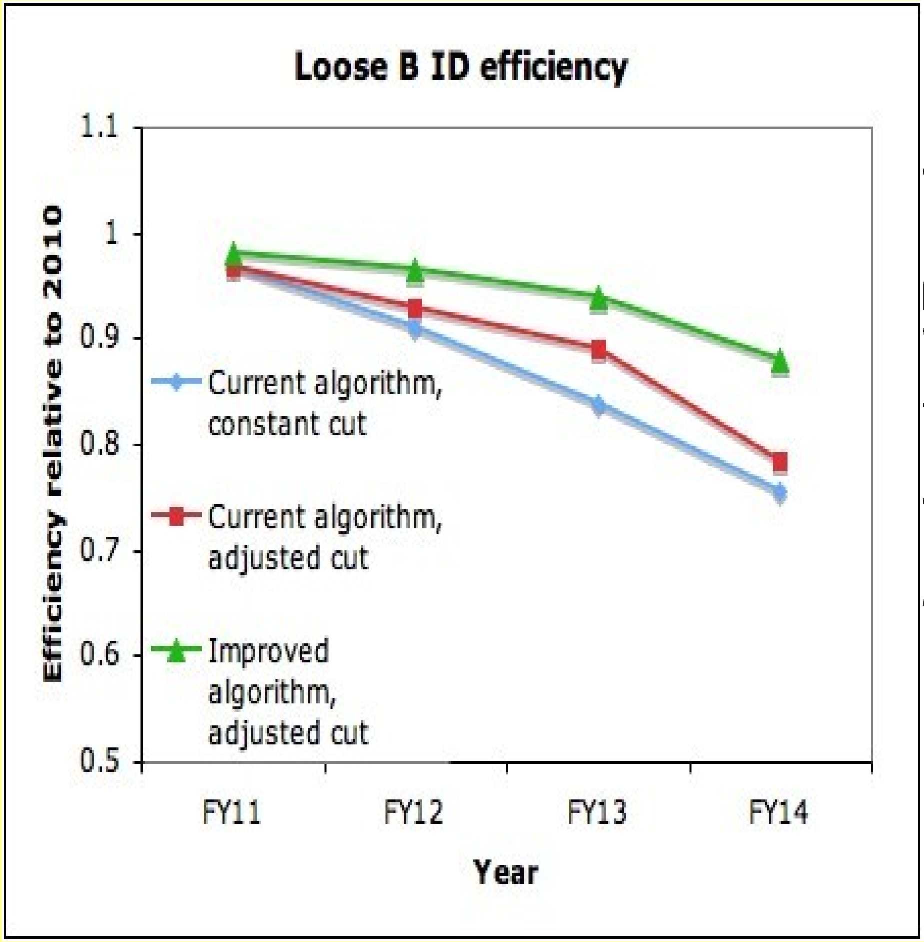
Detector aging

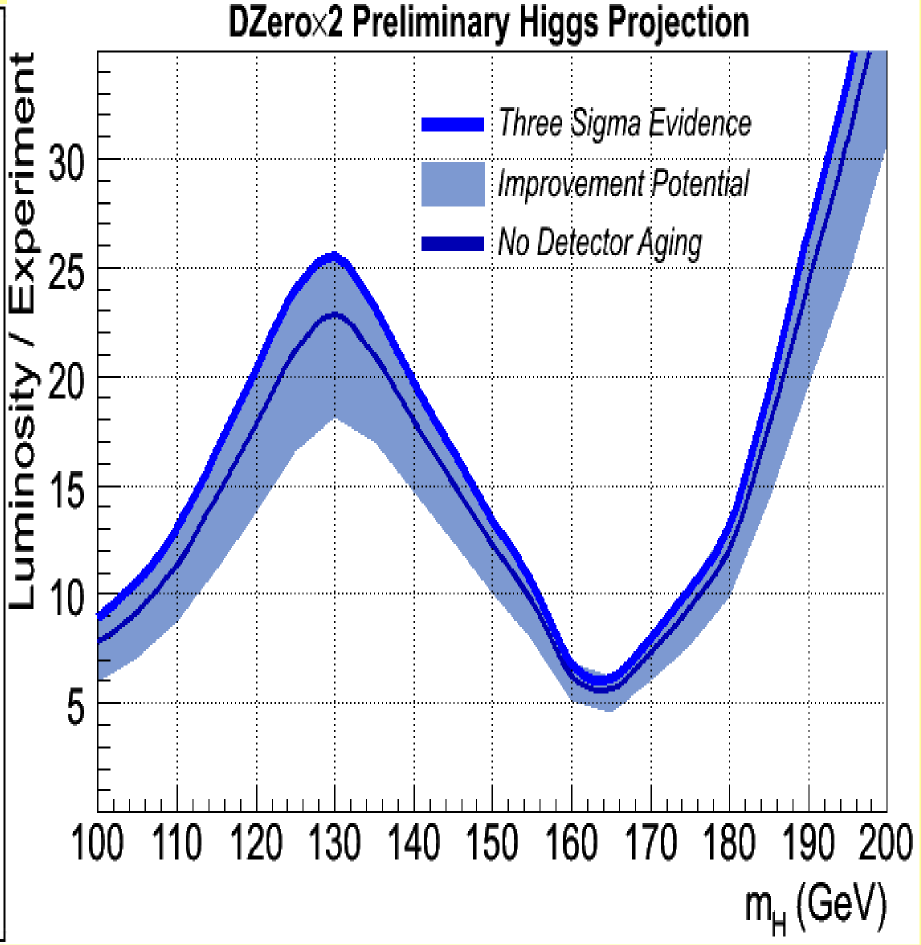




- Propagated deterioration of detectors performance to Higgs sensitivity
- ~10% effect at low mass
- Further improvements expected, silicon channels recovery, etc.
