Neutral B Flavor Tagging for the Measurement of Mixing-induced CP violation at Belle

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Introduction

One of the main subject of the Belle experiment

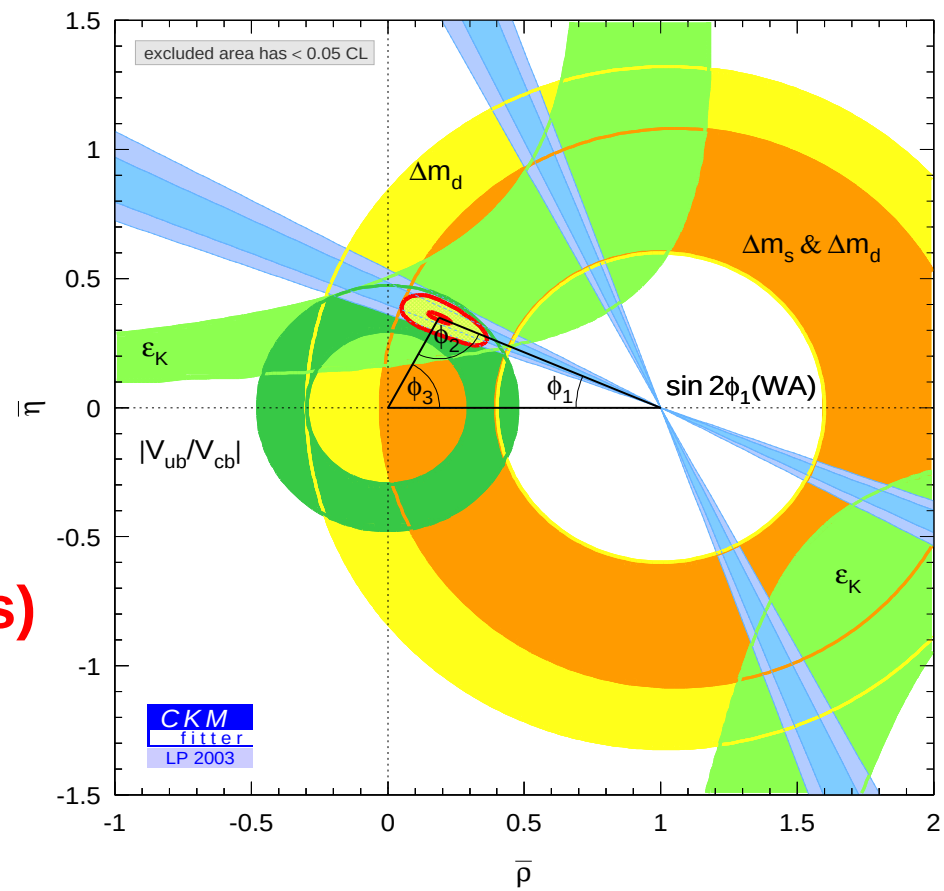
→Study of CP violation in B decays

1. determination of sides and angles of unitatity triangle

2. overconstrain unitarity triangle and search for new physics

mixing induced CP violation (in b→c $\bar{c}$s)
→ clean extraction of an angle ϕ_1

constraints on the unitarity triangle

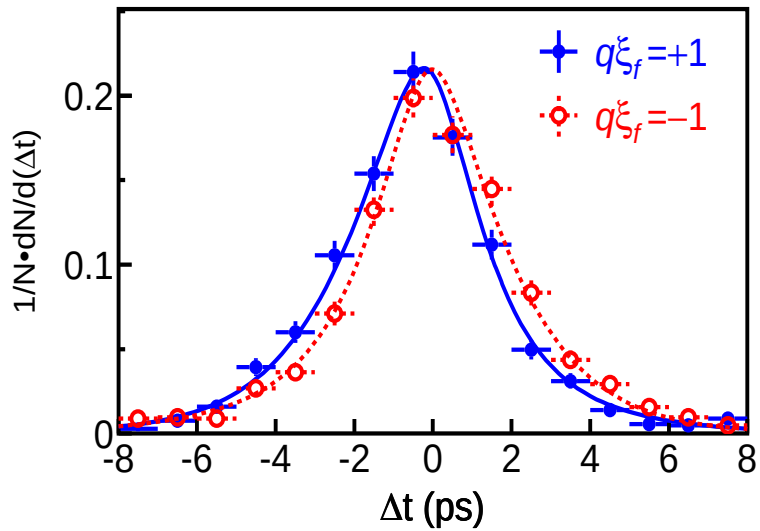


Introduction (cont'd)

Phenomenology of mixing-induced CP-violation:

$$\Gamma(B^0(\Delta t) \to f_{CP}) \neq \Gamma(\overline{B^0}(\Delta t) \to f_{CP})$$

Δt distribution from b$\to$ $\bar{c}$cs



For $\bar{c}$cs transitions

$$\mathcal{A}_{\mathcal{CP}} = \frac{\mathcal{P}(\overline{B^0}(\Delta t) \to f_{CP}) - \mathcal{P}(B^0(\Delta t) \to f_{CP})}{\mathcal{P}(\overline{B^0}(\Delta t) \to f_{CP}) + \mathcal{P}(B^0(\Delta t) \to f_{CP})}$$
$$\propto -\xi_f \sin 2\phi_1 \sin(\Delta m_d \Delta t)$$

where: $\Delta t \equiv t_{CP} - t_{tag}$

need to know whether an event follows $\mathcal{P}(B^0(\Delta t) \to f_{CP})$ or $\mathcal{P}(\overline{B^0}(\Delta t) \to f_{CP})$

↓

Flavor tagging

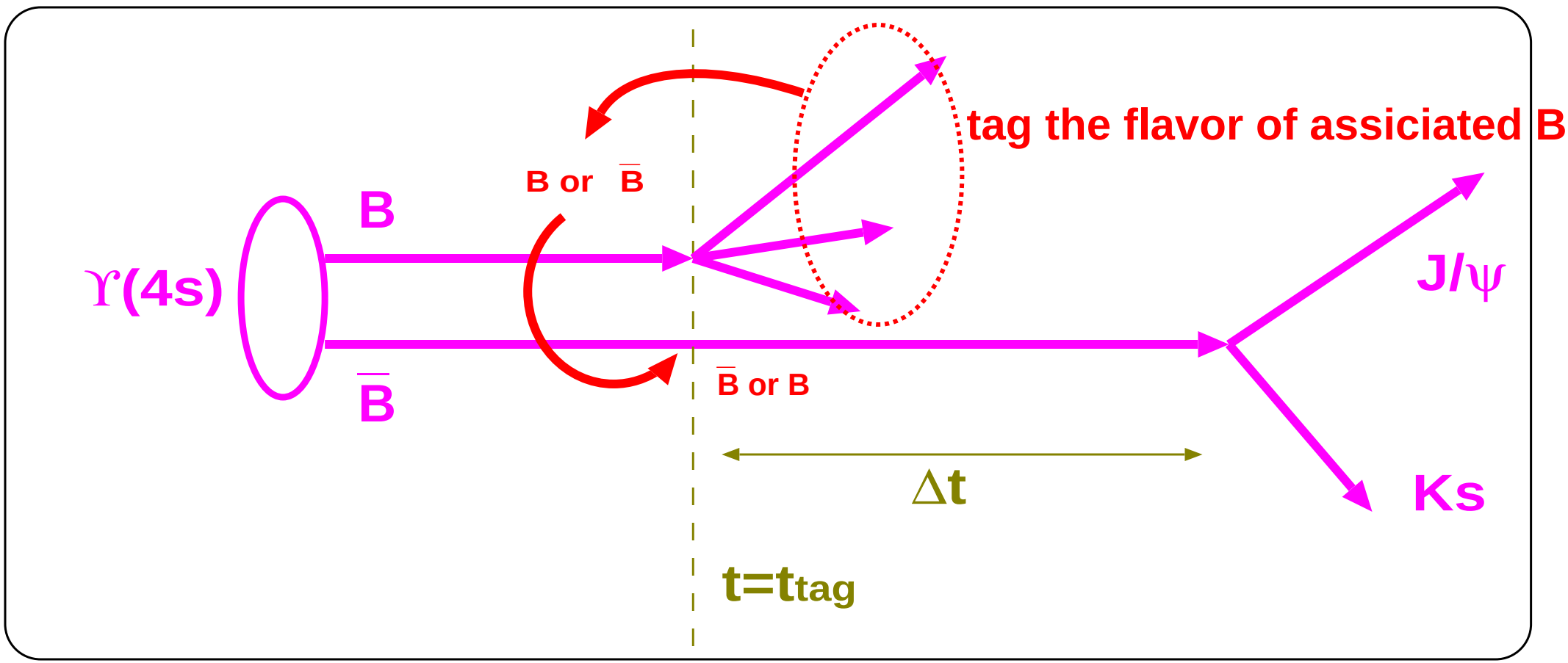
Principle (general)

