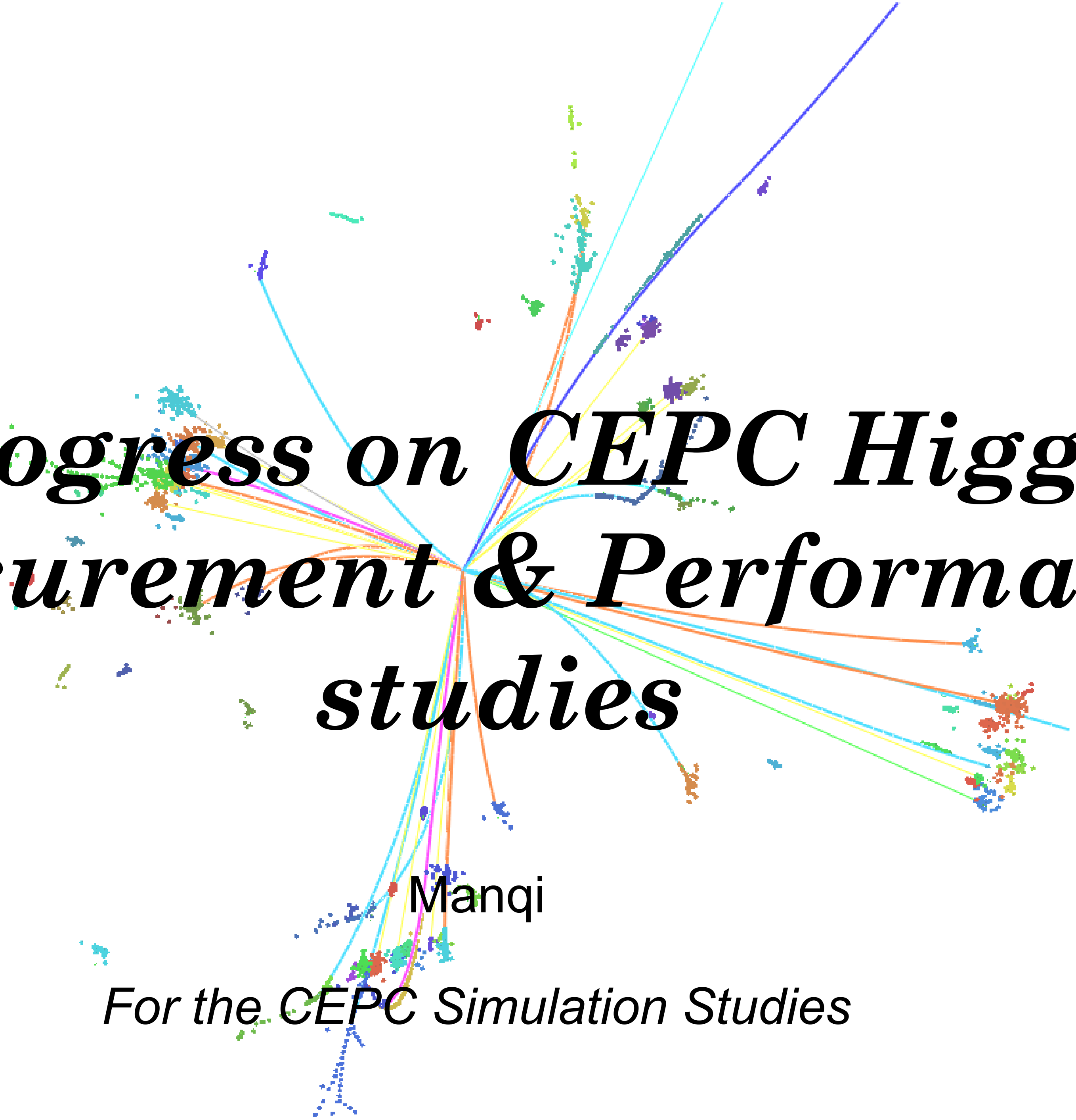
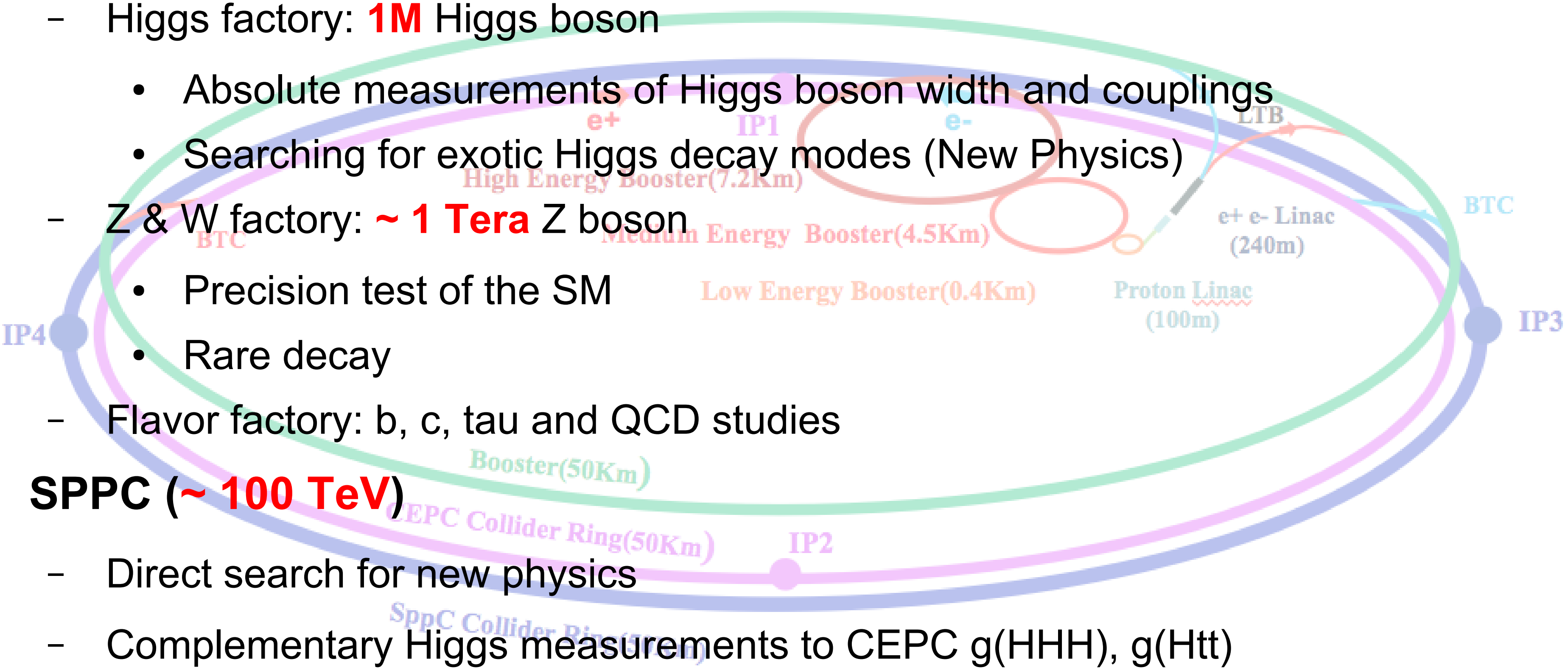


Progress on CEPC Higgs measurement & Performance studies

Manqi

For the CEPC Simulation Studies

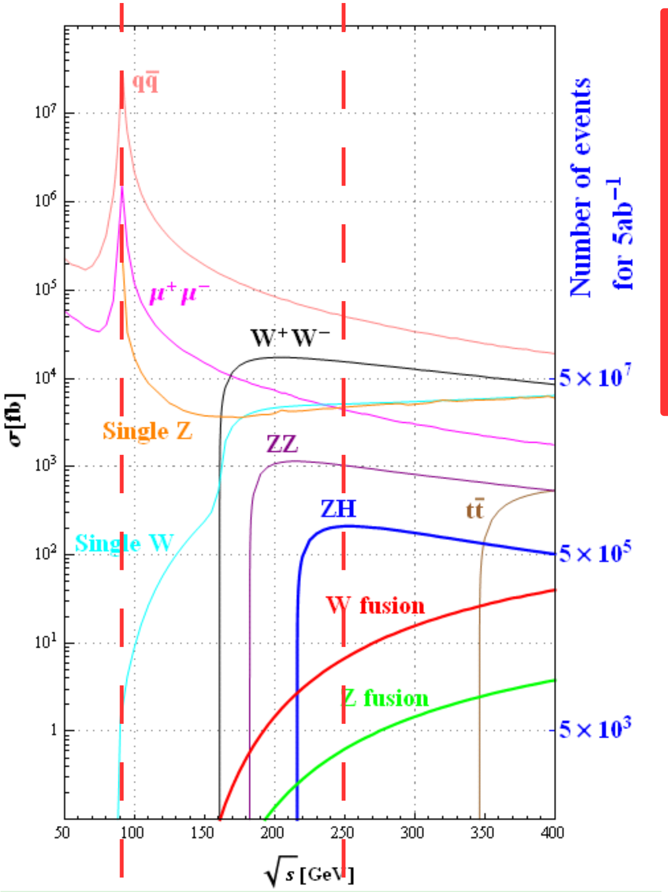
Key figures of the CEPC-SPPC

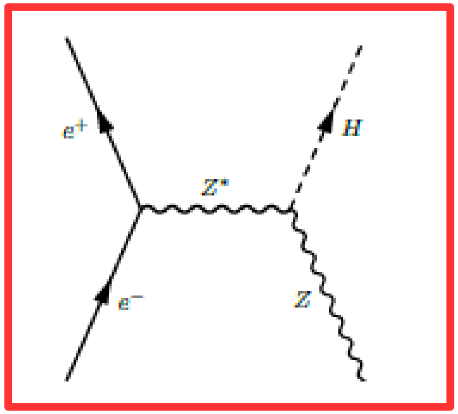


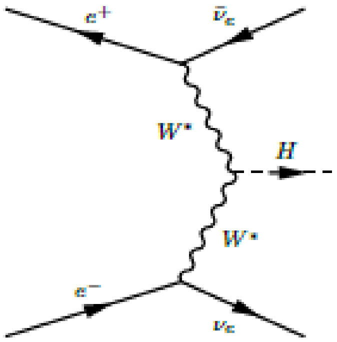
- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **~ 1 Tera** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor factory: b, c, tau and QCD studies
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**

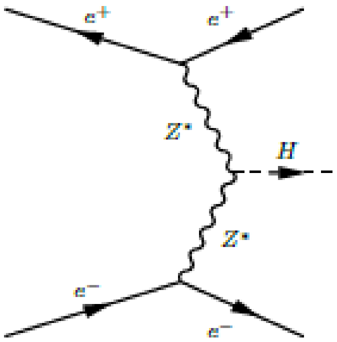
Complementary

Higgs @ CEPC







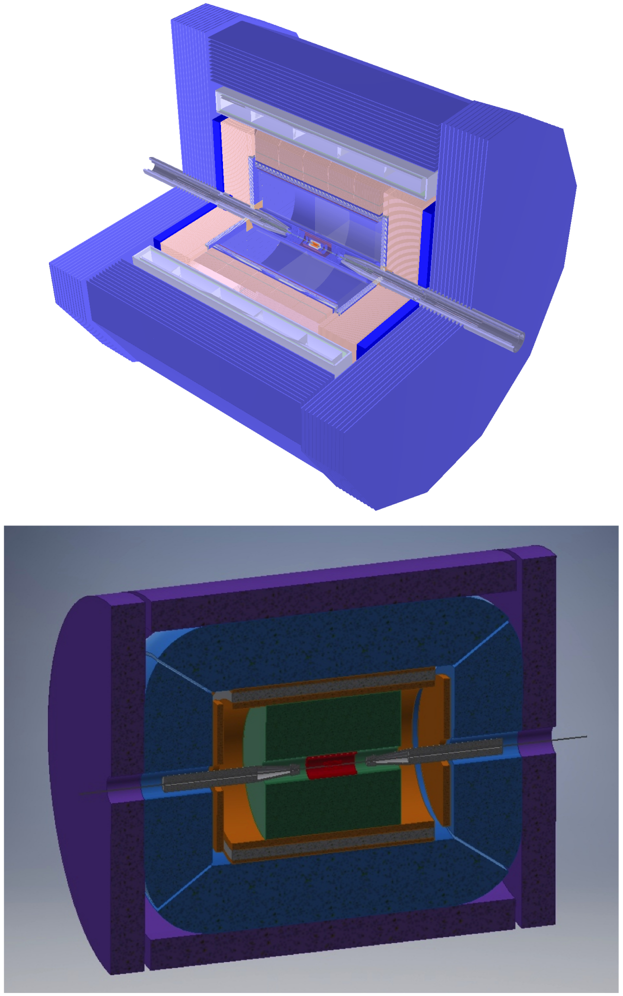


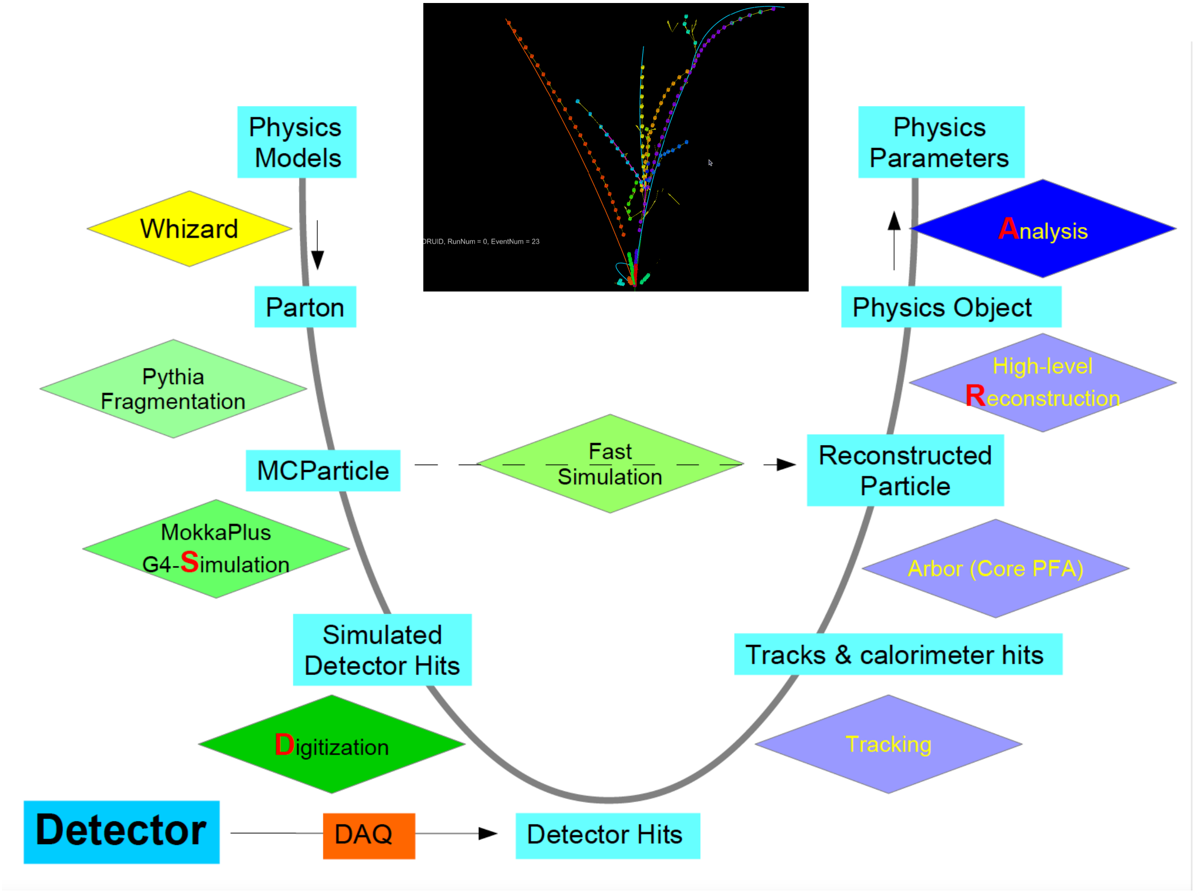
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

Observables: Higgs mass, CP, σ(ZH), event rates (σ(ZH, vvH)*Br(H→X)), Diff. distributions

Derive: Absolute Higgs width, branching ratios, couplings

Detector & Software





Physics Models

Whizard

Parton

Pythia Fragmentation

MCParticle

MokkaPlus G4-Simulation

Simulated Detector Hits

Digitization

Detector

DAQ

Detector Hits

Tracking

Tracks & calorimeter hits

Arbor (Core PFA)

Reconstructed Particle

Fast Simulation

High-level Reconstruction

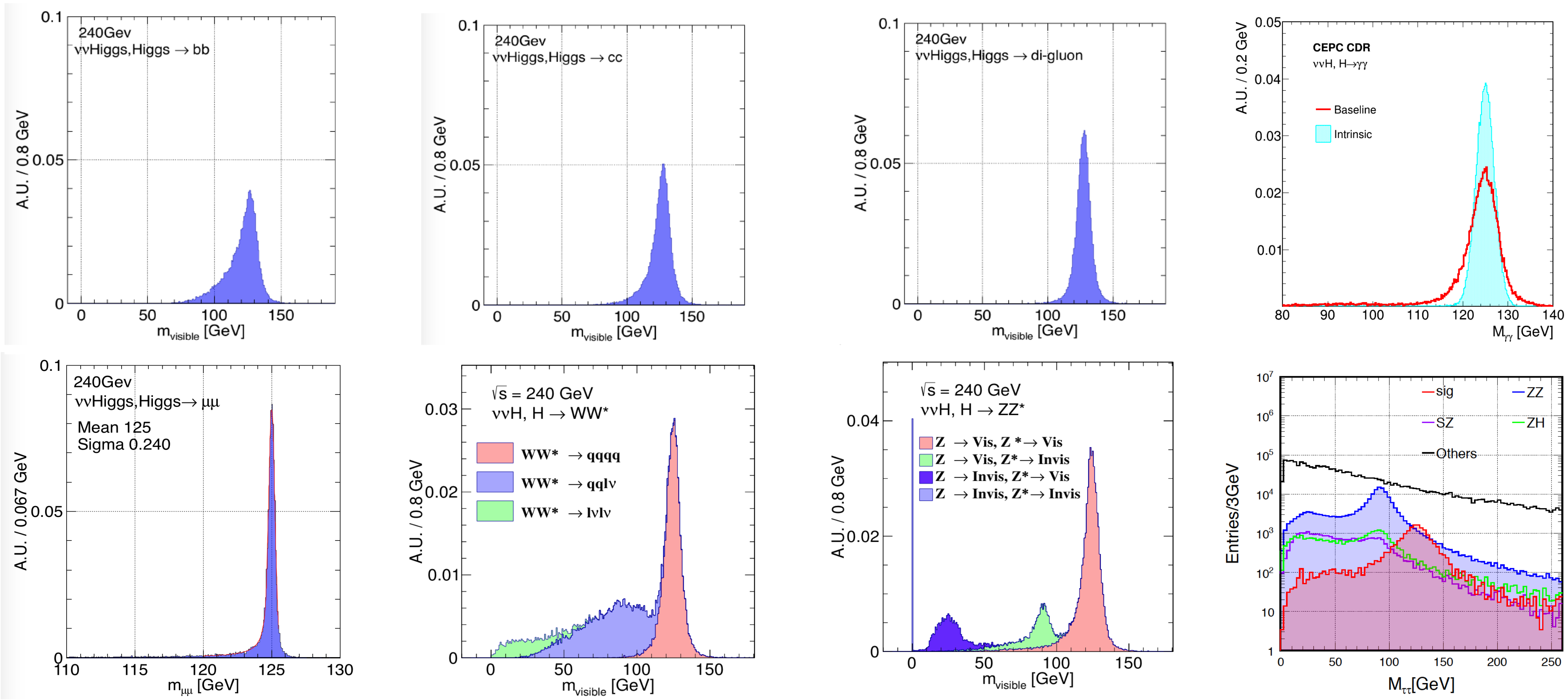
Physics Object

Analysis

Physics Parameters

Baseline: PFA Oriented Design + Arbor

Reconstructed Higgs Signatures

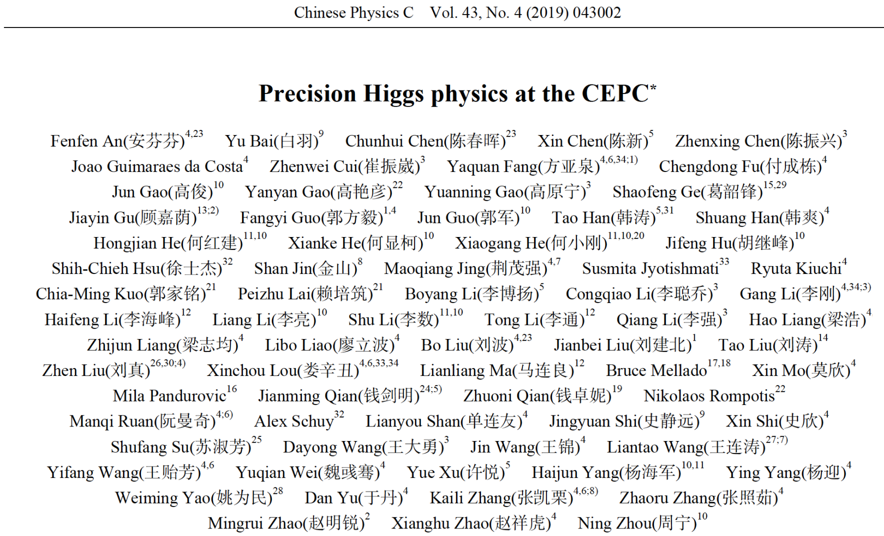


Clear Higgs Signature in all SM decay modes

Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

Right corner: di-tau mass distribution at qqH events using collinear approximation

