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Search for new physics in top quark events with the DØ detector

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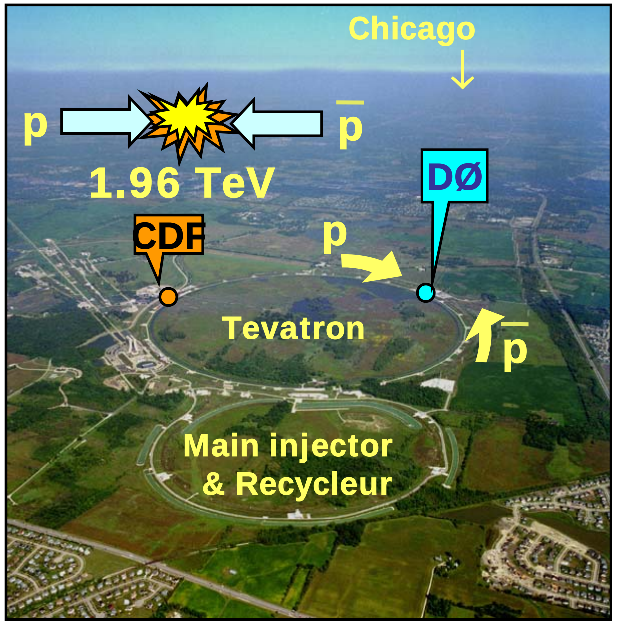
for the DØ collaboration

Outline:

- top production at the Tevatron
- the top and the search for new physics
- structure of the tWb coupling
- top branching ratio
- direct search for Z'
- forward-backward asymmetry
- conclusion

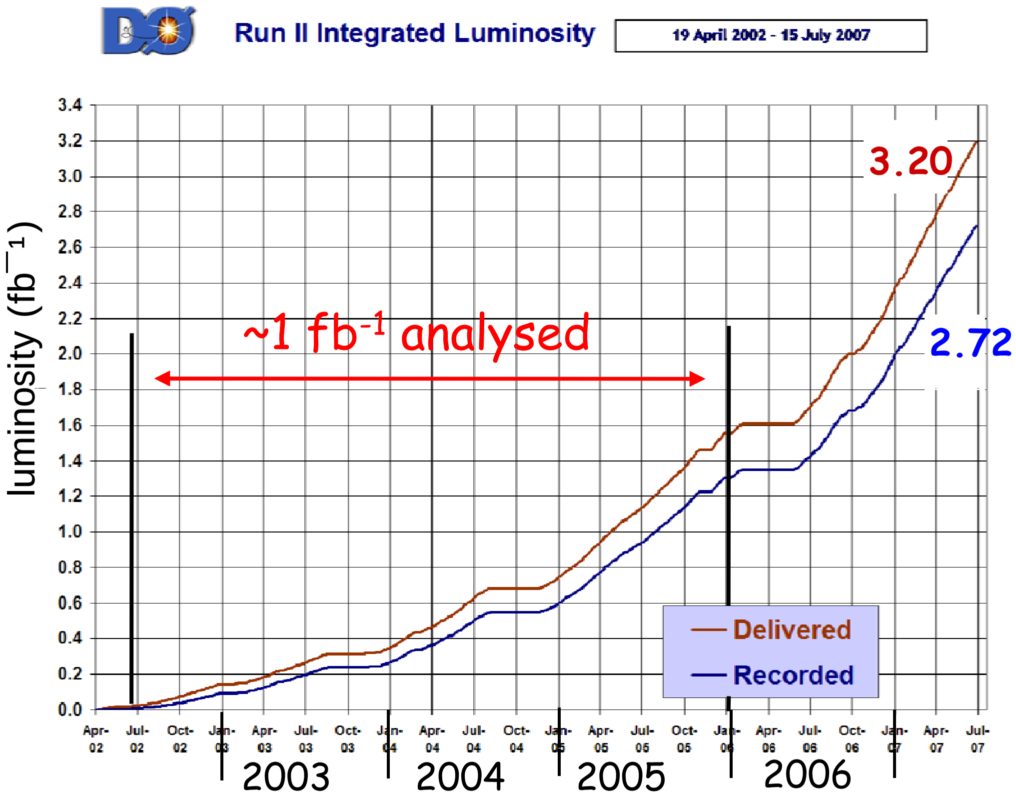
The Tevatron at Fermilab



Run I (1992-1996):

$\sqrt{s}$ = 1.8 TeV

~ 110 pb^{-1} analysed



Run II (since 2001):

$\sqrt{s}$ = 1.96 TeV ($\sigma_{tt}^{1.8\ TeV}$x1.3)

lumi ≤ $3{\cdot}10^{32}\ cm^{-2}s^{-1}$

~ 2.8 fb^{-1} recorded by DØ

Up to 1 fb^{-1} analysed.

2009: 4 to 8 fb^{-1} expected

→ Run I top datasetx50 (x100)

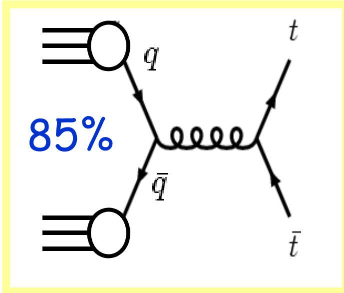
top production at Tevatron

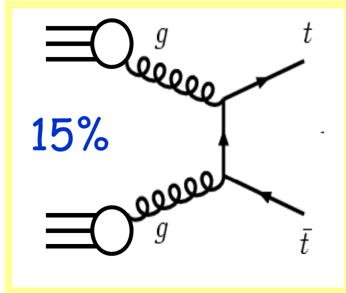
- **Strong interaction production**: produces **$t\bar{t}$ pairs**.

