

# Search for Extra Scalars Produced in Association with a Z boson at the ILC

Yan Wang (DESY, IHEP)

January 30, 2019



## Reminder: Introduction

### Theory:

- ▶ Many BSMs predict one or more extra scalars.
  - ▶ 2HDM, NMSSM, Randall Sundrum model ...

- \* many models.
- \* many parameters.
- \* very weak couplings

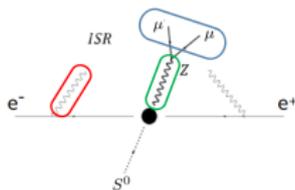
### Current Experiments:

- ▶ LHC/LEP(\*) constraints rely on the model details:
  - ▶ CP, mass hierarchy, couplings, etc.
- ▶ precise constraints are necessary.

### My Analysis at the ILC :

recoil mass  $\rightarrow$  model independence exclusion limits for extra scalars

Higgsstrahlung process  $e^+e^- \rightarrow Z + H^{125}/S^0$

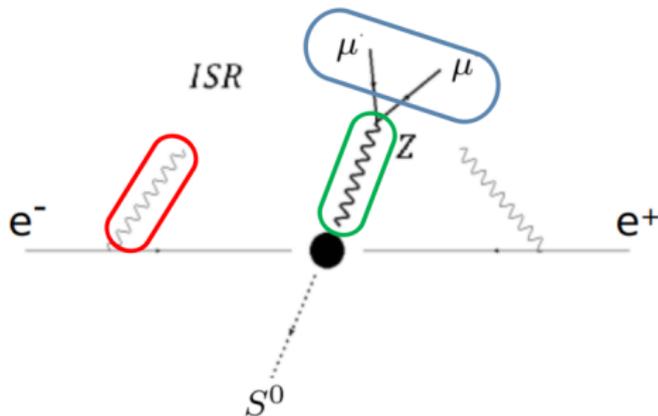


- ▶  $M_{rec}^2 = (\sqrt{s} - E_{\mu\mu})^2 - |\vec{p}_{\mu\mu}|^2$
- ▶  $M_{\mu\mu} \sim M_Z, M_{rec} \sim M_{H^{125}/S^0}$

## Reminder: Analysis Strategy

Principle: using the smallest amount of information of  $S^0$  decay.

- ▶ a pair of isolated muon, with opposite charges.
- ▶ ISR photons may undermine  $S^0$  recoil distribution.



# Reminder: Analysis Strategy

01

a muon pair

$$\chi^2(M_{\mu^+\mu^-}, M_{\text{rec}}) = \frac{(M_{\mu^+\mu^-} - M_Z)^2}{\sigma_{M_{\mu^+\mu^-}}^2} + \frac{(M_{\text{rec}} - M_h)^2}{\sigma_{M_{\text{rec}}}^2}.$$

02

$M_Z \in [73, 120]$  GeV

03

$P_T^Z \in [10, 128 - 4 \times \frac{M_h}{10}]$  GeV

04

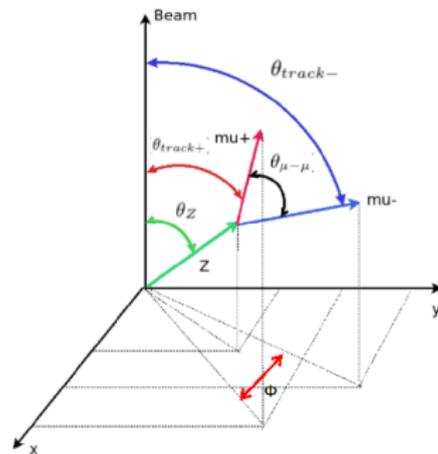
$\cos\theta_{\text{mis}} < 0.98$  when  $E_{\text{mis}} > 10$  GeV