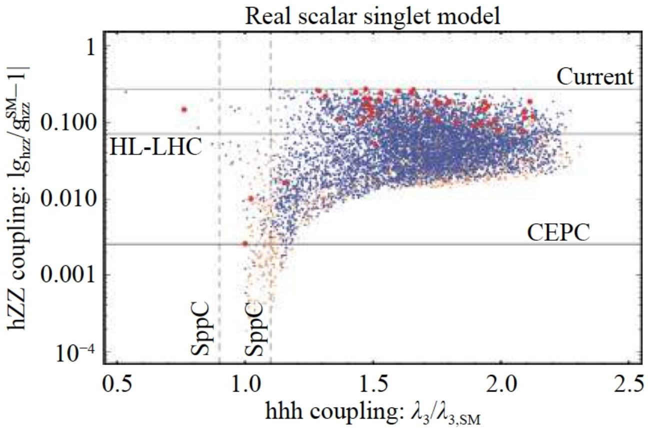
Higgs white paper delivered

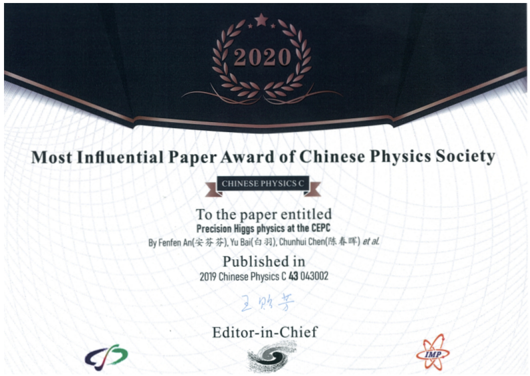


Chinese Physics C Vol. 43, No. 4 (2019) 043002

Precision Higgs physics at the CEPC*

Fenfen An(安芬芬)[4,23] Yu Bai(白羽)[9] Chunhui Chen(陈春晖)[23] Xin Chen(陈新)[5] Zhenxing Chen(陈振兴)[3] Joao Guimaraes da Costa[4] Zhenwei Cui(崔振崴)[3] Yaquan Fang(方亚泉)[4,6,34;1)] Chengdong Fu(付成栋)[4] Jun Gao(高俊)[10] Yanyan Gao(高艳彦)[22] Yuanning Gao(高原宁)[3] Shaofeng Ge(葛韶锋)[15,29] Jiayin Gu(顾嘉荫)[13;2)] Fangyi Guo(郭方毅)[1,4] Jun Guo(郭军)[10] Tao Han(韩涛)[5,31] Shuang Han(韩爽)[4] Hongjian He(何红建)[11,10] Xianke He(何显柯)[10] Xiaogang He(何小刚)[11,10,20] Jifeng Hu(胡继峰)[10] Shih-Chieh Hsu(徐士杰)[32] Shan Jin(金山)[8] Maoqiang Jing(荆茂强)[4,7] Susmita Jyotishmati[33] Ryuta Kiuchi[4] Chia-Ming Kuo(郭家铭)[21] Peizhu Lai(赖培筑)[21] Boyang Li(李博扬)[5] Congqiao Li(李聪乔)[3] Gang Li(李刚)[4,34;3)] Haifeng Li(李海峰)[12] Liang Li(李亮)[10] Shu Li(李数)[11,10] Tong Li(李通)[12] Qiang Li(李强)[3] Hao Liang(梁浩)[4] Zhijun Liang(梁志均)[4] Libo Liao(廖立波)[4] Bo Liu(刘波)[4,23] Jianbei Liu(刘建北)[1] Tao Liu(刘涛)[14] Zhen Liu(刘真)[26,30;4)] Xinchou Lou(娄辛丑)[4,6,33,34] Lianliang Ma(马连良)[12] Bruce Mellado[17,18] Xin Mo(莫欣)[4] Mila Pandurovic[16] Jianming Qian(钱剑明)[24;5)] Zhuoni Qian(钱卓妮)[19] Nikolaos Rompotis[22] Manqi Ruan(阮曼奇)[4;6)] Alex Schuy[32] Lianyou Shan(单连友)[4] Jingyuan Shi(史静远)[9] Xin Shi(史欣)[4] Shufang Su(苏淑芳)[25] Dayong Wang(王大勇)[3] Jin Wang(王锦)[4] Liantao Wang(王连涛)[27;7)] Yifang Wang(王贻芳)[4,6] Yuqian Wei(魏彧骞)[4] Yue Xu(许悦)[5] Haijun Yang(杨海军)[10,11] Ying Yang(杨迎)[4] Weiming Yao(姚为民)[28] Dan Yu(于丹)[4] Kaili Zhang(张凯栗)[4,6;8)] Zhaoru Zhang(张照茹)[4] Mingrui Zhao(赵明锐)[2] Xianghu Zhao(赵祥虎)[4] Ning Zhou(周宁)[10]





2020

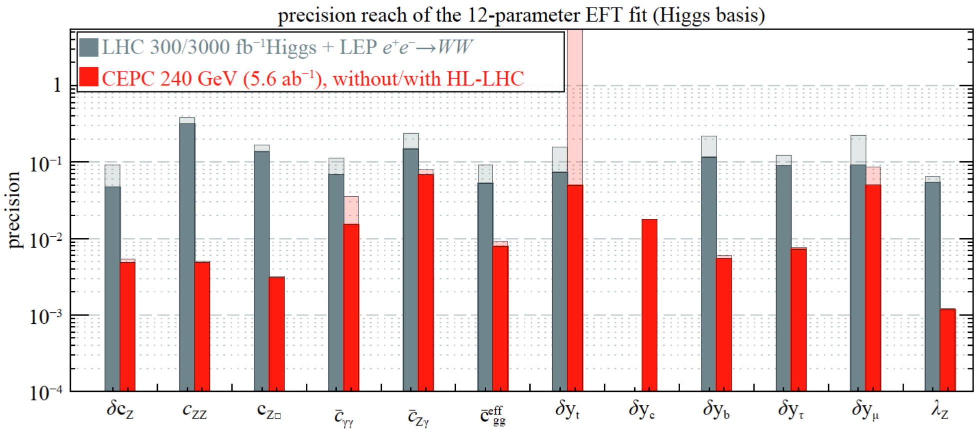
Most Influential Paper Award of Chinese Physics Society

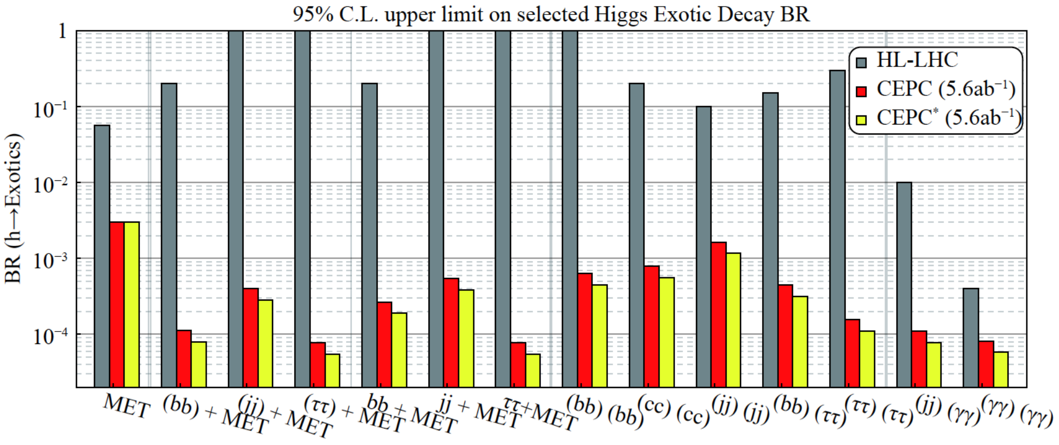
CHINESE PHYSICS C

To the paper entitled
Precision Higgs physics at the CEPC
By Fenfen An(安芬芬), Yu Bai(白羽), Chunhui Chen(陈春晖) *et al.*

Published in
2019 Chinese Physics C **43** 043002

Editor-in-Chief





- *g(HXX), g(HHH), Br(H→exo)*

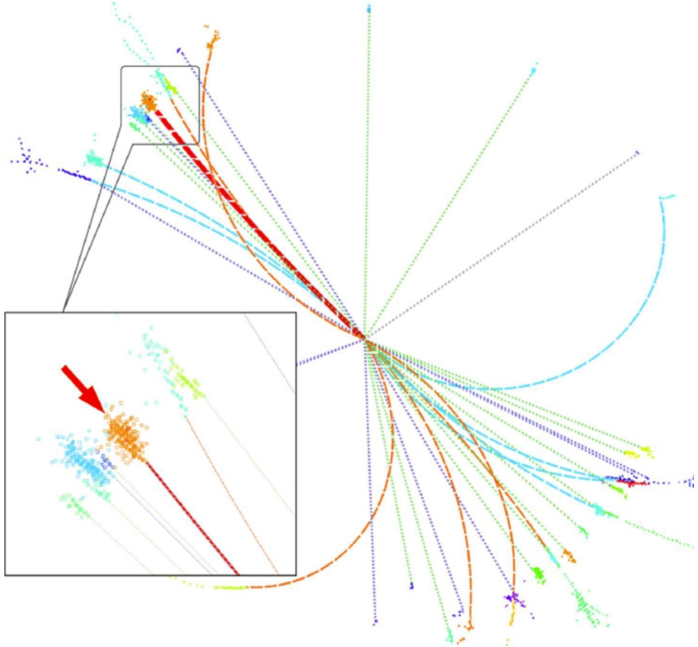
Recent Highlights

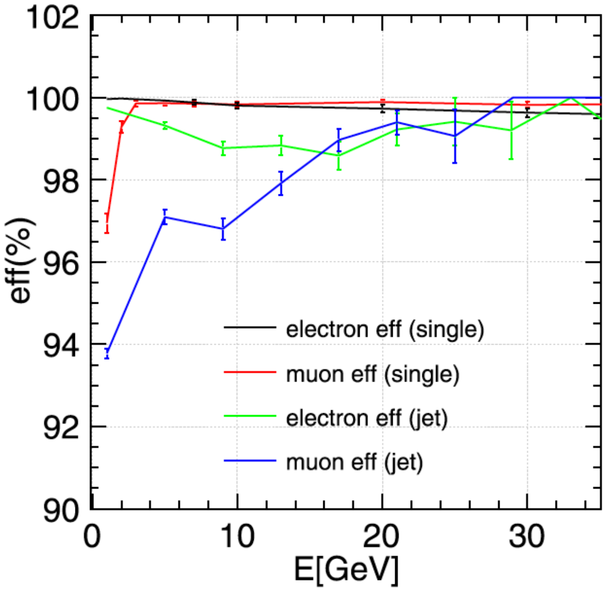
- Performance
  - Jet lepton
  - Tau
  - Jet Charge

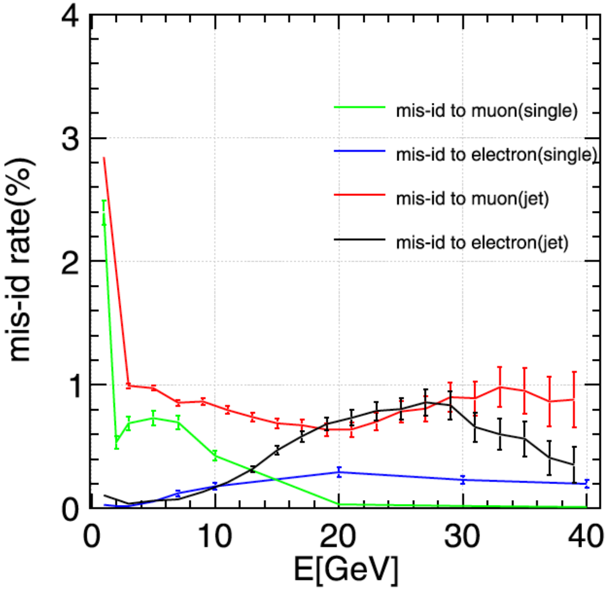
- Physics
  - Top runs
  - H→bb, cc, gg

- Many Preliminary Conclusions: stay tuned...

Jet lepton @ Z->bb

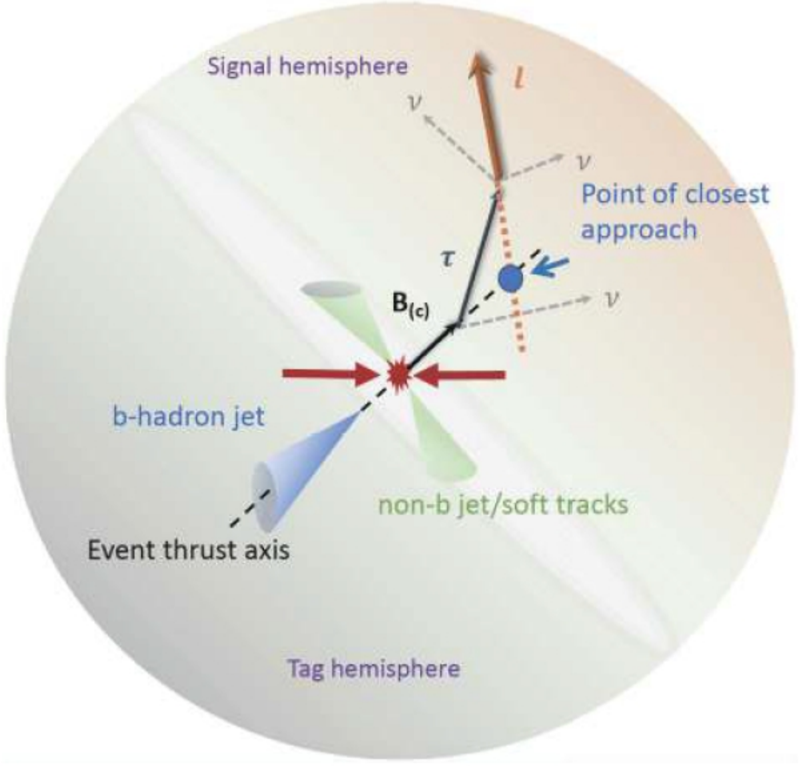


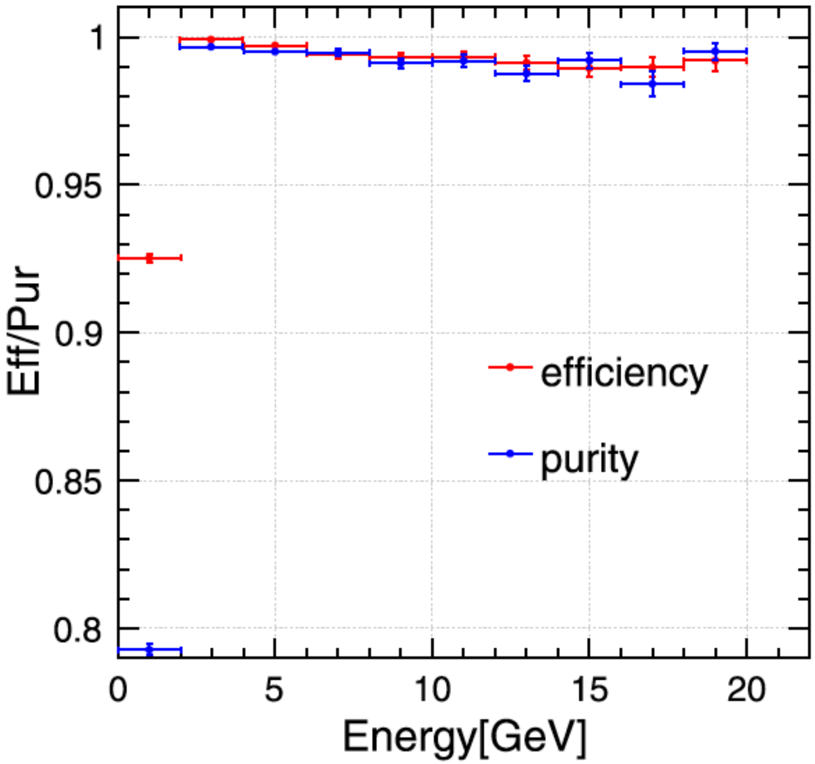




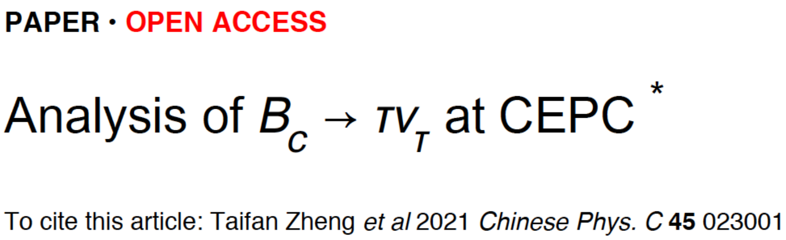
- Marginal Degrading (2021 JINST P06013)
  - Efficiency reduced up to 3% (muon @ low energy); mis-id increased to ~ 1%

At physics benchmark of Bc→τν→eνν





- No significant degrading due to Lepton id

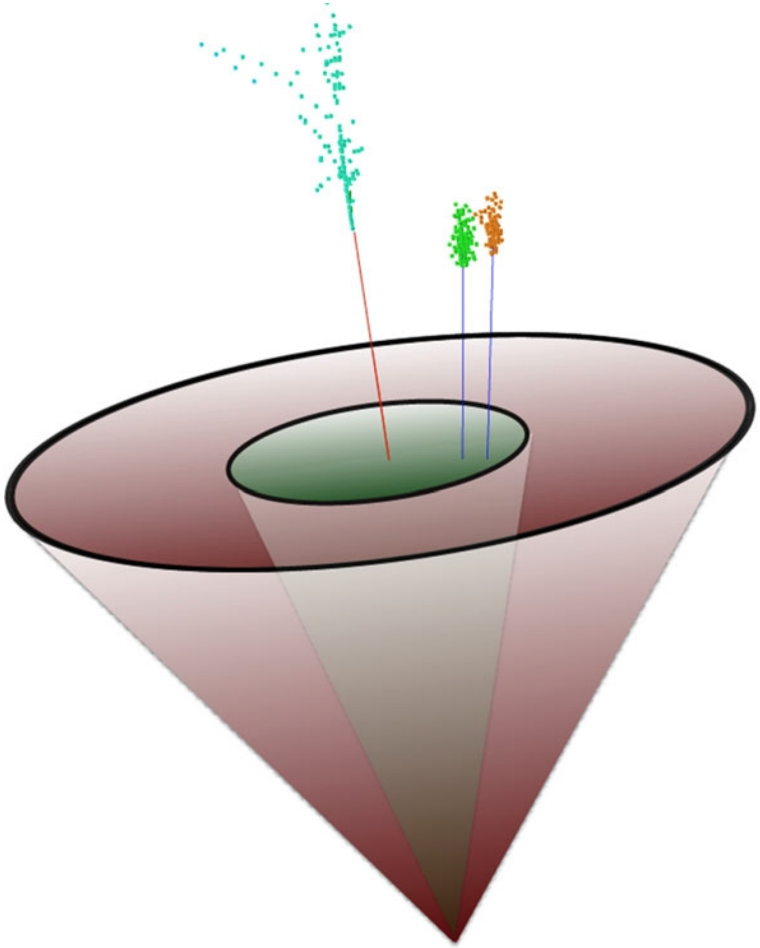


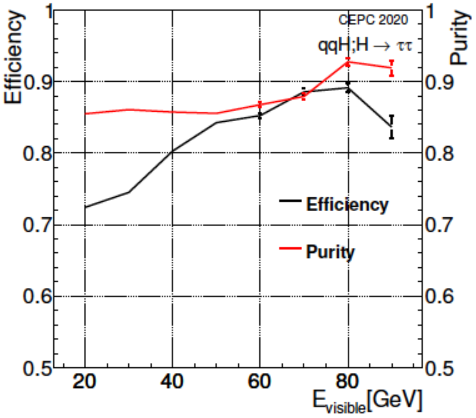
PAPER · **OPEN ACCESS**

Analysis of $B_c \to \tau\nu_\tau$ at CEPC *

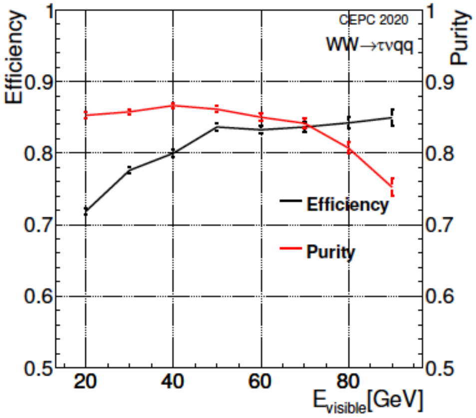
To cite this article: Taifan Zheng *et al* 2021 *Chinese Phys. C* **45** 023001

