Measurements and searches with matrix element techniques in W+jets signatures

International Union of Pure and Applied Physics (IUPAP) Awards talk

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ICHEP – Paris, France
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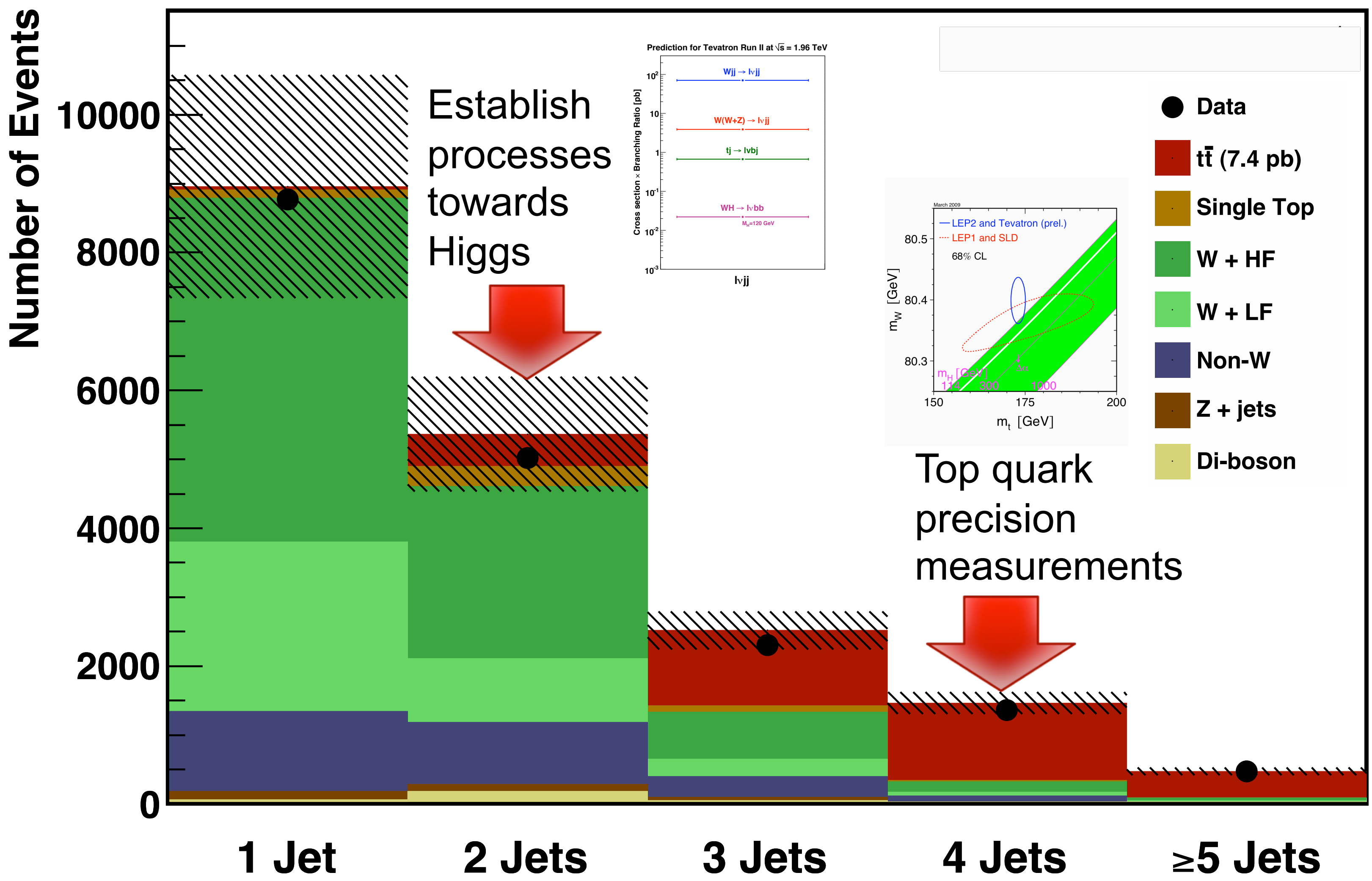
Dedicated to all my mentors and advisors

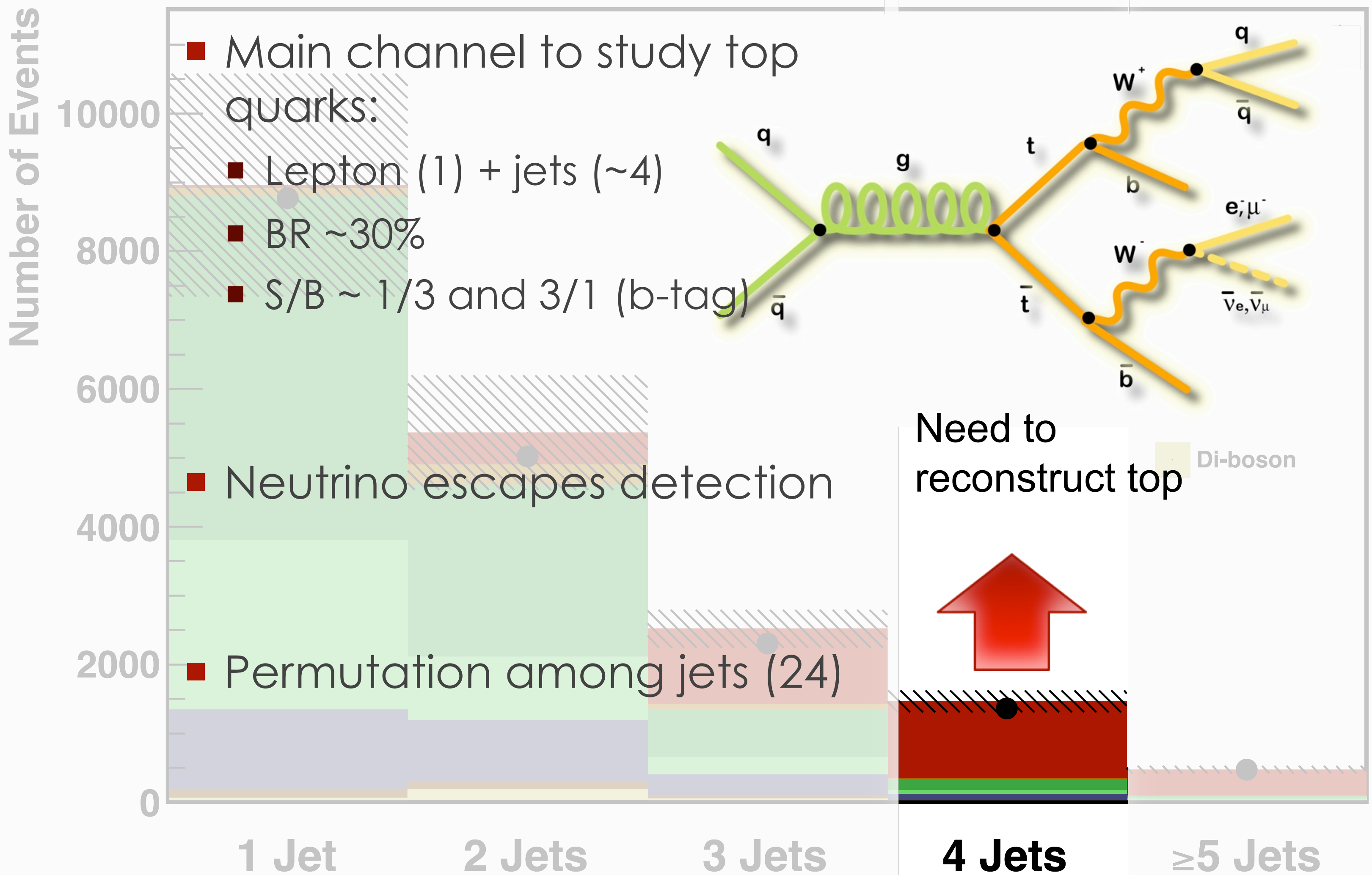
W+Jets Signature



Top Quark Measurements

- Main channel to study top quarks:
  - Lepton (1) + jets (~4)
  - BR ~30%
  - S/B ~ 1/3 and 3/1 (b-tag)
- Neutrino escapes detection
- Permutation among jets (24)

Need to reconstruct top



Matrix Element Technique

- Probability density functions for an event characterized by a set of measurements x

$$P_s(x \mid \alpha) = \frac{1}{\sigma_s(\alpha)} \int d\sigma_s(y \mid \alpha) W(y, x \mid \alpha)$$

measured variables

parameters

partonic integral

partonic variables

mapping between partonic and measured variables

Similar to the methods suggested by R. H. Dalitz and G. R. Goldstein, Phys. Rev. D 45, 1531 (1992), K. Kondo, J. Phys. Soc. Jpn. 60, 836 (1991), K. Kondo, J. Phys. Soc. Jpn. 57, 4126 (1998).

