Top Quark Mass and Width Measurement Using Template Method at CDF

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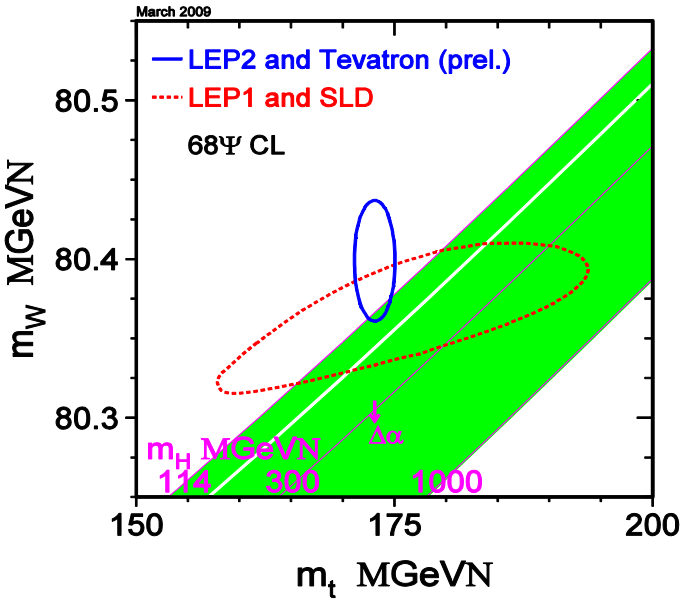
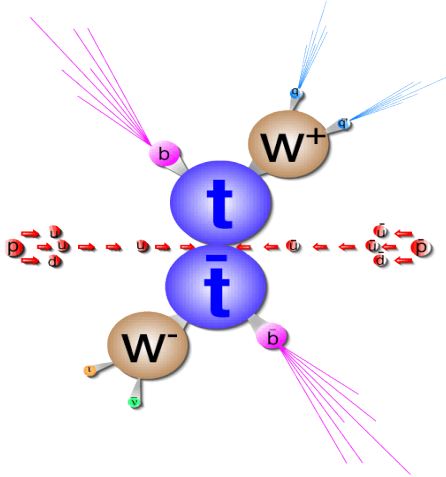
On Behalf of CDF Collboration

