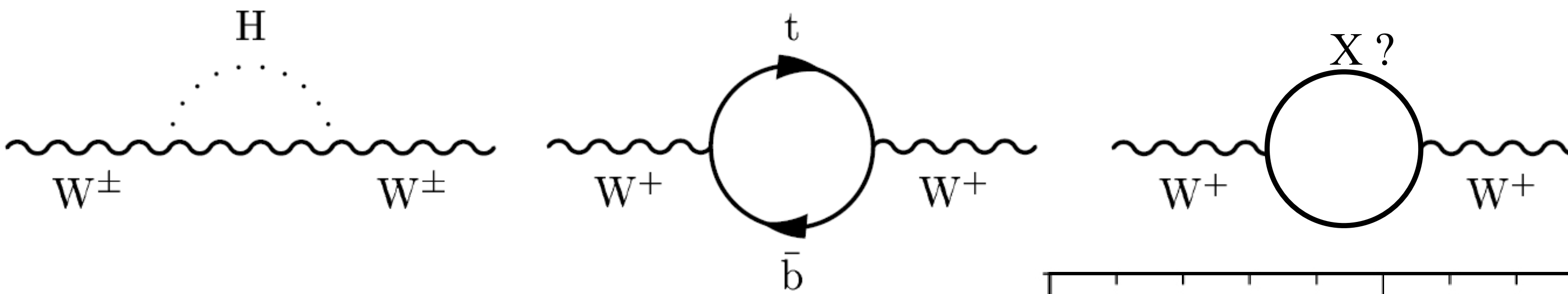
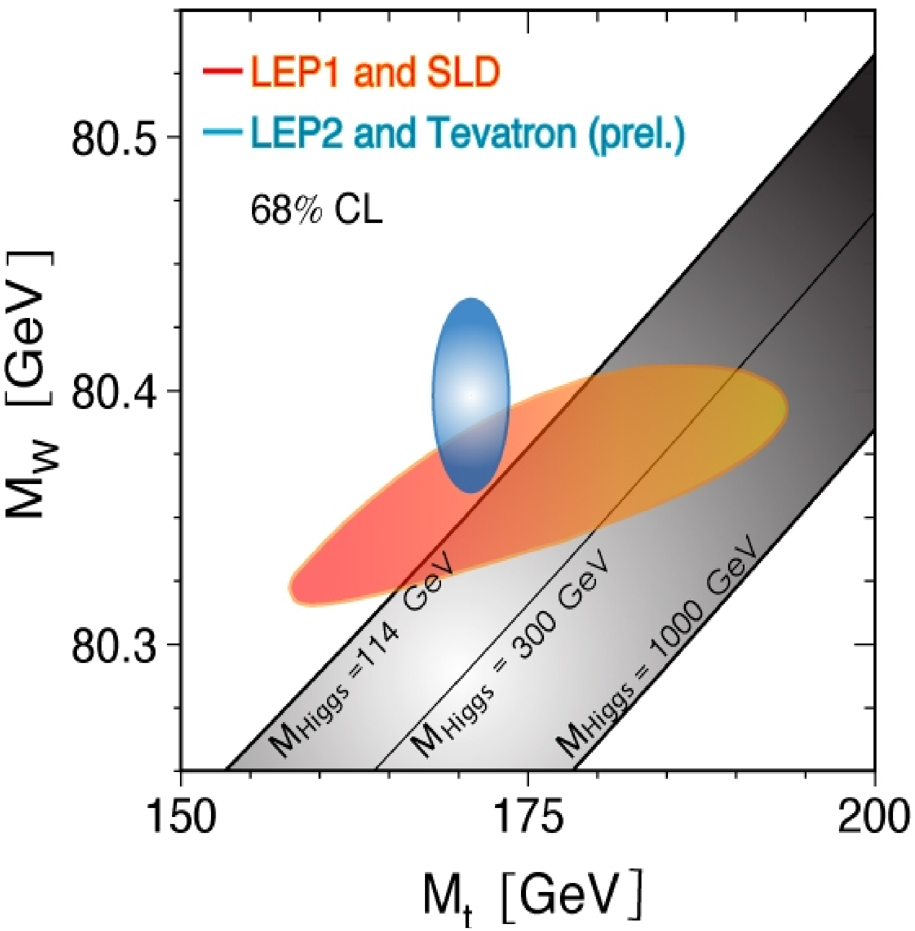
Precision Top Quark Mass From a Simultaneous Fit in Lepton+Jets and Dilepton Channels Using 2fb^{-1}

Wojciech Fedorko
on behalf of the CDF collaboration

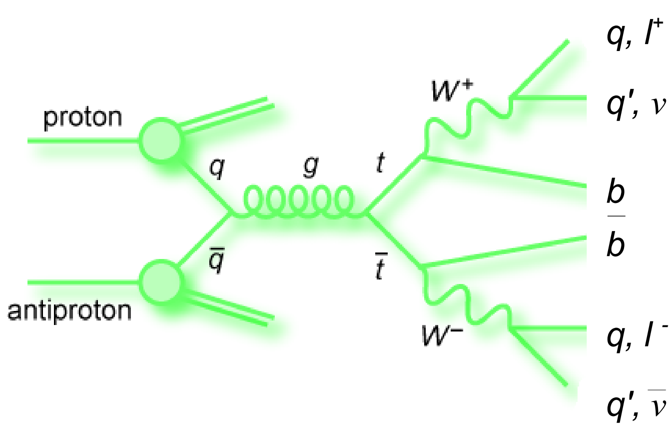
Why measure top quark mass?

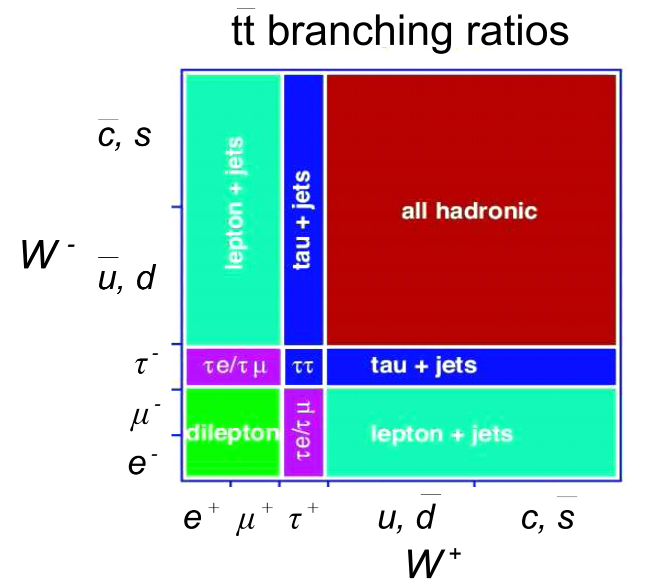


- M_{top} and M_W constrain the SM M_{Higgs} through loop corrections to the W mass.
- We want to understand the origins of mass – look at heaviest particle available



Top production and decay channels





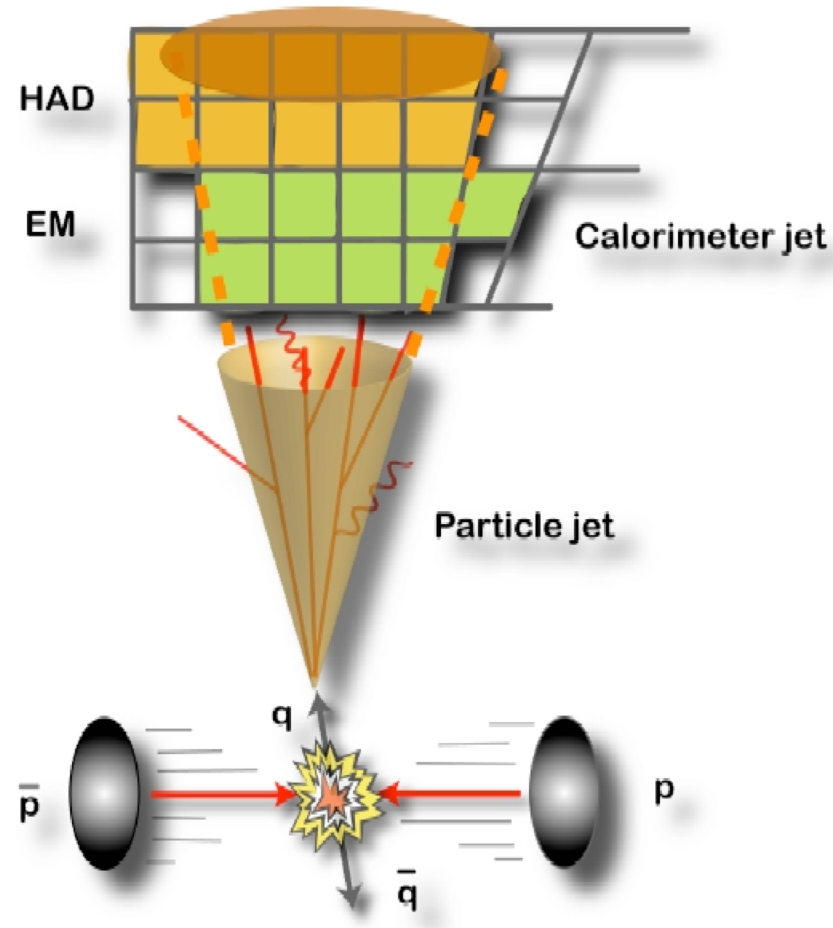
- Why measure M_{top} in multiple channels simultaneously?
  - Intrinsic treatment of systematics
  - Measurements don't have to be Gaussian
  - Jet energy scale calibration is uniform across the channels

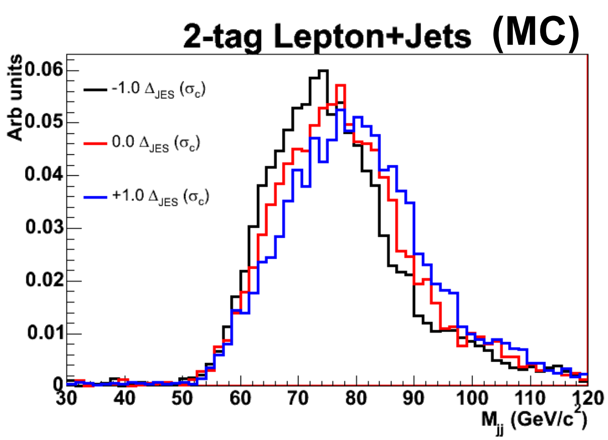
Event Reconstruction

- Need to reduce the complexity of the event to one number
- Want variable sensitive to the top mass: m_t^{reco}
- Use measured quantities: jets, leptons, $\not{E}_T$
- Apply constraints: W mass, masses of quarks and leptons.
- Lepton+Jets channel
  - Overconstrained system – will perform χ^2 fit
- Dilepton channel
  - Underconstrained – integrate over unknown quantites to get best m_t^{reco}

The Jet Energy Scale

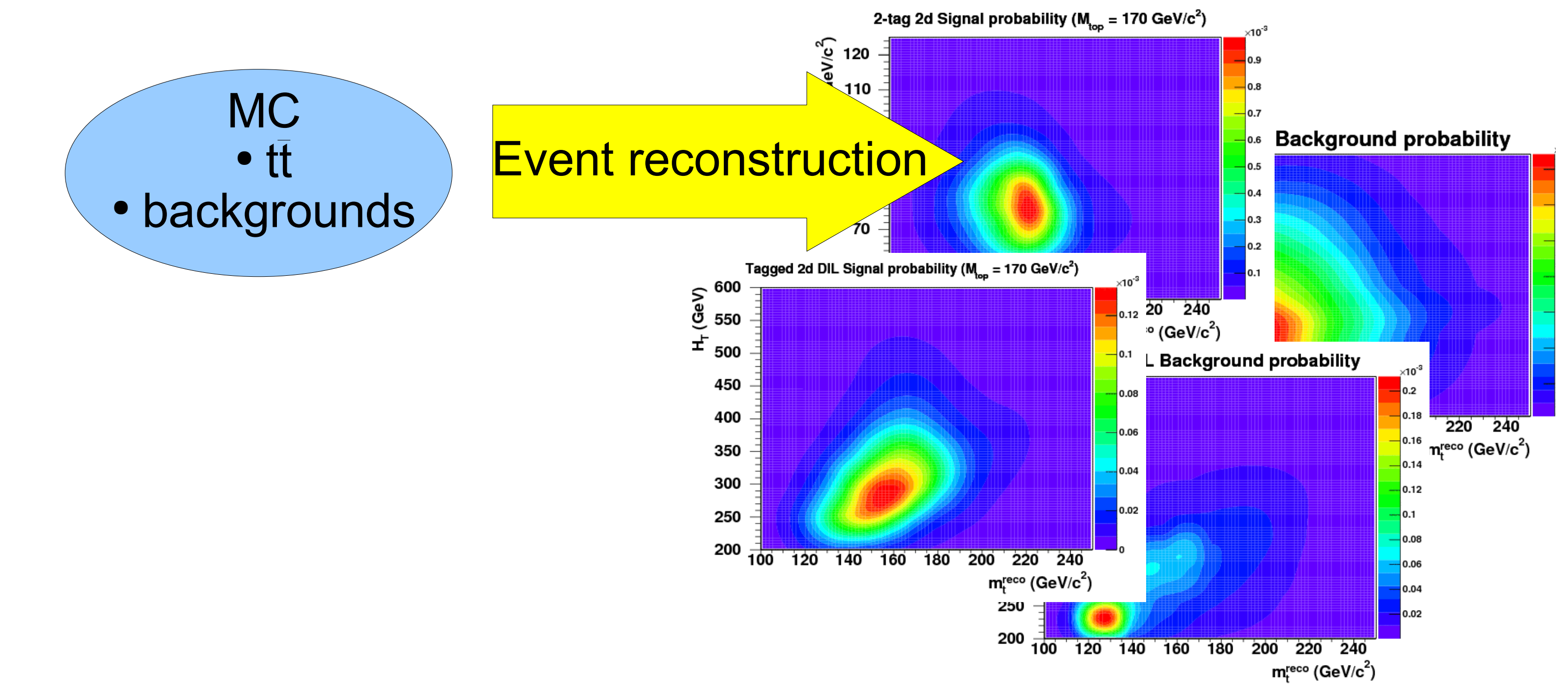
- JES is the biggest systematic
  - Given measured jets what are the quark momenta?
- Use the resonance in Lepton + Jets channel!



