Search for Higgs decaying to exotic scalers

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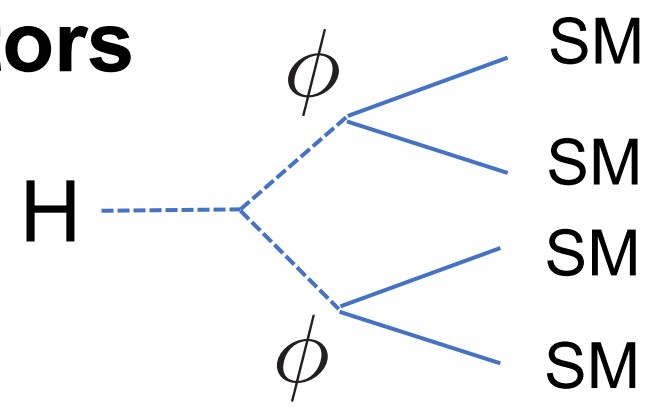
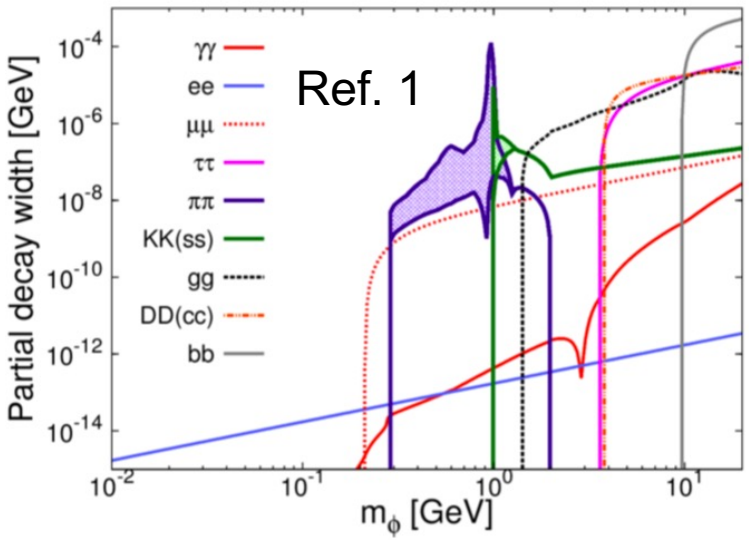
Higgs exotic decay through scalar mediators

- Model: SM + singlet
  - Higgs can couple to WIMP DM through the scalar mediator(φ).
  - The mediator appears as the Higgs exotic decay.
  - Model parameters: mediator mass(mφ), mixing angle(θ)



$$\Gamma(\phi \to \mathrm{SMs}) = \sin^2\theta \times \Gamma(h_{\mathrm{SM}} \to \mathrm{SMs})|_{m^2_{h_{\mathrm{SM}}} \to m^2_\phi}$$
$$\Gamma(h \to \mathrm{SMs}) = \cos^2\theta \times \Gamma(h_{\mathrm{SM}} \to \mathrm{SMs}),$$



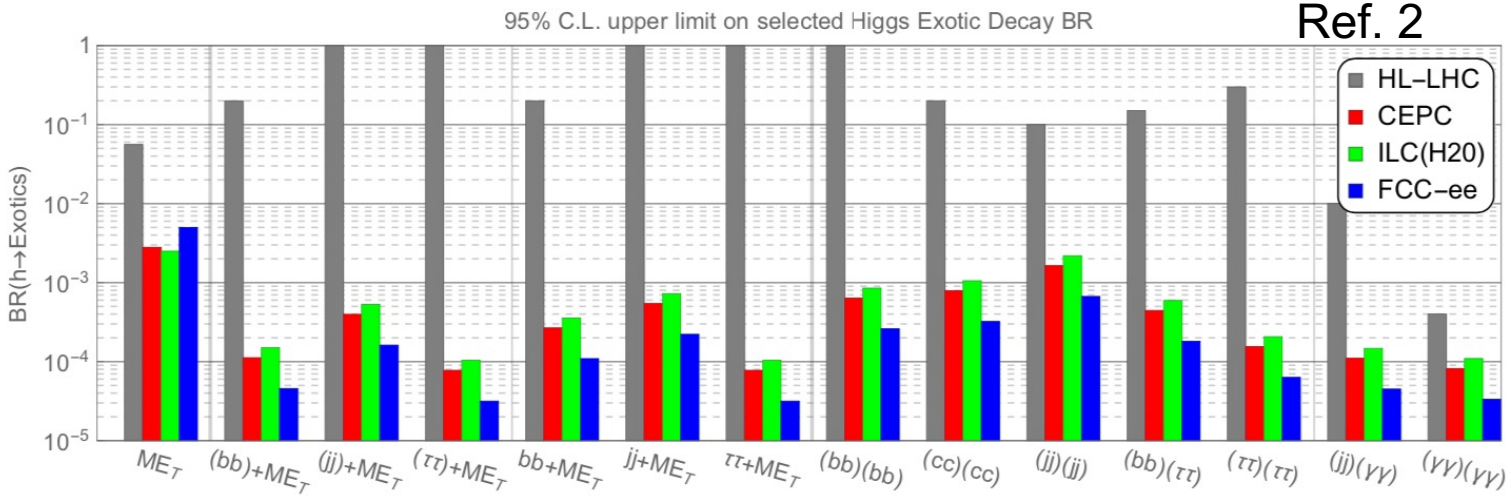
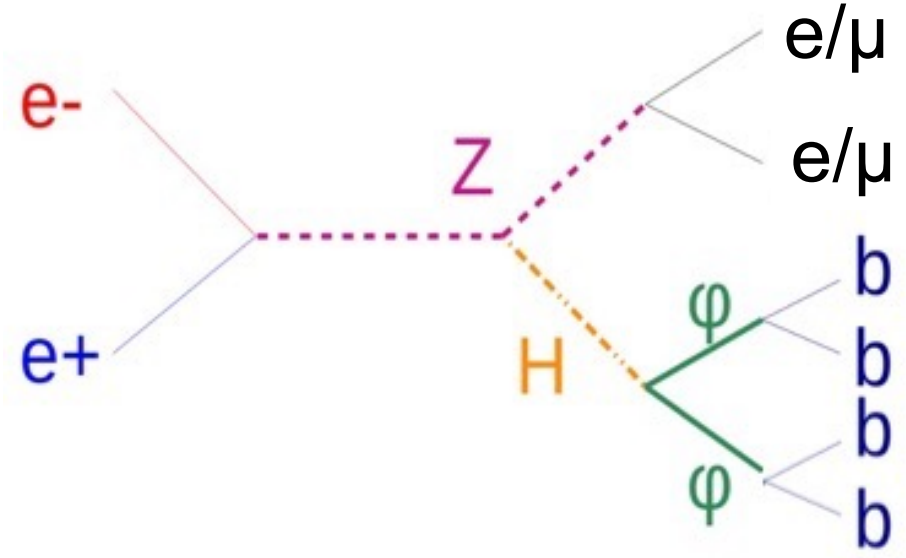


