Update on new light scalar study

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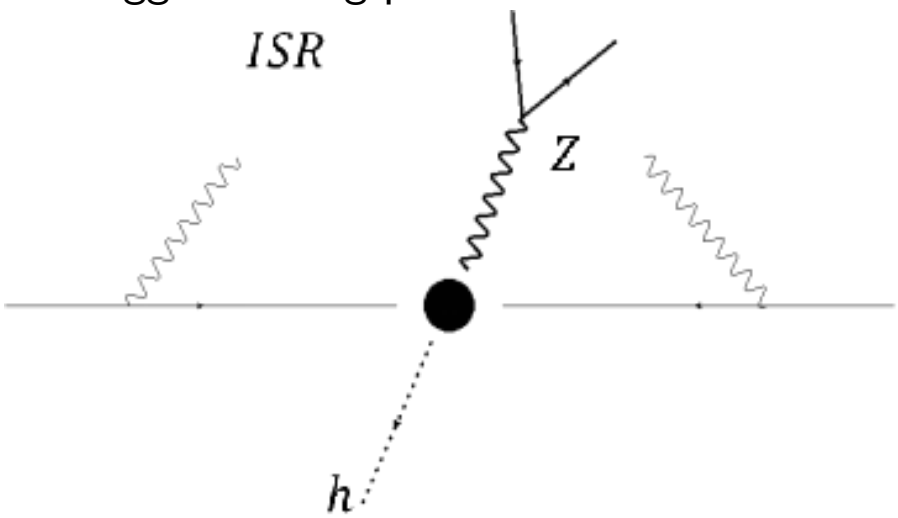
HELMHOLTZ ASSOCIATION

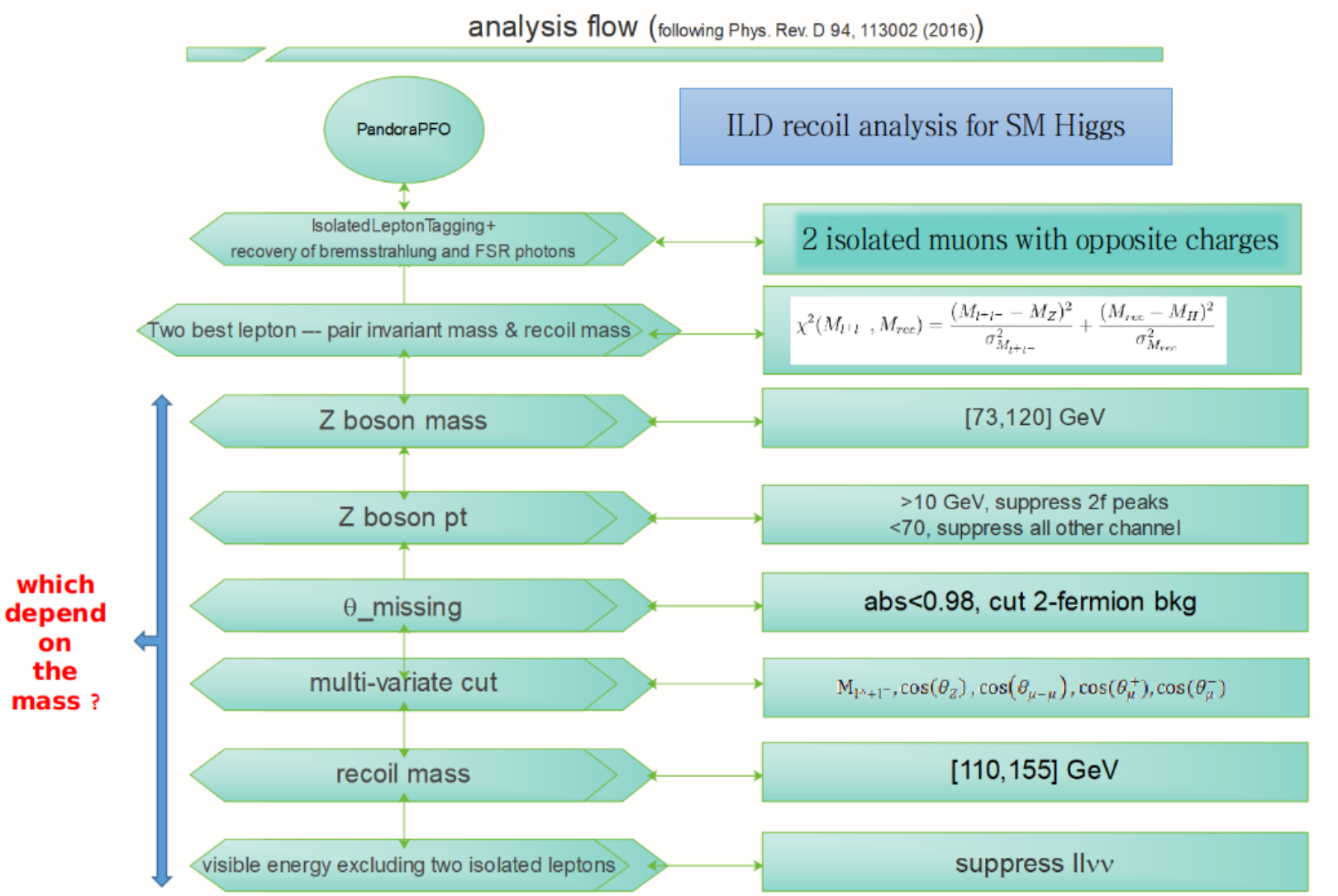
The results in LCWS2017 — basic information