- Combined effect on the Tevatron Higgs search of radiation aging is a few %

Detector aging





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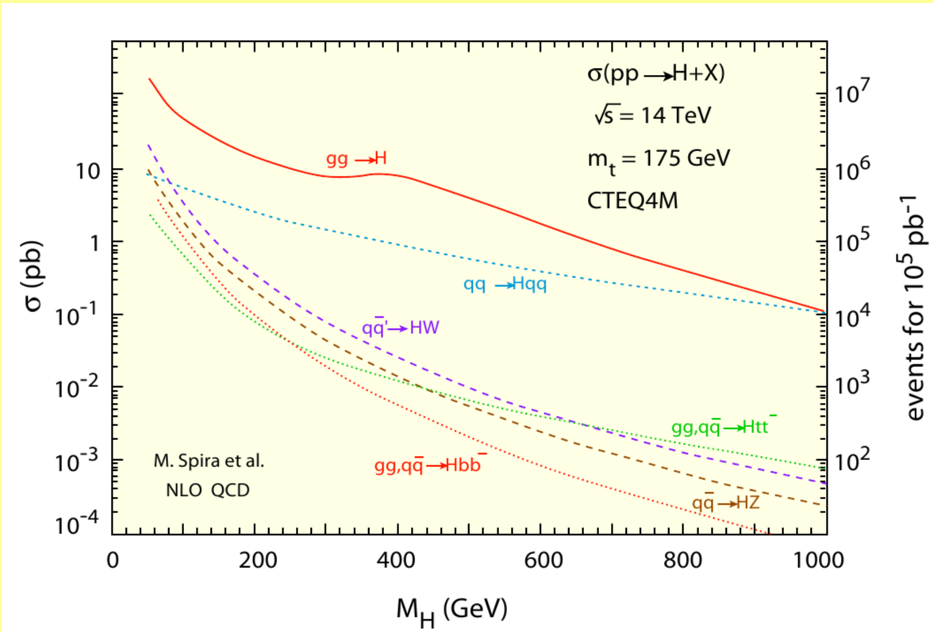
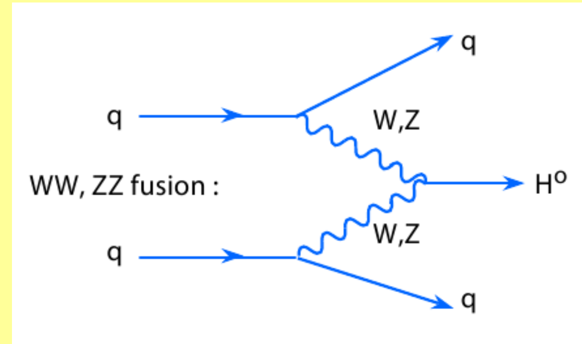
qq(H-->tau tau) @ CMS





