中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Jet Charge at CEPC

Hanhua Cui
Manqi Ruan
cuihanhua@ihep.ac.cn

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Outline

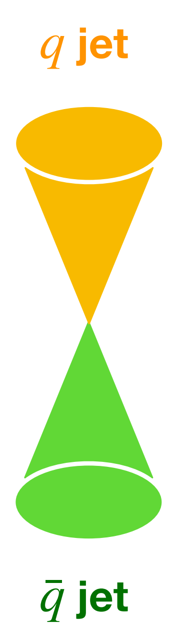
- **Jet Charge Introduction & CEPC Samples**

- **Two Methods & Dependences**

★ **(Leading Particle Method v.s. Weighted Charge Method)**

- **Jet Charge Performance Comparison**

- **Conclusion**



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Jet charge experiments & methods

	Experiments	Methods
LEP SLC	17 (0.6) million Z decays at LEP (SLC) Z pole	prompt lepton weighted jet and vtx charge Kaon
BABAR	integrated luminosity of 425.7 fb^{-1}, Y (4S) resonance.	category based method with NN
Belle2	integrated luminosity of 62.8 fb^{-1}, Y(4S) resonance	category based method & DNN
LHCb	integrated luminosity of 3 fb^{-1}, $\sqrt{s}$ = 8TeV	OS(e, μ, K, charm, Q_{vtx}) Taggers SS(SSπ, SSp, SSK) Taggers
ATLAS CMS	integrated luminosity of 14.3(19.7) fb^{-1}, $\sqrt{s}$ = 8TeV	pT weighted charge method
CEPC	integrated luminosity of 100 ab^{-1}, Z pole	leading particle method - e, μ, K, π, p weighted jet charge (for Bs: OS SSK)

CEPC Z pole operation & flavor physics potential

Operation mode	Z factory	WW threshold	Higgs factory	$t\bar{t}$
$\sqrt{s}$ (GeV)	91.2	160	240	360
Run time (year)	2	1	10	5
Instantaneous luminosity ($10^{34}\text{cm}^{-2}\text{s}^{-1}$, per IP)	191.7	26.6	8.3	0.83
Integrated luminosity (ab^{-1}, 2 IPs)	100	6	20	1
Event yields	3×10^{12}	1×10^{8}	4×10^{6}	5×10^{5}

Applications of Jet Charge:

- *Electroweak measurements of* A_{FB} , $\sin^2\theta_W$
- *CP measurements in neutral B/D system*
- *Differential measurements*

Process	Br	Tera-Z yield
$Z\to d\bar{d}$	15.84%	1.584×10^{11}
$Z\to u\bar{u}$	11.17%	1.117×10^{11}
$Z\to s\bar{s}$	15.84%	1.584×10^{11}
$Z\to c\bar{c}$	12.03%	$\boxed{1.203\times10^{11}}$
$Z\to b\bar{b}$	15.12%	$\boxed{1.512\times10^{11}}$

CEPC Advantages:

- **High productivity of b/c hadrons**
- **Clean collision environment**
- **Good VTX/tracking and PID system**

Our work: jet charge performance at CEPC Z pole using leading particle method & weighted charge method in each jet - test of principle

Samples:

- ~1×10^5 $Z\to b\bar{b}$ at CEPC Z pole (91.2 GeV) by Sherpa
- ~1×10^6 $Z\to b\bar{b}$ at CEPC Z pole (91.2 GeV) by Herwig
- ~1×10^7 $Z\to b\bar{b}$ at CEPC Z pole (91.2 GeV) by WHIZARD195
- ~1×10^7 $Z\to c\bar{c}$ at CEPC Z pole (91.2 GeV) by WHIZARD195

Different Generators

Different Flavor

Effective tagging power

- *Input: momentum, charge & PID of final charged particle in each jet*
- *Performance quantified by misjudgment rate ω and effective tagging power*

Misjudgment rate ω:

➡ *To describe the probability of misjudging the jet charge*

$$\omega = \frac{\text{Number of selected final particles that incorrectly reflect the charge of b jet to } \bar{\text{b}} \text{ jet}}{\text{Number of selected final particles}}$$

Efficiency:

➡ *To describe the selection efficiency of all samples:*

$$\epsilon_{sel} = \frac{\text{Number of selected samples}}{\text{Number of all samples}}$$

Effective tagging power ETP:

➡ *Considering both misjudgment rate ω and efficiency to describe the total performance of jet charge*

$$\text{Effective tagging power } \epsilon_{ETP} = \epsilon_{sel} \; * \; (1 - 2 * \omega)^2$$

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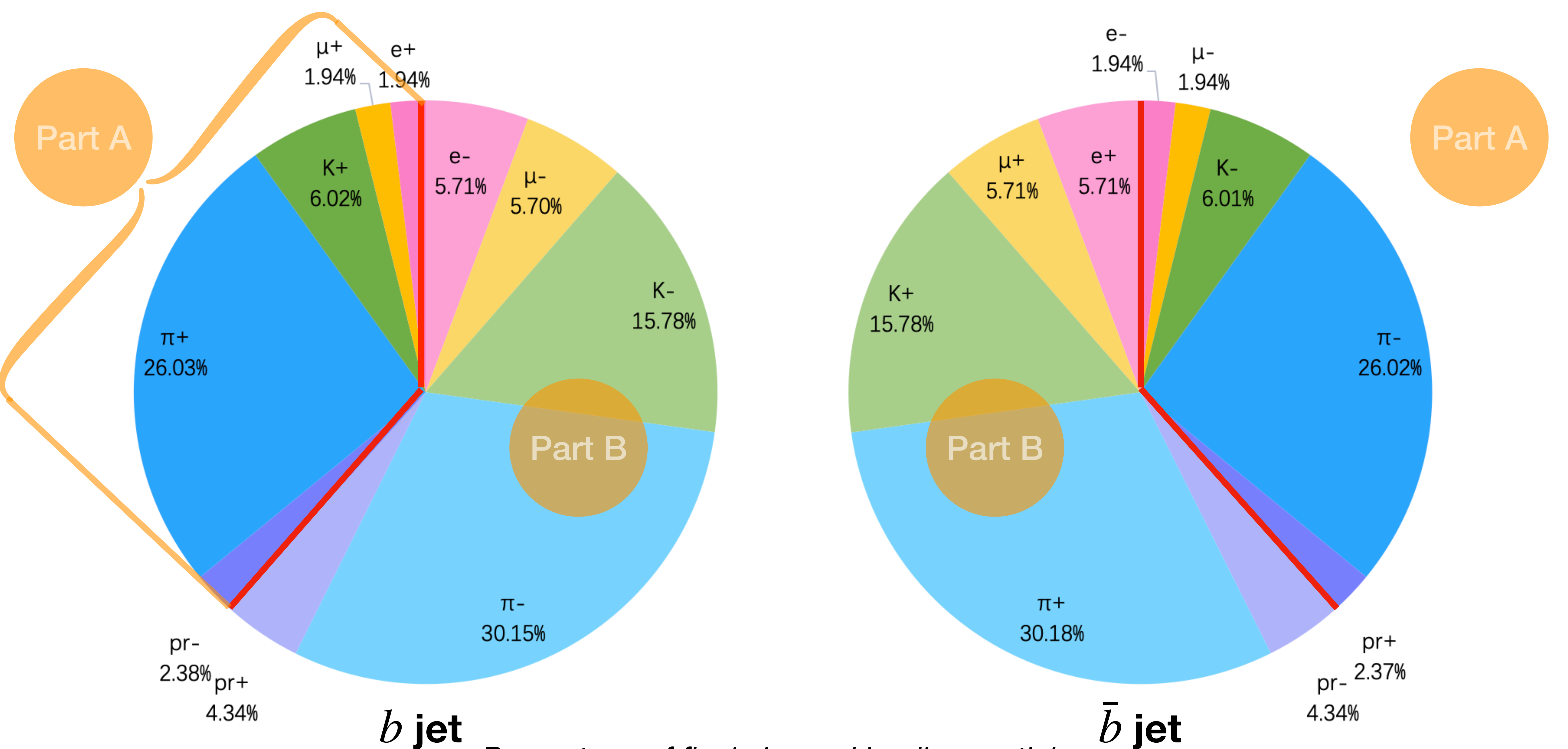
$Z \to b\bar{b}$

How to calculate misjudgment rate ω



Percentage of final charged leading particles

$$P(b\,|\,\text{final}_i) = \frac{P(\text{final}_i\,|\,b)}{P(\text{final}_i\,|\,b) + P(\text{final}_i\,|\,\bar{b})}$$

P(the final particle in b jet is final$_i$)

P(according to final$_i$, we consider this is b jet)

$$\omega = 1 - P(b\,|\,\text{final}_i) = \frac{P(\text{final}_i\,|\,\bar{b})}{P(\text{final}_i\,|\,b) + P(\text{final}_i\,|\,\bar{b})} = \frac{\text{Number of Part A}}{\text{Number of Part (A + B)}}$$

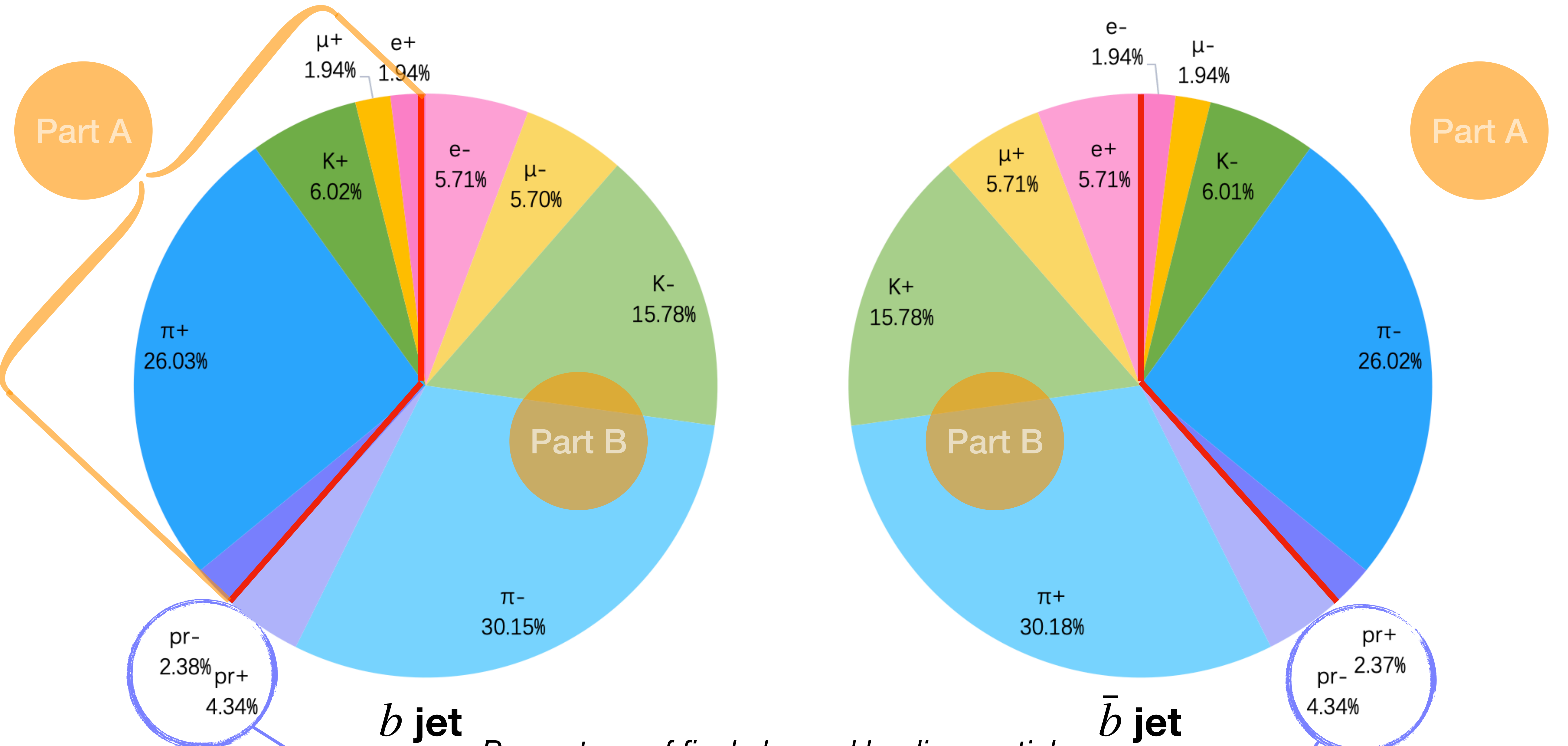
Jet charge performance dependences

1. Dependence on leading particle type

2. Dependence on b/c hadron type

3. Dependence on decay source of leading particle: from b/c hadron or QCD.

Dependence on leading particle type



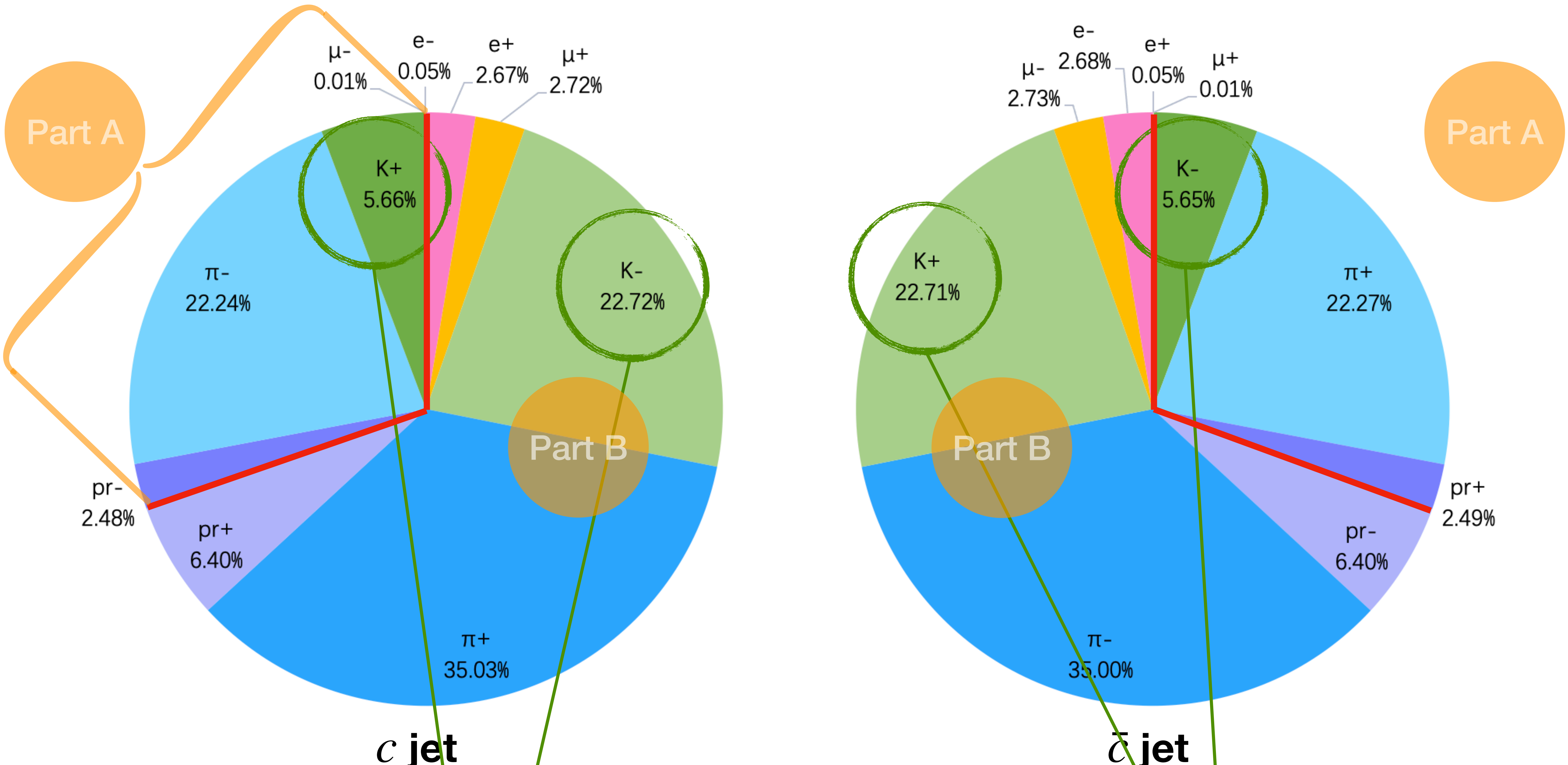
Percentage of final charged leading particles

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

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

$Z \to c\bar{c}$

Dependence on leading particle type



Percentage of final charged leading particles

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

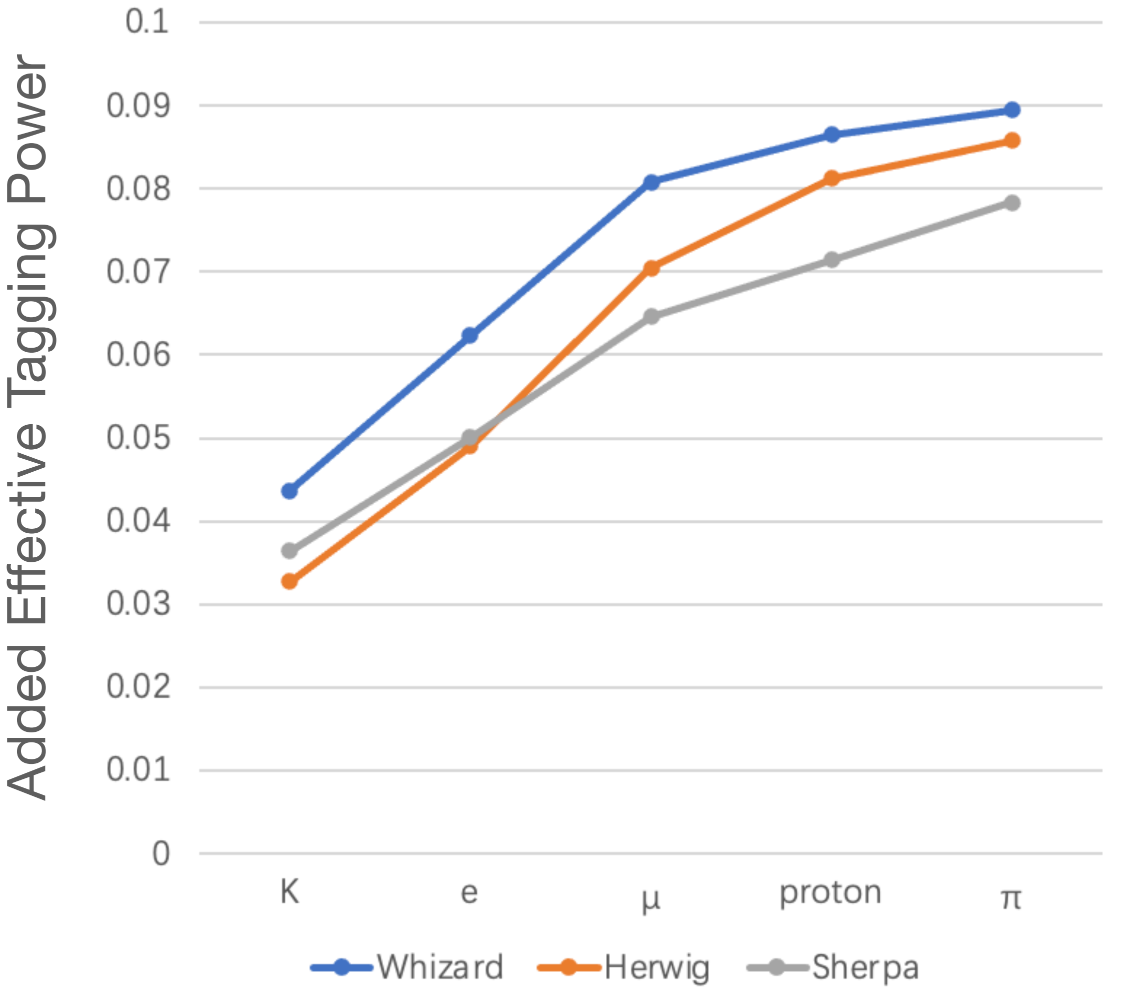
ω(using only charge) = 0.475
ω(using charge & PID) = 0.305

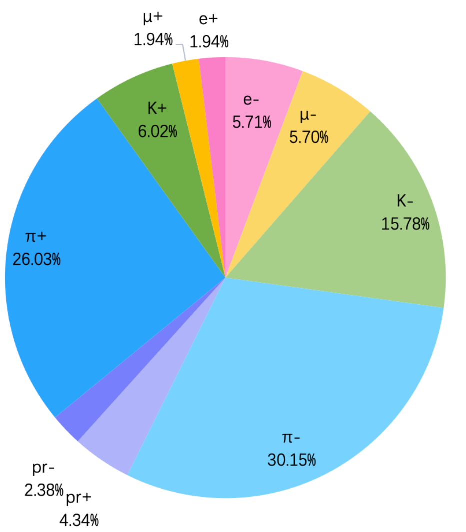
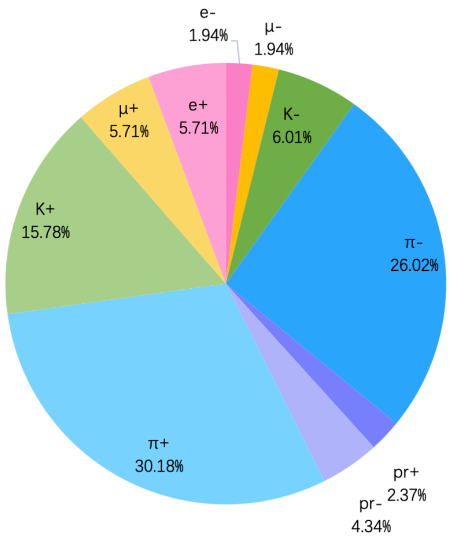
$Z \to b\bar{b}$

