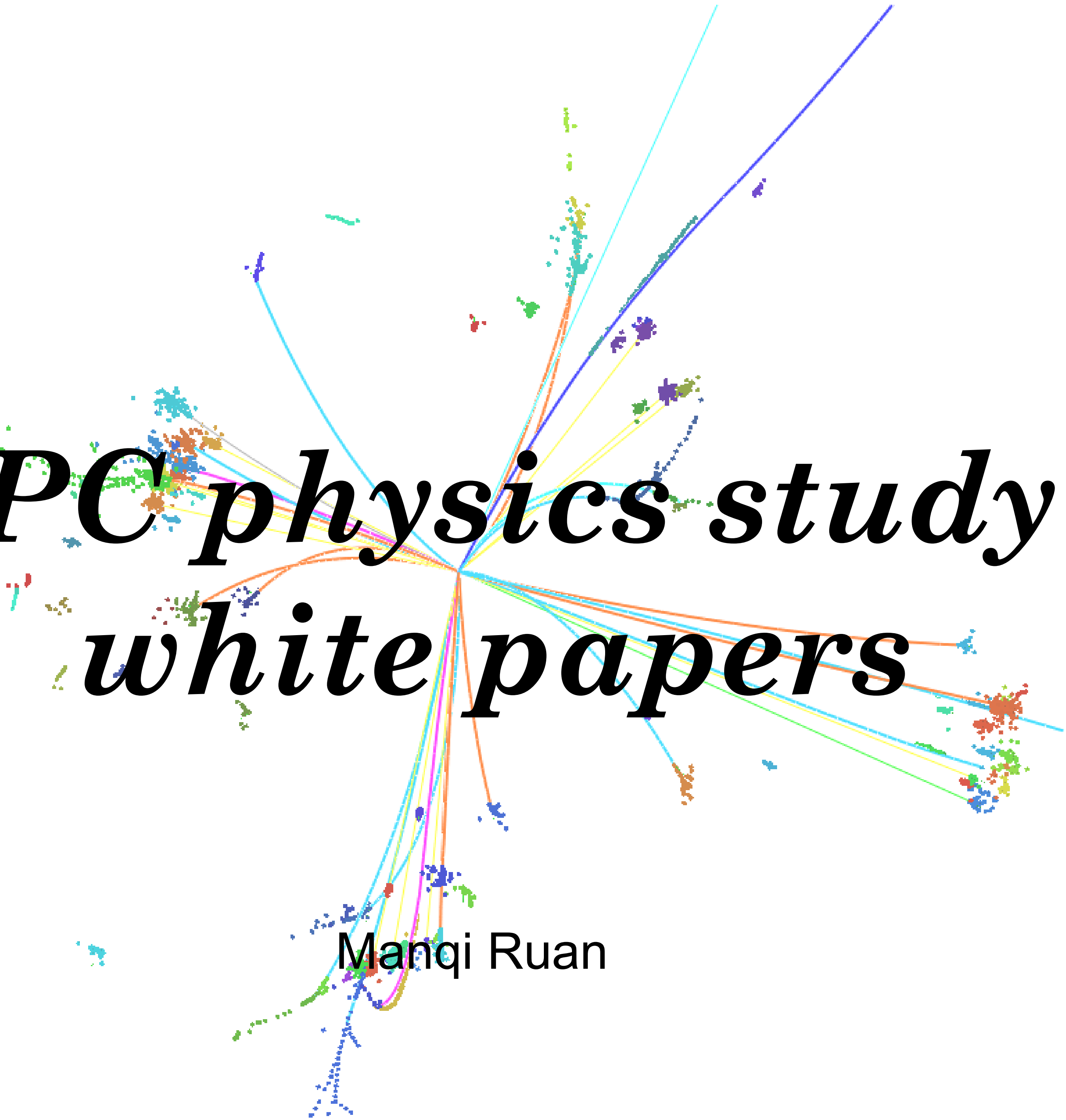
CEPC physics study & white papers



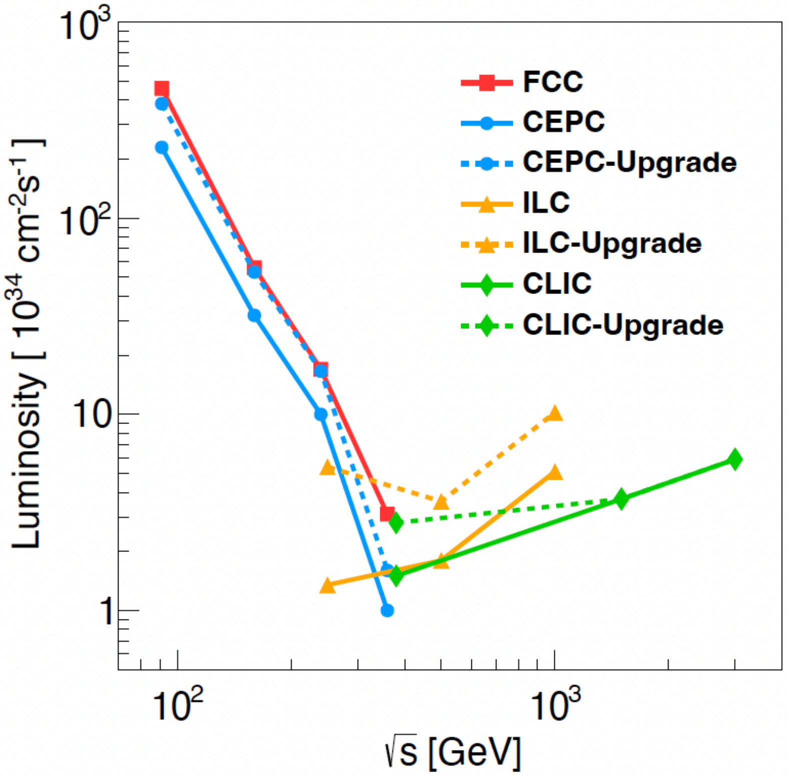
Manqi Ruan

Physics study

- To quantify/enhance the physics merit at the context of global research
- To guide the design - optimization, and key technology R&D
- Identify & illustrate critical topics for future studies
- *In pace with accelerator/detector R&D*

Table 3.1: Main design indicators for the CEPC 30 MW beam power operation scheme

Operation mode	Z	W	Higgs
Center-of-mass energy (GeV)	91	160	240
Operation time (year)	2	1	10
Instantaneous luminosity/IP ($10^{34}\text{cm}^{-2}s^{-1}$)	115	16.0	5.0
Integrated luminosity (ab^{-1}, 2 IPs)	60	3.6	12
Event yield (30 MW)	2.5×10^{12}	1.0×10^{8}	2.5×10^{6}
Event yield (50 MW)	4.0×10^{12}	1.6×10^{8}	4.0×10^{6}



Milestone & Activities

- CDR: 2018
- Higgs white paper: 2019
- Snowmass White paper: 2022
- Flavor white paper anticipated end of 2022
- EW, NP white paper in preparation

- CEPC physics and detector workshops at April/May
- Physics studies at HKIAS
- Physics study at Snowmass
- Communication & collaboration with other Higgs factories & forum, i.e., ECFA studies

o(100) Journal/ArXiv citables

Higgs white paper @ 2019

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

Precision Higgs physics at the CEPC*

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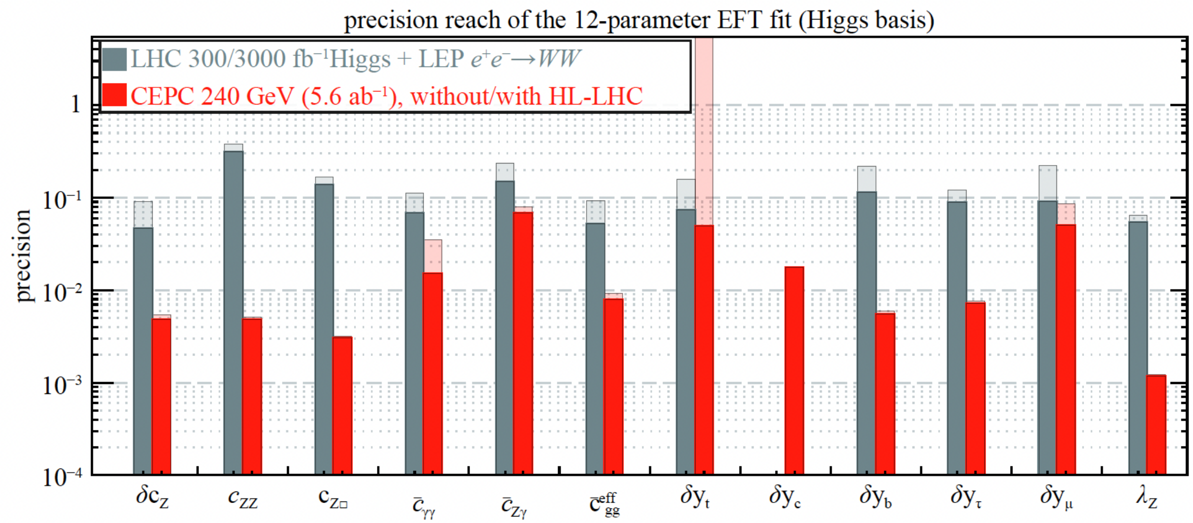
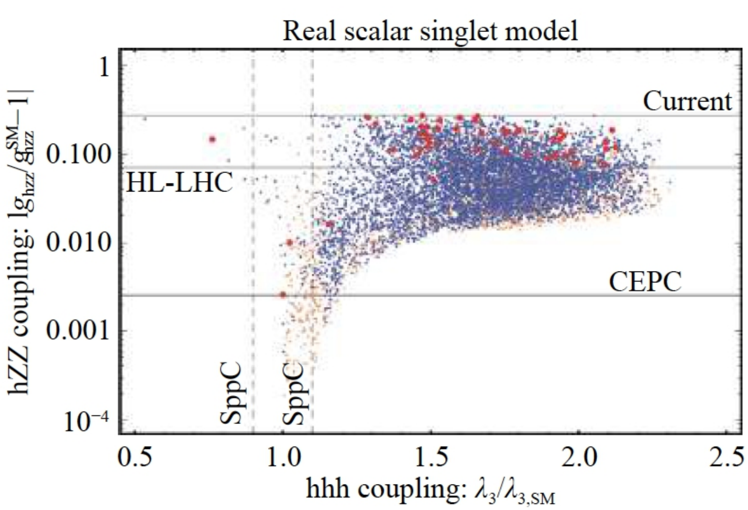
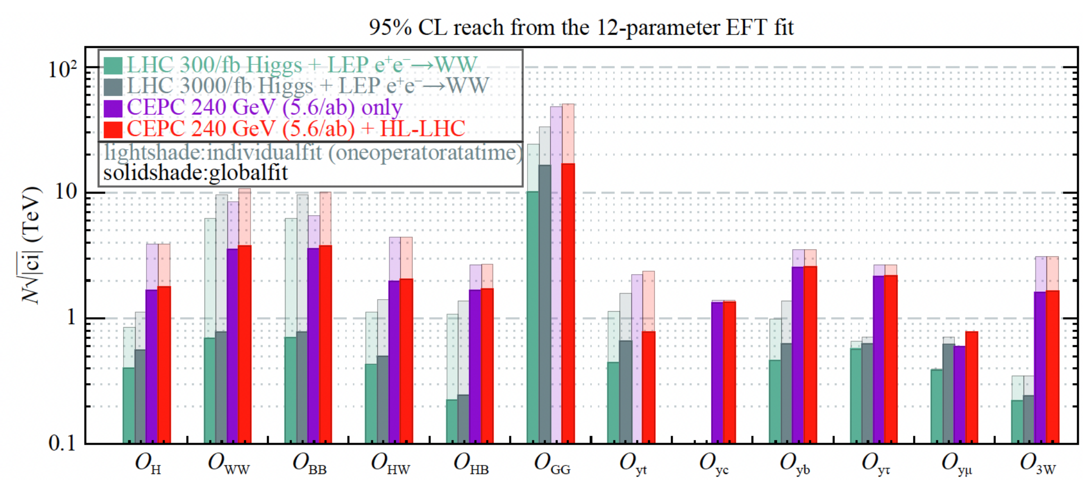
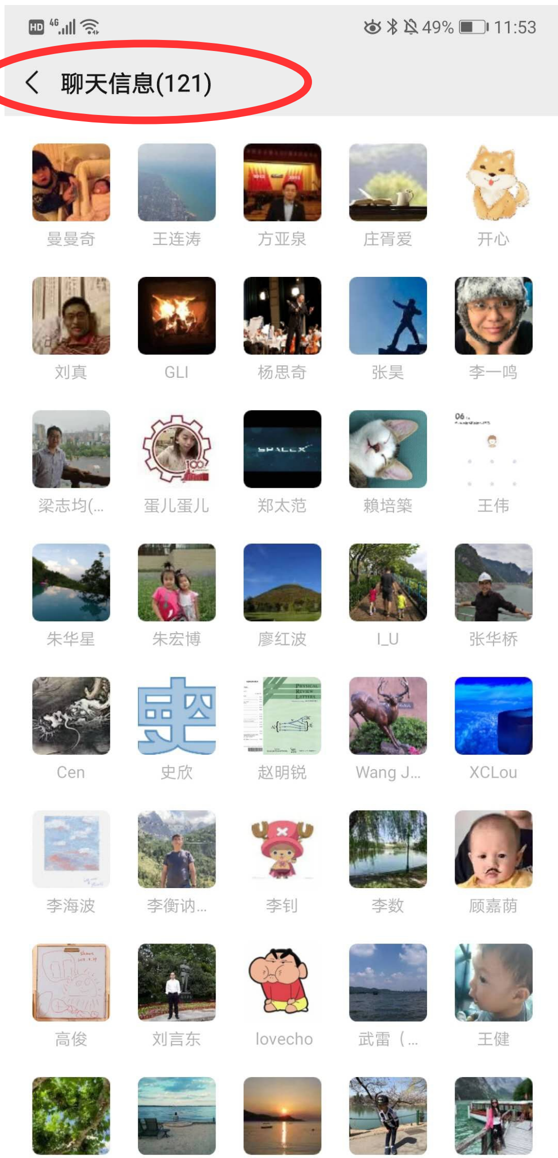


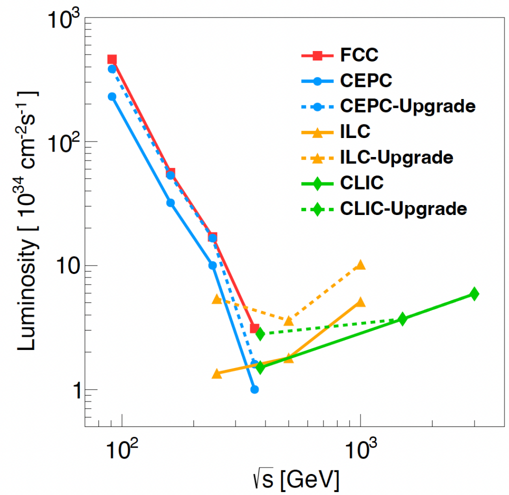




with 5.6 iab @ 240 GeV c.m.s.

CEPC Physics @ Snowmass





CEPC input to the Snowmass 2021 - Physics cases

CEPC Physics Study Group

(Dated: March 28, 2022)

ABSTRACT

The Circular Electron Positron Collider (CEPC) is a large-scale future collider facility that can serve as a factory of the Higgs boson, the W boson and the Z boson, and is upgradable to be also a top-quark factory. This document provides the latest nominal operation scenario and particle yields, and report briefly the physics potential studies. This submission is for the consideration by the Snowmass process.

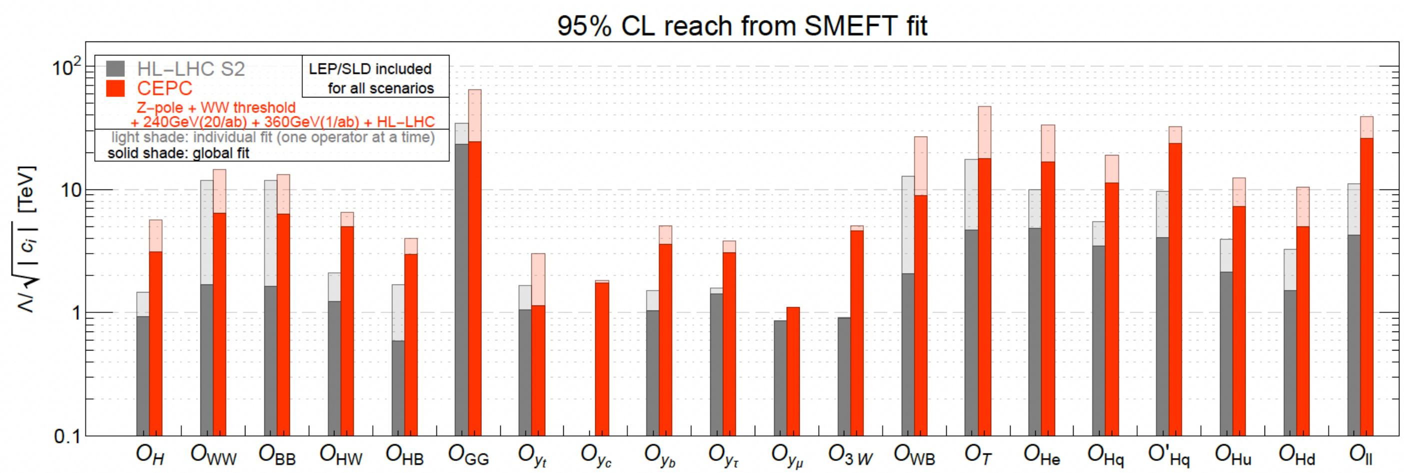
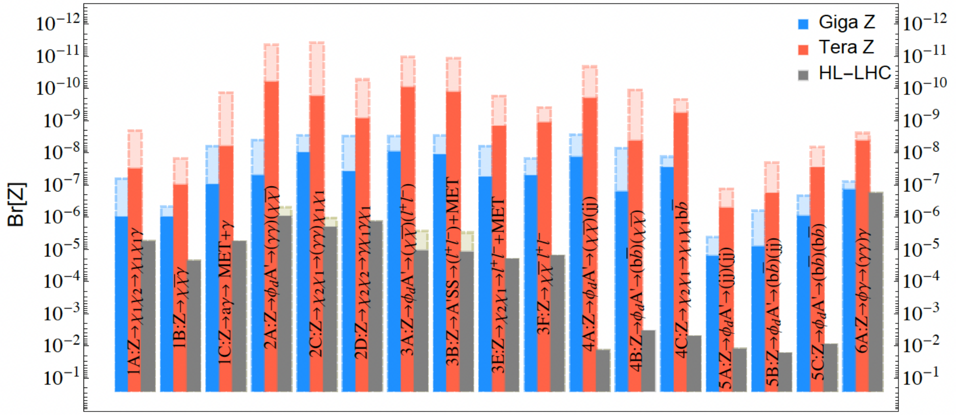


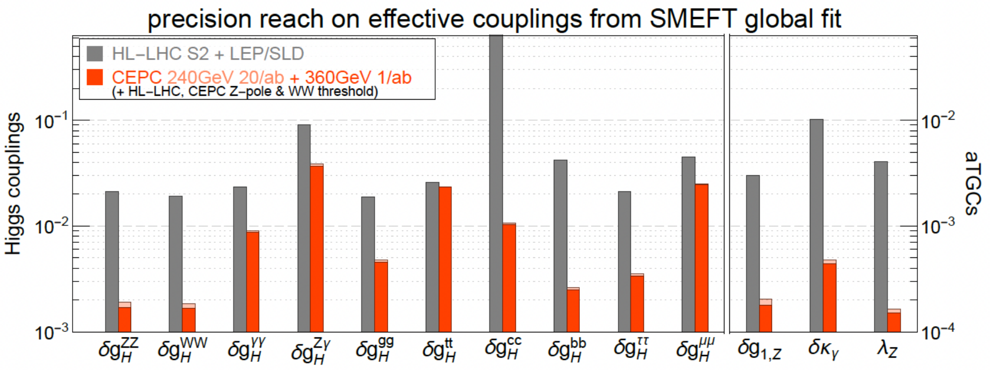
FIG. 3. Reach on new physics scale from SMEFT global fit

CEPC Physics @ Snowmass

Measurement	Current	FCC Projection	Update	Comments
Lifetime [sec]	$\pm 5 \times 10^{-16}$	$\pm 1 \times 10^{-18}$		3-prong decays, stat. limited
$BR(\tau \to \ell\nu\bar{\nu})$	$\pm 4 \times 10^{-4}$	$\pm 3 \times 10^{-5}$		Assumed 0.1× syst.(ALEPH)
$m(\tau)$ [MeV]	± 0.12	$\pm 0.004 \pm 0.1$		$\sigma(\vec{p}_{\rm track})$ limited
$BR(\tau \to 3\mu)$	$< 2.1 \times 10^{-8}$	$\mathcal{O}(10^{-10})$	same	bkg free
$BR(\tau \to 3e)$	$< 2.7 \times 10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau^\pm \to e\mu\mu)$	$< 2.7 \times 10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau^\pm \to \mu ee)$	$< 1.8 \times 10^{-8}$	$\mathcal{O}(10^{-10})$		bkg free
$BR(\tau \to \mu\gamma)$	$< 4.4 \times 10^{-8}$	$\sim 2 \times 10^{-9}$	$\mathcal{O}(10^{-10})$	$Z \to \tau\tau\gamma$ bkg , $\sigma(p_\gamma)$ limited
$BR(\tau \to e\gamma)$	$< 3.3 \times 10^{-8}$	$\sim 2 \times 10^{-9}$		$Z \to \tau\tau\gamma$ bkg, $\sigma(p_\gamma)$ limited
$BR(Z \to \tau\mu)$	$< 1.2 \times 10^{-5}$	$\mathcal{O}(10^{-9})$	same	$\tau\tau$ bkg, $\sigma(\vec{p}_{\rm track})$ & $\sigma(E_{\rm beam})$ limited
$BR(Z \to \tau e)$	$< 9.8 \times 10^{-6}$	$\mathcal{O}(10^{-9})$		$\tau\tau$ bkg, $\sigma(\vec{p}_{\rm track})$ & $\sigma(E_{\rm beam})$ limited
$BR(Z \to \mu e)$	$< 7.5 \times 10^{-7}$	$10^{-8} - 10^{-10}$	$\mathcal{O}(10^{-9})$	PID limited
$Z \to \pi^+\pi^-$			$\mathcal{O}(10^{-10})$	$\sigma(\vec{p}_{\rm track})$ limited, good PID
$Z \to \pi^+\pi^-\pi^0$			$\mathcal{O}(10^{-9})$	$\tau\tau$ bkg
$Z \to J/\psi\gamma$	$< 1.4 \times 10^{-6}$		$10^{-9} - 10^{-10}$	$\ell\ell\gamma$+$\tau\tau\gamma$ bkg
$Z \to \rho\gamma$	$< 2.5 \times 10^{-5}$		$\mathcal{O}(10^{-9})$	$\tau\tau\gamma$ bkg, $\sigma(\vec{p}_{\rm track})$ limited

TABLE III. The summarized projections of τ physics at the Z factory run of FCC-ee [34] and recent updates [42]. Current results are taken from the PDG [43] Absolute precisions are reported instead of relative ones. For $\tau \to 3e$, $\tau \to \mu ee$, and $\tau \to e\mu\mu$ limits, we assume the sensitivities are similar to that of $\tau \to 3\mu$. The expected reaches for several exclusive hadronic Z decays are also listed.





