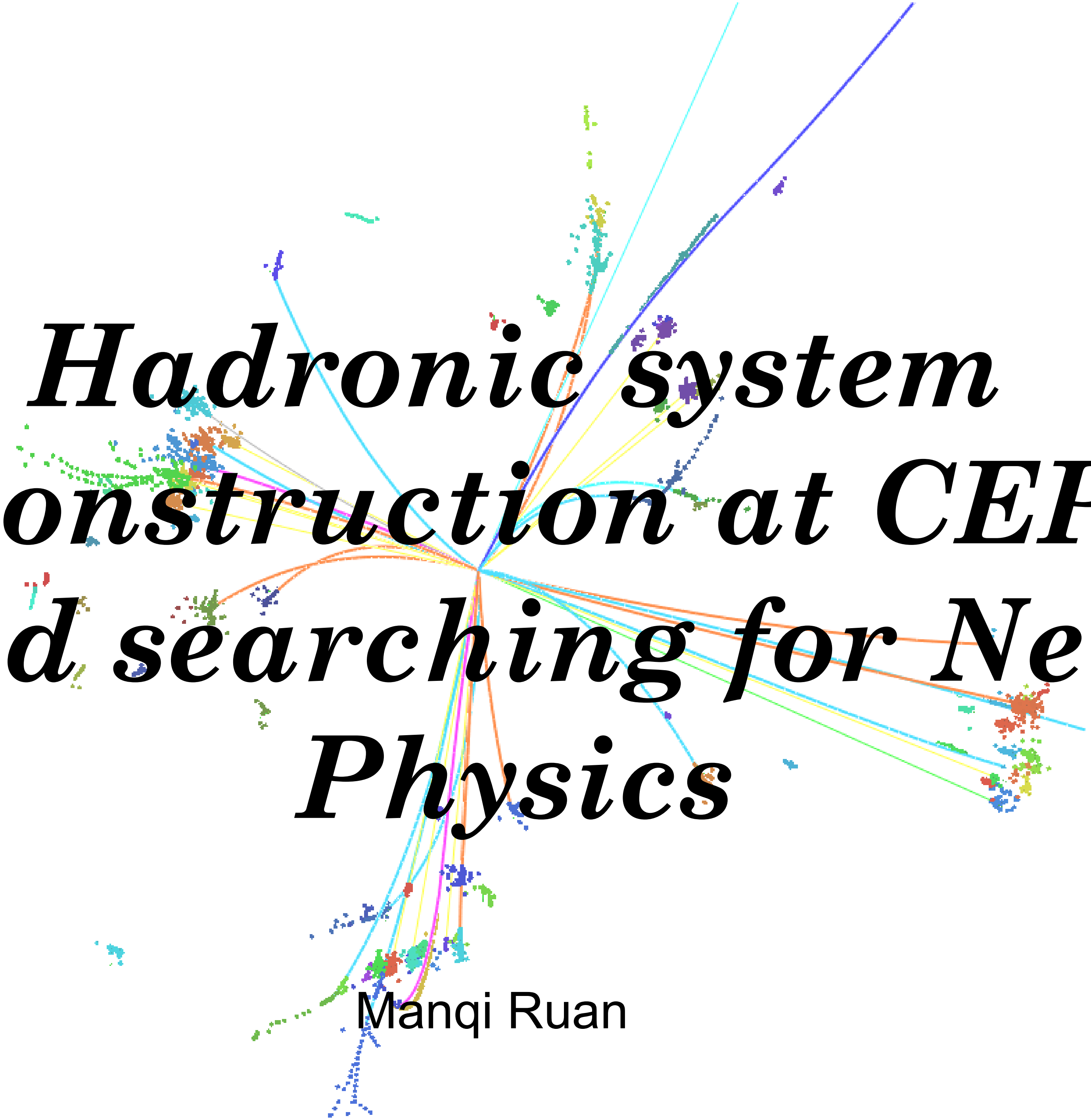
Hadronic system reconstruction at CEPC and searching for New Physics



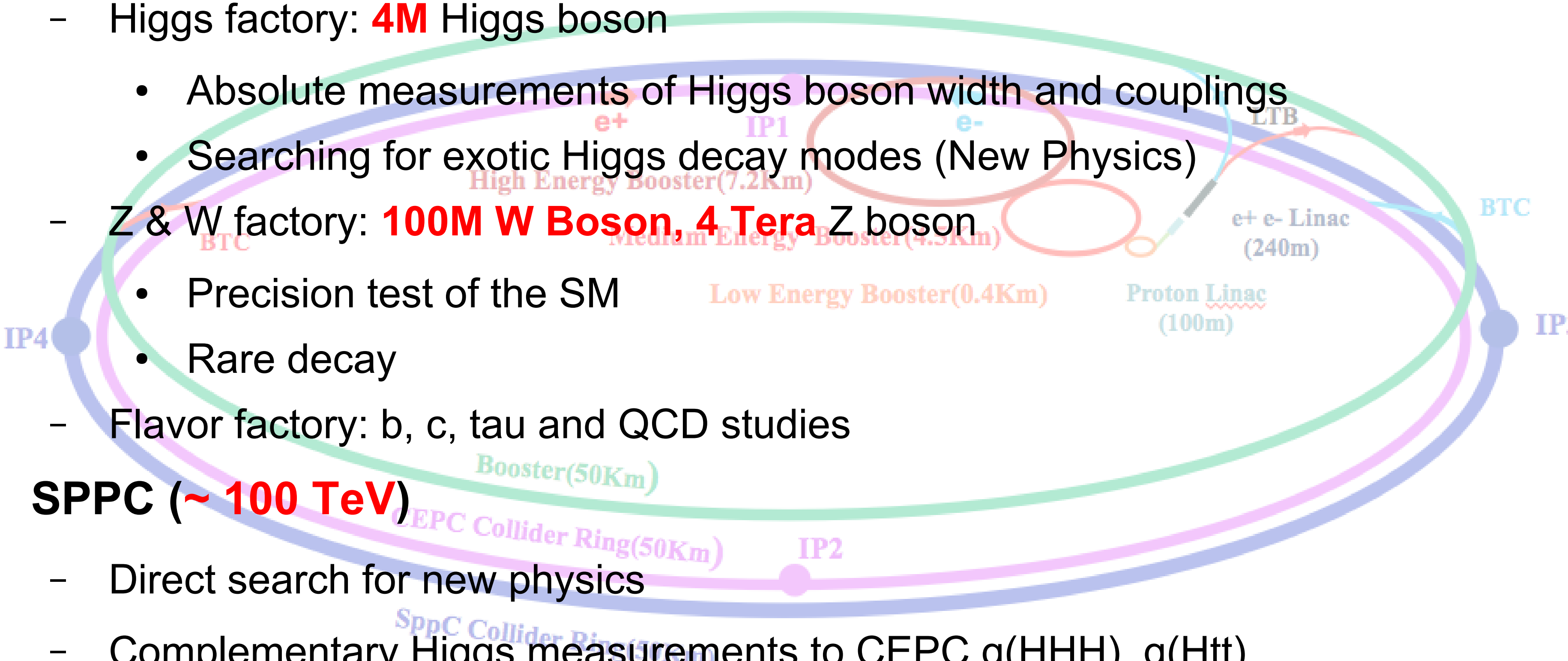
Manqi Ruan

Outline

- Introduction & Motivation
- Boson Mass Resolution (BMR) & Higgs invisible, Higgs width, Higgs to di-tau
- Jet energy response & W mass measurement
- Jet flavor tagging & Higgs$\rightarrow$bb, cc, gg and V_cb from W decay
- Jet charge measurement
- Summary

Science at CEPC-SPPC

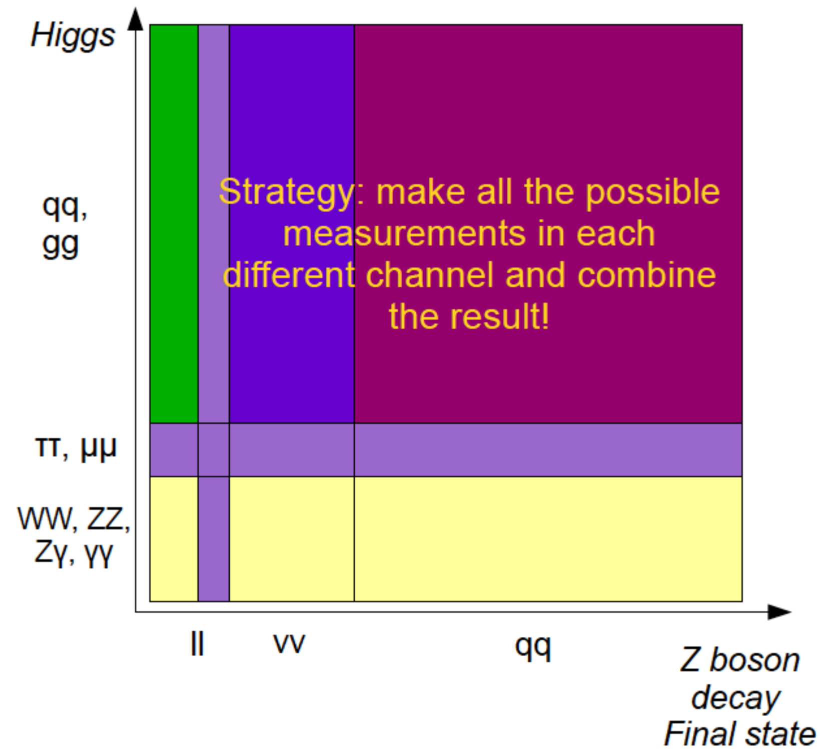
- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **4M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **100M W Boson, 4 Tera** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor factory: b, c, tau and QCD studies
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**



Complementary

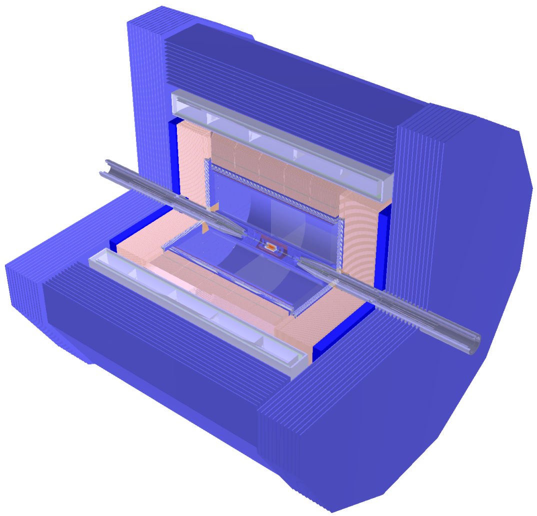
Hadronic final states at Higgs Signal

- SM Higgs
  - **0 jets: 3%**
    - Z→ll, νν (30%); H→0 jets (~10%, ττ, μμ, γγ, γZ/WW/ZZ→leptonic)
  - **2 jets (+n with gluon emission...): 32%**
    - Z→qq, H→0 jets. 70%*10% = 7%
    - Z→ll, νν; H→2 jets. 30%*70% = 21%
    - Z→ll, νν; H→WW/ZZ→semi-leptonic. 3.6%
  - **4 jets: 55%**
    - Z→qq, H→2 jets. 70%*70% = 49%
    - Z→ll, νν; H→WW/ZZ→4 jets. 30%*15% = 4.5%
  - **6 jets: 11%**
    - Z→qq, H→WW/ZZ→4 jets. 70%*15% = 11%



- 97% of the SM Higgsstrahlung Signal involves Jets
- 66% need color-singlet identification: grouping the hadronic final sate particles into color-singlets (Z, H, W, gamma, ...).

BMR @ Baseline



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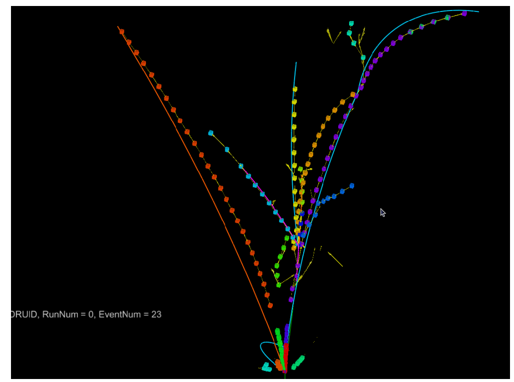

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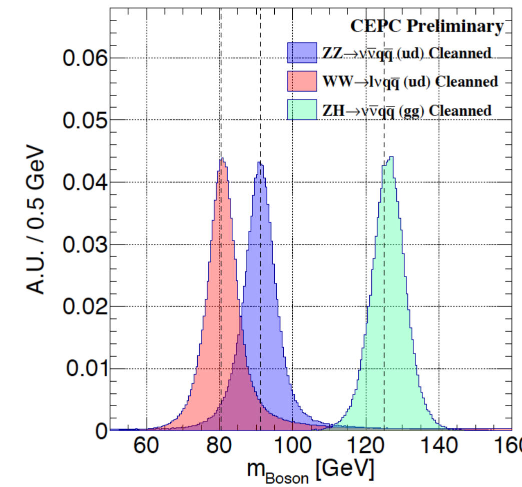
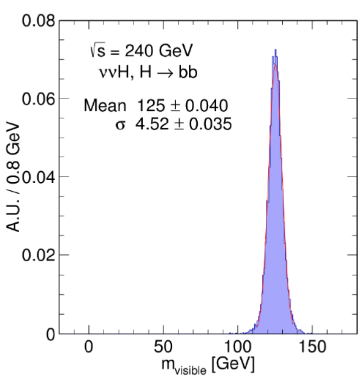
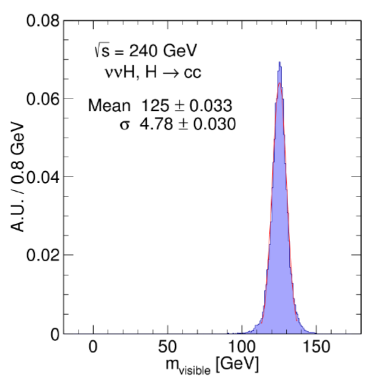
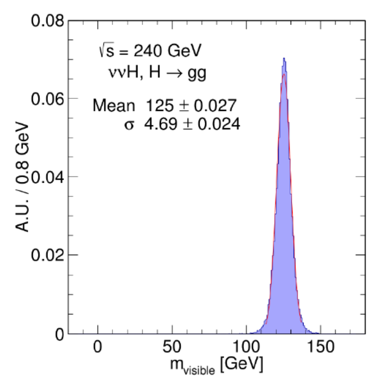
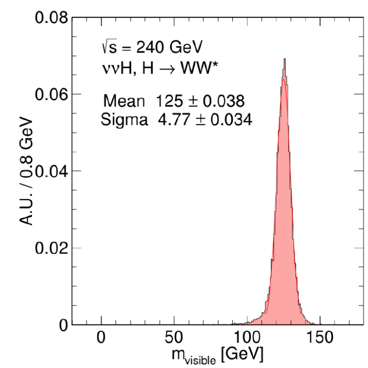










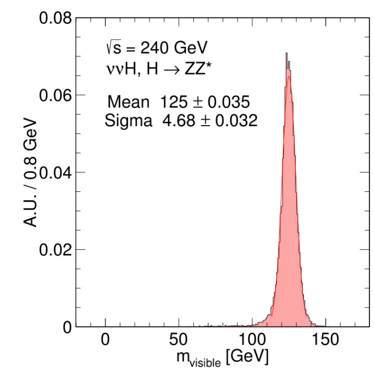
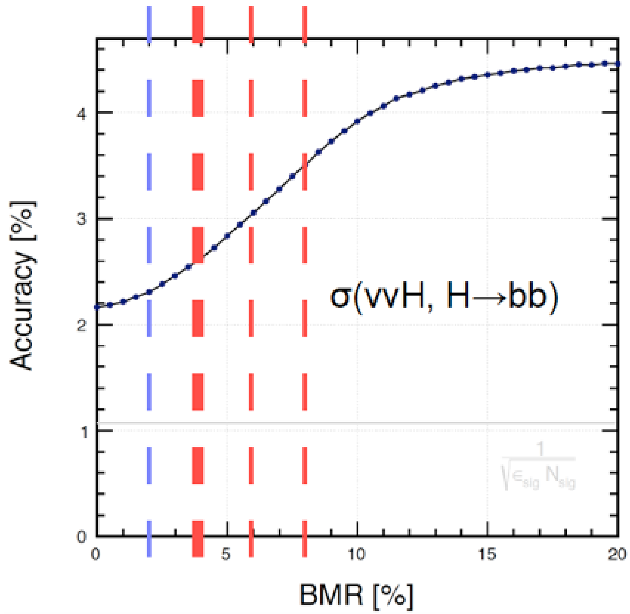
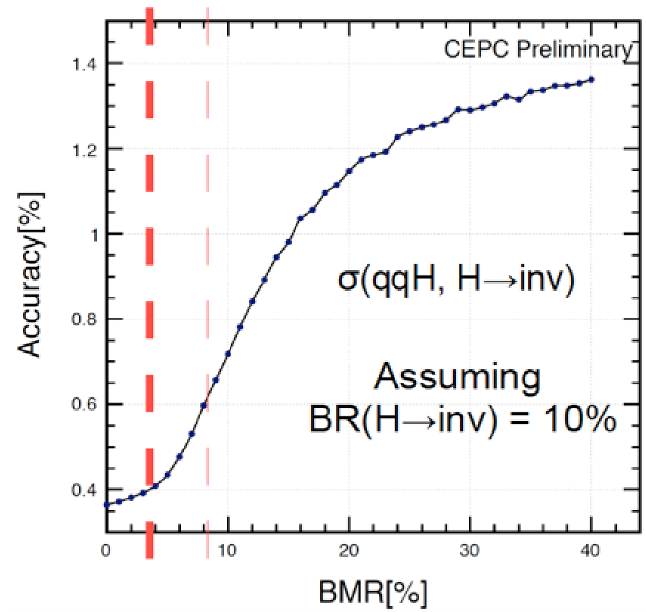


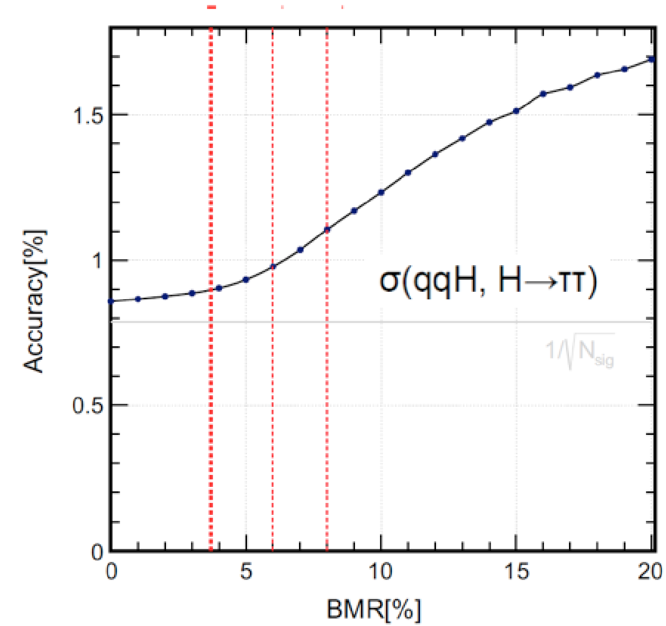
Table 3. Higgs boson mass resolution ($\sigma/Mean$) at different decay modes with jets as final state particles, after the event cleaning.

