Jet Charge at CEPC

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Outline

- Introduction & Samples
- Method & Results
- Conclusion

Introduction & Samples

CEPC Z pole operation & flavor physics potential

Advantages:

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

Impact of Jet Charge Reconstruction:

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

Flavor production at different

Particle	Tera-Z	Belle II	LHCb
b hadrons			
B^+	6×10^{10}	3×10^{10} ($50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$)	3×10^{13}
B^0	6×10^{10}	3×10^{10} ($50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$)	3×10^{13}
B_s	2×10^{10}	3×10^{8} ($5\,\mathrm{ab}^{-1}$ on $\Upsilon(5S)$)	8×10^{12}
b baryons	1×10^{10}		1×10^{13}
Λ_b	1×10^{10}		1×10^{13}
c hadrons			
D^0	2×10^{11}		
D^+	6×10^{10}		
D_s^+	3×10^{10}		
Λ_c^+	2×10^{10}		
τ^+	3×10^{10}	5×10^{10} ($50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$)	

From CEPC CDR 2018

Our work: a truth level analysis of jet charge reconstruction at CEPC, using leading charged particle in each jet - test of principle

Samples:

- *~1×10⁵* $Z\to b\bar{b}$ *at CEPC Z pole (91.2 GeV) by Sherpa*
- *~1×10⁶* $Z\to b\bar{b}$ *at CEPC Z pole (91.2 GeV) by Herwig*
- *~1×10⁷* $Z\to b\bar{b}$ *at CEPC Z pole (91.2 GeV) by WHIZARD195*
- *~1×10⁷* $Z\to c\bar{c}$ *at CEPC Z pole (91.2 GeV) by WHIZARD195*

Different Generators

Different Flavor

Method & Results

Jet Charge Algorithm

q jet

$\bar{q}$ jet

- *Divide final state particles into two jets with the plane perpendicular to the thrust.*
- *Record the energy & PID of leading charged particle in each jet*
- *Determine the jet charge with the leading charged particle type*
- *Performance quantified by misjudgment rate ω and effective tagging power*

Misjudgment rate ω:

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

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

Efficiency:

➡ *To describe the selection efficiency of $Z \to b\bar{b}$ or $Z \to c\bar{c}$ samples:*

$$\text{Efficiency} = \frac{\text{Number of selected jet samples}}{\text{Number of all jet samples}}$$

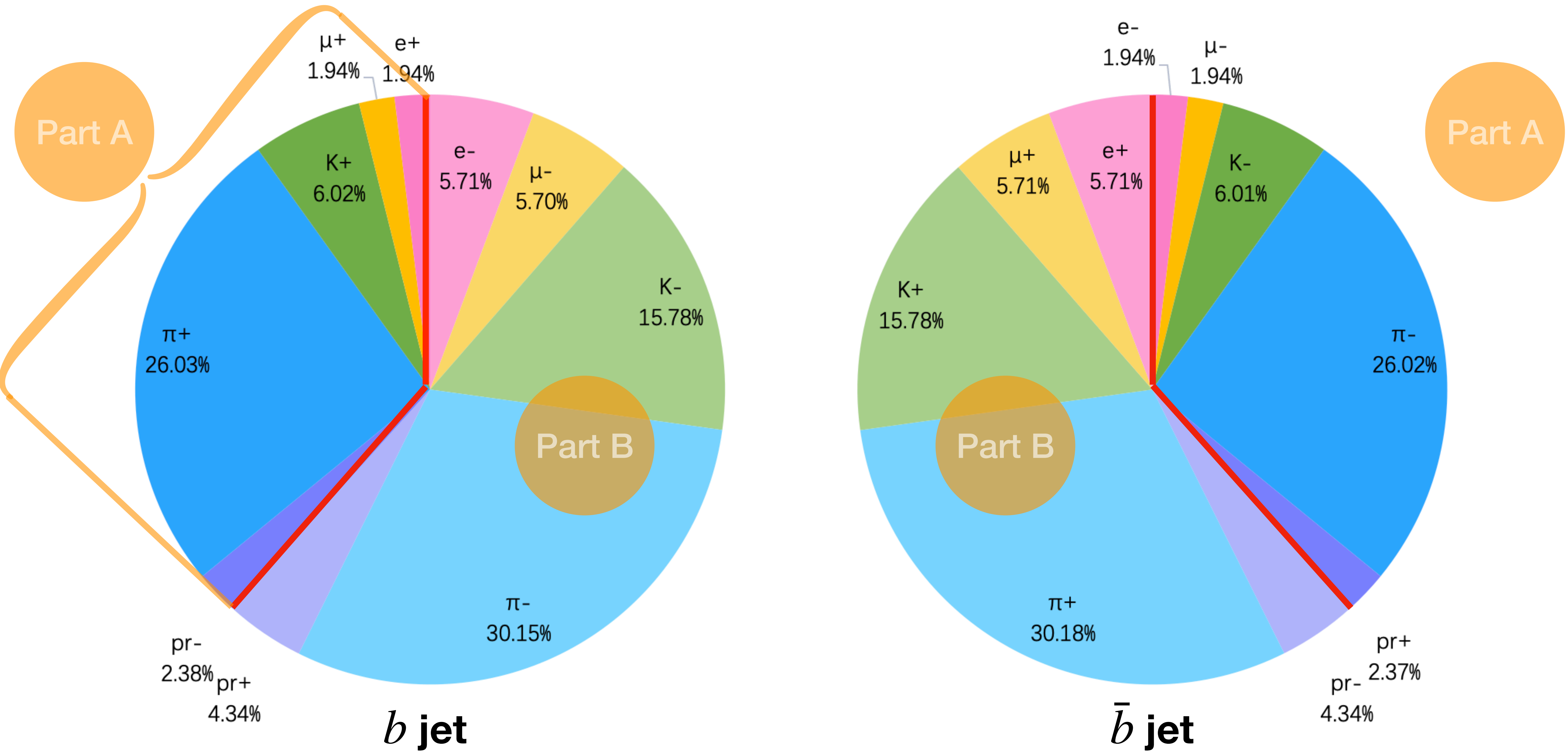
Effective tagging power ETP:

➡ *To consider both misjudgment rate ω and efficiency to describe the total performance of Jet Charge*

$$\text{Effective tagging power} = \text{Efficiency} \ * \ (1 - 2 * \omega)^2$$

$Z \to b\bar{b}$

Percent of final charged leading particles

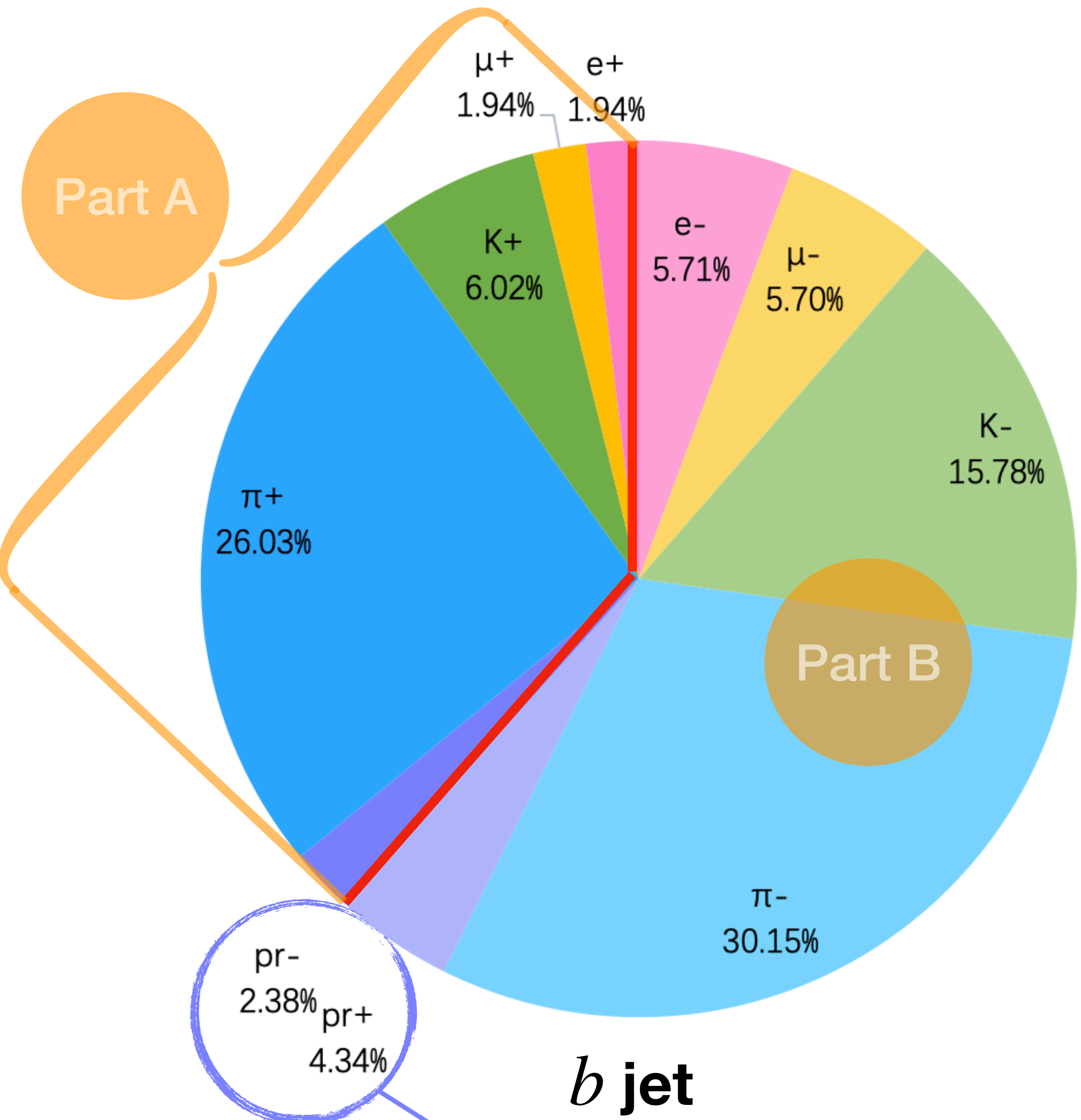


$$P(b\,|\,\mathrm{final}_i) = \frac{P(\mathrm{final}_i\,|\,b)}{P(\mathrm{final}_i\,|\,b) + P(\mathrm{final}_i\,|\,\bar{b})}$$