$\Upsilon(4S) \rightarrow B_{CP} B_{tag}$

At a certain time "t_{tag}":

$q(B_{cp}) = \overline{q(B_{tag})}$

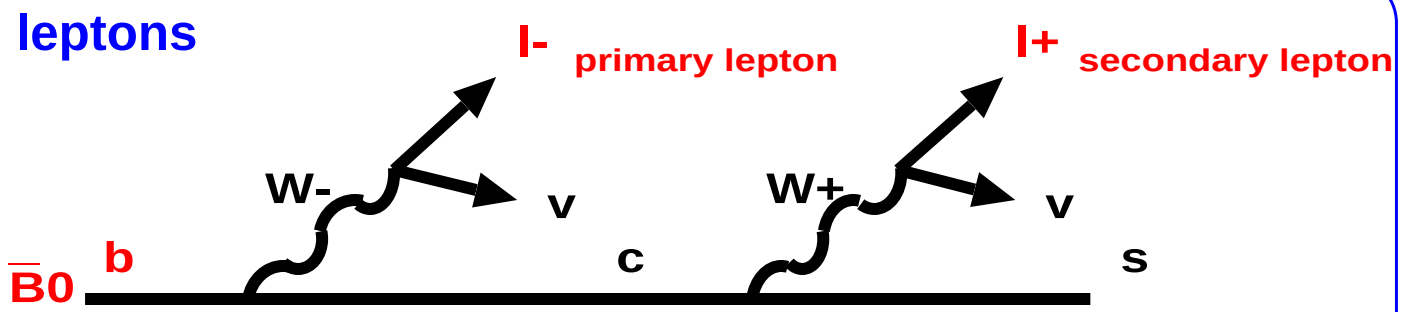
q: flavor of B-meson



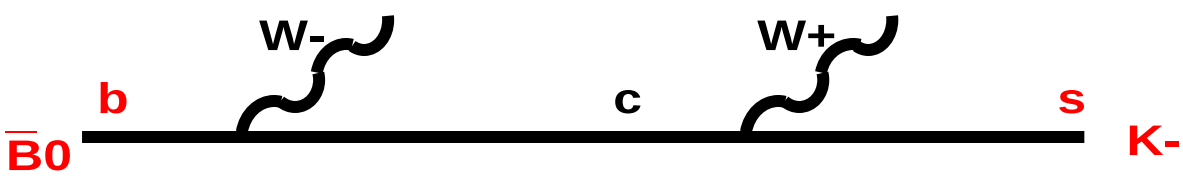
Principle (physics)

- Use the information of charged particles

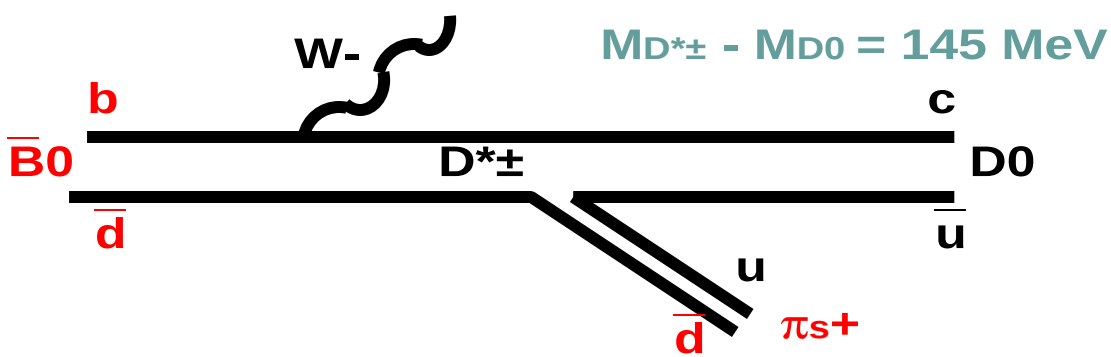
leptons



Kaons



slow pions



Quality of tagging

ε: tagging efficiency

w: wrong tag fraction

$0 \leftarrow w \rightarrow 0.5$

perfect — no flavor info.

	ε	w
lepton	low	low
Kaon	high	high
slow pion	low	high

Principle (mathmatics)

Statistical significance in the CP asymmetry measurement

$$\frac{\delta(\mathcal{A}_{\mathcal{CP}})}{\mathcal{A}_{\mathcal{CP}}} \begin{cases} \propto 1/\sqrt{\varepsilon} & (\varepsilon\text{: tagging efficiency}) \\ \propto 1/(1-2w) & (w\text{: wrong tag fraction}) \end{cases}$$

Now consider... **effective tagging efficiency: $\varepsilon_{eff} = \varepsilon(1-2w)^2$**

$$\begin{aligned} \epsilon_{\text{eff}} &= \epsilon(1-2w)^2 \\ &= \epsilon\left(\frac{\epsilon_1(1-2w_1)+\epsilon_2(1-2w_2)}{\epsilon_1+\epsilon_2}\right)^2 \end{aligned}$$