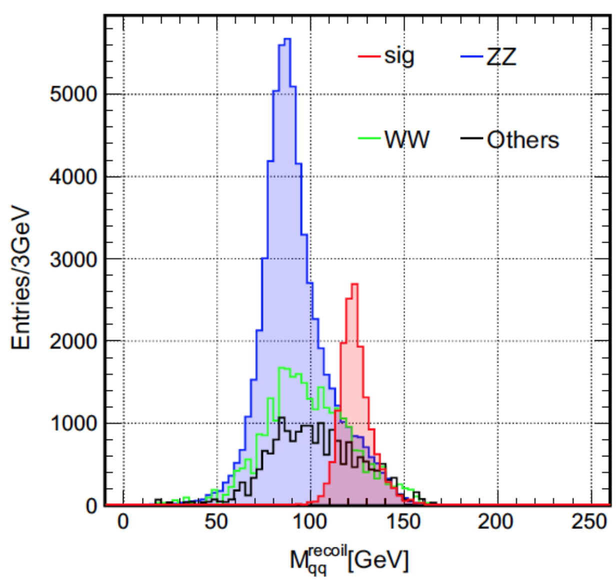
Higgs→bb	Higgs→cc	Higgs→gg	Higgs→ WW*	Higgs→ ZZ*
3.63%	3.82%	3.75%	3.81%	3.74%

BMR Benchmarks





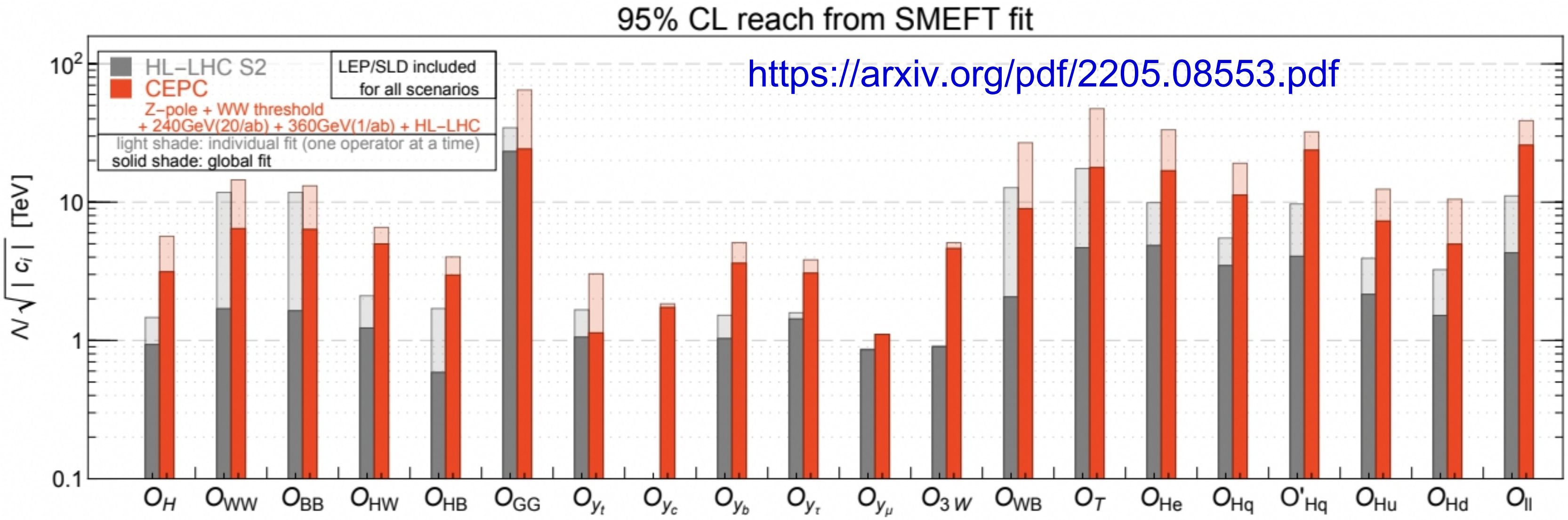




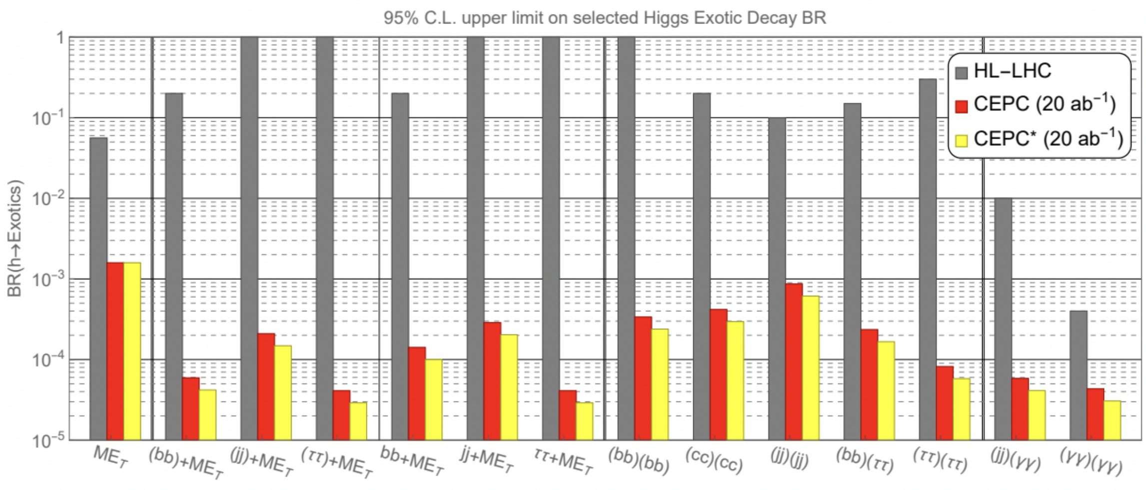
	BMR = 2%	4%	6%	8%
σ(vvH, H→bb)	2.3%	2.6%	3.0%	3.4%
σ(vvH, H→inv)	0.38%	0.4%	0.5%	0.6%
σ(qqH, H→ττ)	0.85%	0.9%	1.0%	1.1%

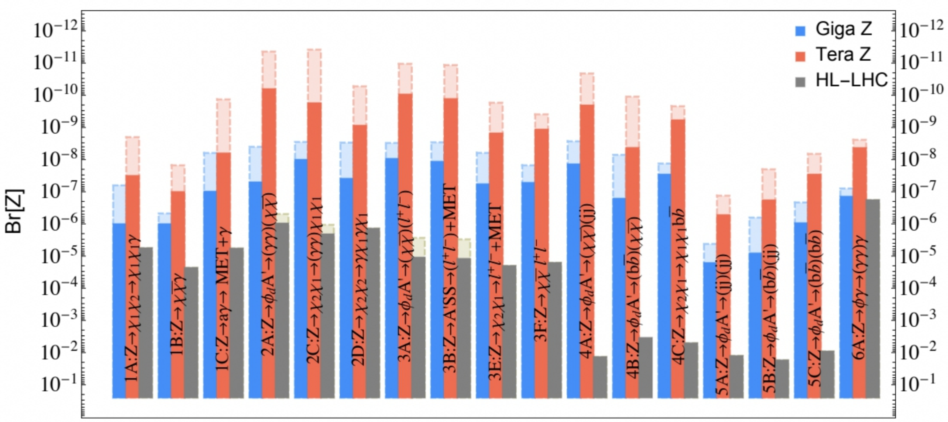
- Relative mass resolution of particles decay into hadronic final state: quantified with vvH, H→gg
- Higgs measurement require BMR < 4%;
- Flavor & NP: much more demanding

Physics reach at CEPC



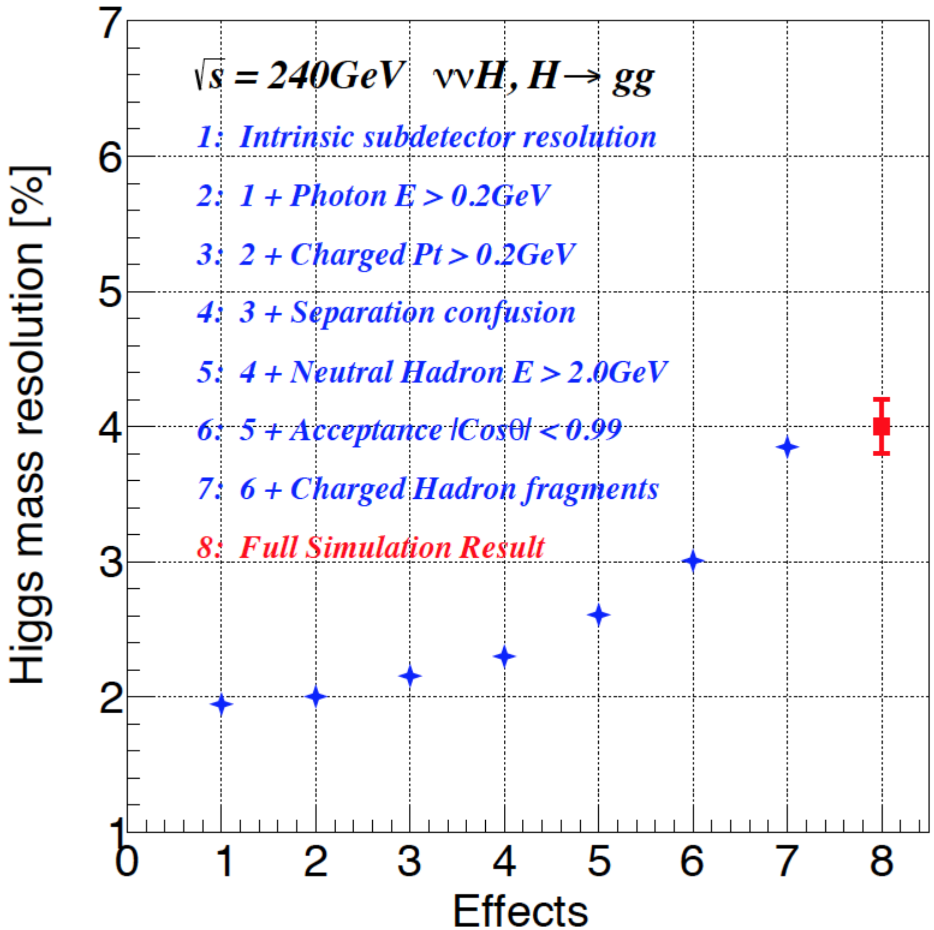
https://arxiv.org/pdf/2205.08553.pdf

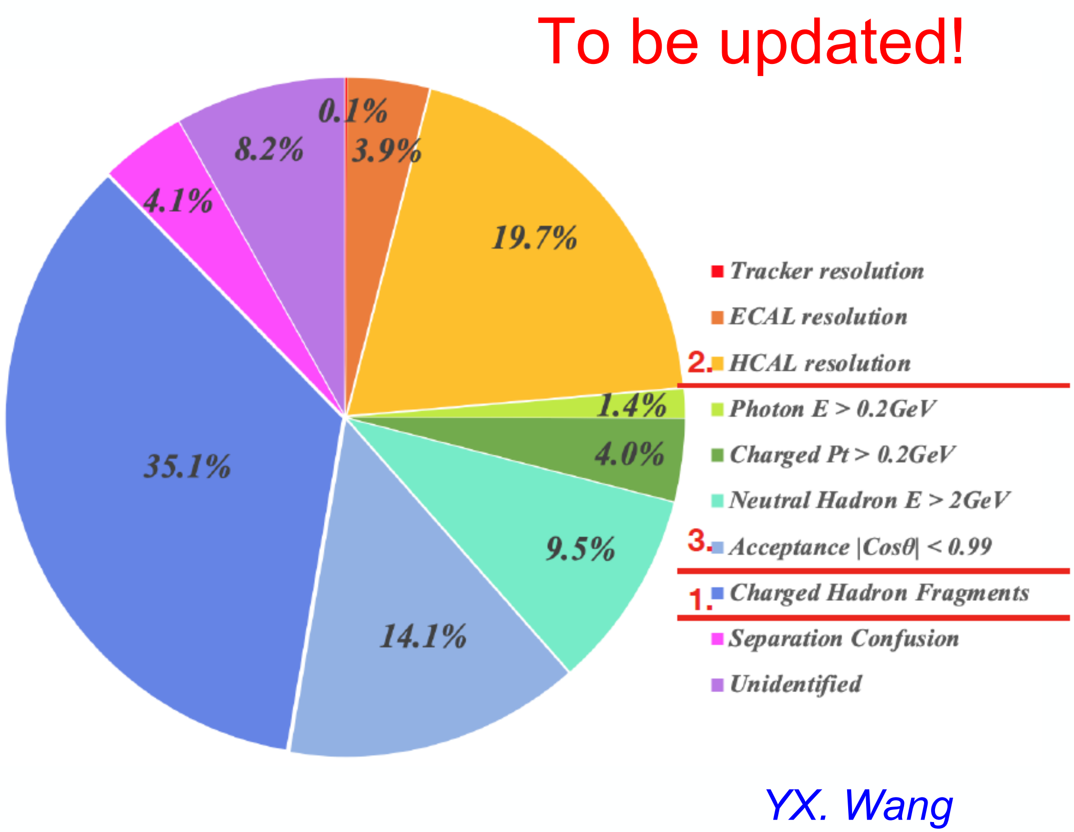




CEPC* scenario further utilizes the hadronically decaying Z boson

PFA Fast simulation



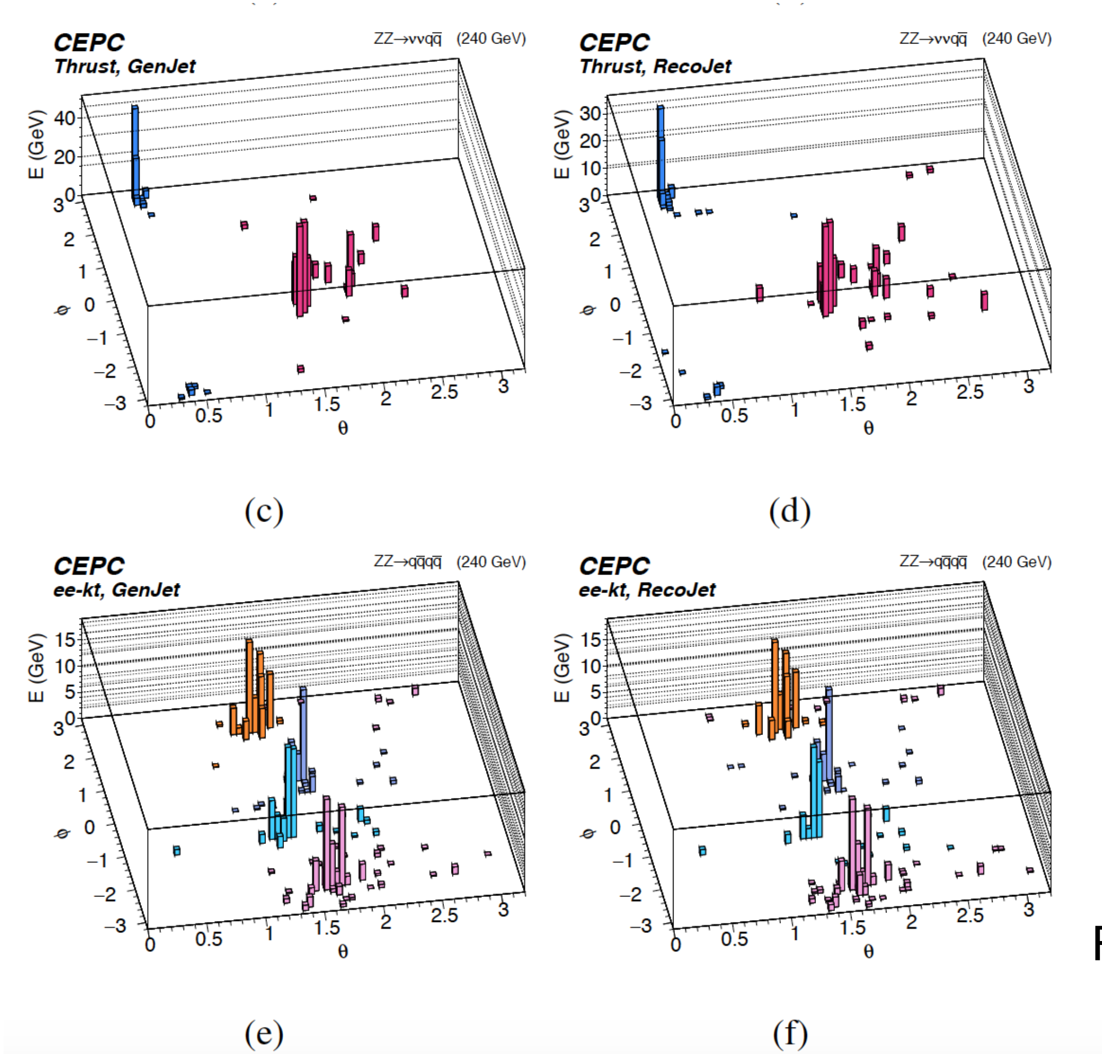


Fast simulation reproduces the full simulation results, factorize/quantifies different impacts

Individual Jet

Remark - BMR dosen't depend on Jet

Individual jet: jet clustering - matching



(c) (d) (e) (f)

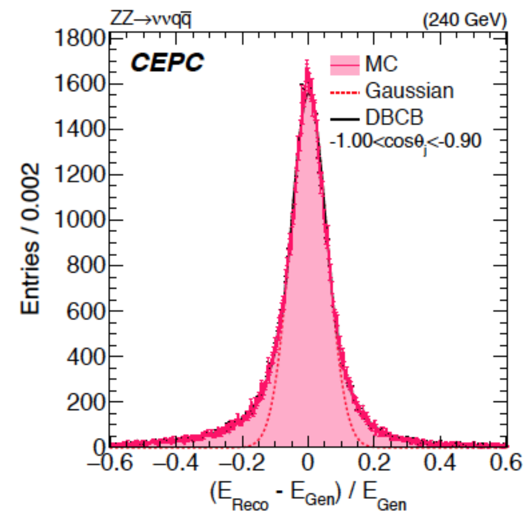


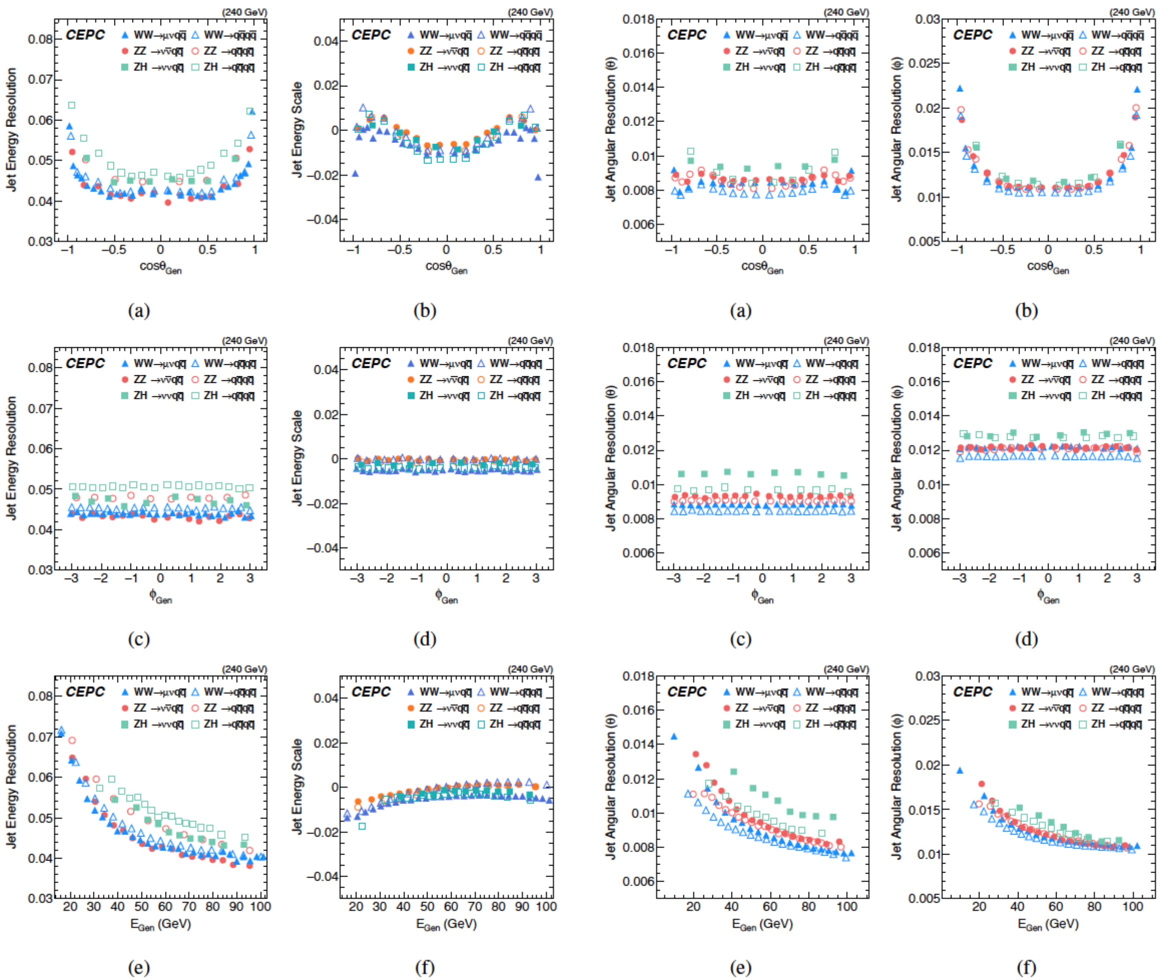
Fig. 7: σ and $\bar{x}$ from the core of the DBCB fit to R are defined as JER/S, respectively. The $cos\theta_j$ indicates the specific polar angle of the jets.

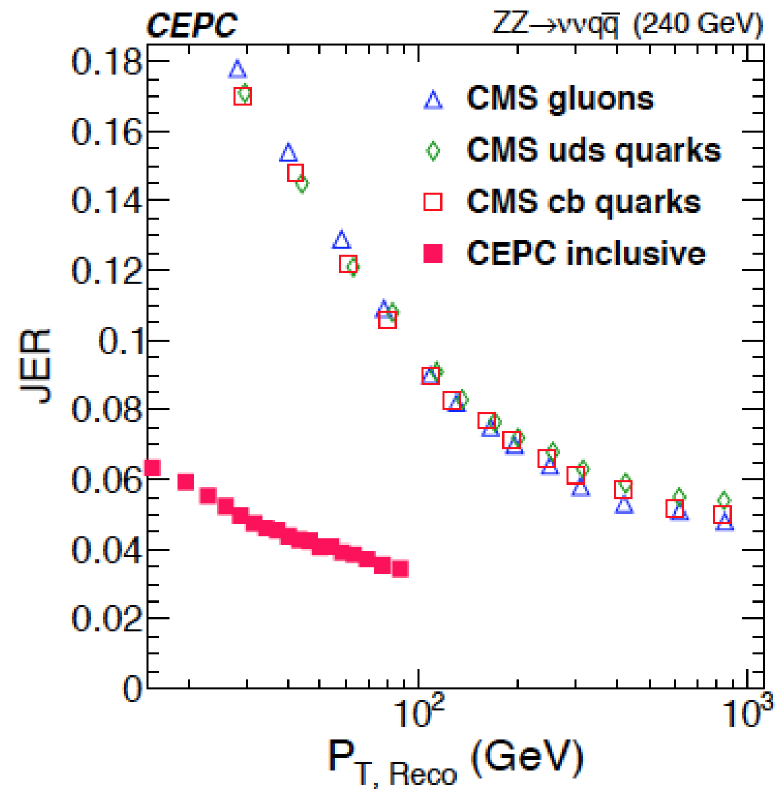
Jet Clustering & Matching is critical:
ee-kt is used as CEPC baseline

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

Jet: lots of ambiguities & large theoretical uncertainty... not ideal, but works

Energy response

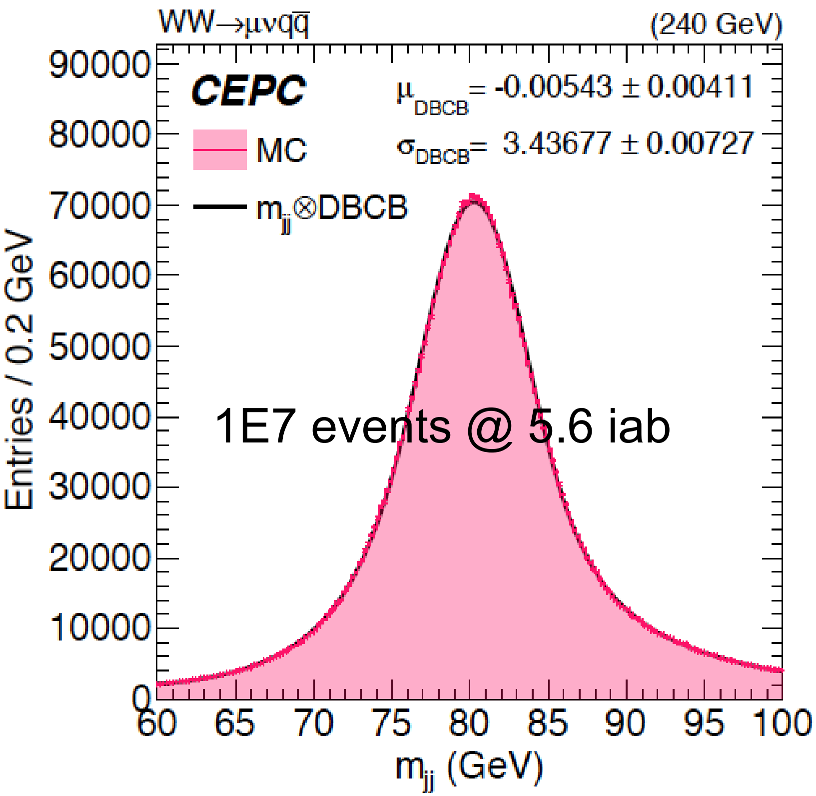




Jet Energy Response: 2.5 – 4 times better than LHC in the same Pt range,
Jet Energy Scale: 3 times better before sophisticated calibration

