Top Studies at CDF

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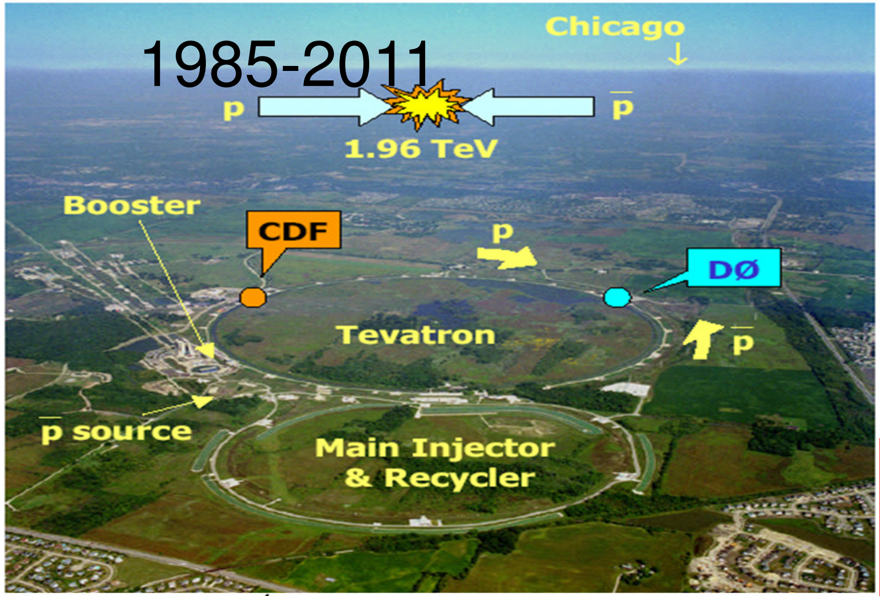
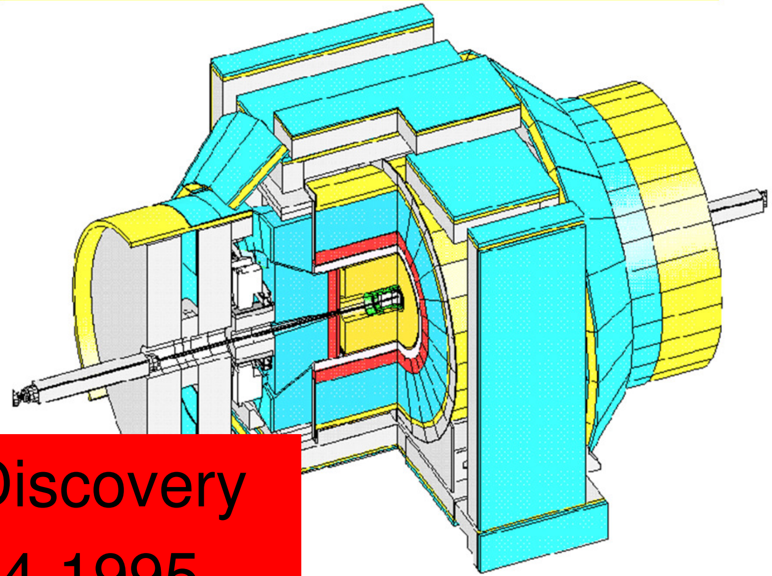
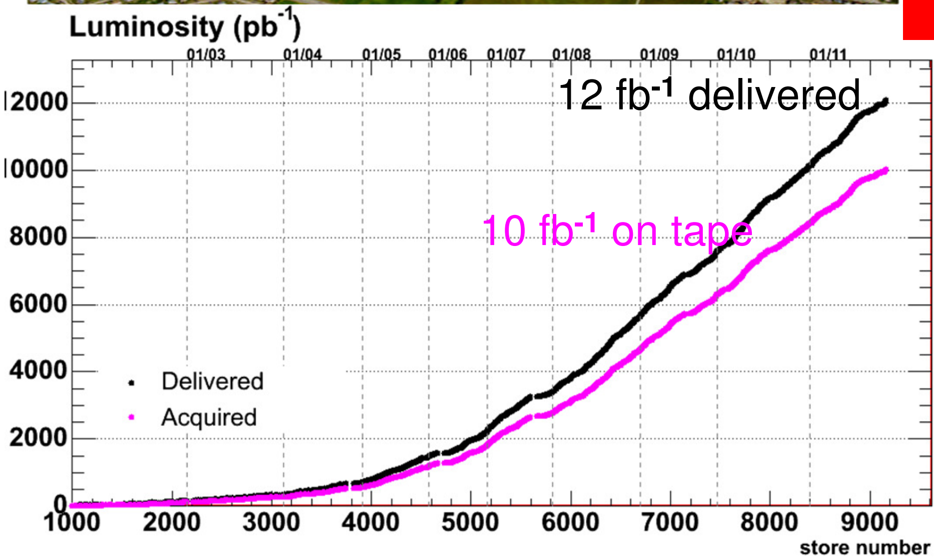
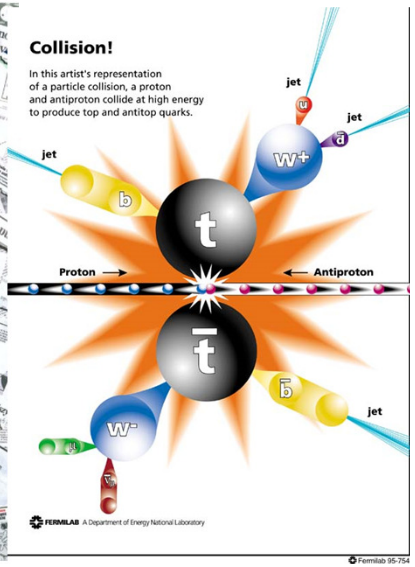
Tevatron, top and CDF >20 years





Top Discovery
1994-1995





Why top is so interesting?

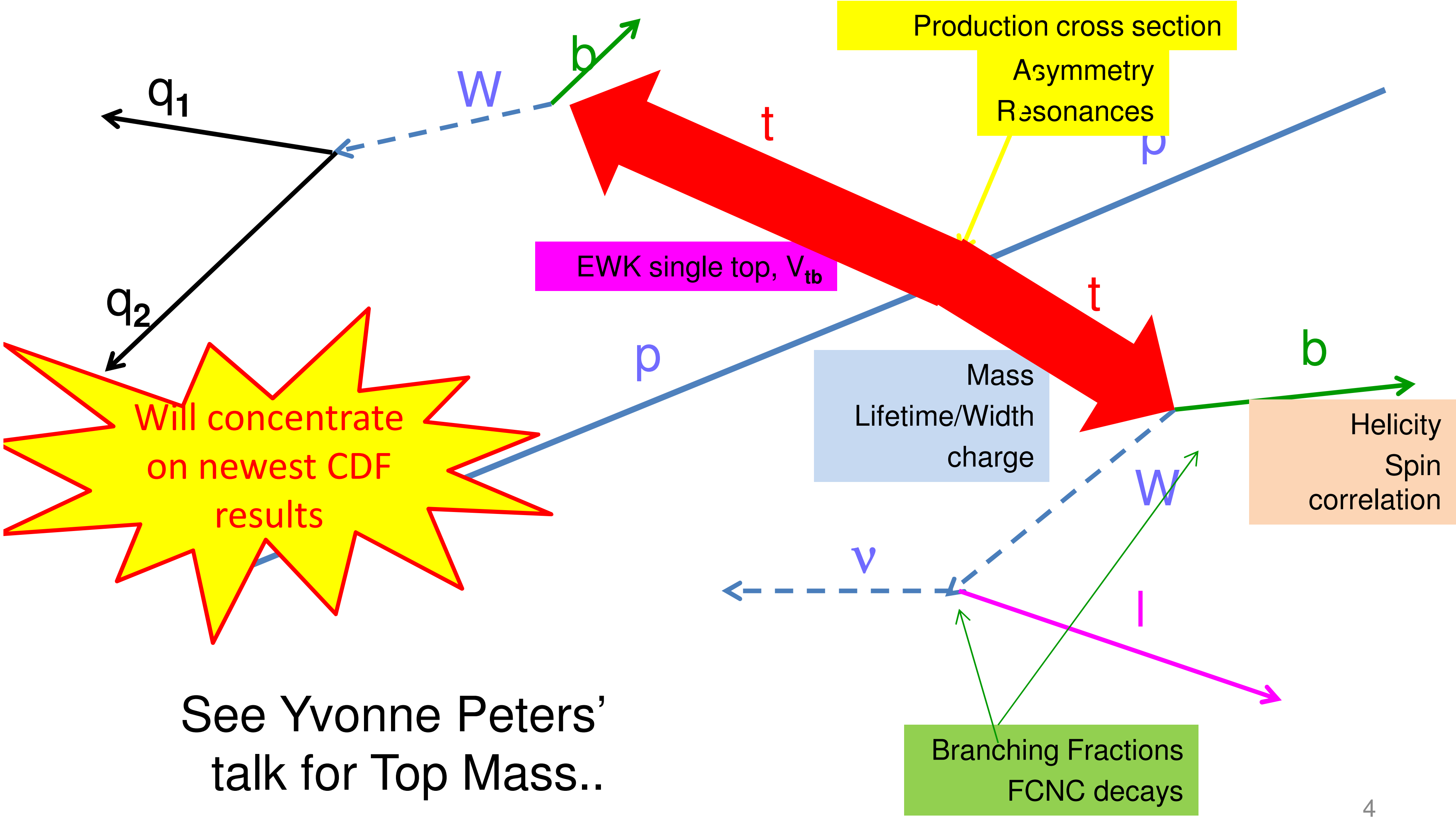
Heaviest quark known (~172.5 GeV/c^2)

