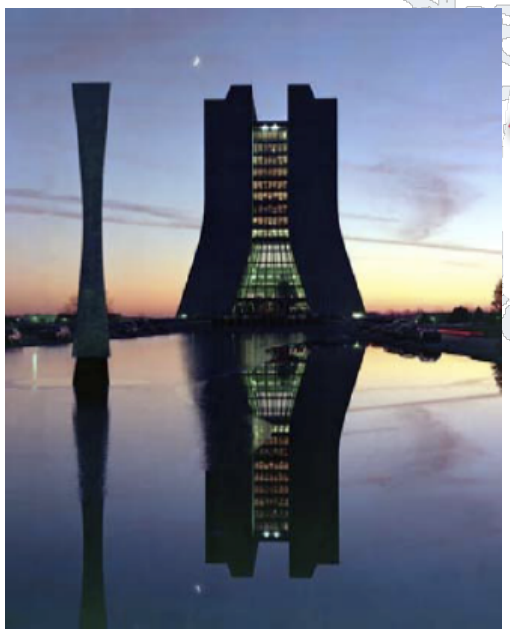
Recent top physics results from the DØ experiment

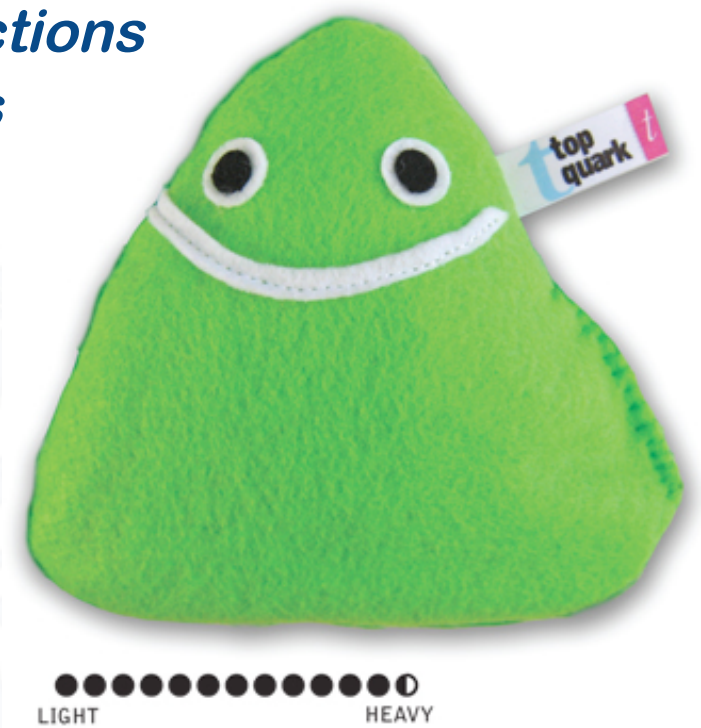
Oleg Brandt on behalf of the DØ collaboration

II Physikalisches Institut, Georg-August-Universität Göttingen

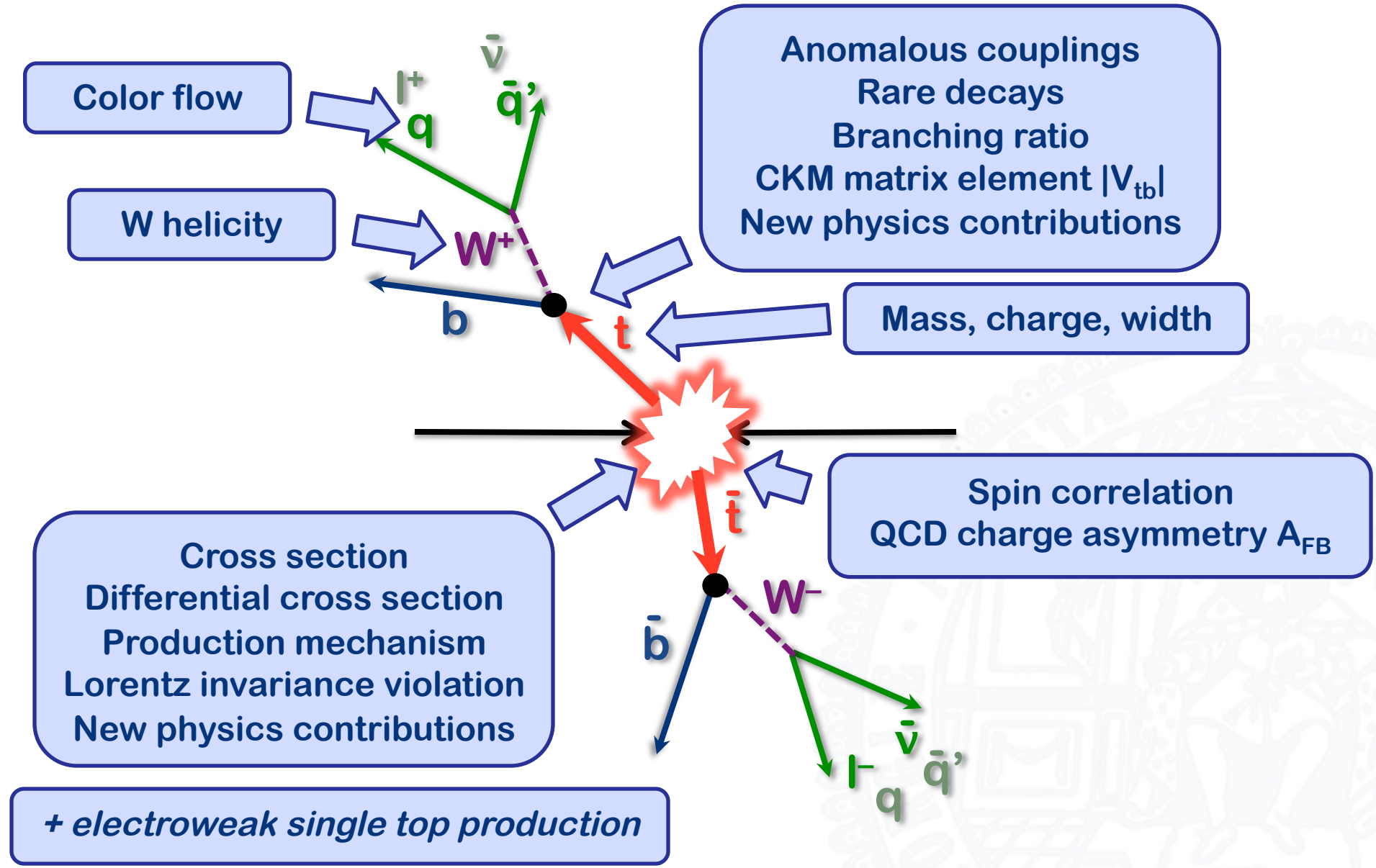


What makes top so interesting?

- Compelling arguments that new physics can show up in the top sector:
  - Top is the heaviest quark discovered so far
  - Its Yukawa coupling is 0.996±0.006
    - Special role in EWSB?
  - Since 17 years, our measurements have been *consistent with SM predictions* in the top sector *within uncertainties*
  - D0 and CDF collected thousands of tt events, enabling precise studies of top properties
    - There are recent measurements displaying tension between Tevatron data and the SM predictions (A_{FB}, R_B)



A wealth of top properties



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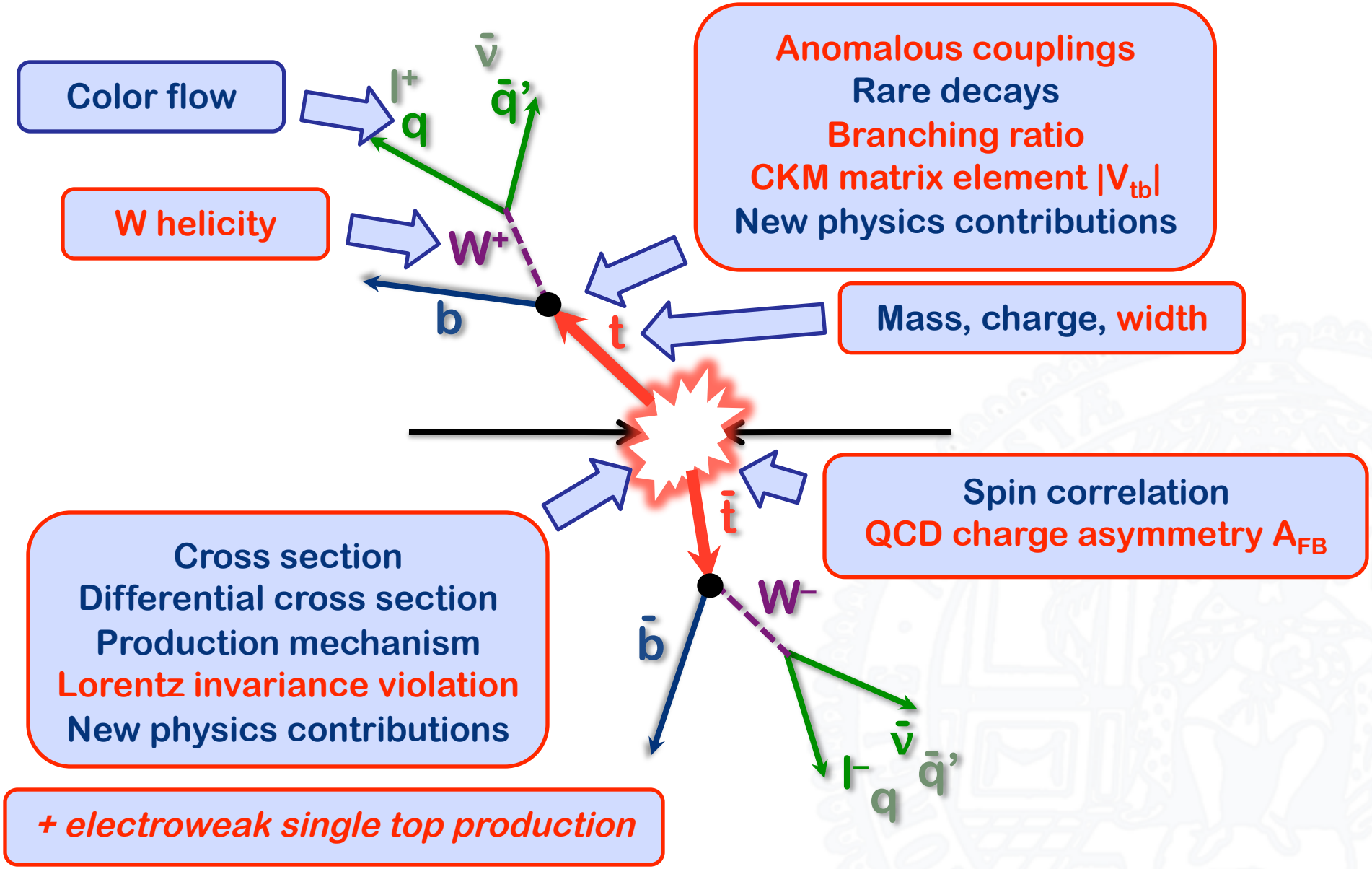

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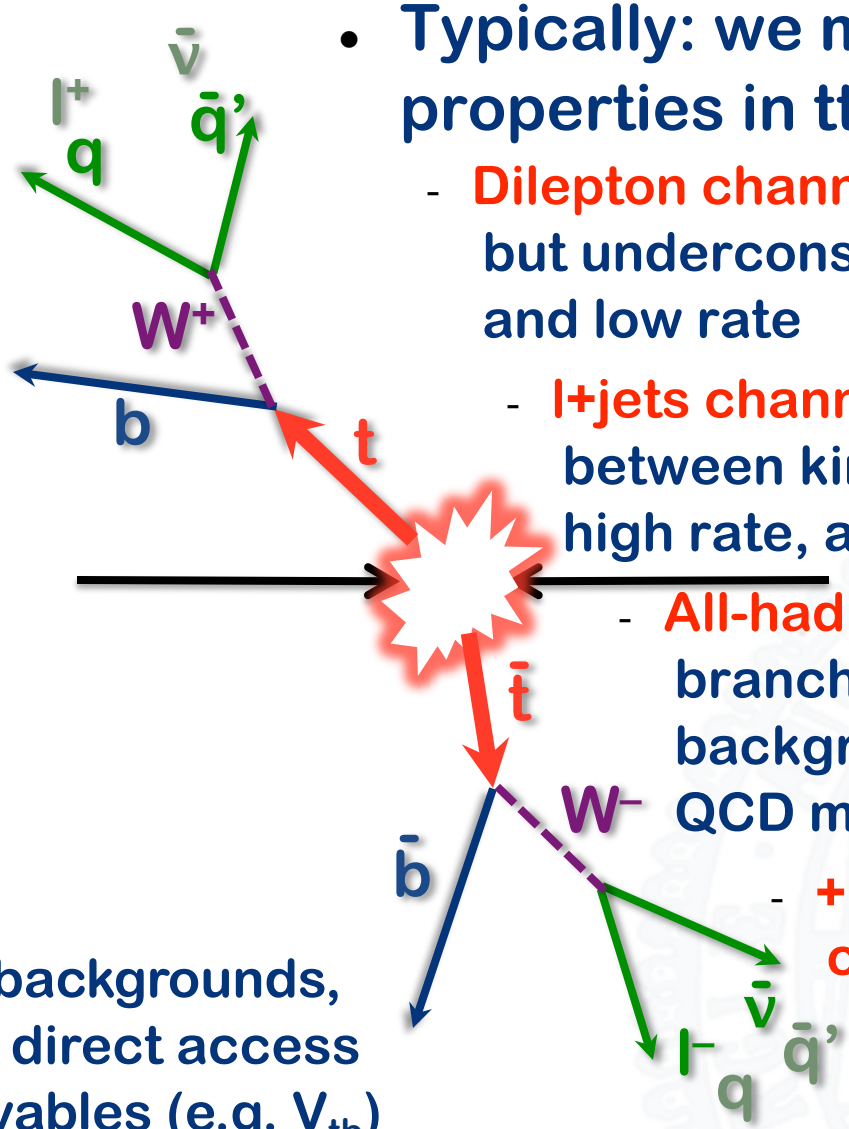
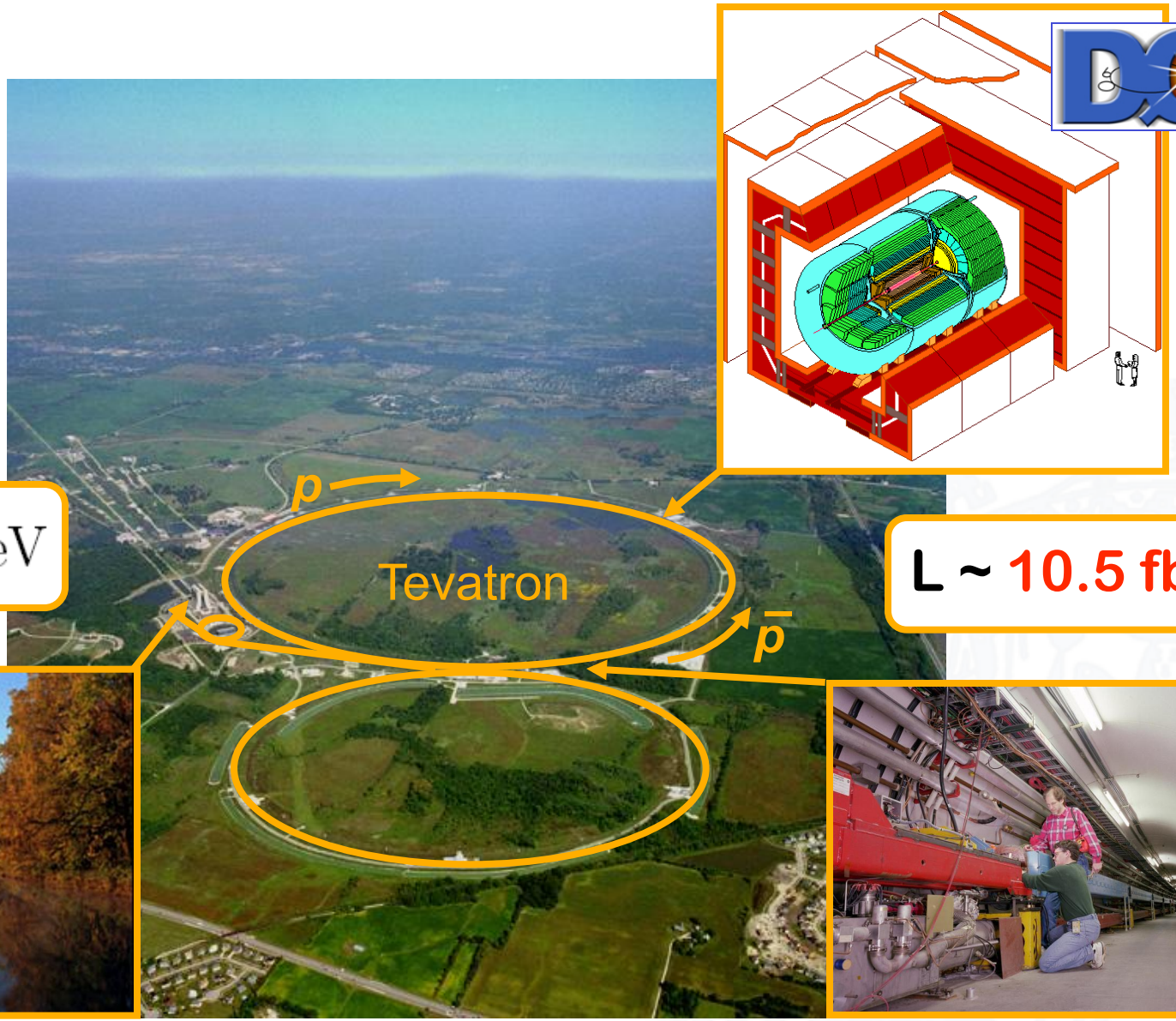


- **Typically: we measure top properties in tt events**
  - **Dilepton channel: low backgrounds, but underconstrained kinematics and low rate**
  - **l+jets channel: good compromise between kinematic reconstr'n, high rate, and backgrounds**
  - **All-hadronic channel: highest branching ratio, very high backgrounds from QCD multijet production**
  - **+ other orthogonal channels…**

Single top: high backgrounds, moderate rate, direct access to some observables (e.g. V_{tb})

More about the top birth place…



$$\sqrt{s} = 1.96\,\mathrm{TeV}$$

L ~ 10.5 fb^{-1}

Initial state @ Tevatron (and LHC)

- **Initial state for top-antitop pair-production rather different between Tevatron and LHC:**

Tevatron	LHC
$p\bar{p}$ initial state → *CP* eigenstate	pp initial state
centre-of-mass energy: 1.96 TeV	centre-of-mass energy: 7 (8) TeV
Initial state: qq (≈85%), gg (≈15%)	Initial state: qq (≈30%), gg (≈70%)

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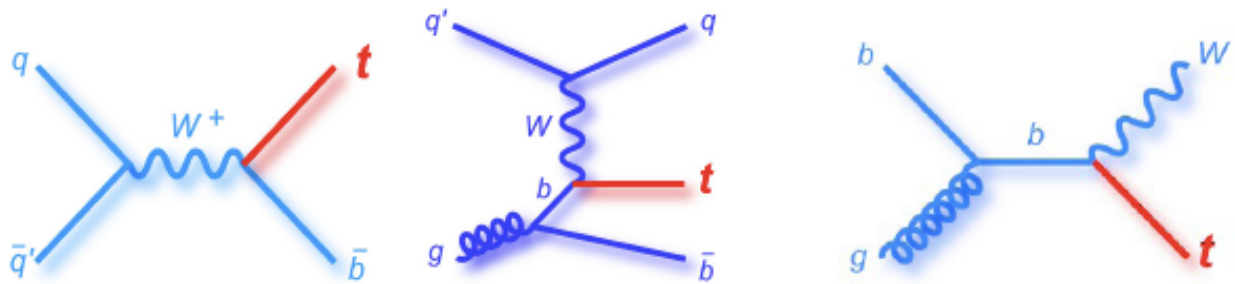
- **Dramatic differences for single top production:**



Collider	s-channel: σ_{tb}	t-channel: σ_{tqb}	Wt-channel: σ_{tW}
Tevatron: $p\bar{p}$ (1.96 TeV)	1.04 pb	2.26 pb	0.28 pb
LHC: pp (7 TeV)	4.6 pb	64.6 pb	15.7 pb

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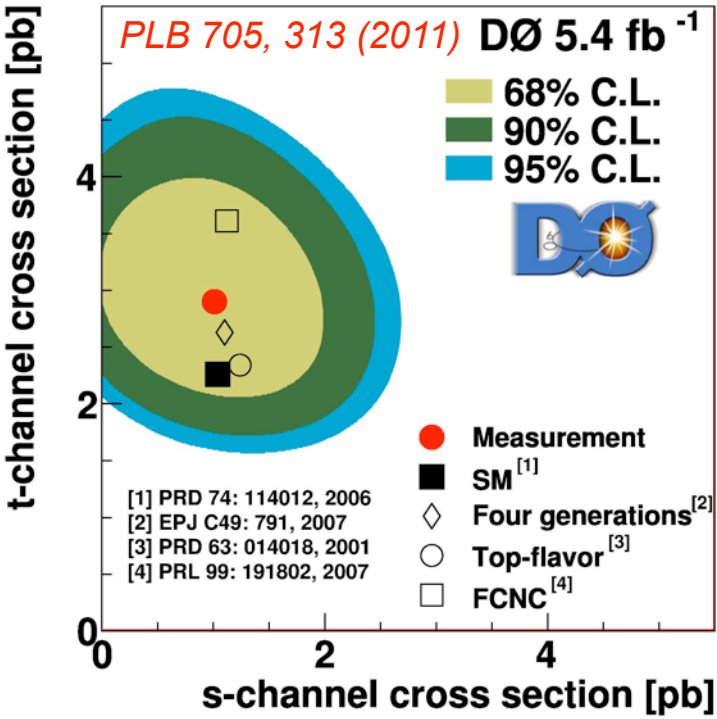
Assume:

Wtb coupling identical in production & decay



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$\mathcal{B}(t \to Wb)$ ← **measured in tt events**

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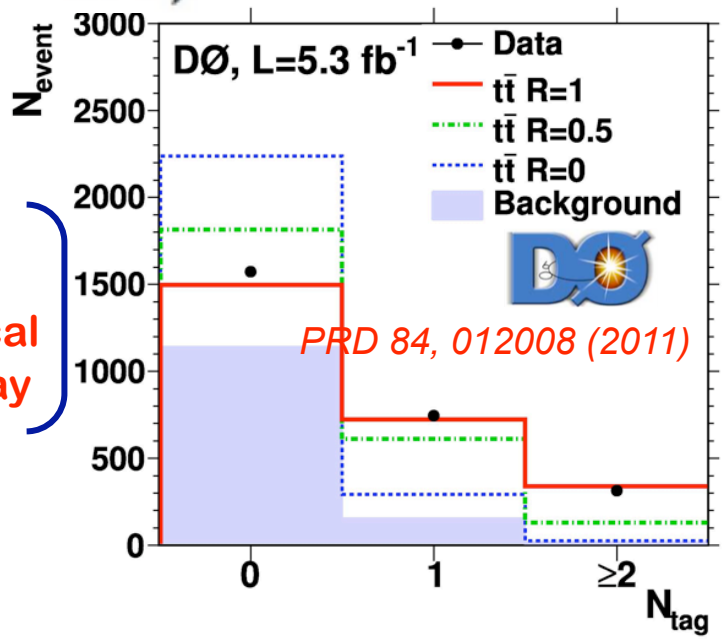

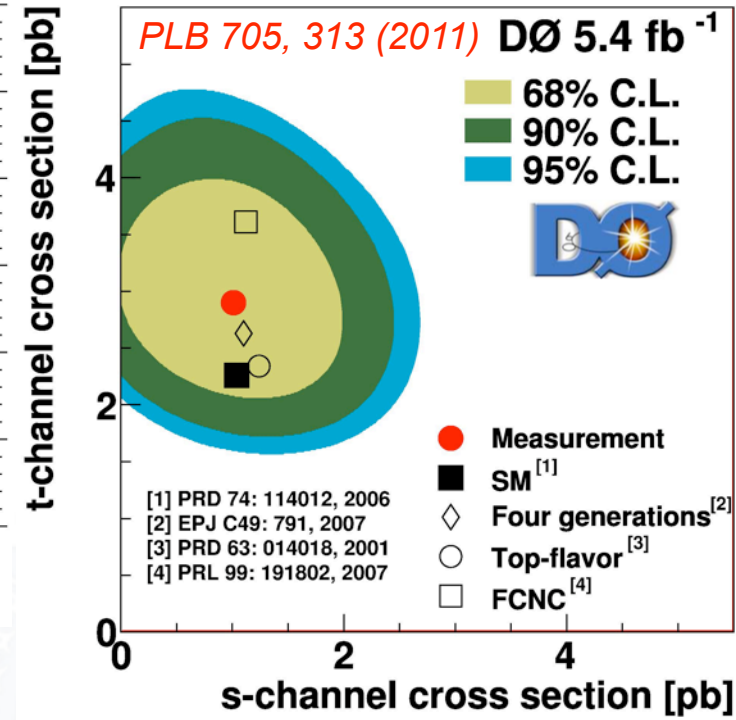

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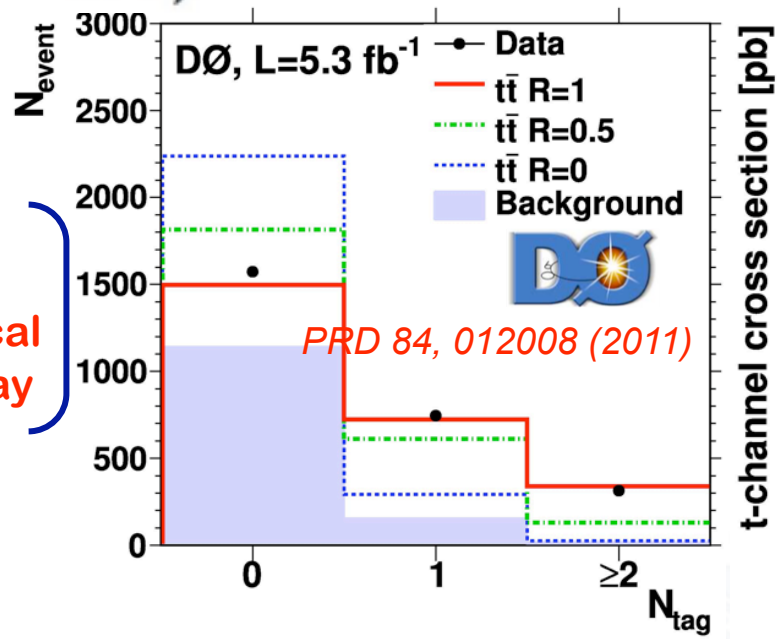

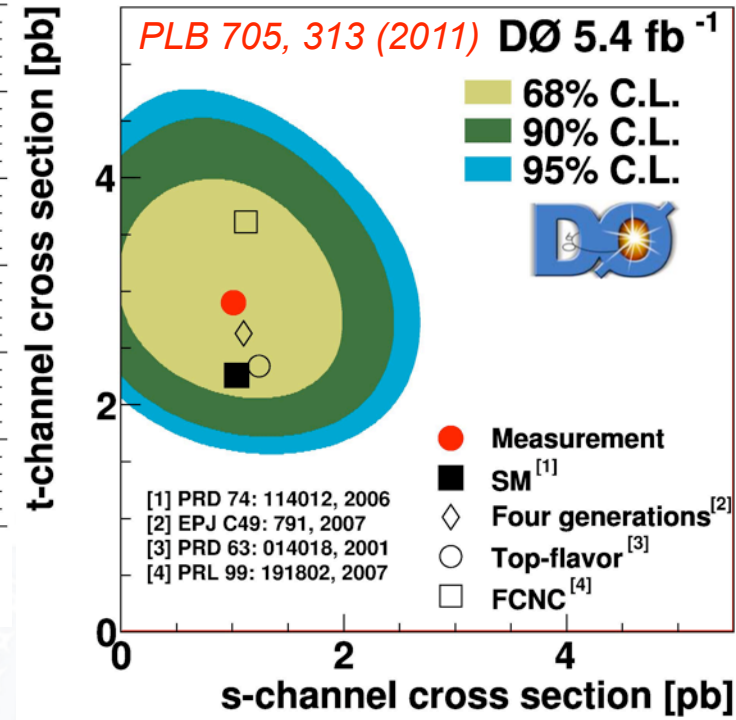

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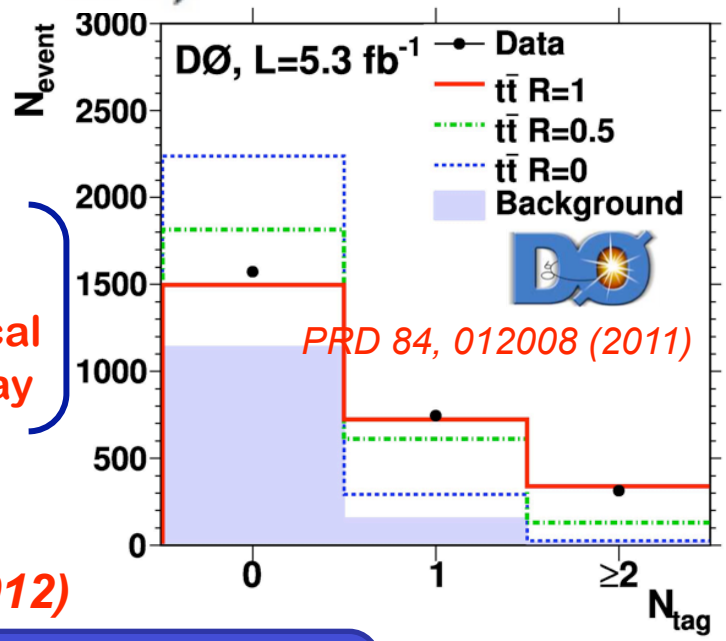

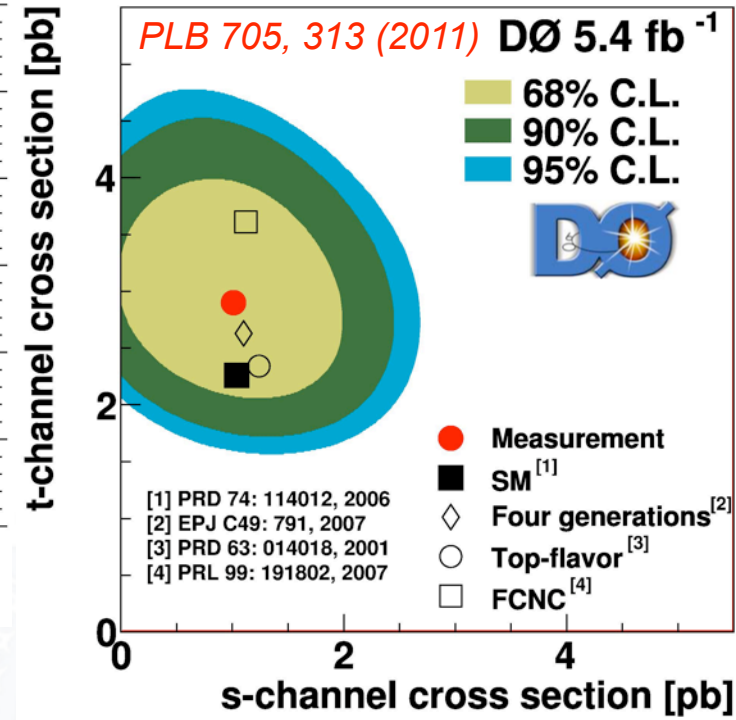

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PRD 85, 091104 (2012)

World's most precise (indirect) determination of Γ_t to date

$$\Gamma_t = 2.00^{+0.47}_{-0.43}\ \text{GeV}$$
$$\tau_t = (3.29^{+0.90}_{-0.63}) \times 10^{-25}\ \text{s}$$

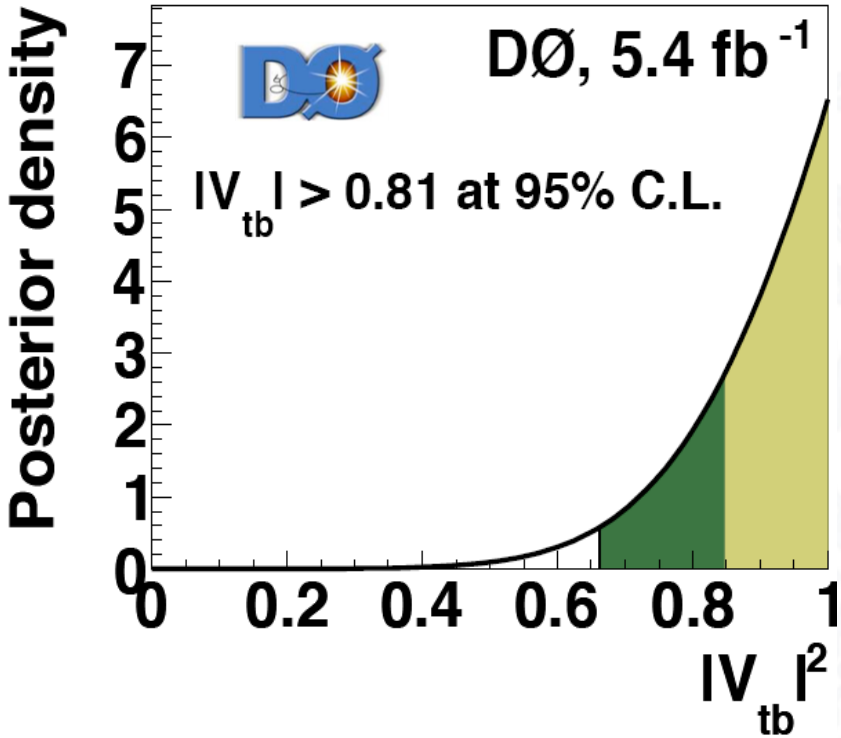
Properly correlate $\sigma(t\text{−channel})$, $\mathcal{B}(t \to Wb)$ → measure Γ_t from LH based on *t*-channel discriminant

Measurement of $|V_{tb}|$

- To extract $|V_{tb}|$, use again *t*-channel discriminant
- Form the LH as before but analyse

$$|V_{tb}|^2 \mathcal{B}(t \to Wb)\sigma(t\text{−channel})_{SM,|V_{tb}|=1}$$

- Form Bayesian posterior density:



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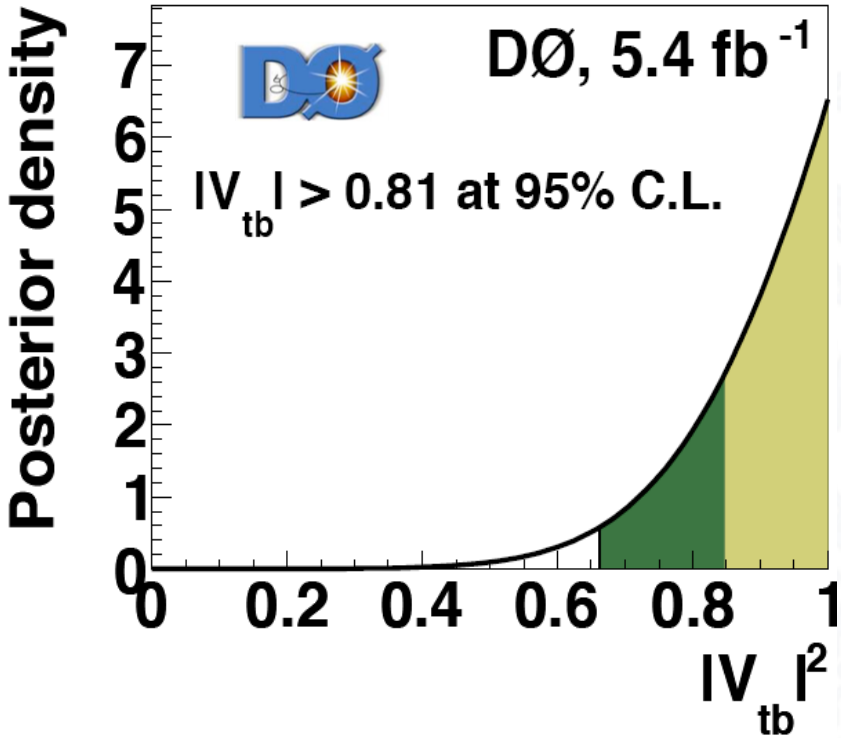

$|V_{tb}| > 0.81$ at 95% C.L.

No assumption that t→Wb exclusively or on relative *t* to *s* channel rates

PRD 85, 091104 (2012)

W Helicity

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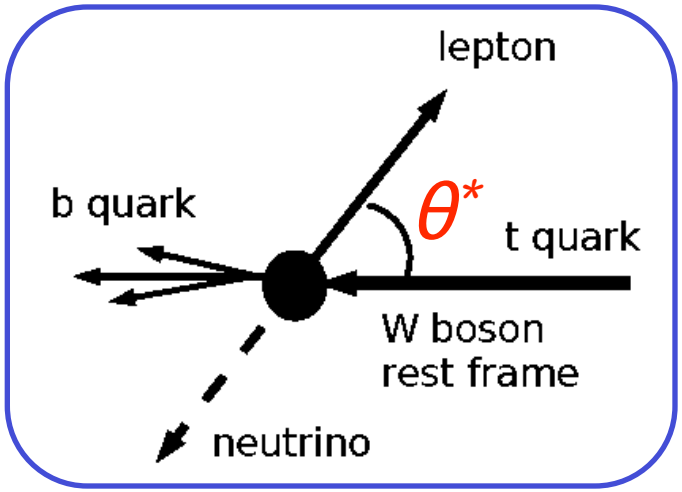
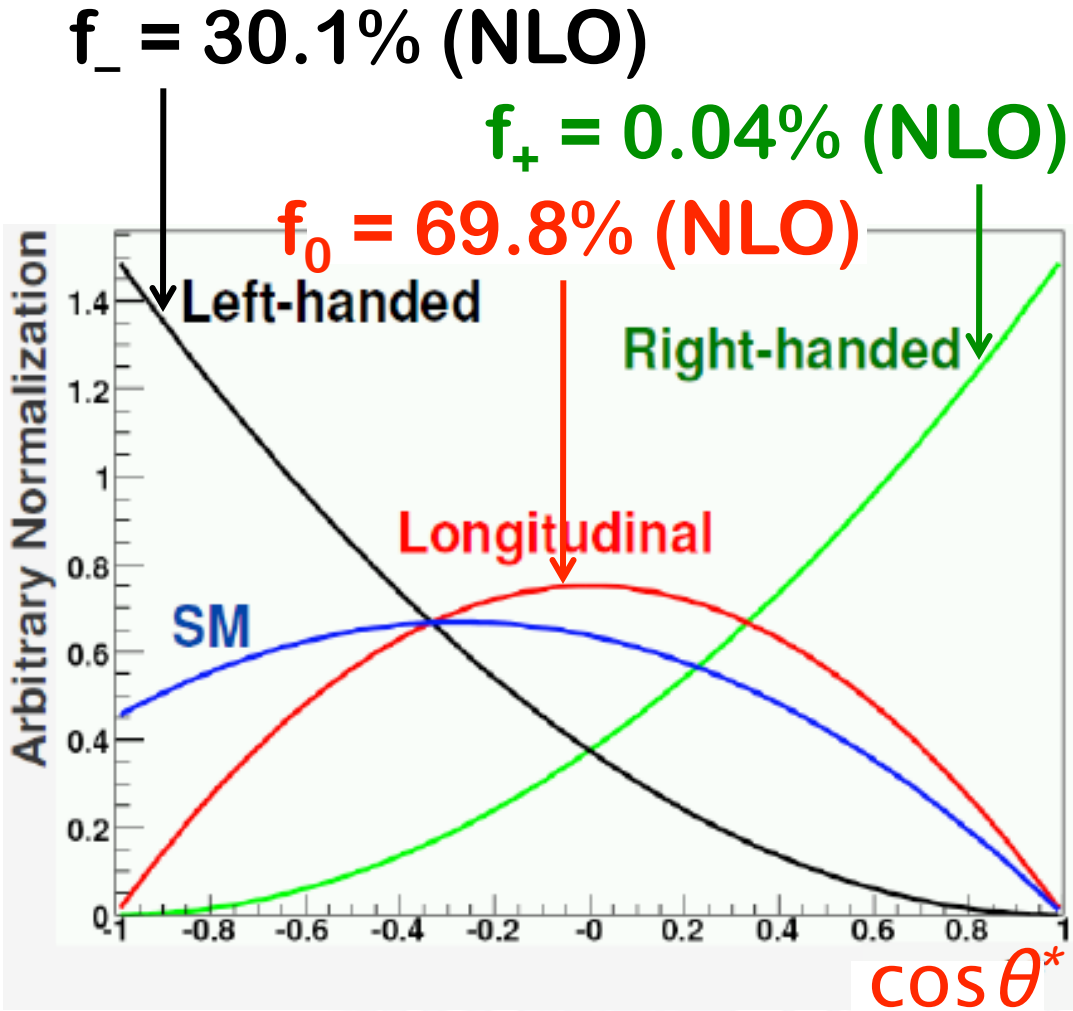
  - Deviations from SM would indicate new physics





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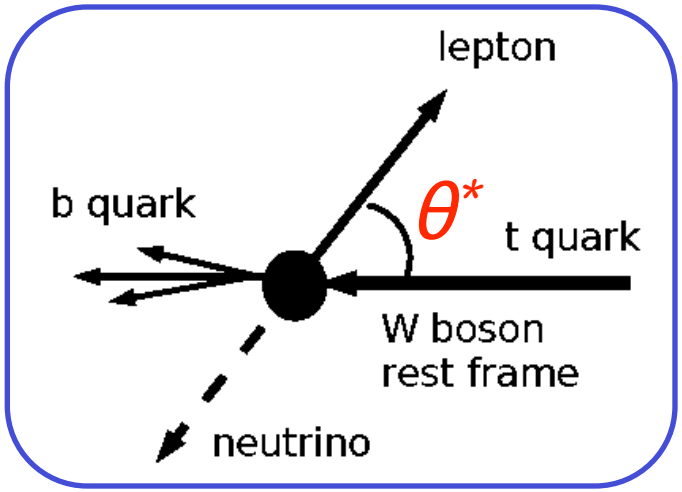
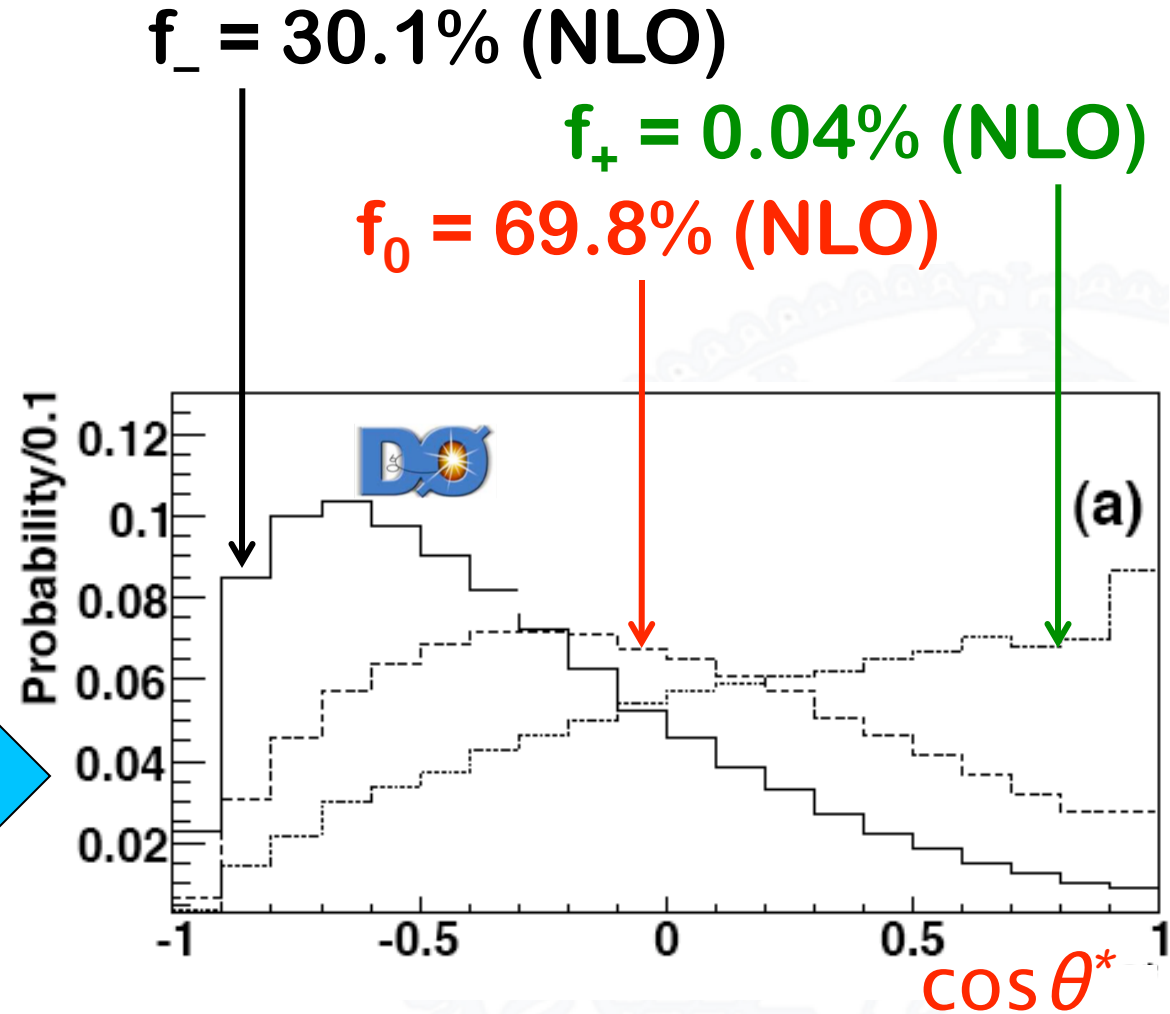
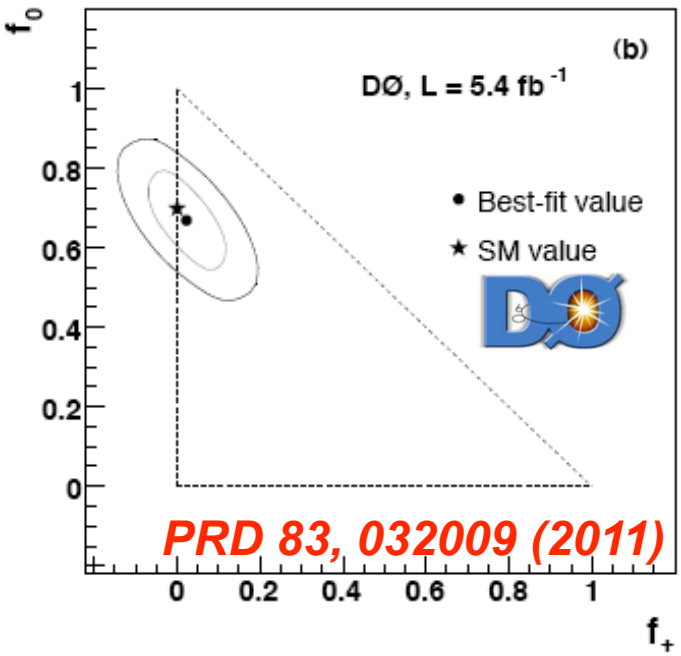




Dilepton & l+jets comb'd

Define channel-dependent templates in cosθ* (leptonic W) and |cosθ*| (hadronic W) + LH fit



Simultaneous 2-D fit results:

$$f_0 = 0.669 \pm 0.078\ (\text{stat.}) \pm 0.065\ (\text{syst.})$$
$$f_+ = 0.023 \pm 0.041\ (\text{stat.}) \pm 0.034\ (\text{syst.})$$

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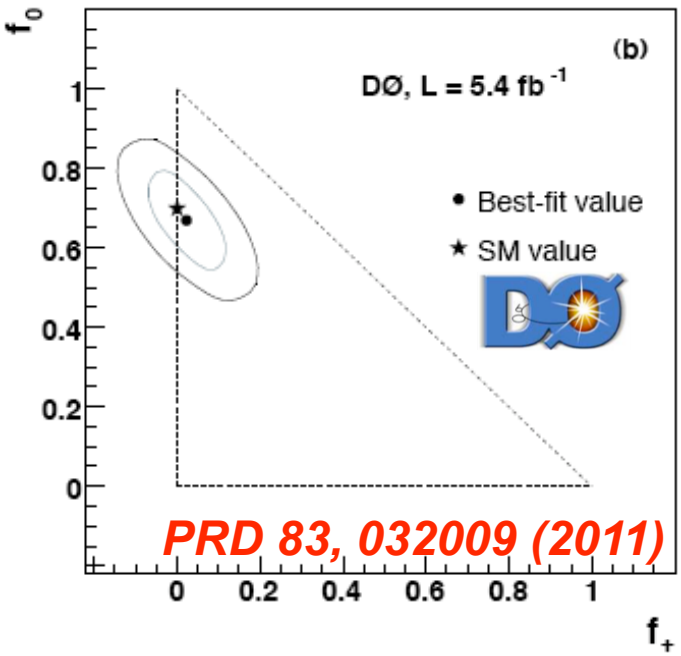

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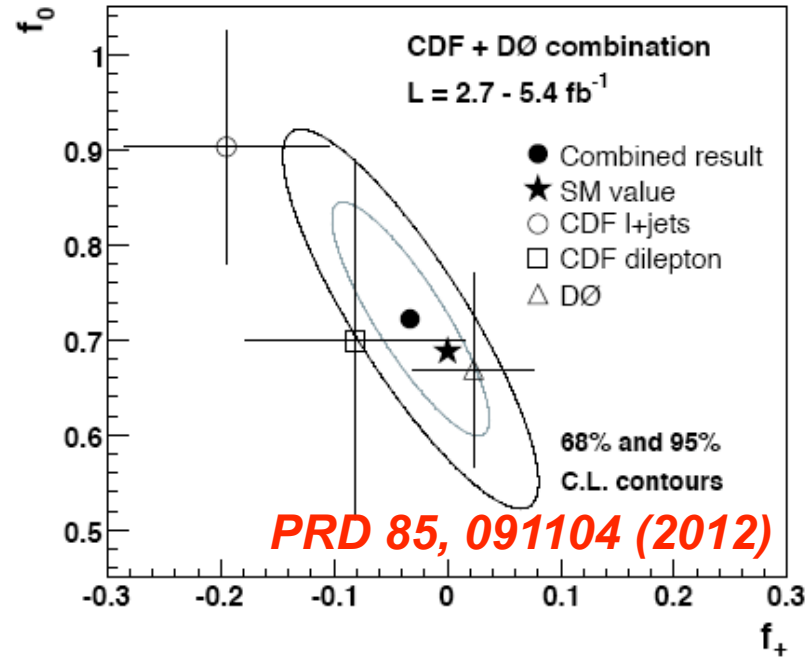
Tevatron combination:



$$f_0 = 0.722 \pm 0.062\ (\text{stat.}) \pm 0.052\ (\text{syst.})$$
$$f_+ = -0.033 \pm 0.034\ (\text{stat.}) \pm 0.031\ (\text{syst.})$$

chi^2/N$_{DOF}$ = 8.82/4, p-value = 6%

Anomalous *Wtb* couplings (*Wtb* AC)

- **Most general, lowest-dim, *CP*-conserving *Wtb* vertex**

$$\mathcal{L} = \frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}(f_V^L P_L + \underline{f_V^R} P_R)tW_{\mu}^{-}$$
$$-\frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}V_{tb}}{M_W}(\underline{f_T^L} P_L + \underline{f_T^R} P_R)tW_{\mu}^{-} + h.c.$$

Underlined couplings are 0 in SM!

arXiv:1110.4592 [hep-ex], PLB acc'd

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- **Extract *Wtb* AC from single top production using:**
  - **shapes of kinematic distributions**
  - **event rate (overall, *s*-channel vs *t*-channel)**
- **Few assumptions:**
  - **Single top quarks produced exclusively via a W boson**
  - $|V_{td}|^2 + |V_{ts}|^2 \ll |V_{tb}|^2$

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- Few assumptions:
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  - $|V_{td}|^2 + |V_{ts}|^2 \ll |V_{tb}|^2$
- Bayesian NN discriminant in 3 N_{jet} x 2 N_{tag} bins:
  - Dedicated training for each signal model
    - Allow *one* of $\{f_V^R, f_T^L, f_T^R\}$!=0, and f_V^L=1 for consistency!

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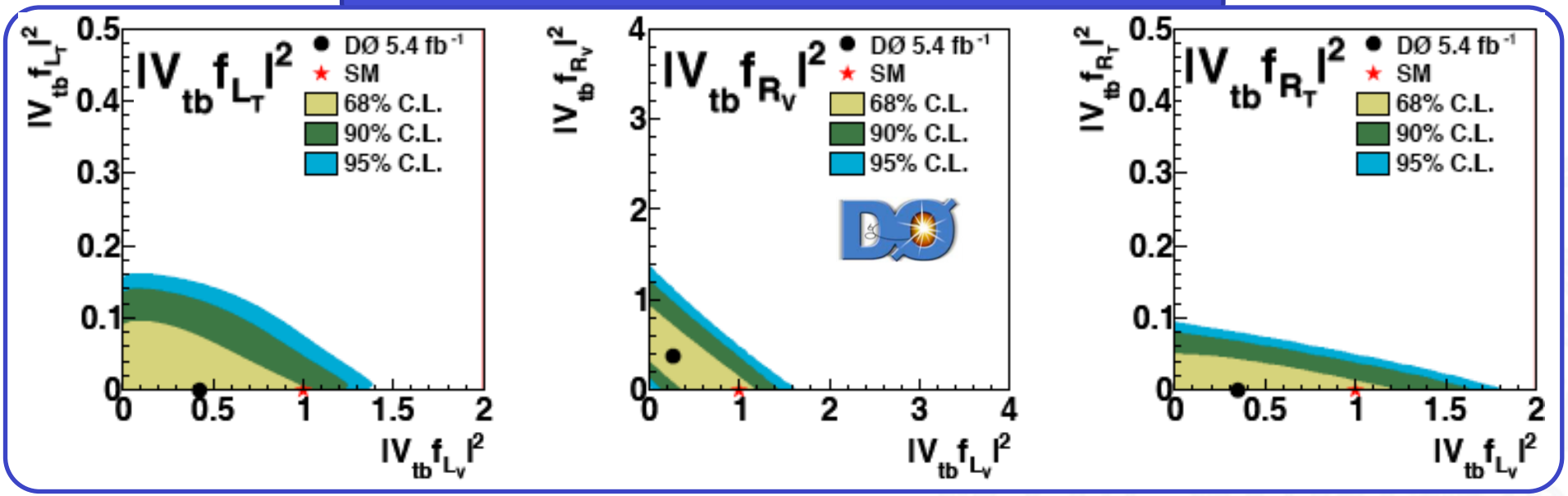
Wtb AC from single top prod'n

- **Obtained limits:**

Limits on Wtb AC from single top production



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Wtb AC from single top + W helicity

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arXiv:1204.2332 [hep-ex], PLB acc'd

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combine!

- **Assume:**
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- **Use the LH from W helicity meas't as prior for single top**
  - Compute LH over all possible analysis channels
  - Remove overlap between selections

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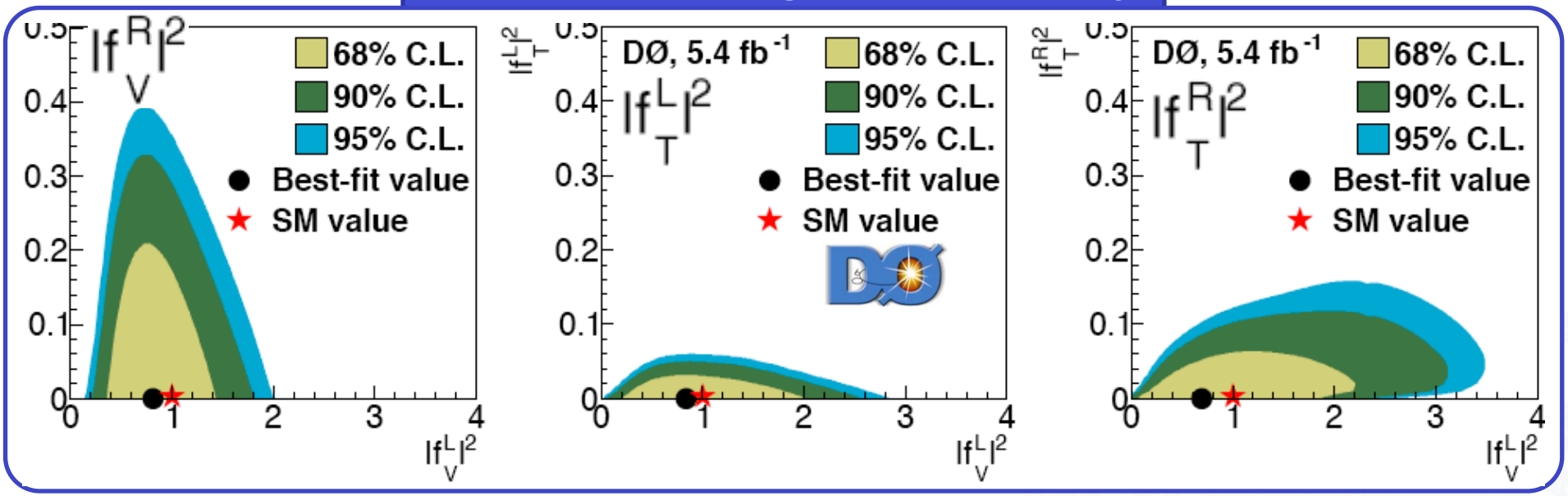
Wtb AC from single top + W helicity

Combination of single top + W helicity



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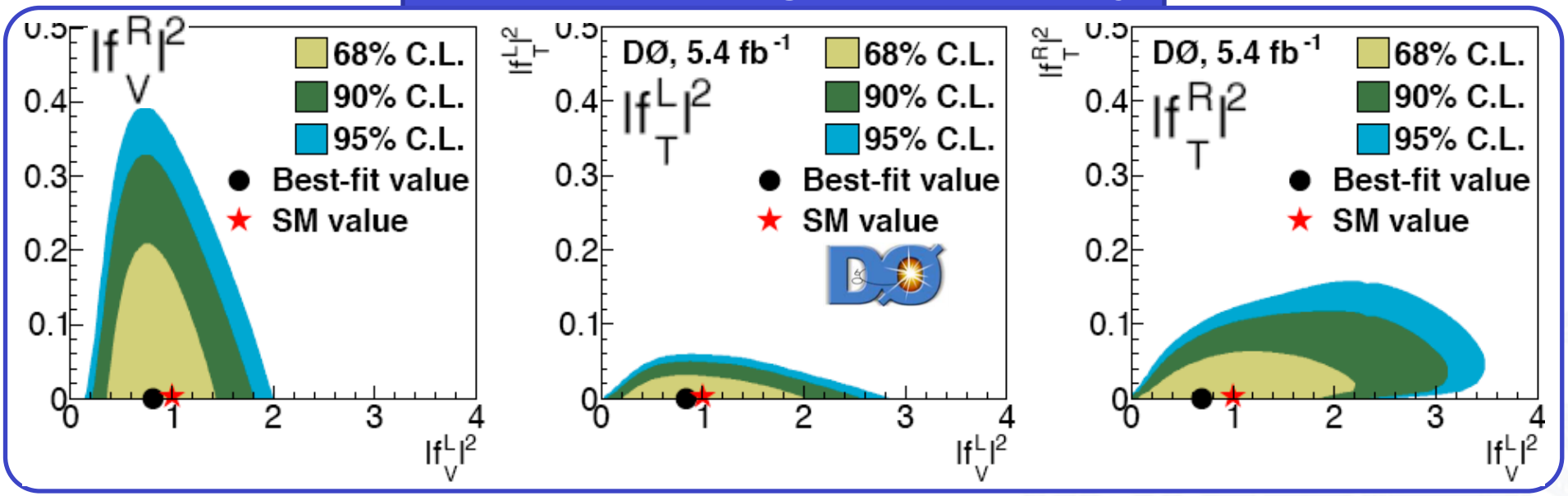

Scenario	only W helicity	only single top	combination
$\lvert f_V^R\rvert^2$	0.62	0.89	0.30
$\lvert f_T^L\rvert^2$	0.14	0.07	0.05
$\lvert f_T^R\rvert^2$	0.18	0.18	0.12

Significant improvement!

Lorentz invariance violation

- Invariance under Lorentz transformation is a fundamental property of the SM
  - Thoroughly tested in the leptonic sector and for first generation, some tests for second generation, b-system

arXiv:1203.6106 [hep-ex], PRL acc'd

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  - Quantify Lorentz invariance violation (LIV) in the top sector using in the SM Extension formalism:

$$|\mathcal{M}|^2_{\mathrm{SME}} = PF\bar{F} + (\delta P)F\bar{F} + P(\delta F)\bar{F} + PF(\delta\bar{F})$$

P @ *prod'n vertex* F @ *decay vertex* δ *Dependence on SM extension coefficiencts*

[D. Colladay and V.A. Kostelecky, Phys. Rev. D 58, 116002 (1998)]
[V.A. Kostelecky, Phys. Rev. D 69, 105009 (2004)]

- Parametrise LIV $f_{\mathrm{SME}}(t)$ in terms of coefficients $C_{\mu\nu}$:
  - $f_{\mathrm{SME}}(t) = C_{\mu\nu} R^{\mu}_{\alpha}(t) R^{\nu}_{\beta}(t) A^{\alpha\beta}$

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  - $f_{\mathrm{SME}}(t) = C_{\mu\nu} R^{\mu}_{\alpha}(t) R^{\nu}_{\beta}(t) A^{\alpha\beta}$
- Non-zero $C_{\mu\nu}$ will result in time dependent *tt* production due to the rotation of the Earth!

arXiv:1203.6106 [hep-ex], PRL acc'd

Lorentz invariance violation

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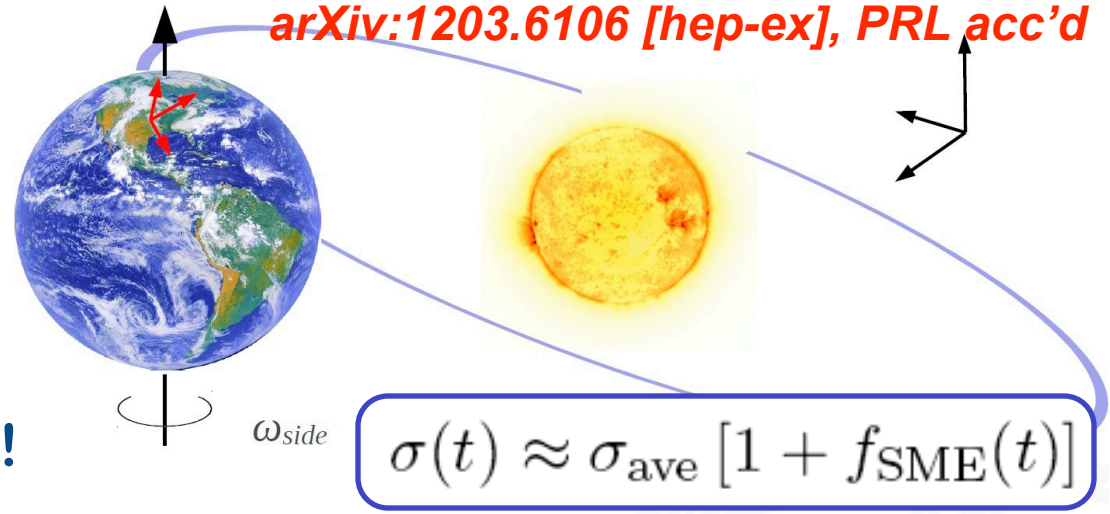
- **The period is 1 or ½ siderial day**
  - 1 Solar day $\approx$ 0.997 siderial day
  - Use time stamp to check perodicity!



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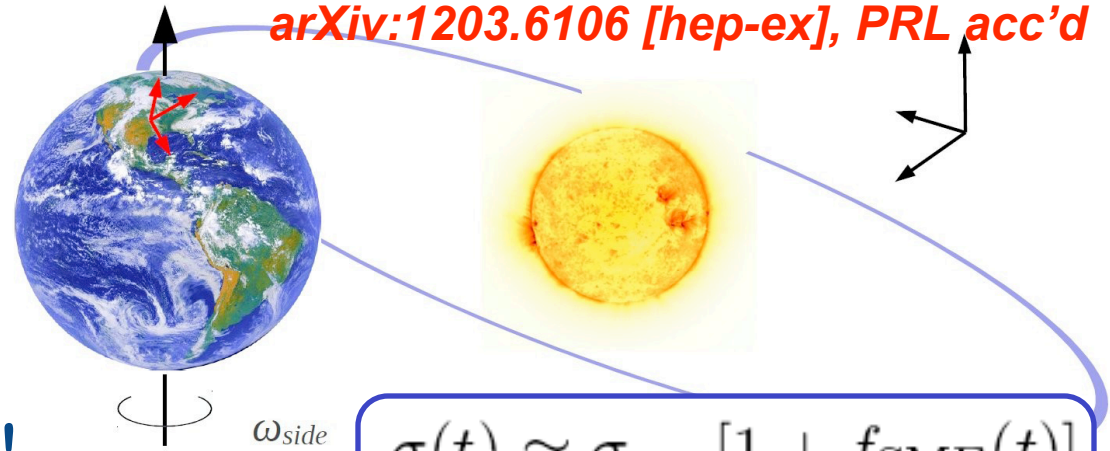
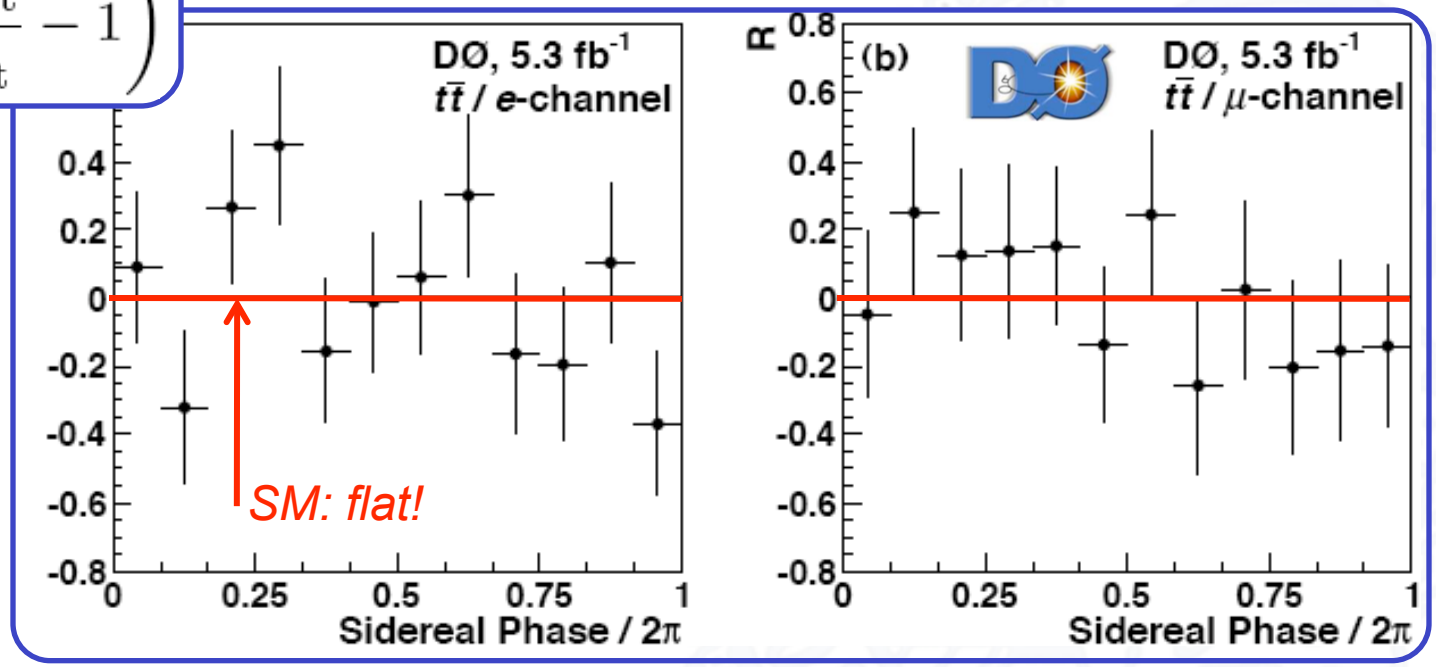


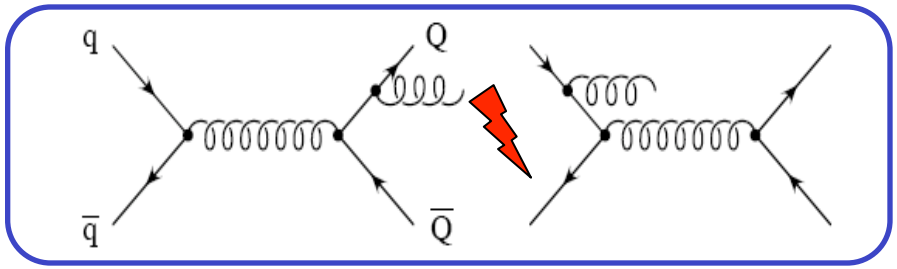
$$\sigma(t) \approx \sigma_{\text{ave}}\left[1 + f_{\text{SME}}(t)\right]$$

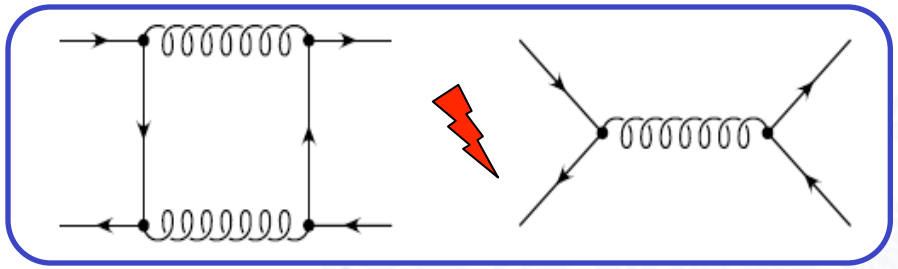
$$R_i \equiv \frac{1}{f_S}\left(\frac{N_i/N_{\text{tot}}}{\mathcal{L}_i/\mathcal{L}_{\text{int}}} - 1\right)$$



Colour Charge Asymmetry (A_{FB})

- **Theoretical predictions (Tevatron-specific!):**
  - At LO, completely symmetric
  - At higher orders, interference terms influence t and tbar production asymmetrically, e.g.:





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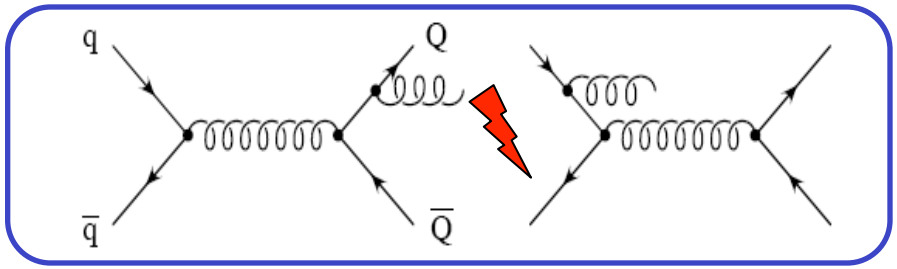

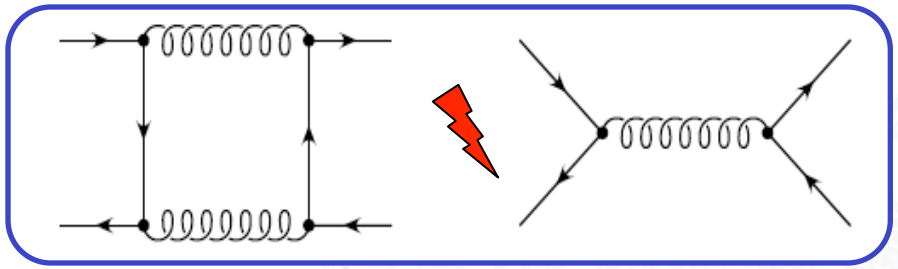

  - New physics contributions to enhance asymmetry?
    - Massive axial vector gluons
    - Massive vector gluons
    - Z', W'
    - Technicolour
    - ?

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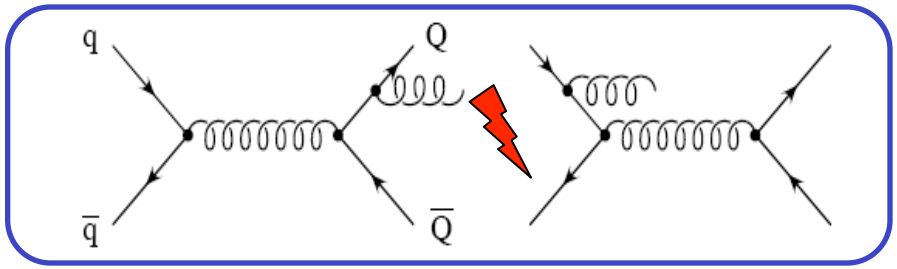

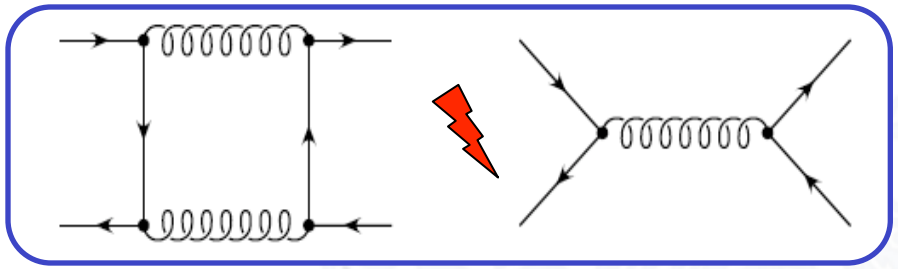

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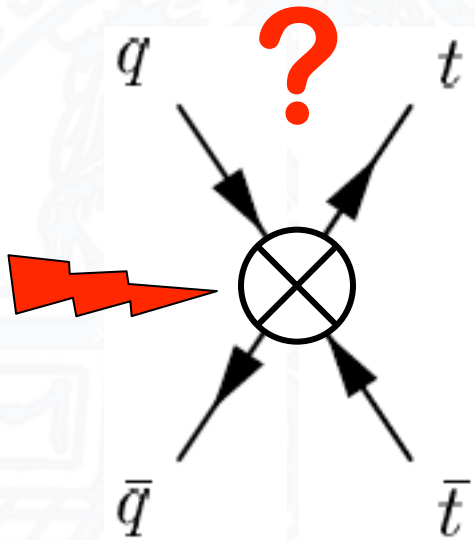


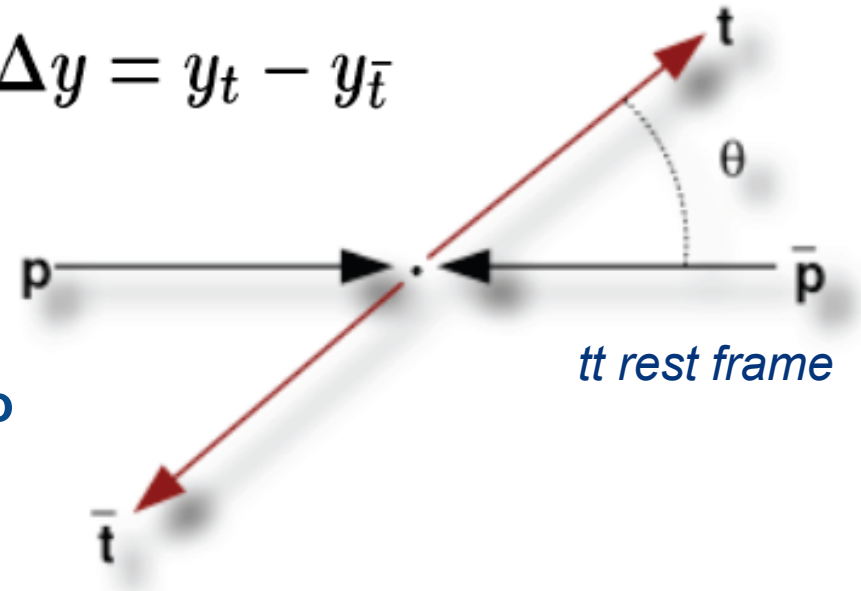
Colour Charge Asymmetry (A_{FB})

- **Form observable:**

$$A_{fb} = \frac{N^{\Delta y>0} - N^{\Delta y<0}}{N^{\Delta y>0} + N^{\Delta y<0}}$$

  - Use b-tagged events
  - Use kinematic fitter for reco

$$\Delta y = y_t - y_{\bar{t}}$$



tt rest frame

PRD 84, 112005 (2011)

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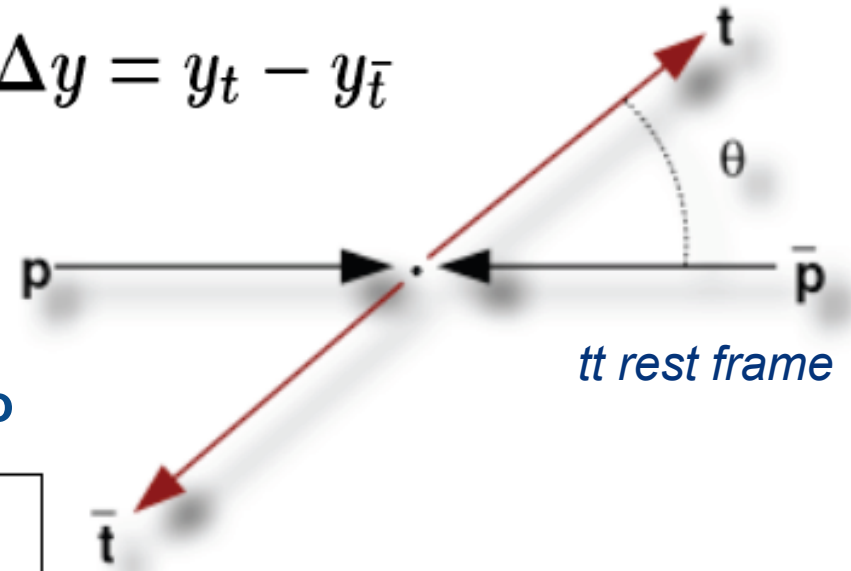

tt rest frame

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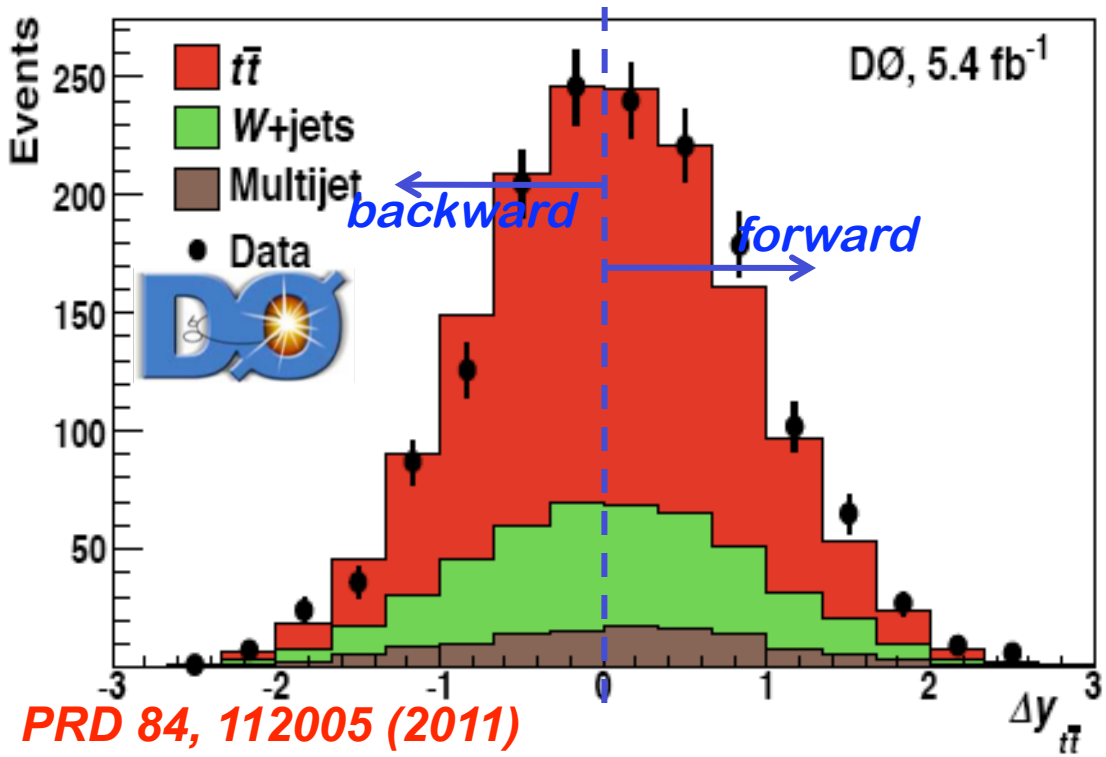

PRD 84, 112005 (2011)

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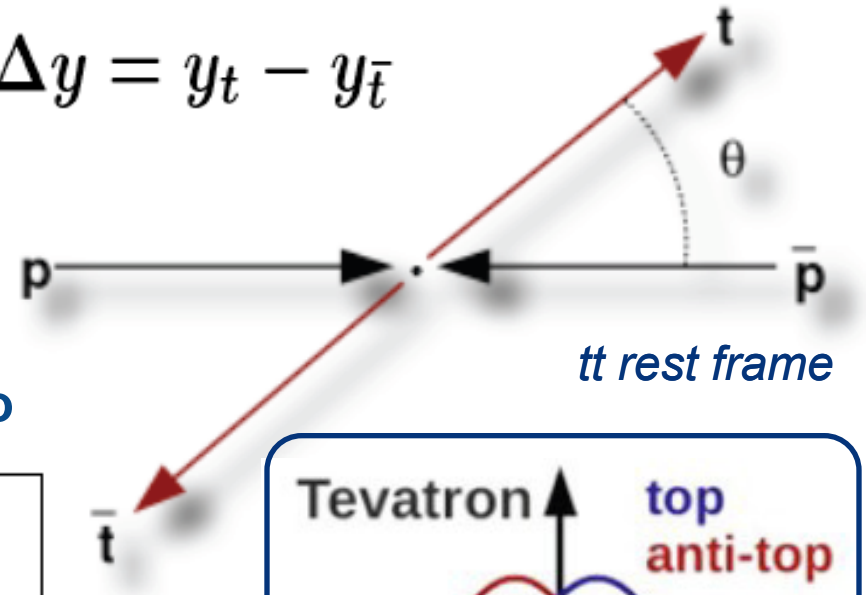
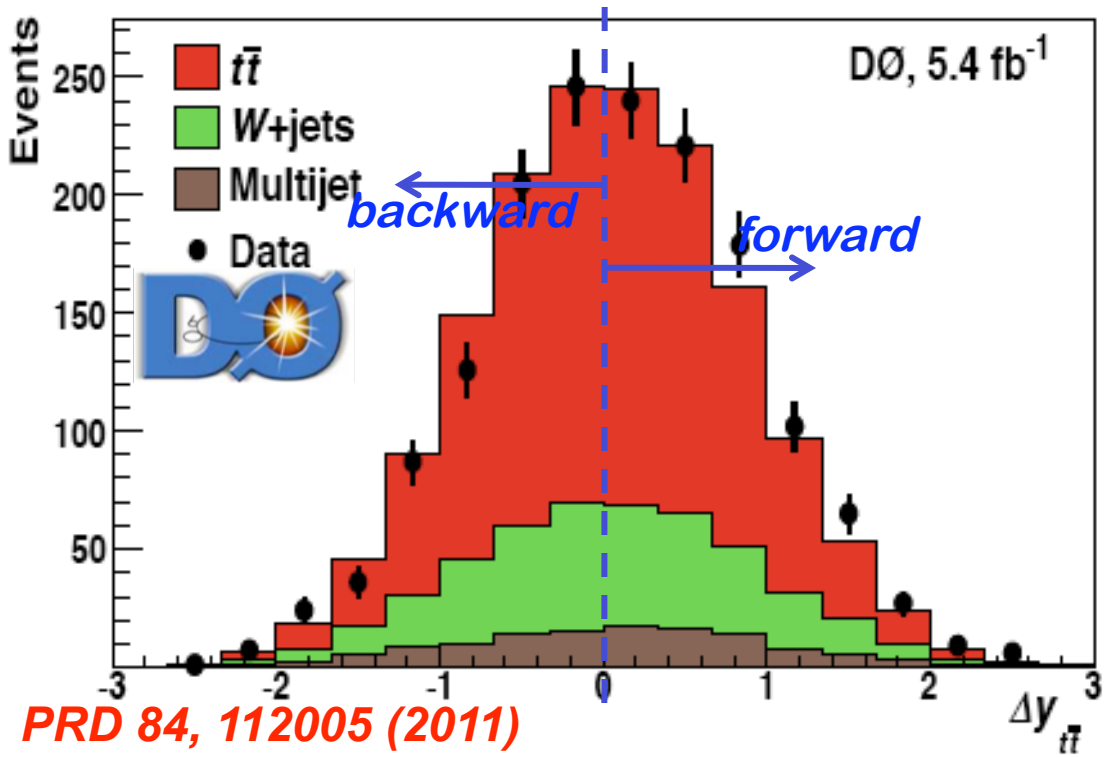
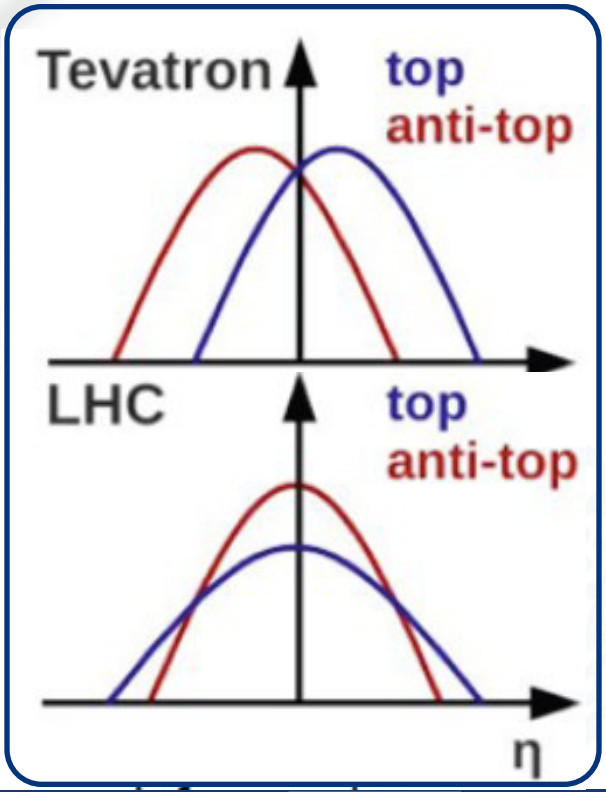


tt rest frame



PRD 84, 112005 (2011)



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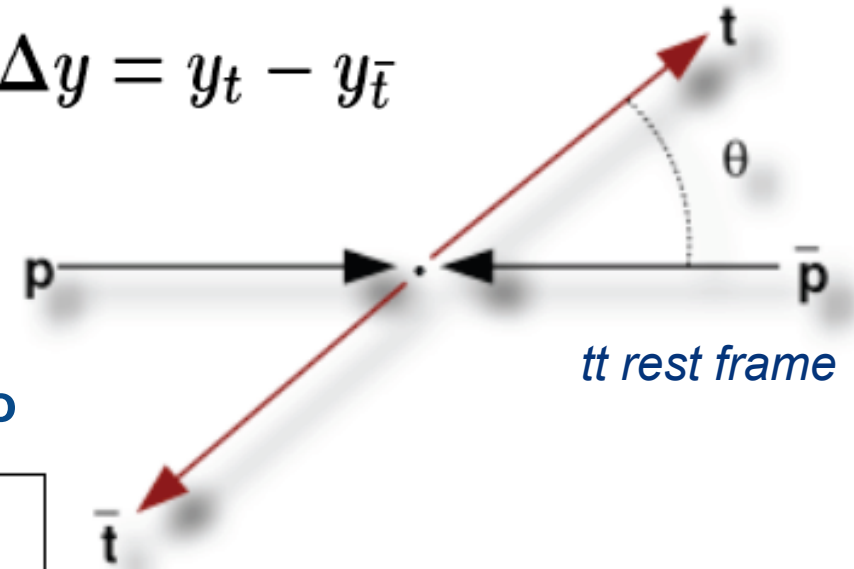

tt rest frame

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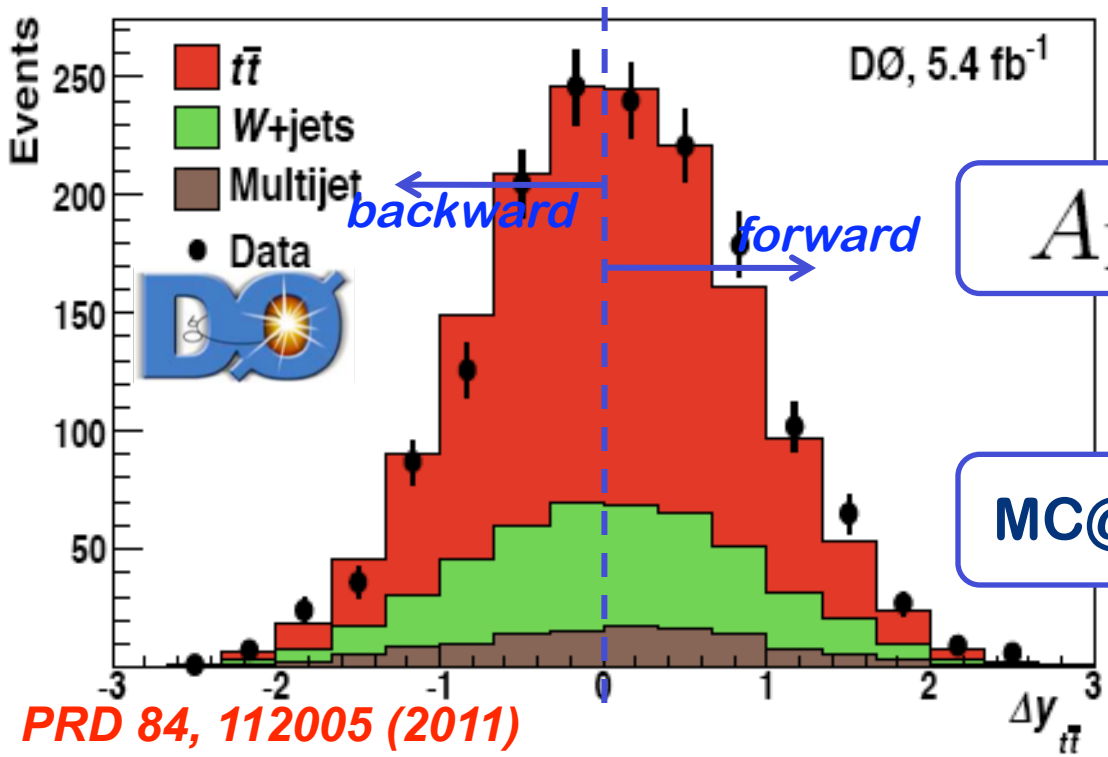

PRD 84, 112005 (2011)

$$A_{\mathrm{FB}} = 9.2 \pm 3.7\%$$

Raw result (not unfolded), after background subtraction

MC@NLO prediction: 2.4 ± 0.7

$\sim 2\sigma$

Colour Charge Asymmetry (A_{FB})

- **Asymmetry would be enhanced:**
  - **For high m_{tt} for an *s*-channel resonance**
  - **For high $|\Delta y|$ for a *t*-channel anomaly**

Subsample	A_{FB} (%) Data	MC@NLO
$m_{t\bar{t}} < 450$ GeV	7.8 ± 4.8	1.3 ± 0.6
$m_{t\bar{t}} > 450$ GeV	11.5 ± 6.0	4.3 ± 1.3
$\lvert\Delta y\rvert < 1.0$	6.1 ± 4.1	1.4 ± 0.6
$\lvert\Delta y\rvert > 1.0$	21.3 ± 9.7	6.3 ± 1.6

Less than 2σ throughout

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Colour Charge Asymmetry (A_{FB})

- Any A_{FB} at generator level will be reduced at reconstruction level due to
  - Limited detector acceptance
  - Limited resolution on Δy (≈ 0.7)

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Colour Charge Asymmetry (A_{FB})

- Any A_{FB} at generator level will be reduced at reconstruction level due to
  - Limited detector acceptance
  - Limited resolution on Δy (≈ 0.7)
- → Unfold Δy to generator level
  - Bin migrations particularly relevant close to $\Delta y = 0$
    - Use sufficiently fine binned, regularised unfolding
    - Correct for possible biases with ensemble tests
    - (Cross-check with coarse-binned unfolding consistent)

	A_{FB} (%)	
	Reconstruction level	Production level
Data	9.2 ± 3.7	19.6 ± 6.5
MC@NLO	2.4 ± 0.7	5.0 ± 0.1

$\approx 2.4\sigma$

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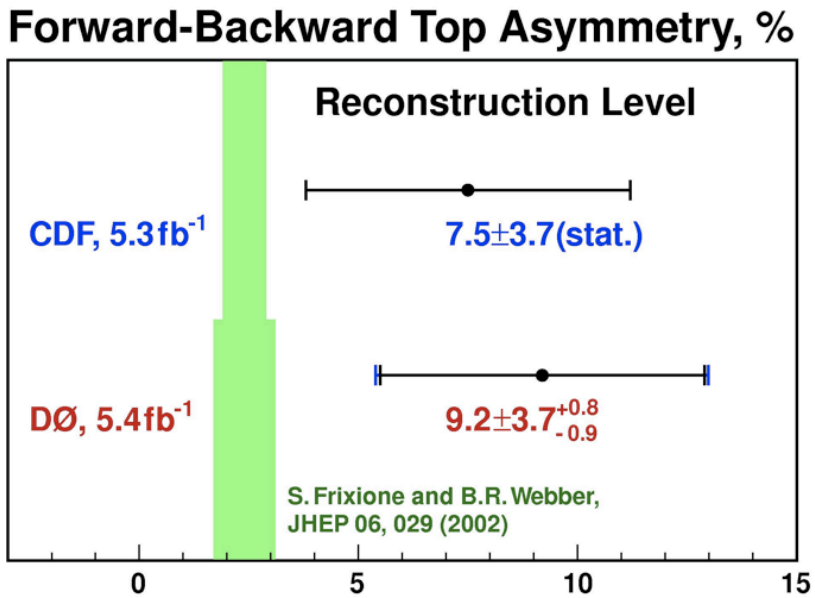
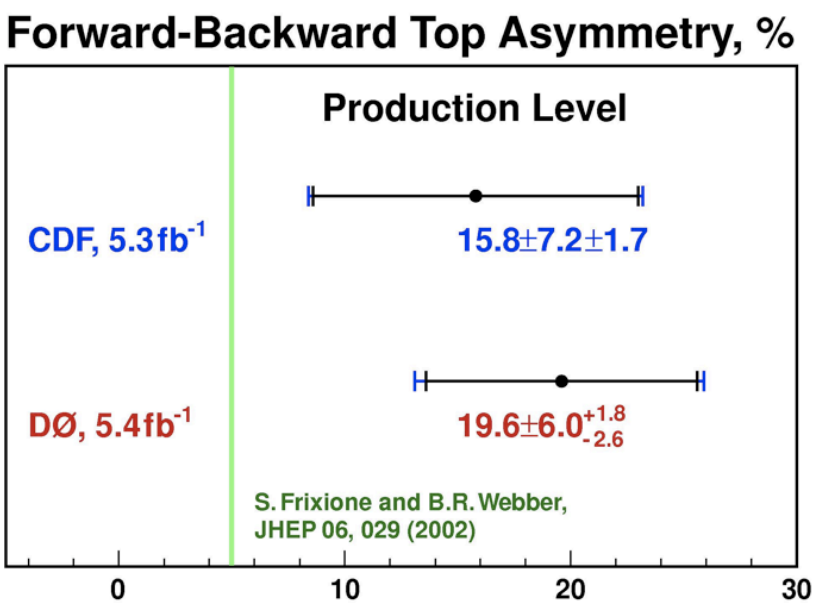
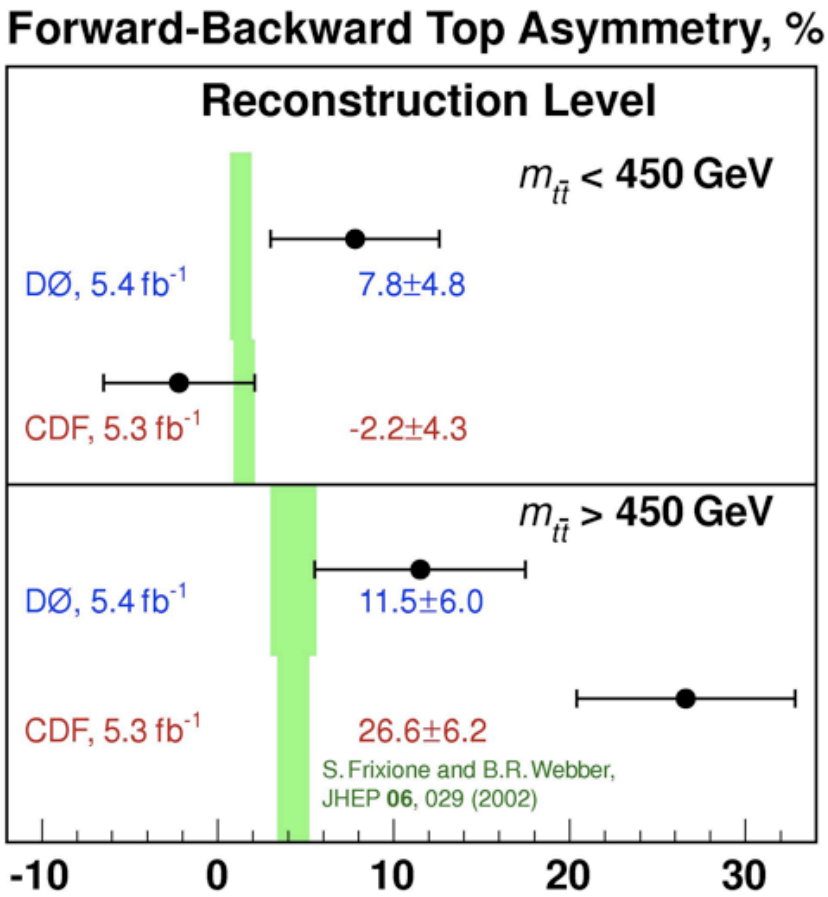
Colour Charge Asymmetry (A_{FB})







There is a new measurement of A_{FB} by CDF (CDF Note 10807, 8.7 fb^{-1})
→ comparison plots are not available yet

Colour Charge Asymmetry (A_{FB})

- Migrations around $\Delta y=0$ are tiny if lepton-based observables are used
  - → define forward, backward events via $q_\ell y_\ell < 0$, $q_\ell y_\ell > 0$

PRD 84, 112005 (2011)

Colour Charge Asymmetry (A_{FB})

- Migrations around Δy are tiny if lepton-based observables are used
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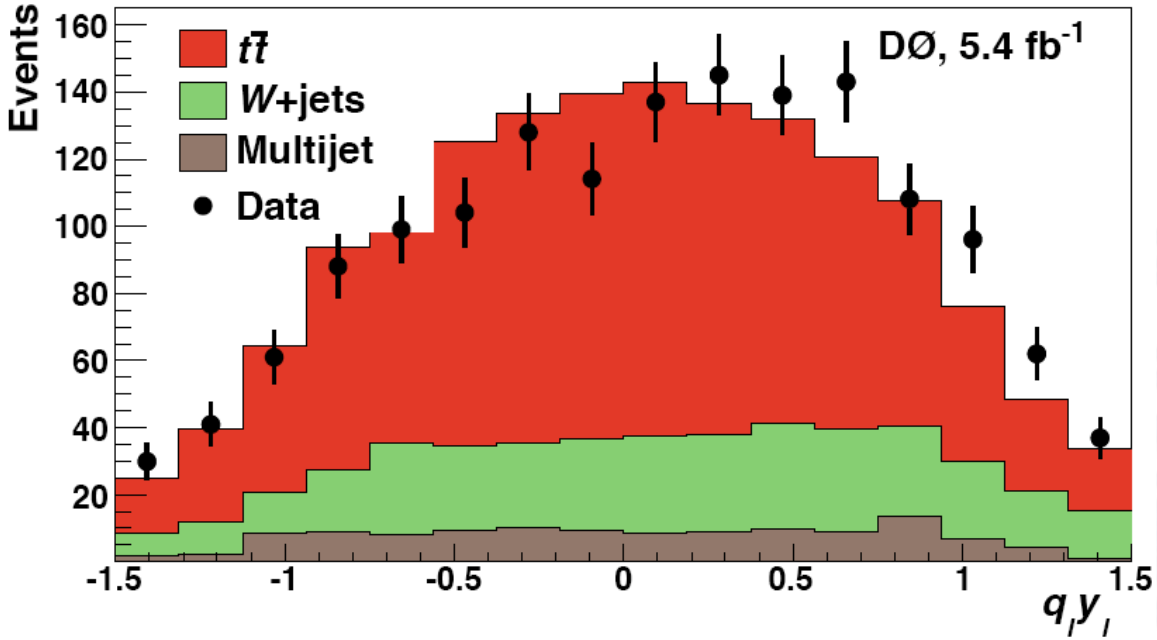


> 3σ

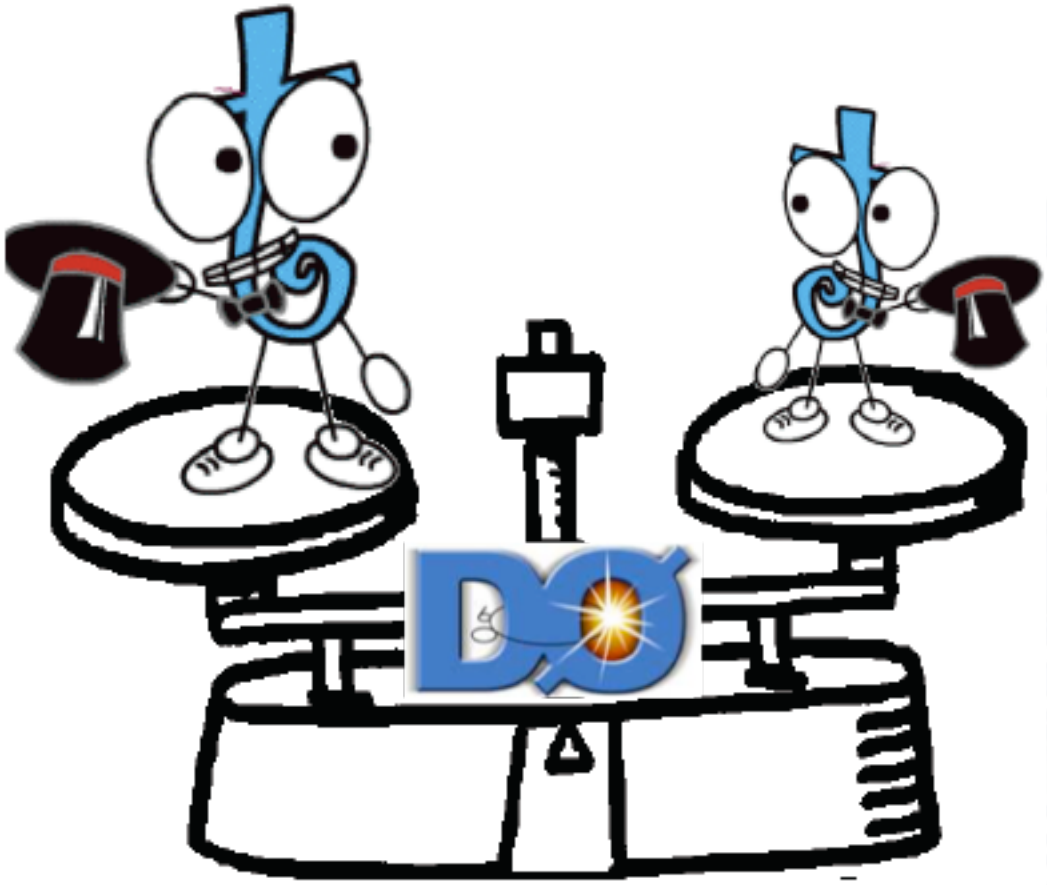
	A^l_{FB} (%) Reconstruction level	Production level
Data	14.2 ± 3.8	15.2 ± 4.0
MC@NLO	0.8 ± 0.6	2.1 ± 0.1

PRD 84, 112005 (2011)

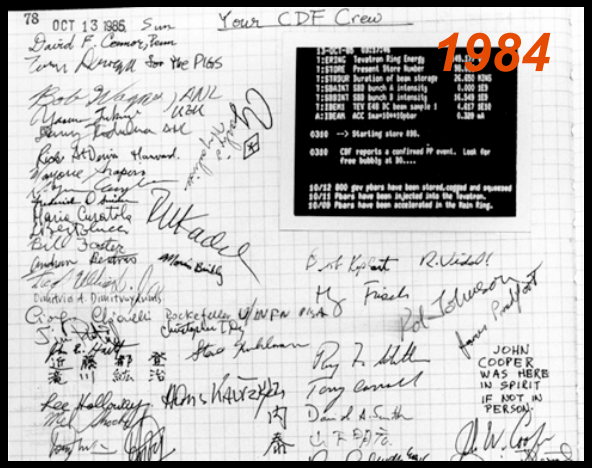

... FOR THE TEVATRON (2011)

Outlook

We are looking ahead to more exciting measurements from the Tevatron!

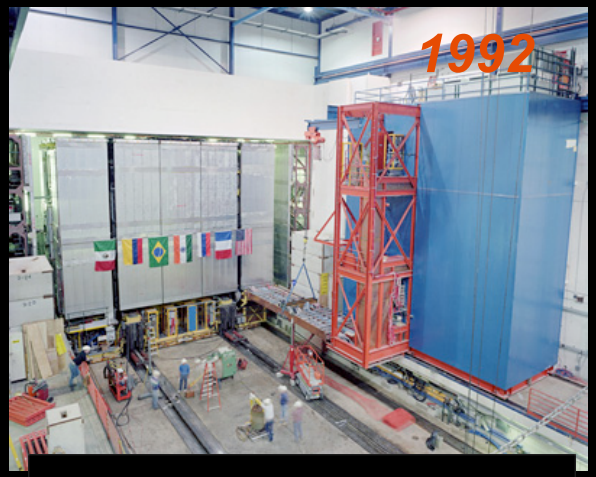



1983


1984
Your CDF Crew
JOHN COOPER WAS HERE IN SPIRIT IF NOT IN PERSON

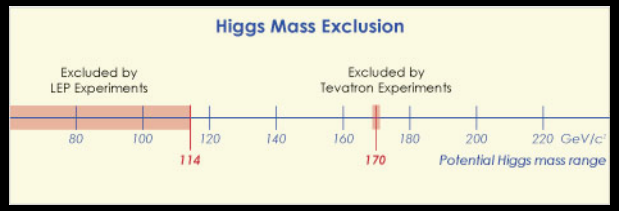

1985

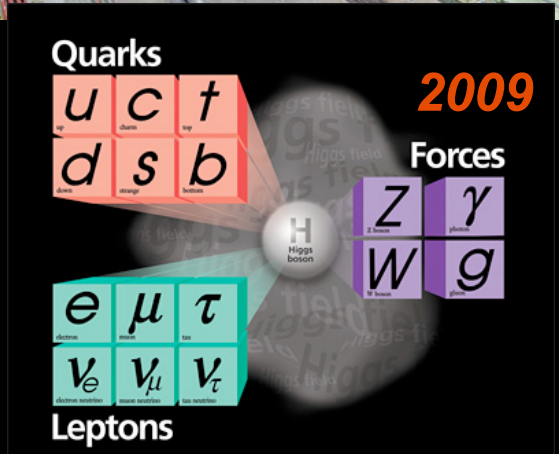

1991


1992

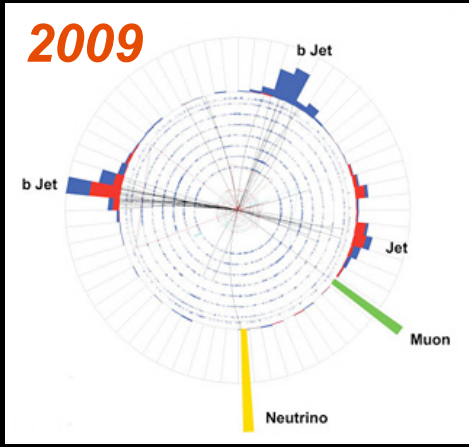

1995
Cultura e Spettacoli
CORRIERE DELLA SERA
Dove vai, cacciatore di quark?
Alles Quark, oder was?
I predatori del quark perduto
Truth by Consensus
For physicists, last piece of a puzzle
RICERCA ITALIANA
EPPUR SI MUOVE

2008

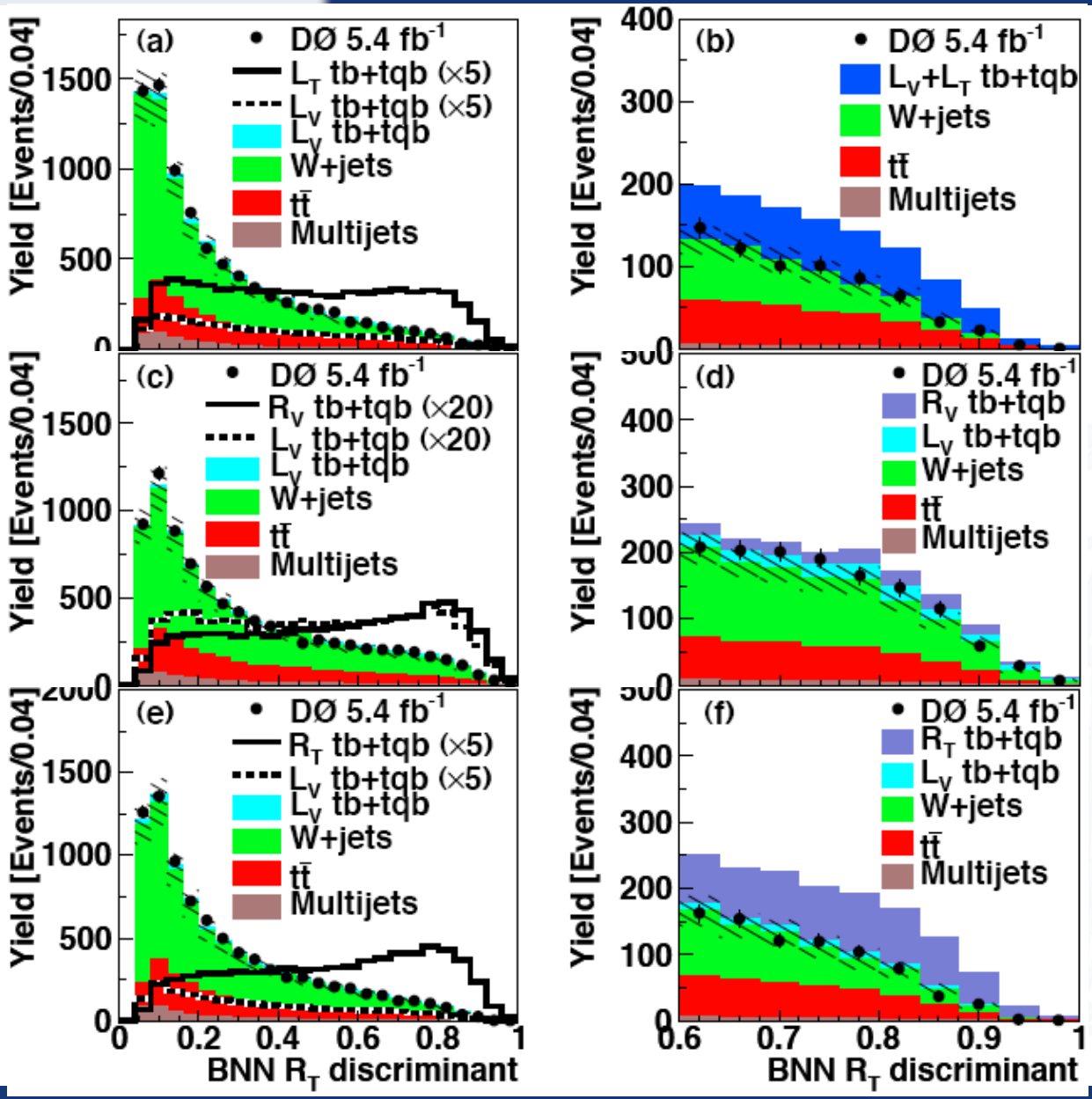

Higgs Mass Exclusion
Excluded by LEP Experiments
Excluded by Tevatron Experiments
80
100
120
140
160
180
200
220 GeV/c²
114
170
Potential Higgs mass range


Quarks
u c t
d s b
Forces
Z γ
W g
H
Higgs boson
e μ τ
νe νμ ντ
Leptons

2009


b Jet
b Jet
Jet
Muon
Neutrino

Wtb AC from single top prod'n

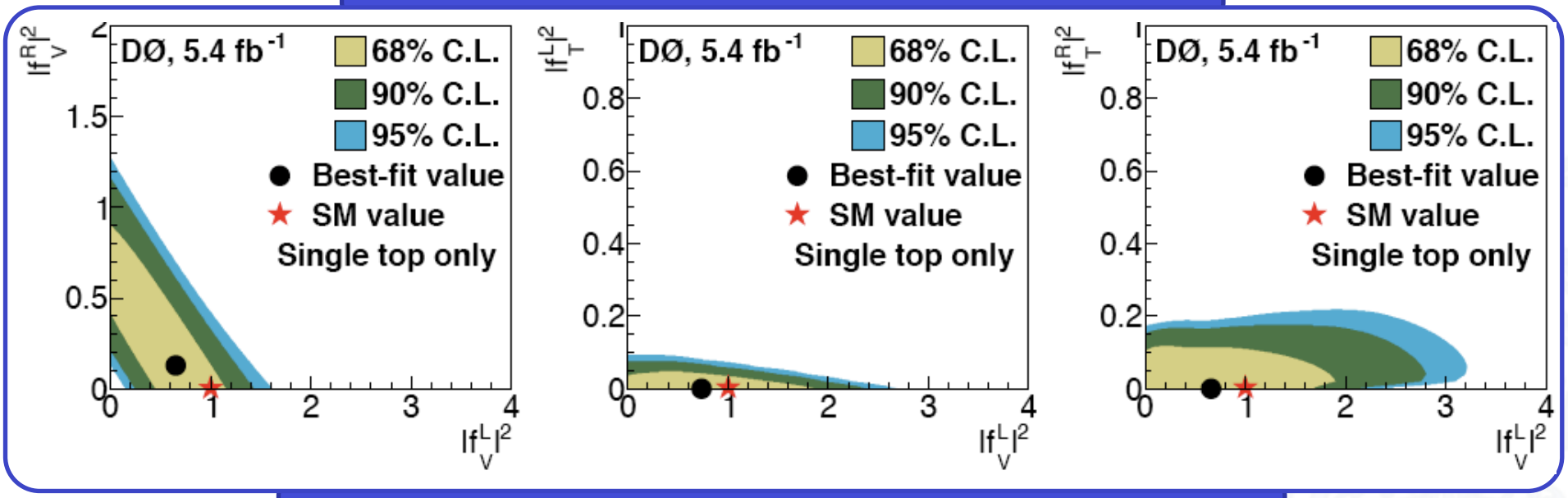


[arXiv:1110.4592]

Wtb AC from single top prod'n

- **Obtained limits:**

Limits on Wtb AC from single top production

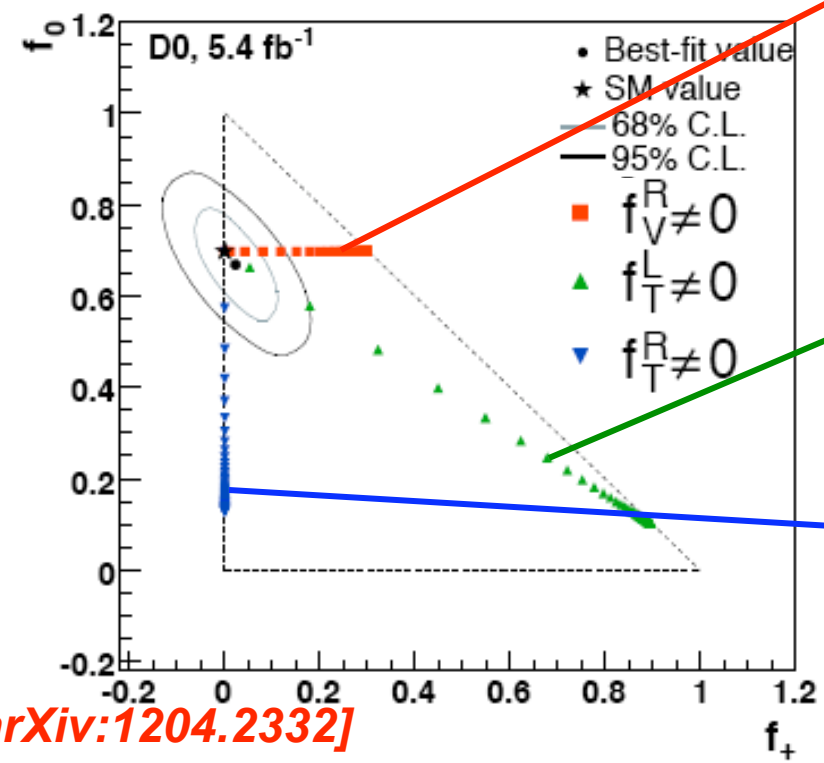


Using events orthogonal to W helicity meas't ONLY

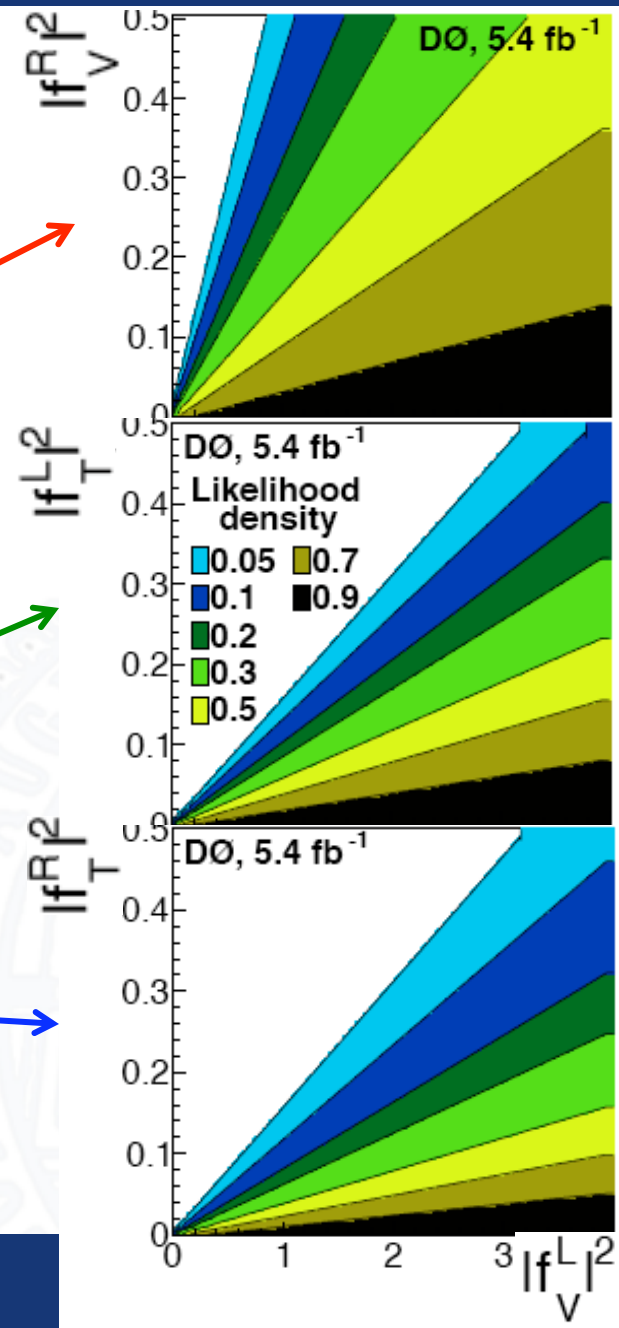
[arXiv:1110.4592]

Wtb AC from single top + W helicity

- **Wtb AC will alter:**
  - single top production (see previous slides)
  - fractions of W bosons in the 3 helicity states:



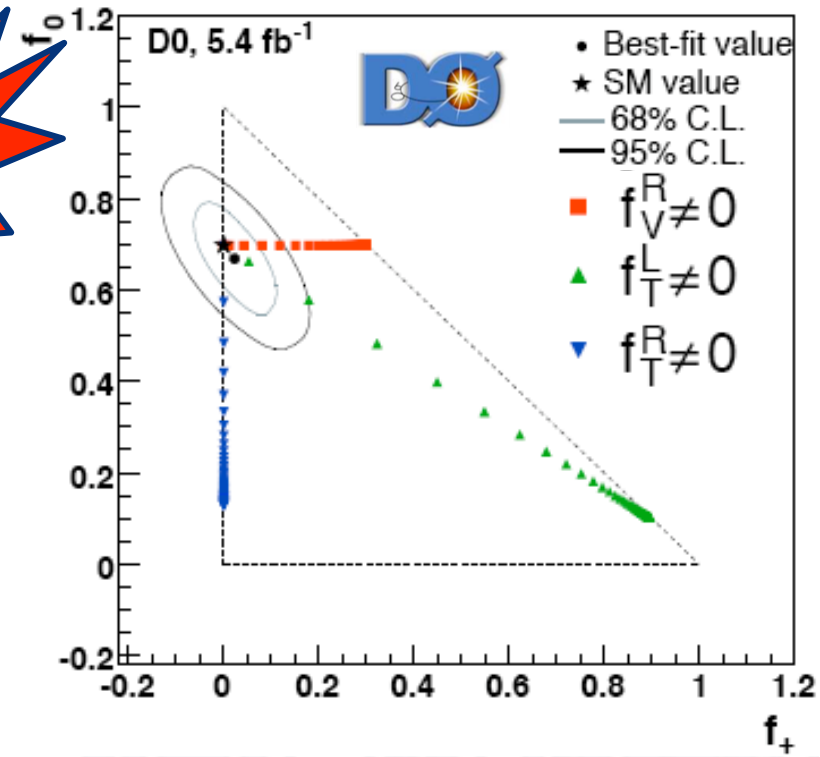
[arXiv:1204.2332]



Wtb AC from single top + W helicity

- ***Wtb* AC will alter:**
  - single top production (see previous slides)
  - fractions of W bosons in the 3 helicity states

combine!



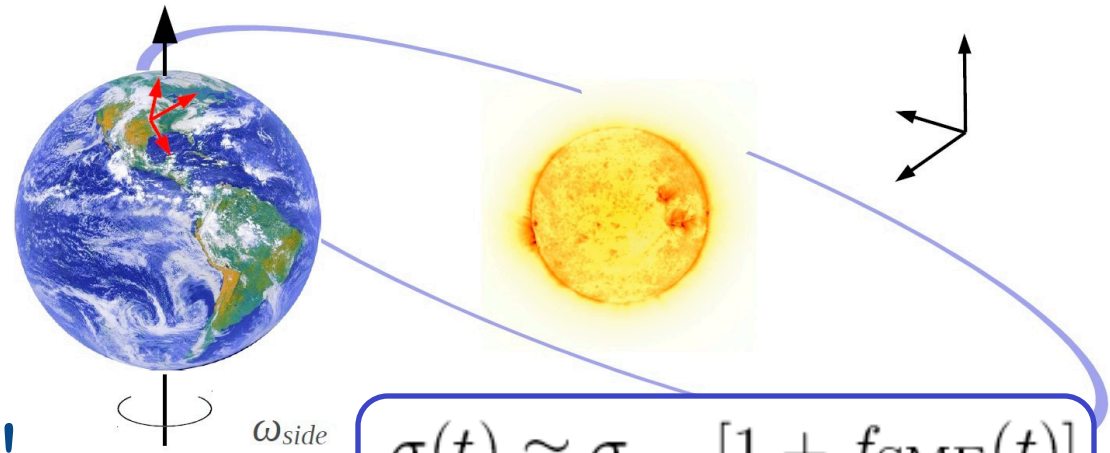
- **Assume:**
  - Single top production through *Wtb* vertex exclusively
  - $|V_{td}|^2 + |V_{ts}|^2 \ll |V_{tb}|^2$

- **Use the LH from W helicity meas't as prior for single top**
  - Compute LH over all possible analysis channels
  - Remove overlap between selections

arXiv:1204.2332 [hep-ex], PLB acc'd

Lorentz invariance violation

- **The period is 1 or ½ siderial day**
  - 1 Solar day $\approx$ 0.997 siderial day
  - Use time stamp to check perodicity!



$$\sigma(t) \approx \sigma_{\text{ave}}\left[1 + f_{\text{SME}}(t)\right]$$

TABLE III: Limits on SME coefficients at the 95% C.L., assuming $(c_U)_{\mu\nu} \equiv 0$.

Coefficient	Value ± Stat. ± Sys.	95% C.L. Interval
$(c_Q)_{XX33}$	$-0.12 \pm 0.11 \pm 0.02$	$[-0.34, +0.11]$
$(c_Q)_{YY33}$	$0.12 \pm 0.11 \pm 0.02$	$[-0.11, +0.34]$
$(c_Q)_{XY33}$	$-0.04 \pm 0.11 \pm 0.01$	$[-0.26, +0.18]$
$(c_Q)_{XZ33}$	$0.15 \pm 0.08 \pm 0.02$	$[-0.01, +0.31]$
$(c_Q)_{YZ33}$	$-0.03 \pm 0.08 \pm 0.01$	$[-0.19, +0.12]$

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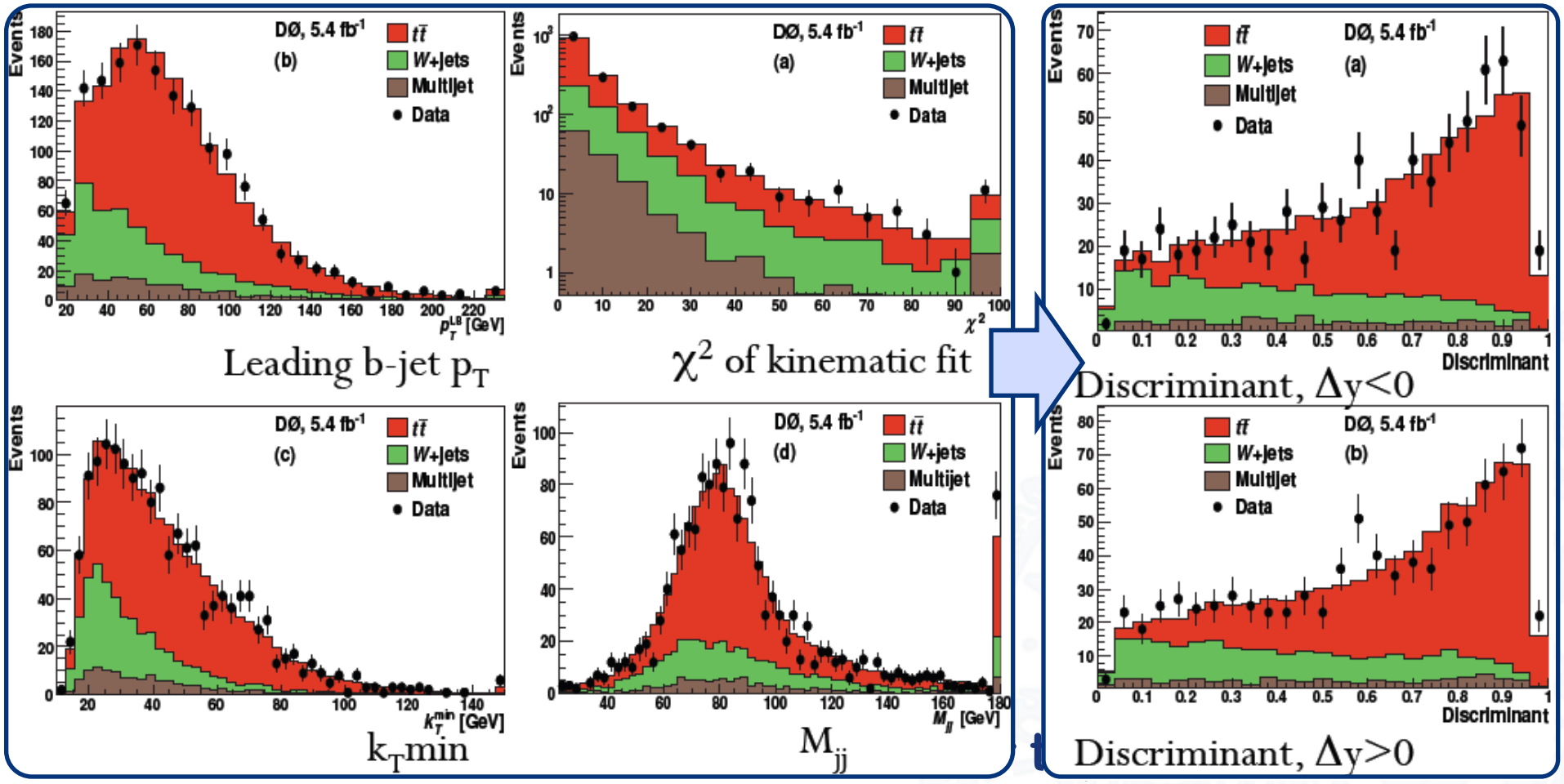
$(c_U)_{YY33}$	$-0.10 \pm 0.09 \pm 0.02$	$[-0.27, +0.08]$
$(c_U)_{XY33}$	$0.04 \pm 0.09 \pm 0.01$	$[-0.14, +0.22]$
$(c_U)_{XZ33}$	$-0.14 \pm 0.07 \pm 0.02$	$[-0.28, +0.01]$
$(c_U)_{YZ33}$	$0.01 \pm 0.07 \pm < 0.01$	$[-0.13, +0.14]$

[arXiv:1203.6106]

Strong charge asymmetry (D0)

- **Strong Colour charge asymmetry (D0, 5.4 fb^{-1})**



$\Delta y>0$ $\Delta y<0$

$$A = (9.2 \pm 3.6^{+0.8}_{-0.9})\% \Leftrightarrow A(MC@NLO) = (2.4 \pm 0.3^{+0.7}_{-0.5})\%$$

	$l+\geq 4$ jets	$e+\geq 4$ jets	$\mu+\geq 4$ jets	$l+4$ jets	$l+\geq 5$ jets
Raw N_{F}	849	455	394	717	132
Raw N_{B}	732	397	335	597	135
$N_{t\bar{t}}$	1126 ± 39	622 ± 28	502 ± 28	902 ± 36	218 ± 16
$N_{W+\mathrm{jets}}$	376 ± 39	173 ± 28	219 ± 27	346 ± 36	35 ± 16
N_{MJ}	79 ± 5	56 ± 3	8 ± 2	66 ± 4	13 ± 2
$A_{\mathrm{FB}}(\%)$	9.2 ± 3.7	8.9 ± 5.0	9.1 ± 5.8	12.2 ± 4.3	-3.0 ± 7.9
MC@NLO A_{FB} (%)	2.4 ± 0.7	2.4 ± 0.7	2.5 ± 0.9	3.9 ± 0.8	-2.9 ± 1.1

	$l+\geq 4$ jets	$e+\geq 4$ jets	$\mu+\geq 4$ jets	$l+4$ jets	$l+\geq 5$ jets
Raw N_{F}^{l}	867	485	382	730	137
Raw N_{B}^{l}	665	367	298	546	119
$N_{t\bar{t}}$	1096 ± 39	622 ± 28	474 ± 27	881 ± 36	211 ± 16
$N_{W+\mathrm{jets}}$	356 ± 39	173 ± 28	198 ± 27	323 ± 36	31 ± 16
N_{MJ}	79 ± 5	56 ± 3	8 ± 2	66 ± 4	14 ± 2
A_{FB}^{l} (%)	14.2 ± 3.8	16.5 ± 4.9	9.8 ± 5.9	15.9 ± 4.3	7.0 ± 8.0
MC@NLO A_{FB}^{l} (%)	0.8 ± 0.6	0.7 ± 0.6	1.0 ± 0.8	2.1 ± 0.6	-3.8 ± 1.2

m_{top} in dilepton channel (DØ)

- **Template method, 4.7 fb^{-1} (DØ):**
  - m_{top} free parameter → dilepton events are kinematically underconstrained
  - Use the so-called neutrino-weighting algorithm:
    - Postulate eta-distributions of neutrinos from MC
    - Calculate weight distribution vs. m_{top}
    - Use 1st and 2nd moment of this distribution to form templates
  - Apply in-situ JES calibration from l+jets channel:

$$1.013 \pm 0.008(\text{stat})$$

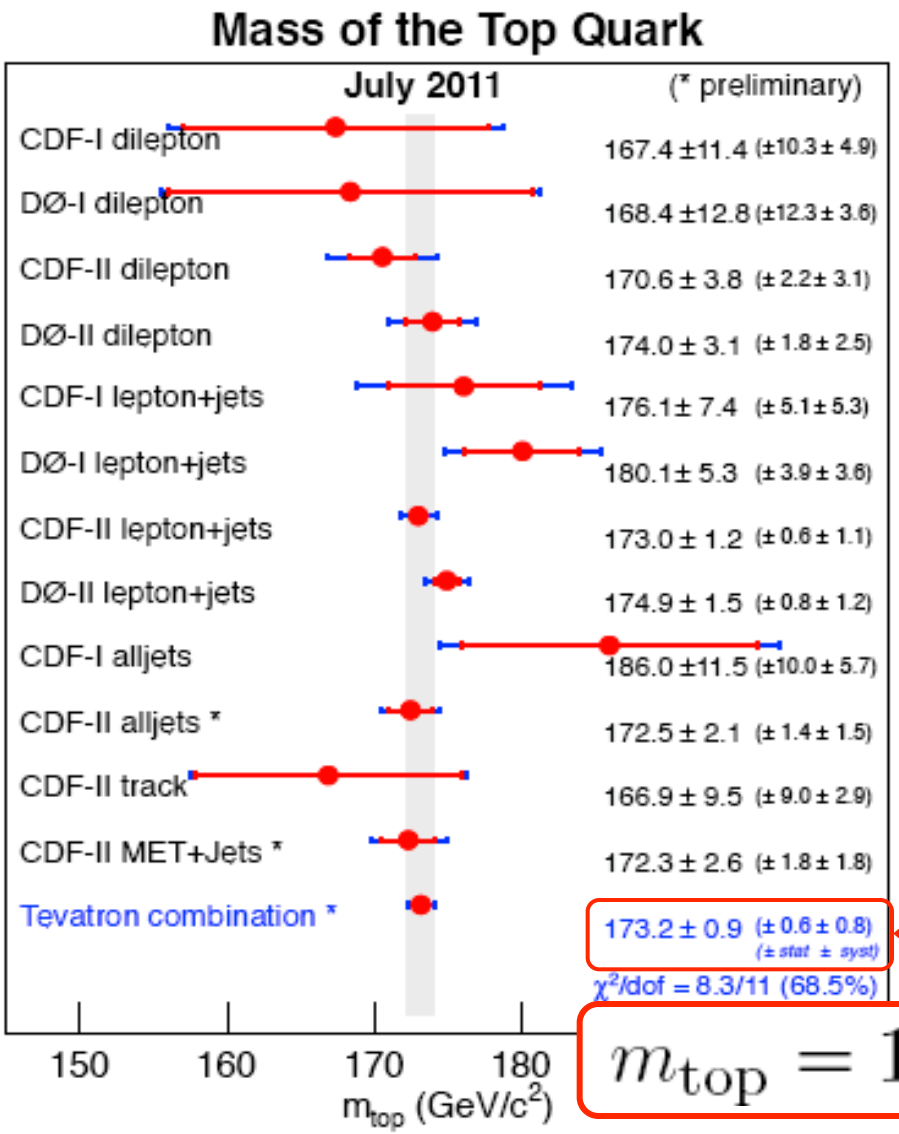
    - Caveat:
      k_{JES} can be final state-dependent, so we derive a dedicated response correction
  - Final result:

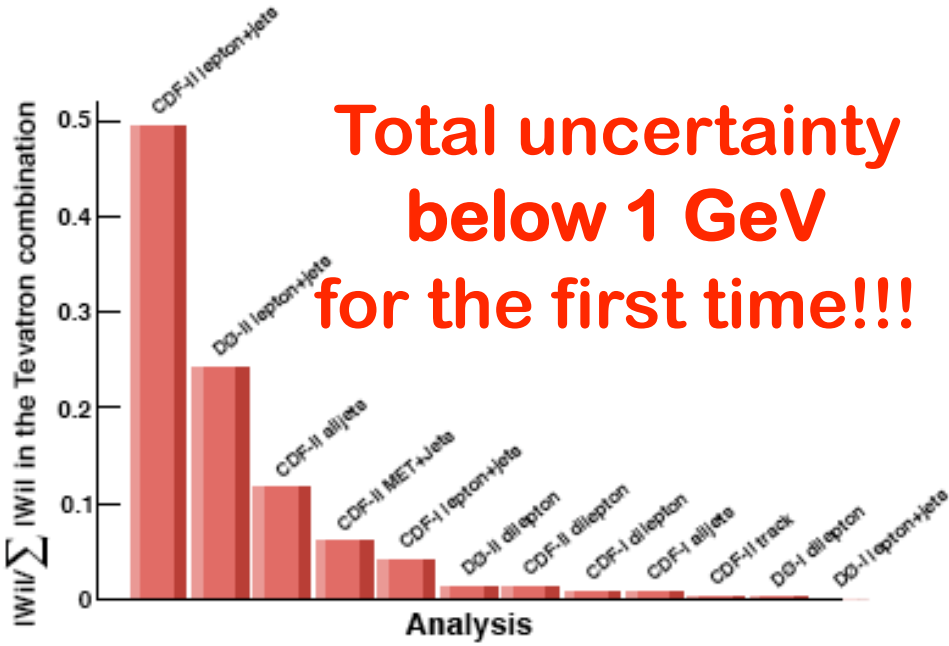
$$m_t = 174.0 \pm 2.4(\text{stat}) \pm 1.4(\text{syst})\ \text{GeV}$$

arXiv:1201.5172 [hep-ex] (2011)

Best Tevatron dilepton result!

Tevatron Combination





Total uncertainty below 1 GeV for the first time!!!

$$m_{\mathrm{top}} = 173.2 \pm 0.6\,(\mathrm{stat}) \pm 0.8\,(\mathrm{syst})$$

arXiv:1107.5255 [hep-ex]

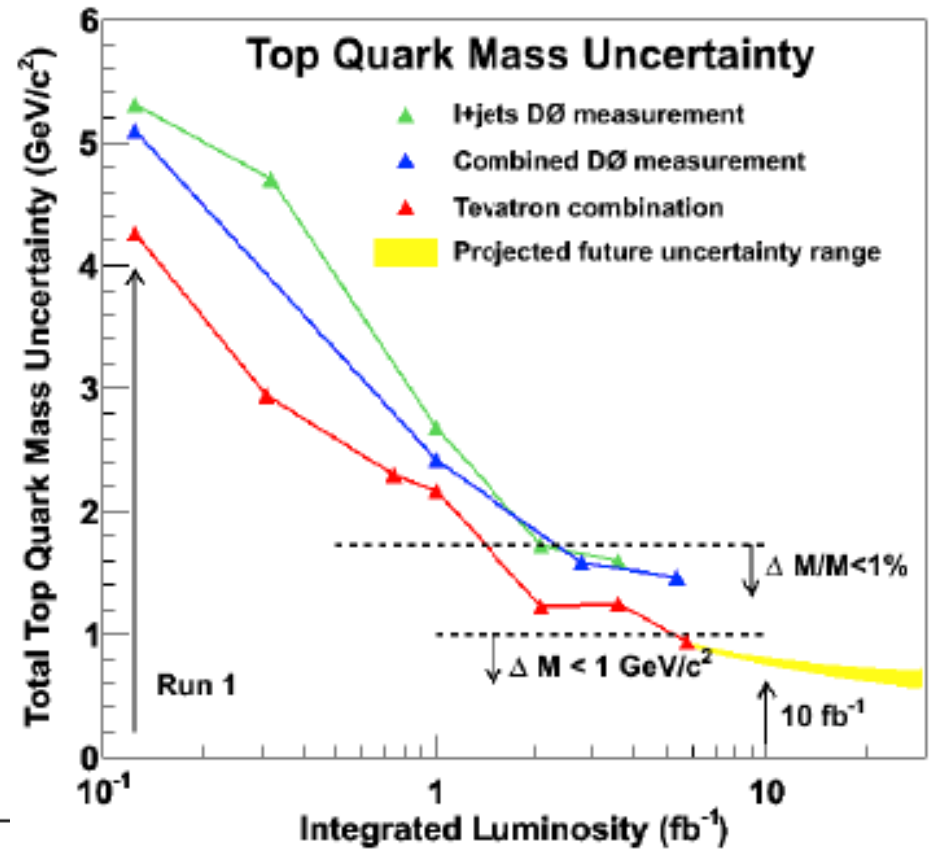
Tevatron Combination

	Tevatron combined values (GeV/c^2)
m_t	173.18
iJES	0.39
aJES	0.09
bJES	0.15
cJES	0.05
dJES	0.20
rJES	0.12
Lepton p_T	0.10
Signal	0.51
Detector Modeling	0.10
UN/MI	0.00
Background from MC	0.14
Background from Data	0.11
Method	0.09
MHI	0.08
Systematics	0.75
Statistics	0.56
Total	0.94

In-situ JES calibration ~ 1/√N

Size of calibration samples ~ 1/√N

Various signal modeling uncert. ~ √brain effort

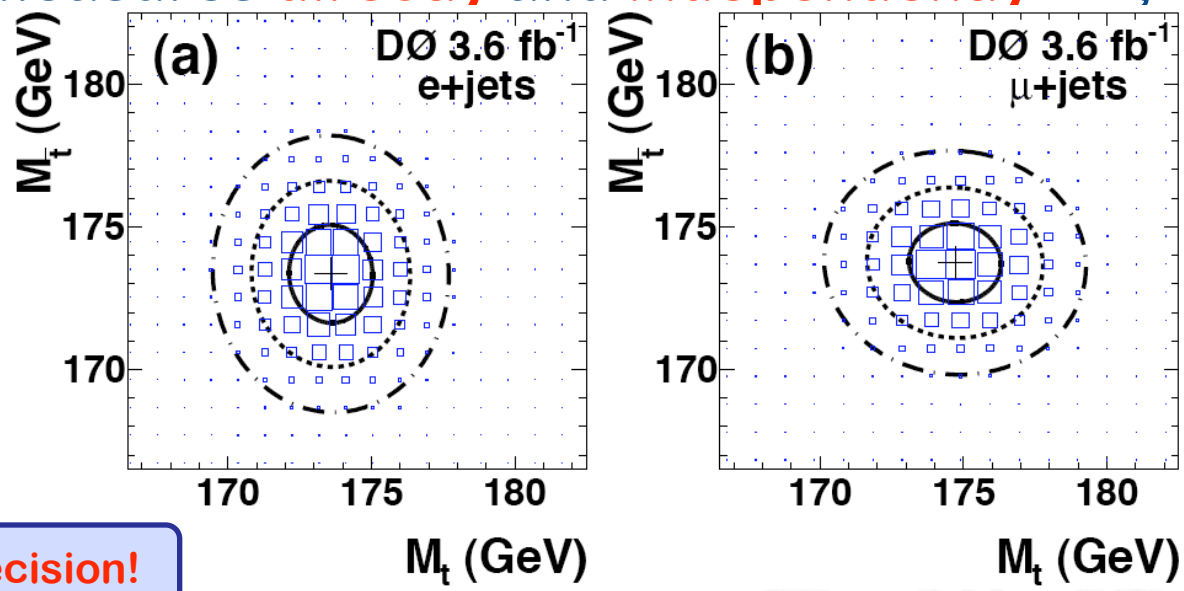


Relative uncertainty: 0.54%
Expect this limit to be improved…

Top-antitop mass difference meas't

- **CPT is essential for a locally Lorentz-invariant QFT**
  - $m_{particle}$!= $m_{antiparticle}$ → CPT violated!
    - Top is the only quark where this test is pc
  - DØ measures directly and independently m_t, $m_{\bar{t}}$ (ME):

$\tau_t = (3.3^{+1.3}_{-0.9}) \times 10^{-25}$ s



<1% relative precision!

$$\Delta m \equiv m_t - m_{\bar{t}} = 0.8 \pm 1.8\ (\text{stat}) \pm 0.5\ (\text{syst})\ \text{GeV}$$

$$\Delta m \qquad \frac{m_t + m_{\bar{t}}}{2} \equiv 172.5\ \text{GeV}$$

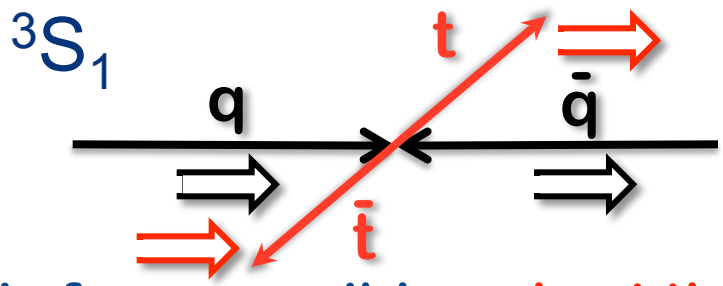
$$\Delta m = -1.95 \pm 1.11\ (\text{stat}) \pm 0.59\ (\text{syst})\ \text{GeV}$$ (8.7 fb^{-1})

- CDF: measures directly with

D0: Phys. Rev. D **84**, 052005 (2011)
CDF: Conf-Note 10777 (2012)

Top-antitop spin correlations

- $\tau_t = (3.3^{+1.3}_{-0.9}) \times 10^{-25}$ s < hadronisation time
  - Decay products carry info about spin of tt system



+ $^1S_0$ (15%)

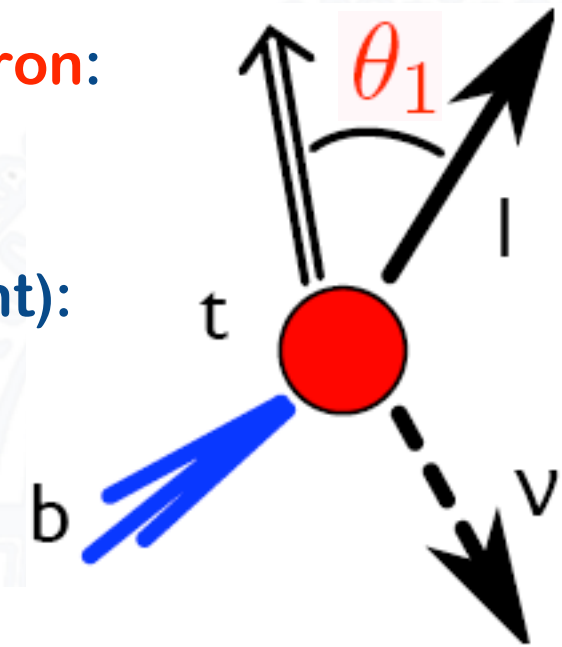
  - In this form possible only at the Tevatron:
    - High qq fraction (LHC: ~10%)
    - production at threshold dominates
  - Correlation strength (frame dependent):

$$C = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\downarrow\uparrow} - N_{\uparrow\downarrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\downarrow\uparrow} + N_{\uparrow\downarrow}}$$

  - Analyse it using angular info:

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}(1 - C\cos\theta_1\cos\theta_2)$$

(for dilepton channel case)



Spin correlations w. matrix element

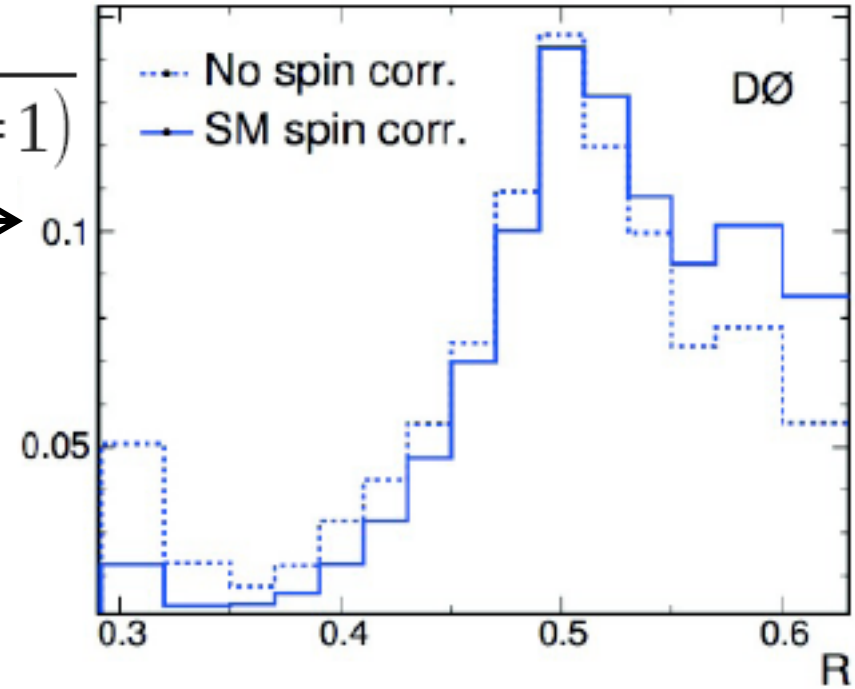
- **How can we adopt the superior matrix element* (ME) technique for the spin correlation measurement?**
  - **Melnikov and Schulze (PLB 700, 17 (2011)):**

$$R(x) = \frac{P_{t\bar{t}}(x, H=1)}{P_{t\bar{t}}(x, H=0) + P_{t\bar{t}}(x, H=1)}$$

  - **Construct templates in R** →
  - **Observable:**
    - **Fraction of events with spin corr.:**

$$f = \frac{N_{t\bar{t}}(w./spin\ correlation)}{N_{t\bar{t}}(all)}$$

  - **Translates into C → f * C_{SM}**
    - **i.e. SM pred'n is f = 1**



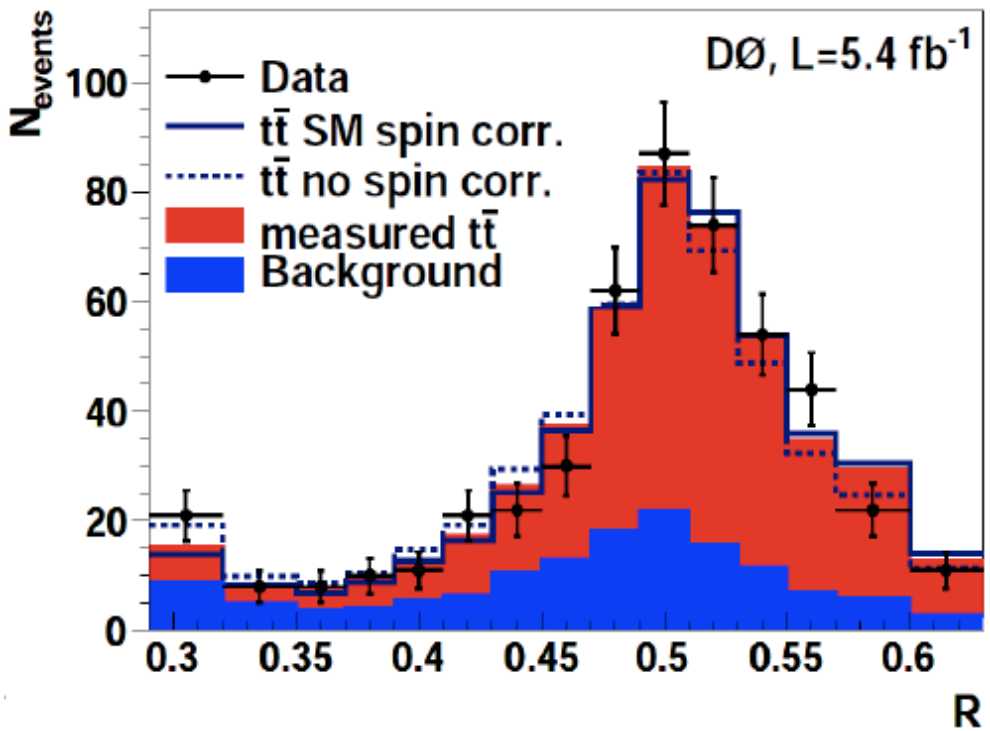
** I will discuss the ME technique in detail in the context of m_{top} meas't*
Here: it gives probability P(x,H) that a given event came from the process described by the ME, given observed kinematics x and hypothesis H

Spin correlations w. matrix element

- Take ME from Mahlon & Parke (PLB 411, 173 (1997)):

$$\sum |(M)|^2 = \frac{1+H}{2}\frac{g_s^4}{9} F\bar{F}(2-\beta^2 s_{qt}^2) - H\frac{g_s^4}{9} F\bar{F}\Delta$$

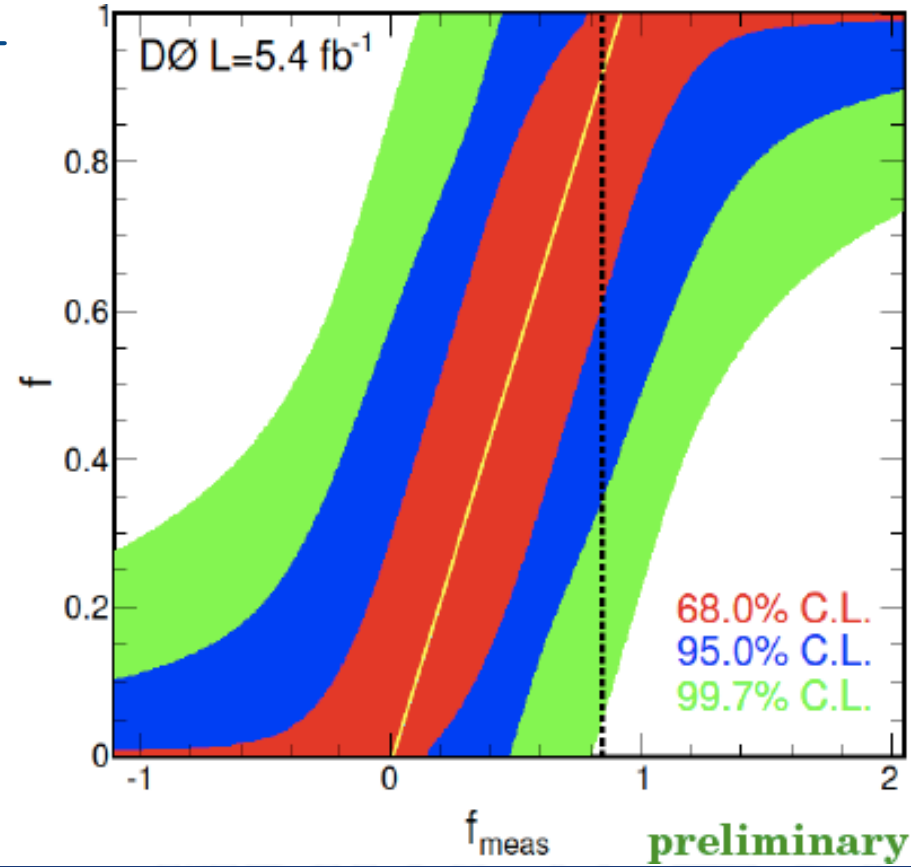
  - H=1: correlated spins
  - H=0: uncorrelated spins
- Perform measurement:
  - Dilepton channel
  - mc@nlo generator
  - dataset as 2 slides ago
- Use binned LH fit with nuisance parameters



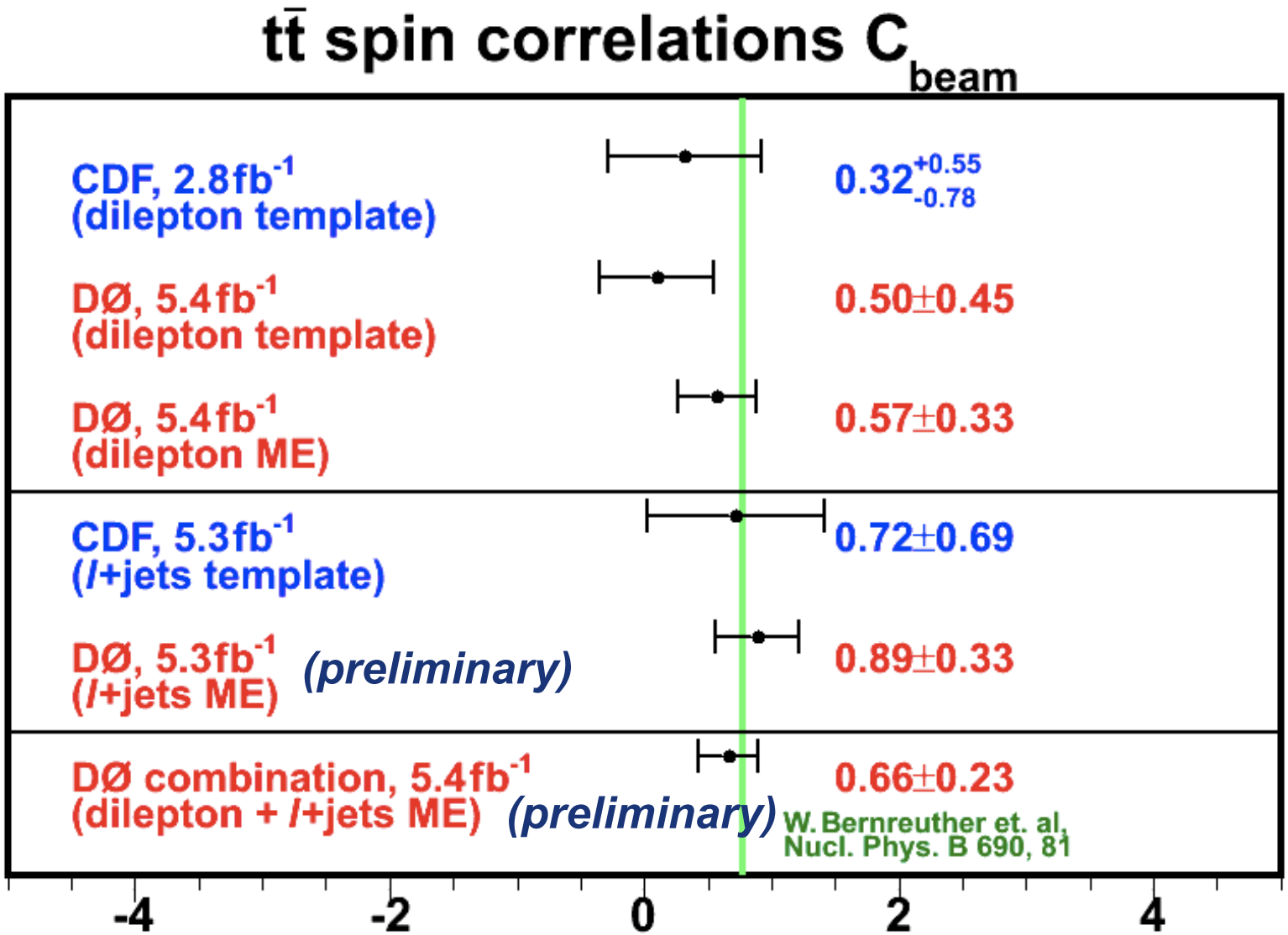
- We obtain:
  - f = 0.74 ± 0.41 (stat+syst)
  - f > 0.14 @ 95% CL
  - f=0 excluded at 97.7% CL (99.6% exp.)
    - 30% more sensitivity!
      - But still statistically dominated (0.27)

Spin correlations w. matrix element

- **Straight forward to extend the lepton+jets channel:**
  - Same ME, mc@nlo as generator
  - Split in 4 and 4+ jet bins
  - Require two b-tags to reduce combinatorics (+ purity 90%)
  - Regard the other two hightes p_T jets as light jets
  - → four permutations
- **Combine with dilepton result:**
  - f = 0.85 ± 0.29 (stat+syst)
  - f < 0.34 @ 95% CL
  - f < 0.05 @ 99.7% CL
  - f = 0 @ 3.1 SD !!!
    - First evidence for non-vanishing spin correlations!