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

Jet Flavor

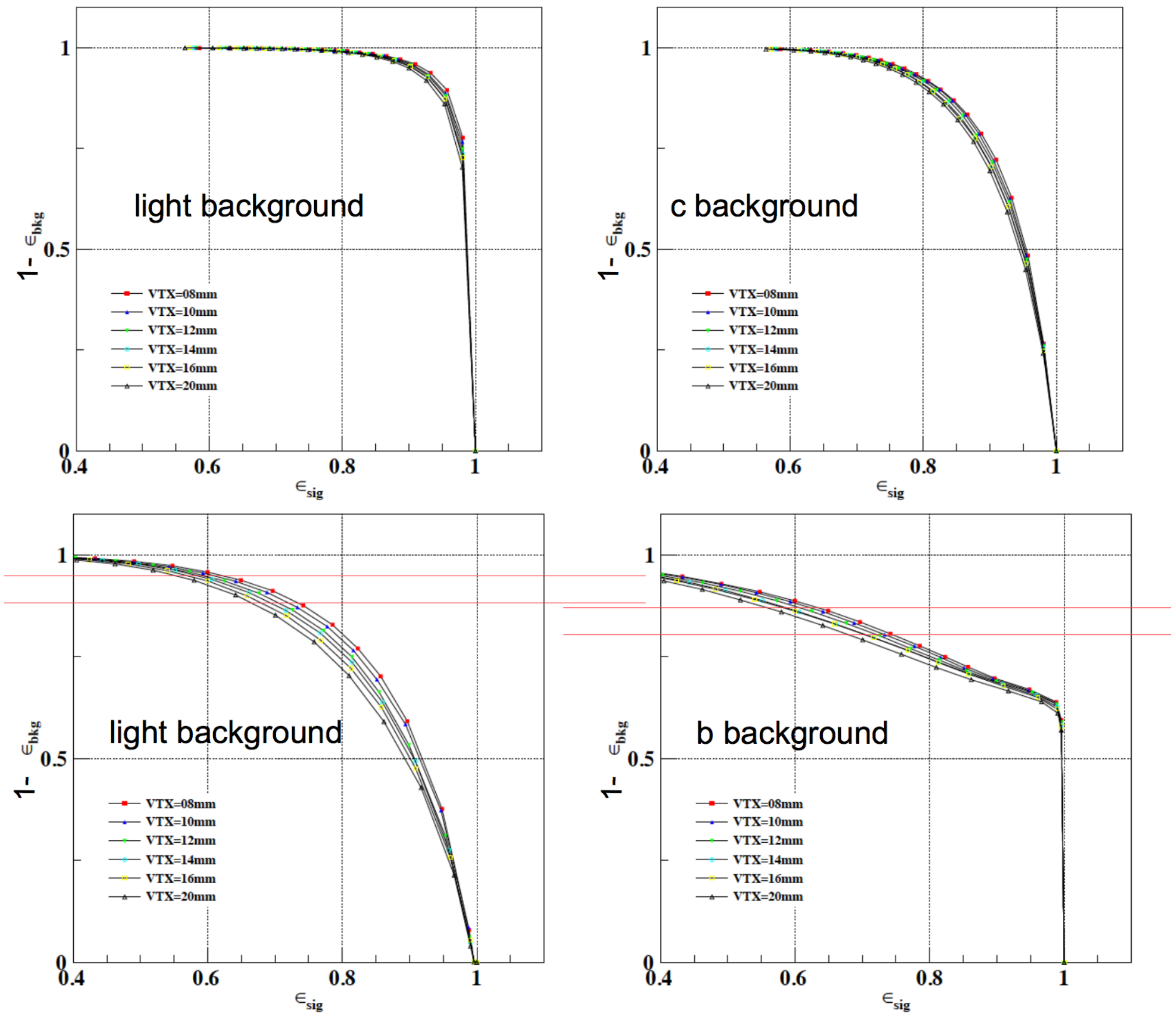
Is a jet fragmented from

b, c, light (gluon or uds) $\rightarrow$

b, c, light, gluon, s?

Flavor Tagging

- LCFIPlus Package
- Typical Performance at Z pole sample:
  - *B-tagging: eff/purity = 80%/90%*
  - *C-tagging: eff/purity = 60%/60%*
- Geometry Dependence of the Performance evaluated



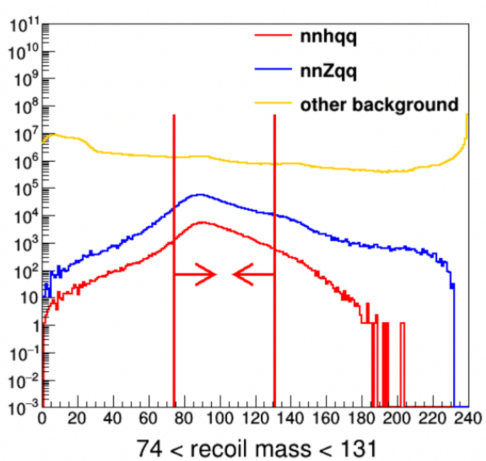
https://agenda.linearcollider.org/event/7645/contributions/40124/

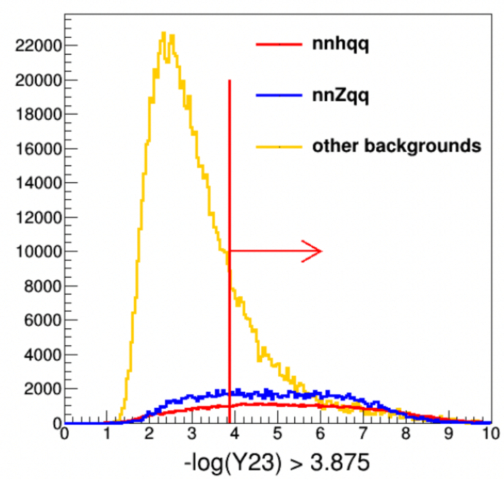
H→bb, cc, gg

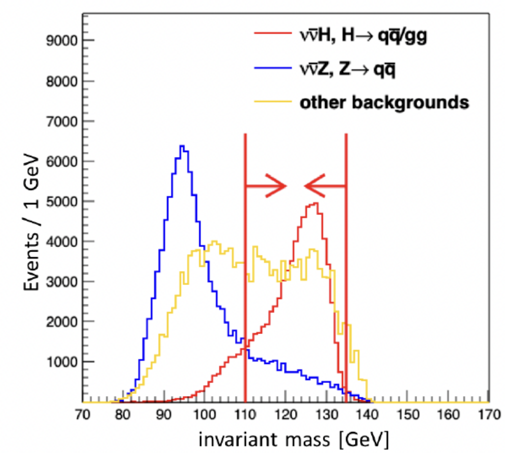
- Core physics measurements, excellent benchmarks for BMR, Flavor Tagging & CSI
- Tactic
  - Analysis
    - Concentrate Higgs to di jet event using Cut Chain + BDT
    - Using Flavor Tagging to disentangle different decay modes, and extract/resolve the relevant signal strengths
  - Optimization
    -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

$\nu\nu$H, H→bb, cc, gg

	$\nu\nu Hq\bar{q}/gg$	2f	SW	SZ	WW	ZZ	Mixed	ZH	$\frac{\sqrt{S+B}}{S}$ (%)
total	178890	8.01E8	1.95E7	9.07E6	5.08E7	6.39E6	2.18E7	961606	16.86
recoilMass (GeV) $\in (74, 131)$	157822	5.11E7	2.17E6	1.38E6	4.78E6	1.30E6	1.08E6	74991	4.99
visEn (GeV) $\in (109, 143)$	142918	2.37E7	1.35E6	8.81E5	3.60E6	1.03E6	6.29E5	50989	3.92
leadLepEn (GeV) $\in (0, 42)$	141926	2.08E7	3.65E5	7.24E5	2.81E6	9.72E5	1.34E5	46963	3.59
multiplicity $\in (40, 130)$	139545	1.66E7	2.36E5	5.24E5	2.62E6	9.07E5	4977	42751	3.29
leadNeuEn (GeV) $\in (0, 41)$	138653	1.46E7	2.24E5	4.72E5	2.49E6	8.69E5	4552	42303	3.12
Pt (GeV) $\in (20, 60)$	121212	248715	1.56E5	2.48E5	1.51E6	4.31E5	999	35453	1.37
Pl (GeV) $\in (0, 50)$	118109	52784	1.05E5	74936	7.30E5	1.13E5	847	34279	0.94
-log10(Y23) $\in (3.375, +\infty)$	96156	40861	26088	60349	2.25E5	82560	640	10691	0.76
InvMass (GeV) $\in (116, 134)$	71758	22200	11059	6308	77912	13680	248	6915	0.64
BDT $\in (-0.02, 1)$	60887	9140	266	2521	3761	3916	58	1897	0.47

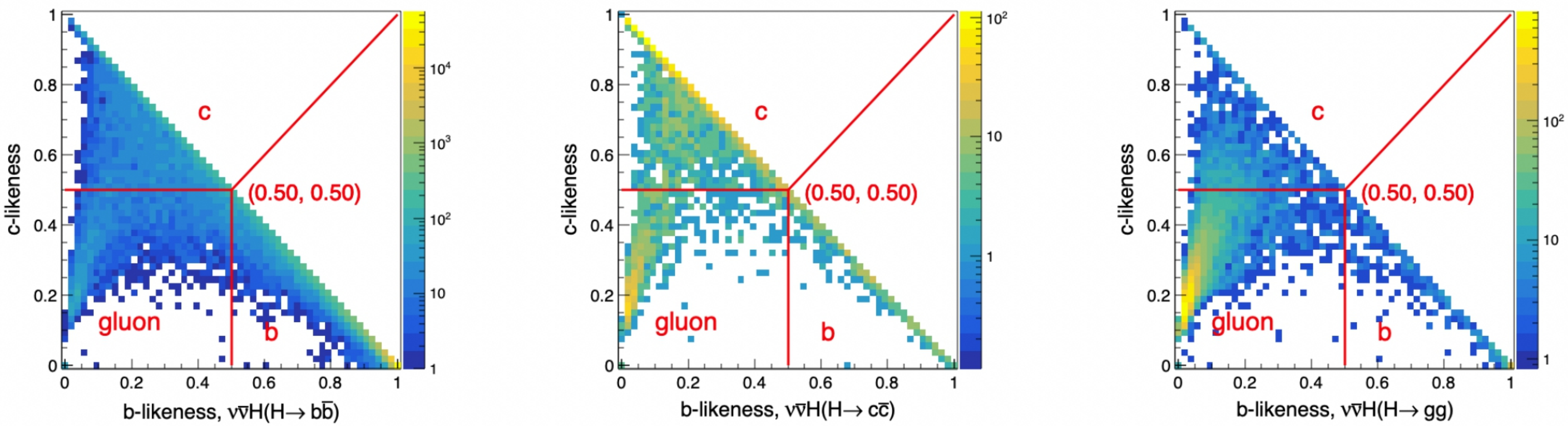




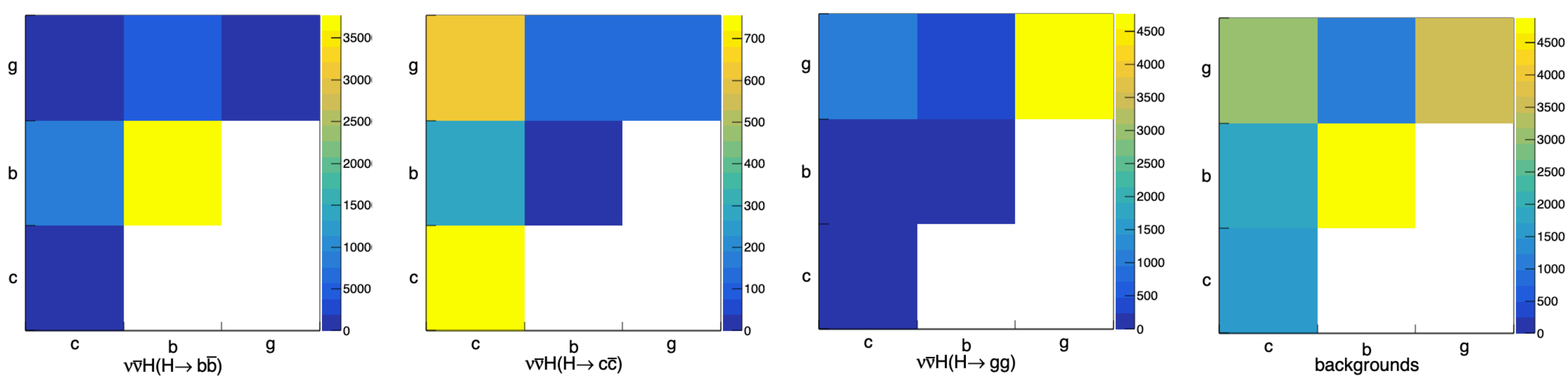


Thanks to BMR ~ 3.8%!

Flavor tagging @ vvH



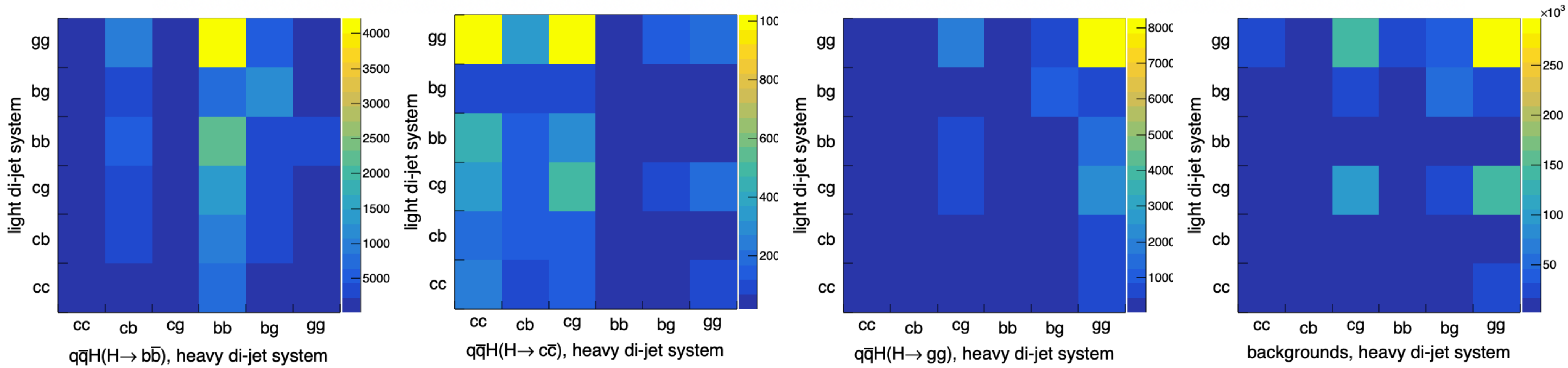
true \ identified as	b	c	g
b	0.8675	0.0887	0.0437
c	0.1136	0.6263	0.2601
g	0.0411	0.1007	0.8582



Relative accuracies on signal strength: 0.5%/5.8%/1.8%, for vvH, H to bb/cc/gg respectively.

qqH, H→bb, cc, gg

	qqHqq	2f	SW	SZ	WW	ZZ	Mixed	ZH	$\frac{\sqrt{S+B}}{S}$ (%)
total	527488	8.01E8	1.95E7	9.07E6	5.08E7	6.39E6	2.18E7	613008	5.71
multiplicity $\in (27, +\infty)$	527488	3.04E8	1.46E7	3.37E6	4.85E7	6.00E6	1.81E7	577930	3.77
leadLepEn $\in (0, 59)$	527036	2, 98E8	6.76E6	2.44E6	3.93E7	5.40E6	1.79E7	531411	3.65
visEn $\in (199, 278)$	510731	1.21E8	1.29E6	551105	2.14E7	3.06E6	1.71E7	180571	2.52
leadNeuEn $\in (0, 57)$	509623	5.68E7	716161	168030	2.04E7	2.93E6	1.65E7	176387	1.94
thrust $\in (0, 0.86)$	460535	7.81E6	473732	132126	1.88E7	2.60E6	1.54E7	167863	1.47
$-log(Y_{34})$ $\in (0, 5.8875)$	451468	4.90E6	181432	119836	1.74E7	2.40E6	1.45E7	165961	1.40
HiggsJetsA $\in (2.18, 2\pi)$	326207	2.83E6	110156	58613	4.54E6	870276	3.74E6	96560	1.08
ZJetsA $\in (1.97, 2\pi)$	279030	1.37E6	33491	37101	2.39E6	496611	2.00E6	74005	0.93
ZHiggsA $\in (2.32, 2\pi)$	274530	1.32E6	17026	33847	2.28E6	468340	1.91E6	69620	0.92
circle	268271	1.20E6	10193	31567	2.13E6	424514	1.79E6	65434	0.90
BDT $\in (0.02, 1)$	192278	378300	40	307	271436	141446	244126	30022	0.57



Relative accuracies on signal strength: 0.35%/7.7%/4.0%, for bb/cc/gg respectively.

Interpolation

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

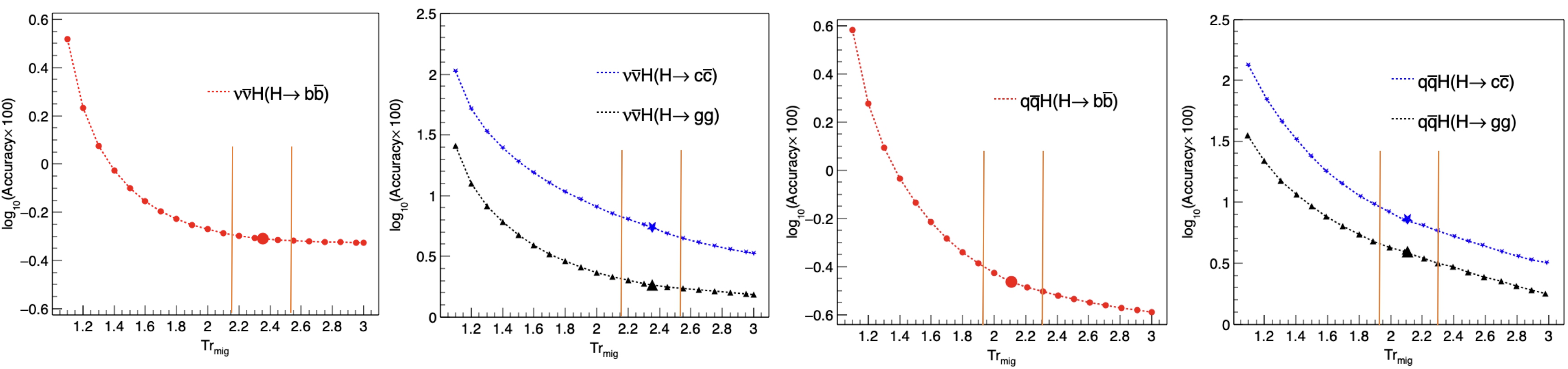
$$M_{mig} = \frac{Tr_{mig} - Tr_{opt}}{Tr_{1/3} - Tr_{opt}} \cdot (M_{1/3} - M_{opt}) + M_{opt}$$

Perfect

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

Worst

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



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

Vcb from W decay

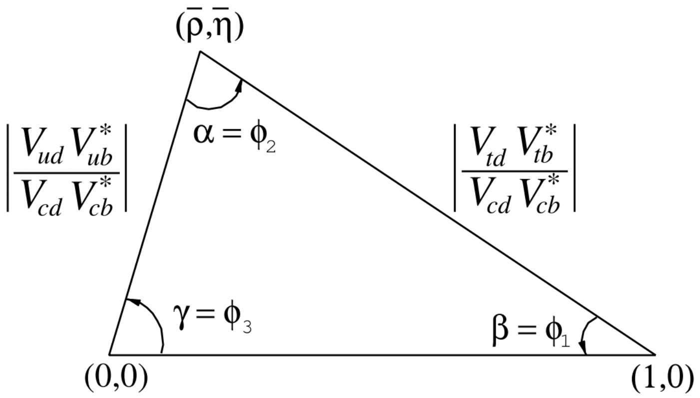


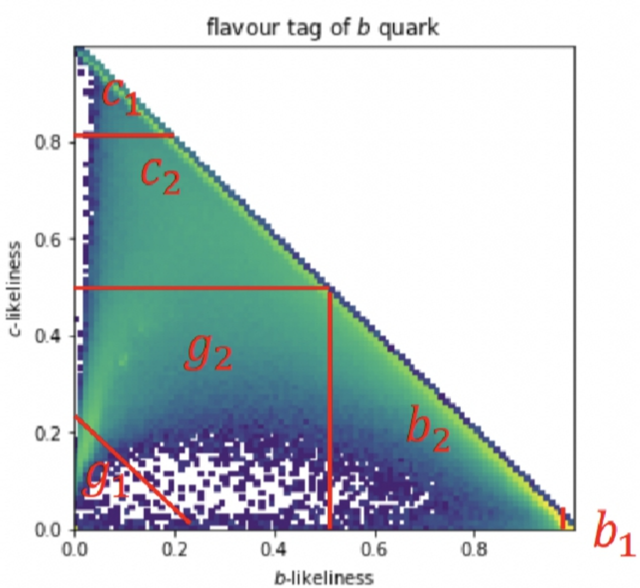
Figure 12.1: Sketch of the unitarity triangle.

