A direct measurement of the total decay width of the top quark CDF collaboration

$\sqrt{s} = 1.96\ TeV, 8.7\ fb^{-1}$

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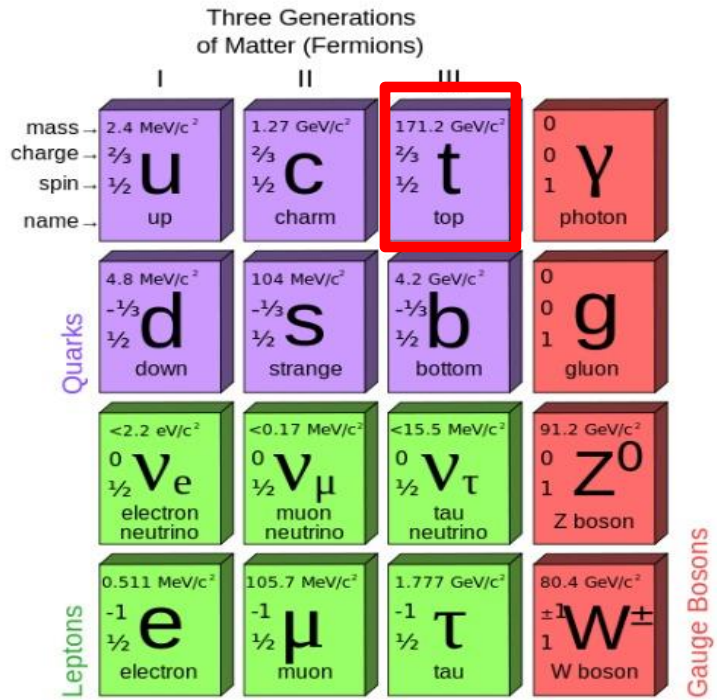
Introduction

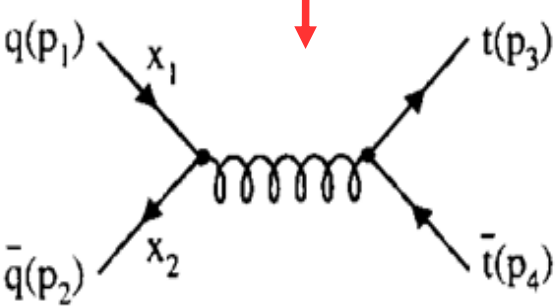
What do we want to measure?

- Top quark **total decay width** → lifetime

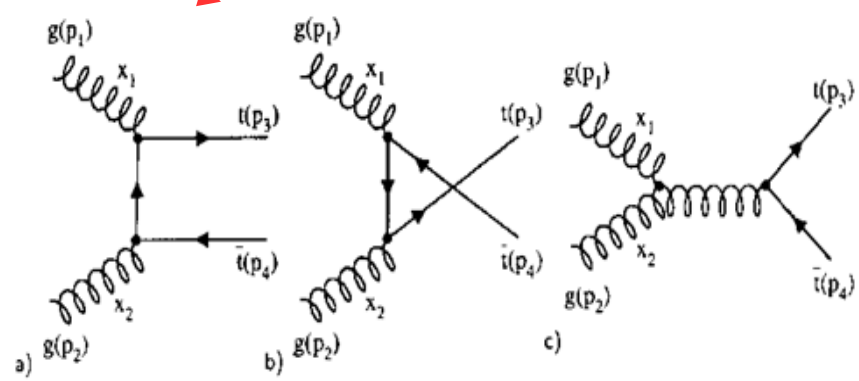
What is the top quark?

- $m_t \approx 173.34 \pm 0.67\ GeV$
  Short lifetime, can't hadronize
- How is it produced?





$q\bar{q}$ **annihilation**



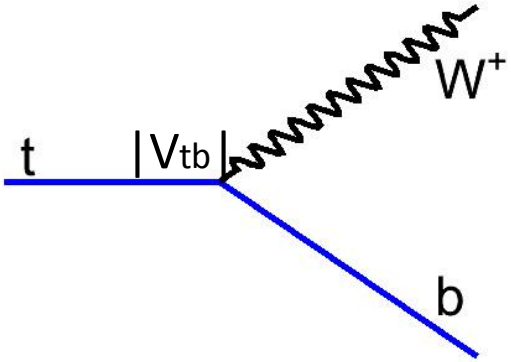
gg **fusion**

Top quark in SM

- Main Decay channel: $t \to Wb$
- Very suppressed channel: $t \to Ws, Wu\ (CKM)$
- LO term with $m_b = 0$: $t \to Wb$