$\sigma_{t\bar{t}}^{NNLO}$ = 6.8 ± 0.6 pb

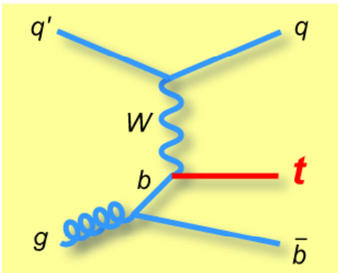
5 $t\bar{t}$ events / h @ $2 \cdot 10^{32}$ $cm^{-2}.s^{-1}$

15 kevt produced / year / experience

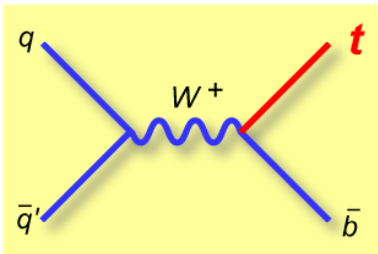




- **Weak interaction production**: produces **single tops**.



1.98 ± 0.25 pb



0.88 ± 0.11 pb

background is more critical than in $t\bar{t}$ events → multivariables analyses.

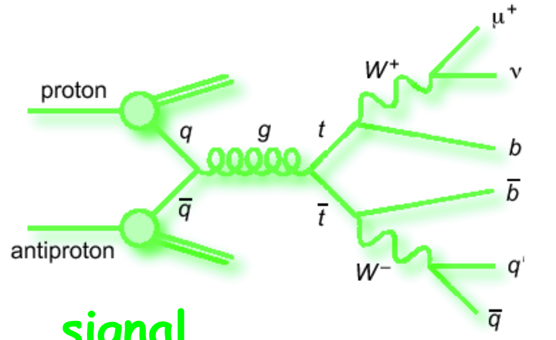
First evidence presented by DØ with a 3.4 σ significance in dec. 2006.

top pair events at Tevatron

- **Largest known mass** (03/2007 : 170.9 ± 1.8 GeV/c^2) and lifetime shorter than hadronization time (~ $5 \cdot 10^{-25}$ s w.r.t. 10^{-23} s) → decays as a **free quark.**

- In S.M.: **top → real W + b.**

$t\bar{t}$ events classified w.r.t. W decay.



signal

all jets BR ~ **45 %**

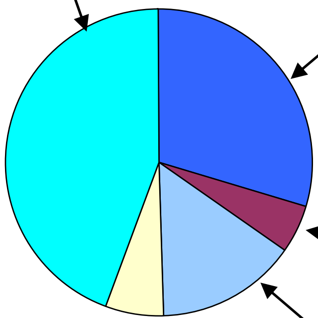
(ℓ = e/μ)

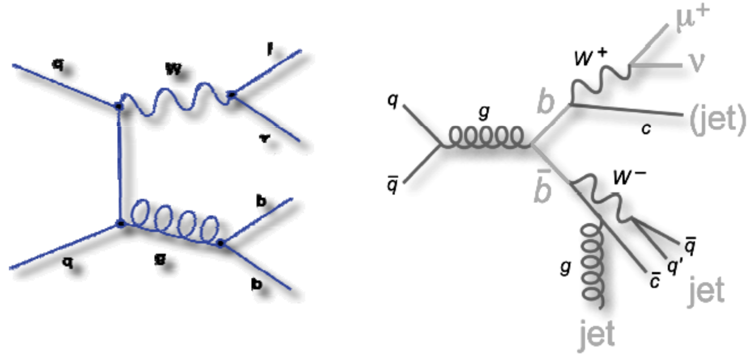
- BR ~ **30 %** **ℓ-jets**
- 4 jets
- optimum stat/bkg

BR ~ **5 %** **ℓ-ℓ**

τ + jets ~ 15%

τ + ℓ ~ 6 %





background: W+jets & multijet

2 bjets in all channels → use of **b-tagging** to improve signal/background.

Characterization of the top quark

Run I: top quark **discovery** by CDF and DØ at Tevatron in 1995.

RunII: considerable increase over the previous datasets → **precision measurements**.

Is this particle the S.M. top quark ?

single top production:

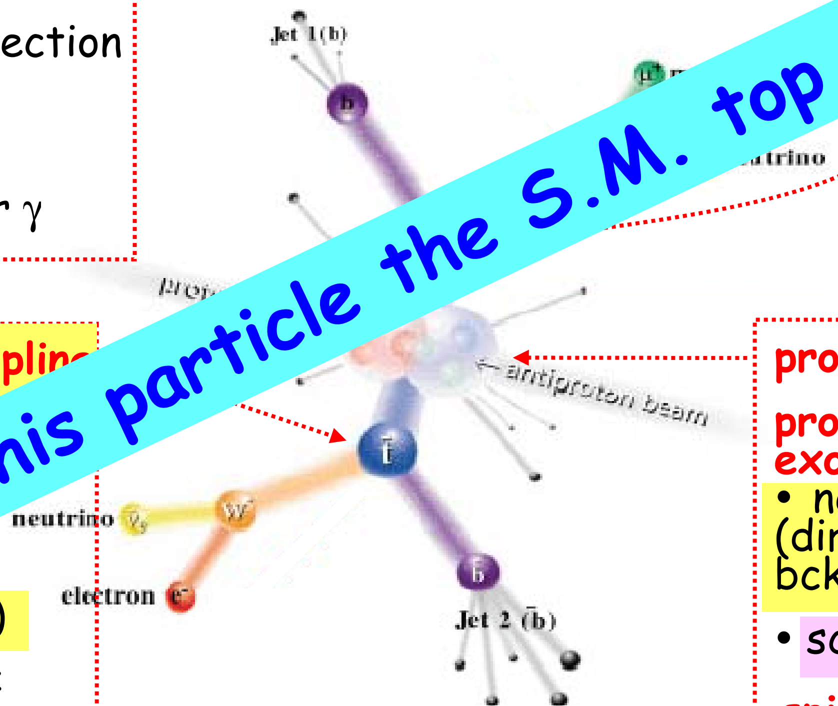
- weak process cross-section → CKM element $|V_{tb}|$
- $W' \to tb$
- Flavour Changing Z or γ

electric charge

lifetime

spin

mass



structure of the tWb coupling
→ W helicity

CP violation

decay channels

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

(in this review)

production rate $\sigma_{t\bar{t}}$

production of something exotic ?

