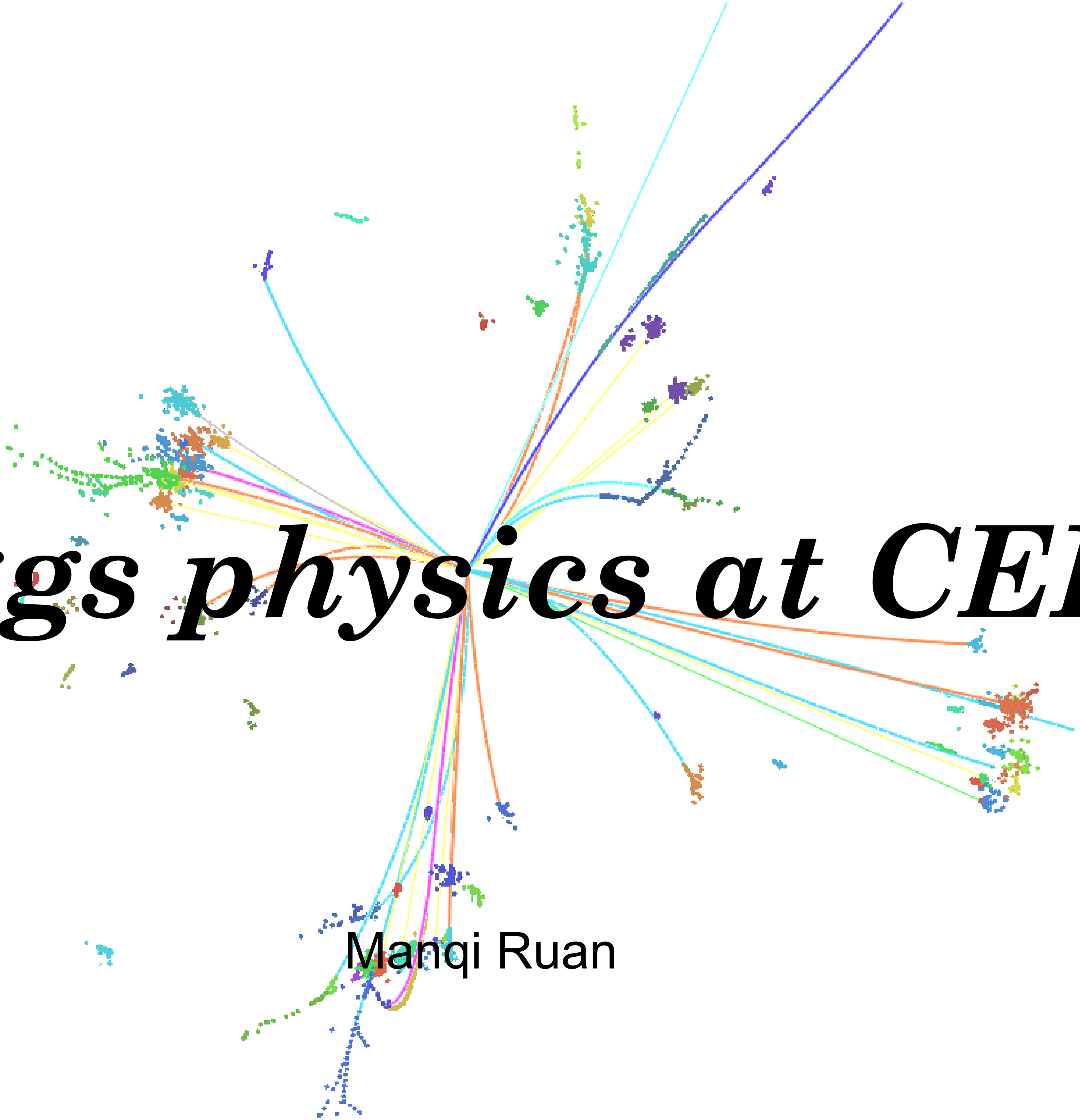
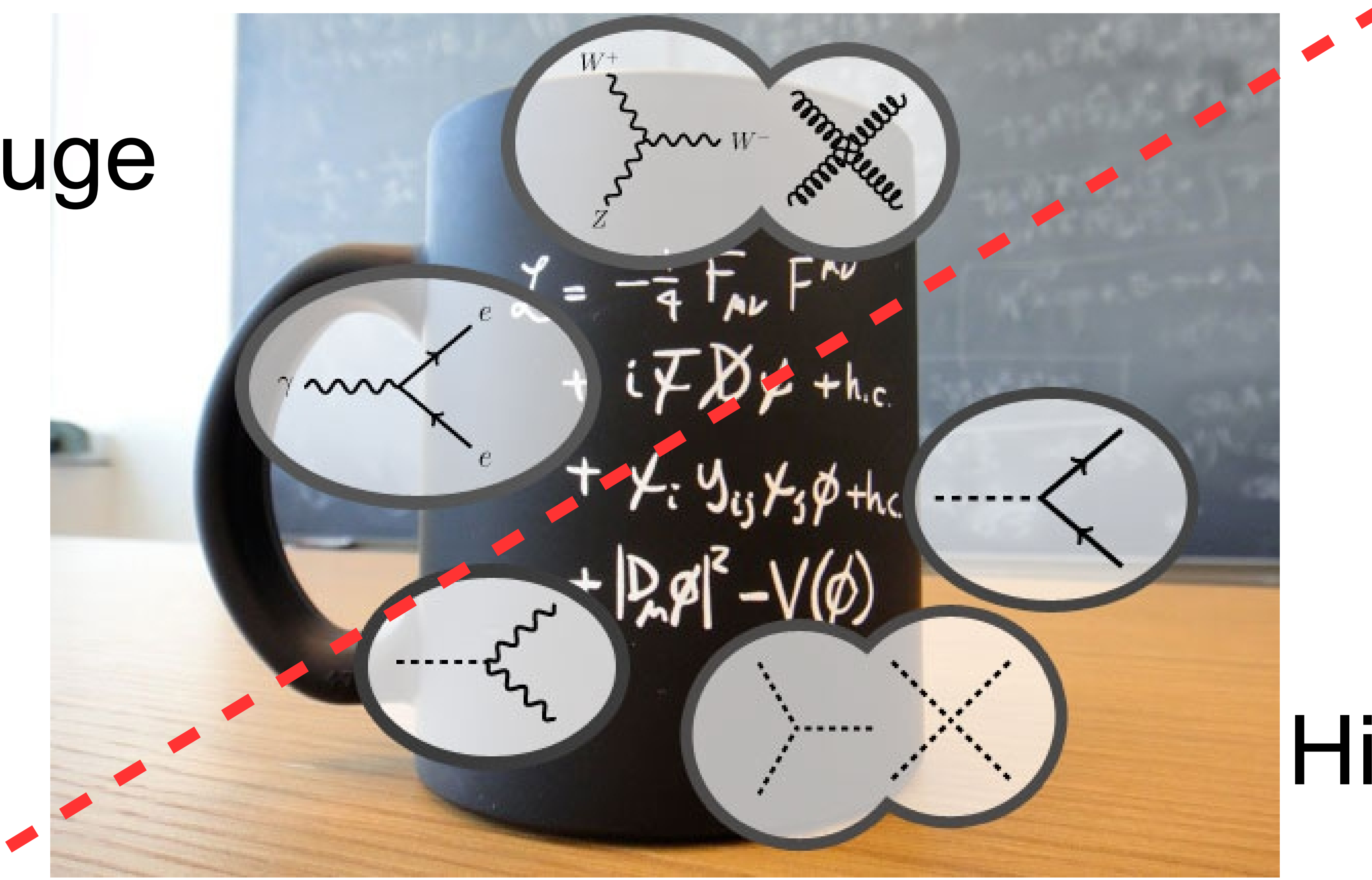
Higgs physics at CEPC



Manqi Ruan

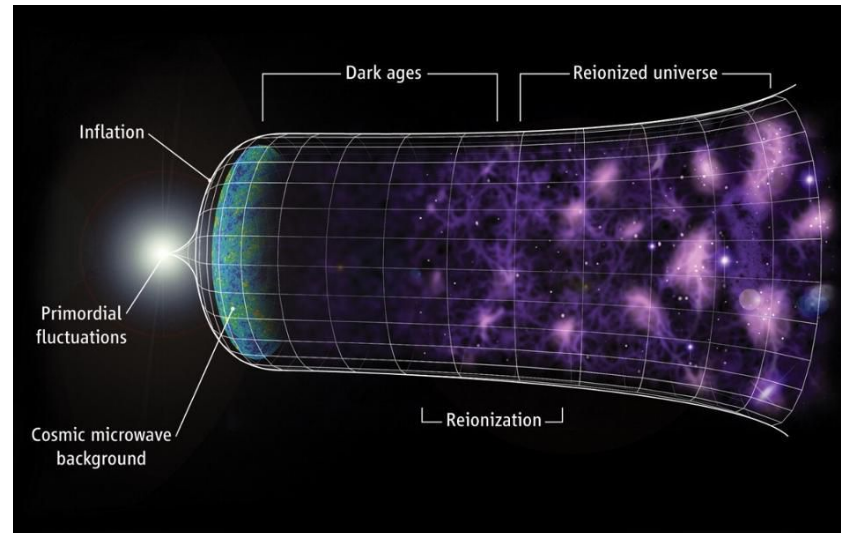
The Higgs field: one of the two pillars of the SM

Gauge



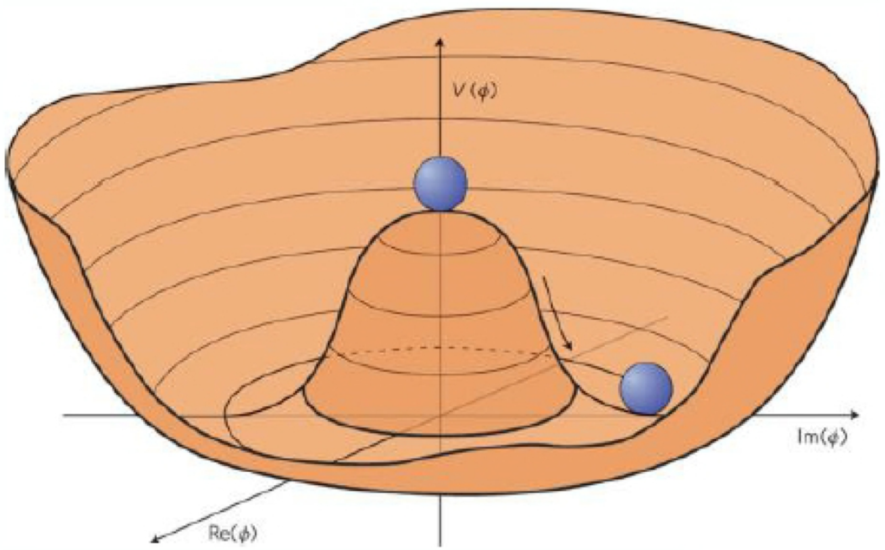
Higgs

Known Unknowns of the SM



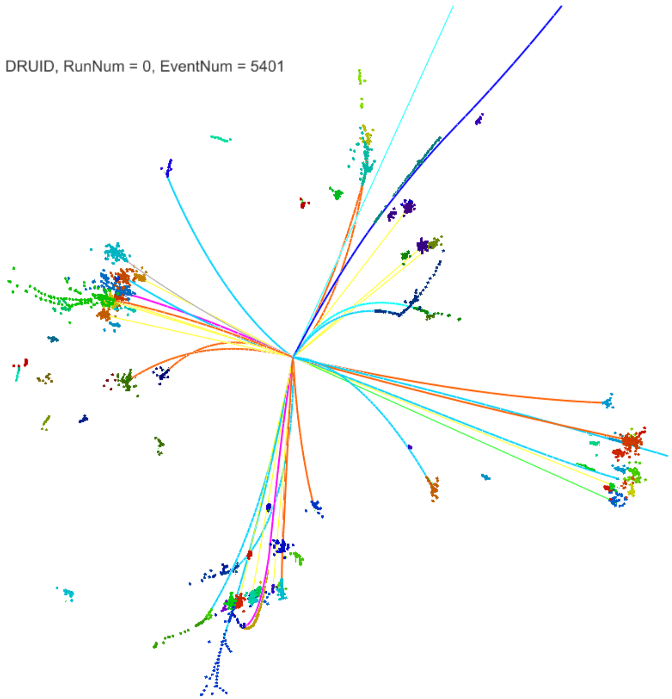
- Inflation
- Mass hierarchy
- Neutrino mass & Oscillation
- Matter anti-matter asymmetry
- Vacuum stabilities: depends on particle mass
- Dark matter, Dark energy: nature & origin of its/their mass
- Naturalness: EW (Higgs mass) V.S. Planck scale
- ...

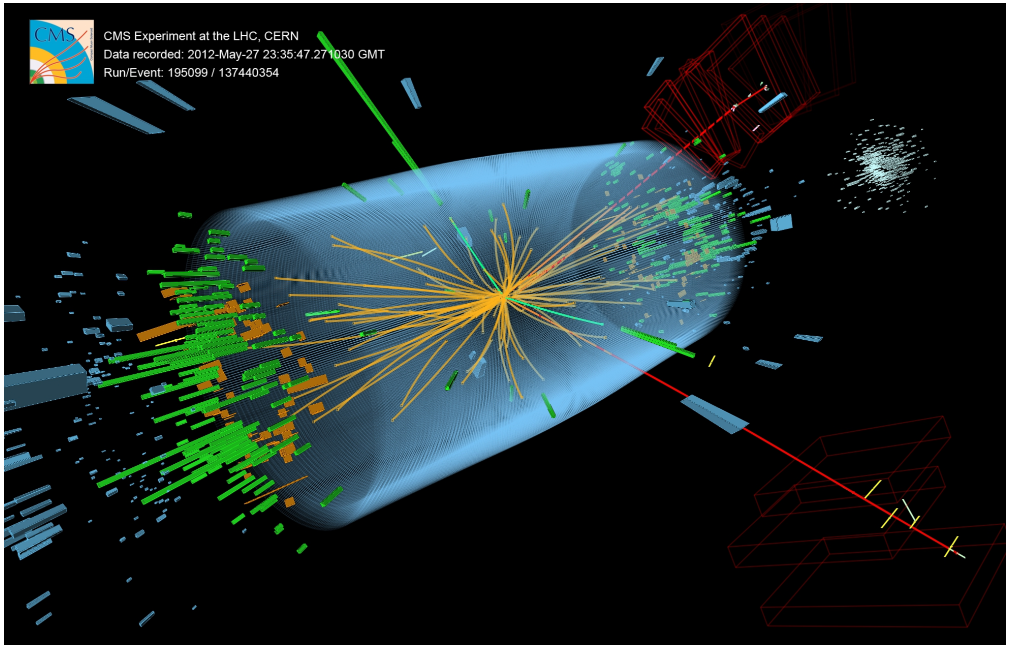
Known Unknowns of the SM



- The Clue:
- 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
- …

Higgs measurement at e+e- & pp





	Yield	efficiency	Comments
LHC	Run 1: 10^6 Run 2/HL: $10^{7\text{-}8}$	~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

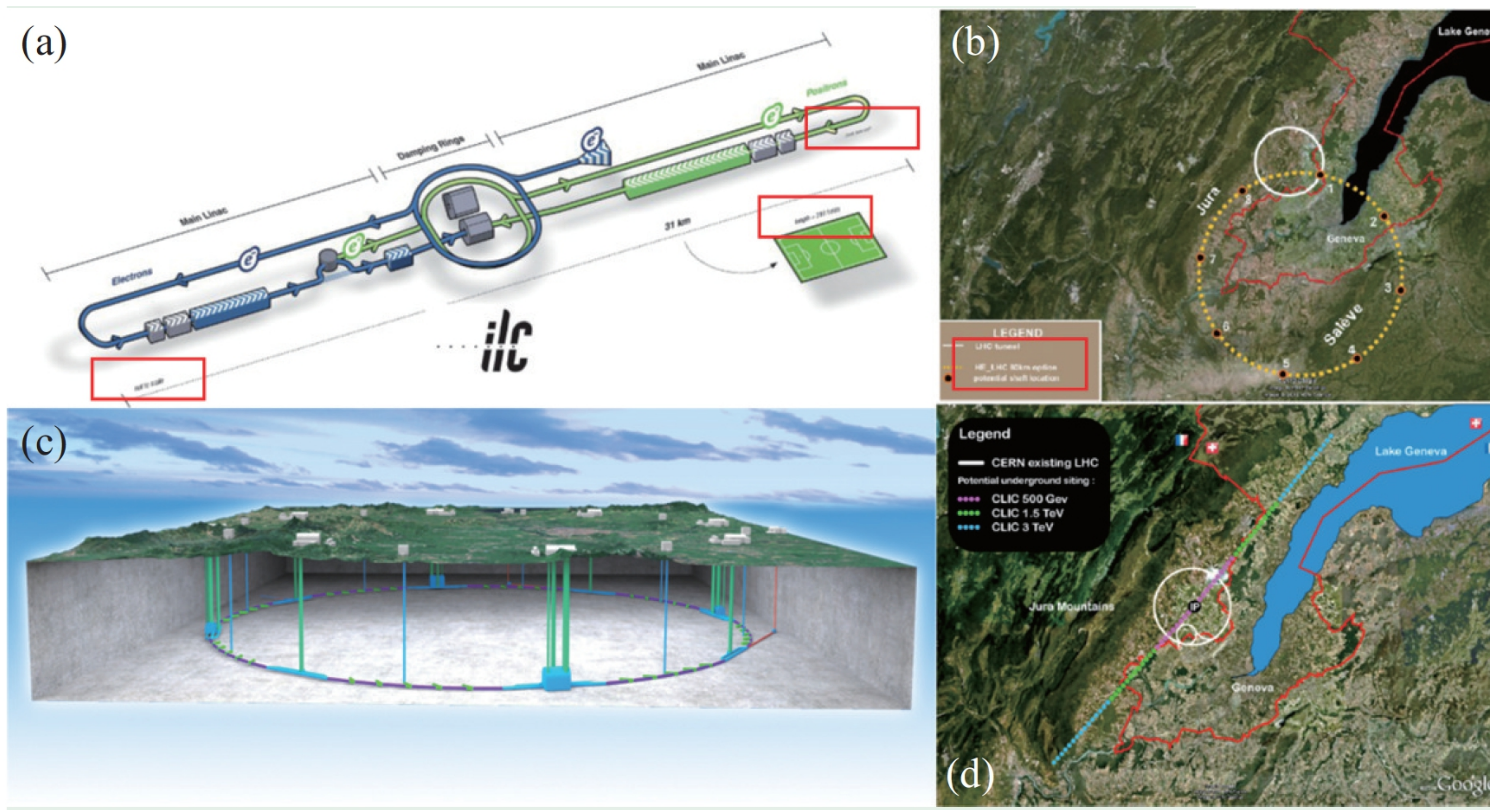
Complementary

Electron Positron Higgs factories

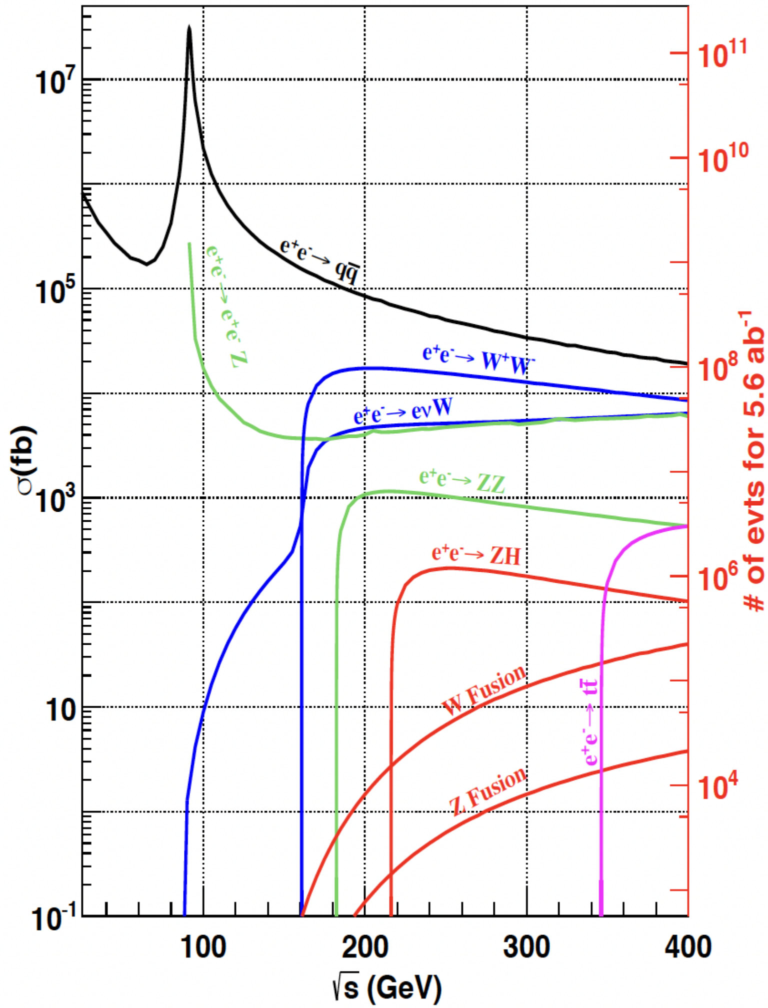
High-priority future initiatives

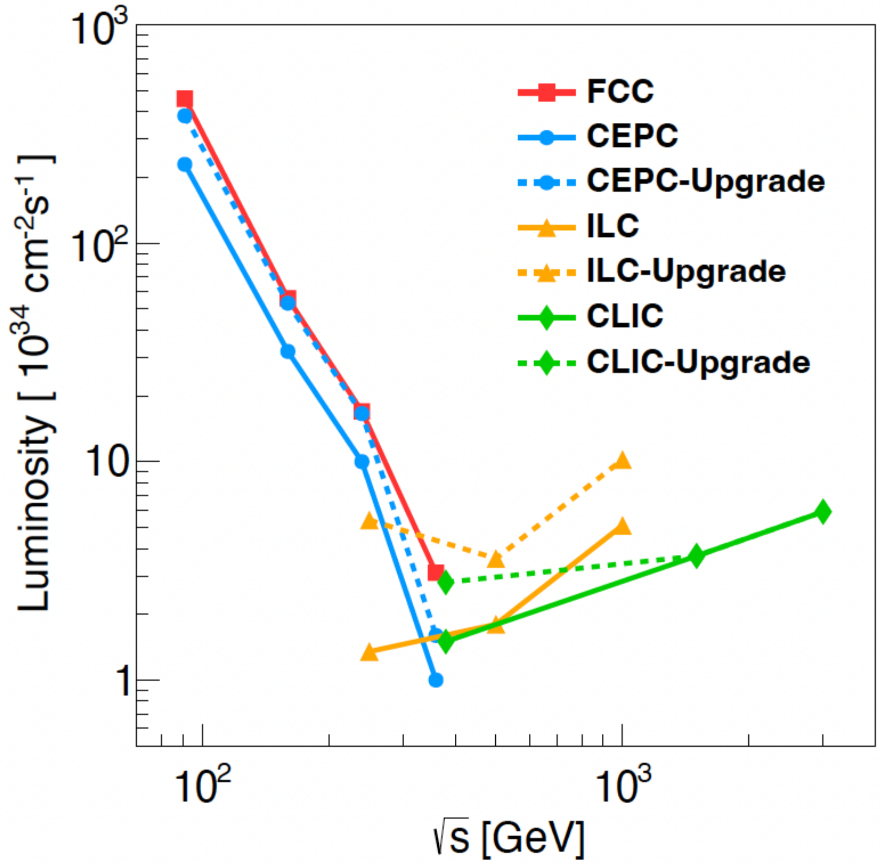
An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