LO with $m_b = 0$

$$\Gamma_t^{(0)} = \frac{G_F m_t^3}{8\sqrt{2}\pi}\left[1 - 3\left(\frac{m_W^2}{m_t^2}\right)^2 + 2\left(\frac{m_W^2}{m_t^2}\right)^3\right]$$



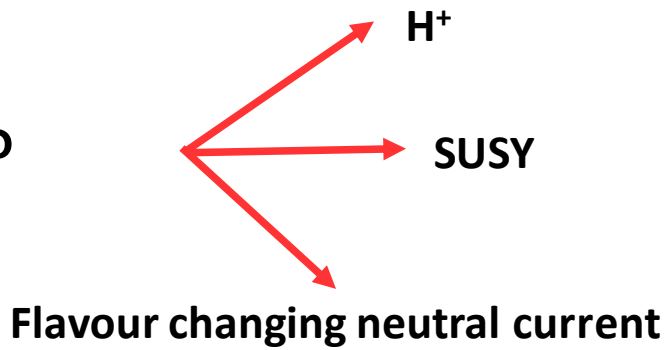
Including NNLO corrections

$$\Gamma_t = \Gamma_t^{(0)}(1 + \delta_f^b + \delta_f^W + \delta_{EW} + \delta_{QCD}^{(1)} + \delta_{QCD}^{(2)}) \approx 1.33\ GeV$$

Motivation

Why should we measure it?

- SM test → new physics?



- Experimental accuracy << theoretical

Measurements

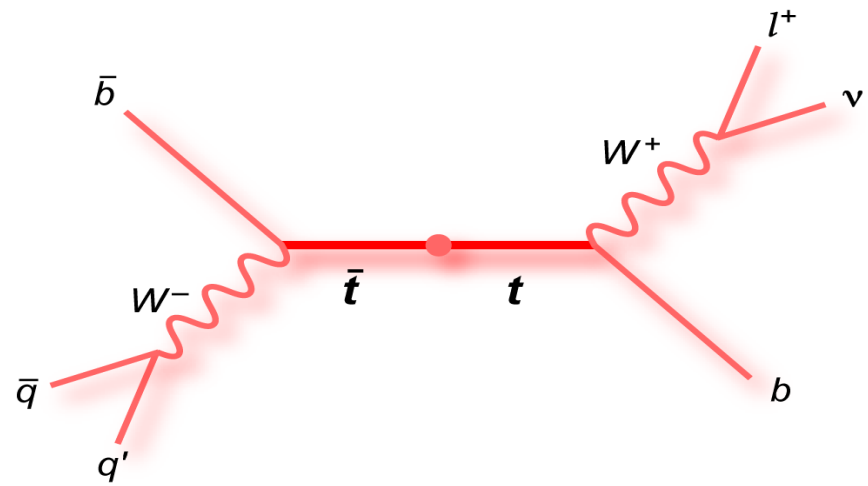
D0:

- **Model-dependent** measurement
- Result: $\Gamma_t = 2.0\ GeV$ (25% accuracy)

