Eur. Phys. J. C 51, 415 (2007) (Plehn, Cranmer)
arXiv: 1311.2591 (Plehn, Schichtel, Wiegand)
arXiv: 16xx.xxxx (FK, Plehn, Schichtel)

↑

Mad-Maximizing Higgs Pair Analyses

↓

arXiv: 1605.xxxx
work with Tilman Plehn and Peter Schichtel

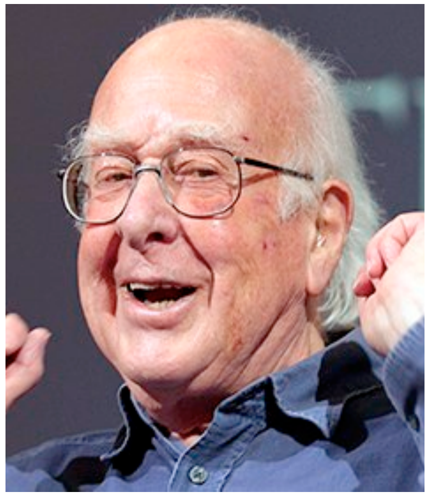
Felix Kling

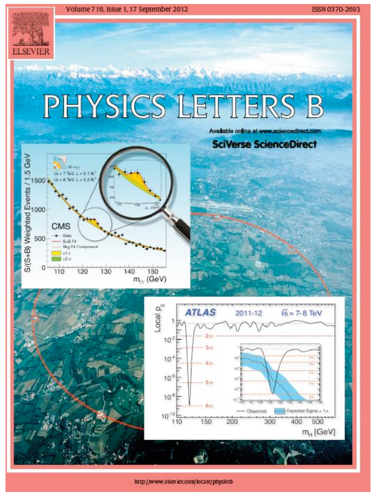
The University of Arizona
Fermilab

Pheno 2016

Introduction

- 2012: LHC found Higgs
  → no new physics found (so far)
  → let's analyze all its properties





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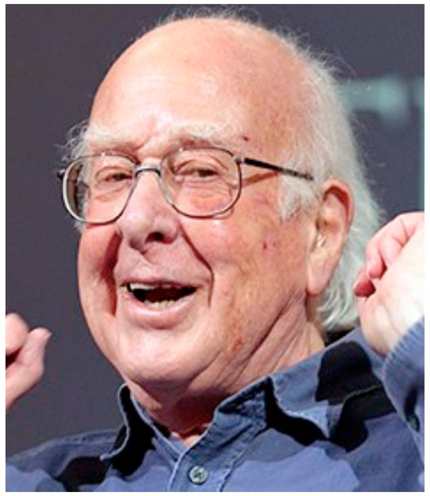

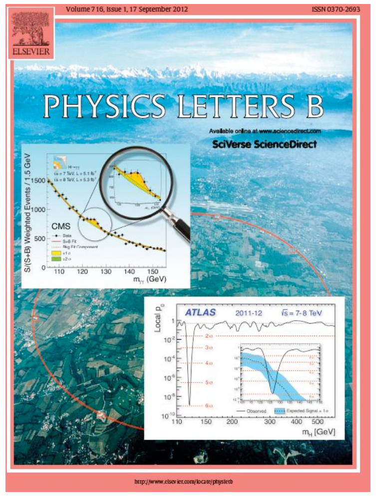

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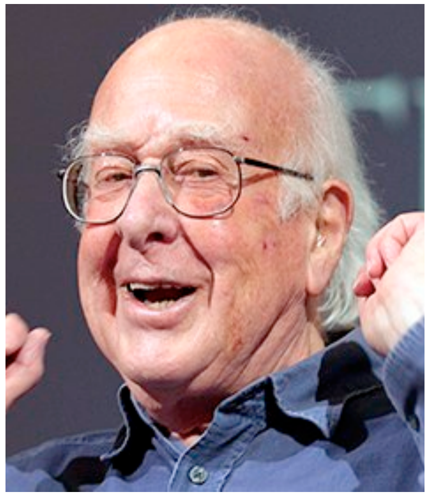

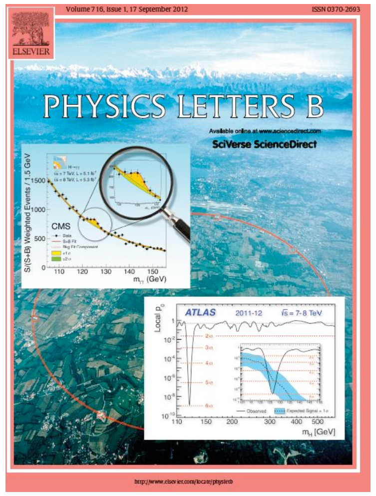

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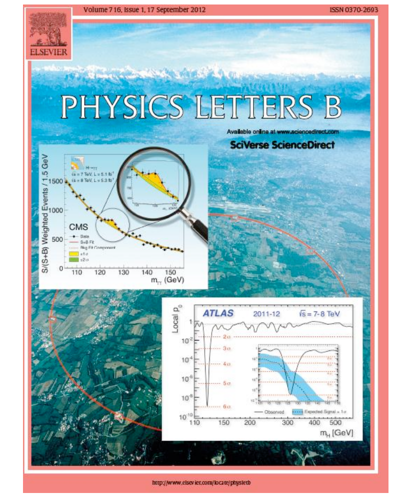

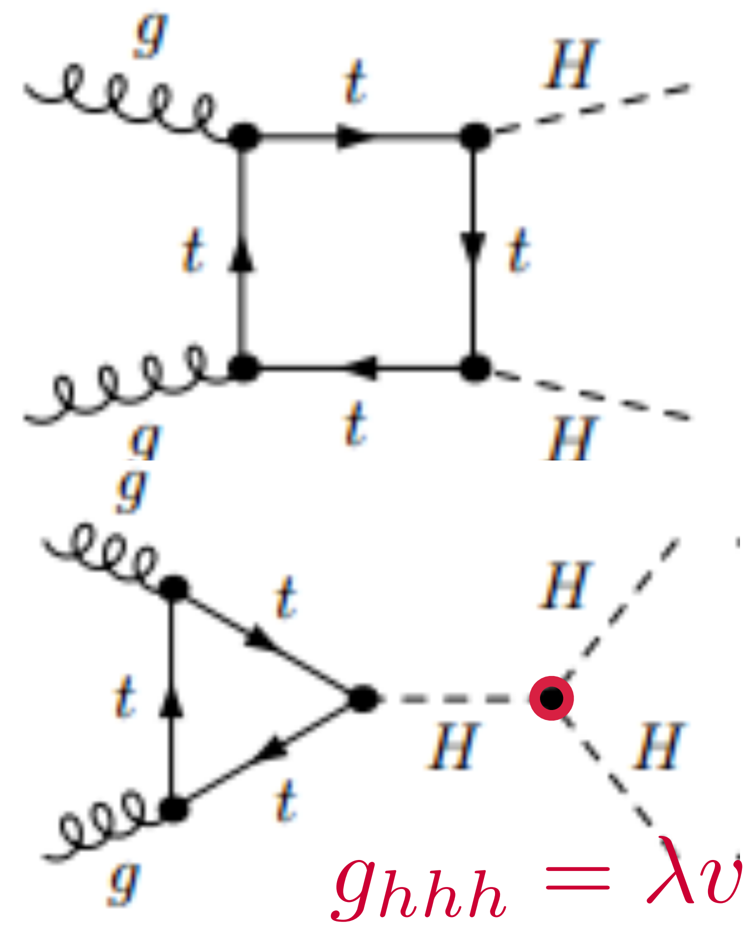

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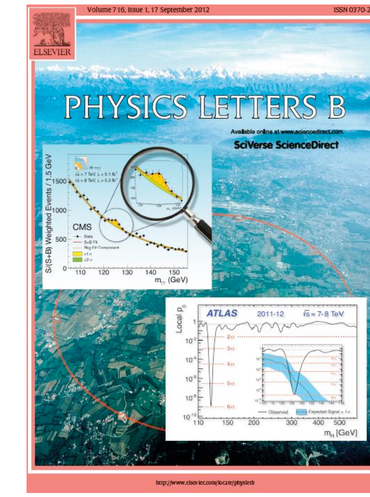

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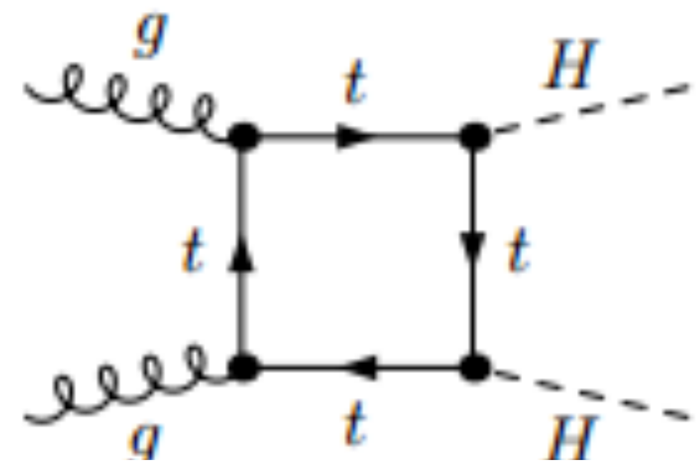

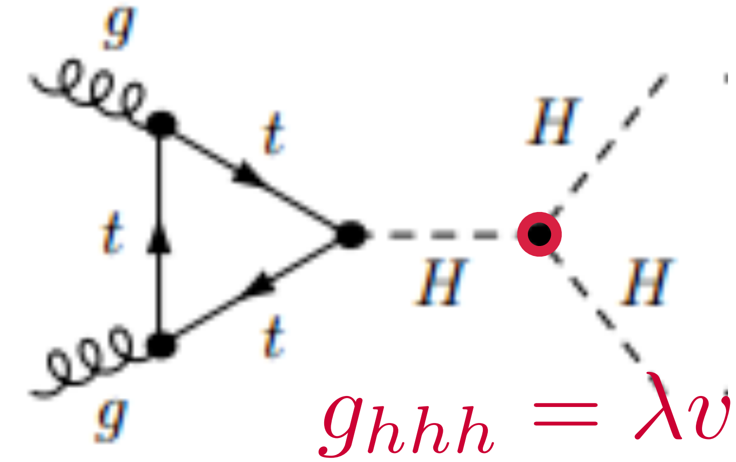

- Previous Studies:
  - arXiv 0310056 (Baur et. al.)
    - → Pre-LHC study
  - arXiv 1206.5001 (Dolan et. al.)
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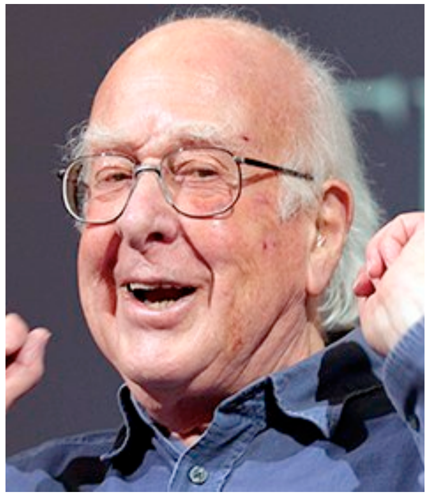

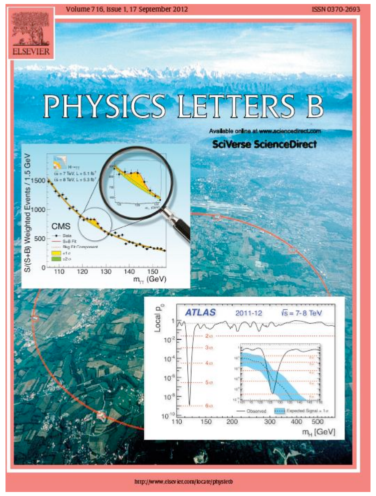

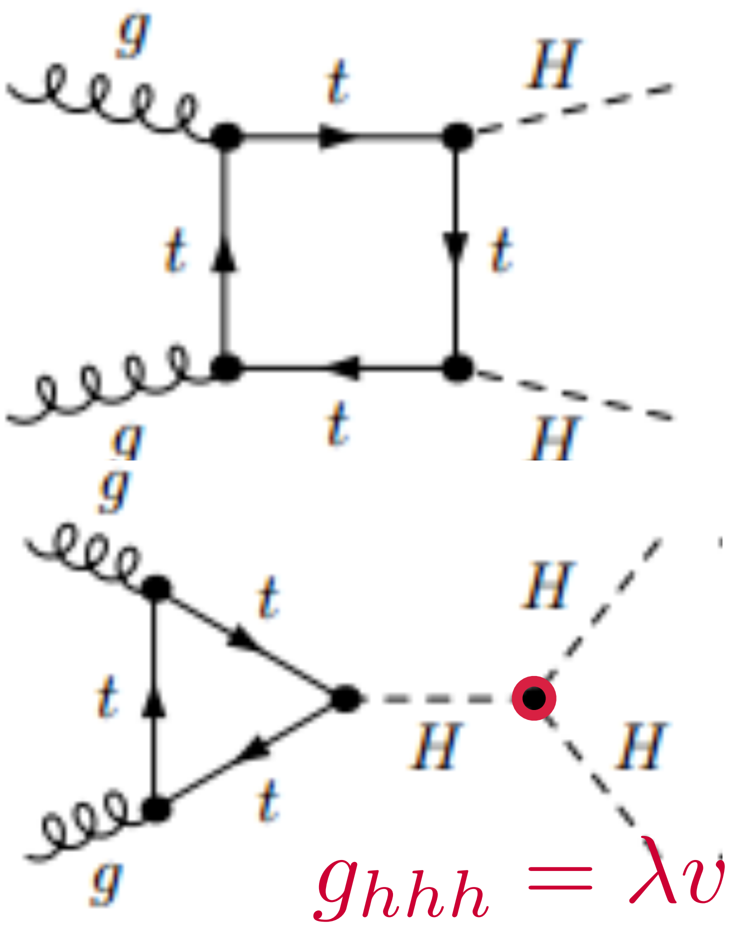

$g_{hhh} = \lambda v$

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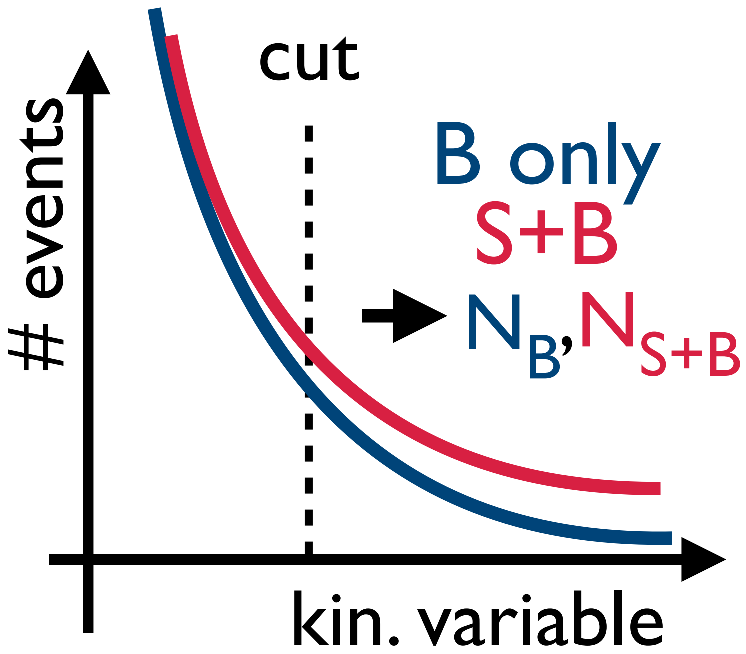
How good can we be?

