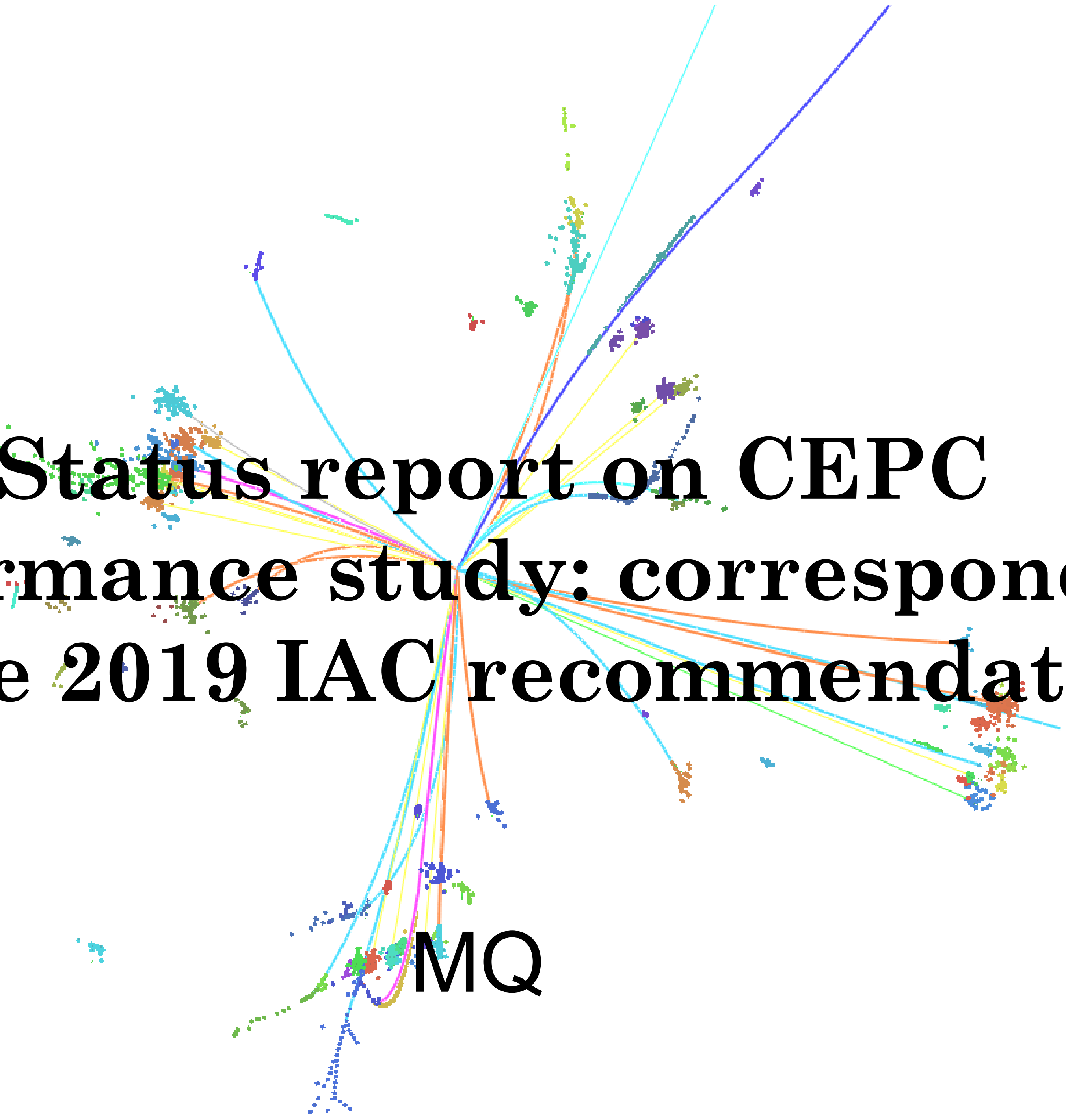

Status report on CEPC Performance study: corresponding to the 2019 IAC recommendation

MQ

From IAC report 2019

Other recommended detector and physics studies:

Recommendation 16:

- *Perform detailed simulation studies to better understand the physics needs from the detector at the various CEPC energy stages; draw consequences about the corresponding detector performance requirements (e.g. photon resolution, jet resolution, added value of PID) and study how this influences the detector design.*
- *Study the physics case for performing flavor physics including the tau lepton at the Z-peak. Draw conclusions on a possible impact on the detector design.*
- *Given that time-of-flight detectors with a time resolution in the 30-50 ps are becoming available, study their potential added value for a CEPC detector by assessing a few key physics benchmarks.*
- *Assess the added value of dE/dx capabilities in the tracker.*
- *Assess the added value of the muon detector system. As a result, define the number of muon detection layers to include, together with their required performance.*

From IAC report 2019

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- Key words: Requirement, and Flavor

From IAC report 2019

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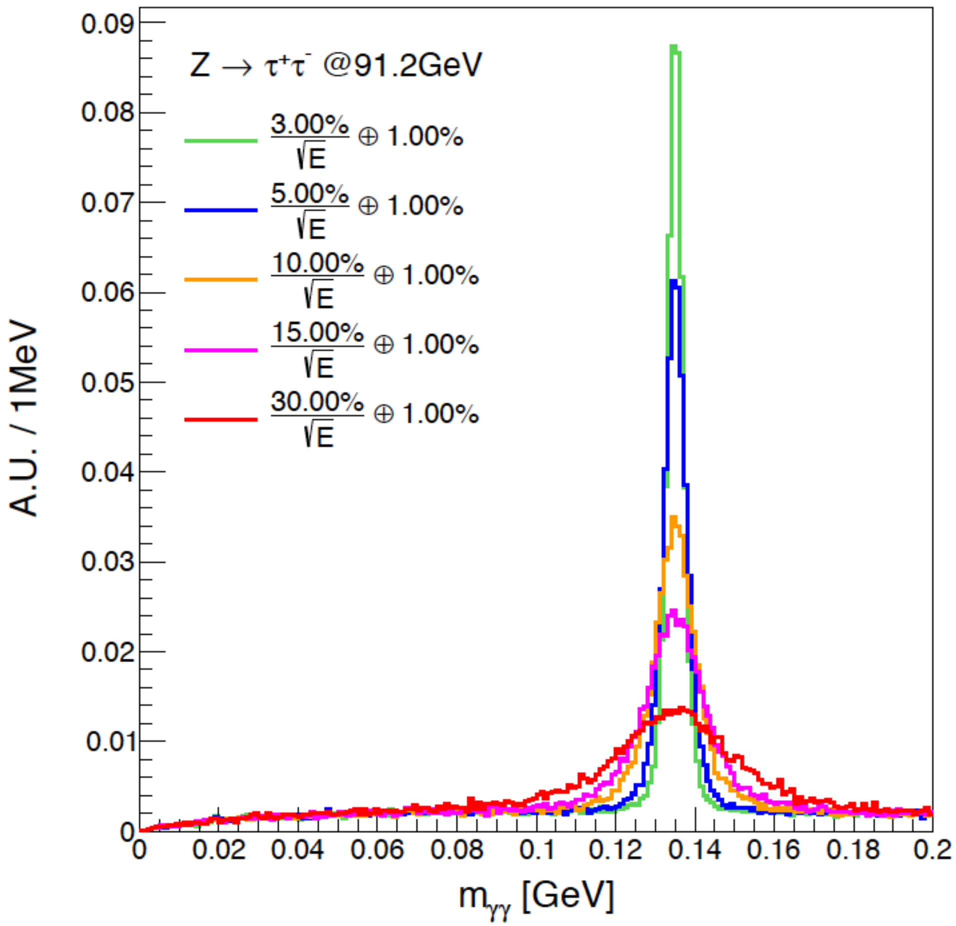
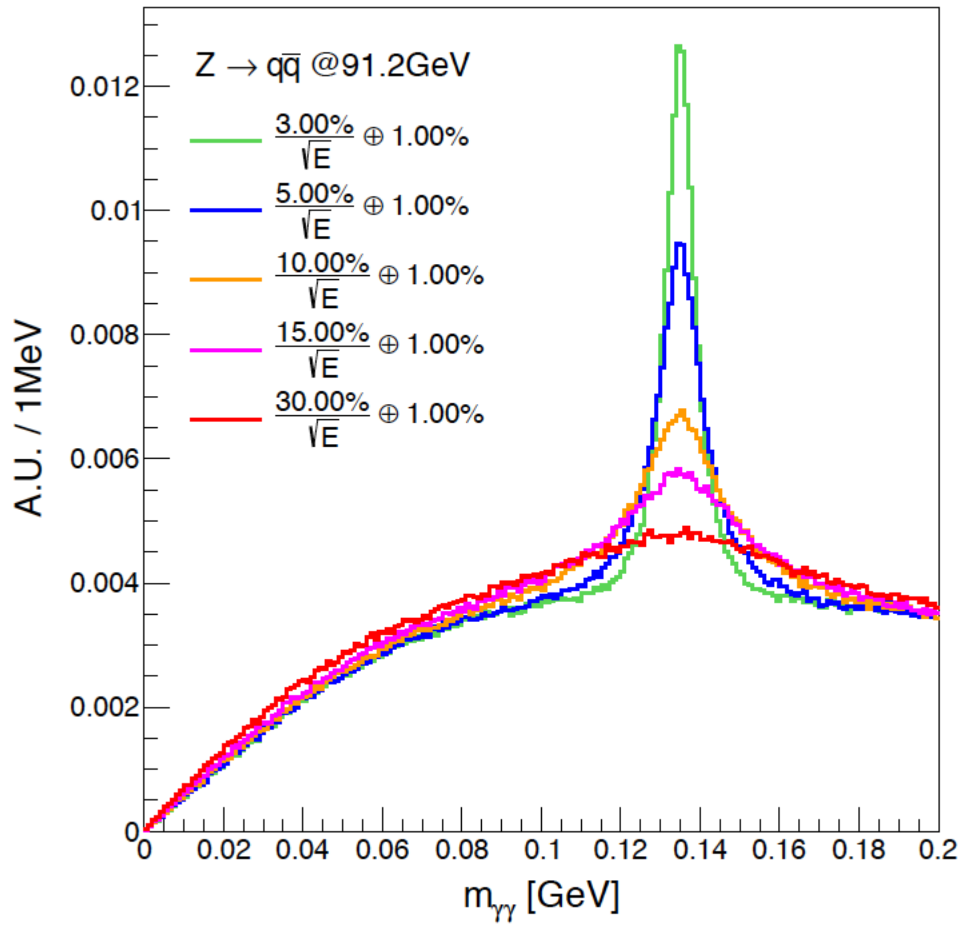
- Key Physics Objects...