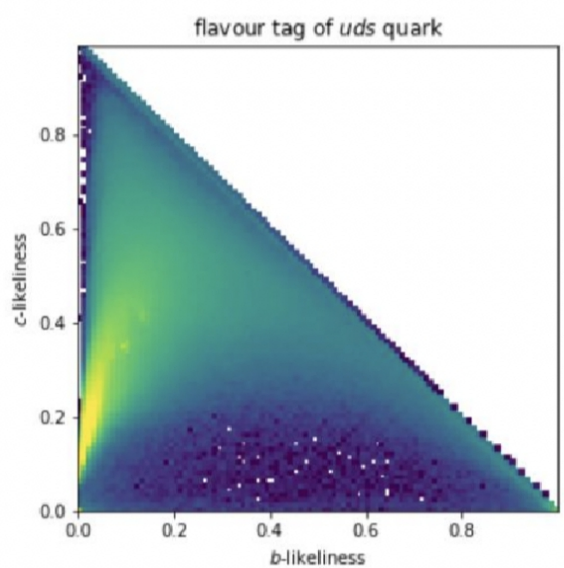
$$|V_{cb}| = (41.0 \pm 1.4) \times 10^{-3}\,.$$

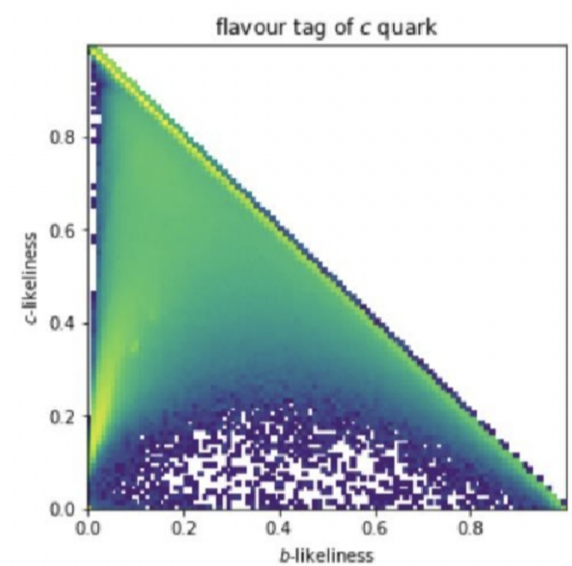
$M =$

	b1	b2	c1	c2	g1	g2
b	0.47	0.378	0.0197	0.0965	0.00397	0.0315
c	0.00042	0.078	0.298	0.373	0.0682	0.182
uds	0.000104	0.00477	0.00145	0.054	0.538	0.401

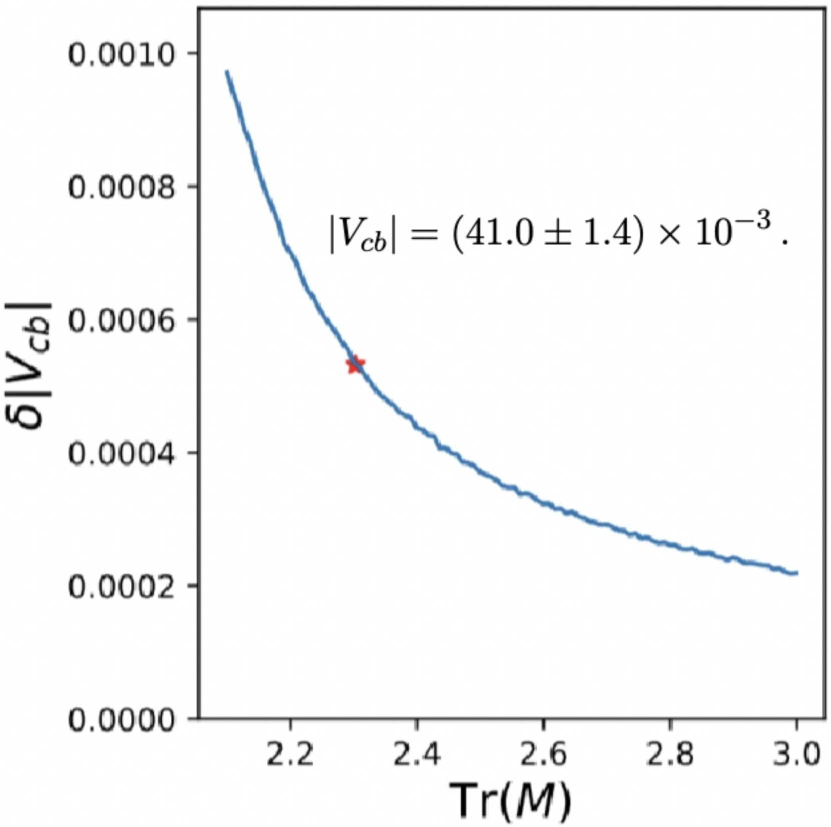
Flavour tagging at Z-pole

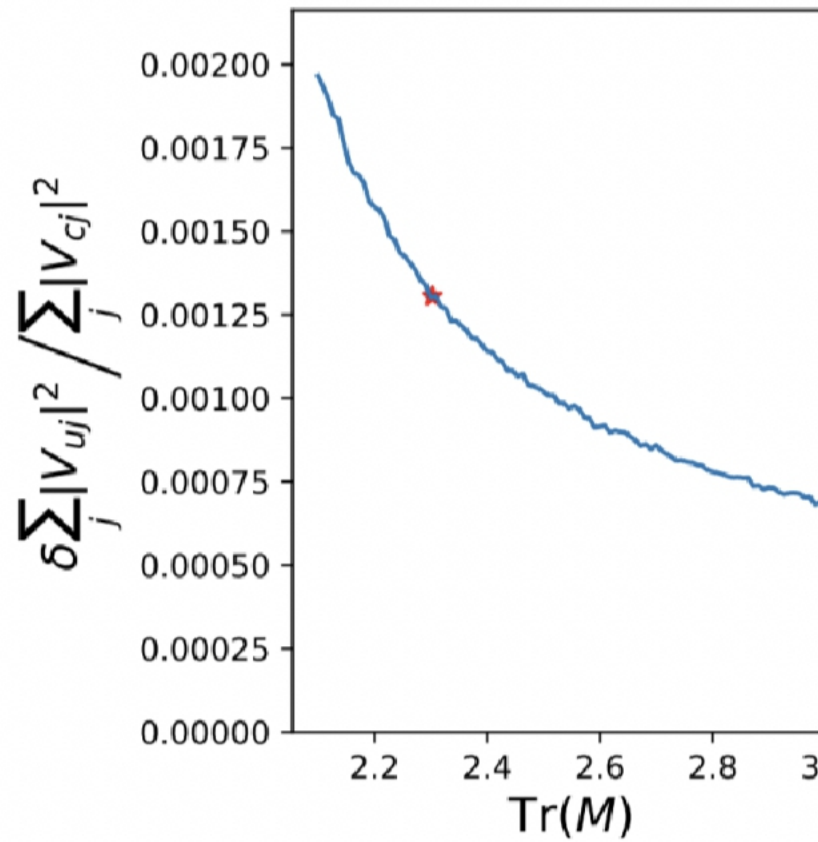






At changing Flavor tagging performance





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

Jet Charge

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

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

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

Effective tagging power

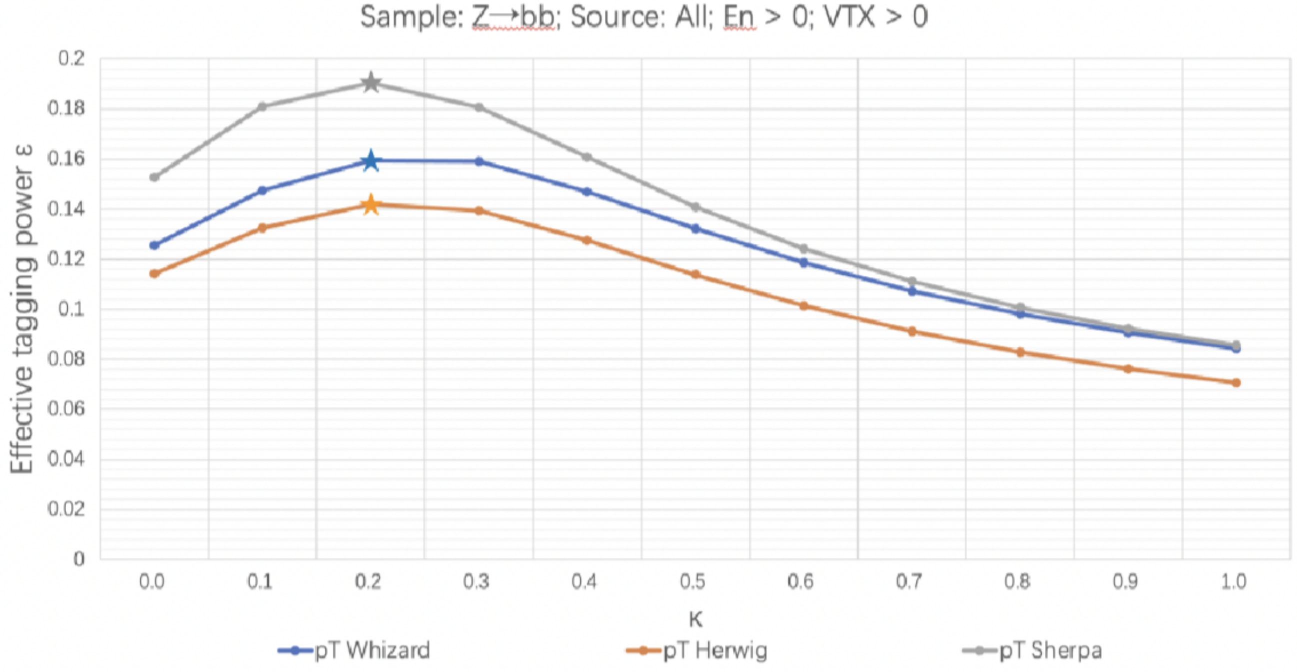
- Tagging power = efficiency * (1 – 2*omega)^2
- Omega ~ chance of mis-id, value between 0 – 0.5.
- To 1st order, accuracy ~ 1/sqrt(N*tagging power).
- Tagging power highly sensitive to mis-id chance.
- Many method to measure Jet Charge: VTX charge, weighted sum, jet lepton/kaon, 2nd leading kaon, ...

Weighted charge method (WCJC)

Method:

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

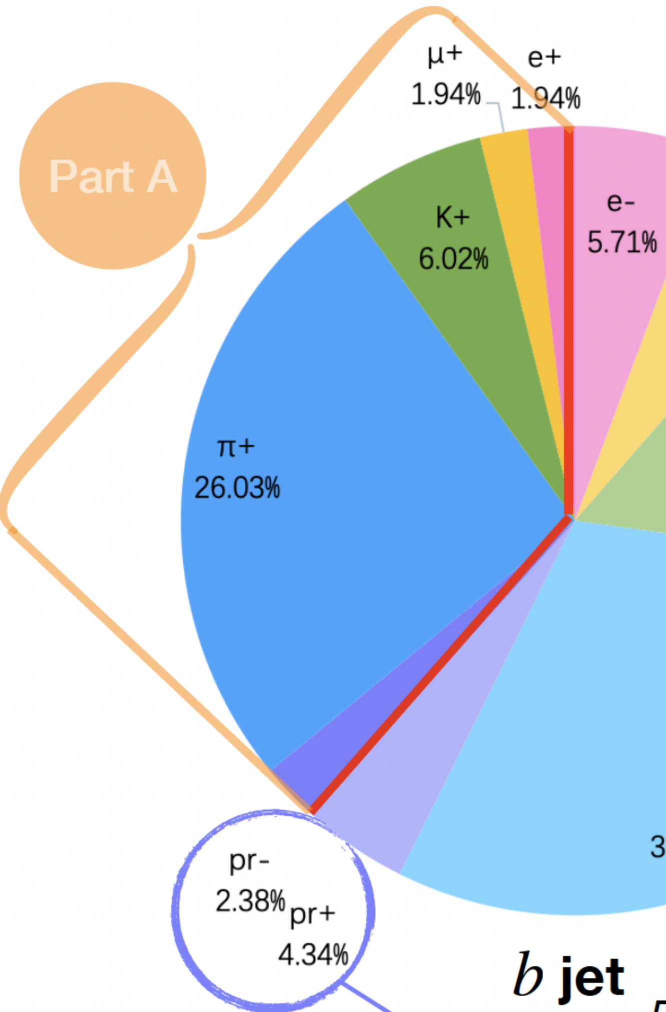
$$Q_{jet}^{\kappa} = \frac{\Sigma_i (E_i)^{\kappa}\, Q_i}{\Sigma_i (E_i)^{\kappa}}$$

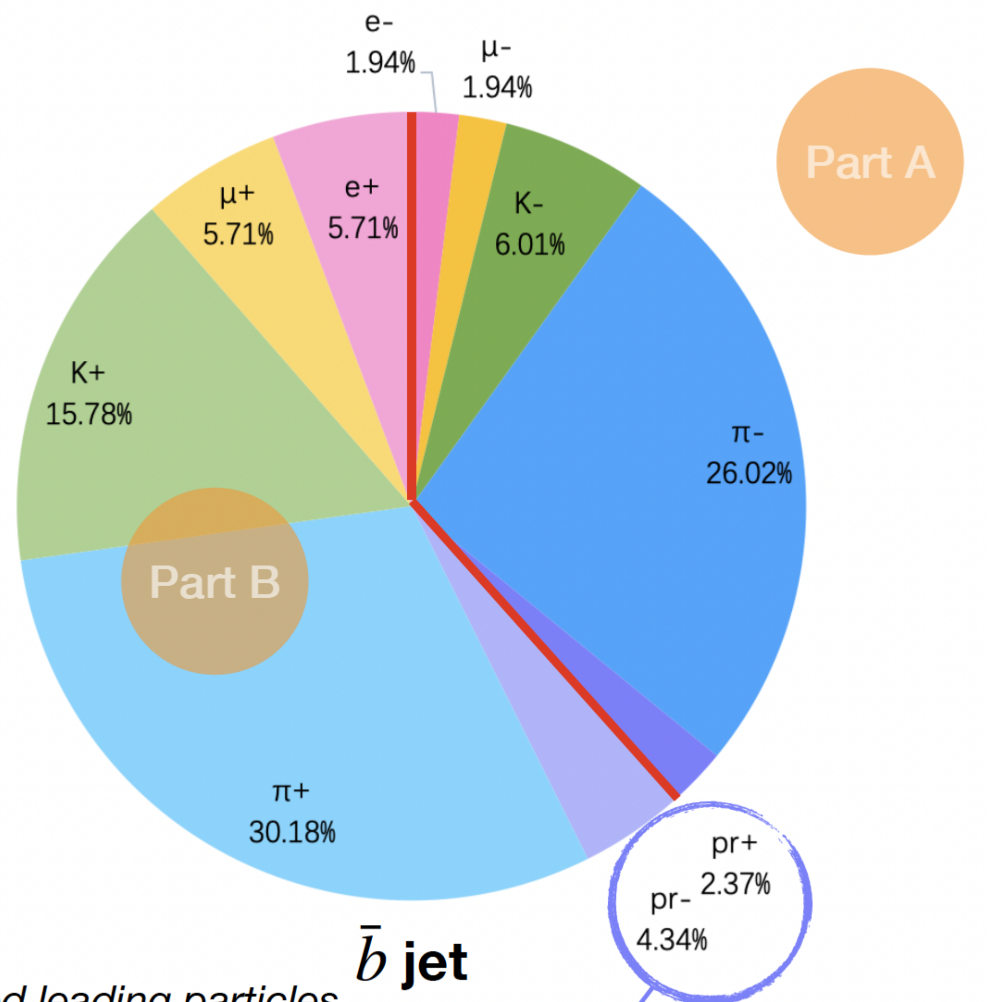


Methods	Optimized κ					
Generator	Whizard		Herwig		Sherpa	
source	all	from B/D	all	from B/D	all	from B/D
All b hadrons	(κ=0.2)	(κ=0)	(κ=0.2)	(κ=0)	(κ=0.2)	(κ=0)
B0/B0bar	(κ=0.2)	(κ=0.6)	(κ=0.2)	(κ=0.6)	(κ=0.3)	(κ=0.6)
B+/B-	(κ=0.3)	(κ=0)	(κ=0.4)	(κ=0)	(κ=0.3)	(κ=0)
Bs/Bsbar	(κ=0)	(κ=0)	(κ=0)	(κ=0)	(κ=0.2)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

$Z \to b\bar{b}$

Dependence on leading particle type





Percentage of final charged leading particles

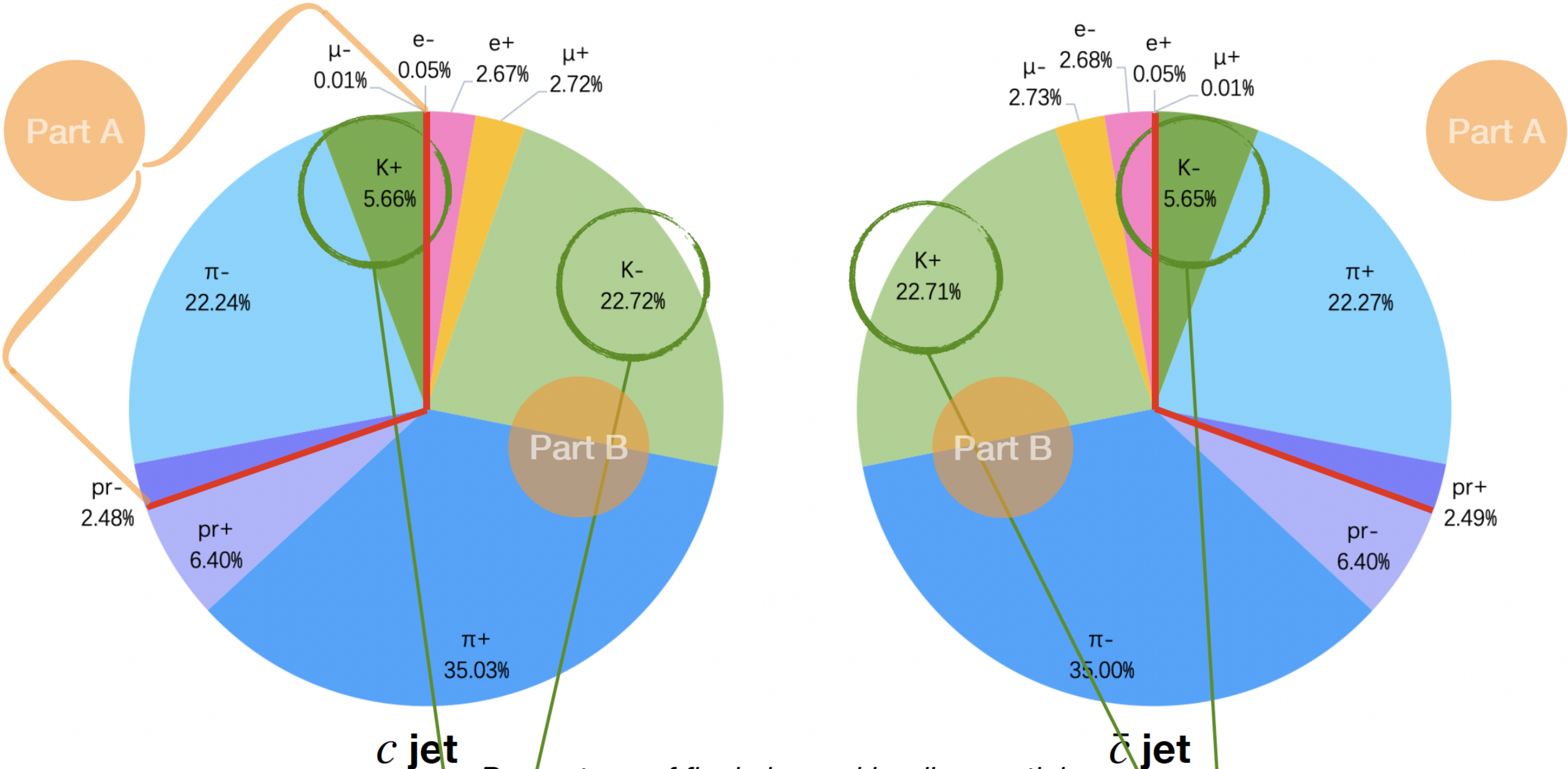
ω(using only charge) = 0.403
ω(using charge & PID) = 0.383

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

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

$Z \to c\bar{c}$

Dependence on leading particle type



Percentage of final charged leading particles

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

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

Strongly Depends on Pid!