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



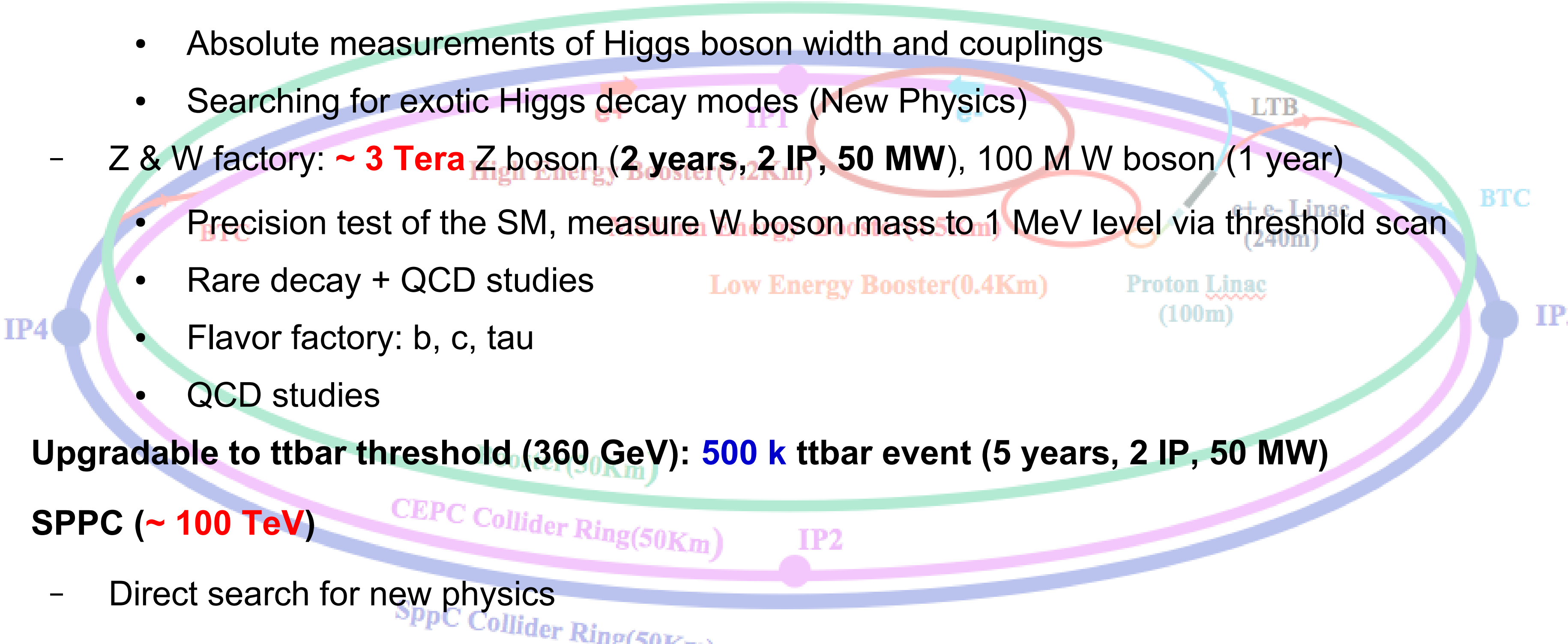
Yields ~ Xsec * Lumi





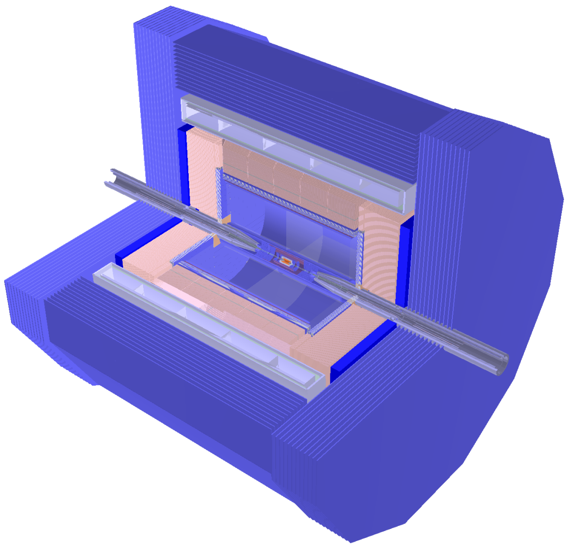
Yields of the CEPC

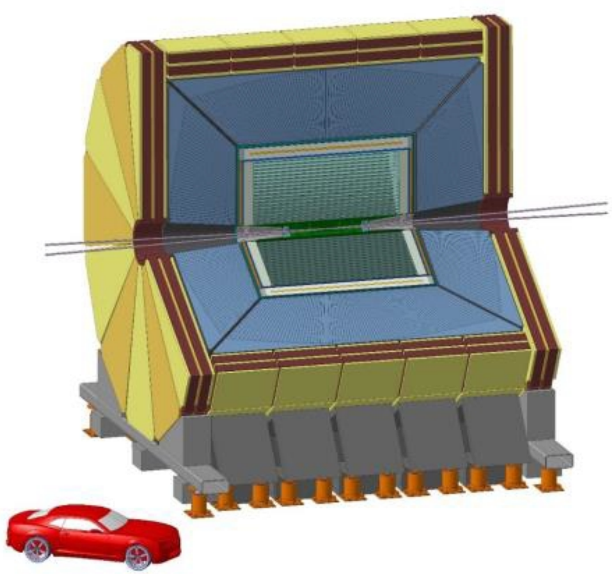
- **Tunnel ~ 100 km，** baseline SR Power/beam **30 MW**, upgradable to **50 MW**
- **CEPC (90 – 240 GeV)**
  - Higgs factory: **4M** Higgs boson (**10 years, 2 IP, 50 MW**)
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & 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...**

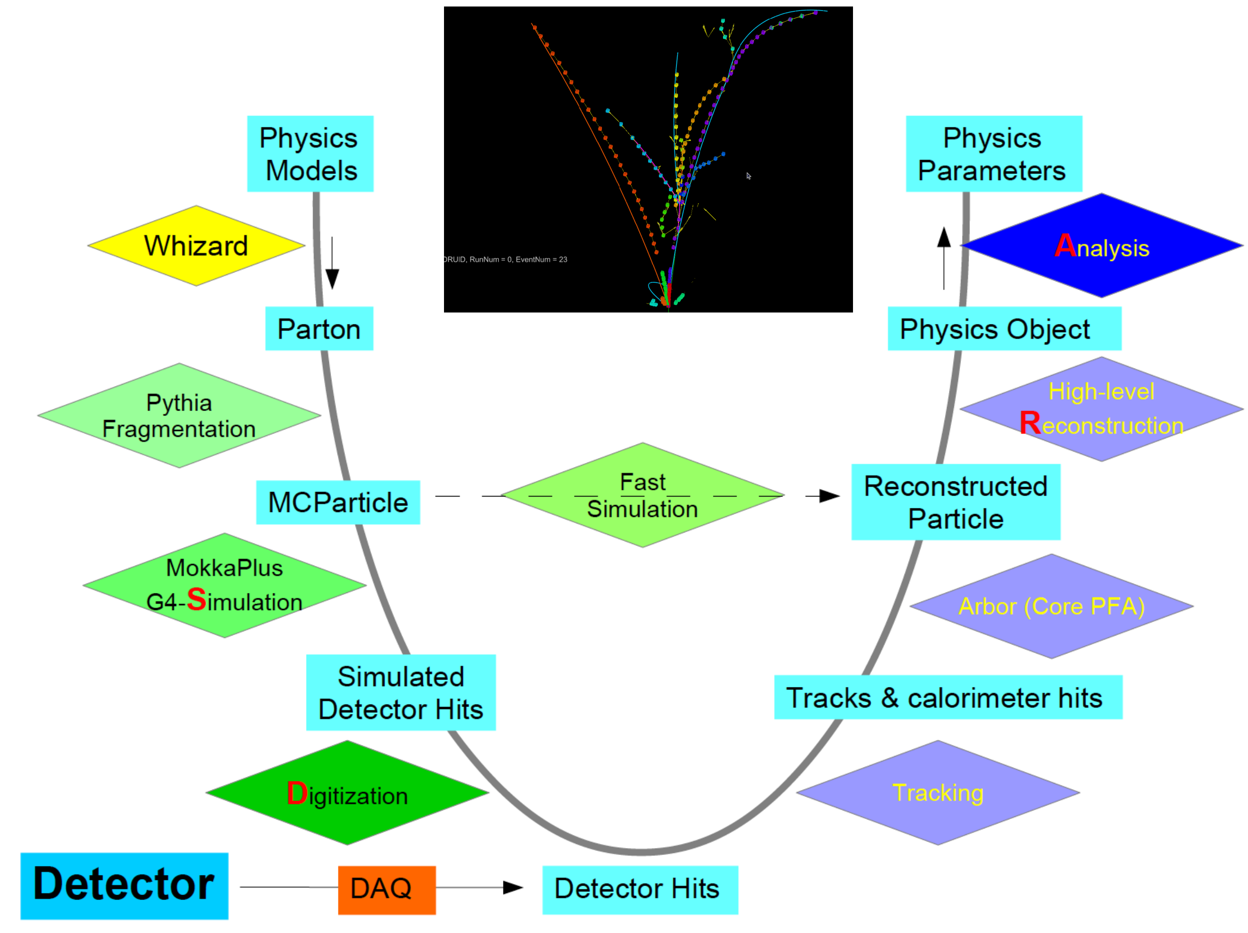


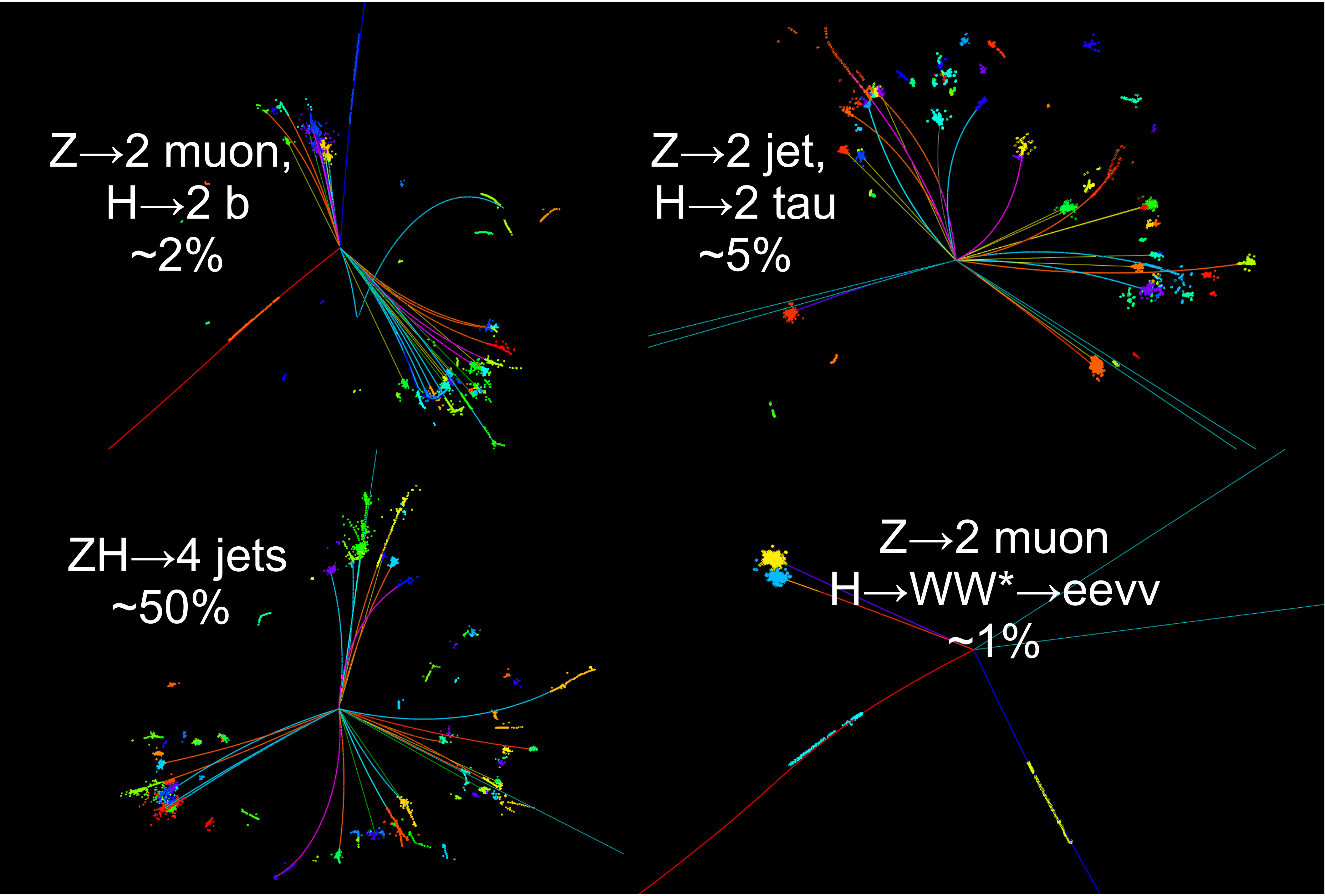
See also: 2205.08553

Detector & Software

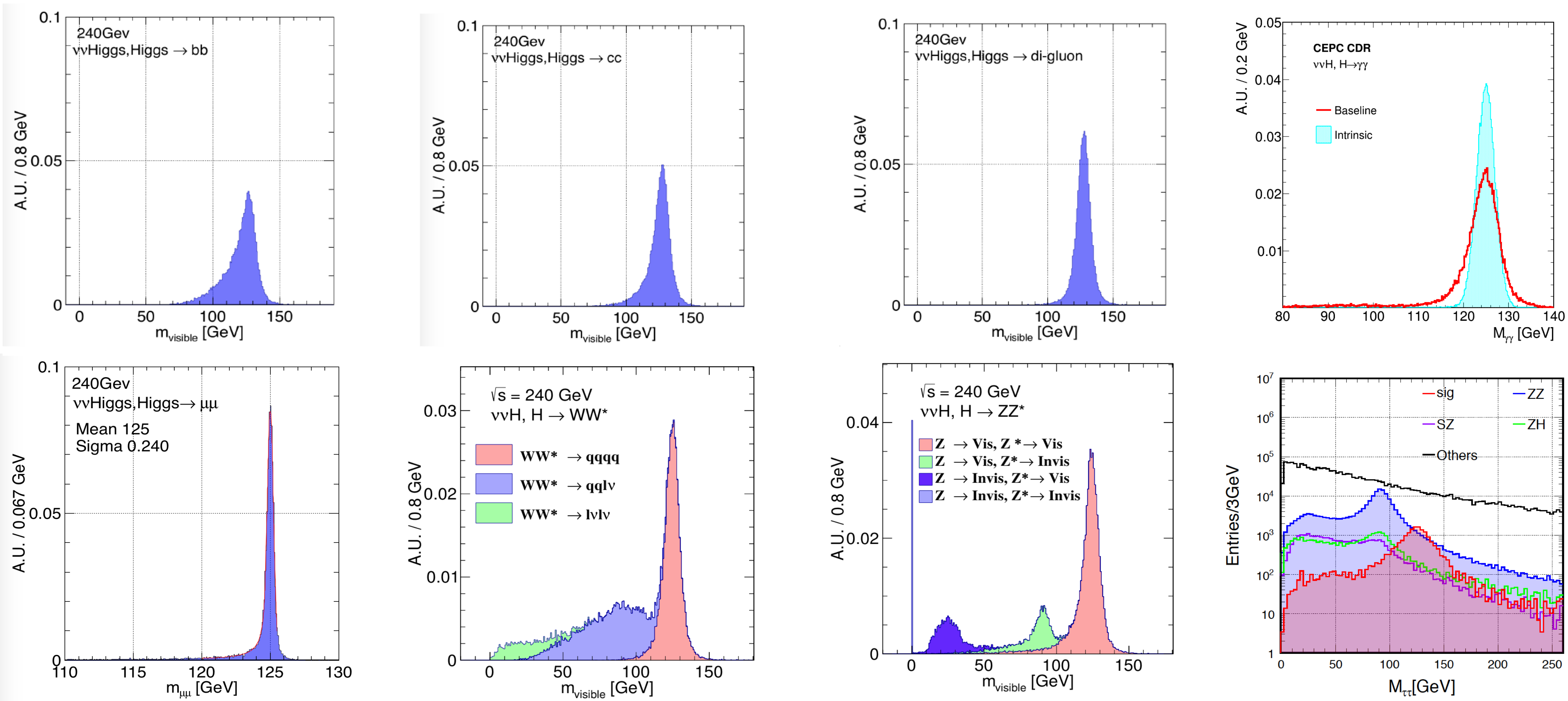







Z→2 muon,
H→2 b
~2%
Z→2 jet,
H→2 tau
~5%
ZH→4 jets
~50%
Z→2 muon
H→WW*→eeνν
~1%

Reconstructed Higgs Signatures



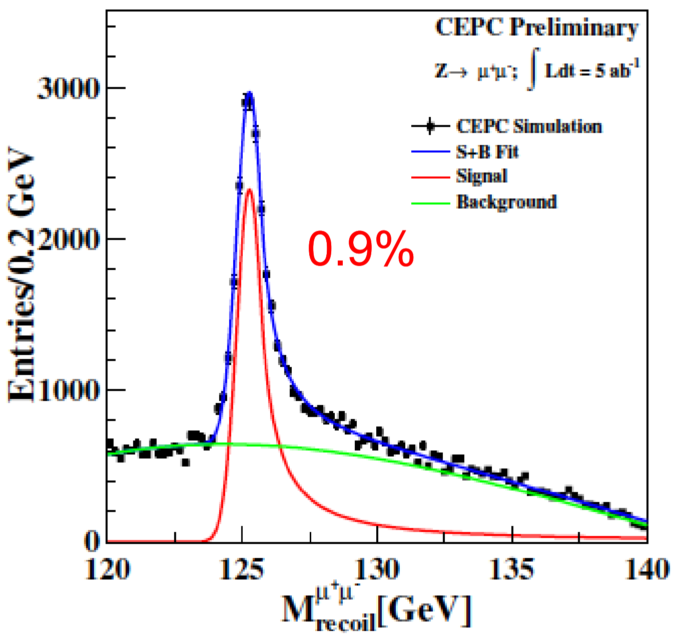
Clear Higgs Signature in all SM decay modes

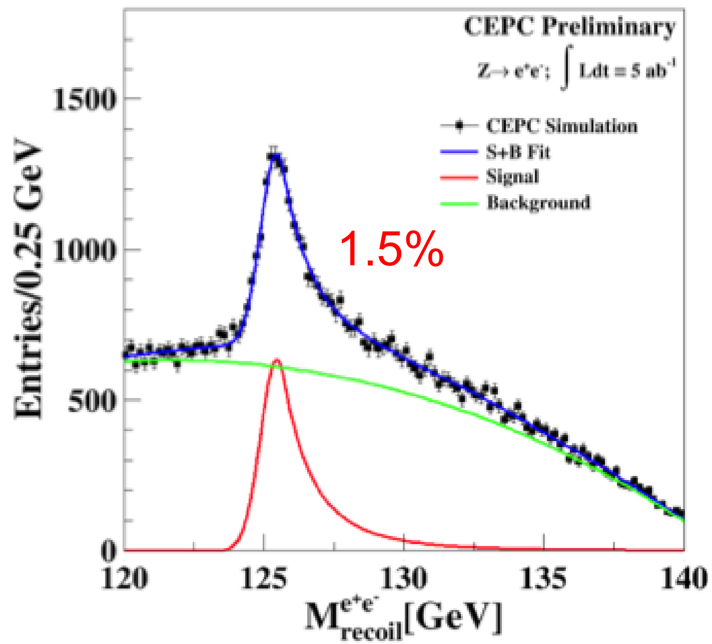
Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

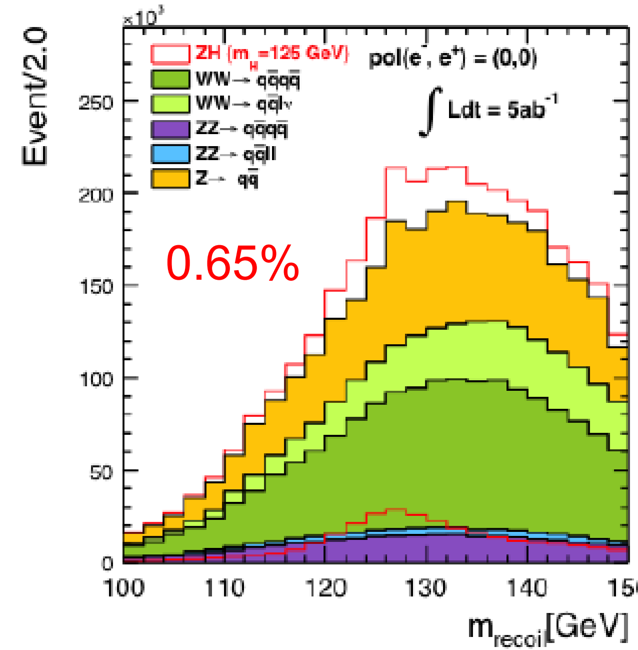
Right corner: di-tau mass distribution at qqH events using collinear approximation

Model-independent measurement of σ(ZH)