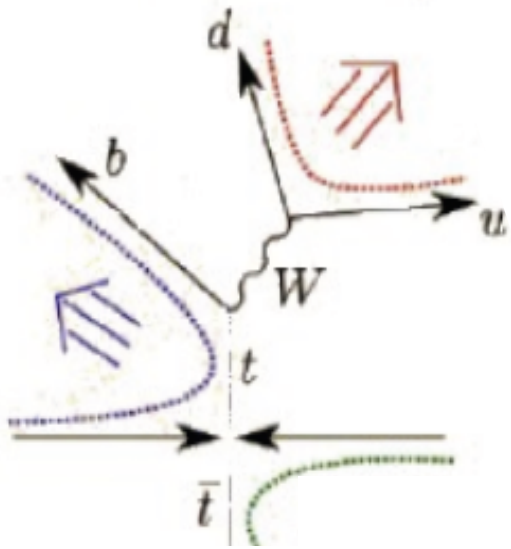


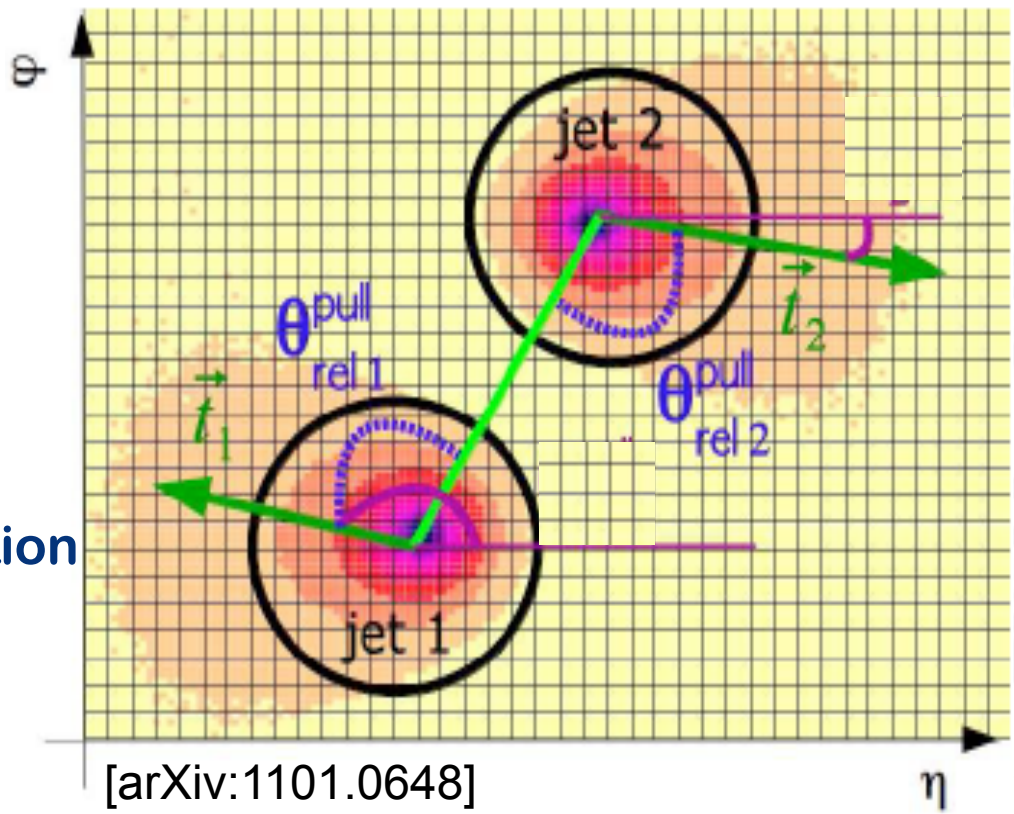
Spin correlations Tevatron



Colour Flow in tt events

- **Use colour-connections as selection tool**
  - $H \rightarrow b\bar{b}$: colour singlet, $g \rightarrow b\bar{b}$: colour octet
  - tt events provide clean samples of **W bosons (colour-singlet)** and **b-jets (colour-octet)**



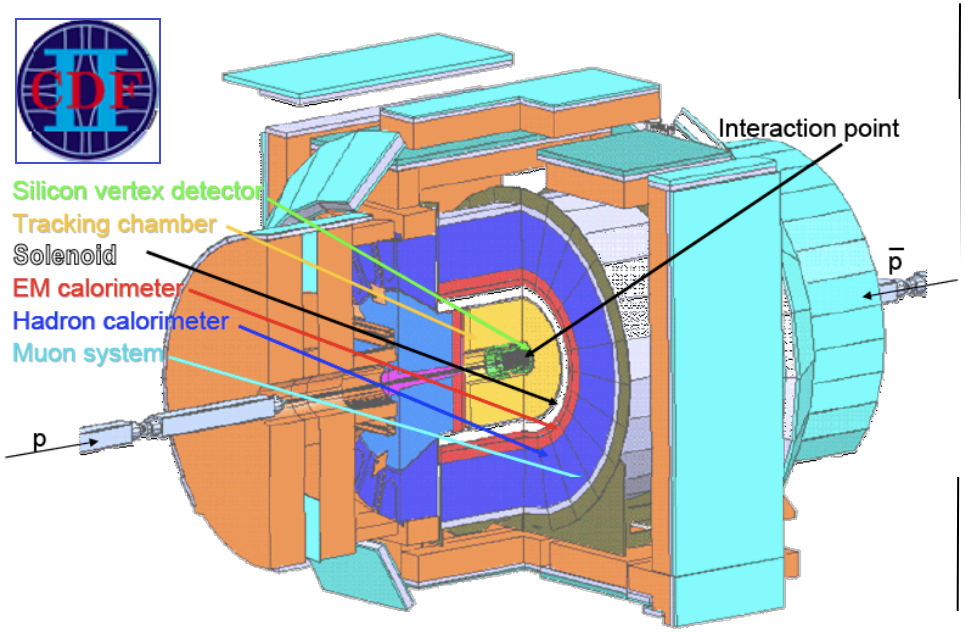


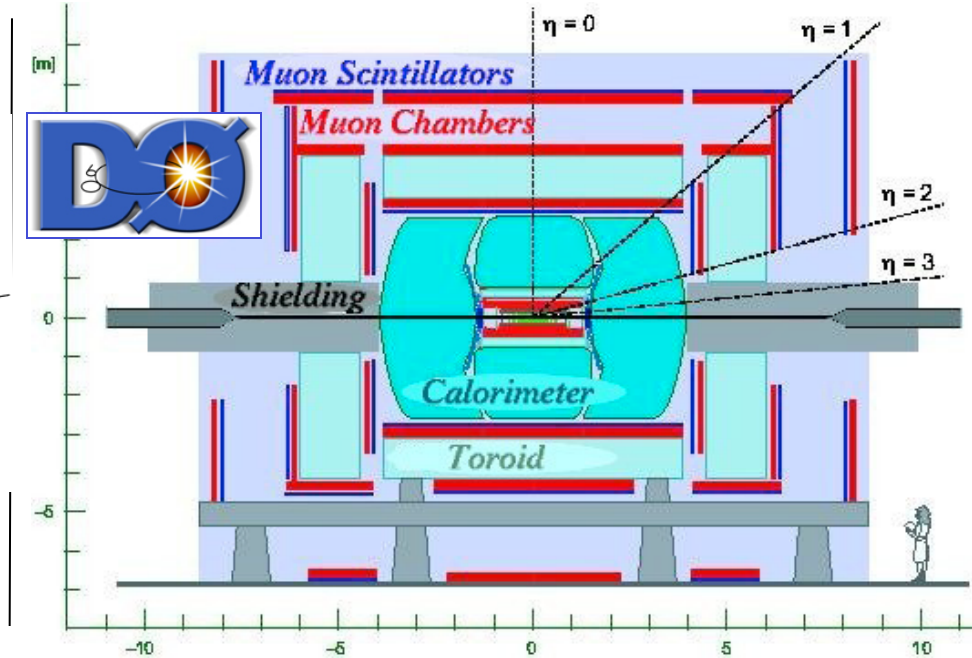
[arXiv:1101.0648]

Fraction of W in singlet configuration

$$f_{\mathrm{Singlet}} = 0.56 \pm 0.42$$
$$f_{\mathrm{Singlet}} = 1 \text{ (SM)}$$

The CDF and D0 detectors





	CDF	DØ
EM calorimeter	14%/√E + 1%	22%/√E + 4%
Hadronic calorimeter	70%/√E + 5%	68%/√E + 5%

The birth size

- 24 Feb. 1995:
  - Simultaneous PRL submission by CDF and DØ

- CDF (67 pb^{-1}) :
  - $\sigma=6.8^{+3.6}_{-2.4}$ pb,
  - observed 19 events, expected 6.9 bkg
    - bkg-only hypothesis rejected at 4.8σ
  - m_{top}=176±13 GeV
- D0 (50 pb^{-1}):
  - σ=6.4±2.2 pb,
  - observed 17 events, expected 3.8 bkg
    - → bkg-only hypothesis rejected at 4.6σ
  - m_{top}=199±30 GeV

The birth weight

- 24 Feb. 1995:
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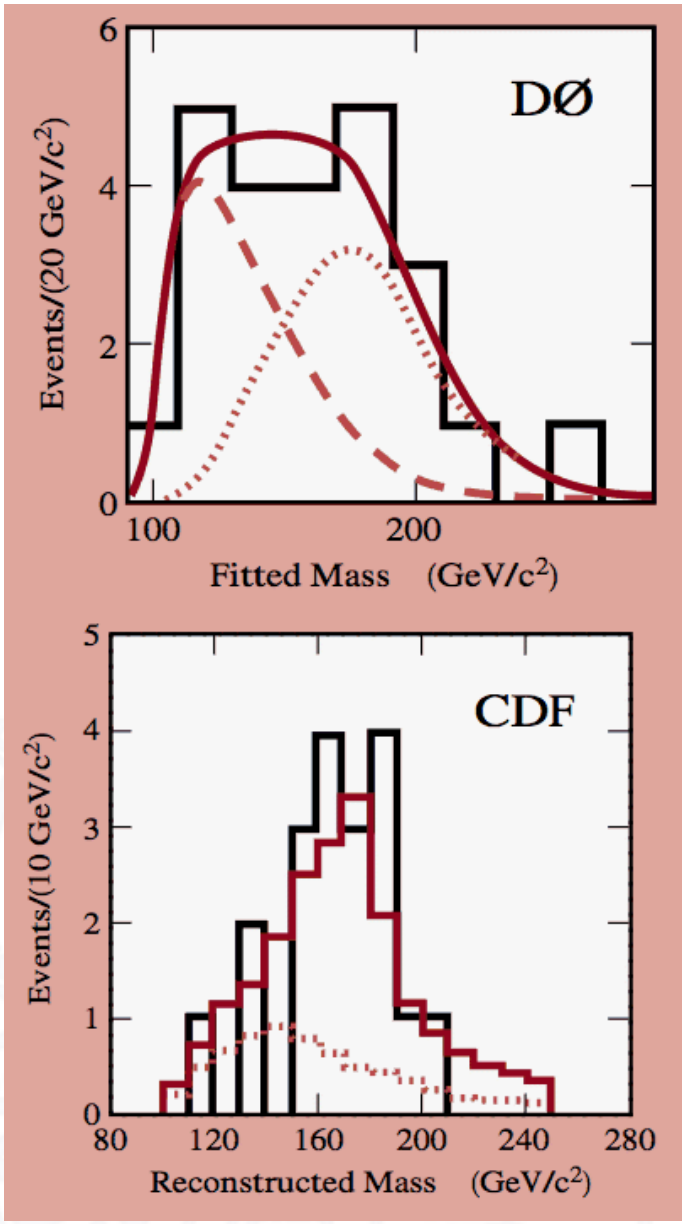
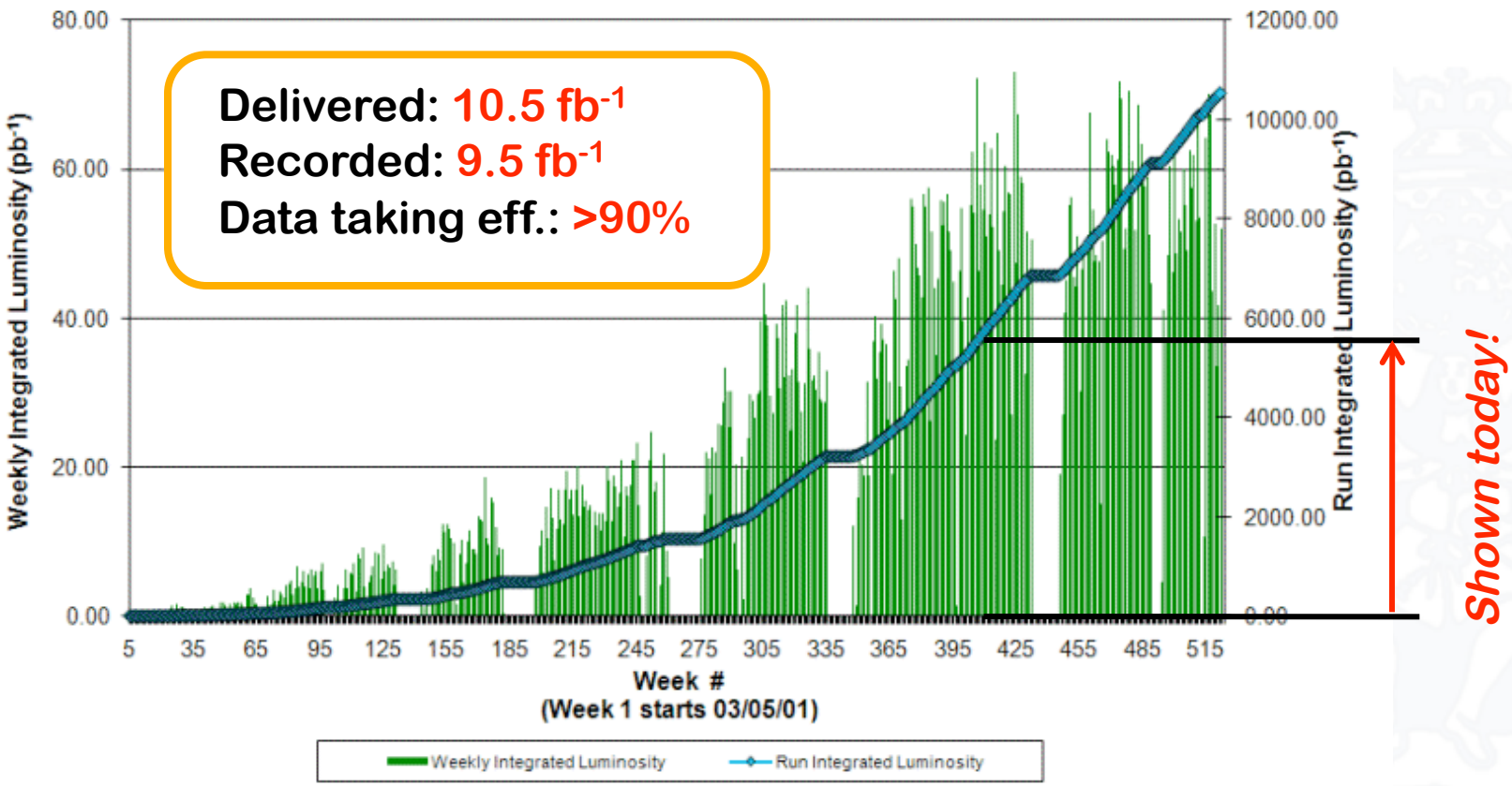


Analyzed dataset

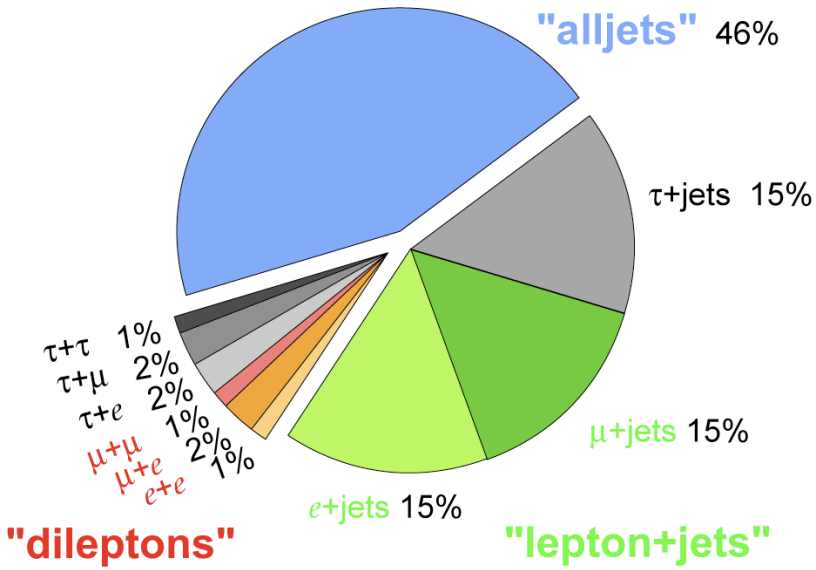
- Tevatron has shown a great performance in FY 2010!
- We keep enlarging our calibration samples
  - Better handles on experimental uncertainties:
    - e.g. Jet Energy Scale (JES), Jet Energy Resolution, etc.

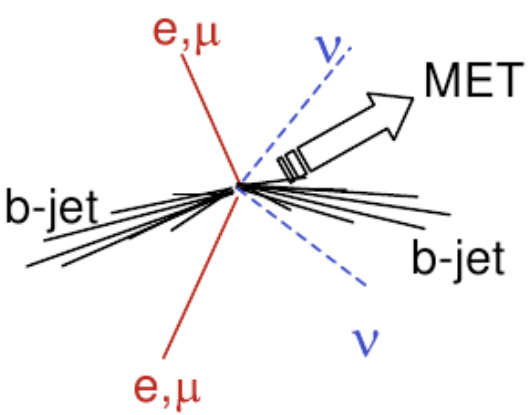


… and Decay

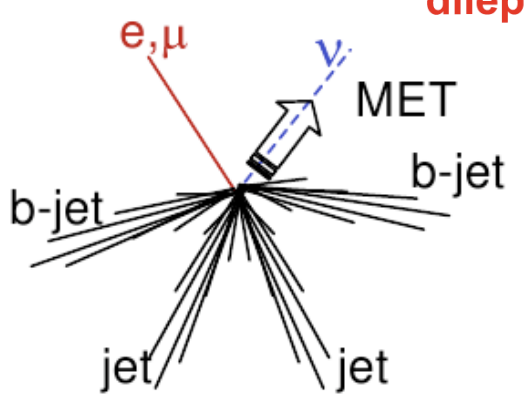
- **In the SM:**
  - $|V_{tb}| = 0.9990\text{-}0.9992$ @ 95% C.L. assuming 3 CKM generations
- **Characterise tt final states by top decays!**

Top Pair Branching Fractions

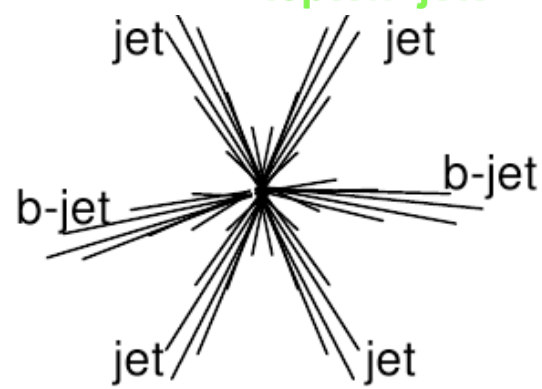




Dilepton
(BR~5%, low bckg)



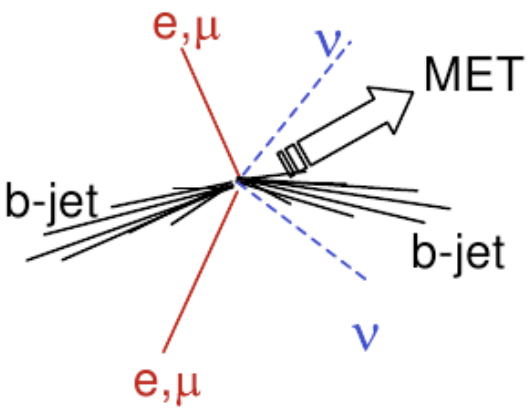
Lepton+jets
(BR~30%, moderate bckg)



All-hadronic
(BR~46%, huge bckg)

Typical ttbar preselection

Dilepton	Lepton+jets	All-hadronic
2 high-p_T leptons	1 high-p_T lepton (>20 GeV)	No leptons
Missing E_T	Missing E_T (>40 GeV)	No missing E_T
2 jets	4 jets (> 20GeV)	6 jets
≥ 0 b-tags	≥ 1 b-tag	≥ 1 b-tag
S/B:		



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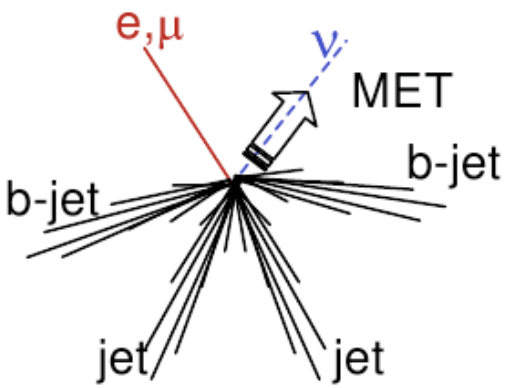

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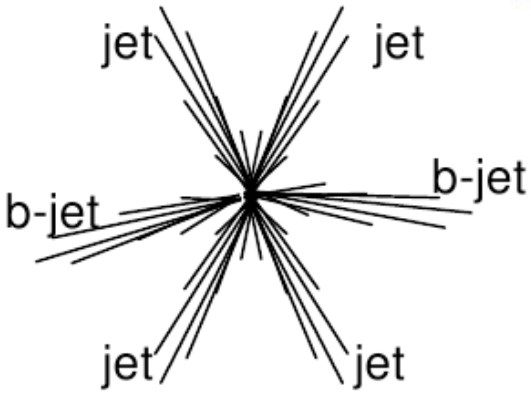

All-hadronic
(BR~46%, huge bckg)

Experimental Challenges

- **We are interested in parton-level quantities for our top measurements**
  - Map the energies of reco-level jets particle jets (D0) / partons (CDF)
  - This is referred to as a Energy Scale (JES) corr'n
  - With the current size of samples:
    - s(JES)/JES ~ 1.5% (D0)
    - s(JES)/JES ~ 3% (CDF)
- **And many more:**
  - Lepton ID, p_T scale