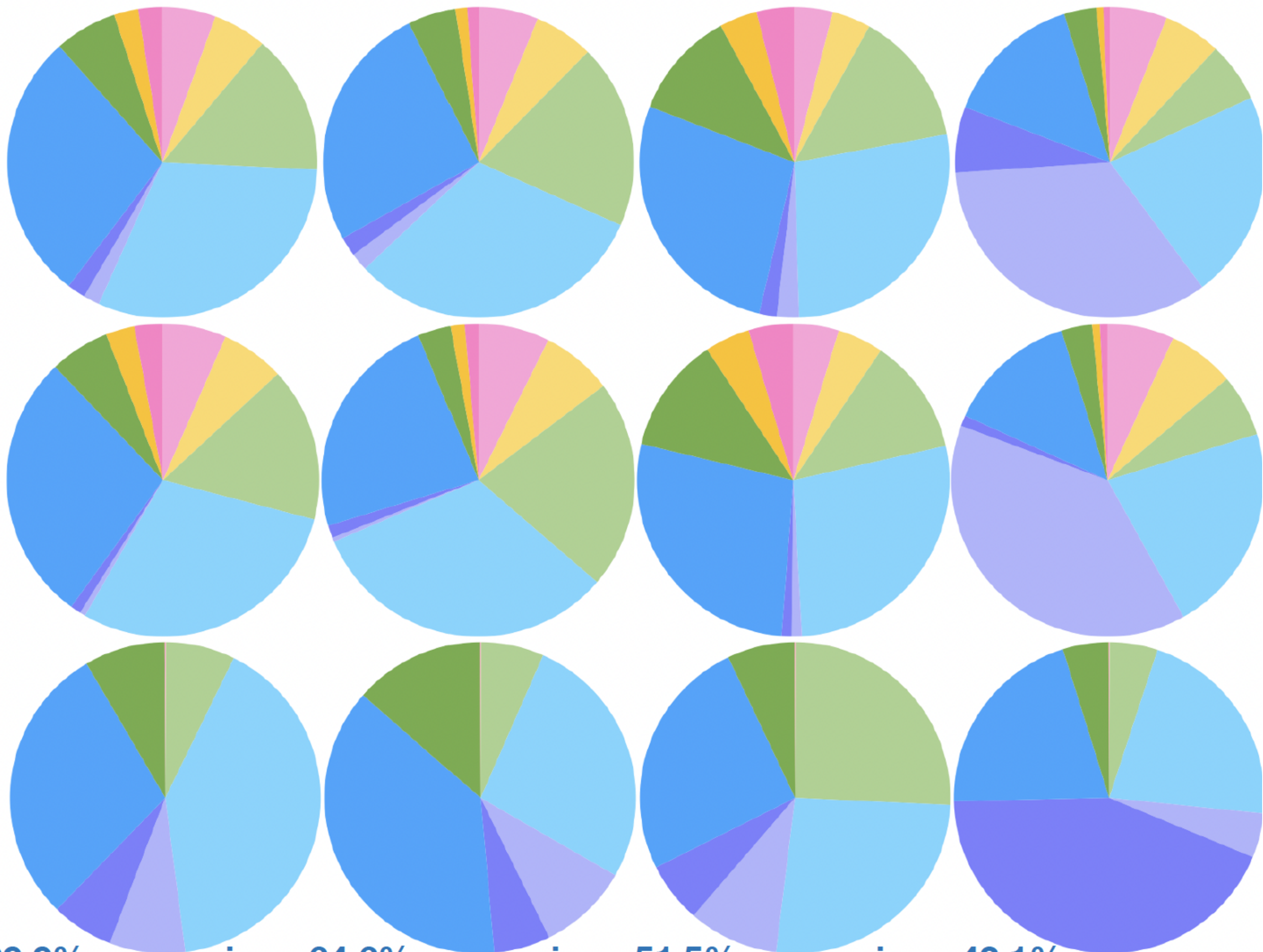
$Z \to b\bar{b}$

Percentage of leading particles (b jet, Whizard195)

All leading particles

Leading particles from leading hadron ~83.1%

Leading particles from QCD ~16.9%

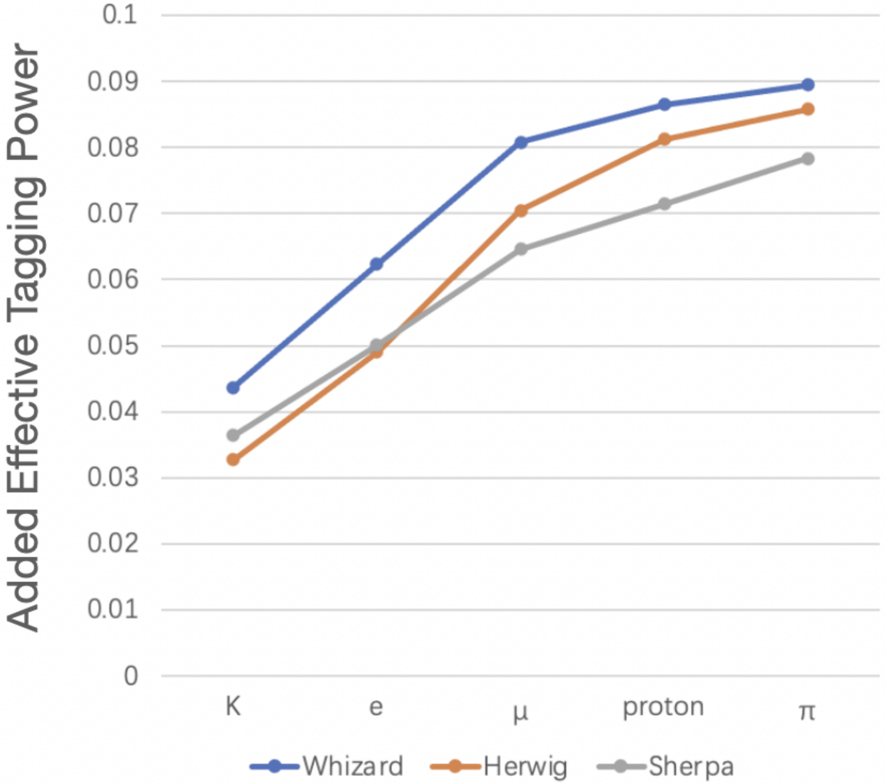


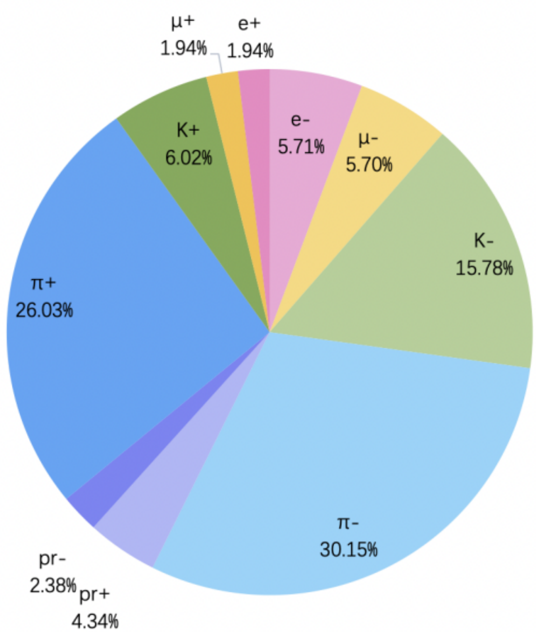
$\bar{B}^0$	B^-	$\bar{B}_s^0$	Λ_b
pion ~69.9%	pion ~64.6%	pion ~51.5%	pion ~42.1%
Kaon ~15.6%	Kaon ~20.0%	Kaon ~32.7%	Kaon ~9.7%
proton ~14.3%	proton ~15.3%	proton ~15.7%	proton ~48.0%

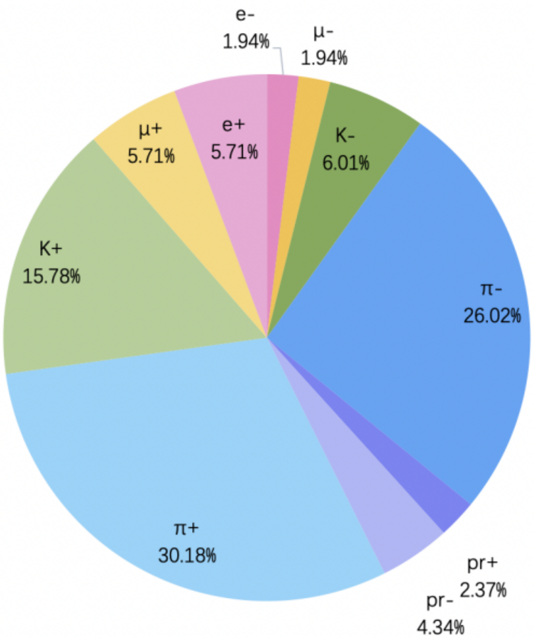
by WHIZARD195

Leading particle method (LPJC)

LP	Whizard	Herwig	Sherpa
e	0.019	0.018	0.015
μ	0.018	0.021	0.015
K	0.045	0.033	0.036
π	0.003	0.005	0.006
p	0.005	0.007	0.006
Tot	0.089	0.084	0.078







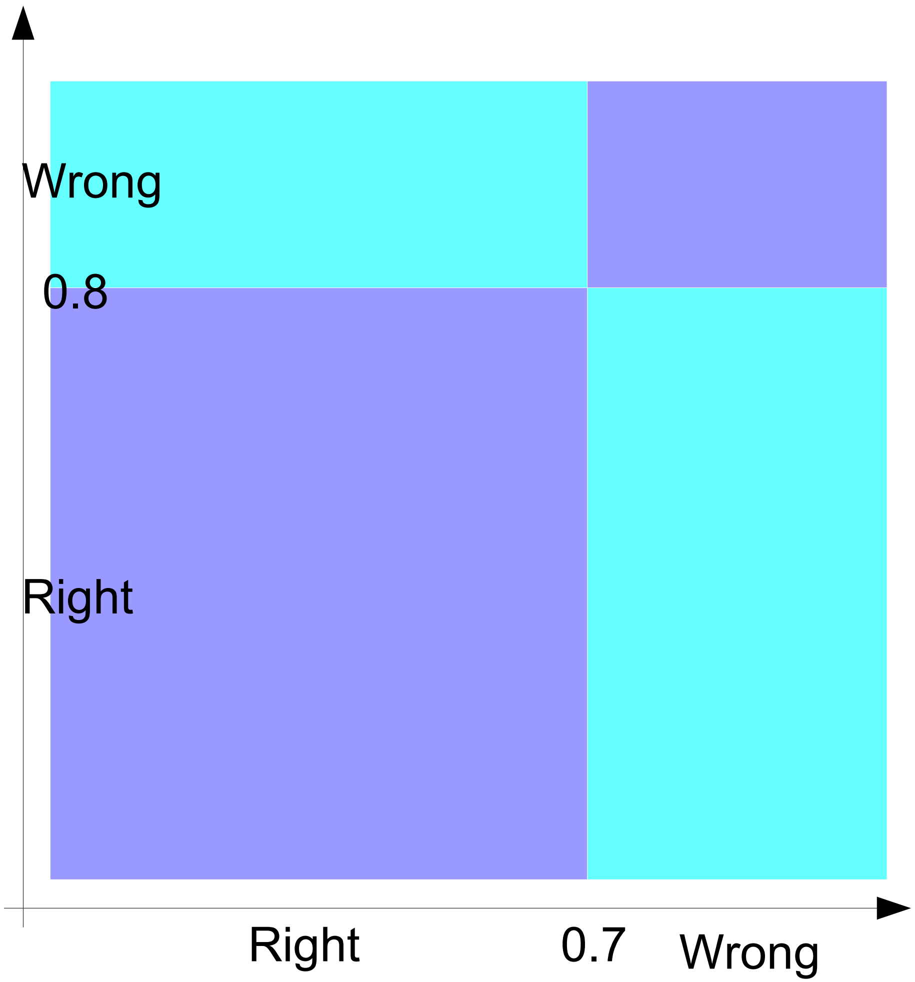
Dependence on leading particle type

Dependence on b/c hadron type

Dependence on decay source of leading particle: hadron or QCD.

Combine...

- Naive case: non correlated two observer
  - O1, omega = 0.3, eff = 1, Tagging Power ~ 16%
  - O2, omega = 0.2, eff = 1, Tagging Power ~ 36%
- Since Tagging power depends stronger on omega rather than efficiency, we can select only event with consistent O1 & O2
  - Efficiency drops to
    - 0.7*0.8 + 0.2*0.3 = 62%
  - Omega:
    - 0.2*0.3/(0.7*0.8 + 0.2*0.3) = 6/62
  - Tagging Power ~ 40.3%



Result @ Truth level

two combination methods combination

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

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

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

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

Summary

- Hadronic system is key to the success of e-e+ Higgs factory, ... has huge impact on the physics reach/NP sensitivity
- At CEPC: comprehensive understanding towards the requirement & performance, via simulation/detector R&D studies.
- BMR
  - 3.8% achieved at baseline + Arbor — Manqi, *Eur. Phys. J. C (2018) 78:426*
  - Informative decomposition (Yuexin, thesis) + update (Yuexin, to be submit)
- Jet, an conventional, but not perfect method to describe hadronic event...
  - Energy Scale & resolution: ~3 times better than LHC, differential relationship quantified, W boson mass ~ 1 MeV — Peizhu, *2021 JINST 16 P07037*
  - Charge: Innovative method developed, achieves decent, possibly the best effective tagging power (~20%/40% for b/c-jets) (Hanhua, to be submit)
  - Flavor tagging:
    - Dependence on VTX geometry — Zhigang, *2018 JINST 13 T09002*

Summary

- CSI: bottleneck for physics measurement with full hadronic final state
  - Concept arises: *Yongfeng, Eur. Phys. J. C (2019) 79:274*
- Physics benchmarks
  - Vcb mesurement: Flavor tragging, to be submit
  - H→bb, cc, gg: BMR + Flavor Tagging + CSI, Yongfeng, *JHEP11(2022)100*
  - Bs→Phi vv: BMR + Pid, Yudong, *Phys.Rev.D 105 (2022) 11*
  - H→tautau: BMR, Dan. *Eur. Phys. J. C (2020) 80:7*
  - H→invisible: BMR, Yuhang. *CPC Vol. 44, No. 12 (2020) 123001*
  - Higgs white paper: Everything, *CPC Vol. 43, No. 4 (2019) 043002*
  - Higgs Snowmass whitepaper, https://arxiv.org/abs/2205.08553
- *...your ideas & requirements...*

Backup

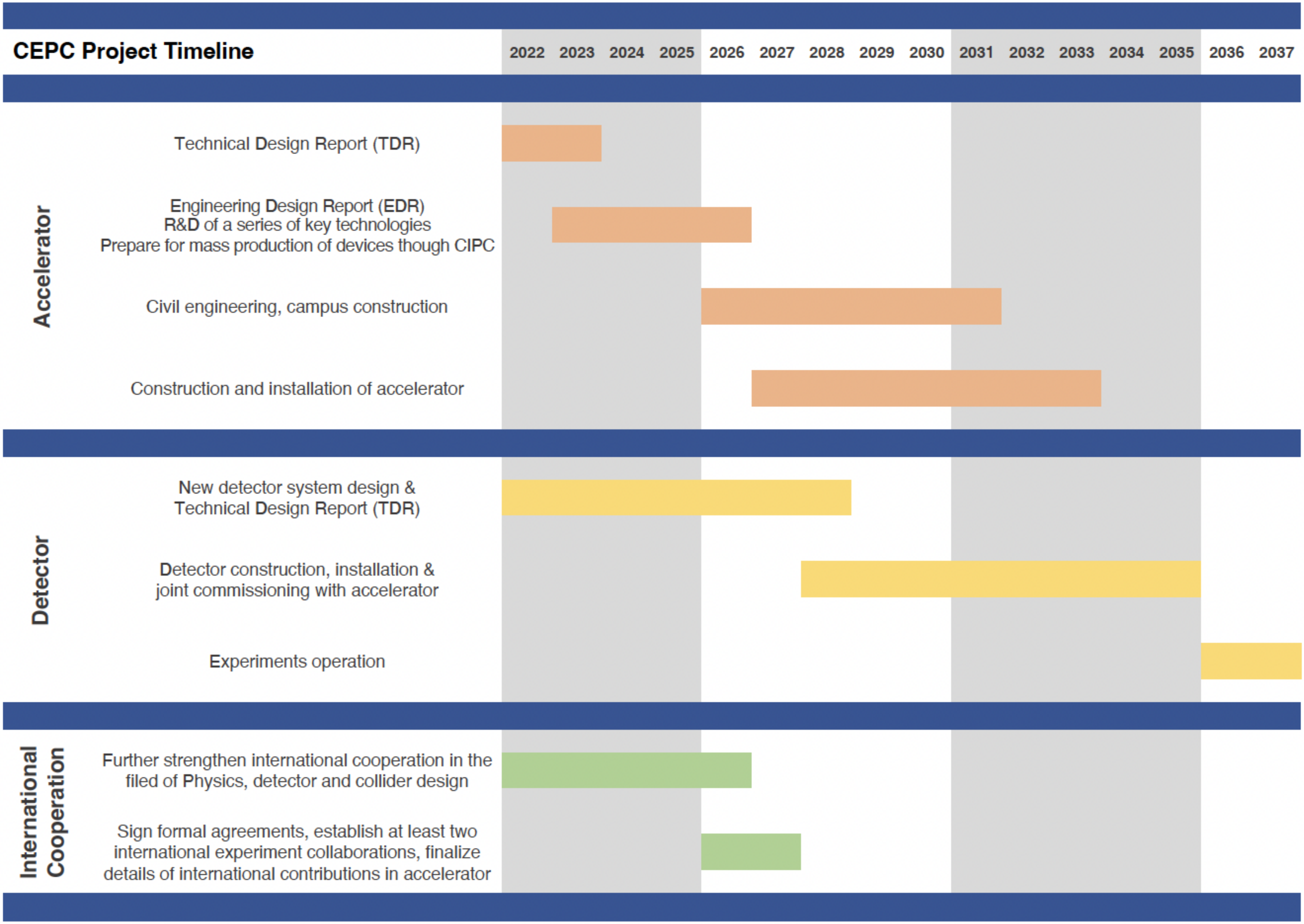


Figure 8.1 The CEPC timeline from the 14th to the 16th Five-Year plan

Summary

- Future Focus
  - BMR ~ **3%**: Arbor upgrade + Detector Design/Optimization
  - Flavor tagging: **Tri_M from ~ 2.2 → 2.5**
    - Algorithm
    - Physics
    - VTX optimization + New tech. Development
  - Jet Charge:
    - Secure b/c tagging power **20%/40%**
    - Detector has sufficient Pid & Low enough threshold
  - CSI:
    - Enhance qqH signal strength accuracy by **~ 50%**
    - Iterate with QCD studies
  - To collaborate closely with QCD community... especially on the understanding of fragmentation & event topology description, etc

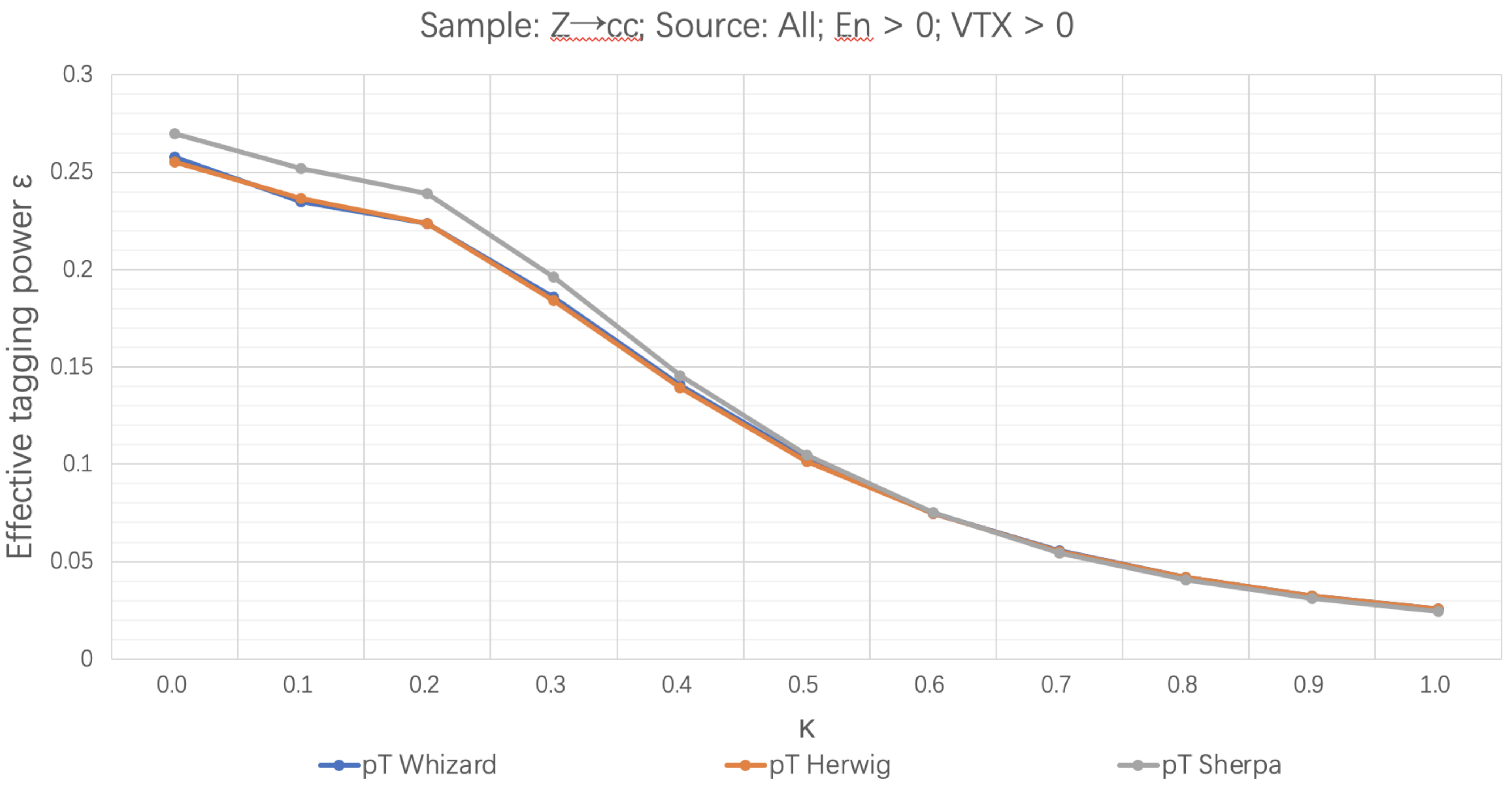
Discussion on Jet charge

- We propose LPJC, a robust method that
  - Provide slightly worse tagging power compared to WCJC (reference method)
  - Significantly enhance the performance once combined with WCJC
    - c-jet with Eff. Tagging power ~ 37%, best of the world?
- LPJC, Preserve the physics information – strongly depends on the
  - Hadron species that quark fragmented into
  - Final state that Heavy Hadron decays into
  - Num. results depends slightly on fragmentation models (Generator type)
- Dependency to the detector performance yet to be quantified. But LPJC & WCJC relies on different performance & highly complementary
  - Both need good acceptance & resolution.
  - LPJC: Pid!!!
  - WCJC: Momentum threshold
- Plan to submit soon.