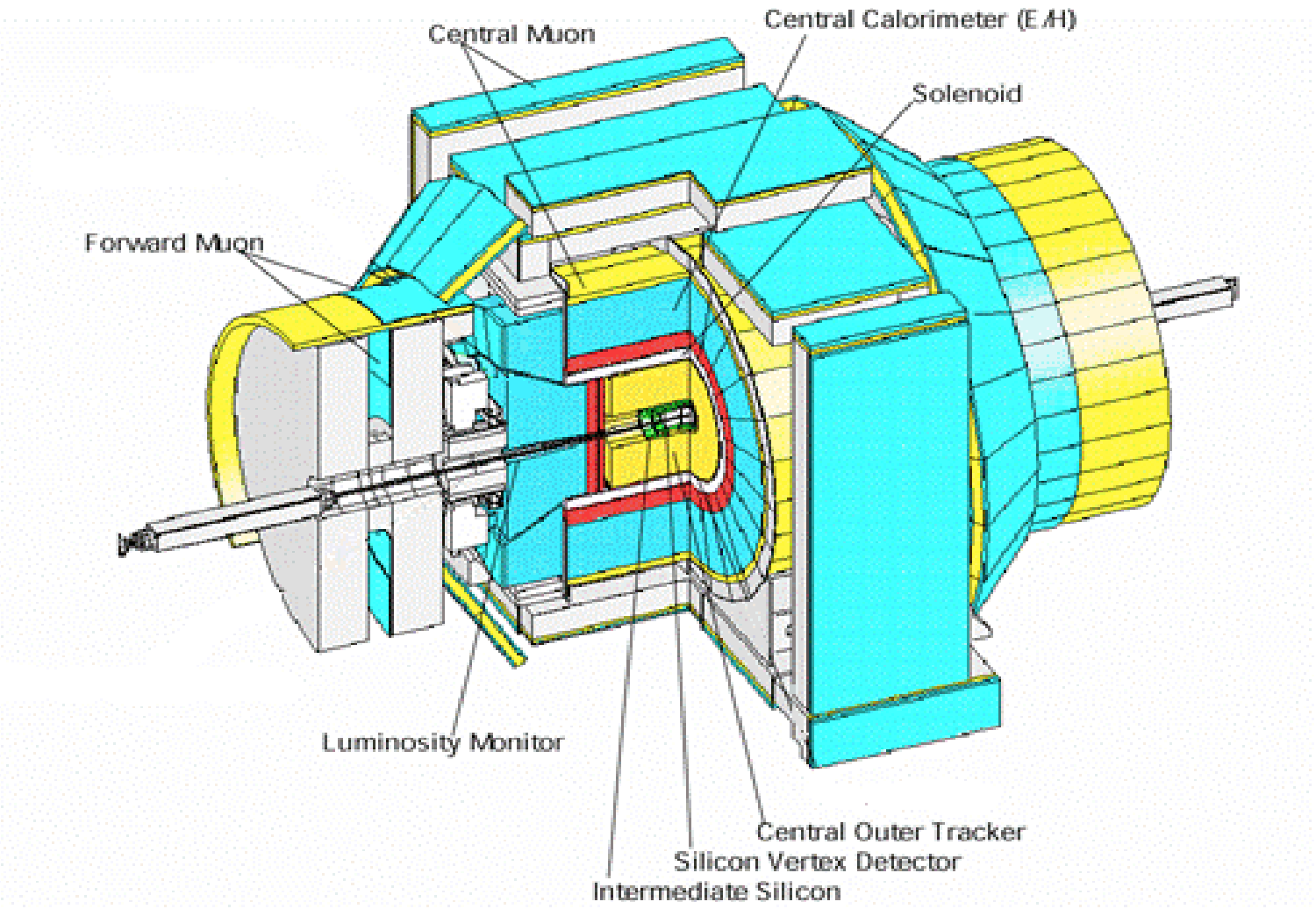
How to perform a model-independent measurement?

- Model-independent measurement

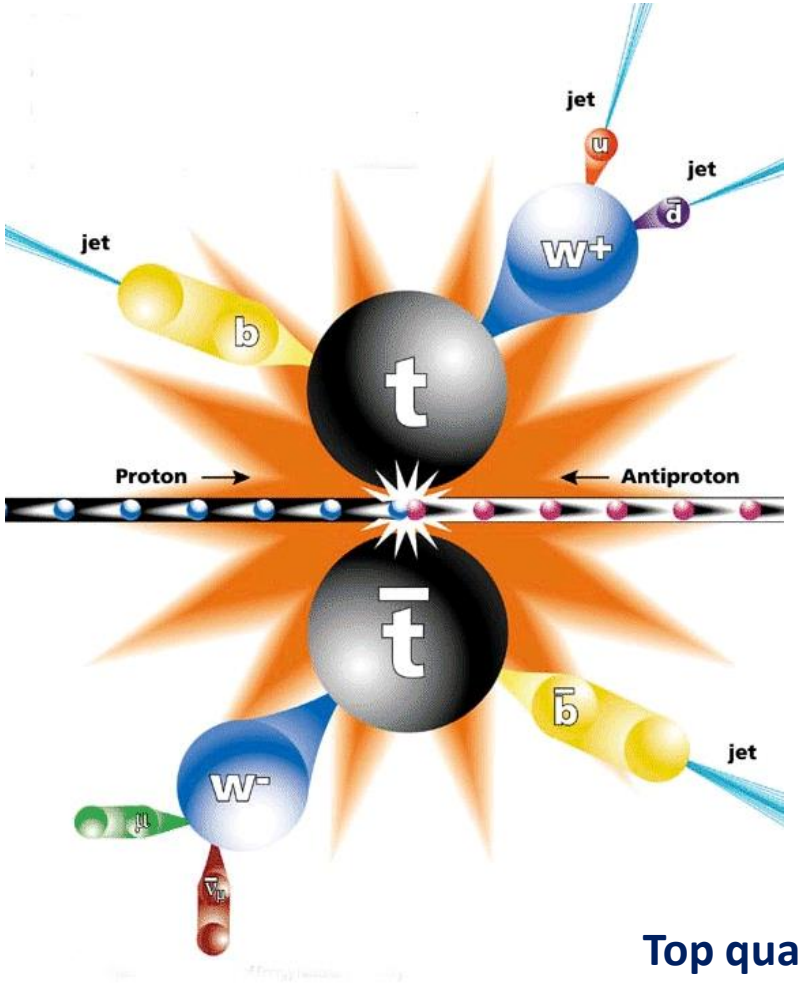
Direct comparison of data with MC top quark mass distributions for different Γ_{top}.