05

Multi-Variate Analysis : angles

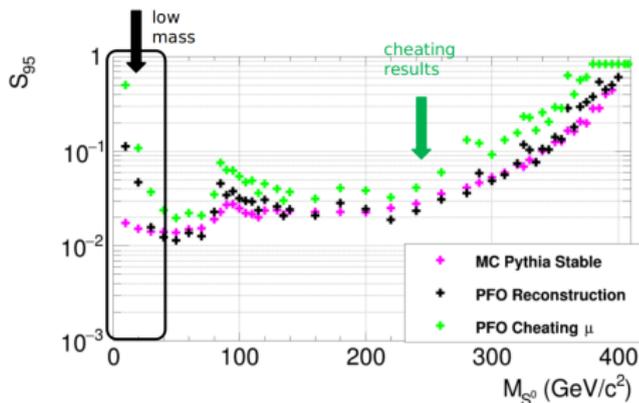
06

photon veto : veto ISR photon



## Reminder: problems in the last ILD meeting

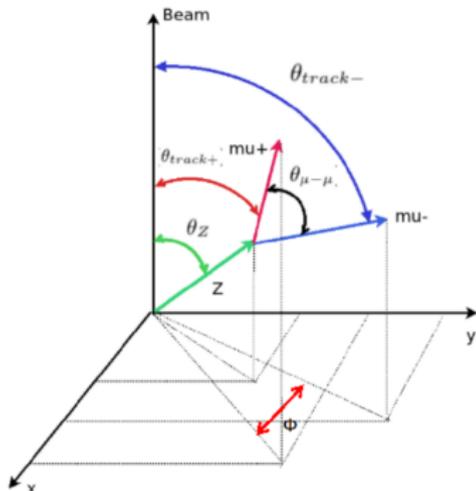
- ▶ add new observables in the effective center-of-mass reference frame
- ▶ bad cheating muon/ISR results: New MC Lepton/Photon Processors
- ▶ For PFO events without overlay, the exclusion limits too large in the small mass.
- ▶ PFO photon energy is not reconstructed well in some regions
- ▶ also many other changes, but not mention them in this talk.



note :  $S_{95}$  is the  $2\sigma$  exclusion limits of  $\frac{\sigma_{S^0 Z}}{\sigma_{H_{SM} Z}(m_{H_{SM}} = m_{S^0})}$

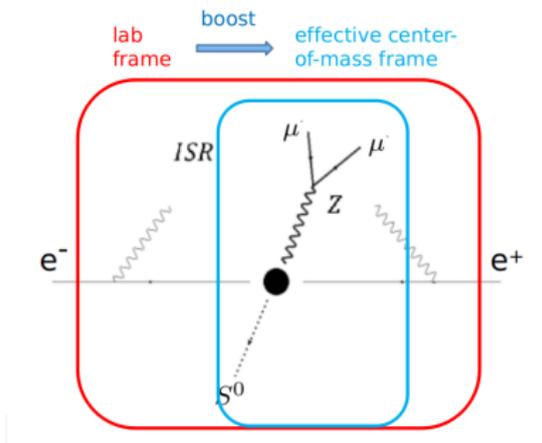
# Update 1 : new observables

old angle observables:



these observables are MVA inputs.

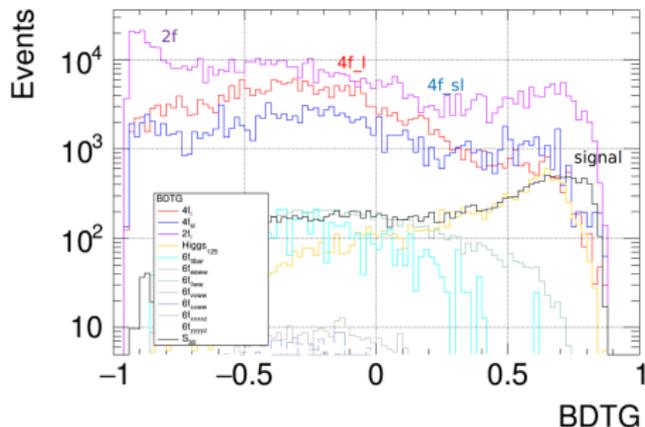
new observables: boost leptons in the effective center-of-mass reference frame



