Fisica del top al Tevatron

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Outline

The top quark : Production and decay

Pair produced top quarks:

- Cross section
- Precision mass measurements
- Production mechanism
- Decay mechanism
- Resonant production?

Single top production:

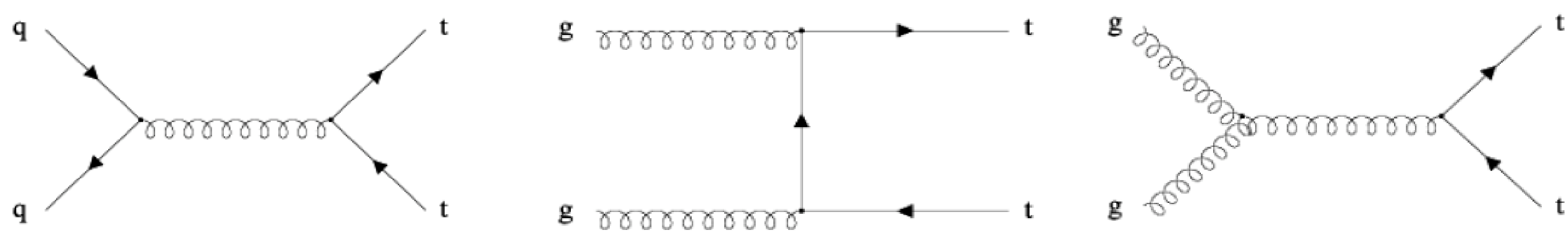
- Cross section
- Cabibbo angle

Top production

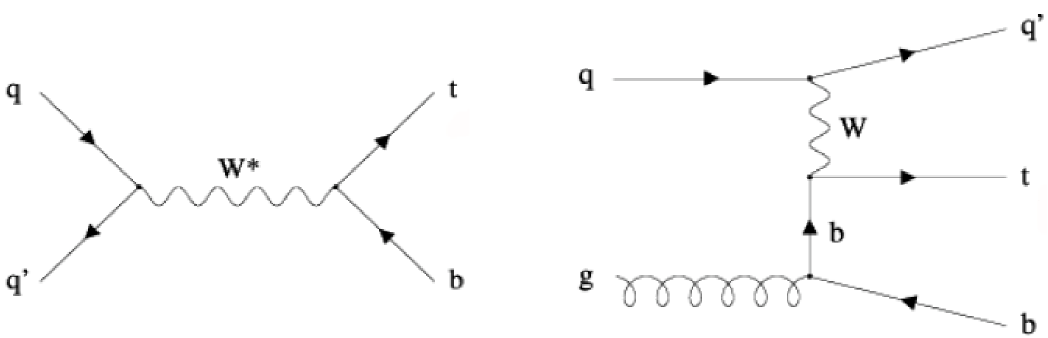
- Huge mass, short lifetime: decays before hadronizing
- Yukawa coupling ~1 → special role in EWSB?
- Probes physics at highest achievable mass scale

Pair production via strong interaction

qq~85%   gg~15%



Single production via electroweak interaction



s channel 0.9pb

t channel 2.0pb

Top pair decays

- **Lepton+Jets**

  golden channel: high statistics
  ***AND* good S/B ratio.**
  Most of the measurements are made here

- **All hadronic**

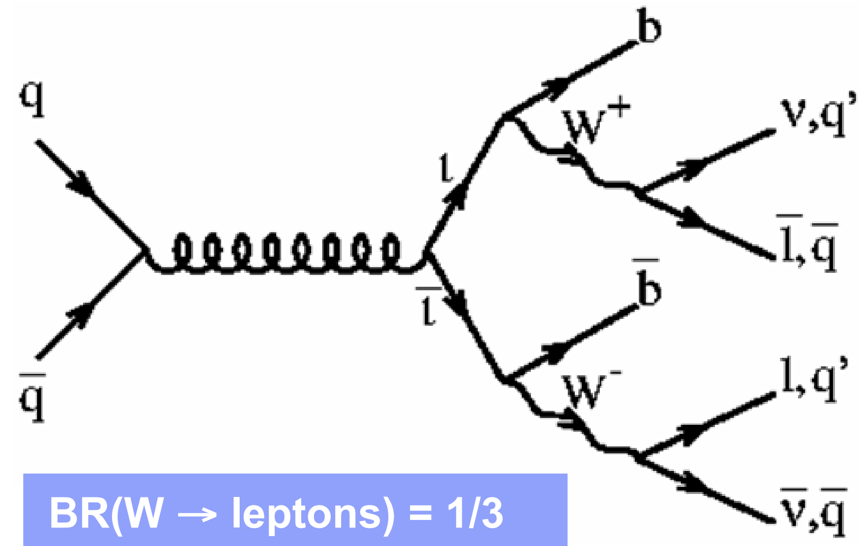
  challenging channel: highest statistics
  ***BUT* huge backgrounds**

- **Dileptons**

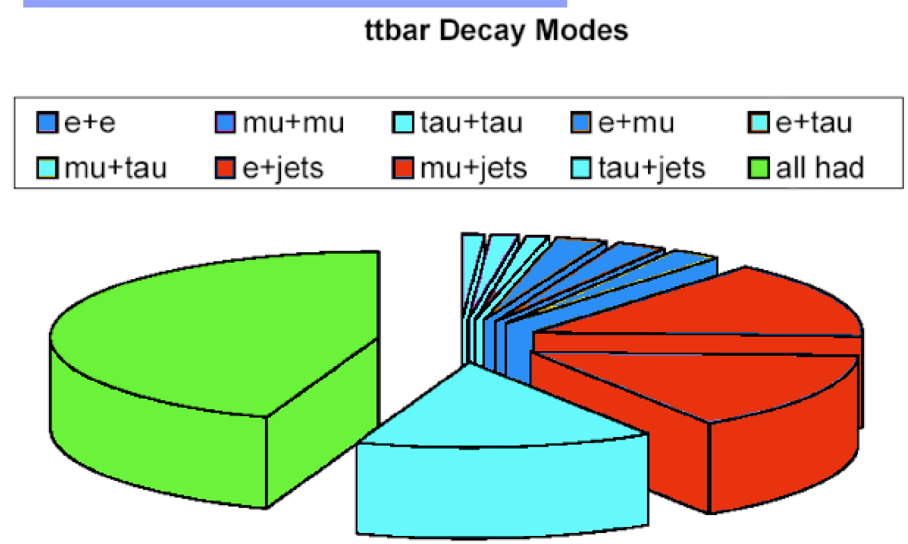
  cleanest sample - no need to b-tag
  ***BUT* lowest statistics & neutrinos**

- **MET+jets**

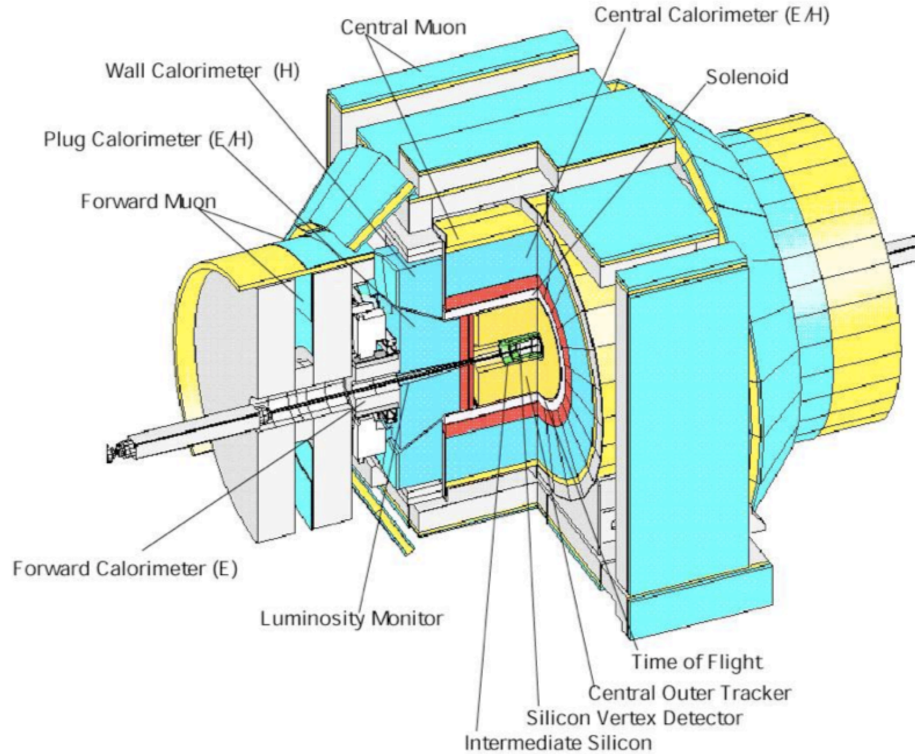
  large acceptance to taus, orthogonal to others