Physics benchmarks

Anticipated Accuracy ~ Key Performance ~ Detector design & optimization

WCJC @ c jet



Very demanding on energy threshold...

$$-2 \cdot log(\ell) = \sum_{i=1}^{i=6} \frac{[S_b \cdot N_{b,i} + S_c \cdot N_{c,i} + S_{light} \cdot N_{light,i} + N_{bkg,i} - N_i]^2}{N_i}$$

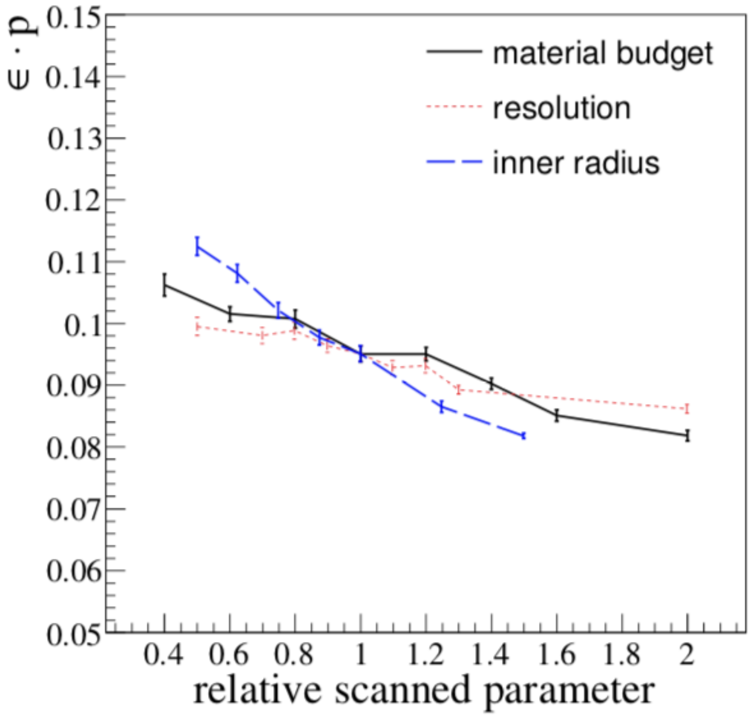
- S_b: the signal strength of $\nu\nu Hb\bar{b}$
- $N_{b,i}$: the event number of $\nu\nu Hb\bar{b}$ in *ith* bin
- N_i: the total event number in *i'th* bin of $\nu\nu Hb\bar{b}$, $\nu\nu H/c\bar{c}$, $\nu\nu Hgg$ and backgrounds
- $N_{bkg,i}$ is the expected event number in *ith* bin of backgrounds,
- similar for S_c, S_{light}, $N_{c,i}$, and $N_{light,i}$

$$hessian\ matrix = \begin{bmatrix} \frac{\partial^2 log(\ell)}{\partial S_g \partial S_c} & \frac{\partial^2 log(\ell)}{\partial S_g \partial S_b} & \frac{\partial^2 log(\ell)}{\partial S_g \partial S_g} \\ \frac{\partial^2 log(\ell)}{\partial S_b \partial S_c} & \frac{\partial^2 log(\ell)}{\partial S_b \partial S_b} & \frac{\partial^2 log(\ell)}{\partial S_b \partial S_g} \\ \frac{\partial^2 log(\ell)}{\partial S_c \partial S_c} & \frac{\partial^2 log(\ell)}{\partial S_c \partial S_b} & \frac{\partial^2 log(\ell)}{\partial S_c \partial S_g} \end{bmatrix}$$

- The error covariance is obtained from the hessian matrix.
- The relative accuracy of signal strength is the square roots of the diagonal elements of the covariance matrix, tt is 0.49%/5.75%/1.82% for $\nu\nu Hb\bar{b}/c\bar{c}/gg$.

For 5.6 iab

Flavor tagging V.S VTX geometry



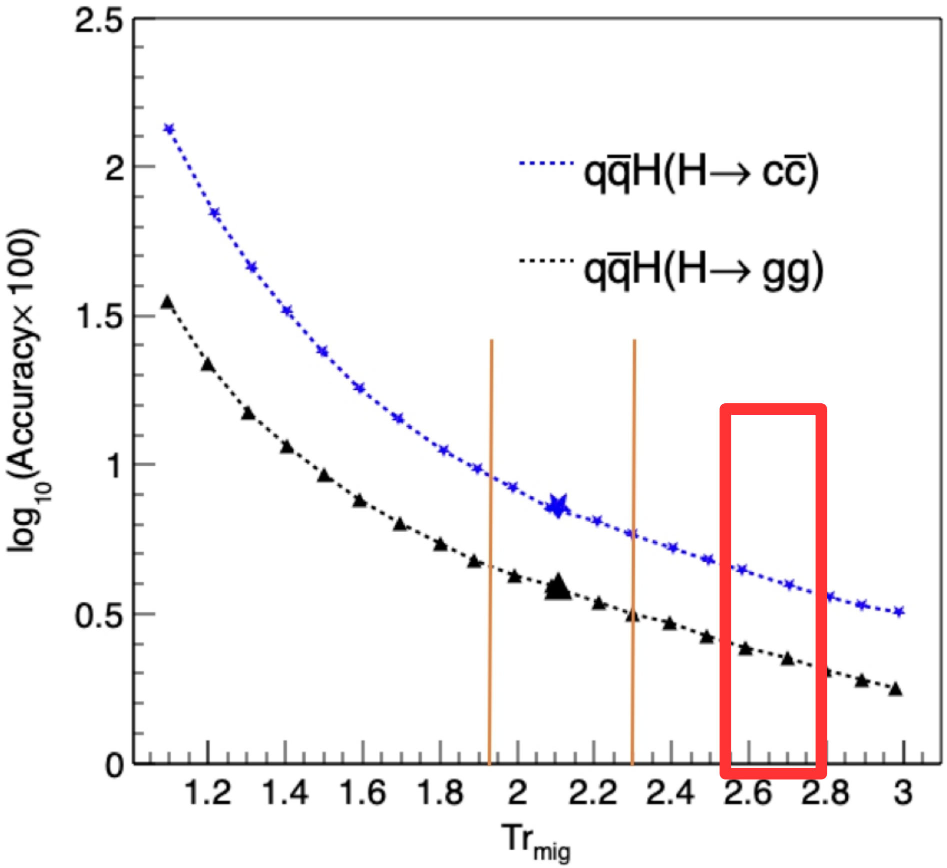
$$\epsilon \cdot p = 0.095(1 - 0.14\frac{\Delta x_{\text{material}}}{x_{\text{material}}})(1 - 0.09\frac{\Delta x_{\text{resolution}}}{x_{\text{resolution}}})(1 - 0.23\frac{\Delta x_{\text{radius}}}{x_{\text{radius}}})$$

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
trace	2.3	2.1	1.9

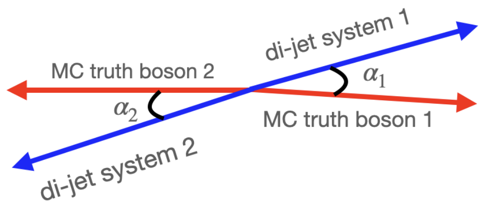
$$Tr_{mig} = 2.118 + 0.054 \cdot log_2 \frac{R^0_{material}}{R_{material}} + 0.040 \cdot log_2 \frac{R^0_{resolution}}{R_{resolution}} + 0.098 \cdot log_2 \frac{R^0_{radius}}{R_{radius}}$$

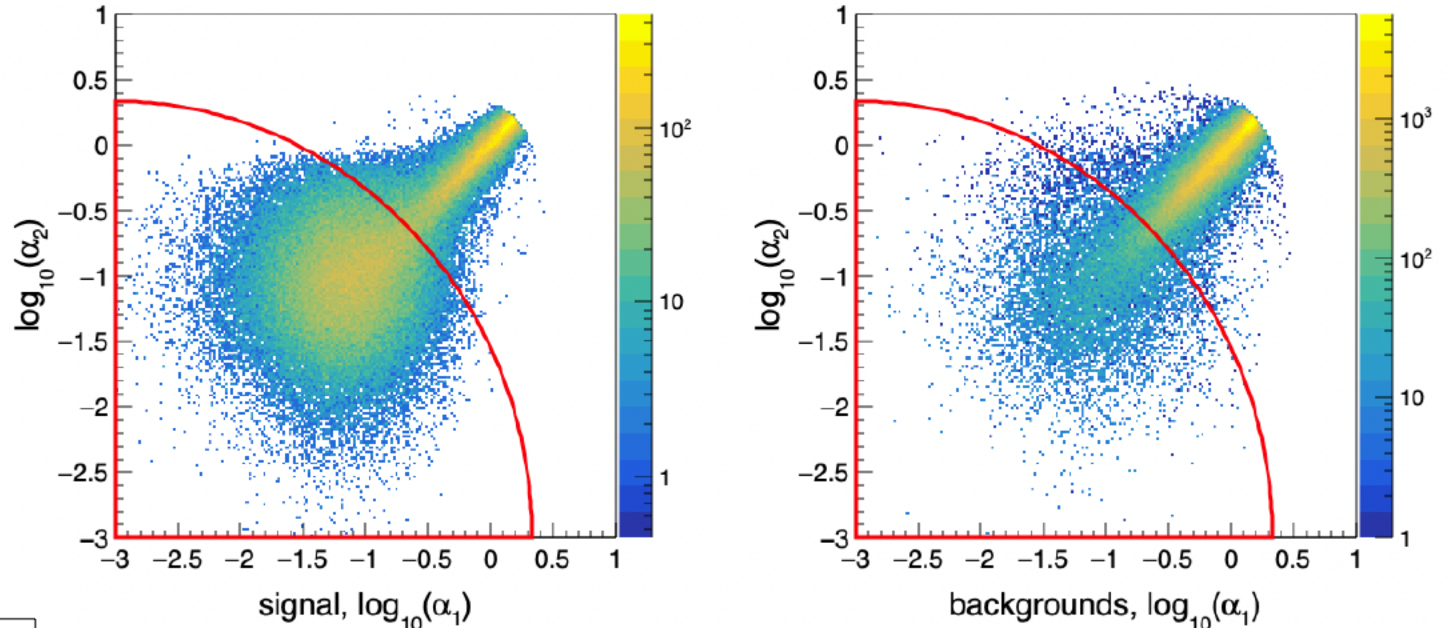
Perspective to the far future

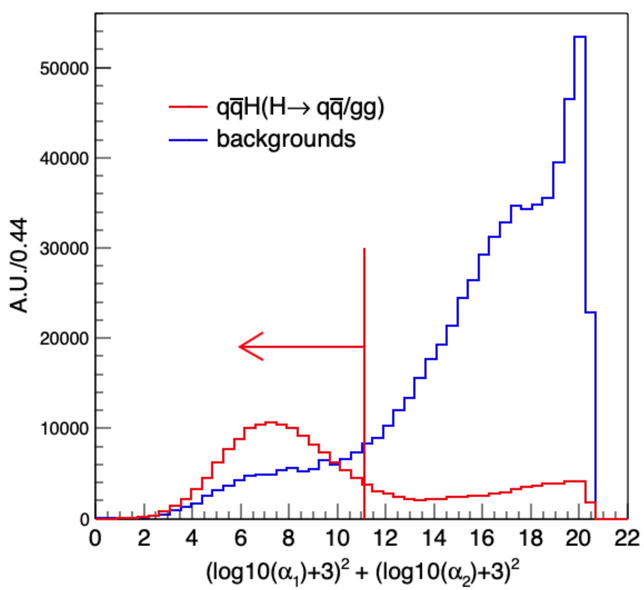


- If we put the VTX inside the beam pipe:
  - the material & radius halves from Aggressive scenario...
  - a much better polar angle coverage...
- Much intelligent algorithm...

CSI: impact on H→bb, cc, gg







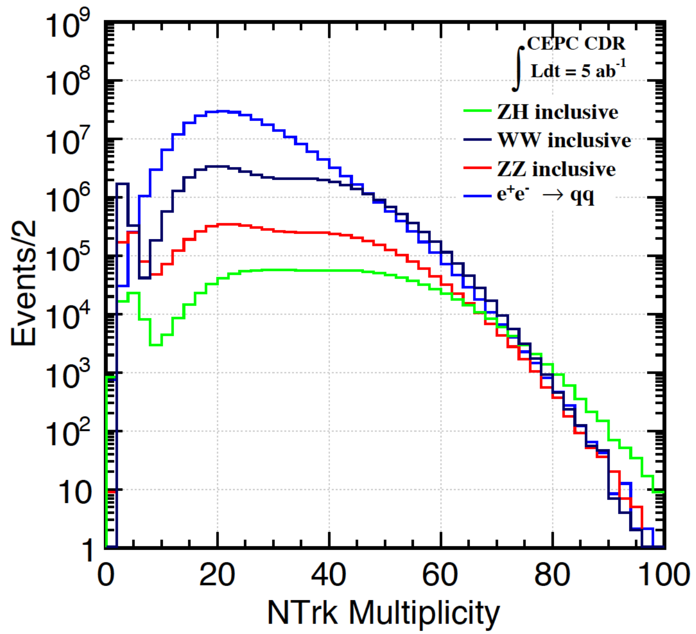
- If we find an observable that evaluates the performance of CSI – and eventually veto events with bad CSI, we can improve the accuracy on H->bb, cc, gg by ~ 2 times at qqH channel.
- Many ppl interested in: Yongfeng Zhu, Huaxing Zhu, Meng Xiao, Chen Zhou, MQ, ... New ideas under test
- Physics Picture, then goes to sophisticated tools.

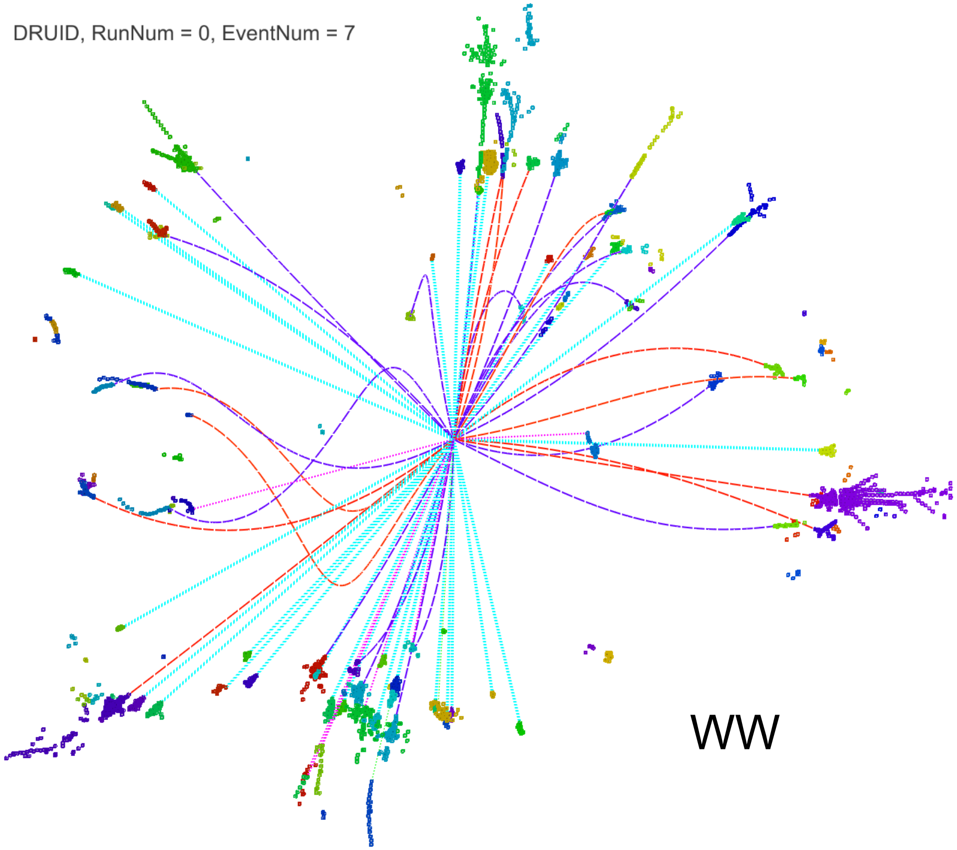
CSI

How to find all the final state particles generated from one boson decay, in a full hadronic WW/ZZ/ZH events?

Jet clustering + matching, or goes beyond?

Full hadronic WW-ZZ separation

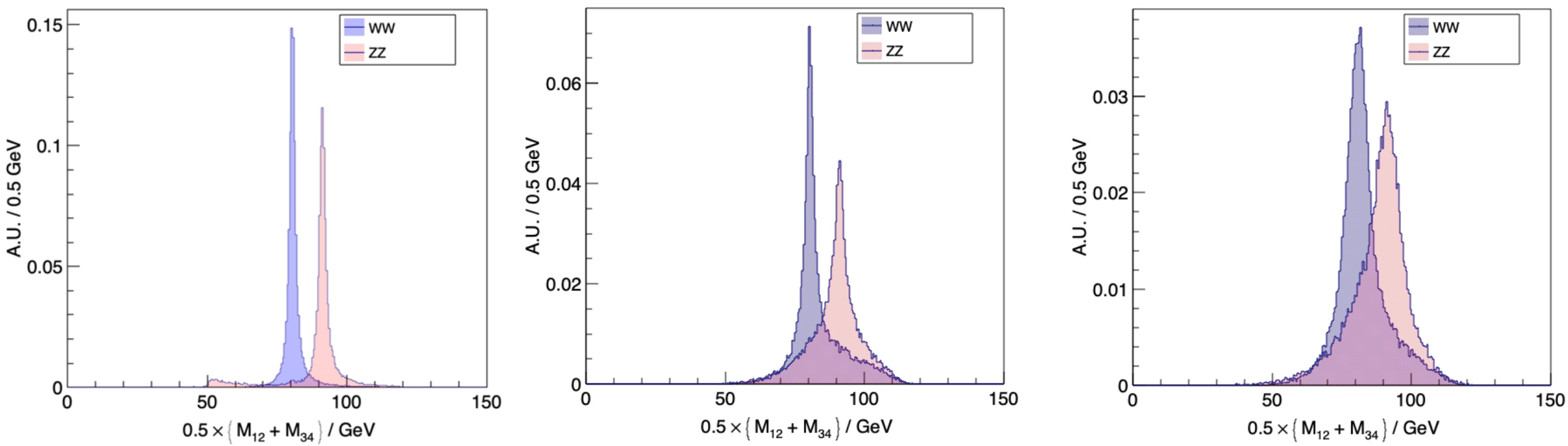




WW

- Low energy jets! (20 – 120 GeV)
- Typical multiplicity ~ o(100)
- WW-ZZ Separation: determined by
  - Intrinsic boson mass/width
  - Jet confusion from color single reconstruction – jet clustering & pairing
  - Detector response

Jet confusion: the leading term



- Separation be characterized by

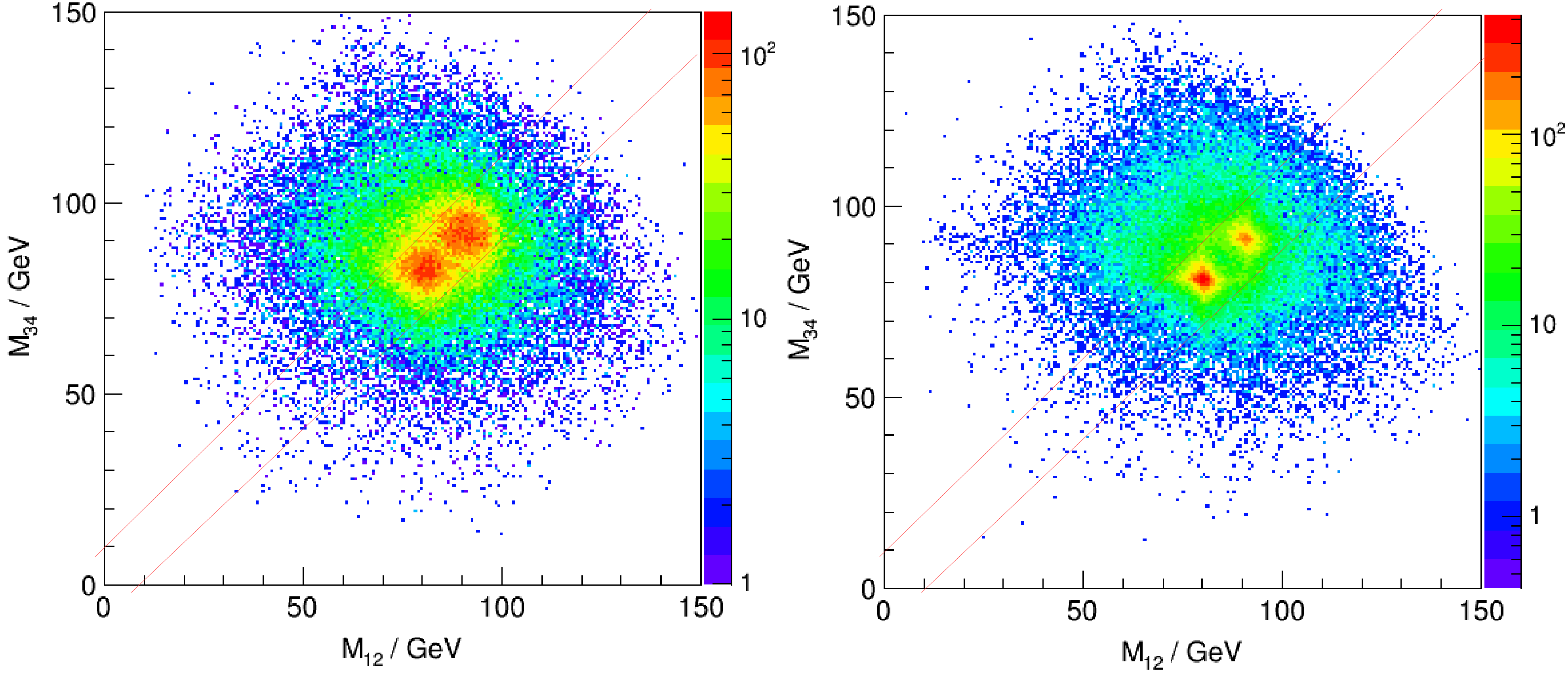
$$overlapping\ ratio = \sum_{bins} min(a_i, b_i)$$

- Final state/MC particles are clustered into Reco/Genjet with ee-kt, and paired according to chi2

$$\chi^2 = \frac{(M_{12} - M_B)^2 + (M_{34} - M_B)^2}{\sigma_B^2}$$

- WW-ZZ Separation at the inclusive sample:
  - Intrinsic boson mass/width - lower limit: Overlapping ratio of 13%
  - + Jet confusion – Genjet: Overlapping ratio of **53%**
  - + Detector response – Recojet: Overlapping ratio of 58%