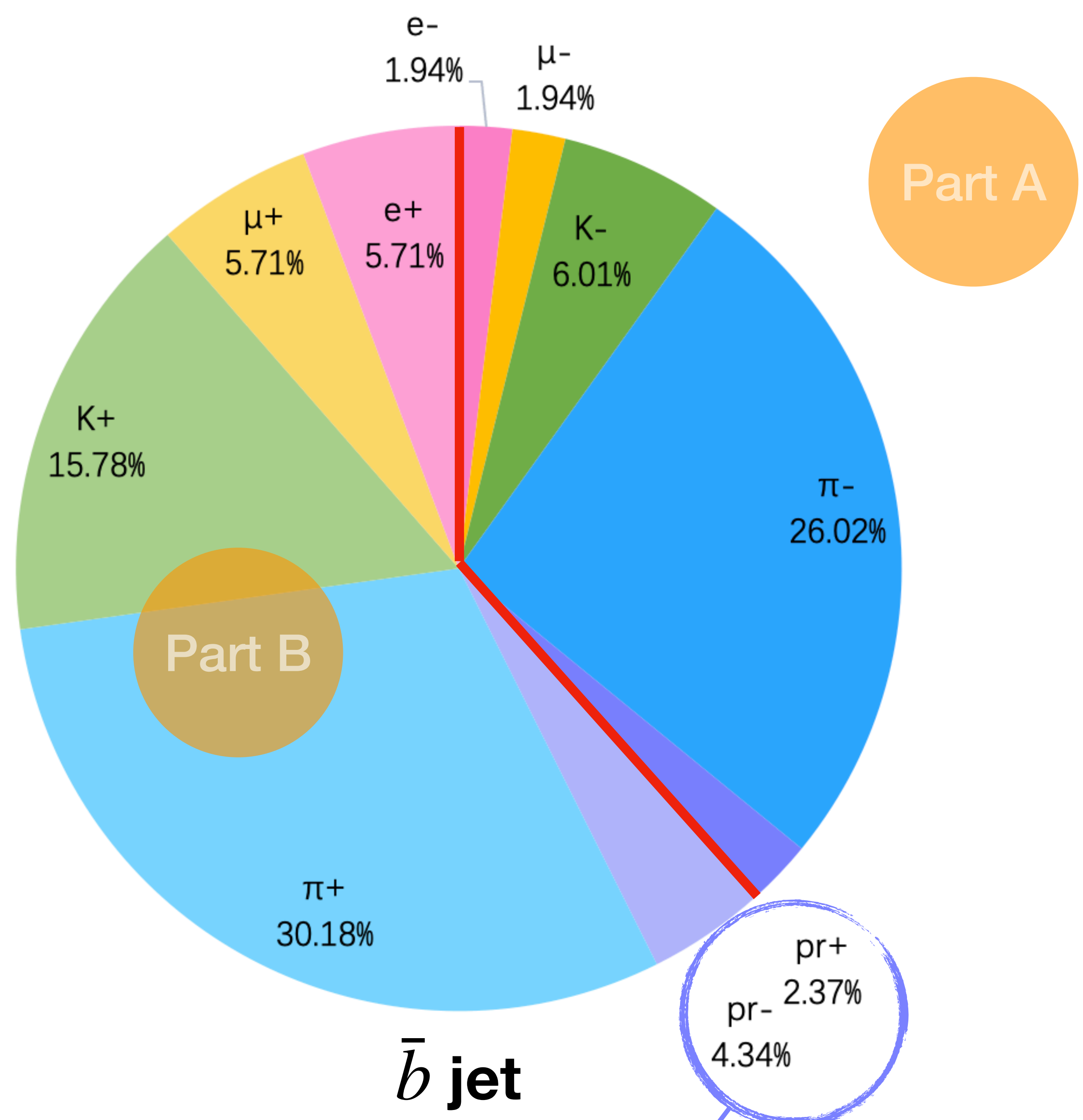
$$\omega = 1 - P(b\,|\,\mathrm{final}_i) = \frac{P(\mathrm{final}_i\,|\,\bar{b})}{P(\mathrm{final}_i\,|\,b) + P(\mathrm{final}_i\,|\,\bar{b})} = \frac{\text{Number of Part A}}{\text{Number of Part }(A+B)}$$

