Searching for new light scalars at the ILC

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ILD meeting

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HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Motivation

The higgs boson found at 2012: the SM Higgs?

Many BSMs predict one or more extra scalars:

- 2HDM, NMSSM, Randall Sundrum model
- a scalar lighter than 125 GeV is well motivated.

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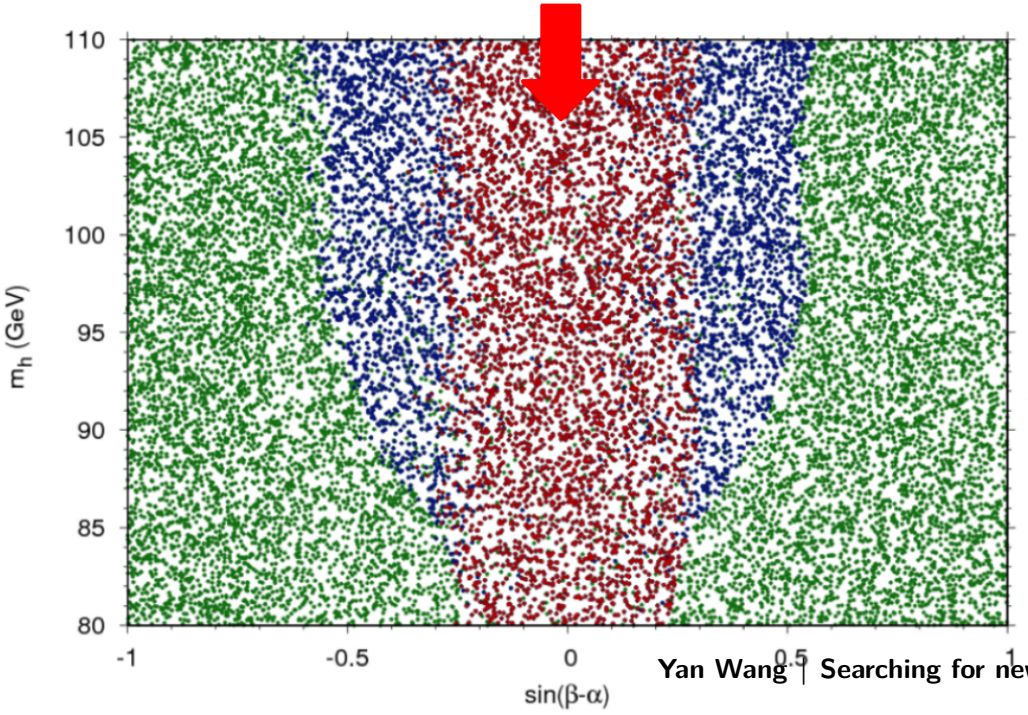
survived after indirect + LEP + LHC constrains

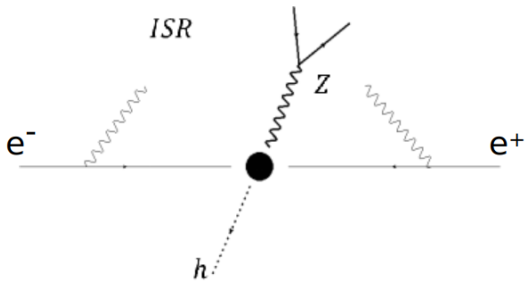


- LEP/LHC constrains rely on the model details: CP, mass hierarchy, couplings, etc.
- want a better result?

The Recoil Method on SM Higgs at ILC

e^+e^- collider $\rightarrow$ know the initial states behaviour $\rightarrow$ recoil technique $\rightarrow$ model independence

