# Charged Particle Identification at Belle II

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IIT Hyderabad

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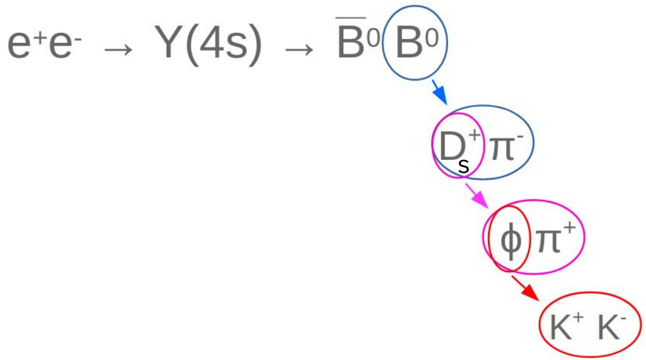
# Outline

- Need of Particle Identification in Belle II
- Belle II & Particle Identification
- Method
- Performance

# Why we need PID?

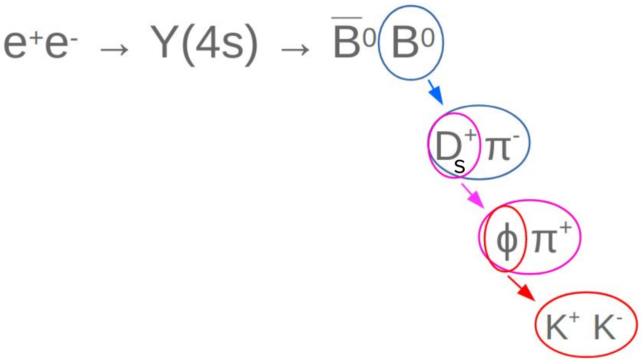
- we are often interested in reconstructing the whole decay chain and hence to reconstruct all final state particles.

