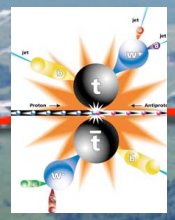
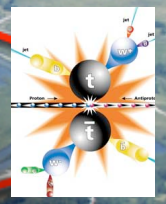
Top Physics from the Tevatron to the LHC

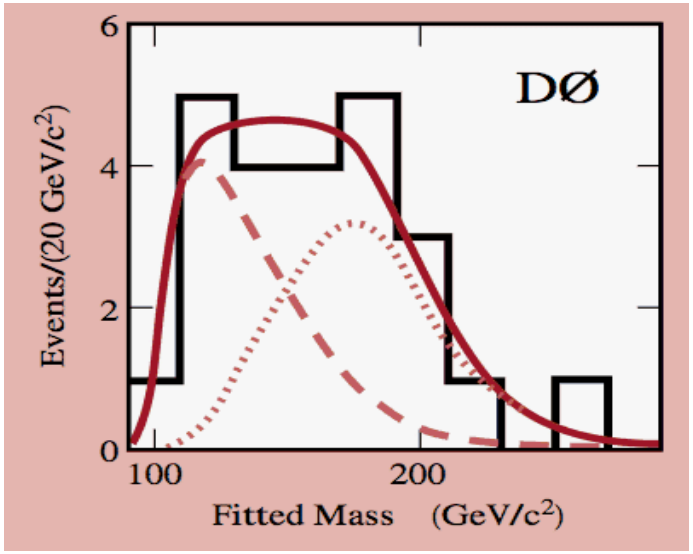


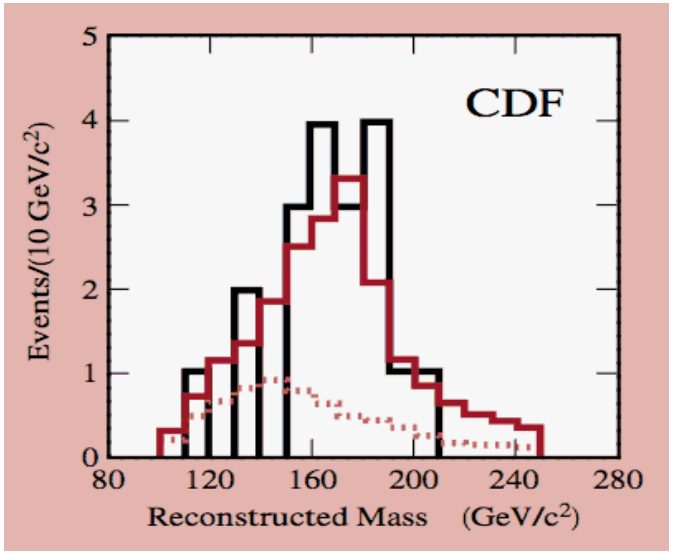


Un-ki Yang
The University of Manchester

3rd Top Workshop, Grenoble, Oct 23-25, 2008

Top Discovery in 1995



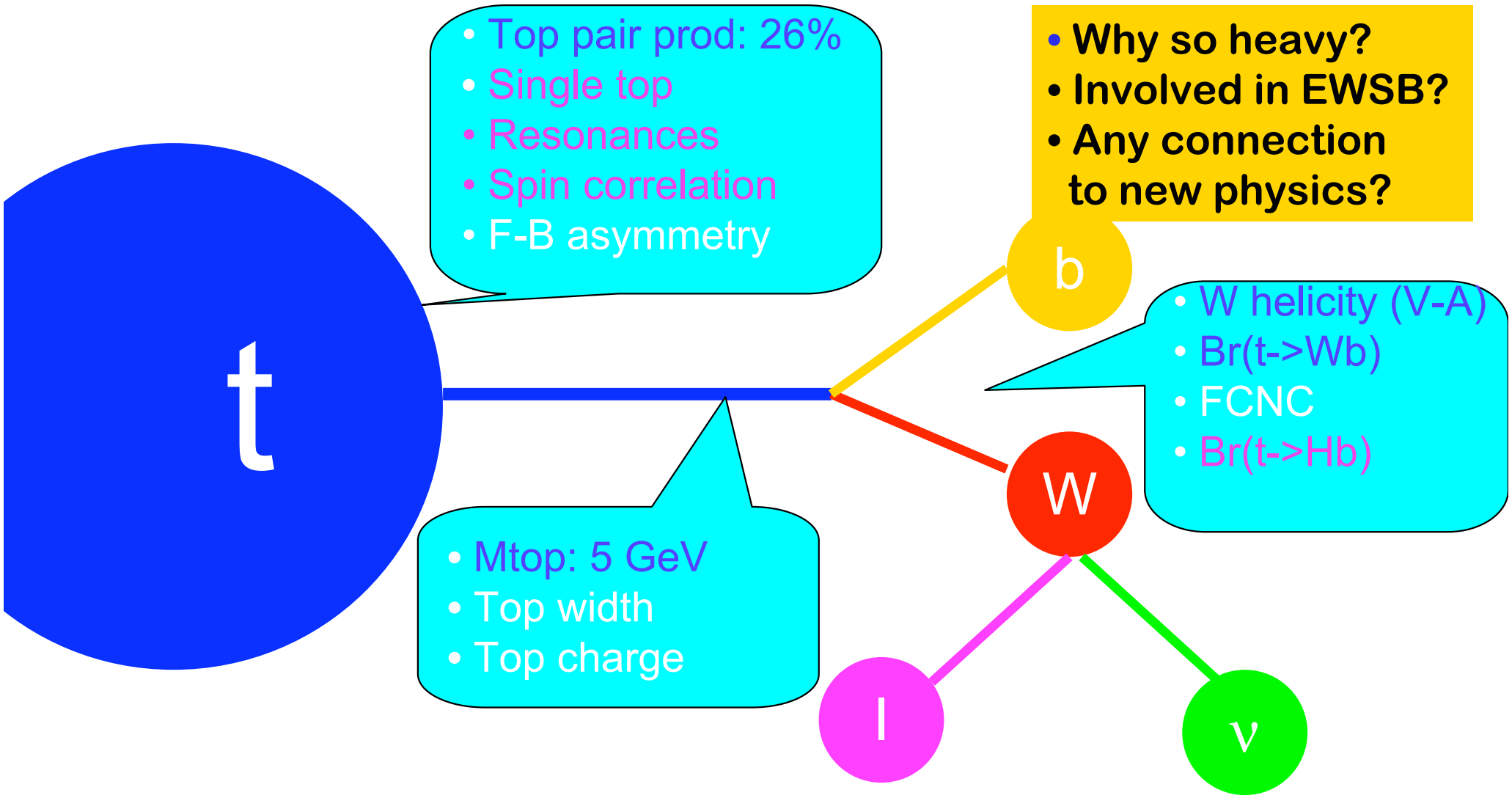


$M_t = 199 \pm 30\ \mathrm{GeV}/c^2$

$M_t = 176 \pm 13\ \mathrm{GeV}/c^2$

- **Surprisingly heavy top!!!**
  - **More surprise to come? like b physics**
  - **b discovery in 1977: large τ (surprise)**
    - **Large B0-$\overline{\text{B0}}$ mixing**
    - **Large ~~CP~~**

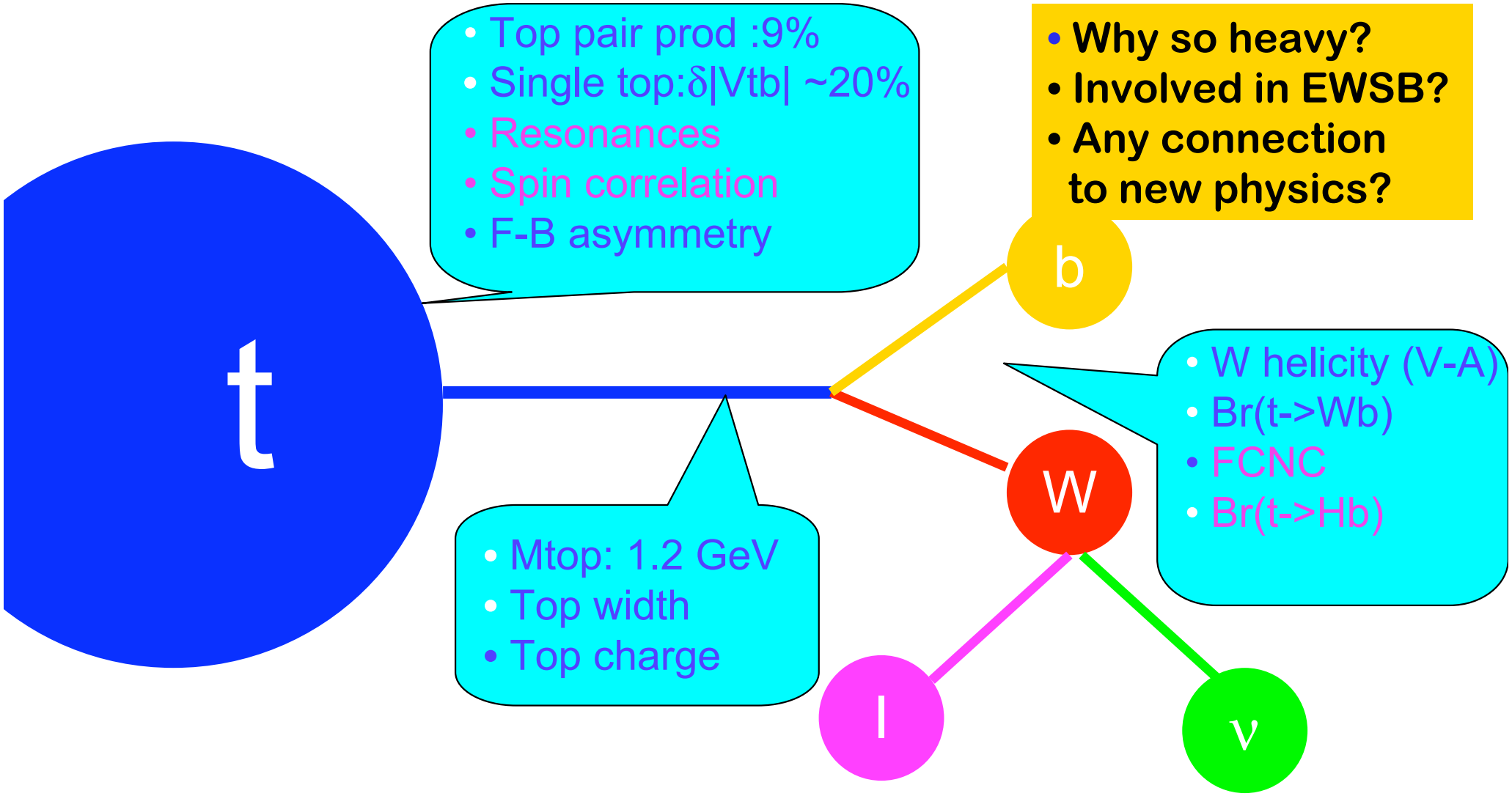
Top Quark Physics



Dark Matter, non-zero m(ν): new physics can be at Terascale.

- **Tevatron & LHC**

Top Quark Physics

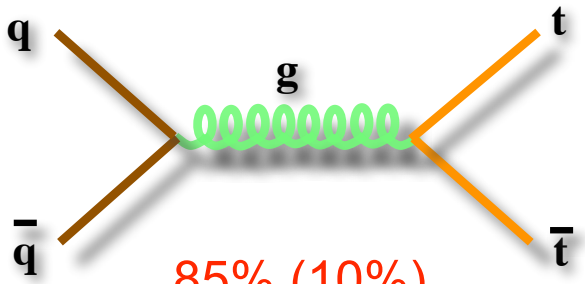


Dark Matter, non-zero m(ν): new physics can be at Terascale.

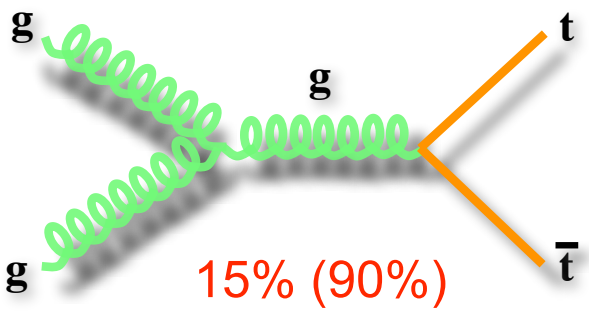
- **Tevatron & LHC**

Top Production

- Mainly produced in pair via strong interaction



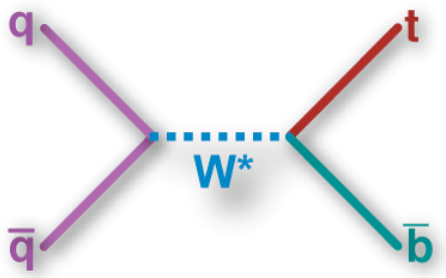
85% (10%)



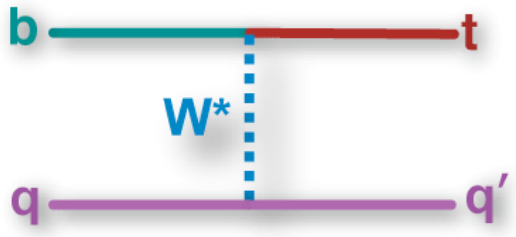
15% (90%)

$$\sigma(\bar{p}p \to t\bar{t}\ @\ M_{\text{top}} = 175\ \text{GeV/c}^2) \approx 6.7\ (840)\ \text{pb}$$

