Latest Highlights from CDF

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Fermilab

for the CDF Collaboration

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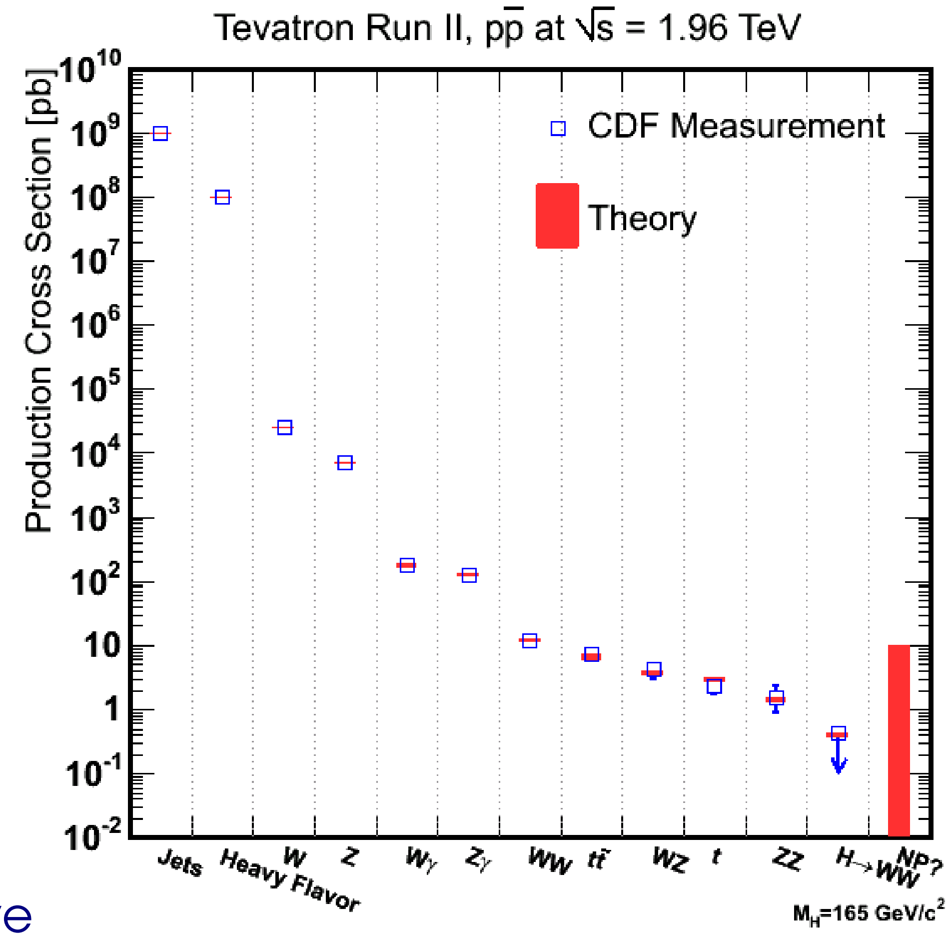
The CDF Run II Physics program

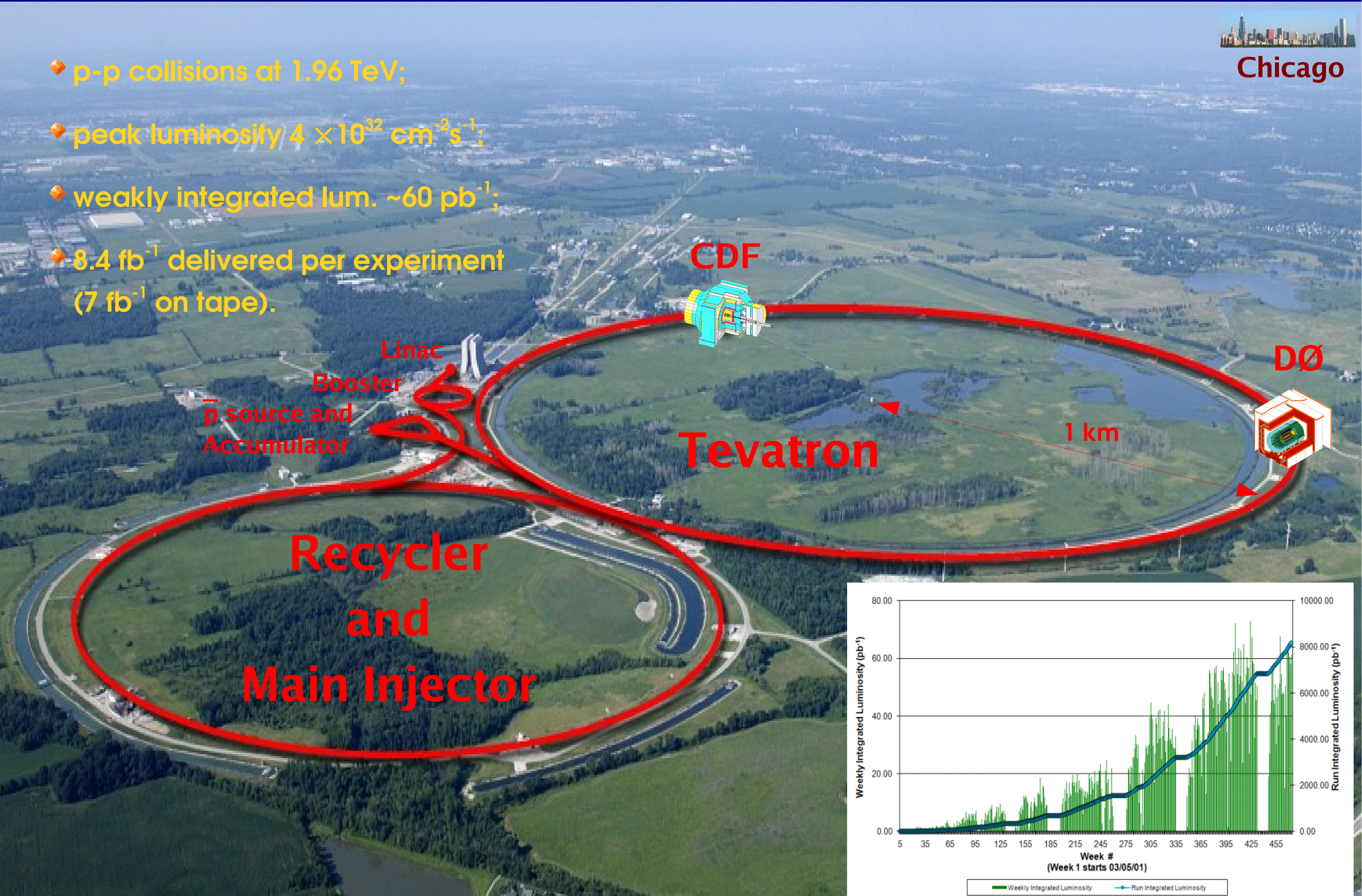
- The CDF II experiment has been running since 2001, pursuing a very rich and broad physics program, which is probing many facets of the Standard Model and its possible extensions over a wide range of processes, whose cross sections span ~10 orders of magnitude:
  - study of the interactions of quarks and gluons;
  - heavy flavor physics;
  - properties of W and Z weak bosons;
  - properties of the top quark;
  - searches for the SM Higgs boson;
  - direct searches for physics beyond the Standard Model.



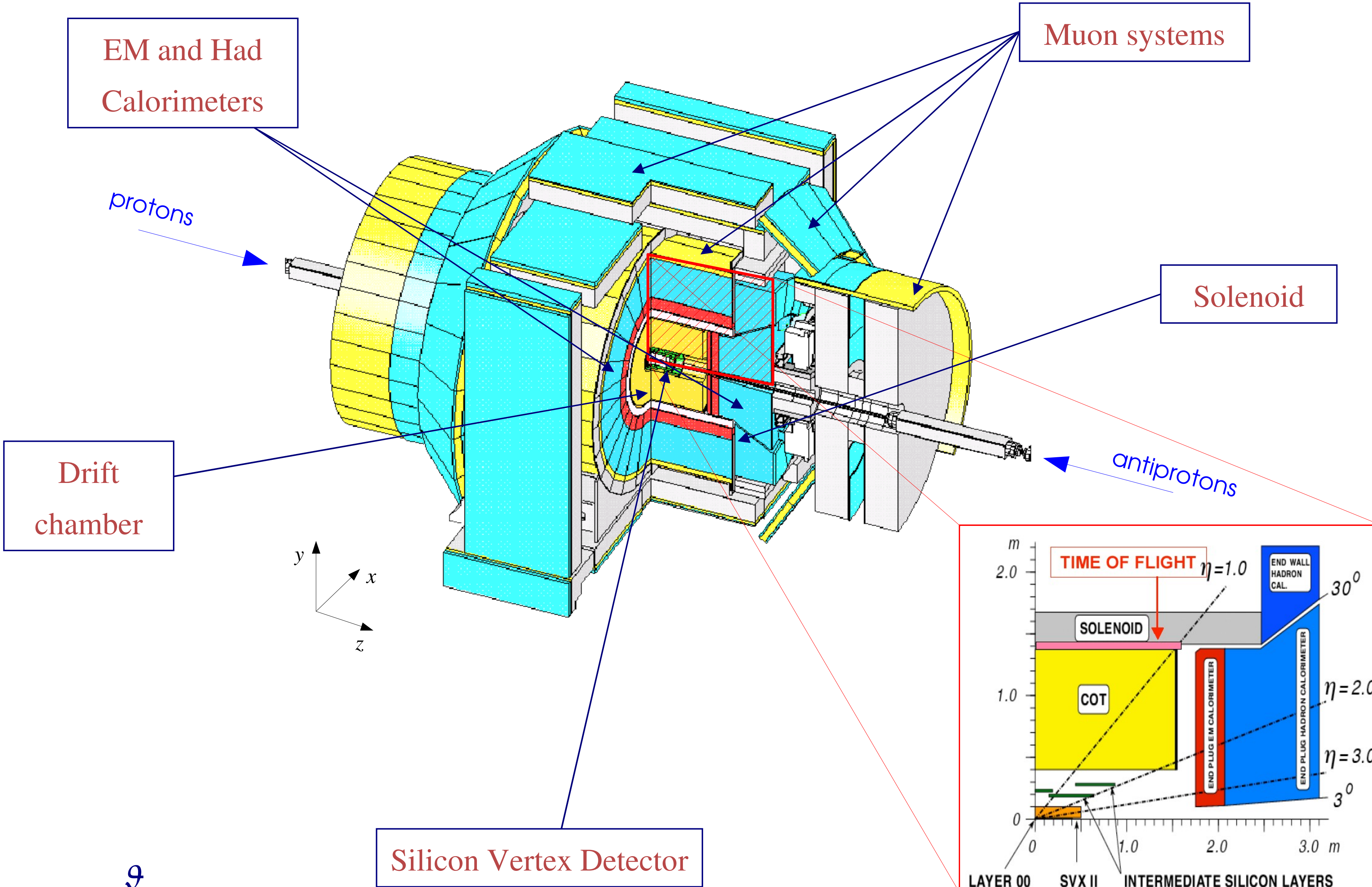
- This talk will give an overview of the above topics, focusing on the most recent results.

The Tevatron accelerator

- $p\text{-}\bar{p}$ collisions at 1.96 TeV;
- peak luminosity 4×10^{32} $cm^{-2}s^{-1}$;
- weakly integrated lum. ~60 pb^{-1};
- 8.4 fb^{-1} delivered per experiment ($7\ fb^{-1}$ on tape).



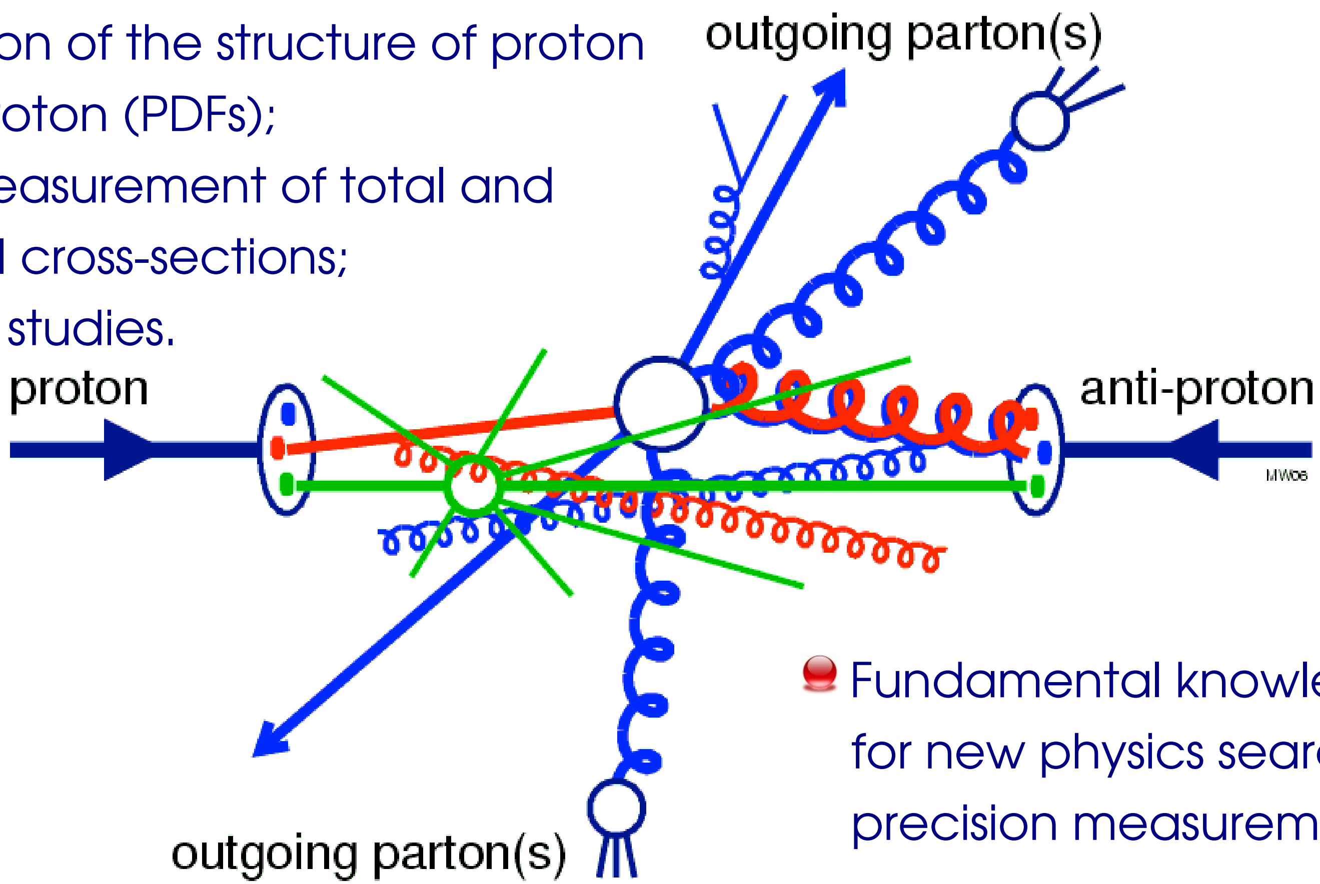
The CDF detector



$$\eta = -\ln \tan \frac{\vartheta}{2}$$

QCD

- Information on the partons which partake in the strong interactions is accessed via the jets reconstructed in the detector:
  - tests of pQCD predictions;
  - investigation of the structure of proton and antiproton (PDFs);
  - precise measurement of total and differential cross-sections;
  - diffractive studies.

