Top W Helicity Measurement (lepton p_T method) Pre-Blessing

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1st April 2004

supporting notes: CDF 6950 and CDF 6949

visit the analysis homepage

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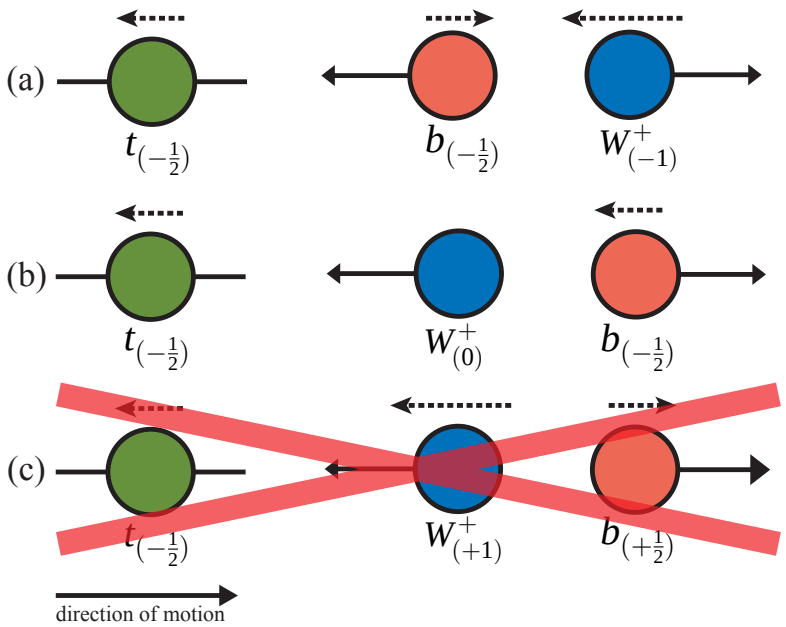
Introduction/Physics Motivation



- SM: Only left-handed and longitudinal W's may be produced in the top-quark rest frame.
- SM: $t \rightarrow W_0 b$ is enhanced

$$F_0 = \frac{\Gamma(W_0)}{\Gamma(W_0) + \Gamma(W_T)}$$

$$= \frac{\frac{1}{2}(\frac{m_t}{M_W})^2}{\frac{1}{2}(\frac{m_t}{M_W})^2 + 1} \simeq 0.7$$

- Exploring the the tWb coupling should lend insight to the nature of EWSB.
- It's a reasonable place to look for new physics.
- It provides us with opportunity to test predictions of the SM.

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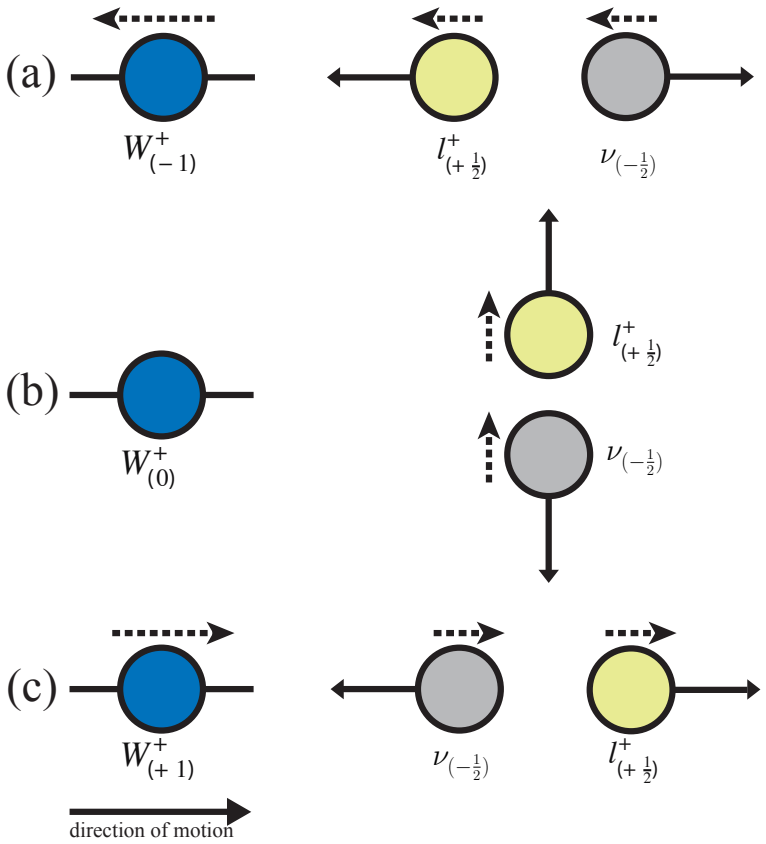
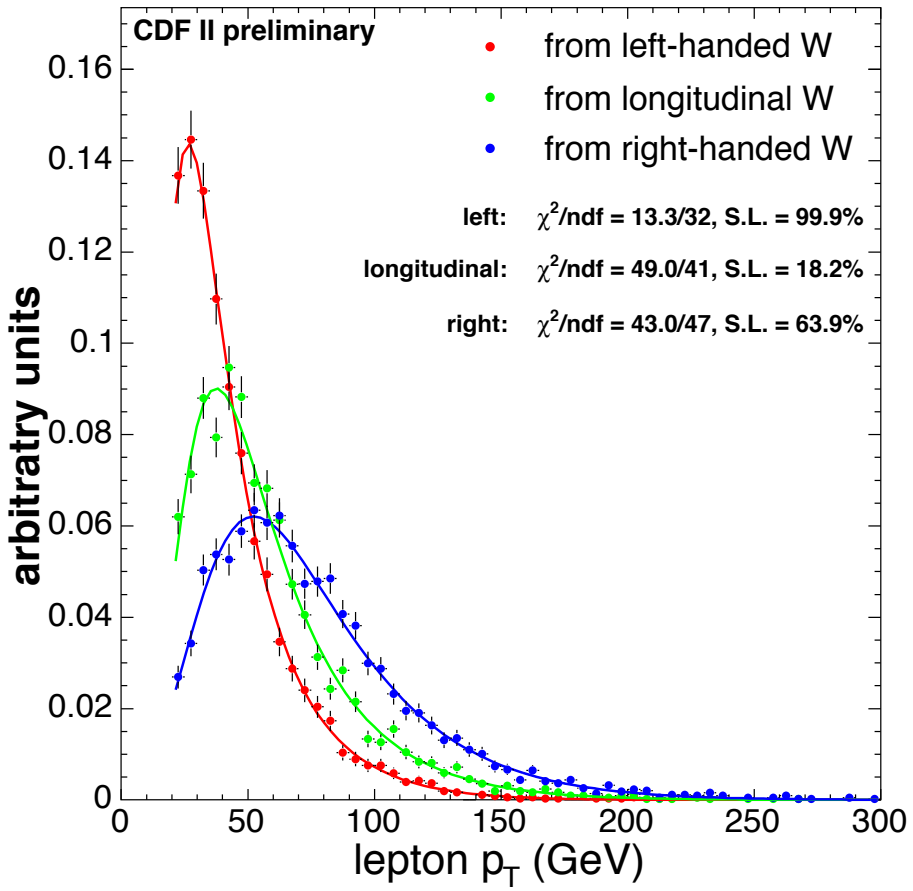
Measurement Strategy





- charged-lepton p_T is affected by the W helicity
- we can estimate the helicity content of $t\bar{t}$ samples by analyzing their charged-lepton p_T shape
- we accomplish this using the maximum-likelihood method

The Lepton+Jets Sample

- We include the lepton+jets $t\bar{t}$ sample
- Drawn from all data recorded up to the September '03 shutdown
- Apply DQM good run list v4, exclude bad CSL and bad SVX beamline runs, require good SVX information
- $\int Ldt = 161$ pb^{-1}
- We require: (see CDF note 6844)
  - an isolated central muon or electron with $p_T > 20$ GeV
  - $\not{E}_T > 20$ GeV
  - ≥ 3 jets with $E_T > 15$ GeV and $|\eta| < 2$
  - ≥ 1 jet have a positive `SECVTX` tag
- We use the background composition estimates of CDF note 6907

The Lepton+Jets Yield

- To improve sensitivity we partition the lepton+jets data into eight sub-samples:

primary lepton type	CEM	CMUP+CMX
single-tag 3 jet events	17	9
single-tag 4 jet events	13	10
double-tag 3 jet events	2	1
double-tag 4 jet events	3	2
total	35	22

- We produce unique background PDFs and acceptance ratios for these sub-samples

The Dilepton Sample

- We include the dilepton $t\bar{t}$ sample
- Drawn from all data recorded up to the September '03 shutdown
- Apply DQM good run list v4, exclude bad CSL and bad SVX beamline runs
- $\int Ldt = 150 - 193$ pb^{-1}
- We require: (see CDF notes 6588 and 6830)
  - two central muon or electron with $p_T > 20$ GeV
  - $\not{E}_T > 25$ GeV
  - ≥ 2 jets with $E_T > 15$ GeV and $|\eta| < 2$
  - $H_T > 200$ GeV
- We use the background composition estimates of CDF note 6830

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The Dilepton Yield

- The dilepton sample is partitioned into three sub-samples:

event type	# of events
ee	1
$e\mu$	9
$\mu\mu$	3
total	13

- We produce unique background PDFs and acceptances for these sub-samples

The Likelihood Function

$$\mathscr{L}(F_0, \beta_1, ..., \beta_S) = \prod_{s=1}^{S} G(\beta_s; \mu_s, \sigma_s) \prod_{i=1}^{N_s} P_s(x_i; F_0, \beta_s)$$

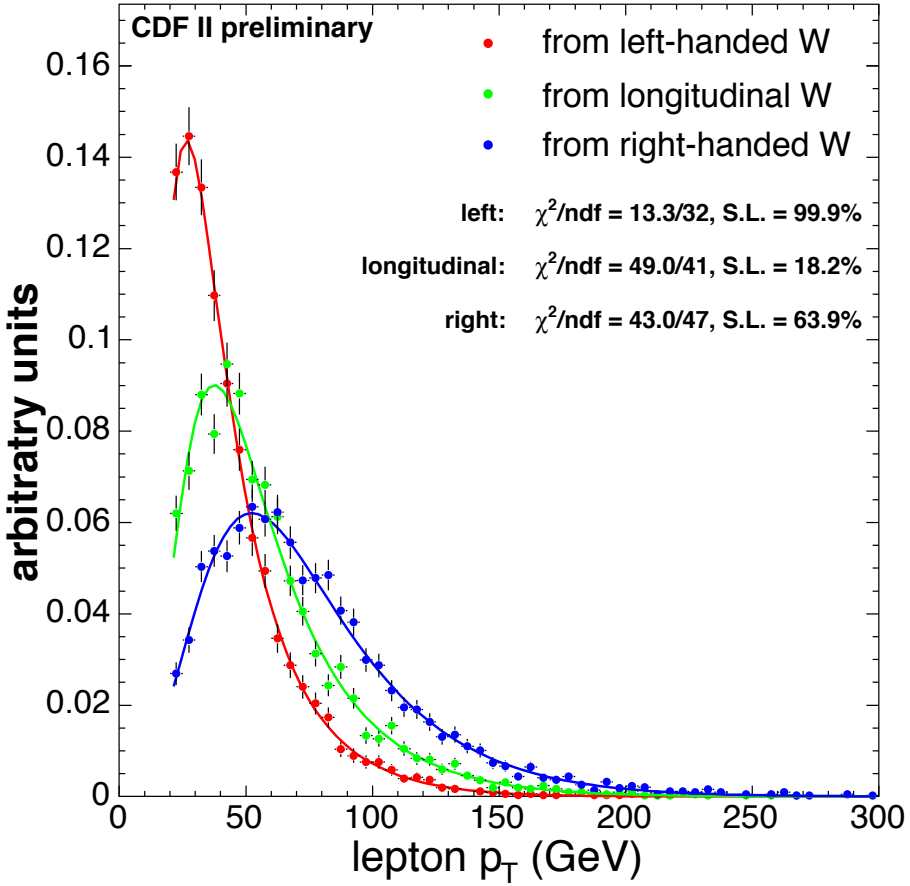
- S: number of samples
- β_s: background fraction in sample s
- $\mu_s \pm \sigma_s$: prior estimate of background fraction in sample s
- N_s: number of leptons in sample s
- x_i: p_T of ith lepton
- $P_s(x_i; F_0, \beta_s)$: probability density of a lepton with $p_T = x_i$ given F_0, β_s