Effective Tagging Power of b jet

leading particle	ω	Effective tagging power
e	0.253	0.0186
μ	0.254	0.0185
K	0.276	0.0437
π	0.463	0.0030
p	0.354	0.0057
Tot	0.350	0.089

by Whizard



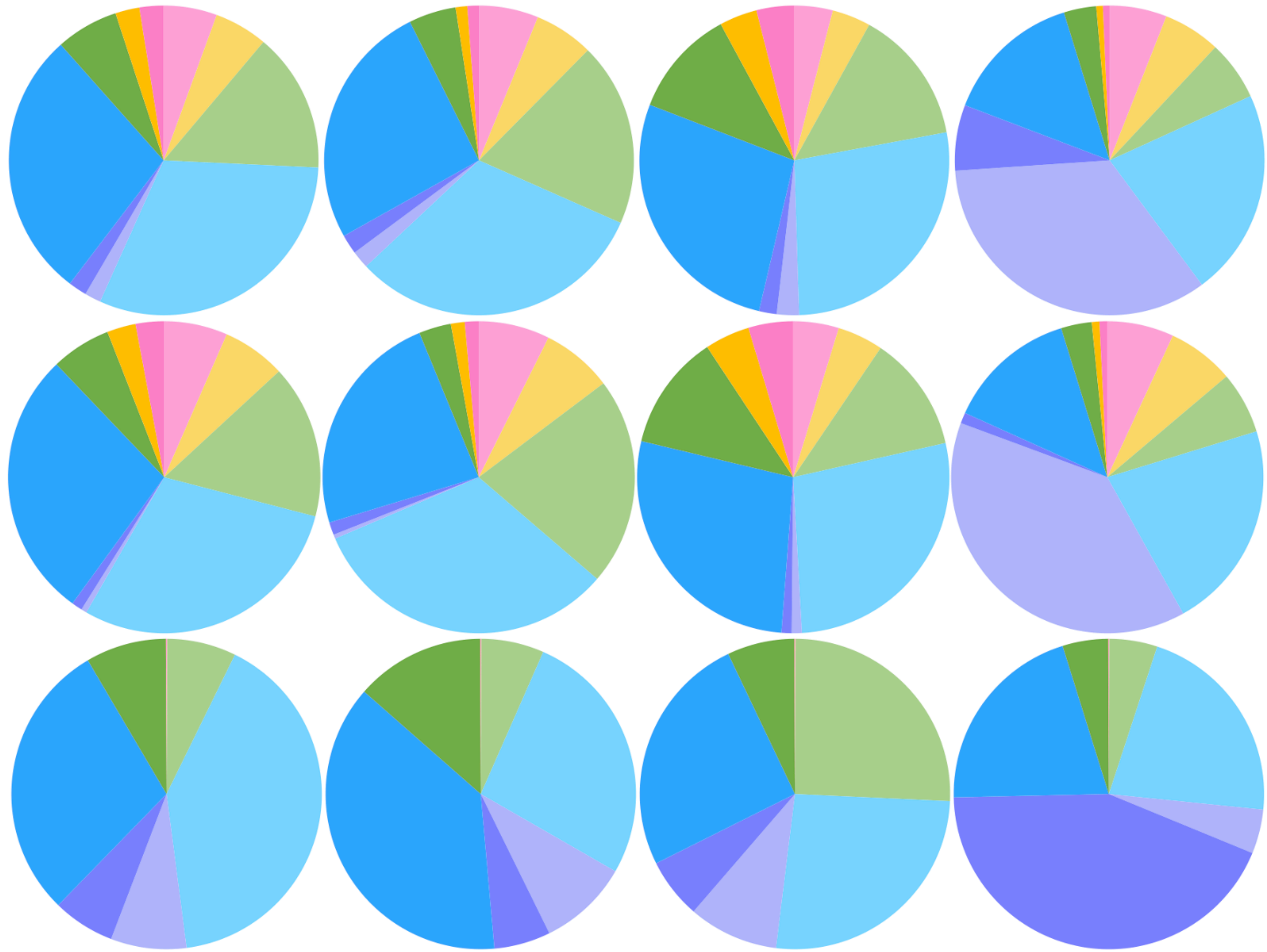
What will   change if decayed from typical hadron?

$Z \to b\bar{b}$ Percentage of leading particles for each b hadron (b jet)

All leading particles

Leading particles from leading hadron

Leading particles from QCD



$\bar{B}^0$ B^- $\bar{B}_s^0$ Λ_b

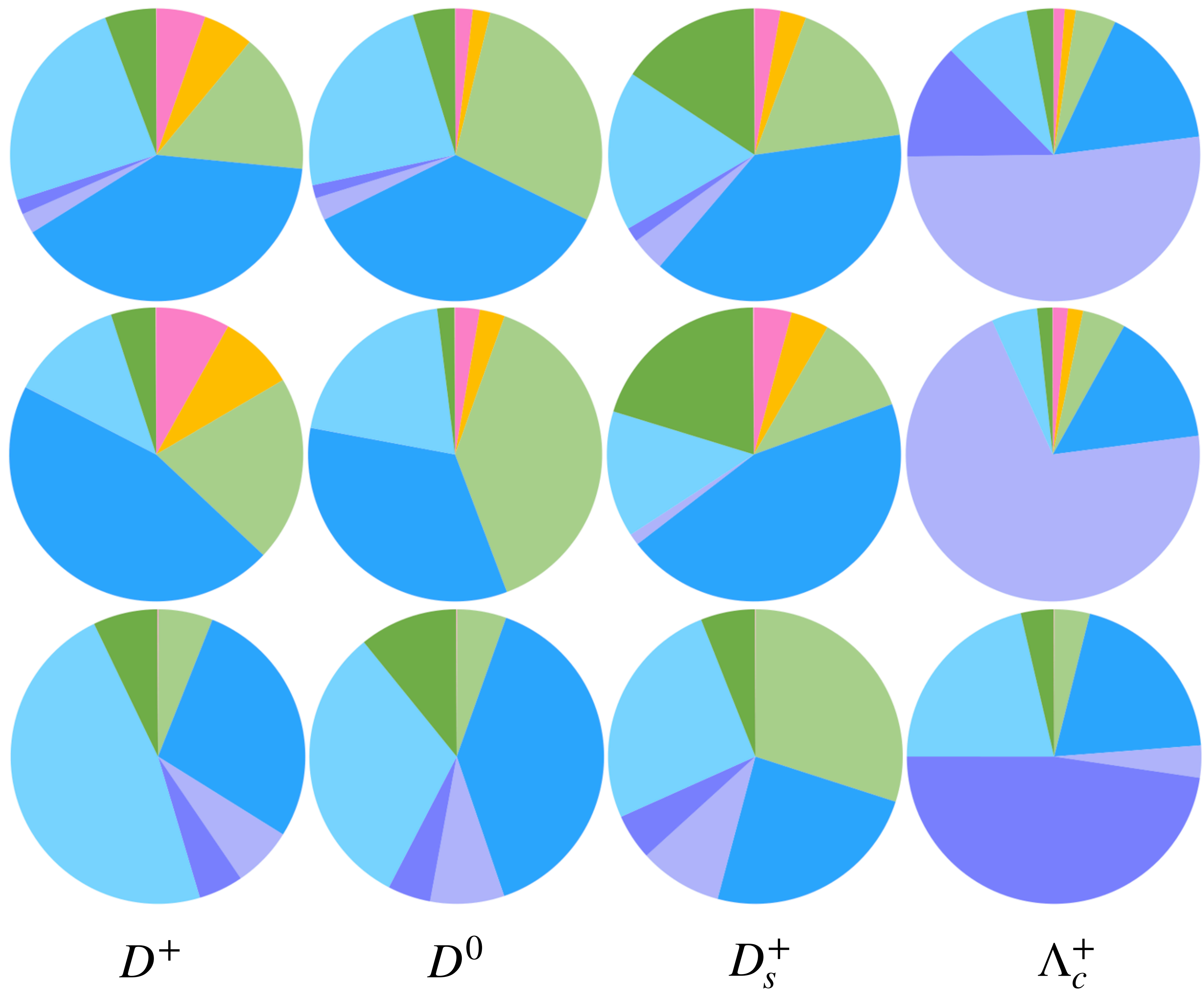
by WHIZARD195

$Z \to c\bar{c}$ Percentage of leading particles for each c hadron (c jet)

All leading particles

Leading particles from leading hadron

Leading particles from QCD



by WHIZARD195

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Weighted jet charge

	Jet Charge Definition
LHC	$Q^\kappa = \frac{1}{(p_T^{jet})^\kappa}\sum_i Q_i (p_T^i)^\kappa,$ $Q_L^\kappa = \sum_i Q_i \left(p_\parallel^i\right)^\kappa \Big/ \sum_i \left(p_\parallel^i\right)^\kappa,$ $\quad p_\parallel^i = \vec{p}^i \cdot \vec{p}_{\rm jet}/\lvert\vec{p}_{\rm jet}\rvert$ $Q_T^\kappa = \sum_i Q_i \left(p_\perp^i\right)^\kappa \Big/ \sum_i \left(p_\perp^i\right)^\kappa.$ $\quad p_\perp^i = \lvert\vec{p}^i \times \vec{p}_{\rm jet}\rvert/\lvert\vec{p}_{\rm jet}\rvert$
CEPC	$Q^\kappa_{jet} = \frac{\Sigma_i (E_i)^\kappa\, Q_i}{\Sigma_i (E_i)^\kappa}$
further	$Q^i_{\rm dyn} = \sum_{h\in i\text{-jet}} z_h^{\kappa(P)} Q_h$ $\quad z_h = \frac{p_{T_h}}{p_{T_J}}$ or $z_h = \frac{E_h}{E_J}$

Article in PRD: Particles and fields · April 2021, DOI: 10.1103/PhysRevD.103.074028

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)

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}^{κ}<0, we consider this is a b quark, and vise versa.**

Mis-judgement rate ω

Methods	Leading Particle Method						Weighted Charge Method					
Generator	Whizard		Herwig		Sherpa		Whizard		Herwig		Sherpa	
source	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D
All b hadrons	0.350	0.332	0.353	0.338	0.360	0.346	0.302 (κ=0.2)	0.035 (κ=0.0)	0.313 (κ=0.2)	0.042 (κ=0.0)	0.283 (κ=0.2)	0.044 (κ=0.0)
B0/B0bar	0.382	0.371	0.412	0.404	0.315	0.301	0.312 (κ=0.2)	0.396 (κ=0.6)	0.324 (κ=0.2)	0.423 (κ=0.6)	0.253 (κ=0.3)	0.311 (κ=0.6)
B+/B-	0.302	0.265	0.296	0.266	0.309	0.278	0.260 (κ=0.3)	0.003 (κ=0.0)	0.263 (κ=0.4)	0.003 (κ=0.0)	0.244 (κ=0.3)	0.003 (κ=0.0)
Bs/Bsbar	0.470	0.493	0.480	0.491	0.336	0.331	0.347 (κ=0.0)	0.453 (κ=0.0)	0.291 (κ=0.0)	0.457 (κ=0.0)	0.289 (κ=0.2)	0.388 (κ=1.0)
Bc+/Bc-	0.385	0.346	0.322	0.316	0.307	0.227	0.316 (κ=0.2)	0.008 (κ=0.0)	0.316 (κ=0.7)	0.007 (κ=0.0)	0.204 (κ=0.6)	0 (κ=0.0)
Λb/Λbbar	0.231	0.160	0.245	0.185	0.234	0.192	0.277 (κ=0.0)	0.432 (κ=1.0)	0.289 (κ=0.0)	0.423 (κ=0.9)	0.239 (κ=0.0)	0.427 (κ=0.0)
All D hadrons	0.276	0.201	0.265	0.189	0.270	0.202	0.175 (κ=0.0)	0.025 (κ=0.0)	0.175 (κ=0.0)	0.025 (κ=0.0)	0.165 (κ=0.0)	0.033 (κ=0.0)
D+/D-	0.180	0.259	0.244	0.125	0.278	0.151	0.128 (κ=0.0)	0.001 (κ=0.0)	0.131 (κ=0.0)	0.001 (κ=0.0)	0.120 (κ=0.0)	0.002 (κ=0.0)
D0/D0bar	0.257	0.192	0.253	0.200	0.246	0.187	0.128 (κ=0.0)	0.007 (κ=0.0)	0.132 (κ=0.0)	0.006 (κ=0.0)	0.119 (κ=0.0)	0.011 (κ=0.0)
Ds+/Ds-	0.312	0.225	0.193	0.198	0.291	0.210	0.128 (κ=0.0)	0.001 (κ=0.0)	0.129 (κ=0.0)	0.001 (κ=0.0)	0.118 (κ=0.0)	0.002 (κ=0.0)
Λc+/Λc-	0.235	0.068	0.245	0.073	0.204	0.066	0.126 (κ=0.0)	0.001 (κ=0.0)	0.132 (κ=0.0)	0.001 (κ=0.0)	0.117 (κ=0.0)	0.001 (κ=0.0)

Effective tagging power

Methods	Leading Particle Method						Weighted Charge Method					
Generator	Whizard		Herwig		Sherpa		Whizard		Herwig		Sherpa	
decay source	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D
All b hadrons	0.0895	0.1124	0.0859	0.1039	0.0786	0.0945	0.1571 (κ=0.2)	0.3750 (κ=0.0)	0.1396 (κ=0.2)	0.3492 (κ=0.0)	0.1877 (κ=0.2)	0.3495 (κ=0.0)
B0/B0bar	0.0555	0.0668	0.0311	0.0368	0.1367	0.1588	0.1419 (κ=0.2)	0.0430 (κ=0.6)	0.1239 (κ=0.2)	0.0236 (κ=0.6)	0.2449 (κ=0.3)	0.1431 (κ=0.6)
B+/B-	0.1576	0.2208	0.1660	0.2193	0.1463	0.1964	0.2301 (κ=0.3)	0.9686 (κ=0.0)	0.2241 (κ=0.4)	0.9655 (κ=0.0)	0.2620 (κ=0.3)	0.9644 (κ=0.0)
Bs/Bsbar	0.0037	0.0002	0.0016	0.0003	0.1082	0.1136	0.1200 (κ=0.0)	0.0003 (κ=0.0)	0.1081 (κ=0.0)	0.0003 (κ=0.0)	0.1787 (κ=0.2)	0.0498 (κ=1.0)
Bc+/Bc-	0.0530	0.0949	0.1268	0.1350	0.1490	0.2976	0.1359 (κ=0.2)	0.9272 (κ=0.0)	0.1352 (κ=0.7)	0.8647 (κ=0.0)	0.3510 (κ=0.6)	0.9716 (κ=0.0)
Λb/Λbbar	0.2885	0.4627	0.2605	0.3972	0.2830	0.3795	0.1217 (κ=0.0)	0.0186 (κ=1.0)	0.1080 (κ=0.0)	0.0236 (κ=0.9)	0.1642 (κ=0.0)	0.0010 (κ=0.0)
All D hadrons	0.2004	0.3574	0.2216	0.3872	0.2121	0.3549	0.3149 (κ=0.0)	0.3384 (κ=0.0)	0.3230 (κ=0.0)	0.3609 (κ=0.0)	0.3342 (κ=0.0)	0.3314 (κ=0.0)
D+/D-	0.1931	0.4654	0.2624	0.5640	0.1968	0.4873	0.5535 (κ=0.0)	0.9947 (κ=0.0)	0.5458 (κ=0.0)	0.9945 (κ=0.0)	0.5772 (κ=0.0)	0.9920 (κ=0.0)
D0/D0bar	0.2353	0.3795	0.2443	0.3607	0.2586	0.3931	0.5530 (κ=0.0)	0.9483 (κ=0.0)	0.5424 (κ=0.0)	0.9346 (κ=0.0)	0.5803 (κ=0.0)	0.9125 (κ=0.0)
Ds+/Ds-	0.1411	0.3024	0.1715	0.3656	0.1755	0.3365	0.5541 (κ=0.0)	0.9952 (κ=0.0)	0.5501 (κ=0.0)	0.9955 (κ=0.0)	0.5823 (κ=0.0)	0.9918 (κ=0.0)
Λc+/Λc-	0.2814	0.7481	0.2610	0.7279	0.3505	0.7537	0.5594 (κ=0.0)	0.9958 (κ=0.0)	0.5426 (κ=0.0)	0.9957 (κ=0.0)	0.5882 (κ=0.0)	0.9933 (κ=0.0)

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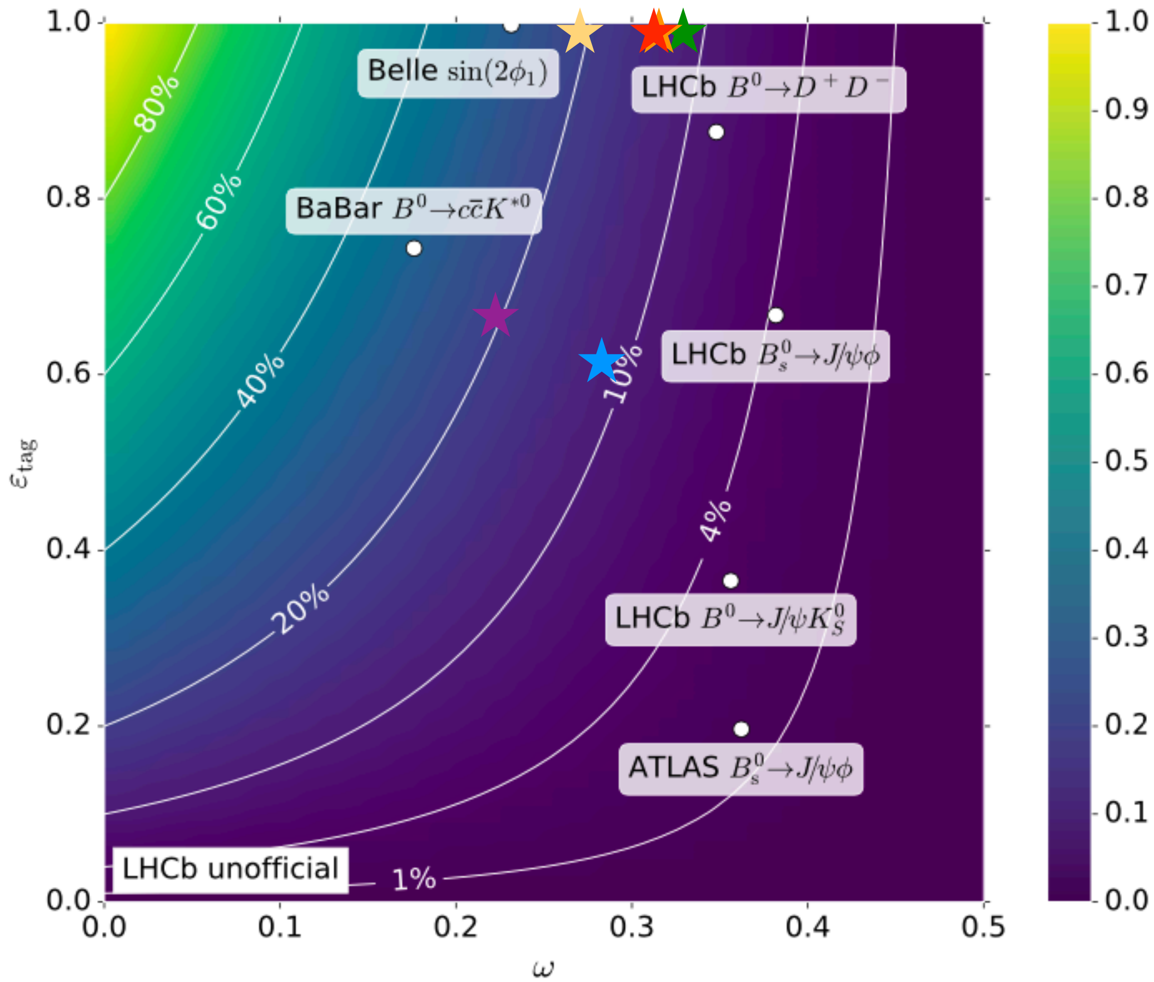
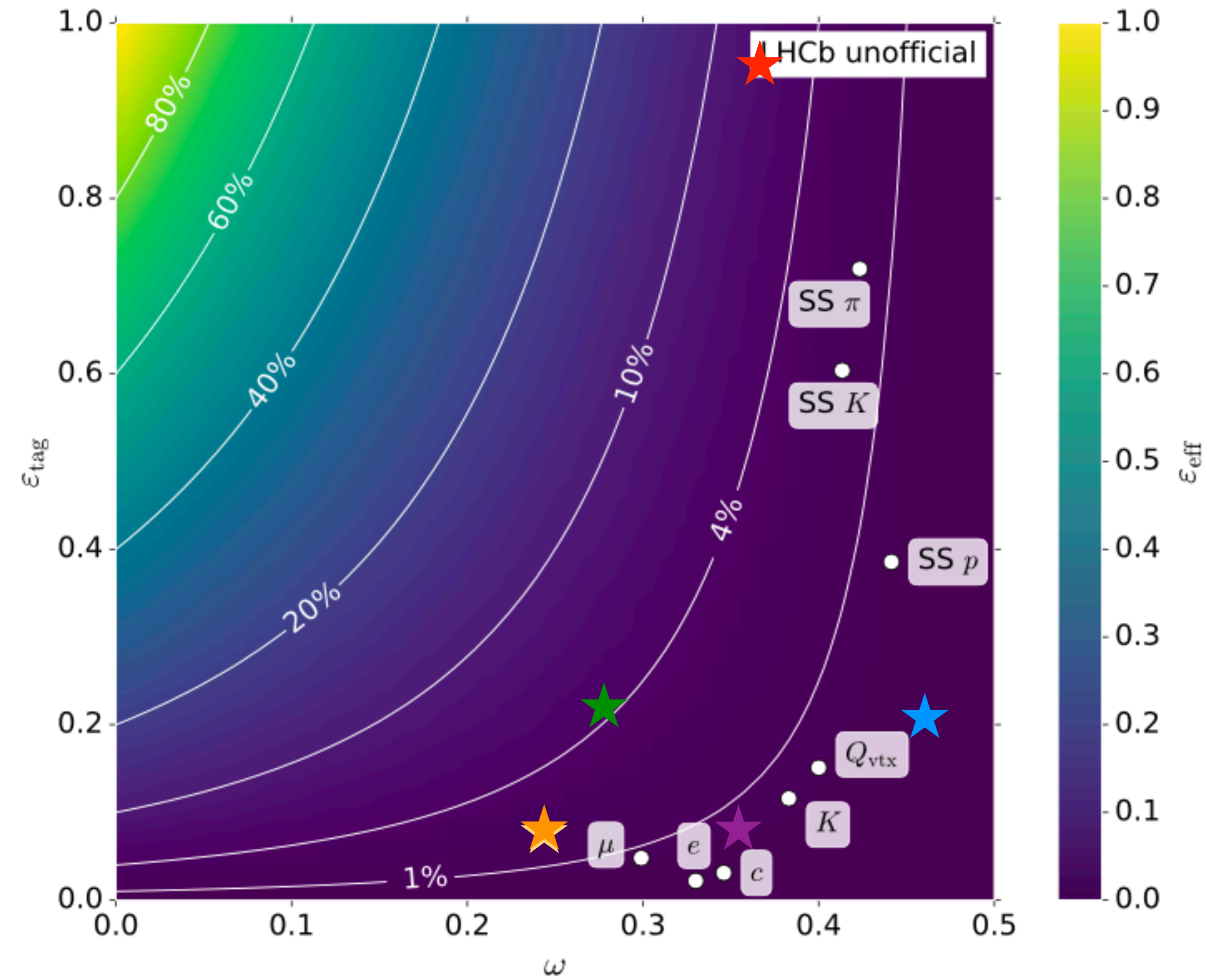
Comparison with other experiments

pT weighted method



Leading particle method



CEPC all B→anything 15.71%

CEPC B0→anything 14.19%

CEPC B-→anything 23.01%

CEPC Bc→anything 13.59%

CEPC Λb→anything 12.17%

CEPC Bs→J/ΨΦ 20.2% (use kaon)

CEPC b quark→anything 8.95%

CEPC b quark→electron 1.86%

CEPC b quark→muon 1.85%

CEPC b quark→Kaon 4.37%

CEPC b quark→pion 0.30%

CEPC b quark→proton 0.57%

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Conclusion

Main results:

Analysis of jet charge performance for single jet at CEPC Z pole using two methods: leading particle method and weighted charged method:

★ *Effective tagging power (Whizard195, Herwig, Sherpa):*

- *For $Z \to b\bar{b}$: Effective tagging power = 0.090, 0.086, 0.079 (using leading particle charge)*
  0.157, 0.140, 0.188 (using weighted jet charge)
- *For $Z \to c\bar{c}$: Effective tagging power = 0.200, 0.222, 0.212 (using leading particle charge)*
  0.315, 0.323, 0.334 (using weighted jet charge)

★ *Dependences:*

- *High dependence on leading particle type*
  - *Lepton and Kaon → better misjudgment rate ω than pion and proton.*
- *High dependence on b/c hadrons type*
  - *especially for B_s, Λ_b, Λ_c, …*
- *High dependence on the source of leading particle:*
  - *From b/c hadron decay → usually better misjudgment rate ω & effective tagging power.*

★ *Requirements:*

- *Good performance of tracking & PID*

Future:

Specific channels using corresponding prompt particles

Function of weight parameter κ

Thanks!