- Single top production



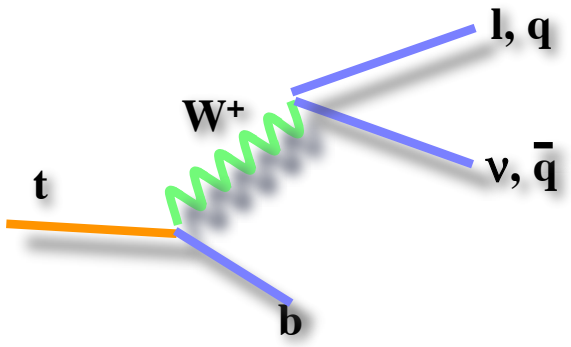
s-channel ~1 (11) pb

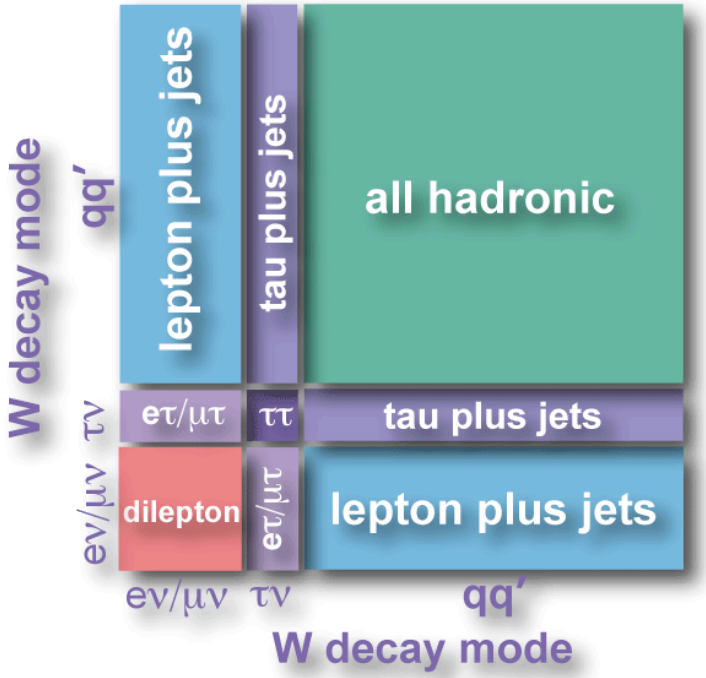


t-channel ~2 (250) pb

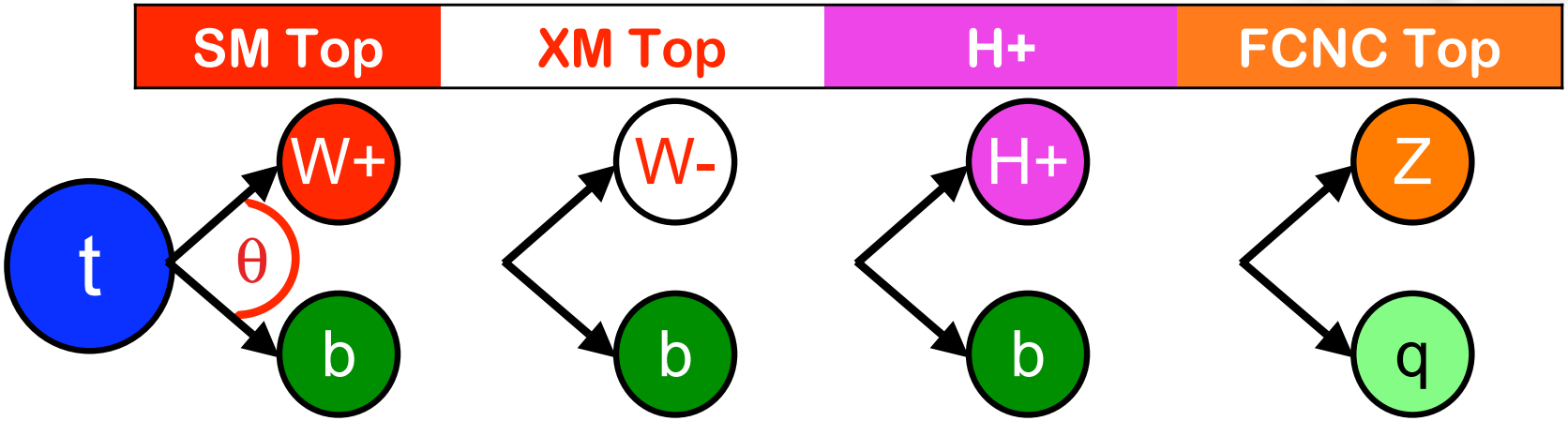
Top Decays

- In SM, top $\rightarrow$Wb (100%) as free quark with $\tau_{top} \sim 10^{-25}$ s

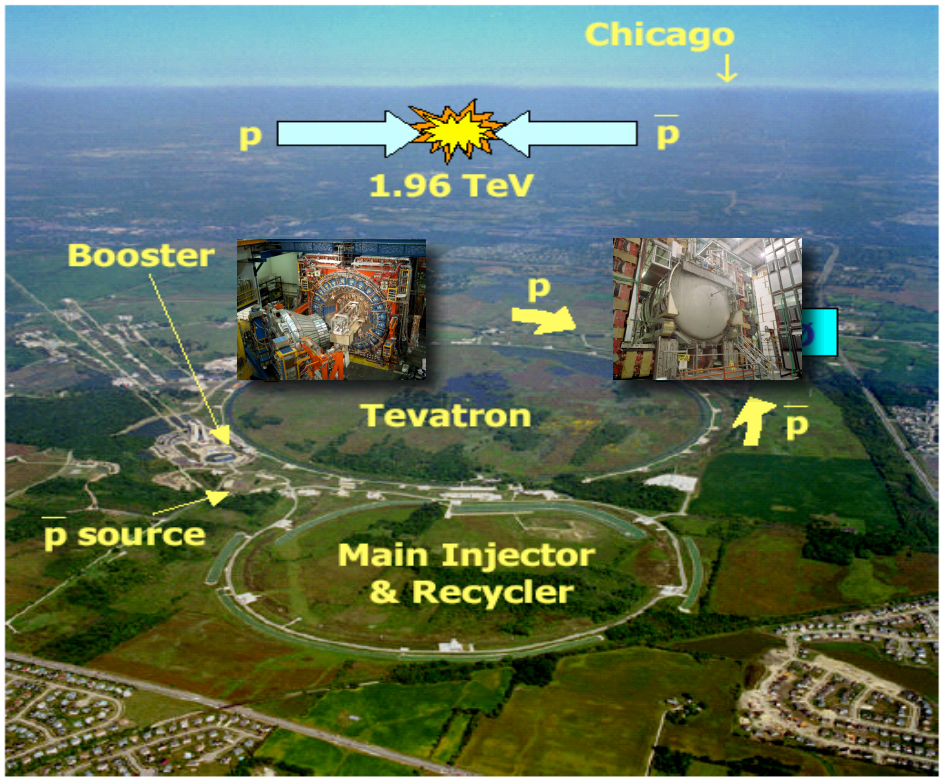


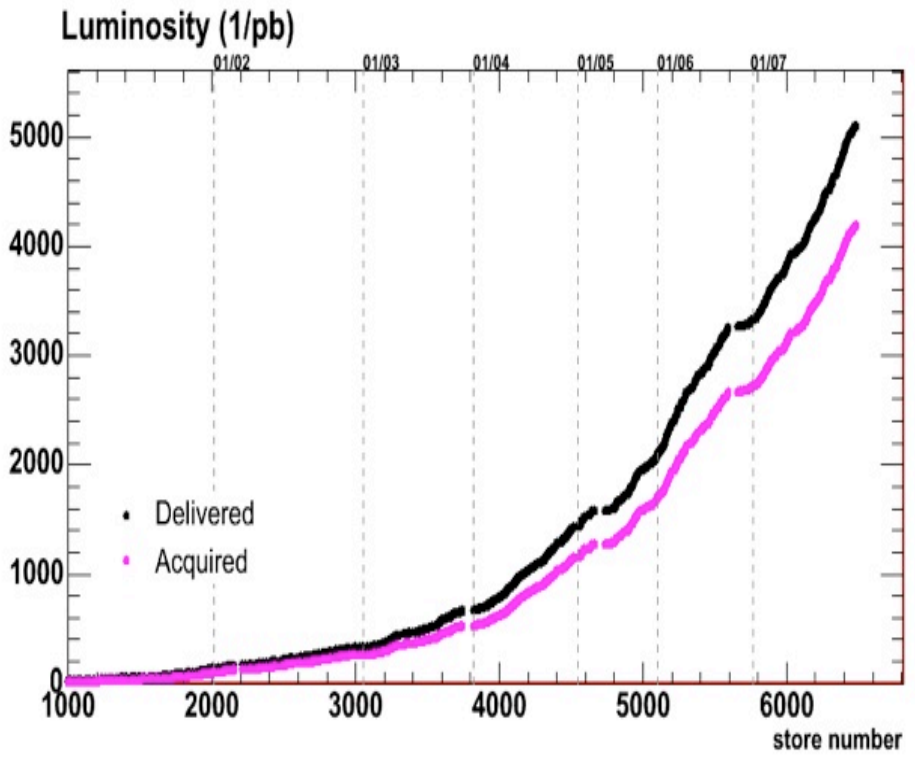


- Explore properties and search for new physics



Tevatron : Great Performance

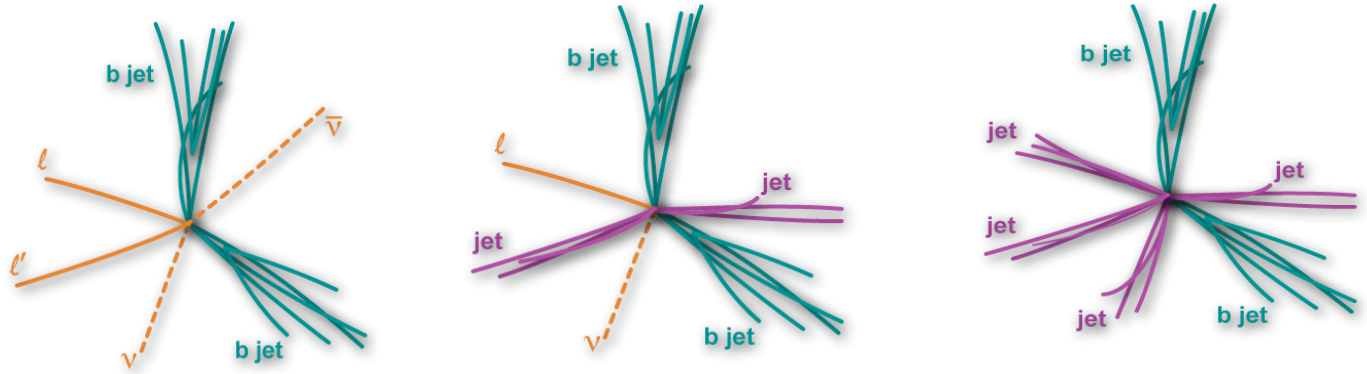




- Record inst. luminosity: $3.15 \times 10^{32}\ /cm^2 s$
- Both experiments: $4.2\ fb^{-1}$ on tape :

Top identification

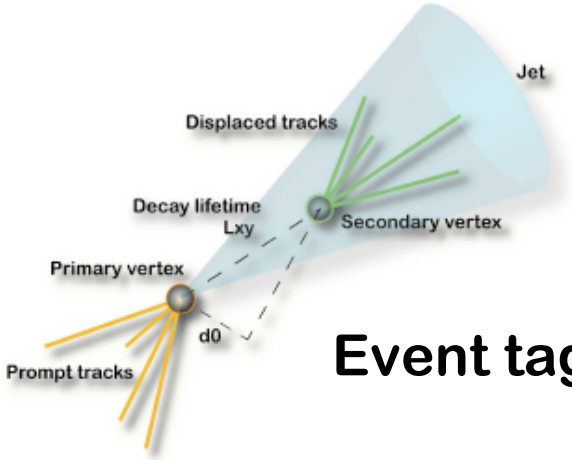
- Top events: high-pt lepton, b jet, light-quark jet, MET(ν)



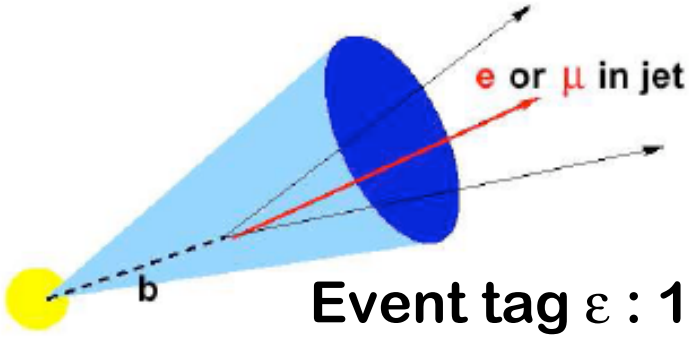
Evts: 2fb^{-1}	Dilepton	Lep + Jets	All Had
13k	0.7k →100	4k→400	6k→600