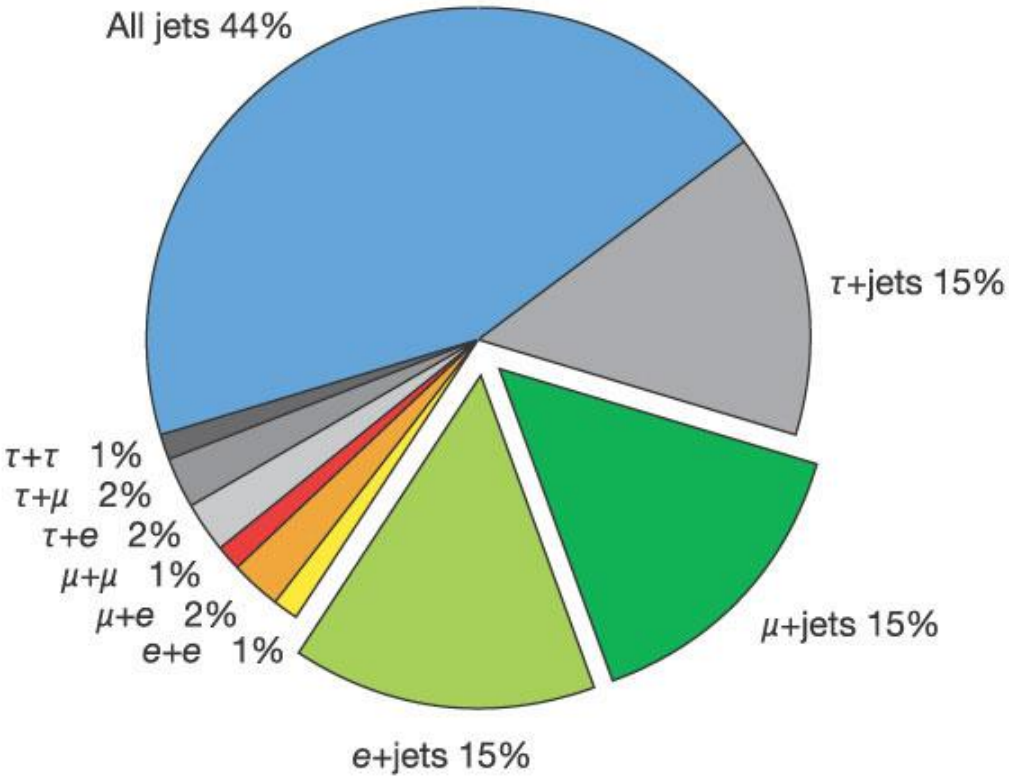


CDF Detector



$t\bar{t} \rightarrow l + jets\ (l = e, \mu)$





Top quark width measurement in $t\bar{t} \rightarrow l + jets$ channel $l = e, \mu$ including $\tau \rightarrow e, \mu$

Event Selection

- Lepton $E_T > 20\ GeV$
- $|\eta| < 1.1$
- $E_{T\_miss} > 20\ GeV$
- $N_{jet} \geq 4$