Measurements using Matrix Elements

- Sum over all states that can lead to the set of measurements x

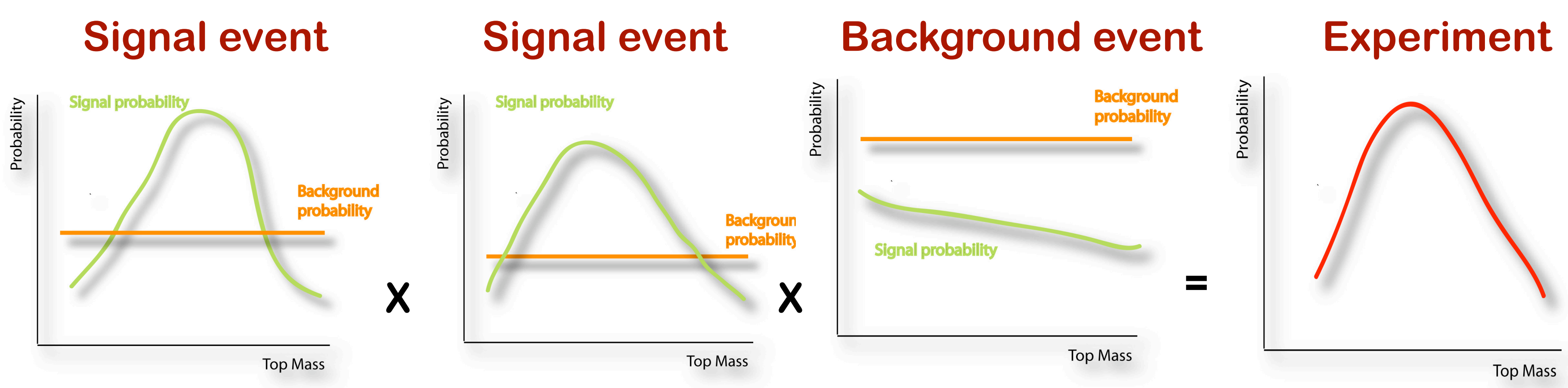
$$P(x \mid \alpha) = \sum_{states} c_s \, P_s(x \mid \alpha)$$

Detector acceptance (e.g. cuts, trigger, …)

$$P_m(x \mid \alpha) = Acc(x) P(x \mid \alpha)$$

- Given N events the optimal estimation of the set of parameters α is obtained by maximizing

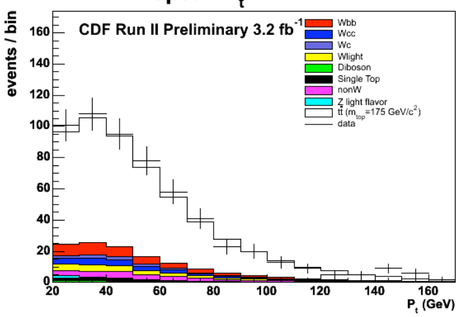
$$L(\alpha) = \prod_{i=1}^{N} P_m(x_i \mid \alpha)$$



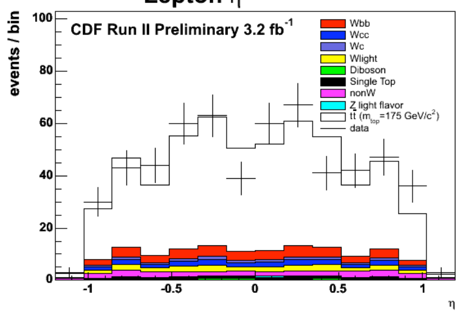
Input Variables

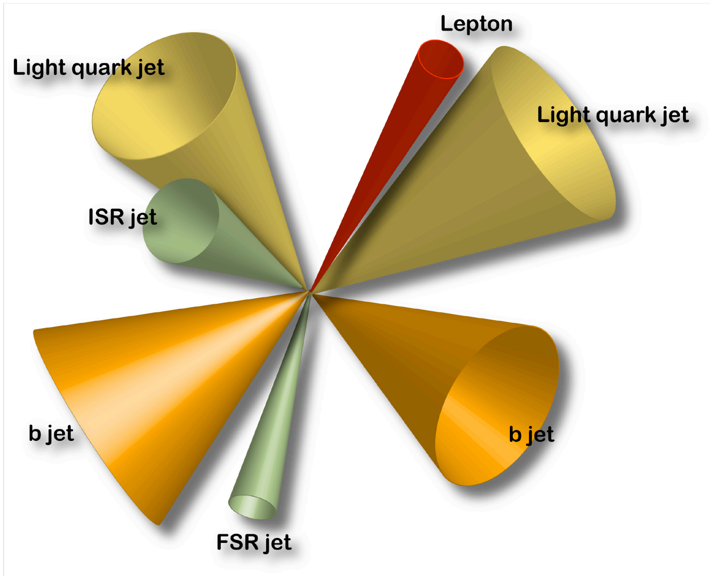
- Good modeling of signal and background is crucial