# BDTG : put all observables in the same BDTG

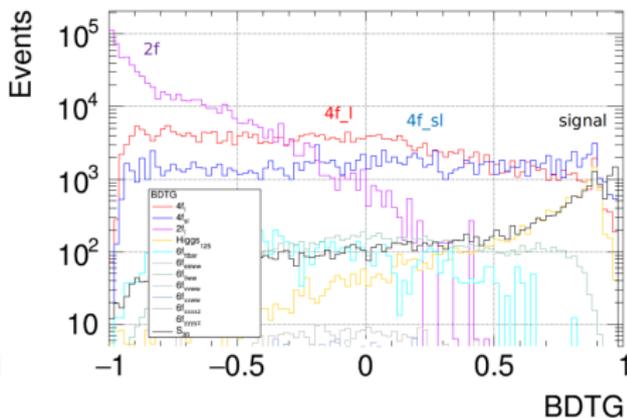
only old observables

$4f_l$  backgrounds  $\checkmark$   
signal and  $2f_l$  backgrounds  $\times$



new : all observables in the same BDTG

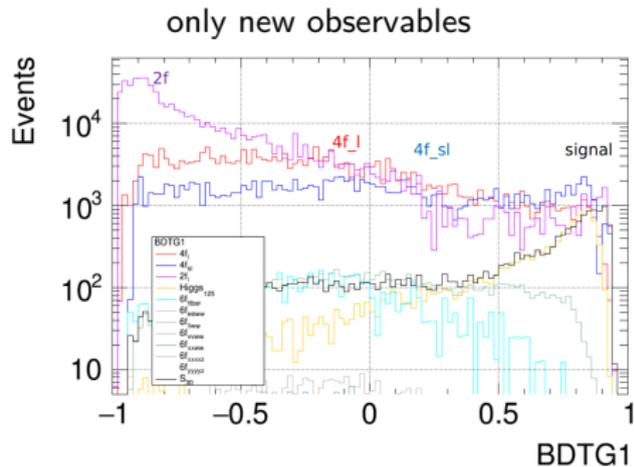
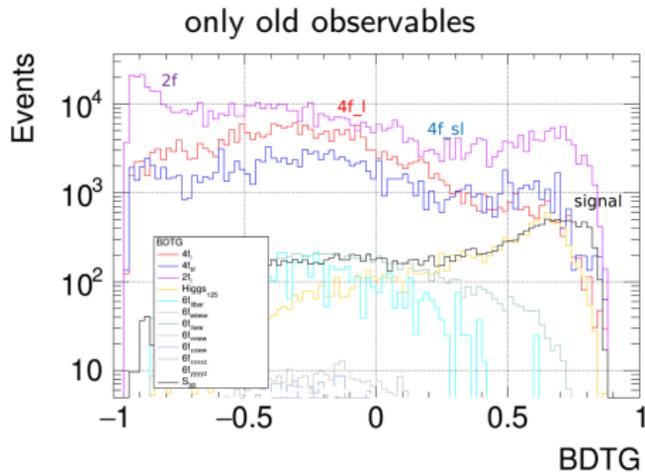
$4f_l$  backgrounds  $\times$   
signal and  $2f_l$  backgrounds  $\checkmark$



If only use one BDTG, the main backgrounds change from  $2f$  to  $4f$ .

The final total background event numbers almost don't change.