Higgsstrahlung process $e^+e^- \to Zh$

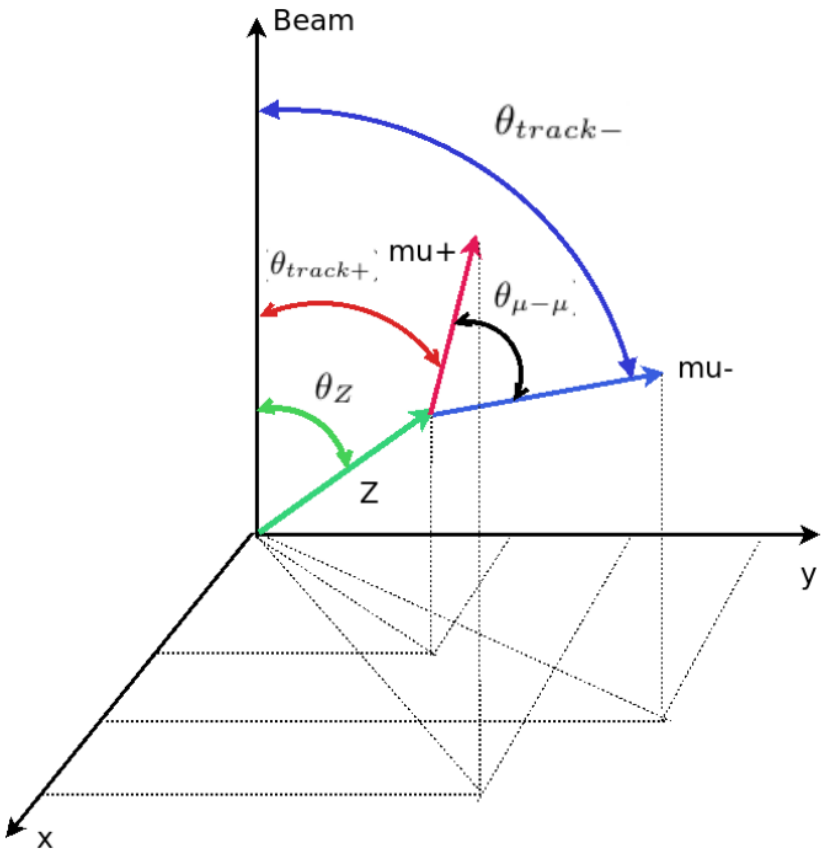


- signal benchmark samples are $M_h = 30, 50, 70, 90, 115$ GeV.
- Backgrounds include 2-fermion leptonic/bhabha, 4-fermion, leptonic, 4-fermion, semi-lepton $(4f^{sl})$, and (2)4-fermion, hadronic $(2f^h, 4f^h)$.
- $\int Ldt = 2000\,\text{fb}^{-1}$, center-of-mass energy is $\sqrt{s} = 250$ GeV.
- beam polarization is $(Pe^-, Pe^+) = (-80\%, +30\%)$.

The results in LCWS2017 — analysis flow



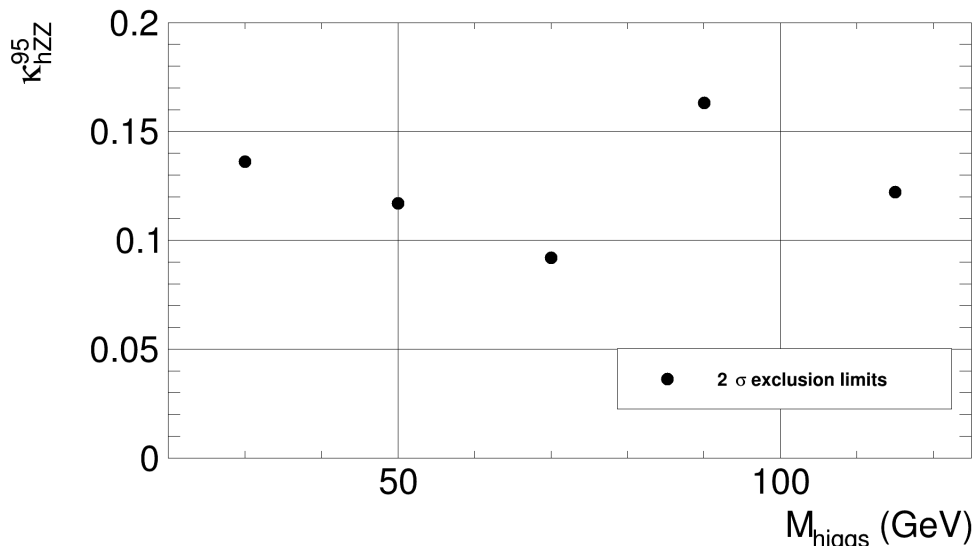
The results in LCWS2017 — variables in MVA