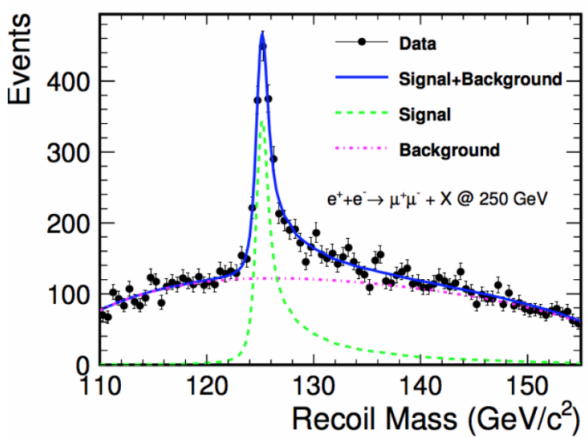
Higgsstrahlung process $e^+e^- \rightarrow Z + H/h$



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

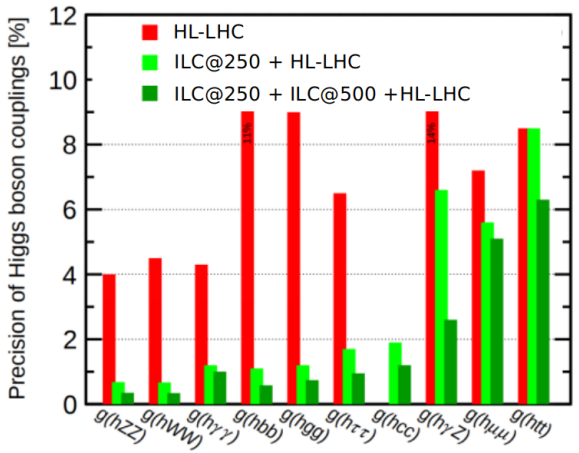
SM Higgs recoil mass distribution (ILD)

Phys. Rev. D 94, 113002 (2016)



SM Higgs coupling for ILC and HL-LHC

arXiv:1710.07621

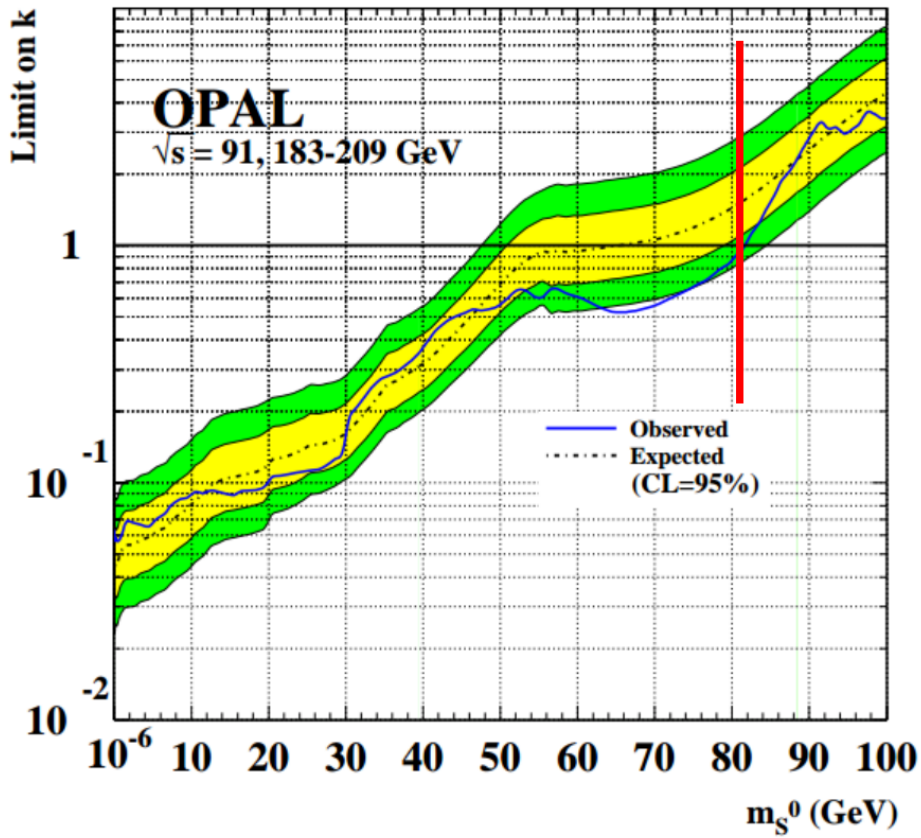


the same method on light scalar searching, **SM $H \rightarrow$ a lighter h.**

The Recoil Method at LEP

LEP results (CERN-EP-2002-032):