Tau reconstruction: Taurus

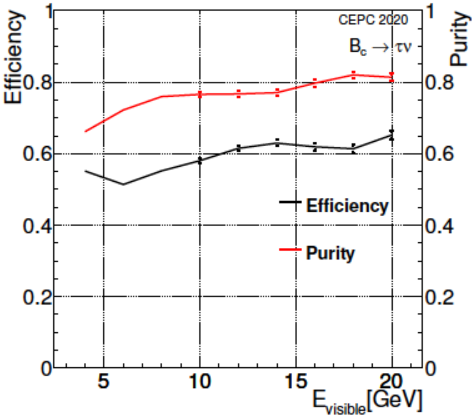




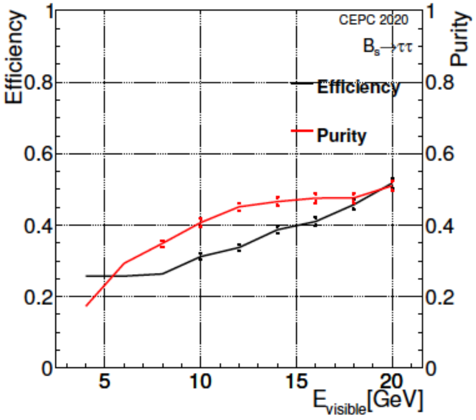
(a) $Z \to qq, H \to \tau\tau$, overall efficiency 80%, overall purity 86%



(b) $WW \to \tau\nu qq$, overall efficiency 79%, overall purity 85%

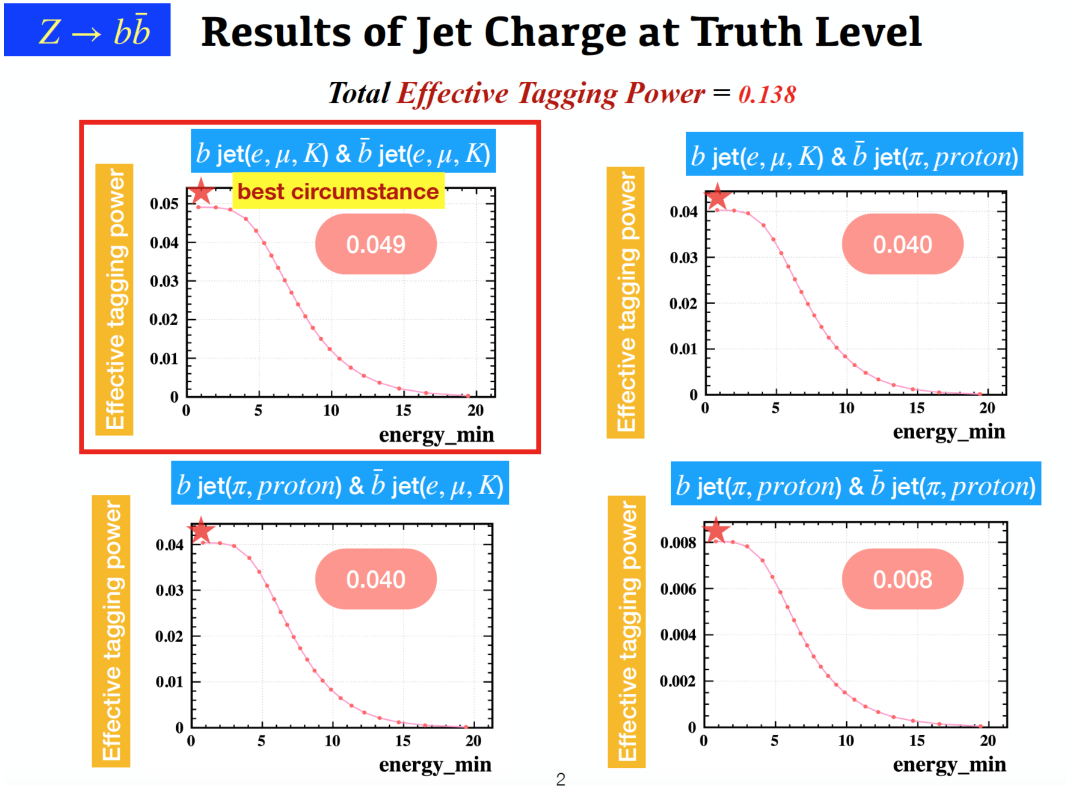


(c) $Z \to b\bar{b}, B_c \to \tau\nu$, overall efficiency 57%, overall purity 74%



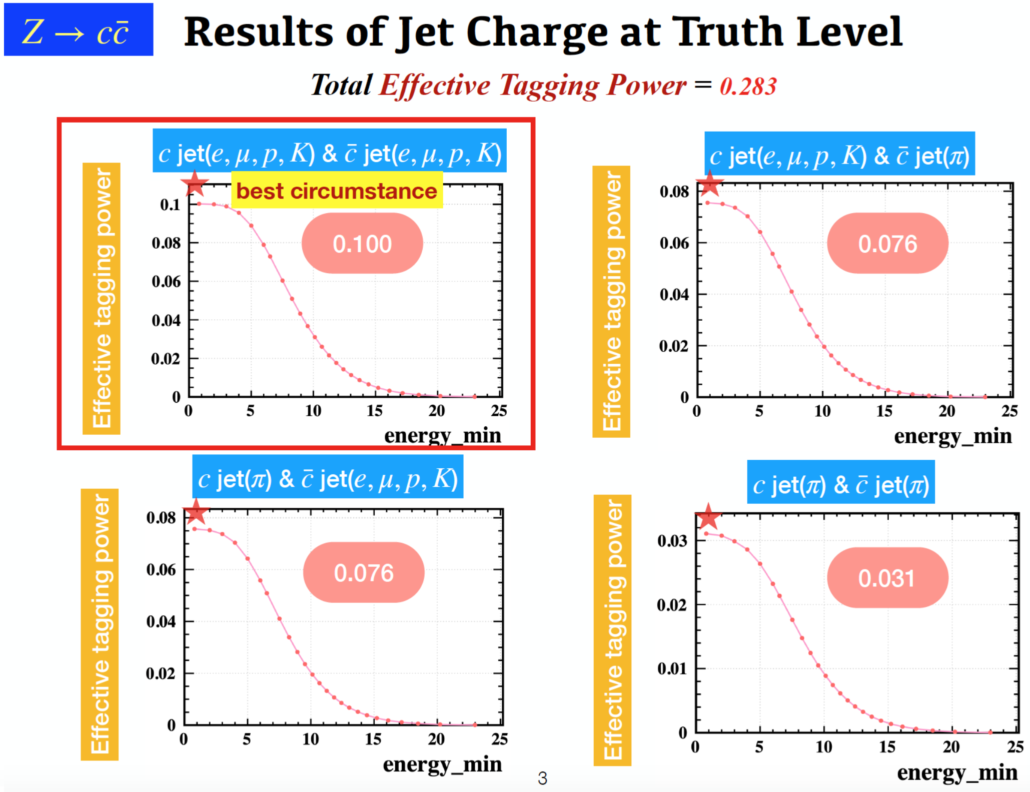
(d) $Z \to b\bar{b}, B_s \to \tau\tau$, overall efficiency 32%, overall purity 33%

Jet charge measurement



$Z \to b\bar{b}$ Results of Jet Charge at Truth Level

Total Effective Tagging Power = 0.138



$Z \to c\bar{c}$ Results of Jet Charge at Truth Level

Total Effective Tagging Power = 0.283

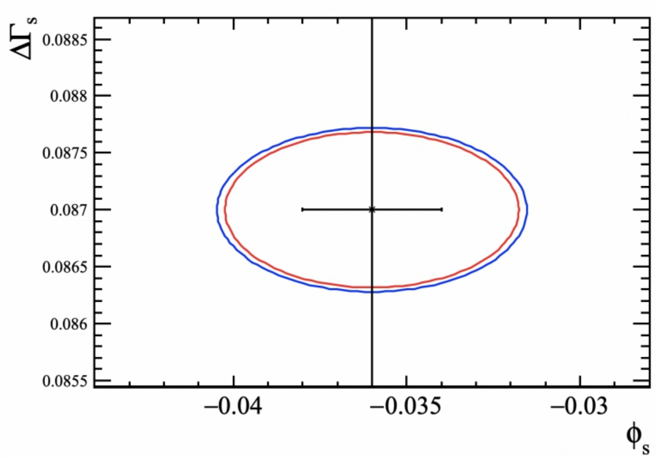
- Via leading charged particle type of each jet: effective tagging power (eff*$(1-2\Omega)^2$) = 14%/28% for inclusive Z→bb/Z→cc event
- Dependence on the heavy flavor hadron type & usage of other information: processing

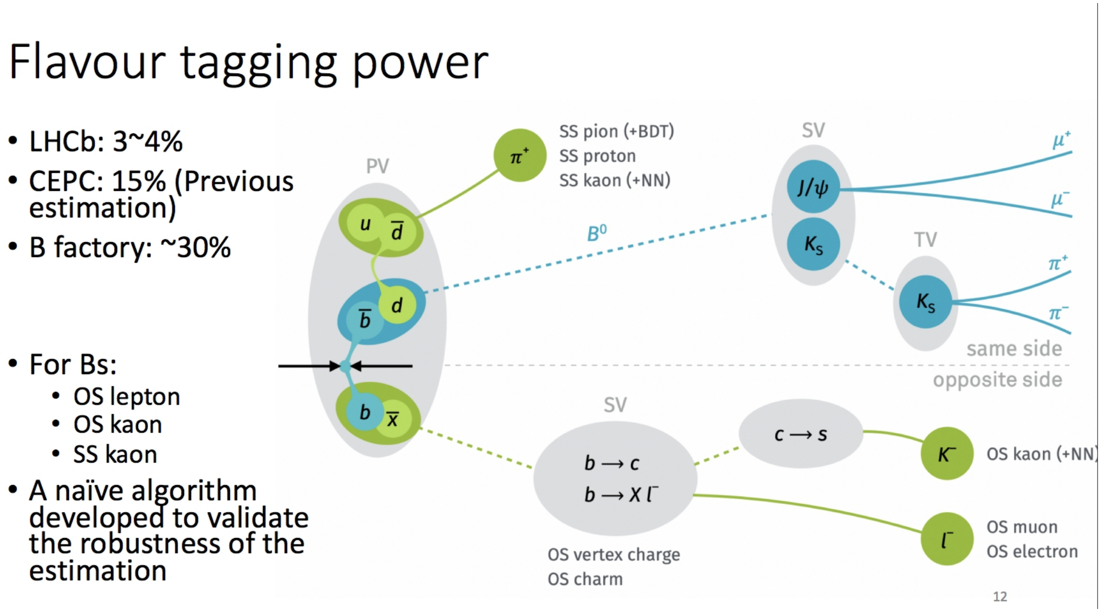
CP measurement with Bs→J/psi Phi... & requires good Pid!

$\Delta\Gamma_s \equiv \Gamma_L - \Gamma_H, \phi_s = -2\arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$

SM: small CPV phase ϕ_s

Contributions from physics beyond the SM could lead to much larger values of ϕ_s.

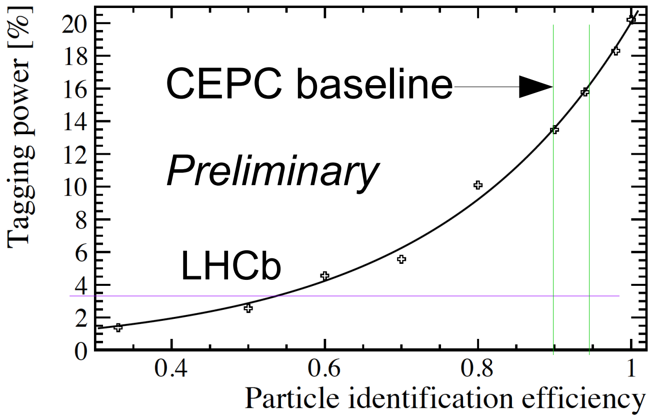




Flavour tagging power

- LHCb: 3~4%
- CEPC: 15% (Previous estimation)
- B factory: ~30%

- For Bs:
  - OS lepton
  - OS kaon
  - SS kaon
- A naïve algorithm developed to validate the robustness of the estimation

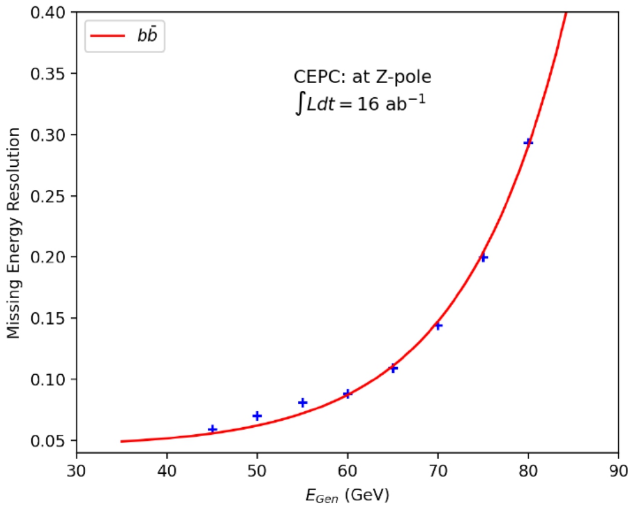


- With a decent Pid, the effective tagging power on jet Charge can be 5-6 times better than LHCb, which can compensate the statistic difference between LHCb & CEPC.
- Strong motivation to higher Luminosity at Z pole

Baseline Detector Performance

- Acceptance: $|\cos(\theta)| < 0.99$
- Tracks:
  - Pt threshold, ~ 100 MeV
  - $\delta p/p$ ~ o(0.1%)
- Photons:
  - Energy threshold, ~ 100 MeV
  - $\delta E/E$: 3 – 15%/sqrt(E)
- BMR: 3.7%
- B-tagging: eff*purity @ Z→qq: 70%
- C-tagging: eff*purity @ Z→qq: 40%
- Pi-Kaon separation: 3-sigma (requirement)
- Pi-0: eff*purity @ Z→qq > 60% @ 5GeV
- Jet charge: eff*$(1-2\omega)^2$ ~ 15%/30% @ Z→bb/cc

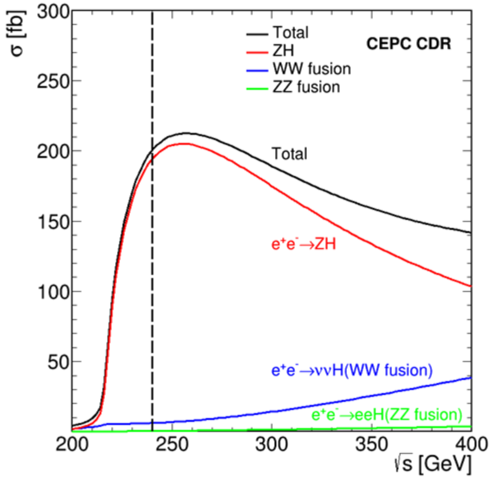
- Lepton inside jets: eff*purity @ Z→qq ~ 90% (energy > 3 GeV): slight degrading in jet
- Tau: eff*purity @ WW→tauvqq: 70%, mis id from jet fragments ~ o(1%)
- Reconstruction of simple combinations: Ks/Lambda/D with all tracks @ Z→qq: 60/75 – 80/85%
- Missing Energy: Consistent with BMR.

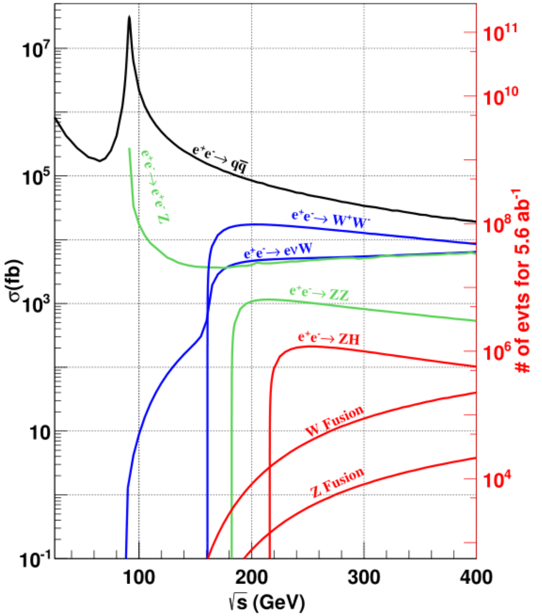


Upgrade option: 360 GeV operation

fb	240	350	360	365	360/240
ZH	196.9	133.3	126.6	123.0	-36%
WW fusion	6.2	26.7	29.61	31.1	+377%
ZZ fusion	0.5	2.55	2.80	2.91	+460%
Total	203.6		159.0		
Total Events	1.14M		0.32M		

pb	240	350	360	365	360/240
$ee(\gamma)$	930	336	325	319	-65%
$\mu\mu(\gamma)$	5.3	2.2	2.1	2.1	-60%
$qq(\gamma)$	54.1	24.7	23.2	22.8	-57%
WW	16.7	10.4	10.0	9.81	-40%
ZZ	1.1	0.66	0.63	0.62	-43%
tt	\	0.155	0.317	0.369	
sZ	4.54	5.72	5.78	5.83	+27%
sW	5.09	5.89	6.00	6.04	+18%

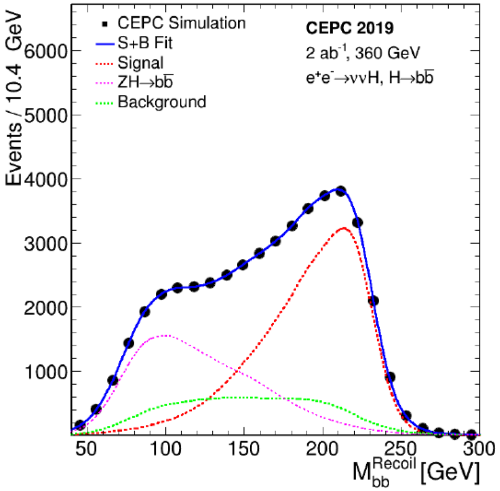


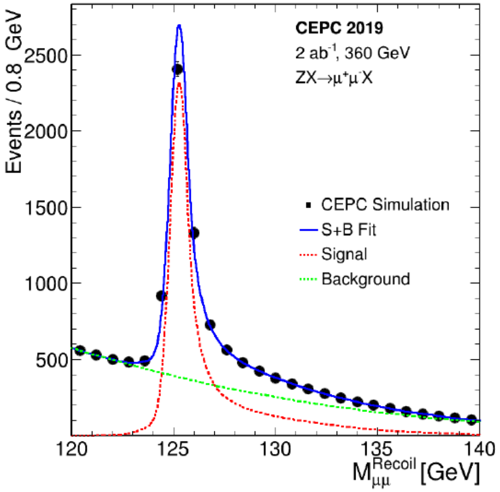


Upgrade option: 360 GeV operation

Results

	240GeV, 5.6ab^{-1}	360GeV, 2ab^{-1}	
	ZH	ZH	vvH
any	**0.50%**	**1%**	****
$\mathrm{H} \to \mathrm{bb}$	**0.27%**	**0.63%**	**0.76%**
$\mathrm{H} \to \mathrm{cc}$	**3.3%**	**6.2%**	**11%**
$\mathrm{H} \to \mathrm{gg}$	**1.3%**	**2.4%**	**3.2%**
$\mathrm{H} \to \mathrm{WW}$	**1.0%**	**2.0%**	**3.1%**
$\mathrm{H} \to \mathrm{ZZ}$	**7.9%**	**14%**	**15%**
$\mathrm{H} \to \tau\tau$	**0.8%**	**1.5%**	**3%**
$\mathrm{H} \to \gamma\gamma$	**5.7%**	**8%**	**11%**
$\mathrm{H} \to \mu\mu$	**12%**	**29%**	**40%**
$\mathrm{Br}_{\mathrm{upper}}(\mathrm{H} \to \mathrm{inv.})$	**0.2%**	****	****
$\sigma(ZH) * \mathrm{Br}(\mathrm{H} \to Z\gamma)$	**16%**	**25%**	****
Width	**2.8%**	**1.4%**	



