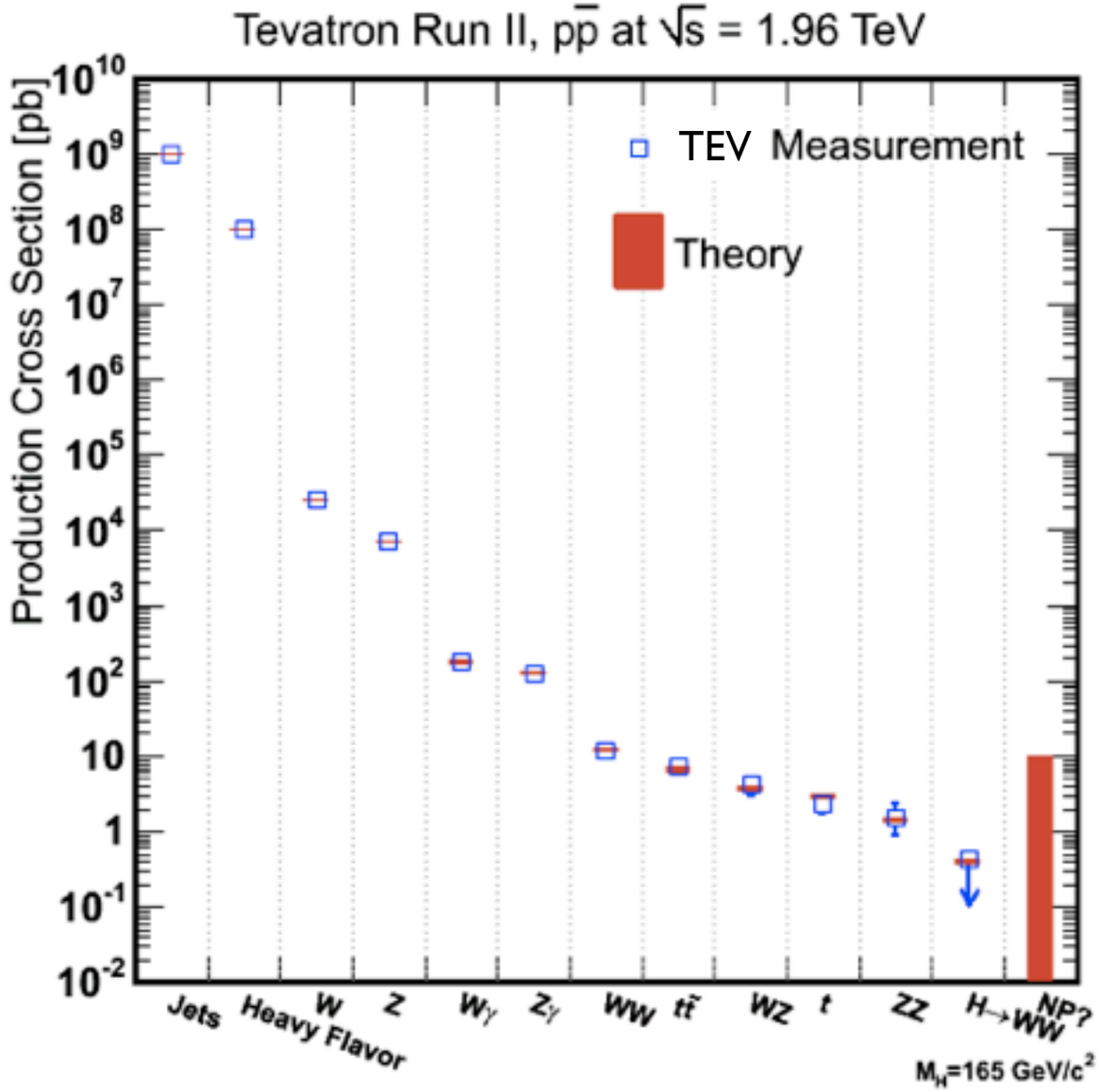
Highlights from TeVatron

Vadim Rusu

Tevatron RunII Physics

- **Rich and wide physics program over ~10 orders of magnitude of physics processes:**
  - quarks and gluons (QCD)
  - Electroweak physics (W, Z, g, gauge couplings)
  - top physics
  - Higgs searches
  - New physics
- **I will only cover the most recent results**
  - **to date >500 Run II publications**



http://www-cdf.fnal.gov/internal/physics/

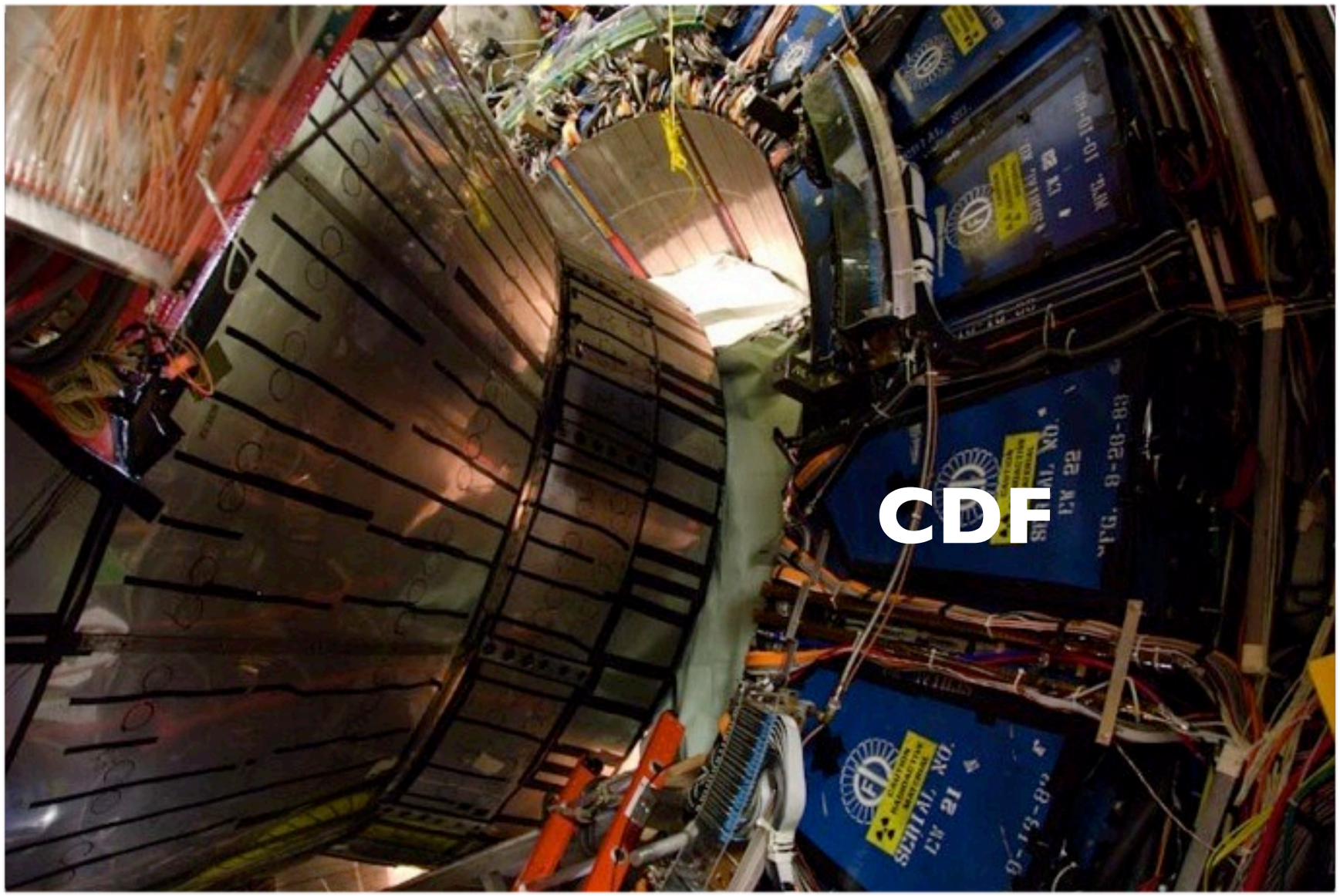
http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

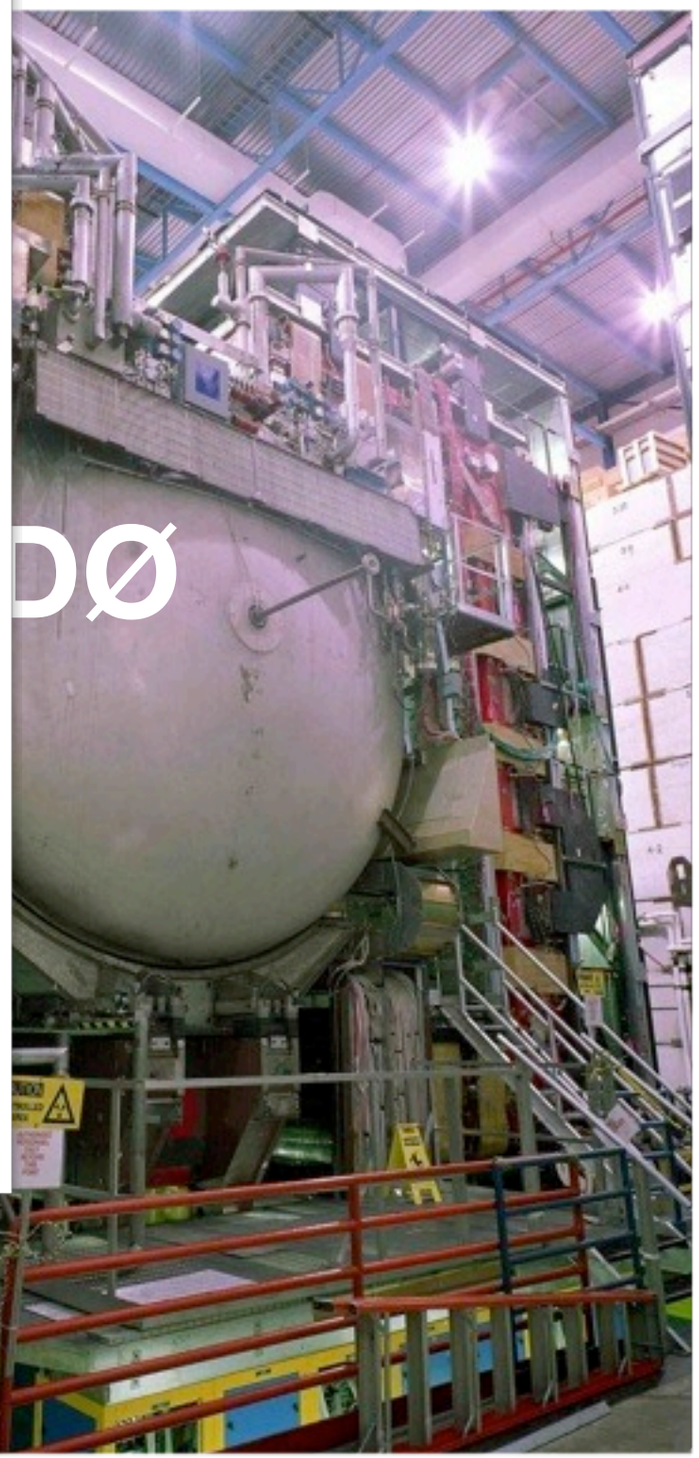
Cast of characters

Cast of characters

Cast of characters

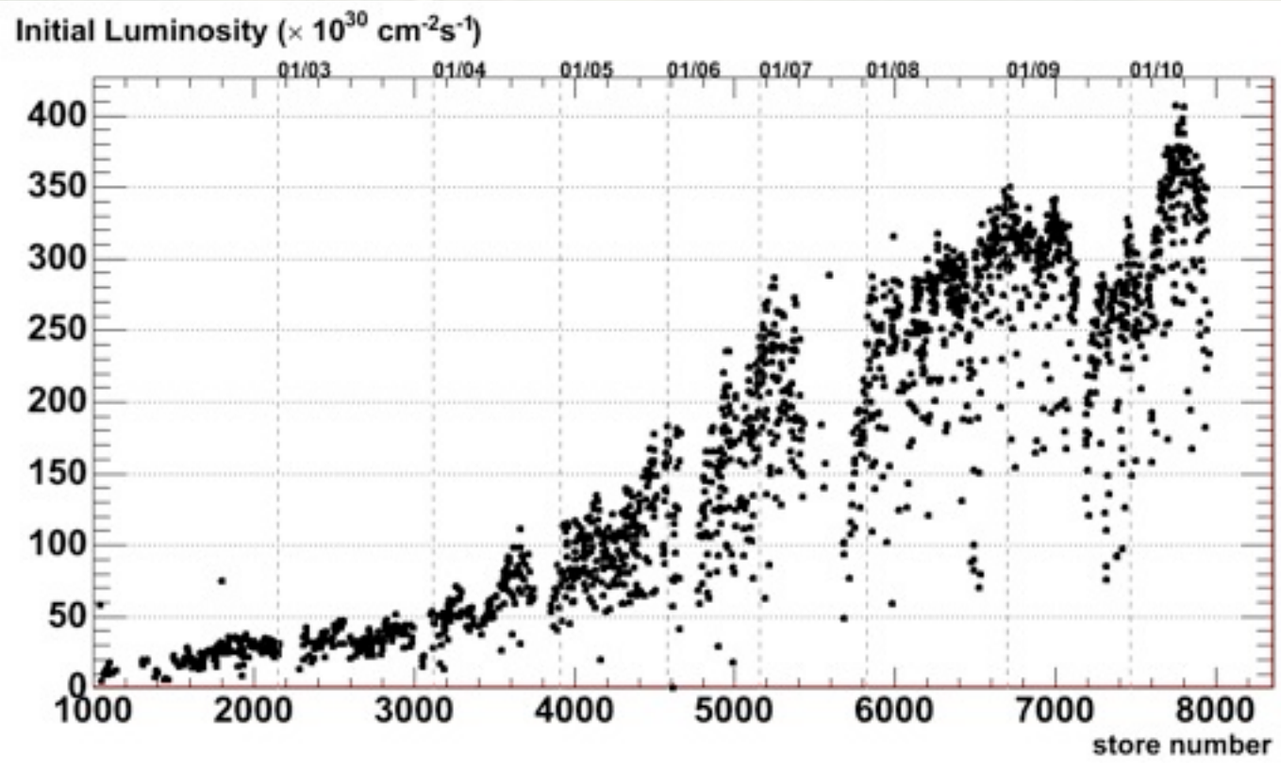
Cast of characters

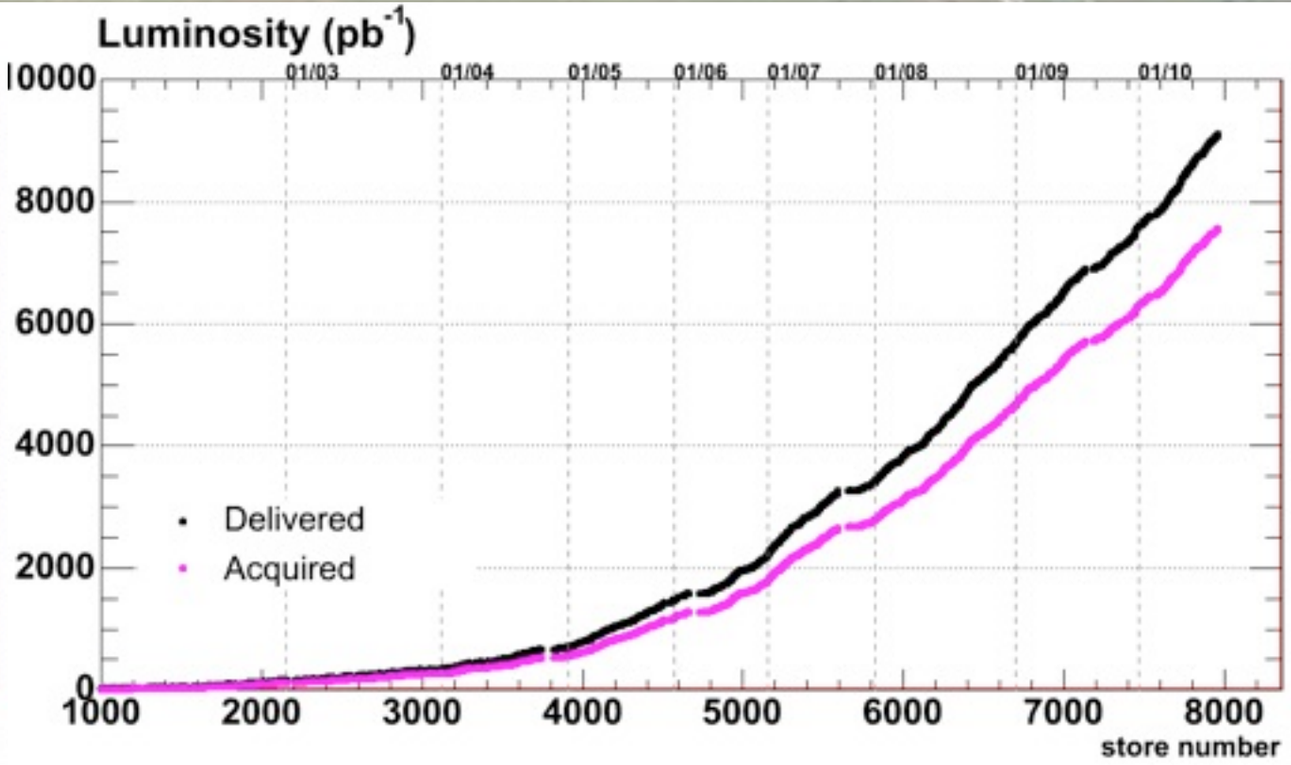




Tevatron Performance

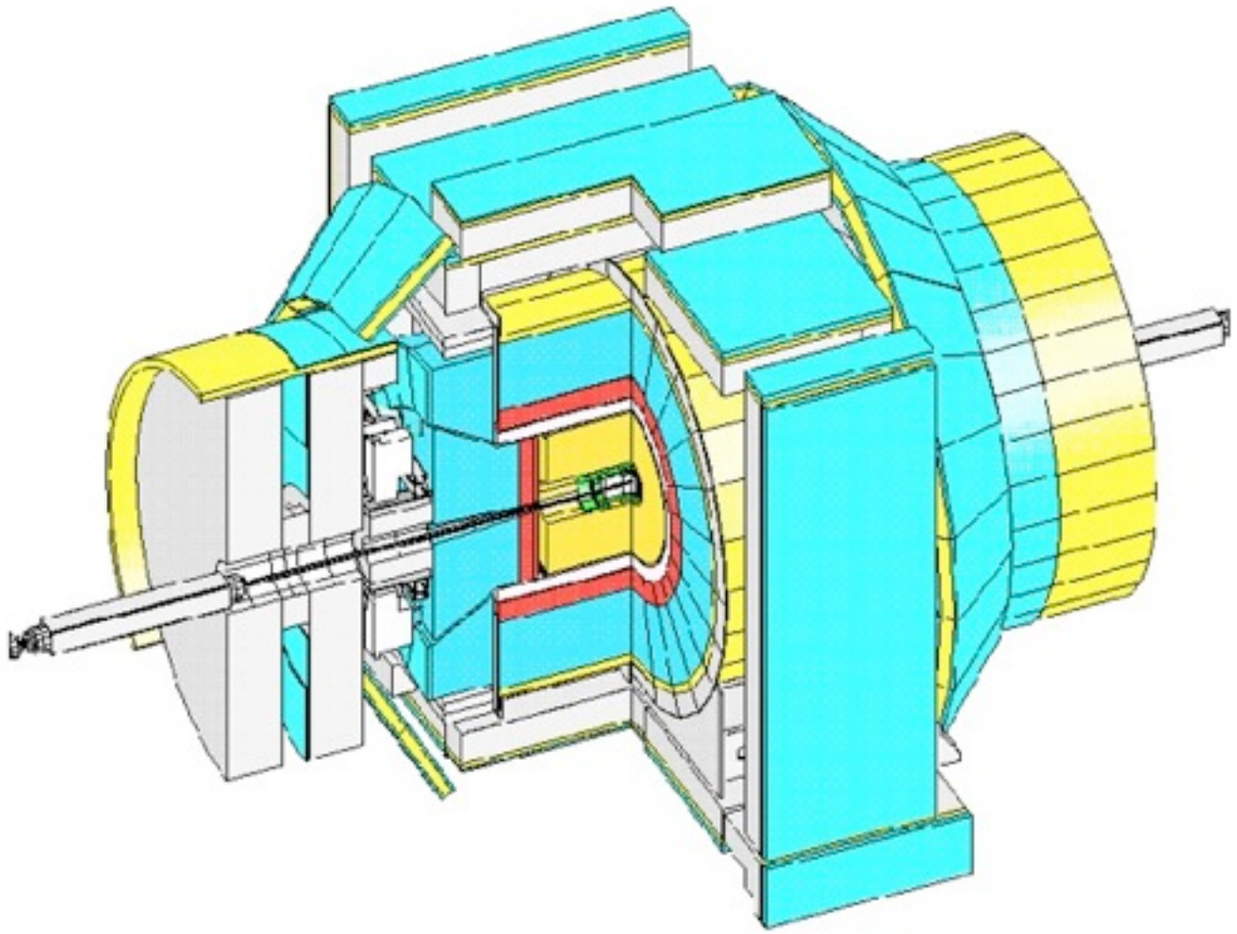
- A well oiled machine (no well and no oil involved)
  - Record inst. luminosities (>$4\times10^{32}cm^{-2}s^{-1}$)
  - Approaching $10fb^{-1}$ mark (already >$2fb^{-1}$ in FY10)
- Will show ~$5fb^{-1}$ data

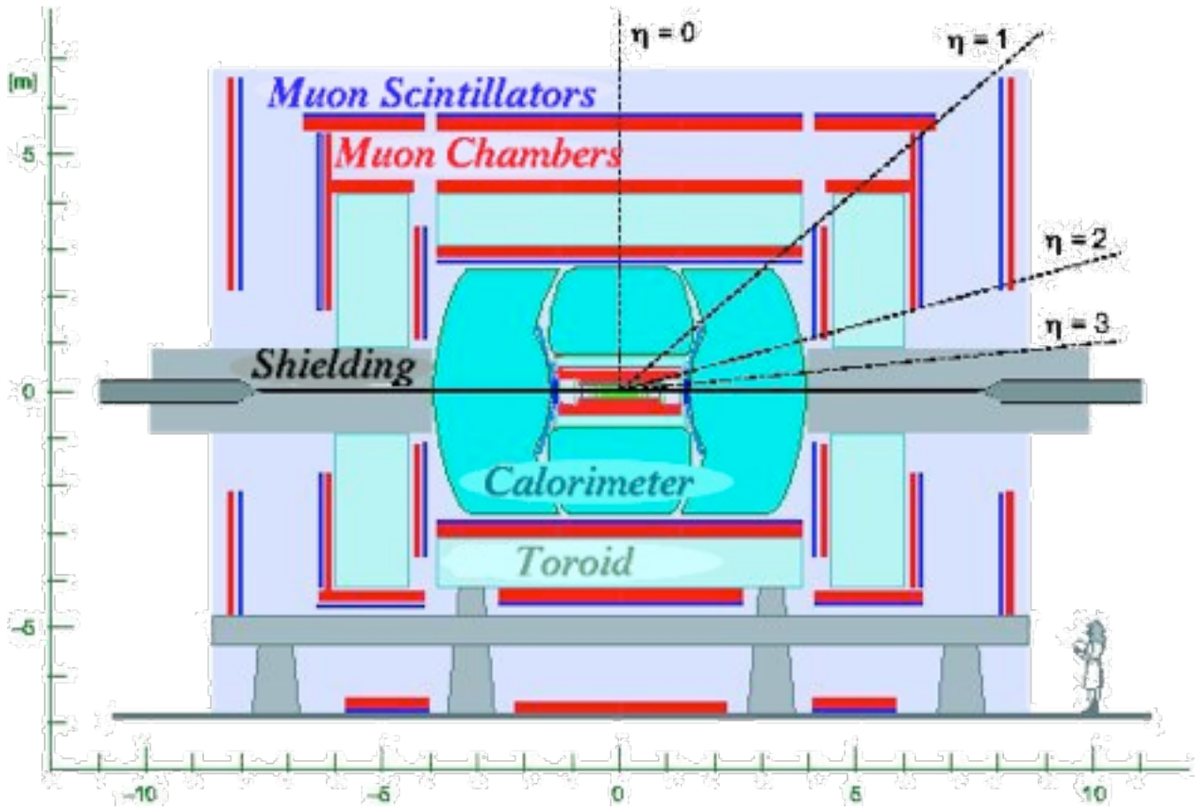




CDF and D0

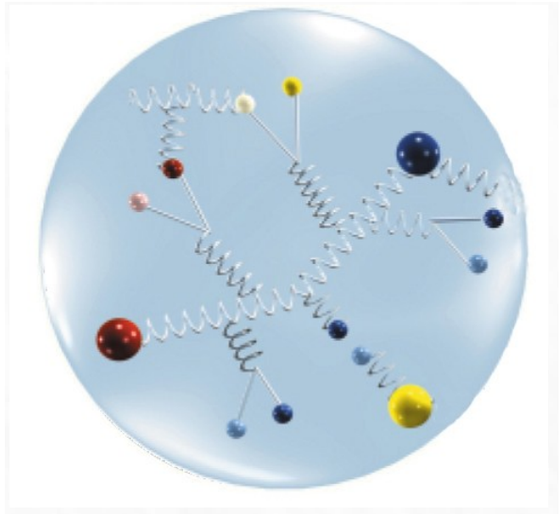
- Typical detectors for hadron colliders
- Top performance (>85% data taking efficiency)
- > 7fb^{-1} per experiment

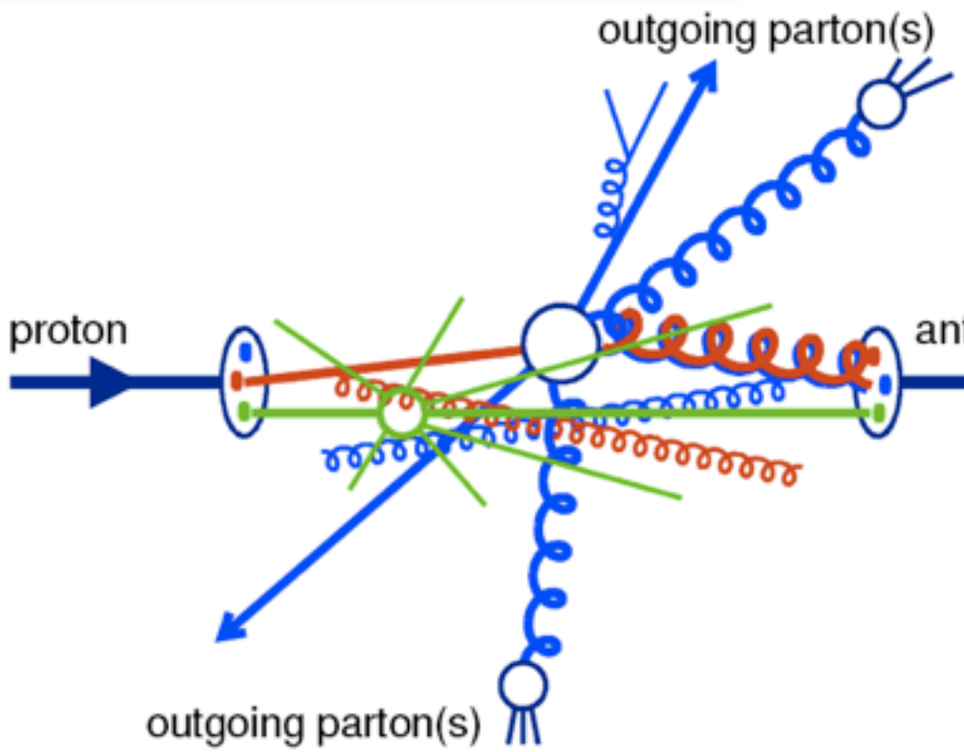




Quarks and Gluons

- pQCD tests
- proton (and antiproton) structure
- diffractive physics



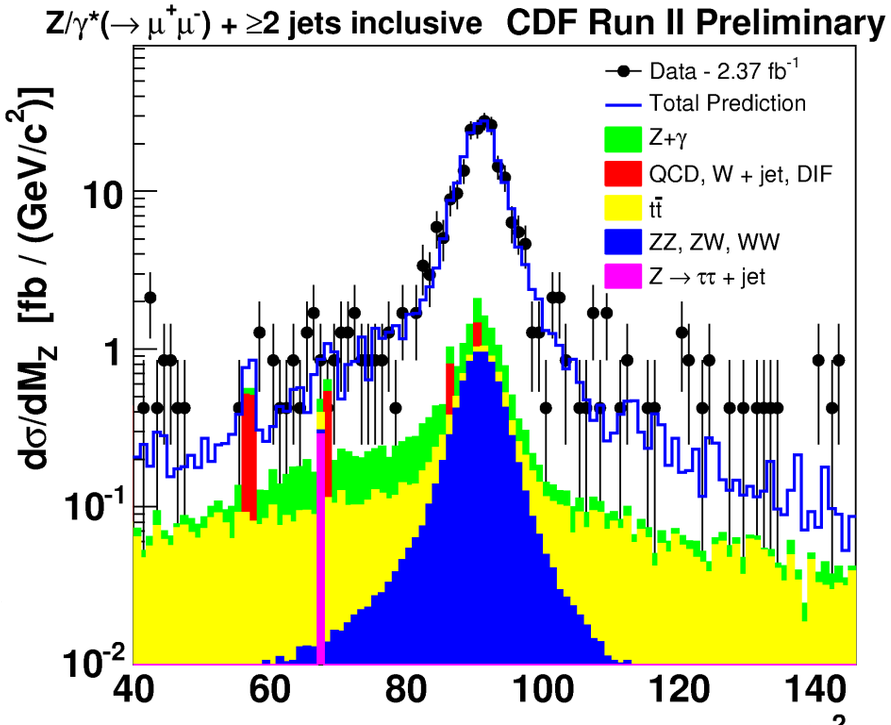


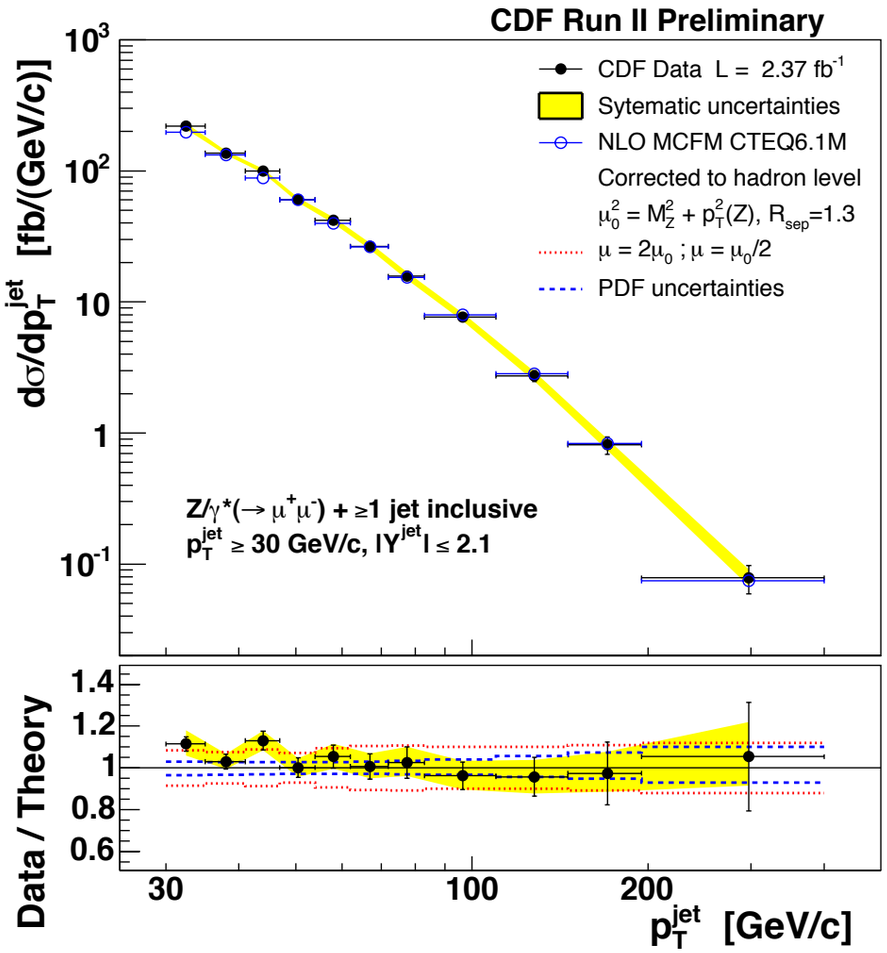
- Parton physics is reached through studies of jets in the detector