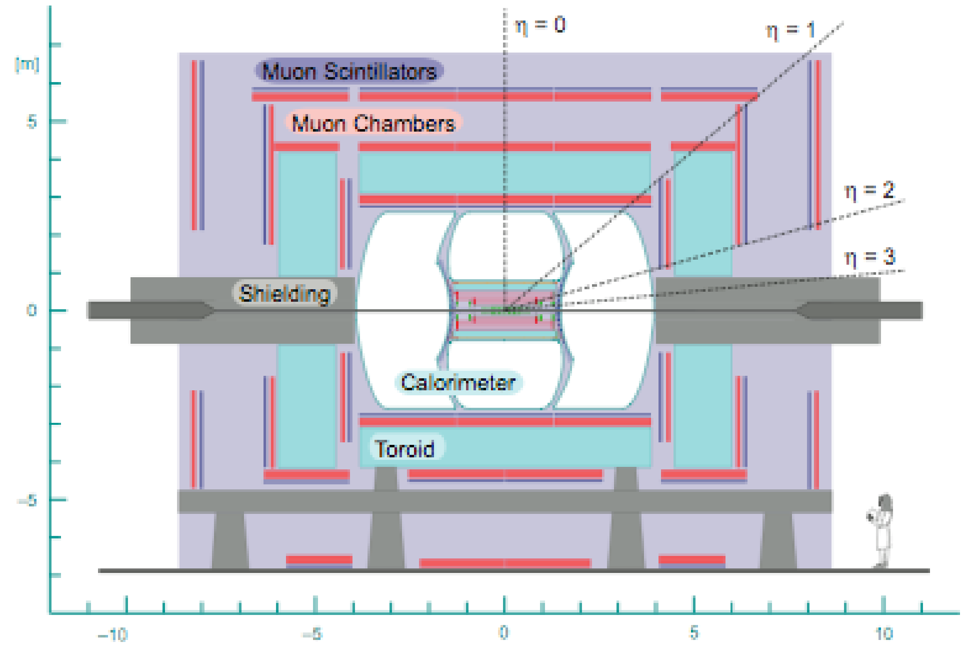


BR(W → leptons) = 1/3
BR(W → quarks) = 2/3



The detectors

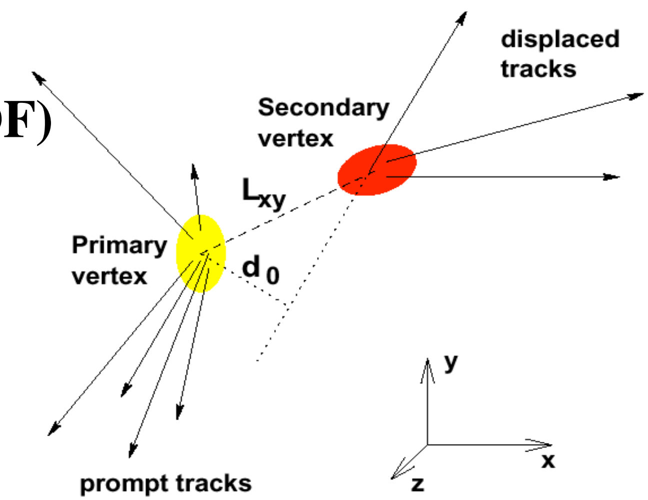




✓ **Tracking: silicon tracker - drift chamber (CDF)**
scint(D0)

✓ **Calorimeters:**
central, wall, plug
overall coverage:
|η|<3.6 CDF
|η|<4.2 D0

✓ **b-quark identification w silicon detector (SVX)**
top event b-tag eff: ~ 55%



Leptonic channels

Trigger	Lepton+jets	Dilepton
CDF	inclusive high E_t lepton	inclusive high E_t lepton
D0	inclusive high E_t lepton + $\geq$ 1 high E_t jet	specific: (e/e) (e/μ) (μ/μ)

Event sel.	Lepton+jets	Dilepton
CDF	high P_T lepton (e/μ) large ME_T 4 high-E_T jets	2 high P_T leptons + 2 jets
D0	as above	as above

Backgrounds	Lepton+jets	Dilepton
Physics	W+jets	diboson
Instrumental	QCD (jets faking leptons)	$Z/\gamma^* \rightarrow l^+l^-$

Objective: to reproduce lν jjjj / lνlν jj topology while getting rid of the large/small background

Hadronic channels

Trigger	All-hadronic	MET+jets
CDF	**≥ 4 jets & high $\sum E_T$**	**≥ 4 jets & high $\sum E_T$**
D0	**as above**	—

Event sel.	All-hadronic	MET+jets
CDF	**up to 11 topological and kinematical variables low MET significance Neural Net *OR* cut based**	**same but *high MET significance***
D0	**as above**	—

Backgrounds	All-hadronic	MET+jets
Physics	**QCD multijet**	**W+jets**
Instrumental	**W+jets (negligible)**	**QCD multijet**

Objective: to reproduce 6 jet topology where at least 1 jet is expected to come from a b quark while getting rid of the **HUGE** background

Cross section measurements

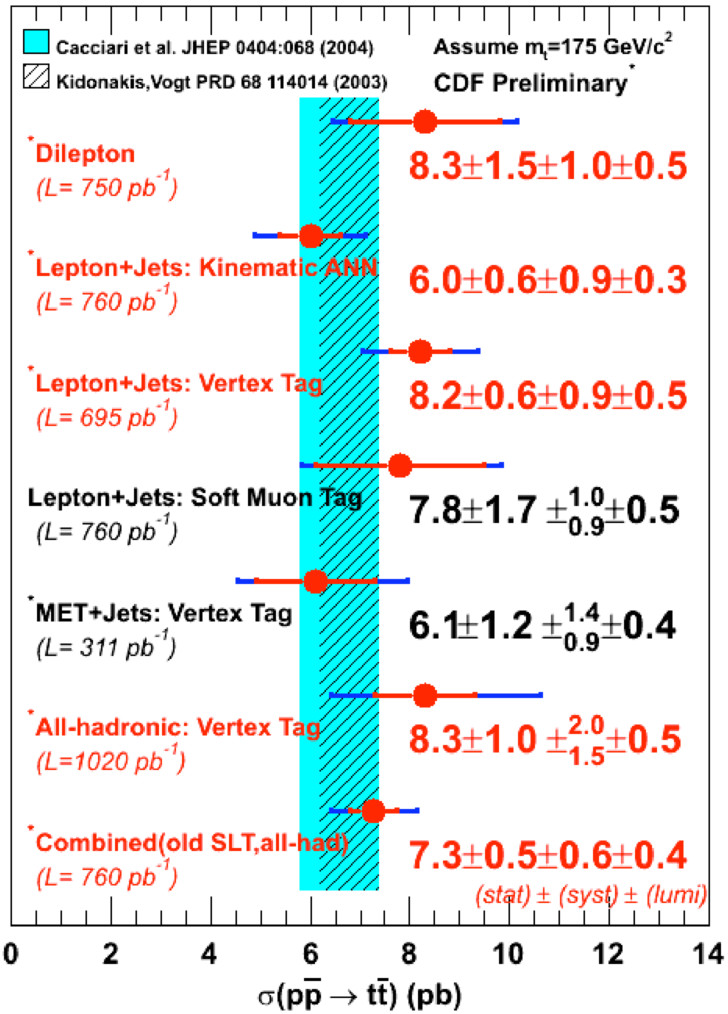
- ✓ Test QCD in high Q^2 regime
- ✓ Each channel is sensitive in a different way to new physics
- ✓ Study of sample composition (useful for measurements of other top properties)

Techniques

1) Counting experiment

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{A \times \int \mathcal{L}dt}$$

2) Kinematical/topological discrimination



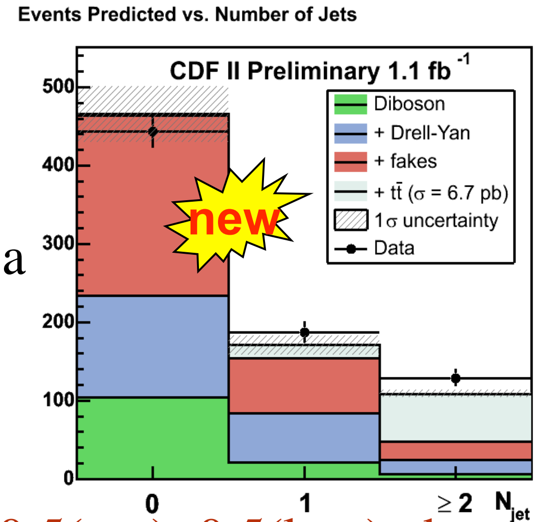
Combination gives 15% improvement wrt best meas. alone

X-sec #1: Counting exps

Dilepton

second track not req.

to be identified as a lepton->higher acceptance to top

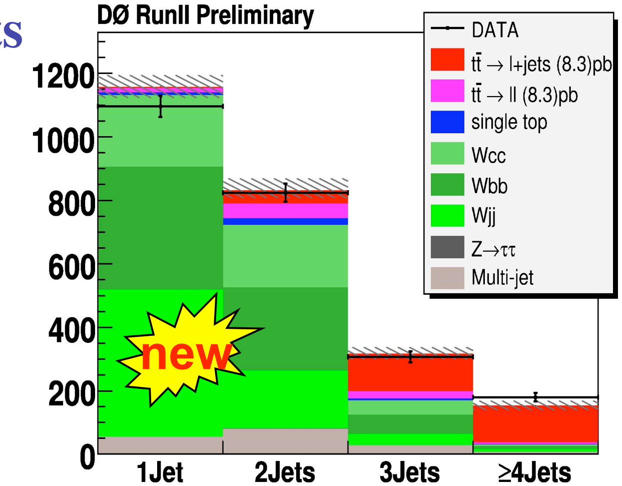


σ_{tt}= 9.0±1.3(stat)±0.5(sys)±0.5(lum) pb.