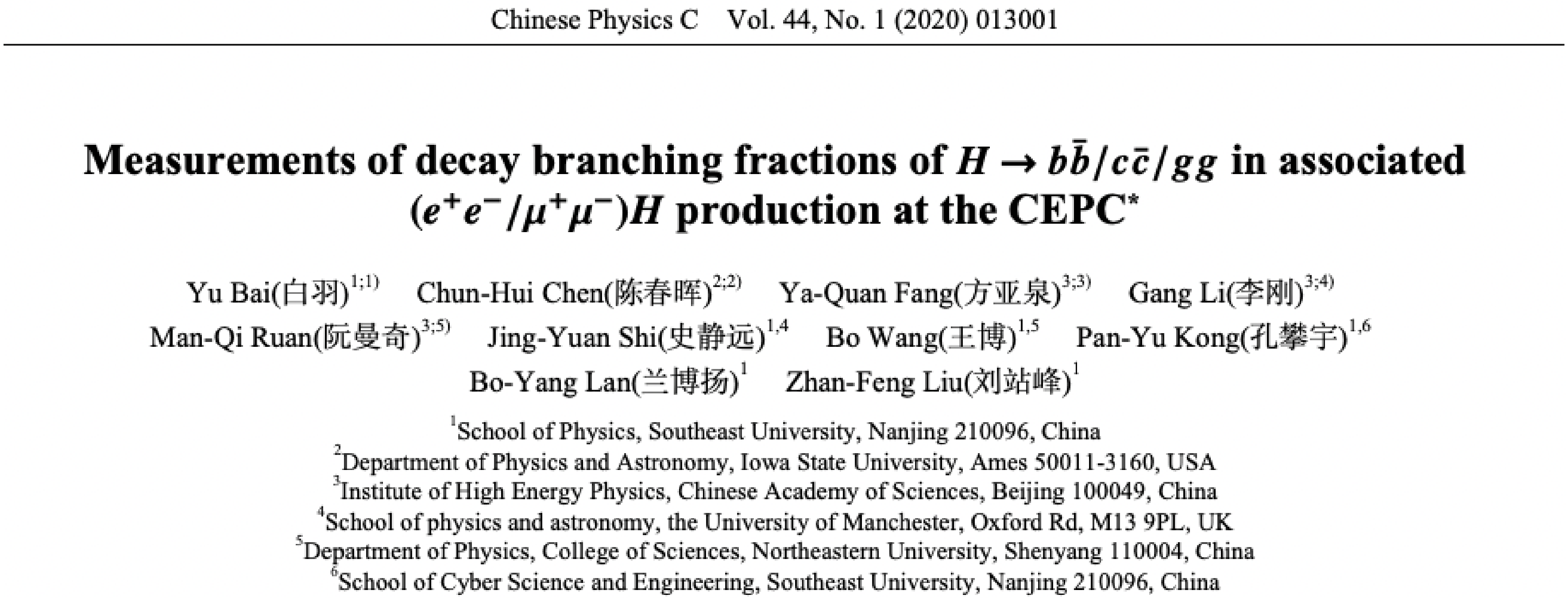


Measurement of H→bb, cc, gg

- llH: published

- **Preliminary analyses** on vvH & qqH based on Full Sim
  - Anticipated accuracies at CEPC baseline
  - Optimization study
    - Flavor Tagging @ vvH & qqH
    - Color Singlet identification @ qqH

llH

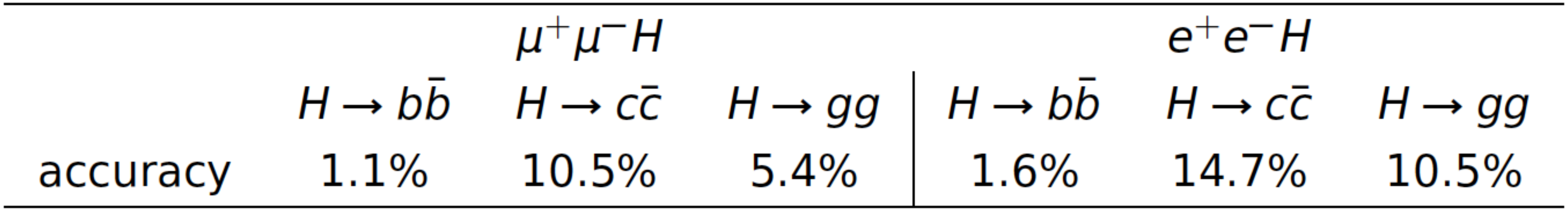


Chinese Physics C Vol. 44, No. 1 (2020) 013001

Measurements of decay branching fractions of $H \to b\bar{b}/c\bar{c}/gg$ in associated $(e^+e^-/\mu^+\mu^-)H$ production at the CEPC*

Yu Bai(白羽)[1;1)] Chun-Hui Chen(陈春晖)[2;2)] Ya-Quan Fang(方亚泉)[3;3)] Gang Li(李刚)[3;4)]
Man-Qi Ruan(阮曼奇)[3;5)] Jing-Yuan Shi(史静远)[1,4] Bo Wang(王博)[1,5] Pan-Yu Kong(孔攀宇)[1,6]
Bo-Yang Lan(兰博扬)[1] Zhan-Feng Liu(刘站峰)[1]

[1] School of Physics, Southeast University, Nanjing 210096, China
[2] Department of Physics and Astronomy, Iowa State University, Ames 50011-3160, USA
[3] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
[4] School of physics and astronomy, the University of Manchester, Oxford Rd, M13 9PL, UK
[5] Department of Physics, College of Sciences, Northeastern University, Shenyang 110004, China
[6] School of Cyber Science and Engineering, Southeast University, Nanjing 210096, China

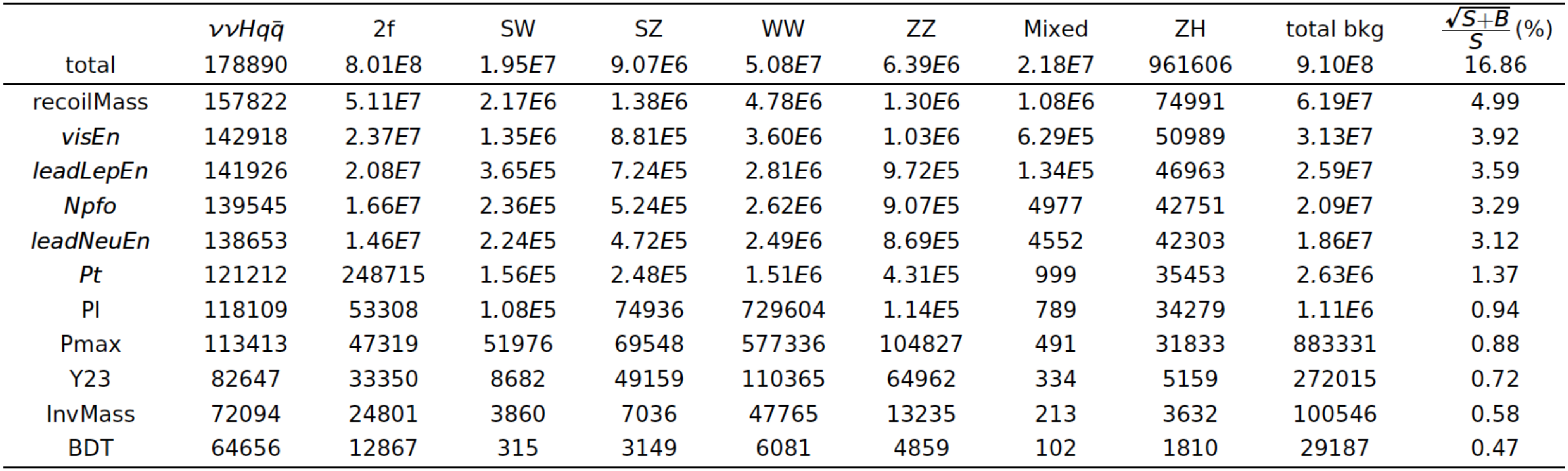


	$\mu^+\mu^-H$			e^+e^-H		
	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
accuracy	1.1%	10.5%	5.4%	1.6%	14.7%	10.5%

for the detail : `https://arxiv.org/abs/1905.12903v2`

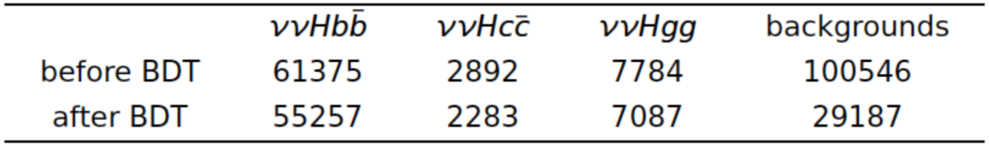
vvH

- Tag H→qq



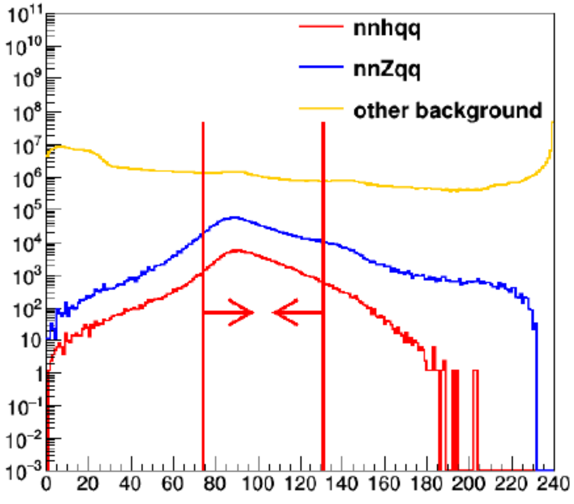
	$\nu\nu Hq\bar{q}$	2f	SW	SZ	WW	ZZ	Mixed	ZH	total bkg	$\frac{\sqrt{S+B}}{S}$ (%)
total	178890	8.01E8	1.95E7	9.07E6	5.08E7	6.39E6	2.18E7	961606	9.10E8	16.86
recoilMass	157822	5.11E7	2.17E6	1.38E6	4.78E6	1.30E6	1.08E6	74991	6.19E7	4.99
visEn	142918	2.37E7	1.35E6	8.81E5	3.60E6	1.03E6	6.29E5	50989	3.13E7	3.92
leadLepEn	141926	2.08E7	3.65E5	7.24E5	2.81E6	9.72E5	1.34E5	46963	2.59E7	3.59
Npfo	139545	1.66E7	2.36E5	5.24E5	2.62E6	9.07E5	4977	42751	2.09E7	3.29
leadNeuEn	138653	1.46E7	2.24E5	4.72E5	2.49E6	8.69E5	4552	42303	1.86E7	3.12
Pt	121212	248715	1.56E5	2.48E5	1.51E6	4.31E5	999	35453	2.63E6	1.37
Pl	118109	53308	1.08E5	74936	729604	1.14E5	789	34279	1.11E6	0.94
Pmax	113413	47319	51976	69548	577336	104827	491	31833	883331	0.88
Y23	82647	33350	8682	49159	110365	64962	334	5159	272015	0.72
InvMass	72094	24801	3860	7036	47765	13235	213	3632	100546	0.58
BDT	64656	12867	315	3149	6081	4859	102	1810	29187	0.47

- Separate the H→bb, cc, gg & background using Flavor Tagging, etc

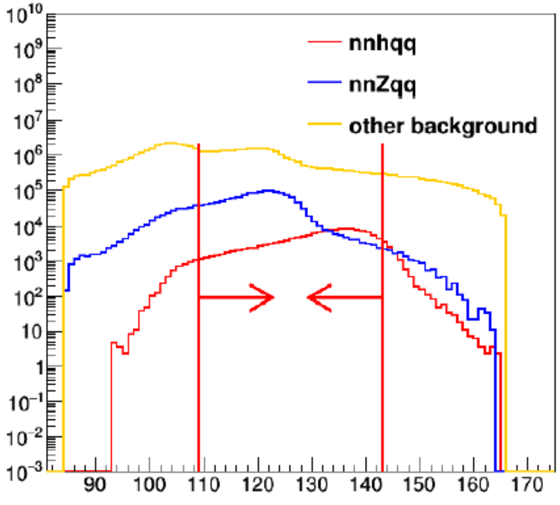


	$\nu\nu Hb\bar{b}$	$\nu\nu Hc\bar{c}$	$\nu\nu Hgg$	backgrounds
before BDT	61375	2892	7784	100546
after BDT	55257	2283	7087	29187

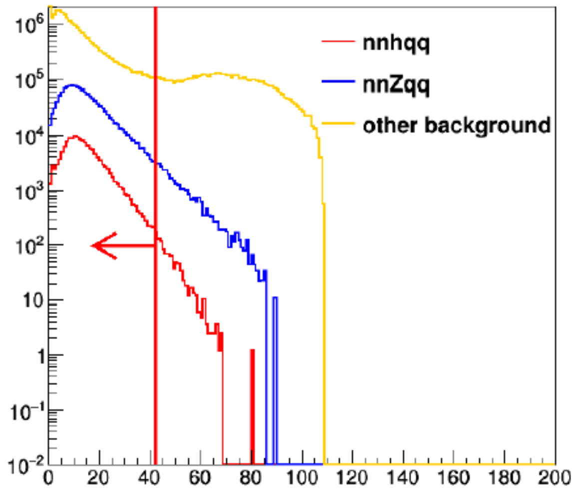
Variables & Cut to tag vvH, H→qq



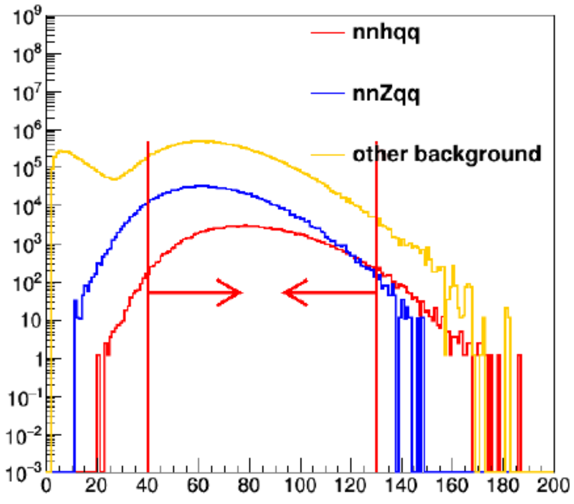
74 < recoil mass < 131



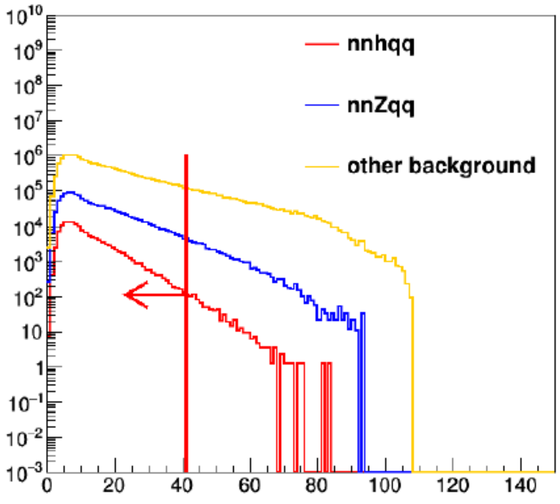
109 < visible energy < 143



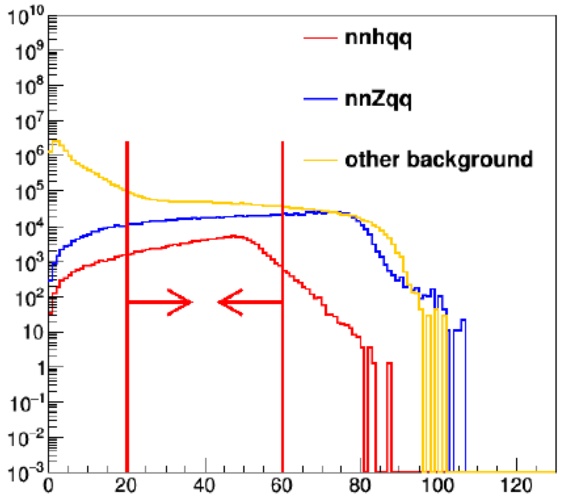
leading lepton energy < 42



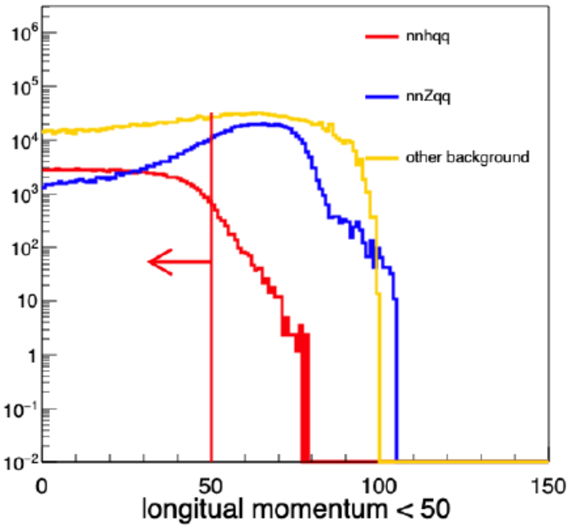
40 < multiplicity < 130

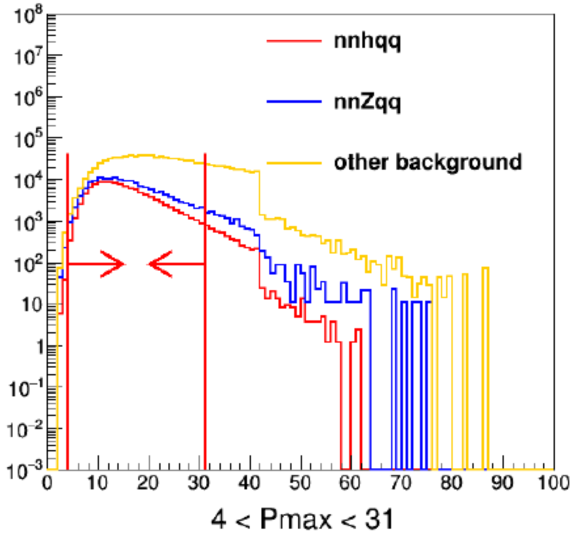


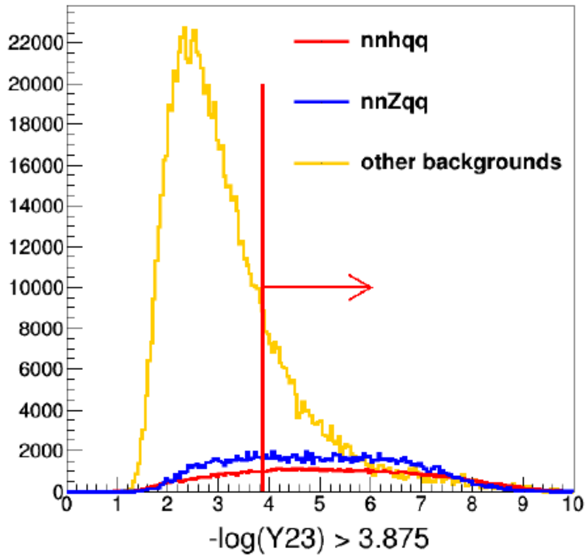
leading neutral energy < 41

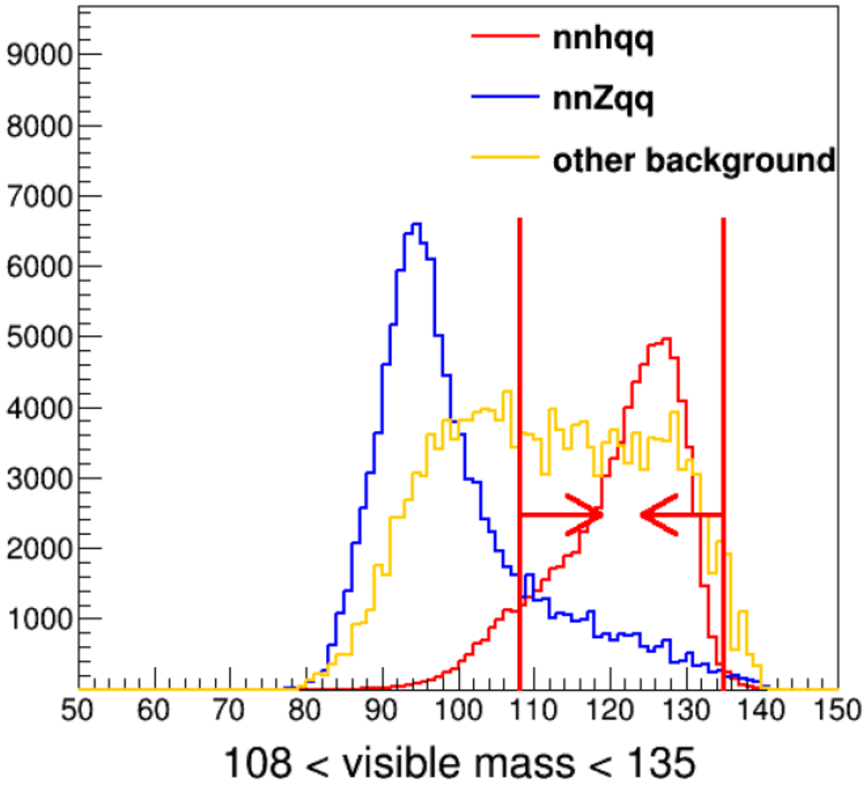


20 < transverse momentum < 60


nnhqq
nnZqq
other background
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
50
100
150
longitual momentum < 50


nnhqq
nnZqq
other background
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
0
10
20
30
40
50
60
70
80
90
100
4 < Pmax < 31


nnhqq
nnZqq
other backgrounds
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
1
2
3
4
5
6
7
8
9
10
-log(Y23) > 3.875


nnhqq
nnZqq
other background
9000
8000
7000
6000
5000
4000
3000
2000
1000
50
60
70
80
90
100
110
120
130
140
150
108 < visible mass < 135

