Higgs$\to \tau\tau$ Analysis at CEPC

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IHEP

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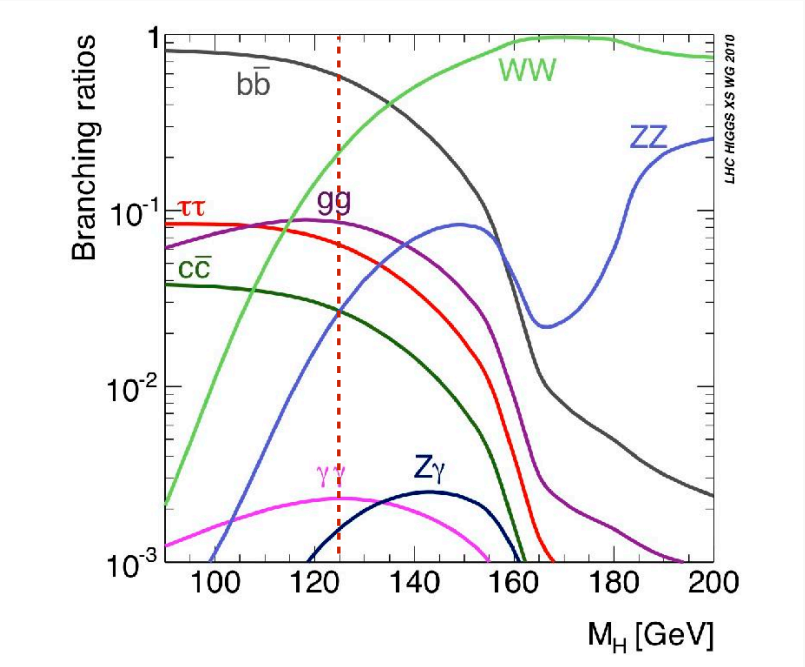
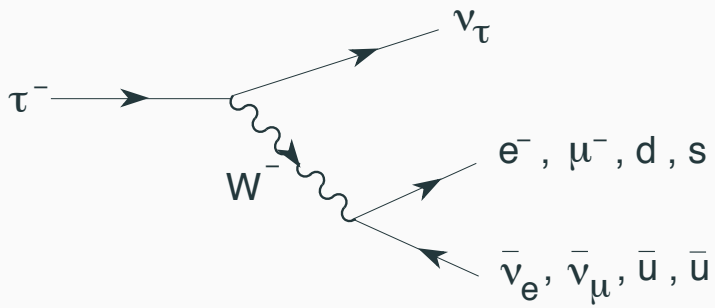
Motivation

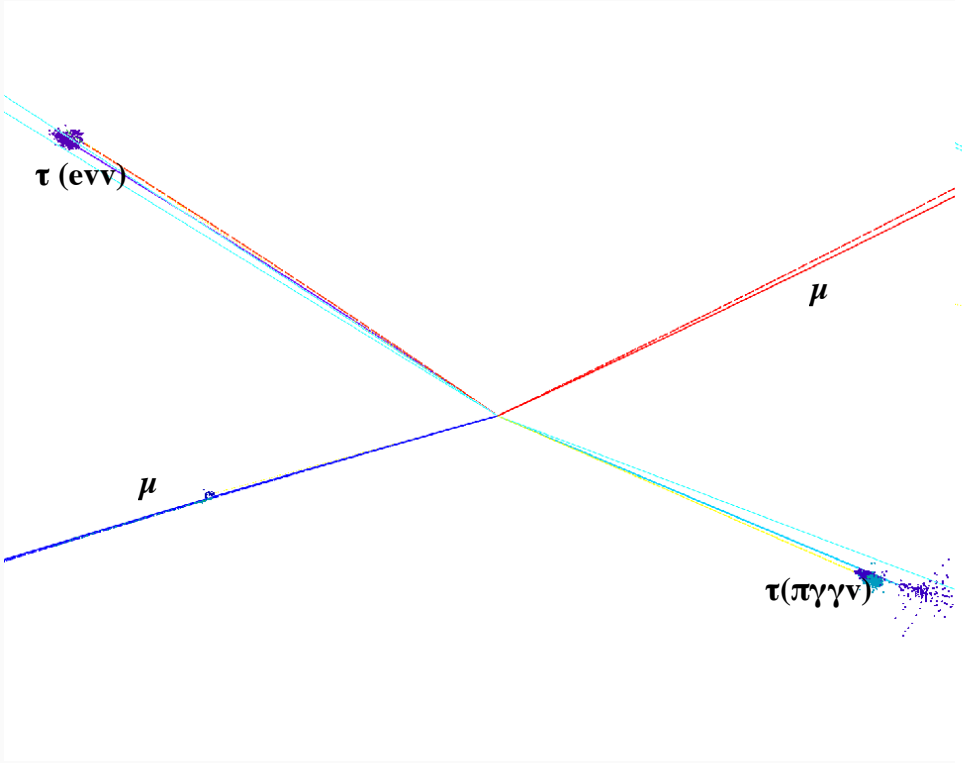
- Tau is the heaviest SM lepton - large coupling to Higgs boson Br($H \to \tau\tau$): 6.27%
- accuracy(BR($H \to \tau\tau$)) $\sim$ 1%
- rich relevant physics
- Performance rely on particle separation
- Objectives for detector optimization
- Testbed for PFA
- Clean: no neutrons in final states; $>$ 90% decaying to 1 or 3 tracks and photon pairs