Lepton+jets

Neural net b-tagger

D0's most precise



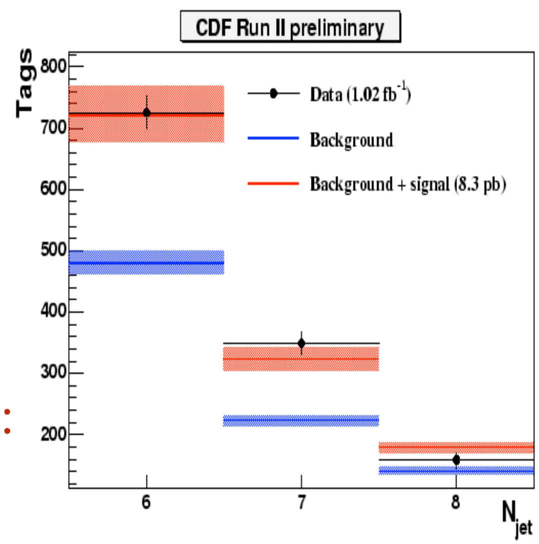
σ_{tt}= 8.3±0.6(stat.)±1.0(syst.)±0.5(lum.)pb

Alljets

NN + b-tag

S/B~1/2 high BR

high acc. 5%



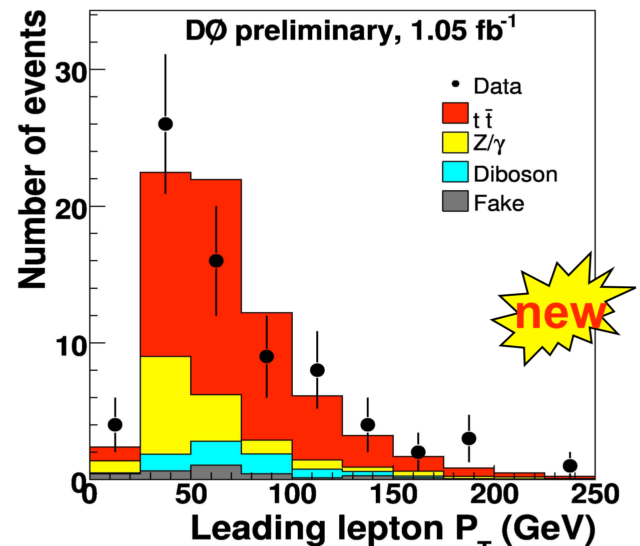
Biggest systematic:

Jet Energy Scale

σ_{tt}= 8.3±1.0(stat.)$^{+2.0}_{-1.5}$(syst.)±0.5(lum) pb

Dilepton

no need to b-tag



σ_{tt}= 6.8±1.2(stat.)±0.9(syst.)±0.4(lum.)pb

X-sec #2: Discrimination

Lepton+jets

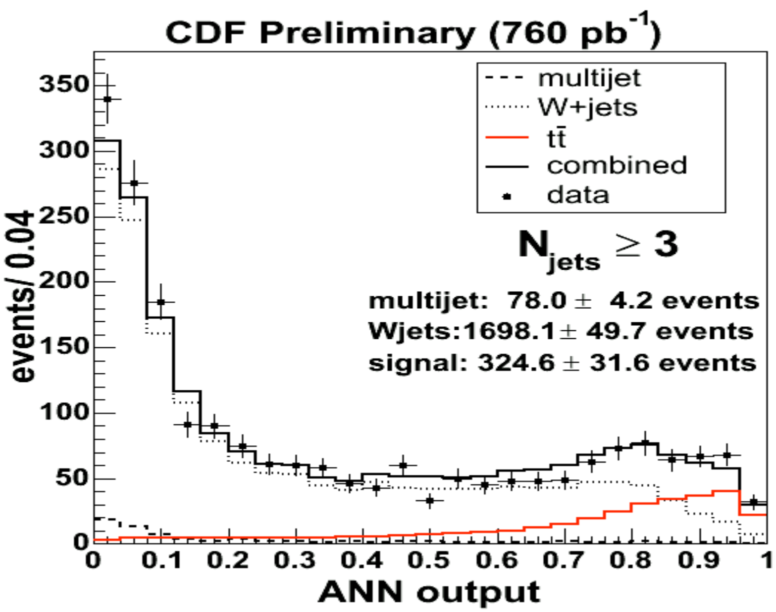
no b-tagging requirement:

larger acceptance ~ 300 tt evts

but larger background -> fit shapes

Discriminant variable: N_{output}

result with **760pb^{-1}**



σ_{tt}=6.0 ± 0.6 (stat.) ± 0.9 (syst.) pb

Lepton+jets

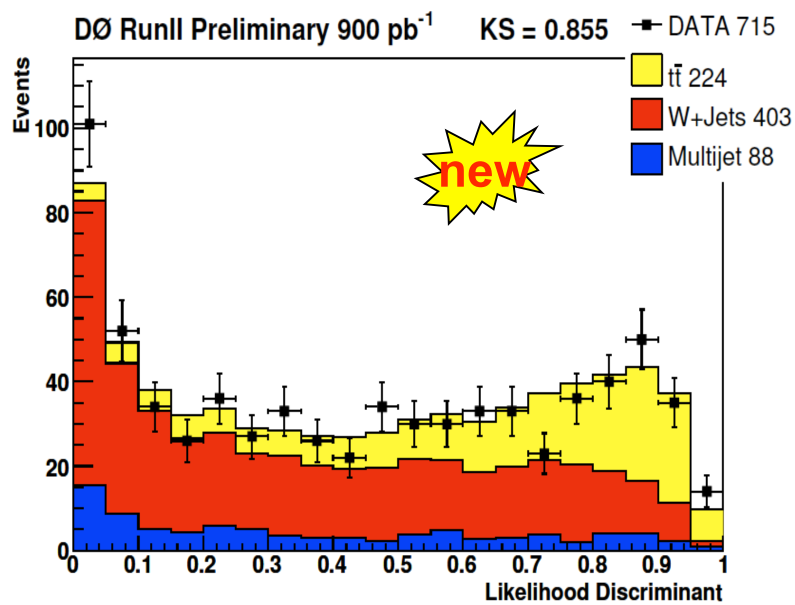
no b-tagging requirement:

larger acceptance ~ 200 tt evts

but larger background -> fit shapes

Discriminant: ad hoc function

result with **900pb^{-1}**



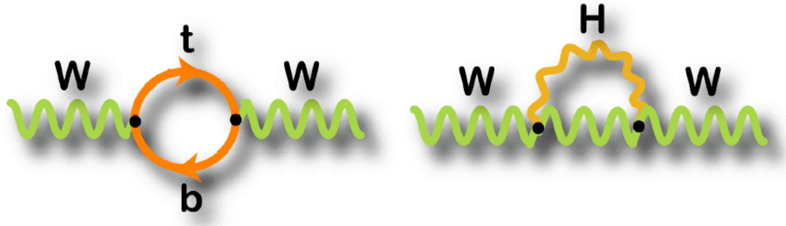
σ_{tt}=6.0 ± 0.6 (stat.) ± 0.9 (syst.) pb

Top mass

Why measure it

- Fundamental parameter in the SM
- M_{top} enter in radiative corrections:

$$\Delta M_W \propto M_{top}^2 \qquad \Delta M_W \propto \ln M_H$$

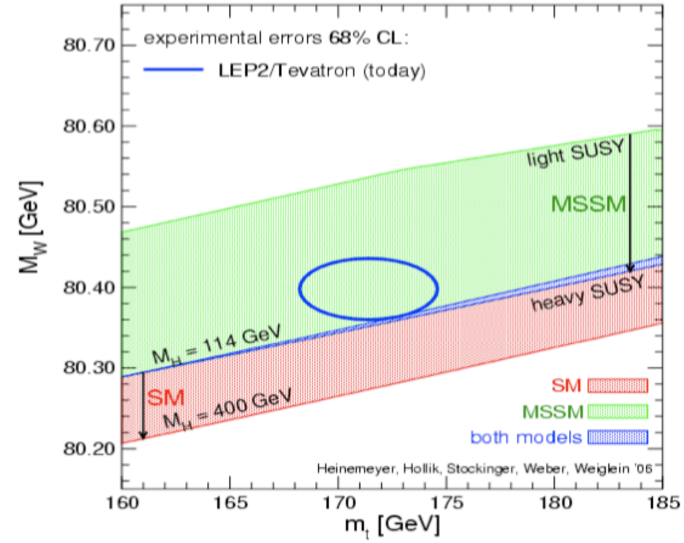


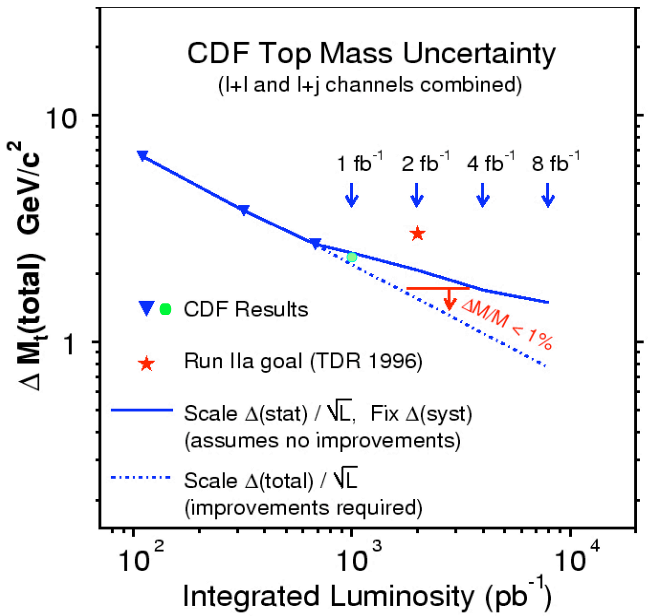
- Together with M_w it constrains M_{Higgs}

RunII design goal: 2-3 GeV O (10 fb^{-1})

RunII results : ~2GeV with just 1 fb^{-1}

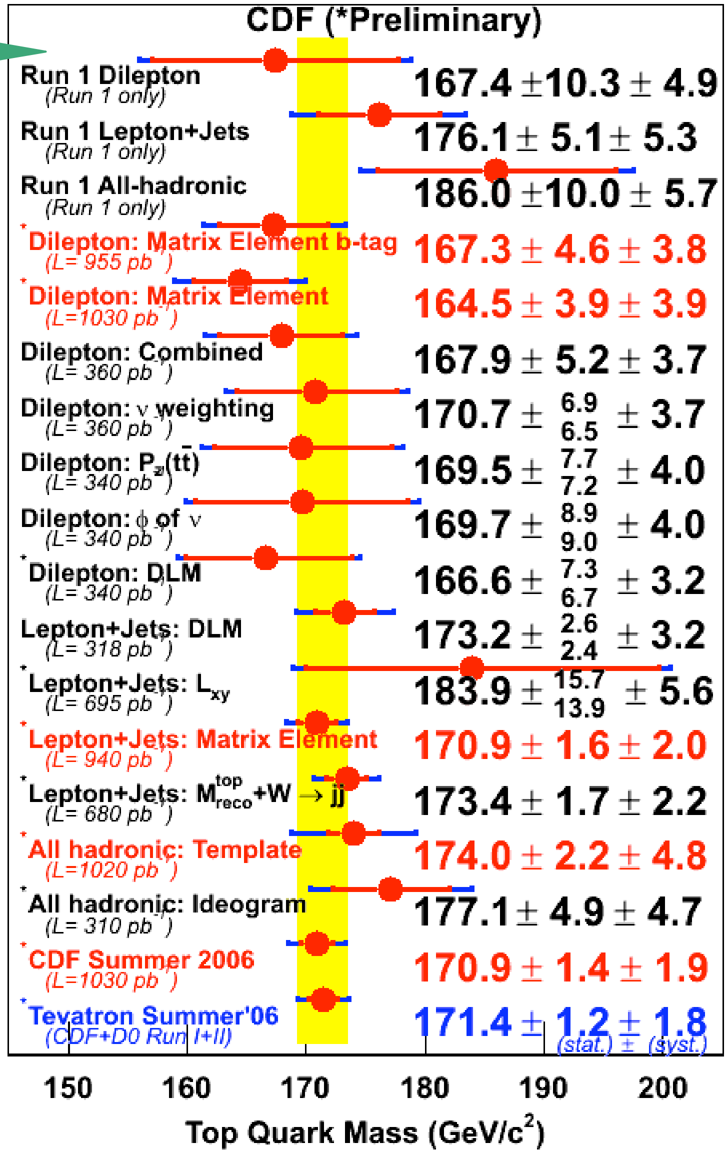
- Different challenges in different channels:
  - statistics/background
  - combinatorics/neutrinos