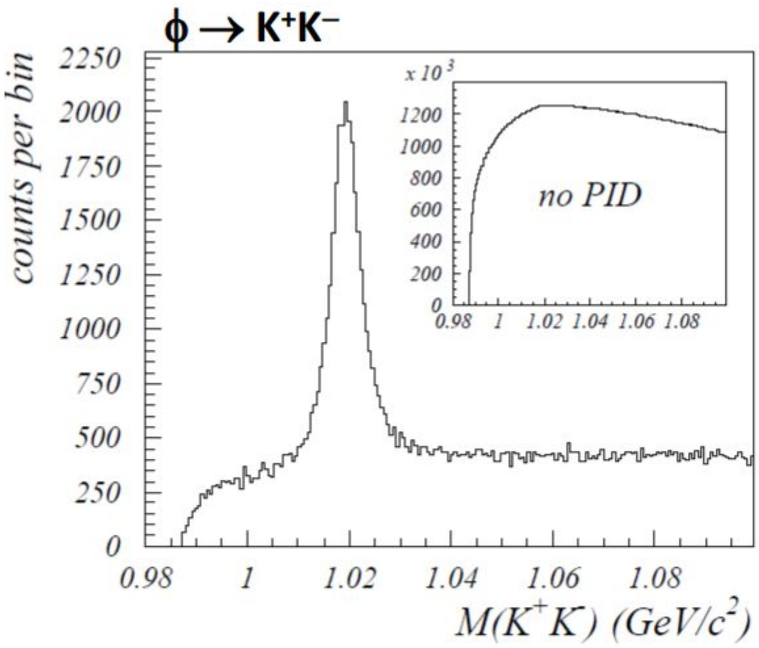


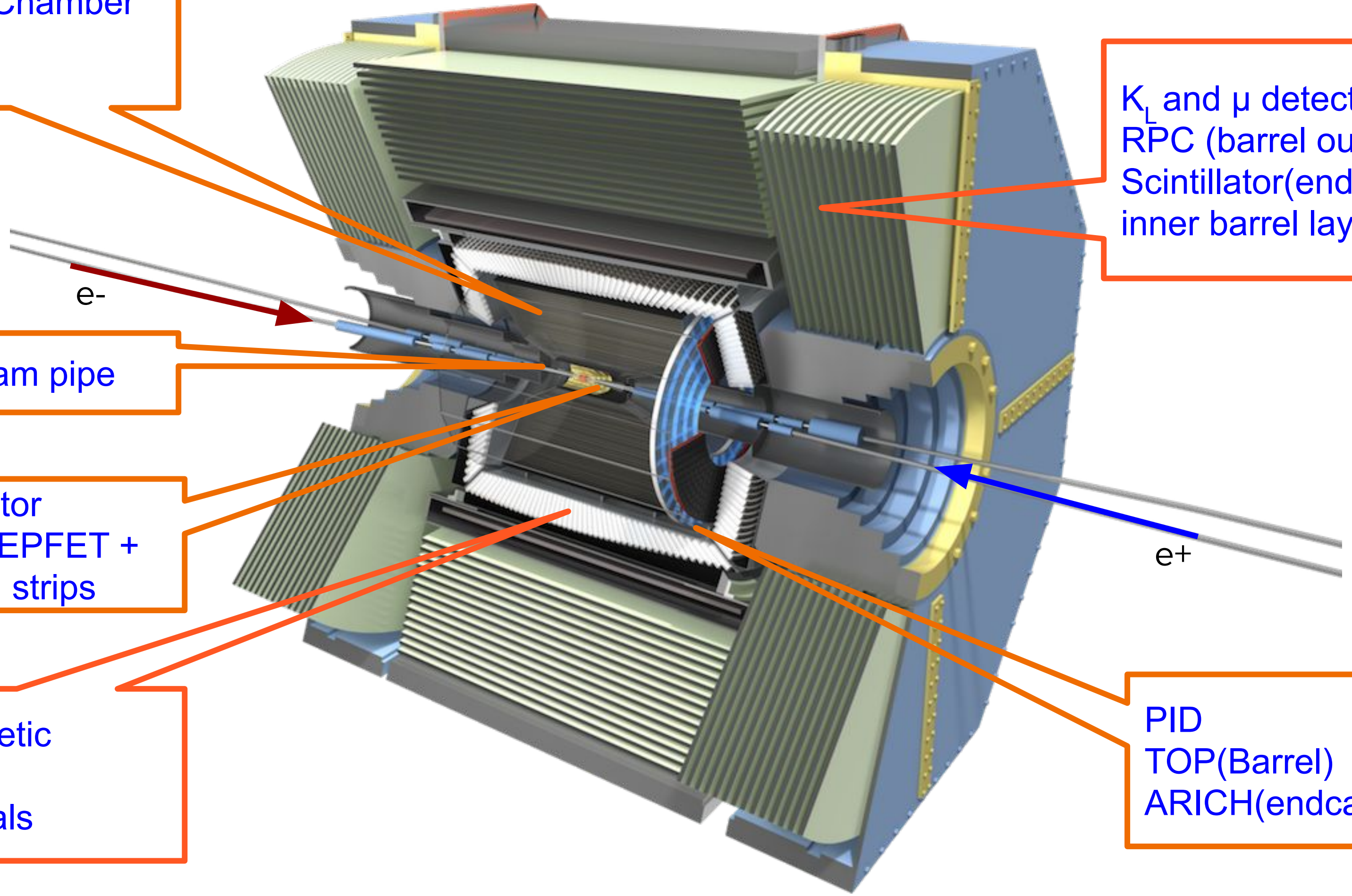
# Why we need PID?

- A clear peak in the invariant mass distribution after PID information is taken into account.
- PID necessary to reduce background.

- we are often interested in reconstructing the whole decay chain and hence to reconstruct all final state particles.




Central Drift Chamber
He-$C_2H_6$
$K_L$ and μ detector
RPC (barrel outer layer)
Scintillator(endcap, 2 inner barrel layer)
e-
Beryllium Beam pipe
Vertex Detector
2 layers of DEPFET +
4 layers of Si strips
e+
Electromagnetic Calorimeter
CsI(Tl) crystals
PID
TOP(Barrel)
ARICH(endcap)

# Belle II PID

Particle ID for a given species is the combination for all detectors:

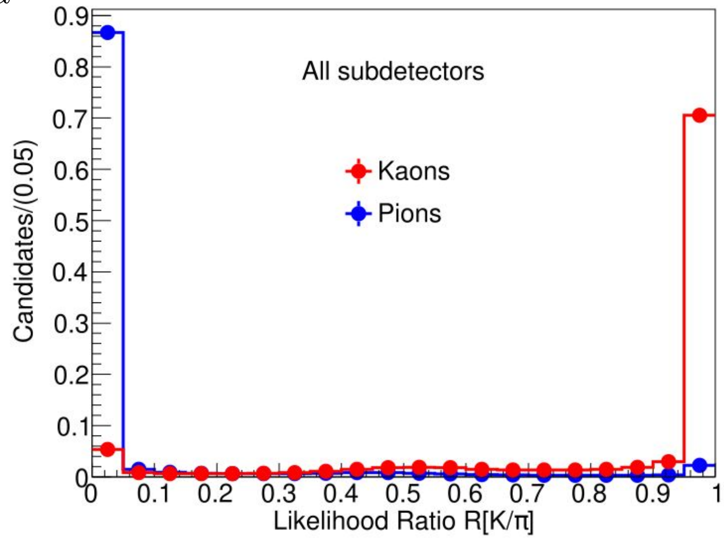
$$\mathcal{L}_i = \prod_{d}^{d \in D} \mathcal{L}_i^d \qquad i \in (e, \mu, \pi, K, p, d)$$

D ∈ (SVD,CDC, TOP, ARICH, ECL, KLM)