# BDTG : seperate into two BDTGs



BDTG with old observables to discard  $4f_l$  backgrounds

BDTG with new observables to discard  $2f_l$  backgrounds ✓

## Update 2 : overlay removal and new MC lepton/photon tagging

old	new PFO	new MC
<ul style="list-style-type: none"><li>▶ Isolated lepton tagging</li></ul>	<ul style="list-style-type: none"><li>▶ Isolated lepton tagging</li></ul>	<ul style="list-style-type: none"><li>▶ Overlay Removal</li></ul>
<ul style="list-style-type: none"><li>▶ Overlay Removal</li></ul>	<ul style="list-style-type: none"><li>▶ Isolated Photon tagging</li></ul>	<ul style="list-style-type: none"><li>▶ Isolated lepton tagging</li></ul>
<ul style="list-style-type: none"><li>▶ Isolated Photon tagging</li></ul>	<ul style="list-style-type: none"><li>▶ Overlay Removal</li></ul>	<ul style="list-style-type: none"><li>▶ FSR photon recovery (<math>\cos\theta = 0.98</math>)</li></ul>
<ul style="list-style-type: none"><li>▶ FSR photon recovery (<math>\cos\theta = 0.98</math>)</li></ul>	<ul style="list-style-type: none"><li>▶ FSR photon recovery (<math>\cos\theta = 0.98</math>)</li></ul>	<ul style="list-style-type: none"><li>▶ Isolated Photon tagging</li></ul>

Old: some Isolated photon will missing by overlay removal.

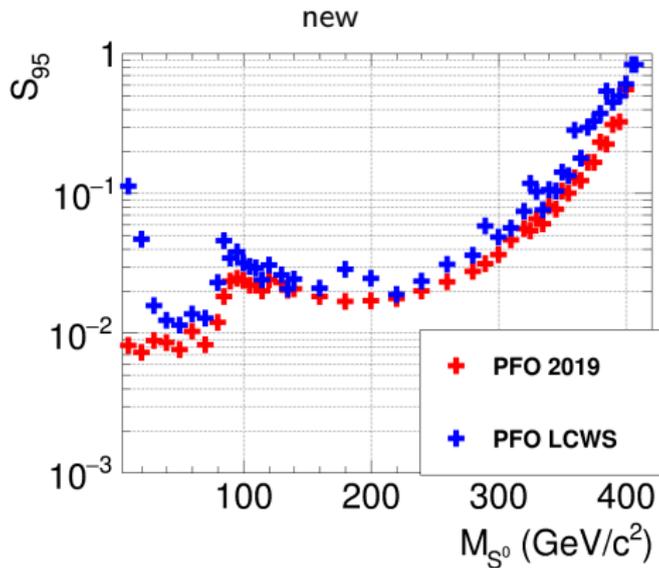
New: ISR related cuts are more powerful.

New: new MC lepton/photon processors to improve MC particles tagging performances

\*: IsolatedLeptonTagging Processor include a FSR recovery with  $\cos\theta = 0.999$ .

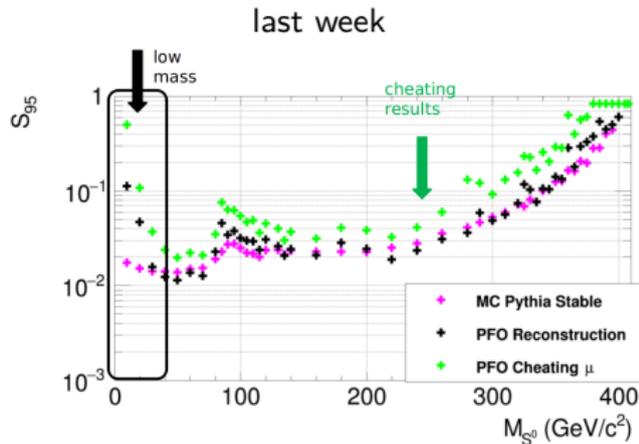
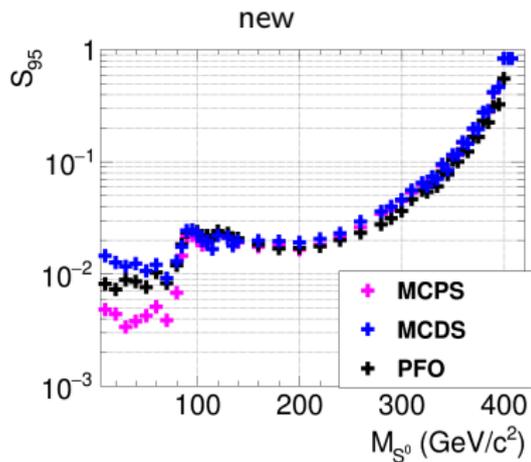


## Comparing old and new PFO results



Better in all regions, especially in the small mass region.

