Search for the Standard Model Higgs Boson Produced in Association with a W boson at CDF

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WH Working Group

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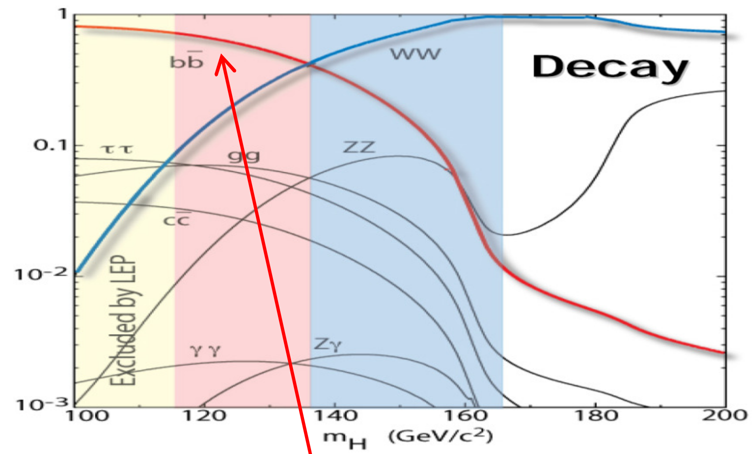
The WH Associated Production

Want to perform a low mass SM Higg search

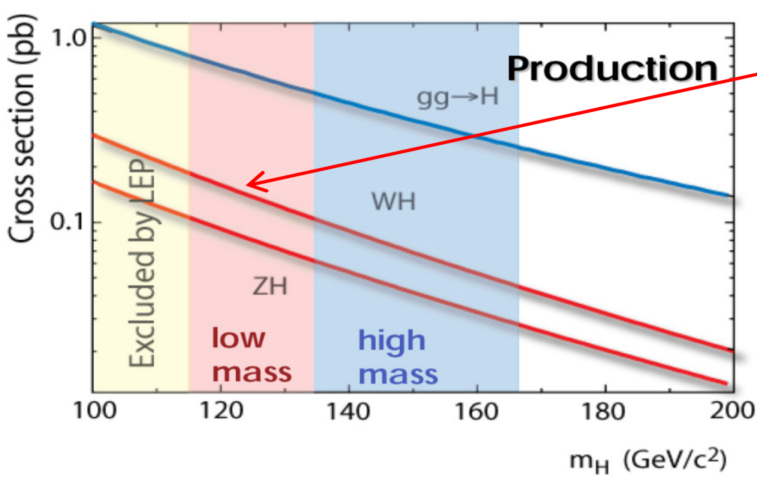
Our search: a W boson + a Higgs boson

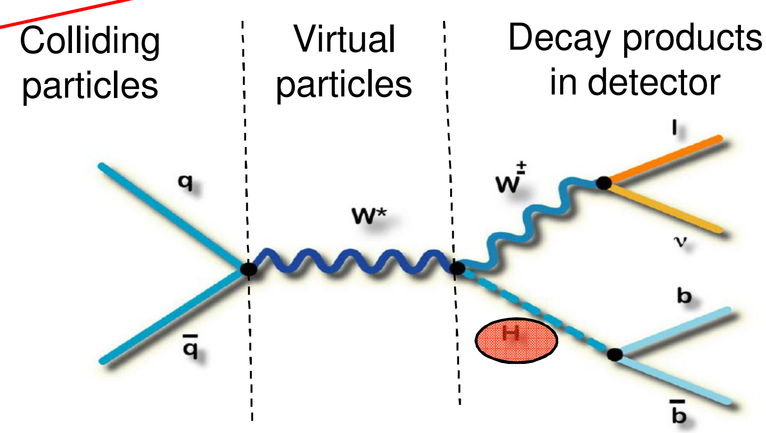
The W boson decays to an electron (muon) + neutrino

It helps us a lot that we can indentify well electrons and muons in the detector



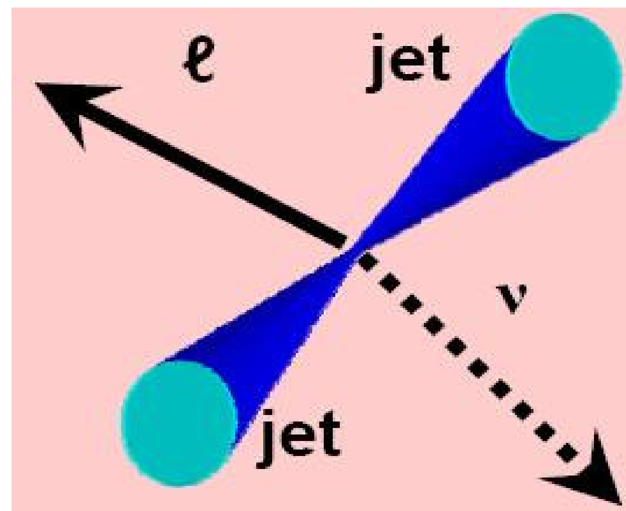
Our search (WH)





Event Selection

- One charged lepton, large missing transverse energy and two jets, out of which at least one originates from a bottom quark
- Also includes ZH $\rightarrow$ llbb, where one lepton is missed
- 4 charged lepton categories
  - Triggered central tight leptons, forward tight electrons
  - Non triggered loose electrons and muons (MET+ jets triggers)
- Pretag used as control region
- 4 orthogonal b-tagging categories as signal regions