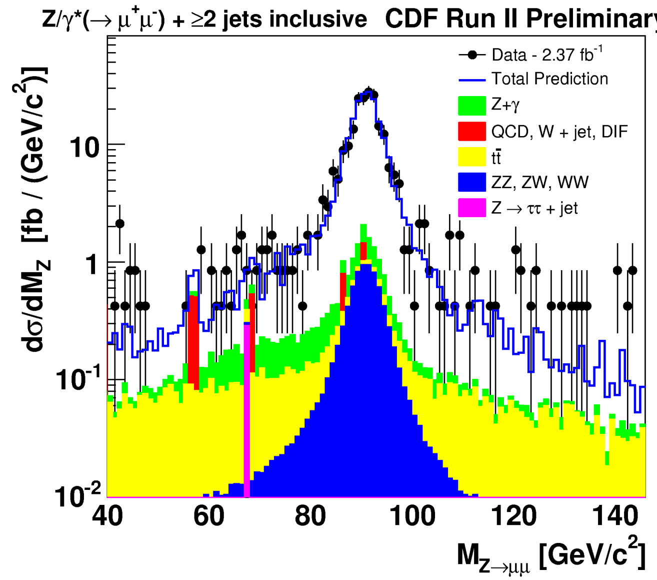


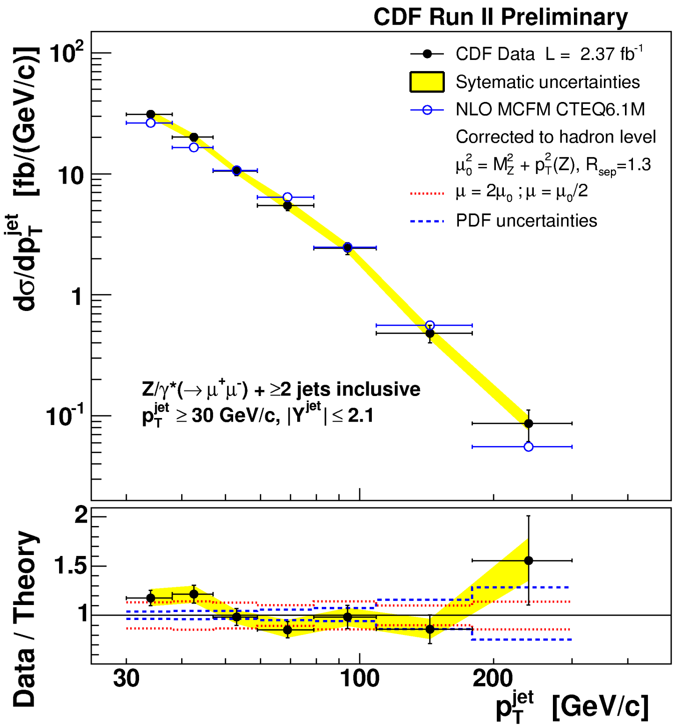
- Fundamental knowledge necessary for new physics searches and precision measurements.

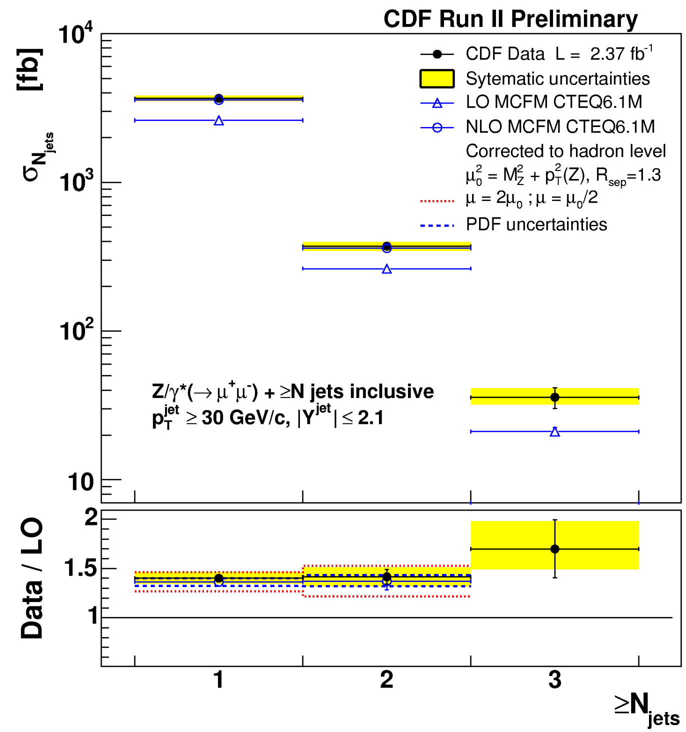
- In this talk: Z/γ^* + jets and hyperon production.
- More results in the QCD and Final States Session (N. Moggi, A. Paramonov, S. Moed) and Small-x and Diffraction Section (J. Huston).

Z/γ* + jets production

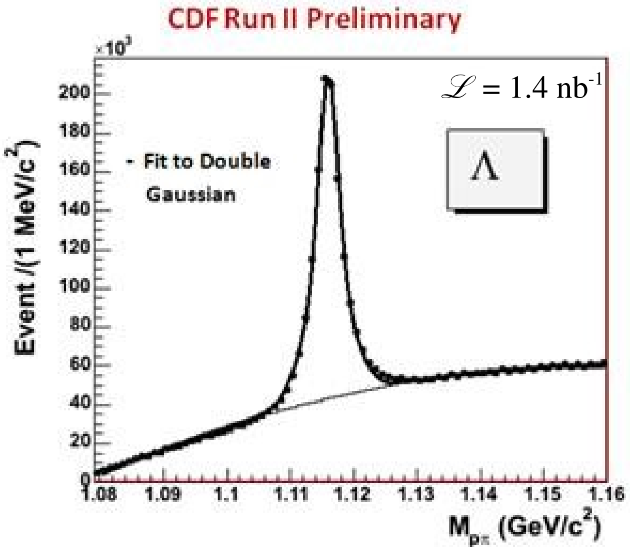
- High-p_T muon data sample with 2.4 fb^{-1}.
- Selected events with two opposite-sign muons:
  - $66 < M_{\mu\mu} < 116$ GeV/c^2;
  - 0.7-cone midpoint jets with E_T>30 GeV and $|y| < 2.1$.
- Results compared to NLO pQCD predictions.

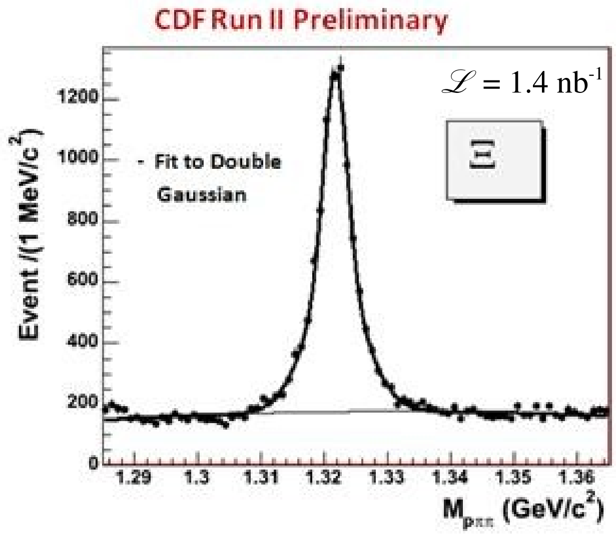


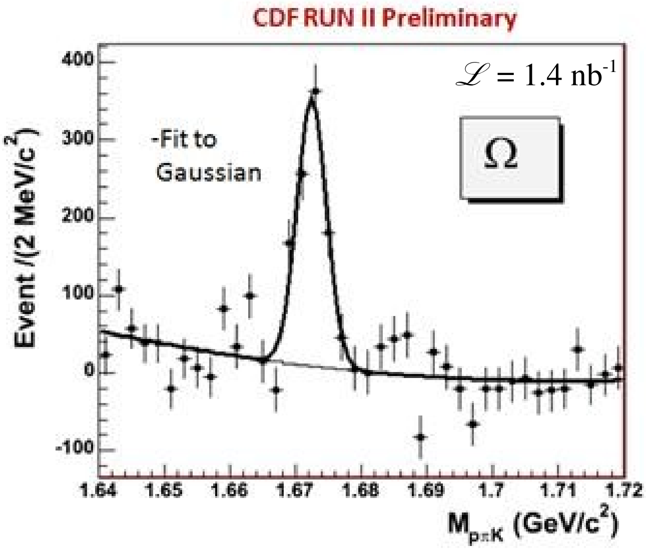




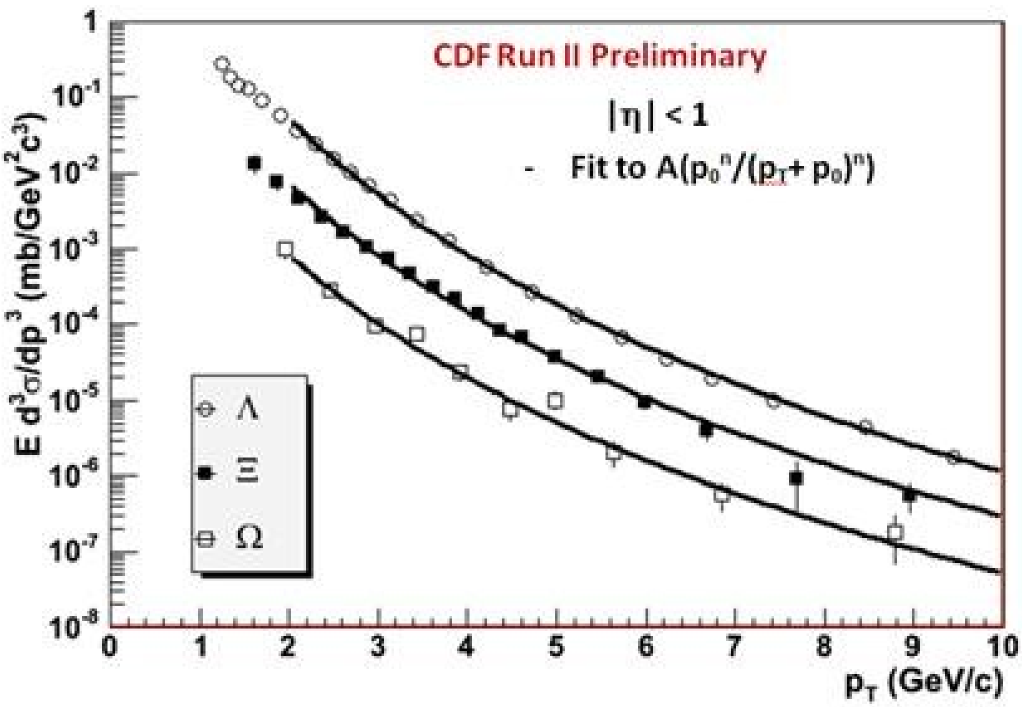
Hyperon production



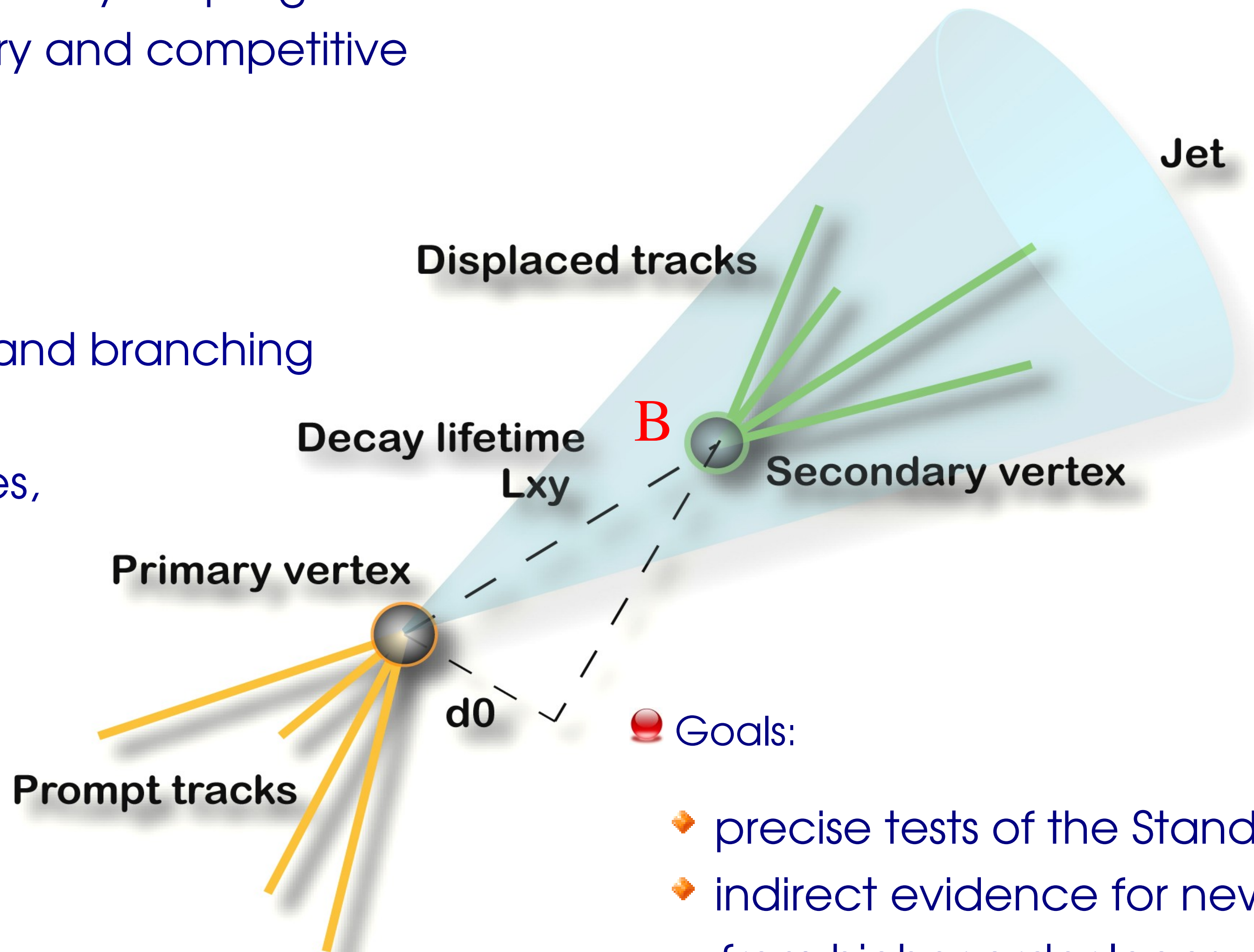




- p_T differential cross-section of hyperons with $|\eta| < 1$.
- In the minimum bias sample:
  - $\Lambda^0 \rightarrow p\pi$;
  - $\Xi^\pm \rightarrow \Lambda^0\pi^\pm$;
  - $\Omega^\pm \rightarrow \Lambda^0 K^\pm$.
- Cross-sections drop by ~7 for each additional *s* quark.



- CDF Heavy Flavor Physics program is complementary and competitive with B-factories':
  - masses,
  - lifetimes,
  - decay widths and branching fractions,
  - CP asymmetries,
  - rare decays properties.

