CDF実験のトップクォークの物理と新粒子探索の結果

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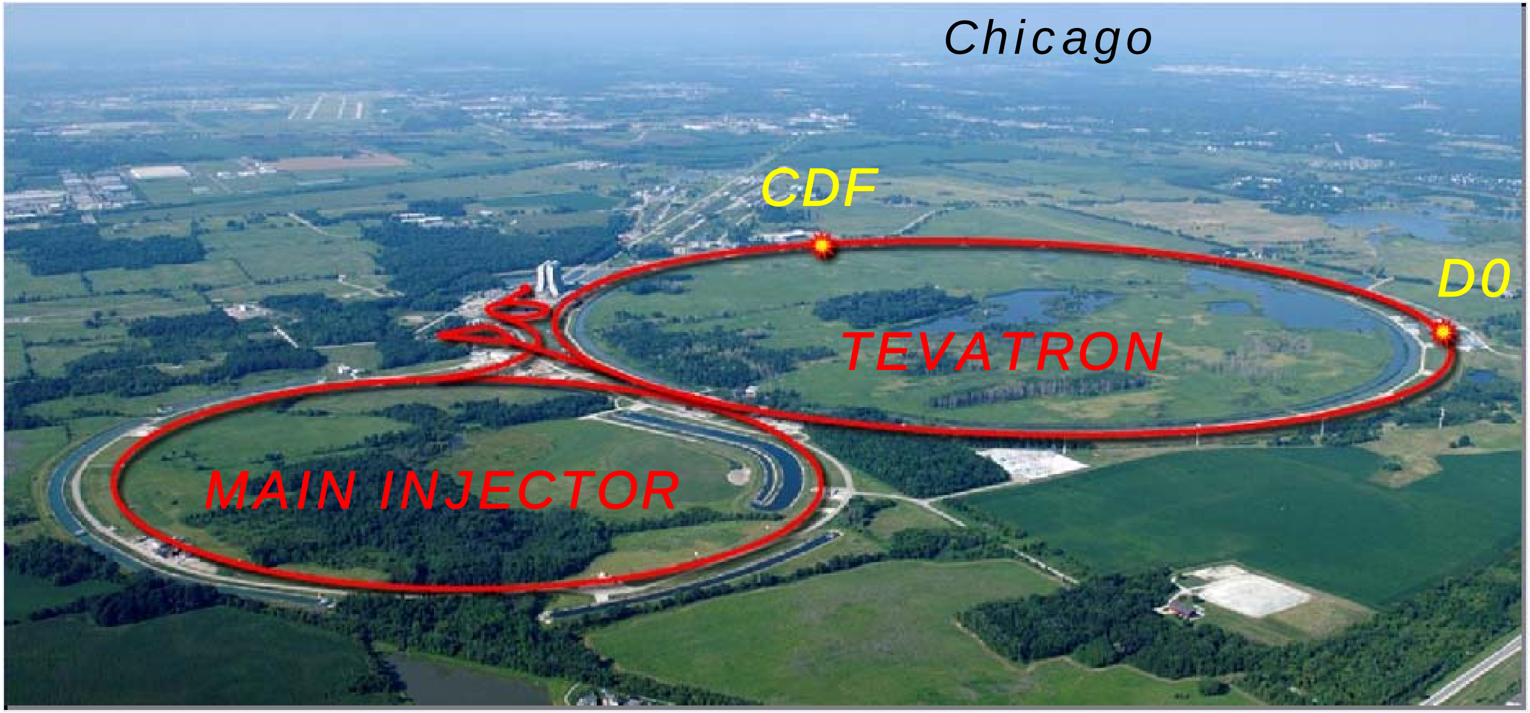
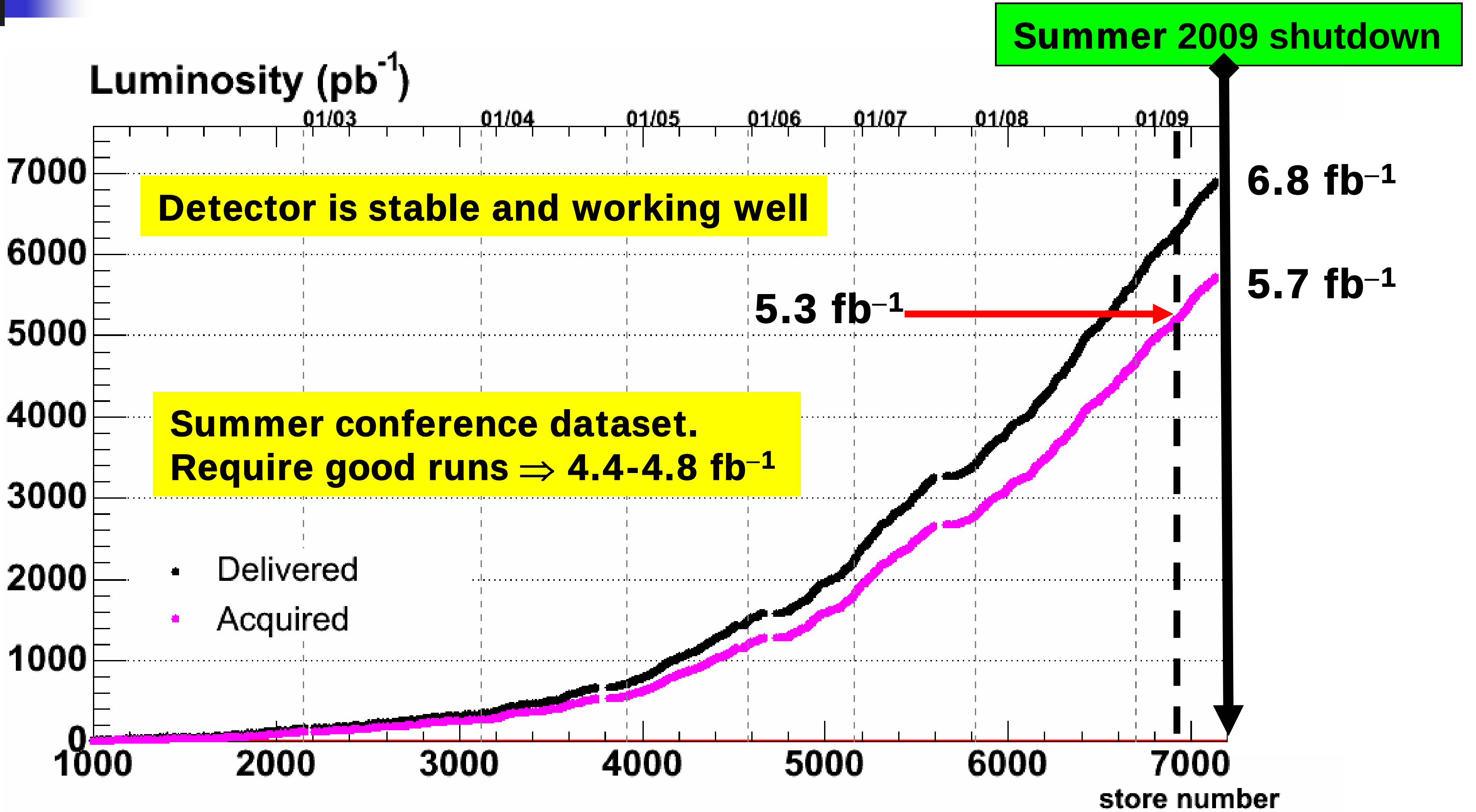
for CDF Collaboration

Tevatron Run II



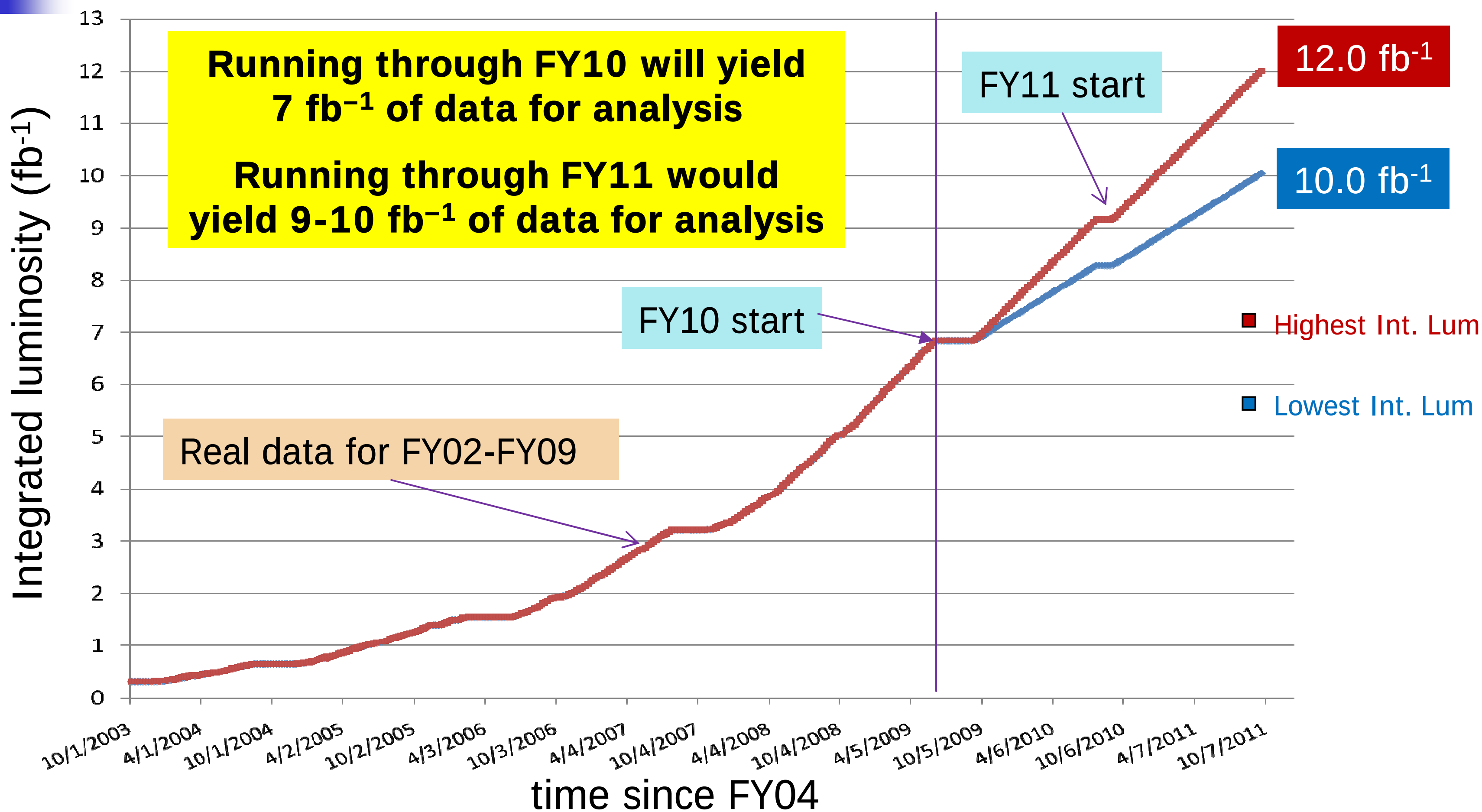
- The world's highest-energy particle collider. (Until LHC starts.)
- Proton-antiproton collisions at sqrt(s) = 1.96 TeV
- Tevatron is performing really well
  - Peak luminosity: ~3.5×10^{32} cm^{-2} s^{-1}

Datasets

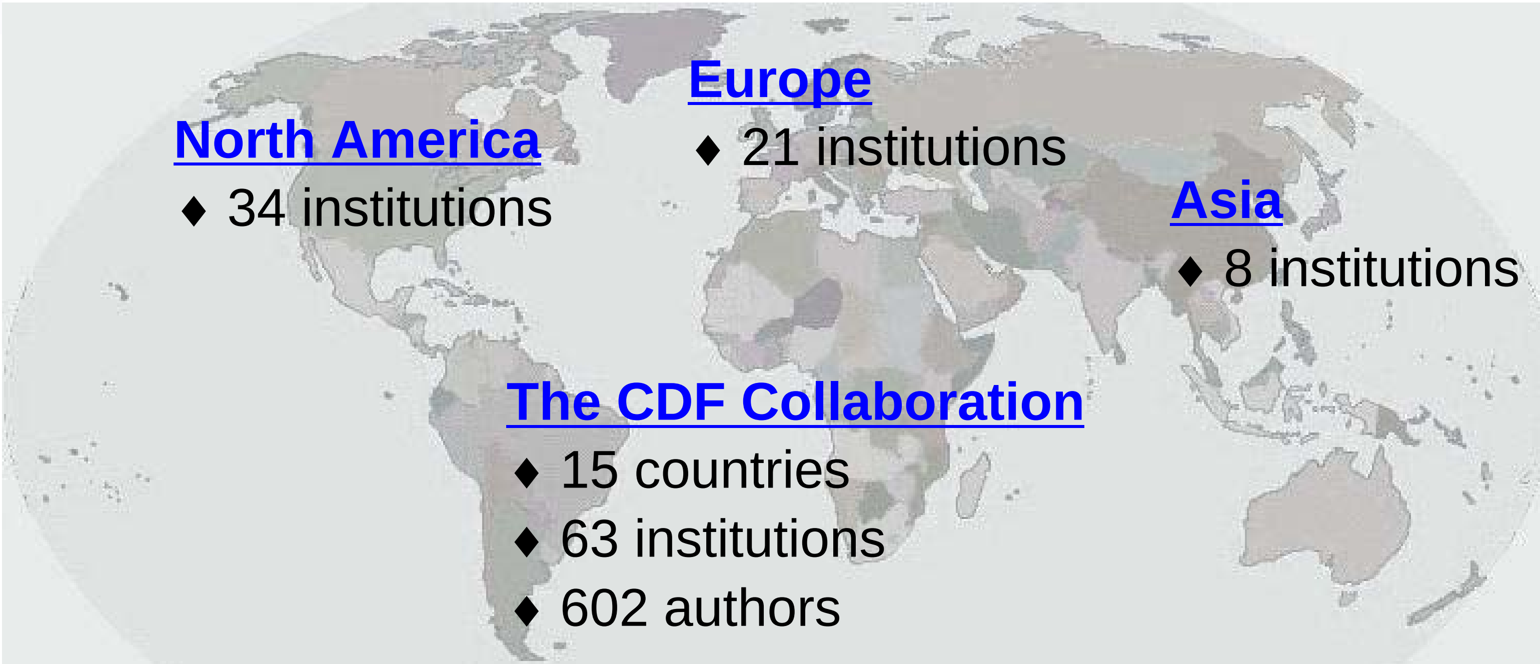


Summer 2009 shutdown
Luminosity (pb-1)
01/03
01/04
01/05
01/06
01/07
01/08
01/09
7000
6000
5000
4000
3000
2000
1000
0
Detector is stable and working well
6.8 fb−1
5.7 fb−1
5.3 fb−1
Summer conference dataset.
Require good runs ⇒ 4.4-4.8 fb−1
Delivered
Acquired
1000
2000
3000
4000
5000
6000
7000
store number

