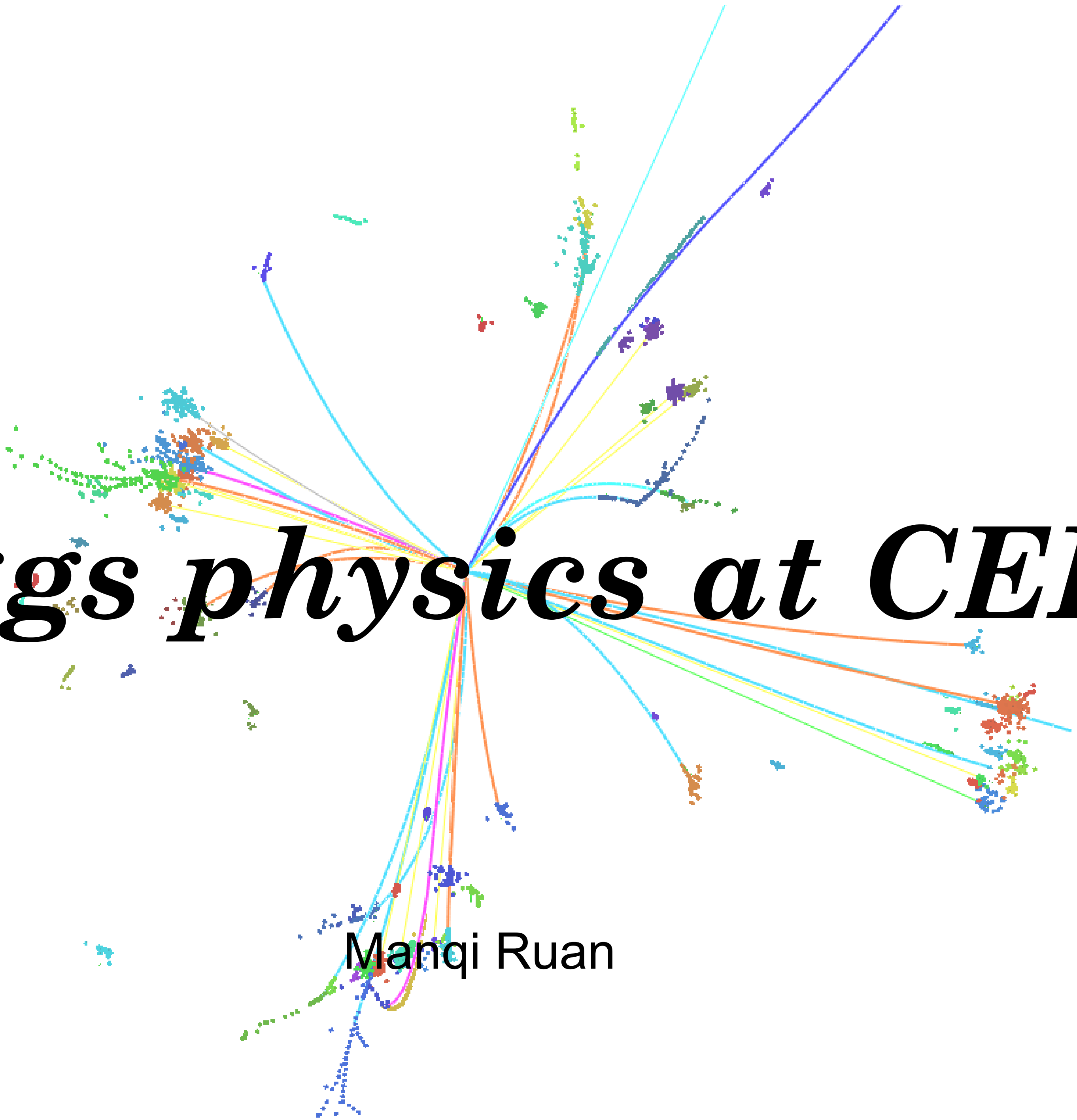
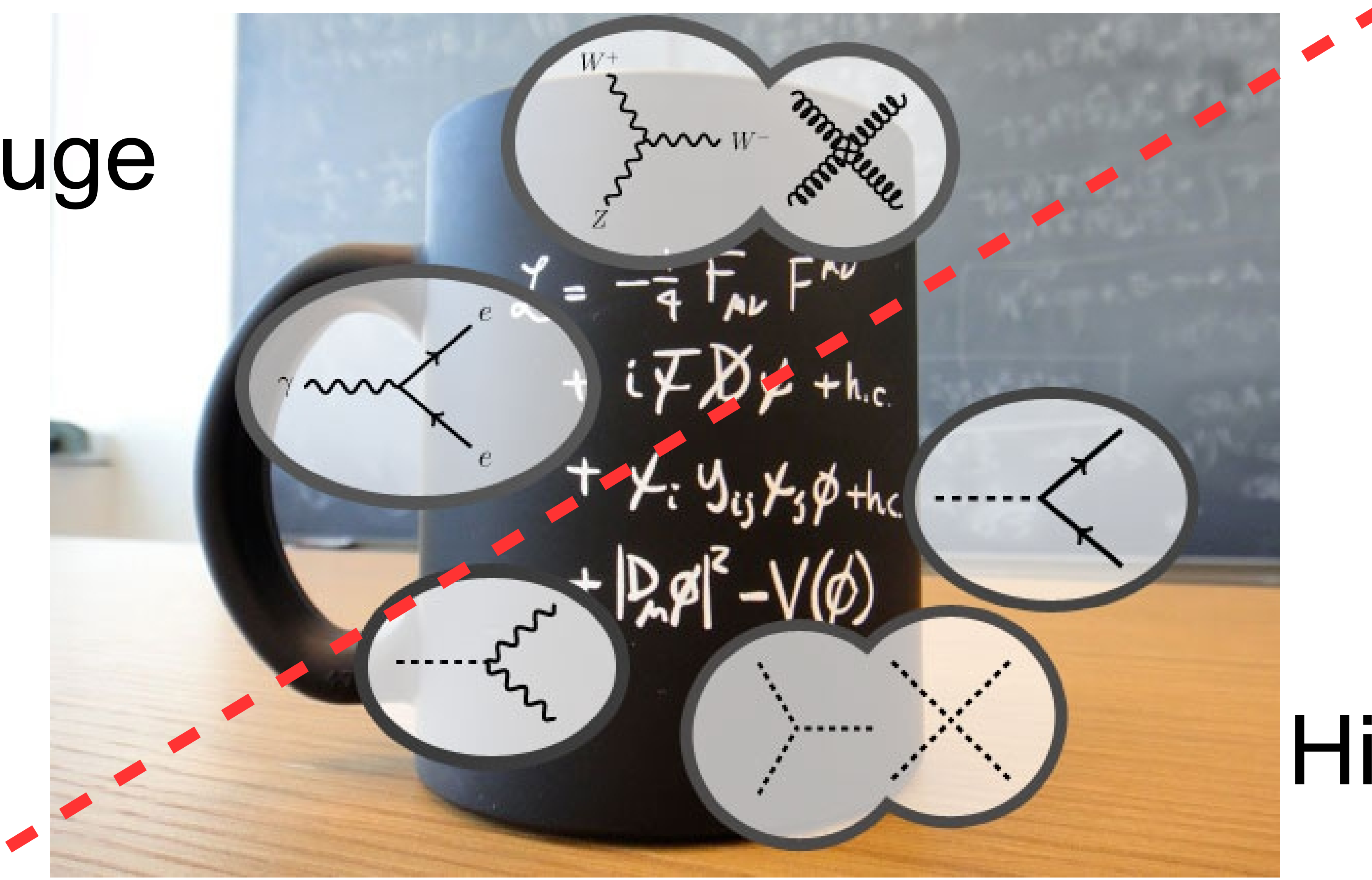
Higgs physics at CEPC



Manqi Ruan

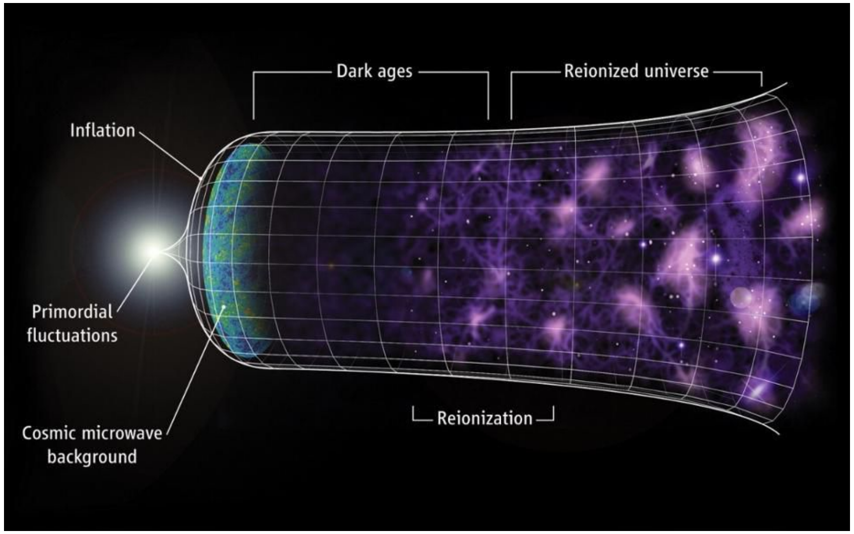
The Higgs field: one of the two pillars of the SM

Gauge



Higgs

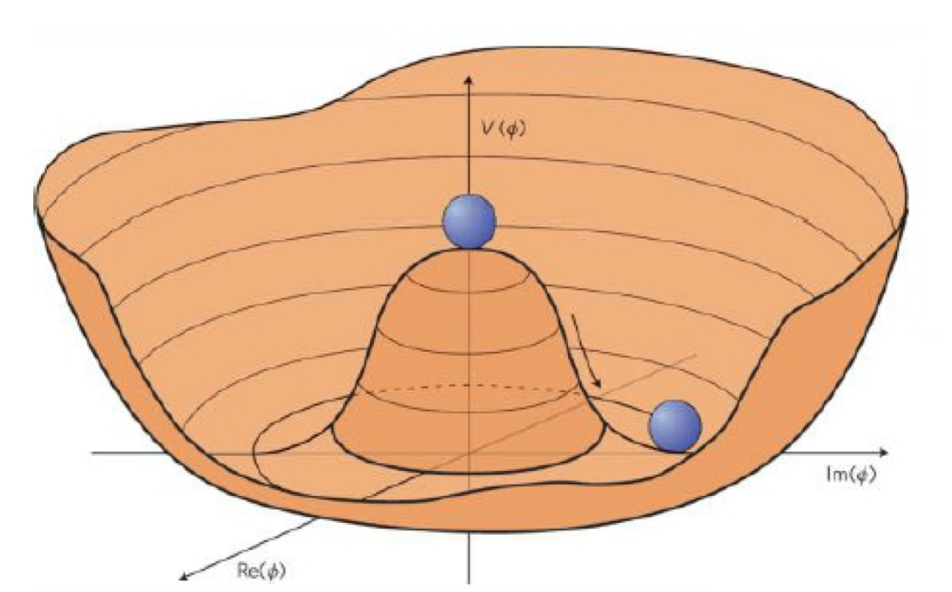
Known Unknowns of the SM



- Inflation
- Mass hierarchy
- Neutrino mass & Oscillation
- Matter anti-matter asymmetry
- Vacuum stabilities: depends on particle mass
- Dark matter, Dark energy: nature & origin of its/their mass
- Naturalness: EW (Higgs mass) V.S. Planck scale
- ...

Known Unknowns of the SM

- The Clue:



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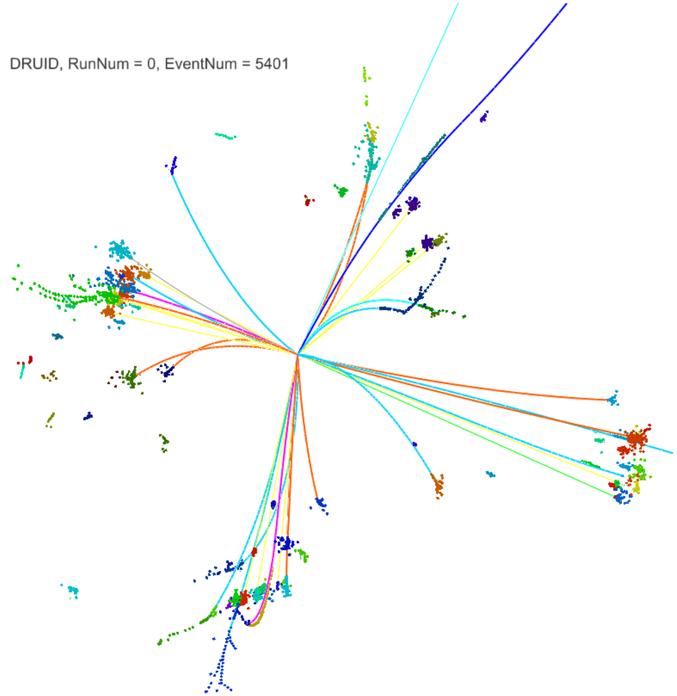
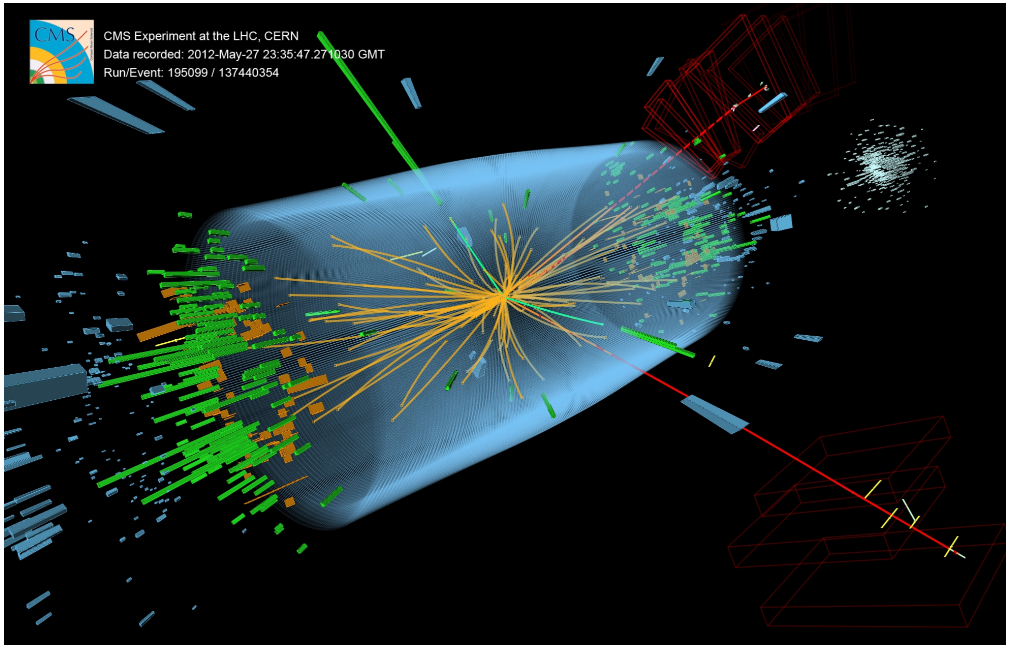
-

Higgs measurement at e+e- & pp





	Yield	efficiency	Comments
LHC	Run 1: 10^6 Run 2/HL: 10^{7-8}	~$o(10^{-3})$	High Productivity & High background, Relative Measurements, Limited access to width, exotic ratio, etc, Direct access to g(ttH), and even g(HHH)
CEPC	10^6	~$o(1)$	Clean environment & Absolute measurement, Percentage level accuracy of Higgs width & Couplings

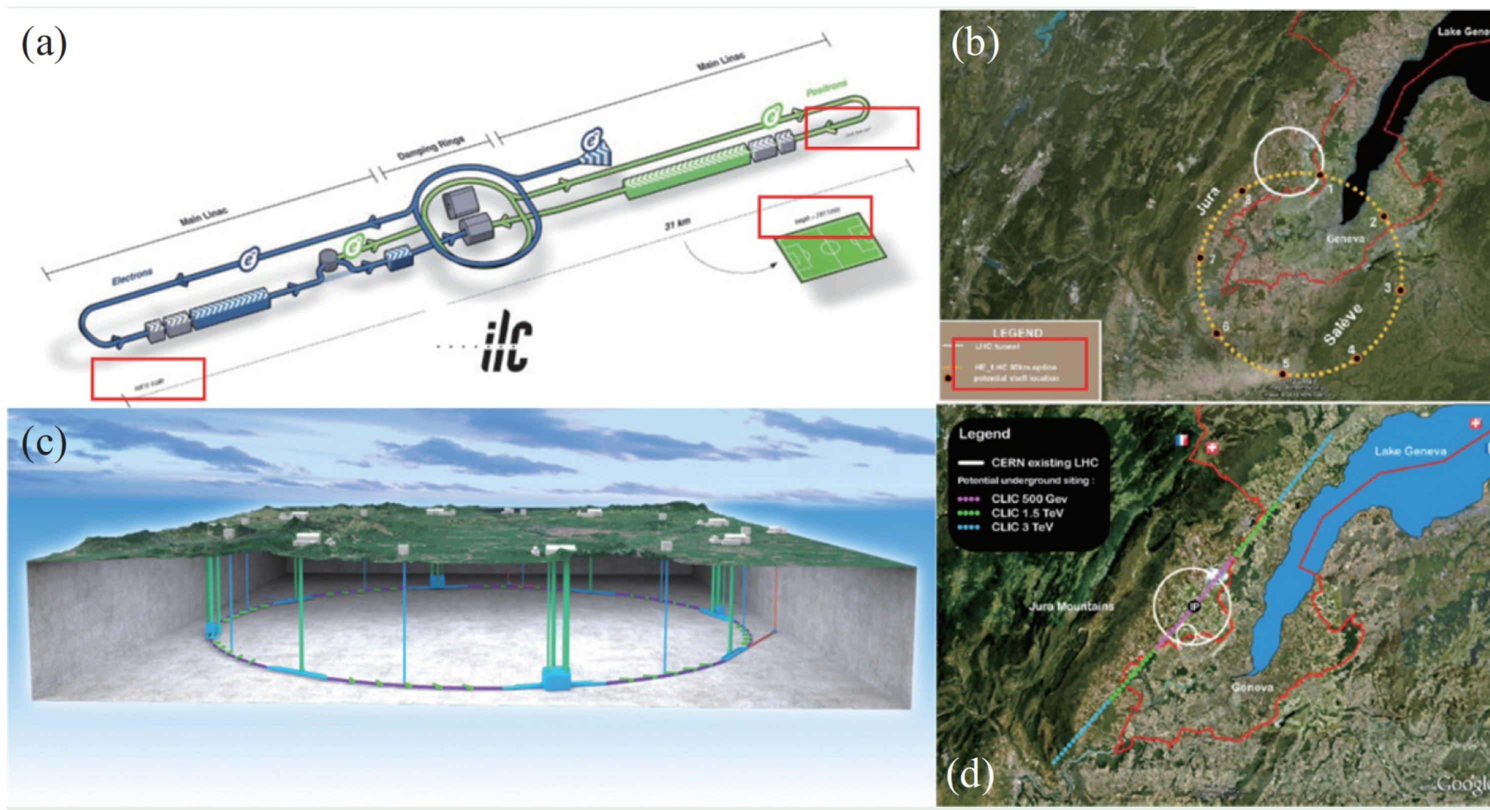
Complementary

Electron Positron Higgs factories

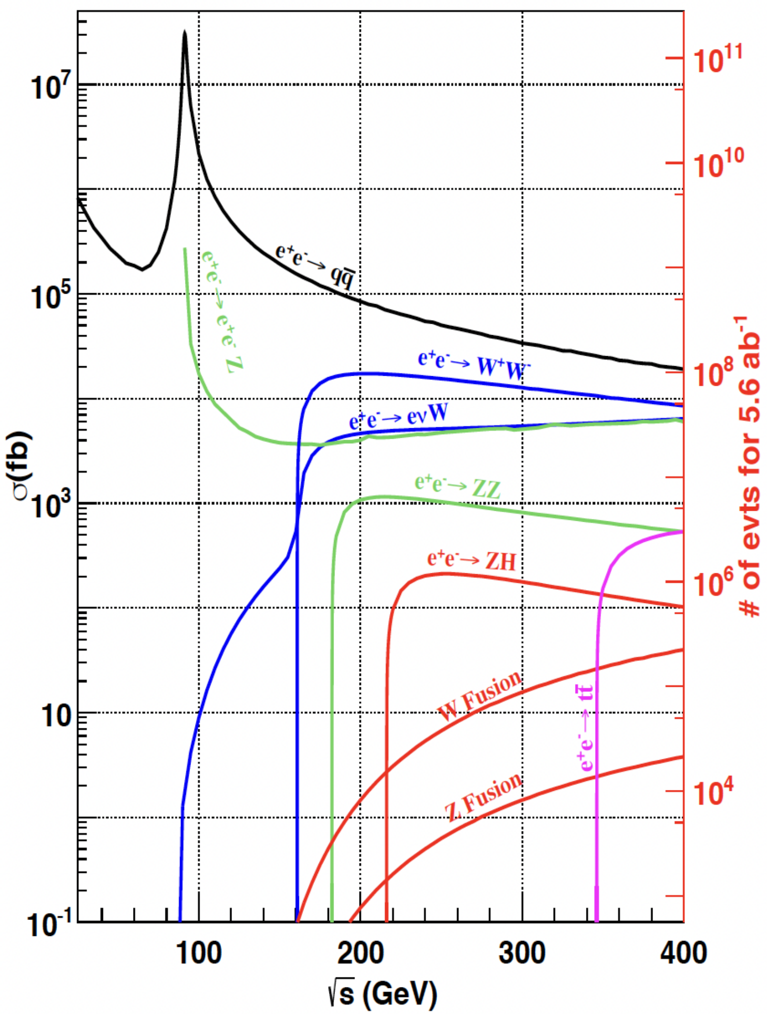
High-priority future initiatives

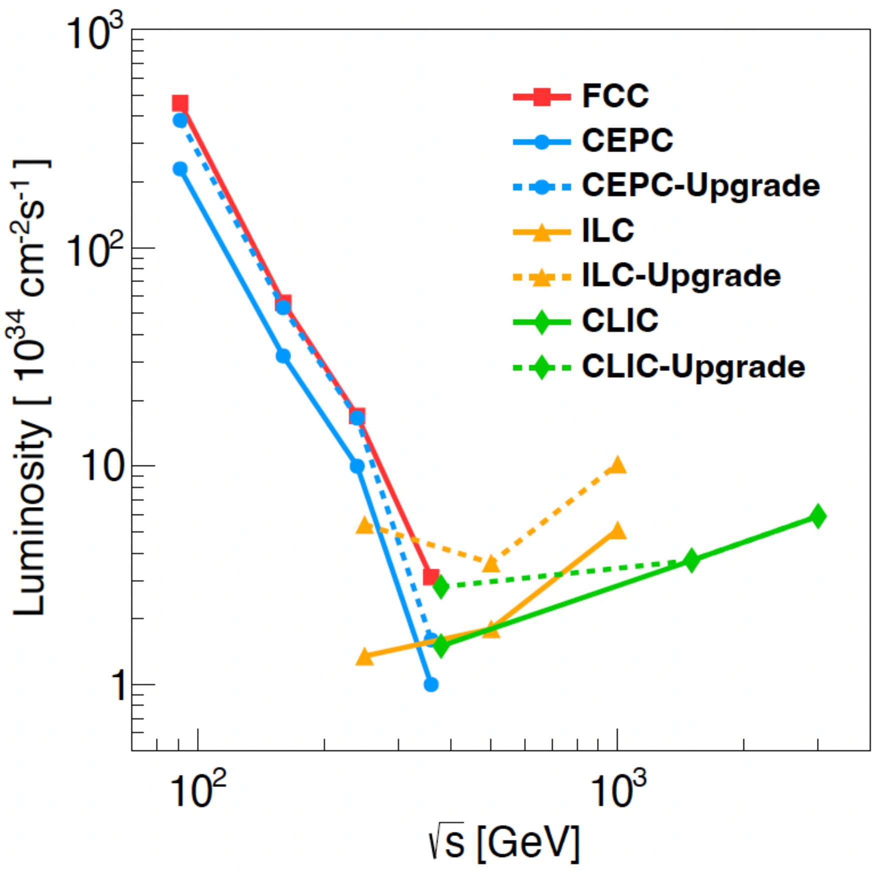
An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

