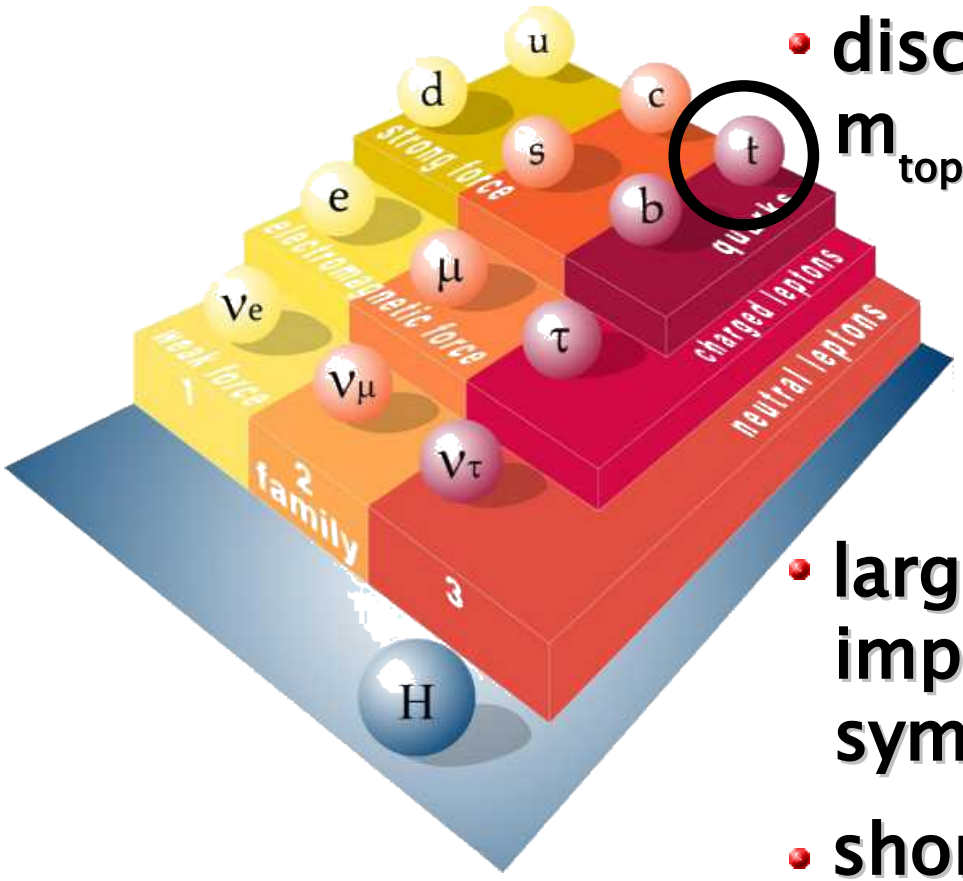
Searches for New Physics in Top Pair Production at DØ

Christian Schwanenberger

University of Manchester

Wine & Cheese Seminar,
Fermilab, 20.07.2007

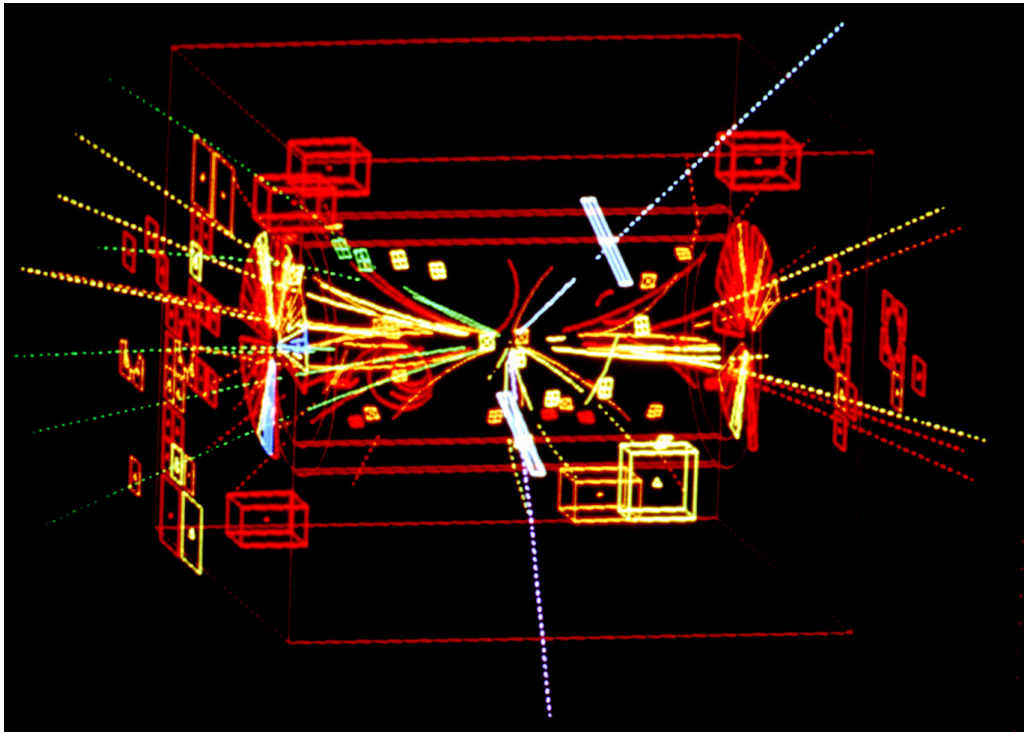
The Top Quark



- needed as isospin partner of bottom quark
- discovered in 1995 by CDF and DØ: m_{top} ~ gold atom
- large coupling to Higgs boson ~ 1: important role in electroweak symmetry breaking?
- short lifetime: $\tau \sim 5 \cdot 10^{-25}$s $\ll \Lambda^{-1}_{QCD}$: decays before fragmenting
  → observe "naked" quark

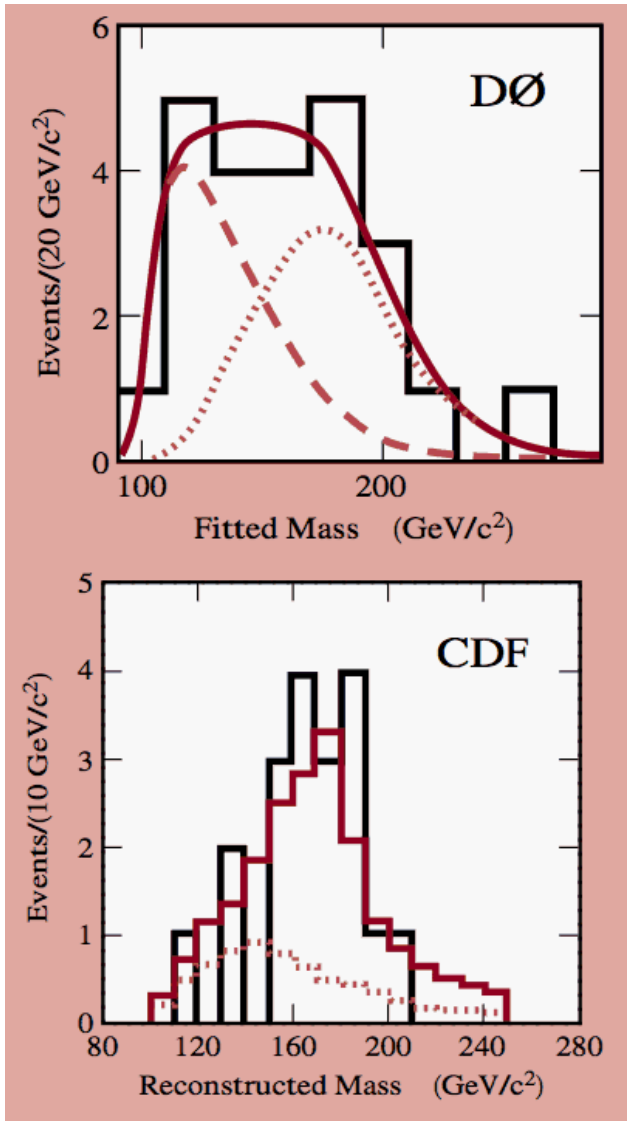
Phase I: Discovery

Z boson



1983, UA1 experiment, CERN

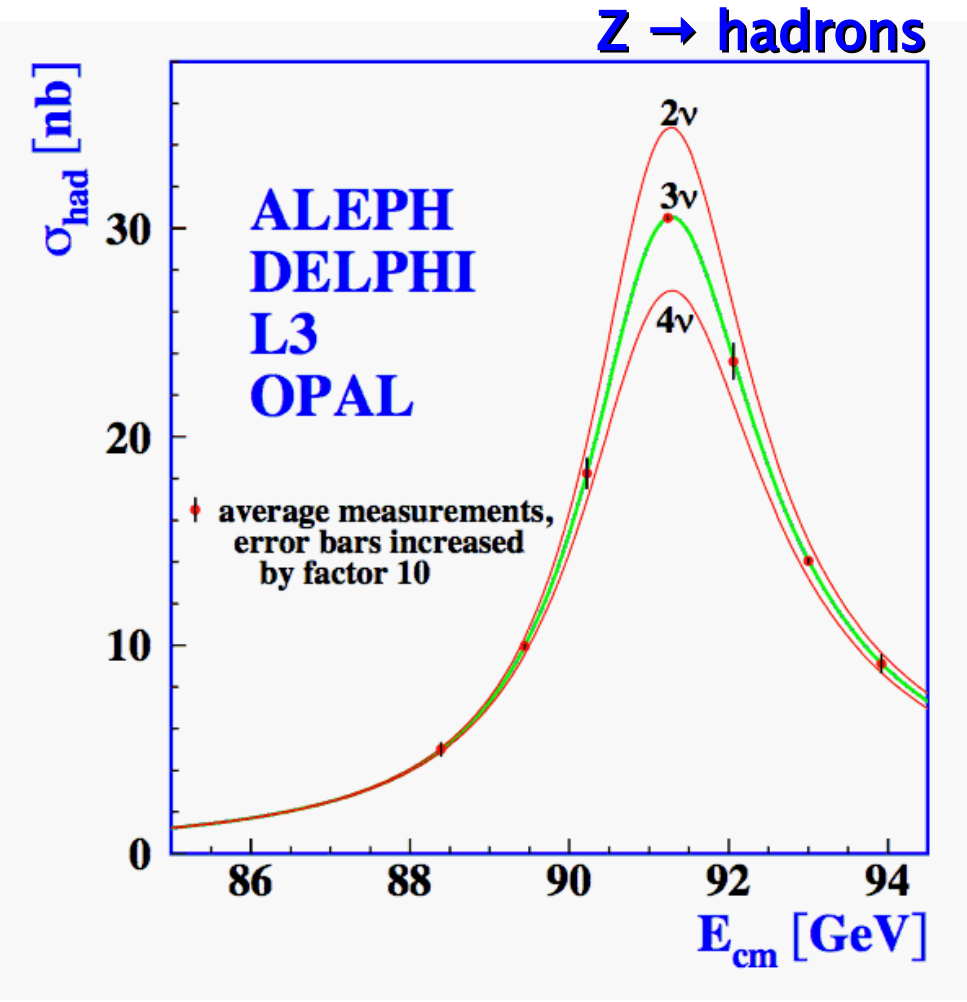
top quark



1995, CDF and DØ experiments, Fermilab

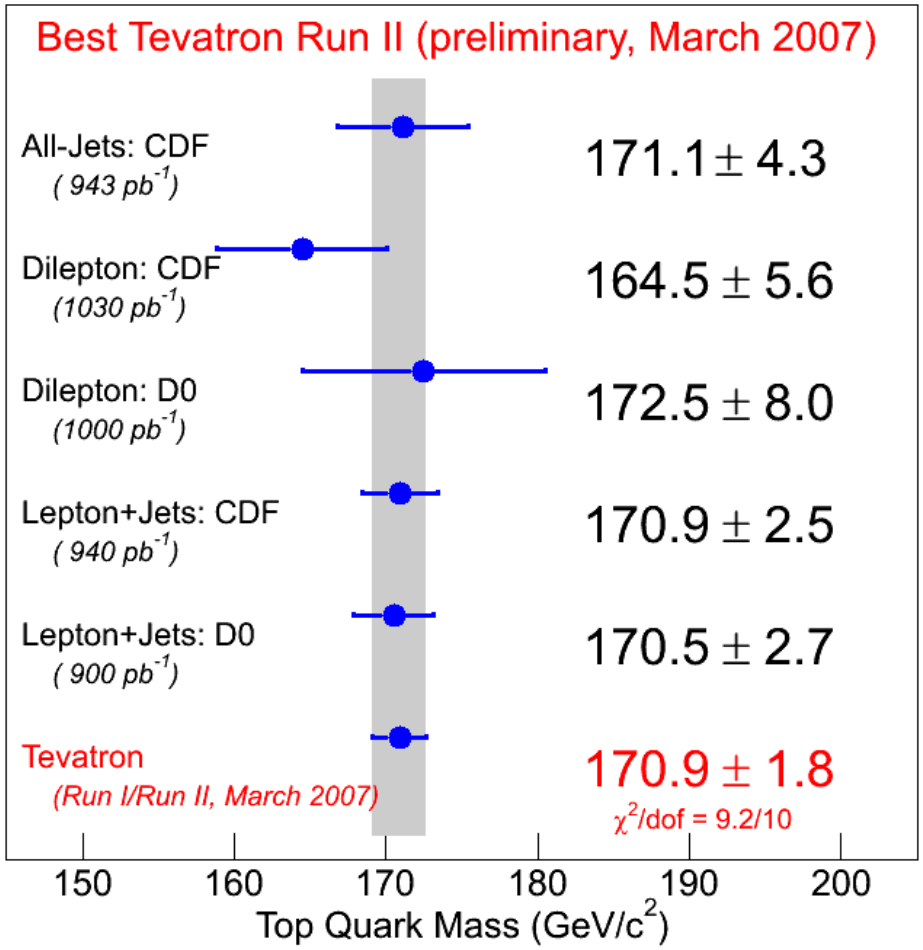
Phase II: Precision Measurements

Z boson



LEP experiments, CERN

top quark

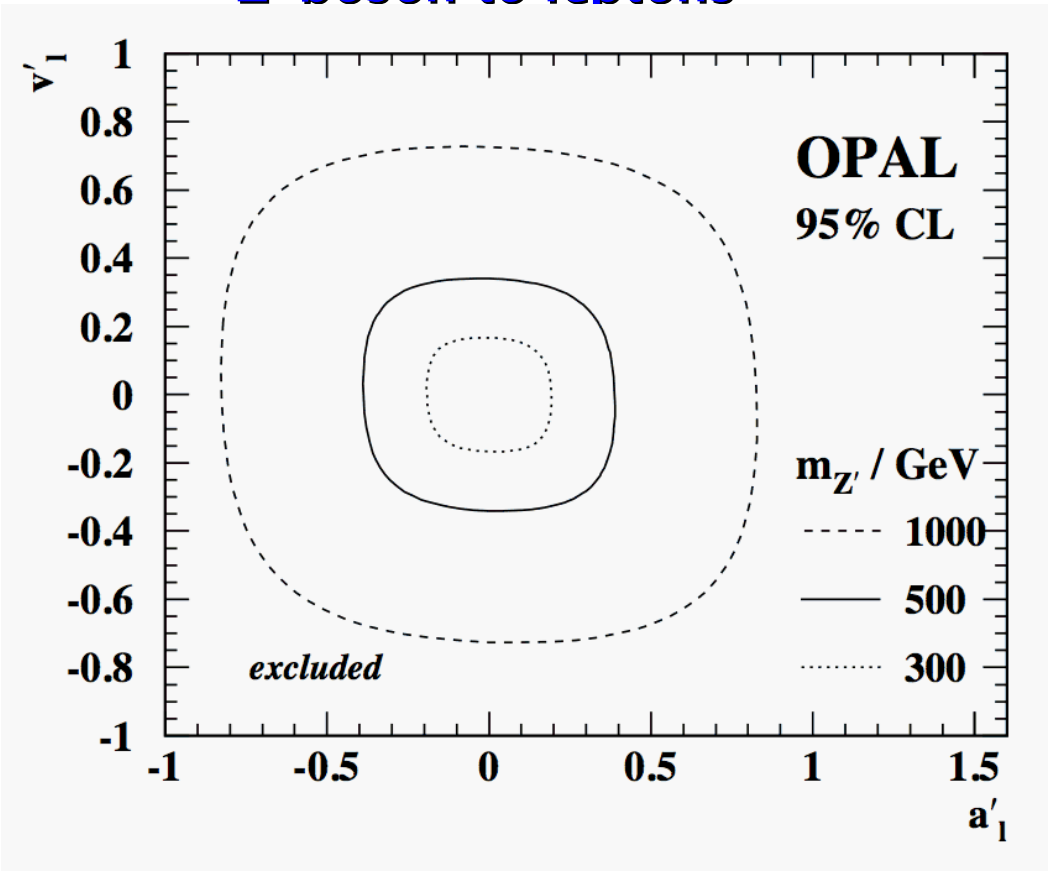


Tevatron experiments, Fermilab

Phase III: Searches for new physics

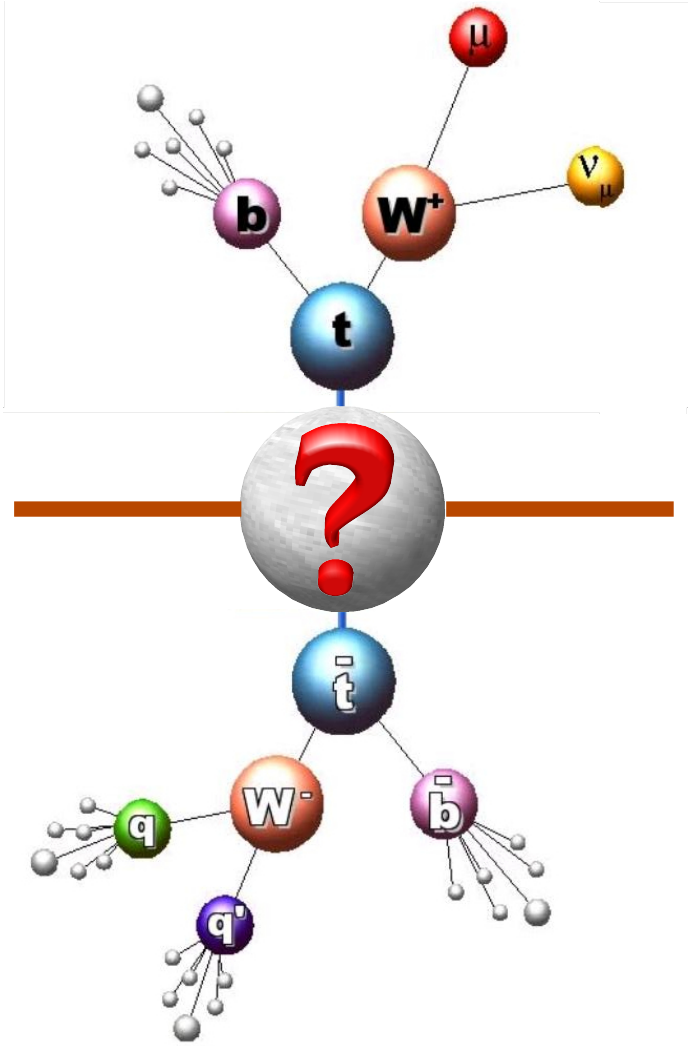
Z boson

vector and axial vector couplings of Z' boson to leptons



OPAL experiment, CERN

top quark



DØ experiment, Fermilab

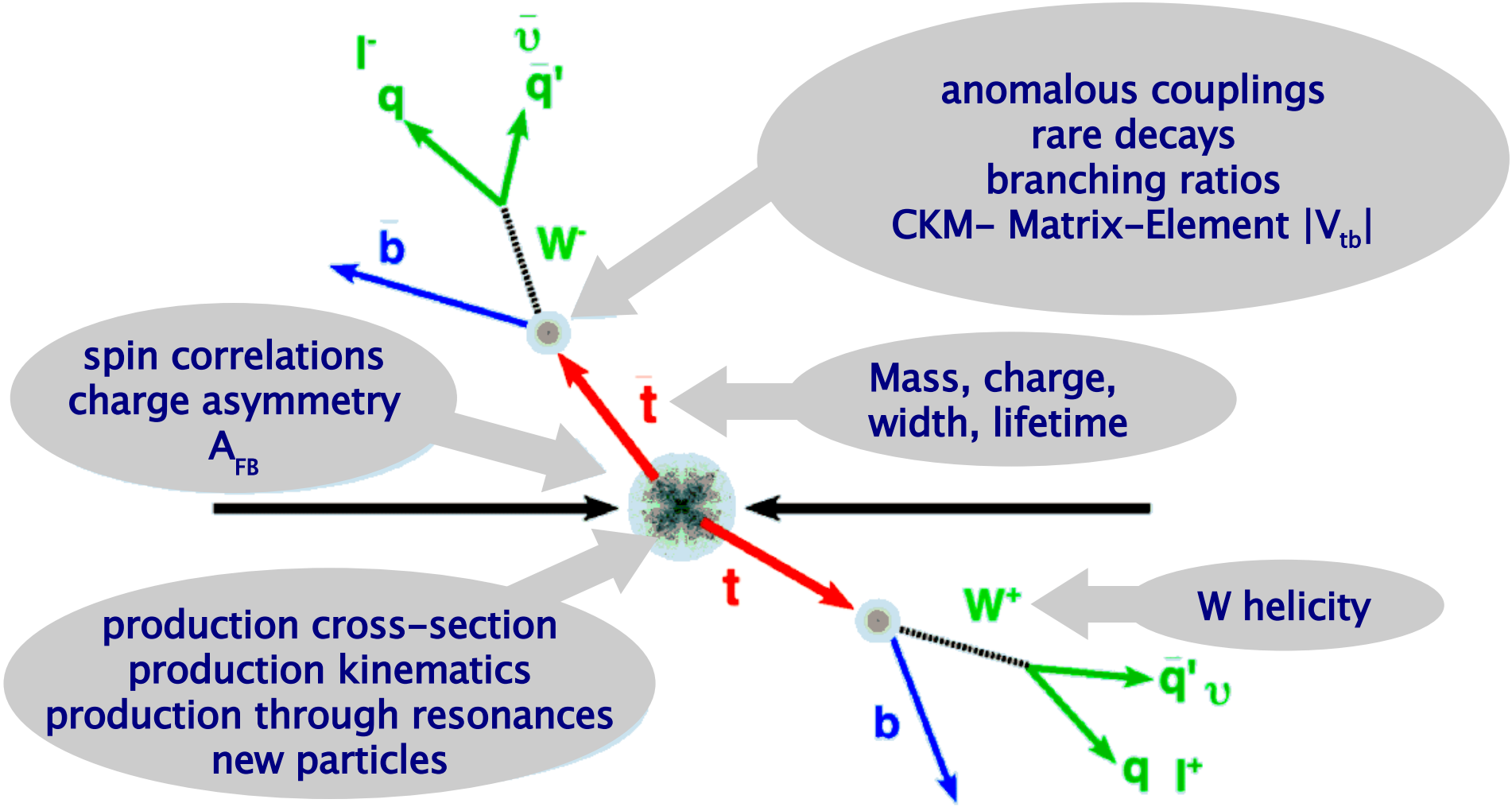
Top Quark Analyses at the Tevatron

1 fb^{-1}

Run I: top quark discovery (~125pb^{-1})

Run II: with high precision answer...