Lepton P_t

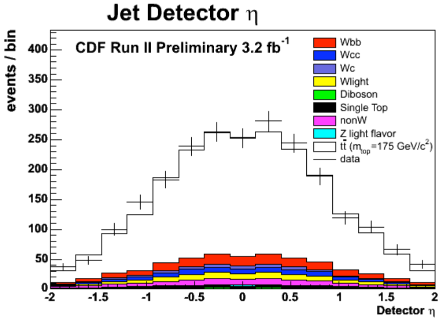


Lepton η

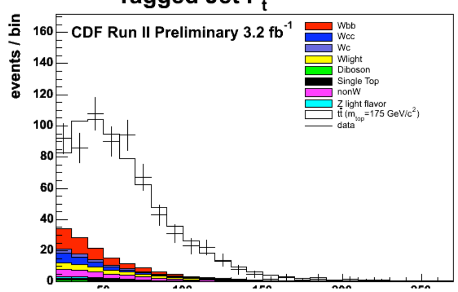




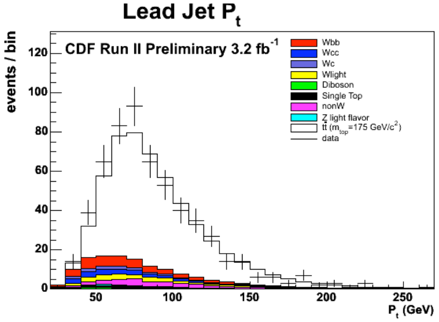
Jet Detector η



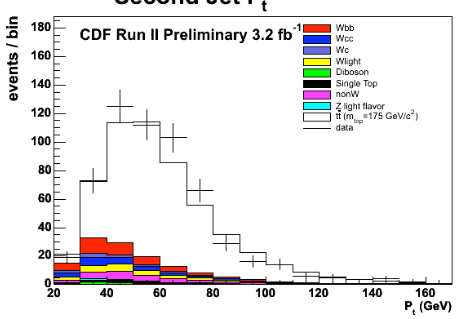
Tagged Jet P_t



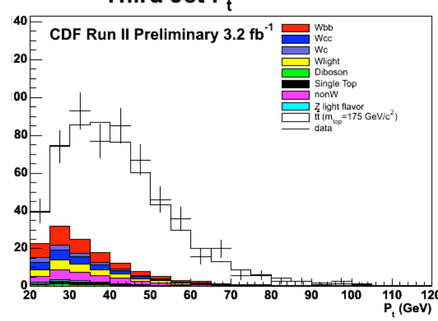
Lead Jet P_t



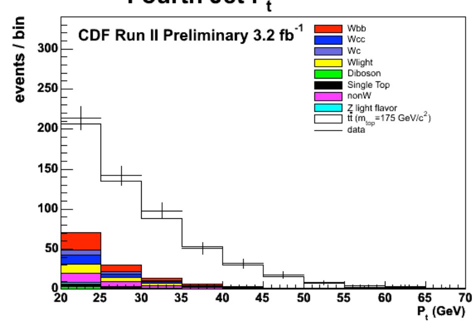
Second Jet P_t



Third Jet P_t



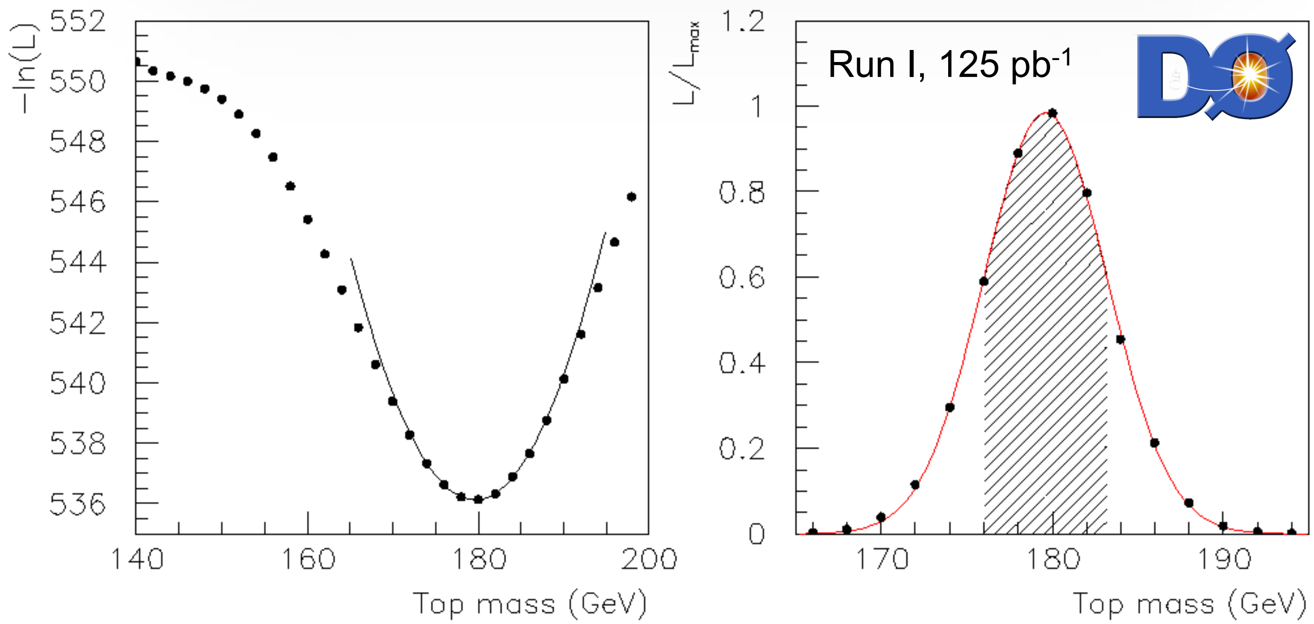
Fourth Jet P_t



Top Quark Mass – Run I

- This technique improved the statistical error on M_t from 5.6 GeV [PRD 58 52001, (1998)] to 3.6 GeV. Equivalent to a factor of 2.4 in the number of events.

M_t= 180.1 ± 3.6 (stat) GeV/c^2

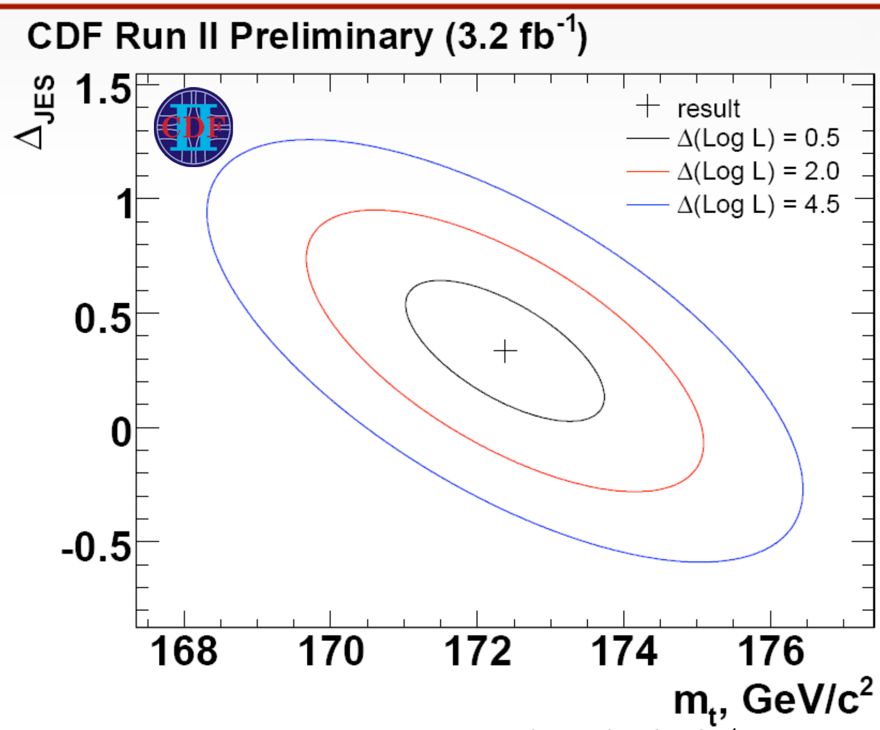


Nature 429, 02589 (2004)

Top Quark Mass – Run II

- Many improvements in the probability calculations
- Main gain has been from 1) including a Jet Energy Scale (JES) parameter in the minimization, 2) including integration over the P_T of the ttbar system, 3) angular integration

M_{top} = 172.4 ± 1.4 (stat + JES) ± 1.3 (syst) GeV/c^2

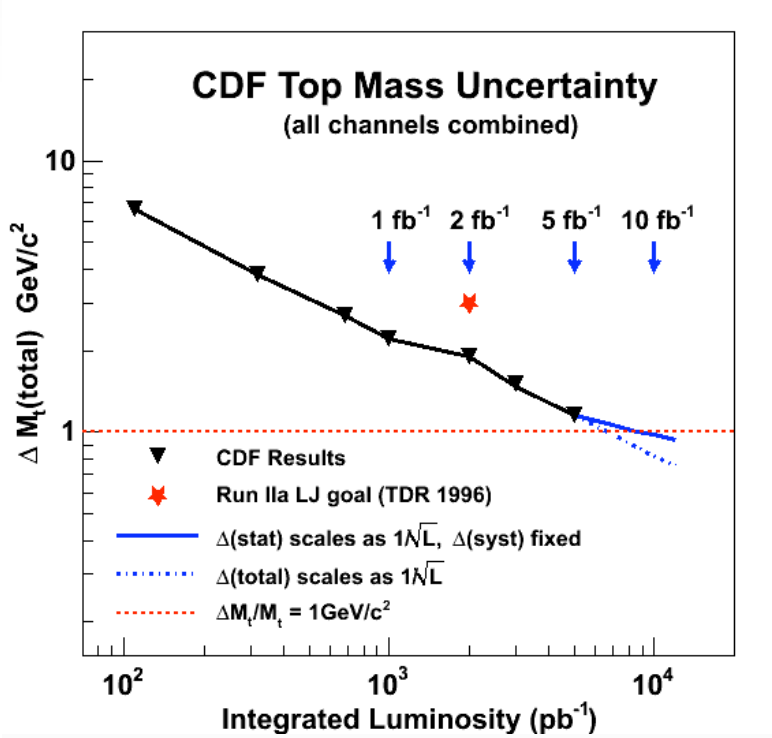


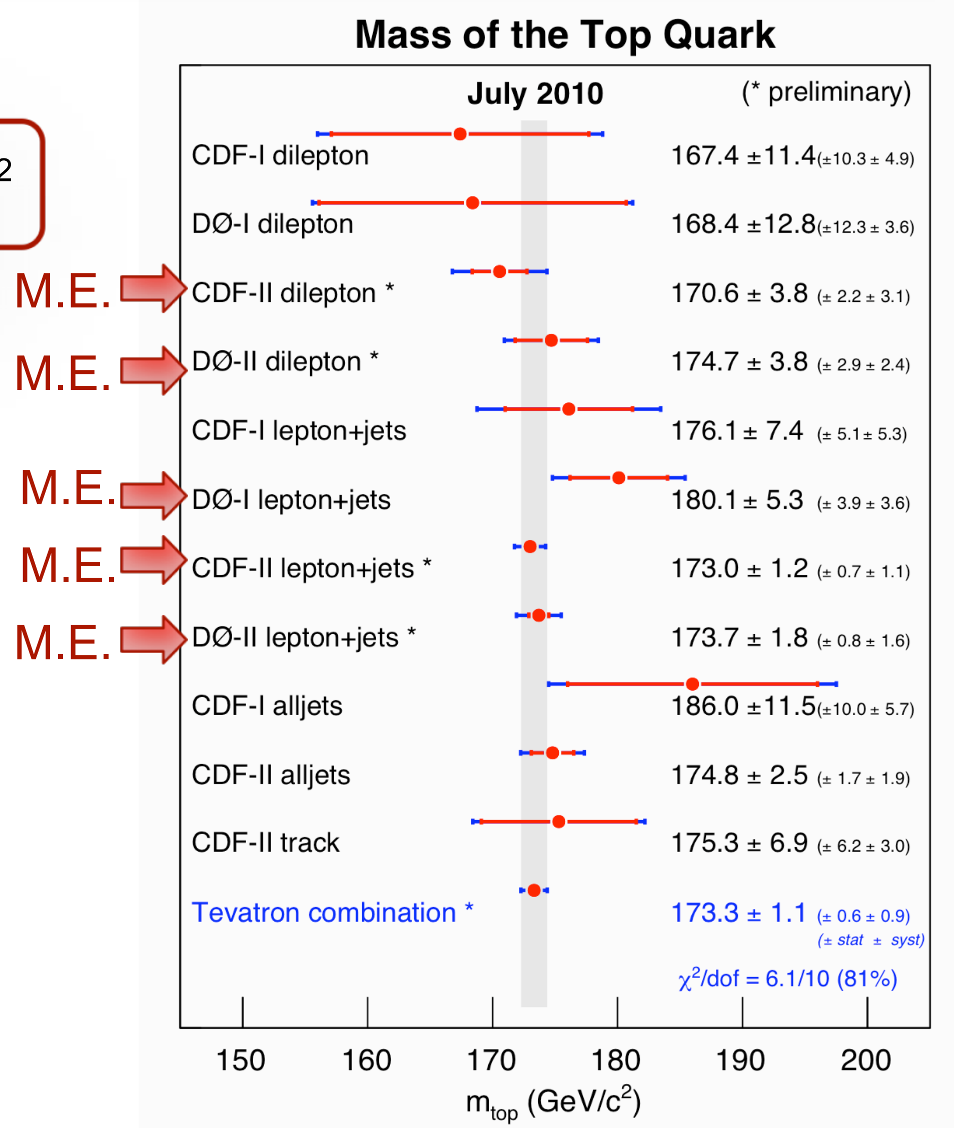
Phys. Rev. Lett. 99, 182002 (2007) w/ 1 fb^{-1}

