Top properties at Tevatron

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IPHC Strasbourg

Top Workshop
Grenoble
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Characterization of the top quark

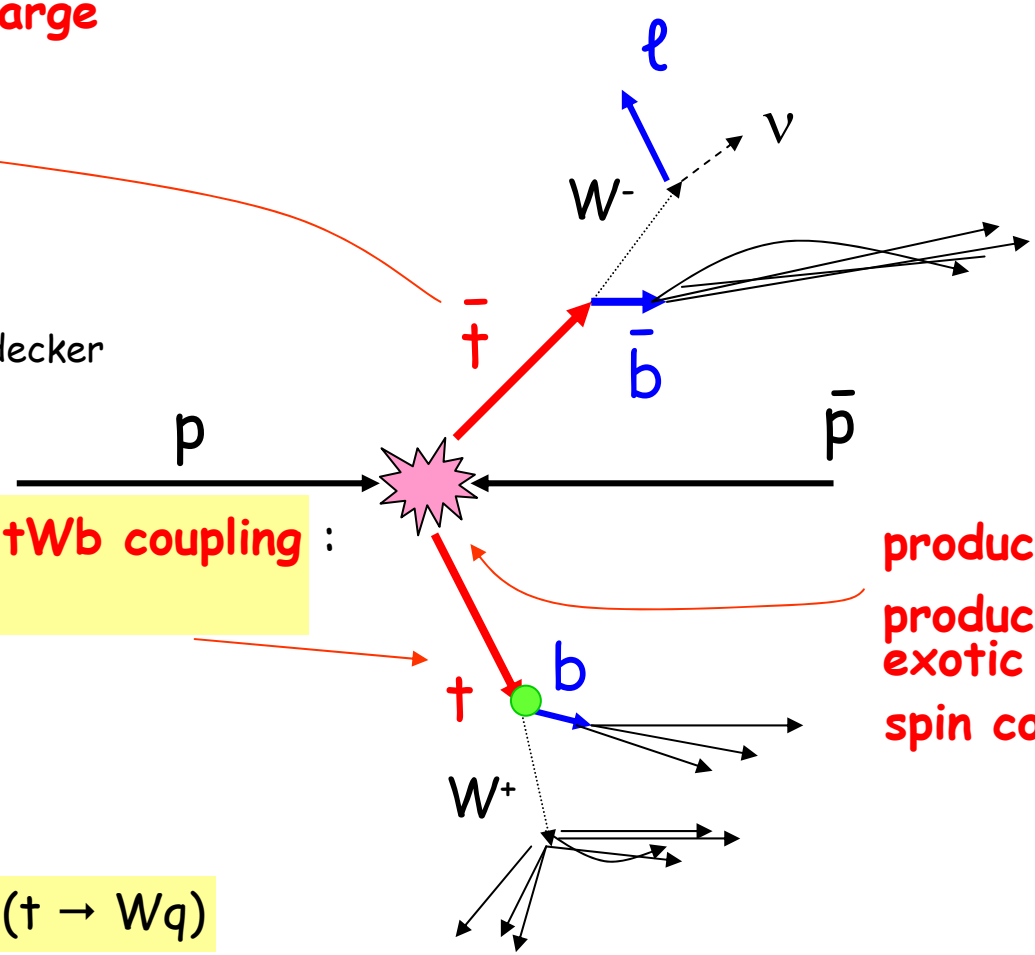
electric charge

lifetime

spin

mass

P. Shieferdecker



S. Crépé-Renaudin
S. Sharry

structure of the tWb coupling :
W helicity

$|V_{tb}|$: single top

CP violation

decay channels :

- $Br(t \to Wb) / Br(t \to Wq)$
- $t \to \tau \nu q$
- rare channels : $t \to Zc, \gamma c$
- susy $t \to H^+ b$

production rate σ_{tt}

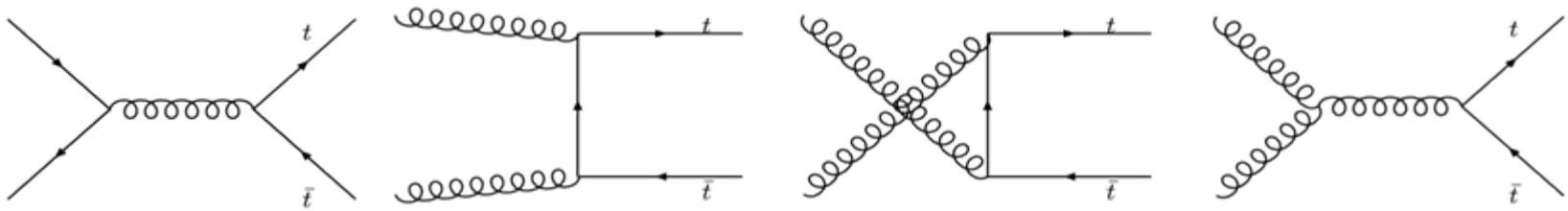
production of something exotic ? new resonance

spin correlation

Is this particle the S.M. top quark ?