- Covers Higgs, EW, Flavor, NP, etc.
- Updated to the latest ~(TDR) beam parameters,
- Strong collaboration with theory/pheno community and detector design

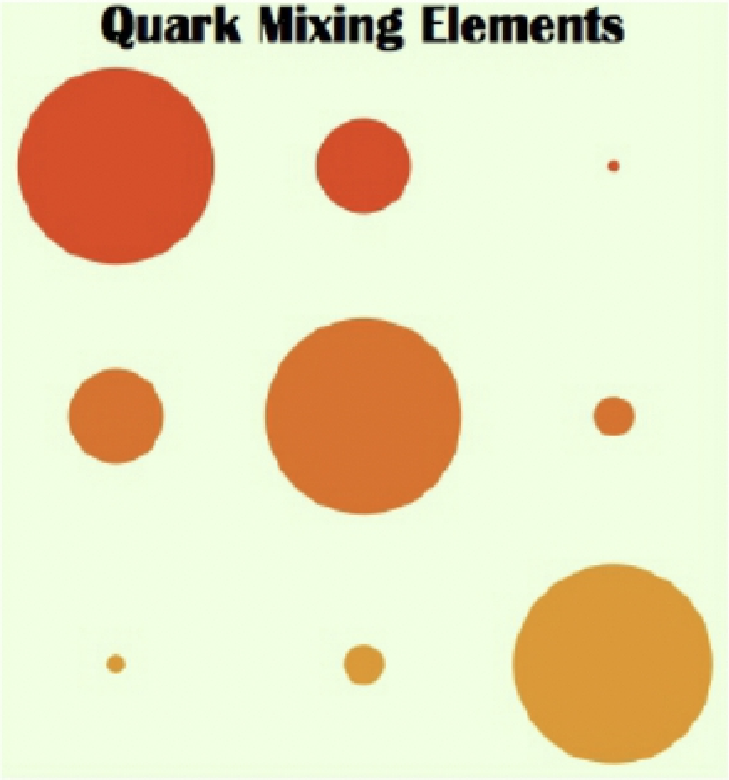
Significant progress & intensive discussions

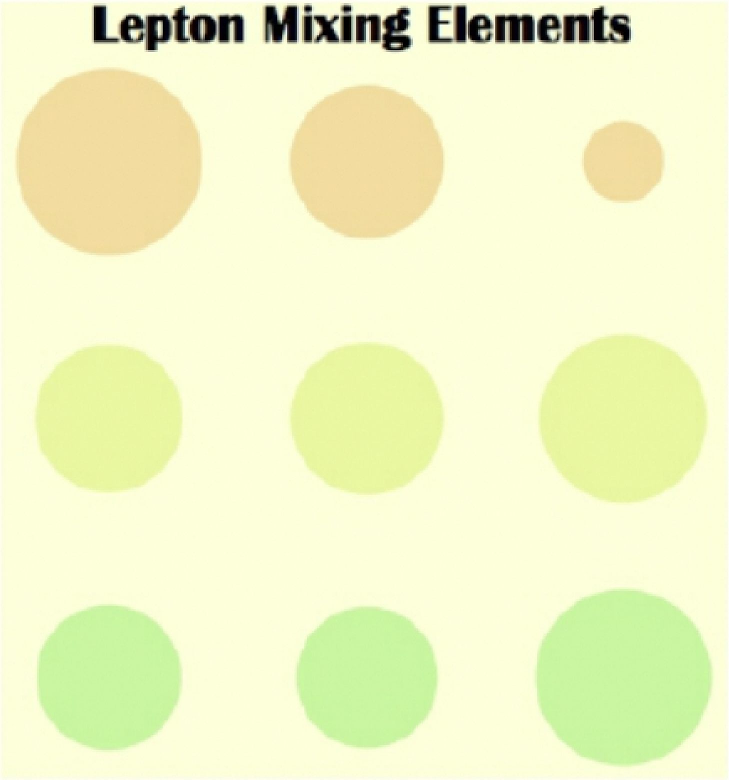
- CEPC workshop 2022
  - Higgs: 13 talks
  - Flavor Physics: 14 talks
  - EW: 7 talks
  - QCD: 9 talks
  - New Physics: 8 talks

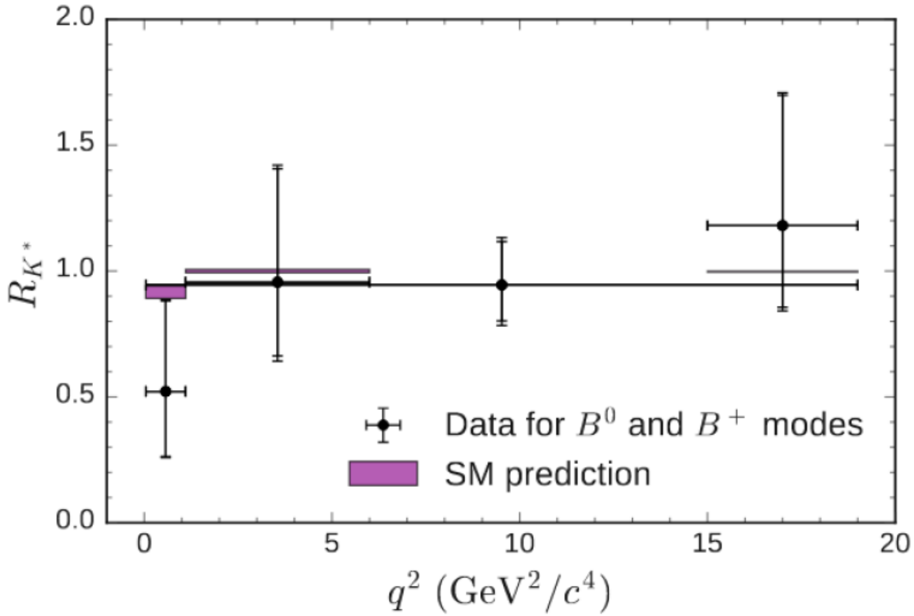
		Monday 24th	Tuesday 25th	Wednesday 26th	Thursday 27th	Friday 28th
Morning	10:00 - 12:00	Higgs, Silicon, Accelerator, CIPC	Flavor, Calorim., Accelerator	EW+tt, Gaseous, Accelerator	QCD, PID+other, Accelerator	Perform., Offline, MDI
	12:00-13:30	Lunch break	Lunch break	Lunch break	Lunch break	Lunch break
Afternoon	13:30-15:30	Higgs, Silicon, Accelerator, CIPC	Flavor, Calorim., Accelerator	EW+tt, Gaseous, Accelerator	BSM, Accelerator, TDAQ	Offline, MDI
	15:30-16:00	Coffee break	Coffee break	Coffee break	Coffee break	Coffee break
	16:00-18:00	Higgs, Silicon, Accelerator, CIPC	Flavor, Calorim., Accelerator	QCD, PID+other, Accelerator	BSM, PID+other, Accelerator, TDAQ	Posters
	18:00-20:00	Dinner	Dinner	Dinner	Dinner	Dinner
Evening	20:00-21:30	Plenary		Posters		Plenary
	21:30-22:00	Coffee break				Coffee break
	22:00-23:30	Plenary				Plenary

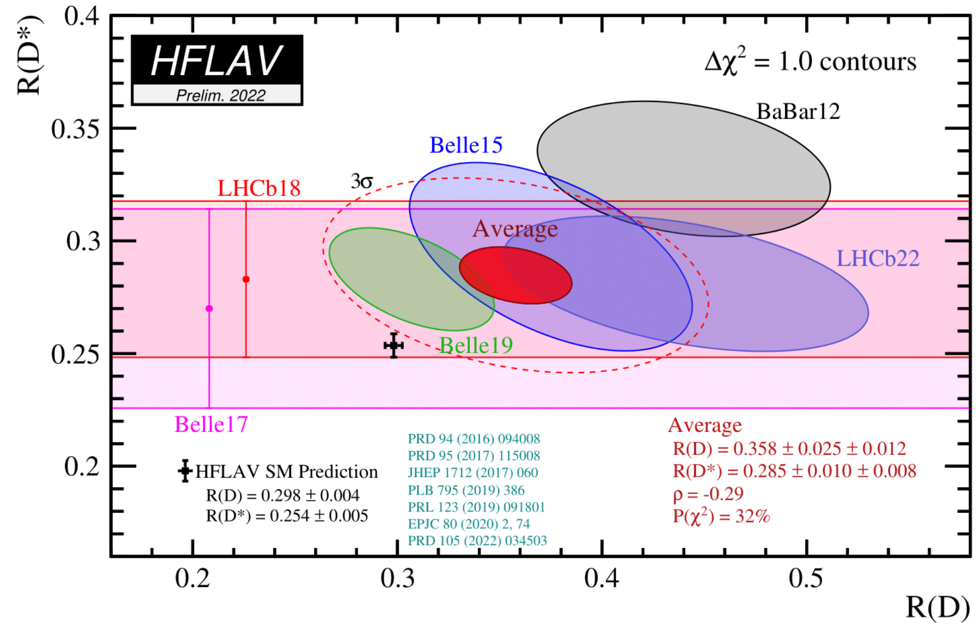
- Provide critical input to the ESPPU/Snowmass, etc
- Invited talk at FPCP, LHCP, eeFACT, etc
- Collaboration with ILC/FCC, actively joining the studies at ECFA workshop, etc
- Strong support from HKIAS

Flavor Physics





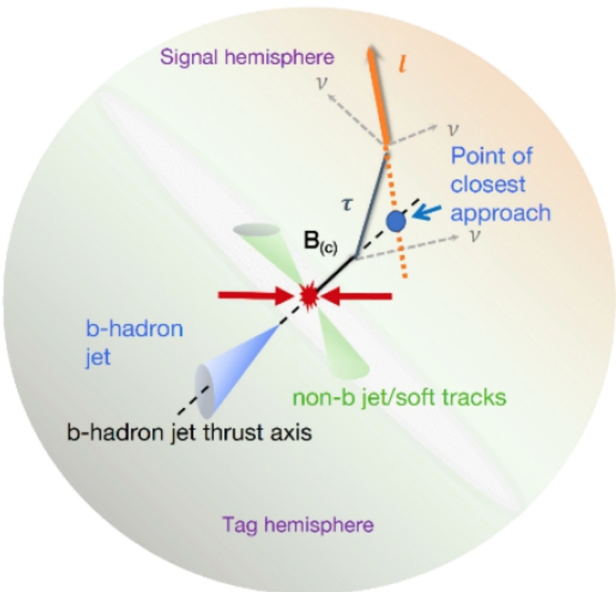




	Experimental	SM Prediction	Comments
R_K	$0.745^{+0.090}_{-0.074} \pm 0.036$	1.00 ± 0.01	$m_{\ell\ell} \in [1.0, 6.0]$ GeV^2, via $B^\pm$.
R_{K^*}	$0.69^{+0.12}_{-0.09}$	0.996 ± 0.002	$m_{\ell\ell} \in [1.1, 6.0]$ GeV^2, via B^0.
R_D	0.340 ± 0.030	0.299 ± 0.003	B^0 and $B^\pm$ combined.
R_{D^*}	0.295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

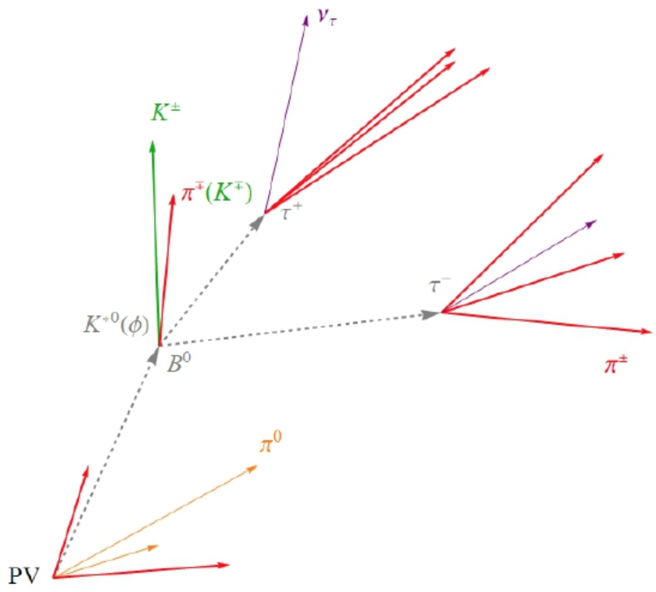
[Tanabashi et al., 2018][Altmannshofer et al., 2018].

Current Progress in LFU Tests



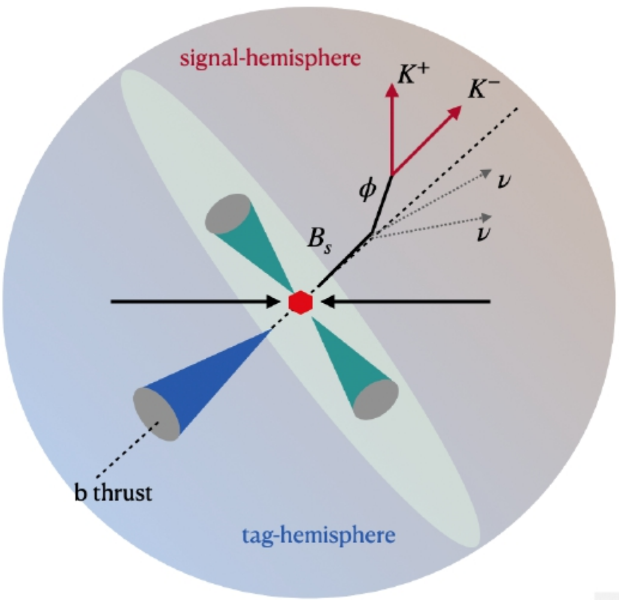
Charged current $B_c \to \tau\nu$ decays [Zheng et al., 2020b].

Absolute precision $\sim 10^{-4}$.



Neutral current $b \to s\tau\tau$ decays [Li and Liu, 2020].

Absolute precision $\lesssim 10^{-6}$: $\sim 10^3 - 10^4$ improvement from current limits.



Neutral current $B_s \to \phi\nu\bar{\nu}$ decay [In preparation]

Absolute precision $\sim 10^{-7}$.

Unique opportunities at the Z-pole

Bs→Φvv

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

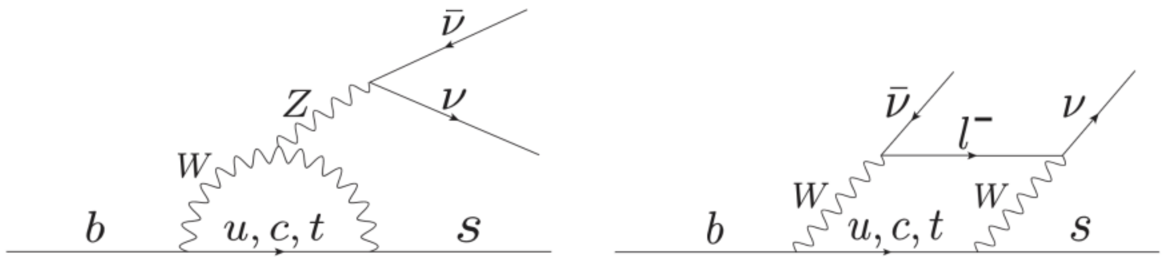
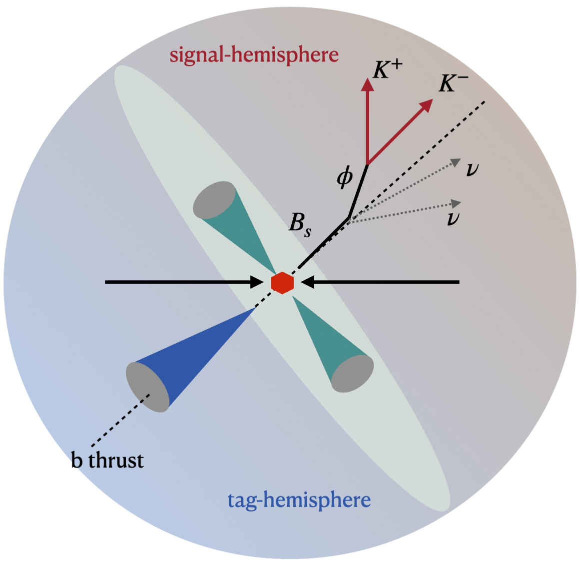
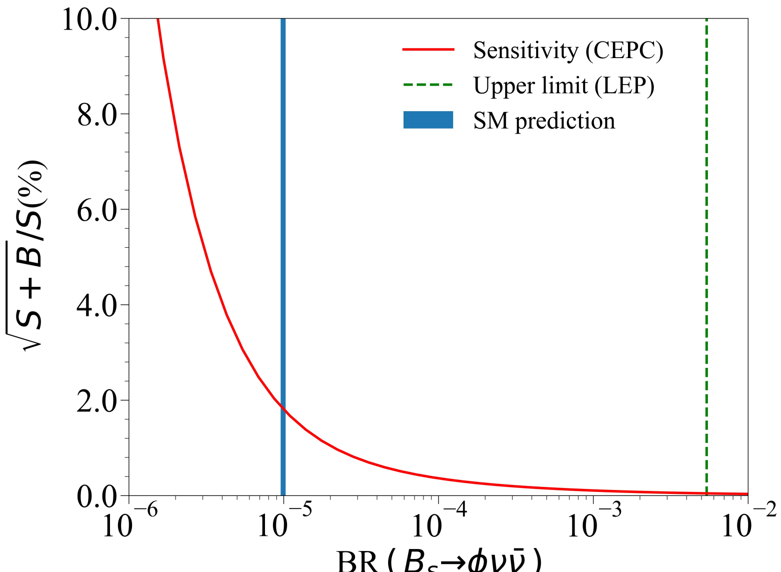


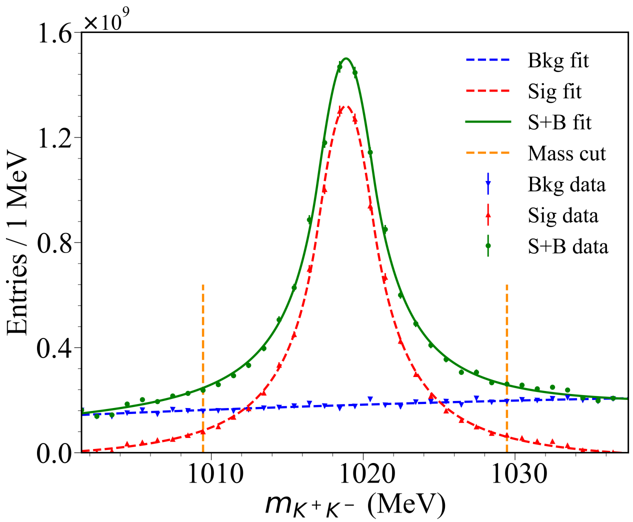
FIG. 1. The penguin and box diagrams of $b \to s\nu\bar{\nu}$ transition at the leading order.

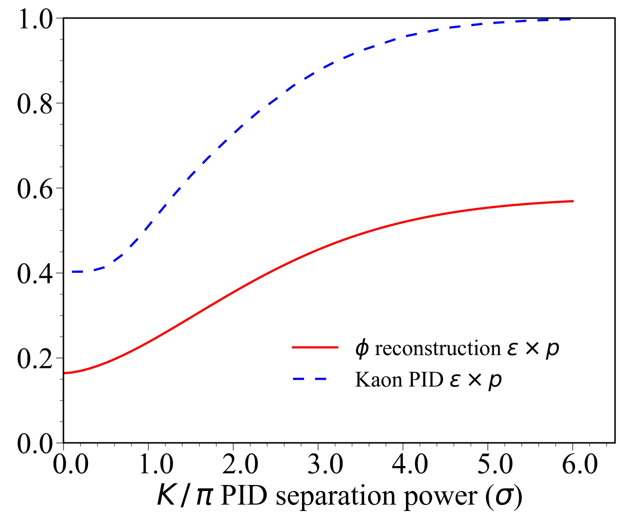


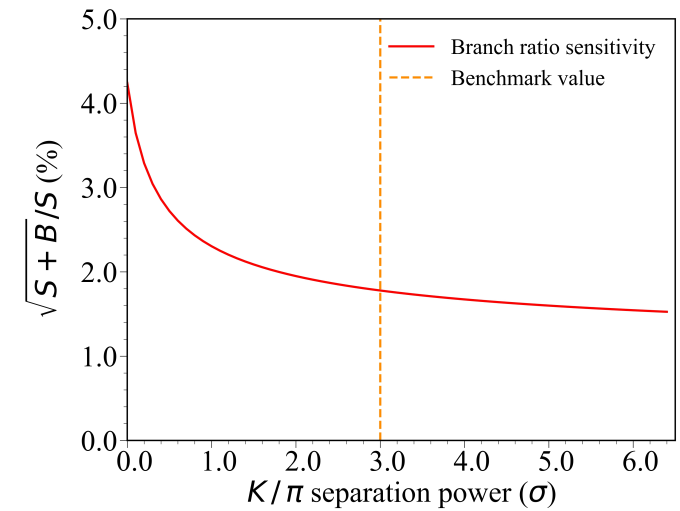
- Key ingredient to understand FCNC anomaly...
- Critical Physics Objects: Phi (and charged Kaon), 2nd VTX, Missing E/P, b-jet at opposite side
- Percentage level accuracy anticipated at Tera-Z

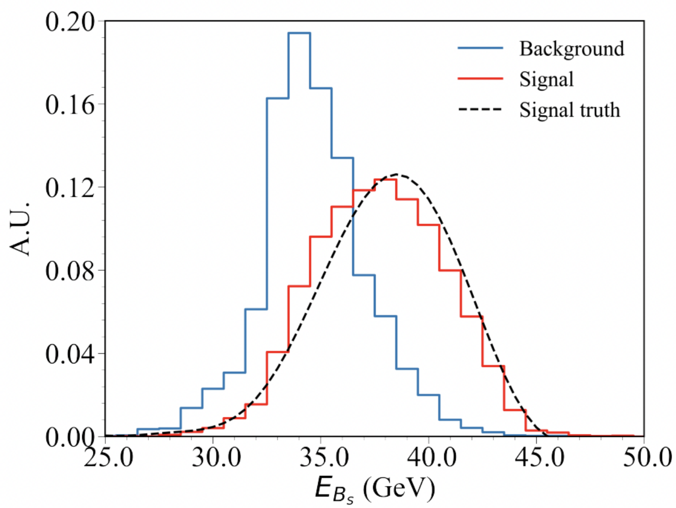


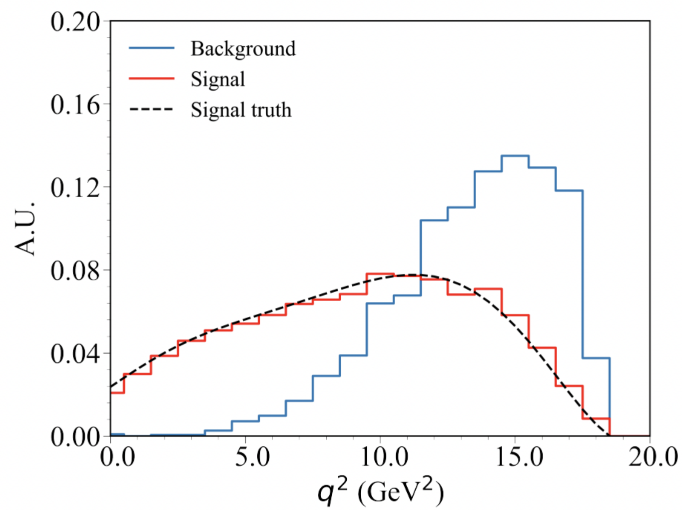
Bs→Φvv











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

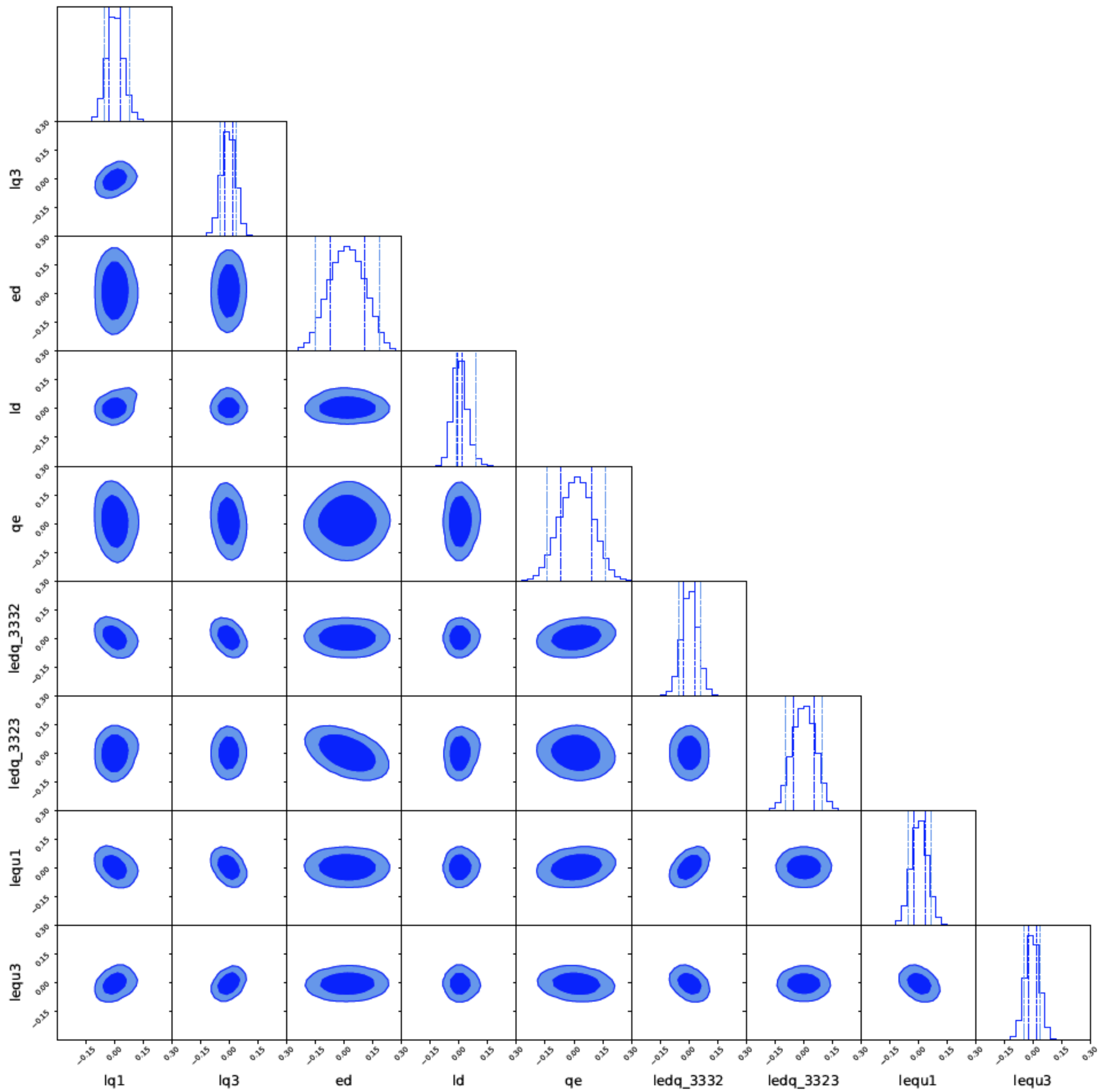
$$M_{\text{sig}}^{(i)} = \sqrt{\left(\sum p_{\text{sig}}^{\text{vis}} + p_{B_s}^{(i-1)} - p_\phi\right)^2},$$

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

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

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-

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

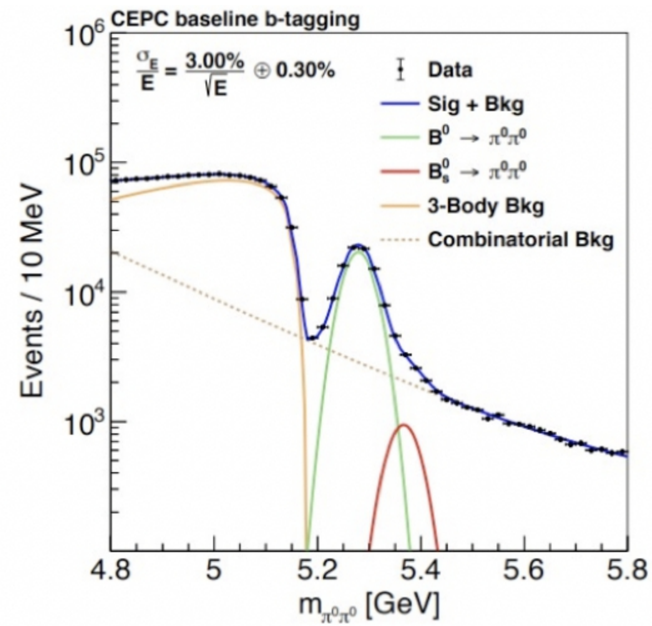
Journal of High Energy Physics **2021**, Article number: 64 (2021) | Cite this article

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.