τ not

- B-jet identification: decay length (Lxy ~ 3mm), semi-lep. b decay

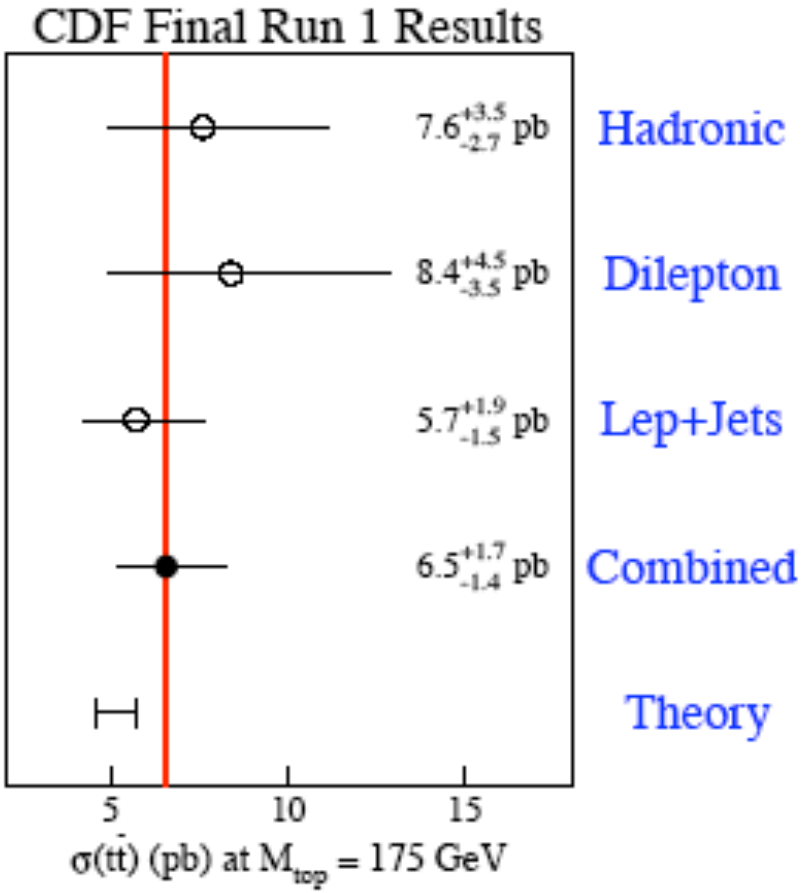


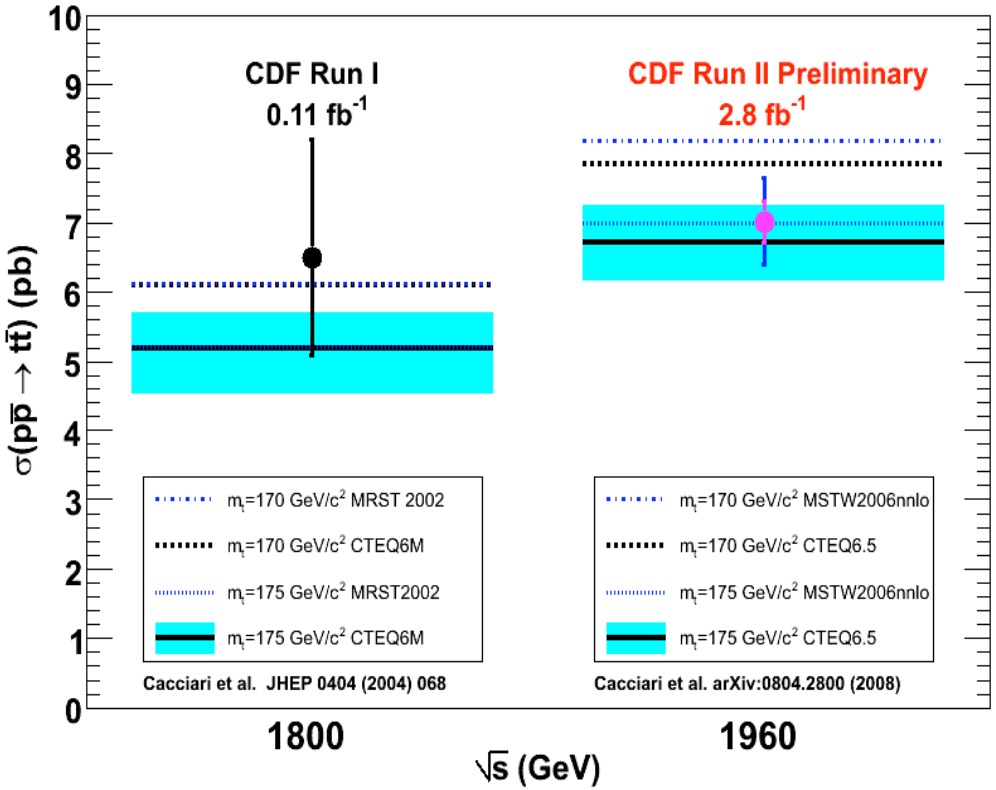
Event tag ε: 60%



Event tag ε : 15%

Top Pair Cross Sections

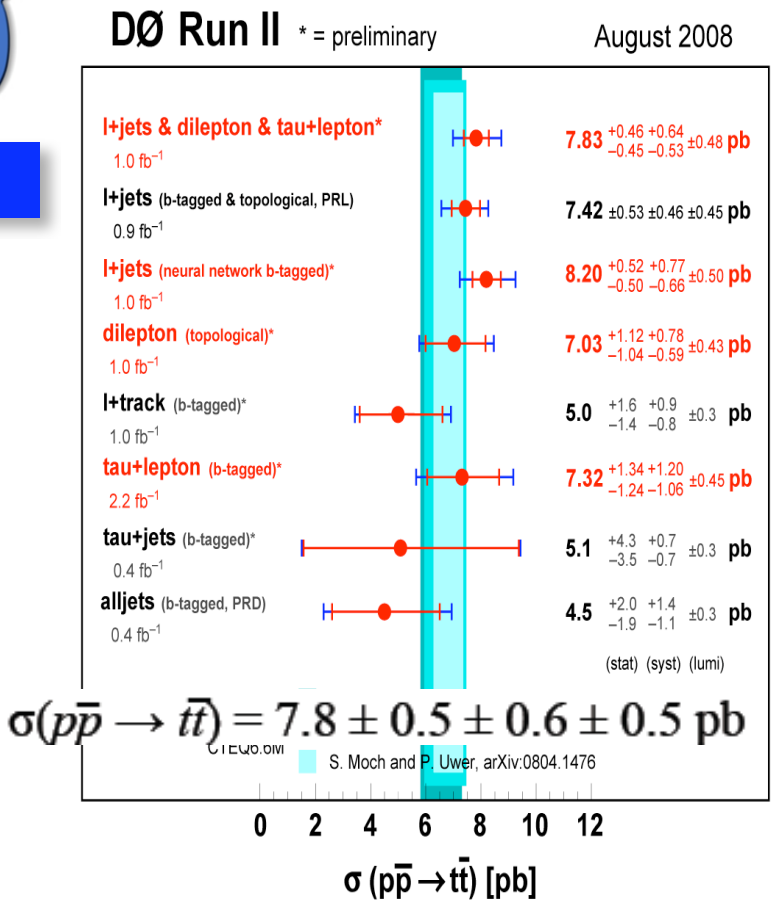


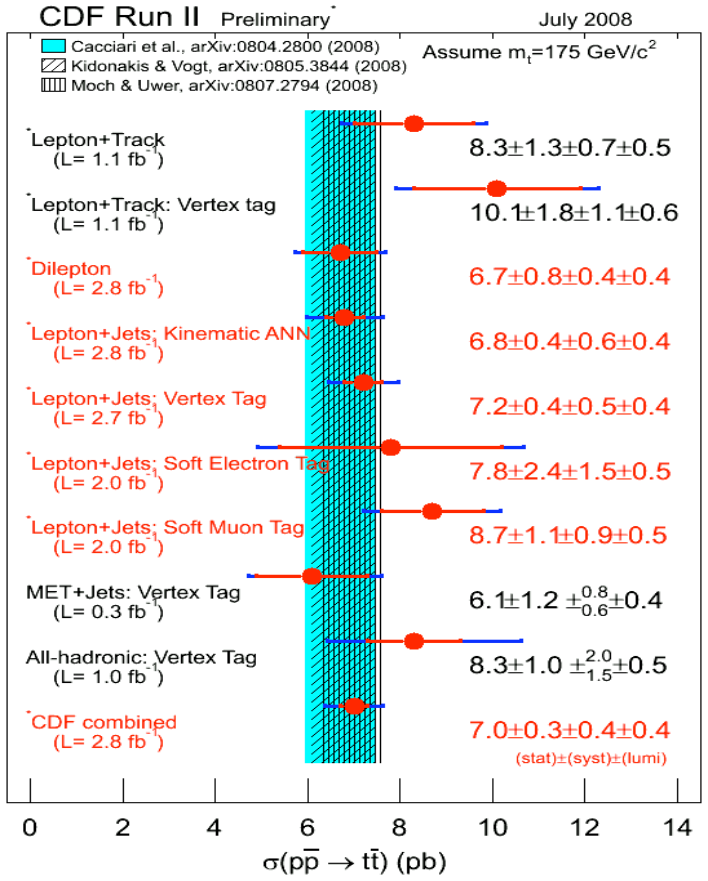


Run I: 26%, Run II goal @ 2 fb^{-1} : <7%
CDF (~9%)@2.8fb^{-1}, D0(~12%)@1-2 fb^{-1}

Cross Section Summary

1~2 fb^{-1}



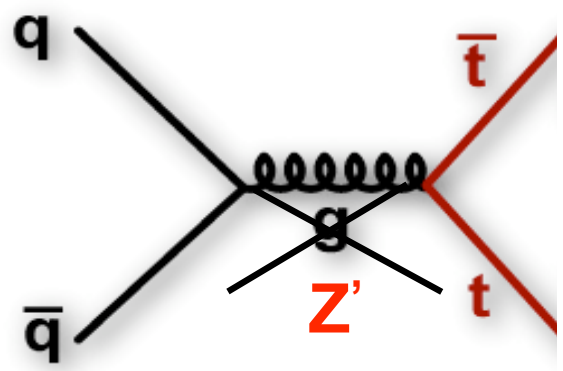


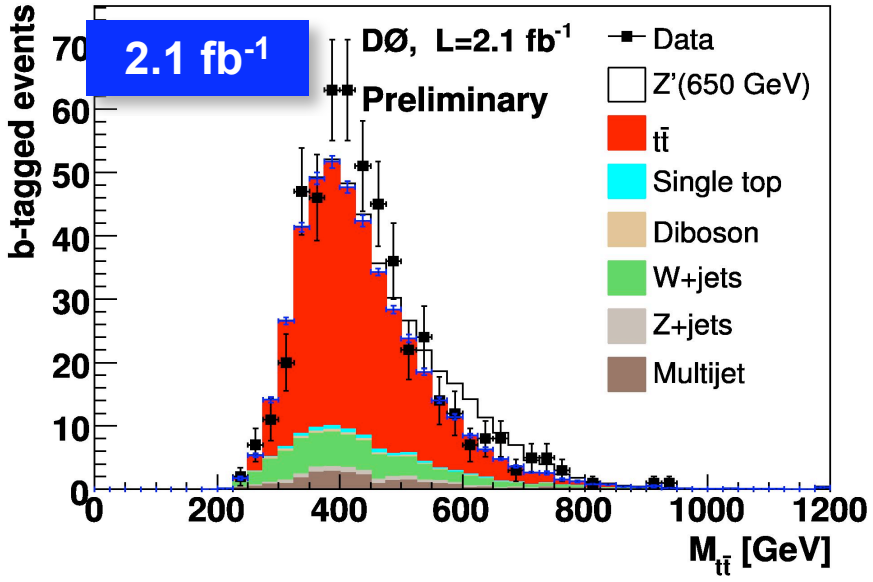
~2.7 fb^{-1}

- All consistent: combined $\delta\sigma$: ~10%, $\delta\sigma$(theory) <15%
- Lepton+jets: the most precise, dominated by b-tag and lum.
- Understanding of b-tag, JES, W+HF, and fake-leptons was crucial: many tool have been developed

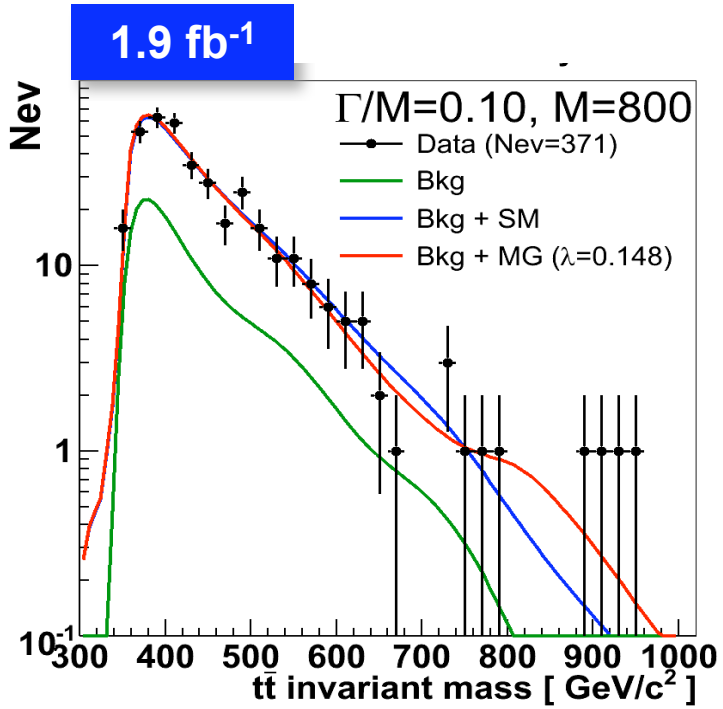
Resonances Search: dσ/dM

- Direct search for heavy resonance
  - New heavy particle coupled with 3rd gen. family
  - A narrow-width Z', top-color



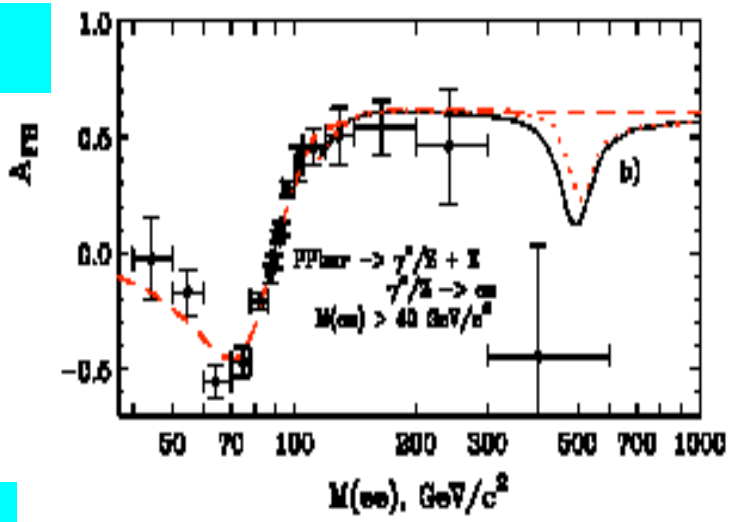


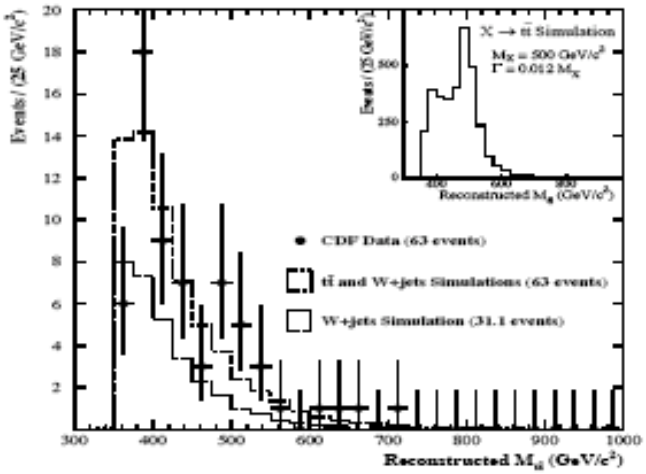
$M_{Z'}$>760 GeV for $\Gamma_{Z'}/M_{Z'}$ =1.2%



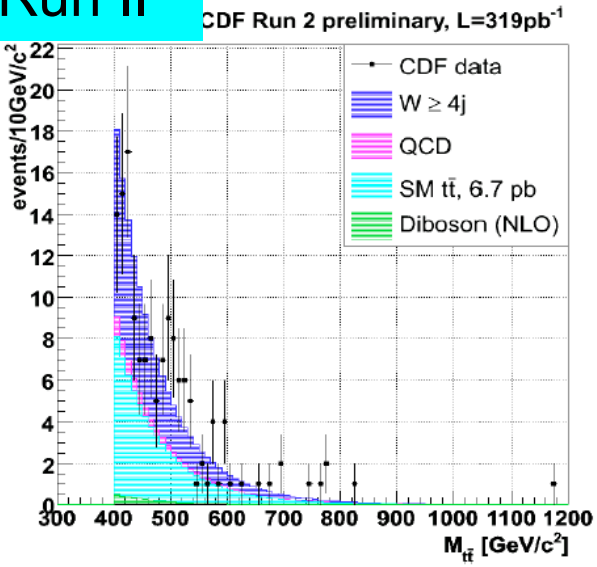
Resonance at 500 GeV/c^2 ?