Improvements Since 2010

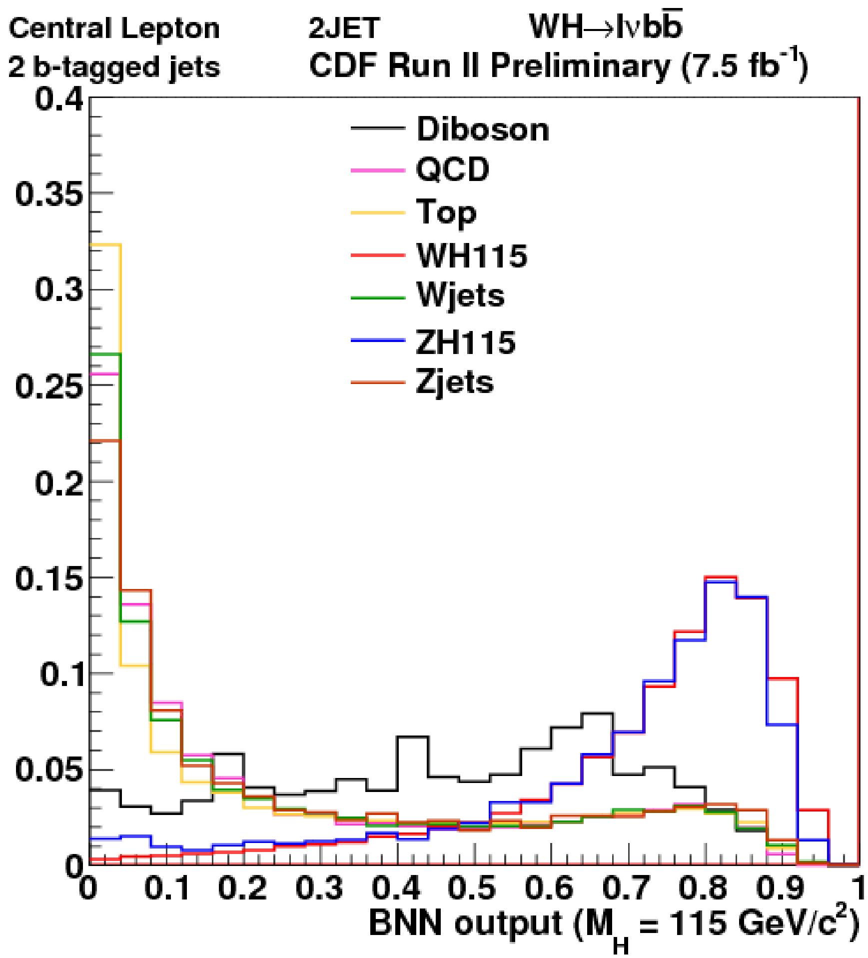
- **Increased the integrated luminosity** from 5.7 to 7.5 fb^{-1}
- **Improvements on the non-W QCD background**
  - Replaced the cut-based non-W QCD veto with a better multivariate technique, which reduces the contribution of this background and increases the signal – see F. Sforza's talk
  - Improved the model for the central for the central electrons
  - Relaxed the MET cut for the central muons
- **Improvements on signal acceptance**
  - Increased acceptance for the non triggered loose muons through the addition of a third MET+jets trigger thanks to a novel in trigger combination method - next slide and backup slides
  - Increased acceptance for the non triggered loose electrons through the use of the high-p_T electron triggers

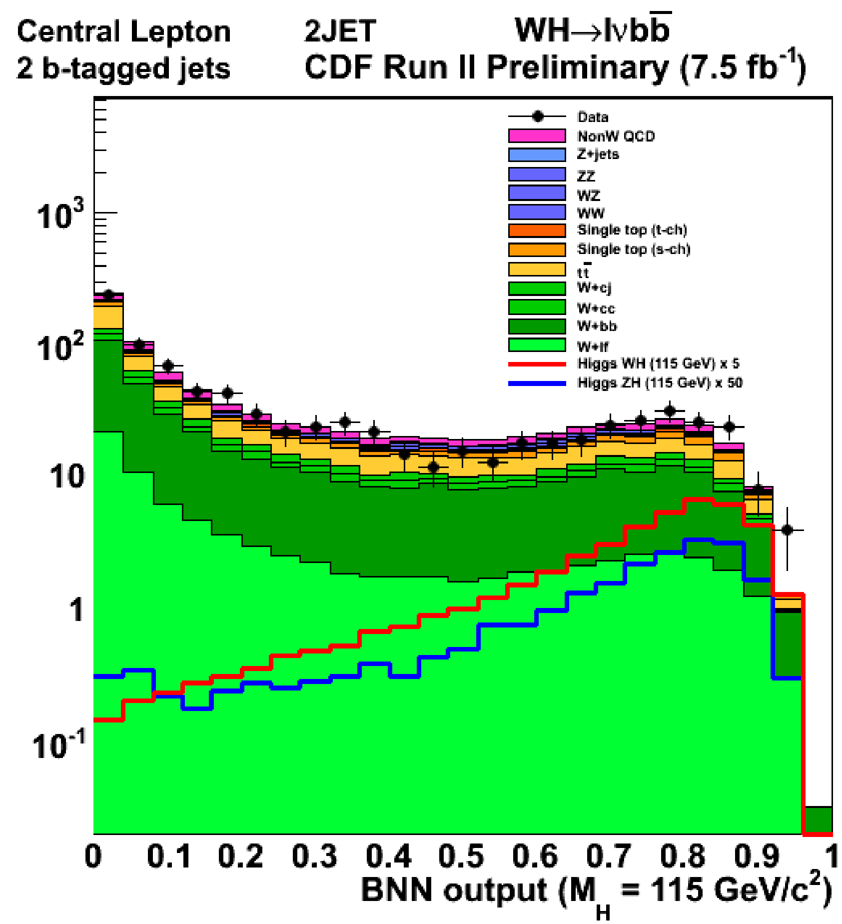
New Trigger Combination Method To Avoid a Logical OR

- Consider each event its own kinematic region
- Equivalent to dividing the kinematic phase space in an infinity of mutually orthogonal kinematic regions
- No more need to study and identify before the analysis all the orthogonal kinematic regions
- **On an event-by-event basis, the trigger with largest a priori probability to fire is chosen (in-situ trigger study), the probability being the product of**
  - Trigger probability to fire each trigger level based on trigger parameterization (trigger MET, jet kinematic quantities)
  - Inverse of the trigger prescale for the event (ex: 0.91)
  - 0 or 1 (if the trigger is defined or not for the event)
    - For MC, a random number simulates in which data period it is
  - 0 or 1 (if the trigger-specific jet event selection is passed)

Final Discriminant

- ❑ Inputs: dijet invariant mass + other kinematic quantities
- ❑ Backgrounds (signal) peak to the left (right)
- ❑ Good agreement between data and background
- ❑ No excess seen, so we continue to set limits