top strong production

is a pair production



Tevatron @ 1.96 TeV : 85 % qq / 15 % gg

$\sigma_{t\bar{t}}$ = **6.7 ± 0.8 pb** 1 $t\bar{t}$ event / 24 min @ 10^{32} $cm^{-2}.s^{-1}$

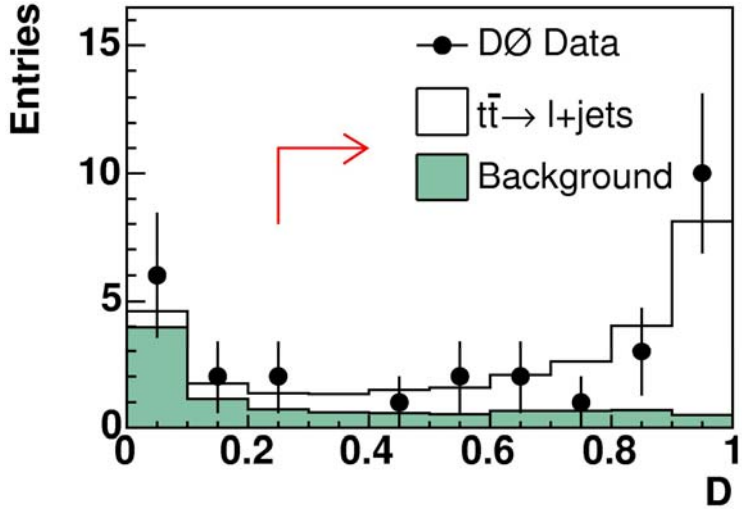
7 kevt / year

$t\bar{t}$ final state selection (ℓ+jets) based on sequential cuts :

- one high p_T lepton
- large $\not{E}_T$
- 4 high p_T central jets
- ≥ 1 b-tagged jets

+ likelihood (kinematic and topological characteristics) to discriminate against **W+n jets** background.

+ constrained fit



Anomalous kinematics

So-called « top » observed sample could contain an admixture of exotic processes.

dilepton sample 193 pb^{-1} (13 events)

Method seeks to isolate the subset of events with the largest concentration of possible non-SM physics → Kolmogorov-Smirnov test with 4 variables : $\not{E}_T$, lepton p_T, angle($\not{E}_T$, lepton), proba to be tt.

Conclusion : • **no particular subset shows a significant discrepancy with S.M.**

• **proba to observe a data sample less consistent with S.M. is 1.0-4.5 %.**

PRL 95, 022001, 2005

Br(t→Wb) / Br(t→Wq)

$$R = \frac{Br(t\to Wb)}{Br(t\to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2} = 1 \text{ if unitarity of CKM in S.M.}$$

Deviation of R from 1 : 4th generation of quarks ? non-S.M. top decay ? exotic background ?

ℓ+jets sample 230 pb^{-1}

$R = 1.03^{+0.17}_{-0.15}\,(stat.)^{+0.09}_{-0.07}\,(syst.)$

$|V_{tb}| > 0.64$ @ 95 % C.L.

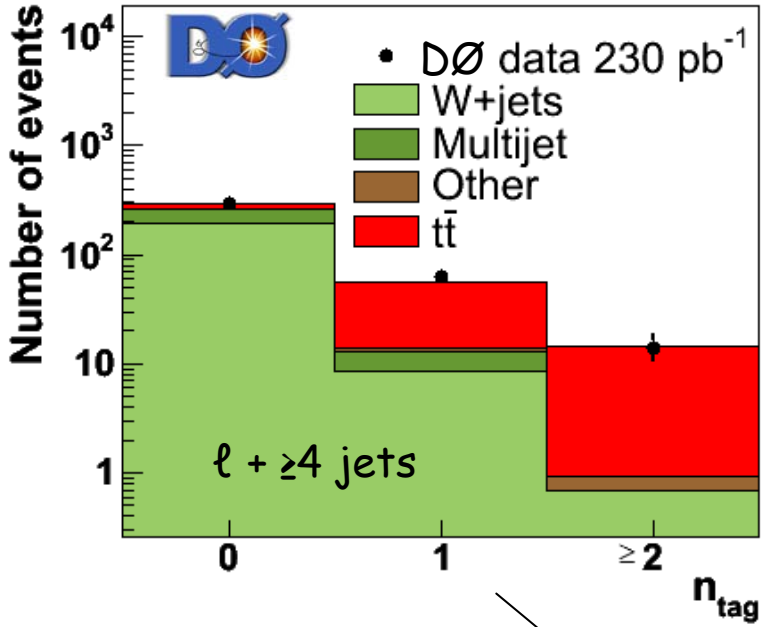
PLB 639, p. 616, 2006

ℓ+jets and dilepton sample 162 pb^{-1}

$R = 1.12^{+0.21}_{-0.19}\,(stat.)^{+0.17}_{-0.13}\,(syst.)$

$|V_{tb}| > 0.61$ @ 95 % C.L.