Top Quark Mass – Current Status

- All Tevatron channels included

M_{top} = 173.3 ± 0.6 (stat) ± 0.9 (syst) GeV/c^2

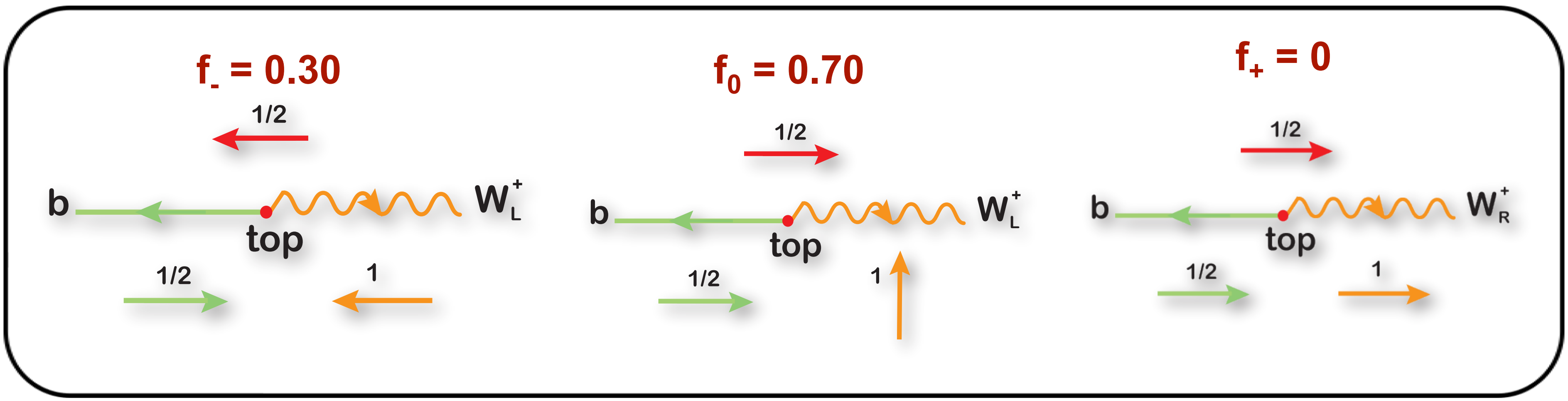




- Tevatron on the way to achieve a precision of 1 Gev/c^2

Top Quark Couplings

- Top is special: **very massive, decays before hadronizing**
- In beyond the SM scenarios, significant deviations from the SM expectation are possible due to the presence of **anomalous couplings in the tWb vertex**
- The V–A structure of the weak interaction can be tested by reconstructing the polarization of the W boson from top-quark decay

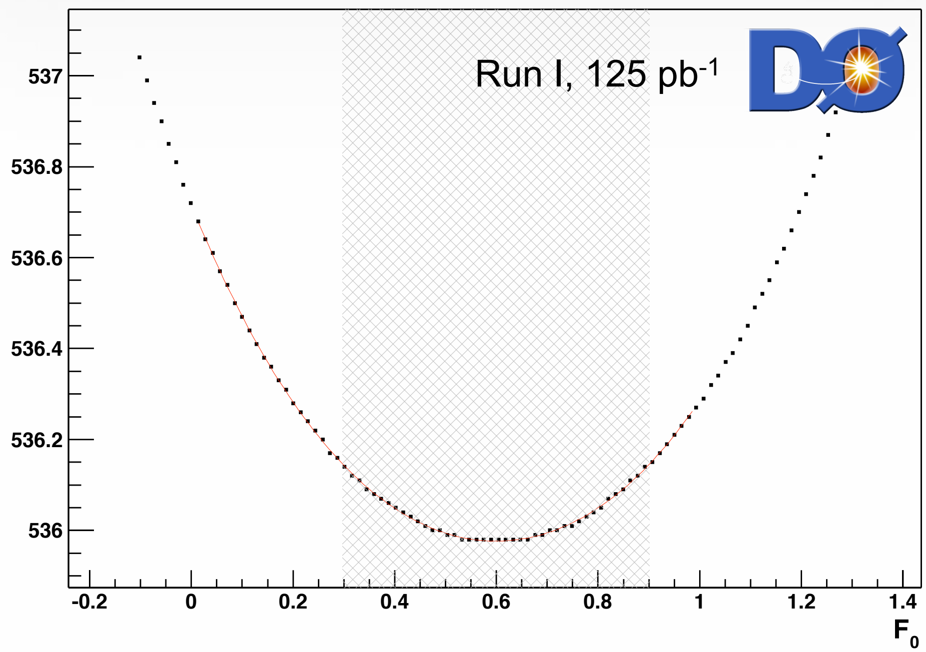


- Parameterize ttbar probability as functions of f_0 and f_+

Top Couplings – Run I

- Measure f_0 while fixing the other fractions to SM predictions
- Limited by the small size of the Run I data, better sensitivity than other methods

$$f_0 = 0.50 \pm 0.31(\text{stat}+M_t) \pm 0.07(\text{syst})$$

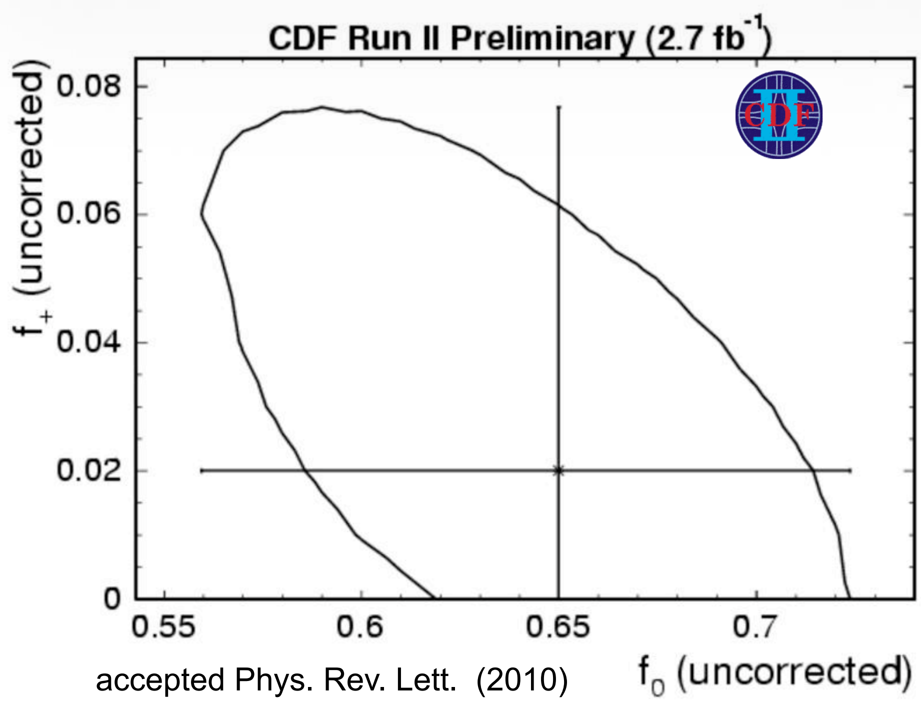


Phys. Lett. B 617, 375 (2005)