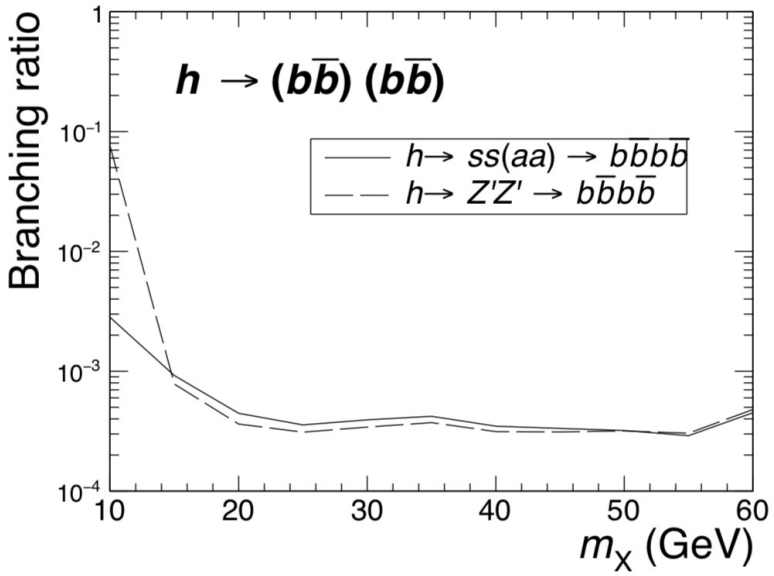
Fig. 12. The 95% C.L. upper limit on selected Higgs exotic decay branching fractions at HL-LHC, CEPC, ILC and FCC-*ee*. The benchmark parameter choices are the same as in Table 3. We put several vertical lines in this figure to divide different types of Higgs exotic decays.

Search for Higgs → φφ → 4b

- Target channel of this study:
  e+e- → ZH, Z → ee/μμ, H → φφ → 4b
  - with ILD full detector simulation
  - Mediator mass range: 15 - 60 GeV
  - 95% C.L. upper limit of BR(H→4b) ~ 0.1%



Ref. 2



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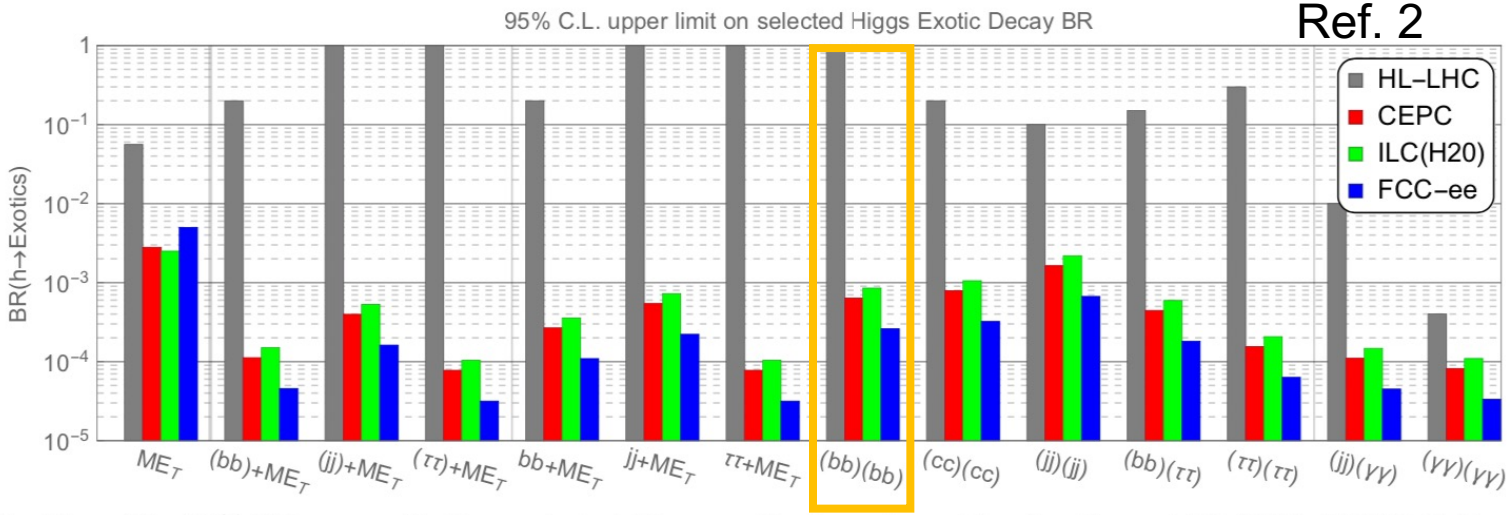

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Simulation setup

- Generator: WHIZARD 2.8.5

  Signal production
  - Model: MSSM_CKM
  - Assumption of φ mass: 15, 30, 45, 60 [GeV]
- Collider parameters:
  - ILC H20 scenario of √s = 250 GeV
  - Polarization: (P_{e^-}, P_{e^+}) = { (-0.8,+0.3), (+0.8,-0.3) }
- Detector: Full simulation of ILD latest setting (mc-2020)

Analysis flow

Event reconstruction

1. Particle reconstruction: `PandoraPFA`
2. Isolated lepton selection: `IsolatedLeptonTaggingProcessor`
3. Jet clustering & Flavor tagging: `LCFIPlus`

   Durham forced to 4 jets
4. Jet pairing

   Requiring the combination which invariant masses of paired jets are closest.

Event selection

- The number of isolated muons / electrons = 2
- The sum of b-probabilities of 4 jets > 3
- The recoil mass within (120, 160) GeV

- We assume BR(H→φφ→4b) = 1 % for event selection.

