# Top Quark Mass and Properties at DØ

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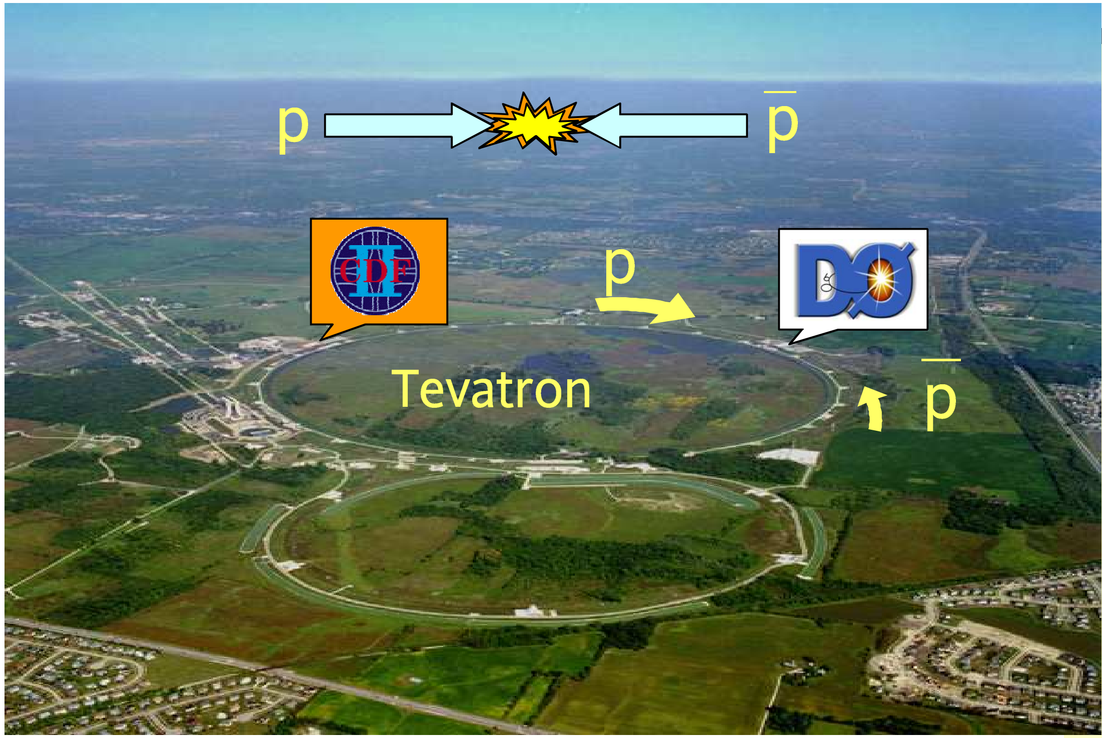
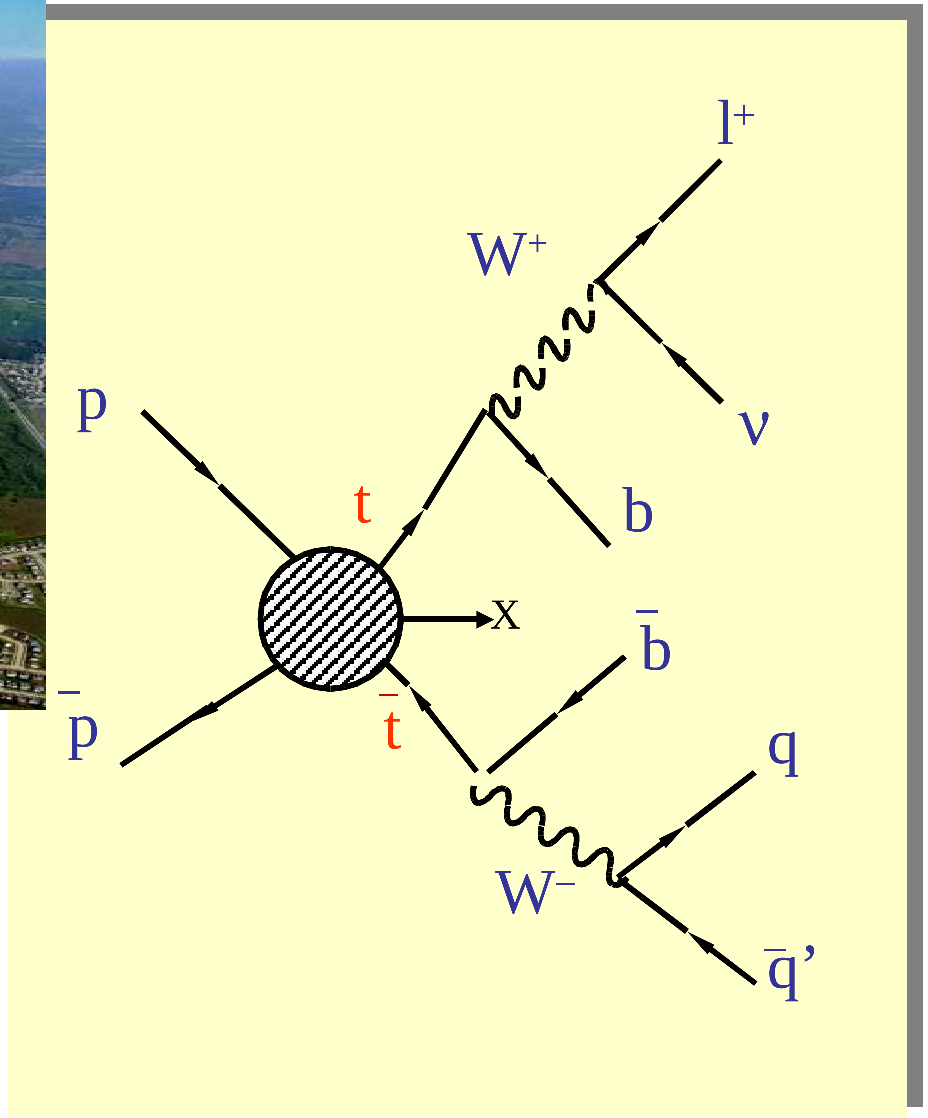
- Introduction
- Optimized method to extract top properties in the lepton + jets channel
- New Run 1 Top Mass Measurement
- Outlook for Run 2
- Summary