PRL 95, 102002, 2005

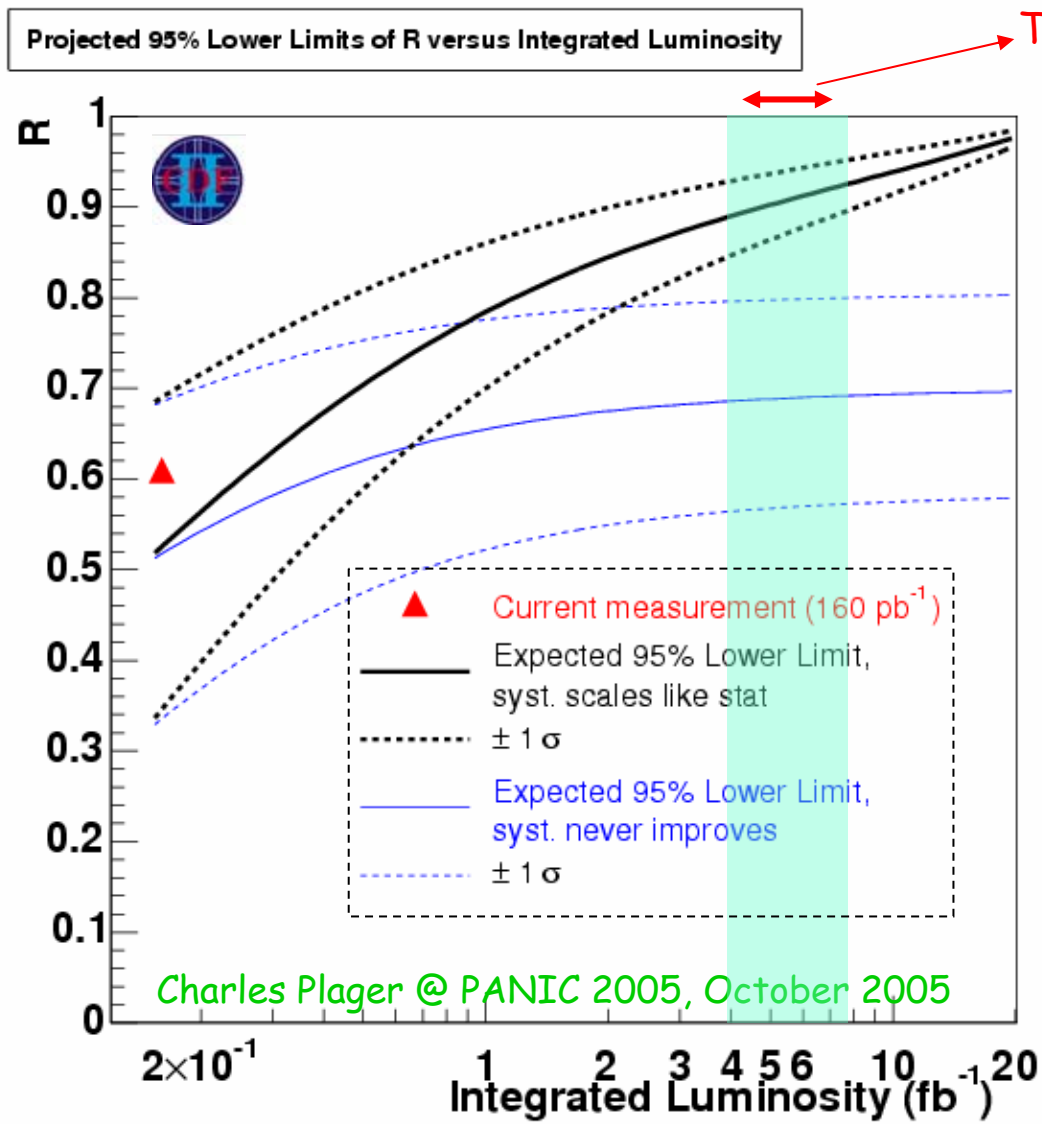


3 bins → R is overdetermined

Likelihood fit on number of selected events in b-tagged jets multiplicity bins (0, 1, ≥2 b-tag).

ε_{btag} = f(R) → systematics. But only relative rates → independent of σ_{tt}.

Br(t→Wb)/Br(t→Wq) reach at Tevatron



- CDF quick estimation of reach
- assuming 3 generations (R=1)
- Examples of non B.S.M. physics :
  - $|V_{ts}|$ = 0.1 and 3 generations
    → R = 0.99
  - $|V_{tb}|$ = 0.5 and 4 generations
    → R = 0.96

☹ will need combination of CDF and DØ analysis to be interesting…

W helicity in t → W b

- Weak interaction : only **V-A structure**.