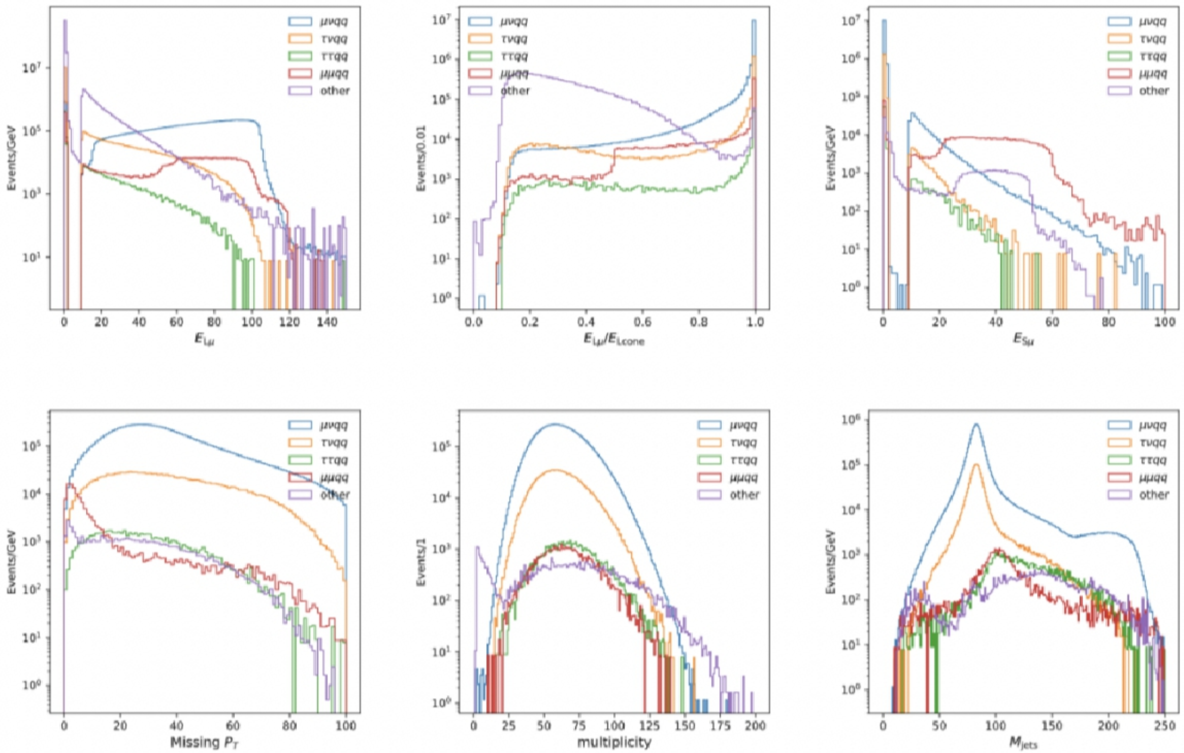
Reconstructed mass of the two di-jet system



Equal mass condition |M12 – M34| < 10 GeV: At the cost of half the statistic, the overlapping ratio can be reduced from 58%/53% to 40%/27% for the Reco/Genjet

Event selections

- Selection criteria are optimized for statistical uncertainty for $\mathrm{Br}(\mathrm{W} \to cb)$



	$\mu\nu cb$	$\mu\nu ub$	$\mu\nu c(d/s)$	$\mu\nu u(d/s)$	$\mu 3\nu cb$	$\mu 3\nu c(d/s)$	$\mu 3\nu u(d/s)$
w.o. slections	11.3k	102	6.78M	6.78M	2.23k	1.18M	1.18M
$E_{L\mu} > 12\mathrm{GeV}$	10.6k	94	6.32M	6.32M	1.5k	834k	829k
$R_{L\mu} > 0.95$	9.23k	78	5.52M	5.53M	1.21k	710k	710k
$\cos(\theta_{L\mu})$	9.23k	78	5.52M	5.53M	1.21k	710k	710k
Second isolation muon veto	9.1k	77	5.5M	5.52M	1.2k	709k	710k
Missing P_T	8.92k	74	5.38M	5.41M	1.13k	685k	686k
multiplicity > 27	8.92k	74	5.37M	5.37M	1.13k	683k	681k
$M_{\mathrm{jets}} > 50\mathrm{GeV}$	8.86k	74	5.34M	5.35M	1.13k	679k	679k
$M_{\mathrm{jets}} < 95\mathrm{GeV}$	7.92k	70	4.79M	4.79M	1.05k	616k	613k
efficiency.	0.701(08)	0.682(88)	0.707	0.707	0.470(40)	0.524(02)	0.520(02)

Table 2: Event selections for signals. The number in the parenthesis are the uncertainties of the last two digits of the efficiencies arise from the statistics of Monte Carlo sample.

	$e3\nu qq$	$\tau_{\mathrm{had.}}3\nu qq$	$\tau\tau qq$	$\mu\mu qq$	other
w.o. slections	2.43M	8.79M	609k	1.25M	364.9M
$E_{L\mu} > 12\mathrm{GeV}$	37.3k	190k	118k	790k	13.6M
$R_{L\mu} > 0.95$	357	9.93k	65.4k	413k	85.1k
Second isolation muon veto	357	9.89k	64.1k	125k	57.9k
Missing P_T	349	9.59k	60.0k	47.7k	46.7k
multiplicity > 27	341	9.51k	59.6k	47.2k	38.0k
$M_{\mathrm{jets}} > 50\mathrm{GeV}$	318	9.41k	58.8k	45.7k	35.0k
$M_{\mathrm{jets}} < 95\mathrm{GeV}$	302	8.47k	6.72k	10.7k	4.02k
Eff.	0.000125	0.000964	0.011	0.00854	1.1e-05

Table 3: Event selections for backgrounds.

V.S. Acceptance

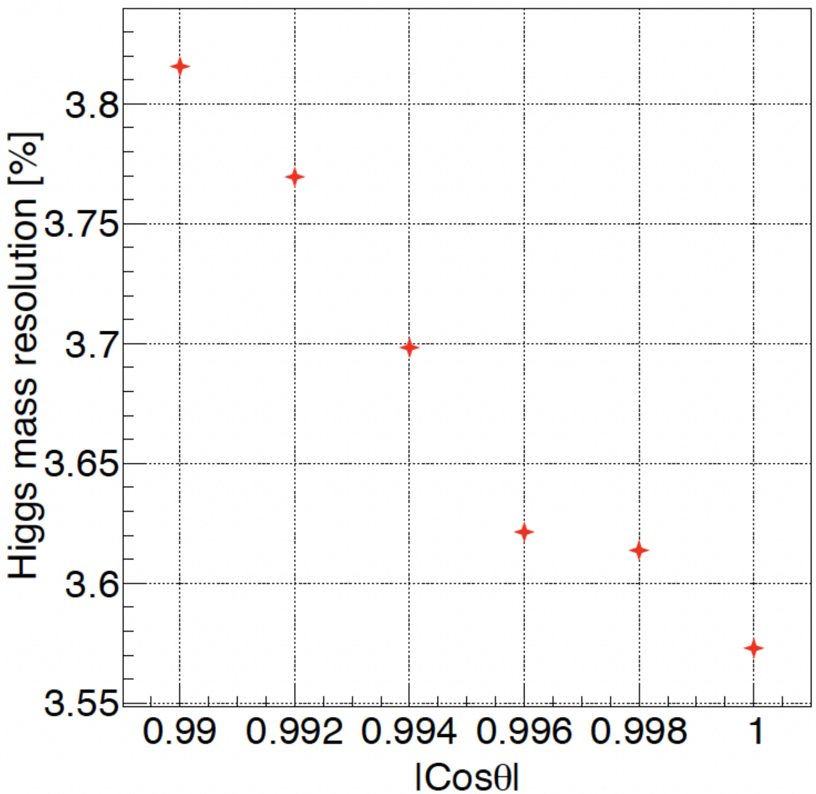
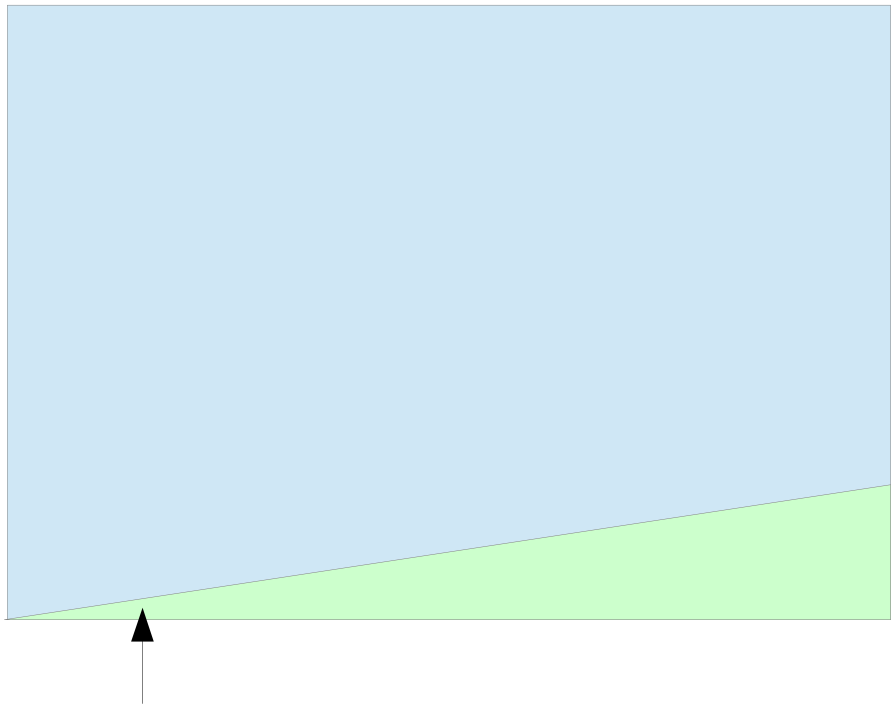
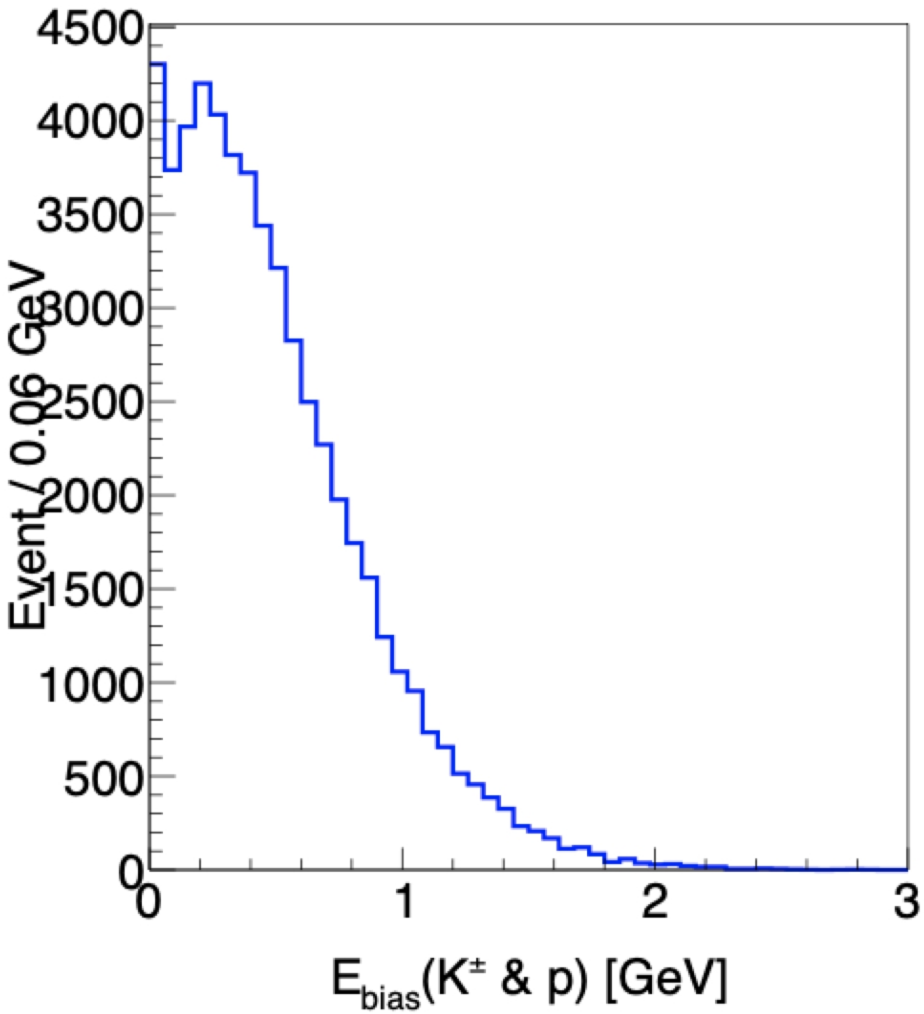


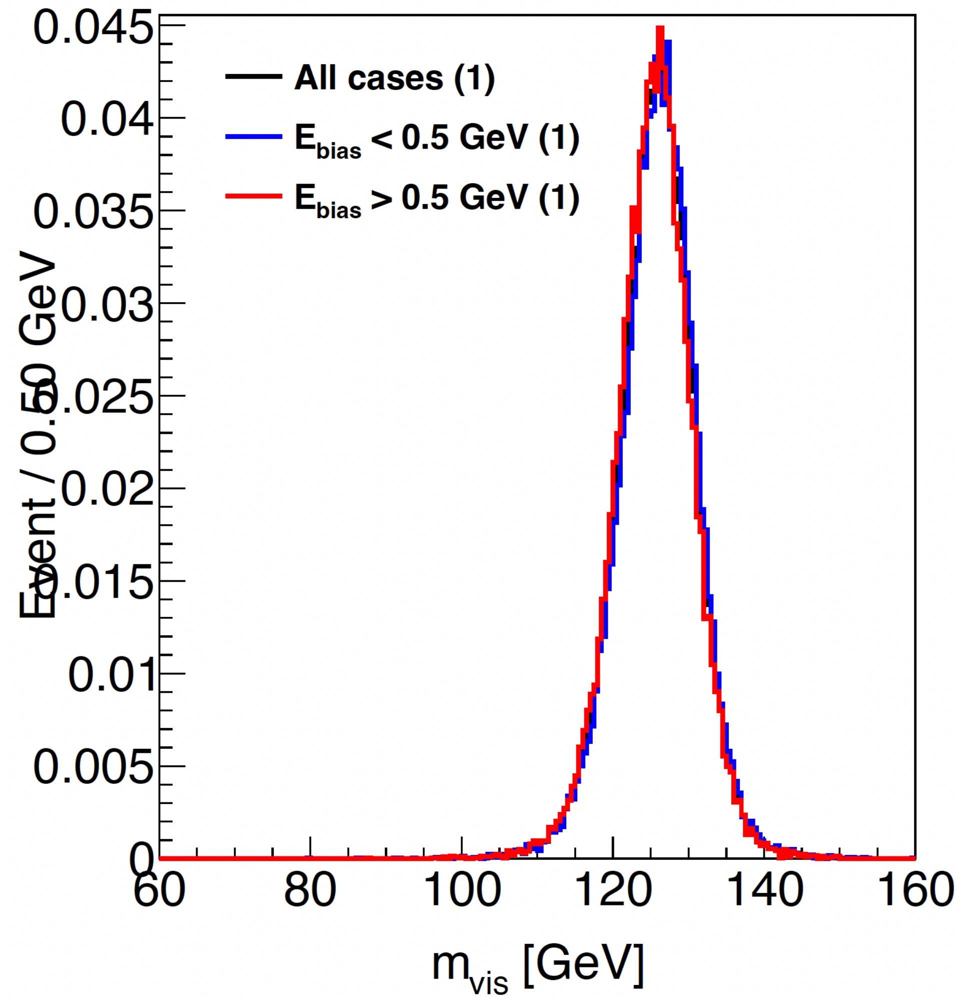
图 4-10 BMR 随探测器接收度的变化。



- 8.1 Degree ~ 0.14 rad
- Radius at endcap: 0.34 m

Update: impact of Pid





- Ebias = E_truth – E_reco
- Perfect Pid will improve BMR by 1-2%

Tagger level combination of two methods

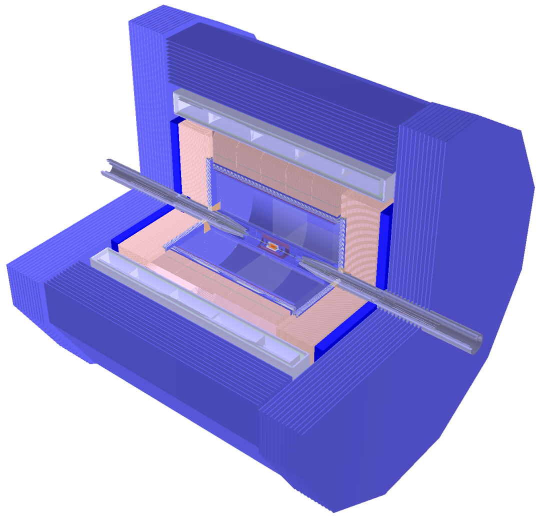
Method	Tagger	κ	$\varepsilon_{tag}=N_{tag}/N$	$\omega_i=N_w/N_{tag}$	$\bar{\omega}$	r^2	ε_{eff}
LPJC	e		7.70%	25.45%		0.241	0.019
	μ		7.70%	25.53%		0.239	0.018
	K		21.97%	27.45%		0.203	0.045
	π		56.33%	46.34%		0.005	0.003
	p		6.30%	36.45%		0.073	0.005
	Total		100.00%	38.35%	35.06%	0.089	**0.089**
WCJC	All	2	100.00%	30.04%		0.159	**0.159**
WCJC combined with LP PID	e	4	7.70%	22.36%		0.306	0.024
	μ	4	7.70%	22.35%		0.306	0.024
	K	4	21.97%	26.32%		0.224	0.049
	π	2	56.33%	31.61%		0.135	0.076
	p	0	3.92%	27.94%		0.195	0.008
	Total		97.62%	28.13%	28.52%	0.185	**0.180**
Total Combined	e		7.65%	22.33%	22.36%	0.306	0.023
	μ		7.65%	22.31%	22.35%	0.306	0.023
	K		21.81%	26.46%	26.32%	0.224	0.049
	π		56.18%	31.72%	31.61%	0.135	0.076
	p		6.72%	30.40%	30.57%	0.151	0.010
	Total		100.00%	29.05%	28.68%	0.182	**0.182**

1 0

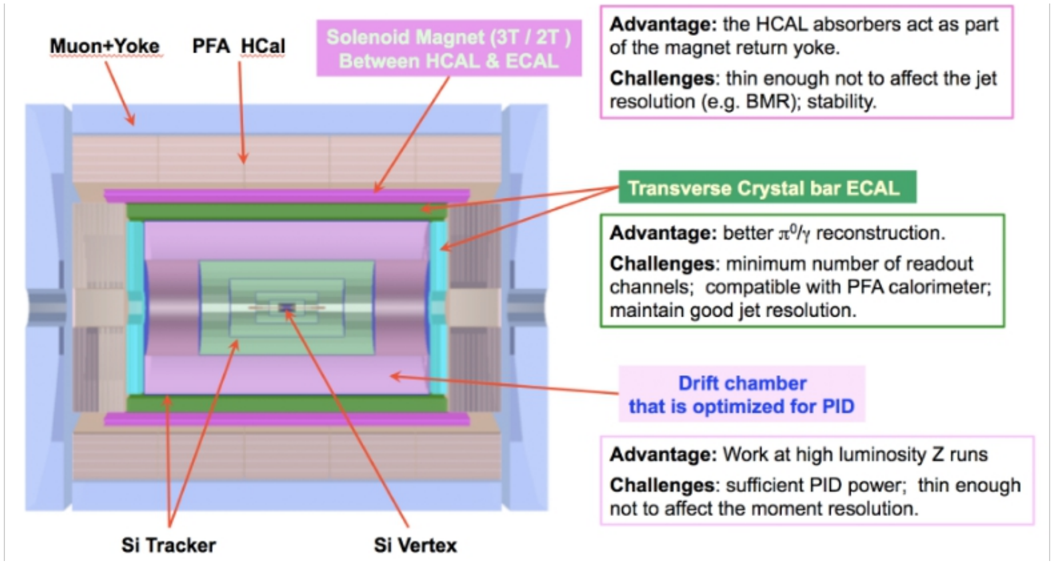
Tagger level combination of two methods

Method	Tagger	κ	$\varepsilon_{tag}=N_{tag}/N$	$\omega_i=N_w/N_{tag}$		r^2	ε_{eff}
LPJC	e		2.75%	1.90%		0.926	0.025
	μ		2.76%	0.47%		0.981	0.027
	K		28.70%	19.73%		0.367	0.105
	π		57.56%	38.79%		0.050	0.029
	p		8.22%	28.00%		0.194	0.016
	Total		100.00%	30.36%	27.49%	0.203	**0.203**
WCJC	All	0	67.39%	19.07%		0.383	**0.258**
WCJC combined with LP PID	e	10	2.75%	7.89%		0.709	0.020
	μ	10	2.76%	6.84%		0.745	0.021
	K	0	19.36%	18.99%		0.385	0.074
	π	0	38.80%	19.11%		0.382	0.148
	p	3	8.22%	22.77%		0.297	0.024
	Total		71.89%	13.37%	18.41%	0.399	**0.287**
Total Combined	e		2.72%	1.91%	1.90%	0.926	0.025
	μ		2.73%	0.46%	0.47%	0.981	0.027
	K		28.38%	19.32%	19.18%	0.380	0.108
	π		57.28%	25.77%	21.49%	0.325	0.186
	p		8.88%	22.78%	22.77%	0.297	0.026
	Total		100.00%	22.33%	19.49%	0.372	**0.372**