- **is it really the particle expected in the SM?**



Top Quark Analyses at the Tevatron

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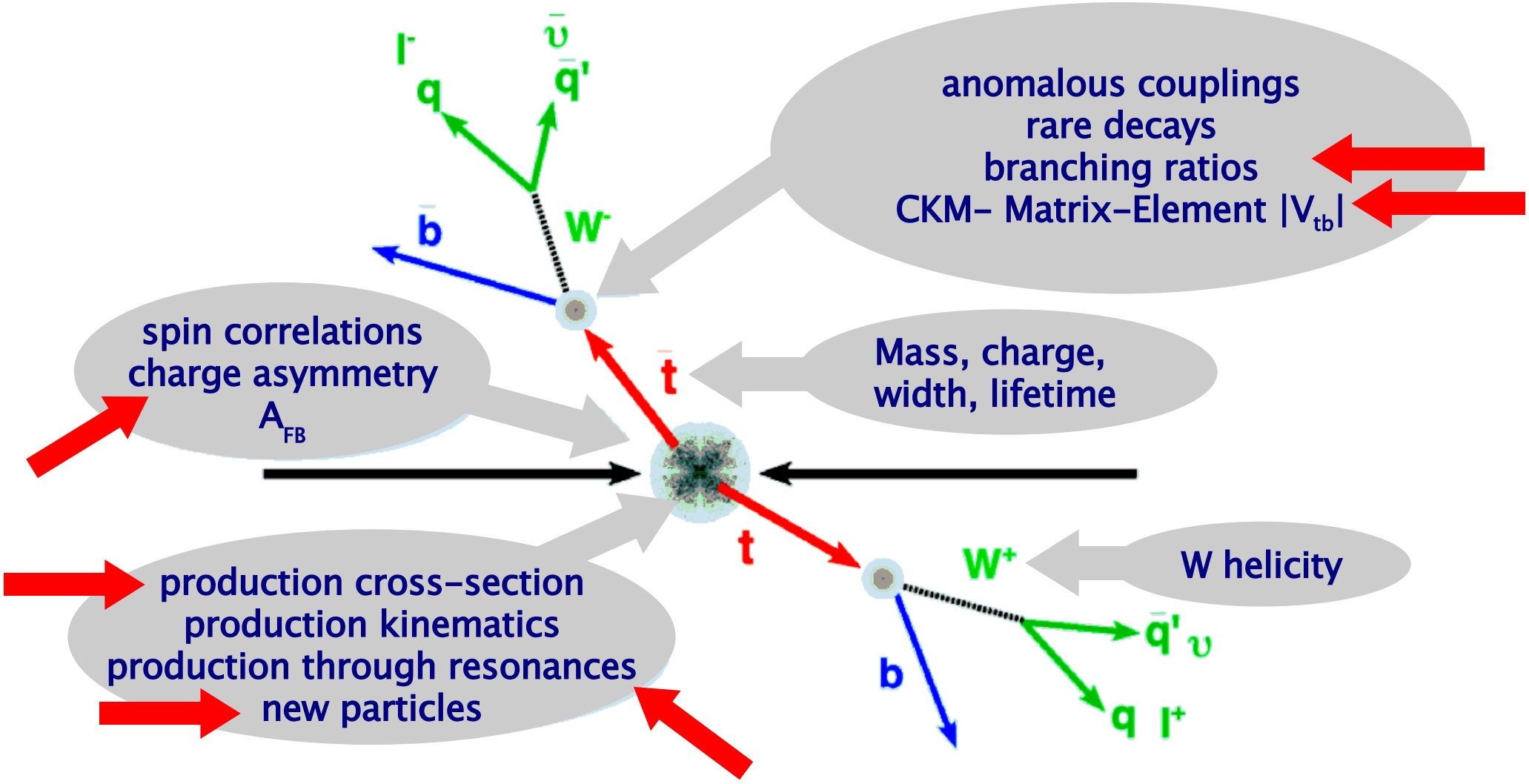
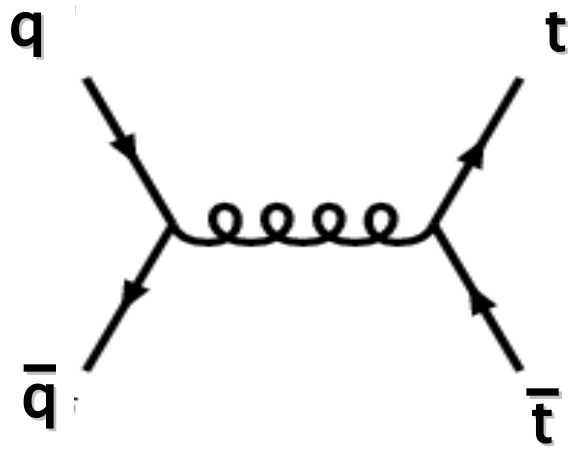
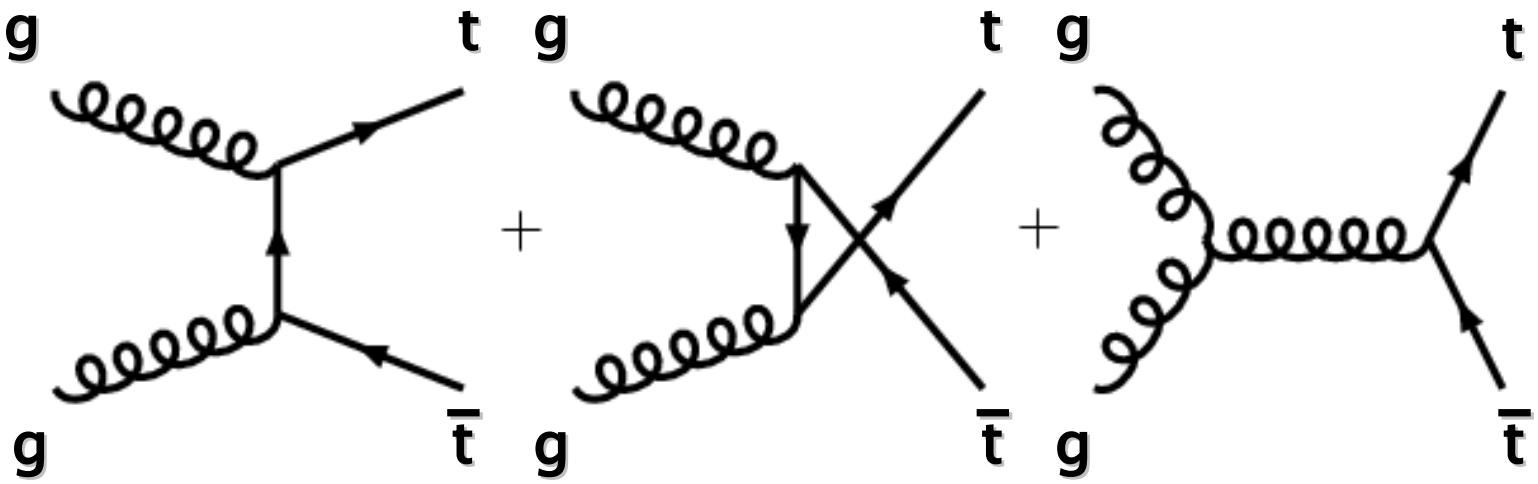


Top Quark Pair Production



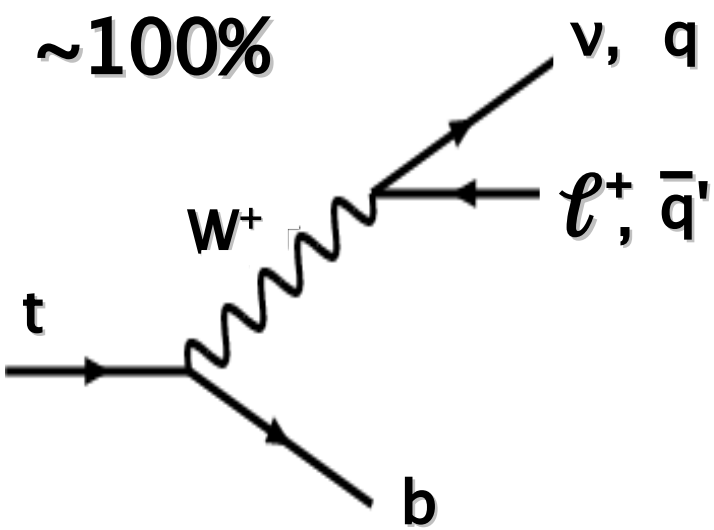
85%



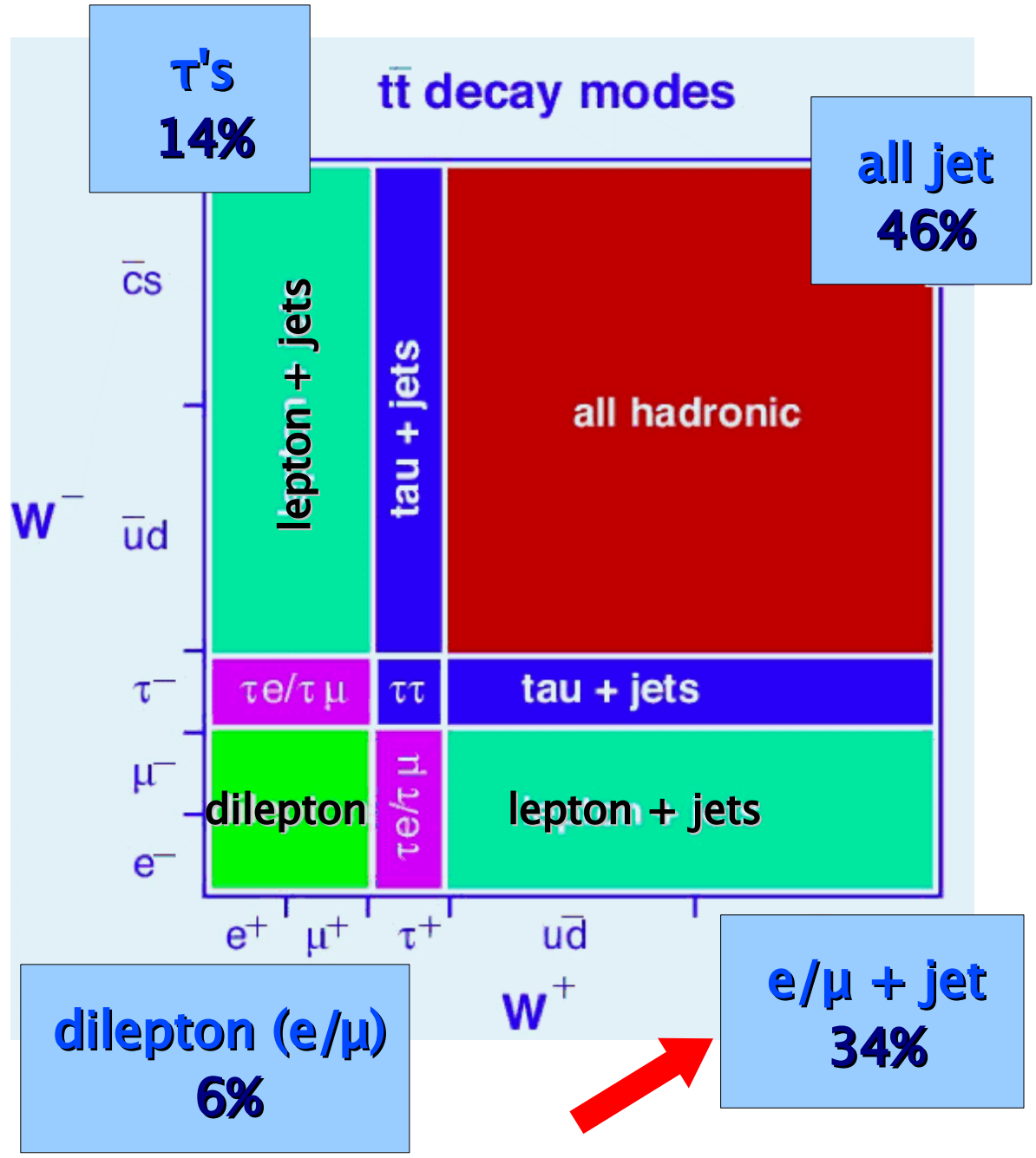
15%

Top Antitop Signatures

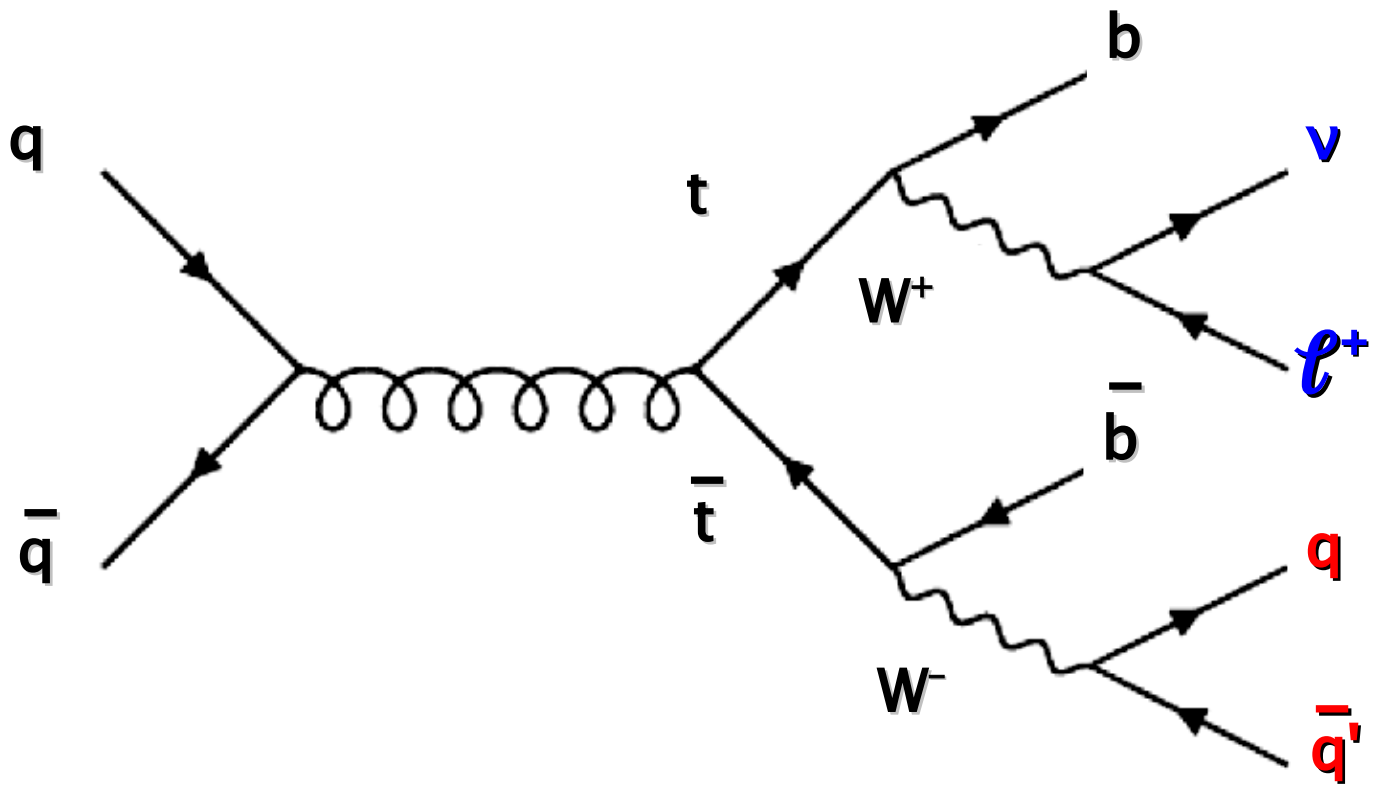
- **top decay:**



- reconstruct and identify: electrons, muons, jets, b-jets and missing transverse energy



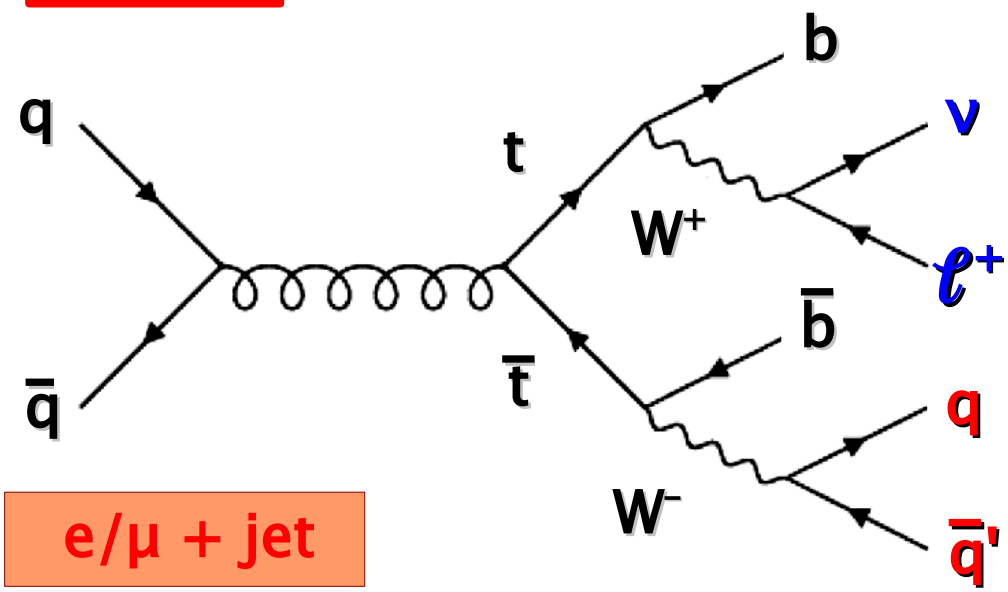
Top pair production cross section in the SM



Top anti-top signatures

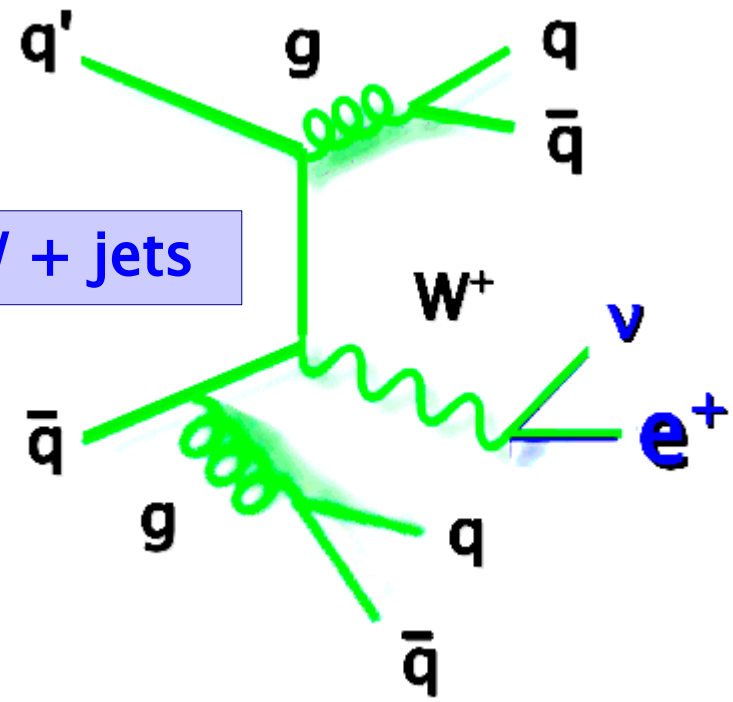
background

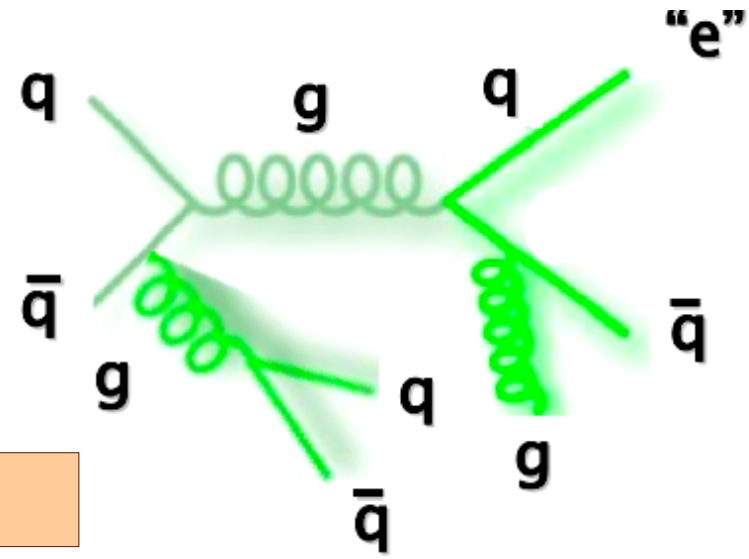
signal



e/μ + jet

W + jets





multijets

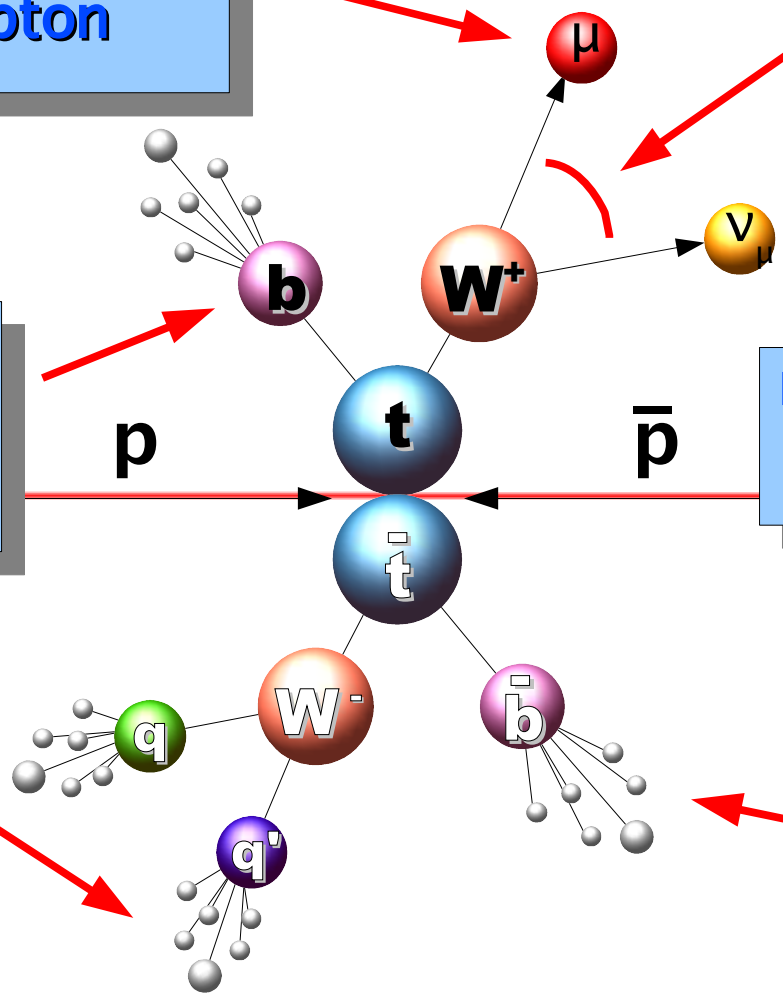
Event Selection in Lepton+Jets

e (μ) isolated, $p_T > 20$ GeV,
$|\eta| < 1.1$ (2.0),
no other high p_T lepton

minimum $\Delta\phi$

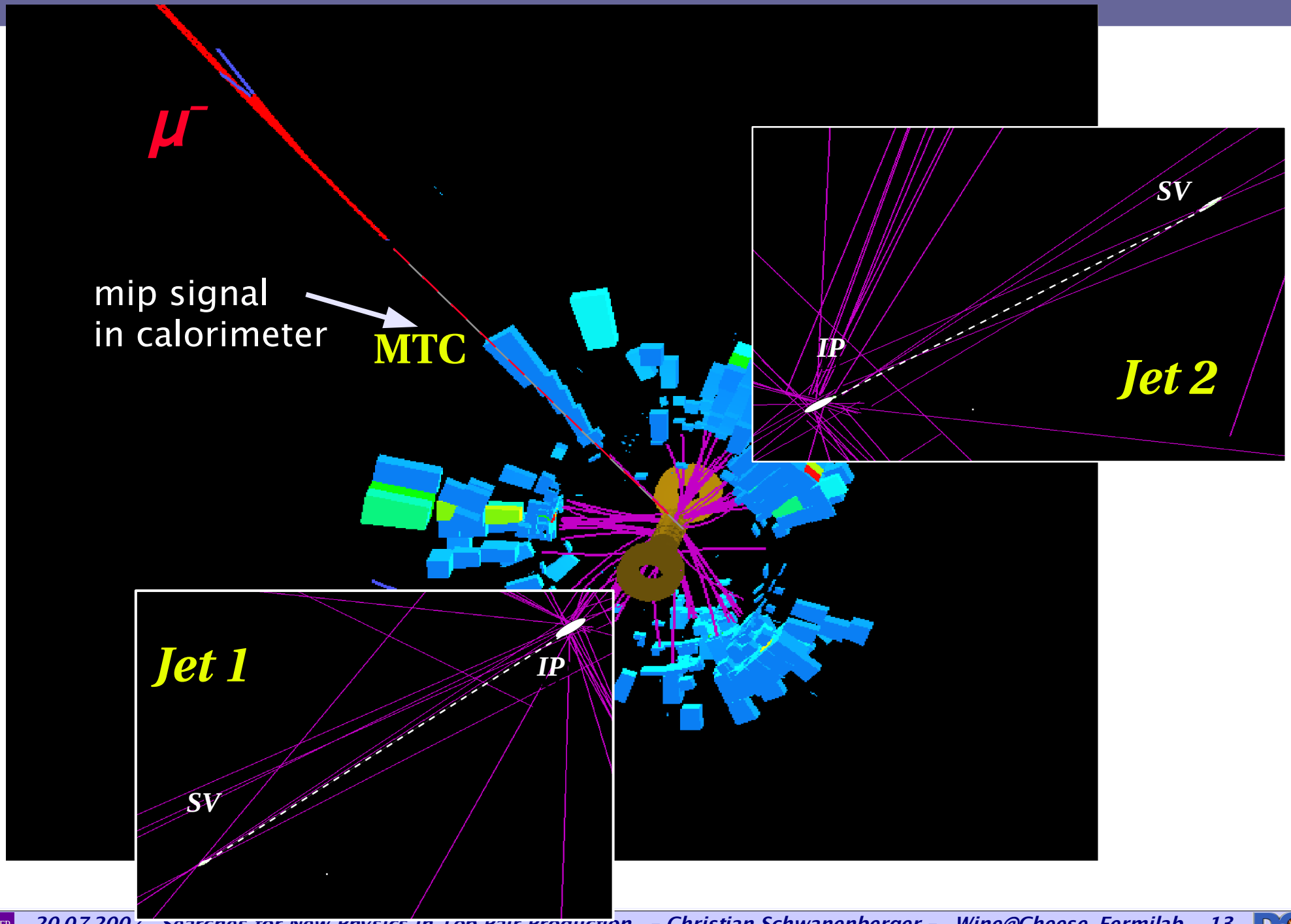
at least 4 jets,
$p_T > 20$ GeV,
$|\eta| < 2.5$

missing $E_T > 20$ (25) GeV
for e (μ)+jets



0, 1 or 2 jets
b–tagged
(Neural
Network)

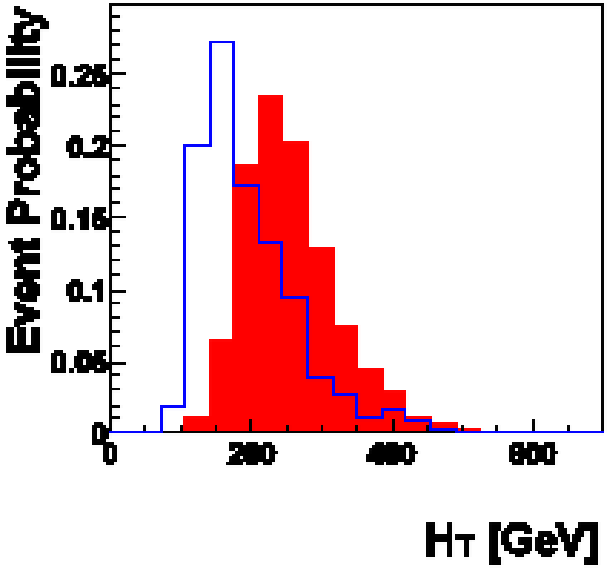
Typical μ+jets Event



Lepton+Jets Topological Cross Section

no b-tag → less model dependent

- **kinematic properties allow separation between signal and background**



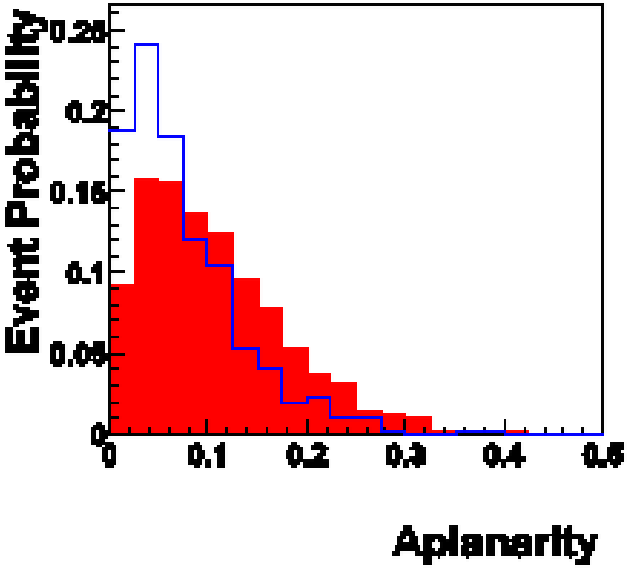
use as variables:

energy-dependent quantities:

- **e.g. H_T (scalar sum of p_T of 4 leading jets)**

angular dependent:

- **e.g. aplanarity**

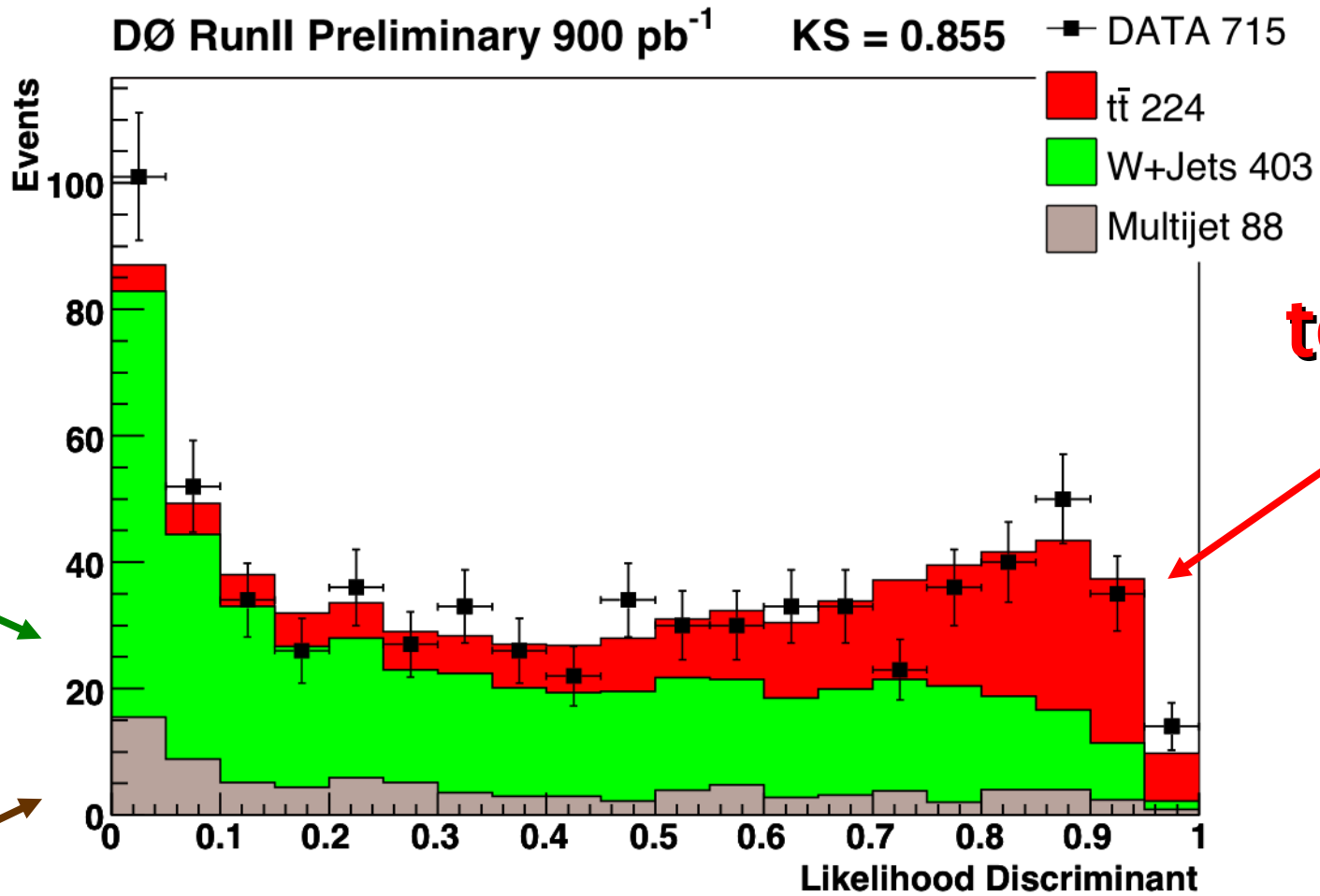


Discriminant function:

$$D = \frac{\prod_i S_i}{\prod_i S_i + \prod_i B_i}$$

i=1,..,5 (6) e (μ)+jets
S = $t\bar{t}$-distribution,
B = Wjjjj-distribution

Lepton+Jets Topological Cross Section



top pair

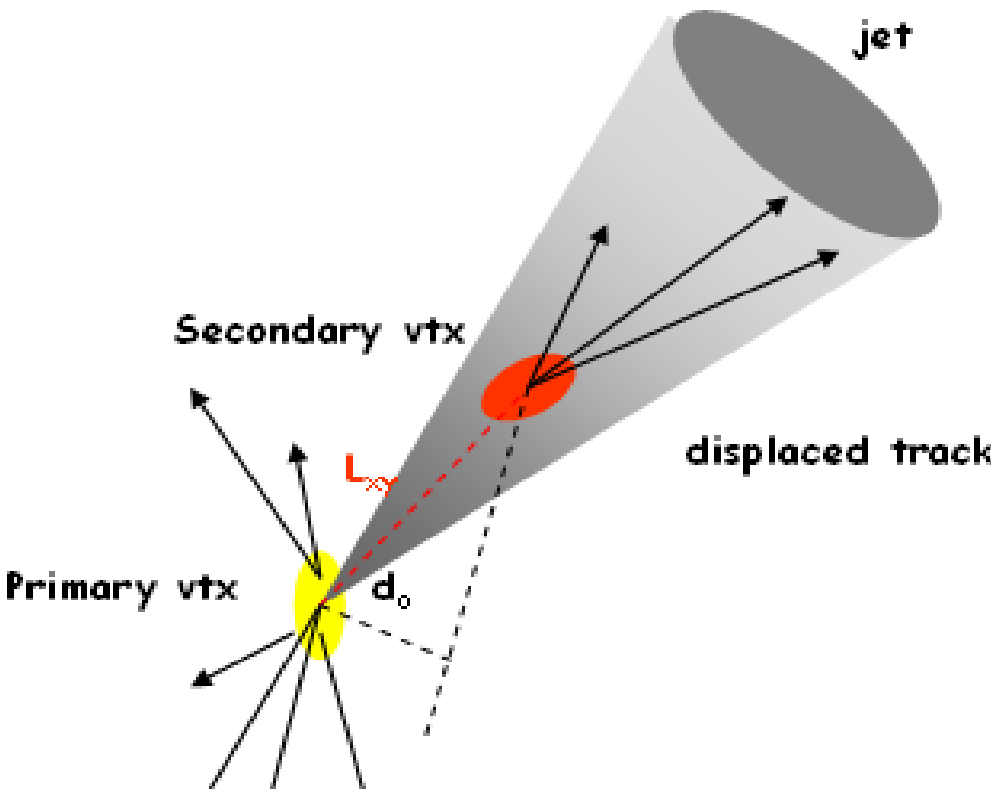
W+jets

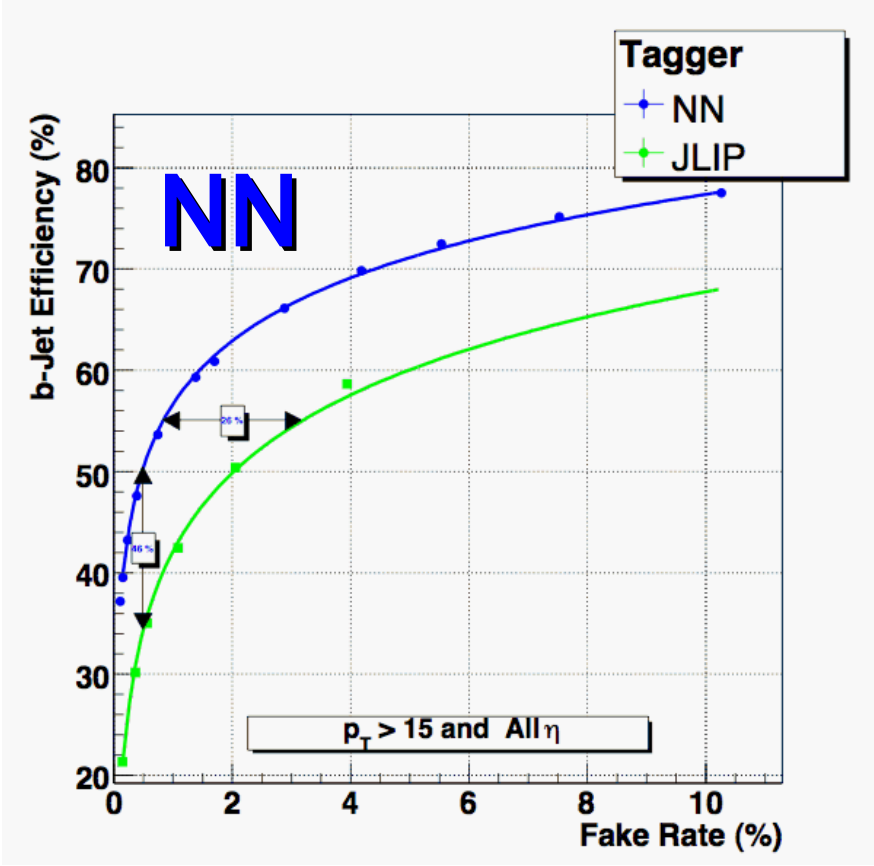
multijets

$$\sigma_{tt} = 6.3^{+0.9}_{-0.8}\ (\text{stat}) \pm 0.7\ (\text{syst}) \pm 0.4\ (\text{lumi})\ \text{pb}$$

b–tagging

- B hadrons lifetime $\tau \sim 1$ ps
- B hadrons travel $L_{xy} \sim 1$ mm before decay





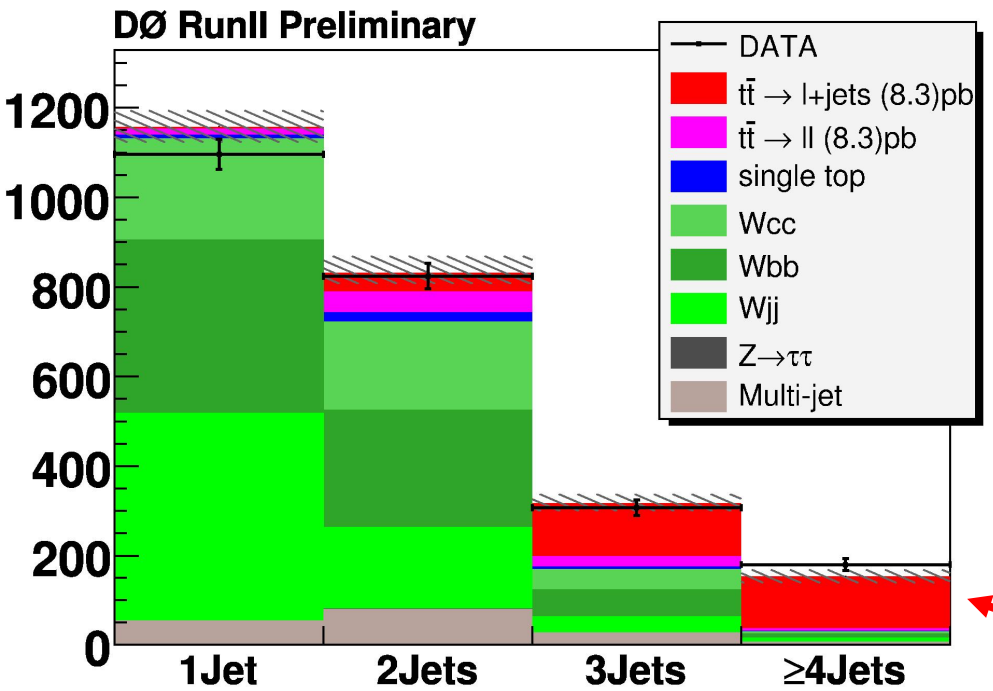
- explicitly reconstruct 3D vertices
- use properties from displaced tracks to form a 7–variable neural network
- improvements of up to 50%
- ttbar event tagging efficiency 54% (with fake rate of 1%)

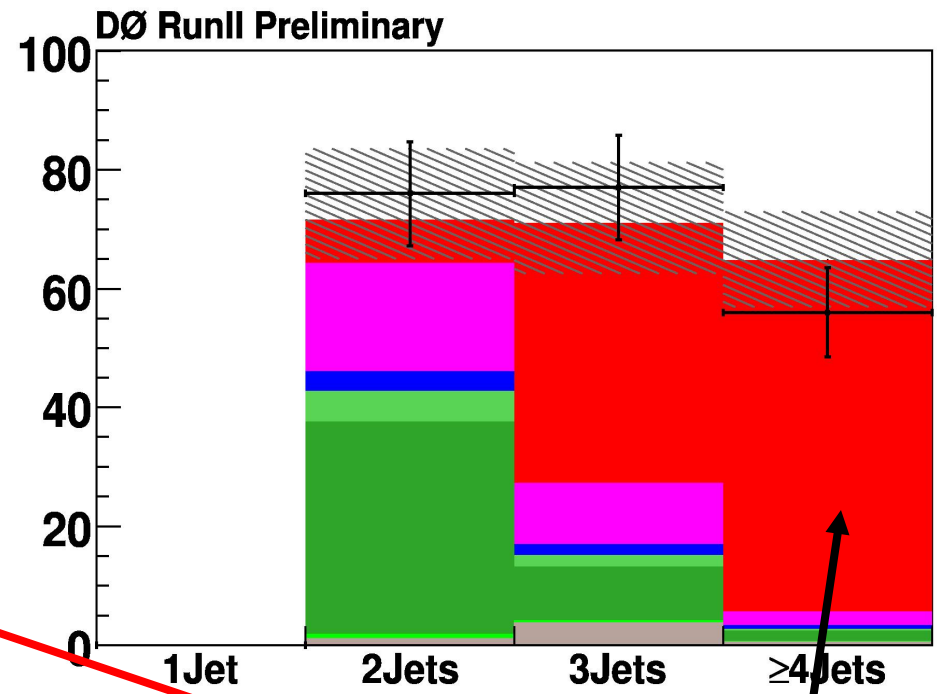
Lepton+jets cross section with b-tagging

1 b tag:

≥2 b tags:

L=900 pb^{-1}

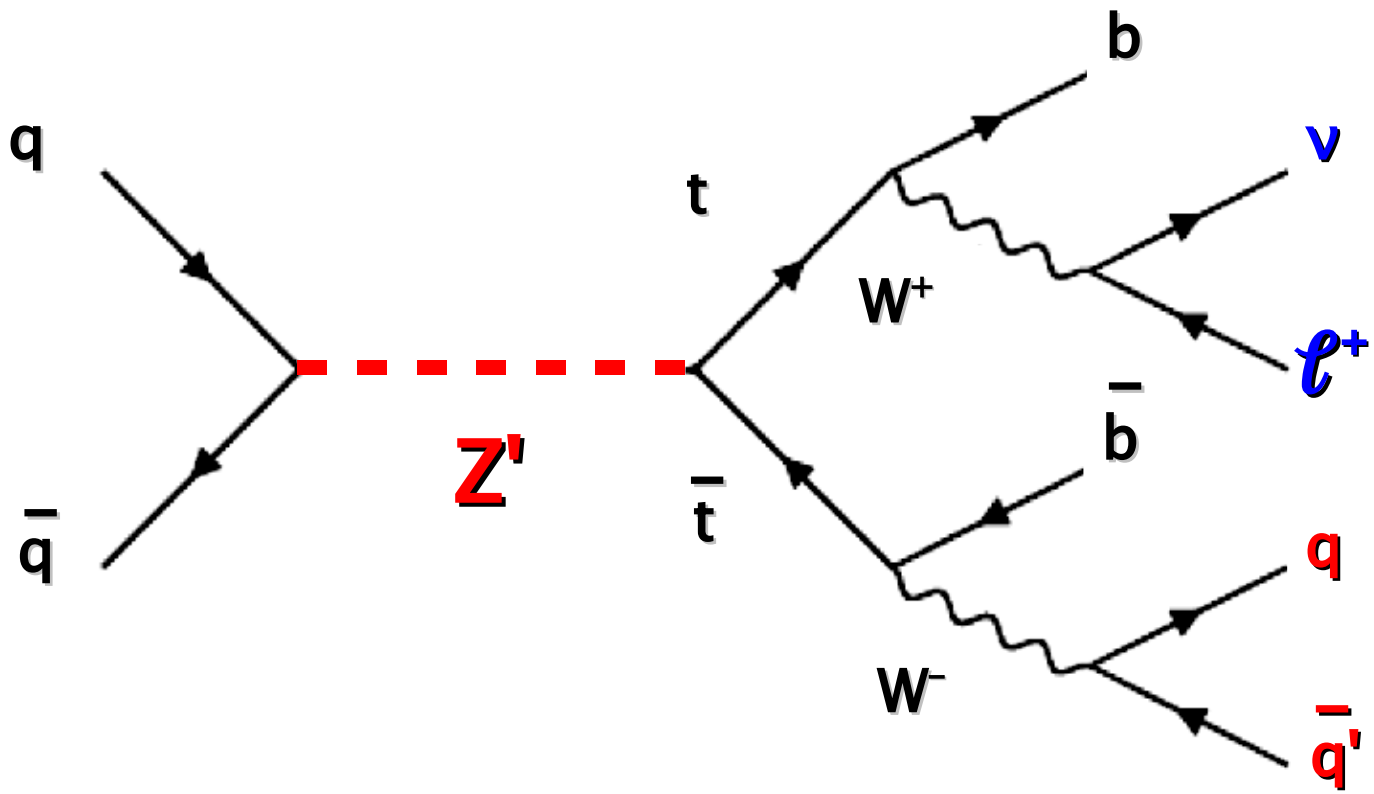




$$\sigma_{tt} = 8.3\,^{+0.6}_{-0.5}\,(\text{stat})\,^{+0.9}_{-1.0}\,(\text{syst}) \pm 0.5\,(\text{lumi})\ \text{pb}$$

top pair

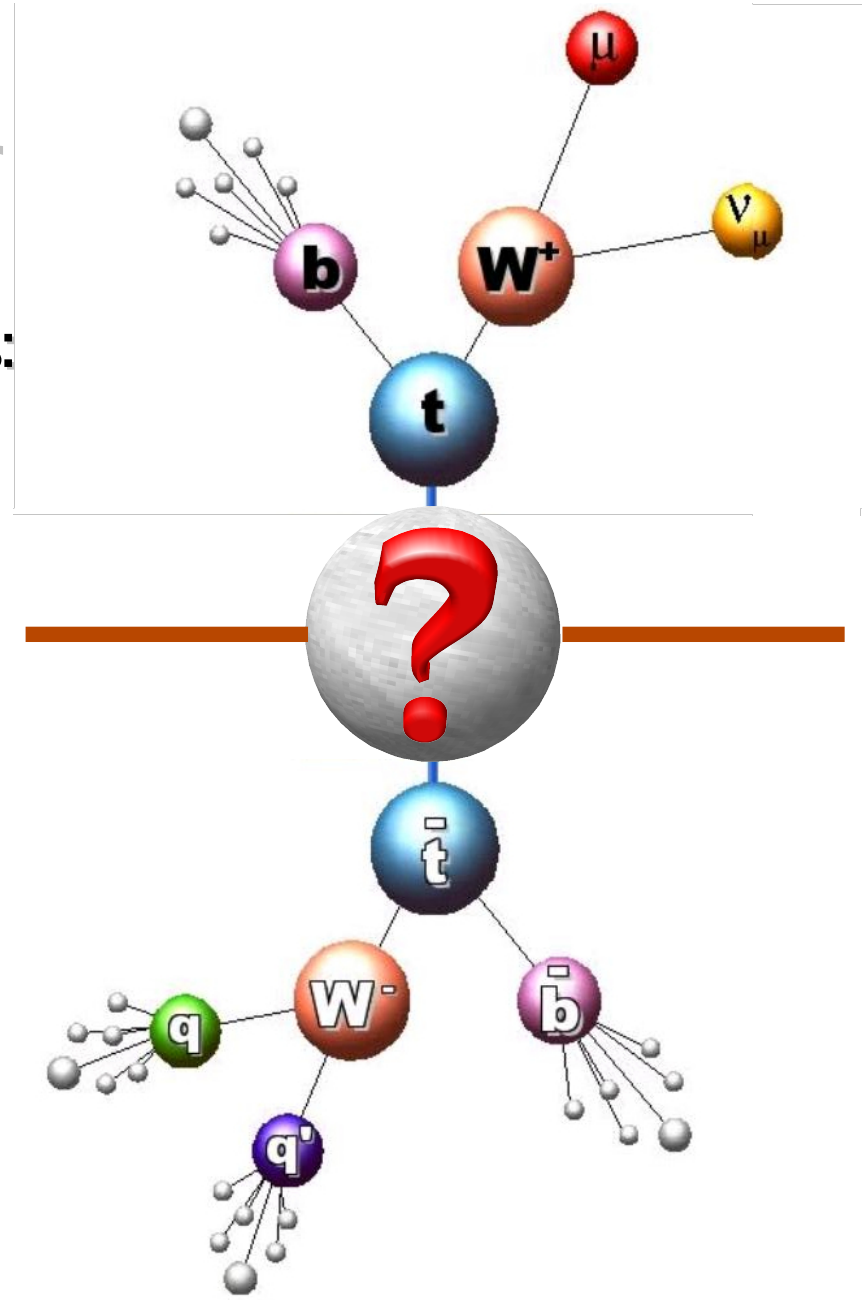
Search for resonances



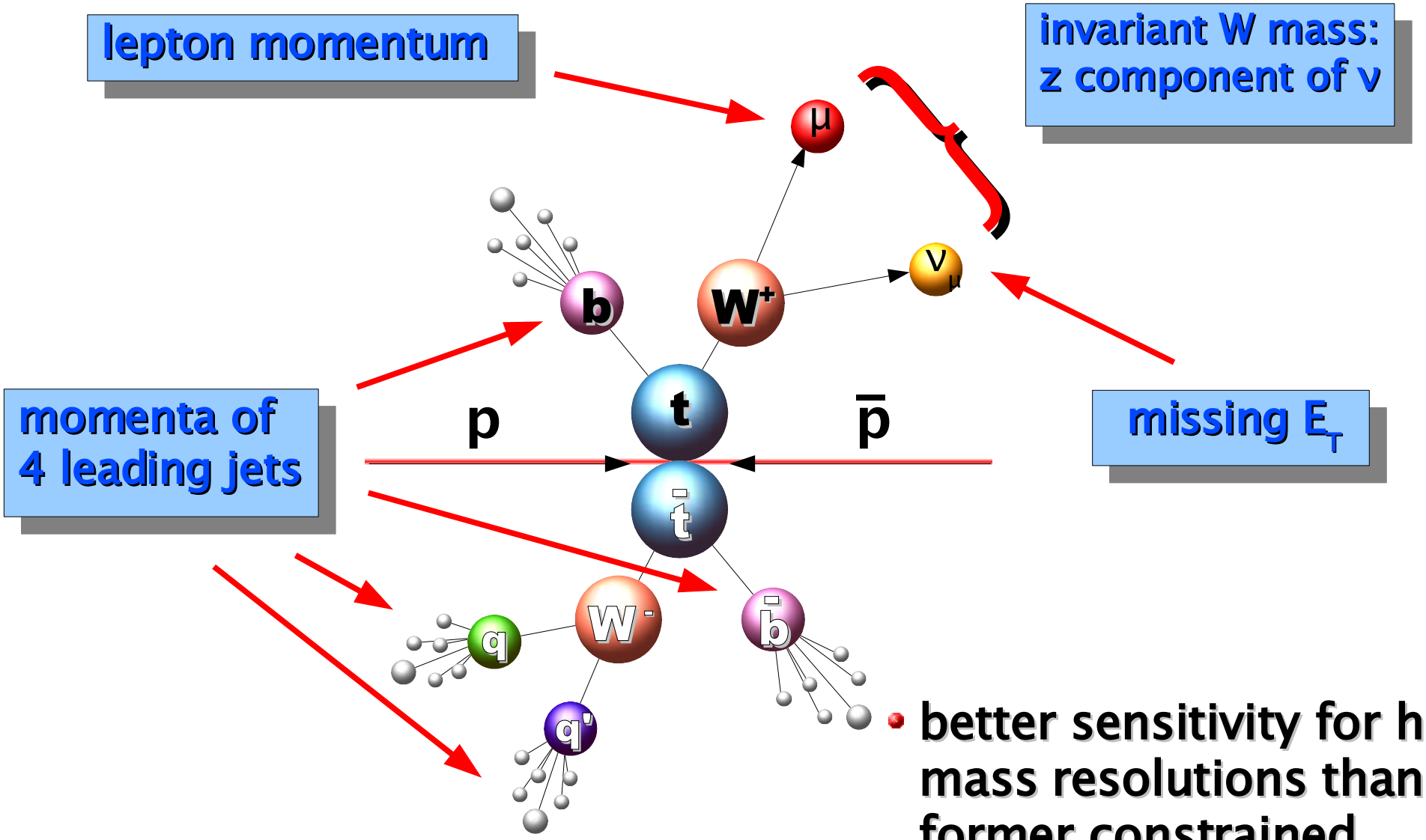
Search for $t\bar{t}$ Production via New Resonances

Harris, Hill, Parke, hep-ph/9911288

- no resonance production in ttbar system is expected in SM
- some models predict ttbar bound states: large top mass can be generated through dynamical ttbar condensate X formed by new strong gauge force coupling to 3rd generation
- e.g. topcolor assisted technicolor predicts leptophobic Z' with strong 3rd generation coupling
- experimental check: search for bumps in ttbar reconstructed mass spectrum
- sufficiently narrow so that width is dominated by detector effects