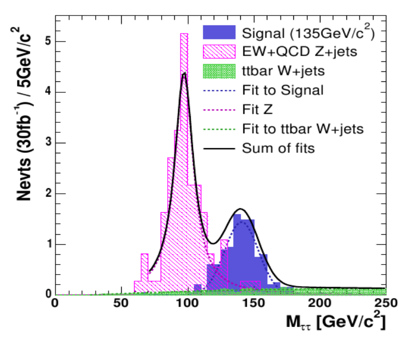
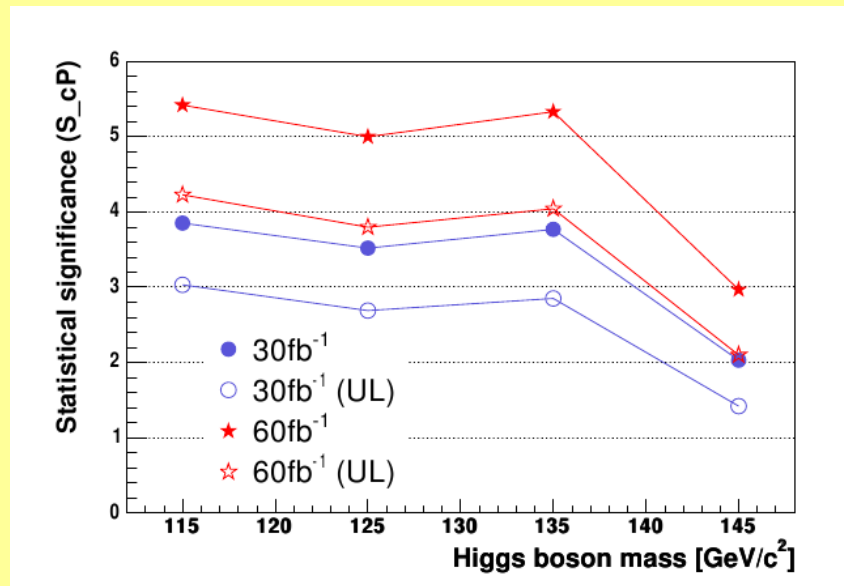
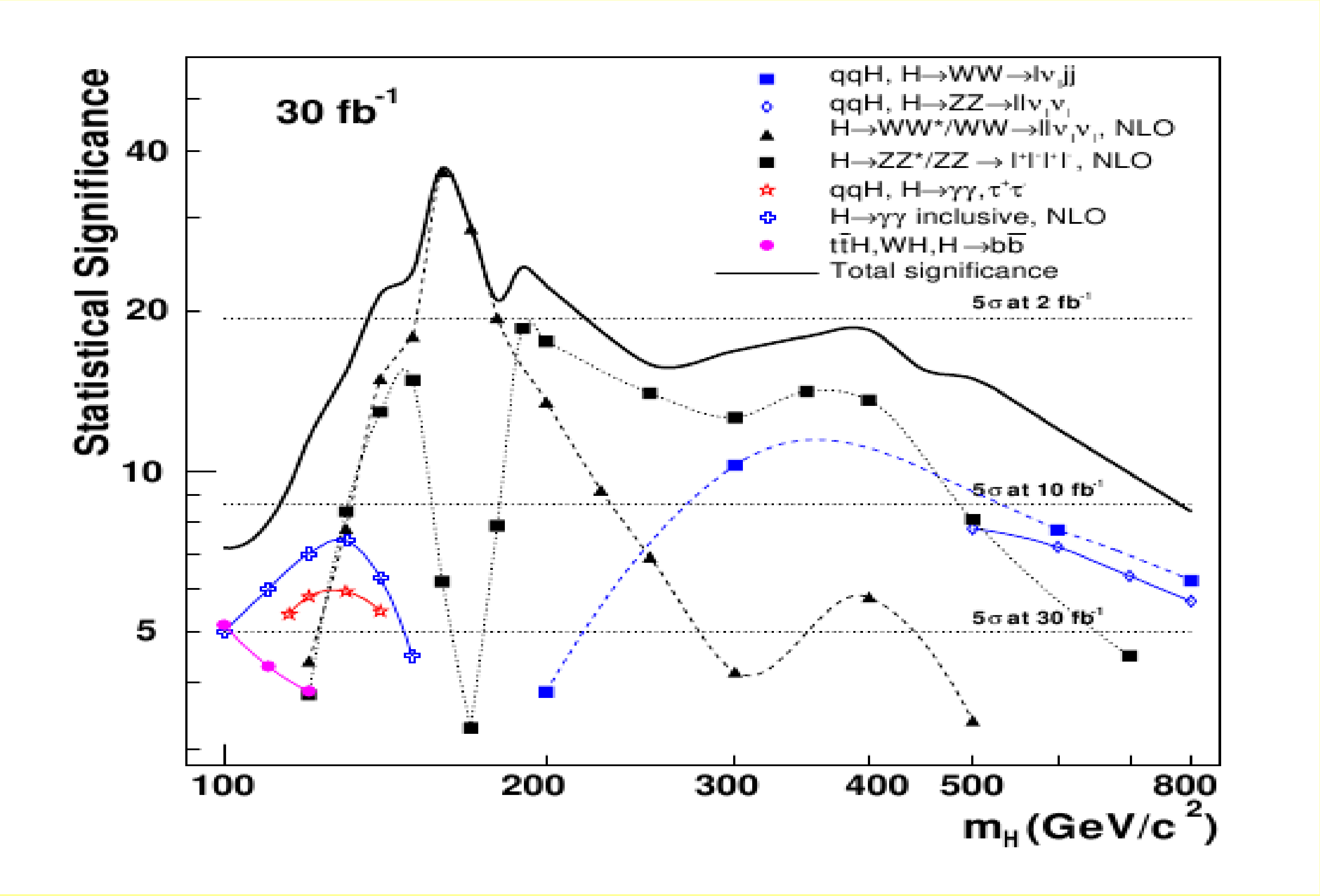