From Baseline to 4th



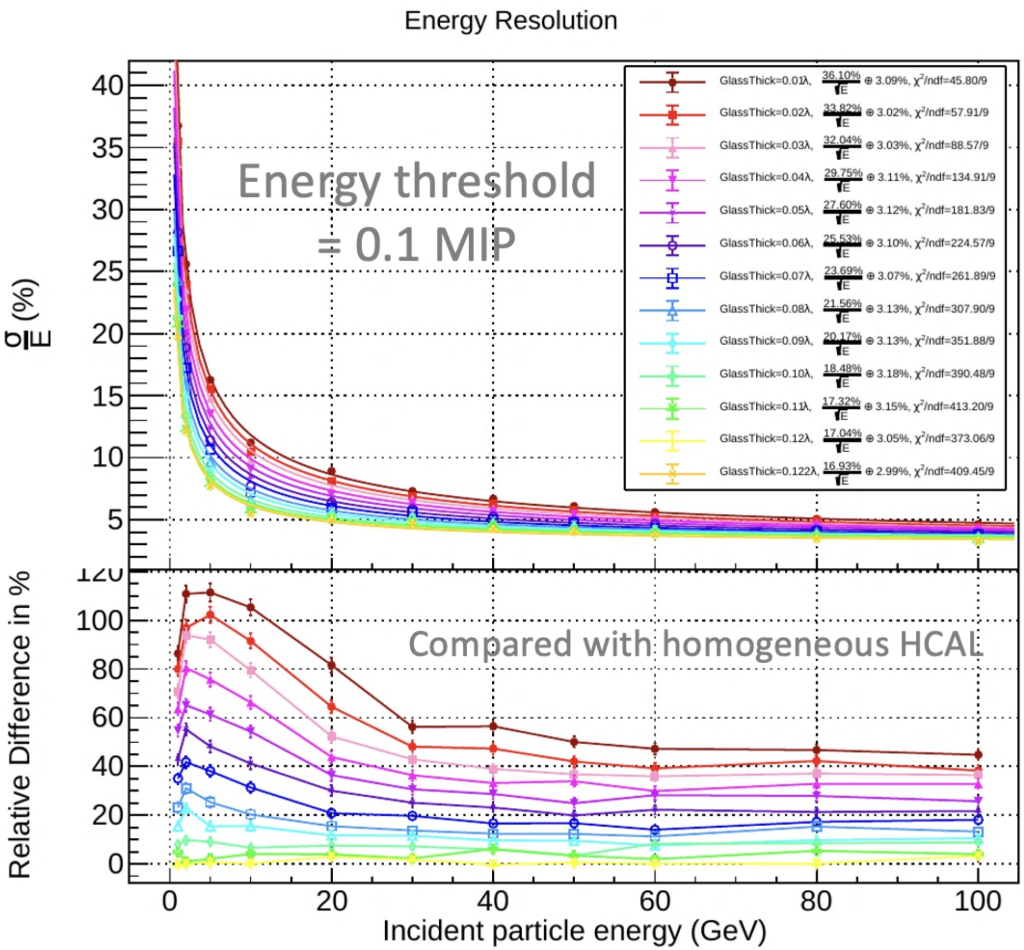
→

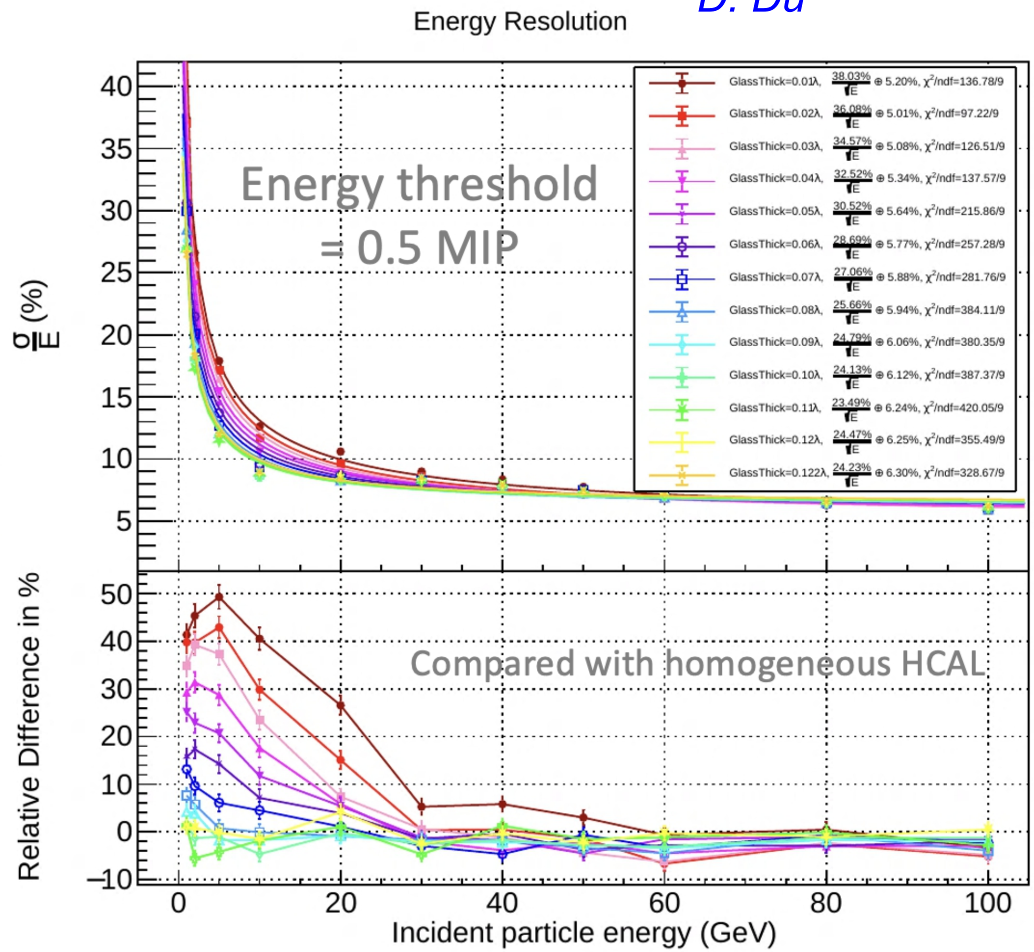


- Tracker: TPC + Silicon → Drift Chamber + Silicon
- ECAL: Si+W → Xstal
- HCAL: GRPC + Iron → Glass + Iron
- Solenoid: Outside HCAL → Between ECAL & HCAL

HCAL

D. Du

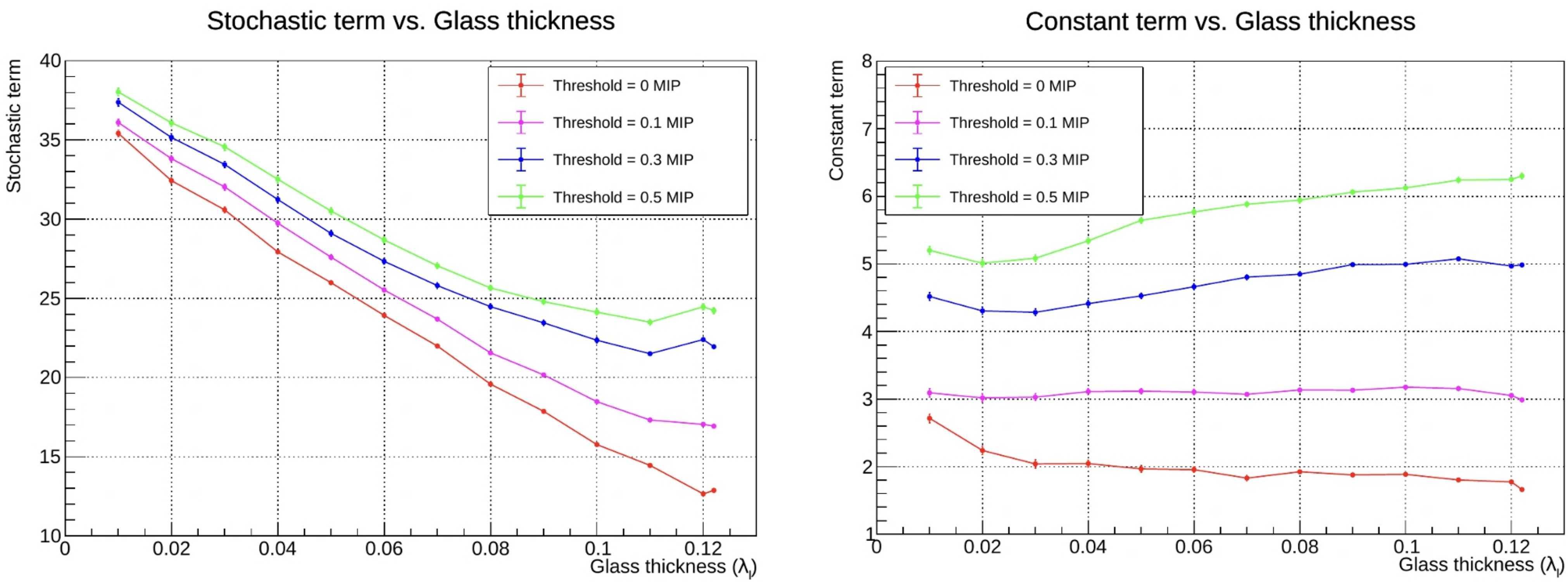




- In an ideal case - ideal Geometry ~ semi infinite...
- HCAL resolution significantly w.r.t. Baseline, at single particle level

Single Particle @ GS HCAL

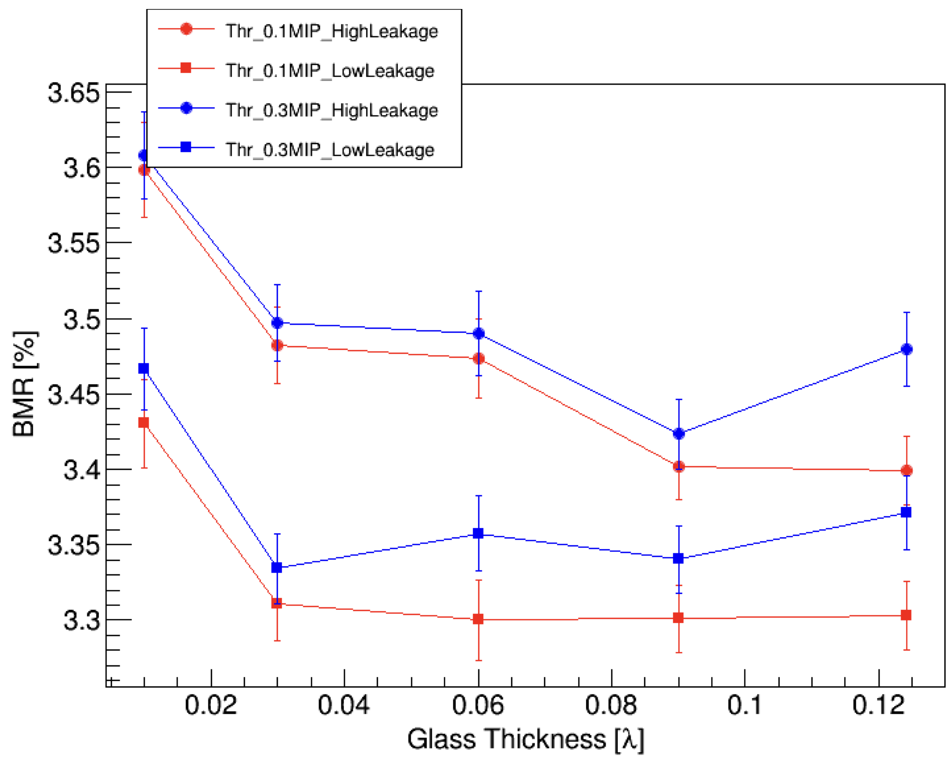
D. Du

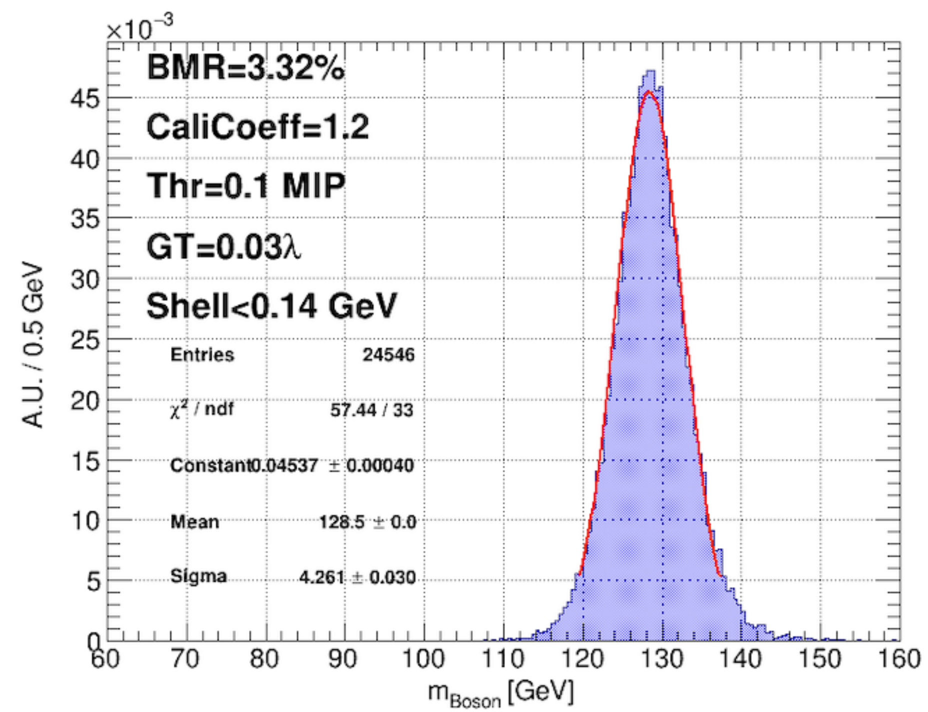


- Performance improves almost linearly at lower energy threshold, and larger sampling fraction

HCAL @ BMR

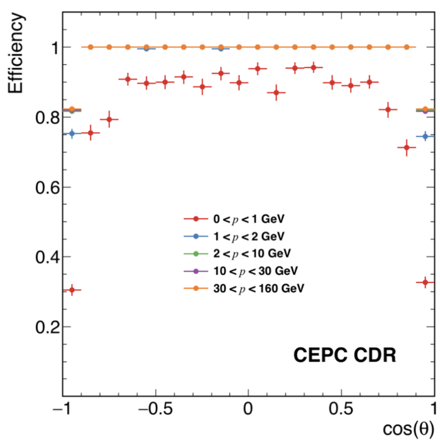
P. Hu & YX. Wang



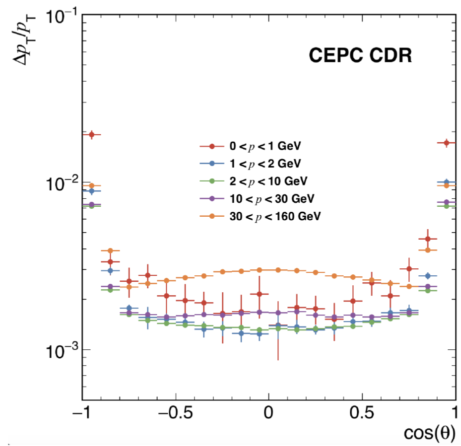


- Fits well with the model...
- Yet, a lot more to be understood

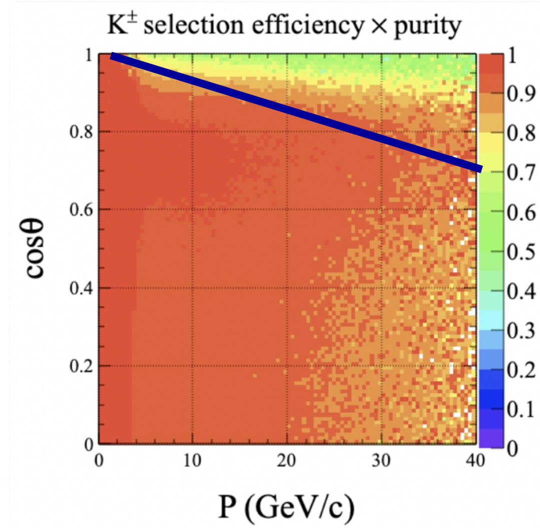
Tracker: tracking & Pid

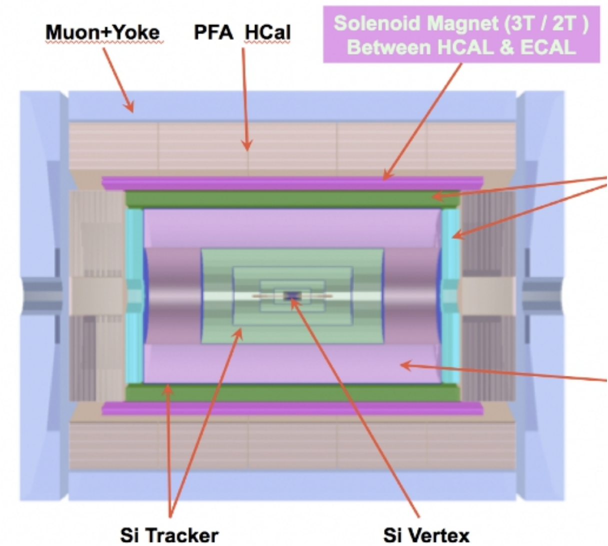


(a)

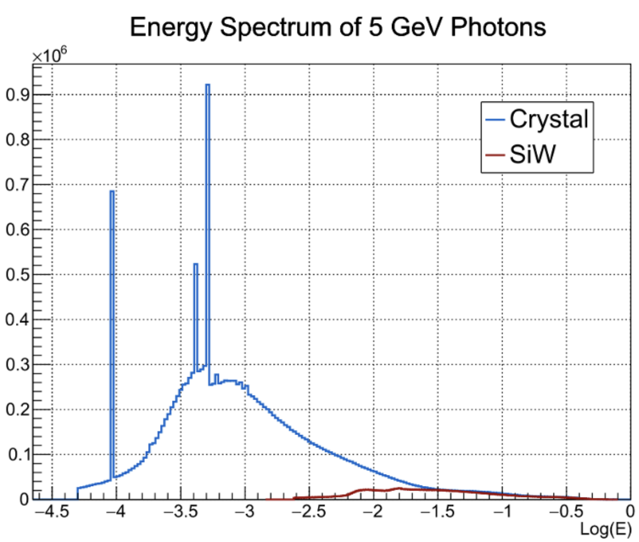


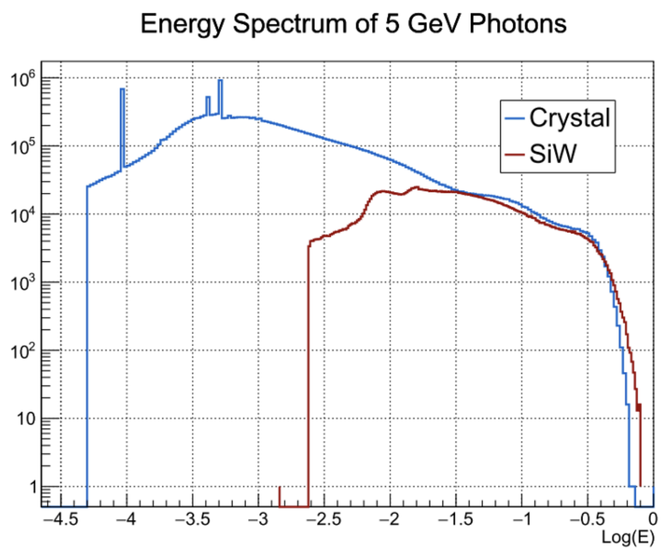
(b)

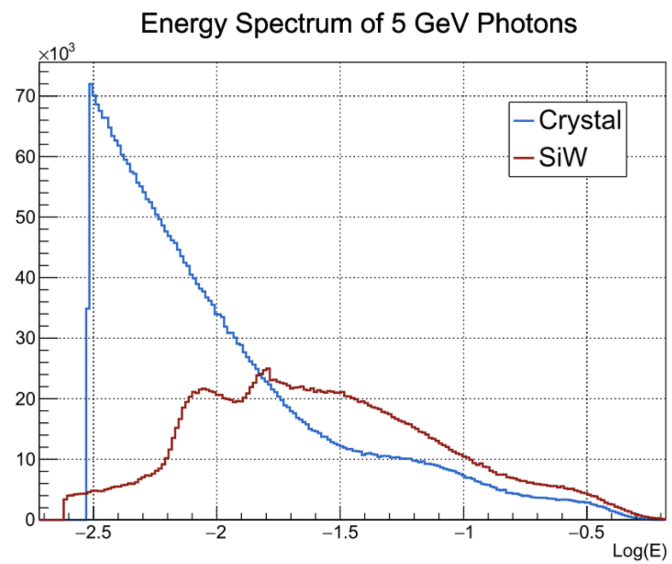




- BMR insensitive to Tracker unless tracker is bad
  - Pid & Lower the threshold shall leads to small improve, by correcting hadron mass
- Baseline set a good reference. Move toward better realizability & performance
- Performance – show the differential one!
  - Momentum resolution ~ 0.1%
  - Threshold ~ 0.1 MeV or lower & Larger Solid Angle Coverage!
  - dEdx or dNdx, if provided, better than 3% in barrel region for GeV level hadron (PS, very doubt for an DC inner radius of 600 mm... or larger)







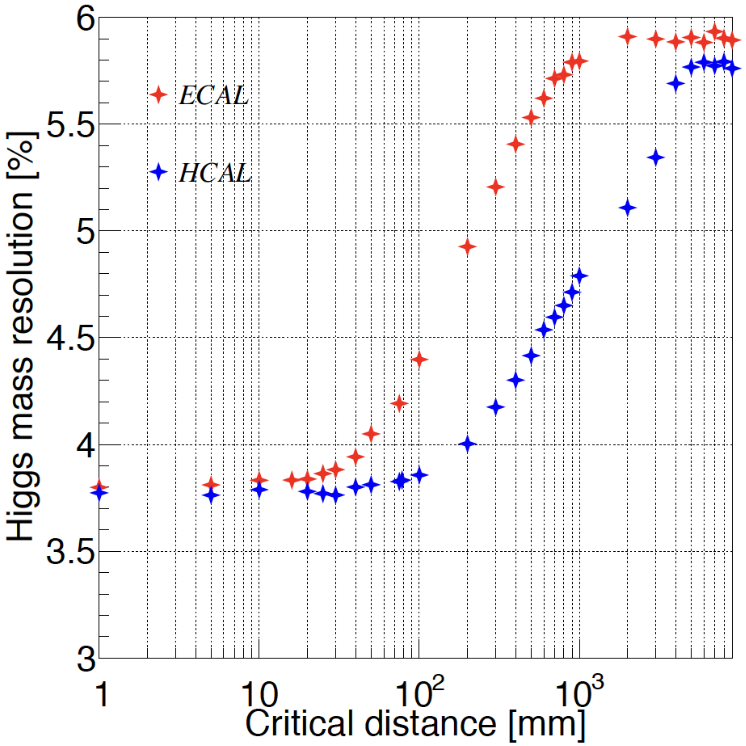
- Original energy spectrum, 10k events, threshold 50 keV
- A large number of low energy hits in crystal ECAL

- Threshold (0.3 MIP): SiW 50 keV, crystal 3 MeV

二、粒子流重建算法中误差源的拆解分析与模型构建

➢ 依赖关系分析——临近粒子分离能力

- ➢ 分离能力越差，BMR 越大，最终趋于强子能量分辨
- ➢ 左侧拐点
  - ➢ 电磁簇射 < 20mm
  - ➢ 强子簇射 < 100mm
- ➢ 基线临界分离距离
  - ➢ 电磁簇射 ~16mm
  - ➢ 强子簇射 ~78mm
  - ➢ 基本满足需求



二、粒子流重建算法中误差源的拆解分析与模型构建

➢ 依赖关系分析——带电强子碎裂簇团

- ➢对 BMR 的影响最显著
- ➢若能完全消除：BMR ~3.8% → 3%
- ➢消除一半：BMR ~3.8% → 3.5%