Motivation

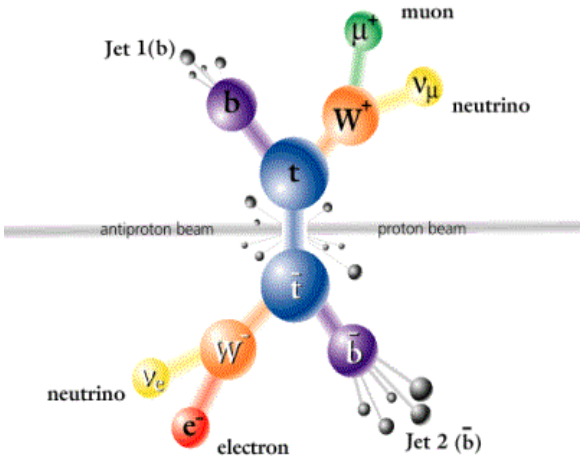
Why Top Mass

- Possible calibration for future experiments
- Constraint on Higgs Mass



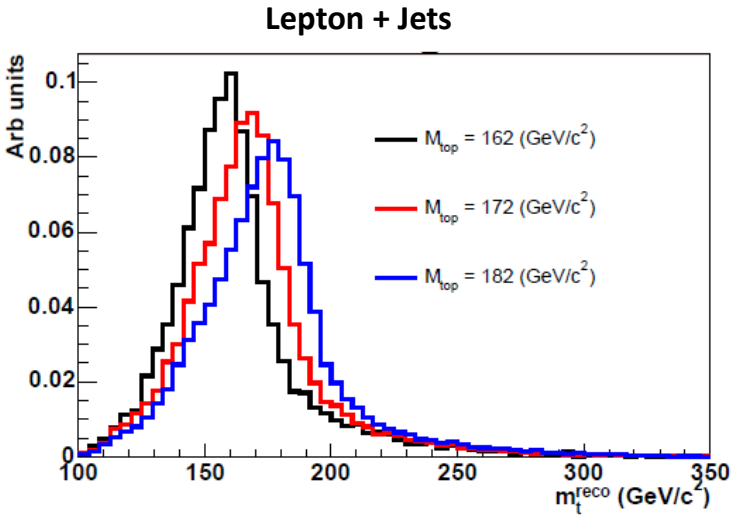


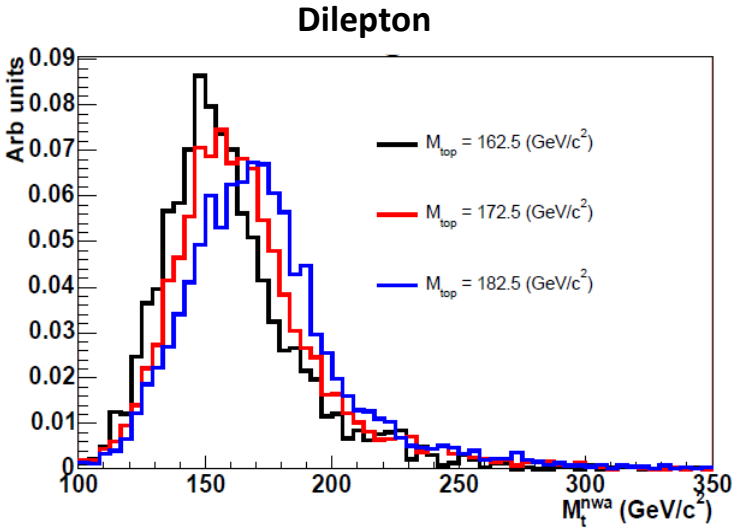
Lepton+Jets Channel



Dilepton Channel

Template Method





❑Event Selection

❑Event Reconstruction – observables:

- ❖ **Lepton+Jets**
  - m_t^{reco} : reconstructed top mass
  - m_{jj} : dijet mass of W
  - $m_t^{reco(2)}$: second best reconstructed top mass
- ❖ **Dilepton**
  - m_t^{NWA} : reconstructed top mass in DIL (Neutrino Weighting Algorithm)
  - m_{T2} : second observable in DIL

❑Build n-dim p.d.f. (using KDE) for MC samples (signal & bkgd)

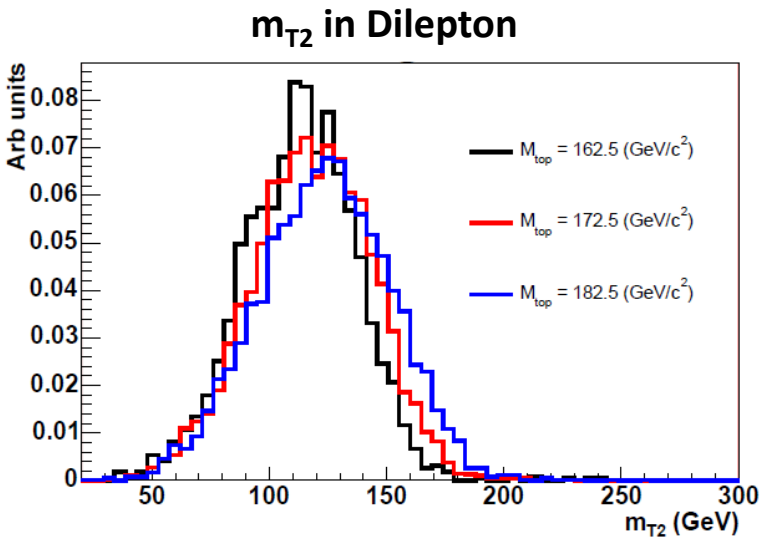
- ❖ Each MC is a "template"