Top Couplings – Run II

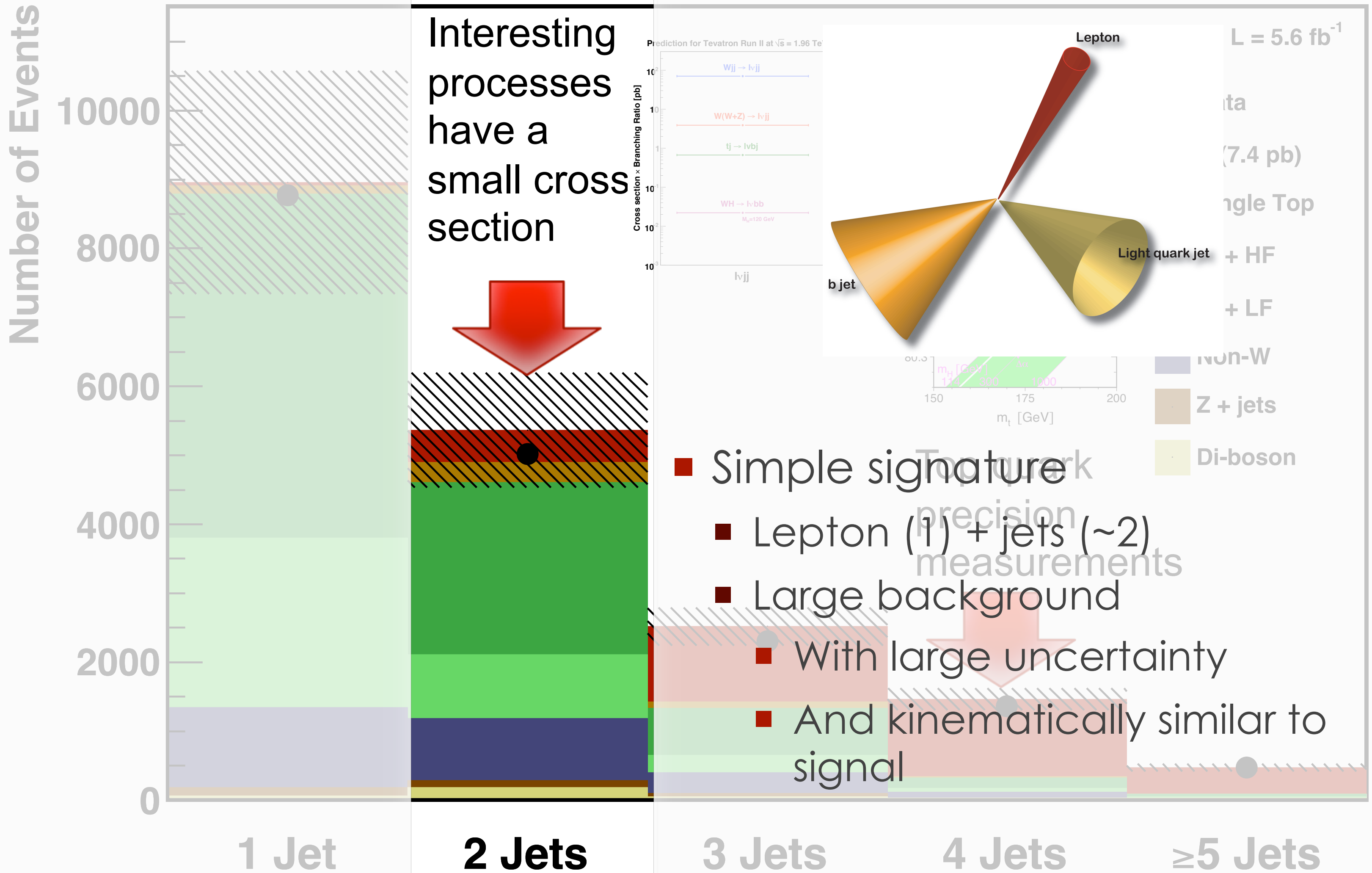
- With the increase statistics of Run II we could move to a model-independent measurement: simultaneous measurements of f_0 and f_+
- After bias corrections, measurements are unphysical, use FC to obtain confidence intervals

$$f_0 = 0.879 \pm 0.106(\text{stat}) \pm 0.062(\text{syst})$$
$$f_+ = -0.151 \pm 0.067(\text{stat}) \pm 0.057(\text{syst})$$



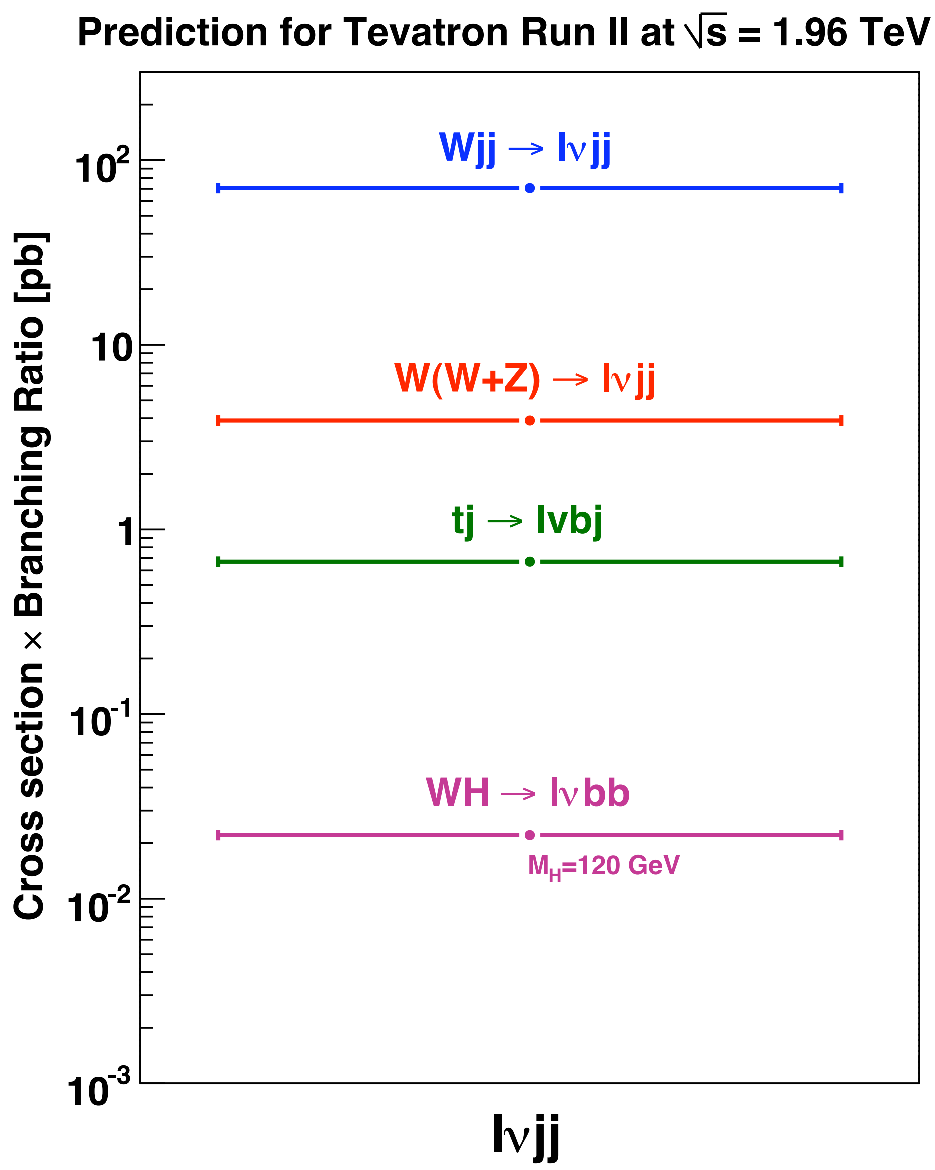
accepted Phys. Rev. Lett. (2010)

W+Jets Signature



- Simple signature
  - Lepton (1) + jets (~2)
  - Large background
    - With large uncertainty
    - And kinematically similar to signal