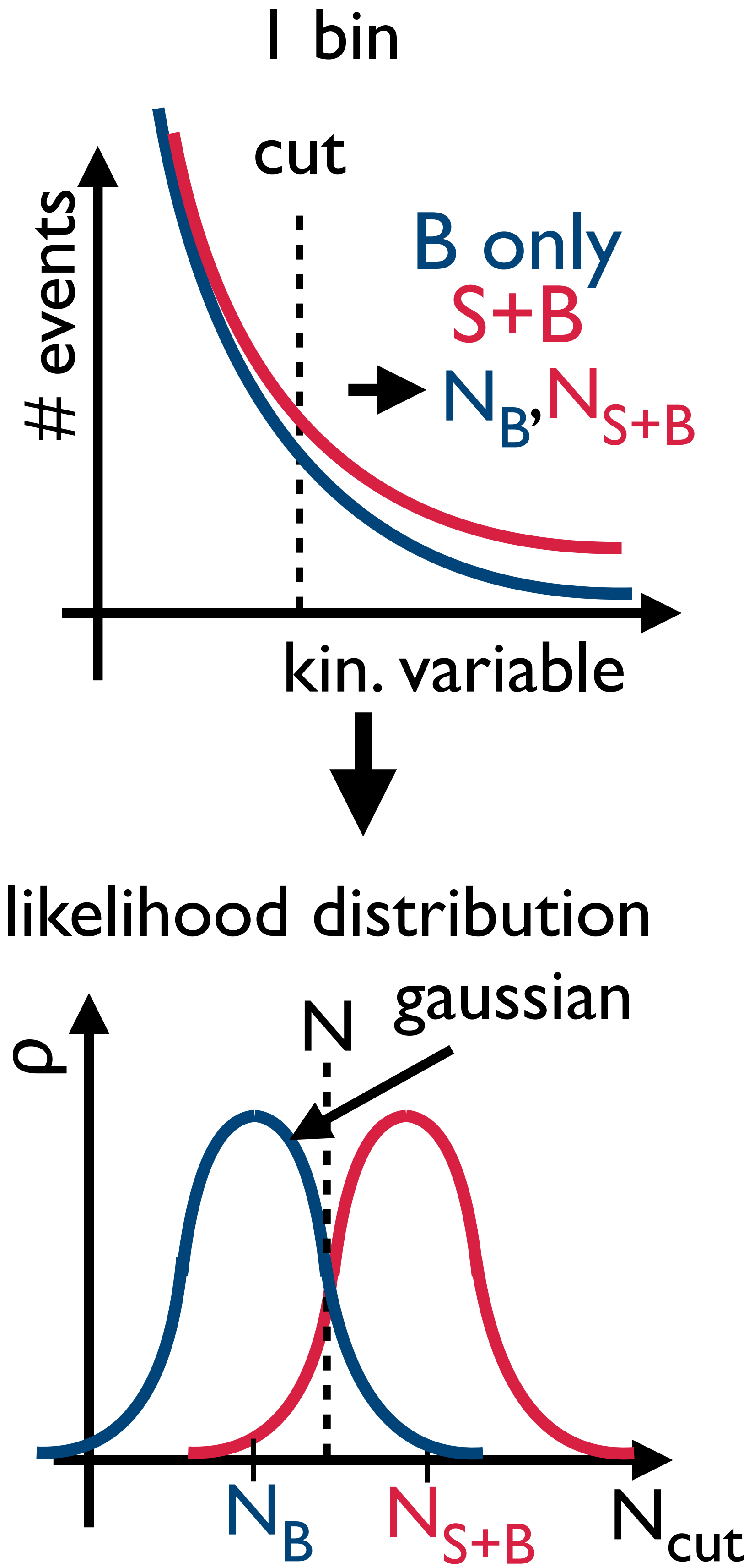
MadMax

MadMax

1 bin

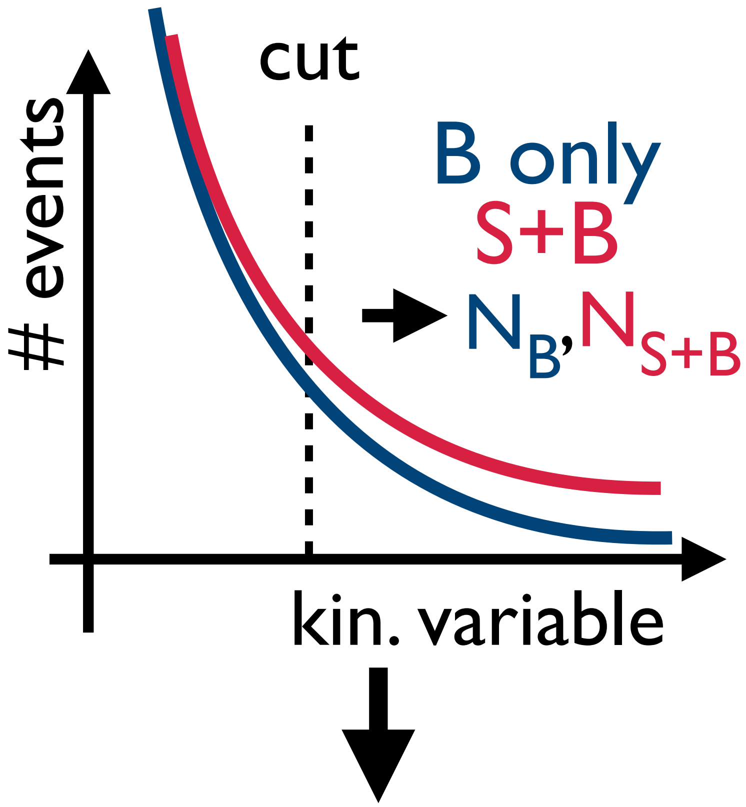


MadMax

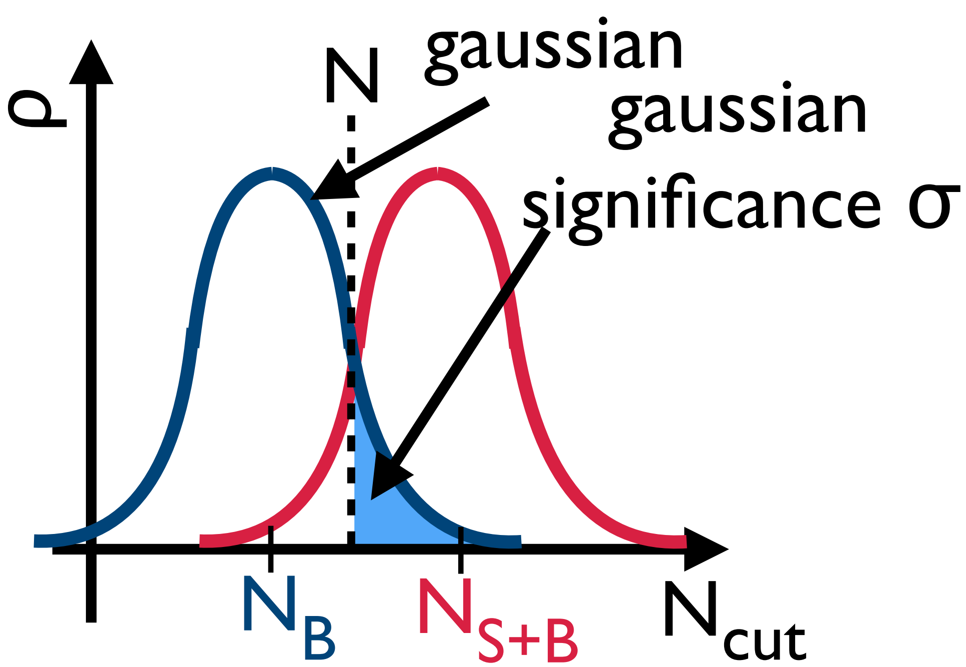

1 bin
cut
events
B only
S+B
N_B,N_{S+B}
kin. variable
likelihood distribution
gaussian
ρ
N
N_B
N_{S+B}
N_{cut}

MadMax

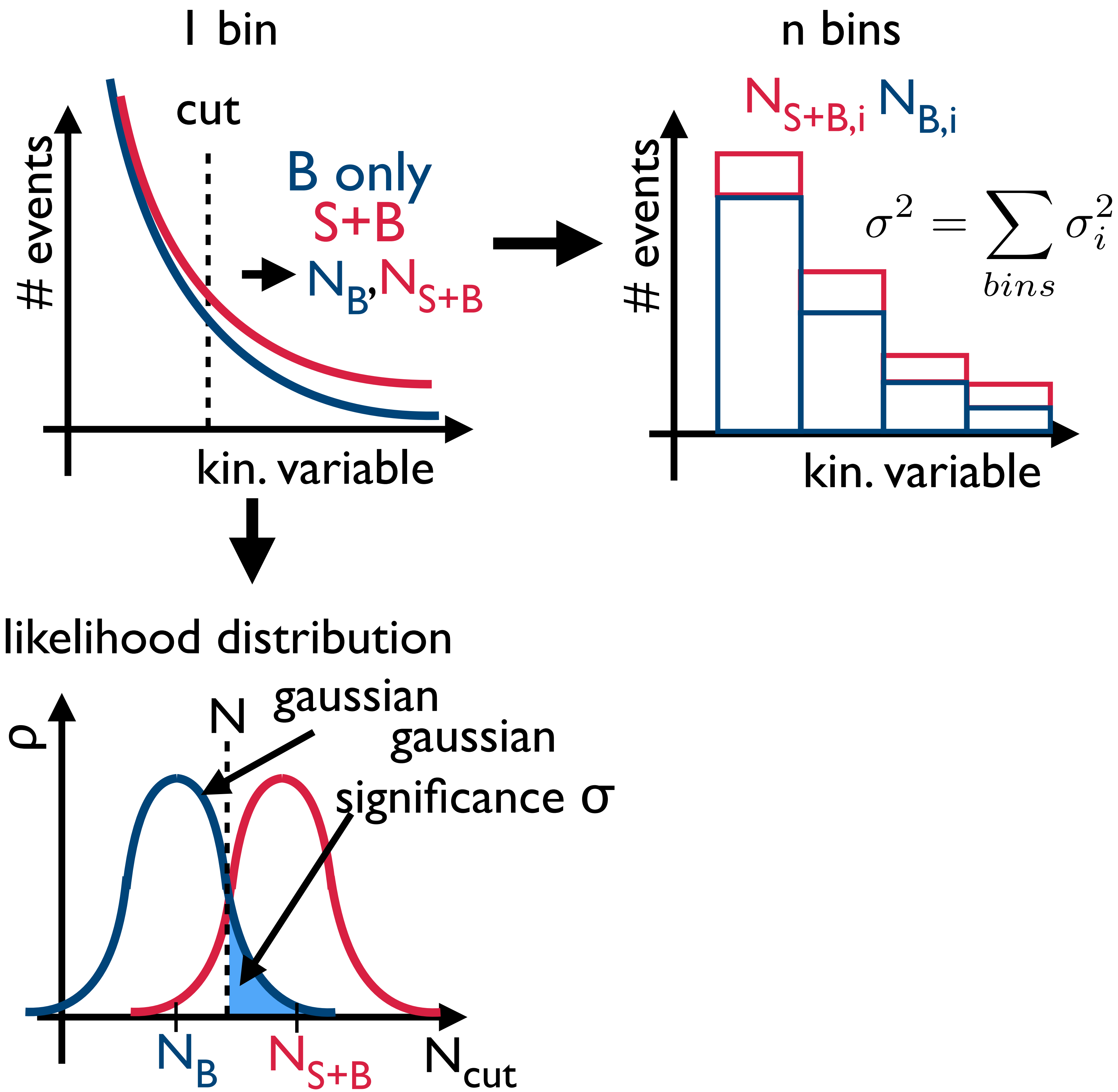
1 bin



likelihood distribution

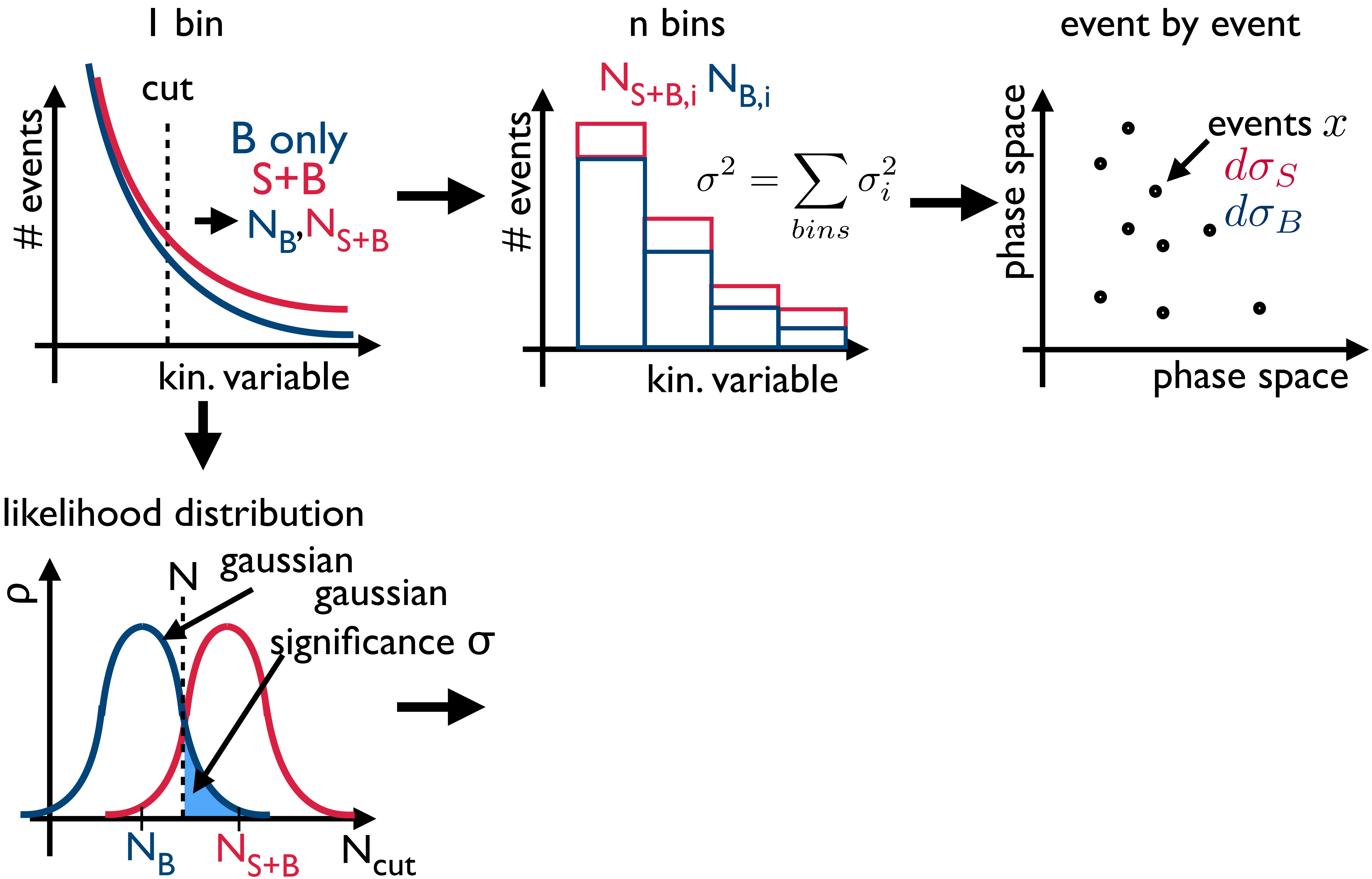


MadMax



1 bin
cut
B only
S+B
events
N_B, N_{S+B}
kin. variable
n bins
$N_{S+B,i}$ $N_{B,i}$
events
$\sigma^2 = \sum_{bins} \sigma_i^2$
kin. variable
likelihood distribution
ρ
N
gaussian
gaussian
significance σ
N_B
N_{S+B}
N_{cut}