❑Compare data event with MC

- ❖ calculate probability of an event to be a signal and background

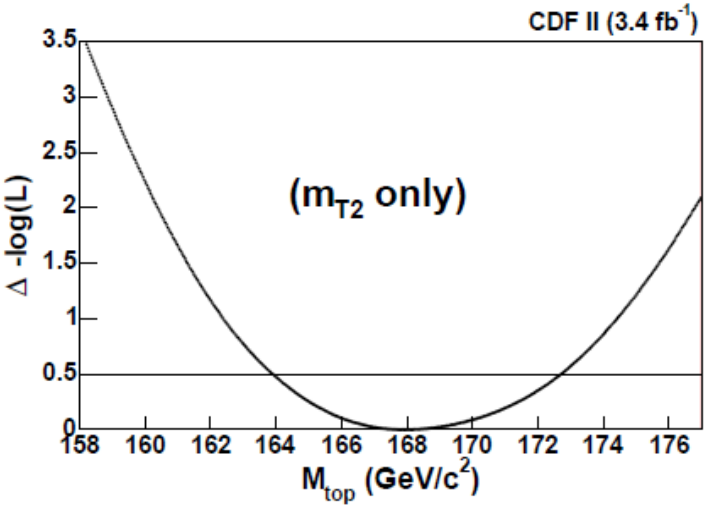
❑ Likelihood fit – find top mass

m_{T2} in dilepton channel



- m_{T2} was introduced for mass determination of new physics particle with pair productions
  - A. Barr, C. Lester & P. Stephens, J.Phys.G: Nucl.Part.Phys. 20(2003) 2343-2363
- We use it as 2nd observable and improve ~15% statistical uncertainty

- We used m_{T2} the first time with real data (3.4 fb^{-1})
  - arXiv:0911.2956
  - Published in PRD: "*Top Quark Mass Measurement using mT2 in the Dilepton Channel at CDF", Hyun Su Lee, et.al*



$$M_{top} = 168.0^{+4.8}_{-4.0}(stat.) \pm 2.9(syst.) GeV/c^2$$

Event Selection

L+Jet Selection	1tag	2tag
b-tags	=1	>1
leading 3 jets ET (GeV)	>20	>20
Missing ET (GeV)	>20	>20
4^{th} jet ET (GeV)	>20	>12
Extra jets ET (GeV)	--	any

Dilepton Selection	Non-tag	1tag
b-tags	=0	>0
leading 2 jets ET (GeV)	>15	>15
Missing ET (GeV)	>25	>25
HT(GeV)	>200	>200

Systematic Uncertainties

Systematic(GeV/c^2)	COMBO	LJ	DIL
Residual JES	0.6	0.6	2.9
Generator	0.7	0.7	0.6
PDF	0.1	0.1	0.3
b jet energy	0.2	0.2	0.3
Background shape	0.1	0.1	0.3
gg fraction	<0.1	<0.1	0.3
Radiation	0.1	0.1	0.3
MC statistics	0.1	0.1	0.3
lepton energy	<0.1	<0.1	0.3
MHI	0.1	0.1	0.2
CR	0.2	0.2	0.6
Total syst.	**1.0**	**1.0**	**3.1**

Results of top mass measurement with 4.8 fb^{-1}

Combined fit of lepton+Jets and dilepton channel

$172.1 \pm 0.8\ (stat) \pm 0.8\ (JES) \pm 1.0(syst)\ GeV/c^2$

$= 172.1 \pm 1.5\ GeV/c^2$

Lepton+Jets channel only

$172.2 \pm 0.9\ (stat) \pm 0.8\ (JES) \pm 1.0\ (syst)\ GeV/c^2$

$= 172.2 \pm 1.5\ GeV/c^2$

Dilepton channel only

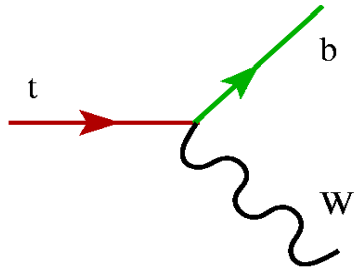
$170.6 \pm 2.2\ (stat) \pm 3.1\ (syst)\ GeV/c^2$

$= 170.6 \pm 3.8\ GeV/c^2$

About Top Quark Width

❑ Top quark decay

- ❖ Largest decay width and the shortest lifetime of the quarks in the standard model (SM)
- ❖ Predicted top width (NLO) from SM



top quark decay

$$\Gamma_t = \Gamma_t^0\left(1-\frac{M_W^2}{m_t^2}\right)^2\left(1+2\frac{M_W^2}{m_t^2}\right)\left[1-\frac{2\alpha_s}{3\pi}\left(\frac{2\pi^2}{3}-\frac{5}{2}\right)\right].$$