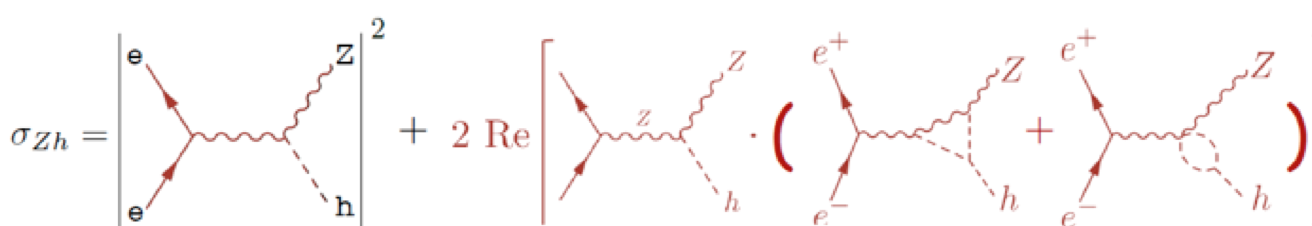
Zhenxing Chen & Yacine Haddad







- 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

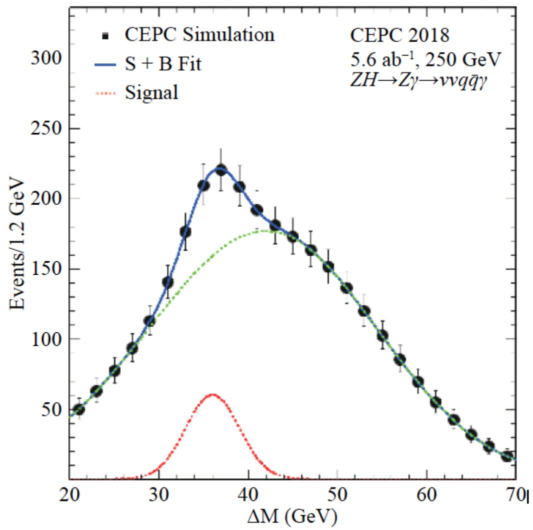
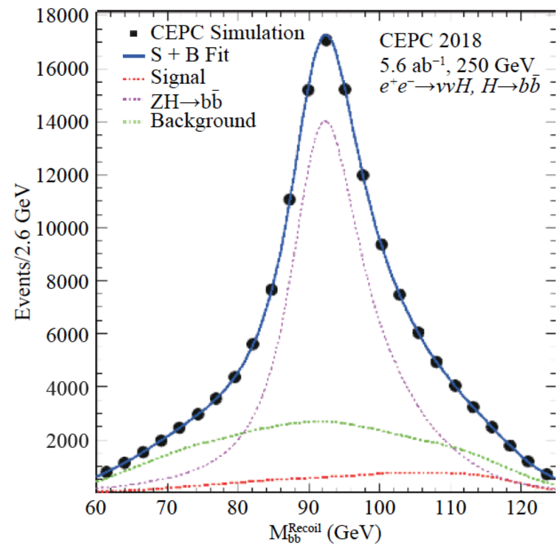
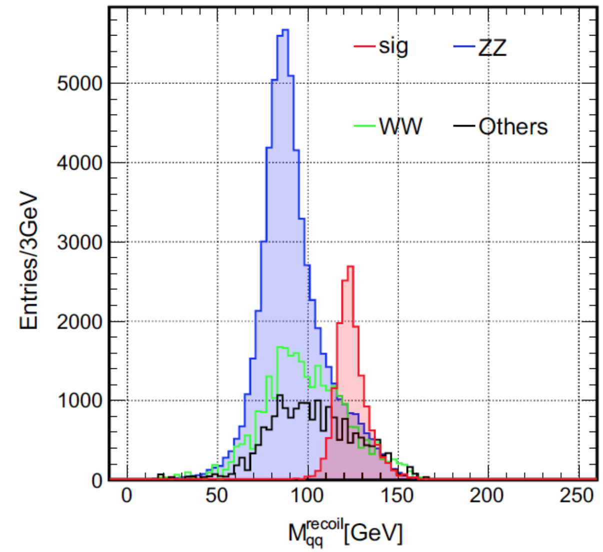
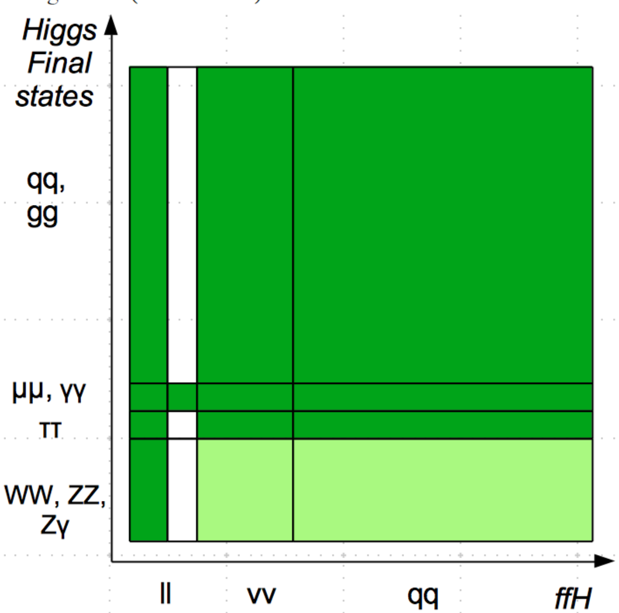
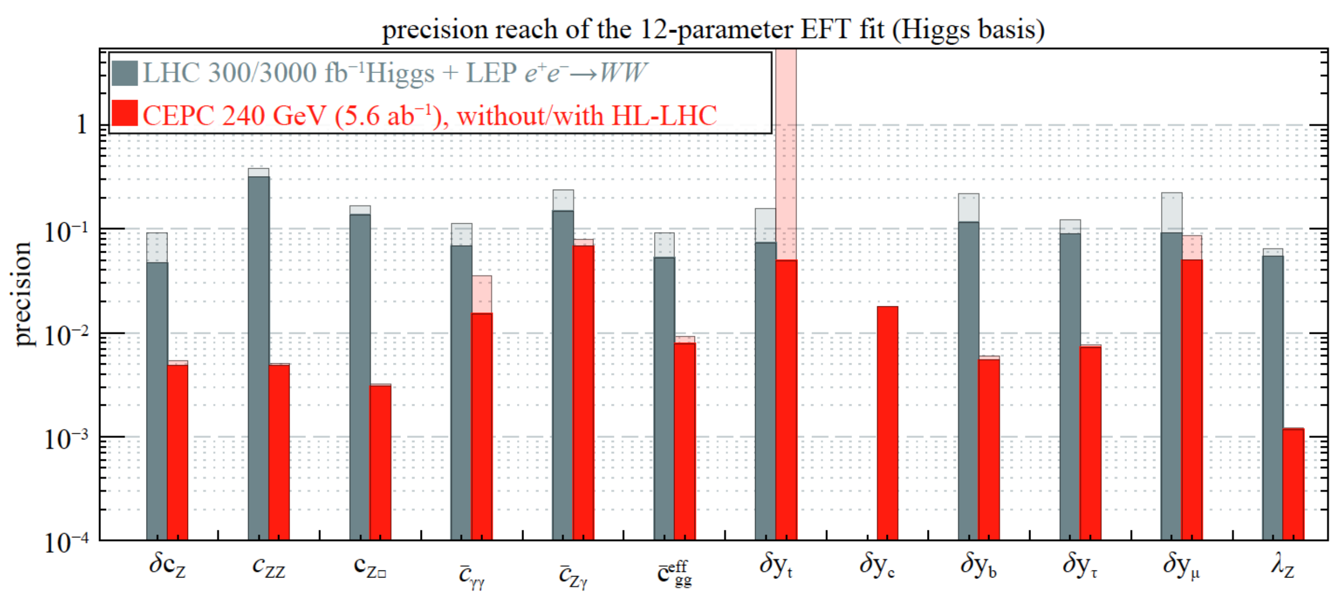


Fig. 15. (color online) The distribution of the mass differ-

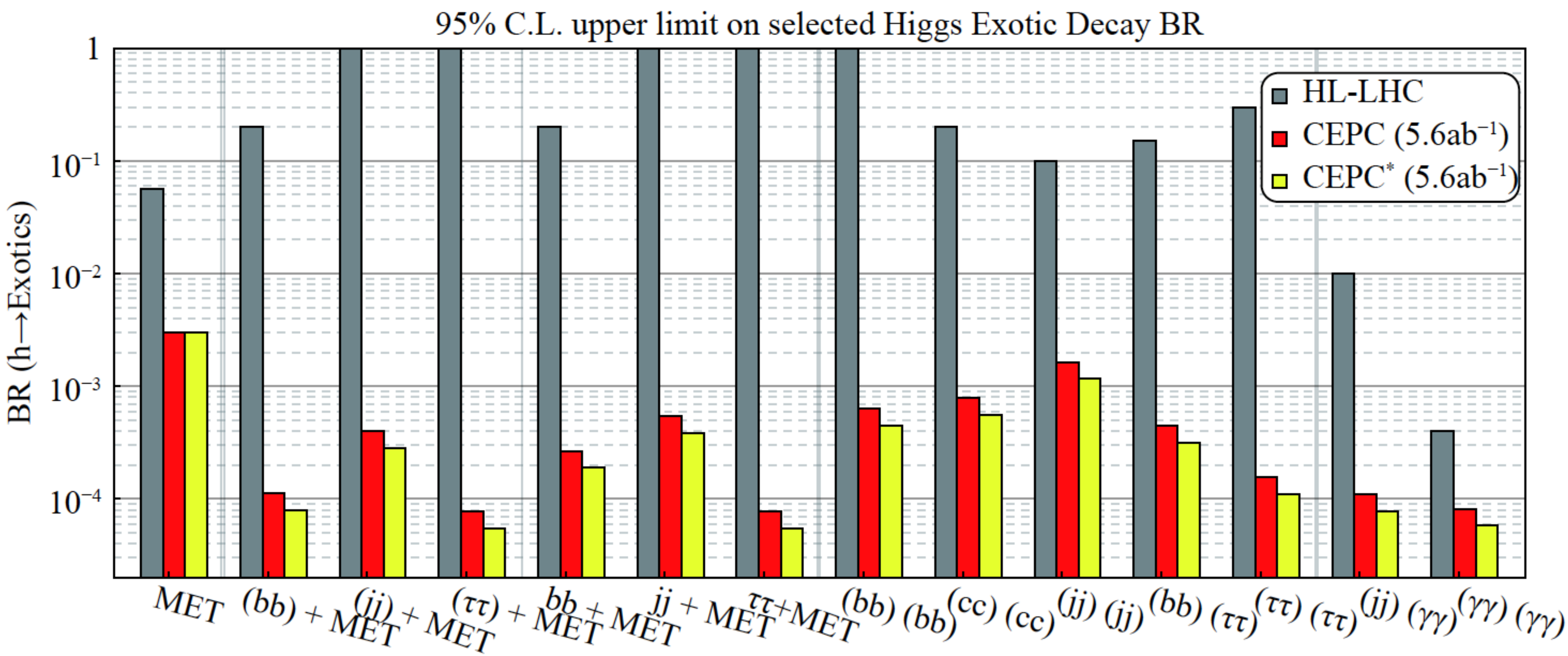








Higgs BSM Decay modes



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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%

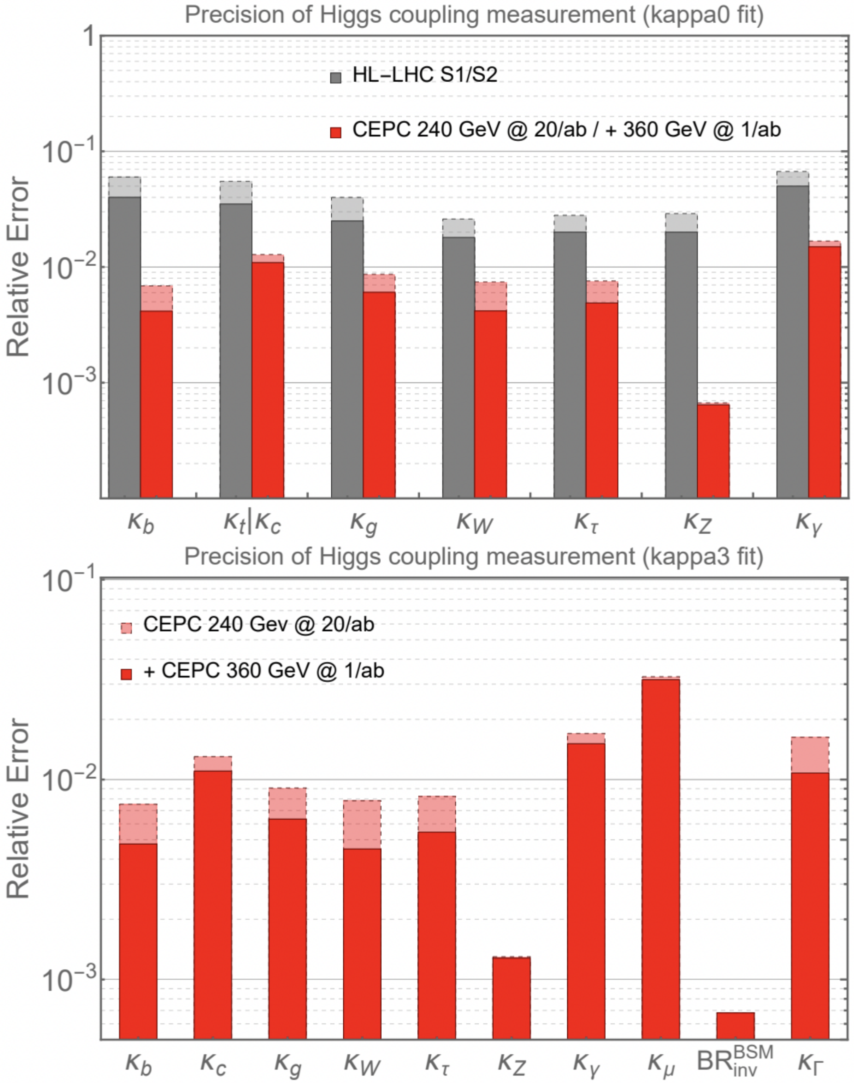
- **These two orthogonal methods can be combined to reach the best precision.**

Precision : 2.8%

With 5.6 iab @ 240 GeV

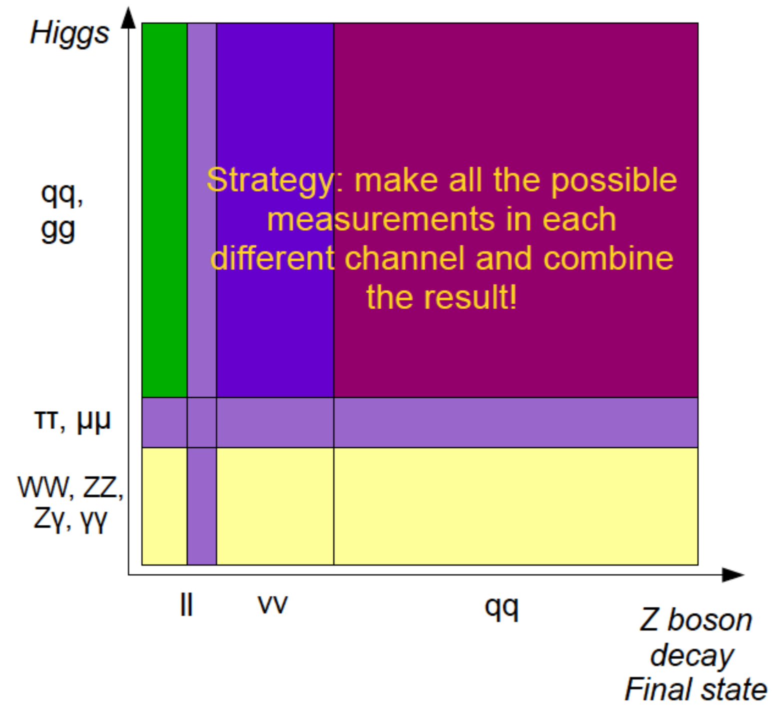
Physics reach via Higgs at CEPC

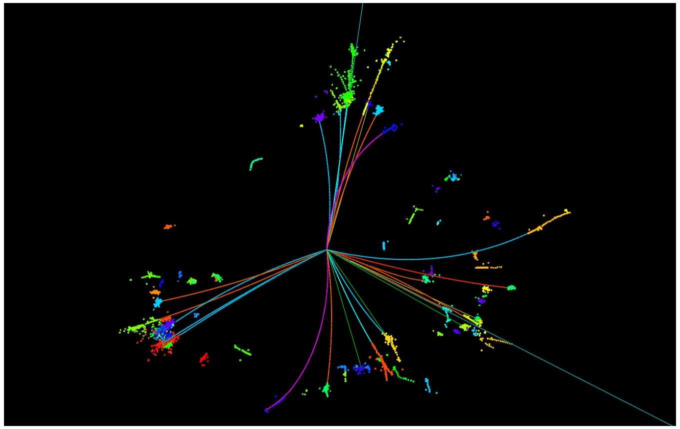
	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	**vvH**	ZH	**vvH**	**eeH**
inclusive	**0.26%**		**1.40%**	\	\
H→bb	**0.14%**	**1.59%**	**0.90%**	**1.10%**	**4.30%**
H→cc	**2.02%**		**8.80%**	**16%**	**20%**
H→gg	**0.81%**		**3.40%**	**4.50%**	**12%**
H→WW	**0.53%**		**2.80%**	**4.40%**	**6.50%**
H→ZZ	**4.17%**		**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%**		



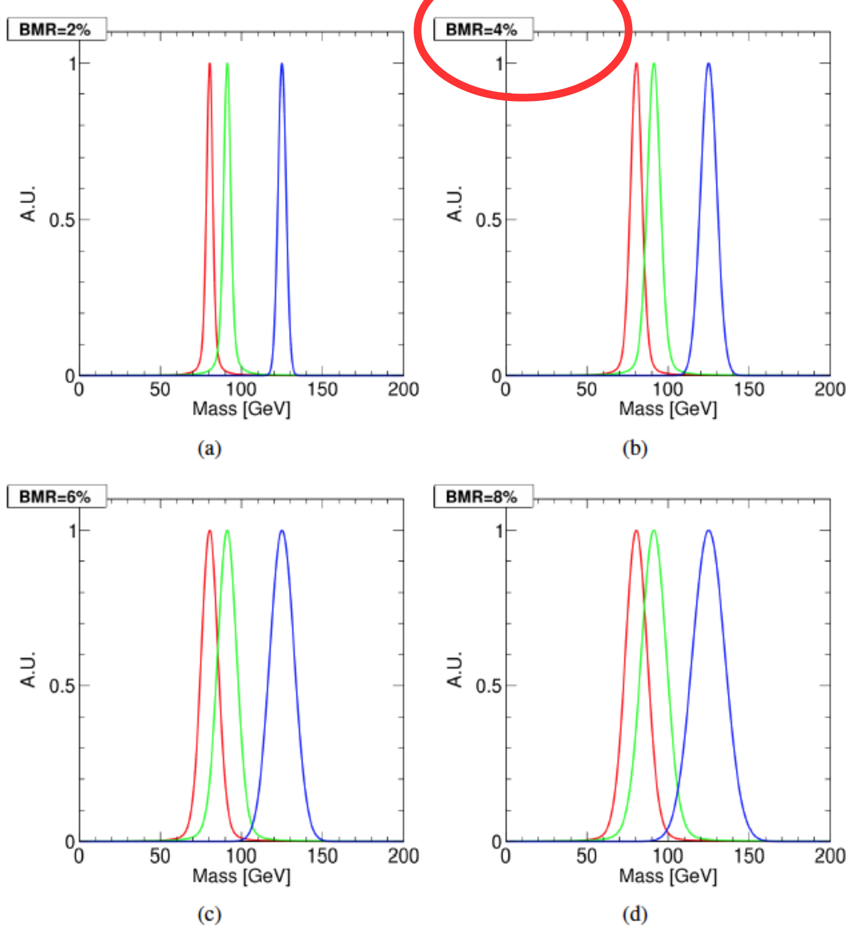
Hadronic system (jet)

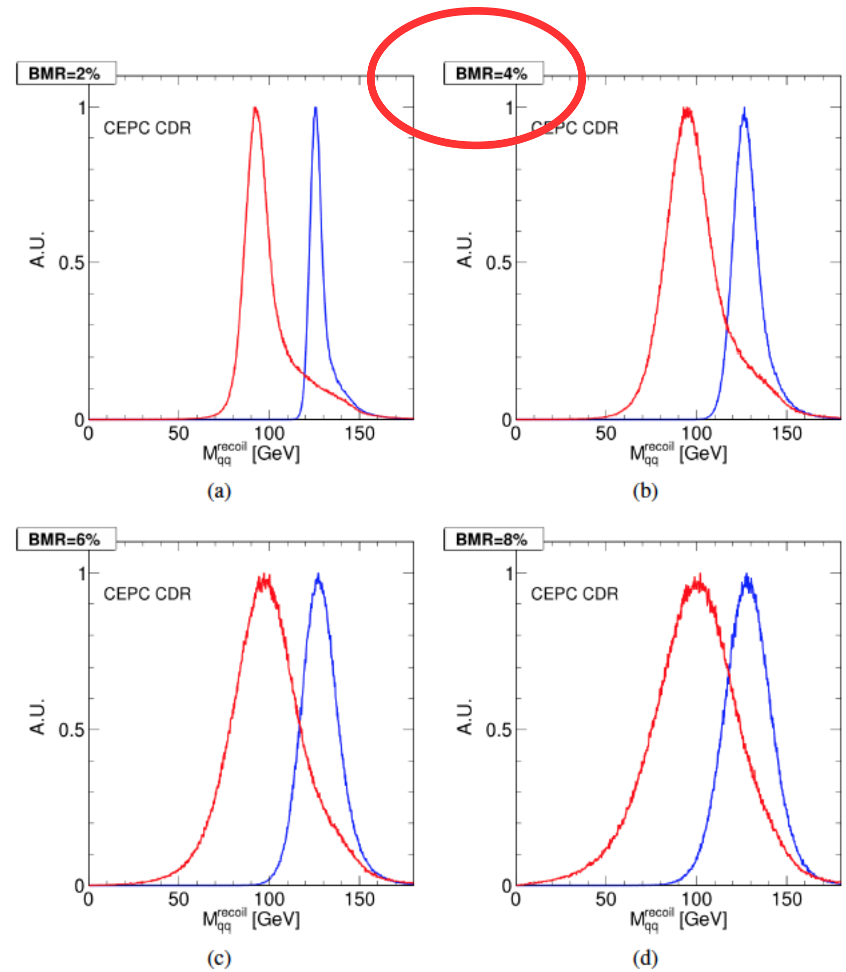
- Core of e+e- Higgs factory Physics measurements
  - 97% of CEPC Higgs events are hadronic/semi-leptonic
- Identify the hadronic system in semi-leptonic events
  - lepton identification & missing energy
- 4-momentum measurement of the hadronic system: BMR: Invariant Mass Resolution
- Jet response: essential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





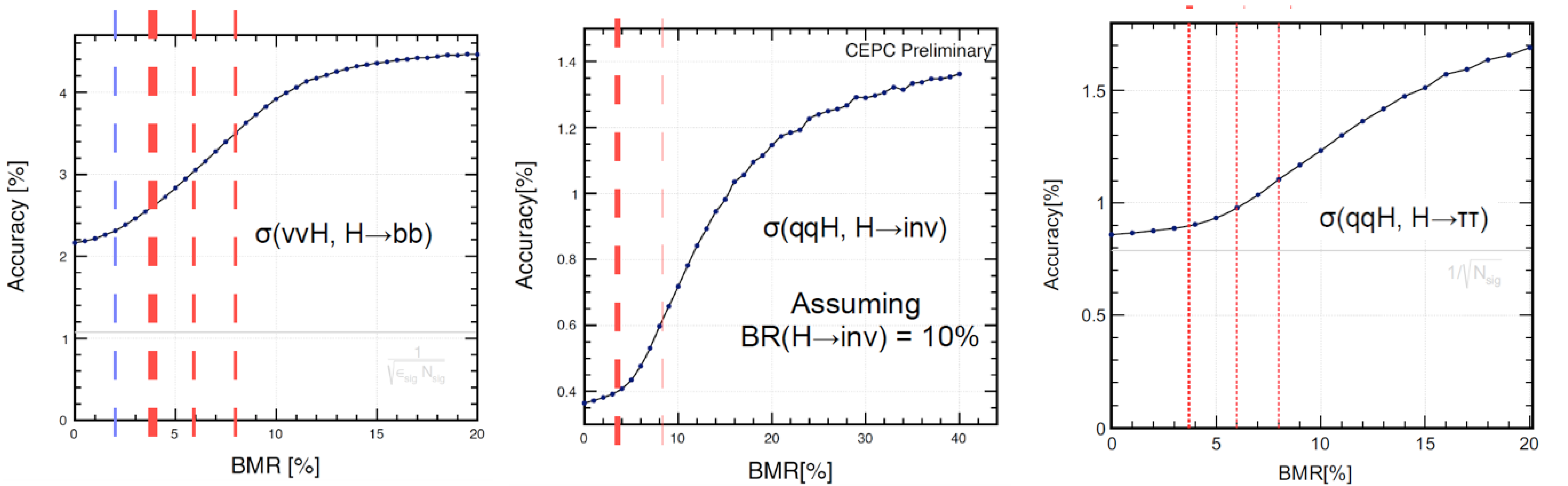
BMR < 4% required...