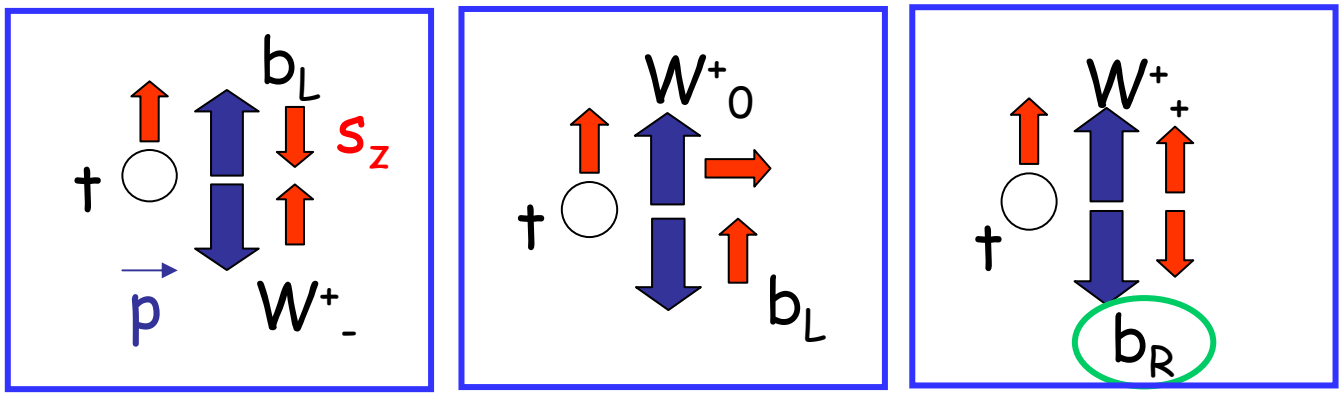
Introduced **by hand** to describe experimental observations.

Can be tested at high energy with top quarks by measuring the **W polarization**.

tWb structure can also be tested through the electroweak single top production, but with lower precision and of course not at Tevatron.

- Relativistic limit : **chirality → helicity** (observable !) when m/p → 0

t → W b decay : $m_b \ll E_b$ and $b_L \rightarrow b_-$



In the S.M. : W^+_+ (right) suppressed by a factor m_b^2/m_t^2 in the t → W^+ b decay :

$$F_- \approx \frac{2\,M_W^2}{m_t^2 + 2\,M_W^2} \approx 0.30 \qquad F_0 \approx \frac{m_t^2}{m_t^2 + 2\,M_W^2} \approx 0.70 \qquad F_+ \approx 0$$

W helicity (cont^d)

In practice :

- **measurement of F_+ → quantification of a V+A contribution.**

Would **decrease F_- in benefit of F_+ and let F_0 unchanged.**

F_0 constrained to 0.7.

By comparing data to M.C. = α (V-A) + β (V+A), neglecting interferences between the two contributions.

Already indirectly limited to a few % by b → s γ measurements (CLEO, BaBar, Belle). But based on theoretical assumptions (penguins, QCD).

- **measurement of F_0 without hypothesis on physics beyond S.M.**

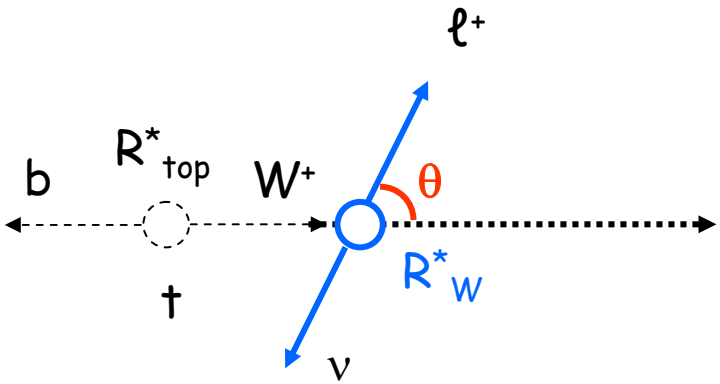
F_+ constrained to 0.