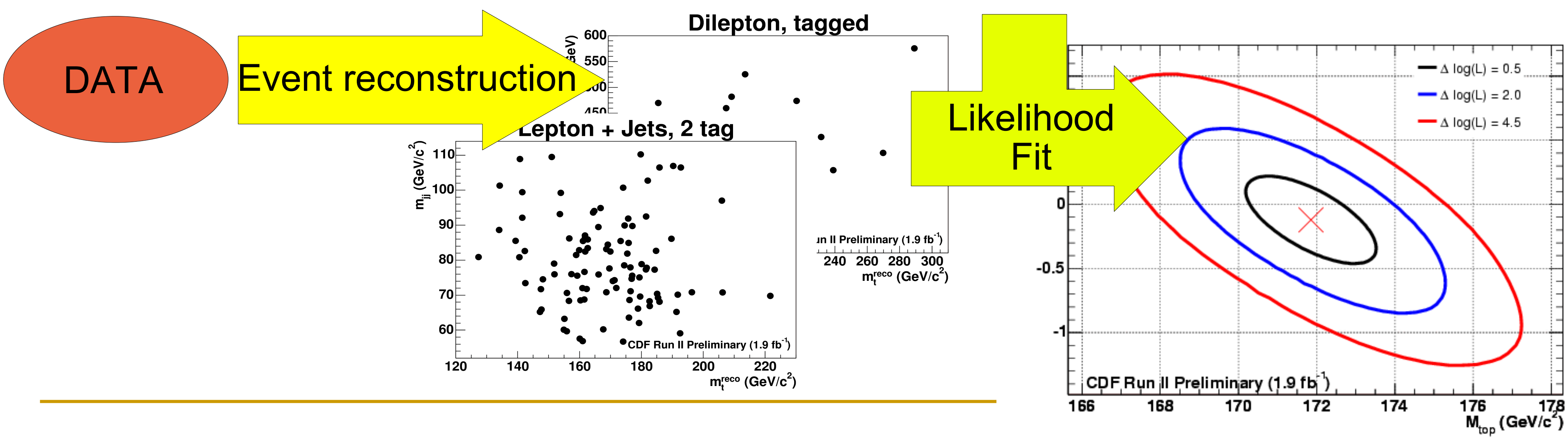


- Apply calibration to both channels

The template technique



- 2d templates
- m_t^{reco}, w_{jj} in Lepton+Jets
- m_t^{reco}, H_T in Dilepton
- signal pdf's depend on M_{top}, Δ_{JES}
- background pdf's depend on Δ_{JES}



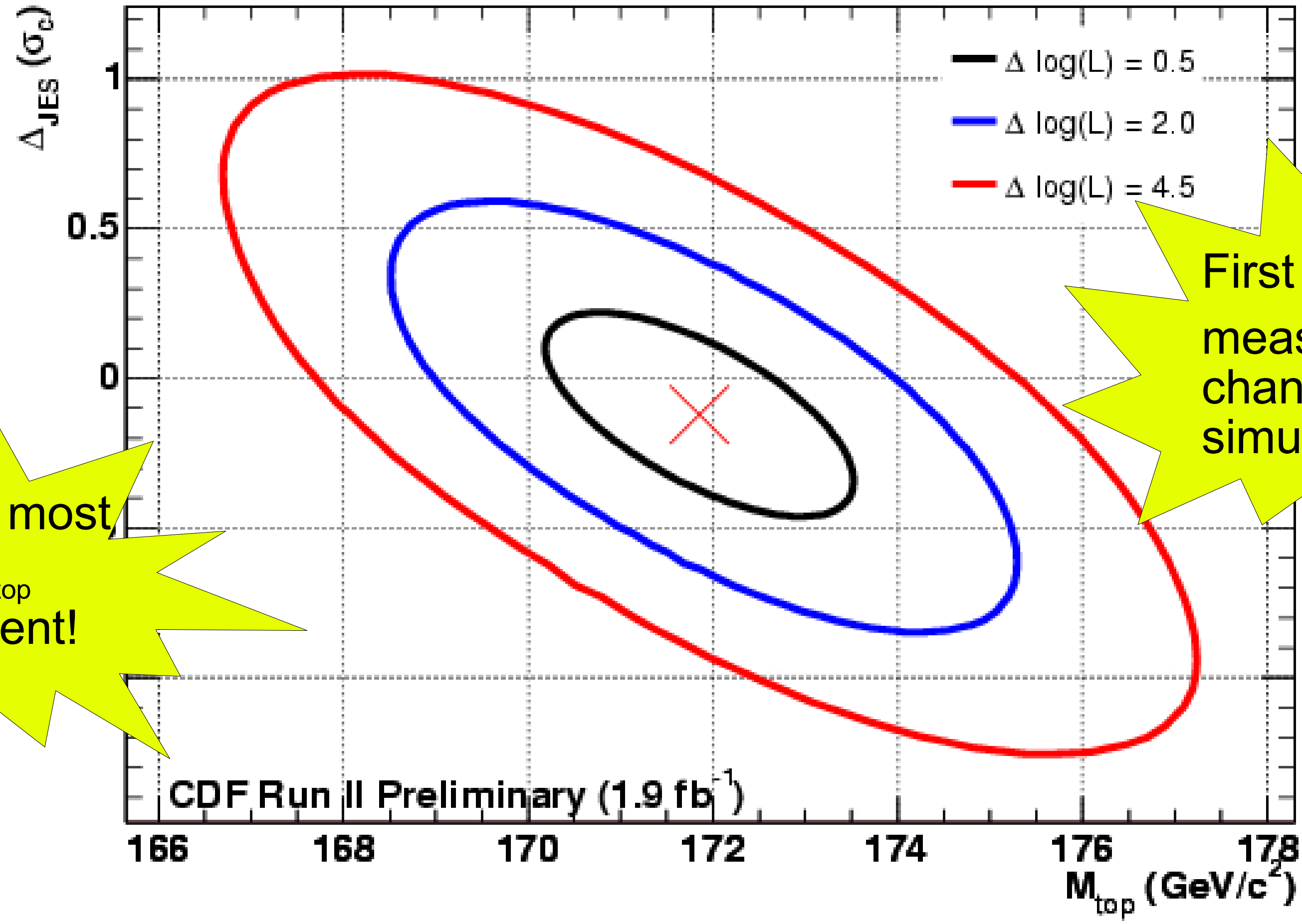
Systematics

CDF run II preliminary $1.9 fb^{-1}$

Source	Size (GeV/c^2)
b-quark energy scale	0.6
Residual JES	0.5
Initial state radiation	0.4
Final state radiation	0.2
Parton distribution functions	0.3
Generator	0.2
Lepton+Jets background shape	0.2
Dilepton background shape	0.1
Monte Carlo statistics	0.1
Lepton energy scale	0.1
Pileup	0.1
Total	**1.0**

We don't need to assume correlations in systematics between channels

The results!



The single most precise M_{top} measurement!

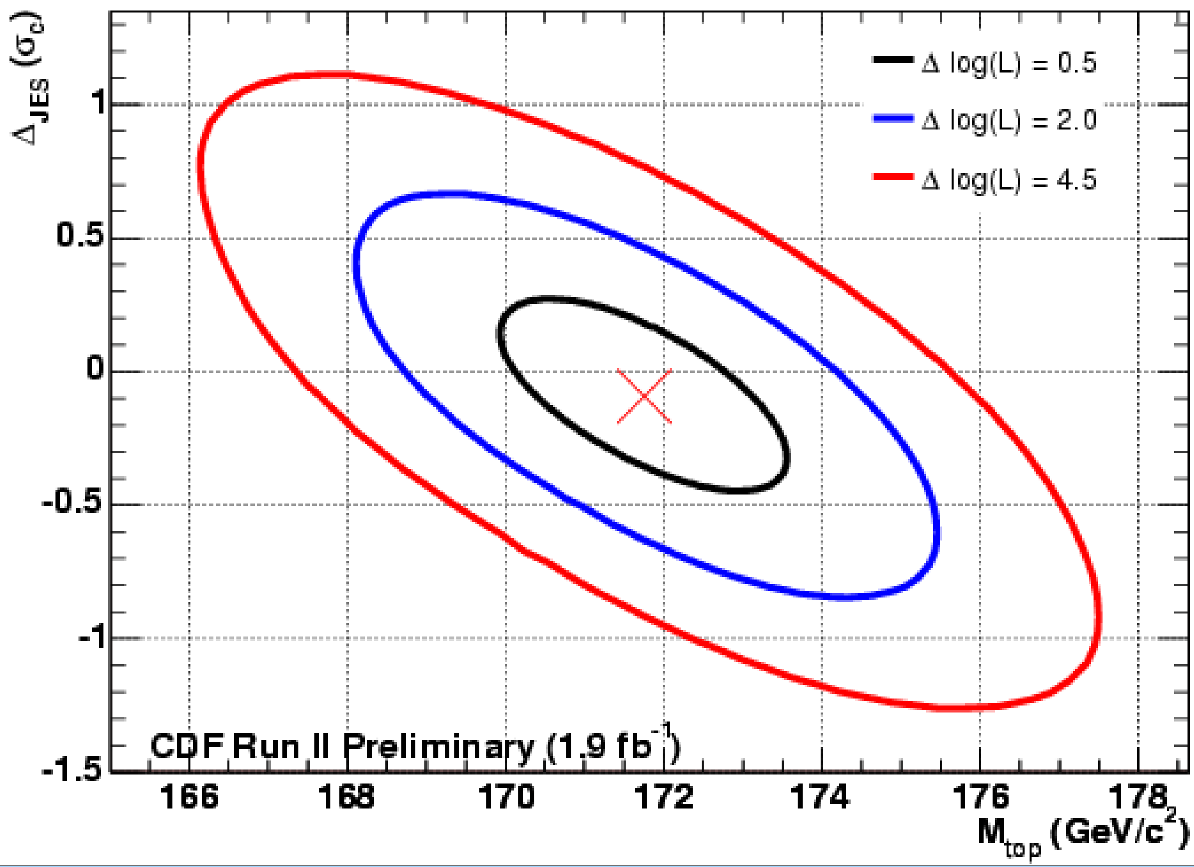
First M_{top} measurement in 2 channels simultaneously!

$$M_{top} = 171.9 \pm 1.7\ (\text{stat.+JES}) \pm 1.0\ (\text{syst})\ \text{GeV}/c^2$$