Limit Setting & Systematic Uncertainties

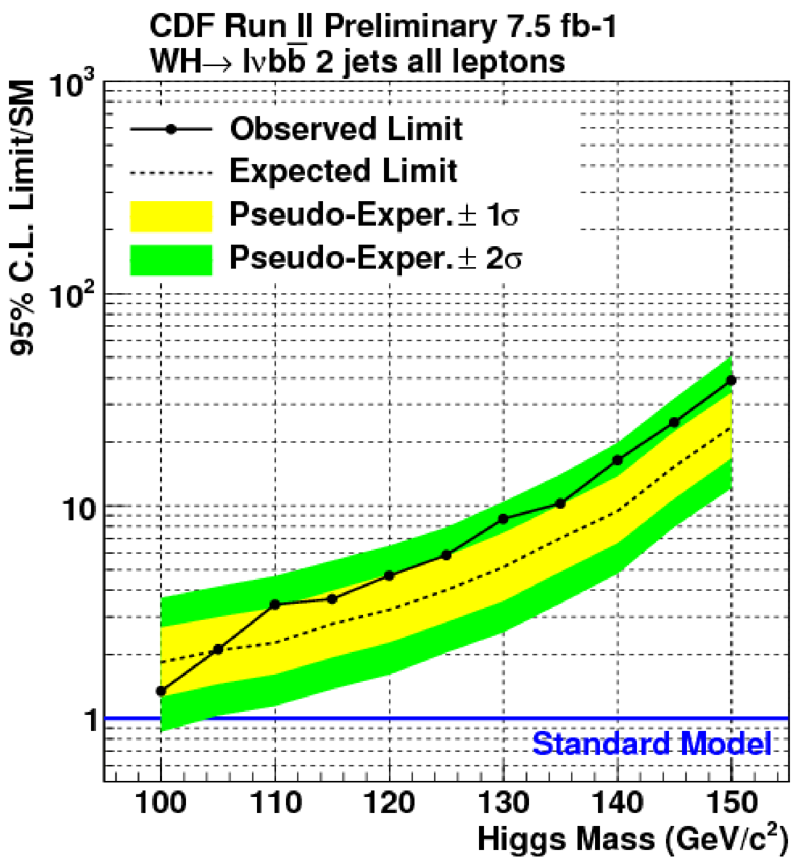
- **Bayesian** approach with **Poisson** statistics and **flat priors**

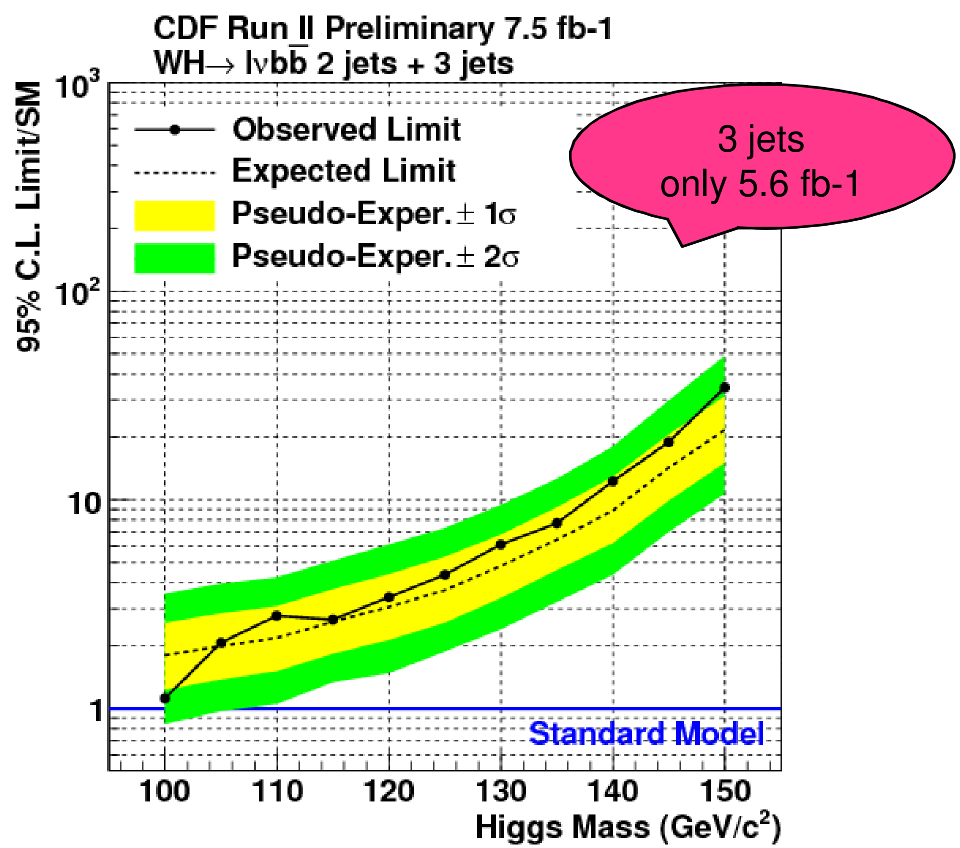
- Rate and shape systematic uncertainties are introduced as **nuisance parameters**
  - Truncated Gaussian distributions

- **Rate**: uncertainty on the total normalizations
- **Shape**: uncertainty on bin-by-bin normalizations
  - Use full discriminant shapes to extract the most information