- Due to its mass decays before hadronization
  - No bound states («top mesons», «Upsilon-like»)
  - «direct» access to production and decay vertex
    - Couplings, CKM elements..
- Related to Higgs mass through loops
  - Precision measurement of M_W, M_{top}
    - Stability of our Universe…
- Yukawa coupling ~1
  - Anything special about top and its relation to EWSB?
    - Window to new physics?

Two different production mechanisms

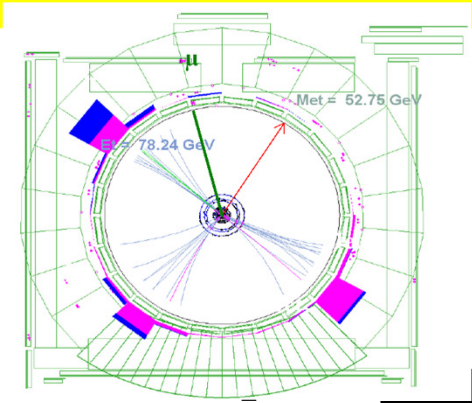
- Ewk processes
- Strong interactions

What can we study?

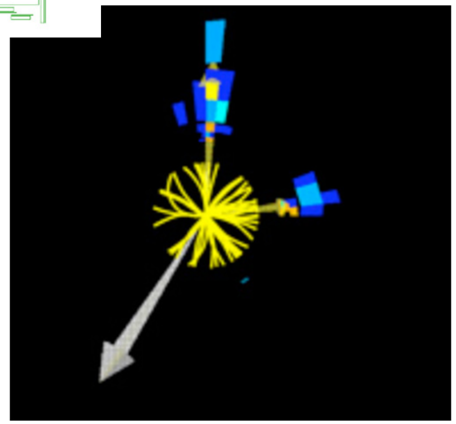


See Yvonne Peters' talk for Top Mass..

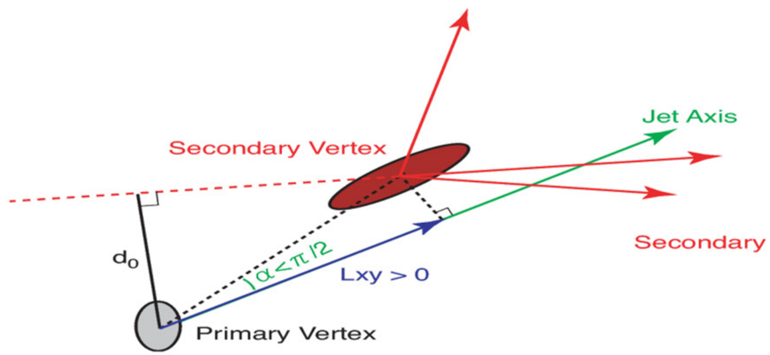
Tools: physics objects



- Hight Pt lepton (e or mu)
  - Isolated as coming from W
- 2 or 3 Jet with large E_T
  - 20 GeV at CDF
  - $|\eta|<2.8$ Tevatron



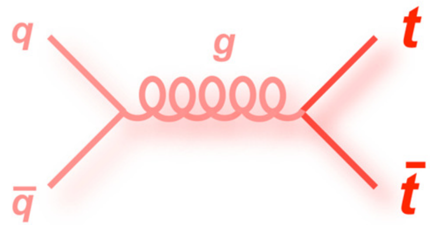
- Missing E_T (MET)
  - 25 GeV (CDF), 20/25 (D0)
- b-tagging of secondary vertices
  - With a variety of tools (from tracks displaced from the primary to NN algorithms)