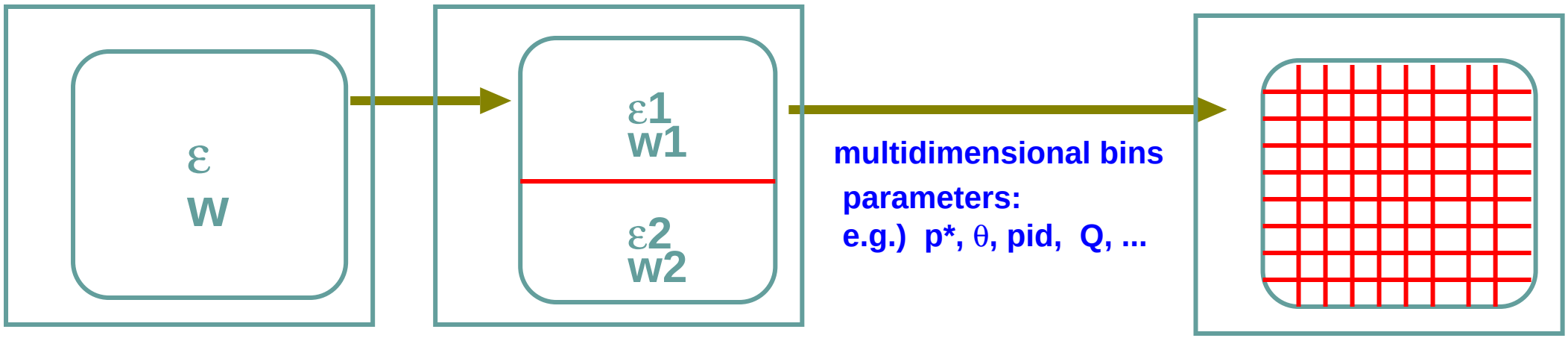
$$\begin{aligned} \epsilon'_{\text{eff}} &= \epsilon_1(1-2w_1)^2+\epsilon_2(1-2w_2)^2 \\ &= \epsilon\frac{\epsilon_1(1-2w_1)^2+\epsilon_2(1-2w_2)^2}{\epsilon_1+\epsilon_2} \end{aligned}$$

$$\langle 1-2w\rangle^2 < \langle (1-2w)^2\rangle$$

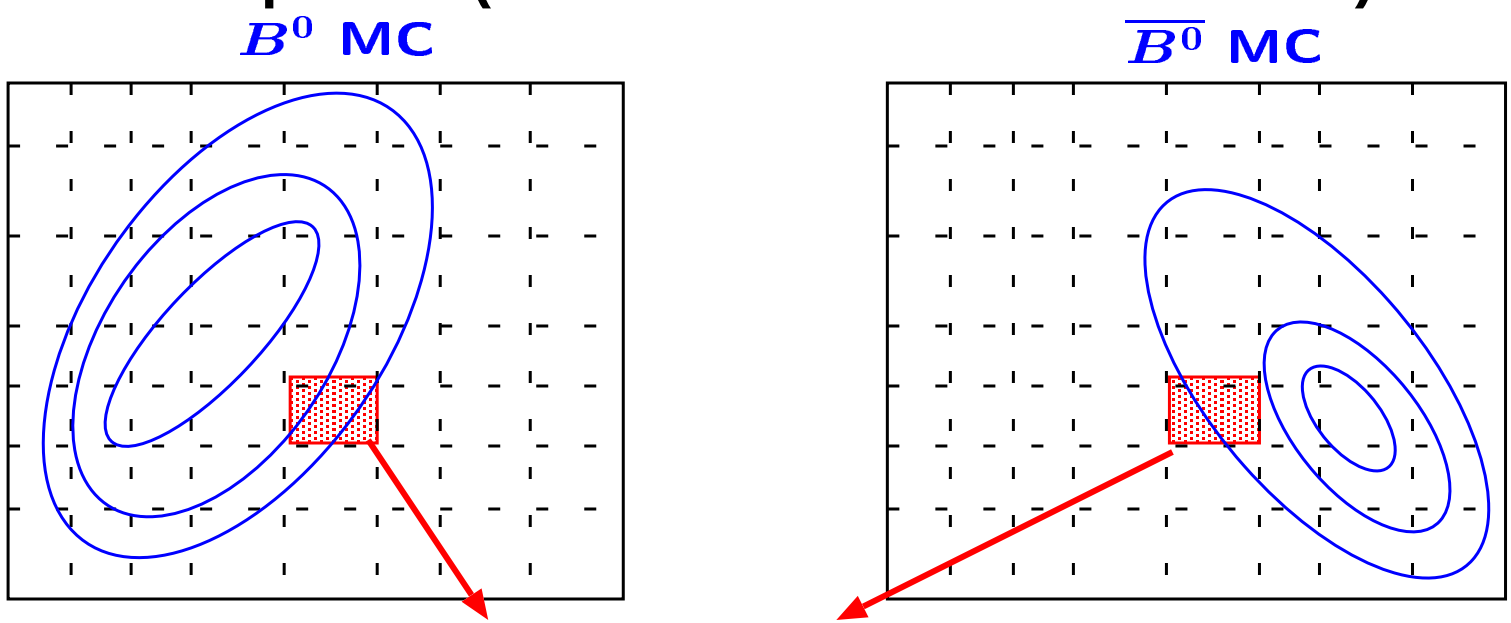
devide events if w1 ≠ w2 → obtain larger ε_{eff}