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



Yields ~ Xsec * Lumi



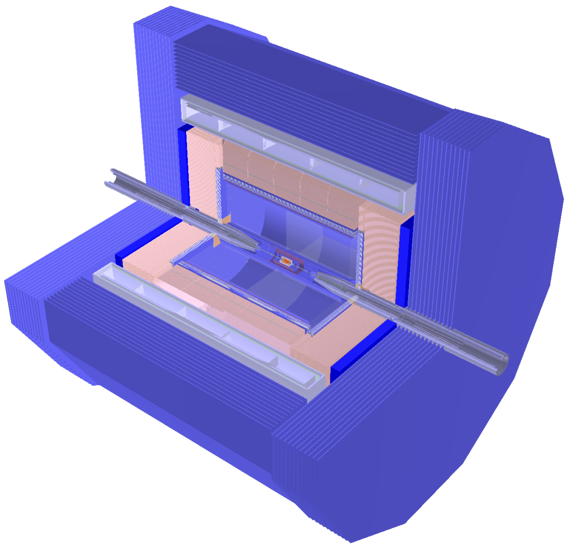


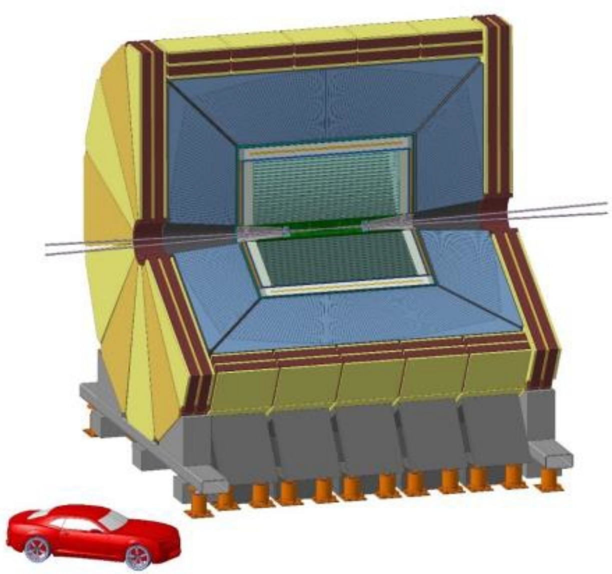
Yields of the CEPC

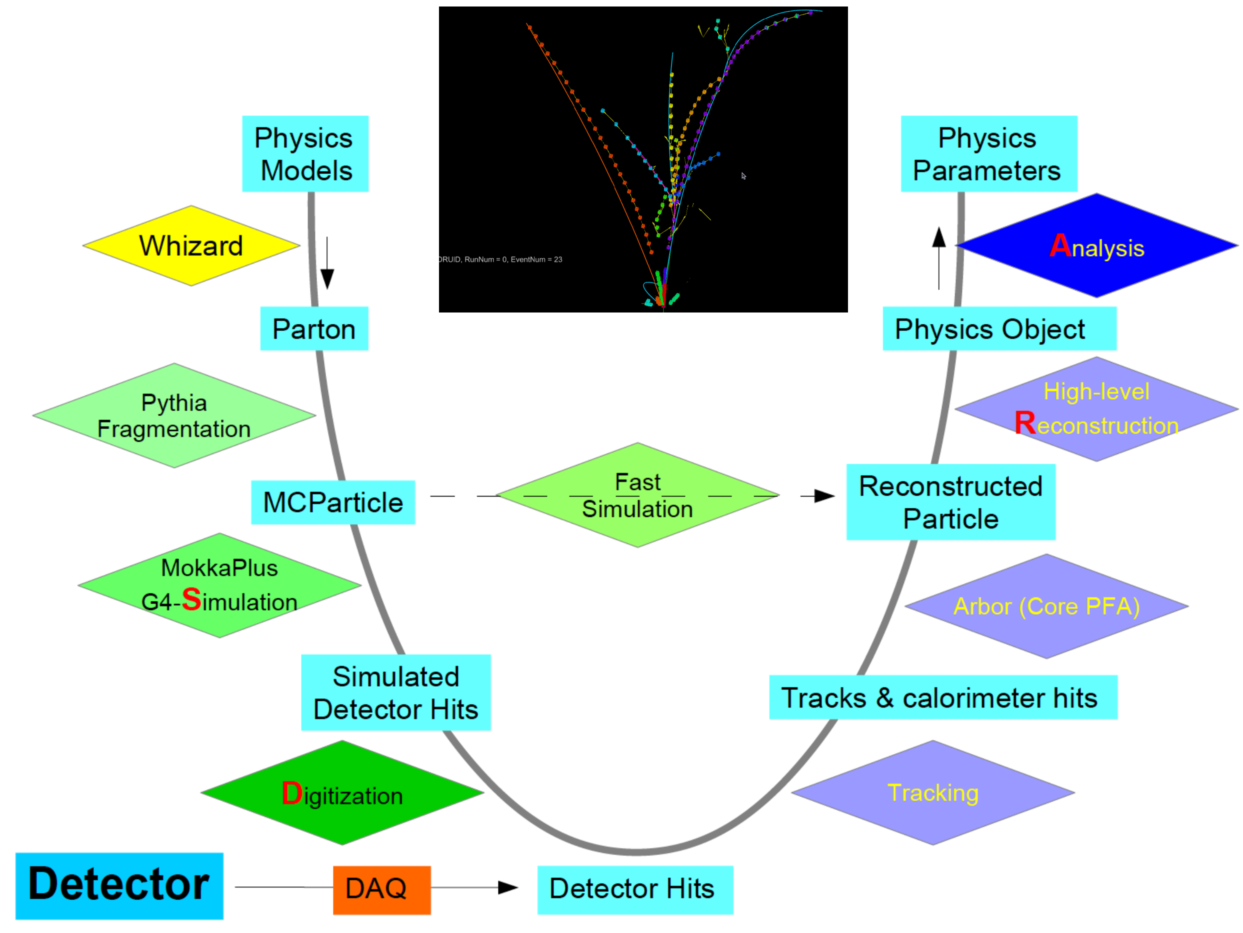
- **Tunnel ~ 100 km，** baseline SR Power/beam **30 MW**, upgradable to **50 MW**
- **CEPC (90 – 240 GeV)**
  - Higgs factory: **4M** Higgs boson (**10 years, 2 IP, 50 MW**)
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **~ 3 Tera** Z boson (**2 years, 2 IP, 50 MW**), 100 M W boson (1 year)
    - Precision test of the SM, measure W boson mass to 1 MeV level via threshold scan
    - Rare decay + QCD studies
    - Flavor factory: b, c, tau
    - QCD studies
- **Upgradable to ttbar threshold (360 GeV): 500 k ttbar event (5 years, 2 IP, 50 MW)**
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**

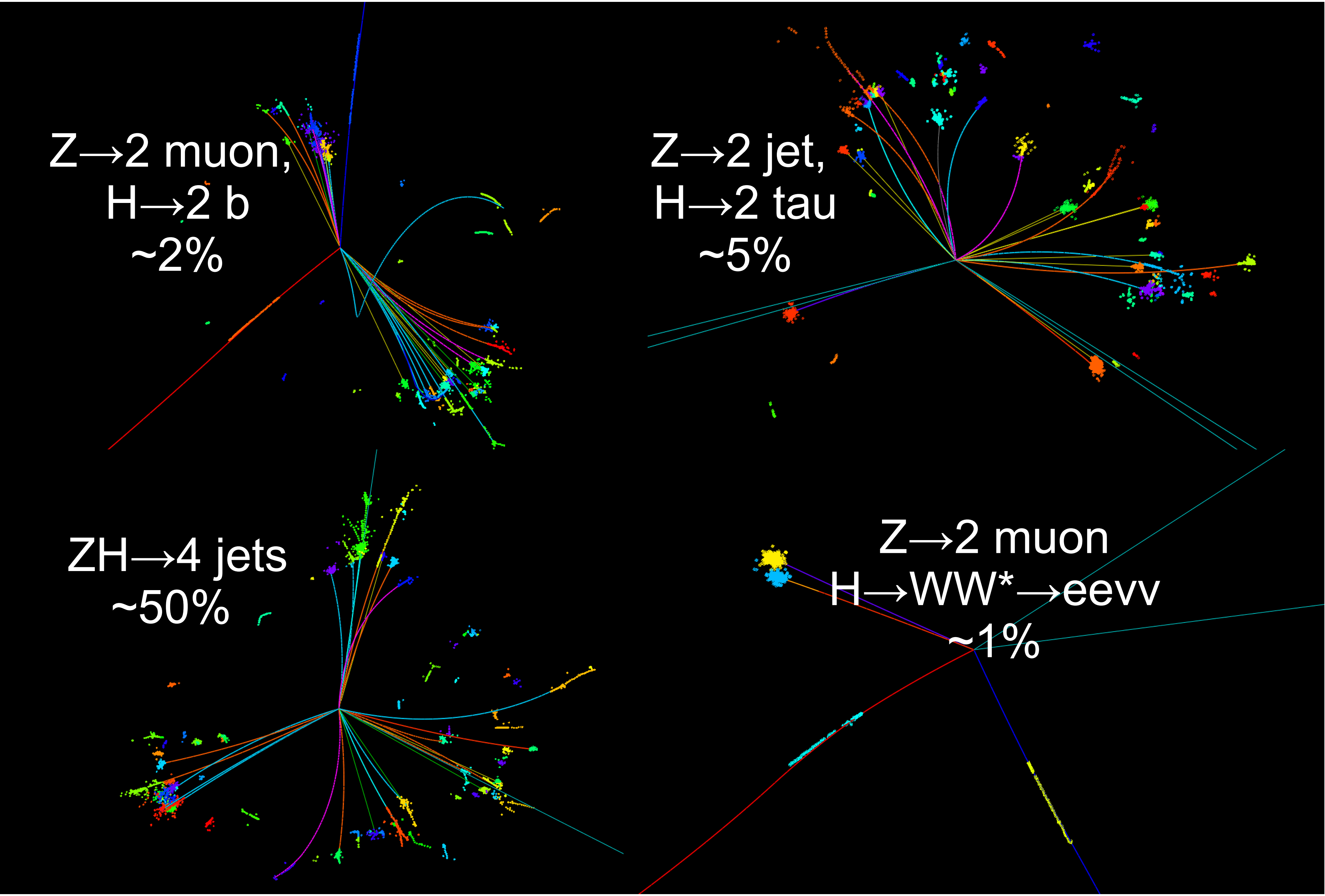
See also: 2205.08553

Detector & Software

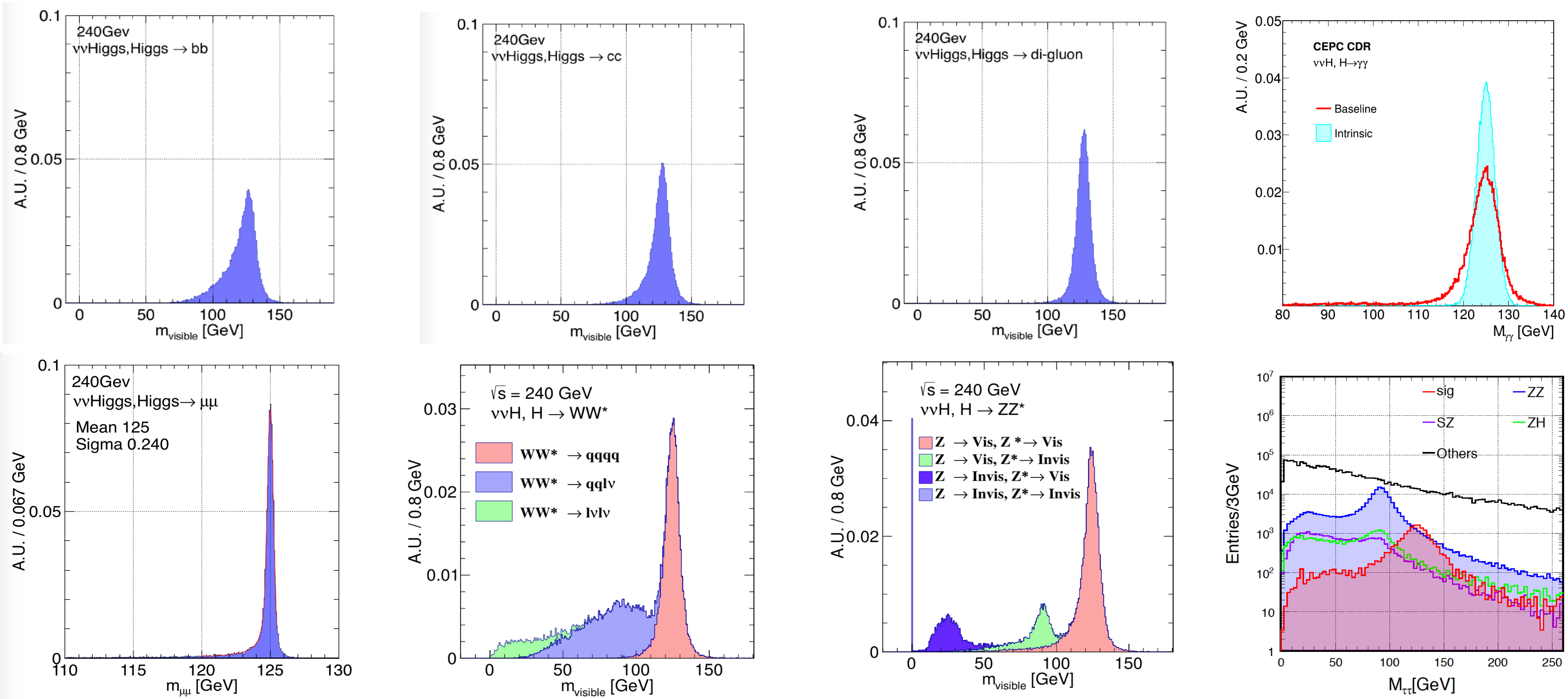







Z→2 muon,
H→2 b
~2%
Z→2 jet,
H→2 tau
~5%
ZH→4 jets
~50%
Z→2 muon
H→WW*→eevv
~1%

Reconstructed Higgs Signatures



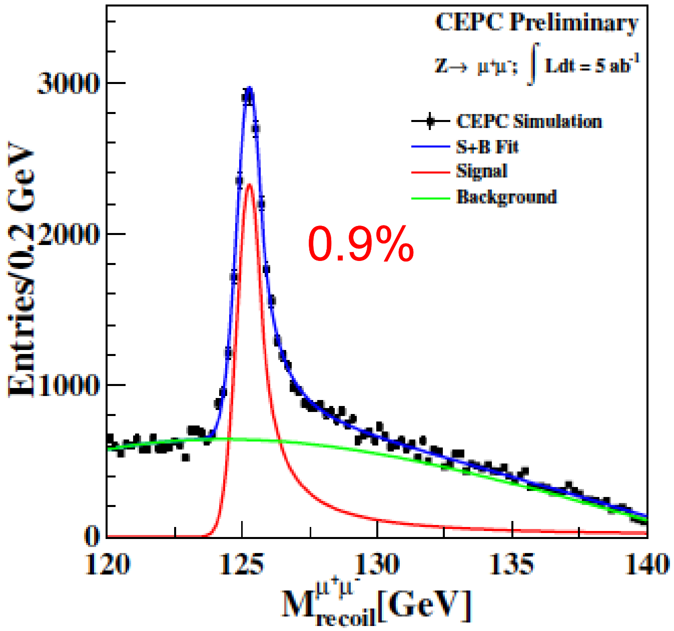
Clear Higgs Signature in all SM decay modes

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

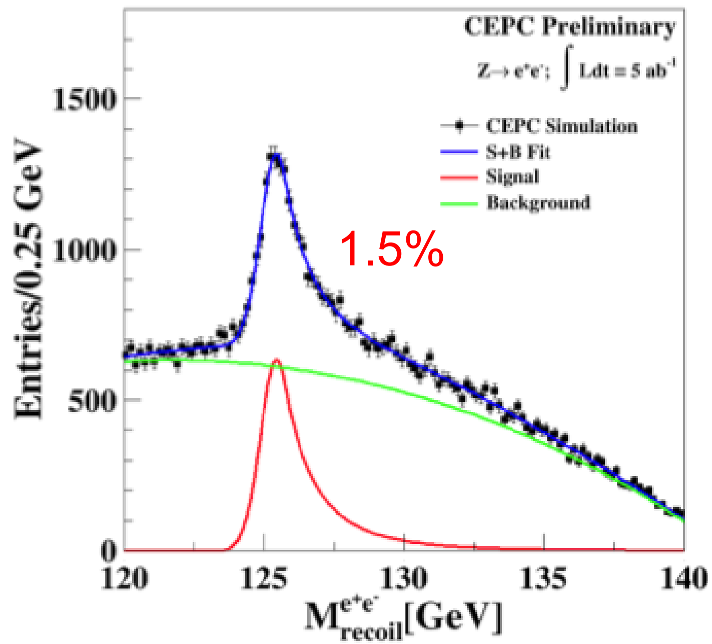
Right corner: di-tau mass distribution at qqH events using collinear approximation

Model-independent measurement of σ(ZH)

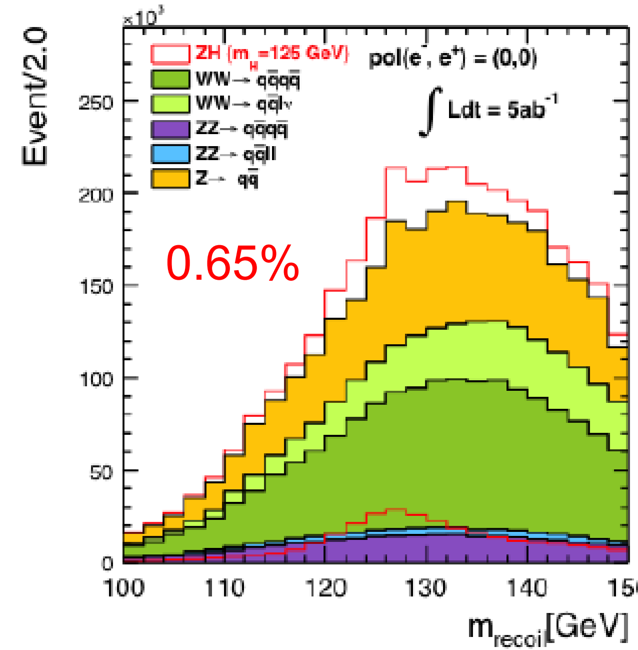
Zhenxing Chen & Yacine Haddad



0.9%

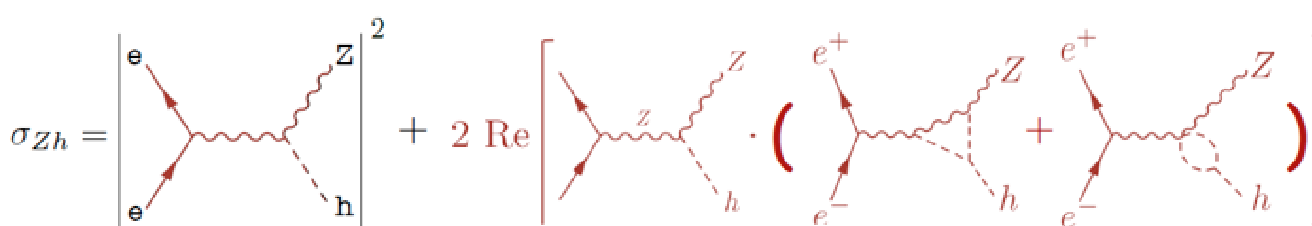


1.5%



0.65%

- Recoil mass method. Combined precision:
  δσ(ZH)/σ(ZH) = 0.5% -
  δg(HZZ)/g(HZZ) = 0.25%
- Indirect Access to g(HHH)



$$\delta_\sigma^{240} = 100\,(2\delta_Z + 0.014\delta_h)\,\%$$

- *M. McCullough, 1312.3322*

Higgs benchmark analyses

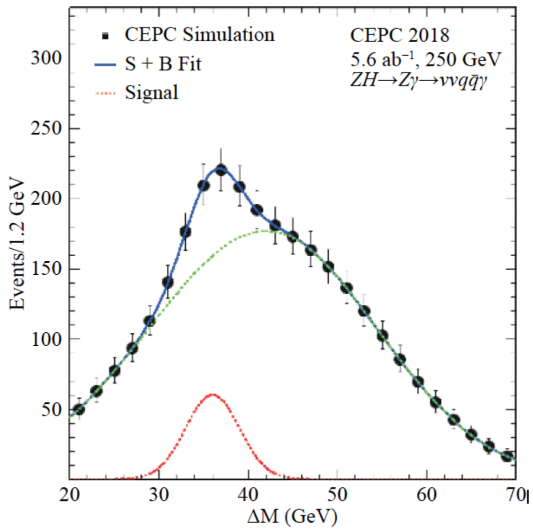
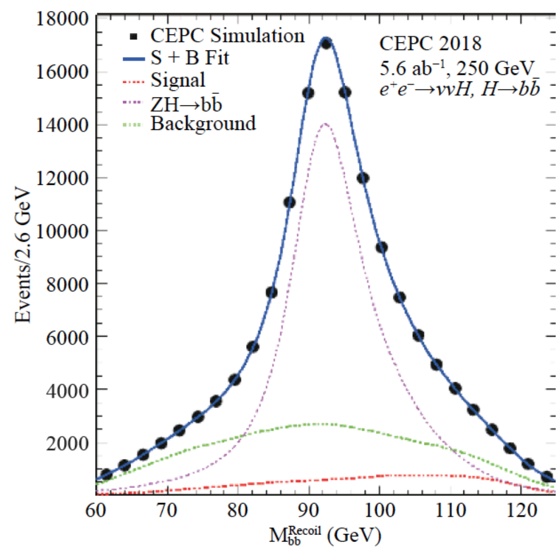
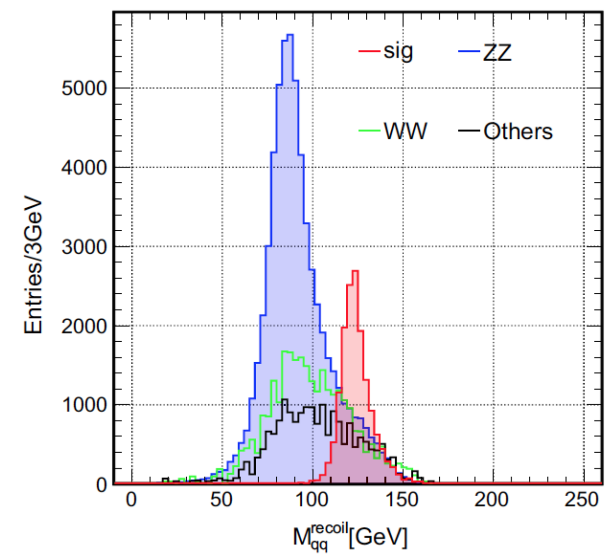
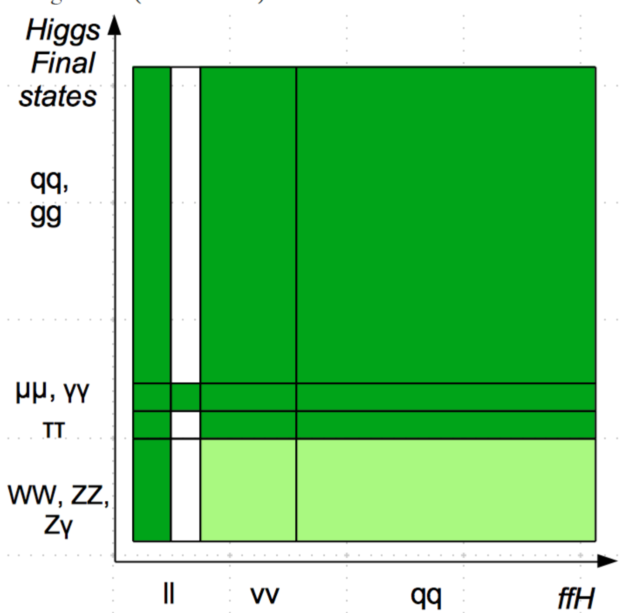
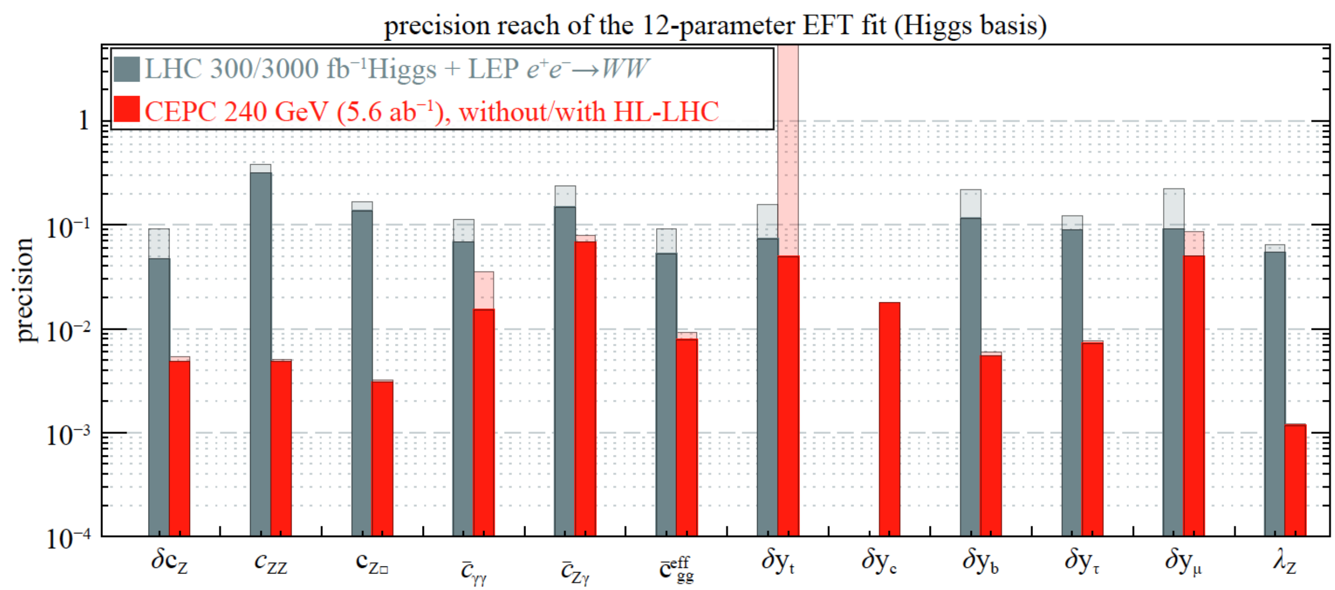


Fig. 15. (color online) The distribution of the mass differ-

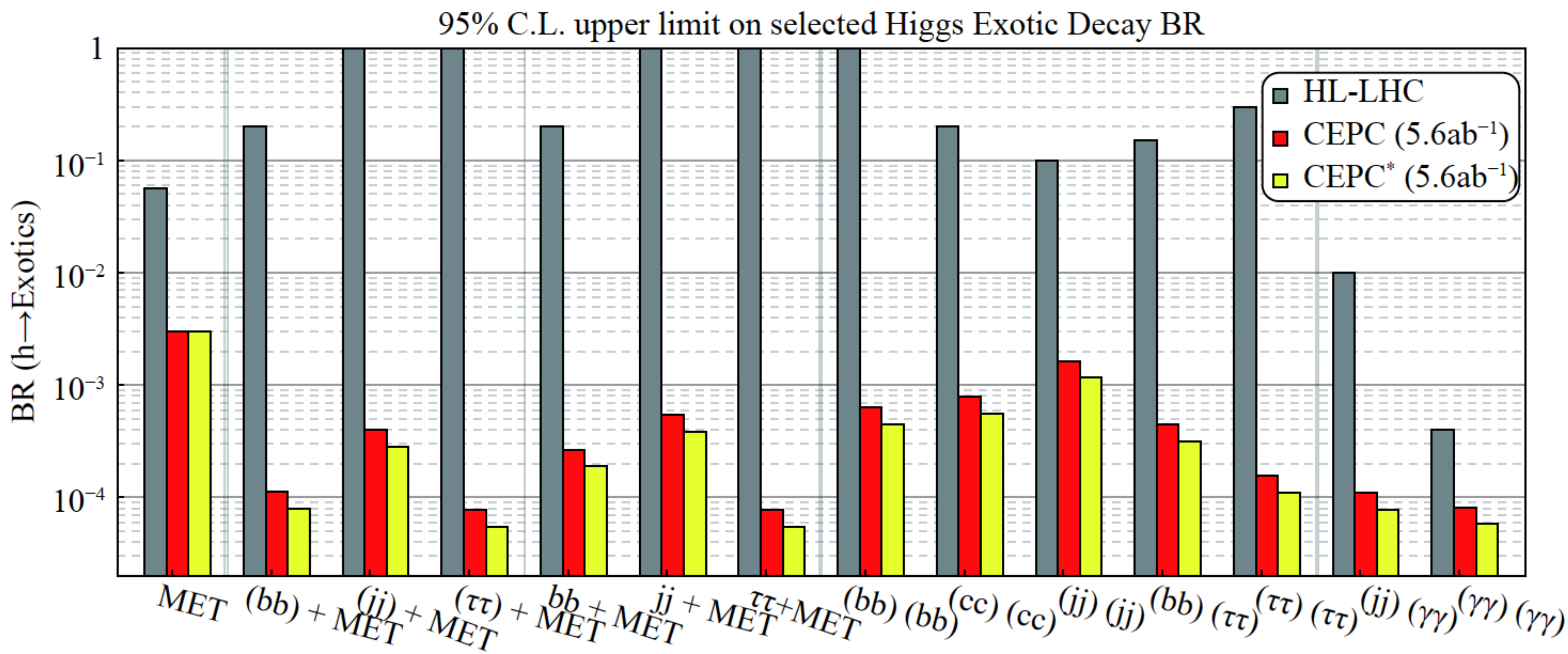








Higgs BSM Decay modes



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Measuring Higgs width

- **Method 1: Higgs width can be determined directly from the measurement of σ(ZH) and Br. of (H->ZZ*)**

$$\Gamma_H \propto \frac{\Gamma(H\to ZZ^*)}{\mathrm{BR}(H\to ZZ^*)} \propto \frac{\sigma(ZH)}{\mathrm{BR}(H\to ZZ^*)}$$