EPS'03 Aachen
Tests of the Standard Model

bmb+f
Großgeräte der physikalischen Grundlagenforschung

# Introduction



# Introduction

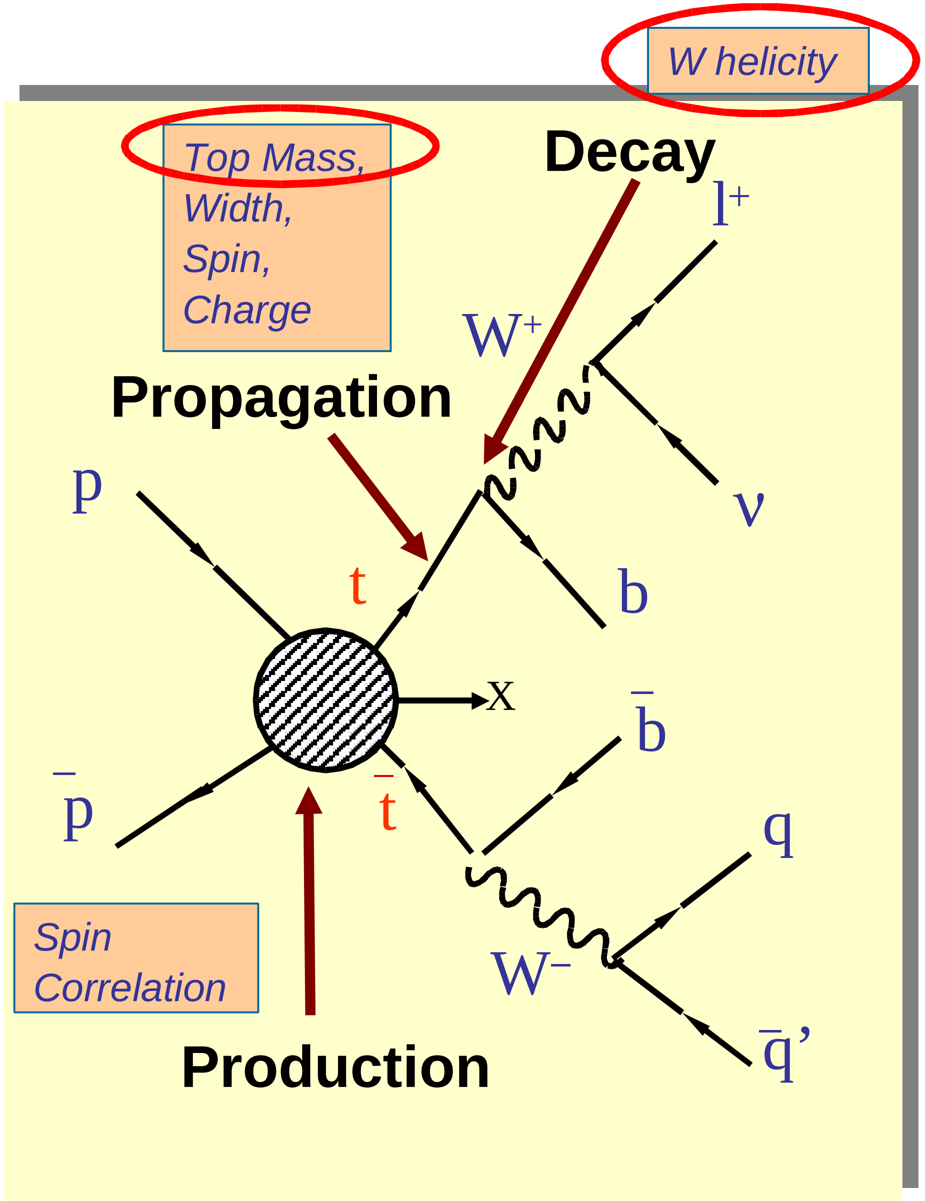
**Top is heavy !**

- ~ mass of a gold atom
- ~ scale of EWSB
- **more precise measurement** of the top mass important since it enters the **electroweak fits** for the Higgs Boson mass

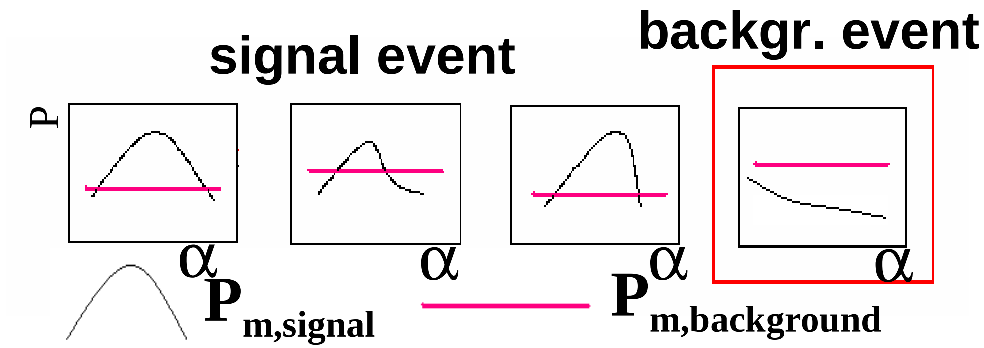
**Top is free !**

- decays before it hadronizes
- spin-information survives
- Spin correlations, W helicity

**Alternative (more sensitive) Method to extract top parameters in Run 1 data!**



# Method used now: Extended Maximum Likelihood




- unknown quantity $\alpha$
- N events with reconstructed objects (leptons, jets,...) and kinematics $x_i$
- best estimate by maximizing the **Likelihoodfunction**:

L(α [redacted]

$$L(\alpha;x_1\ldots x_N)=e^{-N\int P_m(\alpha,x)dx}\prod_{i=1}^{N}P_m(\alpha,x_i)$$