- the OPAL detector
- Decay-mode independent searches for new scalar bosons
- energy & luminosity:
  - 91.2 GeV and 115.4 pb^{-1} at LEP1
  - 161 to 202 GeV and **662.4 pb^{-1}** at LEP2.
- light higgs mass: 10 keV - 100 GeV
- $k = \frac{\sigma_{S^0 Z}}{\sigma_{H_{SM} Z (m_{H_{SM}} = m_{S^0})}}$



full simulation of Signal and SM Background

The signal MC samples

- $M_{S^0} = 10, 15, 20, ..., 120$ GeV, every 5 GeV step.
- decay branch ratios are the same as the 125 GeV SM Higgs boson.

The background MC samples:

- 2-fermion ($2f^l$,$2f^h$) leptonic/bhabha/hadronic
- 4-fermion ($4f^l$, $4f^{sl}$, $4f^h$) leptonic/semi-lepton/hadronic
- SM Higgs, $Higgs_{125}$
- $\gamma\gamma$ backgrounds

analysis flow

01 a muon pair

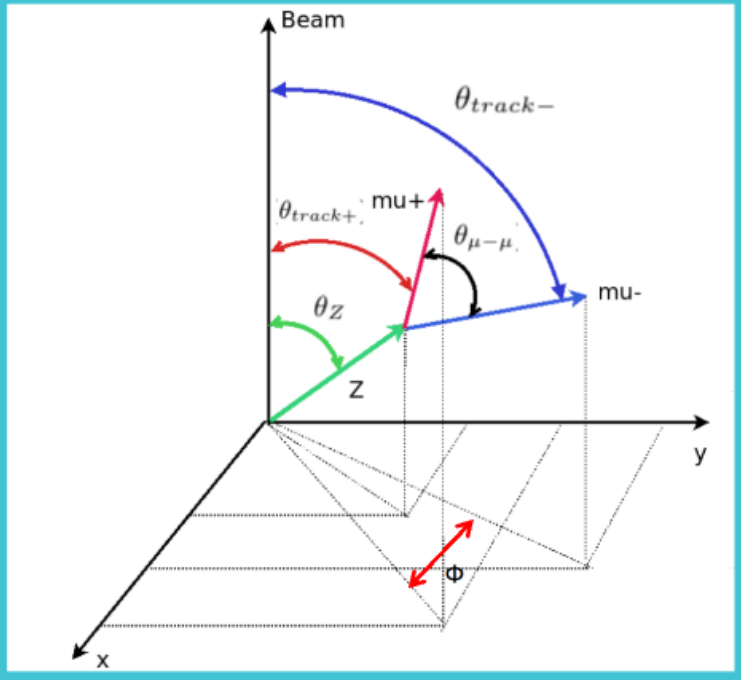
$$\chi^2(M_{\mu^+\mu^-}, M_{\text{rec}}) = \frac{(M_{\mu^+\mu^-} - M_Z)^2}{\sigma^2_{M_{\mu^+\mu^-}}} + \frac{(M_{\text{rec}} - M_h)^2}{\sigma^2_{M_{\text{rec}}}}.$$