- **Correlated** among various channels

WH Upper Limits





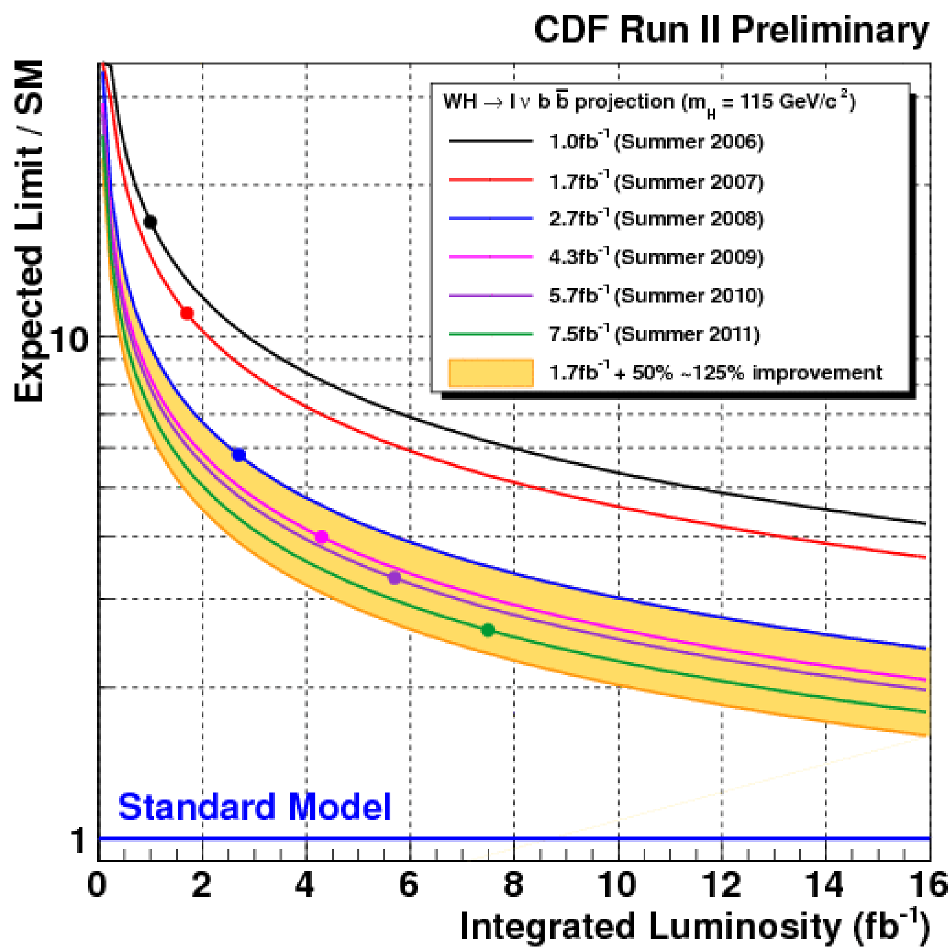
115 GeV/c^2: observed (expected) upper limits at 95% CL

3.64 (2.78) x SM   2.65 (2.60) x SM

Most sensitive analysis in the world for low mass Higgs

WH Search Projection

- Always improved more than just by adding luminosity
- Band: conservative and optimistic improvement plan



Conclusion

- **WH Search, CDF Collaboration**
  - 2 jets: 7.5 fb^{-1}, 3 jets: 5.6 fb^{-1}
  - Pretag sample as control region
  - 4 orthogonal b-tagging categories as signal regions
  - 4 orthogonal charged lepton categories
- **Heavy use of multivariate techniques**
- **No excess is seen, so we set 95% CL upper limits**
  - in the range 100 to 150 GeV/c^2 with 5 GeV/c^2 increments
- **Observed (Expected)**
  - from 1.12 (1.79)xSM for 100 GeV/c^2 to 34.4 (21.6)xSM for 150 GeV/c^2
  - 2.65 (2.60) x SM at 115 GeV/c^2
  - Most sensitive analysis in the world for low mass Higgs!

Backup Slides

The Higgs Boson

- **Motivation**
  - The only elementary particle predicted by the Standard Model not yet observed or refuted
  - Predicted by the Higgs mechanism in 1964, which explains
    - the spontaneous symmetry breaking
    - the masses of the electroweak bosons, the masses of fermions
- **The Higgs boson characterized only by its mass**
  - LEP direct searches
    - exclude masses < 114.4 GeV/c^2 at 95% CL
  - Previous Tevatron direct searches
    - exclude masses in [158-173] GeV/c^2 at 95% CL as of July 1st 2011
  - Indirect electroweak fits
    - exclude masses > 185 GeV/c^2 at 95% CL
- **Higgs production is a very rare process**

Event Yield Table

$WH \rightarrow \ell\nu bb$, 2jets CDF Run II Preliminary 7.5 fb^{-1}				
Total	ST+ST	ST+JP	ST+NN	1-ST
Pretag Events	184050	184050	184050	184050
$t\bar{t}$	142±22	114±12	62.8±6.4	479±49
Single top(s-ch)	45.0±6.7	35.1±3.4	18.9±1.8	106±10
Single top(t-ch)	13.9±2.4	13.3±2.0	8.7±1.2	191±23
WW	1.67±0.42	6.23±2.08	5.14±1.35	186±25
WZ	12.9±2.0	10.7±1.2	5.84±0.62	53.3±6.2
ZZ	0.62±0.09	0.49±0.06	0.29±0.03	2.05±0.23
$Z + jets$	9.64±1.40	11.9±1.7	8.75±1.30	182±25
$Wb\bar{b}$	257±104	228±91	125±50	1450±580
$Wc\bar{c}/c$	31.0±12.6	98.3±40.5	63.8±26.0	1761±708
Mistag	12.1±2.9	52.8±15.2	57.0±14.3	1646±220
non-W QCD	57.9±23.6	85.3±34.1	74.9±29.9	747±299
Total background	584±169	656±194	432±126	6802±1822
Observed Events	519	568	402	6482
WH and ZH signal (115 GeV)	7.28±0.98	5.34±0.39	2.80±0.19	16.0±1.2

Acceptance Improvement

Charged lepton (Electron or Muon)

Our contribution to improve the search:

More charged leptons, which means

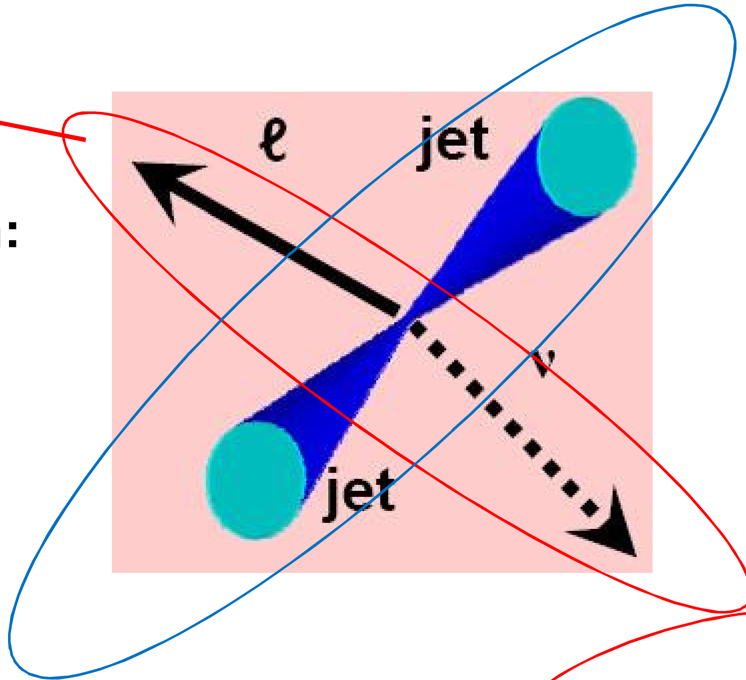
More W bosons, which means

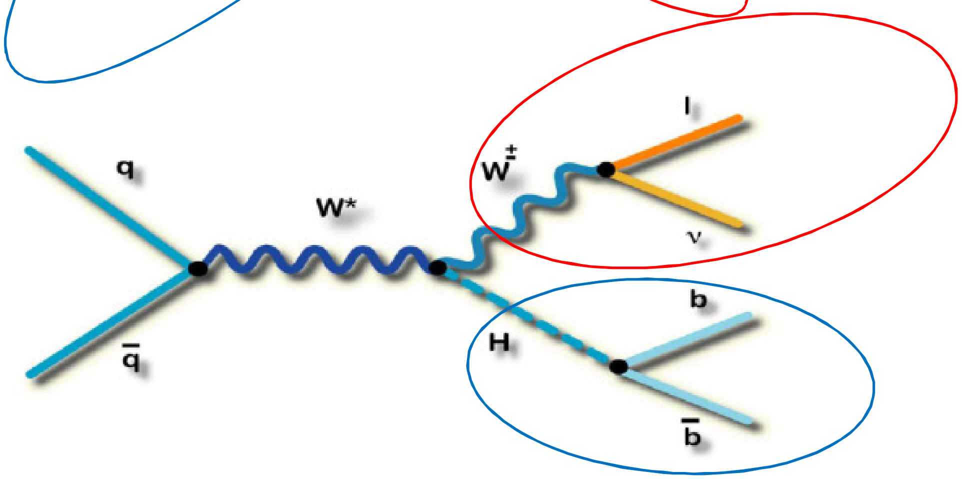
More WH events, which means

More signal selected, which means

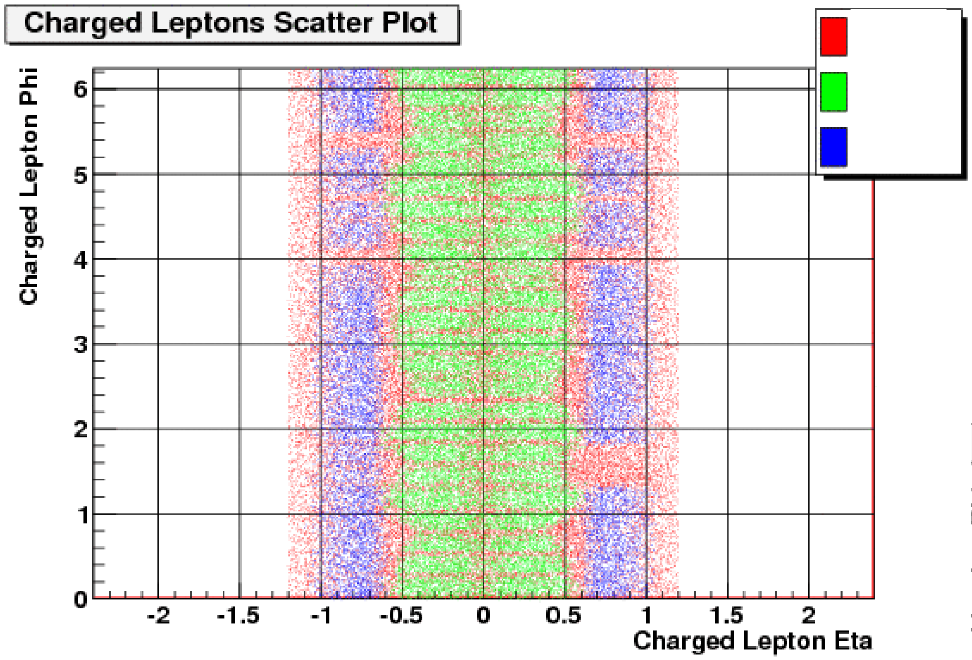
Better Higgs sensitivity!

We introduce a new method to reconstruct electrons and muons that would normally be lost in the non instrumented regions of the detector