Binned Multi-dimensional Likelihood

Divide events into small cells of multidimensional space



prepare lookup table (multi-dimensional binned PDF) using MC

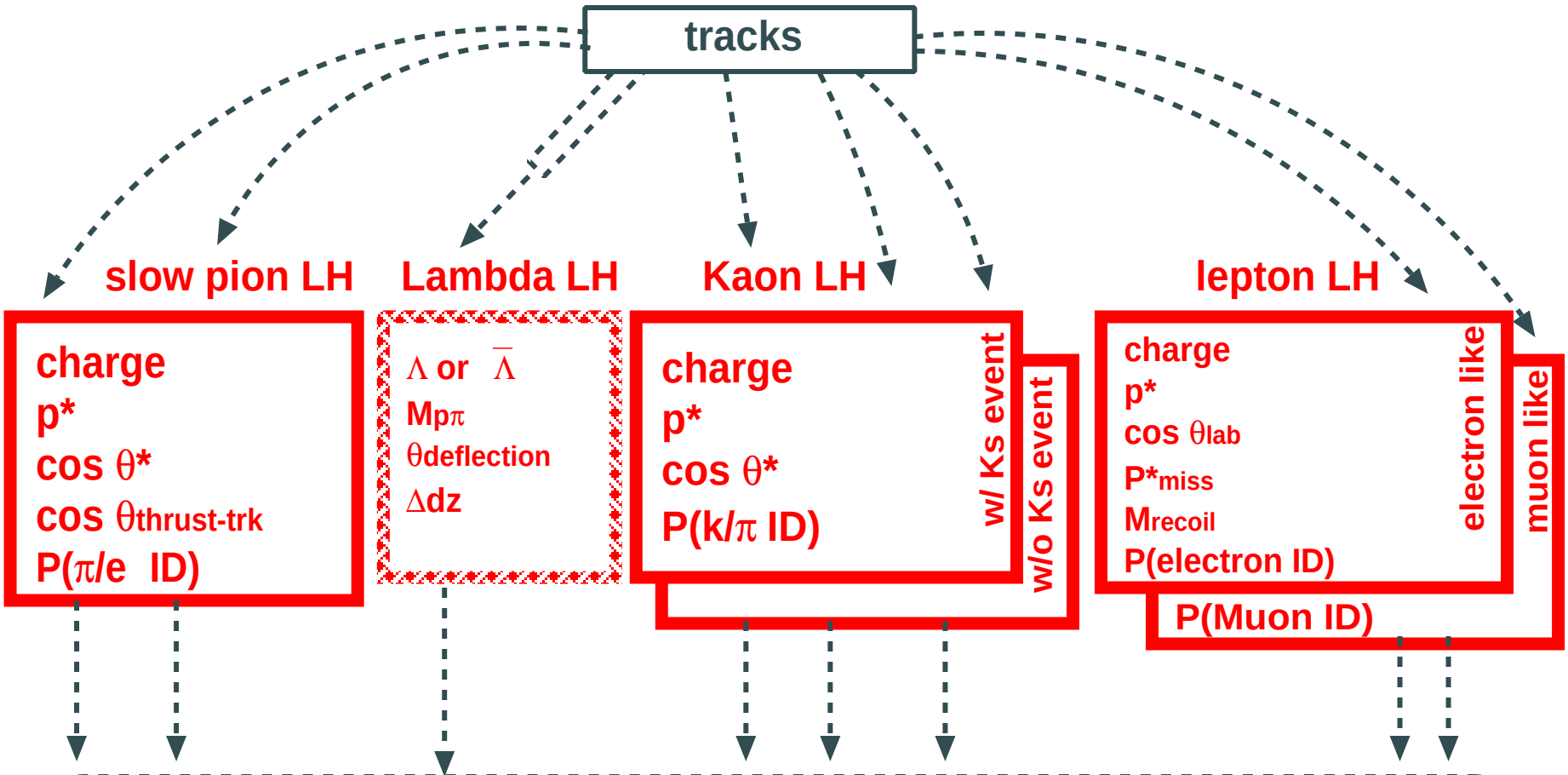


$$q \cdot r = \frac{N(B^0) - N(\overline{B^0})}{N(B^0) + N(\overline{B^0})}$$

q: flavor of B (-1 or 1)
r: MC determined flavor reliability
(r ~ 1-2w)

Track-level flavor tagging (first stage)

- classify tracks(Λ candidates) into 4 categories:



Estimate "qr" for each tracks:

$$(q \cdot r)_{trk} = \frac{N_{trk}(B^0) - N_{trk}(\overline{B^0})}{N_{trk}(B^0) + N_{trk}(\overline{B^0})}$$

Slow pion category

slow pion LH

- charge
- p*
- cos θ*
- cos θthrust-trk
- P(π/e ID)

projection

Lambda LH

- Λ or $\bar{\Lambda}$
- Mpπ
- θdeflection
- Δdz

Kaon LH

- charge
- p*
- cos θ*
- P(k/π ID)

w/ Ks event

w/o Ks event

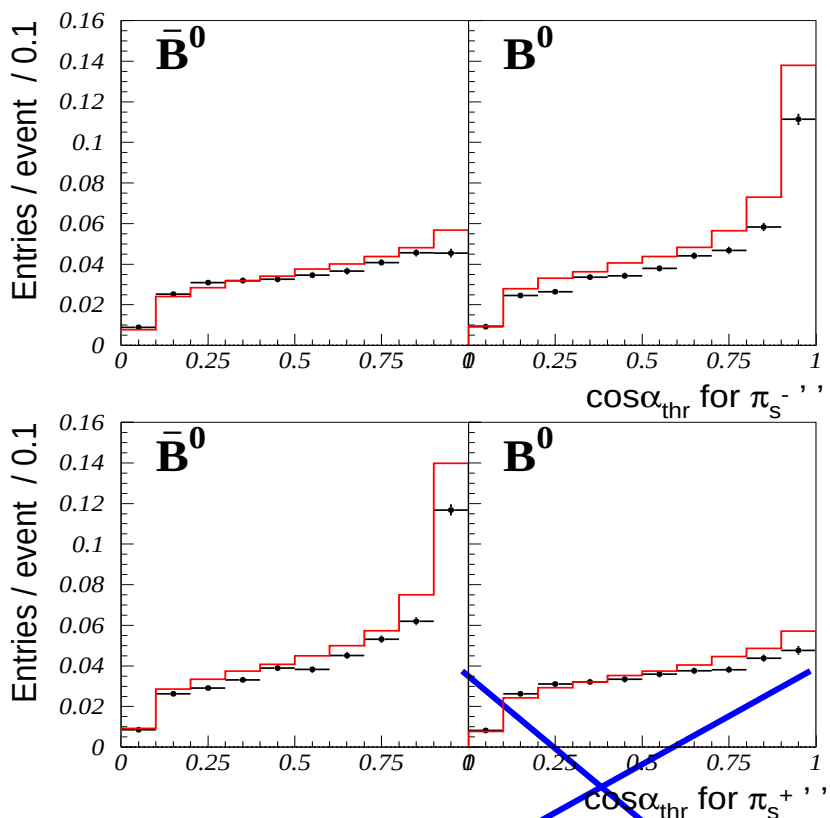
lepton LH

- charge
- p*
- cos θlab
- P*miss
- Mrecoil
- P(electron ID)

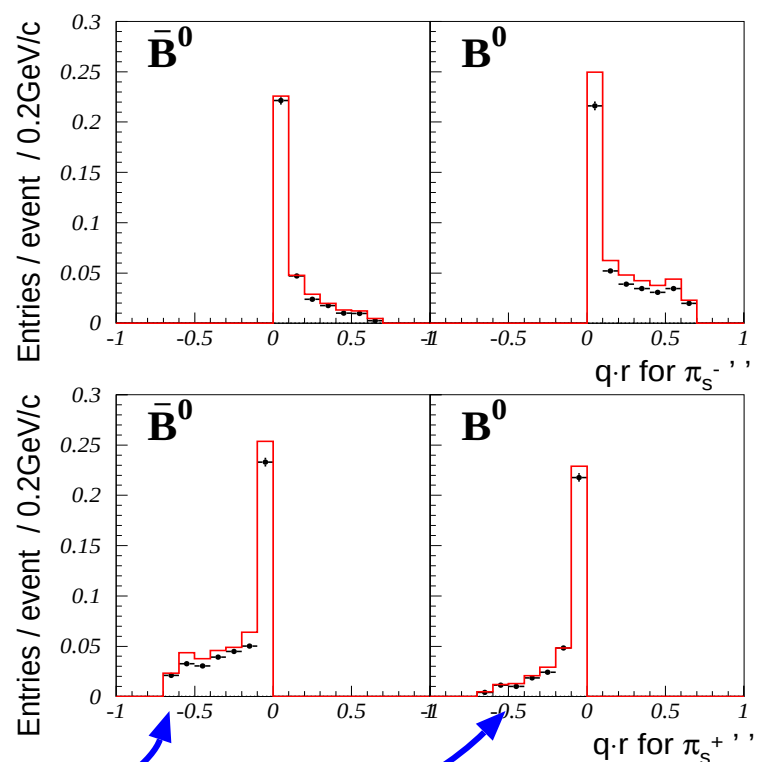
electron like

muon like

P(Muon ID)



output "qr"



example)

$$(q \cdot r)_{trk} = \frac{N_{trk}(B^0) - N_{trk}(\overline{B^0})}{N_{trk}(B^0) + N_{trk}(\overline{B^0})}$$

