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Jet Charge at CEPC

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Outline

- **Jet Charge Introduction & CEPC Samples**

- **Methods & Dependences**
  - **★ Leading Particle method (LPJC)**
  - **★ Weighted Charge method (WCJC)**

- **Combination:**
  - **★ Decision level combination**
  - **★ Tagger level combination**
  - **★ Total combination**

- **Conclusion**

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 $\varepsilon_{eff}(B^0)$=30.05%
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	weighted jet charge
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 & Sample

Applications of Jet Charge:

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

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 : CEPC Z pole (91.2 GeV) heavy flavor jet :

Sample	Whizard195	Herwig	Sherpa
Z→bb	1×10^7	1×10^6	1×10^5
Z→cc	1×10^7	1×10^6	1×10^5

Definition of effective tagging power

$$\varepsilon = \frac{N^{\text{tag}}}{N}$$

$$N^{\text{tag}}_{B^0} = \varepsilon(1-w)N_{B^0} + \varepsilon w N_{\bar{B}^0}$$

$$N^{\text{tag}}_{\bar{B}^0} = \varepsilon(1-w)N_{\bar{B}^0} + \varepsilon w N_{B^0}$$

$$a^{\text{obs}}_{\text{CP}} = \frac{N^{\text{tag}}_{B^0} - N^{\text{tag}}_{\bar{B}^0}}{N^{\text{tag}}_{B^0} + N^{\text{tag}}_{\bar{B}^0}} = (1-2w)\cdot\frac{N_{B^0} - N_{\bar{B}^0}}{N_{B^0} + N_{\bar{B}^0}} = (1-2w)\cdot a_{\text{CP}} \qquad r \equiv |1-2w|$$

$$\delta a_{\text{CP}} = \frac{\delta a^{\text{obs}}_{\text{CP}}}{1-2w} \qquad \delta a^{\text{obs}}_{\text{CP}} \overset{N^{\text{tag}}_{B^0} \approx N^{\text{tag}}_{\bar{B}^0}}{=} \frac{1}{\sqrt{N^{\text{tag}}}}$$

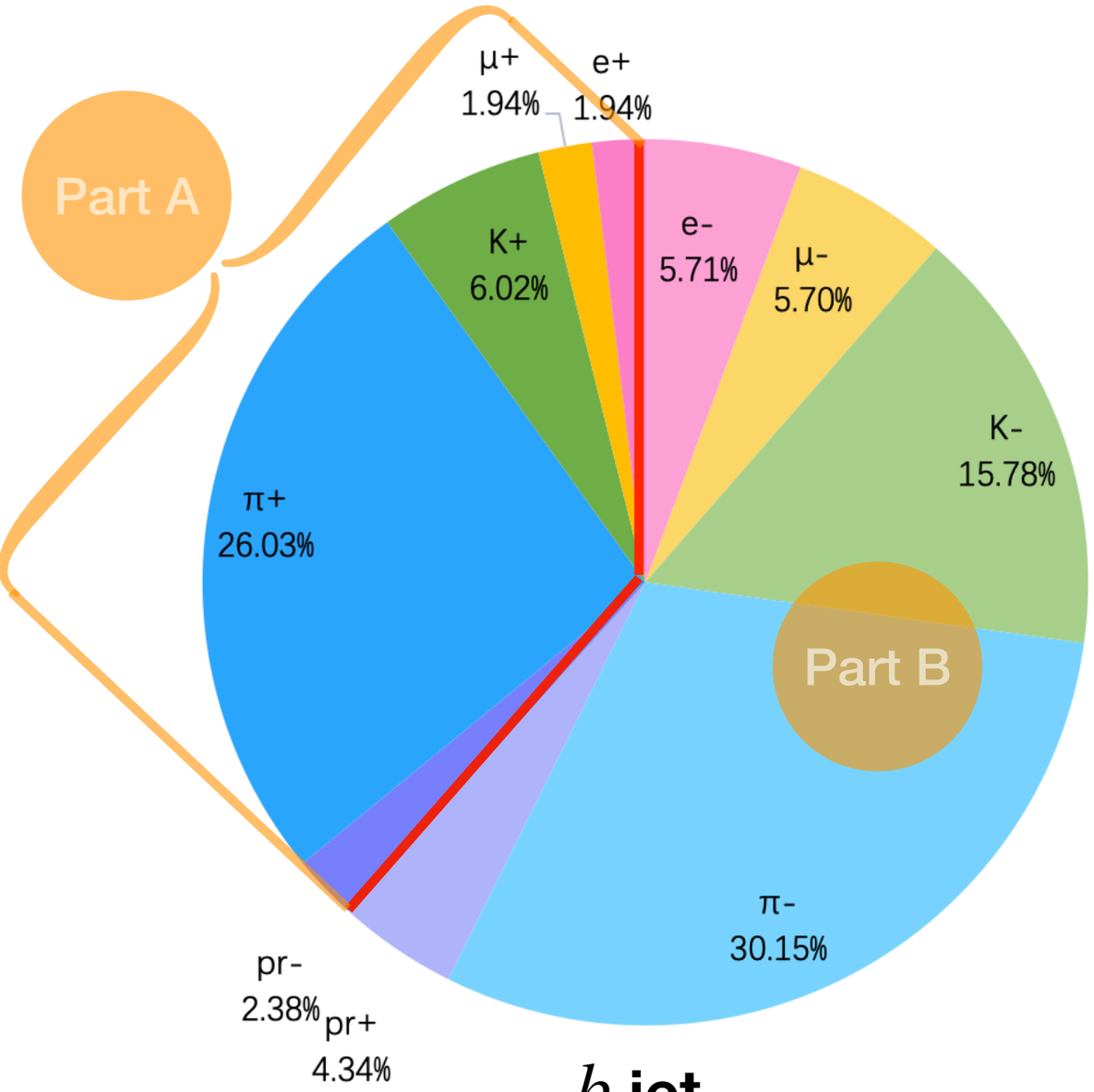
$$\delta a_{\text{CP}} = \frac{1}{\sqrt{N^{\text{tag}}}(1-2w)}$$

$$\varepsilon_{\text{eff}} = \frac{N^{\text{tag}}}{N}\cdot(1-2w)^2 = \varepsilon\cdot r^2$$

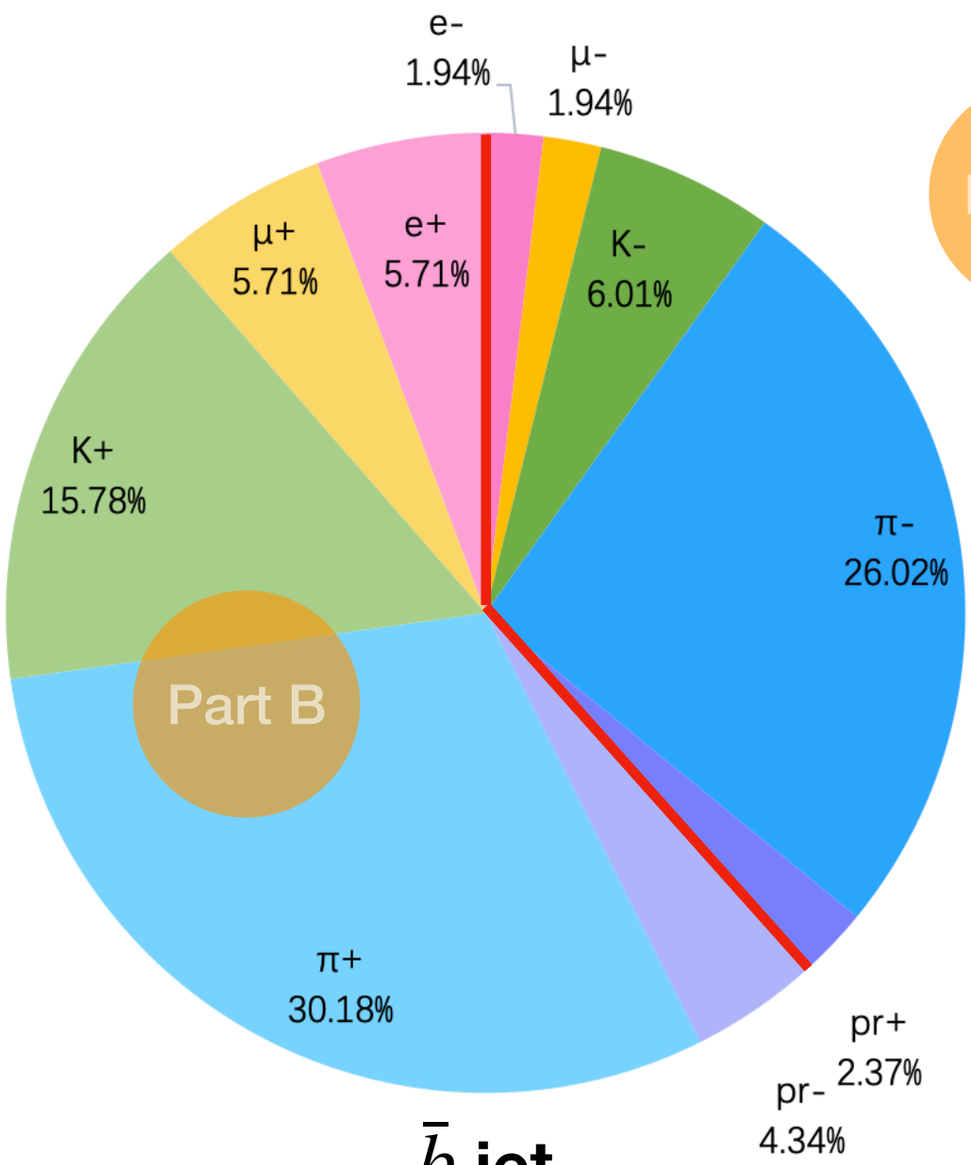
$$\varepsilon_{\text{eff}} = \sum_i \varepsilon_{\text{eff},i} = \sum_i \varepsilon_i\cdot(1-2w_i)^2$$

$Z \to b\bar{b}$

How to calculate misjudgment rate ω



b jet



$\bar{b}$ jet

Percentage of final charged leading particles

$$P(b \mid final_i) = \frac{P(final_i \mid b)}{P(final_i \mid b) + P(final_i \mid \bar{b})}$$

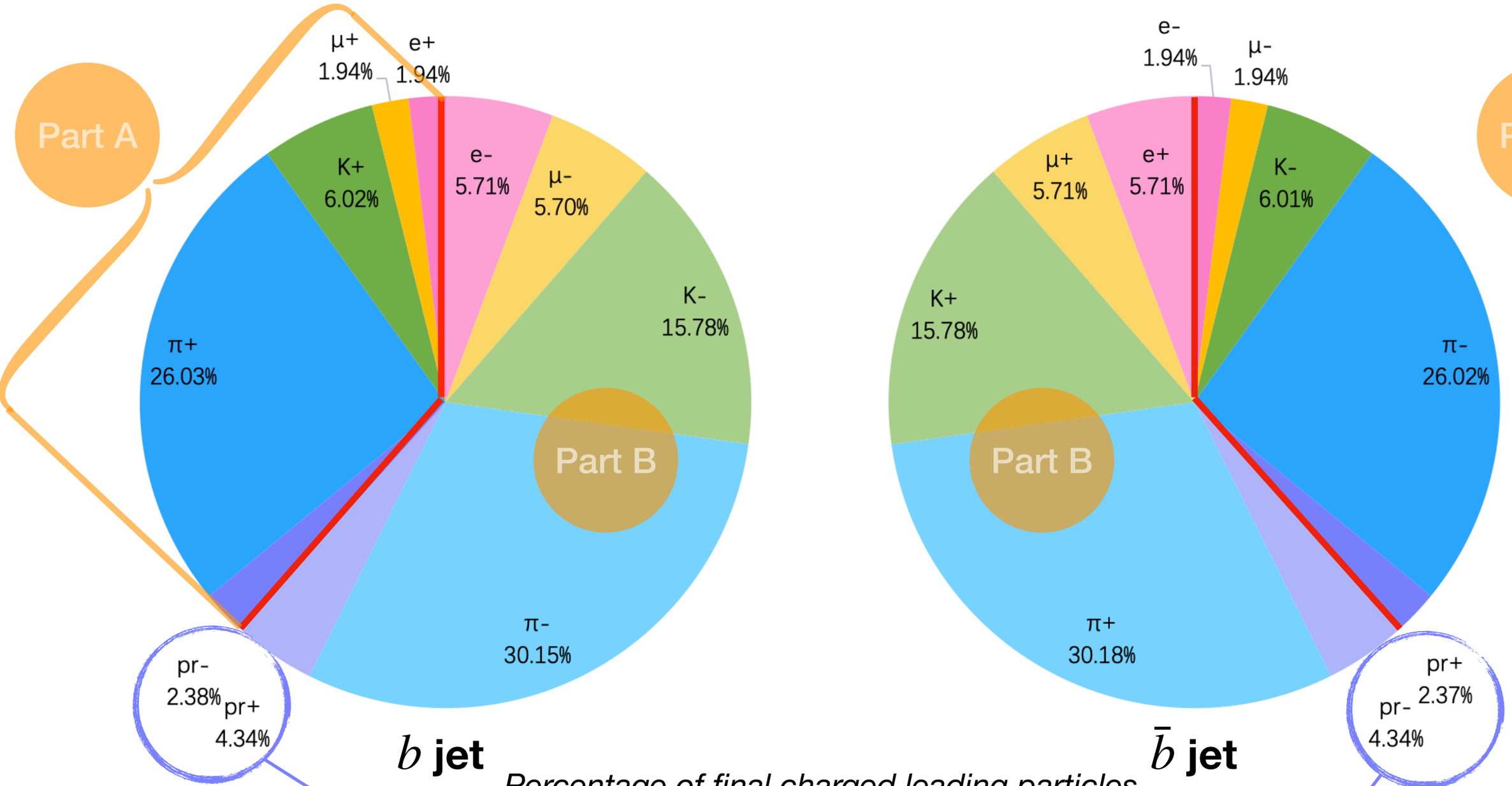
P(the final particle in b jet is final$_i$)

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

$$\omega = 1 - P(b \mid final_i) = \frac{P(final_i \mid \bar{b})}{P(final_i \mid b) + P(final_i \mid \bar{b})} = \frac{\text{Number of Part A}}{\text{Number of Part (A + B)}}$$

$Z \to b\bar{b}$

Dependence on leading particle type



b **jet** $\bar{b}$ **jet**

Percentage of final charged leading particles

ω(using only charge) = 0.403

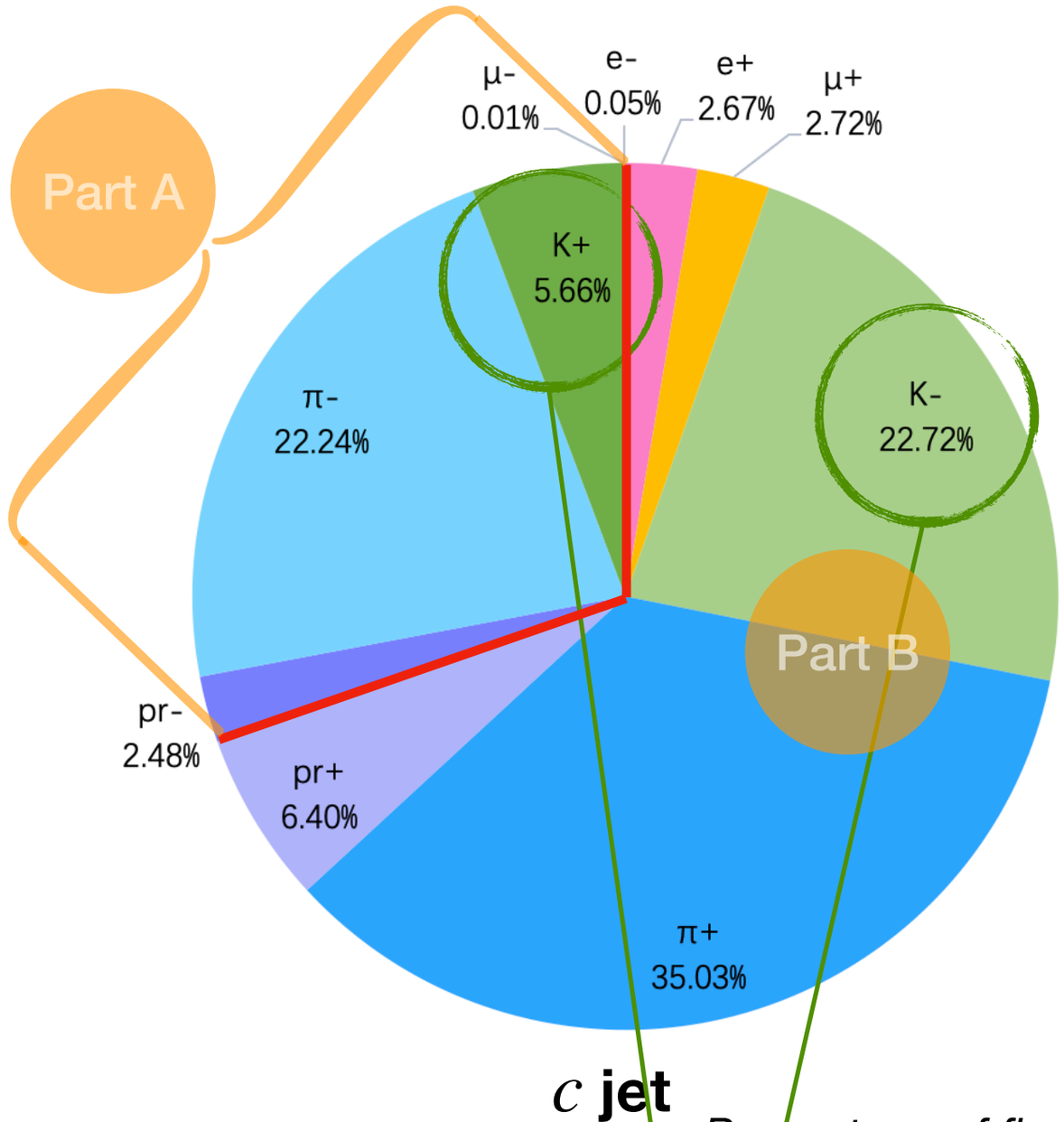
ω(using charge & PID) = 0.383

ω(using only charge) = 0.402

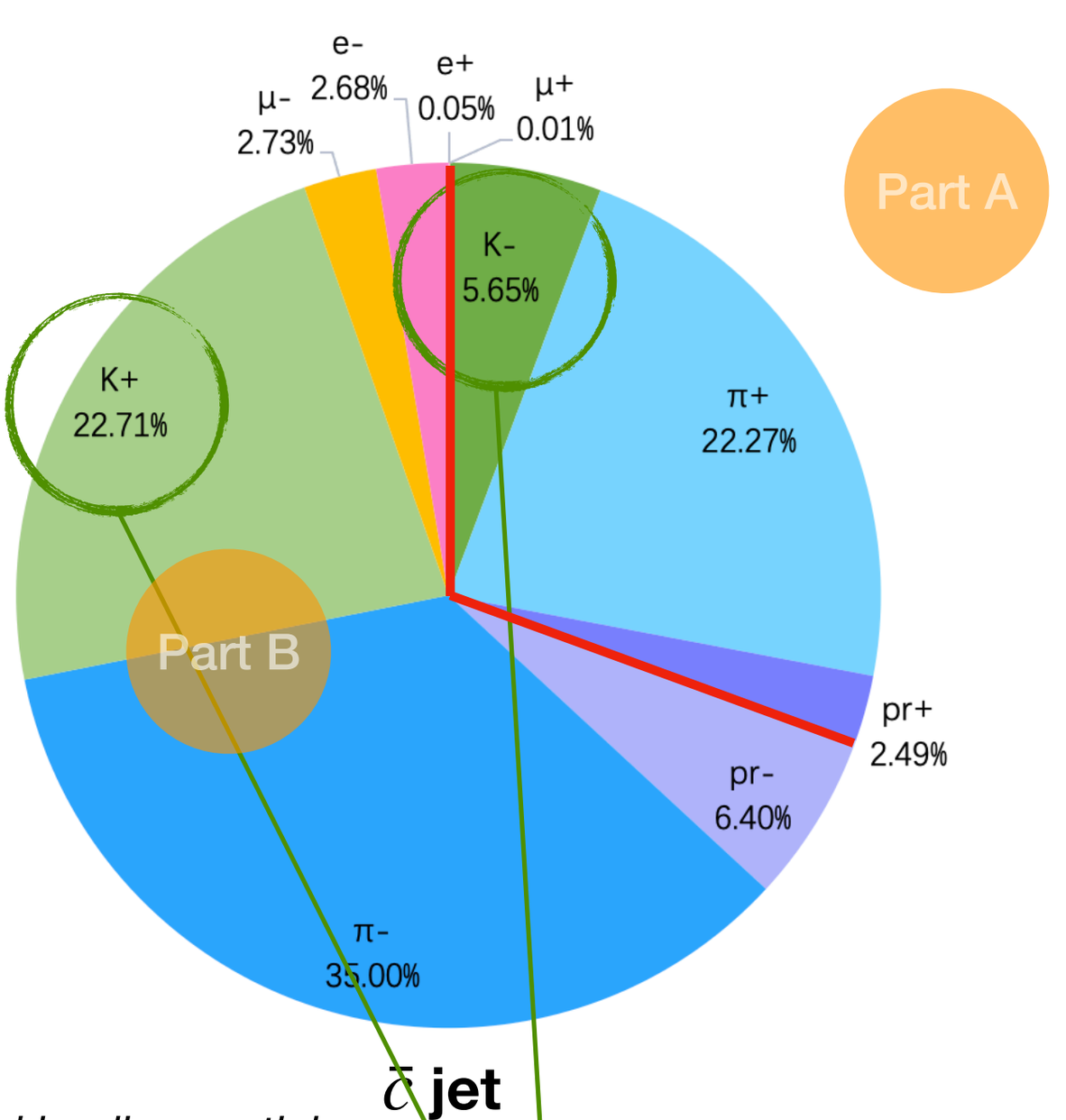
ω(using charge & PID) = 0.383

$Z \to c\bar{c}$

Dependence on leading particle type



c **jet**



$\bar{c}$ **jet**

Percentage of final charged leading particles

ω(using only charge) = 0.473

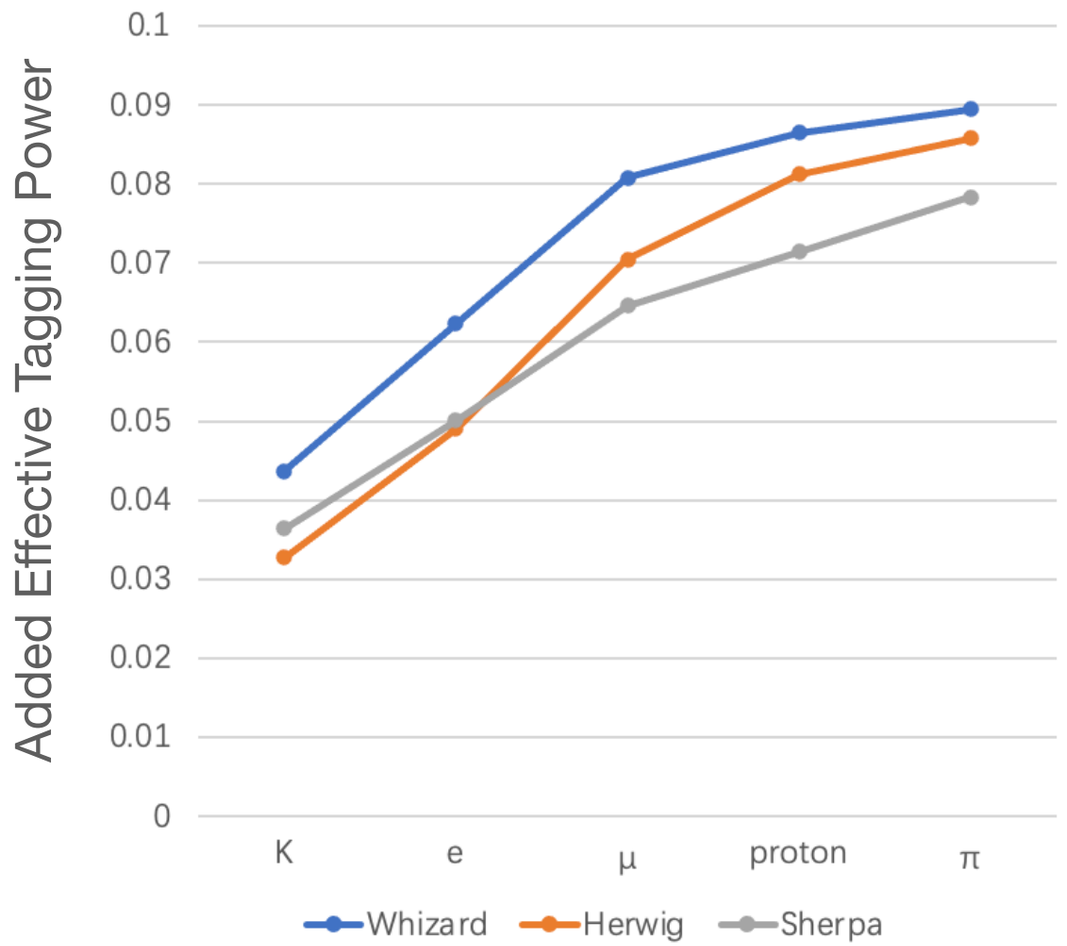
ω(using charge & PID) = 0.304

ω(using only charge) = 0.475

ω(using charge & PID) = 0.305

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

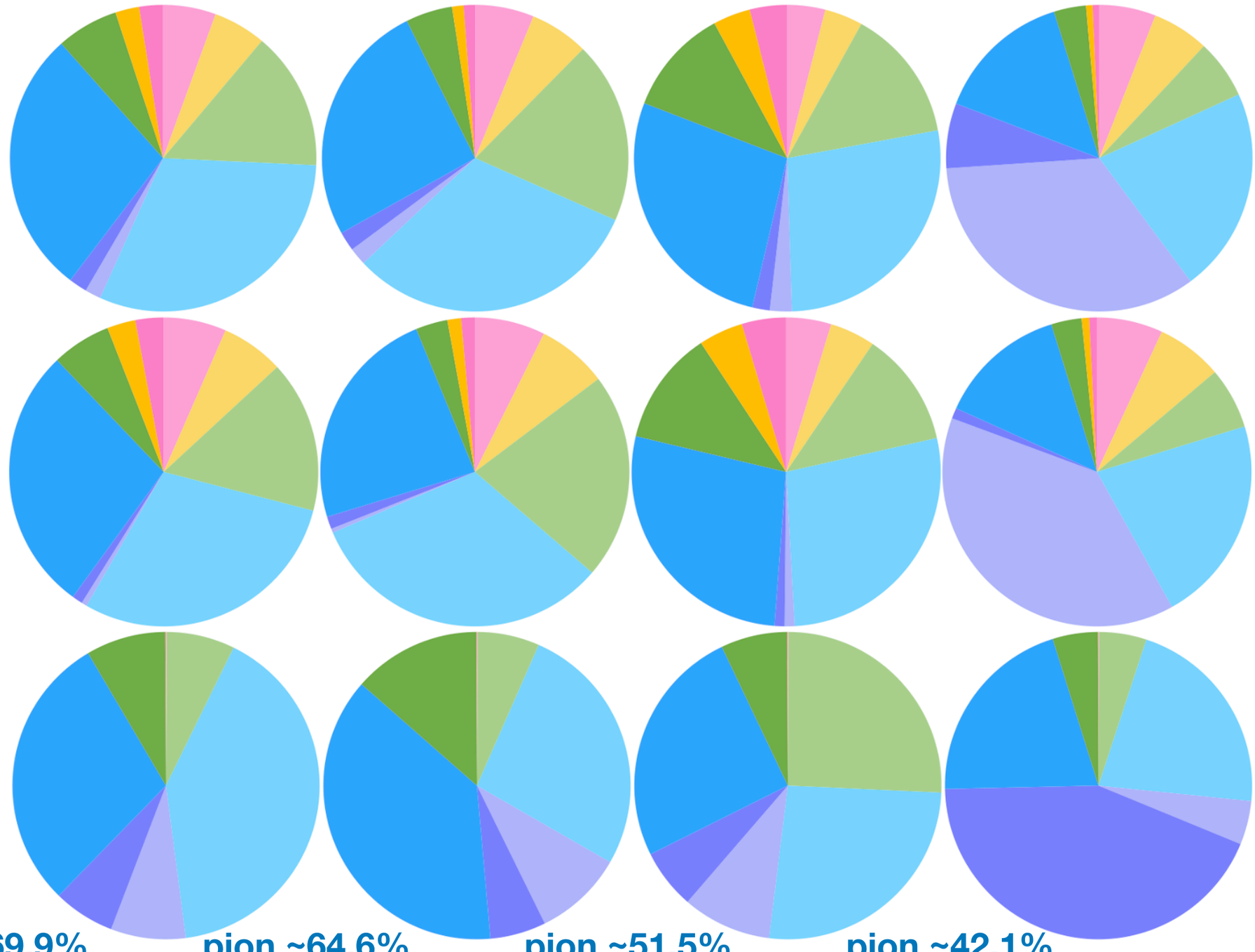
Dependence on decay source of leading particle: hadron or QCD.

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%

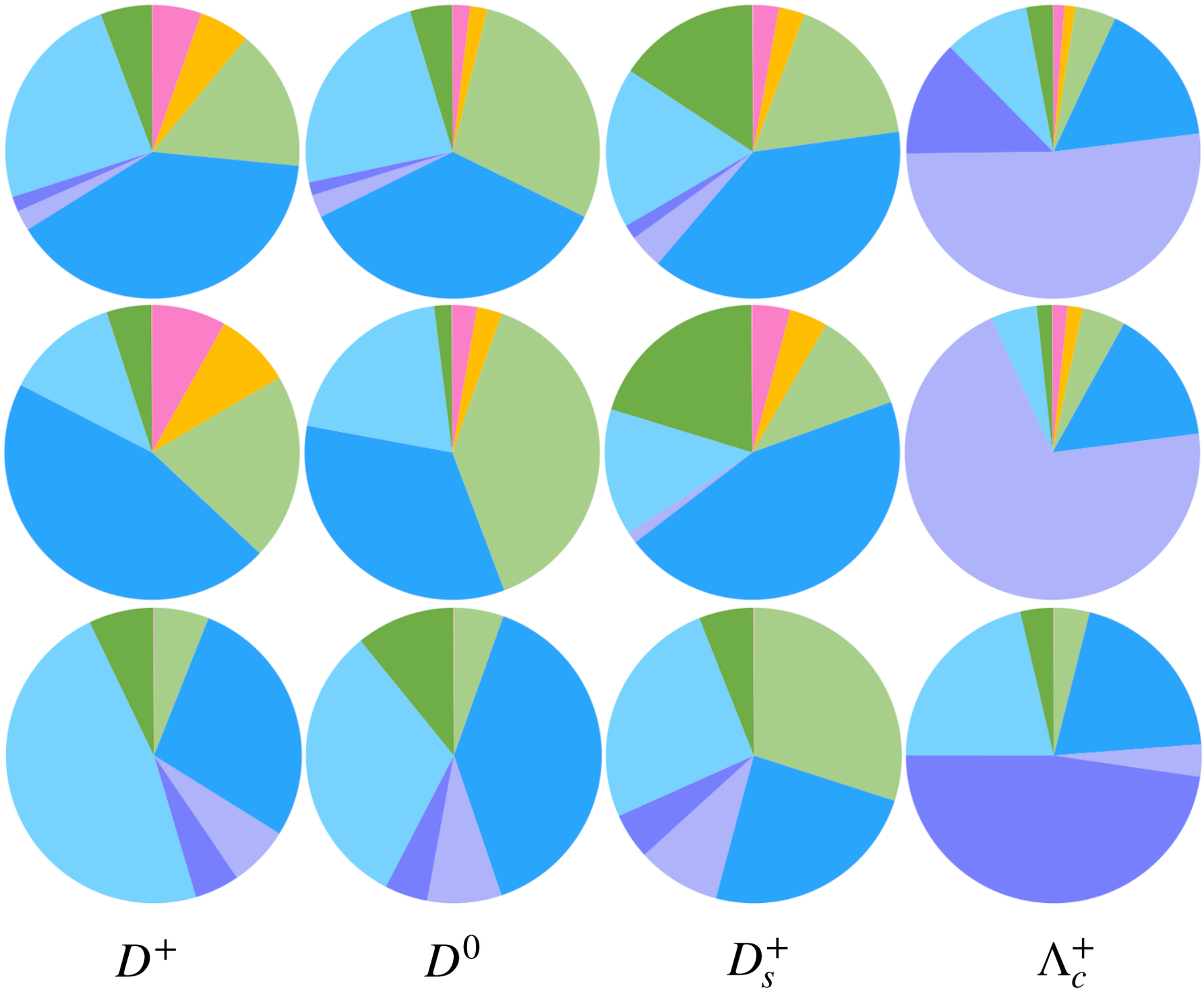
by WHIZARD195

Percentage of leading particles (c jet, Whizard195)

All leading particles

Leading particles from leading hadron

Leading particles from QCD



D^+ D^0 D_s^+ Λ_c^+

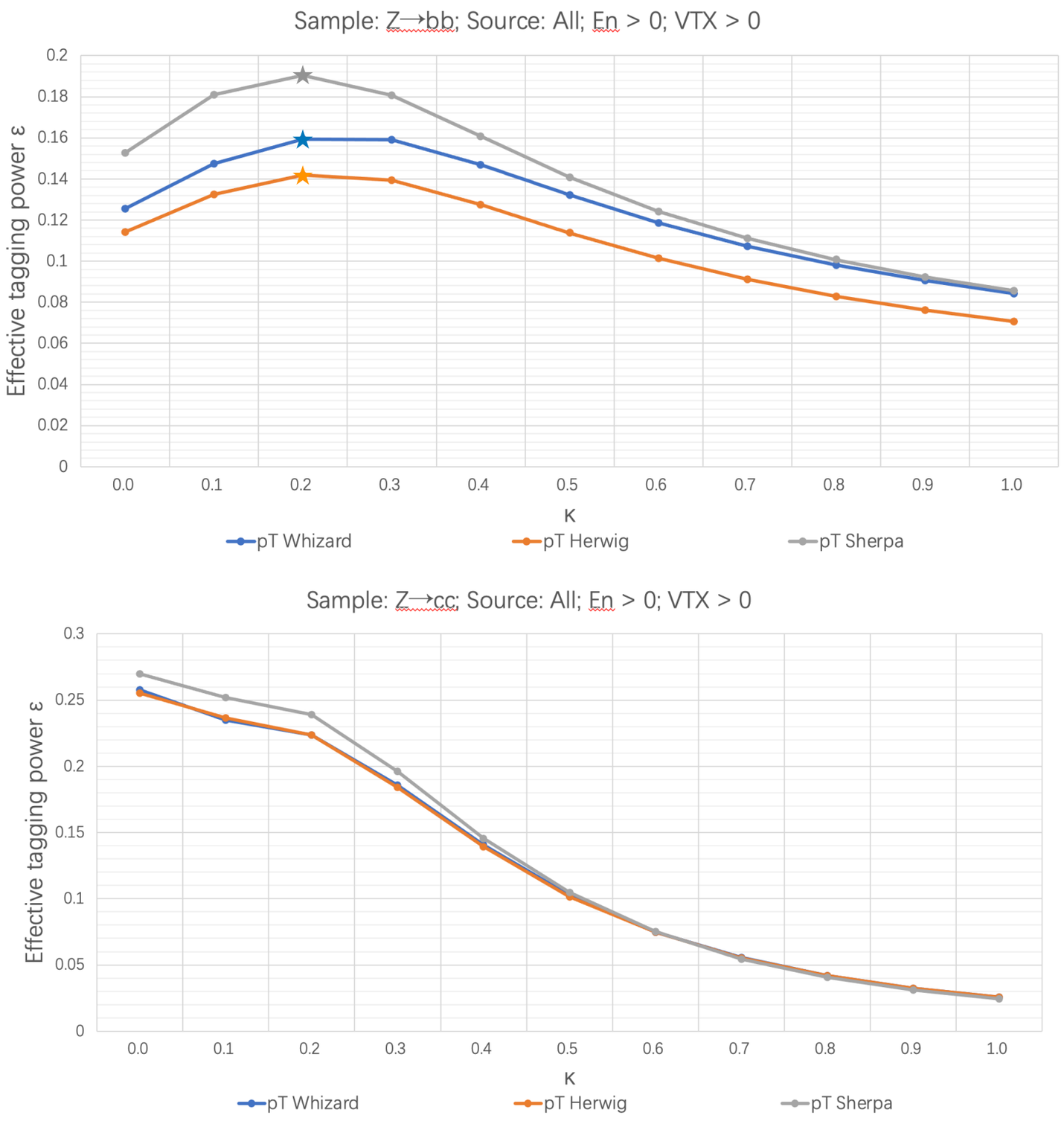
by WHIZARD195

Weighted charge method (WCJC)

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

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

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)



Combination

Decision level combination of two methods

LPJC		Per	ξ = +1	ξ = +1	ξ = -1	ξ = -1	ξ = +1	ξ = -1	Only two decisions			Only one dicision			Total
WCJC			ξ = +1	ξ = -1	ξ = +1	ξ = -1	ξ = 0	ξ = 0	ω	ε_{tag}	ε_{eff}	ω	ε_{tag}	ε_{eff}	ε_{eff}
b jet	e	7.65%	15.71%	9.64%	6.63%	68.03%	0.00%	0.00%	18.76%	6.40%	0.025				0.025
	μ	7.65%	15.68%	9.72%	6.62%	67.97%	0.00%	0.00%	18.75%	6.40%	0.025				0.025
	K	21.81%	15.53%	12.09%	10.93%	61.45%	0.00%	0.00%	20.18%	16.79%	0.060				0.060
	π	56.18%	20.55%	25.77%	11.17%	42.51%	0.00%	0.00%	32.59%	35.43%	0.043				0.043
	p	6.72%	6.09%	16.54%	11.49%	28.24%	12.81%	24.82%	17.75%	2.31%	0.010	34.04%	2.53%	0.003	0.012
	Total	100.00%	17.74%	19.70%	10.44%	49.58%	0.78%	4.11%	25.45%	67.32%	0.162	34.04%	2.53%	0.003	0.165
c jet	e	2.72%	91.76%	6.33%	0.35%	1.55%	0.01%	0.00%	1.66%	2.54%	0.024				0.024
	μ	2.73%	93.09%	6.44%	0.08%	0.39%	0.01%	0.00%	0.41%	2.55%	0.025				0.025
	K	28.38%	43.59%	10.32%	10.95%	2.60%	26.14%	6.41%	5.62%	13.11%	0.103	19.69%	9.24%	0.034	0.137
	π	57.28%	33.49%	7.84%	20.90%	5.23%	19.84%	12.70%	13.50%	22.18%	0.118	39.04%	18.64%	0.009	0.127
	p	8.88%	62.43%	9.65%	14.79%	13.13%	0.01%	0.00%	17.38%	6.71%	0.029				0.029
	Total	100.00%	42.14%	8.63%	16.41%	4.95%	18.05%	1.66%	10.17%	47.09%	0.299	30.38%	27.87%	0.043	0.342

by Whizard

Tagger level combination of two methods

Input final particle candidate i

get its PID

get ω_i(j=LPJC), ω_i(j=WCJC), decision ξ_i(j=LPJC), ξ_i(j=WCJC)

for method j, if $\xi_{i,j} = 0$, $s_{i,j} = 0$

if two $\xi_{i,j}$!= 0, for smaller $\omega_{i,j}$, $s_{i,j}$ =1, for larger $\omega_{i,j}$, $s_i = 0$

put $s_{i,j}$, $\xi_{i,j}$, $\omega_{i,j}$ in this formula and get combined ε_{eff}

$$\epsilon_{ETP_{comb}} = \sum_{i=1}^{N_{candidate}} \sum_{j=1}^{N_{method}} s_{i,j} \, |\xi_{i,j}| \, (1 - 2\omega_{i,j})^2$$

$s_{i,j}$ is the decision weight of j-th method for i-th candidate.

$\omega_{i,j}$ is the mis-judgment rate ω of j-th method for i-th candidate.

$\xi_{i,j}$ is the tagging decision of j-th method for i-th candidate.

The tagging decision ξ_i takes the value of

- +1 when the candidate is tagged as $\bar{b}$ jet
- –1 when the candidate is tagged as b jet
- 0 when the candidate is untagged

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**

b jet by Whizard

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**

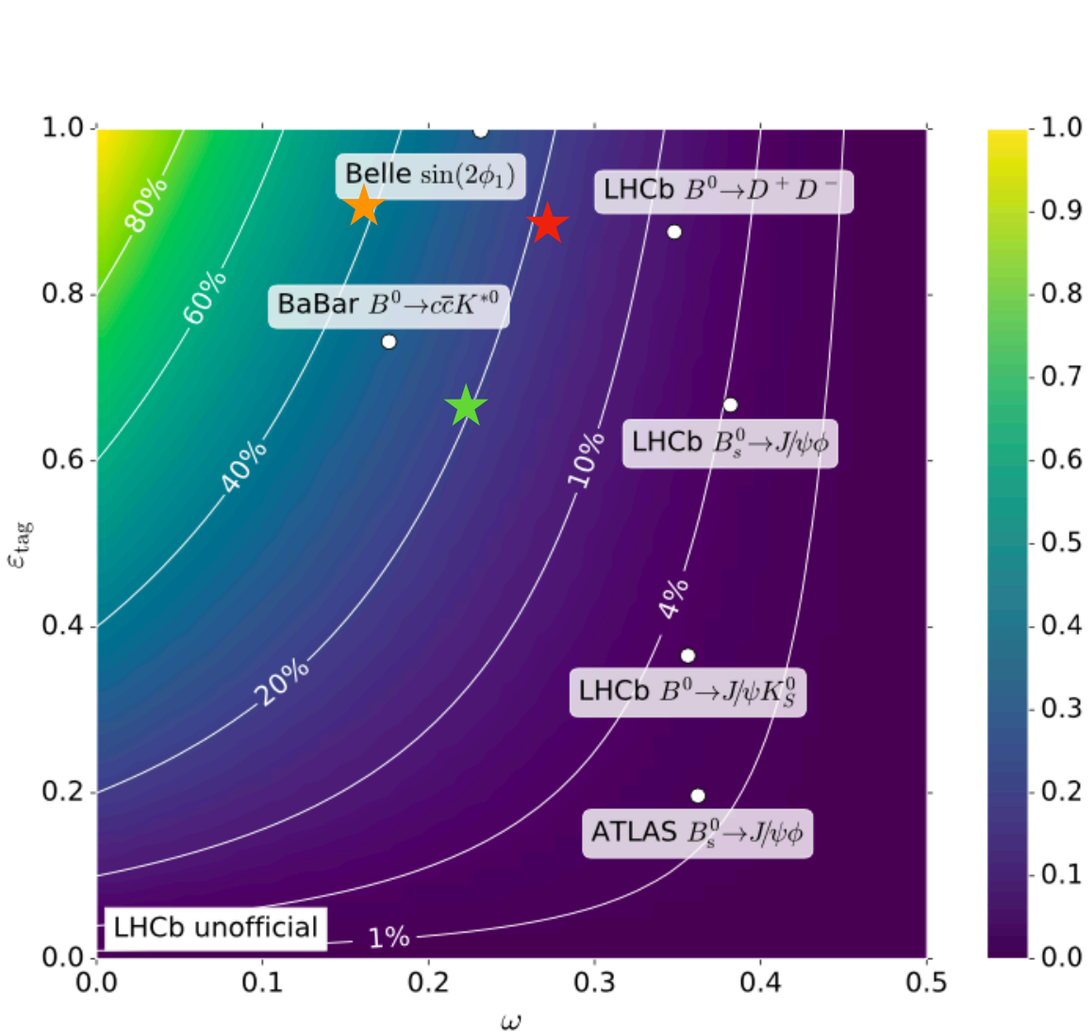
c jet by Whizard

Total combination results

Tagger			ε_{tag}	ω	ε_{eff}
b jet	e	Decision Level	6.40%	18.75%	0.025
	μ	Decision Level	6.40%	18.75%	0.025
	K	Decision Level	16.79%	20.11%	0.060
	π	Tagger Level	56.18%	31.61%	0.076
	p	Decision Level	2.31%	13.96%	0.012
	Total		88.08%	26.29%	0.198
c jet	e	Tagger Level	2.72%	2.10%	0.025
	μ	Tagger Level	2.73%	0.29%	0.027
	K	Decision Level	22.35%	10.85%	0.137
	π	Tagger Level	57.28%	21.51%	0.186
	p	Decision Level	6.71%	17.13%	0.029
	Total		91.80%	16.83%	0.404

by Whizard

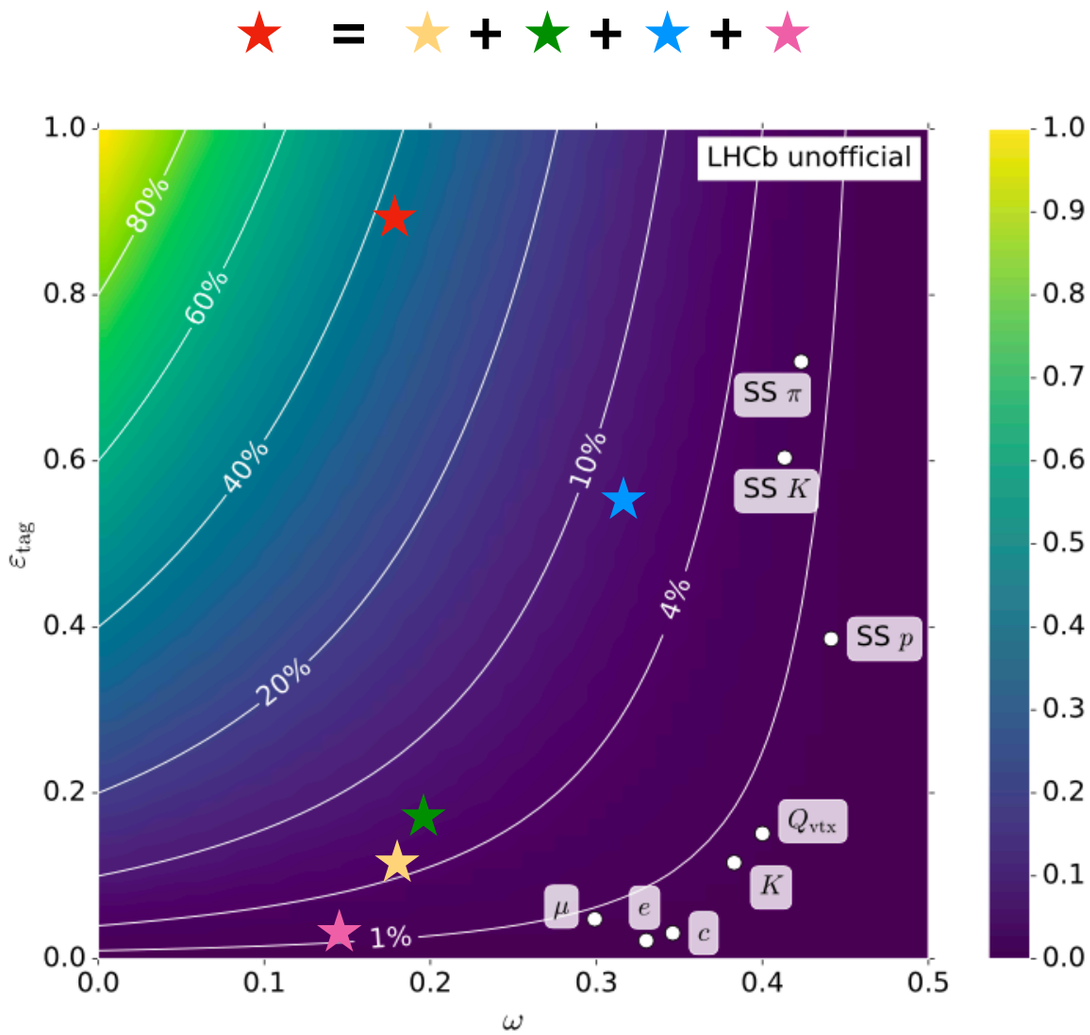
Comparison with other experiments



CEPC b jet (inclusive) 19.8%

CEPC c jet (inclusive) 40.4%

CEPC Bs→J/ΨΦ 20.2% (by Mingrui)



CEPC b jet (inclusive) 19.8%

CEPC b quark→lepton 5.0%

CEPC b quark→Kaon 6.0%

CEPC b quark→pion 7.6%

CEPC b quark→proton 1.2%

Conclusion

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

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

- ★ *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.*

Valuable suggestions from everyone:

Take into account hadron decay

Include charged 2rd/3rd vertex

Understand fragmentation method of diff. generator

Jet charge vs c.m.s energy

Analysis on the dependency of detector performance.

Thanks!

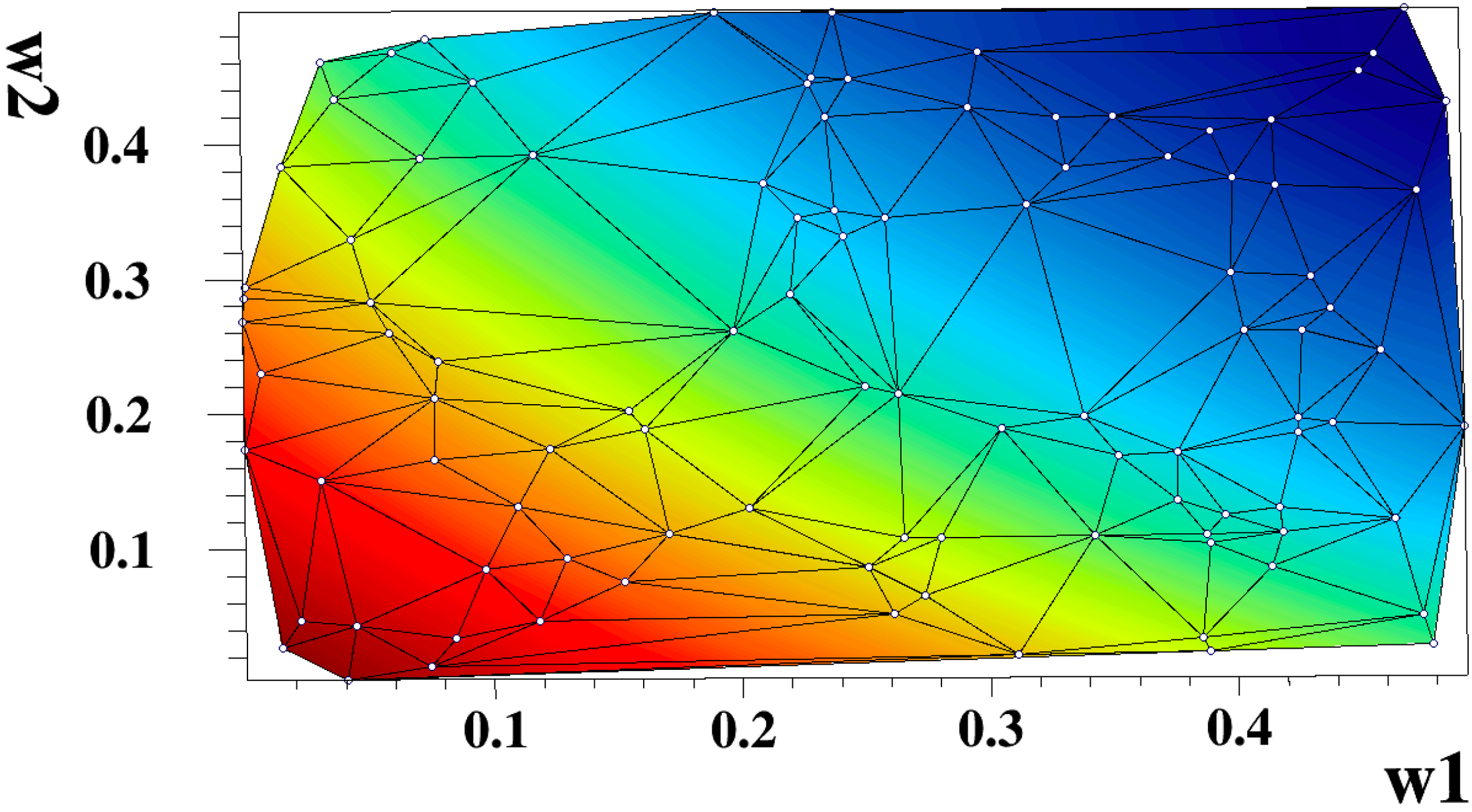
Back Up

TF percentage of two methods

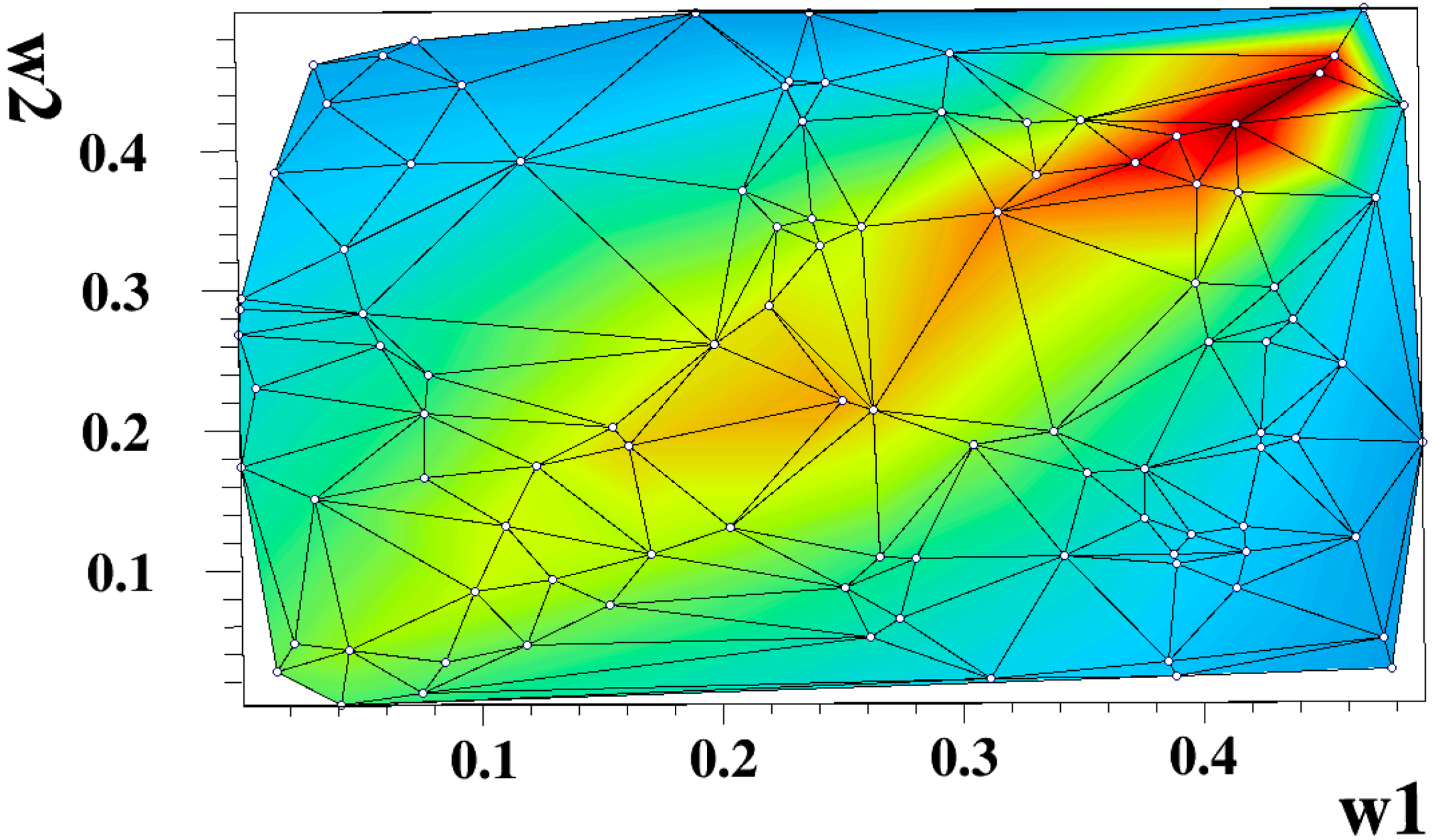
b jet	ξ_{LP} -1 (right)	ξ_{LP} +1 (wrong)	Total
$\xi_{weighted}$ -1 (right)	50.87%	20.22%	71.09%
$\xi_{weighted}$ +1 (wrong)	10.71%	18.21%	28.92%
Total	61.58%	38.43%	100.01%

c jet	ξ_{LP} +1 (right)	ξ_{LP} -1 (wrong)	Total
$\xi_{weighted}$ +1 (right)	58.43%	11.96%	70.39%
$\xi_{weighted}$ -1 (wrong)	22.75%	6.86%	29.61%
Total	81.18%	18.82%	100%

Decision level combined ε_{eff} vs ω_1 ω_2

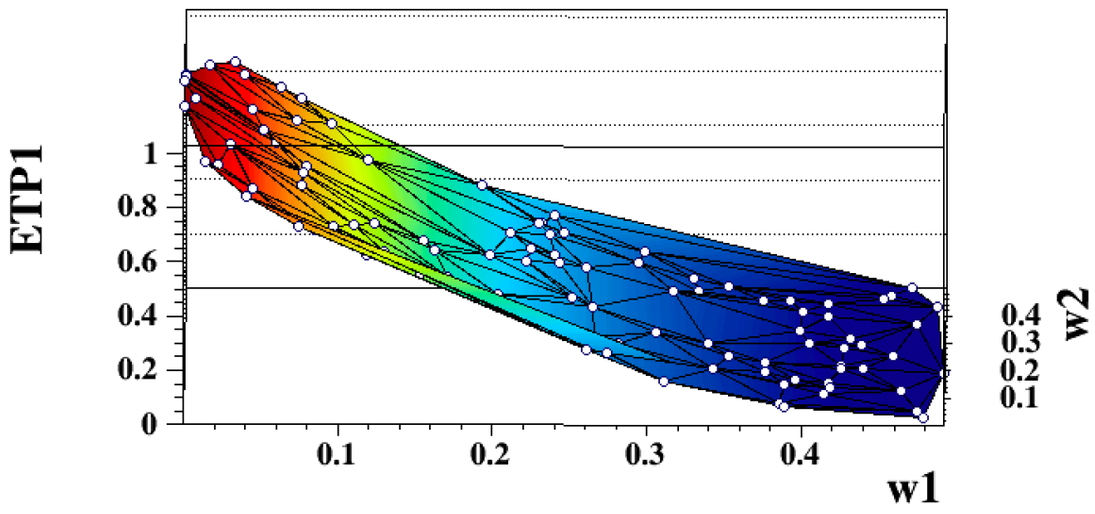


ε_{eff} ratio = ε_{eff}(combined)/ε_{eff}(better single method) vs ω_1 ω_2

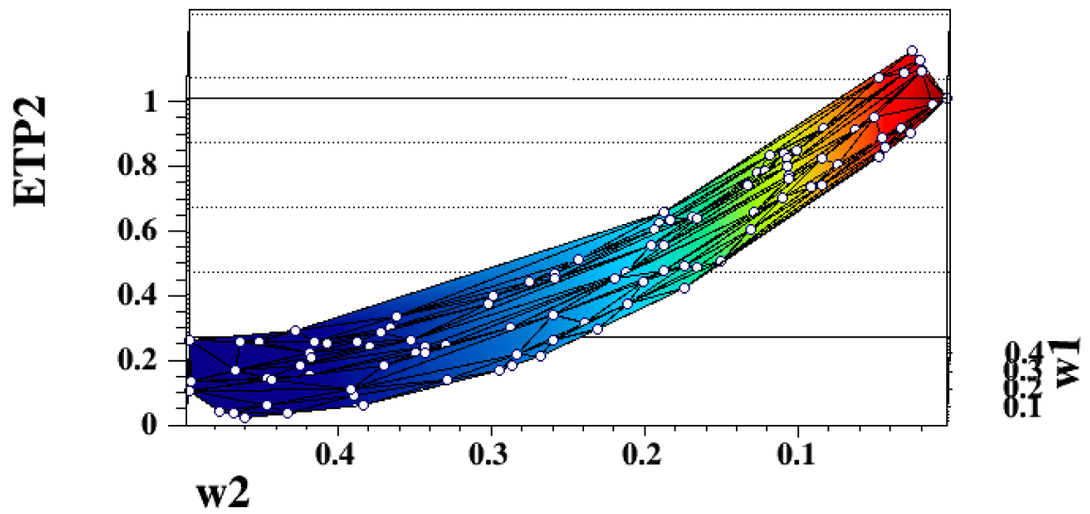


ε_{eff}(method1), ε_{eff}(method2), ε_{eff}(combined), ε_{eff} ratio vs ω_1 ω_2

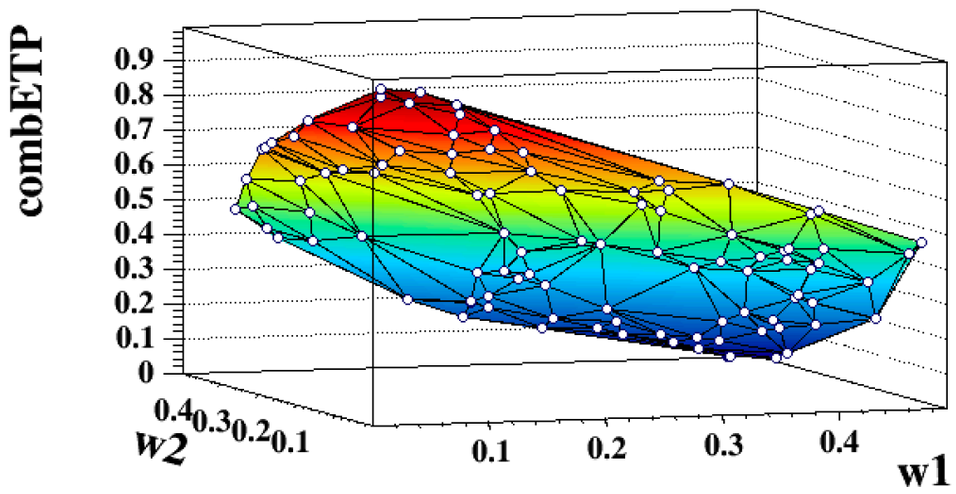
ETP1



ETP2



combETP



ETPratio