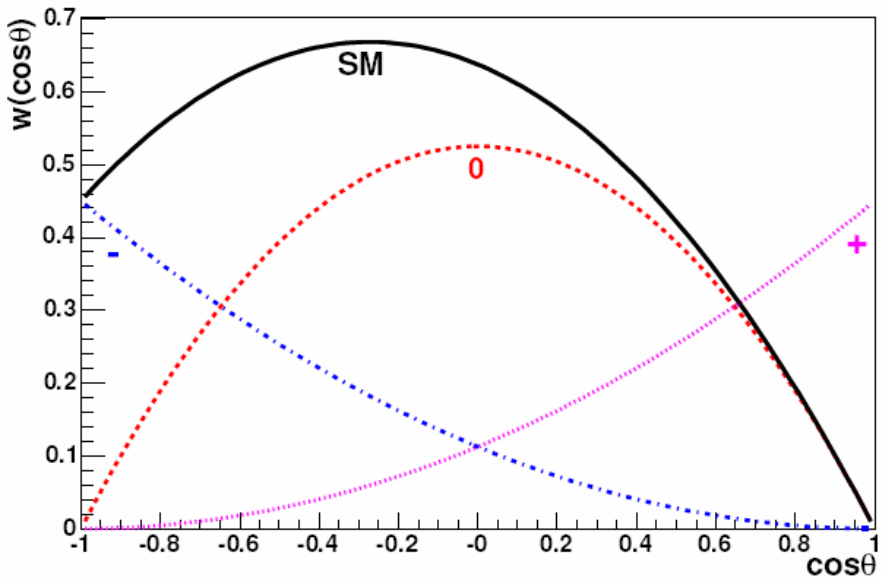
Deviation from its S.M. predicted value would question the EWSB by the Higgs mechanism, responsible for the longitudinal degree of freedom of massive W bosons.

W helicity (cont^d)

Angular distribution (unpolarized top) of the down-type decay products of the W^+ :

$$w(\cos\theta) = \frac{3}{8}(1+\cos\theta)^2 F_+ + \frac{3}{8}(1-\cos\theta)^2 F_- + \frac{3}{4}\sin^2\theta\, F_0$$





→ Helicity fractions F_+ and/or F_0 and/or F_- will be measured from the angular distribution $w(\cos\theta)$.

W helicity estimators

To measure $w(\theta)$ → need to boost to **top and W rest frames** (☹ $E\!\!\!/$ resolution, missing ν…).

Several ideas of estimators :

1) **$M_{\ell b}^2$ approximation :**

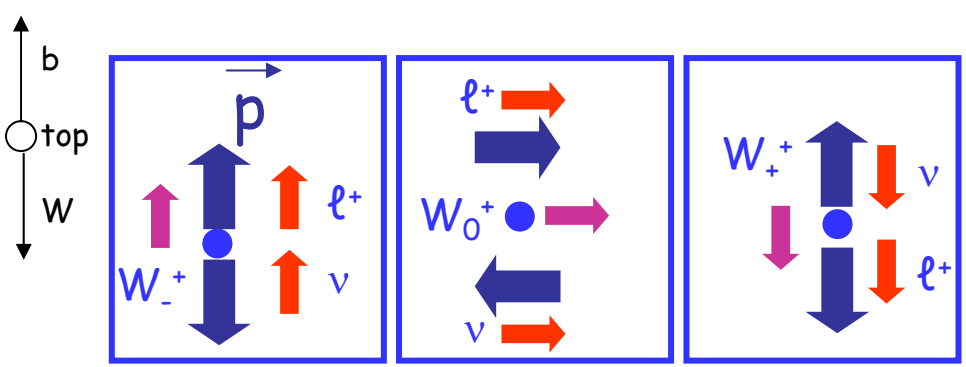
$$\cos\theta \approx \frac{2\,M_{\ell b}^2}{m_t^2 - M_W^2} - 1$$

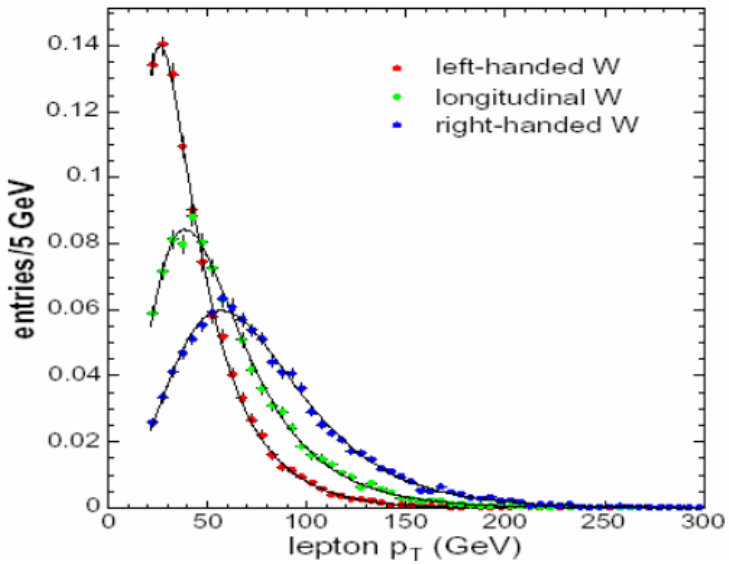
with $m_b \sim 0$

Depends on Δm_{top} and b JES.

2) **Charged lepton p_T spectrum :**

Relies on M.C. templates.