Kaon category

slow pion LH

- charge
- p*
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Lambda LH

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w/ Ks event

w/o Ks event

lepton LH

- charge
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electron like

muon like

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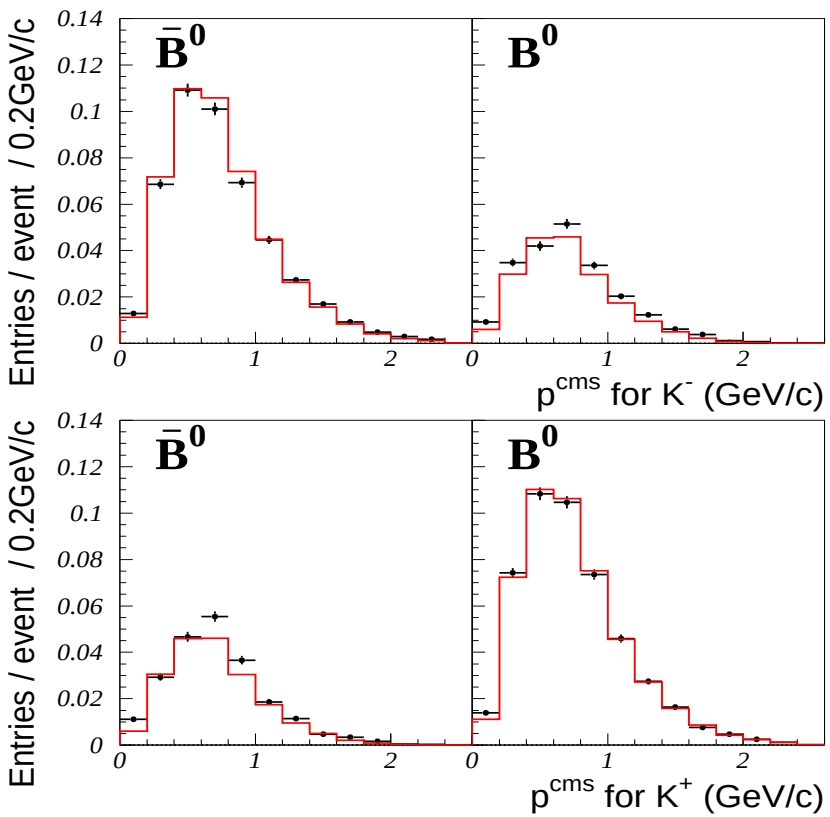
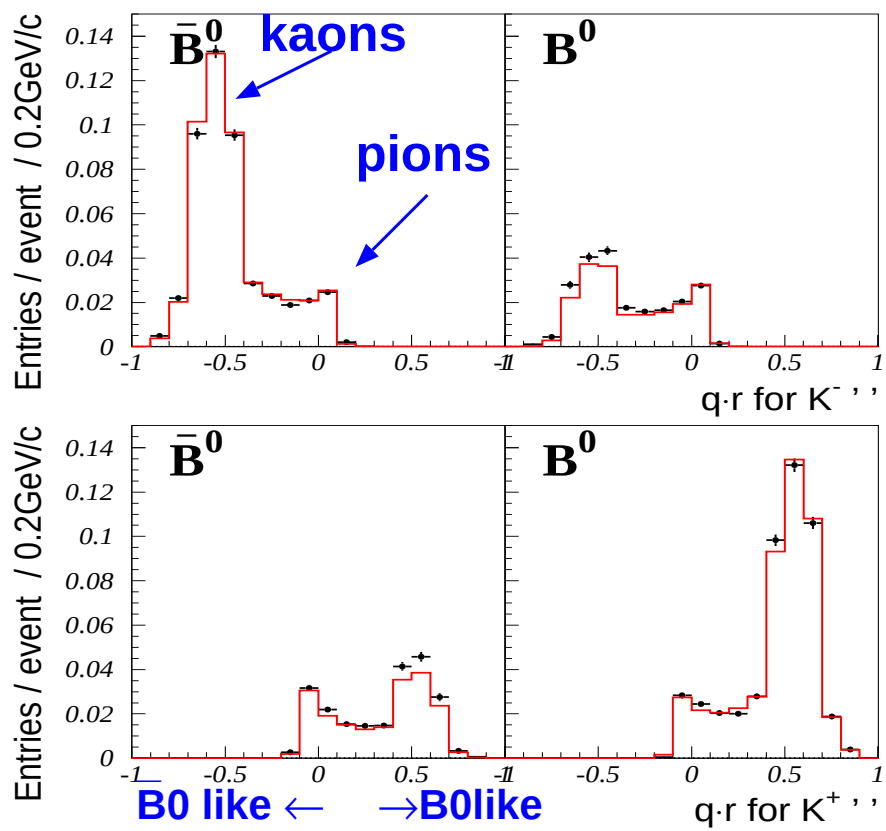
projection



output "qr"



lepton category

slow pion LH

- charge
- p*
- cos θ*
- cos θthrust-trk
- P(π/e ID)

Lambda LH

- Λ or $\bar{\Lambda}$
- Mpπ
- θdeflection
- Δdz

Kaon LH

- charge
- p*
- cos θ*
- P(k/π ID)

w/ Ks event

w/o Ks event

lepton LH

- charge
- p*
- cos θlab
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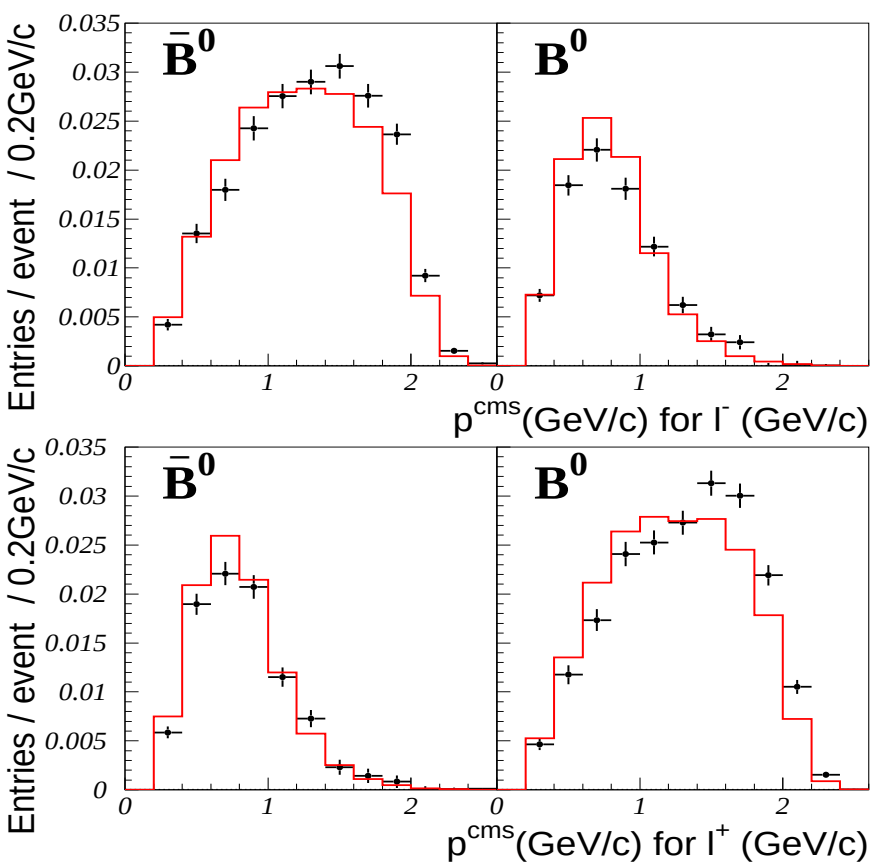
- Mrecoil
- P(electron ID)