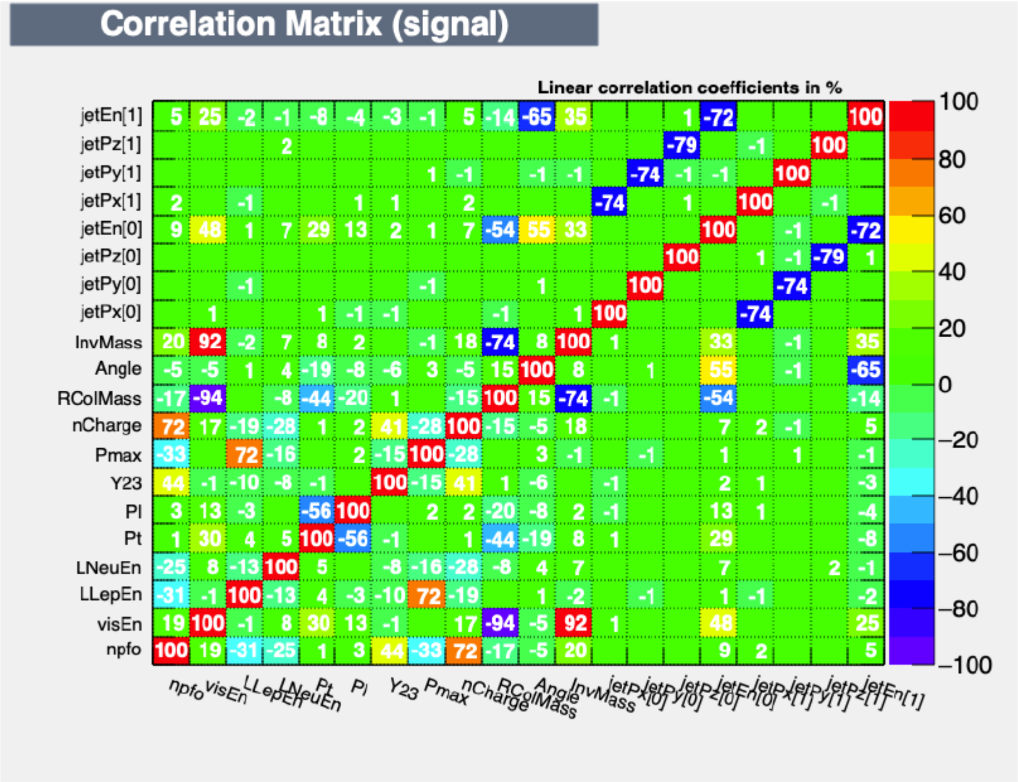
BDT for selecting $\nu\nu Hq\bar{q}$

Relative accuracy: 0.58 → 0.47

input variables :

The remaining events are forced into 2-jets using ee-kt

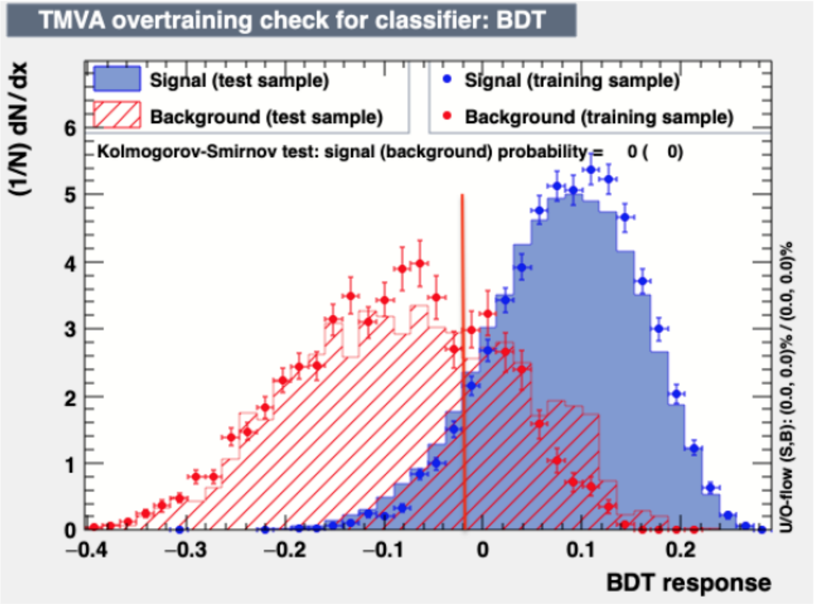
- recoilMass : the recoil mass of final state particles
- visEn : visible energy of final state particles
- Npfo : number of final state particles
- leadLepEn : leading lepton energy,
- leadNeuEn : leading neutral energy
- Pt : the transverse momentum of all final state particles
- Pl : the longitudinal momentum of all final state particles
- Pmax : the maximum transverse momentum among final state particles
- Y23
- InvMass : visible mass
- num_charge : number of charge particles
- Angle : the angle between two jets
- 4 momentum of two jets



Correlation Matrix (signal)

Linear correlation coefficients in %

	npfo	visEn	LLepEn	LNeuEn	Pt	Pl	Y23	Pmax	nCharge	RColMass	Angle	InvMass	jetPx[0]	jetPy[0]	jetPz[0]	jetEn[0]	jetPx[1]	jetPy[1]	jetPz[1]	jetEn[1]
jetEn[1]	5	25	-2	-1	-8	-4	-3	-1	5	-14	-65	35			1	-72				100
jetPz[1]				2											-79		-1		100	
jetPy[1]								1	-1		-1	-1		-74	-1	-1		100		
jetPx[1]	2		-1			1	1		2				-74		1		100		-1	
jetEn[0]	9	48	1	7	29	13	2	1	7	-54	55	33				100		-1		-72
jetPz[0]															100		1	-1	-79	1
jetPy[0]			-1					-1			1			100				-74		
jetPx[0]		1			1	-1	-1			-1		1	100				-74			
InvMass	20	92	-2	7	8	2		-1	18	-74	8	100	1			33		-1		35
Angle	-5	-5	1	4	-19	-8	-6	3	-5	15	100	8		1		55		-1		-65
RColMass	-17	-94		-8	-44	-20	1		-15	100	15	-74	-1			-54				-14
nCharge	72	17	-19	-28	1	2	41	-28	100	-15	-5	18				7	2	-1		5
Pmax	-33		72	-16		2	-15	100	-28		3	-1		-1		1		1		-1
Y23	44	-1	-10	-8	-1		100	-15	41	1	-6		-1			2	1			-3
Pl	3	13	-3		-56	100		2	2	-20	-8	2	-1			13	1			-4
Pt	1	30	4	5	100	-56	-1		1	-44	-19	8	1			29				-8
LNeuEn	-25	8	-13	100	5		-8	-16	-28	-8	4	7				7			2	-1
LLepEn	-31	-1	100	-13	4	-3	-10	72	-19		1	-2		-1		1	-1			-2
visEn	19	100	-1	8	30	13	-1		17	-94	-5	92	1			48				25
npfo	100	19	-31	-25	1	3	44	-33	72	-17	-5	20				9	2			5



TMVA overtraining check for classifier: BDT

Flavor Tagging Migration Matrix

introduce the flavor tagging performance matrix :

eff \ to true	c	b	udsg
udsg	udsg to c	udsg to b	udsg to udsg
b	b to c	b to b	b to udsg
c	c to c	c to b	c to udsg

to : identified as

	c	b	udsg
udsg	0	0	1
b	0	1	0
c	1	0	0

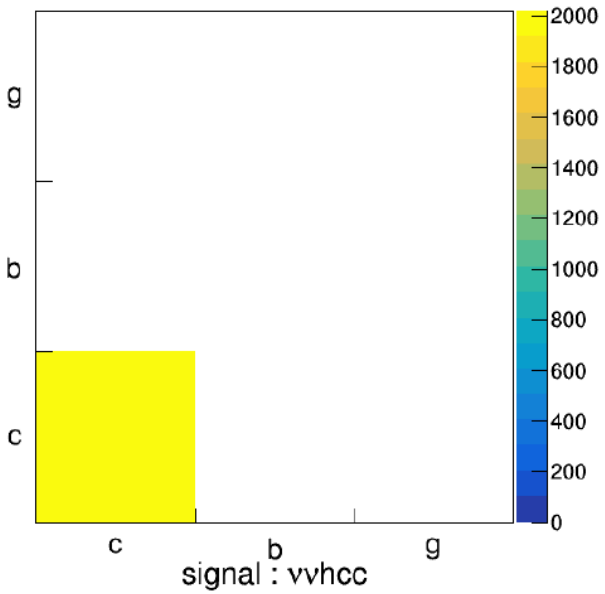
perfect flavor tagging

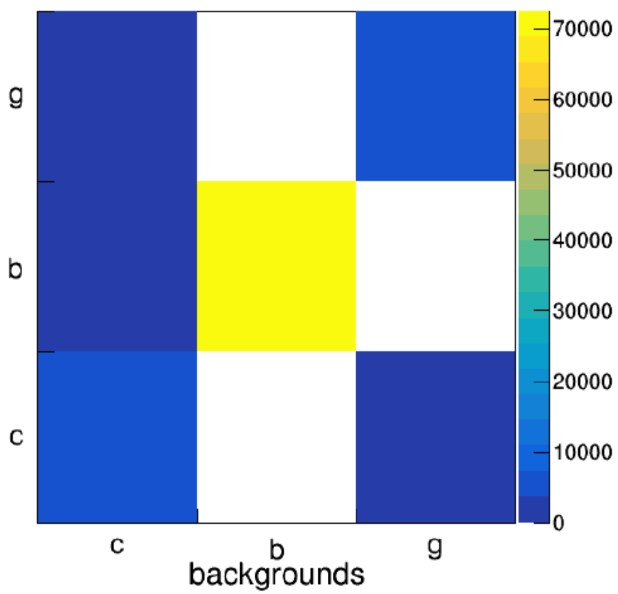
	c	b	udsg
udsg	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
b	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
c	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$

non flavor tagging

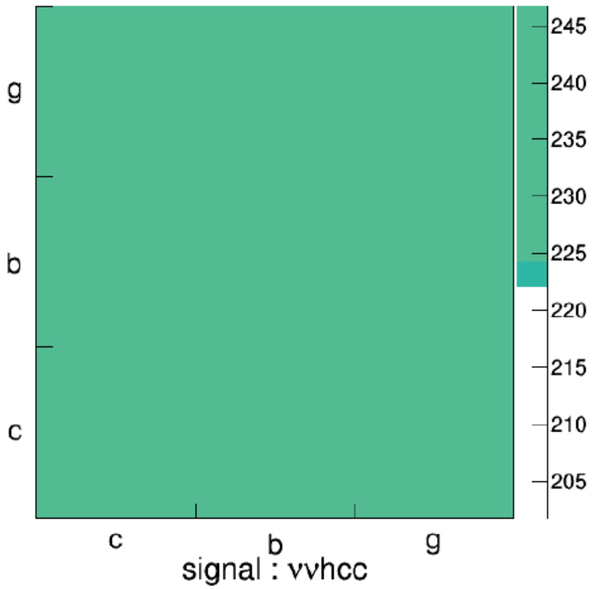
see $\nu\nu Hc\bar{c}$ as signal, and other samples as bkg

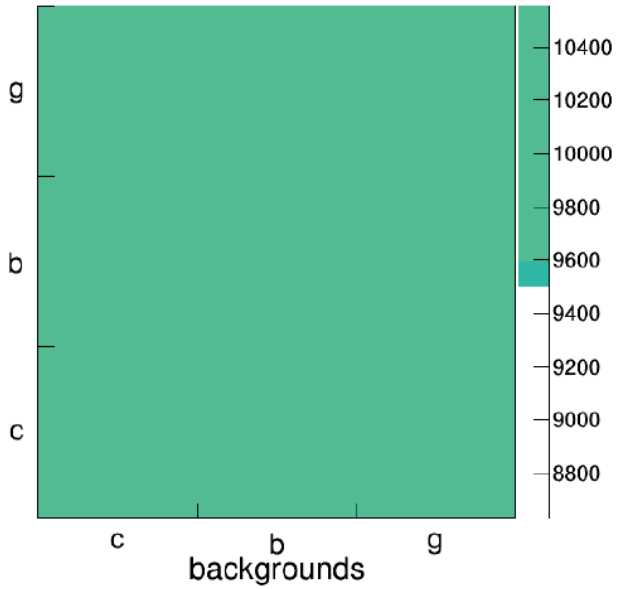
perfect flavor tagging



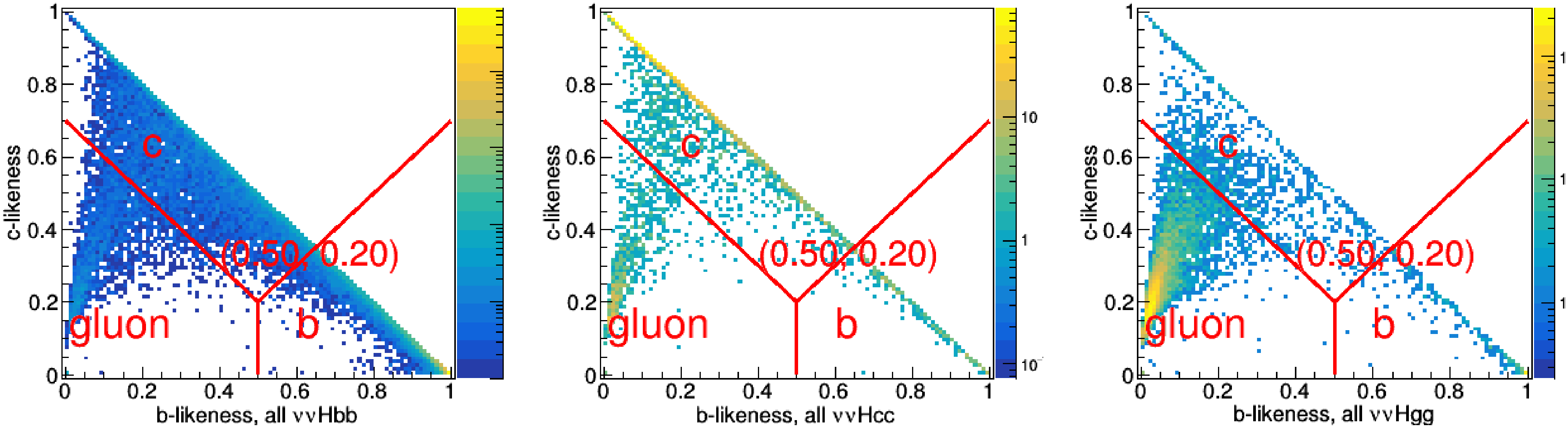


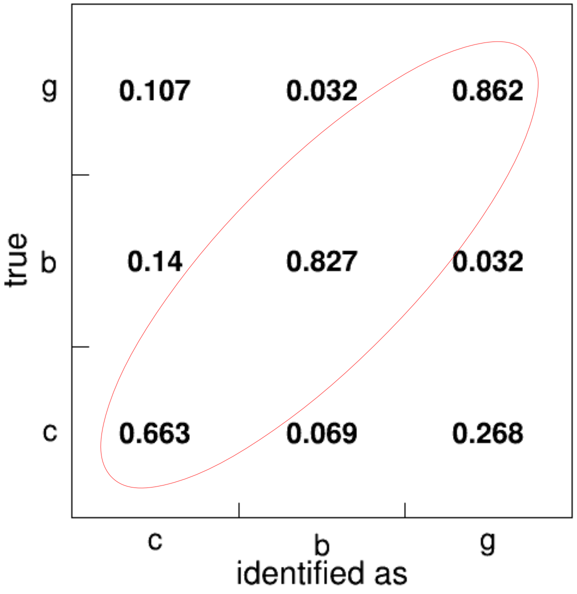
non flavor tagging





Identify Jet Flavor Using LCFIPlus



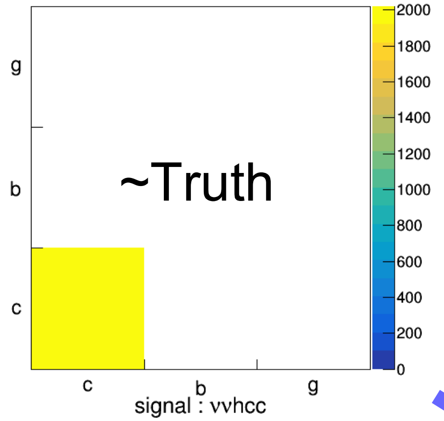


true \ identified as	c	b	g
g	0.107	0.032	0.862
b	0.14	0.827	0.032
c	0.663	0.069	0.268

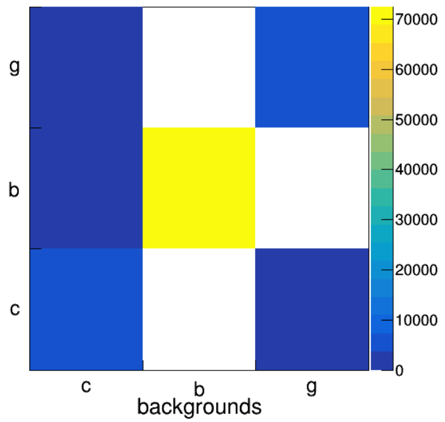
Working point selection:

Maximize the trace of Migration Matrix (Diagonal terms)

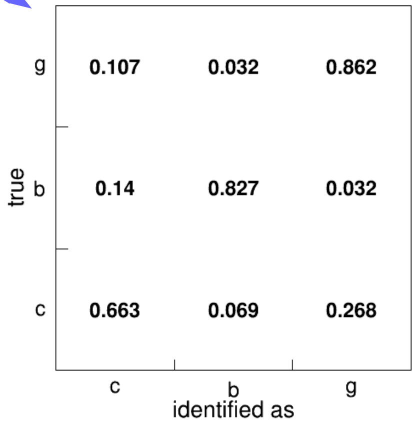
Optimizing Working Point for each decay modes independently leads to percentage level improvement for H→cc/gg



~Truth

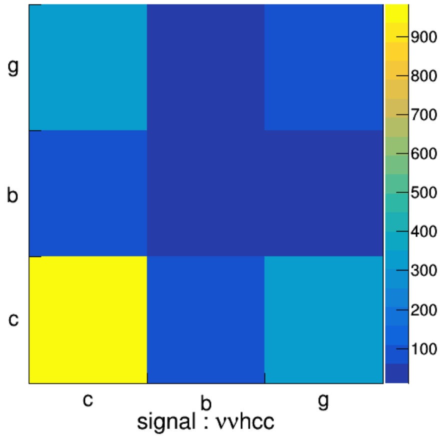


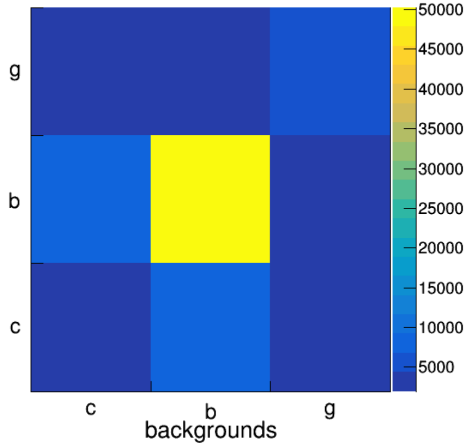
Migration Matrix



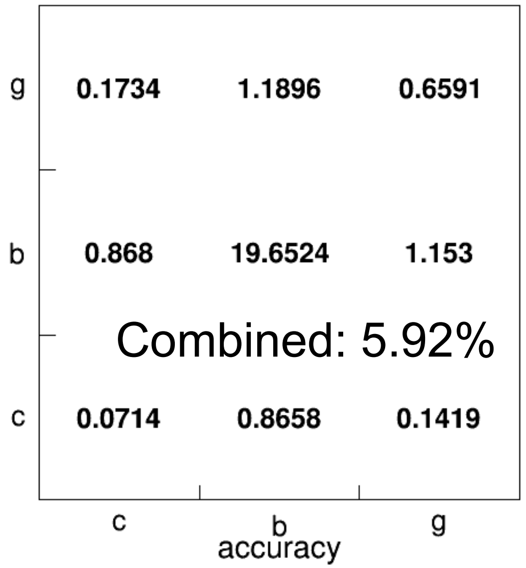
true \ identified as	c	b	g
g	0.107	0.032	0.862
b	0.14	0.827	0.032
c	0.663	0.069	0.268