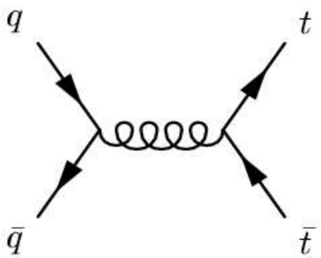
$P_m(\alpha,x_i)$: probability to measure an event with kinematics $x_i$

- include **background**: $P_m(\alpha;x_i)=c_1 P_{m,t\bar{t}}(\alpha,x_i)+c_2 P_{m,bkg}(x_i)$
- minimize -log-Likelihood to measure $\alpha$ and fix the signal/bkg.-fractions !
- The challenge: **Obtain the $P_m(\alpha,x_i)$ !**

# Measured Probabilities

- Obtain probabilities by **folding differential X-section with Object resolutions**:

$$P_m(\alpha,x) = \underbrace{Acc(x)}_{\substack{\text{Acceptance}\\\text{(selection,}\\\text{trigger,...)}}} \times \frac{1}{\sigma}\int \underbrace{d^n\sigma(y;\alpha)}_{\substack{\text{LO-Matrix element}\\\text{x phasespace}}}\, dq_1\, dq_2\, \underbrace{f(q_1)\; f(q_2)}_{\text{PDF's}}\; \underbrace{W(x,y)}_{\substack{\text{Transfer Functions}\\\text{(Probability to measure x}\\\text{when y was produced)}}}$$