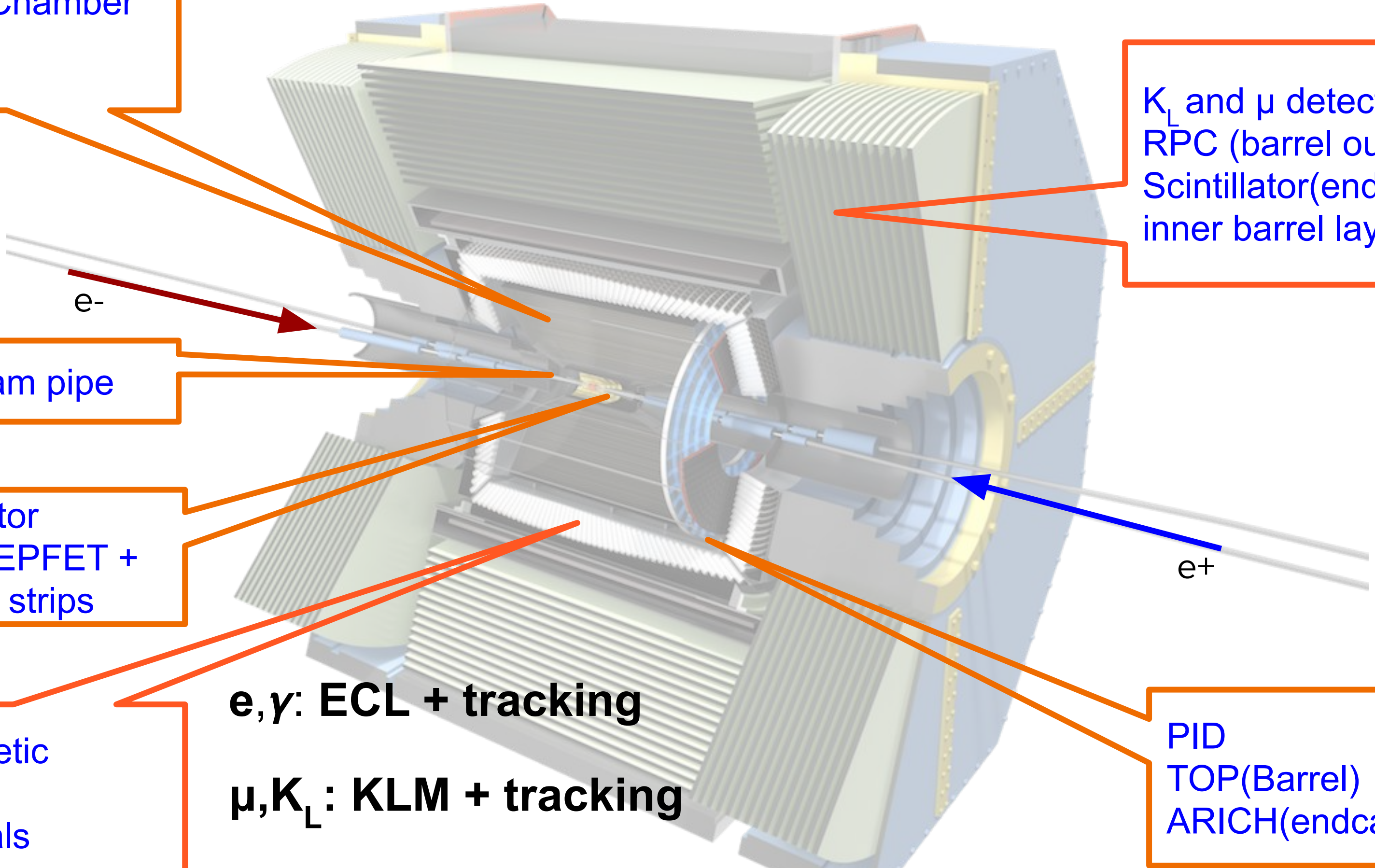
Each sub detector measures the likelihoods for 6 basic species

- Electron
- Muon
- Pion
- Kaon
- Proton
- Deuteron

$$R[K/\pi] = \frac{\mathcal{L}(K)}{\mathcal{L}(K) + \mathcal{L}(\pi)}$$



Central Drift Chamber
He-$C_2H_6$




$K_L$ and μ detector
RPC (barrel outer layer)
Scintillator(endcap, 2 inner barrel layer)