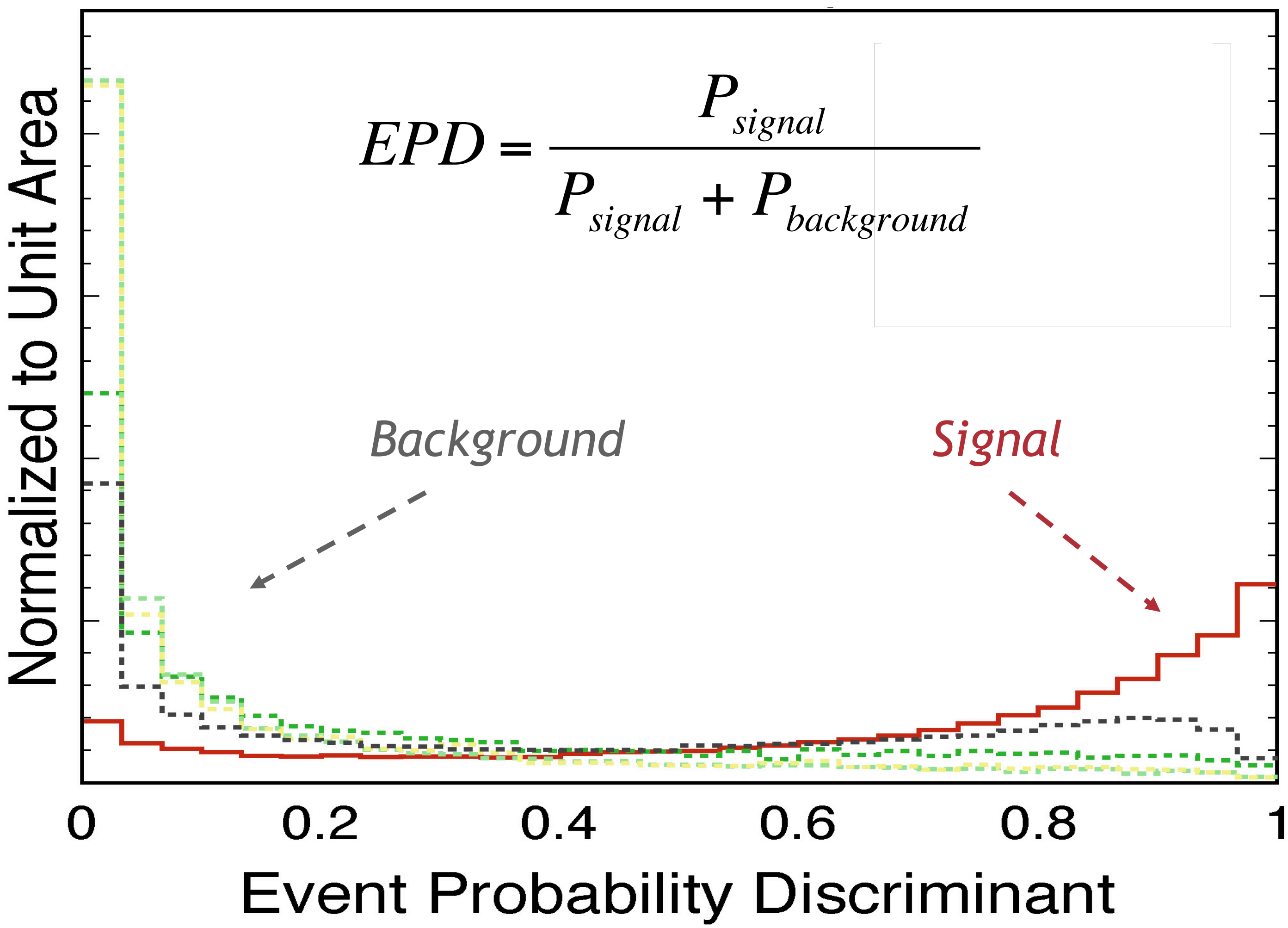
Establishing Processes



Searches using Matrix Elements

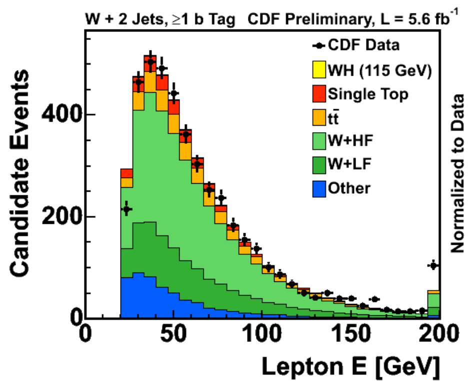
- Define ratio of probability density hypotheses as event probability discriminant (EPD)

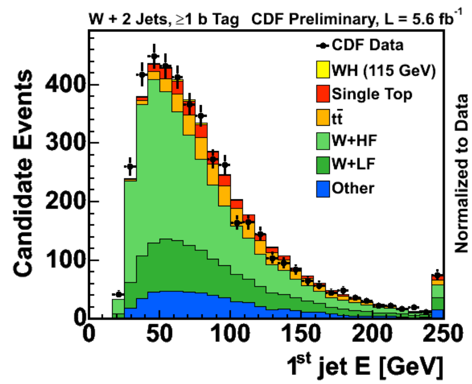
$$EPD = \frac{P_{signal}}{P_{signal} + P_{background}}$$

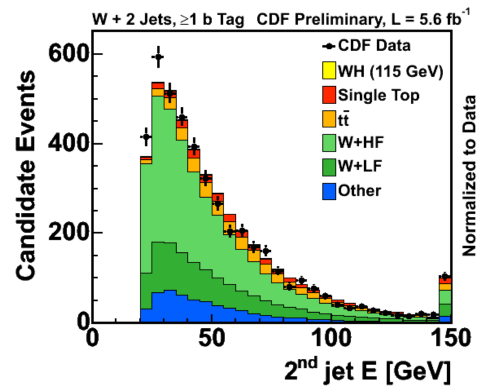


Input Variables

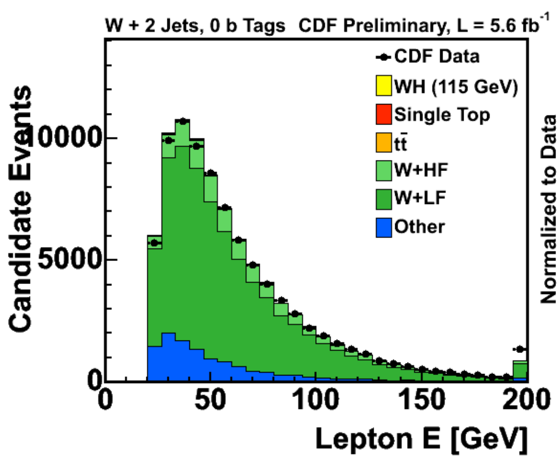
- Inputs to the probability densities (signal included)

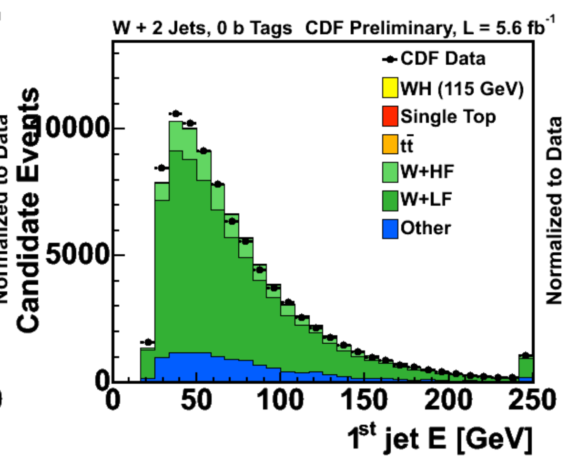


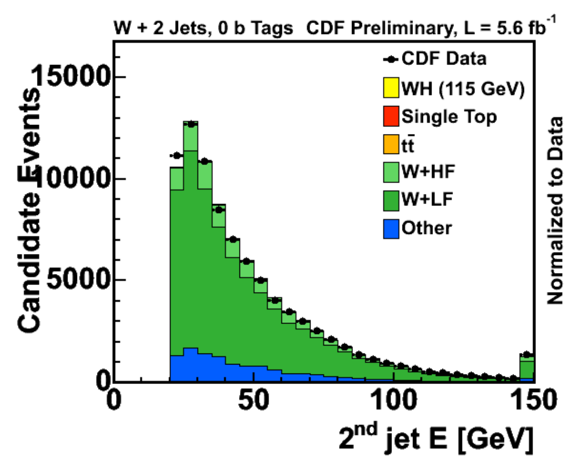




- Good modeling of the background is essential: use many different control regions, discrepancies are taken as systematic uncertainties or we apply additional selection criteria