Lots of measurements!

large number of measurements using all detector signatures



Two different techniques:

1) **Matrix Element**
2) **Template method**

Most precise measurements constrain in situ the biggest source of systematics: the **Jet Energy Scale (JES)**

Previous (Summer 2006) combination:

$$m_{top}=171.4 \pm 1.2 \pm 1.8 \text{ GeV}/c^2$$

Mass extraction techniques

Matrix Element - Extract per-event probability from the knowledge of event dynamics for S and B - need for transfer functions from recontructed objects to physics objects.

$$P_{t\bar{t}}(M_{top}, JES) = \frac{1}{N}\sum_{comb}\int d\sigma_{t\bar{t}}(y, M_{top})\, dq_1 dq_2 f(q_1) f(q_2) W(x, y, JES)$$

M_{top} information through event dynamics

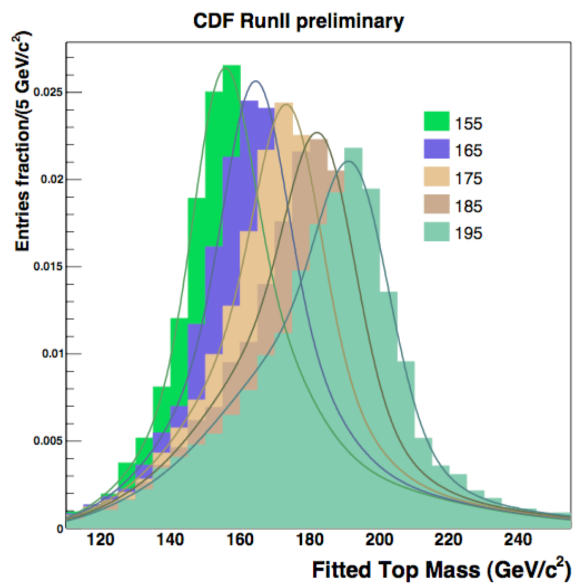
Tranfer functions: from jet (***y***) to parton (***x***) ***JES*** dependence

- Extraction of max. infos
- Extremely CPU-intensive

Template Method - Choose a varable which is strongly correlated with the one we want to measure. Use its distribution as a "model" for S & B. Compare data dist. to simulated S & B trough a likelihood technique.

Same procedure used for M_{top} and JES

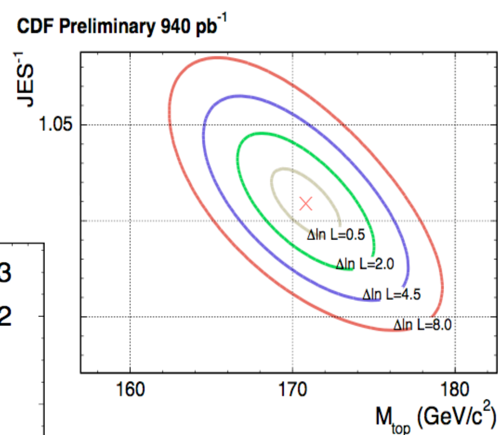
- Traditional technique - fast and robust
- Limited number of infos

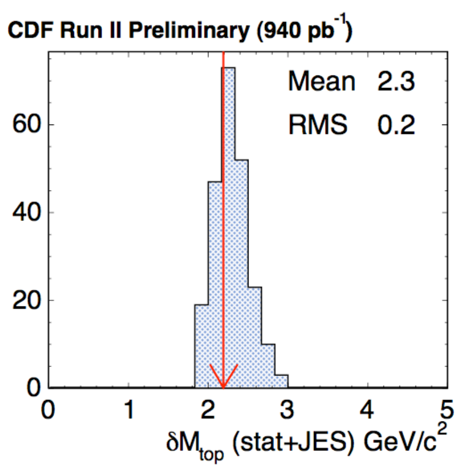


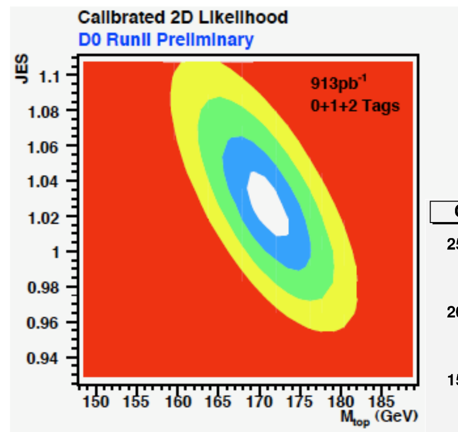
Mass with Matrix Element

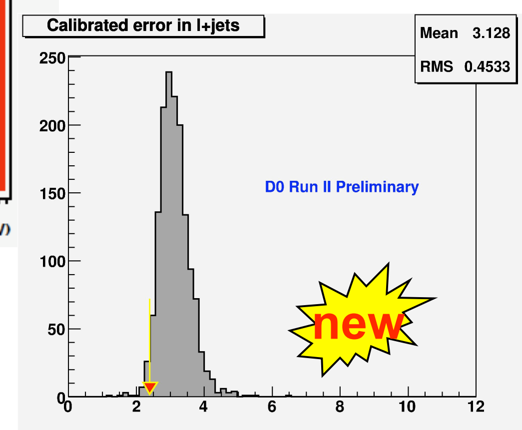
Most precise measurements are 2D (M_{top},JES)in the **lepton+jets** channel. Signal and background probabilities enter a likelihood. Maximization gives final measurement.

$$\mathcal{L}(M_{top}, JES, C_s; \vec{x}) \propto \prod_{i=1}^{N} [C_s P_{t\bar{t}}(\vec{x}; M_{top}, JES) + (1 - C_s) P_{W+\text{jets}}(\vec{x}; JES)]$$









Most precise Tevatron measurement

M_{top}=170.9±2.2(stat+JES)±1.4(syst)GeV/c^2

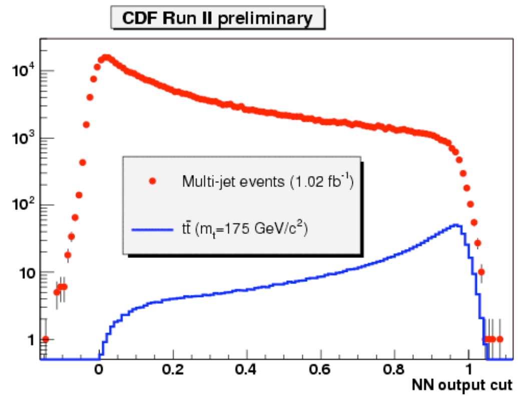
Most precise D0 measurement

M_{top}=170.5±2.4(stat+JES)±1.2(syst)GeV/c^2

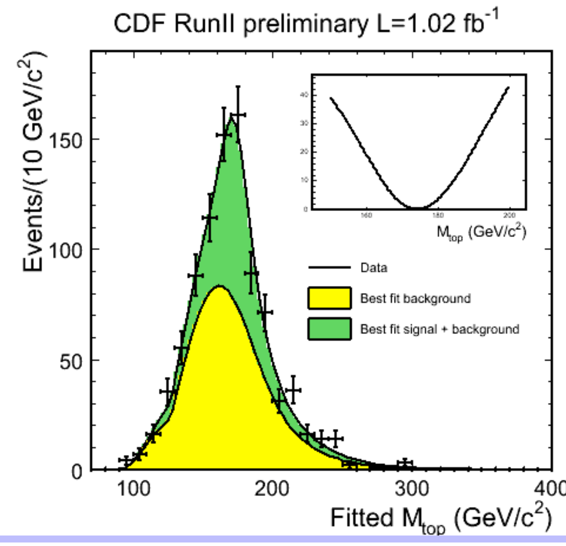
Mass with Template

Template method

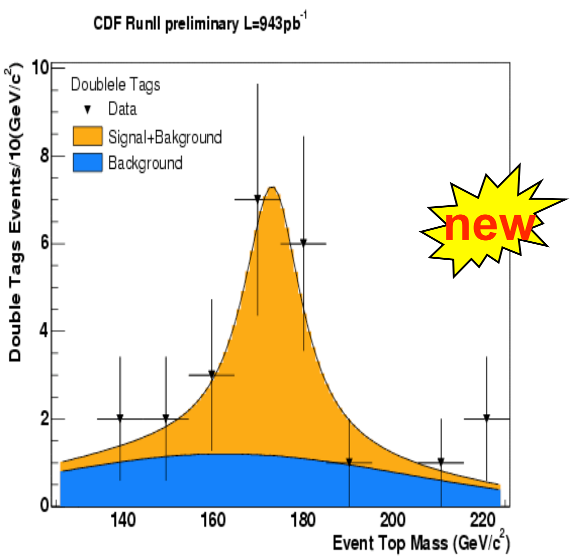
NN kin selection + b-tag:
high efficiency and
good S/B~1/2
(N_S ~ 250 evts)

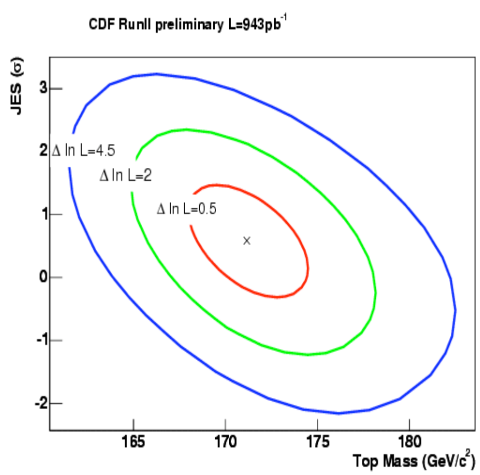


M_{top} = 174.0 ± 2.2(stat.) ± 4.5 (JES) ± 1.7(syst.)GeV/c²



Mixed technique:ME probability as a Template





Kin+dynam cuts + b-tag
S/B~1/1 N_S~30 evts
Use dijets to constrain the JES

Precision measurements in a difficult channel!!