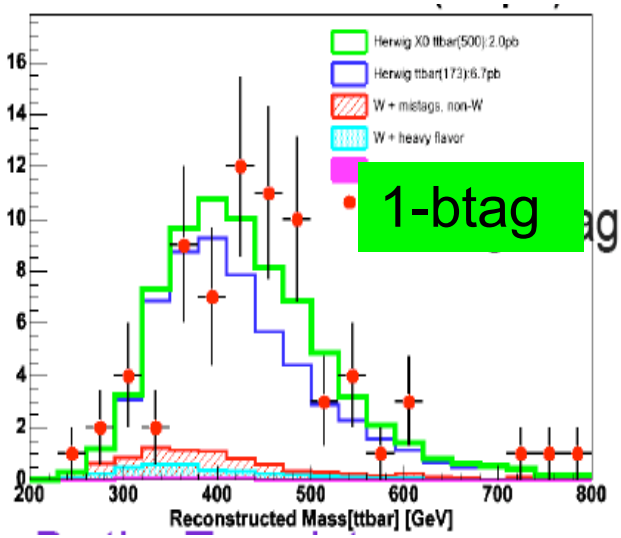
Run 1

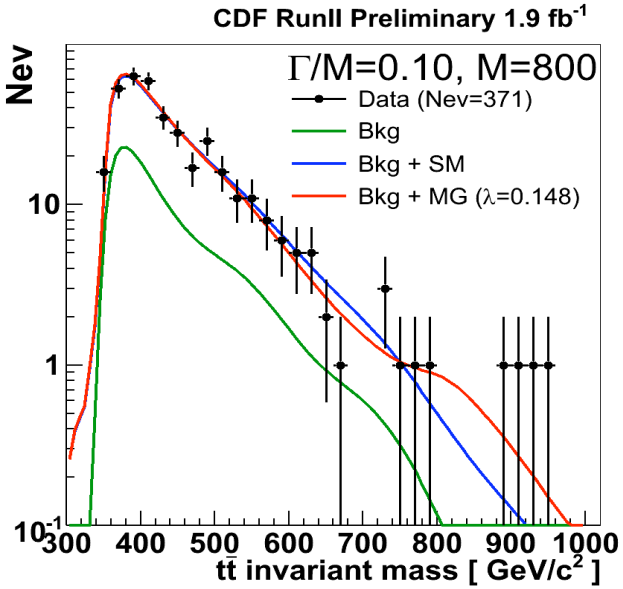




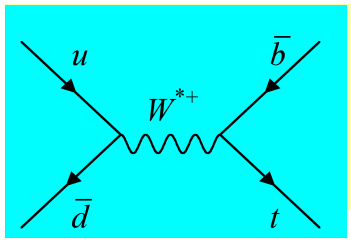
Run II



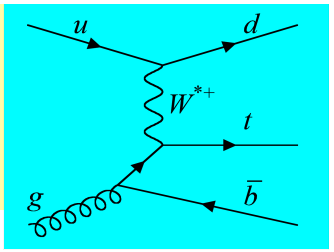


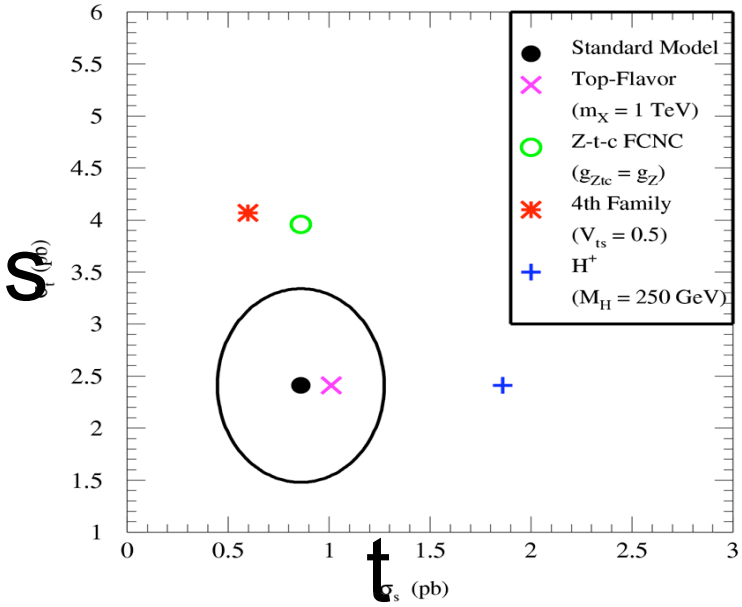


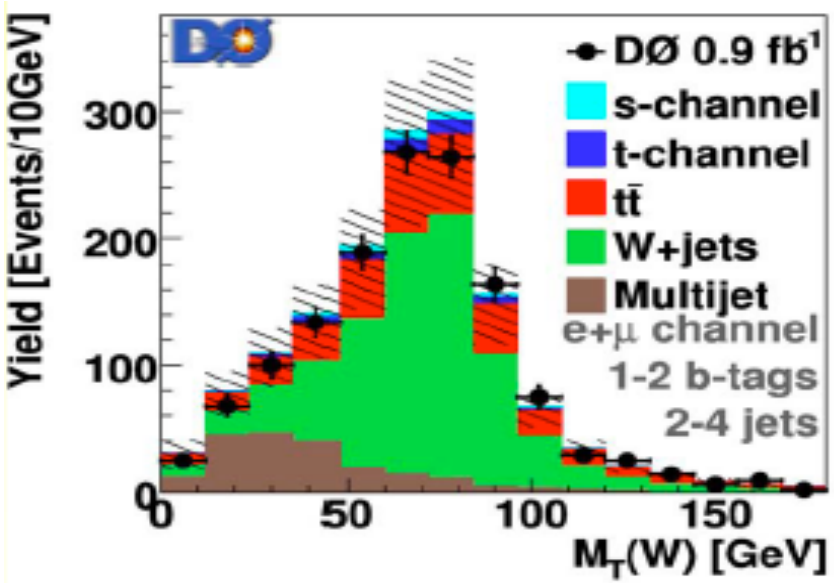
- Interesting fluctuation disappeared.
- Quite interesting exercise!!!



Why Single top?



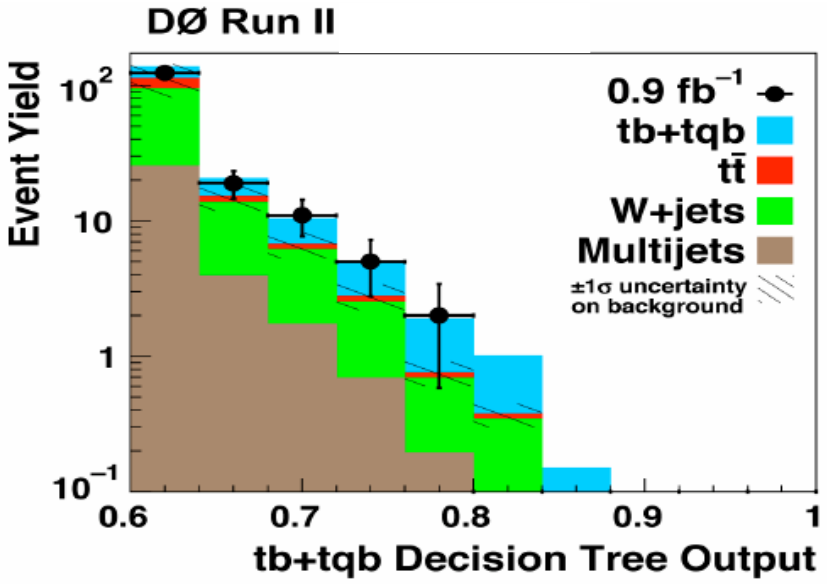


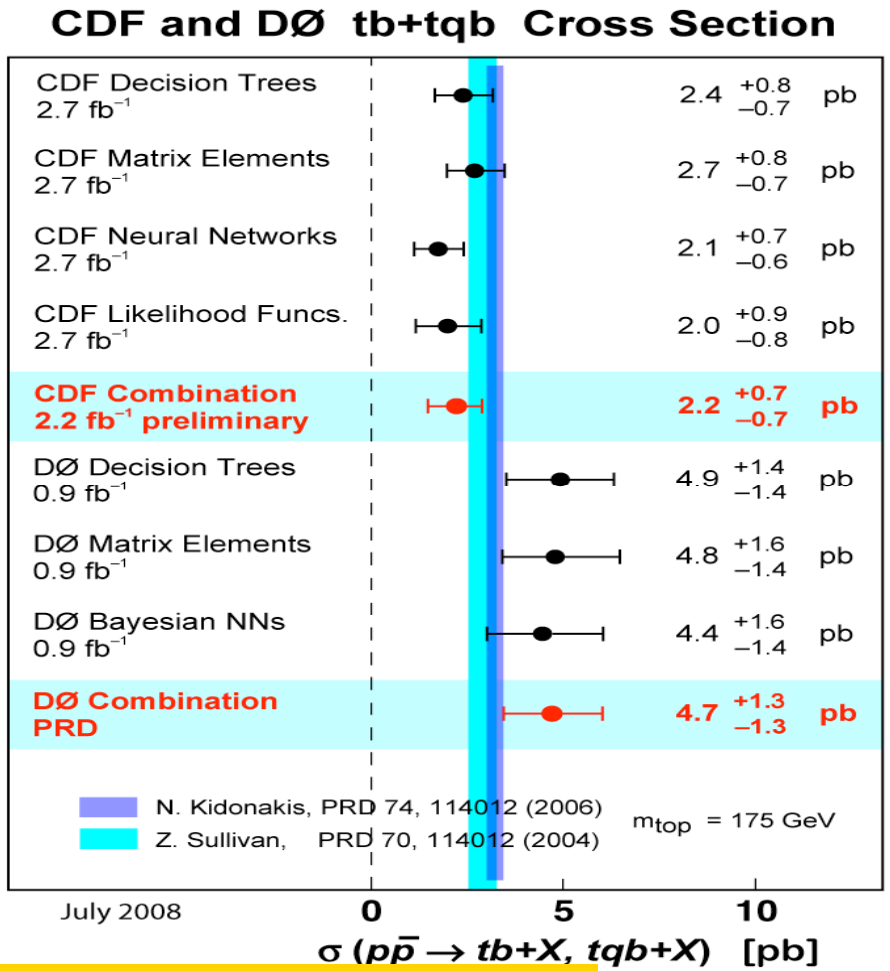


- Direct measurement |Vtb| : run II goal: 10% precision
- Different s/t-ch sensitivity to new physics
- A background to WH→lνbb
- Its backgrounds are backgrounds to WH→lνbb (W+jets, ttbar, QCD, dibosons)

- But signals are swamped by huge backgrounds
- Drive many advanced techniques
  - Neutral networks
  - Boosted Decision Tree
  - Matrix Element
  - Likelihood

Single top cross section





First direct measurement of V_{tb}:
$0.68 < |V_{tb}| < 1$ @ 95%CL
or $|V_{tb}| = 1.3 \pm 0.2$

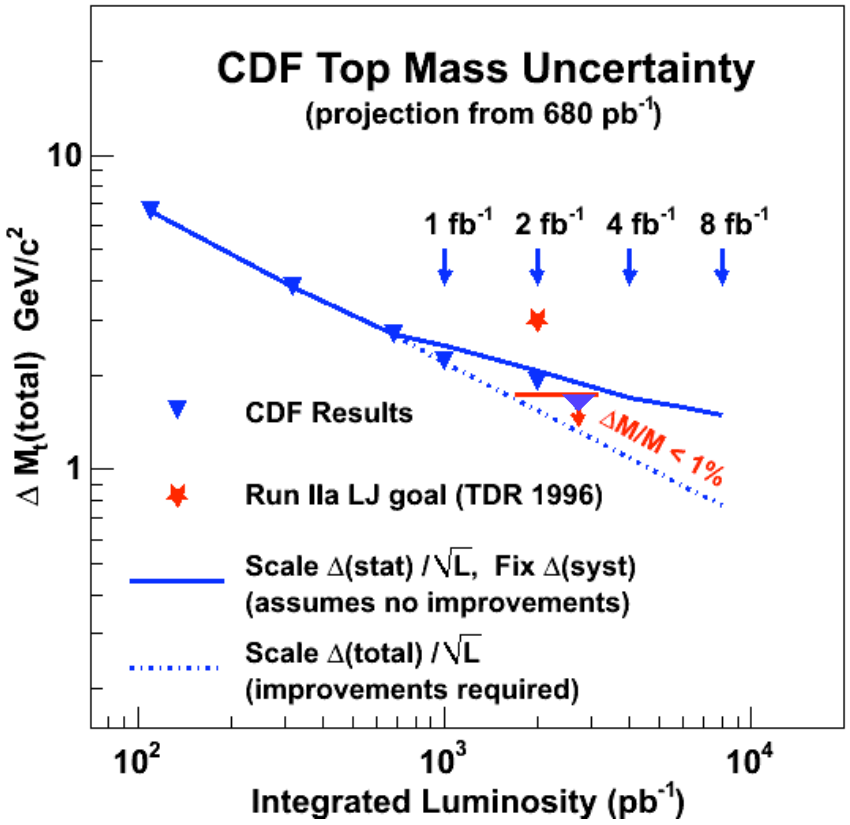
A great testing ground for making a discovery using advanced signal/bkgds separation techniques

