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

CEPC

Jet Charge at CEPC

Hanhua Cui, Manqi Ruan
cuihanhua@ihep.ac.cn

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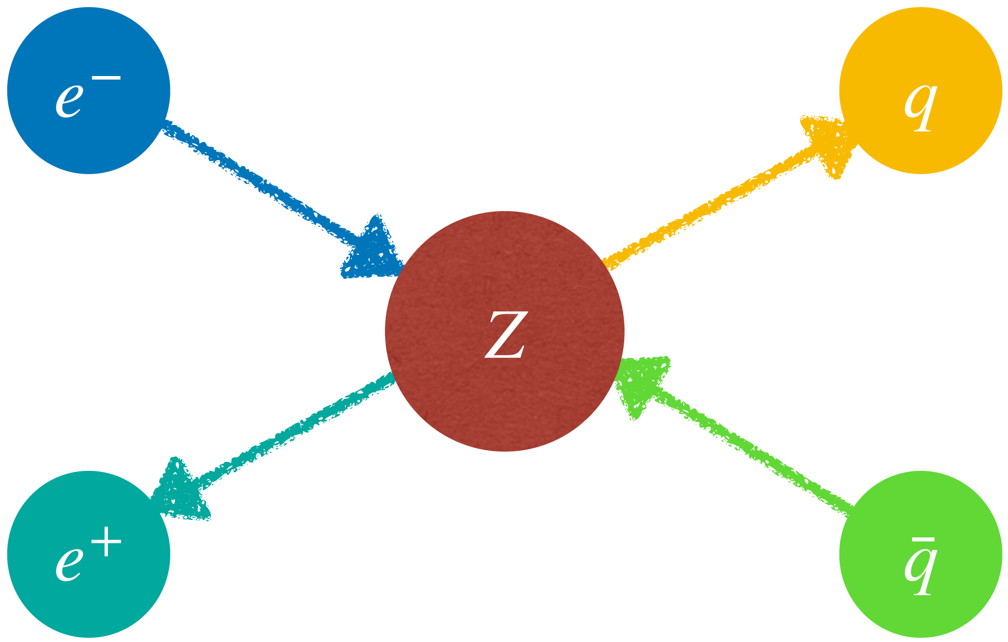
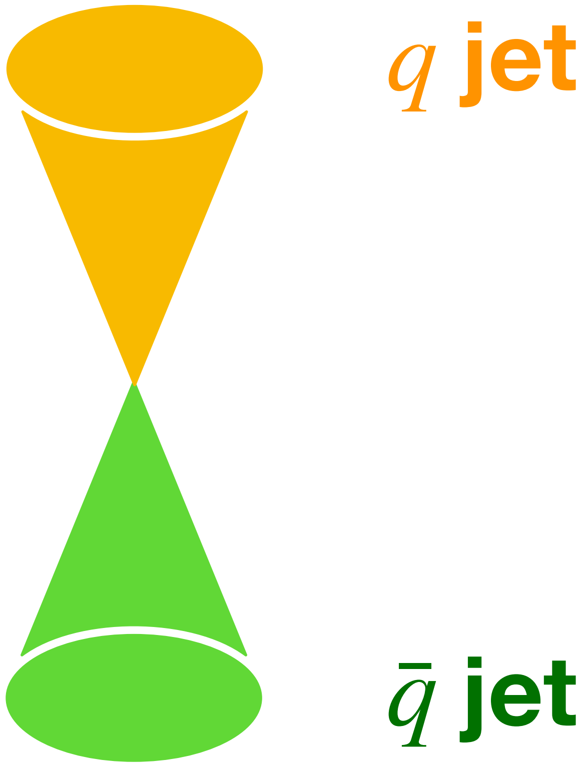
Outline

- **Introduction of Jet Charge**
- **Samples and Method**
- **Results of Jet Charge at Truth Level**
    - *Study of* $e^+e^- \to Z \to b\bar{b}$ *event*
    - *Study of* $e^+e^- \to Z \to c\bar{c}$ *event*
- **Conclusion**

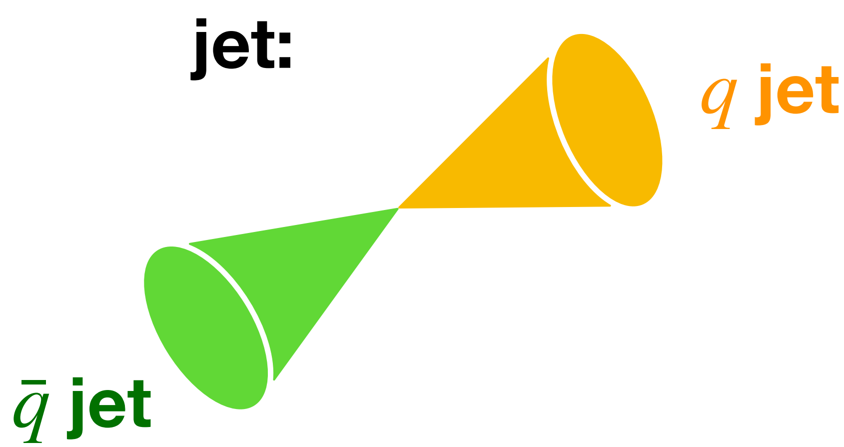




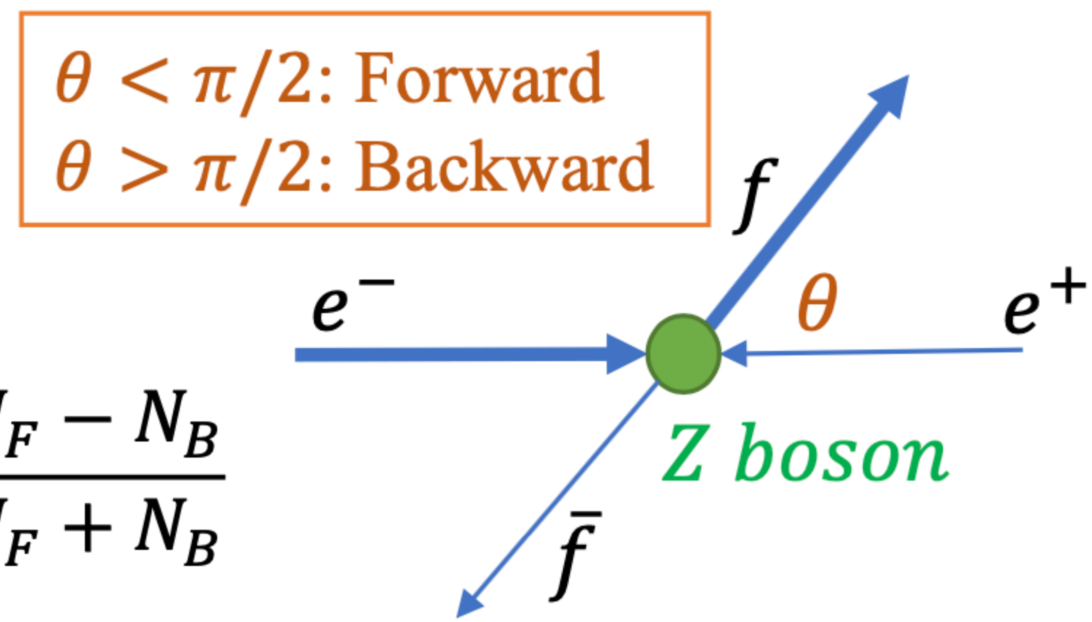
Introduction

Introduction of Jet Charge

We already have flavor tagging algorithm, Jet Charge can help find more physics



$$A_{FB}(\sin^2\theta_W) = \frac{N_F - N_B}{N_F + N_B}$$



What is Jet Charge?

- *To determine initial jet charge, namely b quark v.s. $\bar{b}$ quark / c quark v.s. $\bar{c}$ quark*

Application of Jet Charge:

- *The precision of A_{FB}(Forward and Backward Asymmetry) and $\sin^2\theta_W$ (electroweak mixing angle) measurement*
- *The precision of CP Violation measurement*
- *...*

Jet Charge at CEPC

High productivity

- *3 x 10^{11} - 10^{12} Z bosons in 2 years*
- $b\bar{b}$ *branching fraction: 15.2%*
- *0.152 × 10^{11} - 10^{12}* $b\bar{b}$

Good detector system

- *Good VTX reconstruction*
- *Good PID system*

Clean environment

Different particle flavors

- $\sin^2\theta_W^b$
- $\sin^2\theta_W^c$

Why CEPC?

Flavor production at different experiments

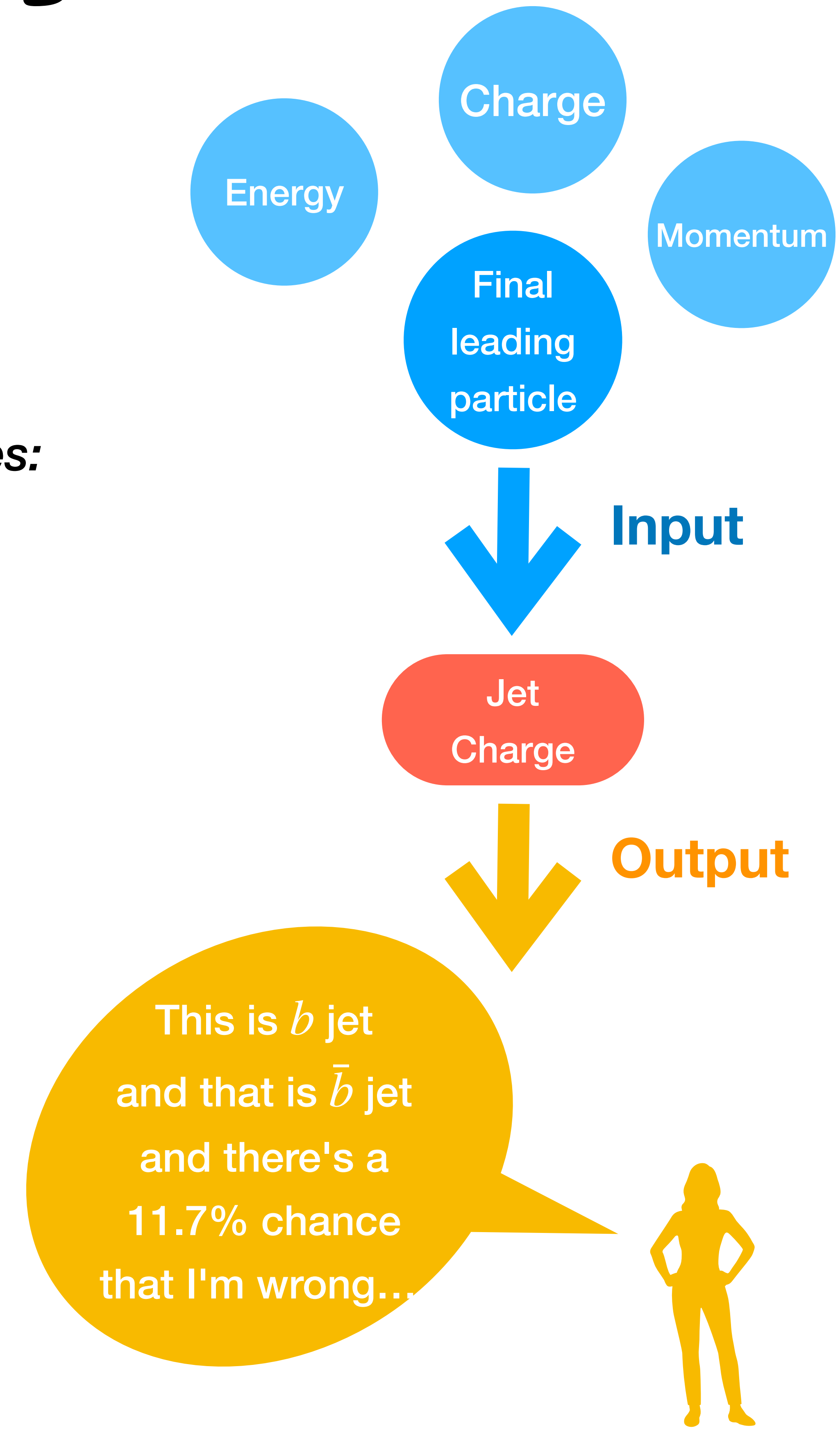
Particle	Tera-Z	Belle II	LHCb
b hadrons			
B^+	6×10^{10}	3×10^{10} ($50\,\text{ab}^{-1}$ on $\Upsilon(4S)$)	3×10^{13}
B^0	6×10^{10}	3×10^{10} ($50\,\text{ab}^{-1}$ on $\Upsilon(4S)$)	3×10^{13}
B_s	2×10^{10}	3×10^{8} ($5\,\text{ab}^{-1}$ on $\Upsilon(5S)$)	8×10^{12}
b baryons	1×10^{10}		1×10^{13}
Λ_b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

From CEPC CDR 2018

Jet Charge Algorithm

Jet Charge Algorithm at Truth Level:

- *Input:*
  - *Information of final leading particles:*
    - *charge*
    - *energy*
    - *momentum*
    - *...*
- *Output:*
  - *The charge of each jet*
  - *Description of Jet Charge*
    - *Misjudgment rate ω*
    - *effective tagging power*

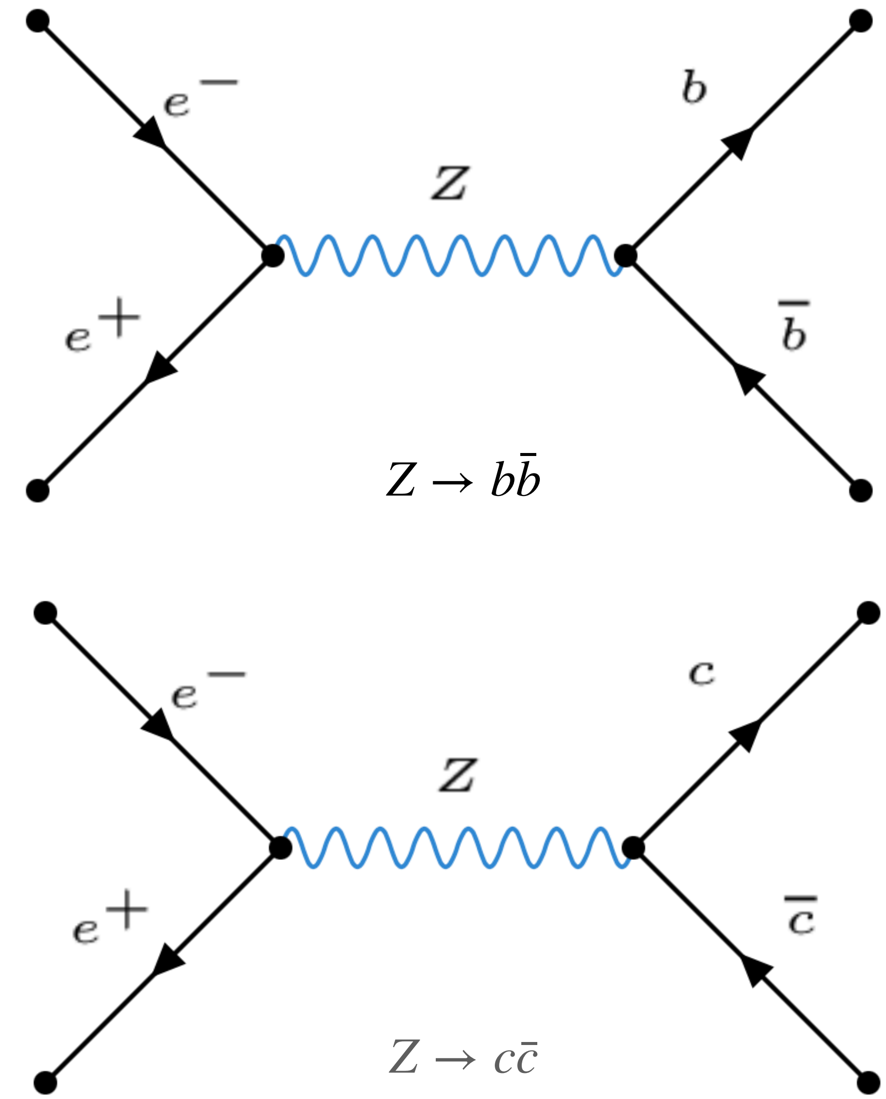


Samples

Samples

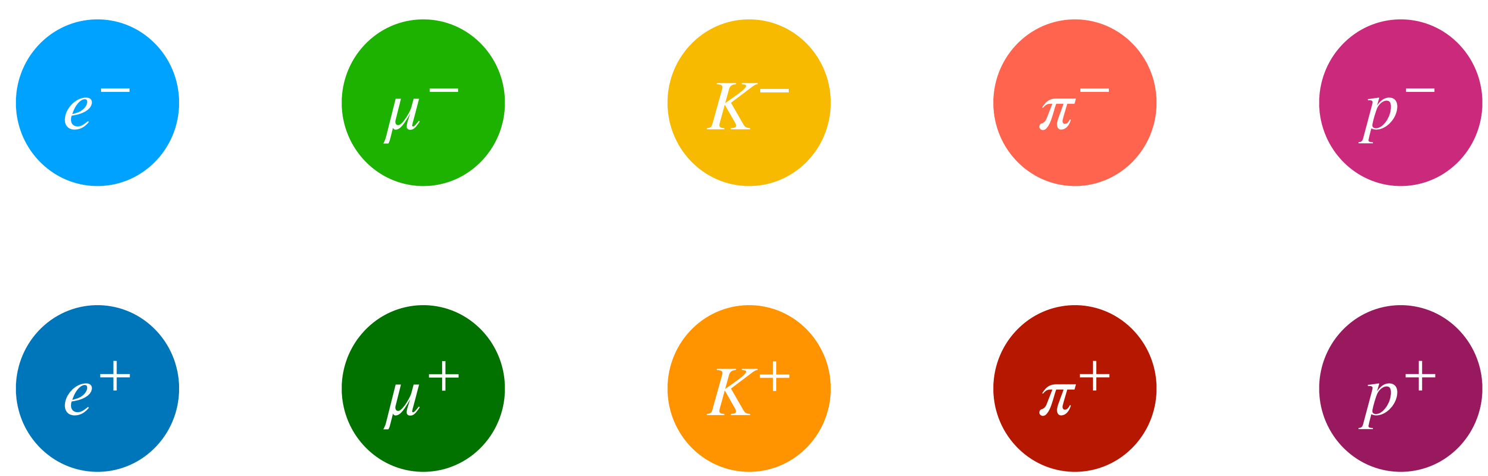
Samples:

- *WHIZARD*
- *CEPC **Z pole** (91.2 GeV) at **Truth level***
- *20 million $Z \to b\bar{b}$ events:*
  - *easy to select*
  - *high sensitivity for $A_{FB}(\sin^2\theta_W)$ v.s. energy*
- *20 million $Z \to c\bar{c}$ events:*
  - *simpler decay behavior*