- new heavy resonance (direct search, fwd-bckwd asymmetry)
- scalar top

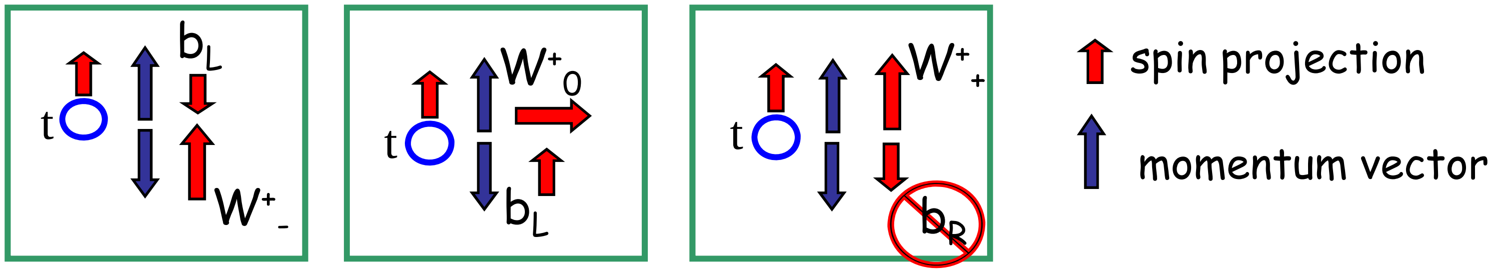
spin correlation

(talk by S.J. Park Friday 07/27)

structure of the tWb coupling

Weak interaction in the S.M.: **V-A structure**. Introduced **by hand** to describe experimental observations.

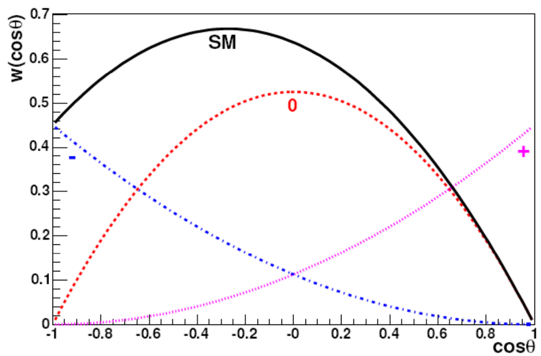
Can be tested at high energy with top quark by measuring the **W polarization**.
In $t \to W\,b$ decay: $m_b \ll E_b$ and $b_L \to b_-$ (chirality ~ helicity).

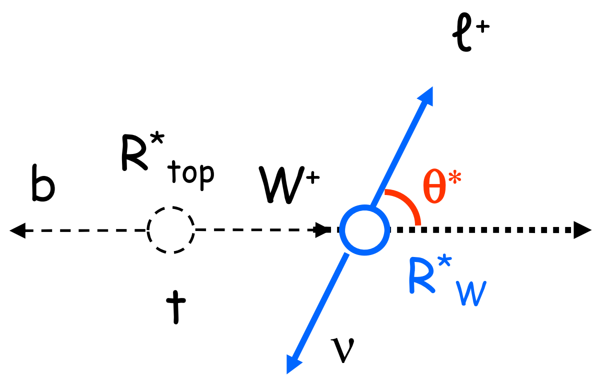


W^+_+ (right) suppressed by a factor m_b^2/m_t^2 in the $t \to W^+ b$ decay:

$F_- \approx 0.30$, $F_0 \approx 0.70$ and $F_+ \approx 3.6 \cdot 10^{-4}$

→ Helicity fractions F_+ and/or F_0 and/or F_- measured from angular distribution $w(\cos\theta^*)$

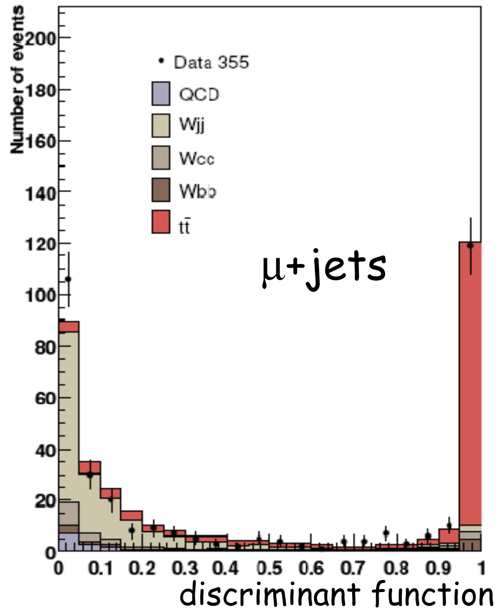




W helicity in t→W b (cont'd)

Dataset: ℓ+jets and dilepton

Selection: sequential cuts + **discriminant likelihood ratio** = f(kinematics, topology, btagging):



$\cos\theta^*$ estimated through a **kinematic constrained fit**.