~ reconstructed one



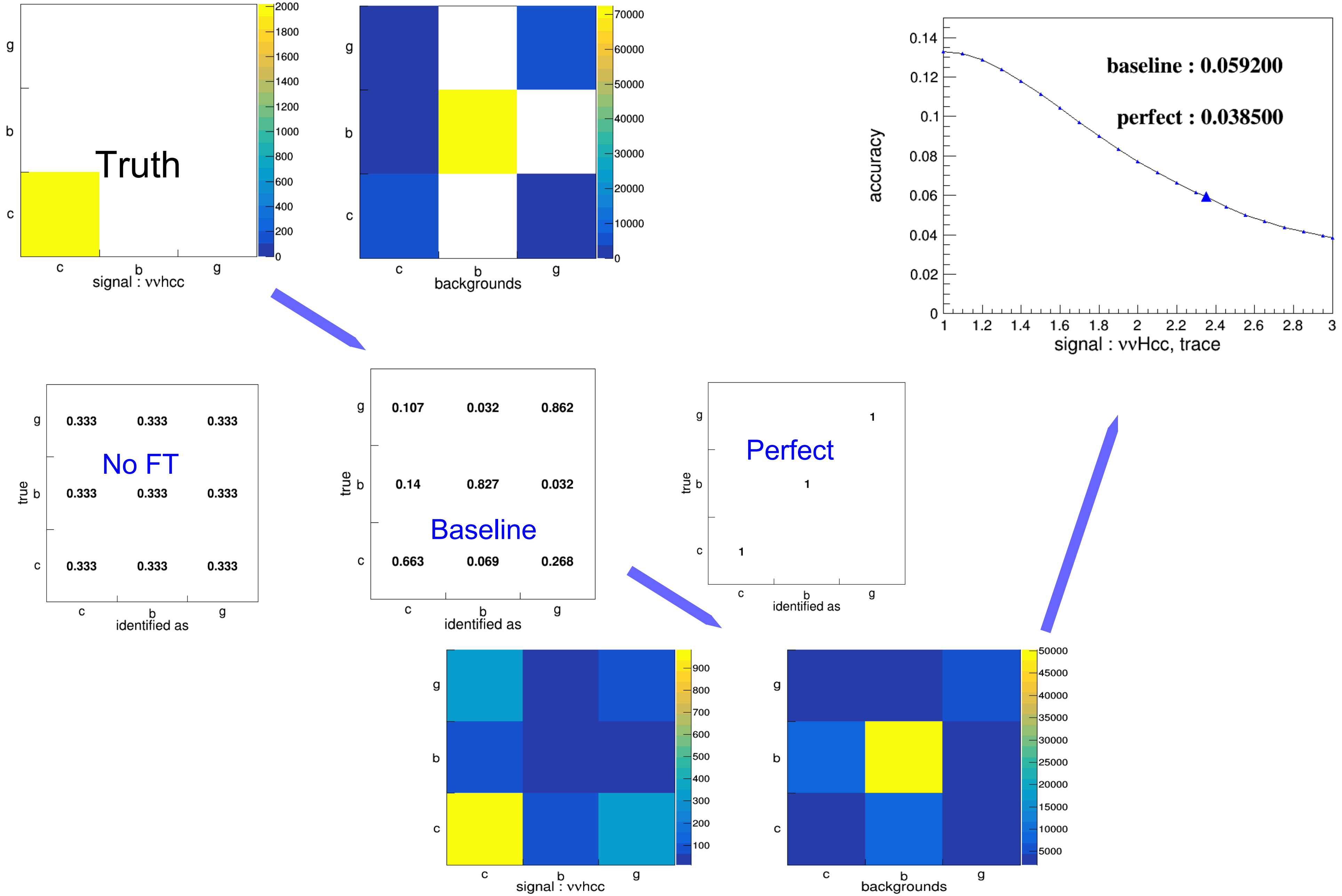


Per Bin Accuracy



	c	b	g
g	0.1734	1.1896	0.6591
b	0.868	19.6524	1.153
c	0.0714	0.8658	0.1419

Combined: 5.92%



No FT

true \ identified as	c	b	g
g	0.333	0.333	0.333
b	0.333	0.333	0.333
c	0.333	0.333	0.333

Baseline

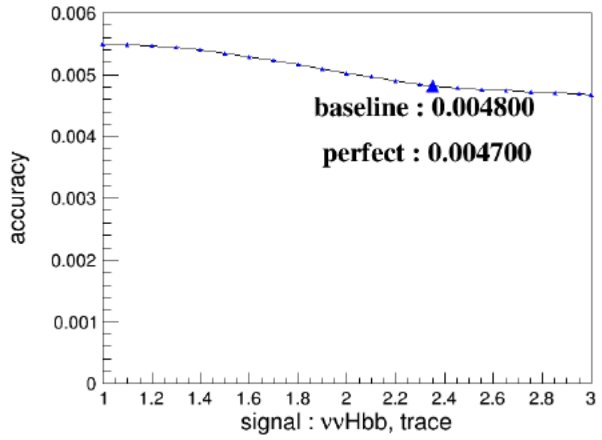
true \ identified as	c	b	g
g	0.107	0.032	0.862
b	0.14	0.827	0.032
c	0.663	0.069	0.268

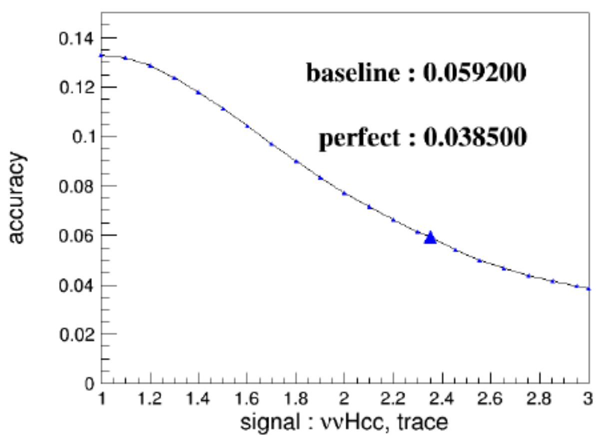
Perfect

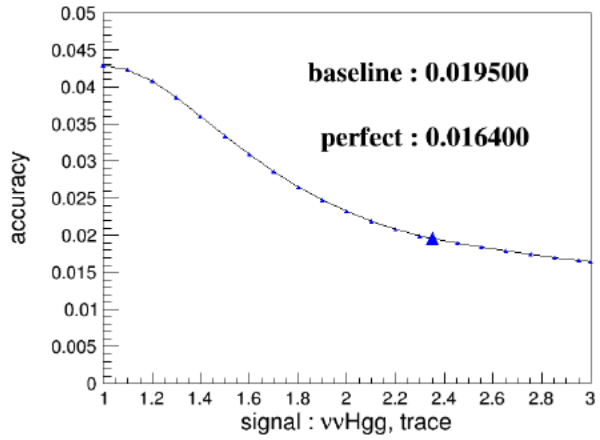
true \ identified as	c	b	g
g			1
b		1	
c	1		

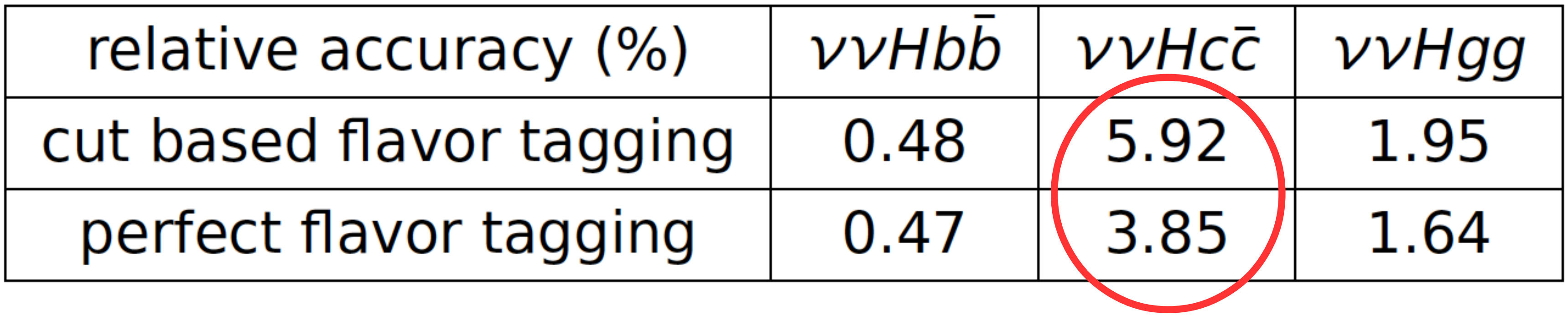
Interpolation: $\text{temp matrix} = \frac{x - trace_I}{trace_T - trace_I} \cdot (T - I) + I \quad (trace_I \leq x \leq trace_T)$

Dependence between accuracies & FT performance









relative accuracy (%)	$\nu\nu Hb\bar{b}$	$\nu\nu Hc\bar{c}$	$\nu\nu Hgg$
cut based flavor tagging	0.48	5.92	1.95
perfect flavor tagging	0.47	3.85	1.64

Margin to improve up to ~50%...

qqH

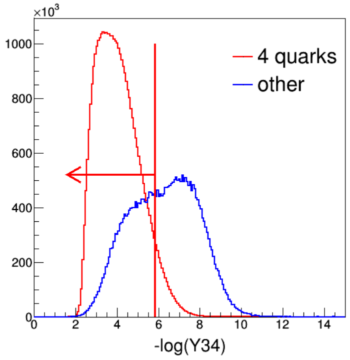
- Tag H→qq:

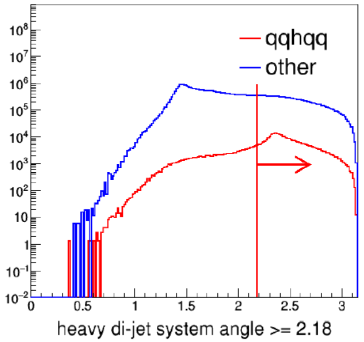
1. Finding the full hadronic samples from all samples.
2. Finding 4-quark samples from the full hadronic samples.
3. Finding $ZH(Z \rightarrow q\bar{q}, H \rightarrow q\bar{q})$ from 4-quark samples.

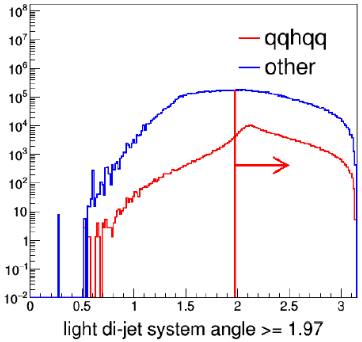
- Distinguish the H→bb, cc, gg & background events using Flavor Tagging information
  - Using BDT information

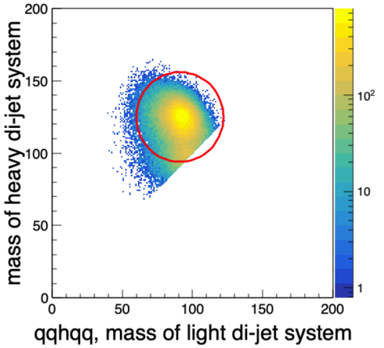
Tag qqH, H→qq

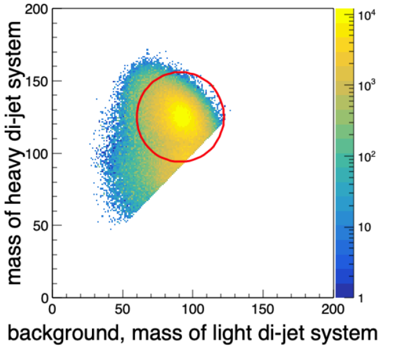
	qqHqq	2f	SW	SZ	WW	ZZ	Mixed	ZH	total bkg	$\frac{\sqrt{S+B}}{S}$ (%)
total	527488	8.01*E*8	1.95*E*7	9.07*E*6	5.08*E*7	6.39*E*6	2.18*E*7	613008	9.09*E*8	5.71
multiplicity	527488	3.04*E*8	1.46*E*7	3.37*E*6	4.85*E*7	6.00*E*6	1.81*E*7	577930	3.95*E*8	3.77
LLepEn	527036	2, 98*E*8	6.76*E*6	2.44*E*6	3.93*E*7	5.40*E*6	1.79*E*7	531411	3.71*E*8	3.65
visEn	510731	1.21*E*8	1.29*E*6	551105	2.14*E*7	3.06*E*6	1.71*E*7	180571	1.65*E*8	2.52
LNeuEn	509623	5.68*E*7	716161	168030	2.04*E*7	2.93*E*6	1.65*E*7	176387	9, 77*E*7	1.94
thrust	460535	7.81*E*6	473732	132126	1.88*E*7	2.60*E*6	1.54*E*7	167863	4.54*E*7	1.47
$-log(Y_{34})$	451468	4.90*E*6	181432	119836	1.74*E*7	2.40*E*6	1.45*E*7	165961	3.97*E*7	1.48
HJetA	326207	2.83*E*6	110156	58613	4.54*E*6	870276	3.74*E*6	96560.3	1.22*E*7	1.08
ZJetA	279030	1.37*E*6	33491	37101	2.39*E*6	496611	2.00*E*6	74005	6.41*E*6	0.93
ZHA	274530	1.32*E*6	17026	33847	2.28*E*6	468340	1.91*E*6	69620	6.10*E*6	0.92
circleqq	268271	1.20*E*6	10193	31567	2.13*E*6	424514	1.79*E*6	65434	5.65*E*6	0.907









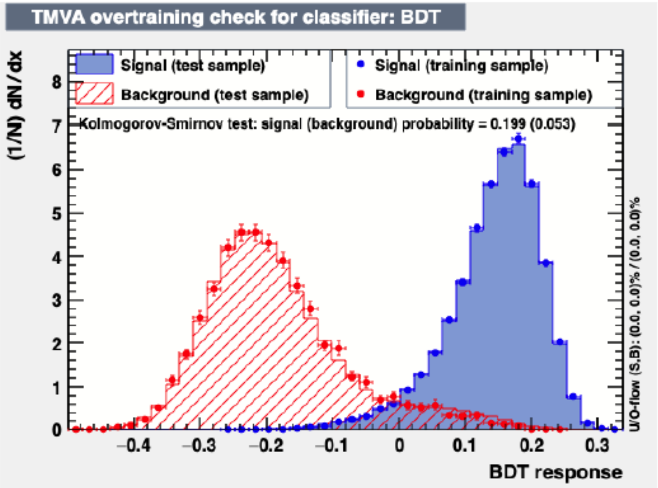


Relative Accuracy on qqH, H→qq: 0.9%

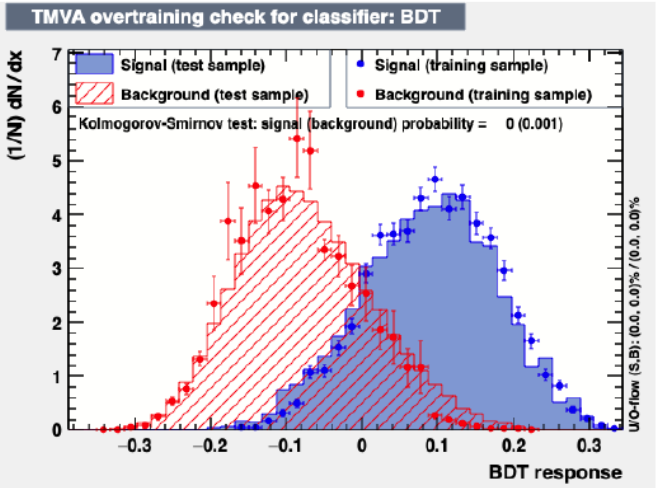
Finally, finding $qqH(H \to b\bar{b}, c\bar{c}, gg)$ from $ZH(Z \to q\bar{q}, H \to q\bar{q})$ with BDT.

- number of final state particles
- visible energy of final state particles
- leading lepton energy, leading neutral energy
- thrust, Y34
- heavy di-jet angle, light di-jet angle

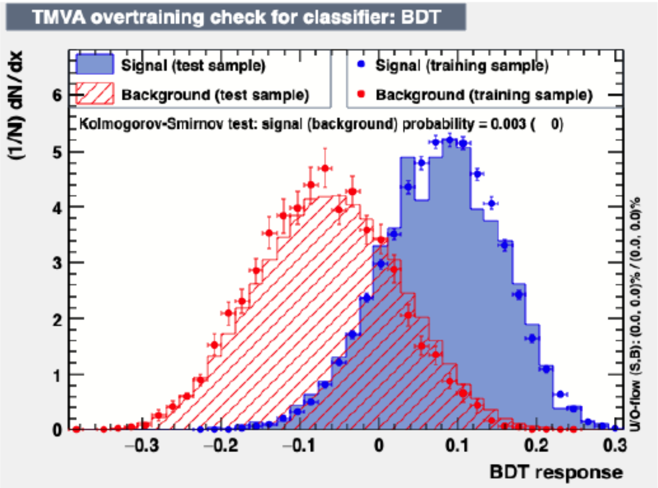
- the invariant mass of light di-jet system
- the invariant mass of heavy di-jet system
- the b/c-likeness of four jets
- four momentum of four jets



qqhbb



qqhcc



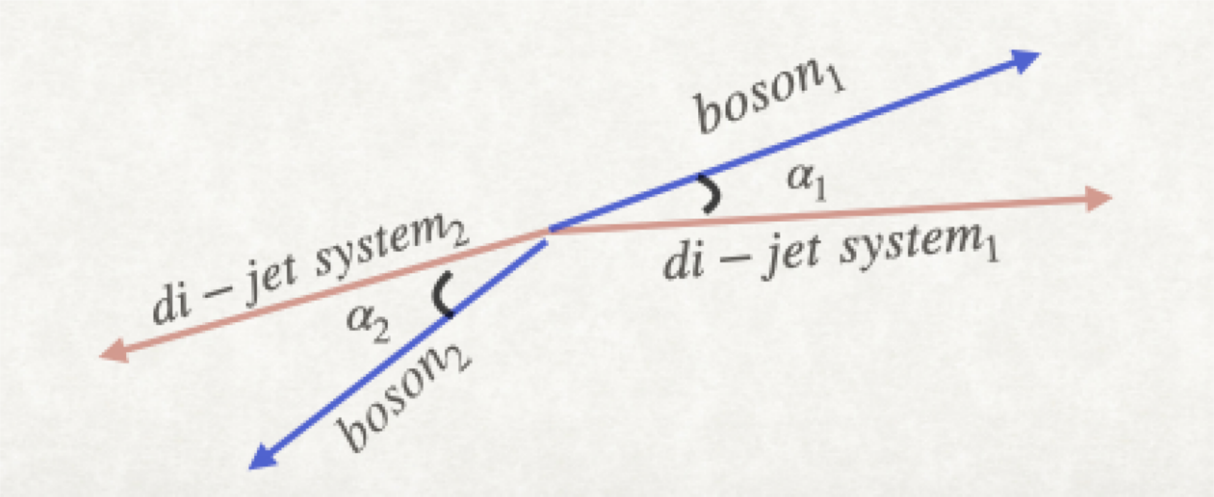
qqhgg

	signal	2f	SW	SZ	WW	ZZ	Mixed	ZH	total bkg	$\frac{\sqrt{S+B}}{S}$ (%)
qqhbb	174201	89168.9	0	67	3596	54373	4094	11264	162566	0.33
qqhcc	5084	76291	10	165	38838	21343	61524	15895	214068	9.2
qqhgg	19564	181982	0	0	140735	50184	134015	41995	548920	3.85

Key performance: CSI

color singlet identification

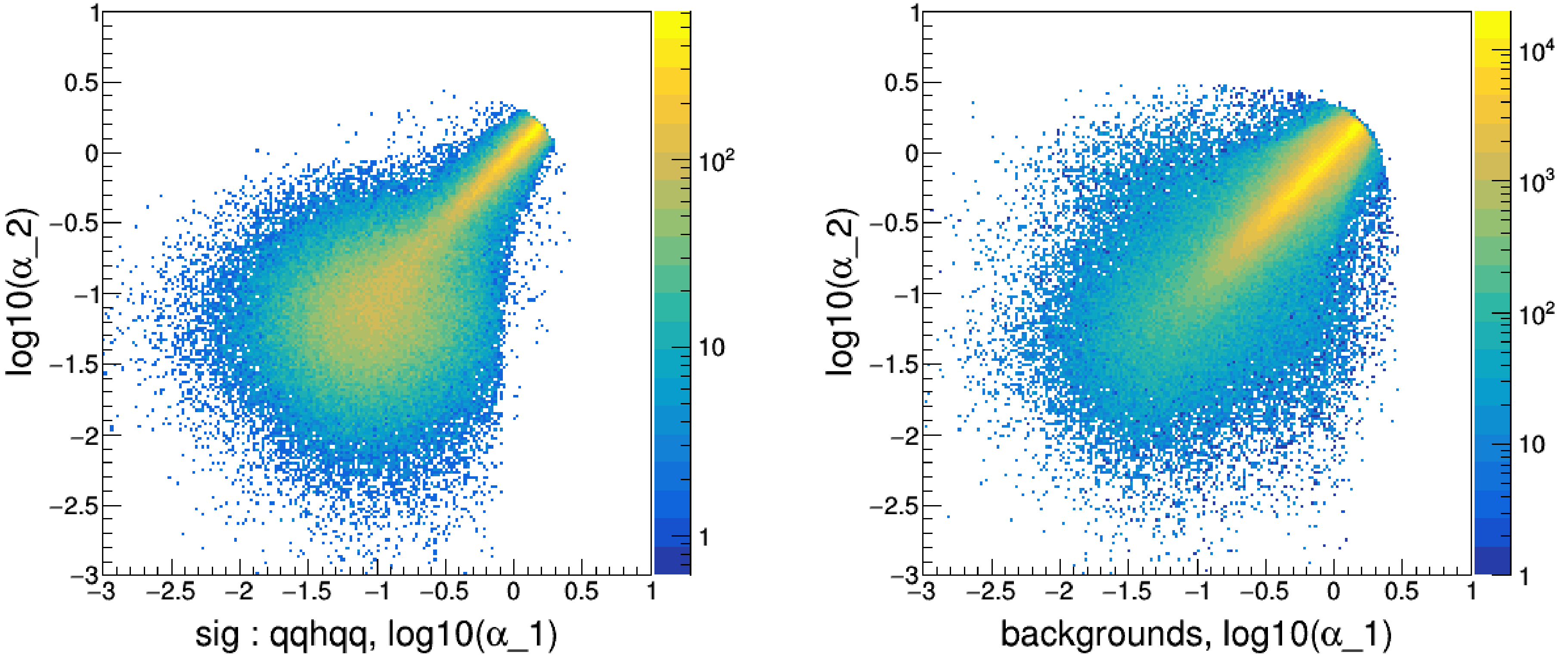
For di-boson event, there are two MC truth bosons and two di-jet systems, the variable $\alpha_i = angle(di-jet\ system_i, truth\ boson_i), (i = 1, 2)$ is used to characterize the performance of jet clustering and jet matching.