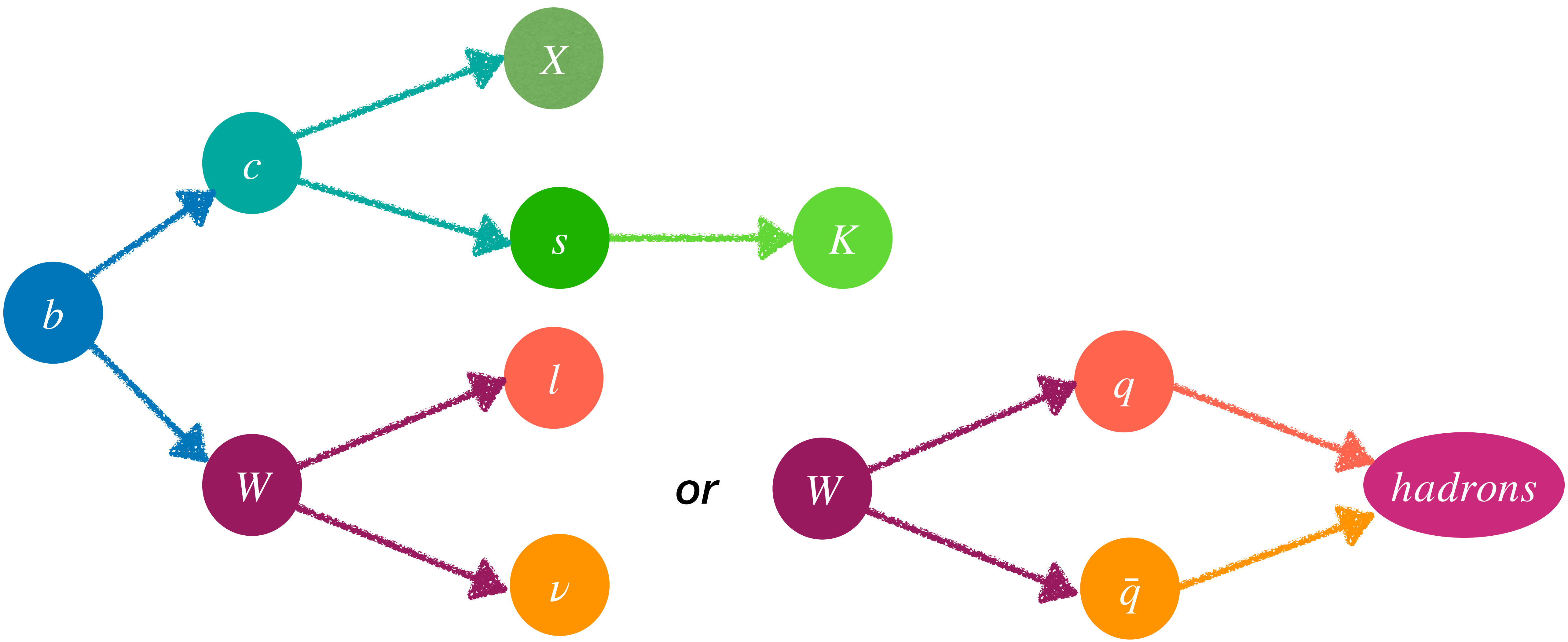
Final particles we consider:

- *leptons: e^+e^-, $\mu^+\mu^-$*
- *Kaons: K^+K^-*
- *pions: $\pi^+\pi^-$*
- *protons: p^+p^-*



b quark decay & c quark decay

- **Dominant decay:**
  - $b \to c + W$
    - $c \to X + s \to X + K$
    - $W \to l + \nu$ *(semi-leptonic decay) or* $W \to qq \to hadrons$*(hadronic decay)*



Method

How to develop Jet Charge?

Steps of Jet Charge:

- *Use Jet Clustering to divide final leading particles into two jets*

- *Find the relationship between observables of final leading particles and jet charge:*
  - *For $Z \to b\bar{b}$ samples:*
    - $e^-, \mu^-, K^-, \pi^-, p^+$ *are closer to* b *jet*
    - $e^+, \mu^+, K^+, \pi^+, p^-$ *are closer to* $\bar{b}$ *jet*
  - *For $Z \to c\bar{c}$ samples:*
    - $e^+, \mu^+, K^-, \pi^+, p^+$ *are closer to* c *jet*
    - $e^-, \mu^-, K^+, \pi^-, p^+$ *are closer to* $\bar{c}$ *jet*

- *Combine the information of final leading particles of two jets*

- *Use those observables of final leading particles to measure jet charge*

- *Use Misjudgment rate ω and effective tagging power to describe Jet Charge*

How to describe Jet Charge?

Misjudgment rate ω:

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

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

Efficiency:

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

$$Efficiency = \frac{Number\ of\ selected\ final\ leading\ particles}{Number\ of\ all\ final\ leading\ particles}$$

- *The selected final leading particles are particles with typical flavor and energy cut and the charges of two leading particles of each jet are verse*

Effective tagging power ETP:

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

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

Results

Results of Jet Charge at Truth Level

We find that:

- *For $Z \to b\bar{b}$ samples:*
    - *The lepton and Kaon can deliver better misjudgment rate ω than pion and proton*

- *For $Z \to c\bar{c}$ samples:*
    - *The lepton, Kaon and proton can deliver better misjudgment rate ω than pion*

We categorize the hadronic Z decay events according to the flavors of the final leading charged particles at each jet

b or $\bar{b}$ jet: (e, μ, K) & $(\pi, proton)$

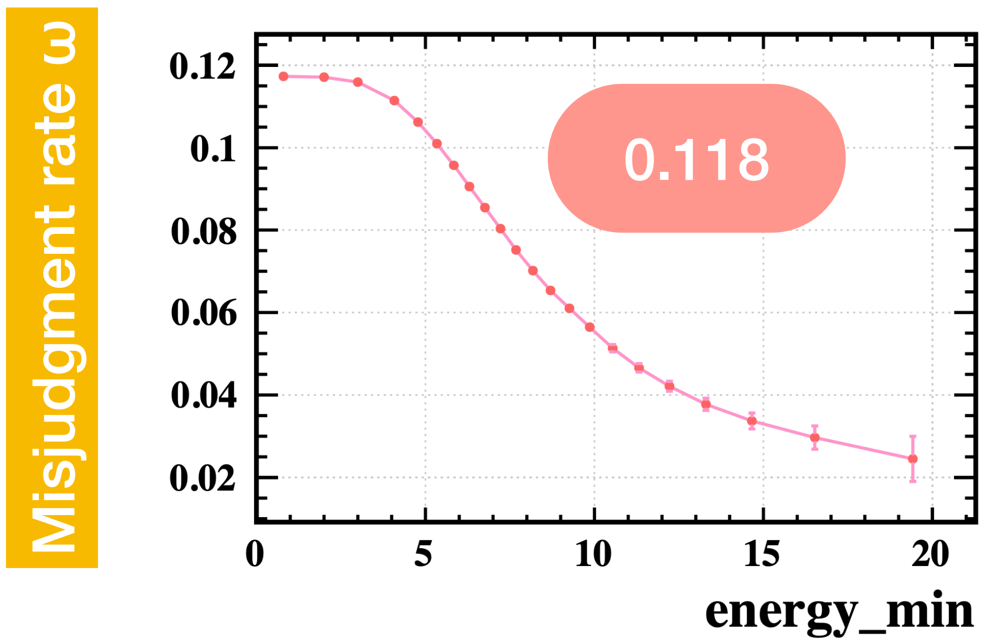
c or $\bar{c}$ jet: (e, μ, p, K) & (π)

We also changed the energy threshold for the final leading charged particles

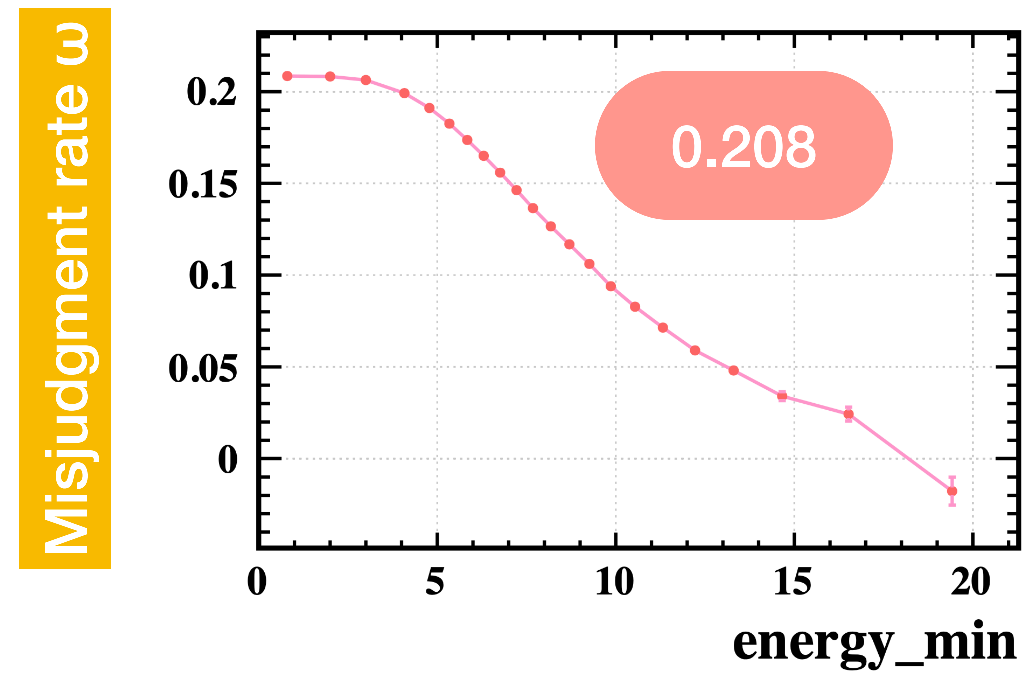
$Z \to b\bar{b}$ Results of Jet Charge at Truth Level

***Misjudgment rate ω** of 4 categories of particle flavors*

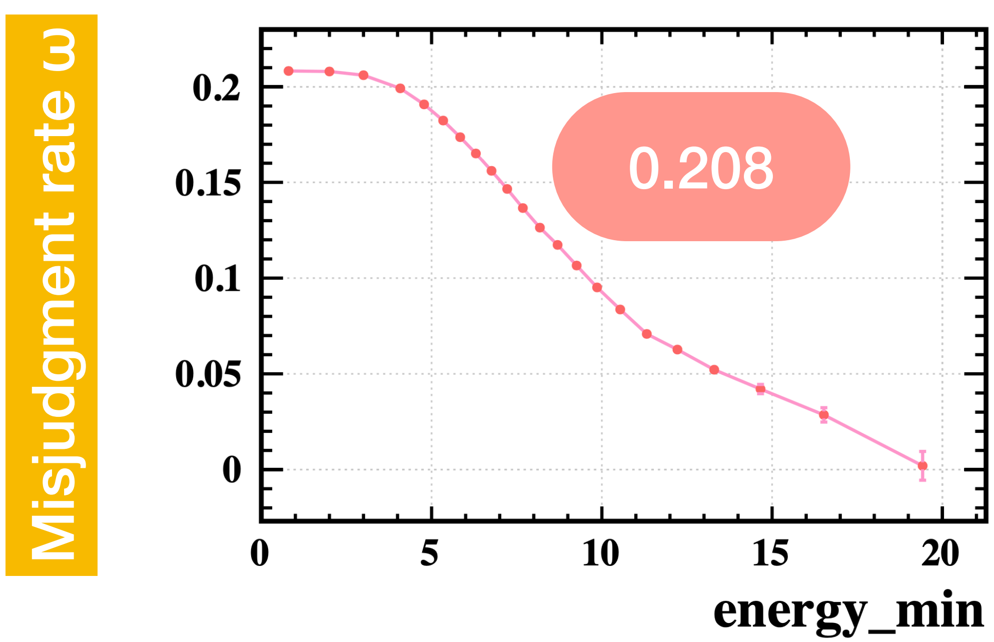
b jet(e, μ, K) & $\bar{b}$ jet(e, μ, K)



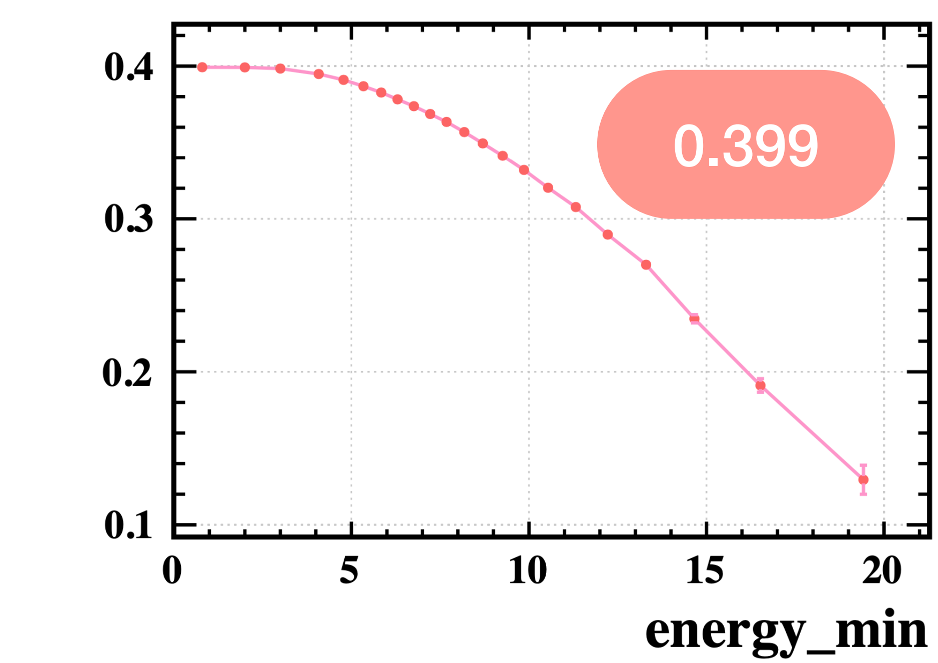
b jet(e, μ, K) & $\bar{b}$ jet$(\pi, proton)$



b jet$(\pi, proton)$ & $\bar{b}$ jet(e, μ, K)



b jet$(\pi, proton)$ & $\bar{b}$ jet$(\pi, proton)$

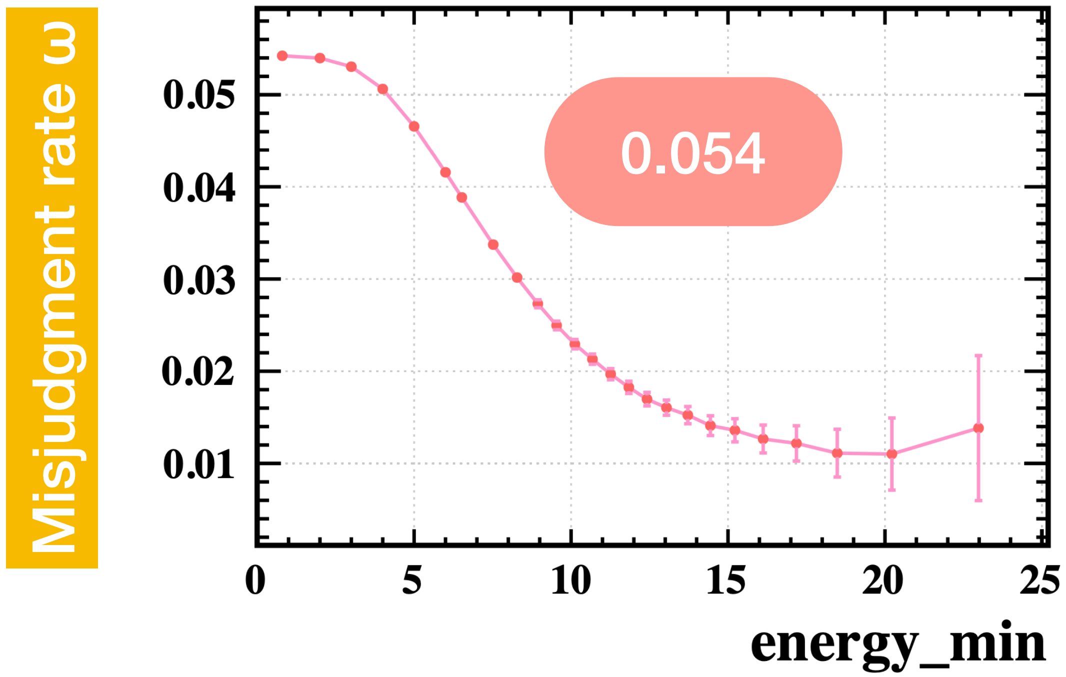


$Z \to c\bar{c}$

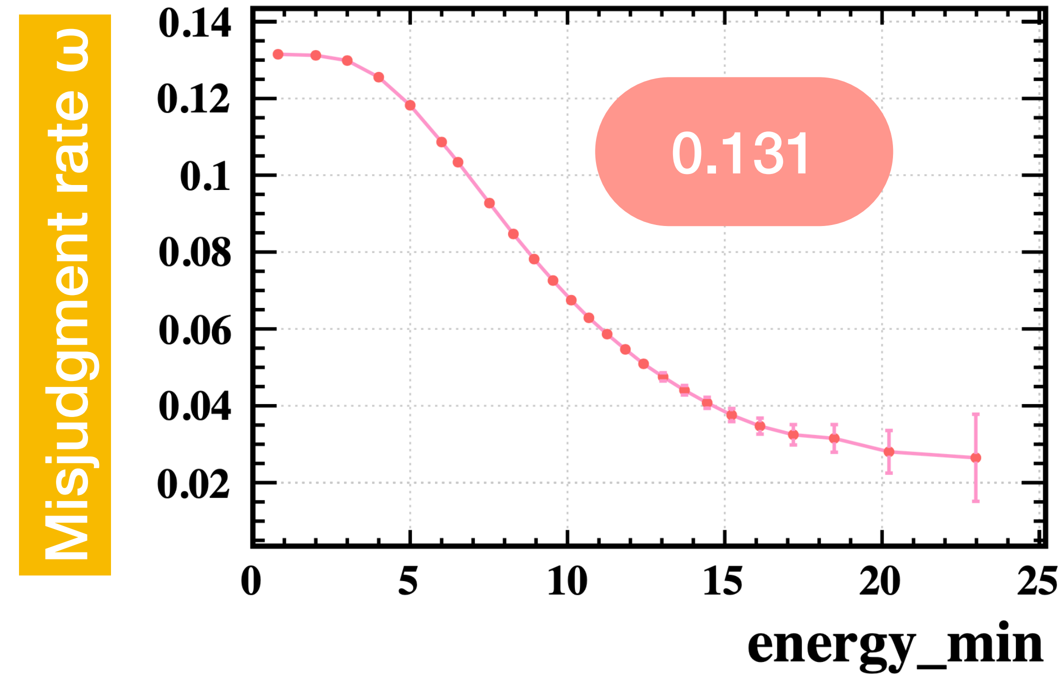
Results of Jet Charge at Truth Level

Misjudgment rate ω of 4 categories of particle flavors

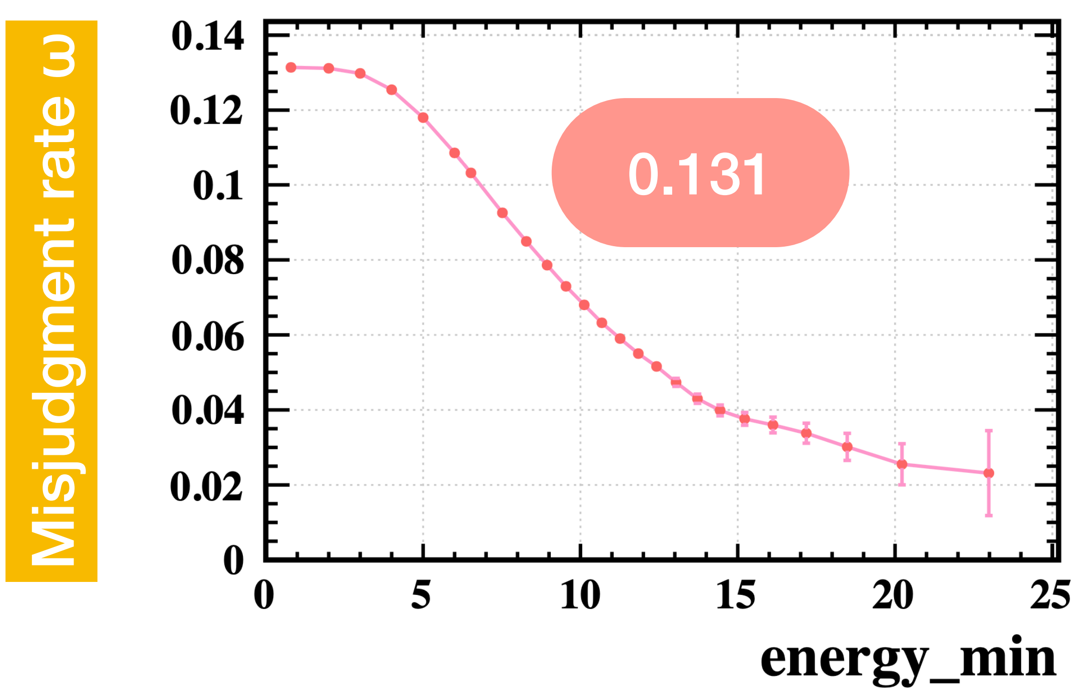
c jet(e, μ, p, K) & $\bar{c}$ jet(e, μ, p, K)