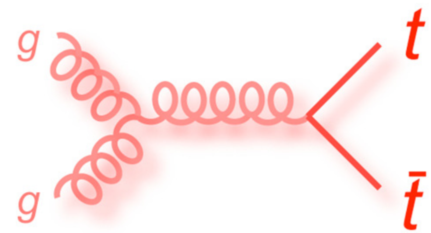


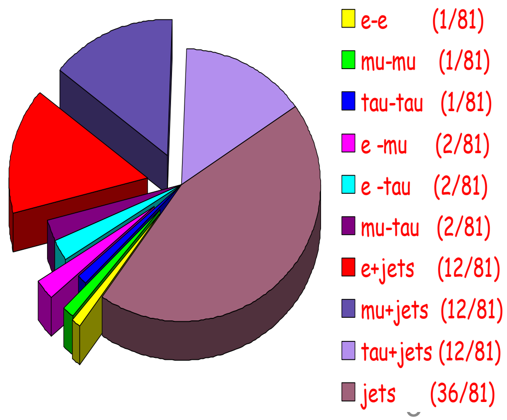
Production vertex

Top Pair production

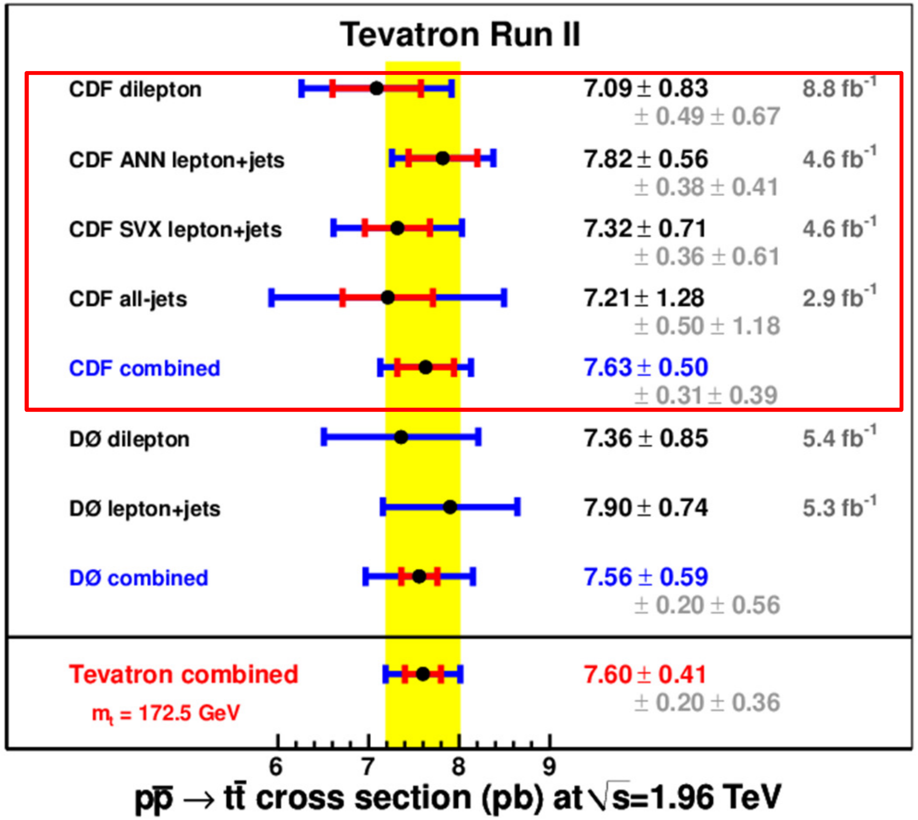
- ~85 % through qqbar annihilation
- Calculated assuming BF ($t \rightarrow Wb$)~100%
- Classified through W decay path
  - Dilepton (both Ws decay leptonically)
  - l+jets (in W decays into quarks)
  - All-hadronic (both Ws decay into quarks
- CDF does not exploit $W \rightarrow \tau\nu$ decays
  - Dilepton (e,μ) ~5%: llννbb
  - l+jets (~30%): lν qqbb
  - All-hadronic (~45%):qqqqbb







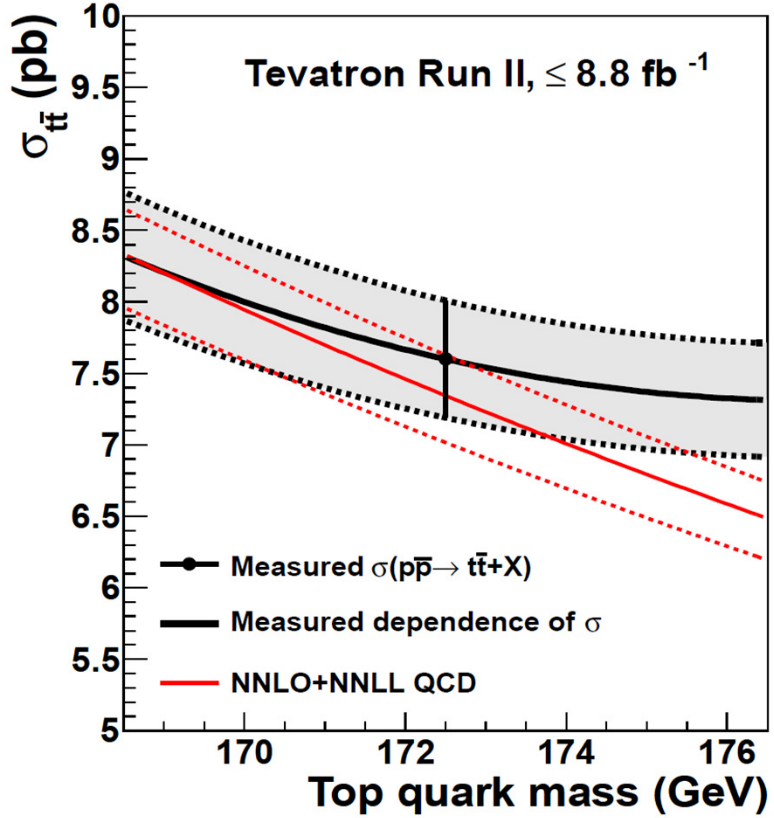
Inclusive cross section



Theoretical prediction accuracy:4.4%

- $\sigma=7.35^{+0.11}_{-0.21}(\text{scale})^{+0.17}_{-0.12}(\text{PDF})$

CDF :7.63±0.5 pb (6.5%)

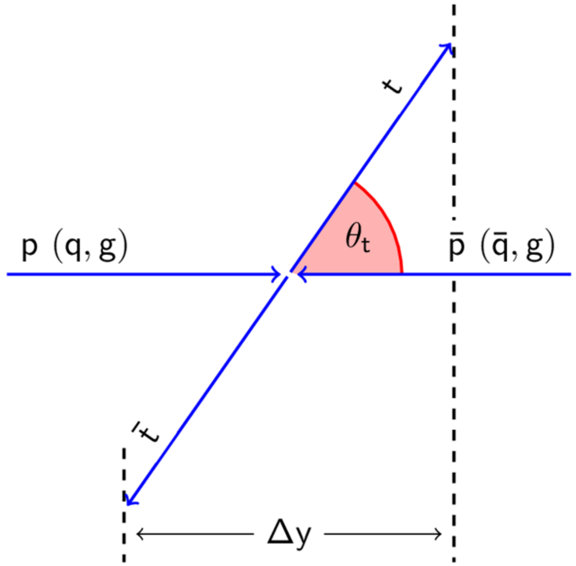


CDF results contribute to TeV combination by 60%

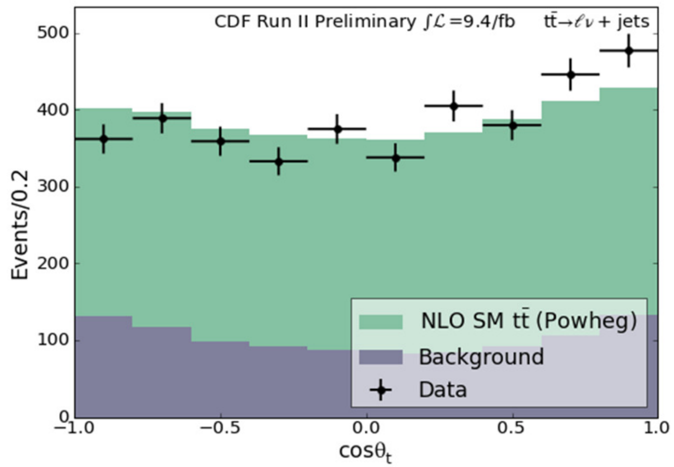
Only dilepton analysis uses the whole dataset

l+jet distribution dσ/dcosθ

CDF studied θ_t angle between
proton and top quark direction in ttbar ref frame



~Agreement with SM

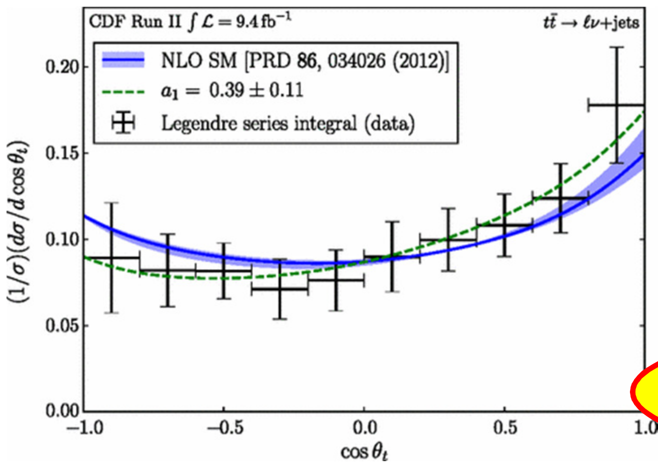


Characterize using
Legendre polinomials

$$\frac{d\sigma}{d\cos\theta_t} = \sum_\ell a_\ell P_\ell(\cos\theta_t)$$

First moment shows
tension with prediction

ℓ	a_ℓ (obs)	a_ℓ (pred)
1	0.40 ± 0.12	$0.15^{+0.066}_{-0.033}$
2	0.44 ± 0.25	$0.28^{+0.053}_{-0.030}$
3	0.11 ± 0.21	$0.030^{+0.014}_{-0.007}$
4	0.22 ± 0.28	$0.035^{+0.016}_{-0.008}$
5	0.11 ± 0.33	$0.0048^{+0.002}_{-0.001}$
6	0.24 ± 0.40	$0.0060^{+0.002}_{-0.003}$
7	-0.15 ± 0.48	$-0.0028^{+0.001}_{-0.001}$
8	0.16 ± 0.65	$-0.0019^{+0.0003}_{-0.0003}$