$$= 171.9 \pm 2.0\ \text{GeV}/c^2$$

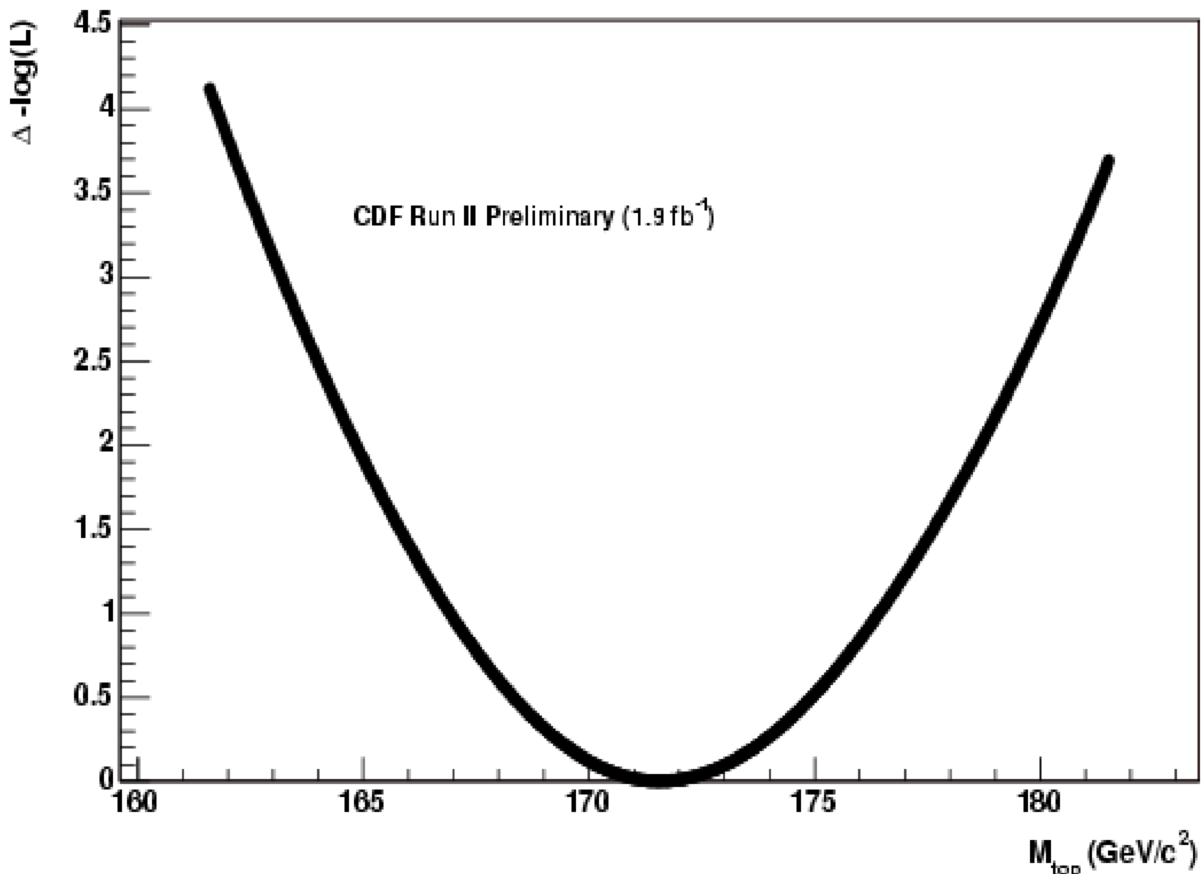
Backup

Lepton + Jets only fit



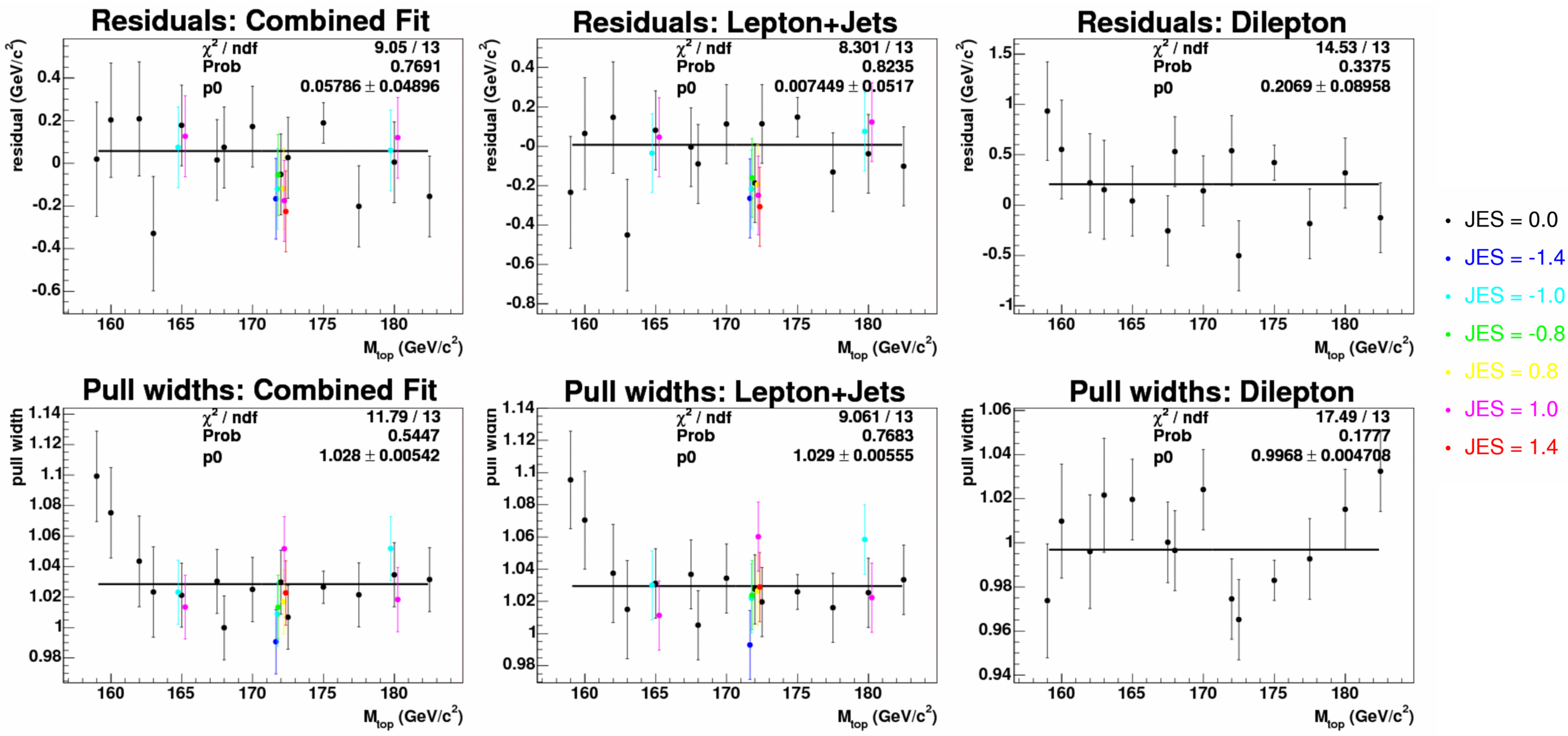
M_{top}=171.8 +/- 1.9 (stat.+JES) +/- 1.0 (syst) GeV/c^2
= 171.8 +/- 2.1 GeV/c^2

Dilepton only fit



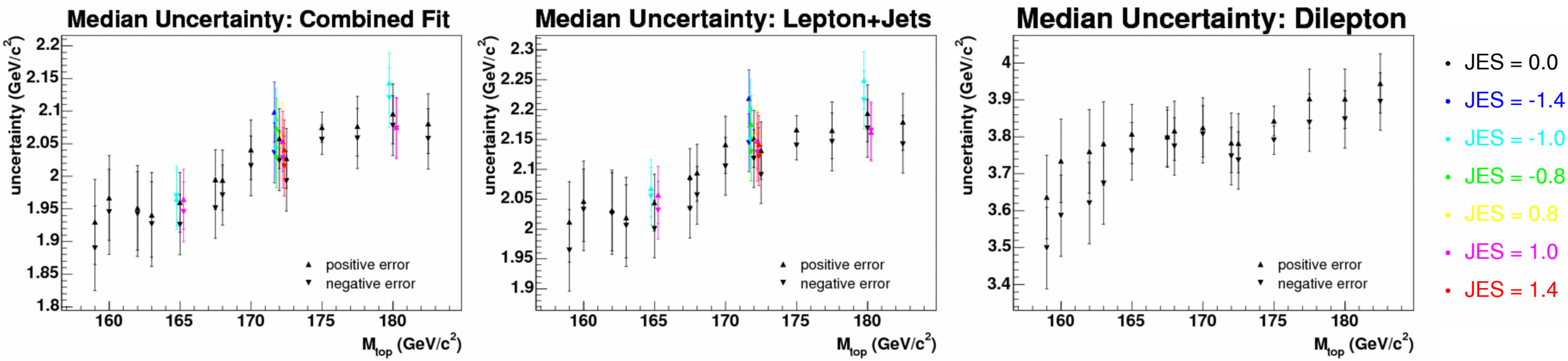
$$M_{top} = 171.6^{+3.4}_{-3.2}\ \text{(stat.+JES)} \pm 3.8\ \text{(syst) GeV/c}^2$$
$$= 171.6^{+5.1}_{-5.0}\ \text{GeV/c}^2$$

Bias check

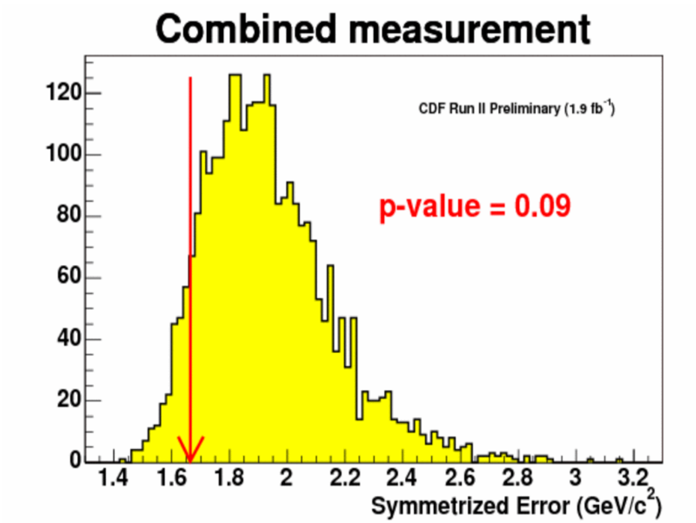


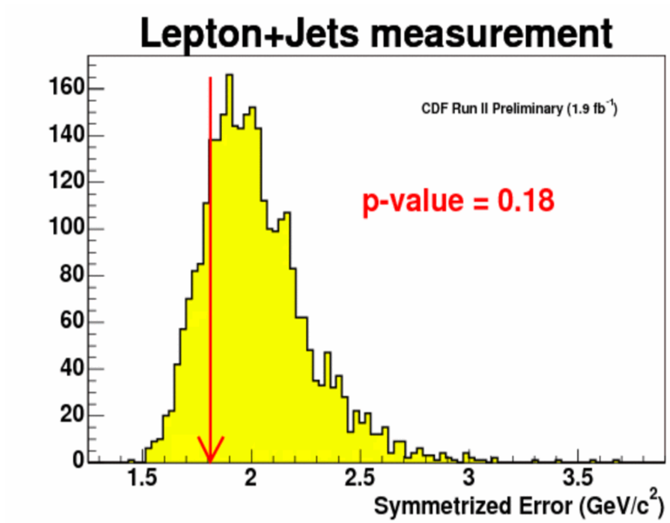
Residuals: Combined Fit
χ² / ndf 9.05 / 13
Prob 0.7691
p0 0.05786 ± 0.04896
Residuals: Lepton+Jets
χ² / ndf 8.301 / 13
Prob 0.8235
p0 0.007449 ± 0.0517
Residuals: Dilepton
χ² / ndf 14.53 / 13
Prob 0.3375
p0 0.2069 ± 0.08958
Pull widths: Combined Fit
χ² / ndf 11.79 / 13
Prob 0.5447
p0 1.028 ± 0.00542
Pull widths: Lepton+Jets
χ² / ndf 9.061 / 13
Prob 0.7683
p0 1.029 ± 0.00555
Pull widths: Dilepton
χ² / ndf 17.49 / 13
Prob 0.1777
p0 0.9968 ± 0.004708
residual (GeV/c²)
pull width
M_top (GeV/c²)
JES = 0.0
JES = -1.4
JES = -1.0
JES = -0.8
JES = 0.8
JES = 1.0
JES = 1.4

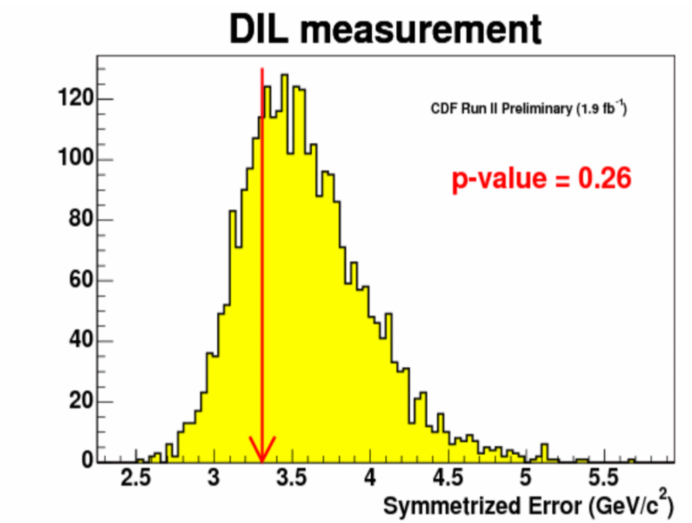
Expected uncertainty at $\sigma_{t\bar{t}}$=6.7pb