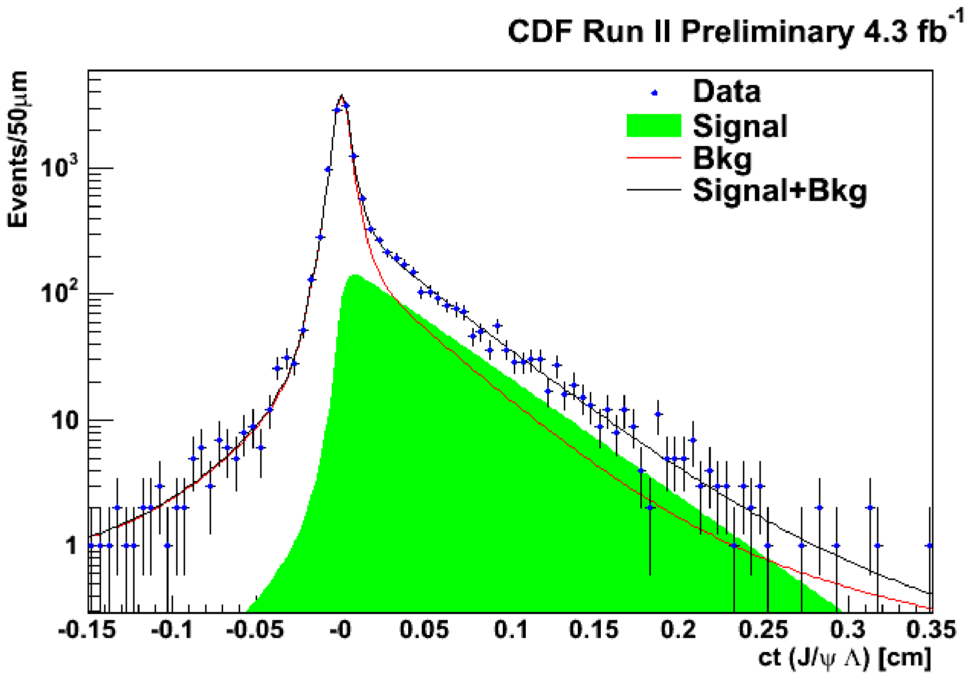


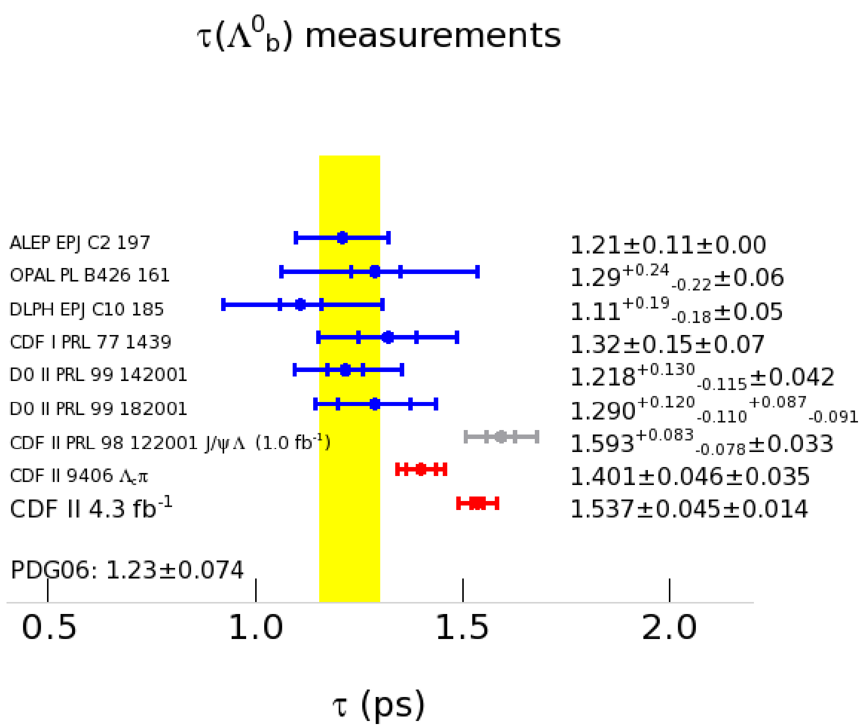
- Goals:
  - precise tests of the Standard Model;
  - indirect evidence for new physics from higher order loops.

- In this talk: b-hadron lifetimes and $B \rightarrow \mu\mu X_s$ rare decays.
- More results in the Heavy Quark Session (T. Kuhr).

b-hadron lifetimes

- Reconstructed modes in 4.3 fb^{-1}: $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{0*}$, $B^0 \to J/\psi K_S$, $\Lambda_b \to J/\psi \Lambda^0$.
- τ extracted from a simultaneous unbinned maximum-likelihood fit to M, ct, σ_{ct}.
- b-hadron decay position estimated from the J/ψ reconstructed vertex.





- World most precise lifetime determinations:

$$\tau(B^+) = 1.639 \pm 0.009_{stat} \pm 0.009_{syst}\ \text{ps}$$
$$\tau(B^0) = 1.507 \pm 0.010_{stat} \pm 0.008_{syst}\ \text{ps}$$
$$\tau(\Lambda_b) = 1.537 \pm 0.045_{stat} \pm 0.014_{syst}\ \text{ps}$$

$$\tau(B^+)/\tau(B^0) = 1.088 \pm 0.009_{stat} \pm 0.004_{syst}$$
$$\tau(\Lambda_b)/\tau(B^0) = 1.020 \pm 0.030_{stat} \pm 0.008_{syst}$$

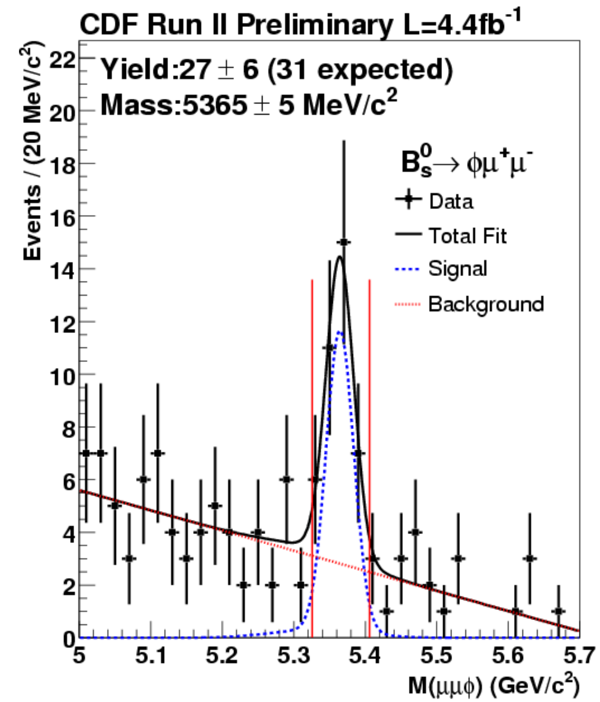
- Expected: $\tau(B^+)/\tau(B^0) \approx 1.04\text{-}1.08$
  $\tau(\Lambda_b)/\tau(B^0) \approx 0.83\text{-}0.93$

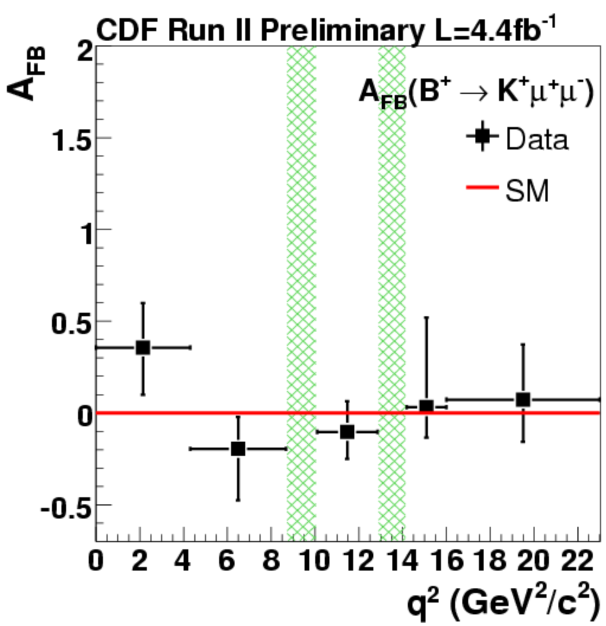
Rare decays $B \to \mu\mu X_s$

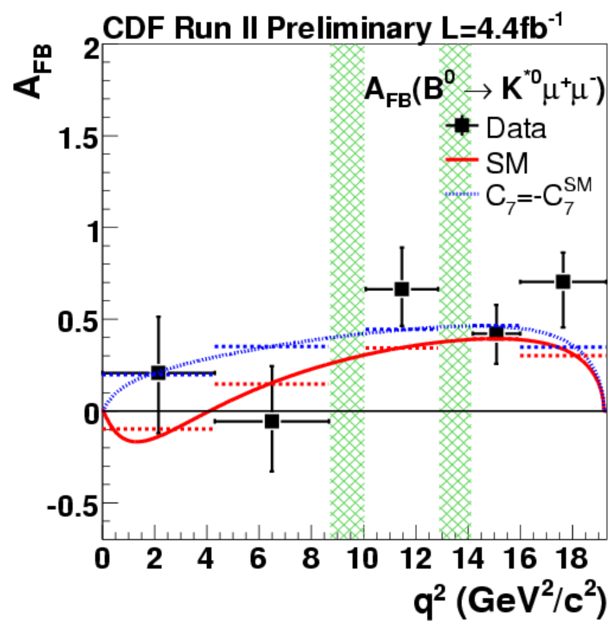
- $B^+ \to \mu\mu K^+$, $B^0 \to \mu\mu K^{0*}$, $B_s \to \mu\mu\phi$ in 4.4 fb^{-1}.
- $b \to s\mu\mu$ FCNC processes:
  - new Physics could modify rate or decay distributions.
- First observation of $B_s \to \mu\mu\phi$:

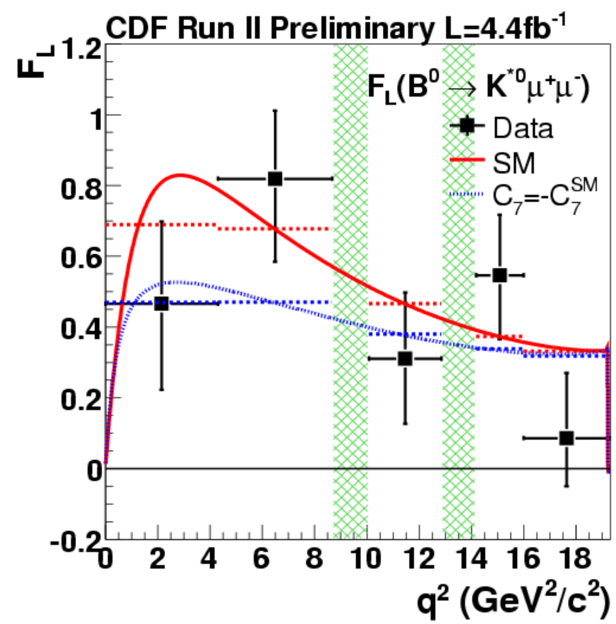
$$BR(B_s) = (1.44 \pm 0.33_{stat} \pm 0.46_{syst}) \times 10^{-6}$$

- $B^+ \to \mu\mu K^+$ and $B^0 \to \mu\mu K^{0*}$: measurement of muons FB asymmetry and K^{0*} longitudinal polarization.
- Result competitive with B-factories.





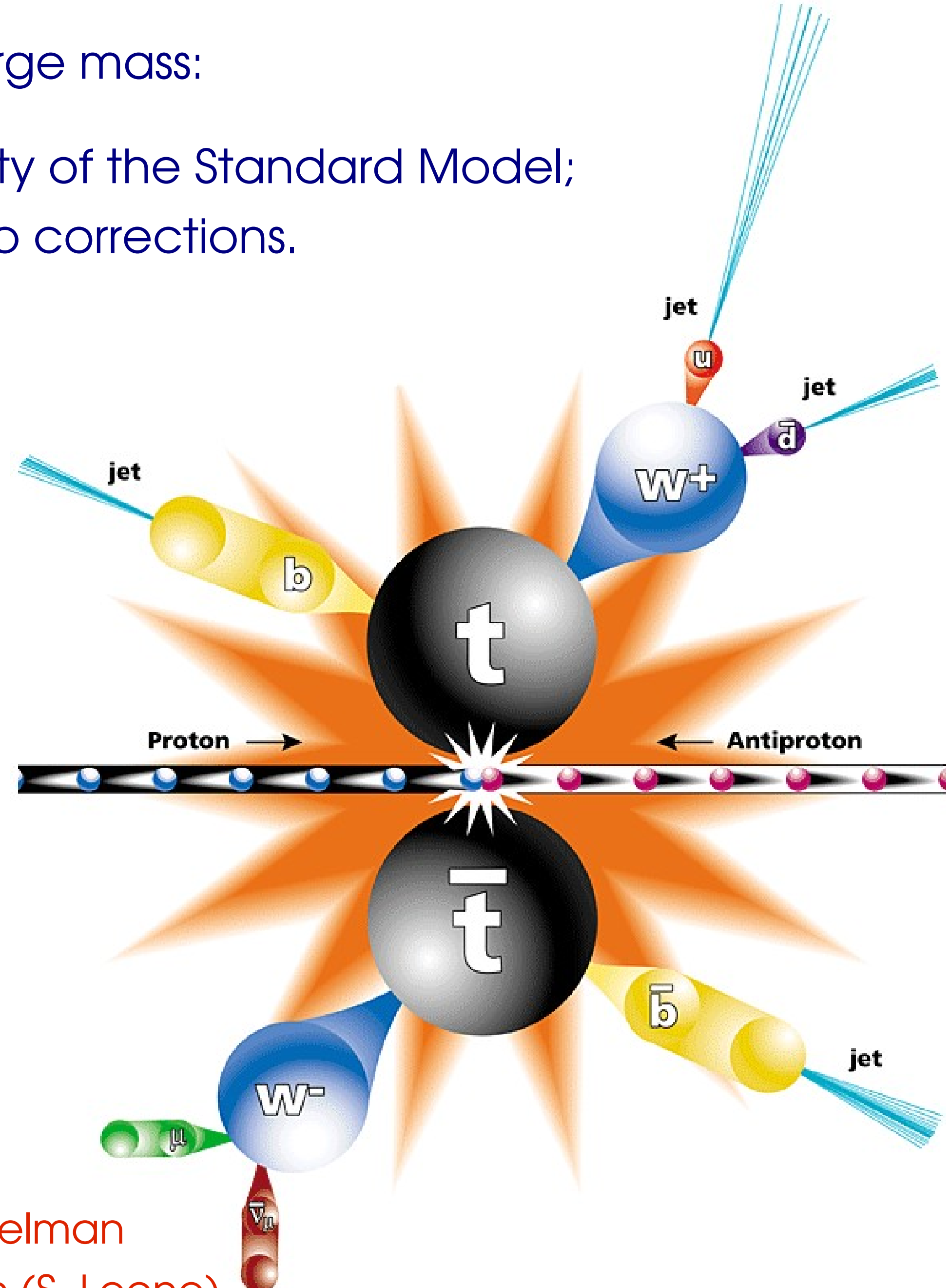




Top quark

- The top quark is unique because of its large mass:
  - provides a testing ground for the validity of the Standard Model;
  - dominant contribution in quantum loop corrections.

- The CDF top sample allows to investigate exhaustively the properties of the top quark:
  - top mass measurement;
  - $t\bar{t}$ production cross section;
  - single top production cross-section;
  - top properties: decay width, lifetime, spin, helicity, charge asymmetries.

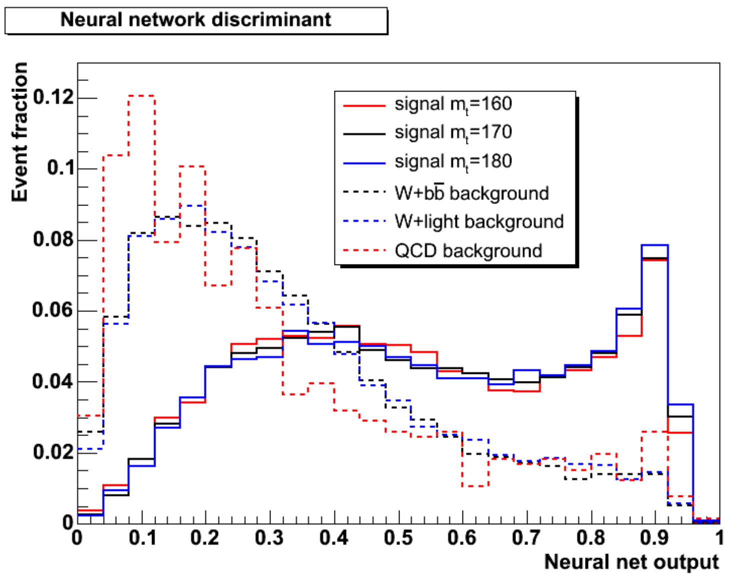


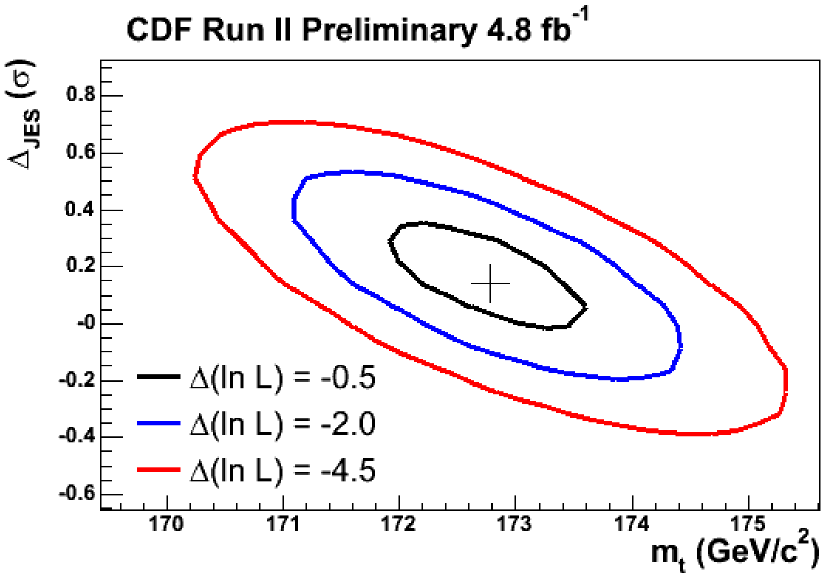
- In this talk: top mass, decay width and spin correlation.

