Signal Significance in the Ideal LHC World

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- What the problem with significance is
- How we can try to solve it
- Where it seems to work

in collaboration with Kyle Cranmer [he did all the statistics]

THE PROBLEM WITH LHC SEARCHES: 1

Haven't we all had this problem?

– some new BSM model predicts a crazy new particle

$\longrightarrow$ extraction from backgrounds at LHC [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 [know-how got people like me a job]

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

$\longrightarrow$ yes: neural net with hugely improved significance [my papers]
yes: parton level analysis proven completely wrong [everyone else's papers]
no: idea forever lost

How to solve it in the ideal world?

– (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, Quayle, Wu]

– WBF H $\rightarrow \tau\tau$ in Standard Model

– cut analysis promising, experimentalists convinced [after years of convincing]

– neural net even better with LEP-type events weighting

– new Higgs discovery channel

$\Rightarrow$ could we have predicted this?

▶ 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

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

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

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

– remember: Gaussian significance approximately $n_\sigma \sim -2\, q$

→ inspiration by LEP-Higgs analyses:
integration over all possible p.s. points by replacing $s, b \to |\mathcal{M}_{s,b}|^2$

$$q(x) = \left(1 + \frac{|\mathcal{M}_s|^2}{|\mathcal{M}_b|^2}\right)_x$$

→ treatment of log likelihood as maesurement function

→ extraction of probability distribution function more involved: $\rho_{s,b}(n)$

→ integrate over background pdf $CL_b = \int_N^\infty dn \rho_b(n)$ [5σ with probability $2.85\, 10^{-7}$]

Beyond Irreducible and Unsmeared

Beyond naive phase space integration

– irreducible & unsmeared: signal and background phase space identical

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

$\longrightarrow$ same randum numbers for S and B, all phase space info included [over-all ϕ?]

$\longrightarrow$ smearing! otherwise e.g. $m_{\mu\mu}^{\text{real}} \neq m_{\mu\mu}^{\text{meas}}$ too distinctive

$\longrightarrow$ smear small number of observables/random numbers with Gaussian G

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

$\longrightarrow$ modified random number vector $\vec{r} = \{\vec{r}_\perp, r_m\}$ without back door

$\longrightarrow$ complete smearing?!

$\longrightarrow$ have to replace phase space by spectrum of set of distributions (can be large and overlapping)

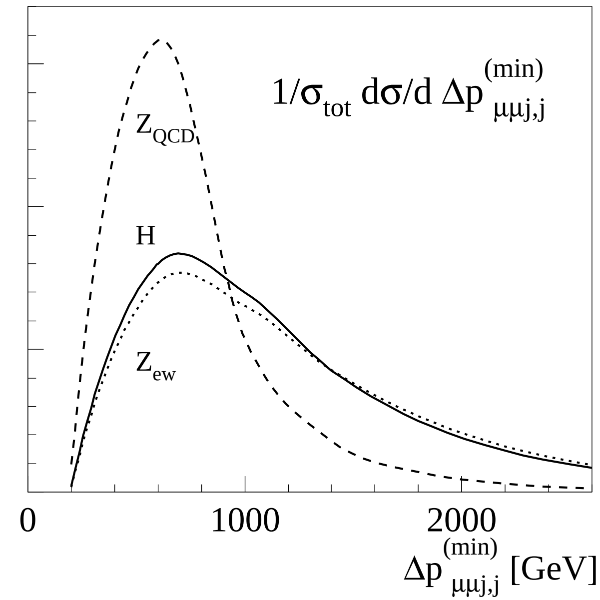
$\longrightarrow$ about to be be implemented in Whizard [Cranmer, TP, Reuter]

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 for neural net analysis



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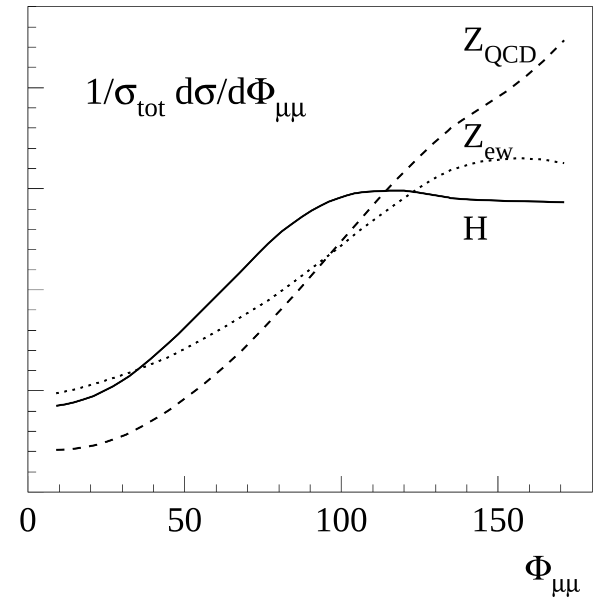


Old results [leading (irreducible) backgrounds]

$\sqrt{S}$ [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.]

$\longrightarrow$ better try WBF alone

– cut analysis impossible

– event weighting in neural net promising

– only irreducible backgrounds

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

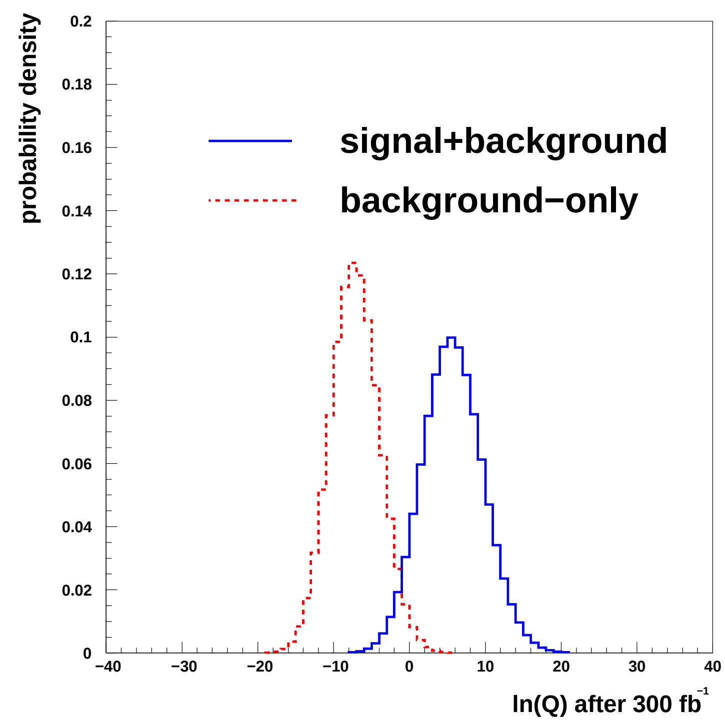
$\longrightarrow$ compute likelyhood for each event

$\longrightarrow$ upper limit on parton level significance

$\longrightarrow$ WBF H $\to \mu\mu$: 3.7 sigma in 300 fb^{-1}

[4.2σ with jet veto; 5.2σ for Atlas+CMS]

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



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