- BDTG contains $\cos(\theta_Z)$, $\cos(\theta_{\mu-\mu})$, $\cos(\theta_{track+})$, $\cos(\theta_{track-})$, $M_{l^+l^-}$.

The results in LCWS2017
— significance and 95% exclusion limits on coupling scale factor

M_h (GeV)	30	50	70	90	115
significance	51.6	59.0	56.4	48.5	41.5



Improvement

LCWS results

- Beam polarization is $(Pe^-, Pe^+) = (-80\%, +30\%)$.
- $\cos(\theta_Z)$, $\cos(\theta_{\mu-\mu})$, $\cos(\theta_{track+})$, $\cos(\theta_{track-})$, $M_{l^+l^-}$ for MVA input.
- Backgrounds include 2-fermion leptonic/bhabha, 4-fermion, leptonic, 4-fermion, semi-lepton ($4f^{sl}$), and (2)4-fermion, hadronic ($2f^h, 4f^h$).
- Signal benchmark samples are $M_h = 30, 50, 70, 90, 115$ GeV, 20 GeV step.

new results

- The staging scenario $(-+, +-, --, ++) = (45\%, 45\%, 5\%, 5\%)$.
- Increase acoplanar in MVA.
- Increase SM Higgs and $\gamma\gamma$ backgrounds.
- Signal benchmark samples are $M_h = 10, 15, 20, ..., 120$ GeV, 5 GeV step.
- Changing the $P_{\mathrm{T}}^{\mu^+\mu^-}$ and recoil mass cut.

Changing the scenario — $P(e^-, e^+) = (-100\%, +100\%)$ for $\int Ldt = 2000$ fb^{-1} at 250 GeV

Take $M_h = 115$ GeV for example.

$\int Ldt = 2000 fb^{-1}$	$higgs_{115}$	$4f_l$	$4f_{sl}$	$2f_l$	$total\ bk$	efficienty	significance
$no\ cut$	42550.3	1.78×10^7	6.26×10^7	4.25×10^7	1.73×10^8	1	3.23
$N_\mu \in [2, 20]$	39951.7	1.98×10^6	400505	1.71×10^7	1.95×10^7	0.94	9.05
$N_{\mu+} \in [1, 10]$	39927.7	1.98×10^6	400301	1.71×10^7	1.95×10^7	0.94	9.04
$N_{\mu-} \in [1, 10]$	39907.7	1.98×10^6	399971	1.71×10^7	1.95×10^7	0.94	9.04
$M_{l^+l^-} \in [73, 120]$	38162	575549	283157	7.70×10^6	8.56×10^6	0.90	13.01
$P_T^{l^+l^-} \in [10, 90]$	37669.5	524326	272793	1.72×10^6	2.52×10^6	0.89	23.56
$\lvert cos\theta_{mis} \rvert < 0.98$	34194.1	485873	220642	862170	1.57×10^6	0.80	27.01
$BDTG \in [0, 1]$	30366.4	144446	97128.1	99044.7	340619	0.71	49.86
$M_{rec} \in [90, 160]$	30354.4	134784	89578.6	26677.9	251040	0.71	57.22
$all\ cut$	30354.4	134784	89578.6	26677.9	251040	0.71	57.22

Changing the scenario — $P(e^-, e^+) = (+100\%, -100\%)$ for $\int Ldt = 2000$ fb^{-1} at 250 GeV

$\int Ldt = 2000 fb^{-1}$	$higgs_{115}$	$4f_l$	$4f_{sl}$	$2f_l$	$total\ bk$	efficienty	significance
$no\ cut$	27090.6	2.56×10^6	2.84×10^6	3.29×10^7	8.67×10^7	1	2.91
$N_\mu \in [2, 20]$	25356.9	275379	201052	1.28×10^7	1.33×10^7	0.94	6.94
$N_{\mu+} \in [1, 10]$	25324.9	274177	201020	1.28×10^7	1.33×10^7	0.93	6.93
$N_{\mu-} \in [1, 10]$	25288.9	273068	201004	1.28×10^7	1.33×10^7	0.93	6.92
$M_{l^+l^-} \in [73, 120]$	24255.9	97909.8	127030	5.08×10^6	5.31×10^6	0.90	10.50
$P_T^{l^+l^-} \in [10, 90]$	23927.5	82159.9	120176	1.15×10^6	1.35×10^6	0.88	20.43
$\lvert cos\theta_{mis}\rvert < 0.98$	21549.2	62346	96019.3	577101	735466	0.80	24.77
$BDTG \in [0, 1]$	19707.4	28357.2	40804.3	62807.7	131969	0.727463	50.60
$M_{rec} \in [90, 160]$	19687.4	25427.7	36330.9	21003.1	82761.7	0.73	61.51
$all\ cut$	19687.4	25427.7	36330.9	21003.1	82761.7	0.73	61.51