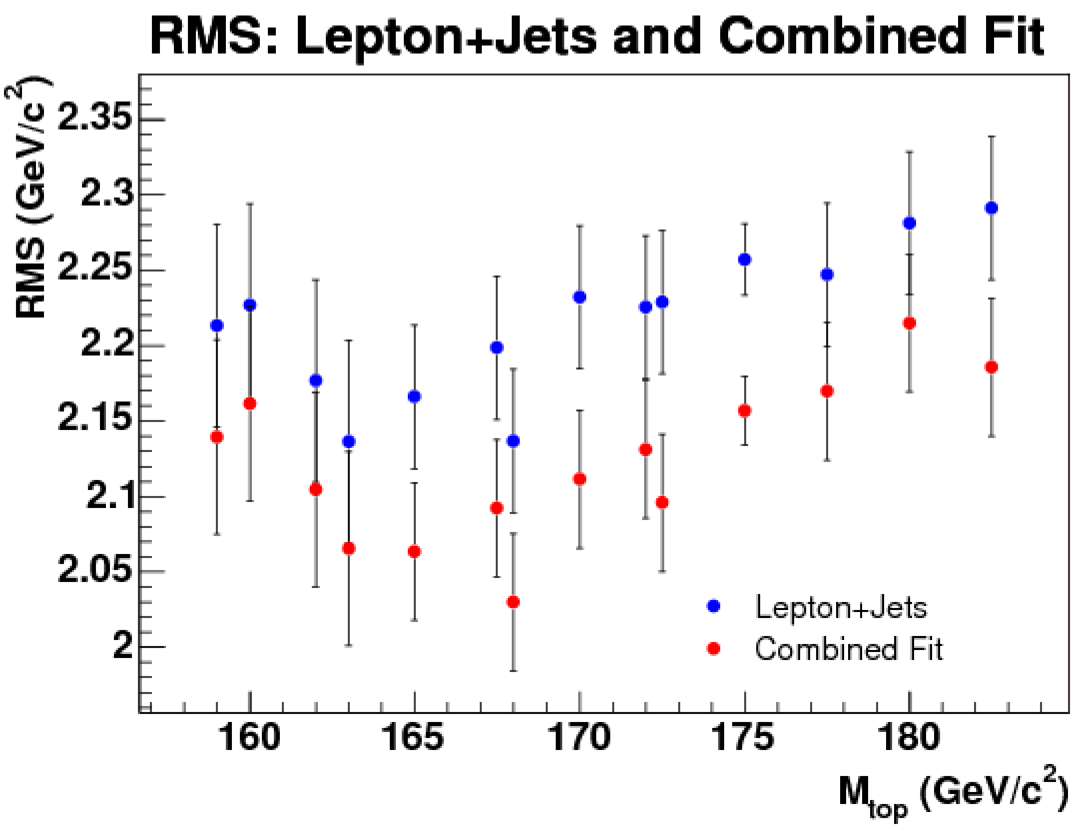
Expected error from PE's at observed #events







gain from DIL

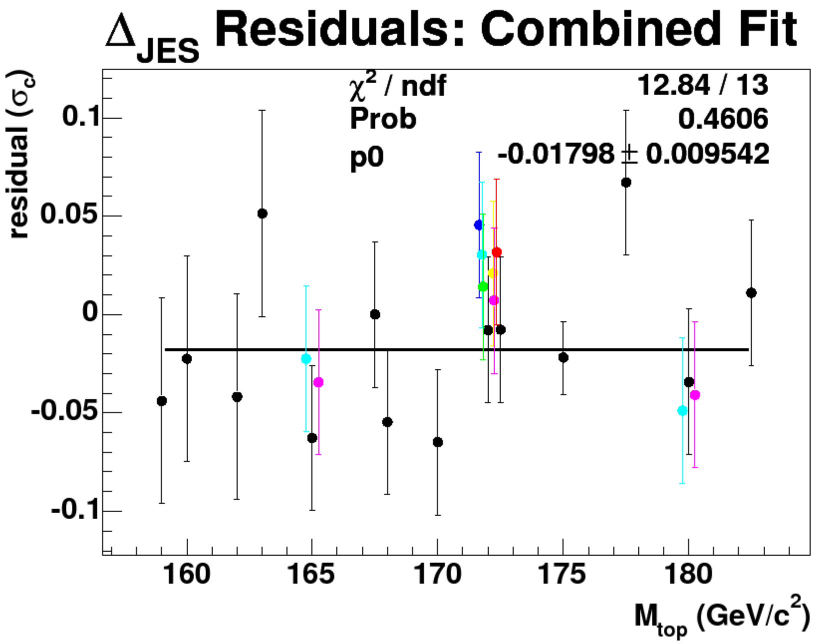


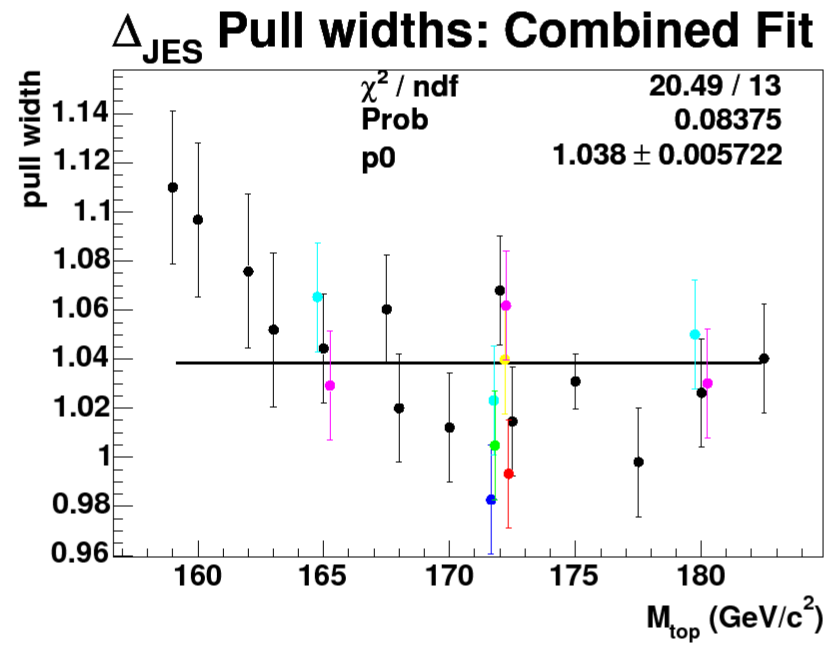
Major cross checks

CDF run II preliminary 1.9fb^{-1}

	Mtop (combo)	Mtop (LJ)	Mtop(DIL)
Nominal	171.9 +/- 1.7	171.8 +/-1.8	171.6 + 3.4 -3.2
No JES prior	171.9 +/-1.7	171.8 +/-1.9	
No bg prior	171.9 +/-1.7	171.8 +/-1.8	171.3 +/-3.5
1tag LJ		169.1 +3.1 -2.6	
2tag LJ		173.6 +2.6 -2.3	
non-tagged DIL			170.4 +5.8 -7.1
tagged DIL			172.2 +4.3 -3.9

JES calibration/result





Combined LJ+DIL fit to data:

$$\Delta_{JES} = -0.1 \pm 0.4\ \sigma_c$$

Signal, Background expectation, observed LJ

CDF run II preliminary 1.9fb^{-1}

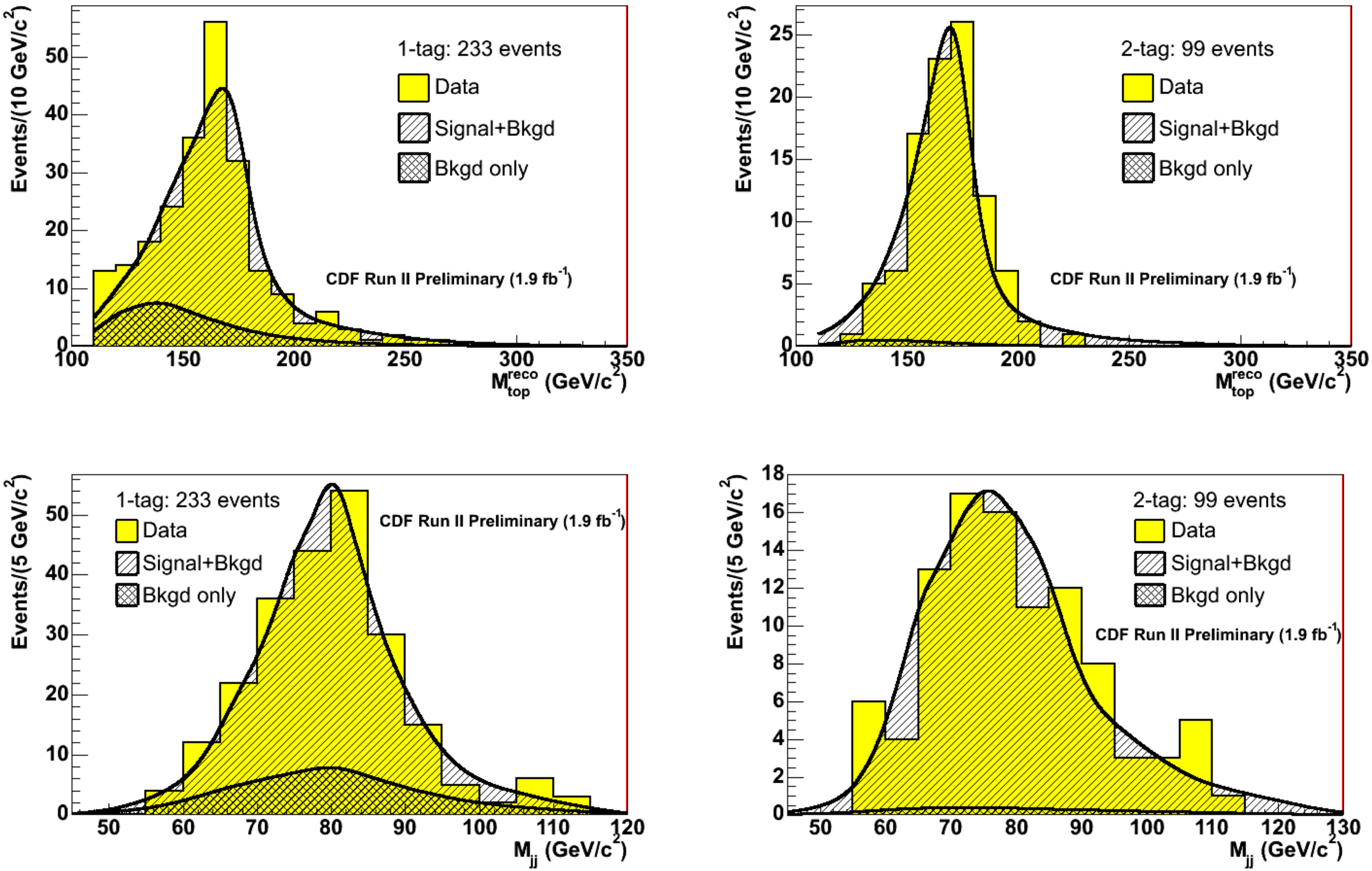
	1 tag	2-tag
Wbb	9.1	2.1
Wcc	5.0	0.4
Wcc	3.3	0.1
W(mistags)	10.4	0.2
single top	2.0	0.7
diboson	2.4	0.2
QCD	10.4	0.3
Total background	42.7 +/- 12.5	4.2 +/- 1.9
ttbar(6.7pb)	156.7	76.6
observed	233	99

Signal, Background expectation, observed DIL

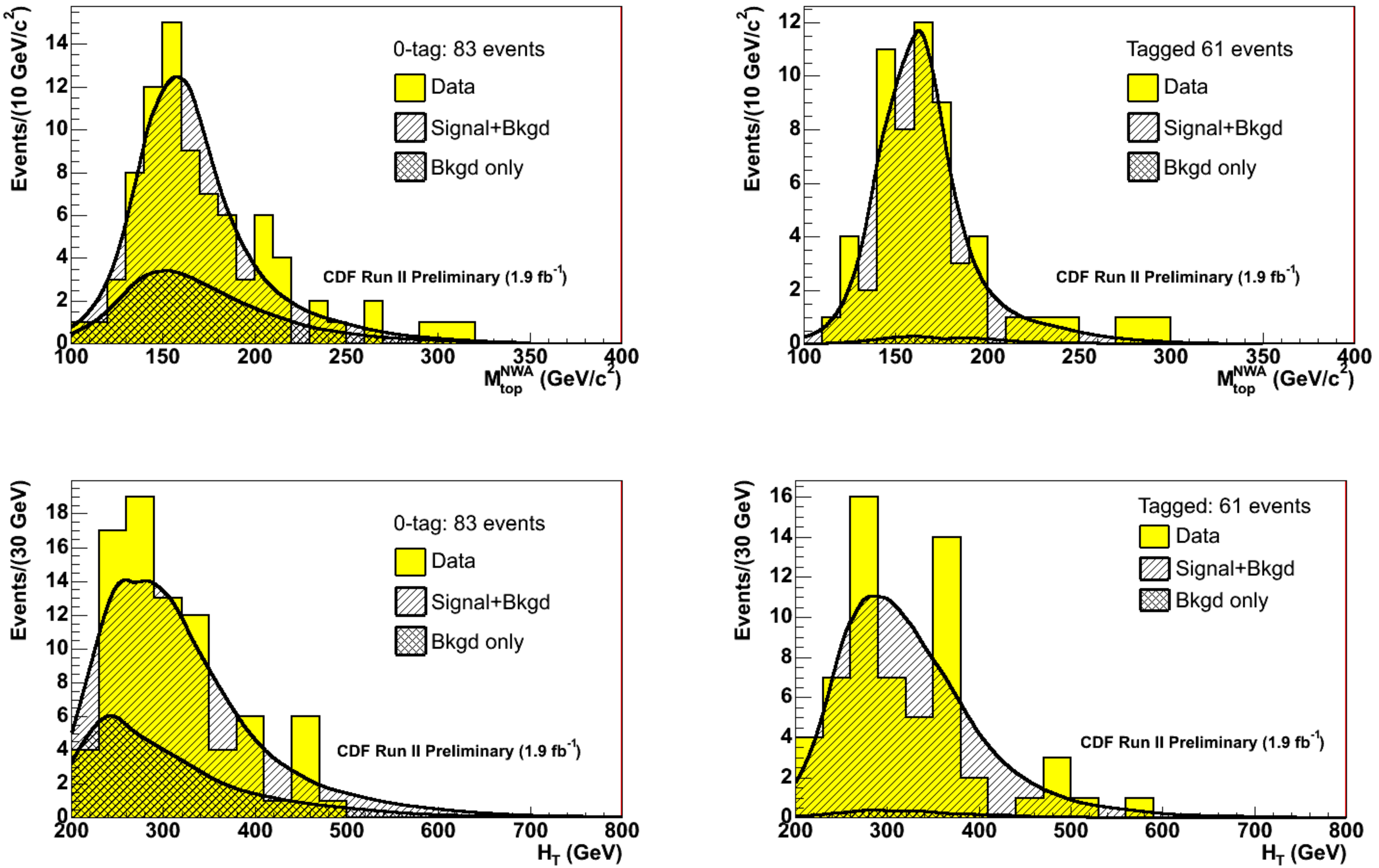
CDF run II preliminary 1.9fb^{-1}

	non-tagged	tagged
diboson	8.9	0.3
DY	16.0	0.9
fakes	6.1	1.2
total bg	31.1 +/- 5.6	2.4 +/- 0.6
ttbar (6.7pb)	40.1	55.8
observed	83	61