Reconstruction of $t\bar{t}$ invariant mass

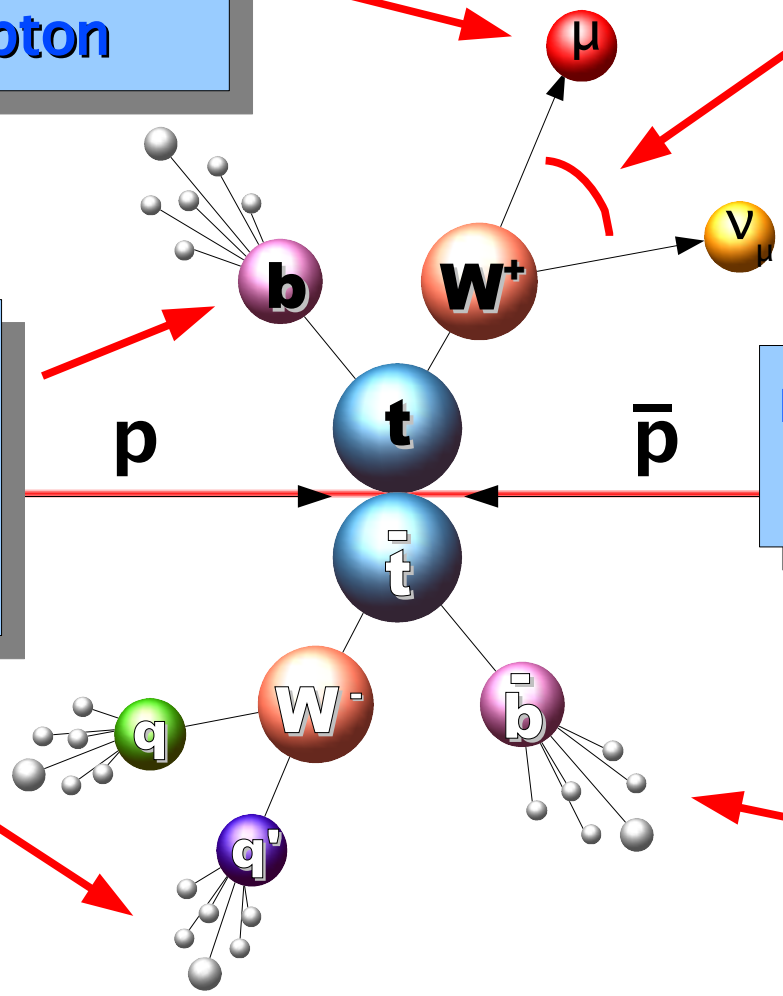


- better sensitivity for high mass resolutions than former constrained kinematic fit technique

Event Selection in Lepton+Jets

e (μ) isolated, $p_T > 20$ GeV,
$|\eta| < 1.1$ (2.0),
no other high p_T lepton

minimum $\Delta\phi$



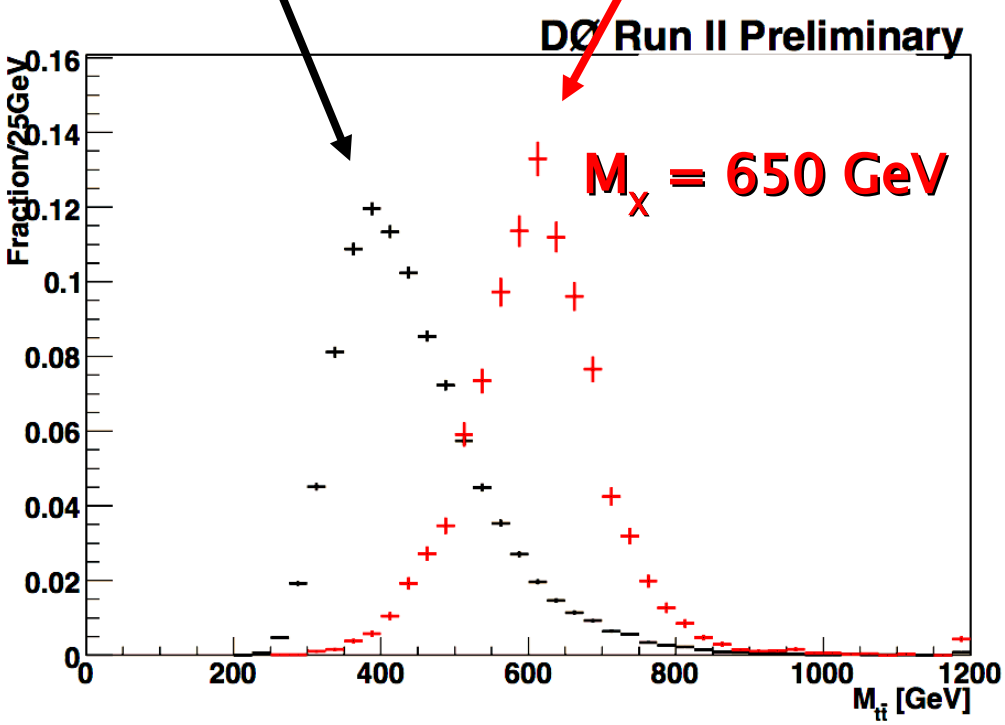
at least 4 jets,
$p_T > 20$ GeV,
$|\eta| < 2.5$,
one jet $p_T > 40$ GeV

missing $E_T > 20$ (25) GeV
for e (μ)+jets

at least 1 jet
b–tagged
(Neural
Network)

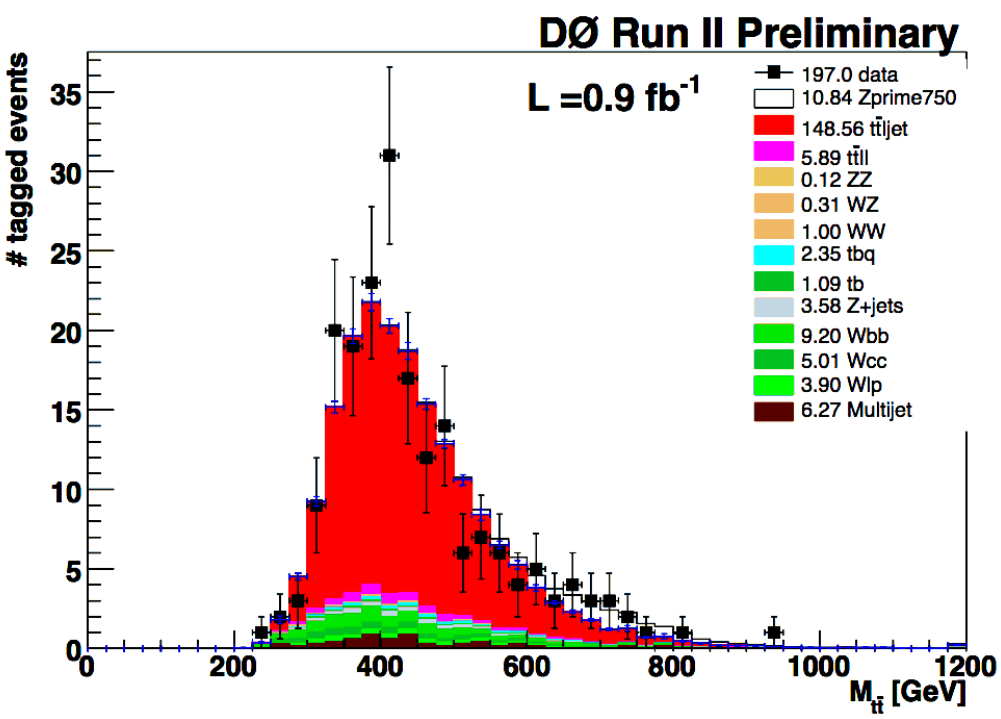
Results for e, μ + jets combined

top pair and signal:



data and SM:

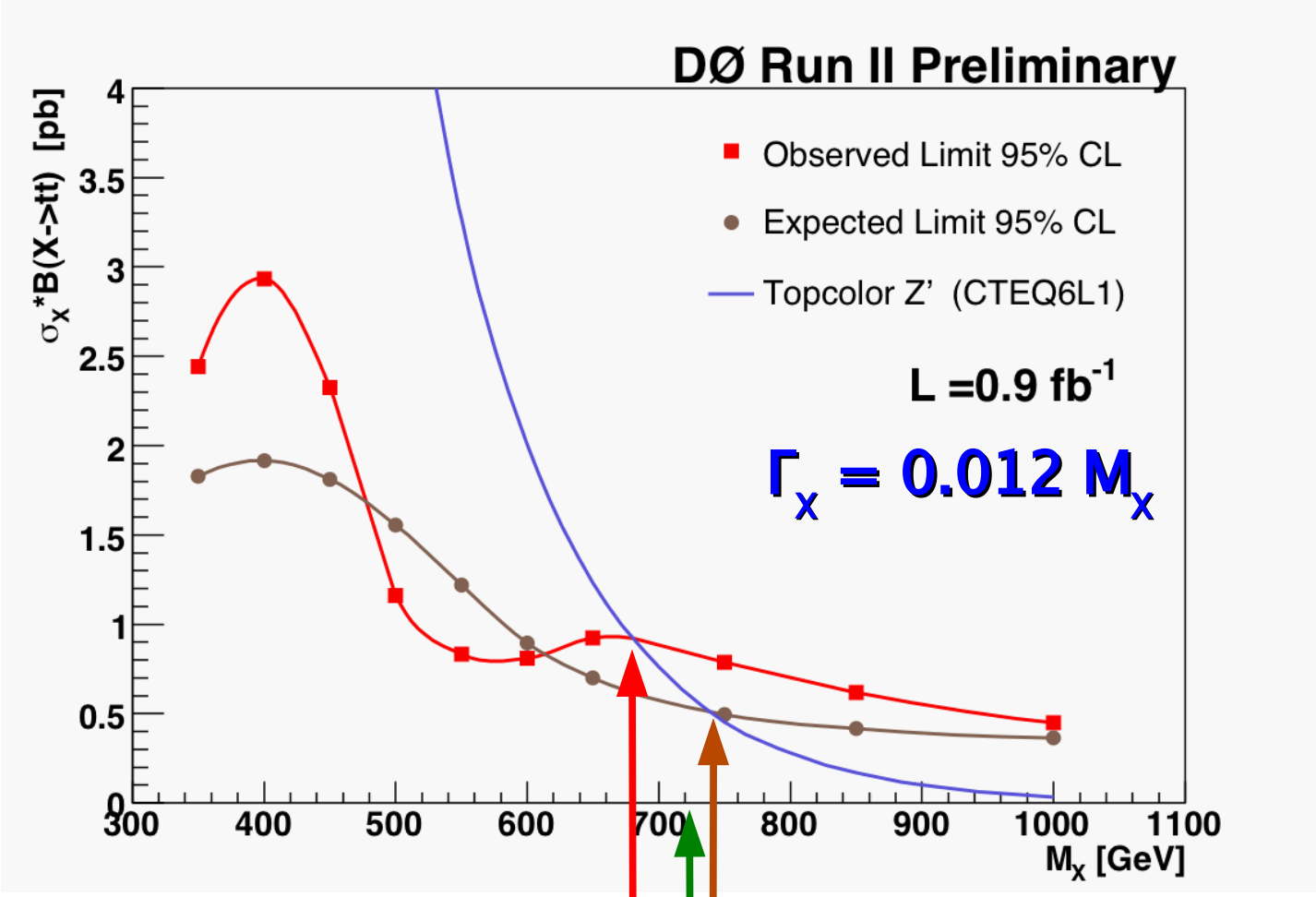
SM: use ttbar cross section
6.77 ± 0.60 pb (NLO+resummations)



⇒ e, μ + jets combined: 197 events, 187 expected

⇒ binned Likelihood fit to get upper limit

Limits for e, μ + jets combined



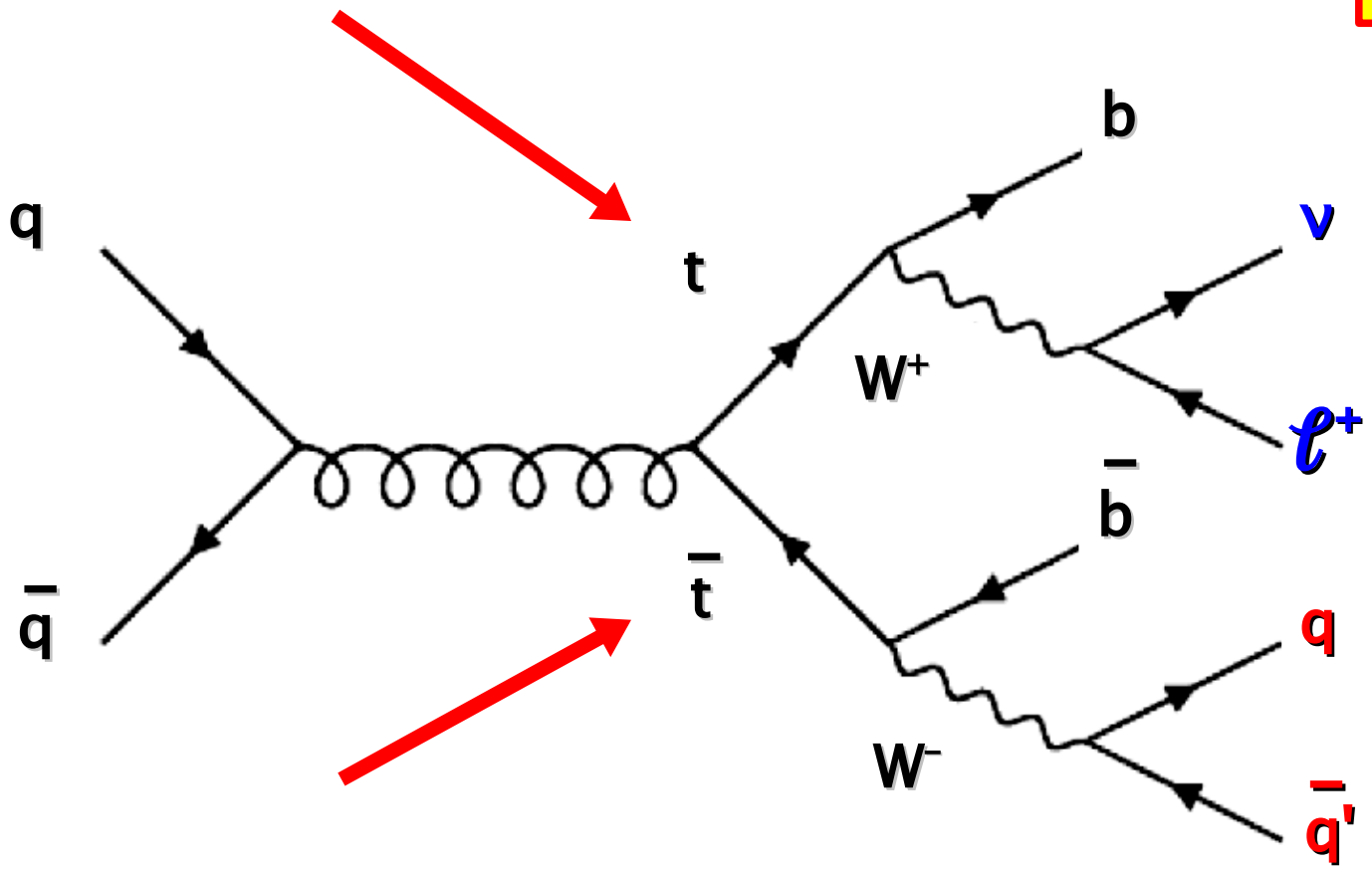
⇒ $M_{Z'}$ > 680 GeV

expected: $M_{Z'}$ > 740 GeV

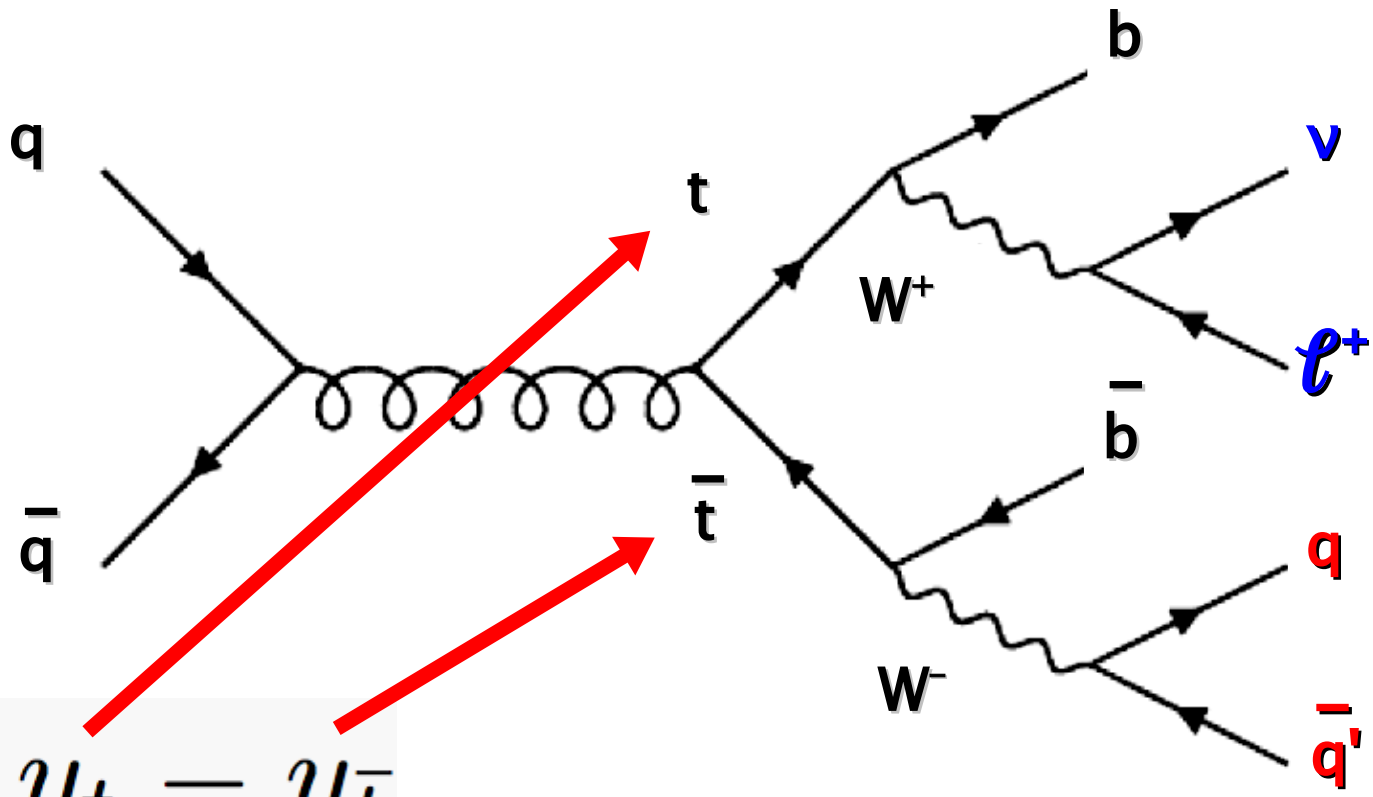
CDF: $M_{Z'}$ > 725 GeV

First measurement of charge asymmetry

NEW



Forward backward asymmetry



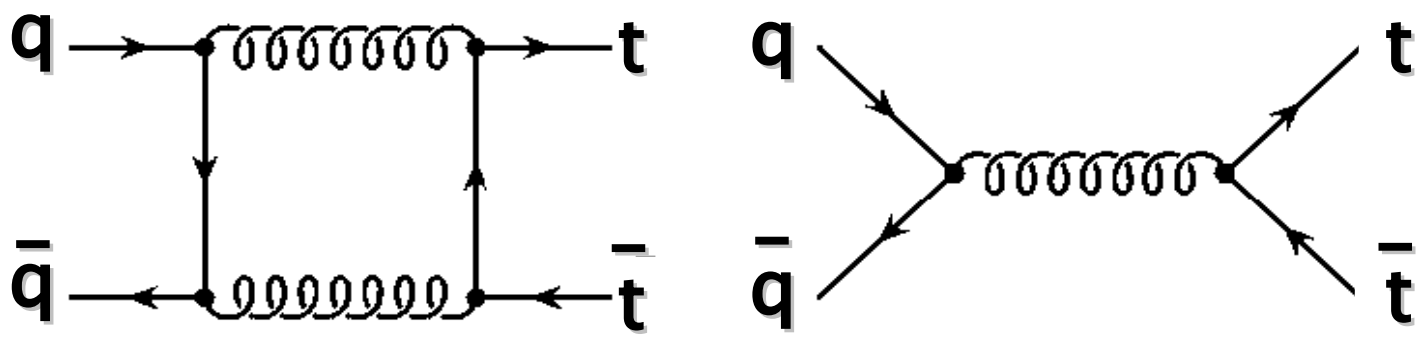
$$\Delta y \equiv y_t - y_{\bar{t}}$$

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

Charge asymmetry in SM

- no asymmetry in $O(\alpha_s^2)$
- asymmetry in $O(\alpha_s^3)$

interference between:



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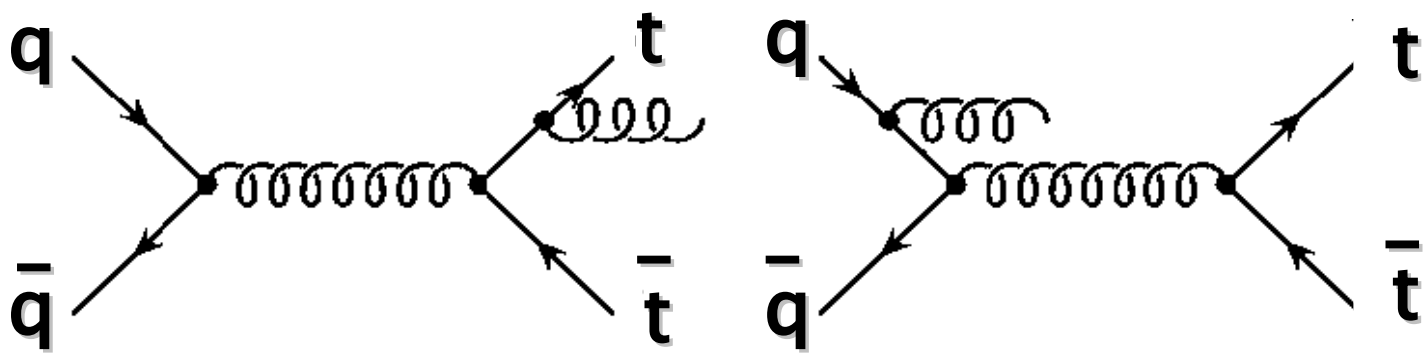
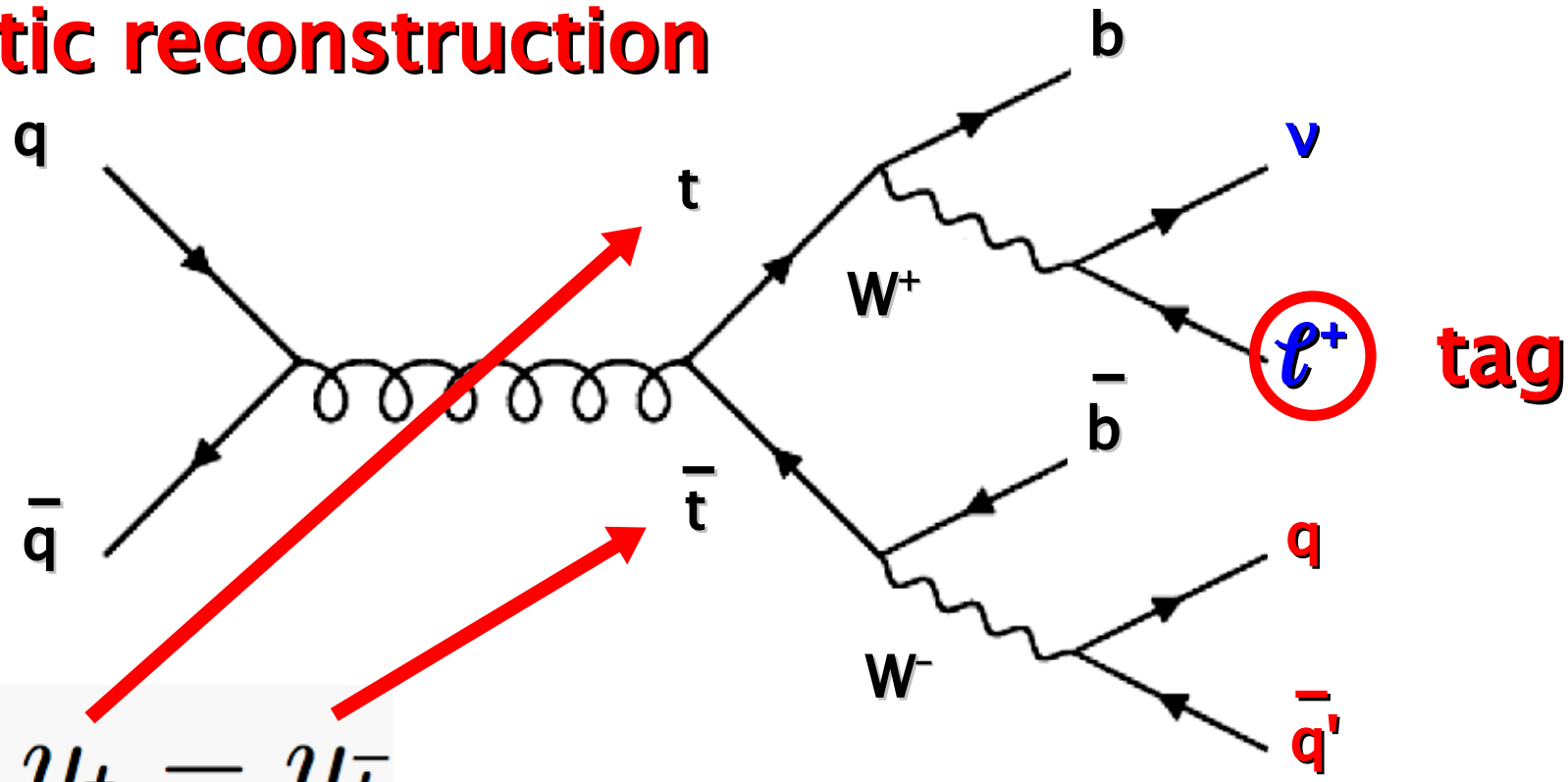