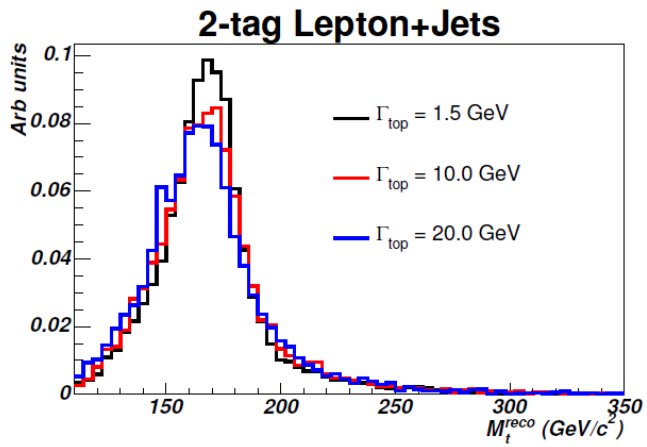
  - ~ 1.4 GeV (assume top mass 172.5 GeV/c^2)
- ❖ Deviation from SM prediction may indicate significant decays of:

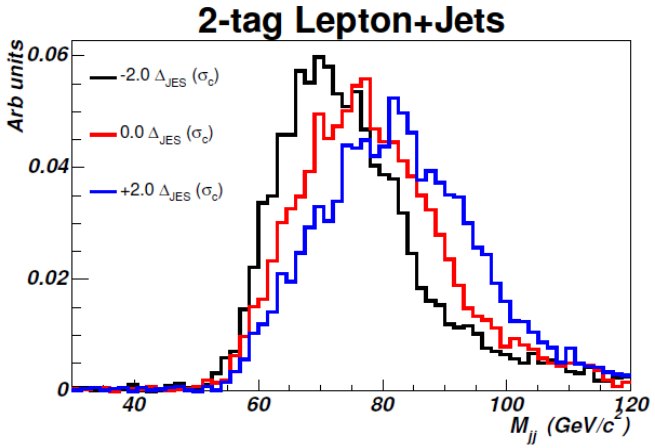
  $t \to bH^+$ or $t \to dW^+$, $t \to sW^+$

  - A way to rule out these decays: Experimental constraint on Γ_t
- ❖ Existing upper limit on top width:

  $\Gamma_t < 13.1$ GeV, 95% CL, 955pb^{-1} *(CDF, **P.R.L**, **102**, 042001(2009))*