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

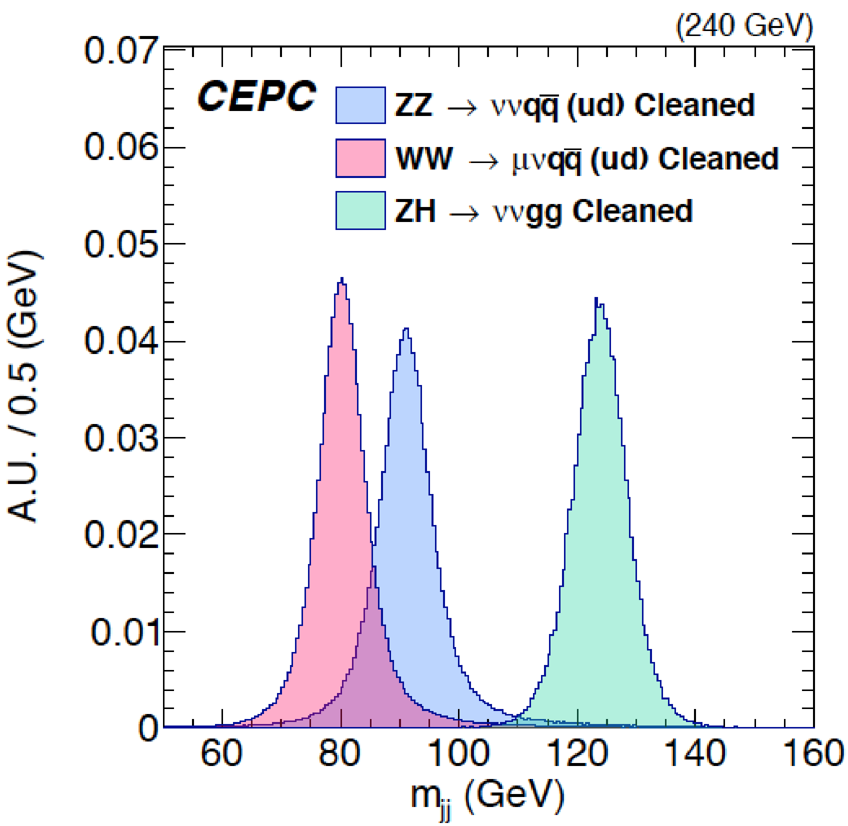
Confirmed with benchmark analyses



- Boson Mass Resolution: relative mass resolution of vvH, 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(vvH, H→bb)	2.3%	2.6%	3.0%	3.4%
σ(vvH, 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%



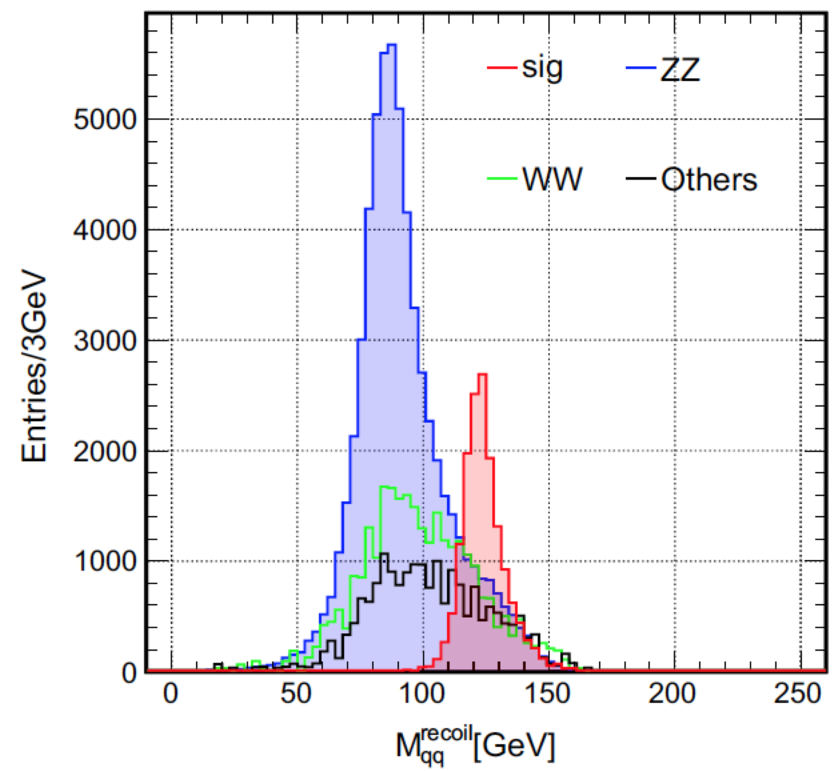
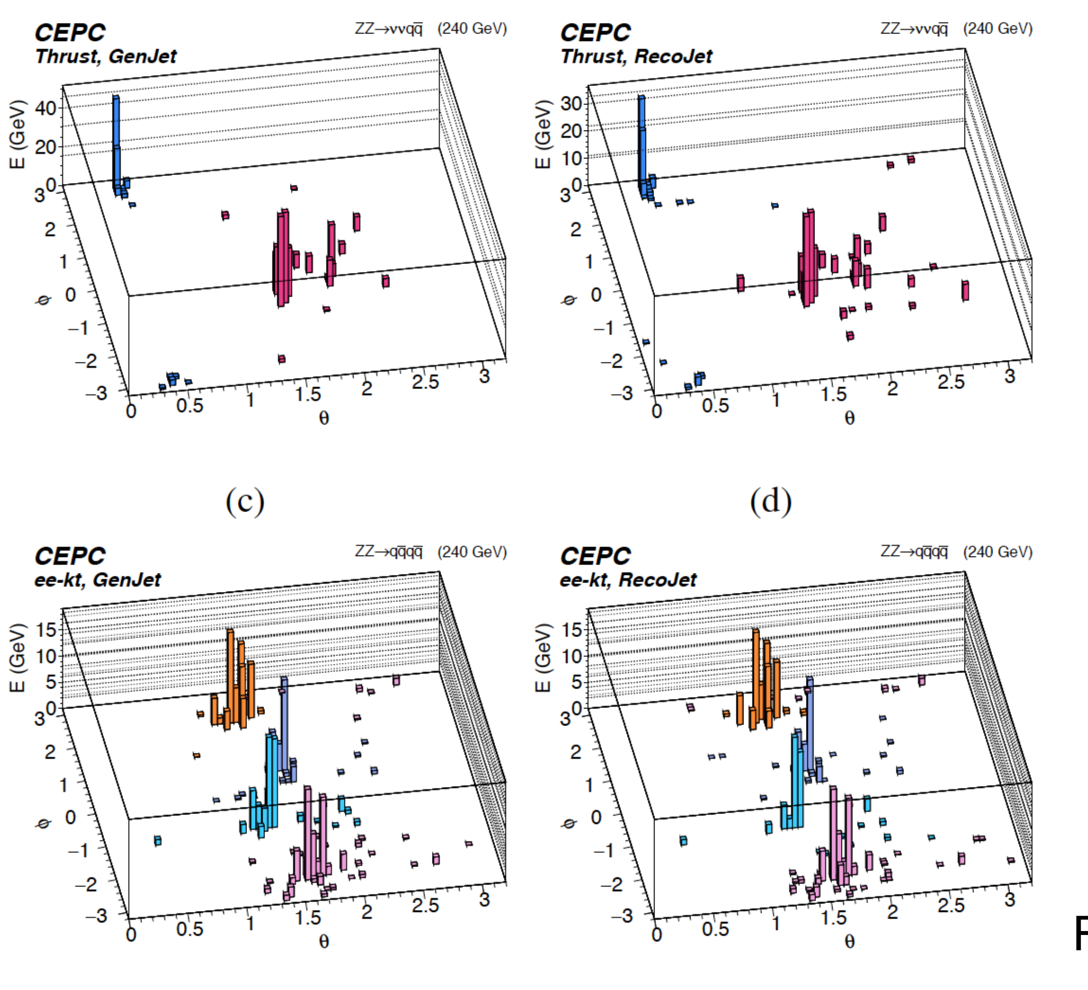


Fig. 7 Distribution of the recoil mass of the qq, M_{qq}^{recoil} for $Z \to qq$, $H \to \tau\tau$ and each background at $\sqrt{s} = 240$ GeV after the previous cuts

@ 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

Individual jet: jet clustering - matching



(c) (d)

(e) (f)

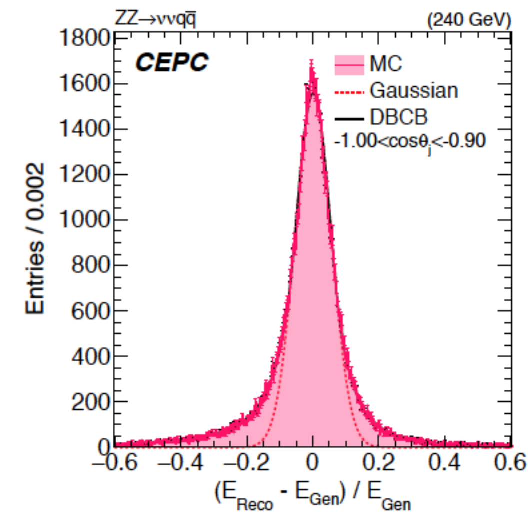
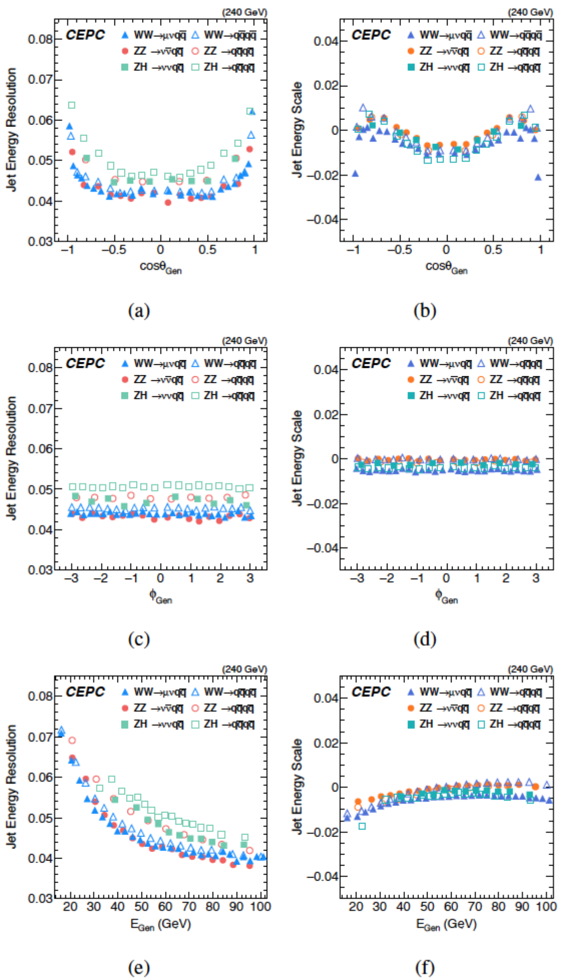


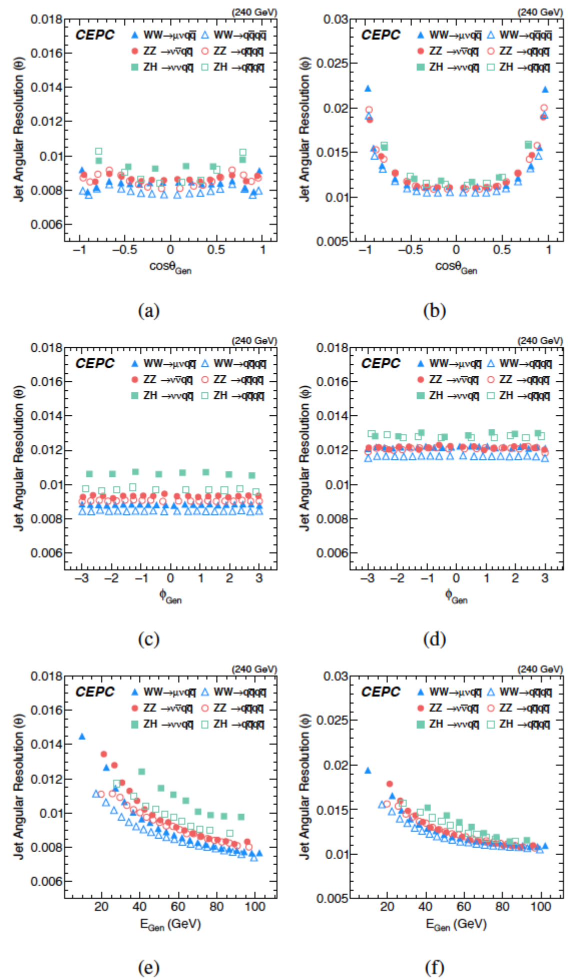
Fig. 7: σ and $\bar{x}$ from the core of the DBCB fit to R are defined as JER/S, respectively. The $cos\theta_j$ indicates the specific polar angle of the jets.

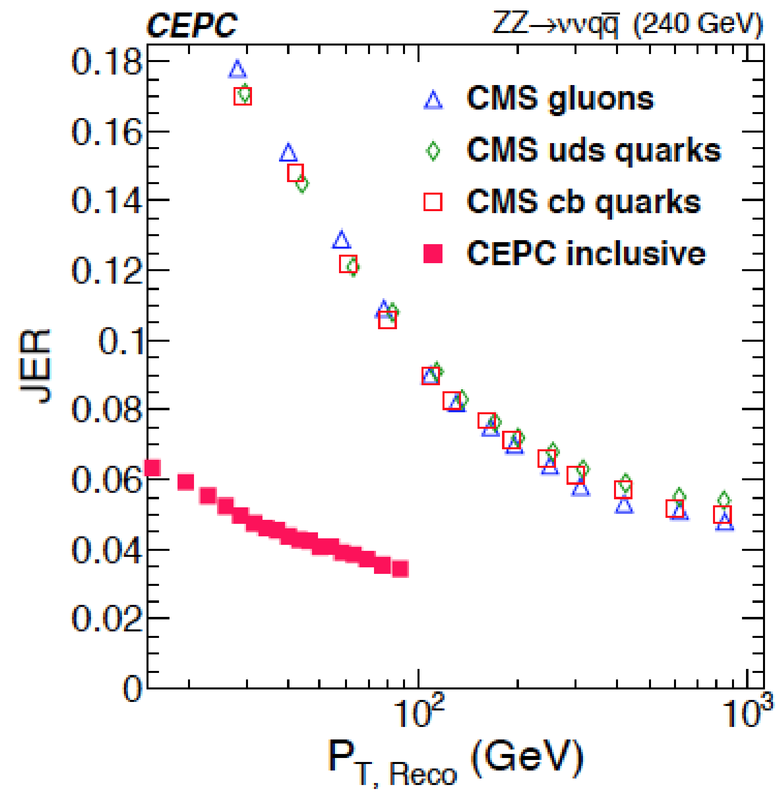
Jet Clustering & Matching is critical: ee-kt is used as CEPC baseline

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

Individual Jet Responses



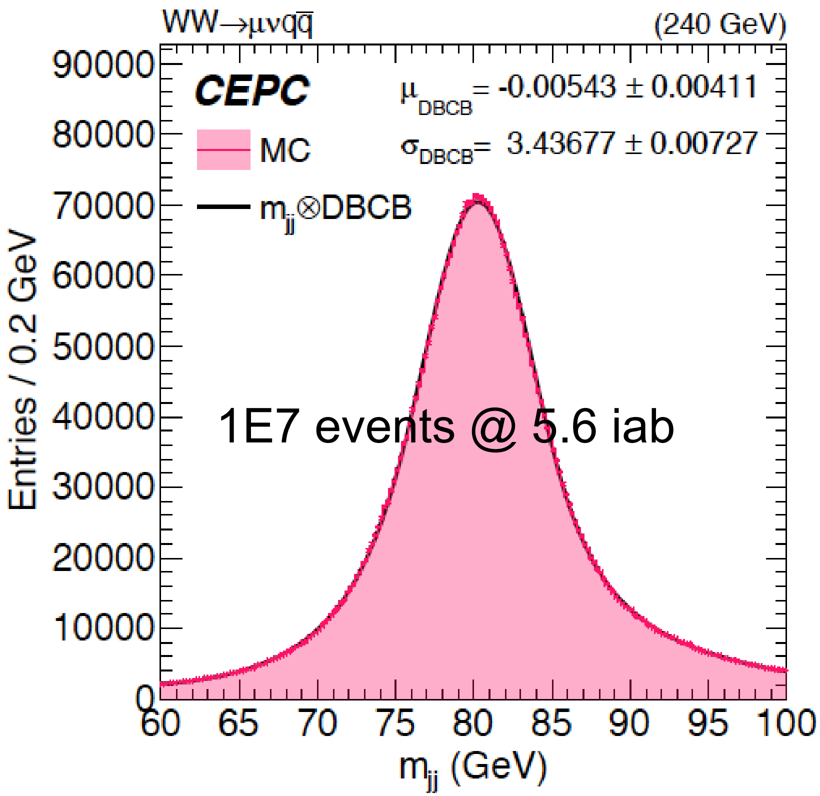




Jet Energy Response: 2.5 – 4 times better than LHC in the same Pt range,
Jet Energy Scale: 3 times better before sophisticated calibration

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? ...*

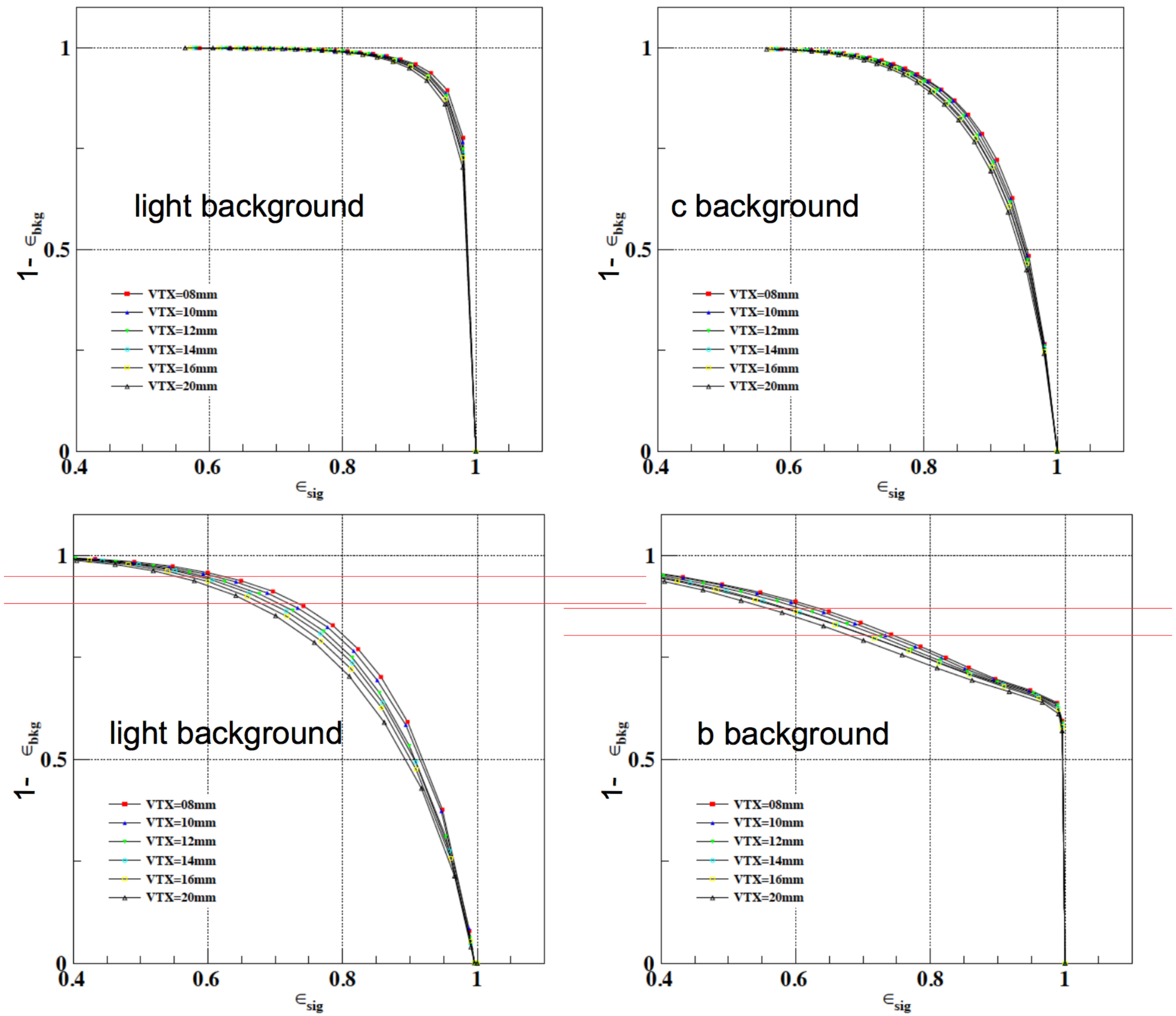


Quasi analysis: JES calibrated to pure ISR return qq sample

Flavor Tagging

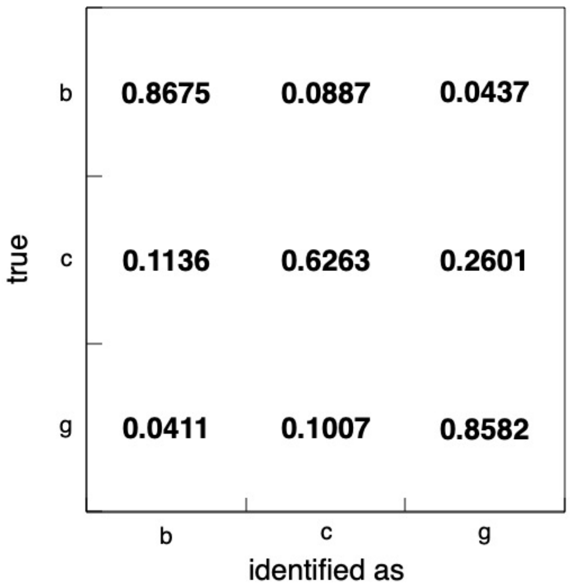
- Flavor Tagging (LCFIPlus), Typical Performance at Z pole sample:
  - *B-tagging: eff/purity = 80%/90%*
  - *C-tagging: eff/purity = 60%/60%*