The Per-Lepton Probability Density

$$P_s(x_i; F_0, \beta_s) = \epsilon_s(x_i)\Big(\beta_s \overbrace{P_s(x_i; \text{b.g.})}^{\text{background}} + (1-\beta_s) \underbrace{\{F_{0,s}^{\text{obs}}(F_0) P_s(x_i; h=0) + (1-F_{0,s}^{\text{obs}}(F_0)) P_s(x_i; h=-1)\}}_{\text{signal}} \Big)$$

- $\epsilon_s(x_i)$: efficiency to trigger on ith lepton
- $F_{0,s}^{\text{obs}}(F_0))$: the observed fraction of longitudinal Ws (*a.k.a. the acceptance correction*)
- $P_s(x_i; \text{b.g.})$: PDF of background leptons with $p_T = x_i$
- $P_s(x_i; h)$: PDF of signal leptons with $p_T = x_i$, given h

Signal Model ($P_s(x_i; h)$)



- Derived from `HERWIG v6.5x` inclusive $t\bar{t}$ Monte Carlo
- These sampled have one W with $h = -1, 0$ or 1
- The other W has $h = 0$ at 70% and $h = -1$ at 30%
- We use the same signal model for all samples
- Parameterizations from each sub-sample are statistically indistinguishable
- We use the parameterization with smallest uncertainties (inclusive lepton+jets sample)

The Acceptance Corrections

- for lepton+jet events:

$$F_{0,s}^{\text{obs}}(F_0) = \begin{cases} \left(1 + a_{L0,s}\left(\frac{1}{F_0} - 1\right)\right)^{-1} & F_0 \in [0,1] \\ F_0 & \text{otherwise} \end{cases},$$

$$a_{LO,s} = \frac{A_{L,s}}{A_{0,s}}$$

- for dilepton events:

$$F_{0,s}^{\text{obs}}(F_0) = \begin{cases} \frac{2A_{00,s}F_0^2 + A_{0L,s}F_0(1-F_0)}{2(A_{00,s}F_0^2 + A_{0L,s}F_0(1-F_0) + A_{LL,s}(1-F_0)^2)} & F_0 \in [0,1] \\ F_0 & \text{otherwise} \end{cases}$$

- A_{00}: dilepton acceptance, both Ws longitudinal
- A_{0L}: dilepton acceptance, one W longitudinal, one left-handed
- A_{LL}: dilepton acceptance, both Ws left-handed

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Lepton+Jets Background Estimates (Electrons)

- these estimates from CDF note 6907
- BG composition of the CEM single-SECVTX tag sample:

Background	W + 3 jets	$W + \geq$ 4jets
Pretag	241	69
QCD	3.9 ± 1.5	1.3 ± 0.5
single top	0.6 ± 0.1	0.1 ± 0.0
WW/WZ	0.3 ± 0.1	0.1 ± 0.0
mistags	2.9 ± 0.7	0.8 ± 0.3
$Wb\bar{b}$	1.7 ± 0.6	0.4 ± 0.2
$Wc\bar{c}$	0.7 ± 0.3	0.2 ± 0.1
Wc	0.9 ± 0.3	0.1 ± 0.1
total background	11.1 ± 2.0	2.9 ± 0.6
observed	17	13

Lepton+Jets Background Estimates (Electrons)

- BG composition of the CEM double-SECVTX tag sample:

Background	W + 3 jets	$W + \geq$ 4jets
single top	0.08 ± 0.04	0.02 ± 0.01
WZ/WZ	0.01 ± 0.01	0.01 ± 0.01
mistags	0.04 ± 0.01	0.01 ± 0.00
$Wb\overline{b}$	0.23 ± 0.08	0.04 ± 0.02
$Wc\overline{c}$	0.02 ± 0.01	0.01 ± 0.00
total background	0.39 ± 0.10	0.08 ± 0.03
observed	2	3

Lepton+Jets Background Estimates (Muons)

- BG composition of the CMUP/CMX single-SECVTX tag sample:

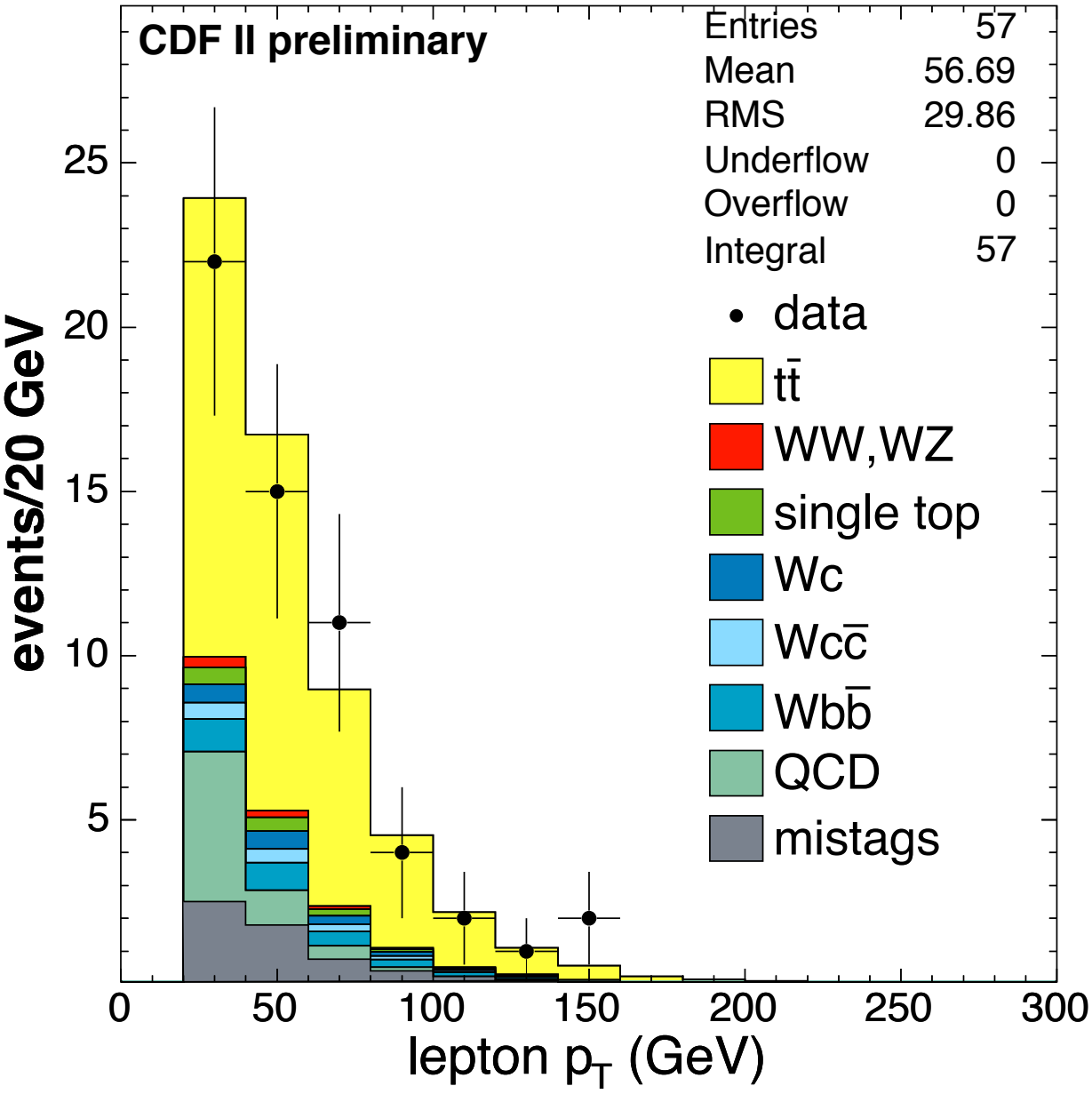
Background	W + 3 jets	W + $\geq$ 4jets
QCD	1.1 ± 0.6	0.4 ± 0.2
single top	0.5 ± 0.1	0.1 ± 0.0
WW/WZ	0.3 ± 0.1	0.0 ± 0.0
mistags	1.7 ± 0.3	0.5 ± 0.1
$Wb\overline{b}$	1.2 ± 0.4	0.2 ± 0.1
$Wc\overline{c}$	0.5 ± 0.2	0.1 ± 0.0
$W\overline{c}$	0.6 ± 0.2	0.1 ± 0.0
total background	5.7 ± 1.0	1.4 ± 0.3
observed	9	10

Lepton+Jets Background Estimates (Muons)

- BG composition of the CMUP/CMX double-SECVTX tag sample:

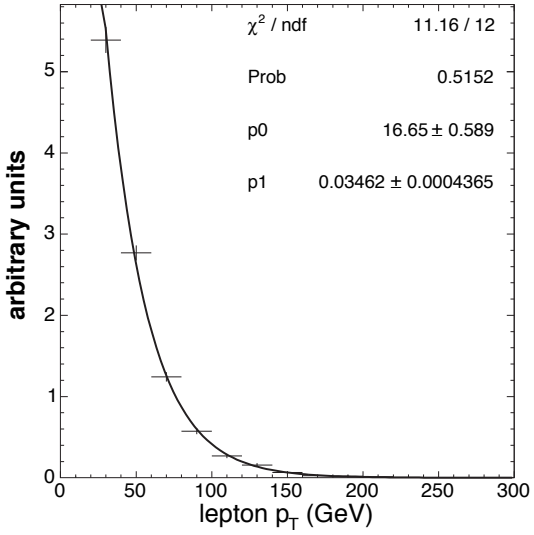
Background	W + 3 jets	$W + \geq$ 4jets
single top	0.06 ± 0.04	0.02 ± 0.01
WZ	0.01 ± 0.01	0.00 ± 0.01
mistags	0.01 ± 0.00	0.00 ± 0.00
$Wb\bar{b}$	0.16 ± 0.05	0.03 ± 0.01
$Wc\bar{c}$	0.01 ± 0.00	0.00 ± 0.00
total background	0.25 ± 0.07	0.05 ± 0.02
observed	1	2

Lepton+Jets Data with Background Model

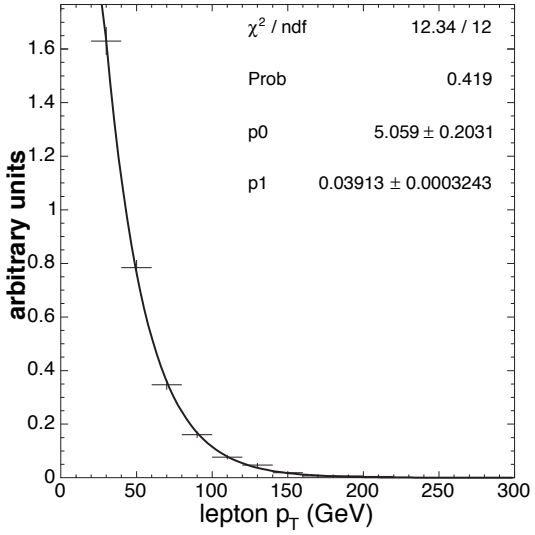


Lepton+Jets Background PDFs (single-tag)