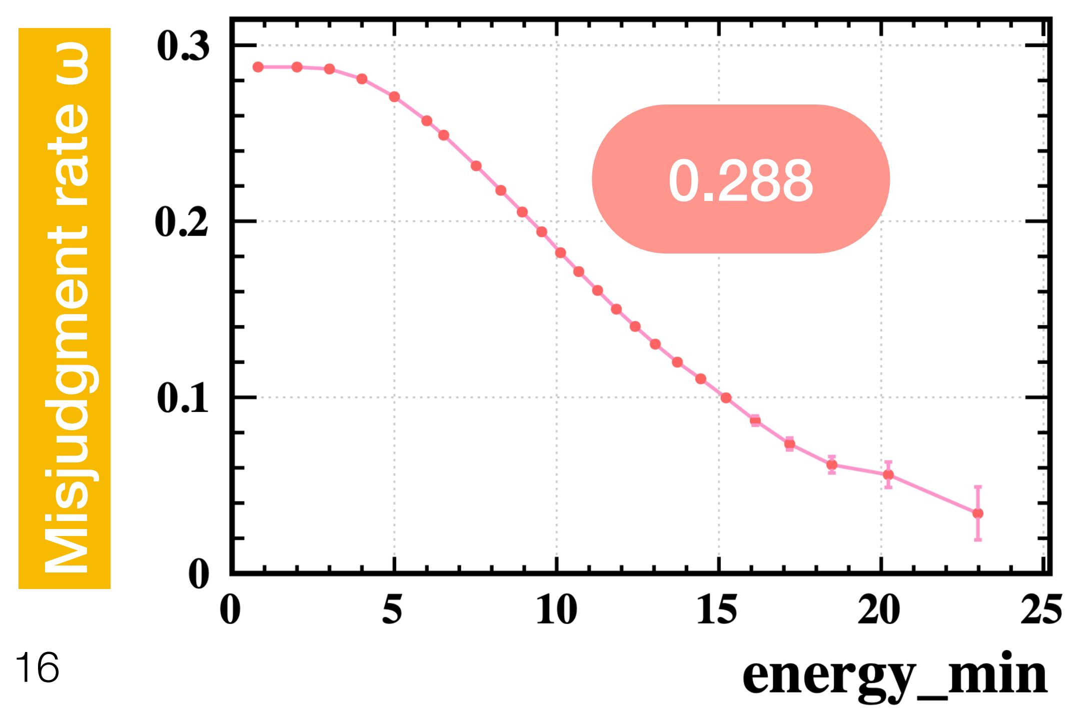
c jet(e, μ, p, K) & $\bar{c}$ jet(π)



c jet(π) & $\bar{c}$ jet(e, μ, p, K)



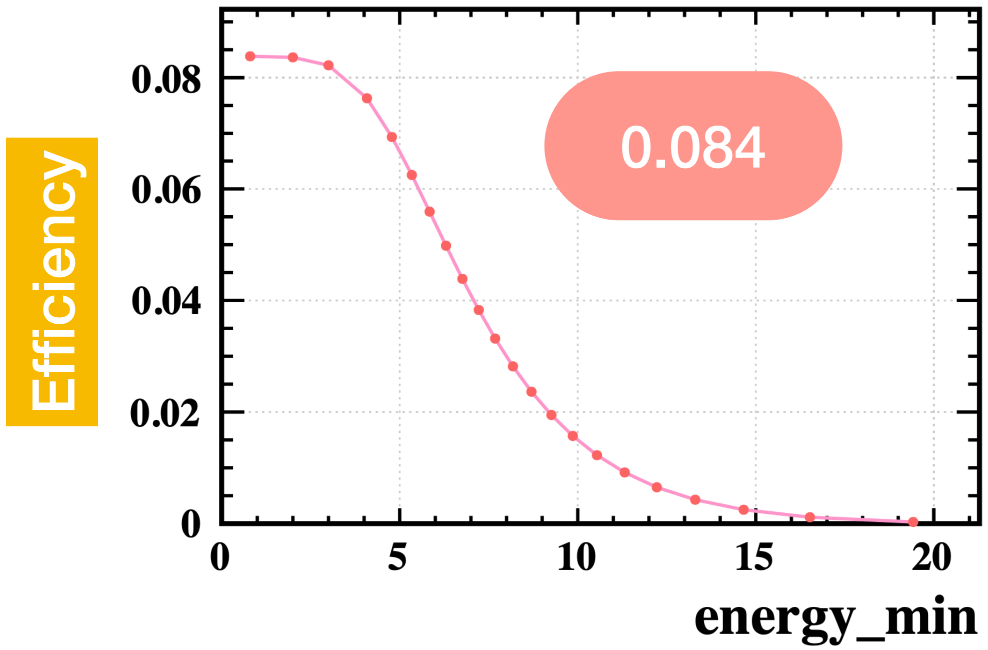
c jet(π) & $\bar{c}$ jet(π)



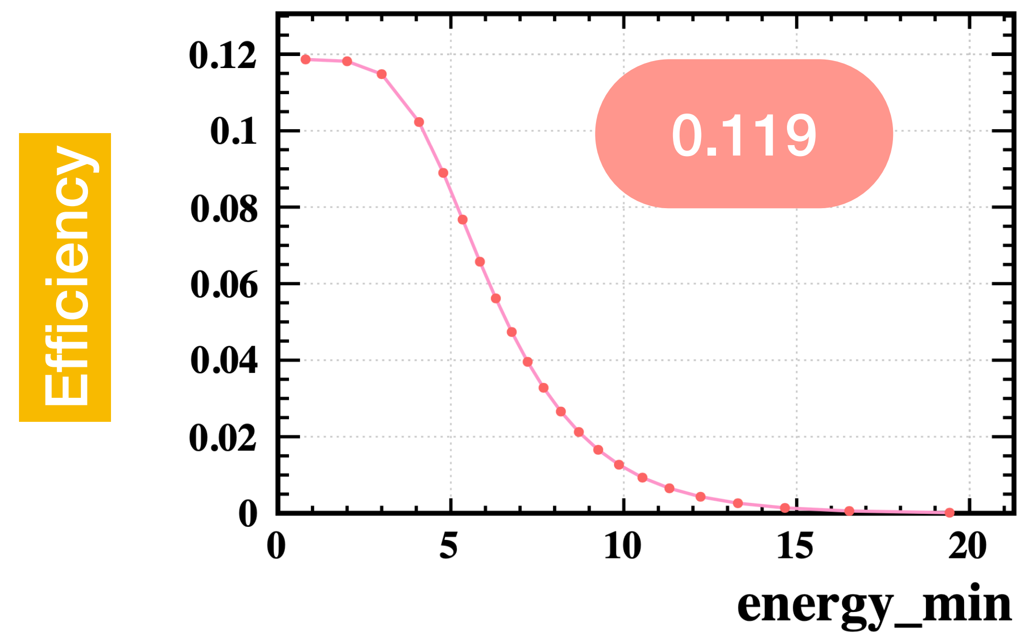
$Z \to b\bar{b}$ Results of Jet Charge at Truth Level

***Efficiency** of 4 categories of particle flavors, total efficiency = 0.519*

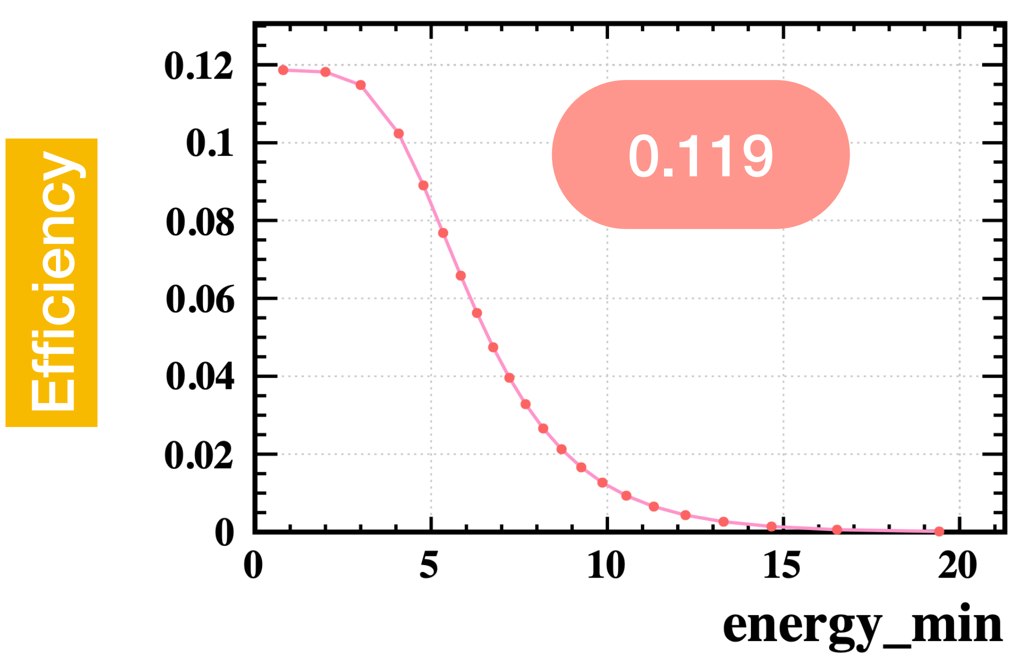
b jet(e, μ, K) & $\bar{b}$ jet(e, μ, K)



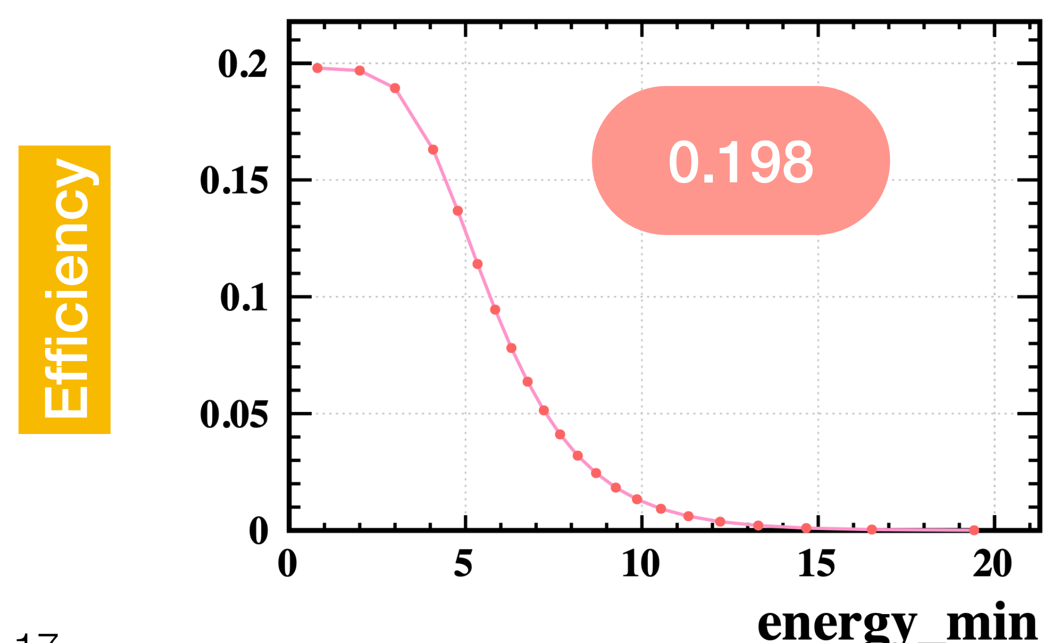
b jet(e, μ, K) & $\bar{b}$ jet($\pi, proton$)



b jet($\pi, proton$) & $\bar{b}$ jet(e, μ, K)



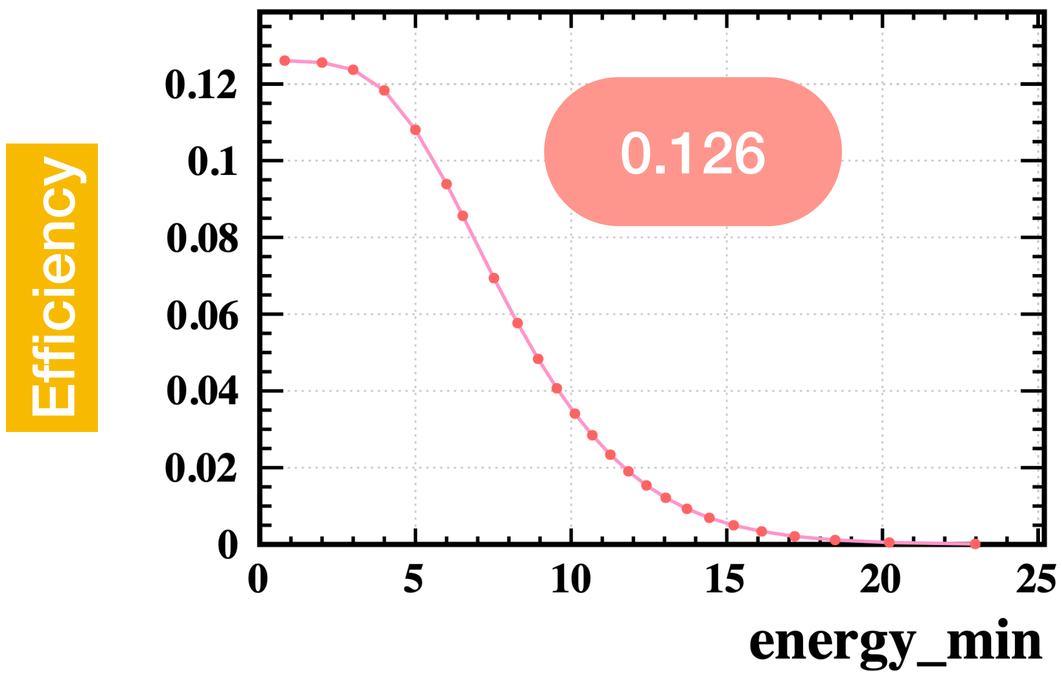
b jet($\pi, proton$) & $\bar{b}$ jet($\pi, proton$)



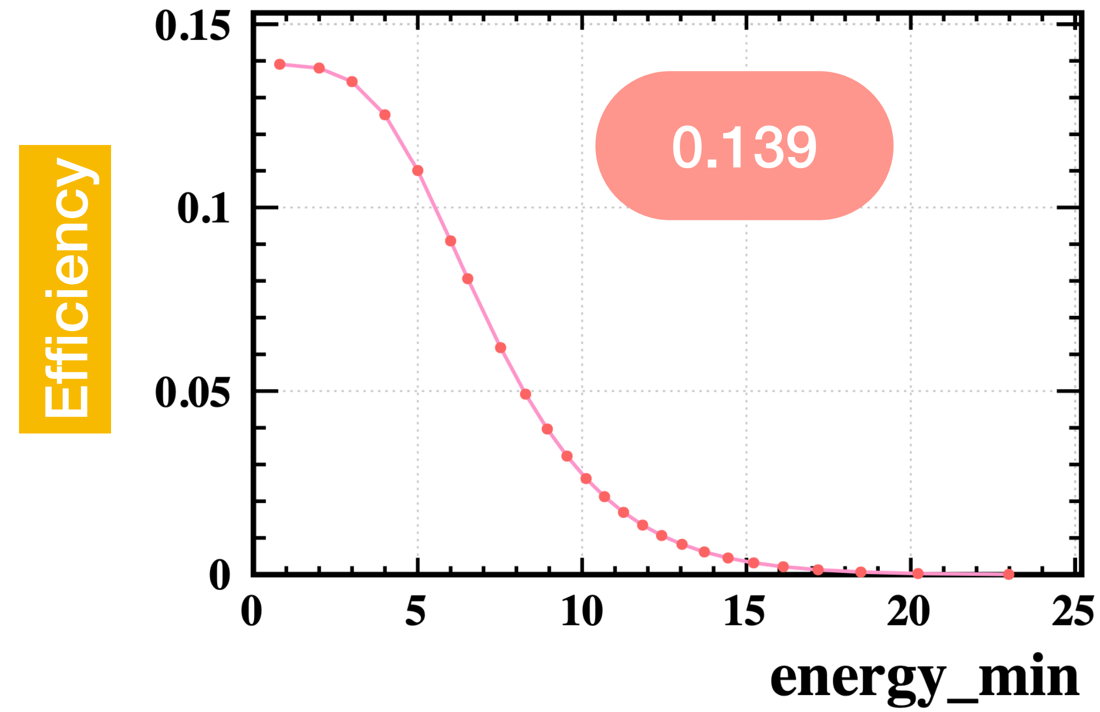
$Z \to c\bar{c}$ Results of Jet Charge at Truth Level