Tevatron Prospects



CDF Collaboration

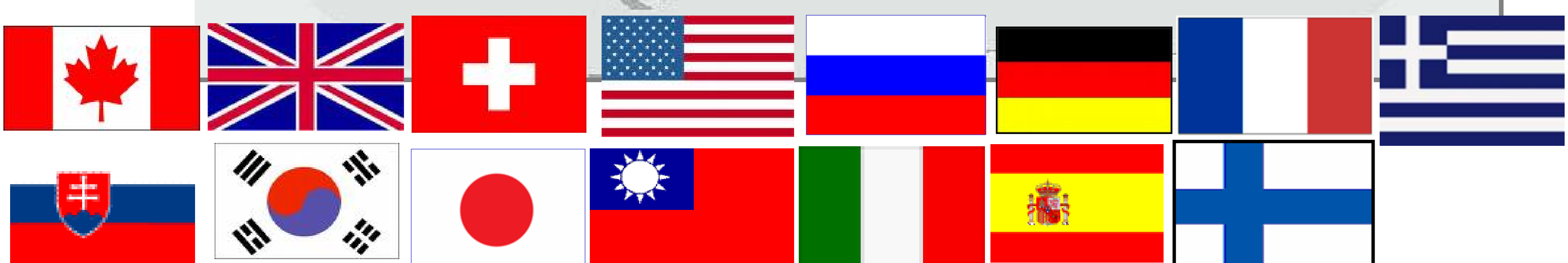


North America
- 34 institutions

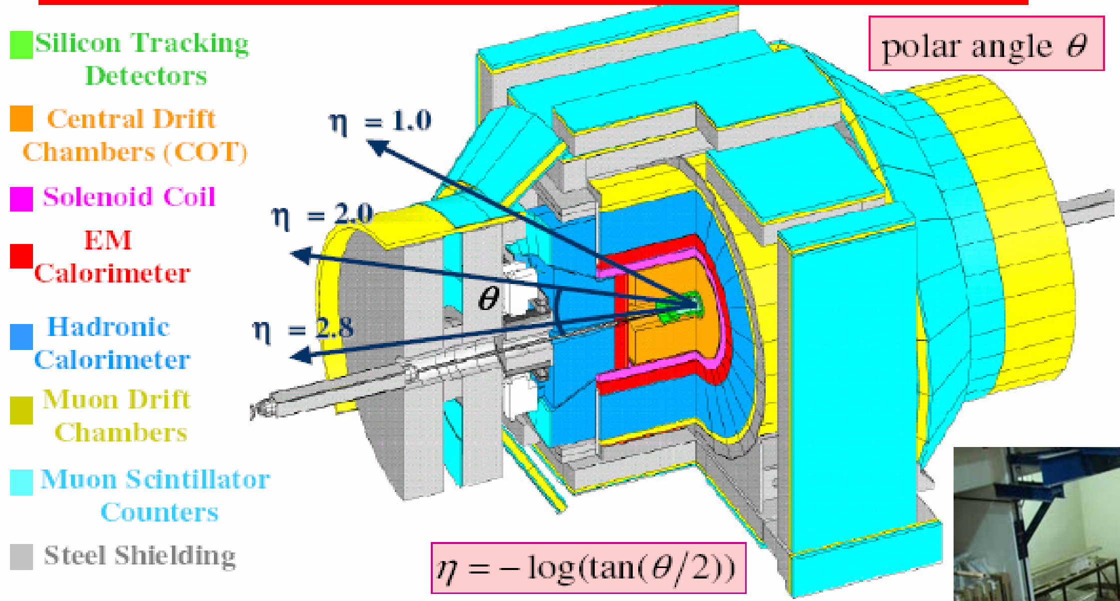
Europe
- 21 institutions

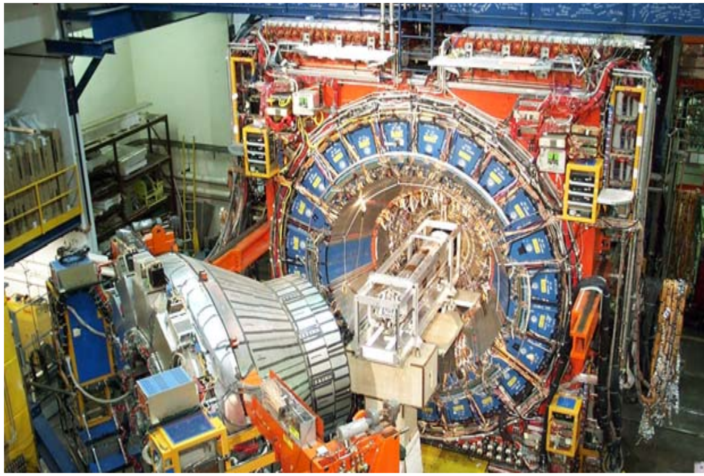
Asia
- 8 institutions

The CDF Collaboration
- 15 countries
- 63 institutions
- 602 authors



CDF II Detector

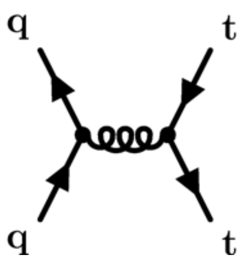




- 8 layer silicon vertex detector
- 8 super layer drift chamber
- 1.4T solenoid
- Good particle identification (K, π)
- Central/Wall/Plug calorimeters
- Scintillator+drift chamber muon detectors

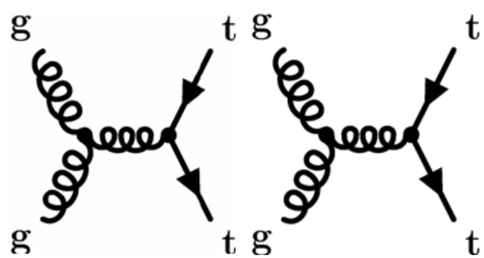
Top Quark Physics

quark-antiquark annihilation



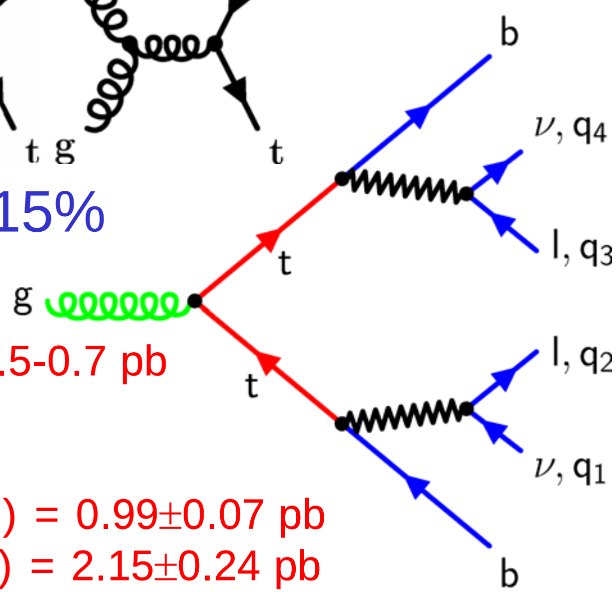
~85%

gluon-gluon fusion

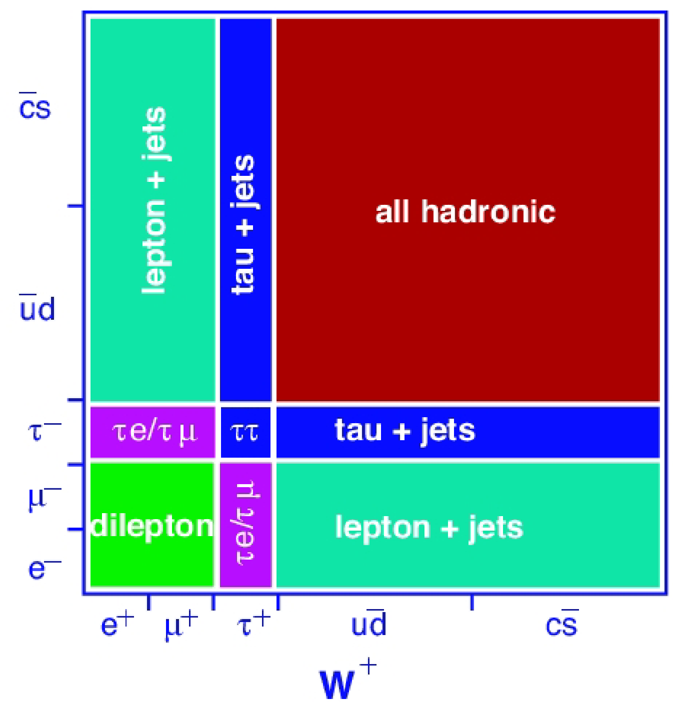


~15%

- Pair production
  - σ(NLO) = 7.4 +0.5-0.7 pb
    (m_t=172.5 GeV)
- Single production
  - s-channel: σ(NLO) = 0.99±0.07 pb
  - t-channel: σ(NLO) = 2.15±0.24 pb
    (m_t=170 GeV)
  - Observed in March 2009.
    (日本物理学会 第64回年次大会 28aSE08)



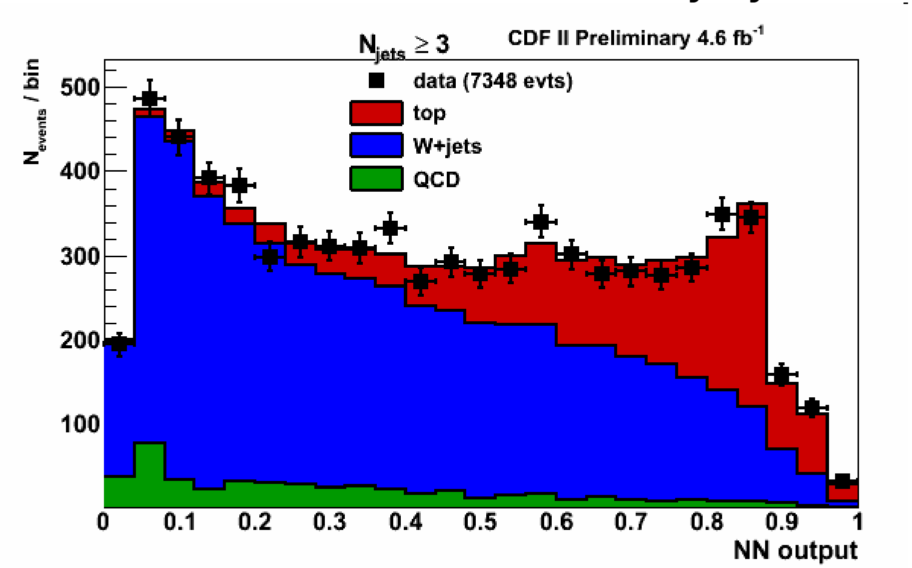
tt̄ decay modes

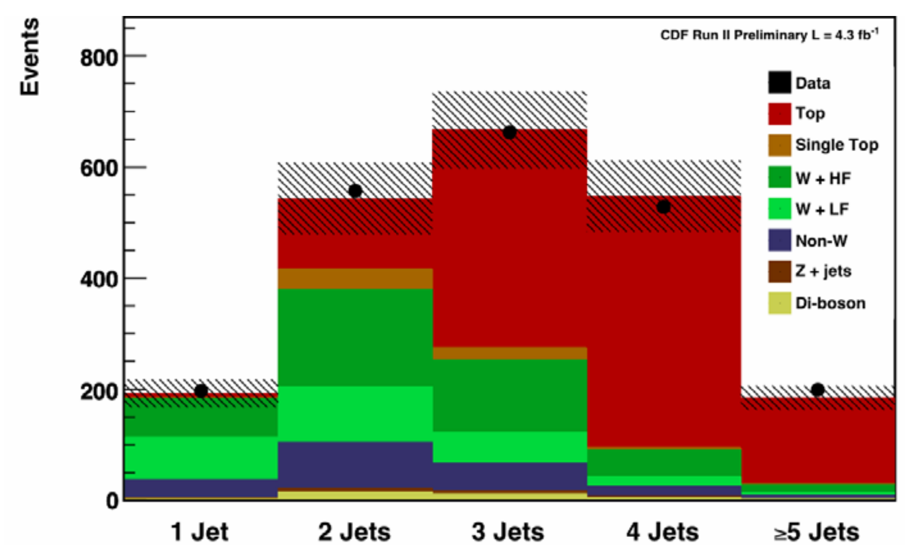


Categorize ttbar events into 3 decay types according to *W* decay mode

ttbar Production Cross Section

- Lepton+jets channel
  - Two different methods
    - Topological separation of signal and background via neural net
    - Counting method with *b*-tagged events.
  - Reduce luminosity systematics by normalizing to $Z \to l^+ l^-$ rate



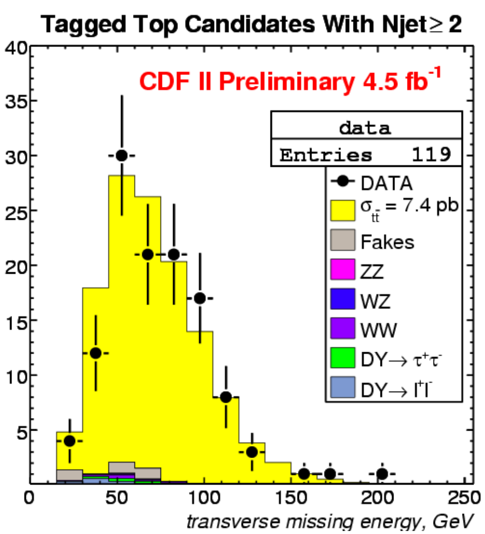


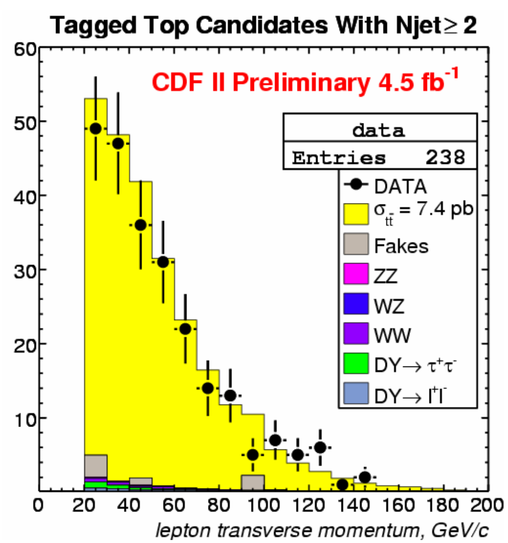
$\sigma_{t\bar{t}} = 7.63 \pm 0.37(\text{stat}) \pm 0.35(\text{syst}) \pm 0.15(\text{theo})$

$\sigma_{t\bar{t}} = 7.14 \pm 0.35(\text{stat}) \pm 0.58(\text{syst}) \pm 0.14(\text{theo})$

ttbar Production Cross Section

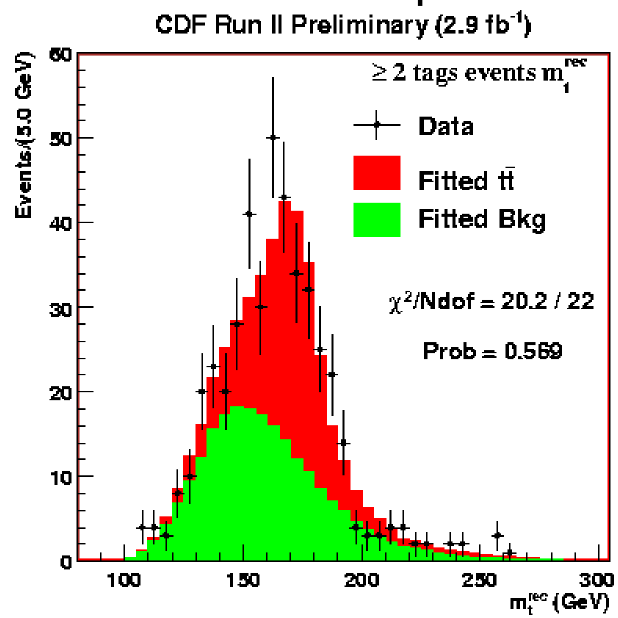
- Dilepton channel
  - 2 leptons, large MET
  - Require ≥1 *b*-tag
    - Low background, lower statistics