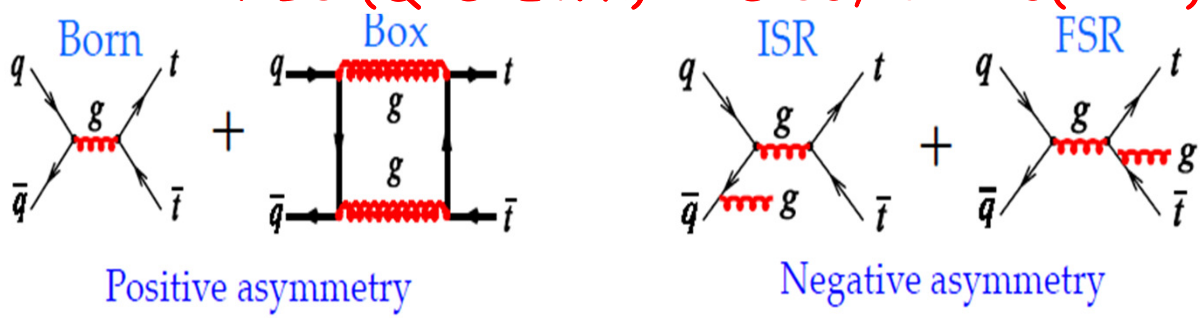
PRL **111**, 182002 (2013)

A_{FB} in ttbar events

A_{FB} is defined as $A_{FB}=\frac{N_{\Delta Y>0}-N_{\Delta Y<0}}{N_{\Delta Y>0}+N_{\Delta Y<0}}$

$\Delta y = y_t - y_{tbar}$

- Inclusive A_{FB}=8.8±6.6 %
  - NLO (QCD+EWK): PRD 86,034026(2012)



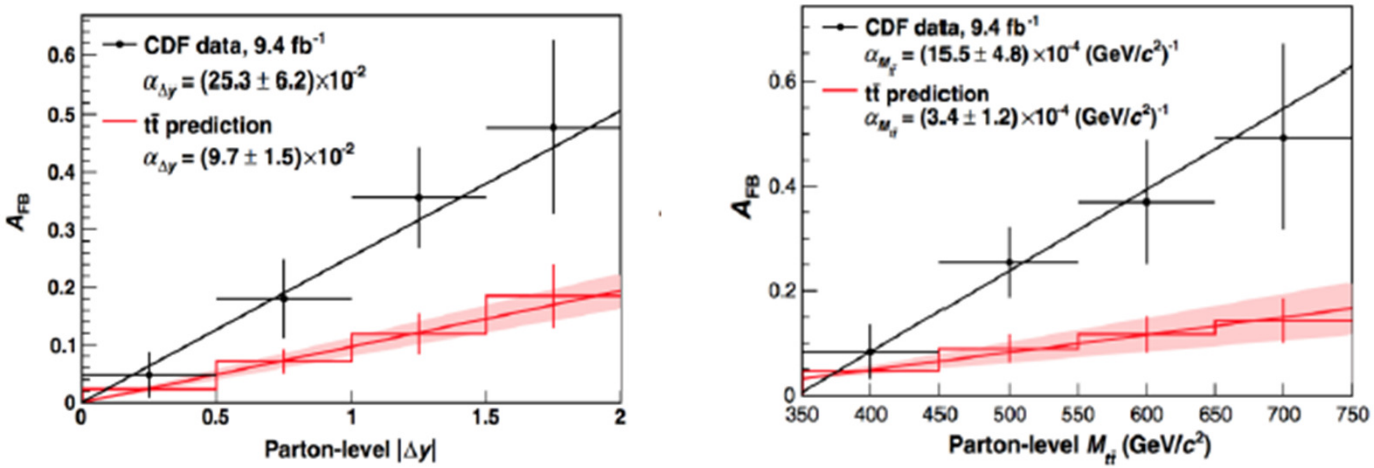
- Deviation from SM generated by
  - Axial Vector, Z' exchange, W' interaction
  - BSM scenarios should –however- be consistent with measured
    - σ_{tt}, $d\sigma/dM_{tt}$, LHC results

Old and new results

A_{FB} in l+jets: observed 6.6±2%,
at parton level 16.4±4.7 %

PRD
87,892002(2012)

- Mass and rapidity dependence



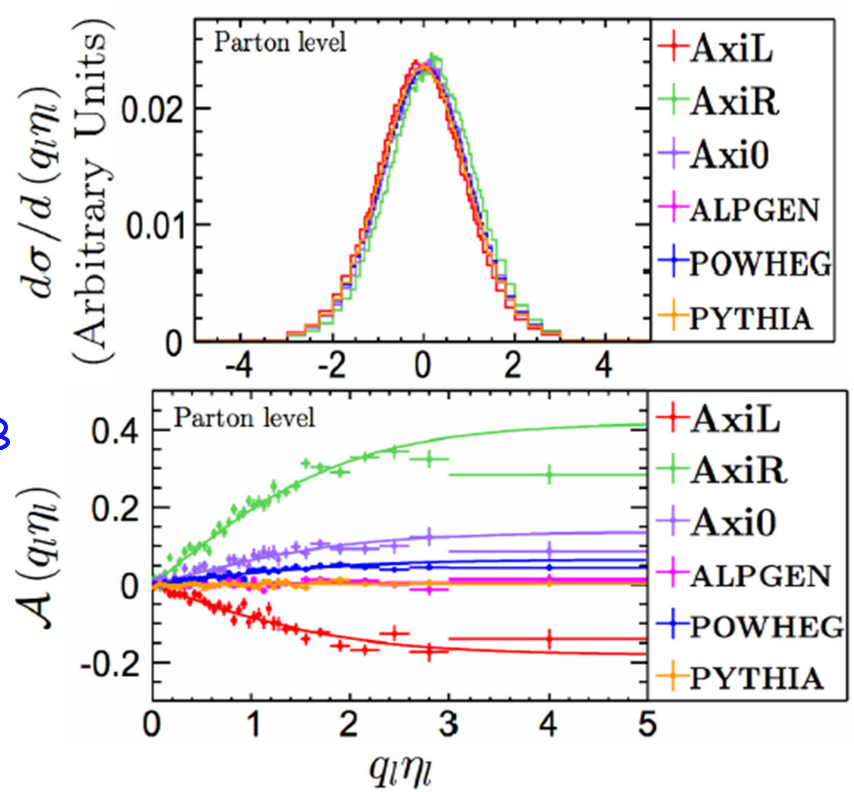
- New results: leptonic asymmetry in dilepton channel
- Combination of ttbar leptonic A_{FB}
- A_{FB} in bbar pairs (not covered here)

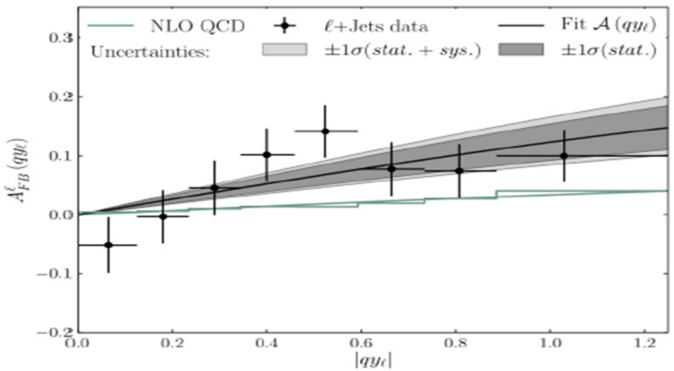
Leptonic asymmetry (l+j)