Isolated Lepton Tagging

- Processor: `MarlinReco/IsolatedLeptonTaggingProcessor`
  - Standard parameters

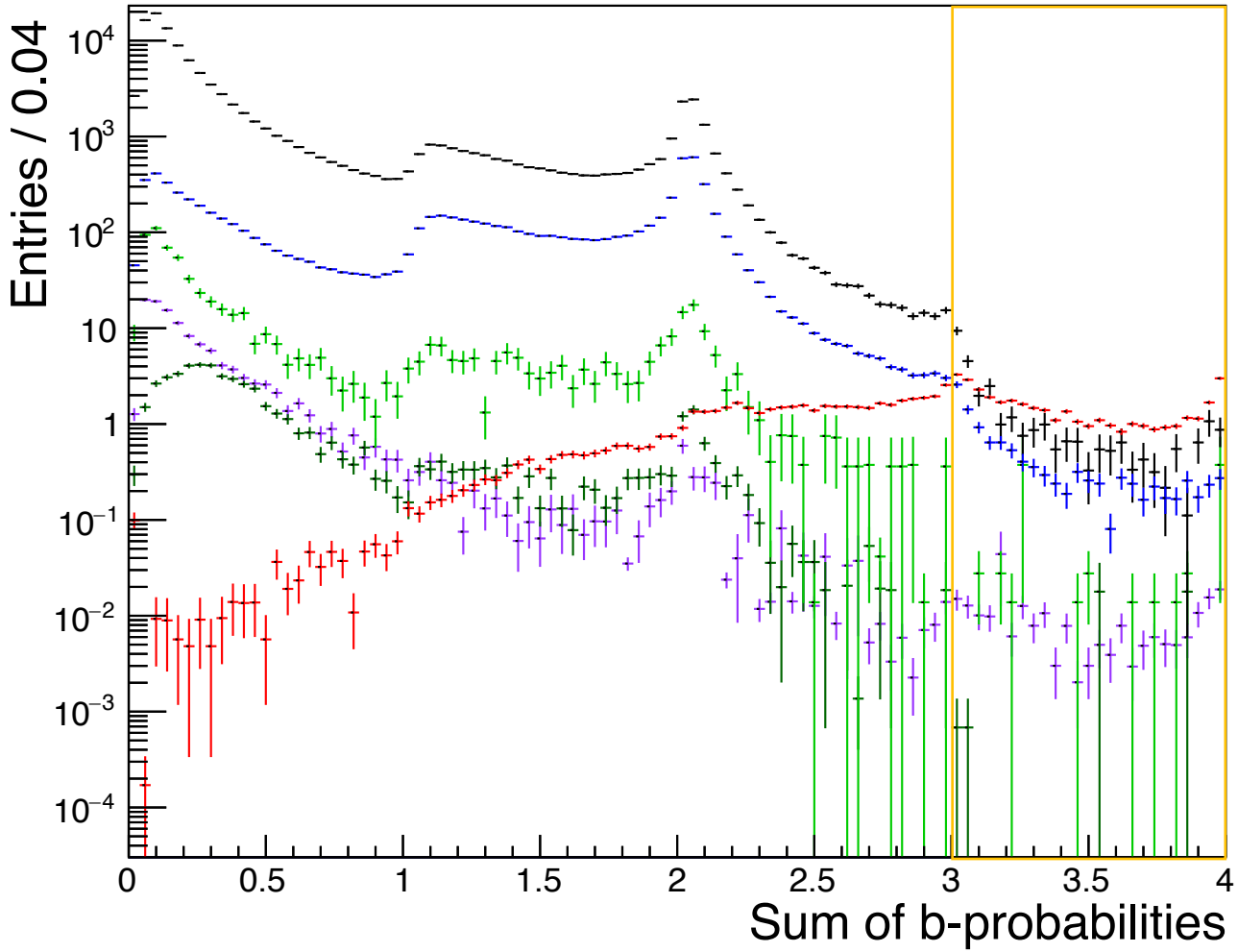
parameter	requirement e / μ	
$\cos\theta_L$	0.95	0.95
$\cos\theta_S$	0.98	0.98
E_{Cal} / p	0.5 - 1.3	< 0.3
E_{ECal} / E_{total}	> 0.9	-
E_{Yoke}	-	> 1.2
p	> 5	> 5
d0 significance	< 50	< 20
z0 significance	< 50	< 20
MVA cut	0.5	0.7

- Selection efficiency for signal
  - μμ: 93.6%
  - ee: 86.4%

Event selection: b-probability

Muon channel

Cut: flvl[0]==13&&flvl[1]==-13



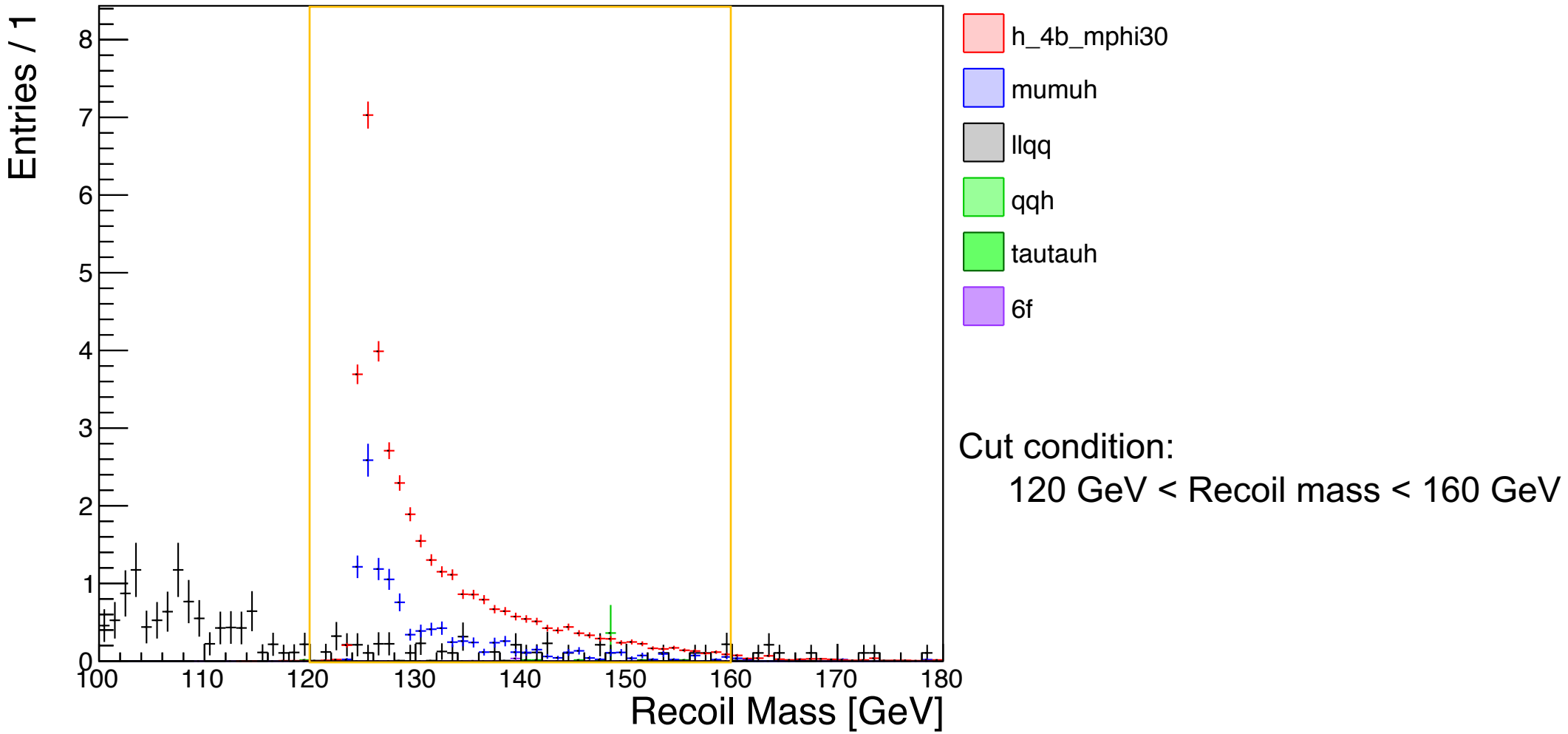
b-probability
- output from LCFIPlus flavor tagging processor