electron like

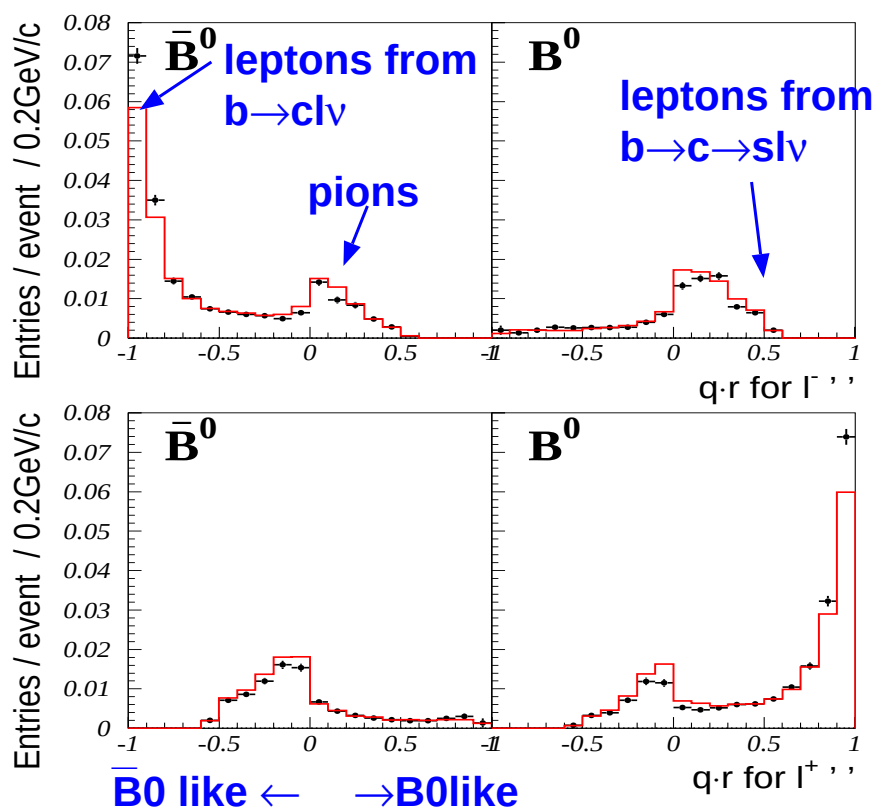
muon like

P(Muon ID)

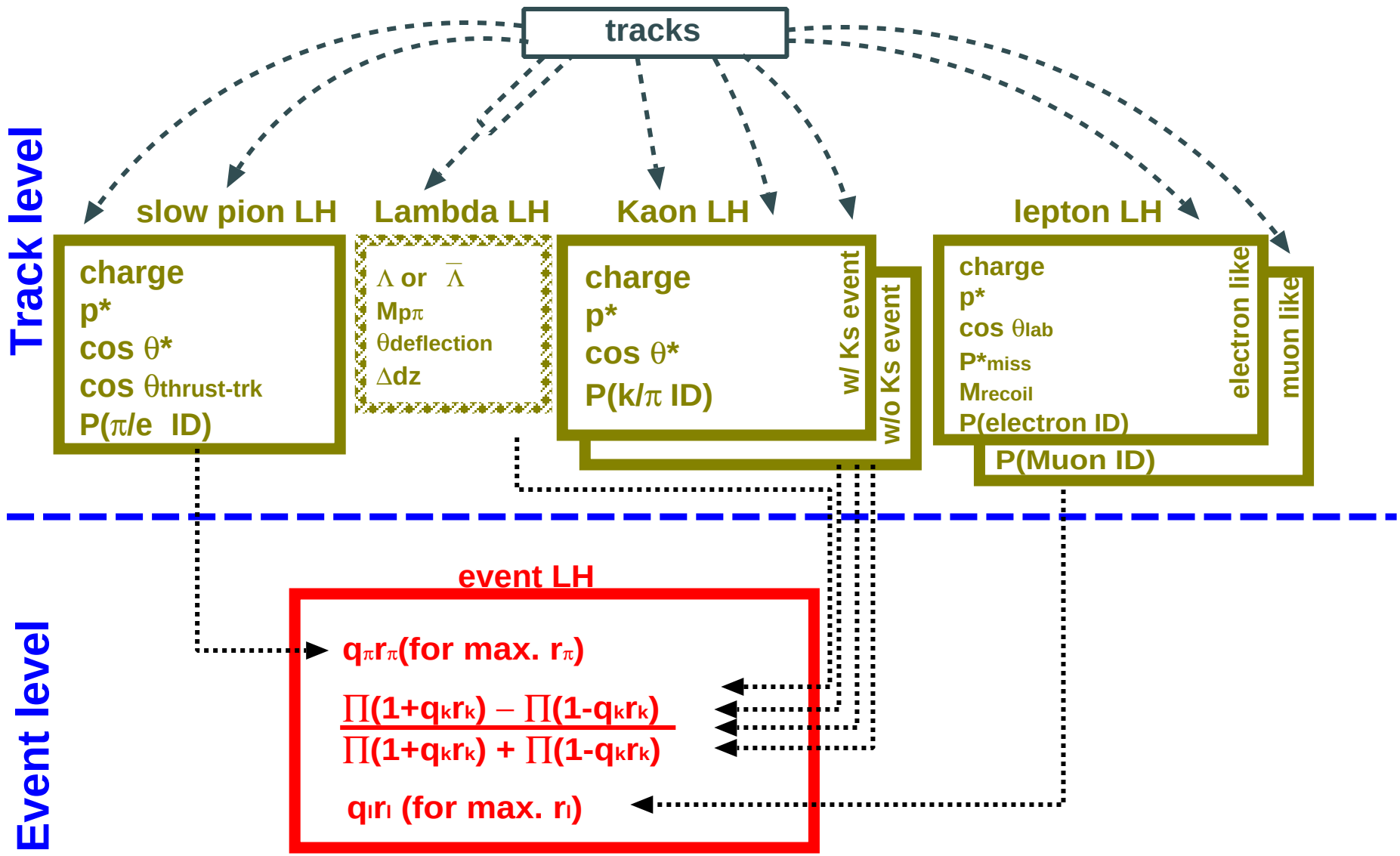
projection



output "qr"



Event-level flavor tagging (second stage)



-Combine track-level "qr"
-Estimate "qr" for a event

Event level likelihood (input)