- More results in the Heavy Quark Session (J. Adelman and G. Compostella) and Electroweak session (S. Leone).

Top mass

- Fundamental parameter of the SM: used in electro-weak predictions, with W mass constraints the Higgs boson mass.
- Lepton + jets sample with 4.8 fb^{-1}:
  - matrix-element based measurement;
  - neural network for background discrimination;
  - in situ $W \rightarrow jj$ jet energy scale (JES) calibration.



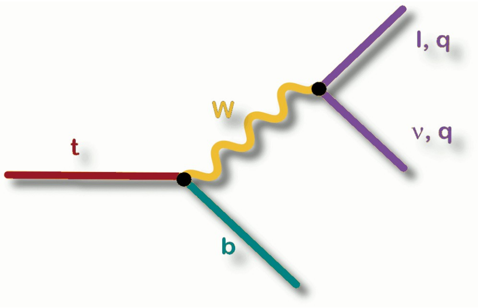


$$m_t = 172.8 \pm 0.7_{stat} \pm 0.6_{JES} \pm 0.8_{syst} \text{ GeV}/c^2$$

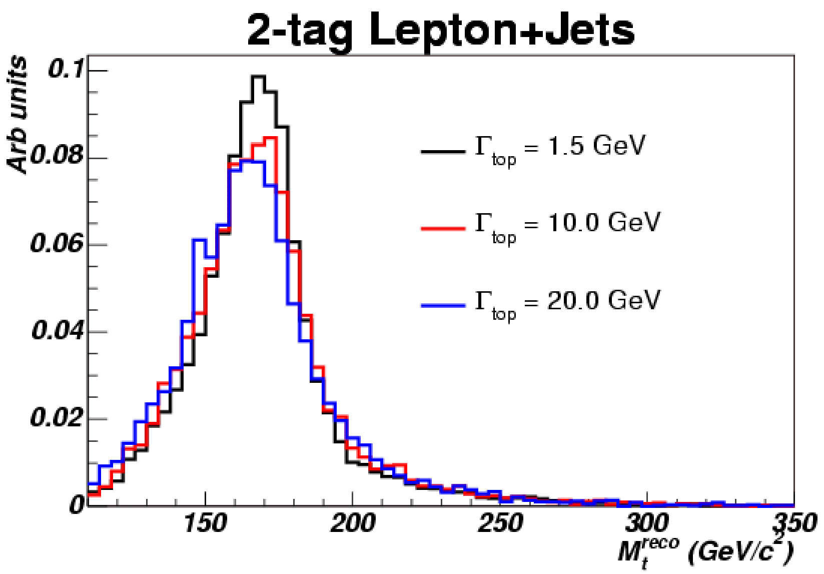
- Result equals in precision the 2009 Tevatron combination!

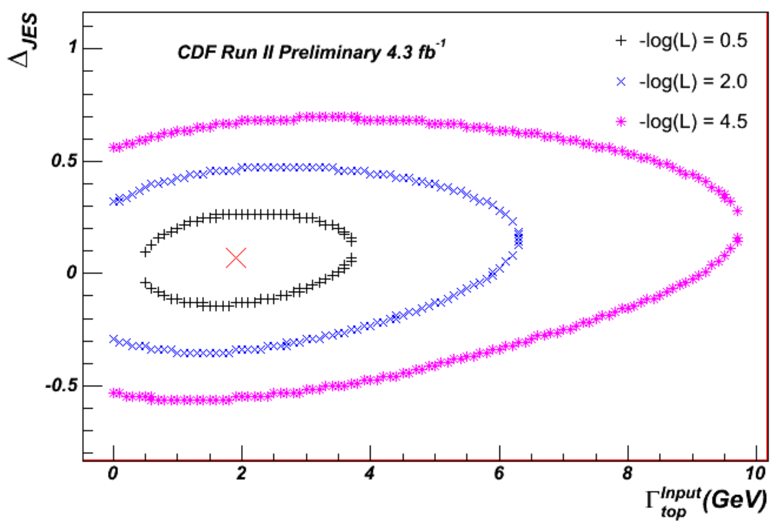
Top width

- Check consistency with SM, limits on $t \to H^+ b$, $t \to Wq$, ...



- Template-based measurement:
  - lepton + jets sample with 4.3 fb^{-1};
  - two-dimensional templates: M_t, M_{jj};
  - simultaneous constraint of jet energy scale using W jets.





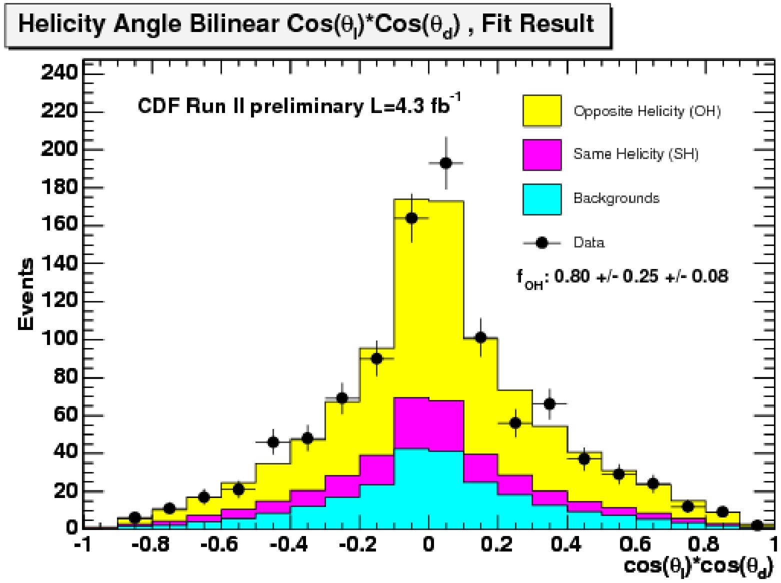
- Upper limit on top quark width:

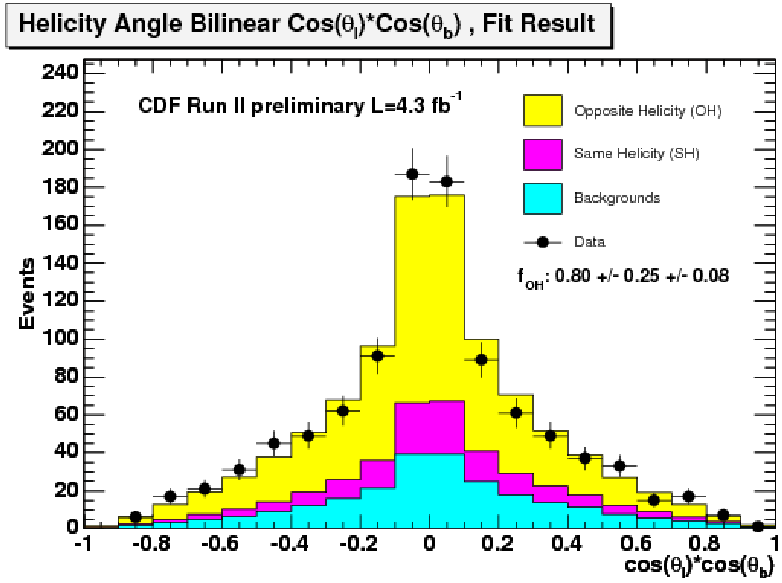
$$\Gamma_{top} < 7.5 \text{ GeV @ 95\% C.L.} \quad \Rightarrow \quad \tau_{top} > 8.7 \times 10^{-26} \text{ s @ 95\% C.L.}$$

$$0.4 \text{ GeV} < \Gamma_{top} < 4.4 \text{ GeV @ 68\% C.L.}$$

Top spin correlation

- Top decays weakly before hadronization, spin conserved in top decay:
  - spin correlation between top and anti-top could be modified by new physics.
- Lepton + jets sample with 4.3 fb^{-1}:
  - exploits the helicity angels of lepton, *d*, and *b* quarks;
  - simultaneous likelihood fit of $\cos(\vartheta_\ell)\cos(\vartheta_d)$ and $\cos(\vartheta_\ell)\cos(\vartheta_b)$.





- Opposite spin fraction:

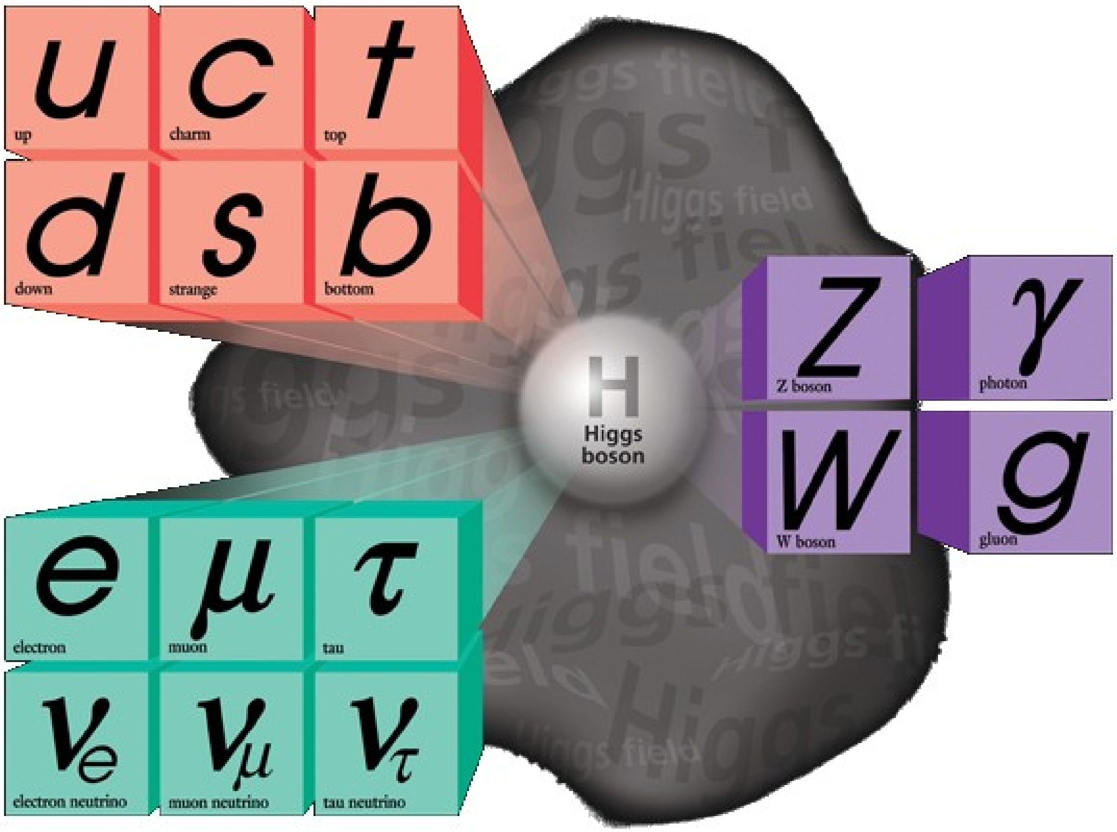
$$f_O = 0.80 \pm 0.25_{\text{stat}} \pm 0.08_{\text{syst}}$$

- Spin correlation coefficient:

$$\kappa = 2f_O - 1 = 0.60 \pm 0.50_{\text{stat}} \pm 0.16_{\text{syst}}$$

Electroweak

- The study of the massive weak W and Z bosons and the photon:
  - test of the Standard Model and indirect constraints on new phenomena;
  - improved background understanding for searches.



- CDF program:
  - W mass and width;
  - W and Z/γ^* cross-sections;
  - $W+\gamma$ and $Z/\gamma^*+\gamma$ cross-sections;
  - WW/WZ/ZZ production cross-sections;
  - rare W decays: $W^- \rightarrow \pi^- \gamma$;
  - search for anomalous triple gauge couplings.

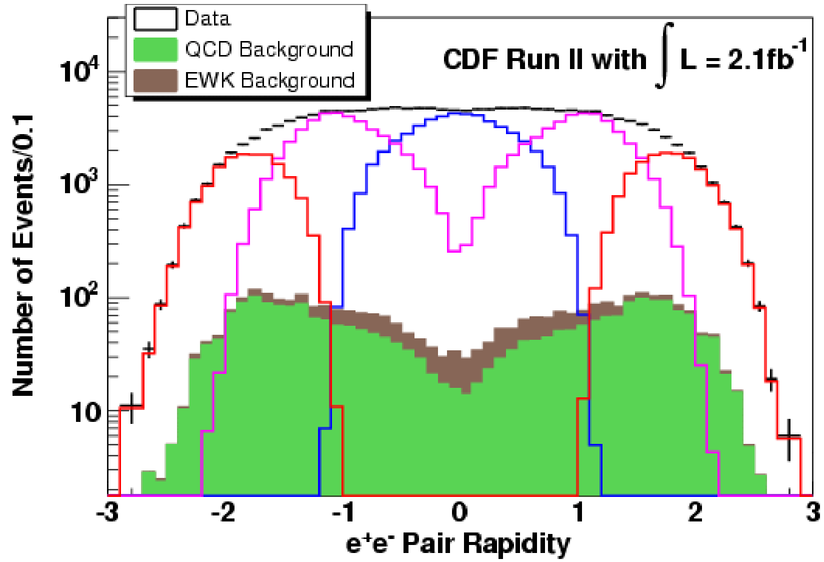
- In this talk: Z/γ^* rapidity, WW/WZ production, $Z\gamma$ production.
- More results in the Electroweak Session (G. Chiarelli).