MadMax


1 bin
n bins
event by event
cut
events
B only
S+B
N_B, N_{S+B}
kin. variable
$N_{S+B,i}$ $N_{B,i}$
events
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phase space
events x
$d\sigma_S$
$d\sigma_B$
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gaussian
gaussian
significance σ
N_B
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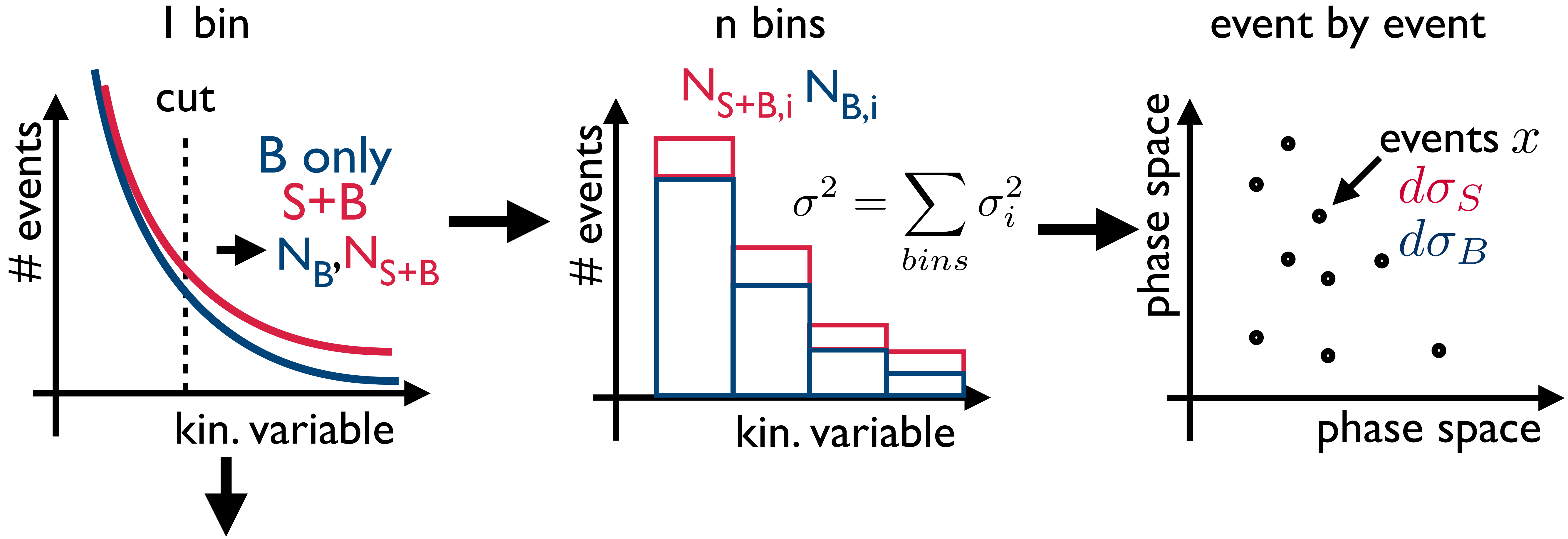
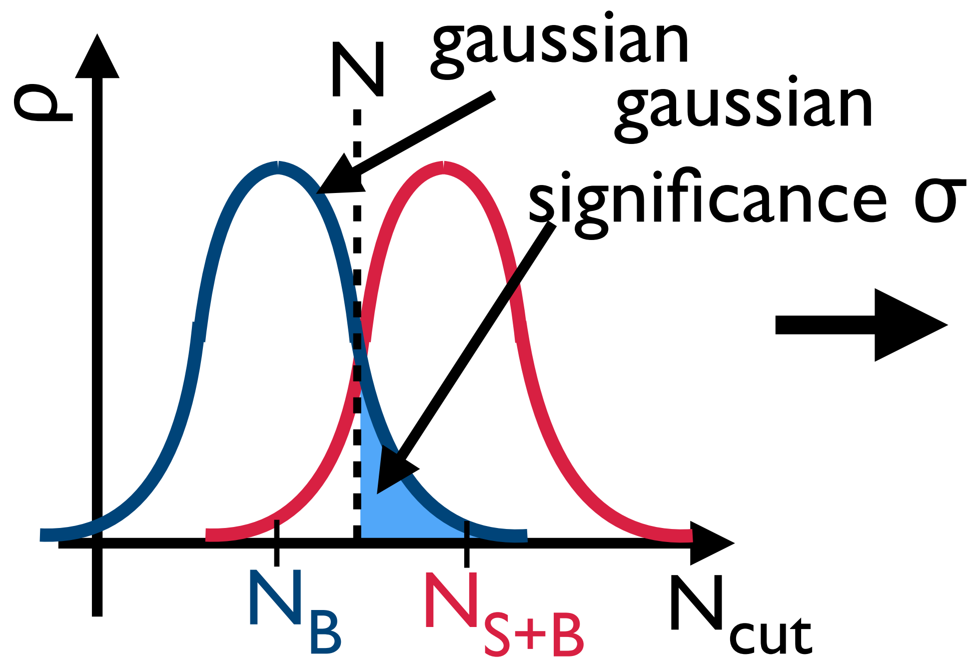
MadMax



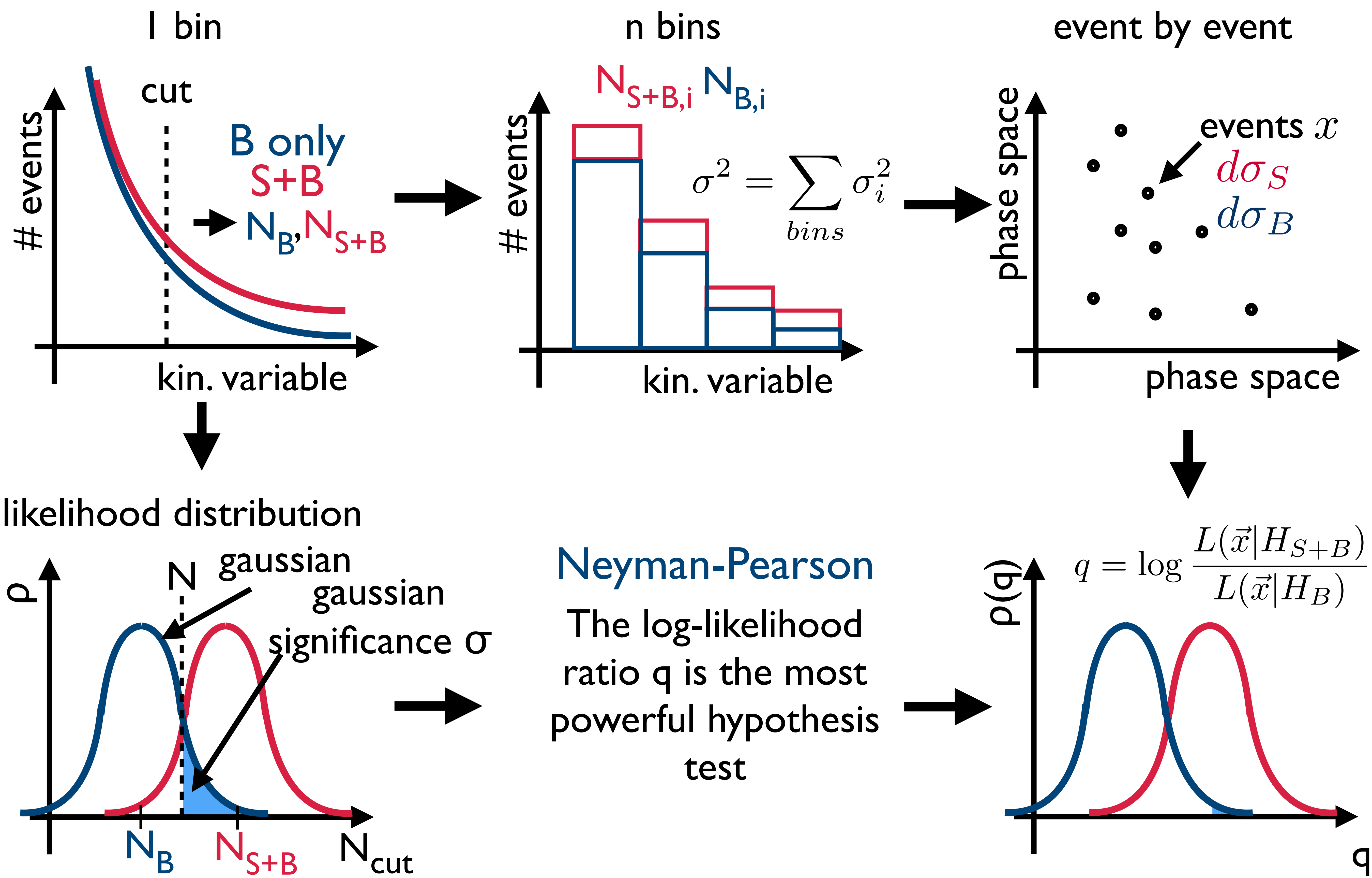
likelihood distribution



Neyman-Pearson

The log-likelihood ratio q is the most powerful hypothesis test

MadMax



1 bin
n bins
event by event
cut
events
B only
S+B
N_B, N_{S+B}
kin. variable
$N_{S+B,i}$ $N_{B,i}$
$\sigma^2 = \sum_{bins} \sigma_i^2$
phase space
events x
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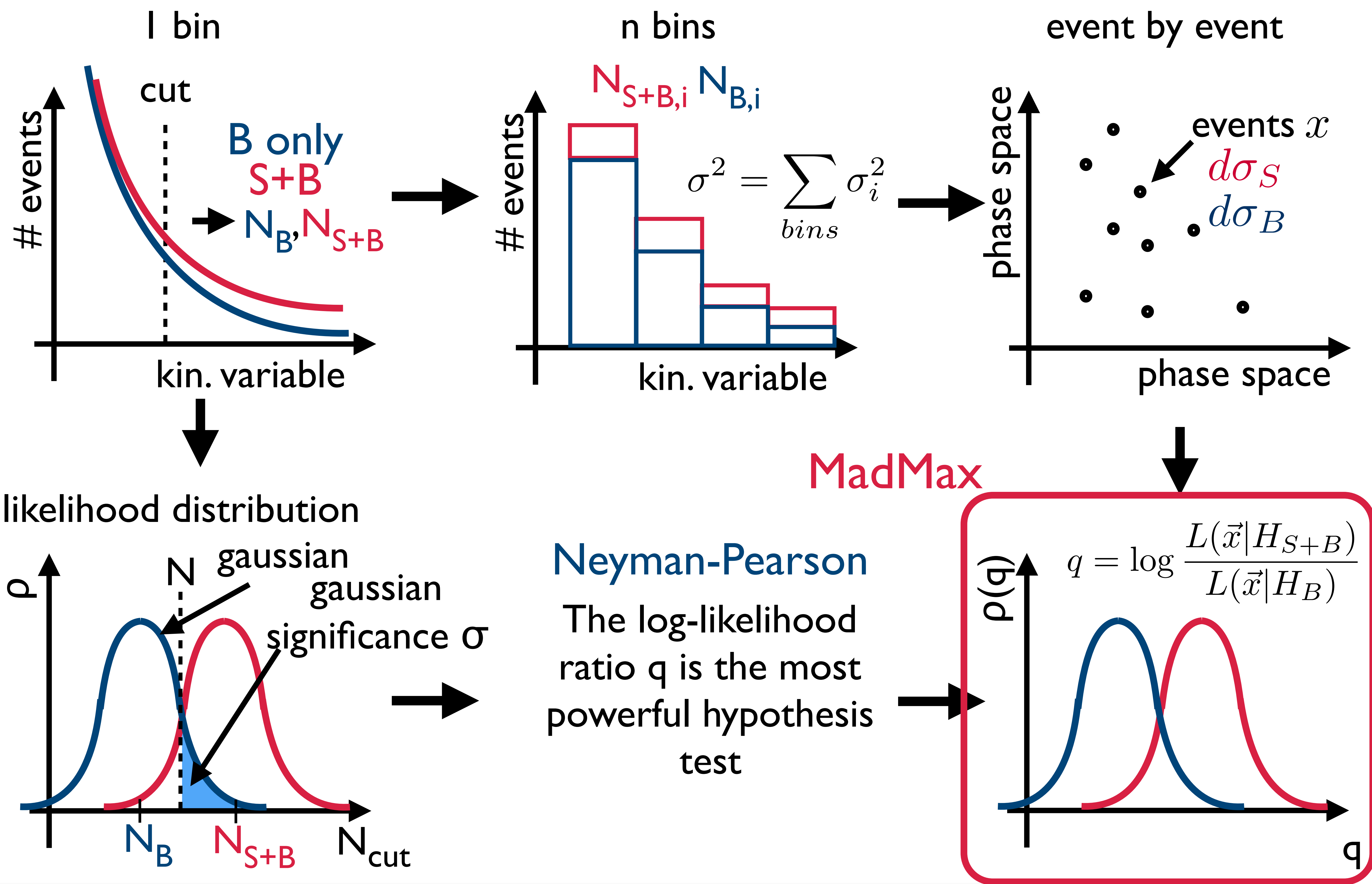
$q = \log \frac{L(\vec{x}|H_{S+B})}{L(\vec{x}|H_B)}$
ρ(q)
q