Precision : 5.1%

  - **But the uncertainty of Br(H->ZZ*) is relatively high due to low statistics.**

- **Method 2: It can also be measured through:**

$$\Gamma_H \propto \frac{\Gamma(H\to bb)}{BR(H\to bb)} \qquad \sigma(\nu\bar{\nu}H\to\nu\bar{\nu}b\bar{b}) \propto \Gamma(H\to WW^*)\cdot \mathrm{BR}(H\to bb) = \Gamma(H\to bb)\cdot \mathrm{BR}(H\to WW^*)$$

$$\Gamma_H \propto \frac{\Gamma(H\to bb)}{\mathrm{BR}(H\to bb)} \propto \frac{\sigma(\nu\bar{\nu}H\to\nu\bar{\nu}b\bar{b})}{\mathrm{BR}(H\to b\bar{b})\cdot \mathrm{BR}(H\to WW^*)}$$

3.0%

Precision : 3.5%

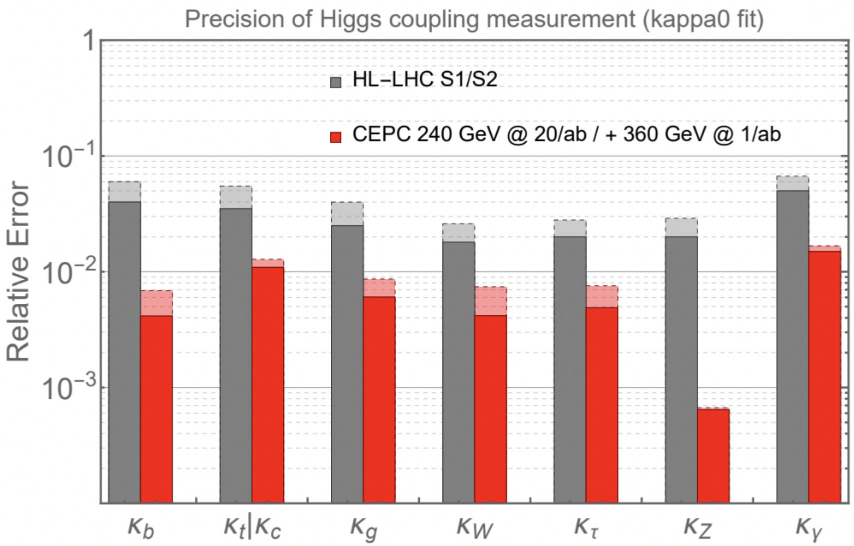
- **These two orthogonal methods can be combined to reach the best precision.**

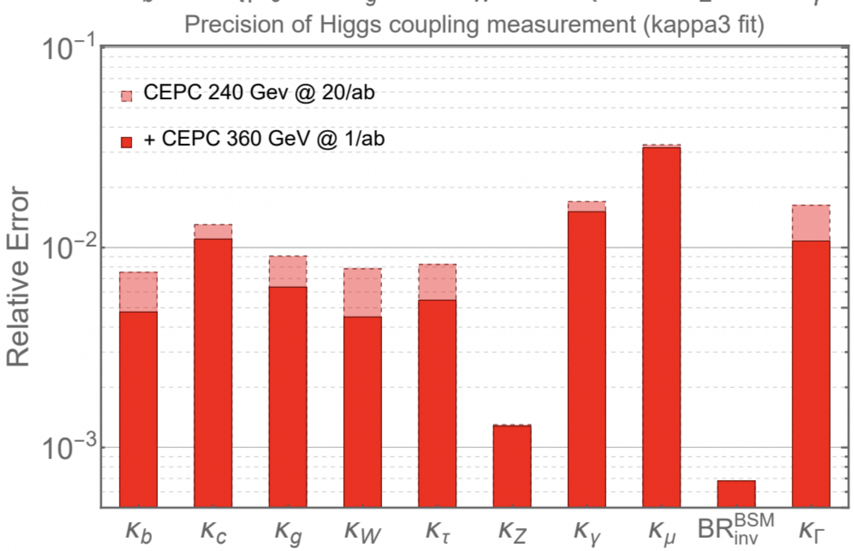
Precision : 2.8%

With 5.6 iab @ 240 GeV

Physics reach via Higgs at CEPC

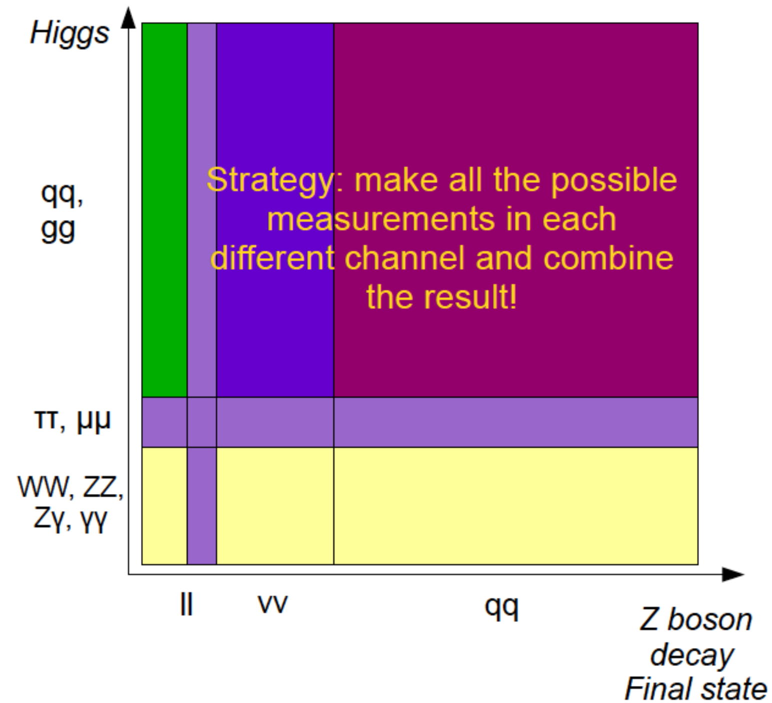
	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	**vvH**	ZH	**vvH**	**eeH**
inclusive	**0.26%**		**1.40%**	\	\
H→bb	**0.14%**	**1.59%**	**0.90%**	**1.10%**	**4.30%**
H→cc	**2.02%**		**8.80%**	**16%**	**20%**
H→gg	**0.81%**		**3.40%**	**4.50%**	**12%**
H→WW	**0.53%**		**2.80%**	**4.40%**	**6.50%**
H→ZZ	**4.17%**		**20%**	**21%**	
$H \to \tau\tau$	**0.42%**		**2.10%**	**4.20%**	**7.50%**
$H \to \gamma\gamma$	**3.02%**		**11%**	**16%**	
$H \to \mu\mu$	**6.36%**		**41%**	**57%**	
$H \to Z\gamma$	**8.50%**		**35%**		
$\mathrm{Br}_{upper}(H \to inv.)$	**0.07%**				
Γ_H	**1.65%**		**1.10%**		

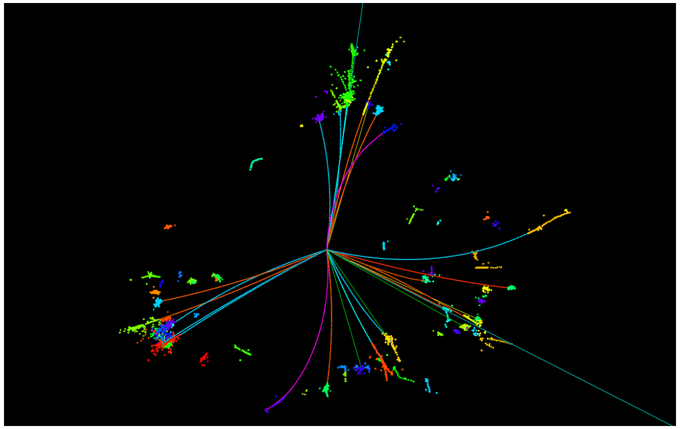




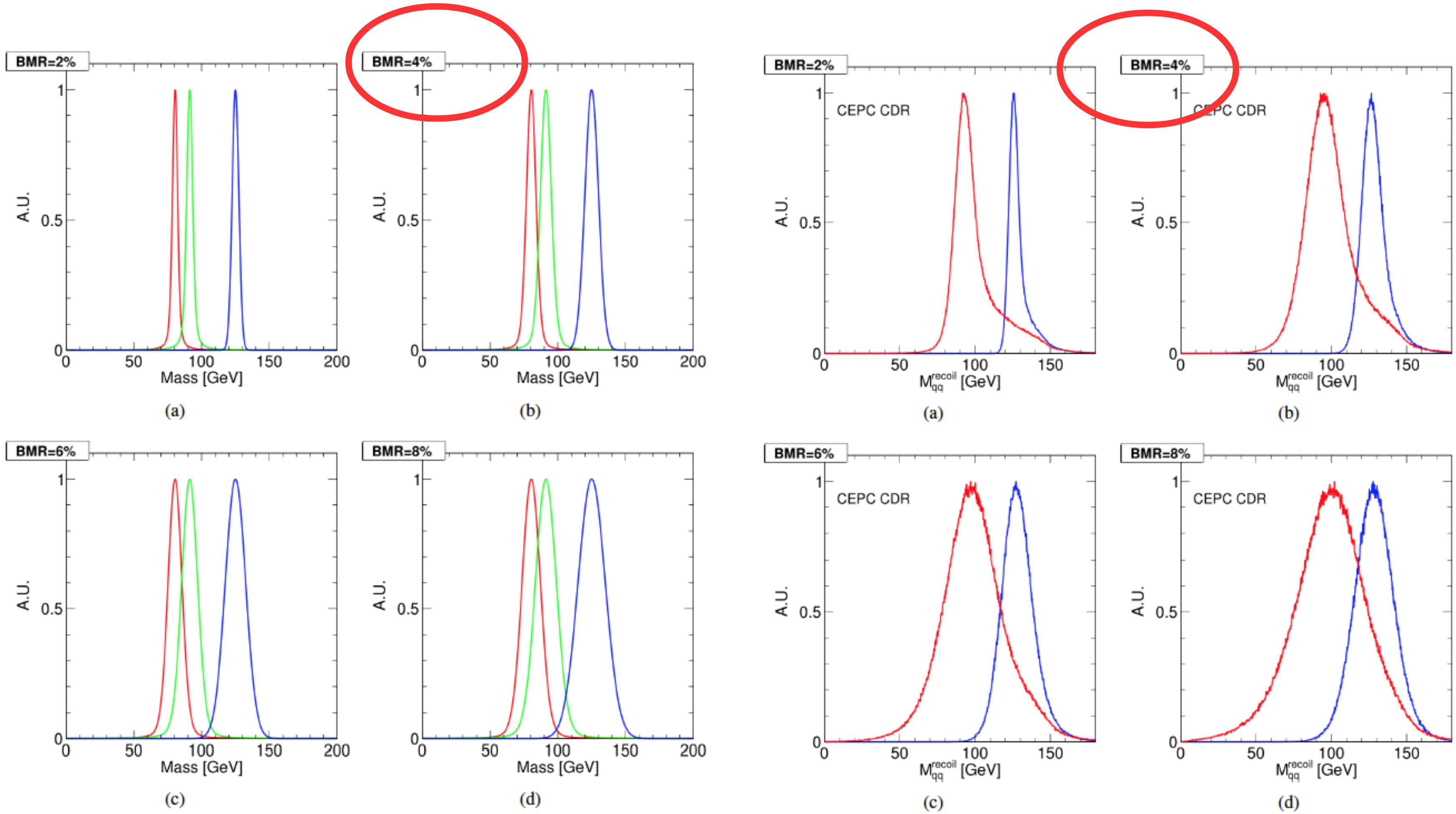
Hadronic system (jet)

- Core of e+e- Higgs factory Physics measurements
  - 97% of CEPC Higgs events are hadronic/semi-leptonic
- Identify the hadronic system in semi-leptonic events
  - lepton identification & missing energy
- 4-momentum measurement of the hadronic system: BMR: Invariant Mass Resolution
- Jet response: essential for differential measurements
  - Color-singlet identification Identify the origin of each final state particle: Jet Clustering & Matching, or beyond?



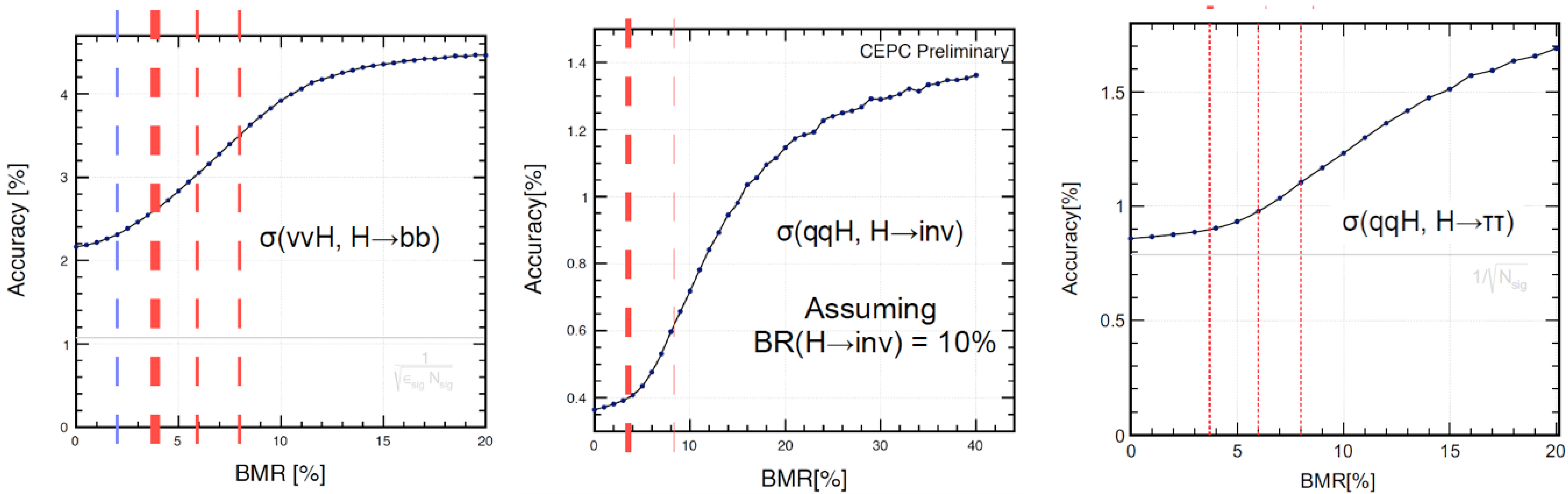


BMR < 4% required...



- W, Z, H mass peak separation
- To separate qqH signal from qqX background with recoil mass information

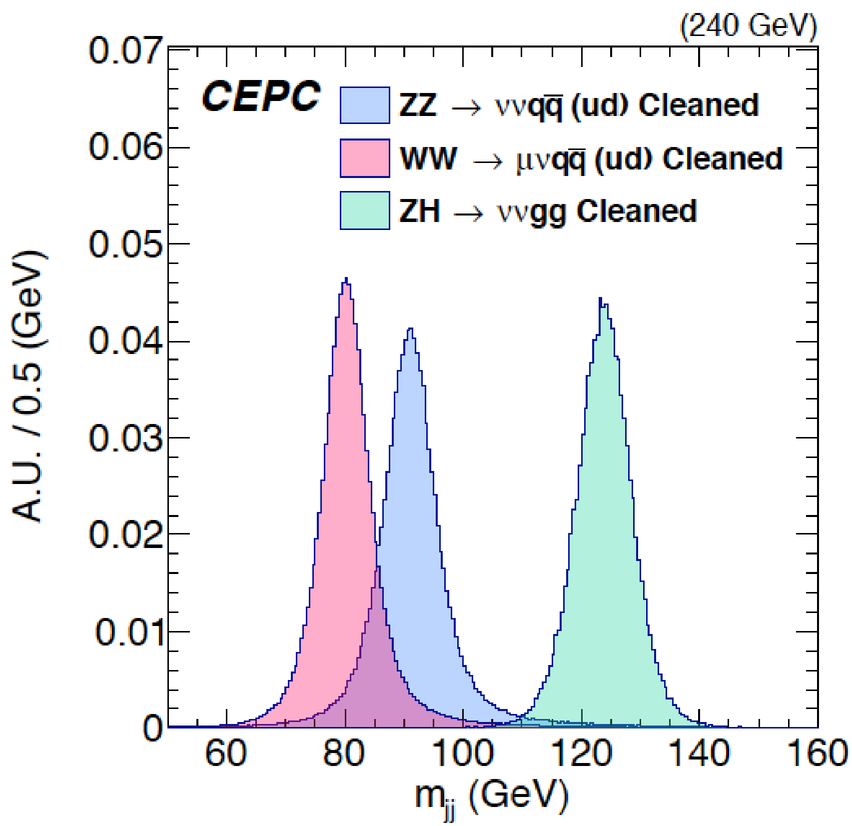
Confirmed with benchmark analyses



- Boson Mass Resolution: relative mass resolution of ννH, H→gg events
  - Free of Jet Clustering
  - Be applied directly to the Higgs analyses
- The CEPC baseline reaches 3.8%

	BMR = 2%	4%	6%	8%
σ(ννH, H→bb)	2.3%	2.6%	3.0%	3.4%
σ(ννH, H→inv)	0.38%	0.4%	0.5%	0.6%
σ(qqH, H→ττ)	0.85%	0.9%	1.0%	1.1%

CEPC Baseline: BMR = 3.75%



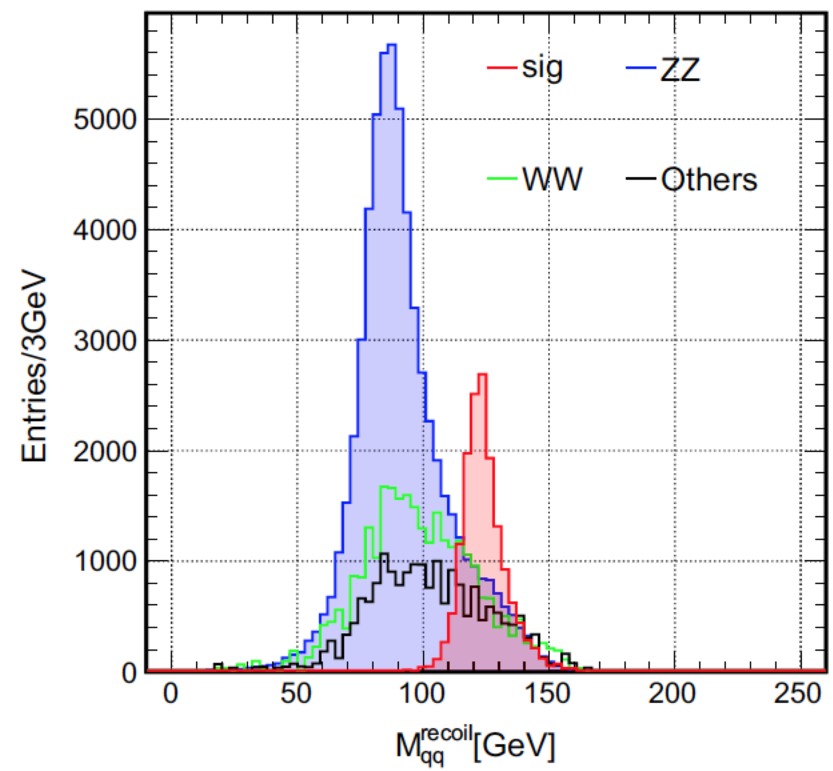
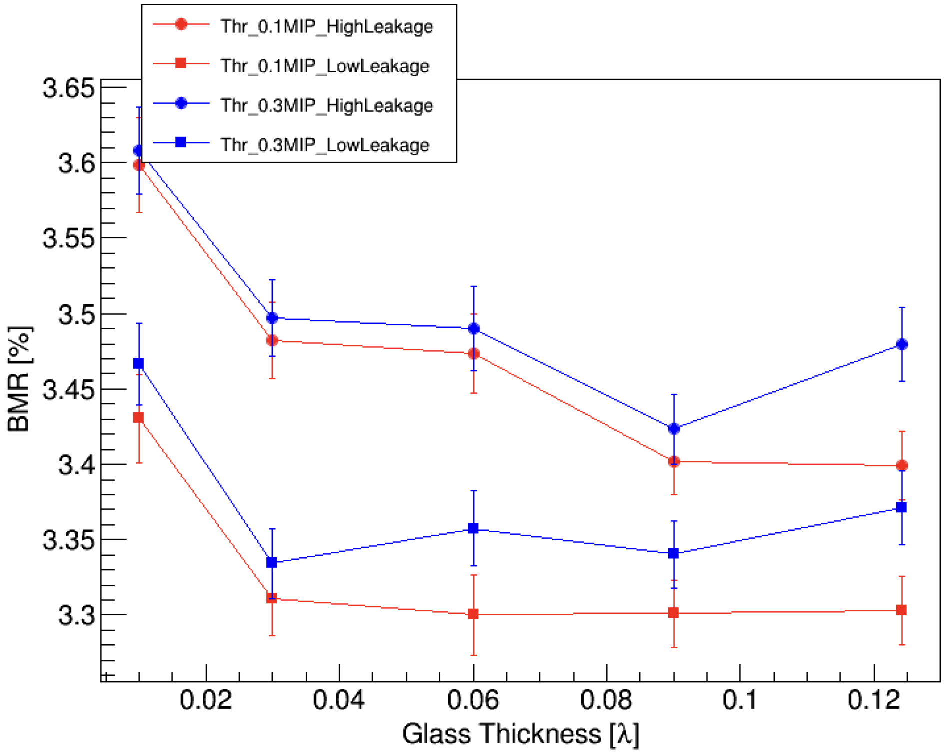


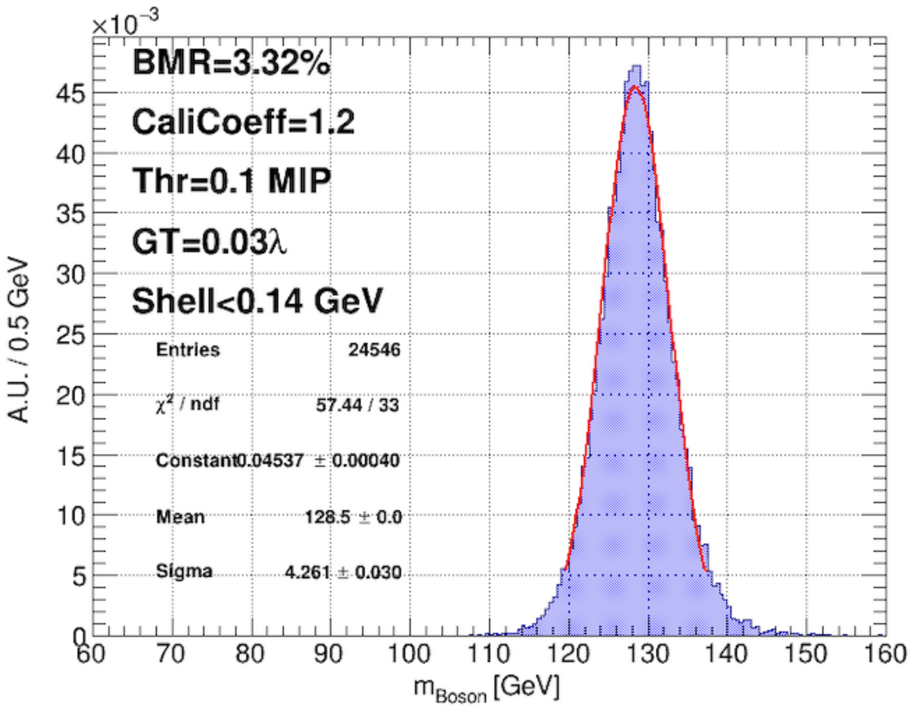
Fig. 7 Distribution of the recoil mass of the qq, M_{qq}^{recoil} for $Z \to qq$, $H \to \tau\tau$ and each background at $\sqrt{s} = 240$ GeV after the previous cuts

@ Hadronically decayed Higgs boson: not sensitive to different modes it decays into
BMR 3.6 – 3.8% for H->bb, cc, gg, WW*/ZZ*->4 jets

Improving BMR...