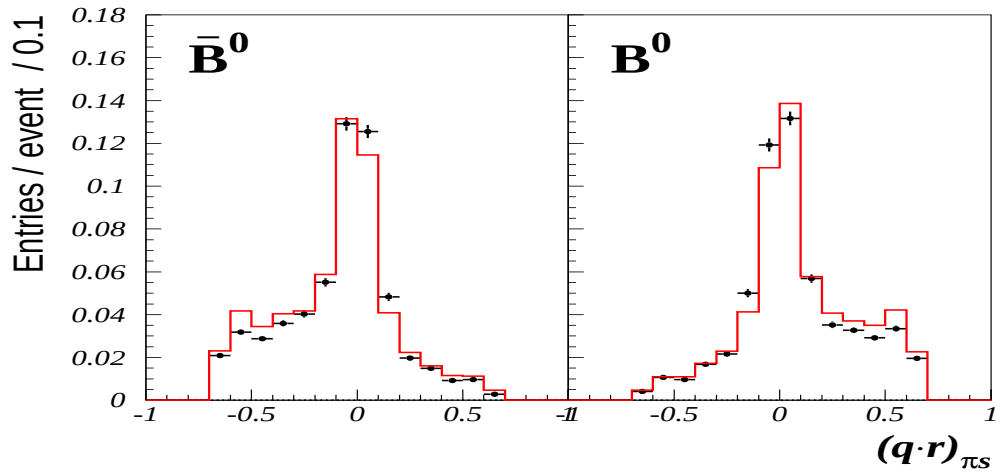
Combine output of track-level tagging

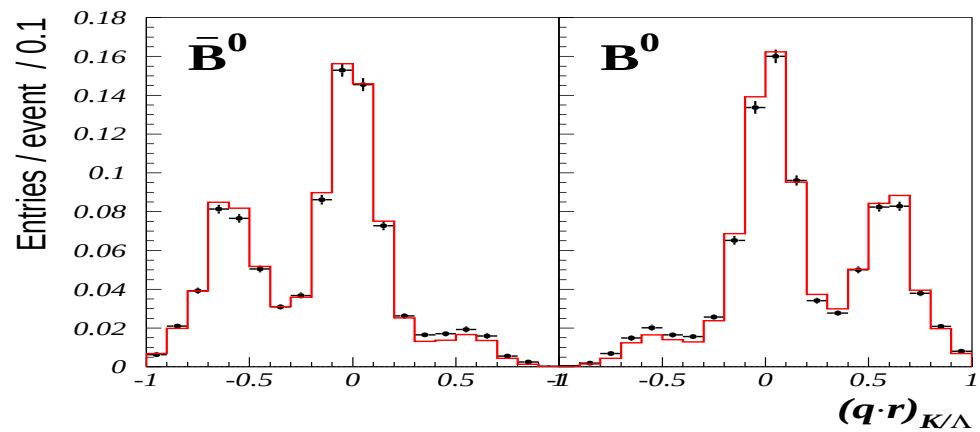
event LH

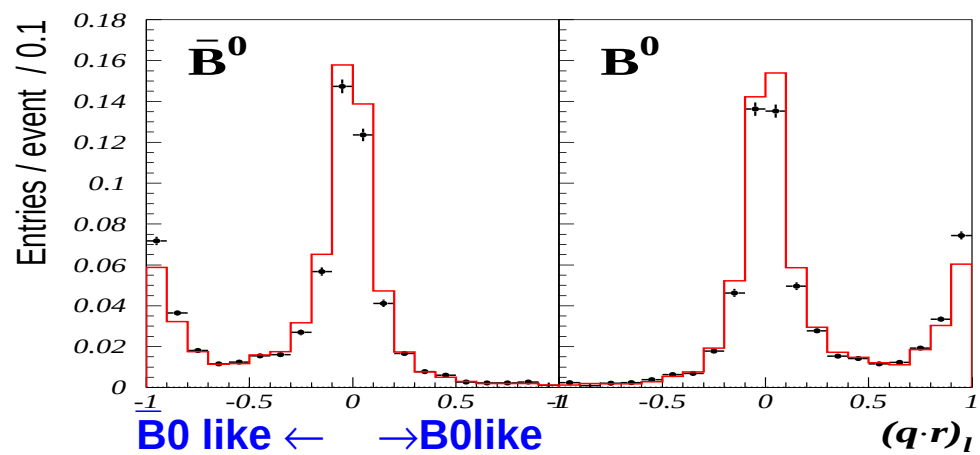
$q_\pi r_\pi$(for max. r_π)

$$\frac{\prod(1+q_k r_k) - \prod(1-q_k r_k)}{\prod(1+q_k r_k) + \prod(1-q_k r_k)}$$

$q_l r_l$ (for max. r_l)







B0 like ← →B0like

Event-level likelihood (output)

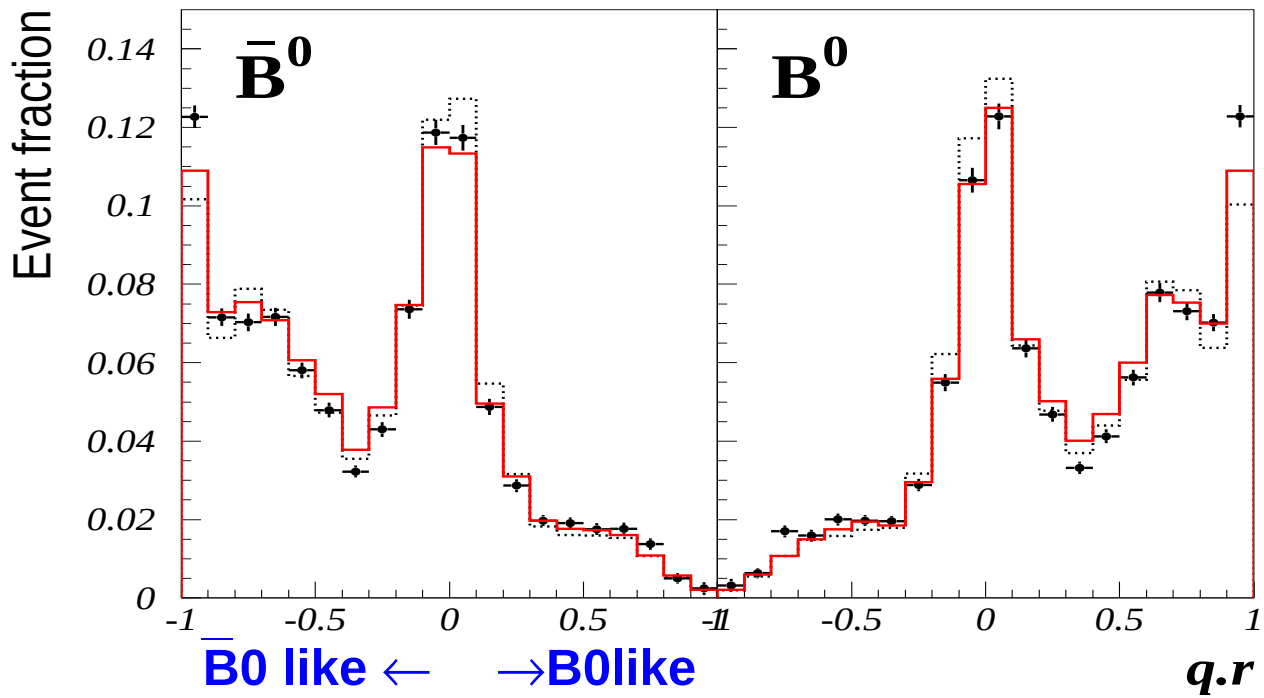
event LH

$q_\pi r_\pi$ (for max. r_π)

$$\frac{\prod(1+q_k r_k) - \prod(1-q_k r_k)}{\prod(1+q_k r_k) + \prod(1-q_k r_k)}$$