Back Up

Other Jet Charge Experiments

Jet charge at LEP & SLC

17 (0.6) million Z decays at LEP (SLC), 91.2GeV

Method:

- Measurements of $\mathcal{A}_b$ and $\mathcal{A}_c$ using leptons [152];
- A measurement of $\mathcal{A}_c$ using D-mesons [153];
- A measurement of $\mathcal{A}_b$ using jet charge [154];
- A measurement of $\mathcal{A}_b$ using vertex charge [155];
- A measurement of $\mathcal{A}_b$ using kaons [156];
- A measurement of $\mathcal{A}_c$ using vertex charge and kaons [155].

The jet charge was calculated by summing over all tracks in a thrust hemisphere:

$$Q_{\text{jet}} = \frac{\sum |p_{||,i}|^\kappa q_i}{\sum |p_{||,i}|^\kappa}, \quad (11)$$

where $p_{||,i}$ is the component of momentum parallel to the thrust axis, and q_i is the charge of track i in the hemisphere.

The 'vertex charge', q_{vtx}, is a weighted sum of the charges of tracks in a jet which contains a tagged secondary vertex:

$$q_{\text{vtx}} = \sum_{\text{tracks } i} \omega_i q_i, \quad (5)$$

where q_i is the charge of track i, and ω_i is related to the probability that a track came from the secondary vertex relative to the probability that it came from the primary vertex, and i runs over all tracks in the jet. The vertex charge has been

Result:

- **(statistical uncertainties are twice bigger than the systematic ones.)**

Table 1: LEP measurements of $A_{\text{FB}}^{0,b}$ and associated statistical, total systematic, and QCD-systematic uncertainties (with the newly-computed QCD systematics quoted in parentheses).

Measurement	$A_{\text{FB}}^{0,b}$	uncertainties stat.	total syst.	QCD syst. (new)
ALEPH lepton (2002) [4]	$0.1003 \pm 0.0038 \pm 0.0017$	4.1%	1.7%	0.6% (0.8%)
DELPHI lepton (2004-5) [5]	$0.1025 \pm 0.0051 \pm 0.0024$	6.4%	2.4%	1.5% (1.3%)
L3 lepton (1999) [6]	$0.1001 \pm 0.0060 \pm 0.0035$	6.9%	3.4%	1.8% (0.8%)
OPAL lepton (2003) [7]	$0.0977 \pm 0.0038 \pm 0.0018$	4.3%	1.5%	1.1% (1.4%)
ALEPH jet-charge (2001) [8]	$0.1010 \pm 0.0025 \pm 0.0012$	2.7%	1.1%	0.5% (0.5%)
DELPHI jet-charge (2005) [9]	$0.0978 \pm 0.0030 \pm 0.0015$	3.3%	1.5%	0.5% (0.4%)
L3 jet-charge (1998) [10]	$0.0948 \pm 0.0101 \pm 0.0056$	10.8%	5.9%	4.1% (0.4%)
OPAL jet-charge (2002) [11]	$0.0994 \pm 0.0034 \pm 0.0018$	3.7%	1.8%	1.5% (0.3%)

Jet charge at BABAR

integrated luminosity of 425.7 fb^{-1}, Υ (4S) resonance

Method:

Input nine different tag signatures:
isolated primary leptons, kaons and pions from B decays to final states containing D* mesons, and high momentum charged particles from B decays.

↓

Single neural network(NN).

↓

Output seven mutually-exclusive categories: (in order of de- creasing signal purity)
Lepton, Kaon I, Kaon II, Kaon-Pion, Pion, Other and No_tag.

Result:

TABLE I: Efficiencies ϵ_i, average mistag fractions w_i, mistag fraction differences between B^0 and $\overline{B}^0$ tagged events Δw_i, and effective tagging efficiency Q_i extracted for each tagging category i from the B_{flav} sample.

Category	ϵ_i (%)	w_i (%)	Δw_i (%)	Q_i (%)
Lepton	8.96 ± 0.07	2.8 ± 0.3	0.3 ± 0.5	7.98 ± 0.11
Kaon I	10.82 ± 0.07	5.3 ± 0.3	-0.1 ± 0.6	8.65 ± 0.14
Kaon II	17.19 ± 0.09	14.5 ± 0.3	0.4 ± 0.6	8.68 ± 0.17
KaonPion	13.67 ± 0.08	23.3 ± 0.4	-0.7 ± 0.7	3.91 ± 0.12
Pion	14.18 ± 0.08	32.5 ± 0.4	5.1 ± 0.7	1.73 ± 0.09
Other	9.54 ± 0.07	41.5 ± 0.5	3.8 ± 0.8	0.27 ± 0.04
All	74.37 ± 0.10			$\boxed{31.2 \pm 0.3}$

Jet charge at Belle2

integrated luminosity of 62.8 fb^{-1}, Υ (4S) resonance

Method:

THE CATEGORY-BASED FLAVOR TAGGER

Categories	Targets for $\bar{B}^0$
Electron	e^-
Intermediate Electron	e^+
Muon	μ^-
Intermediate Muon	μ^+
Kinetic Lepton	ℓ^-
Intermediate Kinetic Lepton	ℓ^+
Kaon	K^-
Kaon-Pion	K^-, π^+
Slow Pion	π^+
Maximum p^*	ℓ^-, π^-
Fast-Slow-Correlated (FSC)	ℓ^-, π^+
Fast Hadron	π^-, K^-
Lambda	Λ

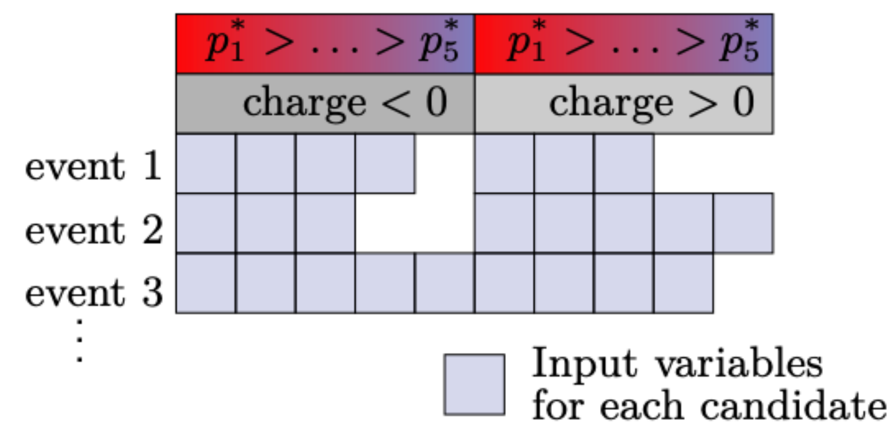
Underlying decay modes

$\bar{B}^0 \to D^{*+}\ \bar{\nu}_\ell\ \ell^-$
$\quad \hookrightarrow D^0\ \pi^+$
$\qquad \hookrightarrow X\ K^-$

$\bar{B}^0 \to D^+\ \pi^-\ (K^-)$
$\quad \hookrightarrow \bar{K}^0\ \nu_\ell\ \ell^+$

$\bar{B}^0 \to \Lambda_c^+\ X^-$
$\quad \hookrightarrow \Lambda\ \pi^+$
$\qquad \hookrightarrow p\ \pi^-$

THE DEEP-LEARNING FLAVOR TAGGER



Result:

Using a category-based flavor tagging algorithm, we obtain for neutral B candidates the total effective efficiency

$$\varepsilon_{\text{eff}} = \big(30.0 \pm 1.2(\text{stat}) \pm 0.4(\text{syst})\big)\%,$$

and for charged B candidates

$$\varepsilon_{\text{eff}} = \big(37.0 \pm 0.6(\text{stat}) \pm 0.2(\text{syst})\big)\%.$$

Using a deep-learning-based flavor tagging algorithm, we obtain for neutral B candidates the total effective efficiency

$$\varepsilon_{\text{eff}} = \big(28.8 \pm 1.2(\text{stat}) \pm 0.4(\text{syst})\big)\%,$$

and for charged B candidates

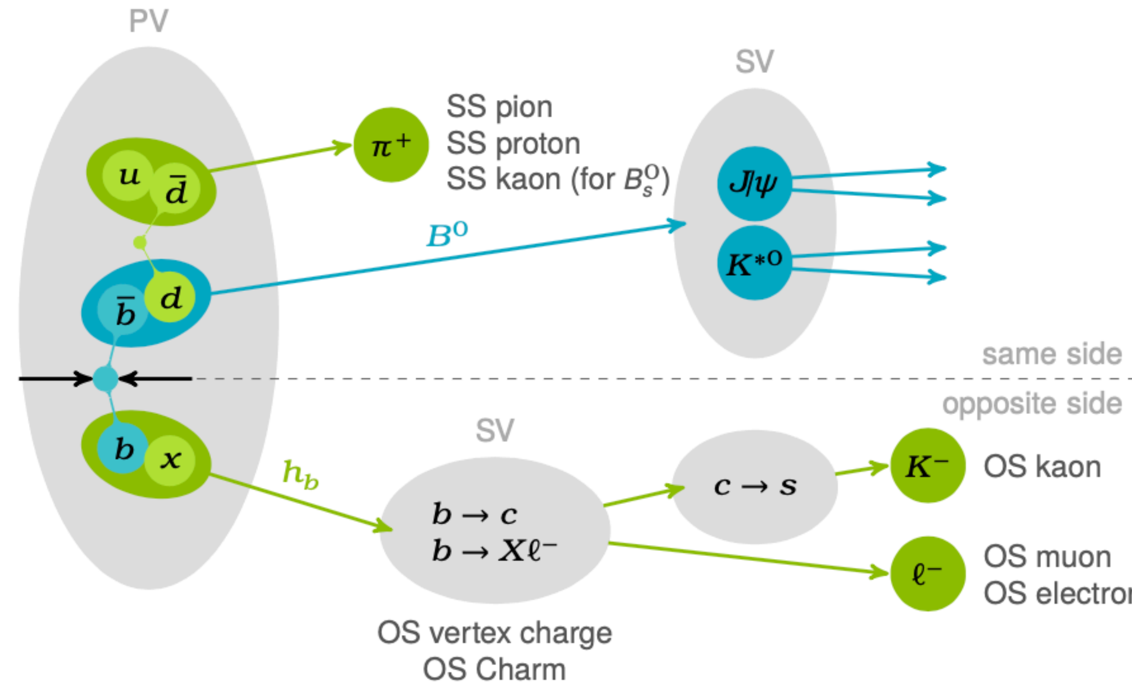
$$\varepsilon_{\text{eff}} = \big(39.9 \pm 0.6(\text{stat}) \pm 0.2(\text{syst})\big)\%.$$

Jet charge at LHCb

integrated luminosity of 3 fb^{-1}, Υ (4S) resonance

Method:

Flavour Tagging Algorithms . . . .
  Opposite Side Single Track Taggers .
  Vertex Charge Tagger . . . .
  Charm Tagger . . . .
  Same Side Proton and Pion Tagger . .
  Same Side Kaon Tagger . . . .



Result:

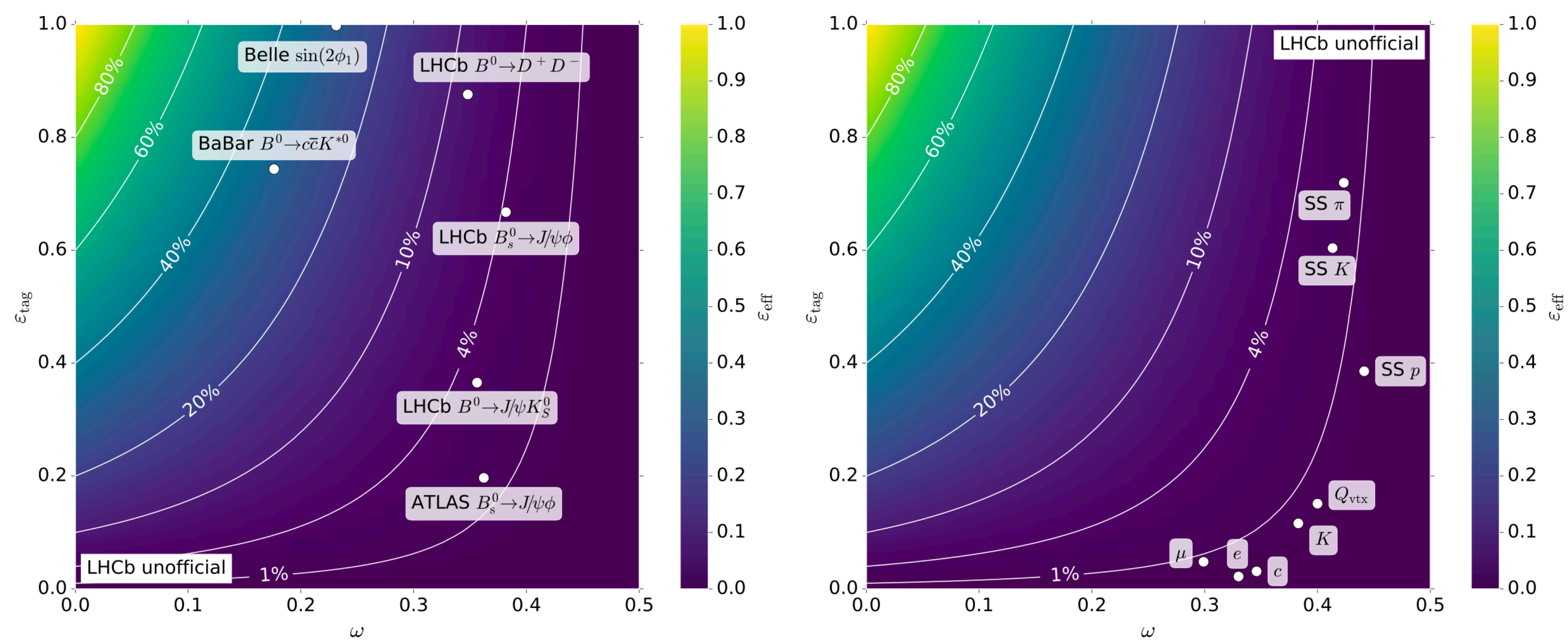


Figure 3.1: Effective tagging efficiency of (left) different HEP experiments and (right) LHCb flavour tagging algorithms [40]. The white lines indicate contours of constant tagging power.

Jet charge at ATLAS

integrated luminosity of 14.3 fb^{-1}, 8TeV

Method: The *jet charge* is defined as

$$Q_{\text{jet}} = \frac{\sum_i^{N \text{ tracks}} q_i \cdot (p_{\text{T}i})^\kappa}{\sum_i^{N \text{ tracks}} (p_{\text{T}i})^\kappa},$$

where $\kappa = 1.1$ and the sum is over the tracks associated with the jet, excluding those tracks associated with a primary vertex other than that of the signal decay and tracks from the signal candidate. Figure 4 shows the distribution of the opposite-side jet-charge for $B^\pm$ signal candidates.

Result:

Tagger	Efficiency [%]	Dilution [%]	Tagging Power [%]
Combined μ	4.12 ± 0.02	47.4 ± 0.2	0.92 ± 0.02
Electron	1.19 ± 0.01	49.2 ± 0.3	0.29 ± 0.01
Segment-tagged μ	1.20 ± 0.01	28.6 ± 0.2	0.10 ± 0.01
Jet-charge	13.15 ± 0.03	11.85 ± 0.03	0.19 ± 0.01
Total	19.66 ± 0.04	27.56 ± 0.06	1.49 ± 0.02

Table 1. Summary of tagging performance for the different flavour tagging methods described in the text. Uncertainties shown are statistical only. The efficiency and tagging power are each determined by summing over the individual bins of the charge distribution. The effective dilution is obtained from the measured efficiency and tagging power. For the efficiency, dilution, and tagging power, the corresponding uncertainty is determined by combining the appropriate uncertainties in the individual bins of each charge distribution.

Jet charge at CMS

integrated luminosity of 19.7 fb^{-1}, 8TeV

Method:

$$Q^\kappa = \frac{1}{(p_T^{\text{jet}})^\kappa} \sum_i Q_i (p_T^i)^\kappa,$$

$$Q_L^\kappa = \sum_i Q_i \left(p_\parallel^i\right)^\kappa \Big/ \sum_i \left(p_\parallel^i\right)^\kappa, \qquad p_\parallel^i = \vec{p}^i \cdot \vec{p}_{\text{jet}} / |\vec{p}_{\text{jet}}|$$

$$Q_T^\kappa = \sum_i Q_i \left(p_\perp^i\right)^\kappa \Big/ \sum_i \left(p_\perp^i\right)^\kappa. \qquad p_\perp^i = |\vec{p}^i \times \vec{p}_{\text{jet}}| / |\vec{p}_{\text{jet}}|$$

Result:

Table 1: Systematic uncertainties in terms of their corresponding inverse-variance-weighted mean in the fractional deviation as defined in Eq. (4) in percent (%).

Sources of uncertainty	$\kappa = 1.0$			$\kappa = 0.6$			$\kappa = 0.3$		
	Q^κ	Q_L^κ	Q_T^κ	Q^κ	Q_L^κ	Q_T^κ	Q^κ	Q_L^κ	Q_T^κ
Jet energy scale	0.7	<0.1	<0.1	0.4	<0.1	<0.1	0.3	<0.1	<0.1
Jet energy resolution	0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Track reconstruction	0.4	0.4	0.5	0.5	0.4	0.5	0.5	0.4	0.4
Track p_T resolution	1.4	1.0	0.8	1.0	0.6	0.7	1.5	0.4	0.4
Pileup	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Response matrix modeling	1.6	1.6	1.8	1.0	0.8	1.3	1.5	1.3	1.3
Response matrix statistics	0.9	0.9	0.6	0.6	0.6	0.5	0.6	0.5	0.4

Jet charge at CEPC for B_s^0

2.4.2 Flavor tagging power

The algorithm is applied to a Monte Carlo truth-level simulation, assuming perfect particle identification. With the tagging algorithm, the tagging efficiency is estimated as 67%. The miss-tagging rate is 22.5%. Thus, the tagging power is estimated to be 20.2%.