Figure 5.24: The invariant mass of the two reconstructed τ's. The number of entries is normalised to the expected number of events at an integrated luminosity of 30 fb^{-1}.





30 fb-1
Statistical Significance
qqH, H→WW→lνjj
qqH, H→ZZ→llνν
H→WW*/WW→llνν, NLO
H→ZZ*/ZZ → l+l-l+l-, NLO
qqH, H→γγ, τ+τ-
H→γγ inclusive, NLO
tt̄H,WH,H→bb̄
Total significance
5σ at 2 fb-1
5σ at 10 fb-1
5σ at 30 fb-1
40
20
10
5
100
200
300
400
500
800
mH (GeV/c2)

Production	Désintégration	Domaine de masse(GeV/c^2)
gg	$H \to \gamma\gamma$	114-150
ttH	$H \to b\bar{b}$	<120
gg	$H \to ZZ$	130-300
gg	$H \to WW$	150-180
qqH	$H \to \tau^+\tau^-$	115-140
qqH	$H \to WW$	>125

Table 3: Canaux utilisés au LHC pour l'observation du boson de Higgs standard.

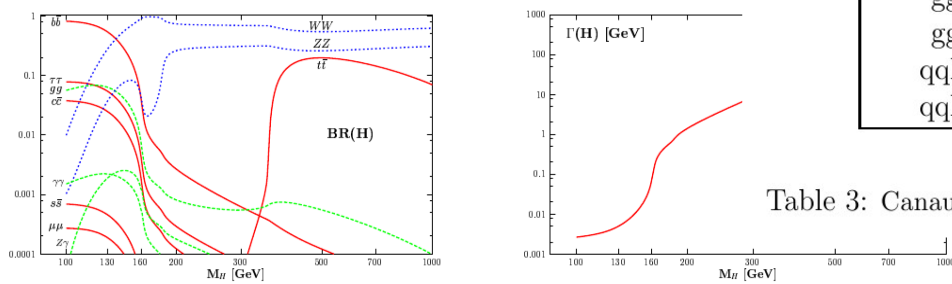


Figure 3: Rapports d'embranchement pour les principaux modes de désintégration et largeur totale en GeV du boson de Higgs standard en fonction de sa masse.