Access to NP ~ 10 TeV

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



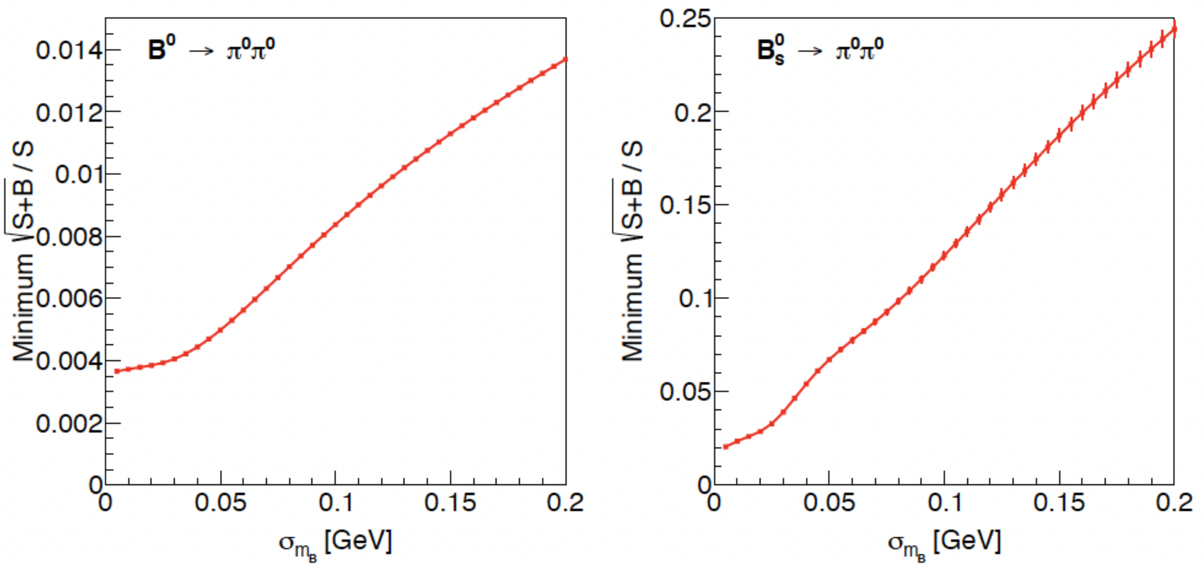


Figure 12: Accuracy of $B^0 \to \pi^0\pi^0$ (left) and $B_s^0 \to \pi^0\pi^0$ (right) versus B mass resolution.

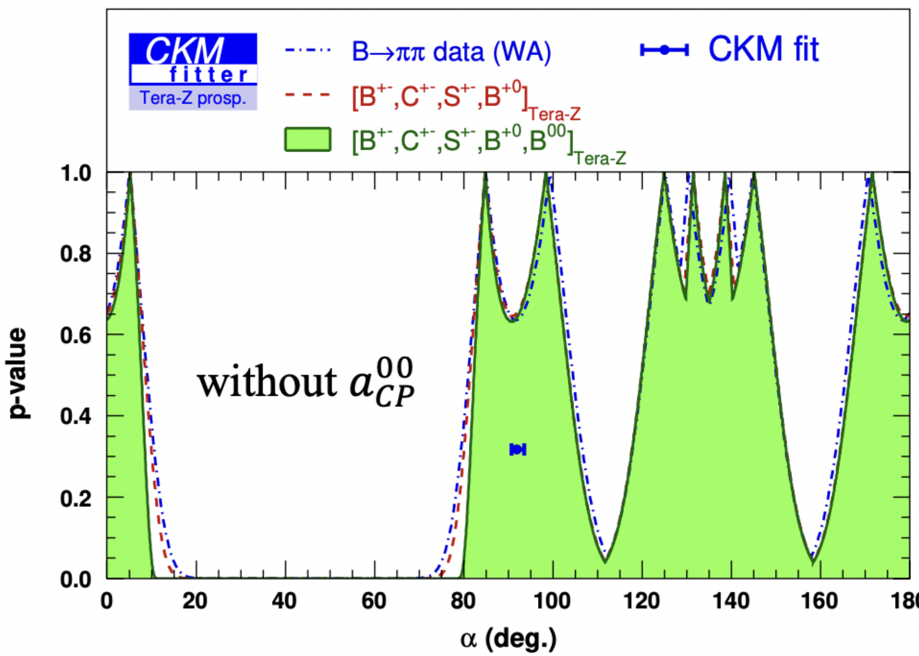
- Provide sub percentage level accuracies on B0->2 pi0, 40/5 times than current world average & Belle II anticipation, have a strong impact on the CKM angle (alpha measurements), discover the other three modes for the 1st time.
- Strongly depends on the b-tagging performance (baseline is good enough)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

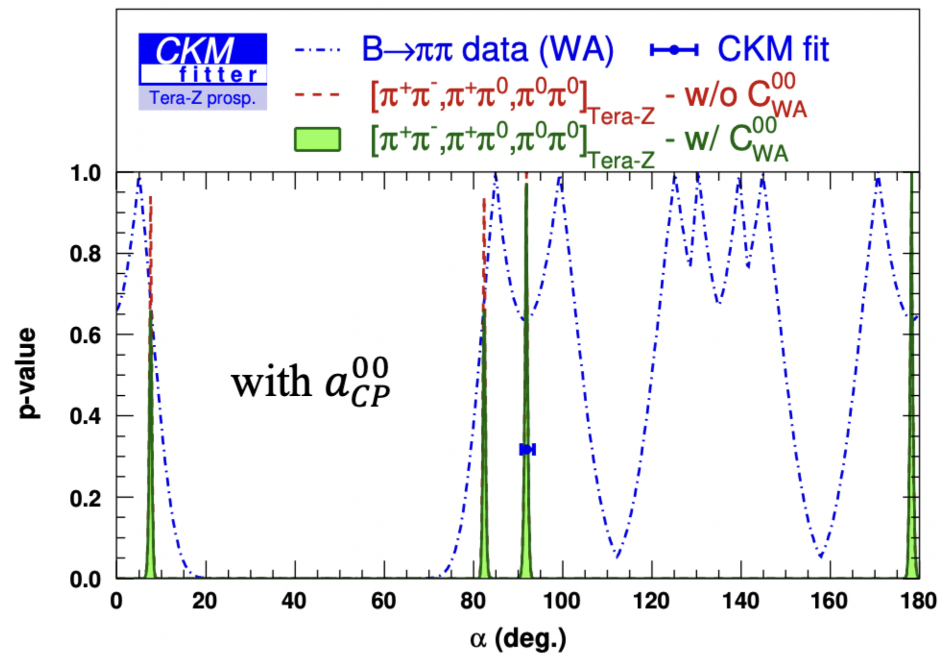
CKM global fit

- Scenario 2: improve all three $B\rightarrow \pi\pi$ modes to Tera-Z projection
  - a_{CP}^{00} and C_{CP}^{00} are central in this improvement
  - Final precision of α:

$$\text{Tera-}Z\text{ scenario 2}: \alpha(\pi\pi) = (91.8 \pm 0.4)^\circ$$

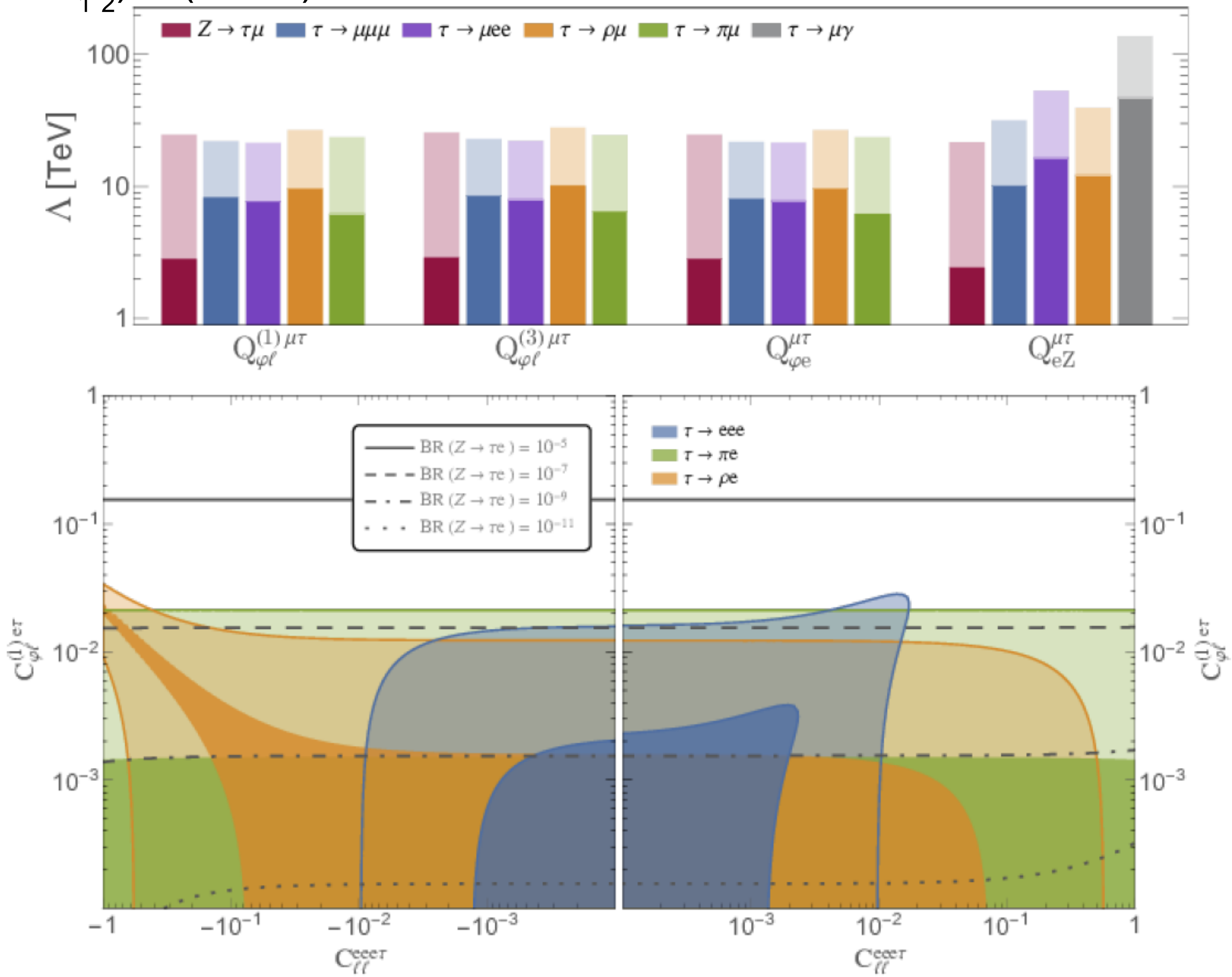
- Need to emphasize:
  - Central values matter a lot.
    - Other values can be seen in [arXiv:2208.08327]
  - Theoretical systematic uncertainties (isospin related) ~ 1-2°, need to reevaluate





Lepton Flavor Violation (II)

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



[Calibbi et al., 2021] 2107.10273

τ Physics [Dam (2019)]

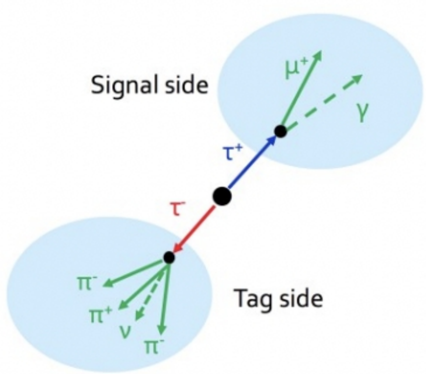
See also: [Dam (2021); Pich (2014); Celis et al. (2014); Calibbi and Signorelli (2018)]

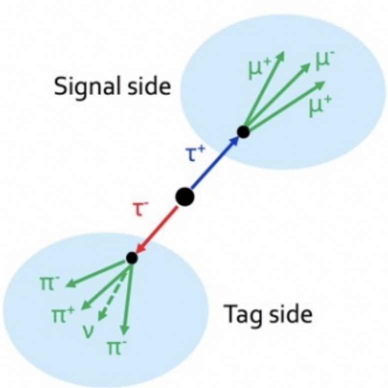
Z factory produces $\sim \mathcal{O}(10^{10})$ $\tau^+\tau^-$ pairs from $Z \to \tau^+\tau^-$

- Measuring BR($\tau \to \ell\nu\bar{\nu}$)
  Improvement: $\sim \mathcal{O}(10^2)$
- Measuring τ lifetime
  Improvement: $\sim \mathcal{O}(10^3)$

Observable	Present value $\pm$ error	FCC-ee stat.	FCC-ee syst.
m_τ (MeV)	1776.86 ± 0.12	0.004	0.1
$\mathcal{B}(\tau \to e\bar{\nu}\nu)$ (%)	17.82 ± 0.05	0.0001	0.003
$\mathcal{B}(\tau \to \mu\bar{\nu}\nu)$ (%)	17.39 ± 0.05	0.0001	0.003
τ_τ (fs)	290.3 ± 0.5	0.001	0.04

- Measuring BR($\tau \to 3\mu$) and BR($\tau \to \mu\gamma$)
  Improvement: $\sim \mathcal{O}(10 - 10^2)$

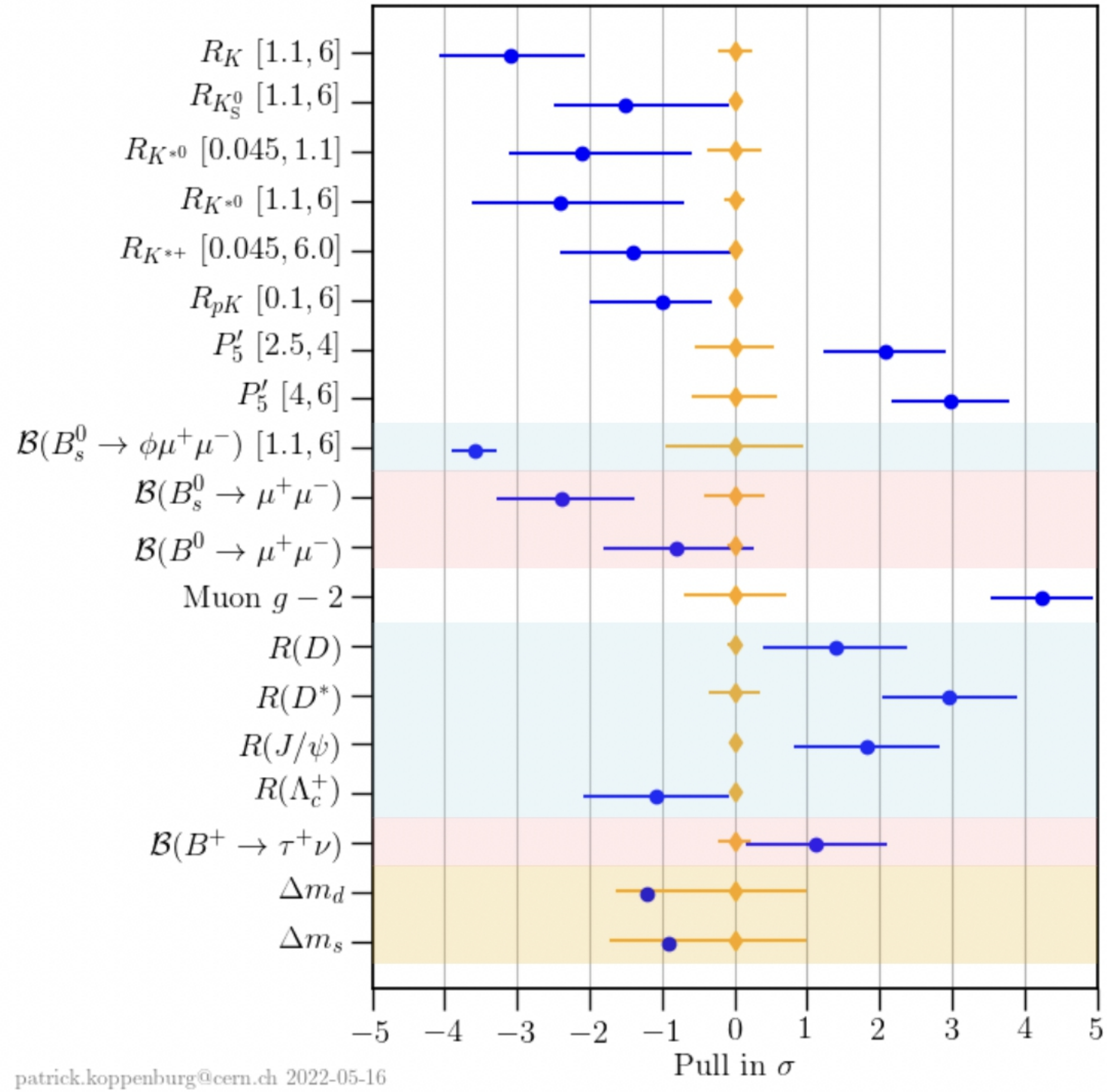




Decay	Present bound	FCC-ee sensitivity
$Z \to \mu e$	0.75×10^{-6}	10^{-10}–10^{-8}
$Z \to \tau\mu$	12×10^{-6}	10^{-9}
$Z \to \tau e$	9.8×10^{-6}	10^{-9}
$\tau \to \mu\gamma$	4.4×10^{-8}	2×10^{-9}
$\tau \to 3\mu$	2.1×10^{-8}	10^{-10}

Flavor Anomalies — Summary

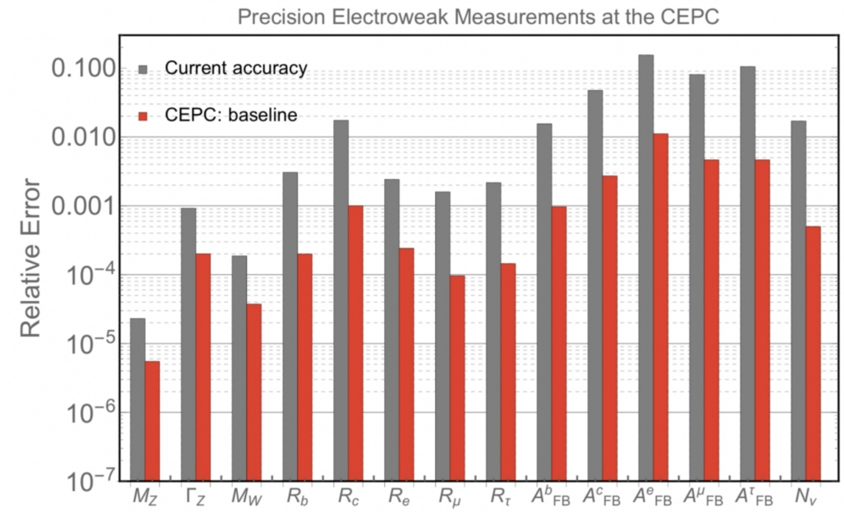
- Many rely on QCD input:
  - decay constants;
  - form factors;
  - four-quark operators.
- (Angular observables and LFUV profit from, but don't rely on, form factors.)
- Plot by Patrick Koppenburg (LHCb).



See Andreas S. Kronfeld's talk:
https://indico.ihep.ac.cn/event/17020/contributions/119667/attachments/64311/75120/cepc.pdf

EW Physics

Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z \to \tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [37, 53]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z \to \mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [37, 51–55]	7.0×10^{-5} (1.2×10^{-5})	Z pole ($Z \to \tau\tau$)	tau decay model
ΔA_b	0.02 [37, 56]	20×10^{-5} (3×10^{-5})	Z pole	QCD effects
ΔA_c	0.027 [37, 56]	30×10^{-5} (6×10^{-5})	Z pole	QCD effects
$\Delta\sigma_{had}$	37 pb [37–41]	2 pb (0.05 pb)	Z pole	lumiosity
δR_b^0	0.003 [37, 57–61]	0.0002 (5×10^{-6})	Z pole	gluon splitting
δR_c^0	0.017 [37, 57, 62–65]	0.001 (2×10^{-5})	Z pole	gluon splitting
δR_e^0	0.0012 [37–41]	2×10^{-4} (3×10^{-6})	Z pole	E_{beam} and t channel
δR_μ^0	0.002 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δR_τ^0	0.017 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δN_ν	0.0025 [37, 66]	2×10^{-4} (3×10^{-5})	ZH run ($\nu\nu\gamma$)	Calo energy scale



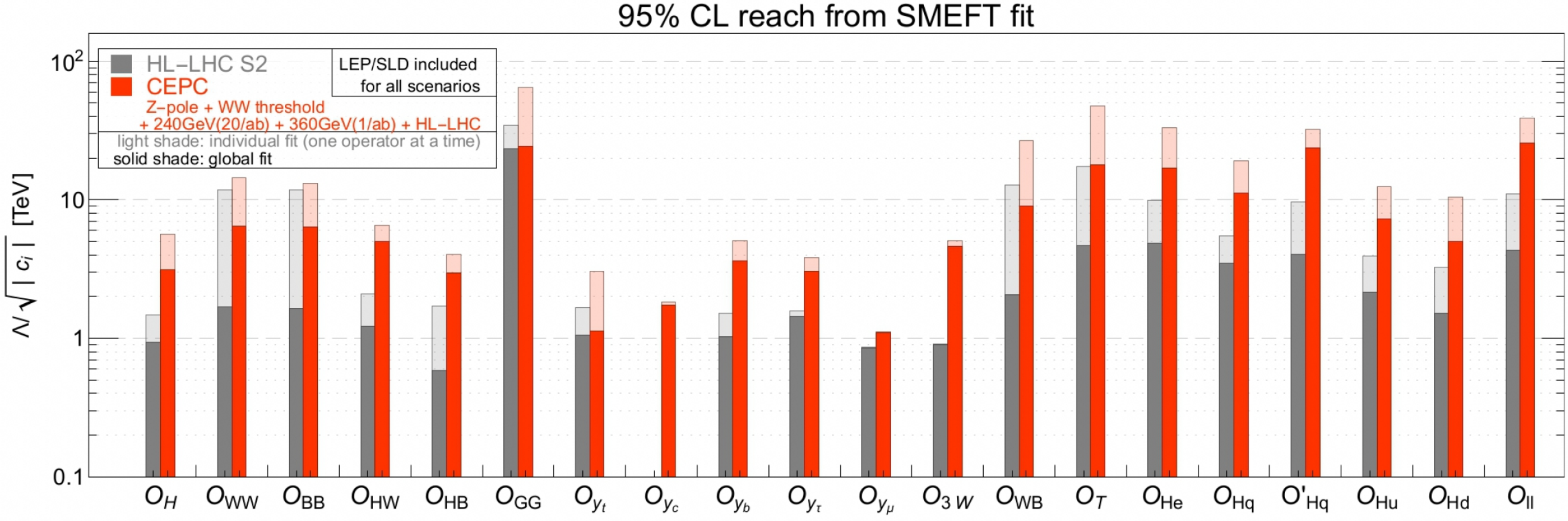
Fundamental constant	δx/x	measurements
$\alpha = 1/137.035999139\,(31)$	1×10^{-10}	$e^\pm\, g_2$
$G_F = 1.1663787\,(6) \times 10^{-5}$ GeV^{-2}	1×10^{-6}	$\mu^\pm$ lifetime
$M_Z = 91.1876 \pm 0.0021$ GeV	1×10^{-5}	LEP
$M_W = 80.379 \pm 0.012$ GeV	1×10^{-4}	LEP/Tevatron/LHC
$\sin^2\theta_W = 0.23152 \pm 0.00014$	6×10^{-4}	LEP/SLD
$m_{top} = 172.74 \pm 0.46$ GeV	3×10^{-3}	Tevatron/LHC
$M_H = 125.14 \pm 0.15$ GeV	1×10^{-3}	LHC

- With increased luminosity, CEPC expect to have 1~2 order of magnitude better than current precision
- Great opportunity to test the consistency of SM EWK sector.