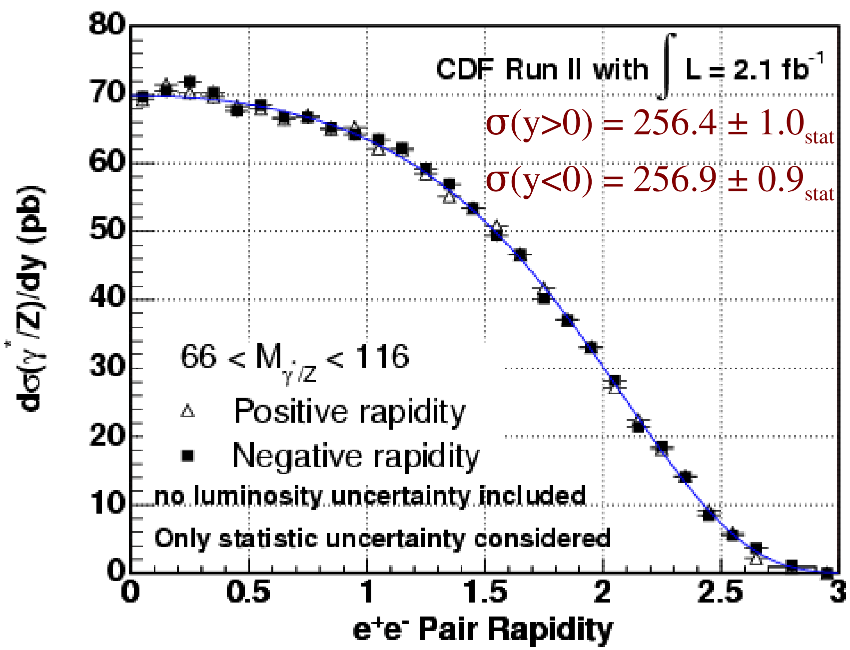
Z/γ^* rapidity

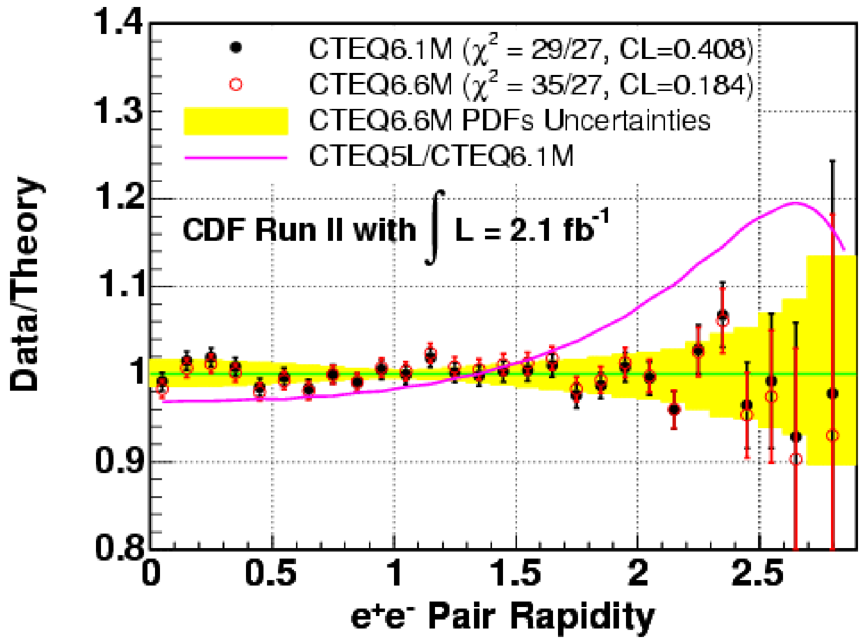
- $d\sigma_{Z/\gamma^*}/dy$ distribution measured in 2.1 fb^{-1} using $Z \rightarrow ee$ events;
- Total production cross-section:

$$\sigma_{Z/\gamma^*} = 256.6 \pm 0.7_{stat} \pm 2.0_{syst} \text{ pb}$$

- $d\sigma_{Z/\gamma^*}/dy$ shape compared to NLO and NNLO QCD calculations: best description of the data provided by the NLO CTEQ6.1M PDF.







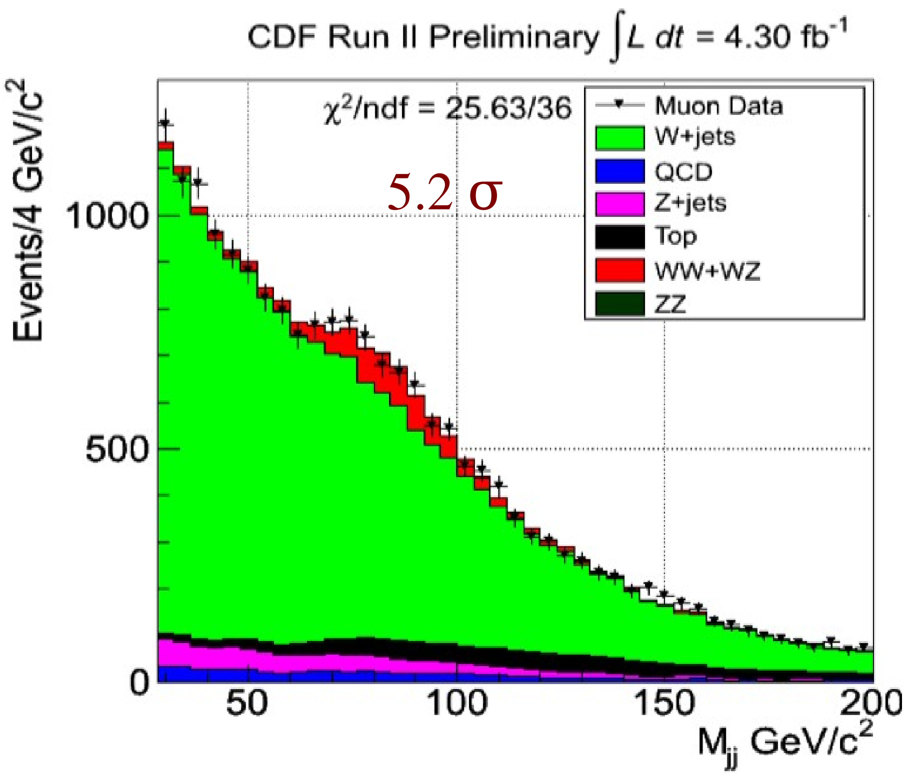
$WW/WZ \rightarrow \ell\nu_{\ell}\, jj$

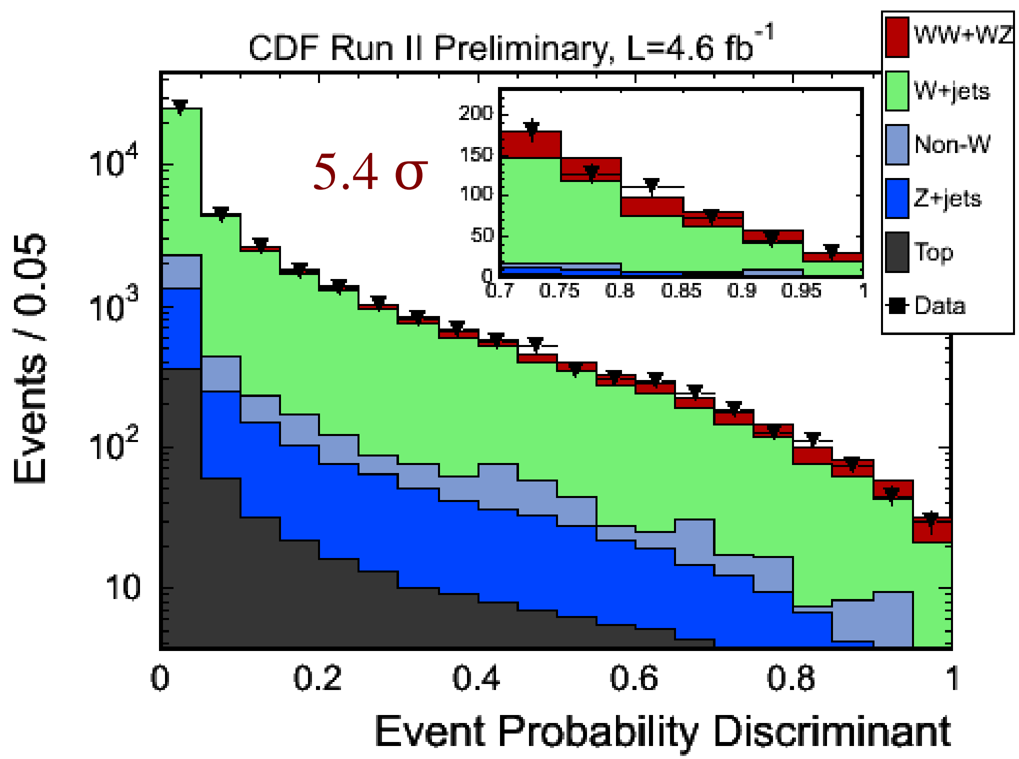
- Observation of WW/WZ in the lepton + jets final state; $\sigma_{SM} = 15.1 \pm 0.9$ pb
- Two analyses use different discriminants:
  - the jet-jet invariant mass M_{jj} (4.3 fb^{-1}):

$$\sigma_{WW/WZ} = 18.1 + 3.3_{stat} \pm 2.5_{syst}\ \text{pb}$$

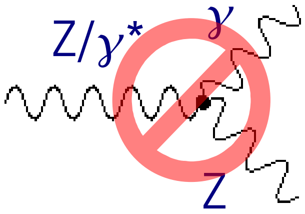
  - event probability based on a matrix element technique (4.6 fb^{-1}):

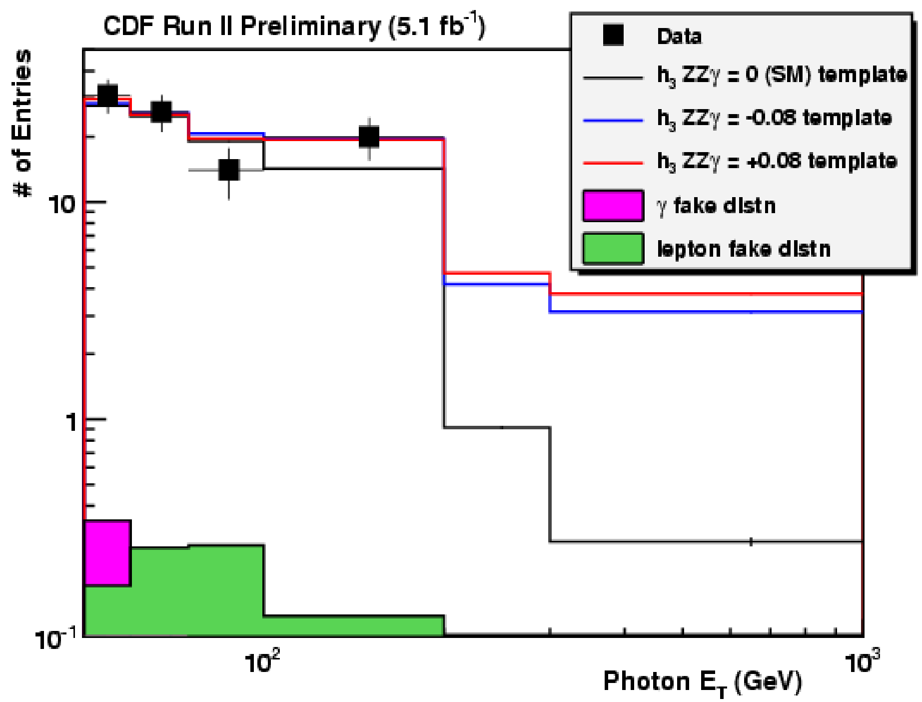
$$\sigma_{WW/WZ} = 16.5\ ^{+3.3}_{-3.0}\ \text{pb}$$

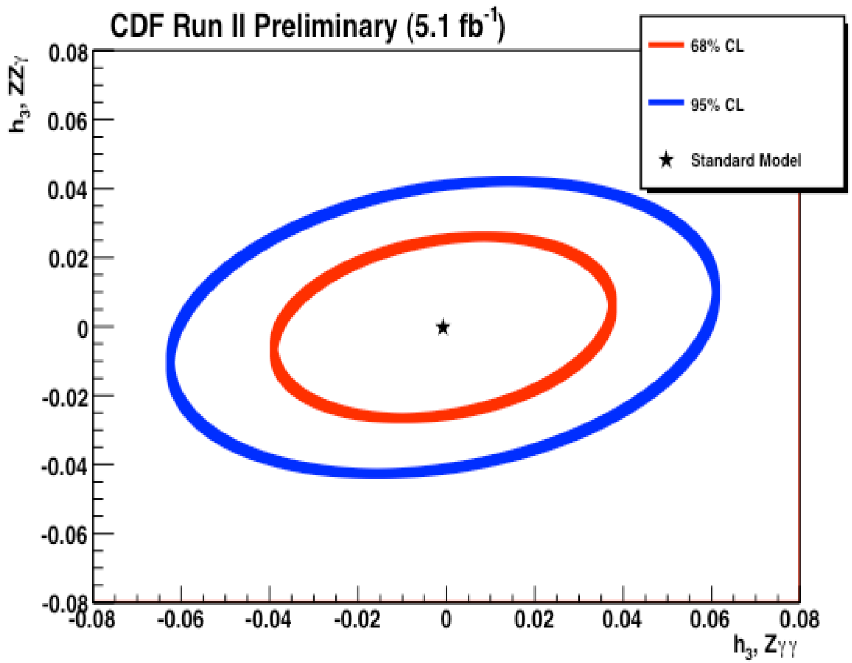




- Zγ direct coupling is forbidden in the Standard Model:
  - SM only contributions from ISR and FSR.
- Search for Zγ with Z→ee and Z→μμ in 5.1 fb^{-1}.
- Photon E_T spectrum sensitive to anomalous couplings.







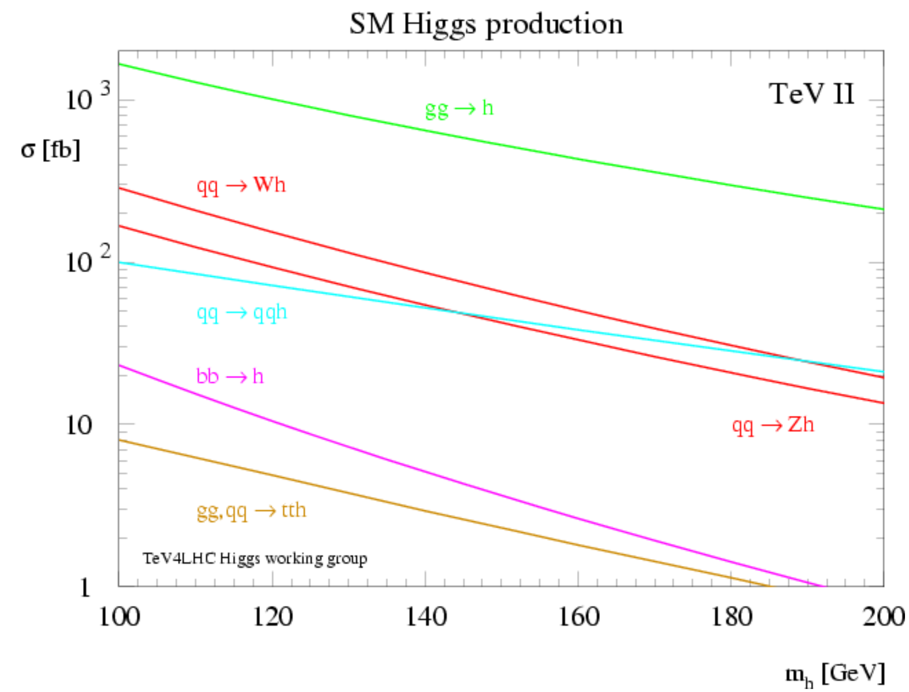
- Set limits on anomalous neutral triple gauge couplings ZZγ and Zγγ (@ 1.2 TeV):

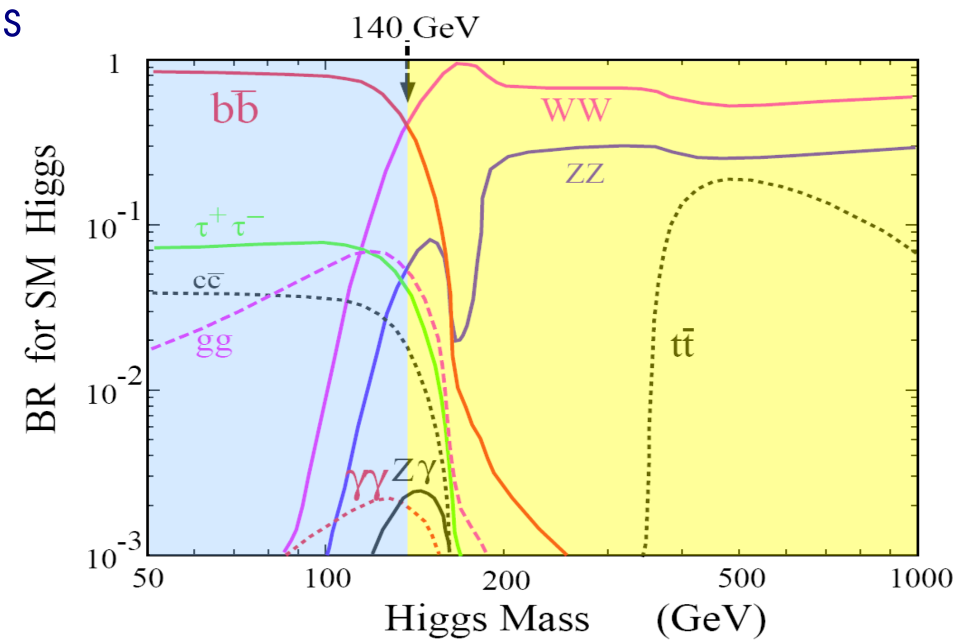
$$|h_3| < 0.038 \qquad |h_4| < 0.0017$$

SM Higgs direct searches

- The Higgs boson represents the missing piece of the Standard Model.
- From indirect constraints and global EWK fits indications of a relatively light Higgs.
- Tevatron experiments sensitive to the mass range 100-200 GeV/c^2.
- Search strategy driven by the dominant Higgs decay mode:
  - $H \rightarrow \bar{b}b$ for $M_H < 135$ GeV/c^2 (low mass);
  - $H \rightarrow WW^*$ for $M_H > 135$ GeV/c^2 (high mass).