$q_l r_l$ (for max. r_l)

$$q \cdot r = \frac{N(B^0) - N(\overline{B^0})}{N(B^0) + N(\overline{B^0})}$$



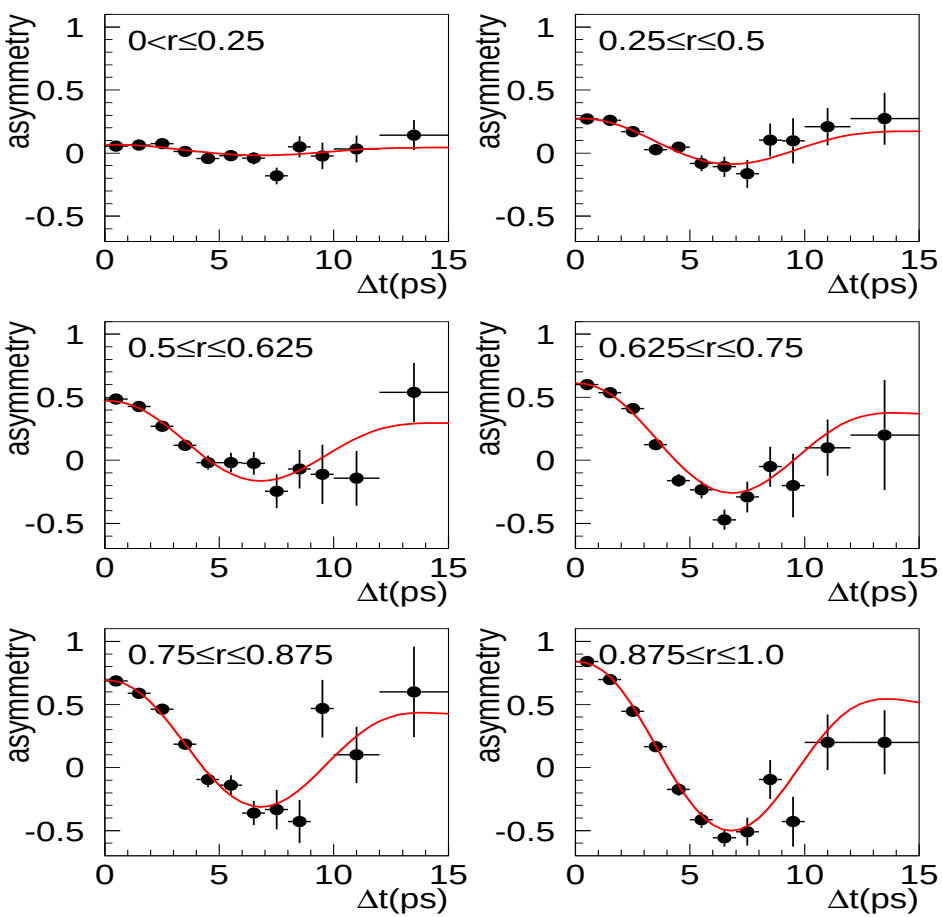
sub devide events into 6 "r" intervals:
$0<r\leq0.25$, $0.25<r\leq0.5$, $0.5<r\leq0.625$, $0.625<r\leq0.75$, $0.75<r\leq0.875$, $0.875<r\leq1.0$
→ measure "w" from data for each regions

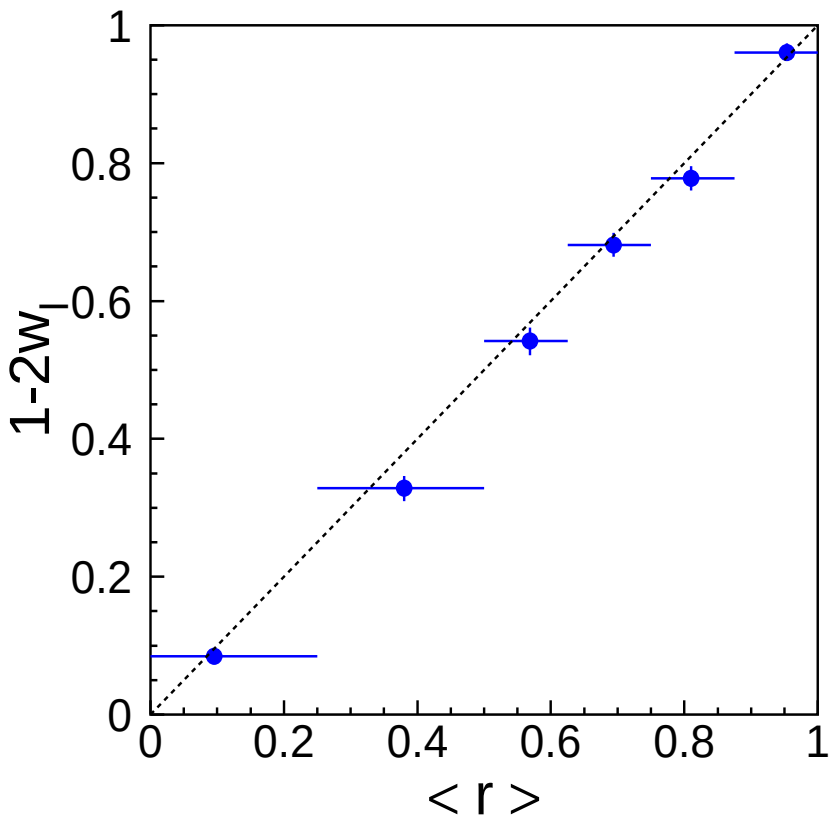
1. evaluation of the flavor tagging performance
2. application to the sin2ϕ1 analysis

Flavor tagging performance

Use self-tagged samples: D*lν, D(*)π, D*ρ for "w" measurement

asymmentry (= (1-2w)cos(Δm$_d$Δt))
for each "r" region





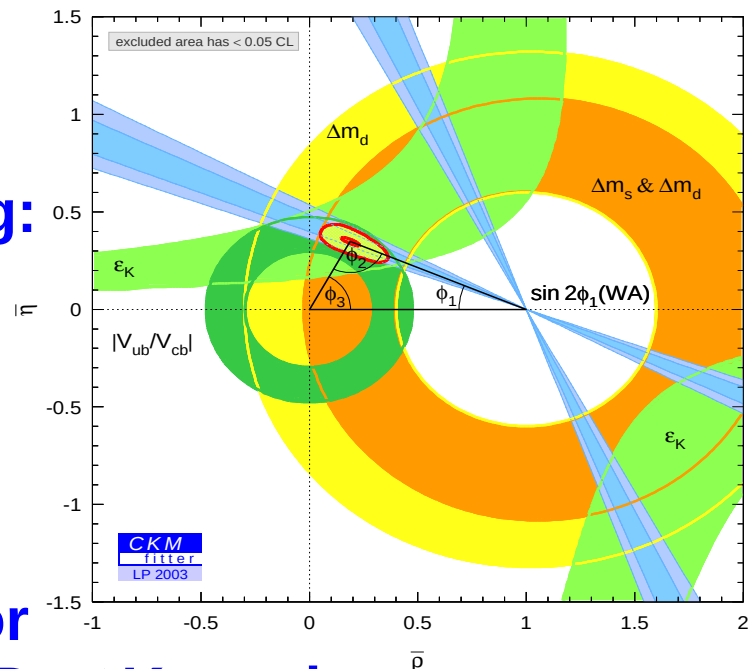
effective tagging efficiency: ε_{eff} = 28.8 ± 0.6%

Summary

-We developed a flavor tagging algorithm based on the binned multi-dimensional likelihood method

-We achevied high effective tagging efficiency:

ε_{eff} = 28.8 ± 0.6%



- sin2ϕ_1 is measured with this flavor tagging:

sin2ϕ_1 = 0.719±0.074(stat.)±0.035(syst.)
[K.Abe et al. PRD 66, 092002 (2002)]

- This flavor tagging method is also used for the recent study of CP violation in B→ππ, B→ϕKs and so on.

→ Flavor tagging is:

important technique in the measurement of time dependent CP violation