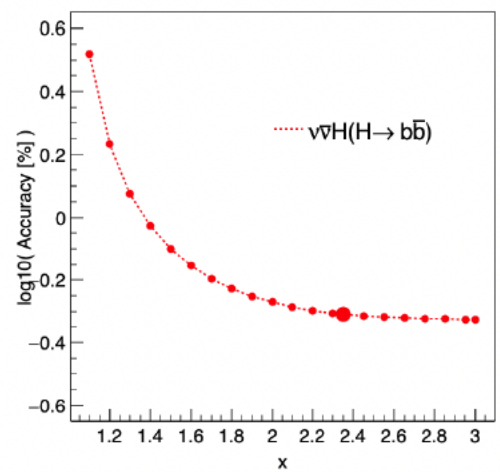
- Charge Measurement：
  - Easily reach 10%/20% for inclusive c/b jet at Z pole
  - For specific hadrons (Bs/Lambda_b), can improve significantly

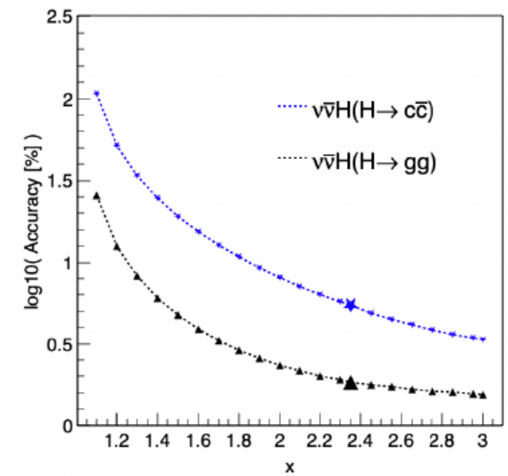


https://agenda.linearcollider.org/event/7645/contributions/40124/

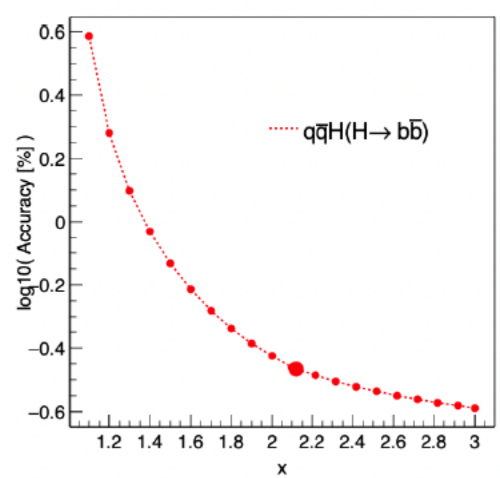
Jet Flavor Tagging for Higgs measurement: good & significant potential to improve

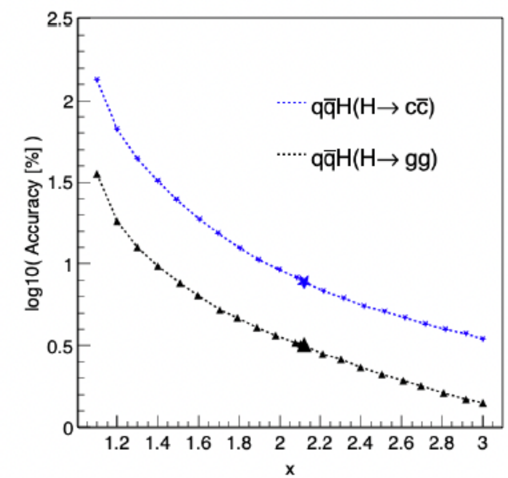






Compared to Baseline, Ideal FT improve the H->bb, cc, gg Measurements significantly. Especially at qqH channel. (up to 2 times.)





Impact of Vertex Optimization

$$Tr_{mig} = 2.118 + 0.054 \cdot log_2 \frac{R^0_{material}}{R_{material}} + 0.040 \cdot log_2 \frac{R^0_{resolution}}{R_{resolution}} + 0.098 \cdot log_2 \frac{R^0_{radius}}{R_{radius}}$$

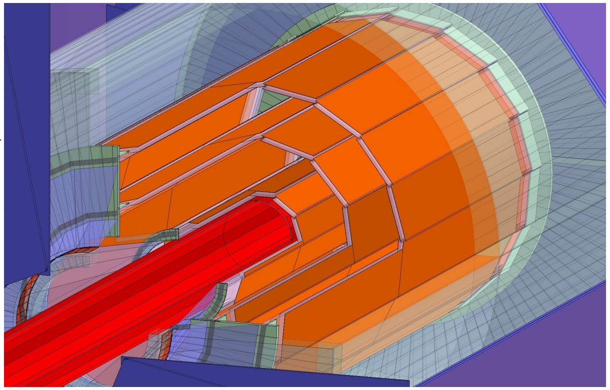
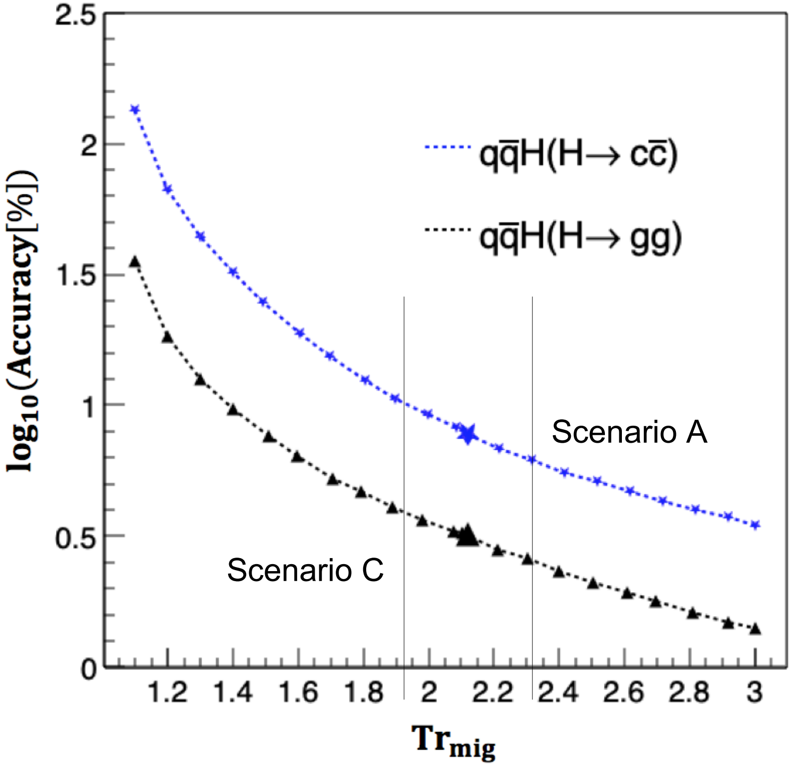


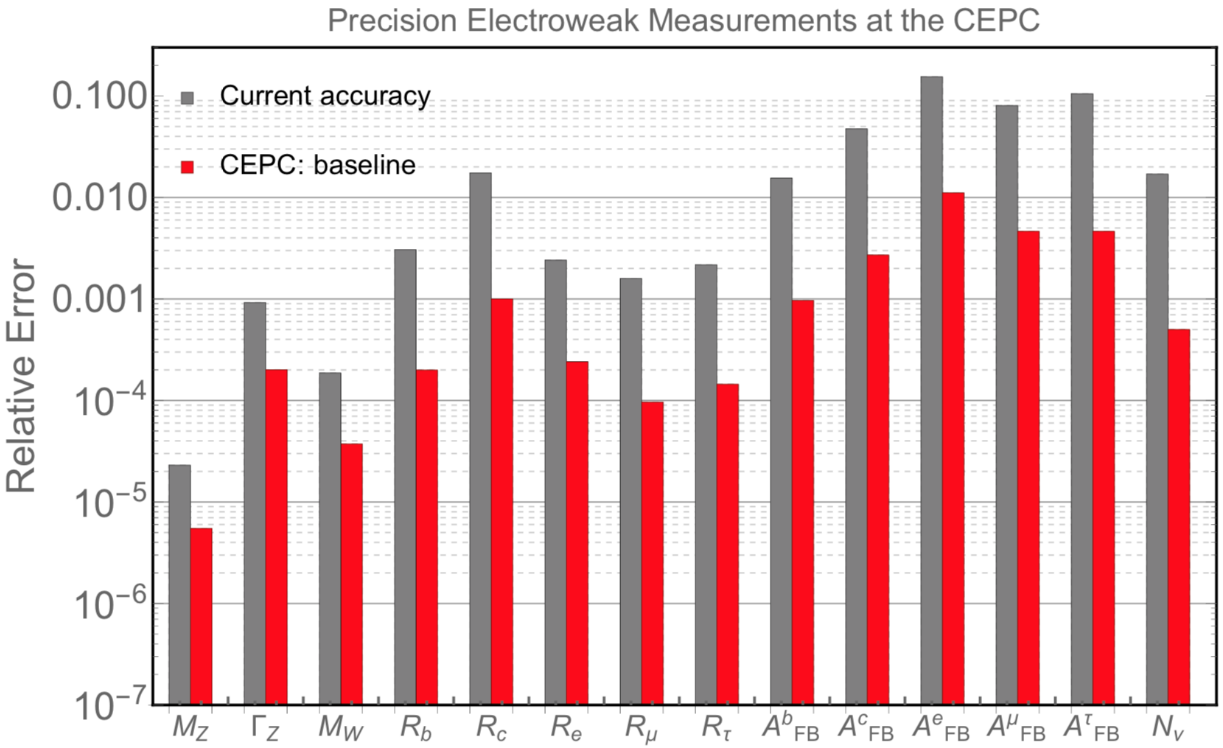
Table 2. Reference geometries.

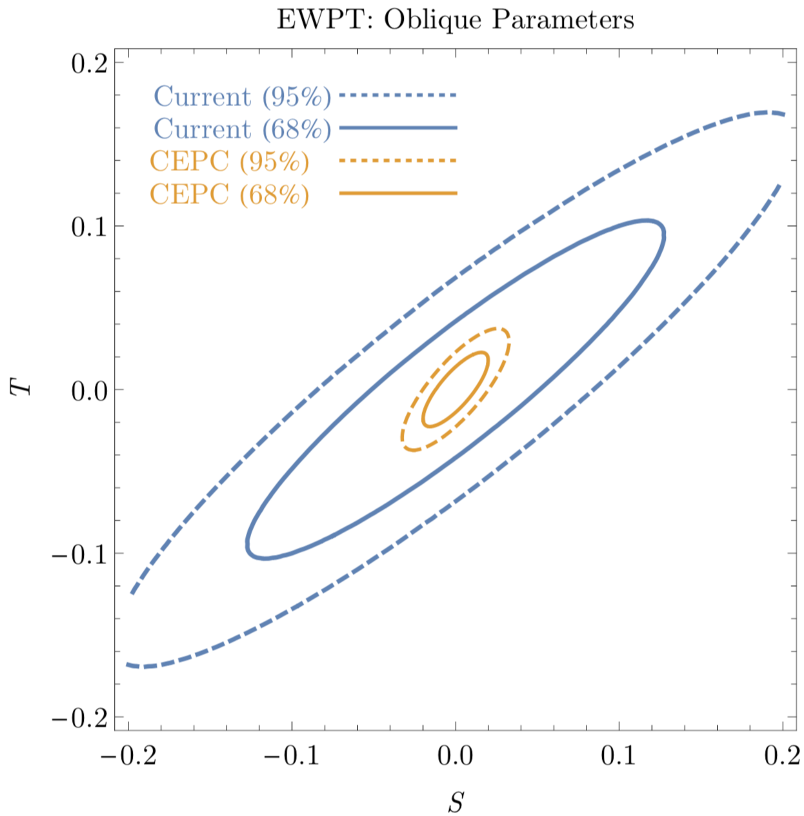
	Scenario A (Aggressive)	Scenario B (Baseline)	Scenario C (Conservative)
Material per layer/X_0	0.075	0.15	0.3
Spatial resolution/µm	1.4 - 3	2.8 - 6	5 - 10.7
R_{in}/mm	8	16	23

- Compared to the baseline:
  - Perfect Flavor tagging improves the accuracy of qqH, H->cc measurement by 2 times
  - Conservative & Aggressive scenario degrades/improves the accuracy by 30%
  - Current Vertex design (with inner radius of 10 mm) improves the accuracy by 10%



EW





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

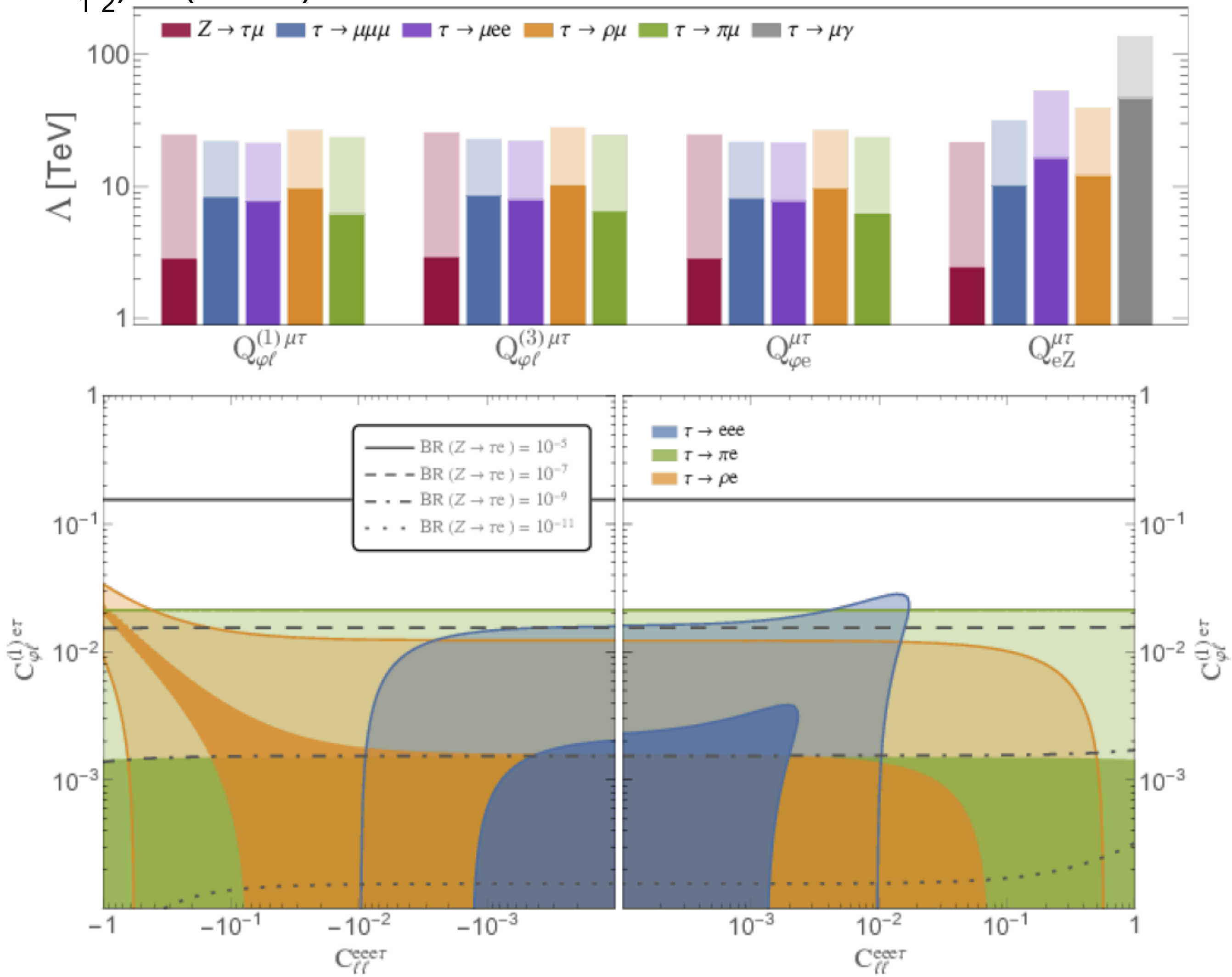
Flavor Physics @ Z pole

- 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.

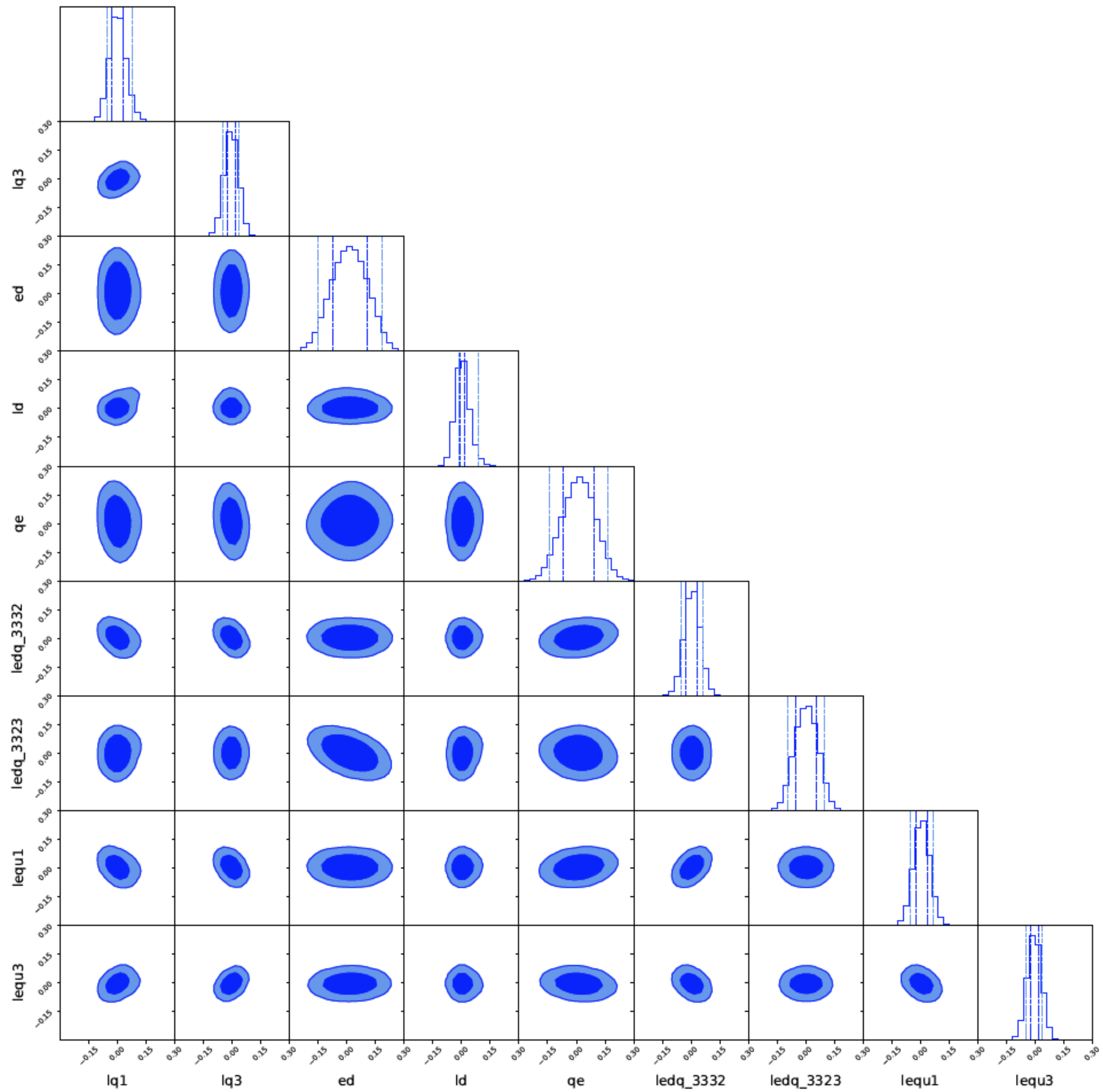
Lepton Flavor Violation (II)

Up limit of Br($Z \to l_1 l_2$)~o(1E-9)



[Calibbi et al., 2021] 2107.10273

Current Progress in LFU Tests (II)