P. Hu & YX. Wang



- ...Yet, a lot more to be understood

Jets: H→bb, cc, gg

- Core physics measurements, excellent benchmarks for BMR, Flavor Tagging & Color Singlet Identification
- Tactic
  - Analysis
    - Concentrate Higgs to di jet event using Cut Chain + BDT
    - Using Flavor Tagging to disentangle different decay modes, and extract/resolve the relevant signal strengths
  - Optimization
    - Modeling the different Flavor tagging performance using interpolation method, and resolve the corresponding accuracies

Impact of Flavor tagging

$$M_{mig} = \frac{Tr_{mig} - Tr_{opt}}{Tr_{I} - Tr_{opt}} \cdot (M_{I} - M_{opt}) + M_{opt}$$

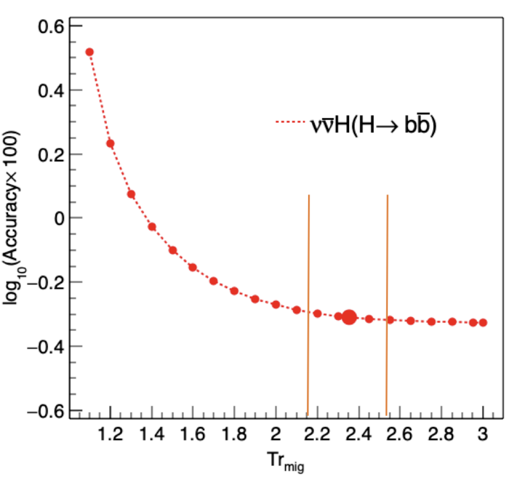
$$M_{mig} = \frac{Tr_{mig} - Tr_{opt}}{Tr_{1/3} - Tr_{opt}} \cdot (M_{1/3} - M_{opt}) + M_{opt}$$

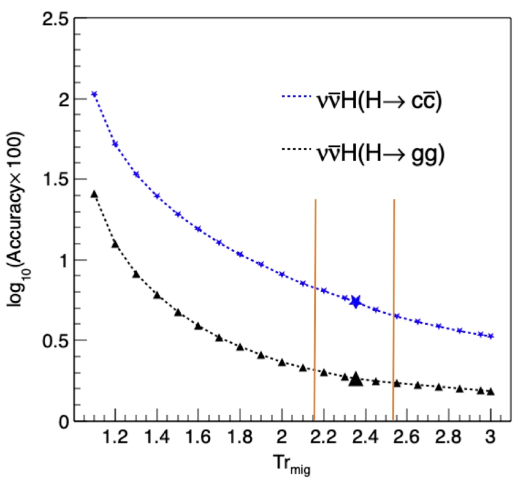
Perfect

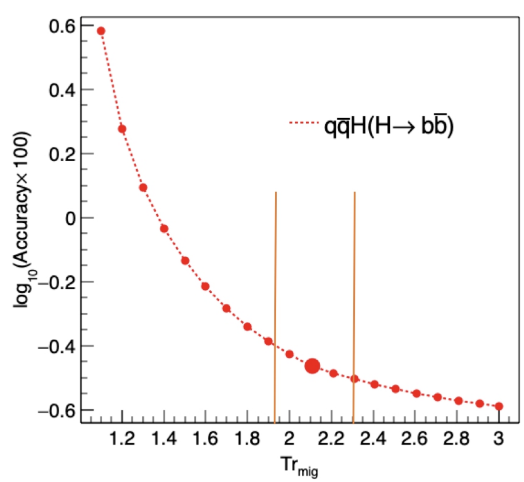
true \ identified as	b	c	g
b	1	0	0
c	0	1	0
g	0	0	1

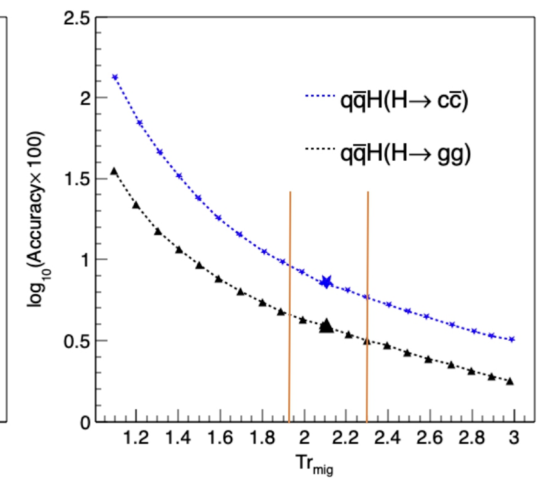
Worst

true \ identified as	b	c	g
b	1/3	1/3	1/3
c	1/3	1/3	1/3
g	1/3	1/3	1/3



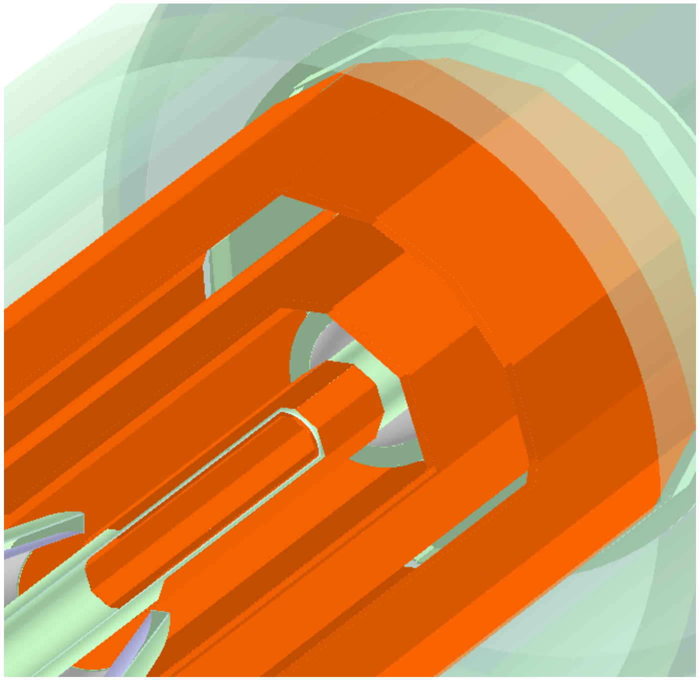


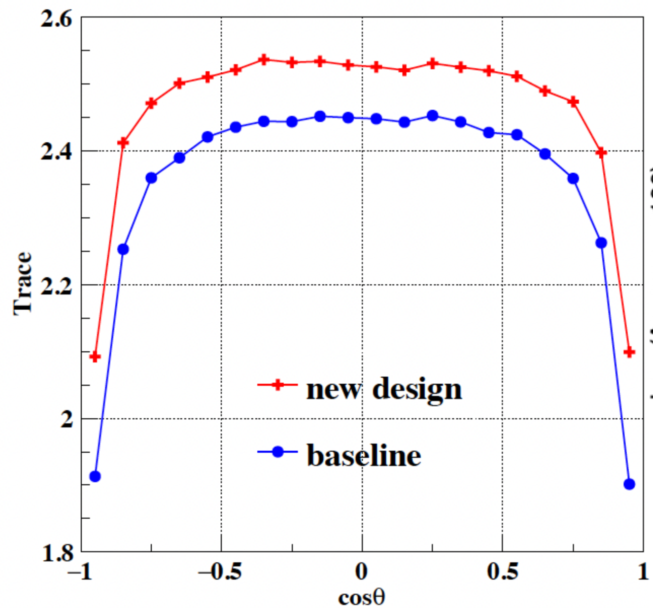


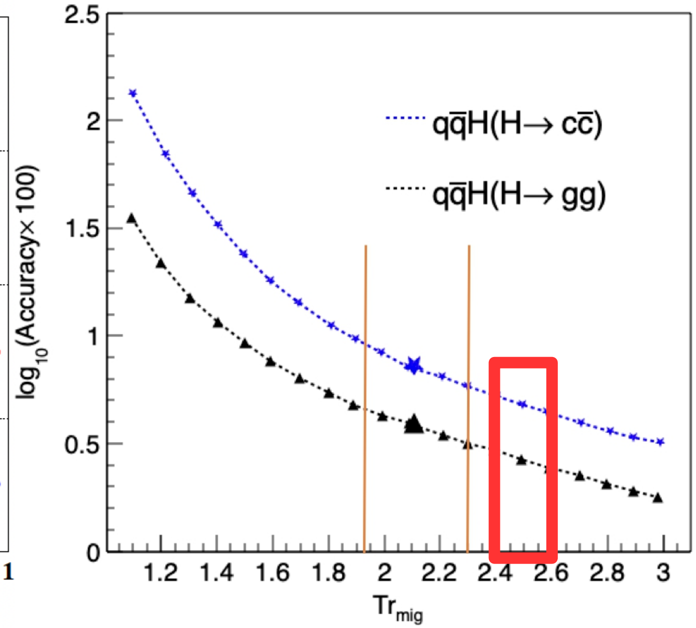


- Compared to baseline, perfect Flavor tagging improves the accuracy by 2%/63%/13% for vvH and 35%/120%/180% for qqH channels (bb, cc, gg)

New design of the VTX system



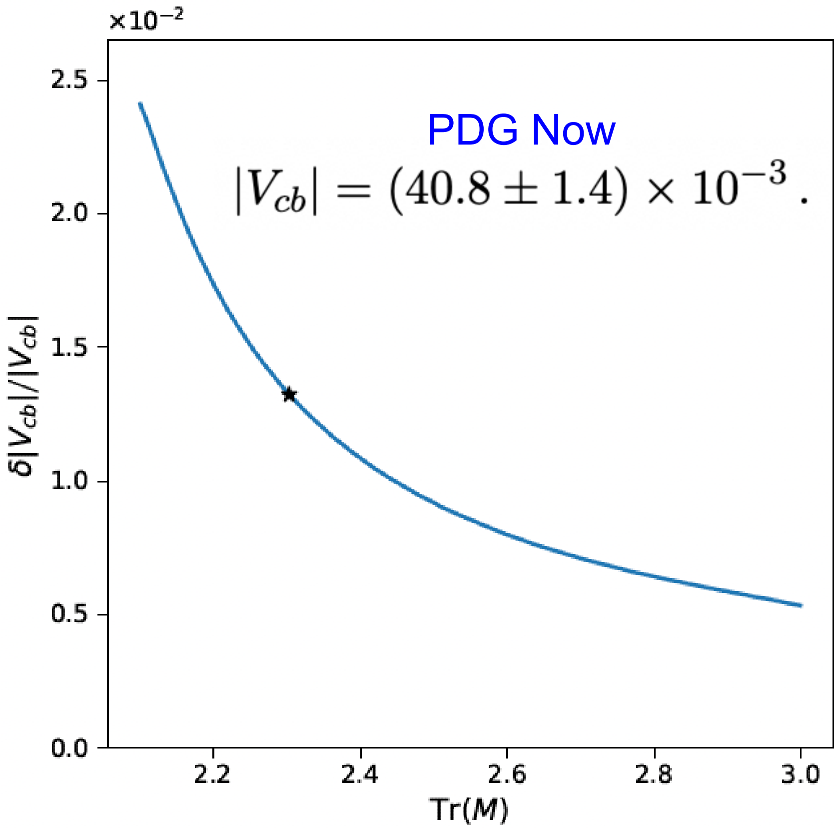


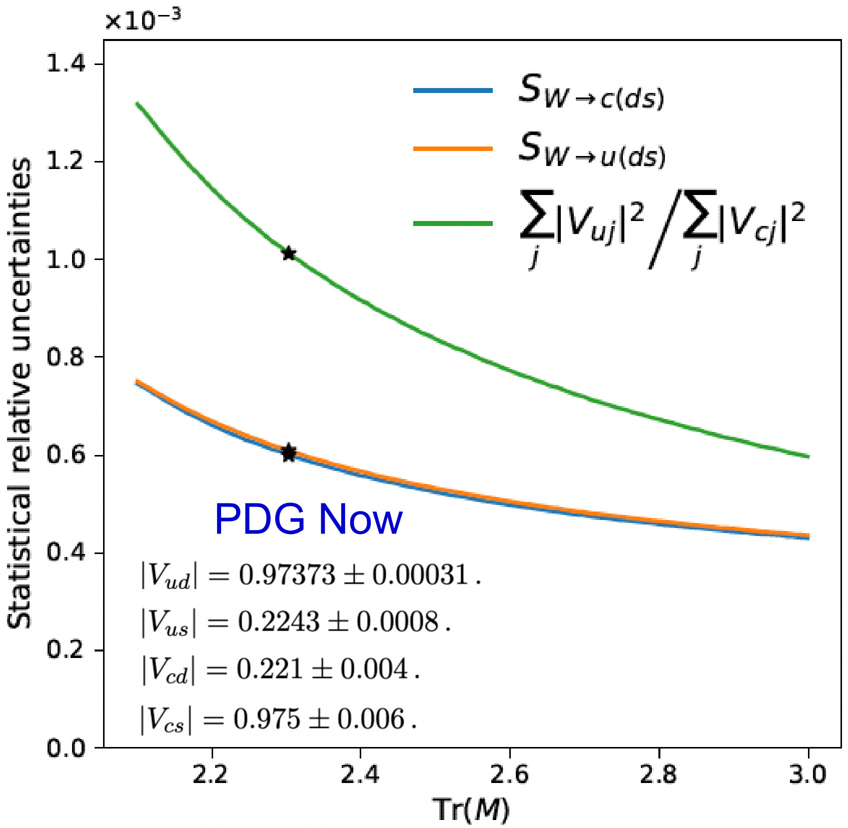


Beam pipe radius reduced from ~15 mm to 9 mm, and put the first silicon layer inside the beam pipe!

Innovative reconstruction algorithm shall also be emphasized, to achieve a better performance

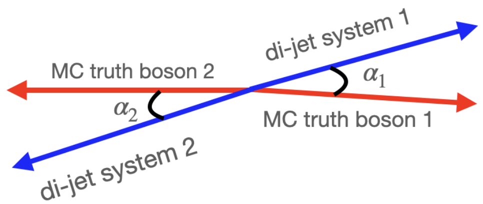
Impact of Flavor tagging

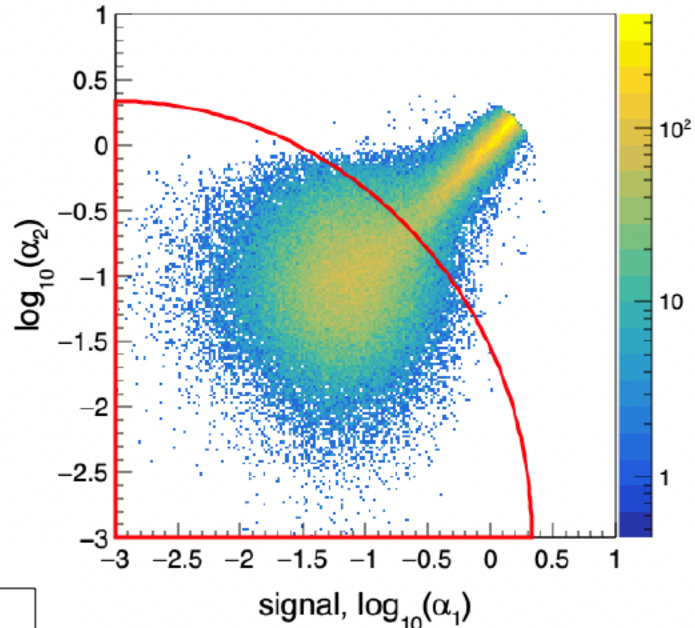


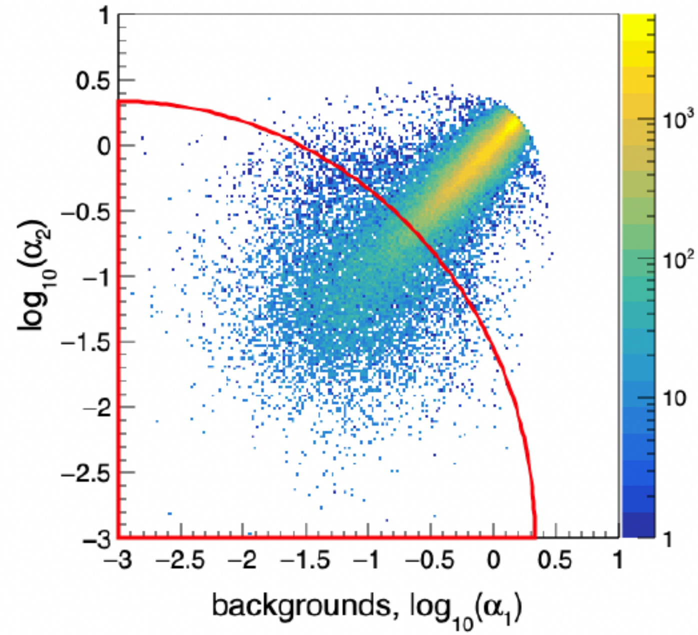


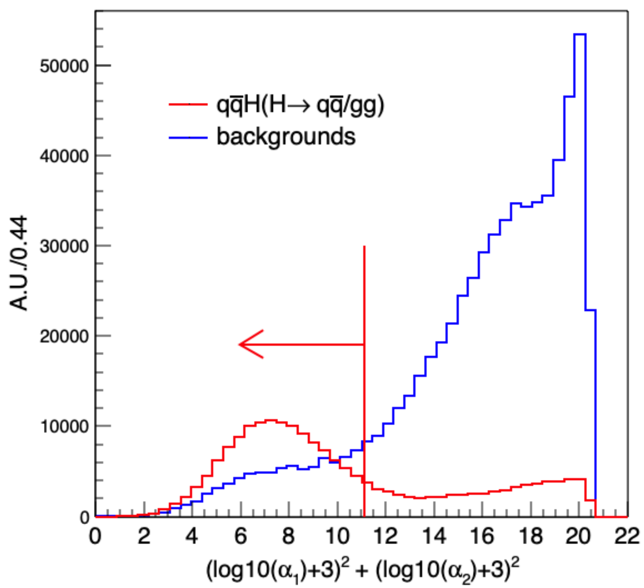
- Percentage level accuracy on Vcb anticipated; using only muvqq events at 5.6 iab. Can be improved by 3-4 times... if using 20 iab and all leptonic channels, plus better analysis method
- Compared to baseline... ideal FT improves the accuracy by 2.5 times

Impact of CSI









- If we find an observable that evaluates the performance of CSI – and eventually veto events with bad CSI, we can improve the accuracy on H->bb, cc, gg by ~ 2 times at qqH channel.
- Need profound understanding of QCD picture, and developments of new tools

Jet Charge

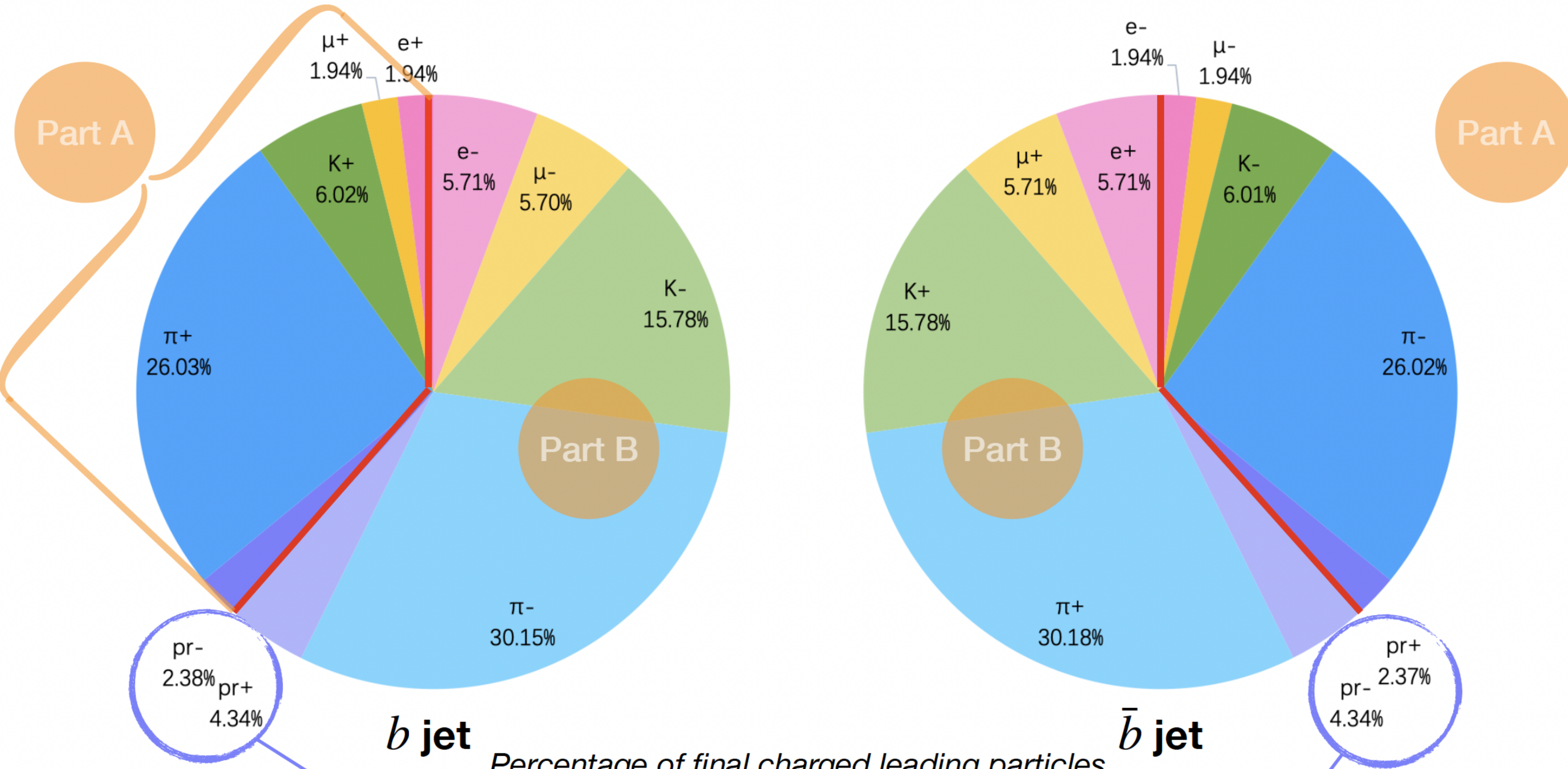
b or b-bar? c or c-bar?

Essential for CKM measurements with neutral hadron oscillations.
enable differential measurements that depends on quark charge

Far future: might be well extended & combine with Jet Flavor tagging → to identify the species & charge of quark/gluon that induces a jet

$Z \to b\bar{b}$

Dependence on leading particle type



Percentage of final charged leading particles

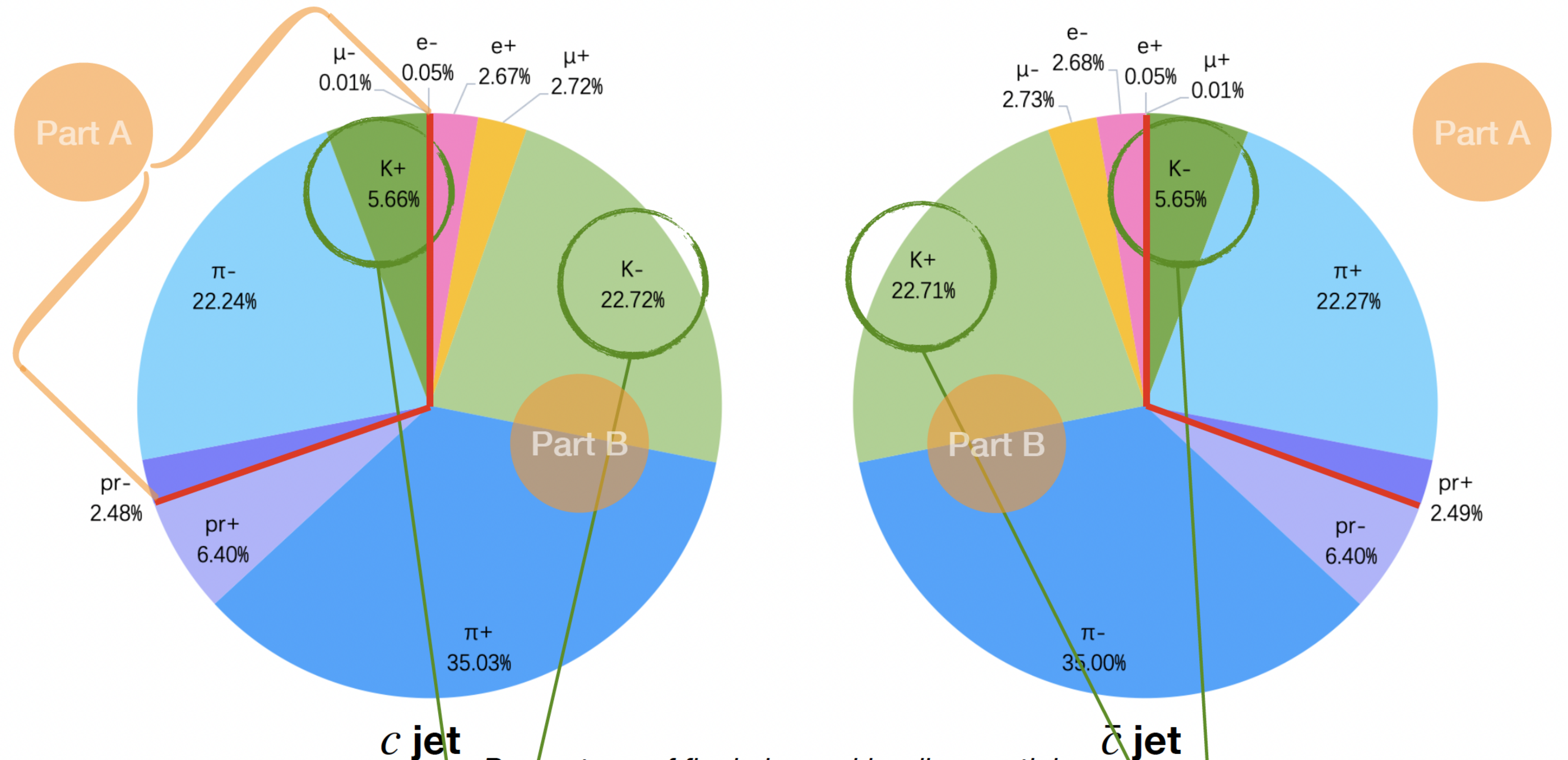
ω(using only charge) = 0.403
ω(using charge & PID) = 0.383

ω(using only charge) = 0.402
ω(using charge & PID) = 0.383

Leptons can be generated from semi-leptonic b decay, or from c from b→c

$Z \to c\bar{c}$

Dependence on leading particle type



Percentage of final charged leading particles

ω(using only charge) = 0.473
ω(using charge & PID) = 0.304

ω(using only charge) = 0.475
ω(using charge & PID) = 0.305

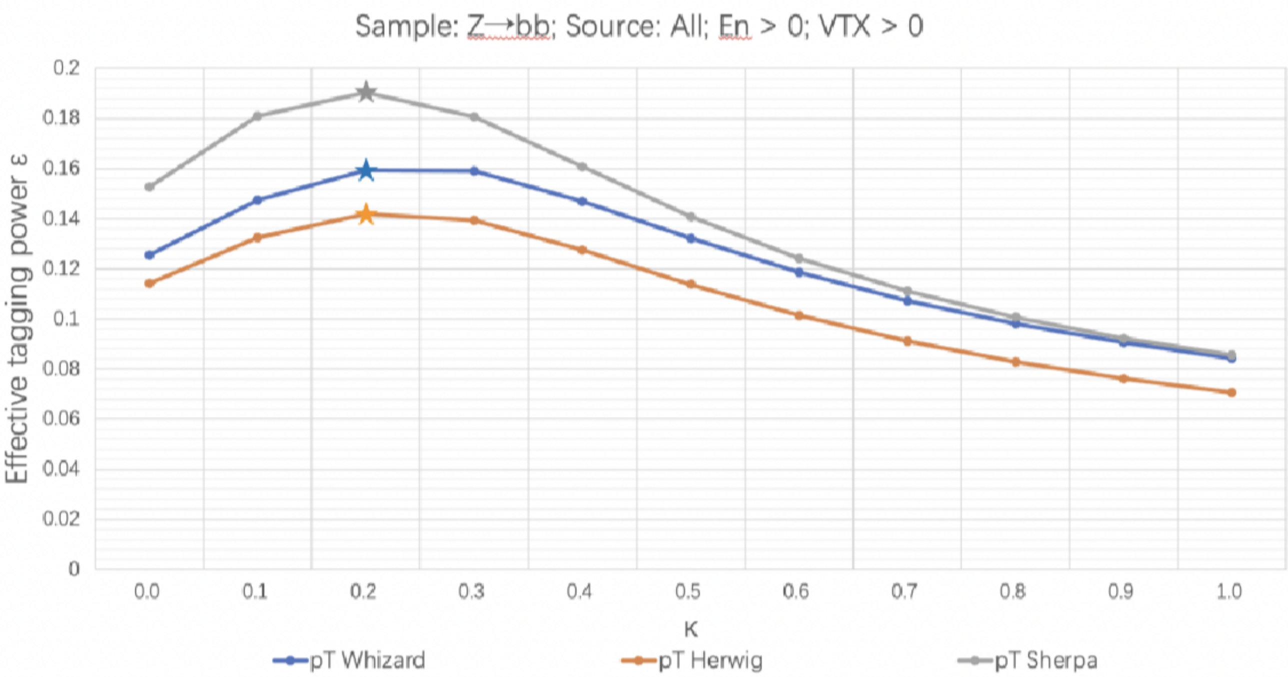
Strongly Depends on Pid!