Global Fit with SMEFT

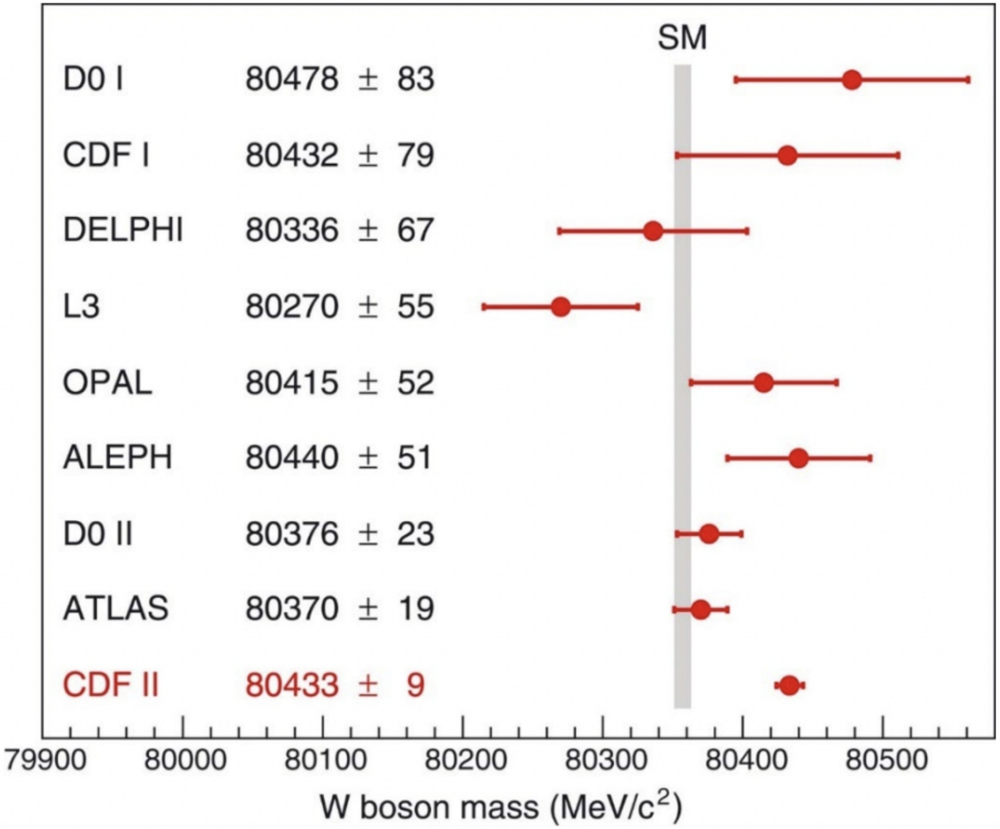
- Combined measurement from EWK and Higgs properties to constrain higher dimension operators in SMEFT

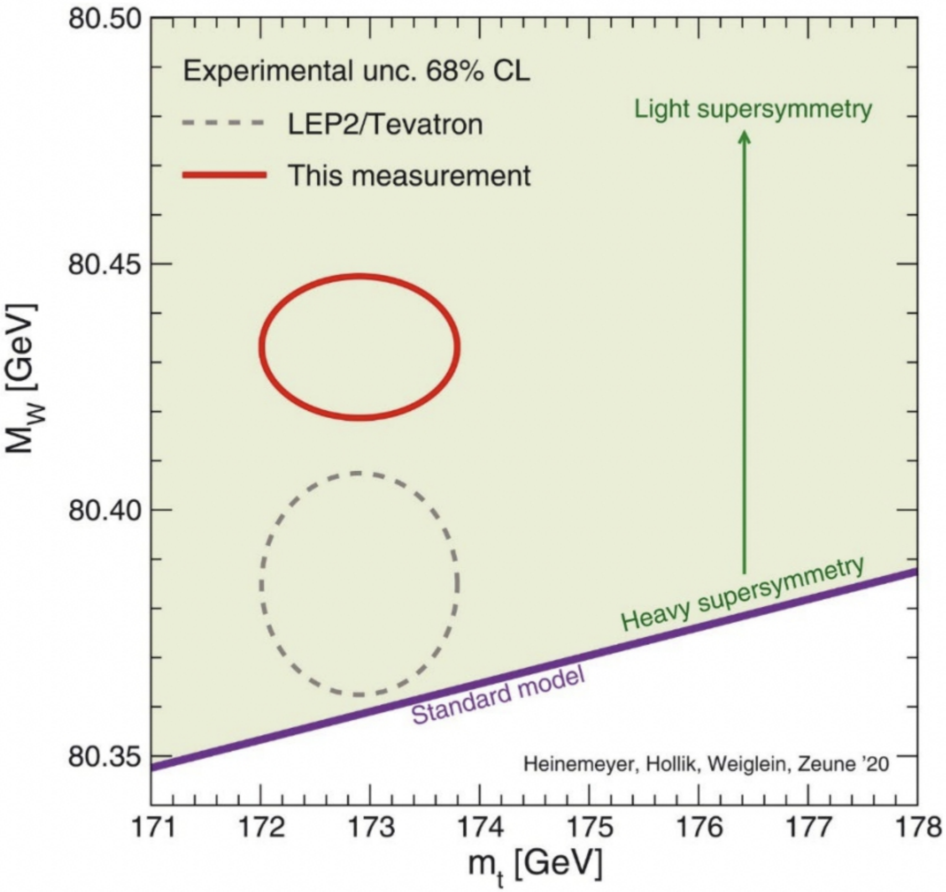
$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4}\mathcal{O}_j^{(8)} + \cdots$$



- EW precision measurements (including top observables): essential for the global interpretation

W Boson Mass



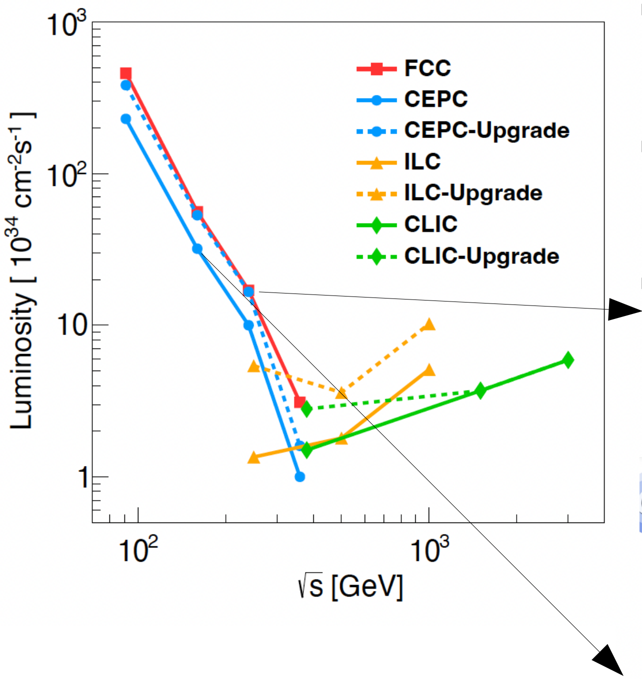


SM prediction: $M_W = 80{,}357 \pm 6$ MeV

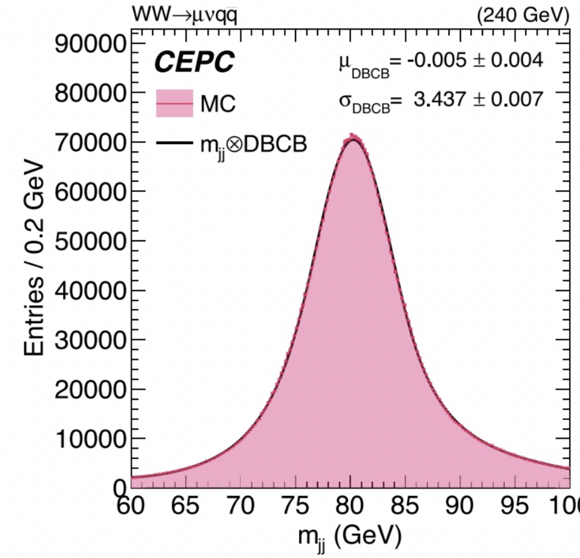
Previous world average: $M_W = 80{,}379 \pm 12$ MeV

A discrepancy of $\sim 7\sigma$ between the measurement and the SM prediction.

W boson mass measurement



- Perform measurement in ZH run
- Expected 2-3 MeV uncertainty on *W* boson mass using two lvqq process at 240 GeV
- About <10 MeV achieved with only μvqq event from 5 ab^{-1} from JINST 16 P07037
- Further studies ongoing

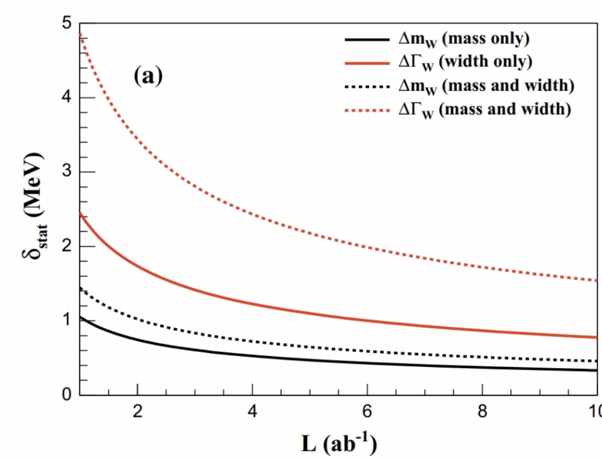


W boson mass measurement

- Joint effort of CEPC/FCC-ee to optimize WW threshold scan data taking strategy
- Assuming 1 year data taking with 2.6 ab^{-1} luminosity (updated design propose x2)
- Expected to reach 1 MeV precision for mW
- Could be further improved with updated calibration method for beam energy
  - With inverse-compton scattering for beam energy calibration, could further reduce systematic uncertainty (Nucl. Instrum. Meth. A 1026 (2022) 166216, Rev. Sci. Instrum. 91 no. 3, (2020) 033109)

Observable	m_W	Γ_W
Source	Uncertainty (MeV)	
Statistics	0.8	2.7
Beam energy	0.4	0.6
Beam spread	–	0.9
Corr. syst.	0.4	0.2
Total	1.0	2.8

Eur. Phys. J. C 80, 66 (2020)

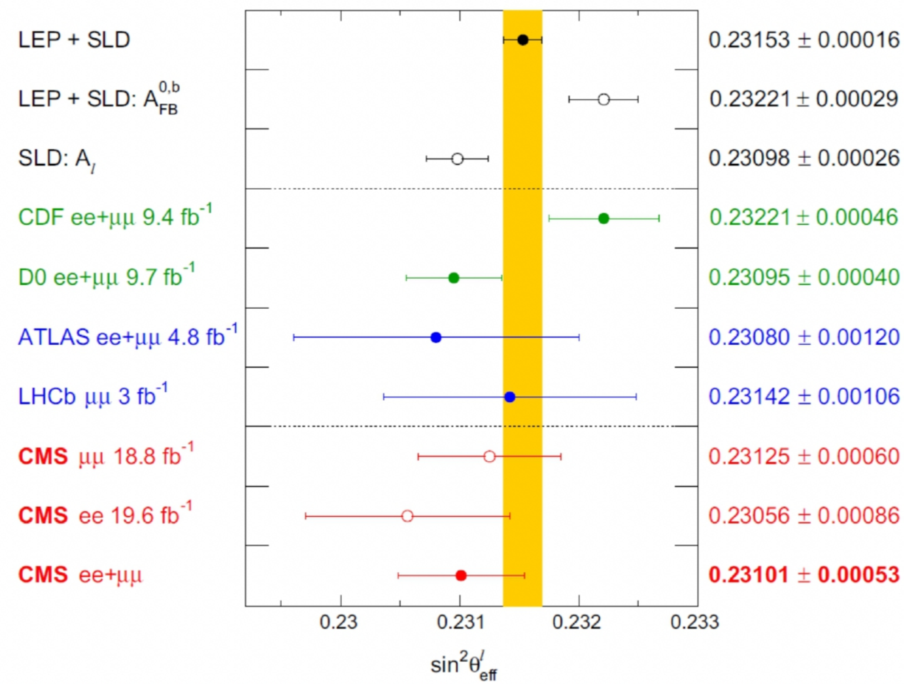


01/11/2022

Weak mixing angle $\sin^2\theta_W$

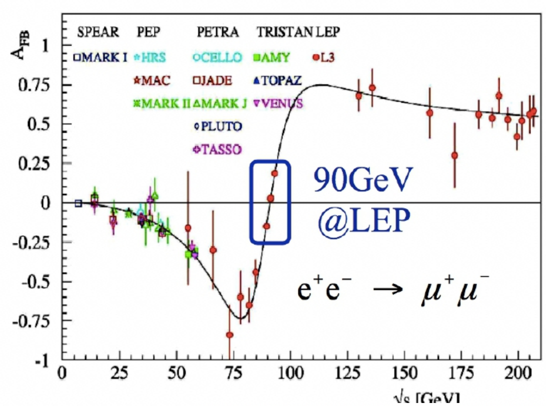
- Key parameter in electroweak sector
  - ~3σ tension between LEP and SLC measurements
  - Experimental syst. much larger than theory syst.

	$\sin^2\theta_W$
LEP	0.23221 ± 0.00029
SLC	0.23098 ± 0.00026
Theory	0.23121 ± 0.00004



- Extract from A_{FB} measurement

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$



CEPC：

could improve the accuracy by 2 orders of magnitude;

need sophisticated uncertainty control: both experimental & theoretical

Experiment	Stat. (10^{-5})	Syst. (10^{-5})	Theory unc. (PDF+QCD) (10^{-5})	Total unc. (10^{-5}) $\delta\sin^2\theta_W$
LEP	29	~ 1	~0	29
Tevatron	27	5	18	33
LHC 8TeV	36	18	35	53
LHC 13TeV By Projection	~15	> 20	> 25	~ 20
CEPC By LEP Projection	~0.2	**~0.2**	**4 (Today)**	**~0.3**

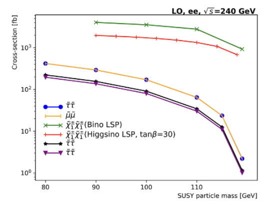
BSM Studies

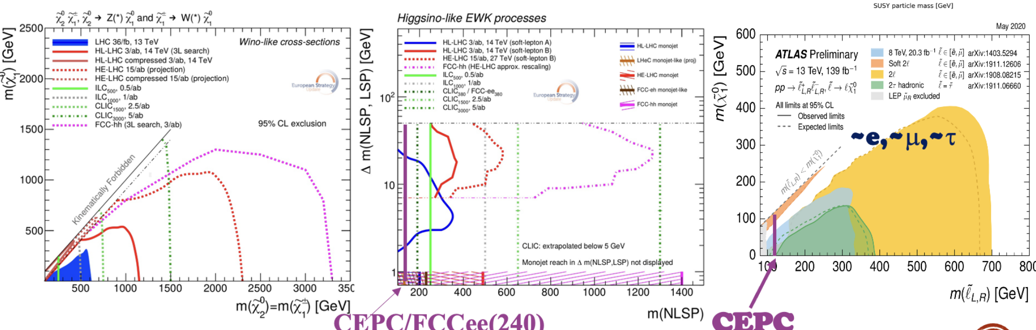
- **BSM Higgs** (1709.06103; 1808.02037; 1912.01431; 2008.05492； 2011.04540)
- **SUSY Searches**
  - Direct SUSY Searches (CPC46(2022)013106; 2101.12131; 2203.10580;2202.11011)
  - Indirect search of SUSY (2010.09782)
  - Global fit of SUSY (2203.04828)
- **Dark Matter and Dark Sector searches**
  - Lepton portal DM (JHEP 06 (2021) 149)
  - Asymmetric DM (PRD 104(2021)055008)
  - Dark Sector from exotic Z decay (1712.07237)
  - DM (Millicharged DM, Vector portal DM, DM with EFT interactions): 1903.1211
  - Mono-gamma (2205.05560)
- **Long-lived particles** (1904.10661, 1911.06576, 2201.08960. **Ongoing:** Yulei Zhang's Talk; Wei Su's Talk; Cen Mo's Talk;)
- **More exotics:**
  - Heavy neutrinos (2102.12826);
  - Axion-like particles (2103.05218, 2204.04702. **Ongoing:** Jia Liu's talk, J. Phys. G)
  - Electroweak phase transition (1911.10210,1911.10206,2011.04540)
  - ……

BSM: SUSY Search

SUSY Searches at CEPC

- Reference: **mainly light EWKino and slepton for CEPC**
  - Electroweakino (wino, higgsino) search: CPC46(2022)013106
  - Bino NLSP at CEP: 2101.12131
  - Slepton search: 2203.10580
  - Heavy selectron search: 2202.11011
  - Indirect search of SUSY: 2010.09782
  - Global fit of SUSY: 2203.04828

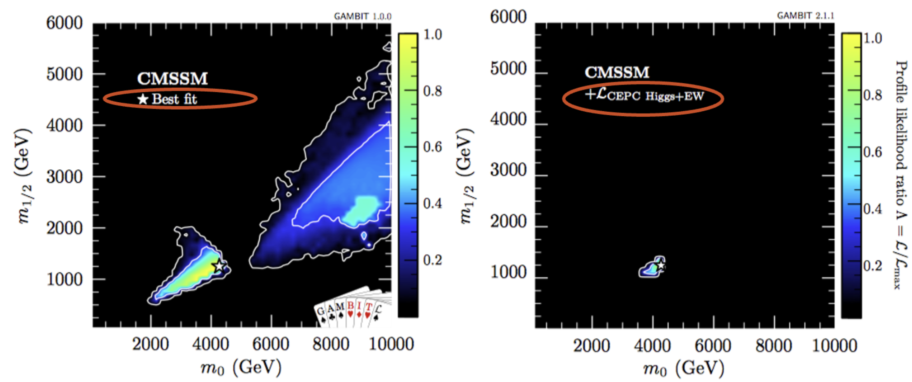




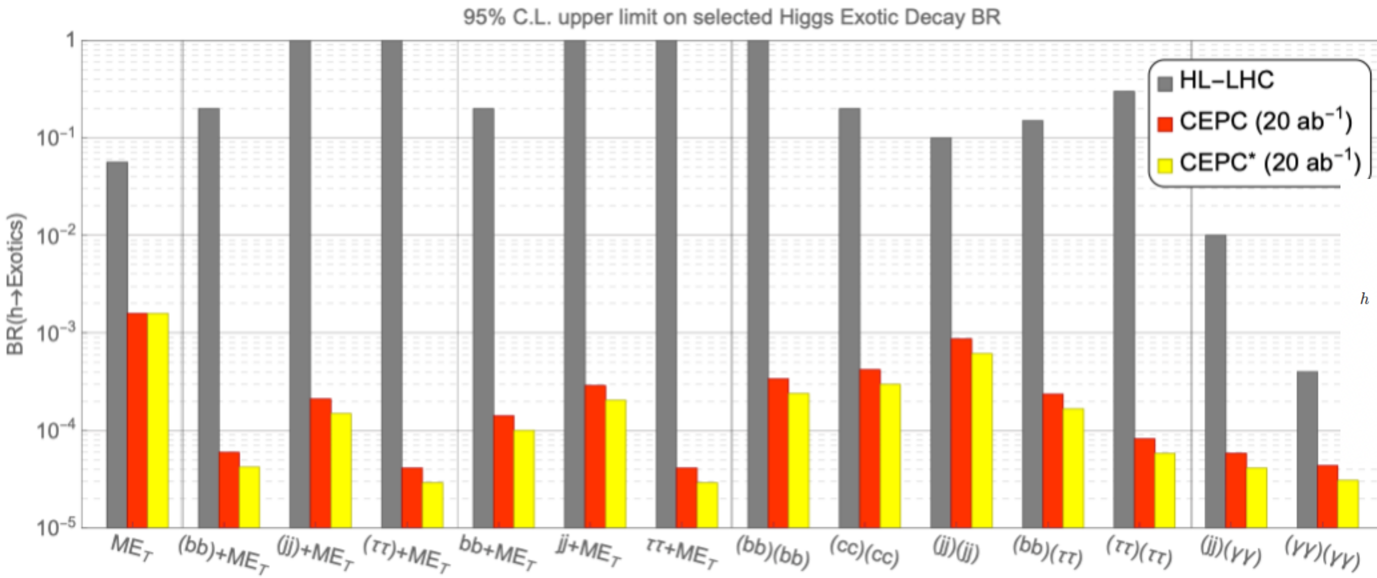
ILC 500/CEPC240: discovery in all scenarios up to kinematic limit: √s/2

SUSY global fits with CEPC using GAMBIT

- **Study of the impact of the Higgs and electroweak precision measurements at the CEPC with GAMBIT global fits of the SUSY models, such as CMSSM, NUHM1, NUHM2 and pMSSM-7, Yang Zhang etc, arXiv: 2203.04828**
- **CEPC can further test the currently allowed parameter space of these models, advance our understanding of the mass spectrum**



BSM: exotic



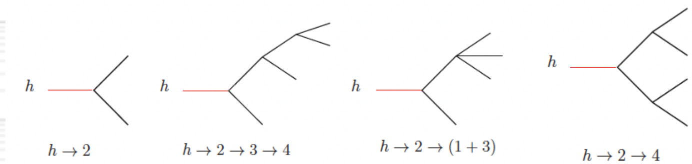
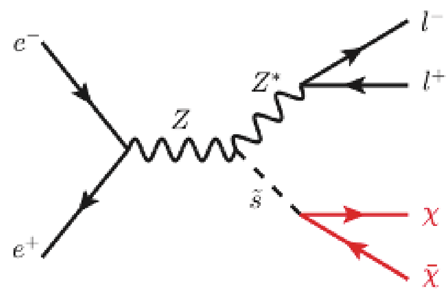
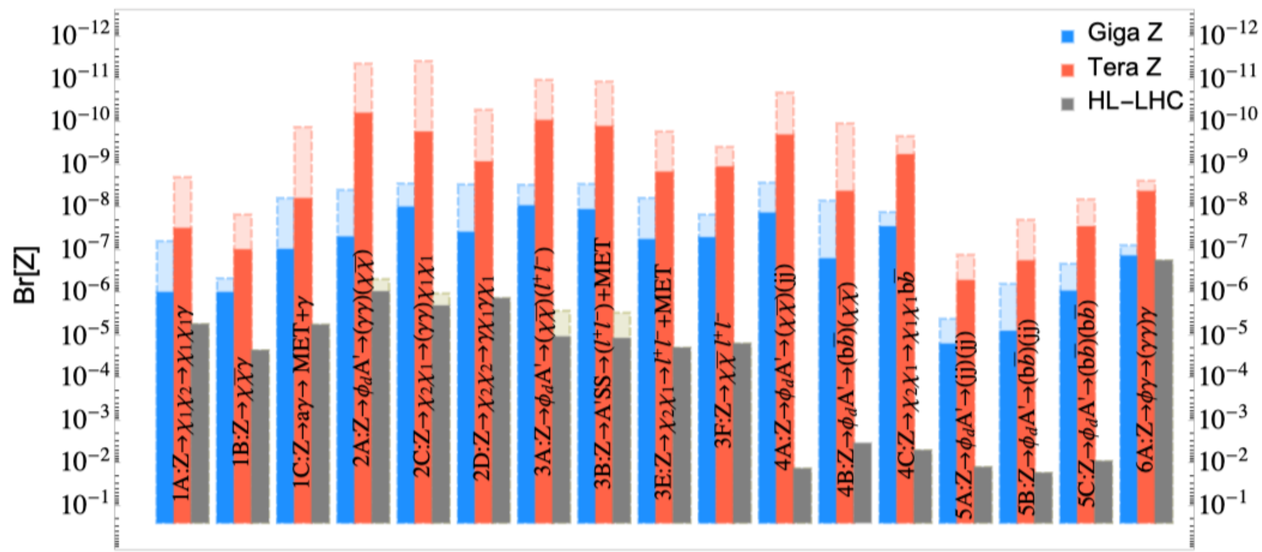
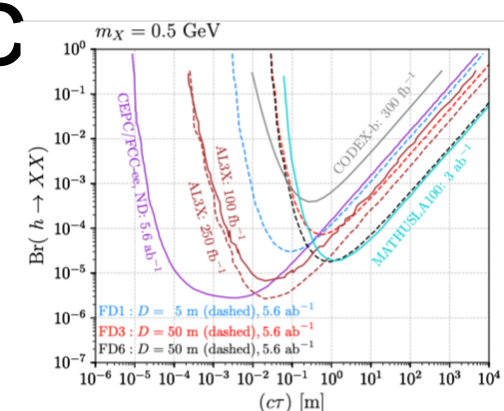


FIG. 5. Representative topologies of the Higgs exotic decays.