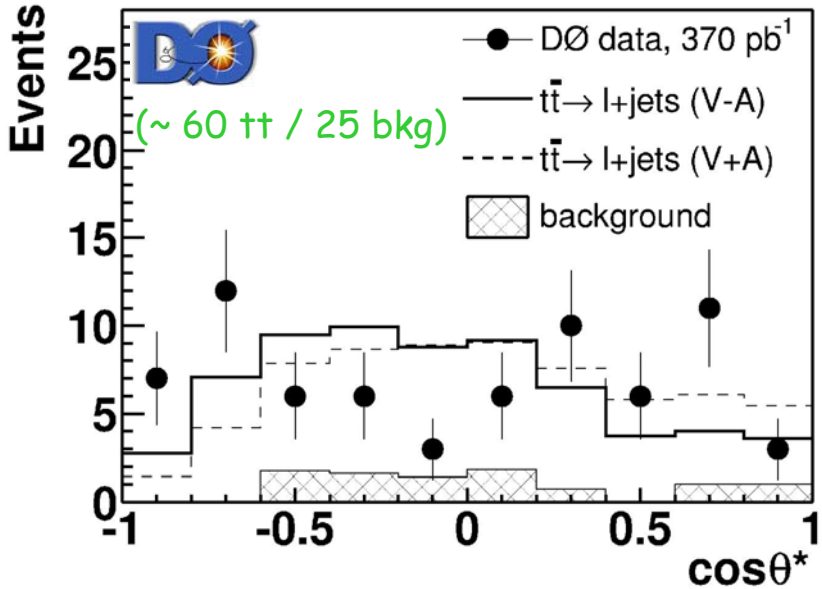


W helicity estimators (cont^d)

3) Constrained kinematic fit :

W and top masses are constrained.

Resolutions on E and p from lepton, jets and $\not{E}_T$ have to be known.



4) Matrix element method :

- used in m_{top} measurement.
- sensitivity improved by using **both W in each event**.
- the **whole information** and **all combinations** of the charged lepton and the 4 jets in 2 W bosons and 2 top quarks are used.
- efficient **discrimination** between the tt signal and the background.
- problem of precision : gluon radiations, order of the computation (L.O. ?), inclusion of the 15 % gg → tt ?

W helicity studies at Tevatron

	162 pb^{-1} ℓ+jets 193 pb^{-1} dilepton PRD 73: 111103, 2006	$M_{\ell b}^2$ lepton p_T	$F_0 = 0.74\ ^{+0.22}_{-0.34}$ (stat + syst) $F_+ < 0.27$ @ 95% C.L
	230 pb^{-1} ℓ+jets PRD 72: 011104, 2005	cos θ	$F_+ < 0.25$ @ 95 % C.L. $F_+ = 0.00 \pm 0.13$ (stat) ± 0.07 (syst)
	370 pb^{-1} ℓ+jets & dilepton submitted to PRL	cos θ	$F_+ < 0.23$ @ 95% CL $F_+ = 0.056 \pm 0.080$ (stat) ± 0.057 (syst)
	955 pb^{-1} ℓ+jets summer 2006 conference	cos θ	$F_0 = 0.61 \pm 0.12$ (stat) ± 0.04 (syst) $F_+ < 0.11$ @ 95% C.L.
	750 pb^{-1} ℓ+jets & dilepton submitted to PRL	$M_{\ell b}^2$ lepton p_T	$F+ < 0.09$ @ 95% C.L.

Outlook for W helicity

W helicity measurement will benefit from increasing stat

And decreasing error on M_{top} and JES.

Precision with **400 pb^{-1}** : **F_+ ~ unconstrained** (< 0.25 with F_0 = 0.7 fixed)

$\Delta F_0/F_0 \approx 30$ %

1 fb^{-1} : **sensitivity $F_+ < 0.1$**

$\Delta F_0/F_0 \approx 20$ %

Expected precision with **2 fb^{-1}** : **$F_+ < 0.05$**

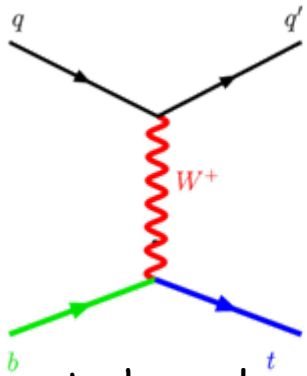
$\Delta F_0/F_0 \approx 5 - 6$ %

And with **10 fb^{-1}** (1 year at LHC) : **$\Delta F_+/F_+$ ~ 1 %**

$\Delta F_0/F_0$ ~ 2 %

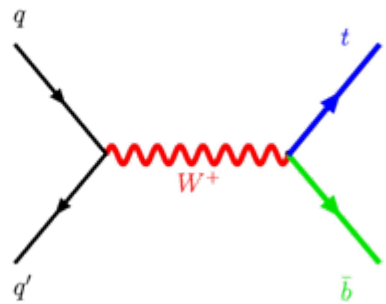
top electroweak production

is a single top production



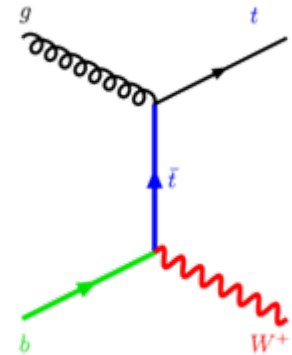
t-channel :

1.98 ± 0.21 pb



s-channel :

0.88 ± 0.07 pb



Associated production :

0.09 pb

Not discovered yet : smaller cross-section and higher background → only limits on this production mode.