Chaning the scenario — Combine
$P(e^-, e^+) = ((-,+),(+,-),(-,-),(+,+))$

using $P(e^-, e^+) = (-80\%, +30\%)$ for $\int Ldt$ 2000 fb^{-1}, the significance is 44.8
(in LCWS2017, this is 45.6, due to code correction, but still checking this part!)

combining polarizations within the scenario $(-+, +-, --, ++) = (45\%, 45\%, 5\%, 5\%)$.
significance for different polarization:

- $(-,-)$: 7.79 for 100 fb^{-1}
- $(-,+)$: 30.04 for 900 fb^{-1}
- $(+,-)$: 31.28 for 900 fb^{-1}
- $(+,+)$: 7.92 for 100 fb^{-1}

$\int Ldt = 2000 fb^{-1}$	$higgs_{115}$	$4f_l$	$4f_{sl}$	$2f_l$	$total\ bk$	significance
combined events	14924.7	49566.8	38225.7	14129	101921	43.66

Adding the acoplanar variable in MVA

The acoplanar — decrease $2f_l$ backgrounds.
Combining polarizations within the scenario $(-+, +-, --, ++) = (45\%, 45\%, 5\%, 5\%)$ for $\int Ldt$ 2000 fb^{-1} at $\sqrt{s} = 250$ GeV.
Significance for different polarization:

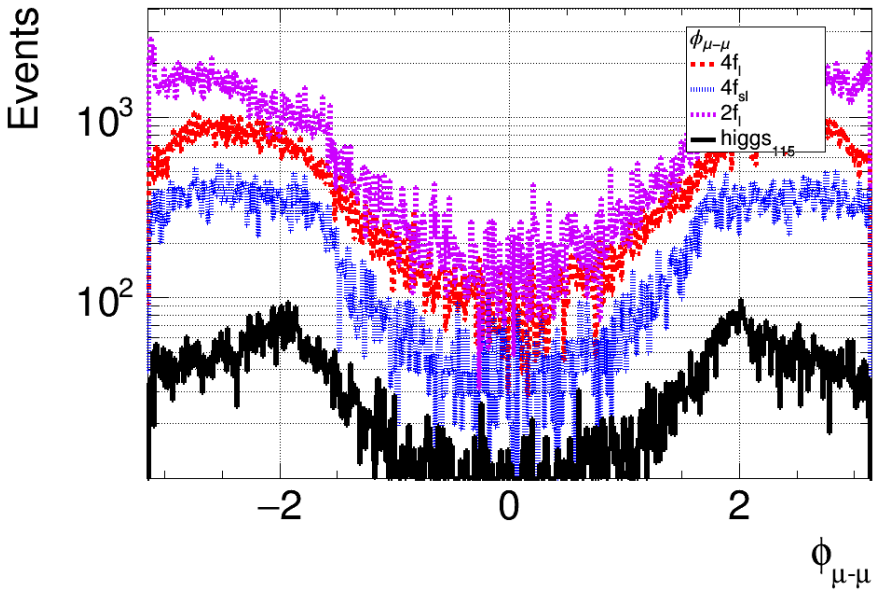
- $(-,-)$: 7.76 for 100 fb^{-1}
- $(-,+)$: 29.97 for 900 fb^{-1}
- $(+,-)$: 31.37 for 900 fb^{-1}
- $(+,+)$: 7.93 for 100 fb^{-1}

$\int Ldt = 2000 fb^{-1}$	$higgs_{115}$	$4f_l$	$4f_{sl}$	$2f_l$	$total\ bk$	significance
combined events	14831.7	49311.5	37886.9	13554.2	100753	43.63