Measurement of charge asymmetry

kinematic reconstruction



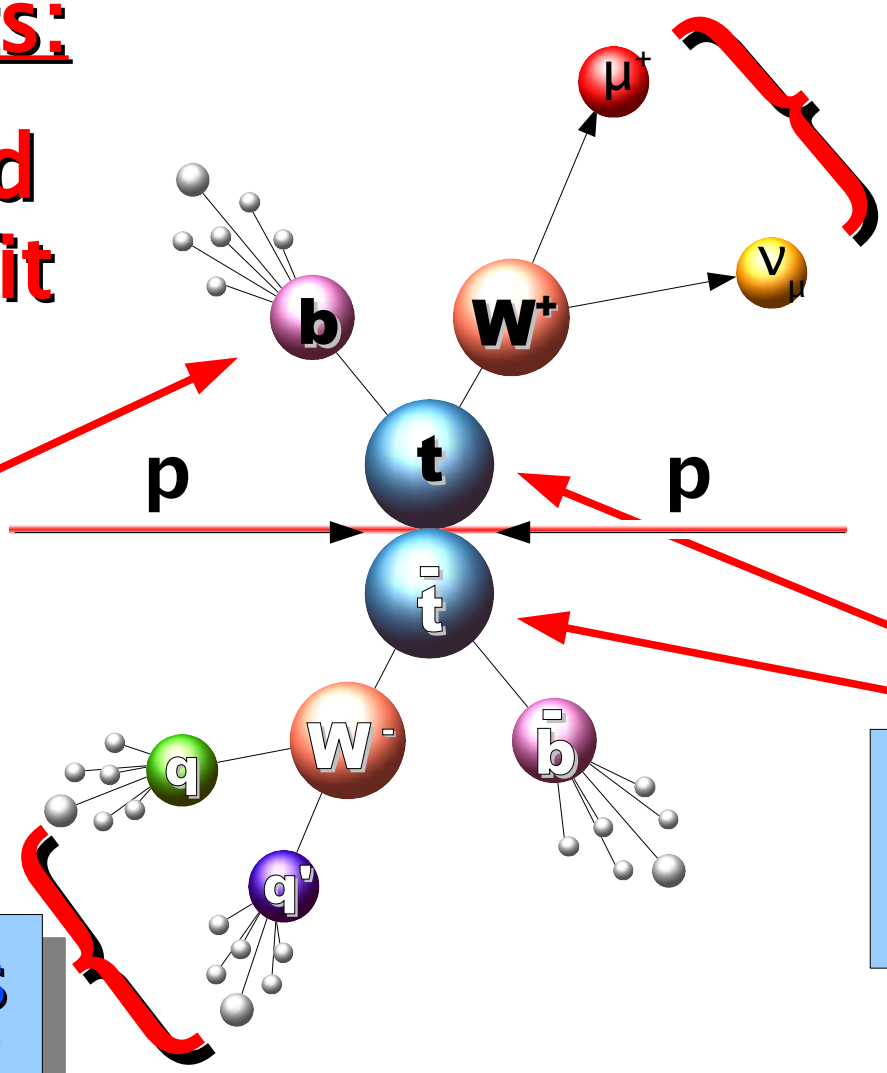
$$\Delta y \equiv y_t - y_{\bar{t}}$$

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

Top pair reconstruction

12 jet–parton assignments:

constrained kinematic fit lowest χ^2



invariant mass m_W=80.4 GeV (2 ν solutions)

b–tag

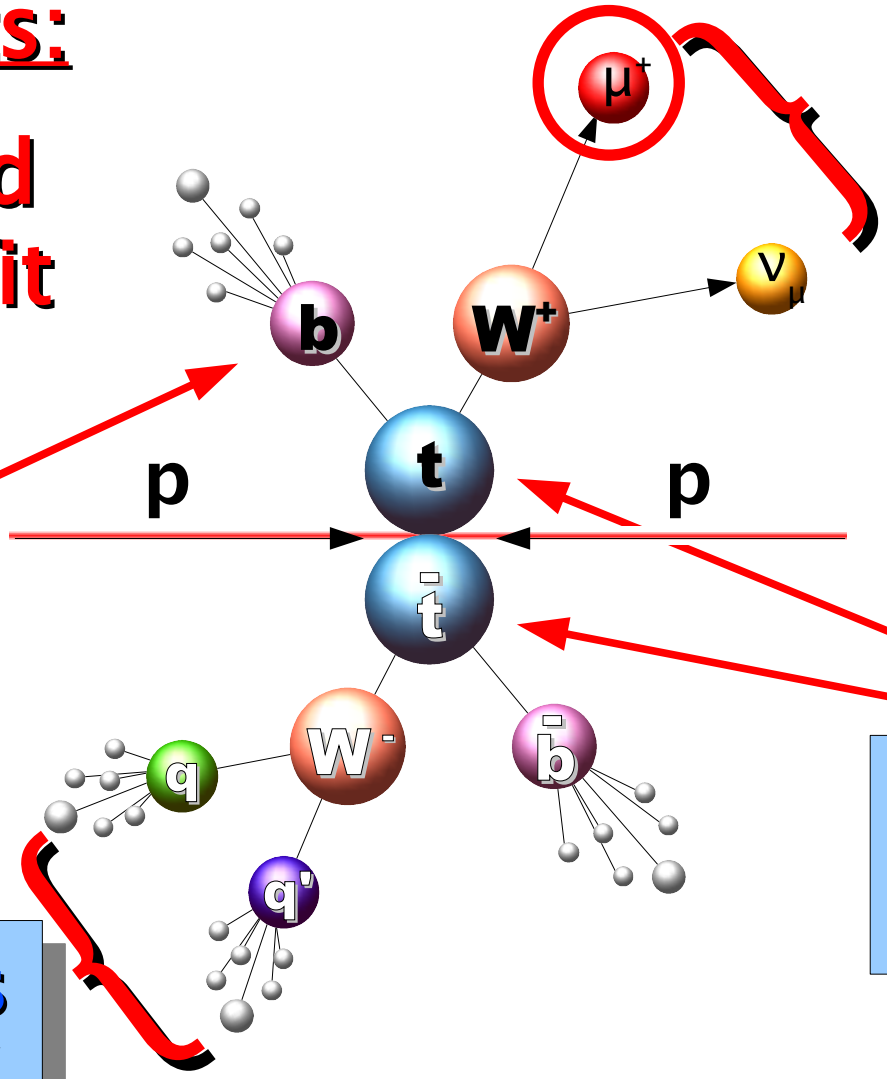
m_{top} = 175 GeV mass constraint

invariant mass m_W=80.4 GeV

Top pair reconstruction

12 jet–parton assignments:

constrained kinematic fit lowest χ^2



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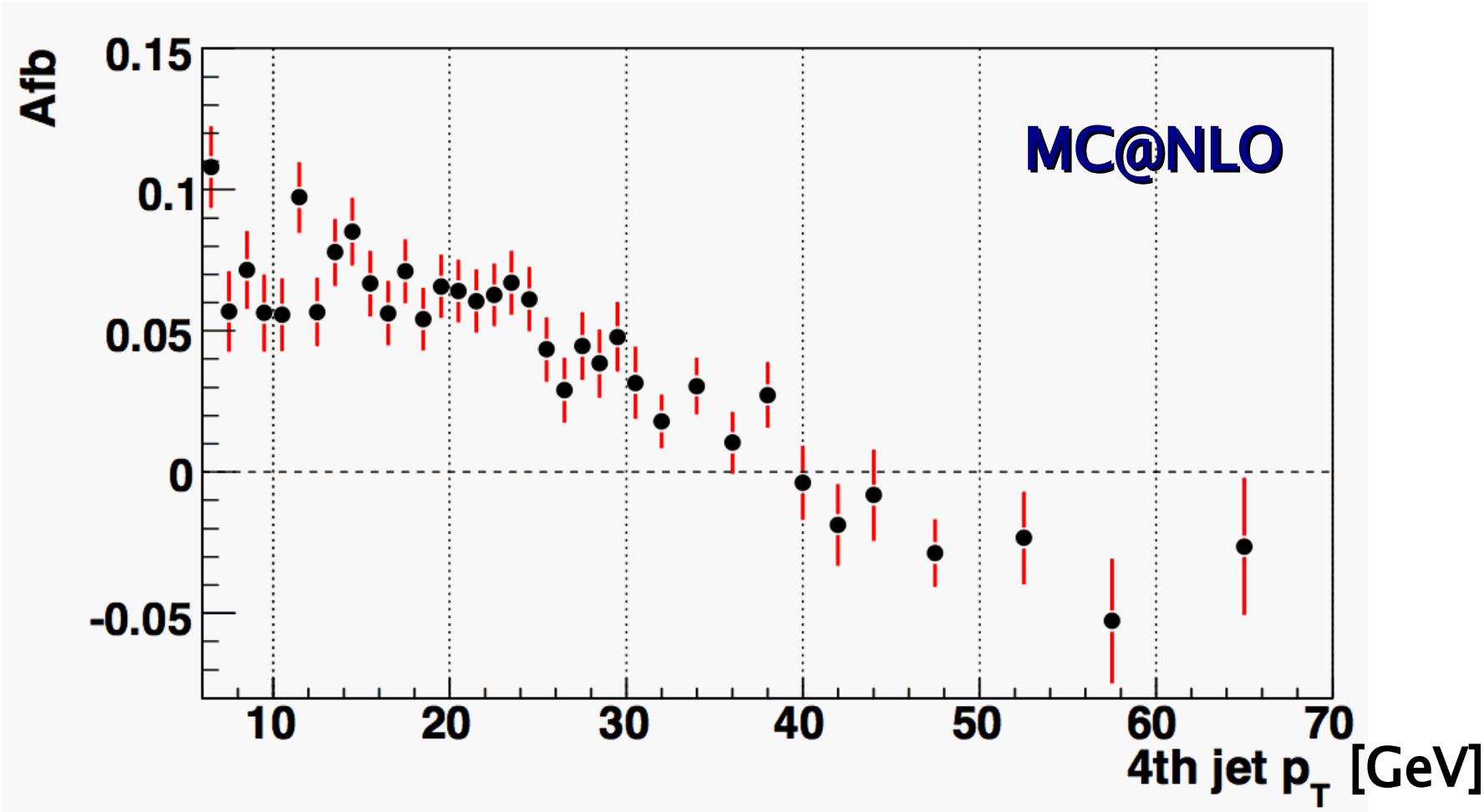
Charge asymmetry in SM

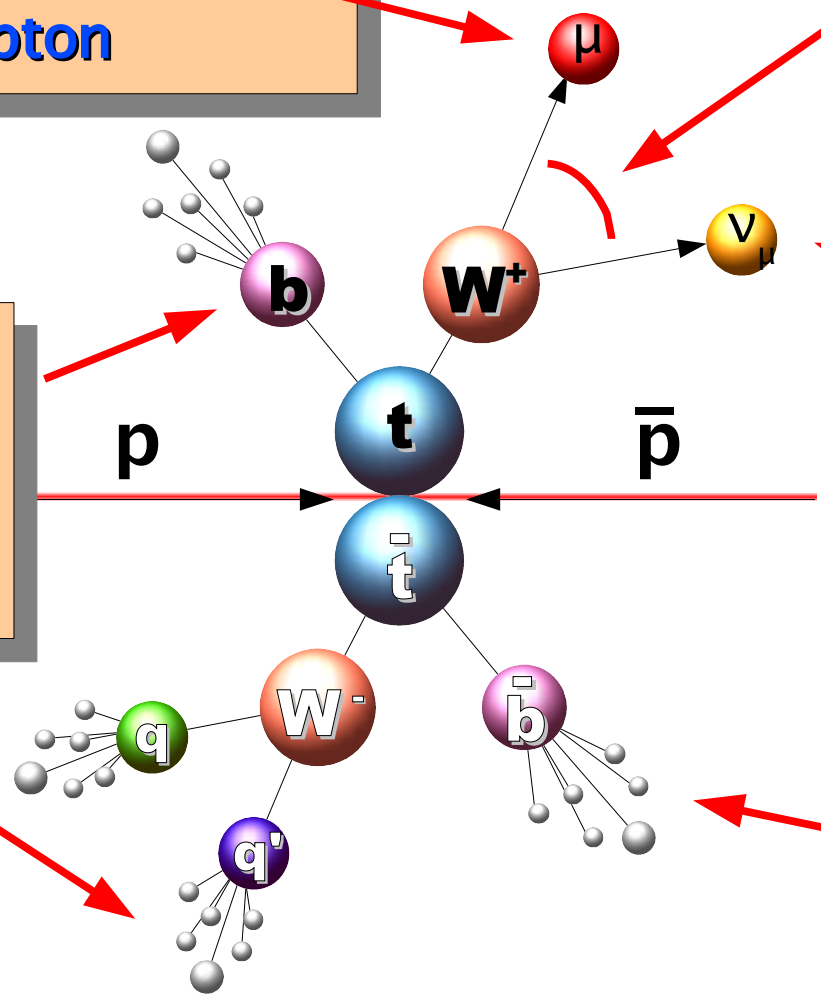


- acceptance effects can be approximated by simple parton level cuts without changing asymmetry by more than 2%

Event Selection in Lepton+Jets

e (μ) isolated, p_T > 15 (18) GeV,
|η|< 1.1 (2.0),
no other high p_T lepton

minimum Δφ



at least 4 jets,
p_T > 20 GeV,
|η|< 2.5,
one jet p_T > 35 GeV

missing E_T > 15 GeV
for e (μ)+jets

at least 1 jet
b–tagged
(Neural
Network)

Asymmetry Reconstruction

misreconstruction of Δy dilutes observed asymmetry:

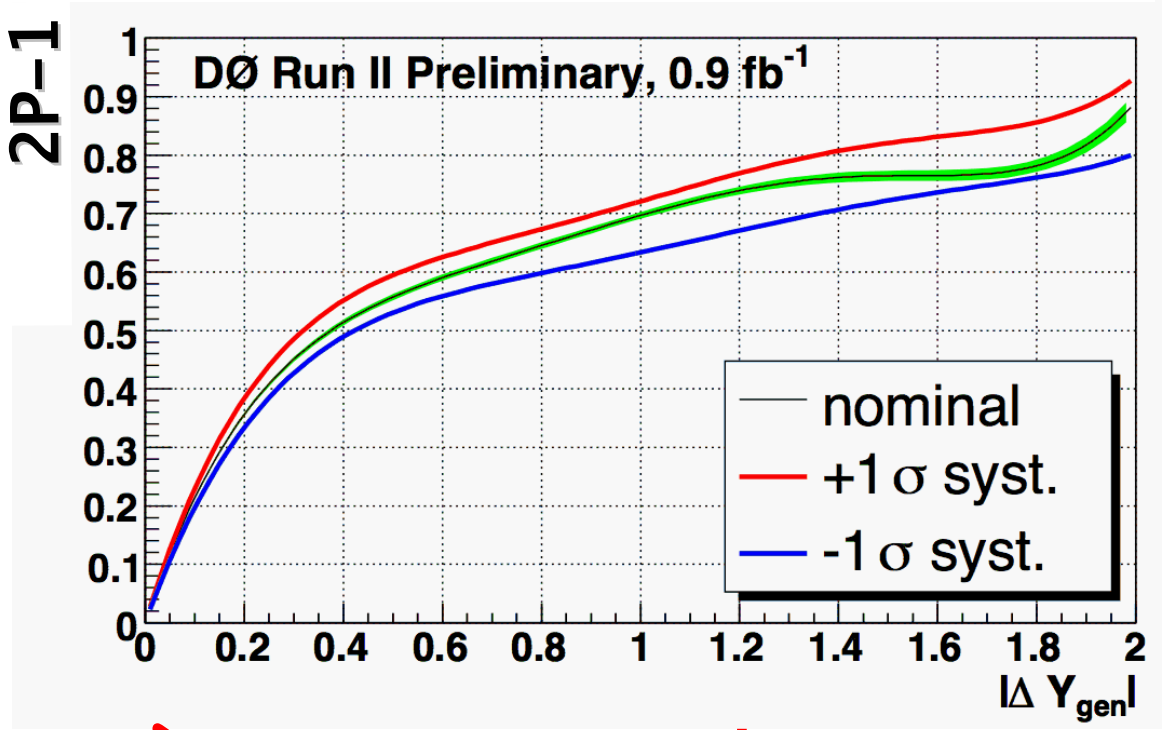
- misreconstruction of event geometry
- misidentification of lepton charge

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

How good are we?

P: is probability to reconstruct correct sign of Δy

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



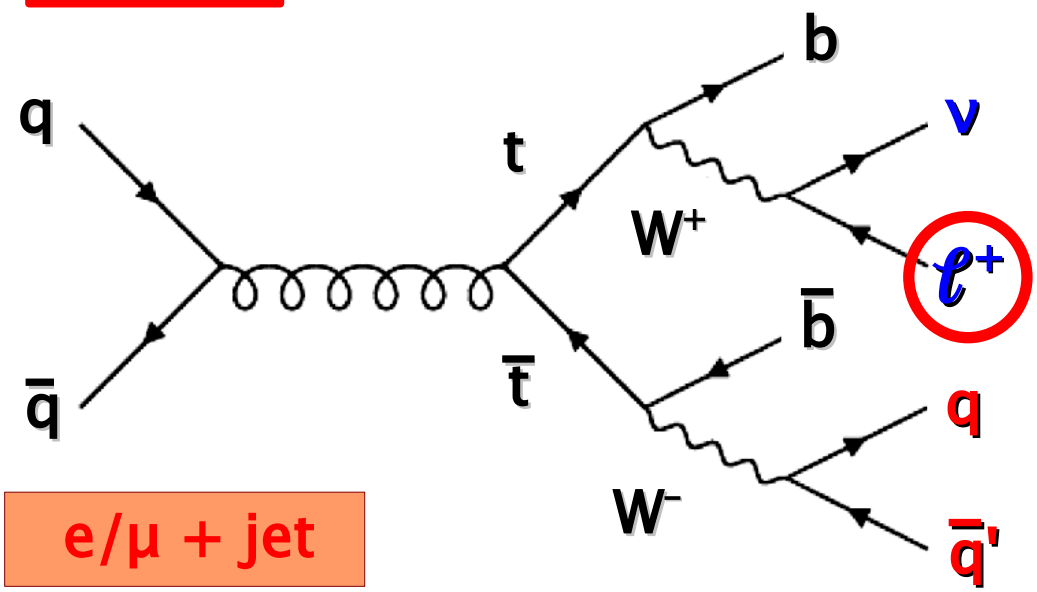
- correction is very model dependent and may kill sensitivity to asymmetry due to new physics...

⇒ no correction, but we provide parameterization

Top anti-top signatures

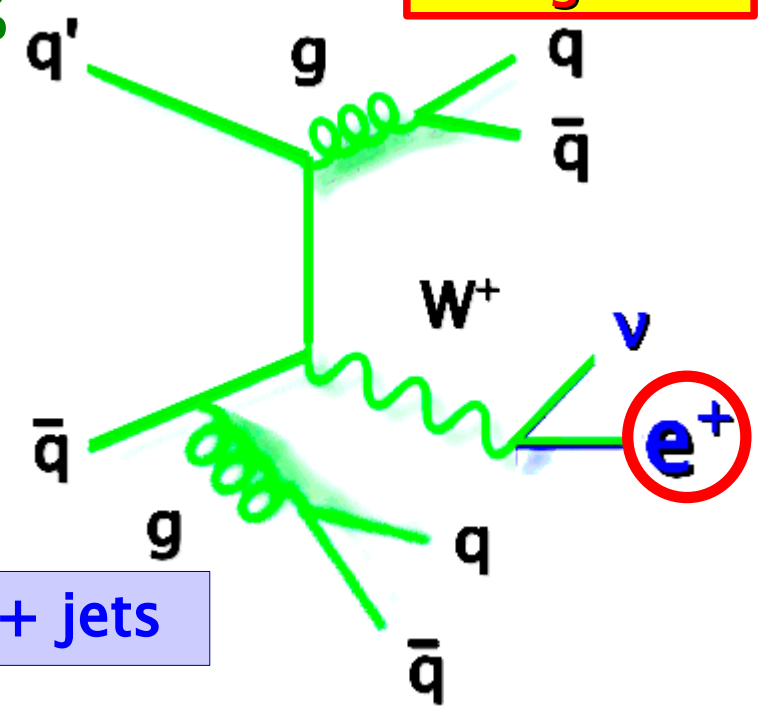
$A_{fb,W}$ = (3.0 ± 1.9) %
(due to top pair reconstruction)
but smaller yield

signal

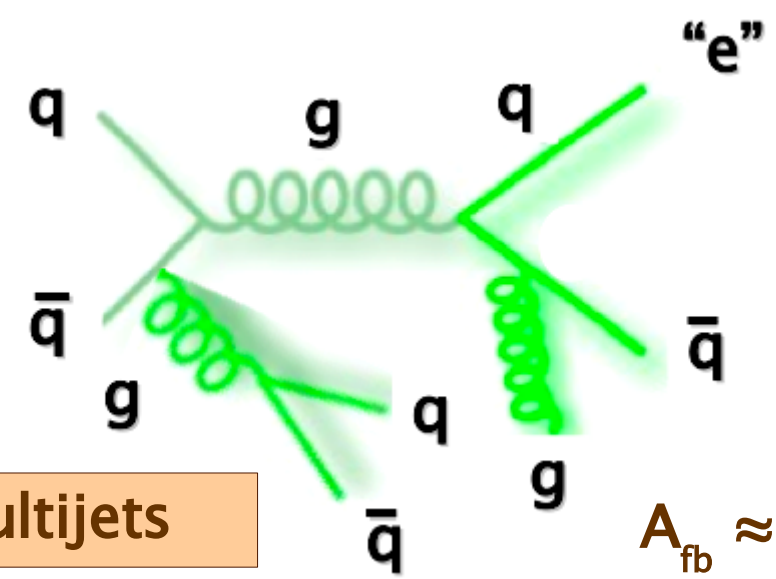


e/μ + jet

background



W + jets



multijets

$A_{fb} \approx 0$

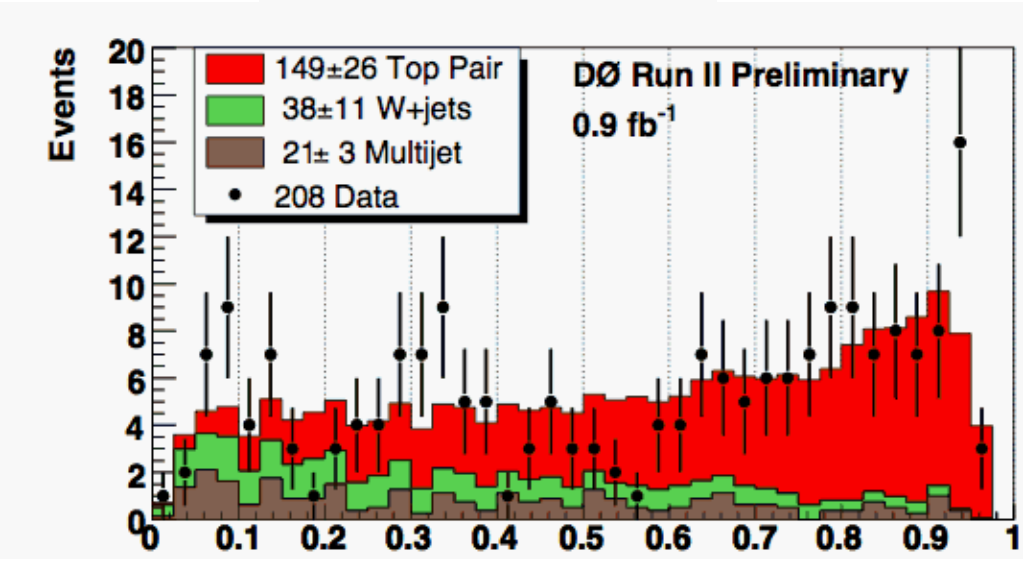
MC@NLO:

A_{fb} = (0.8 ± 0.2 (stat) ± 1.0 (accept)) %

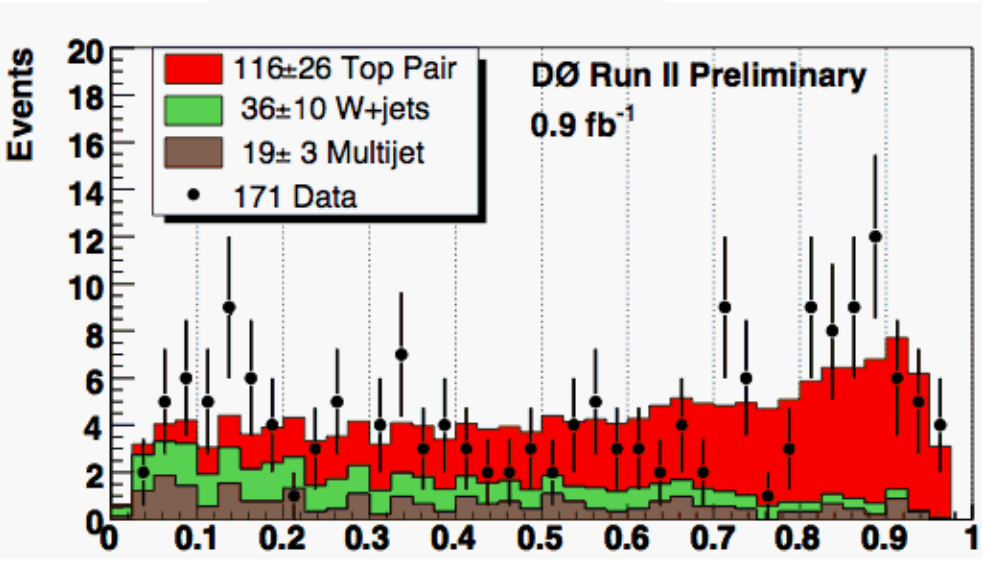
Asymmetry extraction

- **maximum Likelihood fit:**
  extract sample composition and asymmetry simultaneously

$$\Delta y \equiv y_t - y_{\bar{t}} > 0$$



$$\Delta y \equiv y_t - y_{\bar{t}} < 0$$



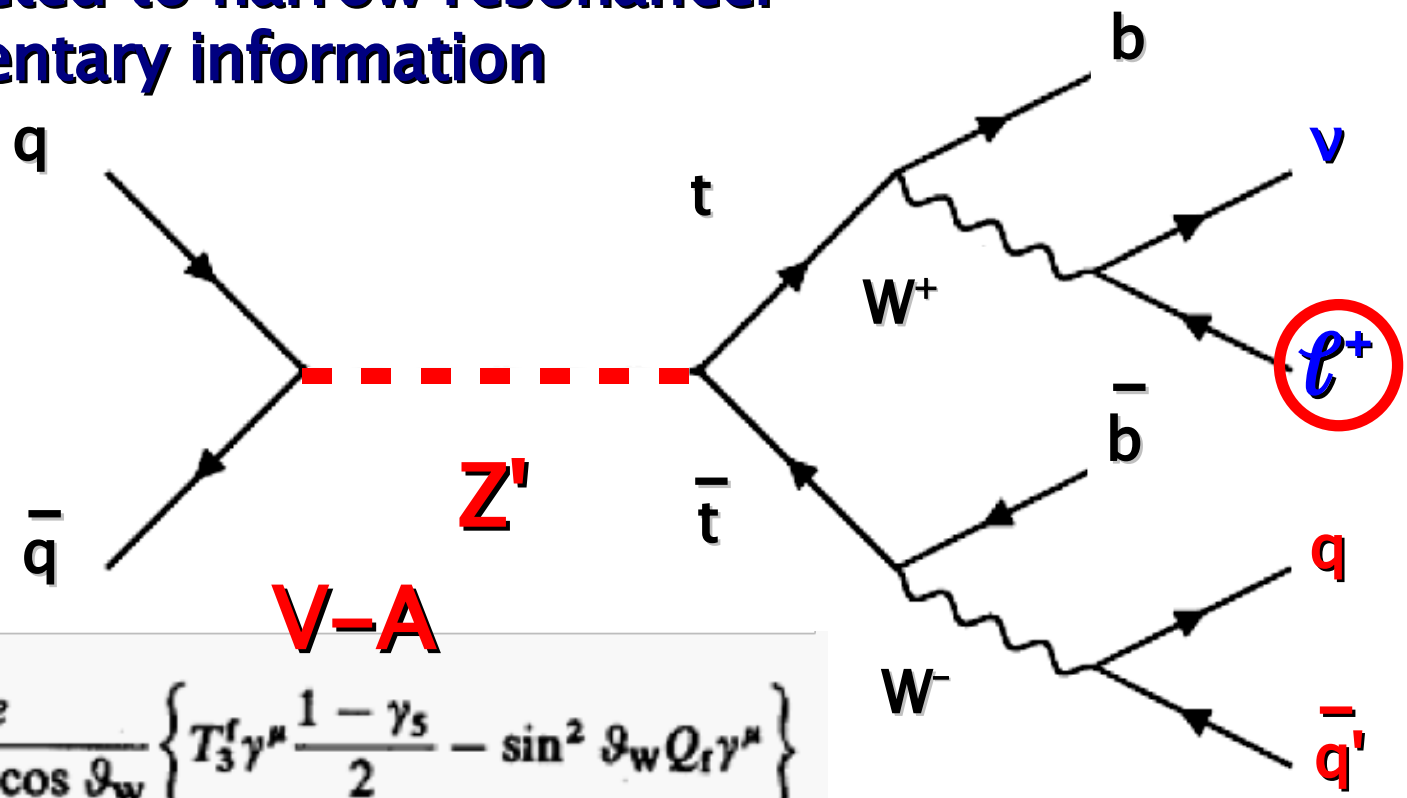
- **top pair production cross sections consistent**
- **asymmetry in W+jets enriched sample consistent**

$$A_{fb} = (12 \pm 8 \text{ (stat)} \pm 1 \text{ (syst)}) \%$$

consistent with prediction in NLO QCD

Asymmetry due to leptophobic Z'

not restricted to narrow resonance: complementary information



V−A

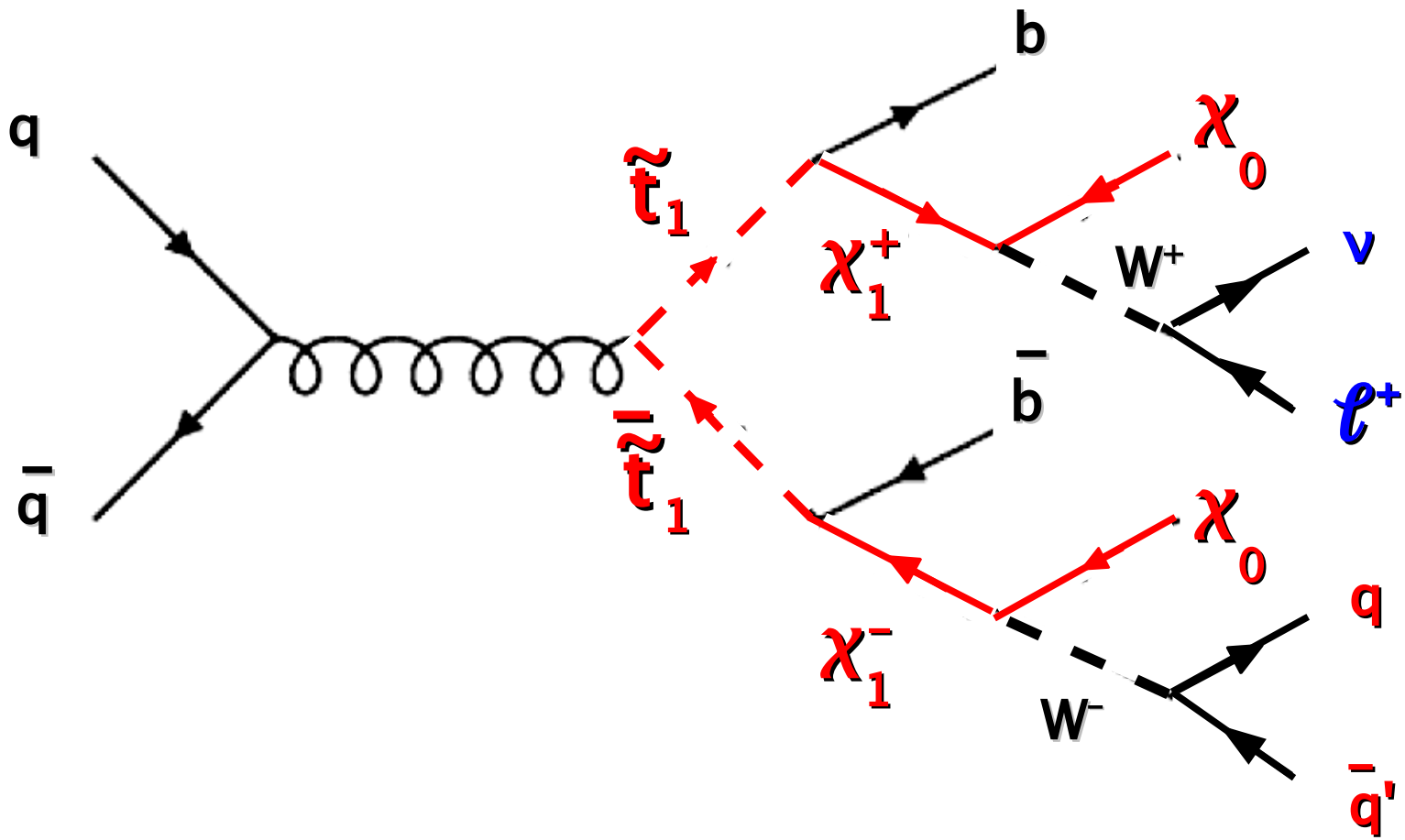
$$-i\frac{e}{\sin\vartheta_W\cos\vartheta_W}\left\{T_3^f\gamma^\mu\frac{1-\gamma_5}{2}-\sin^2\vartheta_W Q_f\gamma^\mu\right\}$$

F: fraction of top pair events produced via Z' resonance

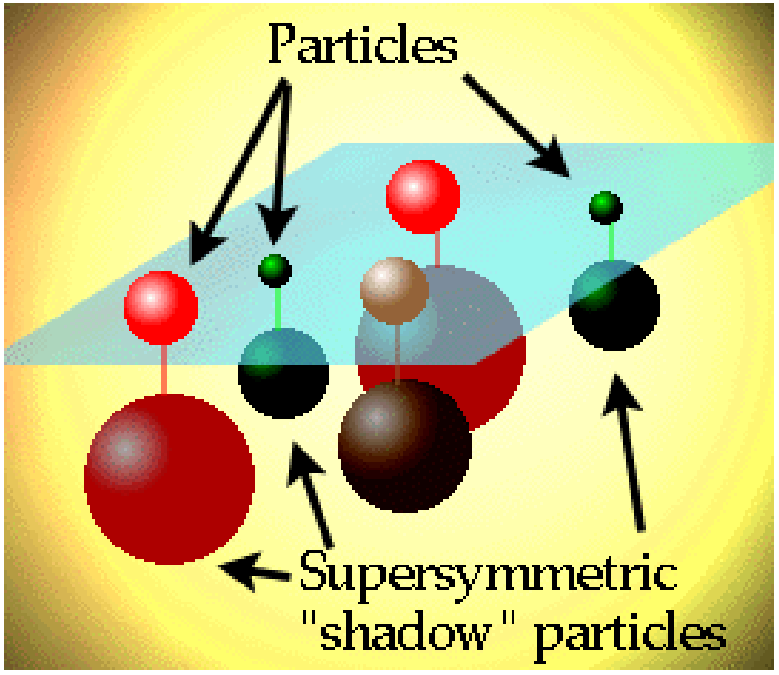
e.g. $M_{Z'}$ = 750 GeV:

F < 0.44 (expected)
F < 0.81 (observed)

Search for stop pair production



Supersymmetry



Name	Spin	Superpartner	Spin
Electron	1/2	Selectron	0
Muon	1/2	Smuon	0
Tau	1/2	Stau	0
Neutrino	1/2	Sneutrino	0
Quark	1/2	Squark	0

Name	Spin	Superpartner	Spin
Graviton	2	Gravitino	3/2
Photon	1	Photino	1/2
Gluon	1	Gluino	1/2
$W^{+,-}$	1	$Wino^{+,-}$	1/2
Z^0	1	Zino	1/2
Higgs	0	Higgsino	1/2

Supersymmetry

- large top quark mass: large mixing between left- and right-handed superpartners
- $\tilde{t}_1$ can be lightest squark, lighter than top quark
- electroweak baryogenesis possible in such a scenario
- we haven't looked at it before...

Name	Spin	Superpartner	Spin
Electron	1/2	Selectron	0
Muon	1/2	Smuon	0
Tau	1/2	Stau	0
Neutrino	1/2	Sneutrino	0
Quark	1/2	Squark	0

stop quark

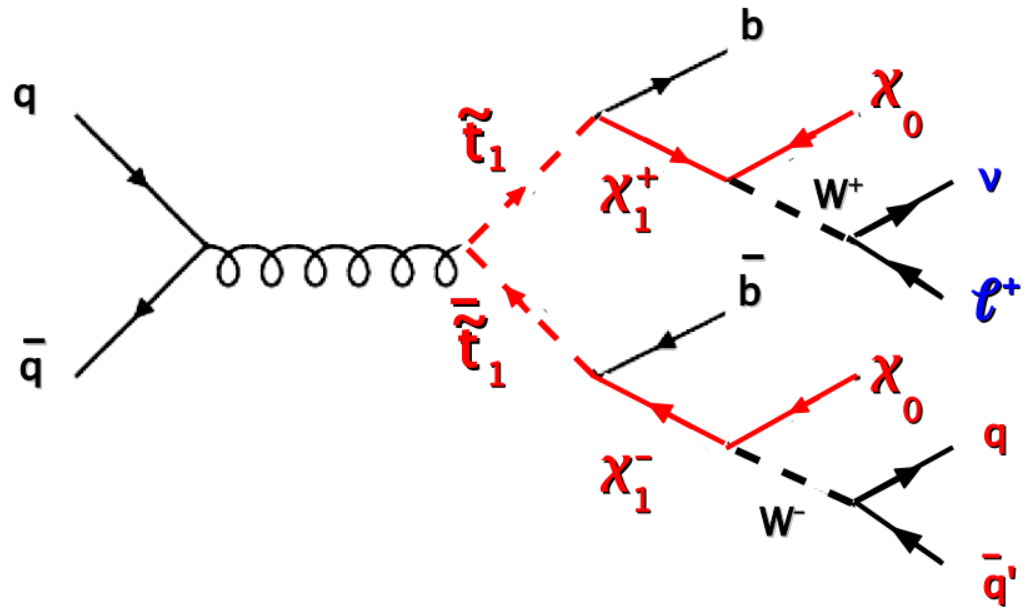
Name	Spin	Superpartner	Spin
Graviton	2	Gravitino	3/2
Photon	1	Photino	1/2
Gluon	1	Gluino	1/2
$W^{+,-}$	1	$\text{Wino}^{+,-}$	1/2
Z^0	1	Zino	1/2
Higgs	0	Higgsino	1/2

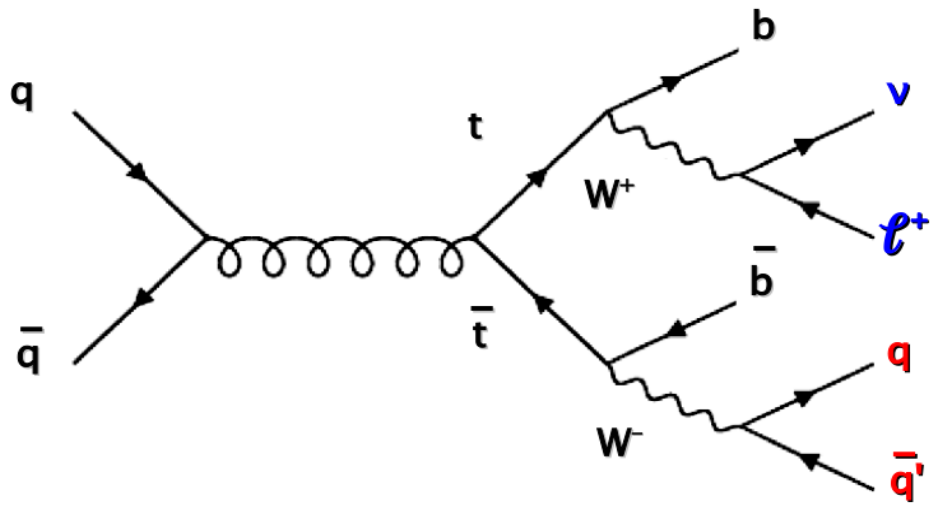
χ^+

χ^0 (LSP)

Stop pair production vs. top pair production

- 2 light jets
- 2 b jets
- one charged lepton
- missing transverse energy





Event Selection in Lepton+Jets

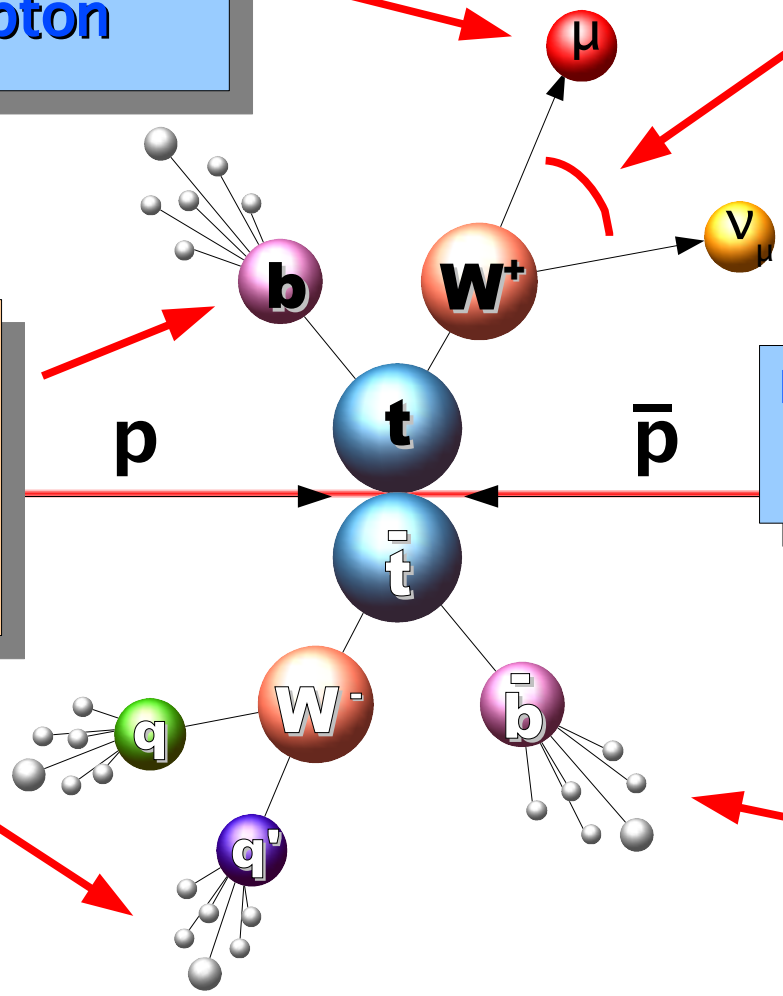
e (μ) isolated, $p_T > 20$ GeV,
$|\eta| < 1.1$ (2.0),
no other high p_T lepton

minimum $\Delta\phi$

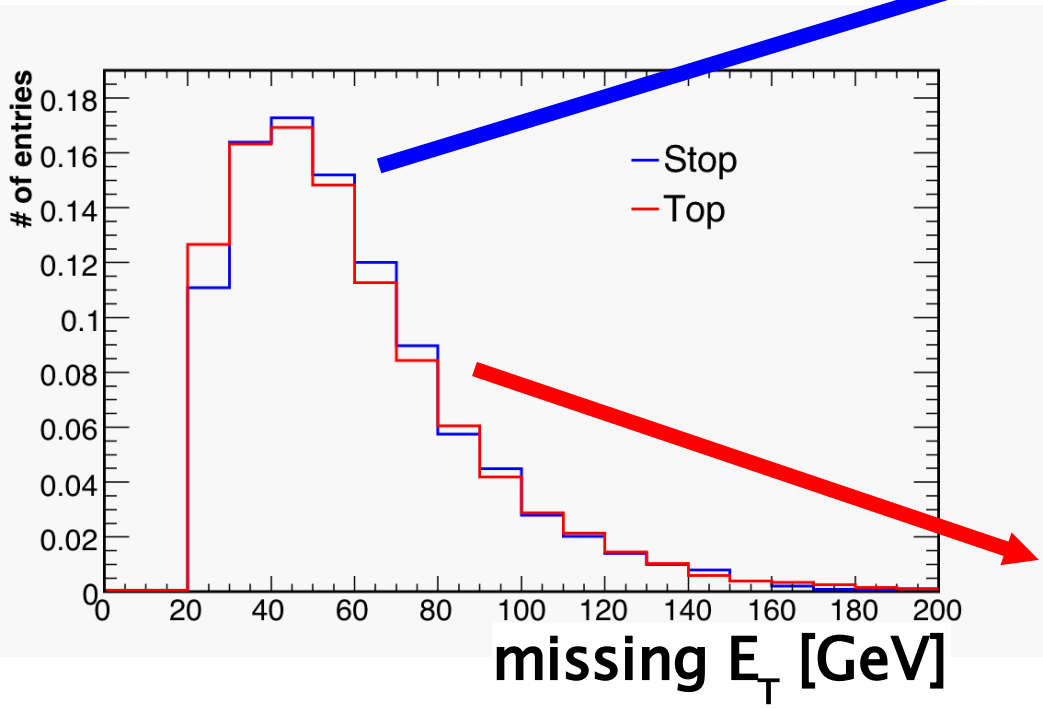
at least 4 jets,
$p_T > 15$ GeV,
$|\eta| < 2.5$,
one jet $p_T > 40$ GeV

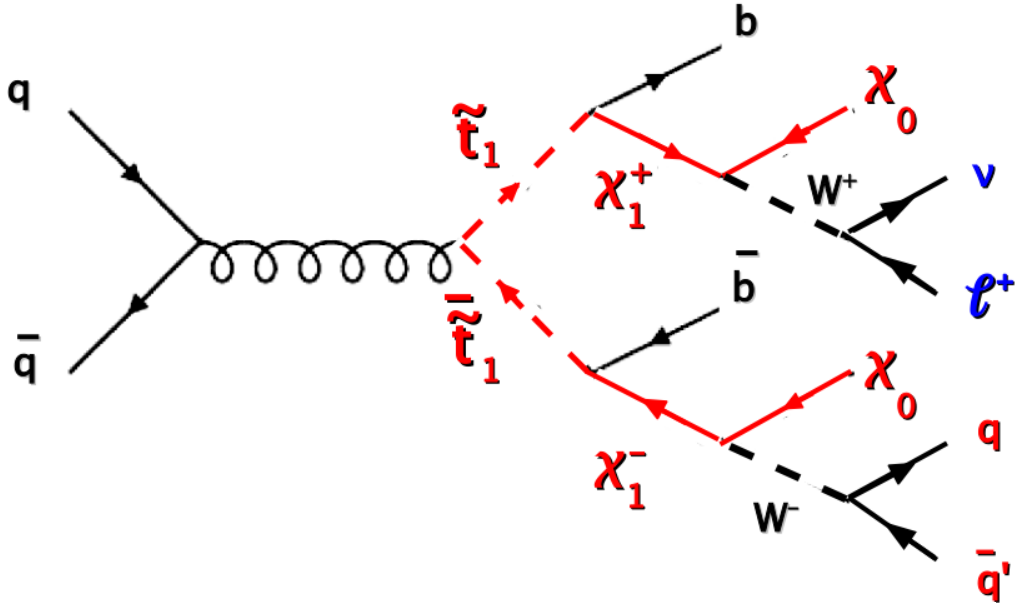
missing $E_T > 20$ (25) GeV
for e (μ)+jets

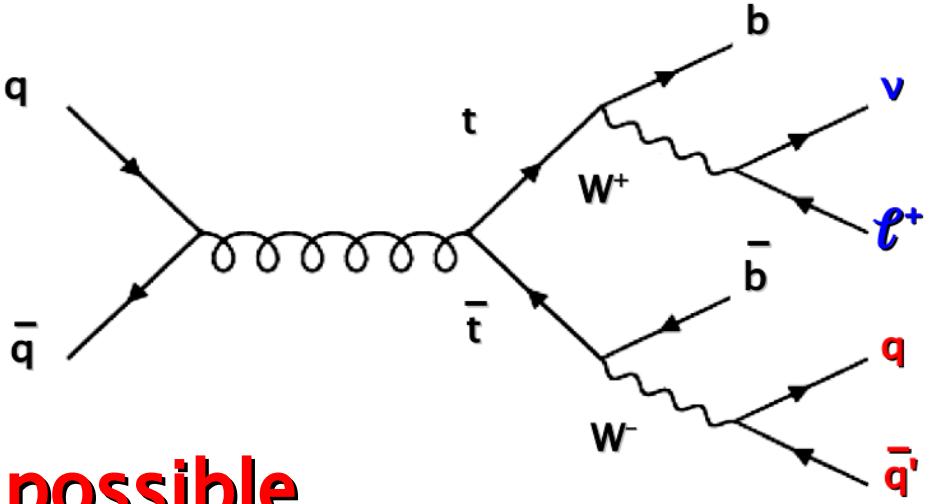
at least 1 jet
b–tagged
(Neural
Network)