MadMax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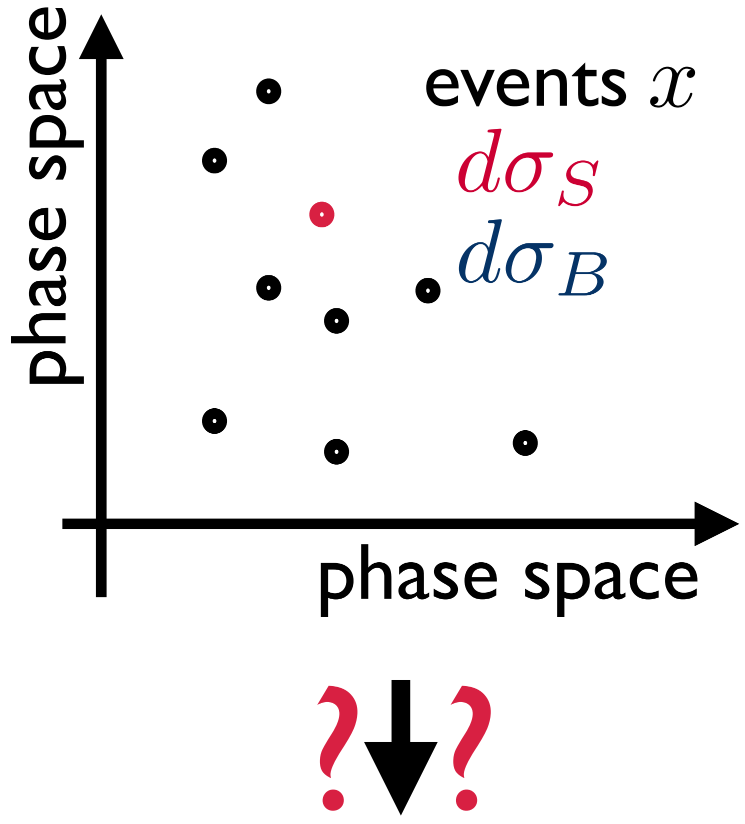
phase space
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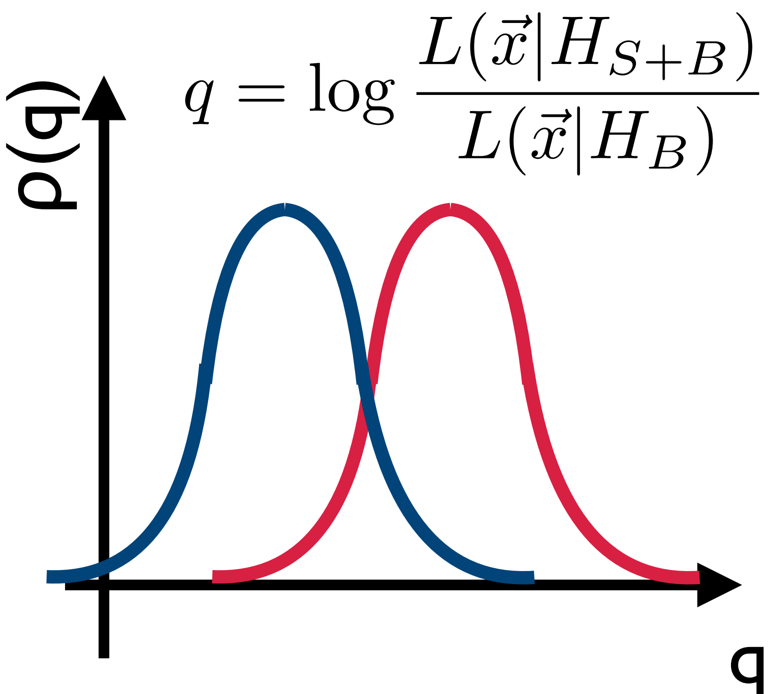
phase space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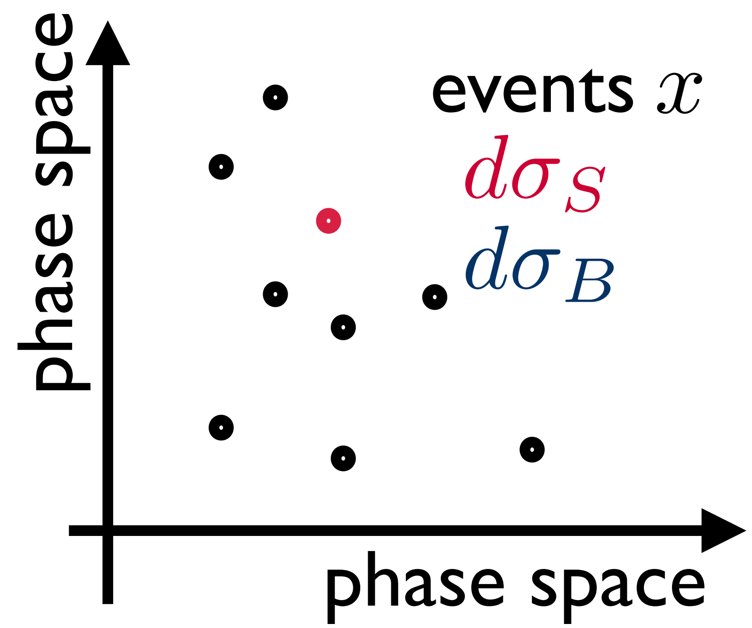
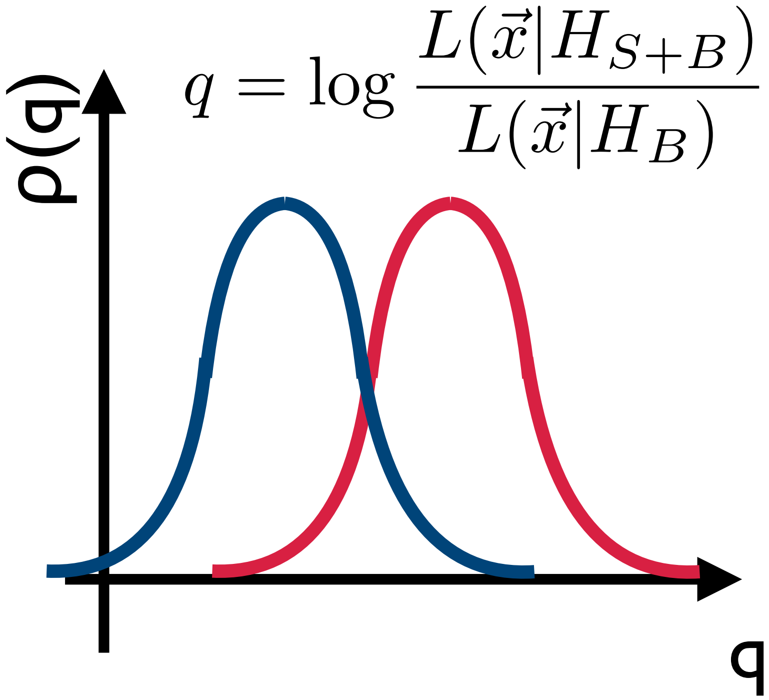
MadMax

- single event log-likelihood ratio

$$dq(x) = \log \frac{L(x|H_{S+B})}{L(x|H_B)} = -n_s + \log\left(1 + \frac{d\sigma_S(x)}{d\sigma_B(x)}\right)$$





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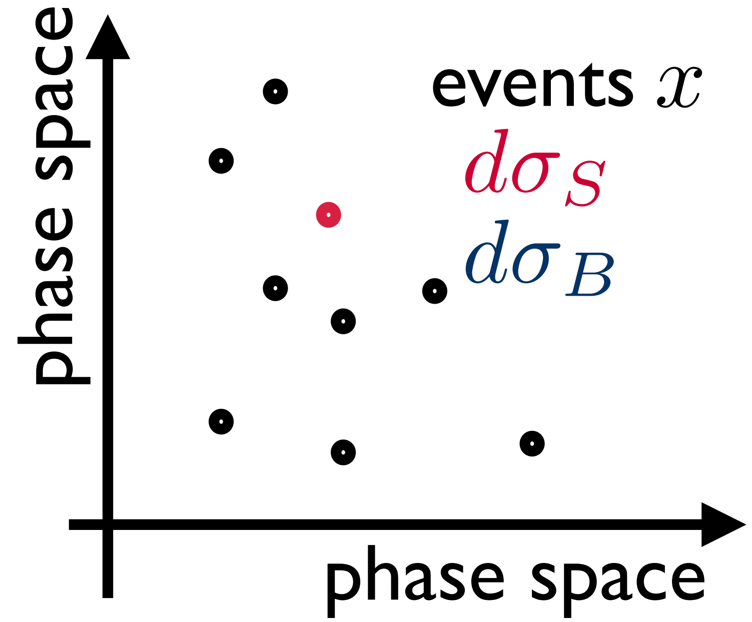
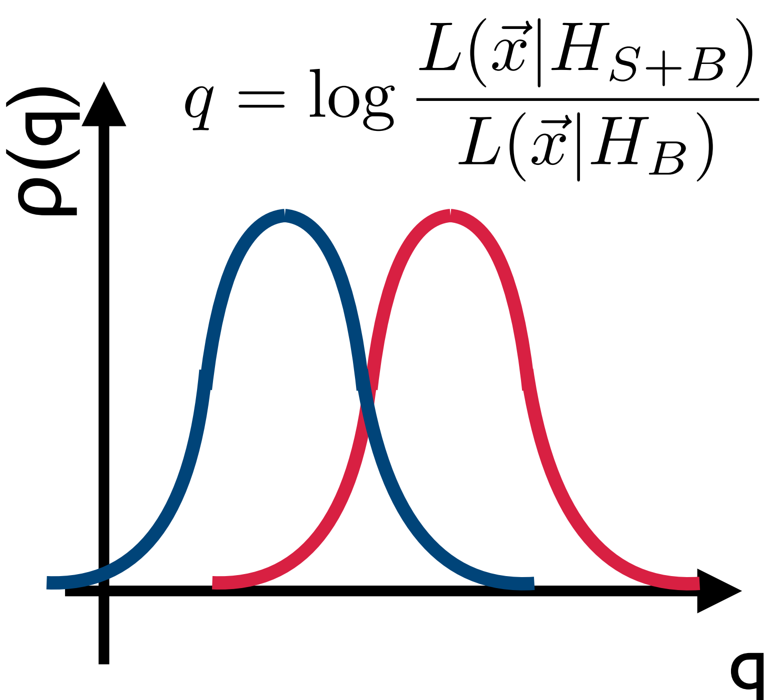
- calculate distribution via Monte Carlo

→ Modified version of MG5

see 1311.2591 or ask Peter Schichtel





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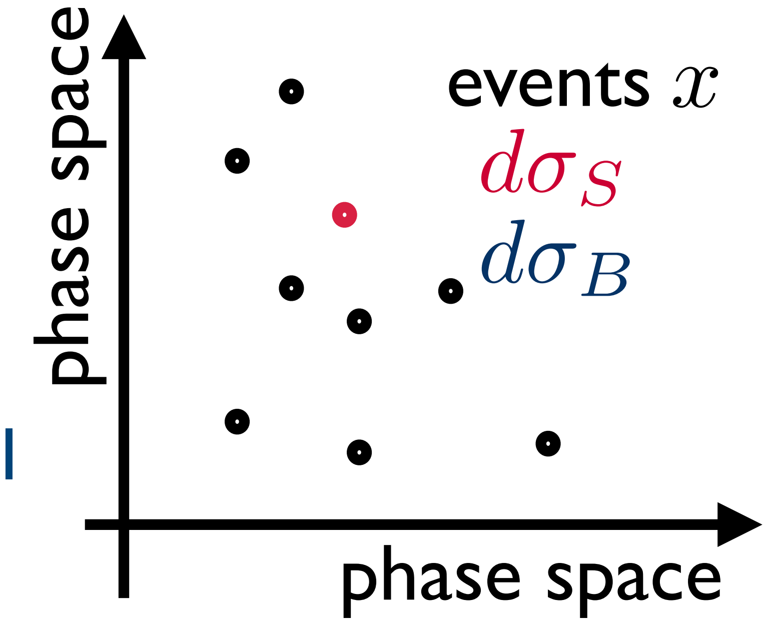

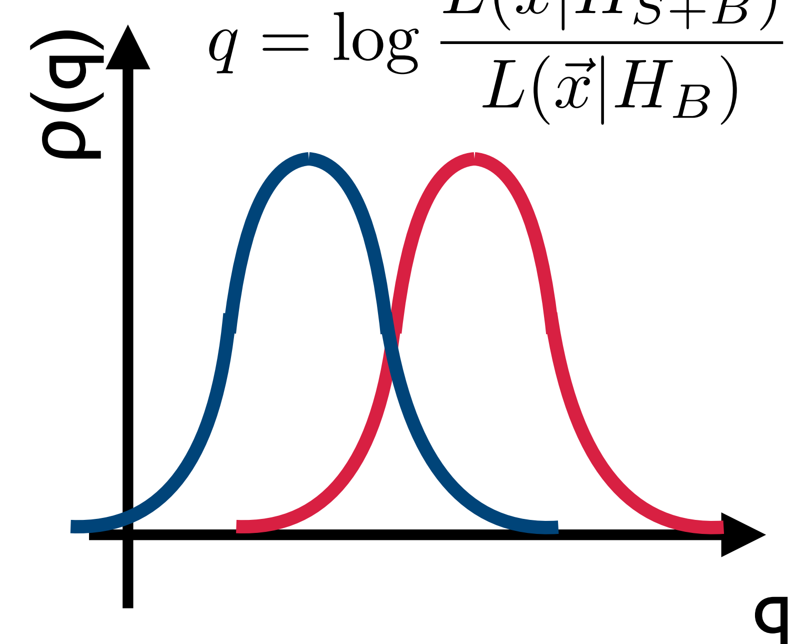

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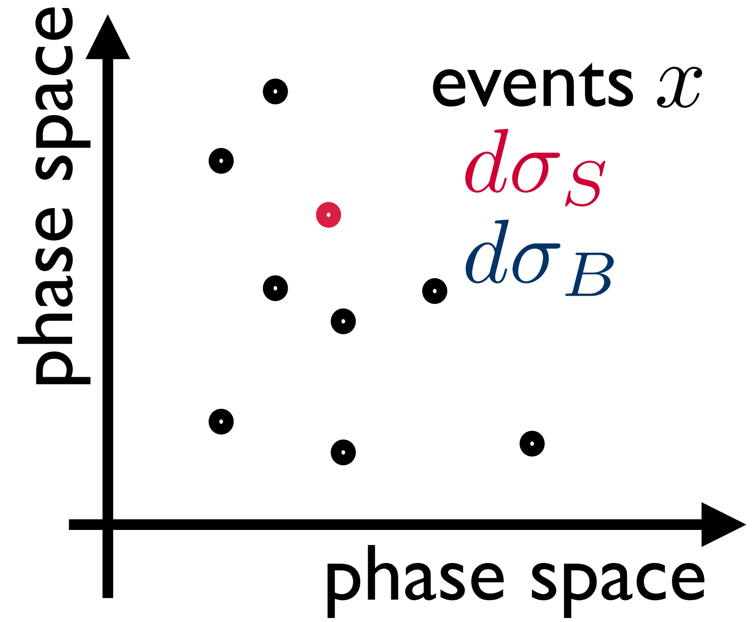
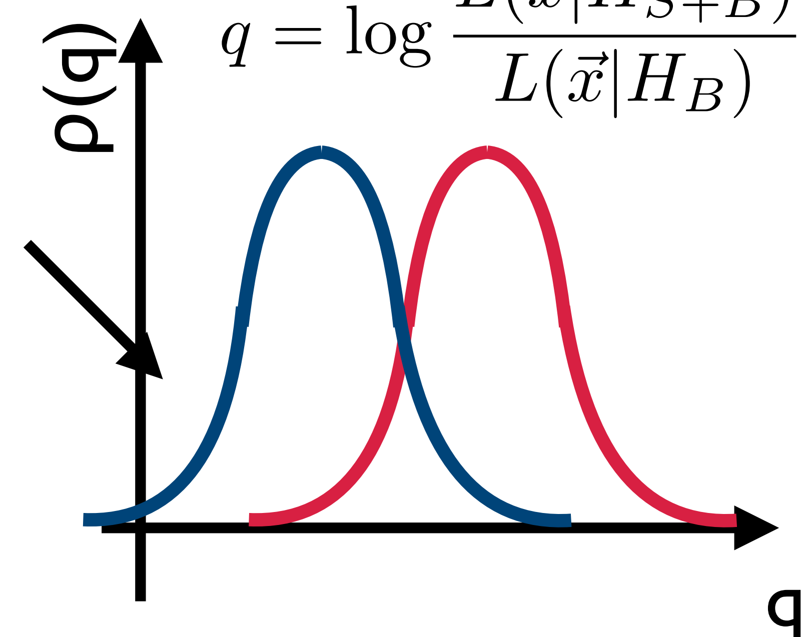
single event likelihood distribution $\frac{d\sigma_S}{dq}$ $\frac{d\sigma_B}{dq}$

↓ LEPStat4LHC

full probability distribution $\rho_B(q)$ $\rho_{S+B}(q)$





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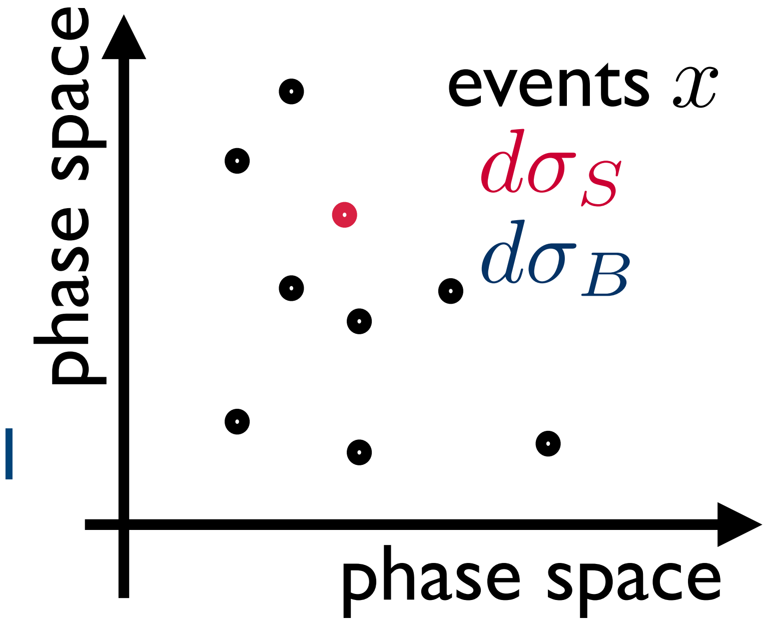


single event likelihood distribution $\frac{d\sigma_S}{dq}$ $\frac{d\sigma_B}{dq}$