Weighted charge method (WCJC)

Method:

- **Use the charge and momentum of all final charged particles in a jet with a weight parameter κ to calculate Q_{jet}^{κ}.**
- **the weight parameter κ is optimized for different decay modes.**
- **if $Q_{jet}^{\kappa}<0$, we consider this is a b quark, and vise versa.**

$$Q_{jet}^{\kappa} = \frac{\Sigma_i (E_i)^{\kappa}\, Q_i}{\Sigma_i (E_i)^{\kappa}}$$



Methods	Optimized κ					
Generator	Whizard		Herwig		Sherpa	
source	all	from B/D	all	from B/D	all	from B/D
All b hadrons	(κ=0.2)	(κ=0)	(κ=0.2)	(κ=0)	(κ=0.2)	(κ=0)
B0/B0bar	(κ=0.2)	(κ=0.6)	(κ=0.2)	(κ=0.6)	(κ=0.3)	(κ=0.6)
B+/B-	(κ=0.3)	(κ=0)	(κ=0.4)	(κ=0)	(κ=0.3)	(κ=0)
Bs/Bsbar	(κ=0)	(κ=0)	(κ=0)	(κ=0)	(κ=0.2)	(κ=1.0)
Bc+/Bc-	(κ=0.2)	(κ=0)	(κ=0.7)	(κ=0)	(κ=0.6)	(κ=0)
Λb/Λbbar	(κ=0)	(κ=1.0)	(κ=0)	(κ=0.9)	(κ=0)	(κ=0)

Result @ Truth level

two combination methods combination

			ε_{eff}
b jet	e	Decision Level	0.025
	μ	Decision Level	0.025
	K	Decision Level	0.060
	π	Tagger Level	0.076
	p	Decision Level	0.012
	Total		0.198
c jet	e	Tagger Level	0.025
	μ	Tagger Level	0.027
	K	Decision Level	0.137
	π	Tagger Level	0.186
	p	Decision Level	0.029
	Total		0.404

Analysis of jet charge performance for single jet at CEPC Z pole:

- ★ ***Effective tagging power:***
- ★ ***LPJC method:*** *0.089 / 0.203*
- ★ ***WCJC method:*** *0.159 / 0.258*
- ★ ***Decision level combination:*** *0.165 / 0.342 (improve 3.8% / 32.6%)*
- ★ ***Tagger level combination:*** *0.182 / 0.372 (improve 14.5% / 44.2%)*
- ★ ***Total combination:*** *0.198 / 0.404 (improve 24.5% / 56.6%)*

- ★ ***Dependences:***
  - *High dependence on leading particle type.*
  - *High dependence on b/c hadrons type, especially for B_s (Mingrui), Λ_b, Λ_c, …*
  - *High dependence on the decay source of leading particle.*

At Z pole hadronic event: >7/8 time correct in guessing the charge of b/c jet

Summary

- Electron Positron Higgs factories: a gigantic boost from LHC
  - CEPC: 4 M Higgs, ~100 Million W, 1 Million Top, and 4 Tera Z.
  - Higgs precision ~ 1 order of magnitude better compared to HL-LHC.
  - Boost the precision on EW by 1-2 orders of magnitudes.
  - Lots of opportunities for flavor physics & NP reach of 10 TeV, or higher.
  - Strong physics cases for BSM & QCD.

- CEPC Higgs precision mainly limited by statistic
  - Higher luminosity is essential
  - The physics requirement on detector performance is well understood, Significant margin to improve:
    - Detector R&D
    - Algorithms
    - Theoretical efforts: Uncertainties, Interpretation, Understanding QCD ...
    - New methodology...

Back up

Effective tagging power

- Tagging power = efficiency * (1 – 2*omega)^2

- Omega ~ chance of mis-id, value between 0 – 0.5.

- To 1st order, accuracy ~ 1/sqrt(N*tagging power).

- Tagging power highly sensitive to mis-id chance.

- Many method to measure Jet Charge: VTX charge, weighted sum, jet lepton/kaon, 2nd leading kaon, ...

Vcb from W decay

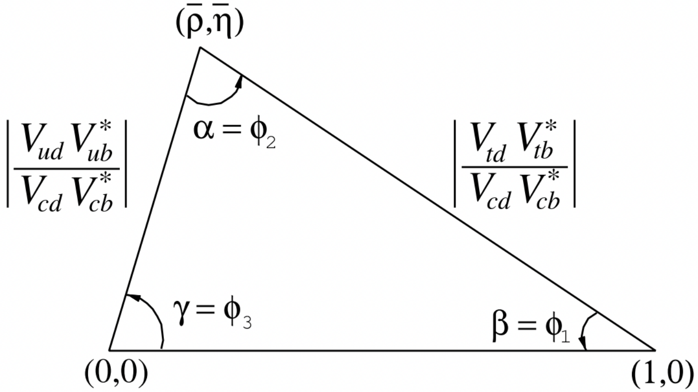
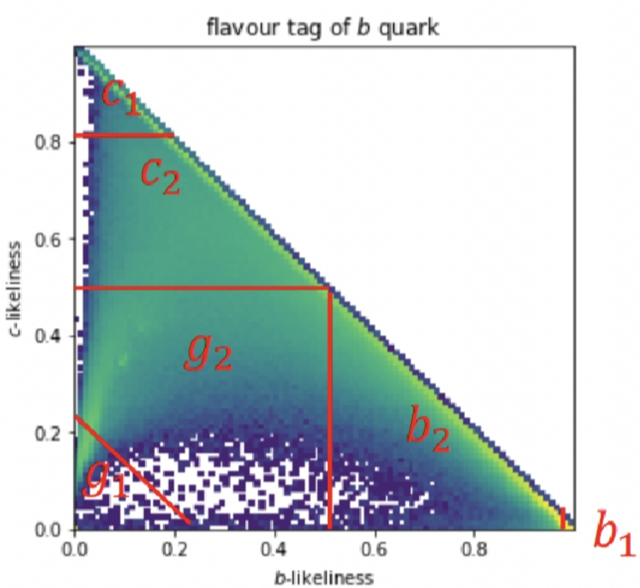


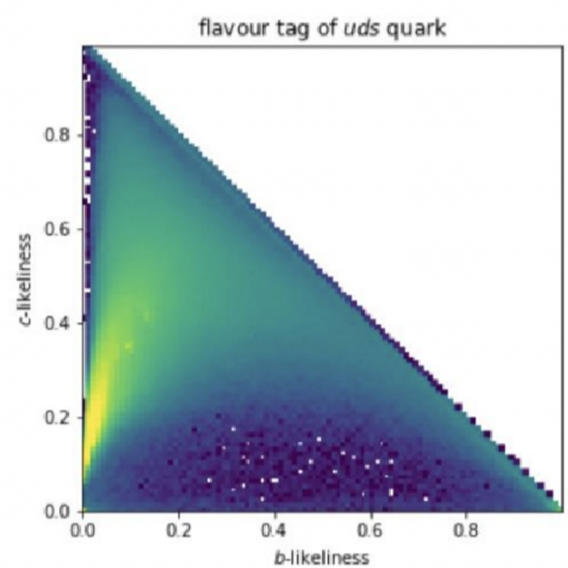
Figure 12.1: Sketch of the unitarity triangle.

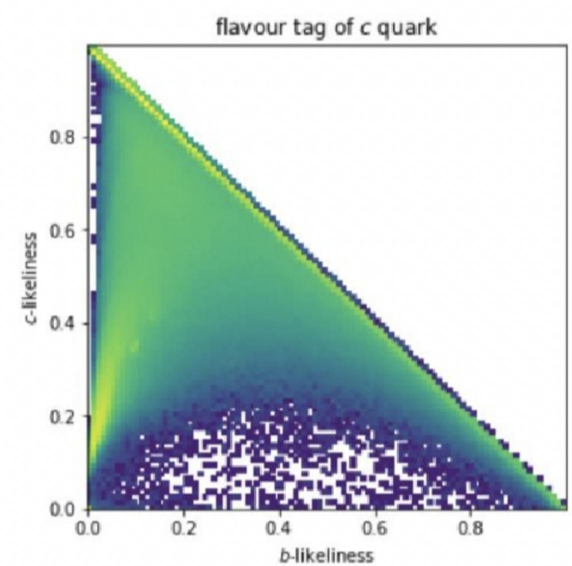
$$|V_{cb}| = (41.0 \pm 1.4) \times 10^{-3}\,.$$

$$
\begin{array}{cc}
 & \begin{array}{cccccc} \mathbf{b1} & \mathbf{b2} & \mathbf{c1} & \mathbf{c2} & \mathbf{g1} & \mathbf{g2} \end{array} \\
M = \begin{array}{c} \mathrm{b} \\ \mathrm{c} \\ \mathrm{uds} \end{array} & \begin{pmatrix} 0.47 & 0.378 & 0.0197 & 0.0965 & 0.00397 & 0.0315 \\ 0.00042 & 0.078 & 0.298 & 0.373 & 0.0682 & 0.182 \\ 0.000104 & 0.00477 & 0.00145 & 0.054 & 0.538 & 0.401 \end{pmatrix}
\end{array}
$$

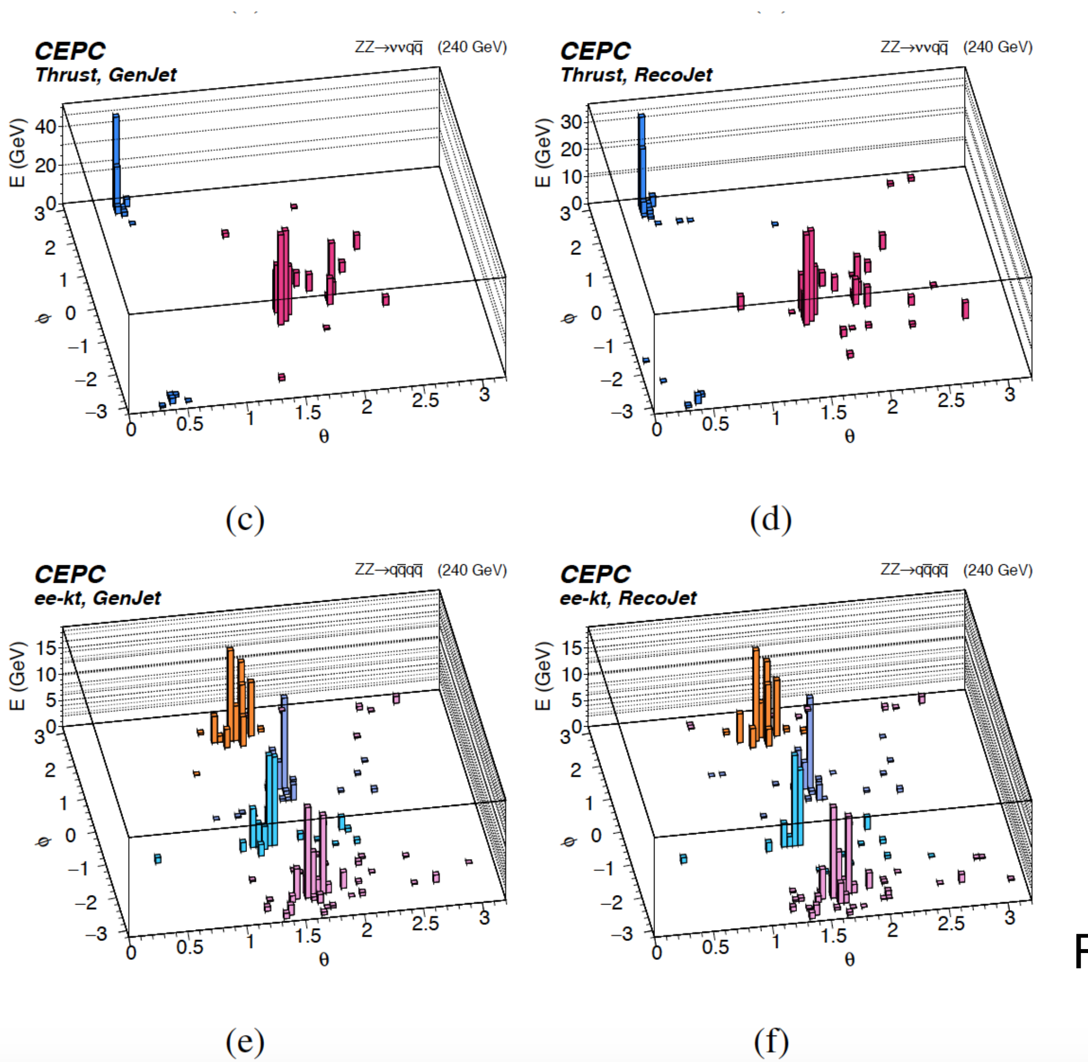
Flavour tagging at Z-pole







Individual jet: jet clustering - matching



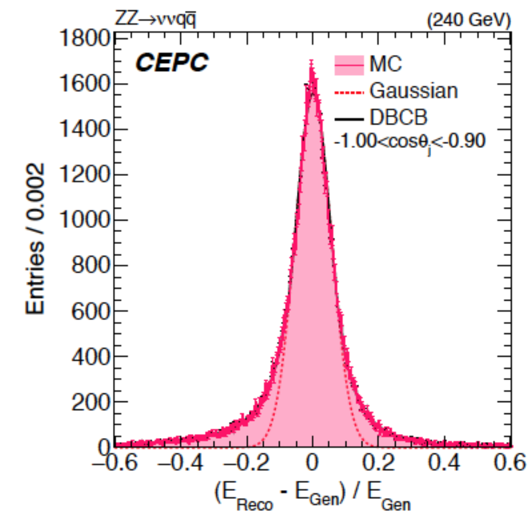
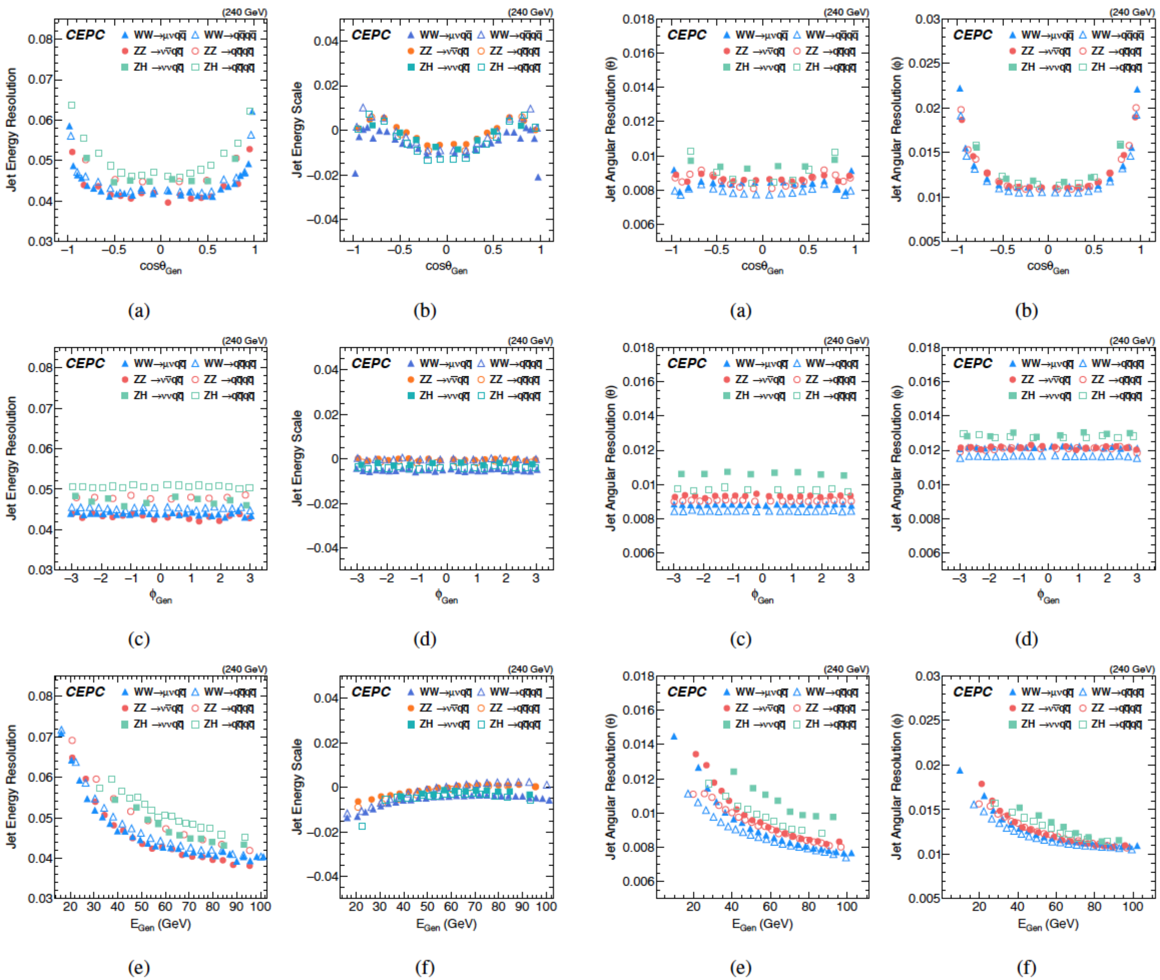


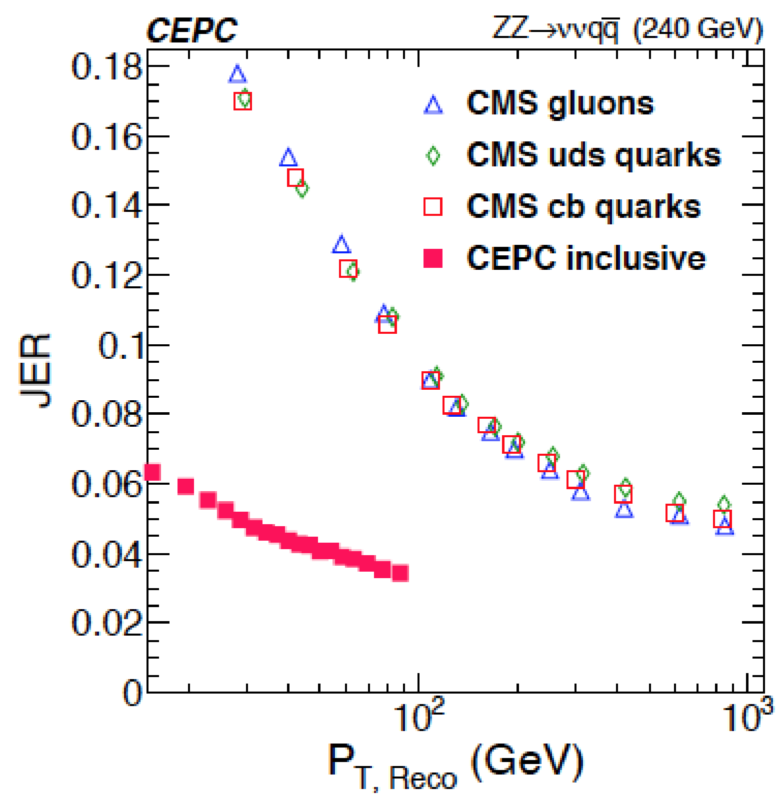
Fig. 7: σ and $\bar{x}$ from the core of the DBCB fit to R are defined as JER/S, respectively. The $cos\theta_j$ indicates the specific polar angle of the jets.

Jet Clustering & Matching is critical: ee-kt is used as CEPC baseline

Relative difference between Gen/Recojet is define to be the detector jet response

Individual Jet Responses

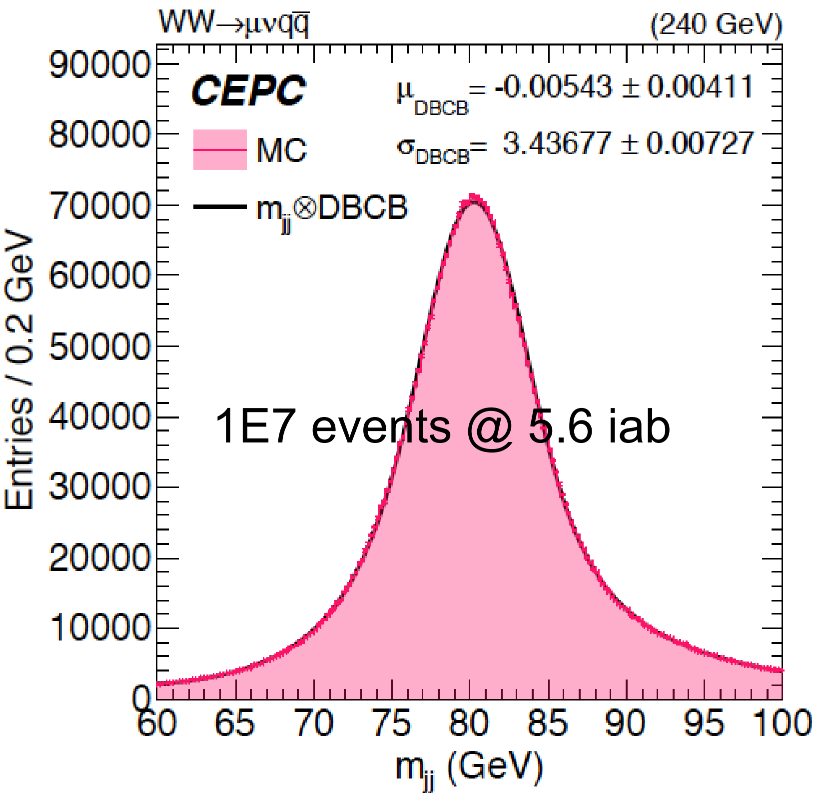




Jet Energy Response: 2.5 – 4 times better than LHC in the same Pt range,
Jet Energy Scale: 3 times better before sophisticated calibration

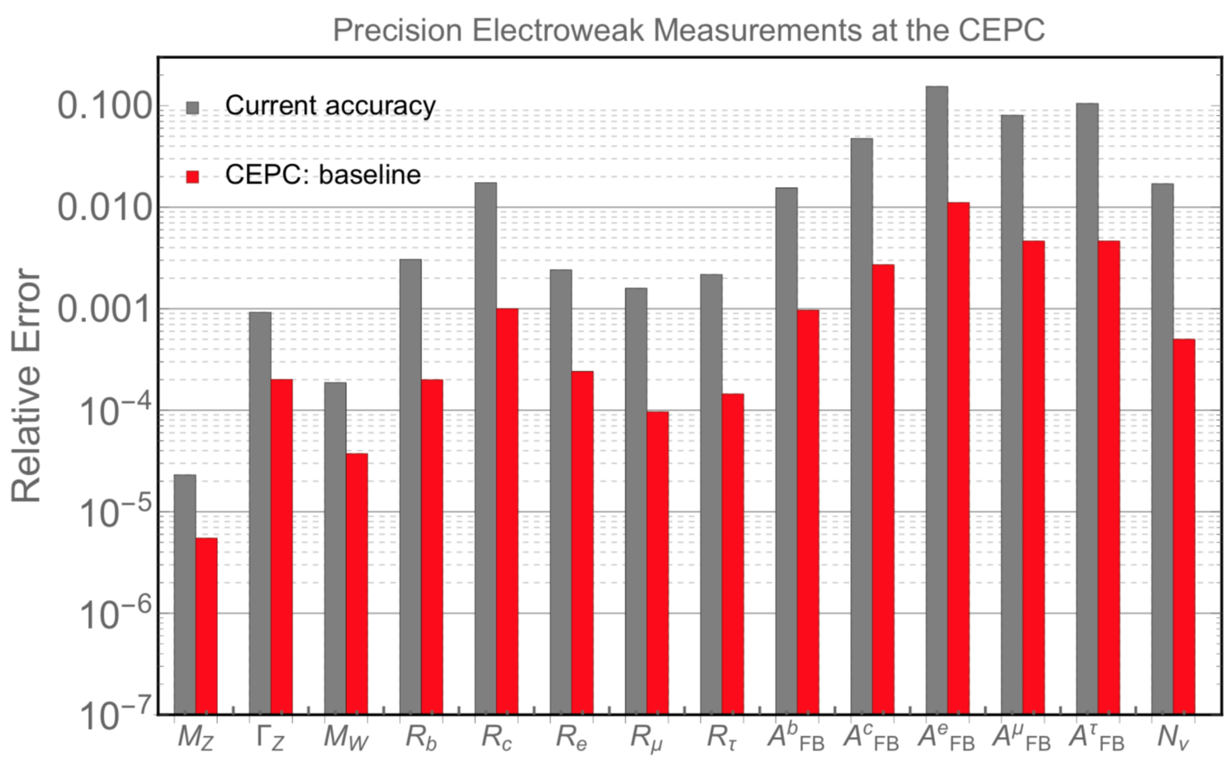
W-mass direct reconstruction at 240 GeV. Challenge & interesting