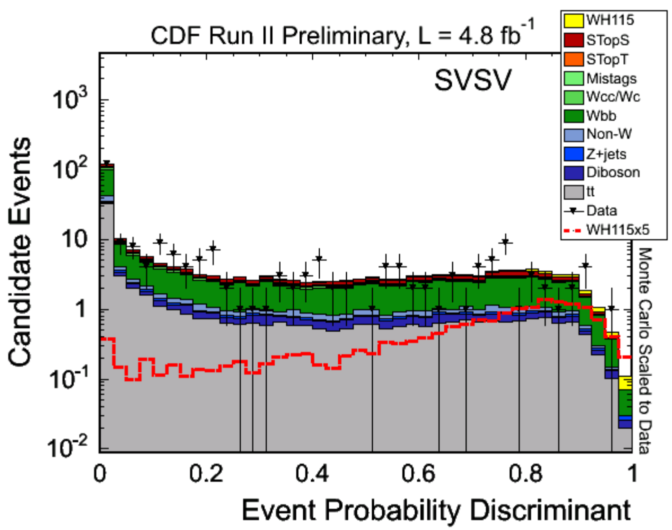
▸ In this talk: new CDF results in the low and high mass searches, Tevatron combination.



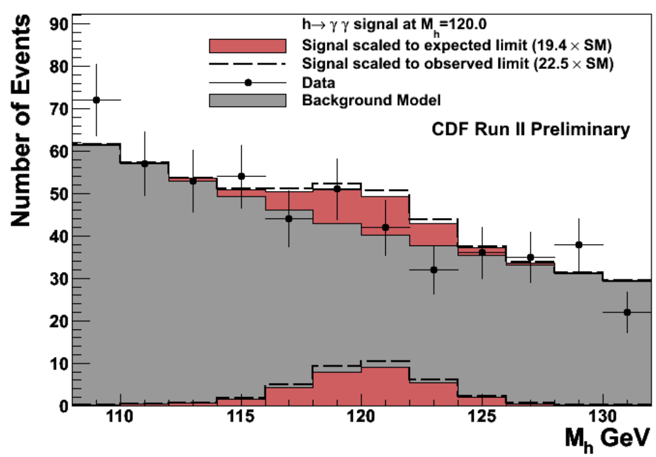


Low mass SM Higgs

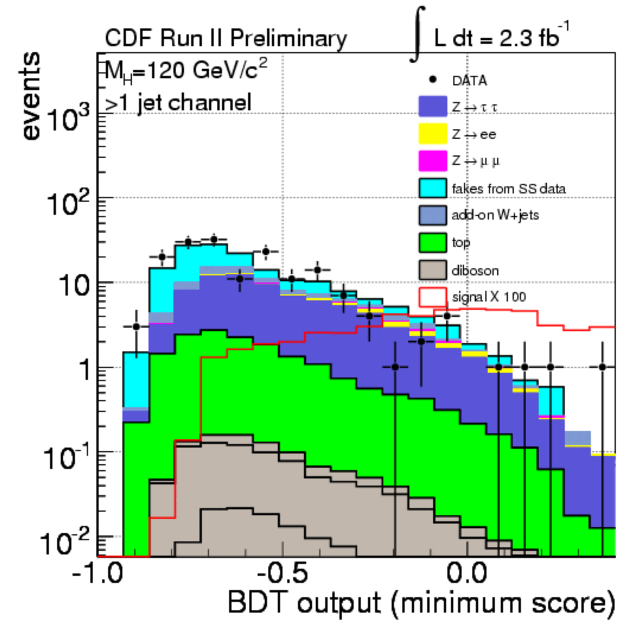
- $WH \to \ell \nu_\ell b\bar{b}$ with 4.8 fb^{-1}:
  - one of the most sensitive channels at low mass;
  - discriminant: event prob. based on the LO Matrix Element calculation.



- $H \to \gamma\gamma$ with 5.4 fb^{-1}:
  - clean signature, but very low BR in SM;
  - BR enhanced in BSM scenarios;
  - $M_{\gamma\gamma}$ used as a discriminant: few GeV/c^2 resolution;



- $H \to \tau\tau$ with 2.3 fb^{-1}:
  - new τ ID based on BDT: 15-20% improvement;
  - different BDTs trained against different bkgs and combined.



- 95% C.L. Upper limits on H production cross section:

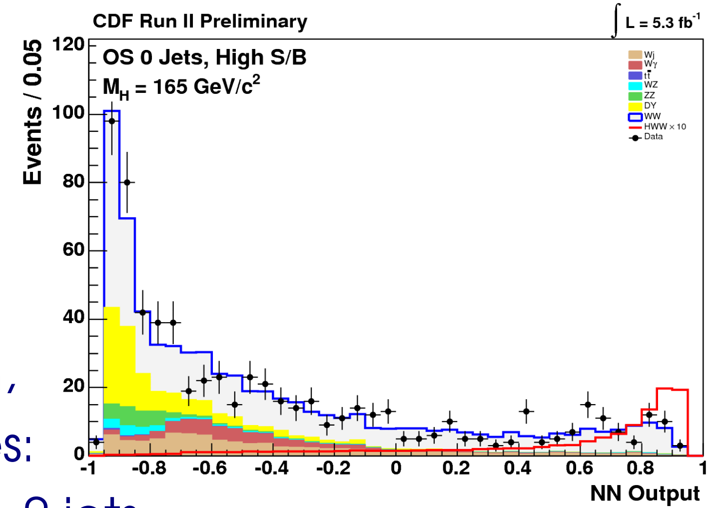
At M_H = 120 GeV/c^2:
- expected = 4.7 $\times \sigma_{SM}$
- observed = 3.9 $\times \sigma_{SM}$

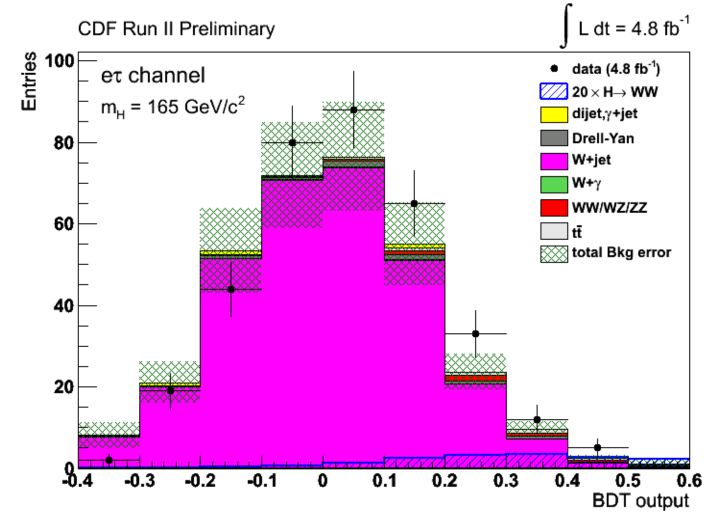
At M_H = 120 GeV/c^2:
- expected = 18.4 $\times \sigma_{SM}$
- observed = 22.3 $\times \sigma_{SM}$

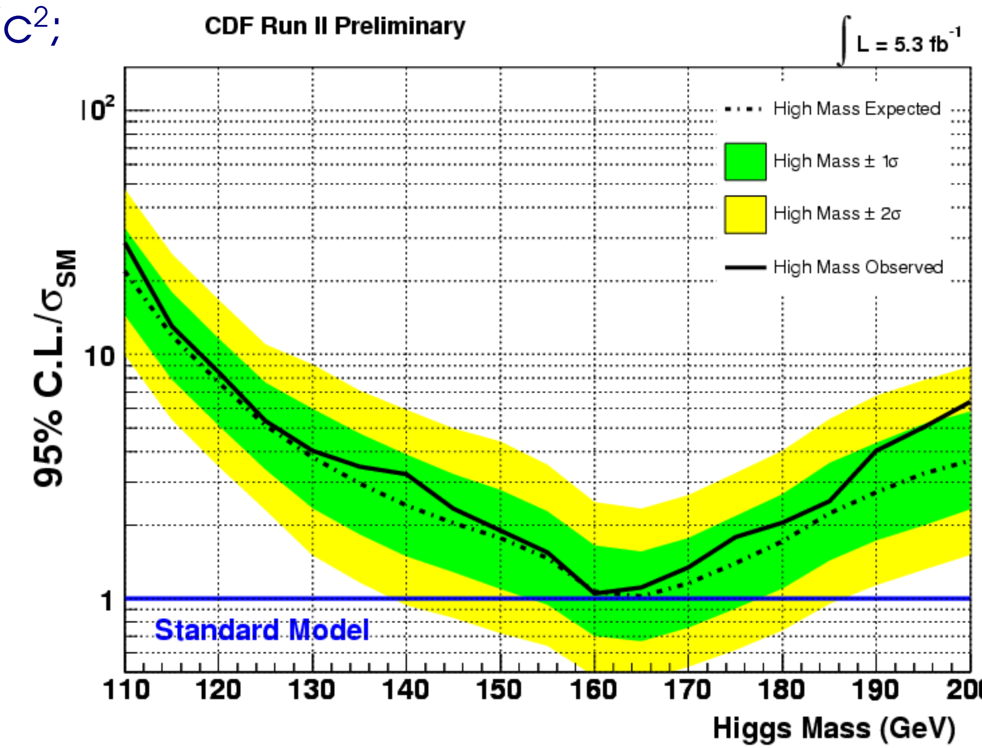
At M_H = 120 GeV/c^2:
- expected = 20.8 $\times \sigma_{SM}$
- observed = 23.2 $\times \sigma_{SM}$

High mass SM Higgs

- $H \to WW^* \to \ell\nu_\ell\ell'\nu_{\ell'}$ with 4.8-5.4 fb^{-1}:
  - 2 leptons + missing E_T;
  - most sensitive channel.
- To improve S/B separation, search split in sub-analyses:
  - opposite sign $\ell\ell'$ + 0, 1, ≥2 jets;
  - opposite sign $\ell\ell'$ and $M_{\ell\ell'} < 20$ GeV/c^2;
  - same sign $\ell\ell'$ + 1 jet;
  - three lepton channel;
  - lepton + hadronic tau.
- ANN and BDT as discriminants.
- 95% C.L. upper limits on σ/σ_{SM}:



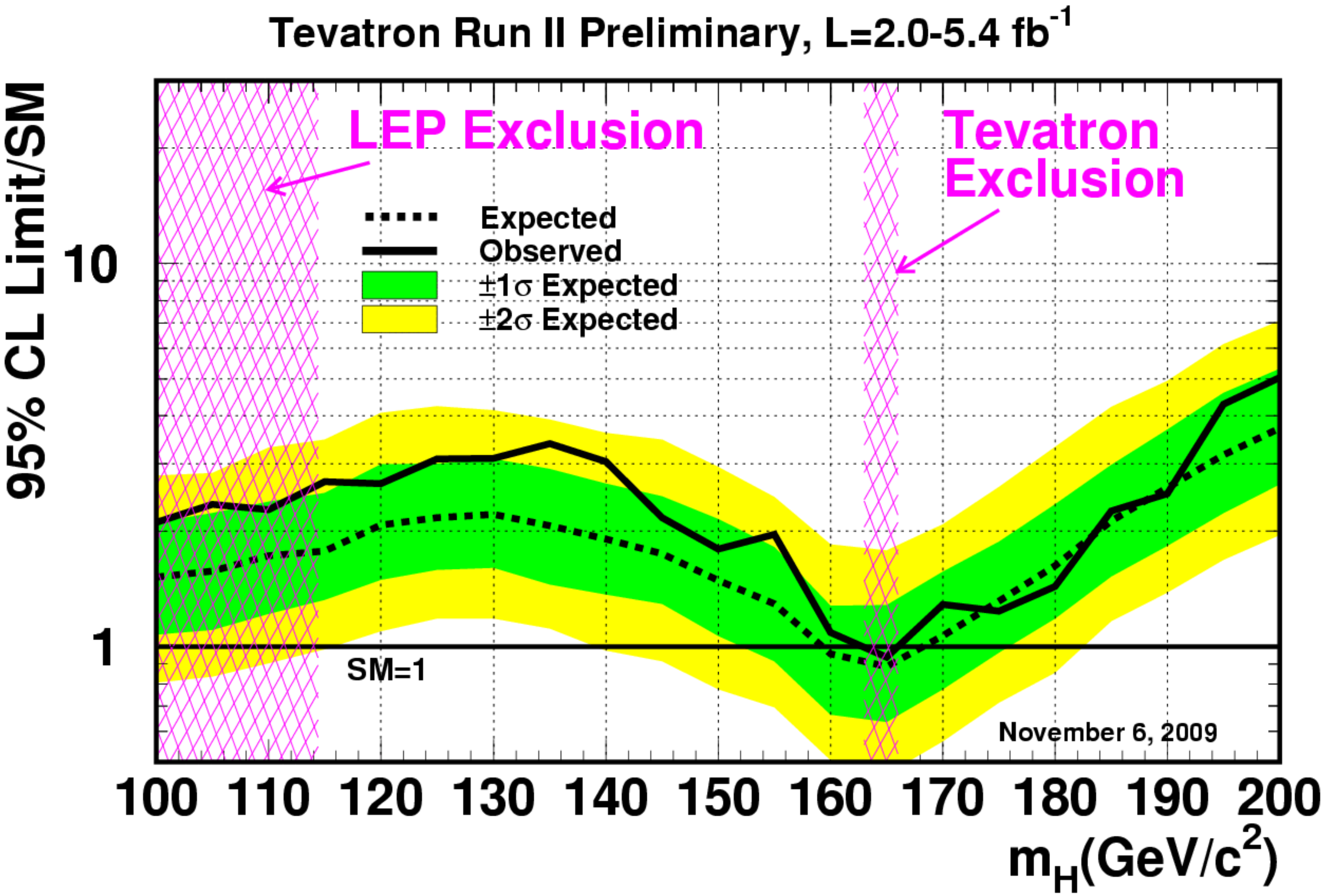




At M_H = 165 GeV/c^2:

- expected = 1.02 × σ_{SM}
- observed = 1.11 × σ_{SM}

Tevatron combination



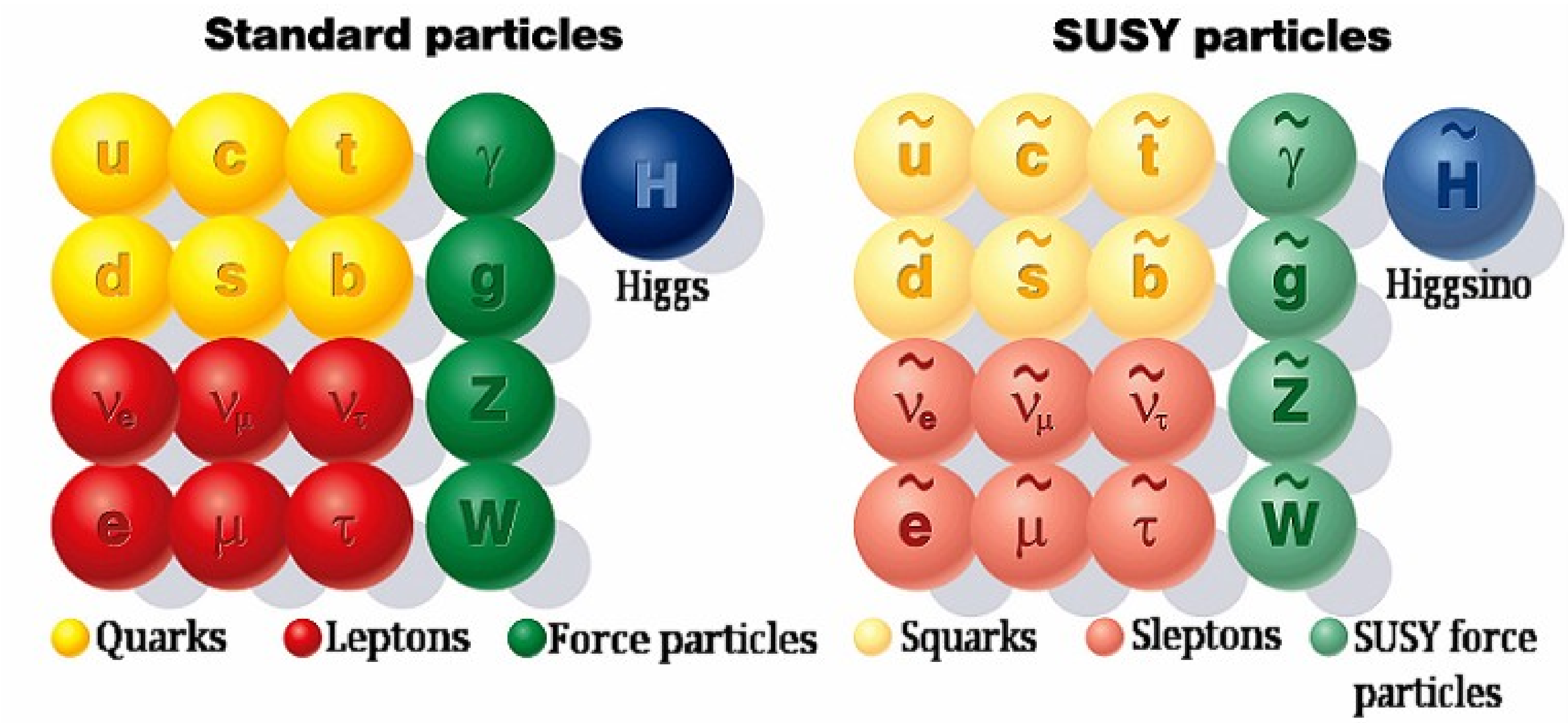
For M_H = 115 GeV/c^2:

- expected limit = 1.8 $\times$ σ_{SM}
- observed limit = 2.7 $\times$ σ_{SM}

95% C.L. exclusion of the mass range $163 < M_H < 166$ GeV/c^2

BSM searches

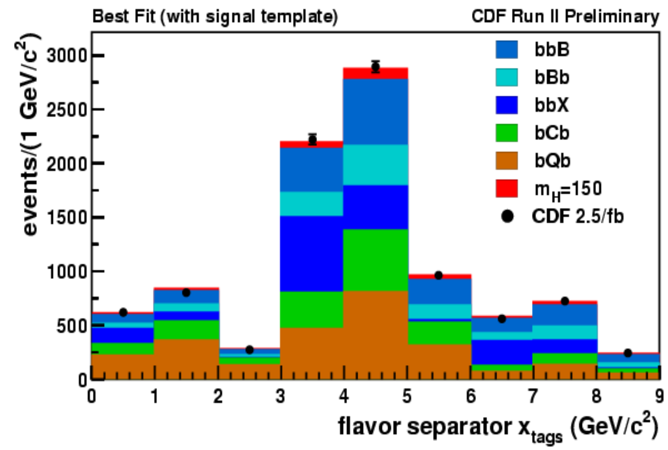
- Besides trying to unhinge the Standard Model with precision measurements which could reveal inconsistencies in its predictions, CDF is also pursuing an extensive direct search for exotic processes that do not fit in the SM framework.

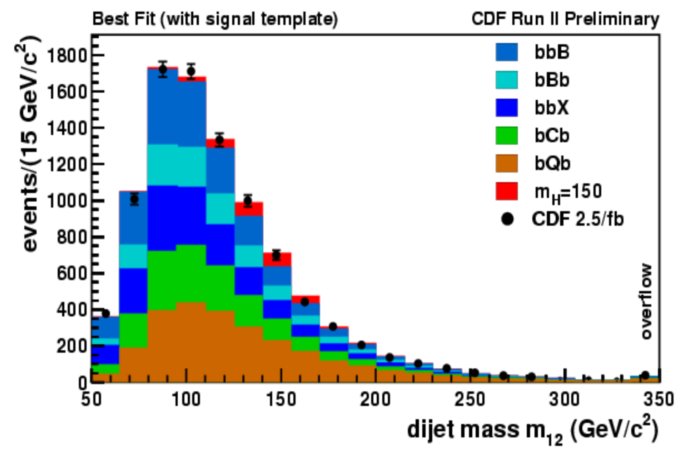


- In this talk: search for a MSSM Higgs, exotic dibosons, CDF and DØ constraints on a 4^{th} generation.
- More results in the Electroweak Session (C. Hays, F. Garberson, S. Somalwar).

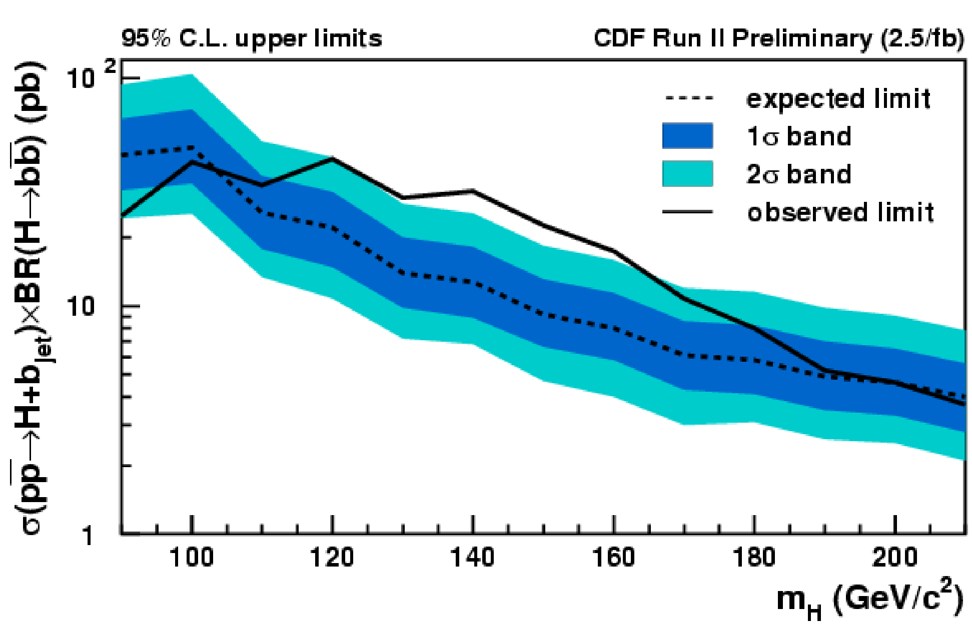
MSSM Higgs: $\phi \to b\bar{b}$

- Cleanest experimental signature from $b\phi \to bb\bar{b}$ channel.
- Selected sample with 3 b-quarks in 2.5 fb^{-1}, using a secondary vertex tagger:
  - flavor separator x_{tags} defined using the displaced vertex masses in b-tagged jets: m_1+m_2 and m_3.
  - search for an enhancement in the mass distribution m_{12} of the two leading jets.

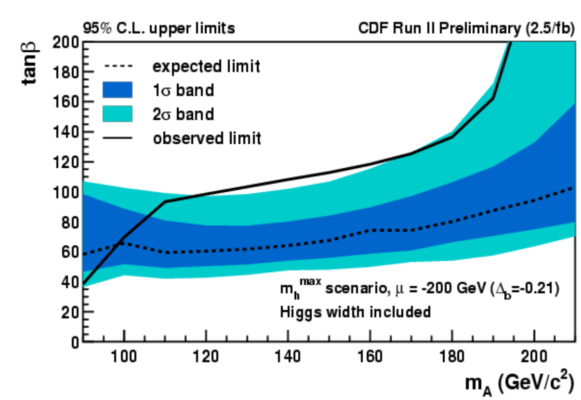




- 95% C.L. upper limits on production cross section:

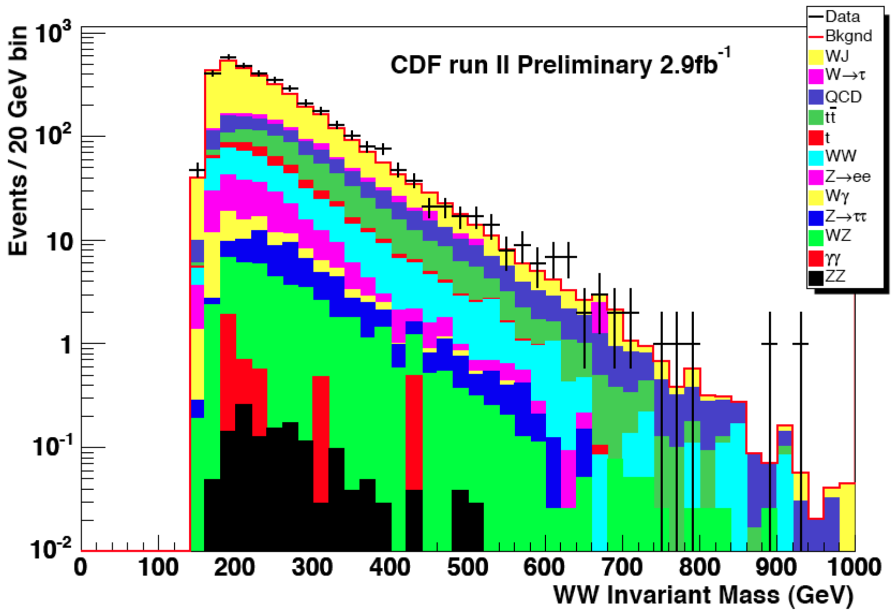


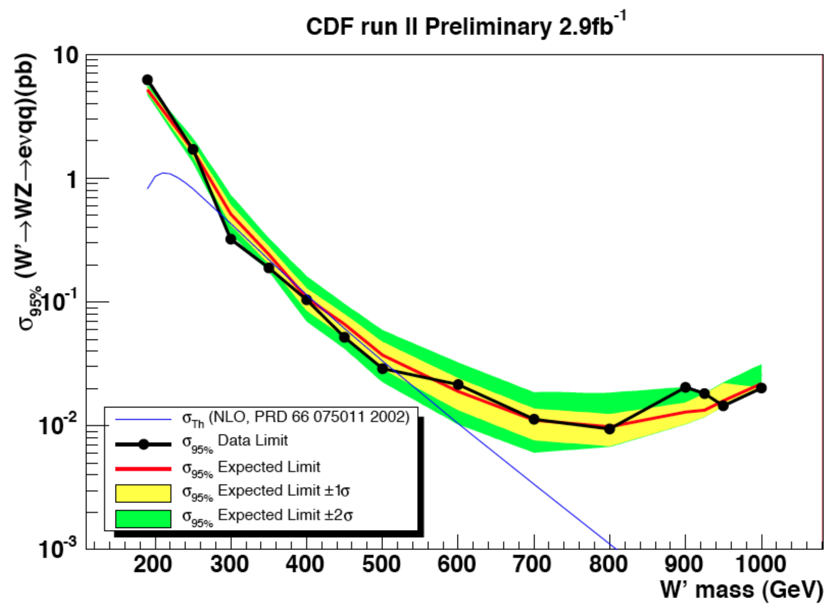
- MSSM interpretation:



Exotic dibosons

- Search for massive resonances decaying to WW/WZ:
  - electron + MET + jets sample with 2.9 fb^{-1};
  - full invariant mass reconstruction with weights for 2 possible solutions.
- 95% C.L. limits set on production σ for the resonance hypotheses R/S gravitons, W', Z'.



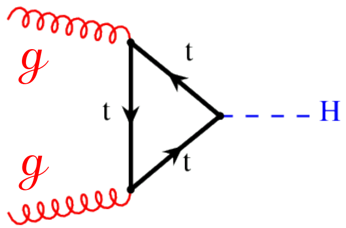


- By comparing the limits with the theoretical cross sections, mass exclusion regions:

	G*	Z'	W'
Expected exclusion	< 632 GeV	257 – 630 GeV	381 – 421 GeV
Data exclusion	< 607 GeV	247 – 544 GeV	285 – 516 GeV

CDF + DØ constraints on a 4th generation

- Standard Model $gg \to$ H production mechanism:



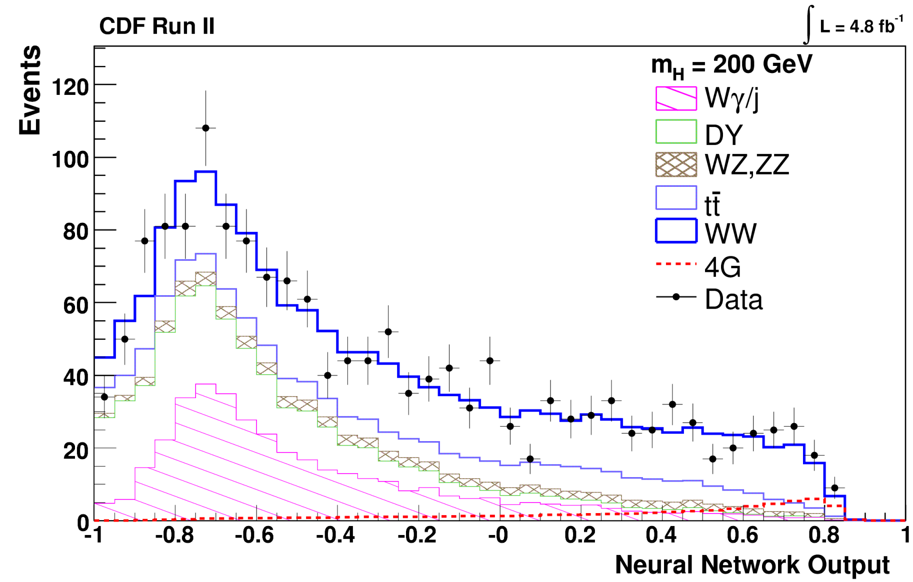
  - proceeds through a quark loop;
  - dominant contribution from the top quark.

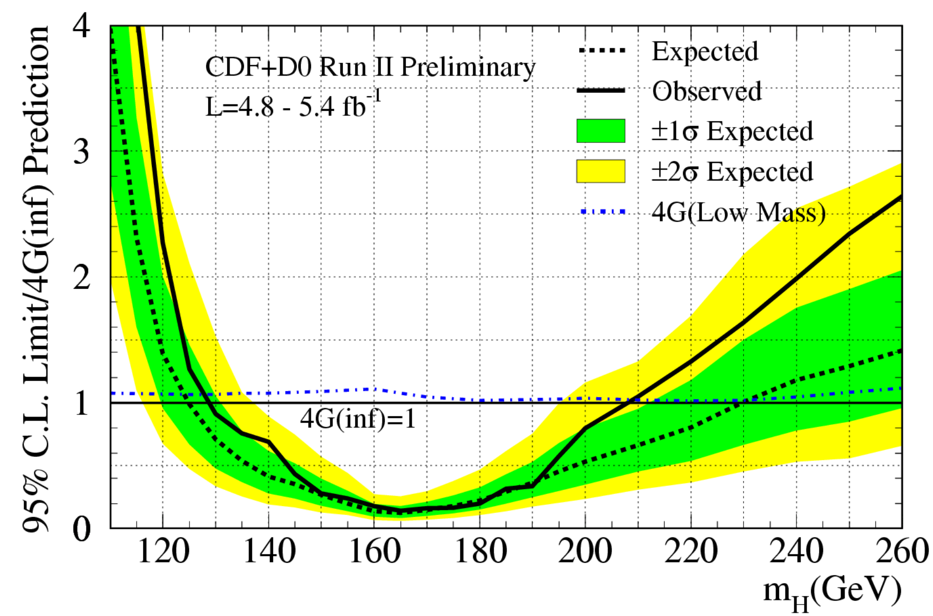
- 4th generation fermion models:
  - additional heavy particles contributions;
  - production cross-section enhanced by ~9,
    WW* still dominant decay at high mass.

- H → WW* $\to \ell \nu_{\ell} \ell' \nu_{\ell'}$ channel with 4.8 fb^{-1}:
  - same techniques as in SM H → WW* search.