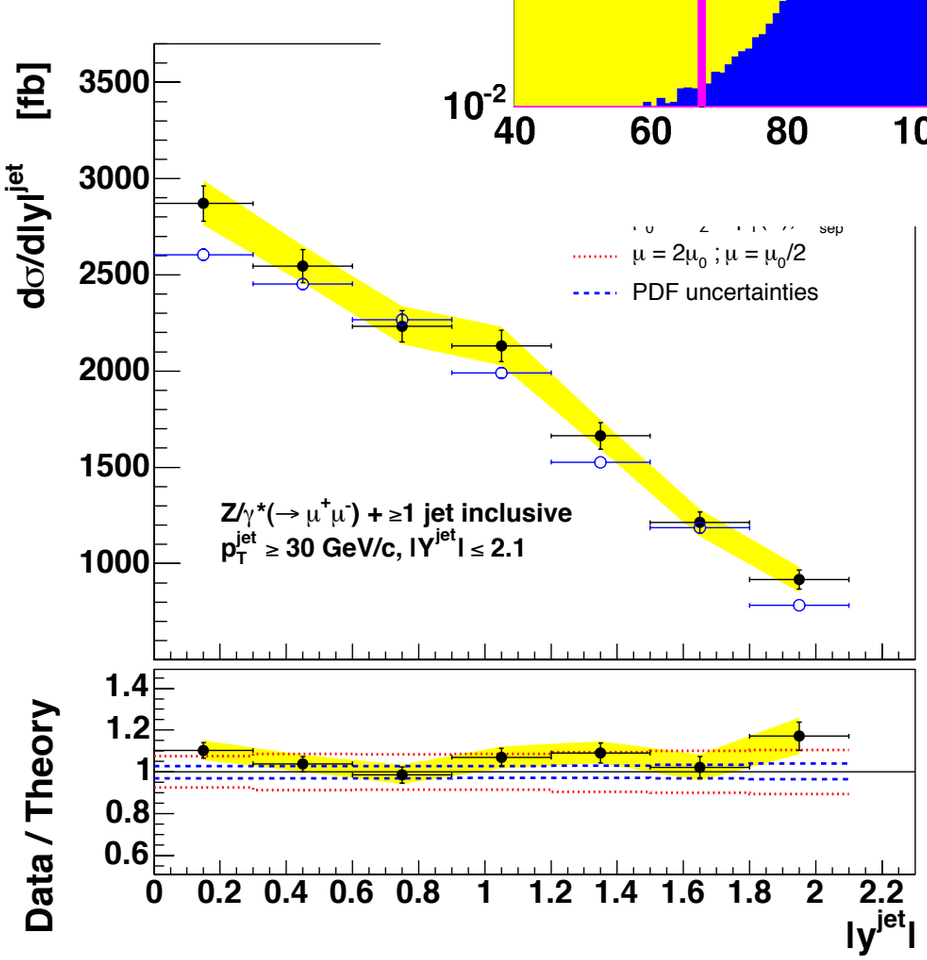
- Crucial background understanding for other measurements

Z/γ* + jets

- Reconstruct the muonic decay of Z
- Jets with E_T>30GeV and $|\eta| < 2.1$
  - cone 0.7 jets
- Good agreement with the NLO MCFM calculations

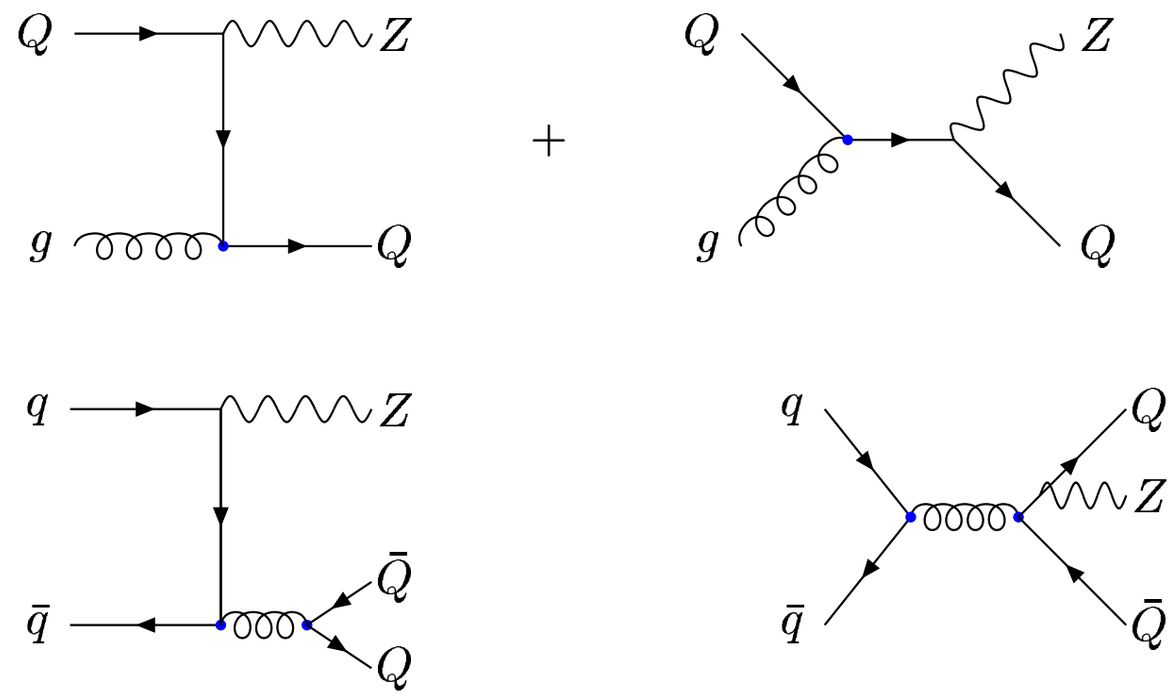


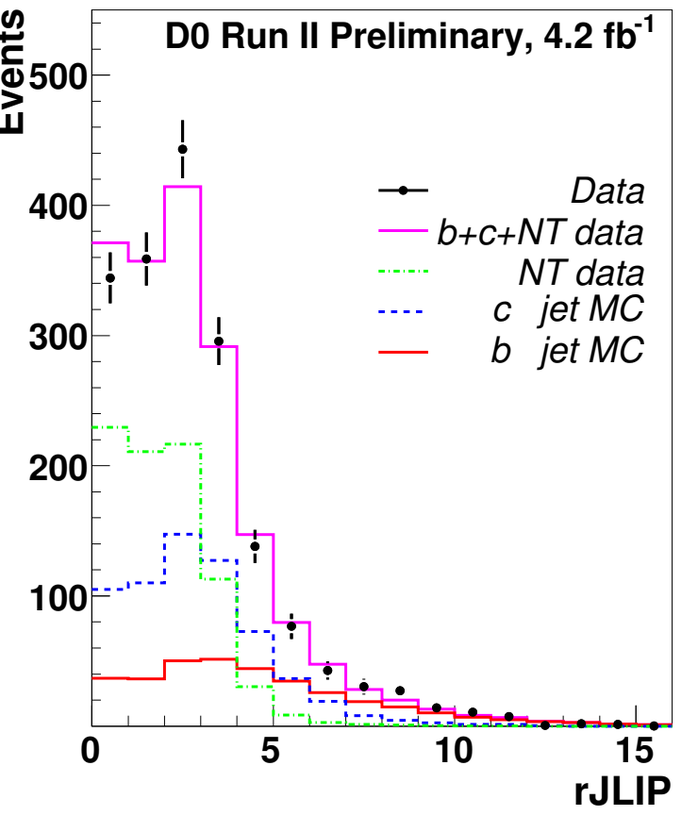


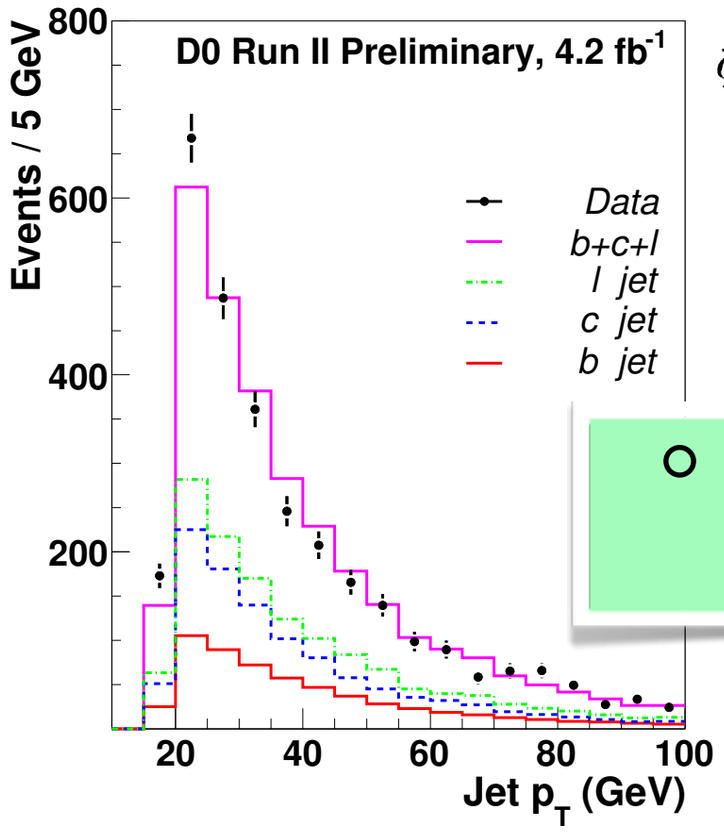


Z+b jets

- σ(Z+b)/σ(Z+jets)
  - Essential for b signatures (H, SUSY)
- Selection:
  - Jet ET>20GeV
  - |η| < 1
- Use jet b-tagging probability



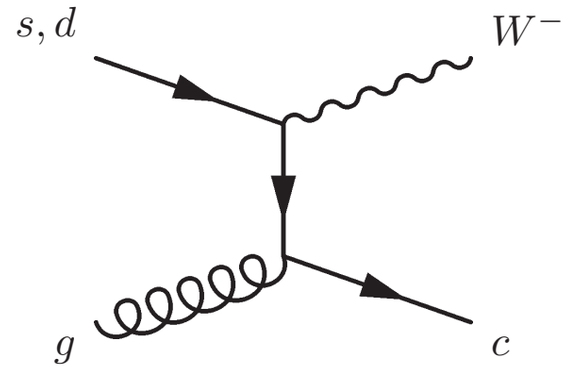


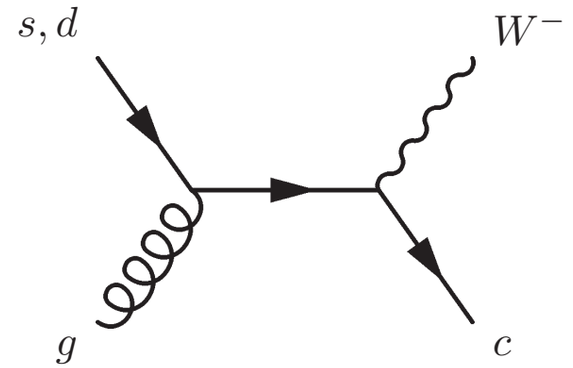


- R = 0.0176± 0.0024(stat.)± 0.0022(syst.)
  - NLO calculation = 0.0184± 0.022

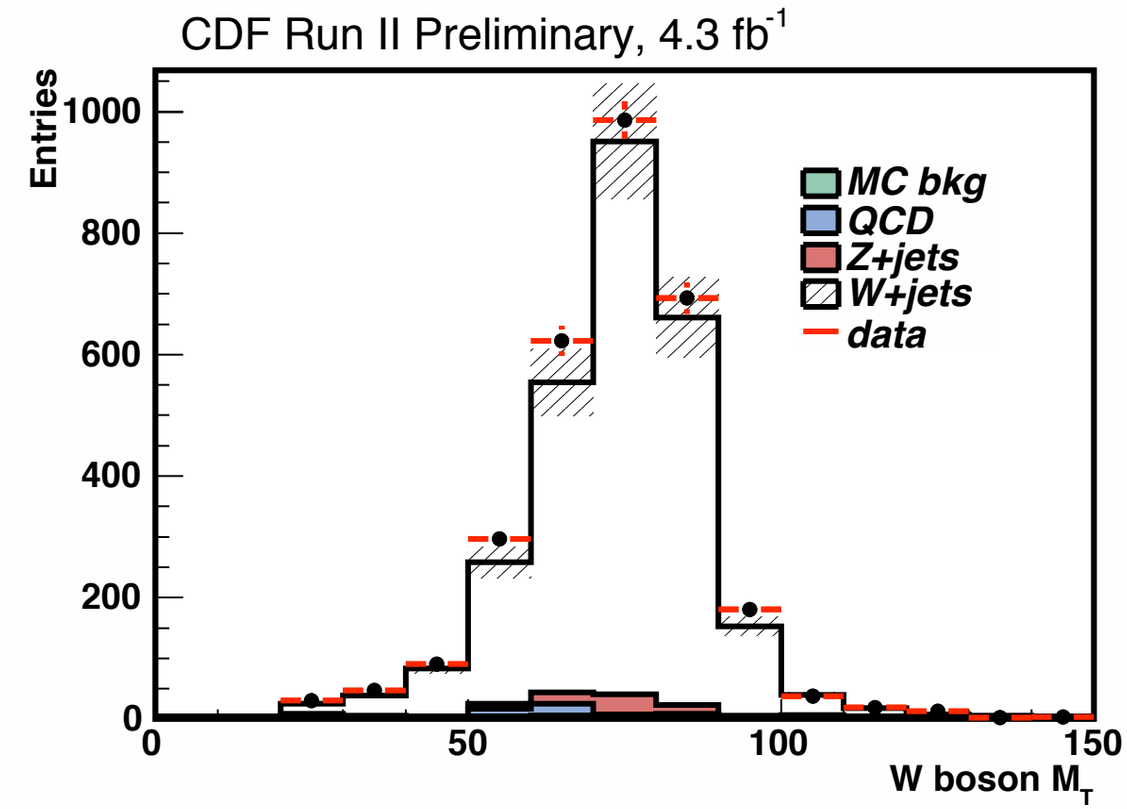
W+charm

- Probing strange PDF
- Exploit the lepton charge correlation
- $N=N^{OS}-N^{SS}$
- $\sigma_{NLO} = 16.5 \pm 4.7$pb





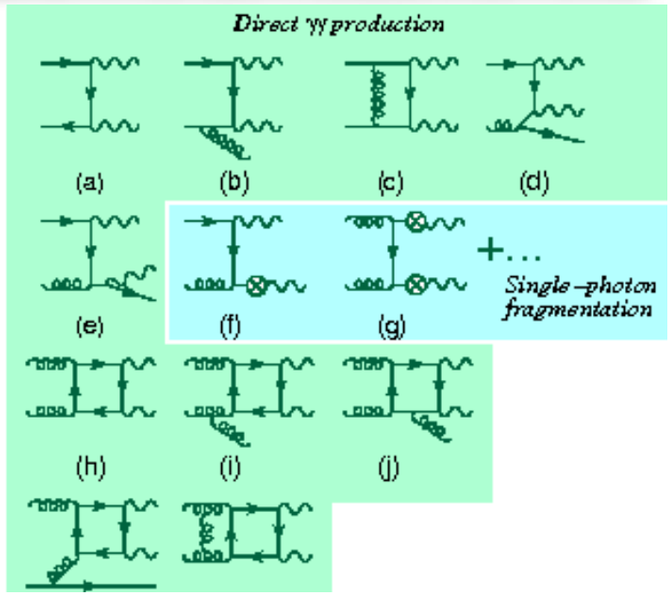
$$\sigma_{Wc} = \frac{N_{obs} - N_{bkg}}{\epsilon \cdot \mathcal{A} \cdot \int \mathcal{L}}$$

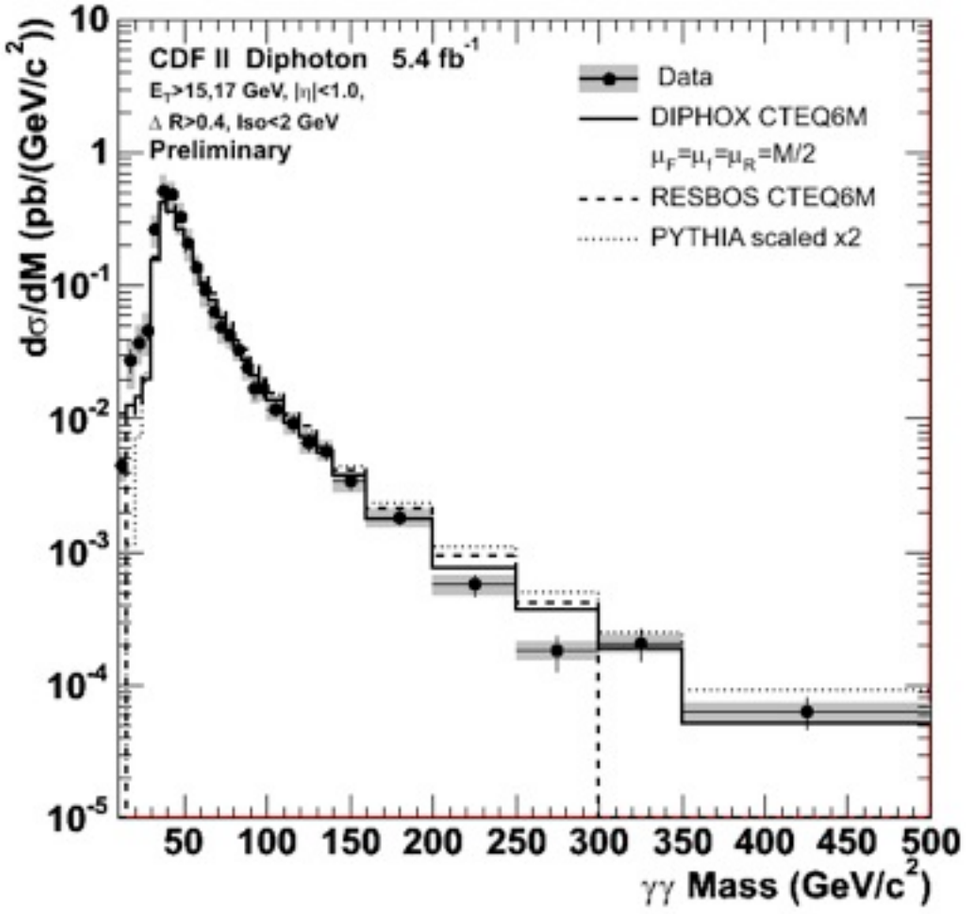


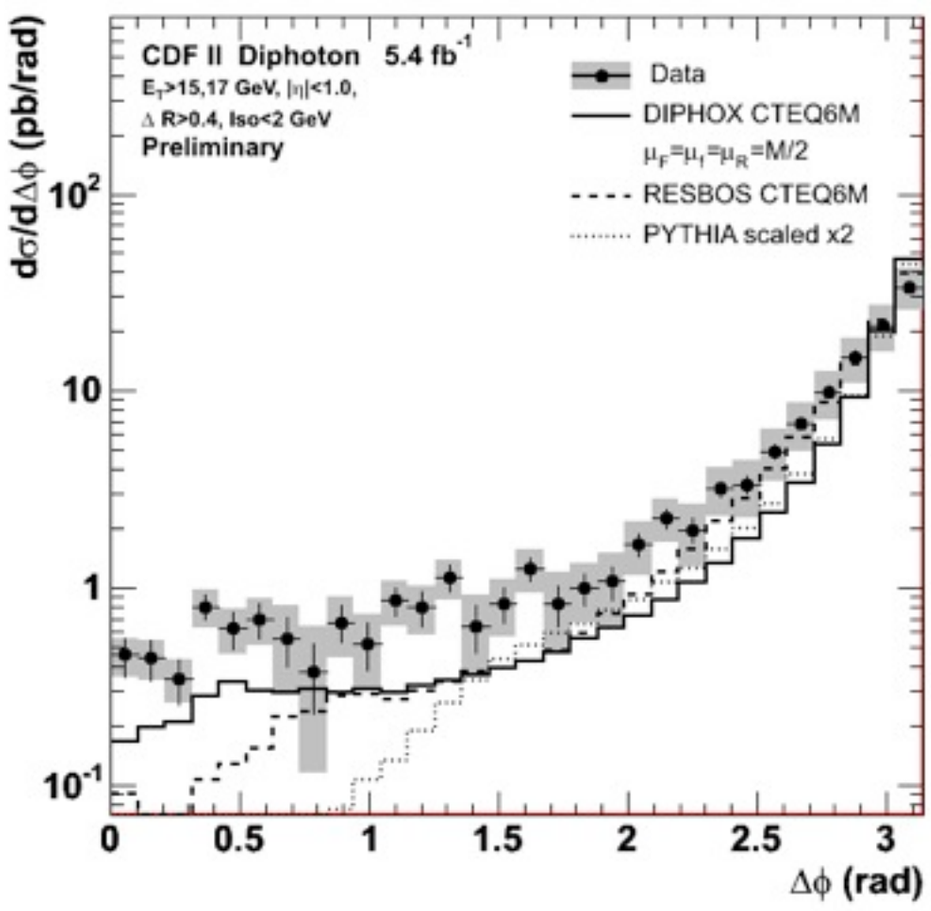
σ(W+single charm) · BR(W-->lν) = 33.7 ± 11.4(stat.) ± 7.3(syst.) pb

Diphotons

- Crucial for H→γγ
- Notoriously difficult to calculate
  - EM radiation from quarks and initial protons
  - various production mechanisms
- Selection:
  - two photons above 17, 15 GeV
  - |η|<1

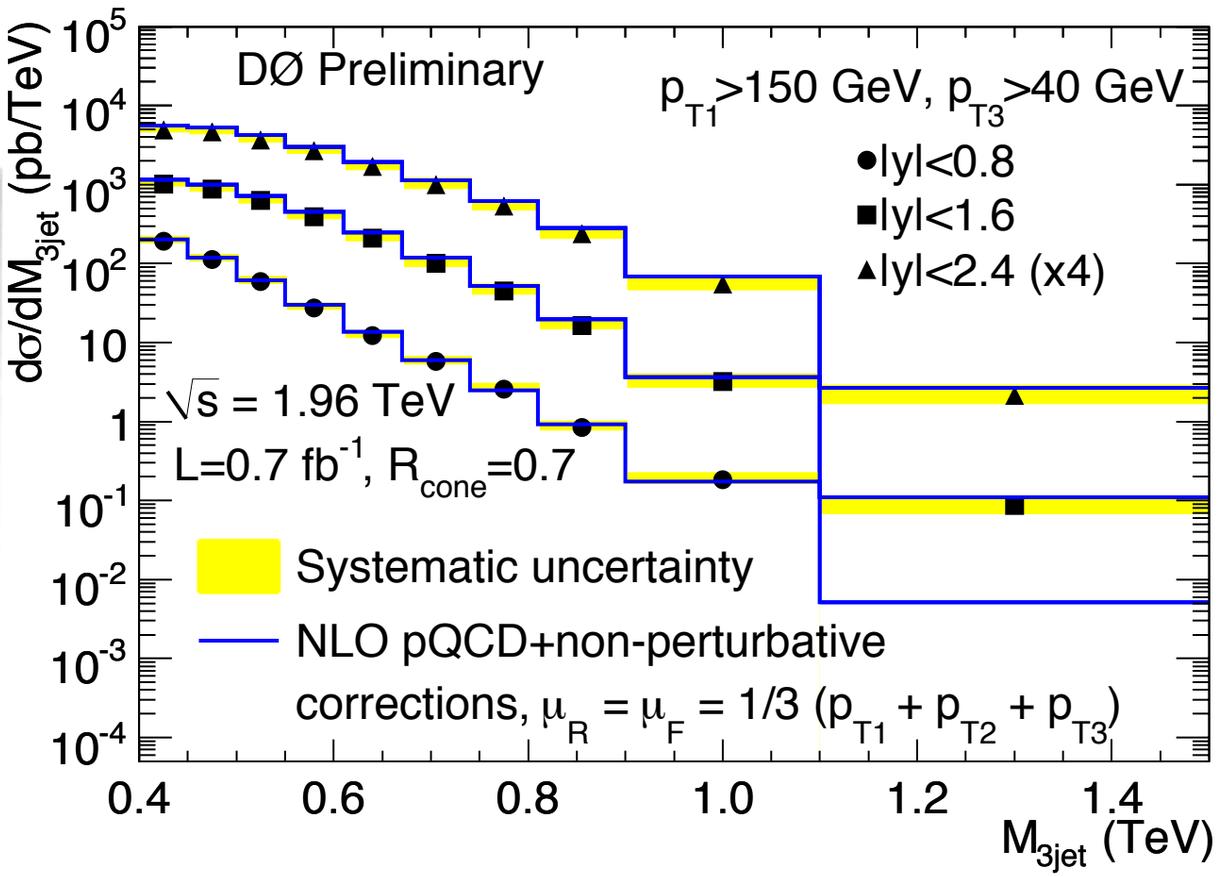


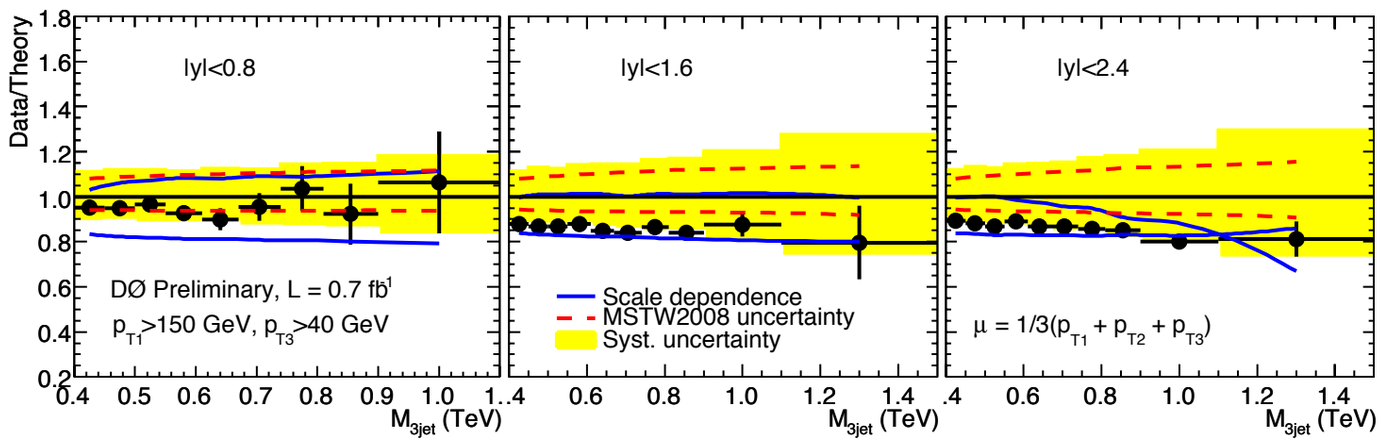




3 jets

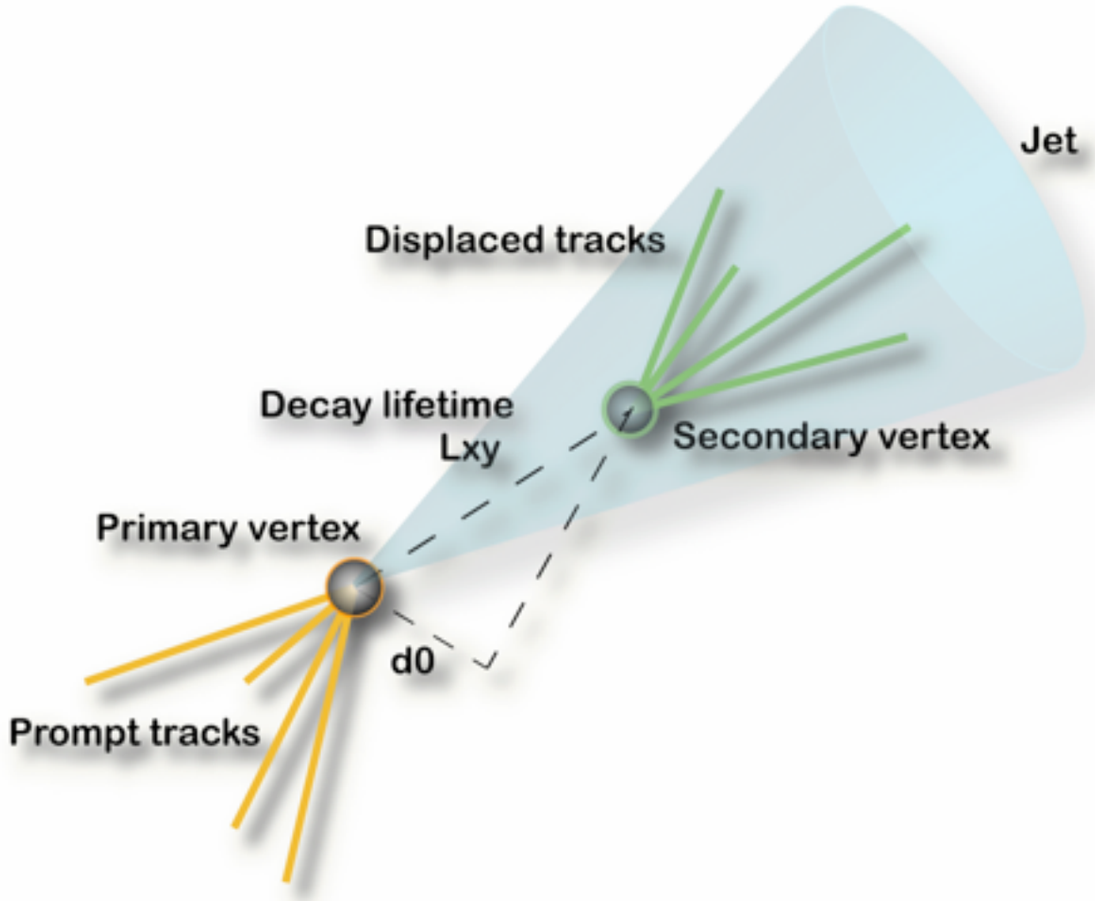
- Can be used to test NLO calculation
- Measure in three different pseudorapidity regions
  - and 3 p_T regions
- Leading p_T>150GeV
- Reasonable agreement with NLOJET++ calculations





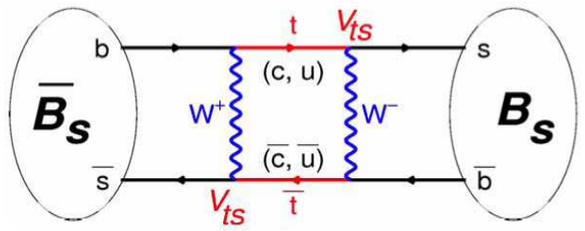
B physics

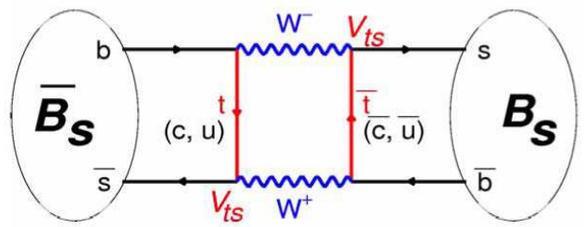
- σ (bb) at Upsilon(4s) = 1nb (B factories)
- σ (bb) at Z0 = 7nb (LEP)
- σ (bb) at 1.96TeV ppbar = 30μb
  - inelastic σ = 10^3 x σ (bb) → large background
- complementary and competitive to B factories:
  - masses
  - lifetimes
  - decay widths and BR
  - CP asymmetries
  - rare decays
- Precise tests of the SM
- Indirect evidence for NP via loops

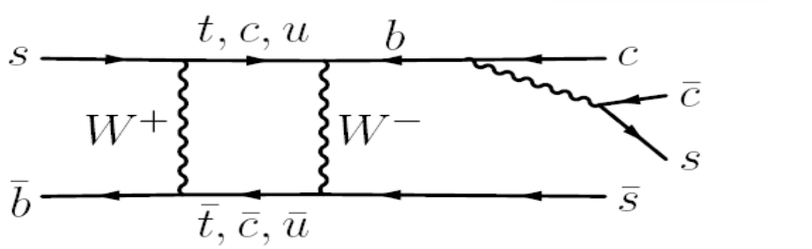


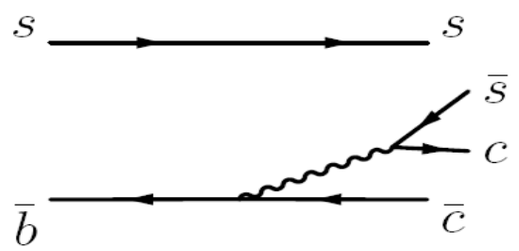
CP violation in $B_s \rightarrow J/\Psi\,\varphi$

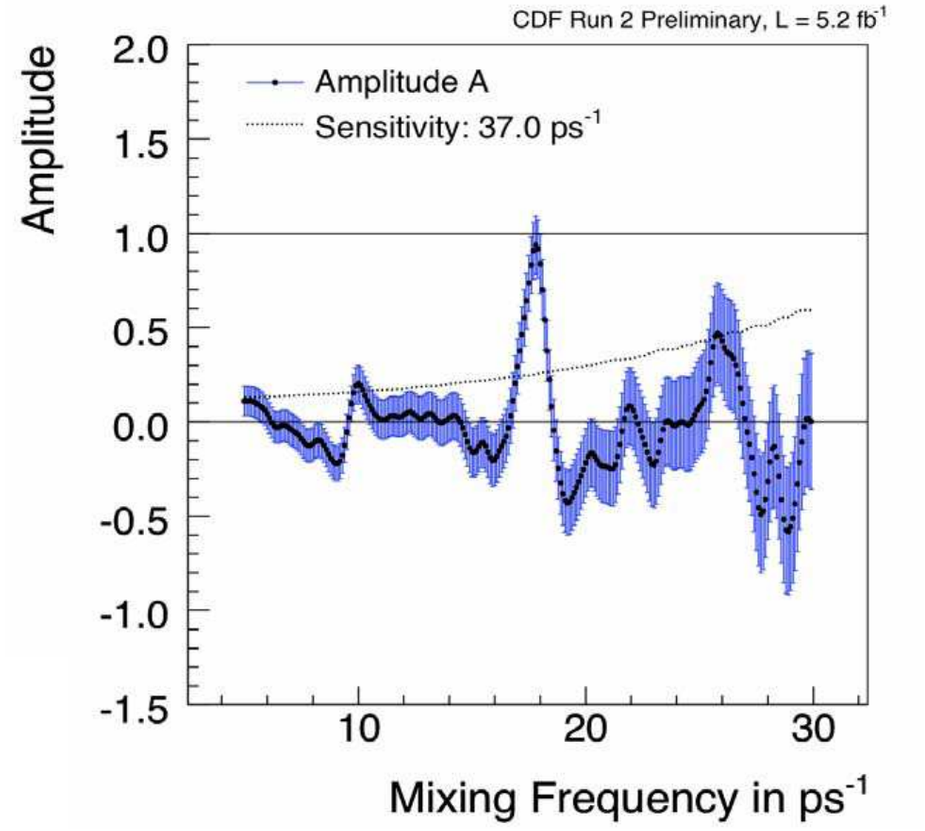
- B mesons born as flavor eigenstates and mix
- Observables are ΔM_s and $\Delta\Gamma_s$
- $B_s \rightarrow J/\Psi\,\varphi$ CP violation - interference between mixed and tree decays