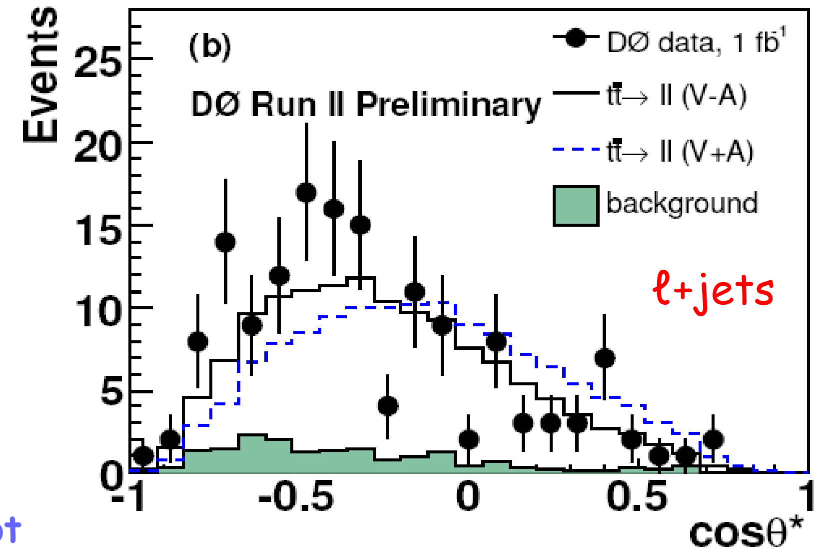
Binned likelihood compares reconstructed $\cos\theta^*$ to **linear combinations of V±A templates**.

F_0 fixed to S.M. value (70 %) and $F_- = 1 - F_+ - F_0$.

$F_+ = 0.017 \pm 0.048$ (stat.) ± 0.047 (syst.)

→ using a Bayesian conf. interval:

$0.000 < F_+ < 0.14$ (95 % C.L.)



Future: • syst ~ √N

• use pure W_+, W_-, W_0 templates and fit simultaneously F_+ and F_0.

top branching ratio

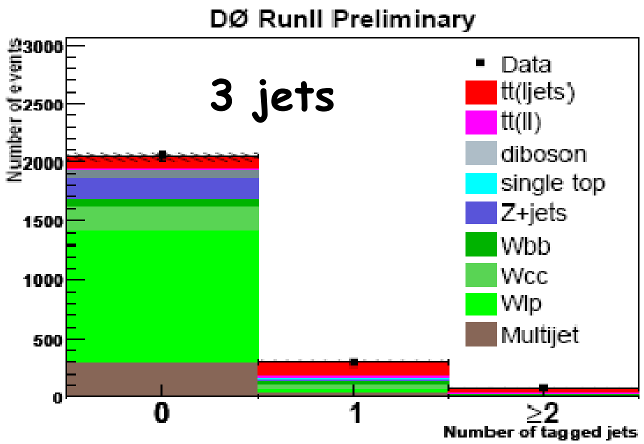
$$R = \frac{Br(t \to Wb)}{Br(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2} = |V_{tb}|^2 \sim 1$$

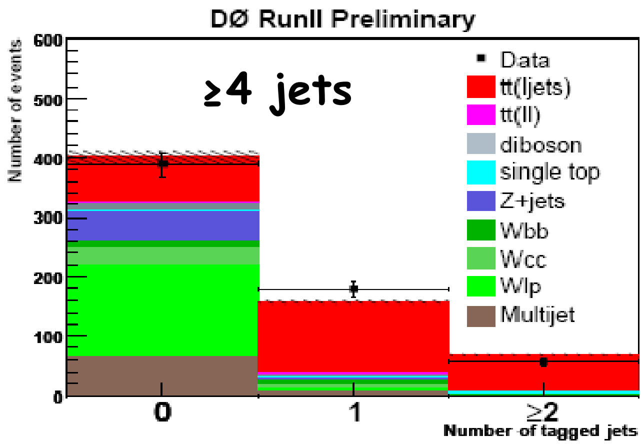
with:
- unitarity of CKM in S.M.
- 3 generations of fermions
- **$t \to Wq$ only** (no H^+ decay)

Deviation $R \neq 1$: 4th generation of quarks ? non-S.M. top decay ? exotic bkg ?

Examples of B.S.M. physics: $|V_{tb}| = 0.5$ & 4 generations → $R = 0.96$ → **need high experimental sensitivity !**

Measurement:
- Binned likelihood fit on number of observed events **with 0, 1 and ≥2 btagged jets** w.r.t. prediction for signal and background.
- **signal prediction = $f(R, \sigma_{t\bar{t}})$**
- in the no-b-tagged-jets bin : tt contribution obtained by **fit on likelihood discriminant.**





top branching ratio (cont^{d})

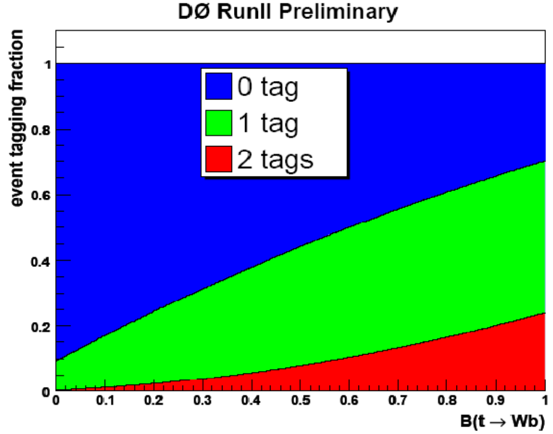
- **Selection criteria & b-tagging probability = f(R):**

other selection criteria

$$P_{sel}\,(n\text{-}btag) = R^2\, P_{n\text{-}btag}(t\bar{t}\to bb)\, P_{presel}(t\bar{t}\to bb) + 2R(1-R)\, P_{n\text{-}btag}(t\bar{t}\to bq_l)\, P_{presel}(t\bar{t}\to bq_l) + (1-R)^2\, P_{n\text{-}btag}(t\bar{t}\to q_lq_l)\, P_{presel}(t\bar{t}\to q_lq_l)$$

in the bin with n b-tagged jets

probability to tag n jets



- Simultaneous 2-dimensional fit of R and $\sigma_{t\bar{t}}$:

$R = 0.991^{+0.094}_{-0.085}$ (stat.+syst.)