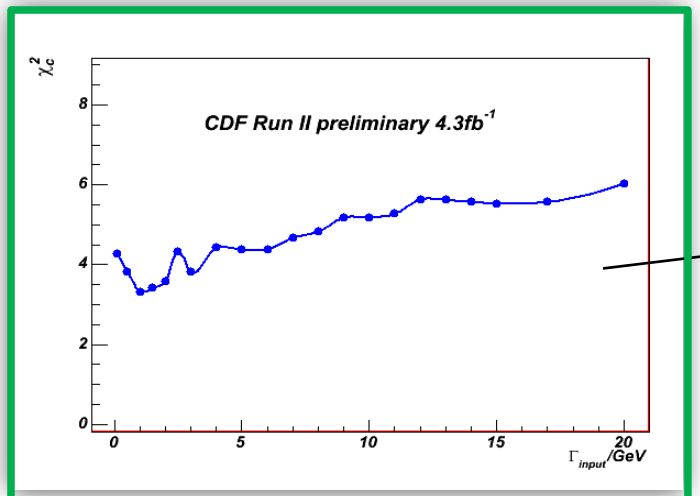
The same template method

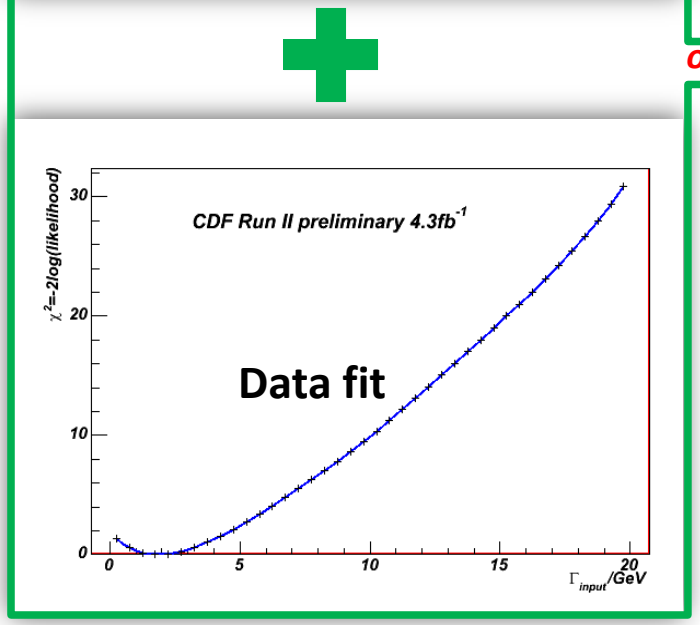




- **Only use Lepton+Jets channel**
- **Event Reconstruction (2 observables)**
  - m_t^{reco} , m_{jj}
- **Build p.d.f. for each MC sample**
- **Compare data event with MC**
- **Likelihood fit**
- **Feldman-Cousins**
  - Set top width limit(s)

Feldman–Cousins

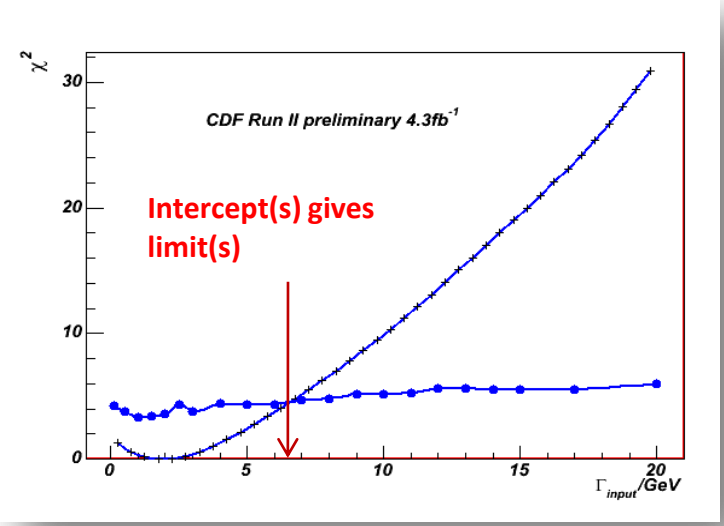




overlap

- "*ordering principle* " $\Delta\chi^2$
- Each MC sample generates a $\Delta\chi_c^2$
- plot $\Delta\chi_c^2$ **vs true Γ**
- Overlap with data fit

χ^2= -2 Log(Likelihood)



Systematics-- Categories

Systematic Effects	Meas. mean top width shift(GeV)
Jet Resolution	1.1
Residual JES	0.3
Generator	0.4
PDF	0.3
B Jet Energy	0.2
LJ Background	0.1
gg Fraction	0.3
IFSR	0.2
Lepton Energy	0.2
Color Reconnection	0.9
Multi. Had. Int.	0.3
Total Systematic	**1.6**

Convolution method to fold syst into likelihood function

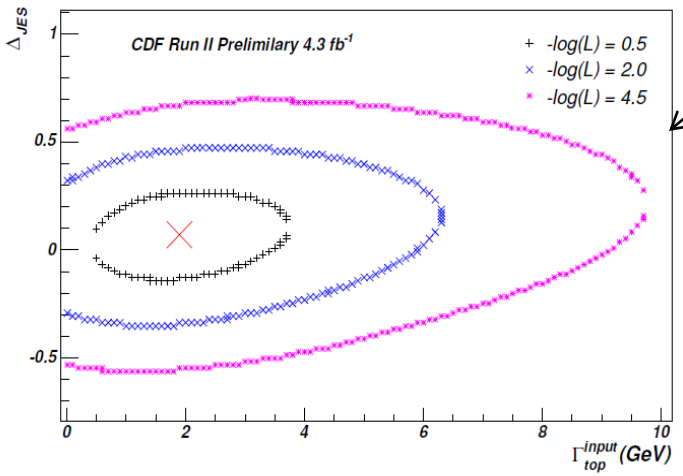
- Convolute Likelihood function with a function related to systematic effects

top width

$$L_{new}(\Gamma) = \int d\Gamma' L_0(\Gamma') \frac{e^{-\frac{1}{2}(\frac{\Gamma-\Gamma'}{\sigma})^2}}{\sigma\sqrt{2\pi}}$$