$Z \to b\bar{b}$

Percent of final charged leading particles



b jet



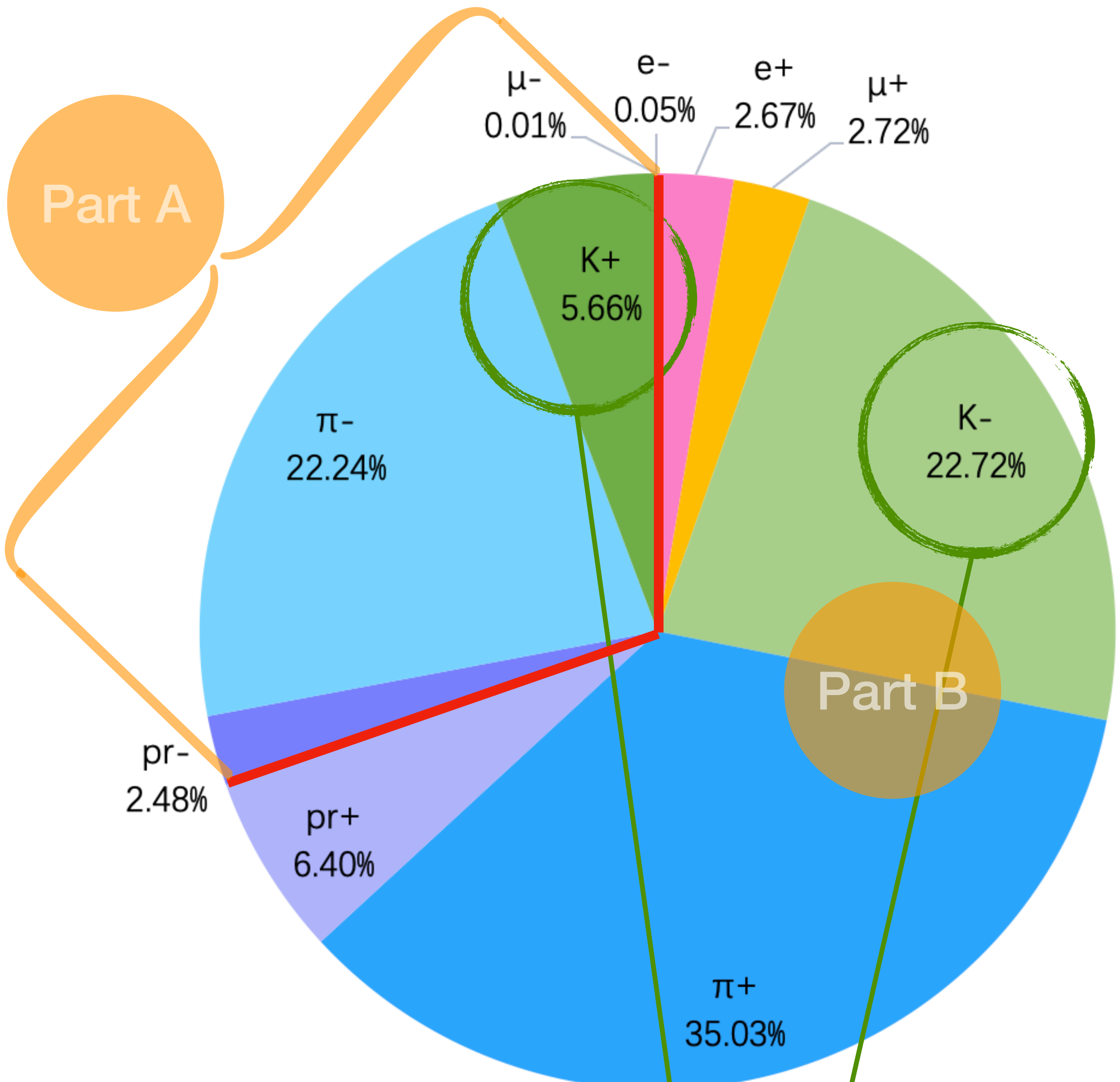
$\bar{b}$ jet

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

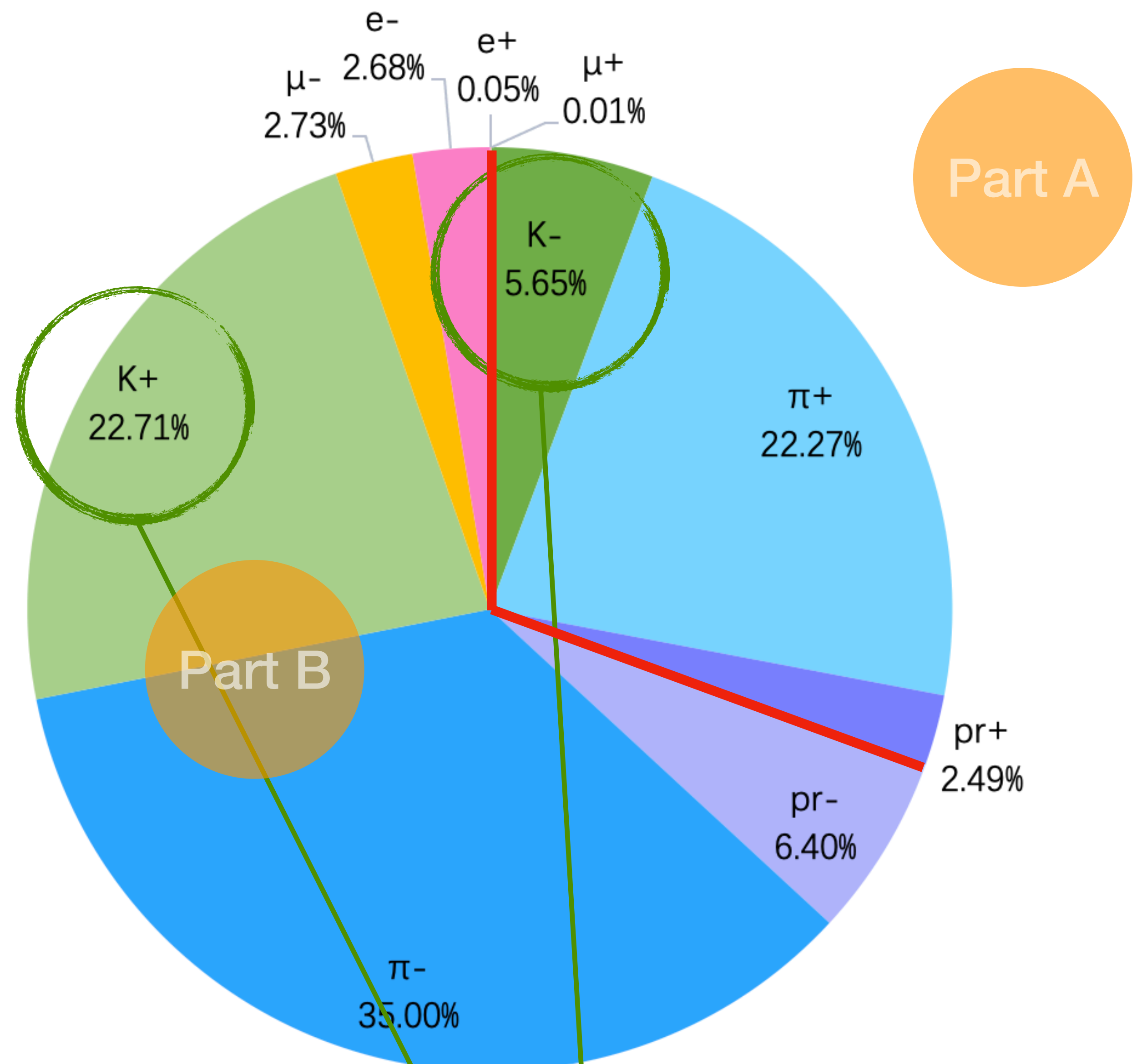
ω(using only charge) = 0.402
ω(using charge & PID) = 0.383

$Z \to c\bar{c}$

Percent of final charged leading particles



c jet



$\bar{c}$ jet

ω(using only charge) = 0.473

ω(using charge & PID) = 0.304

ω(using only charge) = 0.475

ω(using charge & PID) = 0.305

Dependence of misjudgment rate ω

1. Dependence on leading particle type
2. Dependence on B/C hadron type
3. Dependence on the source of leading particle: From B/C hadron decay or not.

Dependence on leading particle type → Categorize leading particles

Lepton and Kaon can deliver better misjudgment rate ω than pion and proton.

→Misjudgment rate ω and effective tagging power of each category

bbar jet → b jet ↓	e,μ,K	π,proton
e,μ,K	13.75% ω = 0.117	23.34% ω = 0.231
π,proton	23.34% ω = 0.231	39.56% ω = 0.404

cbar jet → c jet ↓	e,μ,K	π,proton
e,μ,K	11.46% ω = 0.040	22.38% ω = 0.109
π,proton	22.38% ω = 0.109	43.77% ω = 0.263

$Z \to b\bar{b}$ Percent of B hadrons of b jet and $\bar{b}$ 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

$Z \to c\bar{c}$ Percent of C hadrons of c jet and $\bar{c}$ 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

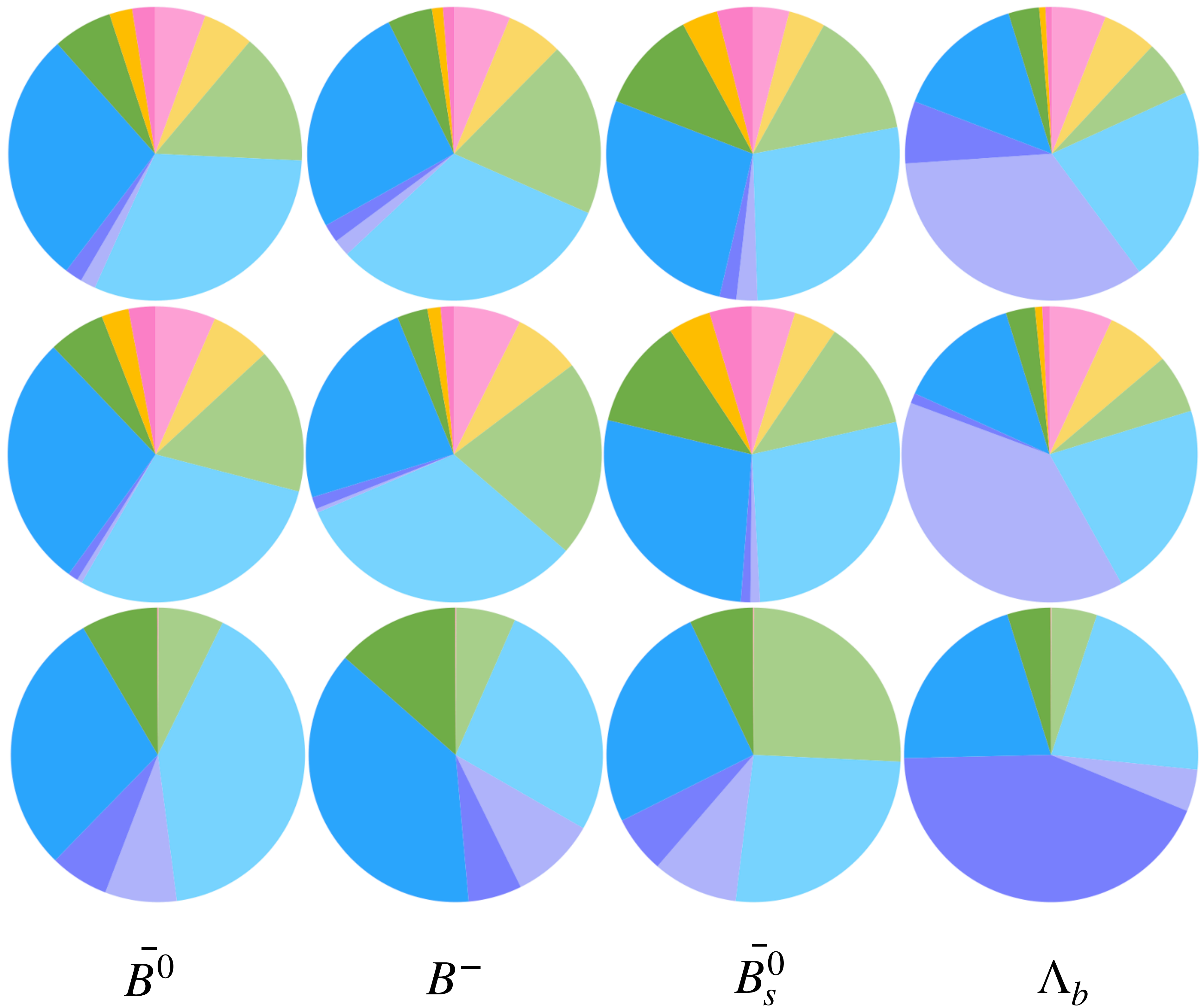
$Z \to b\bar{b}$

Percent of leading particles of each B hadron of b jet

All leading particles

Leading particles from leading hadron

Leading particles from QCD



by WHIZARD195

$Z \to b\bar{b}$

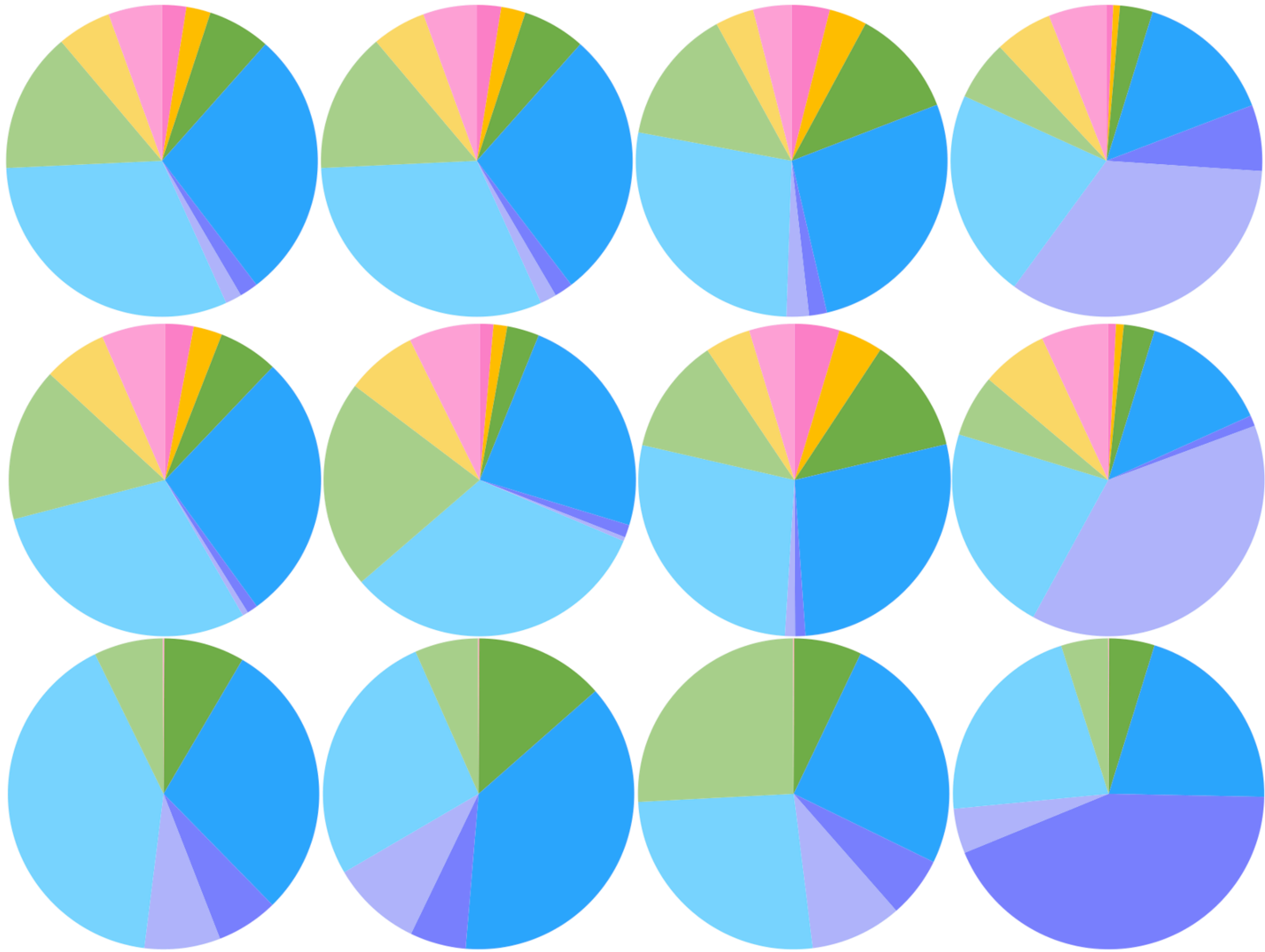
conjugate to b jet

Percent of leading particles of each B hadron of $\bar{b}$ jet

All leading particles

Leading particles from leading hadron

Leading particles from QCD



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

by WHIZARD195

Different Generators
(Whizard195 & Herwig & Sherpa)

