PREDICTING SIGNAL SIGNIFICANCES AT THE LHC

Tilman Plehn

MPI München & University of Edinburgh

– Why we would like to do that
– How we can do it
– What it gives for WBF H $\rightarrow \mu\mu$

in collaboration with Kyle Cranmer

THE PROBLEM WITH LHC SEARCHES: 1

Haven't we all had this problem?

– BSM model with crazy new particle

$\longrightarrow$ extraction from backgrounds at LHC [all LHC physics is statistics]

$\longrightarrow$ parton-level signal/background analysis [all of the U.S. can do that now]

$\longrightarrow$ cuts analysis an art, not a science

$\longrightarrow$ experimentalist reluctant to invest time [no trust because they know us...]

$\longrightarrow$ yes: neural net with hugely improved significance [good papers]
yes: parton level analysis proven completely wrong [most papers]
no: idea lost forever

What we would like to do

(1) predict significance which can be obtained

(2) check if experimental analysis is optimal

$\Rightarrow$ emulate the perfect experimentalist on a laptop [to take him home or to workshops]

The Problem with LHC Searches: 2

An example from real life [TP, Rainwater, Zeppenfeld vs. Cranmer, Mellado, Quayle, Wu]

– WBF H $\to \tau\tau$ in Standard Model [and MSSM]

– cut analysis promising, experimentalists convinced

– neural net even better with LEP-type events weighting

– new Higgs discovery channel

$\Rightarrow$ could we have predicted this outcome?

- Significance for 30 fb^{-1}:

Higgs Mass	Cut Analysis(Pois.)	Cut on NN	NN Sig. w/cut	NN Sig. w/LR
115	2.95	0.89	3.71	4.68
120	3.09	0.93	3.97	4.88
125	3.06	0.92	3.93	4.75
130	2.72	0.94	3.70	4.49
135	2.56	0.96	3.36	4.02
140	1.86	0.97	2.85	3.38

- Improvement of ~30% from Neural Nets
- Improvement of ~60% with Likelihood Ratio

[B. Quayle, ATLAS Higgs meeting, 2003]

Likelihood Ratio: 1

Likelihood ratio and maximum significance

– Neyman–Pearson lemma: likelihood ratio most powerful estimator

[assuming signal true: lowest probability to mistake signal for background fluctuation (type-II error)]

– combined likelihood for N-event Poisson statistics [independent channels]

$$\mathcal{L}_b = \frac{e^{-b}\, b^N}{N!} \qquad \mathcal{L}_{s+b} = \frac{e^{-(s+b)}\, (s+b)^N}{N!}$$

$$q = \log \frac{\mathcal{L}_{s+b}}{\mathcal{L}_b} = -s + N \log\left(1 + \frac{s}{b}\right) \longrightarrow -\sum_j s_j + \sum_j N_j \log\left(1 + \frac{s_j}{b_j}\right)$$

$\rightarrow$ integration over entire phase space replacing $s, b \rightarrow |\mathcal{M}_{s,b}|^2$ [LEP–Higgs inspired]

$$q(\vec{r}) = -\sigma_s \mathcal{L} + \log\left(1 + \frac{|\mathcal{M}_s(\vec{r})|^2/\sigma_s}{|\mathcal{M}_b(\vec{r})|^2/\sigma_b}\right)$$

$\rightarrow$ extraction of probability distribution function via Fourier transform: $\rho_{s,b}(q)$

$\rightarrow$ mathematically optimal significance $CL_b(q) = \int_q^\infty dq' \rho_b(q')$ [5σ is $CL_b = 2.85\, 10^{-7}$]

Likelihood Ratio: 2

Irreducible + unsmeared and beyond

– irreducible & unsmeared: signal and background phase space identical

$$\sigma_{\rm tot} = \int d{\rm PS}\; M_{\rm PS}\; d\sigma_{\rm PS} = \int d\vec{r}\; M(\vec{r})\; d\sigma(\vec{r})$$

→ random numbers $\vec{r}$ basis for phase space configurations

→ smearing! otherwise e.g. $\Delta m_{\mu\mu}^{\rm width} \ll \Delta m_{\mu\mu}^{\rm meas}$ too distinctive