the α variable is just a cheated variable used to characterize the performance of color singlet identification

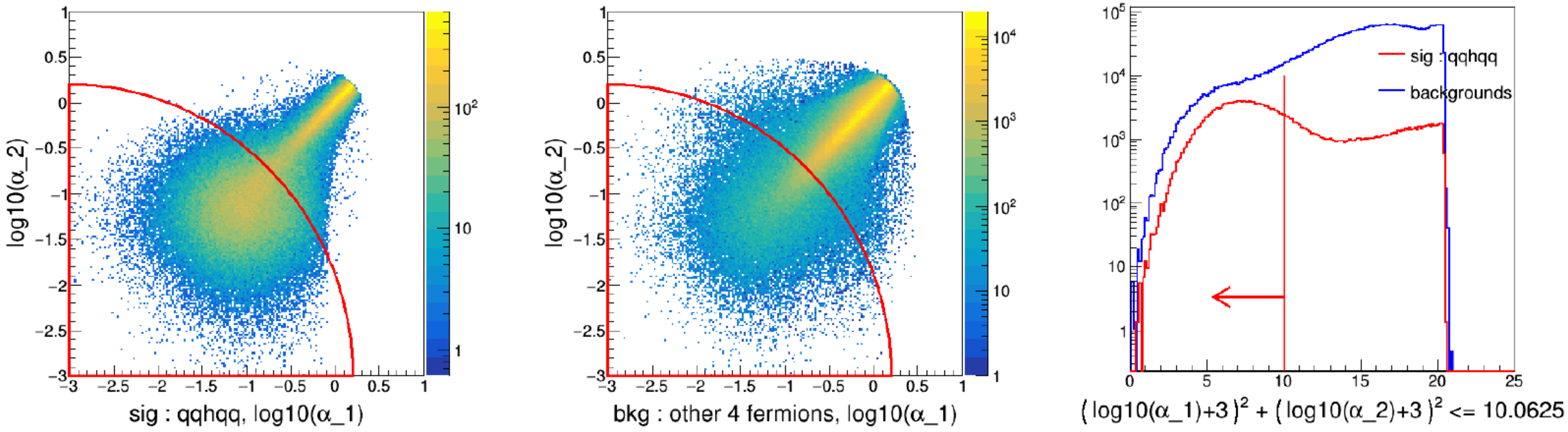
Diagnosis method developed in EPJC(2019) 79:274

Distribution of alphas: Signal & Background



Observation: backgrounds tends to have large alphas – large jet confusion, induced by the Kinematics requirement in event selection

If we know the CSI performance...

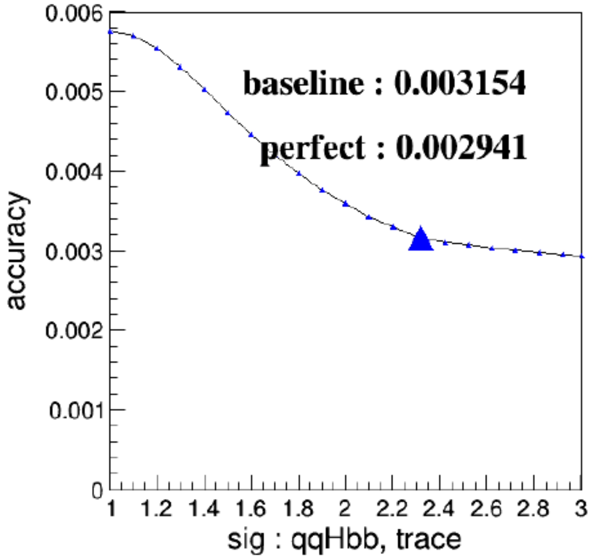


the red curve : $(log10(\alpha_1)+3)^2+(log10(\alpha_2)+3)^2 <= 3.2^2$ used to select events with good color singlet identification

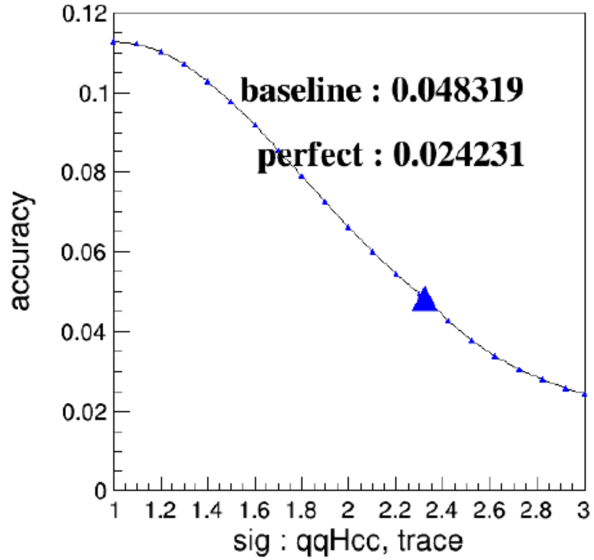
	qqhbb	qqhcc	qqhgg	background
after circle	219360	10430.5	31469.7	5.65E6
after alpha	132697	6776.48	17570	593172

α detail : `https://link.springer.com/article/10.1140/epjc/s10052-019-6719-2`

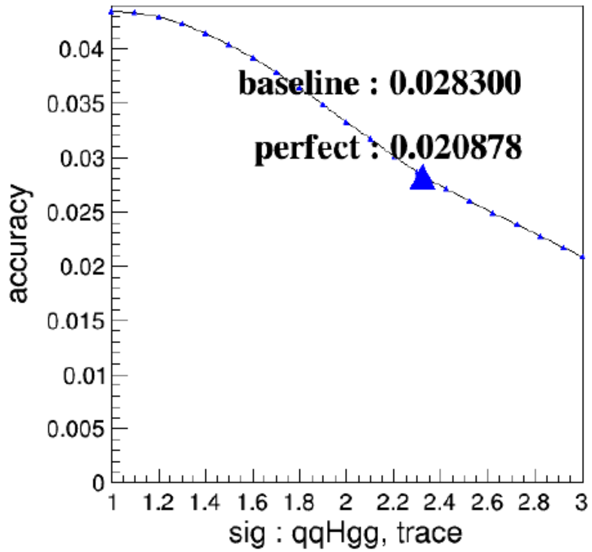
the variation of $qqHq\bar{q}$ measurement accuracy with trace



qqhbb



qqhcc



qqhgg

relative accuracy (%)	$qqHb\bar{b}$	$qqHc\bar{c}$	$qqHgg$
BDT	0.33	9.2	3.85
alpha & cut based flavor tagging	0.31	4.83	2.83
alpha & perfect flavor tagging	0.29	2.42	2.08

Summary

- CEPC Higgs White paper published in 2019: quantifies the core physics potential
- Performance: quantify requirements & baseline performance
- 360 GeV Higgs operation (2 ab^{-1})
  - Provides 30% more Higgs, improve the Higgs width measurement by ~ 2 times
  - Significant impact on top related measurements, etc
- H→qq analyses
  - Accuracies at Baseline: 0.26/4.3/1.6% for H→bb/cc/gg (*To be optimized...*)
  - Key performance
    - Color Singlet Identification: boost the accuracy on H→cc by 2 times or more!
    - Flavor Tagging: up to 50%/2 times (H→cc @ vvH/qqH)
  - Plan:
    - Develop better CSI, from quantify the CSI with reconstructable information.
    - Promote better Flavor tagging

Back up

Electron Positron Higgs factories

High-priority future initiatives

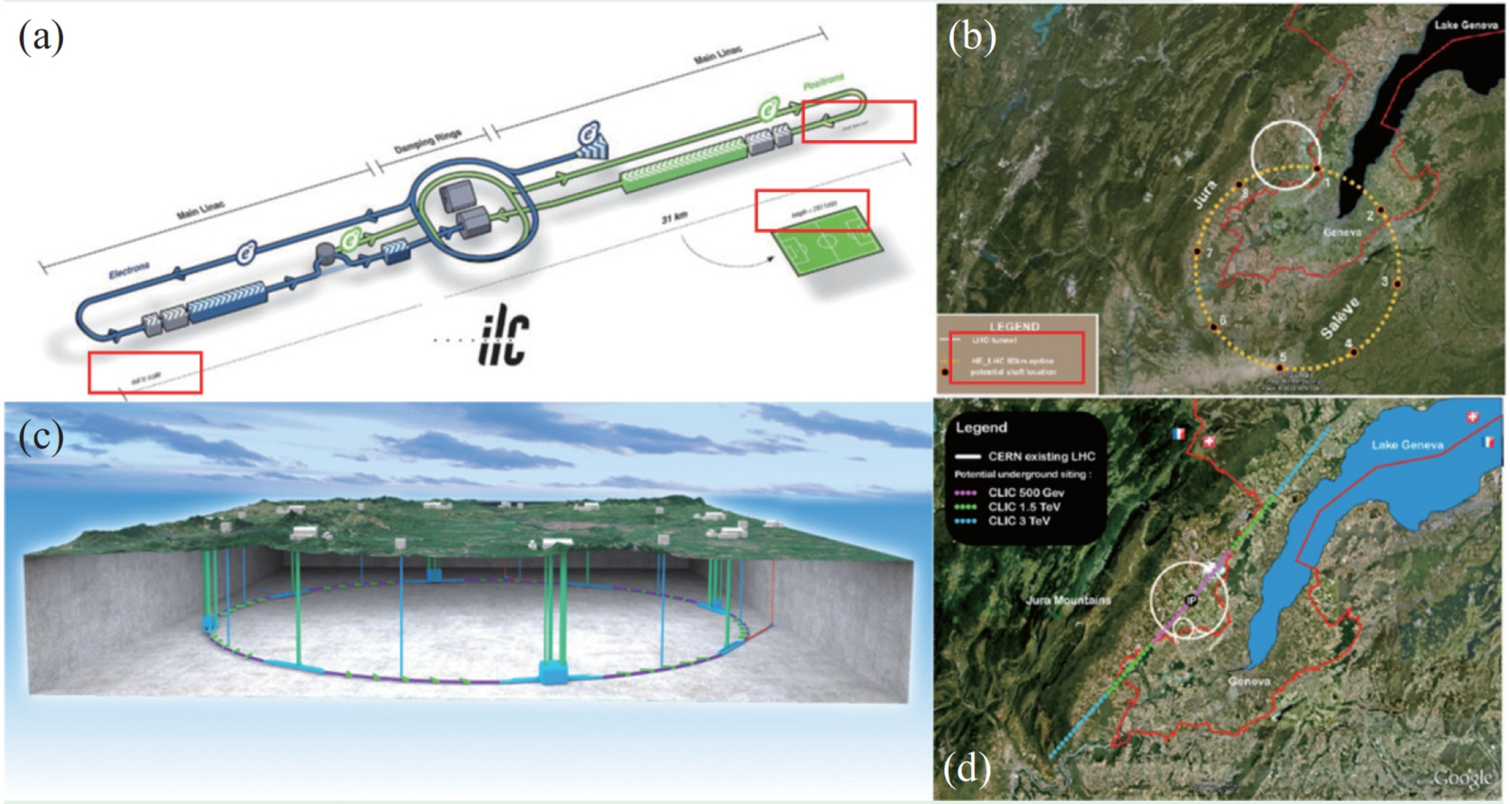
An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

ILC (a):	TDR @ 2013
FCC (b):	CDR @ 2019
CEPC (c):	CDR @ 2018
CLIC (d):	CDR @ 2013

DELIBERATION DOCUMENT
ON THE 2020 UPDATE OF THE EUROPEAN STRATEGY
FOR PARTICLE PHYSICS

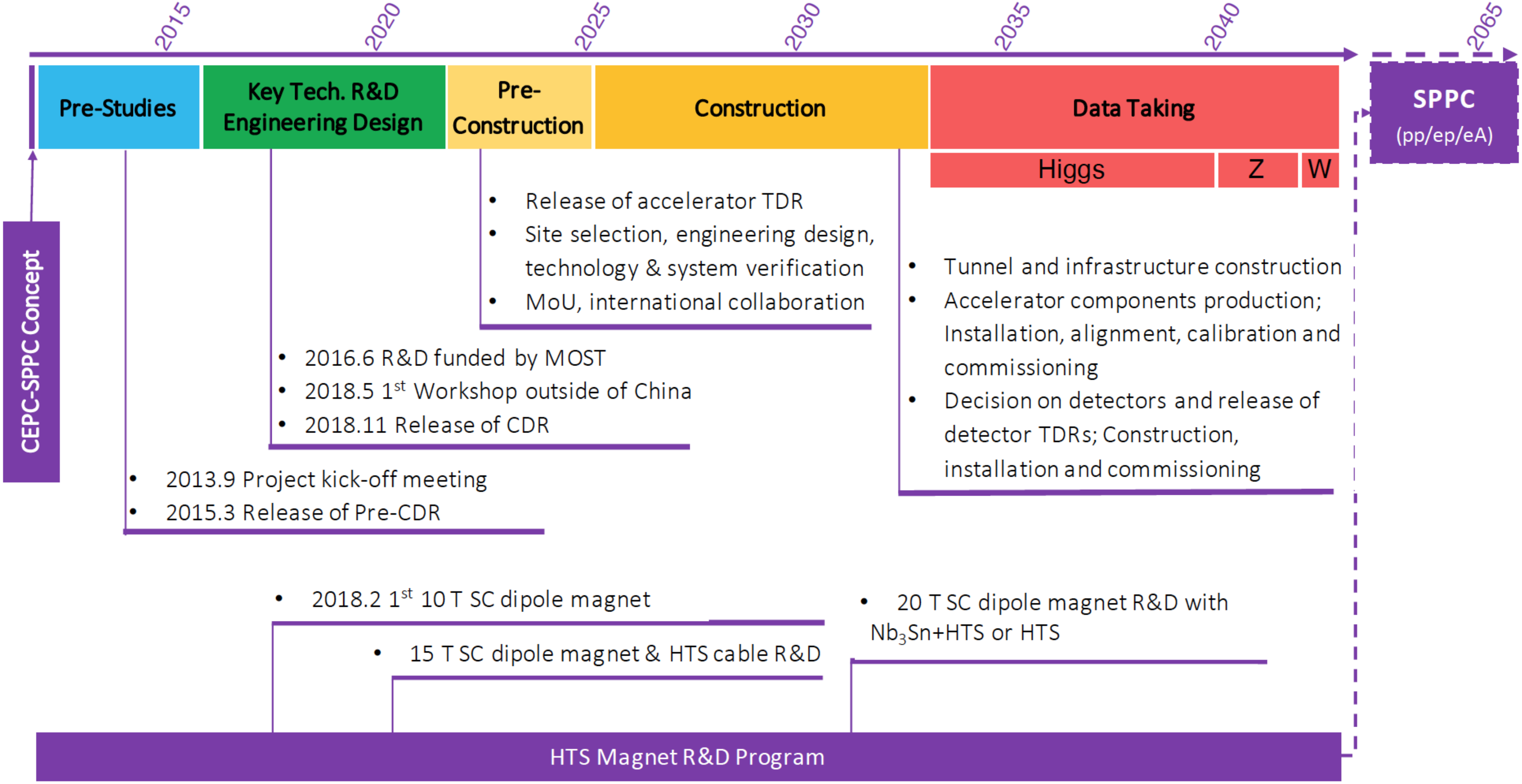
The European Strategy Group

European Strategy
Update



Timeline

CEPC Project Timeline



2015 2020 2025 2030 2035 2040 2065

Pre-Studies | **Key Tech. R&D Engineering Design** | **Pre-Construction** | **Construction** | **Data Taking** (Higgs, Z, W) | **SPPC (pp/ep/eA)**

CEPC-SPPC Concept

- 2013.9 Project kick-off meeting
- 2015.3 Release of Pre-CDR

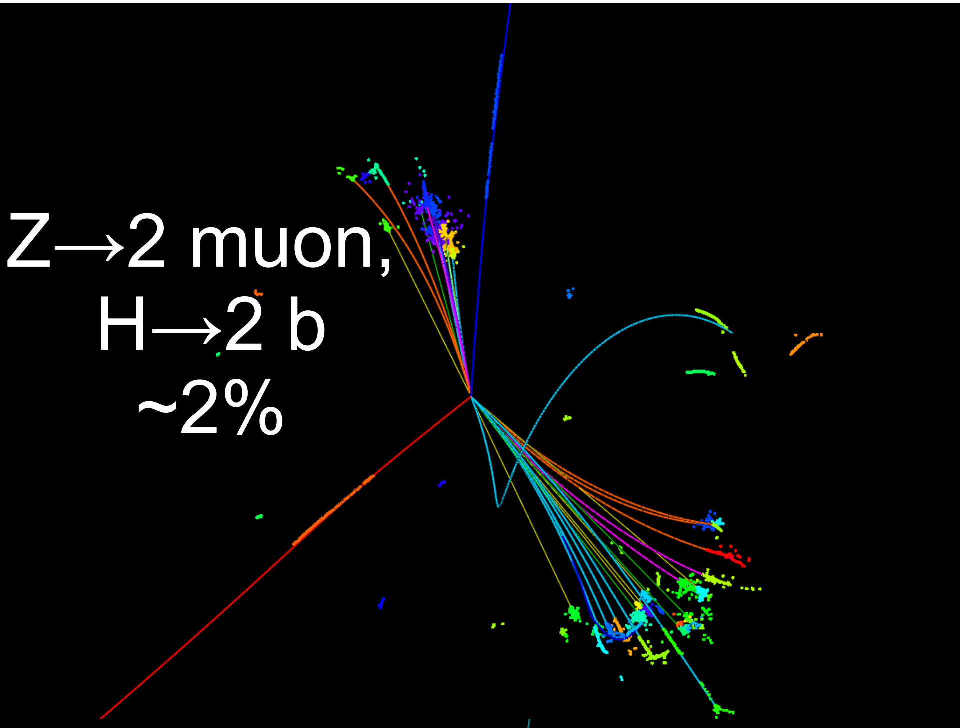
- 2016.6 R&D funded by MOST
- 2018.5 1st Workshop outside of China
- 2018.11 Release of CDR

- Release of accelerator TDR
- Site selection, engineering design, technology & system verification
- MoU, international collaboration

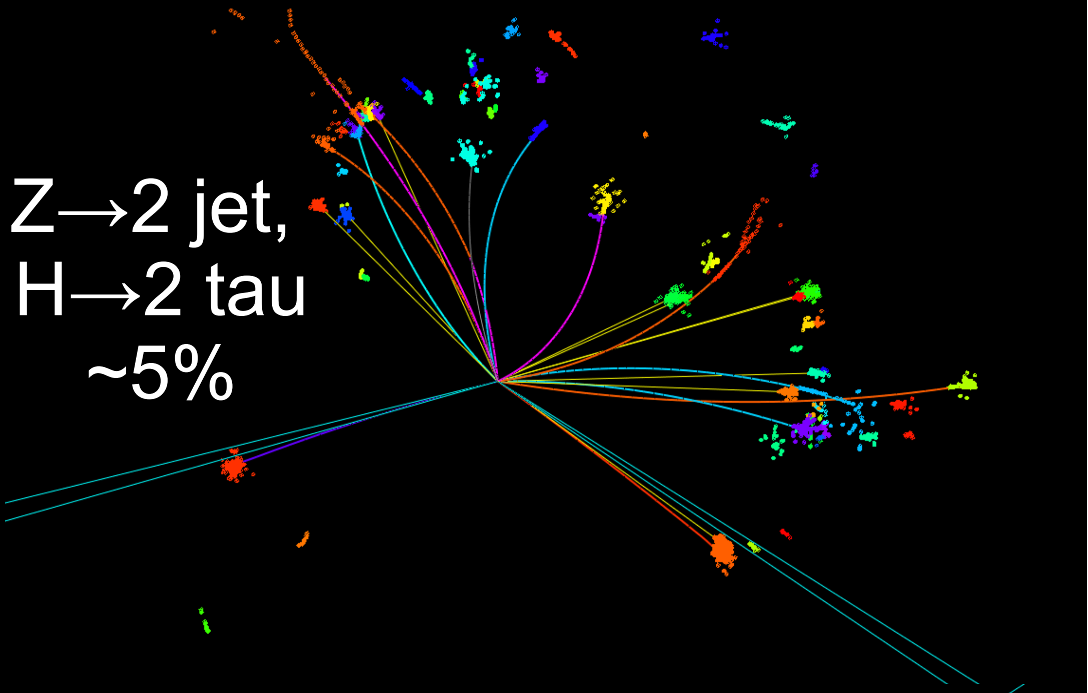
- Tunnel and infrastructure construction
- Accelerator components production; Installation, alignment, calibration and commissioning
- Decision on detectors and release of detector TDRs; Construction, installation and commissioning