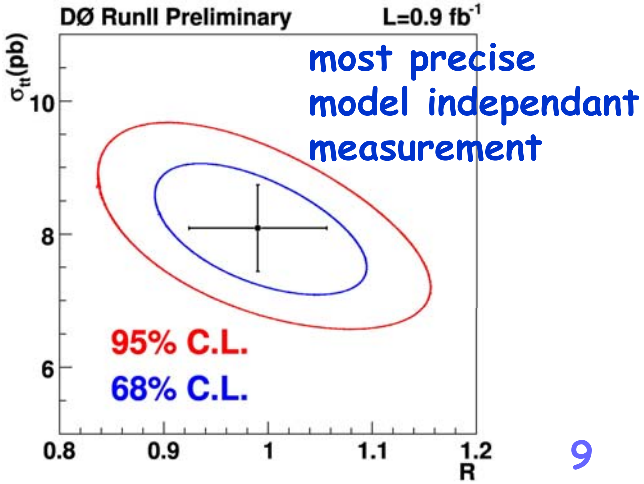
$\sigma_{t\bar{t}} = 8.10^{+0.87}_{-0.82}$ (stat.+syst.) ± 0.49 (lumi) pb

→ lower limit R > 0.812 @ 95 % C.L. (Feldman-Cousins)

→ using measured value of $|V_{ts}|$ and $|V_{td}|$:

$|V_{tb}|$ > 0.901 if CKM unitarity

> 0.096 without CKM unitarity



$t\bar{t}$ resonance production

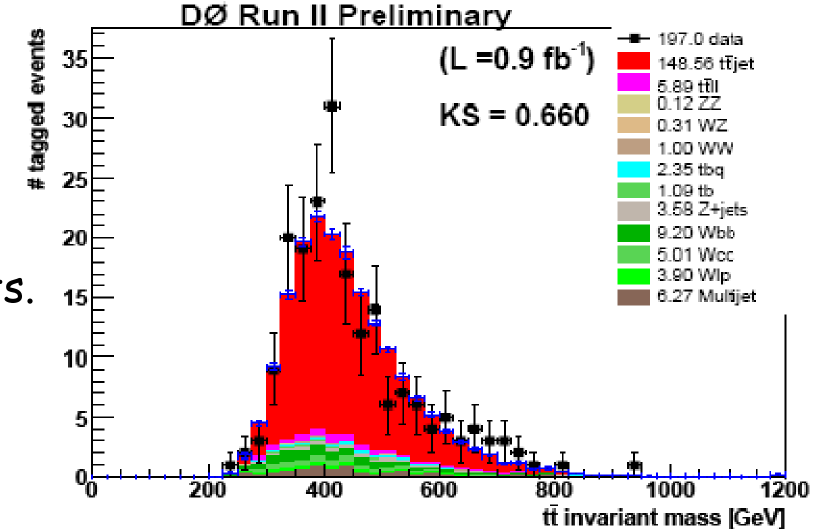
Direct search for heavy vector boson $Z' \rightarrow t\bar{t}$.

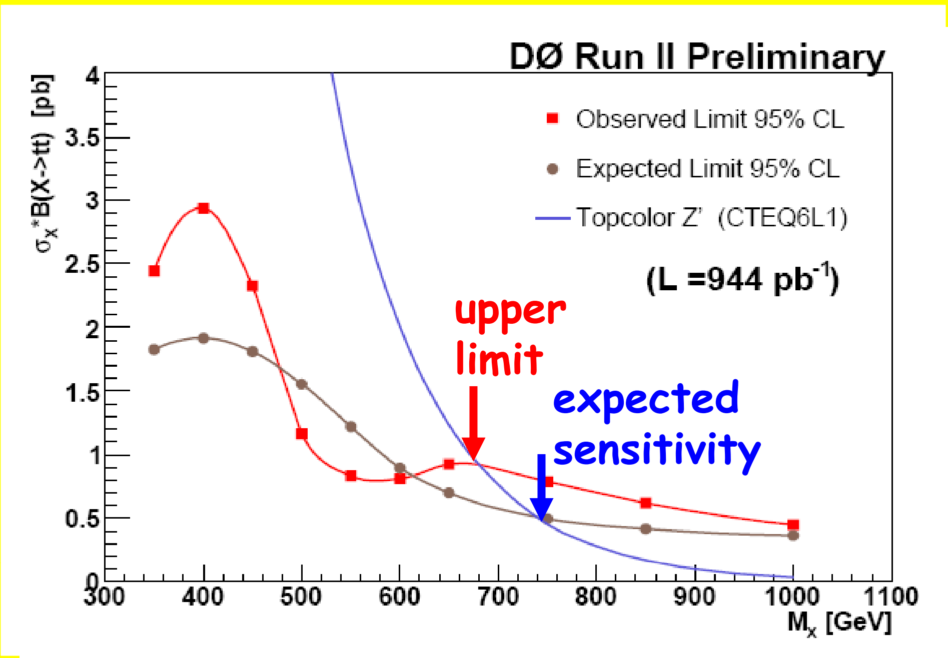
Hypothesis: $\Gamma_{Z'} = 0.012\ M_{Z'}$ << detector resolution

Selection: at least one b-tagged jet

Observable: $M_{t\bar{t}}$ → use of $\not{E}_T$, $p_T(\ell)$ and 4 leading jets.