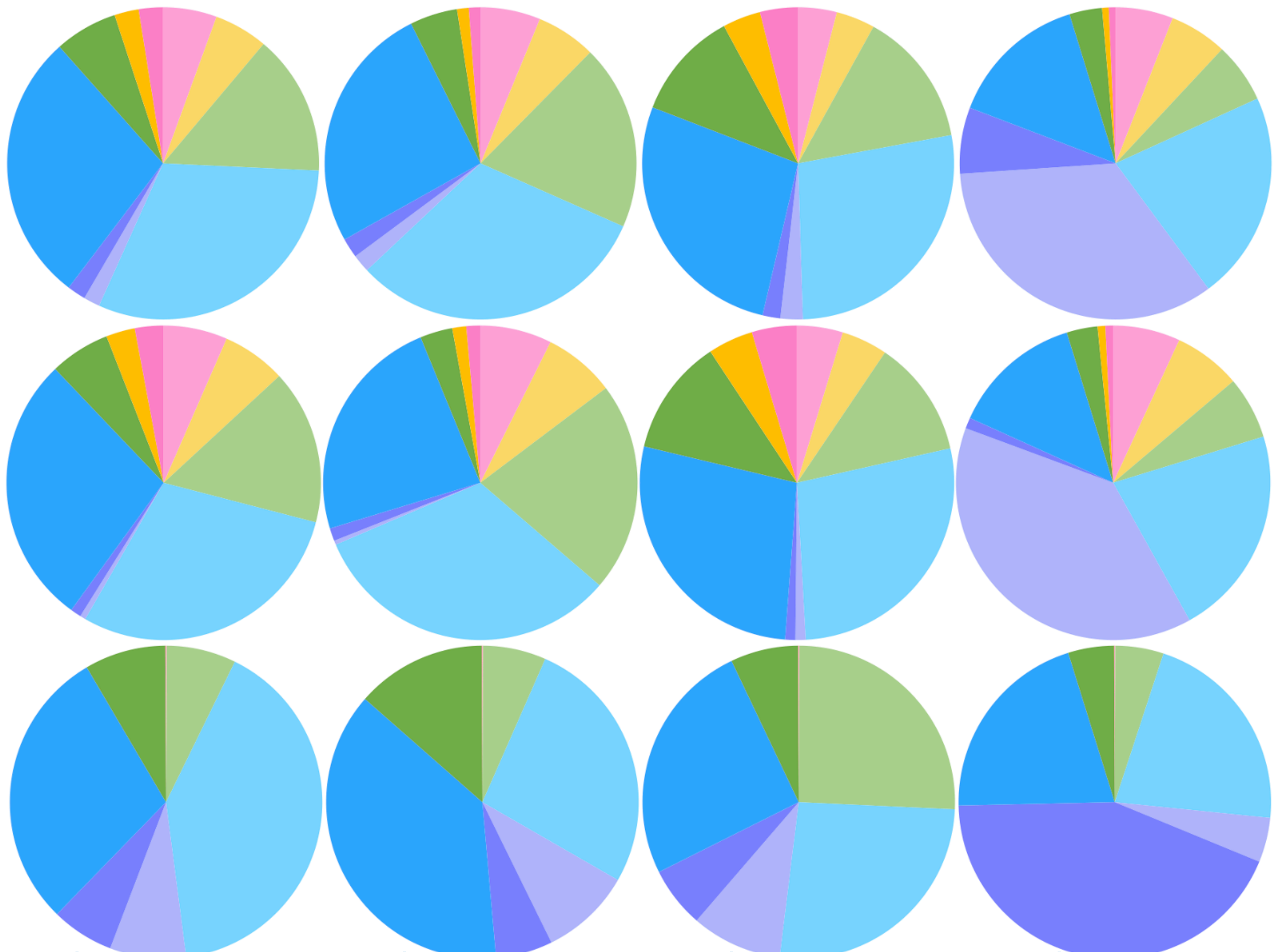
$Z \to b\bar{b}$

Percent of leading particles of each B hadron of b jet

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

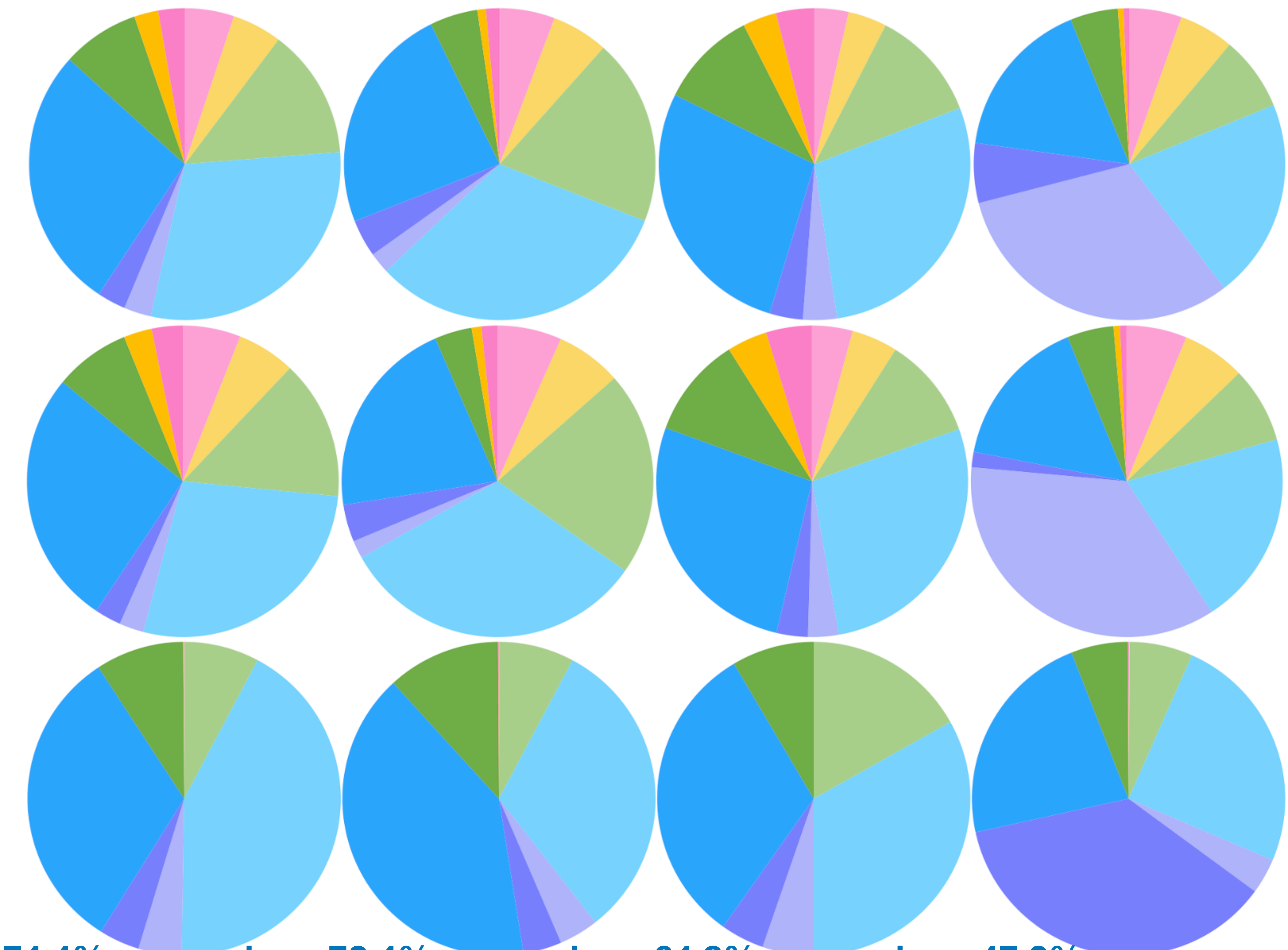
$Z \to b\bar{b}$

Percent of leading particles of each B hadron of b jet

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%	pion ~72.4%	pion ~64.8%	pion ~47.3%
Kaon ~16.8%	Kaon ~19.4%	Kaon ~25.4%	Kaon ~12.4%
proton ~8.7%	proton ~8.0%	proton ~9.8%	proton ~40.1%