$B_s^0 \to J/\psi\,\phi \to \mu^+\mu^- K^+ K^-$ $(e^+e^-K^+K^-)$ by Mingrui arXiv:2205.10565v1

by WHIZARD195

Percentage of Leading Particles

Different Generators (Whizard195 & Herwig & Sherpa)

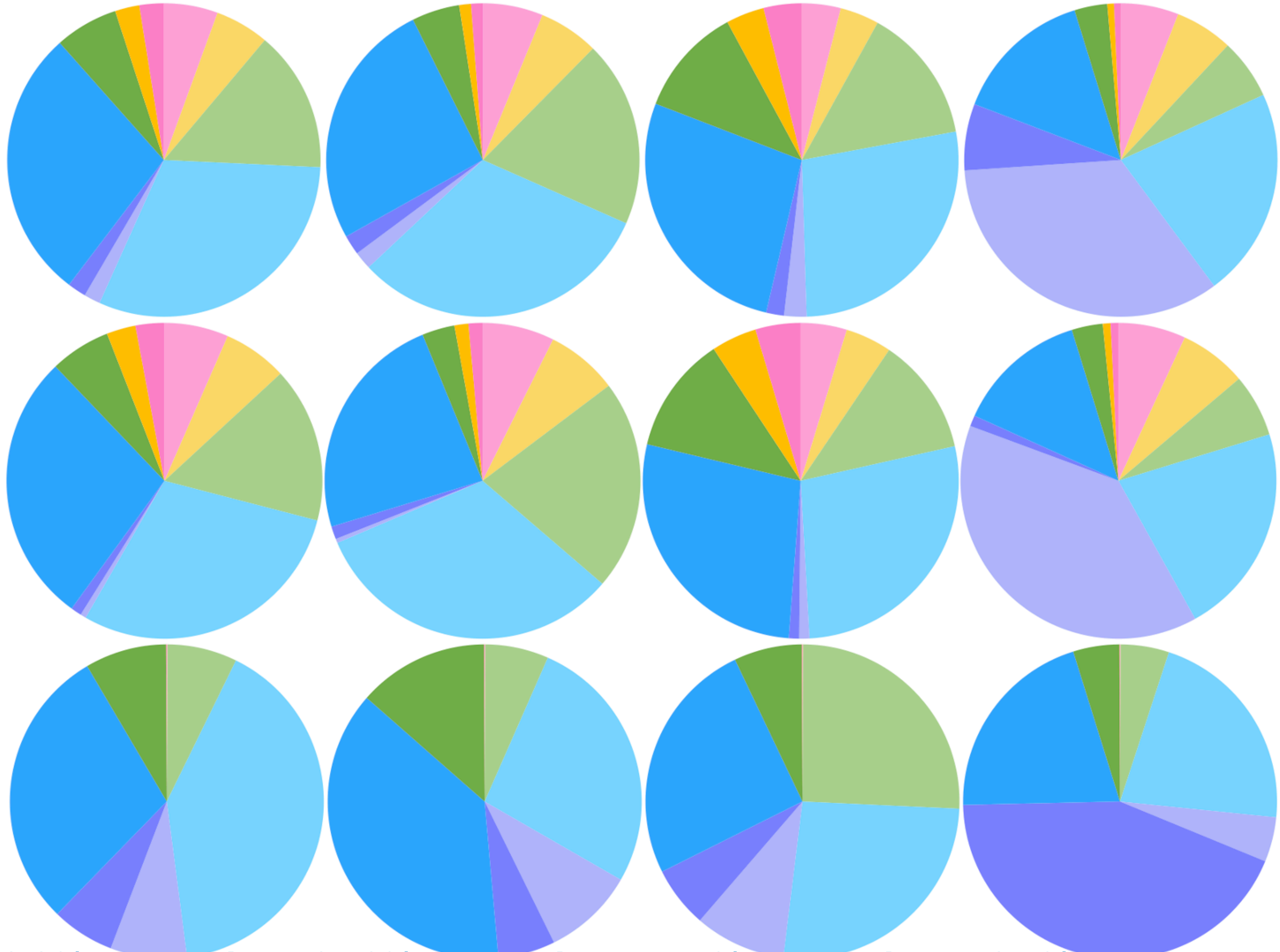
$Z \to b\bar{b}$

Percentage of leading particles (b jet, Whizard195)

All leading particles

Leading particles from leading hadron ~83.1%

Leading particles from QCD ~16.9%



pion ~69.9%
Kaon ~15.6%
proton ~14.3%
$\bar{B}^0$

pion ~64.6%
Kaon ~20.0%
proton ~15.3%
B^-

pion ~51.5%
Kaon ~32.7%
proton ~15.7%
$\bar{B}_s^0$

pion ~42.1%
Kaon ~9.7%
proton ~48.0%
Λ_b

by WHIZARD195

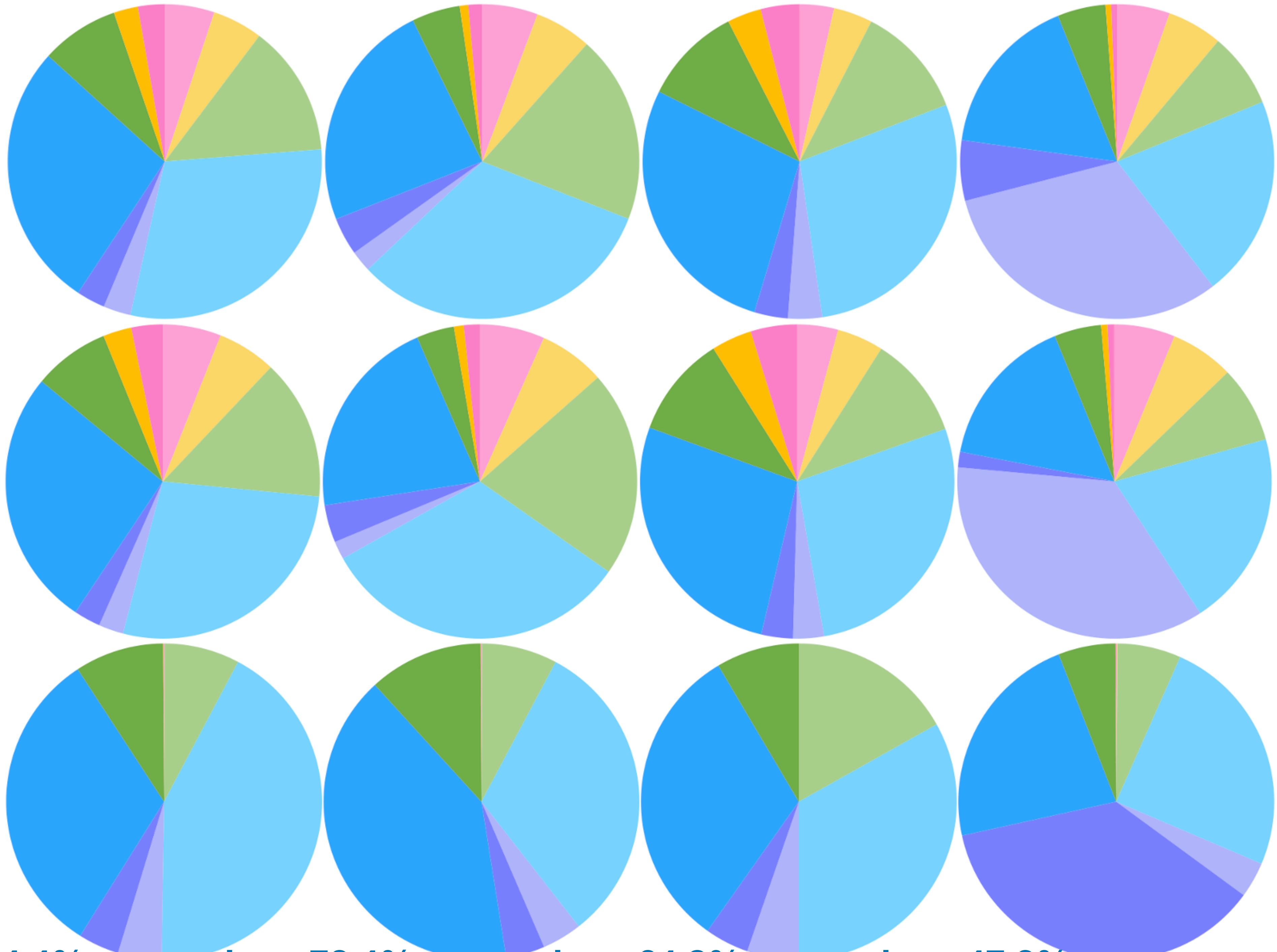
$Z \to b\bar{b}$

Percentage of leading particles (b jet, Herwig)

All leading particles

Leading particles from leading hadron ~82.6%

Leading particles from QCD ~17.4%



	$\bar{B}^0$	B^-	$\bar{B}_s^0$	Λ_b
pion	~74.4%	~72.4%	~64.8%	~47.3%
Kaon	~16.8%	~19.4%	~25.4%	~12.4%
proton	~8.7%	~8.0%	~9.8%	~40.1%

by Herwig

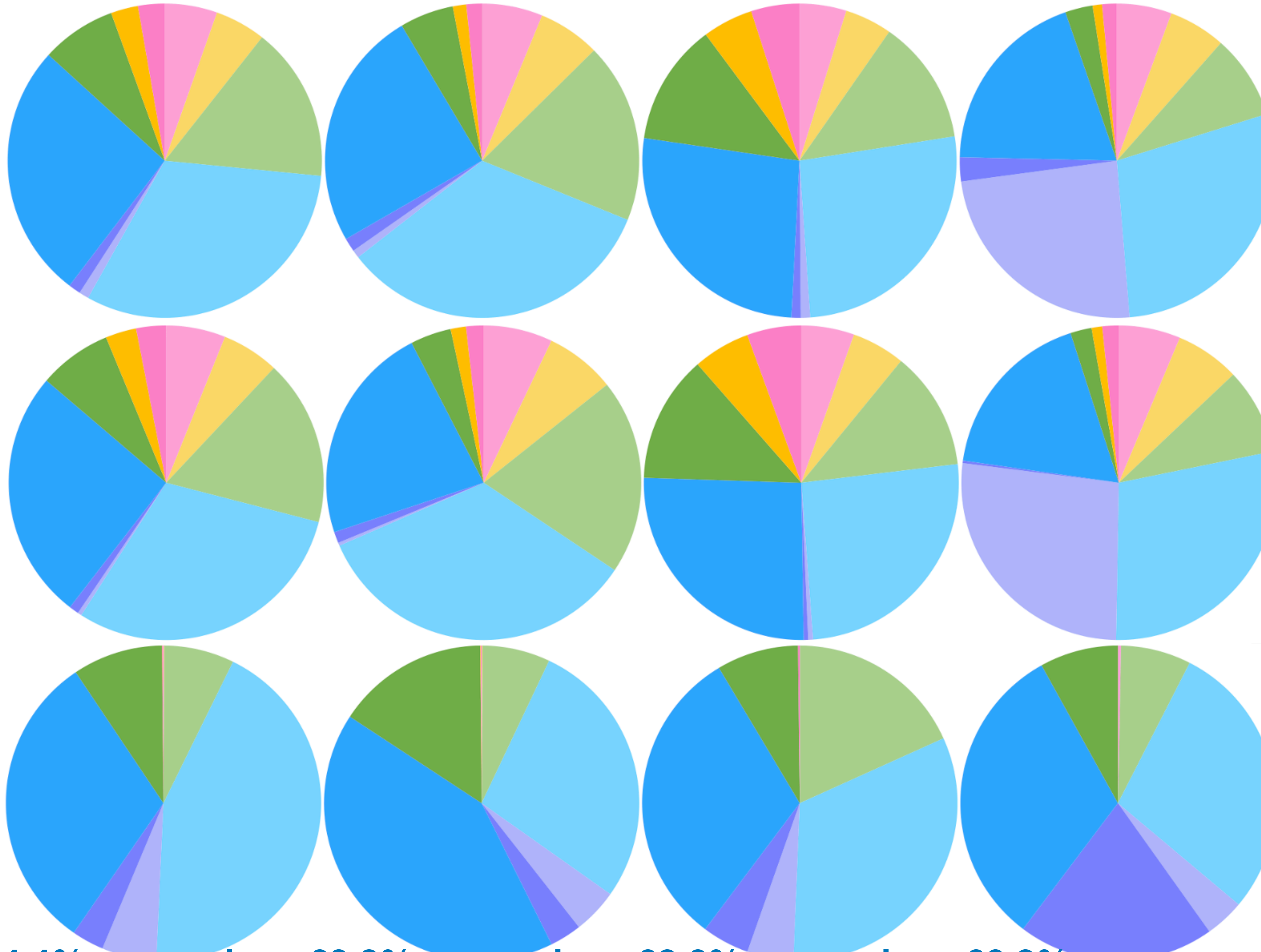
$Z \to b\bar{b}$

Percentage of leading particles (b jet, Sherpa)

All leading particles

Leading particles from leading hadron ~87.0%

Leading particles from QCD ~13.0%



pion ~74.4%
Kaon ~16.4%
proton ~8.9%
$\bar{B}^0$

pion ~69.3%
Kaon ~22.5%
proton ~7.9%
B^-

pion ~63.6%
Kaon ~26.6%
proton ~9.6%
$\bar{B}_s^0$

pion ~60.3%
Kaon ~15.3%
proton ~24.2%
Λ_b

by Sherpa

b **jet** → $\bar{b}$ **jet**

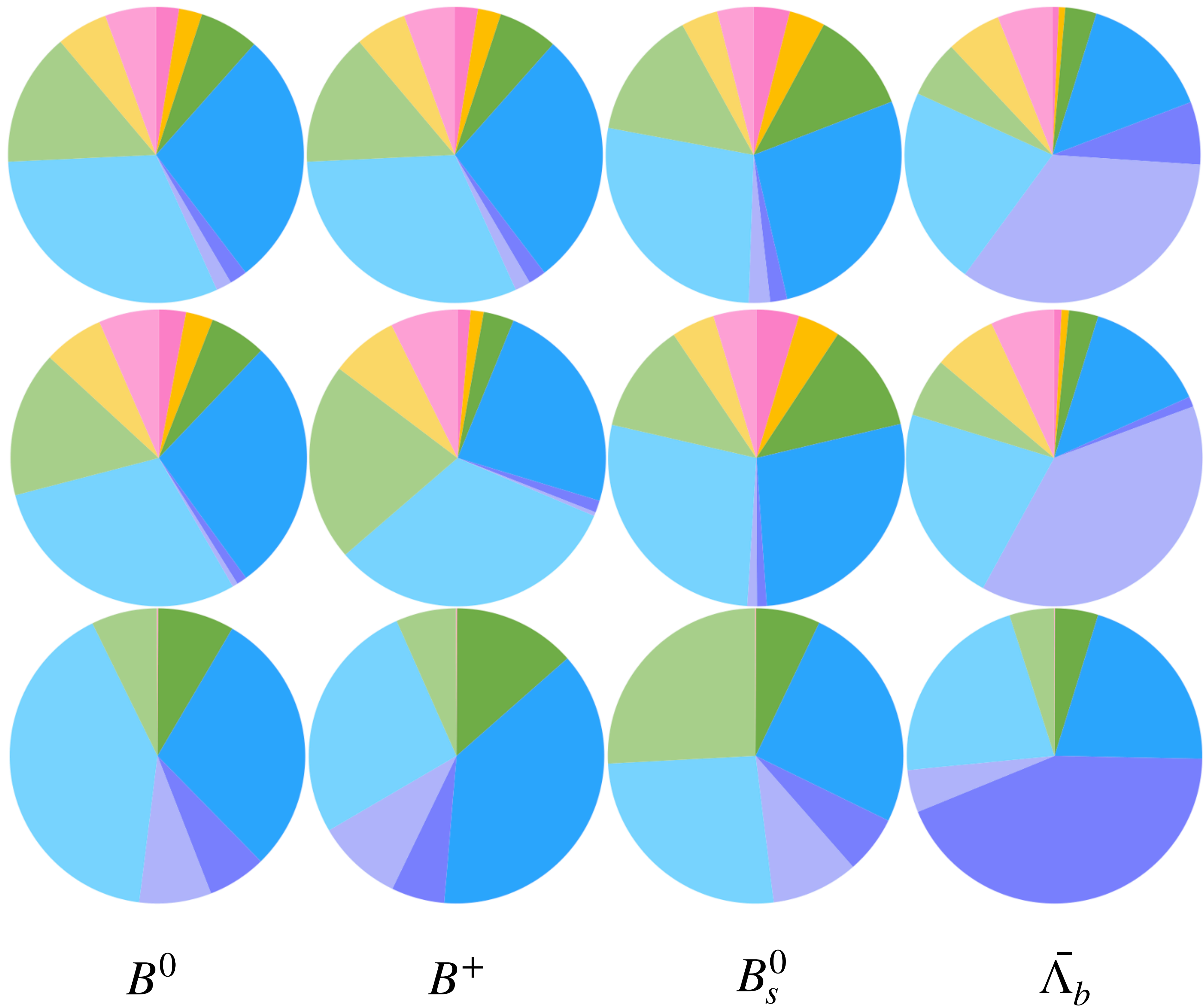
$Z \to b\bar{b}$

Percentage of leading particles ($\bar{b}$ jet, Whizard195)

All leading particles

Leading particles from leading hadron ~83.1%

Leading particles from QCD ~16.9%



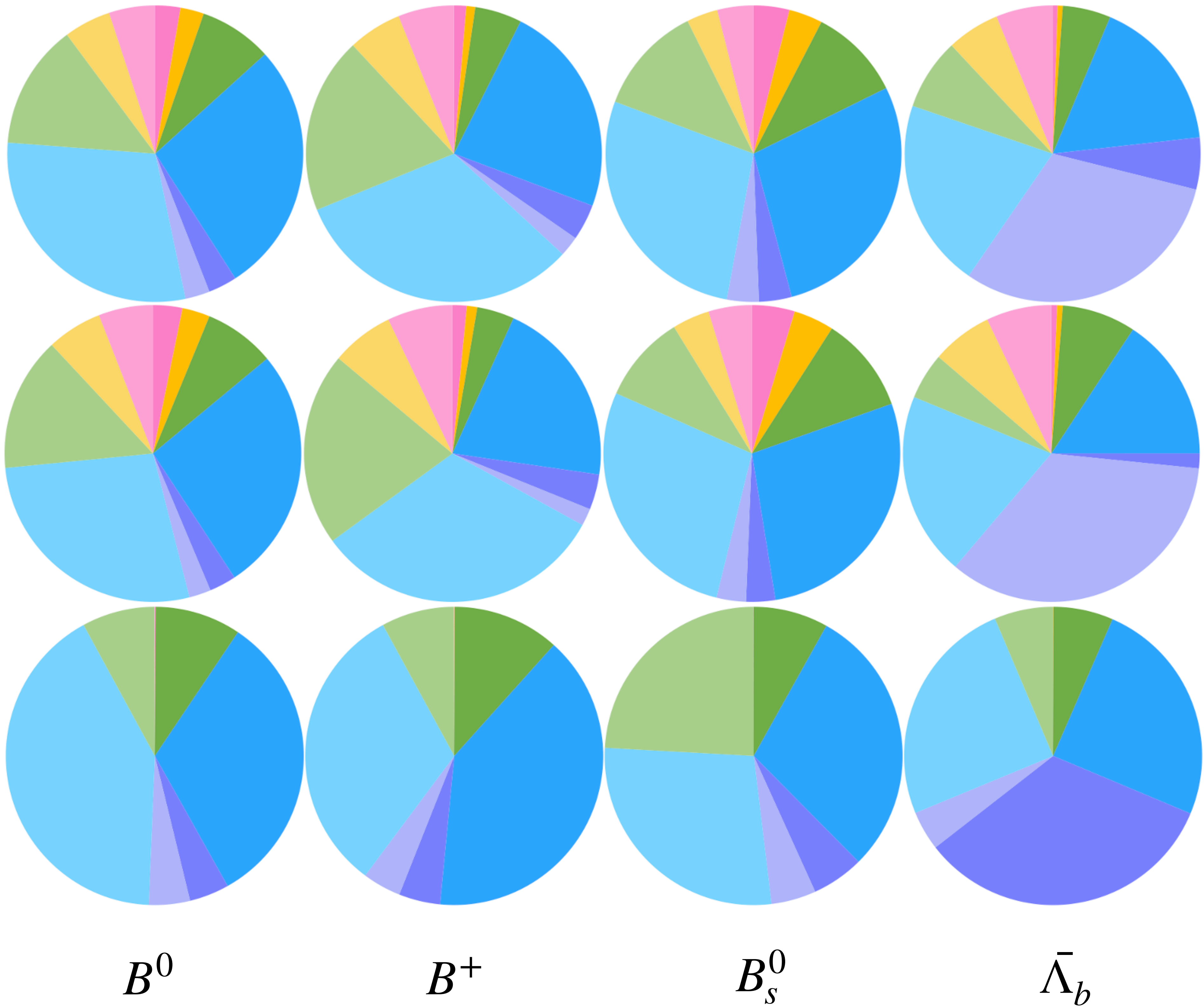
by WHIZARD195

Percentage of leading particles ($\bar{b}$ jet, Herwig)

All leading particles

Leading particles from leading hadron ~82.6%

Leading particles from QCD ~17.4%



by Herwig

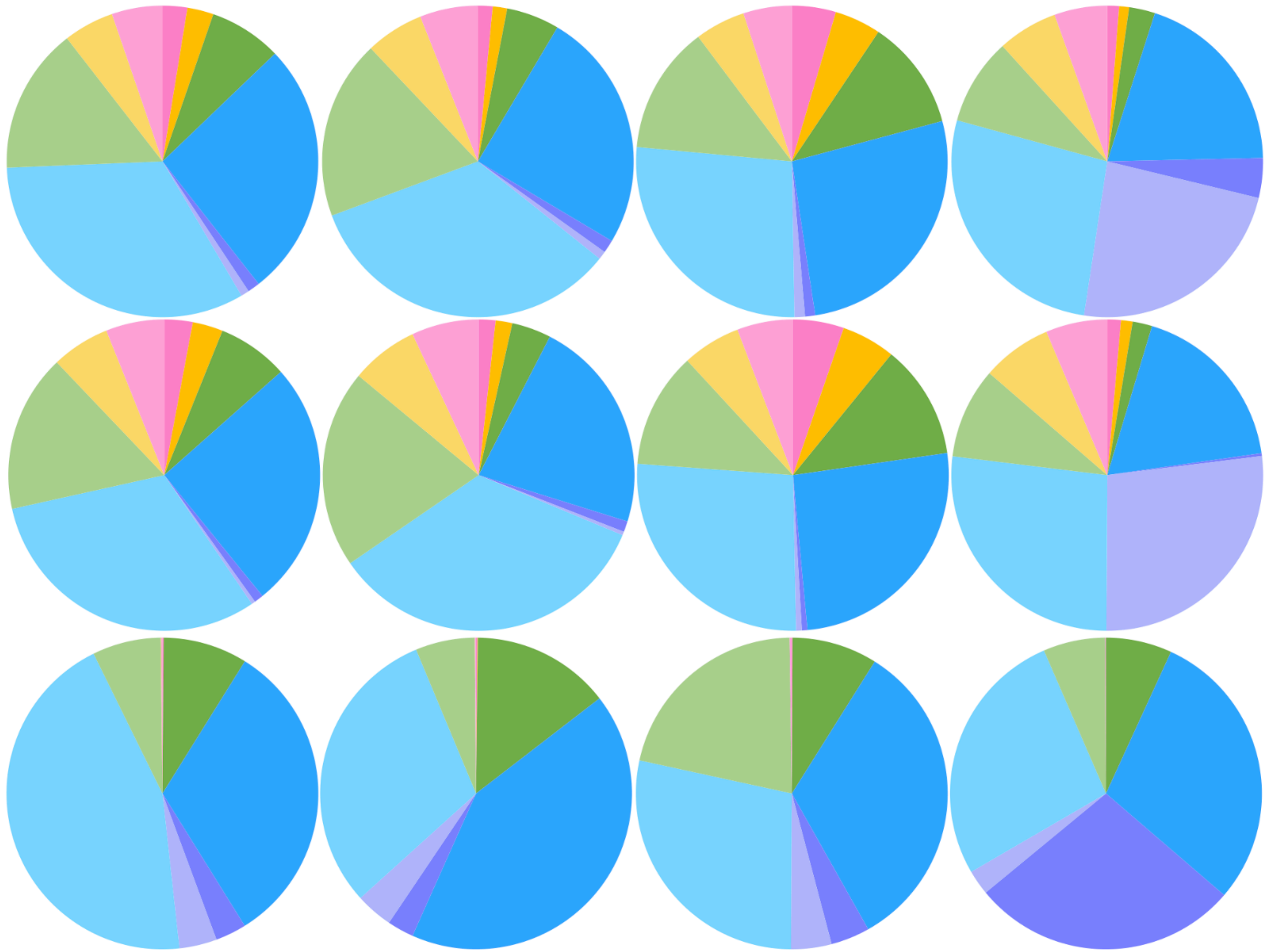
$Z \to b\bar{b}$

Percentage of leading particles ($\bar{b}$ jet, Sherpa)