02 $M_Z \in [73, 120]$ GeV

03 $P_T^Z \in [10, 128 - 4 \times \frac{M_h}{10}]$ GeV

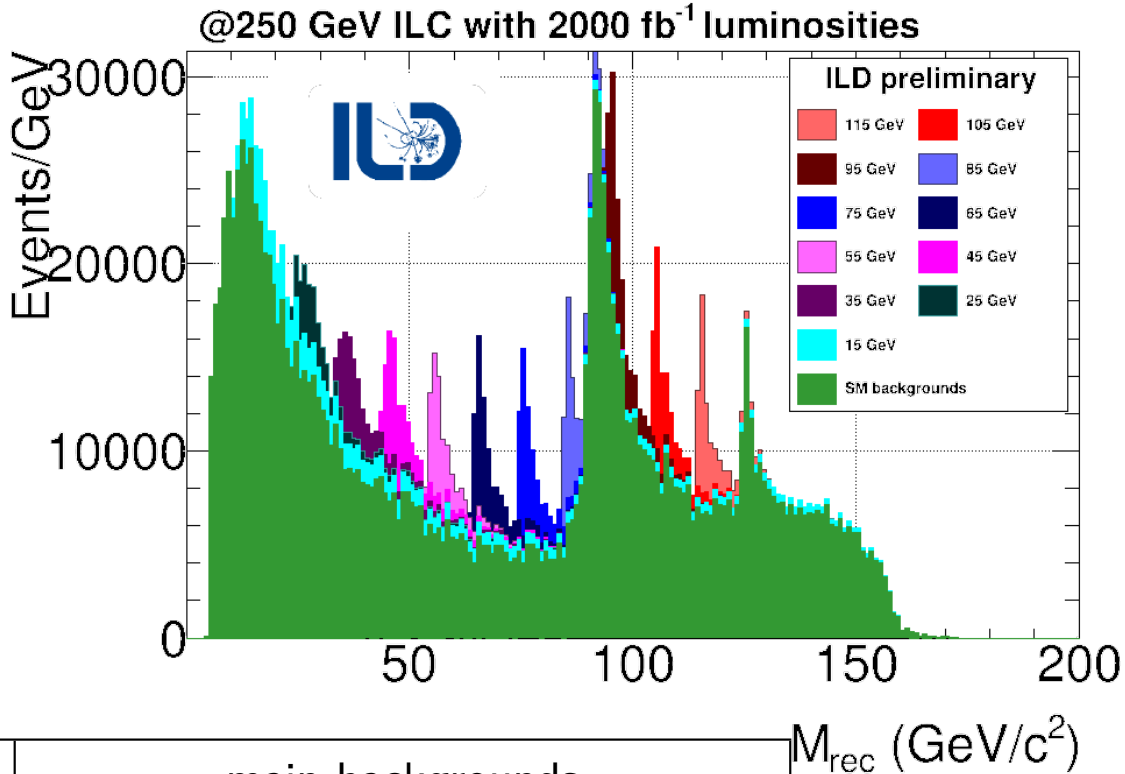
04 $|\cos\theta_{\text{mis}}| < 0.98$ when $M_h > 50$ GeV