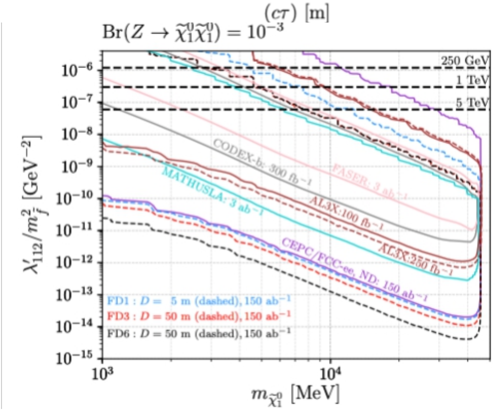


BSM: LLP, Axion, etc



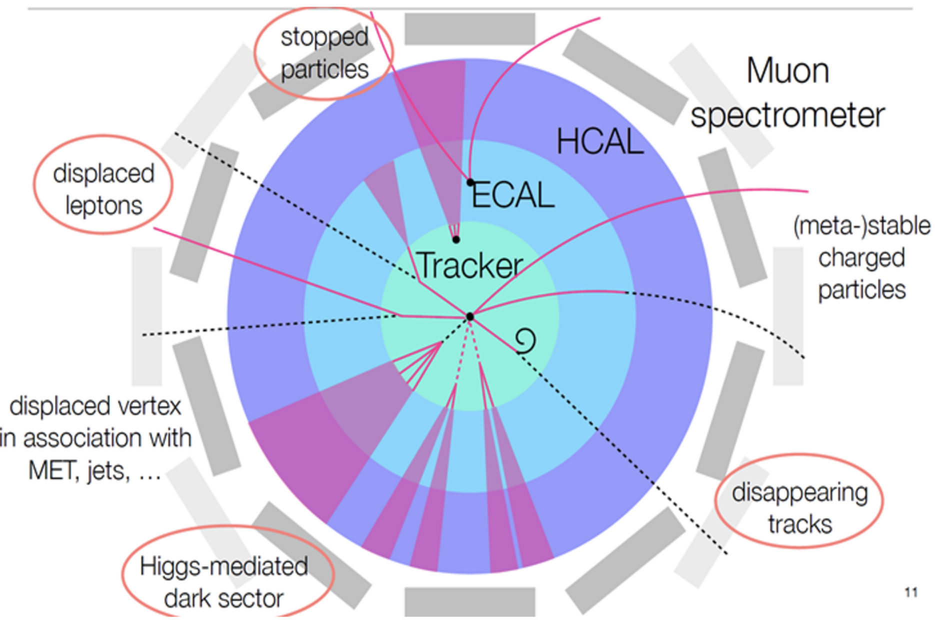
Long-lived particles (LLP)

- **Reference:**
  - LLP at near Detector: 1904.10661
  - LLP at Far Detector: 1911.06576, 2201.0896
  - LL Dark Hadrons: 2110.10691
  - On-going: Yulei Zhang's Talk; Wei Su's Talk; Cen Mo's Talk;

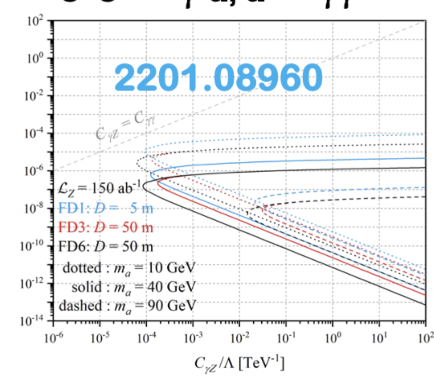


Long lifetimes result from a few simple physical mechanisms:

- Small couplings (ex. RPV SUSY)
- Limited phase space: small mass splitting (ex. compressed SUSY, …)
- Heavy intermediate states
-

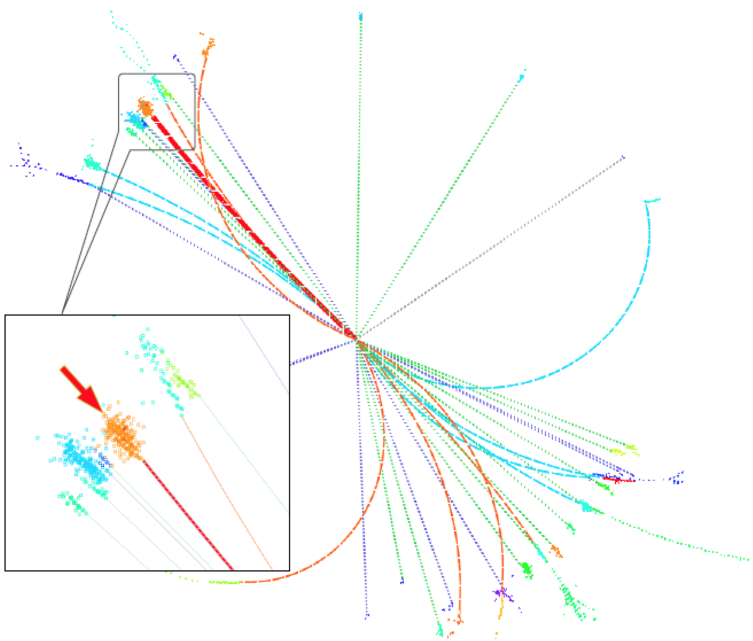


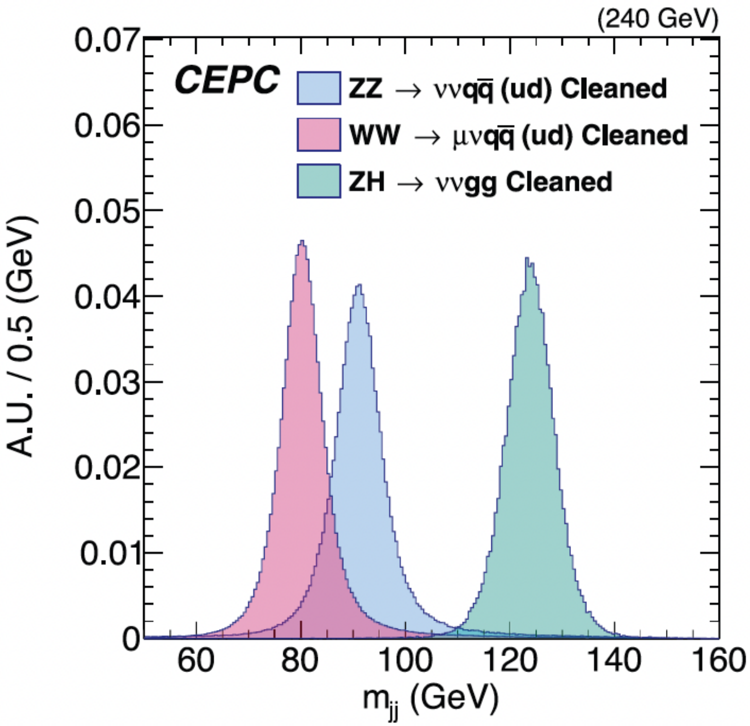
$e^-e^+ \to \gamma\, a,\ a \to \gamma\gamma$



Axion-like Particles

Performance: requirement & optimization





Requirements & technologies

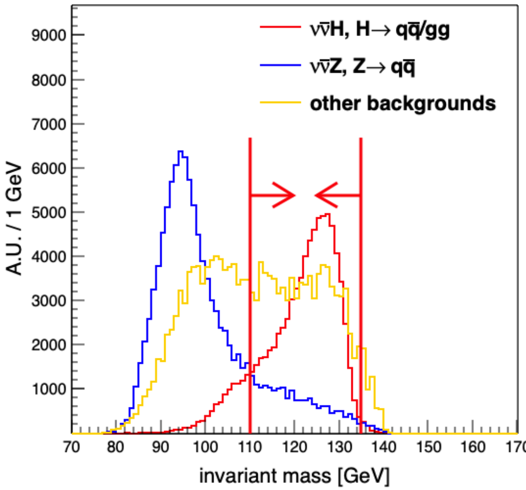
- Be suited to the collision environment: High radiation, High rate, Beam background
- High hermiticity
- Lower energy/momentum threshold (especially for Z)
- Good intrinsic Energy/Momentum resolution
- A clear separation of the final state particles
  - Physics object identification
  - Resolution for composited objects, i.e., jets
- BMR (Boson Mass Resolution)
  - < 4% for Higgs physics, much demanding for New Physics & Flavor Physics Measurements
- Pid: Pion & Kaon separation > 3σ
- Jet: Flavor Tagging & Charge Reconstruction
- Extremely Stable

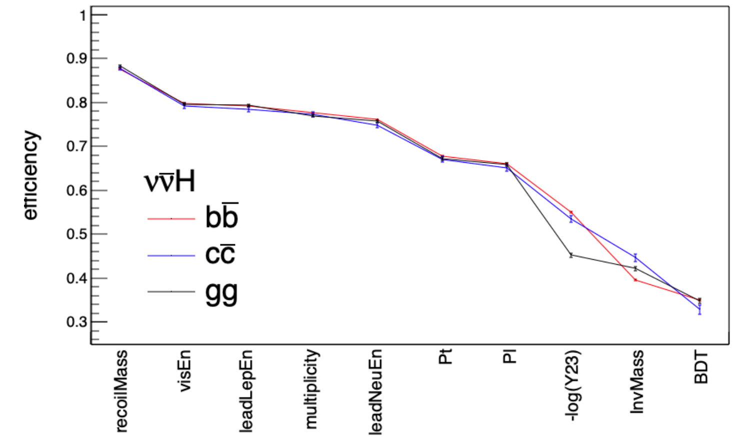
Radiation robust detector Fast & low power electronics
Compact forward region, MDI/detector protection
Tracker & Calorimetry: Low noise, High precision Low threshold calorimeter, adequate B-Field, High efficiency tracker
Particle Flow Oriented detector, or Dual Readout (or alternatives) Abundant high quality detector information + suited algorithm
dEdx or dNdx with resolution ~ 3%, ~ 50 ps ToF (or alternatives)
Low material, high precision vertex placed close to the IP
Mechanic & Integration

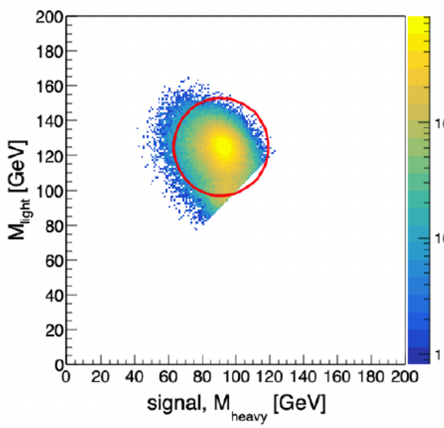
Analysis of H→bb, cc, gg

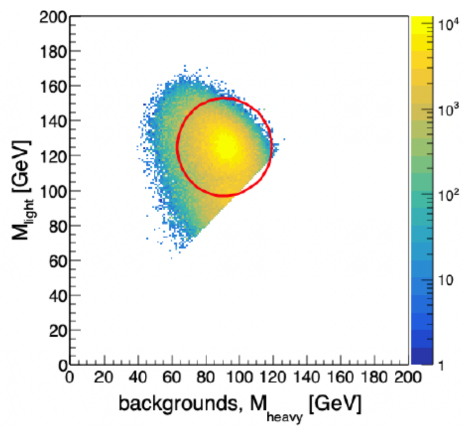
Z decay mode	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
$Z \to e^+e^-$	1.57%	14.43%	10.31%
$Z \to \mu^+\mu^-$	1.06%	10.16%	5.23%
$Z \to q\bar{q}$	0.35%	7.74%	3.96%
$Z \to \nu\bar{\nu}$	0.49%	5.75%	1.82%
combination	0.27%	4.03%	1.56%

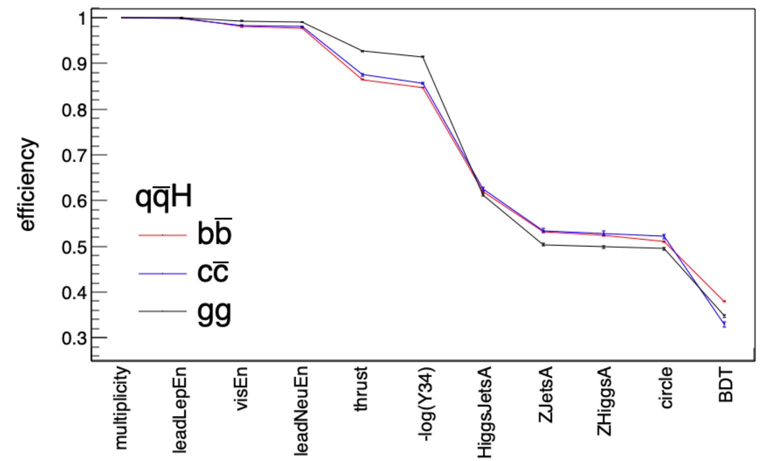
Table 3. The signal strength accuracies for different channels.







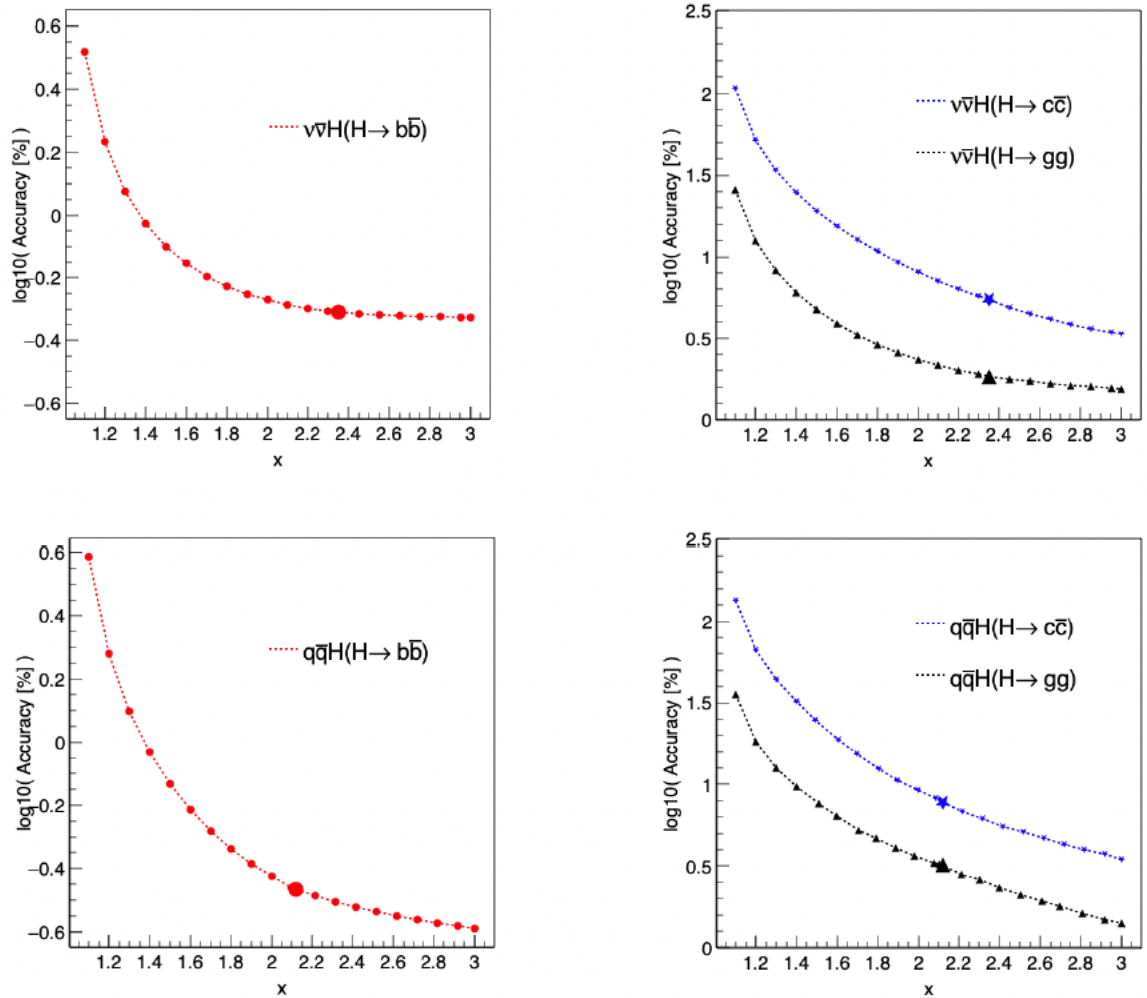




- Updates the anticipated accuracy using full. Simulation
- Evaluate the critical systematic analyses (i.e., gluon jet shape)

Accuracy V.S. Flavor Tagging

true \ identified as	b	c	g
b	0.8675	0.0887	0.0437
c	0.1136	0.6263	0.2601
g	0.0411	0.1007	0.8582



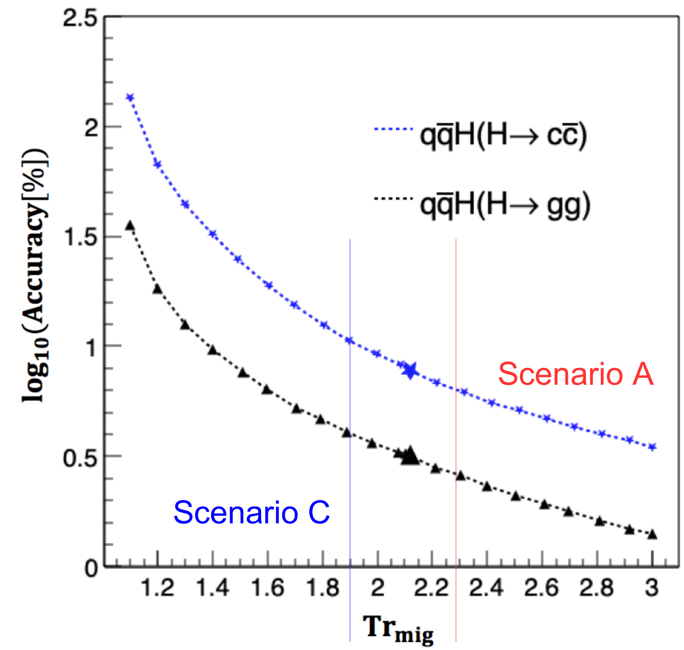
Compared to baseline, Ideal FT improve the H→bb, cc, gg Measurements significantly, especially at qqH channel (up to 2 times.)

Impact of Vertex Optimization

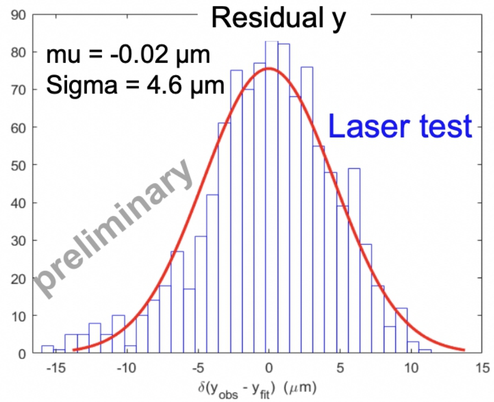
$$Tr_{mig} = 2.118 + 0.054 \cdot log_2 \frac{R^0_{material}}{R_{material}} + 0.040 \cdot log_2 \frac{R^0_{resolution}}{R_{resolution}} + 0.098 \cdot log_2 \frac{R^0_{radius}}{R_{radius}}$$

Table 2. Reference geometries.

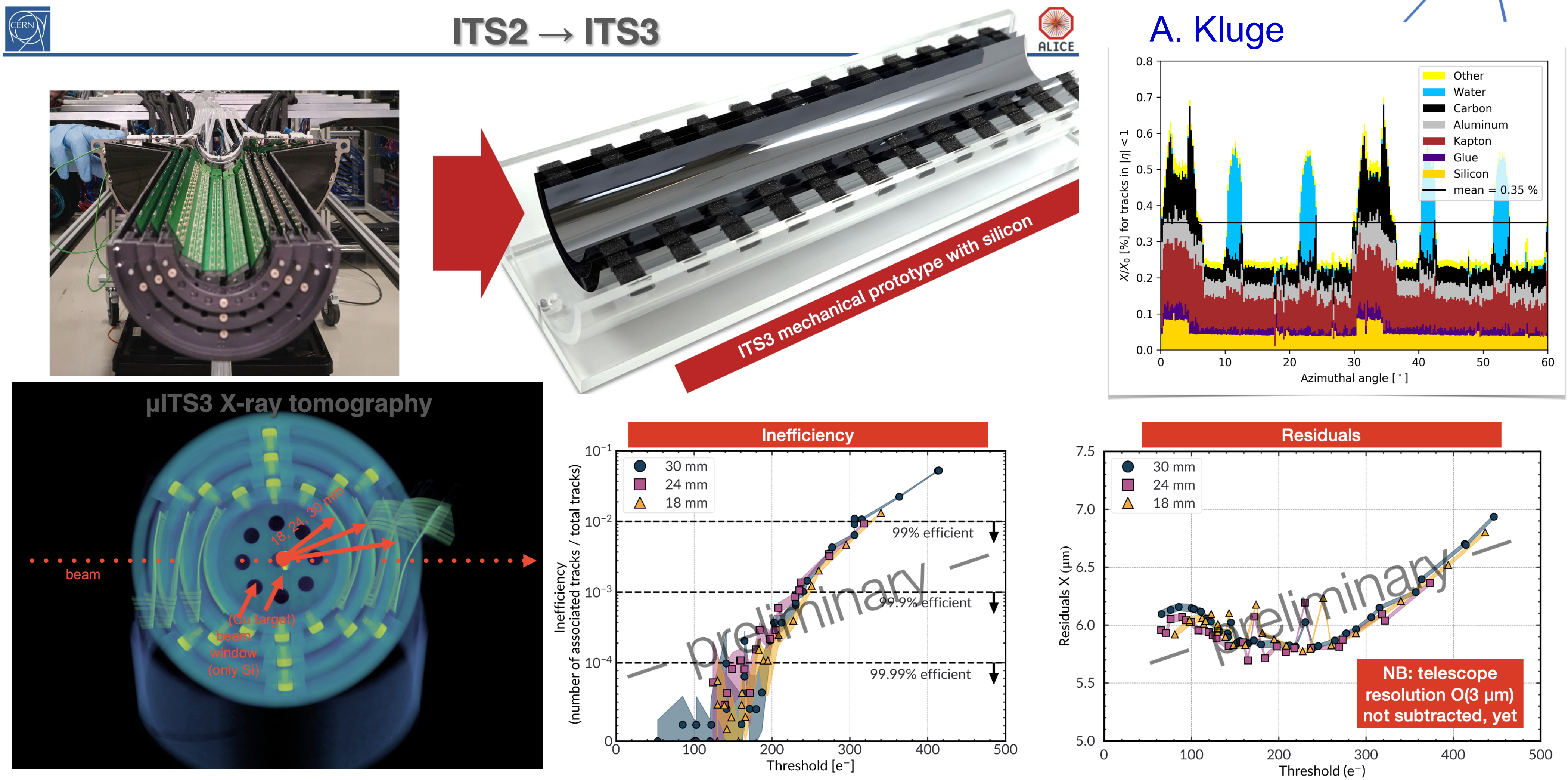
	Scenario A (Aggressive)	Scenario B (Baseline)	Scenario C (Conservative)
Material per layer/X_0	0.075	0.15	0.3
Spatial resolution/μm	1.4 - 3	2.8 - 6	5 - 10.7
R_{in}/mm	8	16	23



- 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%
- CEPC Prototype:
  - ~5 μm resolution, material ~ 0.3% X_0 per layer



ALICE ITS3



- Bending doesn't show effects in main performance figures.
- Next step to prove stitching and power/signal distribution.
- *Far future... put inside the beam pile??*

Color Singlet identification

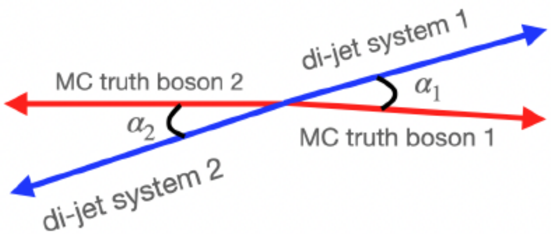
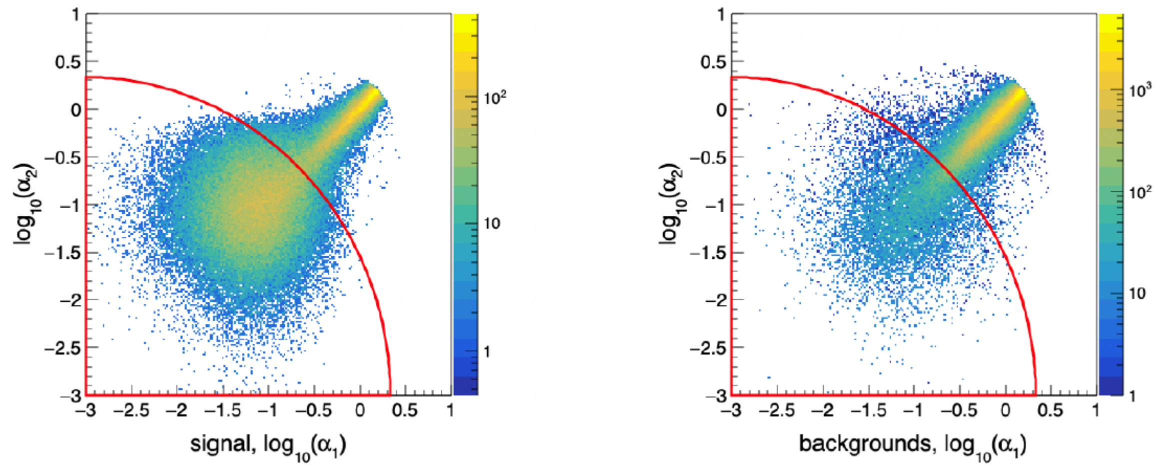
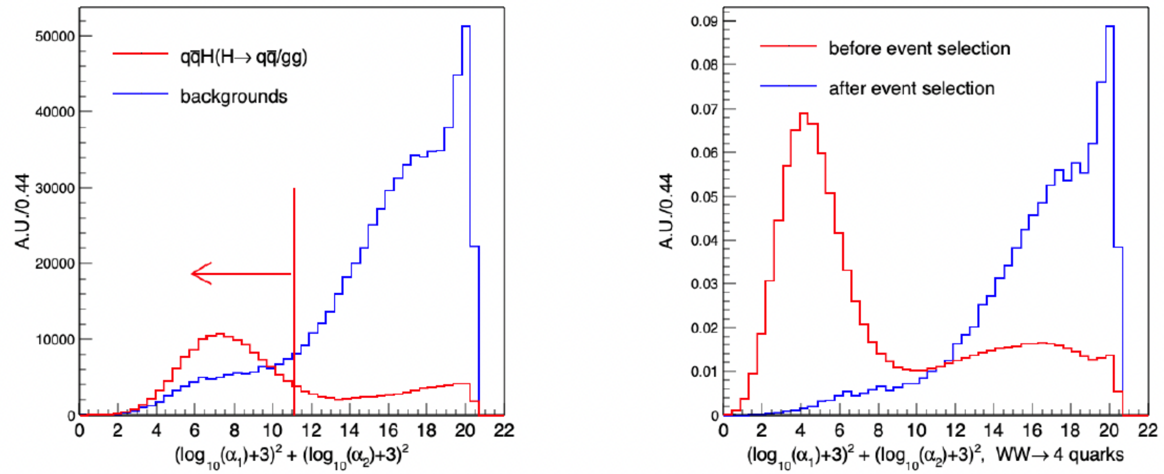


Figure 13. The definition of α_1 and α_2.