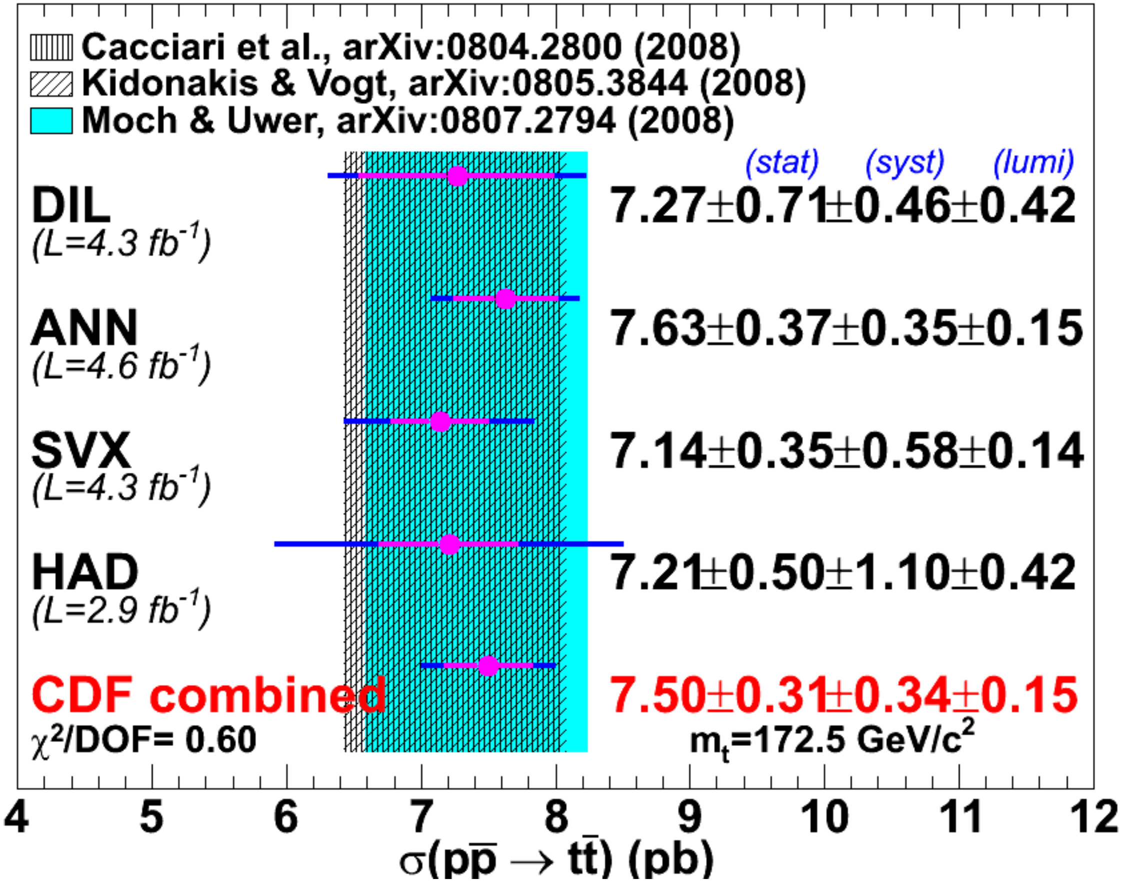
$$\sigma_{t\bar{t}} = 7.27 \pm 0.71(\text{stat}) \pm 0.46(\text{syst}) \pm 0.42(\text{lumi})$$

- All-hadronic channel
  - 6 jets, 1 or ≥2 *b*-tags
  - Enormous QCD background
    - Train NN to improve S/B



$$\sigma_{t\bar{t}} = 7.21 \pm 0.50(\text{stat}) \pm 1.10(\text{syst}) \pm 0.42(\text{lumi})$$

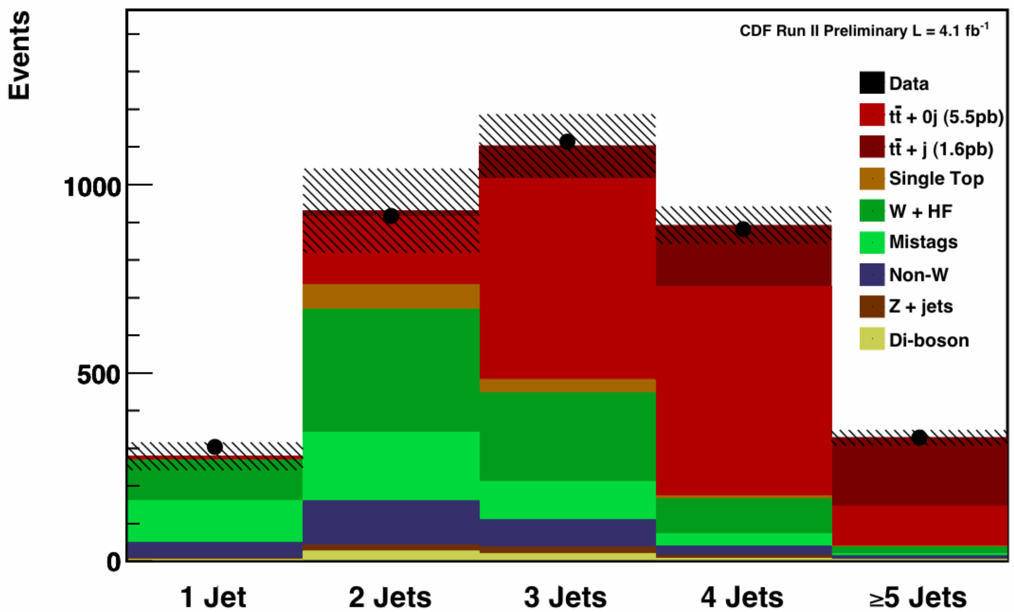
ttbar Production Cross Section

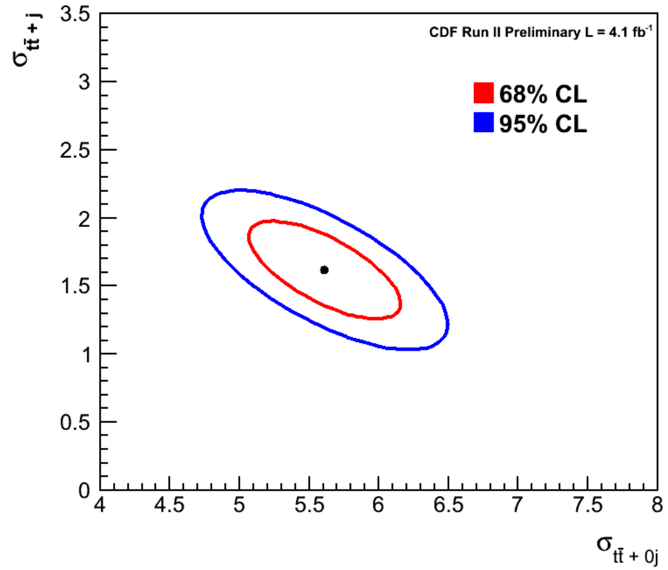


- CDF Combination
  - Precision of 6.5%
  - All channels are consistent with each other and with theory.
  - Different methods to measure σ_{tt} produce consistent results

ttbar+jet Cross Section

- Lepton+jets channel with *b*-tagging
- Check for NLO effects
  - SM prediction: $\sigma_{t\bar{t}+j} = 1.79^{+0.16}_{-0.31}\,\mathrm{pb}$ (E_T^{JET} > 20 GeV)
    (S. Dittmaier, P. Uwer, and S. Weinzierl, Eur. Phys. J. C**59**, 625 (2009))

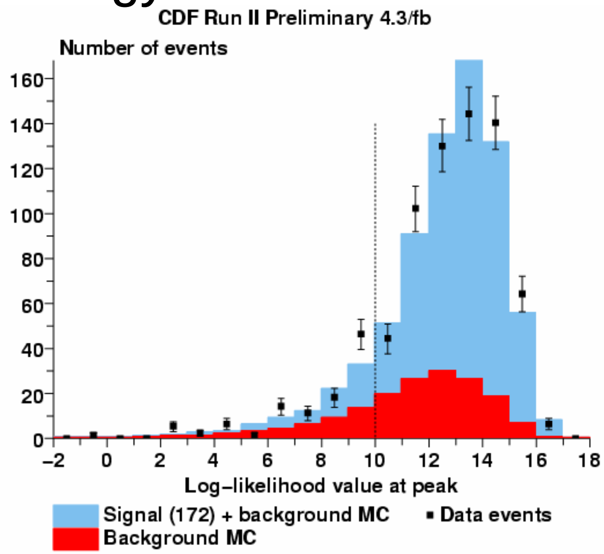


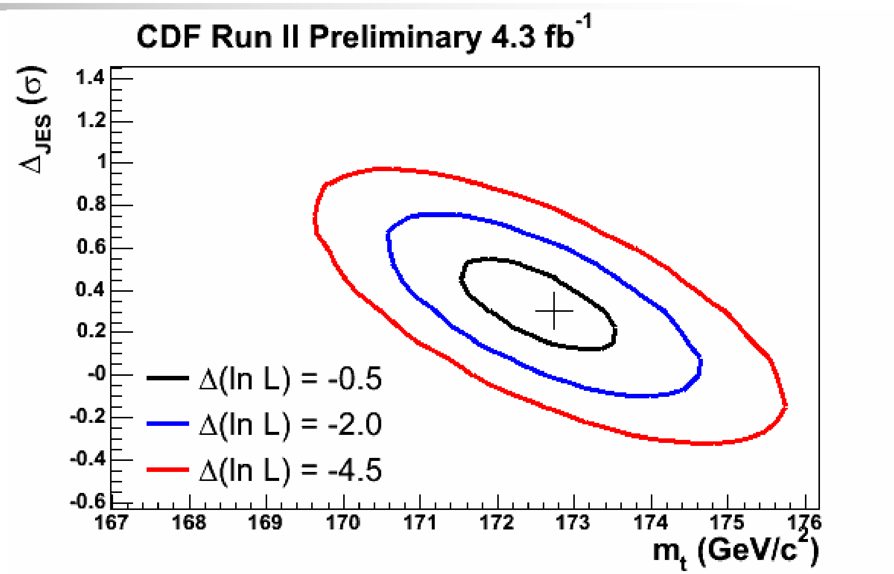


$$\sigma_{t\bar{t}+j} = 1.6 \pm 0.2(\mathrm{stat}) \pm 0.5(\mathrm{syst})\,\mathrm{pb}$$

Top Mass Measurement Using Matrix Element Method

- Matrix element analysis in l+jets
- Dominant mass systematic uncertainty typically due to a lack of understanding of the hadronic jet energy scale.





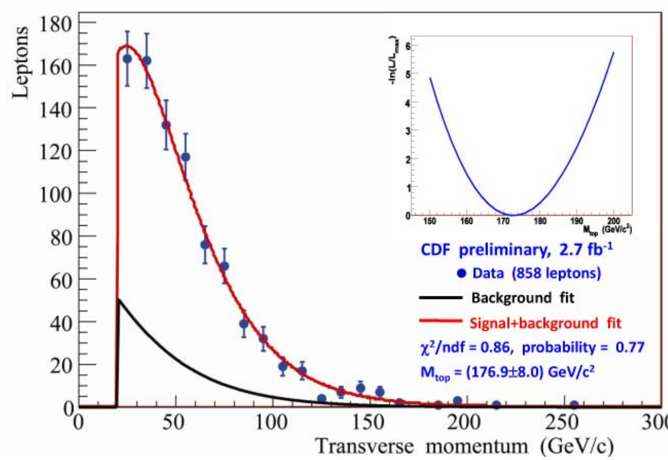
- Simultaneously fit for top quark mass and shift in jet energy scale (JES).
  - JES constrained by the hadronically decaying $W \to qq'$
  - In situ calibration of the hadronic energy response

$$m_t = 172.6 \pm 0.9(\text{stat}) \pm 0.7(\text{JES}) \pm 1.1(\text{syst})\ \text{GeV}/c^2 = 172.6 \pm 1.6(\text{total})\ \text{GeV}/c^2$$

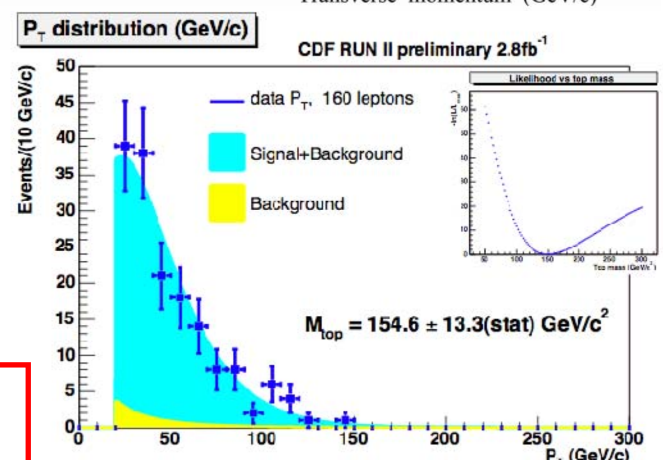
Top Mass Measurement Using Lepton p_T

- Lepton p_T spectrum dependent upon m_{top}.
- Advantages:
  - Decouples from jet energy scale
  - Might be a good technique for LHC
- Disadvantages
  - Requires large event samples
  - Model dependence on ttbar production

L+J

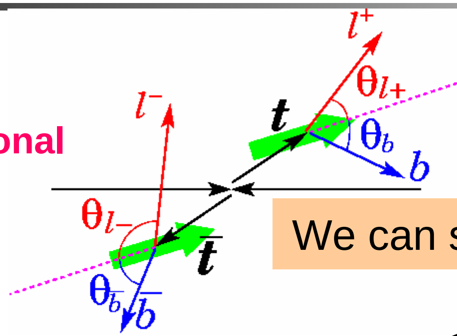


DIL



$$M_{\text{top}}^{\text{comb}} = 172.8 \pm 7.2_{(\text{stat})} \pm 2.3_{(\text{syst})}\ \text{GeV}/c^2$$

ttbar Spin Correlation

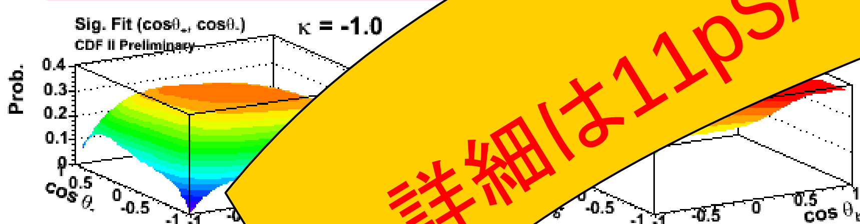


Top quark is supposed to d… …losing polarization at its produ… …bare quark). But not yet confirm…

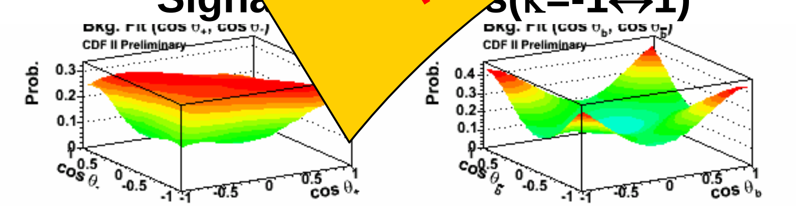
We can see correlatio… …ns of decay products.