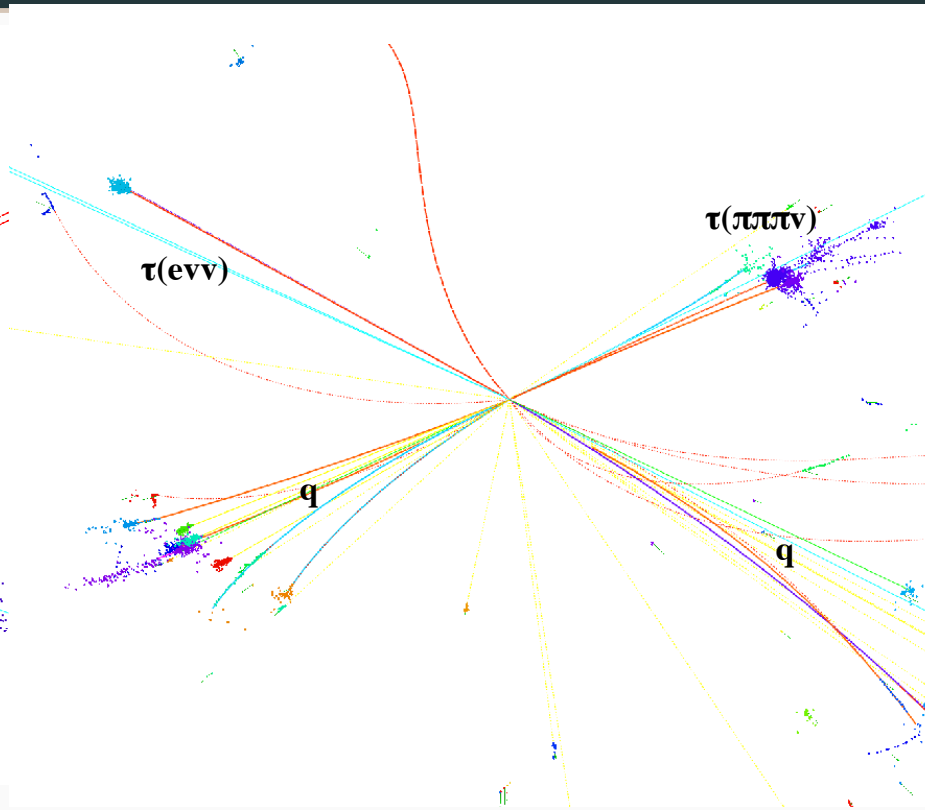




Tau Finding

Tau topology

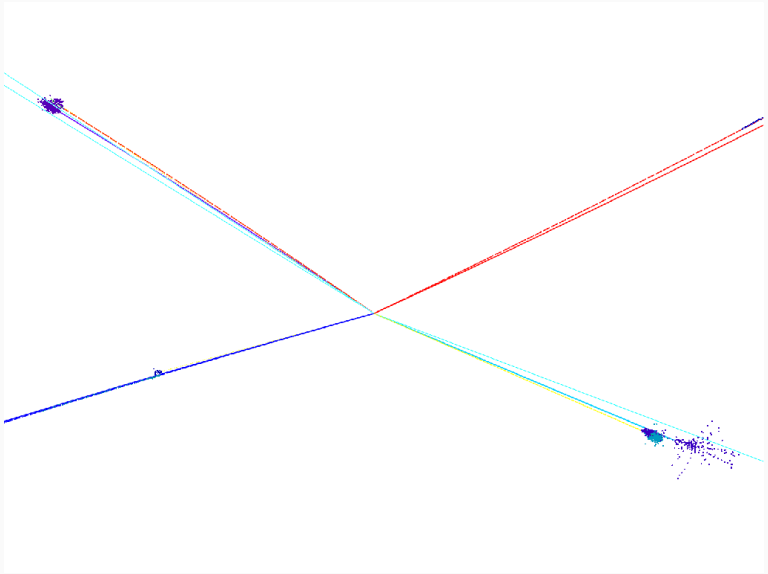




- *llH* channel:
- Signal ($5ab^{-1}$): $\mu\mu H(2247)/\nu\nu H(15504)/(eeH2404)$
- Irreducible background:
  - $ZZ \to \mu\mu\tau\tau/\nu\nu\tau\tau$
  - for $\nu\nu H$: $WW \to \nu\tau\nu\tau$

- *qqH* channel:
- Signal: ($5ab^{-1}$): $qqH(45597)$
- Irreducible background: $ZZ \to qq\tau\tau \sim 500k$

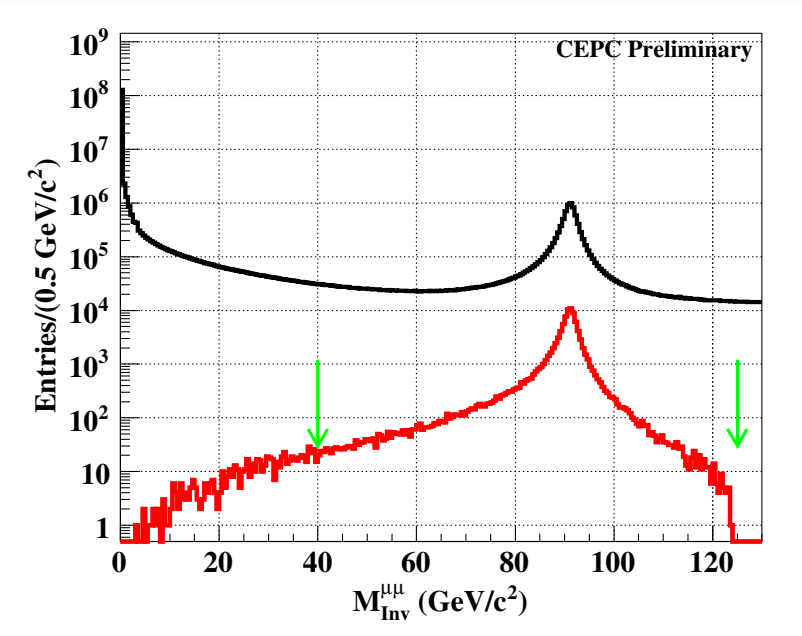
$\mu\mu H$ channel-Tactics

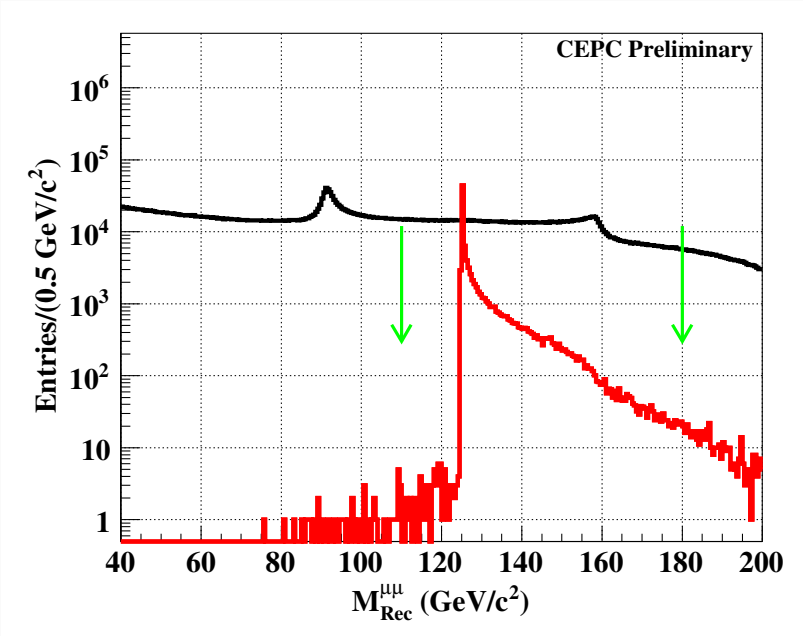


- Pre-selection for $\mu\mu H$
  - $\mu\mu$ information
  - Rejection: background without $Z \to \mu\mu$
- τ finding
  - Multiplicity
  - Rejection: jets
- Impact parameter fitting
  - Vertex information
  - Rejection: $H \to WW^*$

$\mu\mu H$-Pre-selection

- $N_{\mu^+} > 1, N_{\mu^-} > 1$; remove no muon backgrounds
- $110 GeV < M_{recoil} < 180 GeV$; keep Higgs signal
- $40 GeV < M_{invariant} < 180 GeV$; keep Z signal
- Main background after preselection: $2f(\mu\mu), ZZ$