pi-0: truth level analysis

Yuexin





pi-0: truth level analysis

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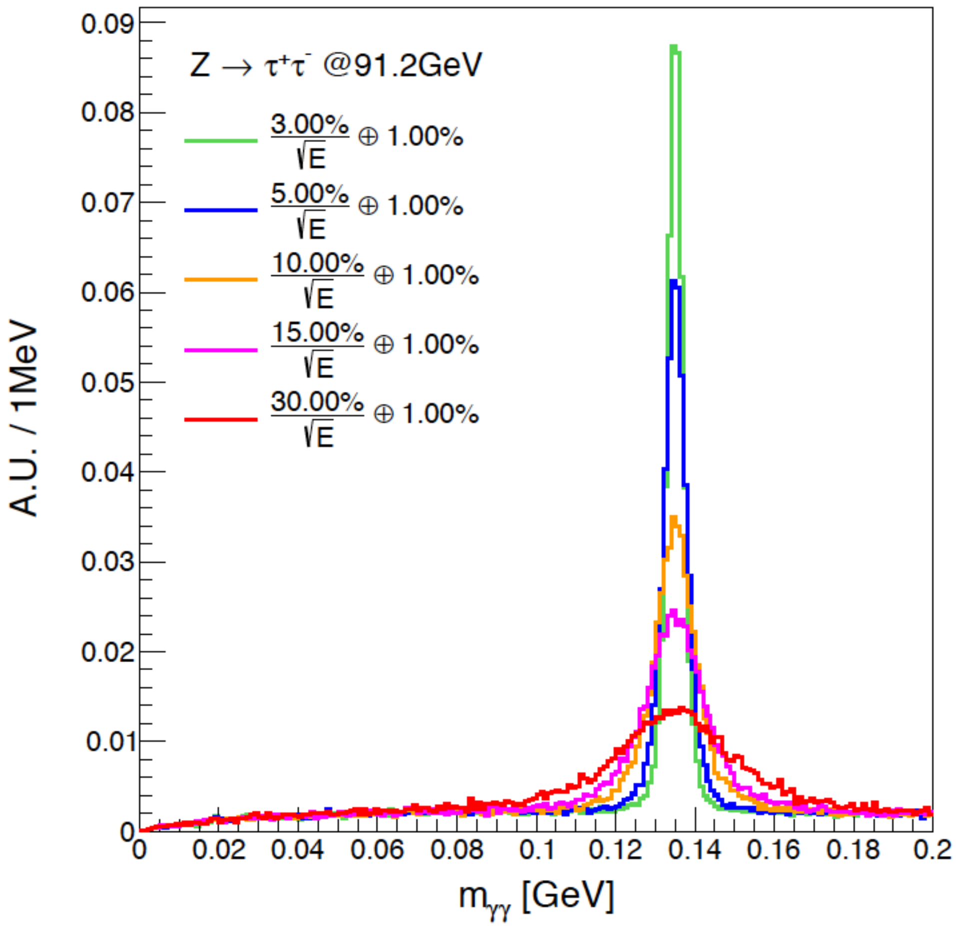
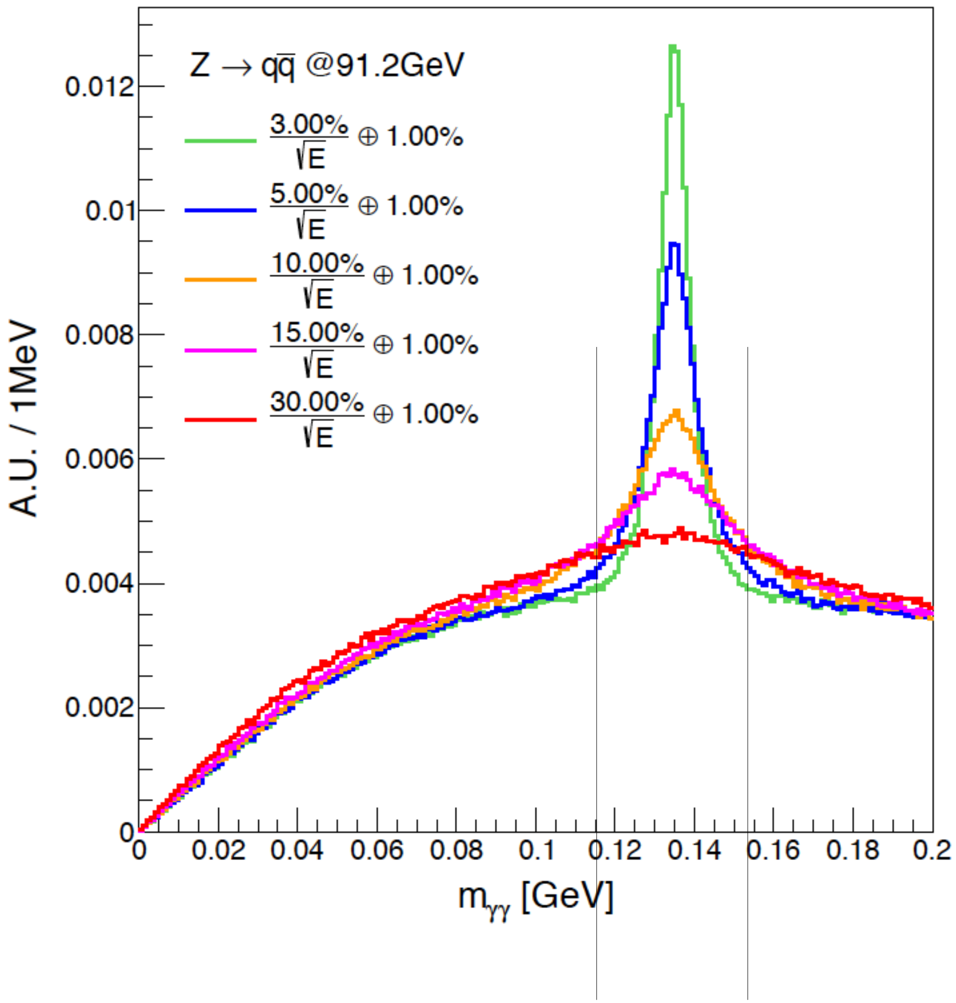
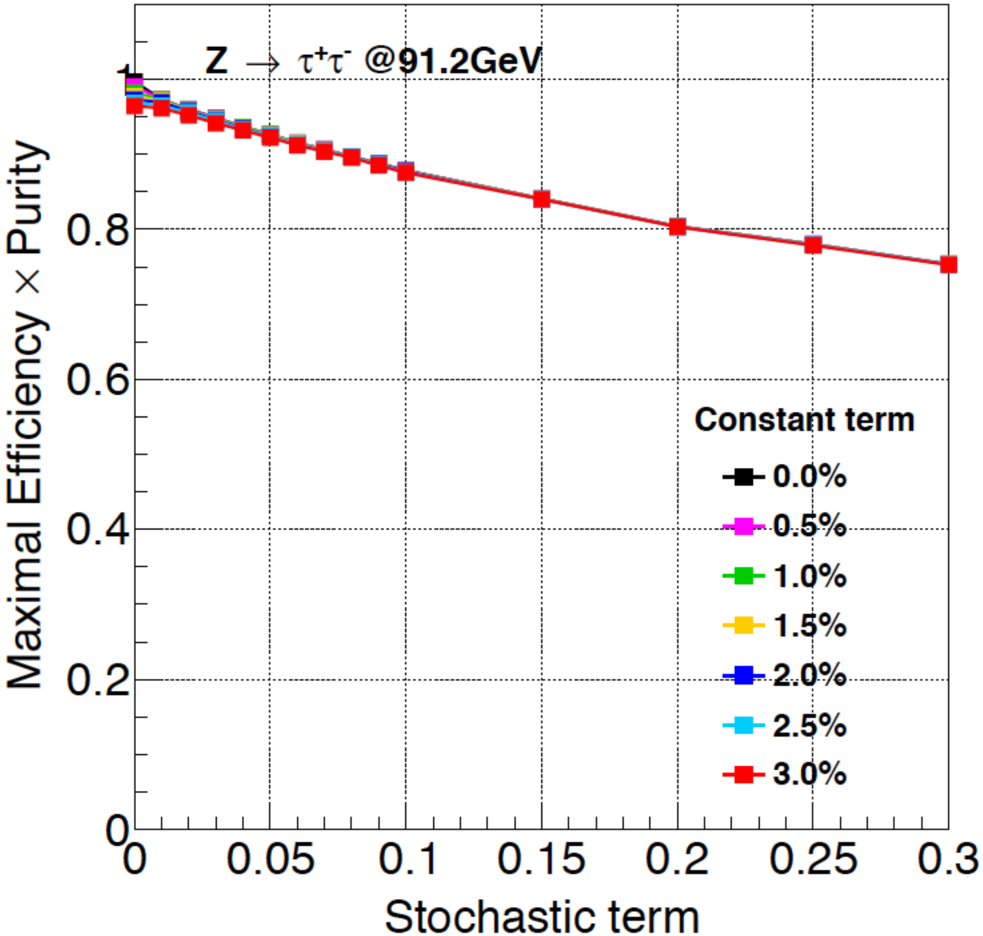
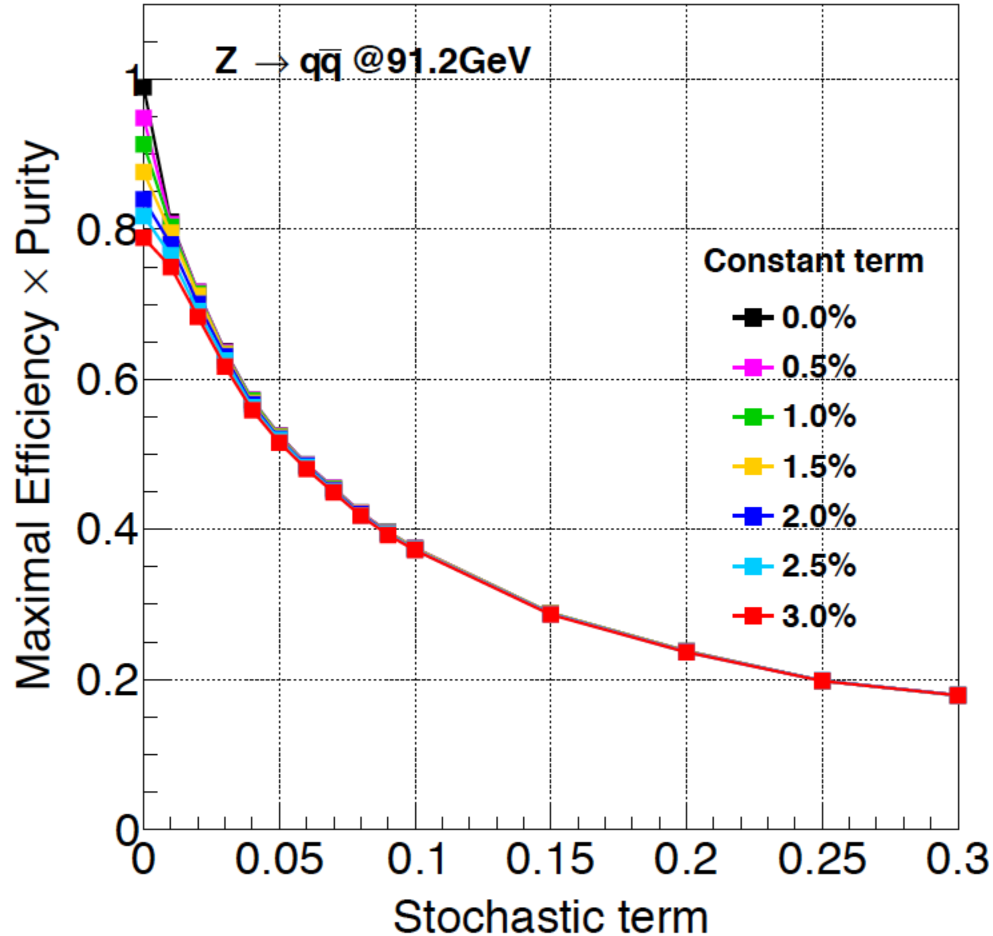




Impact of ECAL resolution on pi-0 finding





Performance dependency on pi-0 energy

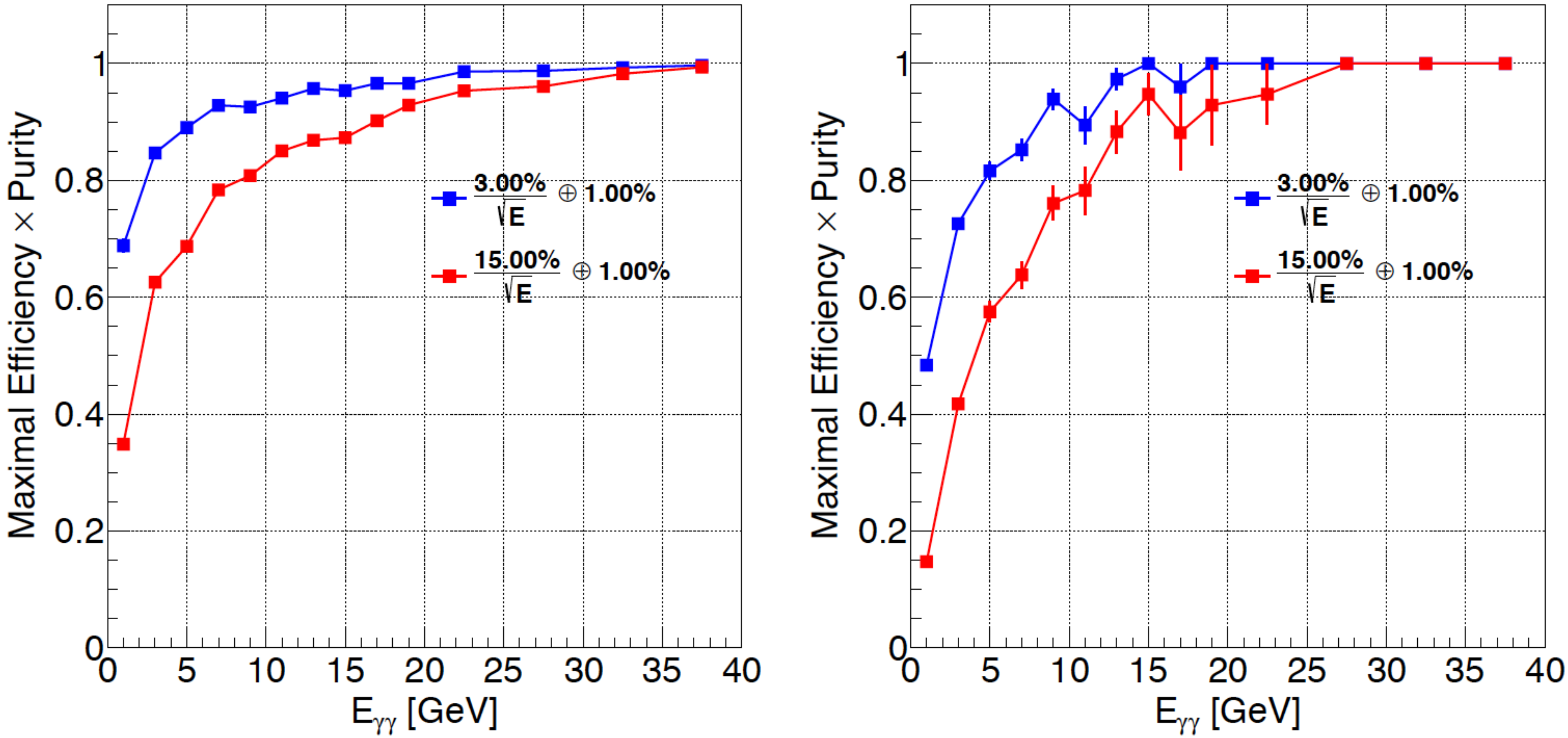


Figure 13: Energy differential maximal $\epsilon \times p$ for $Z \to \tau^+\tau^-$ (left) and $Z \to q\bar{q}$ (right).

...Surely the low energy pi-0 is more sensitive to a better ECAL...

pi-0: energy spectrum of different components

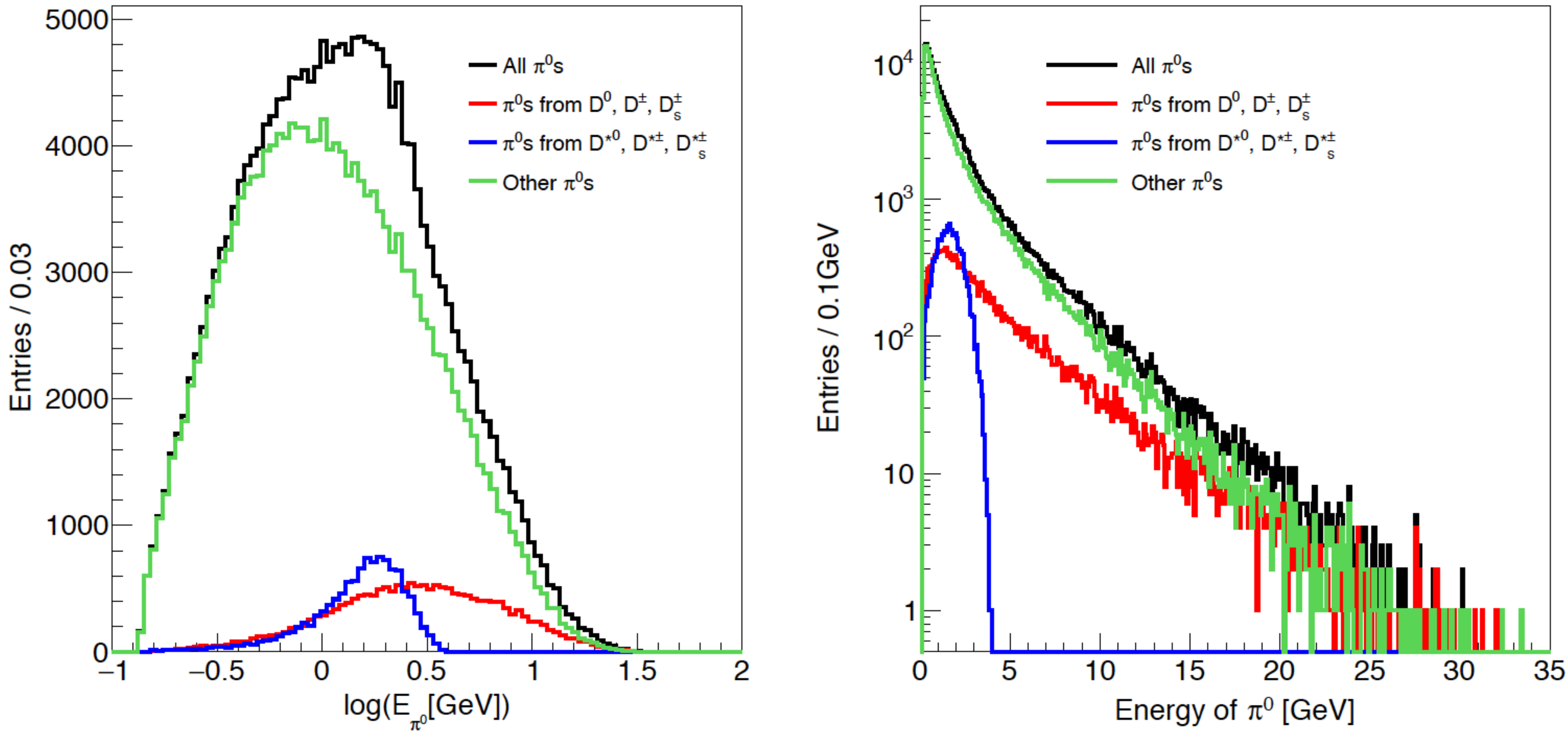


Figure 13: Energy spectrum of π^0 from different origins in $Z \to c\bar{c}$.

pi-0 reco

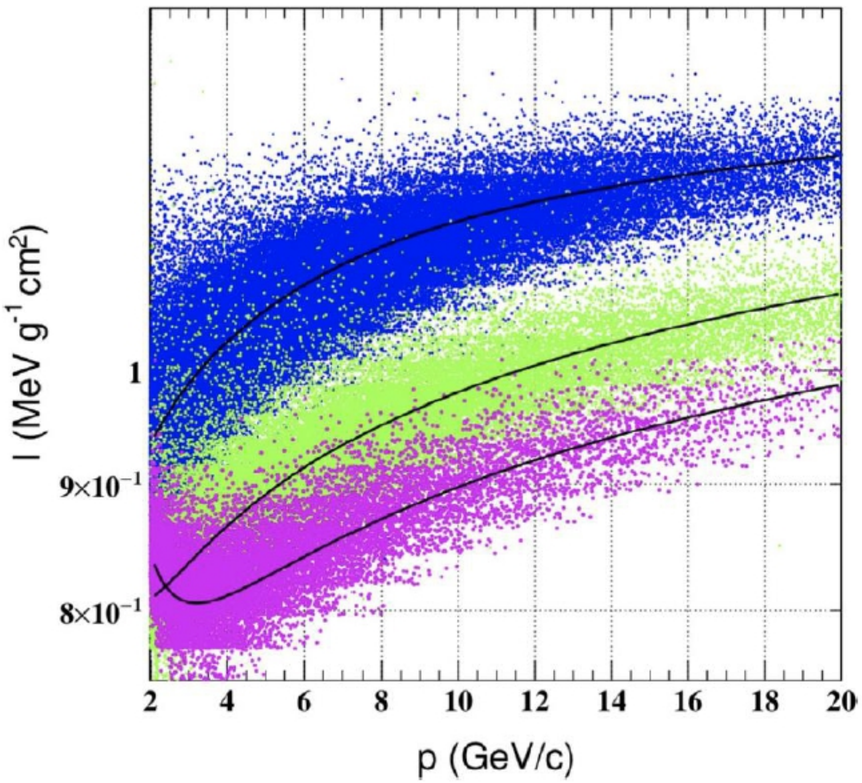
- ECAL resolution is critical: improving the ECAL resolution from 15%/sqrt(E) to 5%/sqrt(E) (with 1% constant term) significantly improve the inclusive pi-0 reconstruction efficiency at jet final state
  - From 85% to 92% at Z→tautau
  - From 30% to 50% at Z→qq

- Low energy pi-0 is more sensitive to ECAL energy resolution.