Cut condition:
"Sum of b-probabilities" > 3

Event selection: Recoil mass

Muon channel

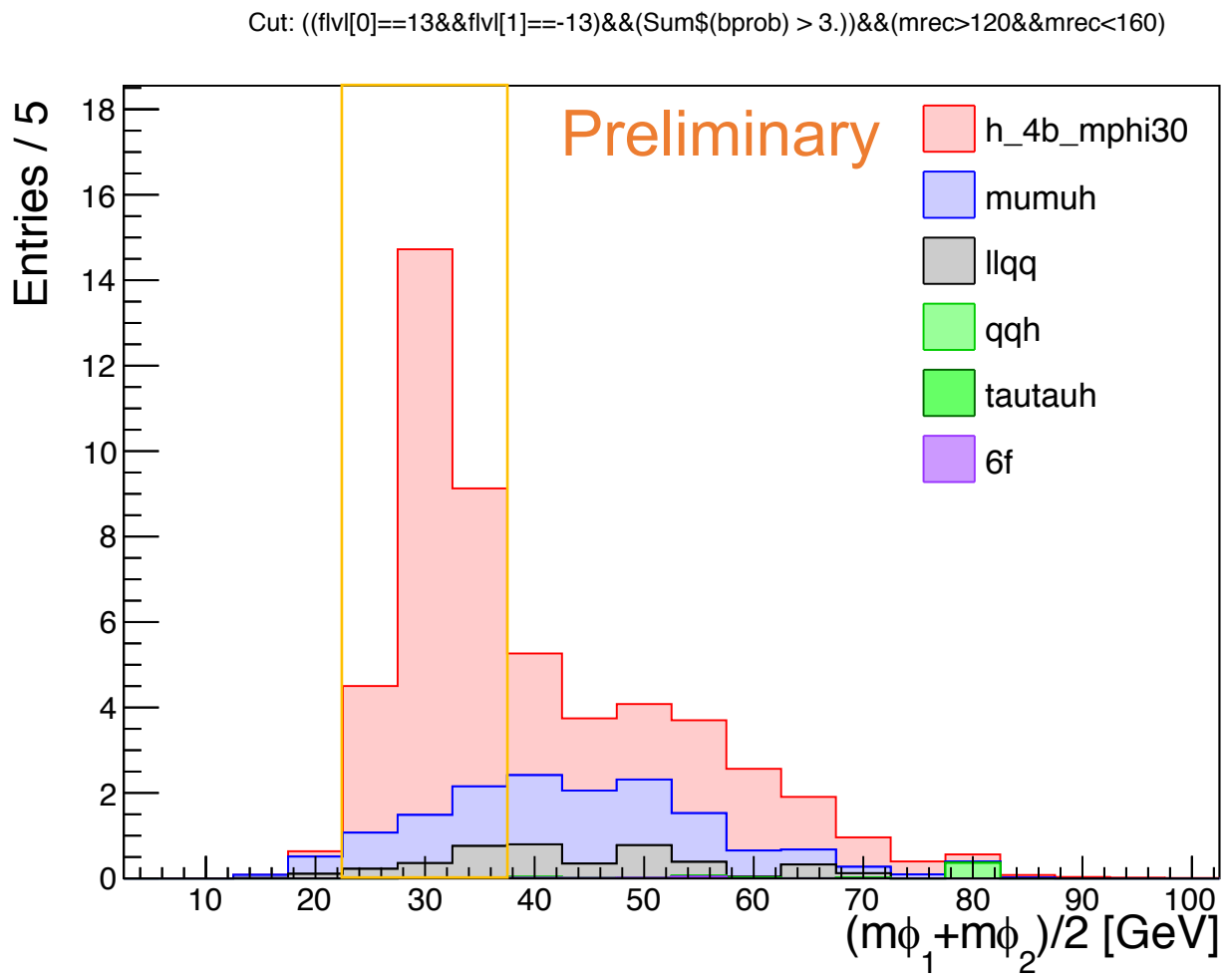
Cut: (flvl[0]==13&&flvl[1]==-13)&&(Sum$(bprob) > 3.)



Cut condition:

120 GeV < Recoil mass < 160 GeV

Result plot of mediator mass: μμ + 4b



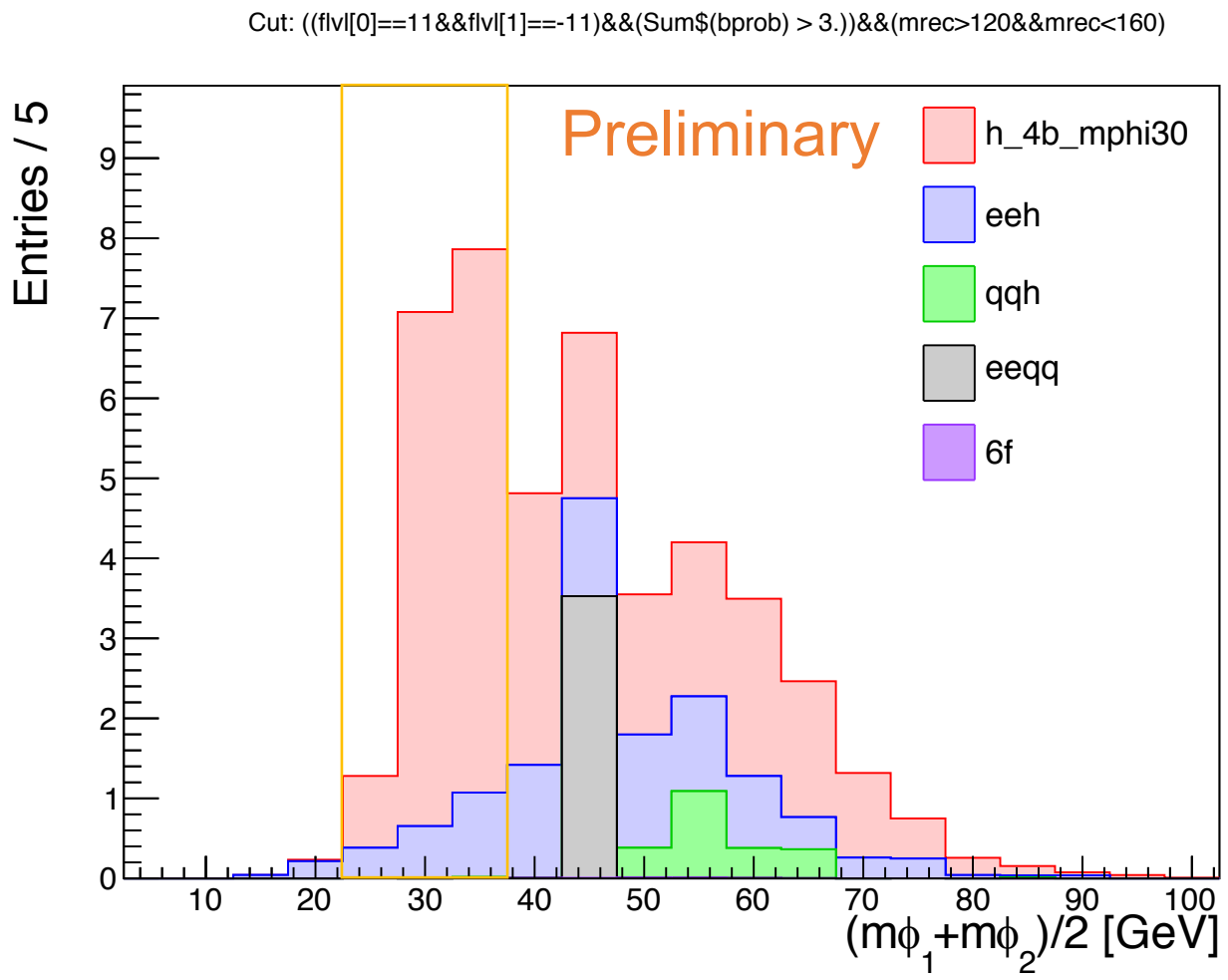
Luminosity = 900 fb^{-1}
Pol = (-0.8,+0.3)
mφ = 30 GeV
assuming BR(H→φφ→4b) = 1 %