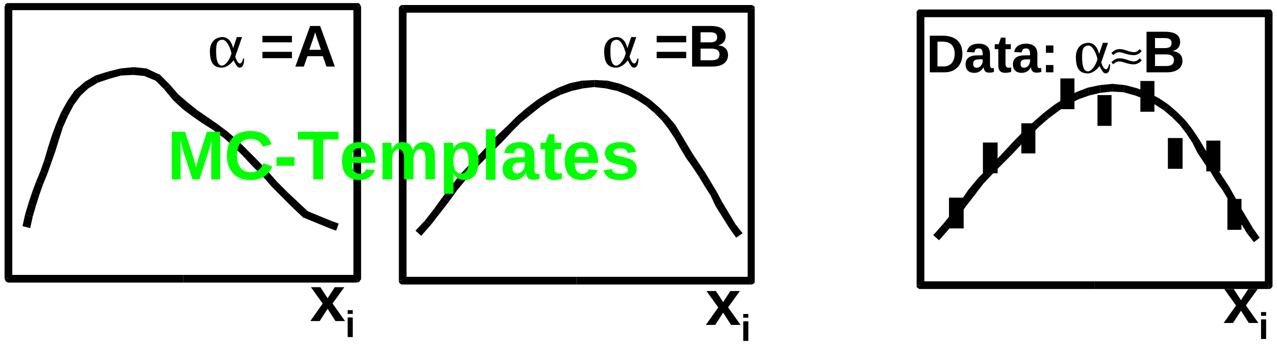

Signal
(No ISR or
FSR)

Background (VECBOS-ME)
W+ 4 Jets
(also found adequate for QCD bkg.)

$\longrightarrow$ need to constrain to exactly 4 Jets

- take **permutations** (jet-parton-assignment) and reconstruction **ambiguities** into account by **summing over different possibilities**
- **Transfer functions** are set to $\delta$-functions for well-measured quantities (jet-angles, electron momentum)
- for jet-energies: $W_{jets}(E_{part},E_{jet})$ relating parton- and jet-energies, obtained as parametrization for b- and non-b-Jets from MC

# Advantages over Template Methods




**E.g.: DØ published top mass measurement in lepton + jets channel (*PRD 58 (1998), 052001*)**

## Template- Method:

1. All the events are presented to the **<u>same template</u>**. Average probability distribution.
2. The template corresponds to a probability distribution for the entire sample, using **<u>selected variables</u>** calculated from MC simulations.
3. The **<u>features of individual events are averaged</u>** over the variables not considered in the template.

## EML- Method:

1. Each event has its **<u>own probability distribution.</u>** Events that constrain the unknown quantity better get larger weight.
2. The probability can in principle depend on **<u>all measured quantities</u>**.
3. Each event contributes with its own specific features to the probability, which **<u>depends on how well it is measured</u>**.

# *Application: Top-Mass in Lepton+Jets channel*

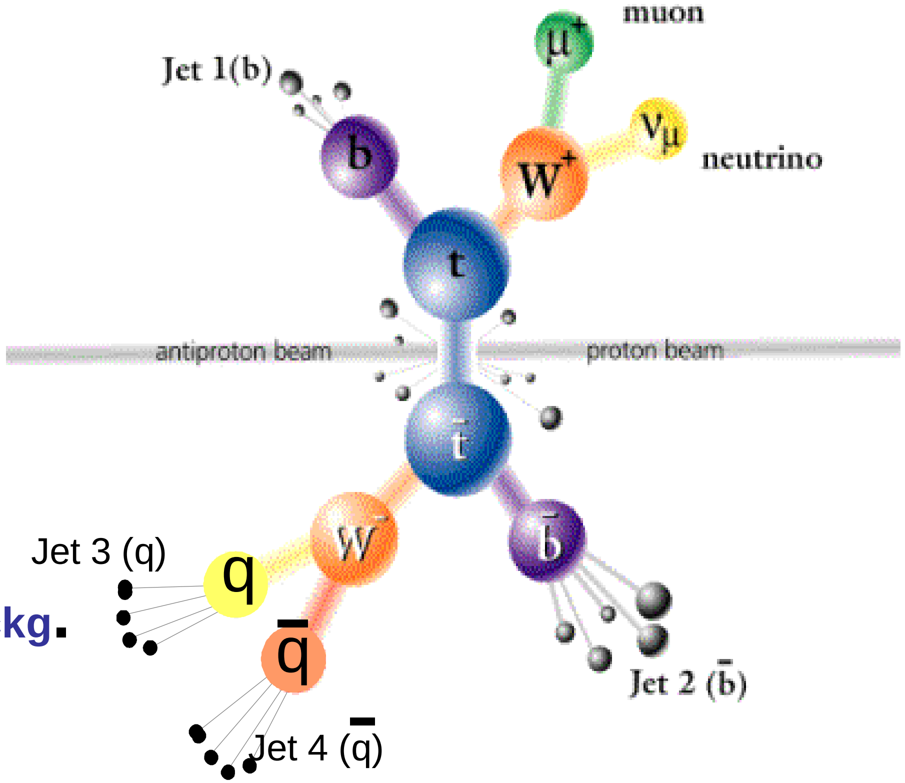
***Signature : 1 charged lepton, 4 jets, Missing energy***