05 Multi-Variate Analysis : angles



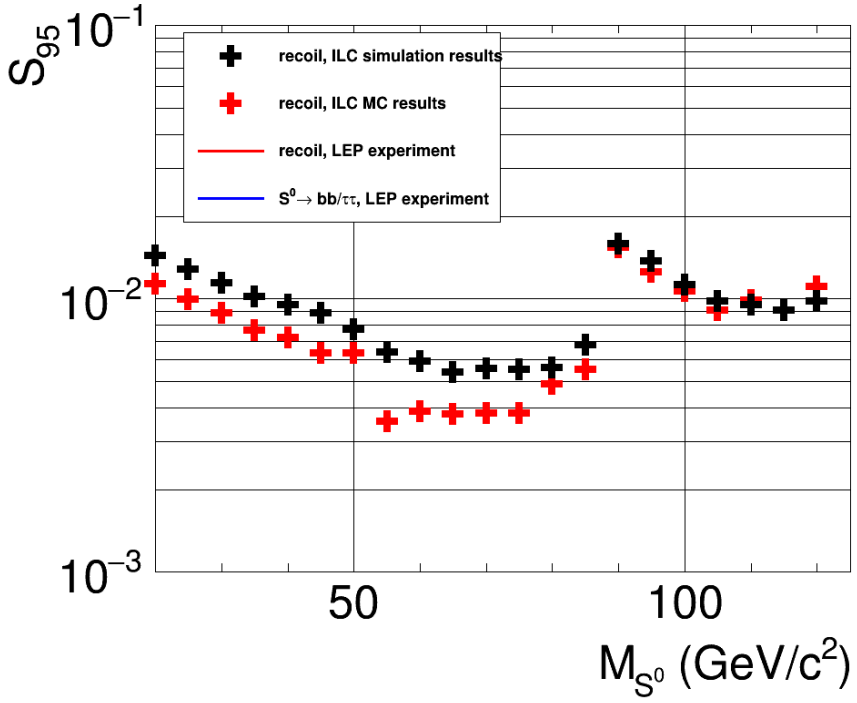
recoil mass distribution

- recoil mass distribution for different M_{S^0}.
- $(-,+)$ / $(+,-)$ 900 fb^{-1}, $(-,-)$ / $(+,+)$ 100 fb^{-1} polarization @ 250 GeV



mass region	main backgrounds
$125 > M_{S^0} > M_Z$	$4f_{zz}^{sl}$, $4f_{zz/ww}$, SM Higgs
$M_{S^0} \sim M_Z$	$4f_{zz}^{l}$, $4f_{zz}^{sl}$, $4f_{zz/ww}$, SM Higgs
$M_Z > M_{S^0} > 40$	$2f_l$, $4f_{zz}$, $4f_{zz/ww}$
$40 > M_{S^0}$	$2f_l$

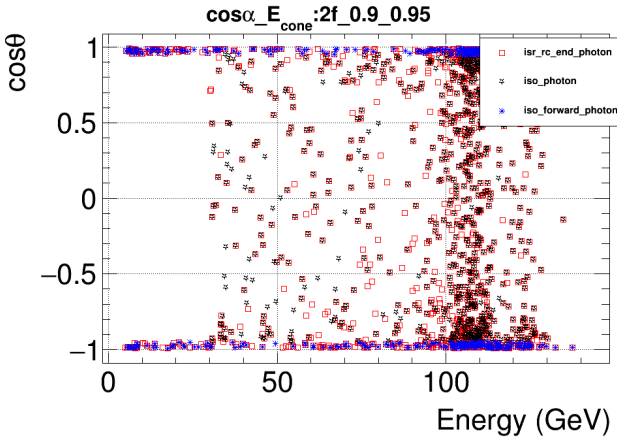
Comparing with MC results



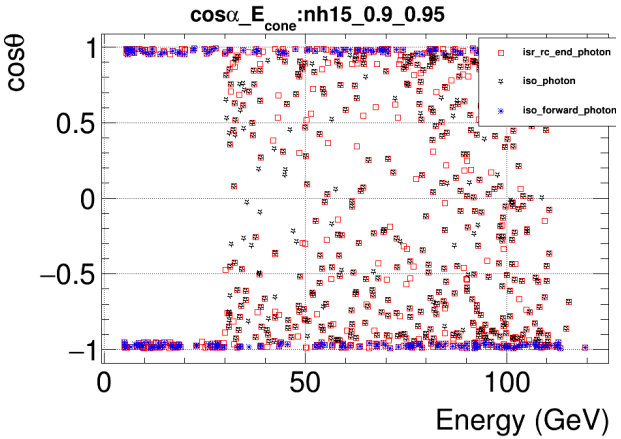
- 95% CL upper bounds on scale factor of cross section with likelihood methods
- MC results with the same cuts.
- slightly different in the low mass region.