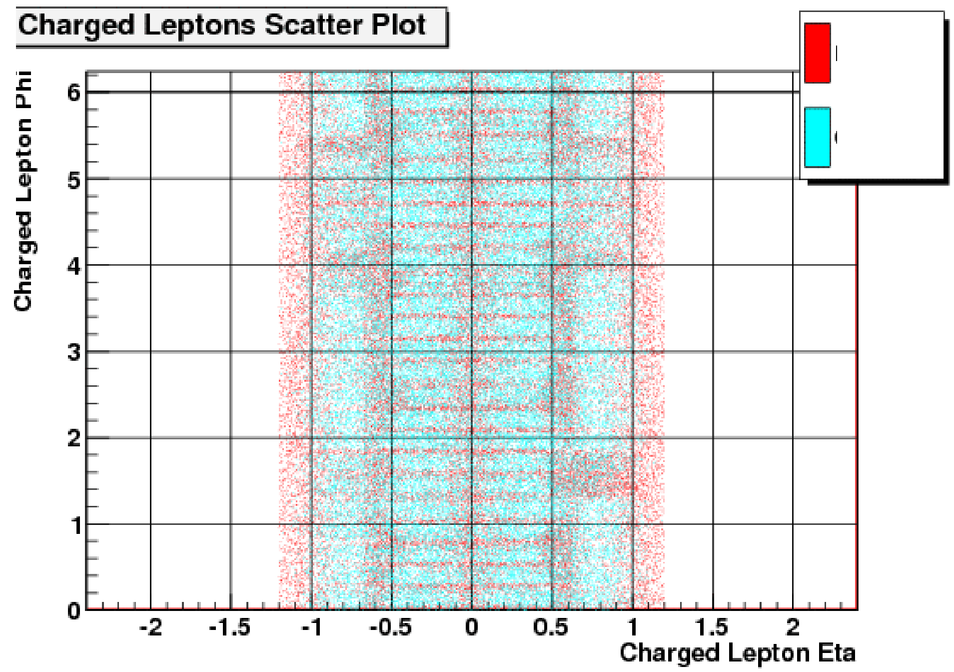


Charged Lepton Improvement



Cylindrical detector rolled on a plane

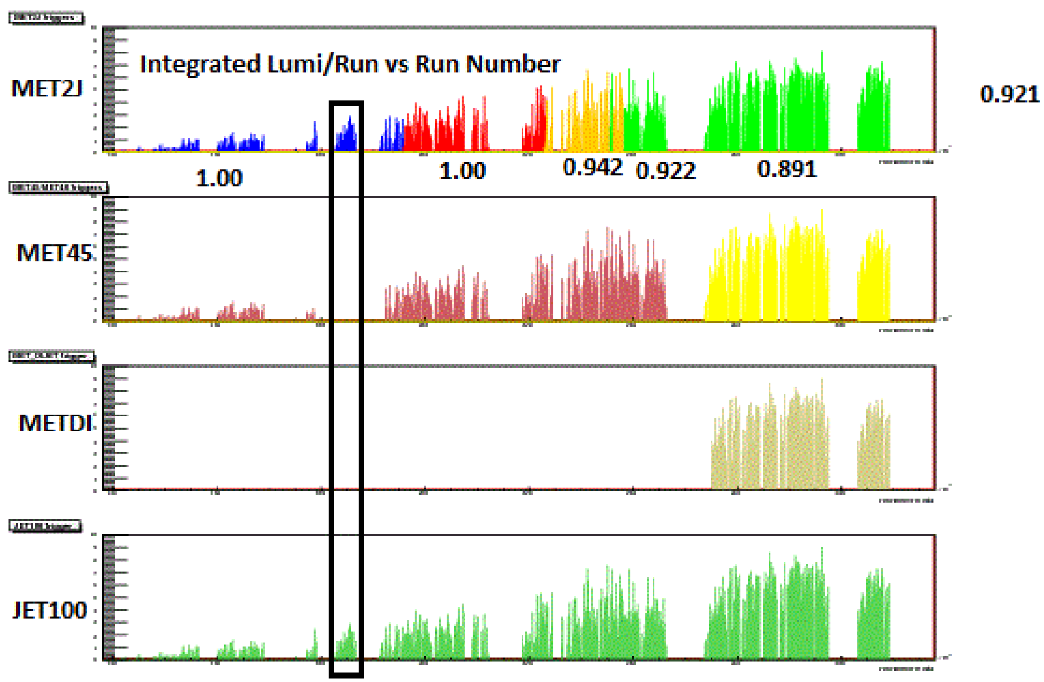
Y axis: 0-2Pi
X axis – 0 for half height



Dark blue, Green – muons
Light blue – electrons
Red – muons or electrons that would be lost in the non instrumented regions of the detector, but we recover

3 MET + jets triggers at CDF

- Not all triggers are defined for all runs
- A trigger had a bug for certain runs, must be treated as not defined
- Some triggers have prescales for certain data periods
- Used for non-triggered loose muon and electron candidates
- **How to combine the three triggers optimally while avoiding correlations as in the case of a logical OR between triggers, which brings extra systematic uncertainties, which are also harder to compute?**



Old Trigger Combination Method To Avoid a Logical OR

- Divide kinematic phase space in orthogonal regions
  - For many triggers, many kinematic regions
  - How to choose them? Study that before the analysis
  - Parameterize each trigger (at each level) in each region
  - **Only this step will be generalized by the new method**
- Assign only one trigger to all events in that region
- For MC events, assign an event weight between 0 and 1 as the probability that the trigger fires
- For data events, check if the trigger fired, if yes, return a weight of 1, if not, return a weight of 0 (reject event)
- For both MC and data, do not check the other triggers
  - To ensure orthogonality between triggers

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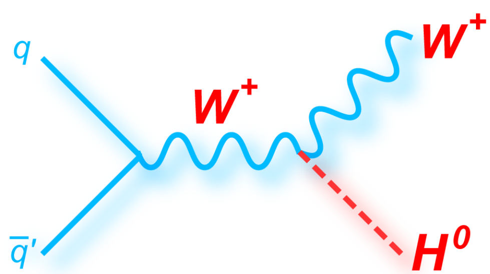
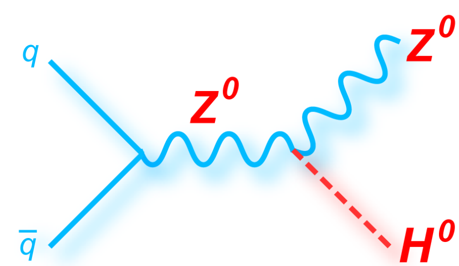
Impact of MET + jets Triggers

- The novel method allows to add new charged lepton categories (non triggered loose muons and non triggered loose electrons)
  - These lepton candidates are isolated tracks that point to non instrumented regions of the detector
  - At CDF we do not have isolated track triggers
  - Use orthogonal trigger information, so MET+jets triggers
  - We have 3 of such triggers
- This increases the signal acceptance by 50% over triggered tight charged leptons only (central electrons, central muons, forward electrons)
- This increases the WH search sensitivity