Once it is observed :

→ direct measurement of **$|V_{tb}|$ without the assumption on unitarity of 3-generations** CKM matrix : $\sigma \propto |V_{tb}|^2$

→ sensitive to B.S.M. physics (Z', H^+, …)

→ top spin physics (100 % polarized top quark). But not at Tevatron !

single top selection

Signature :

- 1 central high p_T b jet from top decay
- 1 or 2 extra jets (including 1 softer b)
- 1 isolated high p_T lepton and $\not{E}_T$. (W boson)

Use b-tagging in selection :

- reduce W+light jets background
- separtate single and double tagged events

→ modify t-channel w.r.t. s-channel acceptance

☹ **background dominated** after selection.

→ need multivariate techniques to improve discrimination (see D.Gele's talk)

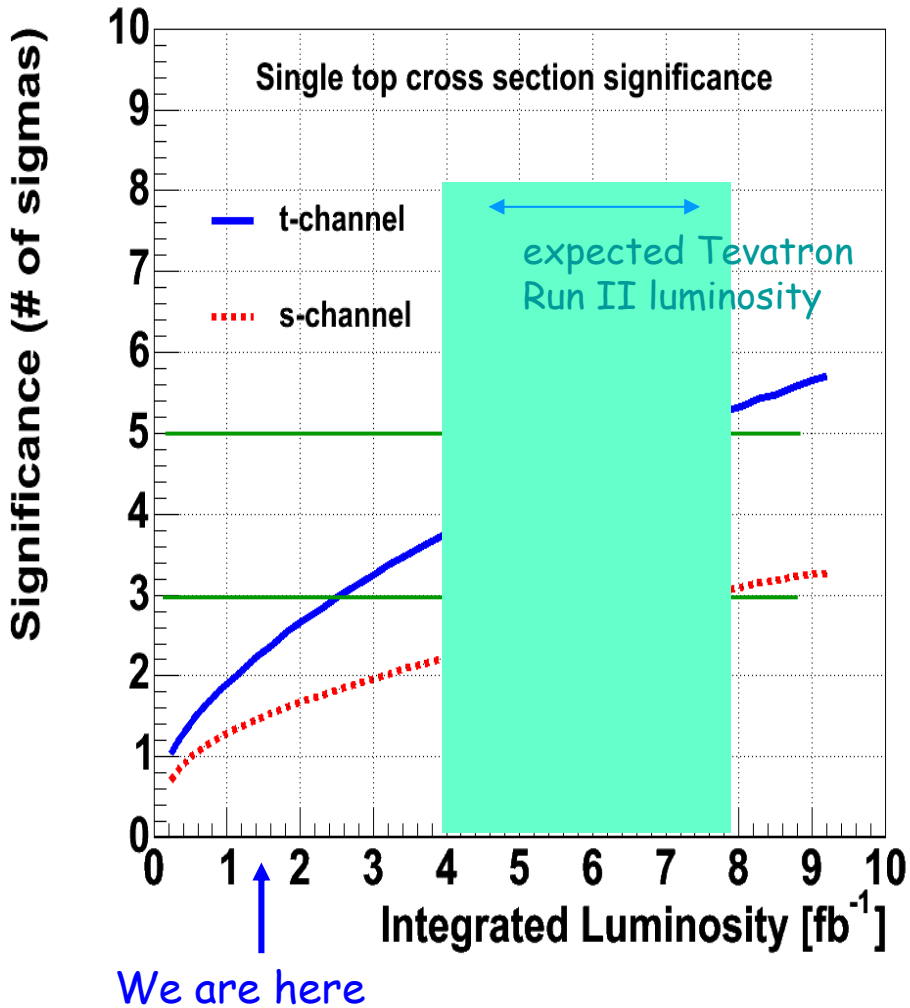
	S. tag	D. tag
W+light	48%	10%
W+HF	10%	14%
Top pairs	25%	61%
Others	12%	7%
Signal (s+t)	5%	8%

single top search at Tevatron

Observed (expected) limits

	σ_s (pb)	σ_t (pb)
S.M. (NLO) prediction	0.88 ± 0.07	1.98 ± 0.21
162 pb^{-1}	13.6 (12.1)	10.1 (11.2)
	PRD 71, 012005, 2005	
230 pb^{-1}	6.4 (4.5)	5.0 (5.8)
	PLB 622, p. 265, 2005	
370 pb^{-1}	5.0 (3.3)	4.4 (4.3)
	Summer 2005 conferences	
695 pb^{-1}	3.2 (3.7)	3.1 (4.2)
	Summer 2006 conferences	

single top prospects at Tevatron



☺ Observation coming soon ?