**DØ Statistics Run I : 125 pb$^{-1}$**

**Standard Selections:**

- **Lepton: $E_t$>20 GeV, $|\eta^e|$<2, $|\eta^\mu|$<1.7**
- **Jets: ≥4, $E_T$>15 GeV, $|\eta|$<2**
- **Missing $E_T$ > 20 GeV**
- **"$E_T^W$"> 60 GeV ; $|\eta_W|$<2**

**91 events**




***Ref. PRD 58 (1998), 052001:***

**After kinematic cut (77 events): ~29 signal + ~48 backg.**

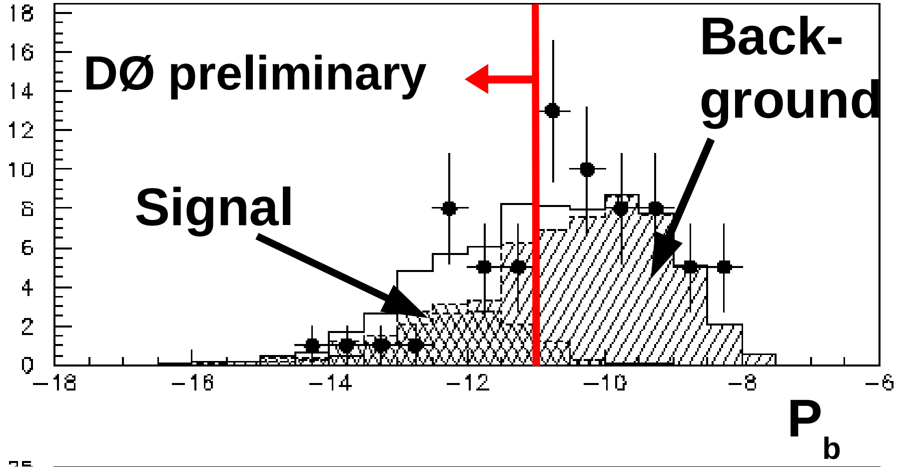
**(80% *W+jets* and 20% QCD)**

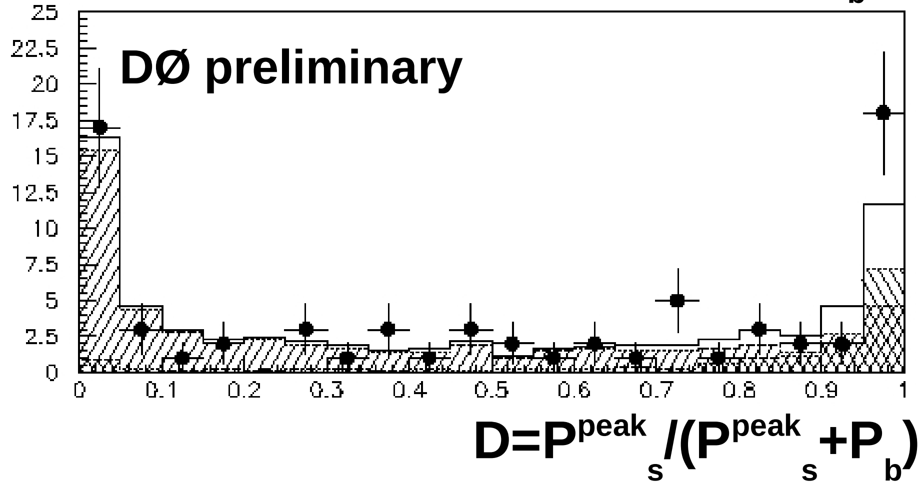
**Specific cuts for this analysis:**

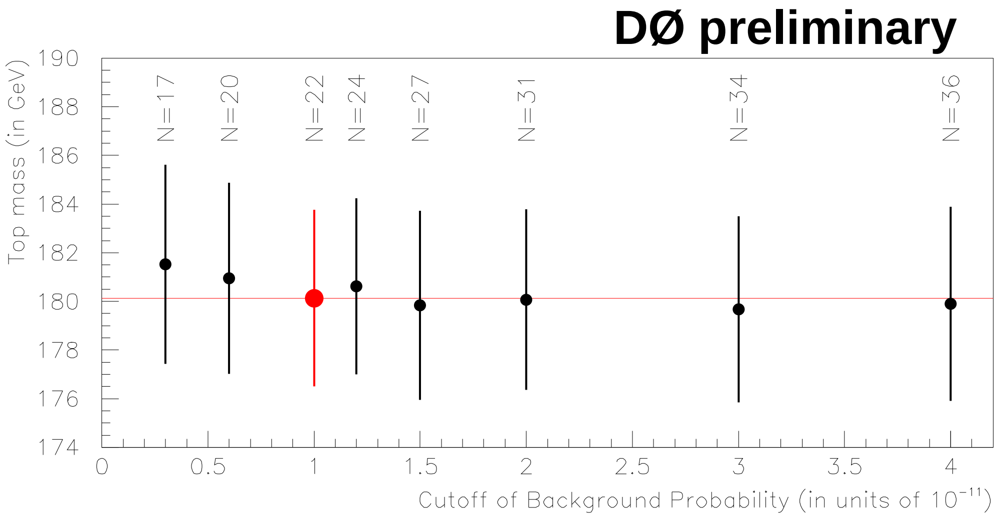
- **4 Jets only : 71 events**
- **Background Prob. : <u>22 events</u>**

# Background-Probability

- MC-Studies indicate systematic shift in $M_t$ dependent on background contribution
- cut on background probability density (differential X-section)
- no cut on discriminant from PRD, would be mass-dependent