Binned likelihood on $t\bar{t}$ invariant mass distribution.





Bayesian approach

→ upper limits on $\sigma_{Z'} \times B(Z' \rightarrow t\bar{t})$

→ exclusion of a leptophobic Z′ with $M_{Z'} < 680\ GeV/c^2$ @ 95 % C.L.

forward-backward asymmetry

S.M. top pair production → small forward-backward charge asymmetry ≤ 5-10 % (NLO, NNLO), whereas Z′ → $t\bar{t}$ leads to higher charge asymmetries.

Observable: $A_{FB} = \dfrac{N^{\Delta y>0} - N^{\Delta y<0}}{N^{\Delta y>0} + N^{\Delta y<0}}$ y = rapidity $\Delta y = y(t) - y(\bar{t})$

Observed A_{FB} = f(acceptance, dilution)

→ selection has to be described at particle level

→ predictions are ~1 % for S.M. and ~30 % for Z′.

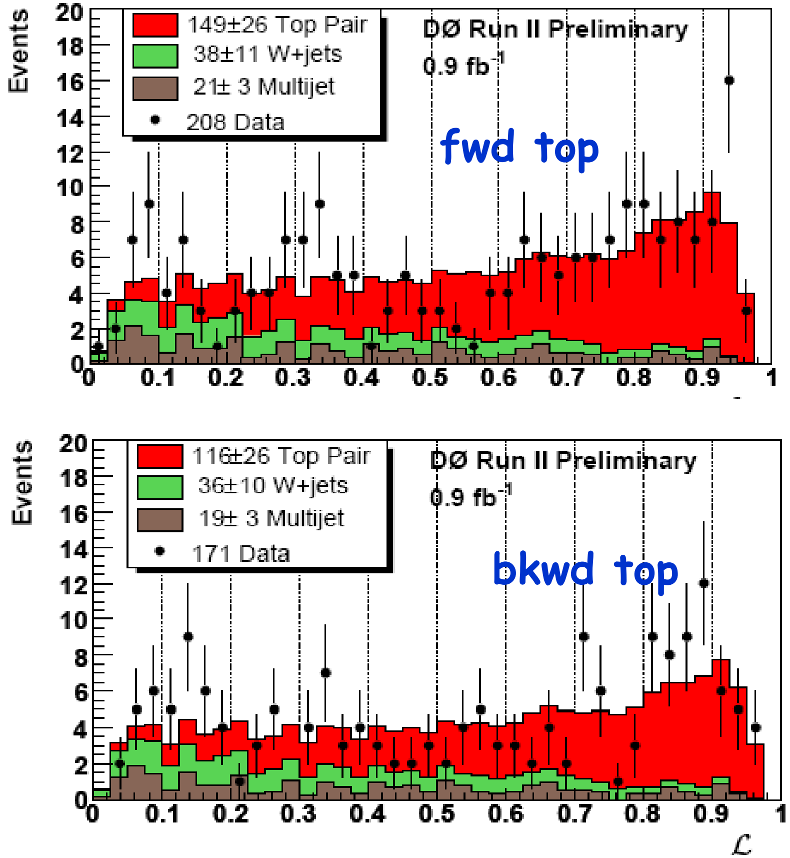
Simultaneous fit of discriminant and A_{FB}:

A_{FB} = (12 ± 8 (stat) $^{+1.1}_{-1.0}$ (syst)) %

Uncorrected for acceptance and reconstruction effects → **dilution parametrization and description of the selection at particle level provided.**

→ A_{FB} < 25.1 % @ 95 % C.L.

→ high measured A_{FB}: lots of room for production via Z′



Conclusion

Tevatron is currently the world's only source of **top quarks**.

The top quark is a unique object to search for **new physics at the highest energy scale**. If observed, it will help to disentangle the nature of new physics.