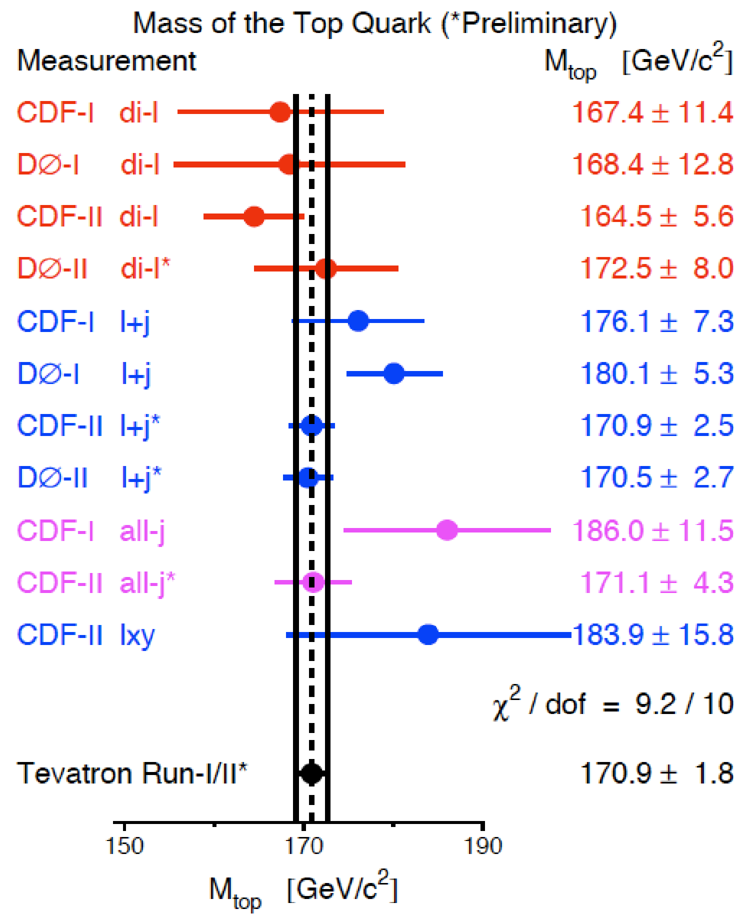
M_{top} = 171.1 ± 2.8 (stat.) ± 2.4 (JES) ± 2.1(syst.) GeV/c²

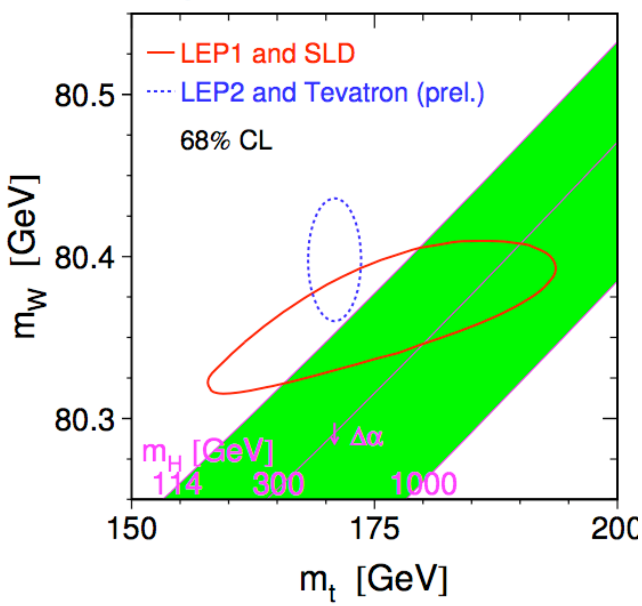
Mass summary

- Combination of best Run I and Run II measurements using BLUE

m_{top}=170.9±1.1(stat)±1.5(syst) GeV/c^2
=170.9±1.8 GeV/c^2

- **Results far exceeds expectations!**
- **It will take LHC many years of data-taking to achieve it!**



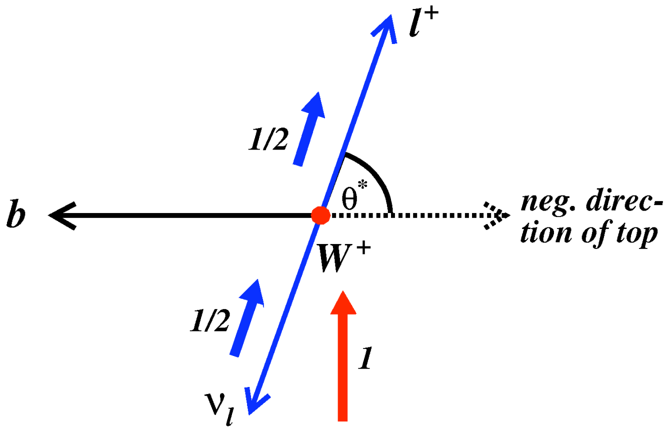


Low mass Higgs favoured again chance for the Tevatron?

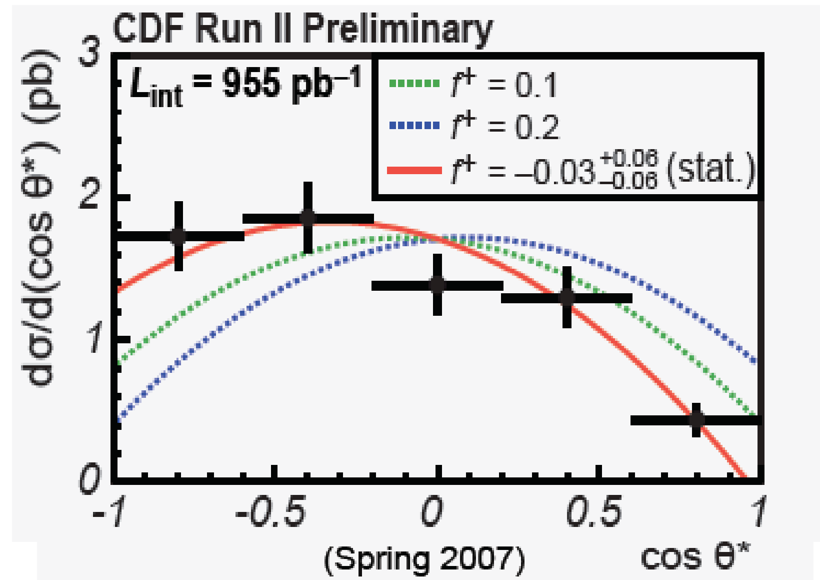
W helicity in top decays

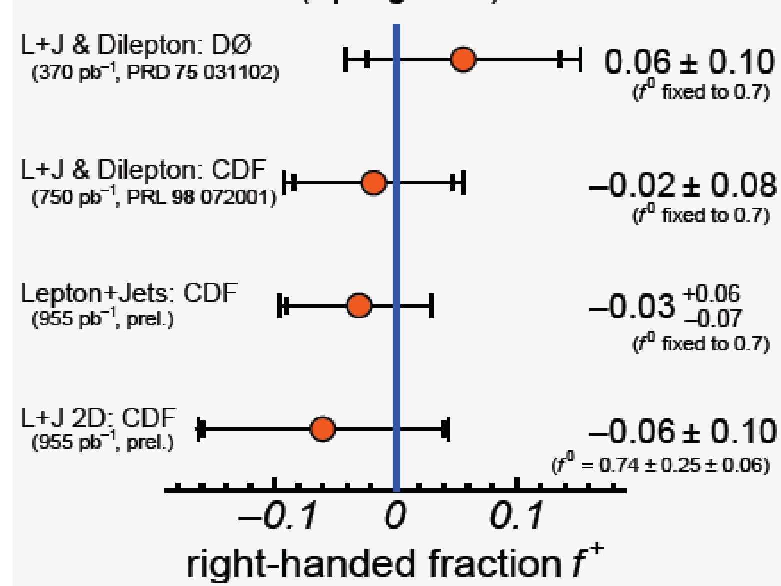
Tests V-A interaction

- Measure the W's helicity fraction using $\cos\theta^*$
- SM predicts F_0=0.7 F_-=0.3 F_+=0
- Use lepton+jets & dilepton events and fully reconstruct event kinematics



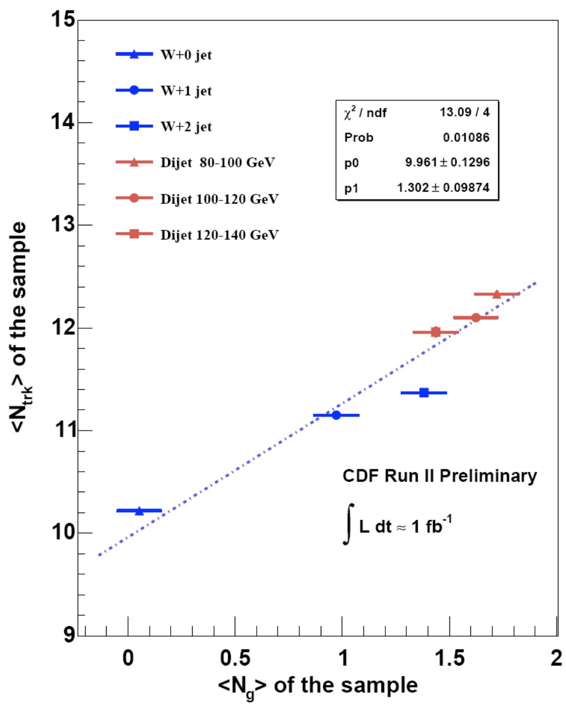
- **Statistically dominated**
- **Consistent with the Standard Model**