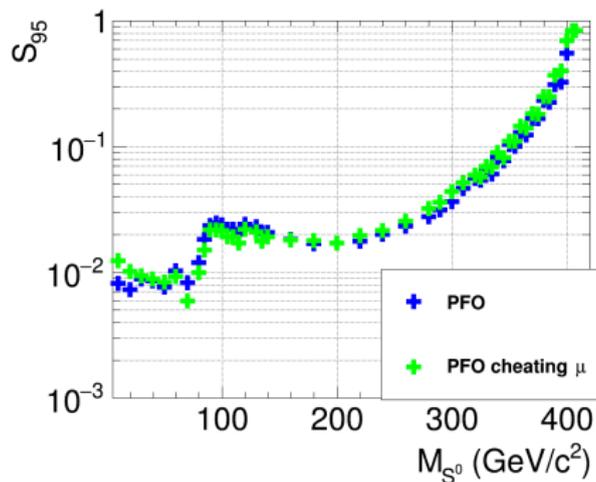
# Comparing old and new MC results



MCPS: inputs are MC Pythia Stable particles.

MCDS: inputs are MC Detector Simulation particles.

Better than the past in almost all regions, especially in the small mass region.

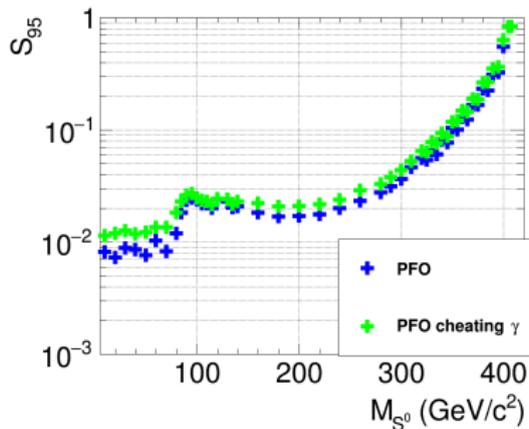


Cheating results are closed to but not better than PFO results.

Reason: These are the final exclusion limits, they are highly cuts-dependent.

Cuts are a little more suitable for PFO. so cheating Results will not only get more signal events, but also more background events.

note :  $S_{95}$  is the  $2\sigma$  exclusion limits of  $\frac{\sigma_{S^0 Z}}{\sigma_{H_{SM} Z}(m_{H_{SM}}=m_{S^0})}$



only cheating when the difference between pythia photon energy and PFO photon energy is larger than 5%.

replace pythia photon with all the PFOs, which linked to that pythia photon.

- ▶ add new observables
- ▶ rewrite processors
- ▶ change analysis strategy
- ▶ new results are much better than the old ones, especially in the small mass region.
- ▶ cheating results are similar to the PFO, but depend on the cuts.