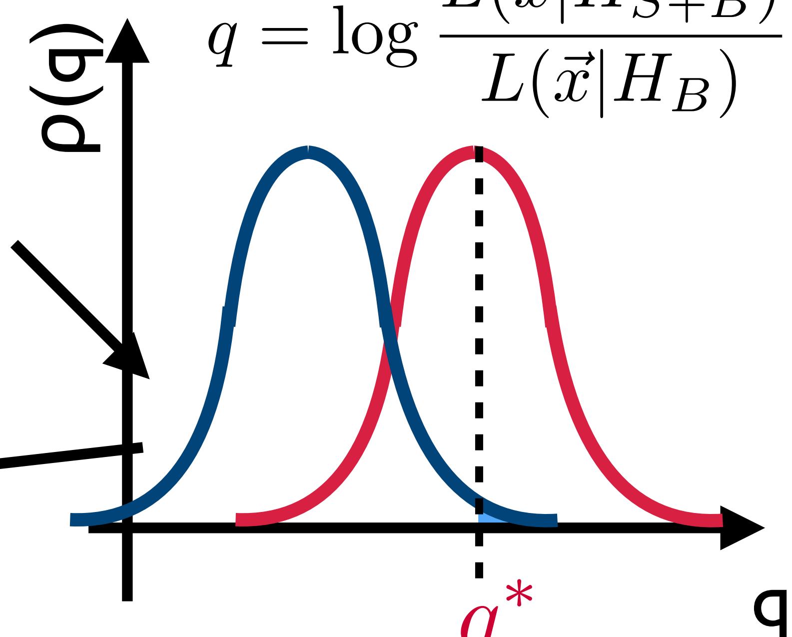
↓ LEPStat4LHC

full probability distribution $\rho_B(q)$ $\rho_{S+B}(q)$

- obtain maximum significance Z

$$\mathrm{CL}(q^*) = \int_{q^*}^{\infty} dq' \rho_B(q') = \frac{1}{2}\left(1 - \mathrm{erf}\left(\frac{Z}{\sqrt{2}}\right)\right)$$

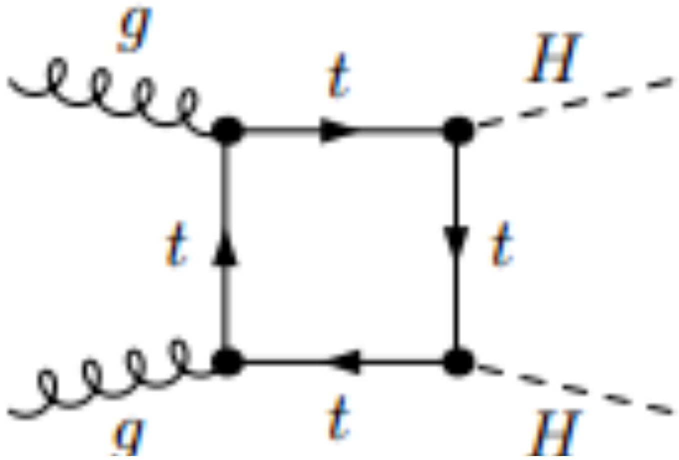
$$q = \log \frac{L(\vec{x}|H_{S+B})}{L(\vec{x}|H_B)}$$

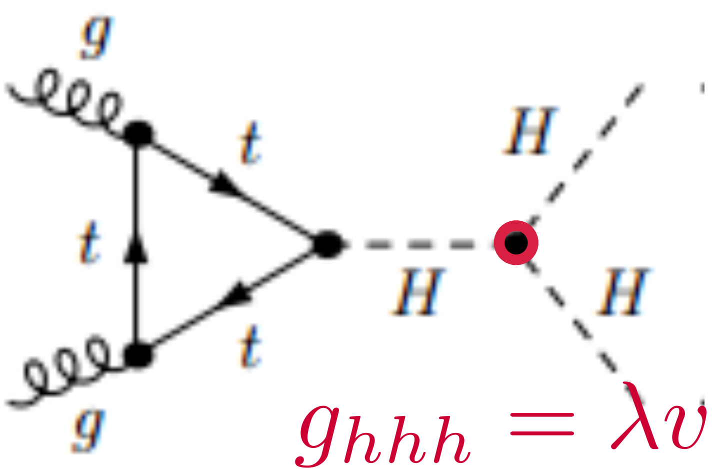


Higgs Pairs

Signal: both box and triangle diagram

→ Higgs self coupling sensitive to λ





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Signal: both box and triangle diagram

⟶ Higgs self coupling sensitive to λ

Background:

	continuum	resonant
	$bb\gamma\gamma$ $\;bbj\gamma$ $\;jj\gamma\gamma$	$ZH \to bb\gamma\gamma$

Higgs Pairs

Signal: both box and triangle diagram

→ Higgs self coupling sensitive to λ

Background: continuum resonant

see 1603.06896 (CMS)

continuum: $bb\gamma\gamma$ $bbj\gamma$ ~~$jj\gamma\gamma$~~

resonant: ~~$ZH \to bb\gamma\gamma$~~

Higgs Pairs

Signal: both box and triangle diagram

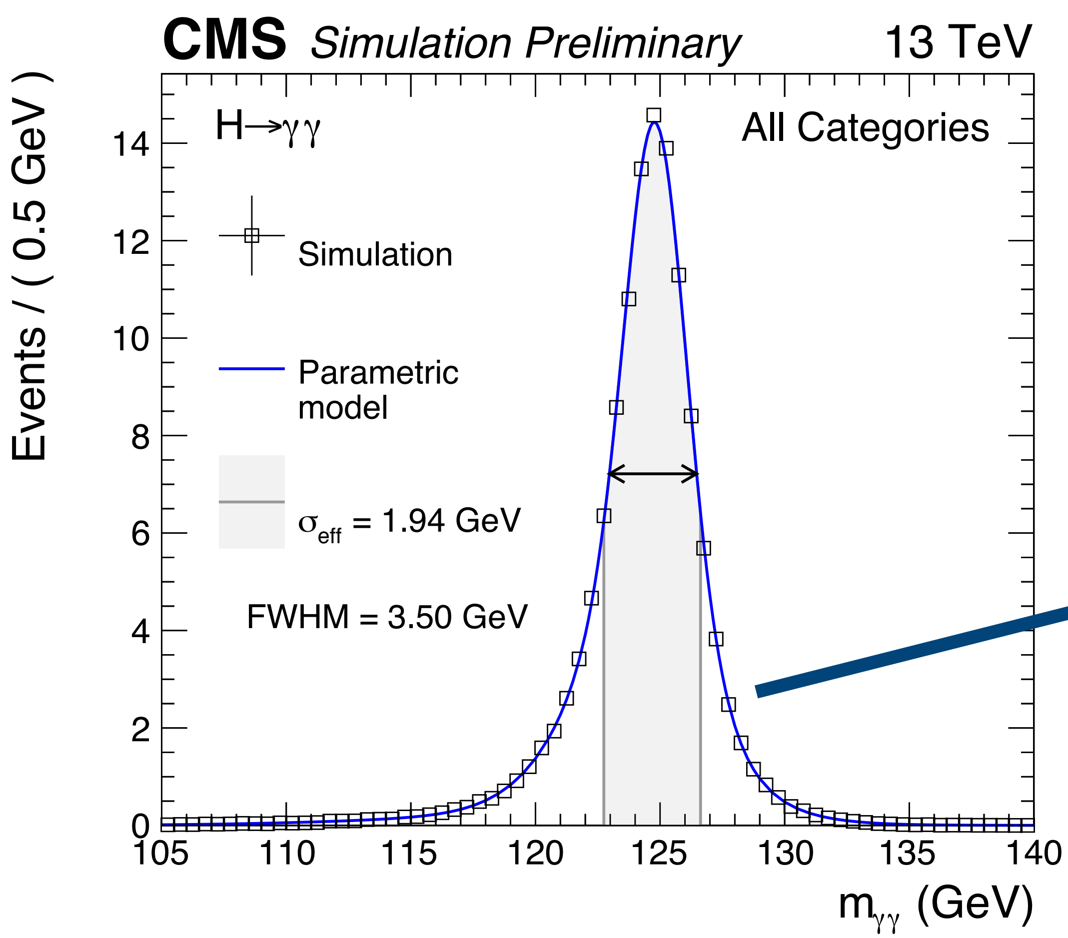
→ Higgs self coupling sensitive to λ

Background: continuum: $bb\gamma\gamma$ $bbj\gamma$ ~~$jj\gamma\gamma$~~ resonant: ~~$ZH \to bb\gamma\gamma$~~

see 1603.06896 (CMS)

Smearing: MadMax → parton level study

→ modify propagator



$$\frac{1}{p^2 - m^2 - i\Gamma} \to e^{-\frac{\left(\sqrt{p^2} - m\right)^2}{4\sigma^2}}$$

gaussian width

arXiv:1411.4362 (photons)

CMS-PAS-HIG-15-005 (bottom)

Higgs Pairs

Signal: both box and triangle diagram

→ Higgs self coupling sensitive to λ

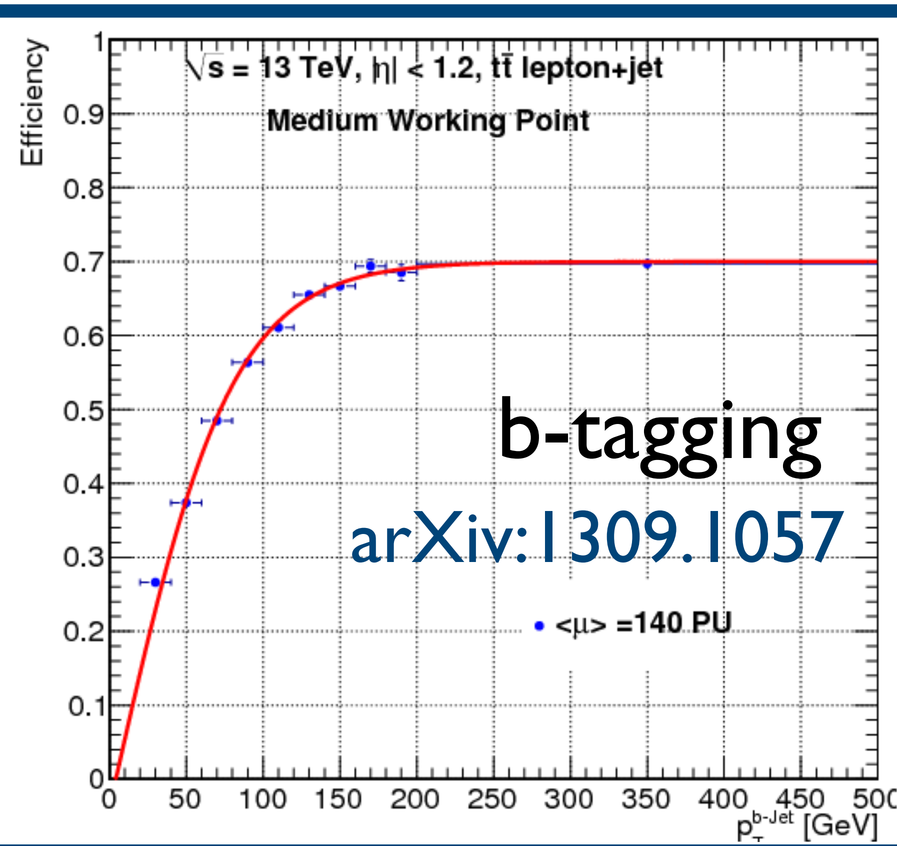
Background: continuum: $bb\gamma\gamma$ $bbj\gamma$ ~~$jj\gamma\gamma$~~ resonant: ~~$ZH \to bb\gamma\gamma$~~

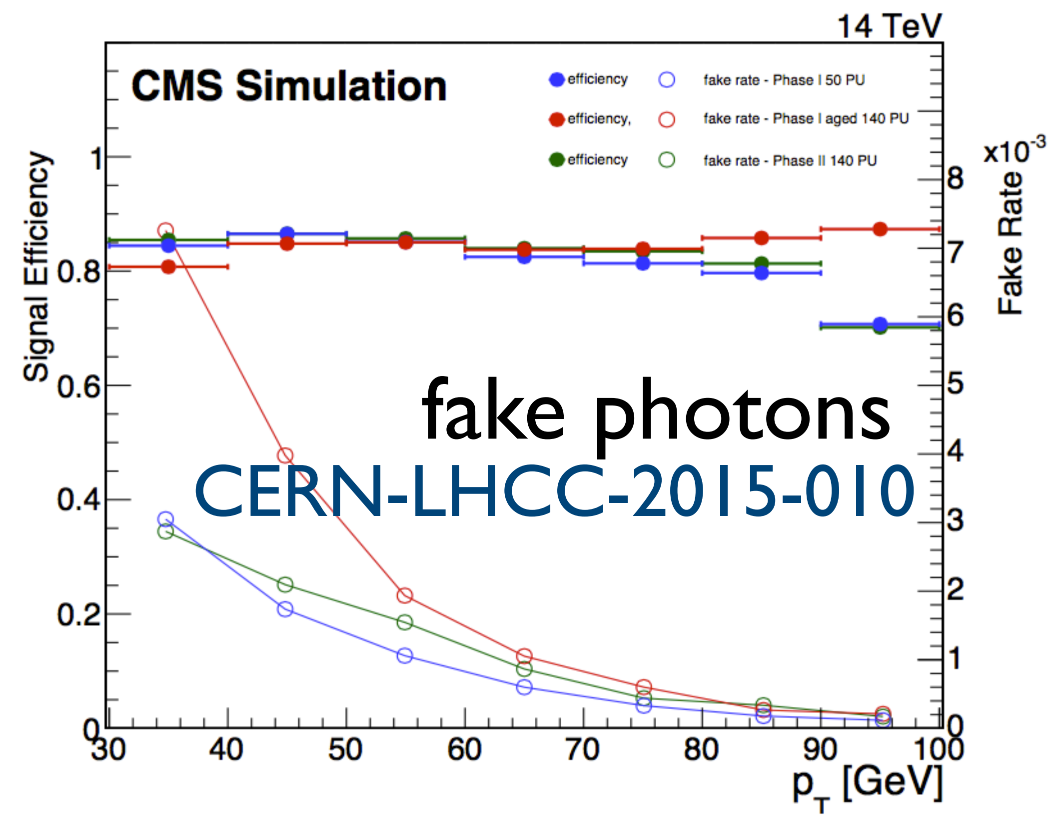
see 1603.06896 (CMS)

Smearing: MadMax → parton level study

→ modify propagator

Efficiencies:





Higgs Pairs - Results

High Luminosity LHC: $\mathcal{L} = 3000 \text{ fb}^{-1}$

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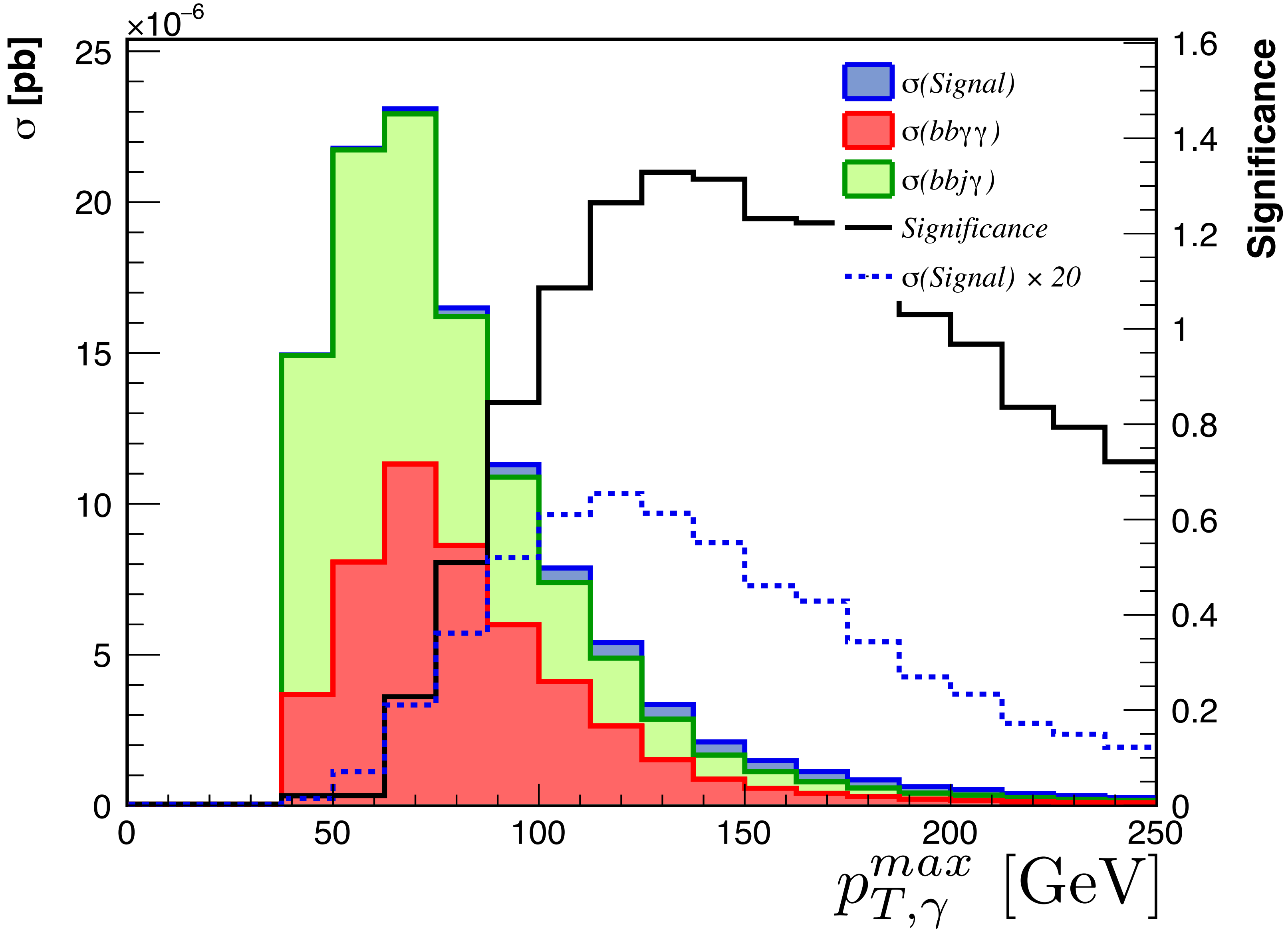
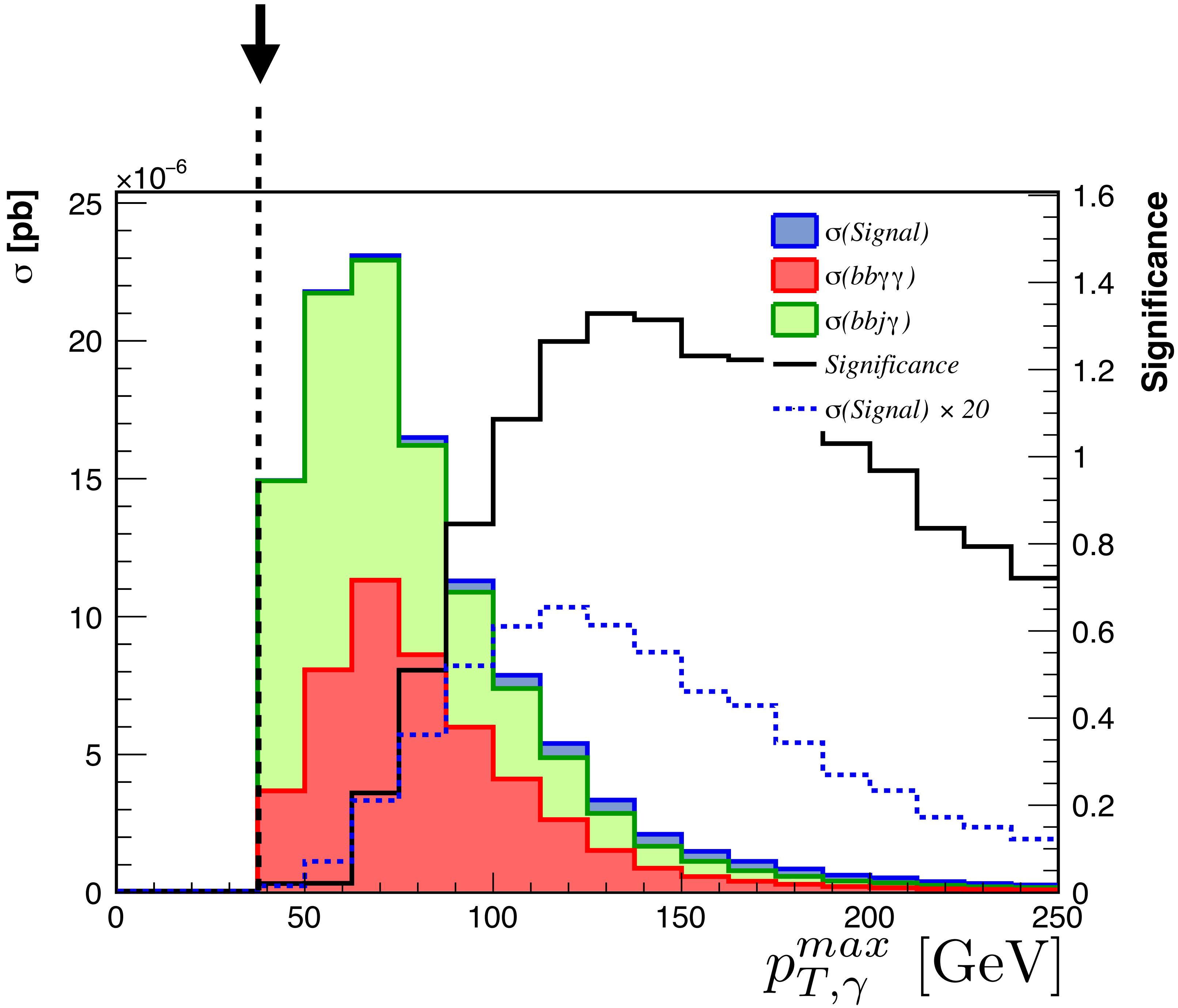


Higgs Pairs - Results

High Luminosity LHC: $\mathcal{L} = 3000\ \text{fb}^{-1}$

CMS diphoton trigger

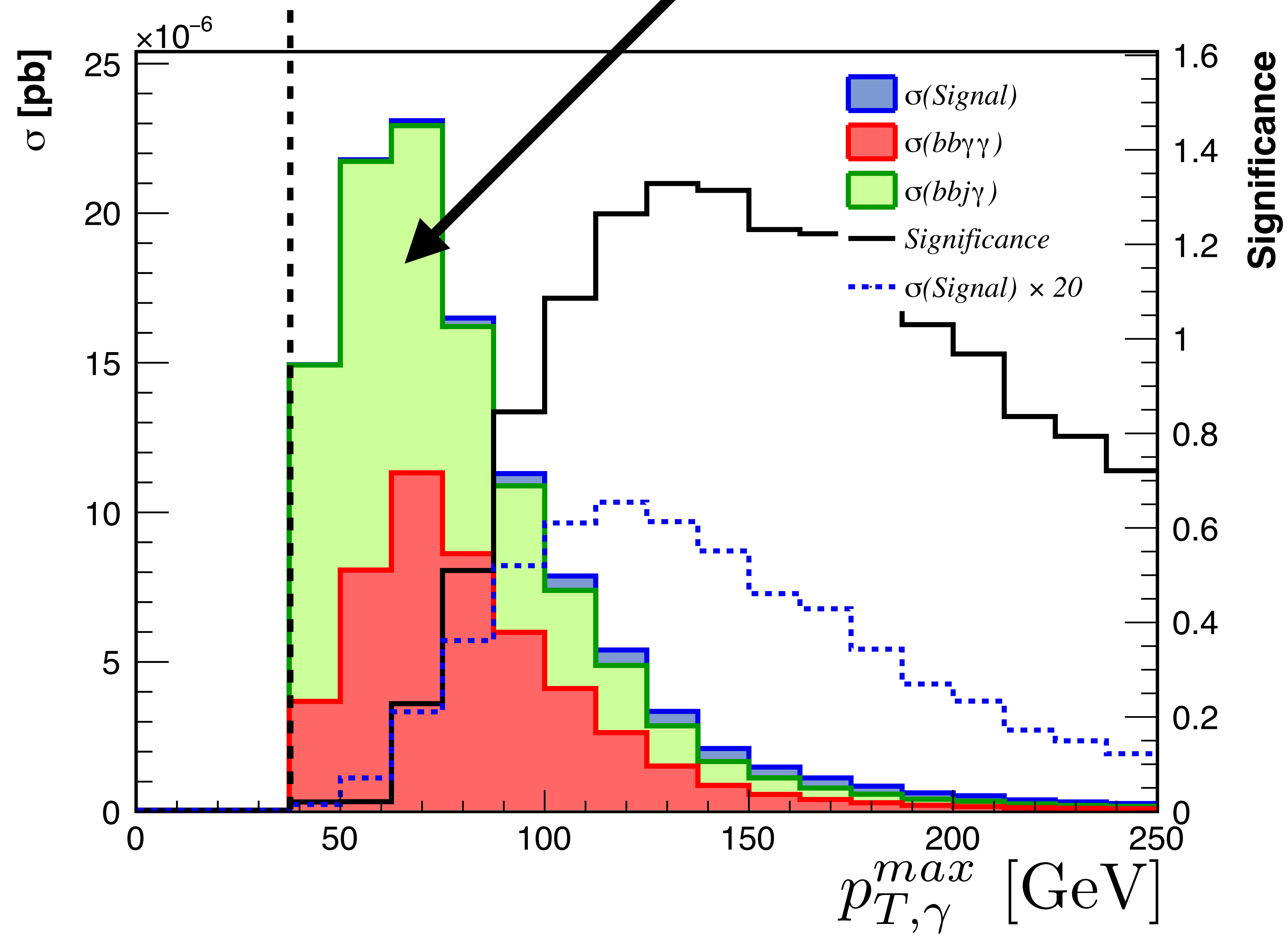


Higgs Pairs - Results

High Luminosity LHC: $\mathcal{L} = 3000\ \text{fb}^{-1}$

CMS diphoton trigger

differential cross section including efficiencies



Higgs Pairs - Results

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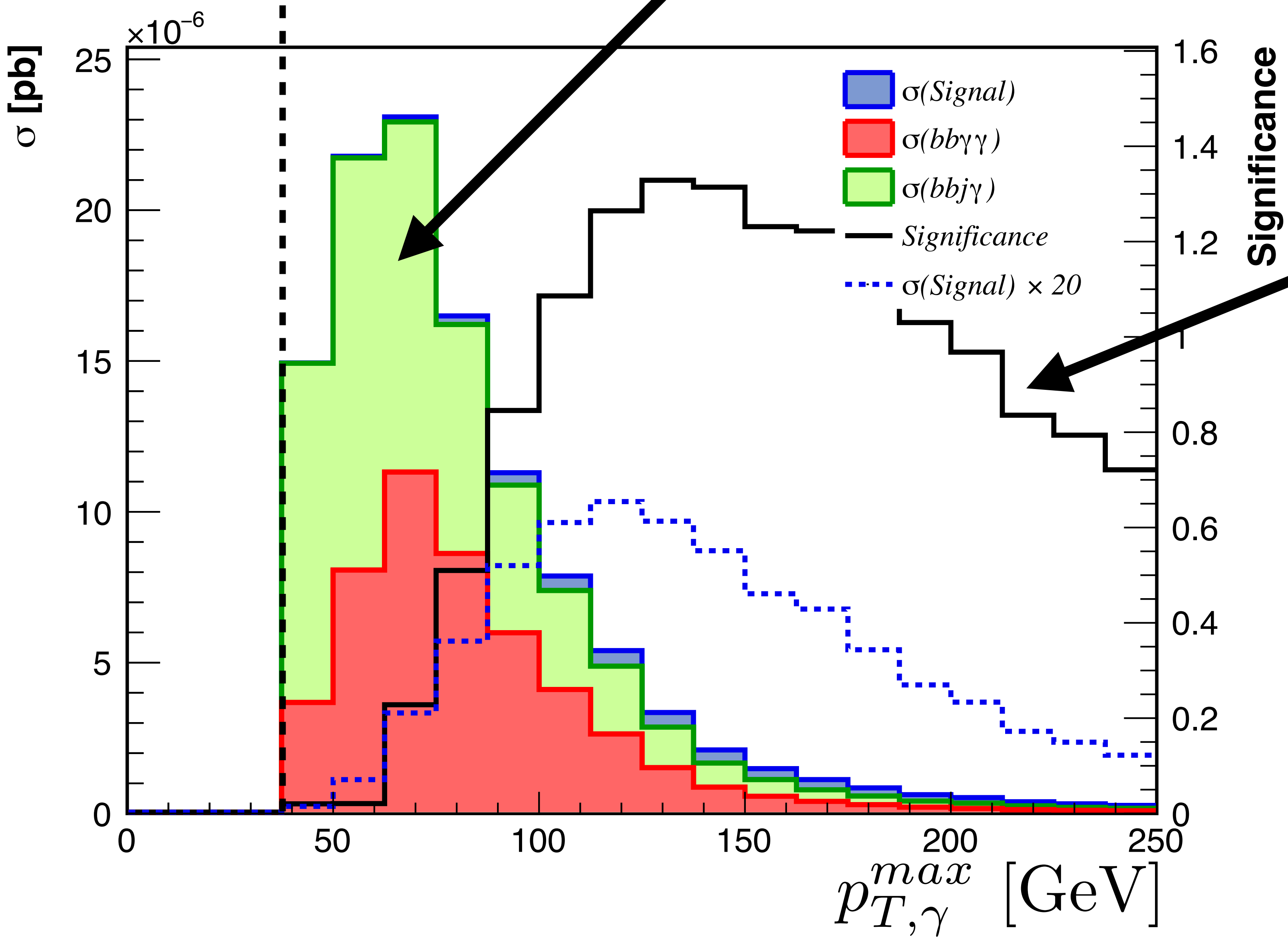
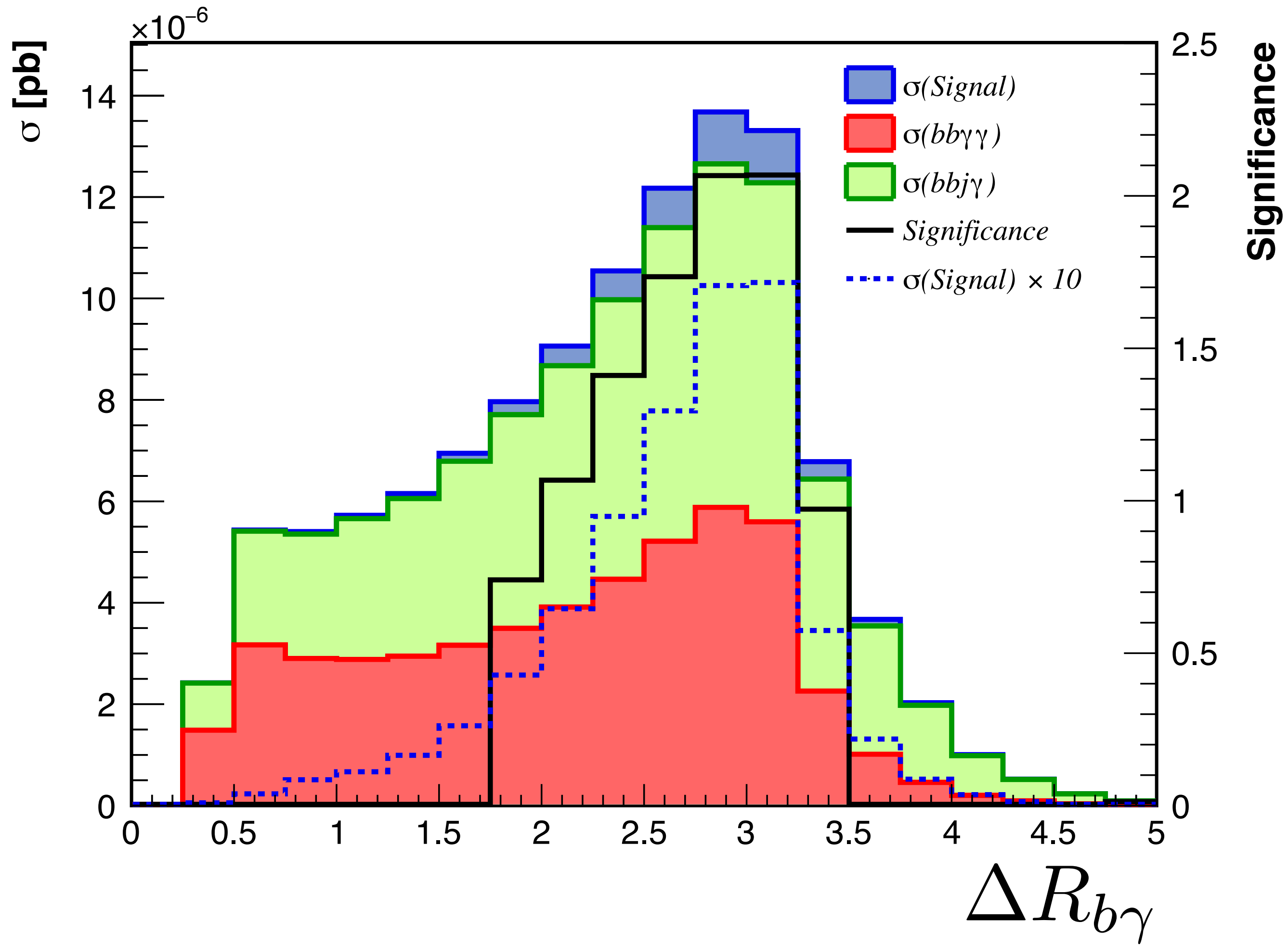