→ smear observable/random number with Gaussian W

$$\sigma_{\rm tot} = \int d\vec{r}_\perp dr_m^* \int_{-\infty}^{\infty} dr_m\; M(\vec{r})\; d\sigma(\vec{r})\; W(r_m, r_m^*)$$

→ modified phase space vector $\vec{r} = \{\vec{r}_\perp, r_m\}$ without back door

→ complete smearing: replace phase space by set of distributions

[lose mathematical maximum signifi cance claim]

→ about to be be implemented in Whizard [Cranmer, TP, Reuter]

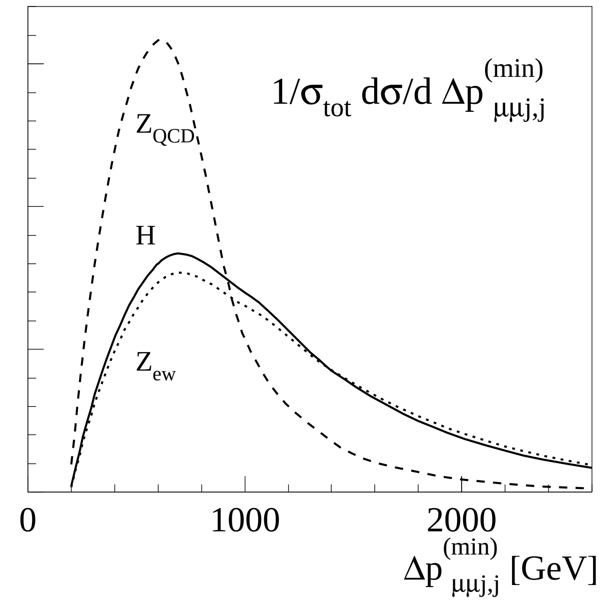
WBF-Higgs to Muons: 1

WBF Higgs with decay $H \to \mu\mu$ [TP & Rainwater, 0107180]

– number of signal events small [$\sigma \cdot$ BR ~ 0.25fb]

– no distribution with golden cut

$\longrightarrow$ perfect form multivariate analysis



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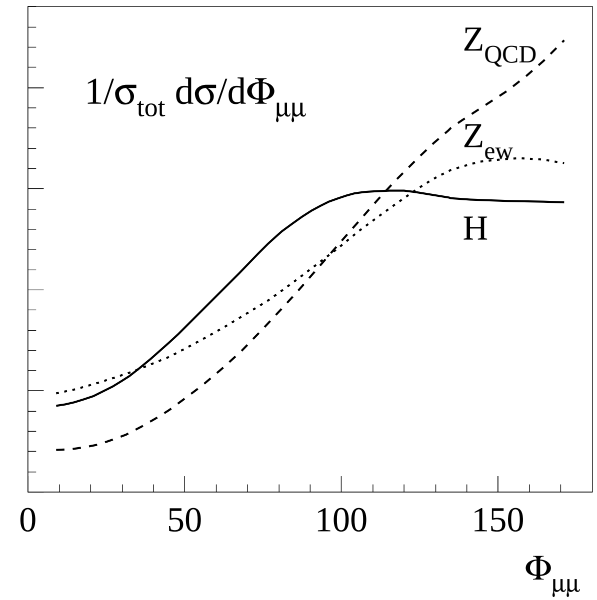


Old results [leading (irreducible) backgrounds]

$\sqrt{S}$ [TeV]	M_H [GeV]	σ_H [fb]	σ_Z^{QCD} [fb]	σ_Z^{ew} [fb]	S/B	significance σ	$\triangle\sigma/\sigma$	$\mathcal{L}_{5\sigma}$ [fb^{-1}]
14	115	0.25	3.57	0.40	1/9.1	1.7	60%	2600
14	120	0.22	2.60	0.33	1/7.5	1.8	60%	2300
14	130	0.17	1.61	0.24	1/6.5	1.7	65%	2700
14	140	0.10	1.11	0.19	1/7.5	1.2	85%	4900
200	115	2.57	39.6	5.3	1/10.1	5.3	20%	270
200	120	2.36	29.2	4.0	1/8.0	5.7	20%	230
200	130	1.80	18.7	2.7	1/6.9	5.3	20%	260
200	140	1.14	13.4	2.0	1/7.9	4.0	27%	500

WBF-HIGGS TO MUONS: 2

Statistical promise of WBF H $\to \mu\mu$

– relevant for physics: confirm Yukawa coupling to 2nd generation

– gluon–fusion channel helpful? [Han & McElrath, Boos etal.]