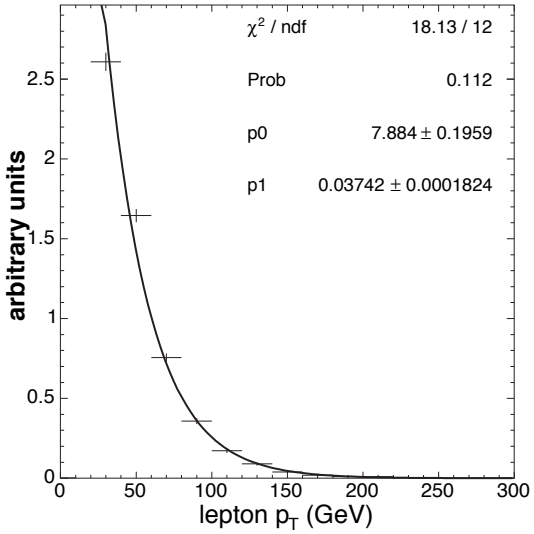
CEM 3 jets



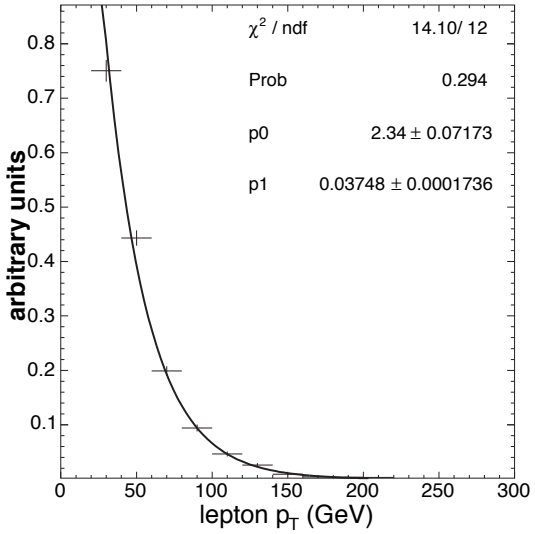
CEM $\geq 4jet$



CMUP/CMX 3 jets



CMUP/CMX $\geq$ 4 jets



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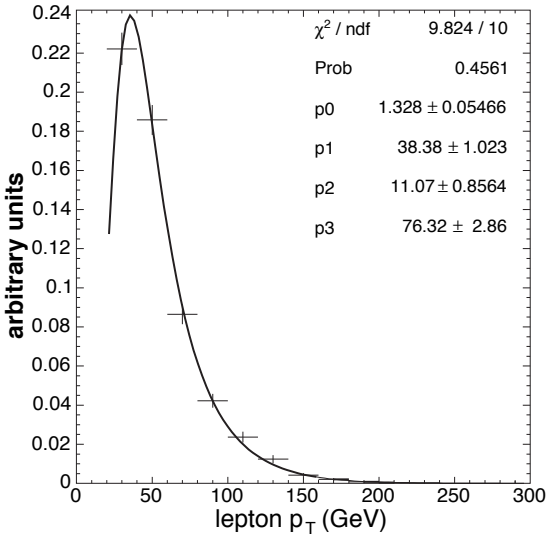
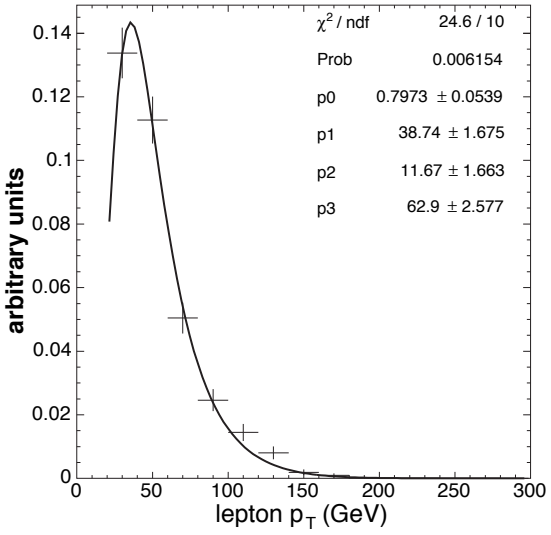
Lepton+Jets Background PDFs (double-tag)

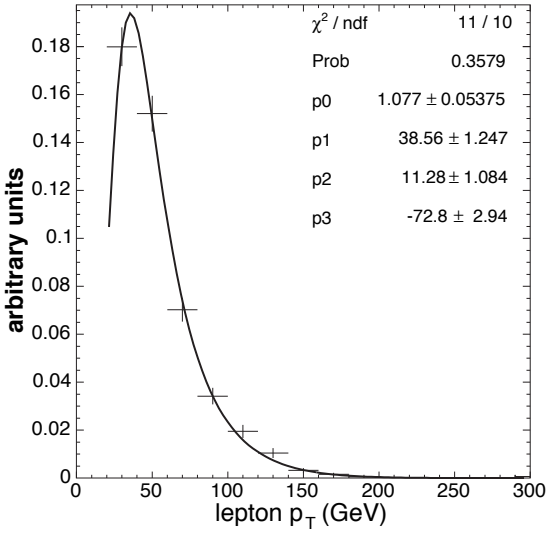
CEM 3 jets



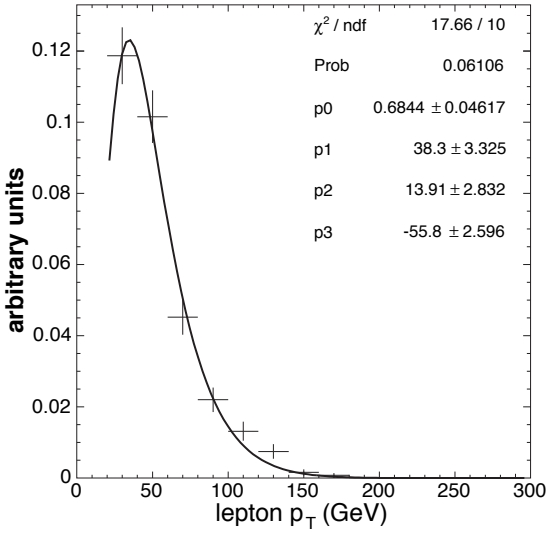
CEM $\geq 4jet$



CMUP/CMX 3 jets



CMUP/CMX $\geq$ 4 jets



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Lepton+Jets Acceptance Ratios

- Parametrize the acceptance correction $F_{0,s}^{\text{obs}}(F_0)$
- These ratios were estimated using the `ttopmi-ri` `HERWIG` `v6.5x` inclusive $t\bar{t}$ Monte Carlo
- `ttopmi-ri` have one W with $h = -1, 0$ or $+1$
- The other has W $h = 0$ at 70% and $h = -1$ at 30%
- $a_{LO,s}$ for the lepton+jet samples:

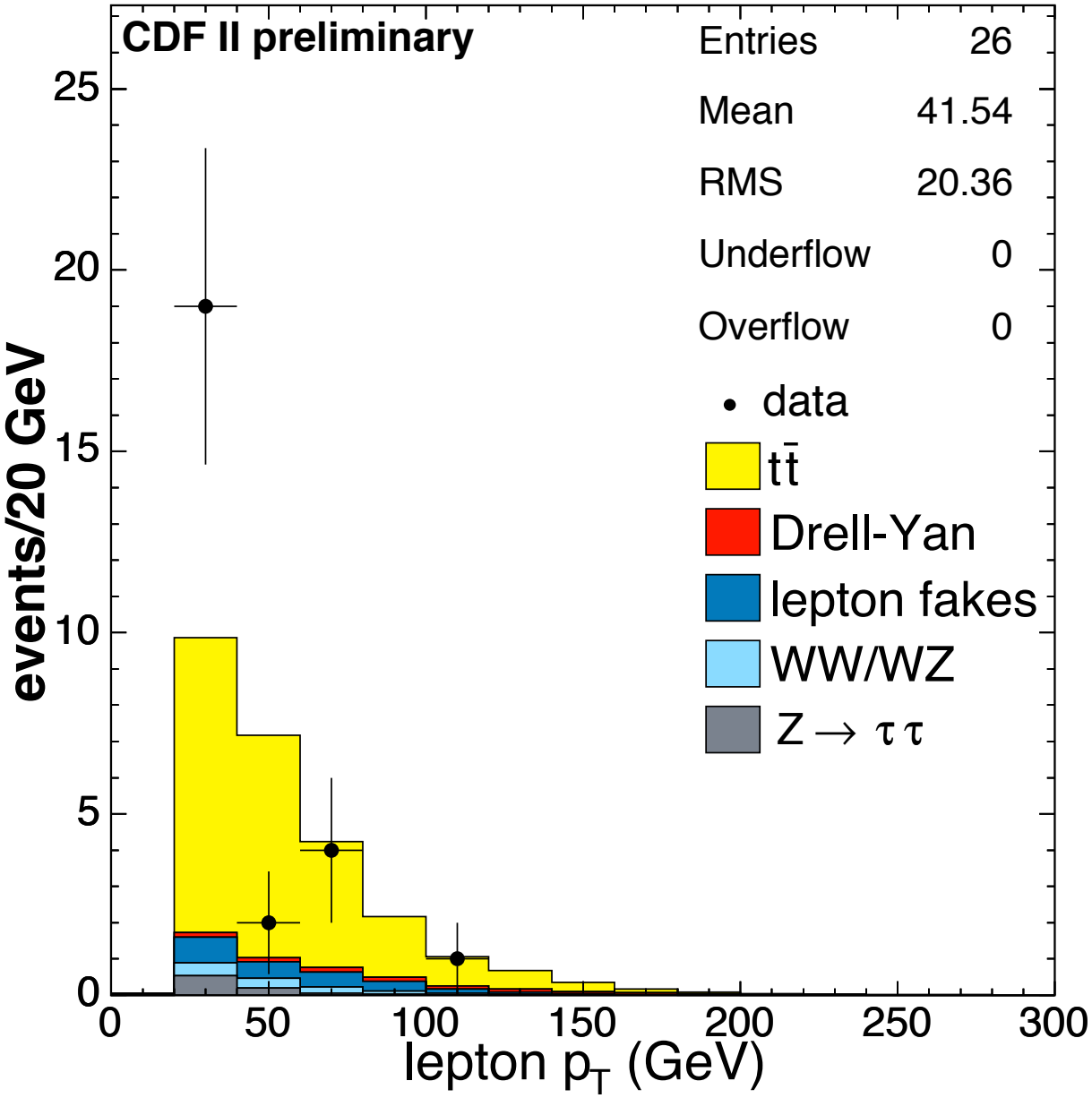
# of jets	3	≥ 4
CEM	0.790 ± 0.036	0.715 ± 0.030
CMUP+CMX	0.712 ± 0.035	0.751 ± 0.034
combined	0.754 ± 0.025	0.732 ± 0.022

Dilepton Background Estimates

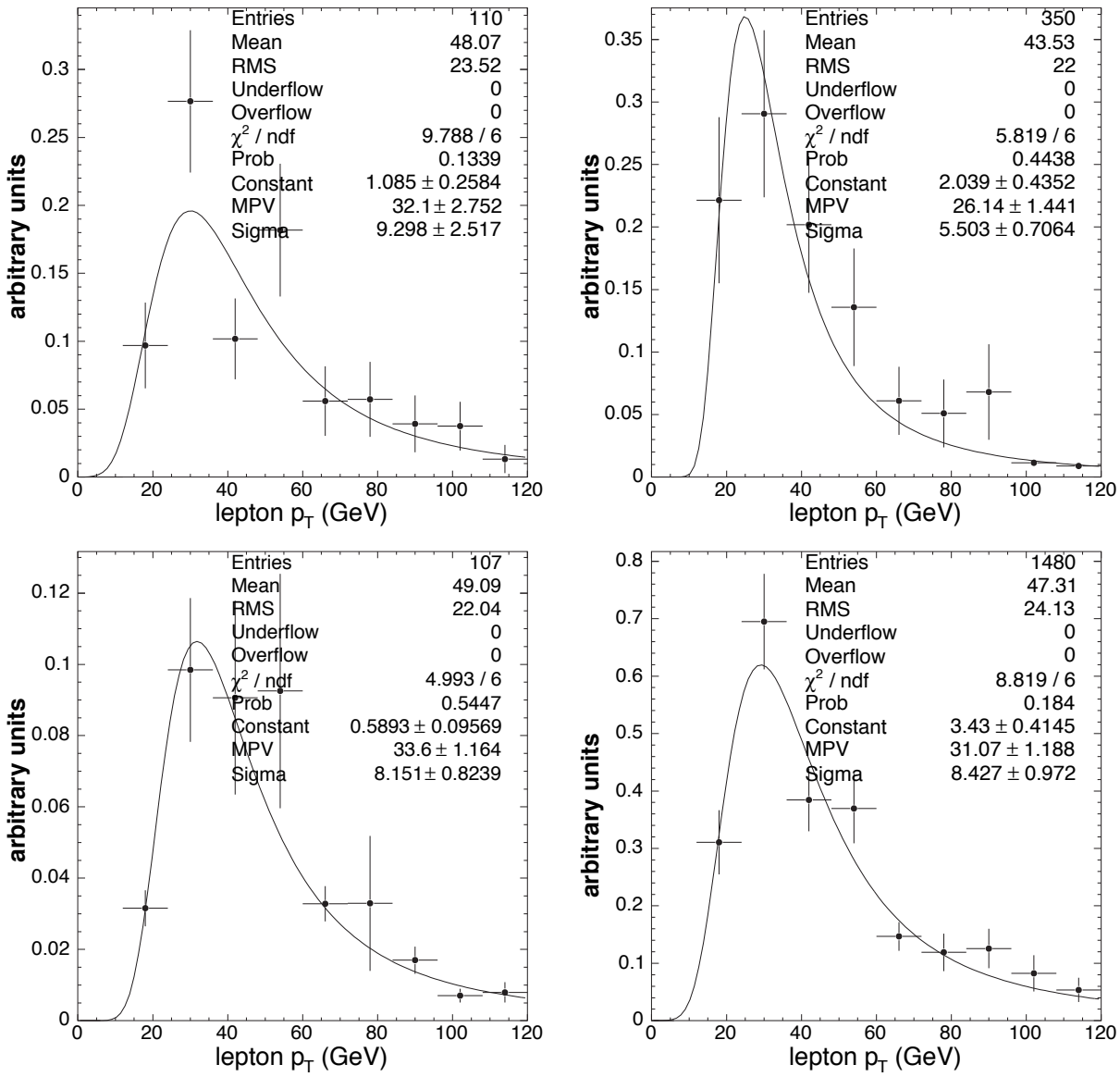
- these estimates from CDF note 6830

event type	ee	$\mu\mu$	$e\mu$	$\ell\ell$
WW/WZ	0.15 ± 0.06	0.12 ± 0.05	0.22 ± 0.09	0.49 ± 0.21
Drell-Yan	0.36 ± 0.28	0.07 ± 0.34	-	0.43 ± 0.44
$Z \rightarrow \tau\tau$	0.09 ± 0.03	0.11 ± 0.03	0.22 ± 0.07	0.42 ± 0.13
Fakes	0.30 ± 0.10	0.15 ± 0.05	0.62 ± 0.22	1.07 ± 0.35
Total Background	0.9 ± 0.3	0.4 ± 0.4	1.1 ± 0.2	2.4 ± 0.7
observed	1	3	9	13

Dilepton Data with Background Model



Dilepton Background Templates

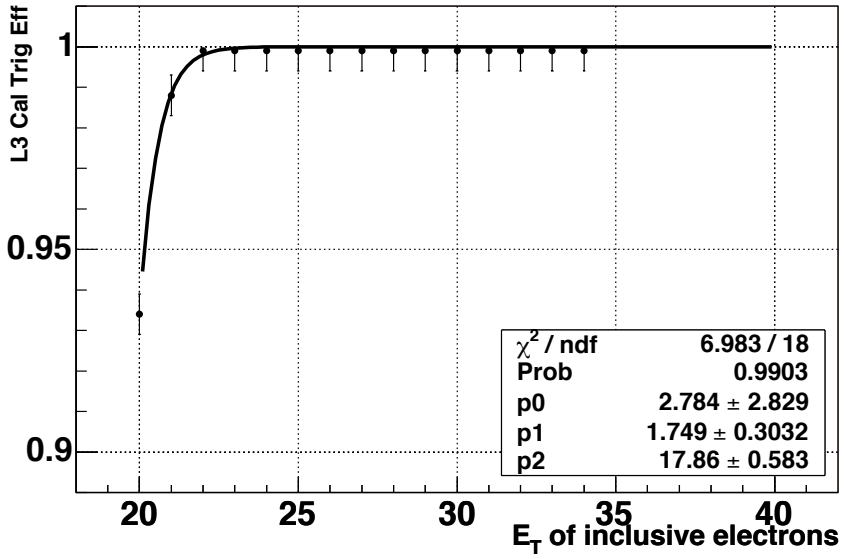


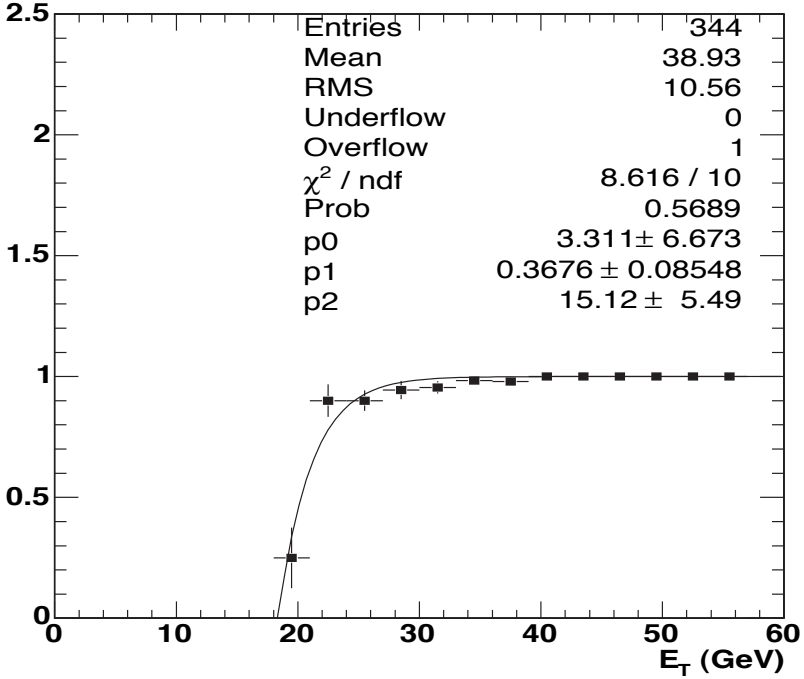
Dilepton Acceptance

- These acceptances were estimated using the `ttopmi-ri` `HERWIG v6.5x` inclusive $t\bar{t}$ Monte Carlo
- we re-weighted events according to the $cos(\theta^*)$ of the "second" W

sample	ee	$\mu\mu$	$e\mu$
A_{00}	0.0024 ± 0.0002	0.0027 ± 0.0002	0.0060 ± 0.0003
A_{0L}	0.0019 ± 0.0001	0.0023 ± 0.0002	0.0049 ± 0.0002
A_{LL}	0.0016 ± 0.0001	0.0022 ± 0.0002	0.0040 ± 0.0002

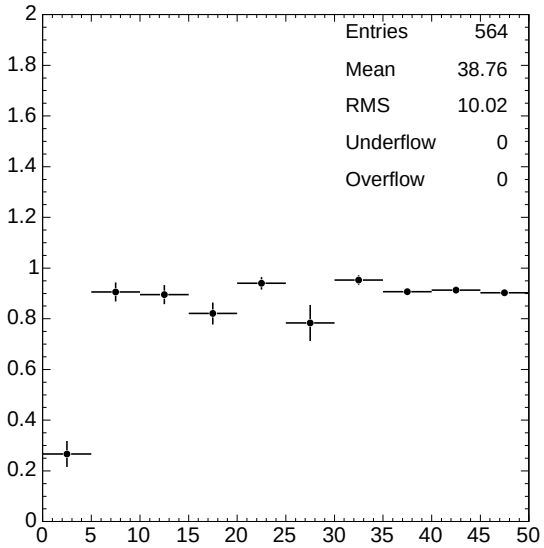
Trigger Correction (Electrons)

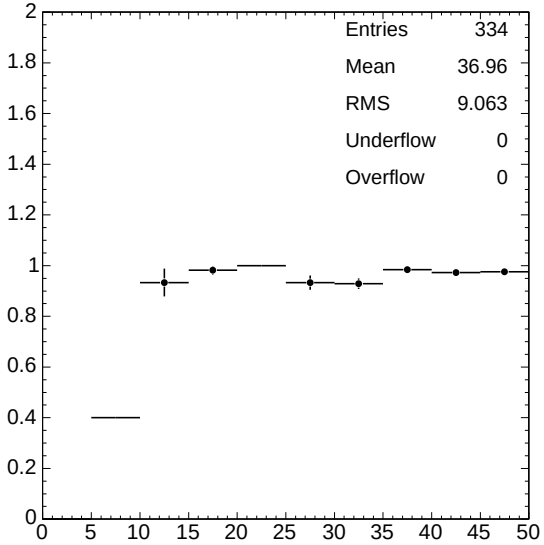




- Top: parametrization of `ELECTRON_CENTRAL_18` efficiency as a function of electron E_T, taken from CDF note 6234
- Bottom: parametrization of `MET_PEM` efficiency as a function of electron E_T, taken from CDF note 6864

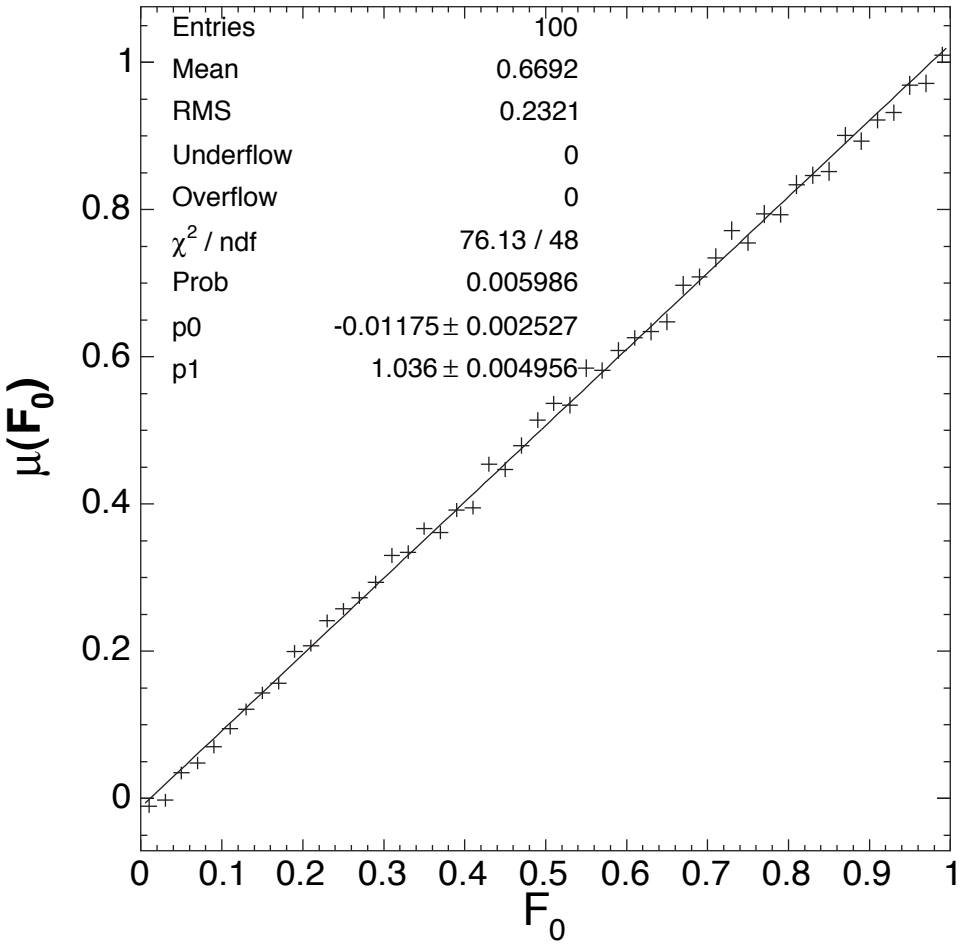
Trigger Correction (Muons)

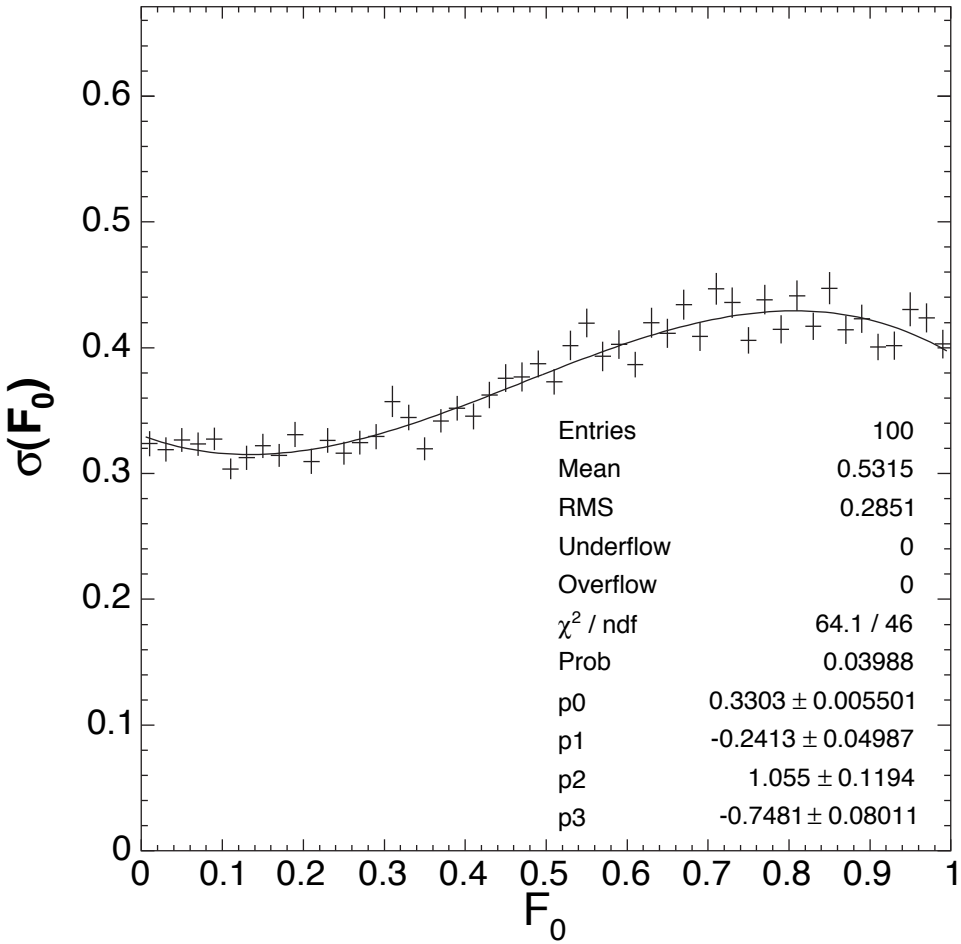




- Top: efficiency of the `MUON_CMUP_18` trigger as a function of the track p_T
- Bottom: efficiency of the `MUON_CMX_18` trigger as a function of the track p_T
- These from looking at second-leg of $Z \rightarrow \mu\mu$ candidates (courtesy of Jian Kang)
- No correction applied to CMUP or CMX muons

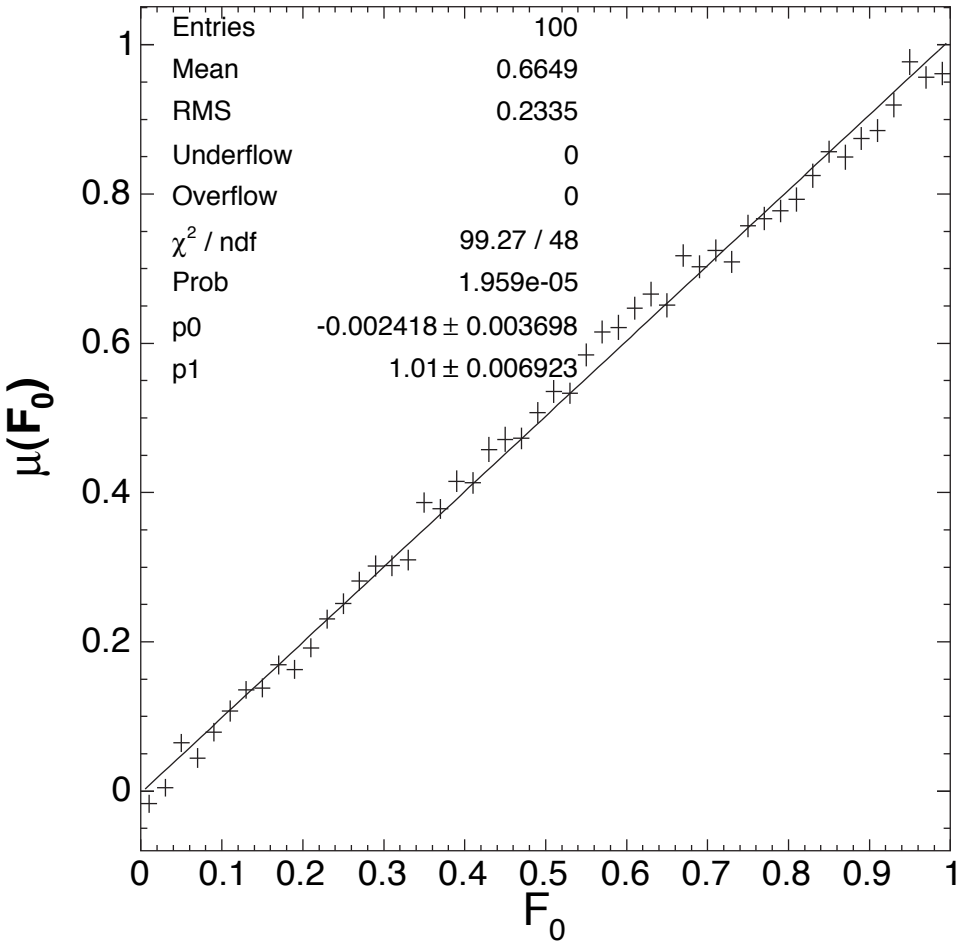
Fitter Performance (Lepton+Jets Only)

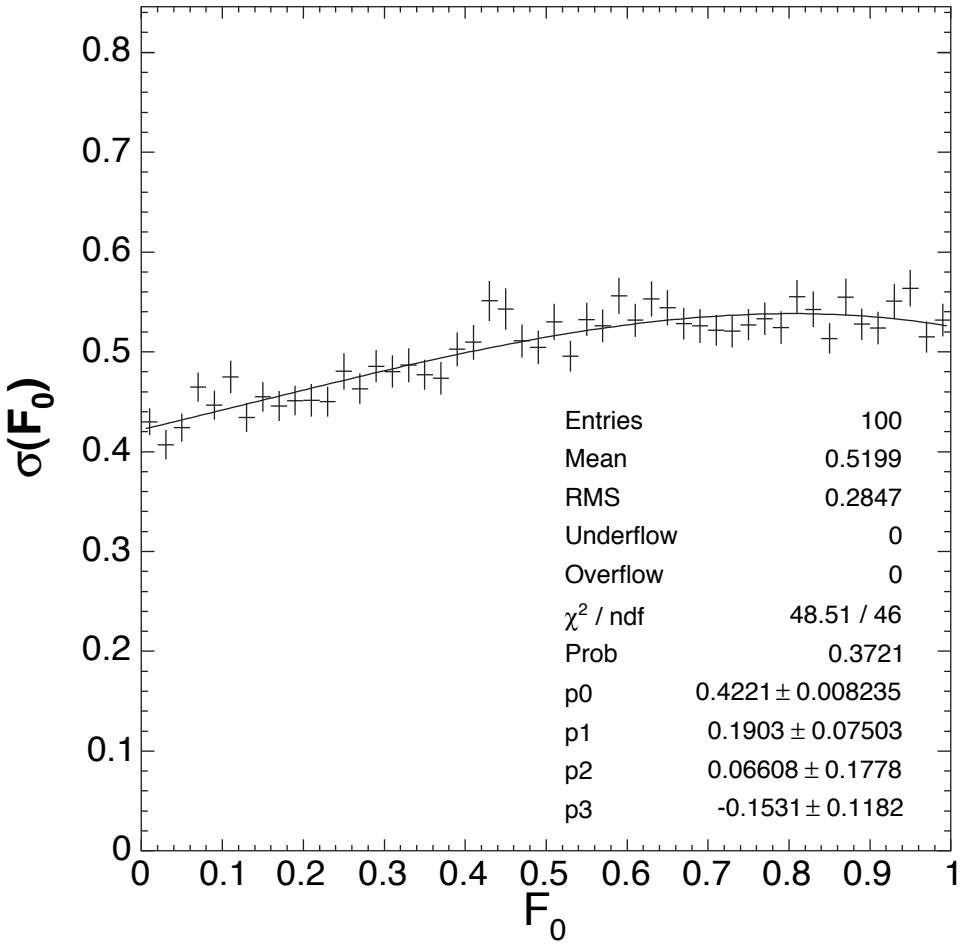




- Left: input vs. mean output, fit procedure is unbiased
- Right: input vs. width of output

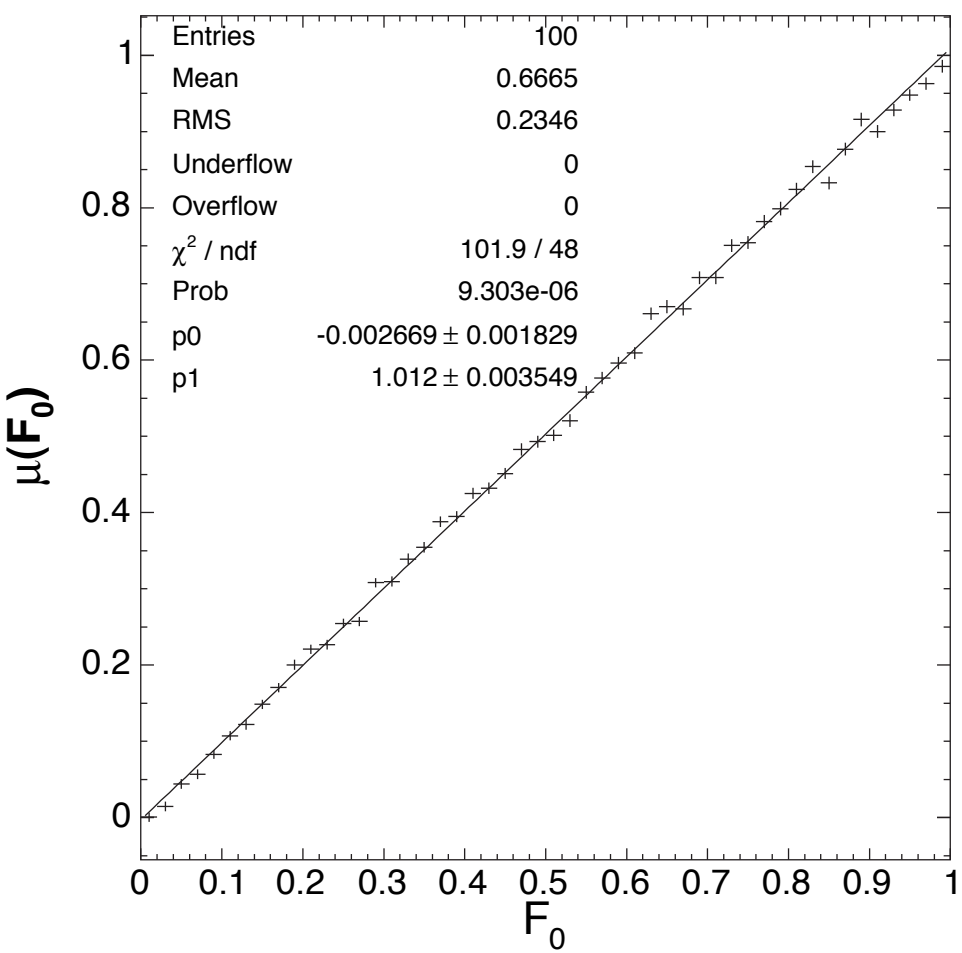
Fitter Performance (Dileptons Only)

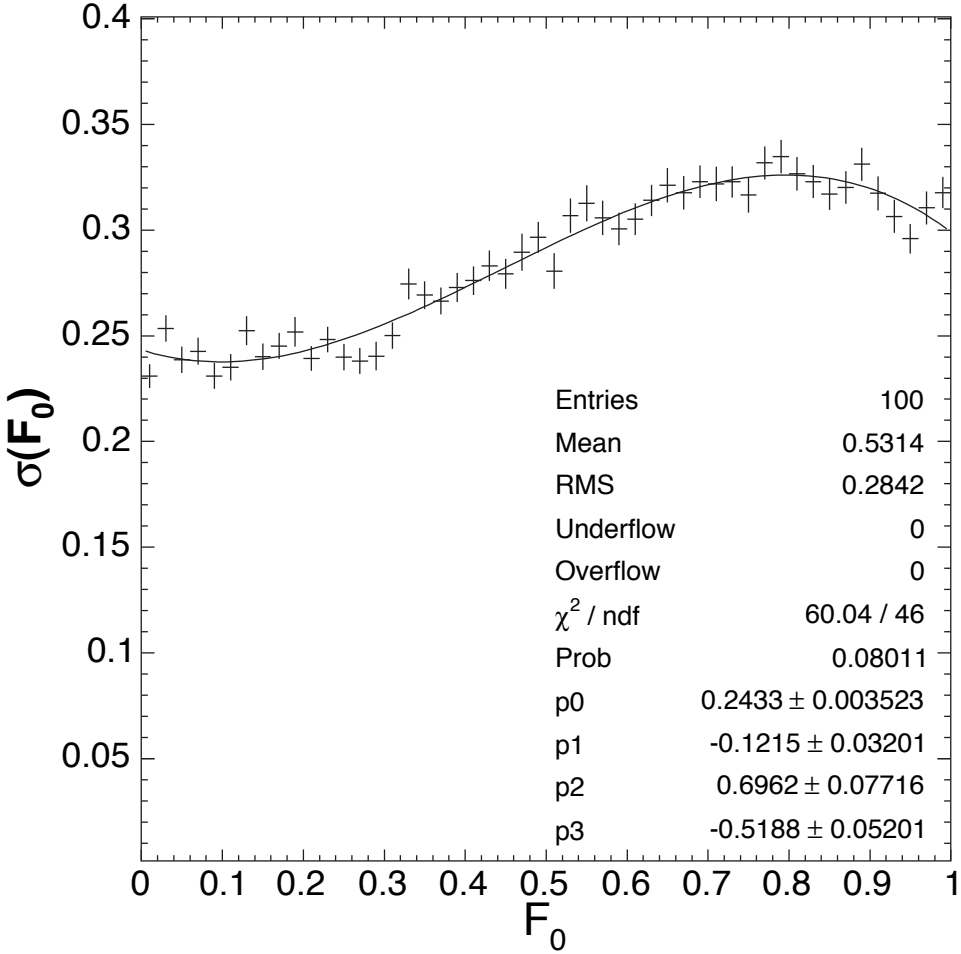




- Left: input vs. mean output, fit procedure is unbiased
- Right: input vs. width of output

Fitter Performance (Combined Analysis)





- Left: input vs. mean output, fit procedure is unbiased
- Right: input vs. width of output

Systematic Uncertainties

- Estimate of systematic uncertainty from pseudo-experiments
- We generate pseudo-data where one aspect of our model is varied within its uncertainties
- Then fit pseudo-data using default procedure
- We take the maximum separation of means between the varied and un-varied ensembles as the systematic
- Especially subtle is lepton+jets bg normalization systematic
  - QCD fractions
  - Heavy-flavor fractions
  - Scale factor
  - Mistag rate

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Systematic Uncertainties (Lepton+Jets Only)

Source	$\Delta\hat{F}_0$
background normalization	0.11
top mass uncertainty	0.09
ISR/FSR	0.04
PDF uncertainty	0.03
shape uncertainty	0.03
MC statistics	0.01
acceptance correction	0.01
trigger correction	0.01
total	0.17

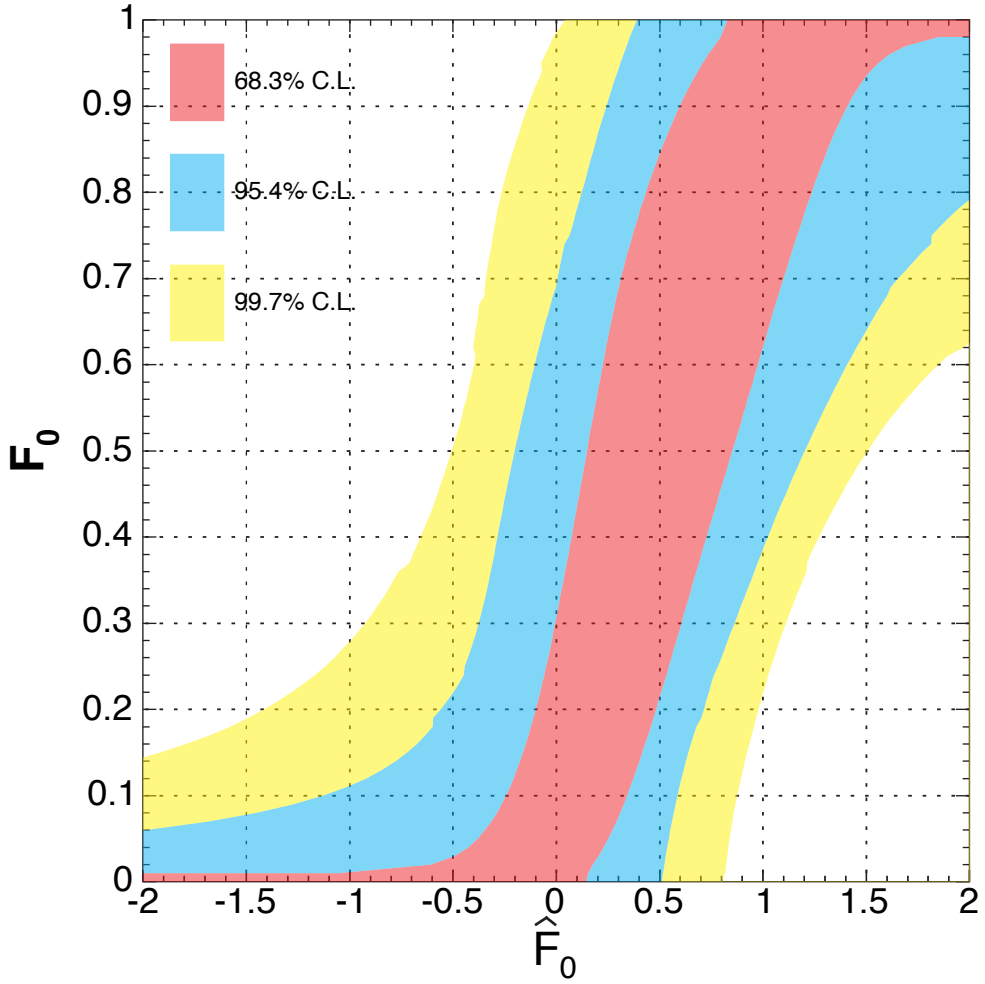
Systematic Uncertainties (Dileptons Only)

Source	$\Delta\hat{F}_0$
top mass uncertainty	0.12
ISR/FSR	0.06
background normalization	0.04
PDF uncertainty	0.04
acceptance correction	0.03
shape uncertainty	0.02
trigger correction	0.02
MC statistics	0.01
total	0.16

Combined Analysis

Source	$\Delta\hat{F}_0$
top mass uncertainty	0.11
l+jets bg. normalization	0.10
ISR/FSR	0.05
PDF uncertainty	0.03
dilepton bg. normalization	0.02
l+jets shape uncertainty	0.02
acceptance correction	0.02
trigger correction	0.02
dilepton shape uncertainty	0.01
MC statistics	0.01
total	0.17

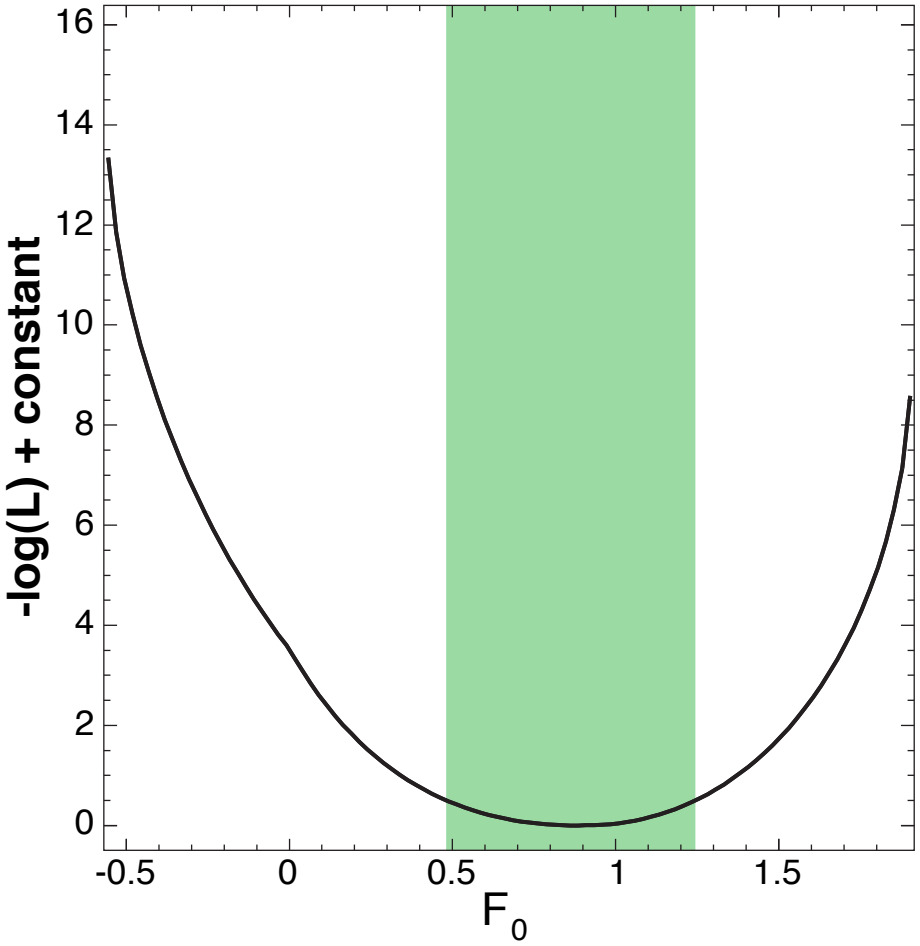
Feldman Cousins Confidence Belts

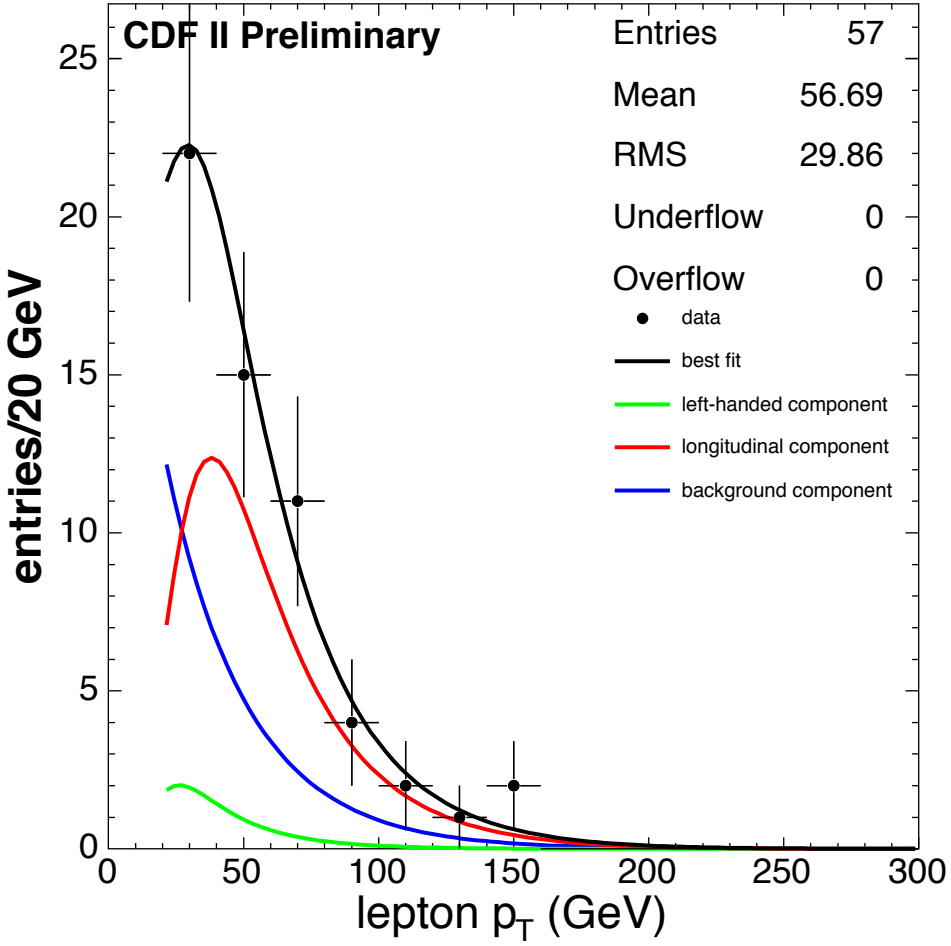


- the input for these belts is the resolution function

$$P(\hat{F}_0; F_0) = G(\hat{F}_0; \mu(F_0), \sqrt{\sigma^2(F_0) + \sigma^2_{\text{syst.}}})$$

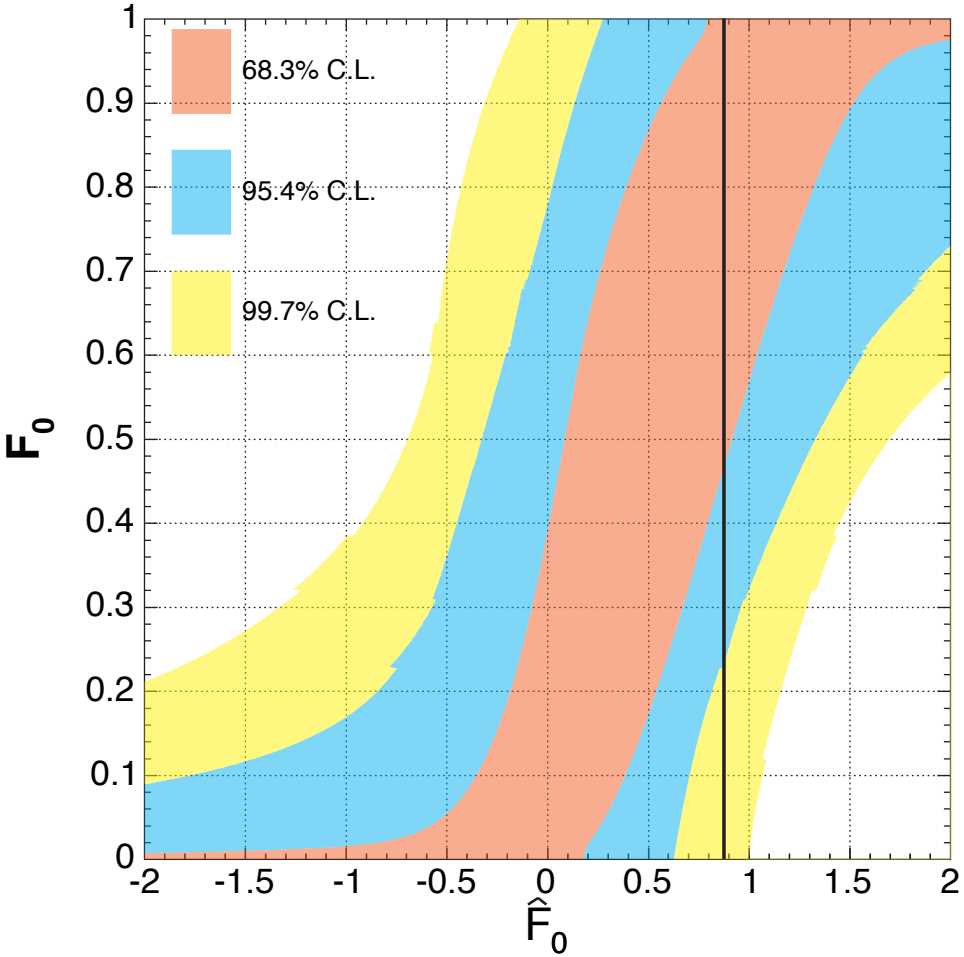
Lepton+Jets Only Result





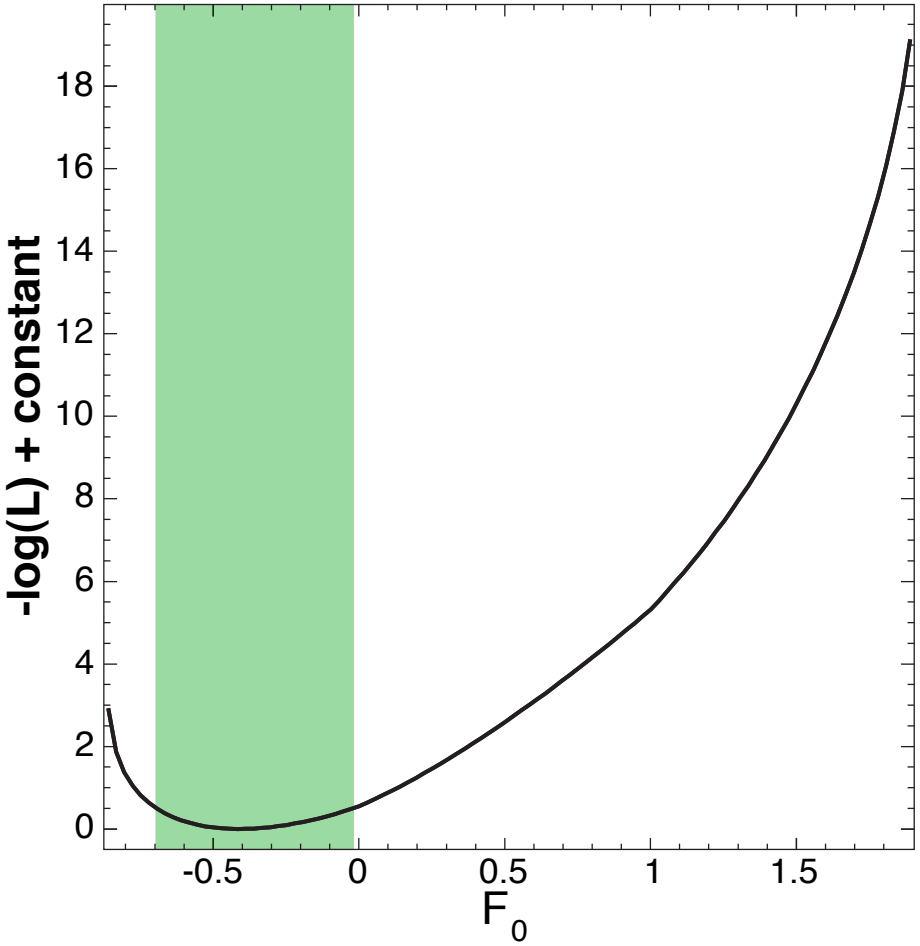
- Left: projection of $-\log(\mathscr{L})$
- Right: distribution of charged-lepton p_T overlaid with PDFs
- $\hat{F}_0 = 0.88$

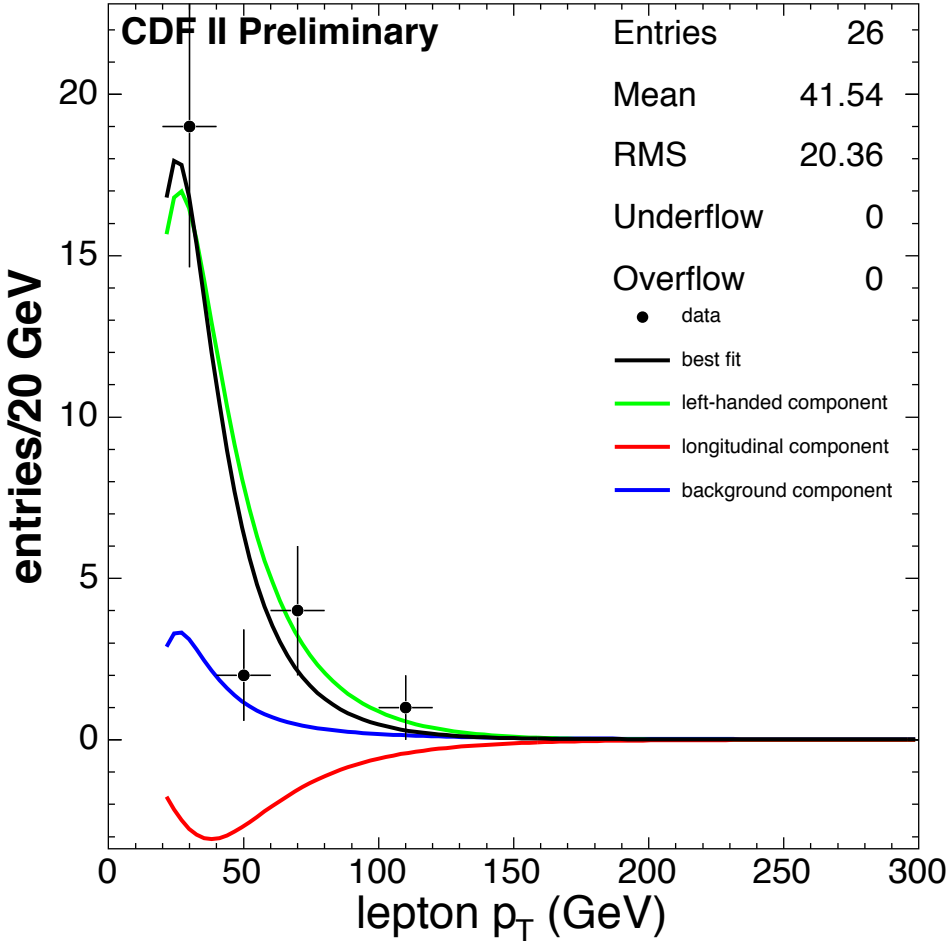
Lepton+Jets Only Result



- 1, 2 and 3 σ Feldman Cousins confidence belts for the lepton+jets only analysis
- The heavy line represents the experimental outcome, $\hat{F}_0 = 0.88$
- $F_0 = 0.88^{+0.12}_{-0.47}$ (stat. + syst.)
- $F_0 > 0.24$ @ 95%CL

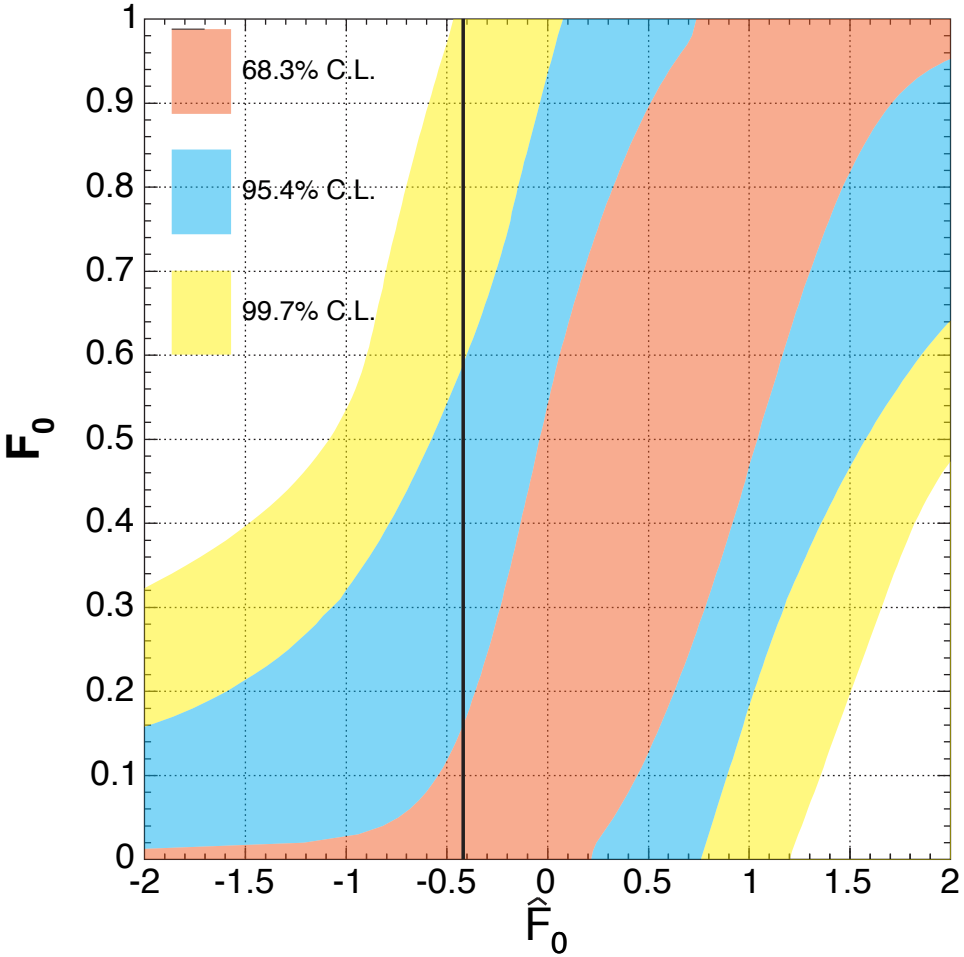
Dileptons Only Result





- Left: projection of $-\log(\mathscr{L})$
- Right: distribution of charged-lepton p_T overlaid with PDFs
- $\hat{F}_0 = -0.41$

Dileptons Only Result



- 1, 2 and 3 σ Feldman Cousins confidence belts for the dileptons only analysis
- The heavy line represents the experimental outcome, $\hat{F}_0 = -0.41$
- $F_0 < 0.59$ @ 95% CL

Should We Combine These Data?

- The dilepton data are inconsistent with the SM at the 2 σ level
- We are unable to make a statement about the dilepton data at the ≥ 3 σ level
- However, the dilepton data *is* consistent with the lepton+jets data at the 2 σ level
- lepton+jets: $F_0 > 0.24$ @ 95%CL
- dileptons: $F_0 < 0.59$ @ 95% CL
- It's reasonable to assume these data are due to the same underlying process
- I claim it is appropriate to combine

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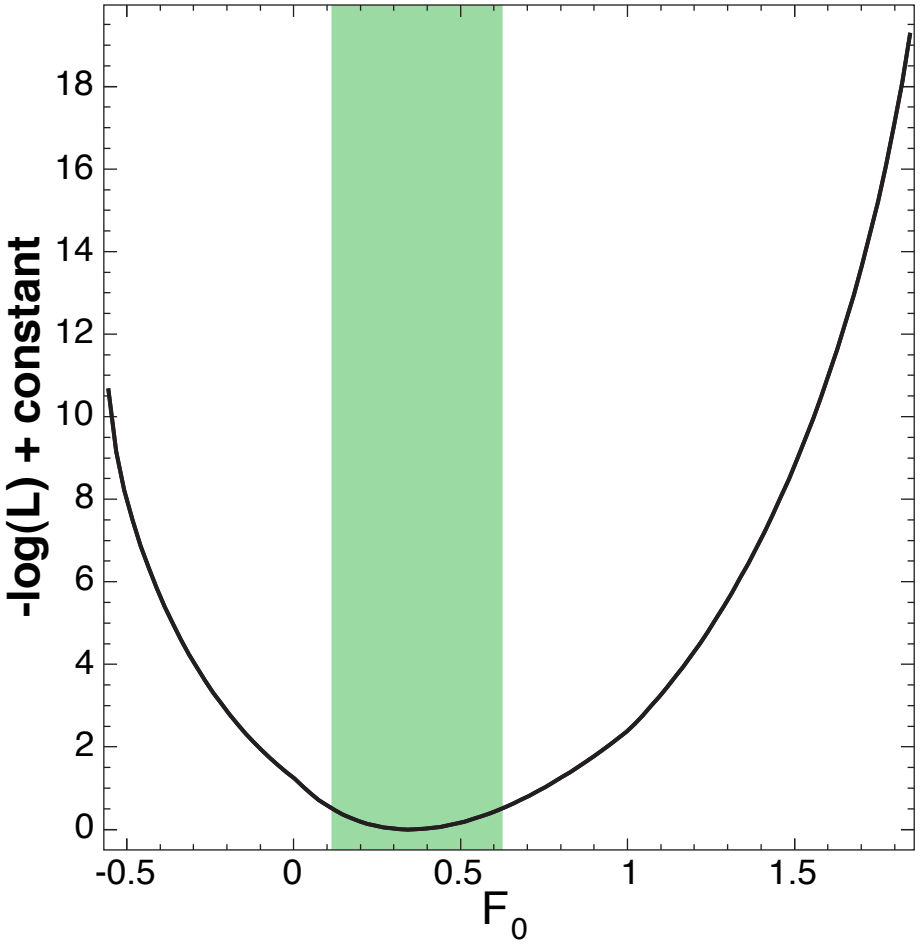
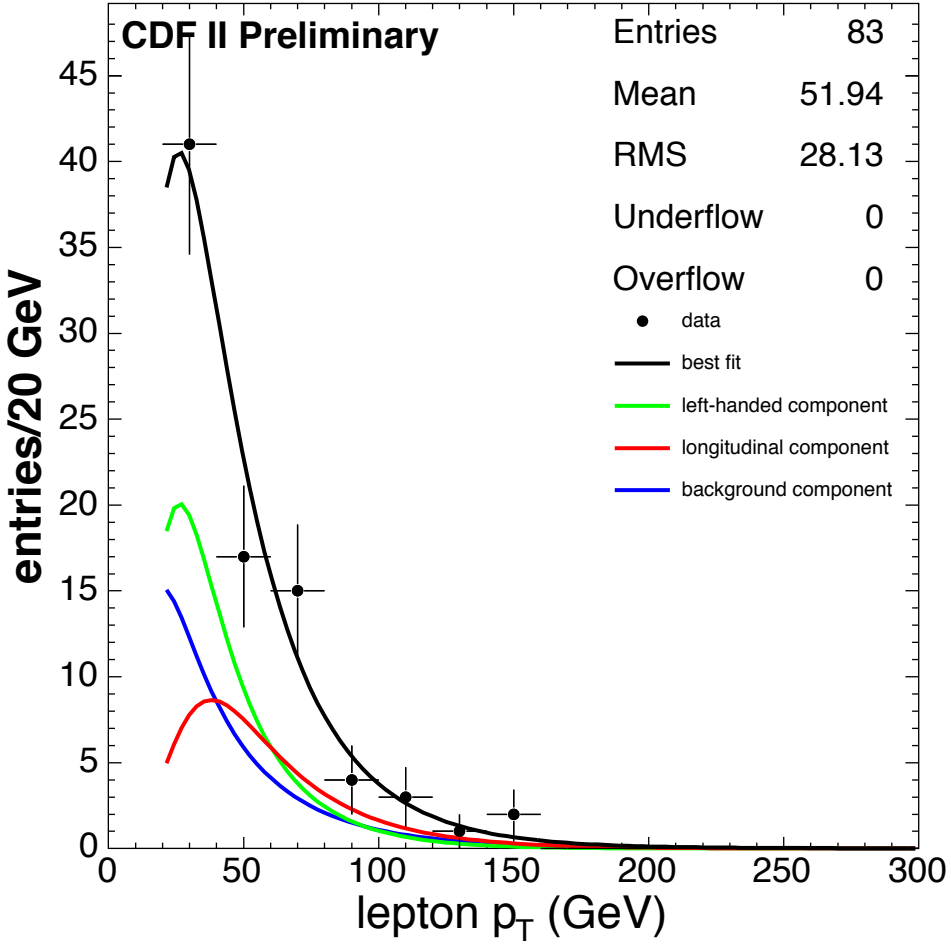
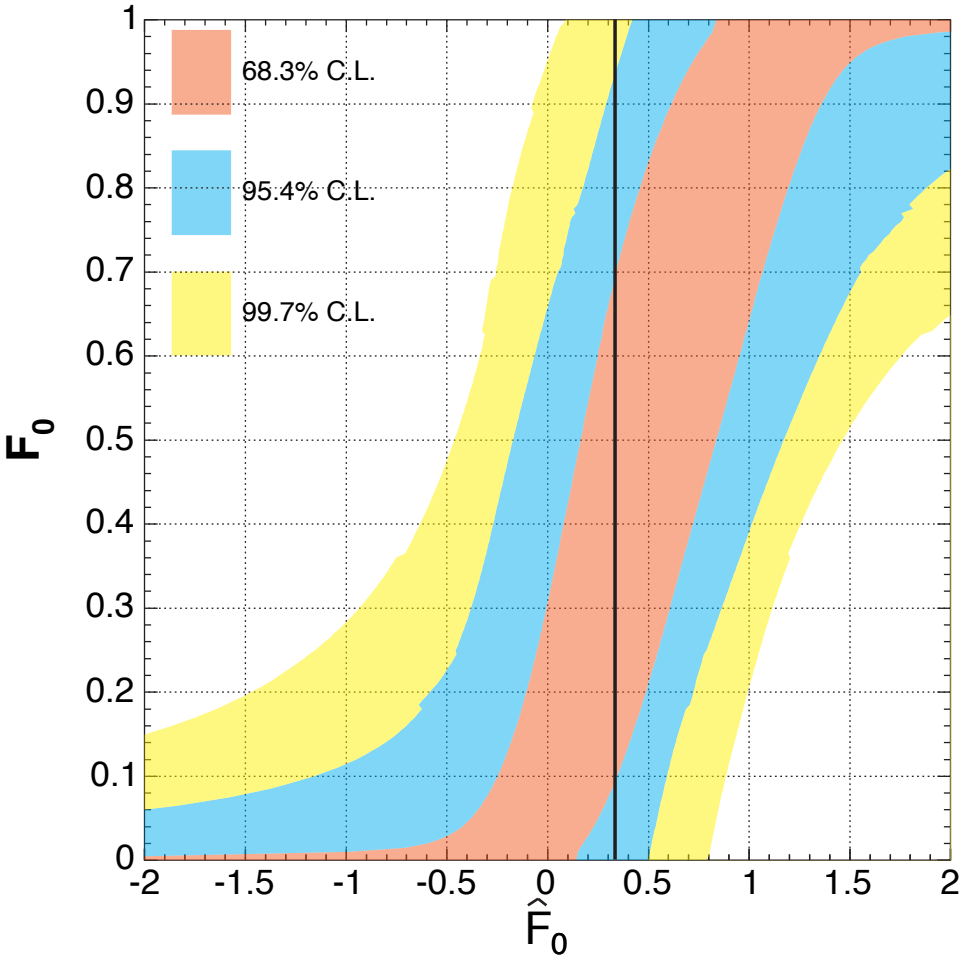
Combined Result





- Left: projection of $-\log(\mathscr{L})$
- Right: distribution of charged-lepton p_T overlaid with PDFs
- $\hat{F}_0 = 0.33$

Combined Result



- 1, 2 and 3 σ Feldman Cousins confidence belts for the combined analysis
- The heavy line represents the experimental outcome, $\hat{F}_0 = 0.33$
- $F_0 = 0.33^{+0.35}_{-0.24}$ (stat. + syst)
- $F_0 < 0.93$ @ 95% CL

Conclusions

- We measured the F_0 in the lepton+jets and dilepton channels
- the combined result, $F_0 = 0.33^{+0.35}_{-0.24}$ (stat. + syst) is consistent with the SM prediction $F_0 = 0.7$
- The lepton+jets result, $F_0 = 0.88^{+0.12}_{-0.47}$ (stat. + syst.). is consistent with the SM
- The discrepancy in the dilepton sample, $F_0 < 0.59$ @ 95% CL, *is* interesting, but it's only at the 2 σ level.

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