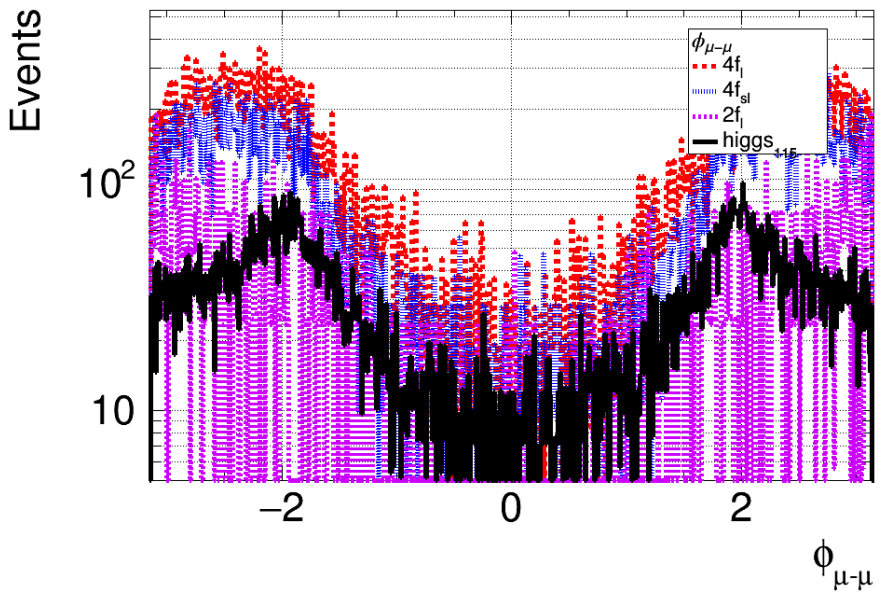
Without acoplanar in MVA, the result is 43.66.
NO effect on final results ...

distribution for the acoplanar variable in MVA

The case when acoplanar is included in MVA, this figure is the distribution after pre cuts.



The case when acoplanar is NOT included in MVA, This figure is the acoplanar distribution after BDTG cut.



Adding SM Higgs and $\gamma\gamma$ backgrounds

combining polarizations within the scenario $(-+, +-, --, ++) = (45\%, 45\%, 5\%, 5\%)$.
significance for different polarization:

- $(-,-)$: 7.43 for 100 fb^{-1}
- $(-,+)$: 28.79 for 900 fb^{-1}
- $(+,-)$: 29.25 for 900 fb^{-1}
- $(+,+)$: 7.47 for 100 fb^{-1}

$\int Ldt = 100 fb^{-1}$	$higgs_{115}$	$4f_l$	$4f_{sl}$	$2f_l$	$Higgs_{125}$	significance
combined events	14807.4	48868.6	37775.1	13490.2	12294.9	41.5

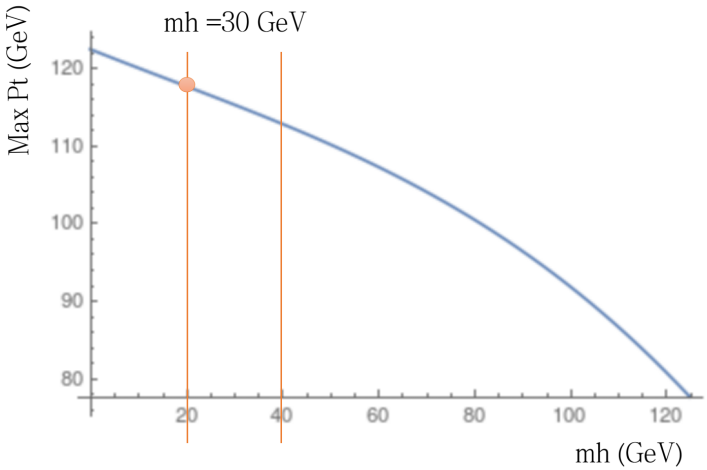
Without SM Higgs and $\gamma\gamma$ backgrounds, the result is 43.6.

New samples and new cuts

New signal samples from $10\,\text{GeV}$ to $120\,\text{GeV}$ with $5\,\text{GeV}$ step.

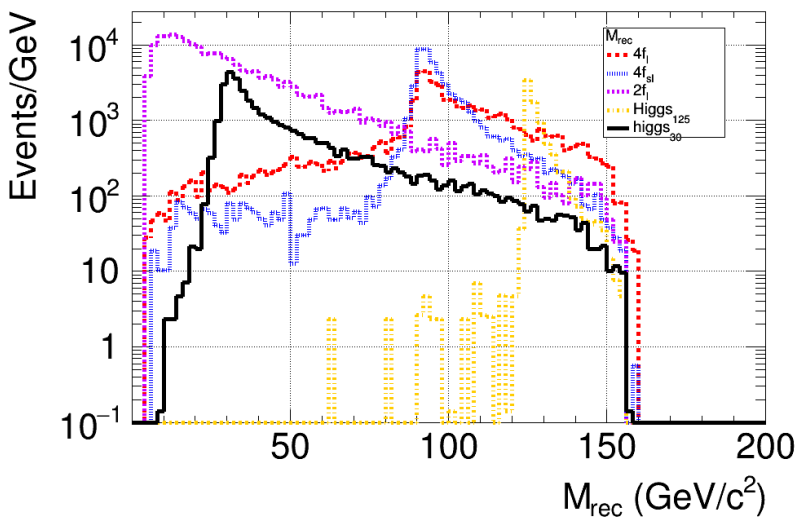
LCWS cuts

- Max $P_{\text{T}}^{\mu^+\mu^-}$ cut: max $P_{\text{T}}^{\mu^+\mu^-}$ in $[M_h - 10,\ M_h + 10]$ GeV region
- recoil mass cut: $[(M_h - 20), 160]$ GeV