- Further quantification needs physics benchmarks
  - Narrow States → n*pi0 + X, X are a set of charged Particle
  - Existed States?

Pid & dEdx

Fenfen, Taifan, Zhiyang, etc



MC result of single-particle events with the theoretical prediction by the Bethe equation [16] overlaid. In the right plot the dots are from simulation of $e^+e^- \to Z \to q\bar{q}$ events

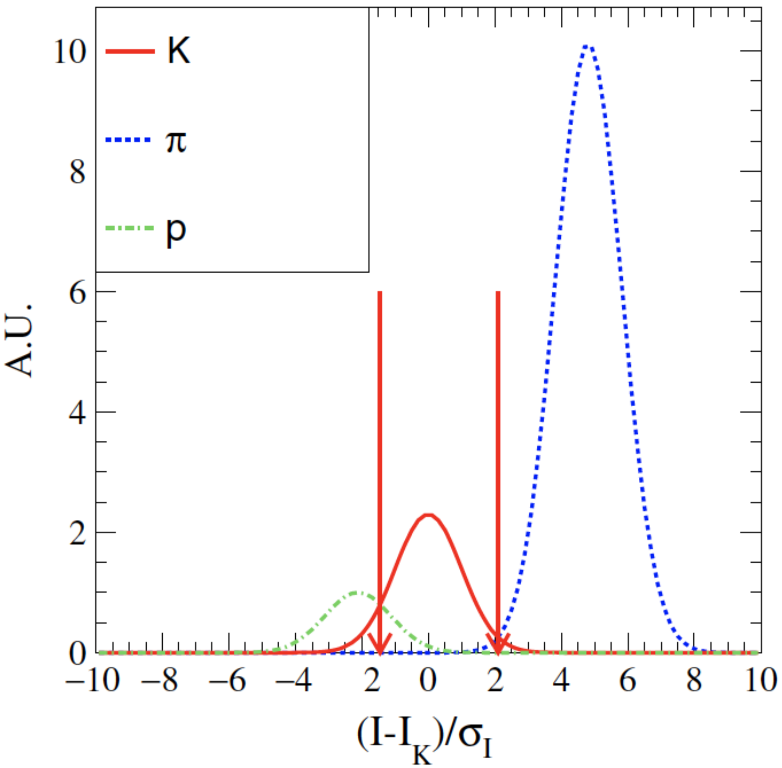


Fig. 6 The scaled spectra of $(I - I_K)/\sigma_I$ using dE/dx measurements alone for particles with a momentum of 5 GeV/c, assuming a 20% degradation. The relative populations are $N_\pi = 4.4N_K$ and $N_K = 2.3N_p$ according to MC simulation. The intersections marked by the arrows are chosen as the cut points

Kaon: energy up to 20 GeV ... even higher

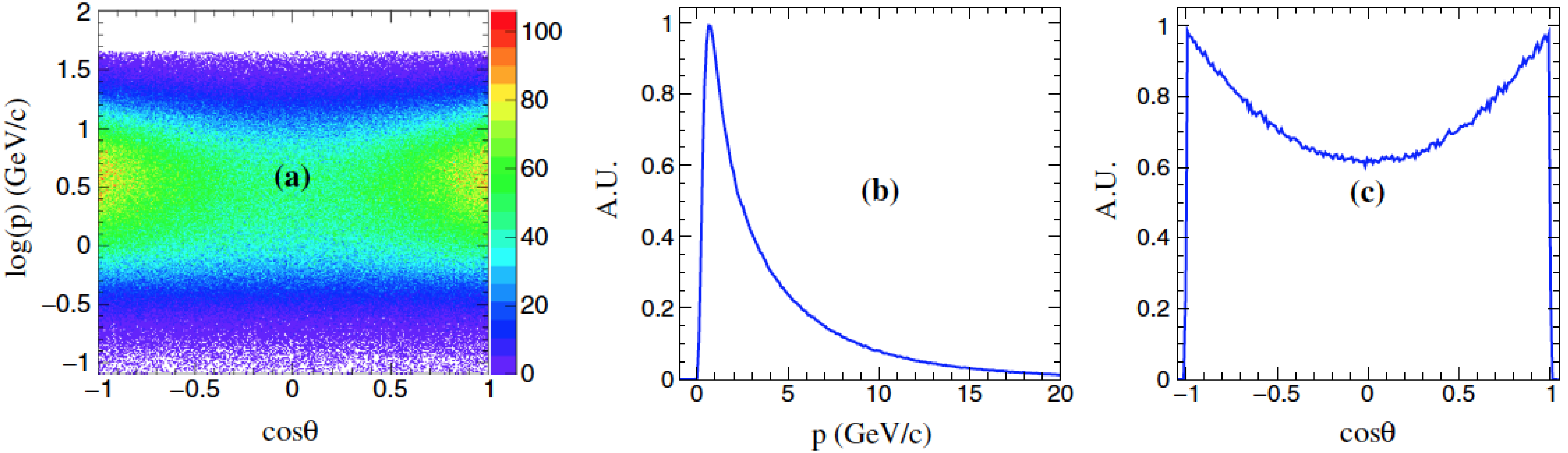
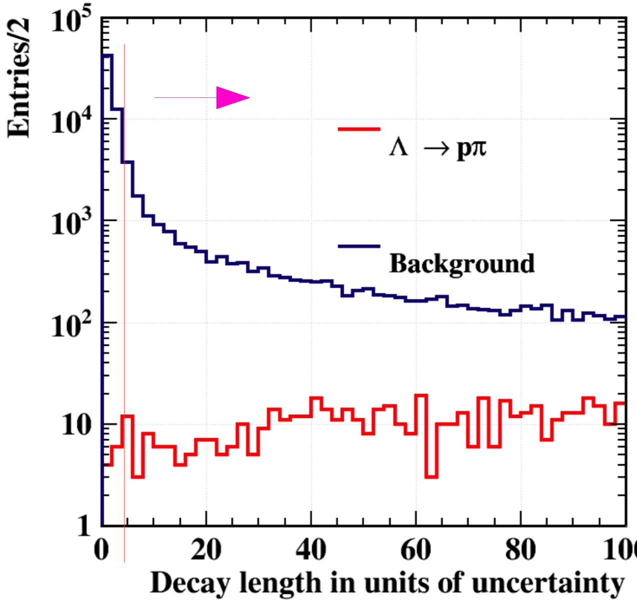
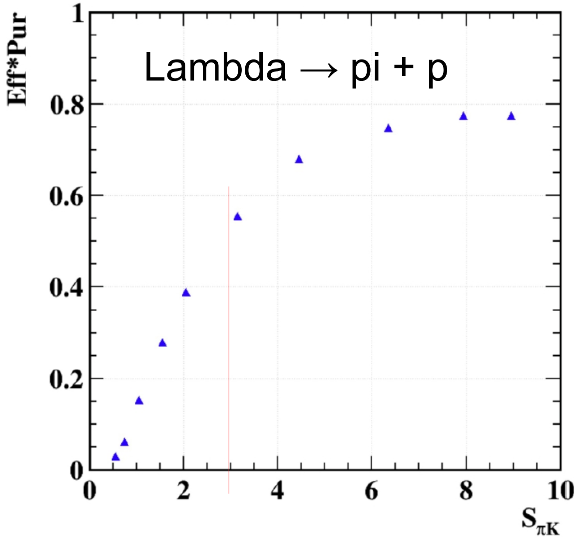


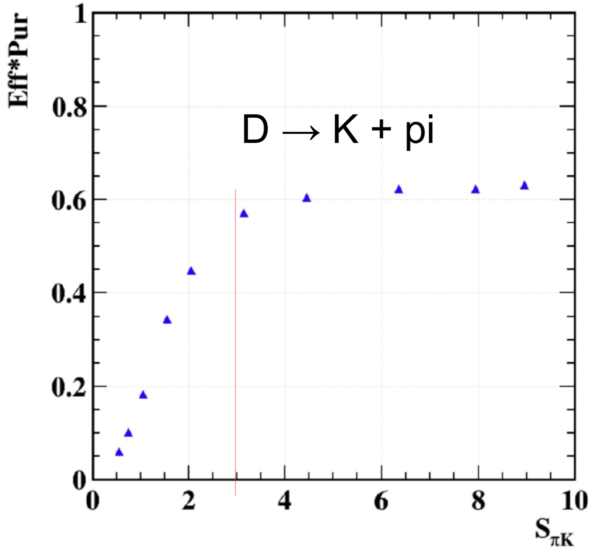
Fig. 3 Kinematic distribution of kaons in $e^+e^- \to Z \to q\bar{q}$ MC events as a function of $\log(p)$ and $\cos\theta$ (**a**), p (**b**), and $\cos\theta$ (**c**)

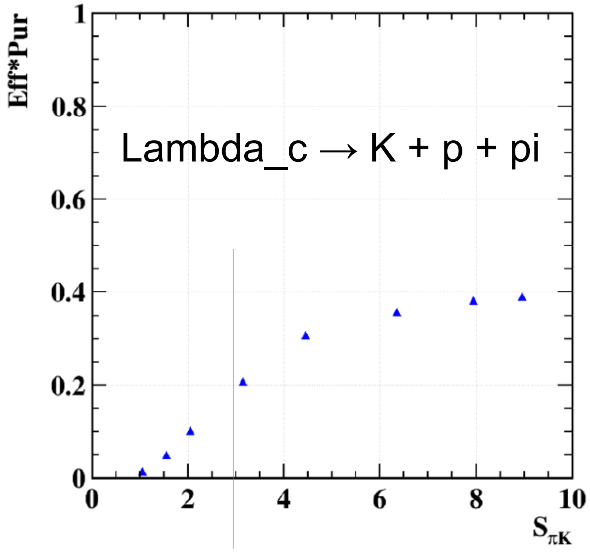
Pid & Objective Hadron finding

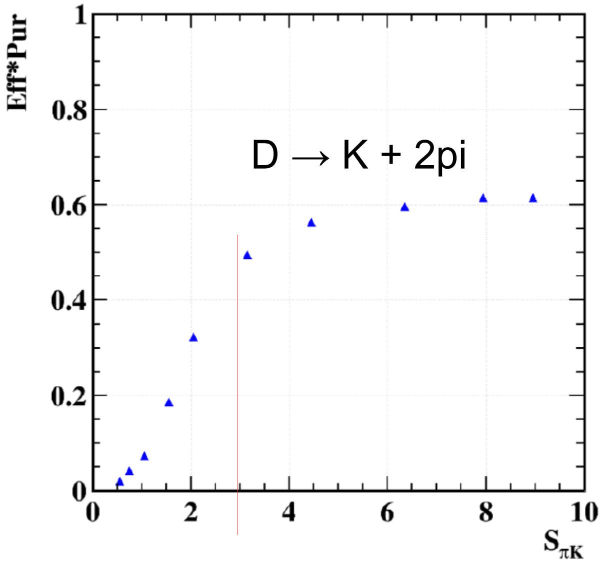
$$S_{AB} = \frac{|I_A - I_B|}{\sqrt{\sigma^2_{I_A} + \sigma^2_{I_B}}},$$











Pid & dEdx

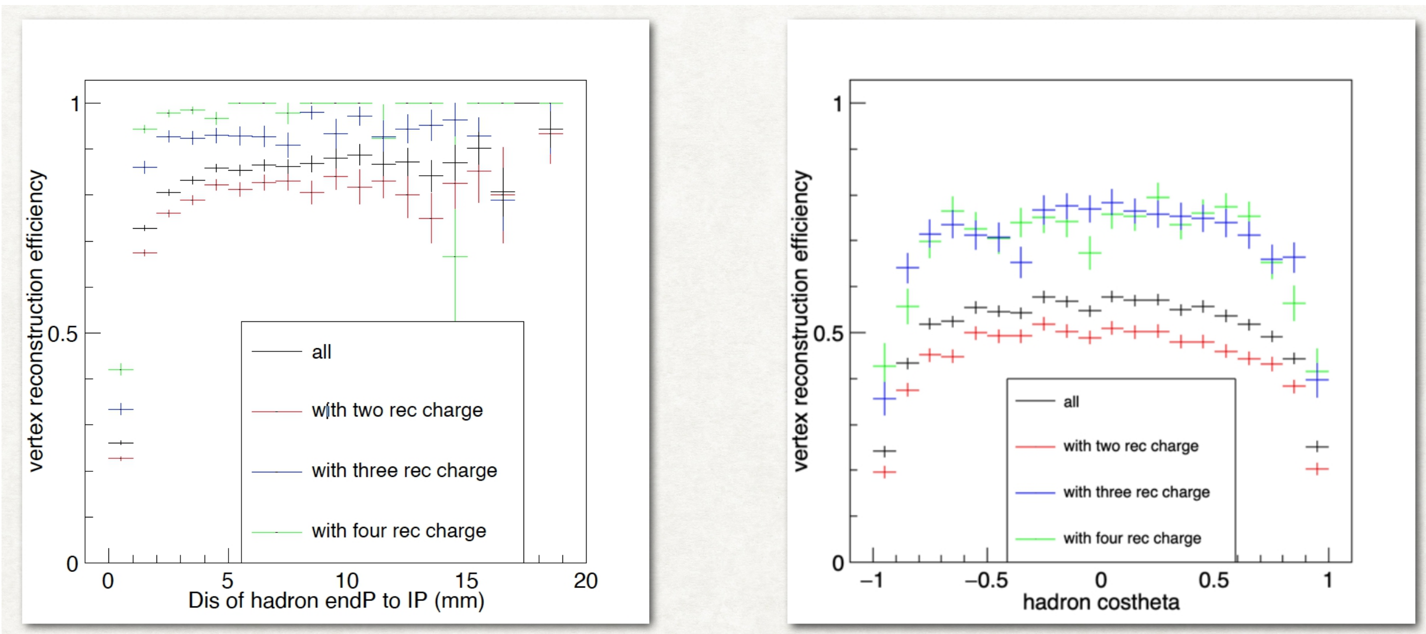
- Physics: Kaon up to 20 GeV should be identified...
- For objects with kaon and/or proton in its decay product: performance depends on
  - Momentum (fully charged final state)
  - Hadron separation, especially pi-K separation
  - VTX reco. (for heavy flavor hadrons)
- Preliminary: 3-sigma separation of pi-Kaon, corresponding to 2% of dEdx resolution, is appreciated

VTX reconstruction: Diagnosis

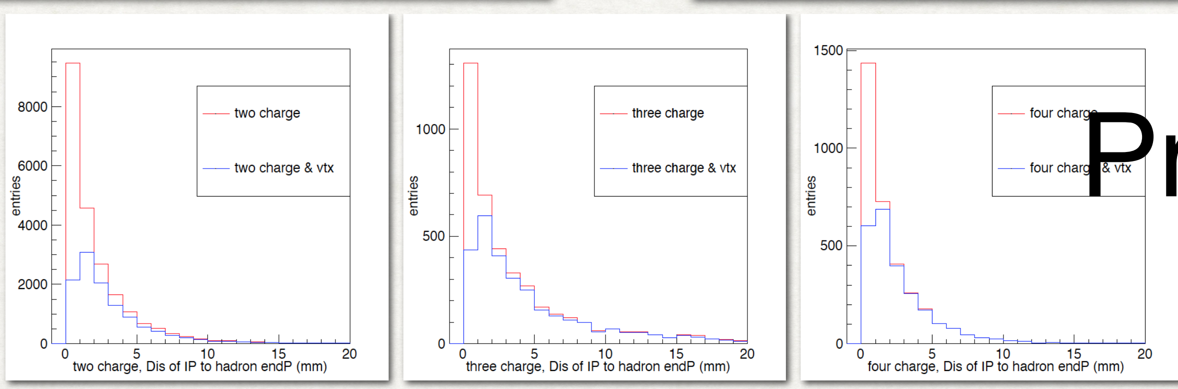
$$\frac{\textit{should been reconstructed vertex} \;\&\&\; \textit{have been reconstructed vertex}}{\textit{should been reconstructed vertex}}$$

C-hadron with given charge multiplicity && corresponding tracks reconstructed

- At vvH, H→cc events.