All leading particles

Leading particles from leading hadron ~83.4%

Leading particles from QCD ~16.6%



B^0 B^+ B_s^0 $\bar{\Lambda}_b$

by Sherpa

$$Z \to b\bar{b} \to Z \to c\bar{c}$$

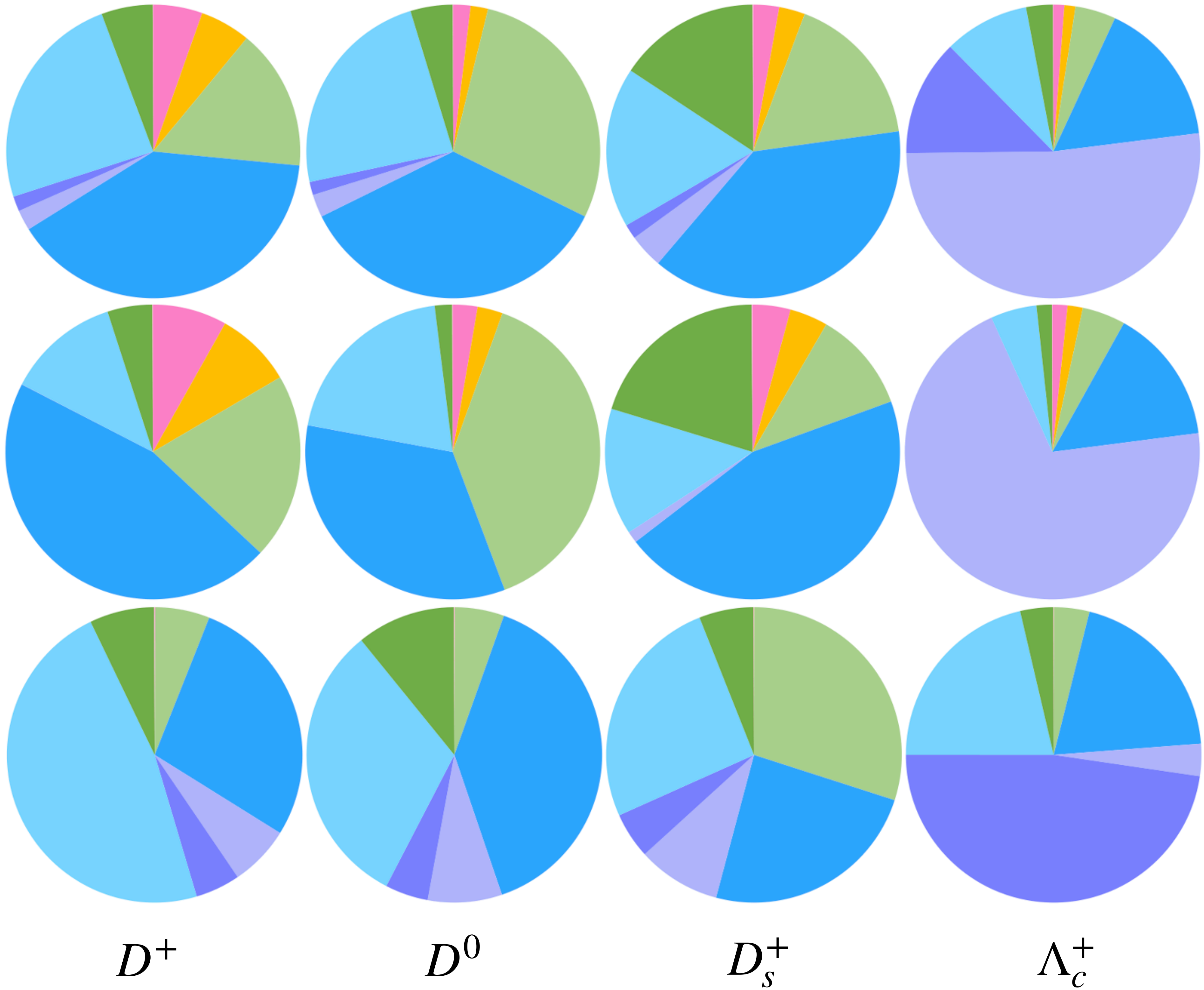
$Z \to c\bar{c}$

Percentage of leading particles (c jet, Whizard195)

All leading particles

Leading particles from leading hadron

Leading particles from QCD



by WHIZARD195

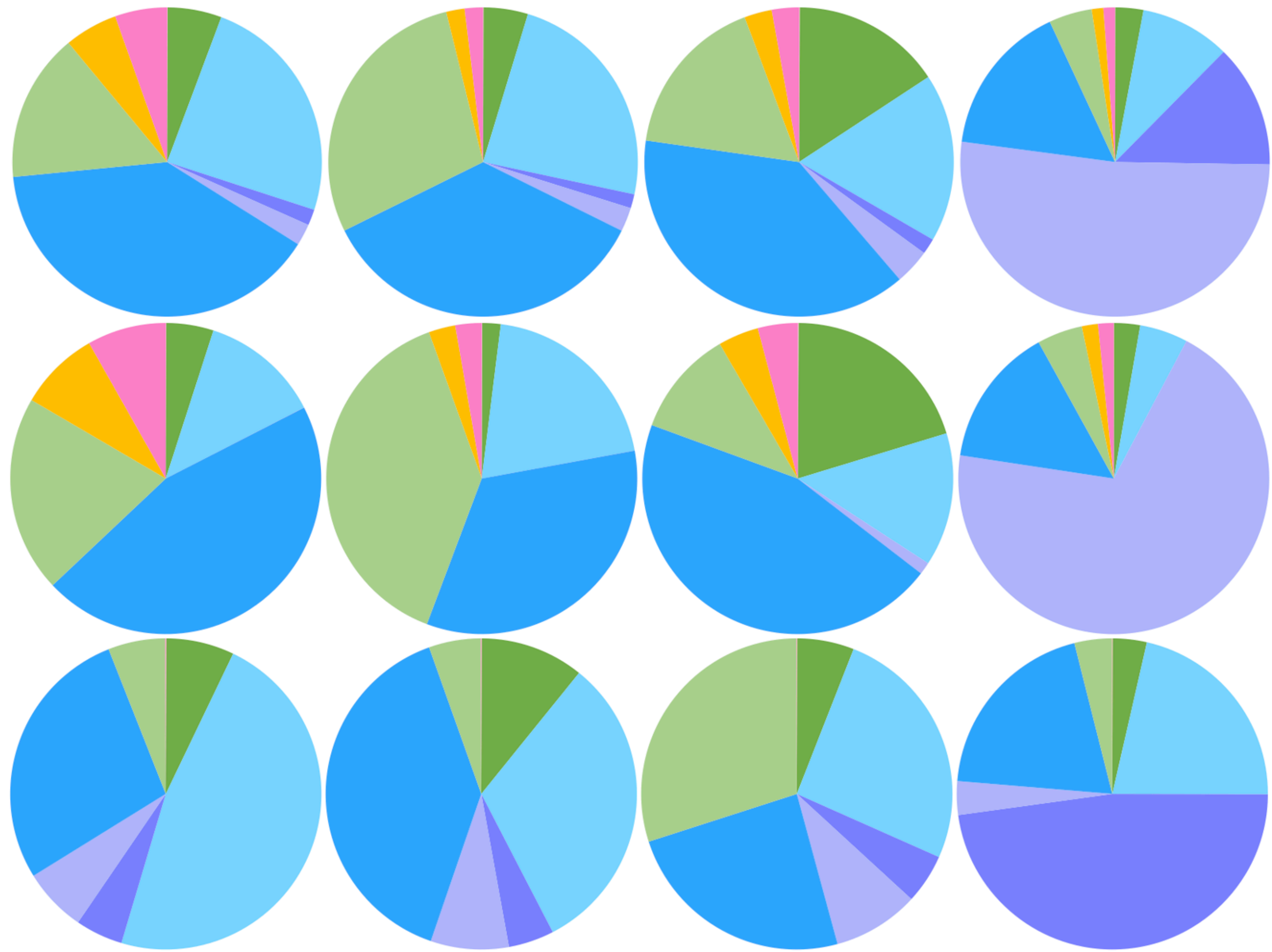
$Z \to c\bar{c}$

Percentage of leading particles ($\bar{c}$ jet, Whizard195)

All leading particles

Leading particles from leading hadron

Leading particles from QCD



D^- $\bar{D}^0$ D_s^- Λ_c^-

by WHIZARD195

Effective Tagging Power
Single Jet

Optimized κ for weighed charge method

Methods	Weighted Charge Method					
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)
All D hadrons	(κ=0)	(κ=0)	(κ=0)	(κ=0)	(κ=0)	(κ=0)
D+/D-	(κ=0)	(κ=0)	(κ=0)	(κ=0)	(κ=0)	(κ=0)
D0/D0bar	(κ=0)	(κ=0)	(κ=0)	(κ=0)	(κ=0)	(κ=0)
Ds+/Ds-	(κ=0)	(κ=0)	(κ=0)	(κ=0)	(κ=0)	(κ=0)
Λc+/Λc-	(κ=0)	(κ=0)	(κ=0)	(κ=0)	(κ=0)	(κ=0)

Two calculations of mis-judgement rate ω

Methods	Leading Particle Method(calculated from percentage)						Leading Particle Method(calculated from effective tagging power)					
Generator	Whizard		Herwig		Sherpa		Whizard		Herwig		Sherpa	
source	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D
All b hadrons	0.383	0.360	0.379	0.350	0.382	0.360	0.350	0.332	0.353	0.338	0.360	0.346
B0/B0bar	0.413	0.410	0.435	0.433	0.350	0.340	0.382	0.371	0.412	0.404	0.315	0.301
B+/B-	0.349	0.306	0.329	0.293	0.340	0.305	0.302	0.265	0.296	0.266	0.309	0.278
Bs/Bsbar	0.482	0.498	0.489	0.498	0.389	0.385	0.470	0.493	0.480	0.491	0.336	0.331
Bc+/Bc-	0.421	0.371	0.374	0.348	0.346	0.256	0.385	0.346	0.322	0.316	0.307	0.227
Λb/Λbbar	0.260	0.204	0.293	0.247	0.274	0.240	0.231	0.160	0.245	0.185	0.234	0.192
All D hadrons	0.304	0.216	0.295	0.203	0.301	0.214	0.276	0.201	0.265	0.189	0.270	0.202
D+/D-	0.316	0.169	0.272	0.130	0.310	0.163	0.180	0.259	0.244	0.125	0.278	0.151
D0/D0bar	0.297	0.236	0.301	0.243	0.293	0.234	0.257	0.192	0.253	0.200	0.246	0.187
Ds+/Ds-	0.350	0.242	0.333	0.210	0.325	0.226	0.312	0.225	0.193	0.198	0.291	0.210
Λc+/Λc-	0.251	0.086	0.251	0.086	0.226	0.078	0.235	0.068	0.245	0.073	0.204	0.066

Mis-judgement rate ω(calculated from percentage)

Methods	Leading Particle Method						Weighted Charge Method					
Generator	Whizard		Herwig		Sherpa		Whizard		Herwig		Sherpa	
source	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D
All b hadrons	0.383	0.360	0.379	0.350	0.382	0.360	0.302 (κ=0.2)	0.035 (κ=0.0)	0.313 (κ=0.2)	0.042 (κ=0.0)	0.283 (κ=0.2)	0.044 (κ=0.0)
B0/B0bar	0.413	0.410	0.435	0.433	0.350	0.340	0.312 (κ=0.2)	0.396 (κ=0.6)	0.324 (κ=0.2)	0.423 (κ=0.6)	0.253 (κ=0.3)	0.311 (κ=0.6)
B+/B-	0.349	0.306	0.329	0.293	0.340	0.305	0.260 (κ=0.3)	0.003 (κ=0.0)	0.263 (κ=0.4)	0.003 (κ=0.0)	0.244 (κ=0.3)	0.003 (κ=0.0)
Bs/Bsbar	0.482	0.498	0.489	0.498	0.389	0.385	0.347 (κ=0.0)	0.453 (κ=0.0)	0.291 (κ=0.0)	0.457 (κ=0.0)	0.289 (κ=0.2)	0.388 (κ=1.0)
Bc+/Bc-	0.421	0.371	0.374	0.348	0.346	0.256	0.316 (κ=0.2)	0.008 (κ=0.0)	0.316 (κ=0.7)	0.007 (κ=0.0)	0.204 (κ=0.6)	0 (κ=0.0)
Λb/Λbbar	0.260	0.204	0.293	0.247	0.274	0.240	0.277 (κ=0.0)	0.432 (κ=1.0)	0.289 (κ=0.0)	0.423 (κ=0.9)	0.239 (κ=0.0)	0.427 (κ=0.0)
All D hadrons	0.304	0.216	0.295	0.203	0.301	0.214	0.175 (κ=0.0)	0.025 (κ=0.0)	0.175 (κ=0.0)	0.025 (κ=0.0)	0.165 (κ=0.0)	0.033 (κ=0.0)
D+/D-	0.316	0.169	0.272	0.130	0.310	0.163	0.128 (κ=0.0)	0.001 (κ=0.0)	0.131 (κ=0.0)	0.001 (κ=0.0)	0.120 (κ=0.0)	0.002 (κ=0.0)
D0/D0bar	0.297	0.236	0.301	0.243	0.293	0.234	0.128 (κ=0.0)	0.007 (κ=0.0)	0.132 (κ=0.0)	0.006 (κ=0.0)	0.119 (κ=0.0)	0.011 (κ=0.0)
Ds+/Ds-	0.350	0.242	0.333	0.210	0.325	0.226	0.128 (κ=0.0)	0.001 (κ=0.0)	0.129 (κ=0.0)	0.001 (κ=0.0)	0.118 (κ=0.0)	0.002 (κ=0.0)
Λc+/Λc-	0.251	0.086	0.251	0.086	0.226	0.078	0.126 (κ=0.0)	0.001 (κ=0.0)	0.132 (κ=0.0)	0.001 (κ=0.0)	0.117 (κ=0.0)	0.001 (κ=0.0)

Mis-judgement rate ω(calculated from effective tagging power)

Methods	Leading Particle Method						Weighted Charge Method					
Generator	Whizard		Herwig		Sherpa		Whizard		Herwig		Sherpa	
source	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D
All b hadrons	0.350	0.332	0.353	0.338	0.360	0.346	0.302 (κ=0.2)	0.035 (κ=0.0)	0.313 (κ=0.2)	0.042 (κ=0.0)	0.283 (κ=0.2)	0.044 (κ=0.0)
B0/B0bar	0.382	0.371	0.412	0.404	0.315	0.301	0.312 (κ=0.2)	0.396 (κ=0.6)	0.324 (κ=0.2)	0.423 (κ=0.6)	0.253 (κ=0.3)	0.311 (κ=0.6)
B+/B-	0.302	0.265	0.296	0.266	0.309	0.278	0.260 (κ=0.3)	0.003 (κ=0.0)	0.263 (κ=0.4)	0.003 (κ=0.0)	0.244 (κ=0.3)	0.003 (κ=0.0)
Bs/Bsbar	0.470	0.493	0.480	0.491	0.336	0.331	0.347 (κ=0.0)	0.453 (κ=0.0)	0.291 (κ=0.0)	0.457 (κ=0.0)	0.289 (κ=0.2)	0.388 (κ=1.0)
Bc+/Bc-	0.385	0.346	0.322	0.316	0.307	0.227	0.316 (κ=0.2)	0.008 (κ=0.0)	0.316 (κ=0.7)	0.007 (κ=0.0)	0.204 (κ=0.6)	0 (κ=0.0)
Λb/Λbbar	0.231	0.160	0.245	0.185	0.234	0.192	0.277 (κ=0.0)	0.432 (κ=1.0)	0.289 (κ=0.0)	0.423 (κ=0.9)	0.239 (κ=0.0)	0.427 (κ=0.0)
All D hadrons	0.276	0.201	0.265	0.189	0.270	0.202	0.175 (κ=0.0)	0.025 (κ=0.0)	0.175 (κ=0.0)	0.025 (κ=0.0)	0.165 (κ=0.0)	0.033 (κ=0.0)
D+/D-	0.180	0.259	0.244	0.125	0.278	0.151	0.128 (κ=0.0)	0.001 (κ=0.0)	0.131 (κ=0.0)	0.001 (κ=0.0)	0.120 (κ=0.0)	0.002 (κ=0.0)
D0/D0bar	0.257	0.192	0.253	0.200	0.246	0.187	0.128 (κ=0.0)	0.007 (κ=0.0)	0.132 (κ=0.0)	0.006 (κ=0.0)	0.119 (κ=0.0)	0.011 (κ=0.0)
Ds+/Ds-	0.312	0.225	0.193	0.198	0.291	0.210	0.128 (κ=0.0)	0.001 (κ=0.0)	0.129 (κ=0.0)	0.001 (κ=0.0)	0.118 (κ=0.0)	0.002 (κ=0.0)
Λc+/Λc-	0.235	0.068	0.245	0.073	0.204	0.066	0.126 (κ=0.0)	0.001 (κ=0.0)	0.132 (κ=0.0)	0.001 (κ=0.0)	0.117 (κ=0.0)	0.001 (κ=0.0)

Effective tagging power

Methods	Leading Particle Method						Weighted Charge Method					
Generator	Whizard		Herwig		Sherpa		Whizard		Herwig		Sherpa	
decay source	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D
All b hadrons	0.0895	0.1124	0.0859	0.1039	0.0786	0.0945	0.1571 (κ=0.2)	0.3750 (κ=0.0)	0.1396 (κ=0.2)	0.3492 (κ=0.0)	0.1877 (κ=0.2)	0.3495 (κ=0.0)
B0/B0bar	0.0555	0.0668	0.0311	0.0368	0.1367	0.1588	0.1419 (κ=0.2)	0.0430 (κ=0.6)	0.1239 (κ=0.2)	0.0236 (κ=0.6)	0.2449 (κ=0.3)	0.1431 (κ=0.6)
B+/B-	0.1576	0.2208	0.1660	0.2193	0.1463	0.1964	0.2301 (κ=0.3)	0.9686 (κ=0.0)	0.2241 (κ=0.4)	0.9655 (κ=0.0)	0.2620 (κ=0.3)	0.9644 (κ=0.0)
Bs/Bsbar	0.0037	0.0002	0.0016	0.0003	0.1082	0.1136	0.1200 (κ=0.0)	0.0003 (κ=0.0)	0.1081 (κ=0.0)	0.0003 (κ=0.0)	0.1787 (κ=0.2)	0.0498 (κ=1.0)
Bc+/Bc-	0.0530	0.0949	0.1268	0.1350	0.1490	0.2976	0.1359 (κ=0.2)	0.9272 (κ=0.0)	0.1352 (κ=0.7)	0.8647 (κ=0.0)	0.3510 (κ=0.6)	0.9716 (κ=0.0)
Λb/Λbbar	0.2885	0.4627	0.2605	0.3972	0.2830	0.3795	0.1217 (κ=0.0)	0.0186 (κ=1.0)	0.1080 (κ=0.0)	0.0236 (κ=0.9)	0.1642 (κ=0.0)	0.0010 (κ=0.0)
All D hadrons	0.2004	0.3574	0.2216	0.3872	0.2121	0.3549	0.3149 (κ=0.0)	0.3384 (κ=0.0)	0.3230 (κ=0.0)	0.3609 (κ=0.0)	0.3342 (κ=0.0)	0.3314 (κ=0.0)
D+/D-	0.1931	0.4654	0.2624	0.5640	0.1968	0.4873	0.5535 (κ=0.0)	0.9947 (κ=0.0)	0.5458 (κ=0.0)	0.9945 (κ=0.0)	0.5772 (κ=0.0)	0.9920 (κ=0.0)
D0/D0bar	0.2353	0.3795	0.2443	0.3607	0.2586	0.3931	0.5530 (κ=0.0)	0.9483 (κ=0.0)	0.5424 (κ=0.0)	0.9346 (κ=0.0)	0.5803 (κ=0.0)	0.9125 (κ=0.0)
Ds+/Ds-	0.1411	0.3024	0.1715	0.3656	0.1755	0.3365	0.5541 (κ=0.0)	0.9952 (κ=0.0)	0.5501 (κ=0.0)	0.9955 (κ=0.0)	0.5823 (κ=0.0)	0.9918 (κ=0.0)
Λc+/Λc-	0.2814	0.7481	0.2610	0.7279	0.3505	0.7537	0.5594 (κ=0.0)	0.9958 (κ=0.0)	0.5426 (κ=0.0)	0.9957 (κ=0.0)	0.5882 (κ=0.0)	0.9933 (κ=0.0)

Mis-judgement rate ω(calculated from percentage)

Methods	Leading Particle Method						Weighted Charge Method					
Generator	Whizard		Herwig		Sherpa		Whizard		Herwig		Sherpa	
source	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D
All b hadrons	0.383	0.360	0.379	0.350	0.382	0.360	0.302	0.035	0.313	0.042	0.283	0.044
B0/B0bar	0.413	0.410	0.435	0.433	0.350	0.340	0.312	0.396	0.324	0.423	0.253	0.311
B+/B-	0.349	0.306	0.329	0.293	0.340	0.305	0.260	0.003	0.263	0.003	0.244	0.003
Bs/Bsbar	0.482	0.498	0.489	0.498	0.389	0.385	0.347	0.453	0.291	0.457	0.289	0.388
Bc+/Bc-	0.421	0.371	0.374	0.348	0.346	0.256	0.316	0.008	0.316	0.007	0.204	0
Λb/Λbbar	0.260	0.204	0.293	0.247	0.274	0.240	0.277	0.432	0.289	0.423	0.239	0.427
All D hadrons	0.304	0.216	0.295	0.203	0.301	0.214	0.175	0.025	0.175	0.025	0.165	0.033
D+/D-	0.316	0.169	0.272	0.130	0.310	0.163	0.128	0.001	0.131	0.001	0.120	0.002
D0/D0bar	0.297	0.236	0.301	0.243	0.293	0.234	0.128	0.007	0.132	0.006	0.119	0.011
Ds+/Ds-	0.350	0.242	0.333	0.210	0.325	0.226	0.128	0.001	0.129	0.001	0.118	0.002
Λc+/Λc-	0.251	0.086	0.251	0.086	0.226	0.078	0.126	0.001	0.132	0.001	0.117	0.001