new cuts

- Max $P_{\text{T}}^{\mu^+\mu^-}$ cut: max $P_{\text{T}}^{\mu^+\mu^-}$ in $[M_h - 2.5,\ M_h + 2.5]$ GeV region
- recoil mass cut: $[(M_h - 5), 160]$ GeV



Compare final results for LCWS2017 and new

- including $\gamma\gamma$, SM Higgs backgrounds.
- including acoplanar of the two muon in MVA.
- combining polarizations within the scenario $(-+, +-, --, ++) = (45\%, 45\%, 5\%, 5\%)$.
- $P_{\mathrm{T}}^{\mu^+\mu^-}$ cut and recoil mass cut.

M_h (GeV)	LCWS results	new results with old cuts	new results with new cuts
30	56.9	51.6	62.6
50	66.4	59.0	61.6
70	64.0	56.4	59.0
90	52.5	48.5	49.7
115	45.6	41.5	50.2

The new results — combining all improvements

- combining polarizations within the scenario $(-+, +-, --, ++) = (45\%, 45\%, 5\%, 5\%)$.
- including acoplanar of the two muon in MVA.
- including $\gamma\gamma$, SM Higgs backgrounds.
- using the new $P_{\mathrm{T}}^{\mu^+\mu^-}$ cut and recoil mass cut.

M_h (GeV)	LCWS results
30	56.9
50	66.4
70	64.0
90	52.5
115	45.6

New results after all improvements. (preliminary)

M_h (GeV)	10	15	20	25	30	35	40	45	50	55
significance	56.8	58.3	59.9	61.8	62.6	63.2	62.8	62.4	61.6	63.8
M_h (GeV)	60	65	70	75	80	85	90	95	100	105
significance	62.5	60.9	59.0	56.5	54.3	51.9	49.7	49.5	52.6	52.0
M_h (GeV)	110	115	120							
significance	51.3	50.2	49.7							

Future plan: comparing with OPAL's result. — Data sets in OPAL searching

OPAL detector

- 1991-1995 $\sqrt{S} = 91$ GeV (LEP1) — 115.4 pb^{-1}
- 1997-2000 $\sqrt{S} = 183 - 209$ GeV (LEP2) — 662.4 pb^{-1}

MC samples

- 1 keV - 110 GeV with HZHA generator
- decay mode:
  - all possible SM Higgs decay channels
  - inisible decay ($S^0 \to \chi^0\chi^0 + S^0 \to \chi_2^0\chi_1^0, \chi_2^0 \to \chi_1^0 + \gamma/Z^{0*}$ $+ S^0 \to AA, A \to cc/gg/\tau\tau$)
- 500-1000 events for each S^0 mass and decay mode.
- bkg samples: The luminosity of main bkg MC samples is 4 times than the real 2fermion bkg and 50 times than 4fermion bkg

comparing LEP2 and my strategy for searching light scalars

- at least two opposite charged leptons
- find two best leptons $m_{ll} \sim m_Z$
- acoplanarity
- polar angle of missing momentum, $|\theta_{mis}|$<0.95 for $p_{mis} > 5$ GeV
- isolation of lepton tracks, $\alpha^1_{iso} > 15^\circ$, $\alpha^1_{iso} > 10^\circ$
- invariant mass of the lepton pair, $M_{\mu\mu} \in [81.2, 101.2]$ GeV
- photon veto
- $p^z_{ll} < 50$ GeV

- at least two isolated muon, with IsolatedLeptonTagging Processor
- find two best leptons, $m_{ll} \sim m_Z$ and $m_{rec} \sim m_h$
- Recovery of bremsstrahlung and FSR photons
- Reconstruct Z boson mass $M_{\mu\mu} \in [73, 120]$ GeV.
- Z boson $70 > P_T > 10$ GeV
- the polar angle of the missing momentum, $|\theta_{mis}|$<0.98
- multivariate cut :$M_{l^+l^-}$, $cos(\theta_Z)$, $cos(\theta_{\mu-\mu})$,$cos(\theta_{track+})$ and $cos(\theta_{track-})$
- recoil mass cut $M_{rec} \in [110, 155]$ GeV.
- visible energy cut, $Evis > 10$ GeV