Low Mass Searches

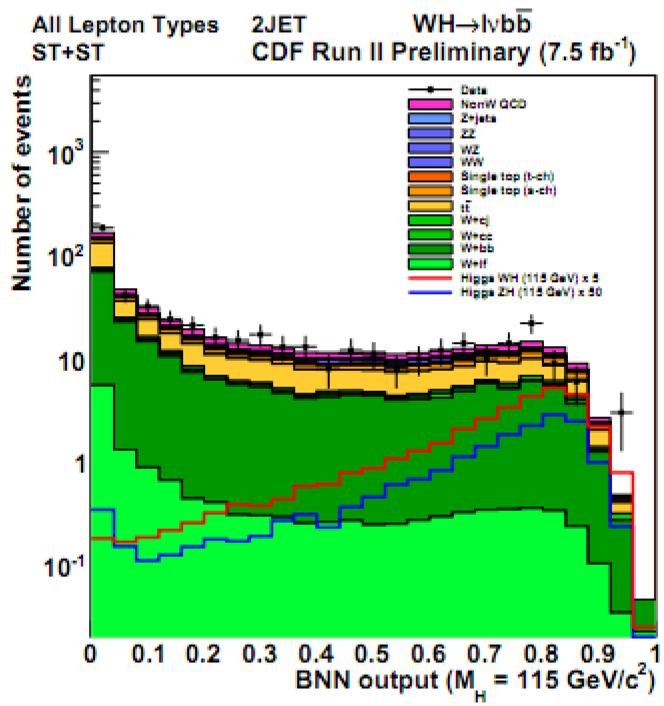
- Masses smaller than 135 GeV/c^2
- Higgs decays mostly to bottom quark pairs
- Single Higgs production (gluon fusion)
  - Largest cross section
  - Not feasible for bottom quark decay: 10^9 more QCD background
  - Still, use it for Higgs decays to photon or tau lepton pairs
- Associated production (WH, ZH, ttH)
  - Take advantage of the leptonic decays of the W or Z bosons
  - Charged-lepton and missing-transverse-energy based triggers
  - Identify jets that originate from bottom quarks





Example of Discriminant

- WH → lvbb search 2jet b-tagging category with best s/b ratio; all charged leptons combined
- Artificial neural network as final discriminant trained for a Higgs boson mass of 115 GeV/c^2



Statistical Approach

Bayesian Posterior Probability

$$p(R|\vec{n}) = \frac{\int\int d\vec{s}d\vec{b}L(R,\vec{s},\vec{b}|\vec{n})\pi(R,\vec{s},\vec{b})}{\int\int\int dRd\vec{s}d\vec{b}L(R,\vec{s},\vec{b}|\vec{n})\pi(R,\vec{s},\vec{b})} \Rightarrow \int_0^{R_{0.95}} p(R|\vec{n})dR = 0.95$$

$R = (\sigma \times BR)/(\sigma_{SM} \times BR_{SM})$, $R_{0.95}$: 95% Credible Level Upper Limit

$\vec{s},\vec{b},\vec{n} = s_{ij}, b_{ij}, n_{ij}$(# of signal, background and observed events in j-th bin for i-th channel)

π : Bayes' prior density

Combined Binned Poisson Likelihood

$$L(R,\vec{s},\vec{b}|\vec{n}) = \prod_{i=1}^{N_{\text{channel}}} \prod_{j=1}^{N_{\text{bin}}} \frac{\mu_{ij}^{n_{ij}} e^{-\mu_{ij}}}{n_{ij}!}$$

Principle of ignorance

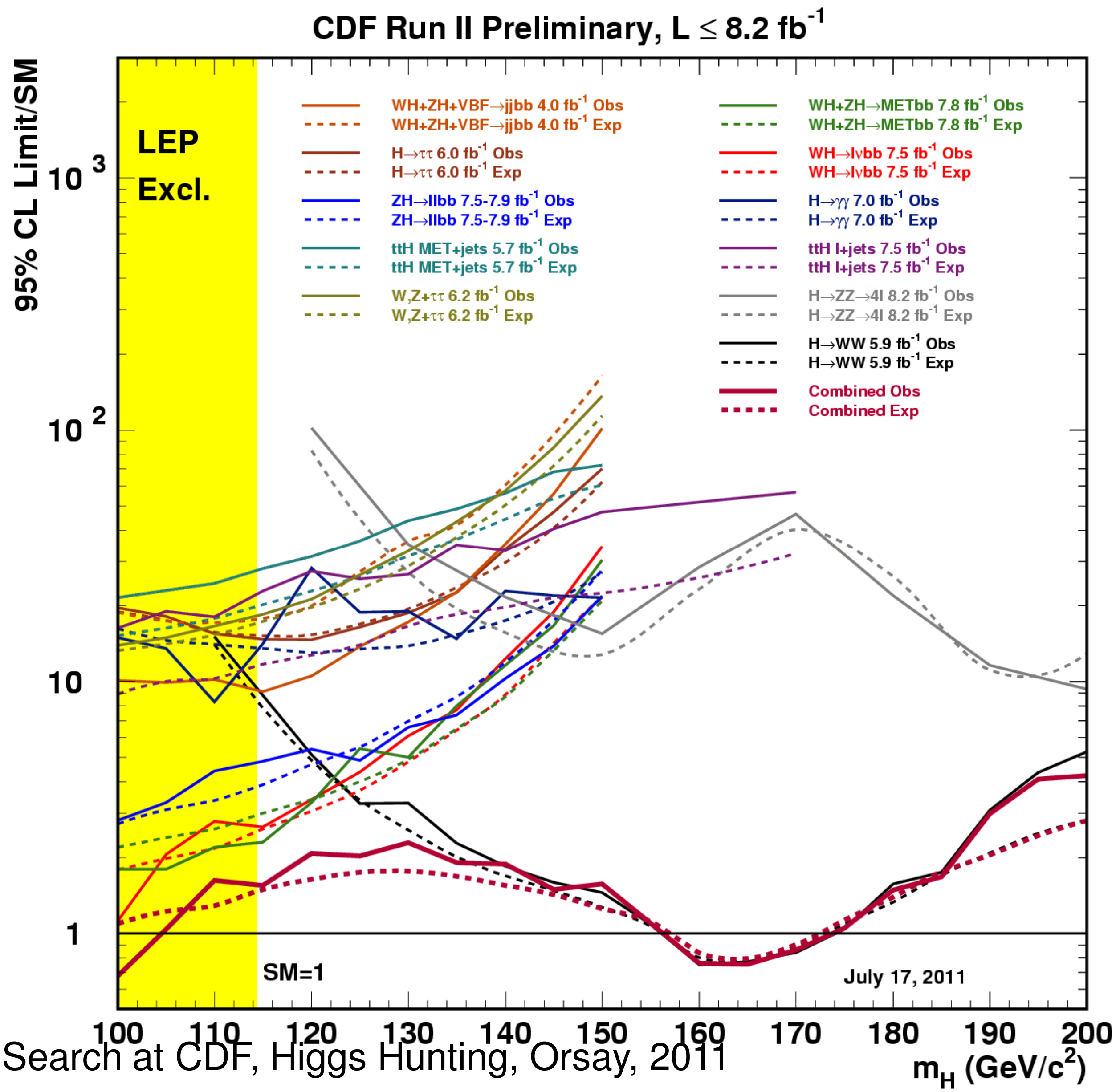
- for the number of higgs events (instead of higgs Xsec)