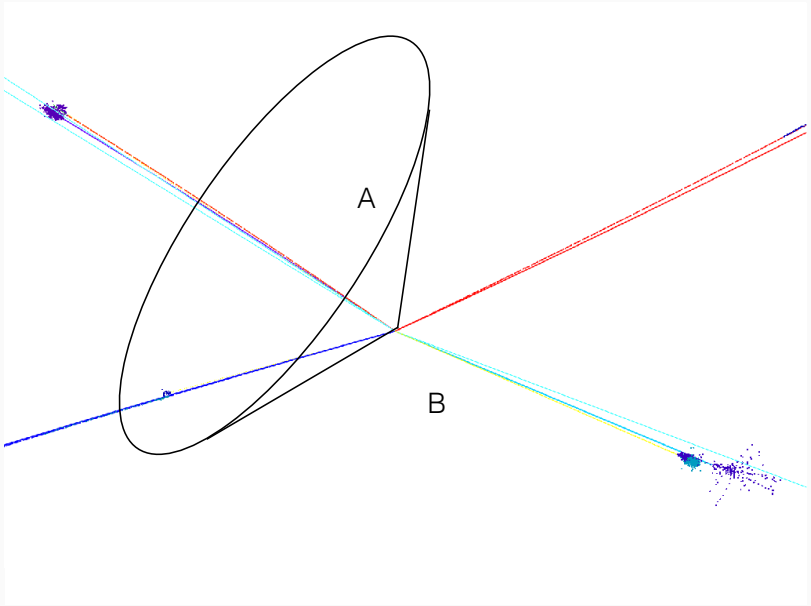




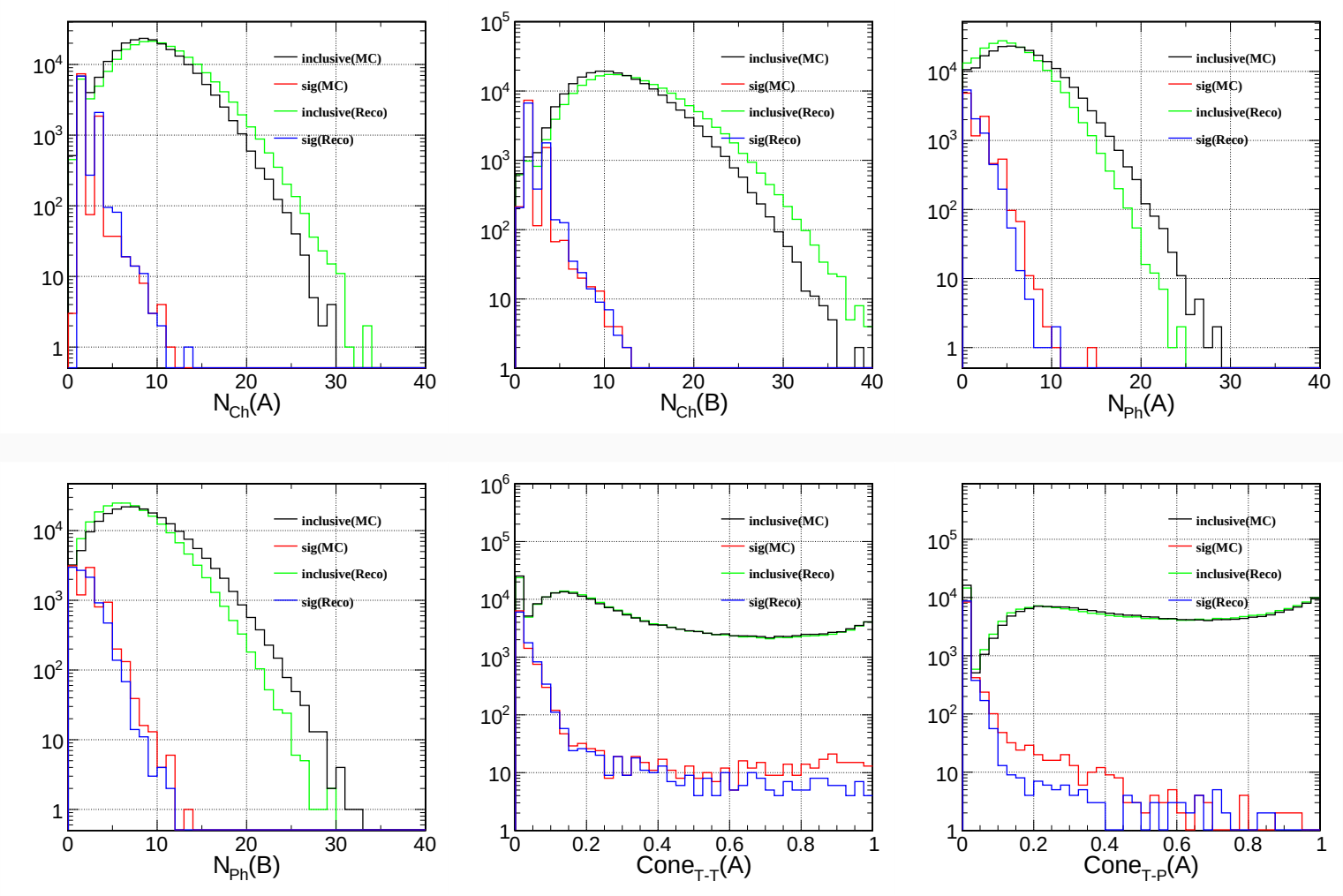
	$\mu\mu H\tau\tau$	$\mu\mu H$ inclusive bkg	ZZ	WW	single$W$	single$Z$	$2f$
total generated	2292	33557	5711445	44180832	15361538	7809747	418595861
after preselection	2246	32894	122674	223691	0	86568	1075886

$\mu\mu H$-τ Finding

- Muon veto (Inv M $\sim M_Z$)
- Find leading track
- Collect particles nearby and in the opposite direction (energy>0.5GeV)
- Count number of tracks and photons: Ntrk(A/B), Nphoton(A/B)
- Get track-track angles (Cone_TT), track-photon angles (Cone_TP), photon-photon angles (Cone_PP)
- Training of these variables in TMVA