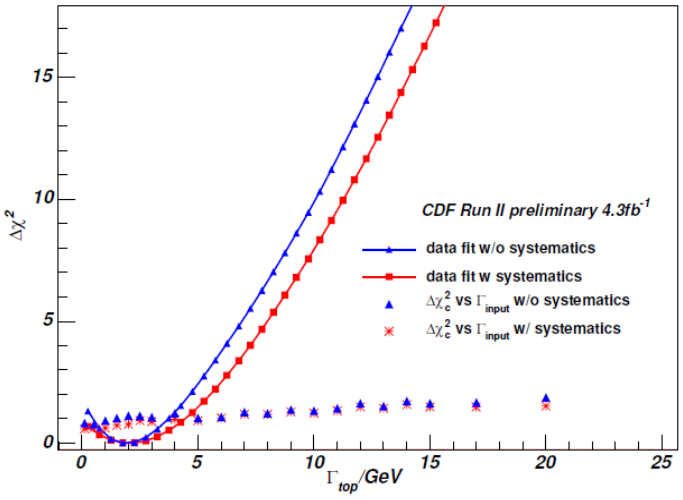
At leading order, it's top width shift due to systematic effects

Results of top width limit(s) with 4.3fb^{-1}



Data fit

- 95% CL
  - pure statistic : $\Gamma_{top} < 6.6$ GeV
  - w/ systematic: $\Gamma_{top} < 7.6$ GeV



- 68% CL
  - pure statistic : $0.6 < \Gamma_{top} < 3.9$ GeV
  - w/ systematic : $0.3 < \Gamma_{top} < 4.4$ GeV

Conclusion

- **Top mass measurement: Combined fit of lepton+Jets and dilepton channel, 4.8 fb^{-1}**