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1 + \kappa \cos \ldots}{\ldots}$$

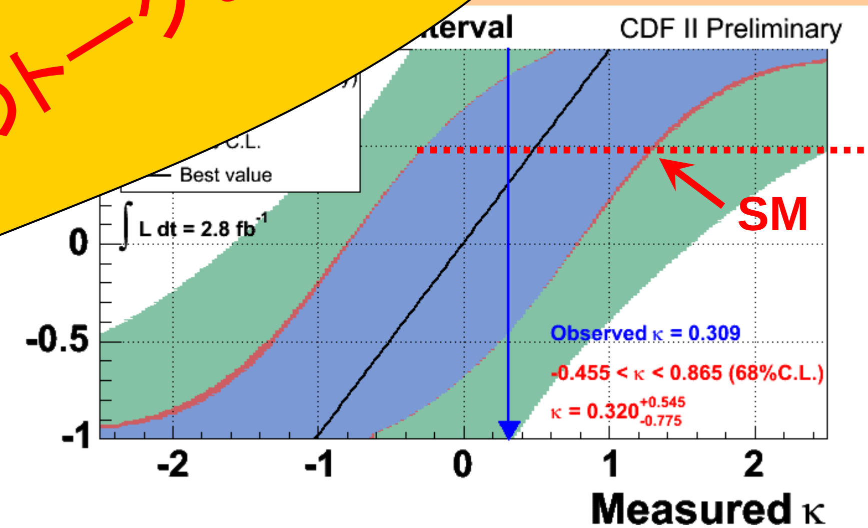
詳細は11pSA09のトークを参照。



Signa… …s(κ=-1↔1)



Background Templates



$-0.455 < \kappa < 0.865$ (68% C.L.)

or

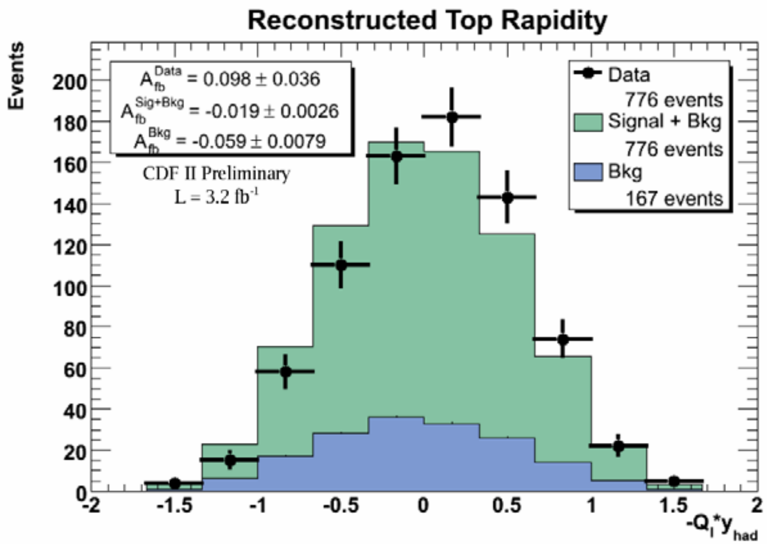
$\kappa = 0.320^{+0.545}_{-0.775}$ ($M_t = 175 GeV/c^2$)

Forward-Backward Asymmetry

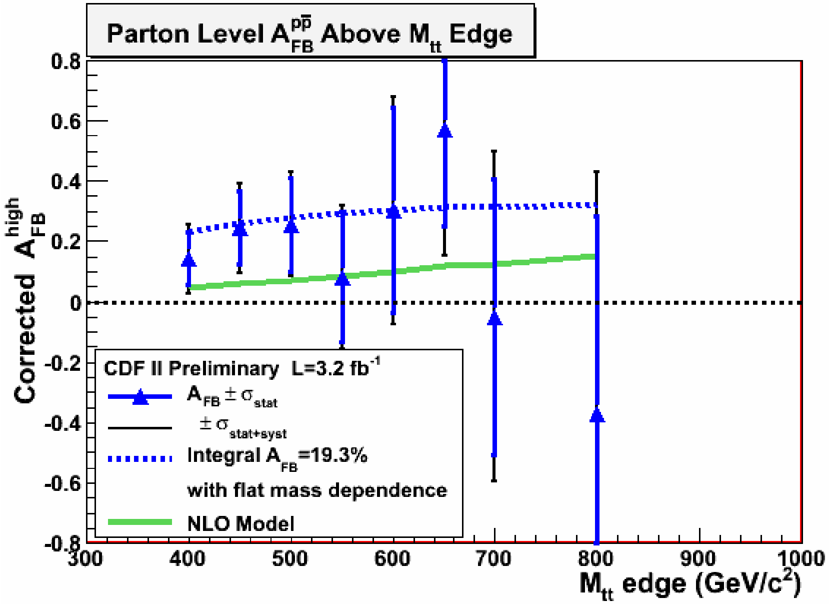
- In L=3.2 fb^{-1} data sample, observed an integral asymmetry:
  (Cf. 日本物理学会 第64回年次大会 28aSE06)

$$A_{fb}^{pp} = (19.3 \pm 6.5_{stat} \pm 2.3_{syst})\%$$

  - More than 2σ excess from NLO prediction A_{FB}^{pp} = 5 ± 1.5%



- Is "excess" spread out or localized in mass?



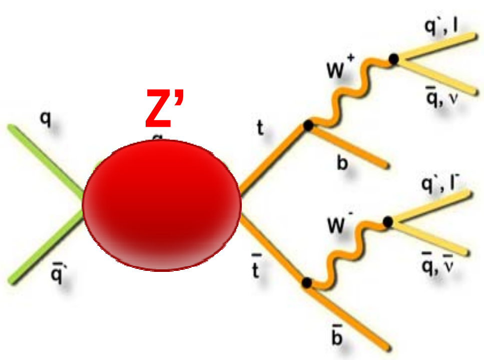
  - Dashed line are predictions for a integral A_{FB}=19.3%, as measured in data, with no mass dependence.
  - Green solid line is for a NLL prediction (Almeida et al. arXiv:0805.1885) with A_{FB} linearly dependent on partonic invariant mass.

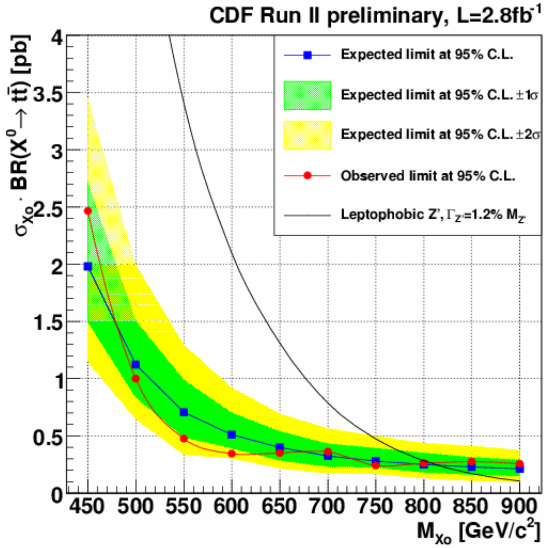
Search for ttbar Resonance

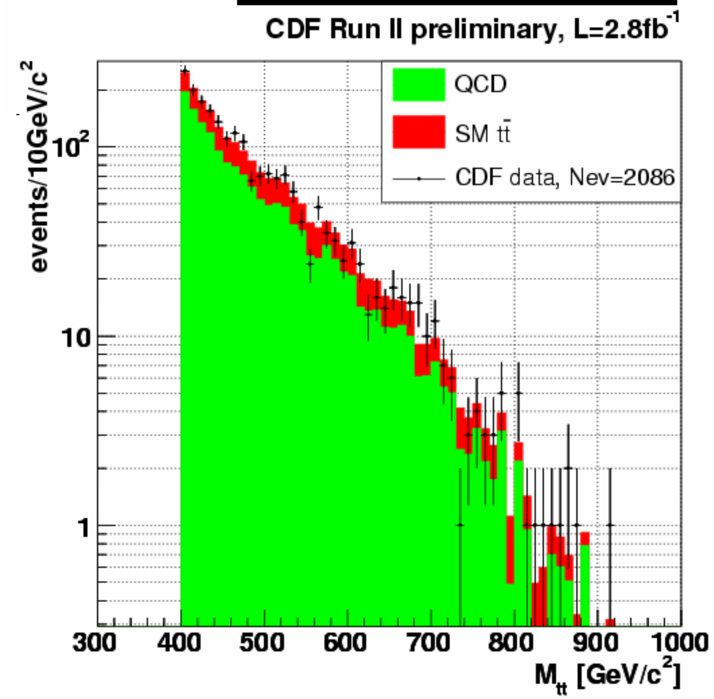
- Some models predict ttbar bound states
- Top color assisted technicolor predicts leptophobic *Z'* with strong 3rd generation coupling
- Search in all hadronic channel

Z' with 1.2% width:

CDF (2.8 fb^{-1}): >805 GeV

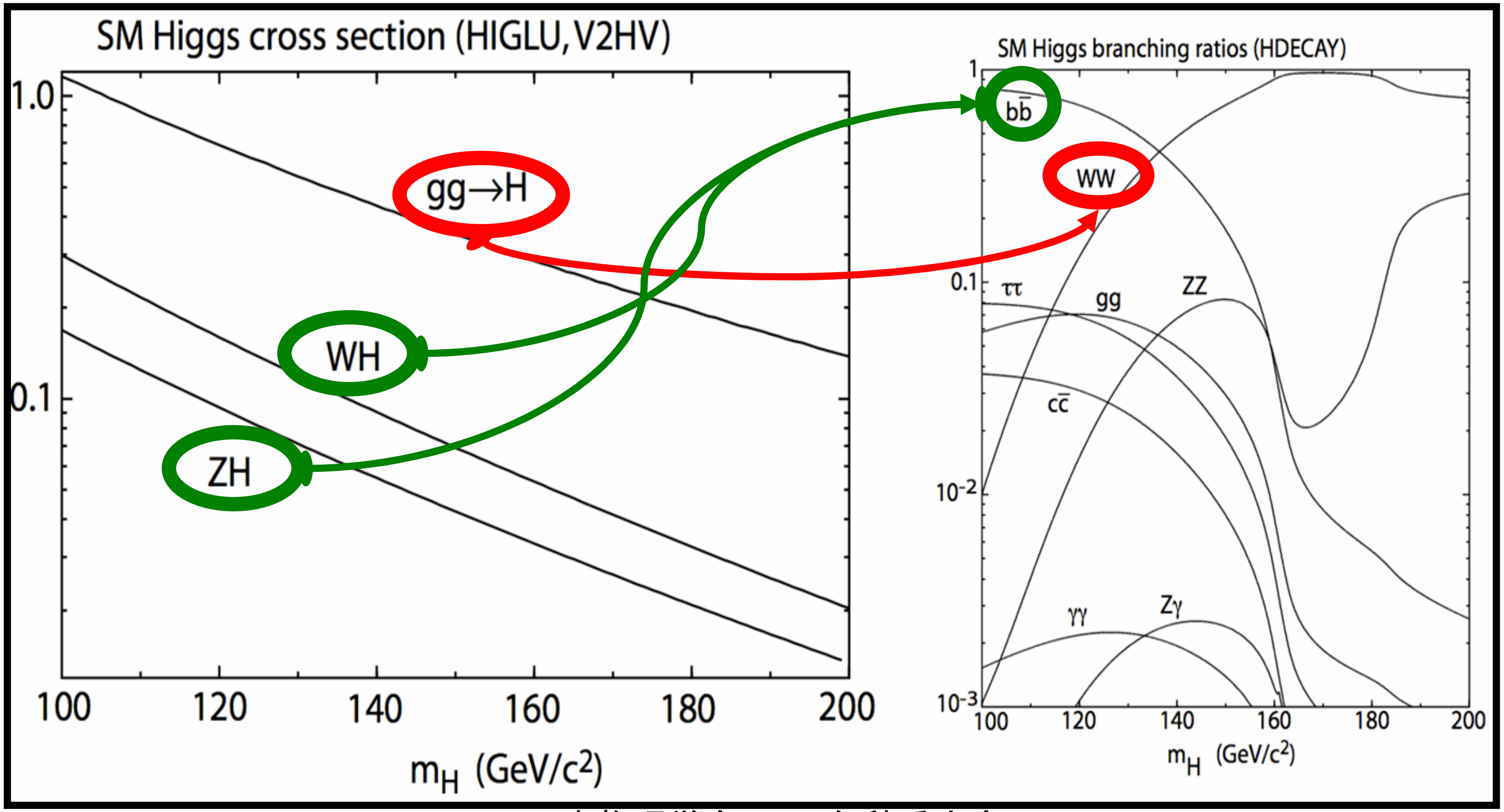






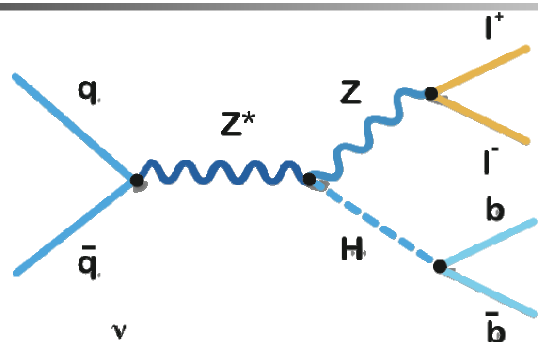
SM Higgs Search

- Cross Section and Branching Ratio @Tevatron

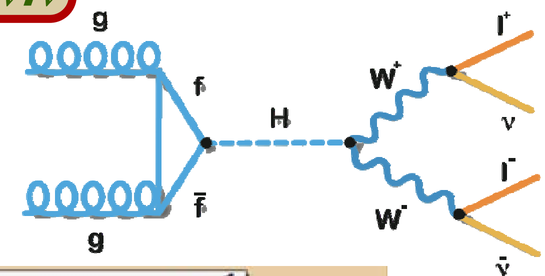


Higgs Search Channels

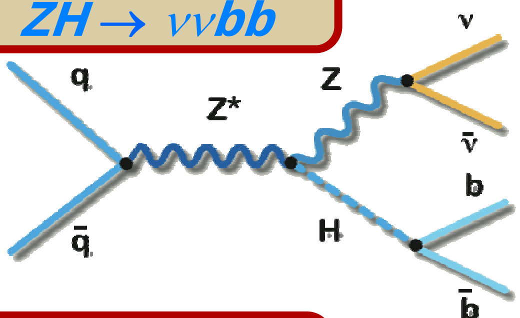
ZH → llbb



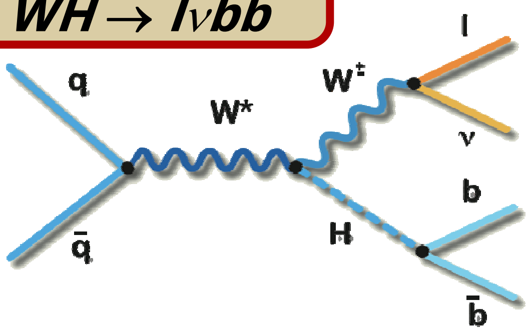
H → WW → lνlν

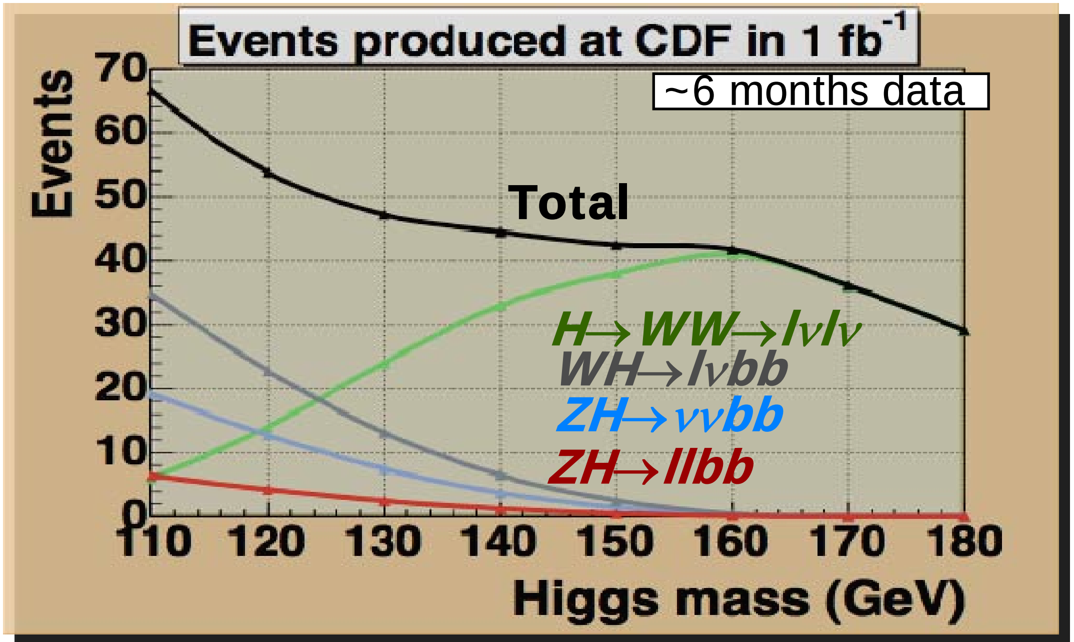


ZH → ννbb

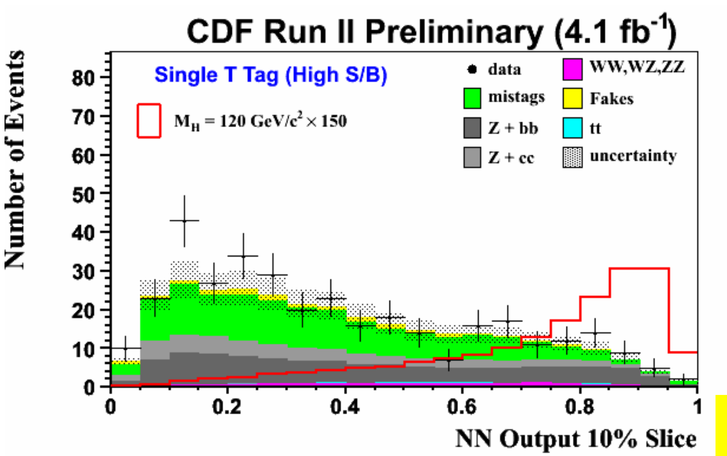


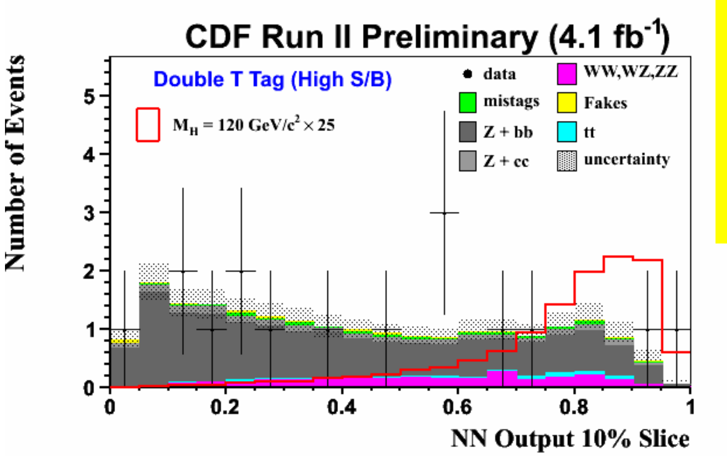
WH → lνbb





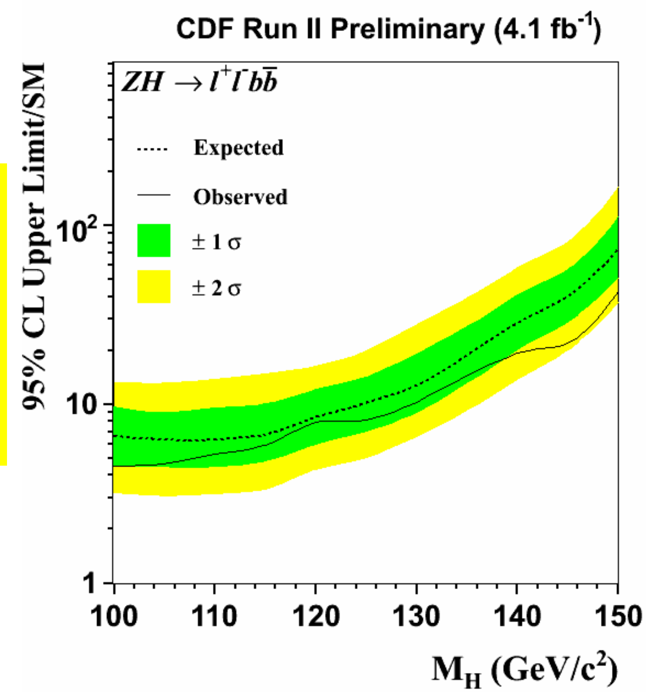
Low Mass Higgs: *ZH* → *llbb*





- Improve lepton acceptance
- Use neural network to correct jets for missing energy
- Use matrix elements and NN for event selection

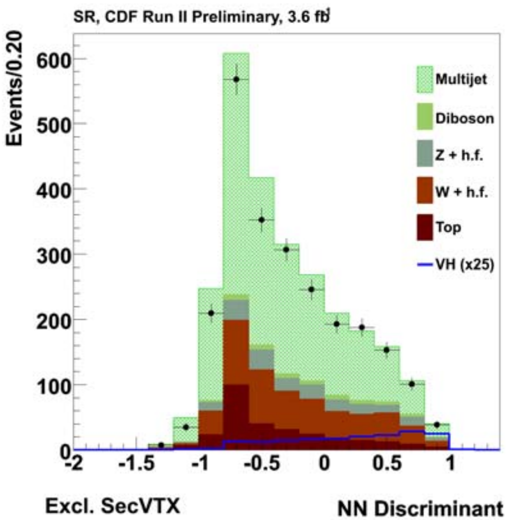
For m_H = 115 GeV/c^2
- Expected limit: 6.8 × σ_{SM}
- Observed limit: 5.9 × σ_{SM}

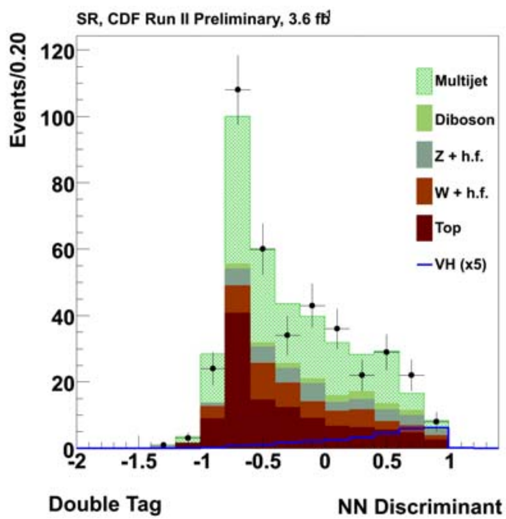


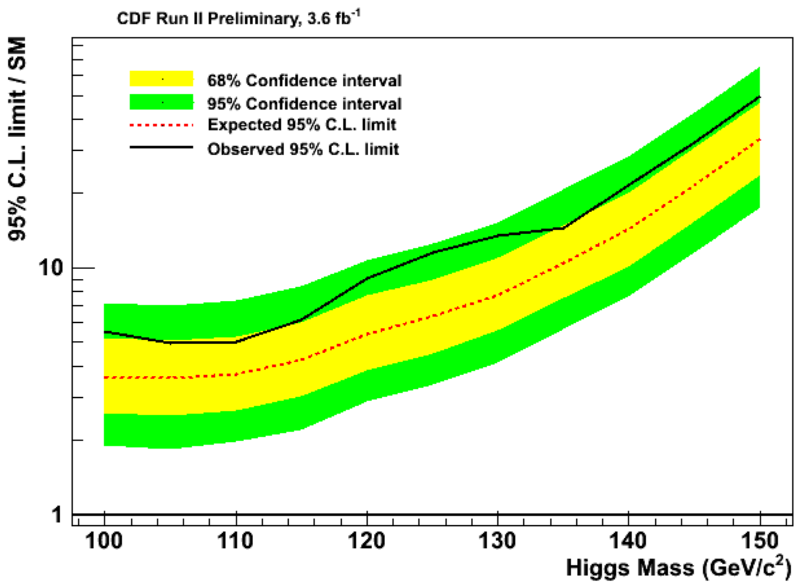
Low Mass Higgs: *ZH/WH* Search in MET+jets

- Good signal acceptance, complementary to other searches
  - Sensitive to: $ZH \to \nu\nu bb$, $ZH \to llbb$ (mostly τ), $WH \to l\nu bb$ (missed l)
- Dominant backgrounds:
  - QCD with fake MET due to cal resolution
  - *W*/*Z*+jets, top, diboson
- *b*-tagging and neural net selection

For m_H = 115 GeV/c^2
- Expected limit: $4.2 \times \sigma_{SM}$
- Observed limit: 6.1$\times \sigma_{SM}$





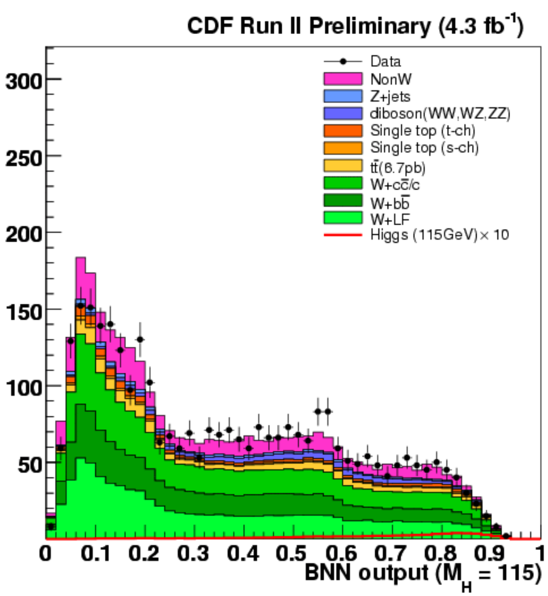


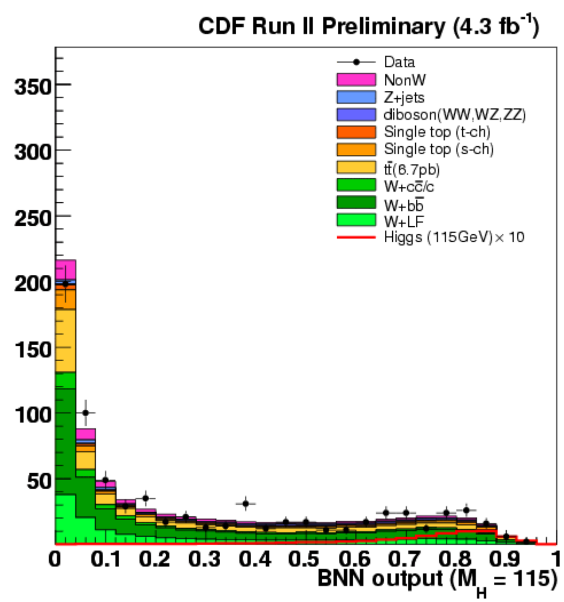
Low Mass Higgs: $WH \rightarrow l\nu bb$

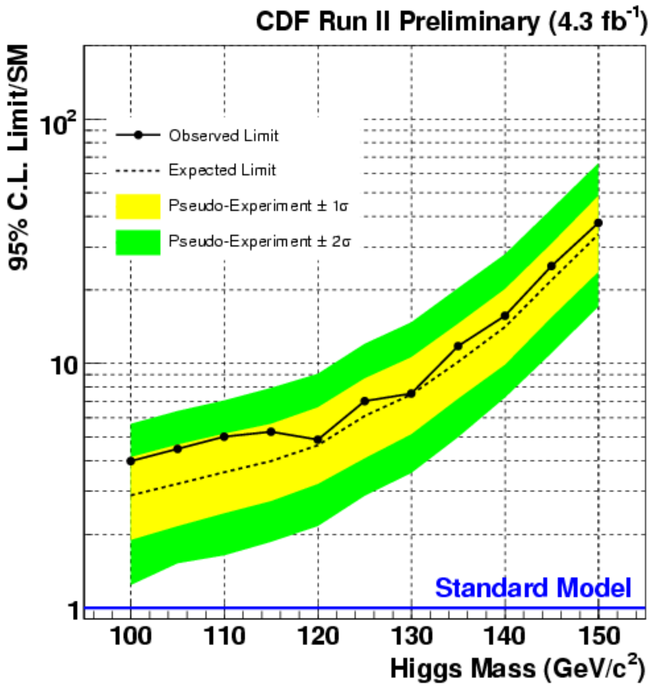
- Bayesian NN selection
- New NN *b*-jet energy correction
- 4 *b*-tagging categories
  - New: NN *b*-tag

For m_H = 115 GeV/c^2

- Expected limit: $4.0 \times \sigma_{SM}$
- Observed limit: $5.3 \times \sigma_{SM}$

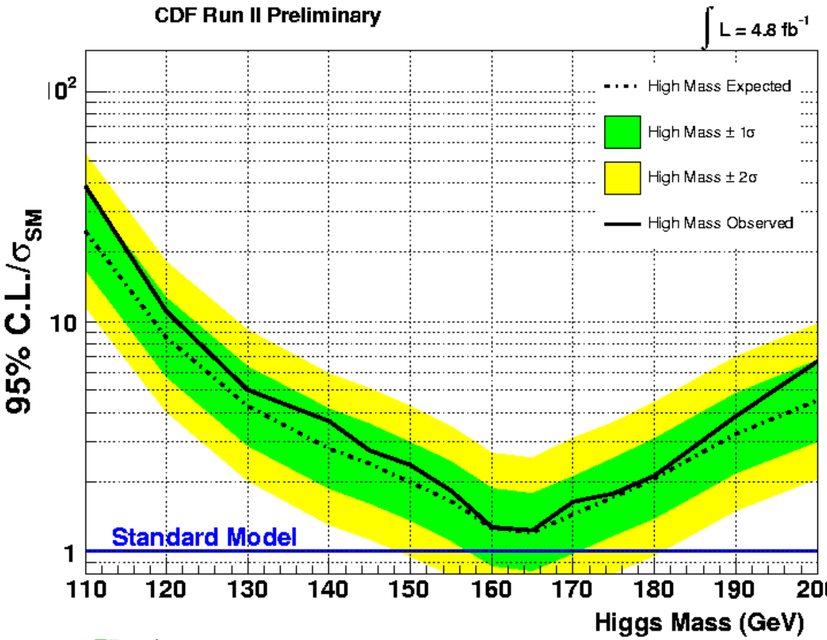


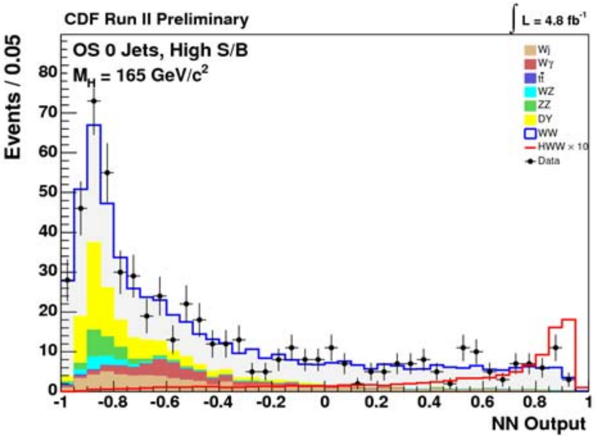


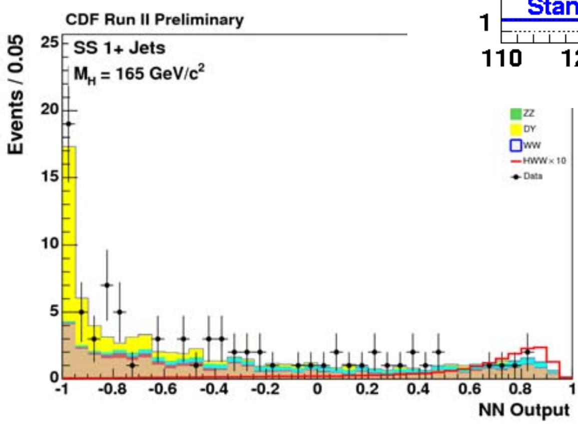


High Mass Higgs: $H \to WW^*$

- Opposite sign leptons: $H \to WW \to l\nu l\nu$
- Same sign leptons for $WH \to WWW$
- Improved lepton acceptance
- Better lepton ID (likelihood)
- Better acceptance and improved sensitivity at low dilepton mass region
- Train NN for each category
  - OS 0/1/2+ jets, SS, OS low M_{ll}