Yongfeng

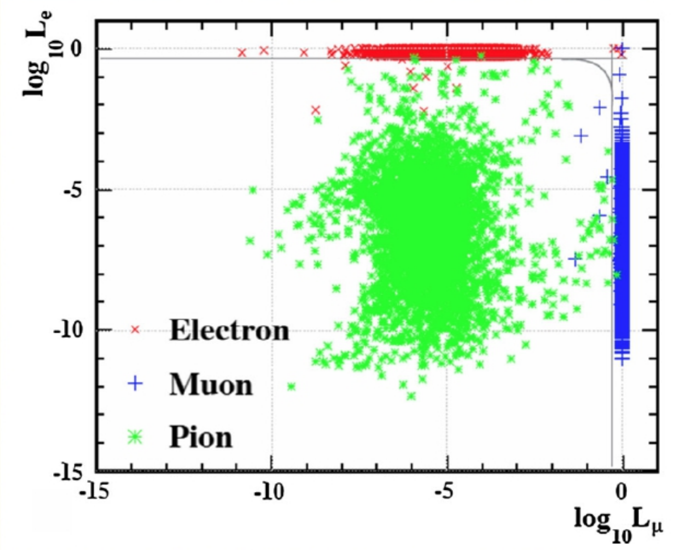


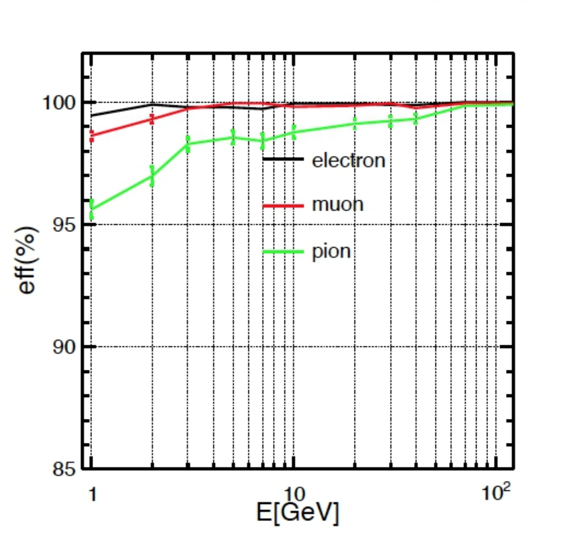
Preliminary

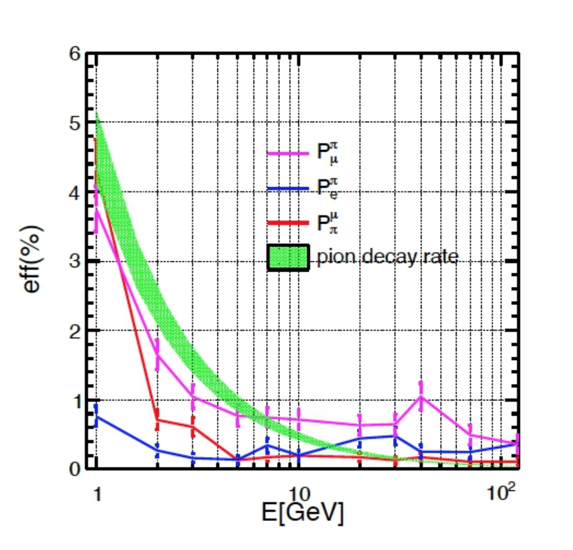
Light Lepton Identification

Dan Yu

- LICH uses TMVA methods to summarize 24 input variables into two likelihoods, corresponding to electrons and muons.
- The efficiency for electron and muon is higher than 99.5% (E>2 GeV). Pion efficiency ~ 98%.







Migration Matrix at 40GeV (LICH)

Type	e^- like	μ^- like	π^+ like
e^-	99.71 ± 0.08	< 0.07	0.21 ± 0.07
μ^-	< 0.07	99.87 ± 0.08	0.05 ± 0.05
π^+	0.14 ± 0.05	0.35 ± 0.08	99.26 ± 0.12

Migration Matrix for ALEPH PID ($> 2GeV$)(*Eur.Phys.J.C20:401-430,2001*)

Type	e^- like	μ^- like	π^+ like	undefined
e^-	99.57 ± 0.07	< 0.01	0.32 ± 0.0	0.09 ± 0.04
μ^-	< 0.01	99.11 ± 0.08	0.88 ± 0.08	0.01 ± 0.01
π^+	0.71 ± 0.04	0.72 ± 0.04	98.45 ± 0.06	0.12 ± 0.03

Eur. Phys. J. C (2017) 77: 591

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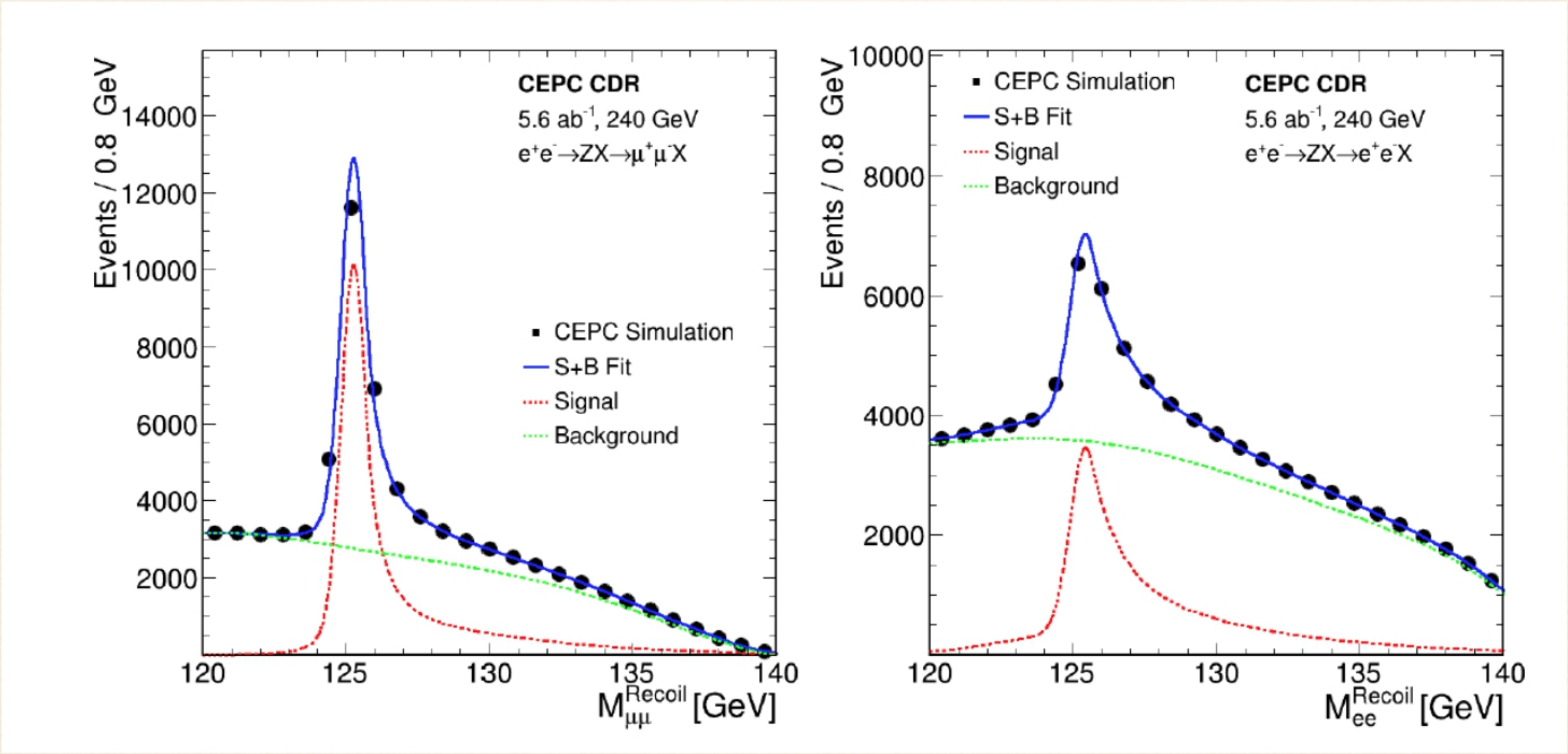
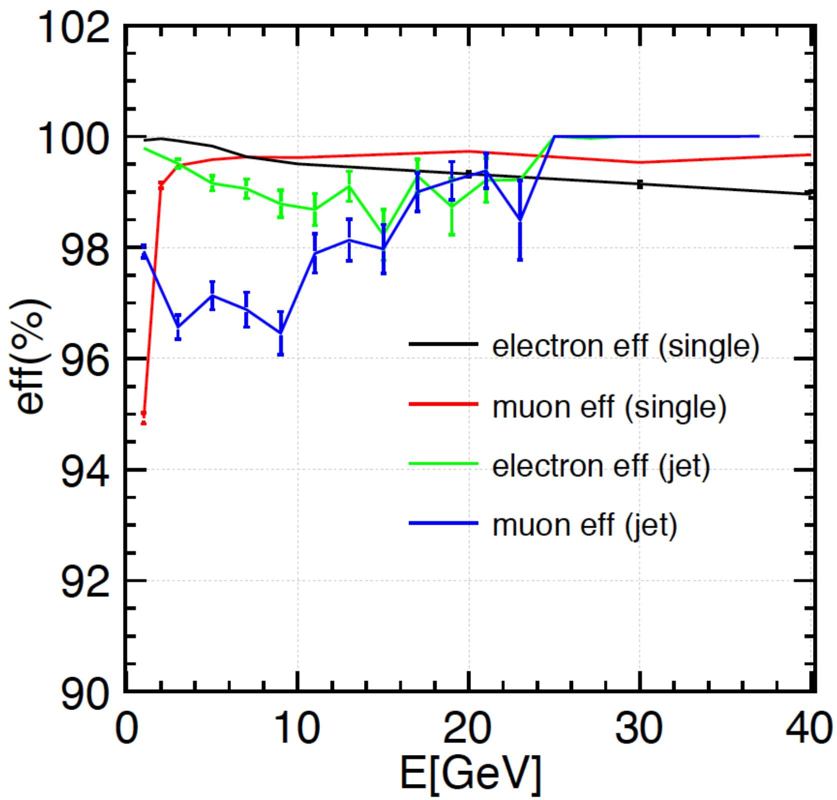
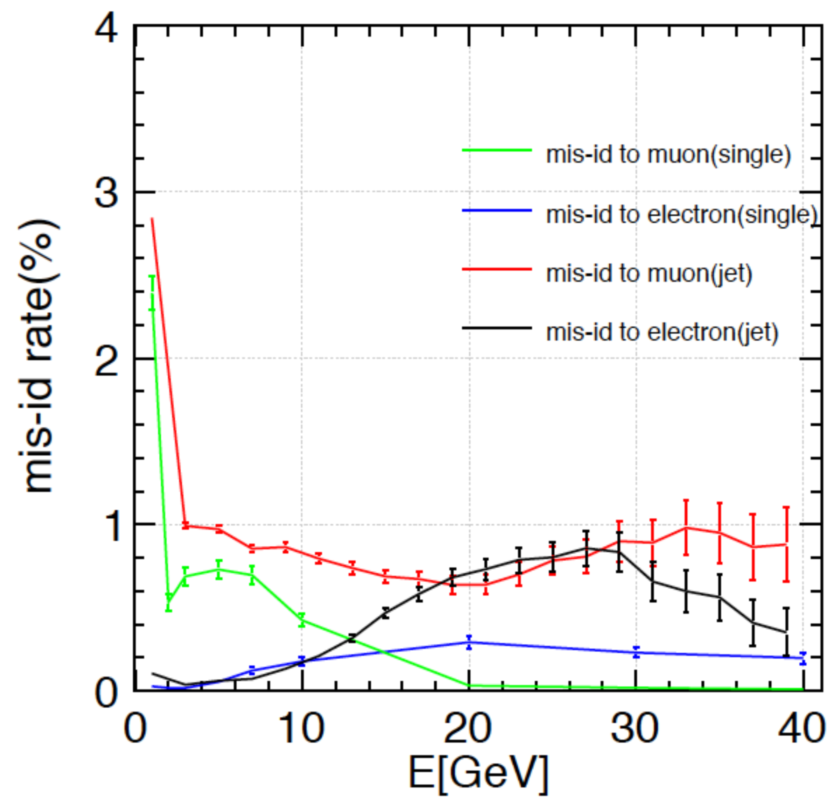