Mis-judgement rate ω(calculated from effective tagging power)

Methods	Leading Particle Method						Weighted Charge Method					
Generator	Whizard		Herwig		Sherpa		Whizard		Herwig		Sherpa	
source	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D
All b hadrons	0.350	0.332	0.353	0.338	0.360	0.346	0.302	0.035	0.313	0.042	0.283	0.044
B0/B0bar	0.382	0.371	0.412	0.404	0.315	0.301	0.312	0.396	0.324	0.423	0.253	0.311
B+/B-	0.302	0.265	0.296	0.266	0.309	0.278	0.260	0.003	0.263	0.003	0.244	0.003
Bs/Bsbar	0.470	0.493	0.480	0.491	0.336	0.331	0.347	0.453	0.291	0.457	0.289	0.388
Bc+/Bc-	0.385	0.346	0.322	0.316	0.307	0.227	0.316	0.008	0.316	0.007	0.204	0
Λb/Λbbar	0.231	0.160	0.245	0.185	0.234	0.192	0.277	0.432	0.289	0.423	0.239	0.427
All D hadrons	0.276	0.201	0.265	0.189	0.270	0.202	0.175	0.025	0.175	0.025	0.165	0.033
D+/D-	0.180	0.259	0.244	0.125	0.278	0.151	0.128	0.001	0.131	0.001	0.120	0.002
D0/D0bar	0.257	0.192	0.253	0.200	0.246	0.187	0.128	0.007	0.132	0.006	0.119	0.011
Ds+/Ds-	0.312	0.225	0.193	0.198	0.291	0.210	0.128	0.001	0.129	0.001	0.118	0.002
Λc+/Λc-	0.235	0.068	0.245	0.073	0.204	0.066	0.126	0.001	0.132	0.001	0.117	0.001

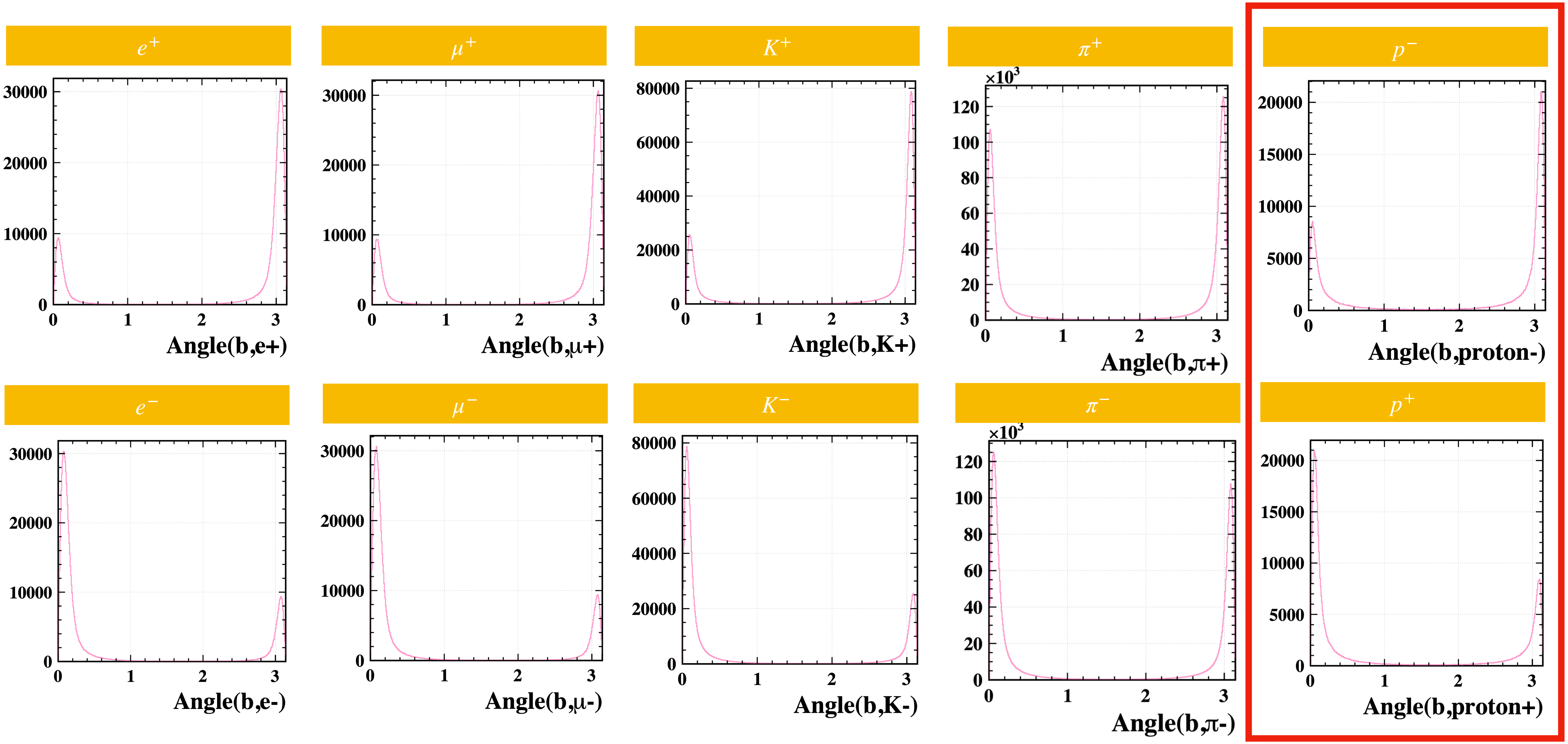
Effective tagging power

Methods	Leading Particle Method						Weighted Charge Method					
Generator	Whizard		Herwig		Sherpa		Whizard		Herwig		Sherpa	
decay source	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D	all	from B/D
All b hadrons	0.0895	0.1124	0.0859	0.1039	0.0786	0.0945	0.1571	0.3750	0.1396	0.3492	0.1877	0.3495
B0/B0bar	0.0555	0.0668	0.0311	0.0368	0.1367	0.1588	0.1419	0.0430	0.1239	0.0236	0.2449	0.1431
B+/B-	0.1576	0.2208	0.1660	0.2193	0.1463	0.1964	0.2301	0.9686	0.2241	0.9655	0.2620	0.9644
Bs/Bsbar	0.0037	0.0002	0.0016	0.0003	0.1082	0.1136	0.1200	0.0003	0.1081	0.0003	0.1787	0.0498
Bc+/Bc-	0.0530	0.0949	0.1268	0.1350	0.1490	0.2976	0.1359	0.9272	0.1352	0.8647	0.3510	0.9716
Λb/Λbbar	0.2885	0.4627	0.2605	0.3972	0.2830	0.3795	0.1217	0.0186	0.1080	0.0236	0.1642	0.0010
All D hadrons	0.2004	0.3574	0.2216	0.3872	0.2121	0.3549	0.3149	0.3384	0.3230	0.3609	0.3342	0.3314
D+/D-	0.1931	0.4654	0.2624	0.5640	0.1968	0.4873	0.5535	0.9947	0.5458	0.9945	0.5772	0.9920
D0/D0bar	0.2353	0.3795	0.2443	0.3607	0.2586	0.3931	0.5530	0.9483	0.5424	0.9346	0.5803	0.9125
Ds+/Ds-	0.1411	0.3024	0.1715	0.3656	0.1755	0.3365	0.5541	0.9952	0.5501	0.9955	0.5823	0.9918
Λc+/Λc-	0.2814	0.7481	0.2610	0.7279	0.3505	0.7537	0.5594	0.9958	0.5426	0.9957	0.5882	0.9933

Angle Distributions

$Z \to b\bar{b}$ Angle distribution of each flavor of final leading particles

☞ *Angle distribution of two jets is asymmetry*



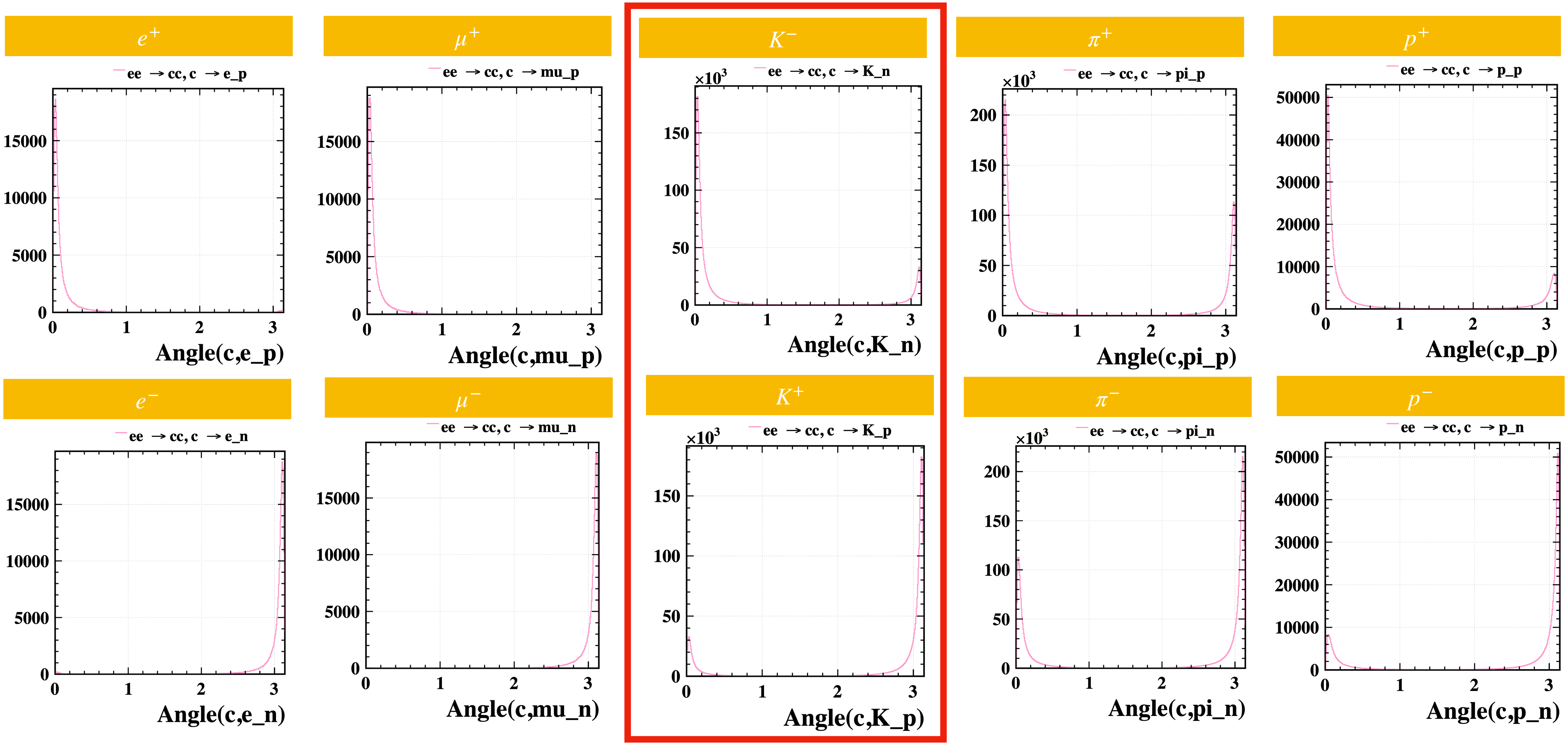
☞ *The more asymmetrical, the more accurate*

☞ *The lepton and Kaon is more asymmetrical than pion and proton*

☞ *Proton behaves different from others*

$Z \to c\bar{c}$ Angle distribution of each flavor of final leading particles

☞ *Angle distribution of two jets is asymmetry*



☞ *The more asymmetrical, the more accurate*

☞ *The lepton and Kaon is more asymmetrical than pion and proton*

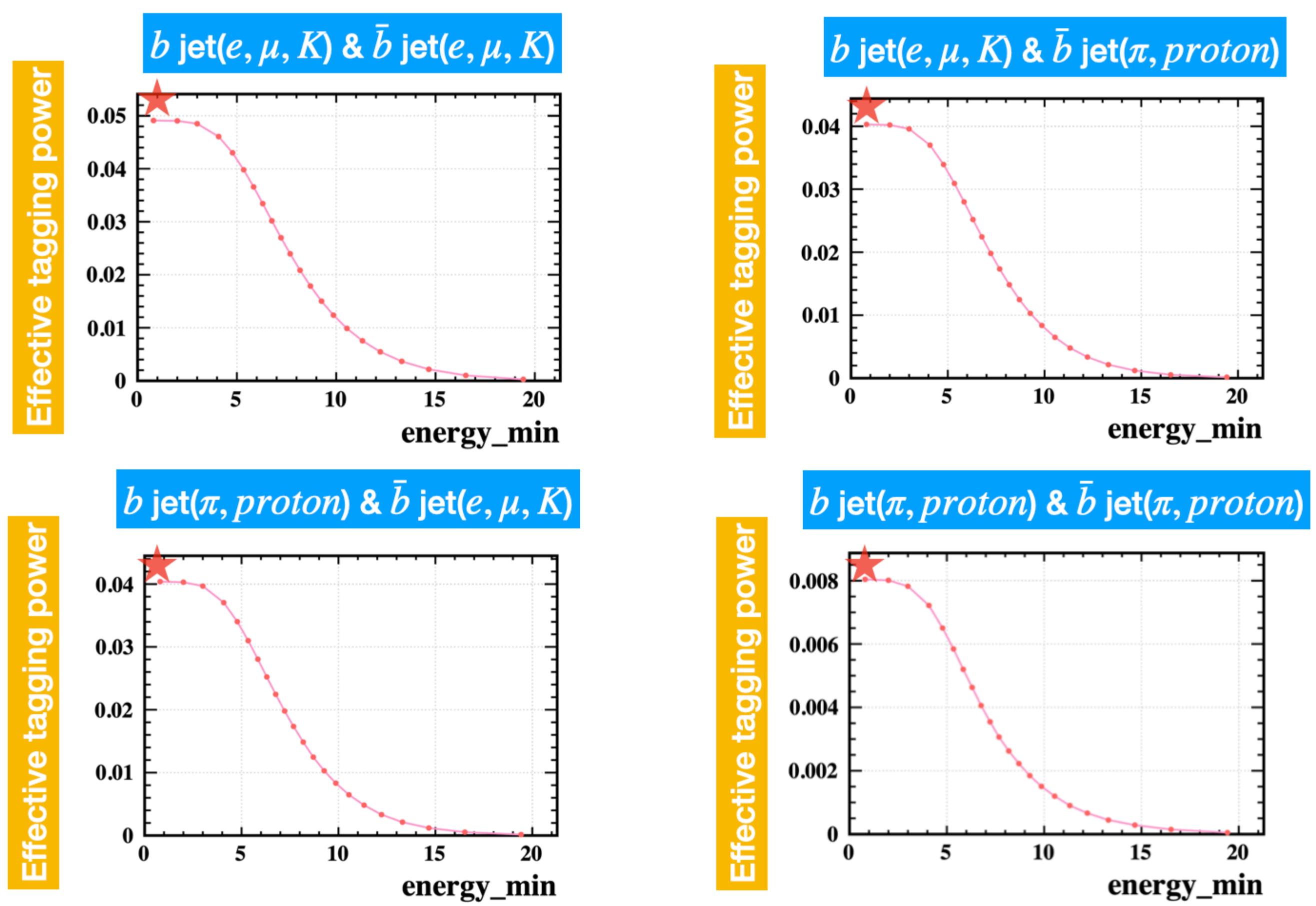
☞ *Kaon behaves different from others*

Dependence on Energy Threshold using Leading Particle Method

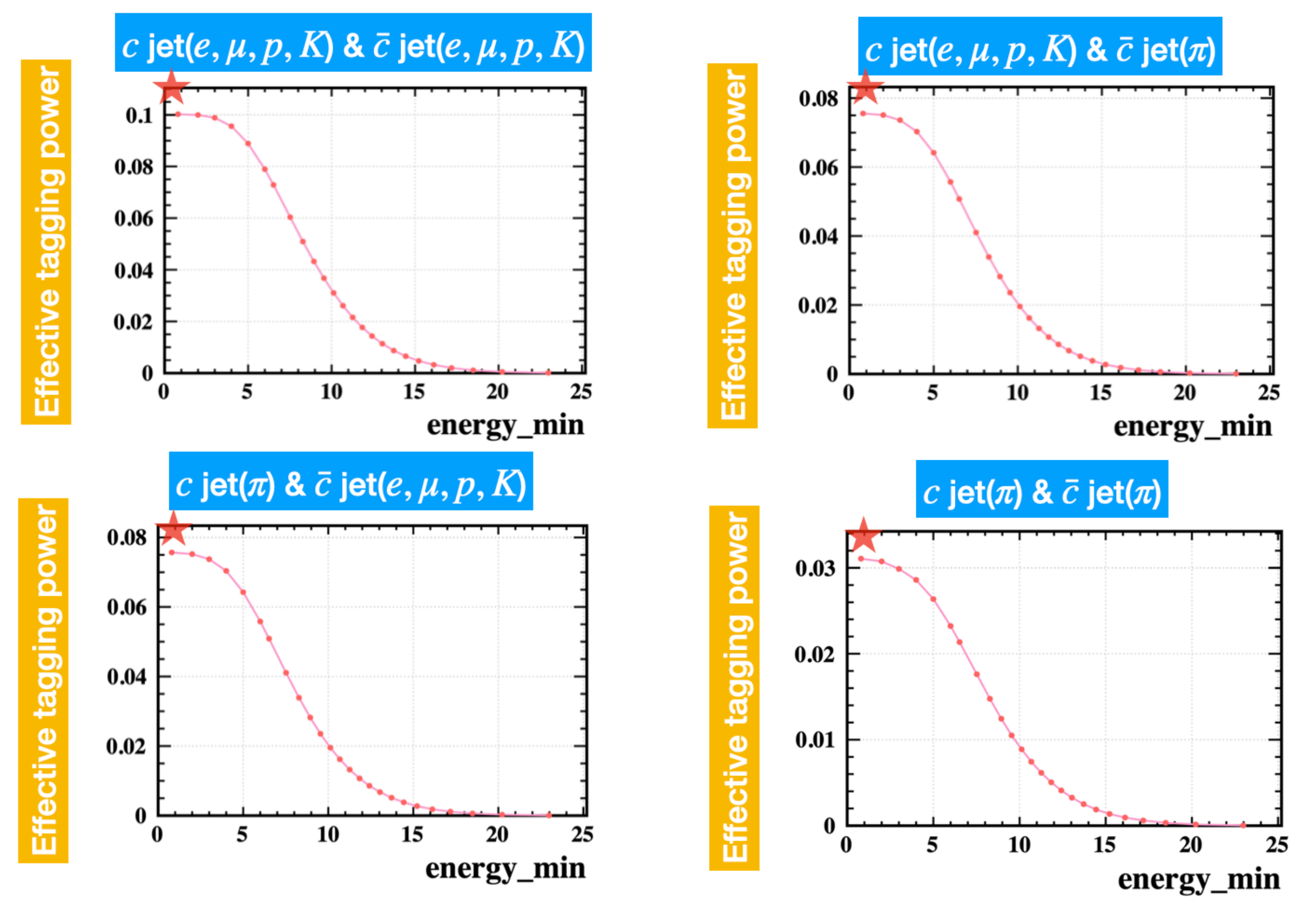
Dependence on Energy threshold of final leading particles

No energy threshold of final leading particles → best effective tagging power.