## PFO

$\int Ldt = 4000fb^{-1}$	$nh_{30}$	$h_{e2}$	$4f_l$	$4f_{sl}$	$2f_l$	$6f_{ee\omega\omega}$	$6f_{ll\omega\omega}$	$6f_{tt\bar{b}b}$	$6f_{\dots}$
$nocutMCevent$	11618	8263	16550	3903	7893	1581	25361	898	
$nocut$	17224.4	11458.1	232927	136195	591229	358.335	8672.03	5986.52	1
$N_{\mu} \in [2, 20]$	17224.4	11458.1	232927	136195	591229	358.335	8672.03	5986.52	1
$N_{\mu^+} \in [1, 10]$	17224.4	11458.1	232927	136195	591229	358.335	8672.03	5986.52	1
$N_{\mu^-} \in [1, 10]$	17224.4	11458.1	232927	136195	591229	358.335	8672.03	5986.52	1
$M_{\mu^+\mu^-} \in [80, 100]$	17224.4	11458.1	232927	136195	591229	358.335	8672.03	5986.52	1
$P_T^{\mu^+\mu^-} \in [10, 245]$	17224.4	11458.1	232927	136195	591229	358.335	8672.03	5986.52	1
$BDTG \in [0.5, 1]$	7177.86	5374.86	8218.62	13140	63105.5	8.98782	431.815	25.4604	4
$BDTG1 \in [0.5, 1]$	7118.76	5363.52	8139.11	13011.1	10825.2	8.98782	427.714	25.4604	4
$\cos\theta_{mis} \in [-0.99, 0.99]$	6489.24	4816.15	7476.14	10475.3	10265.1	8.98782	408.611	25.4604	4
$E_{\gamma}^1 \in [-10000.2, 230]$	6486.9	4816.15	7466.46	10475.3	2731.5	8.98782	408.611	25.4604	4
$E_{\gamma}^2 \in [-10000.2, 150]$	6486.76	4816.15	7466.46	10475.3	2731.5	8.98782	408.611	25.4604	4
$M_{rec} \in [10, 450]$	5906.24	4813.39	7437.41	10411.7	1910.17	8.98782	408.611	25.4604	4
$all\ cut$	5906.24	4813.39	7437.41	10411.7	1910.17	8.98782	408.611	25.4604	4

## cheating muon

$\int L dt = 4000 fb^{-1}$	$nh_{30}$	$h_{e2}$	$4f_l$	$4f_{sl}$	$2f_l$	$6f_{ee\omega}$	$6f_{ll\omega}$	$6f_{tt\bar{a}r}$	$6f_{\dots}$
$nocutMCevent$	12623	8925	19208	4267	9085	1911	27686	1097	
$nocut$	18749.1	12358.8	281099	149711	678112	428.956	9324.12	7053.99	1
$N_{\mu} \in [2, 20]$	18749.1	12358.8	281099	149711	678112	428.956	9324.12	7053.99	1
$N_{\mu^+} \in [1, 10]$	18749.1	12358.8	281099	149711	678112	428.956	9324.12	7053.99	1
$N_{\mu^-} \in [1, 10]$	18749.1	12358.8	281099	149711	678112	428.956	9324.12	7053.99	1
$M_{\mu^+\mu^-} \in [80, 100]$	18749.1	12358.8	281099	149711	678112	428.956	9324.12	7053.99	1
$P_T^{\mu^+\mu^-} \in [10, 245]$	18749.1	12358.8	281099	149711	678112	428.956	9324.12	7053.99	1
$BDTG \in [0.5, 1]$	8096.43	6090.85	9352.34	15376.3	71874.9	10.973	514.808	13.4653	4
$BDTG1 \in [0.5, 1]$	8032.51	6073.99	9291.61	15185.5	13326.7	10.6072	513.871	13.4653	4
$\cos\theta_{mis} \in [-0.99, 0.99]$	8032.51	6073.99	9115.55	15185.5	13326.7	10.6072	513.855	13.4653	4
$E_{\gamma}^1 \in [-10000.2, 230]$	8030.17	6073.99	9105.27	15185.5	4277.96	10.6072	513.855	13.4653	4
$E_{\gamma}^2 \in [-10000.2, 150]$	8025.49	6073.99	9105.27	15185.5	4277.96	10.6072	513.855	13.4653	4
$M_{rec} \in [10, 450]$	8004.15	6073.99	9085.31	15185.5	3724.14	10.6072	513.855	13.4653	4
$all\ cut$	8004.15	6073.99	9085.31	15185.5	3724.14	10.6072	513.855	13.4653	4