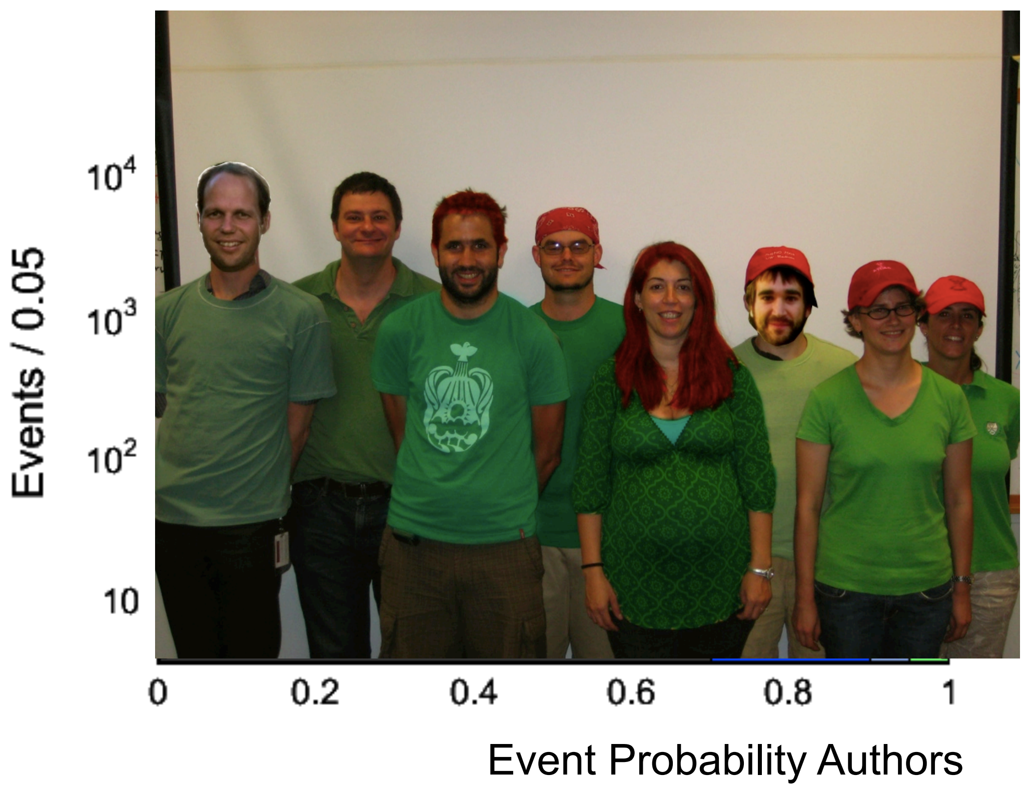


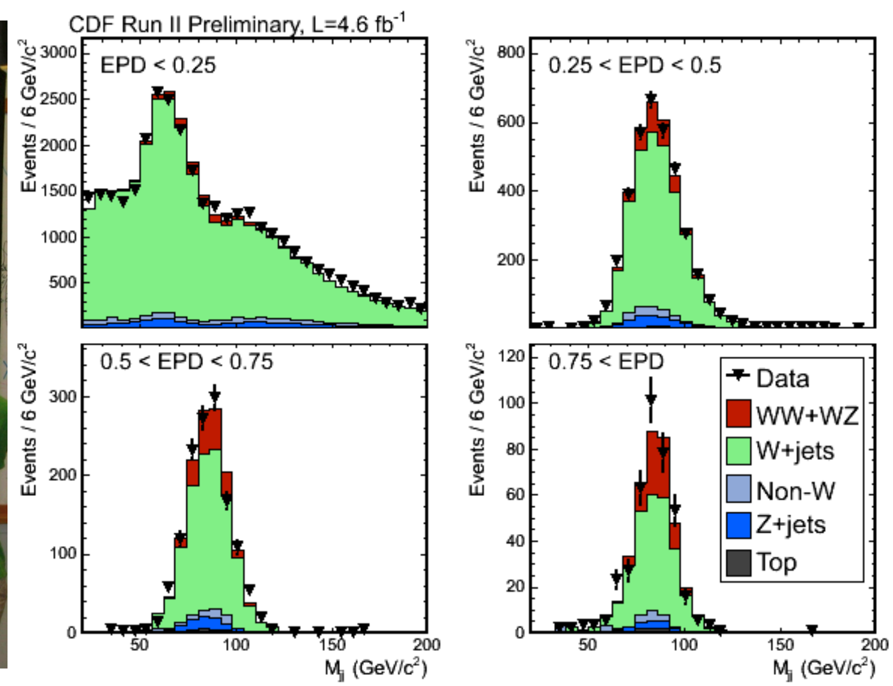
Diboson: WW+WZ

- S/B ~ 1/30
- Establish confidence in techniques for Higgs
  - Resonant dijet search
  - Similar issues in background modeling and systematic uncertainties

$\sigma(WW/WZ) = 17.7 \pm 3.9(stat) \pm {}^{1.6}_{1.4}(syst)$ pb

- First observation, 5.4 σ significance
- Standard Model prediction σ = 16.1 ± 0.9 pb





Phys. Rev. Lett. 104, 101801 (2010)

Single Top Quark

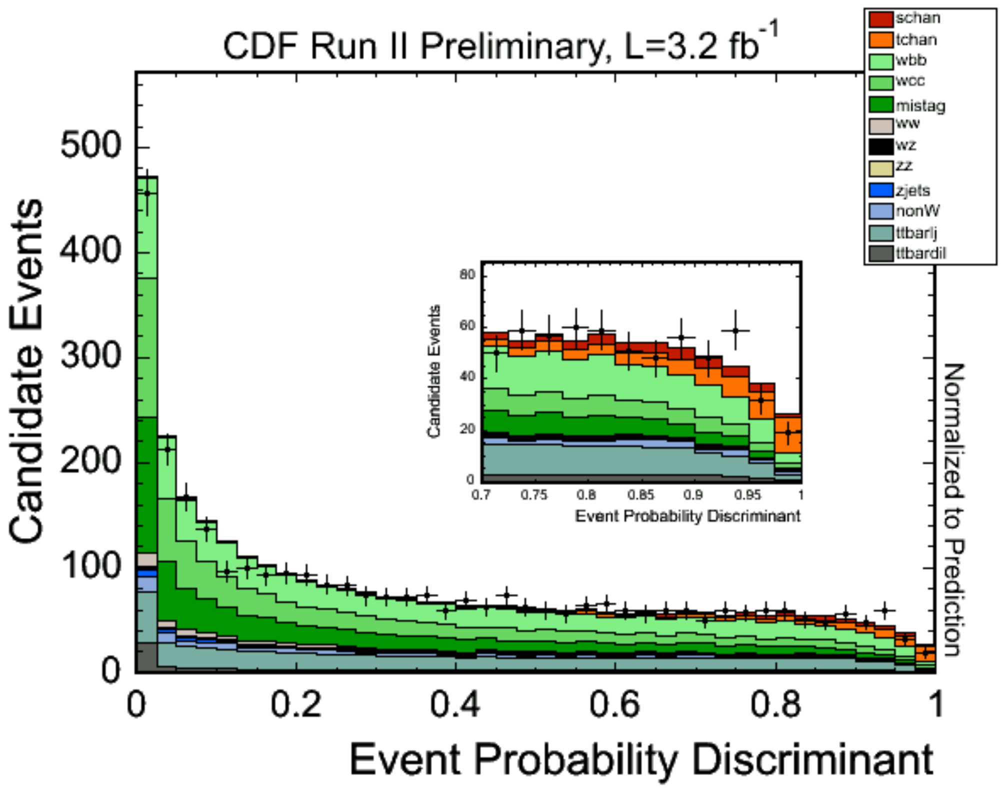
- S/B ~1/17
- Jets must be b-tagged:
  - Similar techniques as Higgs search

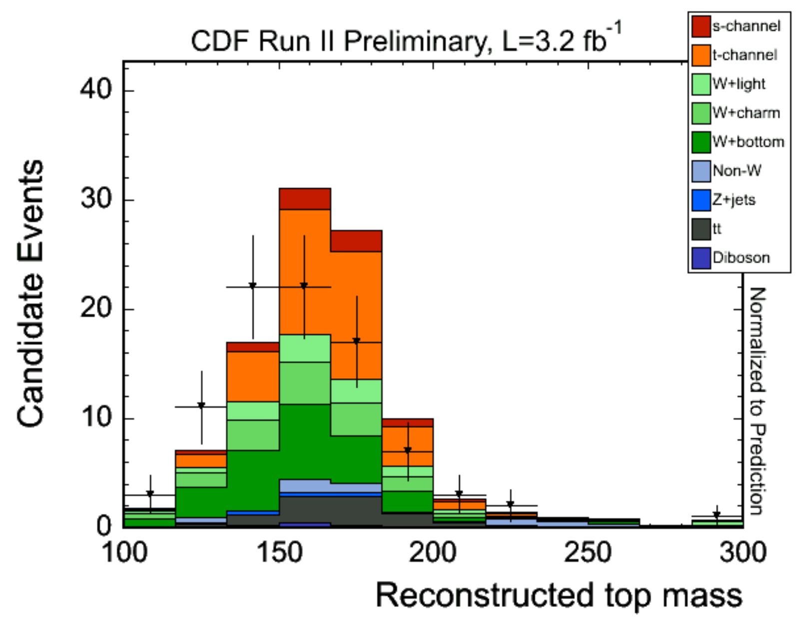
$\sigma(\text{single-top}) = 2.5 \pm^{0.7}_{0.6}(\text{stat+syst})$ pb

- Observed (expected) 4.3 (4.9) σ significance
- Standard Model prediction

$\sigma_{\text{t-channel}}$(NLO @ m_t=175 GeV) = 0.98 ± 0.04 ps

$\sigma_{\text{s-channel}}$(NLO @ m_t=175 GeV) = 2.16 ± 0.12 pb

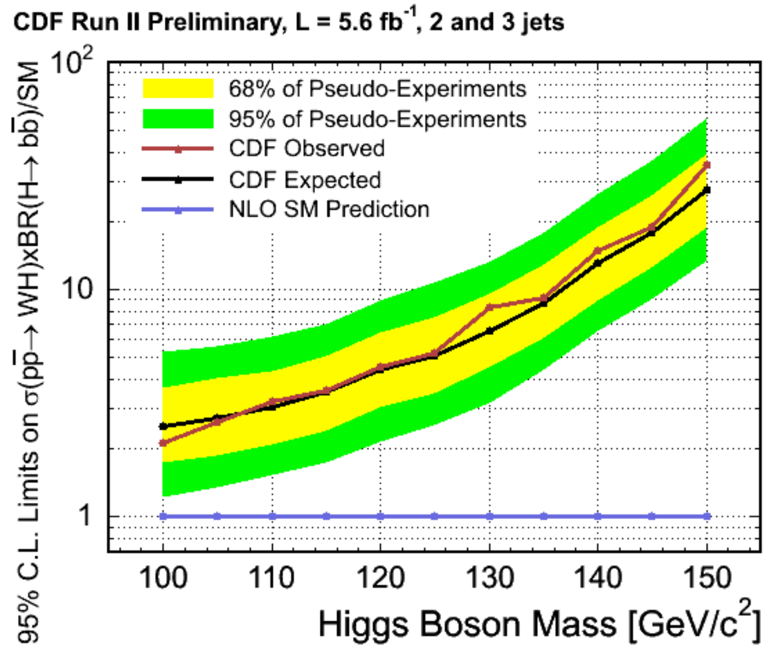


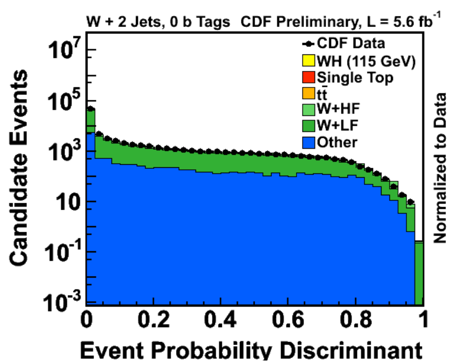


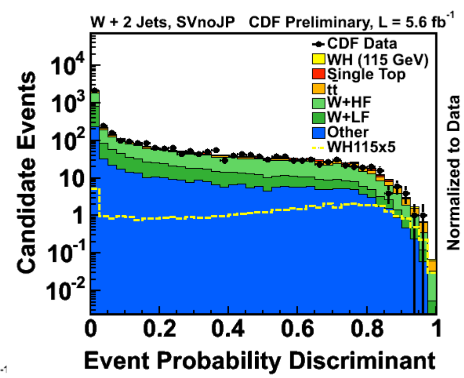
Phys. Rev. Lett. 101, 252001 (2008), Phys. Rev. Lett. 103, 092002 (2009)