in 30 ± 7.5 GeV
Ns = 23.6, Nb = 4.7

UL_{95} = 0.15%

- The remaining backgrounds are mainly μμH and μμqq.

Result plot of mediator mass: ee + 4b



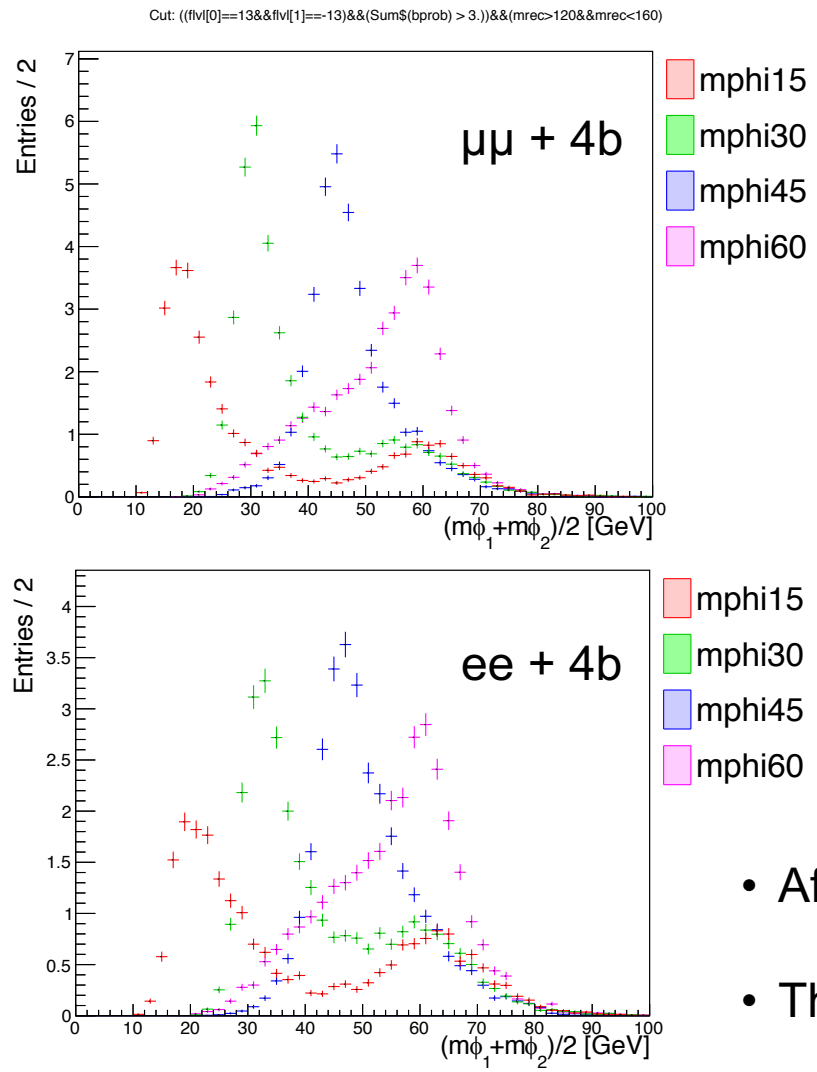
Luminosity = 900 fb^{-1}
Pol = (-0.8,+0.3)
mφ = 30 GeV
assuming BR(H→φφ→4b) = 1 %

in 30 ± 7.5 GeV
Ns = 14.1, Nb = 2.1

UL_{95} = 0.17%

- The statistics of eeqq are not enough yet. Work in progress…

Comparison of φ mass & Combined results



Preliminary

μμ + 4b

mφ	UL-left	UL-right	combined
15	0.09%	0.10%	0.07%
30	0.15%	0.19%	0.12%
45	0.16%	0.21%	0.13%
60	0.14%	0.20%	0.11%

ee + 4b

mφ	UL-left	UL-right	combined
15	0.13%	0.16%	0.10%
30	0.17%	0.22%	0.13%
45	0.25%	0.40%	0.21%
60	0.21%	0.21%	0.15%

mφ	ee + μμ
15	0.06%
30	0.09%
45	0.11%
60	0.09%

- After the analysis, we obtained UL_{95} ~ 0.1% for all mφ.
  - The ee-channel should be updated by adding bkg statistics.
- The smaller peaks would be due to mis-pairing of jets.

Summary and Prospect

- Higgs can couple to WIMP DM through the scalar mediator.
- The ILC has the possibility to search for Higgs exotic decays to the scalar mediators.
- We performed a full simulation study at the 250 GeV ILC using ILD concept.
- The target channels are $e^+e^- \to ZH$, $Z \to ee/\mu\mu$, $H \to \varphi\varphi \to 4b$.
- We obtained UL_{95} of $BR(H \to \varphi\varphi \to 4b) \sim 0.1\%$ in the range of 15 - 60 GeV for $m\varphi$.
- Ideas for update:
  - Apply the kinematic fitting for good jet pairing
  - Add the hadronic channel $Z \to qq$

References

1. S. Matsumoto, Y. S. Tsai, P. Y. Tsng, ”*Light Fermionic WIMP Dark Matter with Light Scalar Mediator*”, **JHEP07**, **2019**
2. Zhen Liu, Lian-Tao Wang, Hao Zhang, “*Exotic decays of the 125 GeV Higgs boson at future e+e− lepton colliders*”, ***Chinese Phys. C* 41 063102, 2017**