Beryllium Beam pipe

Vetrex Detector
2 layers of DEPFET +
4 layers of Si strips

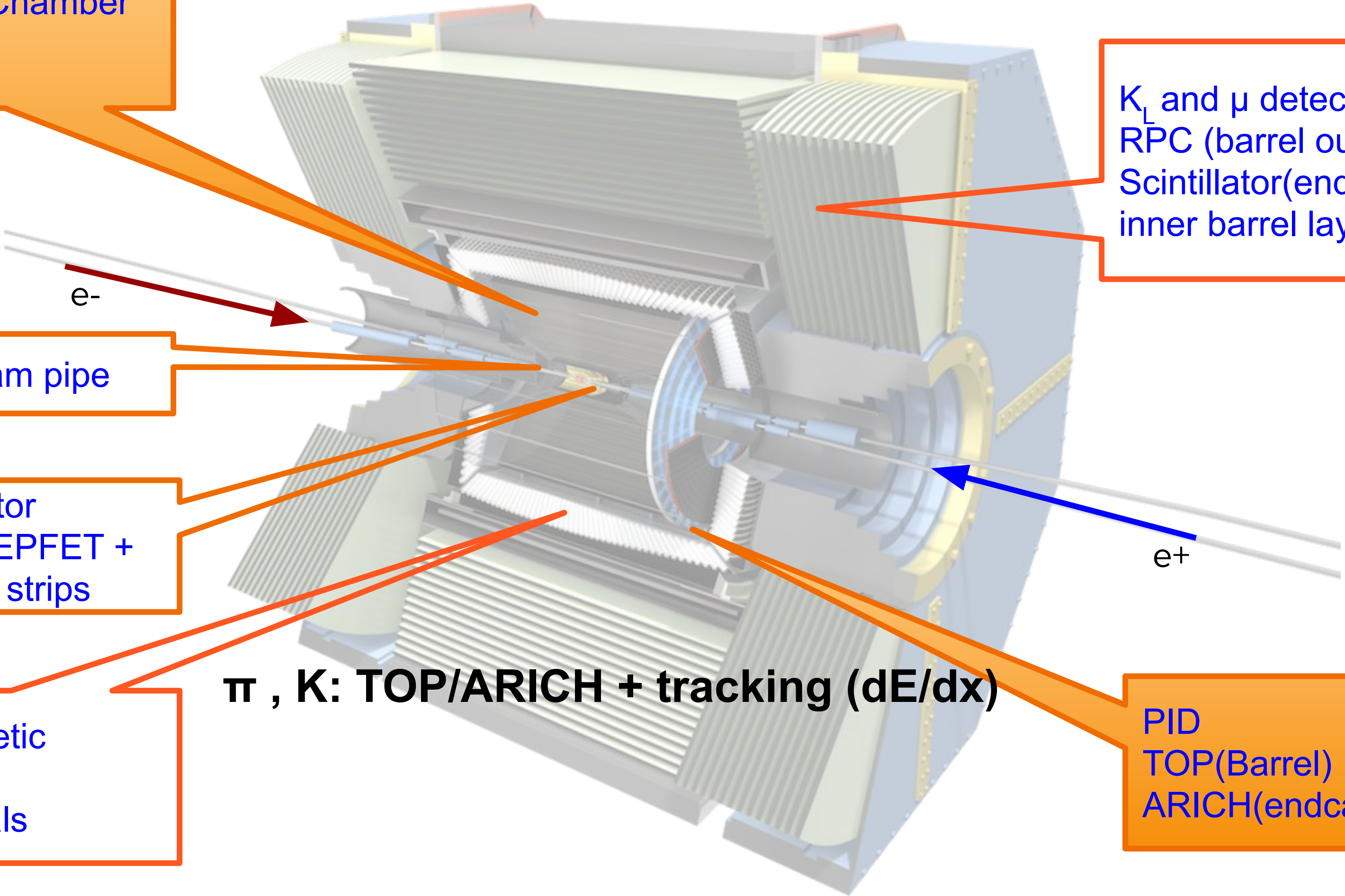
Electromagnetic Calorimeter
CsI(Tl) crystals

PID
TOP(Barrel)
ARICH(endcap)

**e,$\gamma$: ECL + tracking**

**μ,$K_L$: KLM + tracking**

**π , K, p: TOP/ARICH + tracking (dE/dx)**



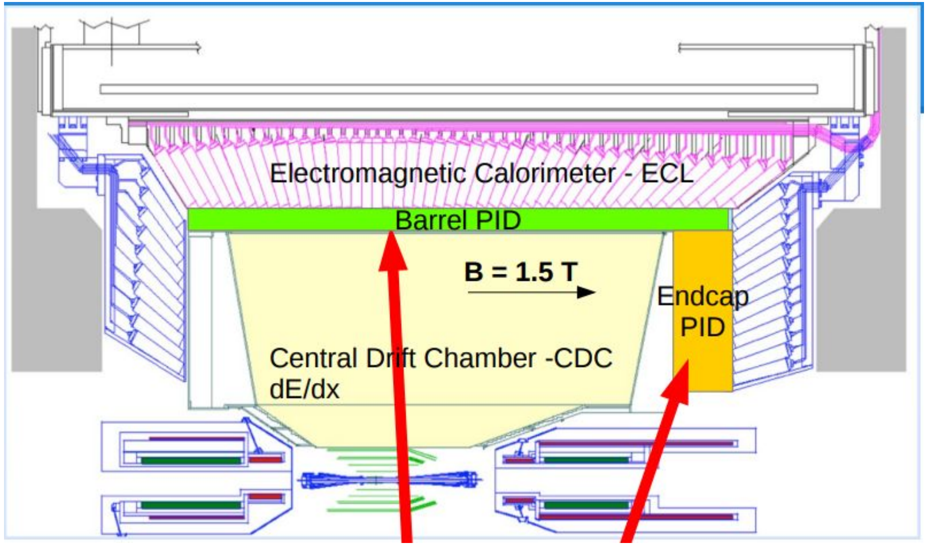

**π , K: TOP/ARICH + tracking (dE/dx)**

# PID

Two dedicated particle ID devices:

- Barrel: TOP
- EndCap: ARICH

In both regions, PIDs at Belle II are Ring Imaging Cherenkov devices.