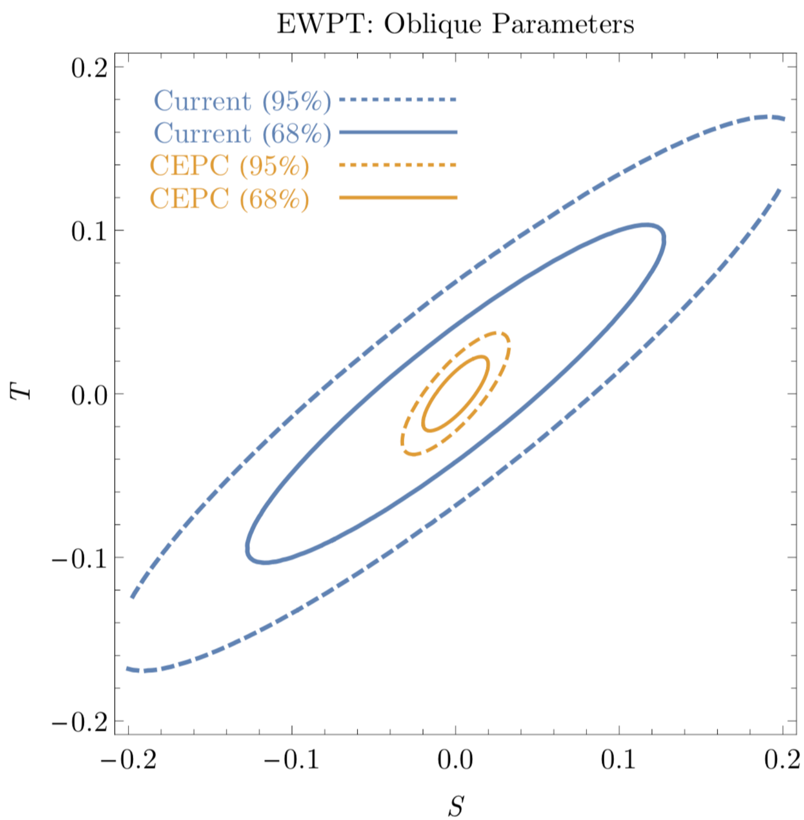
- W mass measurement at 240 GeV:
  - Statistic uncertainty @ 20 iab~
    - *0.3 MeV using only μvqq final state*
    - *Bias ~ 2.5 MeV once Z mass calibrated to known value*
  - Ultimate accuracy?
    - *Can we better control the systematic using the differential information?*
    - *Control the jet confusion?...*
    - *Identify & tame ISR?*
    - *Better calibrate?*
    - *Can we maintain sufficient stability over 7/10 years? ...*



Quasi analysis: JES calibrated to pure ISR return qq sample

EW





With 2 years of Z pole operation (~ 1 Tera Z) and 1 year of W mass scan (~1E7 W)

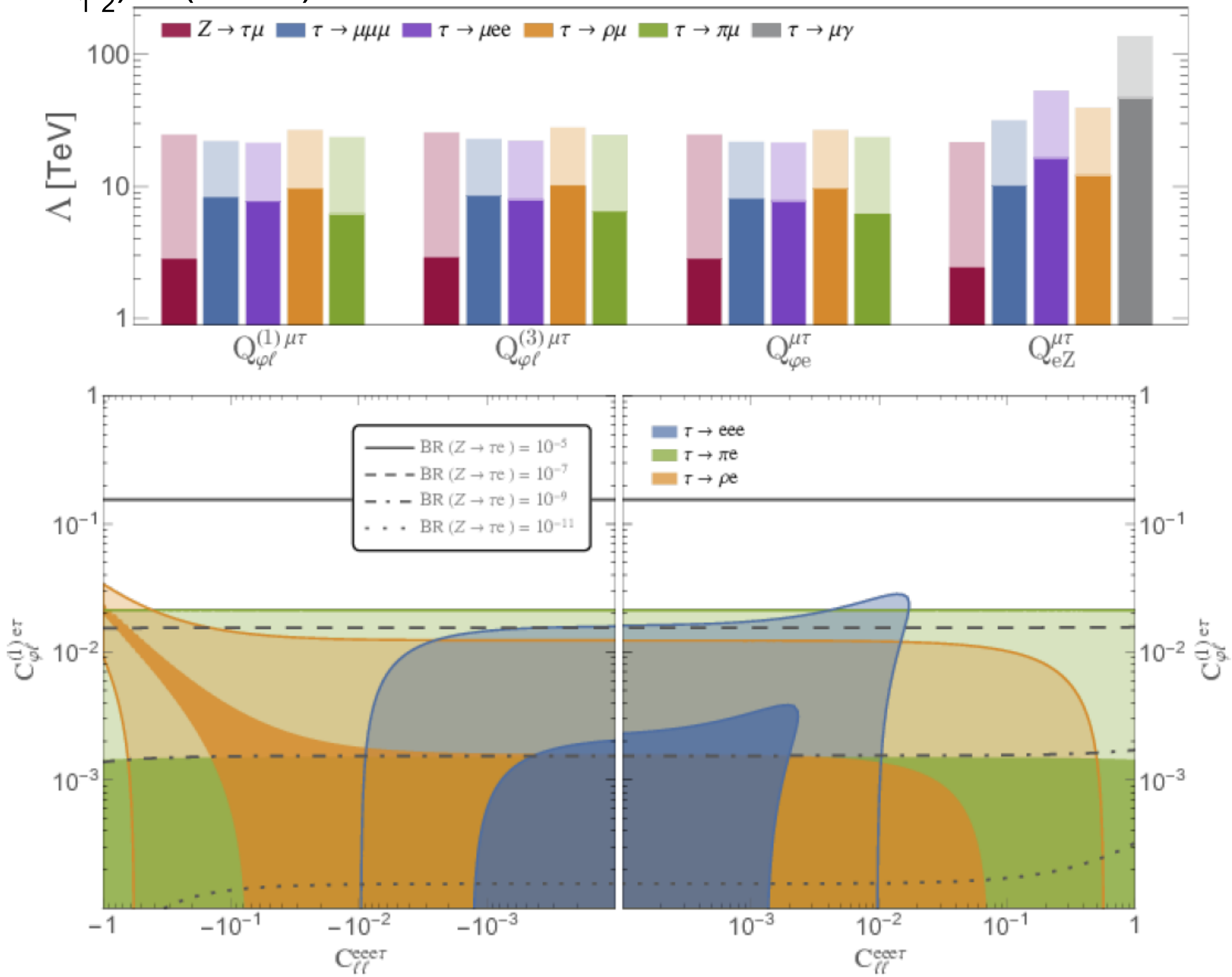
Flavor Physics @ Z pole

- Extremely rich physics & strong competition from Belle-II & LHCb
- Comparative advantages of a Tera-Z
  - V.S. BelleII, Access to particles heavier than Bs, large boost
  - V.S. LHCb, much lower yields (2 orders of magnitudes) Better Acceptance, better reconstruction of neutral final state (photon, missing energy, and even Klong, neutron) and Jet Charge

- Observations
  - For CP measurement, a Tera-Z can compete with LHCb @ HL-LHC thanks to the capability of precise Jet Charge measurements...
  - Brings lots of critical information on measurements with neutral final states...
  - Yet, Pid is essential.

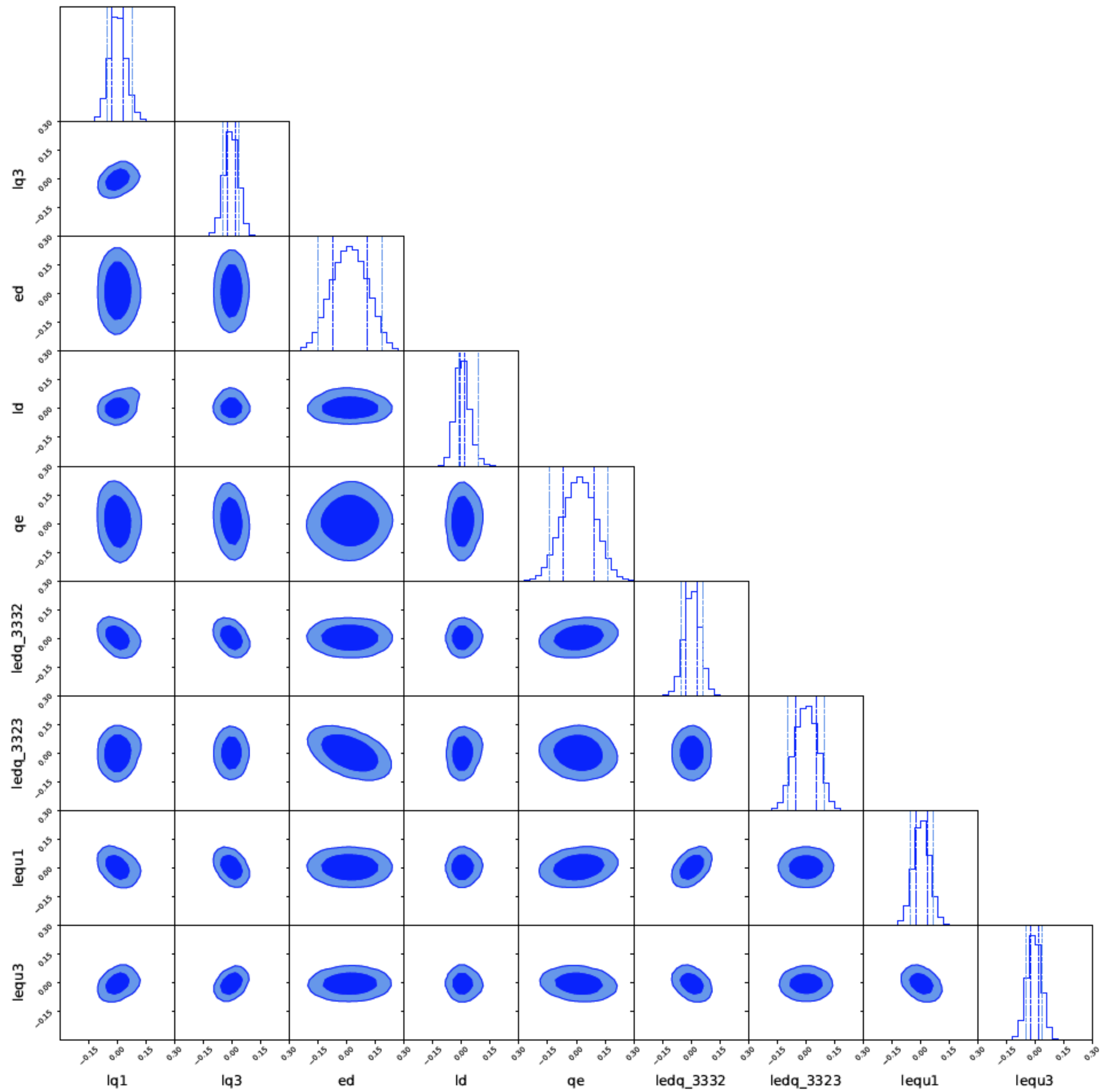
Lepton Flavor Violation (II)

Up limit of $Br(Z \to l_1 l_2) \sim o(\text{ 1E-9})$



[Calibbi et al., 2021] 2107.10273

Current Progress in LFU Tests (II)



Regular Article - Theoretical Physics | Open Access | Published: 09 June 2021

$b \to s\tau^+\tau^-$ physics at future Z factories

Lingfeng Li & Tao Liu

Journal of High Energy Physics **2021**, Article number: 64 (2021) | Cite this article

Preliminary: 9 effective channels:($R_{J/\psi}$, R_{D_s}, $R_{D_s^*}$, R_{Λ_c}, $B_c \to \tau\nu$, $B \to K\nu\bar{\nu}$, $B_s \to \phi\nu\bar{\nu}$, $B^0 \to K\tau\tau$, $B^+ \to K^+\tau\tau$, $B_s \to \tau\tau$...)

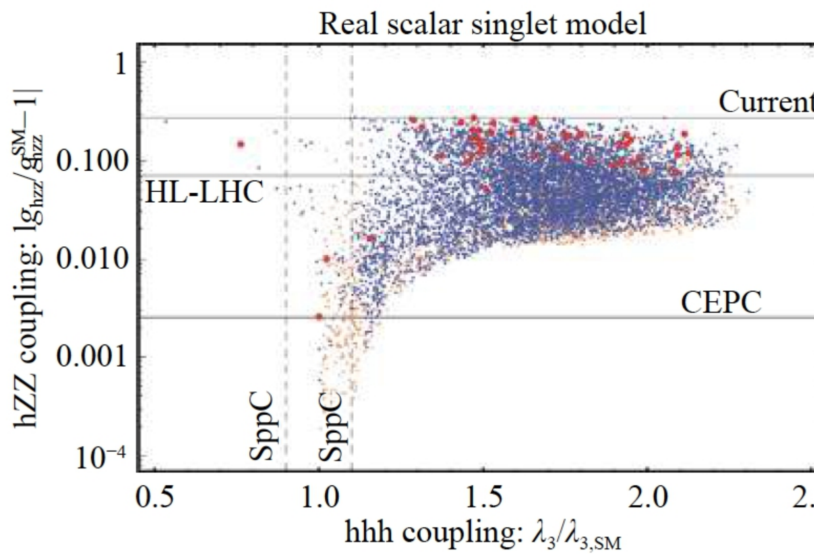
Dim-6 SMEFT basis at NP scale Λ=3 TeV.

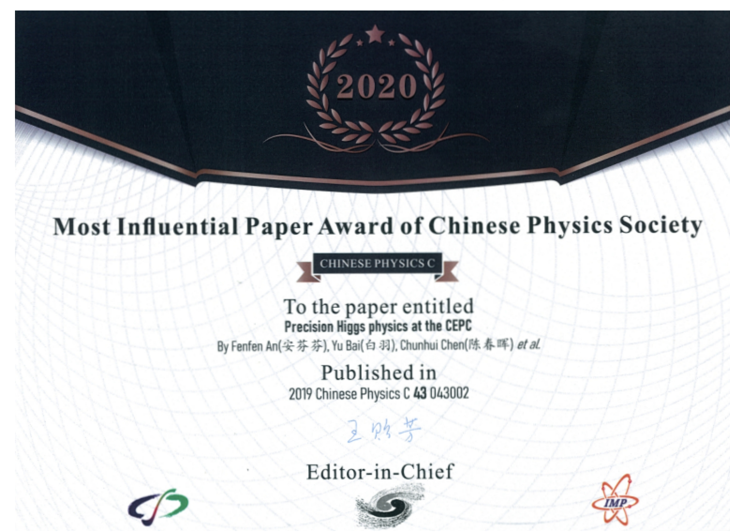
Higgs white paper delivered

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

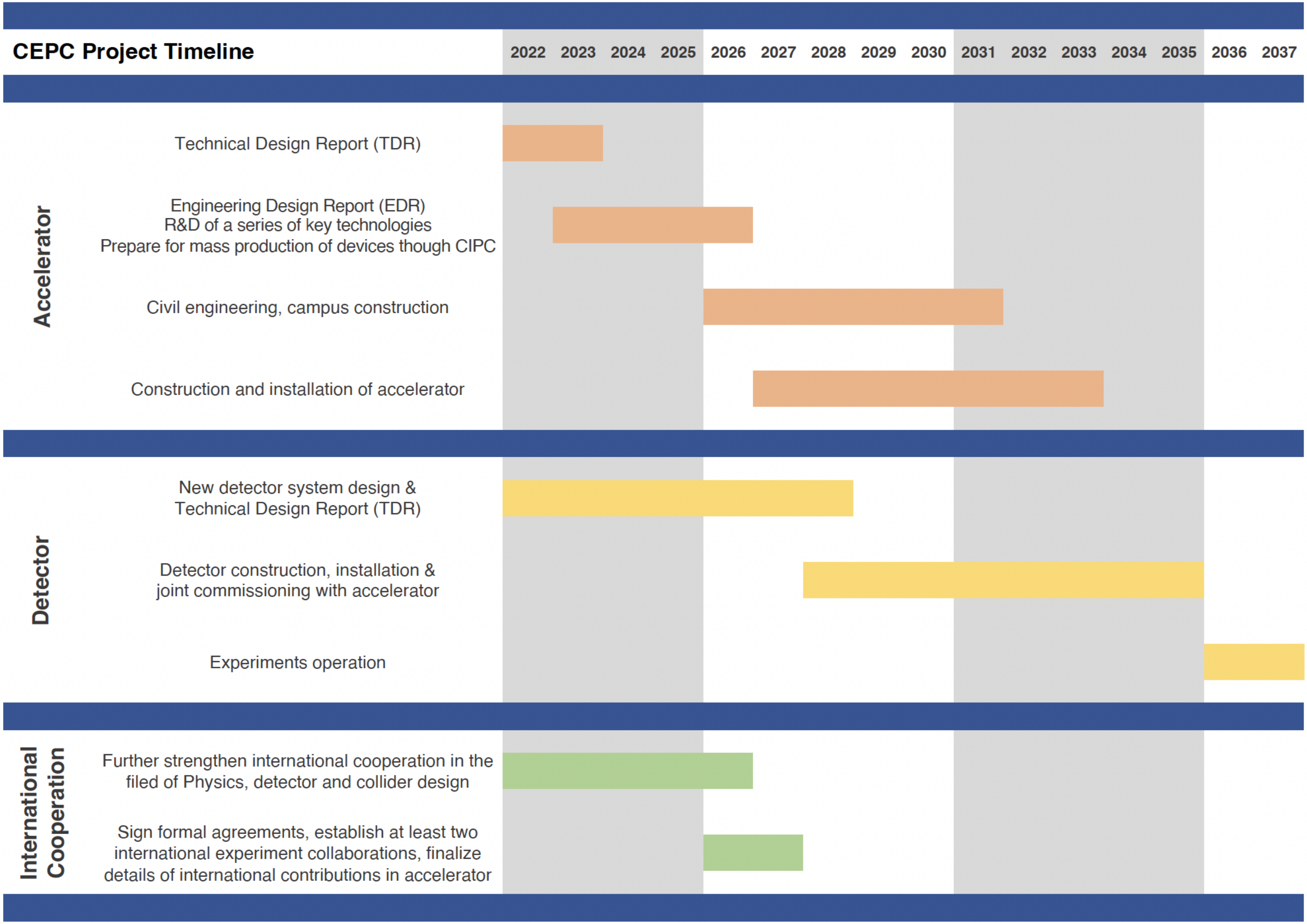
Precision Higgs physics at the CEPC*

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
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)
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)
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 Kiu
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
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(
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)[1
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]





Timeline

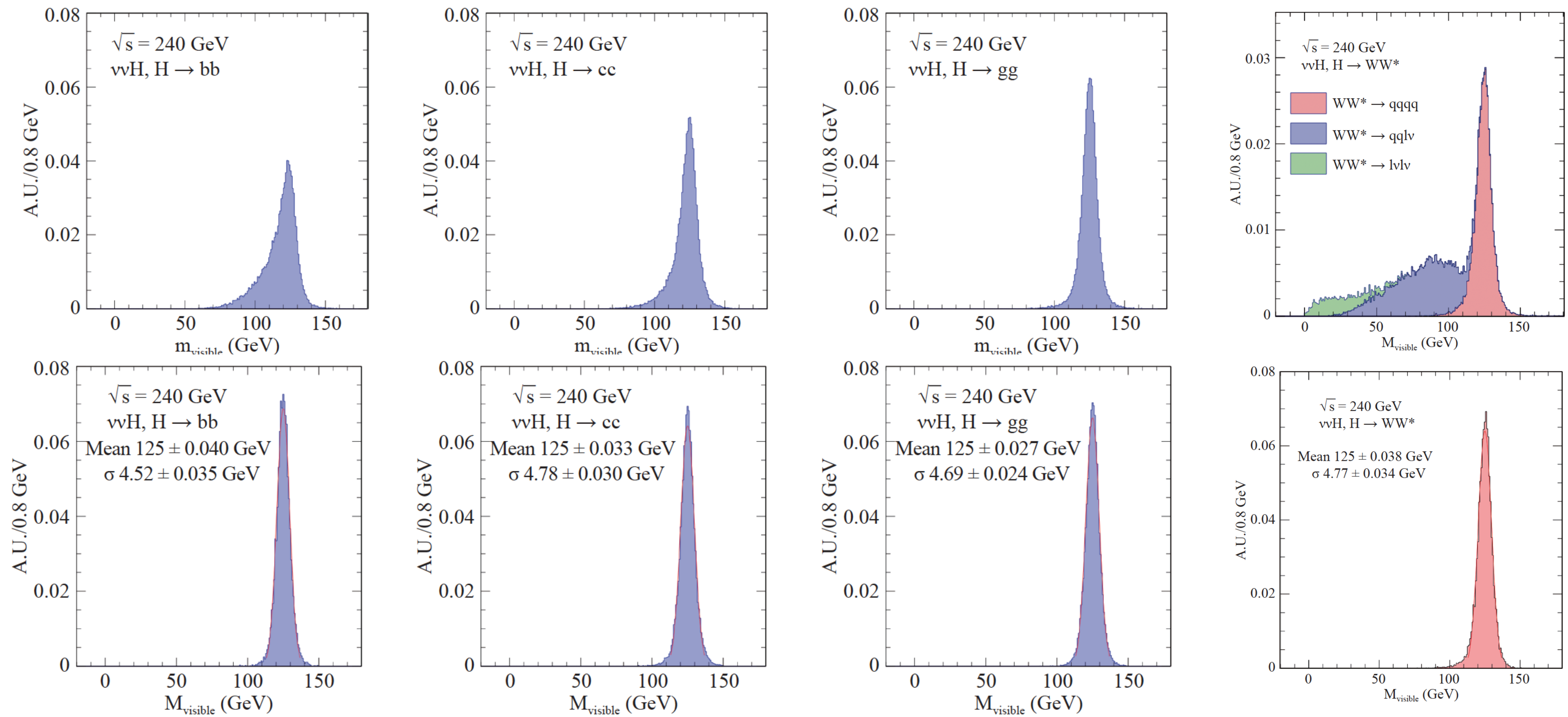


CEPC Project Timeline
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
Accelerator
Technical Design Report (TDR)
Engineering Design Report (EDR)
R&D of a series of key technologies
Prepare for mass production of devices though CIPC
Civil engineering, campus construction
Construction and installation of accelerator
Detector
New detector system design &
Technical Design Report (TDR)
Detector construction, installation &
joint commissioning with accelerator
Experiments operation
International Cooperation
Further strengthen international cooperation in the
filed of Physics, detector and collider design
Sign formal agreements, establish at least two
international experiment collaborations, finalize
details of international contributions in accelerator

Performance requirements

- A clear separation of the final state particles
  - Better Identify Physics Objects
    - Single particle objects: Leptons, photons, Charged hadron, isolated or inside jets
    - Composited objects:
      - With two/three final state particles: Pi-0, K-short, Lambda, Phi, Tau, D meson...
      - Jets
  - Improving the resolution for composited objects, especially jets
- BMR (Boson Mass Resolution)
  - $< 4\%$ for Higgs measurements
  - Much demanding for NP tagging & Flavor Physics Measurements
- Pid: Pion & Kaon separation > 3-sigma
- Jet: Flavor Tagging & Charge Reconstruction
- Flavor Physics: requires good intrinsic Energy/Momentum resolution

BMR: no significant dependence on #jets...



Fi

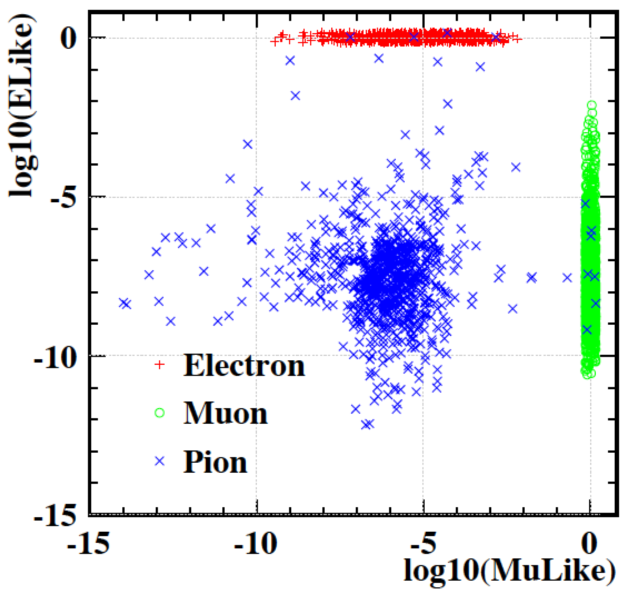
Table 1. Event cumulative efficiency for Higgs boson exclusive decay at the CEPC with $\sqrt{s} = 240$ GeV.

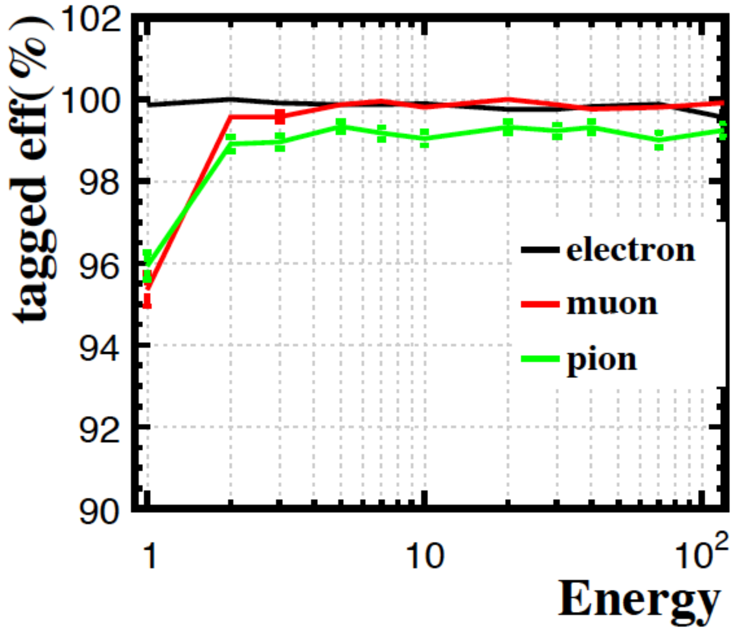
	gg(%)	bb(%)	cc(%)	WW^*(%)	ZZ^* (%)
Pt_ISR < 1 GeV	95.15	95.37	95.30	95.16	95.24
Pt_neutrino < 1 GeV	89.33	39.04	66.36	37.46	41.39
|Cos(Theta_Jet)| < 0.85	67.30	28.65	49.31	–	–

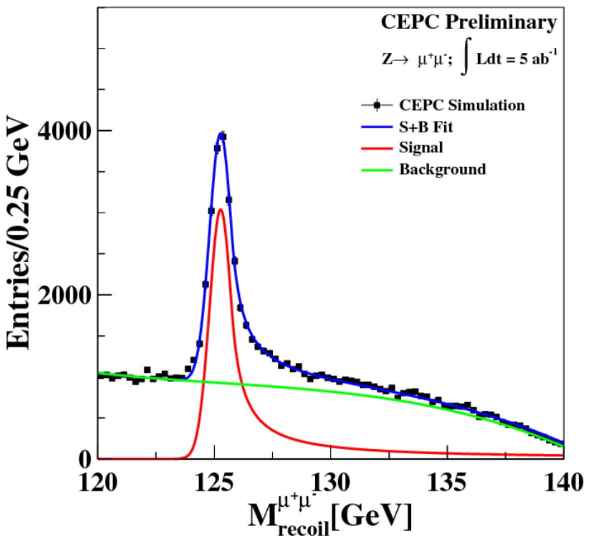
Table 3. Higgs boson mass resolution (sigma/Mean) for different decay modes with jets as final state particles, after event cleaning.