We can study the leptonic observable:

$$A^{l}_{FB}=\frac{N(q_l\eta_l>0)-N(q_l\eta_l<0)}{N(q_l\eta_l>0)+N(q_l\eta_l<0)}$$

- A^{l}_{FB} correlated to top A_{FB}
- l+jets :$9.32^{+3.2}_{-2.9}\%$ (SM: $3.8\pm0.3\%$)



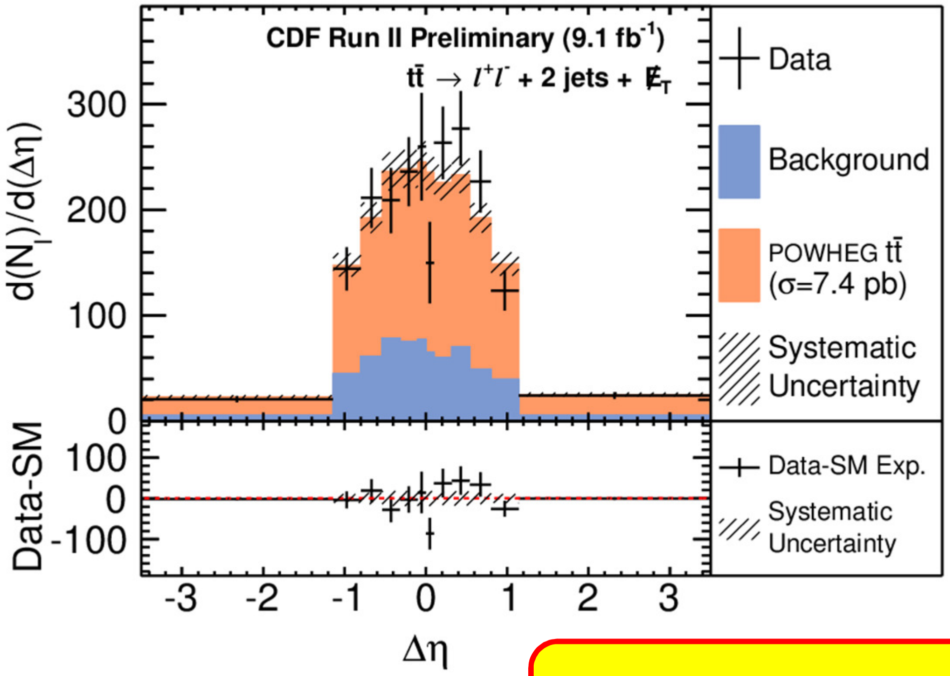


Best fit curves shown for NLO prediction (green) and measured (black)

PRD 88,072003(2013)

Leptonic asymmetry in dilepton channel

- Comparison of the number of leptons as a function of $q_l \eta_l$ wrt SM (POWHEG) prediction



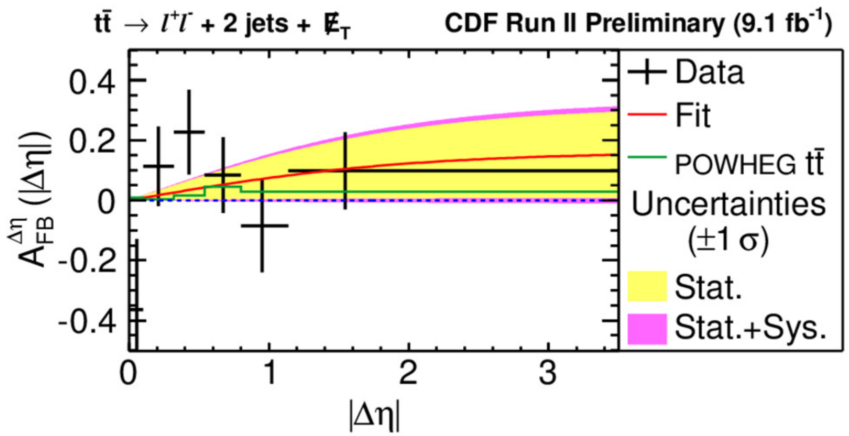
Asymmetric part of the distribution, with best fit and expectations

Result:

A^l_{FB}=(7.2±5.2(stat)±3(syst))%

=(7.2±6.0)%

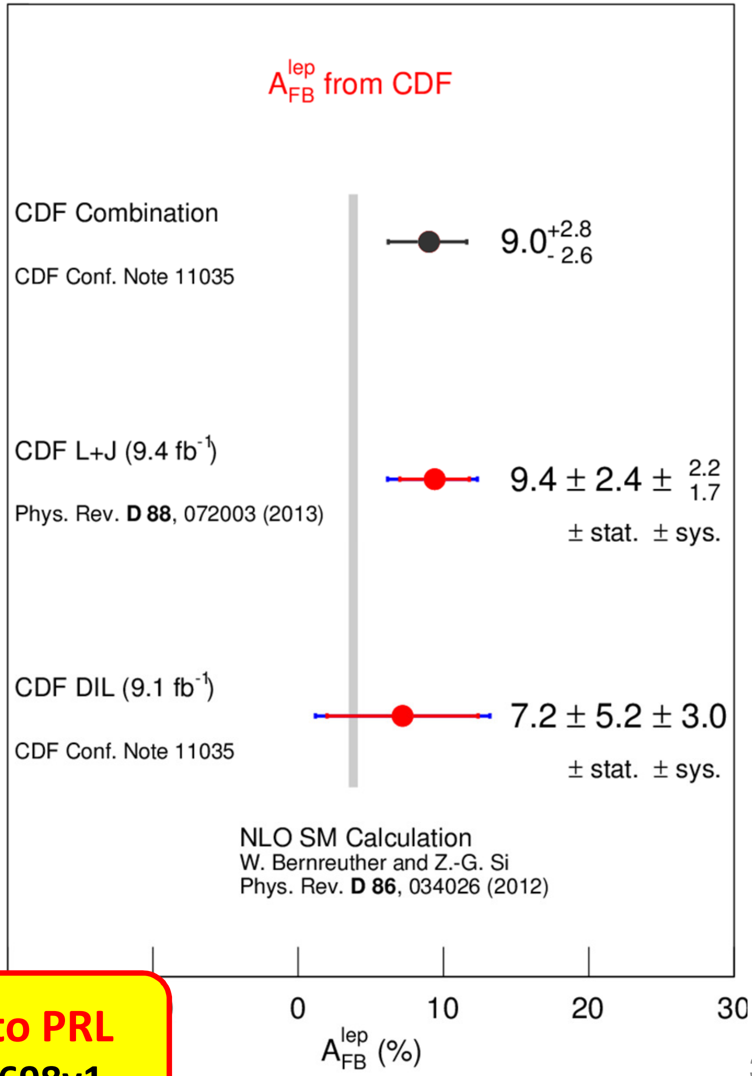
SM Exp: (3.8±3)%



Submitted to PRL
arXiv.1404.3698v1

Combination of leptonic asymmetries

- Two measurements are combined using BLUE
- l+jets uses 3864 events, 72.8% purity:
  - $A_{FB}=9.4^{+3.2}_{-2.9}\%$
- Dilepton channel uses 569 events, 71.8% purity
  - $A_{FB}=7.2\pm6\%$
- Combined result
  - $A_{FB}=9.0^{+2.8}_{-2.6}\%$ (80%l+jets, 2.6% correlation)
- Combined result is ~1.8σ from SM