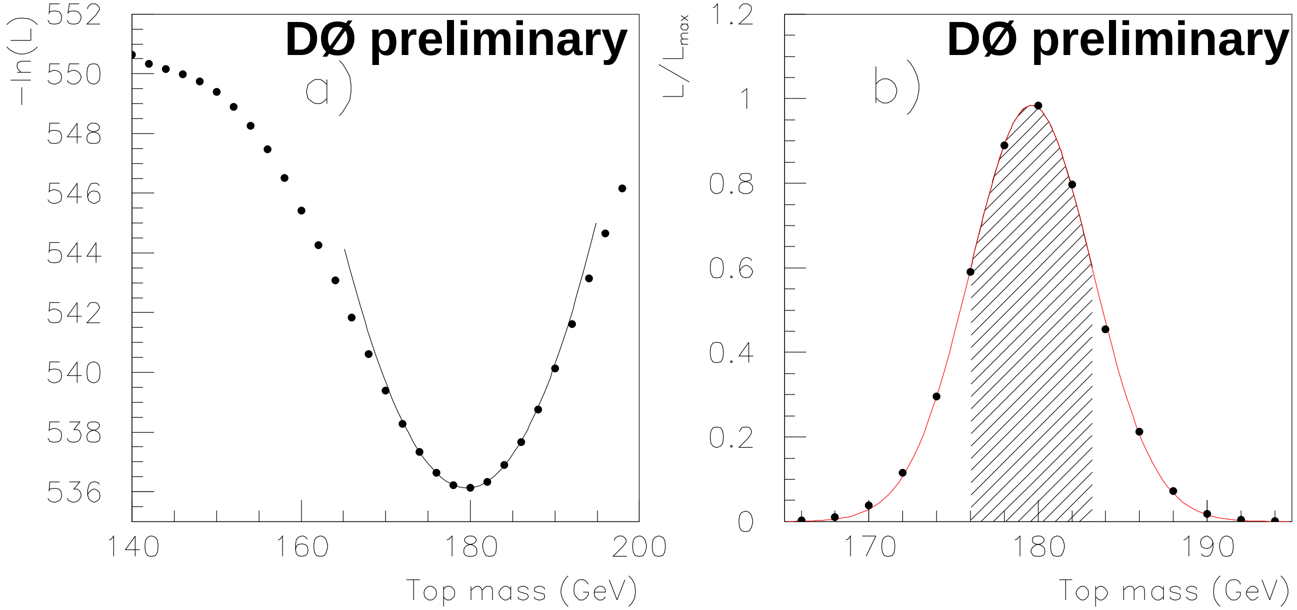




- cutoff does not change ttbar-content
- weak influence on measured $M_t$

# Result

$M_t = 180.1 \pm 3.6_{stat} \pm 4.0_{sys}$ GeV
preliminary

including +0.5 GeV bias correction obtained from MC studies



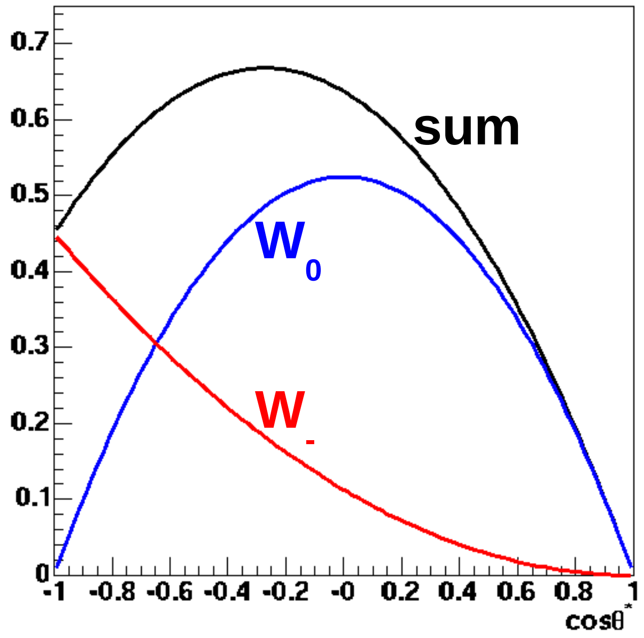

Result compatible with previous measurement in the lepton+jets channel at about the 1.7 sigma level !

| | |
|---|---|
| ttbar model | 1.5 GeV |
| W+jets model | 1.0 GeV |
| Noise and multiple i.a. | 1.3 GeV |
| Jet energy scale (JES) | 3.3 GeV |
| PDF's | 0.2 GeV |
| Acceptance correction | 0.5 GeV |

Error estimated by rescaling jet energies by the JES uncertainty and taking the maximum difference.

# Outlook

- **W-helicity:** W's as decay-products should have helicities -1 or 0 due to V-A structure of Wtb-Vertex
  - Standard Model predicts 70% longitudinal polarization
    - measurement using matrix-element technique in internal collaboration review
    - expect large improvement in Run 2

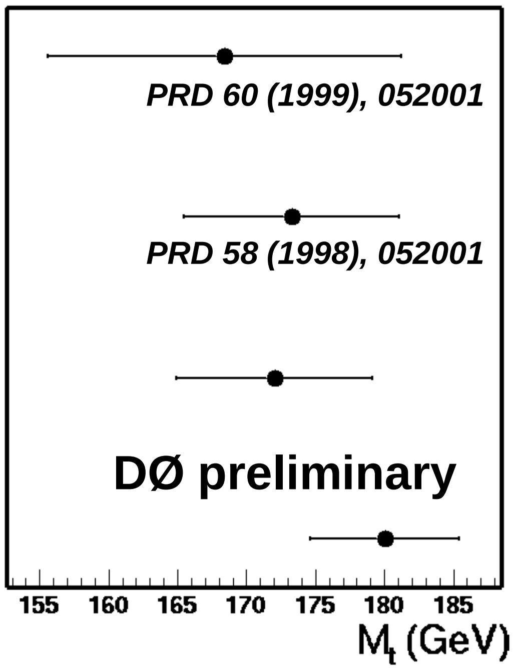



- **Spin-correlations:** should be observable to up to $4\sigma$ level (b-tagging, increased acceptance)
  - Run 1 limit from DØ: Phys. Rev. Lett. {85} 256 (2000)

- **Run 2 mass measurement** underway, expect 2.7 GeV total uncertainty with $2fb^{-1}$