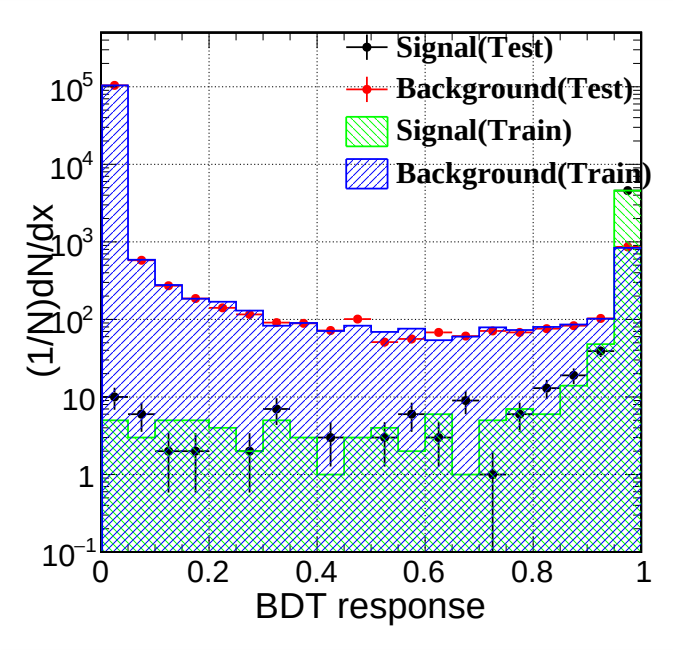


$\mu\mu H$-τ Finding



$\mu\mu H$-τ Finding

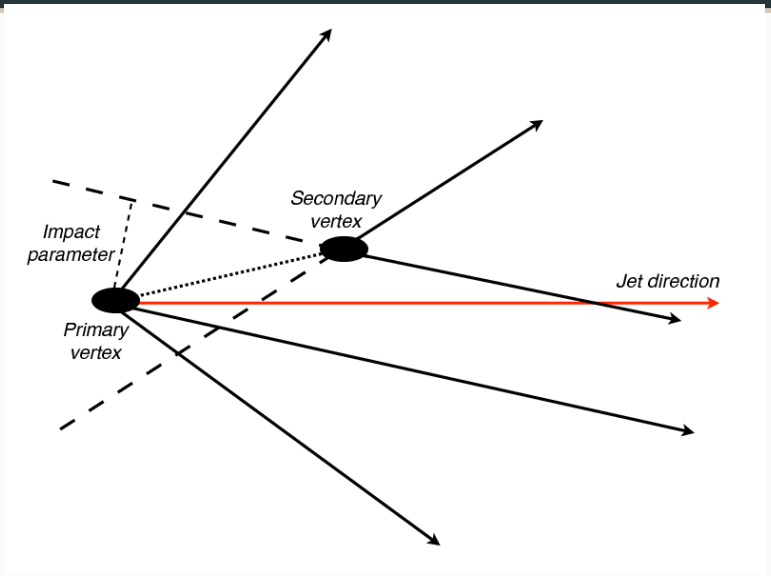
- TMVA Training: BDTG
- TMVA cut: BDTG>0.78
- Signal efficiency: 93.15%
- $\sqrt{S+B}/S \sim 2.9\%$
- Remaining backgrounds:
  - ZH: $H \to WW$ with W leptonic decay
  - SM: WW/ZZ leptonic decay

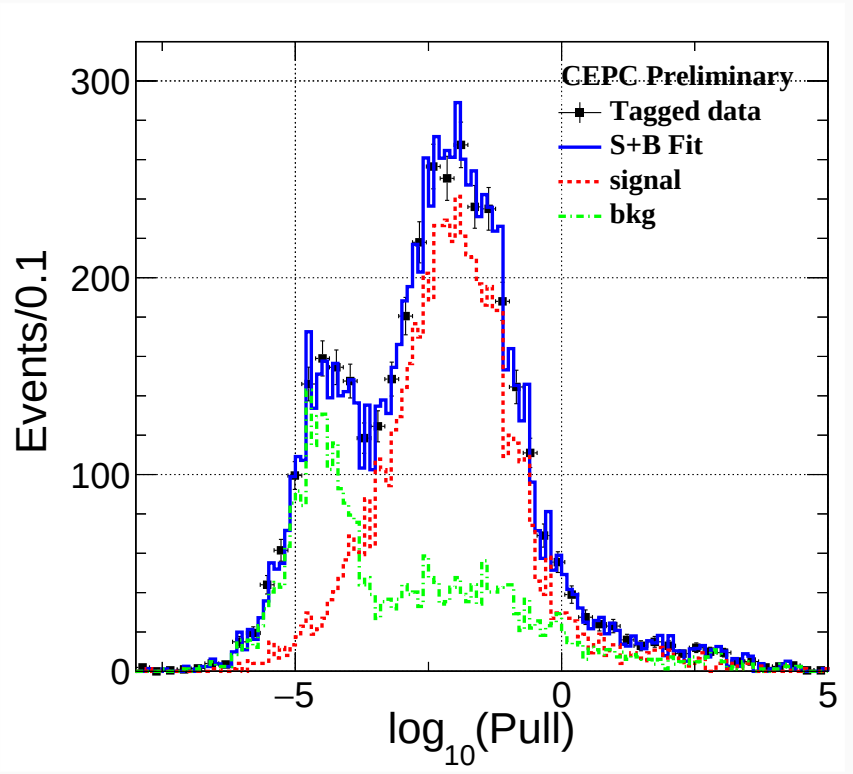


	$\mu\mu H\tau\tau$	$\mu\mu H$ inclusive bkg	ZZ	WW	single$W$	single$Z$	$2f$
after preselection	2246	32894	122674	223691	0	86568	1075886
$N_{trk/ph}$	2219	1039	2559	352	0	9397	25583
BDT$>$0.78	2135	885	484	24	0	157	161
efficiency	93.15%	2.63%	$<$0.01%	$<$0.01%	$<$0.01%	$<$0.01%	$<$0.01%

$\mu\mu H$-Impact parameter Fitting

- idea: starting points for tracks decayed from τs $>$ others
- Pull: $D0^2 + Z0^2$
- Fit result: signal $\sim 2137 \pm 48$
- Accuracy: 2.26±0.05%
- Depends on vertex resolution
- Simple extrapolating to eeH: preselection for background 4 times larger than in $\mu\mu H$ accuracy 2.72%



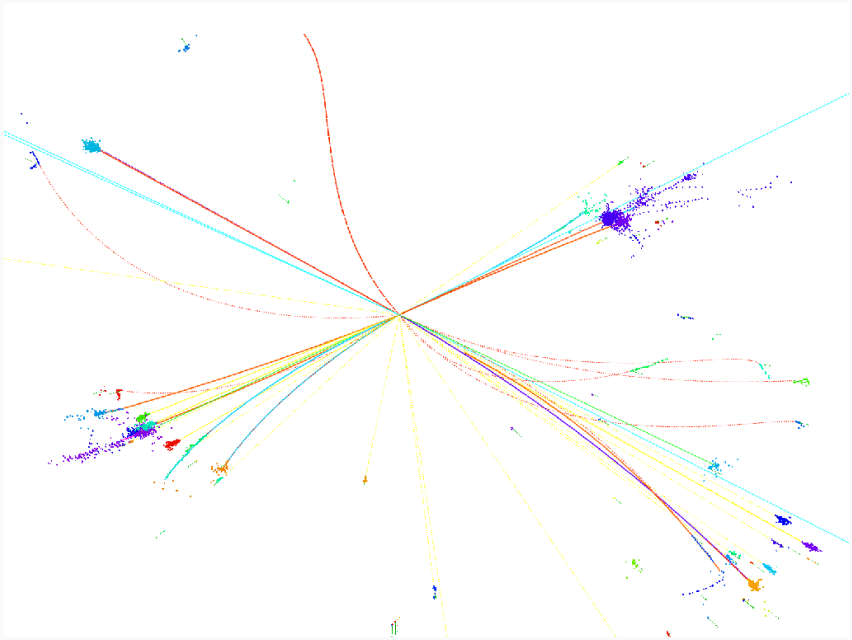


$\nu\nu H$

- Similar procedure as $\mu\mu H$, without vetoing charged track
- Signal efficiency after pre-selection: 60.8% (not optimized)
- Signal efficiency after τ finder: 57.02%
- Huge irreducible background: tough to fit...
- Accuracy: 4.29%

	$\nu\nu$H$\tau\tau$	$\nu\nu$H inclusive bkg	ZZ	WW	singleW	single Z	$2f$
total generated	15497	231670	5711445	44180832	17361538	7809747	418595861
after preselection	9434	214830	1239457	7463105	3327803	956694	12826280
$N_{Trk}(A/B) < 6$ & $N_{Ph}(A/B) < 7$	9260	8858	24760	1354852	17389	676185	1535029
BDT > 0.78	8836	6587	15450	89729	1355	10739	11243
efficiency	57.02%	2.84%	0.27%	0.20%	<0.01%	0.14%	<0.01%