Stop pair production vs. top pair production



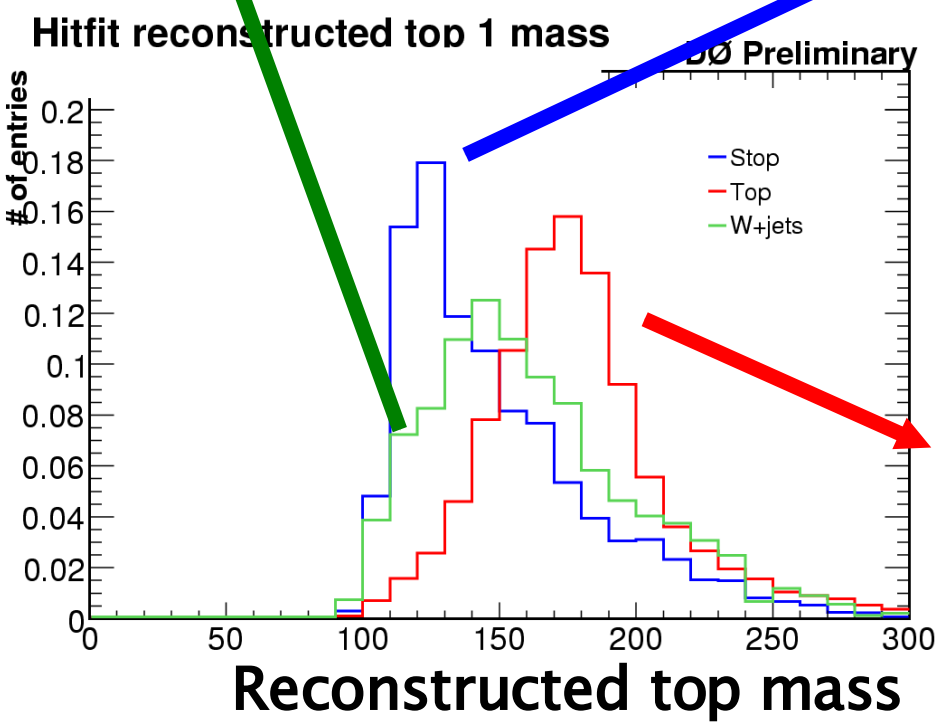


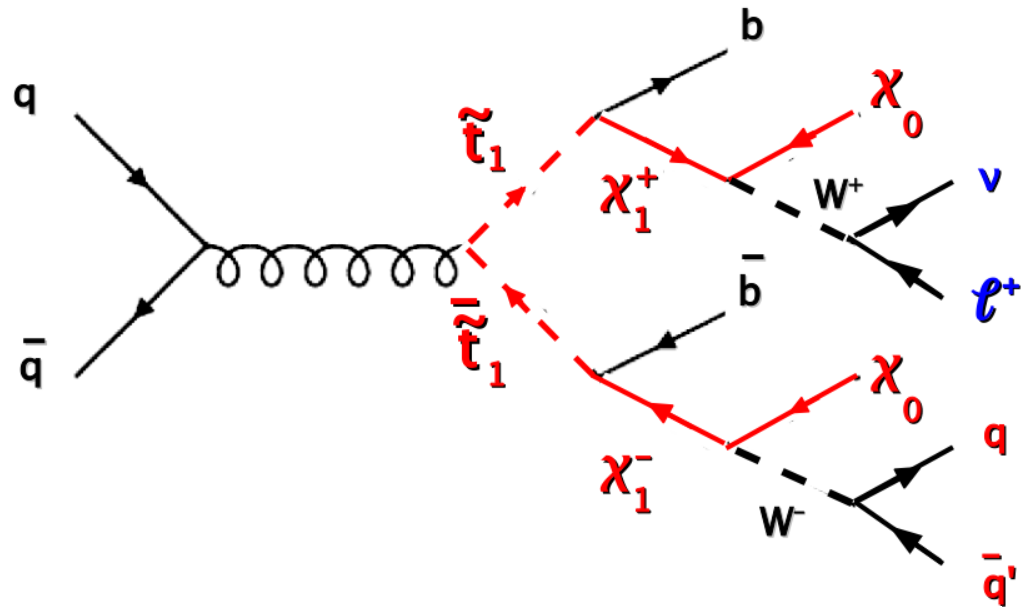


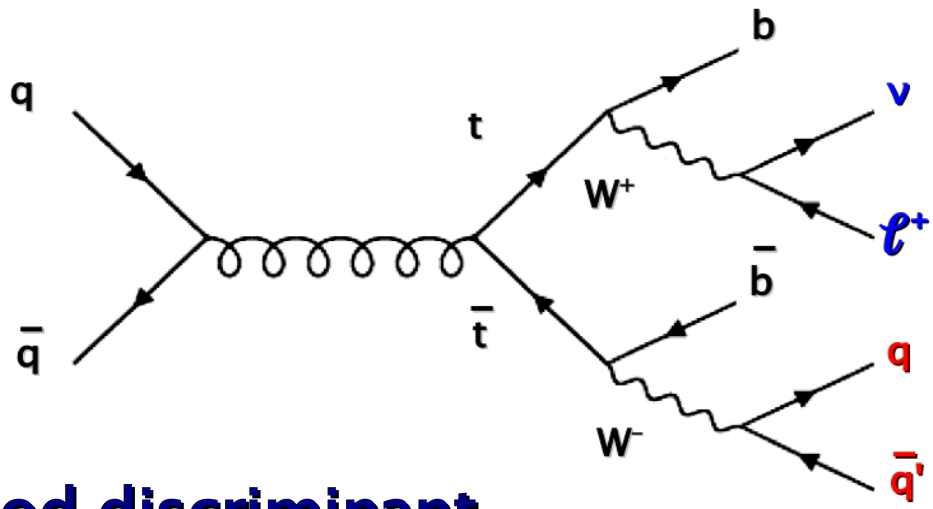
⇒ no cut based separation possible

Stop pair production vs. top pair production

W+jets

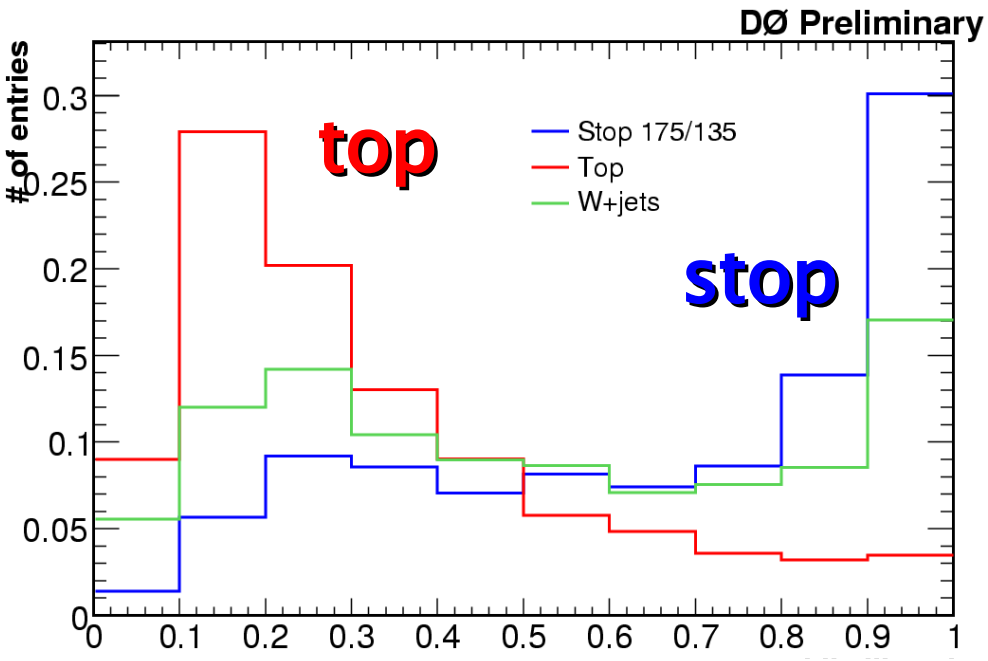


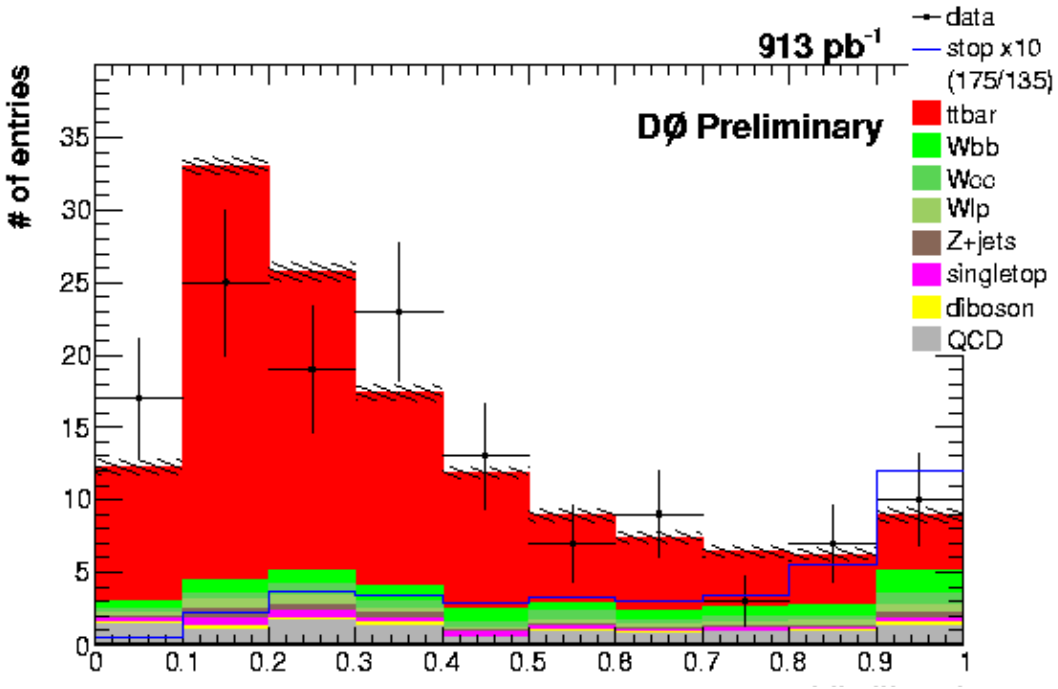




⇒ **calculate topological Likelihood discriminant**

Likelihood discriminant in e+jets channel

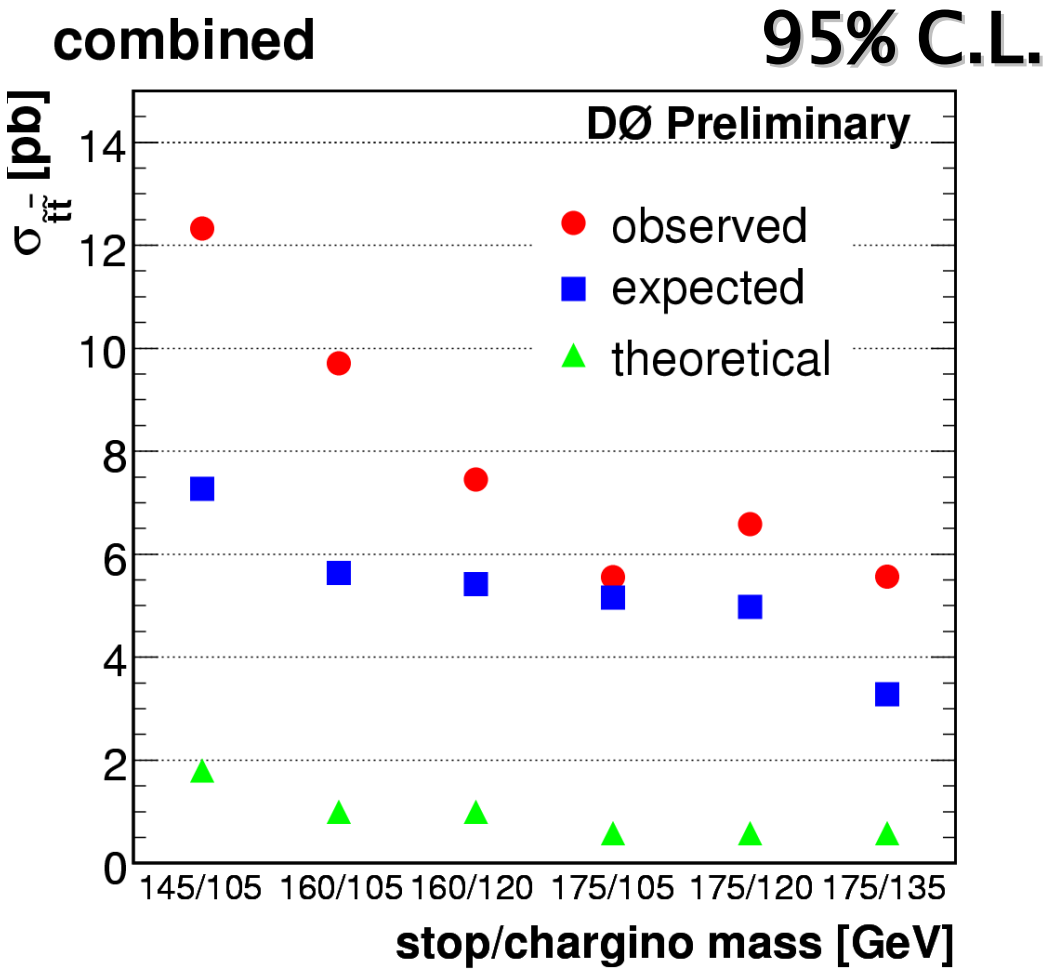




⇒ **no indication for stop pair production**

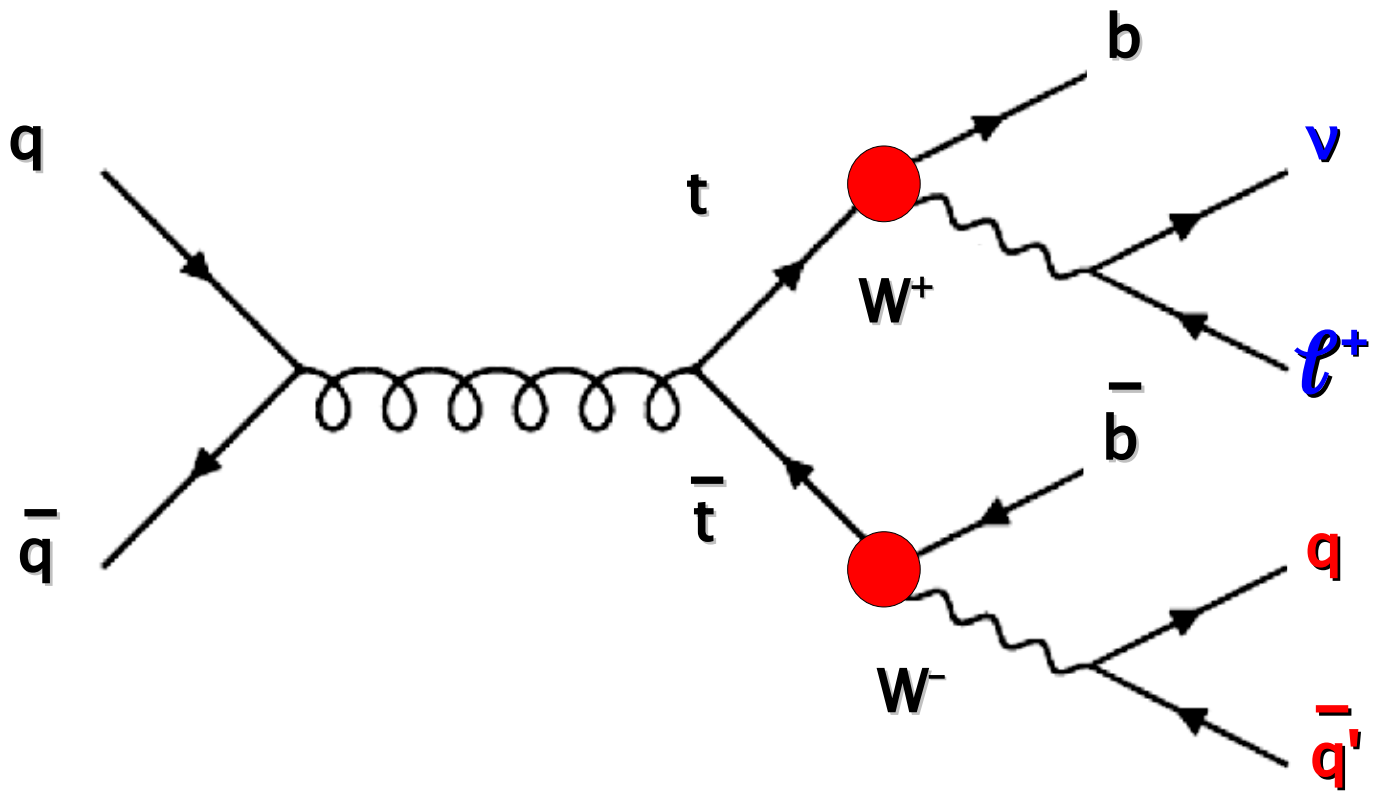
Cross section limits for e,μ+jets combined

use Likelihood discriminant to calculate limits (Bayesian approach)



⇒ **limits are factor ≈7–12 above MSSM prediction**

Search for new physics in top decays



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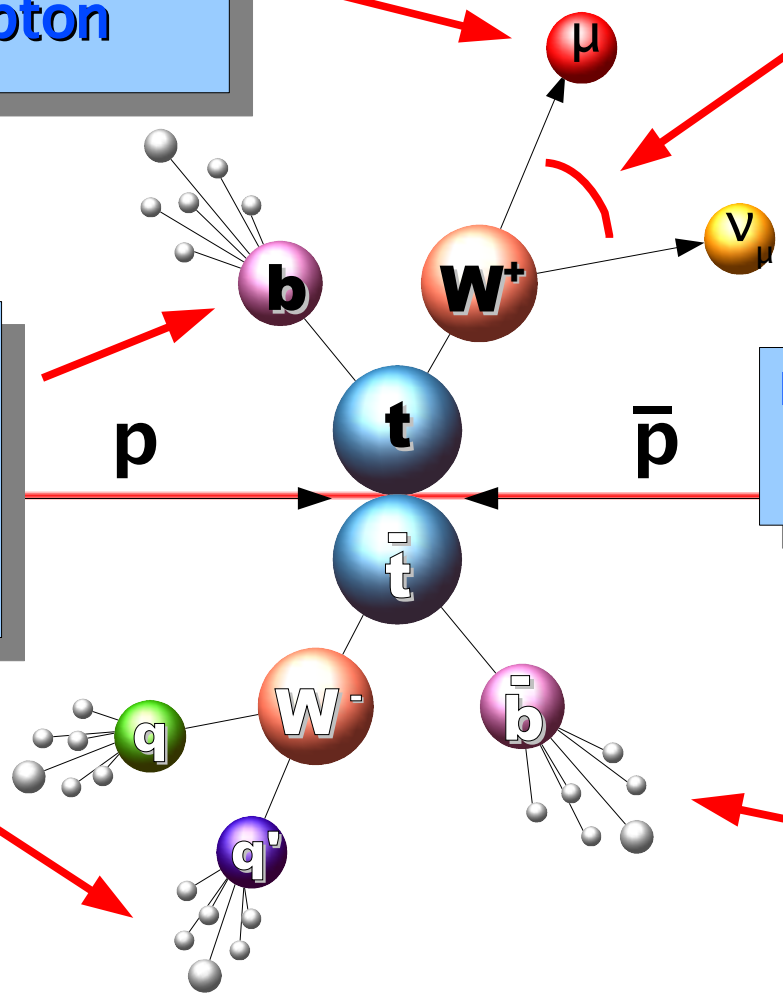
$|\eta| < 2.5$,
one jet $p_T > 40$ GeV

missing $E_T > 20$ (25) GeV
for e (μ)+jets

0, 1 or 2 jets
b–tagged
(Neural
Network)



Measurement of Branching Fractions

$$R = \frac{B(t \to Wb)}{B(t \to Wq)}$$

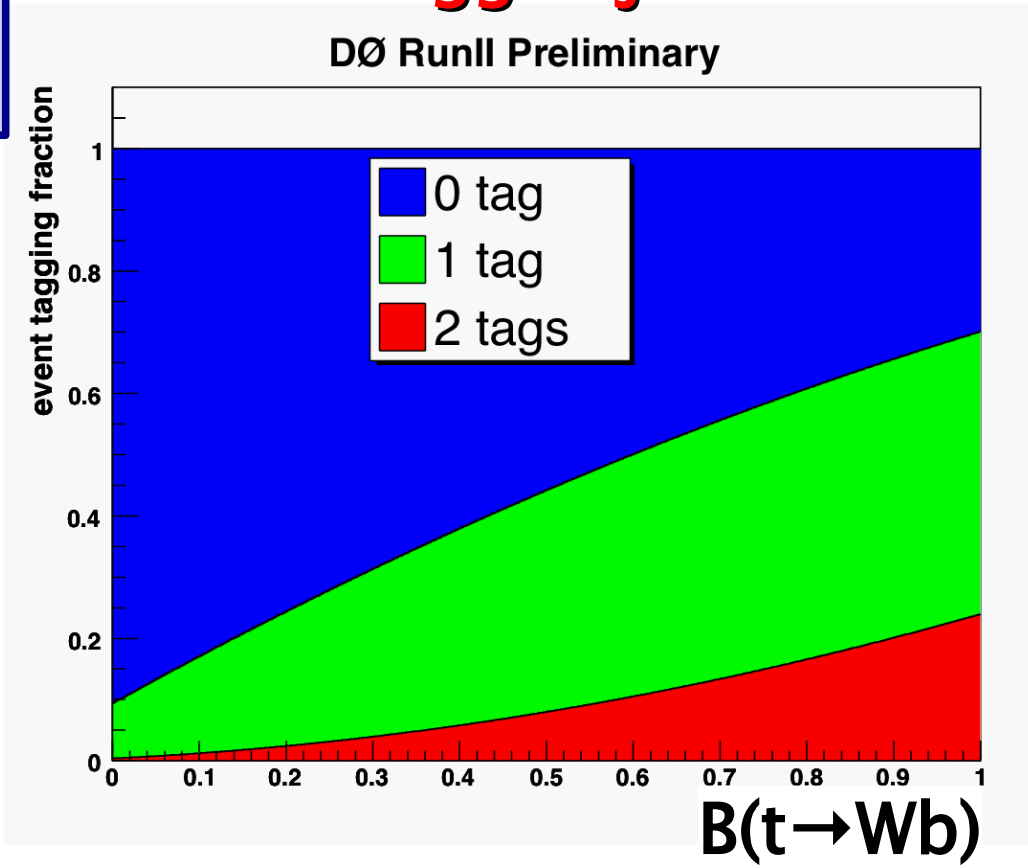
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Standard Model:

$$R_{SM} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2} = |V_{tb}|^2 = 1$$

unitarity of CKM matrix

R changes fractions of b-tagged jets:



beyond SM:

R ≠ 1

we assume: B(t→Wq) = 1

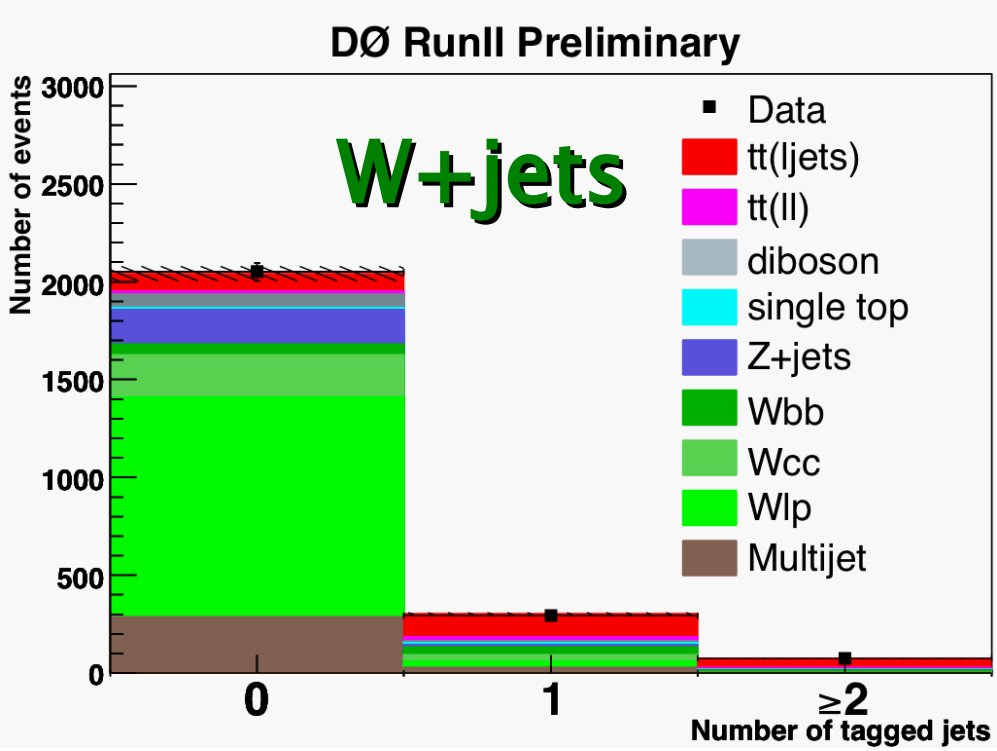
e.g. decay into 4th generation quark: R<1