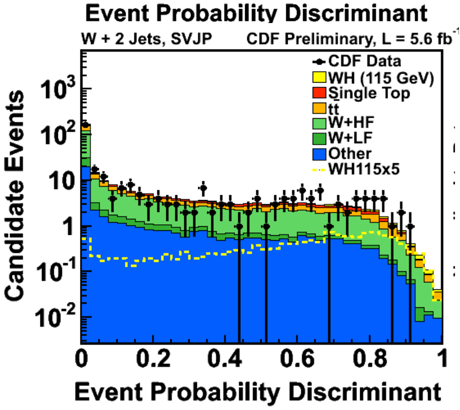
Higgs: WH

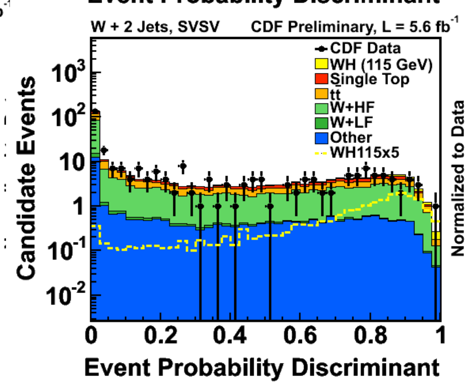
- S/B ~ 1/100
- More b-tagging divisions:
  - Separate different S/B regions
- More acceptance:
  - Secondary triggers, events with 3 jets, etc.

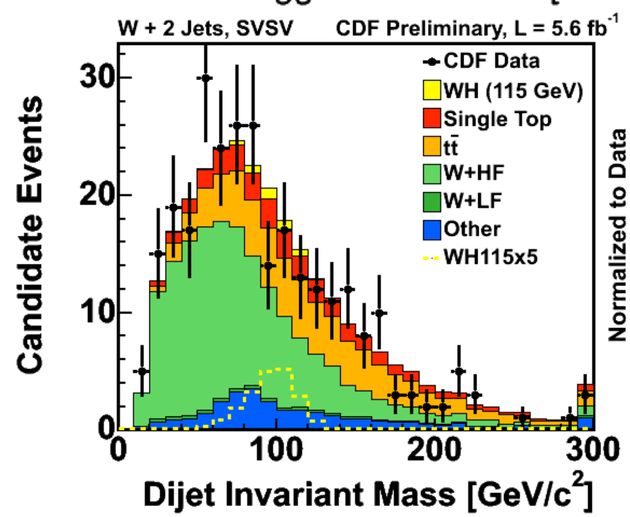








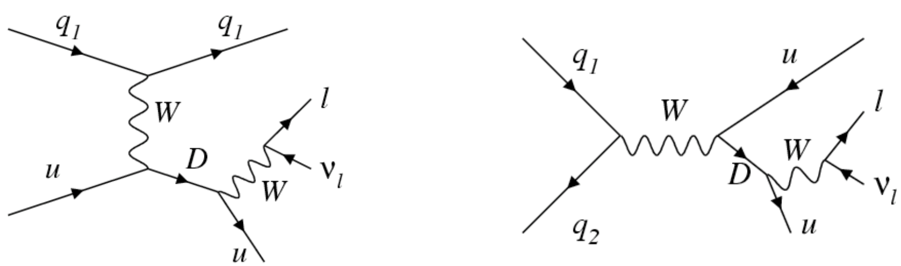


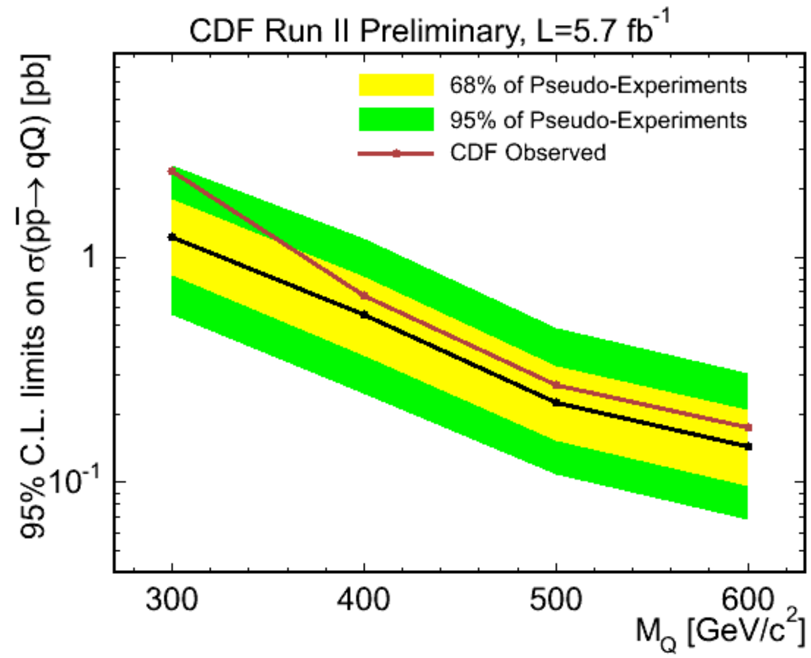


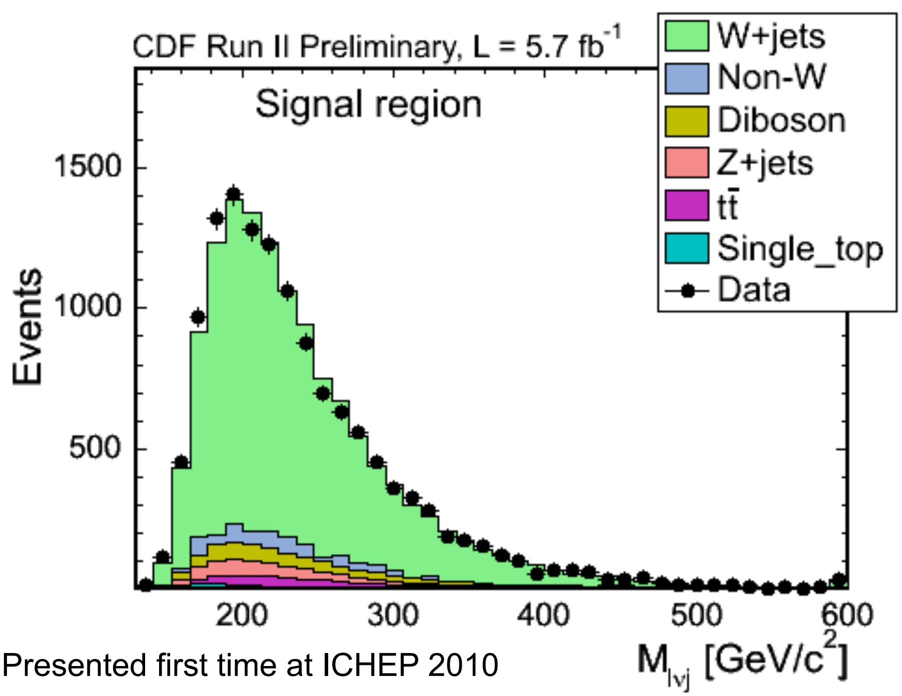
Phys. Rev. Lett. 103, 101802 (2009)

Heavy Quarks

- Search for single production of new heavy quarks via a charged current interaction







Presented first time at ICHEP 2010

- Feature of many non SM theories
- Focus on new D and U, assuming B.R.($Q \to Wq$)=100%, where q is a first generation SM quark.
- S/B ~1/10 (M_D=300) – 1/130 (M_D=600)

Summary

- The matrix element technique developed over the last decade has improved precision measurements and also helped establish new processes
  - This is in great part possible due to the availability of CPU
  - The improved modeling of the Monte Carlo tools
- W+jets physics has given us strong **SM foundation for beyond SM**
  - Top quark mass measurements
  - Top quark coupling probes
  - Single top observation
  - Diboson w/jets observation
  - Higgs searches
  - Heavy quark searches
- Tevatron data has inspired many of us
- The LHC is making us all dream even bigger
- I would like to **thank my colleagues** (some in pictures) for these exciting times !