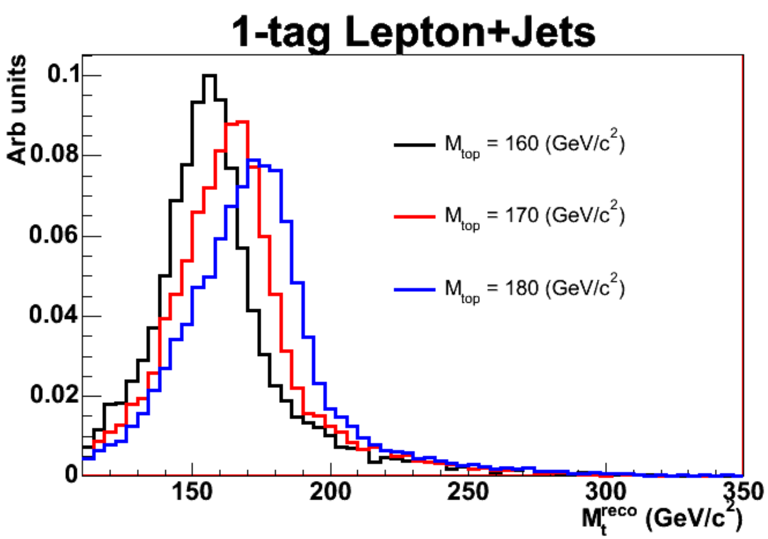
Data plots: LJ

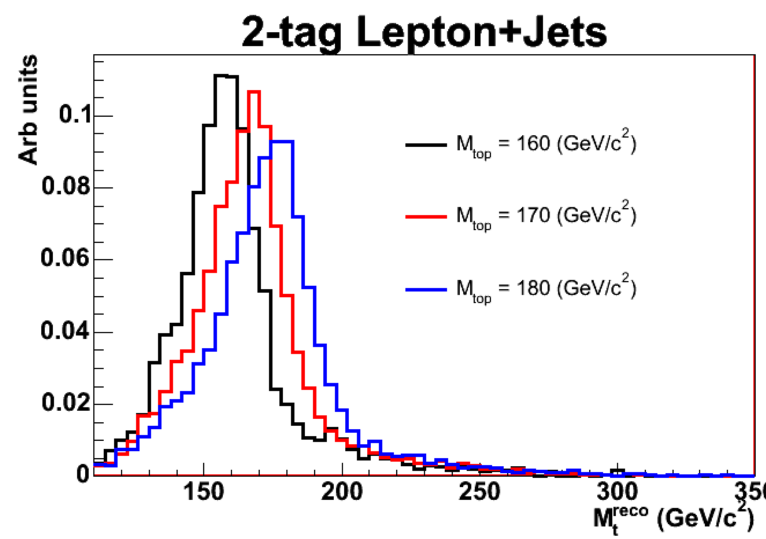


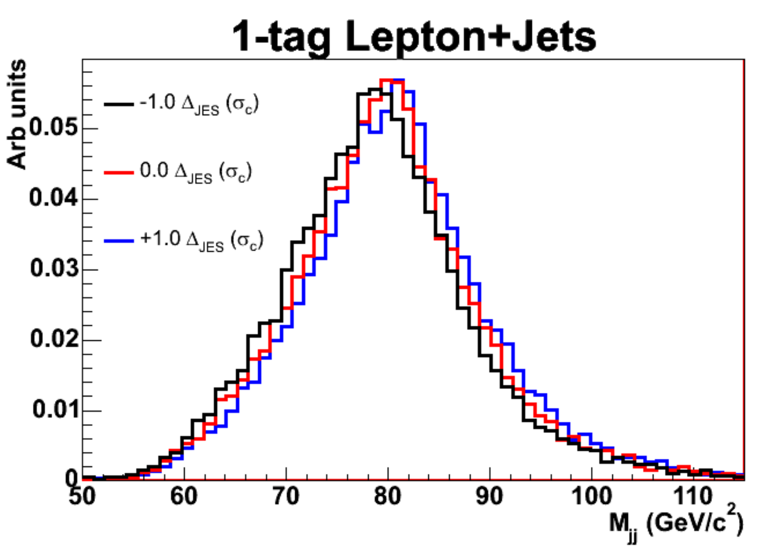
Data plots: DIL

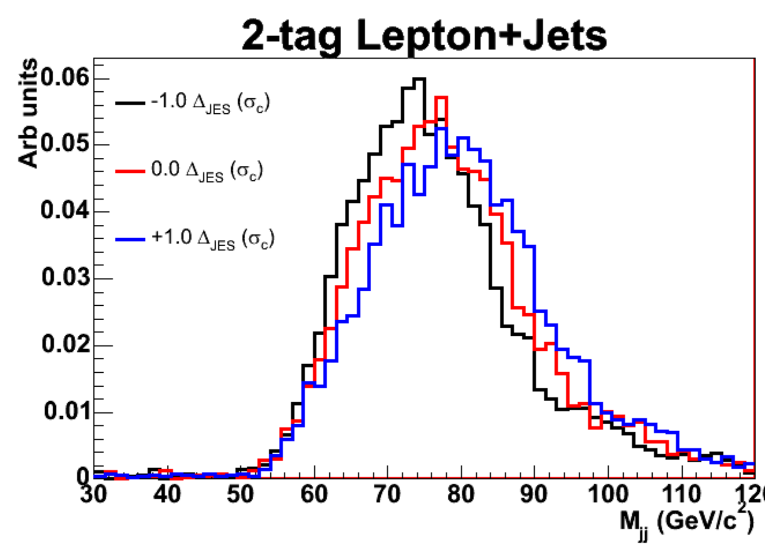


LJ distributions

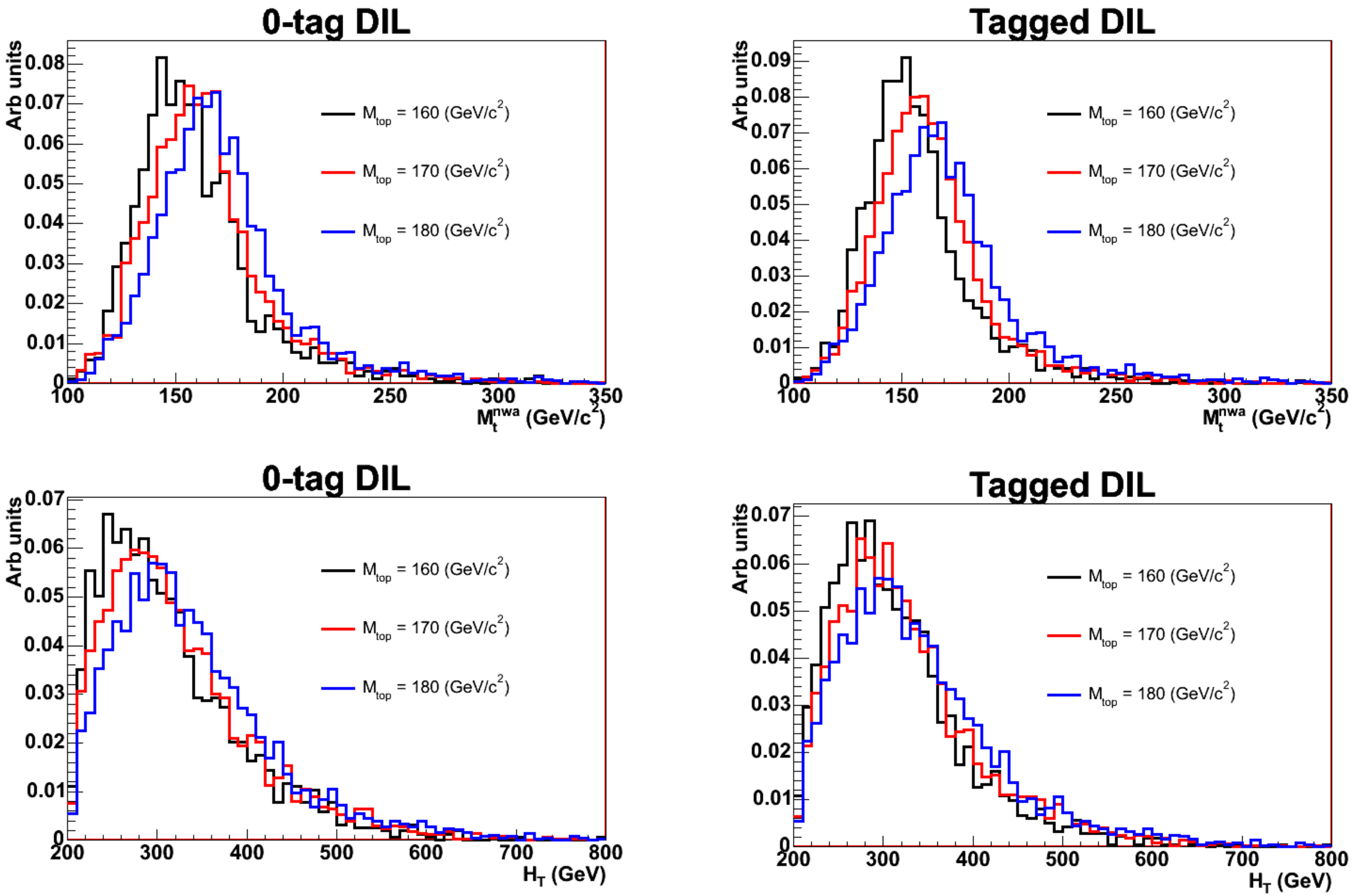




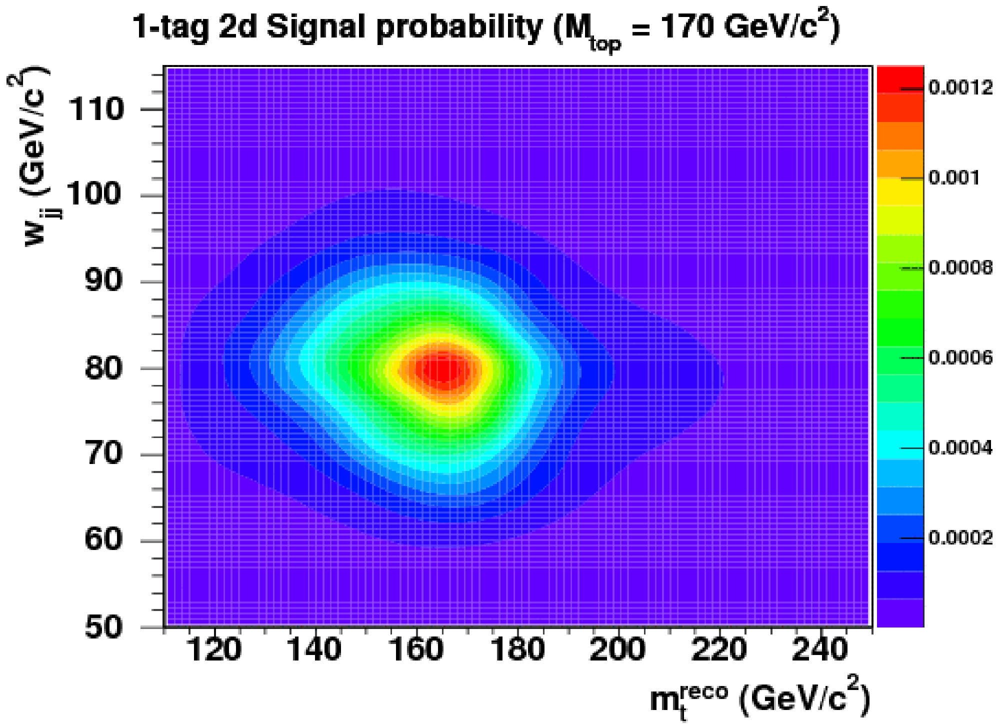


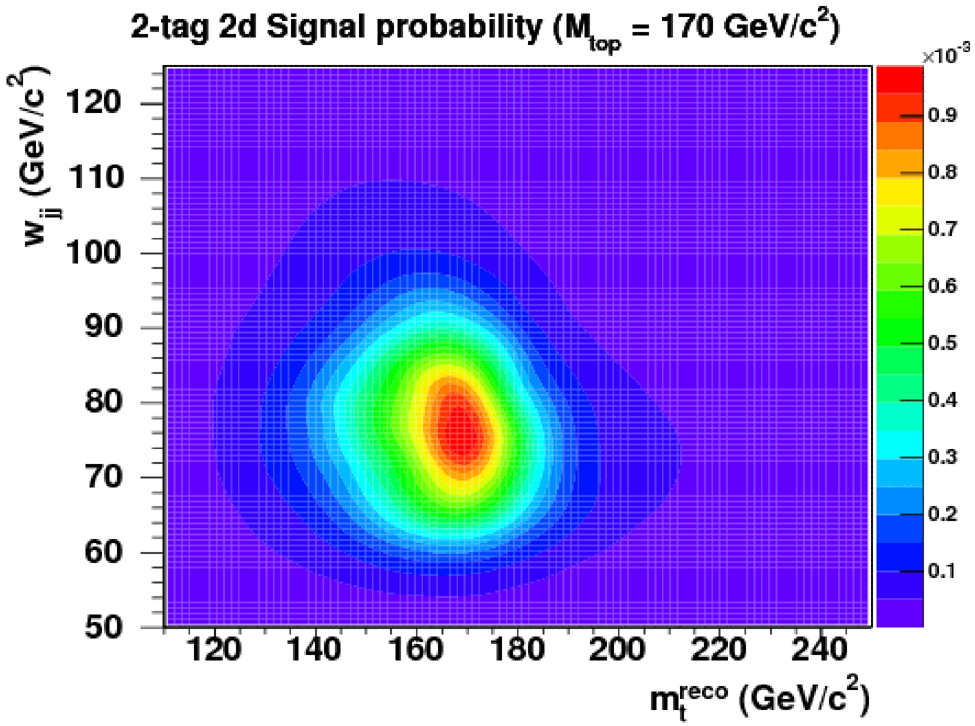


DIL distributions

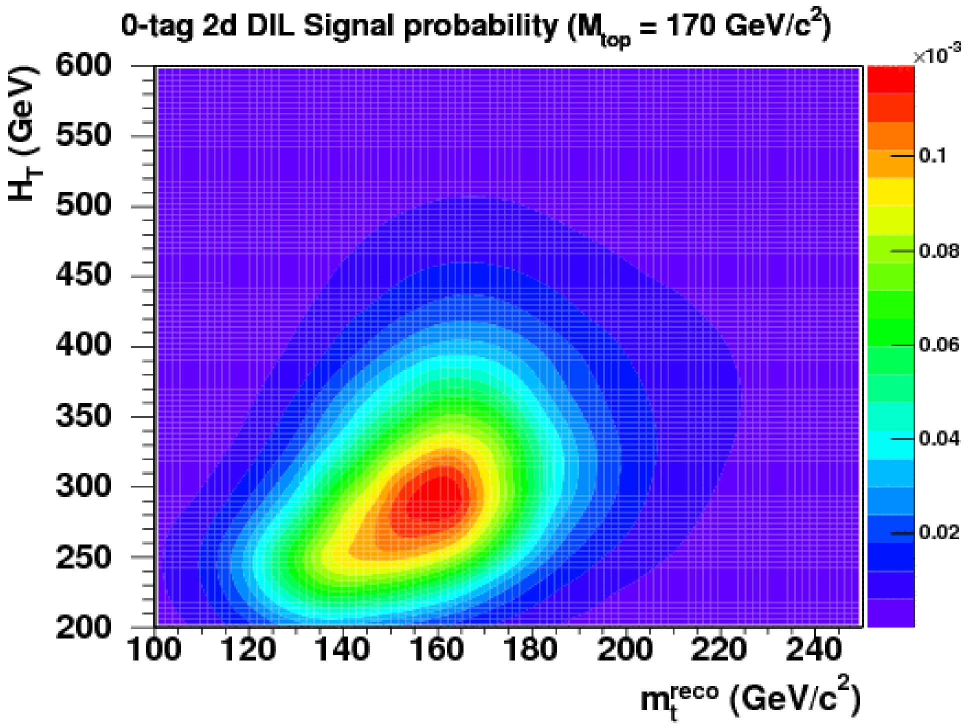


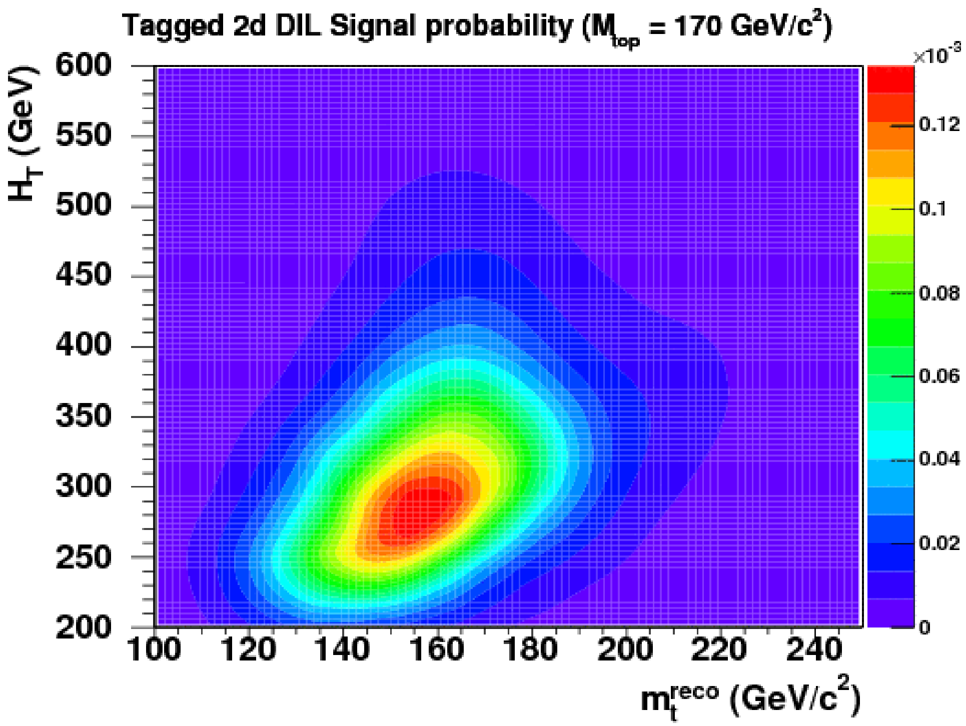
Signal Templates LJ



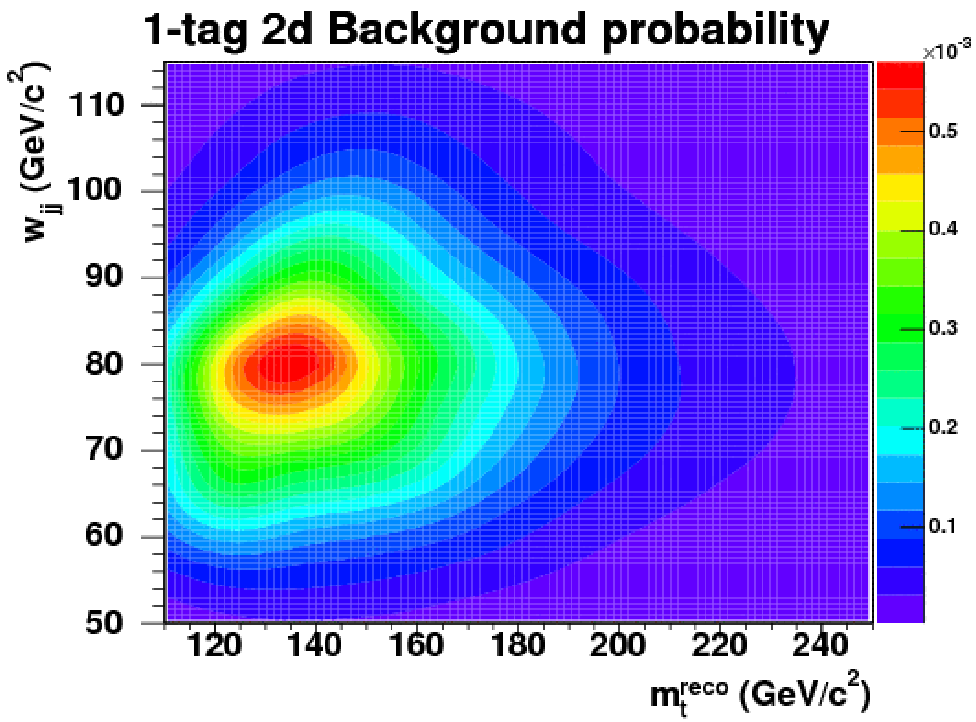


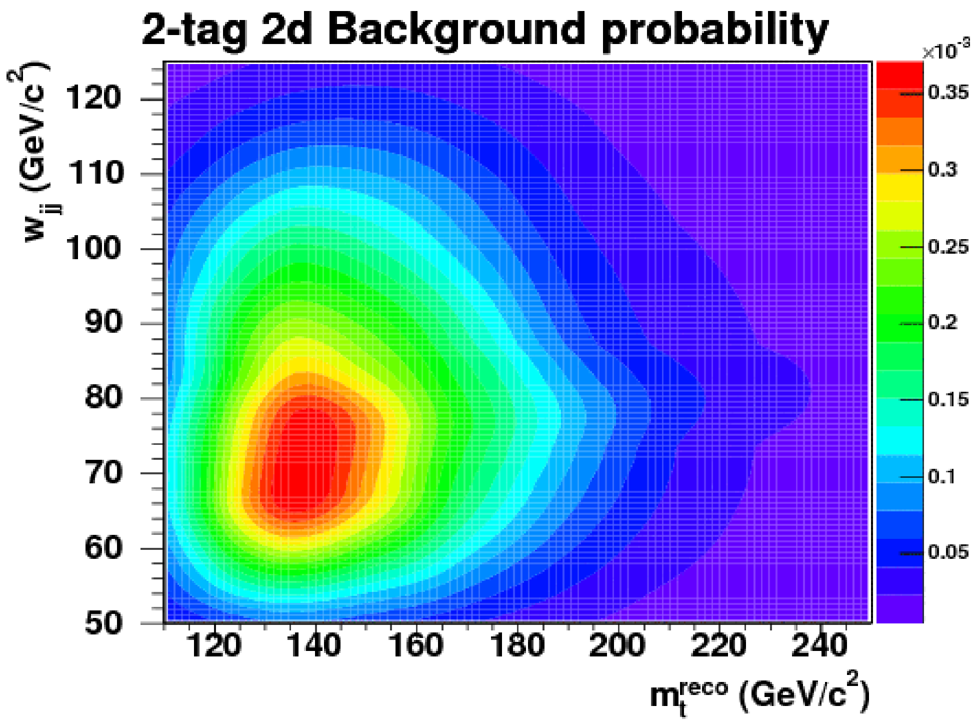
Signal Templates DIL



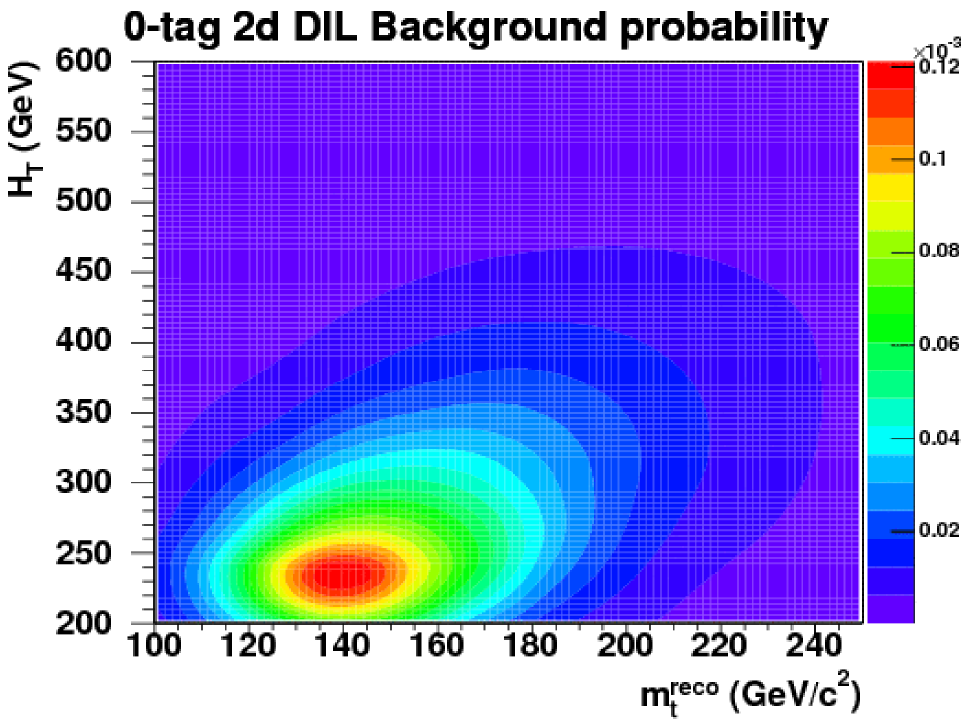


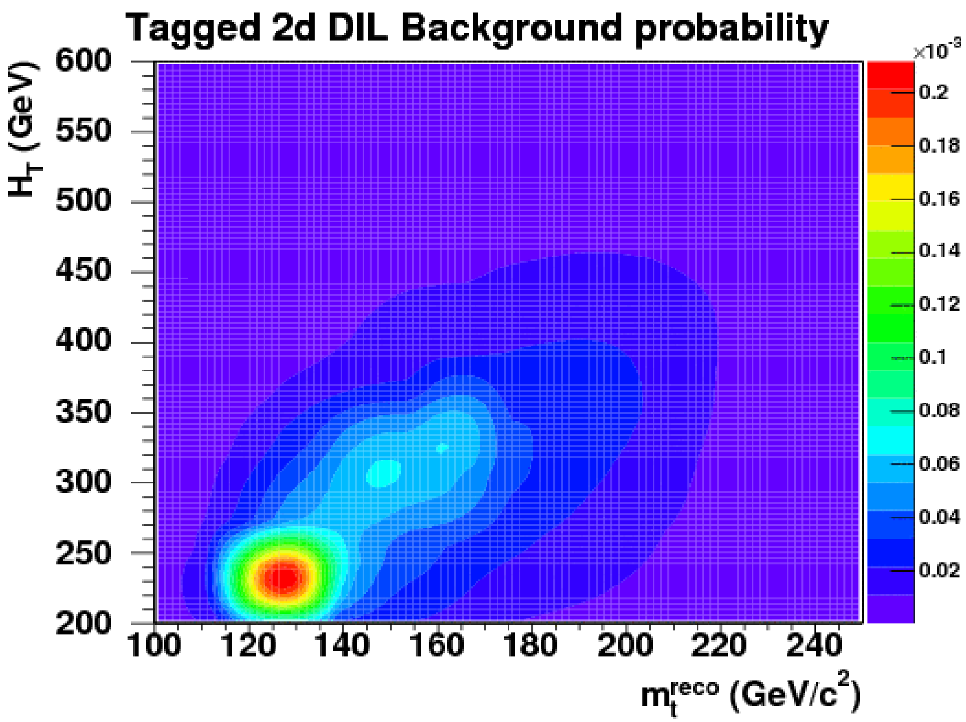
Bg Templates LJ





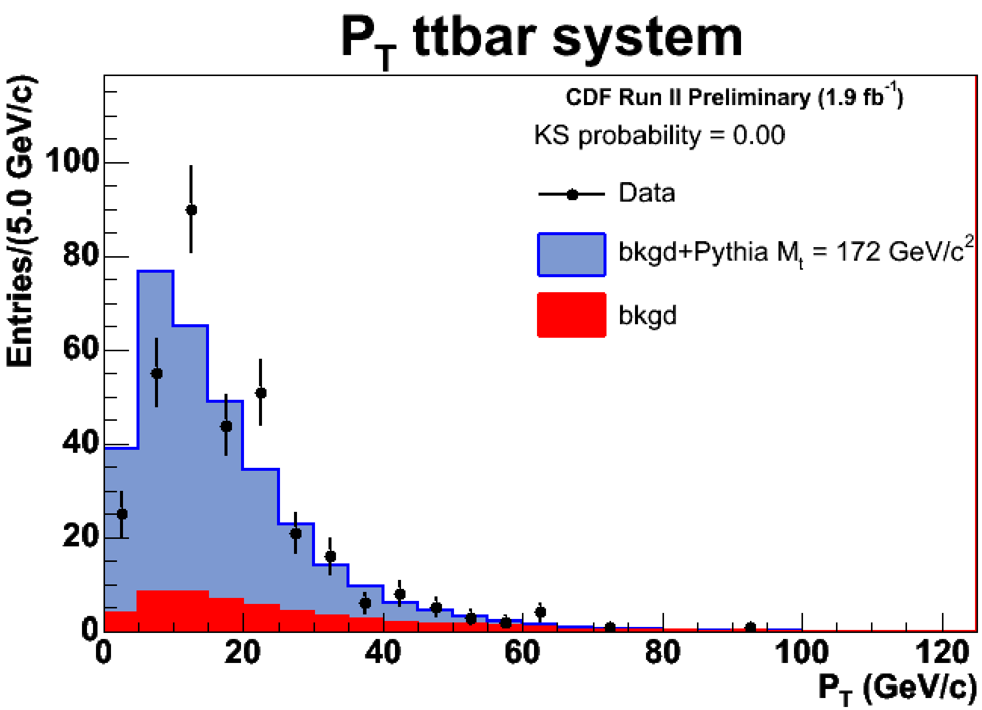
Bg Templates DIL

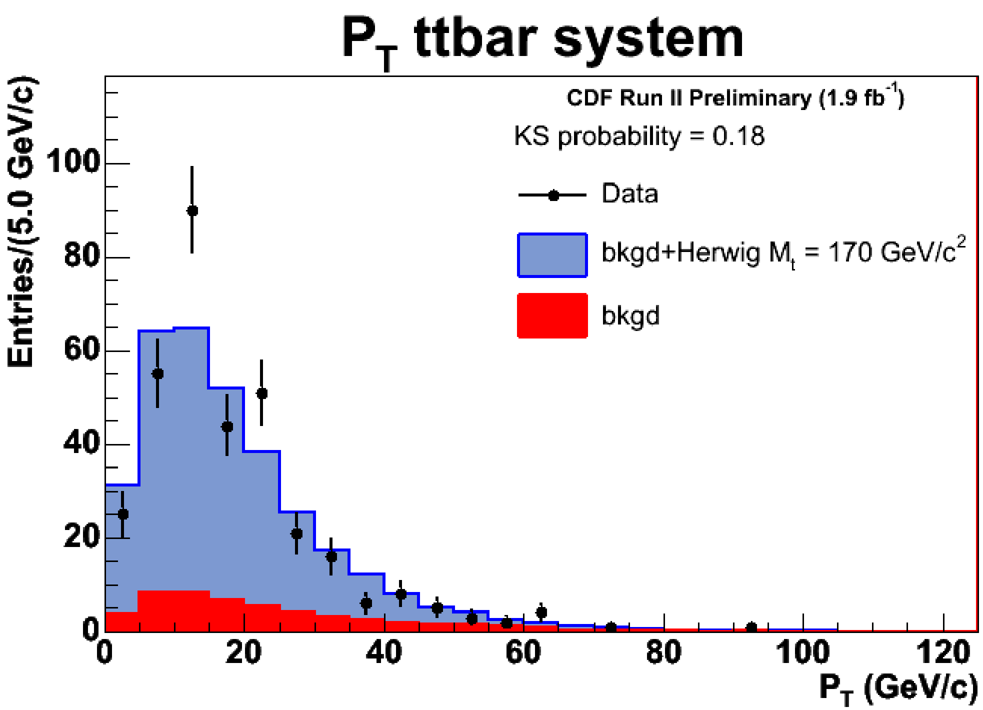




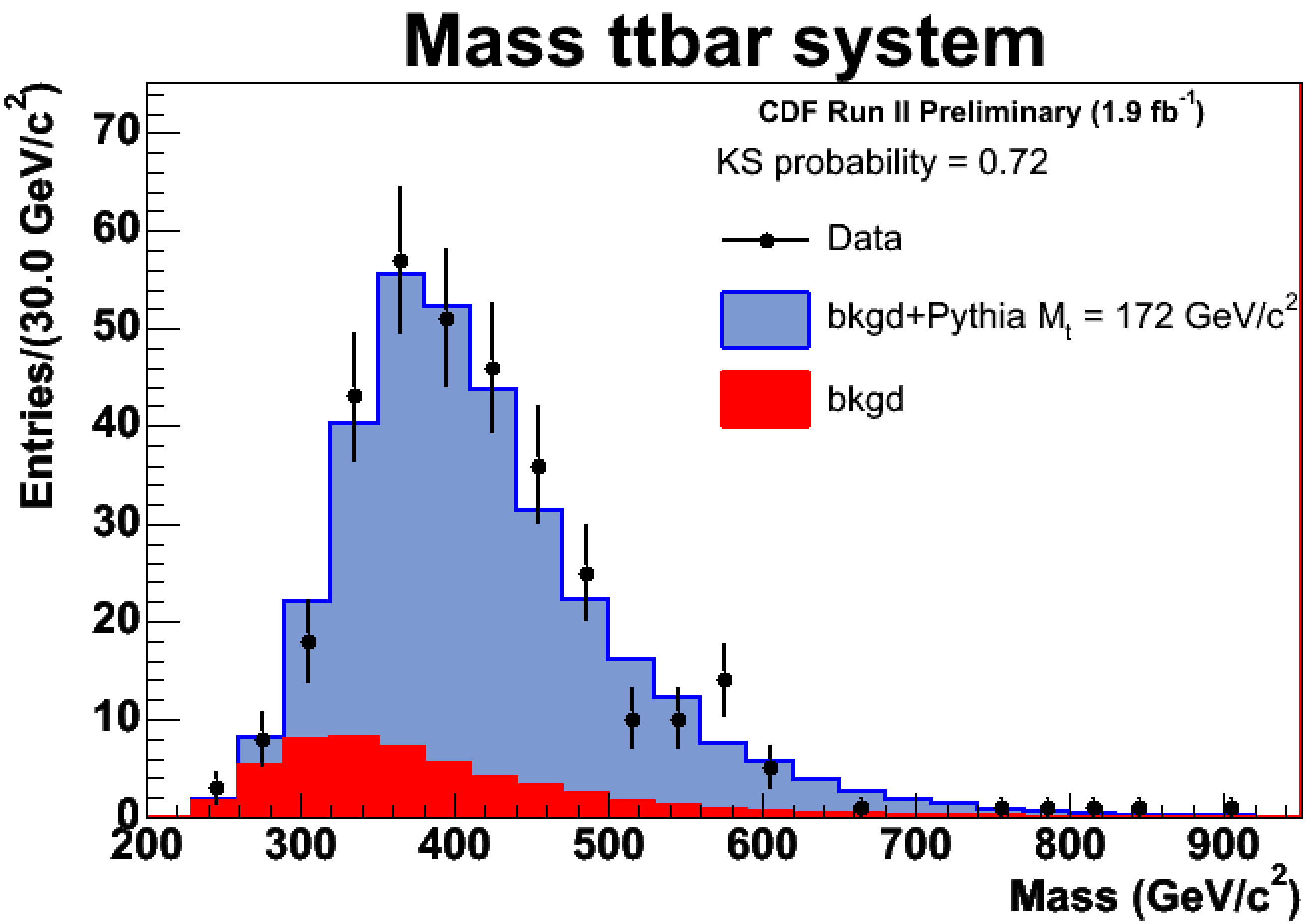
kinematic distributions

- All quantities out of $\chi 2$ fitter