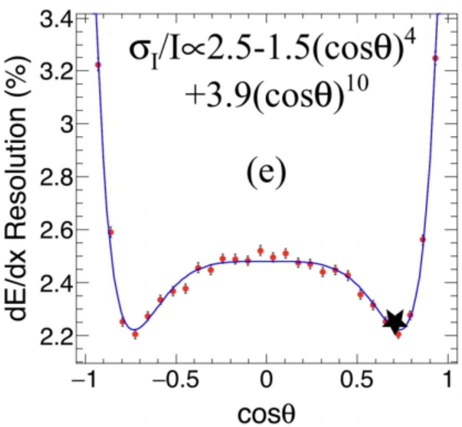


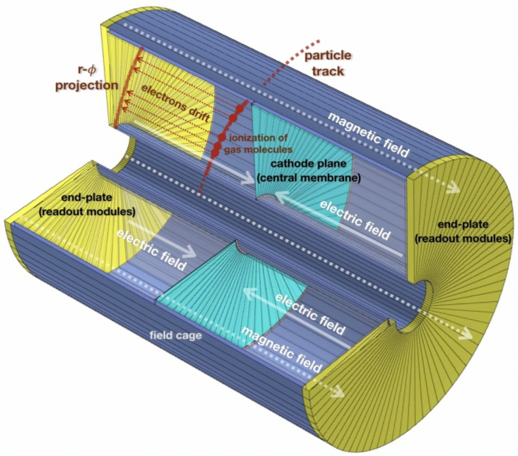
- To be collaborated with QCD community
  - Color Singlet identification
  - Gluon Jet Characterization

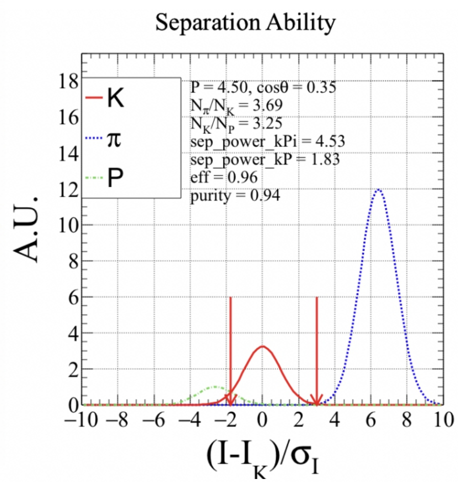
Figure 15. The distributions of $(log_{10}(\alpha_1)+3)^2 + (log_{10}(\alpha_2)+3)^2$. The left plot corresponds to the signal and backgrounds after the whole event selection in table 2. The right plot corresponds to the $e^+e^- \to W^+W^- \to 4\ quarks$ before and after the whole event selection in table 2 to illustrate that the event selection process was able to strongly suppress the backgrounds with good CSI performance.

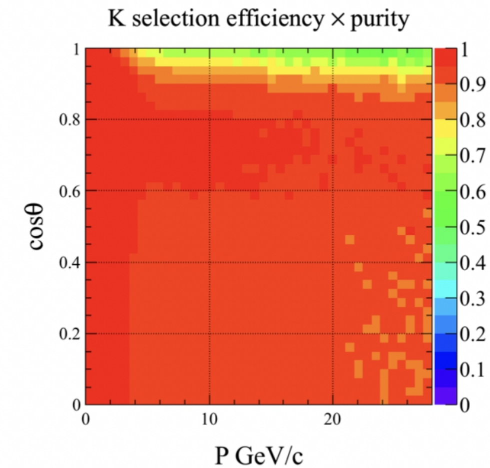
Pid requirement

Yongfeng Zhu



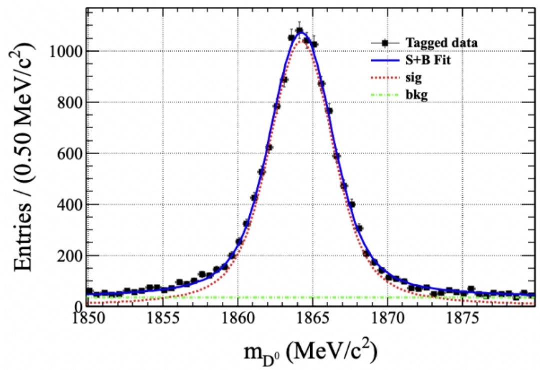




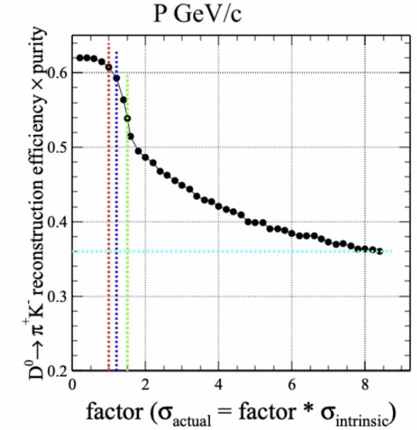


$D^0 \to \pi^+ K^-$ reconstruction

	ϵ (%)	p (%)
$\|mass - mass_{D0}\| < 0.01\,GeV/c^2$	90.39	2.16
IMP > 0.02 mm^2	79.12	5.04
vertex fitted $\chi^2 < 5.15$	72.62	15.36
dis of vertex to IP > 0.305 mm	69.24	28.41
PID	68.19	89.05



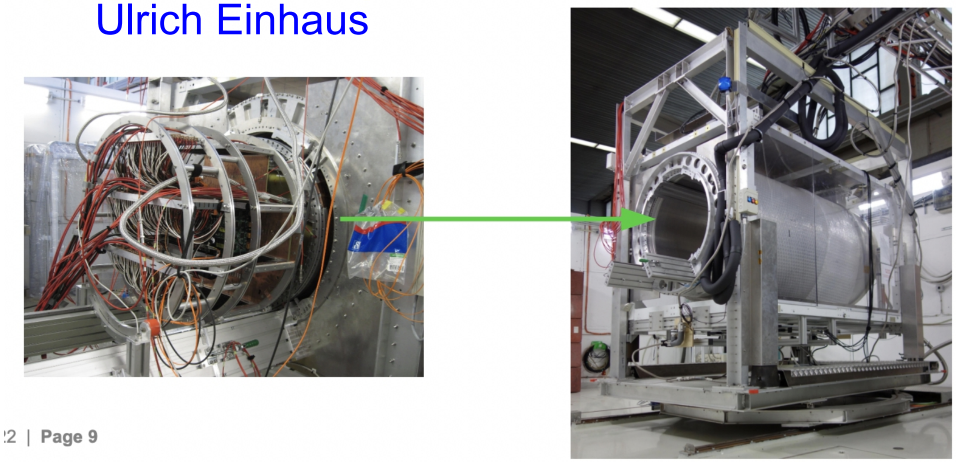
fitted mass : $1864.259 \pm 0.025\,MeV/c^2$

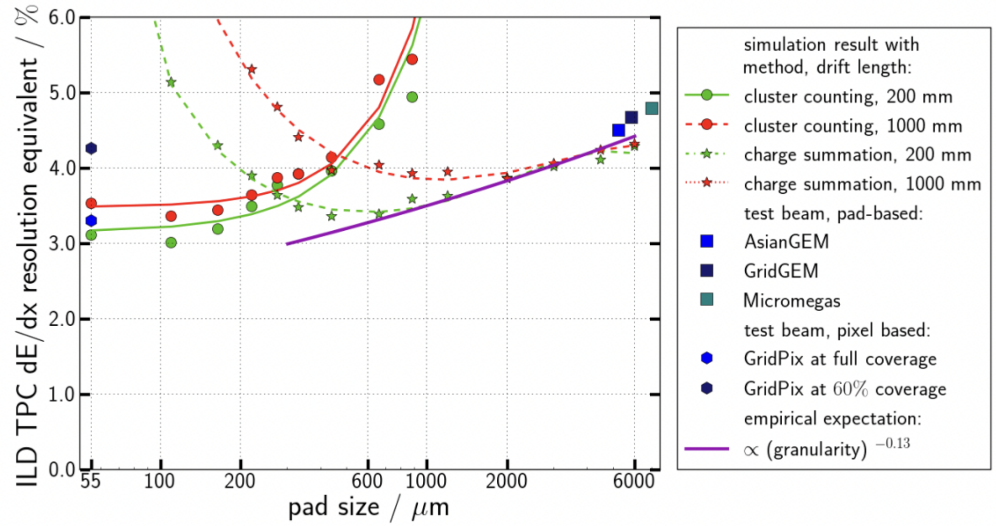


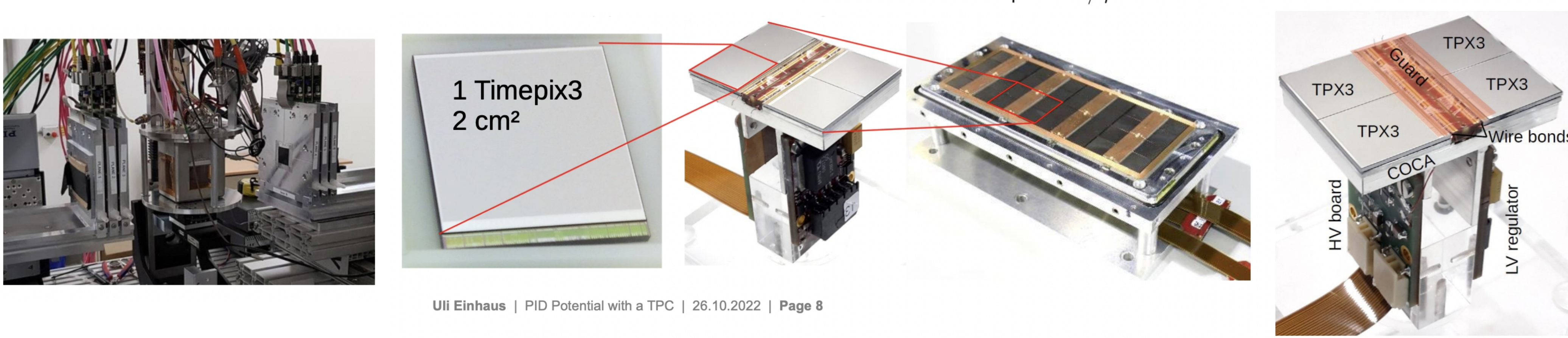
- Geant4: TPC @ baseline gives a resolution of 2.5% at MCTruth, together with 50 ps ToF, an overall eff/purity of 98%/97% is anticipated for Kaon@Z->qq, with significant dependence on polar angle.
- Physics object (D, Φ) reconstruction strongly suggest dE/dx resolution < 3%

TPC: Pad or Pixel

Ulrich Einhaus

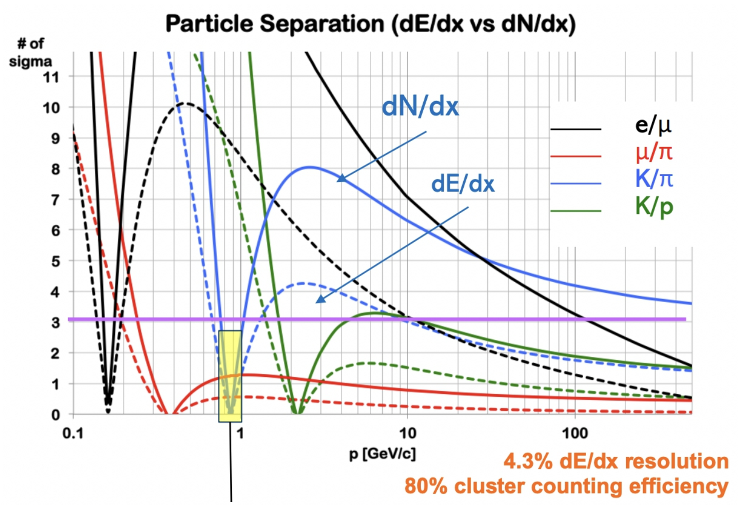


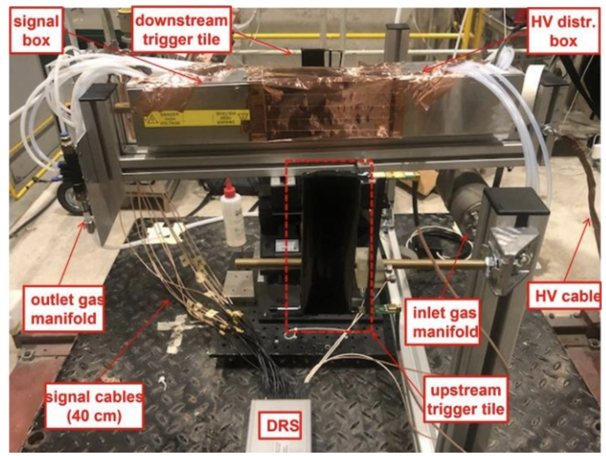


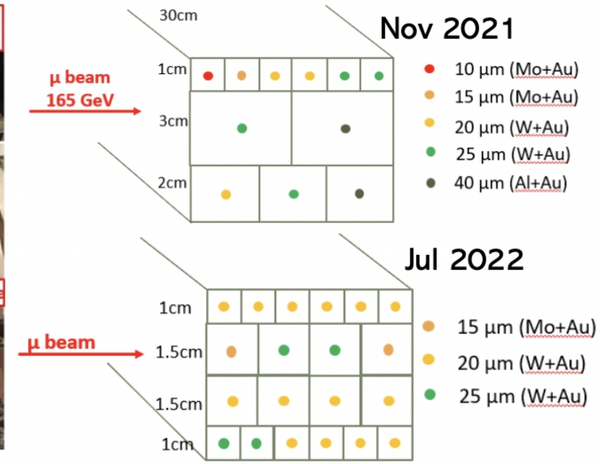


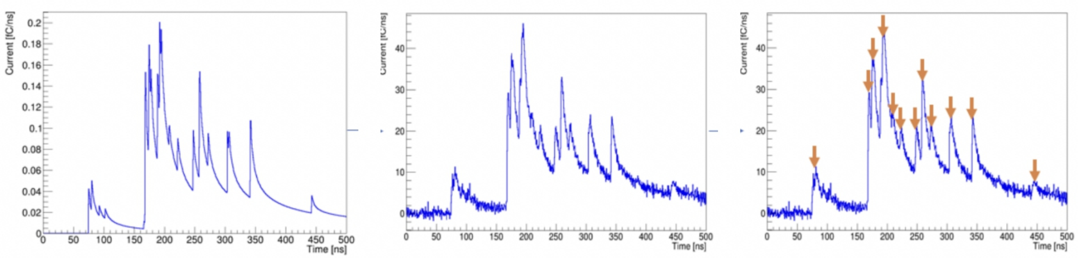
- 4.6 - 5%/3.3 - 3.6% dEdx resolution measured from TB, with Pad/Pixel readout
- Hopefully to be further improved with pad size optimization, noise control, etc

Drift Chamber: Cluster counting in time

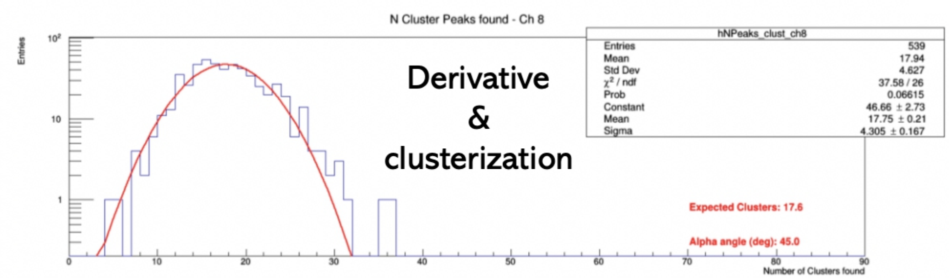


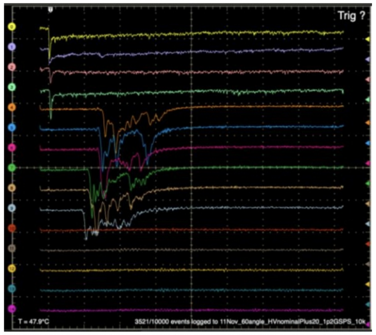






Simulation | Digitization | Reconstruction

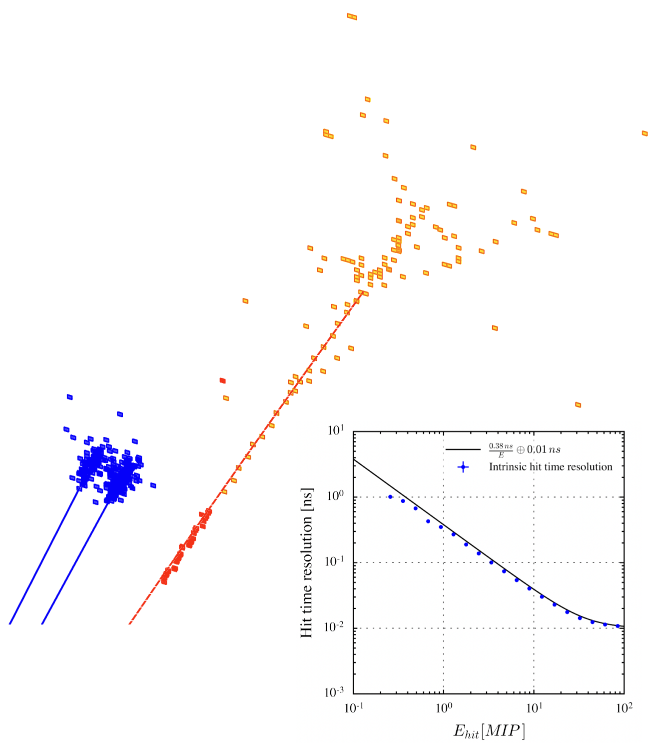


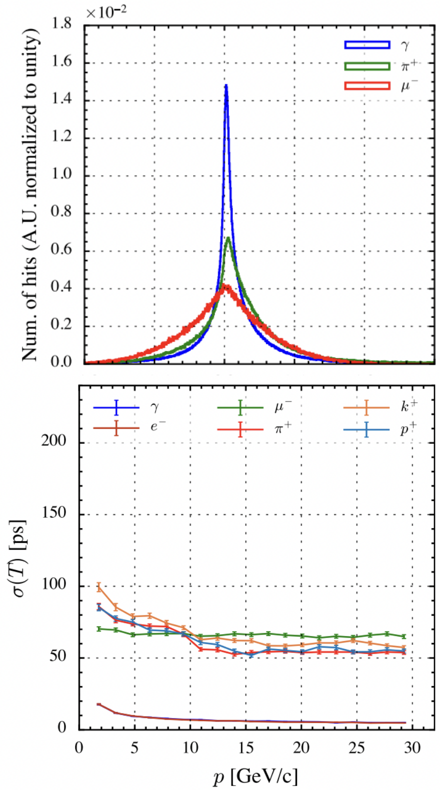


- Essential to have a high efficiency and accurate counting of Clusters
- Multiple peak finding algorithm are developed & tested
- Test beam result seems matched the expectation

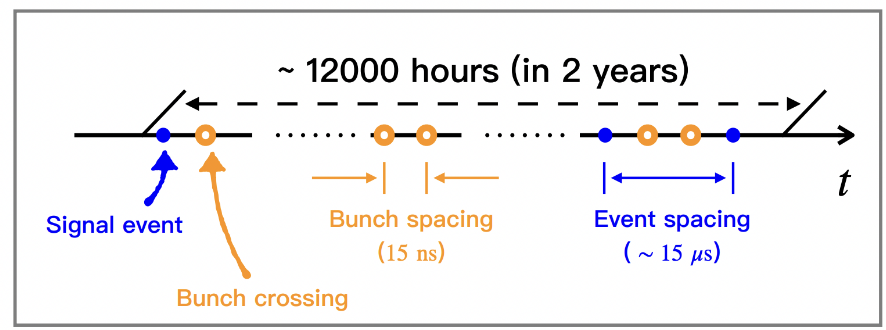
Brunella D'Anzi
Federica Cuna,
Yue Chang,
Shuiting Xin

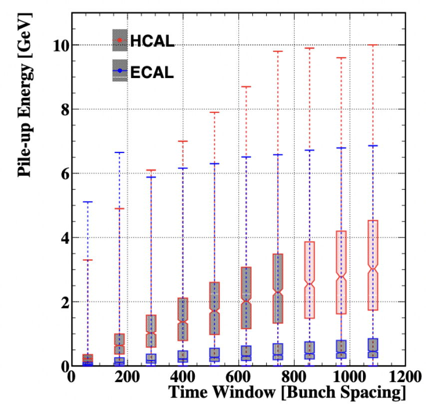
Cluster timing, Leakage in time, Pile up

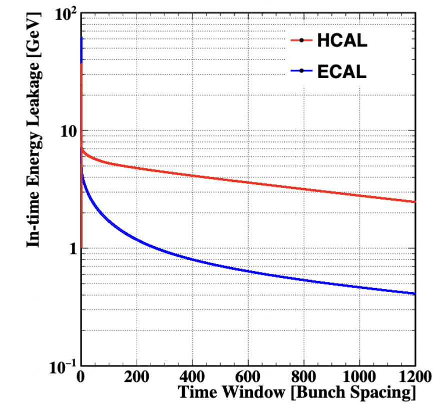




CEPC Z pole scheme





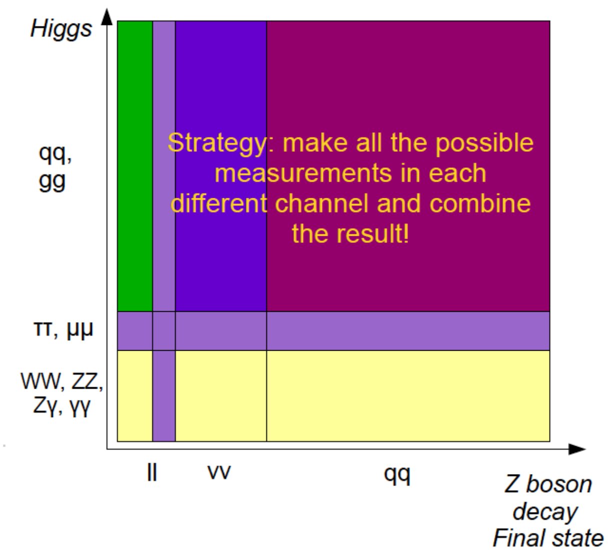


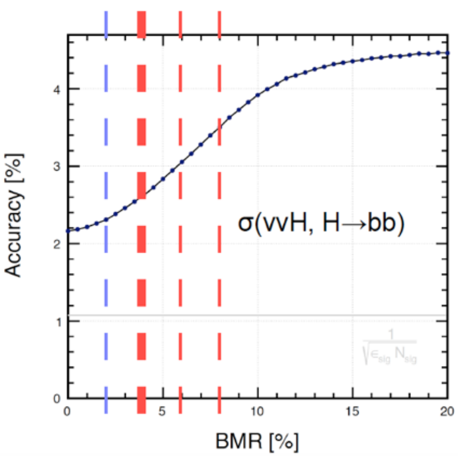
Using Baseline Geometry & Silicon detector comparable to CMS HGC, A Cluster timing algorithm is developed, leads to a time resolution of 5 ps at EM Cluster with o(10)GeV energy.