backup

Event samples

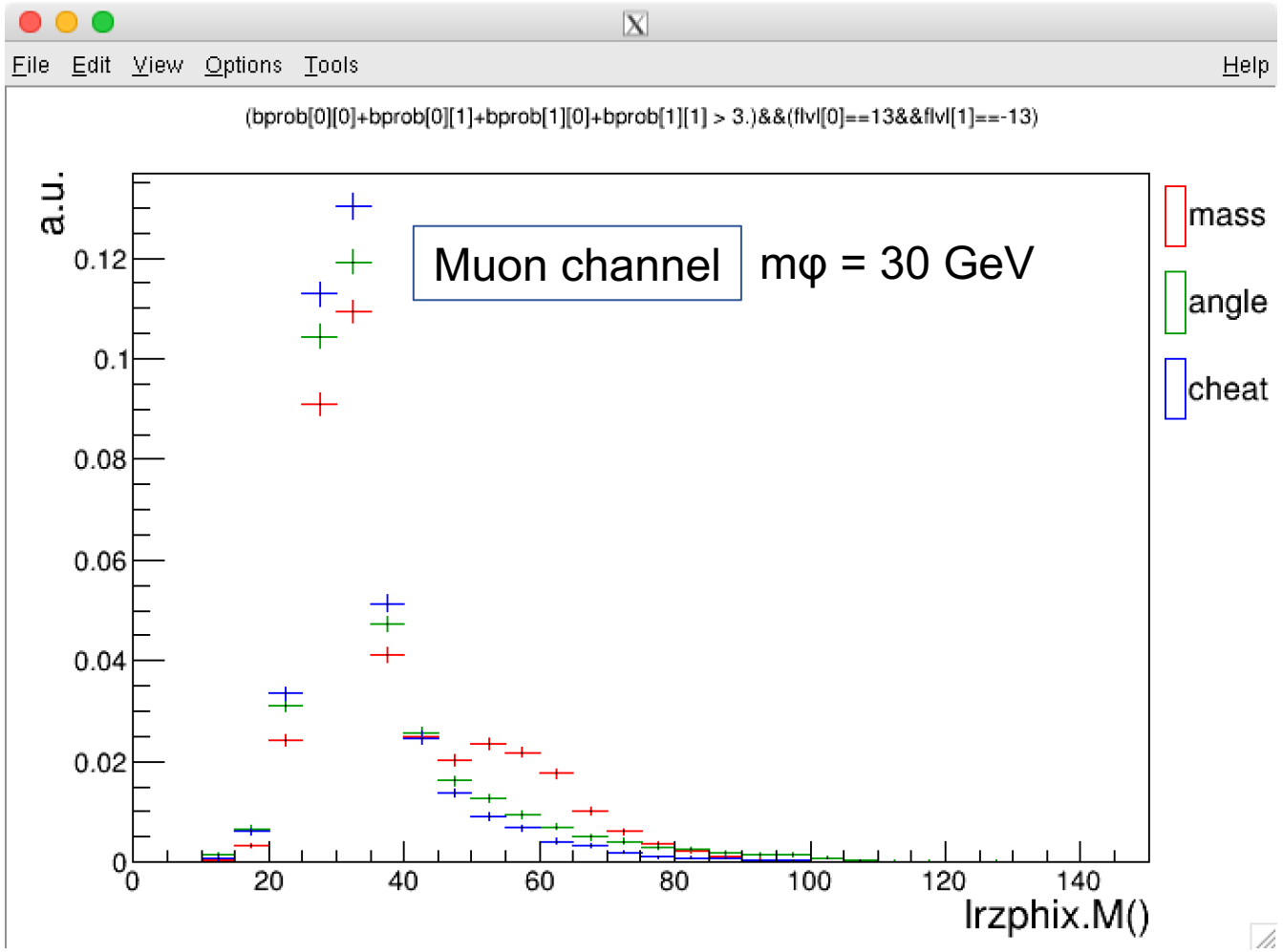
- Signal
  - 20,000 events / mφ / pol.
- Background
  - ffh
    - 500,000 events / process / pol.
  - 4f_zz_sl
    - _lr 4,200,000 events
    - _rl 2,400,000 events
  - Other 2f, 4f, 6f
    - 10,000 events / process / pol.

Parameters for Isolated Lepton Tagging

- Processor: MarlinReco / IsolatedLeptonTaggingProcessor

parameter	value	description
CosConeLarge	0.95	cosine of the larger cone
CosConeSmall	0.98	cosine of the smaller cone
MaxEOverPForElectron	1.3	maximum ratio of energy in calorimeters over momentum for electron
MaxEOverPForMuon	0.3	maximum ratio of energy in calorimeters over momentum for muon
MinEOverPForElectron	0.5	minimum ratio of energy in calorimeters over momentum for electron
MinEecalOverTotEForElectron	0.9	minimum ratio of energy in ecal over energy in ecal+hcal
MinEyokeForMuon	1.2	minimum energy in yoke for electron
MinPForElectron	5	minimum momentum for electron
MinPForMuon	5	minimum momentum for muon
MaxD0SigForElectron	50	maximum d0 significance for electron
MaxD0SigForMuon	20	maximum d0 significance for muon
MaxZ0SigForElectron	50	maximum z0 significance for electron
MaxZ0SigForMuon	20	maximum z0 significance for muon
CutOnTheISOElectronMVA	0.5	cut on the MVA output of isolated electron selection
CutOnTheISOMuonMVA	0.7	cut on the MVA output of isolated muon selection

Fast Analysis of hφφ: Jet pairing



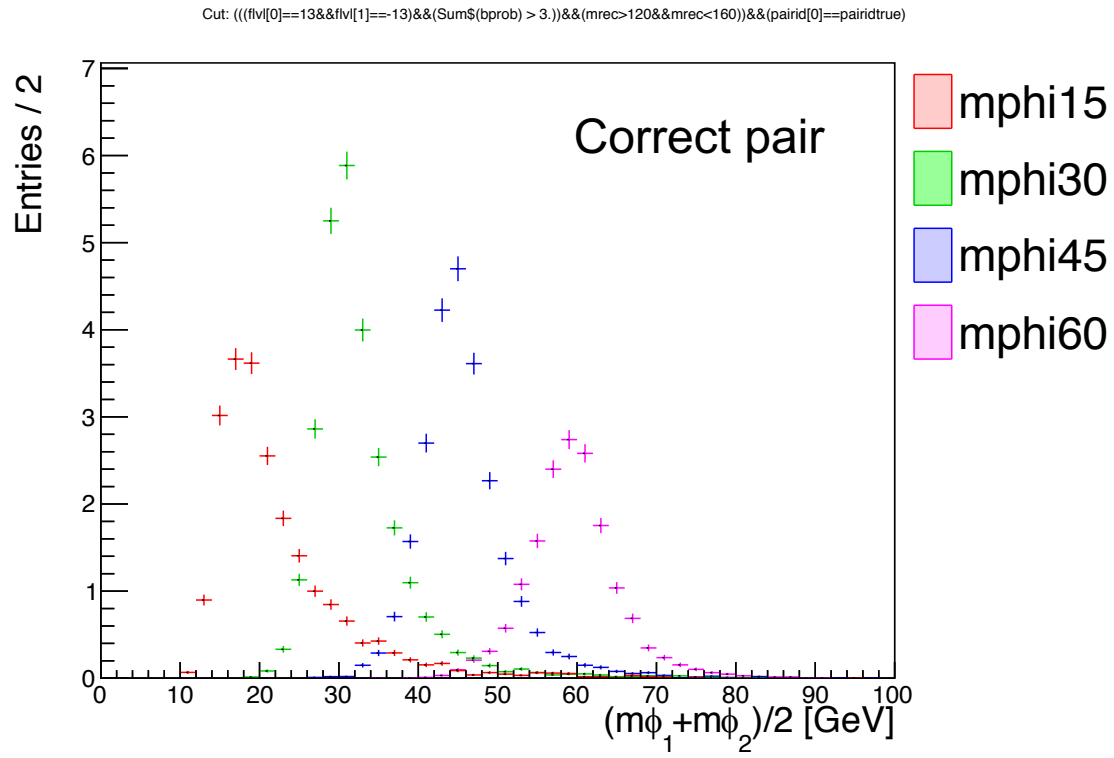
- $m_{12} = m_{34}$ (equal mass)
- back-to-back φ pair in H rest frame
- Jet direction matching b/w Rec/MC