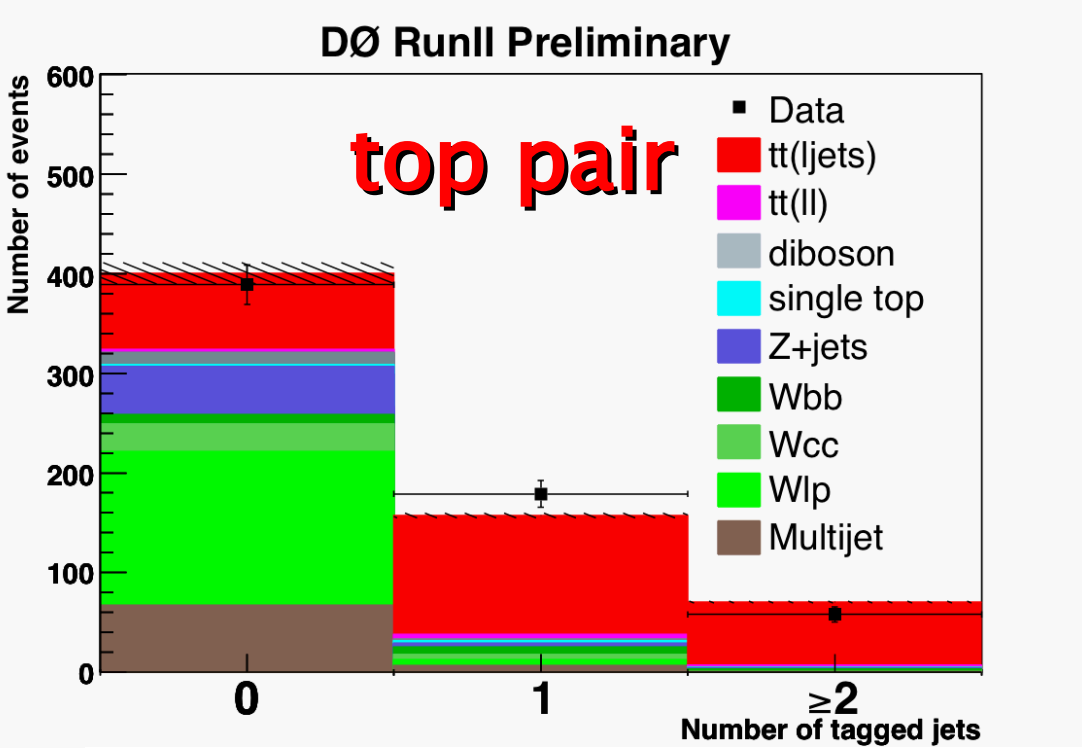
sensitive to b disappearance

Binned Likelihood fit in e,μ+jets channels

= 3 jets

≥ 4 jets

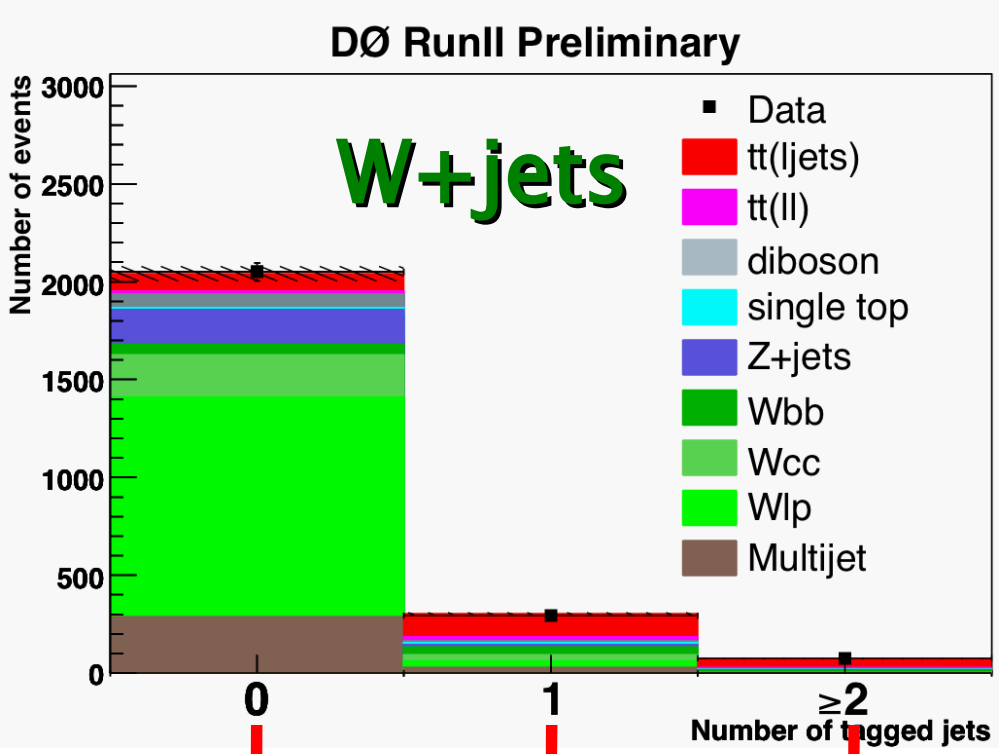


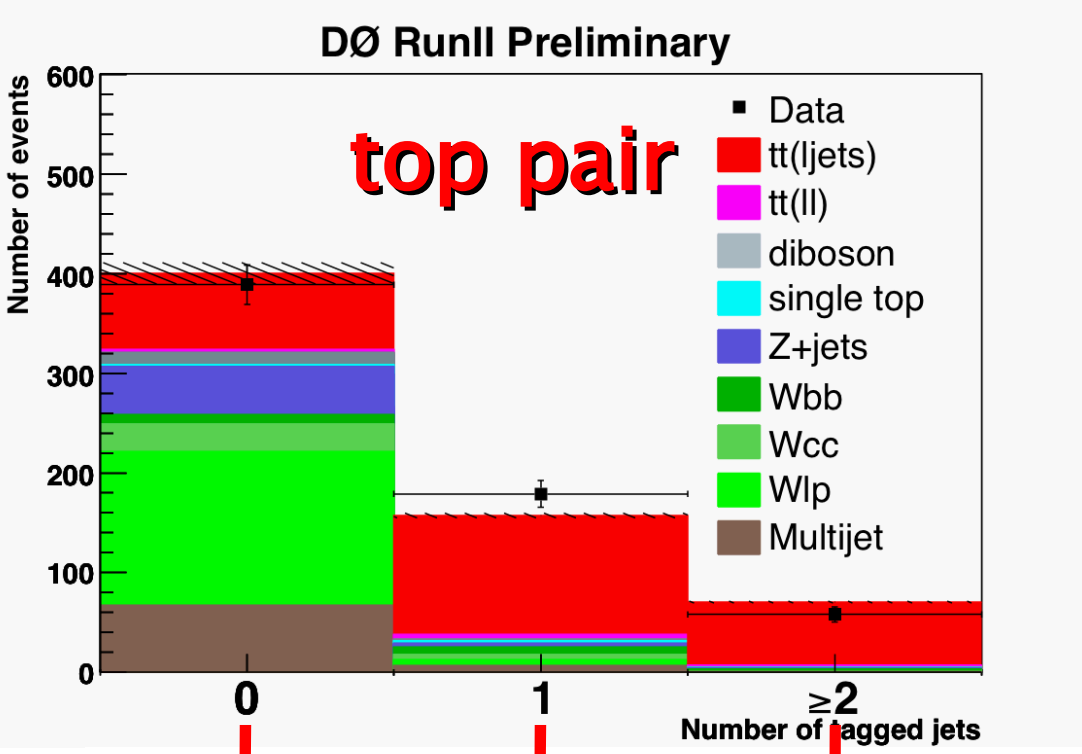


Binned Likelihood fit in e,μ+jets channels

= 3 jets

≥ 4 jets





topological discriminant

Maximize total Likelihood function simultaneously for branching ratio R and top pair production cross section

Lepton+jets cross section in SM

M_{top} = 175 GeV

R = 1

$\sigma_{tt} = 8.08^{+0.85}_{-0.82}$ (stat+syst) ± 0.49 (lumi) pb

12%

L=900 pb^{-1}

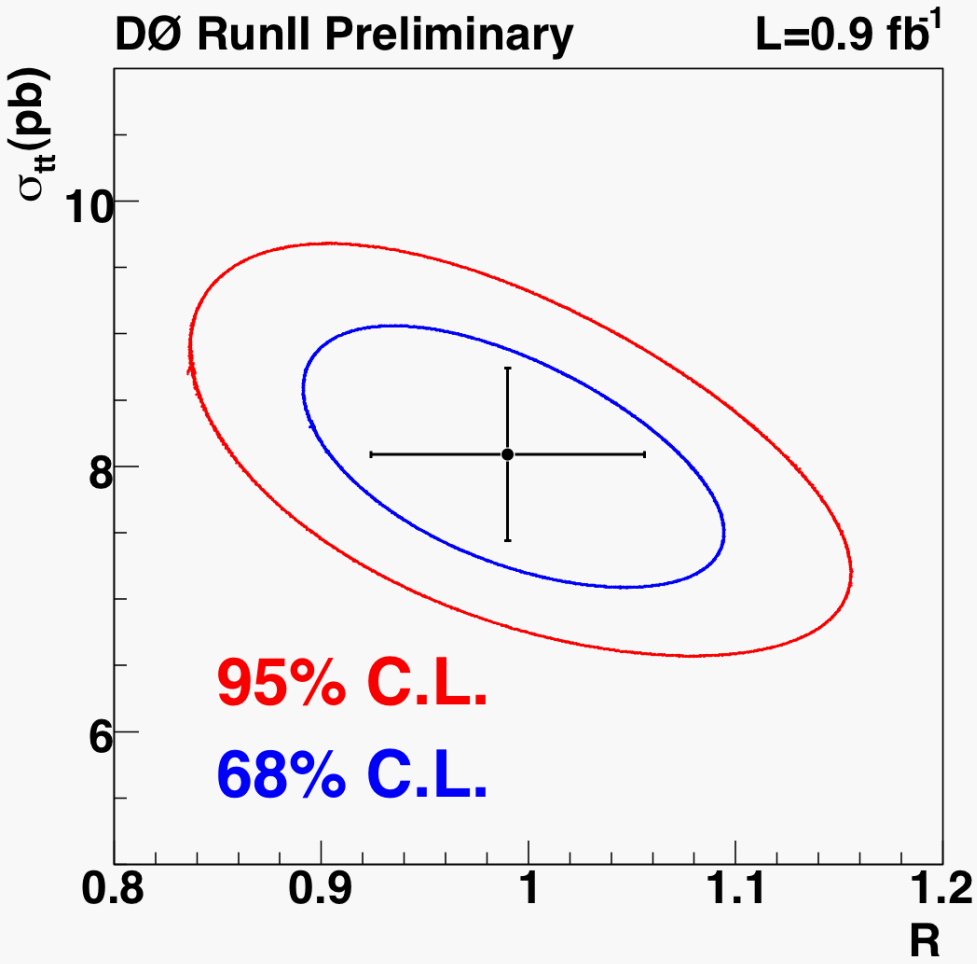
σ_{tt} = 8.2 ± 0.5 (stat) ± 0.8 (syst) ± 0.5 (lumi) pb

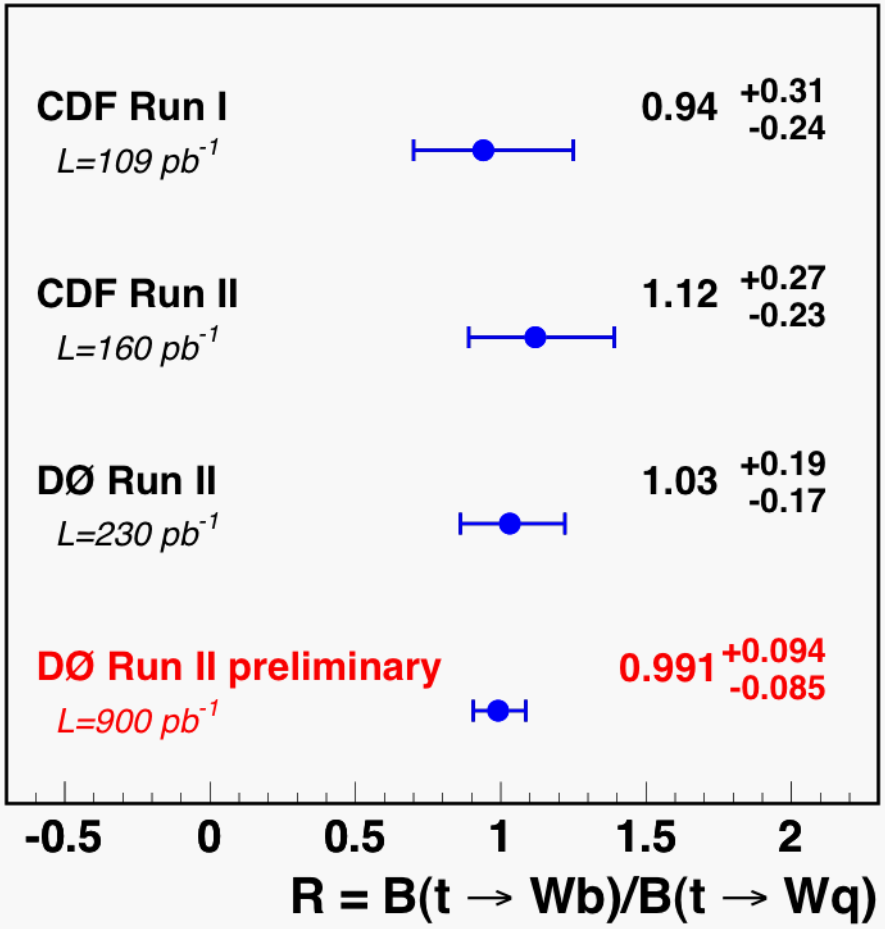
13%

L=1120 pb^{-1}

⇒ combine results

Simultaneous Measurement of σ and R



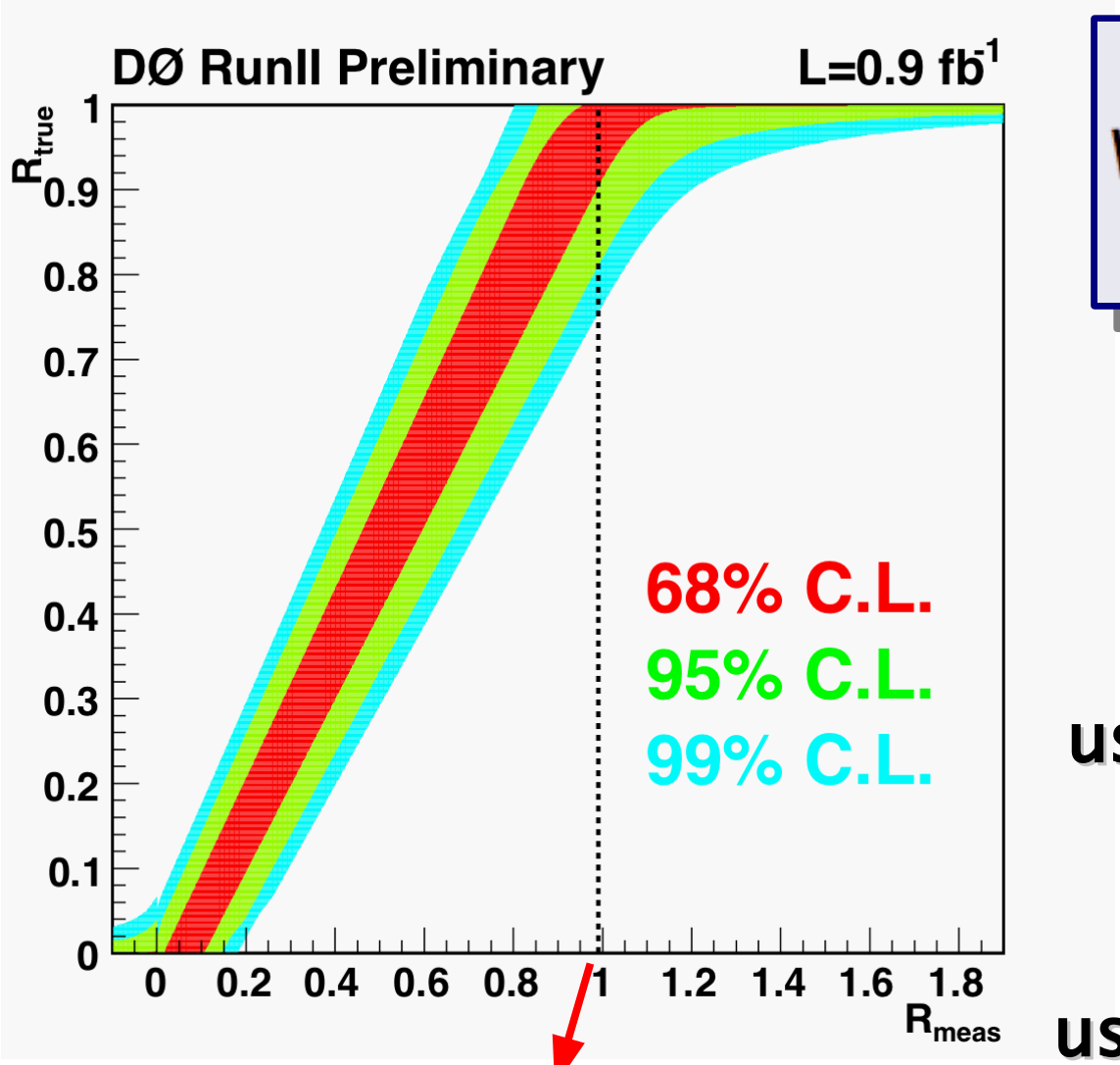


$\sigma_{tt} = 8.10^{+0.87}_{-0.82}$ (stat+syst) ± 0.49 (lumi) pb

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

⇒ agree with SM

Lower limit to branching fraction R



$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$R = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$

using measured $|V_{td}|$ and $|V_{ts}|$:

$|V_{tb}| > 0.096$ @ 95% C.L.

using unitary of CKM matrix:

$R > 0.812$ @ 95% C.L.

$|V_{tb}| > 0.901$ @ 95% C.L.

Conclusions

new era of top physics at the Tevatron: searches in the top sector

- cross section measurement
- search for resonances decaying in top pairs
- charge asymmetry in production of top and anti-top
- search for stop pair production
- search for new physics in top decays

⇒ all measurements are in agreement with SM

⇒ more interesting results will follow with more data

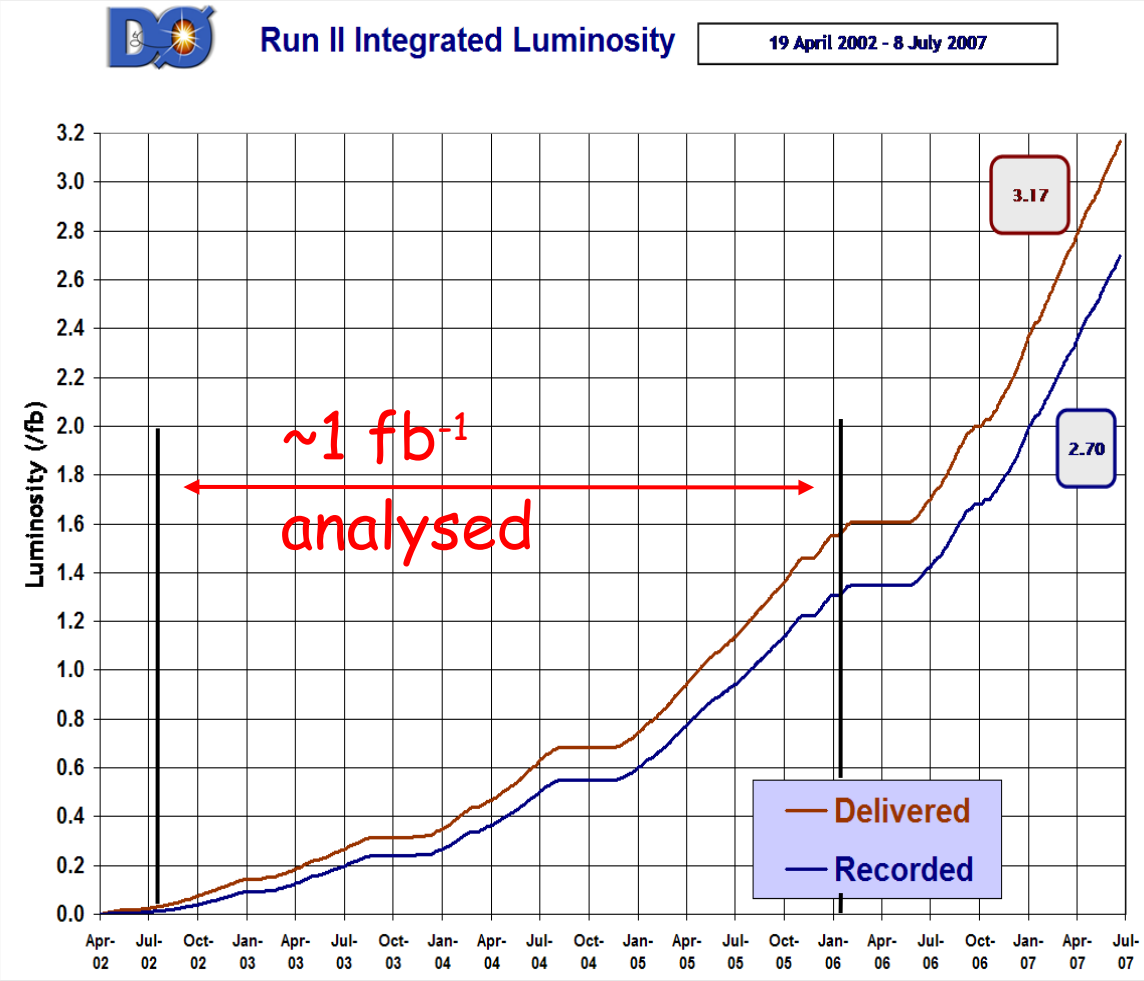
⇒ will continue to explore top sector in detail

⇒ role of top quark in electroweak symmetry breaking

The Tevatron at Fermilab: Luminosity

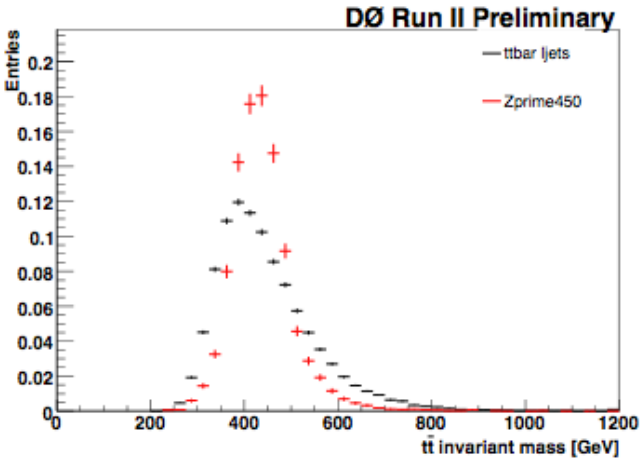
- Tevatron has delivered ~2.8 fb^{-1} per experiment
- CDF and DØ ~2.8 fb^{-1} recorded each
- current data taking efficiency is approaching ~90%

⇒ **thanks!**

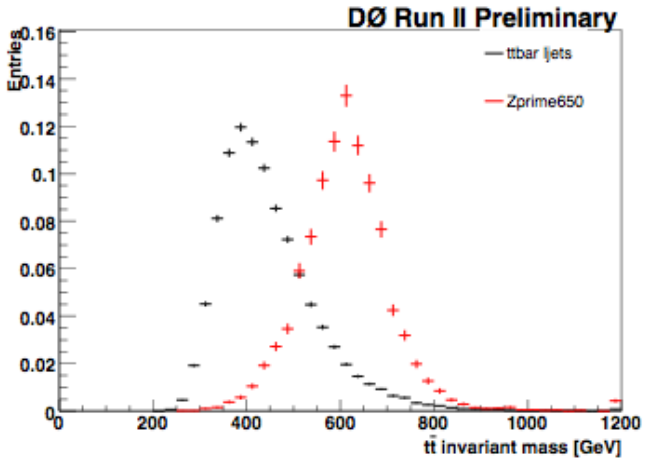


Backup

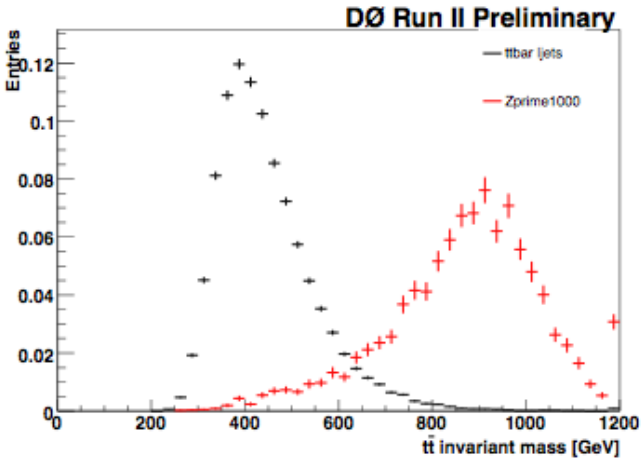
Mass dependence of resonance



$M_X = 450\,\mathrm{GeV}$

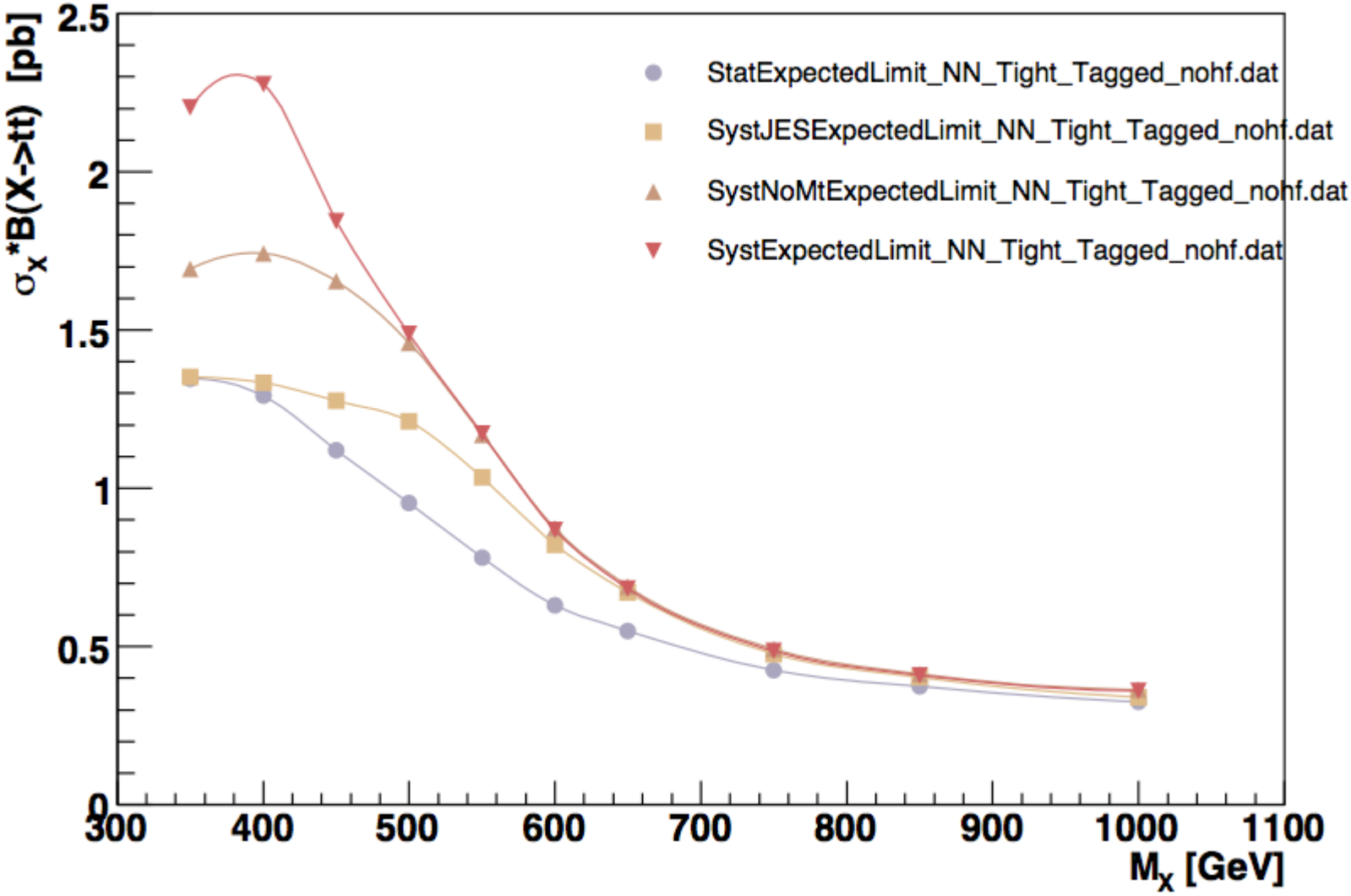


$M_X = 650\,\mathrm{GeV}$



$M_X = 1\,\mathrm{TeV}$

Error dependence on resonance limit



MSSM parameters

- $\tan\beta = 20$, $\mu = 225$ GeV, $M_A = 800$ GeV, $M_1 = 53$ GeV, $M_3 = 500$ GeV,
- Trilinear couplings $A_b = A_\tau = 200$ GeV,
- Scalar lepton masses $M_{\tilde{l}_L} = M_{\tilde{l}_R} = M_{\tilde{\tau}_L} = M_{\tilde{\tau}_R} = 200$ GeV,
- Scalar quark masses $M_{\tilde{q}_L} = M_{\tilde{q}_R} = M_{\tilde{b}_R} = M_{\tilde{t}_R} = 250$ GeV.