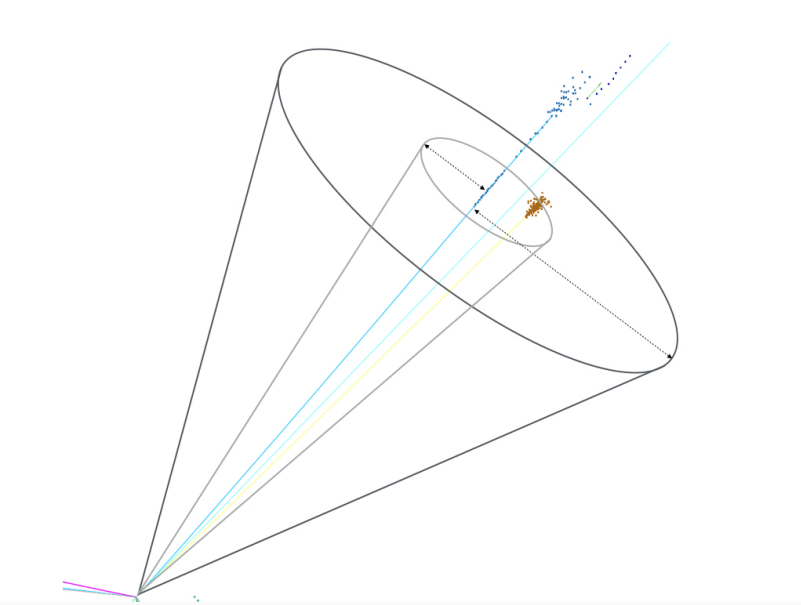
qqH Tactics



- Pre-selection
  - Missing mass, transverse momentum, multiplicity
  - Reject: leptonic; high energy neutrinos / without neutrinos
- τ candidate finding
  - Multiplicity and isolation
  - Reject: Jets
- Event finding
  - $\tau\tau$ information
  - Reject: $2f$; fake τ candidate
  - qq information
  - Reject: ZH conjugation; ZZ
- Impact parameter fitting
  - Vertex information
  - Reject: $H \to WW^*$

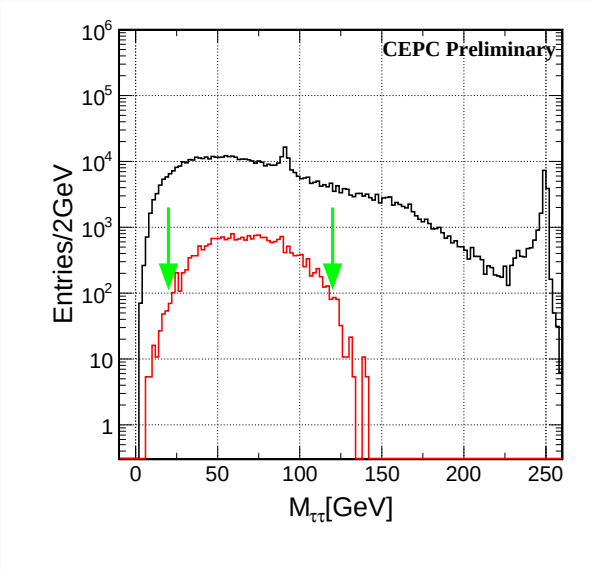
qqH-τ finding

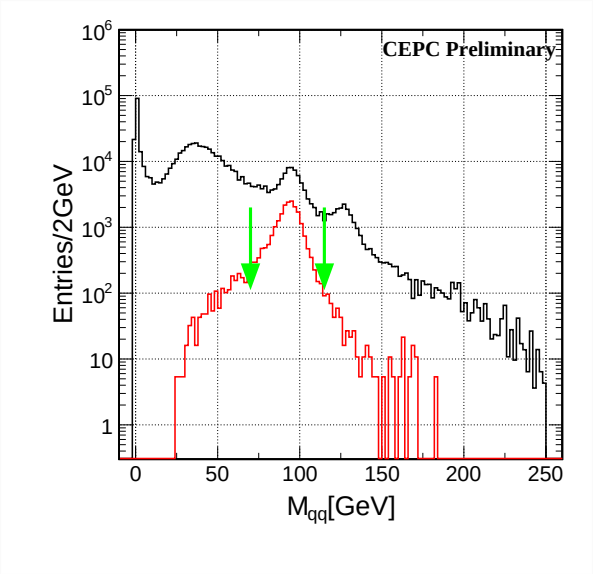
- Tracks energy ($> 1.5 GeV$)
- Ntracks$<$ 7, Nphotons$<$ 10 in cone_s(0.15)
- Isolated: energy ratio of cone_s to cone_l(0.45) > 0.92
- visible mass ($< 2.0 GeV$)
- existing opposite charged τs
- optimized to efficiency$\times$purity (58%)
  efficiency:
  $N(\tau^+\tau^-)/N(qqH\tau\tau)$
  purity:
  $1 - N(\tau^+\tau^-)/N(qqH\text{inclusive})$

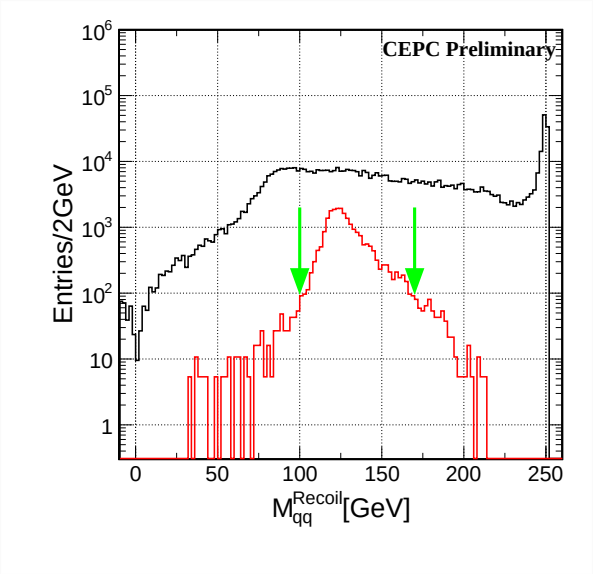


qqH-Event finding

- Steps:
  - leading opposite charged τs defined to be $\tau\tau$ system
  - remaining particles defined to be qq system
- Variables:
  - visible $\tau\tau$ invariant mass
  - qq invariant mass
  - qq recoil mass
- $\sqrt{S+B}/S \sim 1.14\%$