Jet lepton

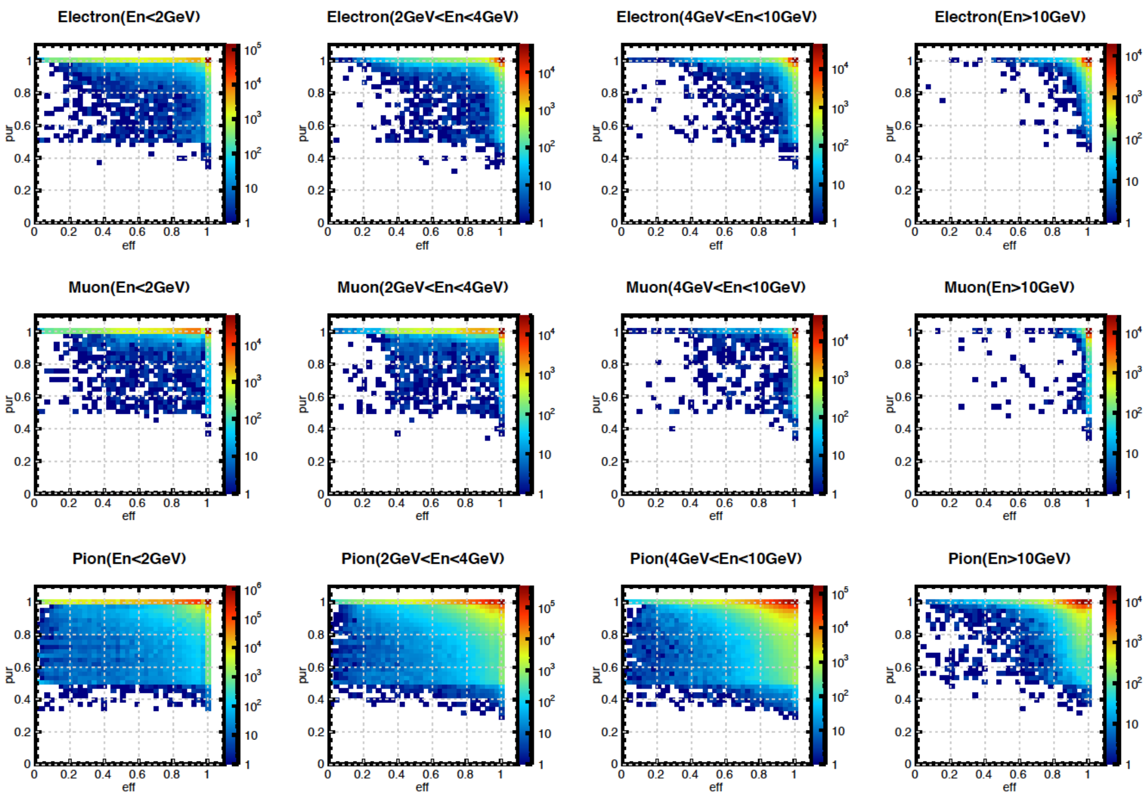


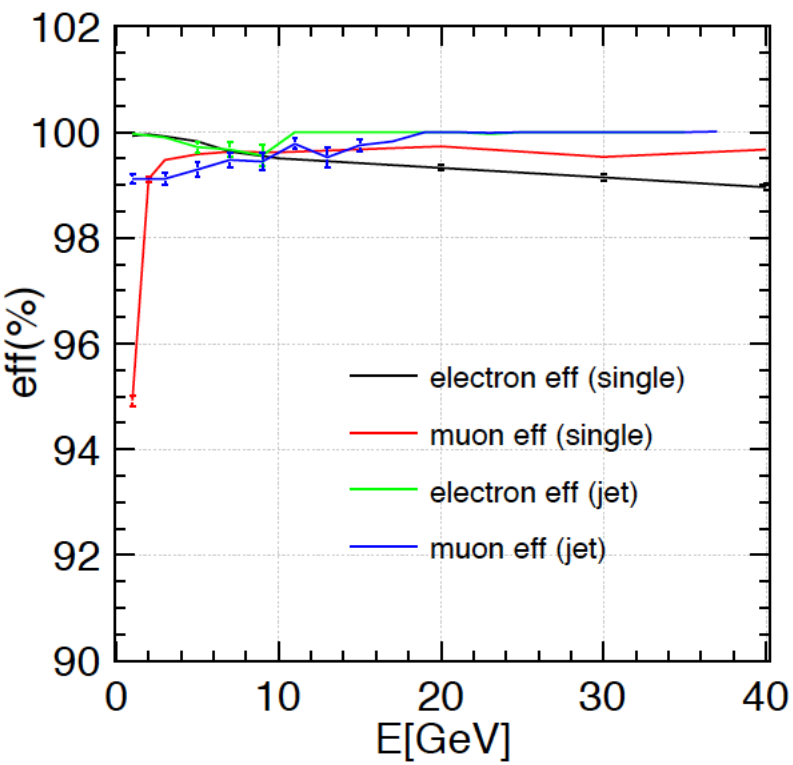


Compared the single particle sample, the jet lepton (at Z->bb sample at sqrt = 91.2 GeV) Performance will be slightly degraded. At the same working point,

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.

Jet lepton: identification performance dependence on calorimeter clustering

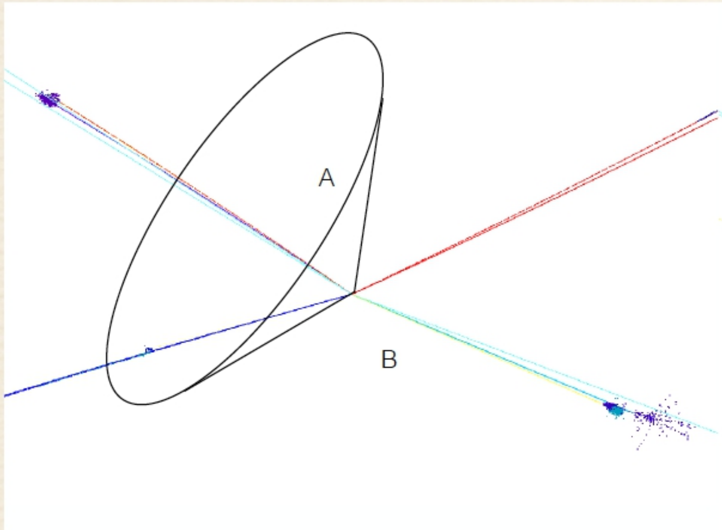


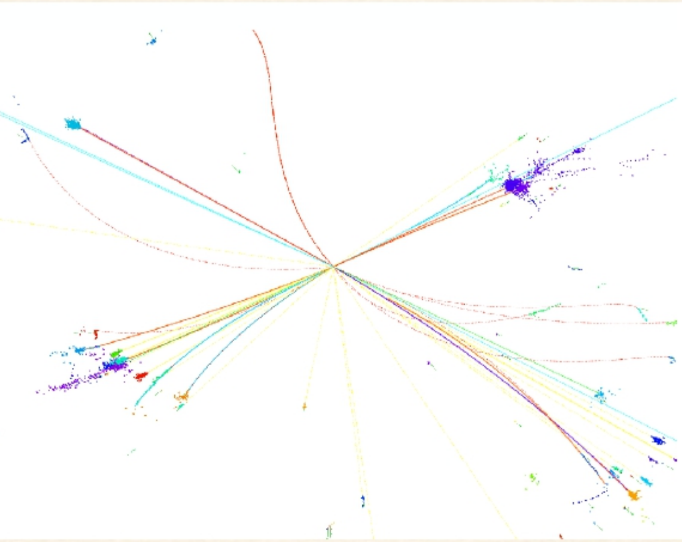


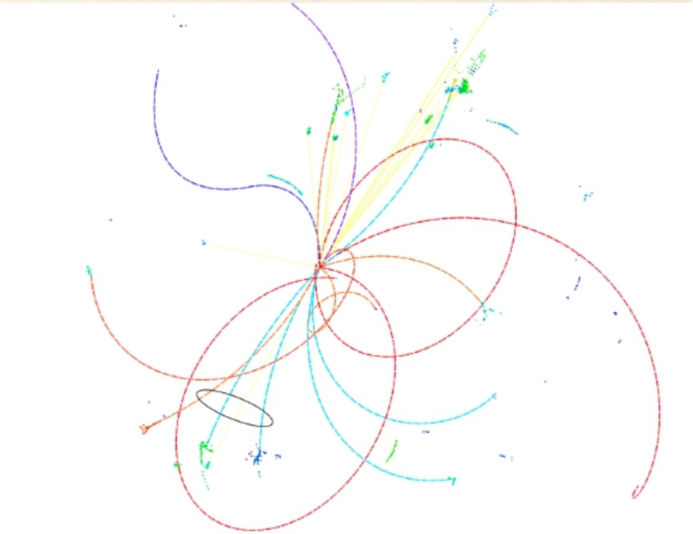
Relative difference reduced once require a good Calorimeter Clustering Performance

Event topology

- llH channel / Z→ττ
- qqH (isolate τ with jets)
- τ inside jets





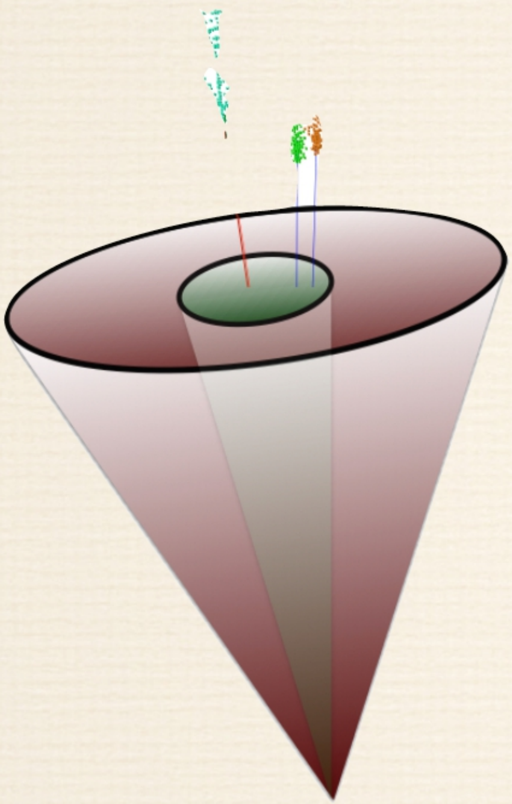


- (Veto the two isolate lepton)
- Divide the whole space into 2 part
- Multiplicity & Impact parameter

- Tau jet reconstruction package: TAURUS

- TAURUS with different parameters

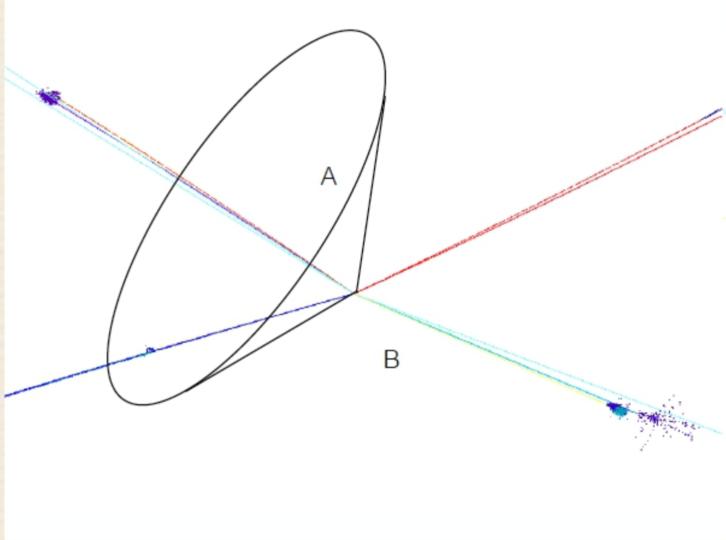
Taurus

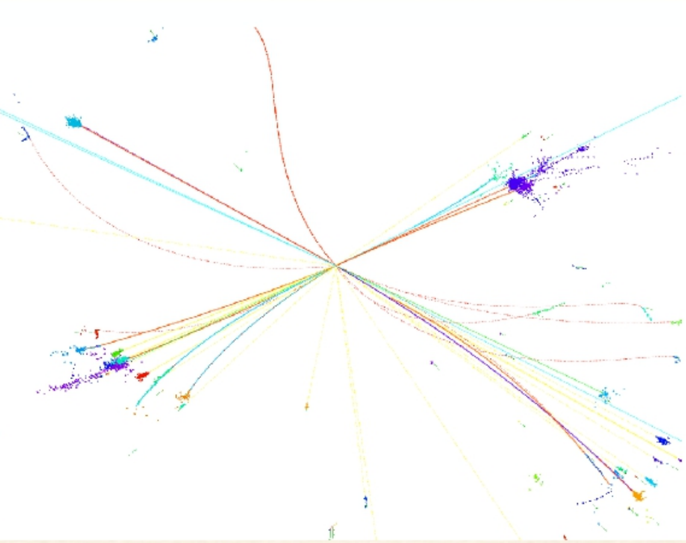


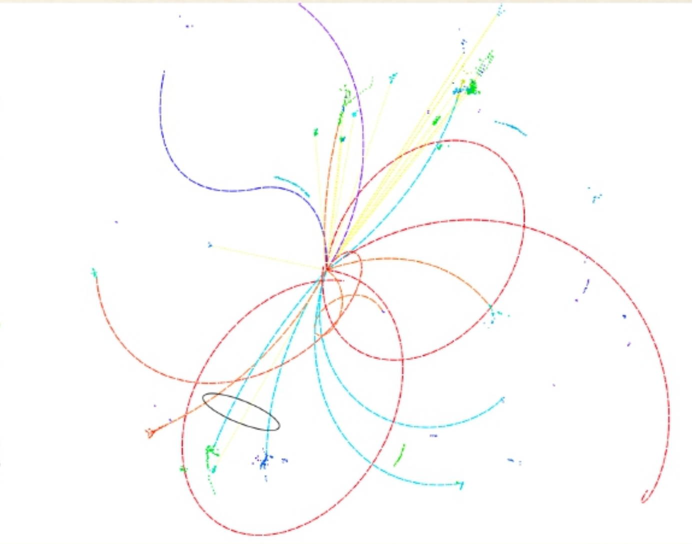
- Double cone based algorithm
    - Find seeds(Tracks with enough energy)
    - Collect particle in two cones
    - Use the multiplicity, energy ratio between two cones, invariant mass for τ tagging

Event topology

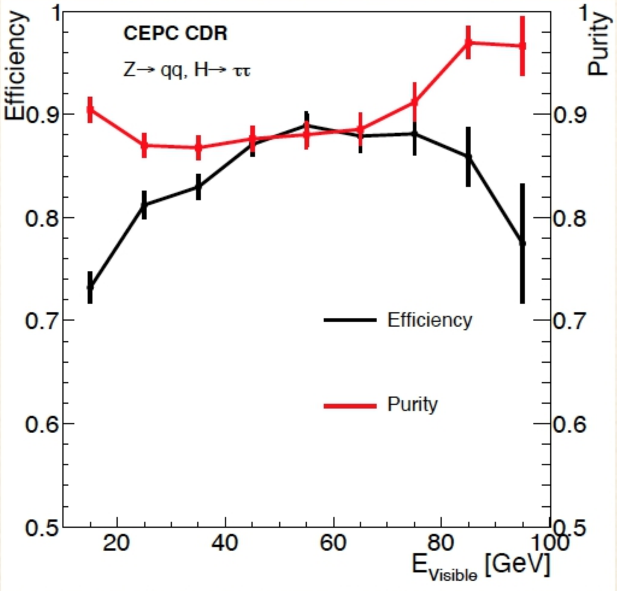
- llH channel / Z→ττ
- qqH (isolate τ with jets)
- τ inside jets

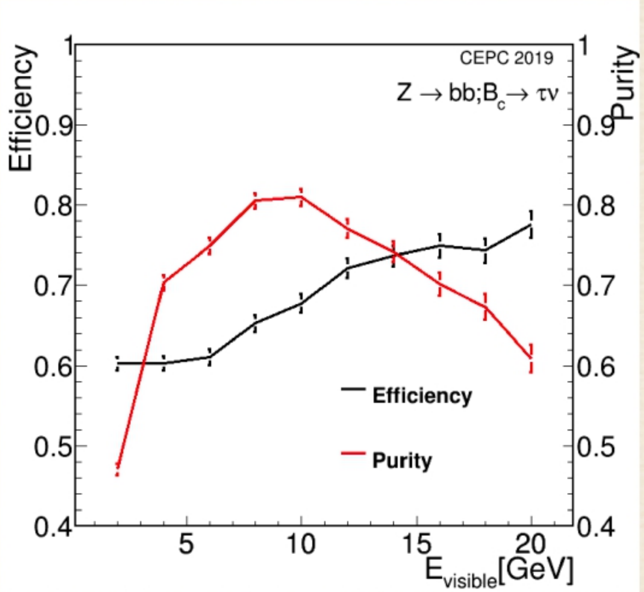






- (Veto the two isolate lepton)
- Divide the whole space into 2 part
- Multiplicity & Impact parameter
- Efficiency > 90%