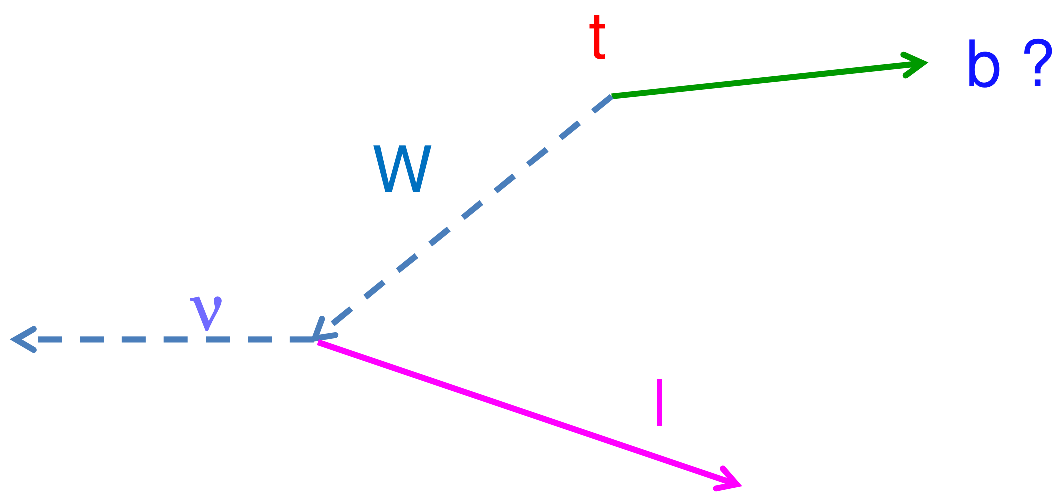


Submitted to PRL
arXiv.1404.3698v1

$|V_{tb}|$ and BF

Decay vertex is related to CKM element $|V_{tb}|$

- Direct studies of the decay vertex
  - Measurement of branching fractions
- Direct measurement of $|V_{tb}|$
  - Detection of single top events, measurement of cross section



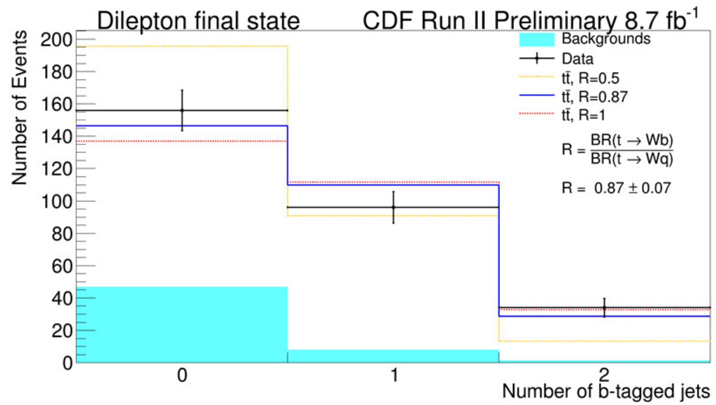
Ratio BF(t→Wb)/BF(t→Wq) in ttbar dilepton sample

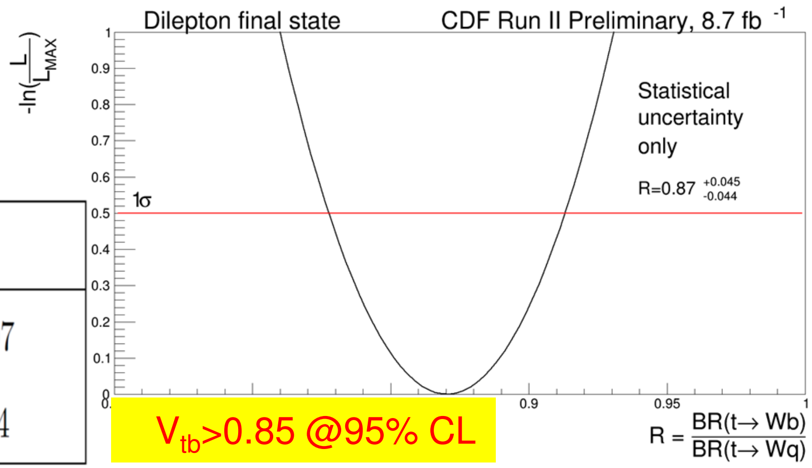
- In the SM:

$$\sum |Vtd|2 + |Vts|2 + |Vtb|2 = 1$$

$$R = \frac{\mathscr{B}(t \to Wb)}{\mathscr{B}(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$

- Comparison between observed data and expectations in samples (ee,eμ,μμ) x(0,1,2) (leptons)(b-tags)
  - Check:x-section:
    σ=7.64±0.55(stat)±0.46(lum) pb
- BR is measured fitting a ML





V_{tb}>0.85 @95% CL

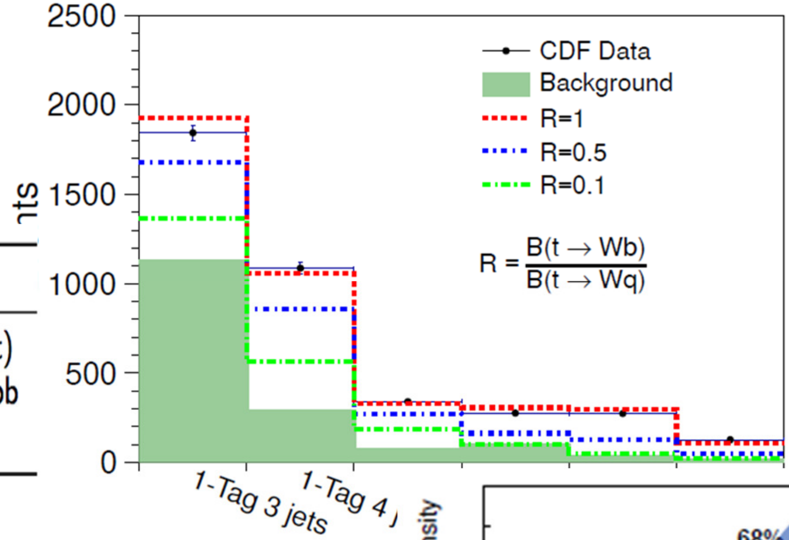
PRL
112, 221801
(2014)

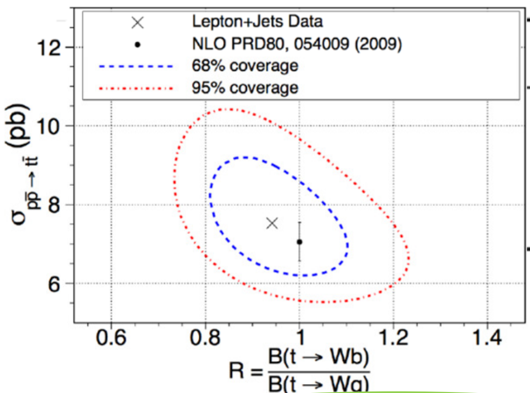
Parameter	Result
$R = \frac{BR(t\to Wb)}{BR(t\to Wq)}$	0.87 ± 0.07
$\lvert V_{tb}\rvert$	0.93 ± 0.04

R in l+jets

CDF measured R in the l+jets channel

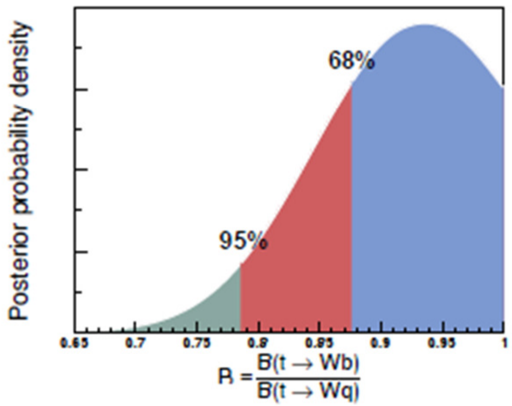
- Study the number of b-tagged jets in ttbar-enriched sample:
- Simultaneous fit to cross section and R:





Parameter	Fit Result
R	0.94 ± 0.09 (stat+syst)
$\sigma_{p\bar{p}\to t\bar{t}}$	7.5 ± 1.0 (stat+syst) pb
$\rho_{R\sigma_{p\bar{p}\to t\bar{t}}}$	-0.434