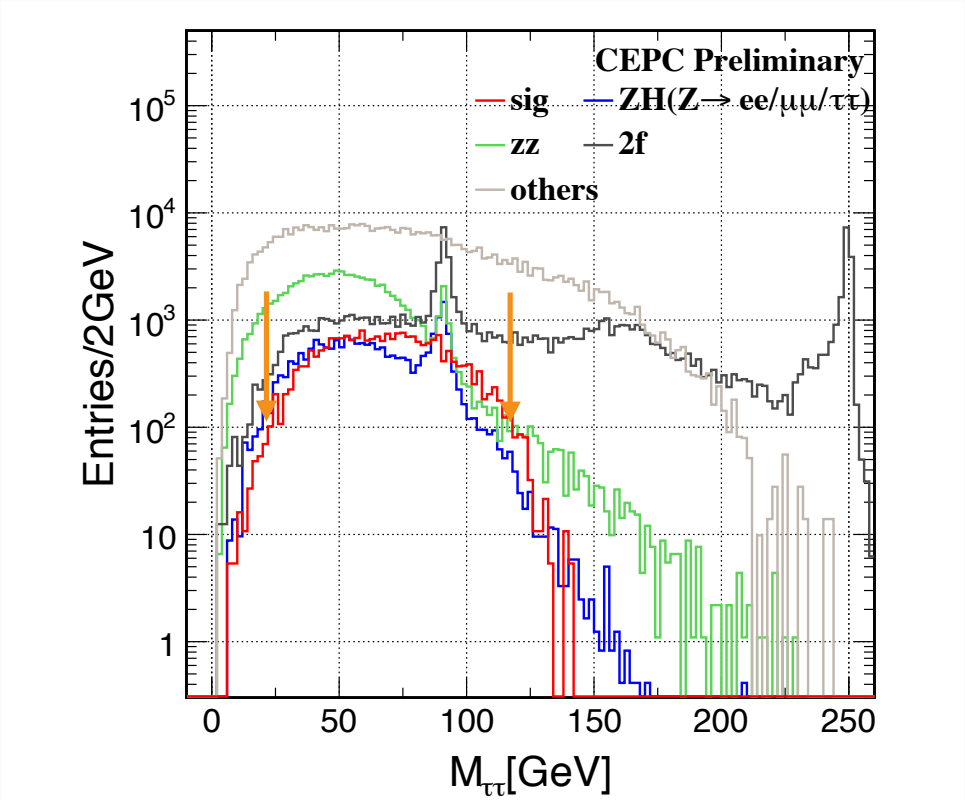






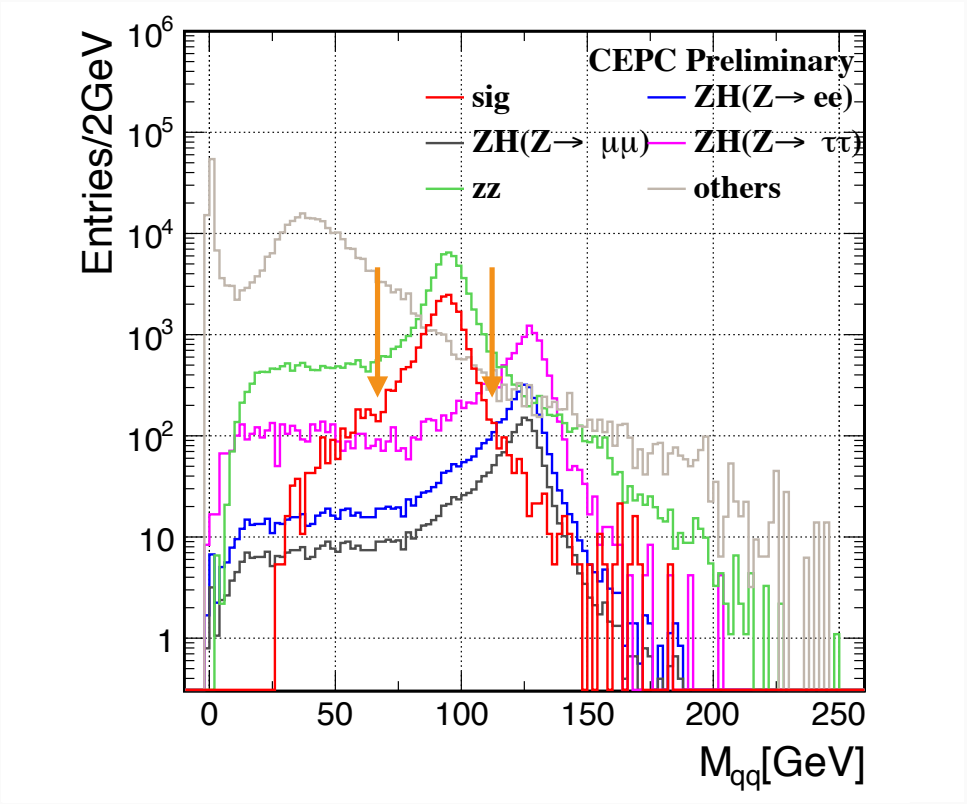
$\tau\tau$ invariant mass

- (20GeV, 120GeV)
- Main background reduced:
  - 2f
  - fake tau candidate
- Main background remaining:
  - ZH
  - ZZ
  - WW



qq invariant mass

- Peak @ M_Z
- Main background reduced:
  - ZH with Z to tau
  - WW semi-leptonic
- Main background remaining:
  - ZZ

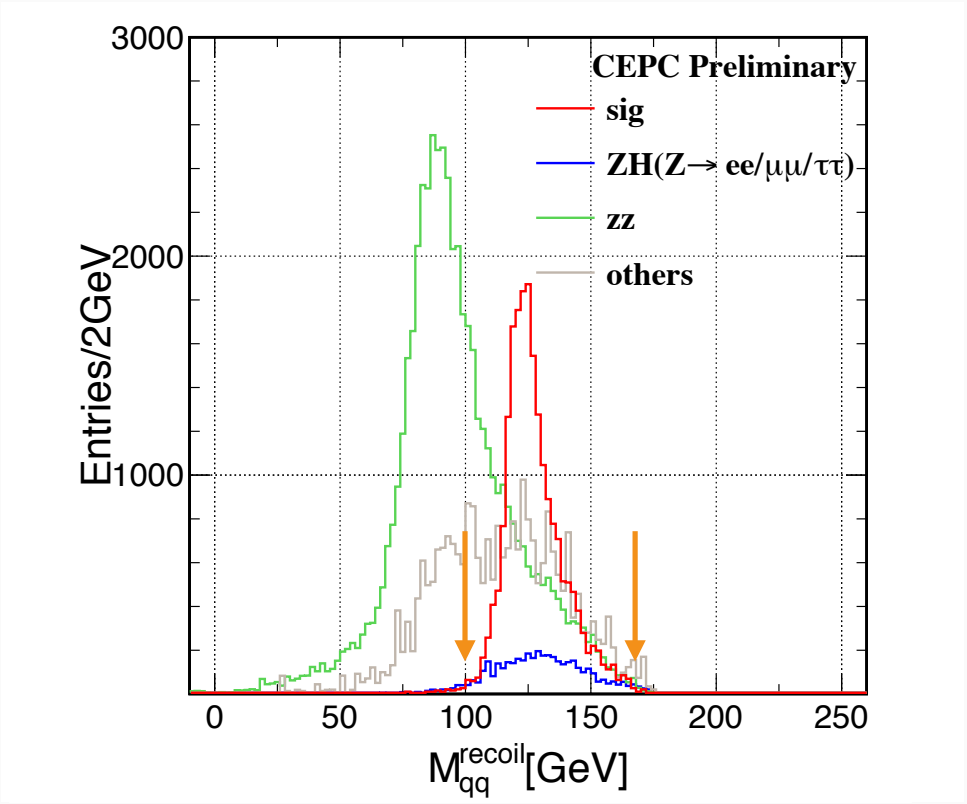


M_Z: signal, ZZ

M_H: ZH conjugation

qq recoil mass

- Peak @ M_H
- Main background reduced:
  - $ZZ \to qq\tau\tau$
- Main background remaining:
  - irreducible backgrounds