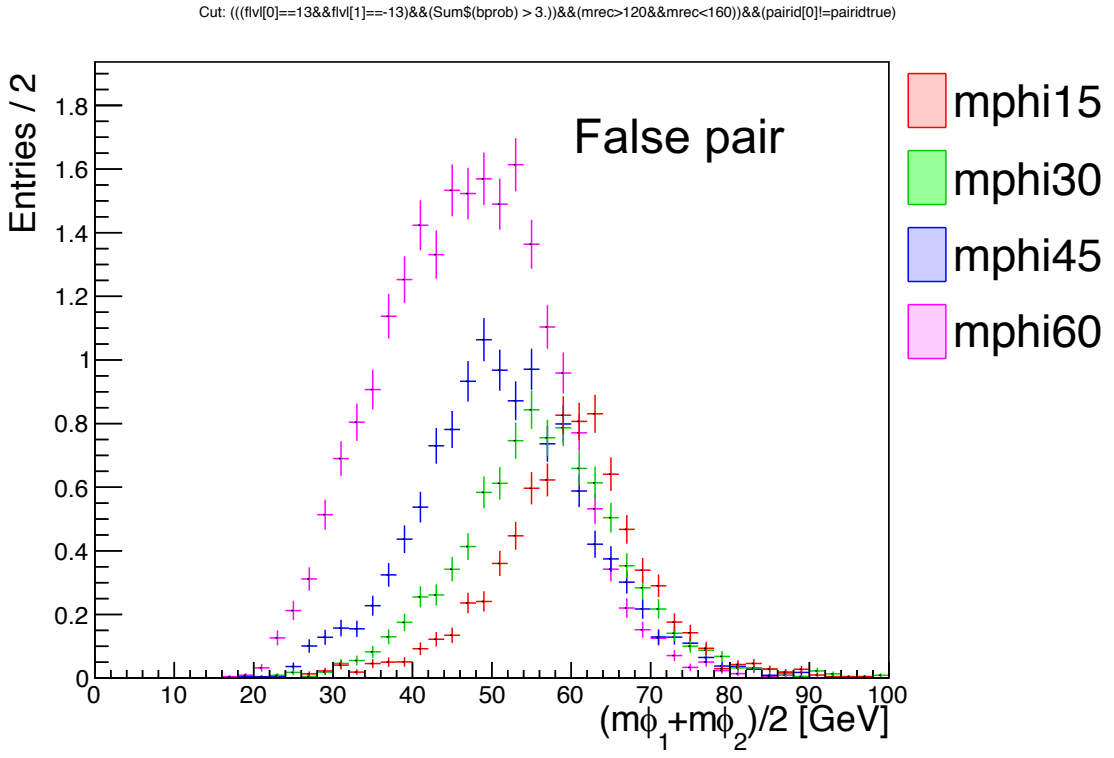
Pairing accuracy

mphi	equal mass	back-to-back
15	79.1%	93.6%
30	75.1%	85.0%
45	62.8%	52.4%
60	37.1%	5.8%