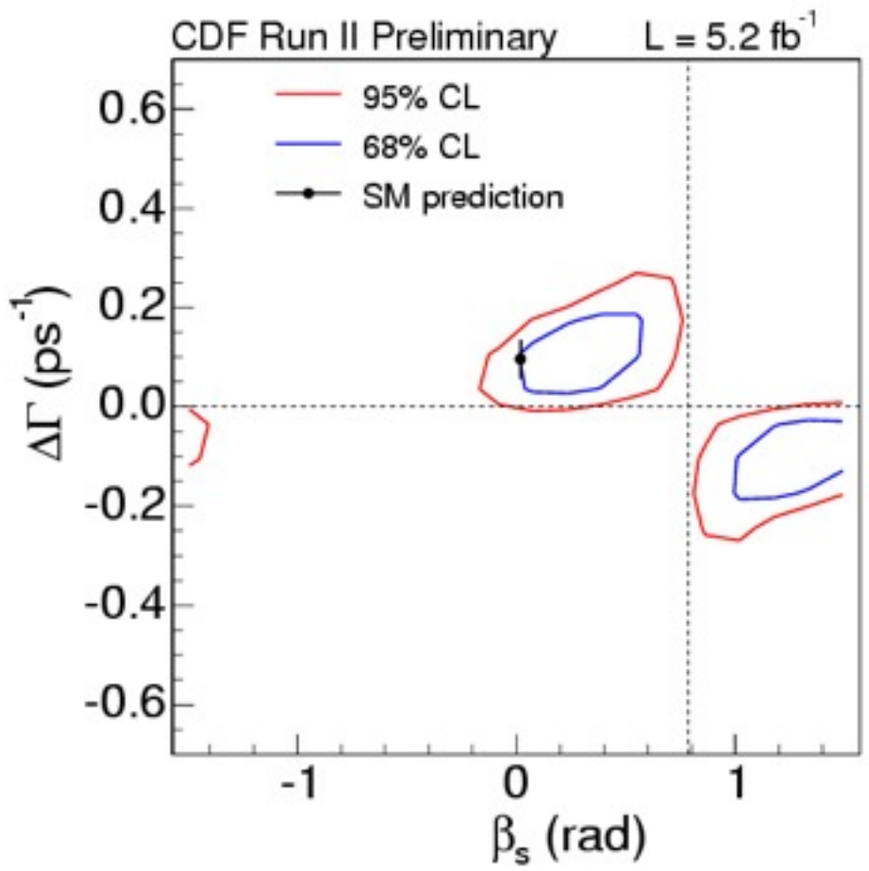






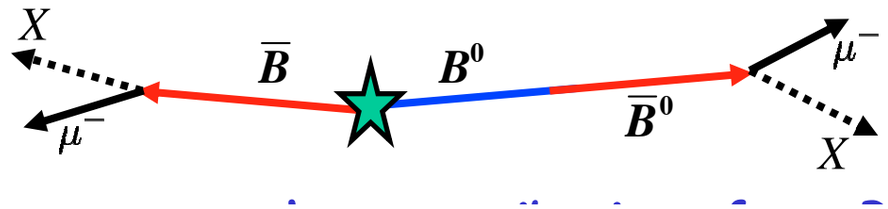






CP violation in mixing

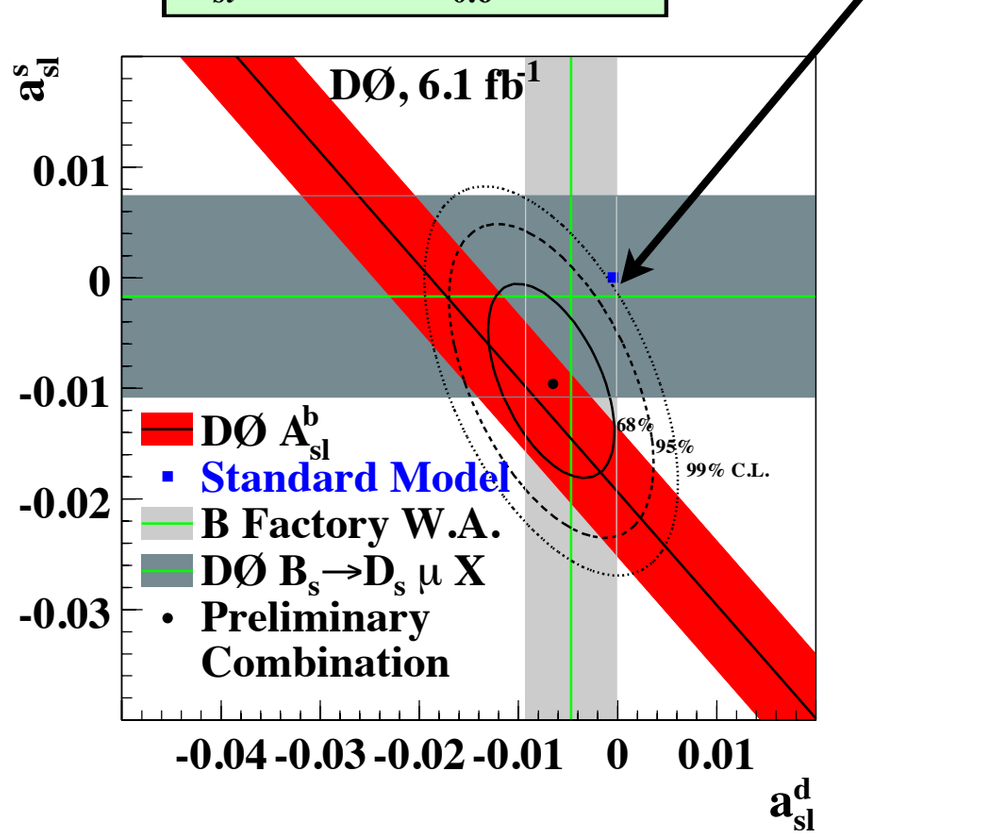
- b and bbar are produced in equal numbers - 50% will hadronizse into a neutral B (B^0 or B_s)
- 1.3% of the time both B decay to mu
- Two like sign muons from BB pair guarantees oscillations
- N(++)≠N(--) → CP violation
- 3.2σ from SM prediction



$$A_{sl}^b \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

$$A_{sl}^b = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$$

SM



$$A_{sl}^b = (-0.957 \pm 0.251\,(\text{stat}) \pm 0.146\,(\text{syst}))\%$$

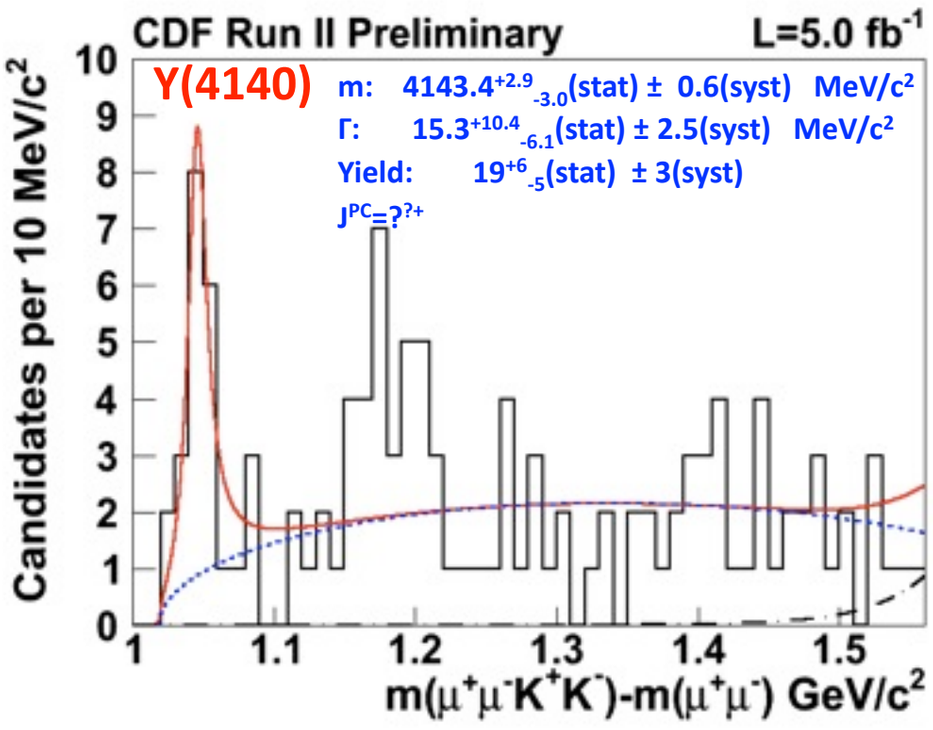
Y(4140)

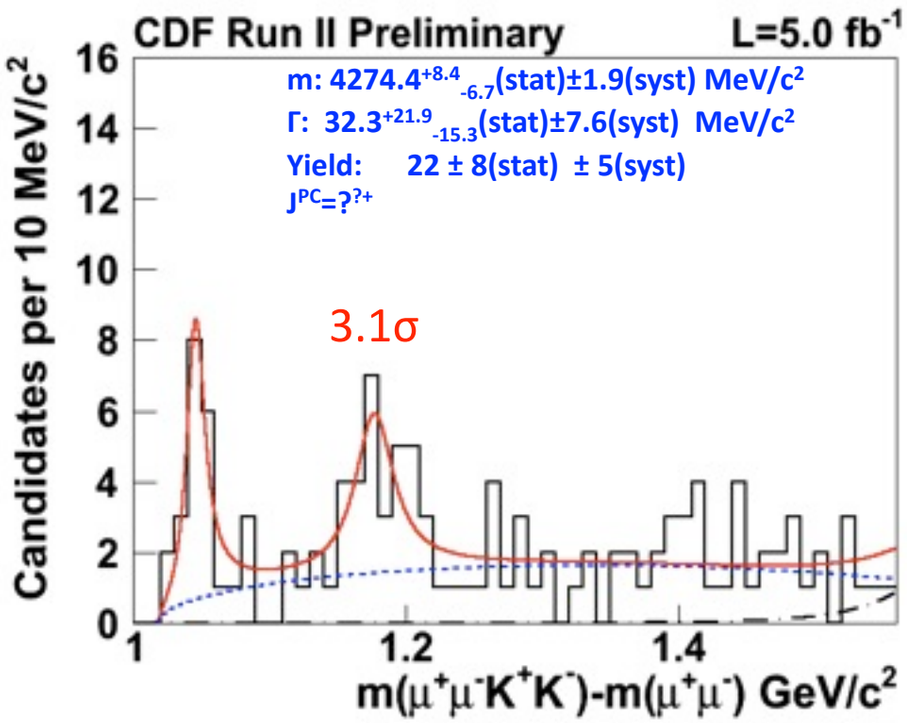
Evidence (>3.8σ) of a new structure Y(4140) was found @CDF using 2.7 fb^{-1}

$Y(4140) \rightarrow J/\psi\varphi$ through exclusive $B^+ \rightarrow Y(4140)K^+$ decay (PRL 102, 242002)

Y(4140) significance >5σ with the same cuts as before using 5.0fb^{-1} data

Suggestive evidence emerging for another structure at 4270 MeV/c^2

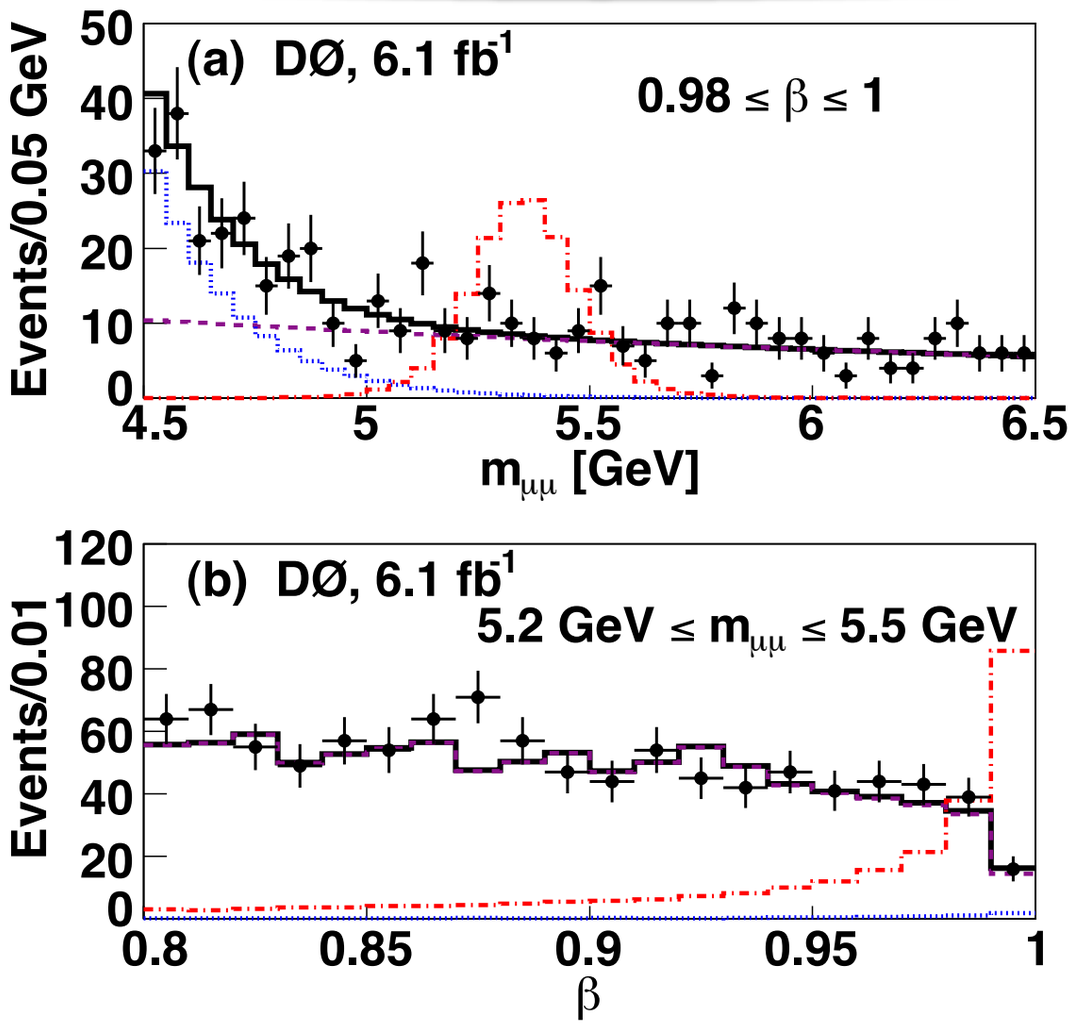


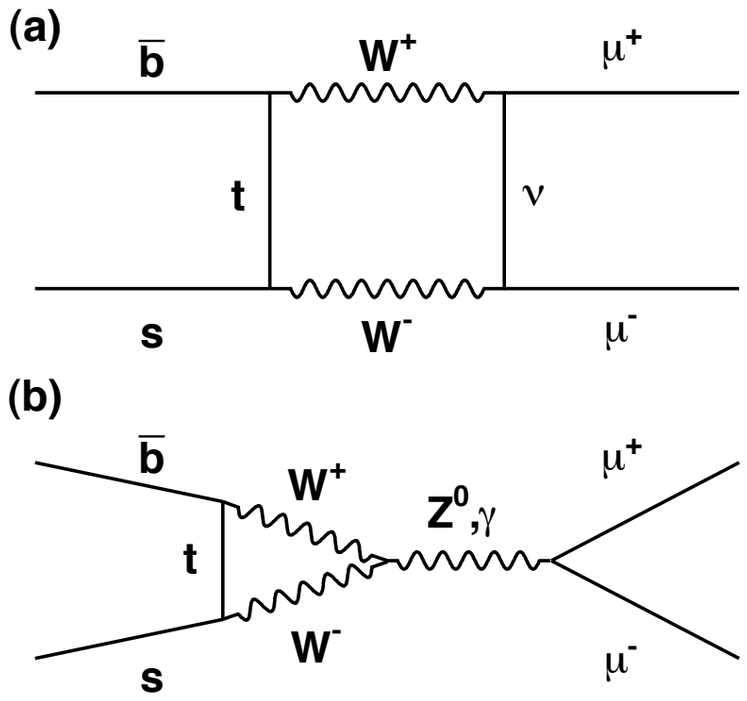


$$\frac{\mathcal{B}(B^+ \rightarrow Y(4140)K^+, Y(4140) \rightarrow J/\psi\phi)}{\mathcal{B}(B^+ \rightarrow J/\psi\phi K^+)} = 0.149 \pm 0.039(\text{stat}) \pm 0.034(\text{syst})$$

$B_s \to \mu\mu$

- $B^{SM}(B_s \to \mu\mu) = 3.6 \pm 0.3 \times 10^{-9}$
- Enhance by new physics in loops
  - tanβ in SUSY
- Separate signal from background using model of background from sidebands
  - Check with $B^+ \to J/Psi(\mu^+\mu^-)K^+$ decays





- Normalize BR to $B^+ \to J/Psi(\mu^+\mu^-)\, K^+$

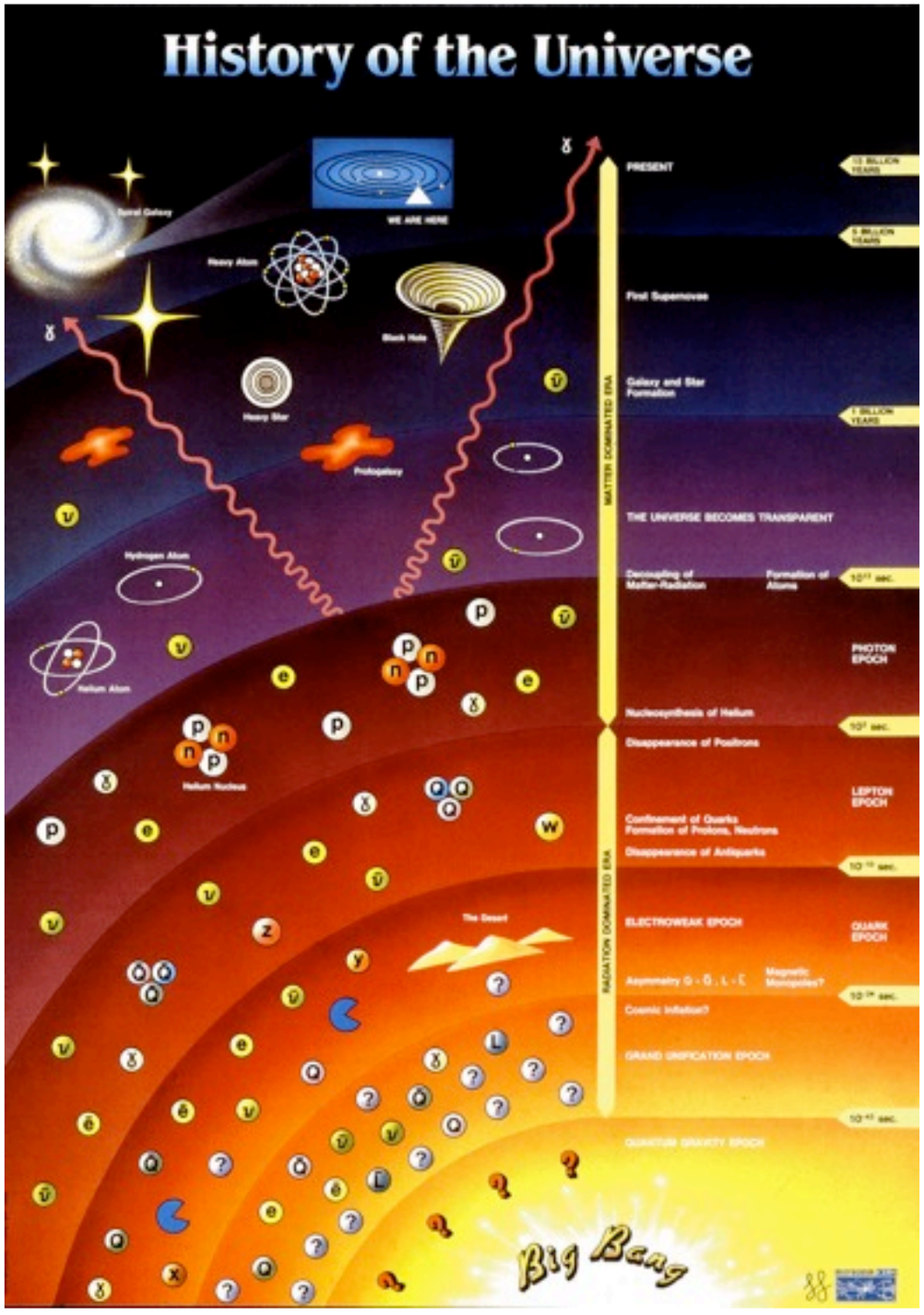
World best

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 4.0 \times 10^{-8}$$

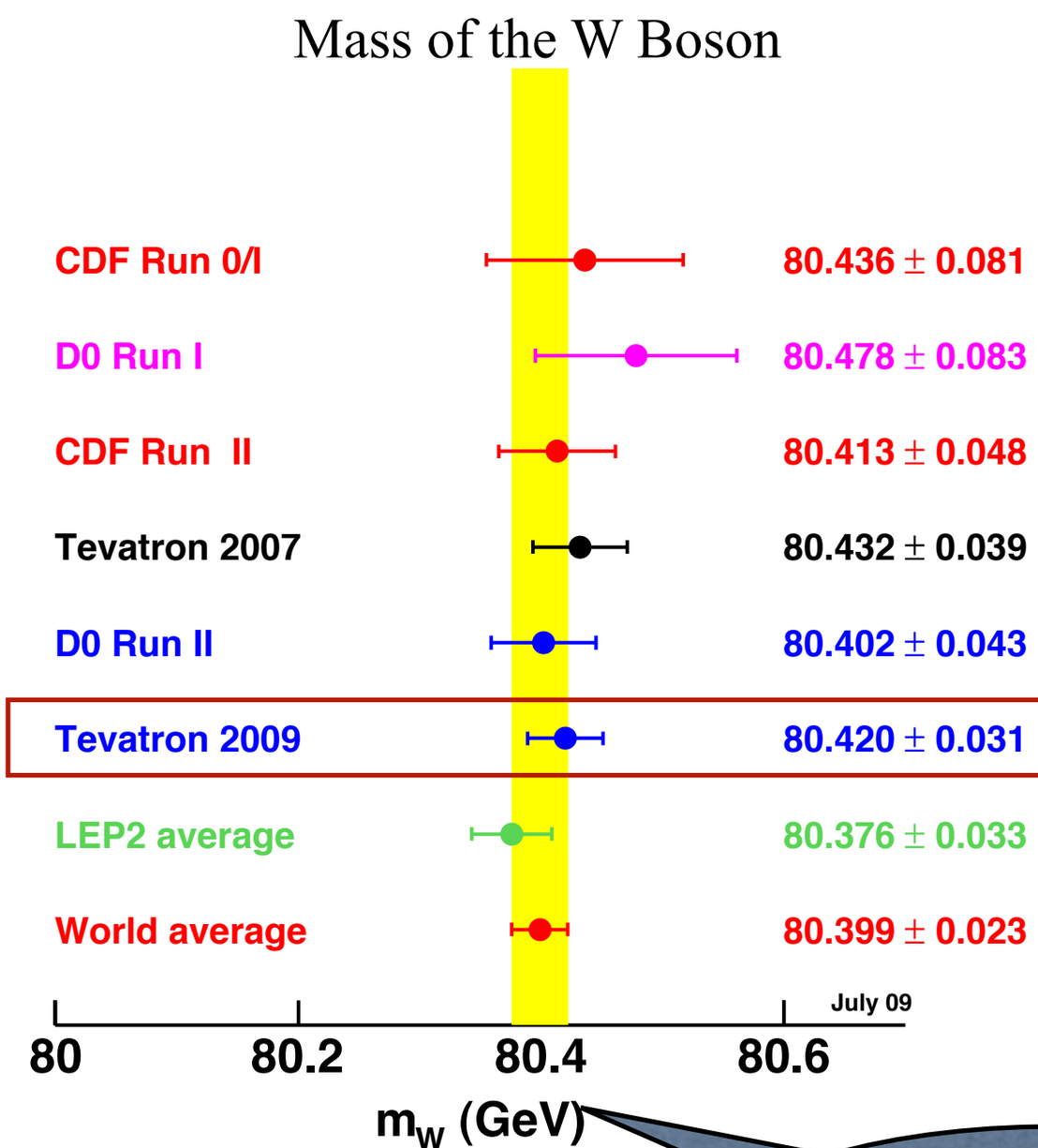
arXiv.org:1006.3469 [hep-ex]

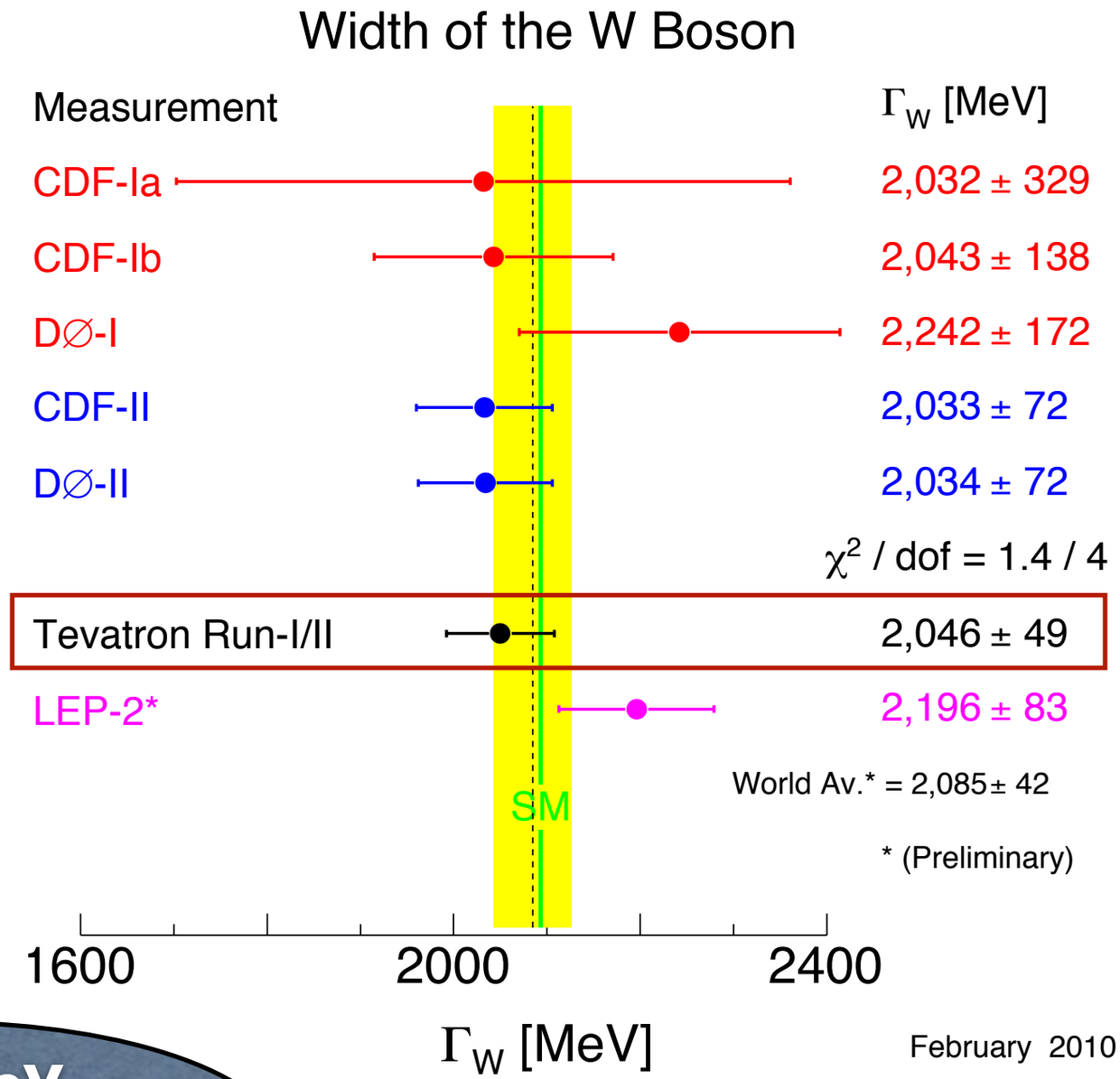
Electroweak physics

- Study the gauge sector
  - W mass and width
  - W and Z cross section
  - dibosons (VV)
  - rare decays



W Mass and Width

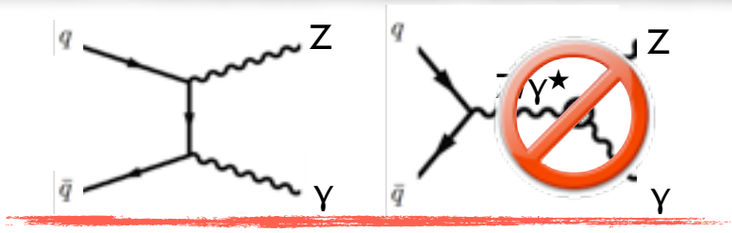




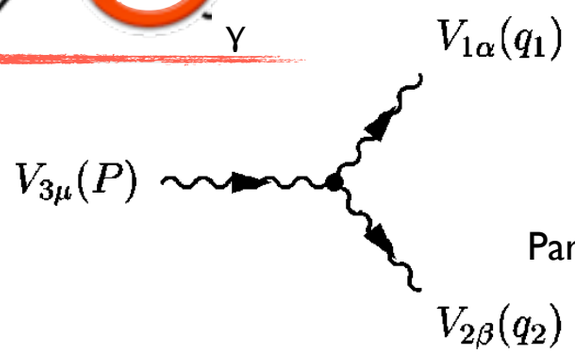
New TeV combination coming soon

Anomalous Triple Gauge Couplings

- Two leptons and a high E_T photon
- FSR/ISR only
  - New physics can contribute
  - H→Zγ
- Add MET channel
  - Z→νν+photon
  - MET+photon final state
  - MET = Missing Momentum in the Transverse Plane
- TGC in high E_T photons



- CP: h_1, h_2
- CP: h_3, h_4

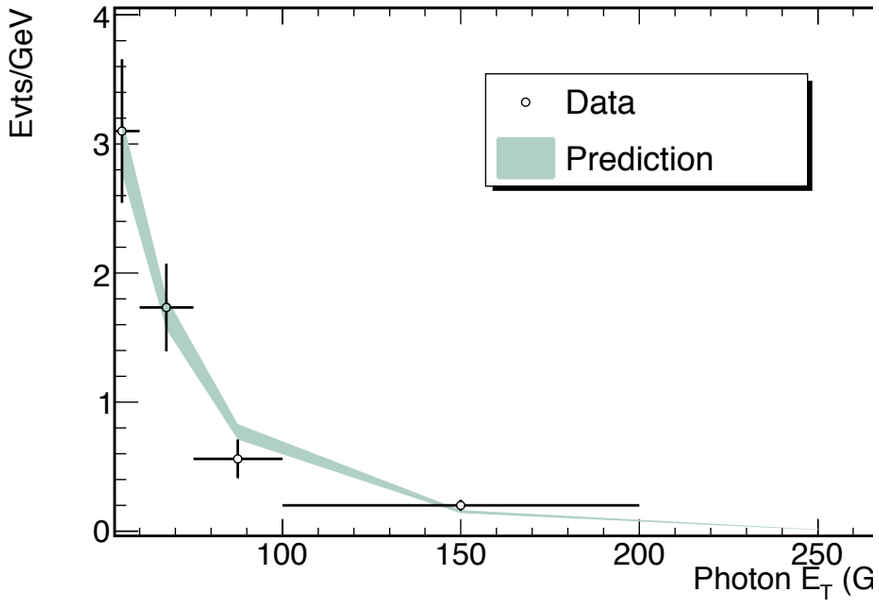


$$= ie\,\Gamma^{\alpha,\beta,\mu}_{V_1V_2V_3}(q_1,q_2,P)$$

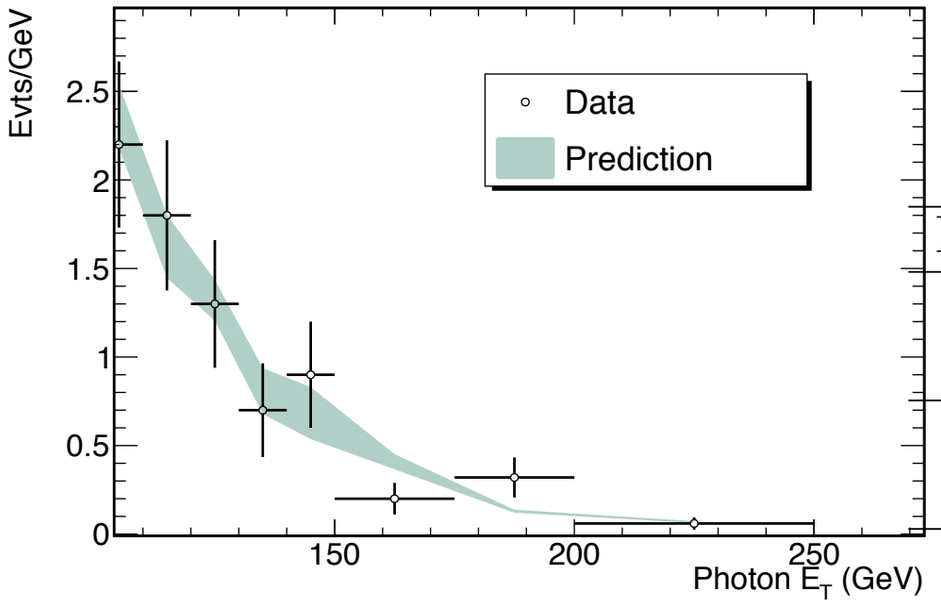
Parameterization from Gounaris et al PRD 62 073012

Experiment Luminosity(fb^{-1})	LEP II 0.7	D0 1.1	CDF (+MET) 1.5	D0(+MET) 3.6
h_3^Z	-0.20, 0.07	-0.083, 0.082	-0.05, 0.05	-0.033, 0.033
h_4^Z	-0.05, 0.12	-0.005, 0.005	-0.0034, 0.0034	-0.0017, 0.0017
h_3^γ	-0.049, 0.008	-0.085, 0.084	-0.051,0.051	-0.033, 0.033
h_4^γ	-0.02, 0.034	-0.005, 0.005	-0.0034, 0.0034	-0.0017, 0.0017

CDF Run II Preliminary (5.1 fb^{-1})



CDF Run II Preliminary (4.9 fb^{-1})

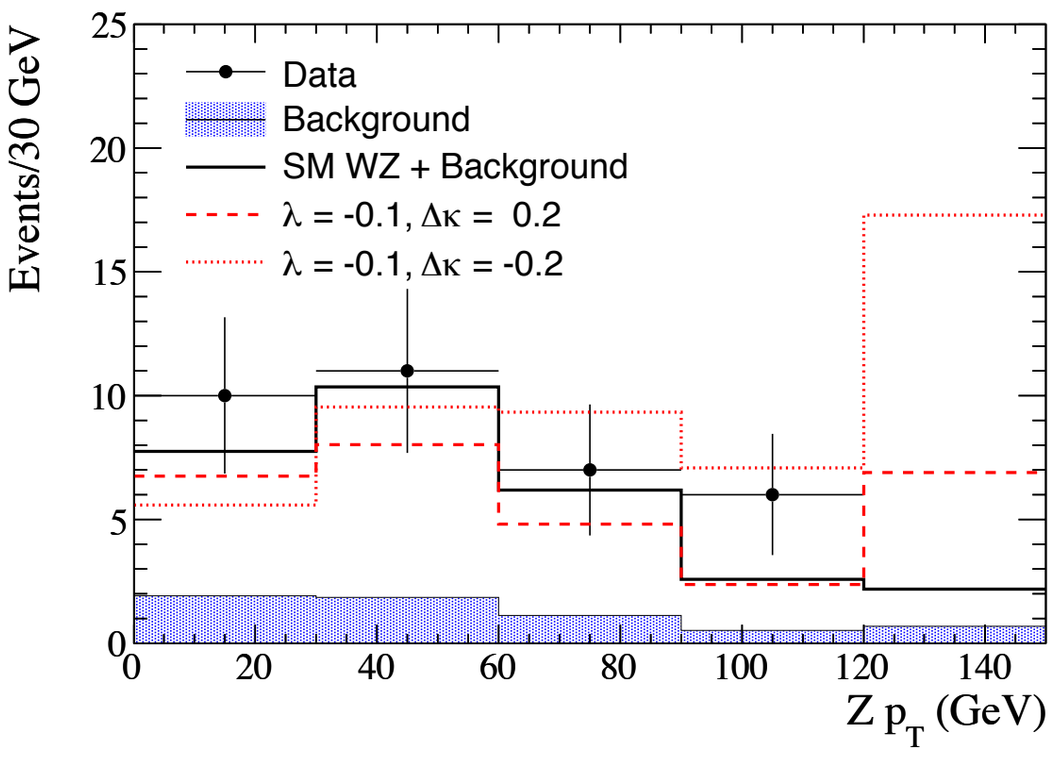


Parameter	Measured Limit in D
h_3^γ	(-0.021, 0.020)
h_4^γ	(-0.0007, 0.0007)
h_3^Z	(-0.020, 0.020)
h_4^Z	(-0.0008, 0.0007)

Anomalous Triple Gauge Couplings

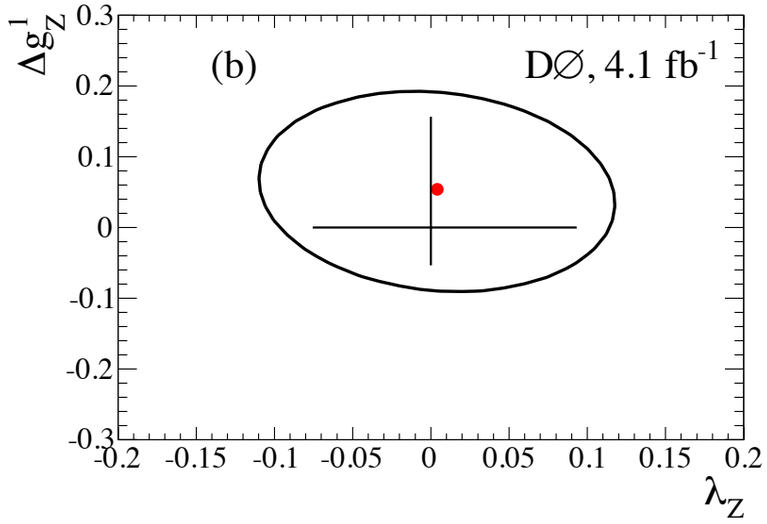
- **WZ selection**
  - **3 leptons and MET**
- **$\sigma = 3.9^{+1.06}_{-0.90}$ pb (SM=3.45)**

Source	eee	$ee\mu$	$e\mu\mu$	$\mu\mu\mu$
ZZ	0.39 ± 0.07	1.48 ± 0.20	0.40 ± 0.07	1.26 ± 0.23
V+jets	0.63 ± 0.17	0.56 ± 0.24	0.03 ± 0.01	0.17 ± 0.05
$Z\gamma$	0.28 ± 0.08	< 0.001	0.66 ± 0.34	< 0.001
$t\bar{t}$	0.03 ± 0.01	0.05 ± 0.01	0.04 ± 0.01	0.03 ± 0.01
Total bkg.	1.33 ± 0.21	2.11 ± 0.31	1.13 ± 0.35	1.46 ± 0.24
WZ signal	5.9 ± 0.8	6.9 ± 0.8	4.7 ± 0.6	5.8 ± 0.8
Observed	9	11	9	5



Parameterization from Hagiwara et al
PRD 48 2182

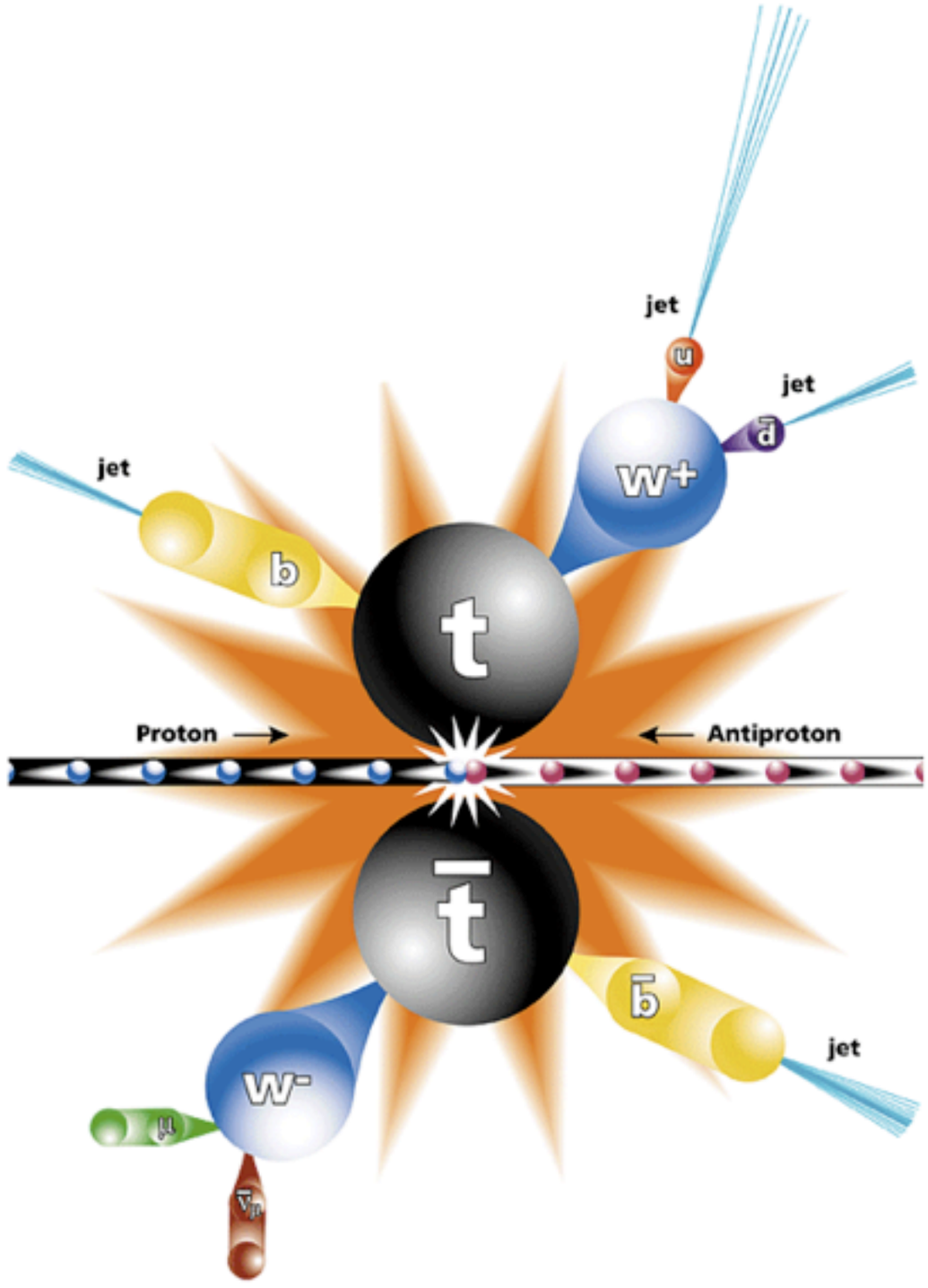
$$\frac{\mathcal{L}_{WWV}}{g_{WWV}} = ig_1^V (W^\dagger_{\mu\nu} W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + i\kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{i\lambda_V}{M_W^2} W^\dagger_{\lambda\mu} W^\mu{}_\nu V^{\nu\lambda}$$



arXiv.org:1006.0671 [hep-ex]

Top quark

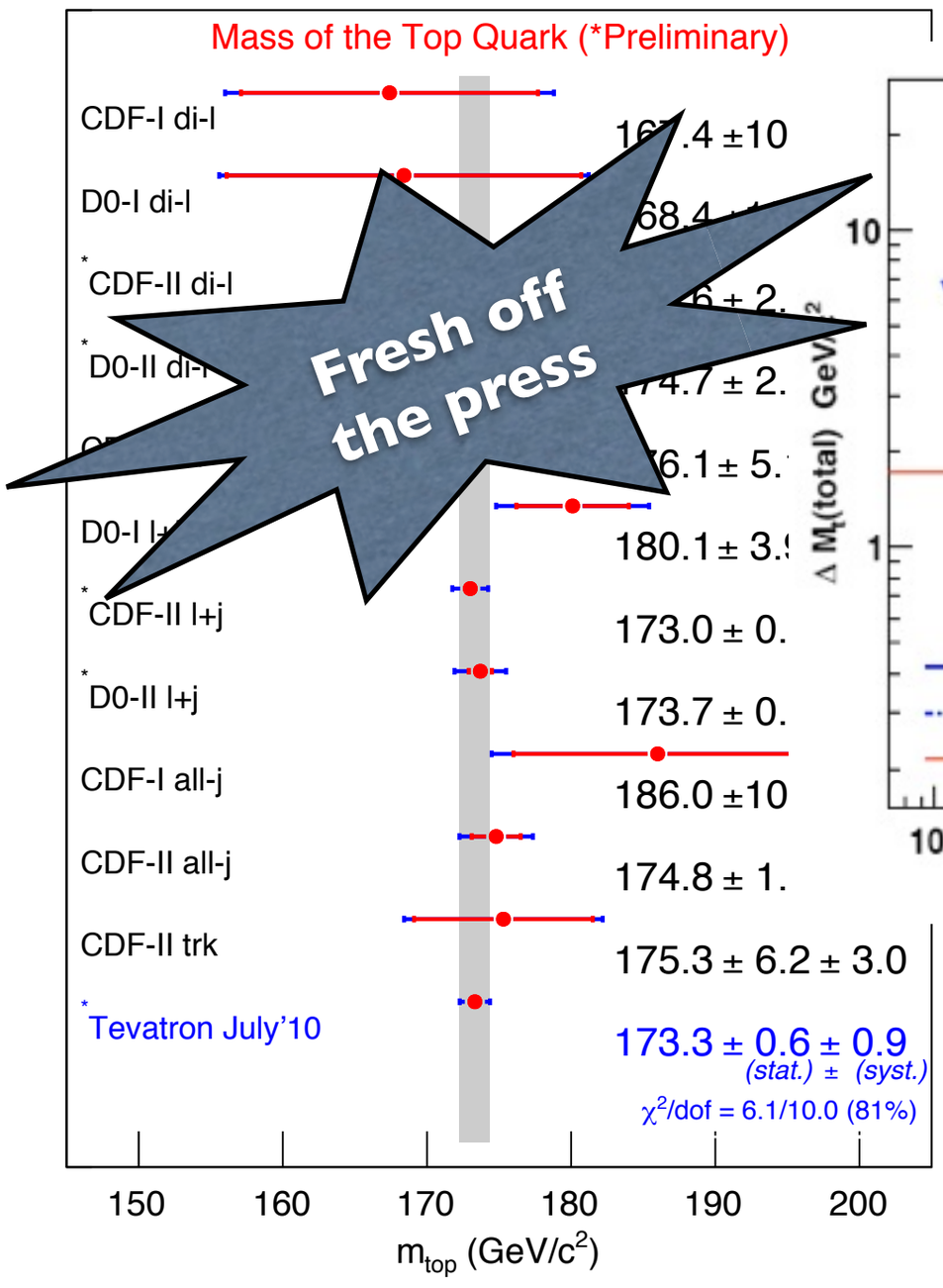
- Long history at the Tevatron since its discovery
- Heaviest particle in the SM
  - dominant contribution in quantum loops
  - might hold some key to the origin of mass question
  - might couple to new physics more strongly
- Attack top from all possible angles
  - mass, cross section
  - single top production
  - properties: lifetime, spin, helicity, asymmetries

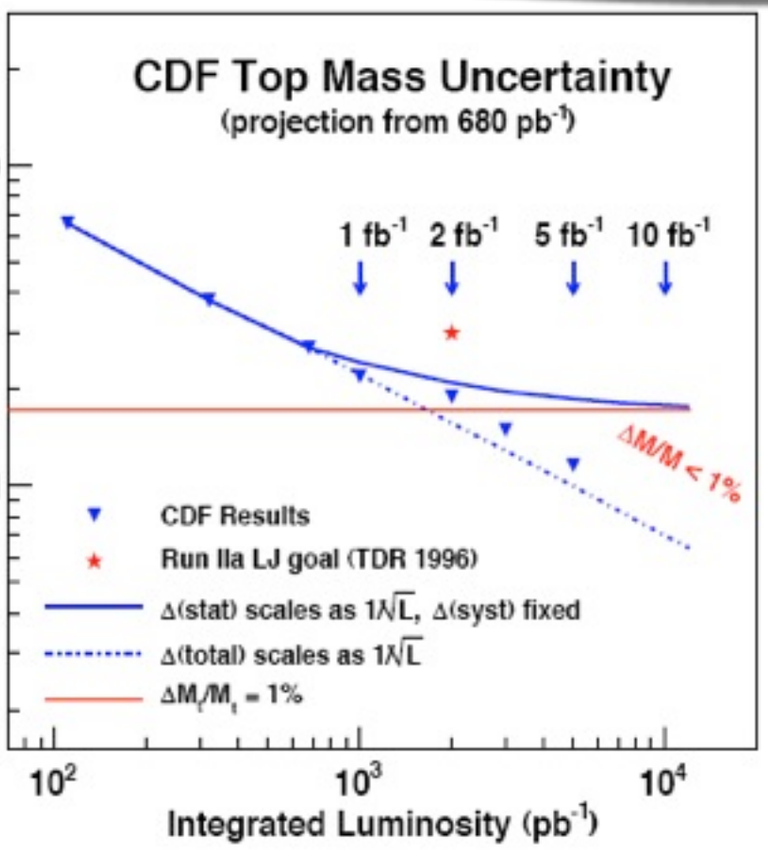


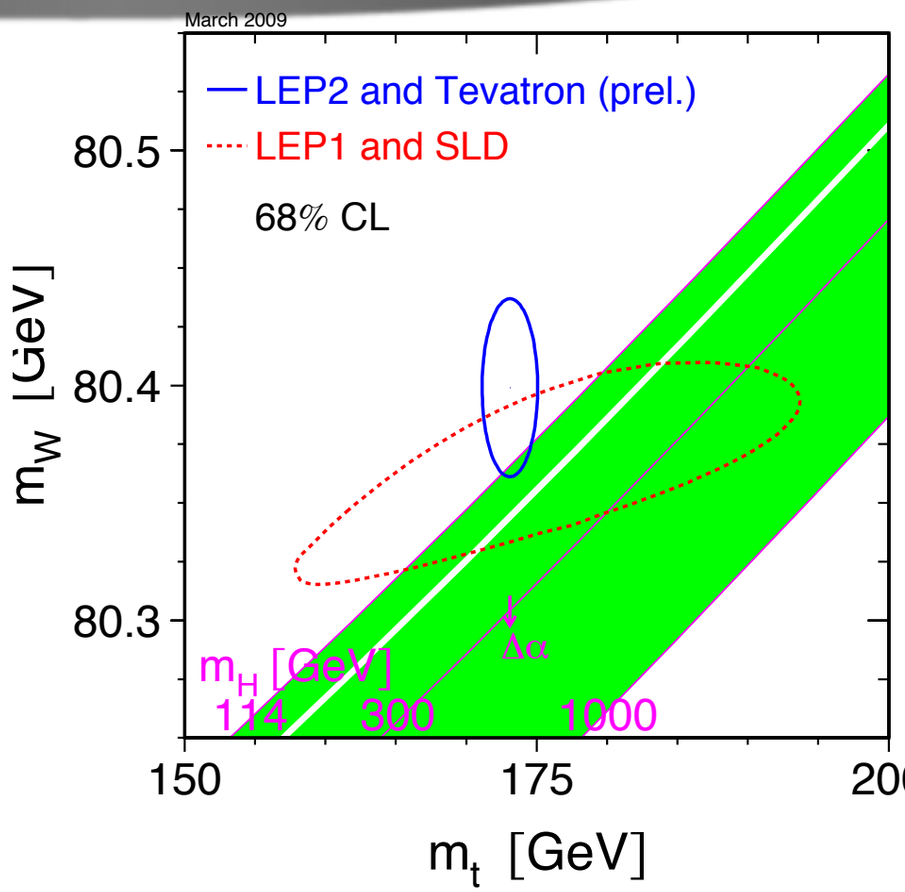
Top Mass

$m_t = 173.3 \pm 1.1\ \mathrm{GeV}/c^2$

0.6% precision





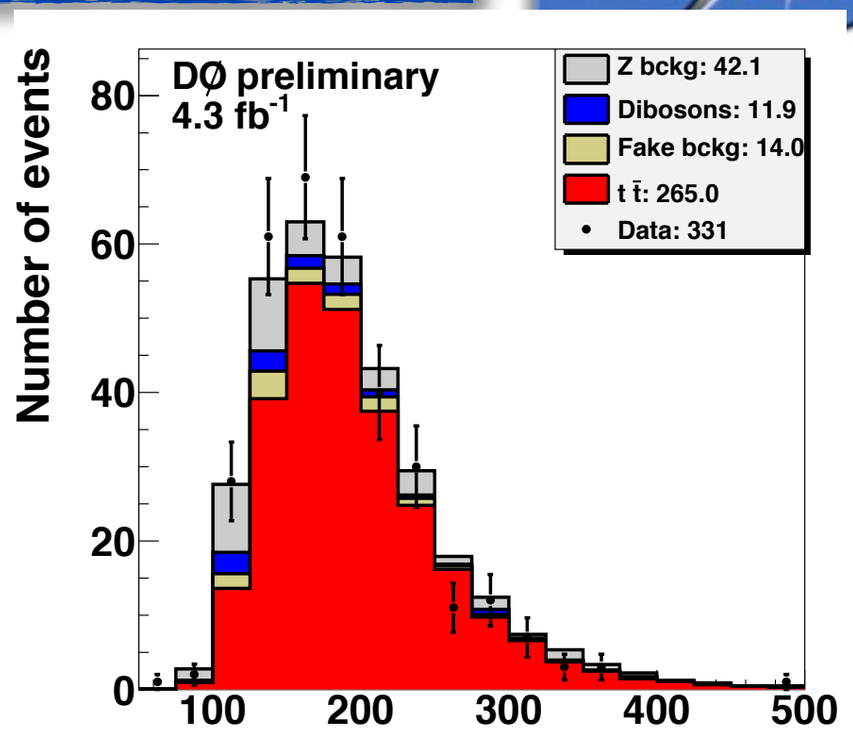


- Approaching <1GeV uncertainty
- Way better than simple $\sqrt{L}$
- Entering precision era

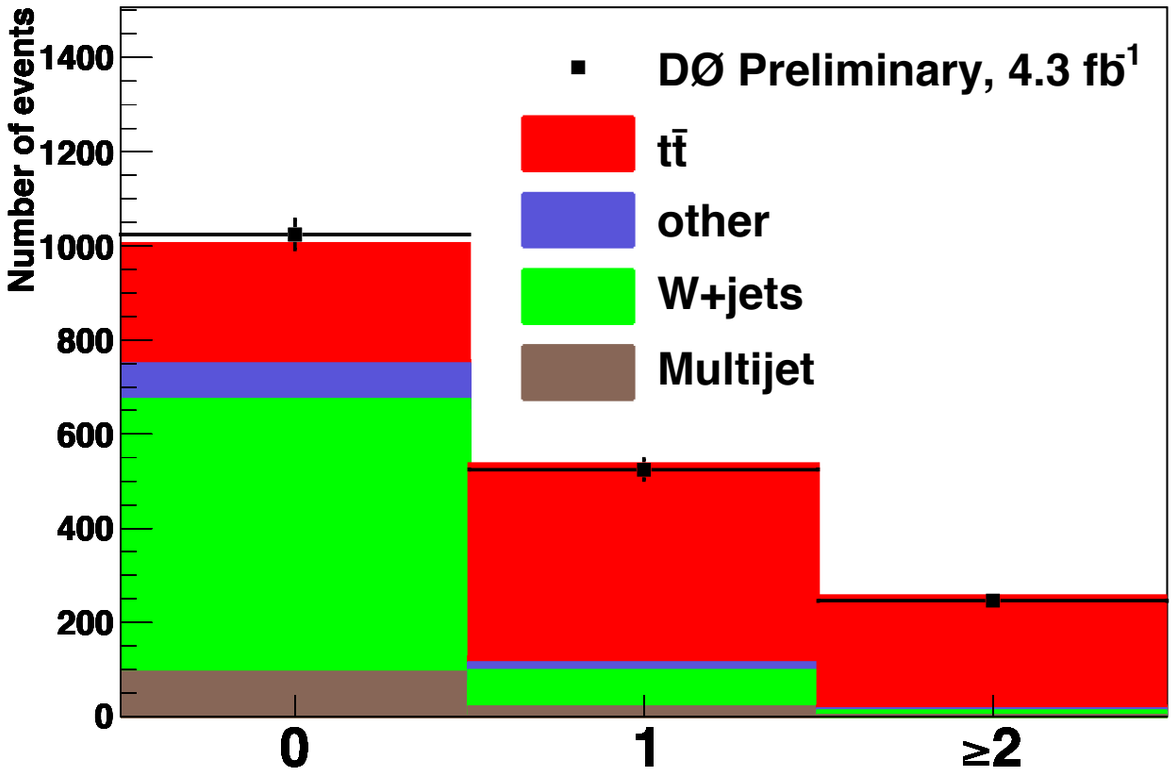
$t\bar{t}$ cross section

$\sigma_{NLO} = 7.46^{+0.48}_{-0.67}$ pb

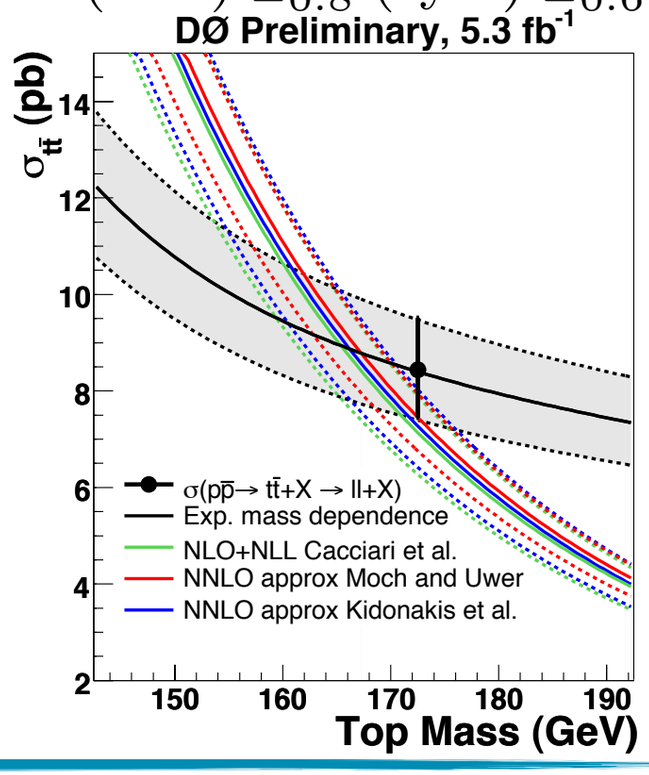
- All channels:
  - lepton+jets
  - dileptons
  - all hadronic
- With and without b-tagging



$\sigma_{t\bar{t}} = 7.93^{+1.04}_{-0.91}$ (stat + syst + lumi) pb



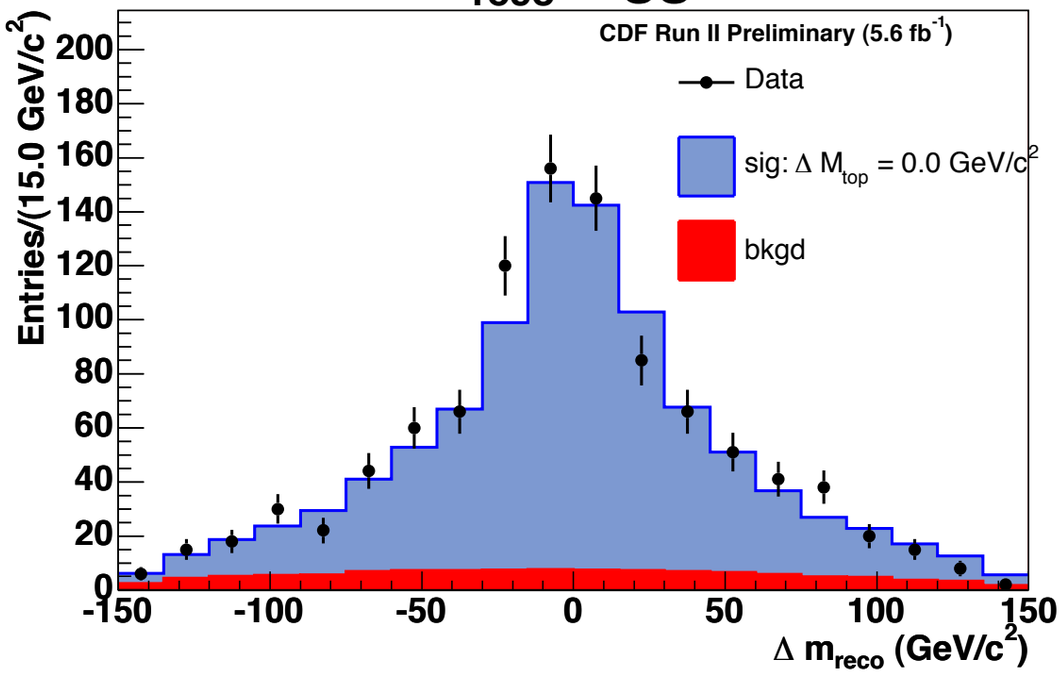
$\sigma_{t\bar{t}} = 8.4 \pm 0.5$ (stat) $^{+0.9}_{-0.8}$ (syst) $^{+0.7}_{-0.6}$ (lumi)



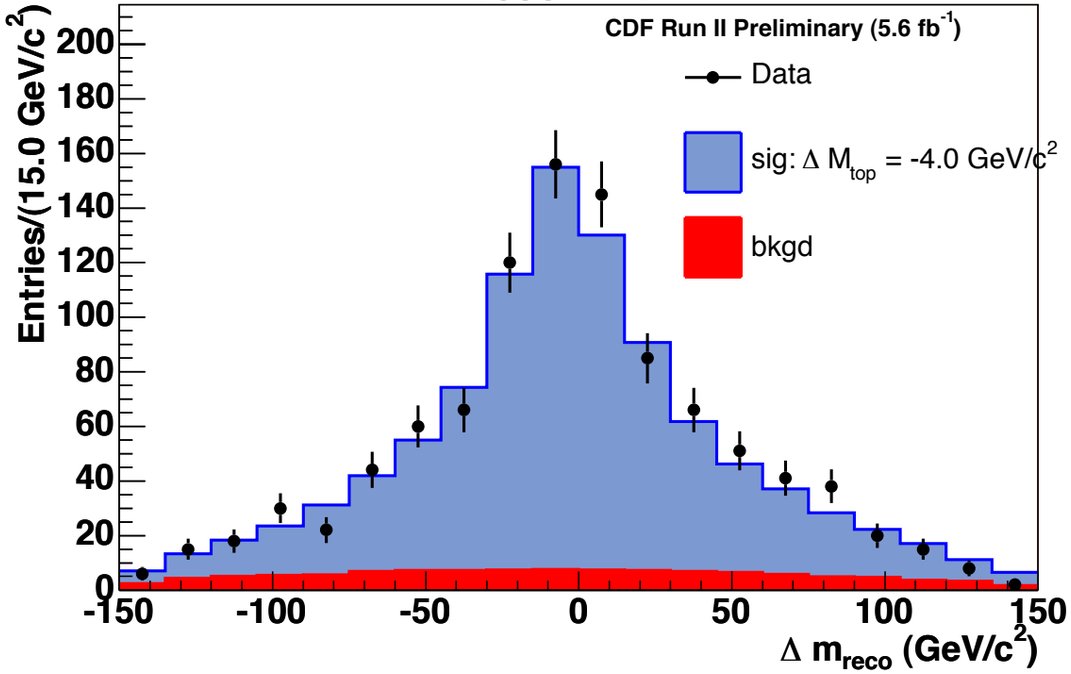
Top-Antitop mass difference

- Test of CPT
- 5.6fb^{-1} ~ 2300 reconstructed top events (lepton+jets)
  - Perfect example of utilizing existing machinery with large datasets
  - Introduce $\Delta M_{reco} = M_{top} - M_{antitop}$ in the fit
- $\Delta M_{top} = -3.3 \pm 1.7$ GeV/c^2

Δm_{reco} tagged

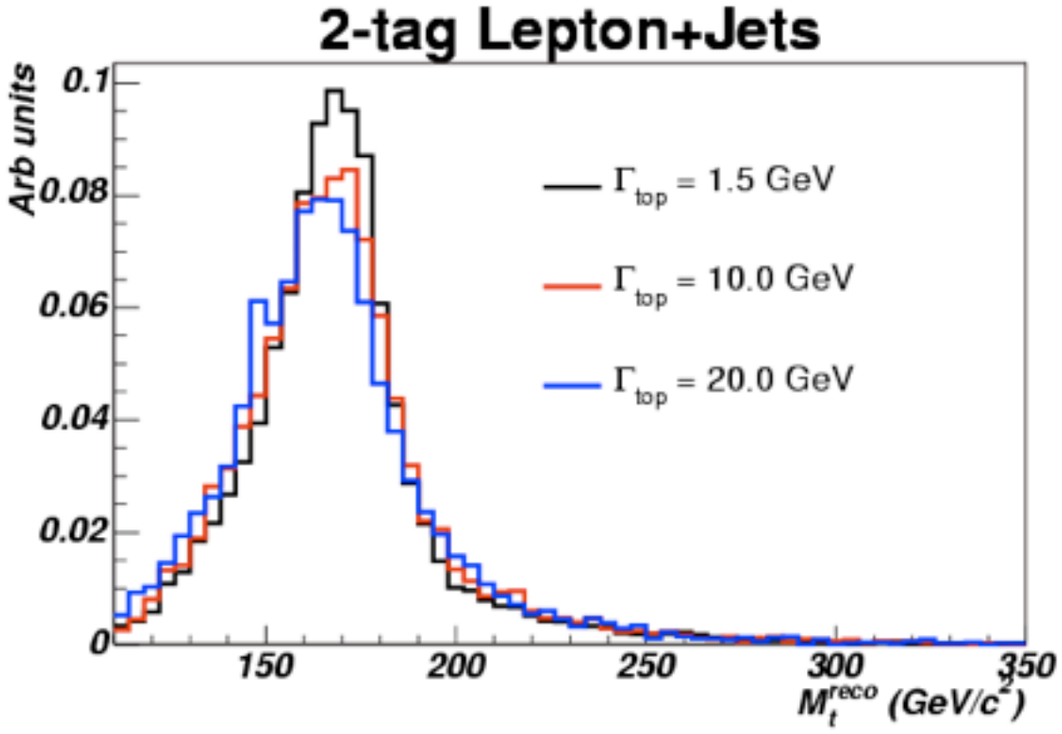


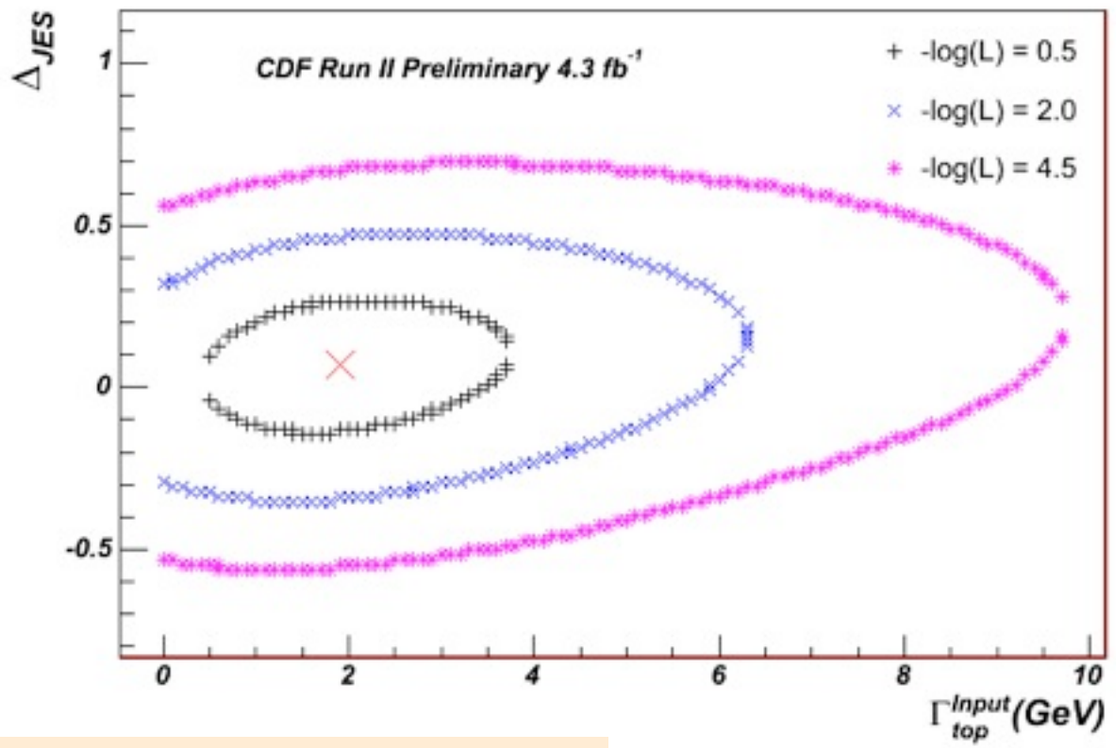
Δm_{reco} tagged



Top Width

- Γ^{SM}=1.5GeV → τ_{top} = 5×10^{-25}s





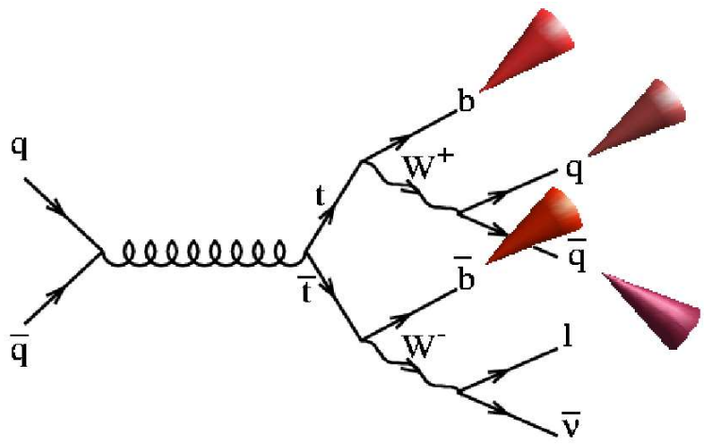
- Same fitting machinery
- Introduce Γ_{top} as extra parameter in the fit
- Study the M^{reco} vs Γ_{top}

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

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

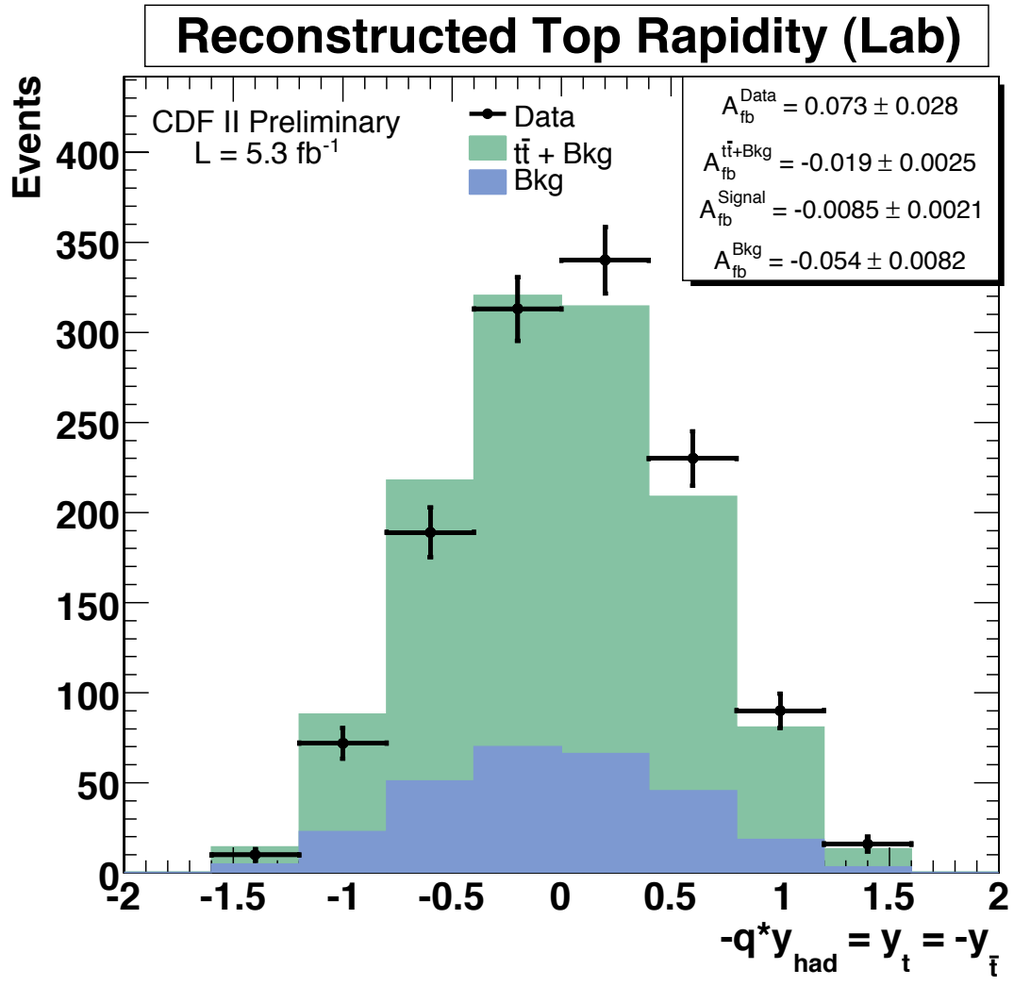
A_{fb} in $t\bar{t}$

- **Semileptonic decays**



- **Assume CP - measure the asymmetry in $-Q \times y_{had}$**

$$A_{fb} = \frac{N(-Q \cdot y_{had} > 0) - N(-Q \cdot y_{had} < 0)}{N(-Q \cdot y_{had} > 0) + N(-Q \cdot y_{had} < 0)}$$



unfolded to parton level

A_{lab}: $A_{FB} = 0.150 \pm 0.050_{stat} \pm 0.024_{syst}$

A_{ttbar}: $A_{FB} = 0.158 \pm 0.072_{stat} \pm 0.017_{syst}$

Study rapidity dependence using A_{ttbar}

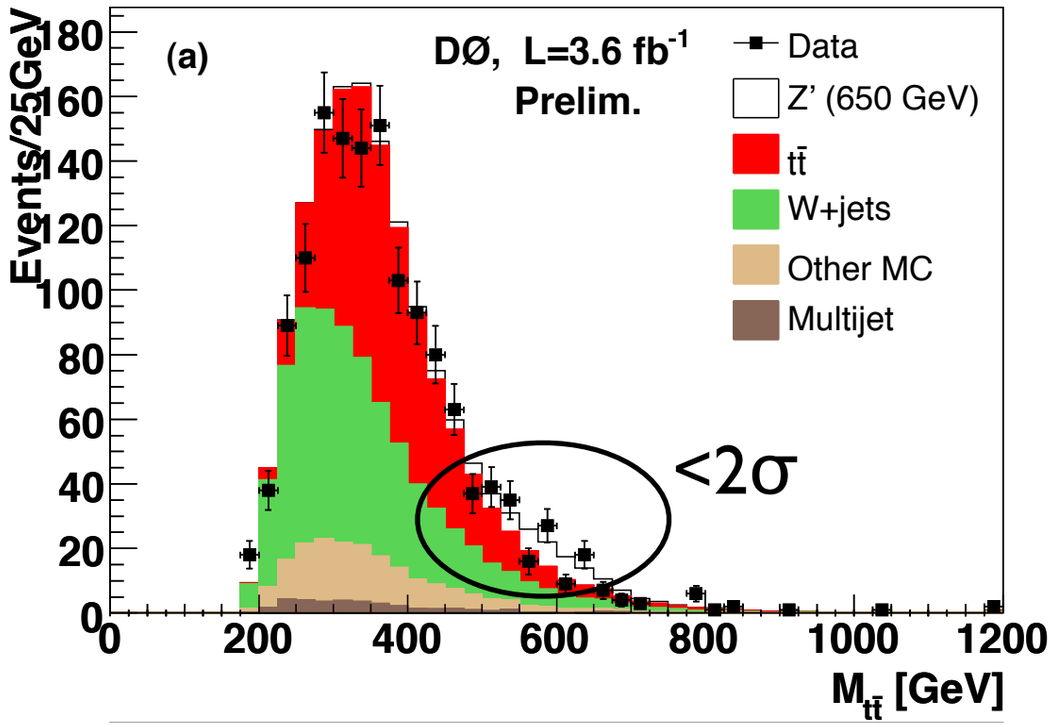
$\Delta y<1.0$: $A_{FB} = 0.026 \pm 0.104_{stat} \pm 0.055_{syst}$

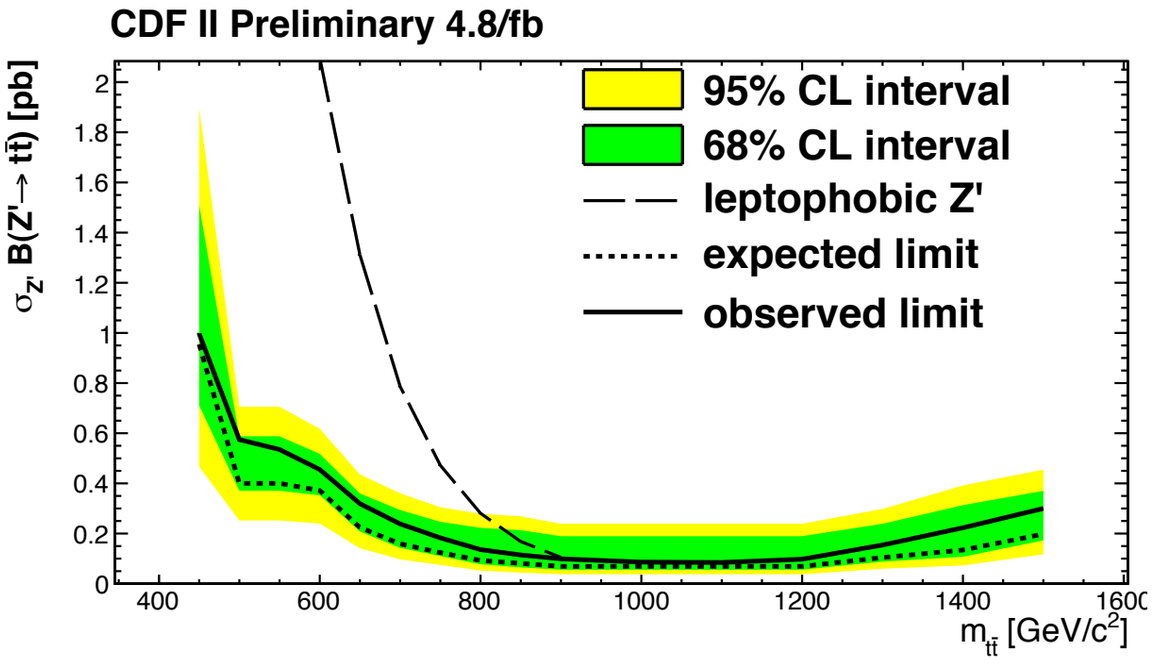
$\Delta y>1.0$: $A_{FB} = 0.611 \pm 0.210_{stat} \pm 0.141_{syst}$

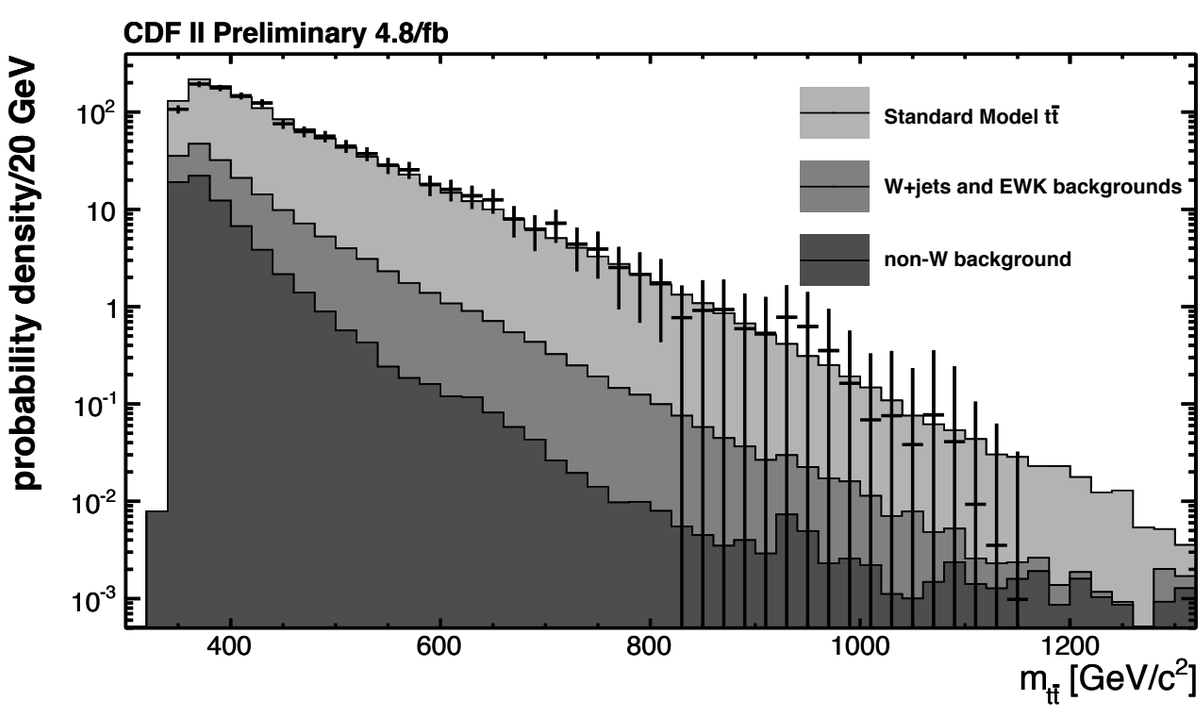
MCFM : 0.039 ± 0.006 (<1), 0.123 ± 0.018 (>1)

Resonant $t\bar{t}$

- A classic interplay between the two experiments
- typical ttbar selection
  - lepton+MET+jets (b tagged)
  - signal and background separated based on ME calculation
- Z` → ttbar

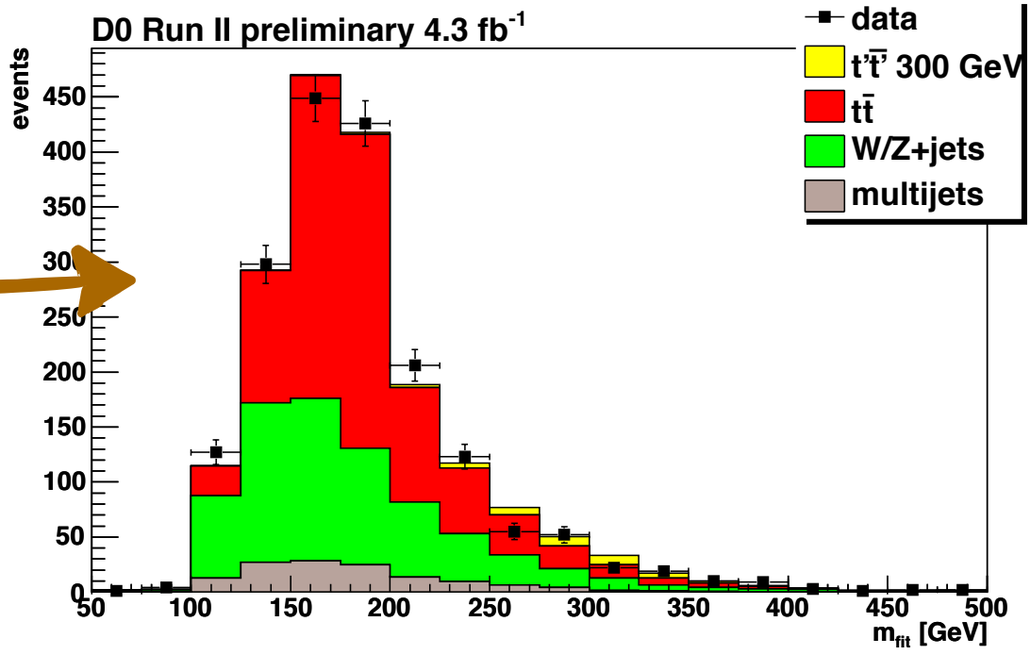


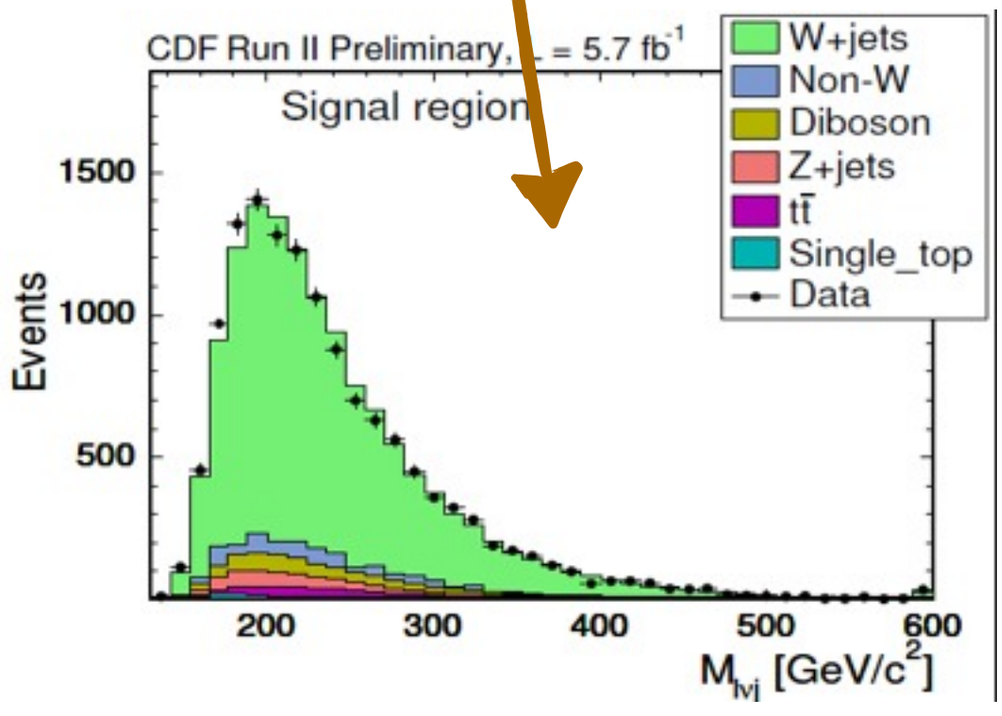


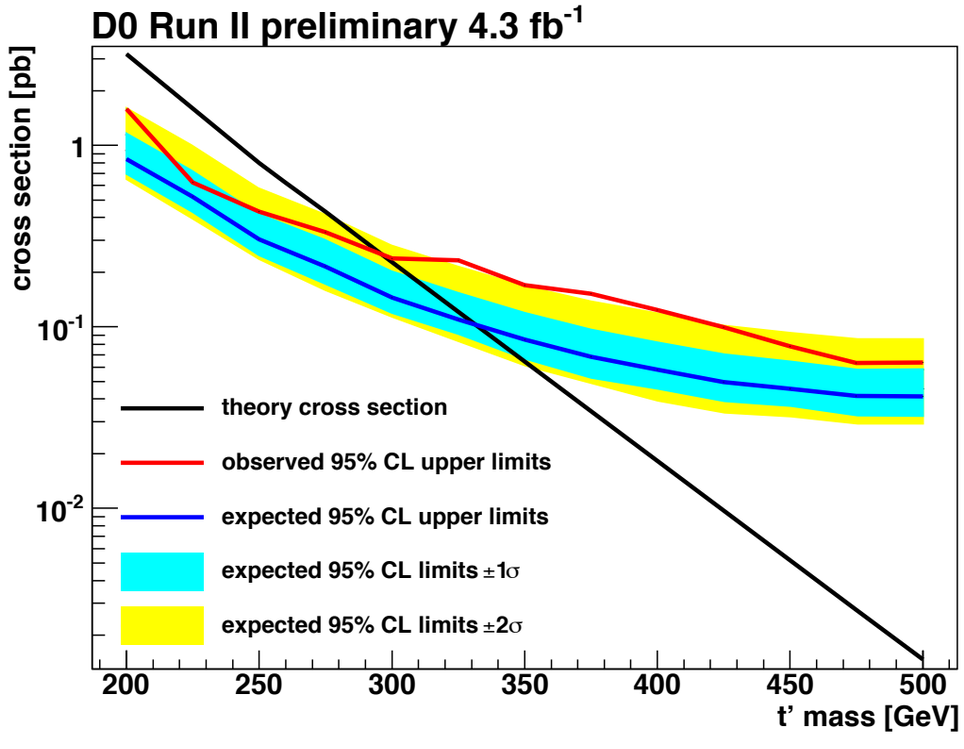


t’

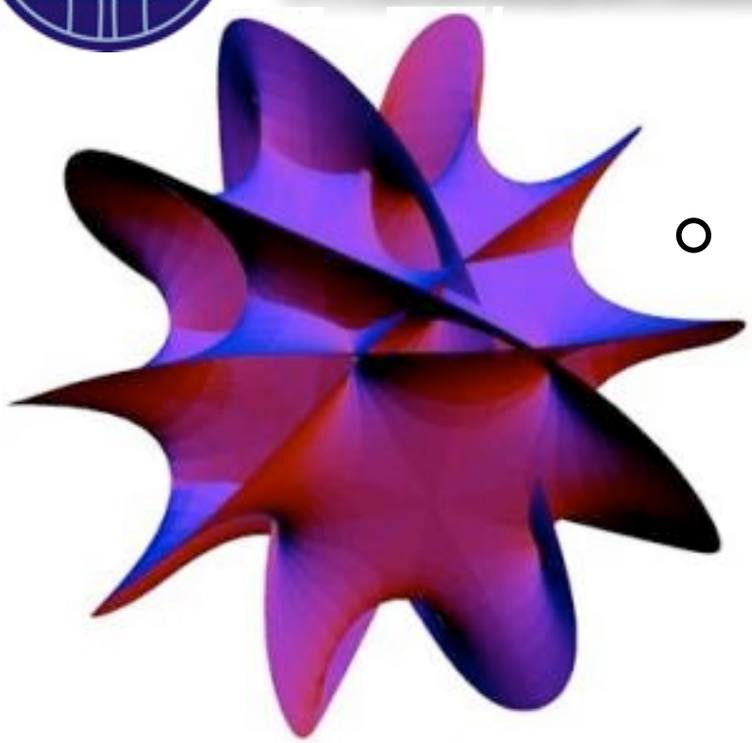
- Fourth gen fermions
- t’→ Wq ($m_{t'}$-$m_{b'}$<m_W)
- reconstruct t’ based on kinematic fit
- or simply look at lvj mass







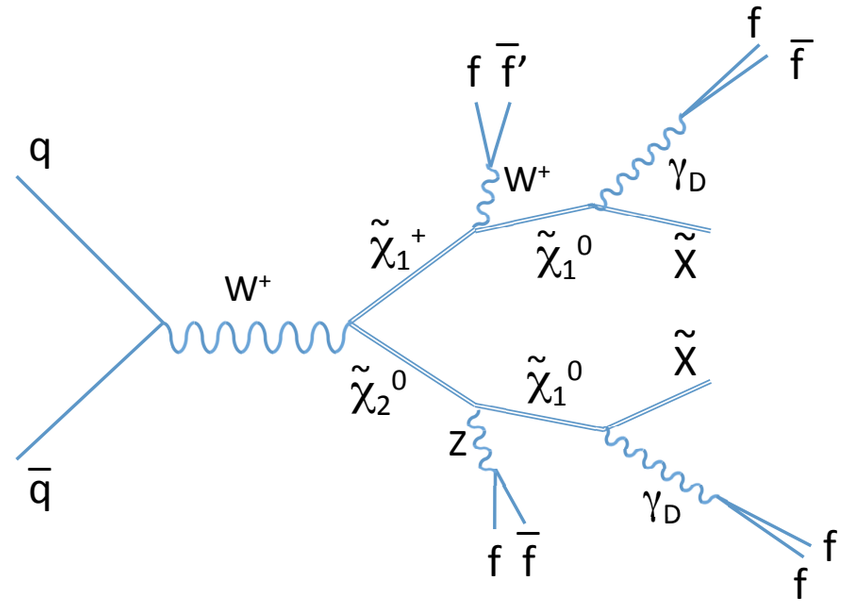
New Physics

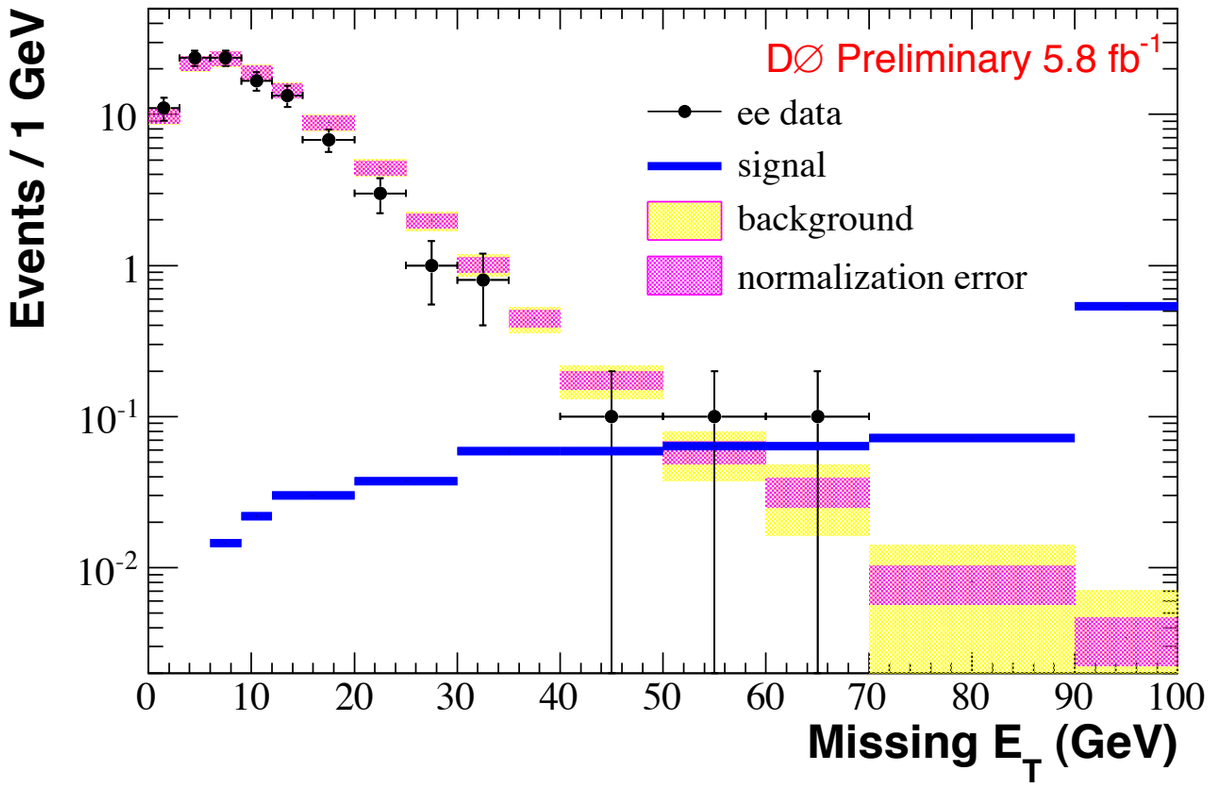


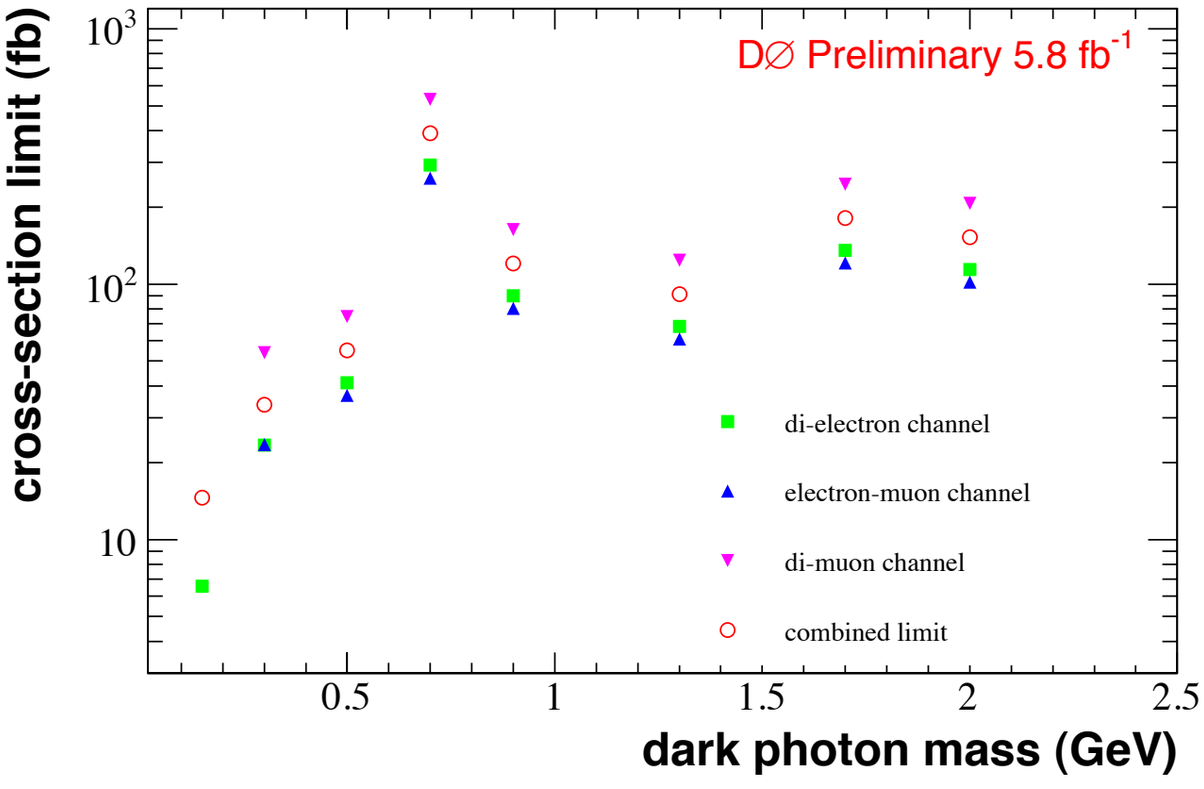
- Active program for BSM physics
  - SUSY
  - Extra dimensions
  - Hidden Valley
  - New Fermions
  - Heavy Bosons
  - Signature based searches
  - …

Hidden Valley with Leptonic Jets

- Hidden particles → light and boosted
- Collimated lepton pairs→ lepton jets
- Large MET from χ - LSP in hidden sector
- Background = multijet production

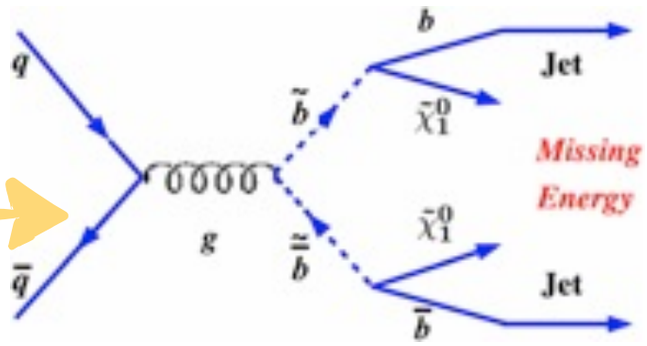


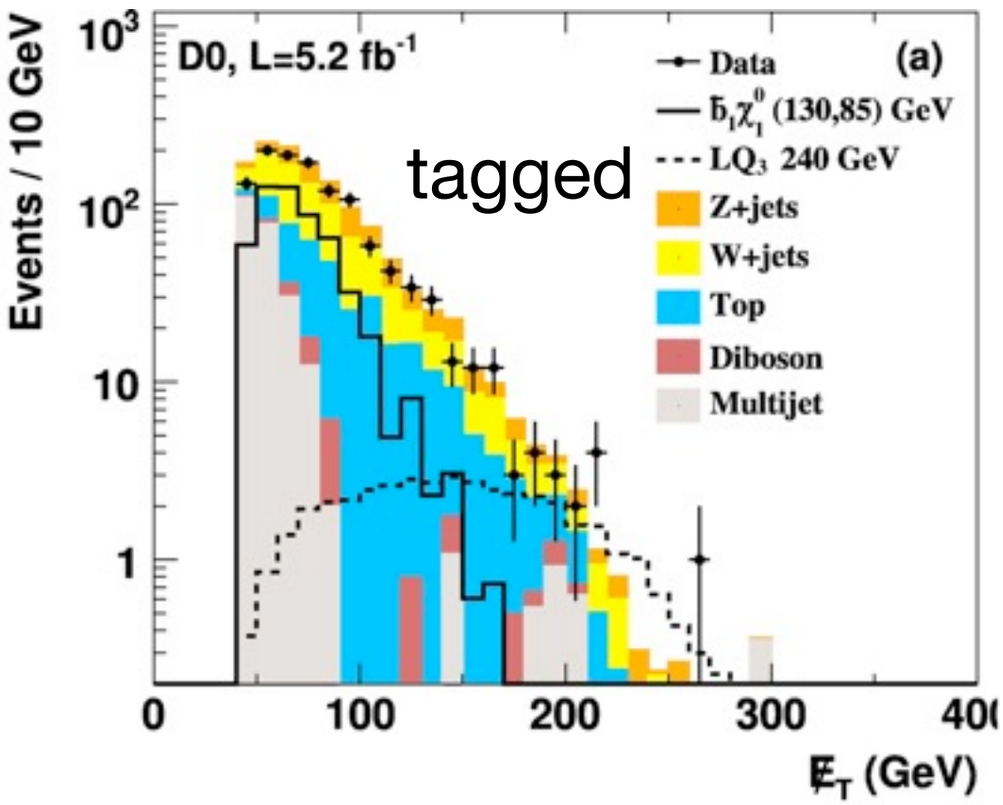


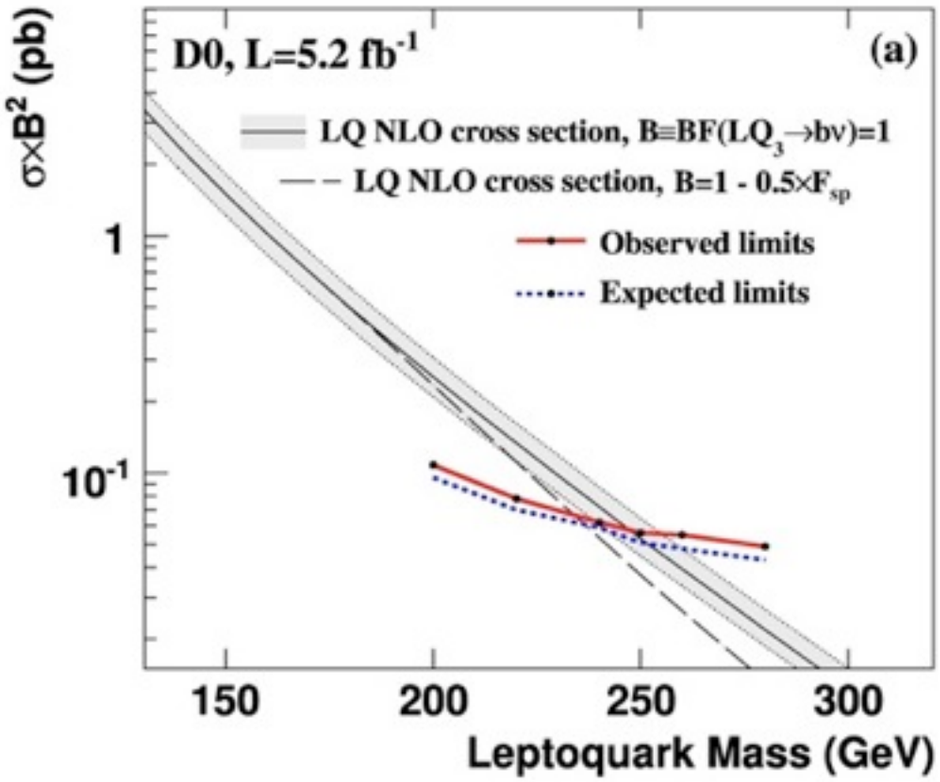


Leptoquarks or sbottom pairs

- MET and b quarks
- SUSY and leptoquarks
  - sbottom pair production
  - $LQ_3 \rightarrow \nu_\tau + b$
- Selection:
  - two b-tagged jets and MET
  - Optimize for each signal



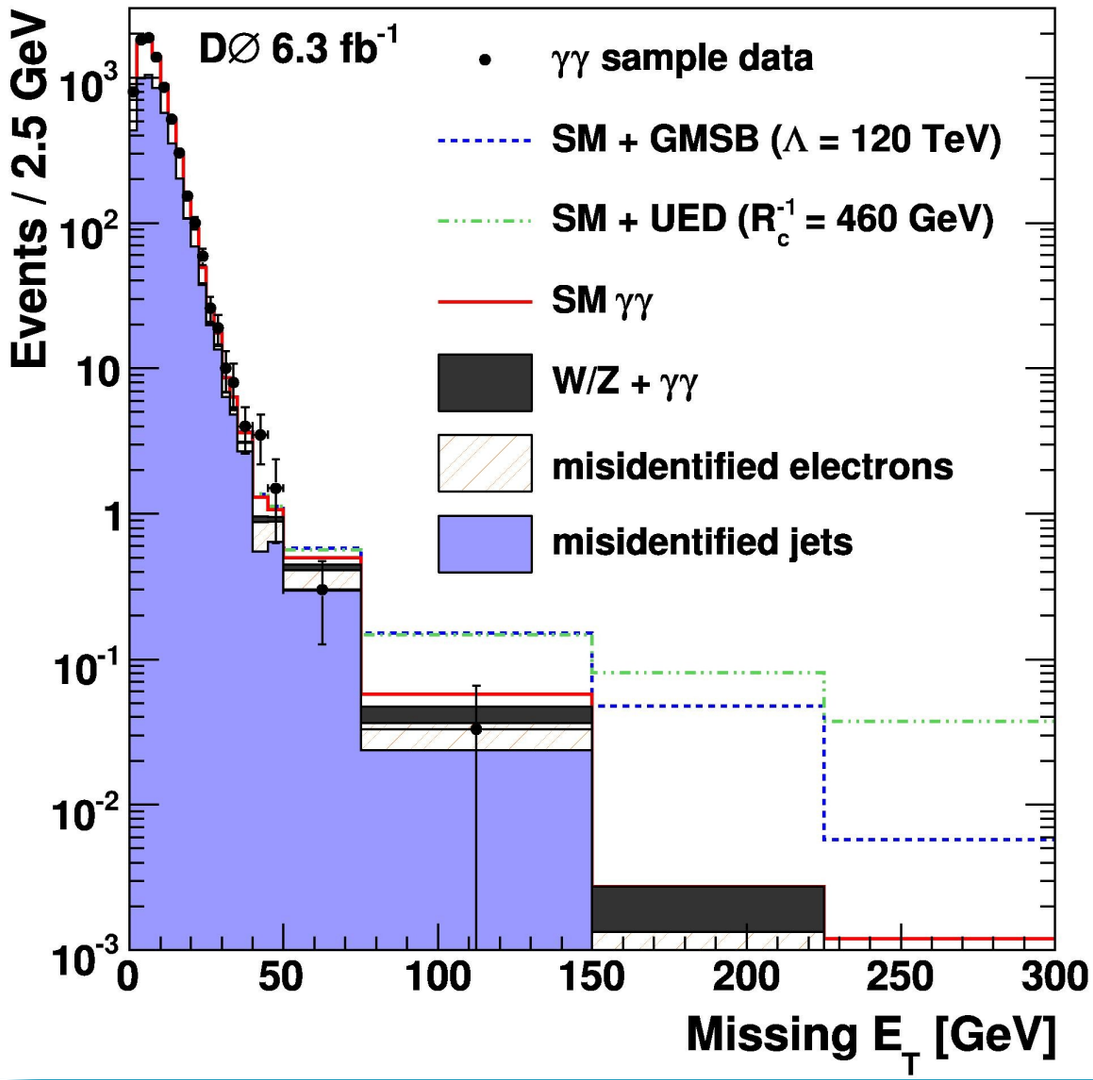


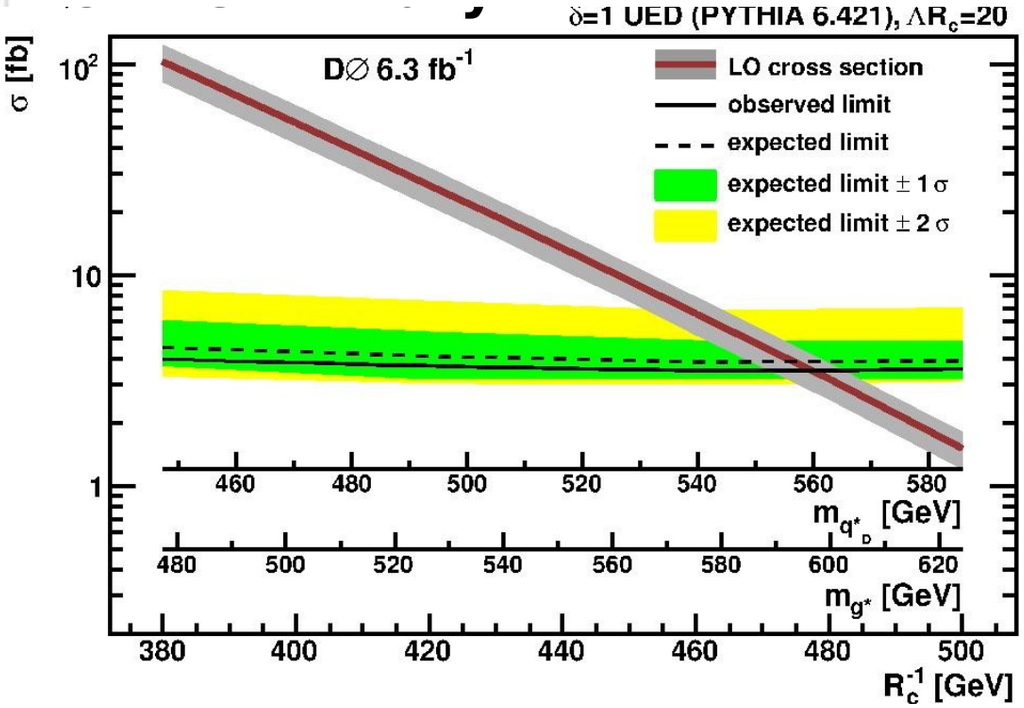


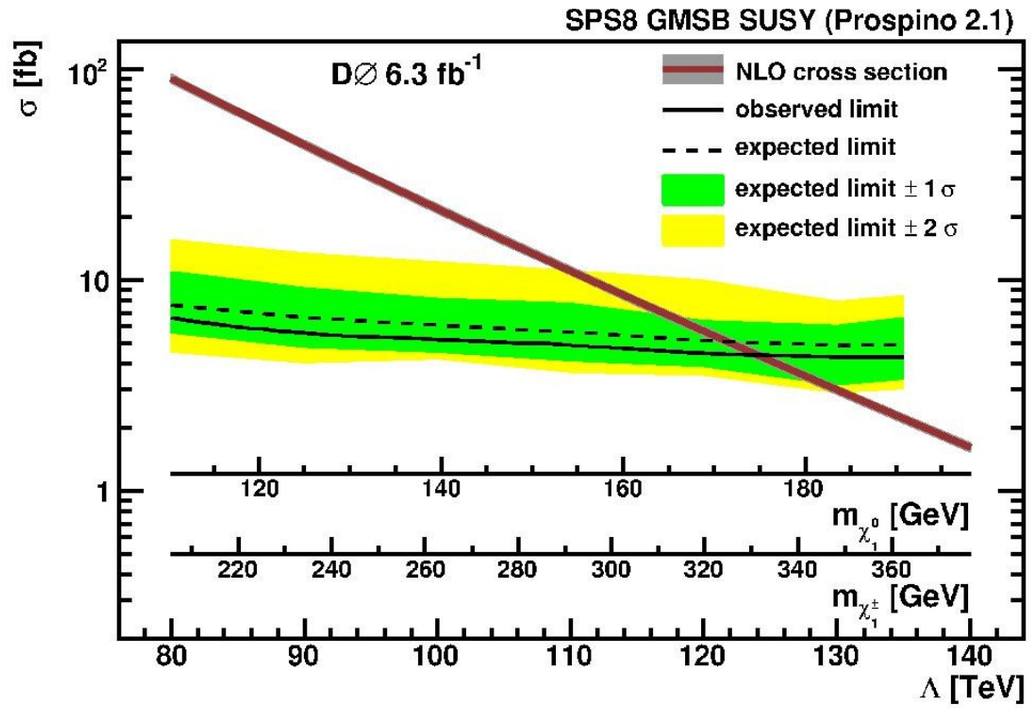
Submitted to *Phys Lett B;* arXiv:1005.2222v2

GMSB SUSY

- diphoton + MET
- GMSB SUSY or UED
  - NLSP→ G+γ
- 4 events observed with MET>50GeV
  - 6.9±1.0 expected from background

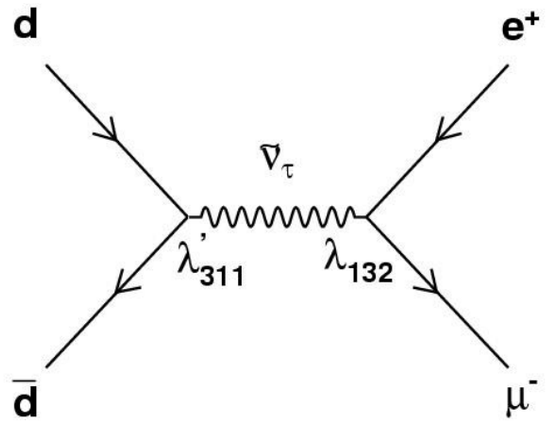




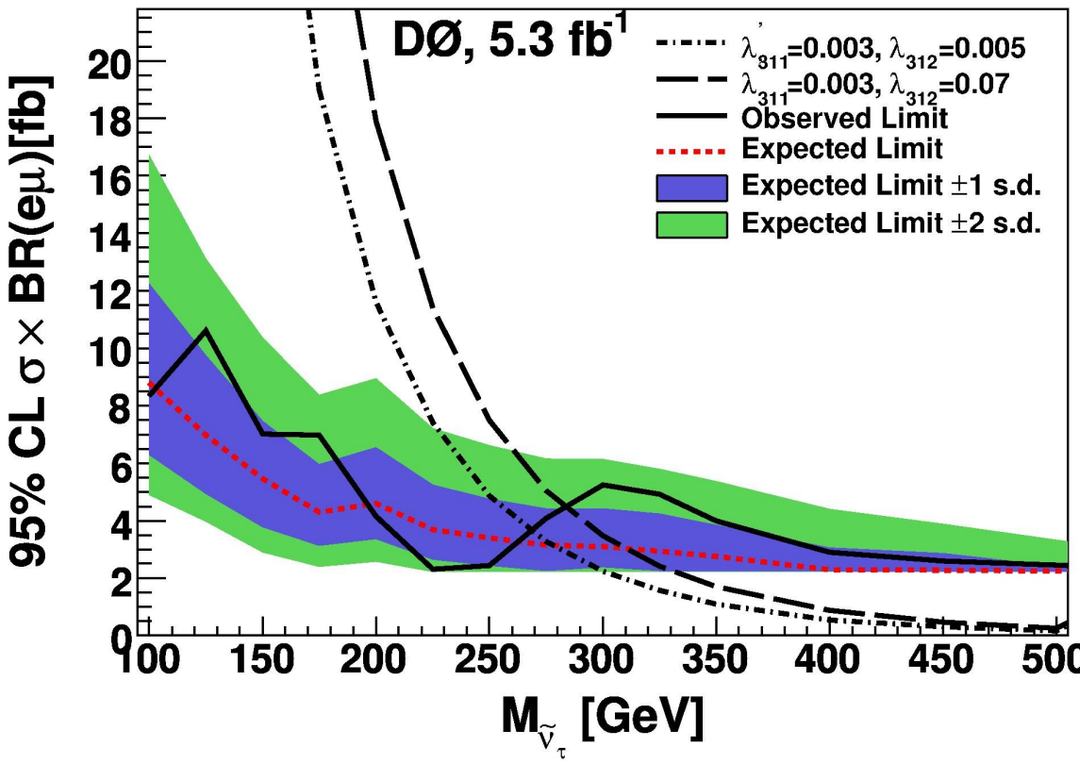


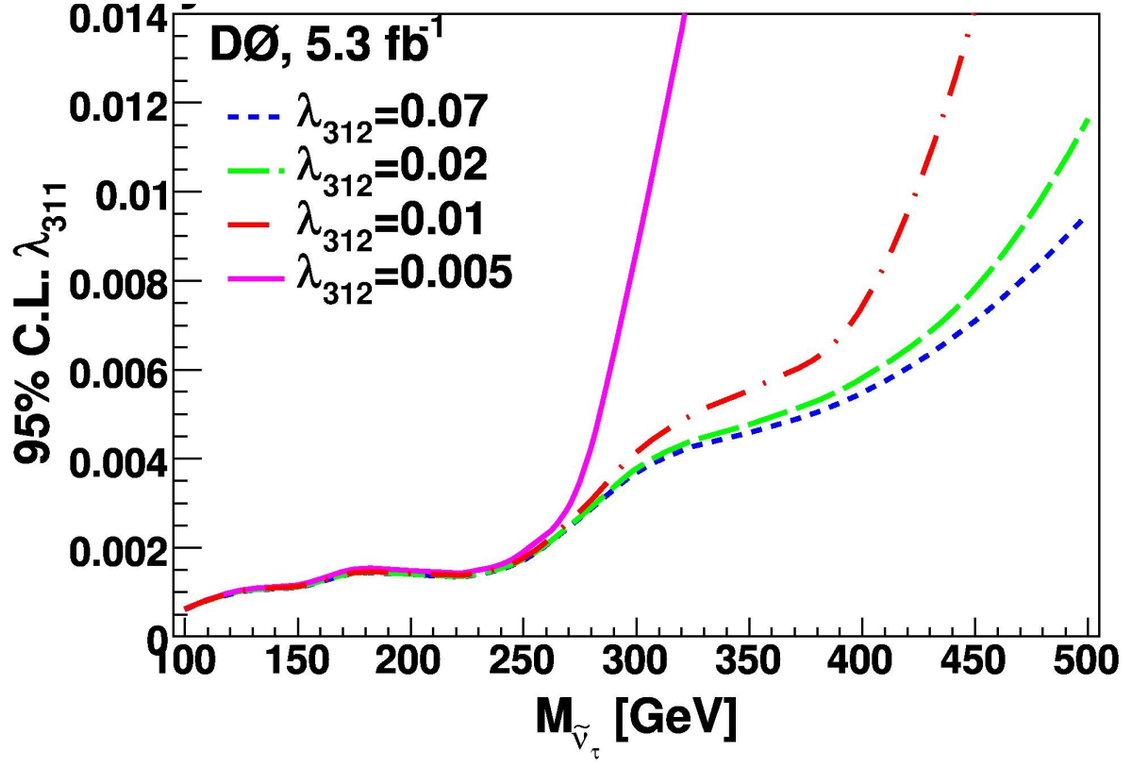
sneutrinos

- RPV SUSY sν→ eμ
- Search for e - μ pair at high invariant mass
- Main background Z → τ τ
  - semileptonic τ decays



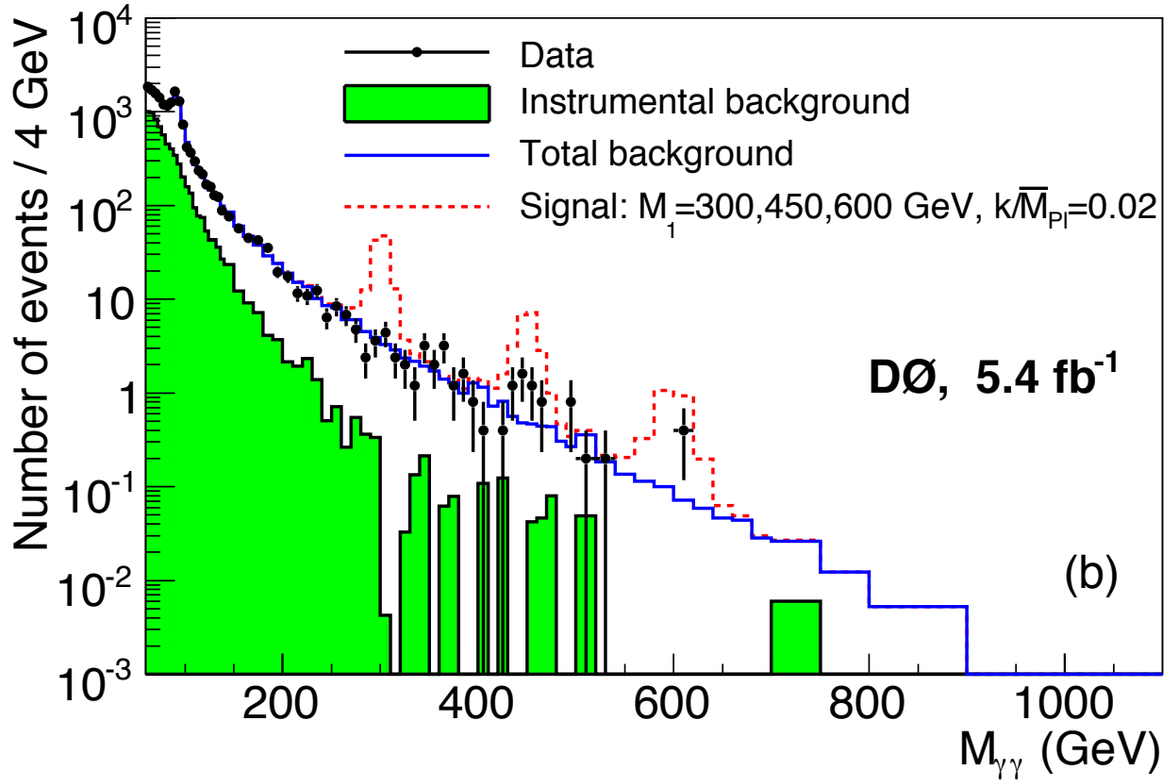
DØ Preliminary

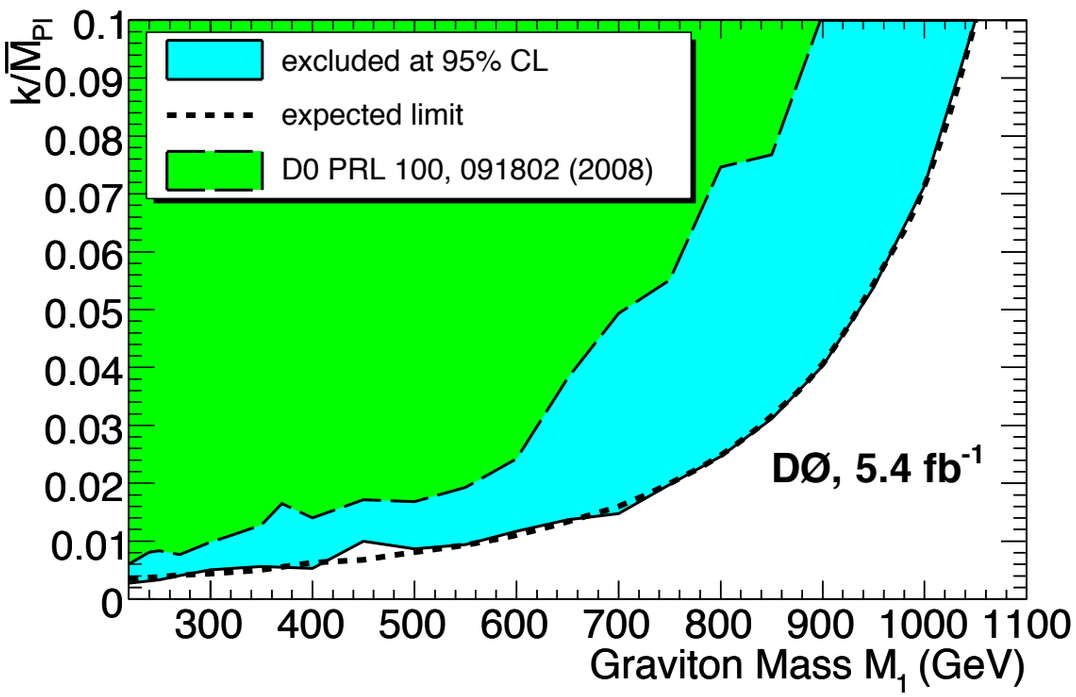


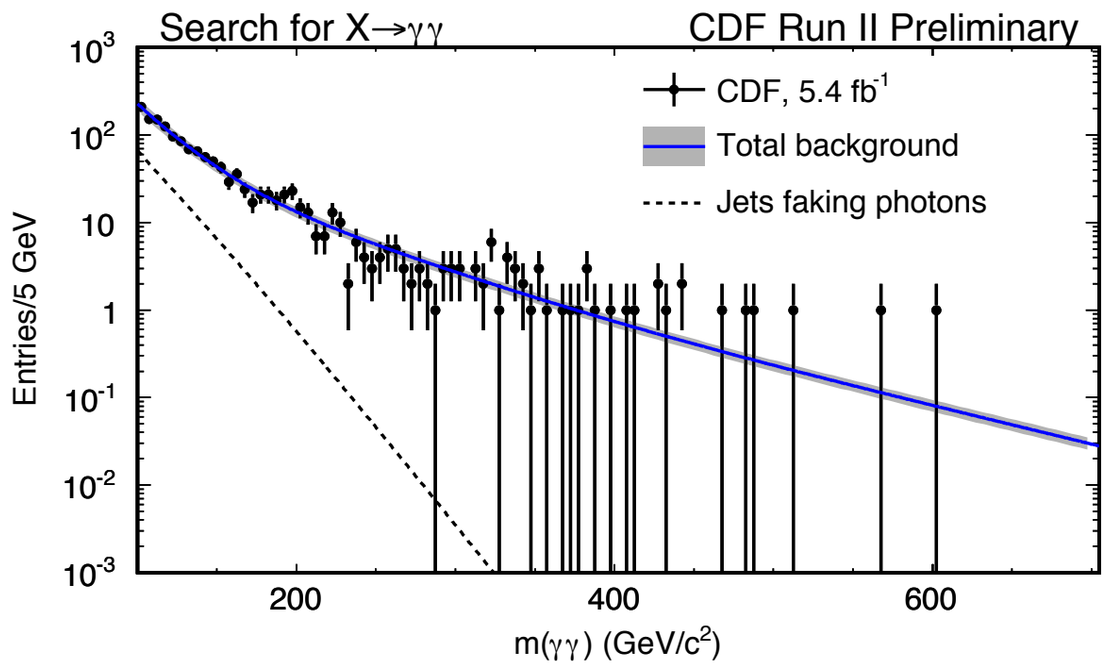


Bump Hunting

- **High Mass in two photons**
- **Use DIPHOX generator to infer a background shape**
  - **Other instrumental from the data**
- **Fit to $m_{\gamma\gamma}$ distribution**
  - **normalize to low mass region**
- **Largest excess around 450 in $m_{\gamma\gamma}$**
  - **2.3 σ (D0)**

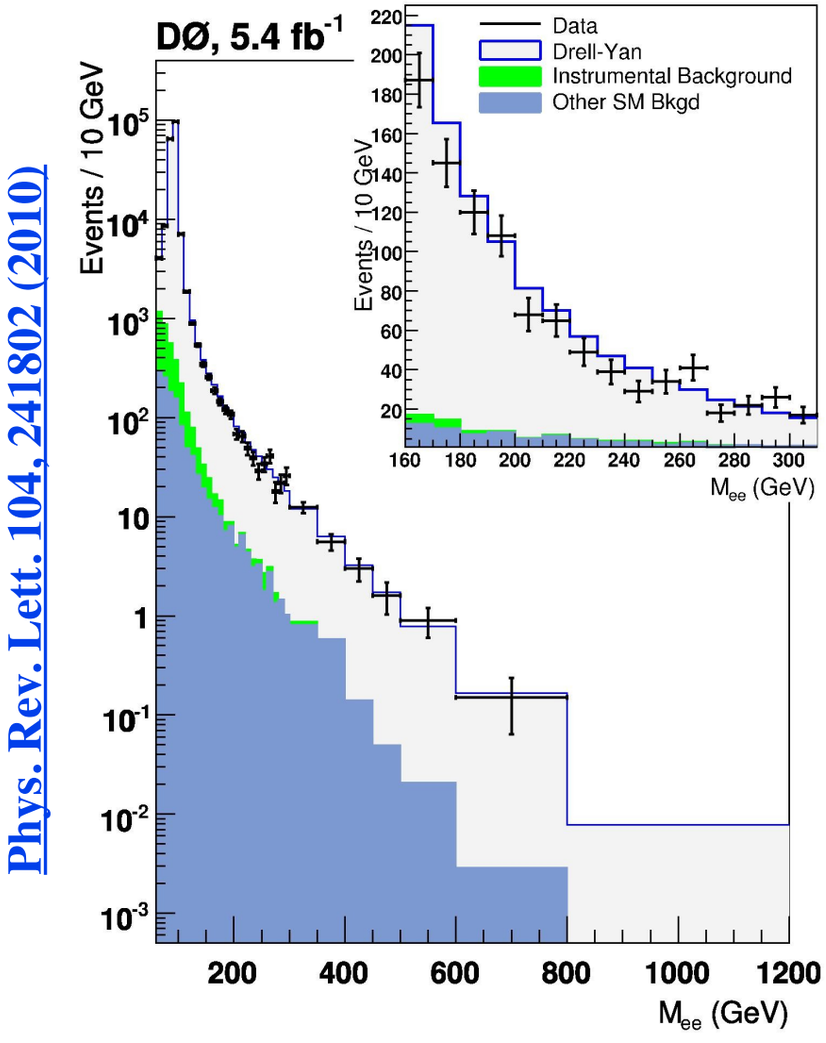


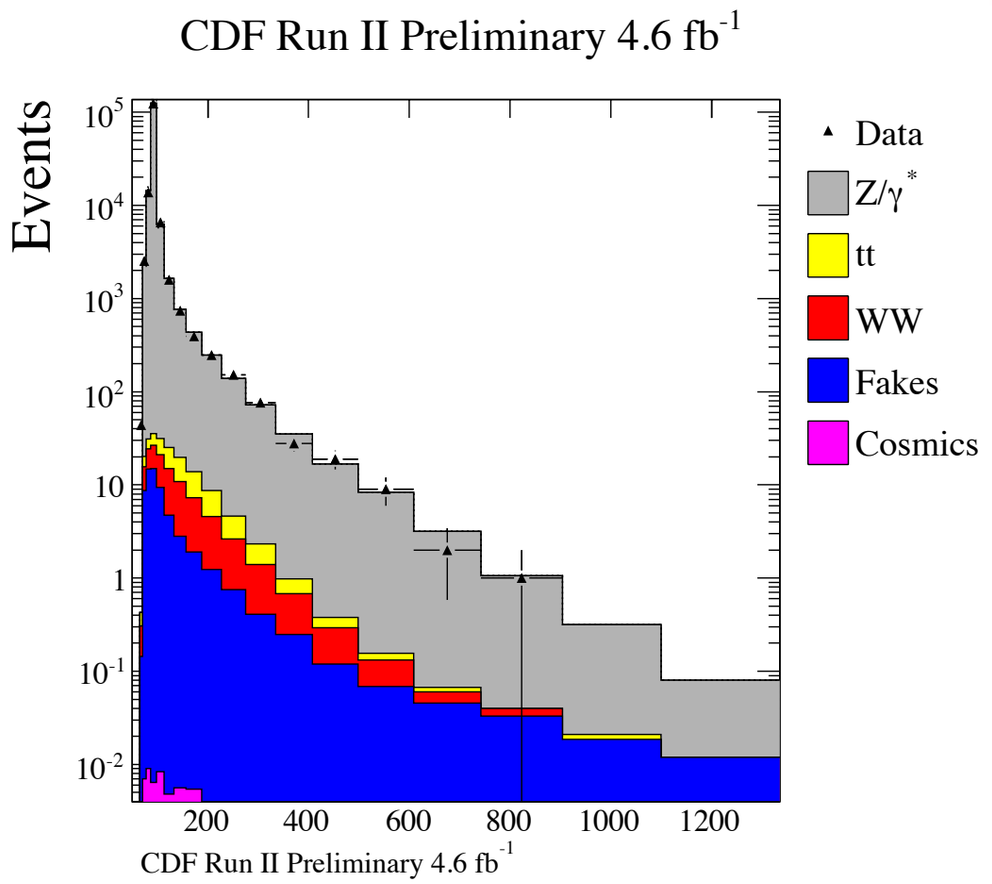


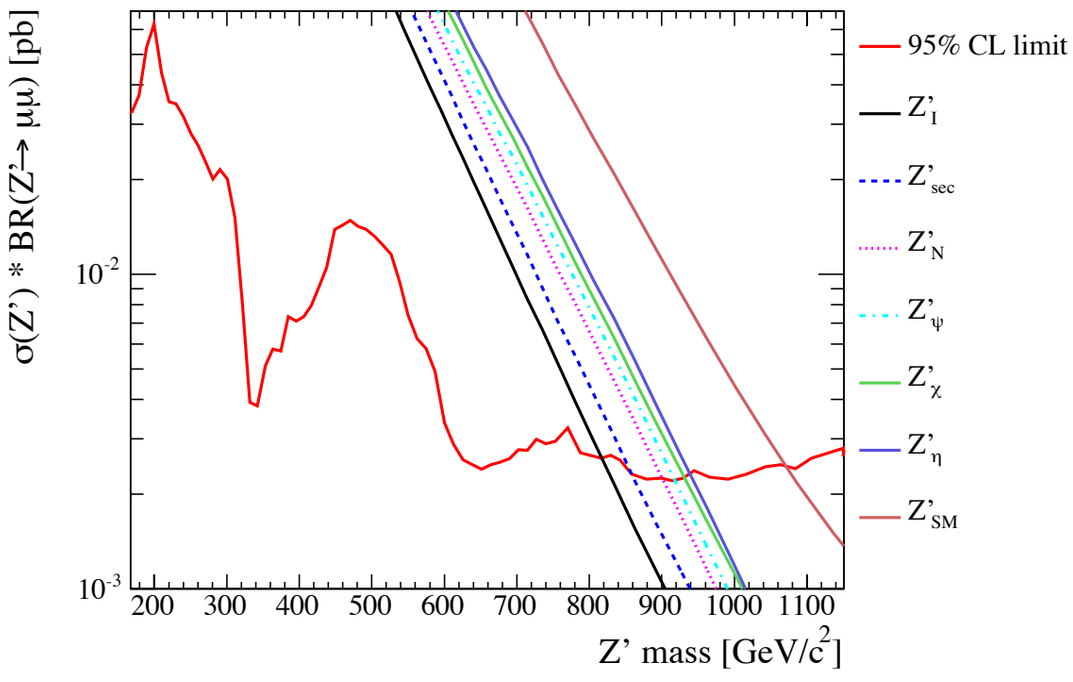


Bump Hunting

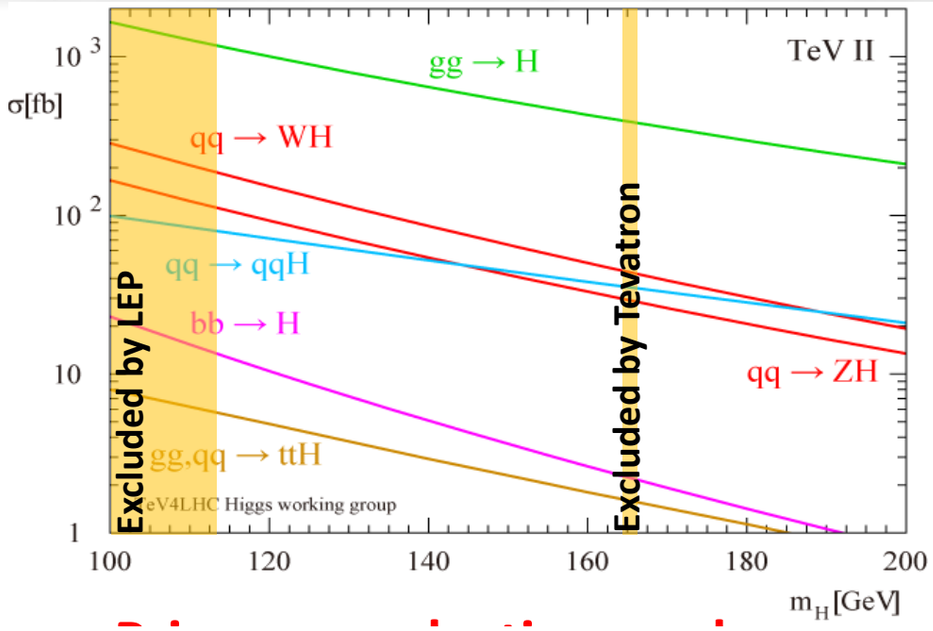
- **High mass dielectron or dimuon resonances**
  - Each experiment has now more than 1M Zs datasets
- $m_{Z'SM}$>1.071TeV (CDF)
- $m_{Z'SM}$>1.023 TeV (D0)

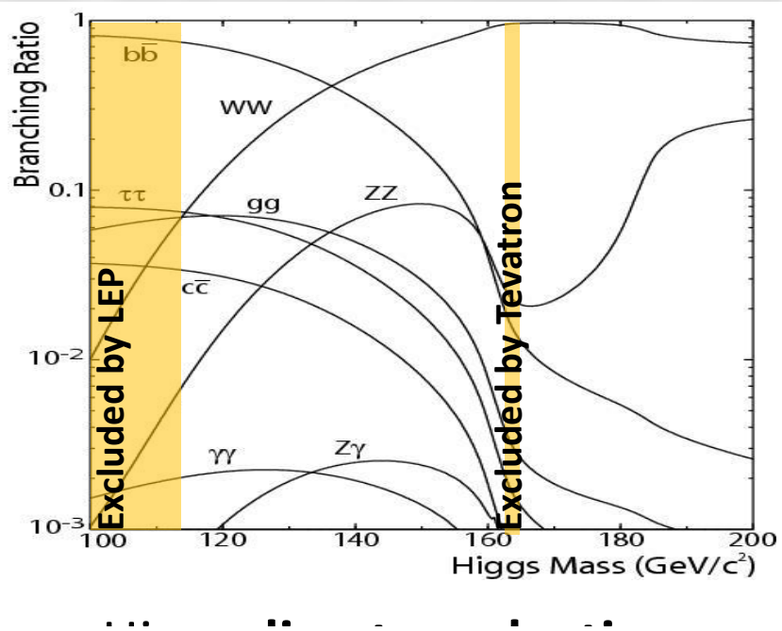




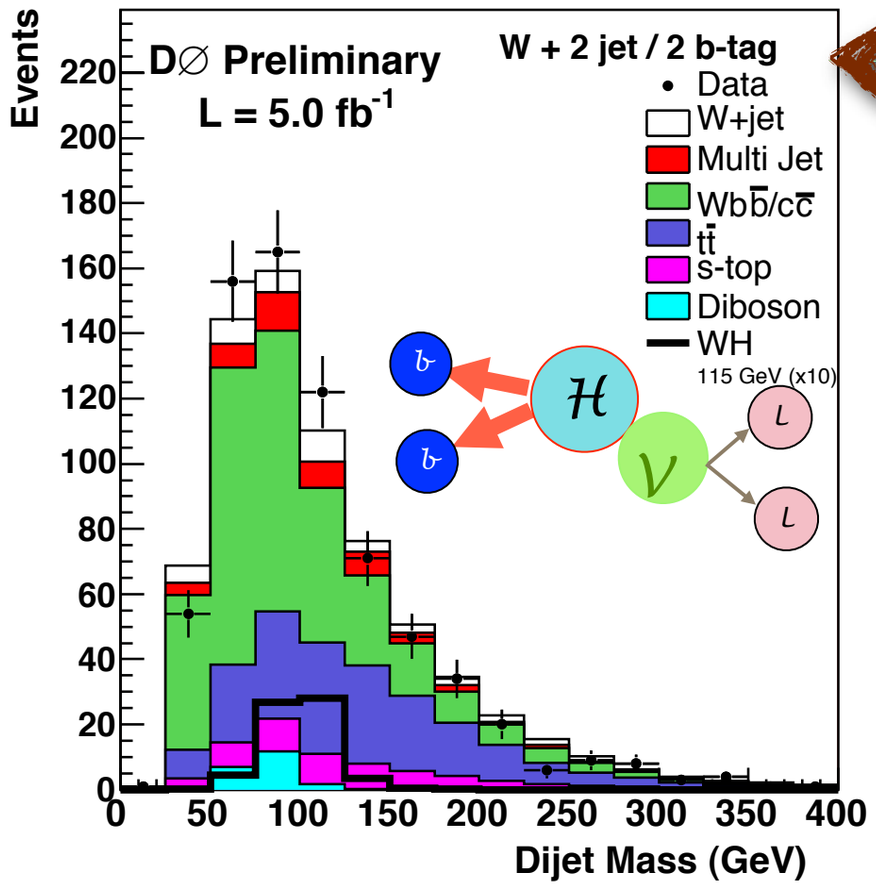


Higgs Hunting Guide

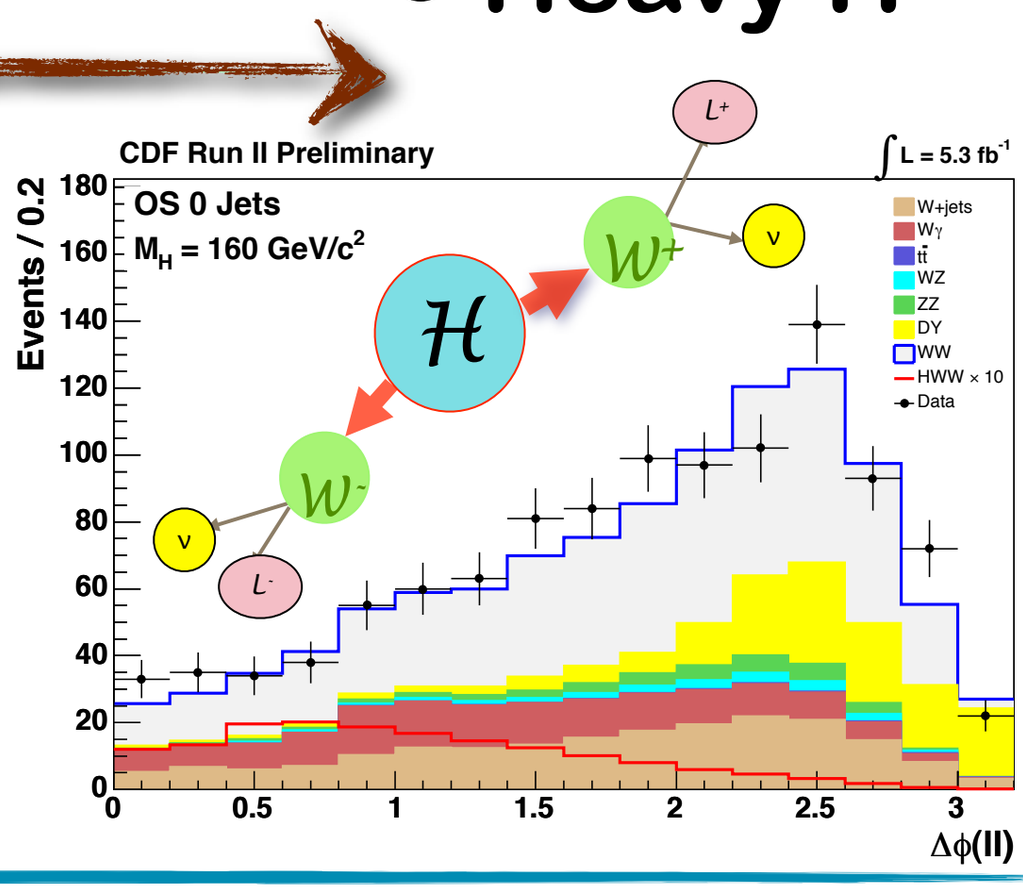




○ Light H

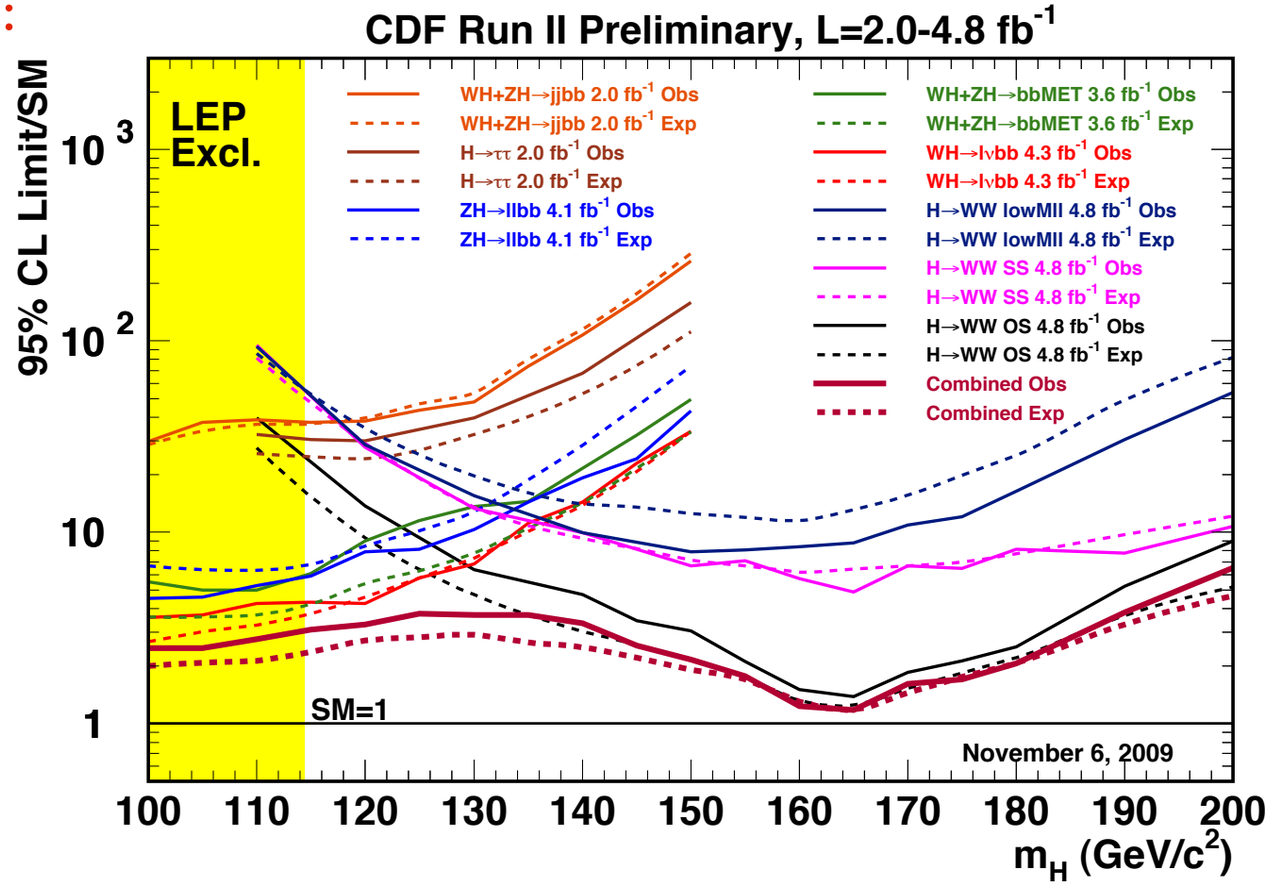


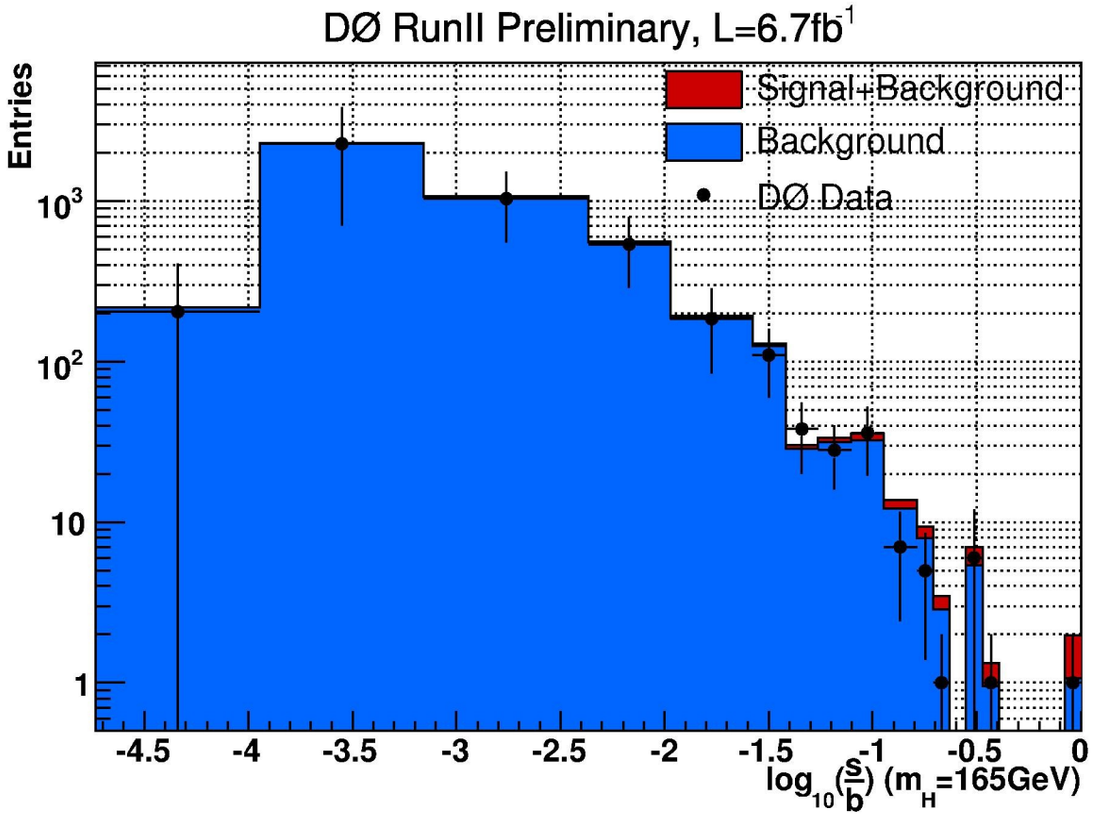
○ Heavy H



All fronts

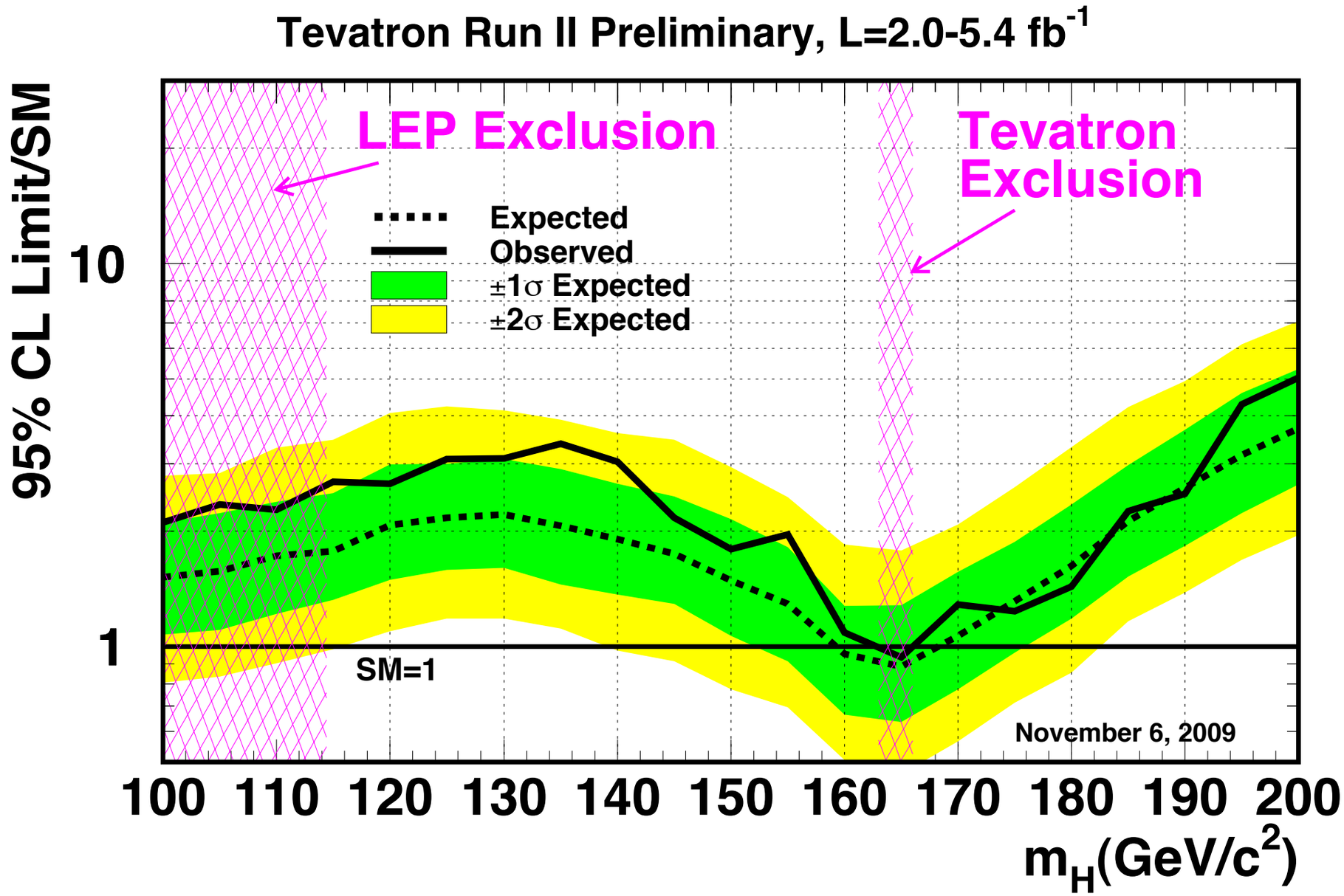
- More information than simple mass or angular distributions
  - Sophisticated analysis techniques: ANN, BDT, etc.
- Large number of final states being investigated:
  - WH → l ν bb (l=e, μ , τ)
    - WH→ WWW
  - ZH → ll bb (l = e, μ, τ, ν)
  - H → WW
  - H→ γ γ
  - H → τ τ





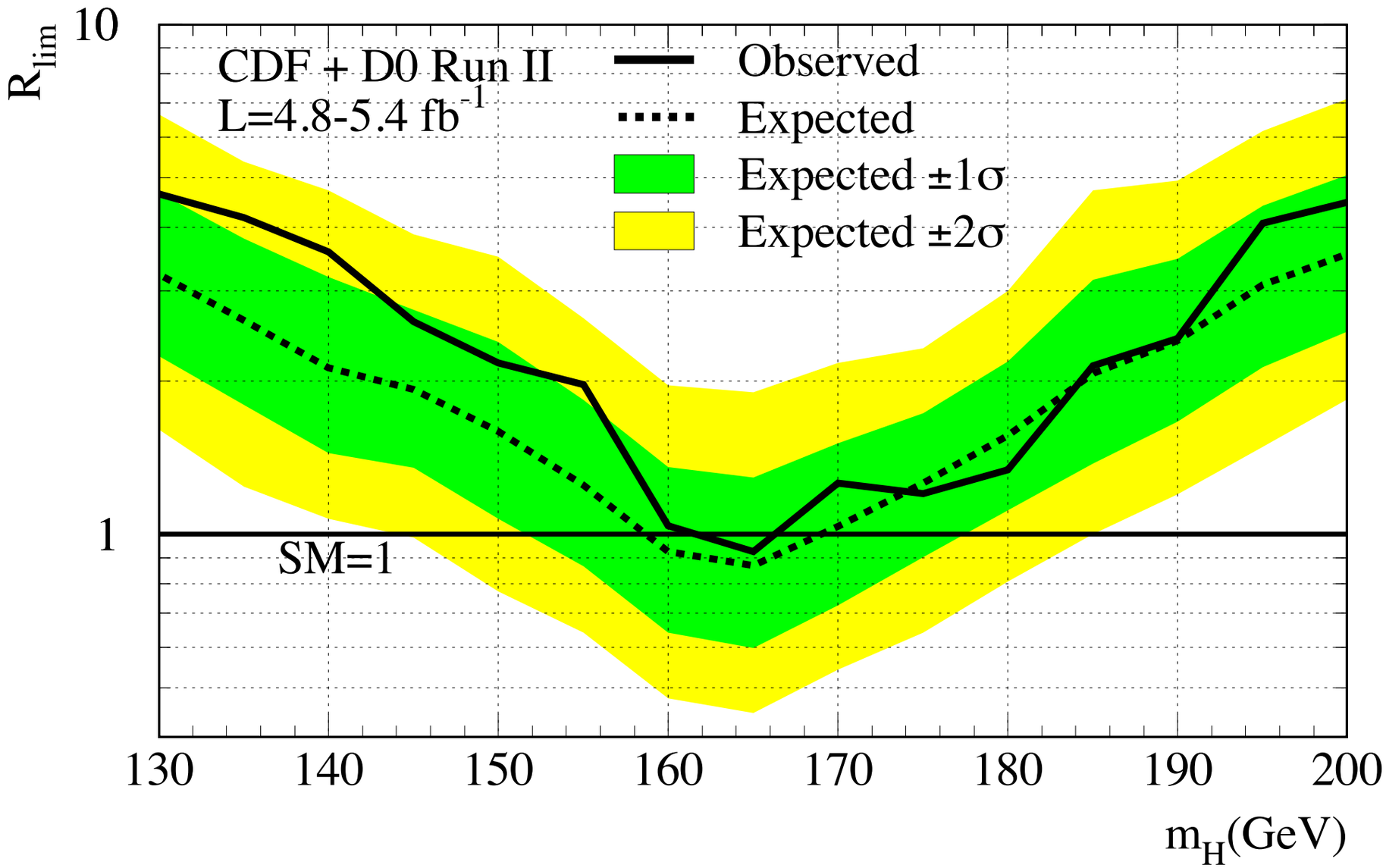
For example

SM Higgs searches



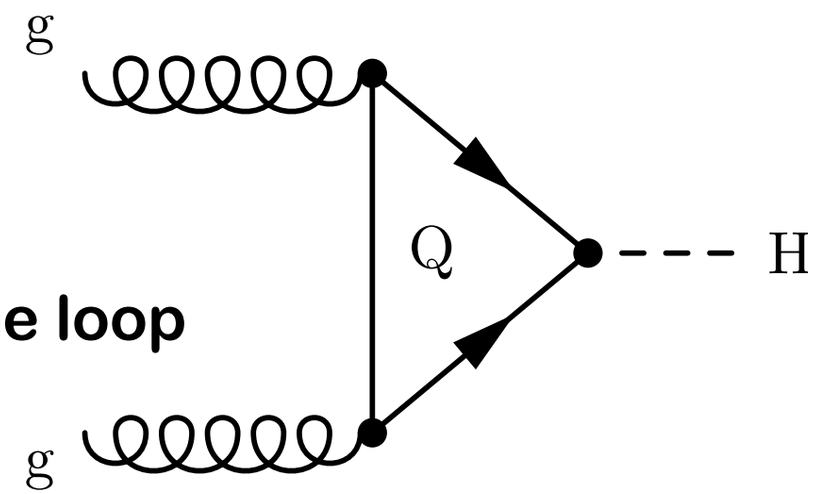
SM Higgs searches

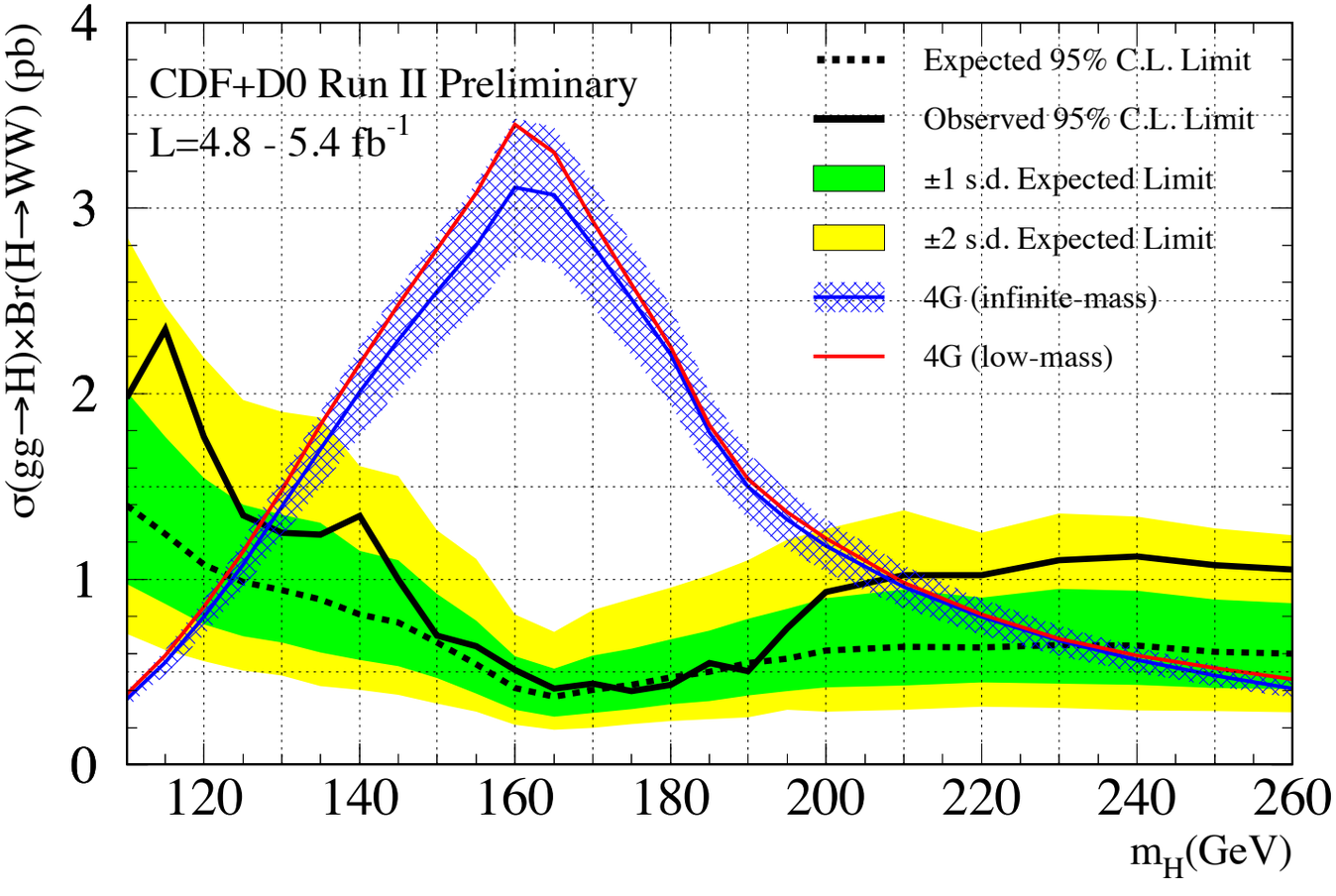
- Full range TeV wide combination in the works



Fourth generation

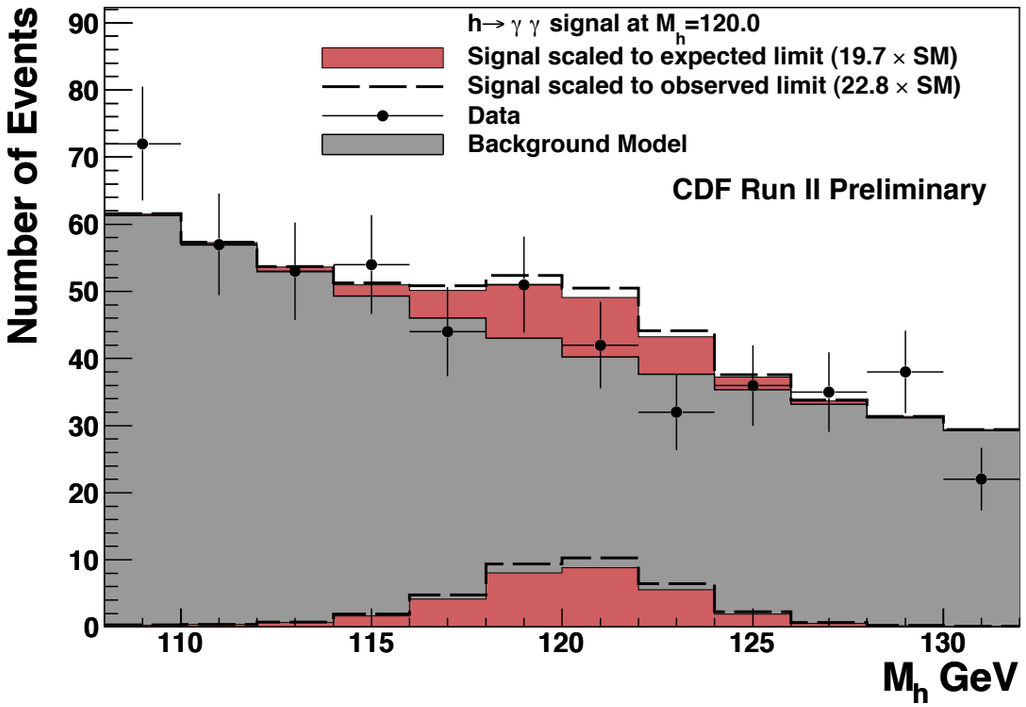
- Fourth generation quarks and leptons
- σ (ggH) enhanced by ~3
  - Each additional quark contributes ~top in the loop

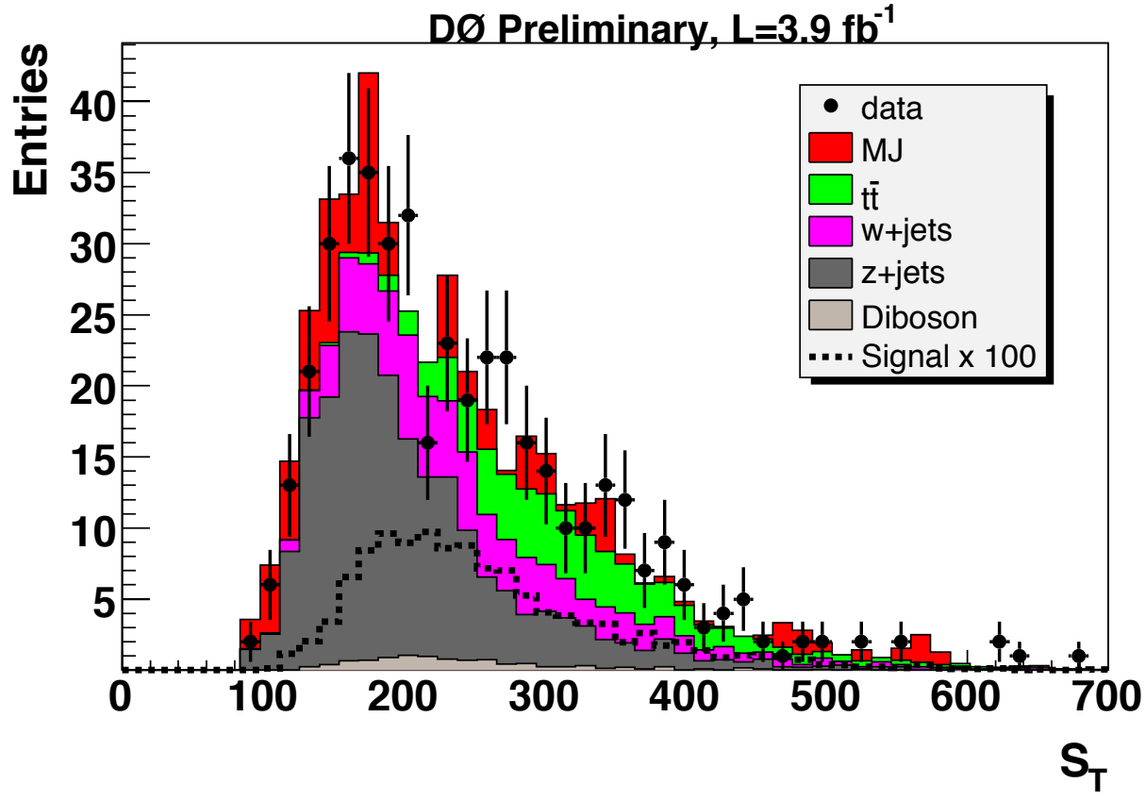




Some new additions?