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

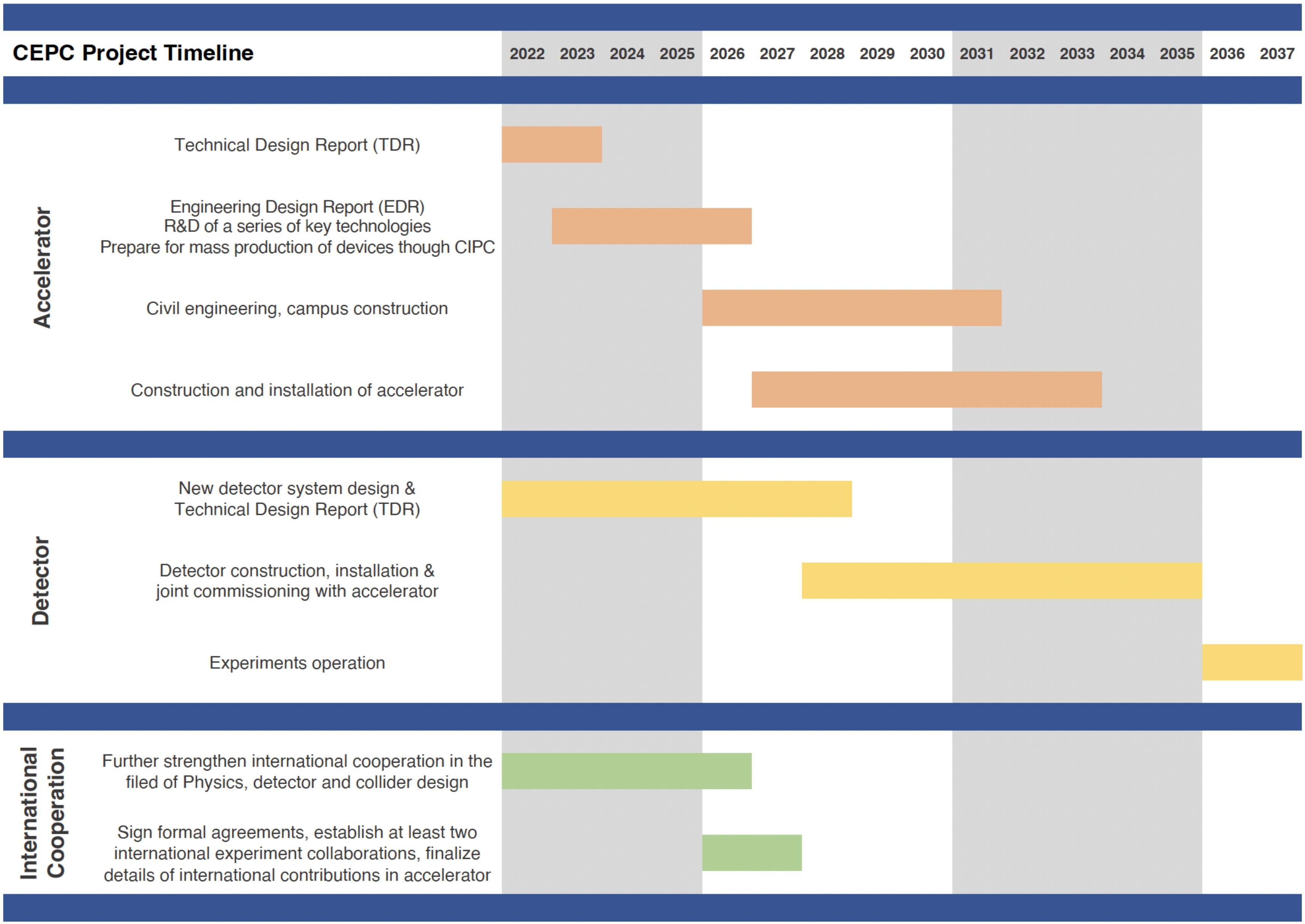
Lingfeng Li & Tao Liu

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.

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

Summary

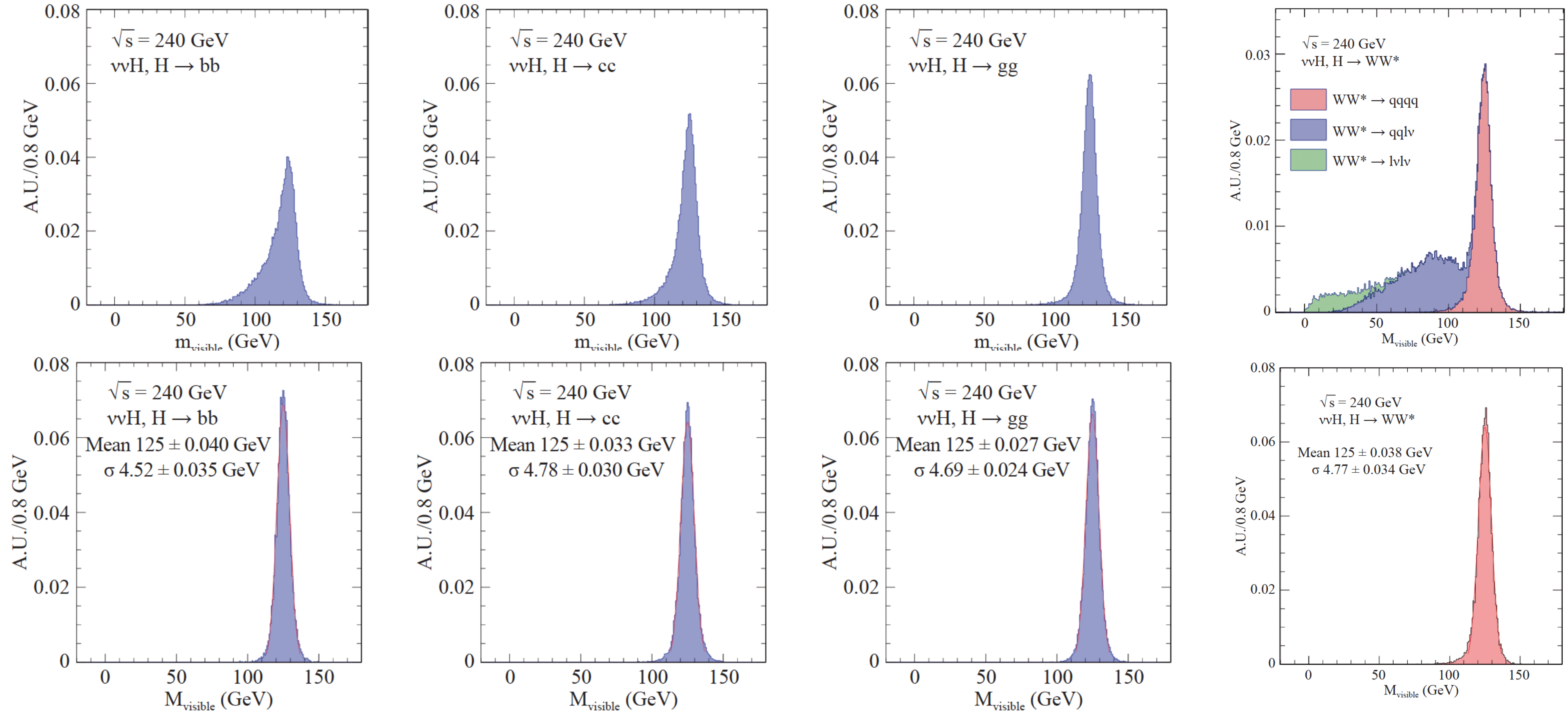
- Electron Positron Higgs factories: a gigantic boost from LHC
  - CEPC: 4 M Higgs, ~100 Million W, 1 Million Top, and 4 Tera Z.
  - Higgs precision ~ 1 order of magnitude better compared to HL-LHC.
  - Boost the precision on EW by 1-2 orders of magnitudes.
  - Lots of opportunities for flavor physics & NP reach of 10 TeV, or higher.
  - Strong physics cases for BSM & QCD.
- The ultimate precision of Higgs measurement will be mainly limited by statistic
  - We are grateful to Accelerator community that design/build colliders with higher & higher luminosity: please continue!
  - The physics requirement on detector performance is well understood, and pursued by Intensive detector R&D efforts
- Giving the importance of Higgs factory, we hope at least one of the electron positron Higgs factories will be constructed in the recent future.
- We hope the CEPC construction will start in 2026

Back up

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%

Higgs white paper delivered

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

Precision Higgs physics at the CEPC*

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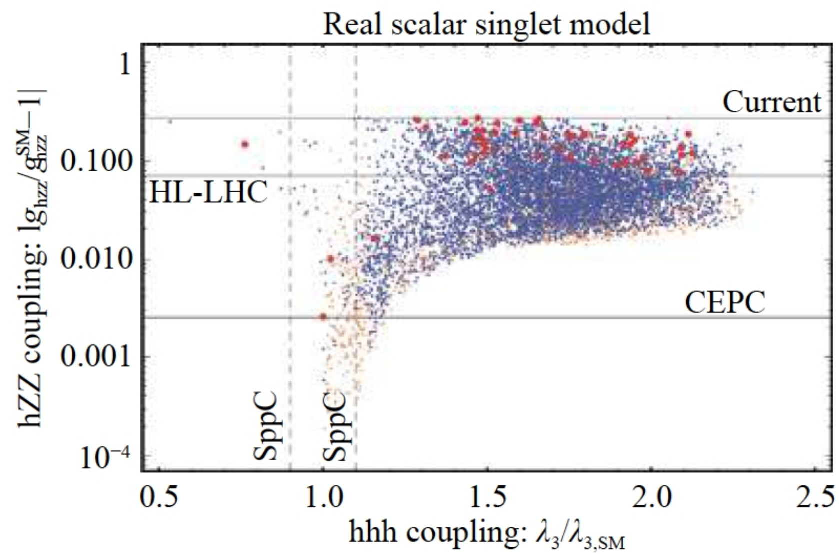
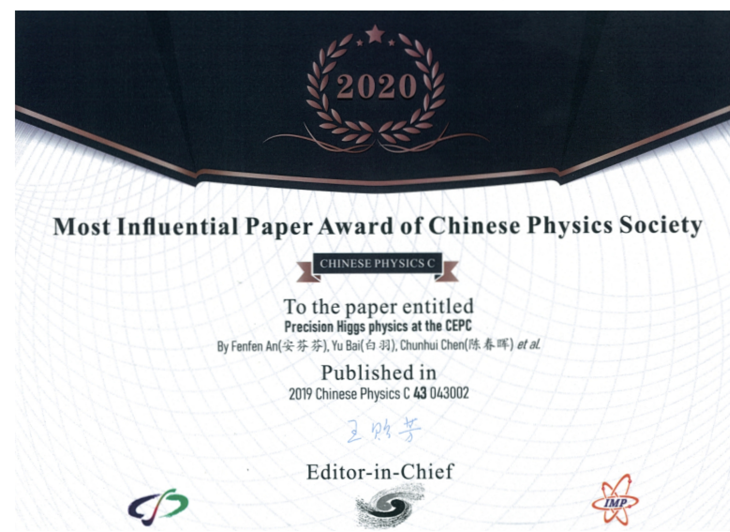
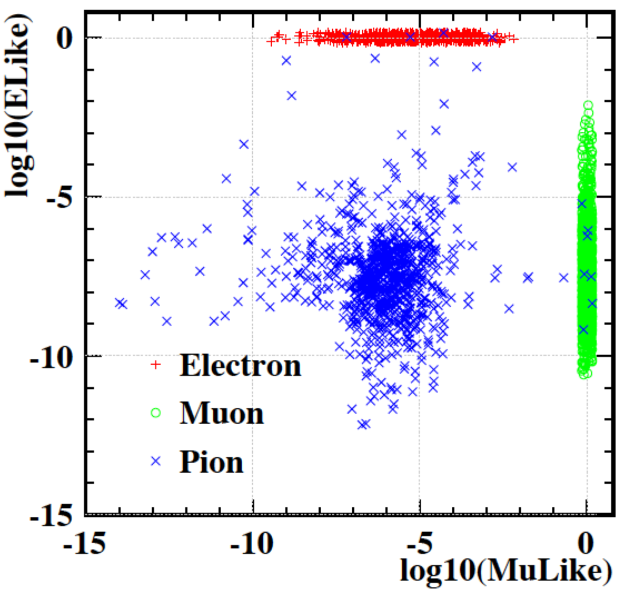
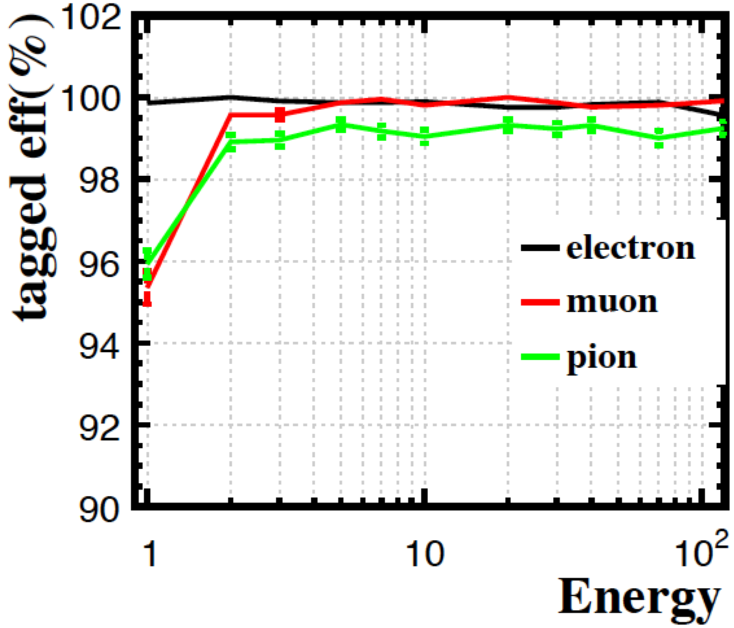
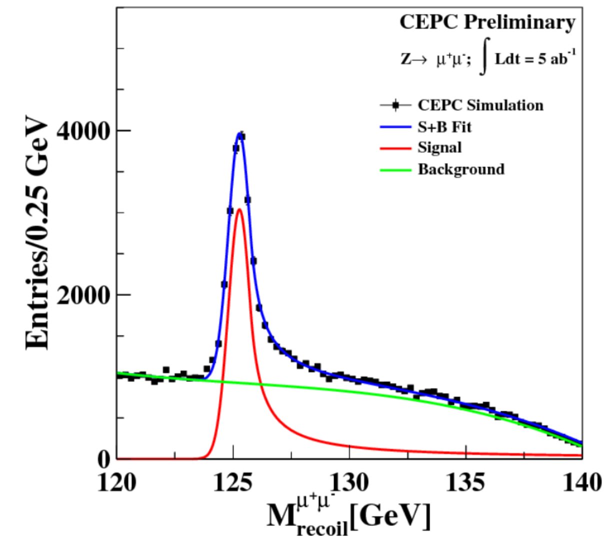


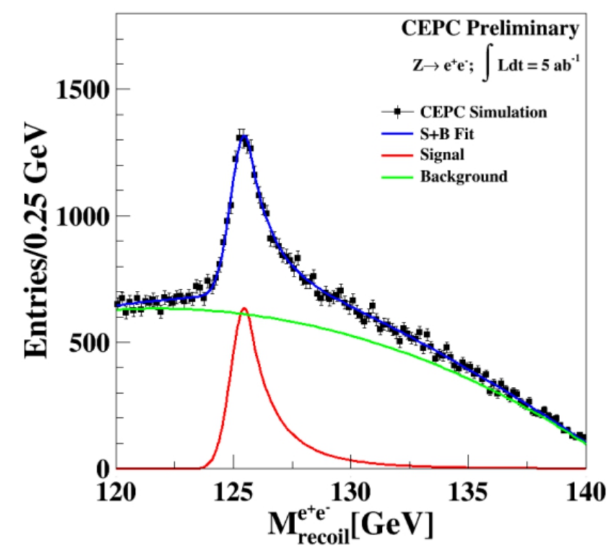


Lepton: isolated







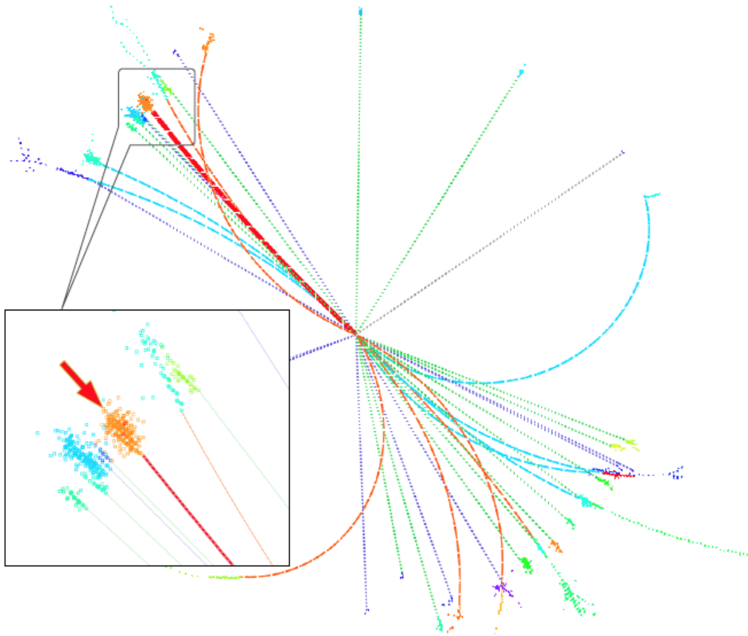


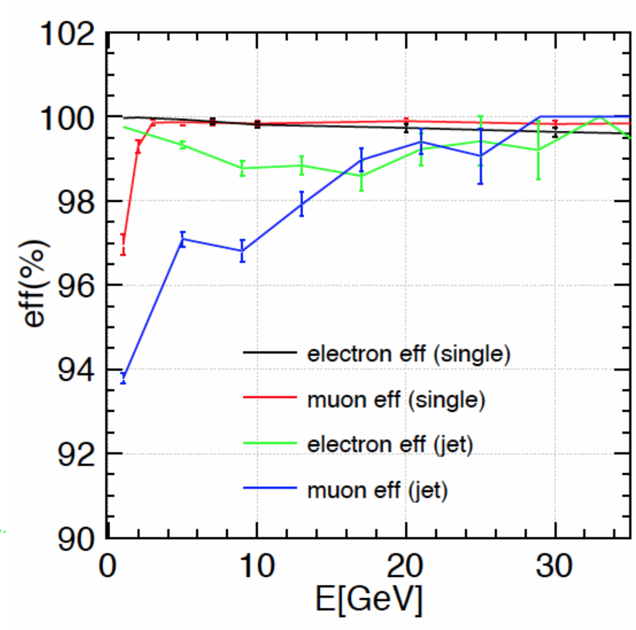
BDT method using 4 classes of 24 input discrimination variables.

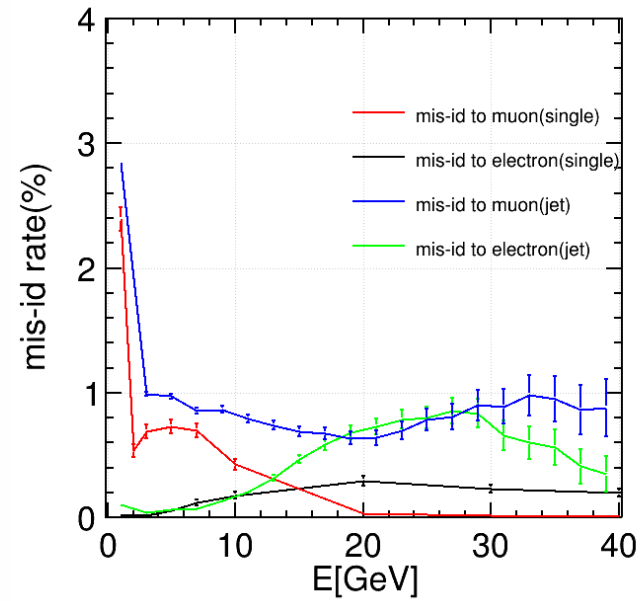
Test performance at: Electron = E_likeness > 0.5 ;
Muon = Mu_likeness > 0.5
Single charged reconstructed particle, for E > 2 GeV:
lepton efficiency > 99.5% && Pion mis id rate ~ 1%

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



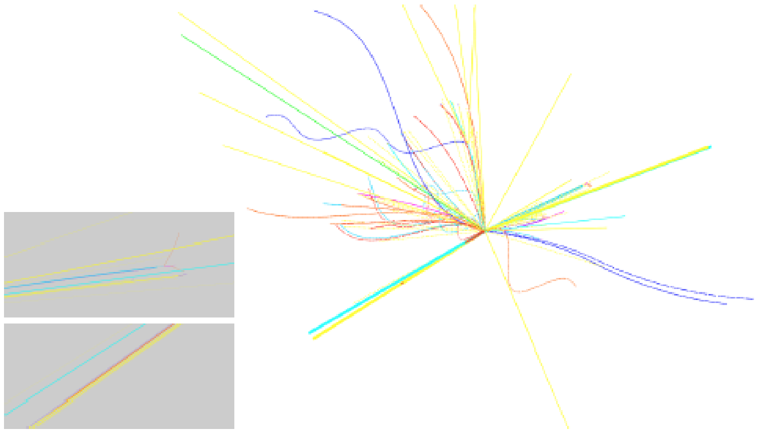




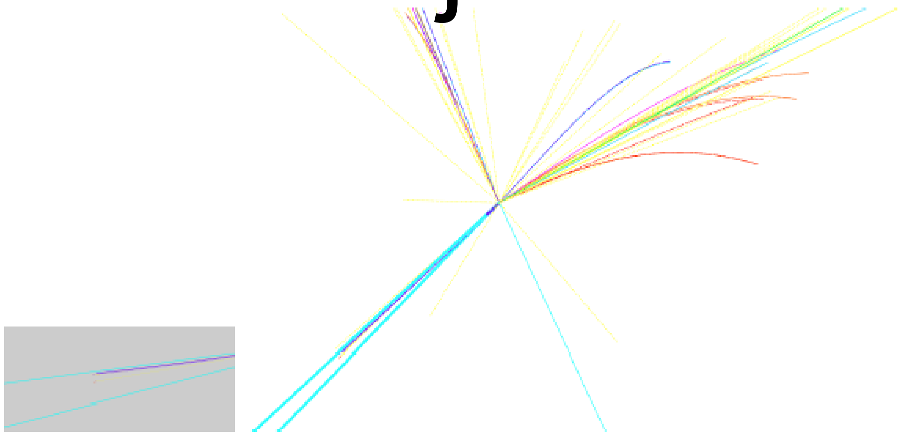
Compared the single particle sample, the jet lepton (at Z->bb sample at sqrt = 91.2 GeV) Performance will be slightly degraded – Due to the limited clustering performance (splitting & containmination).