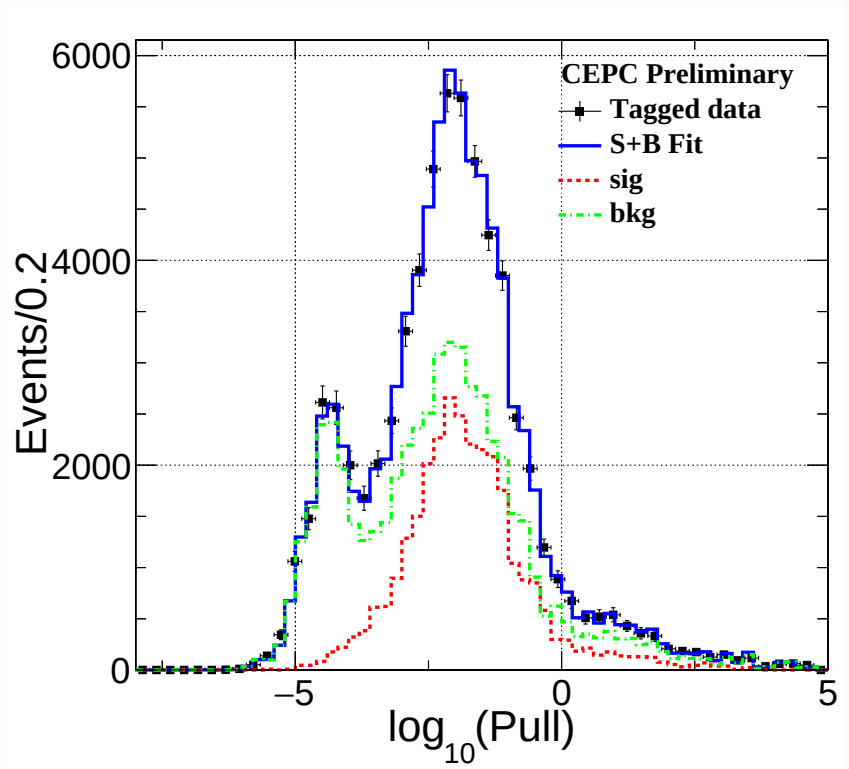


M_Z: ZZ

M_H: signal

qqH-Fit impact parameter

- Fit result: signal 22153 ± 206
- Accuracy: $0.93 \pm 0.01\%$



Combination

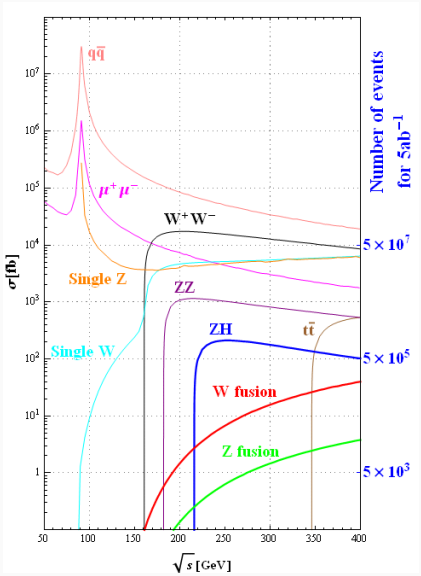
Combined result for CEPC (5 ab^{-1})

	δ ($\sigma\times$ BR)/($\sigma\times$ BR)
$\mu\mu$H	2.26$\pm$0.05%
eeH(extrapolated)	2.72$\pm$0.05%
$\nu\nu$H	4.29$\pm$0.02%
qqH	0.93$\pm$0.01%
combined	0.81$\pm$0.01%

CEPC_V4 - APODIS

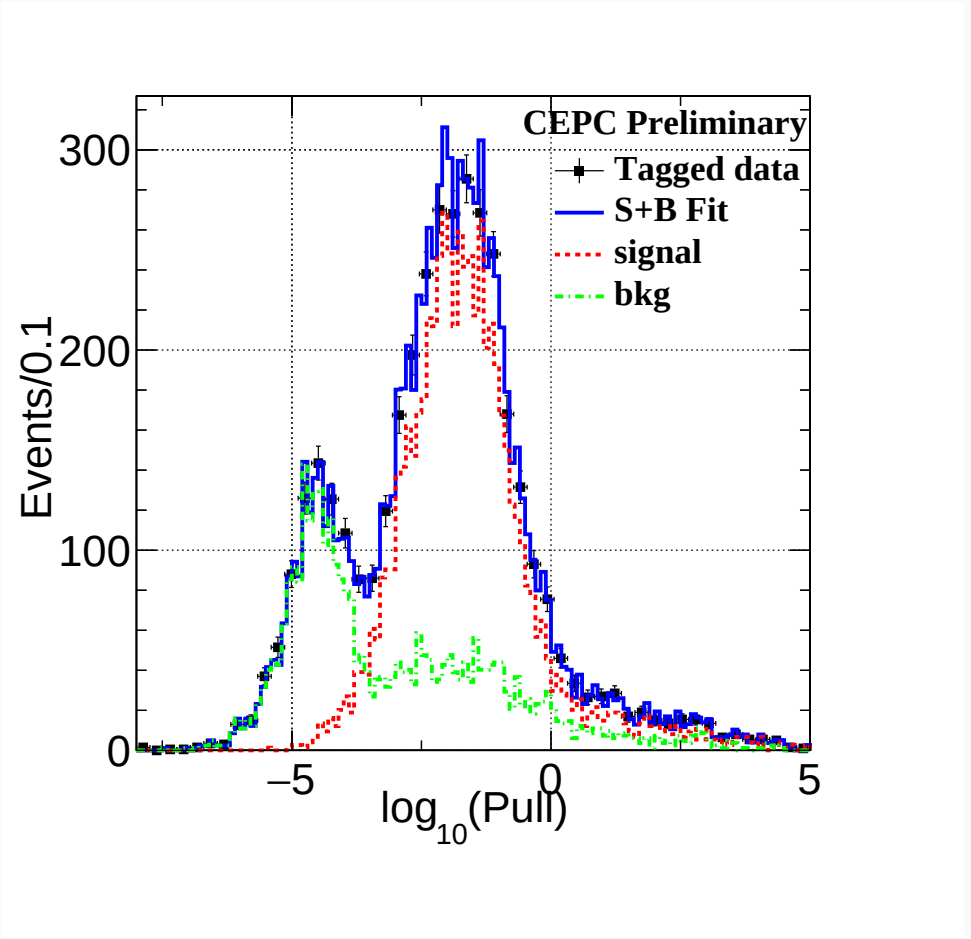
APODIS+240GeV

	CEPC_v1 (~ ILD)	APODIS (Optimized)	Comments
Track Radius	1.8 m	>= 1.8 m	Requested by Br(H->di muon) measurement
B Field	**3.5 T**	**3 T**	**Requested by MDI**
ToF	**-**	**50 ps**	**Requested by pi-Kaon separation at Z pole**
ECAL Thickness	84 mm	84(90) mm	84 mm is optimized on Br(H->di photon) at 250 GeV; 90mm for bhabha event at 350 GeV
ECAL Cell Size	5 mm	10 mm	Passive cooling request ~ 20 mm. 10 mm should be highly appreciated for EW measurements – need further evaluation
ECAL NLayer	30	30	Depends on the Silicon Sensor thickness
HCAL Thickness	**1.3 m**	**1 m**	-
HCAL NLayer	**48**	**40**	Optimized on Higgs event at 250 GeV; Margin might be reserved for 350 GeV.