Un-ki Yang, Grenoble, 2008

Top Mass

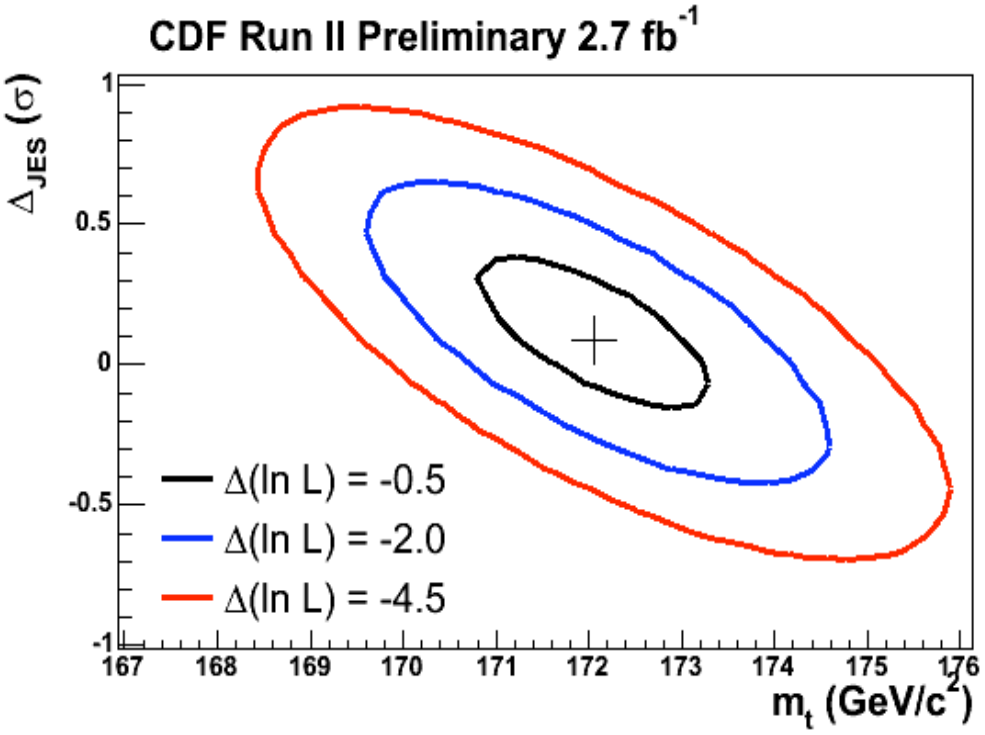
- A fundamental SM parameter
- Constrain the SM Higgs mass
- Main player in BSM physics

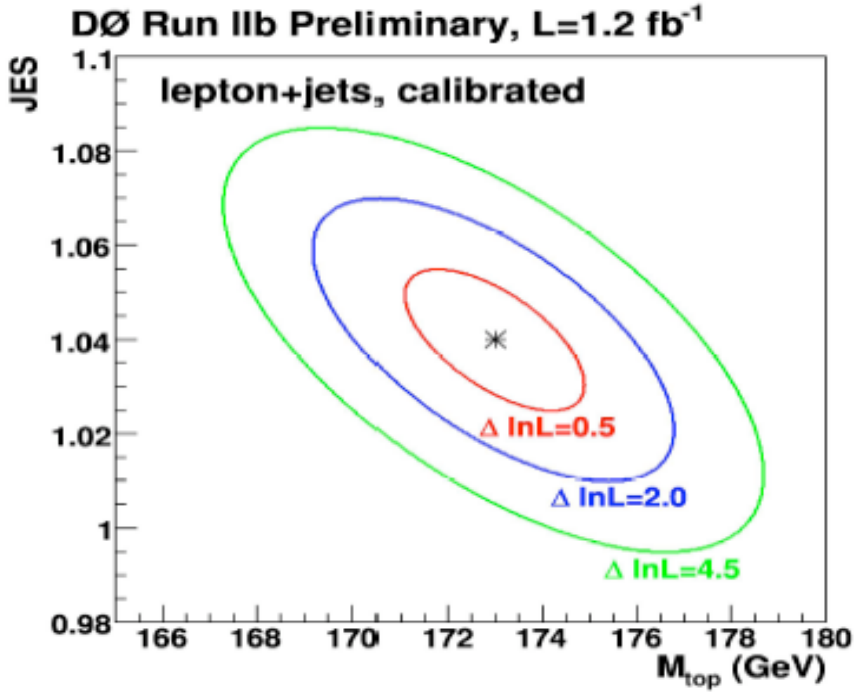
- RunII goal: 2GeV
- Challenges
  - Extra jets
  - Combinatorics
  - Jet energy scale
- Solutions
  - In-situ W→jj calibration:
    ~1.3%@1.7fb^{-1}
  - Sophisticated methods:
    - ME (powerful in low statistics)
  - Coherent works with many diff. Groups (MC, Jet, ID, triggers etc)



Top Mass

- Precision & consistency
  - Different channels (with/out b-tag)
  - Different methods (template, ME, Lxy, Pt(lep))
- New Physics (bias)





$m_t = 172.2 \pm 1.0 \pm 1.3$ GeV

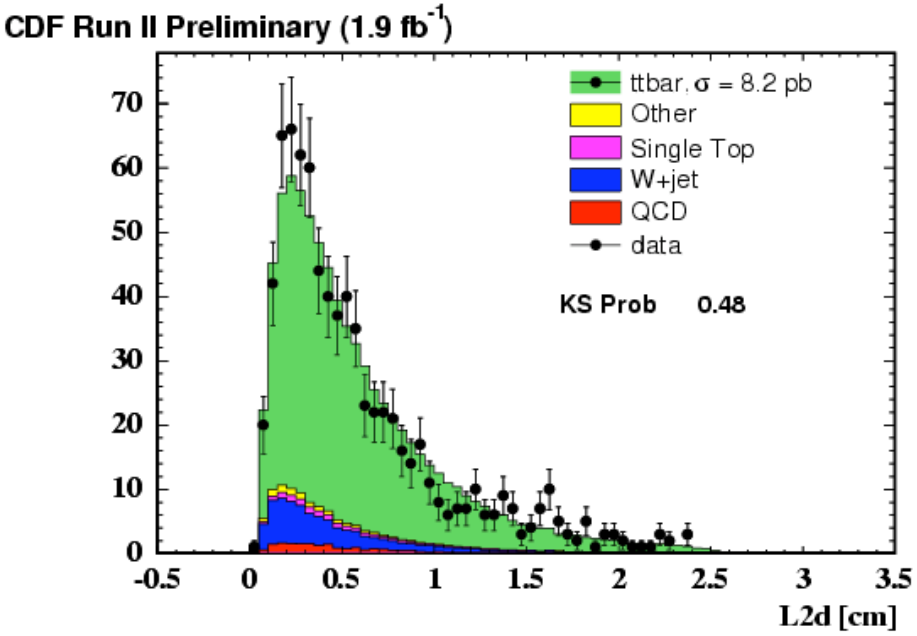
DØ Run II combined (2.2 fb^{-1})

$m_t = 172.2 \pm 1.0 \pm 1.4$ GeV

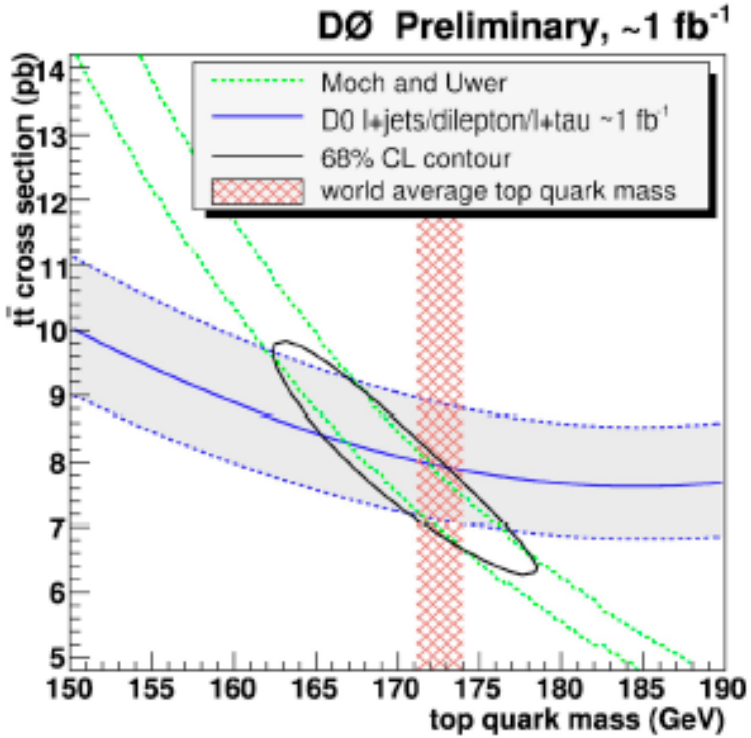
Lepton+Jets: Matrix Elements

New Ideas: Top Mass

- Lepton Pt, b decay length
  - Insensitive to JES
- Cross sections
  - Well defined mass



$m_t = 175.3 \pm 6.2 \pm 3.0$ GeV



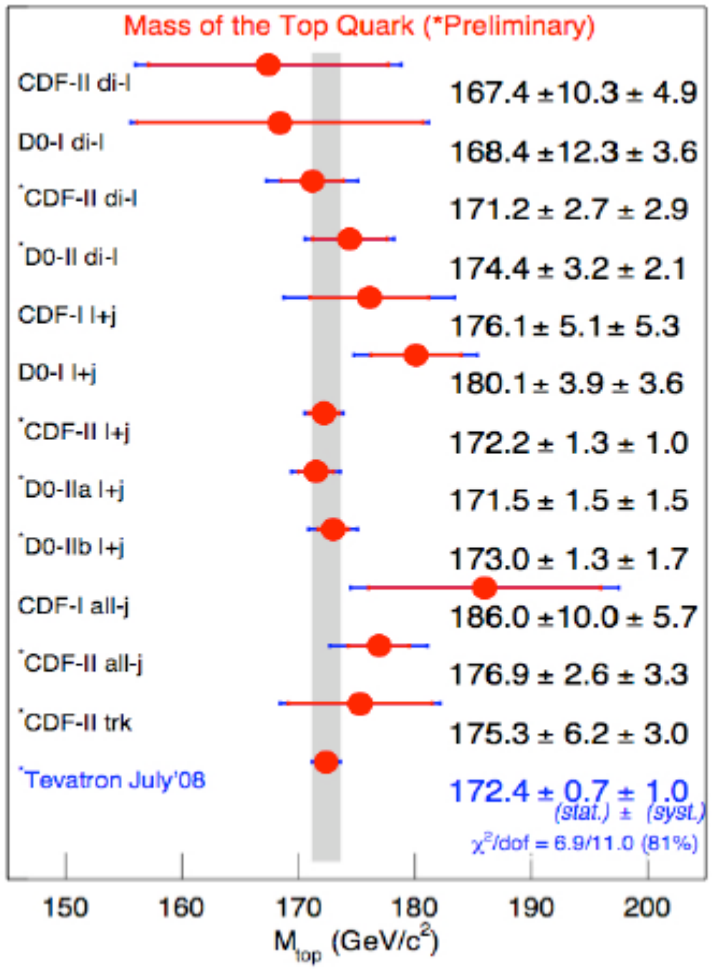
Approx NNLO cross section:

S. Moch and P. Uwer (2008)

$m_t = 169.6 \pm 5.4$ GeV

- Stat. limited
- Promising at the LHC

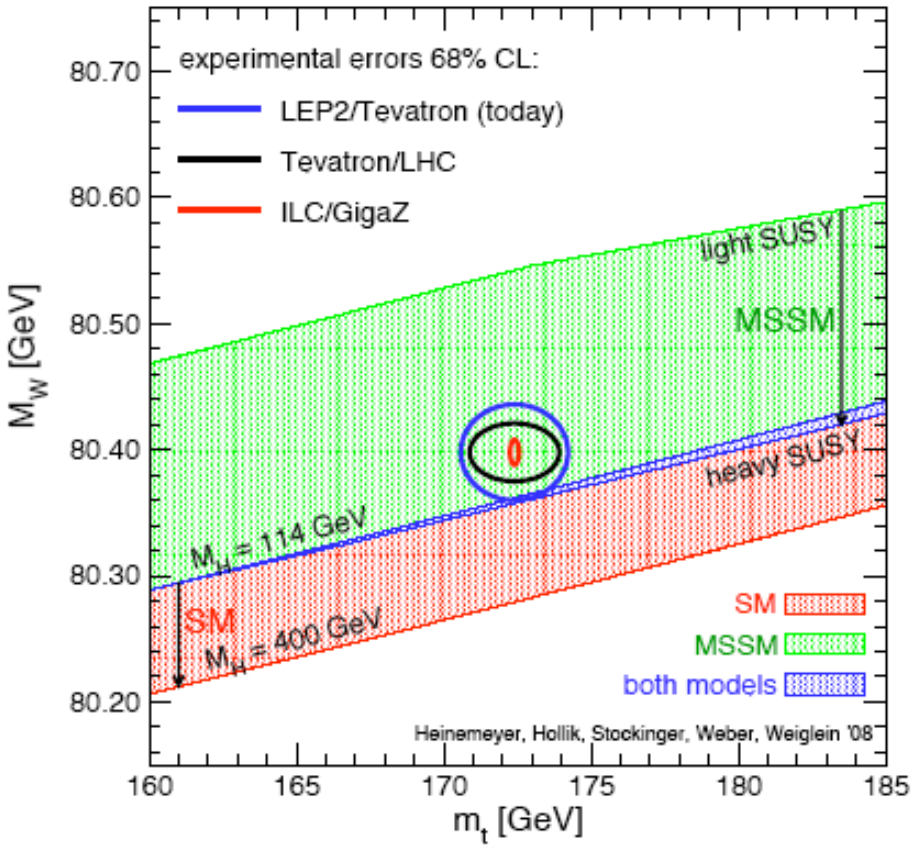
Tevatron Combination: July 2008



$M_{top} = 172.4 \pm 1.2$ GeV

0.7% precision

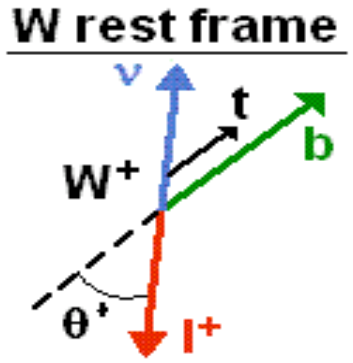
$M_H < 154$ GeV/c^2 @95%C.L

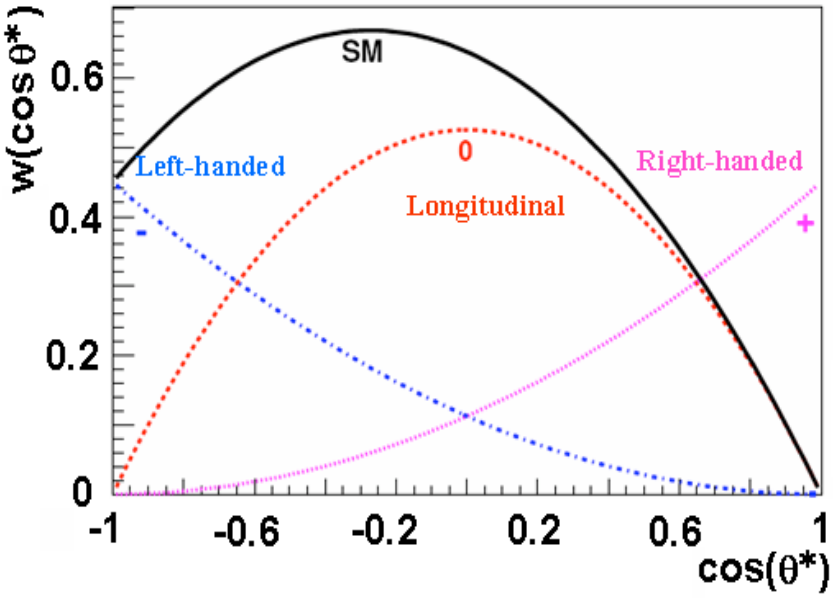


Into a new phase
- **color connection**
- **mass definition**

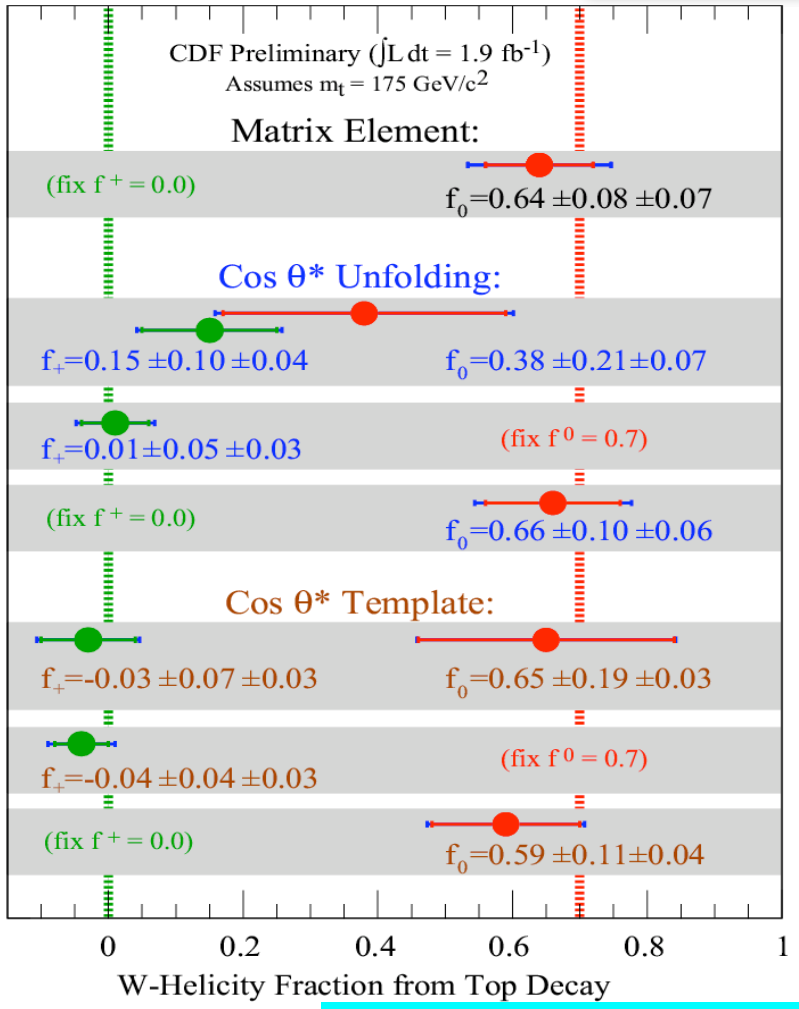
W Helicity

- The V-A nature of the decays:
  only 2 helicities allowed
  SM : $F_- = 0.3$, $F_0 = 0.7$, $F_+ \approx 0$





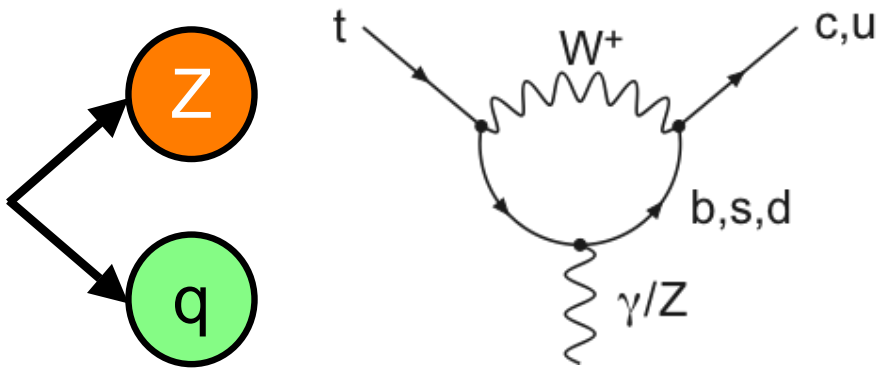
1.9 fb^{-1}

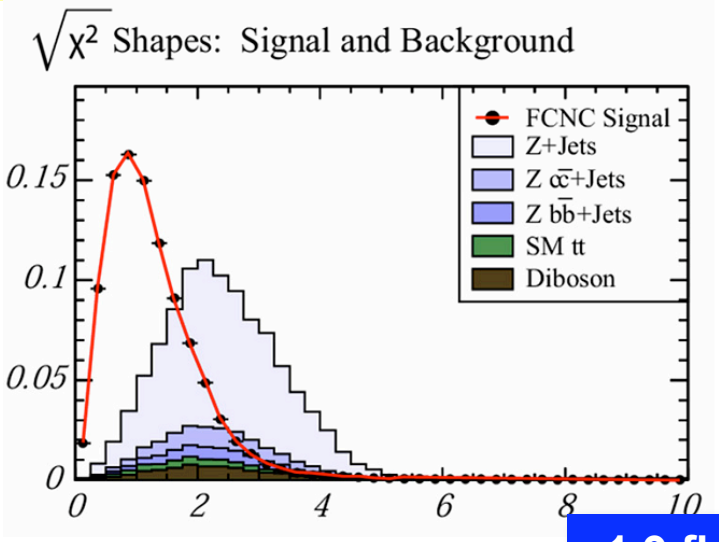


Combined

$F_0 = 0.66 \pm 0.16$
$F_+ = -0.03 \pm 0.07$

FCNC Search

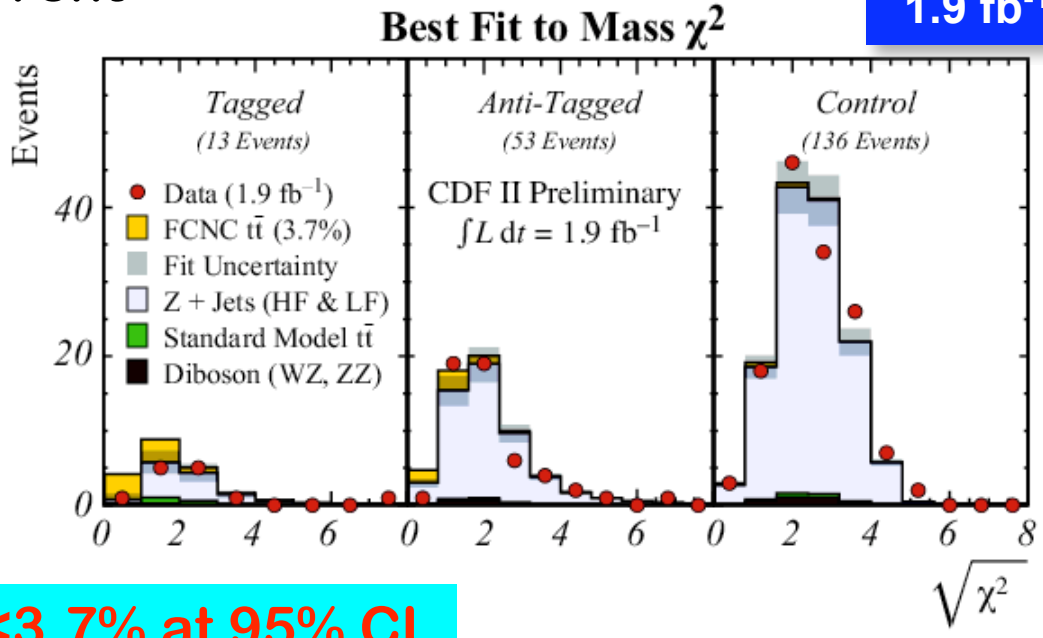




- **Flavor Changing Neutral Current**
  - **Highly Suppressed**
  - **Br(t →Zq) = O(10^{-14})**
  - **Any signal: new physics**

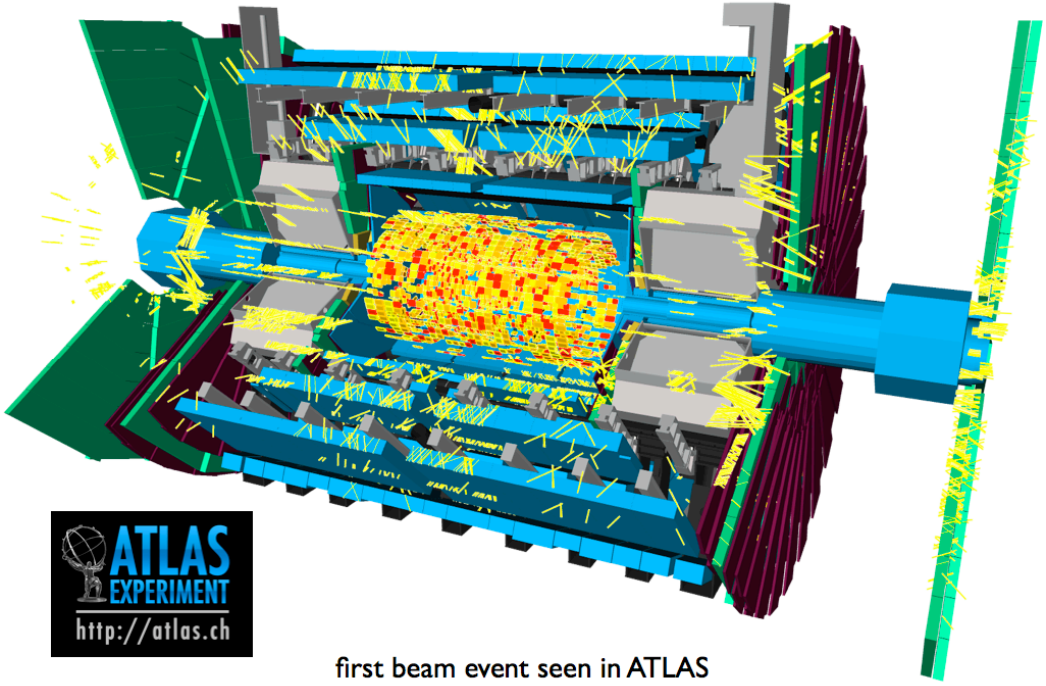
- **Method:**
  - **Z + 4 Jets (t →Wb, t →Zq)**