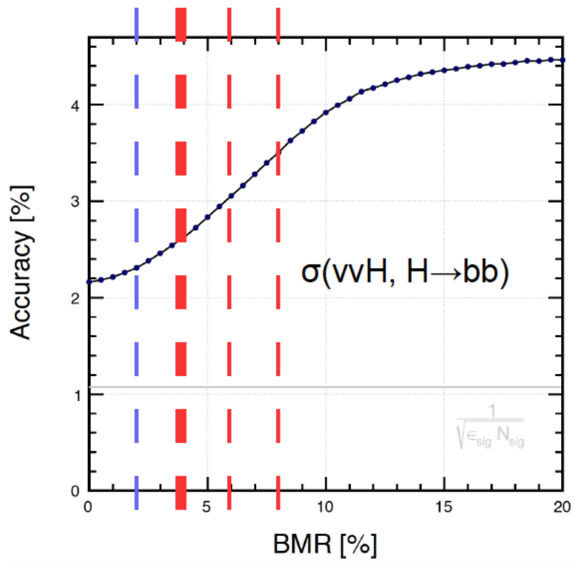


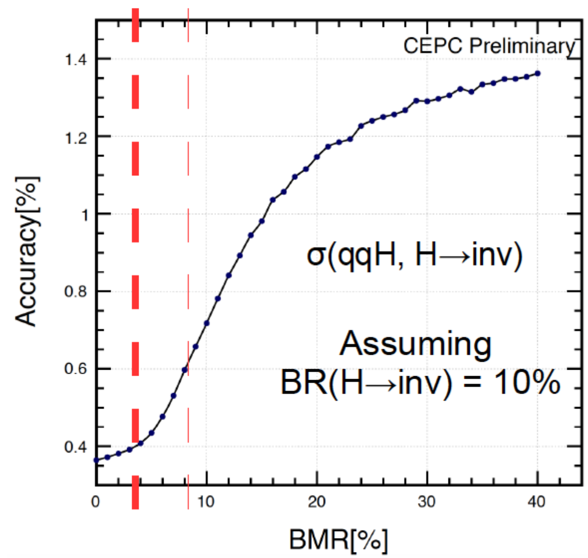


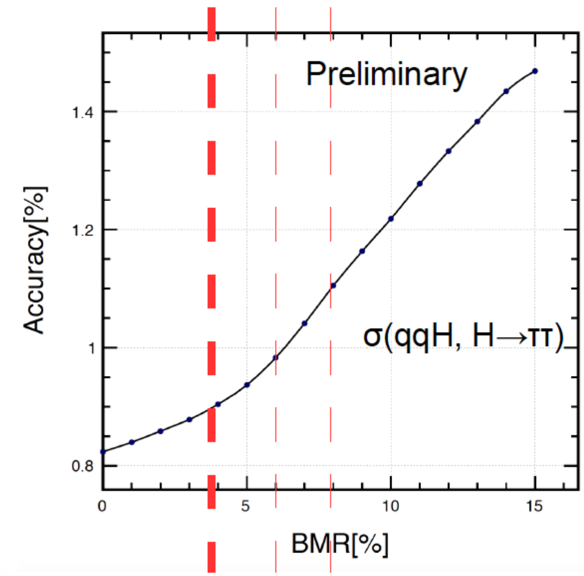
Lepton & Tau at the baseline

- Leptons: identified with LICH
  - Isolated ones: (eff ~ 99.5-99.9%, mis-id < 1%) the best for e+e- Higgs factories full simulation, approaching the physics limit
  - Jet leptons: ~o(1%) degrading w.r.t. Isolated ones
    - not signifiant impact on current physics benchmarks
    - caused by calorimeter clustering performance, in-turn become an estimator on clustering performance
- Taus: identified with Taurus
  - Isolated ones: eff*purity ~ 0.7;
  - Inside jets (as Z->bb): eff*purity ~ 0.5;
  - Further optimization on going.
  - Next step: Identification of tau decay modes at different benchmark.

Requirement from benchmark analysis: BMR < 4%







- 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%

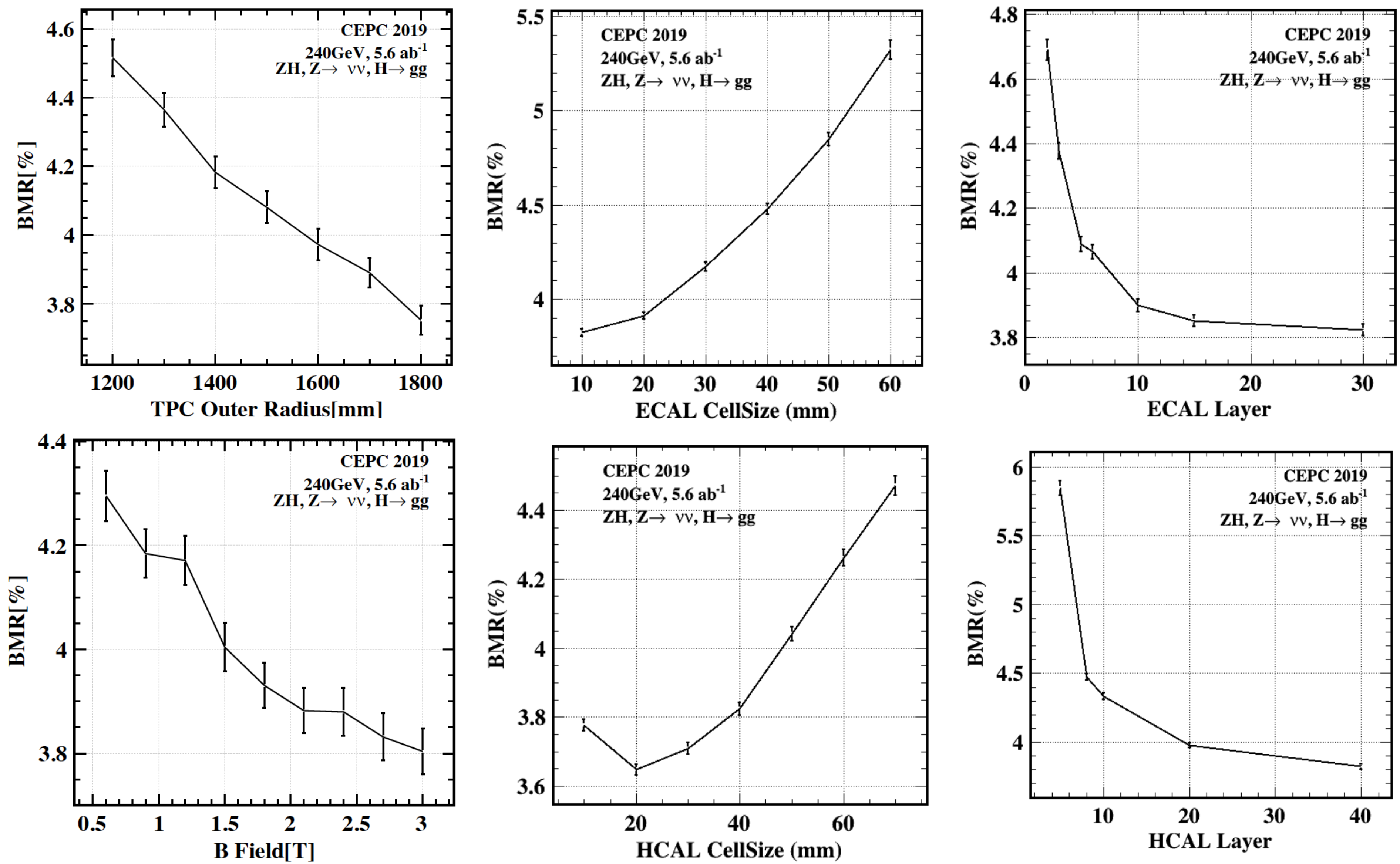
	BMR = 2%	4%	6%	8%
σ(vvH, H→bb)	2.3%	2.6%	3.0%	3.4%
σ(vvH, H→inv)	0.38%	0.4%	0.5%	0.6%
σ(qqH, H→ττ)	0.85%	0.9%	1.0%	1.1%

18/09/19 CEPC WS@Chicago U 14

BMR: an example from Higgs measurements

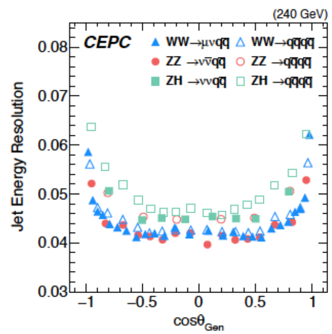
Goal: Provide similar plots for Flavor Benchmarks

BMR V.S. Geometry



New Progress: Differential jet response on Jet energy & Polar angle

Peizhu



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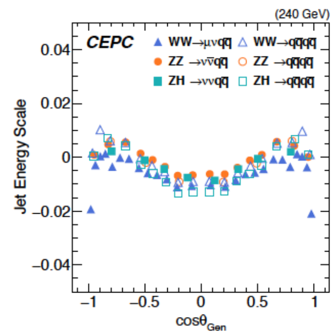

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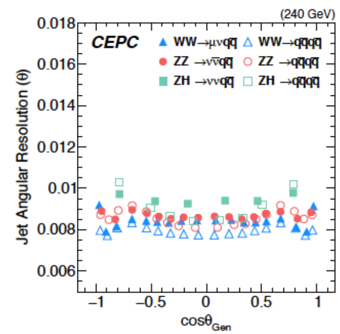

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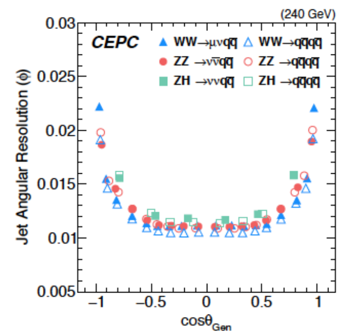

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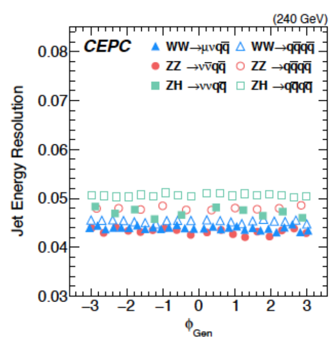

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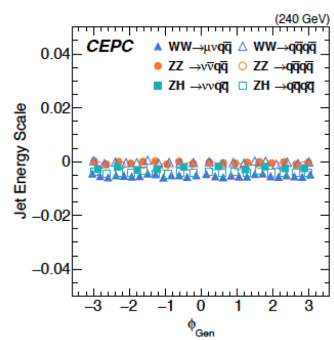

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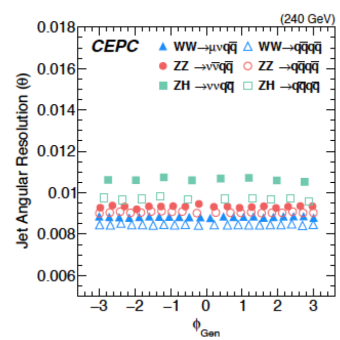

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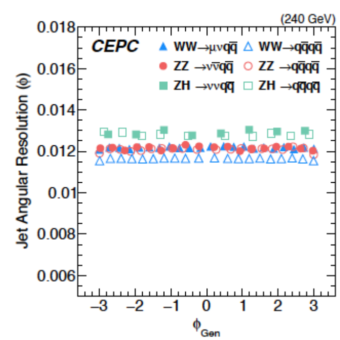

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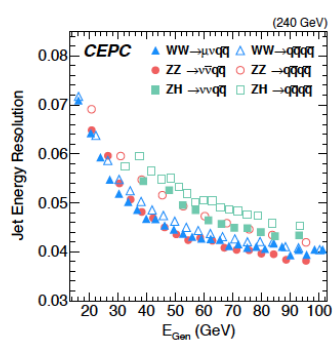

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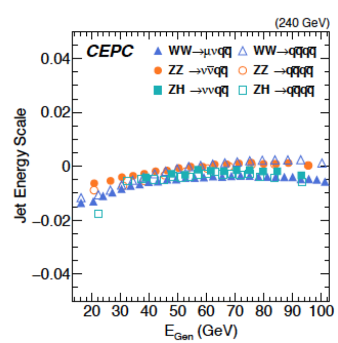

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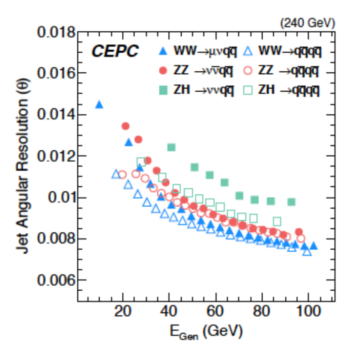

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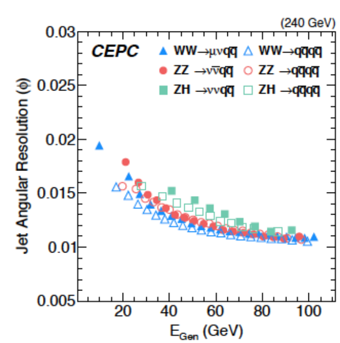
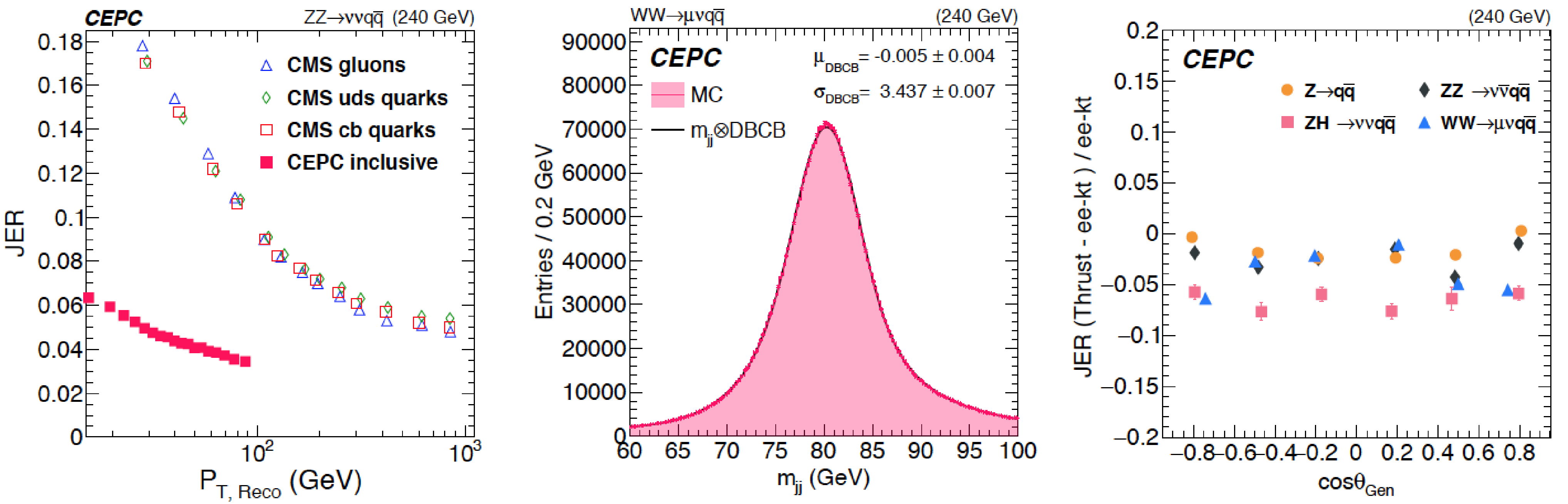