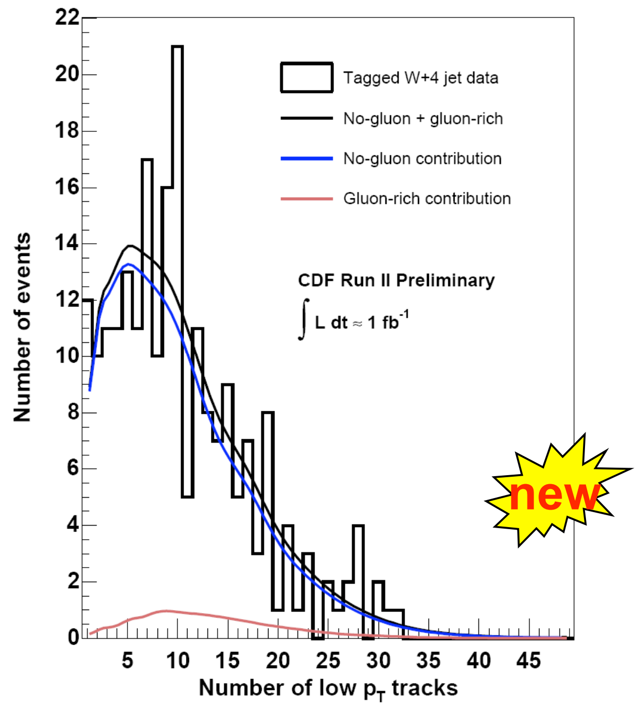




Pair production mechanism

Test of pQCD (~15% gg→ttbar, ~85% qqbar →ttbar) and is sensitive to new physics. Multiplicity of low pt tracks is correlated to gluon content.





Calibrate $\langle N_{trk} \rangle$ vs. $\langle N_g \rangle$ using W+jets and dijet data (and MC)

Fit data to **gluon rich** and **no-gluon** $\langle N_{trk} \rangle$ templates

Statistically dominated

σ(gg→tt)/σ(pp→tt) = 0.01 ± 0.16(stat.) ± 0.07(syst.)

Searches for physics: resonance?

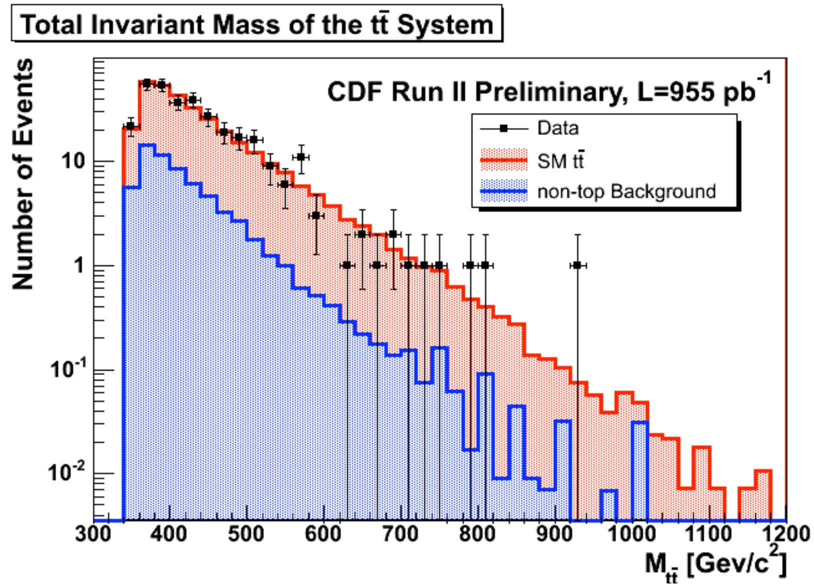
Top as a probe for new physics at very high mass scale!

Look for a heavy neutral boson with the same couplings as the Z^0

$$p\bar{p} \rightarrow X^0 \rightarrow t\bar{t}$$

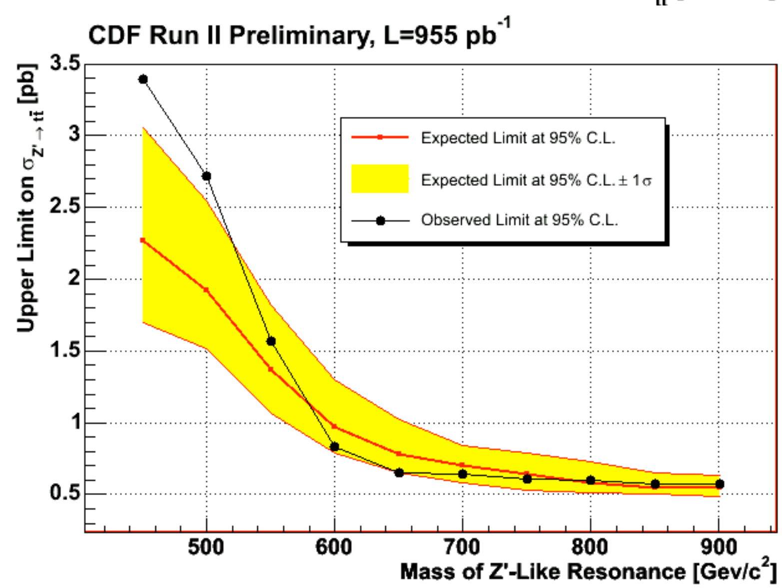
$450 < M_X < 900$ GeV/c^2

- **signal shape is totally dominated by resolution and combinatoric effects**



Fully reconstruct the event:

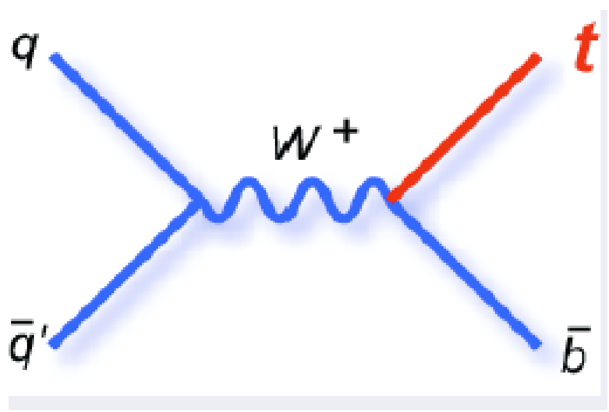
look for invariant mass in the t-tbar system through binned likelihood fit

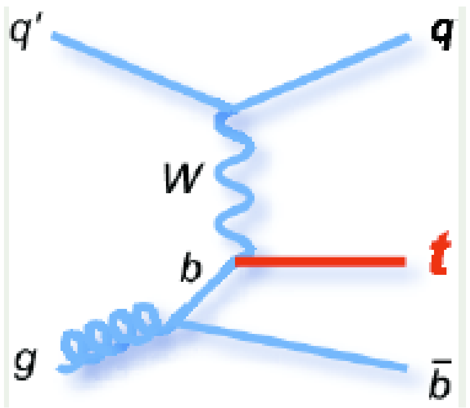


Set limits to σ x BR(X^0)->ttbar

Single top production

- Single top production probes SM predictions
  - Allows measurement of V_{tb}
  - Same final state signature as Higgs: WH, H → bbbar at theTevatron.
- Test non-SM phenomena
  - Hints for existence of a 4th generation ?
  - Search W' or H^+ (s-channel signature)





- Difficult signature: after evts selection on average S/B~1/30

Event selection

Trigger	Sample
CDF	1 isolated high-P_T lepton (e,μ)
D0	1 isolated high-P_T lepton (e,μ) +1 jet

More cuts	Sample
CDF	event topology + ≥ 1 b tag (NN tagger) + *from 6 to 26 more kinematic variables*
D0	*up to 49 variables* used with different statistical approaches

Backgrounds	Sample
Physics	W +jets, ttbar(leptonic channels)
Instrumental	multijets

Objective: to reproduce W+2 jet topology where at least 1 jet is expected to come from a b quark while getting rid of the **HUGE** background

- Restrict to W ➔ lν to reduce background
- Assume m_{top}=175

Single top results

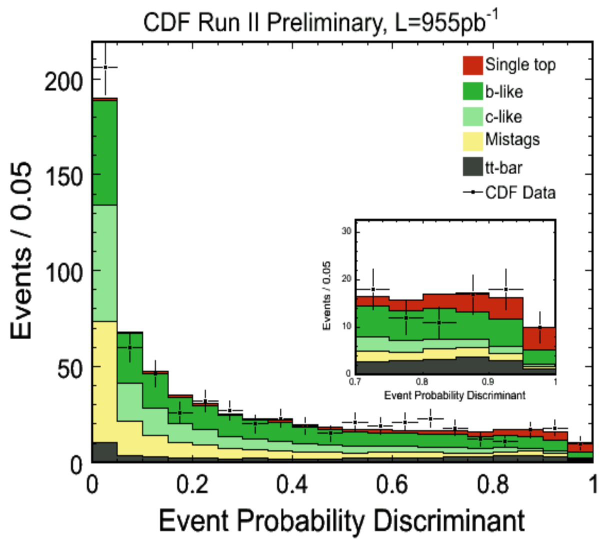
Matrix Element Discriminant

s+t channel

$\sigma = 2.7^{+1.5}_{-1.3}$ pb

obs p-value=

1.0% (2.3 σ)