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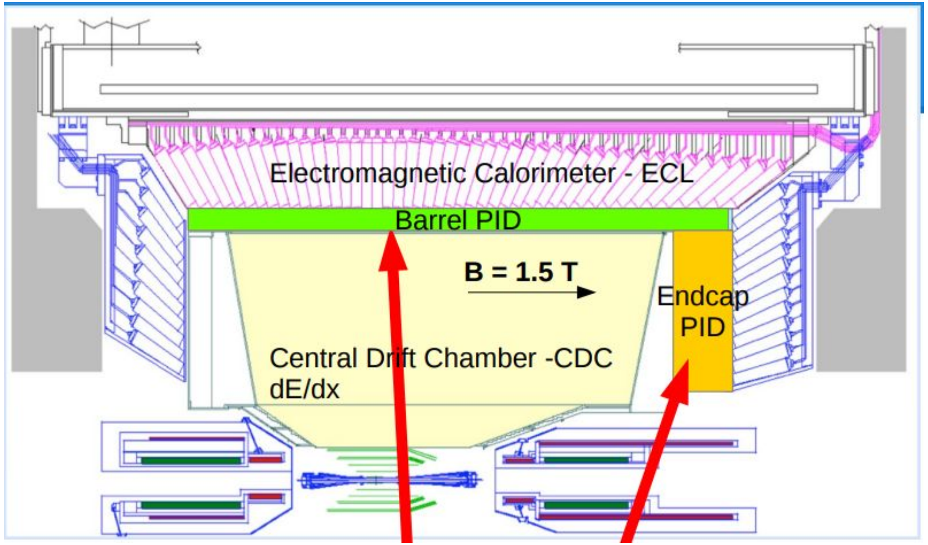
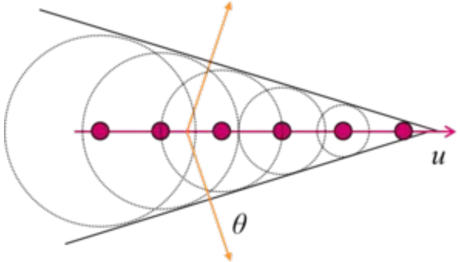


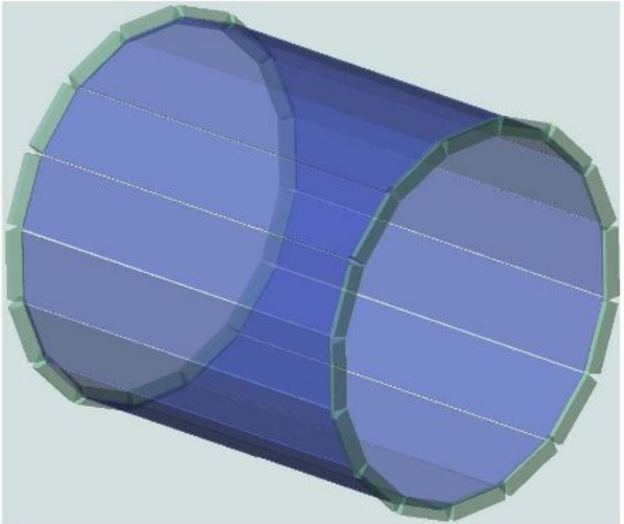

## Cherenkov radiation:

light produced by charged particles when they pass through an optically transparent medium at speeds greater than the speed of light in that medium.

- The speed is given by $\beta c = v = c/n$
- so a particle emitting cherenkov radiation must satisfy $v_{part} > c/n$
- characteristic angle: $\cos\theta_c = 1/n\beta$



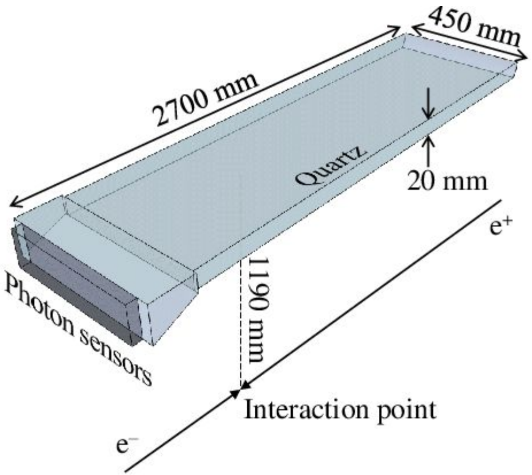
# Time of Propagation Counter(TOP)



16 TOP modules, arranged in barrel region of the detector

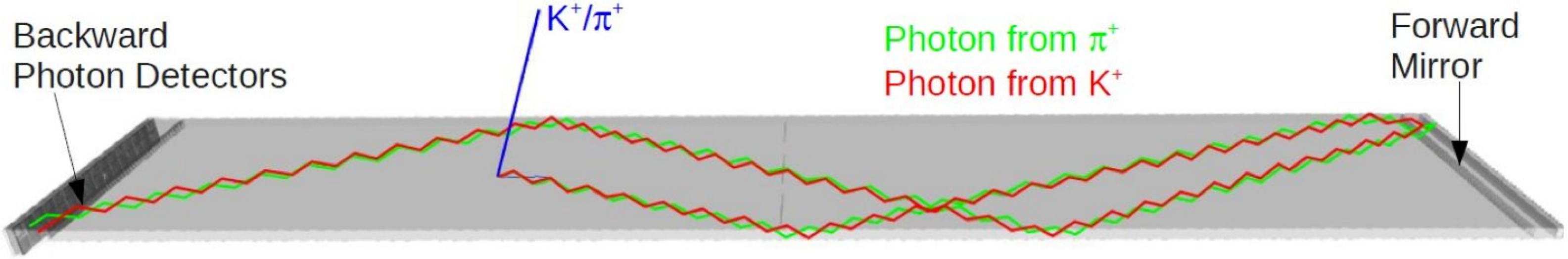
Each module contain-

- Silica bars ⟶ Radiators
- Mirror ⟶ focus emitted photons to the sensor plane
- Prism ⟶ expand the image and improving resolution.
- MCPPMT ⟶ two rows of fast multi-anode photon detectors