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.

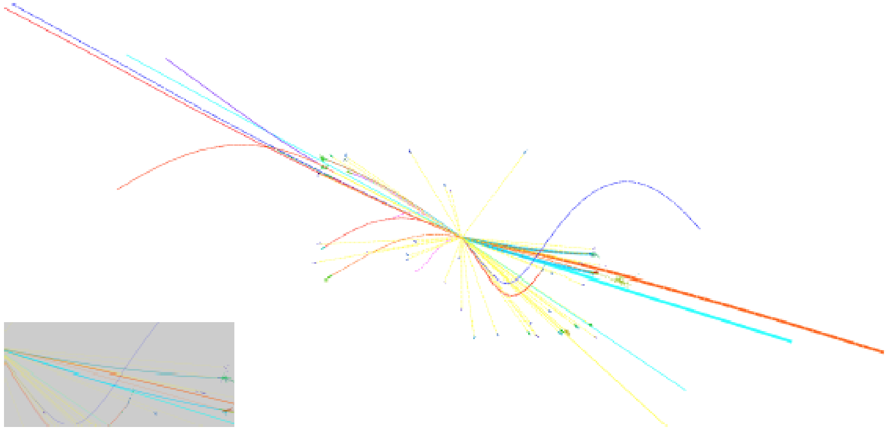
Taus: isolated or inside jets



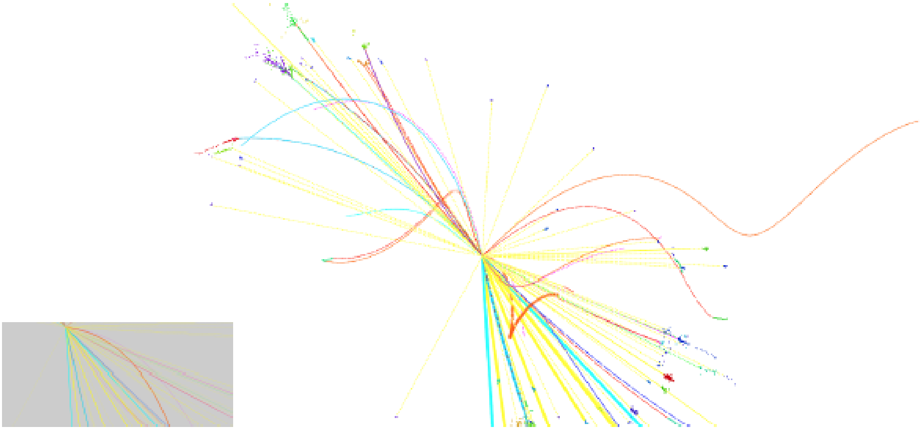
(a) $Z \to qq, H \to \tau\tau$ with two hadronic decay.



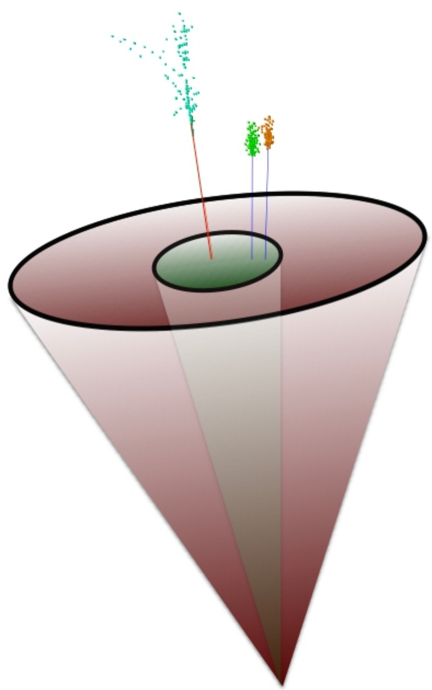
(b) $WW \to \tau\nu qq$ with one leptonic decay.

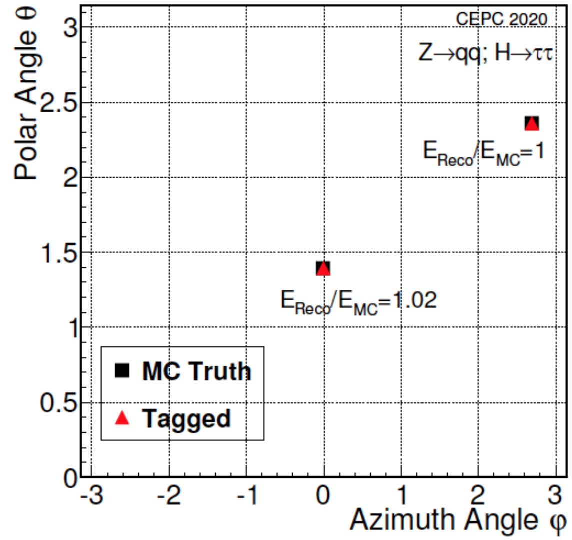


(c) $Z \to b\bar{b}, B_c \to \tau\nu$ with one hadronic dacay.

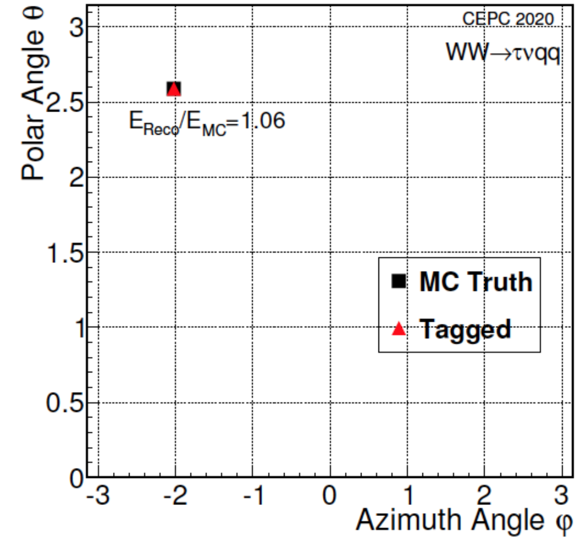


(d) $Z \to b\bar{b}, B_s \to \tau\tau$ with two hadronic decay mixed together.

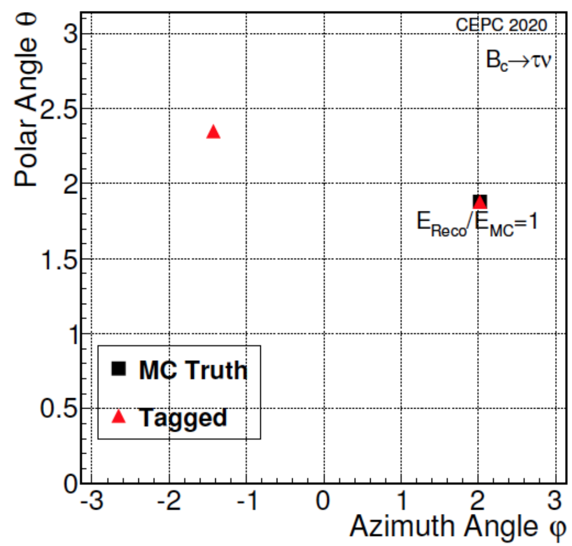




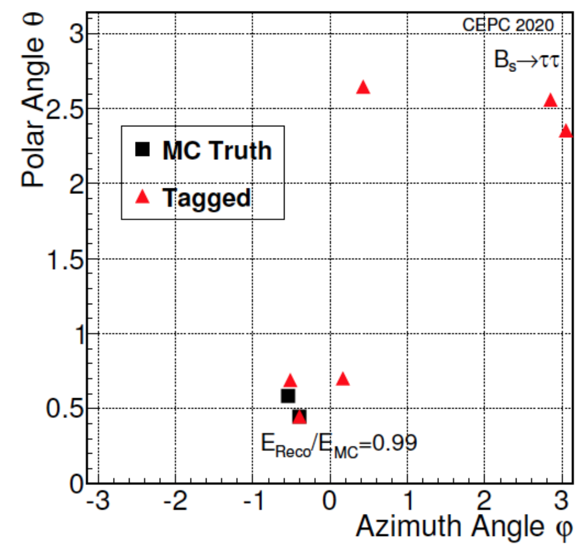
(a) $Z \to qq, H \to \tau\tau$, efficiency=1, purity=1



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

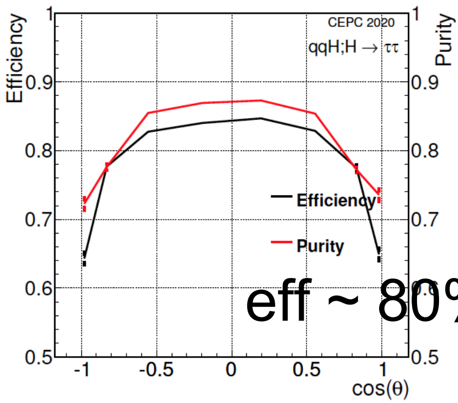


(c) $Z \to b\overline{b}, B_c \to \tau\nu$, efficiency=1, purity=0.5

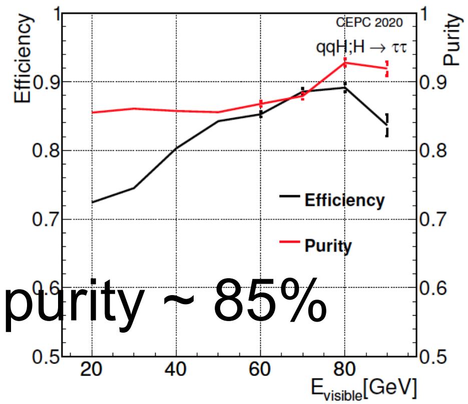


(d) $Z \to b\overline{b}, B_s \to \tau\tau$, efficiency=0.5, purity=0.167

Tau id

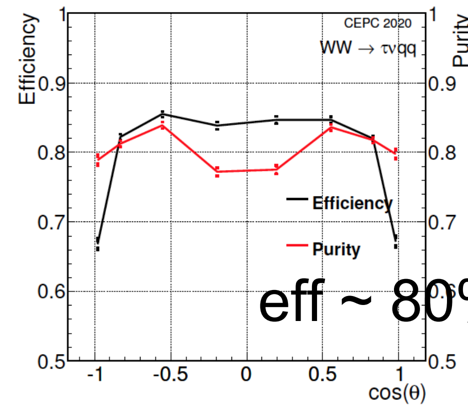


(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

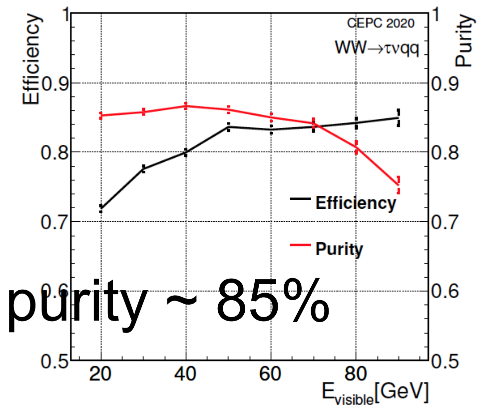


(b) Efficiency and purity performance along with visible energy. The performance above 80 GeV falls as a result of stringent cone selection.

eff ~ 80%, purity ~ 85%

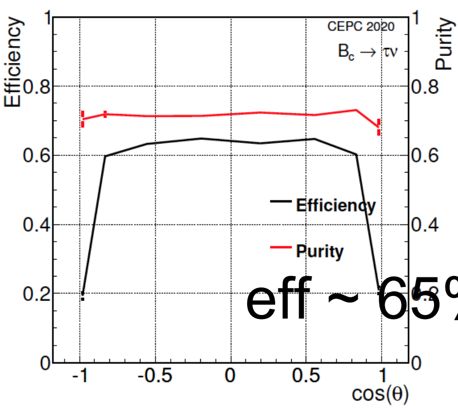


(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

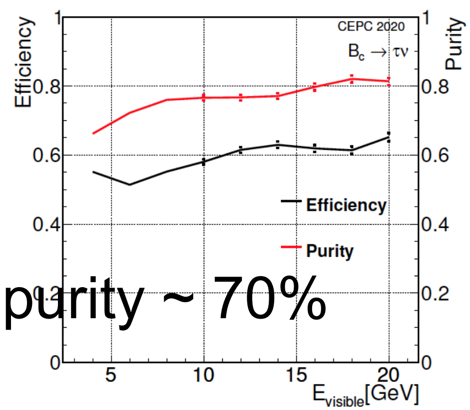


(b) Efficiency and purity performance along with visible energy

eff ~ 80%, purity ~ 85%

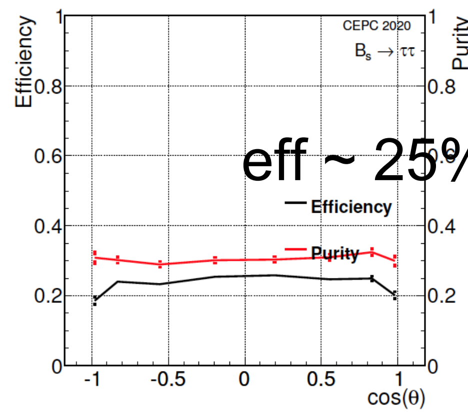


(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

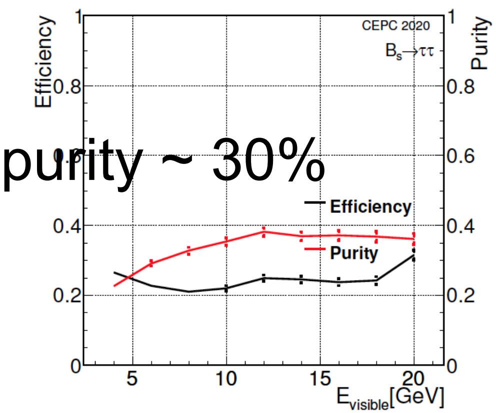


(b) Efficiency and purity performance along with visible energy

eff ~ 65%, purity ~ 70%



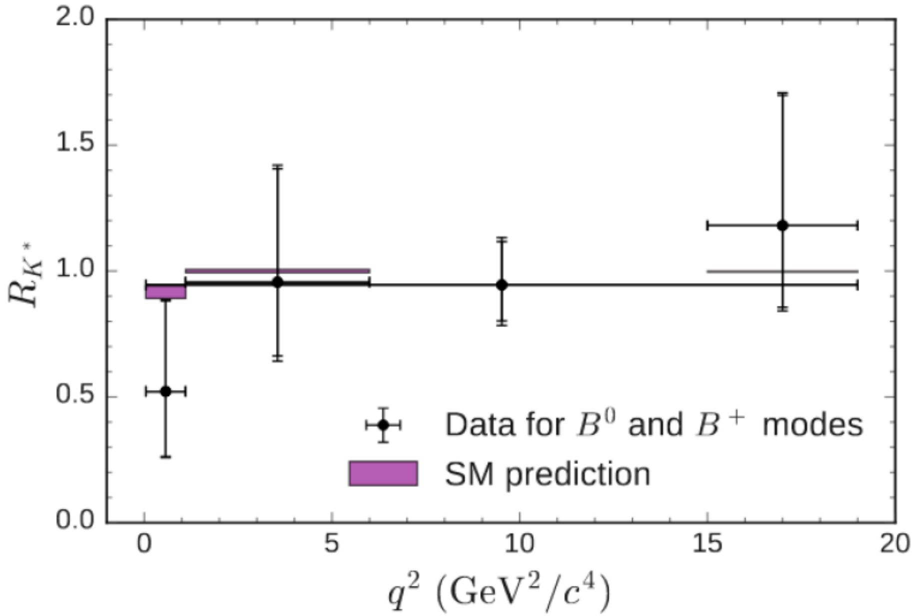
(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

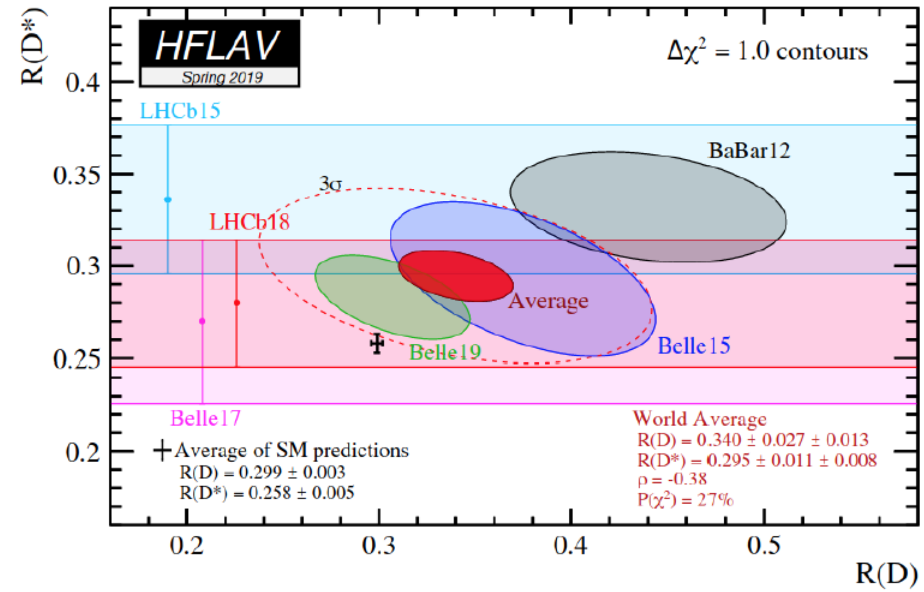


(b) Efficiency and purity performance along with visible energy

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

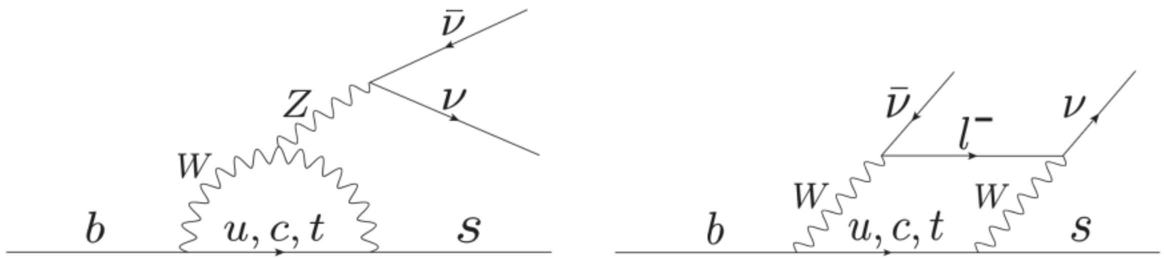
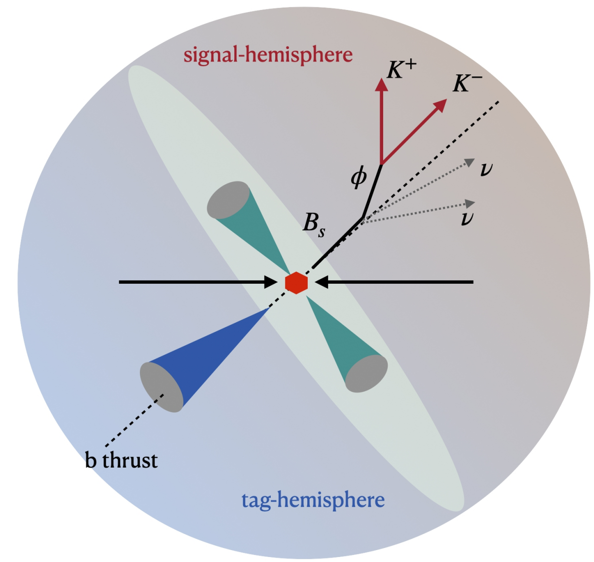
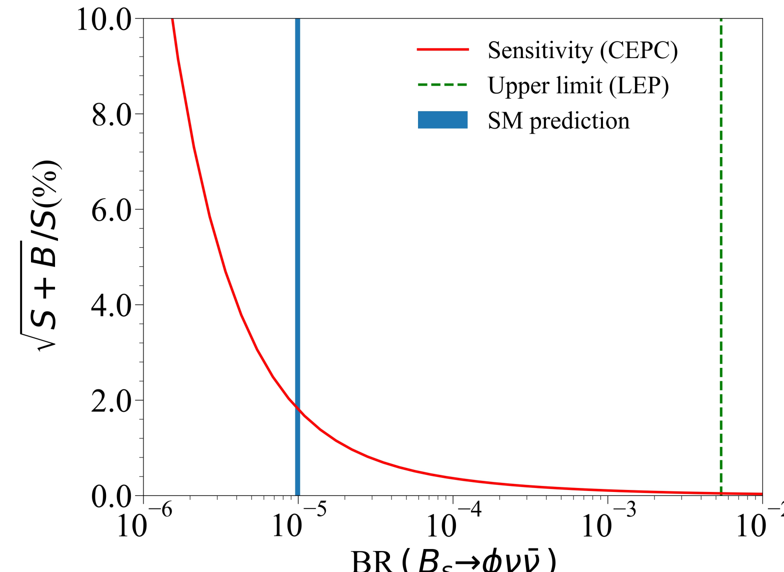


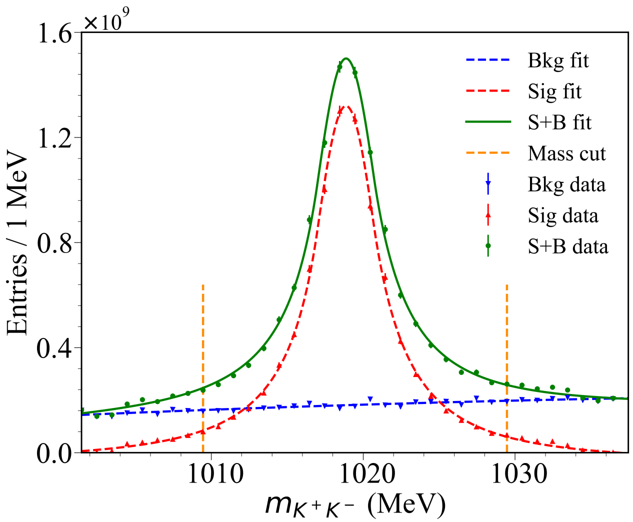
FIG. 1. The penguin and box diagrams of $b \to s\nu\bar{\nu}$ transition at the leading order.