$Z \rightarrow b\bar{b}$ ***Effective tagging power of 4 categories of particle flavors***



$Z \rightarrow c\bar{c}$ ***Effective tagging power of 4 categories of particle flavors***

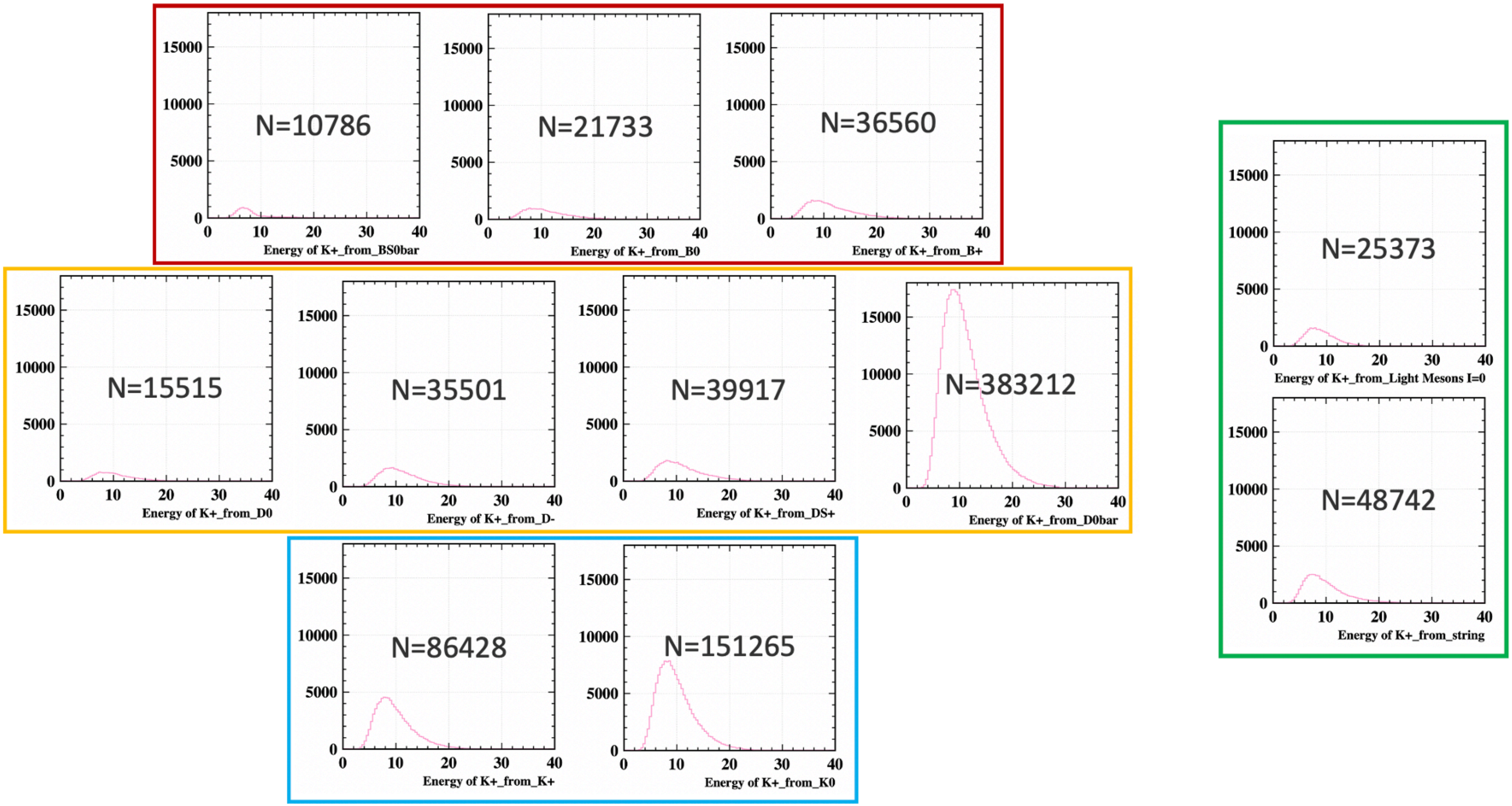


Dependence on Decay Modes

Take Leading Kaon and Muon as Examples

$Z \to b\bar{b}$

Energy spectrum of final leading K^+

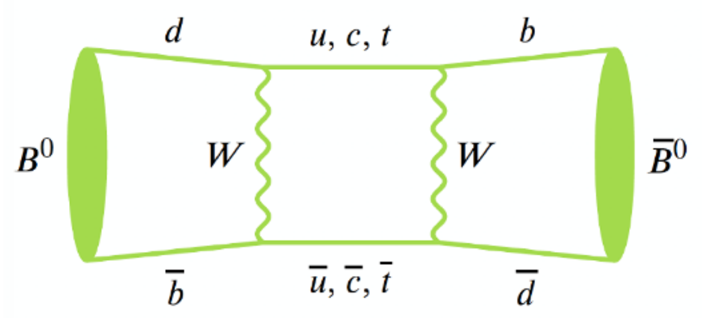


☞ *Energy spectrum of final leading K^+ from different decay modes is different*

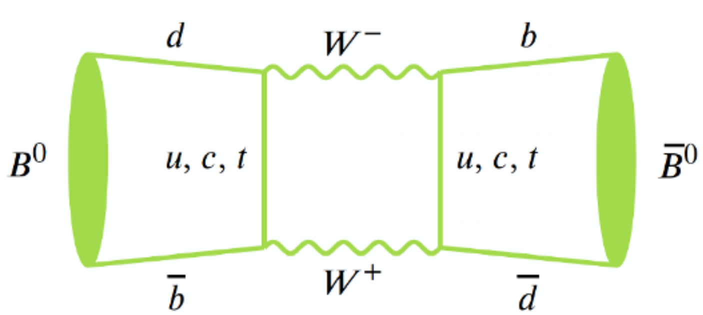
$Z \to b\bar{b}$

Percent of leading K^+ from different decays

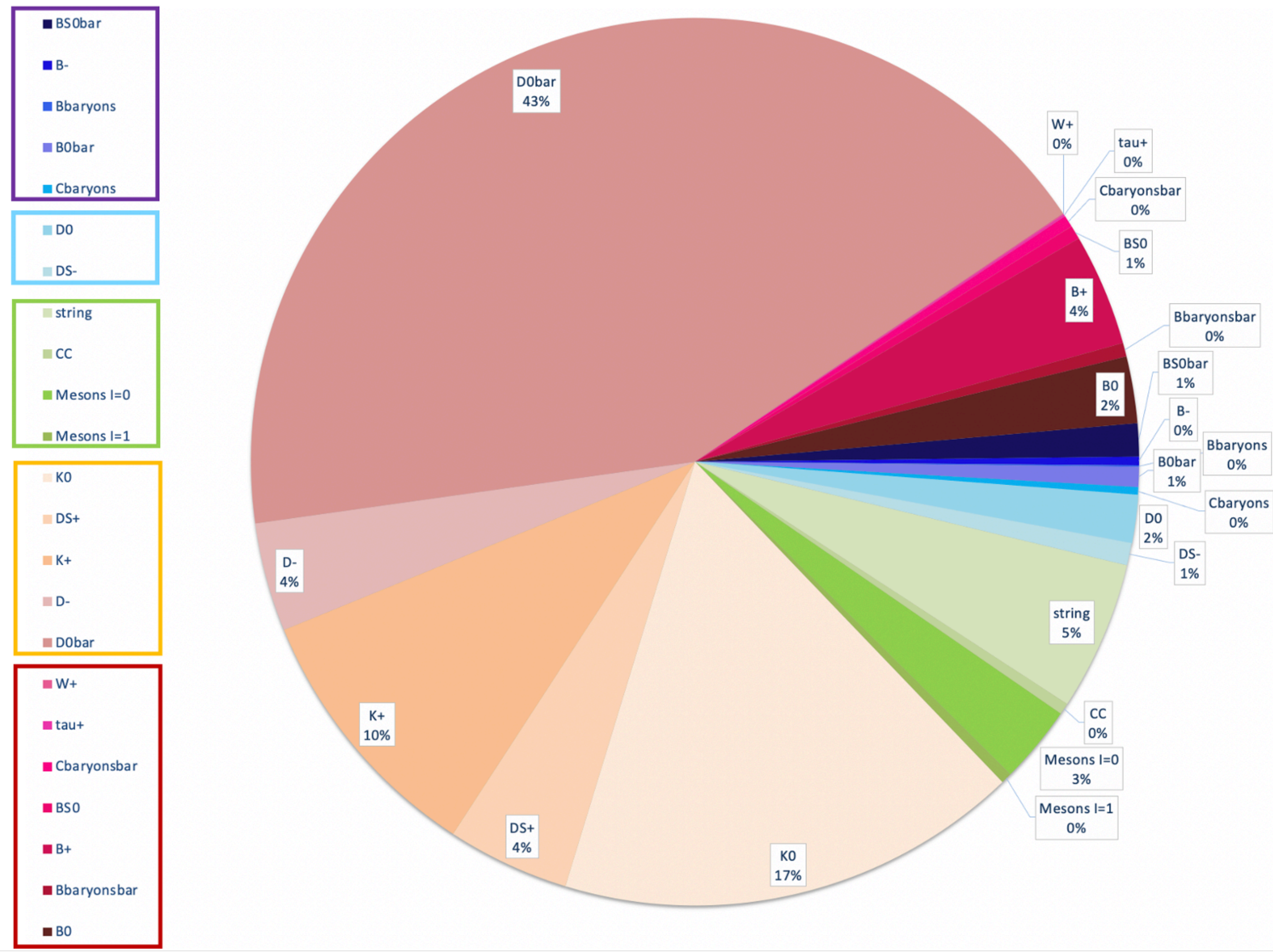
b jet



$B^0 - \bar{B}^0$ mixing



$\bar{b}$ jet



☞ *The purple end final leading K^+ is closer to b **jet***

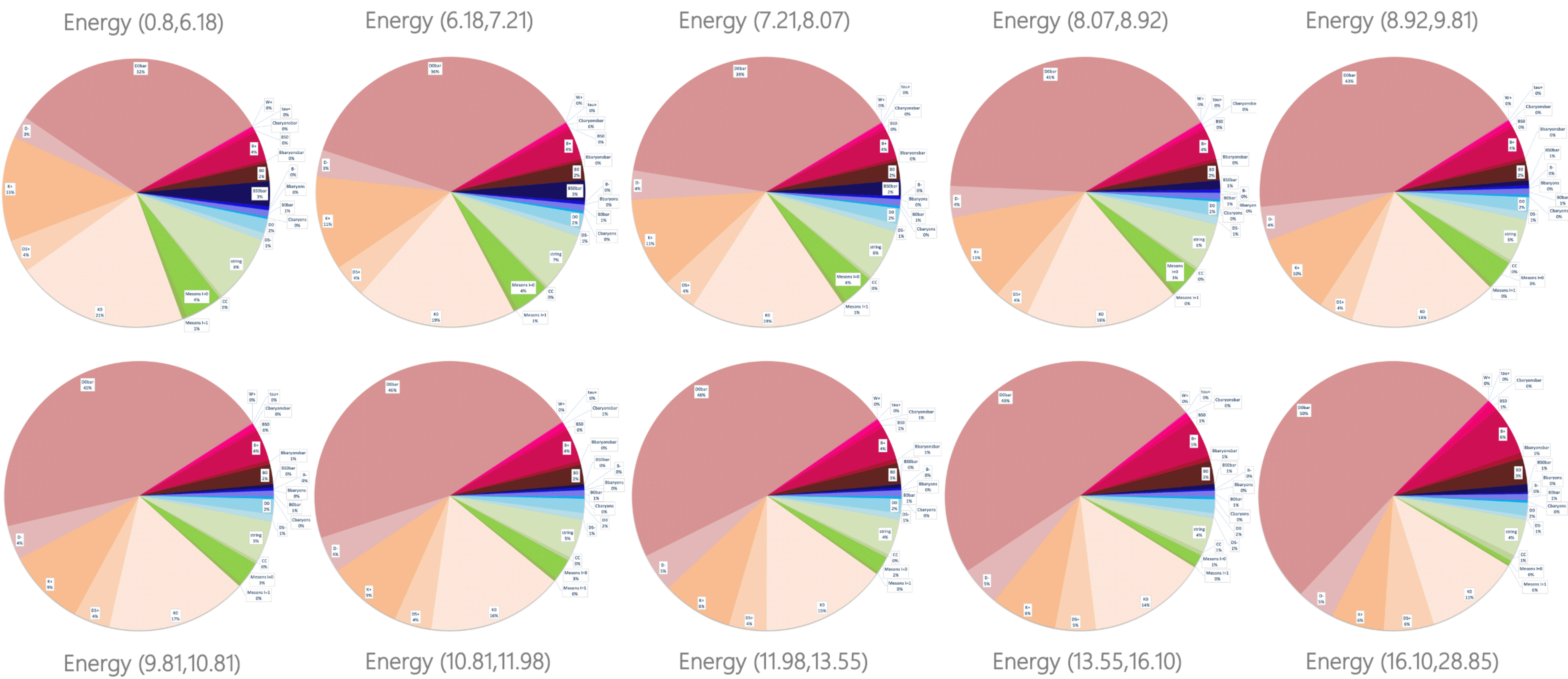
☞ *The green part final leading K^+ is neither closer to b jet nor closer to $\bar{b}$ jet*

☞ *The red end final leading K^+ is closer to $\bar{b}$ **jet***

$Z \to b\bar{b}$

Different decays v.s. Energy Threshold

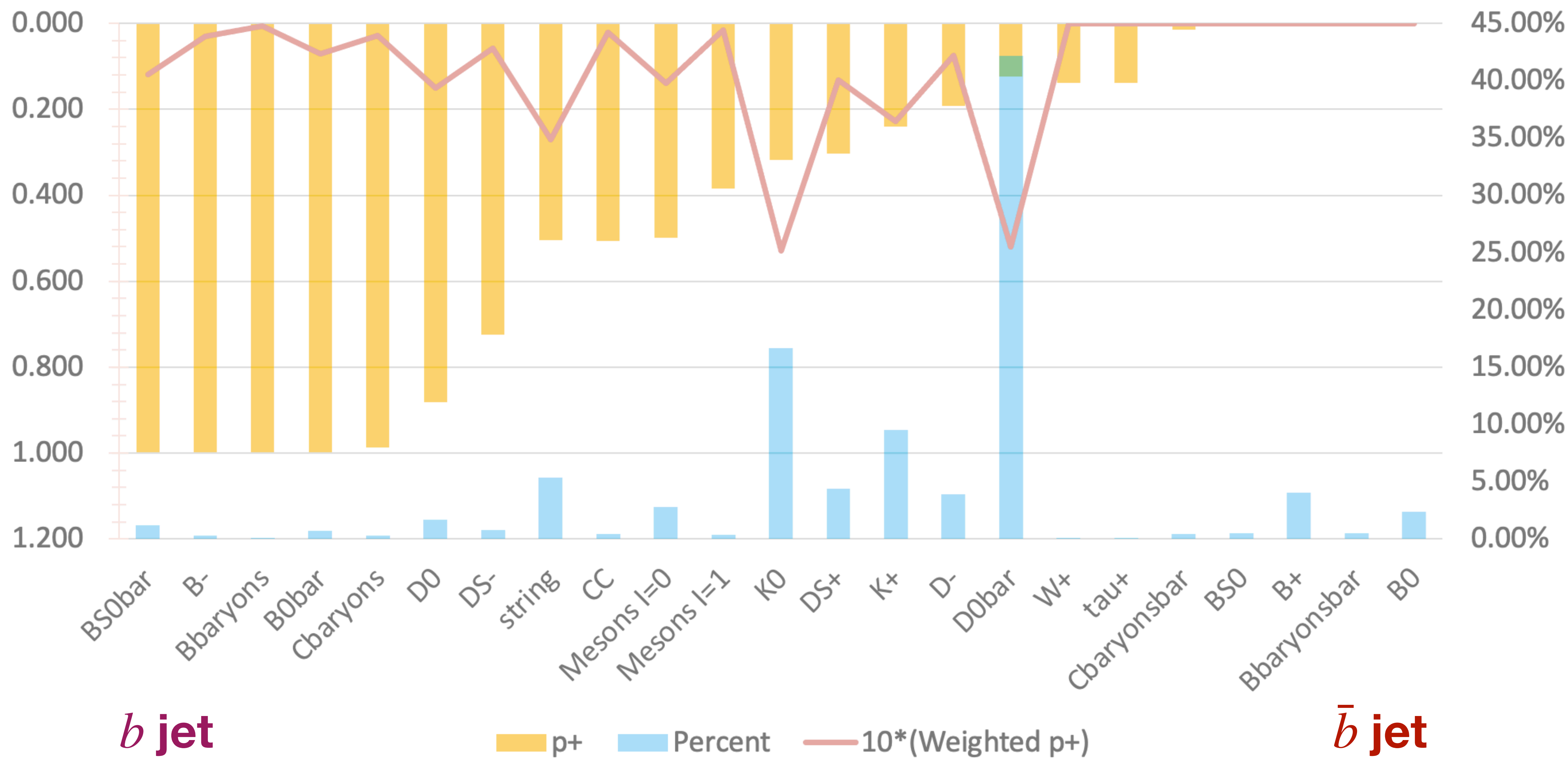
Percent of final leading K^+ from different decay modes v.s. Energy Threshold



- ☞ *Percent of final leading K^+ from different decay modes varies with energy threshold*
- ☞ *The purple end K^+ (closer to b **jet**) increase as the energy threshold goes up*
- ☞ *The red end K^+ (closer to $\bar{b}$ **jet**) decrease as the energy threshold goes up*

$Z \to b\bar{b}$ ω of different decay modes v.s. Energy Threshold

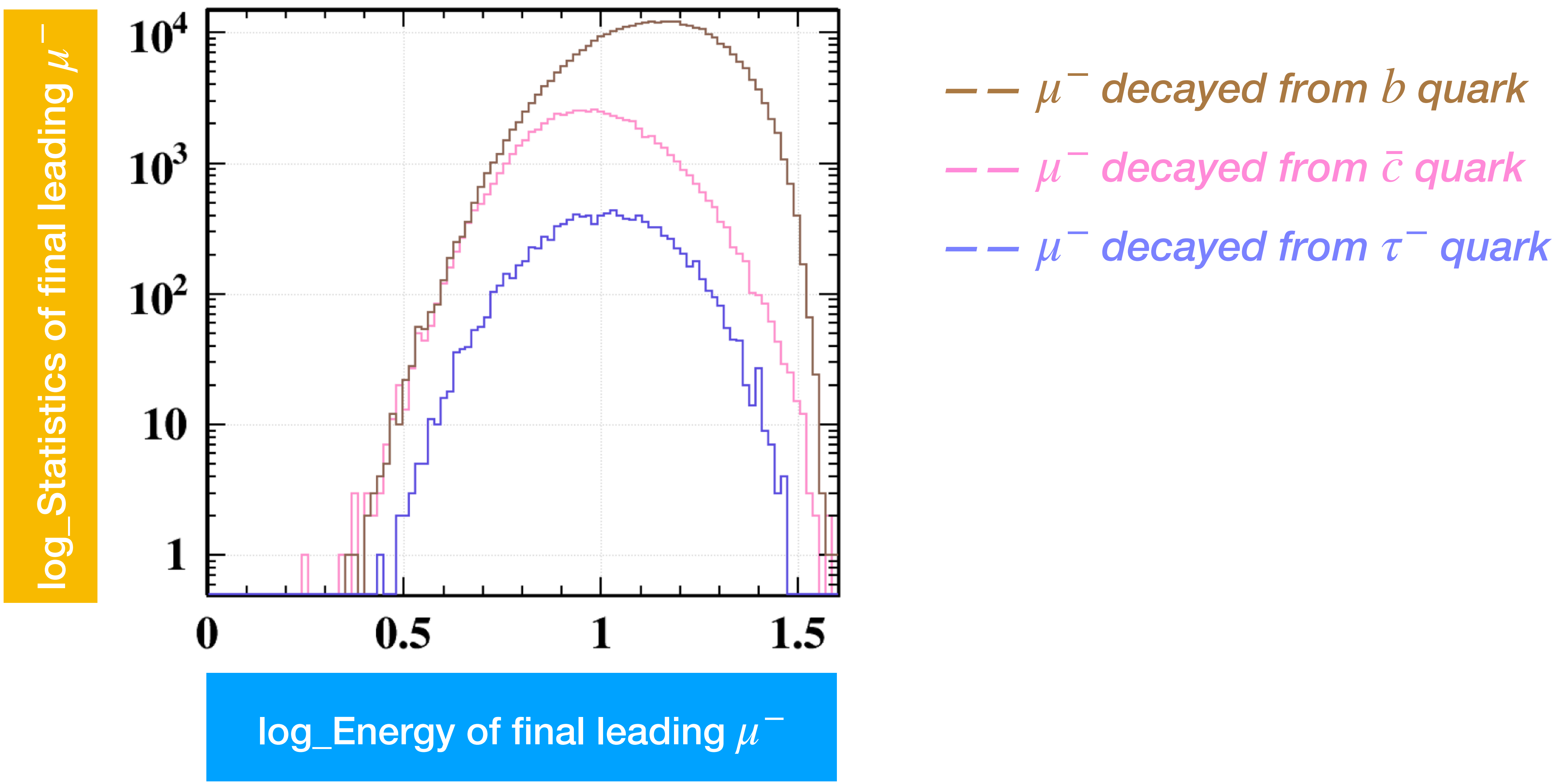
Misjudgment rate ω of final leading K^+ from different decay modes v.s. Energy Threshold



☞ $p+ = \int_{0}^{\pi/2} angle(x,b)$, $p- = \int_{\pi/2}^{\pi} angle(x,b)$, $\omega = min(p+,p-)$

☞ p+ close to 1 makes K^+ closer to b jet, p+ close to 0 makes K^+ closer to $\bar{b}$ jet

$Z \to b\bar{b}$ **Energy spectrum of leading μ^- from different decays**



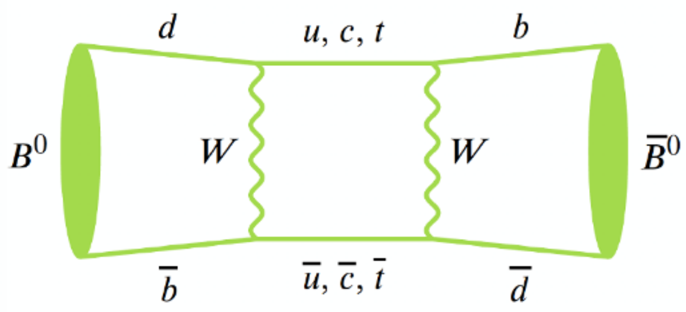
☞ *Energy spectrum of final leading μ^- from different decay modes is different*

☞ *Energy spectrum of final leading μ^- from different decay modes varies with energy threshold*