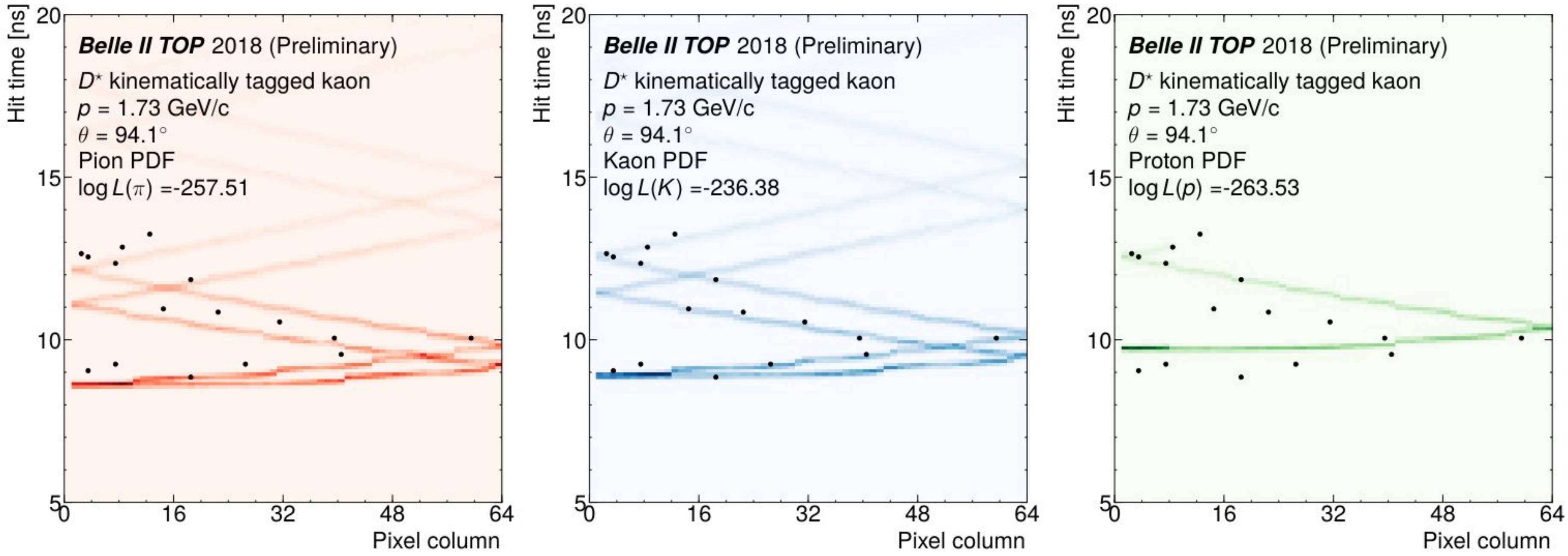
# Time of Propagation Counter(TOP)

- Cherenkov photons emitted in the quartz radiator → internally reflected → registered at the end of the bar by a fast position sensitive detector.




Same momentum pions and kaons will have different velocities (β) and hence the angle of Cherenkov photons.
K /π different θc →different path length → different time of propagation.

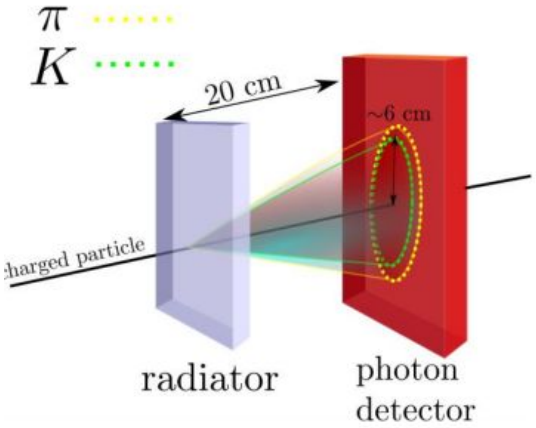
# Time of Propagation Counter(TOP)



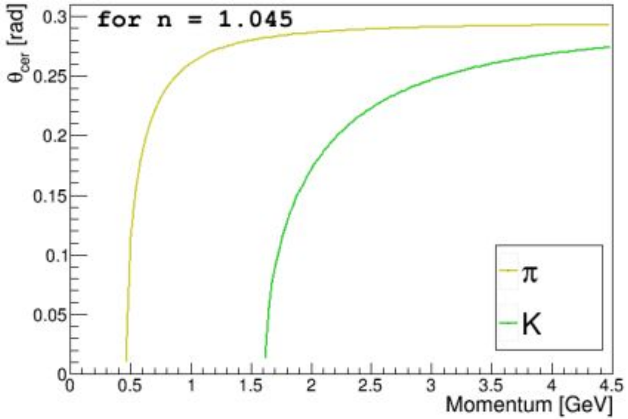

[The TOP counter of Belle II: status and first results]