$\to$ for now try WBF alone

– cut analysis impossible

– event weighting promising

– only irreducible backgrounds

– smearing only relevant for $m_{\mu\mu}$ [mimic by Γ'_H]

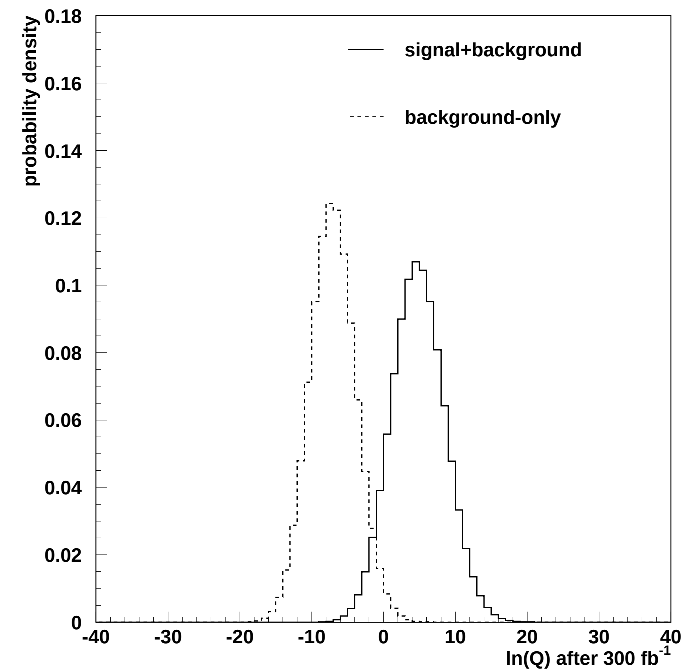
$\to$ compute likelihood from matrix elements

$\to$ upper limit on parton level significance

$\to$ WBF H $\to \mu\mu$: 3.5 sigma in 300 fb^{-1}

[$\sim 4.2\sigma$ with jet veto; $\gtrsim 5\sigma$ for Atlas+CMS]

$\Rightarrow$ see if we can find an experimental group now



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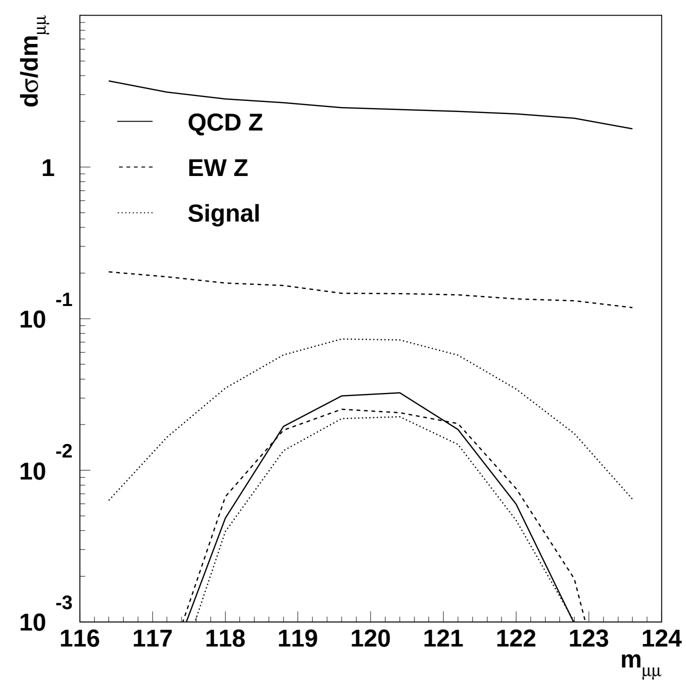

OUTLOOK

Higgs/BSM news for LHC

– we can emulate the perfect experimentalist!

– another cool tool in the pipeline

– concept and feasibility shown

– incorporation into Whizard over summer