ISR photon veto

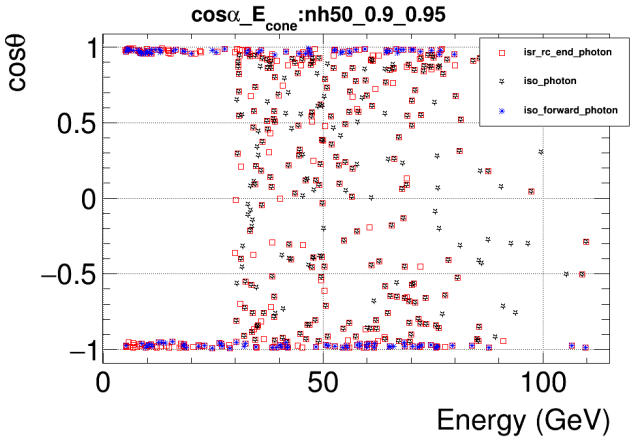
$2f_l$ process



$M_{S^0} = 15\,\text{GeV}$ process

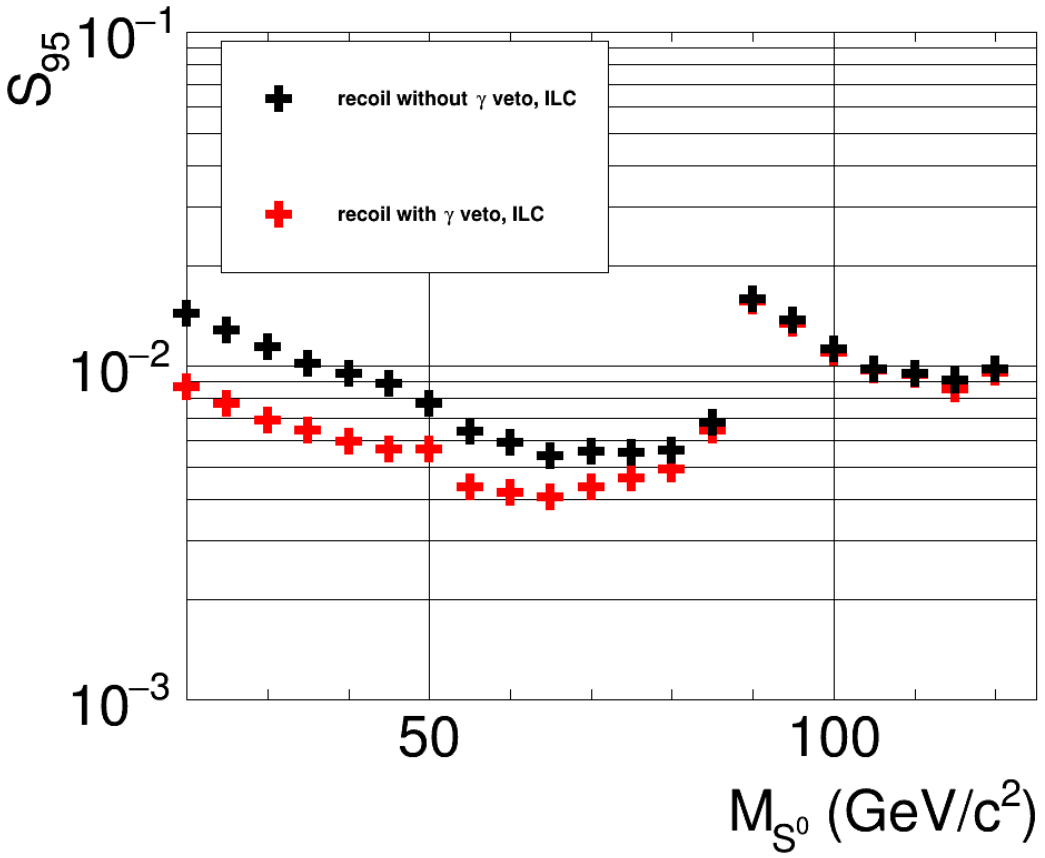


$M_{S^0} = 50\,\text{GeV}$ process



- There is photon return effects in $2f$ process.
- identify ISR photon by
  - ISR photon in the central region ($\cos\theta < 0.95$): $E_{\text{central}} > 100\,\text{GeV}$
  - ISR photon in the forward region ($0.95 < \cos\theta < 0.99$): $E_{\text{forward}} > 60\,\text{GeV}$
  - ISR cone around photon axis: $\cos\alpha = 0.90$
  - Energy ratio inside the ISR photon cone: $\frac{E}{E_{\text{cone}}} = 0.95$

Comparing w/o photon veto results



- remove large amount of $2f_l$ background in small mass region.
- $S^{95} \in (0.0025 - 0.015) \rightarrow \kappa^{95}_{hZZ} \in$ (0.05-0.12).