***Efficiency** of 4 categories of particle flavors, total efficiency = 0.577*

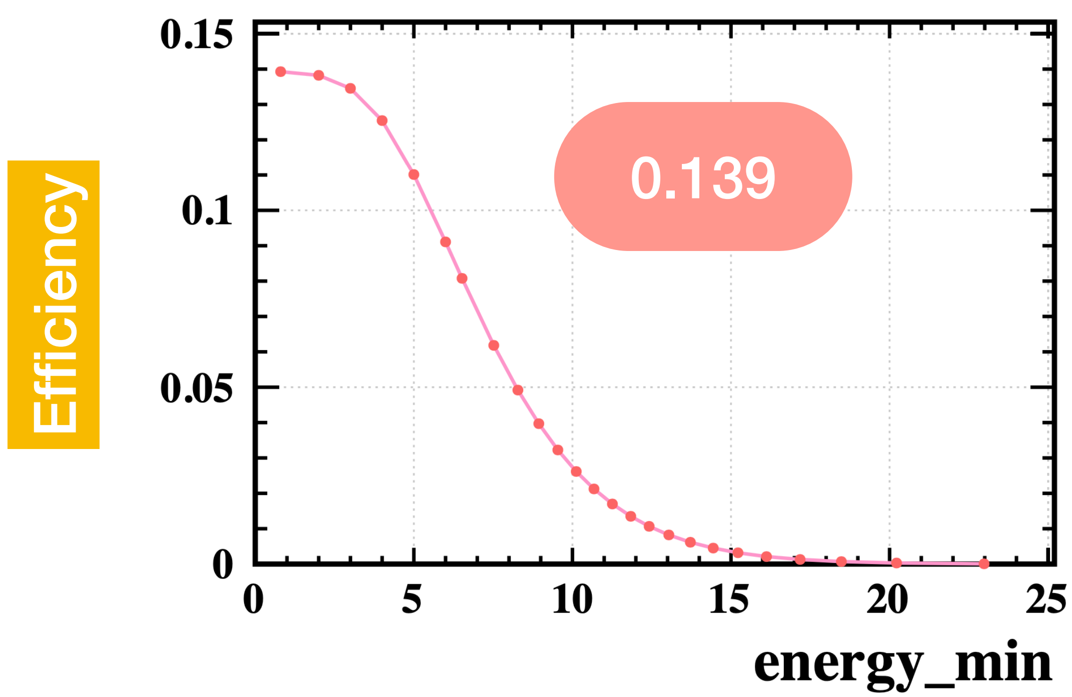
c jet(e, μ, p, K) & $\bar{c}$ jet(e, μ, p, K)



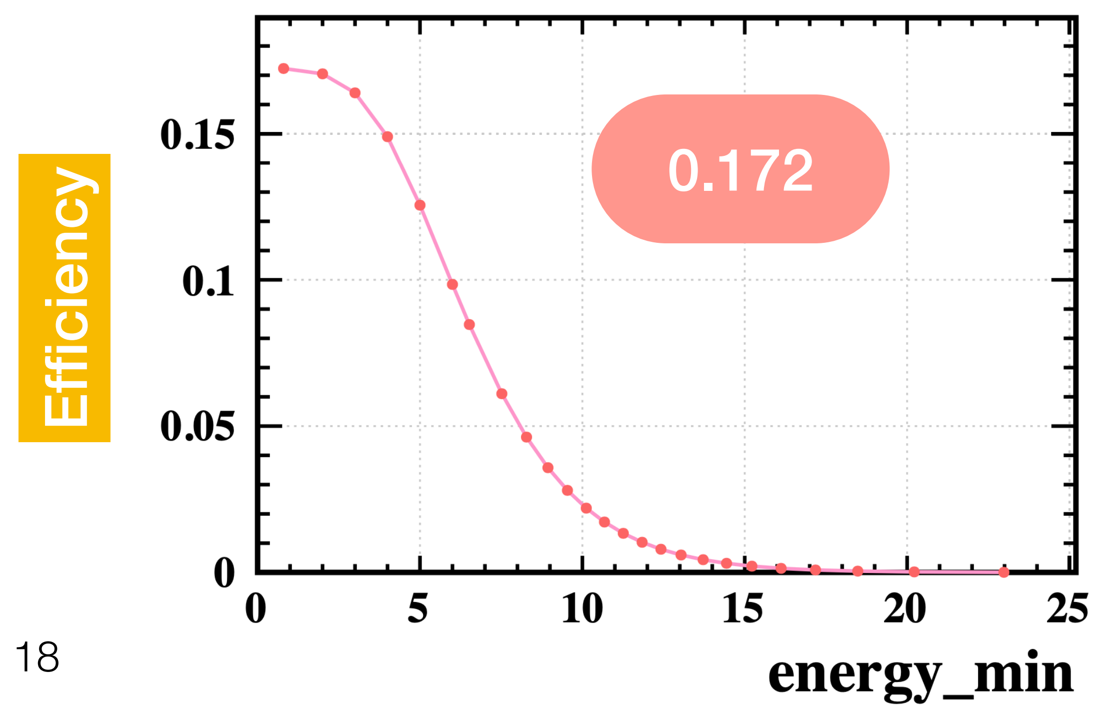
c jet(e, μ, p, K) & $\bar{c}$ jet(π)



c jet(π) & $\bar{c}$ jet(e, μ, p, K)



c jet(π) & $\bar{c}$ jet(π)



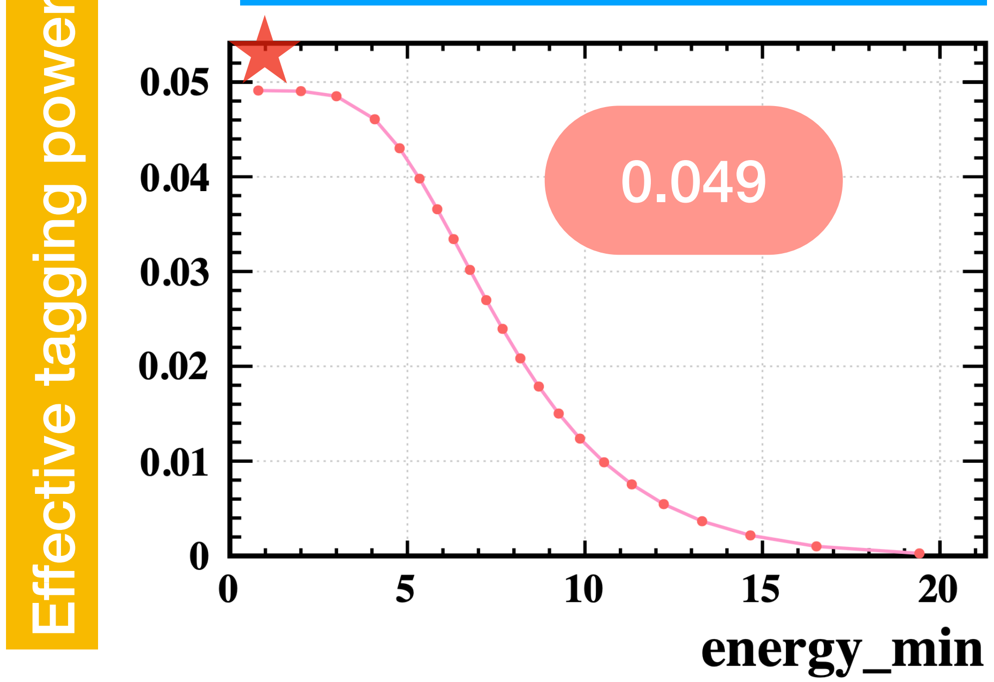
$Z \to b\bar{b}$

Results of Jet Charge at Truth Level

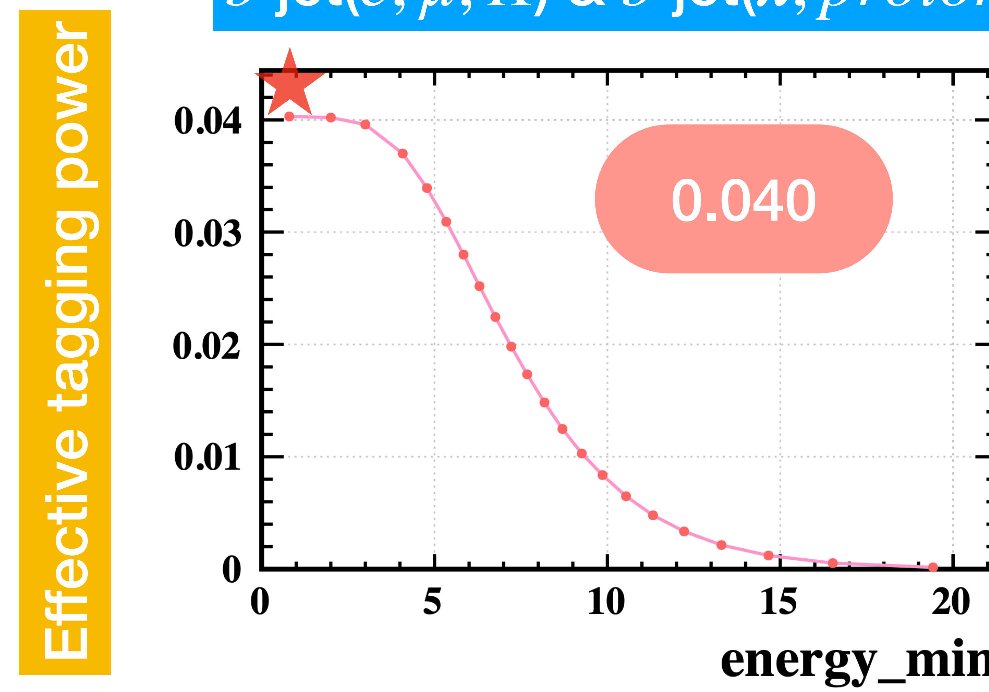
***Effective tagging power** of 4 categories of particle flavors*

*total effective tagging power = **0.138***

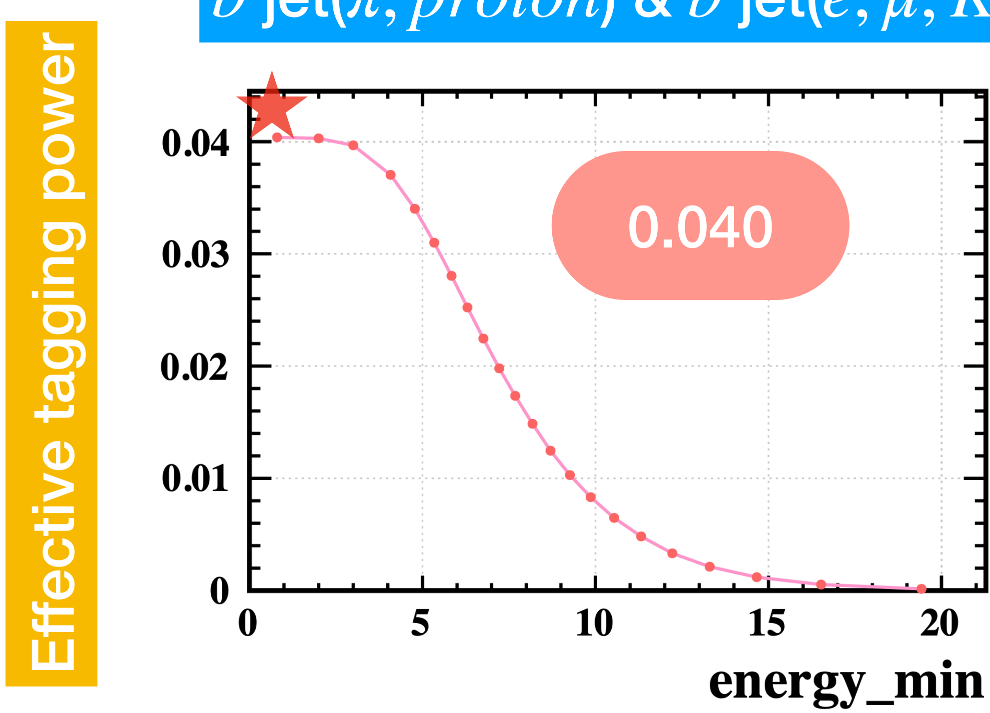
b jet(e, μ, K) & $\bar{b}$ jet(e, μ, K)



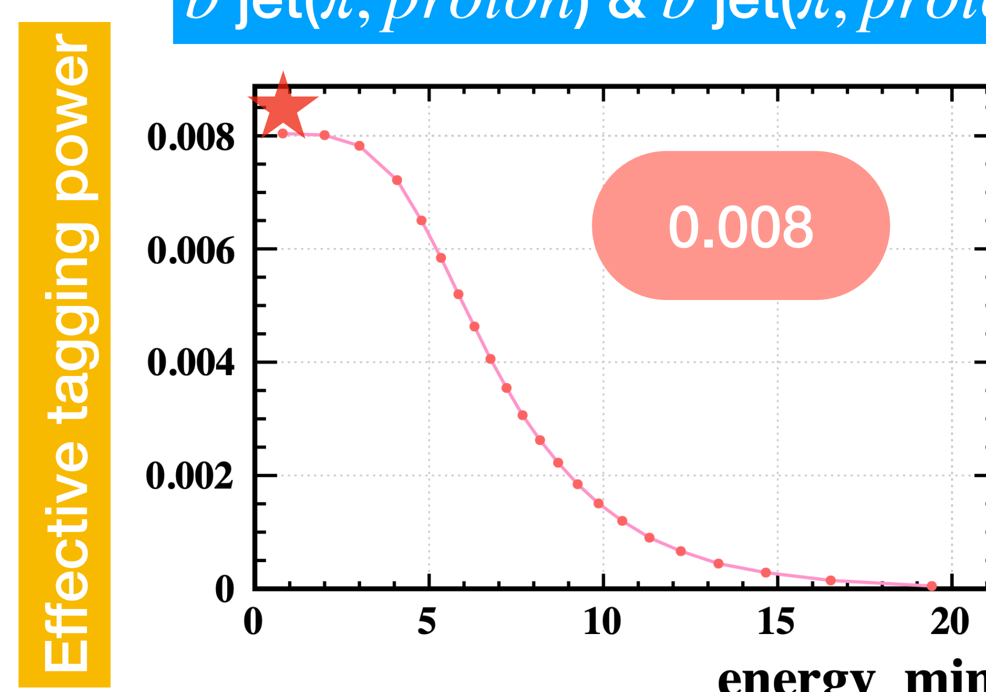
b jet(e, μ, K) & $\bar{b}$ jet($\pi, proton$)



b jet($\pi, proton$) & $\bar{b}$ jet(e, μ, K)



b jet($\pi, proton$) & $\bar{b}$ jet($\pi, proton$)



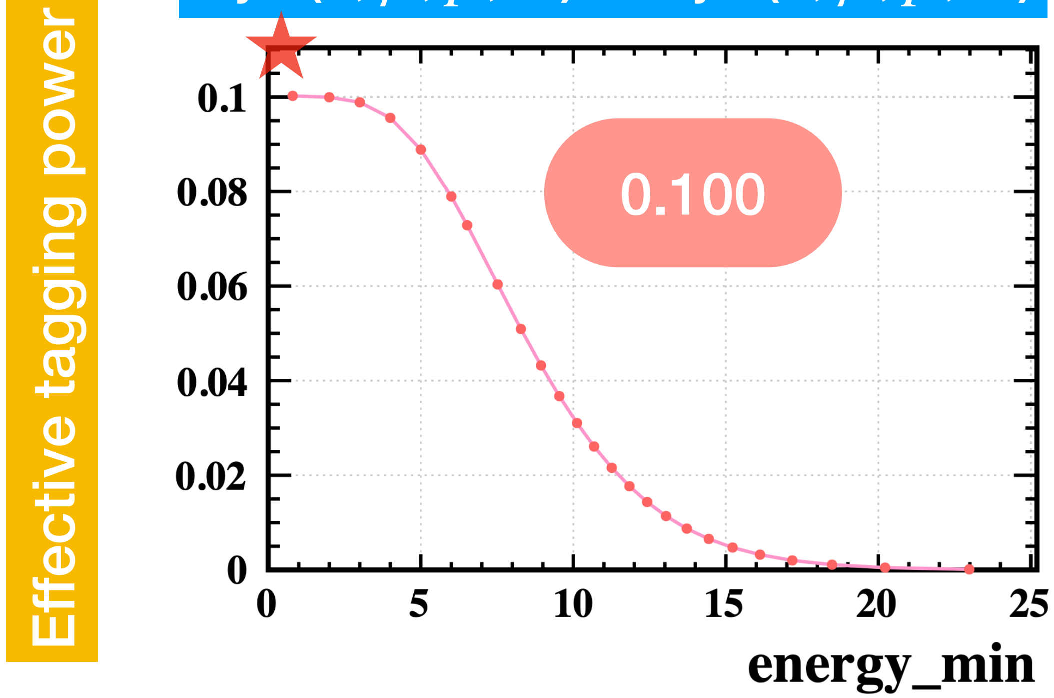
$Z \to c\bar{c}$

Results of Jet Charge at Truth Level

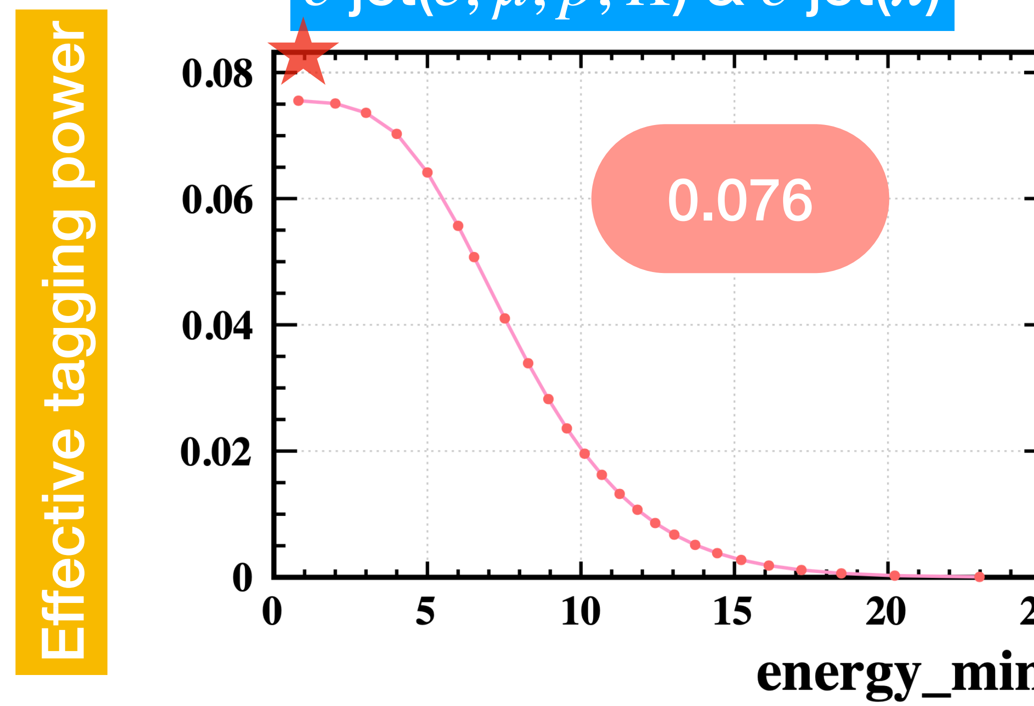
***Effective tagging power** of 4 categories of particle flavors*

total effective tagging power = 0.283

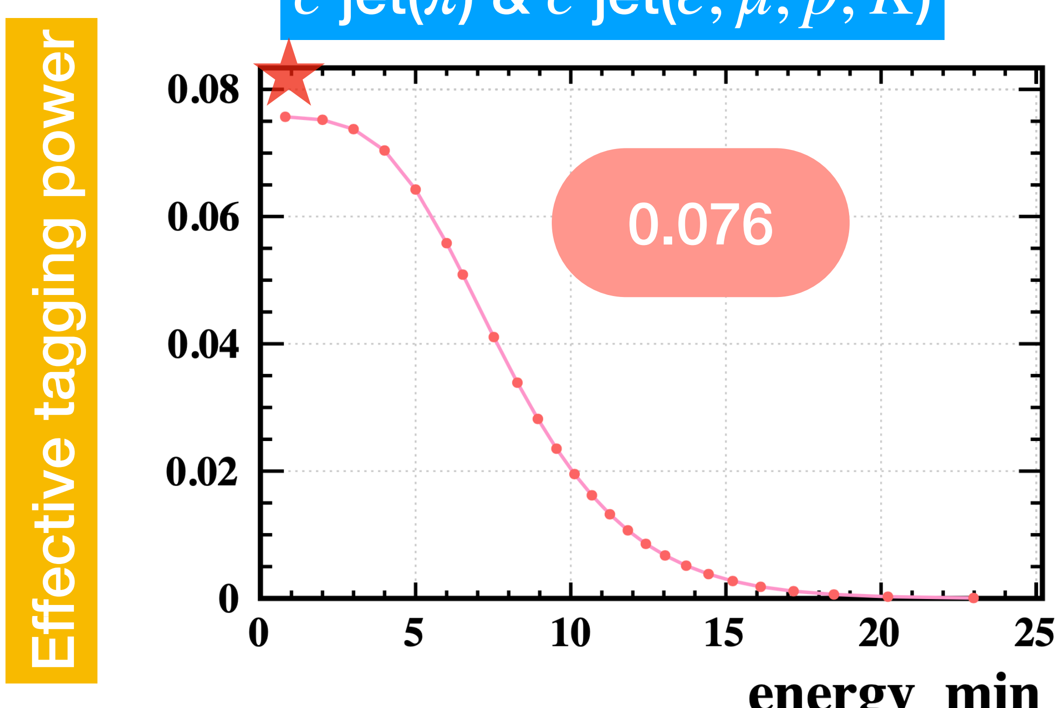
c jet(e, μ, p, K) & $\bar{c}$ jet(e, μ, p, K)