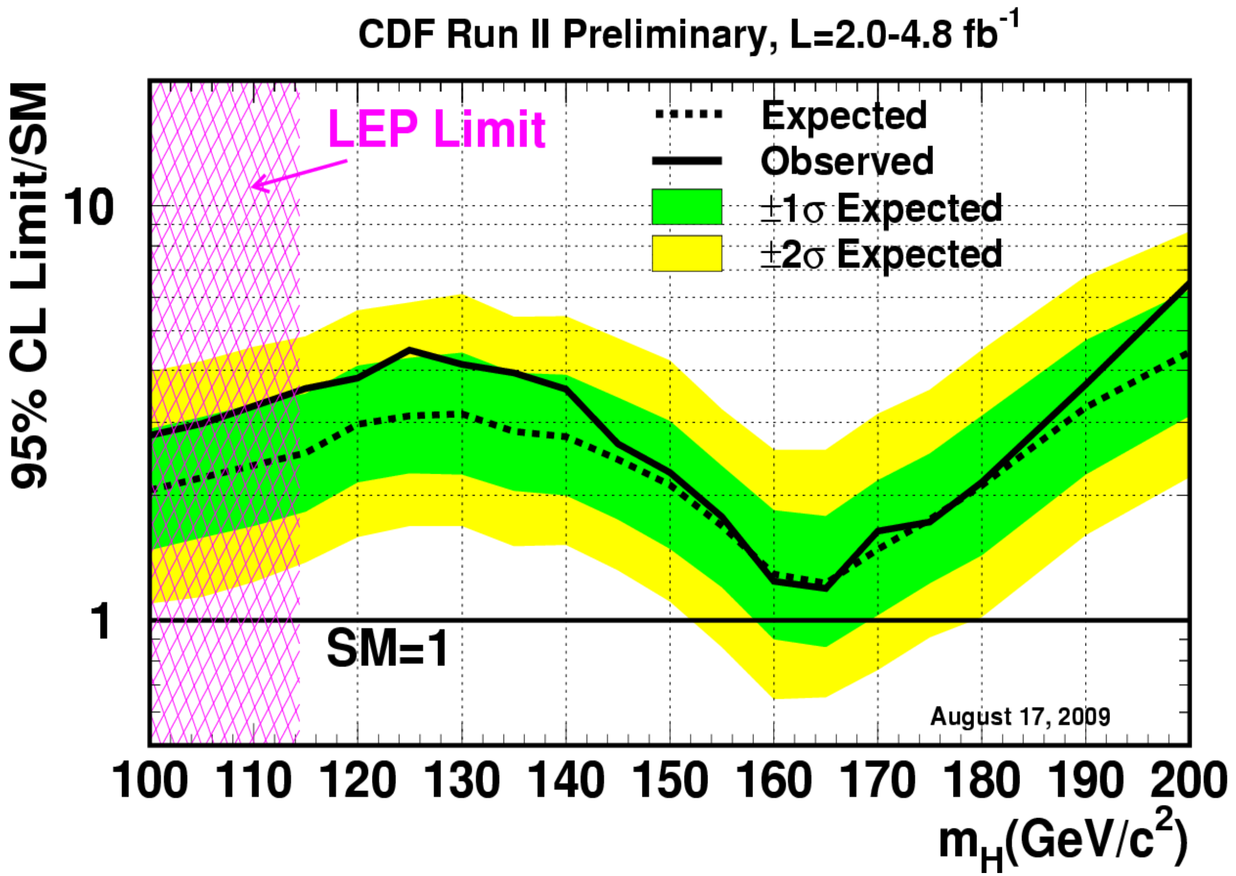


For m_H = 165 GeV/c^2

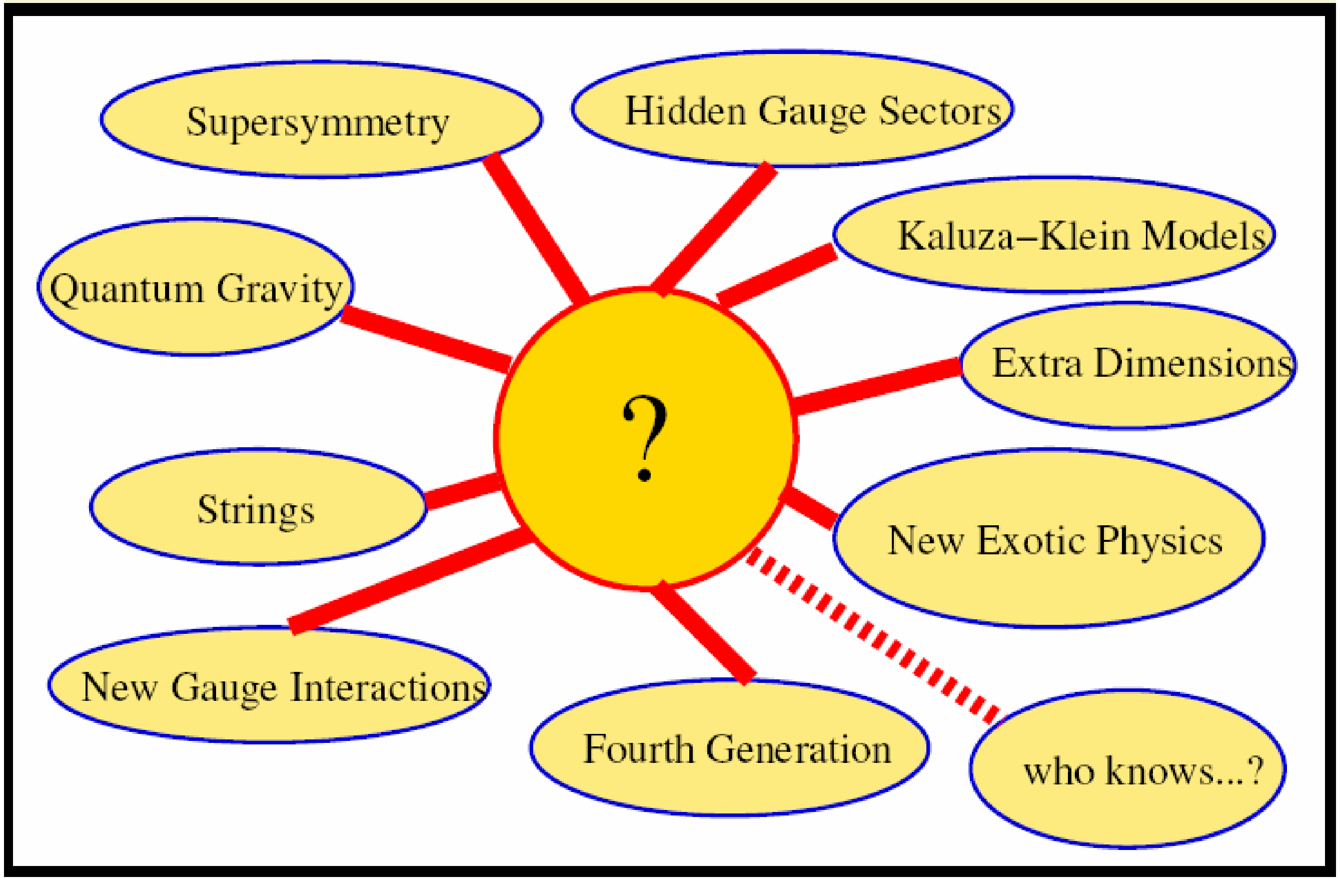
- Expected limit: $1.21\times\sigma_{SM}$
- Observed limit: $1.23\times\sigma_{SM}$

Combined Limit on Higgs

- $m_H = 115\ \mathrm{GeV}/c^2$
  - Expected limit: $2.53 \times \sigma_{SM}$
  - Observed limit: $3.62 \times \sigma_{SM}$
- $m_H = 160\ \mathrm{GeV}/c^2$
  - Expected limit: $1.29 \times \sigma_{SM}$
  - Observed limit: $1.24 \times \sigma_{SM}$

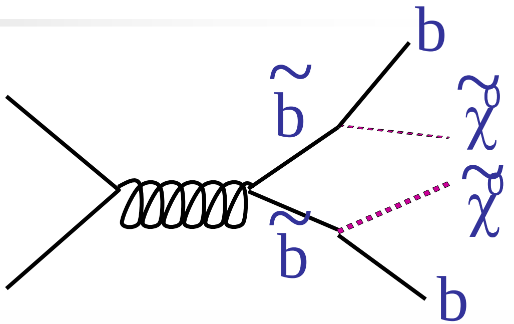


Searches for New Physics

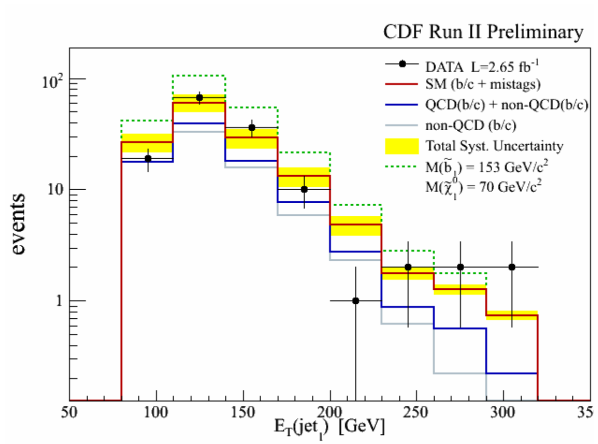


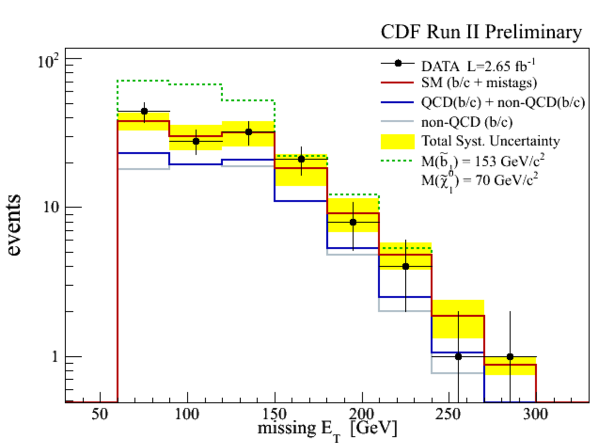
- Mainly SUSY search results this time.

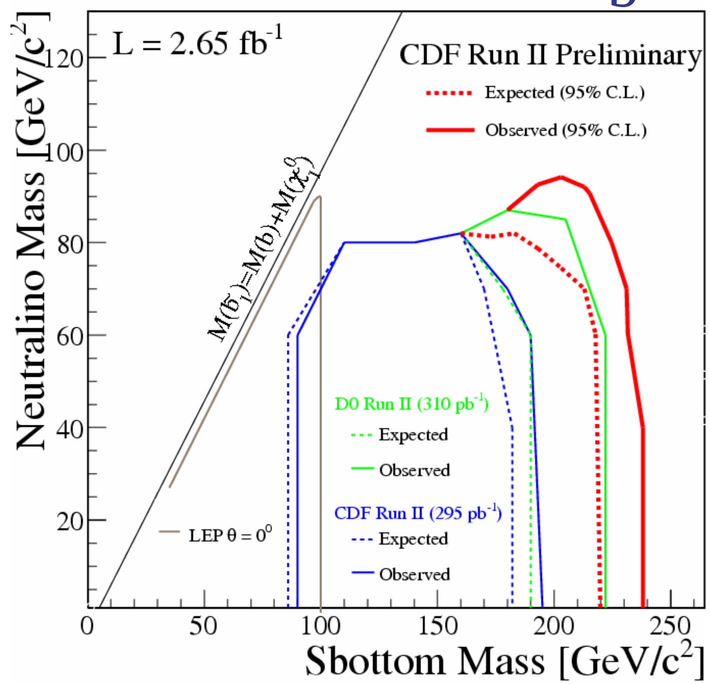
Sbottom Pair Production in MSSM



- For 3rd gen squarks, large mixing could lead to one of the stop and sbottom quarks to be light
  - Large cross section at Tevatron
- Signature: 2 high E_T *b*-jets and MET
- QCD background (mistags/heavy flavor) estimated from untagged samples.