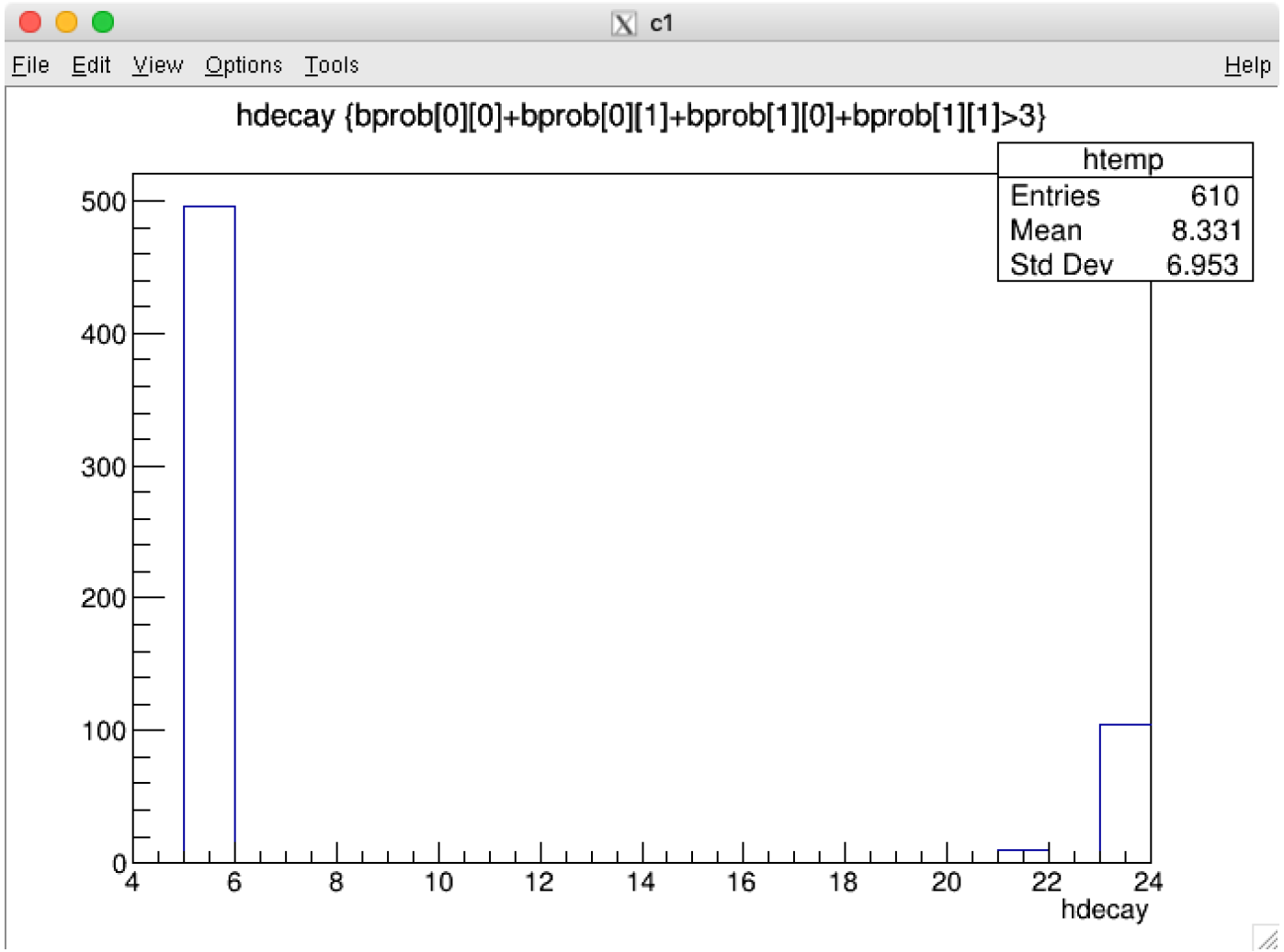
Jet pairing effect

Muon channel





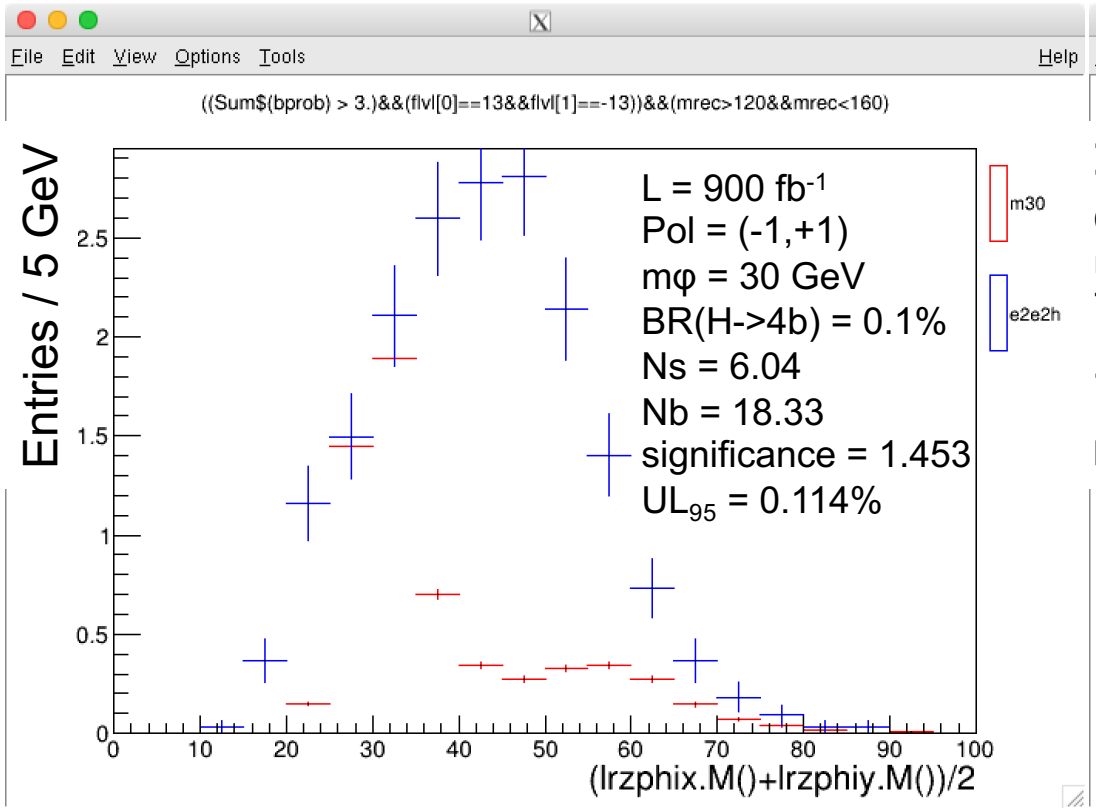
Higgs decay mode in remaining μμH process

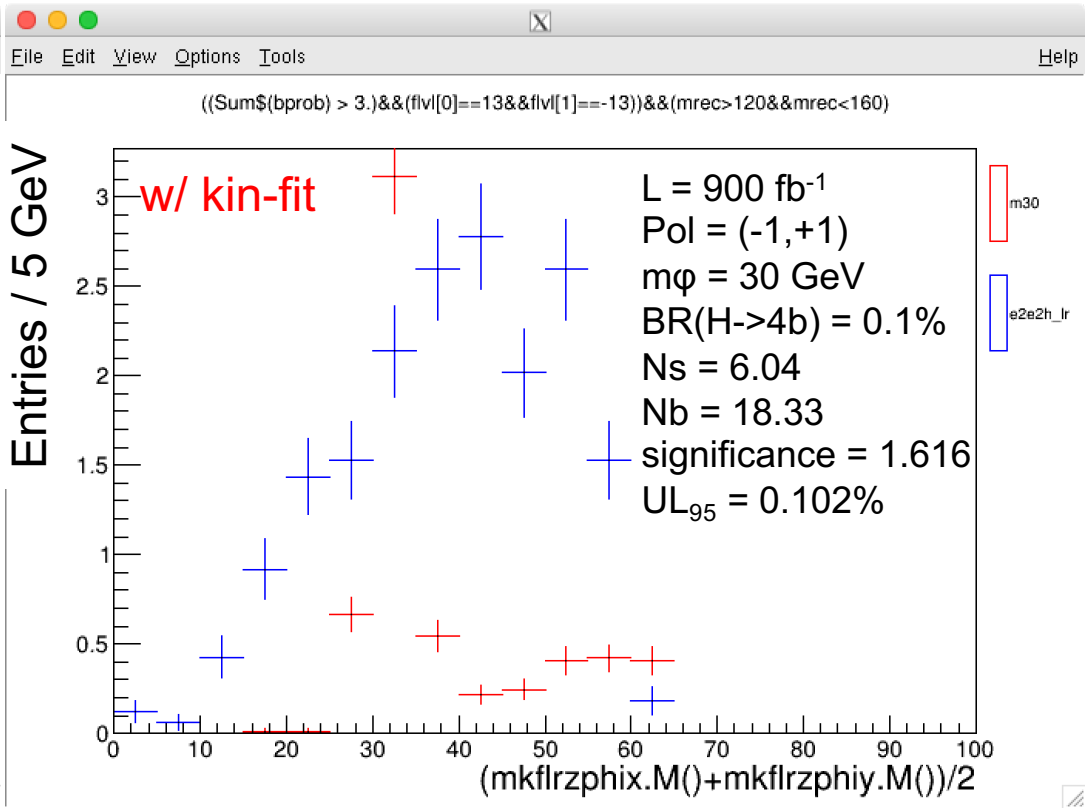


- Pol. = (-1,+1)
- Cut: Sum$(bprob)/4 > 3
- Efficiency = 0.122%
- Remaining decay mode
  - H->bb: ~82%
  - H->ZZ: ~16%
  - H->gg: ~2%

Ideas for update: Kinematic fitting

- The kinematic fitting is performed with a part of events and improved the result.
  - Fit Object
    - 2 muons
    - 4 jets with b-jet resolution
    - 1 ISR photon
  - Constraint
    - Total Energy/Px/Py/Pz for all FOs
    - Higgs mass = 125 GeV
    - Same mass of φs





Test kinematic fitting

- Signal: 20,000 events / pol.
- e2e2h: 500,000 events / pol.