- Top Width, Spin, CP, $\gamma$/Z-couplings, FCNC, Rare Decays,...

# Summary




Dilepton
168.4 ± 12.8 GeV

Lepton+ Jets
173.3 ± 7.8 GeV

combined
172.1 ± 7.1 GeV

new prelim. result
180.1 ± 5.4 GeV

- presented a new preliminary top mass measurement in the lepton+jets channel using Run 1 data:

$$M_t = 180.1 \pm 3.6_{stat} \pm 4.0_{sys} \text{ GeV}$$

preliminary

- statistical error much reduced due to an optimized matrix element technique
- equivalent to 2.4 times more events
- measurement of W helicity with Run1 data using the same technique in internal collaboration review, expect preliminary result by LP'03

**Future:** Run 2 mass measurement underway (to ~2.7 GeV with 2 inv. fb)
W helicity, spin-correlations
rare decays, FCNC, couplings,...
single-top production

# Compatibility of Results

Backup

$M_t$=180.1 ± 3.6$_{stat}$ GeV ⟷ $M_t$=173.3 ± 5.6$_{stat}$ GeV

(*PRD 58 (1998), 052001*)

**Simple model:** from cut efficiencies expect to have 12 of 24 ttbar events in PRD analysis to be present in new analysis as well !
Assume all events are drawn from the same distribution:

$$M = \frac{(x_1 + ... + x_{12}) + (x_{13} + ... + x_{24})}{24}$$

Events 1 through 12 constant, 13 through 24 drawn from distribution with rms $\sigma$.