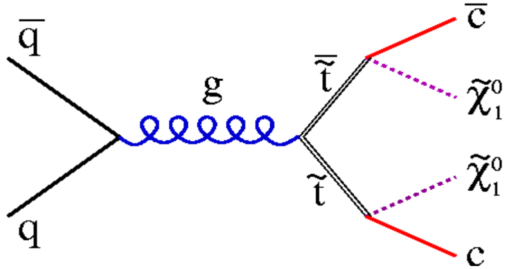


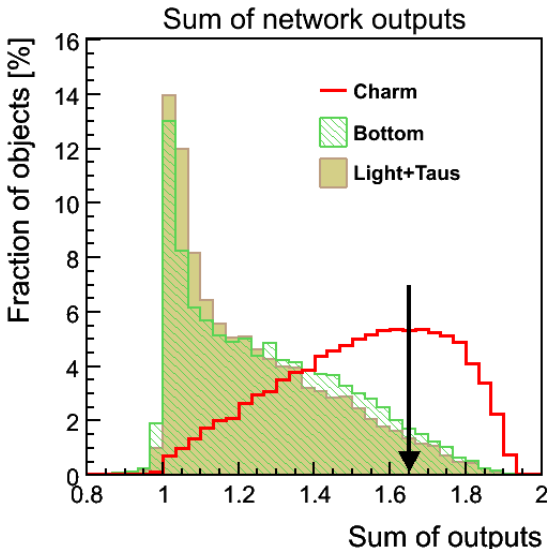


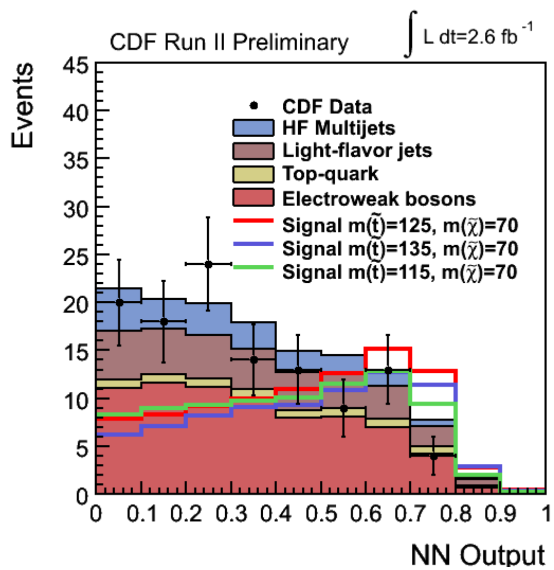


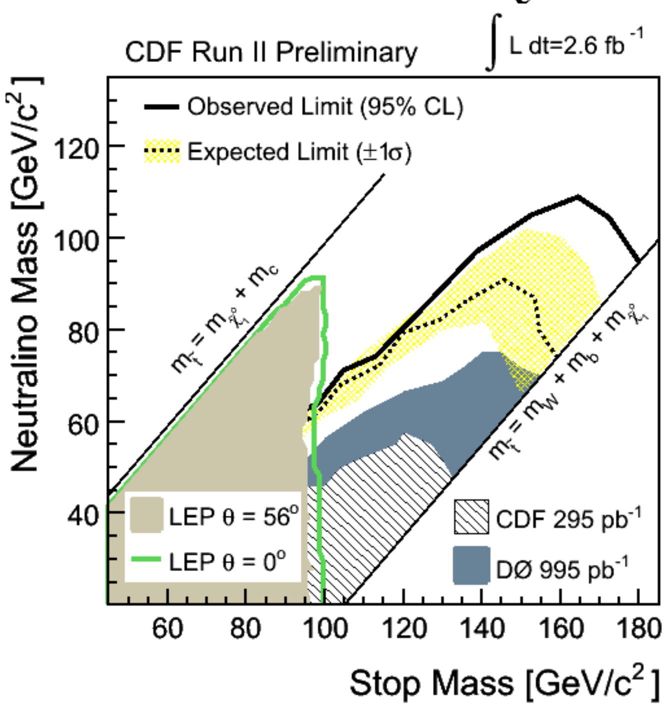
Stop Decaying into Charm and Neutralino

- If stop is light and stop→chargino+*b* is kinematically forbidden, then stop→neutralino+*c* might dominate.
- Signature: two charm jets + MET
- Developed a flavor separator to enhance charm separation



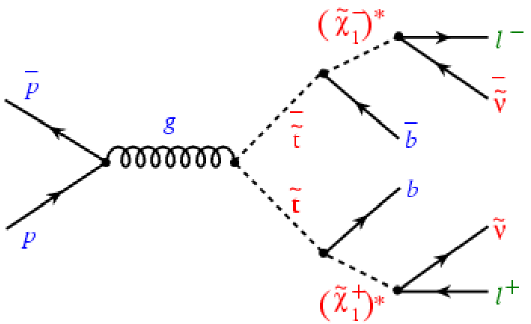


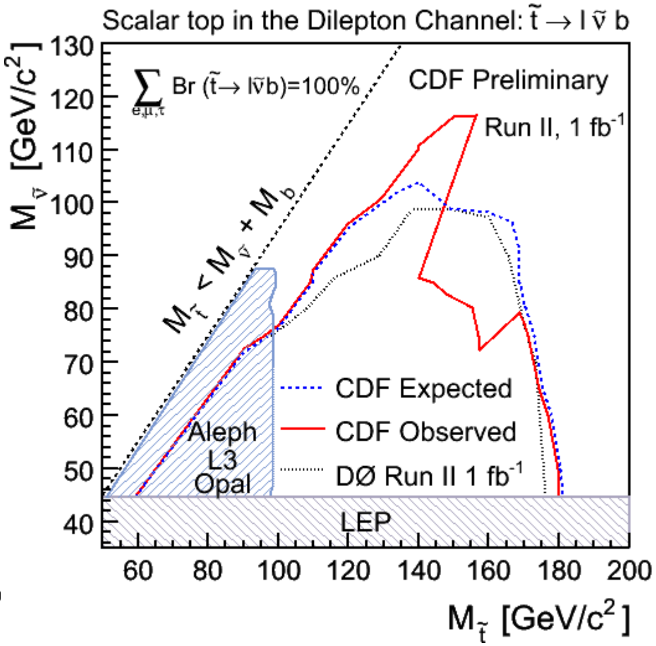


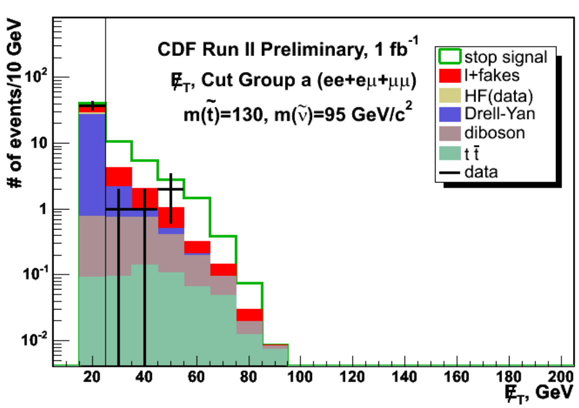


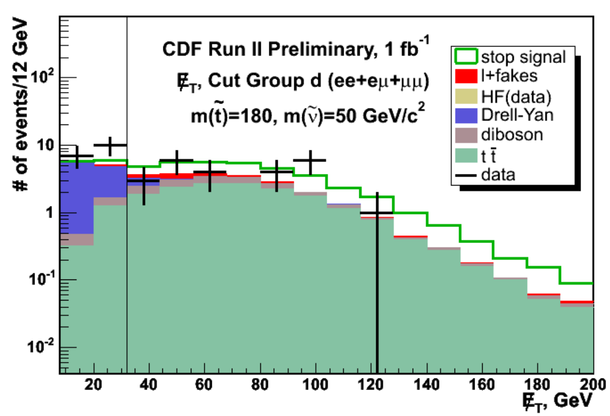
Stop Search in Dilepton Channel

- If the sneutrinos are lighter than stop, the dominant decay is into leptons.
  - Signature similar to ttbar dileptons, but with soft leptons.
  - Kinematics slightly different due to sneutrino mass.







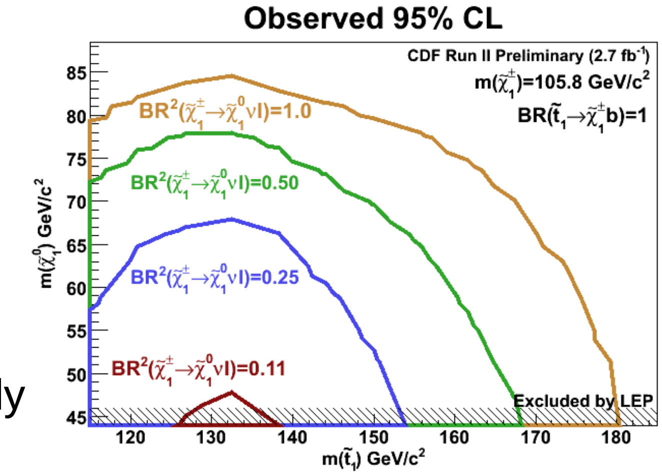


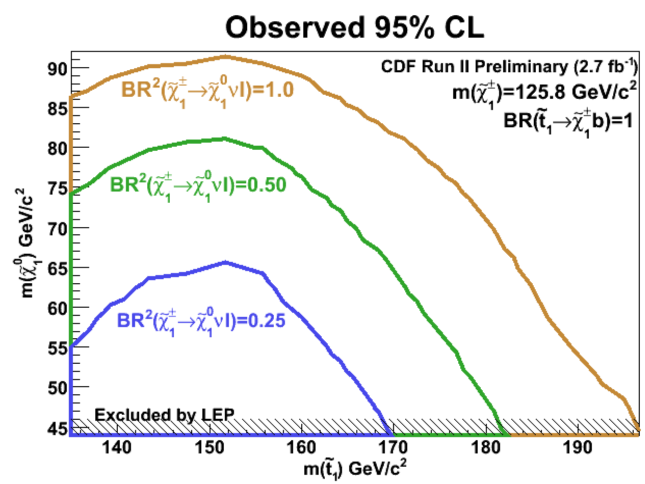
Stop Decaying into Bottom and Chargino

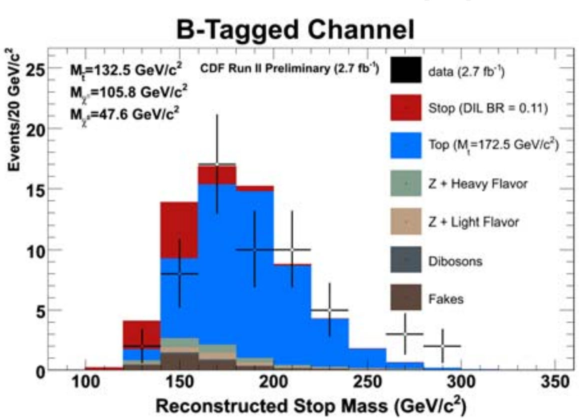
- When stop is more massive than the lightest chargino, the dominant decay is very top-like:

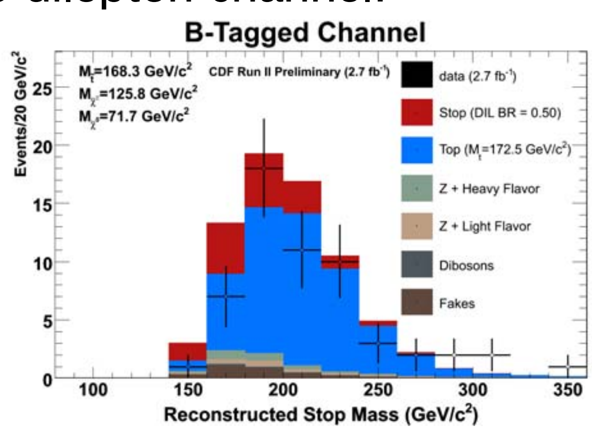
$$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm} \rightarrow b\tilde{\chi}_1^0 W^{\pm(*)} \rightarrow b\tilde{\chi}_1^0 l\nu$$

- The differences are:
  - Mass distribution of the stop
  - Different "escaping particles" makes topology slightly different.
- Search in stop pair to dilepton channel.



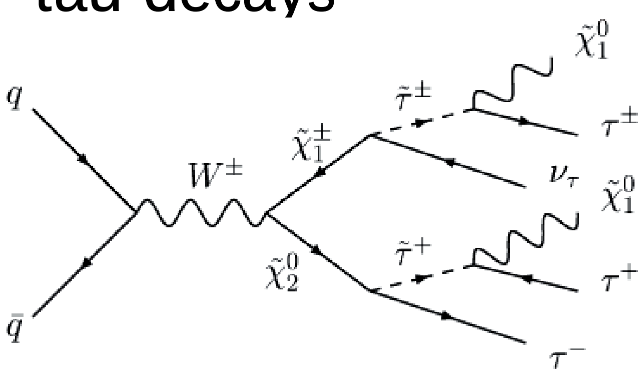


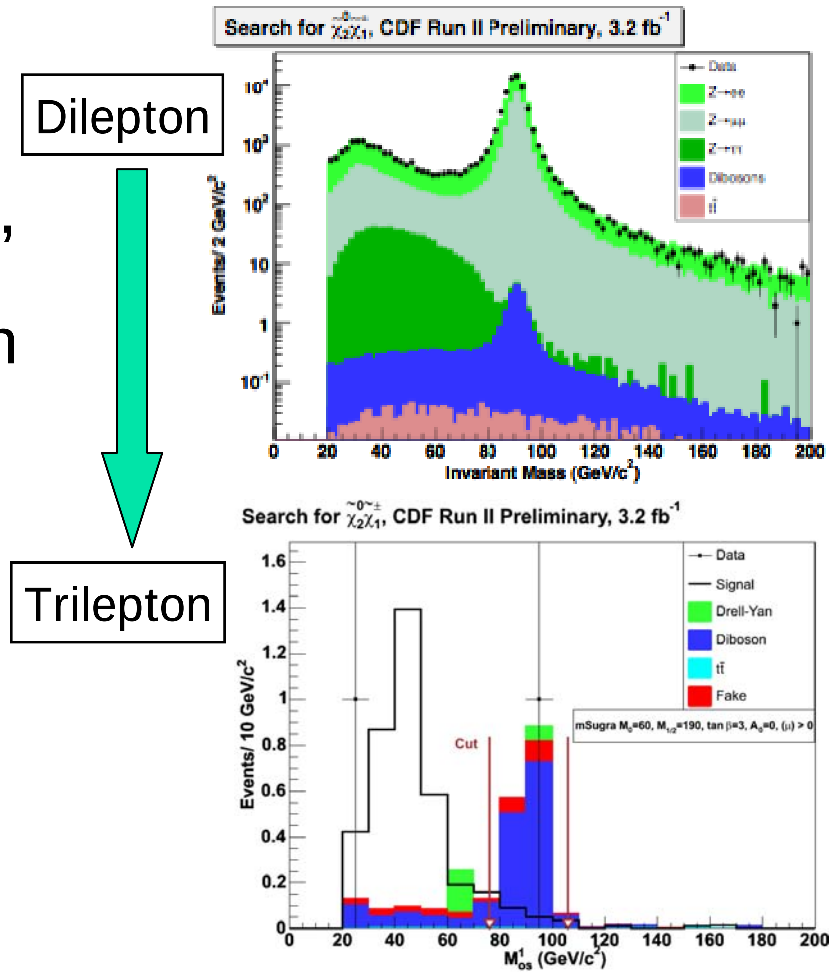




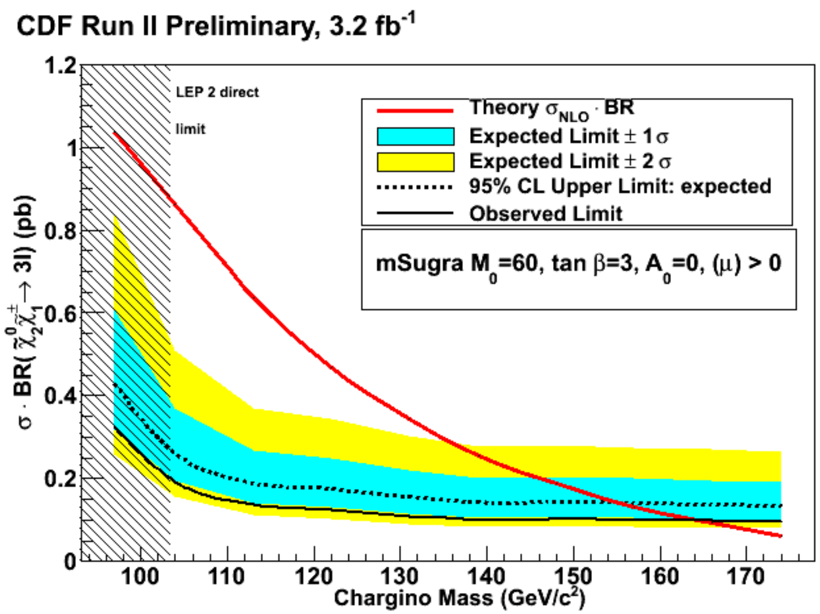
Chargino-Neutralino Production in Trilepton Mode