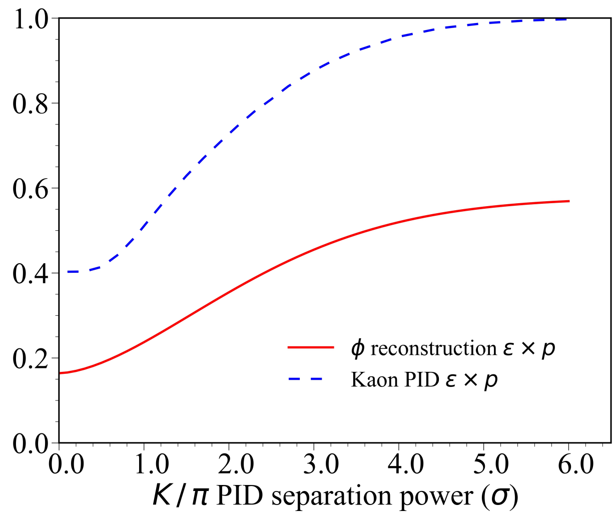


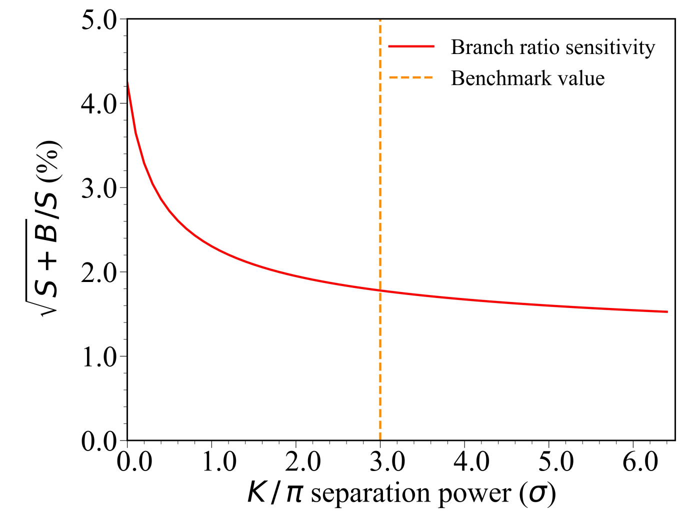


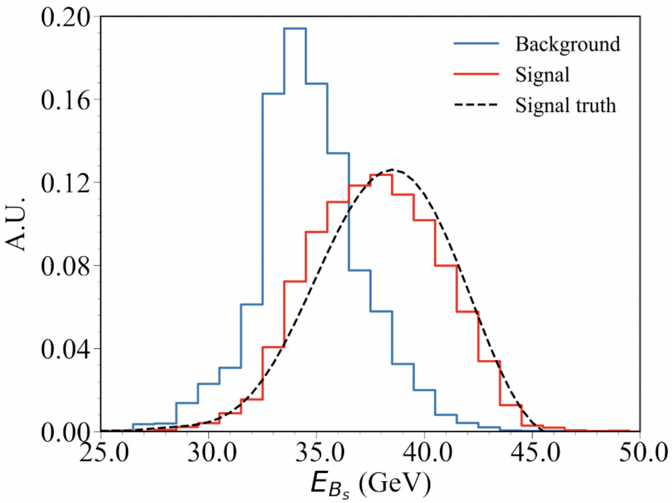
- Key ingredient to understand FCNC anomaly...
- Critical Physics Objects: Phi (and charged Kaon), 2nd VTX, Missing E/P, b-jet at opposite side
- Percentage level accuracy anticipated at Tera-Z

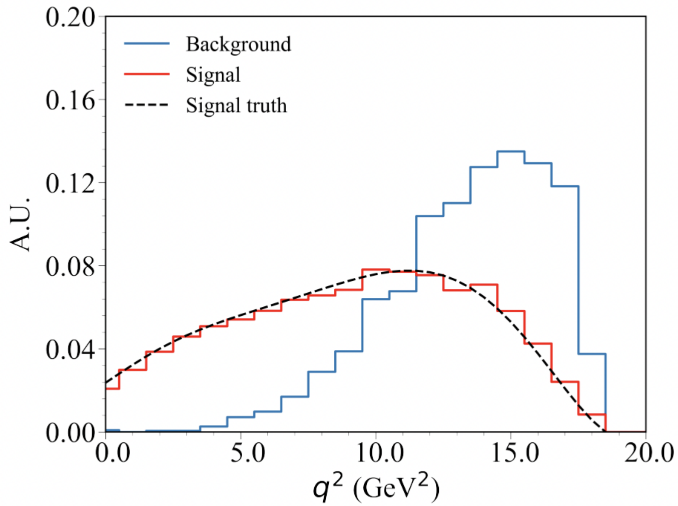
Bs→Phi νν











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

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

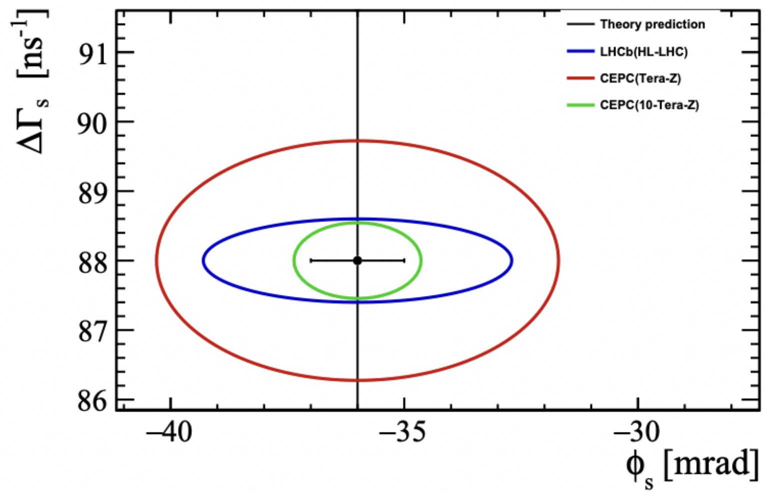
$$E_{B_s}^{(i)} = \frac{s + (M_{\text{sig}}^{(i-1)})^2 - M_{\text{tag}}^2}{2\sqrt{s}} - E_{\text{sig}} + E_\phi,$$

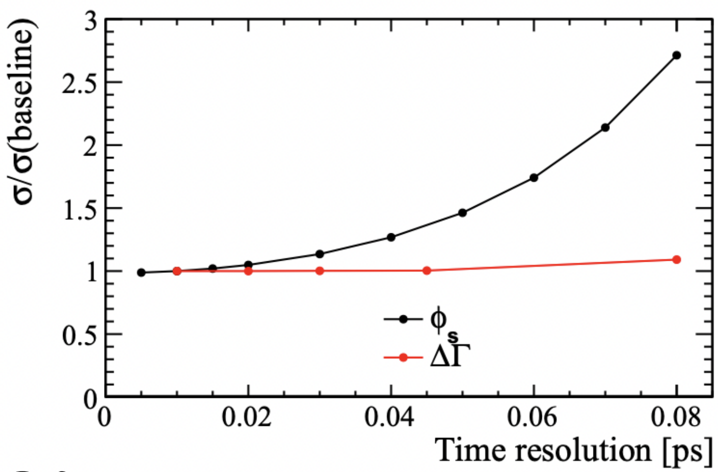
$$(q^2)^{(i)} = (p_{B_s}^{(i-1)} - p_\phi)^2,$$

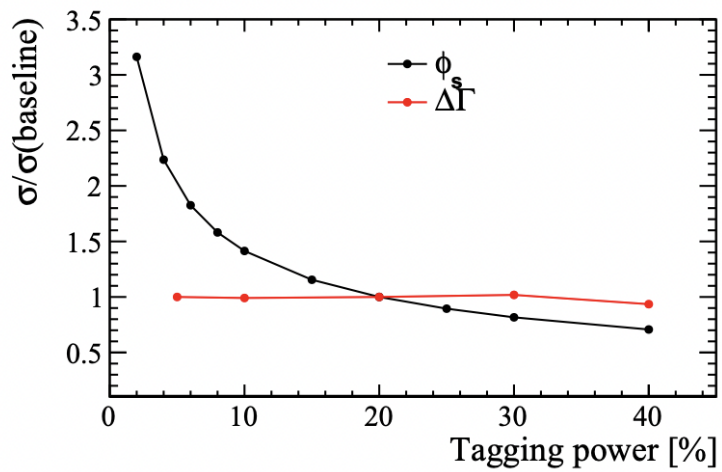
The separation power is defined as $2|\mu_\pi - \mu_K|/(\sigma_\pi + \sigma_K)$. Without loss of generality, we set $\sigma_\pi = \sigma_K$. Com-

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...

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

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

Preliminary...

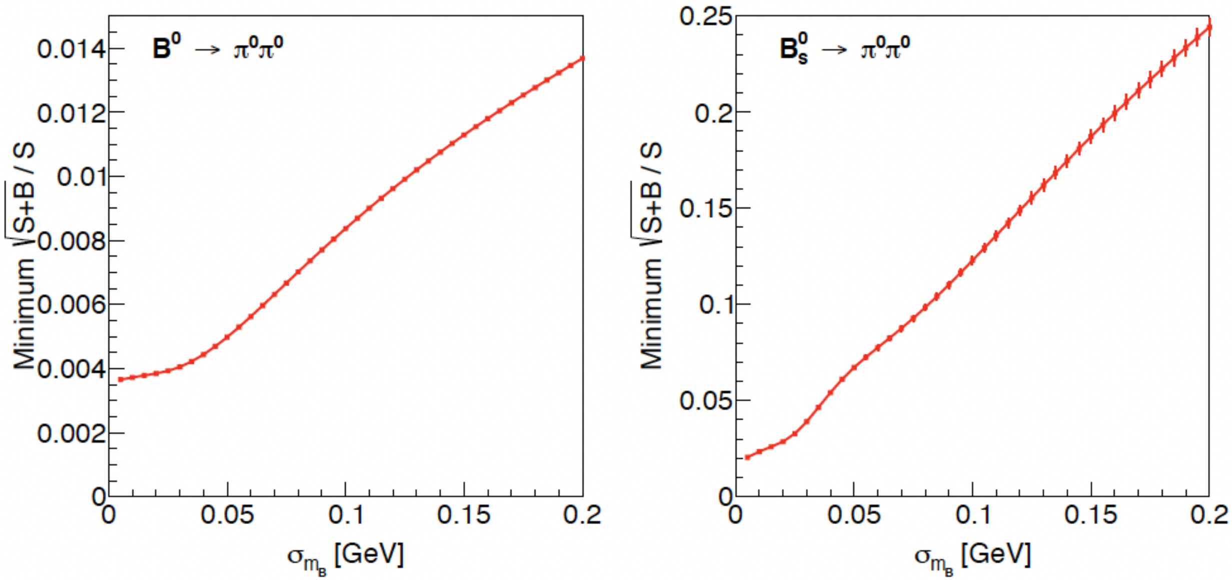
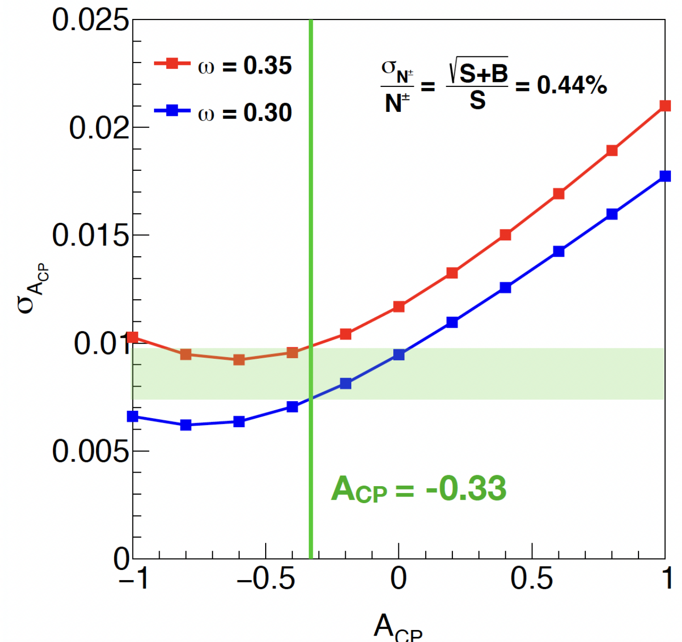
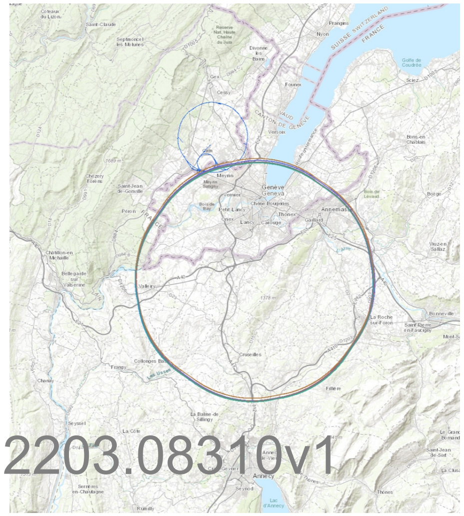


Figure 12: Accuracy of $B^0 \to \pi^0\pi^0$ (left) and $B^0_s \to \pi^0\pi^0$ (right) versus B mass resolution.



- 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)

Other Higgs factories

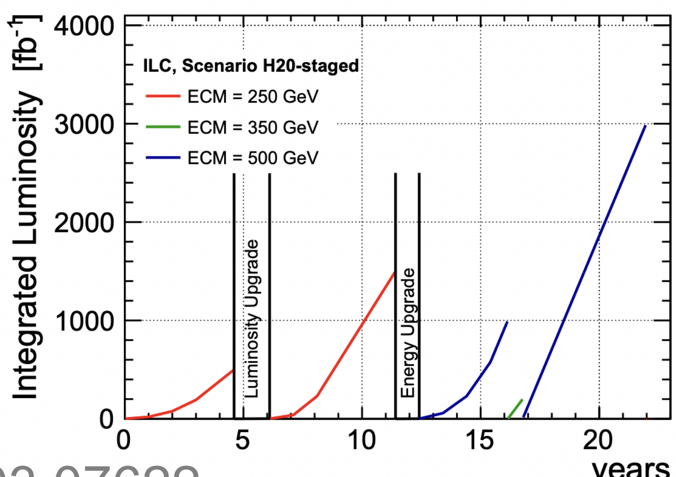


FCC: 2203.08310v1

Table 1: Performance figures of FCC-ee. The ongoing Feasibility Study allows for a 4 IP collider ring with a total integrated luminosity higher by almost a factor 2. For the Z pole (or $t\bar{t}$) running the regular integrated luminosity is show in the table, while over the first two (one) years, the luminosity production is expected to be, on average, about 2 times lower.

c.m. energy [GeV]	lum./ IP [10^{34} cm^{-2}s^{-1}]	int. lum./year (2 IPs) [ab^{-1}/yr]	run time [yr]	power [MW]
91	200	48	4	259
160	20	6	1–2	277
240	7.5	1.7	3	282
365	1.3	0.34	5	354

It is planned to operate the FCC-ee first on the Z pole (91 GeV c.m., 4 years), then on the W threshold (160 GeV, 2 years), on the ZH production peak (240 GeV c.m., 3 years), and, after a 1 year shutdown, at the $t\bar{t}$ threshold (365 GeV, 5 years). In general as the energy is increased and the beam current decreases, additional RF systems are installed with higher RF voltage and higher impedance. As mentioned, an additional optional running mode at 125 GeV c.m. (direct Higgs production), with monochromatization, for a couple of years.



ILC: 2203.07622

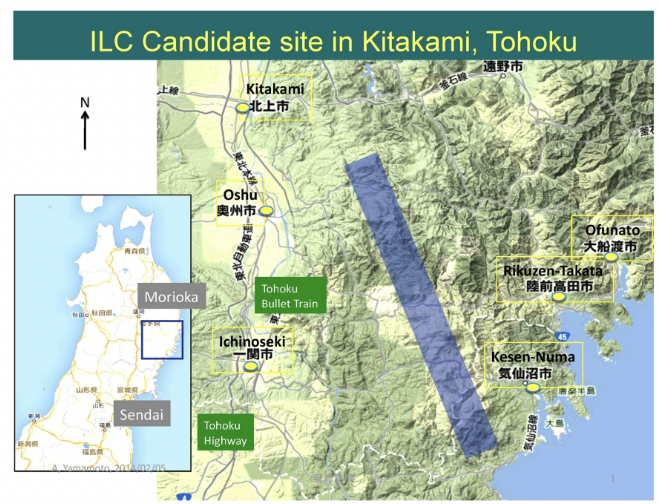
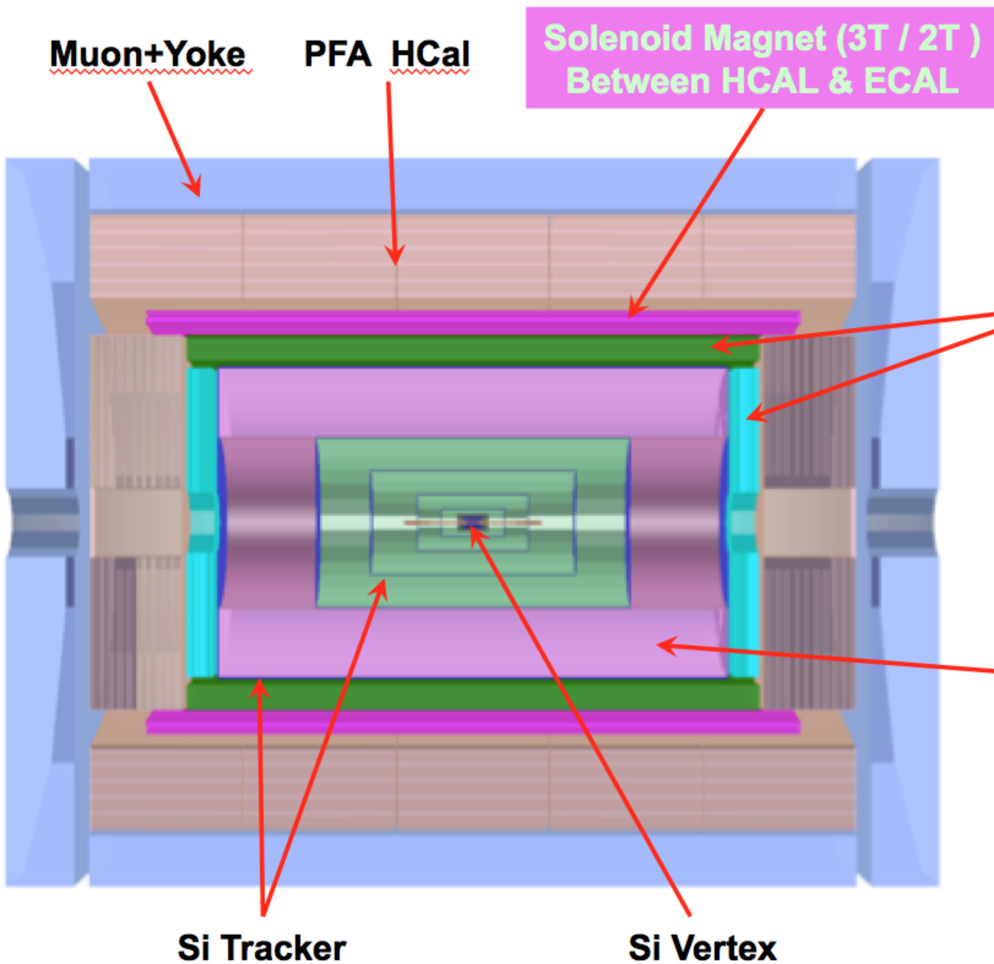


Figure 4.15: The Kitakami candidate site for the ILC [94].

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

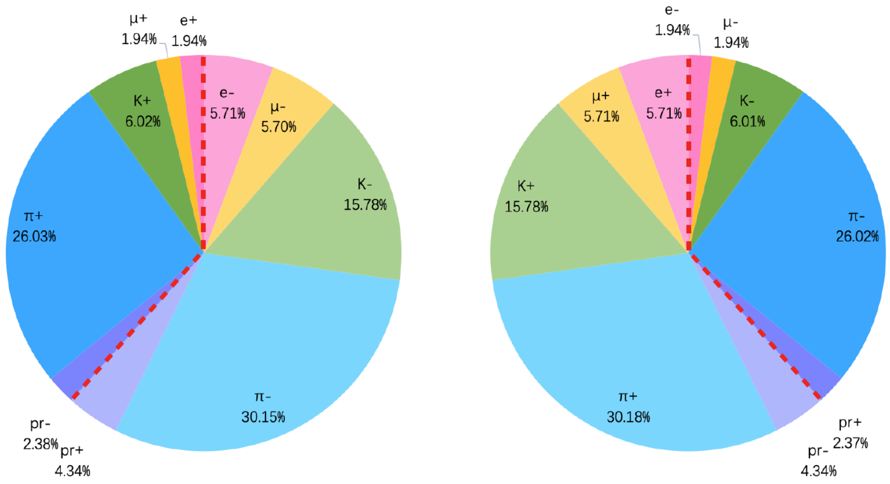
Challenges: sufficient PID power; thin enough not to affect the moment resolution.

6

+ innovative software system...

Jet charge

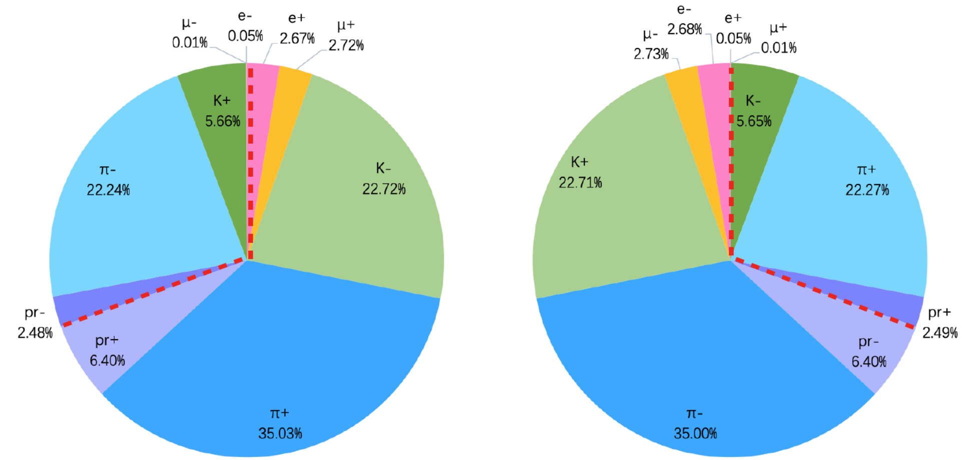
$Z \to b\bar{b}$ Percent of final charged leading particles of b jet and $\bar{b}$ jet



b jet $\quad$ $\bar{b}$ 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 $\quad$ $\bar{c}$ 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...