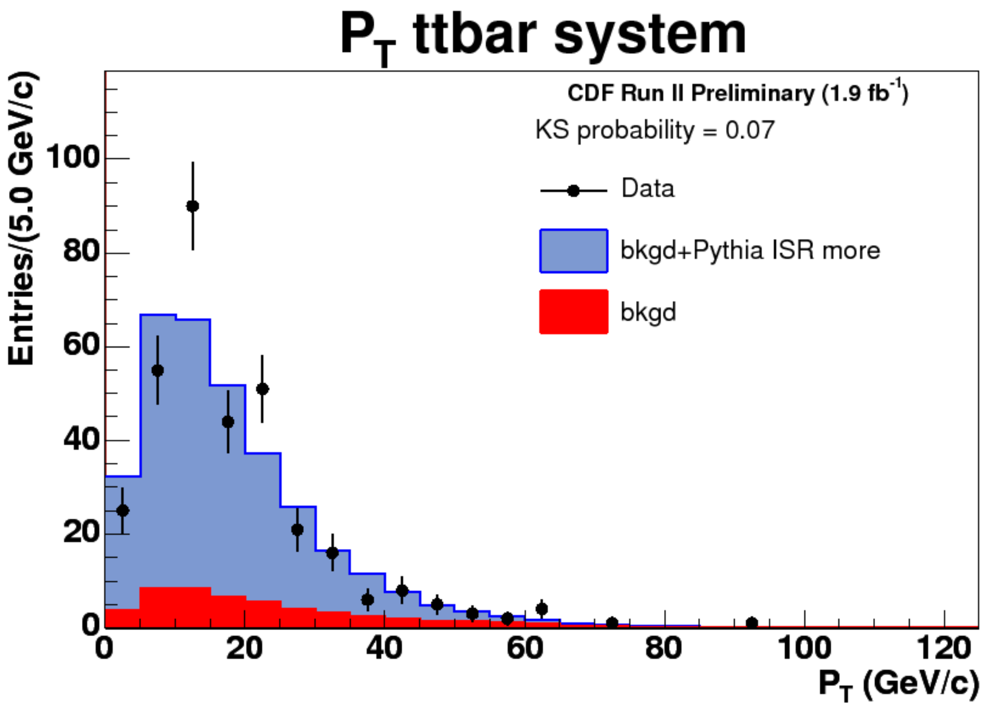


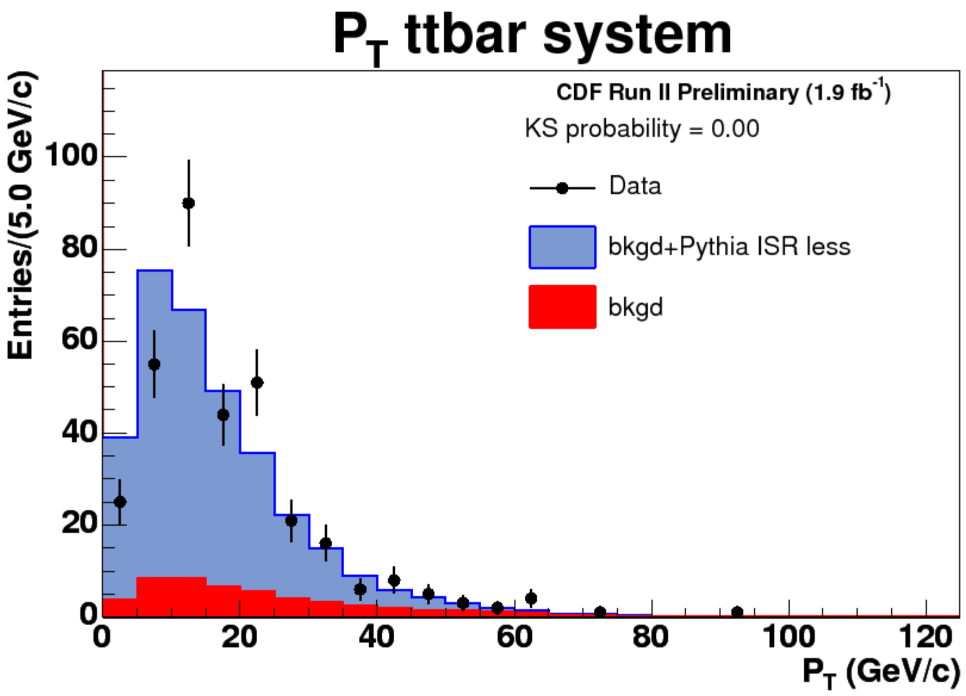


kinematic distributions

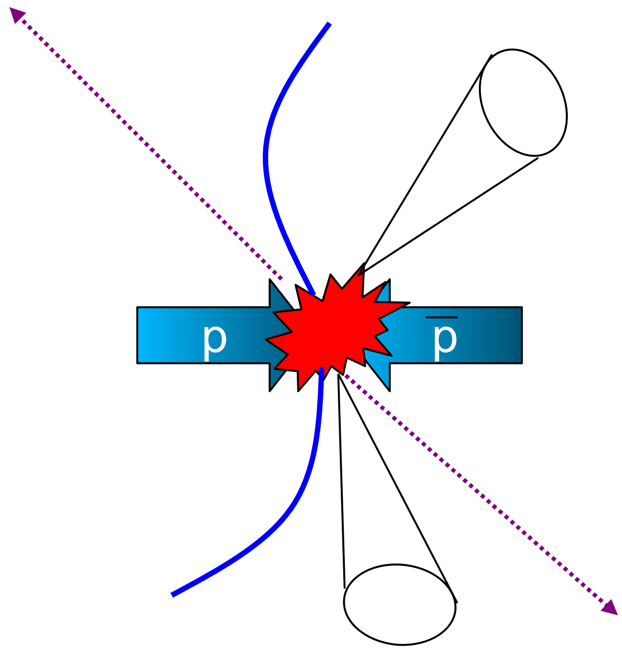


More/Less ISR pt(ttbar)





What can we measure in an event?



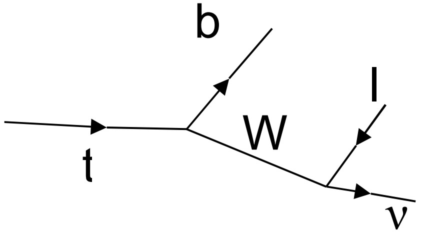
- quarks - response in the calorimeter clustered into jets
- e,μ- get p_t from curvature or calorimeter response
- υ escape – we can only infer p_t (p_z unknown)
- b-jets may be 'tagged'

- Why not just add 4-vectors and calculate invariant mass?
  - υ p_z unknown, only total missing p_t known
  - Which jets and leptons go together?
  - Background events contamination
- We need to 'reconstruct' the event- form m_t^{reco} using all available information

Dilepton event reconstruction: Neutrino Weighting Algorithm

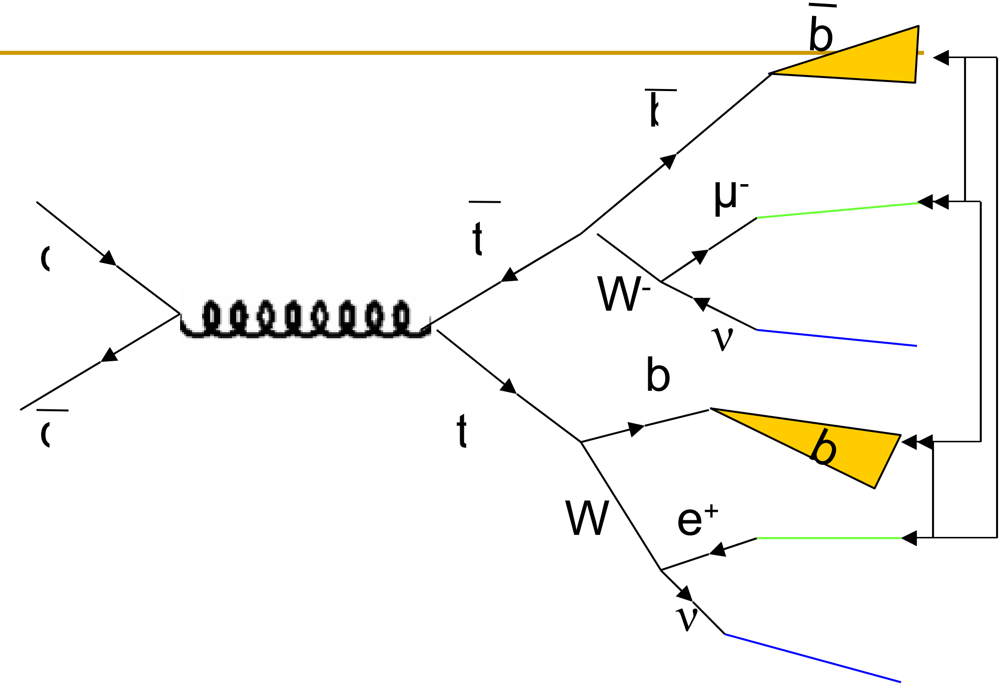
- Assume we know the correct parton assignment neutrino polar angles and the top mass:
  - On each side of the decay we can form two scalars:

$$
\begin{aligned}
B \equiv 2b\nu &= m_t^2 - m_W^2 - m_b^2 - 2b\ell \\
L \equiv 2\ell\nu &= m_W^2 - m_\ell^2 - m_\nu^2 \\
&= m_W^2 - m_\ell^2
\end{aligned}
$$



  - Two equations, two unknowns: We solve for P_x^ν P_y^ν
- Solve for the other leg

NWA continued...



- Compare to the measured missing energy and assign weight:

$$w_i = exp(-\frac{(\not{E}_x - P_x^{\nu} - P_x^{\bar{\nu}})^2}{2\sigma_x^2}) \cdot exp(-\frac{(\not{E}_y - P_y^{\nu} - P_y^{\bar{\nu}})^2}{2\sigma_y^2})$$

- Sum over neutrino rapidities, lepton-jet assignments and solutions:

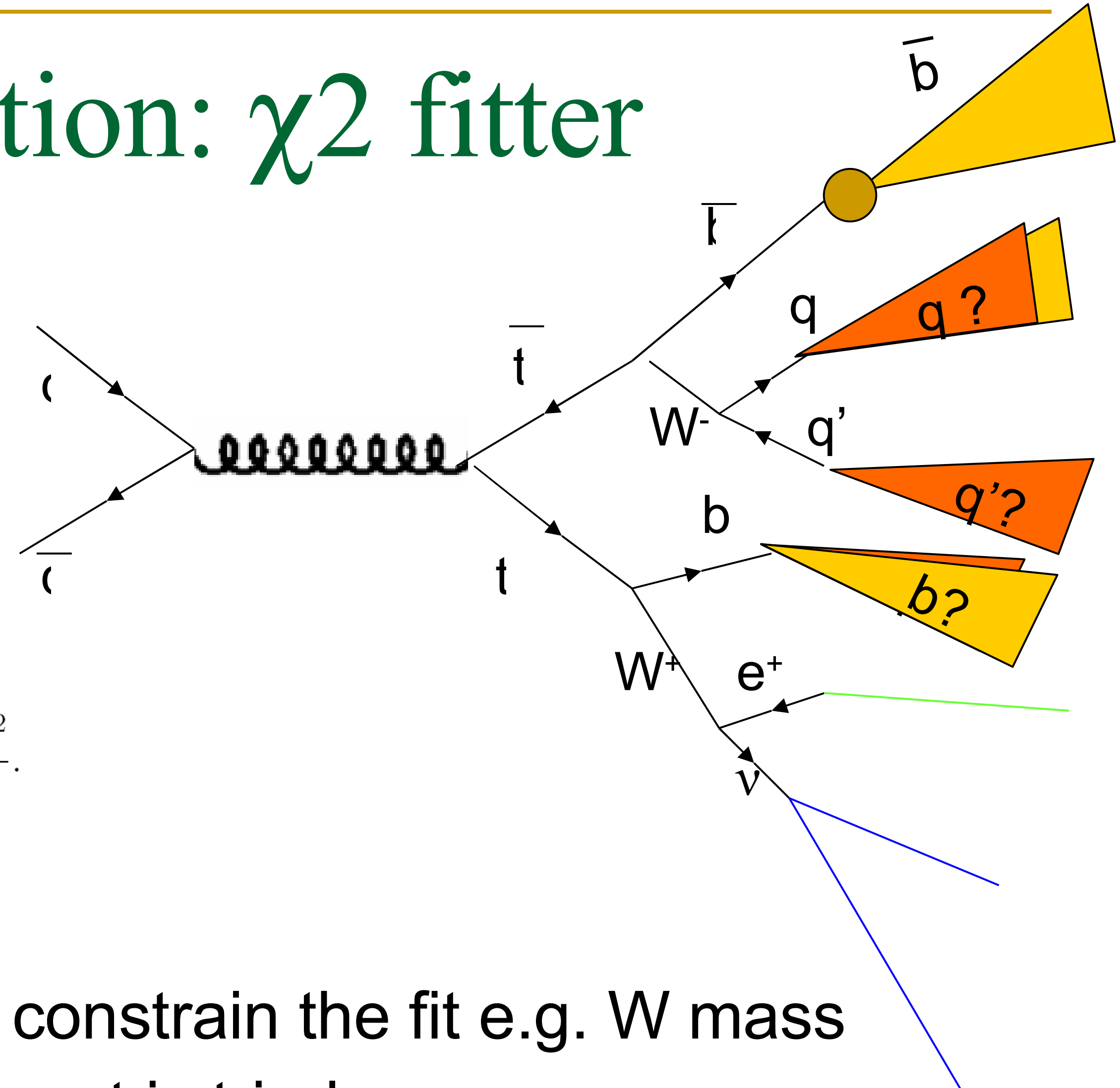
$$W(m_t) = \int d\eta_1 \int d\eta_2 P(\eta_1) P(\eta_2) \sum_j \sum_i w(m_t)_{i,j}$$

- Scan over a range of top masses and return the mass for which weight is the greatest

Mass reconstruction: $\chi 2$ fitter