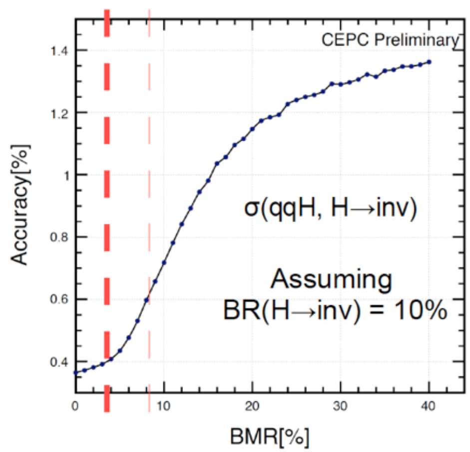
Leakage and off-time pile up effect evaluated, showing at 9 μs integration time (~ 600 BX at CEPC Z pole), the in time leakage and off time pile up reaches 2-3 GeV level for hadronic Z events: Need to develop **Fast detector** and **novel Clustering algorithm with time information**.

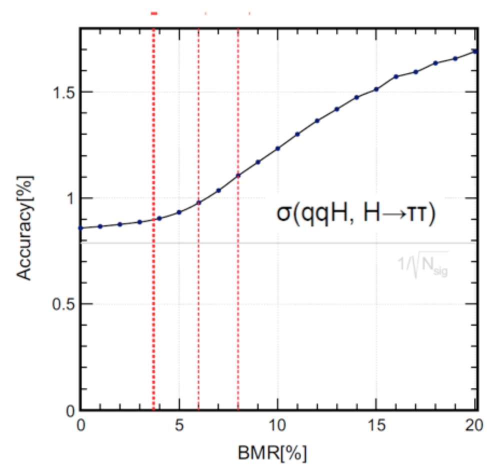
Hadronic event & BMR

- Core of e+e- Higgs factory Physics measurements
  - 97% of CEPC Higgs events are hadronic/semi-leptonic
- Higgs measurement require BMR < 4%;
- Flavor & NP: much more demanding



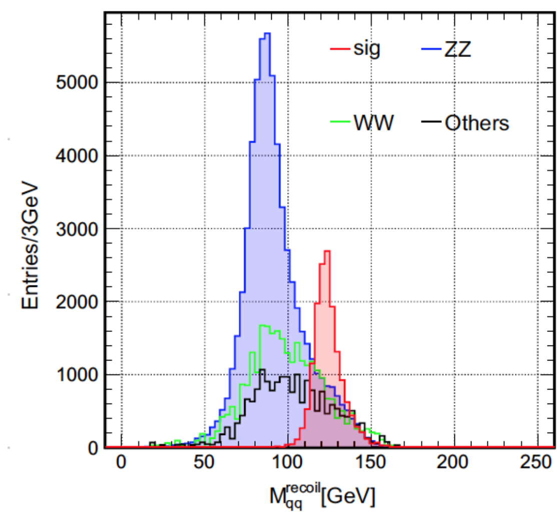




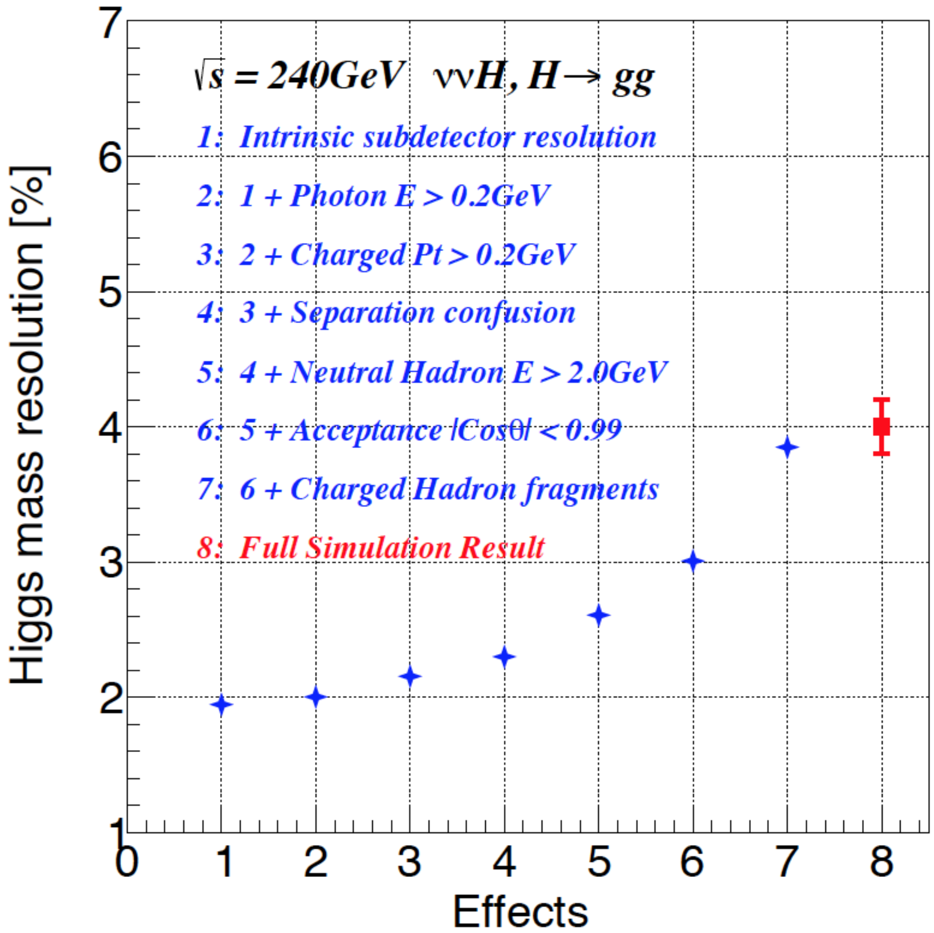


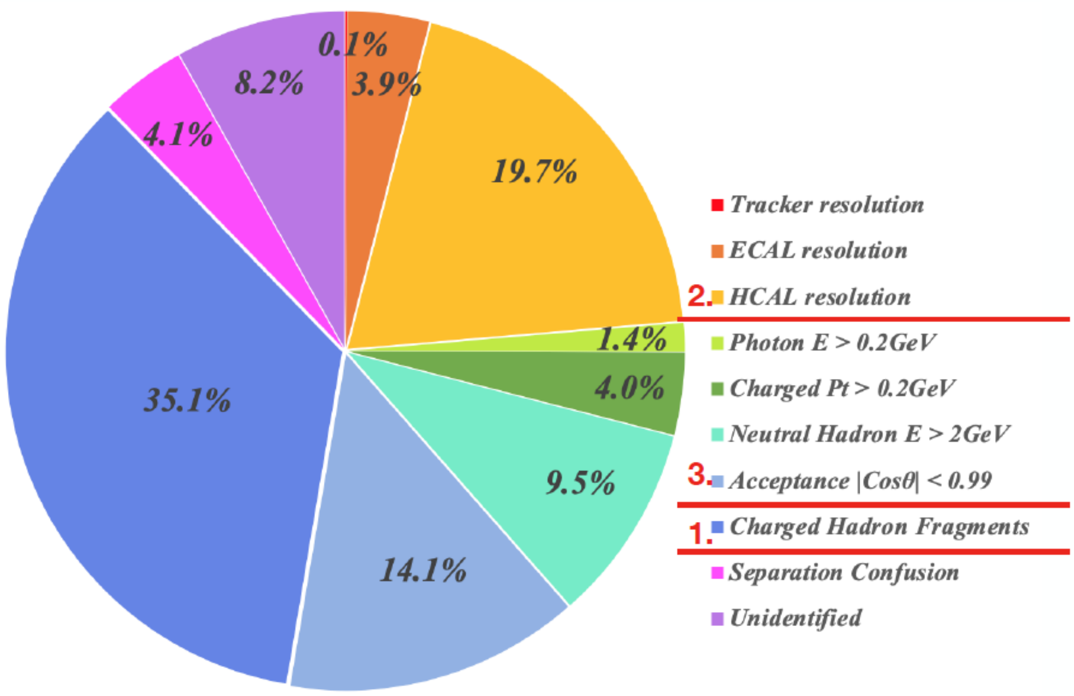
- Boson Mass Resolution: relative mass resolution of ννH, H→gg events
  - Free of Jet Clustering
  - Be applied directly to the Higgs analyses
- The CEPC baseline reaches 3.8%

	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%



PFA Fast simulation

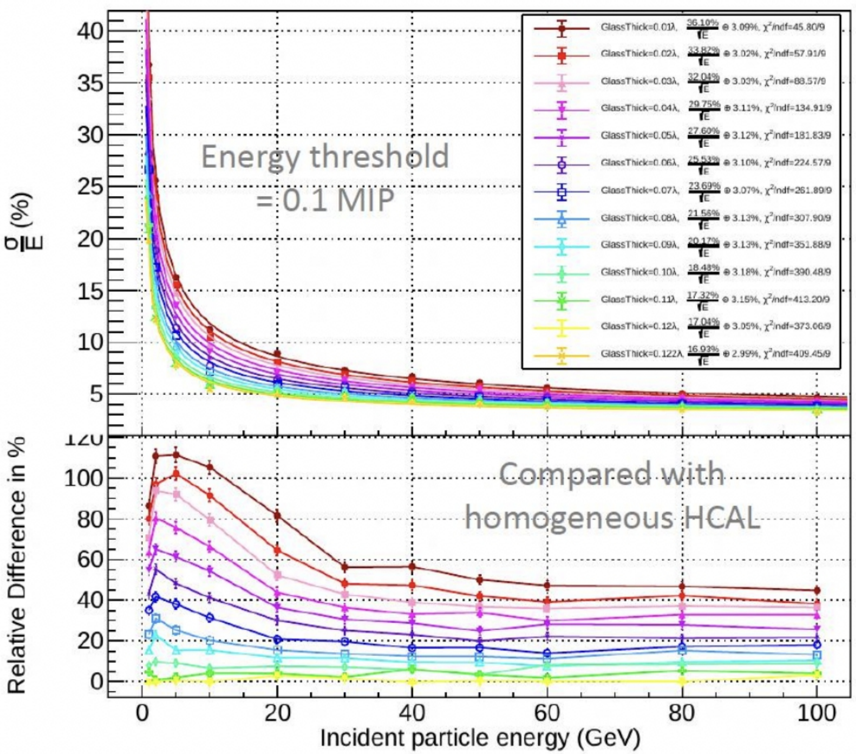


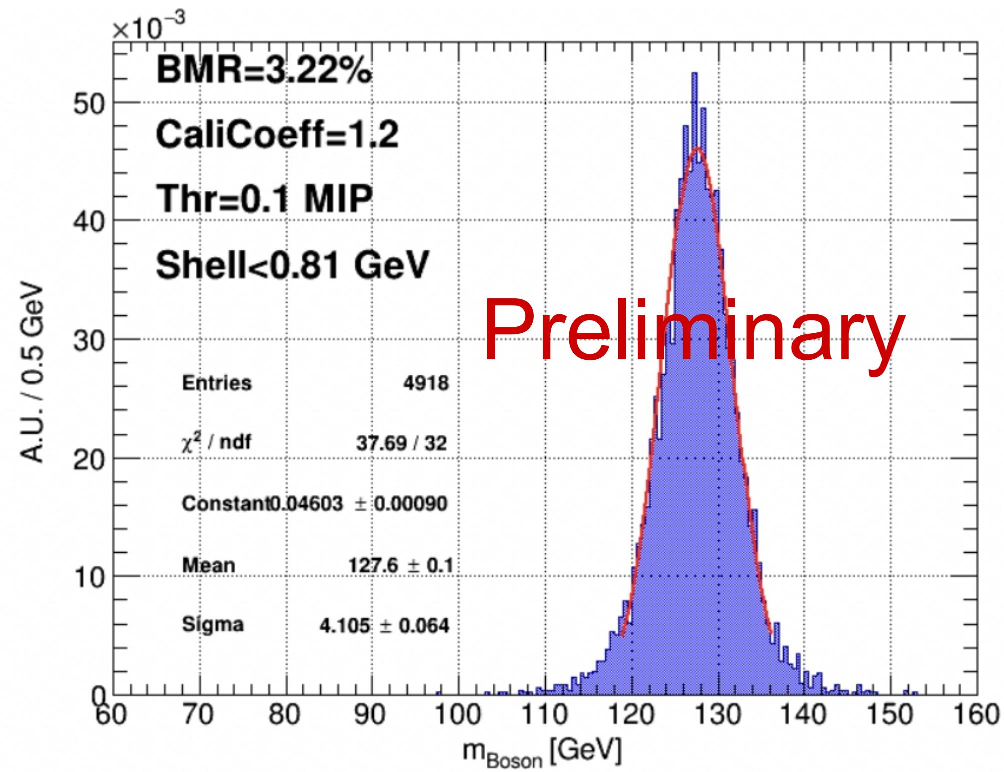


YX. Wang

Fast simulation reproduces the full simulation results, factorize/quantifies different impacts
Same cleaning condition as in the Full simulation applied
Early phase of modeling/tuning

Performance using Glass HCAL

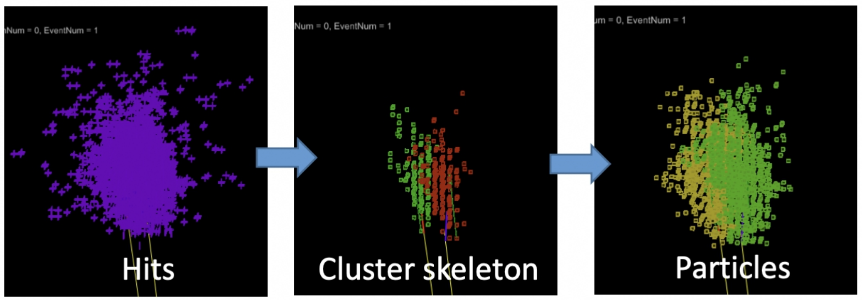




Preliminary result shows o(10%) improvement is possible:

BMR 3.8% → 3.3%

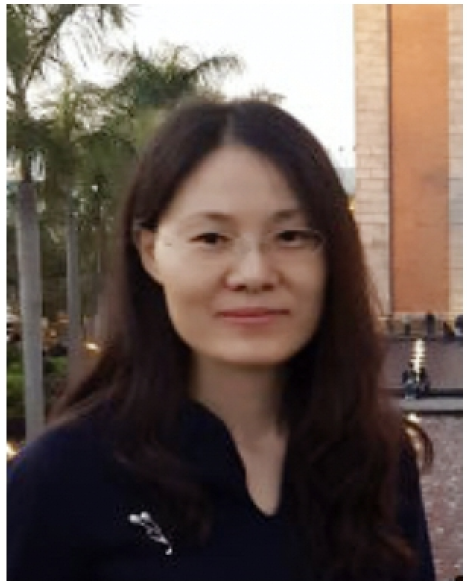
A lot need to be done.

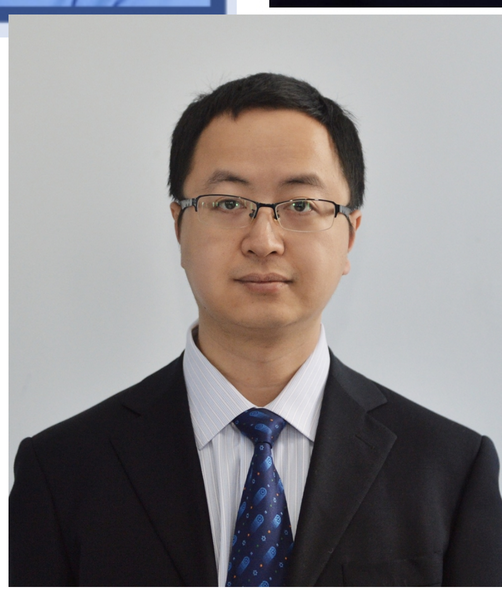


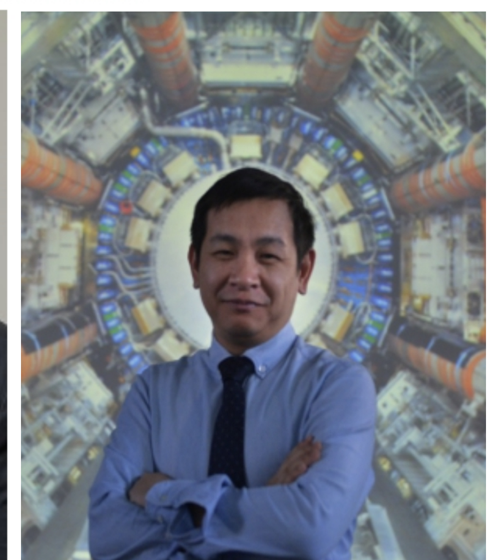
Summary

- CEPC physics study:
  - Efficient collaboration + communications with international community
  - Critical input for ESPPU, Snowmass
- Physics merit quantified
  - Higgs white paper delivered, Flavor, EW, NP on its way
  - Flavor physics: multiple observation windows + strong physics cases & sensitive to New Physics of 10 TeV or higher + stringent performance requirements
- Performance study: guides & iterates detector R&D
- Multiple critical topics identified:
  - Color singlet identification, High precision calculation, clustering algorithm in time...
- Current difficulties: Manpower + Expertise
  - Profound collaboration needed to promote critical topics...
  - Strong support from the community & young talents emerges.

Many Thanks to

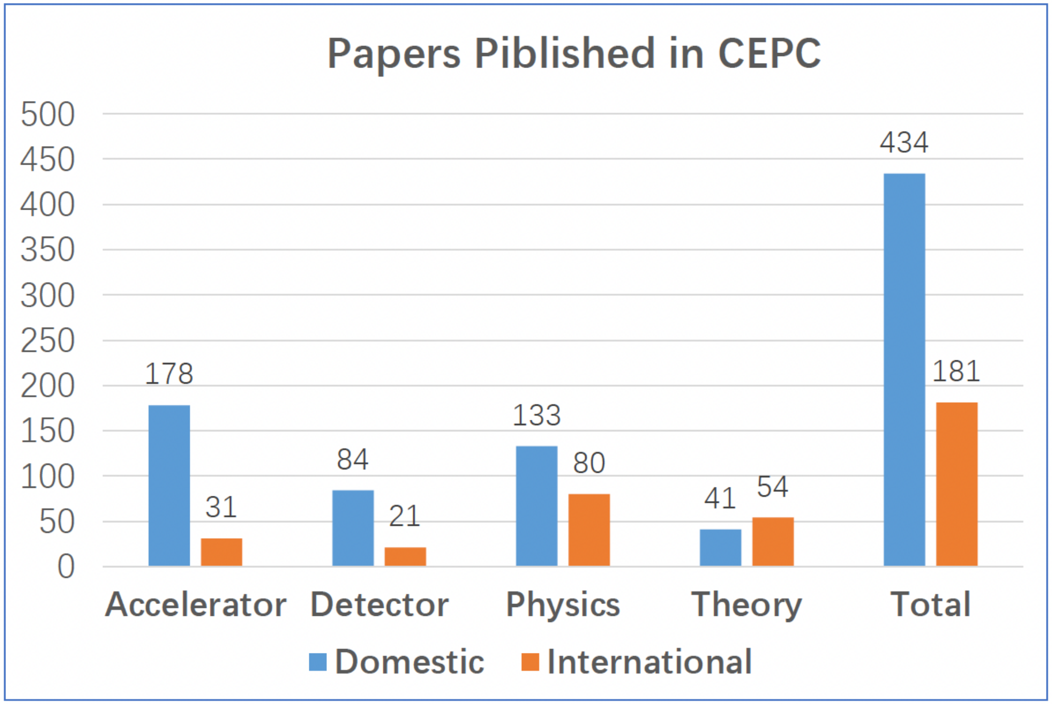



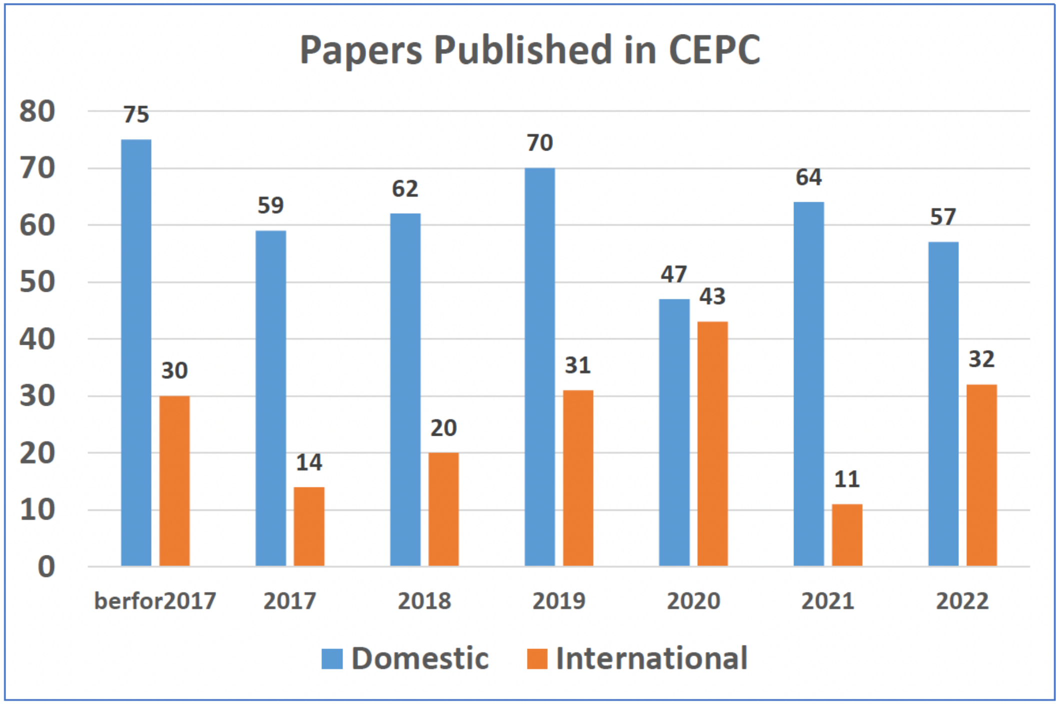





...