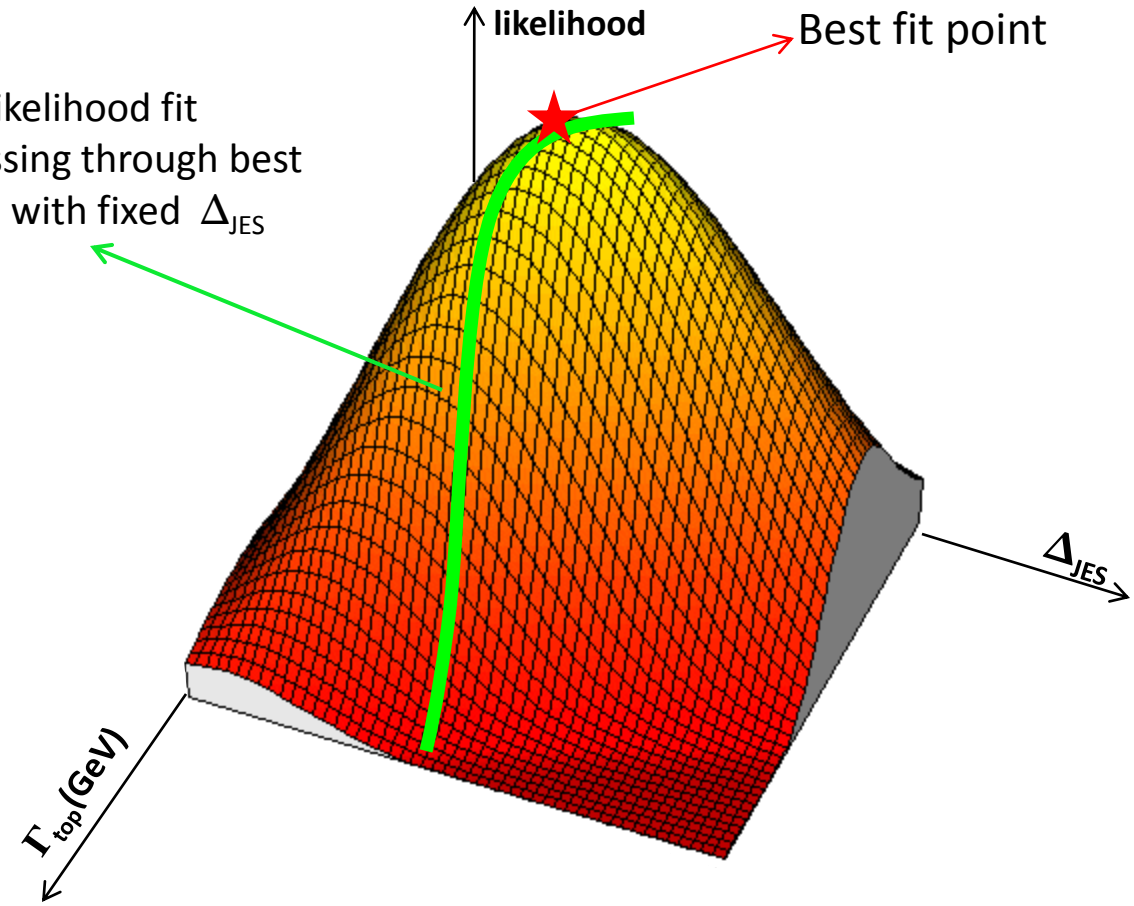
  172.1 ± 1.5 GeV/c^2

- **Top width measurement: lepton+Jets channel, 4.3 fb^{-1}**

  - 95% CL: $\Gamma_{top} < 7.6$ GeV
  - 68% CL: $0.3 < \Gamma_{top} < 4.4$ GeV

Back up slides

2D likelihood fit



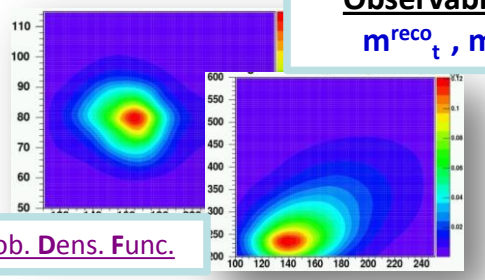
Template Method

MC

$Sig : \Gamma_{top}, \Delta_{JES}$

$Bkgd : \Delta_{JES}$

Event reconstruction



Observables

m^{reco}_{t} , m_{jj}

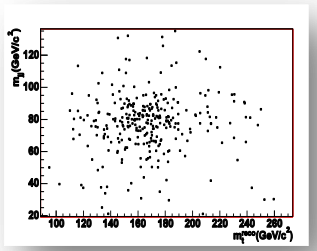
Prob. Dens. Func.

Estimation

P_{sig}, P_{bkgd}

Data

Event reconstruction



Likelihood Fit

- PEs
- Data Fit Result

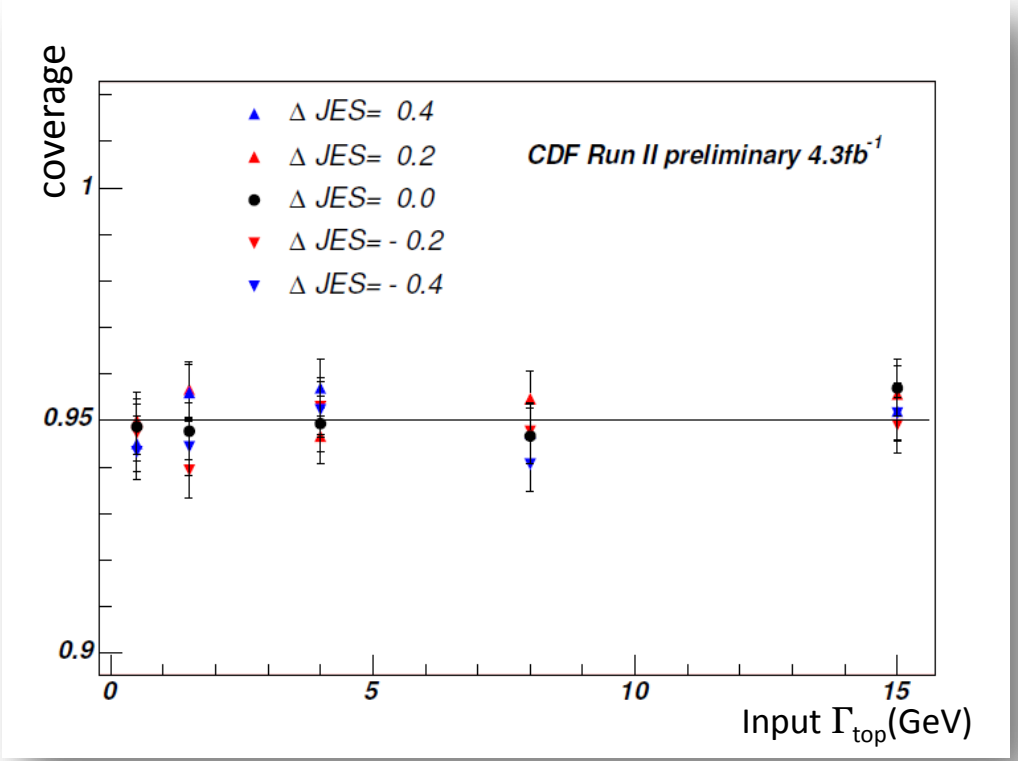
Feldman-Cousins

Γ_{top} limit(s)