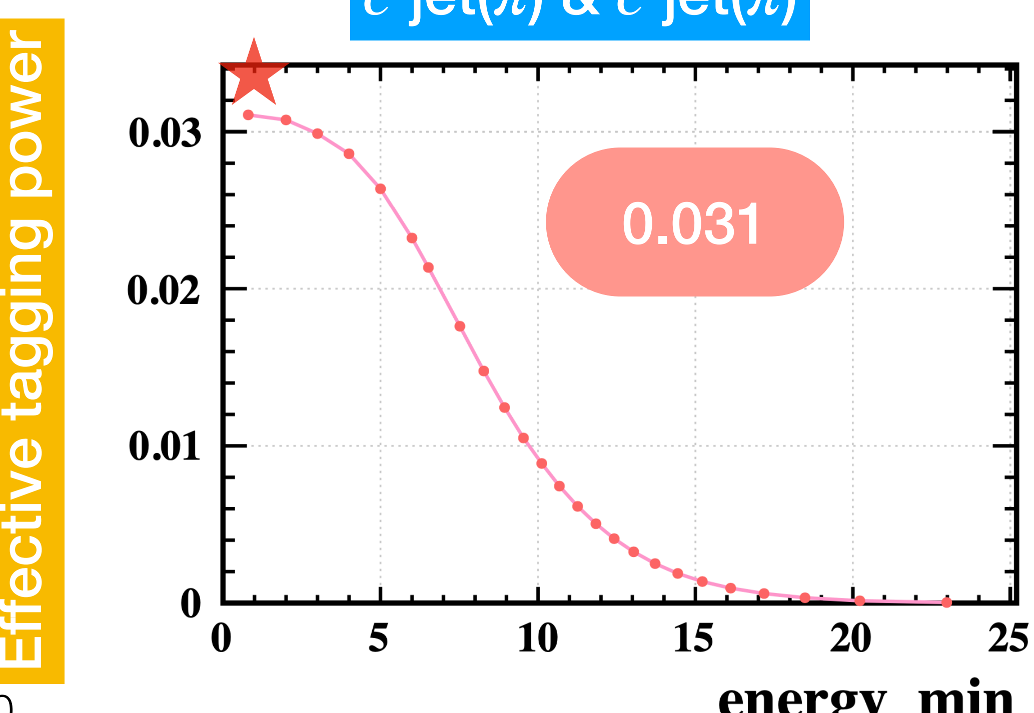
c jet(e, μ, p, K) & $\bar{c}$ jet(π)



c jet(π) & $\bar{c}$ jet(e, μ, p, K)



c jet(π) & $\bar{c}$ jet(π)



Conclusion

Main results of Jet Charge at Truth level

- *For $Z \to b\bar{b}$ samples:*
  - *Total effective tagging power = **0.138***
  - *The lepton and Kaon without energy cut can deliver better effective tagging power*
- *For $Z \to c\bar{c}$ samples:*
  - *Total effective tagging power = **0.283***
  - *The lepton, Kaon and proton without energy cut can deliver better effective tagging power*
- *$Z \to c\bar{c}$ deliver better misjudgment rate ω and effective tagging power than $Z \to b\bar{b}$*

Future:

☞ *Jet Charge in typical channel (e.g. Bs, …)*

☞ *Jet Charge at Full Simulation level → Compare Truth level and Full Simulation level → CEPC detector performance*

☞ *Apply Jet Charge to the precision measurement of relative benchmark*

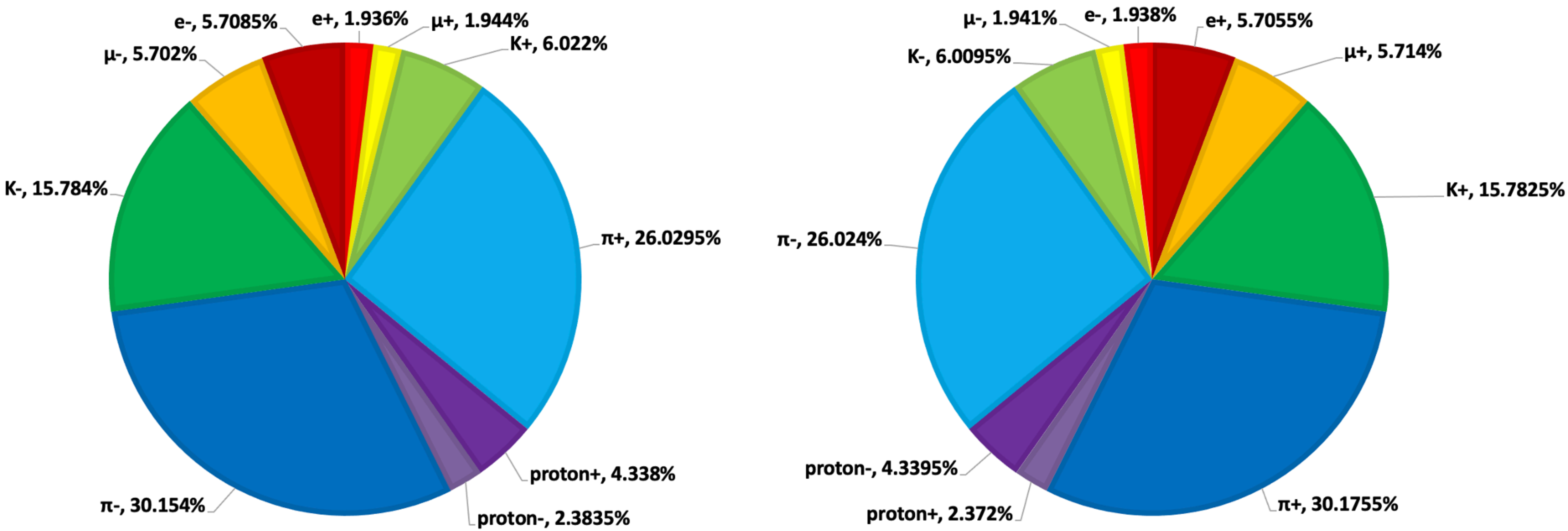
Thanks!

Backup

$Z \to b\bar{b}$

Results of Jet Charge at Truth Level

***Percent** of final charged leading particles of b jet and $\bar{b}$ jet*



Point:

☞ *The distribution of each charged particle of two jets is asymmetry*

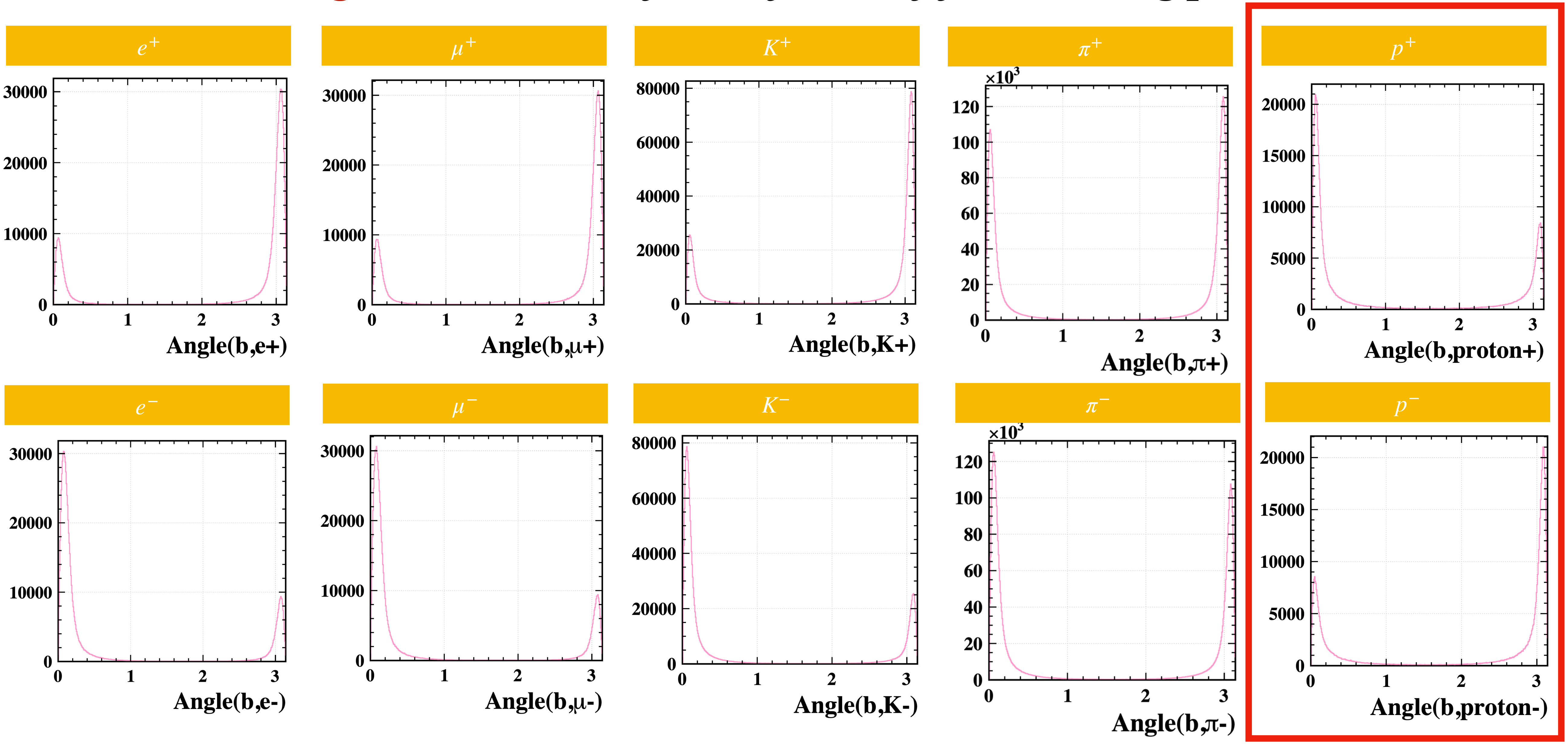
☞ *The percent of that the final leading particle of both jet is e, μ, K is 13.75%*

☞ *The percent of the each flavor of final leading particles varies with energy threshold*

$Z \to b\bar{b}$

Results of Jet Charge at Truth Level

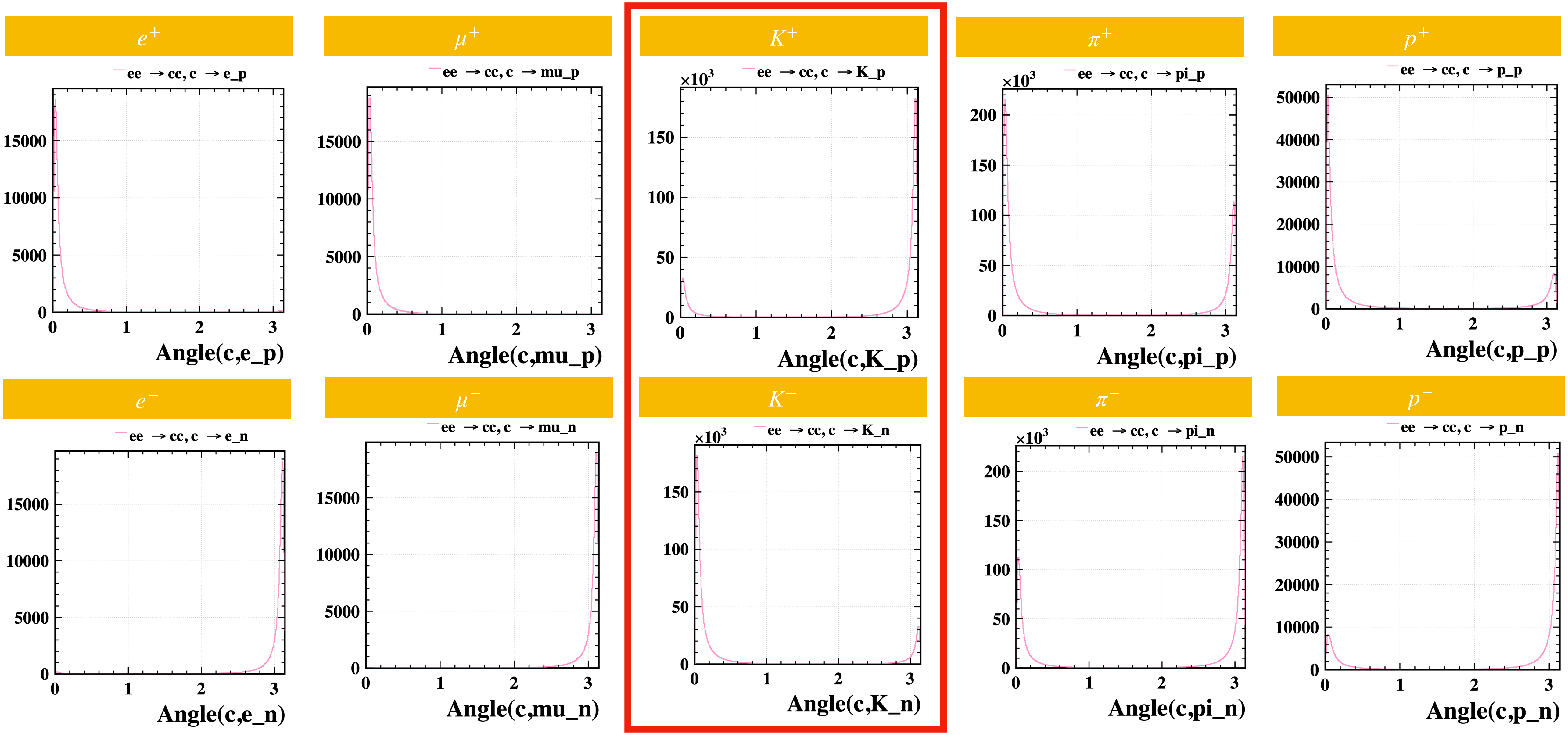
Angle distribution of each flavor of final leading particles



- ☞ *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*

$Z \to c\bar{c}$ Results of Jet Charge at Truth Level

Angle distribution of each flavor of final leading particles

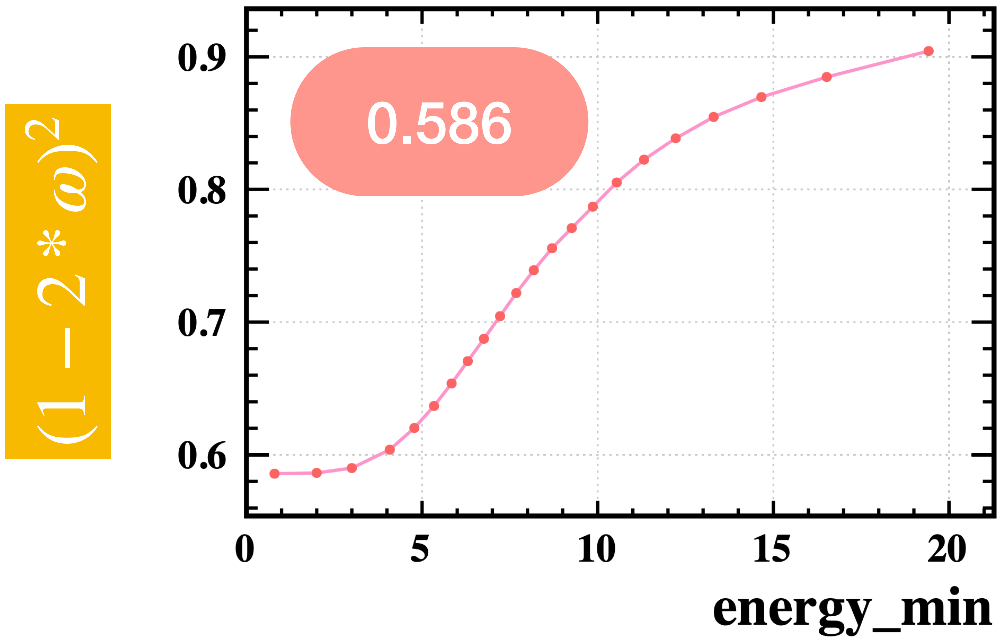


- ☞ *Angle distribution of two jets is asymmetry*
- ☞ *The more asymmetrical, the more accurate*
- ☞ *The lepton and Kaon is more asymmetrical than pion and proton*
- ☞ *Kaon behaves different from others*

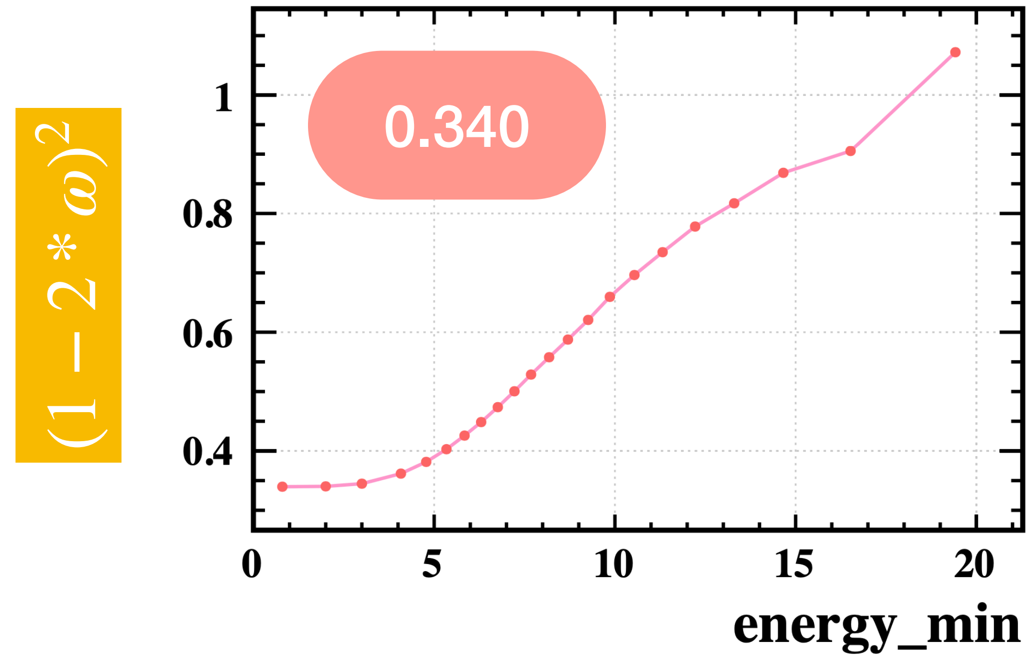
$Z \to b\bar{b}$ Results of Jet Charge at Truth Level

$(1-2*\omega)^2$ *of 4 categories of particle flavors*

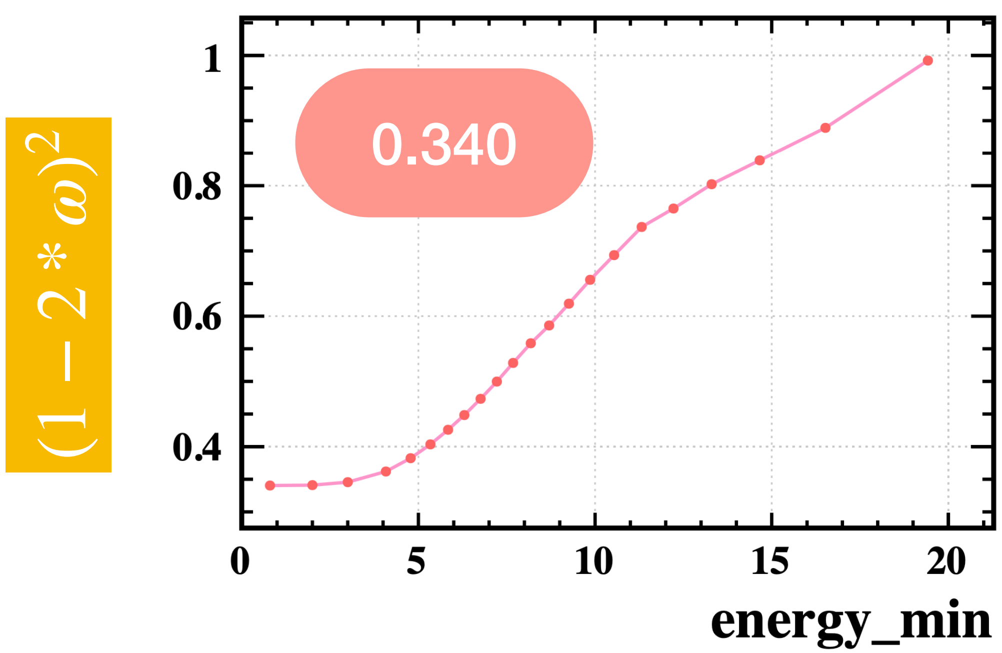
b jet(e, μ, K) & $\bar{b}$ jet(e, μ, K)



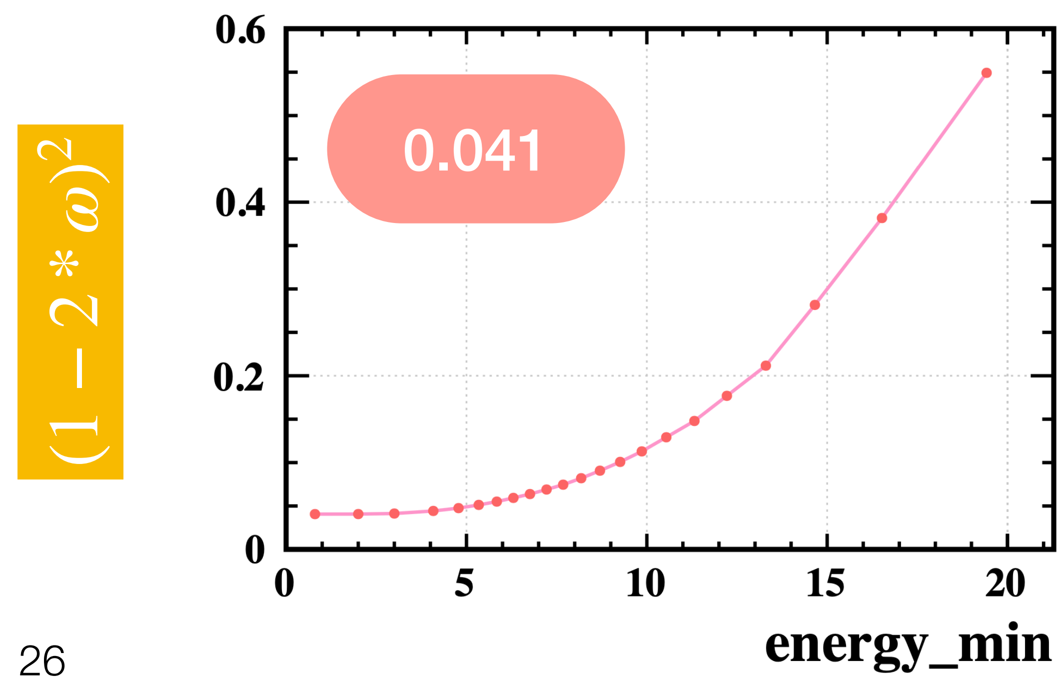
b jet(e, μ, K) & $\bar{b}$ jet($\pi, proton$)



b jet($\pi, proton$) & $\bar{b}$ jet(e, μ, K)



b jet($\pi, proton$) & $\bar{b}$ jet($\pi, proton$)

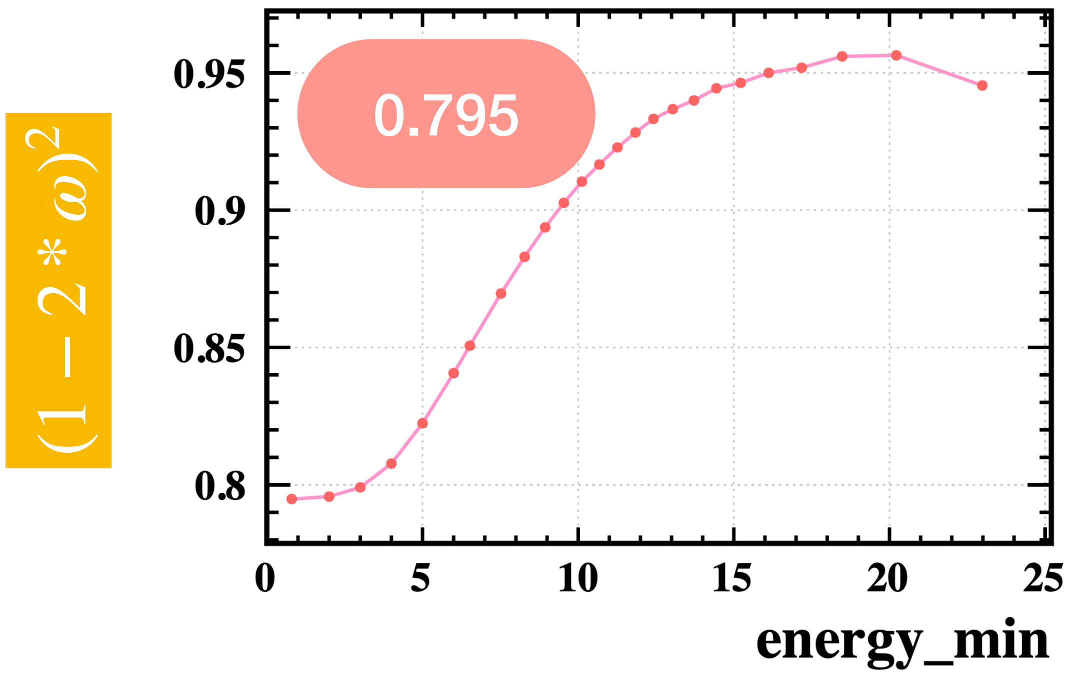


$Z \to c\bar{c}$

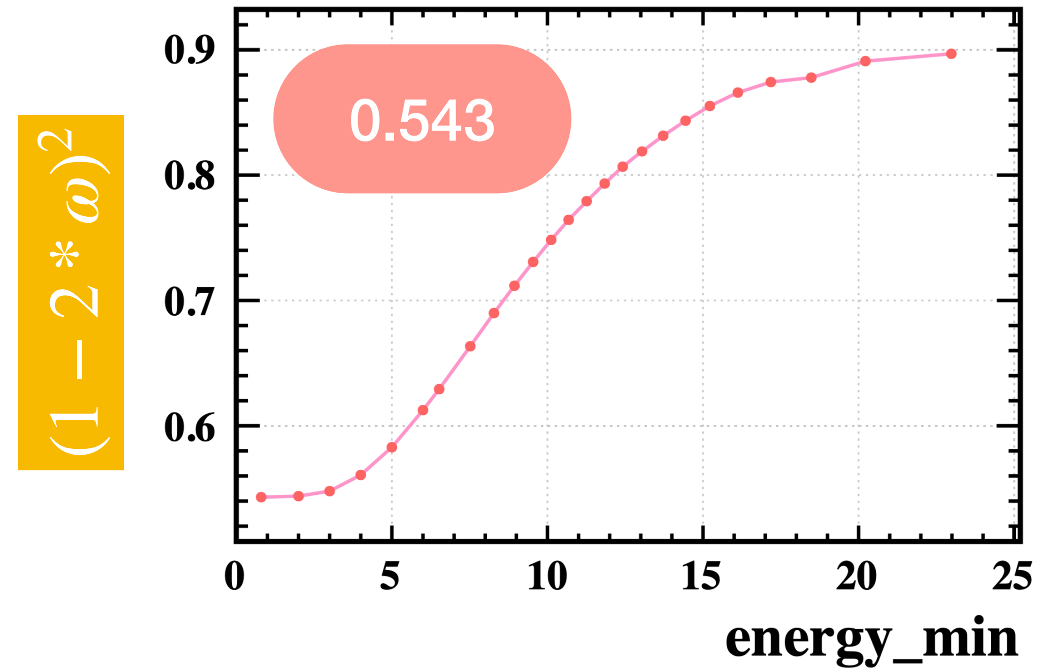
Results of Jet Charge at Truth Level

$(1-2*\omega)^2$ *of 4 categories of particle flavors*

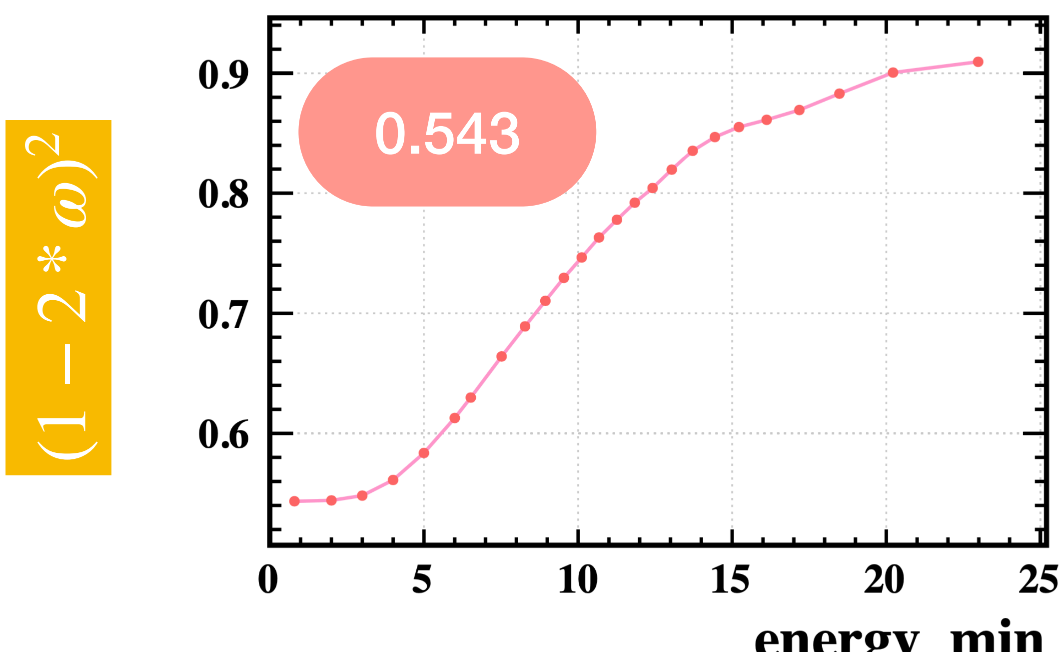
c jet(e, μ, p, K) & $\bar{c}$ jet(e, μ, p, K)



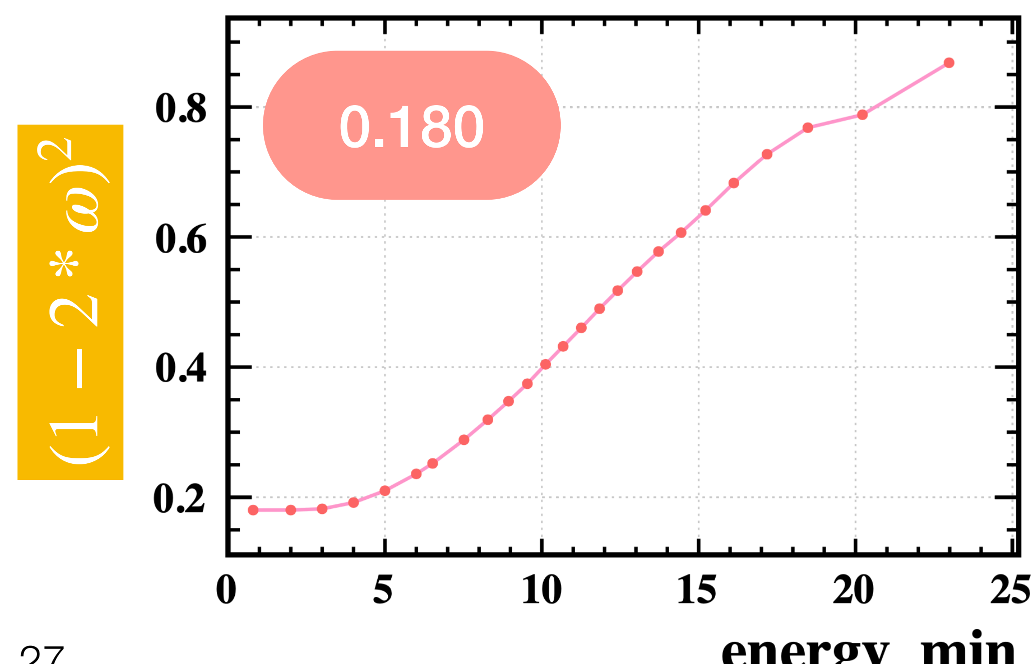
c jet(e, μ, p, K) & $\bar{c}$ jet(π)



c jet(π) & $\bar{c}$ jet(e, μ, p, K)



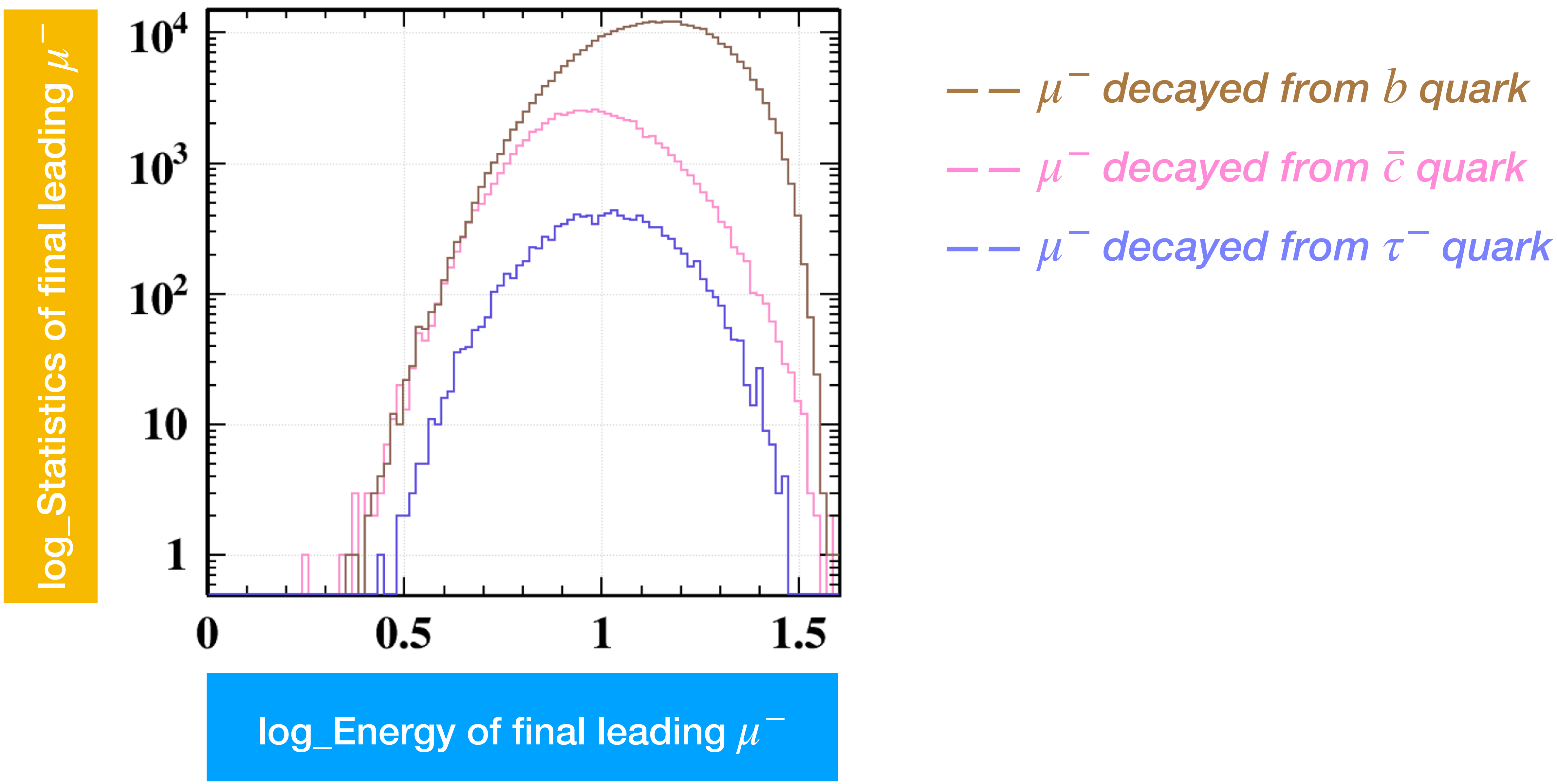
c jet(π) & $\bar{c}$ jet(π)



$Z \to b\bar{b}$

Results of Jet Charge at Truth Level

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



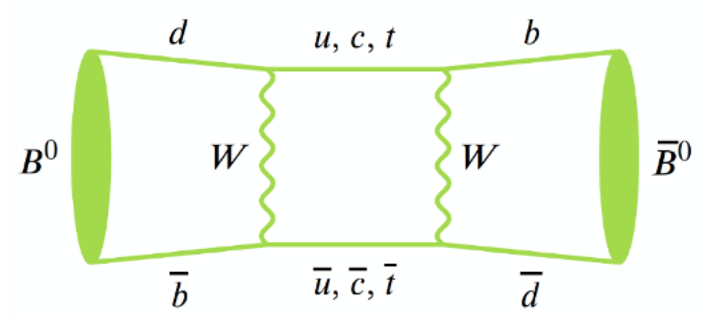
- ☞ *Energy spectrum of final leading μ^- from different decay modes is different*
- ☞ *Energy spectrum of final leading μ^- from different decay modes varies with energy threshold*

$Z \to b\bar{b}$

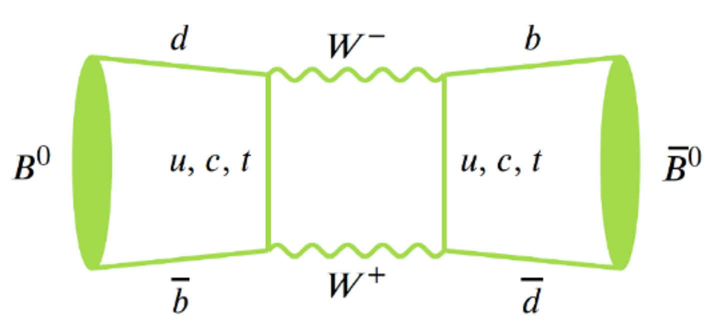
Results of Jet Charge at Truth Level

***Percent** of final leading μ^- from different decay modes*

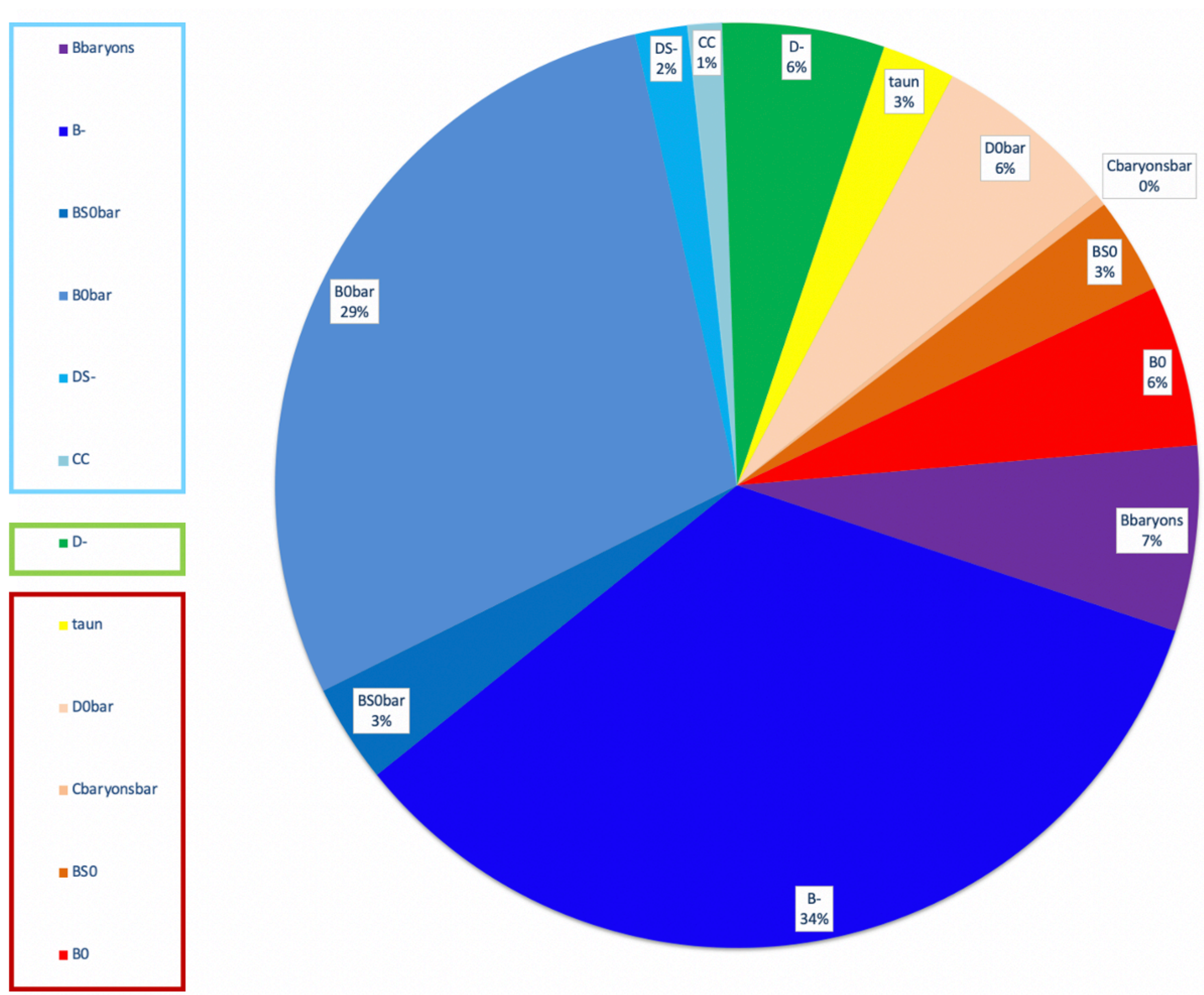
b **jet**



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



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



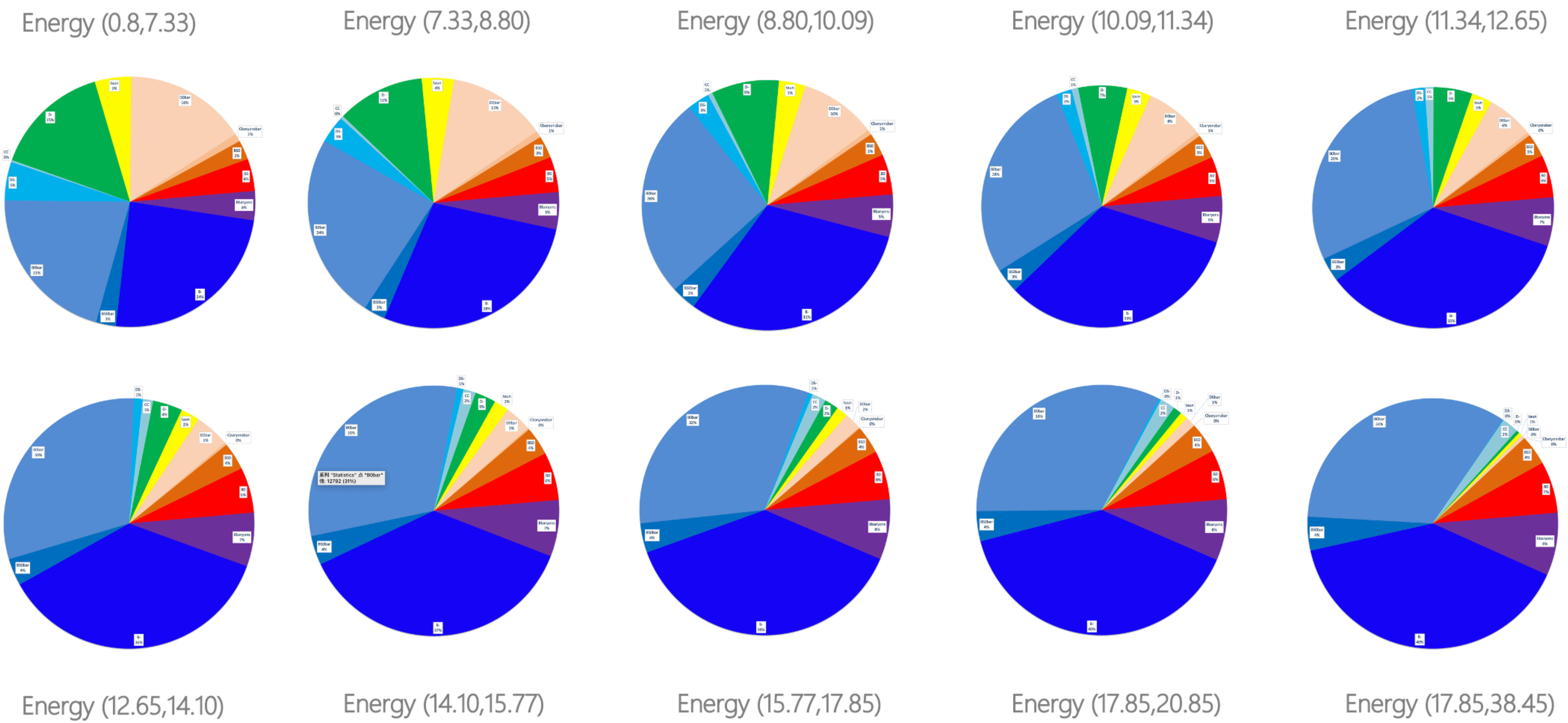
☞ *The purple end final leading μ^- is closer to b **jet***

☞ *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***

$Z \to b\bar{b}$ Results of Jet Charge at Truth Level

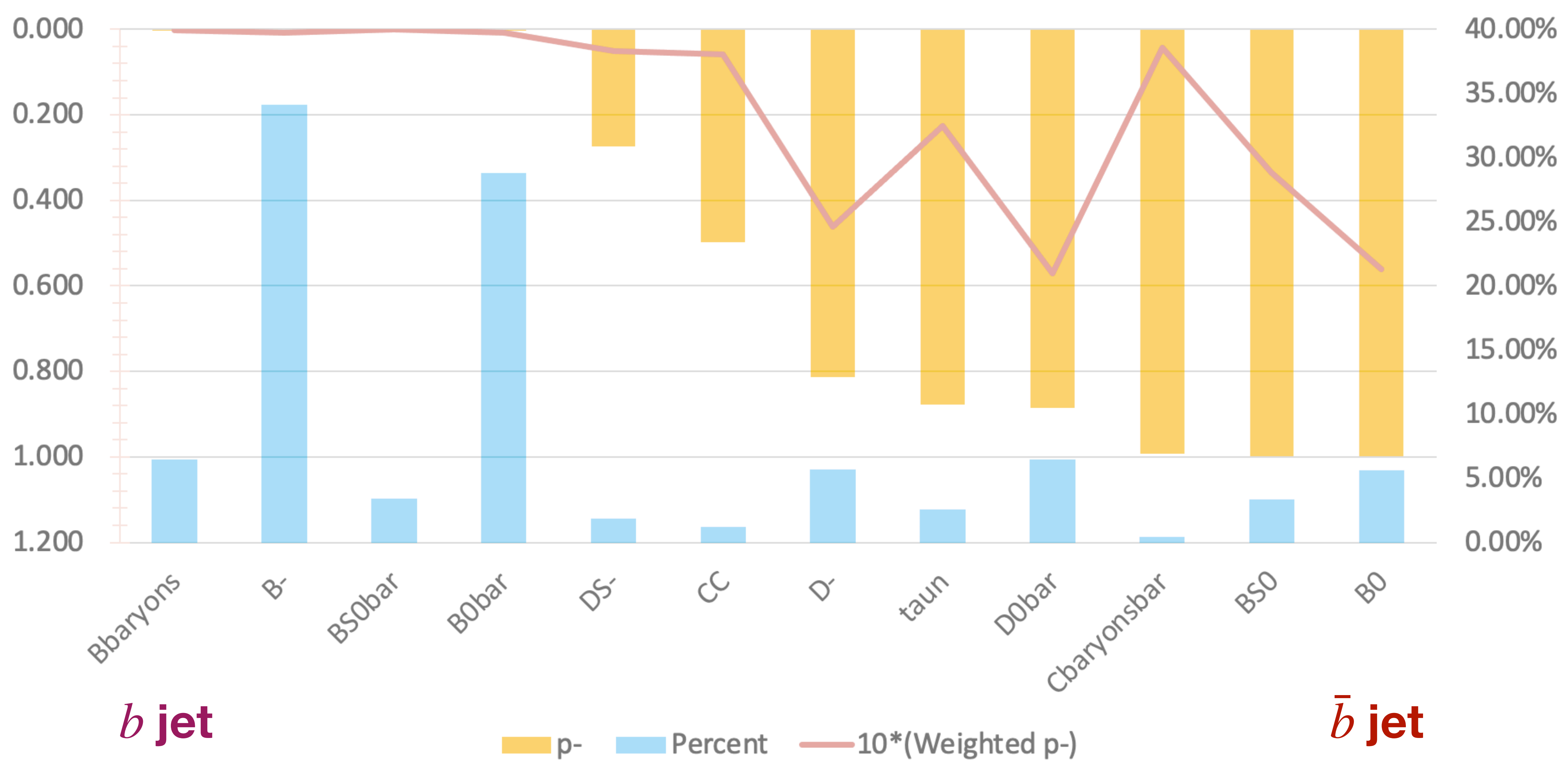
Percent** of final leading μ^- from different decay modes v.s. **Energy Threshold



- ☞ ***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*

$Z \to b\bar{b}$ Results of Jet Charge at Truth Level

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



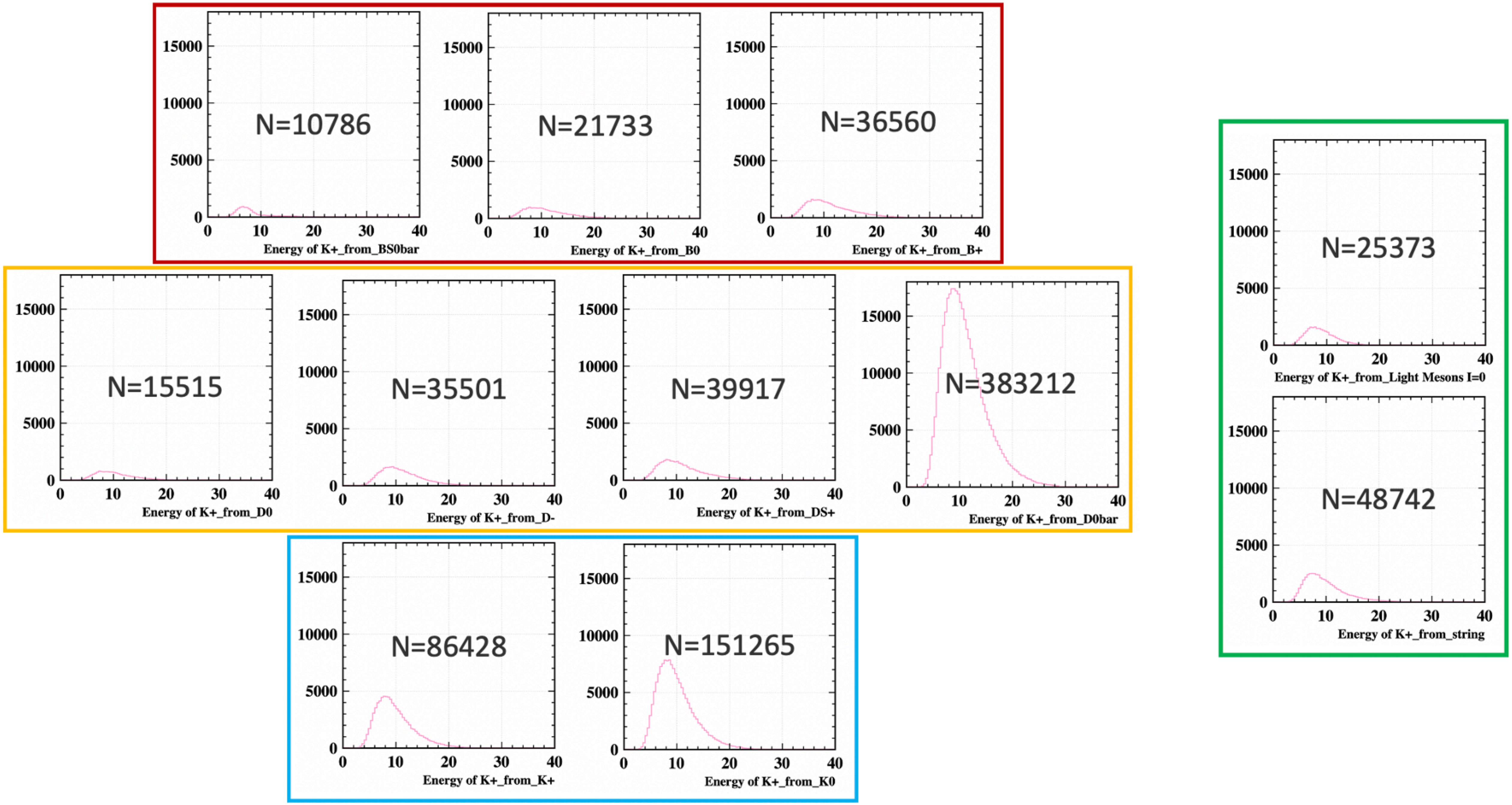
☞ $p+ = \int_0^{\pi/2} angle(x,b)$, $p- = \int_{\pi/2}^{\pi} angle(x,b)$, $\omega = min(p+,p-)$

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

$Z \to b\bar{b}$

Results of Jet Charge at Truth Level

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



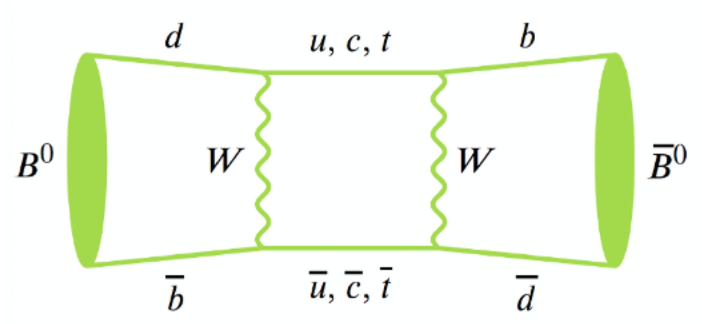
☞ *Energy spectrum of final leading K^+ from different decay modes is different*

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

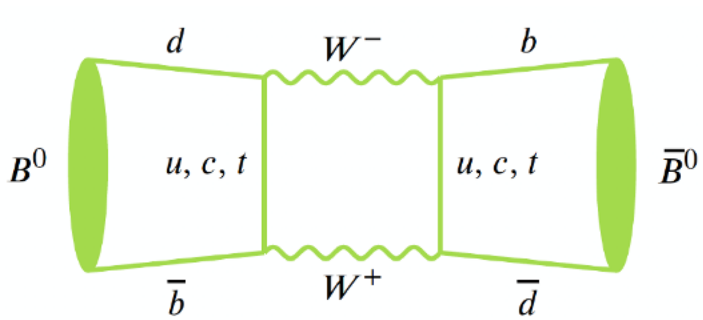
$Z \to b\bar{b}$ Results of Jet Charge at Truth Level

Percent of final leading K^+ from different decay modes

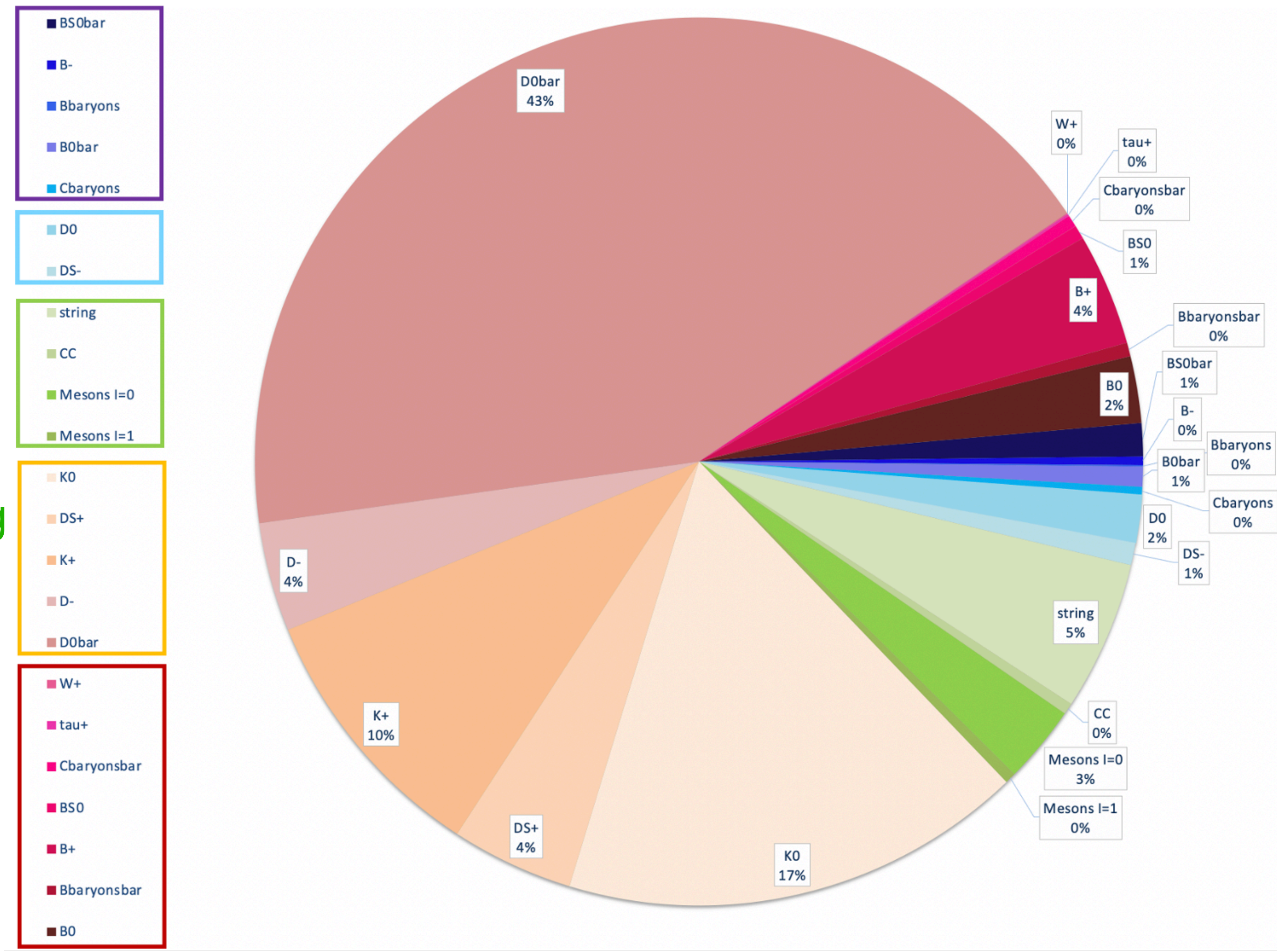
b **jet**



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



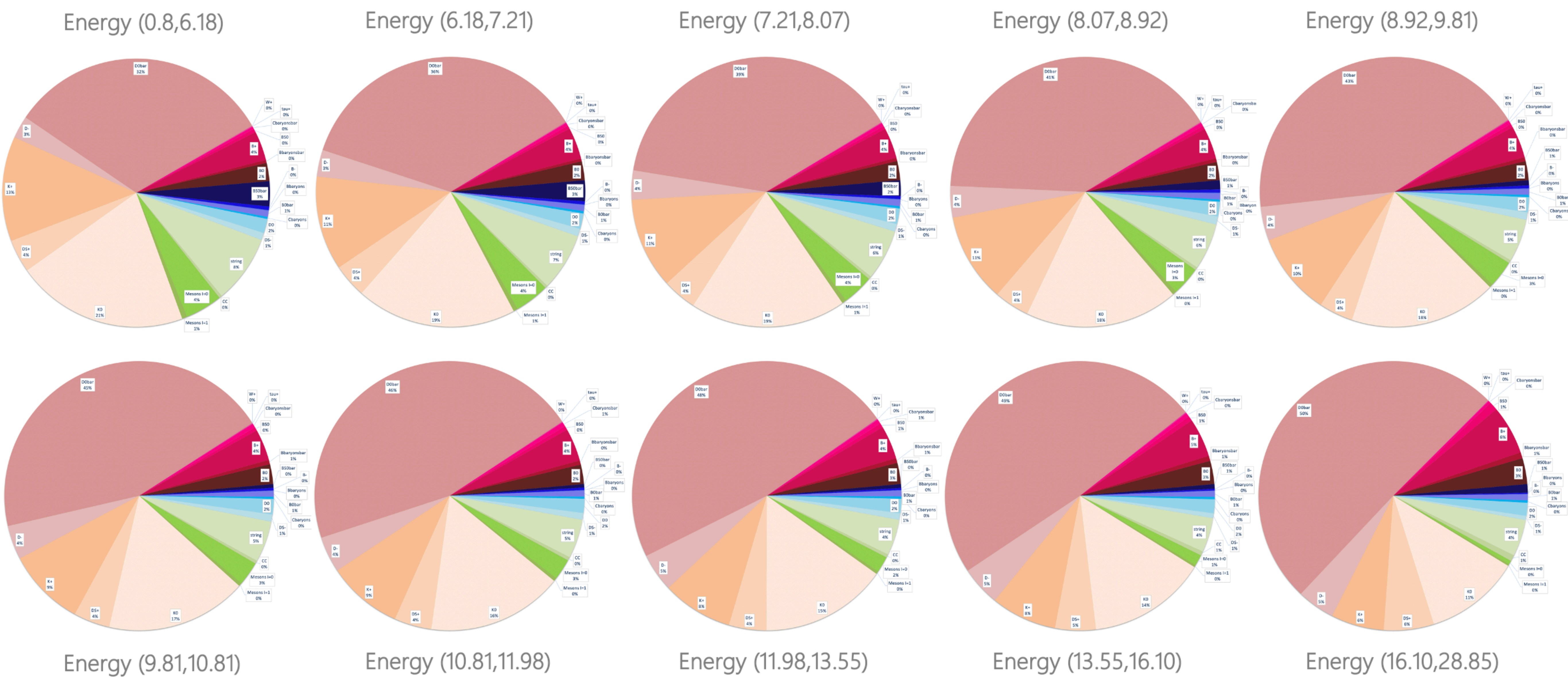
$\bar{b}$ **jet**



- ☞ *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***

$Z \to b\bar{b}$ Results of Jet Charge at Truth Level

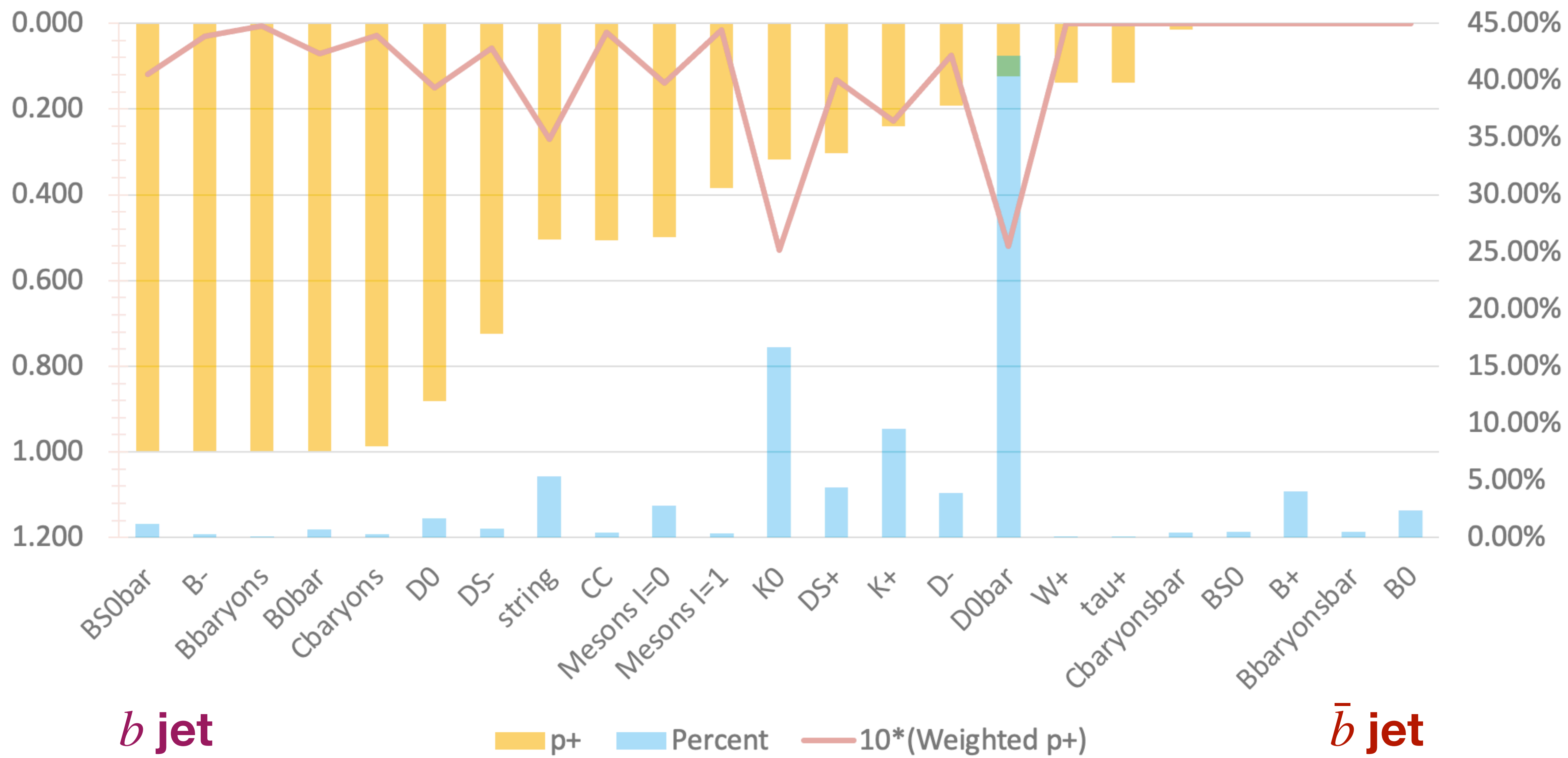
Percent** of final leading K^+ from different decay modes v.s. **Energy Threshold



- ☞ *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*

$Z \to b\bar{b}$ Results of Jet Charge at Truth Level

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

$A_{FB}(\sin^2\theta_W)$

A_{FB} has roughly a linear relationship to $\sin^2\theta_W$

$$\frac{d\sigma}{d\cos\theta} \propto 1 + \cos^2\theta + \frac{8}{3} A_{\mathrm{FB}}^{\mathrm{b}} \cos\theta$$

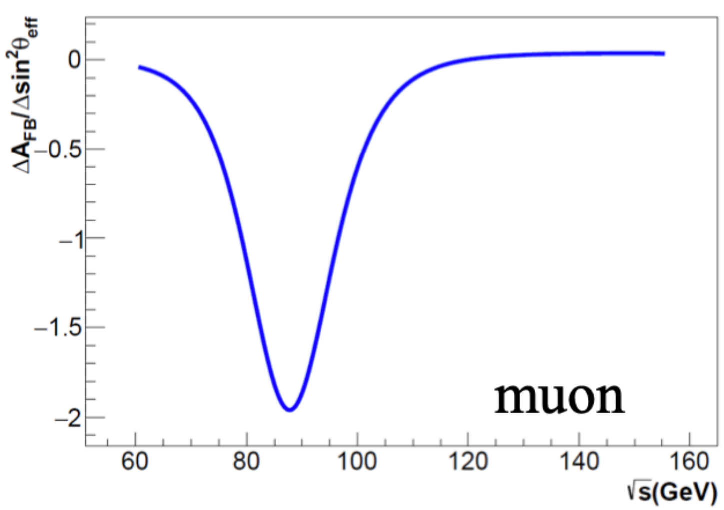
$$A_{\mathrm{FB}}^{\mathrm{b},0} = \frac{3}{4}\left(\frac{2 g_V^{\mathrm{e}} g_A^{\mathrm{e}}}{(g_V^{\mathrm{e}})^2 + (g_A^{\mathrm{e}})^2}\right)\left(\frac{2 g_V^{\mathrm{b}} g_A^{\mathrm{b}}}{(g_V^{\mathrm{b}})^2 + (g_A^{\mathrm{b}})^2}\right)$$

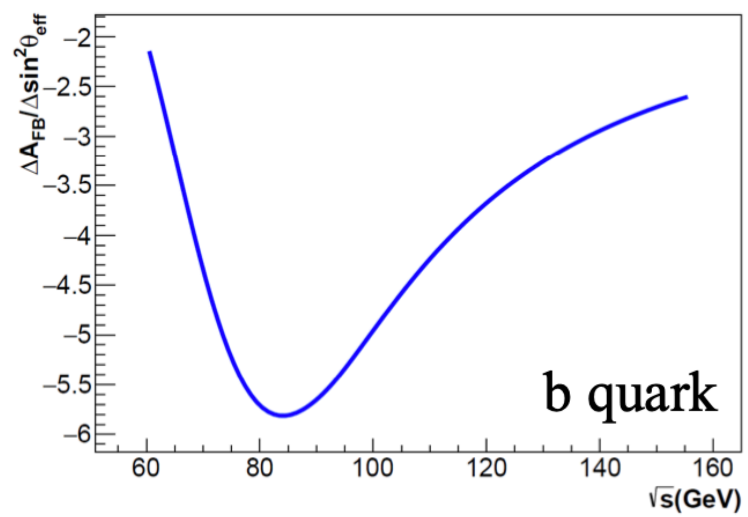
$$\sin^2\theta_{\mathrm{W}}^{\mathrm{eff,f}} = \frac{1}{4|q_{\mathrm{f}}|}\left(1 - \frac{g_V^{\mathrm{f}}}{g_A^{\mathrm{f}}}\right)$$

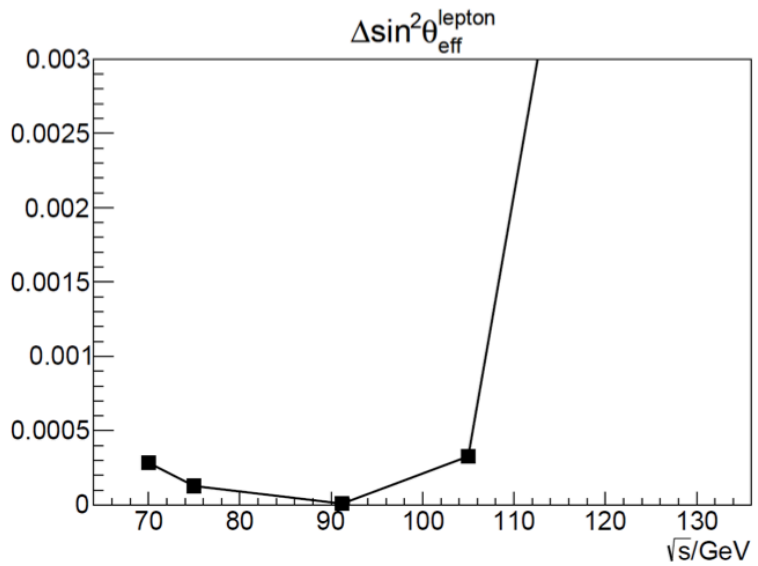
Sensitivity of $A_{FB}(\sin^2\theta_W)$

The sensitivity of A_{FB} to $\sin^2\theta_W$ depends on center-of-mass energy and particle flavors

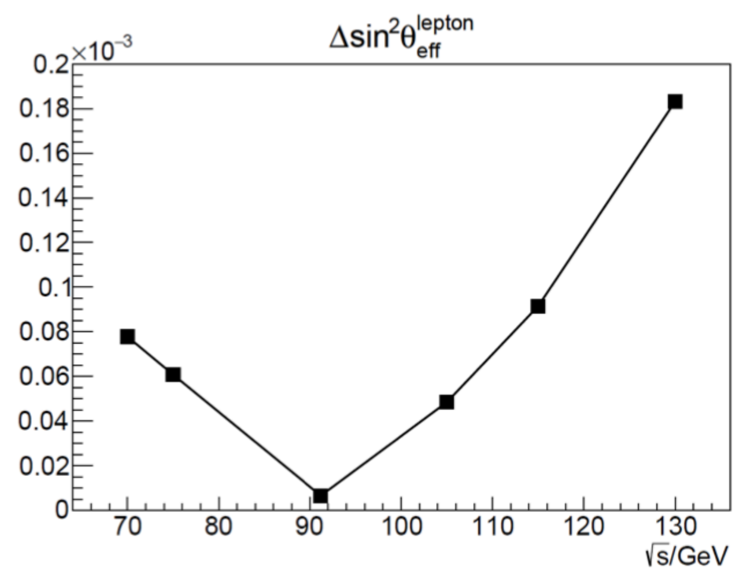
$$sensitivity = S_{phy} := \frac{\Delta A_{FB}}{\Delta \sin^2\theta_{eff}}$$







lepton final state
$(ee + \mu\mu + \tau\tau)$



b quark final state

A_{FB}^b:
Sensitive to
$\sin^2\theta_{eff}$ at Z pole
and off Z pole