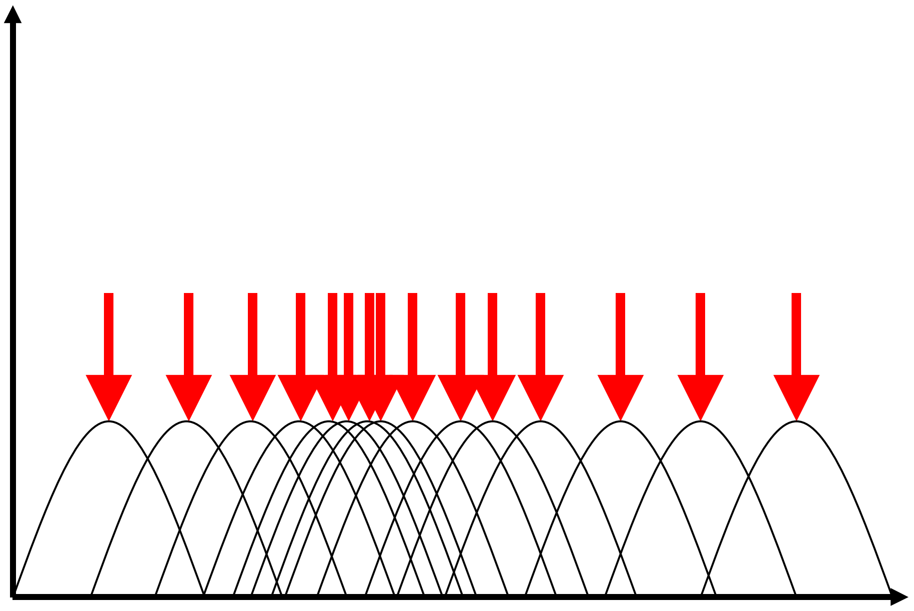
- We minimize:

$$\chi^2 = \sum_{i=\ell,4jets} \frac{(p_T^{i,fit} - p_T^{i,meas})^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(p_j^{UE,fit} - p_j^{UE,meas})^2}{\sigma_{UE}^2} + \frac{(M_{\ell\nu} - M_W)^2}{\Gamma_W^2} + \frac{(M_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(M_{b\ell\nu} - m_t^{\mathrm{reco}})^2}{\Gamma_t^2} + \frac{(M_{bjj} - m_t^{\mathrm{reco}})^2}{\Gamma_t^2}.$$



- Fit for m_t^{reco}
- Use a-priori knowledge to constrain the fit e.g. W mass
- Each jet-to-parton assignment is tried.
- Neutrino p_z is initialized so that it forms M_W with the lepton (2 solutions) and allowed to float

Constructing pdf's – Kernel Density Estimation



- No need to assume form of the shape
- Naturally extendible to more than 1 dimensions (correlations treated intrinsically)
- No way to interpolate between mass points