$$\sigma_M^2 = \frac{\sigma_{x13}^2 + ... + \sigma_{x24}^2}{24^2} = \frac{12\sigma^2}{24^2} = \left(\frac{12}{24}\right)^2 \frac{\sigma^2}{12} \qquad \sigma_M = \frac{1}{2}\frac{\sigma}{\sqrt{12}} = \frac{\sigma_2}{2}$$

$\sigma = \sqrt{24}$ x 5.6 GeV = 27.5 GeV $\rightarrow$ $\sigma_2$= 7.9 GeV $\rightarrow$ $\sigma_M$=4 GeV

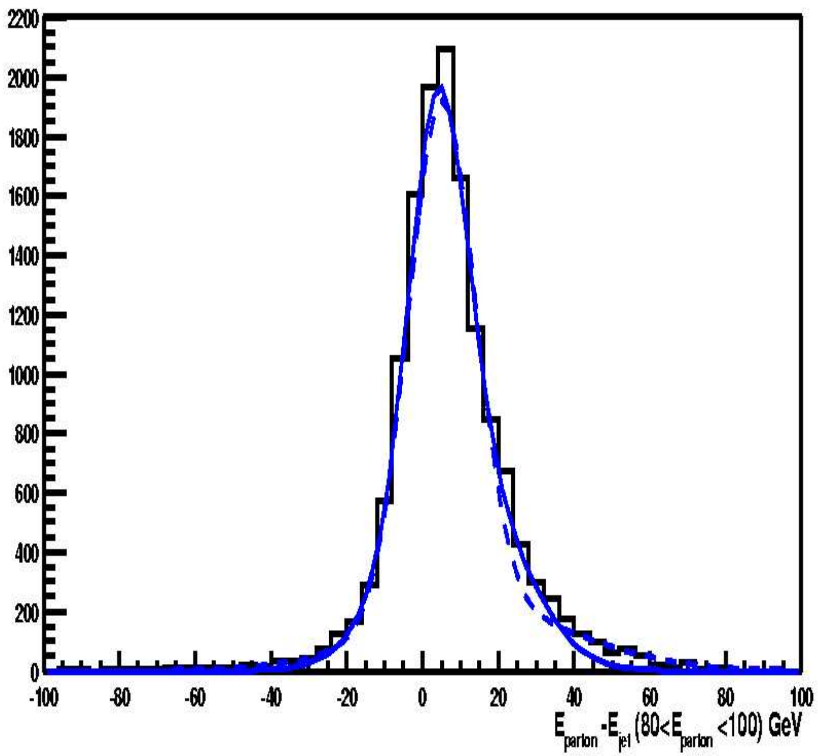
**(180.1 – 173.3)/4 = 1.7 sigma statistical deviation !**

**Compatibility also confirmed using different distributions for all events and more refined comparison technique !**

# Transferfunction for e+jets

Backup

$$W(x,y)=\delta^3(p_e^y-p_e^x)\prod_{j=1}^{4}W_{jet}(E_j^y,E_j^x)\prod_{i=1}^{4}\delta^2(\Omega_i^y-\Omega_i^x)$$




| | |
|---|---|
| $E^y$ | energy of the produced quarks |
| $E^x$ | measured and corrected jet energy |
| $p^y_e$ | produced electron momenta |
| $p^x_e$ | measured electron momenta |
| $\Omega^y{}_j$, $\Omega^x{}_j$ | produced and measured jet angles |

**parametrization from MC**
**different for b-and non b-Jets**

$$W_{jet}(x,y)=F(\delta_E)=\frac{1}{\sqrt{2\pi}(p_1+p_2p_5)}[\exp\frac{-(\delta_E-p_1)^2}{2p_2^2}+p_3\exp\frac{-(\delta_E-p_4)^2}{2p_5^2}$$

# Probabilities

Backup

$$P_{t\bar{t}} = \frac{1}{12\sigma_{tot}} \int d\rho_1\, dm_1^2\, dM_1^2\, dm_2^2\, dM_2^2 \sum_{perm.,\nu} |M|^2 \frac{f(q_1)\, f(q_2)}{|q_1| \cdot |q_2|} \varphi_6 W_{jet}(x, y)$$

$$P_{bkg}(x) = \frac{1}{\sigma_{tot}^{bkg}} \left[ \frac{1}{N} \sum_{i=1}^{N} P_{W+\,jet}\left(\Omega_1, \ldots, \Omega_4, \overline{p_{lep}}, M_W, \underline{E_1^{part}, \ldots, E_4^{part}}\right) \right]_{W(E_i^{jet}, E_i^{part})}$$