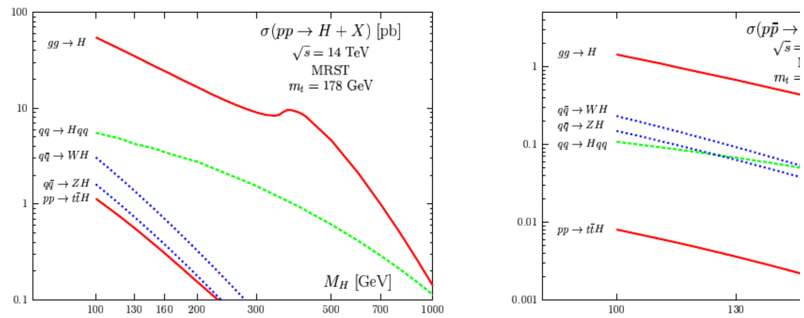


Figure 4: Section efficaces pour différents modes de production du boson de Hig
TeVatron (à gauche) et au LHC (à droite).

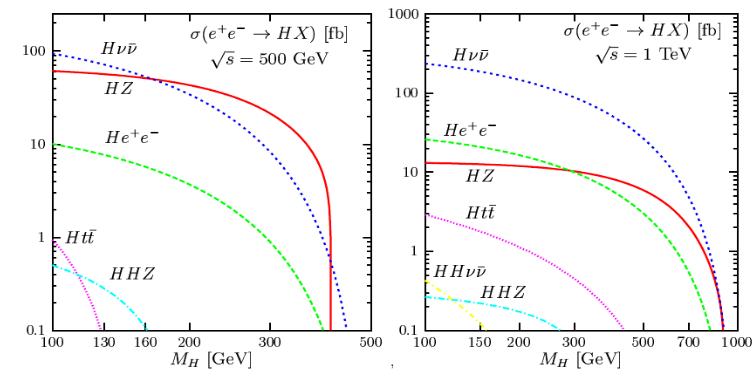


Figure 5: Sections efficaces pour différents modes de production du boson de Higgs standard en fonction de sa masse dans un collisionneur linéaire à 500 GeV (à gauche)et 1 TeV (à droite).

DØ recently updated H→γγ with 4.2 fb^{-1}.

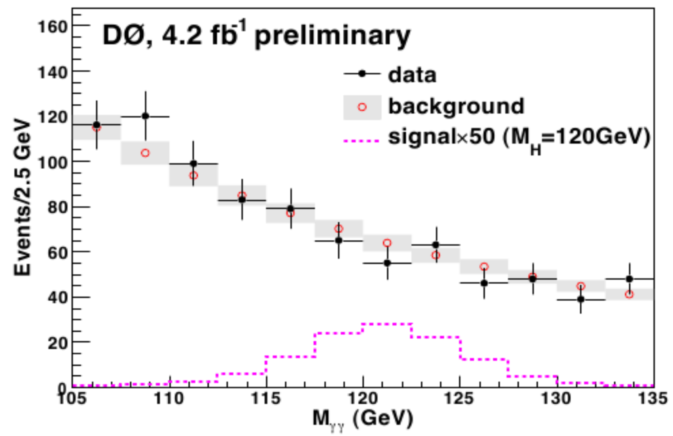
➡ QCD diphoton backgrounds modeled using data.

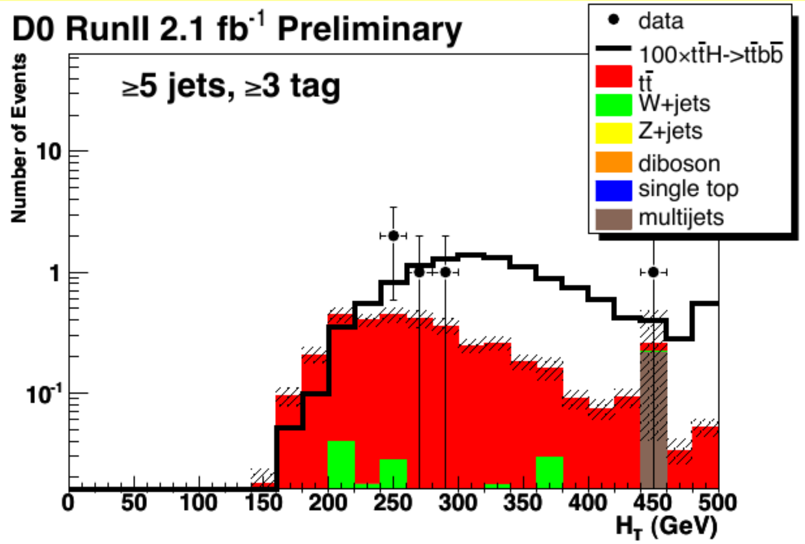
Search for Higgs in ±15 GeV diphoton mass window.