1.9 fb^{-1}

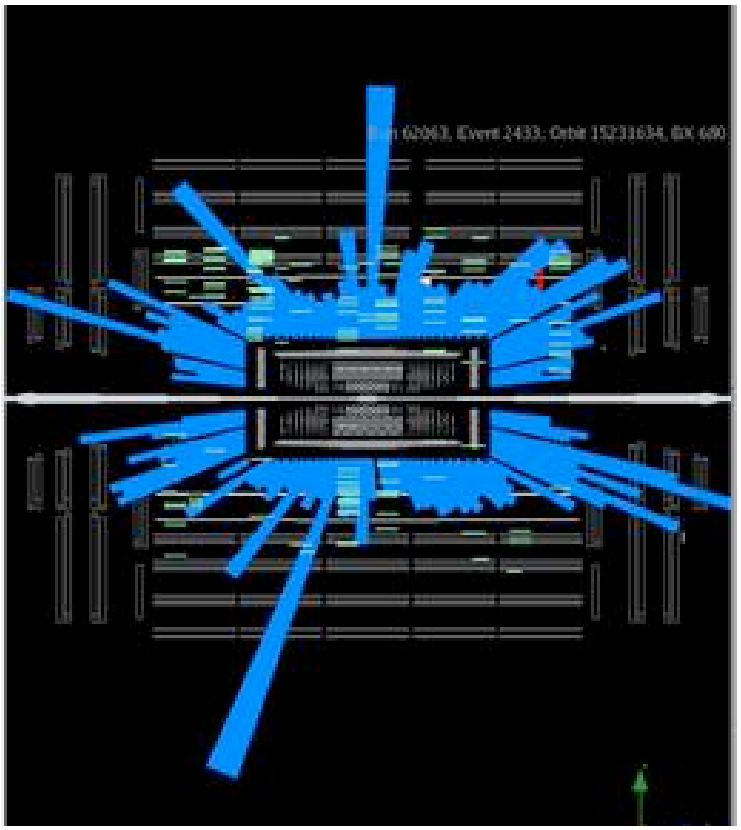


BR(t→Zq)<3.7% at 95% CL
improved by factor of 3.5

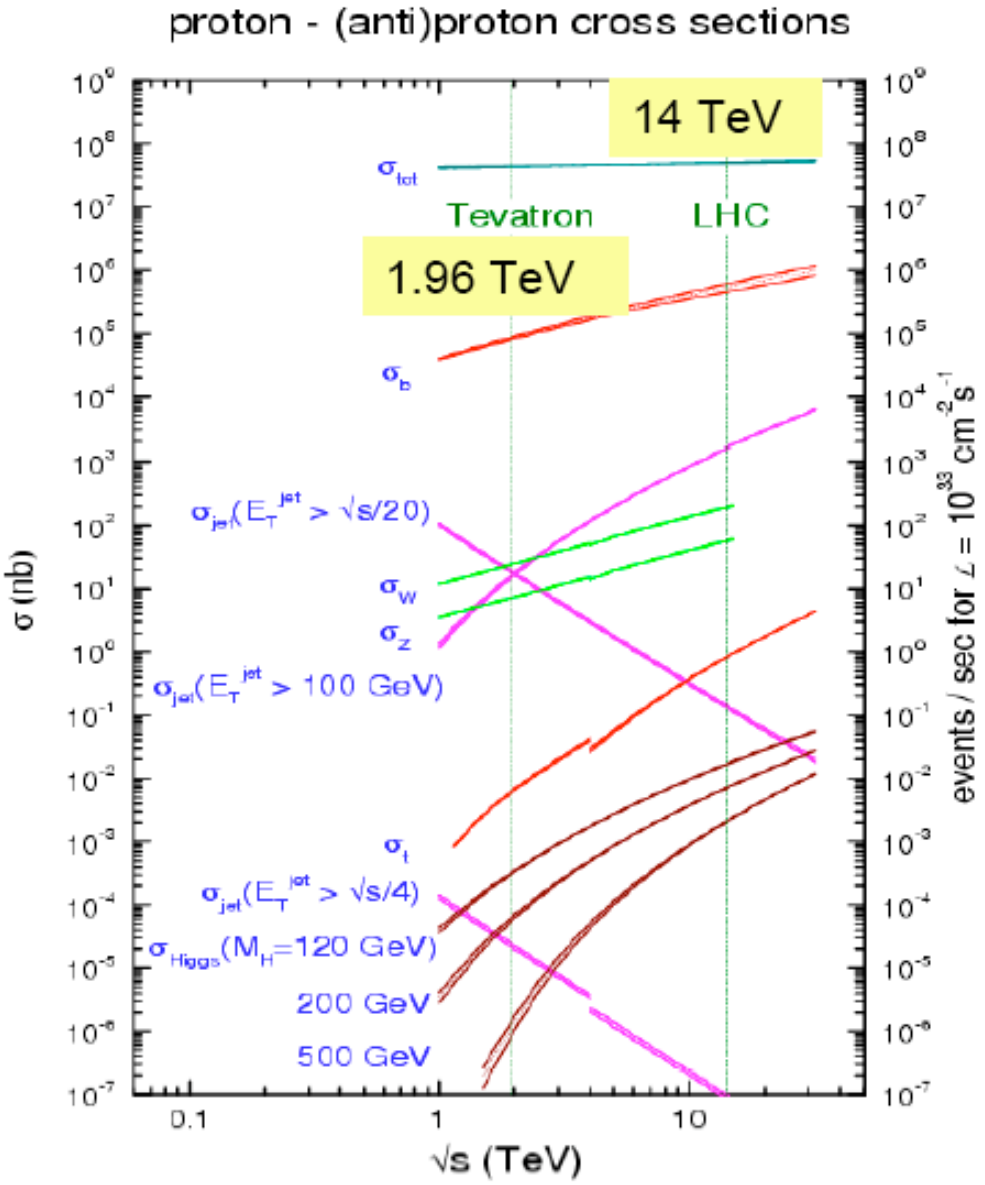
Prospects at the LHC



first beam event seen in ATLAS



Top Physics at the LHC

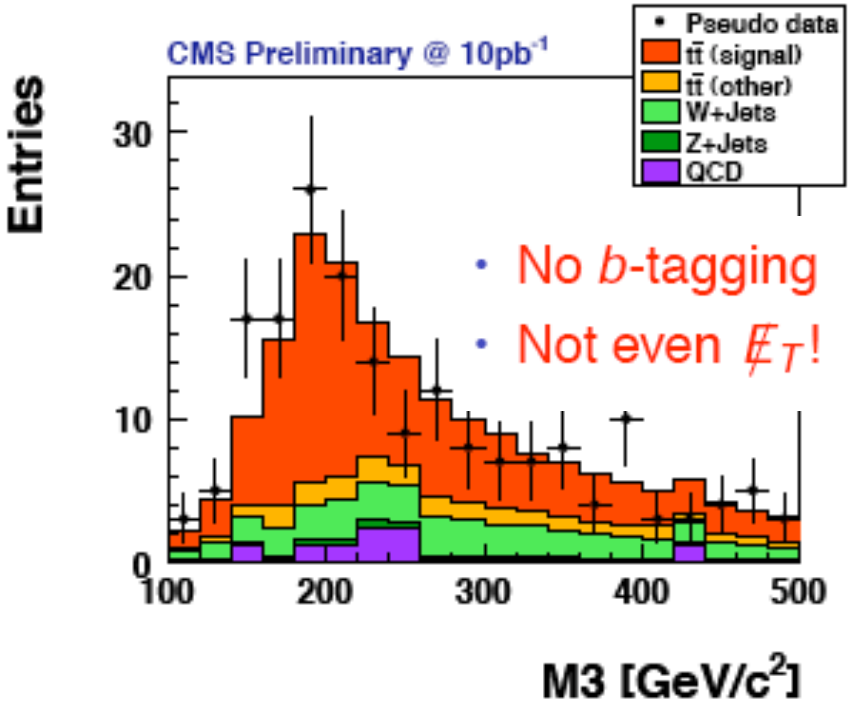


- 1 ttbar per second at 10^{33}
- ttbar:
  - Signal x 100, bkds x10
  - Signal can be established without b-tagging
- Single top:
  - t-channel x 100
  - s-channel x 10

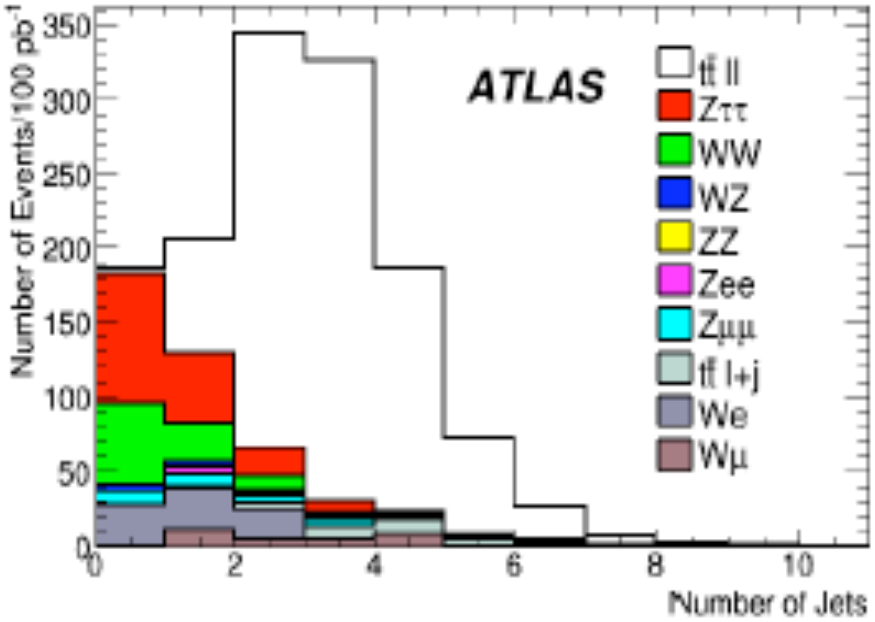
- Strategy at the LHC
  - Re-establishment the top
  - Top as tools
  - Precision measurements
  - Search for new physics

Re-establishing top quark

- Lepton+jets channel @10pb-1



- Dilepton channel @100pb-1



Fit $\not\!\!E_T$ vs N(jets) templates

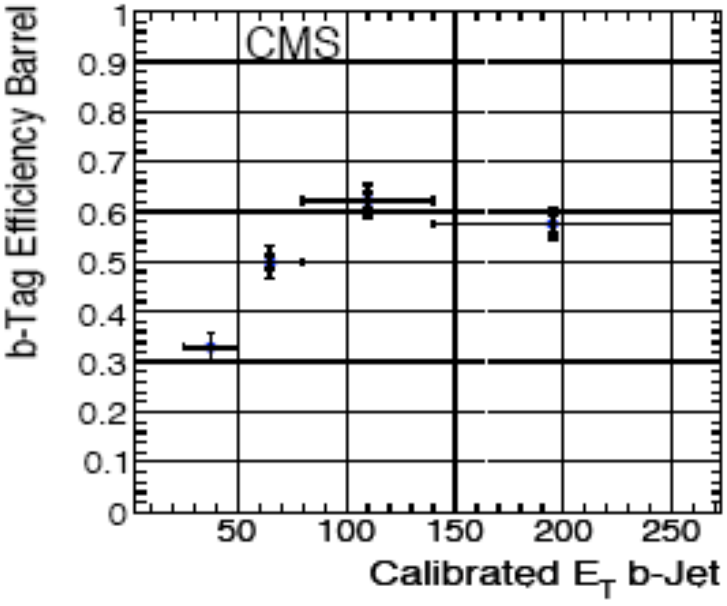
Hi-pt muon with 4 jets

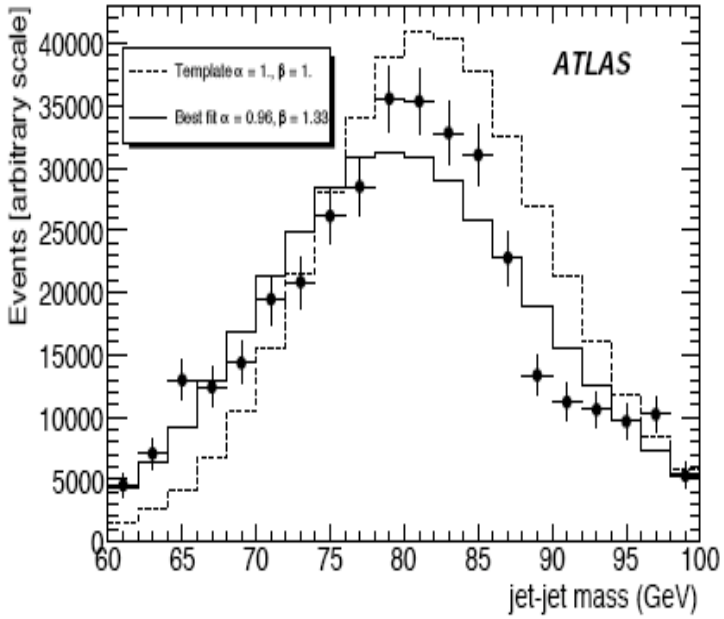
- 128 signals+90 bkgds

$$\delta\sigma/\sigma = 4(stat) \pm 4(sys) \pm 2(pdf) \pm 5(lum)\%$$

Top as tools

- Top pair events
  - enriched b-jet sample: b-tagging
  - W->jj resonance decays: in-situ JES calibration



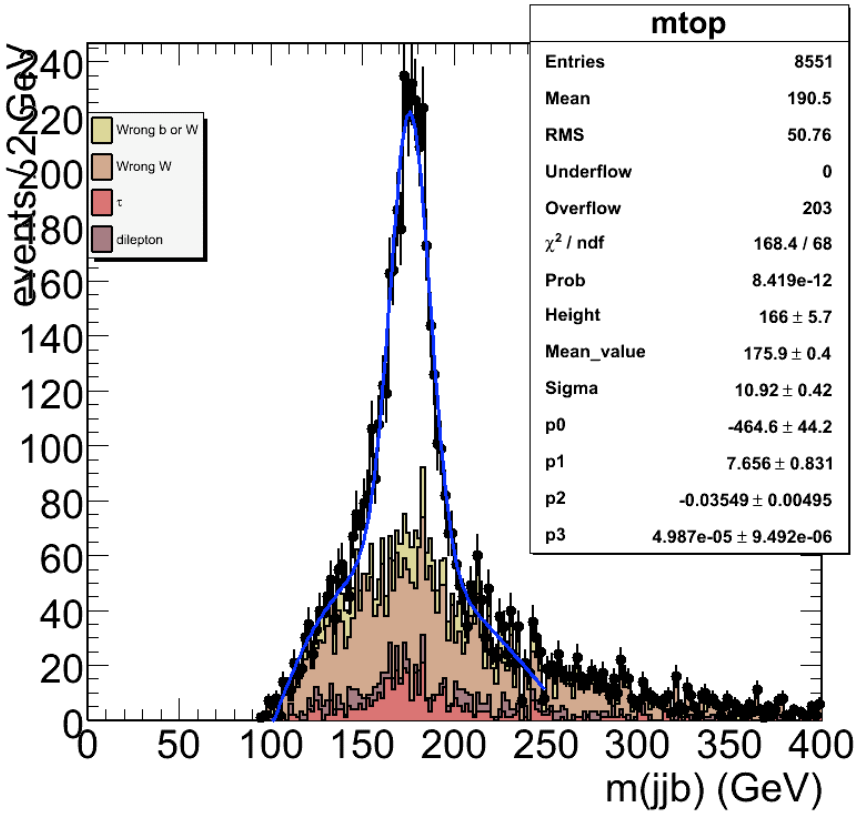


6% precision using 1fb-1

JES to 2% using 50pb^{-1}

Top Mass

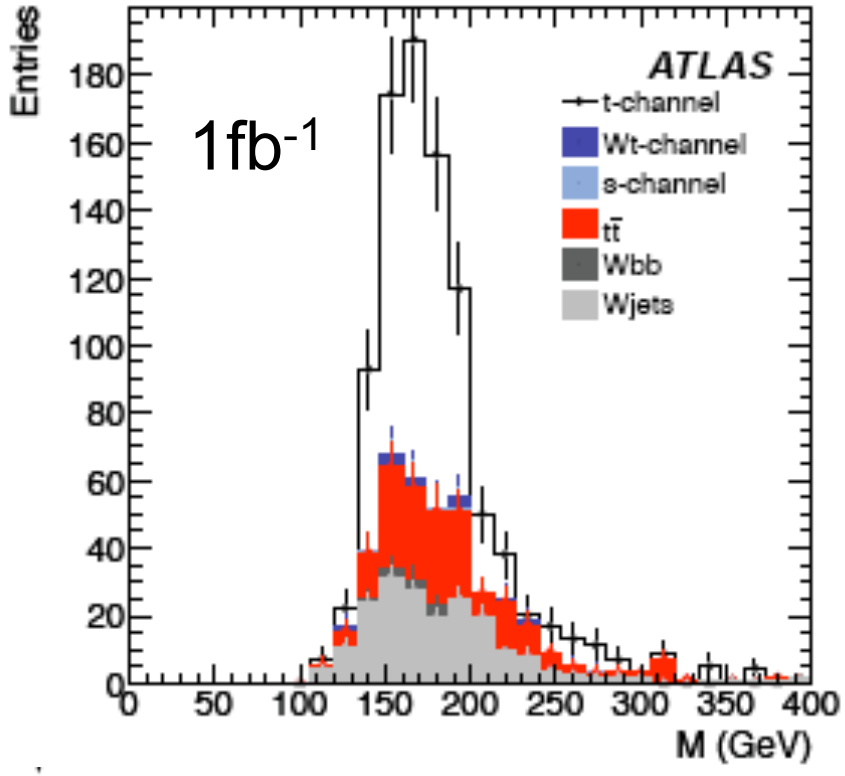
- Lepton + 4 jets with 2-btag
  - Template method using kinematic fitter
  - In-situ Wjj calib
- Jet energy scale syst.
  - 1% on light jet : 0.2 GeV
  - 1% on b-jet : 0.7 GeV
- b-jet energy calib.
  - Central exclusive events
  - Gamma + b-jets
  - Z(ll)+b-jets
- With high statistics
  - Explore CPT violation: m(t) - m(tbar)

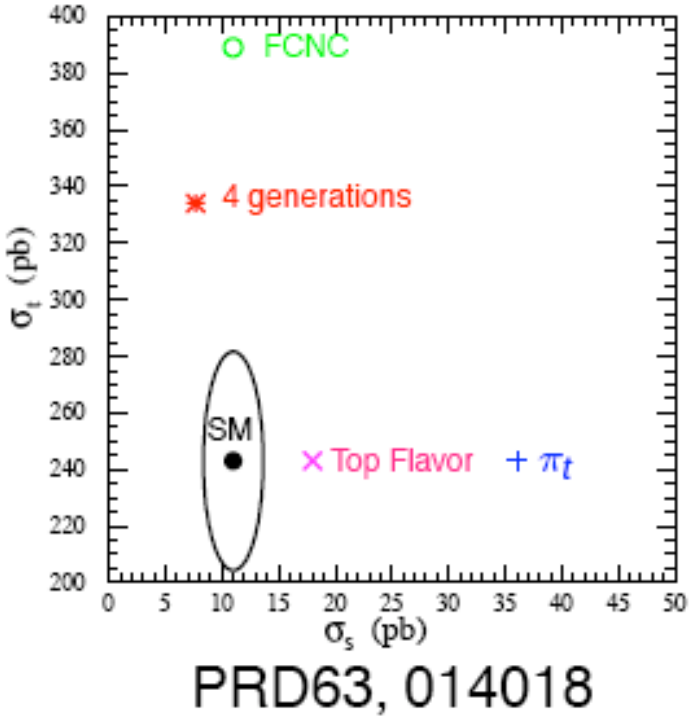


$$\delta M_t = 0.4\ \mathrm{GeV/c^2}\,(stat)@1fb^{-1}$$

Single top at the LHC

t-channel x 100





PRD63, 014018

$|V_{tb}|$: $\pm 11\%$(stat+sys) $\pm 4\%$(theor)

Tevatron runII goal we planned!!