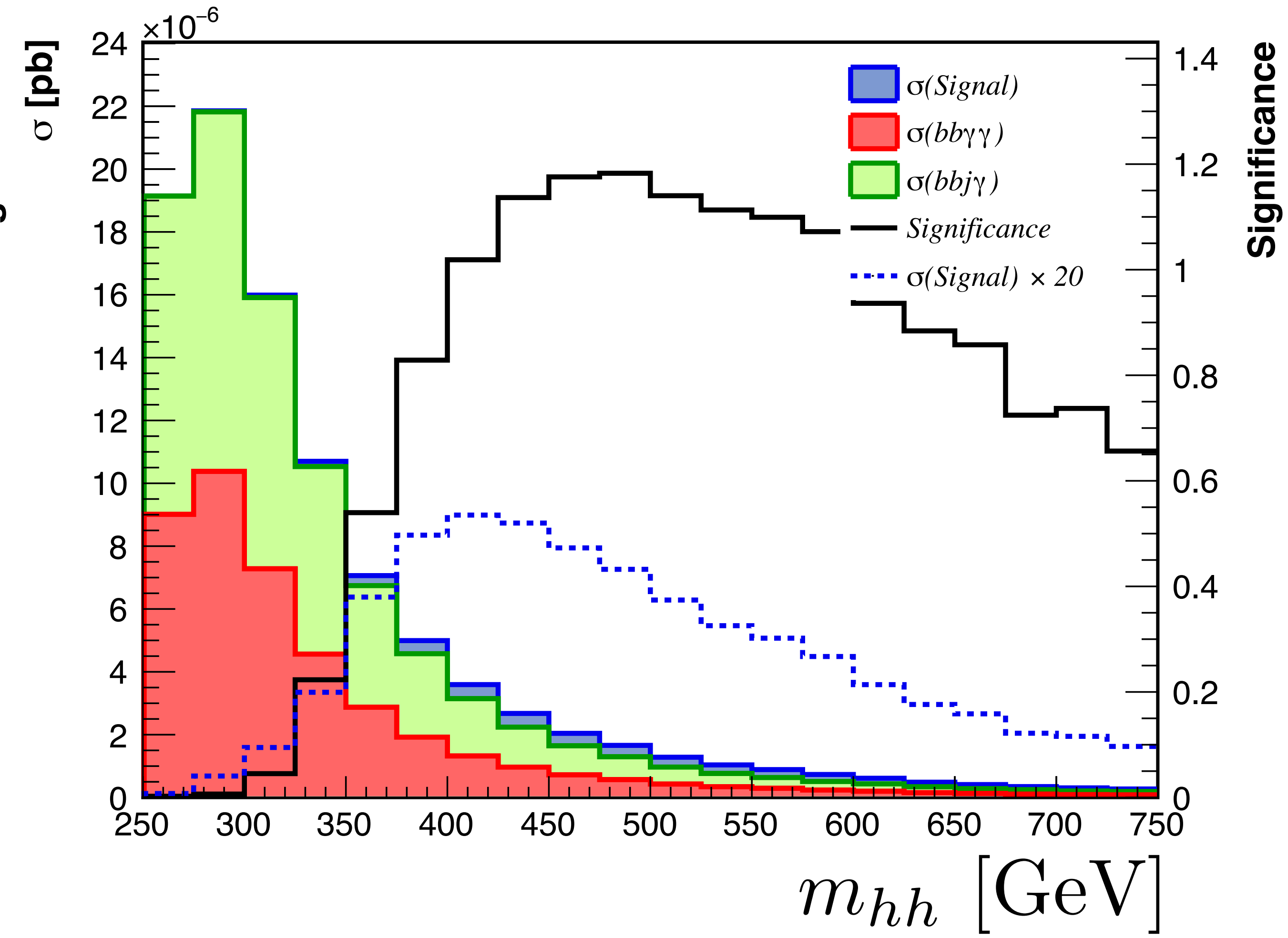
differential significance

- → find regions with high significance
- → same for all other kinematic variables

Higgs Pairs - Results

High Luminosity LHC: $\mathcal{L} = 3000 \text{ fb}^{-1}$

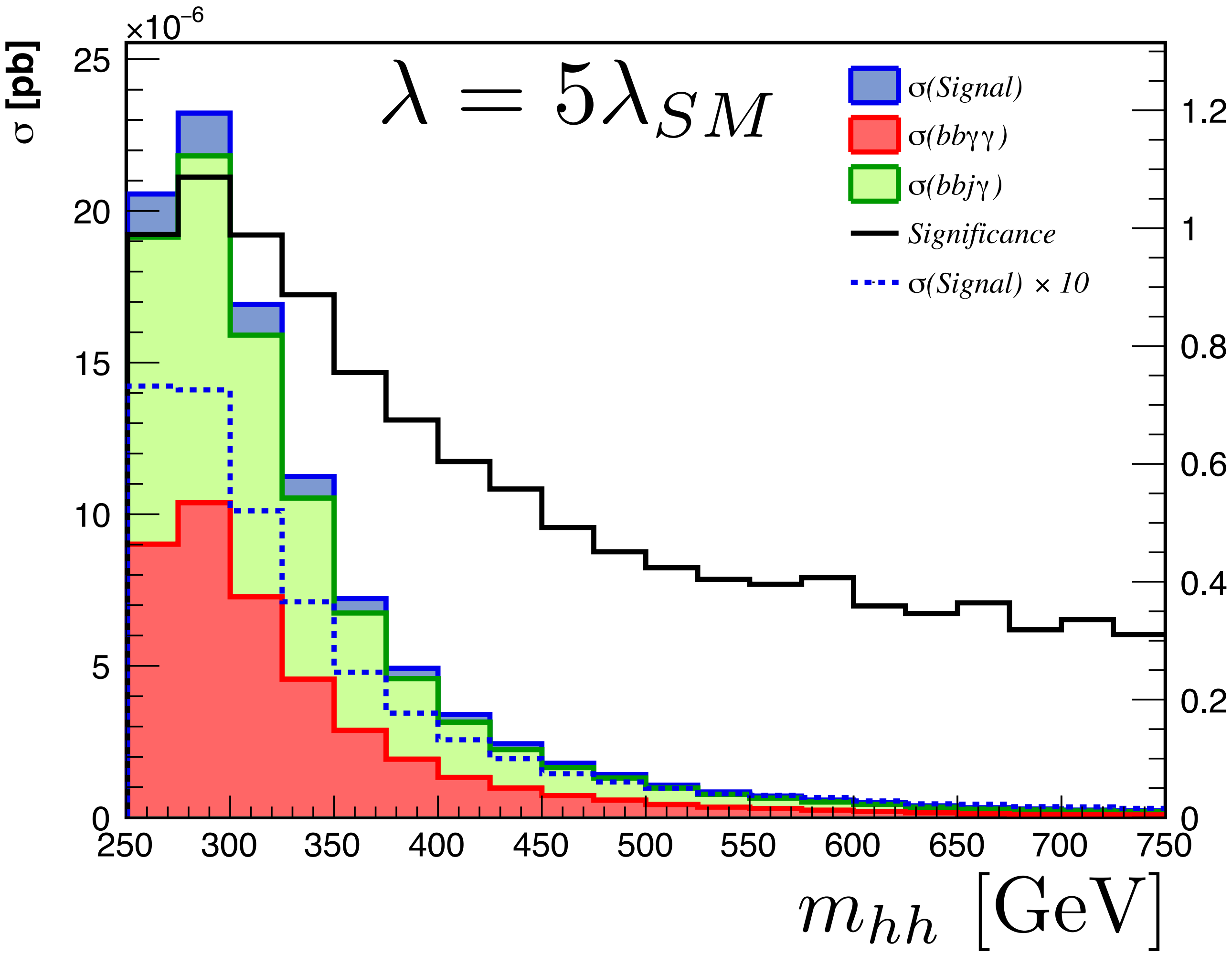


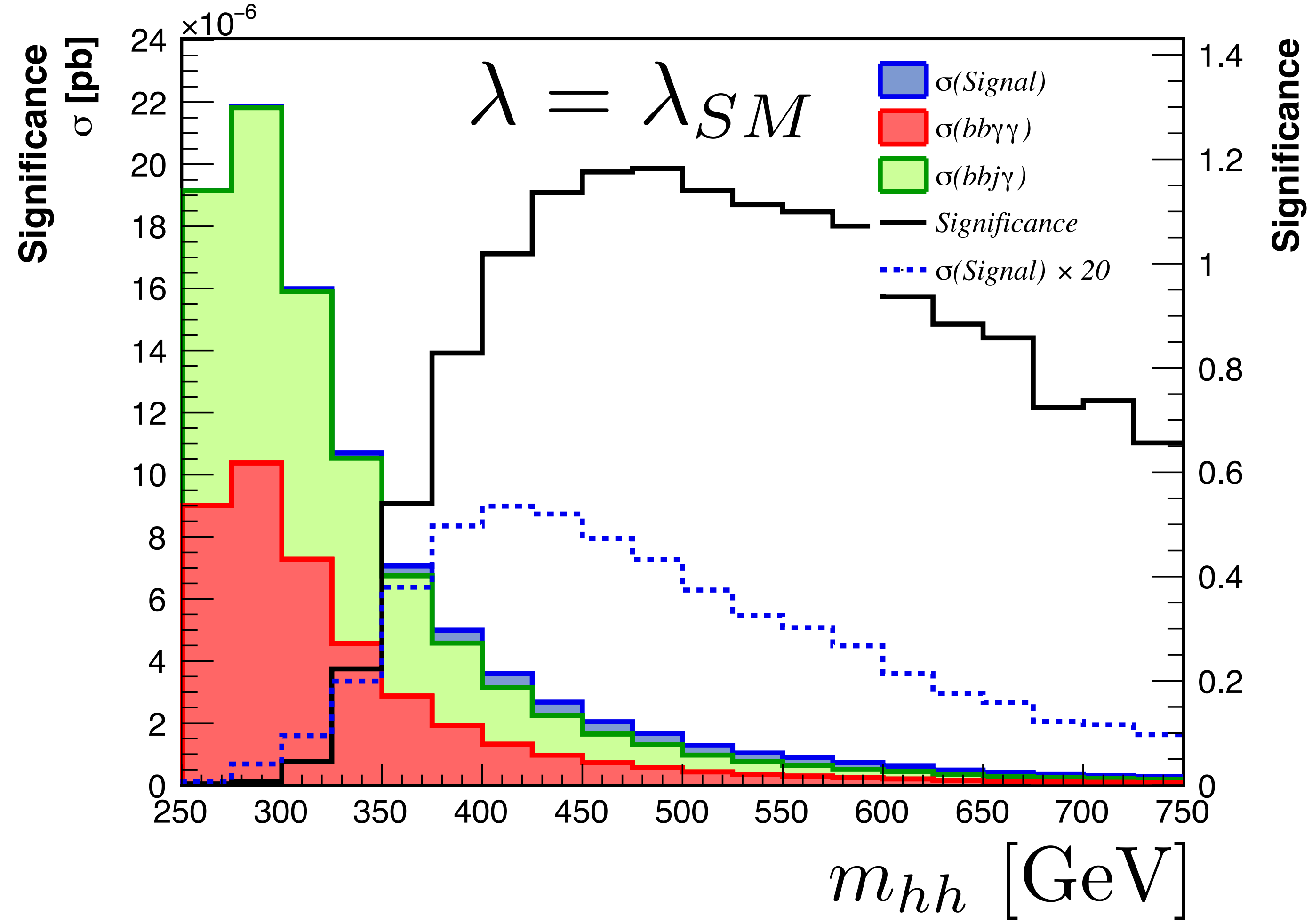


Total Significance $Z = 4.76$

Higgs Pairs - Results

Measuring λ:



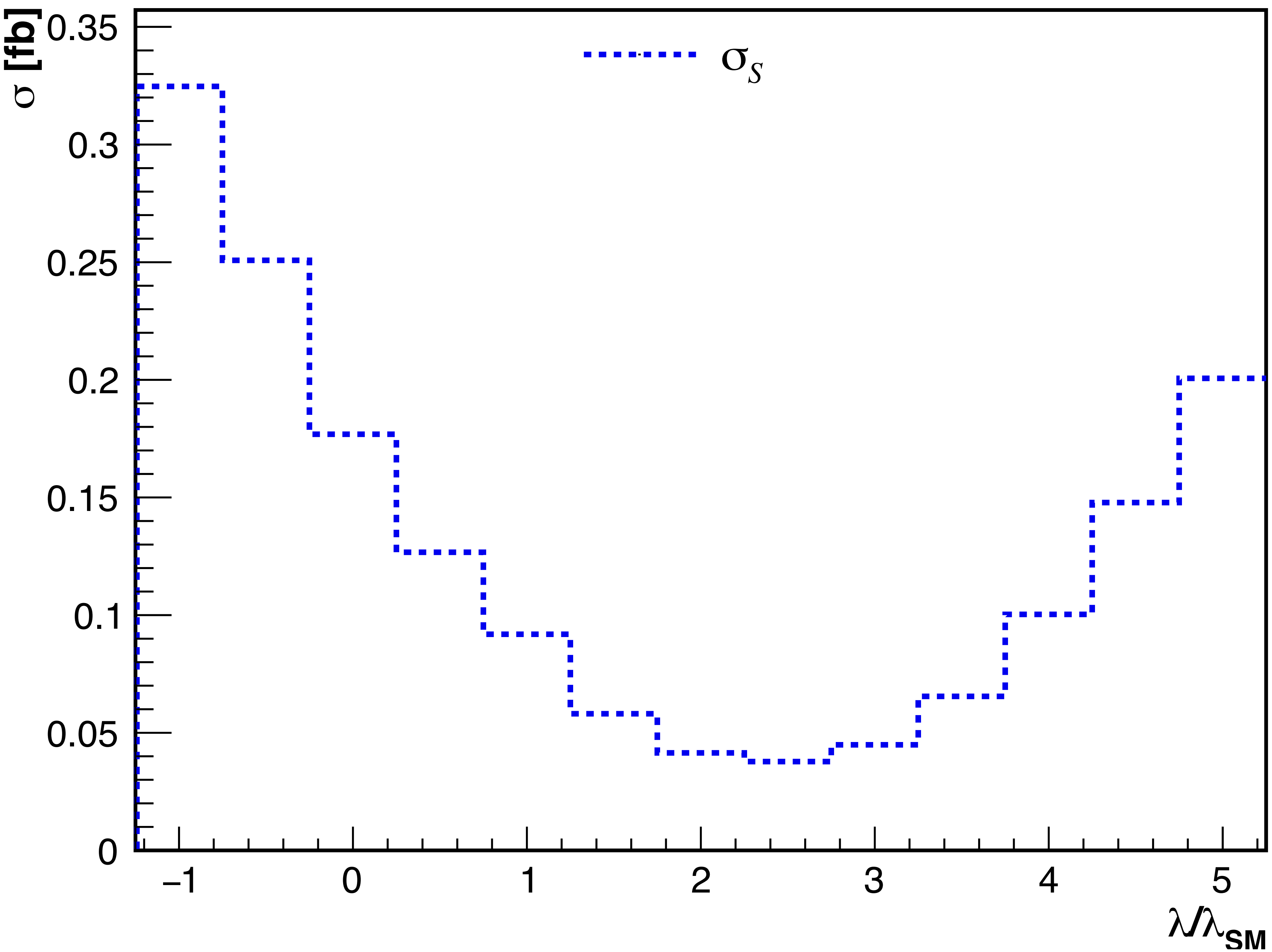


$Z = 3.21$ $\qquad$ $Z = 4.76$

→ different region of parameter space carry significance

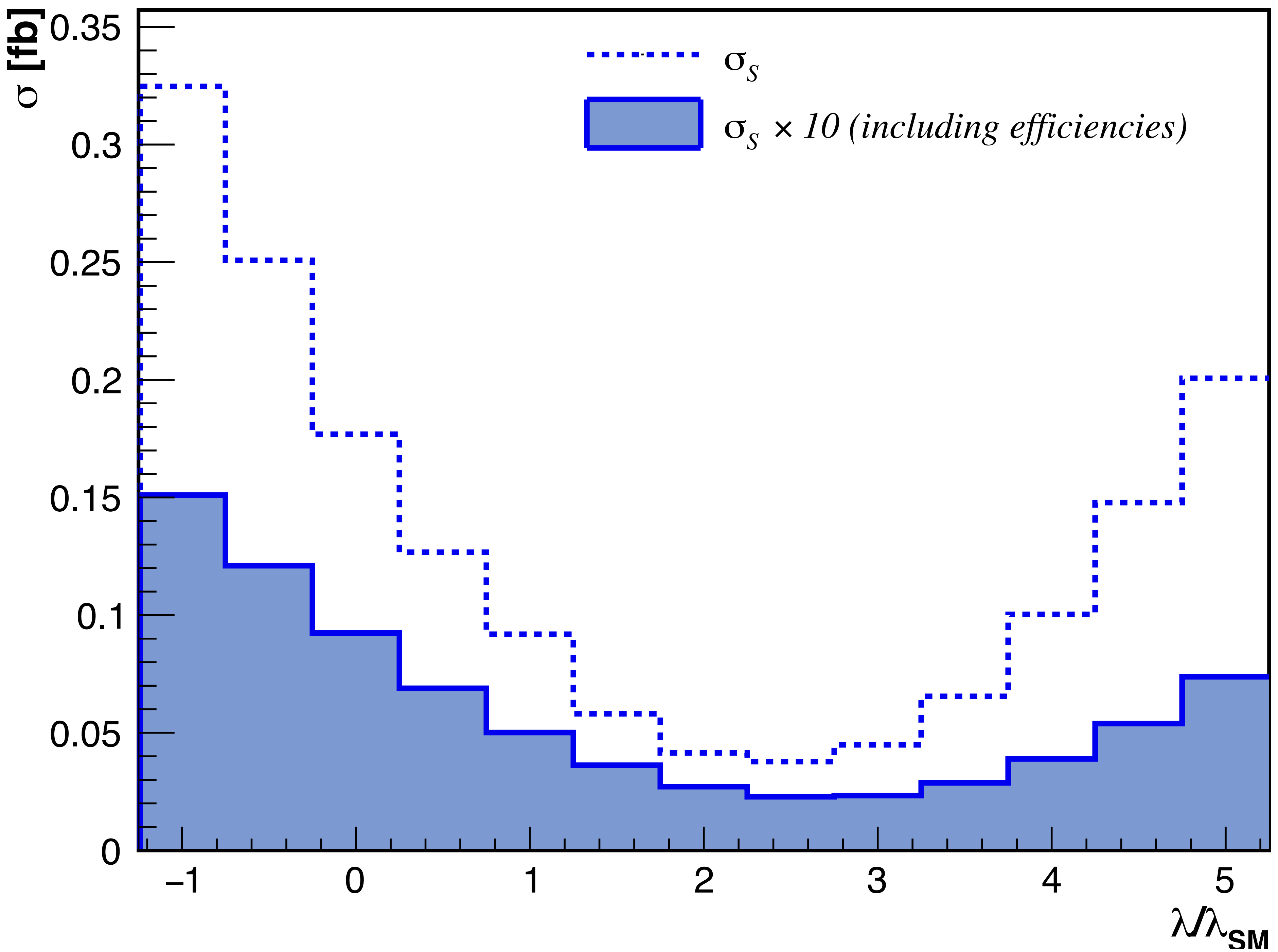
Higgs Pairs - Results

Measuring λ:

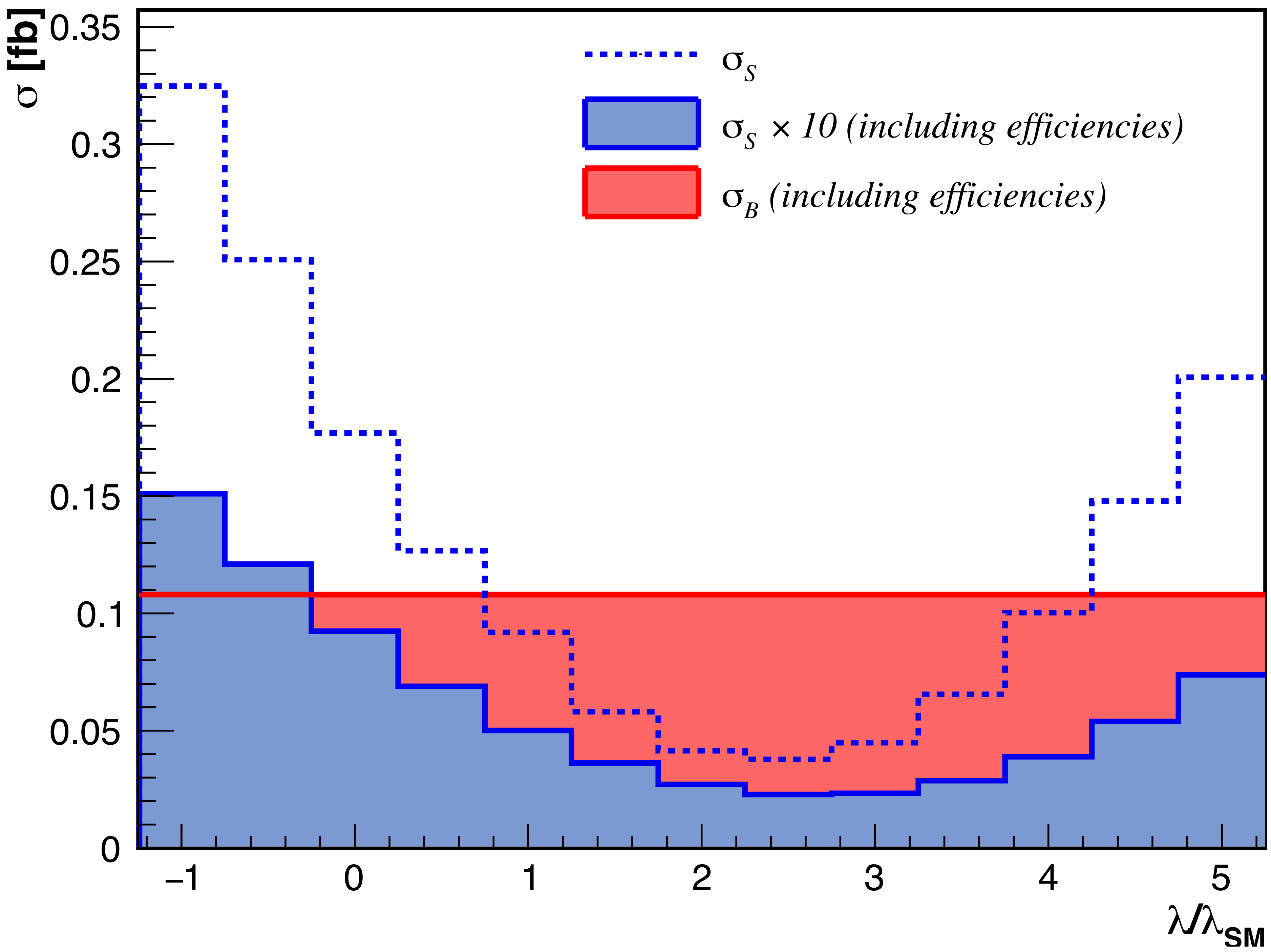


Higgs Pairs - Results

Measuring λ:

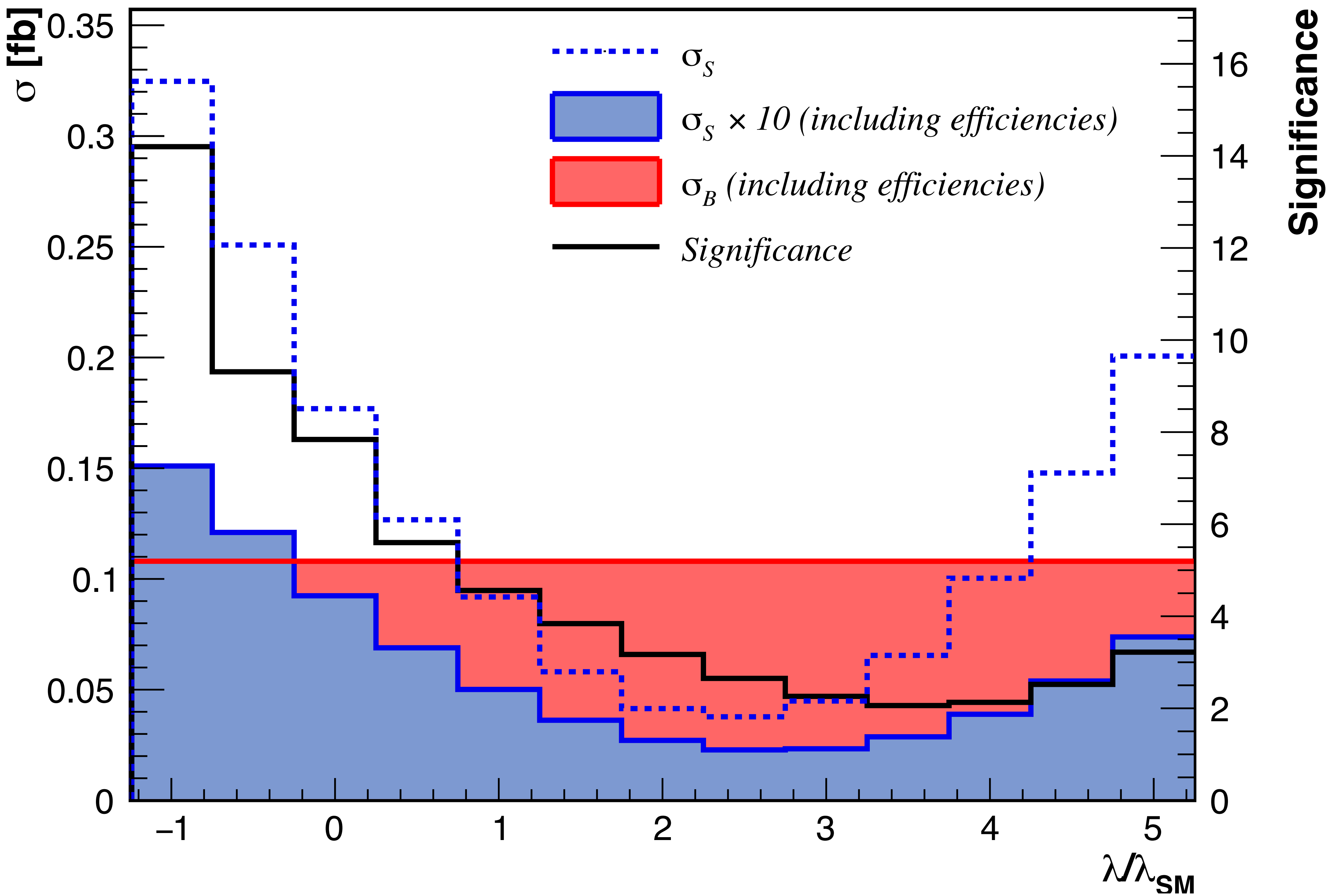


Measuring λ:



Higgs Pairs - Results

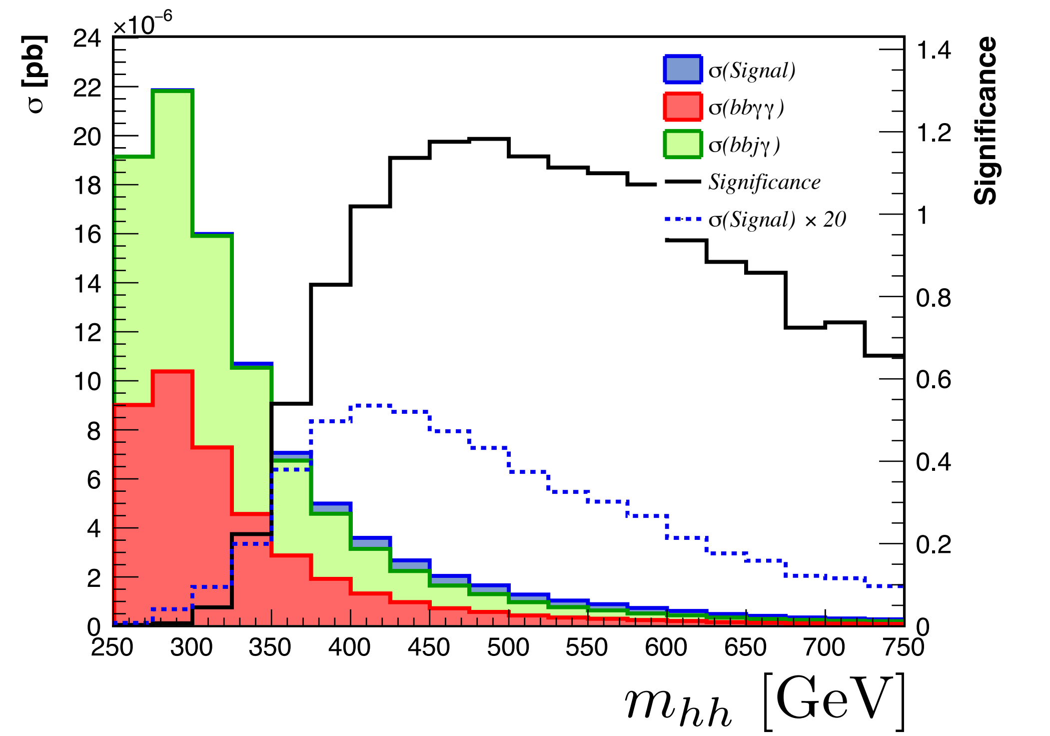
Measuring λ:



Conclusion and Outlook

MadMax

- maximum significance
- fully differential significance
  - ⟶ track regions of significance
- automated and fast



Higgs Pair Analysis

Outlook

- test signal hypotheses: S_2+B vs. S_1+B
- explicit particle smearing