- CDF and DØ combined 95% C.L. upper limits on the production cross-section.

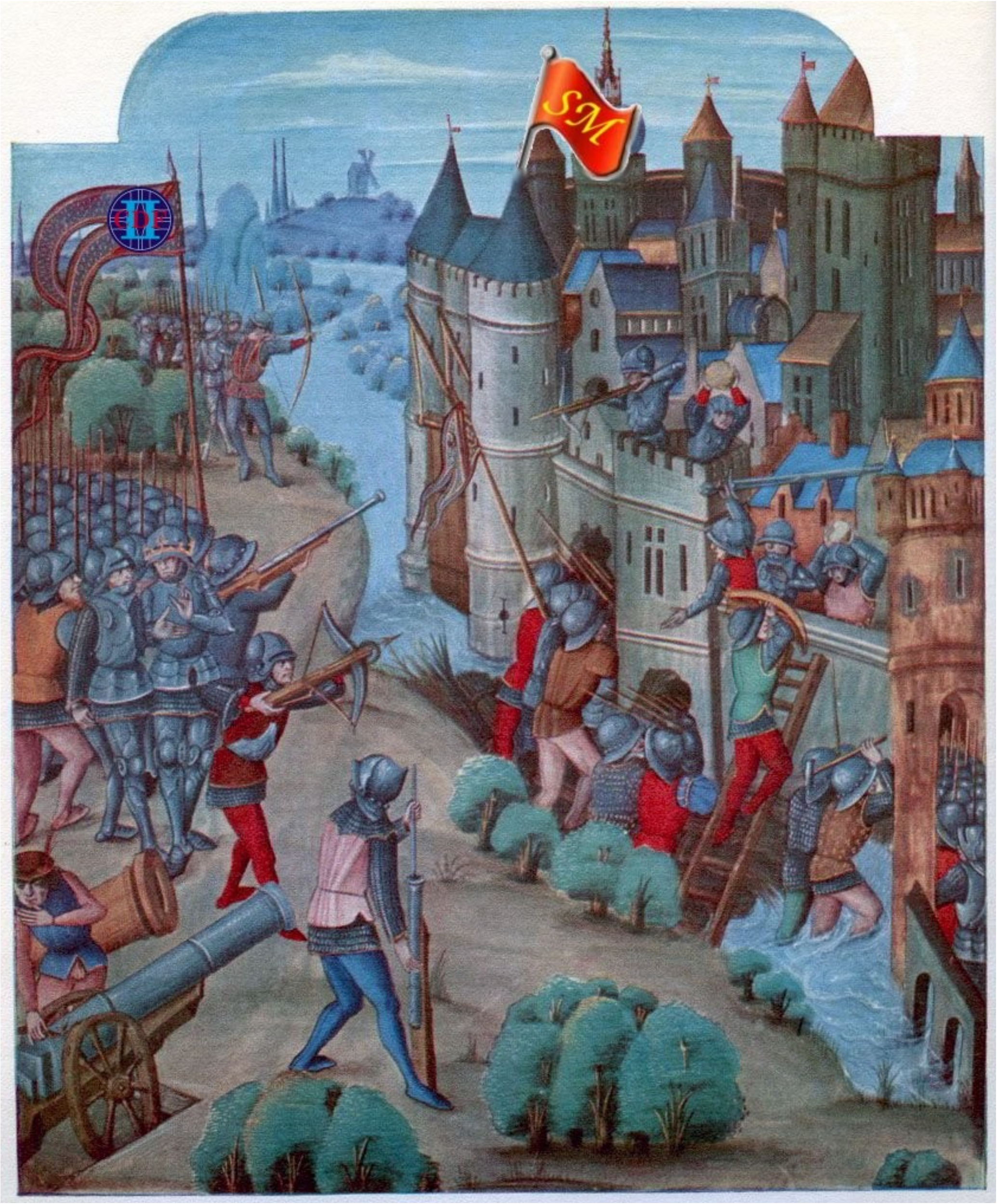
- Excluded at 95% C.L. the mass range:
  $130 < m_H < 210$ GeV/c^2.





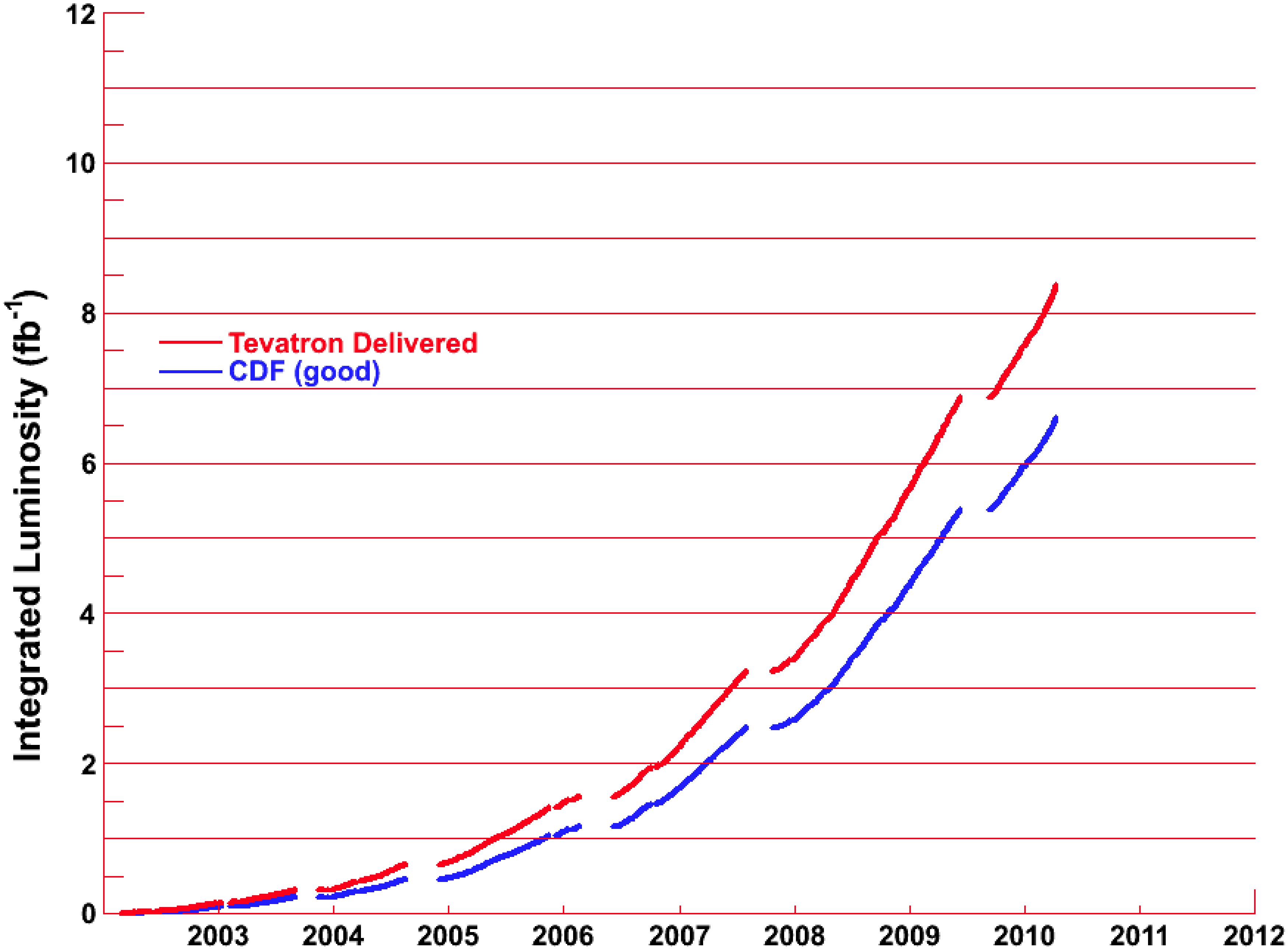
- The Tevatron and the CDF detector are performing very well.
- Datasets keep growing on tape: >10 fb^{-1} are expected by 2011.
- Measurements precision scales better than $1/\sqrt{\int \mathscr{L}\, dt}$.
- Currently CDF is sensitive to processes, whose cross-sections are <1 pb.

The siege to the Standard Model continues relentless.

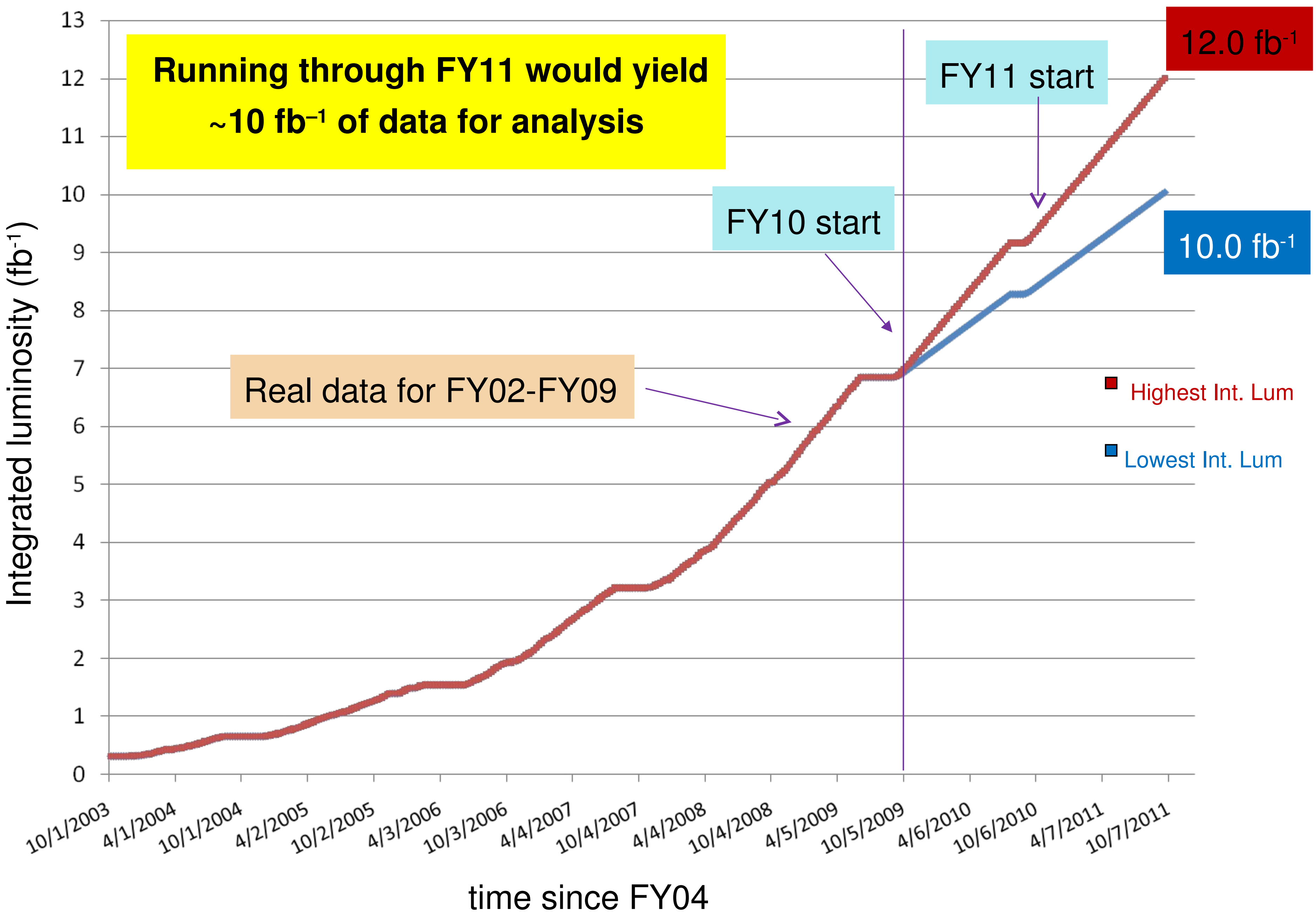


Back-up slides

CDF Run II integrated luminosity

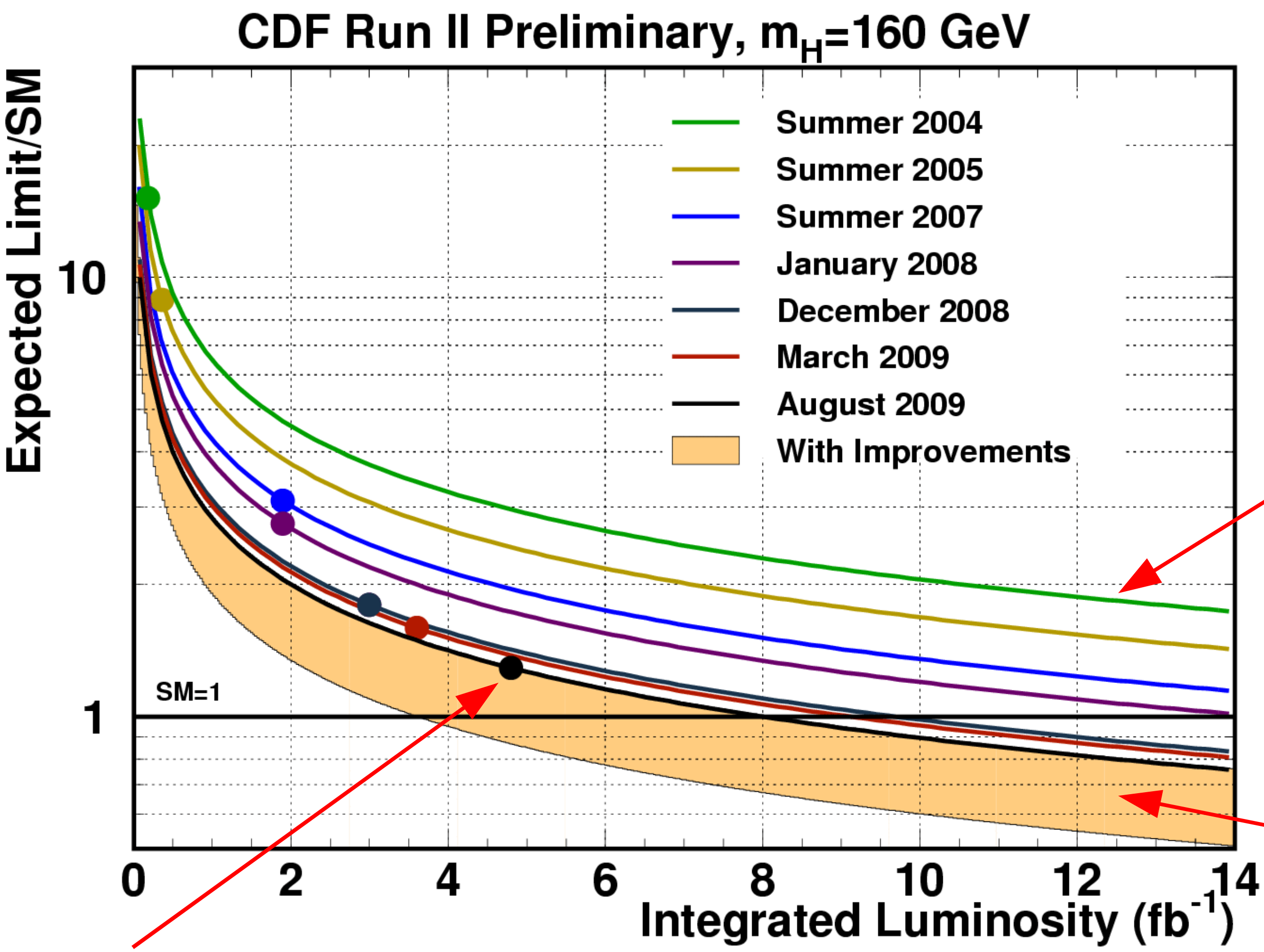


Luminosity projection curves for Run II



Expected limit projections

- CDF projections for the expected upper limit on the SM Higgs boson production cross section at M_H = 165 GeV/c^2:



scales with $1/\sqrt{\int \mathscr{L}\, dt}$

expected improvements as estimated in Summer 2007

analyses updates

- 2xCDF projections for the expected upper limit on the SM Higgs boson production cross section at M_H = 115 GeV/c^2: