# CDF/D0 Combined Upper Limit on Higgs Production

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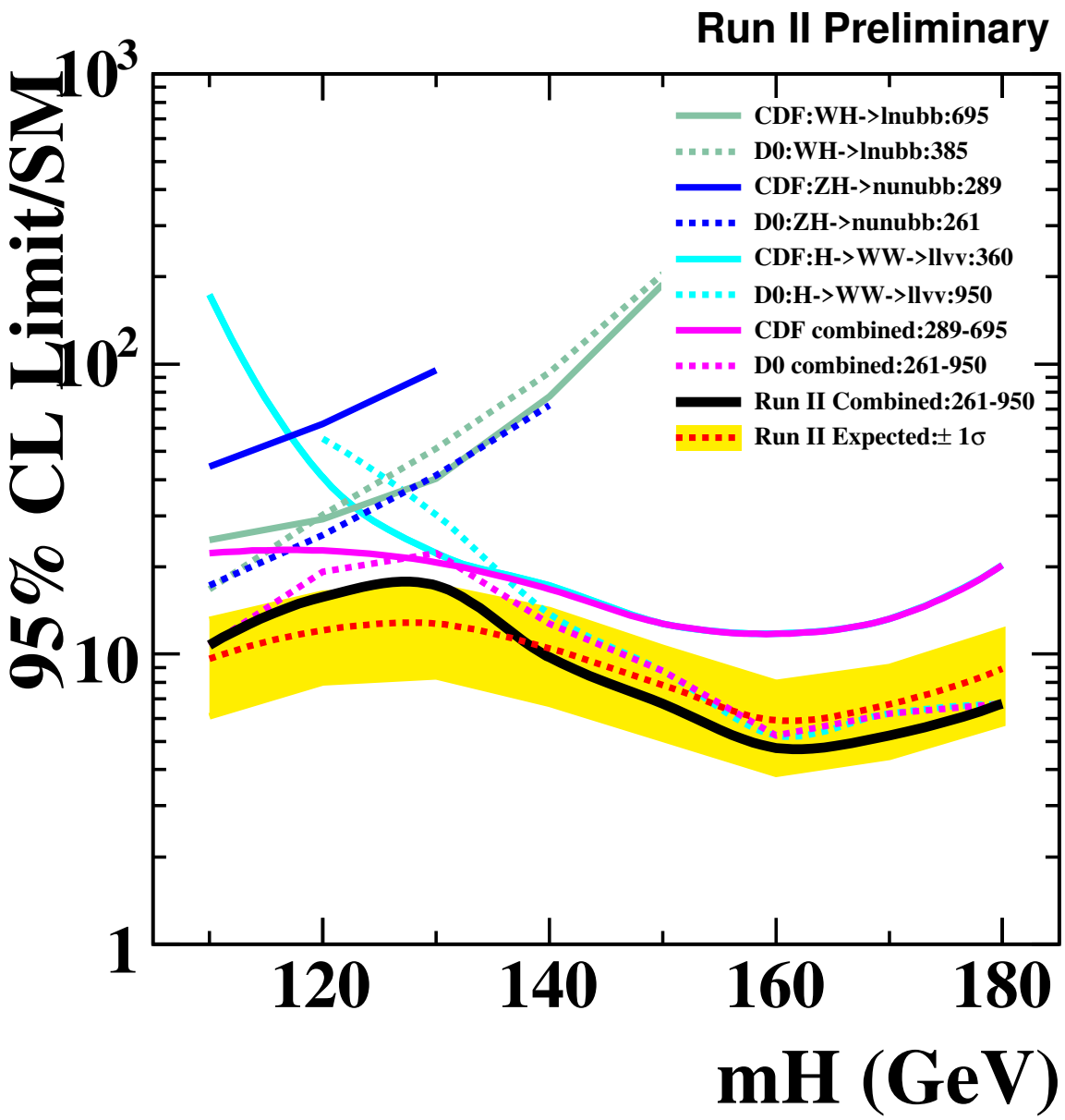
## What's New

- Fix the data histogram in D0: $WW \rightarrow \mu\mu$ at mH=150 GeV/c$^2$ from Wade
- Rerun the observed and expected limited
- Impact of systematic on the limits
- Reminder: A Bayesian framework is used to compute the upper limit with all 13 channels combined.

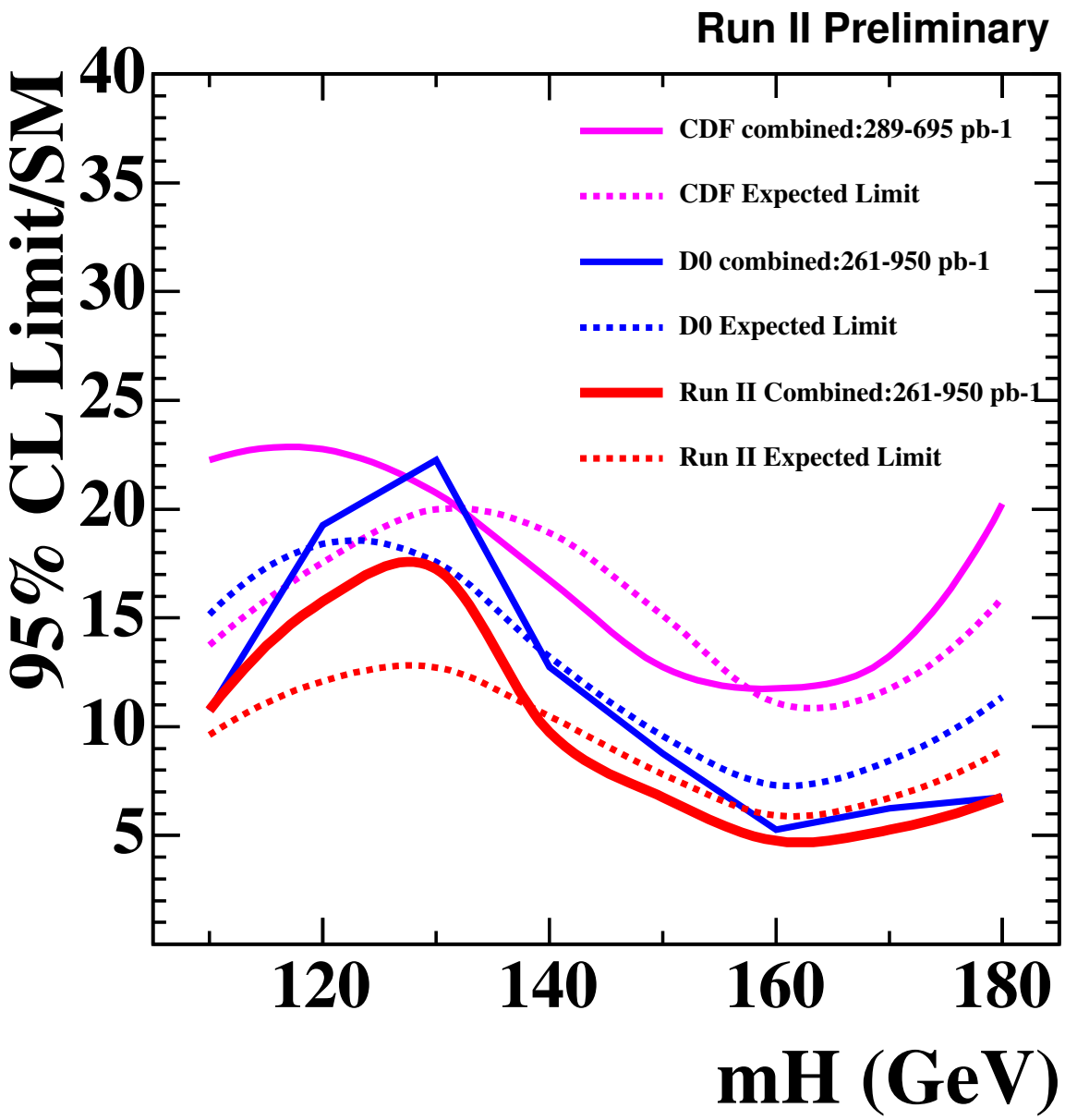
# Individual and Combined Limits



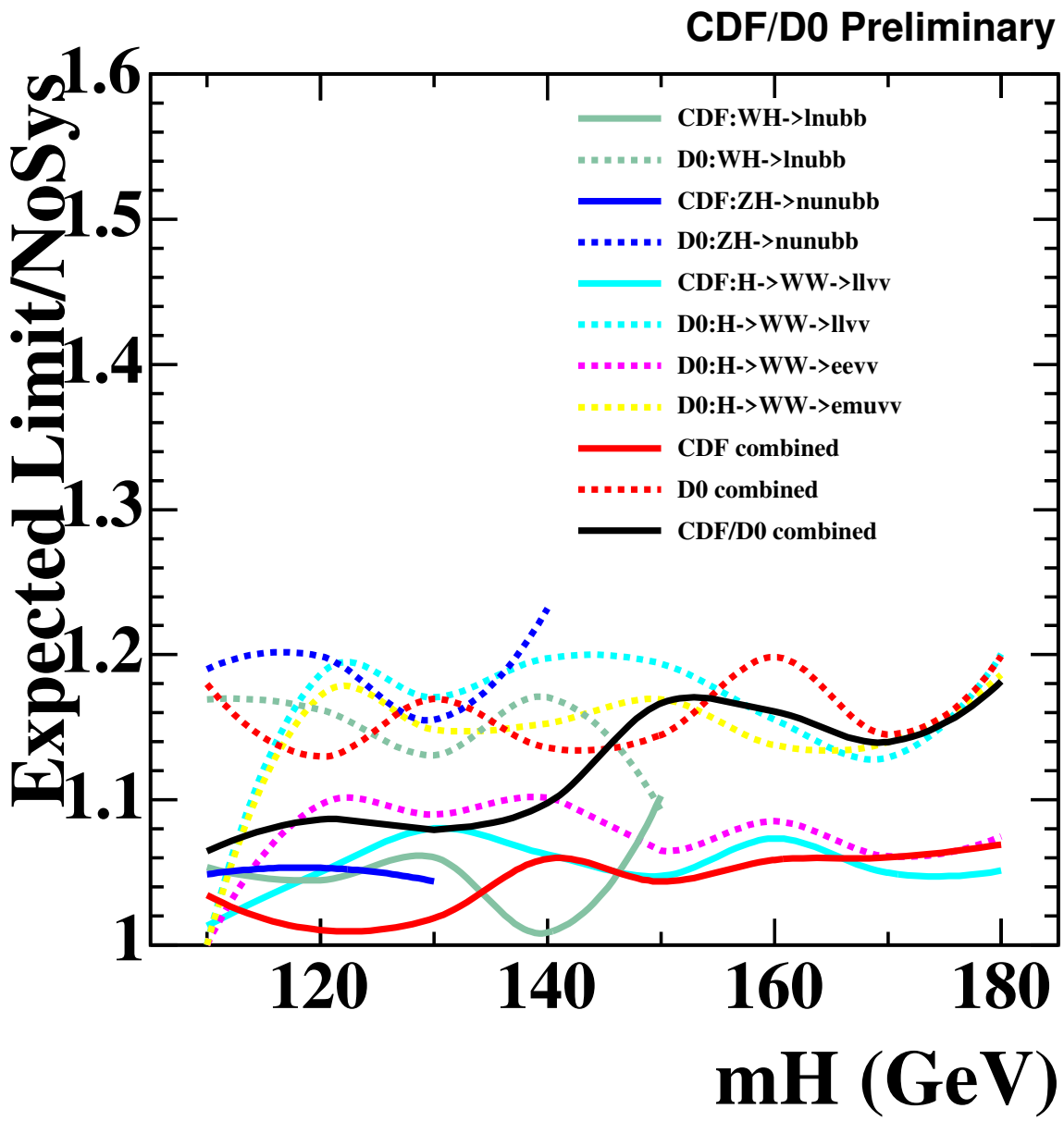
# Table of Limits/NoSys

| mh | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 |
|---|---|---|---|---|---|---|---|---|
| CDF:WH | 24.8/20.2 | 29.2/25.8 | 40.2/36.2 | 77.2/69.8 | 189/173 | | | |
| Expected | 16.4/15.5 | 22.6/21.6 | 35.2/33.2 | 64.4/63.8 | 155/140 | | | |
| D0:WH | 16.8/13.8 | 30.2/24.8 | 51.2/41.8 | 93.8/76.2 | 205/176 | | | |
| Expected | 25.1/21.5 | 36.1/31.0 | 57.4/50.7 | 106/90 | 214/196 | | | |
| CDF:ZH | 44.2/43.2 | 62.2/60.8 | 95.2/92.8 | | | | | |
| Expected | 33.0/31.4 | 40.9/38.8 | 63.4/60.8 | | | | | |
| D0:ZH | 17.2/16.2 | 25.8/23.2 | 41.2/37.2 | 72.2/65.2 | | | | |
| Expected | 20.0/16.8 | 27.0/22.5 | 41.1/35.6 | 73.0/59.3 | | | | |
| CDF:WW | 174/165 | 40.8/38.2 | 22.2/20.8 | 17.2/16.2 | 12.8/12.2 | 11.8/11.2 | 13.2/12.8 | 20.2/19.2 |
| Expected | 186/184 | 65.2/62.1 | 32.0/29.6 | 20.3/19.1 | 15.1/14.4 | 11.2/10.4 | 12.0/11.3 | 16.0/15.3 |
| D0:WW | | 55.2/37.8 | 30.2/17.8 | 13.8/9.8 | 8.8/6.2 | 5.2/3.8 | 6.2/4.2 | 6.8/5.2 |
| Expected | | 47.1/39.7 | 22.4/19.1 | 14.1/11.8 | 9.7/8.1 | 7.2/6.2 | 8.5/7.5 | 11.2/9.3 |
| D0:ee | | 114/106 | 51.2/46.8 | 30.2/27.2 | 16.8/15.2 | 13.2/12.2 | 16.8/15.8 | 19.2/17.8 |
| Expected | | 82.5/75.2 | 41.6/38.2 | 27.5/24.9 | 18.7/17.6 | 14.2/13.1 | 16.5/15.6 | 20.9/19.5 |
| D0:emu | | 44.2/37.2 | 21.8/18.2 | 14.2/11.8 | 10.2/8.2 | 5.8/4.8 | 5.8/4.8 | 7.2/6.2 |
| Expected | | 62.8/53.6 | 28.5/24.5 | 17.7/15.3 | 12.1/10.4 | 9.2/8.1 | 10.7/9.4 | 13.8/11.6 |
| CDF:Comb | 22.2/19.2 | 22.8/21.2 | 20.8/20.2 | 16.8/16.8 | 12.8/12.2 | 11.8/11.2 | 13.2/12.8 | 20.2/19.2 |
| Expected | 13.8/13.3 | 17.5/17.4 | 20.0/19.6 | 18.9/17.9 | 15.1/14.5 | 11.1/10.5 | 11.7/11.1 | 15.9/14.9 |
| D0:Comb | 10.8/9.8 | 19.2/14.8 | 22.2/14.8 | 12.8/9.8 | 8.8/6.2 | 5.2/3.8 | 6.2/4.2 | 6.8/5.2 |
| Expected | 15.2/12.9 | 18.4/16.3 | 17.6/15.0 | 13.2/11.6 | 9.6/8.4 | 7.3/6.1 | 8.4/7.4 | 8.9/9.5 |
| Tev Comb | 10.8/10.2 | 15.8/13.2 | 17.2/12.2 | 9.8/7.8 | 6.8/5.2 | 4.8/3.2 | 5.2/3.8 | 6.8/5.2 |
| Expected | 9.6/9.0 | 12.1/11.1 | 12.7/11.8 | 10.5/9.5 | 7.8/6.7 | 5.9/5.1 | 6.7/5.9 | 8.9/7.5 |

# Observed and Expected Limits



# Impact of Systematic on Expected Limits



# Conclusion

- We obtain a combined Higgs limit from CDF/D0 using a Bayesian method.
- The returned limit for each individual channel seems reasonable after fixing D0:$WW \to \mu\mu$ problem.
- The combined limit and expectation of Pseudo-experiments are also consistent.
- The impact of systematic seems small in the CDF model because the correlations between signal and background are minimized.

# BACKUP SLIDES

## Likelihood Function

- $\mathcal{L}(R, \vec{s}, \vec{b}|\vec{n}) = \prod_{i=1}^{Nc} \prod_{j=1}^{Nbins} \frac{\mu_{ij}^{n_{ij}} \cdot e^{-\mu_{ij}}}{n_{ij}!}$
  - $R = \sigma \cdot B/SM$; s= $\sigma_i^{SM} \cdot B^{SM} \cdot \epsilon_{acc} \cdot L$.
  - $\vec{b}$: backgrounds
  - $\vec{n}$: data
  - $N_C$: channels
  - $N_{bins}$: histogram bins.
  - $\mu_{ij} = R \cdot s_{ij} + b_{ij}$.

- The expected signal event depends on:
  luminosity, btag sf, lepton id, jes, ISR/FSR+PDF, and the rest uncertainties

- The background consists of:
  HF, Mistag, top, non-W, diboson (WW), and other.

# Priors, Posterior Densities and Upper Limit on R

- The priors for efficiencies and backgrounds are truncated Gaussian densities with its expected value within its uncertainty.

- Assign a flat prior to the number of Higgs events, instead of Higgs xsec.
  $\pi(R, \vec{s}, \vec{b}) = s_{tot} \cdot \theta(R \cdot s_{tot}) \cdot \pi(\vec{s}) \cdot \pi(\vec{b})$

- Posterior density:
  $p(R|\vec{n}) = \frac{\int d\vec{s} \int d\vec{b} \mathcal{L}(R,\vec{s},\vec{b}|\vec{n}) \cdot s_{tot}}{\int dR \int d\vec{s} \int d\vec{b} \mathcal{L}(R,\vec{s},\vec{b}|\vec{n}) \cdot s_{tot}}$

- 95% Upper Limit:
  $\int_0^{R_{0.95}} p(R|\vec{n}) dR = 0.95$

## Source of Correlated Systematic (CDF)

| Channels | $l\nu b\bar{b}_S$ | $l\nu b\bar{b}_D$ | $\nu\nu b\bar{b}$ | $W^+W^-$ |
|---|---|---|---|---|
| Luminosity (%) | 6.0 | 6.0 | 6.0 | 6.0 |
| btag SF(%) | 5.3 | 16.0 | 6.3 | 0. |
| Lepton ID (%) | 2.0 | 2.0 | 2.0 | 3.0 |
| JES (%) | 3.0 | 3.0 | 8.0 | 1.0 |
| I(F)SR+PDF(%) | 4.0 | 10.0 | 2.0 | 5.0 |
| Trigger (%) | 0.0 | 0.0 | 2.0 | 0.0 |
| Backgrounds | | | | |
| HF (%) | 33.0 | 34.0 | 0. | 0. |
| Mistag (%) | 22.0 | 15.0 | 16.0 | 0. |
| Top (%) | 13.5 | 20.0 | 18.0 | 0.0 |
| QCD (%) | 17.0 | 20.0 | -34.0 | 0. |
| Diboson (%) | 16 | 25 | 18 | 11 |
| Others (%) | 0. | 0. | 0. | -(12-18) |

- The positive value means correlated, the negative value means uncorrelated
- The results seems insensitive to these correlations changing from 100% to 0%
- Common to D0: 4% on Luminosity; 8% on $\sigma_t$; 6% on $\sigma_{EW}$; 10% on $\sigma_{H\to WW}$

# Source of Signal Systematic (D0)

0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 ! sig_Lumi_pos 0 and bkgd_Lumi_pos 0

0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 ! bkgd_Xsec_Top_pos 1

0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 ! bkgd_Xsec_EW_pos 2

0.025 0.025 0.025 0.025 0.025 0.025 0.025 0.025 0.025 ! DZero_sig_Lumi_pos 0

0.05 0.05 0.05 0.05 0.05 0.05 0 0 0 ! DZero_sig_JetID_pos 1

0.04 0.04 0.04 0.04 0.06 0.06 0.04 0.04 0.03 ! DZero_sig_JES_pos 2

0.03 0.03 0.03 0.03 0 0 0 0 0 ! DZero_sig_JetMult_pos 3

0.035 0.035 0.035 0.035 0 0 0 0 0 ! DZero_sig_JetMLM_pos 4

0.03 0.03 0.03 0.03 0.01 0.01 0 0 0 ! DZero_sig_Taggability_pos 5

0.055 0.055 0.04 0.055 0.03 0.07 0 0 0 ! DZero_sig_bTag_HF_pos 6

0.03 0.03 0 0 0 0 0 0 0 ! DZero_sig_EMTrigger_pos 7

0.03 0.03 0 0 0 0 0.03 0.02 0 ! DZero_sig_EMID_pos 8

0.04 0.04 0 0 0 0 0.02 0.02 0 ! DZero_sig_EMSmear_pos 9

0.03 0.03 0 0 0 0 0 0 0 ! DZero_sig_EMlike_pos 10

0 0 0.02 0.02 0 0 0 0 0 ! DZero_sig_MUTrigger_pos 11

0 0 0.02 0.02 0 0 0 0.022 0.03 ! DZero_sig_MUID_pos 12

0 0 0.041 0.041 0 0 0 0.024 0.01 ! DZero_sig_MUSmear_pos 13

0 0 0 0 0.05 0.05 0 0 0 ! DZero_sig_JetSmear_pos 14

0 0 0 0 0.05 0.05 0 0 0 ! DZero_sig_MJETTrigger_pos 15

0 0 0 0 0 0 0.01 0.01 0.01 ! DZero_sig_DiEMTrigger_pos 16, EMUTrigger_pos 17, DiMUTrigger_pos 18

# Source of Background Systematic (D0)

0.025 0.025 0.025 0.025 0.025 0.025 0.025 0.025 0.025 ! DZero_bkgd_Lumi_pos 0
0.05 0.05 0.05 0.05 0.06 0.06 0 0 0 ! DZero_bkgd_JetID_pos 1
0.04 0.04 0.04 0.04 0.06 0.06 0.05 0.05 0.03 ! DZero_bkgd_JES_pos 2
0.03 0.03 0.03 0.03 0 0 0 0 0 ! DZero_bkgd_JetMult_pos 3
0.035 0.035 0.035 0.035 0 0 0 0 0 ! DZero_bkgd_JetMLM_pos 4
0.03 0.03 0.03 0.03 0.01 0.01 0 0 0 ! DZero_bkgd_Taggability_pos 5
0.055 0.055 0.04 0.055 0.04 0.07 0 0 0 ! DZero_bkgd_bTag_HF_pos 6
0.03 0.03 0 0 0 0 0 0 0 ! DZero_bkgd_EMTrigger_pos 7
0.03 0.03 0 0 0 0 0.04 0.03 0 ! DZero_bkgd_EMID_pos 8
0.01 0.01 0 0 0 0 0.03 0.02 0 ! DZero_bkgd_EMSmear_pos 9
0.03 0.03 0 0 0 0 0 0 0 ! DZero_bkgd_EMlike_pos 10
0 0 0.02 0.02 0 0 0 0 0 ! DZero_bkgd_MUTrigger_pos 11
0 0 0.02 0.02 0 0 0 0.029 0.031 ! DZero_bkgd_MUID_pos 12
0 0 0.041 0.041 0 0 0 0.024 0.01 ! DZero_bkgd_MUSmear_pos 13
0 0 0 0 0.02 0.02 0 0 0 ! DZero_bkgd_JetSmear_pos 14
0 0 0 0 0.04 0.04 0 0 0 ! DZero_bkgd_MJETTrigger_pos 15
0 0 0 0 0 0 0.02 0 0 ! DZero_bkgd_DiEMTrigger_pos 16
0 0 0 0 0 0 0 0.02 0 ! DZero_bkgd_EMUTrigger_pos 17
0 0 0 0 0 0 0 0 0.02 ! DZero_bkgd_DiMUTrigger_pos 18
0.08 0.08 0.06 0.08 0.07 0.1 0 0 0 ! DZero_bkgd_bTag_LF_pos 19
0.15 0.15 0.15 0.15 0.15 0.15 0 0 0 ! DZero_bkgd_Xsec_HF_pos 20
0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 ! DZero_bkgd_Xsec_LF_pos 21
0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 ! DZero_bkgd_Xsec_QCD_pos 22

- Generate a common Gaussian for each systematic source
- Multiply them to count for total systematic for each individual backgrounds