Jet Selection

- B tagging, secondary vertex algorithm
- $t\bar{t}$ candidates divided: 0 b-tag, 1 b-tag, ≥2 b-tag. Different sig/bkg ratio
- Tight:
  $N_{jet} = 4,\ E_T > 20\ GeV,\ |\eta| < 2.0$
- Loose:
  $N_{jet} \geq 3, E_T > 20\ GeV,\ |\eta| < 2.0$
  $4^{th}\ jet: E_T > 12\ GeV,\ |\eta| < 2.4$
- $H_T = E_T^l + E_T^{miss} + \sum E_T^{jet} > 250\ GeV$

Expacted Backgrounds

- $W + jets$
- $Z + jets$
- $Dibosons: WW, WZ, ZZ$
- $Single\ top$
- $Multijet\ (data - driven\ techniques)$

Yields are normalized on NLO cross section

Number of events
Sig., Bkg., Observed

Candidate $l + jets$ events are divided into 5 categories

TABLE I. Expected and observed numbers of signal and background events assuming a $t\bar{t}$ production cross section $\sigma_{t\bar{t}} = 7.45$ pb and $M_{\text{top}} = 172.5$ GeV/c^2.

	0-tag	1-tagL	1-tagT	2-tagL	2-tagT
W + jets	703 ± 199	170 ± 60	102 ± 37	11.6 ± 4.9	8.4 ± 3.5
Z + jets	52.3 ± 4.4	8.9 ± 1.1	5.9 ± 0.7	0.8 ± 0.1	0.5 ± 0.1
Single top	4.8 ± 0.5	10.5 ± 0.9	6.8 ± 0.6	2.2 ± 0.3	1.7 ± 0.2
Diboson	60.3 ± 5.6	11.1 ± 1.4	8.5 ± 1.1	1.0 ± 0.2	0.8 ± 0.1
Multijets	143 ± 114	34.5 ± 12.6	20.7 ± 16.6	4.4 ± 2.5	2.5 ± 2.4
Background	963 ± 229	235 ± 61	144 ± 41	19.9 ± 5.5	13.8 ± 4.2
$t\bar{t}$ signal	645 ± 86	695 ± 87	867 ± 108	192 ± 30	304 ± 47
Expected	1608 ± 245	930 ± 106	1011 ± 115	212 ± 30	318 ± 47
Observed	1627	882	997	208	275

Final Selection

- **Reconstruct top mass, sensitive to Γ_{top}: χ^2 minimization and 4 jets.**
- **Data is compared with total MC (Sig.+Bkg.) templates, where the signal template is take for different Γ_{top} ($[0.1, 30] GeV/c^2$)**
- **Dijet mass , to reconstruct W boson , is calculated <u>independently</u>, inv. mass of two non-b jets.**
- **JES(main unc.), m_{jj} is used to reconstruct JES *in situ***
- **In data Jet energies are corrected to account energy scale error in calorimeter with σ_c Unc., The SDF JES fractional Uncertainty.**
- **In simulation JES with corr. Factor of jet energies $1 + \Delta_{jes}$ (Δ_{jes} $[-0.3\sigma_c, 0.3\sigma_c]$)**