Conclusion

- Top quark high mass → hope to open the window on the physics hiding B.S.M.
- Tevatron is currently the world's only source of top quarks and will be until the successful beginning of LHC.
- Excellent performance of Tevatron Run II :

→ large top samples

→ transition from the discovery phase to a **new phase of precision measurements** of the top quark properties.

backups

top electric charge

Top discovered by CDF and DØ → **twofold ambiguity in the pairing W/b**

B.S.M. theories → heavy quark with $q = -\frac{4}{3}e$ mixed with the actual top (mass 270 GeV)

Compatible with experimental data (R_b, A_{FB}^b).

ℓ + jets sample 370 pb^{-1} (17 double tagged events)

Two b-tagged jets

jet-parton assignement through kinematic fit.

Top charge estimation with a jet charge algorithm.

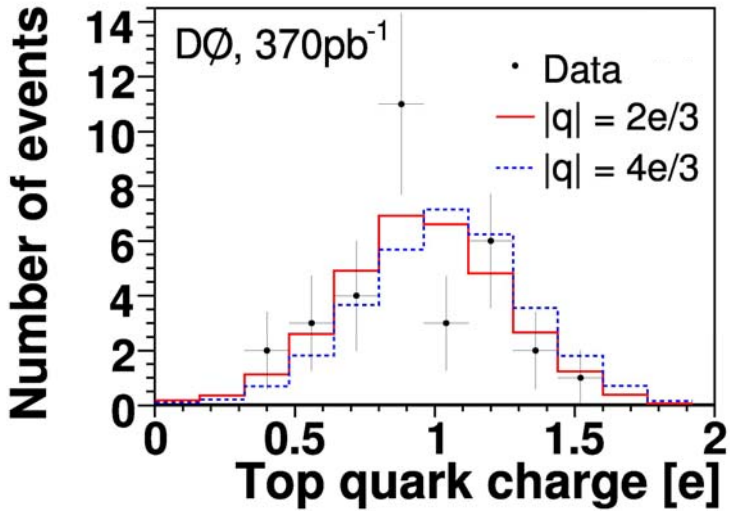
Likelihood to compare to exotic models.

$$q_{top} = q_\ell + \frac{\Sigma\, q\, p_T^{0.6}}{\Sigma\, p_T^{0.6}}$$

Sample of quark pairs with charge 4e/3 excluded @ 94 % C.L.

submitted to PRL

results coming soon with 955 pb^{-1}



top lifetime

Top is the heaviest known fundamental particle. Decays as a free quark $\tau \sim 10^{-25}$ s.

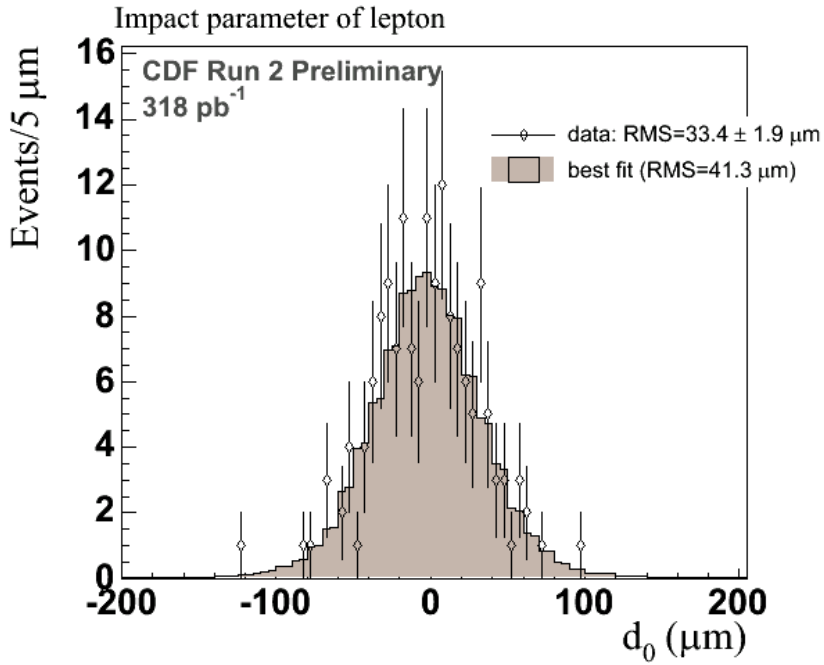
ℓ+jets sample 320 pb^{-1}

≥ 3 jets + btagging

lifetime estimated with the lepton I.P.

first (and only one) direct measurement :

$c\tau$ < 52.5 mm @ 95 % C.L.

(~ $1.8 \cdot 10^{-13}$ s…)

(preliminary results Winter conf. 2006)