Search for many new physics signals are realistic!!!

Un-ki Yang, Grenoble, 2008

Conclusions and Prospects

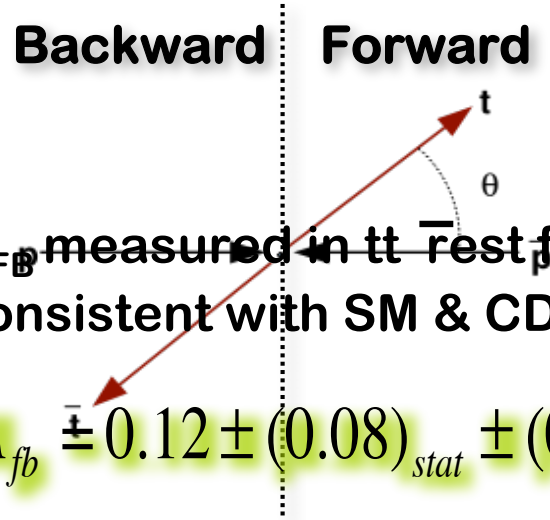
- The top physics program is very active at the Tevatron
  - Precise measurements, many first measurements, but all consistent with the SM
  - However, starting to have sensitivity to the unexpected and new phenomena in the top quark sector
  - Many tools have been developed
- LHC will provide incisive test of SM top physics with unprecedented precision and hints for New Physics beyond SM
  - But nothing comes free, even if new physics is there; many dedicated & coherent efforts among many diff. groups are crucial.

Real Funs
will come to us with exciting physics in Top

First beam at ATLAS

Forward-Backward Asymmetry

- Asymmetry from interference between LO and NLO terms

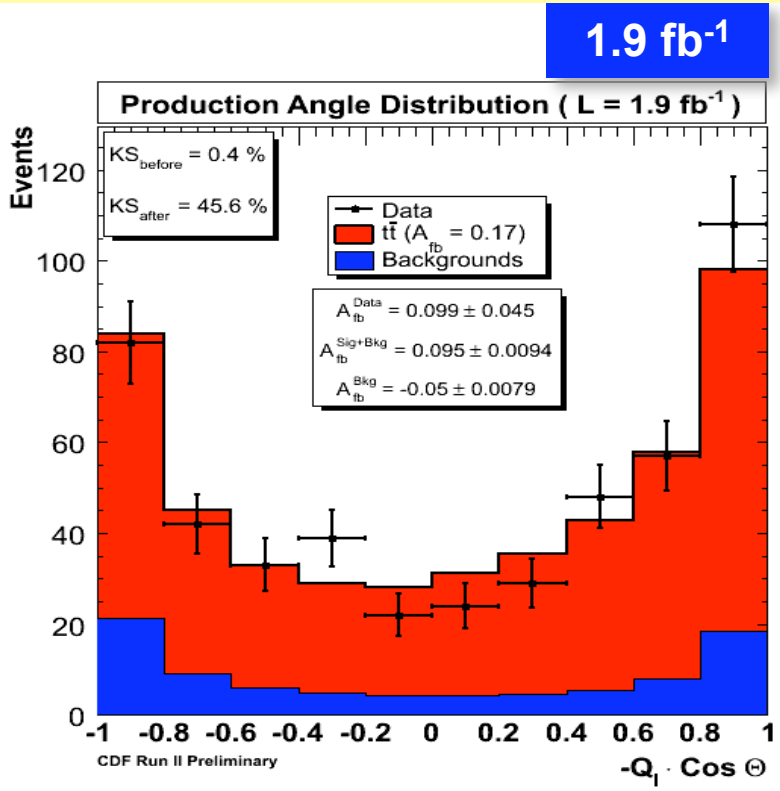


- A_{FB} measured in $t\bar{t}$ rest frame
- consistent with SM & CDF

$$A_{fb} = 0.12 \pm (0.08)_{stat} \pm (0.01)_{syst}$$

$$A_{fb} = \frac{N_{(-Q_\ell)\cdot Cos\Theta>0} - N_{(-Q_\ell)\cdot Cos\Theta<0}}{N_{(-Q_\ell)\cdot Cos\Theta>0} + N_{(-Q_\ell)\cdot Cos\Theta<0}}$$

measured in both $p\bar{p}$ and $t\bar{t}$ (30%↑) rest frames



$$A_{FB}^{p\bar{p}} = 0.17 \pm (0.07)_{stat} \pm (0.04)_{syst}$$

$$A_{fb}^{Theory\ NLO} = 0.03 - 0.05$$

Charged Higgs

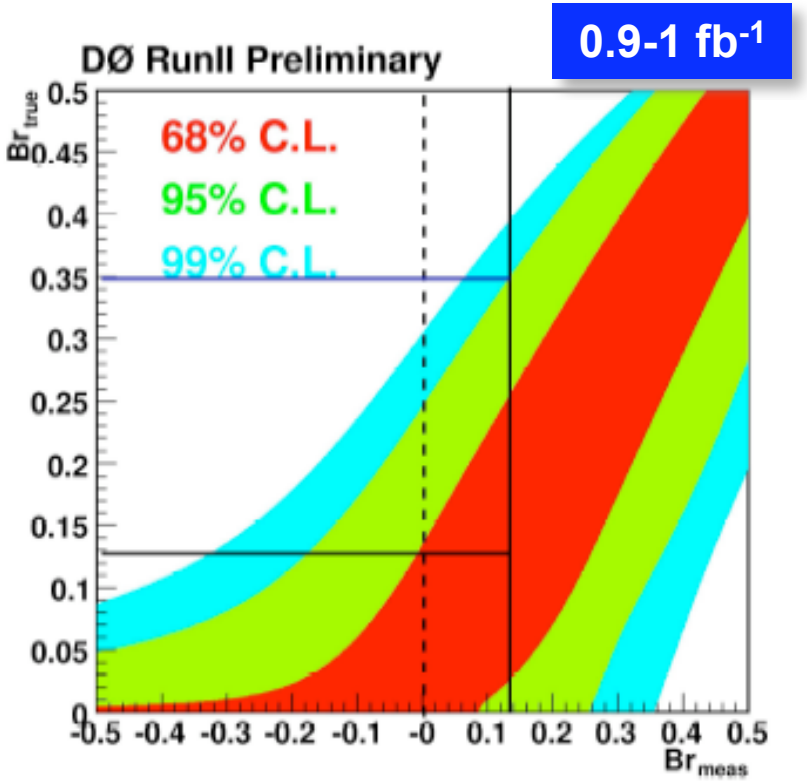
- Another approach

$$R_\sigma = \frac{\sigma(p\bar{p} \to t\bar{t})_{\text{lep+jets}}}{\sigma(p\bar{p} \to t\bar{t})_{\text{dilepton}}} = 1?$$

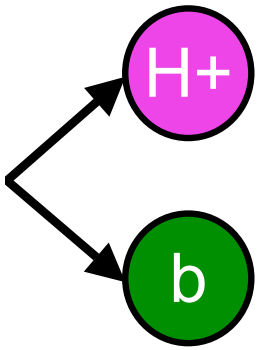
if $H^+ \to c\bar{s}$, R > 1

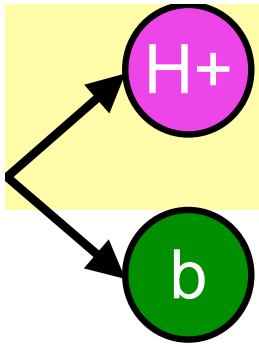
- Result: agree with SM

$$R_\sigma = 1.21^{+0.27}_{-0.26}(\text{stat+sys})$$



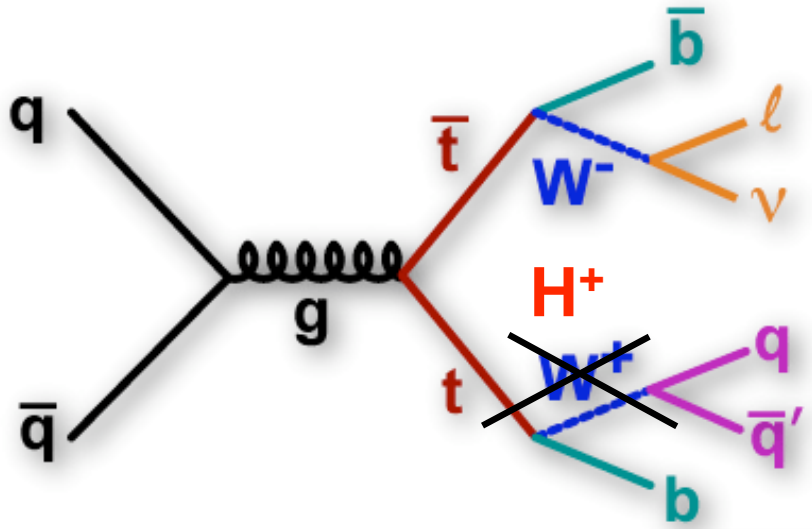
- Upper limit on BR($t \to H^+ b$)<0.35 at 95% CL, assuming m(H)=80 GeV, Br($H^+ \to c\bar{s}$)=1



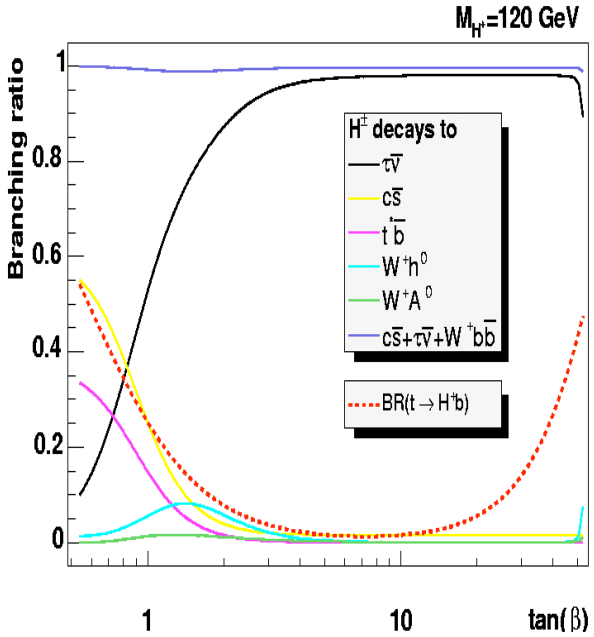


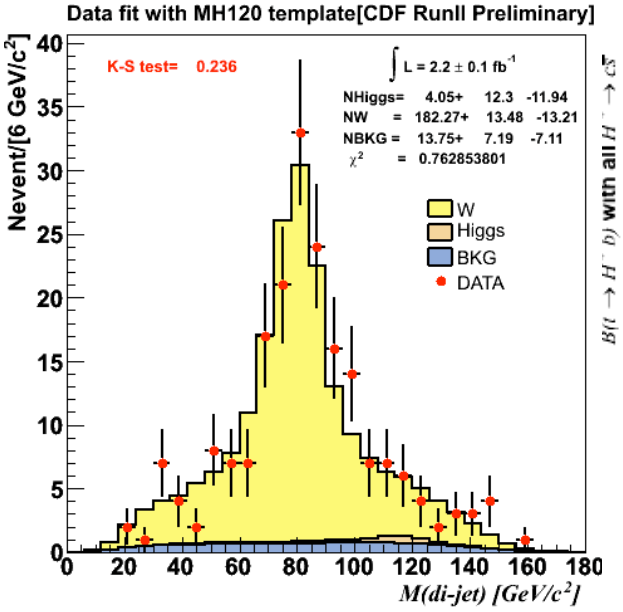
Charged Higgs Search

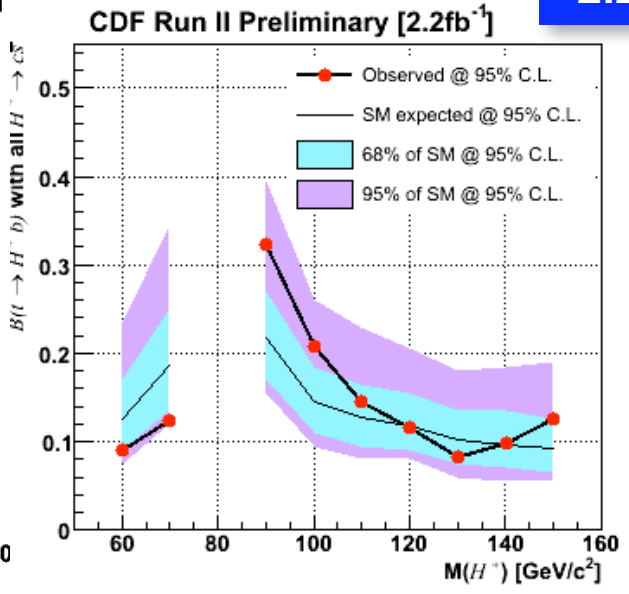
- In MSSM, charged Higgs exists:
  H^+ decays into cs, $\tau\nu$
- Search for a second bump
  in W di-jet mass from top decays
  in lep+4jets: use mass fitter



2.2 fb^{-1}







Un-ki Yang, Grenoble, 2008