"Unfortunatly" the top looks **very standard up to now**…

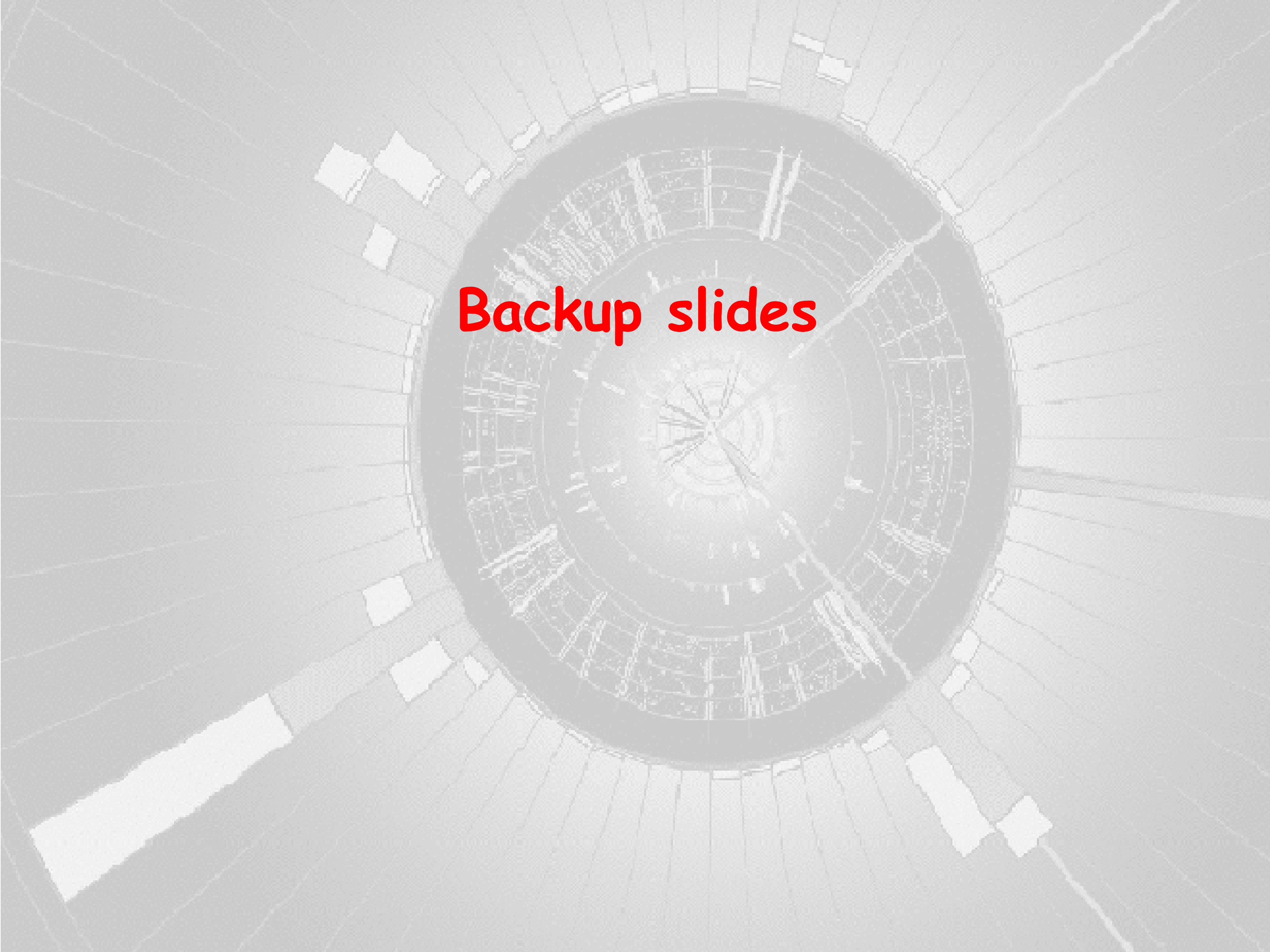
Very good performance from the Tevatron: 1 fb^{-1} analysed up to now, **3 fb^{-1} already delivered**.

Some analyses still limited by stat, but statistics also allows systematics improvements.

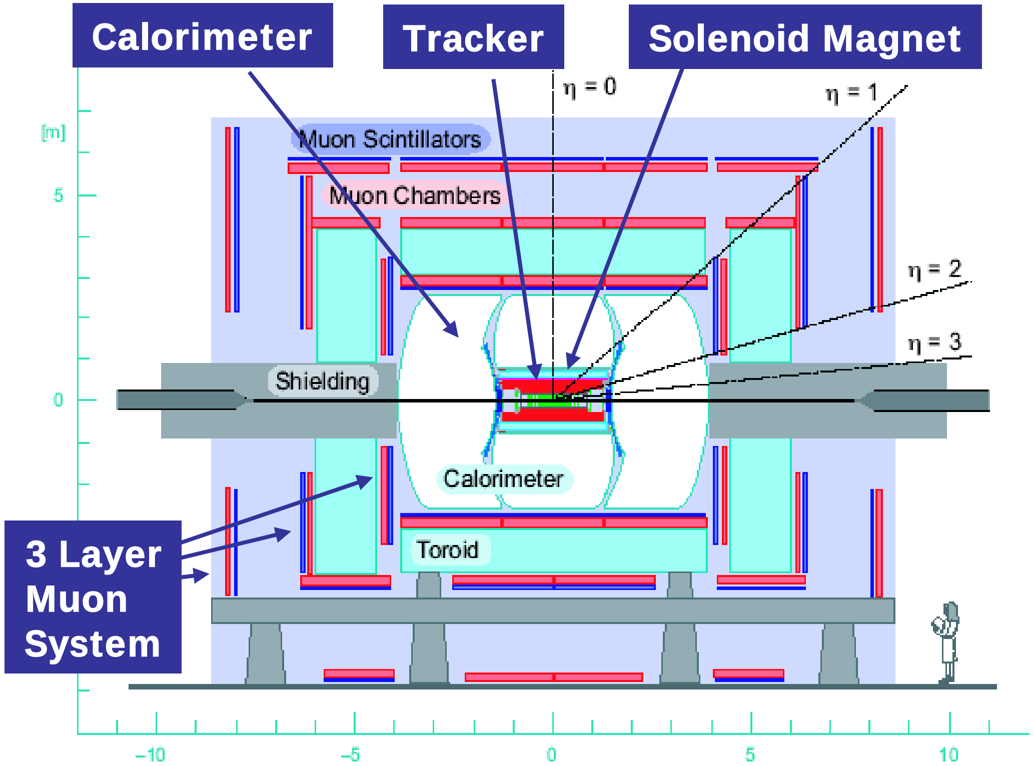
4-8 fb^{-1} expected around 2009

⇨ **lots of interesting results from Tevatron to come.**

Backup slides



The DØ detector



top studies need :