Neural Network

s+t channel < 2.6 pb @ 95% C.L

t-channel = $0.2^{+1.1}_{-0.2}$ pb

s-channel = $0.7^{+1.5}_{-0.7}$ pb

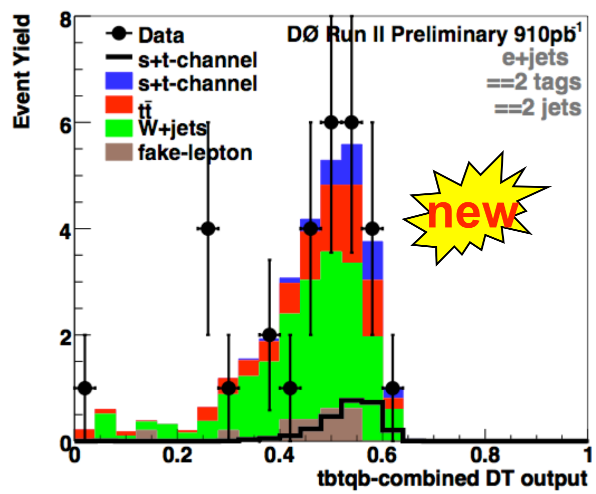
Multivariate Likelihood Function

s+t channel < 2.7 pb @ 95% C.L.

t-channel = $0.2^{+0.9}_{-0.2}$ pb

s-channel = $0.1^{+0.7}_{-0.1}$ pb

Boosted Decision Tree



➔ *Evidence!*

s+t channel

σ= 4.9 ± 1.4 pb

3.4σ from background only hypothesis

➔ *Evidence!*

$0.68 < |V_{tb}| \leq 1$

Matrix element

s+t channels = $4.6^{+1.8}_{-1.5}$ pb

(2.9σ) significance

Bayesian Neural Network

s+t channel = 3.8 ±1.5 pb (2.4σ)

t-channel = $3.7^{+2.0}_{-1.8}$ pb

s-channel = 5.0 ± 1.9 pb

Summary & Conclusions

Observable	Measurements	SM expectation
M_{top}(GeV/c²)	170.9 ± 1.8	178^{+12}_{-9}
σ_{tt} (pb)	7.3 ± 0.9	6.7 ± 0.9
F_0	0.59 ± 0.14	0.70
F_+	<0.1@ 95% C.L.	0
gg/pp	0.01±0.16±0.07	0.15
σ_t (pb)	4.9 ± 1.4	2.9 ± 0.4

Non SM process	Limits
resonance	(BRxσ) < 1 pb @ 95 C.L. for M_X> 600GeV/c²

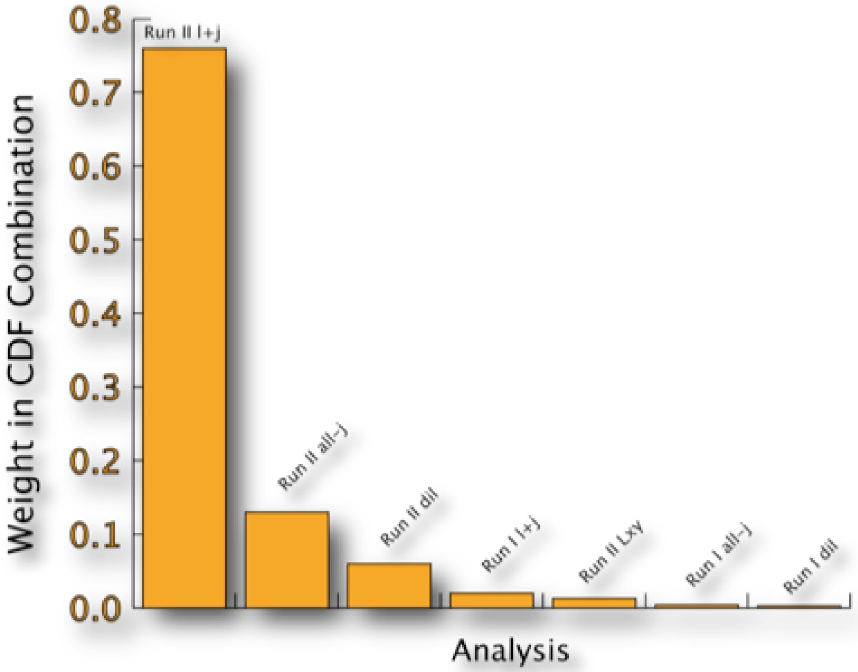
- **Tevatron** only place to study the top
- Ideal training ground for **LHC**
- Expectional precision on ***top quark mass***
- Lots of ***new*** and ***updated*** results

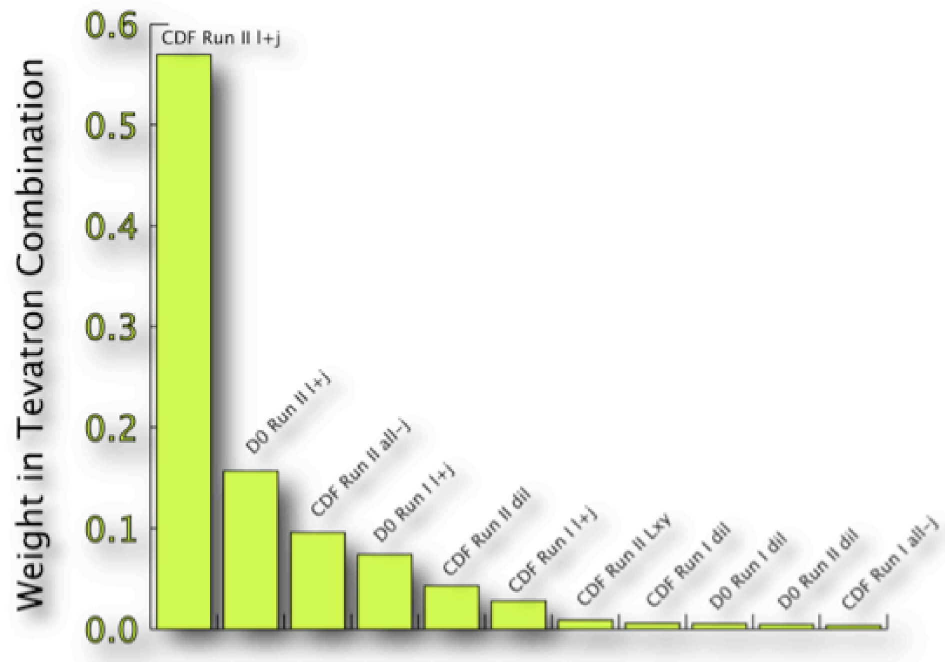
No surprises yet......

BACK UP SLIDES

CDF and Tevatron mass average

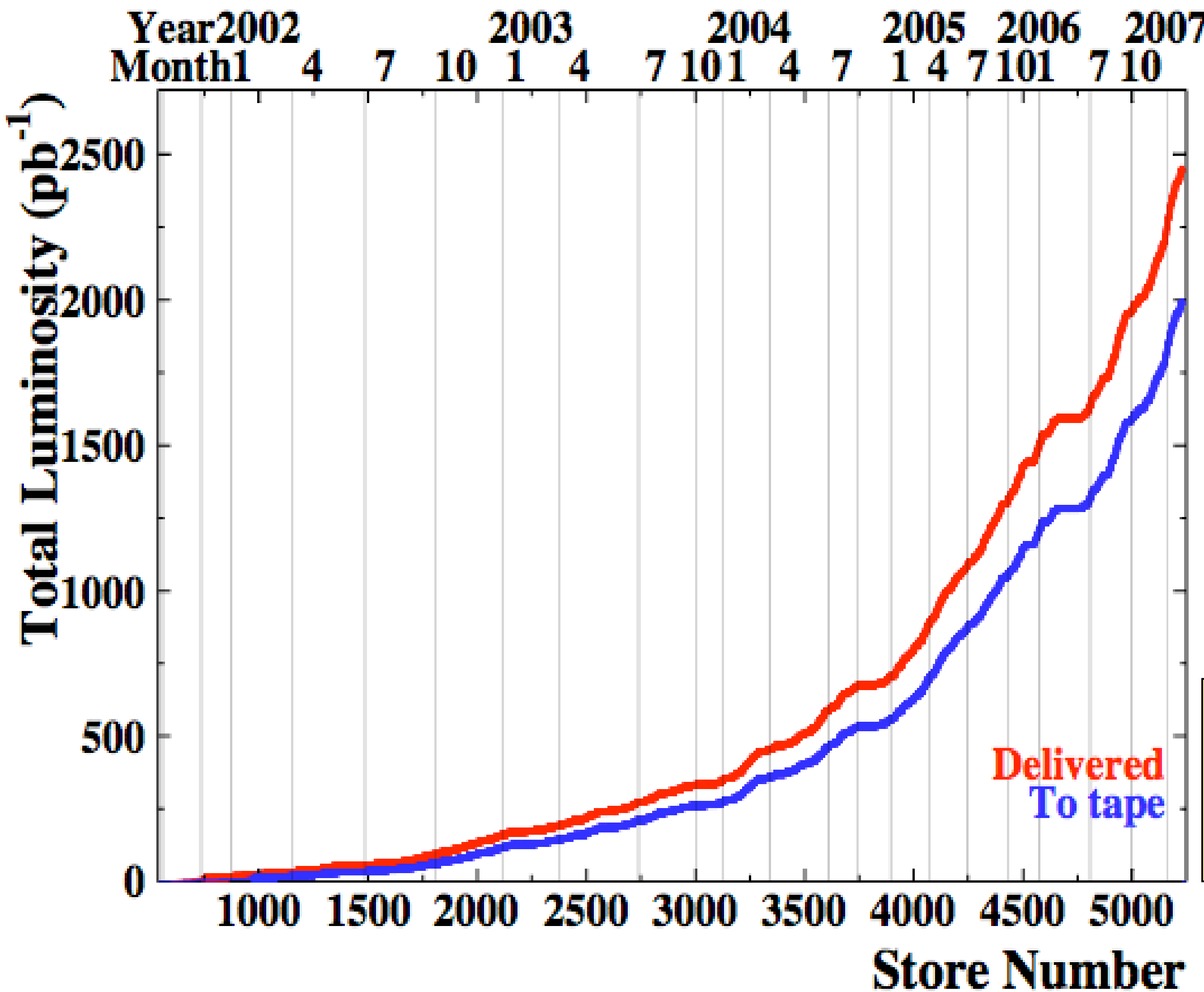
Weights of the various decay channels in the CDF and Tevatron combination:





Best measurements from l+jets; second best from all-hadronic channel, third from dilepton. Trend is well-estabilished @ CDF

Luminosity



2.5 fb^{-1} delivered

2.0 fb^{-1} on tape

up to 1.0 fb^{-1} used in the following analysis

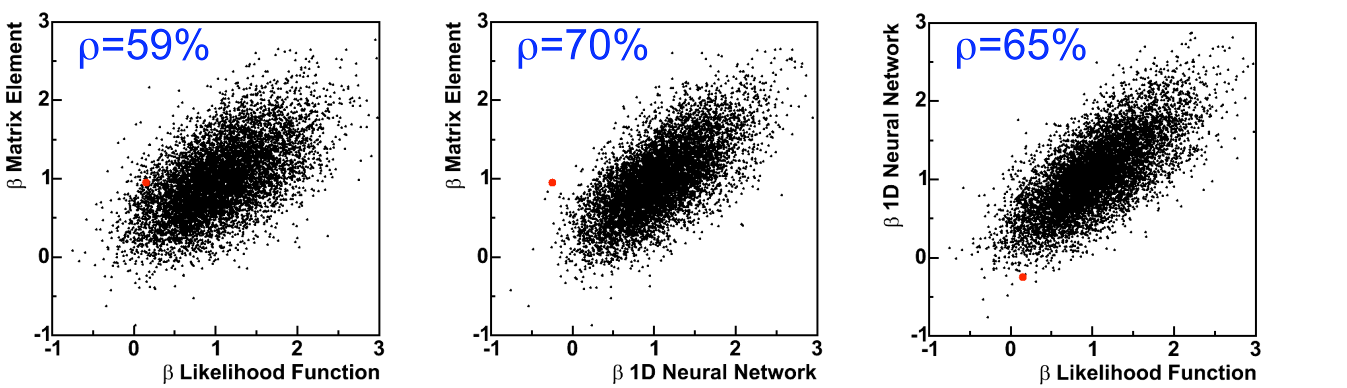
Compatibility

Method	Neural Networks		Matrix Elements	Likelihood Function
	1D	2D	1D	2D
Expected p-value	0.5% ≅ 2.6 σ	0.4% ≅ 2.6 σ	0.6% ≅ 2.5 σ	2.5% ≅ 2.0 σ
Observed p-value	54.6%	21.9%	1.0% ≅ 2.3 σ	58.5%

At present, CDF results (955 pb^{-1}) differ:
two analyses see no evidence, one has a signal at almost the SM rate.

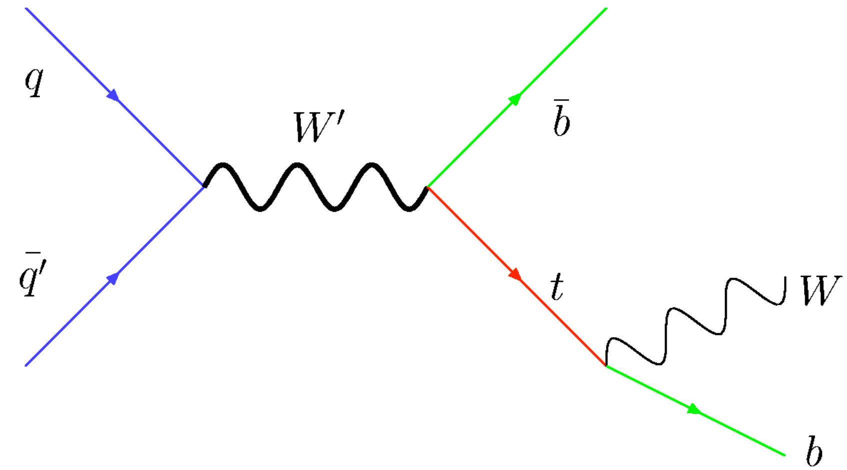
Consistency of 4 analyses based on common ensemble tests assuming the SM ratio of t-channel to s-channel: ~ 1%.

correlation



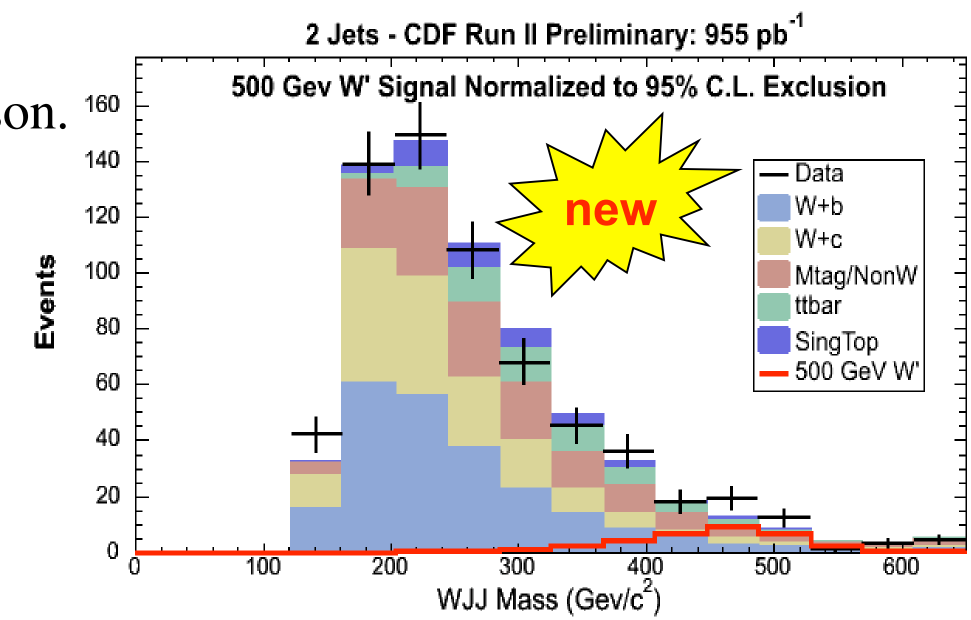
W' searches

- W' occurs in some extensions of the SM with higher symmetry.
- Complementary to searches in $W' \to e\nu$ / $\mu\nu$ (e.g. W' of leptophobic nature).
- Select W + 2 or 3 jets events.
- Background estimate same as SM search.
- Use $M(l\nu jj)$ as discriminant
- Neglect interference with SM W boson.

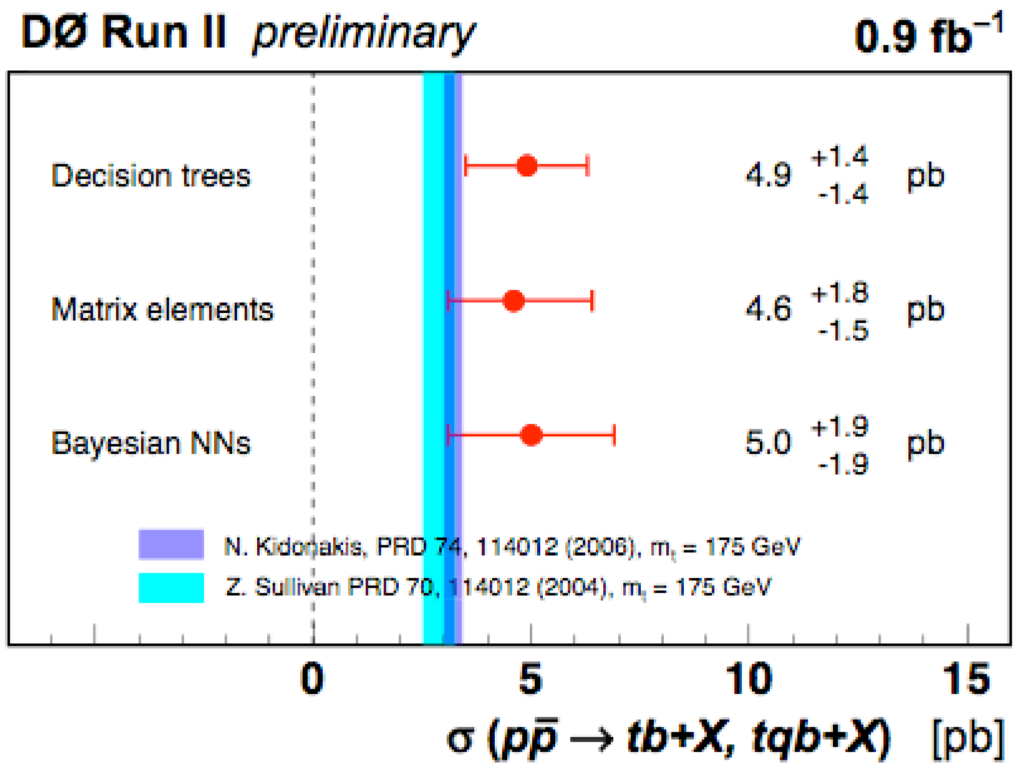


CDF mass limits:
$M(W') > 760$ GeV if $M(W'_R) > M(\nu_R)$
$M(W') > 790$ GeV if $M(W'_R) < M(\nu_R)$

DØ mass limits:
$M(W'_L) > 610$ GeV
$M(W'_R) > 630$ GeV (670 GeV)
Phys. Lett. B 641, 423 (2006)



Top quark



DØ Run II preliminary
0.9 fb^{-1}
Decision trees
4.9 +1.4 -1.4 pb
Matrix elements
4.6 +1.8 -1.5 pb
Bayesian NNs
5.0 +1.9 -1.9 pb
N. Kidonakis, PRD 74, 114012 (2006), m$_t$ = 175 GeV
Z. Sullivan PRD 70, 114012 (2004), m$_t$ = 175 GeV
0
5
10
15
σ (p$\bar{p}$ → tb+X, tqb+X) [pb]