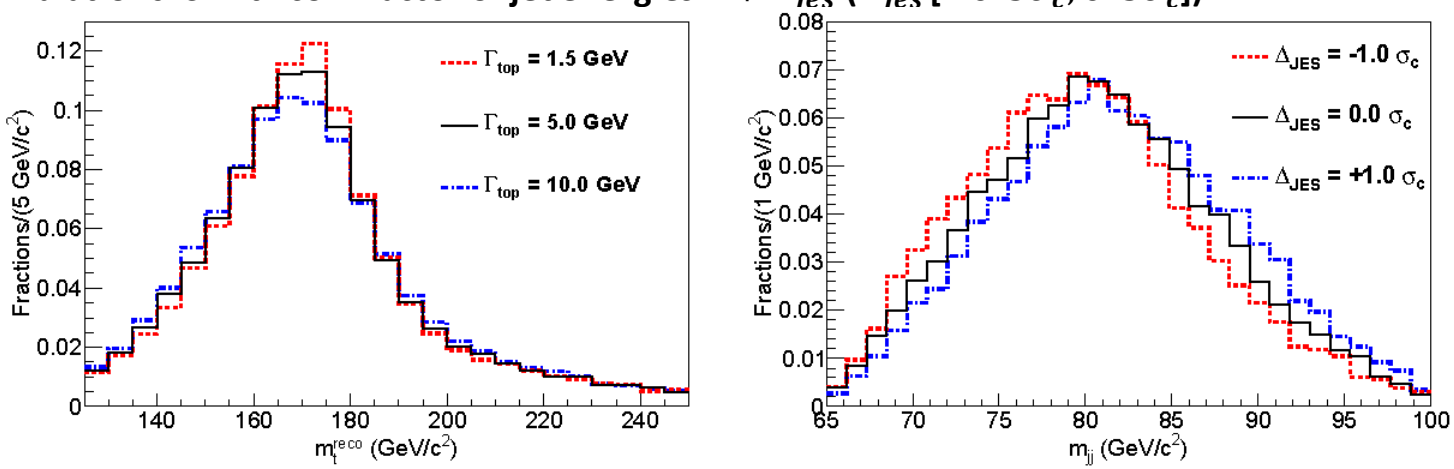


FIG. 1. Distributions for simulated events meeting the lepton + jets selection: (a) m_t^{reco} distributions displayed with three values of Γ_{top} and with the nominal $\Delta_{\mathrm{JES}} = 0.0$; (b) m_{jj} distributions displayed with three values of Δ_{JES} and with $\Gamma_{\mathrm{top}} = 1.5$ GeV.

Systematic Unsertanties

TABLE II. Summary of systematic uncertainties on Γ_{top}.

Source	Uncertainty (GeV)
Jet resolution	0.56
Color reconnection	0.69
Event generator	0.50
Higher-order effects	0.21
Residual jet-energy scale	0.19
Parton distribution functions	0.24
b-jet energy scale	0.28
Background shape	0.18
Gluon fusion fraction	0.26
Initial- and final-state radiation	0.17
Lepton energy scale	0.03
Multiple hadron interaction	0.23
Total systematic uncertainty	1.22

Results

$\Gamma_{top} < 6.38\ GeV$, 95% C.L

$1.10\ GeV < \Gamma_{top} < 4.03\ GeV$, 68% C.L

$1.6 \cdot 10^{-25} < \tau_{top} < 6.0 \cdot 10^{-25}$

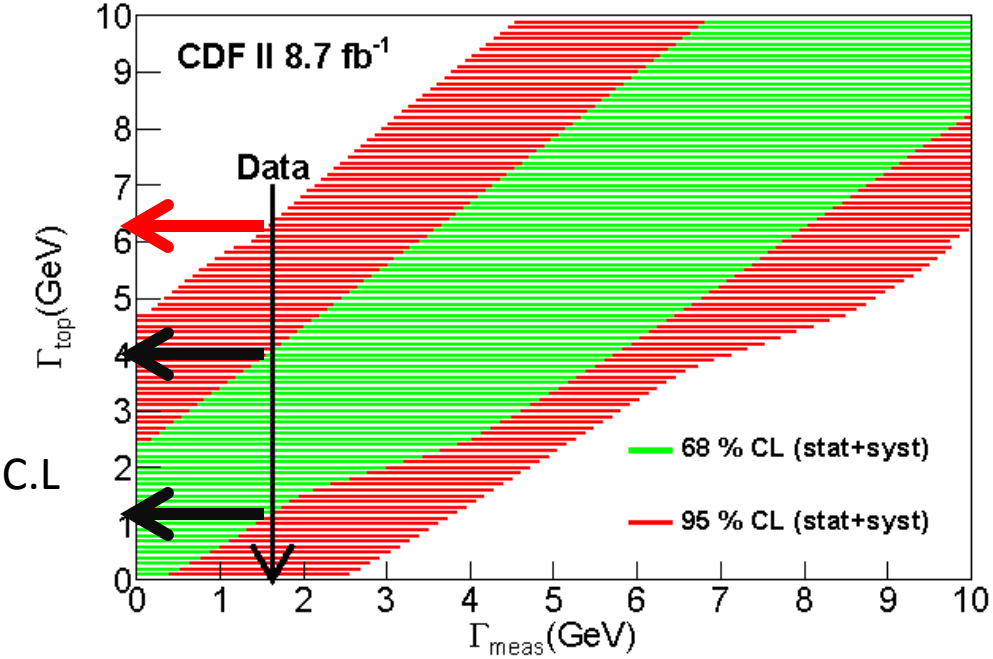


FIG. 2. Confidence bands of Γ_{top} as a function of Γ_{meas} for 68% and 95% C.L. limits. Results from simulated experiments assuming 8.7 fb^{-1} of data at different values of Γ_{top} are convoluted with a smearing function to account for systematic uncertainties. The value observed in data is indicated by an arrow.

Thanks for your attention!