Conclusion

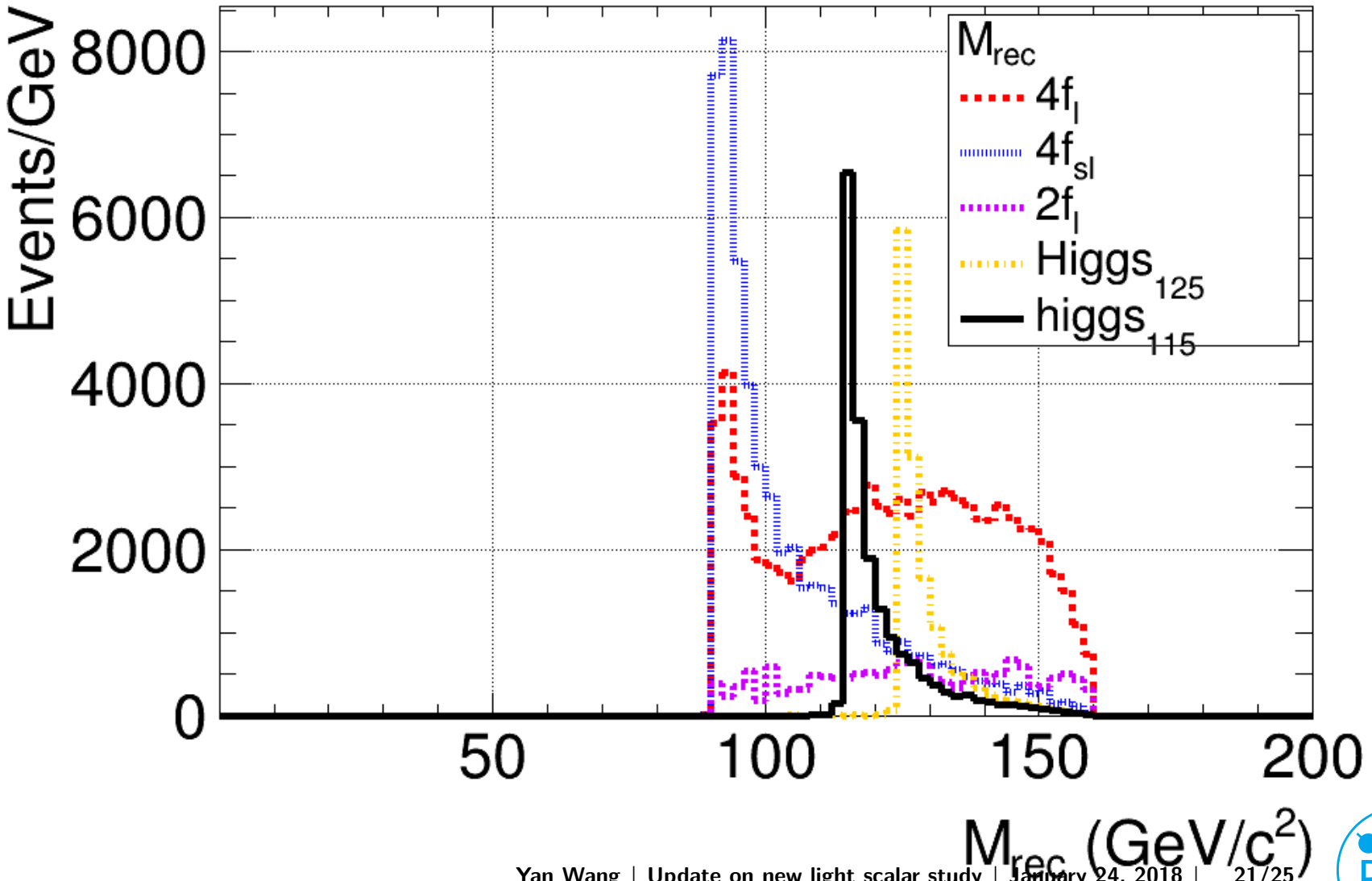
- The preliminary new results for $(-+, +-, --, ++) = (45\%, 45\%, 5\%, 5\%)$ scenario.
- The results use complete backgrounds, new observables, new cuts and new benchmark mass points.
- Checking and further understanding the new results.
- Studying ISR photon to decrease $2f_l$ backgrounds.

backup

Corelation table for aoplanar

	$M_{l^+l^-}$	cos(θ_Z)	cos($\theta_{\mu^-\mu}$)	cos(θ_{track^+})	cos(θ_{track^-})	acoplanar
$M_{l^+l^-}$	+1.000	+0.017	-0.244	-0.000	+0.005	+0.00
cos(θ_Z)	+0.017	+1.000	-0.000	+0.370	+0.364	-0.00
cos($\theta_{\mu^-\mu}$)	-0.244	-0.000	+1.000	+0.009	-0.008	+0.01
cos(θ_{track^+})	-0.000	+0.370	+0.009	+1.000	-0.597	-0.01
cos(θ_{track^-})	+0.005	+0.364	-0.008	-0.597	+1.000	+0.01
acoplanar	+0.002	-0.007	+0.012	-0.019	+0.010	+1.00

recoil mass distribution for $M_h = 115\,\text{GeV}$



Event selection for $Z \to \mu\mu$ channel at LEP 2

preselection:

- two opposite charged muon
  - $\frac{E}{p} < 0.2$ for muon, at least 3 hits in muon chambers+hadronic calorimeters
  - p — track momentum, E—associated electromagnetic energy
- $E_{\mu}^{1eading} > 0.22 \cdot \sqrt{s}, E_{\mu}^{subleading} > 0.12 \cdot \sqrt{s}$
- isolation angle $\alpha_{iso}^{1} > 15^{\circ}$ $\alpha_{iso}^{2} > 10^{\circ}$
  - maximum angle for which the energy in the cone is less than 1 GeV
- detector angle $cos|\theta| > 0,94$
- if more than one leptons. $m_{\mu\mu} \sim m_Z$.

comparing IsolatedLeptonTagging with MVA variables:
$E_{cone}^{charged}$,$E_{cone}^{neutral}$, momentum P,
$cos\theta$ of large cone, energe ratio of large cone,
D0, Z0, E_{yoke}, total E_{cal}...

Event selection for LEP2

- acoplanarity angle $\pi - \phi_{open} > 0.15 - 0.20$ —- reject 2fermion bkgs
  - ϕ_{open} the opening angle between the two lepton tracks in the plane perpendicular to the beam axis
- $|cos\theta_{missing}|$<0.95 —- reject $\gamma\gamma$ bkg
- $|m_{ll} - m_Z| < 10$ GeV for muon
- γ veto — reject Z with energetic ISR photon
  - if there is only one cluster in the eletromagnetic calorimeter not assoiated to a track and $E_{cluster} > 60$ GeV
- forward calorimeters two tracks with $E_{forward} > 3$ GeV in the forward calorimeters.
  - two tracks with $E_{forward} > 3$ GeV in the forward calorimeters.
- $p_z^{l1} + p_z^{l2} < 50$ GeV — reject Z with energetic ISR photon

Event selection for $Z \to ee/\mu\mu$ channel at LEP 1/2

- two opposite charged particle (electrons or muon),
  - $\frac{E}{p} > 0.8$ for electron, energy loss $\frac{dE}{dx}$
  - p —track momentum, E—associated electromagnetic energy
  - $\frac{E}{p} < 0.2$ for muon, at least 3 hits in muon chambers+hadronic calorimeters
- The leading electron/muon with $E_e^1 > 20 - 27$ GeV and $E_\mu^1 > 20 - 27$ GeV in LEP I, the second lepton with $E_l^2 > 10 - 20$ GeV
- $E_e^1 > 0.22 \cdot \sqrt{s}, E_e^2 > 0.11 \cdot \sqrt{s}$, $E_\mu^1 > 0.22 \cdot \sqrt{s}, E_\mu^2 > 0.12 \cdot \sqrt{s}$
- isolation angle $\alpha_{iso}^1 > 20^\circ$ $\alpha_{iso}^2 > 10^\circ$ for LEP 1, $\alpha_{iso}^1 > 15^\circ$ $\alpha_{iso}^2 > 10^\circ$ for LEP 2— maximum angle for which the energy in the cone is less than 1 GeV
- detector angle $cos|\theta| > 0,9$ for electron, $cos|\theta| > 0,94$ for muon
- more than one leptons. two highest momentum leptons in LEP I, two leptons whose invariant mass closest to m_Z.
- acoplanarity angle 0.11 rad $< \alpha < 2.0$ rad, $\phi_a > 0.15 - 0.20$ —- reject 2fermion bkgs $\alpha = \phi_a \times < \sin\theta >$ — $\phi_a = \pi - \phi_{open}$. in LEP 1, θ is the polar angle of tracks. in LEP 2, $sin\theta$ =1.
- $|cos\theta_{missing}|$<0.98 for LEP 1 and $|cos\theta_{missing}|$<0.95 for LEP 2. —- reject γ

Event selection for LEP1

- $M_{\mu^+\mu^-} > 20\,\text{GeV}$
- γ veto:
  - track number < 4, if there is an unassociated cluster in the electromagneti calorimeter with E_{cal} 1 GeV outside a 10 degree cone around a lepton candidate
- $E_{forward} > 2$ GeV, polar angle in 47-200 mrad
- conversion veto: events with one, two or three tracks in addition to the lepton are excluded if at least one of them is identified as a track from a conversion — reject $\gamma \to ee$, satisfy the sensitivity of decay mode $S \to \gamma\gamma, S \to \gamma + inv$, using $Z \to \nu\nu, S \to \gamma\gamma$ to compensate sensitivity.