$$\pi(R,\vec{s},\vec{b}) = \pi(R)\pi(\vec{s})\pi(\vec{b}) = s_{tot}\theta(Rs_{tot})\pi(\vec{s})\pi(\vec{b})$$

$s_{tot} = \Sigma_{i,j} s_{ij}$: Total number of signal prediction

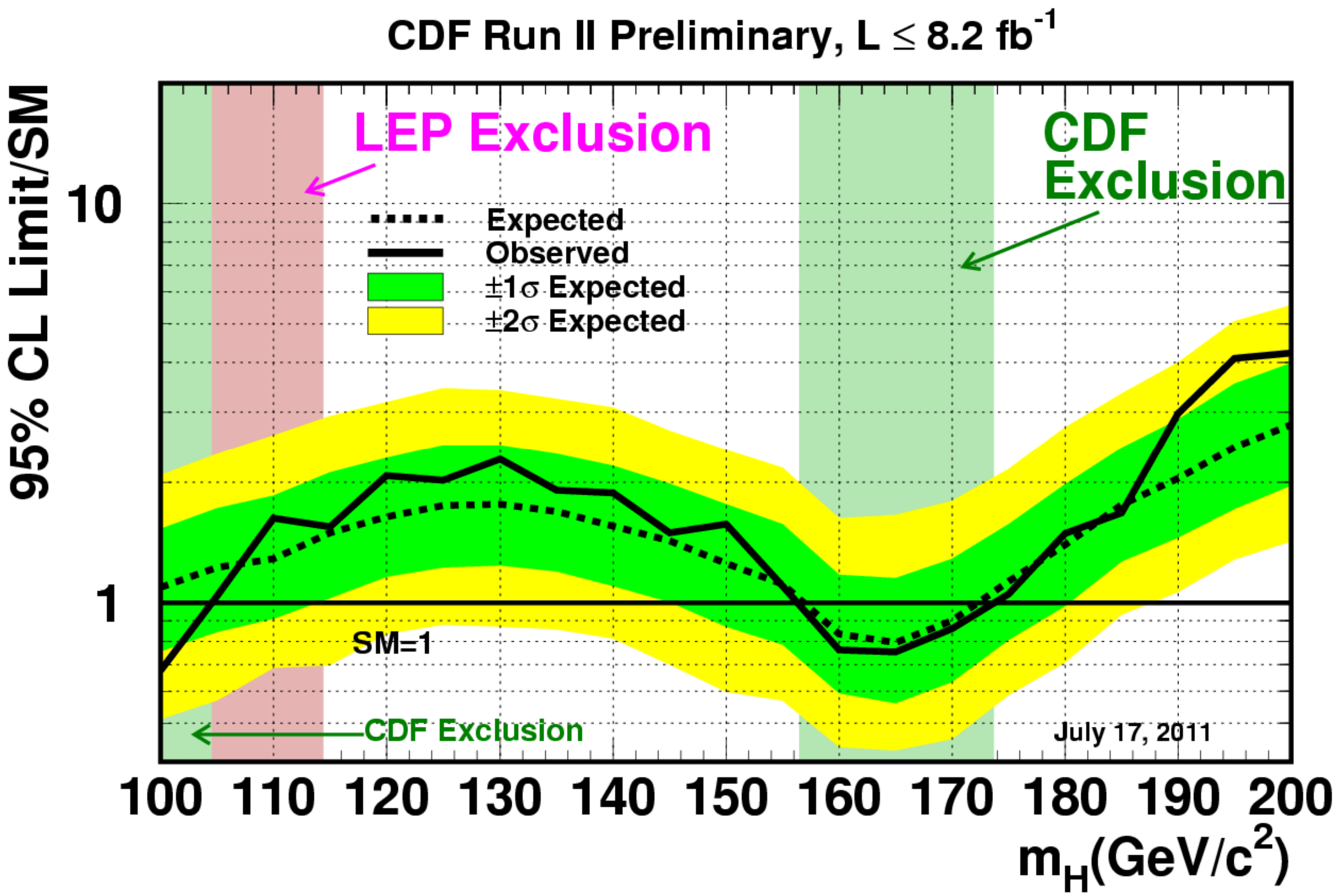
$\pi(x) = G(x|\hat{x},\sigma_x)$ $(x = s, b)$ $\hat{x}$: expected mean, σ_x: total uncertainty

CDF Combination – 1



CDF Combination - 2

- Exclude at 95% CL: [100.0 -104.5] & [156.7-173.8] GeV/c^2
- Expect to exclude at 95% CL: [156.5-173.7] GeV/c^2



CDF Combination

- CDF Collaboration, up to 8.2 fb^{-1}
- Search for the Standard Model Higgs Boson
- Very many channels
- None sees an excess of signal over backgrounds
- We combine all channels and use a Bayesian statistical approach to compute 95% CL upper limits on the cross section of the Higgs boson
- We expect to exclude at 95% CL Higgs masses in the range : [157.0-172.2] GeV/c^2
- We exclude at 95% CL Higgs masses in the ranges [100.0 -104.5] & [156.5-173.7] GeV/c^2
- Stay tuned for the Tevatron combination result!

CDF Combination Trajectory of Sensitivity

- Sensitivity improved continuously more than just by increasing the integrated luminosity; showing 115 and 160 GeV/c^2