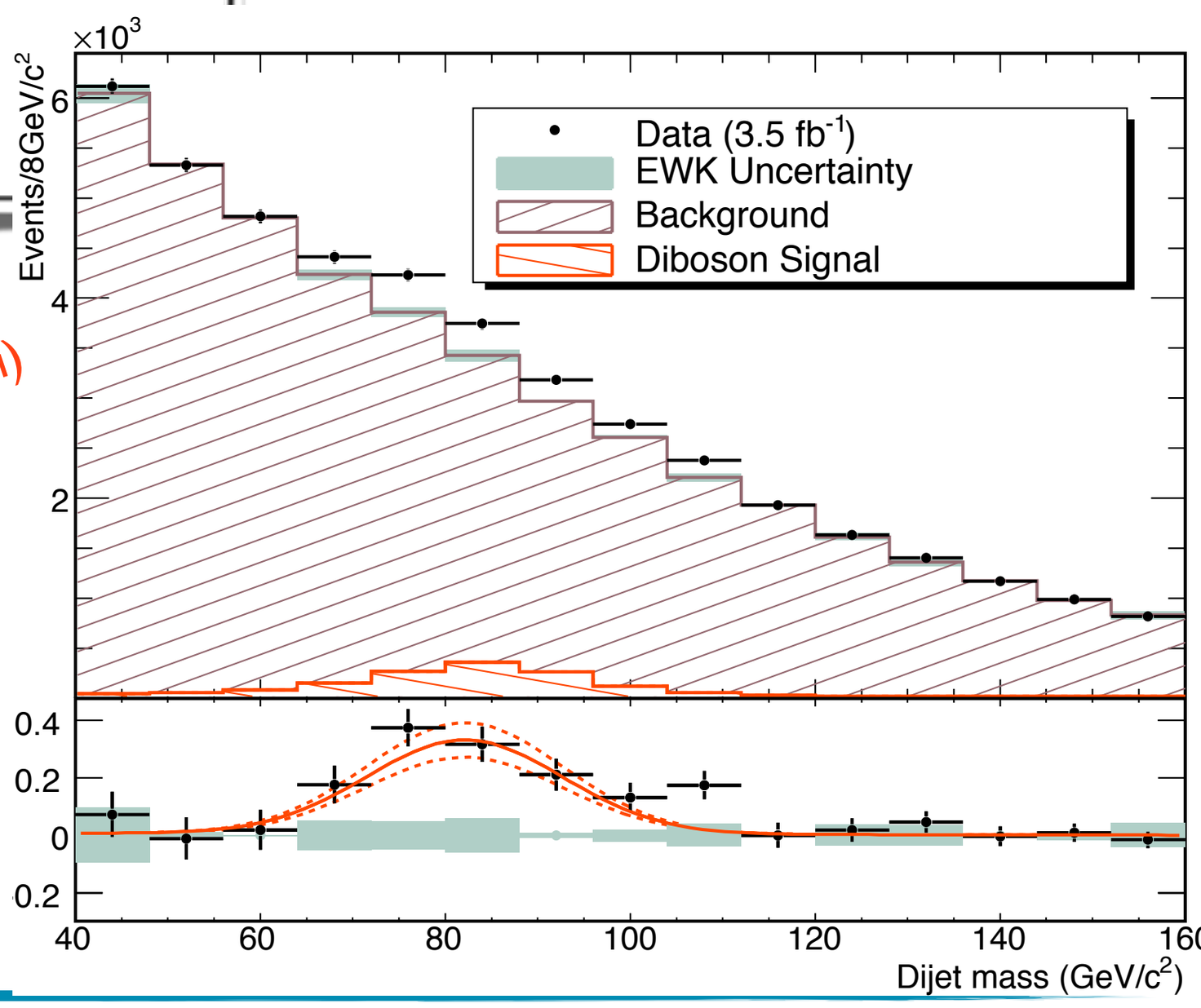
- Searches with taus (D0)
  - $WH \rightarrow qq + \tau\tau$
- Searches with photons (CDF)
  - $H \rightarrow \gamma\gamma$





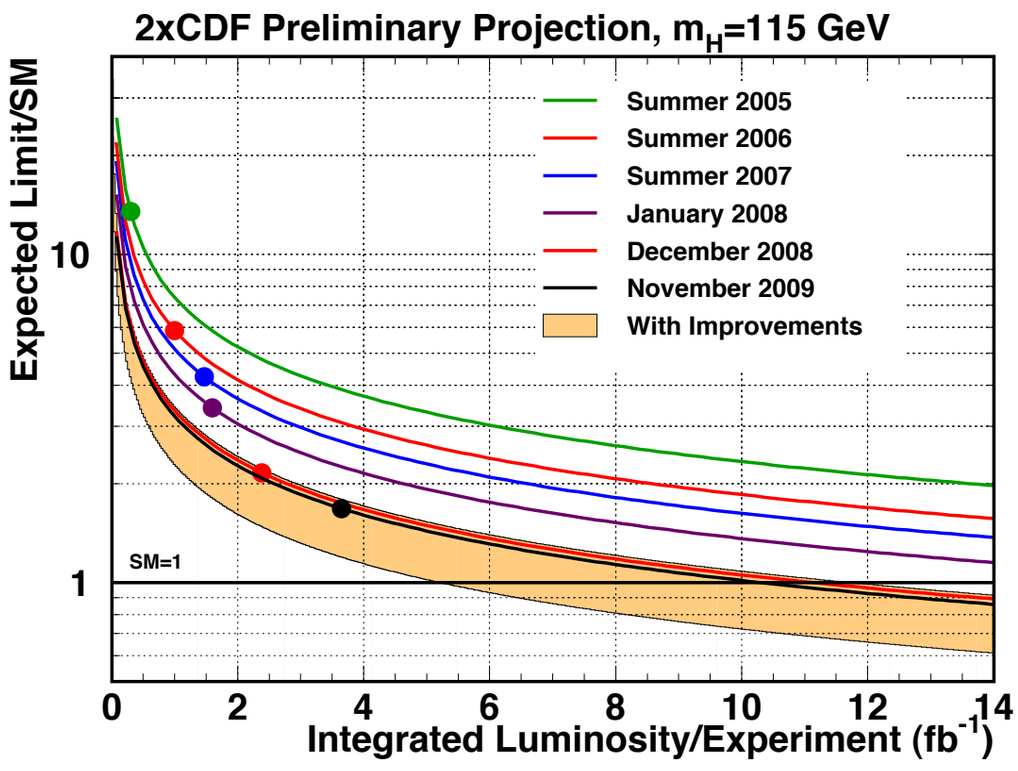
A Precursor to the Higgs

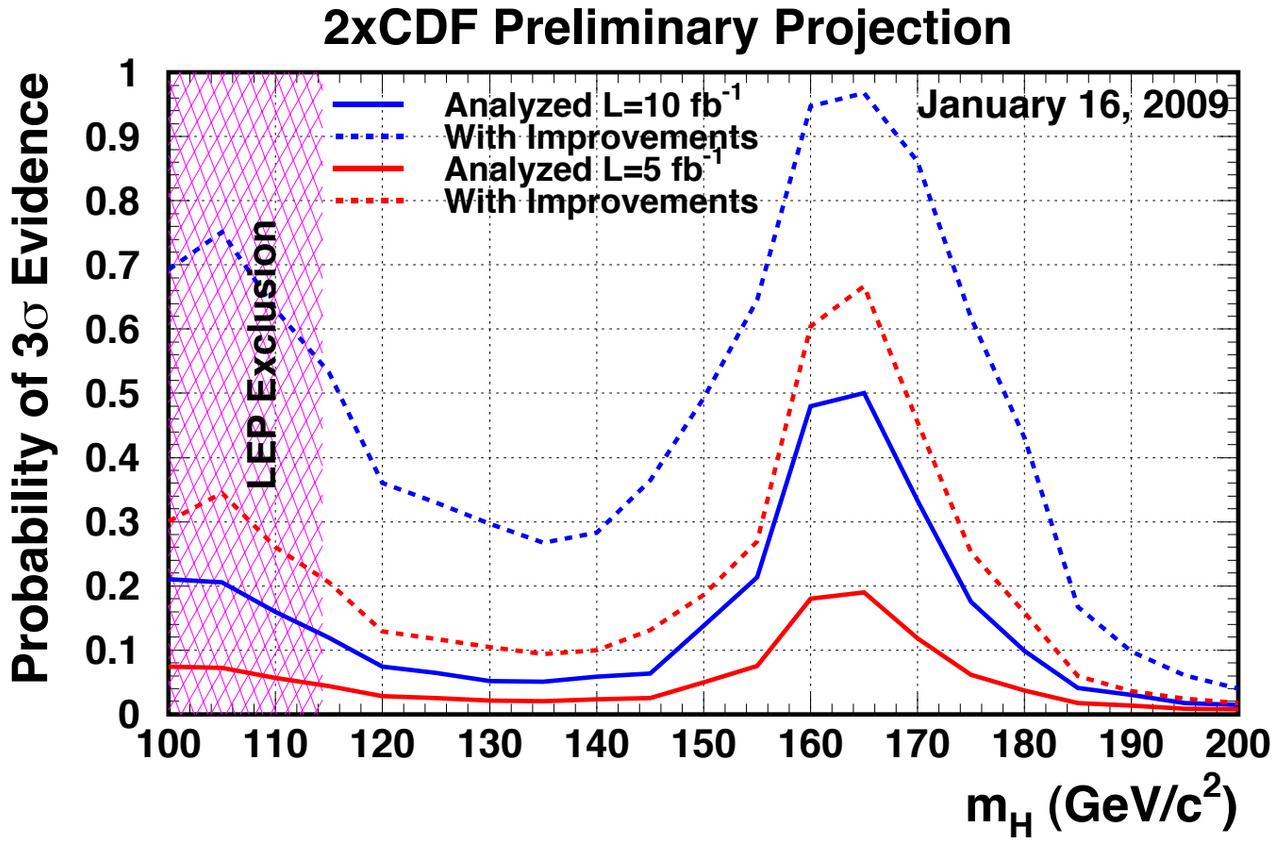
- Low mass Higgs: WH → l ν + bb
- Dibosons: W+W/Z → l ν + jj
  - larger cross section
  - should be observed first



σ(pb) = 18.0± 2.8(stat)± 2.4(syst)± 1.1(lumi)
NLO=16.8±0.5pb

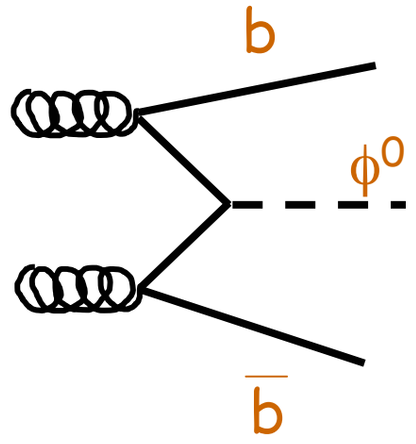
Prospects


2xCDF Preliminary Projection, m_H=115 GeV
Expected Limit/SM
10
1
SM=1
Summer 2005
Summer 2006
Summer 2007
January 2008
December 2008
November 2009
With Improvements
0
2
4
6
8
10
12
14
Integrated Luminosity/Experiment (fb^{-1})

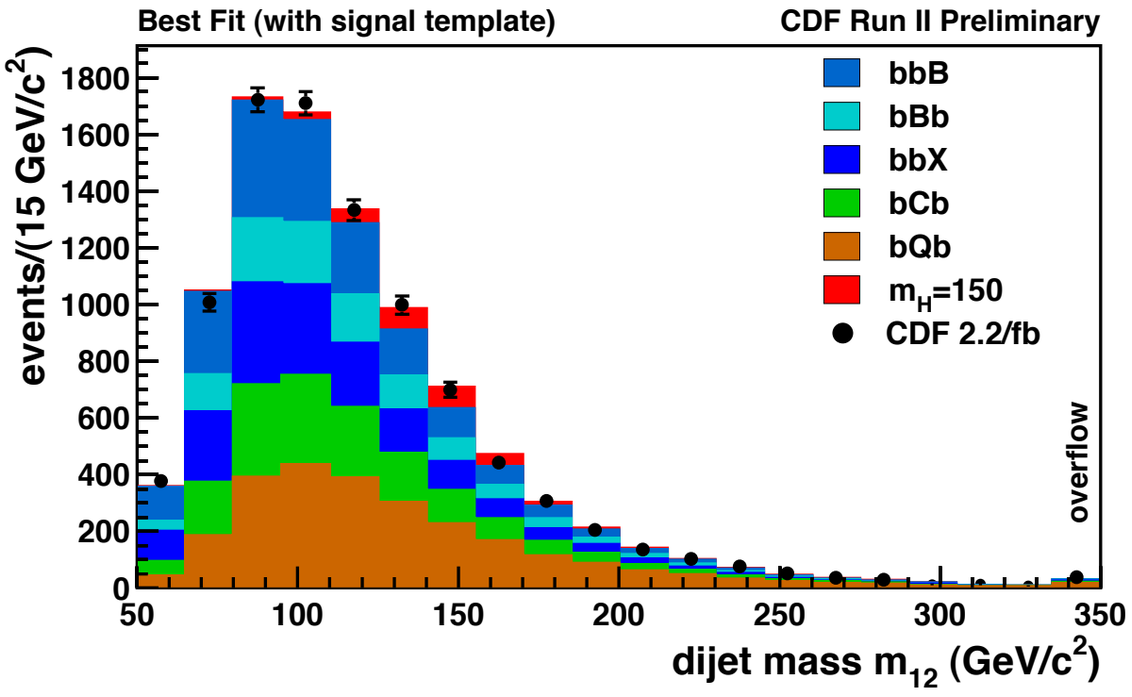

2xCDF Preliminary Projection
Probability of 3σ Evidence
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
LEP Exclusion
Analyzed L=10 fb^{-1}
With Improvements
Analyzed L=5 fb^{-1}
With Improvements
January 16, 2009
100
110
120
130
140
150
160
170
180
190
200
m_H (GeV/c^2)

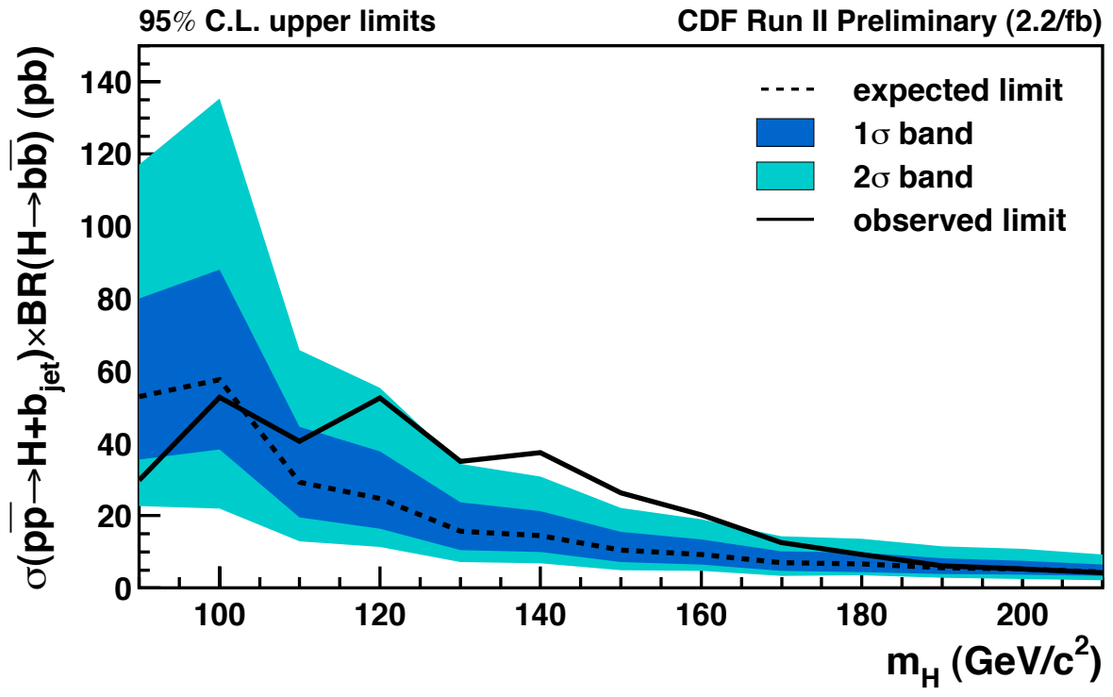
3b Higgs

- Enhanced at high tanβ in MSSM
- Look for three jets b tagged
- Estimate based on data - two b tags and X and use P(x→b)



5.7% p value when taking into account trial factors





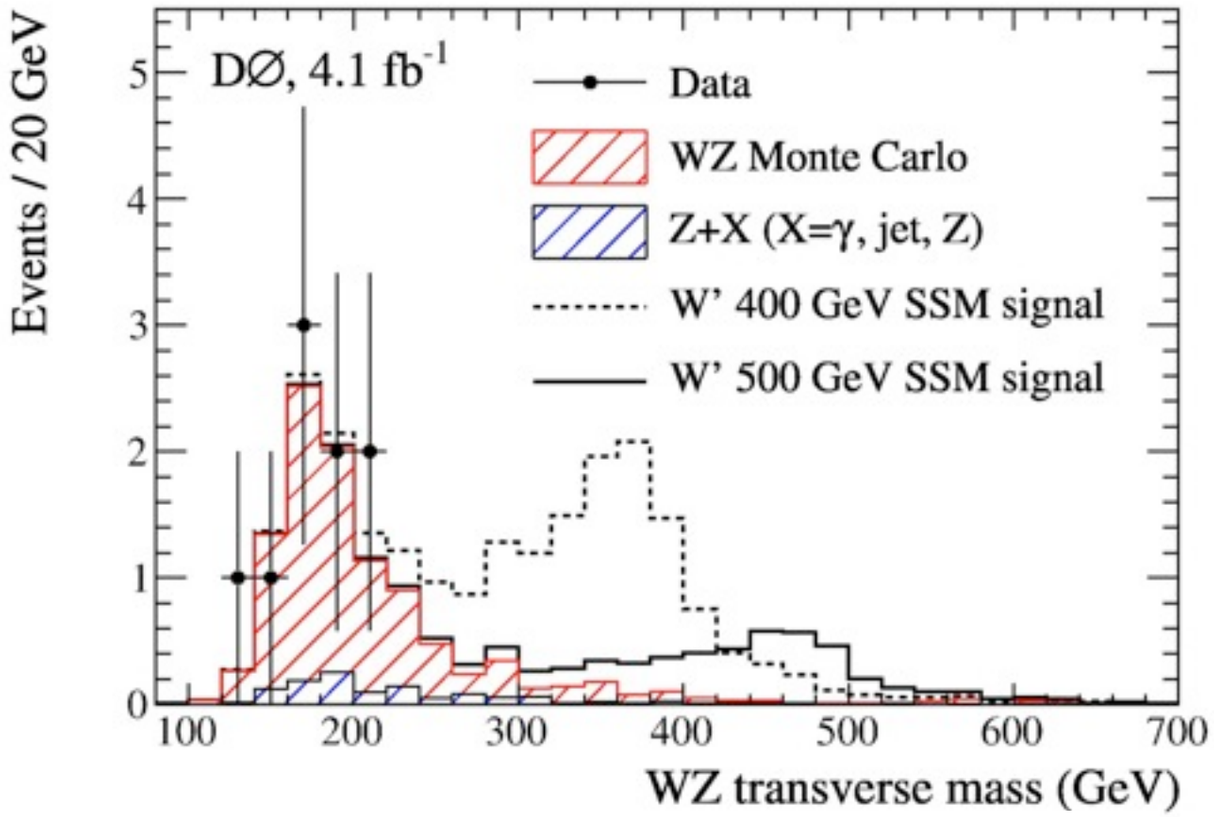
Conclusions

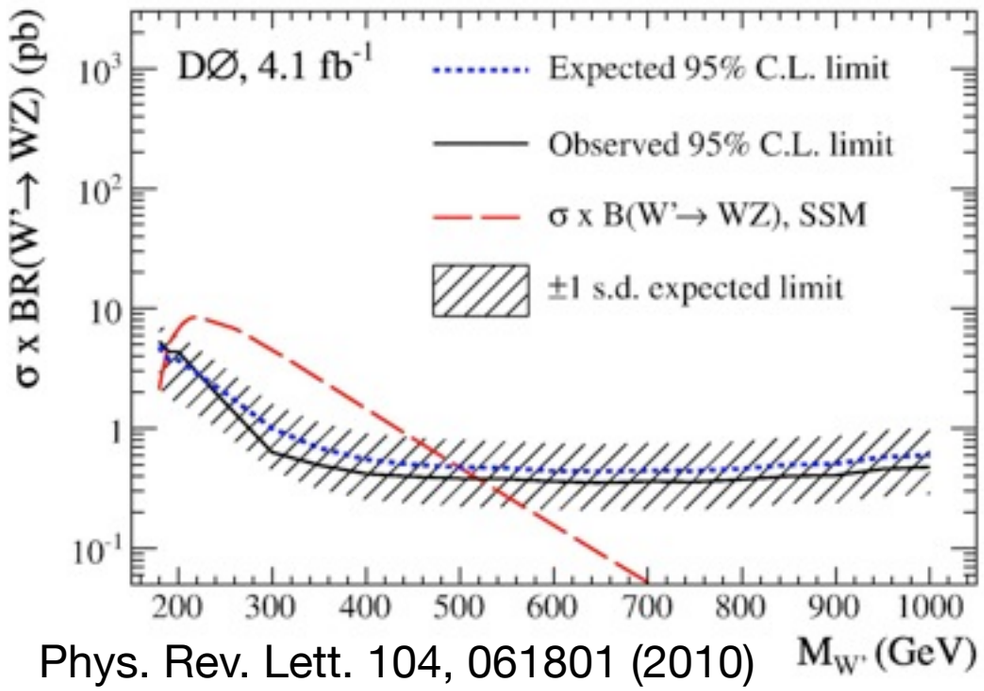
- This is the prime time for the Tevatron
  - RunII game was the luminosity
- 2011 running means >10fb^{-1} per exp.
- Higgs will be very tough but not impossible

BACKUP

Trileptons - Heavy Gauge Boson

- Similar to SUSY chargino/neutralino but high pT → decays to SM gauge boson pair
- large MET and three leptons
  - opposite sign same flavor pair consistent with Z
- Data consistent with SM expectation

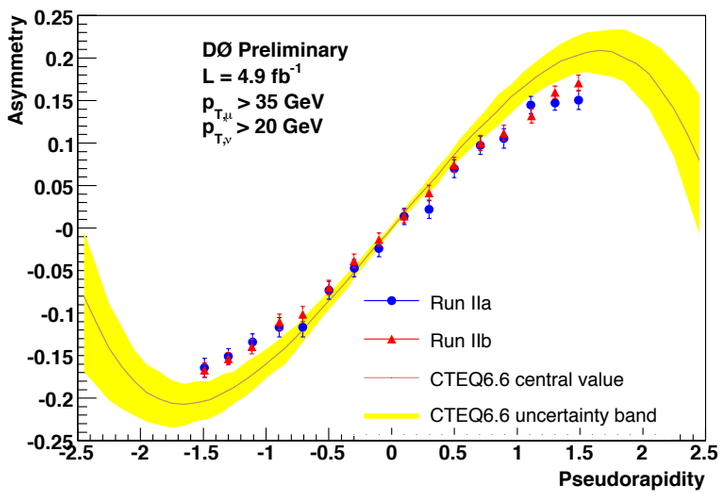


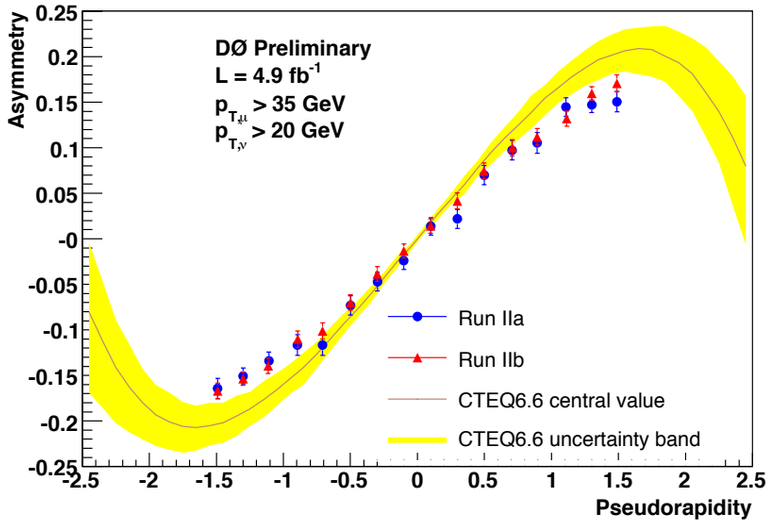


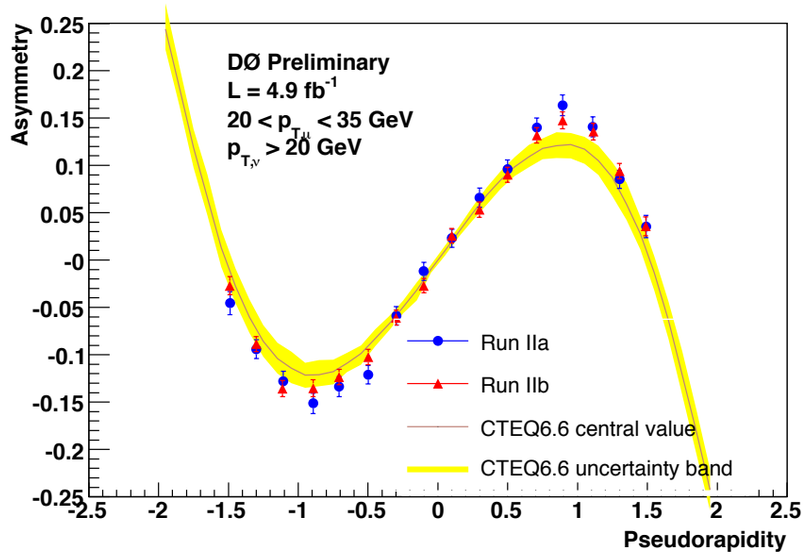
Phys. Rev. Lett. 104, 061801 (2010)

Muon Charge Asymmetry

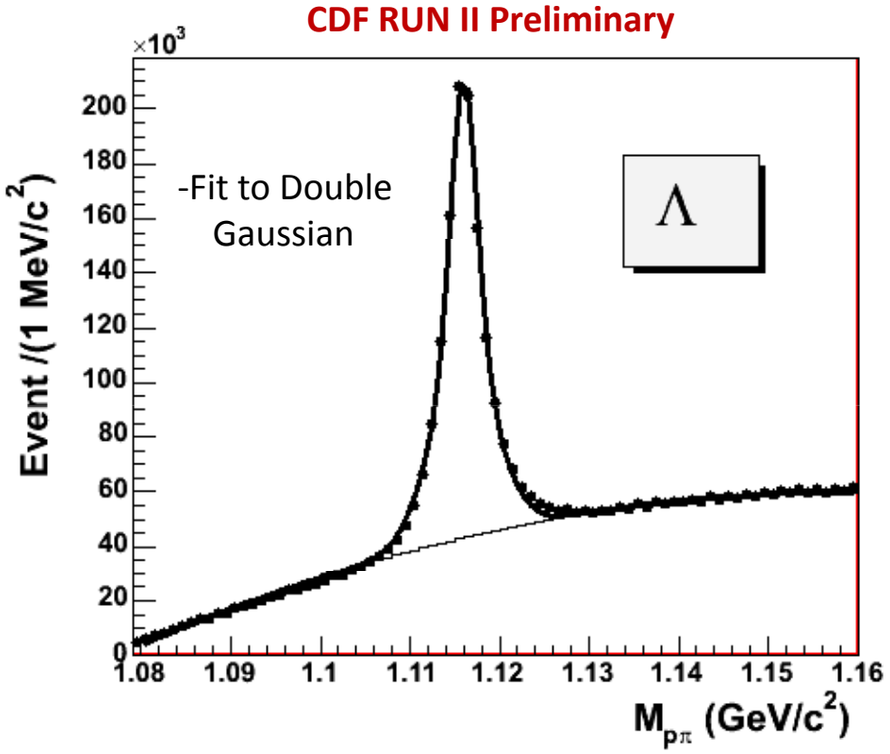
- $pp \rightarrow W+X \rightarrow \mu\nu + X$

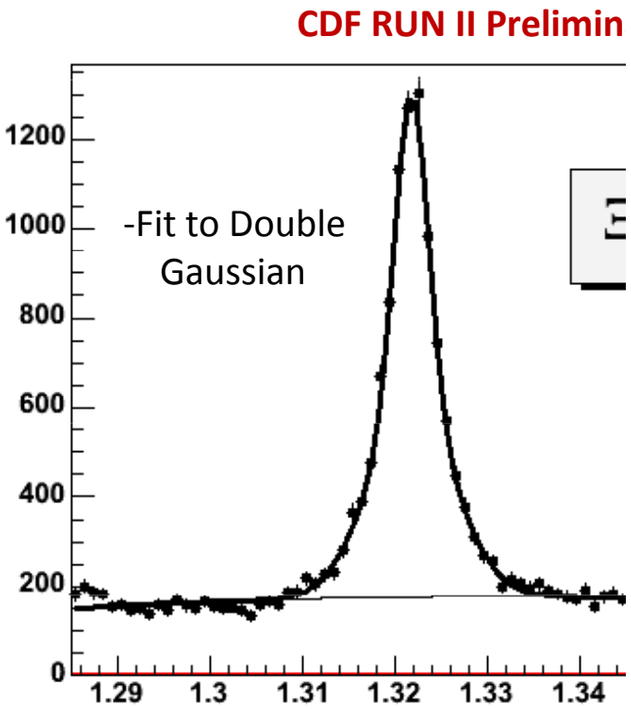


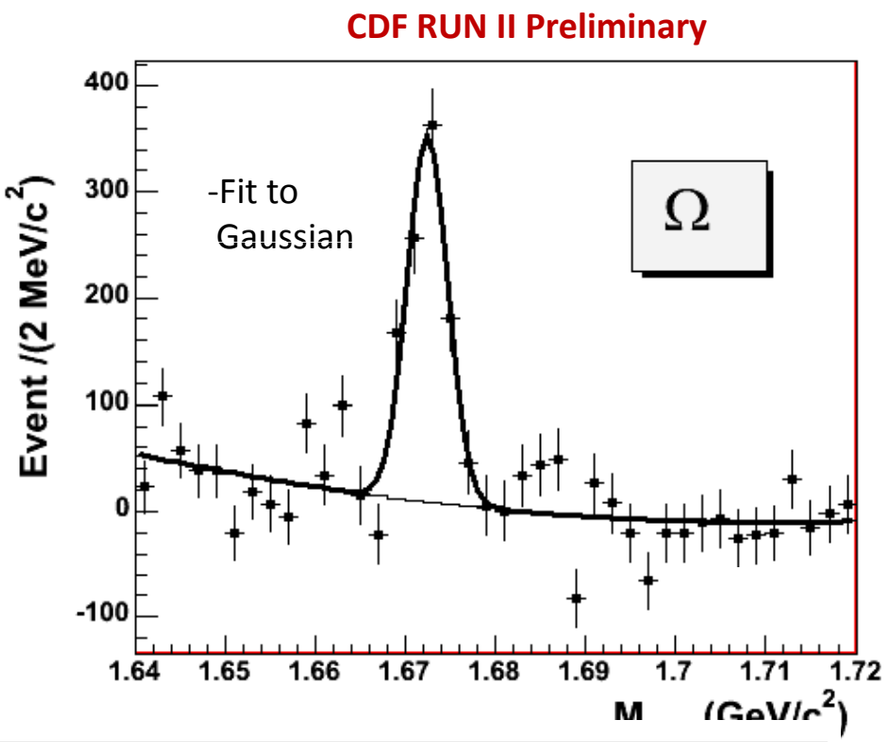




Hyperons







- In the min bias sample:
  - $\Lambda^0 \rightarrow p\pi$
  - $\Xi^{\pm} \rightarrow \Lambda^0\pi^{\pm}$
  - $\Omega^{\pm} \rightarrow \Lambda^0 K^{\pm}$
- pT cross section for hyperon with $|\eta|<1$