(f)

Jet Response

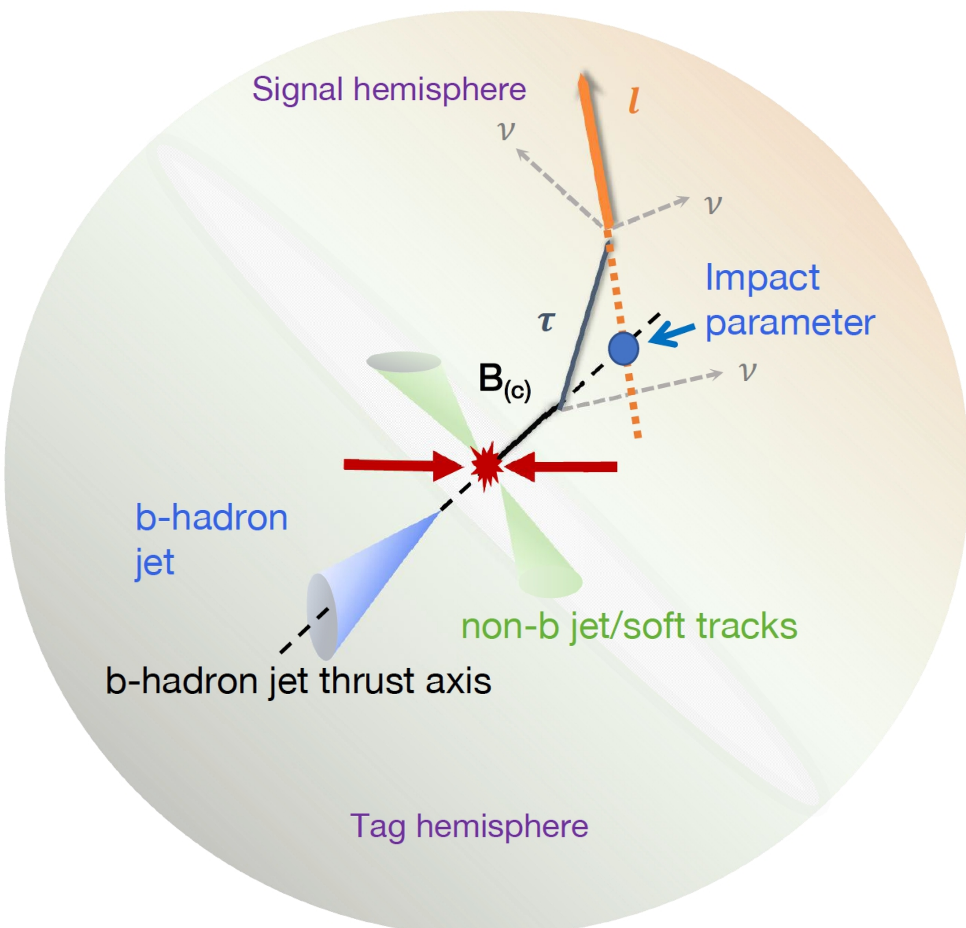


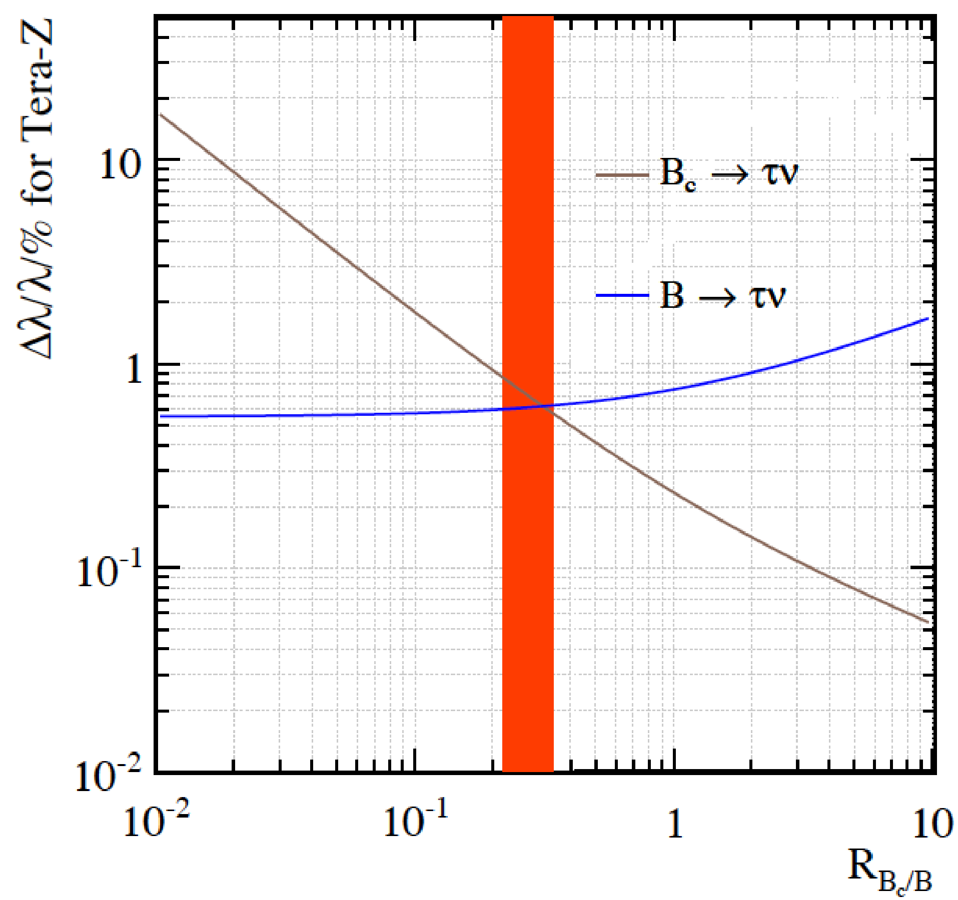
- Significantly better than LHC experiments (at 0 PU);
- Jet Calibration: control the W mass measurements at Higgs run ~ 10 MeV
- Thrust based JC could improve JER ~ 5-10% w.r.t baseline (ee-kt);

Flavor Benchmark analyses: status

- Bc -> tau+v -> e + 3v (In finalization, by Taifan Zhen, Fenfen An, Lu. Cao)
  - *Rely on the flavor tagging (Z->bb), jet lepton identification*
  - *Percentage level accuracy could be achieved at the CEPC*
  - *Current identification of jet lepton is good enough for this channel*
- B0 -> J/psi + Phi -> mumu KK (by Mingrui Zhao of 401)
  - *Rely on the Jet Charge measurement,*
  - *MCTruth level study, to mount/Xcheck corresponding performance study*
- Tau -> muon + photon (by Yudong Wang, etc)
  - *Photon energy resolution, lepton id*
  - *MCTruth + Smearing level.*
- b -> stautau (by Linfeng Li of HKUST)
  - *Reducible background might strongly limit the final accuracy*

Bc->Tauv

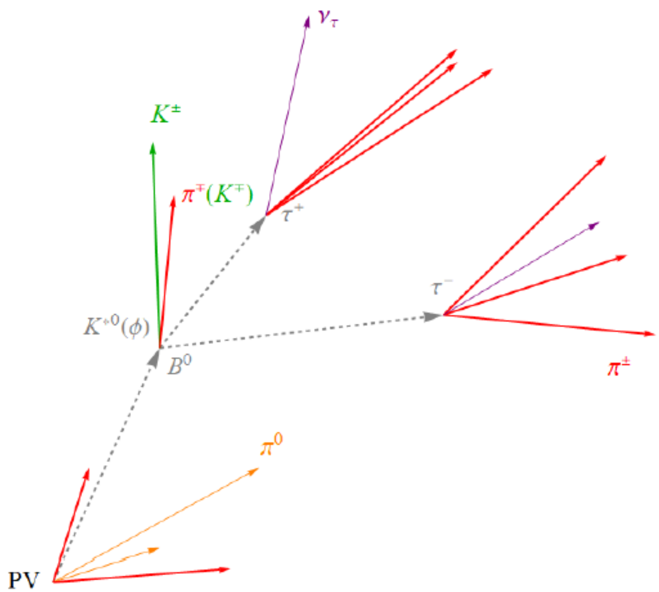




Taifan, etc, Submitted to CPC.

Example 1: $b \to s\tau\tau$ measurements

Use $\tau \to \pi^{\pm}\pi^{\pm}\pi^{\mp}\nu$ decay, locate each vertex and reconstruct



BR$(B^0 \to K^{*0}\tau^+\tau^-) \sim 10^{-7}$ in the SM

Overwhelmingly large background from $D^{\pm}_{(s)} \to \pi^{\pm}\pi^{\pm}\pi^{\mp} + X$ decays:

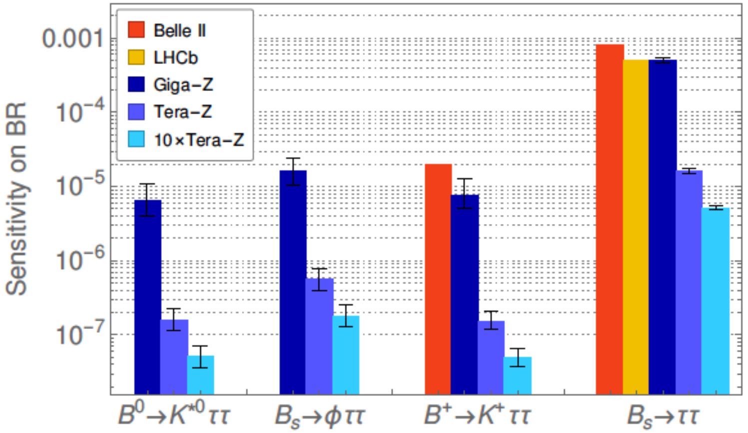
Example	Typical BR
$b \to c\bar{c}s$ Type	
e.g. $B_s \to K^{*0}D_s^{(*)+}D^{(*)-}$	$\mathcal{O}(10^{-2} - 10^{-3})$
$b \to c\tau\nu$ Type	
e.g. $B^0 \to K^{*0}D_s^{(*)-}\tau^+\nu$	$\mathcal{O}(10^{-3} - 10^{-5})$
$b \to c\bar{u}d$ Type	
e.g. $B^0 \to D^{(*)-}\pi^+\pi^+\pi^-$	$\mathcal{O}(10^{-2} - 10^{-3})$

No relevant background studies before!

Result of $b \to s\tau\tau$ at Z Pole (Preliminary)

$\mathcal{O}(10^{-5} - 10^{-7})$ precision at

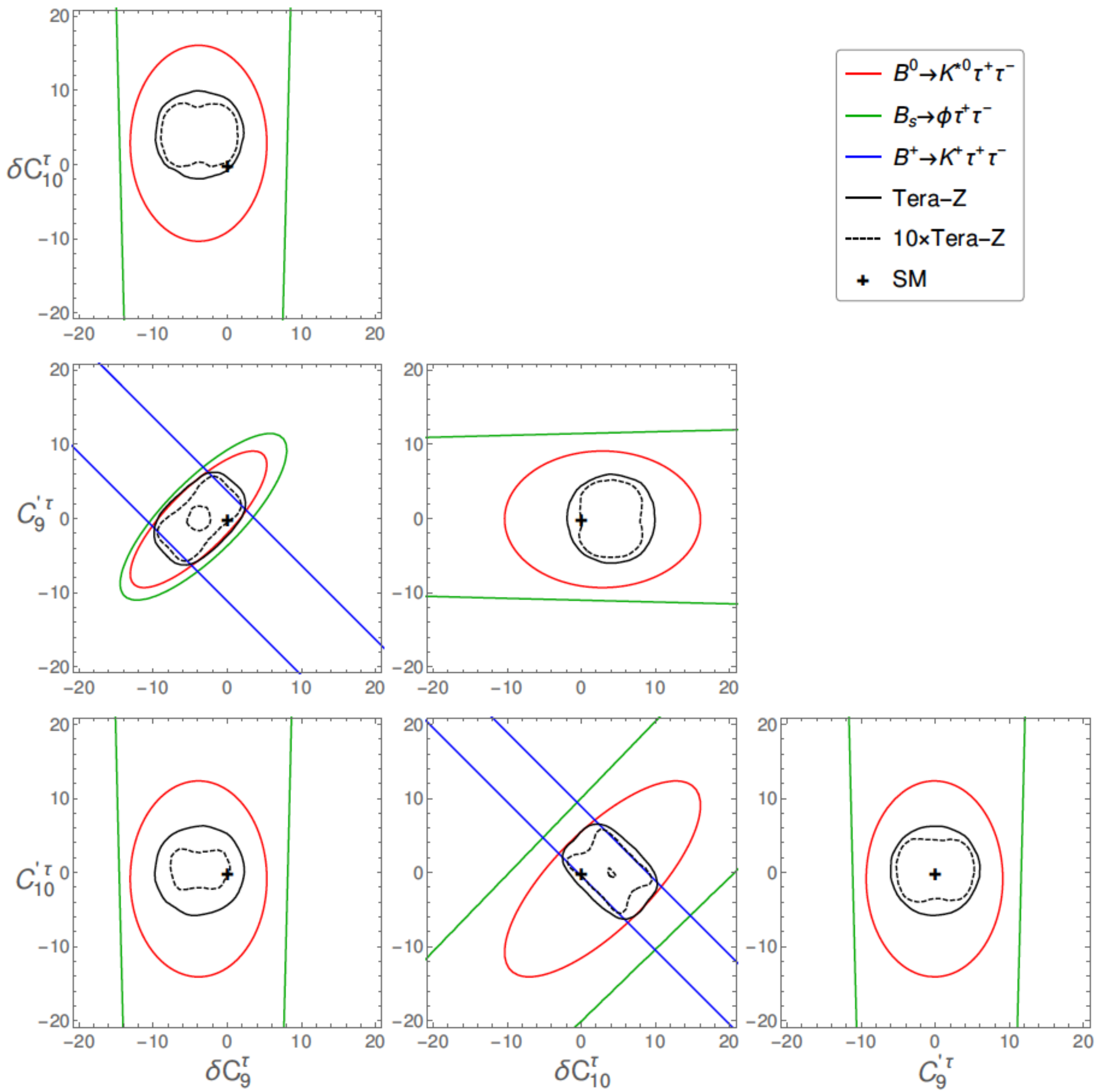
Tera-Z:



$$O^{\tau}_{9(10)} = \frac{\alpha}{4\pi}[\bar{s}\gamma^{\mu}P_L b][\bar{\tau}\gamma_{\mu}(\gamma^5)\tau] \ ,$$

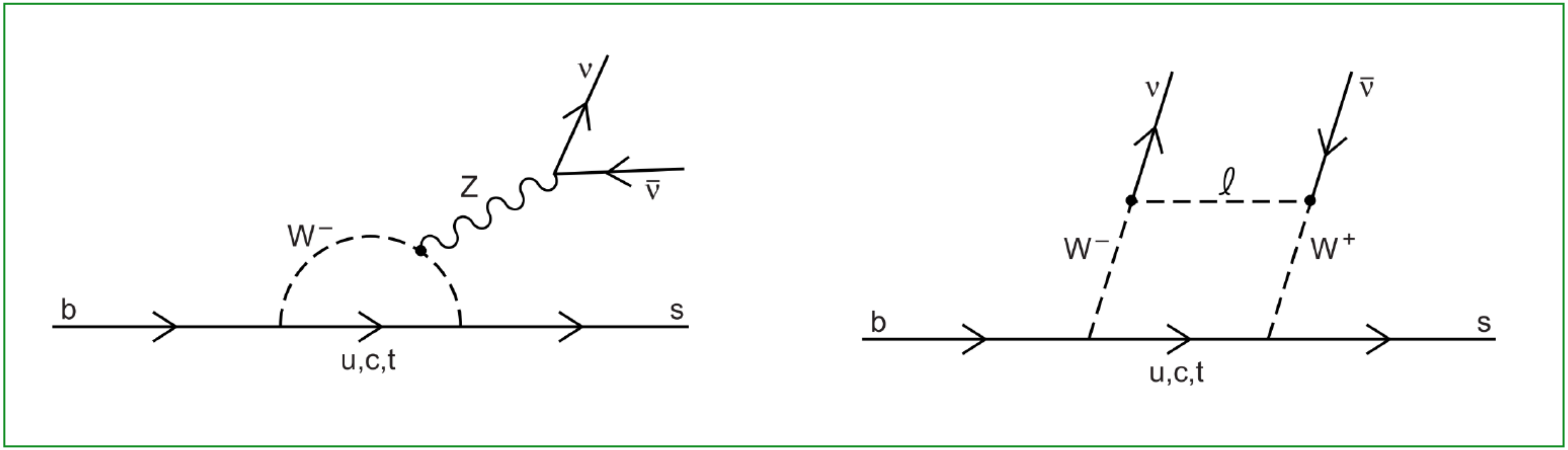
$$O'^{\tau}_{9(10)} = \frac{\alpha}{4\pi}[\bar{s}\gamma^{\mu}P_R b][\bar{\tau}\gamma_{\mu}(\gamma^5)\tau] \ .$$

Constraining LFUV new physics:



$b \to s\nu\bar{\nu}$

Flavor-change-neutral-current(FCNC) process. Be suppressed by the loop factor and heavy weak boson mass .