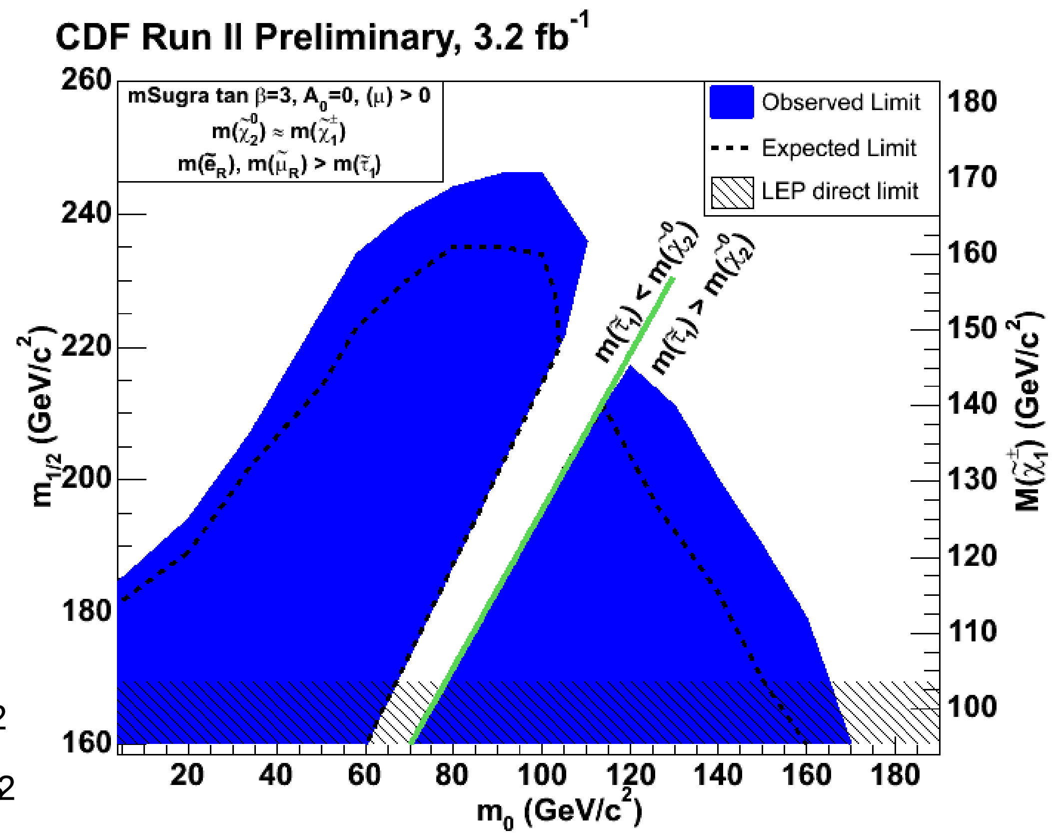
- Trilepton channel in chargino-neutralino production: “golden mode”
  - 3 leptons + MET: very clean for hadron colliders
  - Include isolated tracks for tau decays





Chargino-Neutralino Limit in mSUGRA





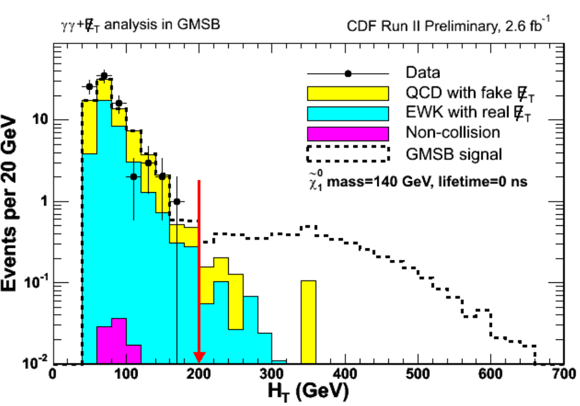
- For chargino mass
  - Expected limit: 156 GeV/c^2
  - Observed limit: 164 GeV/c^2

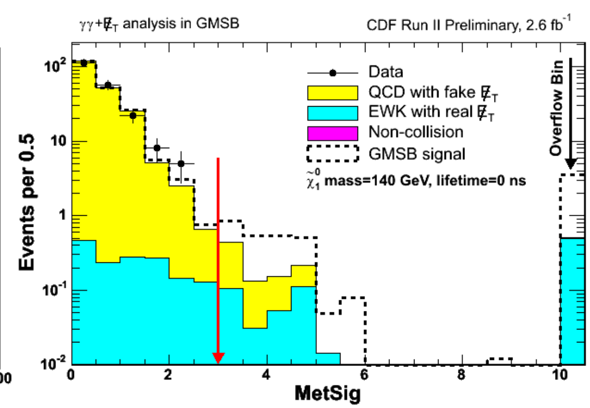
GMSB Neutralino Search Using Photons

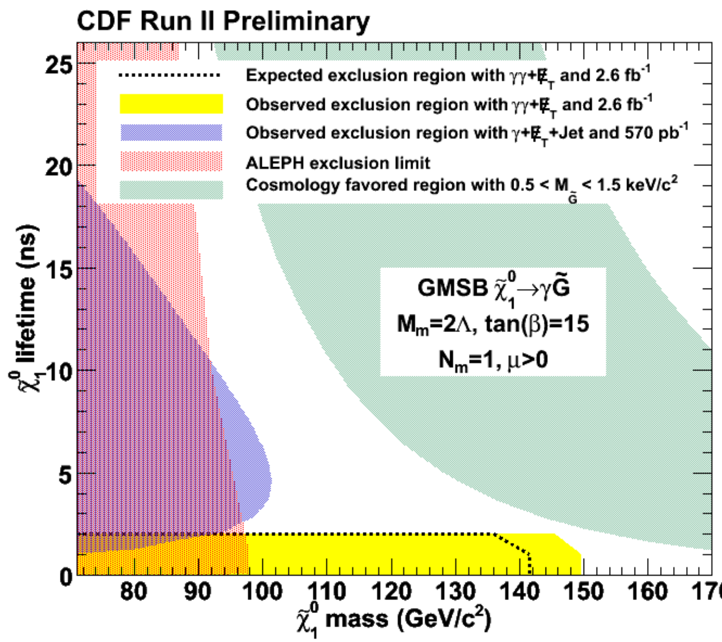
- Gauge-Mediated Supersymmetry Breaking (GMSB) models usually allow neutralino to decay in photon and gravitino (LSP).
- Search for neutralino pair production.
  - Signature is: 2 photons and MET.
- Background rejection
  - EMTiming (non-collision bkg)
  - MET Resolution Model (QCD)

$$\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$$

Observed	**0** event
Expected	1.2 ± 0.3 ± 0.2

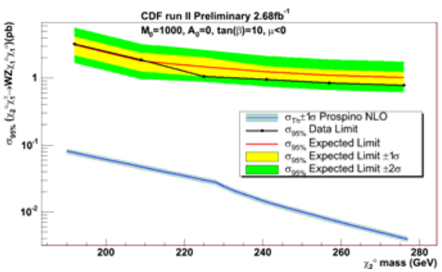


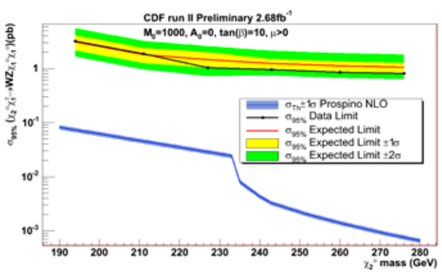


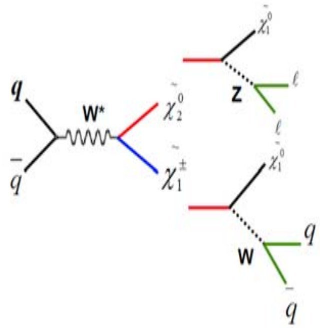


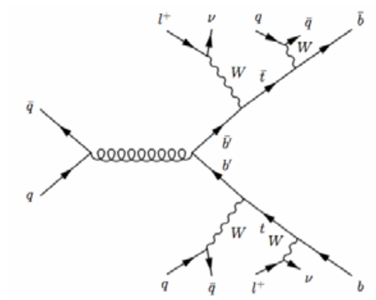
Other BSM Searches

Gaugino Pair Production in W+Z+MET

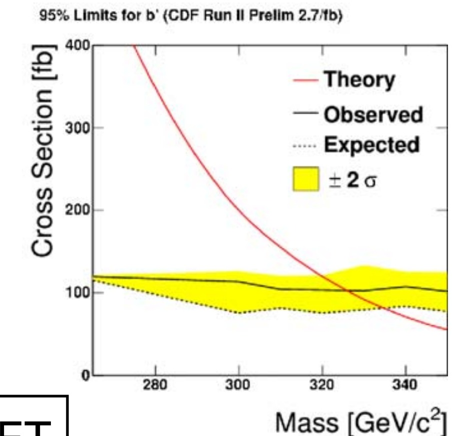




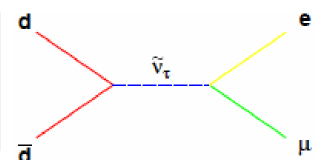


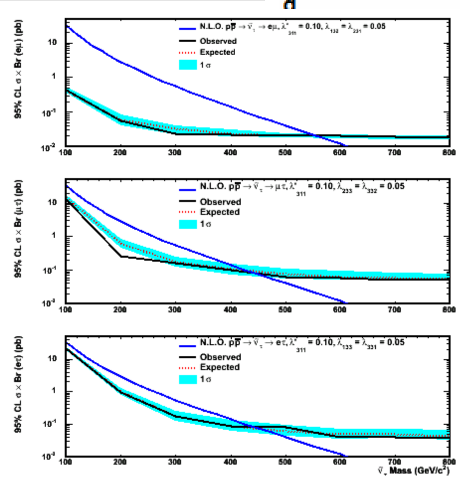


4th Generation b' in Same-Sign Dilepton

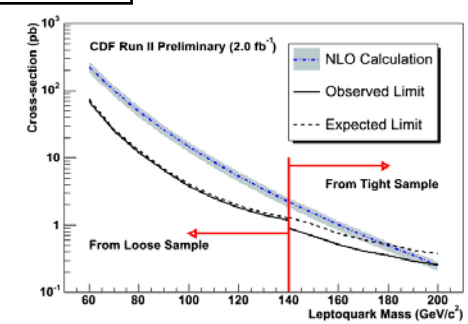


R-Parity Violating Sneutrino





Dijet+MET



WW/WZ Resonance

	G*	Z'	W'
Expected exclusion	< 632 GeV	257 – 630 GeV	381 – 420 GeV
Data exclusion	< 607 GeV	247 – 545 GeV	284 – 515 GeV

CDF Run II Preliminary. $\int L\,dt = 2.9\,fb^{-1}$

Summary

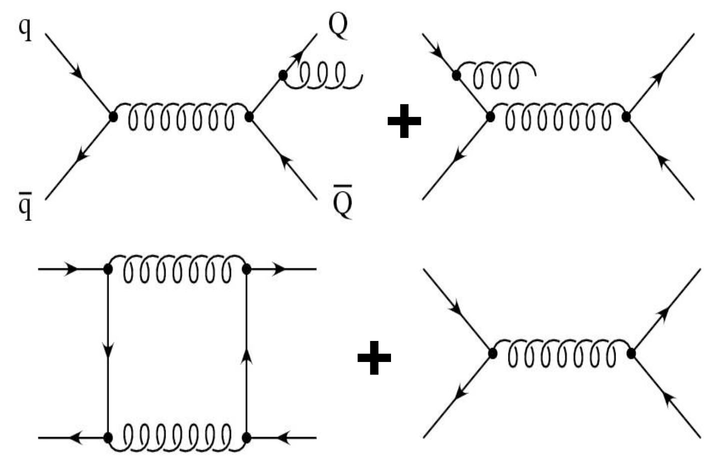
- Tevatron is operating well. Better than ever!
  - CDF is ready to run for FY2011. $\int L dt \sim 12\ \mathrm{fb}^{-1}$ is expected.

- Successful application of multivariate analysis techniques.
- Top quark properties are being measured more and more precisely. Mass precision is now less than 1%.
  - Top quark properties are consistent with SM so far.
- Still improving the Higgs sensitivity.
- No signs of physics beyond SM, but search continues actively.

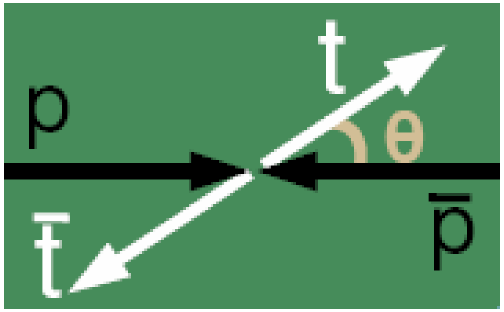
- Stay tuned for interesting results from Tevatron in the near future!
  - New top mass combination and new EW fit
  - New Tevatron combined Higgs limit
  - New search channels and updates on the search results

Backup Slides

Forward-Backward Asymmetry in ttbar Production

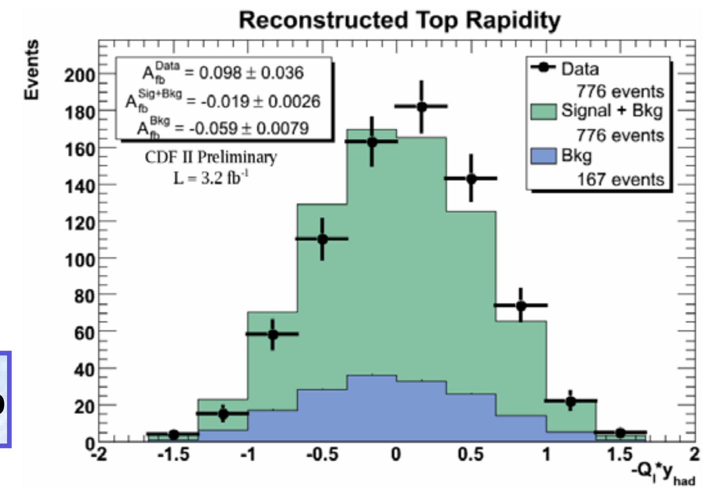


- Charge asymmetry in ttbar production
  ⇒ Forward-backward asymmetry
  - LO QCD predicts 0 asymmetry
  - NLO predicts A_{fb} = (5±1.5)%
    (O. Antuñano *et al.*, Phys. Rev. D**77**, 014003(2008))
    - Interference between initial and final state radiation
    - Interference between box diagram and Born process
  - DØ (0.9 fb^{-1}): A_{fb}^{rec} = 0.12 ± 0.08 ± 0.01
    (Reconstruction level, i.e., no correction)



$$A_{fb} = \frac{N_t(y>0) - N_t(y<0)}{N_t(y>0) + N_t(y<0)}$$

$$A_{fb}^{pp} = (19.3 \pm 6.5_{stat} \pm 2.3_{syst})\%$$



Charm Tagging in Stop Search

- Charm Hadron Analysis-Oriented Separator (CHAOS)
  - 2D-output NN to distinguish flavor of jets:
    - *b* jets, light jets, and *c* jets
    - 22 input variables:

M_{vtx}
Q_{vtx}
L_{xy}/σ_{Lxy}
$N_{passed\ trk}/N_{good\ trk}$
$\Sigma p_T^{good\ trk}/E_T^{jet}$
p_T^{vtx}/E_T^{jet}
p_T^{1st}/p_T^{vtx}
p_T^{2nd}/p_T^{vtx}
$<|d_0|>_{good\ trk}$
$<|d_0/\sigma_{d0}|>_{good\ trk}$
ϕ_{jet}
η_{jet}

$z_t=\Sigma p_T^{passed\ trk}/\Sigma p_T^{good\ trk}$
$r_{vtx}=p_T^{vtx}/\Sigma p_T^{good\ trk}$
frac. of good trk w/ $|d_0/\sigma_{d0}|>1,3,5$
signed d_0 of 1st/2nd trk
signed d_0/σ_{d0} of 1st/2nd trk