by Herwig

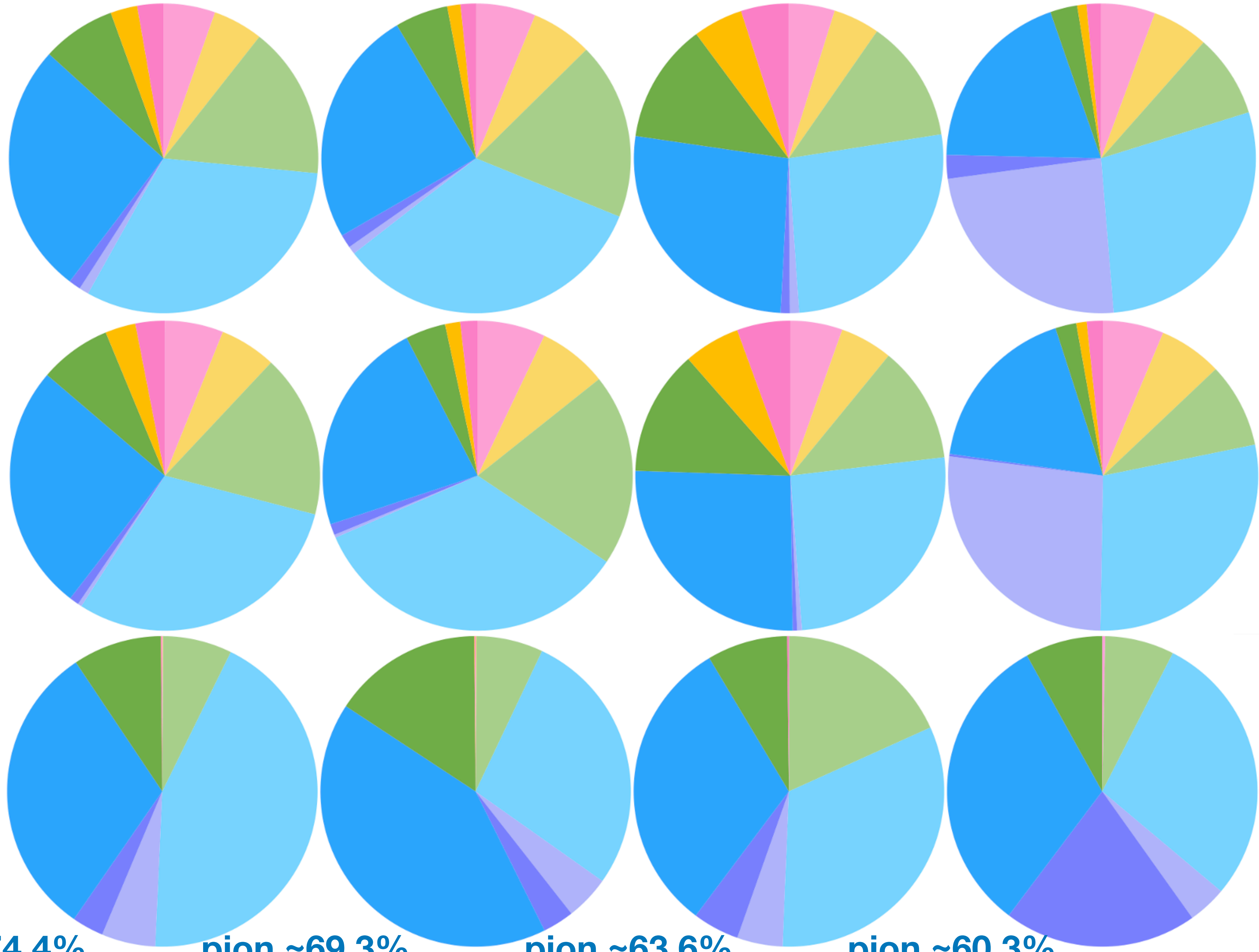
$Z \to b\bar{b}$

Percent of leading particles of each B hadron of b jet

All leading particles

Leading particles from leading hadron ~87.0%

Leading particles from QCD ~13.0%



$\bar{B}^0$	B^-	$\bar{B}_s^0$	Λ_b
pion ~74.4%	pion ~69.3%	pion ~63.6%	pion ~60.3%
Kaon ~16.4%	Kaon ~22.5%	Kaon ~26.6%	Kaon ~15.3%
proton ~8.9%	proton ~7.9%	proton ~9.6%	proton ~24.2%

by Sherpa

$Z \to b\bar{b}$

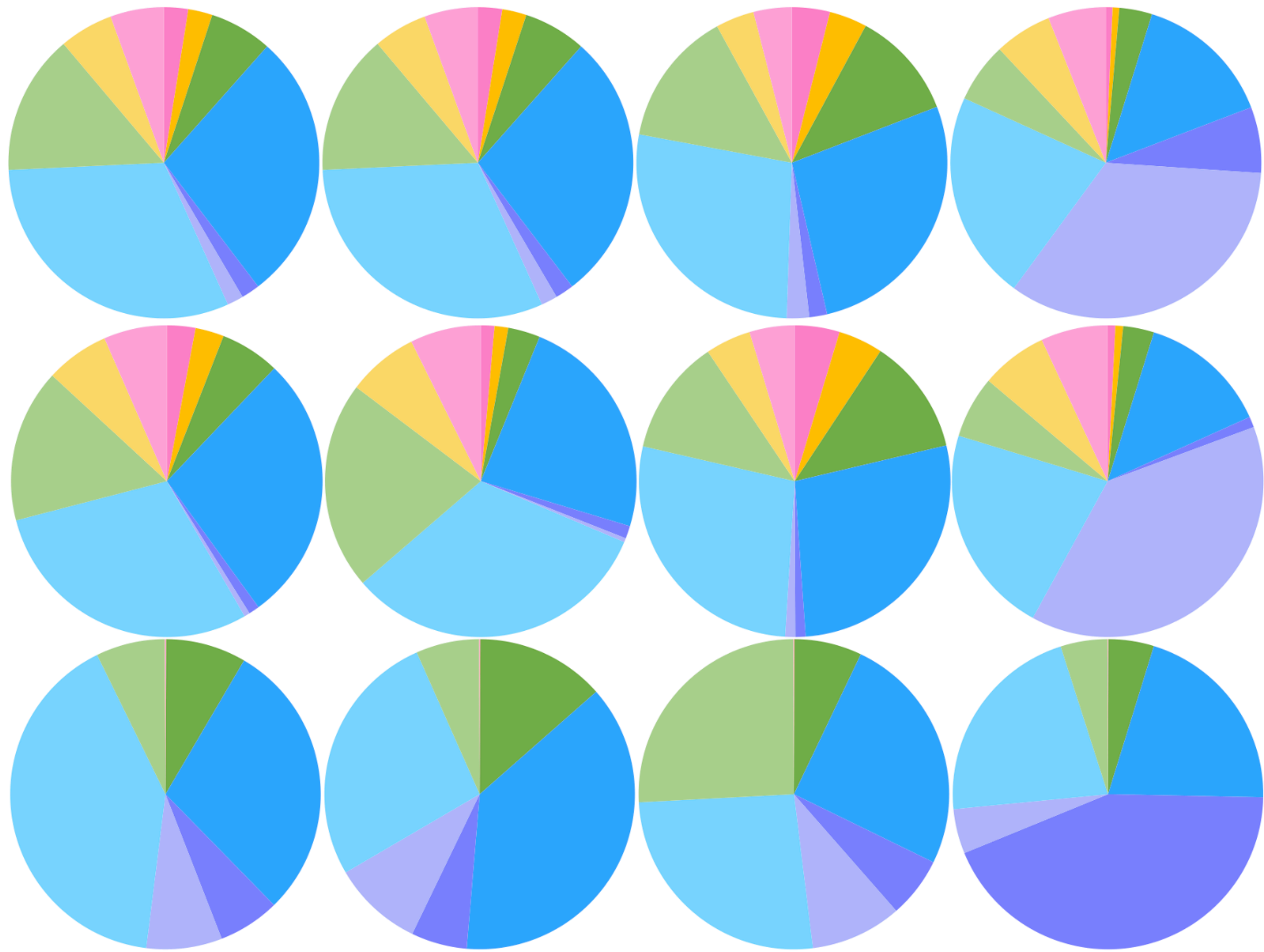
conjugate to b jet

Percent of leading particles of each B hadron of $\bar{b}$ jet

All leading particles

Leading particles from leading hadron ~83.1%

Leading particles from QCD ~16.9%



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

by WHIZARD195

conjugate to b jet

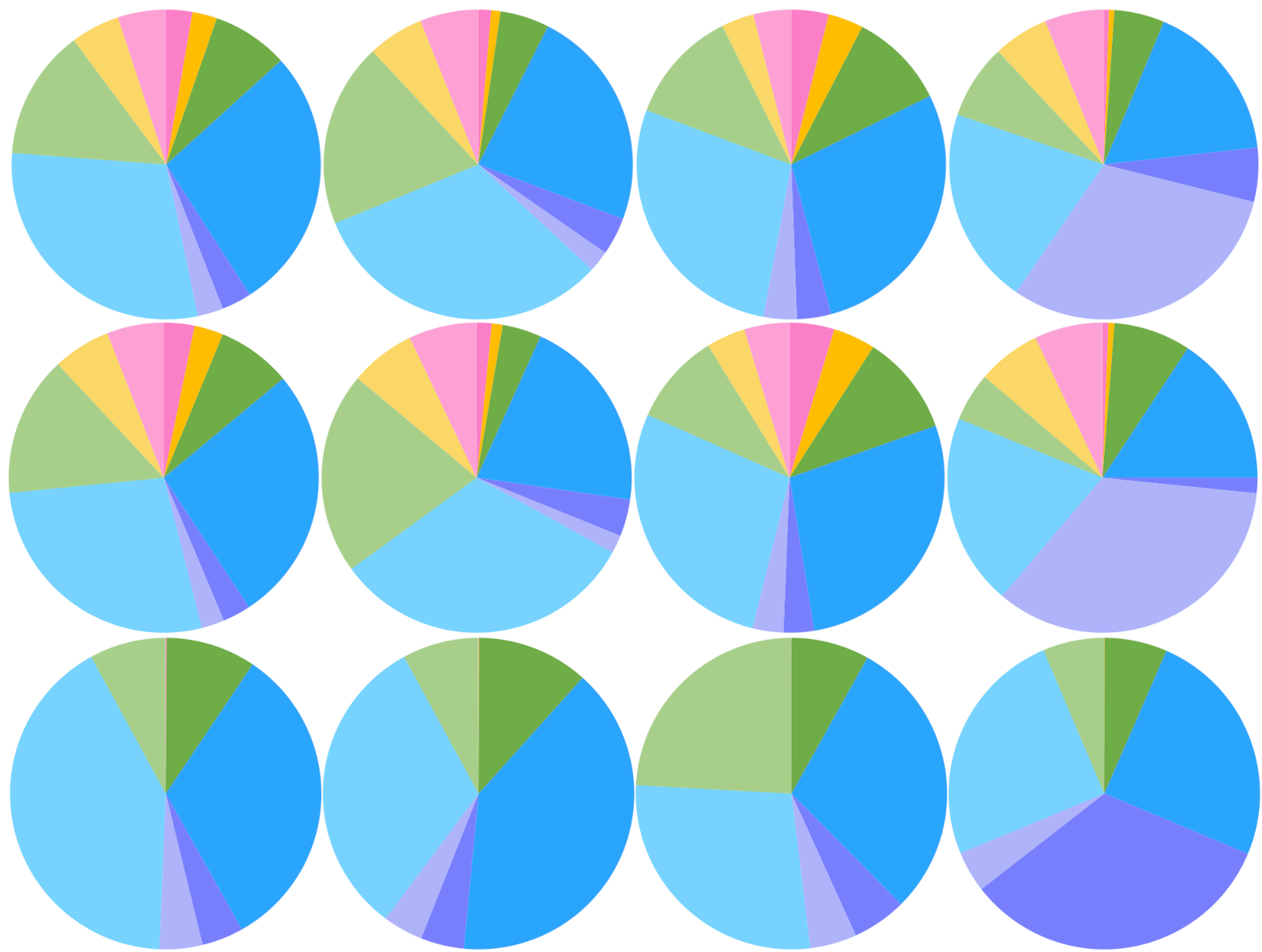
$Z \to b\bar{b}$

Percent of leading particles of each B hadron of $\bar{b}$ jet

All leading particles

Leading particles from leading hadron ~82.6%

Leading particles from QCD ~17.4%



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

by Herwig

$Z \to b\bar{b}$

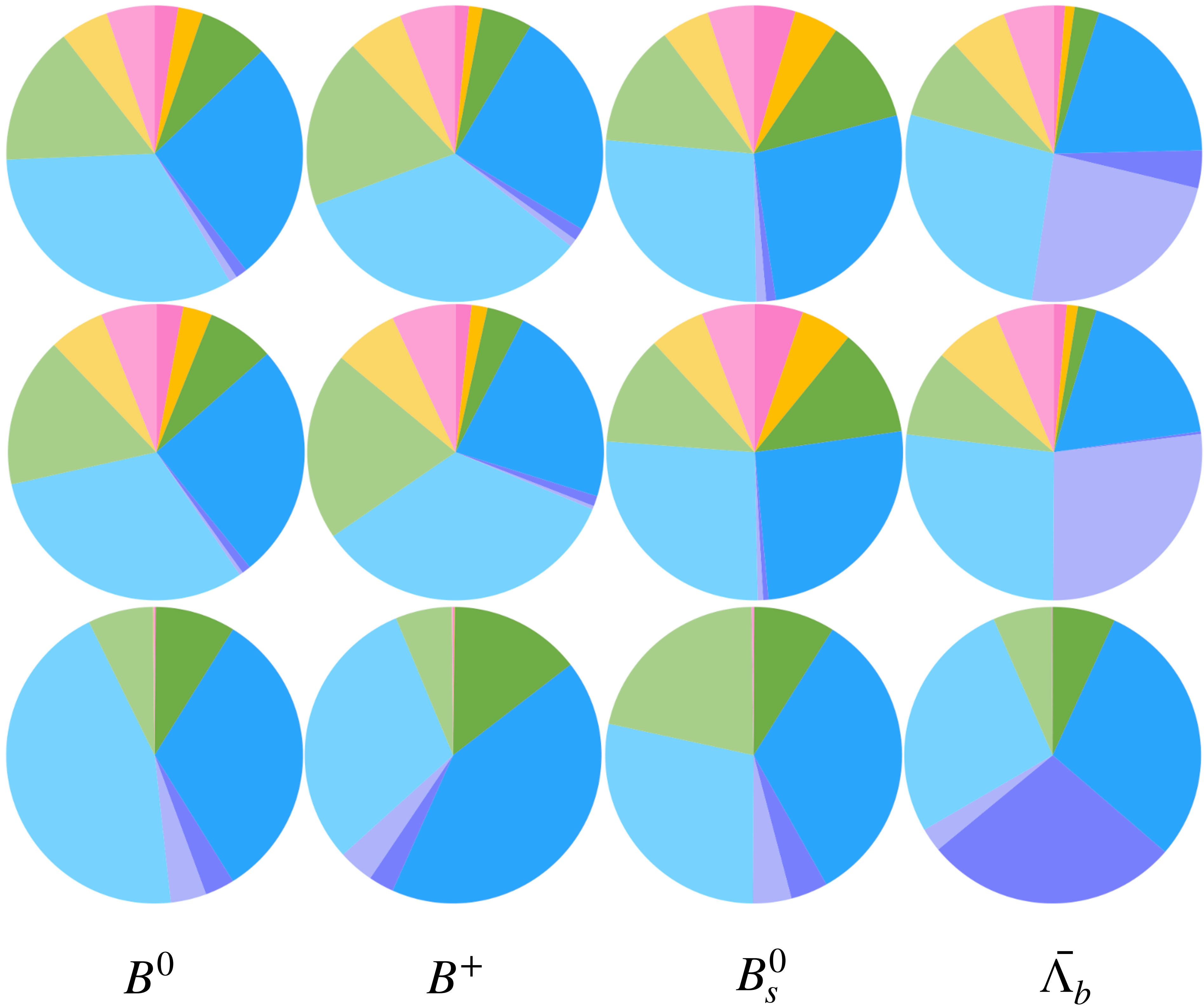
conjugate to b jet

Percent of leading particles of each B hadron of $\bar{b}$ jet

All leading particles

Leading particles from leading hadron ~83.4%

Leading particles from QCD ~16.6%



by Sherpa

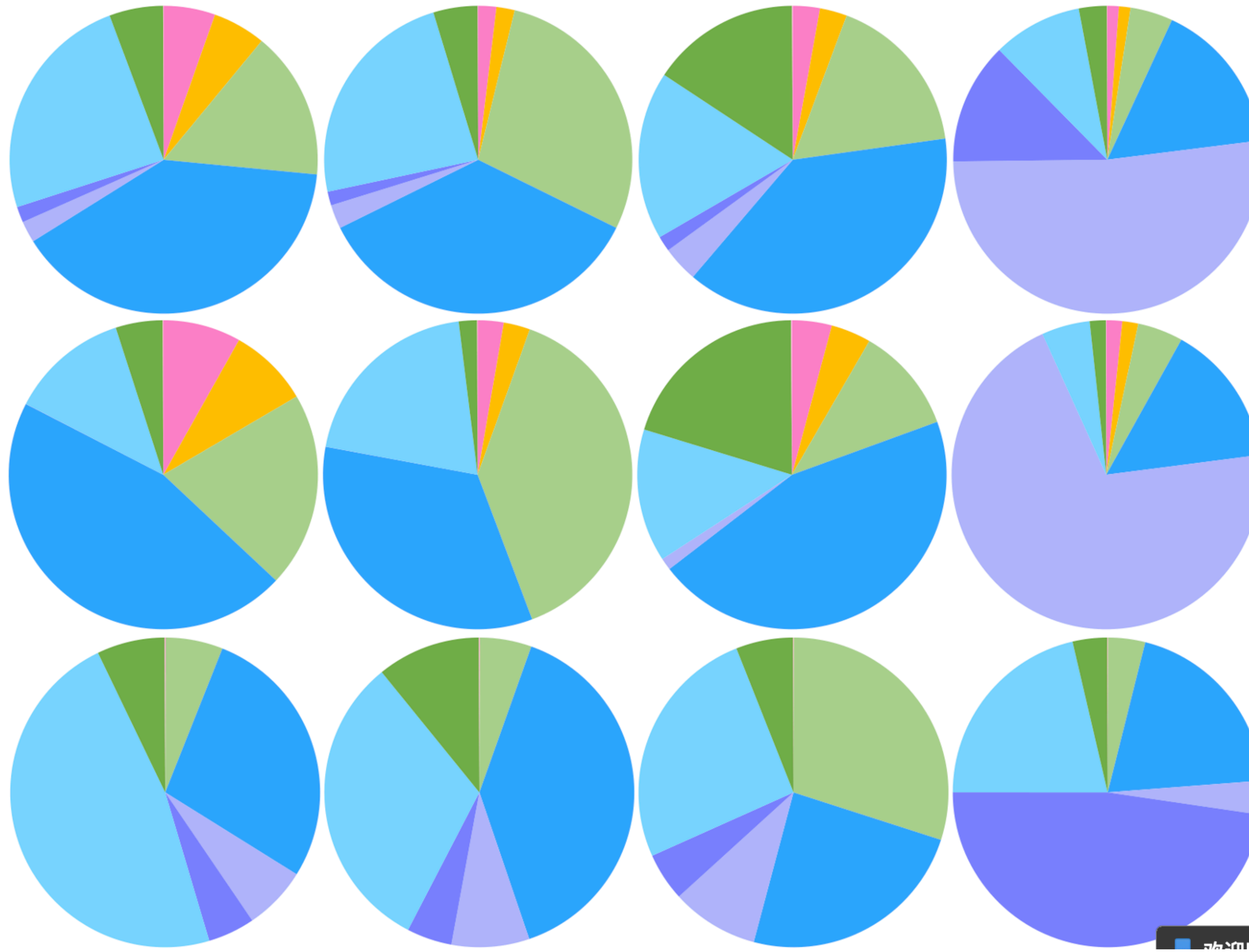
Different flavor
($Z \to b\bar{b}$ v.s. $Z \to c\bar{c}$)

Percent of leading particles of each C hadron of c jet

All leading particles

Leading particles from leading hadron

Leading particles from QCD



D^+ D^0 D_s^+ Λ_c^+

by WHIZARD195

$Z \to c\bar{c}$

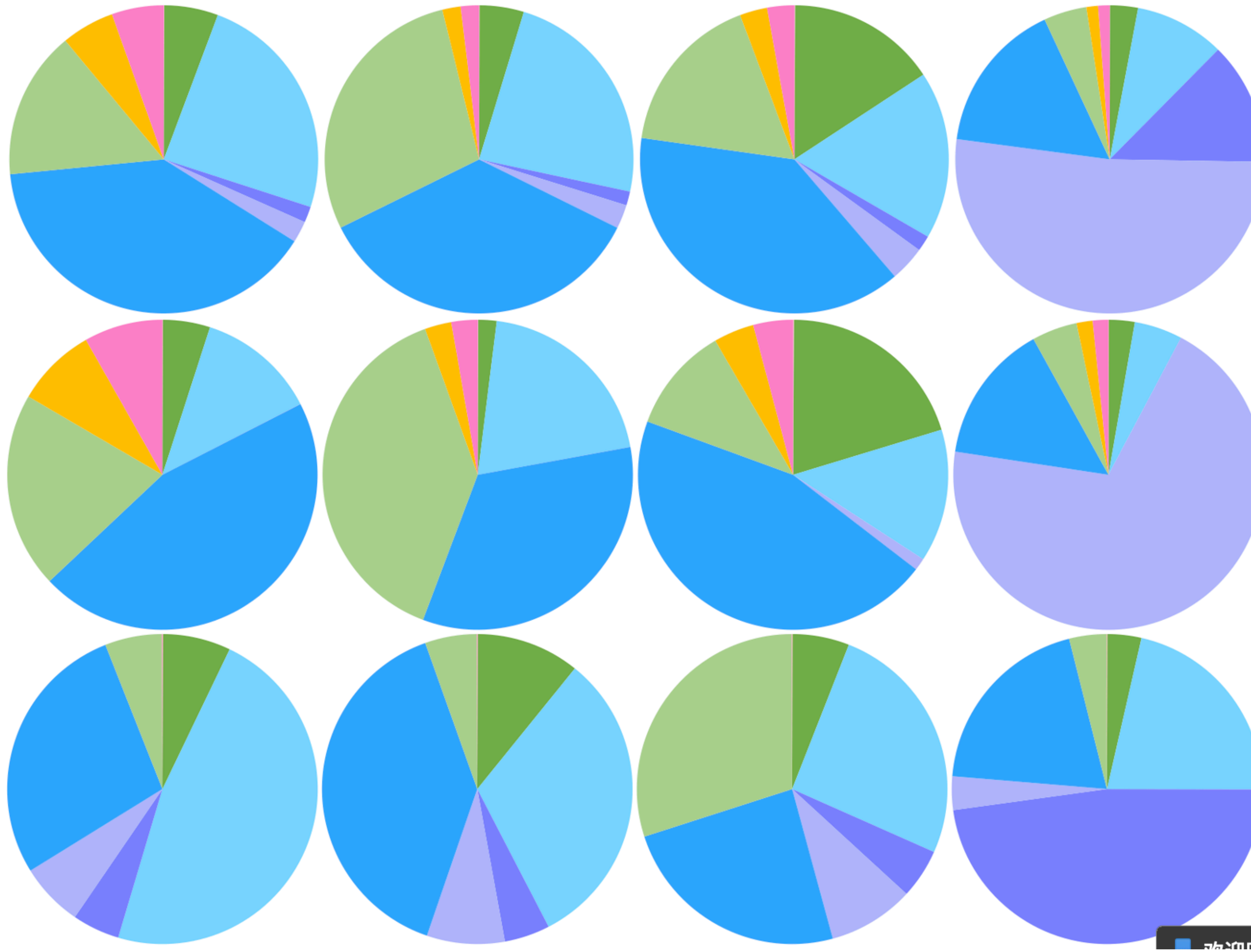
conjugate to c jet

Percent of leading particles of each C hadron of $\bar{c}$ jet

All leading particles

Leading particles from leading hadron

Leading particles from QCD



D^- $\bar{D}^0$ D_s^- Λ_c^-

by WHIZARD195

Conclusion

Main results:

A truth level analysis of jet charge at 91.2 pole using leading charged particle information:

★ *Effective tagging power between different generators:*

- *For $Z \to b\bar{b}$ by Whizard195: Total effective tagging power = 0.090(single jet)*
- *For $Z \to b\bar{b}$ by Herwig: Total effective tagging power = 0.086(single jet)*
- *For $Z \to b\bar{b}$ by Sherpa: Total effective tagging power = 0.078(single jet)*

★ *Effective tagging power between different flavor (by Whizard195):*

- *For $Z \to b\bar{b}$: Total effective tagging power = 0.090(single jet) → 0.137(double jets)*
- *For $Z \to c\bar{c}$: Total effective tagging power = 0.200(single jet) → 0.301(double jets)*

★ *Misjudgment rate ω & Effective tagging power 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 → better misjudgment rate ω & effective tagging power.*

Future:

☞ *More information from final particles (primary/secondary vertex, different categories of leading particles, sub-leading particles, K_s, …)*

☞ *Truth level → Full simulated level → CEPC detector performance*

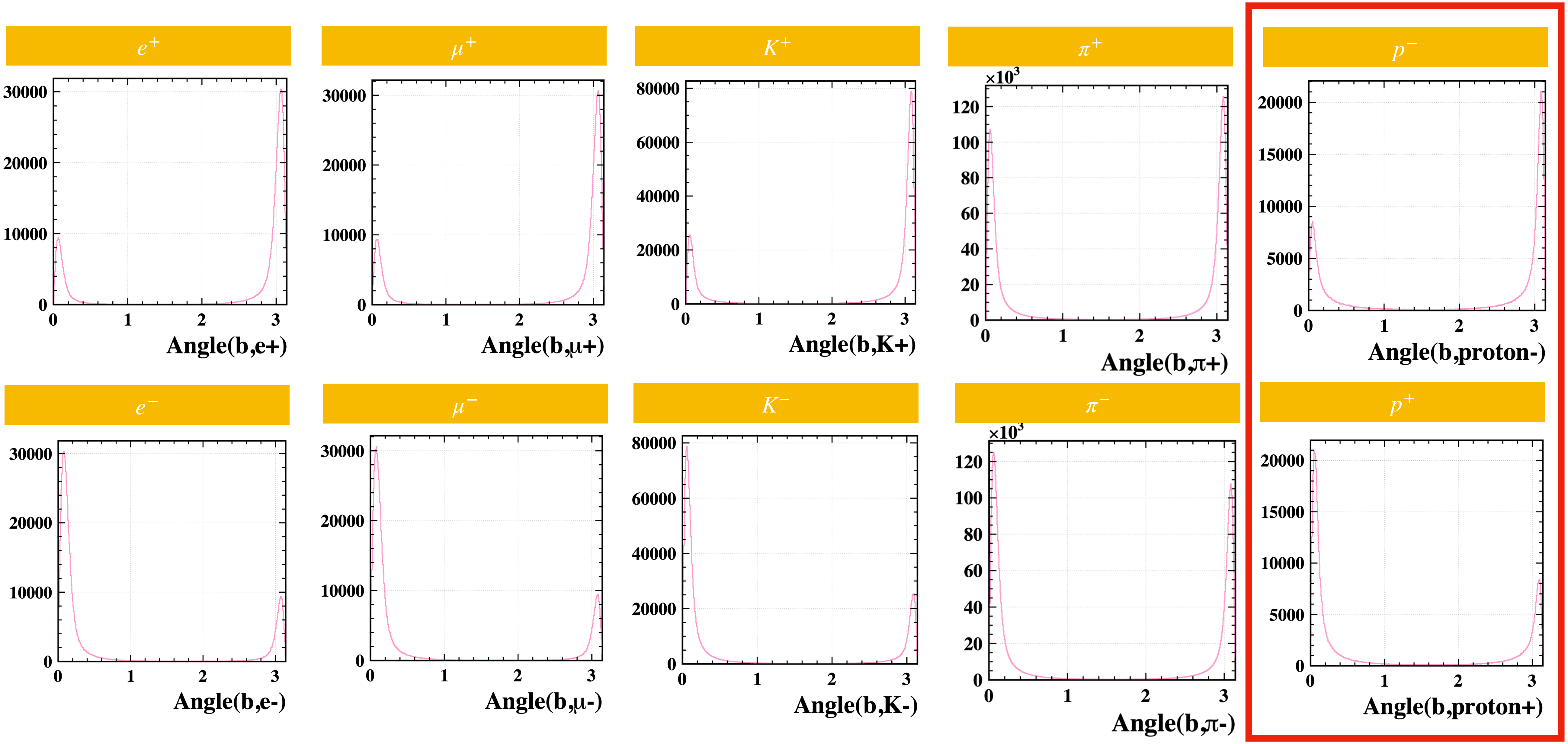
☞ *Machine Learning…*

Thanks!

Back Up

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

☞ *Angle distribution of two jets is asymmetry*



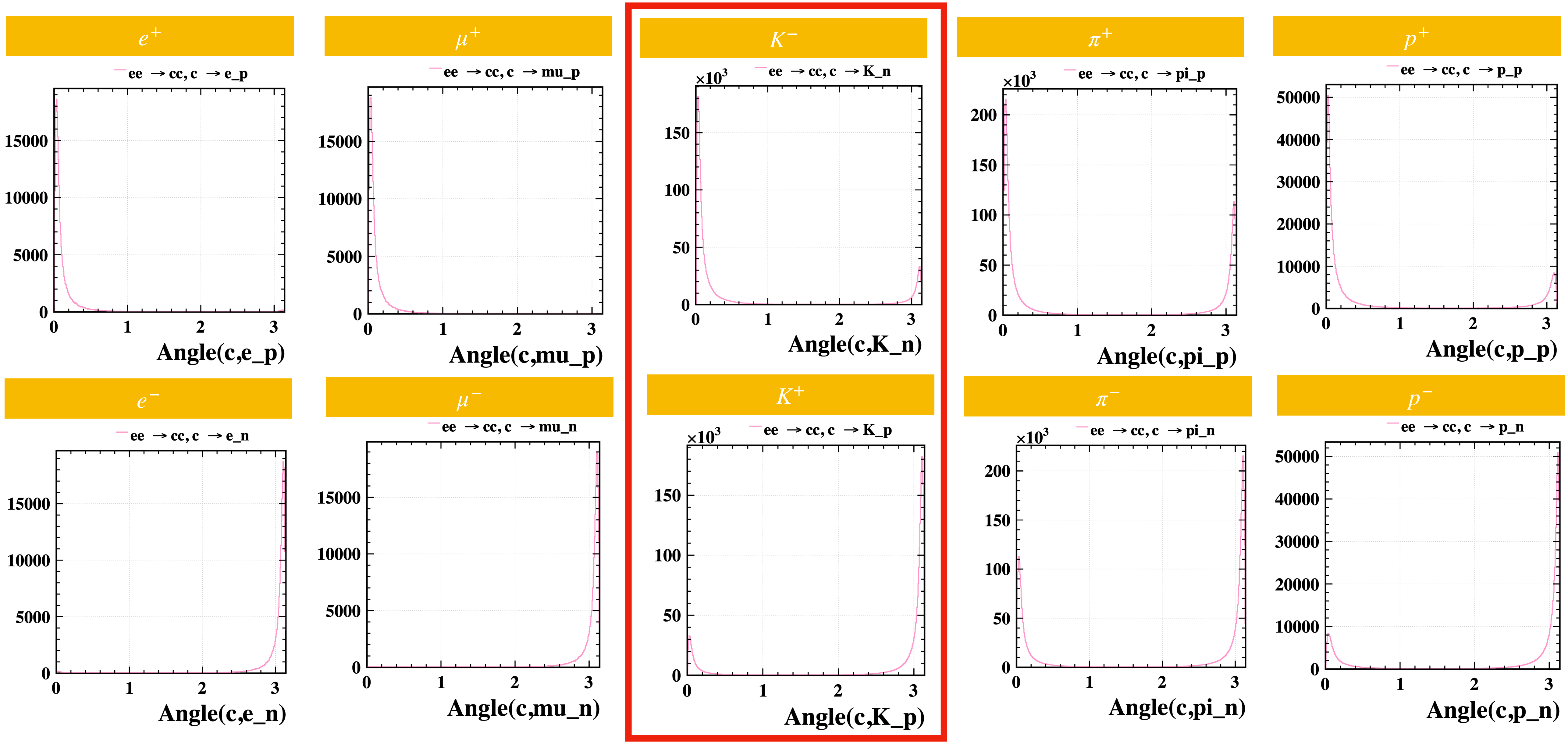
☞ *The more asymmetrical, the more accurate*

☞ *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*

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 = $(13.716 \pm 0.014)\%$

% bbar jet → b jet ↓	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

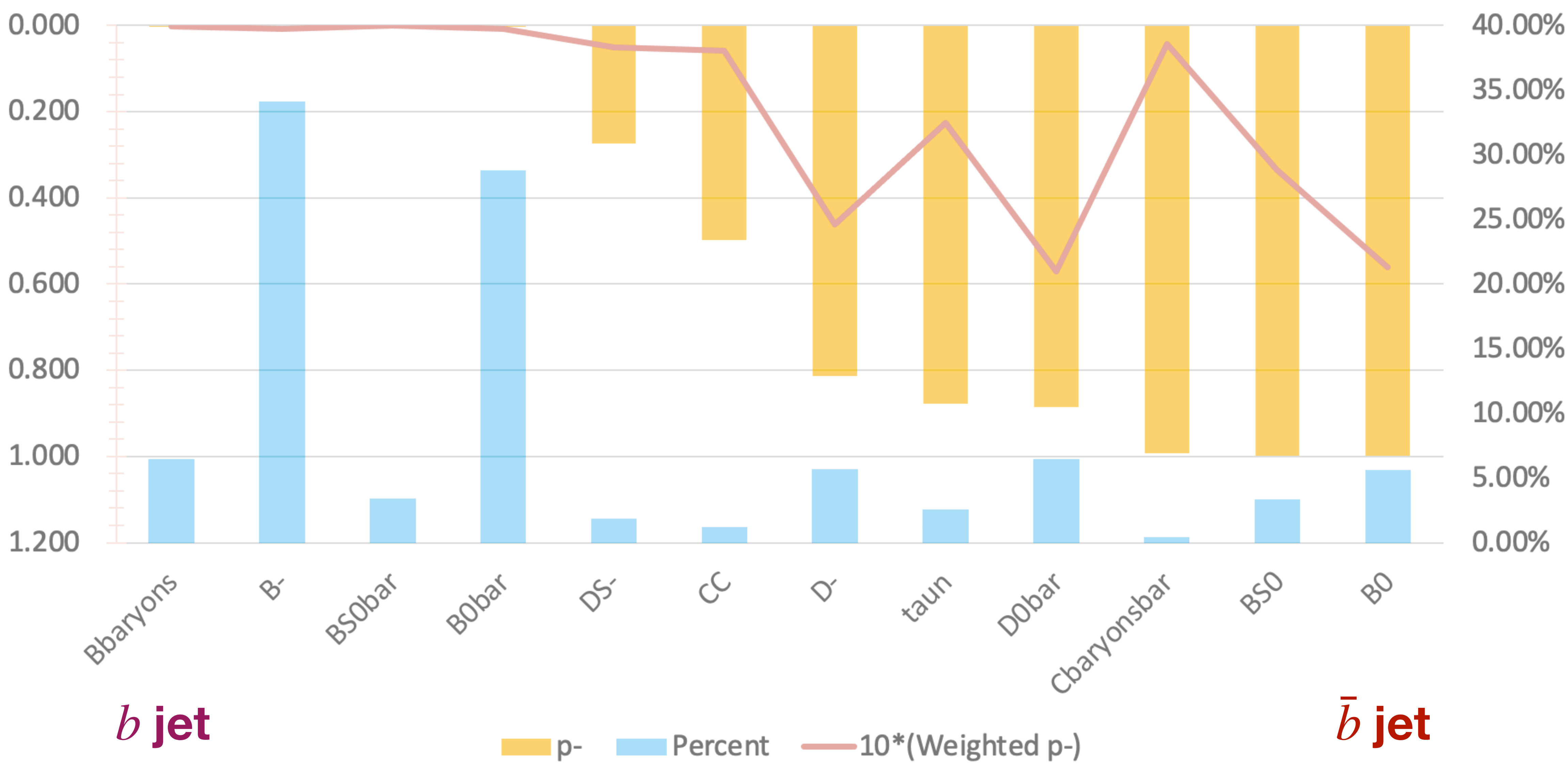
Total Effective Tagging Power = *(30.116 ± 0.022)%*

% cbar jet → c jet ↓	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

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

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



b jet

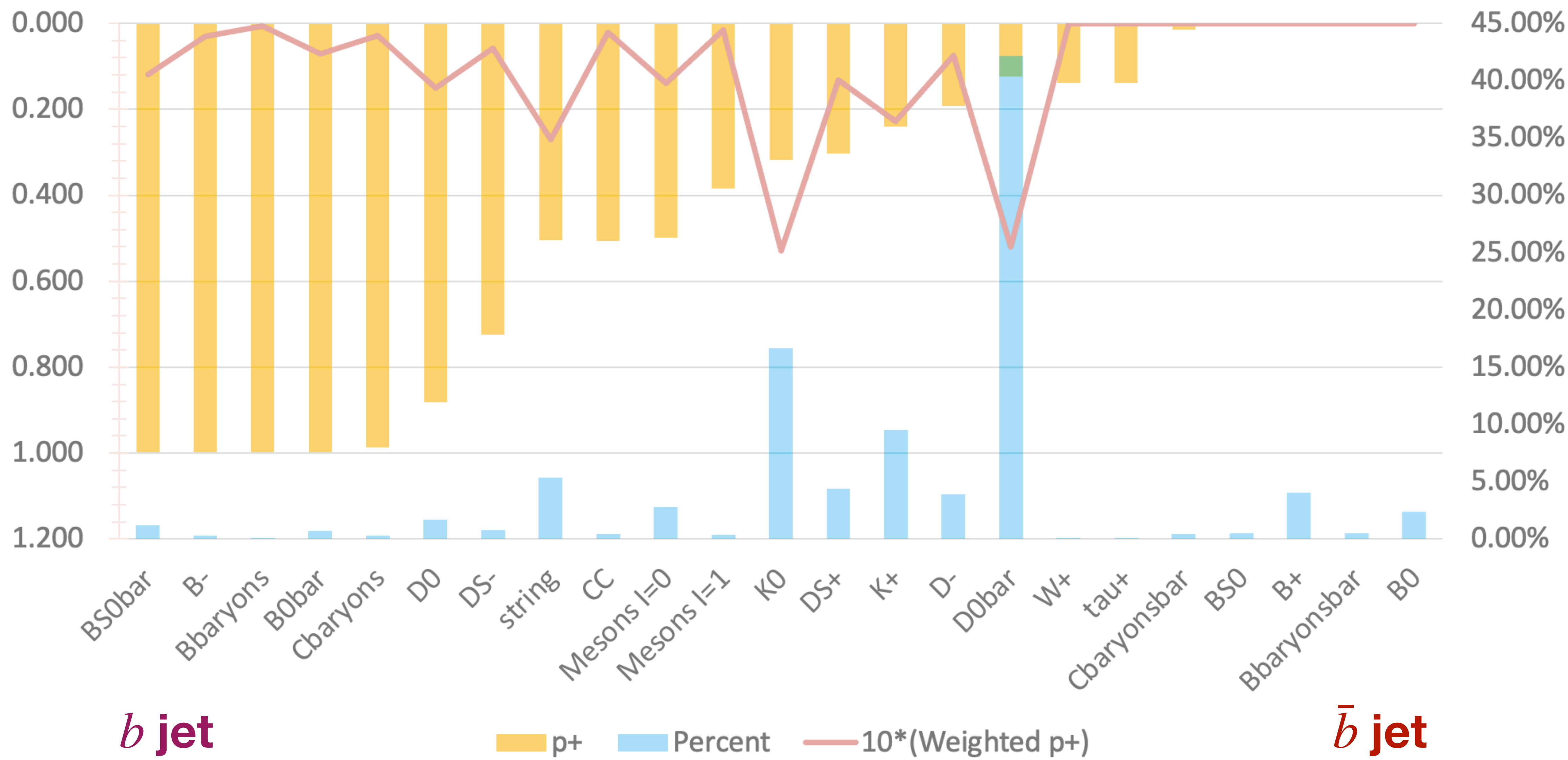
$\bar{b}$ jet

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

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

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