Back up

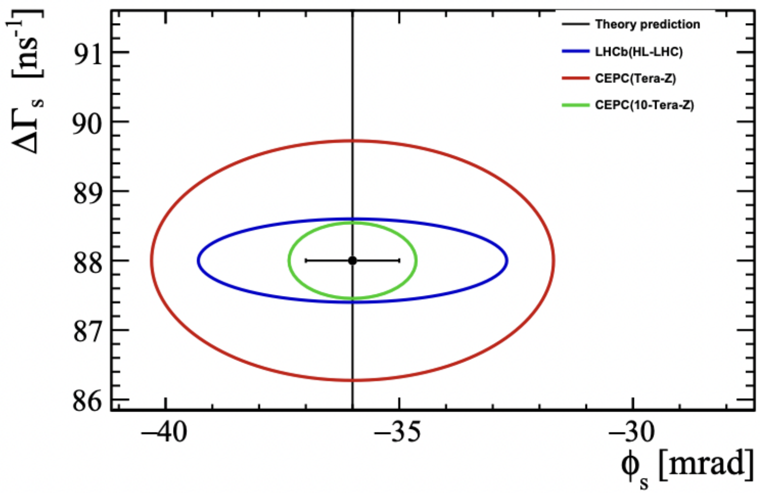


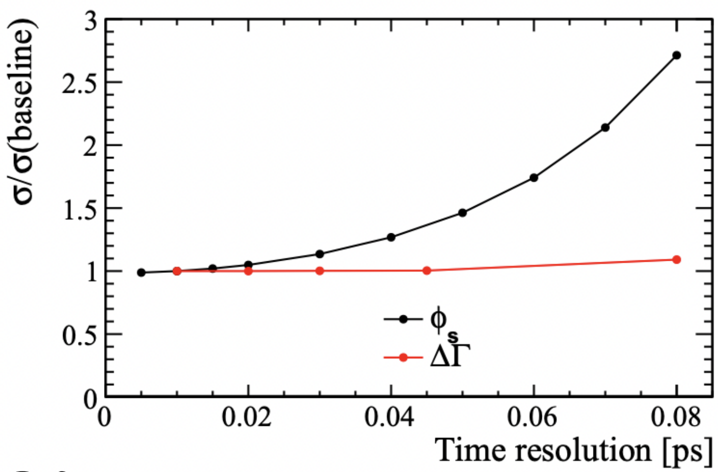


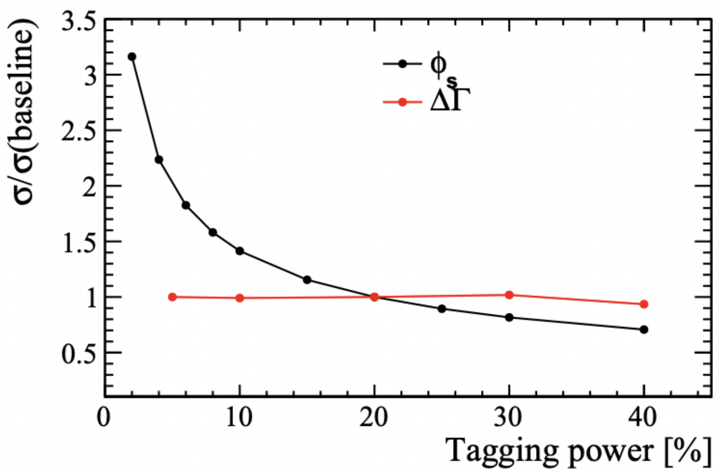
Citable @ inspire

Bs→Jpsi/Phi

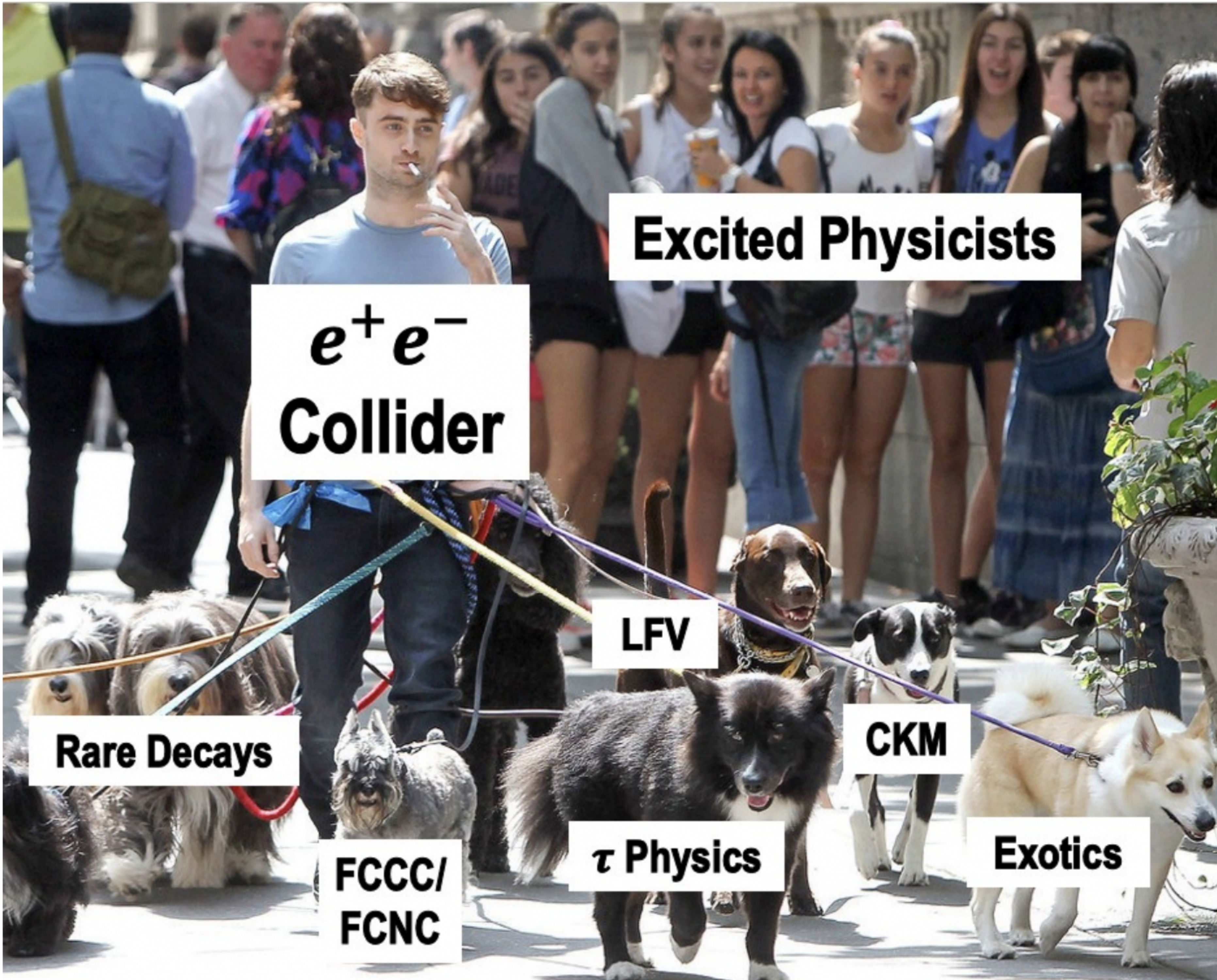
	LHCb(HL-LHC)	CEPC(Tera-Z)	CEPC/LHCb
$b\bar{b}$ statics	43.2×10^{12}	0.152×10^{12}	1/284
Acceptance×efficiency	7%	75%	10.7
Br	6×10^{-6}	12×10^{-6}	2
Flavour tagging	4.7%	20%	4.3
Time resolution $(\exp(-\frac{1}{2}\Delta m_s^2 \sigma_t^{2\,2})$	0.52	1	1.92
scaling factor ξ	0.0014	0.0019	0.8
$\sigma(\phi_s)$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





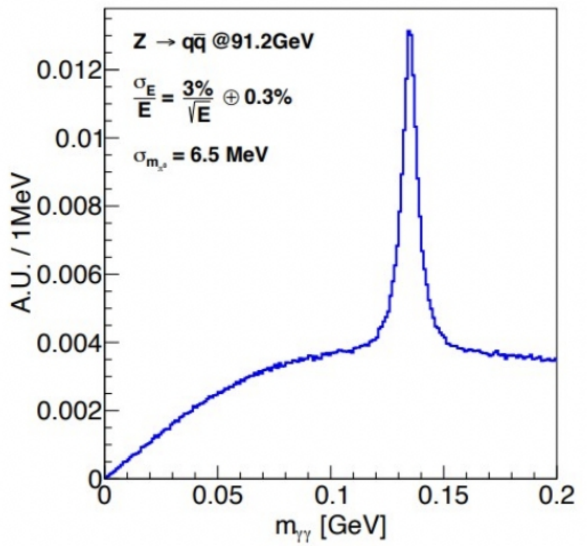


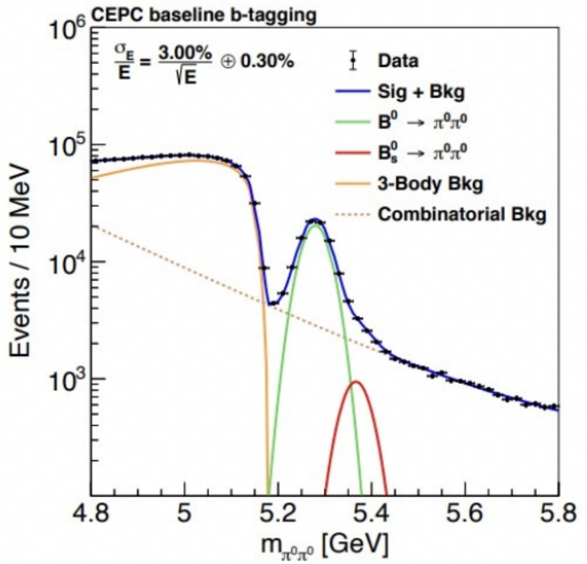
Preliminary...


Excited Physicists
e^+e^-
Collider
LFV
Rare Decays
CKM
FCCC/
FCNC
τ Physics
Exotics

Flavor Physics @ Z pole

- Extremely rich physics:
  - Multiple observation window (CKM, exotic, LFU, LFV, anomalies...), access to NP of 10 TeV or higher
  - Need sophisticated interpretation
- Strong comparative advantage + added value on top of Belle-II & LHCb
  - V.S. BelleII, Access to heavy hadron, large boost
  - V.S. LHCb, Acceptance, neutral final state, and Jet Flavor/Charge reconstruction
- Stringent requirements on detector performance
  - Final state particle separation + BMR/missing energy reconstruction
  - Low energy/momentum thresholds
  - Intrinsic resolution: track & photon
  - Vertexing: Jet Flavor/Charge reconstruction
  - Pid (Pion-Kaon > 3 sigma, or dE/dx(dN/dx) < 3% at Barrel)
- Explored via series of physics simulation + pheno studies



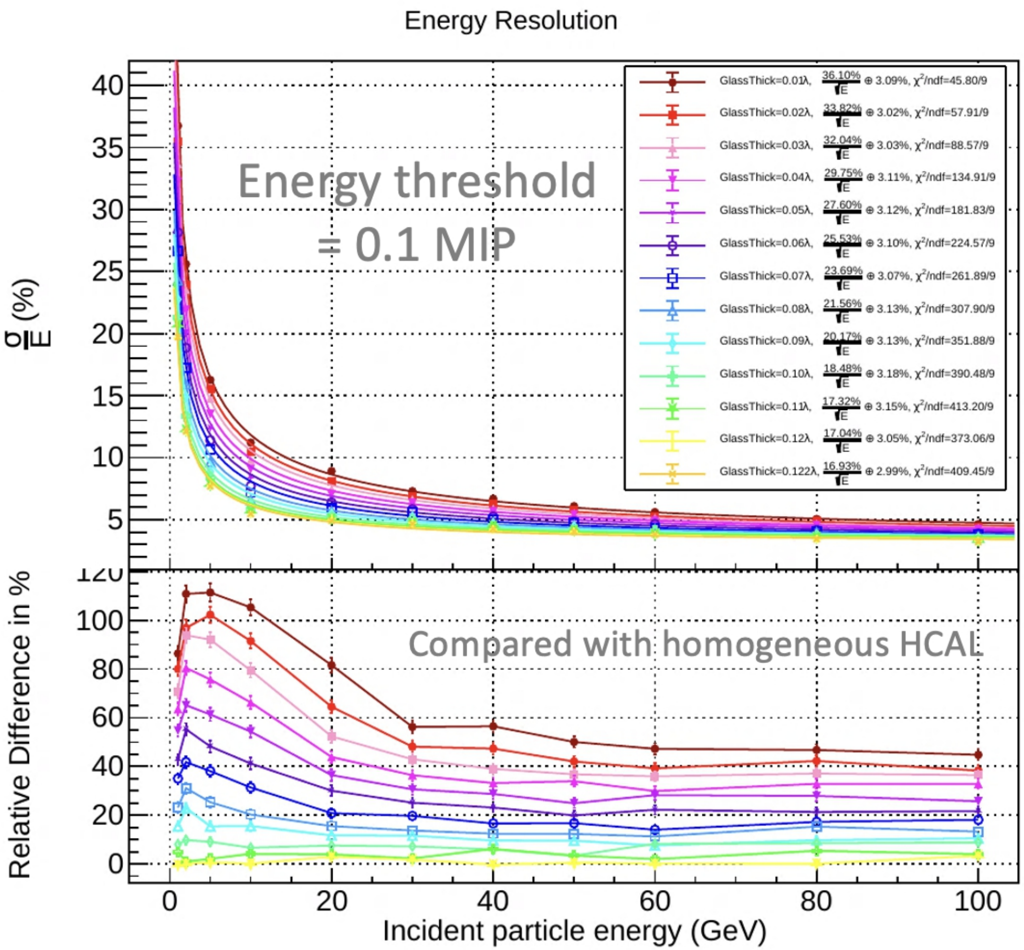


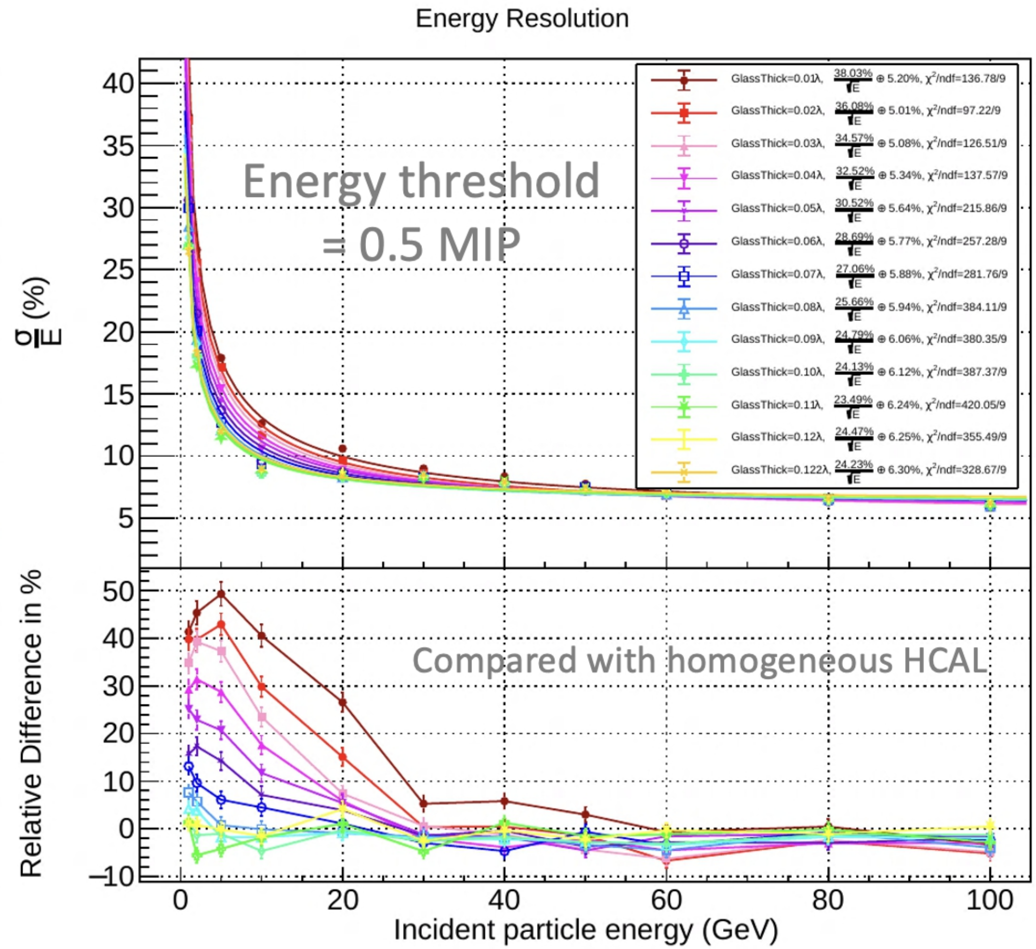
Yields of the CEPC

- **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

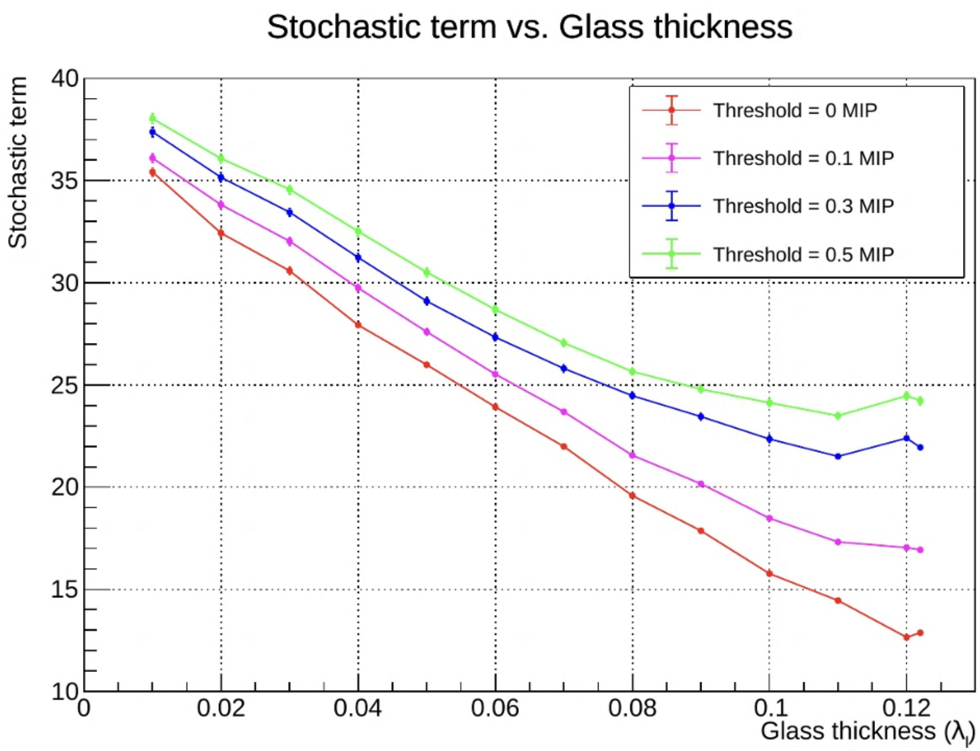
HCAL

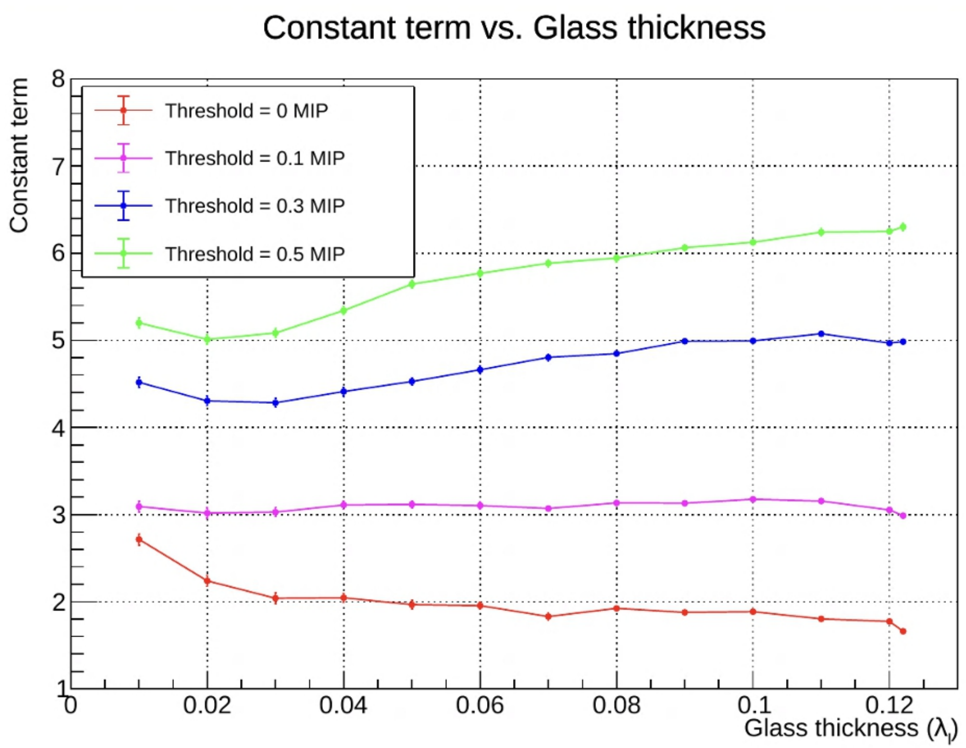




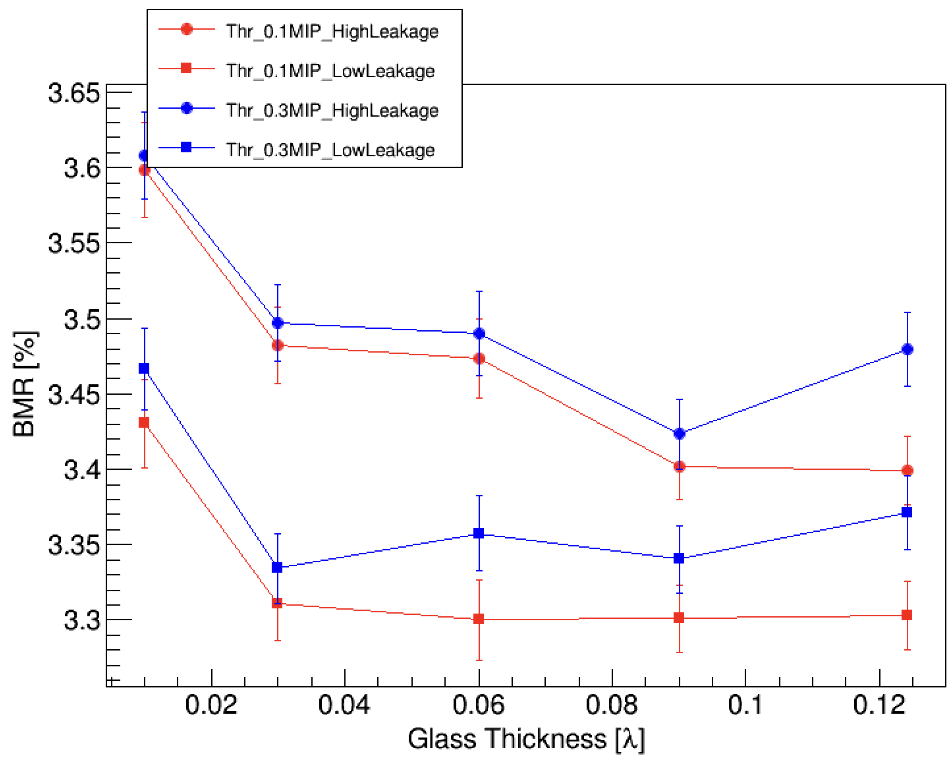
- In an ideal case - ideal Geometry ~ semi infinite...
- HCAL resolution significantly w.r.t. Baseline, at single particle level

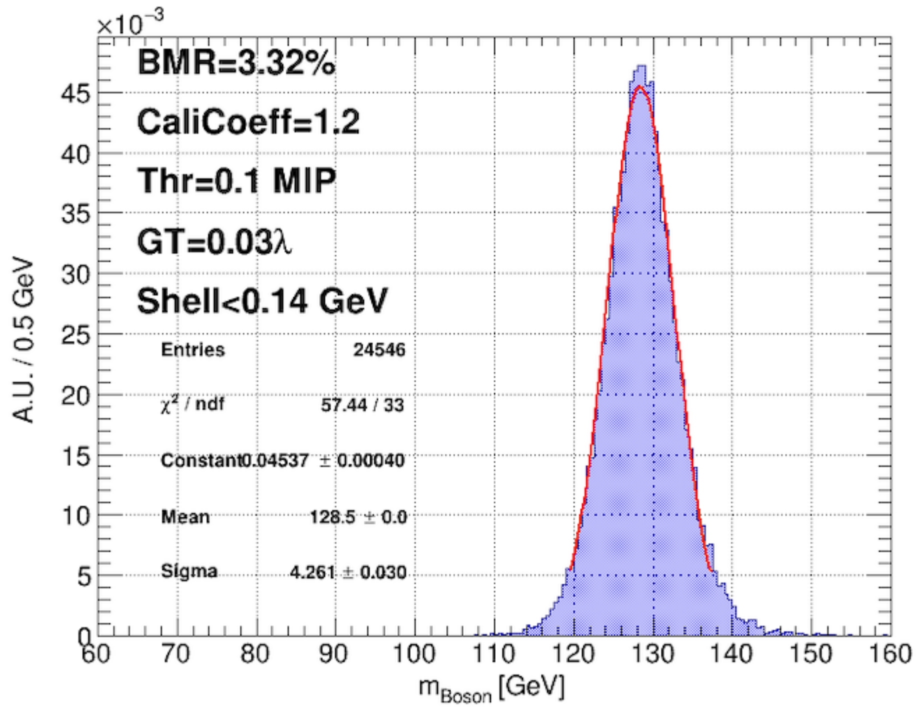
Single Particle @ GS HCAL





HCAL @ BMR





- Fits well with the model...
- Yet, a lot more to be understood