$|V_{tb}|>0.89$ @95 %CL



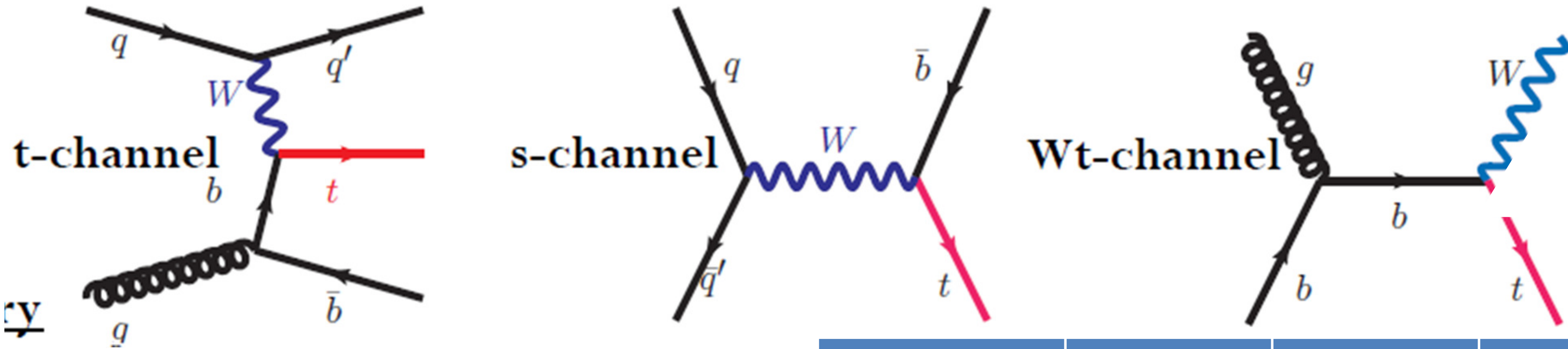
PRD 87,11 111101(2013)

Work in progress on combination

What is single top?

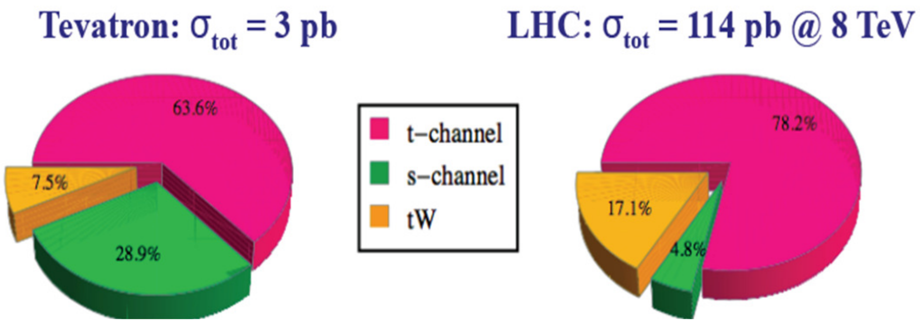
Electroweak production of top quark

- All Feynman diagrams below have a Wtb vertex



x-sec in pb

	t	s	Wt
Tevatron	2.26±0.2	1.04±0.1	0.3±0.06
LHC (7 TeV)	64.2±2.4	4.6±0.2	15.7±1.1
LHC (8 TeV)	87.8±3.4	5.6±0.3	22.4±1.5



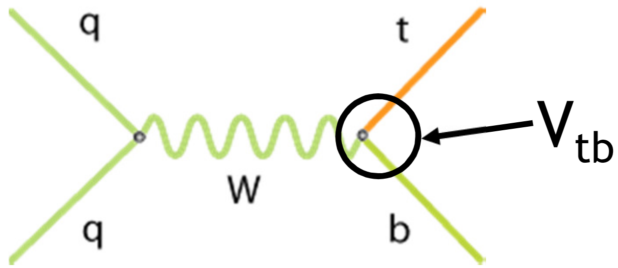
s-channel difficult at the LHC

Why measure Single Top Production ?

$\sigma_{\text{single top}} \propto |V_{tb}|^2$

Access to the W-t-b vertex

- probe V-A structure
- access to top quark spin



Allows direct measurement of Cabibbo-Kobayashi-Maskawa (CKM) matrix element $|V_{tb}|$:

- Is this Matrix 3x3 ?
  - Is there a 4th generation ?
- Does unitarity hold ?

$$|V_{ub}|^2 + |V_{cb}|^2 + |V_{tb}|^2 \stackrel{?}{=} 1$$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{uX}? \\ V_{cd} & V_{cs} & V_{cb} & V_{cX}? \\ V_{td} & V_{ts} & V_{tb} & V_{tX}? \\ V_{Yd}? & V_{Ys}? & V_{Yt}? & V_{YX}? \end{pmatrix}$$

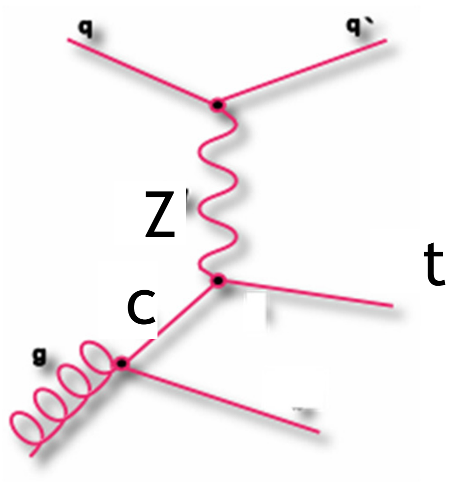
Precision electroweak measurements rule out "simple" fourth generation extensions, but see for example:

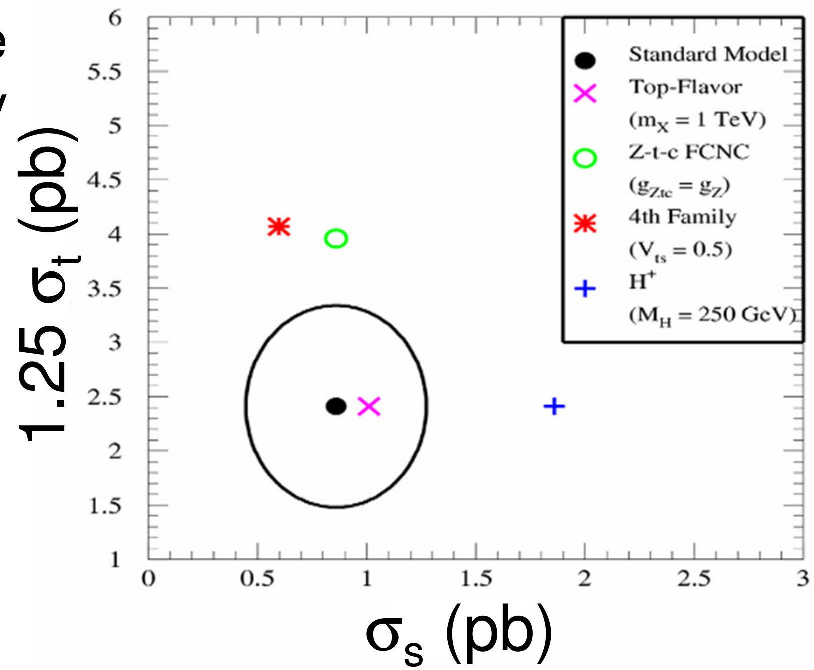
J. Alwall et. al., "Is $|V_{tb}|$~1?" Eur. Phys. J. C49 791-801 (2007).