comparing LEP2 and my strategy for searching light scalars

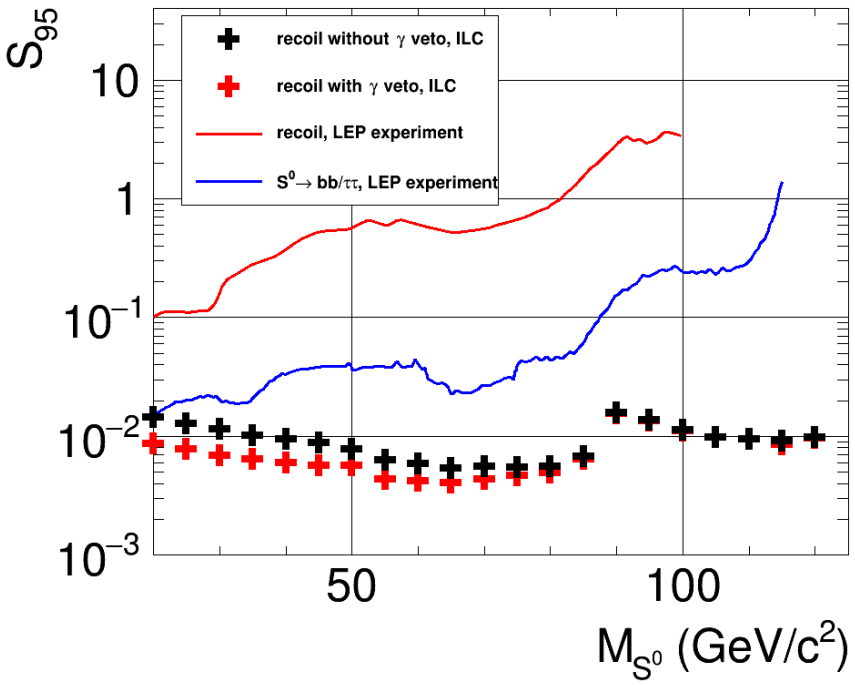
OPAL's strategy

- at least two opposite charged leptons
- isolation of lepton tracks, $\alpha^1_{iso} > 15°$, $\alpha^2_{iso} > 10°$
- find two best leptons $m_{ll} \sim m_Z$
- invariant mass of the lepton pair, $M_{\mu\mu} \in [81.2, 101.2]$ GeV
- $p^Z_{ll} < 50$ GeV
- polar angle of missing momentum, $|\theta_{mis}|$<0.95 for $p_{mis} > 5$ GeV
- acoplanarity
- ISR photon veto

my strategy

- 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.
- 70 GeV $> P^Z_T >$ 10 GeV
- the polar angle of the missing momentum, $|\theta_{mis}| < 0.98$
- MVA:$M_{\mu^+\mu^-}$, $cos(\theta_Z)$, $cos(\theta_{\mu^+\mu^-})$, $cos(\theta_{\mu^+})$, $cos(\theta_{\mu^-})$,acoplanarity
- ISR photon veto

Comparing with LEP results



- LEP recoil: LEP2 data from 161 GeV to 202 GeV, combined LEP1 data.
- LEP traditional: exclusive reconstruction of Z and h decay, mainly $h \to bb$, $h \to \tau\tau$.
- when $100 \geq M_h \geq 50$ GeV, trend are similar with LEP.
- generally, 1 order better than LEP recoil results

Conclusion

- A lighter higgs is favored in many BSM models
  - 2HDM, NMSSM, RS ...
- A model-independent analysis has been performed.
  - mass range [10, 120) GeV
  - 2000 fb^{-1}, when $\sqrt{s} = 250$ GeV.
  - $(-+, +-, --, ++) = (45\%, 45\%, 5\%, 5\%)$ polarization scenario
- Exclusion limits for κ^{95}_{hZZ} coupling factor
  - $\kappa^{95}_{hZZ} \in$ (0.05-0.12).
  - 1 order better than LEP recoil results.