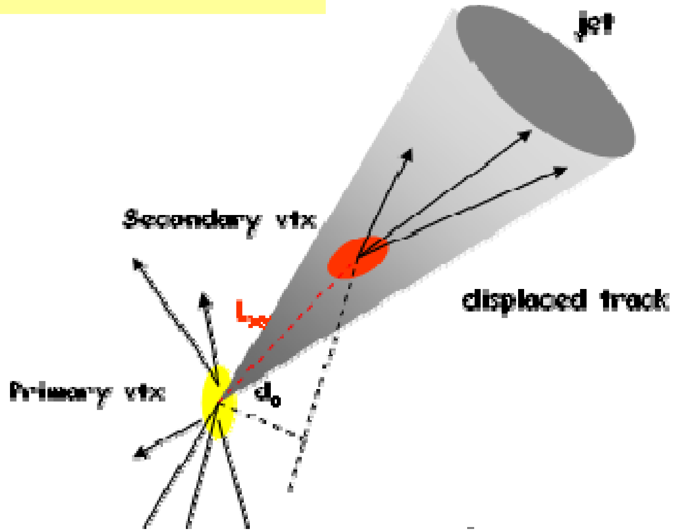
- electrons, muons
- missing transverse energy
- jets
- b-jets identification

Muon : excellent coverage |η|<2.0 + toroïdal magnet

Tracking system : 2 T solenoïdal B + 4 layers Si-strips + 8 layers Fiber tracker. Coverage |η|<3.0.

Calorimeter : liquid Ar with U/Cu absorber. Small segmentation $\Delta\phi \times \Delta\eta$ + good hermiticity. Coverage |η|<4.2

b identification in DØ



- Based on an NN algorithm with 7 input variables:

  - secondary vertex,

  - number of tracks with high impact parameter,

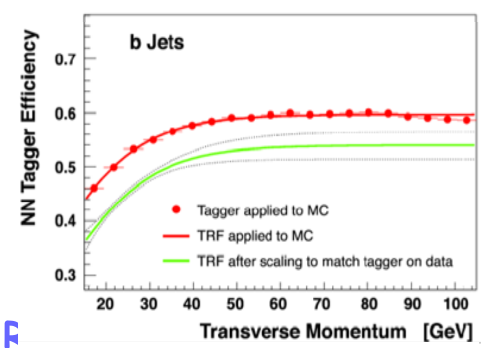
  - proba to come from primary vertex.

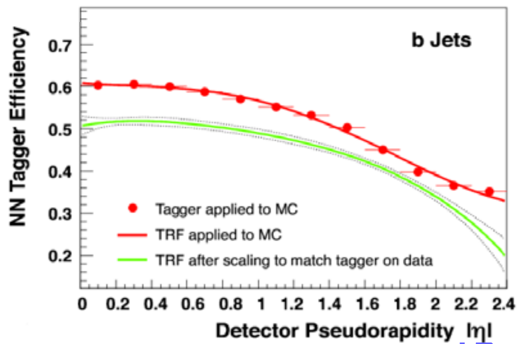
- Some working points used in top physics:

efficiency of b identification	47.6 %	53.7 %	60.8 %
proportion of misidentified light jets	0.55 %	0.96 %	2 %

- In Monte-Carlo simulation:

  parametrization of NN performances as $f(P_T) \times P(\eta)$ estimated with data and applied to MC → better data/MC agreement.





discriminant likelihood ratio

- Neyman-Pearson optimal test of hypothesis Signal against hypothesis Background for an event $\vec{x}$:

$$\ell(\vec{x}, S, B) = \frac{P(\vec{x}|S)}{P(\vec{x}|B)} = \frac{P_S(\vec{x})}{P_B(\vec{x})}$$

→ more convenient (because C[0,1]):

$$\ell'(\vec{x}, S, B) = \frac{\ell(\vec{x},S,B)}{\ell(\vec{x},S,B)+1} = \frac{P_S(\vec{x})}{P_S(\vec{x}) + P_B(\vec{x})}$$

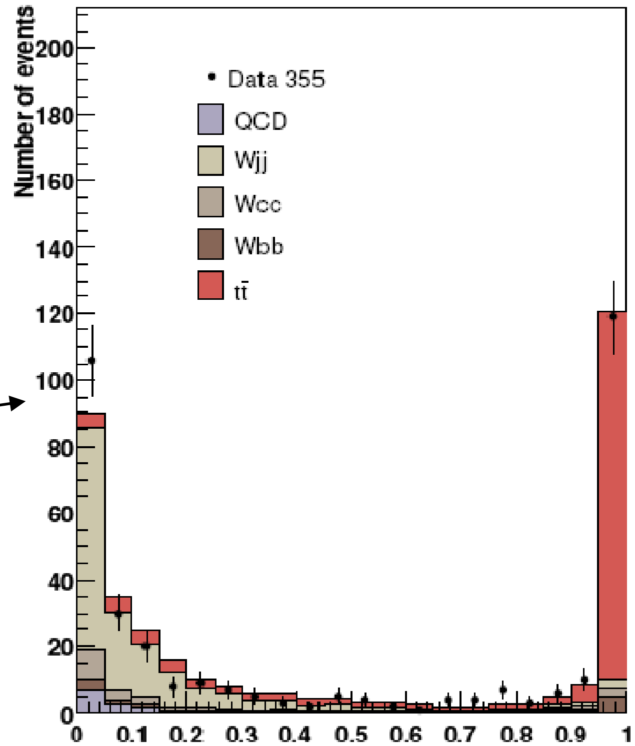
→ our discriminant variable $D_S(\vec{x})$ = Bayesian probability of S given $\vec{x}$:

$$D_S(\vec{x}) = P(S/\vec{x}) = \ell'(\vec{x}, S, B)$$

Example of $D_S(\vec{x})$ used in the μ+jets channel in the W helicity measurement.

Variables used for P_S and P_B:

Centrality, Sphericity, H_T, K'_{Tmin}, NN batgging variable.



Precision on R = Br(t→bW)