Sensitivity to New Physics

- New physics may affect the rate of t and s channel differently

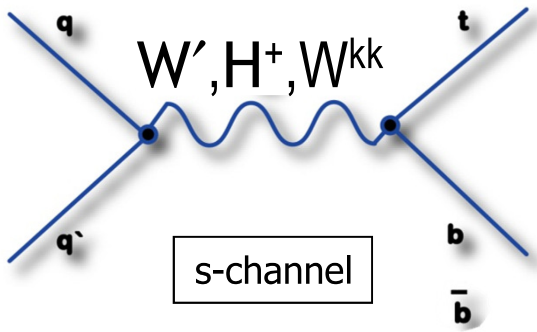
t-channel





T. Tait, CP Yuan PRD63, 014018 (2001)

- Flavor changing neutral currents (t-Z-c, t-γ-c, t-g-c)



s-channel

- heavy W' boson
- charged Higgs H^+
- Kaluza Klein excited W^{kk}

Single top

The challenge is

- To measure a process with yield smaller than background fluctuations
- Separate the different (s,t) components

Strategy

- Combine several channels
- ANN to identify the signal
- Extract CKM element:

$$|V_{tb}|^2 = |V^{SM}{}_{tb}|^2 \times \sigma^{obs}/\sigma^{SM}$$

s+t:

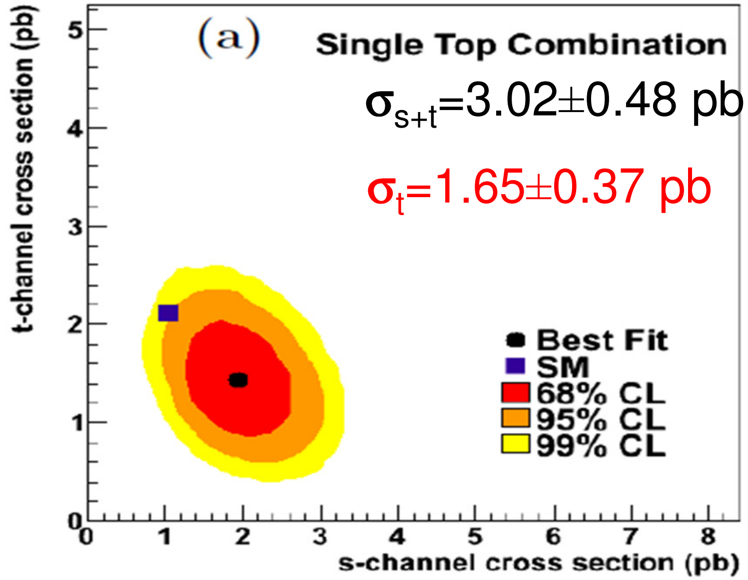
- l+jets analysis (lnbb)
  - s+t and s vs t
- Met-bb (forget l)
  - s+t and s vs t

s-optimized analysis

- Evidence for single top in s-channel
  - Eventually combined with D0
- s-channel observation
  - 6.3 σ (Tev combination)
    - see Yvonne Peters's talk

Results (s+t channel)

- Extract separate s and t channel x-sections (ratio fixed to SM value)
- Obtain $|V_{tb}|$ by integrating the ML and assuming a flat prior $0<|V_{tb}|<1$

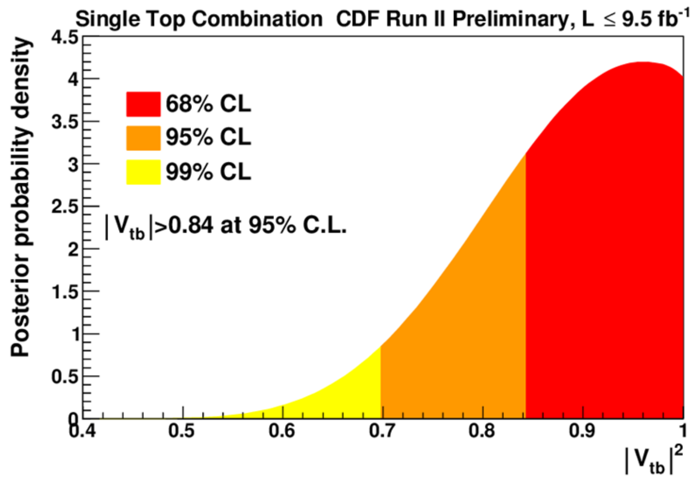


Submitted to PRL
arXiv.1407.4031

l+jets, 7.5 fb^{-1}:

$|V_{tb}|$ = 0.95 ±0.09 (stat+syst) ± 0.05 (theo)

$|V_{tb}|$ > 0.78 (95 % C.L.)



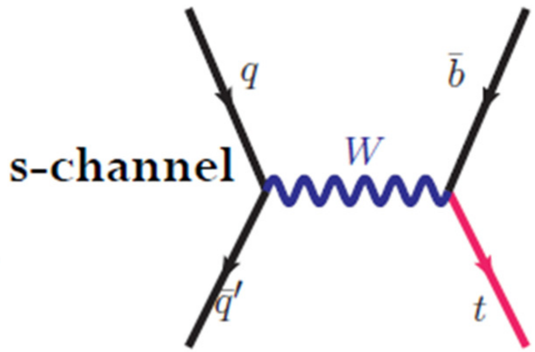
Combining with the MET bb analysis: $|V_{tb}|$>0.84 (95 % C.L.)

New

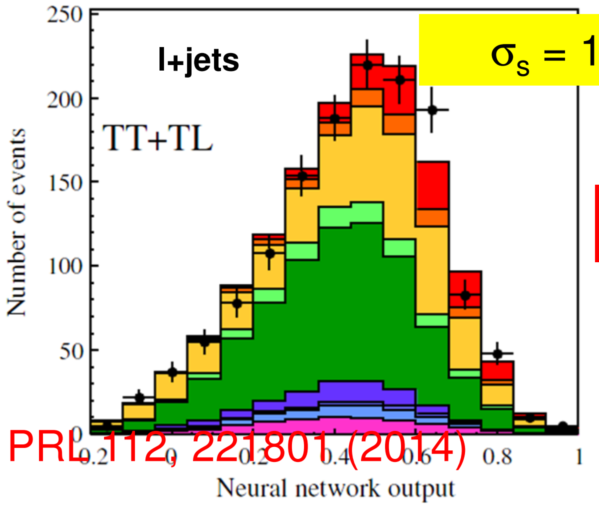
Result (s-channel)

CDF optimized its analyses to observe single top production in the s-channel

- New l+jets and MET+jets optimized analyses
  - Innovative multivariate tagger (used in VH evidence)
  - NN s-optimized

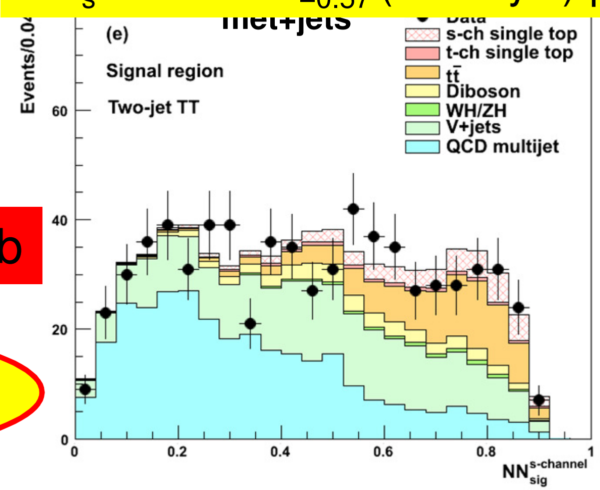


$\sigma_s = 1.12^{+0.61}_{-0.57}$ (stat+syst) pb



$\sigma_s = 1.41^{+0.44}_{-0.42}$ (stat+syst) pb

PRL 112, 221801 (2014)



$\sigma_s = 1.12^{+0.61}_{-0.57}$ (stat+syst) pb

PRL **112**, 231804 (2014)

Conclusions

Top studies are still ongoing

- Some channels are unique to the Tevatron
  - At least «challenging» at the LHC
- A_{FB} still an open question
  - Will it be solved?
- Some measurements are real legacies
  - Both in terms of results and of technical developments
  - CKM element V_{tb} deserves a closer look
- Is the third generation the path to new physics?