Coverage Check

- Signal MC depends on Γ_{top}, Δ_{JES} ususally → 2D Feldman-Cousins

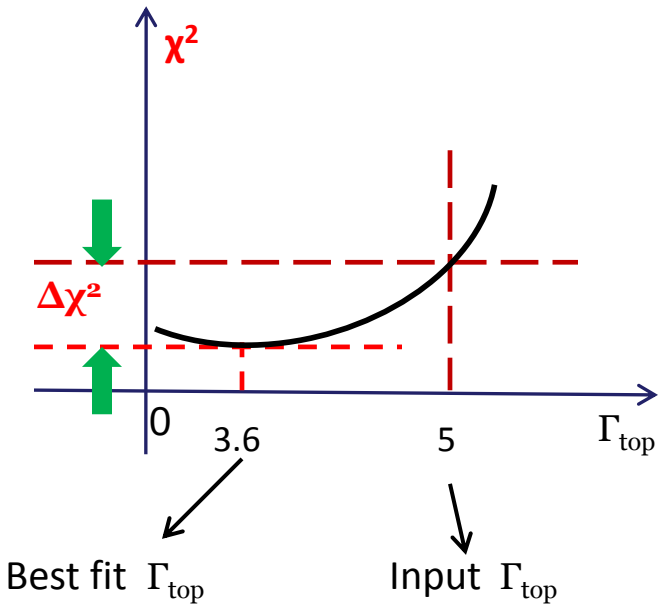
- Measuring Δ_{JES} is not our interest, so we only use sample with $\Delta_{JES} = 0$, and check the coverage of MC with none-zero Δ_{JES} , if coverage is fine → 1D Feldman-Cousins



Feldman–Cousins

"ordering principle " $\Delta\chi^2$

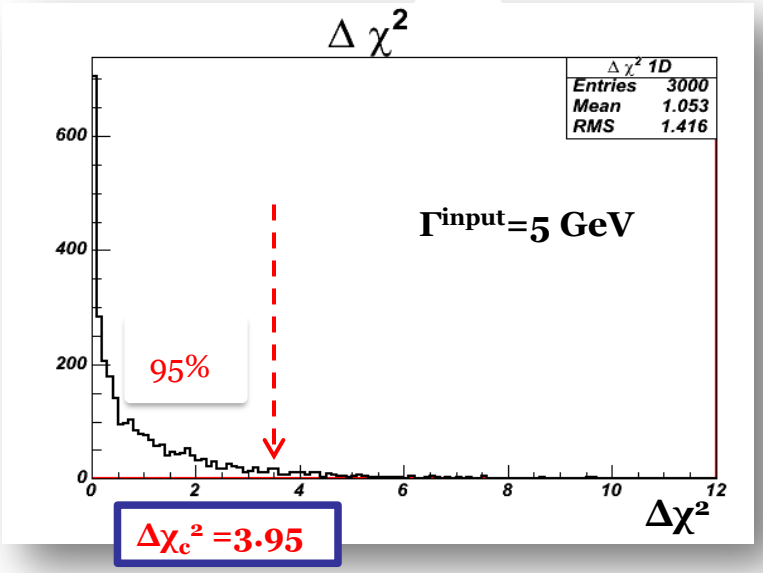
χ^2= -2 Log(Likelihood)



An Example:

a PE from sample twid50(input Γ_{top} =5GeV, Δ_{JES} = 0)

I. When performing a PE, we record its χ^2 of the best fit
II. Also record the χ^2 at point of input top width(here 5GeV)
III. Calculate the diff of the two χ^2 above
IV. Perferm thousands of PEs → $\Delta\chi^2$ distribution



Theoretical value 3.84