M_H = 115 GeV

Exp: 18 Obs: 13

No excess is seen. Limit also interpreted in fermiophobic Higgs scenario.





✦ DØ recently added a search for ttH → ttbb using 2.1 fb^{-1}.

➡ Direct access to top Yukawa coupling.

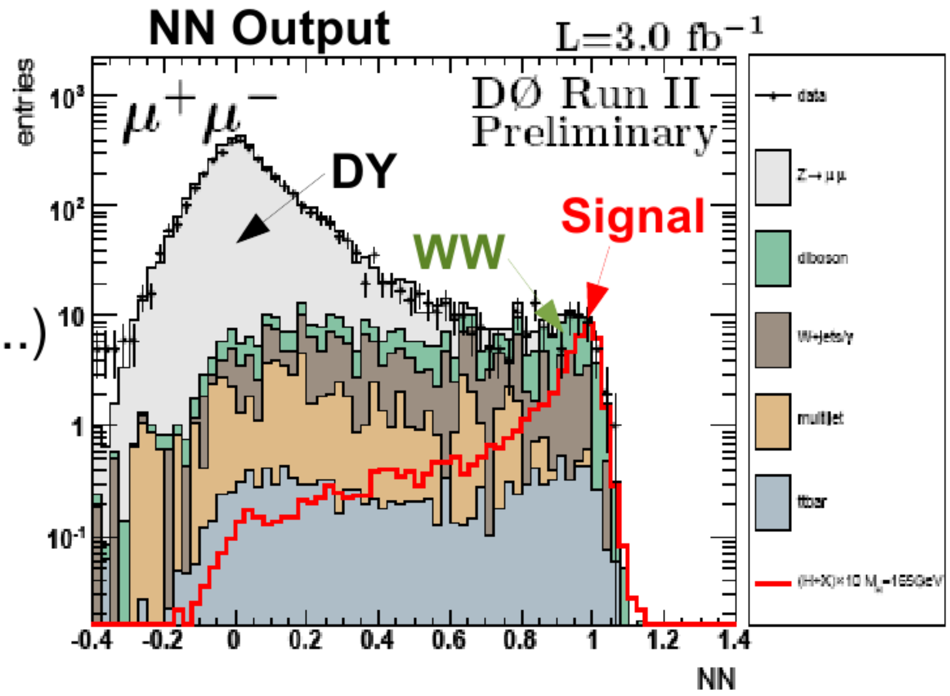
✦ No excess is seen. Limits set using H_T output.

M_H = 115 GeV

Exp: 45 Obs: 64

NN inputs include variables

- Lepton-specific ($p_T(l)$, ...)
- Kinematics ($H_T=\Sigma_i |p_T(jet_i)|$, $\not{E}_T$, ...)
- Angular ($\Delta\phi(l,l)$, $\Delta\phi(l,\not{E}_T)$, ...)



Main background contributions depend on lepton flavor

- WW for eμ events
- Drell-Yan for ee,μμ events, but WW still the most difficult to separate from signal

$\mathcal{L} = 3.0 - 4.2$ fb^{-1}, $M_H = 160$ GeV

Ch.	$\mathcal{L}$ (fb^{-1})	Signal	Bkgd	Data
$e\mu$	4.2	12.2 ± 0.1	337 ± 10	329
ee	4.2	6.13 ± 0.01	332 ± 15	336
$\mu\mu$	3.0	4.85 ± 0.01	4325 ± 24	4084

“Taggabilite”

- **Run IIb:** augmentation de la luminosite instantate => activite hadronique plus intense
- **Taggabilite:** critere (minimum) de qualite de reconstruction des traces dans les jets.