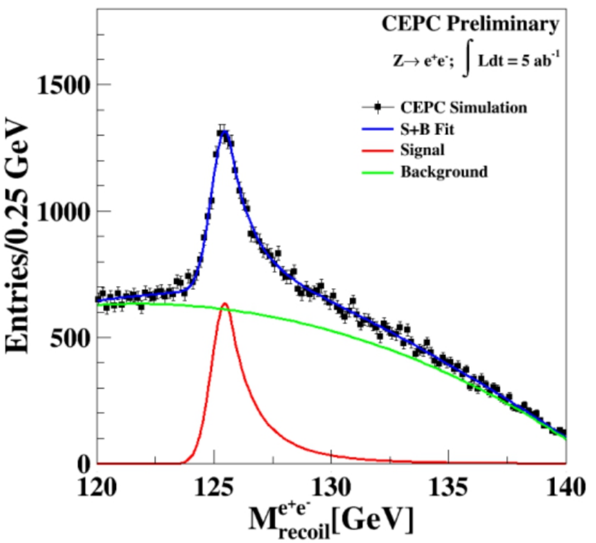
$H \to bb$	$H \to cc$	$H \to gg$	$H \to WW^*$	$H \to ZZ^*$
3.63%	3.82%	3.75%	3.81%	3.74%

Lepton: isolated







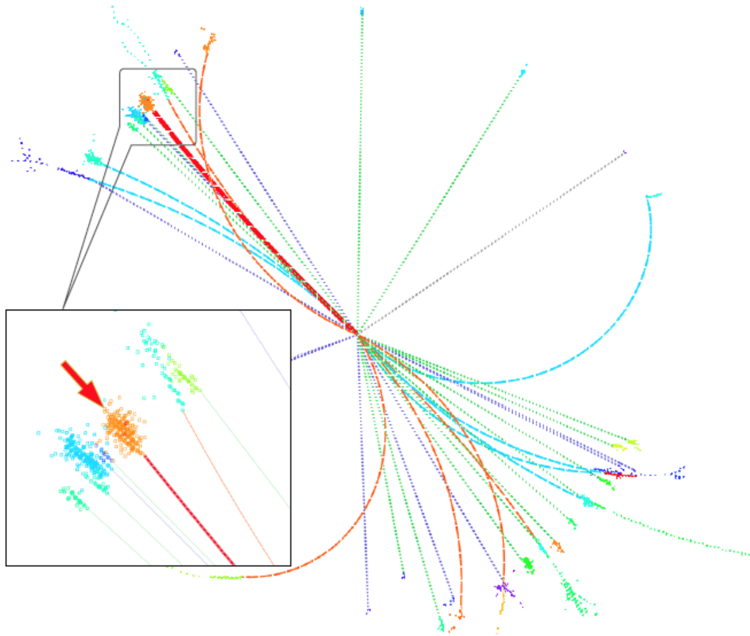


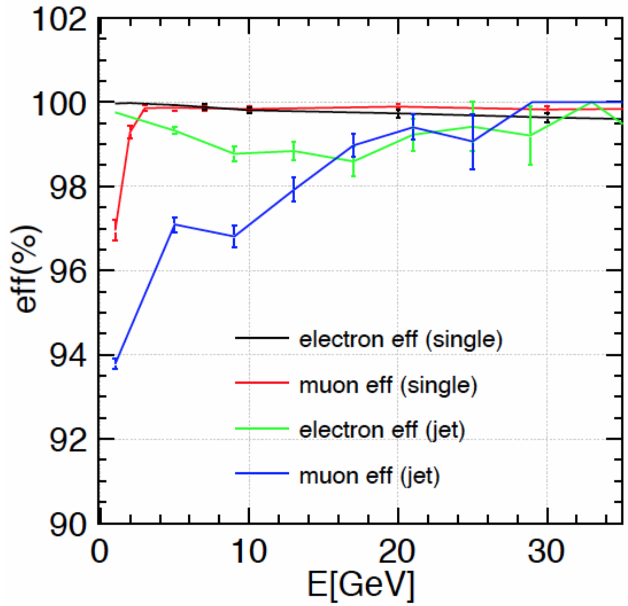
BDT method using 4 classes of 24 input discrimination variables.

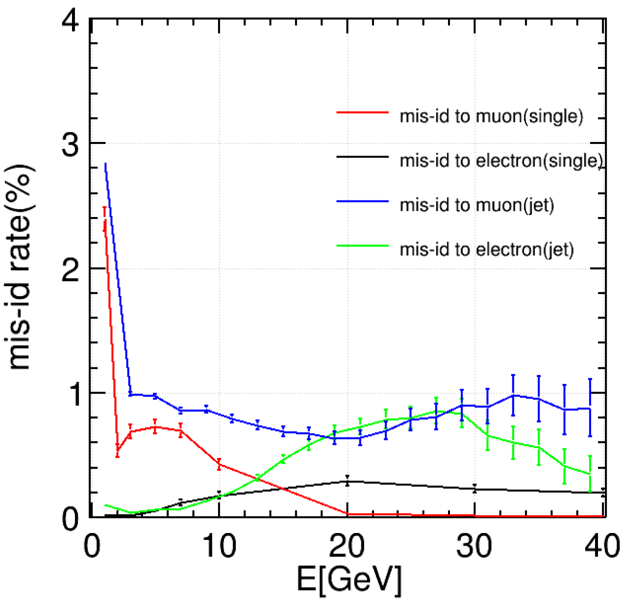
Test performance at: Electron = E_likeness > 0.5 ;
Muon = Mu_likeness > 0.5
Single charged reconstructed particle, for E > 2 GeV:
lepton efficiency > 99.5% && Pion mis id rate ~ 1%

https://link.springer.com/article/10.1140/epjc/s10052-017-5146-5
CEPC-DocDB-id:148, Eur. Phys. J. C (2017) 77: 591

Lepton: inside jet



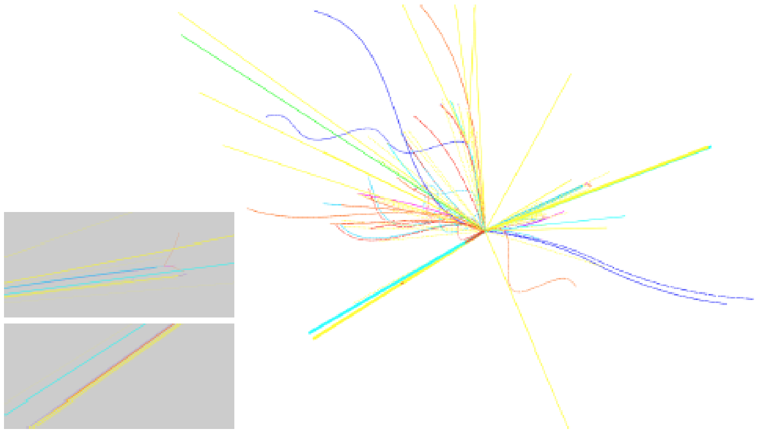




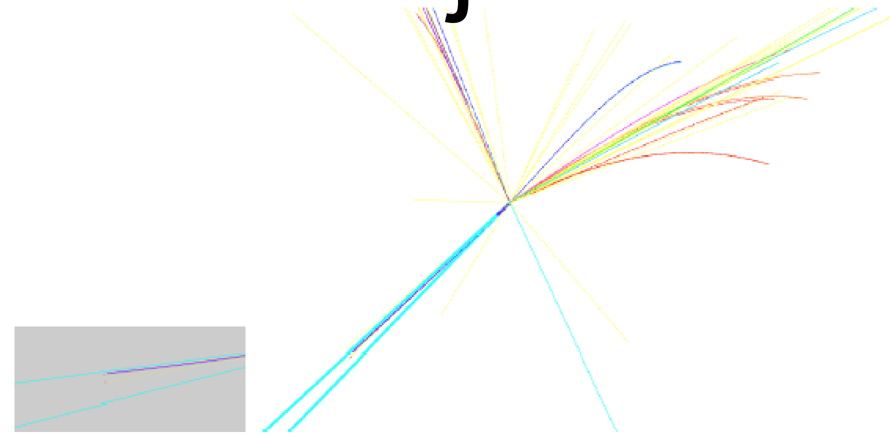
Compared the single particle sample, the jet lepton (at Z->bb sample at sqrt = 91.2 GeV) Performance will be slightly degraded – Due to the limited clustering performance (splitting & containimation).

At the same working point, the efficiency can be reduced by up to 3%; while mis-id rate increases up to 1%. Marginal Impact on Flavor Physics measurements as Bc->tauv.

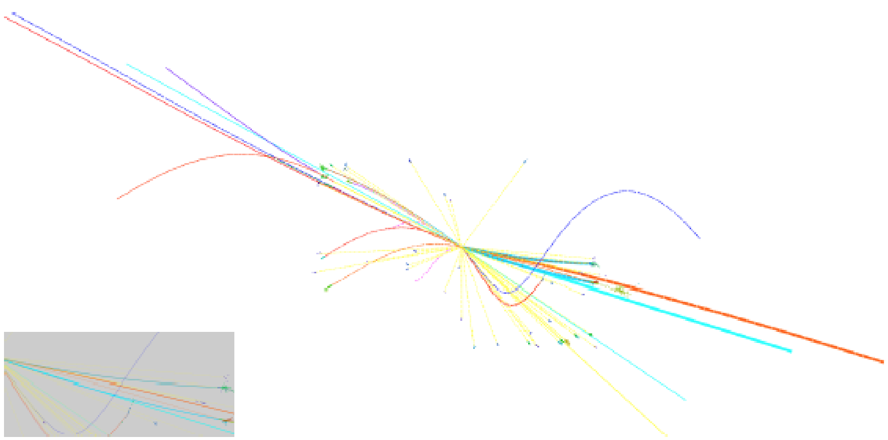
Taus: isolated or inside jets



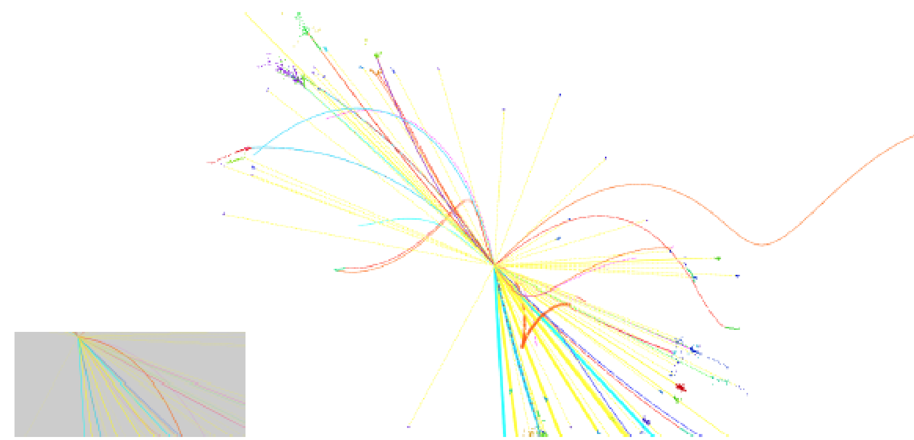
(a) $Z \to qq, H \to \tau\tau$ with two hadronic decay.



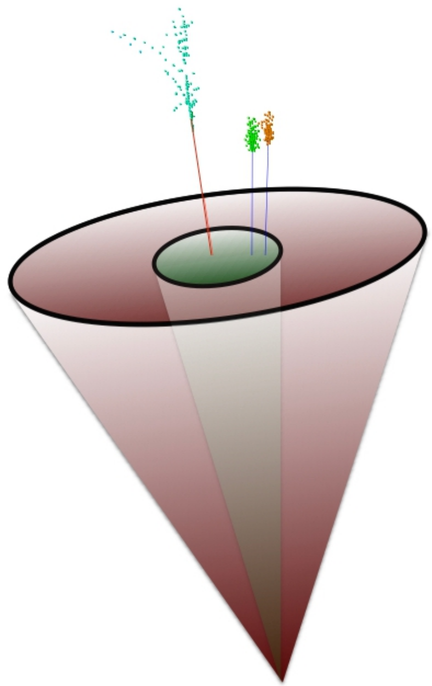
(b) $WW \to \tau\nu qq$ with one leptonic decay.

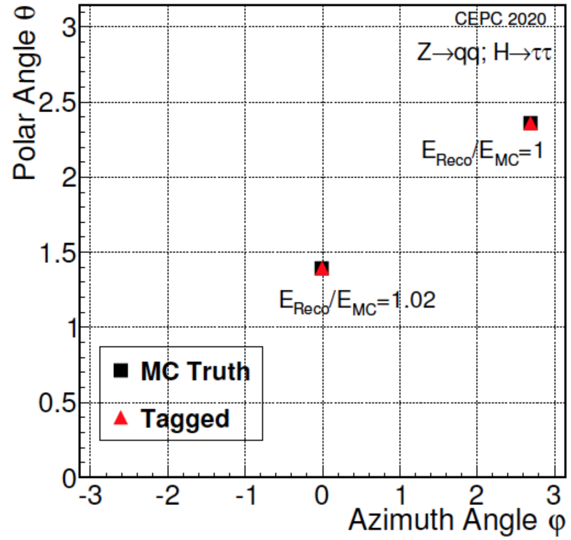


(c) $Z \to b\overline{b}, B_c \to \tau\nu$ with one hadronic dacay.

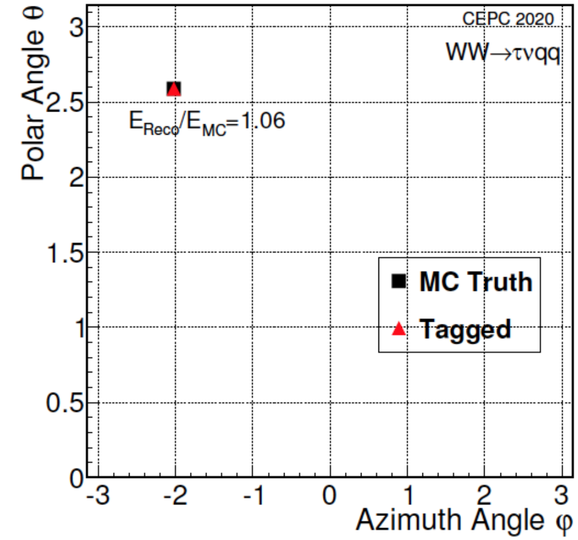


(d) $Z \to b\overline{b}, B_s \to \tau\tau$ with two hadronic decay mixed together.

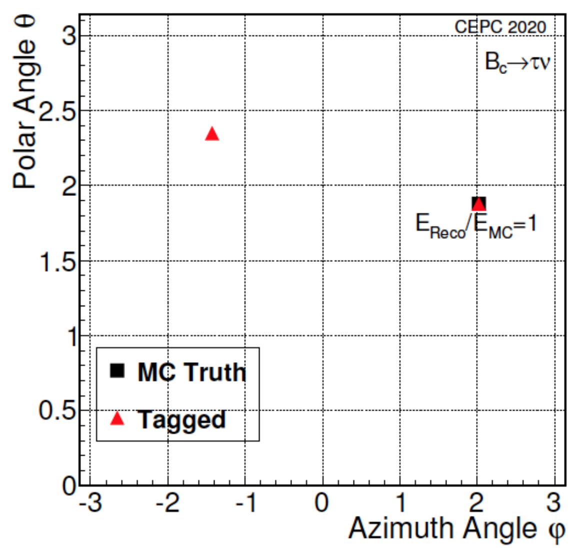




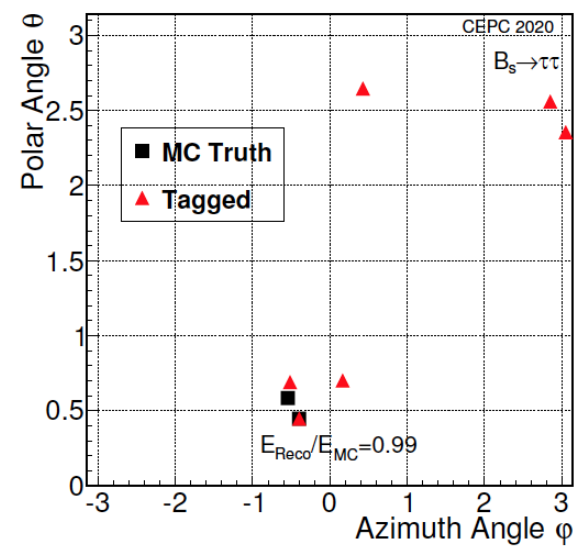
(a) $Z \rightarrow qq, H \rightarrow \tau\tau$, efficiency=1, purity=1



(b) $WW \rightarrow \tau\nu qq$, efficiency=1, purity=1

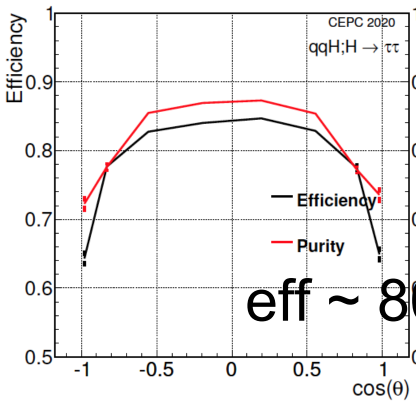


(c) $Z \rightarrow b\overline{b}, B_c \rightarrow \tau\nu$, efficiency=1, purity=0.5

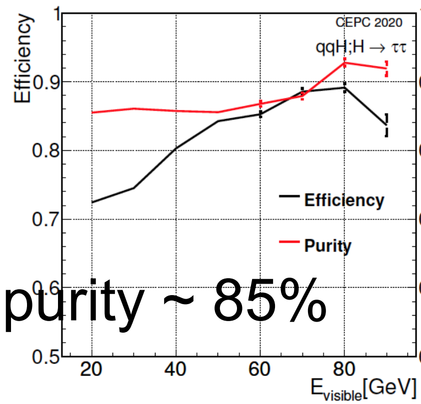


(d) $Z \rightarrow b\overline{b}, B_s \rightarrow \tau\tau$, efficiency=0.5, purity=0.167

Tau id

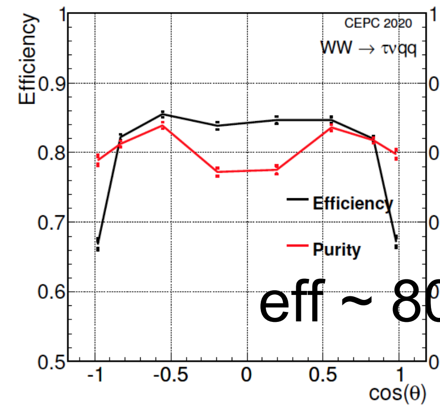


(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

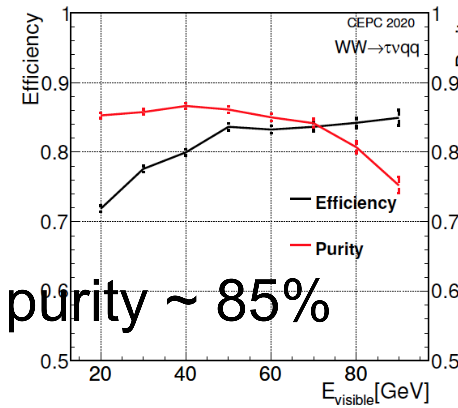


(b) Efficiency and purity performance along with visible energy. The performance above 80 GeV falls as a result of stringent cone selection.

eff ~ 80%, purity ~ 85%

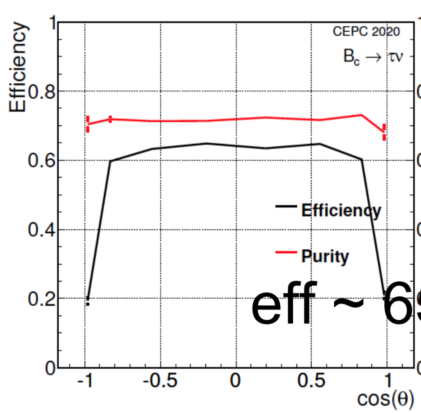


(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

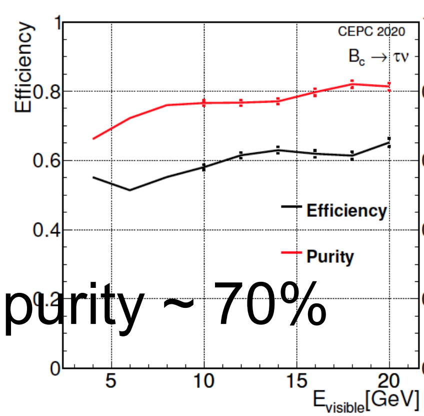


(b) Efficiency and purity performance along with visible energy

eff ~ 80%, purity ~ 85%

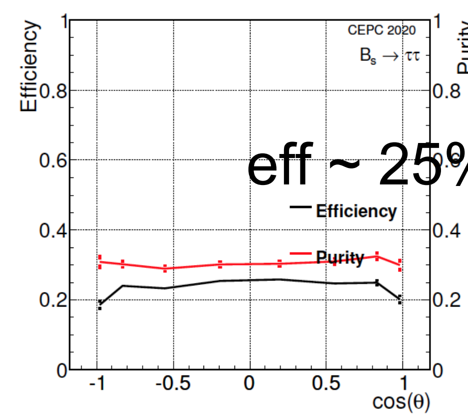


(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

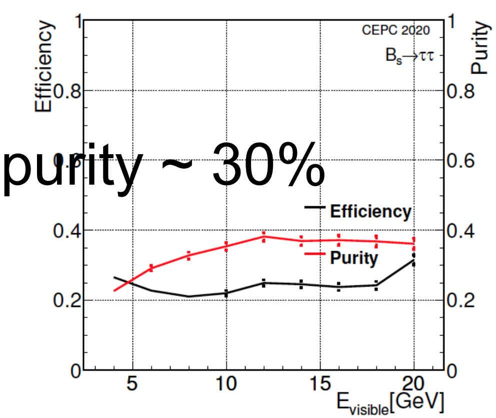


(b) Efficiency and purity performance along with visible energy

eff ~ 65%, purity ~ 70%



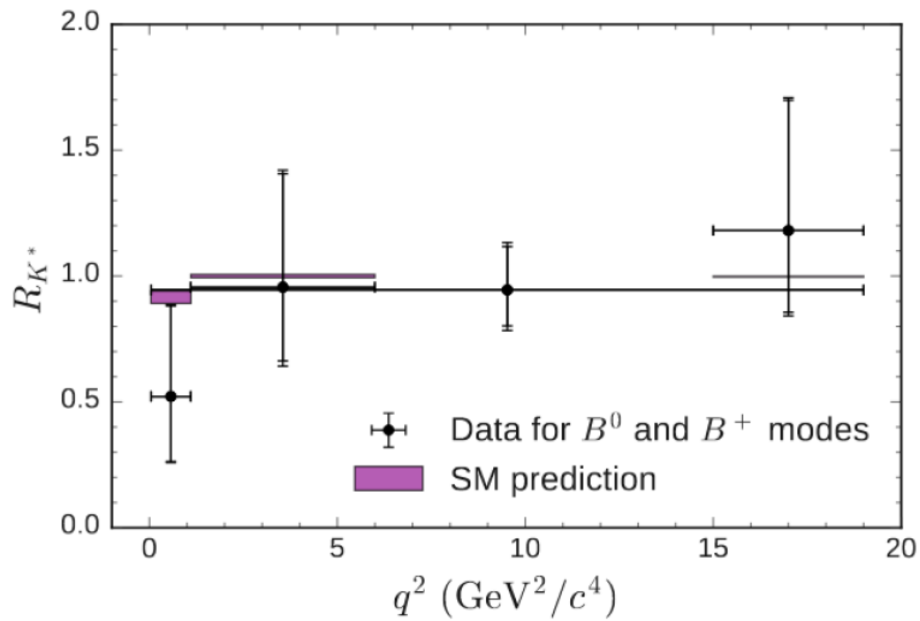
(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

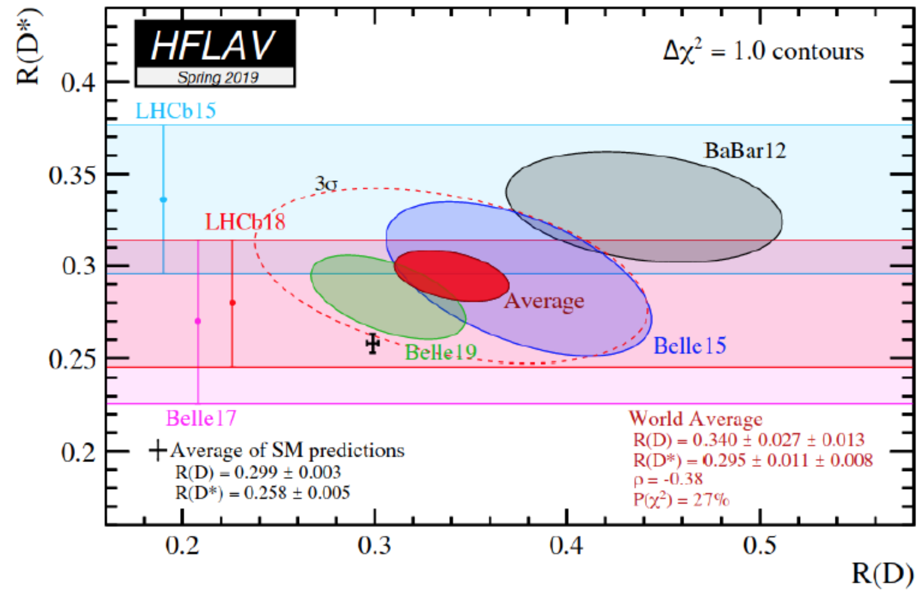


(b) Efficiency and purity performance along with visible energy

eff ~ 25%, purity ~ 30%

B Anomalies Indicating LFUV





	Experimental	SM Prediction	Comments
R_K	$0.745^{+0.090}_{-0.074} \pm 0.036$	1.00 ± 0.01	$m_{\ell\ell} \in [1.0, 6.0]$ GeV^2, via $B^{\pm}$.
R_{K^*}	$0.69^{+0.12}_{-0.09}$	0.996 ± 0.002	$m_{\ell\ell} \in [1.1, 6.0]$ GeV^2, via B^0.
R_D	0.340 ± 0.030	0.299 ± 0.003	B^0 and $B^{\pm}$ combined.
R_{D^*}	0.295 ± 0.014	0.258 ± 0.005	B^0 and $B^{\pm}$ combined.
$R_{J/\psi}$	$0.71 \pm 0.17 \pm 0.18$	0.25-0.28	

[Tanabashi et al., 2018][Altmannshofer et al., 2018].