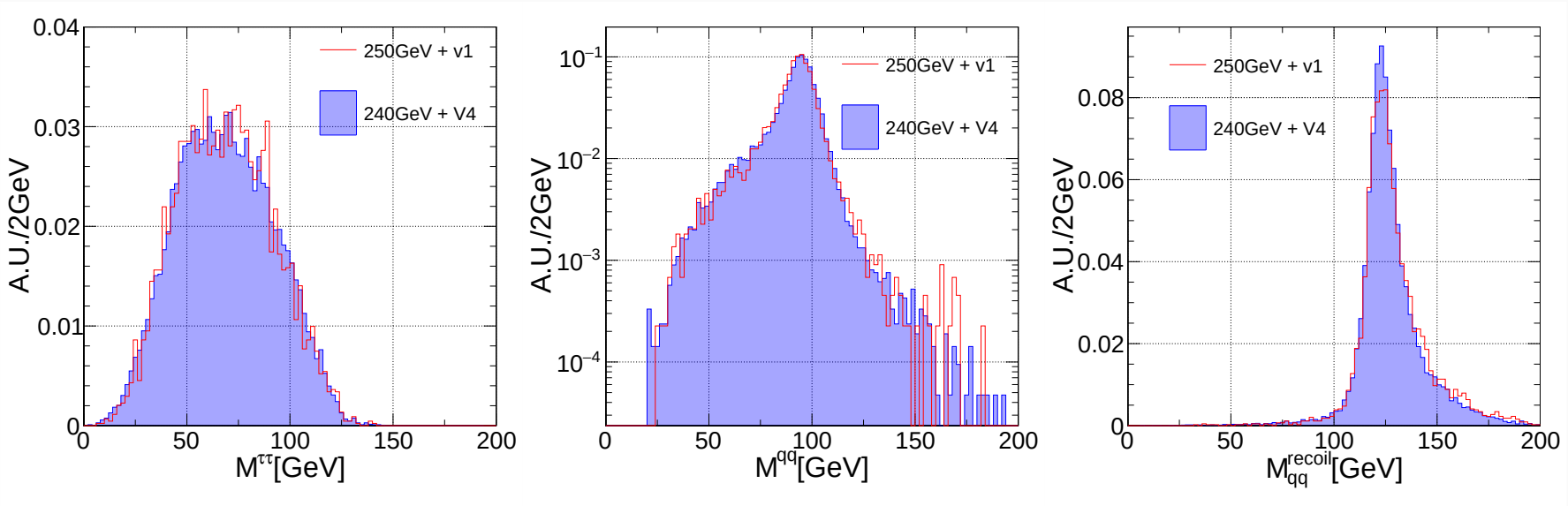


3T + 240GeV - $\mu\mu H$

- Cut efficiency: 95.81%
- Fit result: signal $\sim 2037 \pm 45$
- mumuH Accuracy: 2.21±0.05%



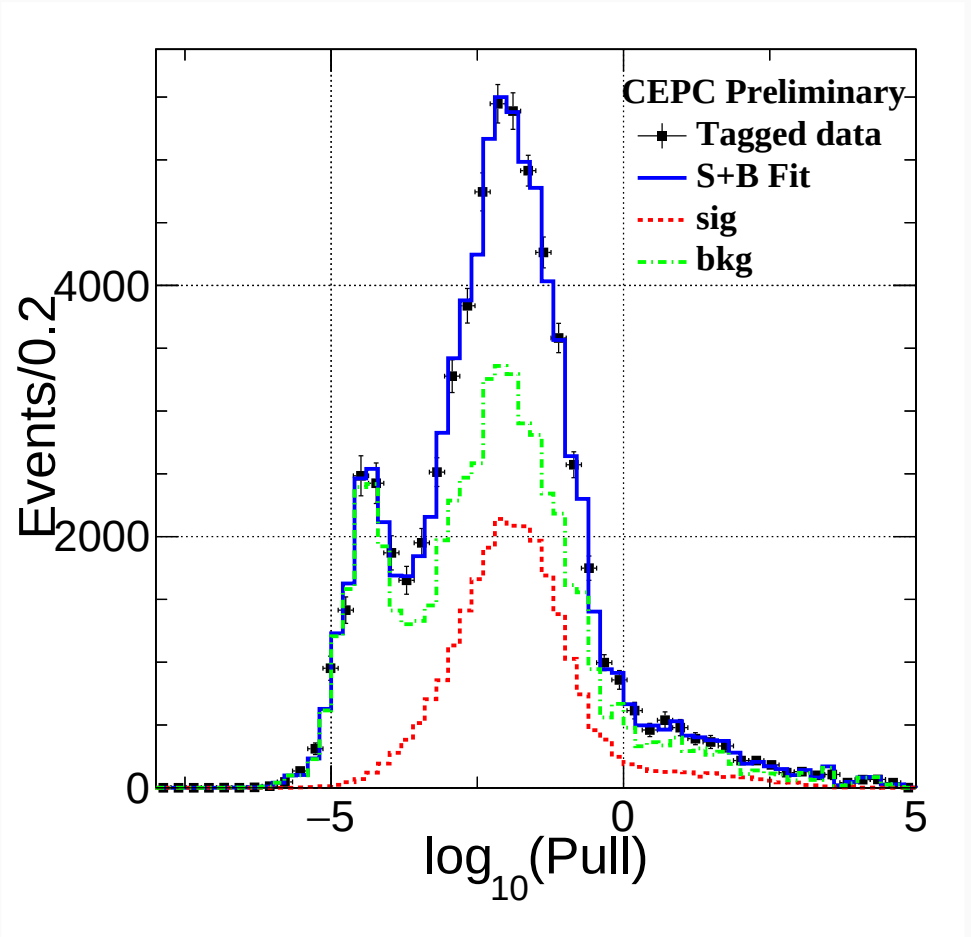
3T + 240GeV - *qqH*



Eff(%) Sample / Cut	CEPC_V1		CEPC_V4	
	sig	bkg	sig	bkg
$\exists\ \tau$ pair	54.66	4.20	54.16	4.34
$20 < M_{\tau\tau} < 120$	53.79	3.60	53.10	3.67
$70 < M_{qq} < 110$	50.80	1.21	48.38	1.26
$100 < M^{rec}_{qq} < 160$	50.29	1.17	47.80	1.19

qqH channel

- Cut efficiency: 47.80%
- Fit result: signal
  $\sim 19343 \pm 187$
- mumuH Accuracy:
  0.97±0.01%



Summary

- High efficiency and purity identification of τ candidates
- PFA oriented design provide excellent access to $g(H\tau\tau)$ measurement
  - τ information
  - Jet information
  - Vertex information

	$\mu\mu H$	qqH	combination
CEPC_v1	2.26±0.05	0.93±0.01	0.81±0.01
APODIS	2.21±0.05	0.97±0.01	0.87±0.01

- No obvious degrading in CEPC_V4 at $\sqrt{S}$ =240GeV (less than 8%)

Thank you!

Backup