One-loop level in the Standard Model (SM) via "penguin" and "box" diagrams.

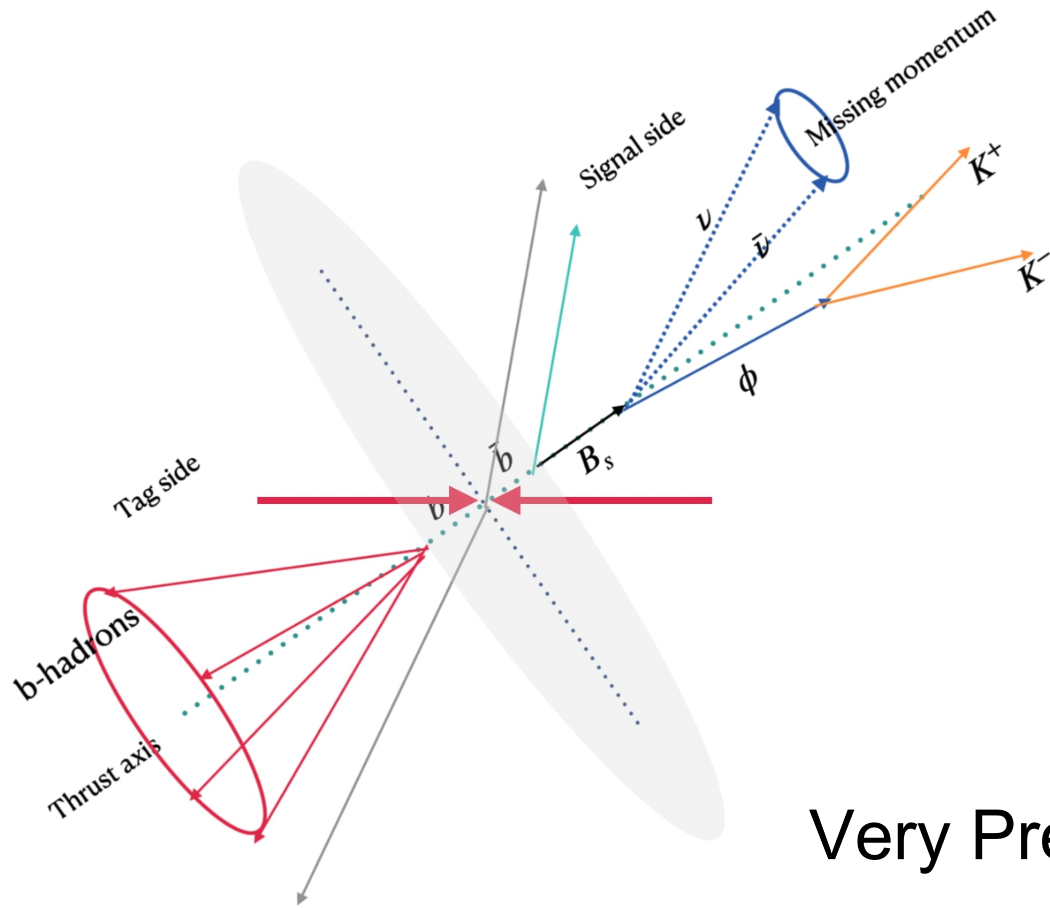
	Experimental [1]	SM Prediction [2]
$\mathrm{BR}(B^0 \to K^0\nu\bar{\nu})$	$< 2.6 \times 10^{-5}$	$(2.17 \pm 0.30) \times 10^{-6}$
$\mathrm{BR}(B^0 \to K^{*0}\nu\bar{\nu})$	$< 1.8 \times 10^{-5}$	$(9.48 \pm 1.10) \times 10^{-6}$
$\mathrm{BR}(B^\pm \to K^\pm\nu\bar{\nu})$	$< 1.6 \times 10^{-5}$	$(4.68 \pm 0.64) \times 10^{-6}$
$\mathrm{BR}(B^\pm \to K^{*\pm}\nu\bar{\nu})$	$< 4.0 \times 10^{-5}$	$(10.22 \pm 1.19) \times 10^{-6}$
$\mathrm{BR}(B_s \to \phi\nu\bar{\nu})$	$< 5.4 \times 10^{-3}$	$(11.84 \pm 0.19) \times 10^{-6}$

Table 1: Constraints and predictions for various $b \to s\nu\bar{\nu}$ decays.

Yudong

[1] M. Tanabashi *et al.*, "Review of Particle Physics," *Phys. Rev.*, vol. D98, no. 3, p. 030001, 2018.

[2] D. M. Straub, "$b \to k^{(*)}\nu\bar{\nu}$ sm predictions," Dec 2015.



Very Preliminary

Conditions	Signal	$b\bar{b}$	$\sqrt{S+B}/S$
Total	150000	3e+11	3.651
$N_\phi > 0$	68798	8.15e+09	1.312
$E_{lepton} > 0.2$ GeV	66039	3.55e+09	0.902
m_{inv}>2.2 GeV	52385	1.06e+08	0.197
$\alpha < 0.8$	20578	204783	0.023
$M^*_{B_s}$ > 4.5 GeV	20571	163044	0.021
$M^*_{B_s}$ < 6.5 GeV	10153	2608	0.011
Efficiency	0.068	8.70e-09	

Summary

- Much better understanding to IAS recommendation 2019 topics.
- Pi-0 (photon...)
  - ECAL impact on different benchmark analyzed
  - Increasing the pi-0 reconstruction eff*purity from 30% to 50% at Z->qq sample once stochastic term improved from 15%/sqrt(E) to 5%/sqrt(E).
  - Significantly depends on the process (abundance of photon) & pi-0 energy
  - Benchmark physics channel analysis is needed
- Charged Kaon
  - Decent Kaon id required, up to 20 GeV
  - VTX, Momentum resolution & Pid: complementary to each other
  - Preliminary: dE/dx of o(2%) will be needed.

Summary

- Leptons
  - A solved problem for both isolated leptons and Jet lepton
  - Taus, both isolated and inside jet, can be decently identified; further optimization is expected to improve the performance significantly;
- Jet
  - BMR: standard, physics requirements, geometry dependence.
  - Differential Jet response analyzed, confirming
    - Jet energy response (JER/JES) ~3 times better than LHC experiments;
    - W mass could be measured ~ o(10) MeV using Higgs run data
  - Jet Clustering is essential
- Several Flavor Physics benchmarks are processing as the Snowmass LoIs. One is submitted; others need ~1 year to converge.

Back up

BMR oriented Optimization

- BMR = 3.8%, 3.6% seems reachable without fundamental change..
  - Preliminary... HCAL optimal size ~ 2 cm → reduce the HCAL # Channel to a quarter (digital read mode at AHCAL...)
- Allowance of 4%, BMR = 3.6/3.8% means:
  - *Reduce the tracker R&Z by 24/12%*
  - *Reduce the ECAL #Channels to a quarter or more: either by double Cell size, or reduce the #Layer*
  - *Reduce the B-Field from 3T to 1T/1.5T*
  - *Increase the HCAL Cell size ~ 5 cm or even larger! HCAL #Cell reduced to 4%...*
  - *Reduce the HCAL #Layer by 50%*
  - Optimal geometry can be determined once cost dependence on above parameters is clear.
- Improving BMR... is the key objective for reconstruction.

Working Group and Conveners

Chapter One: Introduction
Conveners: Hai-Bo Li, Jonathan Rosner

Chapter Two: Leptonic and semileptonic b-hadron decays
Conveners: Sebastien Descotes-Genon , Jeorme Charles, Abner Soffer,Florian Bernlochner, Bob Kowalewski

Sebastien Descotes-Genon

Chapter Three: b-hadronic decays and CP violation
Conveners: I.I. Bigi, Chao-Qiang Geng, Abner Soffer, Yue-Hong Xie

Abi Soffer
Yu-Kuo Hsiao

Chapter Four: Rare and forbidden b-hadron decays
Conveners: Wolfgang Altmannshofer, Soeren A. Prell, Emmanuel Stamou

Chapter Five: Charm physics
Conveners: Chun-Hui Chen, Hai-Yang Cheng, Jonathan Rosner

Marek Karliner & Jon Rosner
Hai-Yang Cheng

Chapter Six: Exotic hadron and Spectroscopy with heavy flavors
Conveners: Marek Karliner, Jonathan Rosner, Wei Wang

Marek Karliner & Jon Rosner

Chapter Seven: τ Physics
Conveners: Emilie Passemar, Emmanuel Stamou, Lorenzo Calibbi

Lorenzo Calibbi

Chapter Eight: Flavor physics in Z decays
Conveners: Wolfgang Altmannshofer, Lorenzo Calibbi

Lorenzo Calibbi

Chapter Nine: Two photon and ISR physics with heavy flavors
Conveners: S. I. Eidelman, Alexey Zhemchugov, D. Dedovich, Lian-Tao Wang ??

Vladimir Bytev

Chapter Ten: Summary and Conclusion
Conveners: Hai-Bo Li, Manqi Ruan

Dan Yu & Taifan Zheng

Flavor: Performance and Analysis

- Flavor: Tera Z data cannot all be processed with Full simulation
- Method
  - Performance via Full Simulation:
    - Understand the dependence on detector, provide different working curve/working points
  - Physics analysis relies strongly on Fast Simulation.
    - MCTruth level analysis – ideal detector – analysis the irreducible background;
    - Smearing: irreducible background with different detector resolution;
    - Identification: contamination by mis-id (using different working point provided by the full sim studies)
  - Theory interpretation (i.e. Wei Wang from SJTU)

Performance

- Isolated Leptons (EPJC 2017):
  - *Baseline provides excellent identification for isolated Lepton with energy > 2 GeV, without muon chamber.*
- VTX Optimization on Flavor tagging (JINST 2018)
  - *Closer > Lighter > Smaller Pixel*
- Pid (EPJC 2018)
  - *eff & purity of 95% at Z->qq samples, for tracks with E > 2 GeV*
- K_long, Lambda performance (EPJP accepted, 2020)
  - *Inclusive eff of 40%/30% achieved with purity > 90%*
- Photon/pi-0 reconstruction performance (EPJP submitted)
  - *pi-0 with E < 30 GeV can be successfully reconstructed*
- Jet lepton identification (On going)
  - *Degrading induced by the separation/calorimeter - clustering performance*
- Jet Charge measurement using Kaon, Lepton, and VTX charge (initiated)
  - Subtle, Critical for CP and EW (AFB) measurements!

Flavor Physics benchmarks

- Many Benchmarks proposed at PKU meeting (July 2019)
  - Sebastian Descotes-Genon: B->tau physics
  - Marek Karliner: Pc, 4/5 quark states, ISR return
  - Lorenzo Calibbi & Haibo: Tau exotic decays
  - Abi Soffer: semileptonic b-decay and CP violation
  - Wenbing: CP measurement via J/psiphi
  - Yu-Kuo: Baryonic B-decay...

- Half of these topics are covered by current flavor physics analysis effort

Benchmark analyses: status

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  - *Reducible background might strongly limit the final accuracy*

Flavor Physics benchmarks + Key performances

	B->tau	B semileptonic	B Baryonic	Tau	CP	Pc
Flavor Tagging	Y	Y	Y		Y	
Jet lepton	Y	Y		Y		
Pid			Y		Y	Y
Jet Charge					Y	
ECAL	Y	Y	Y	Y	Y	Y
Tracker			Y	Y	Y	Y
Current Benchmark	Bc→tauv→ evvv; B→stautau			Tau exotic decays	B0 → J/psi + Phi → mumu KK	

Goal: CEPC Flavor Physics white paper (report)

- The IAC recommendation shall be addressed by this report and corresponding supporting studies/citables
  - Landscape of CEPC flavor program + A series of Benchmark analysis
  - Performance – requirement analysis
  - Physics interpretation and comparison with other facilities
- Timeline: Many performance/benchmark studies will take lots of time. Status report can be made in 2020 IAC meeting.
- Difficulties: Lacking of manpower and communication
  - Many topics – important topics, such as the VTX reconstruction and jet charge measurement, are very subtle and need lots of experiences.
  - The current analysts – for example my students – are good at performance but lacking flavor physics experiences
  - Key physics benchmark analysis would be, ideally composed of actually analysts from other experiments, analysts, and theorists
  - Topical WS would be very helpful – not easy now

Conclusion

- The IAC recommendation is highly consistent with current CEPC simulation efforts: requirements, performance, analysis, and flavor physics
- Plan to address the IAC recommendation by the CEPC flavor physics white paper and corresponding documents. Performance – accuracy plots analogy to the BMR – Higgs accuracy plots shall be included.
- CEPC flavor simulation/analyses need to combine different methods:
  - Performance via Full Simulation and Analysis relies on Fast Simulation.
  - Proper modeling of the identification & reducible background contamination
- Significant progress on the flavor physics simulation
  - Good progress/coverage in Performance & object reconstruction
  - Multiple benchmark channels proposed, and half are covered by existing analysis

Conclusion

- Strong collaboration interests
  - Involvement of HKUST, 401, SJTU, Shanxi Normal University, etc
  - Domestic experts can be further activated...
  - Many international leading experts
- Difficulties: manpower & communication
  - The flavor physics is very rich and sometime complicated, and facing strong competition from LHCb/Belle-II
  - Dedicated Workshops, to review the progress on physics studies, conclusions, and report writing are essential
  - The Corona Virus brings extra difficulties/uncertainties
  - Extra manpower, Postdoc - analysts, and supporting for the WS would be really helpful.