Bs→Phi vv

https://arxiv.org/pdf/2201.07374.pdf

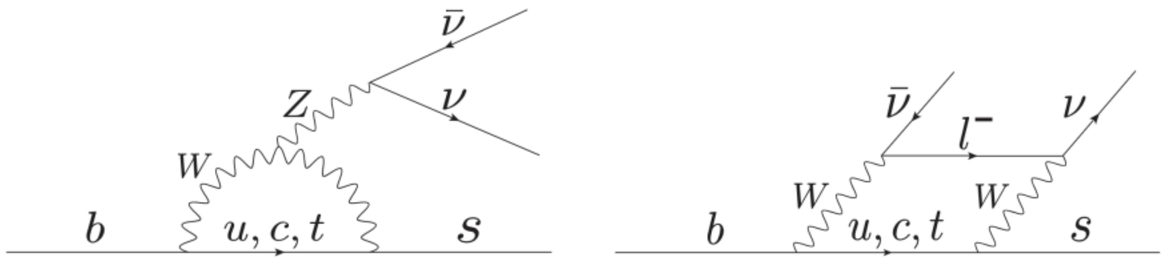
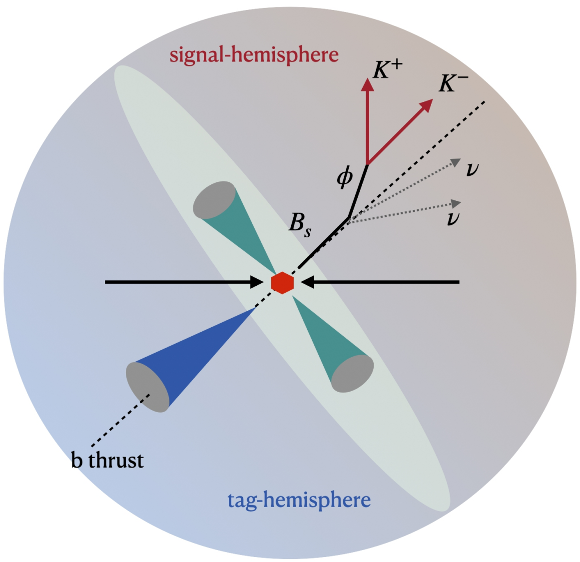
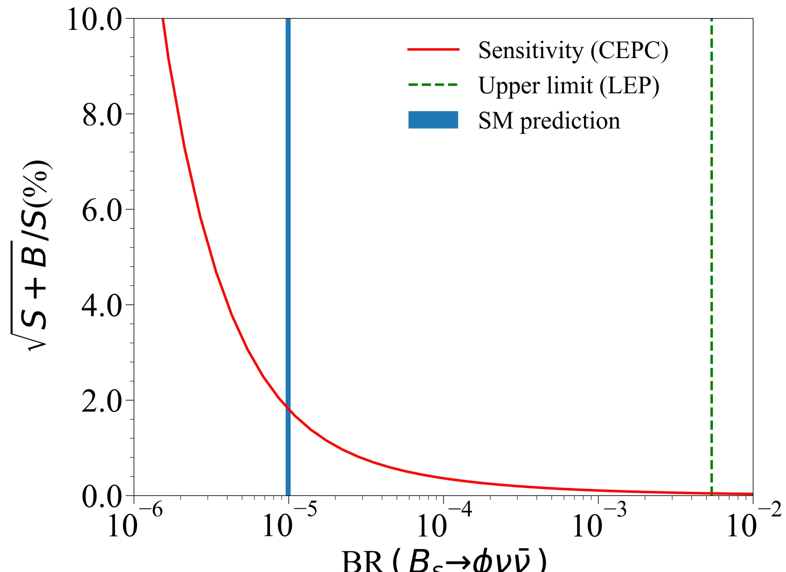


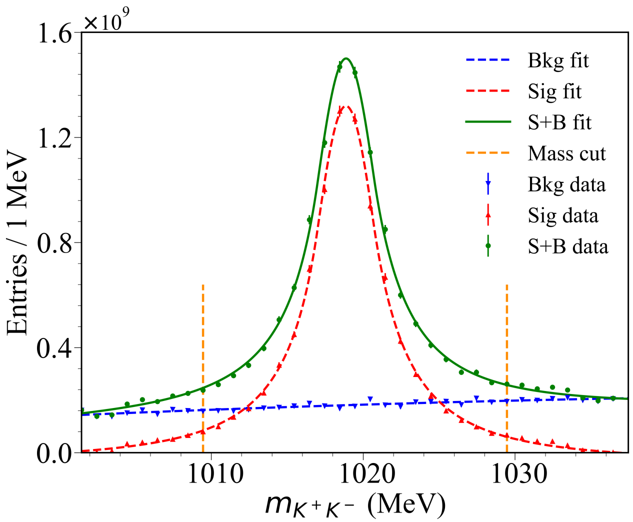
FIG. 1. The penguin and box diagrams of $b \to s\nu\bar{\nu}$ transition at the leading order.

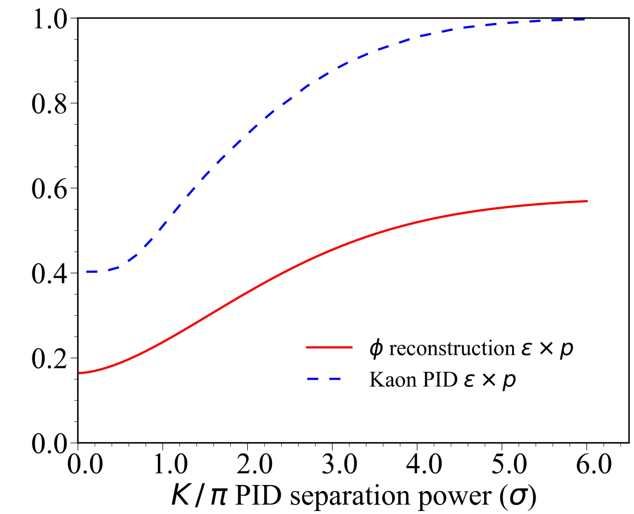


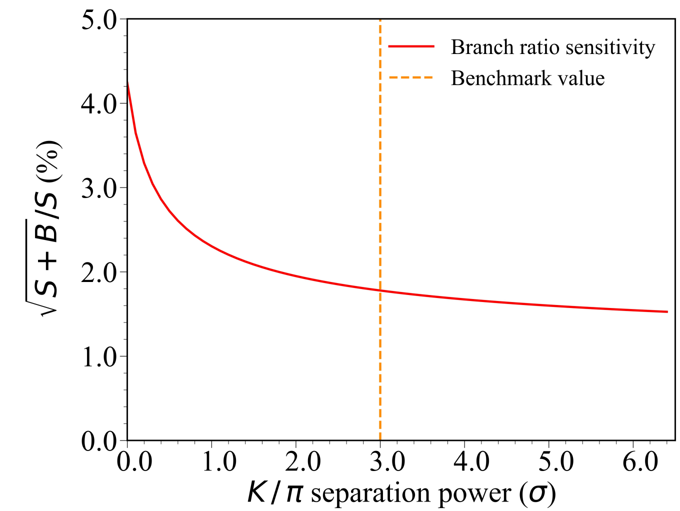
- Key ingredient to understand FCNC anomaly...
- Critical Physics Objects: Phi (and charged Kaon), 2nd VTX, Missing E/P, b-jet at opposite side
- Percentage level accuracy anticipated at Tera-Z

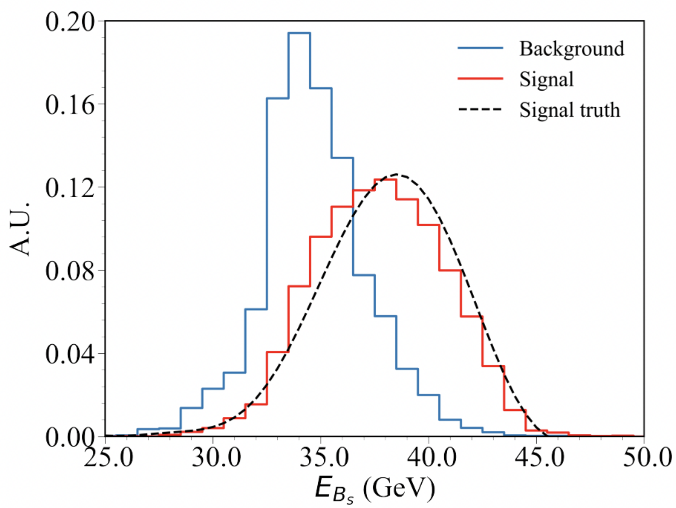


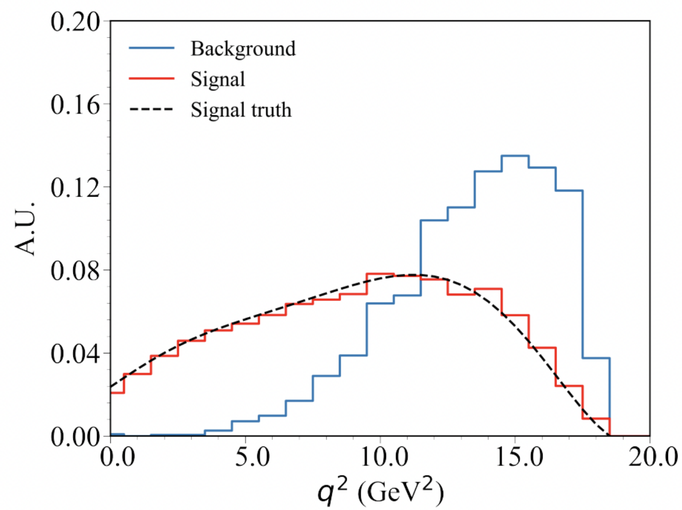
Bs→Phi vv











$$M_{\text{tag}} = \sqrt{\left(\sum p_{\text{tag}}^{\text{vis}}\right)^2}\,,$$

$$M_{\text{sig}}^{(i)} = \sqrt{\left(\sum p_{\text{sig}}^{\text{vis}} + p_{B_s}^{(i-1)} - p_\phi\right)^2}\,,$$

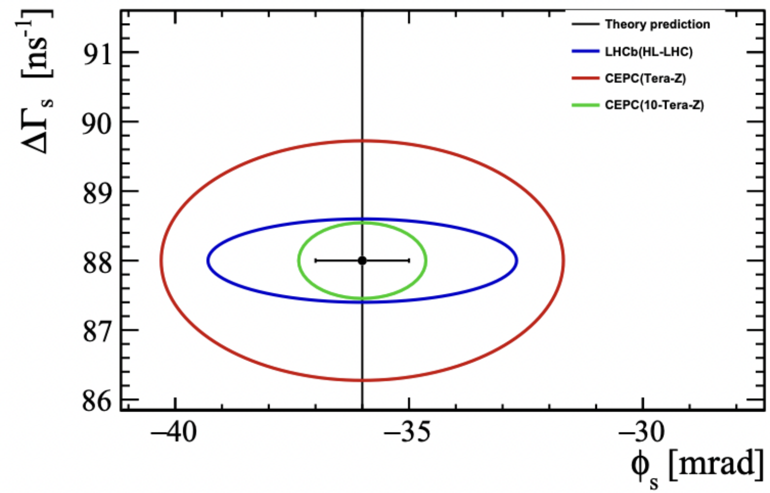
$$E_{B_s}^{(i)} = \frac{s + (M_{\text{sig}}^{(i-1)})^2 - M_{\text{tag}}^2}{2\sqrt{s}} - E_{\text{sig}} + E_\phi\,,$$

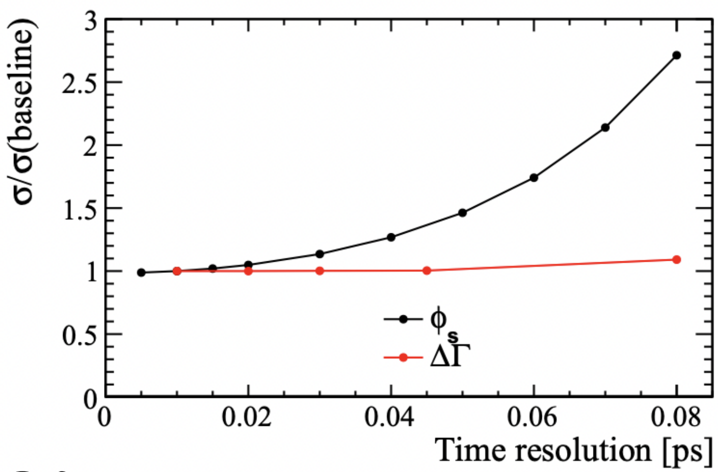
$$(q^2)^{(i)} = (p_{B_s}^{(i-1)} - p_\phi)^2\,,$$

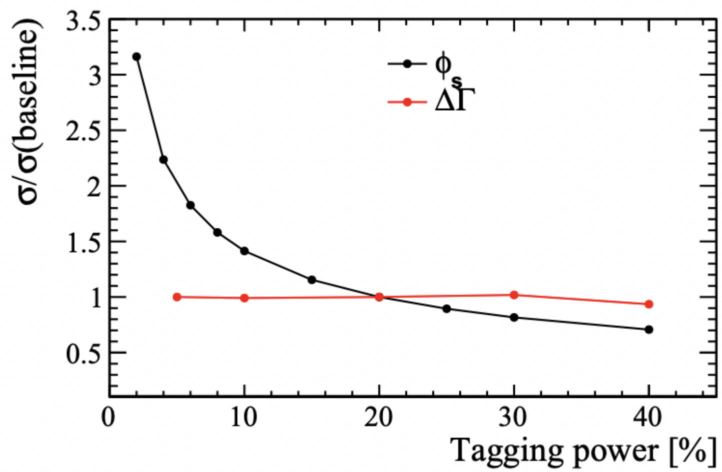
The separation power is defined as $2|\mu_\pi - \mu_K|/(\sigma_\pi + \sigma_K)$. Without loss of generality, we set $\sigma_\pi = \sigma_K$. Com-

Bs→Jpsi/Phi

	LHCb(HL-LHC)	CEPC(Tera-Z)	CEPC/LHCb
$b\bar{b}$ statics	43.2×10^{12}	0.152×10^{12}	1/284
Acceptance×efficiency	7%	75%	10.7
Br	6×10^{-6}	12×10^{-6}	2
Flavour tagging	4.7%	20%	4.3
Time resolution $(\exp(-\frac{1}{2}\Delta m_s^2 \sigma_t^{2\,2})$	0.52	1	1.92
scaling factor ξ	0.0014	0.0019	0.8
$\sigma(\phi_s)$	3.3 mrad	4.3 mrad	





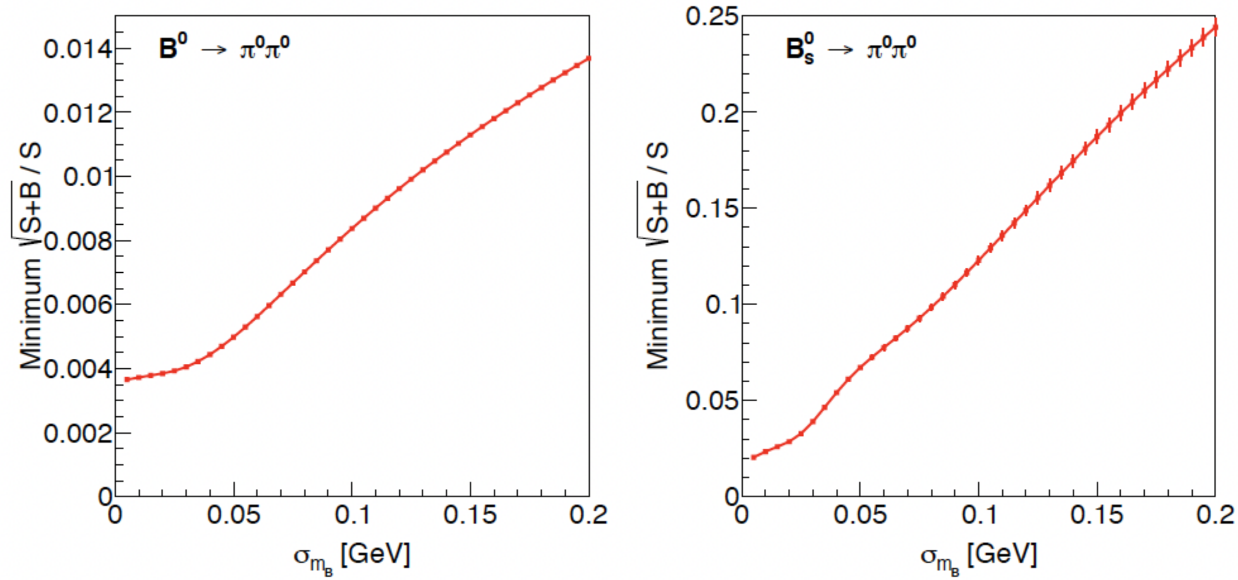


Preliminary...

$B_s/B^0 \rightarrow 2$ pi0/eta

Preliminary...

$$A_{CP}\ (or\ C^{00}_{\pi\pi}) = \frac{\Gamma(B^0 \to \pi^0\pi^0) - \Gamma(\bar{B}^0 \to \pi^0\pi^0)}{\Gamma(B^0 \to \pi^0\pi^0) + \Gamma(\bar{B}^0 \to \pi^0\pi^0)}$$



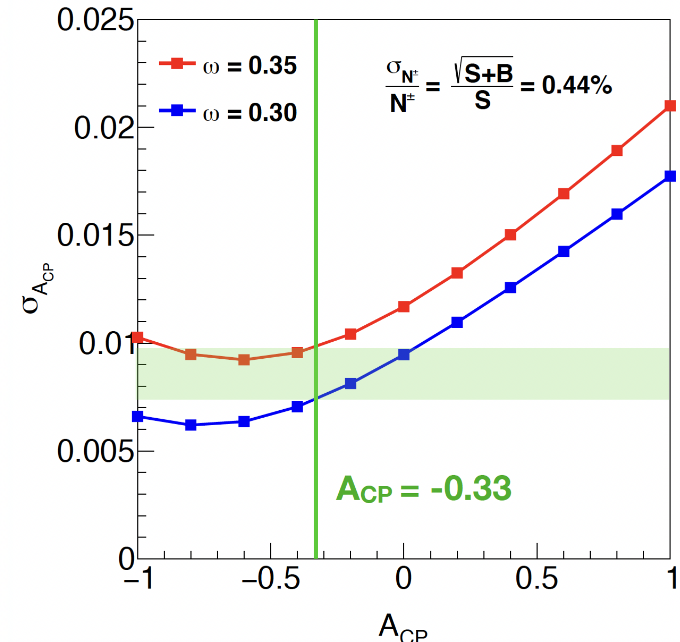
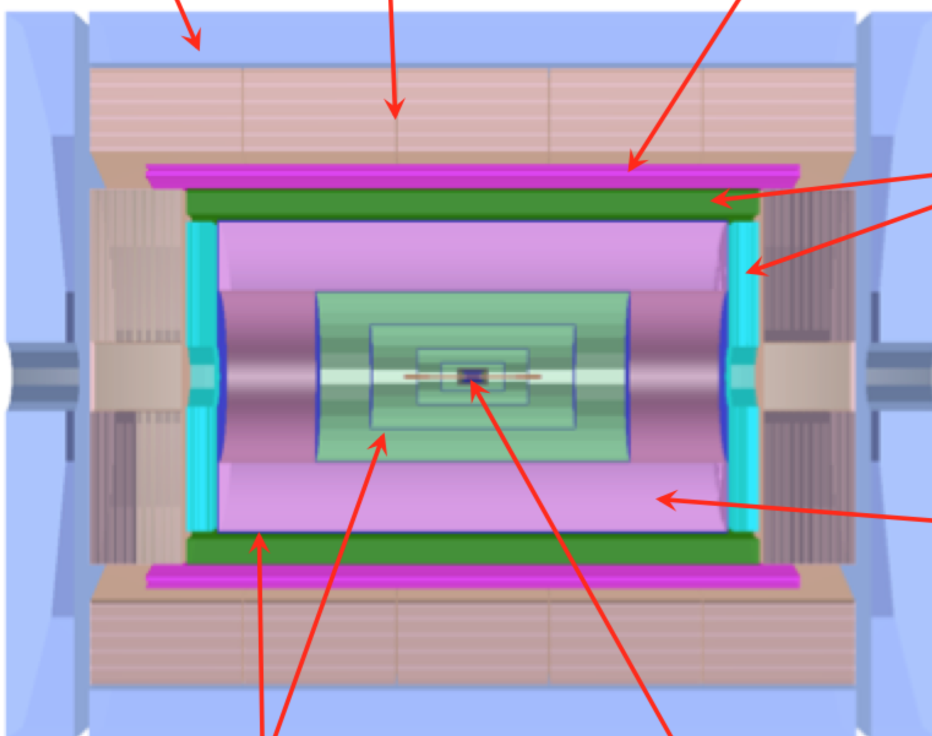


Figure 12: Accuracy of $B^0 \to \pi^0\pi^0$ (left) and $B_s^0 \to \pi^0\pi^0$ (right) versus B mass resolution.

- Provide sub percentage level accuracies on B0->2 pi0, 40/5 times than current world average & Belle II anticipation, have a strong impact on the CKM angle (alpha measurements), discover the other three modes for the 1st time.
- Strongly Depends on the b-tagging performance (ILD is good enough) and the ECAL intrinsic resolution (provide 30 MeV mass resolution for B-meson... 5 times better than ILD ECAL)

The 4th Conceptual Detector Design



Advantage: the HCAL absorbers act as part of the magnet return yoke.

Challenges: thin enough not to affect the jet resolution (e.g. BMR); stability.

Transverse Crystal bar ECAL

Advantage: better π^0/γ reconstruction.

Challenges: minimum number of readout channels; compatible with PFA calorimeter; maintain good jet resolution.

Drift chamber that is optimized for PID

Advantage: Work at high luminosity Z runs

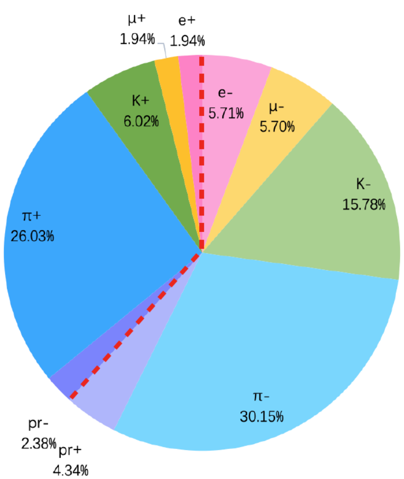
Challenges: sufficient PID power; thin enough not to affect the moment resolution.

6

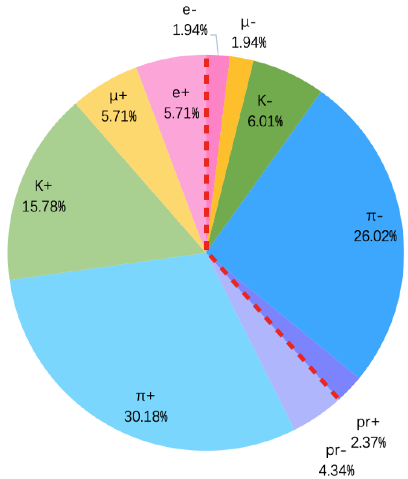
+ innovative software system...

Jet charge

$Z \to b\bar{b}$ Percent of final charged leading particles of b jet and $\bar{b}$ jet



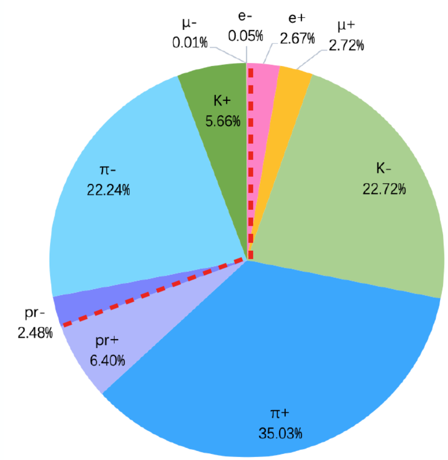
b jet



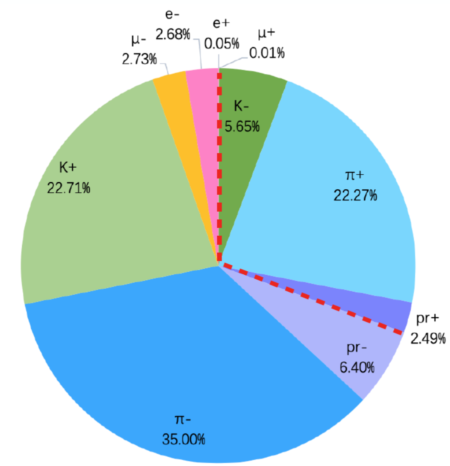
$\bar{b}$ jet

☞ *The distribution of each charged particle of two jets is asymmetry*

$Z \to c\bar{c}$ Percent of final charged leading particles of c jet and $\bar{c}$ jet



c jet



$\bar{c}$ jet

☞ *The distribution of each charged particle of two jets is asymmetry*

percent bbar jet → b jet ↓	B^0	B^+	B_s^0	B_c^+	$\Lambda_b$bar	others	all
B^0bar	17.360%	17.350%	3.369%	0.022%	2.759%	0.688%	41.548%
B^-	17.350%	17.359%	3.364%	0.022%	2.765%	0.689%	41.550%
B_s^0bar	3.355%	3.362%	0.652%	0.004%	0.545%	0.144%	8.062%
B_c^-	0.022%	0.022%	0.004%	0.00003%	0.004%	0.001%	0.052%
Λ_b	2.762%	2.762%	0.543%	0.004%	0.451%	0.121%	6.644%
others	0.653%	0.655%	0.136%	0.001%	0.119%	0.579%	2.144%
all	41.503%	41.511%	8.068%	0.053%	6.641%	2.225%	100%

... we understand how the jet charge information eventually incarnated into Leading final state particles...