- 2018.2 1st 10 T SC dipole magnet
- 15 T SC dipole magnet & HTS cable R&D
- 20 T SC dipole magnet R&D with Nb_3Sn+HTS or HTS

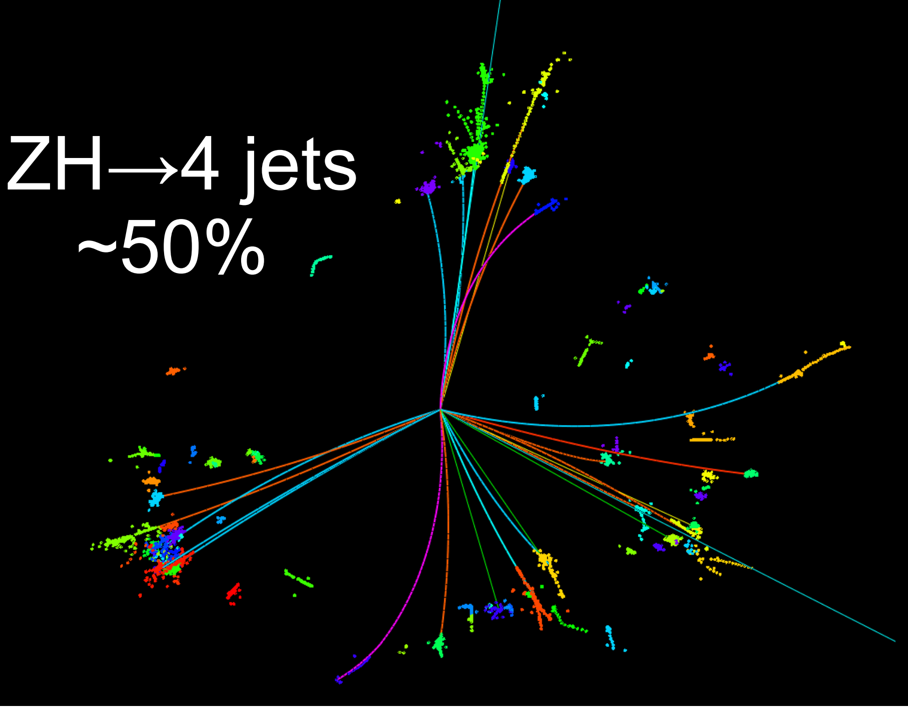
HTS Magnet R&D Program



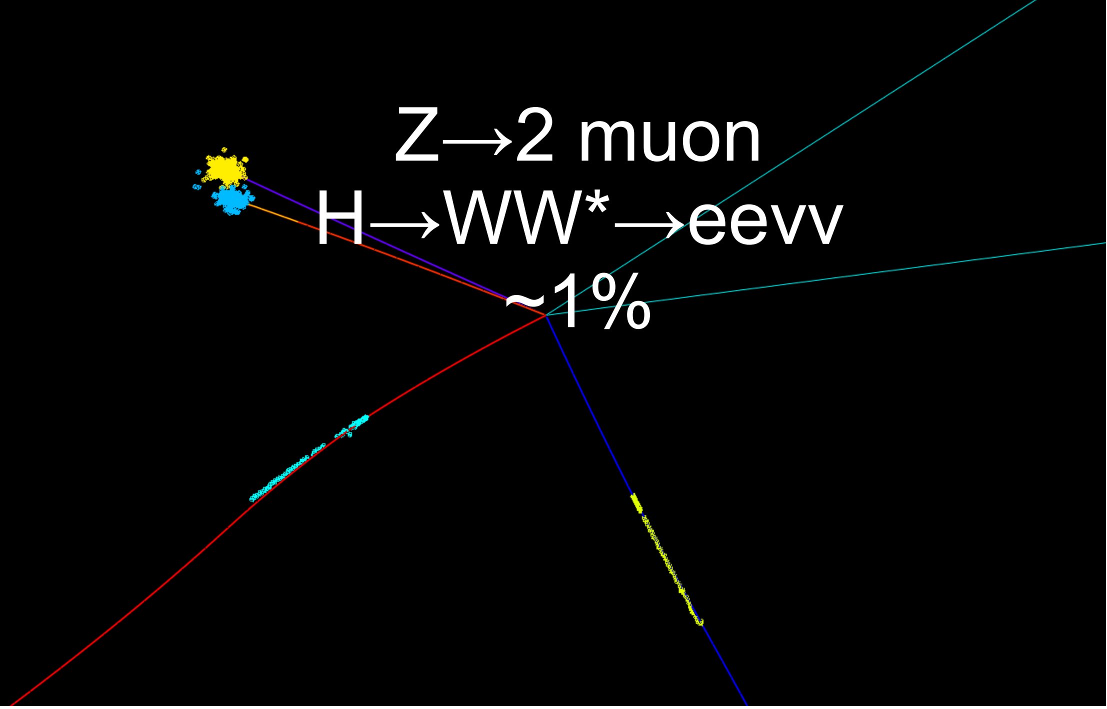
Z→2 muon,
H→2 b
~2%



Z→2 jet,
H→2 tau
~5%



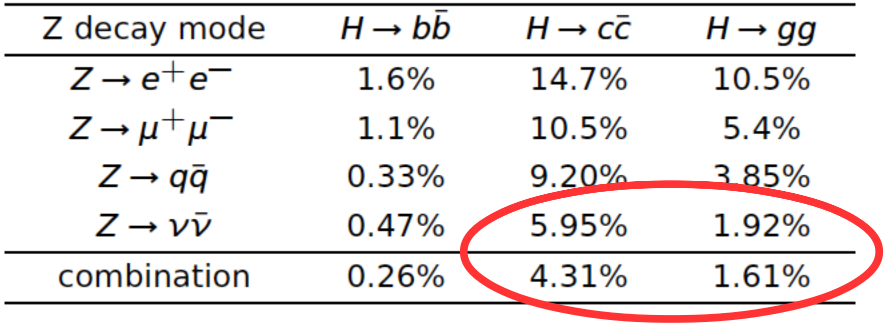
ZH→4 jets
~50%



Z→2 muon
H→WW*→eevv
~1%

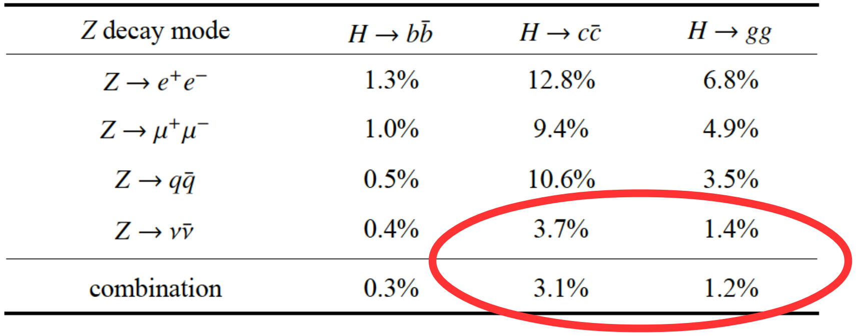
Comparison

Current



Z decay mode	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
$Z \to e^+e^-$	1.6%	14.7%	10.5%
$Z \to \mu^+\mu^-$	1.1%	10.5%	5.4%
$Z \to q\bar{q}$	0.33%	9.20%	3.85%
$Z \to \nu\bar{\nu}$	0.47%	5.95%	1.92%
combination	0.26%	4.31%	1.61%

White paper



Z decay mode	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
$Z \to e^+e^-$	1.3%	12.8%	6.8%
$Z \to \mu^+\mu^-$	1.0%	9.4%	4.9%
$Z \to q\bar{q}$	0.5%	10.6%	3.5%
$Z \to \nu\bar{\nu}$	0.4%	3.7%	1.4%
combination	0.3%	3.1%	1.2%

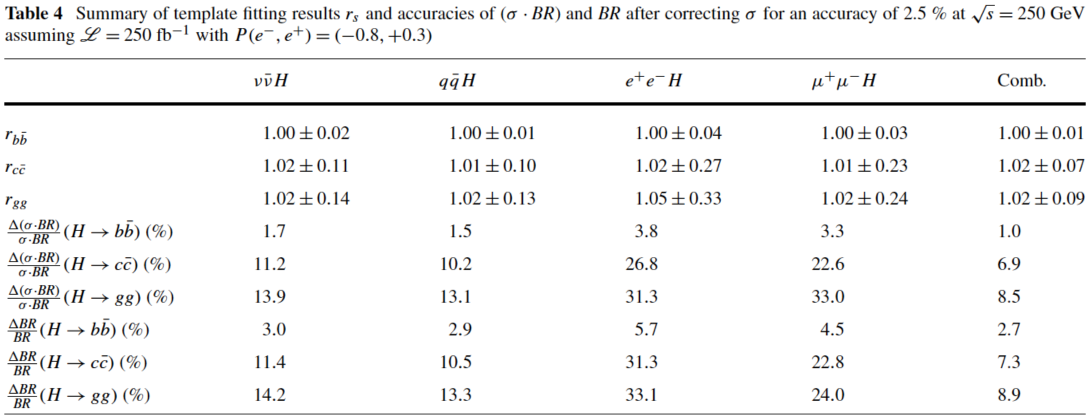


Table 4 Summary of template fitting results r_s and accuracies of $(\sigma \cdot BR)$ and BR after correcting σ for an accuracy of 2.5 % at $\sqrt{s} = 250$ GeV assuming $\mathscr{L} = 250\ \mathrm{fb}^{-1}$ with $P(e^-, e^+) = (-0.8, +0.3)$

	$\nu\bar{\nu}H$	$q\bar{q}H$	e^+e^-H	$\mu^+\mu^-H$	Comb.
$r_{b\bar{b}}$	1.00 ± 0.02	1.00 ± 0.01	1.00 ± 0.04	1.00 ± 0.03	1.00 ± 0.01
$r_{c\bar{c}}$	1.02 ± 0.11	1.01 ± 0.10	1.02 ± 0.27	1.01 ± 0.23	1.02 ± 0.07
r_{gg}	1.02 ± 0.14	1.02 ± 0.13	1.05 ± 0.33	1.02 ± 0.24	1.02 ± 0.09
$\frac{\Delta(\sigma \cdot BR)}{\sigma \cdot BR}(H \to b\bar{b})$ (%)	1.7	1.5	3.8	3.3	1.0
$\frac{\Delta(\sigma \cdot BR)}{\sigma \cdot BR}(H \to c\bar{c})$ (%)	11.2	10.2	26.8	22.6	6.9
$\frac{\Delta(\sigma \cdot BR)}{\sigma \cdot BR}(H \to gg)$ (%)	13.9	13.1	31.3	33.0	8.5
$\frac{\Delta BR}{BR}(H \to b\bar{b})$ (%)	3.0	2.9	5.7	4.5	2.7
$\frac{\Delta BR}{BR}(H \to c\bar{c})$ (%)	11.4	10.5	31.3	22.8	7.3
$\frac{\Delta BR}{BR}(H \to gg)$ (%)	14.2	13.3	33.1	24.0	8.9

	ILC-120	CYR-120	CYR-125
Br(bb)	66%	65%	58%
Br(cc)	3.6%	3.2%	2.9%
Br(gg)	5.5%	8.4%	8.2%

CERN Yellow Report (CYR): https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageBR

- Accuracy improves (from ILC to CEPC): ~4/2/5 times; tension in cc...
- Compared to vvH, qqH provides similar sensitivities at ILC, while 2 times worse at CEPC

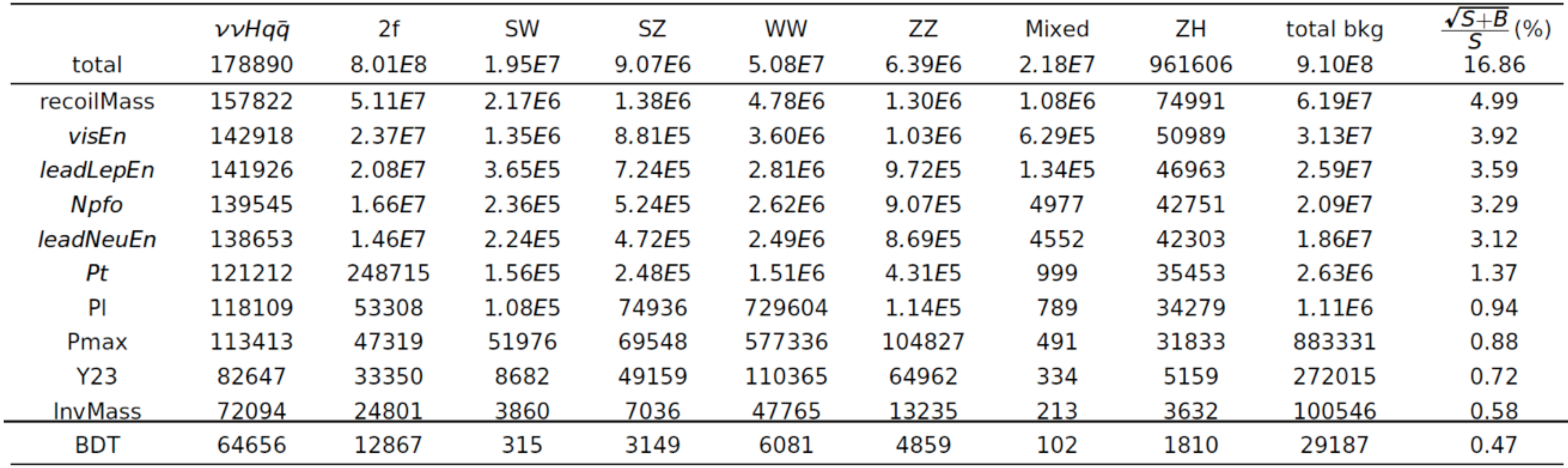
Comparison on vvH: with ILC

	ILC	CEPC
Total Signal	19360 (Higgs inclusive)	178890 (H->bb, cc, gg)
Total Background	4.5E7	9E8
1st stage Cut	Finding H->2j	
Signal (H→bb, cc, gg)	6293	64656
Background	10940	29187
Eff*Purity in 1st stage	12% (32.5%, 37%)	25% (36%, 69%)
2nd stage Cut	Separate Different Flavors	
Signal (H→cc)	226 – 300 (??)	2283
Irreducible background		5443
Final Accuracy	11%	5.9%
Effective eff*purity in 2nd stage	28 - 36%	12.5% < 2283/(2283 + 5443) ~ 29.5%

- The 2nd stage event selection performance is much better at the ILC (approach the perfect Flavor Tagging at CEPC with irreducible background from ZZ) – to be understood

Comparison in vvH

- Tag H→qq
- Eff*Purity



	$\nu\nu Hq\bar{q}$	2f	SW	SZ	WW	ZZ	Mixed	ZH	total bkg	$\frac{\sqrt{S+B}}{S}$ (%)
total	178890	8.01E8	1.95E7	9.07E6	5.08E7	6.39E6	2.18E7	961606	9.10E8	16.86
recoilMass	157822	5.11E7	2.17E6	1.38E6	4.78E6	1.30E6	1.08E6	74991	6.19E7	4.99
visEn	142918	2.37E7	1.35E6	8.81E5	3.60E6	1.03E6	6.29E5	50989	3.13E7	3.92
leadLepEn	141926	2.08E7	3.65E5	7.24E5	2.81E6	9.72E5	1.34E5	46963	2.59E7	3.59
Npfo	139545	1.66E7	2.36E5	5.24E5	2.62E6	9.07E5	4977	42751	2.09E7	3.29
leadNeuEn	138653	1.46E7	2.24E5	4.72E5	2.49E6	8.69E5	4552	42303	1.86E7	3.12
Pt	121212	248715	1.56E5	2.48E5	1.51E6	4.31E5	999	35453	2.63E6	1.37
Pl	118109	53308	1.08E5	74936	729604	1.14E5	789	34279	1.11E6	0.94
Pmax	113413	47319	51976	69548	577336	104827	491	31833	883331	0.88
Y23	82647	33350	8682	49159	110365	64962	334	5159	272015	0.72
InvMass	72094	24801	3860	7036	47765	13235	213	3632	100546	0.58
BDT	64656	12867	315	3149	6081	4859	102	1810	29187	0.47

0.4 * 0.41

0.36 * 0.69

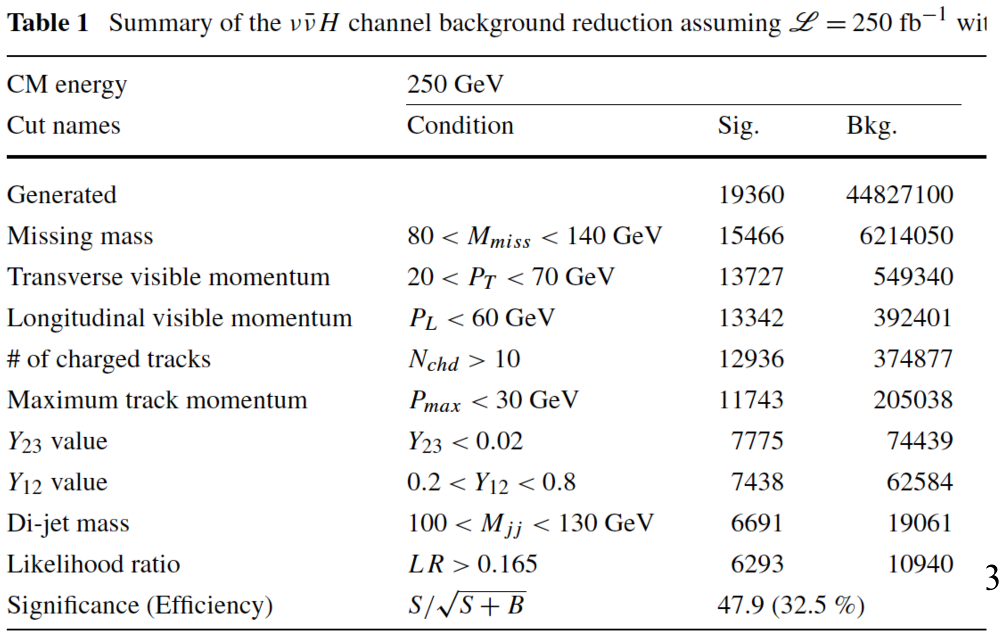


Table 1 Summary of the $\nu\bar{\nu}H$ channel background reduction assuming $\mathscr{L} = 250\ \text{fb}^{-1}$ wi

CM energy	250 GeV		
Cut names	Condition	Sig.	Bkg.
Generated		19360	44827100
Missing mass	$80 < M_{miss} < 140$ GeV	15466	6214050
Transverse visible momentum	$20 < P_T < 70$ GeV	13727	549340
Longitudinal visible momentum	$P_L < 60$ GeV	13342	392401
# of charged tracks	$N_{chd} > 10$	12936	374877
Maximum track momentum	$P_{max} < 30$ GeV	11743	205038
Y_{23} value	$Y_{23} < 0.02$	7775	74439
Y_{12} value	$0.2 < Y_{12} < 0.8$	7438	62584
Di-jet mass	$100 < M_{jj} < 130$ GeV	6691	19061
Likelihood ratio	$LR > 0.165$	6293	10940
Significance (Efficiency)	$S/\sqrt{S+B}$	47.9 (32.5 %)	

- Eff & Purity Comparison for the vvH tagging
- CEPC: 16%/25% wo/wi BDT
- ILC: 11.8% (eff = 32.5%, purity = 37%)
- Initial S/N Ratio:
  - CEPC: 178890/9.1E8
  - ILC: 19360/4.5E7

Comparison in vvH - 2

	S	B	Hcc in Signal	X-cc in Backgroundd	Accuracy
ILC	6293	10940	6293 * 0.036 = 226		11%
CEPC(BDT)	64656	29187	2283	5443	5.92%

2nd stage selection/Cut (Flavor tagging): To select 226/2283 H->cc events from 17k/94k total

Identification Performance Efficiency*Purity (Accuracy ~ 1/sqrt(N*eff*purity))

ILC: 36%;

CEPC: 12.5%; Hard limit eff*purity ~ 1 * 2283/(2283+5443) = 29%;