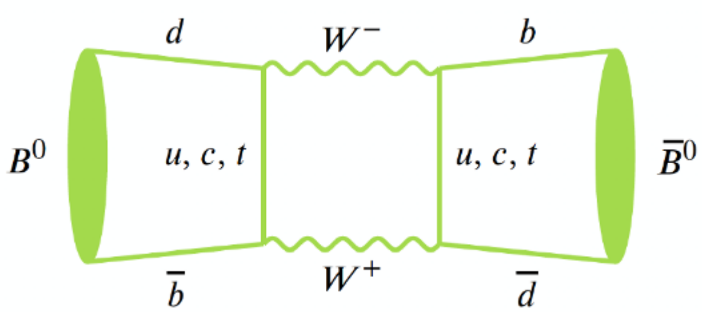
$Z \to b\bar{b}$

Percent of leading μ^- from different decays

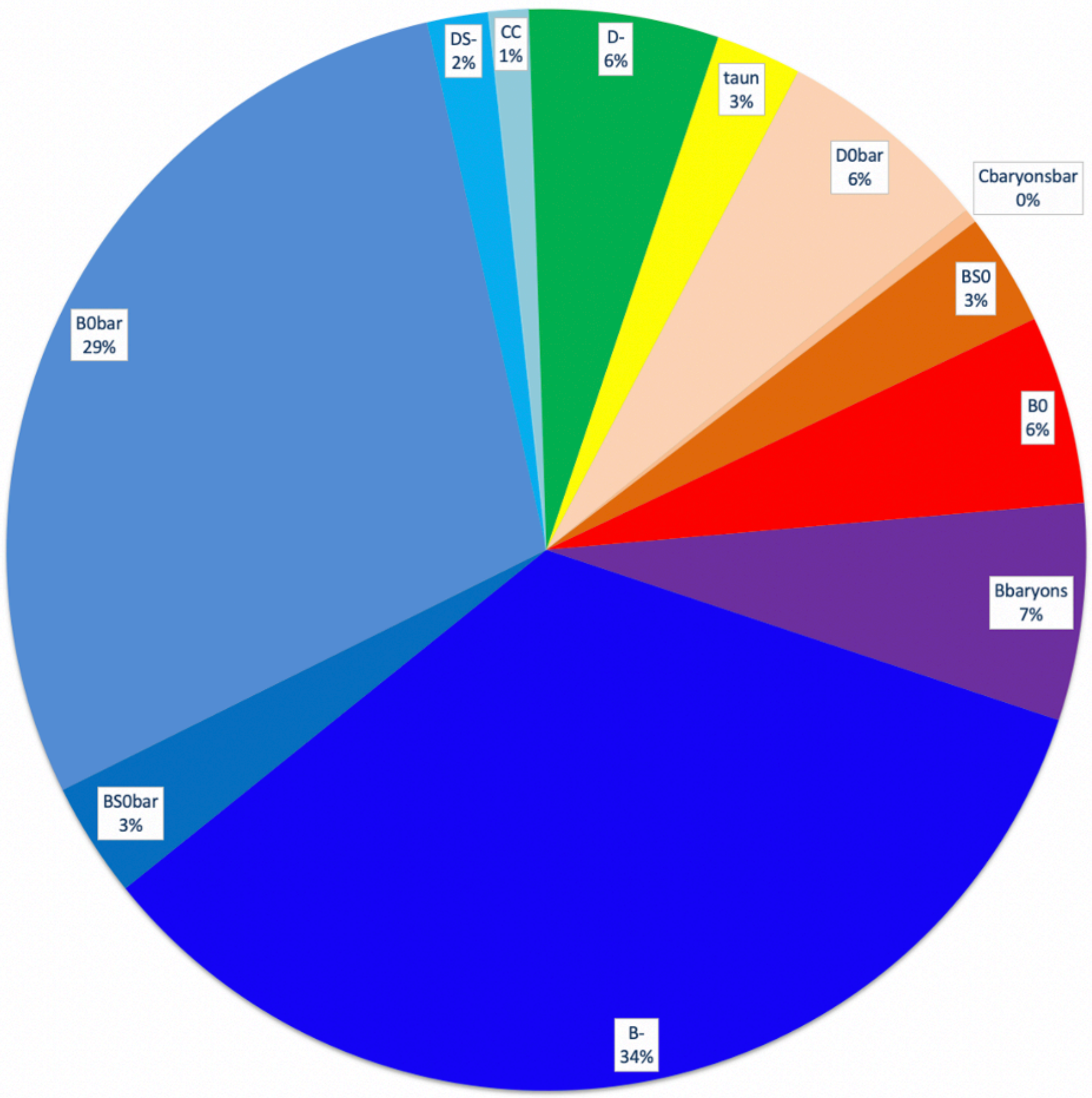
b jet



$B^0 - \bar{B}^0$ mixing



$\bar{b}$ jet



☞ *The purple end final leading μ^- is closer to b jet*

☞ *The green part final leading μ^- is neither closer to b jet nor closer to $\bar{b}$ jet*

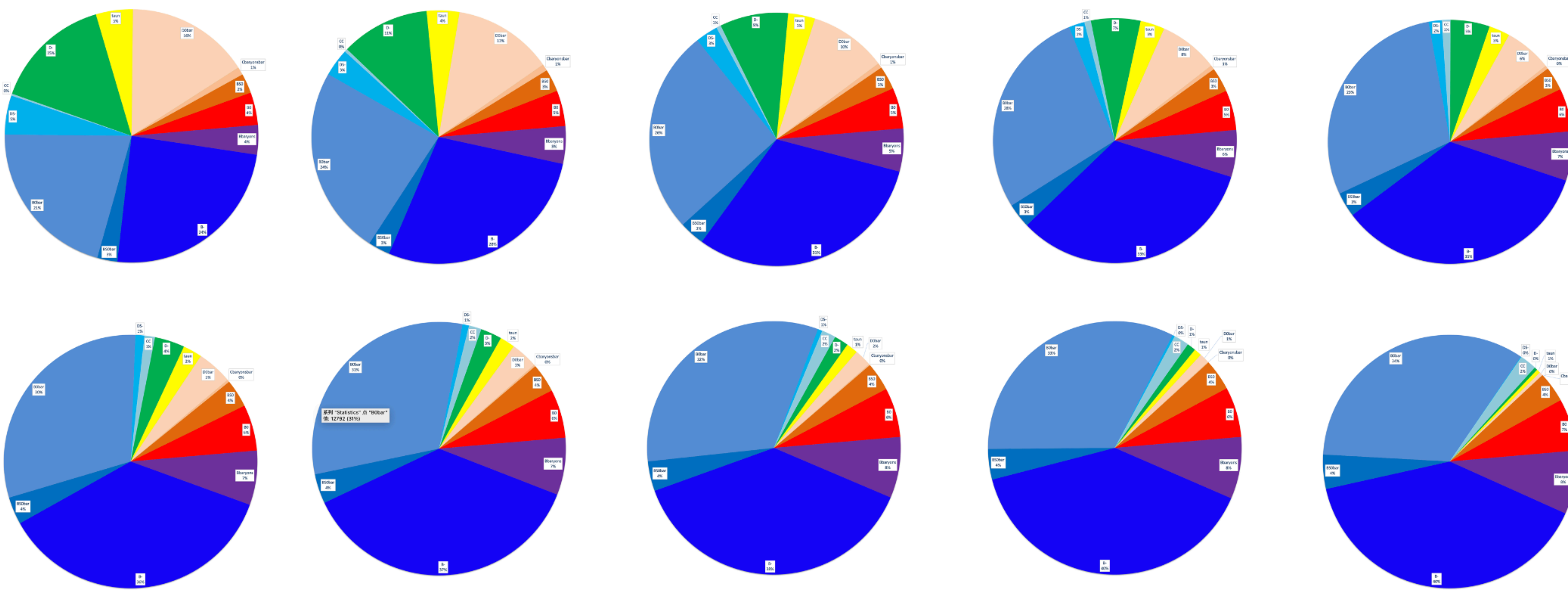
☞ *The red end final leading μ^- is closer to $\bar{b}$ jet*

$Z \to b\bar{b}$

Different decays v.s. Energy Threshold

Percent of final leading μ^- from different decay modes v.s. Energy Threshold

Energy (0.8,7.33) Energy (7.33,8.80) Energy (8.80,10.09) Energy (10.09,11.34) Energy (11.34,12.65)

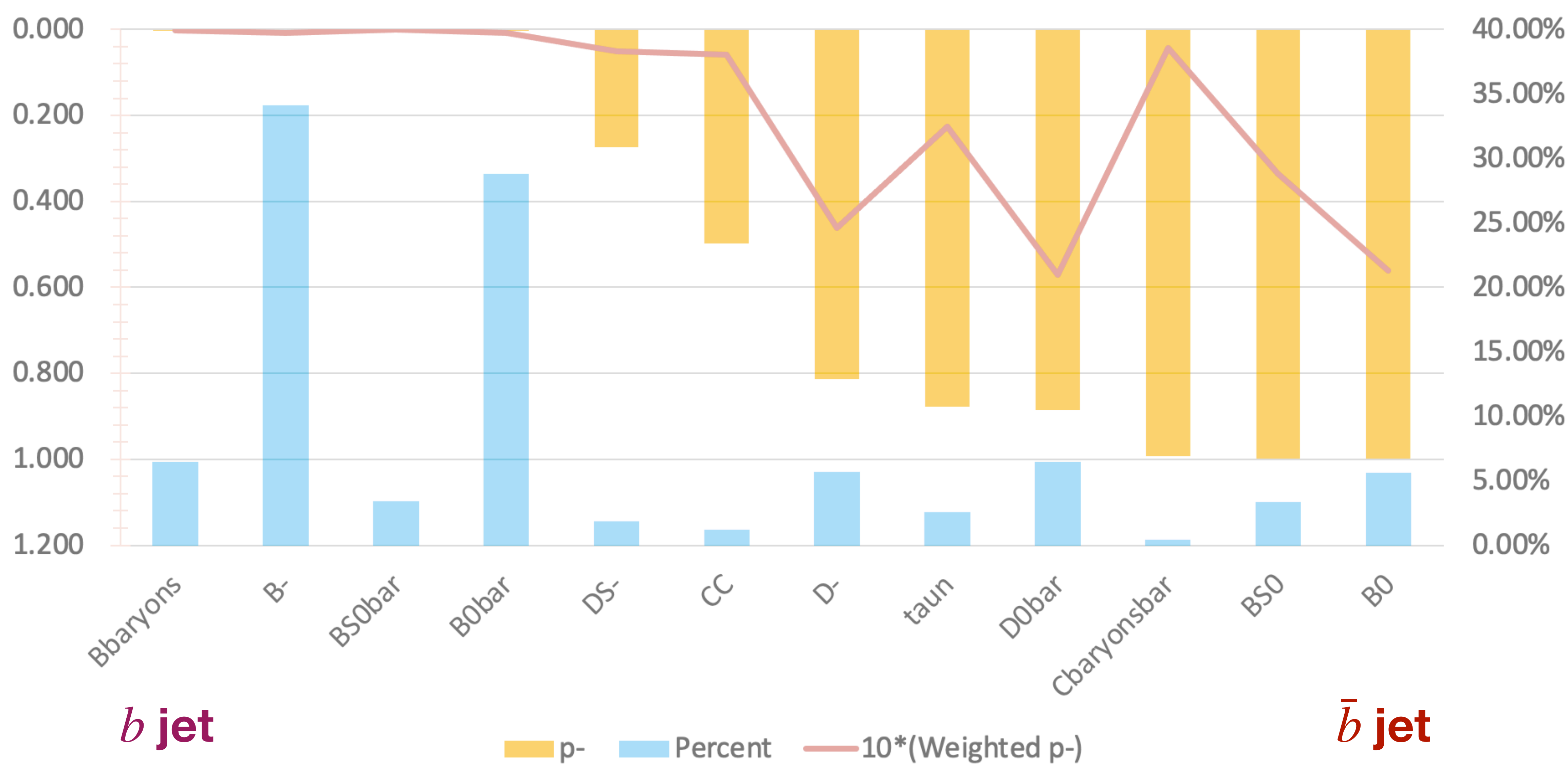


Energy (12.65,14.10) Energy (14.10,15.77) Energy (15.77,17.85) Energy (17.85,20.85) Energy (17.85,38.45)

- ☞ *Percent of final leading μ^- from different decay modes varies with energy threshold*
- ☞ *The purple end μ^- (closer to b jet) increase as the energy threshold goes up*
- ☞ *The red end μ^- (closer to $\bar{b}$ jet) decrease as the energy threshold goes up*

$Z \to b\bar{b}$ ω of different decay modes v.s. Energy Threshold

Misjudgment rate ω of final leading μ^- from different decay modes v.s. Energy Threshold



☞ $p+ = \int_0^{\pi/2} angle(x,b)$, $p- = \int_{\pi/2}^{\pi} angle(x,b)$, $\omega = min(p+,p-)$

☞ p- close to 0 makes μ^- closer to b **jet**, p- close to 1 makes μ^- closer to $\bar{b}$ **jet**

Effective Tagging Power
Single Jet → Double Jets

For "same charged" samples

If the leading particles of two jets have same charge, select the leading particle with higher energy.

For $Z \to b\bar{b}$: from 0.127 to 0.137

(Improve ~7.9%)

bbar jet → b jet ↓	+	-
+	19.54%	7.15%
-	53.81%	19.50%

For $Z \to c\bar{c}$: from 0.127 to 0.136

(Improve ~6.7%)

cbar jet → c jet ↓	+	-
+	13.96%	69.12%
-	2.90%	14.01%

charge verse

Charge correct

Charge same

$Z \to b\bar{b}$ Percentage of b hadrons (b jet vs $\bar{b}$ jet)

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

by WHIZARD195

$Z \to c\bar{c}$ Percentage of c hadrons (c jet vs $\bar{c}$ jet)

percent cbar jet → c jet ↓	D^-	D^0 bar	D_s^-	Λ_c^-	others	all
D^+	4.654%	13.302%	1.717%	1.444%	0.529%	21.532%
D^0	13.290%	37.933%	4.887%	4.110%	1.122%	61.342%
D_s^+	1.712%	4.894%	0.631%	0.533%	0.159%	7.929%
Λ_c^+	1.442%	4.111%	0.533%	0.449%	0.141%	6.676%
others	0.402%	1.066%	0.148%	0.135%	0.656%	2.521%
all	21.500%	61.306%	7.916%	6.671%	2.607%	100%

by WHIZARD195

b/c hadron multiplicity

Num_B bbar jet → b jet ↓	0	1	2	3
0	0.02%	1.25%	0.61%	1E-05
1	1.25%	96.08%	0.03%	0.05%
2	0.61%	0.03%	0.03%	2E-07
3	8E-06	0.05%	3E-07	2E-07

82.4% decayed to leading particle

Num_C cbar jet → c jet ↓	0	1	2	3
0	0.02%	1.24%	0.76%	6E-05
1	1.24%	94.74%	0.03%	0.46%
2	0.75%	0.03%	0.21%	6E-05
3	6E-05	0.46%	5E-05	2E-05

66.2% decayed to leading particle

by WHIZARD195

$Z \to b\bar{b}$

Effective Tagging Power of different b hadrons combination

Total Effective Tagging Power = (13.716 ± 0.014)%

effective tagging power	B^0	B^+	B_s^0	B_c^+	$\Lambda_b$bar
B^0bar	8.403 ±0.026	15.213 ±0.037	3.775 ±0.037	8.961 ±0.768	22.144 ±0.110
B^-	15.137 ±0.047	22.434 ±0.062	9.500 ±0.063	16.784 ±1.071	30.450 ±0.134
B_s^0bar	3.730 ±0.037	9.673 ±0.063	0.382 ±0.024	3.406 ±0.954	14.756 ±0.187
B_c^-	8.639 ±0.732	15.817 ±1.063	1.061 ±0.495	-	25.021 ±3.309
Λ_b	22.224 ±0.110	30.313 ±0.134	14.518 ±0.186	26.729 ±3.322	40.840 ±0.3915

charge verse & same

$Z \to c\bar{c}$

Effective Tagging Power of different c hadrons combination

Total Effective Tagging Power = *(30.116 ± 0.022)%*

effective tagging power	D^-	D^0bar	D_s^-	Λ_c^-
D^+	27.184 ±0.098	30.702 ±0.062	22.353 ±0.144	35.202 ±0.200
D^0	30.644 ±0.062	33.779 ±0.039	25.816 ±0.093	37.813 ±0.124
D_s^+	22.287 ±0.144	25.670 ±0.093	18.006 ±0.204	30.236 ±0.298
Λ_c^+	35.135 ±0.200	37.930 ±0.124	29.543 ±0.295	42.924 ±0.395

charge verse & same

$Z \to b\bar{b}$ Effective Tagging Power of B Hadrons

Total Effective Tagging Power = *12.736%*

% bbar jet → b jet ↓	B^0	B^+	B_s^0	B_c^+	$\Lambda_b$bar
B^0bar	7.792	14.044	3.491	8.346	20.179
B^-	13.965	20.604	8.734	14.568	27.854
B_s^0bar	3.486	8.882	0.363	3.046	13.346
B_c^-	7.820	14.426	0.774	-	23.294
Λ_b	20.268	27.788	13.064	22.841	37.460

charge verse

Total Effective Tagging Power = *13.716%*

% bbar jet → b jet ↓	B^0	B^+	B_s^0	B_c^+	$\Lambda_b$bar
B^0bar	8.403	15.213	3.775	8.961	22.144
B^-	15.137	22.434	9.500	16.784	30.450
B_s^0bar	3.730	9.673	0.382	3.406	14.756
B_c^-	8.639	15.817	1.061	-	25.021
Λ_b	22.224	30.313	14.518	26.729	40.840

charge verse & same

$Z \to c\bar{c}$ Effective Tagging Power of C Hadrons

Total Effective Tagging Power = 28.214%

% cbar jet → c jet ↓	D^-	D^0bar	D_s^-	Λ_c^-
D^+	25.605	28.561	21.514	32.280
D^0	28.544	31.285	24.395	34.759
D_s^+	21.452	24.252	17.423	28.135
Λ_c^+	32.148	34.849	27.635	39.511

charge verse

Total Effective Tagging Power = 30.116%

% cbar jet → c jet ↓	D^-	D^0bar	D_s^-	Λ_c^-
D^+	27.184	30.702	22.353	35.202
D^0	30.644	33.779	25.816	37.813
D_s^+	22.287	25.670	18.006	30.236
Λ_c^+	35.135	37.930	29.543	42.924

charge verse & same

$Z \to b\bar{b}$ Weighted Effective Tagging Power of B Hadrons

Total Effective Tagging Power = 12.736%

% bbar jet → b jet ↓	B^0	B^+	B_s^0	B_c^+	$\Lambda_b$bar
B^0bar	1.353	2.437	0.118	0.002	0.557
B^-	2.423	3.577	0.294	0.003	0.770
B_s^0bar	0.117	0.299	0.002	0.0001	0.073
B_c^-	0.002	0.003	0.00003	-	0.0008
Λ_b	0.560	0.768	0.071	0.0008	0.169

charge verse

Total Effective Tagging Power = 13.716%

% bbar jet → b jet ↓	B^0	B^+	B_s^0	B_c^+	$\Lambda_b$bar
B^0bar	1.459	2.640	0.127	0.002	0.611
B^-	2.627	3.895	0.320	0.004	0.842
B_s^0bar	0.125	0.325	0.003	0.0001	0.080
B_c^-	0.002	0.003	0.00005	-	0.0009
Λ_b	0.614	0.837	0.079	0.001	0.184

charge verse & same

$Z \to c\bar{c}$ Weighted Effective Tagging Power of C Hadrons

Total Effective Tagging Power = 28.214%

% cbar jet → c jet ↓	D^-	D^0bar	D_s^-	Λ_c^-
D^+	1.192	3.800	0.370	0.466
D^0	3.794	11.870	1.1925	1.429
D_s^+	0.367	1.187	0.110	0.150
Λ_c^+	0.464	1.433	0.147	0.177

charge verse

Total Effective Tagging Power = 30.116%

% cbar jet → c jet ↓	D^-	D^0bar	D_s^-	Λ_c^-
D^+	1.265	4.085	0.384	0.508
D^0	4.074	12.817	1.262	1.554
D_s^+	0.382	1.257	0.114	0.161
Λ_c^+	0.507	1.560	0.157	0.193

charge verse & same

$Z \to b\bar{b}$

Misjudgment rate ω of $\{e, \mu, K\}\{e, \mu, K\}$

Total Misjudgment rate ω = 11.73%

% bbar jet → b jet ↓	B^0	B^+	B_s^0	B_c^+	$\Lambda_b$bar
B^0bar	16.73	9.42	27.80	12.80	10.51
B^-	9.51	5.09	17.08	9.55	5.78
B_s^0bar	28.07	16.59	43.62	36.21	19.09
B_c^-	19.74	7.30	46.81	-	11.43
Λ_b	10.63	5.52	19.20	3.85	6.11

All b hadrons

Total Misjudgment rate ω = 9.20%

% bbar jet → b jet ↓	B^0	B^+	B_s^0	B_c^+	$\Lambda_b$bar
B^0bar	14.74	6.55	29.20	7.22	8.67
B^-	6.62	2.74	14.74	3.77	3.89
B_s^0bar	29.29	14.41	50.47	27.27	19.61
B_c^-	14.56	4.63	50.00	-	18.18
Λ_b	8.99	3.59	19.80	0	4.80

b hadrons that decayed to leading particles

$Z \to c\bar{c}$

Misjudgment rate ω of $\{e, \mu, K\}\{e, \mu, K\}$

Total Misjudgment rate ω = 4.03%

% cbar jet → c jet ↓	D^-	D^0bar	D_s^-	Λ_c^-
D^+	4.53	2.98	12.90	8.50
D^0	3.03	2.05	8.80	6.29
D_s^+	12.64	9.13	31.45	21.65
Λ_c^+	8.32	5.96	23.37	15.07

All c hadrons

Total Misjudgment rate ω = 1.11%

% cbar jet → c jet ↓	D^-	D^0bar	D_s^-	Λ_c^-
D^+	1.80	0.55	11.78	4.16
D^0	0.57	0.17	4.08	1.26
D_s^+	11.87	4.32	51.86	25.84
Λ_c^+	4.27	1.37	26.06	10.57

c hadrons that decayed to leading particles

$Z \to b\bar{b}$

Correlation of b jet and $\bar{b}$ jet

σ bbar jet → b jet ↓	B^0	B^+	B_s^0	B_c^+	$\Lambda_b$bar
B^0bar	12.475	11.195	4.459	0.612	0.069
B^-	11.216	11.930	3.359	0.670	1.456
B_s^0bar	1.424	2.830	0.749	-0.185	4.988
B_c^-	-0.658	-0.598	-0.181	0.200	0.537
Λ_b	0.848	0.829	3.774	0.537	5.644

$$\sigma = \frac{Residual}{Uncertainty}$$

$Z \to c\bar{c}$ Correlation Measurement of c hadrons of c jet and $\bar{c}$ jet

percent cbar jet → c jet ↓	D^-	D^0bar	D_s^-
D^+	4.898	13.006	4.039
D^0	11.554	27.343	5.356
D_s^+	2.389	6.724	1.483

$$\sigma = \frac{Residual}{Uncertainty}$$

Commonly Used

ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩ
αβγδεζηθικλμνξοπρστυφχψω
A_{FB} $\sin^2\theta_W$
$Z \to b\bar{b}$ $Z \to c\bar{c}$
b jet $\bar{b}$ jet
c jet $\bar{c}$ jet
$e^-, \mu^-, K^-, \pi^-, p^+$
$e^+, \mu^+, K^+, \pi^+, p^-$
(e, μ, K) ($\pi, proton$)
$\bar{B}^0$ B^0 B^- B^+ $\bar{B}_s^0$ B_s^0 B_c^- B_c^+ Λ_b $\bar{\Lambda}_b$
D^0 $\bar{D}^0$ D^+ D^- D_s^0 $\bar{D}_s^0$ Λ_c^+ Λ_c^-
Misjudgment rate ω, Effective tagging power