# ARICH

- Provides particle identification system in the front-end endcap region.
- ARICH also relies on the relation between the emission angle of Cherenkov photons and the charged particle velocity.
- Two aerogel layers with different refraction indices (n1 = 1.045, n2 = 1.055) are used as radiator.
- Photons, emitted in aerogel, then propagate through ~20 cm of an expansion volume and hit the photon detectors.




pions and kaons of equal momenta

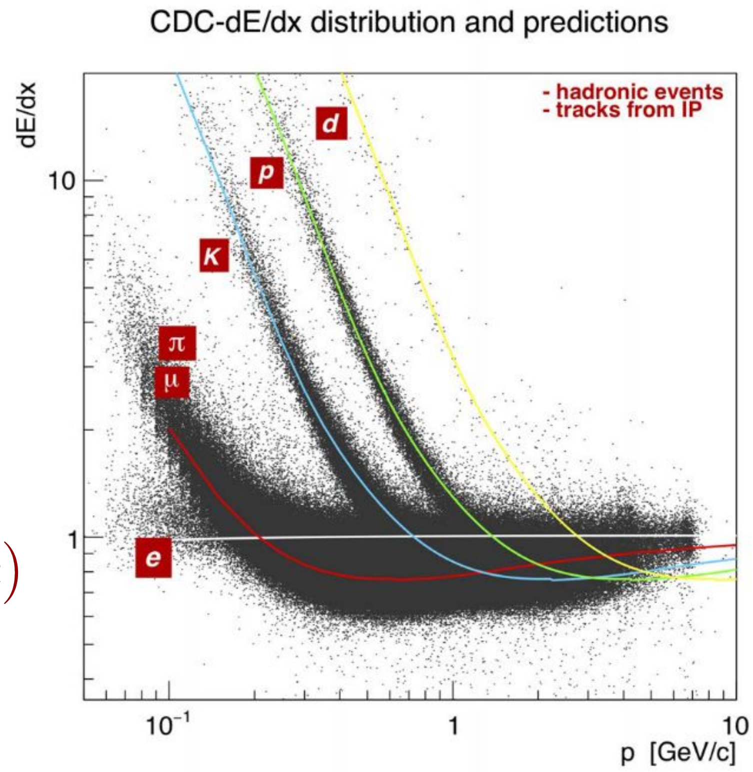



Cherenkov angle vs. particle momentum

# Central Drift Chamber(CDC)

- Reconstructs charged tracks and measures their momenta precisely
- Low-momentum tracks, which do not reach the particle identification device, can be identified using the CDC alone.
- PID possible by comparing with distributions of dE/dx and combining with information PXD/SVD.

$$-dE/dx \propto \frac{z^2 Z}{A\beta^2}(ln\frac{2mc^2\beta^2\gamma^2}{I} - \beta^2 + c)$$



# Method-

Previous studies with $D^0 \to K\pi$ (poster by Vismaya V S)

- $D^* \to D^0[K^-\pi^+\pi^0]\pi^+$ decay mode is reconstructed to study the PID performance.
- Two opposite sign tracks with kaon and pion mass hypothesis are combined with a neutral pion to reconstruct a $D^0$ meson candidate.
- $D^0$ is combined with another charged track with pion mass hypothesis to reconstruct $D^{*+}$
- $D^* \to D^0[K^-\pi^+\pi^0]\pi^+$ Mode helps probe the performance in lower momentum regions.

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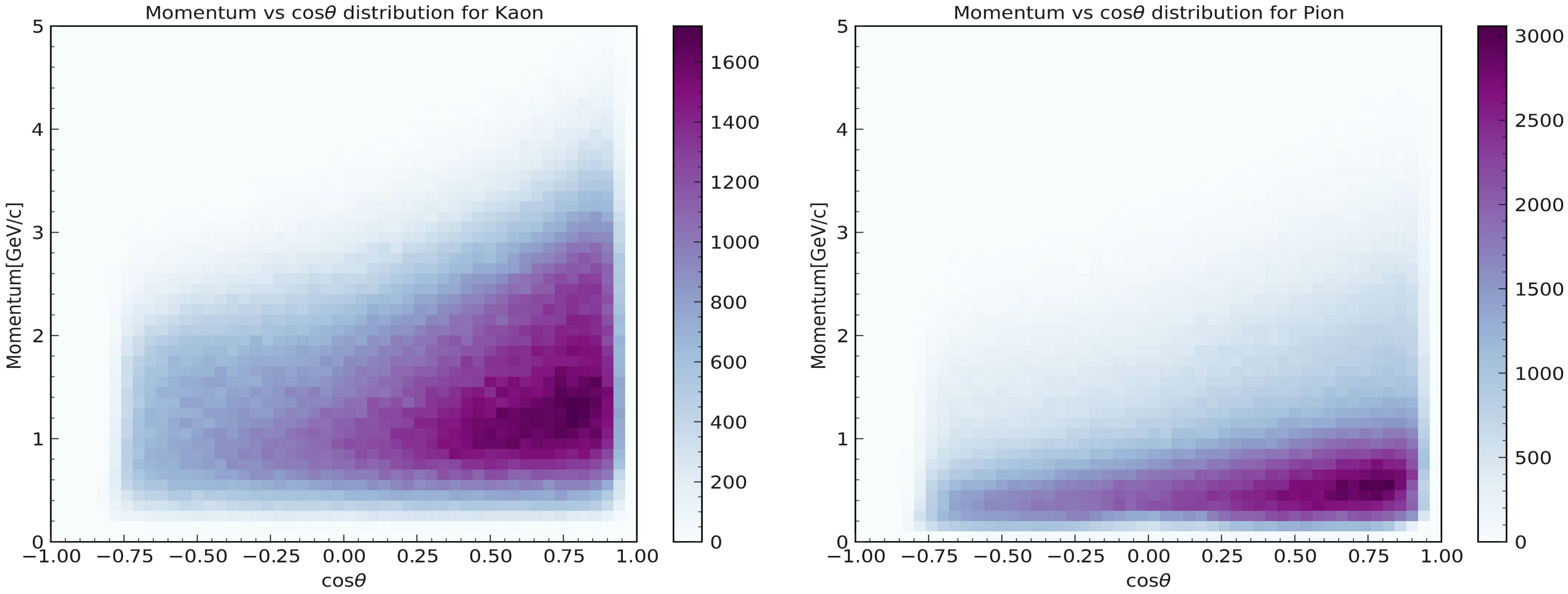
## Data Sample:

Belle II data (207$fb^{-1}$) compared with Monte Carlo simulation

## Selection Criteria:

- $| d0 | < 0.5$ cm
- $| z0 | < 2$ cm
- nCDCHits > 20
- $|\Delta M - 0.14543| < 1.5$ MeV/$c^2$
- $M[D^0] \in [1.75, 1.95]$ GeV/$c^2$
- $M[\pi^0] \in [0.121, 0.147]$ GeV/$c^2$
- $P^*[D^*] > 2.5$ GeV/c
- $P[\pi^0] > 0.35$GeV/c
- $E[\gamma 1, \gamma 2] > 0.075$GeV/$c^2$
- $E9/E25 > 0.9$
- $\chi^2 > 0.01$
- $d[D^0] > 40\mu m$

# Kinematic Distribution of Kaon and Pion




Kaons and pions are more populated towards the lower momentum region.

# Efficiency and mis-ID probability

**Efficiency:**

Ability to correctly assign the ID

ε(K) = N(K identified as K)/N(real K)

The “probability of a kaon to be called kaon”

$$\epsilon_K(\mathcal{R}_{K/\pi} > t) = \frac{N_K(\mathcal{R}_{K/\pi} > t)}{N_K}$$

**Mis-ID probability:**

Ability not to assign the incorrect ID

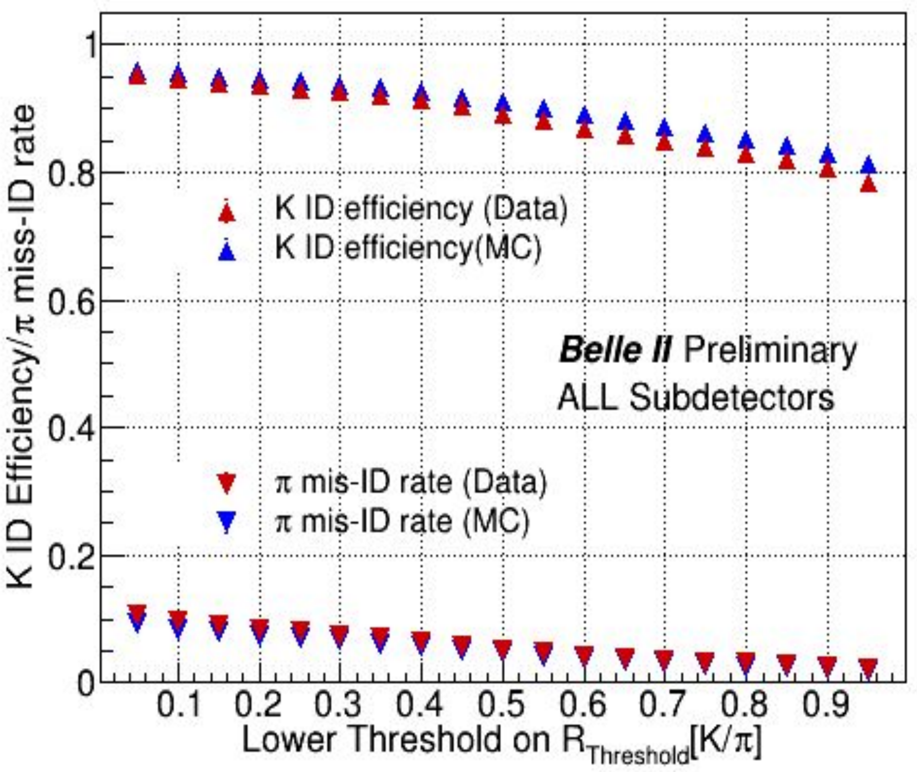
Mis-ID(K) = N(non-K identified as K)/N(non K)

The “probability for a non-kaon to be called kaon”

$$f_\pi(\mathcal{R}_{K/\pi} > t) = \frac{N_\pi(\mathcal{R}_{K/\pi} > t)}{N_\pi}$$

# Performance

- Kaon efficiency and π mis-identification for different PID criteria for ALL sub-detectors




<u>For example at R[K/π] > 0.5:</u>

**K-eff (data) : 89.20 ± 0.04%**

**K-eff (MC) : 90.95 ± 0.03%**

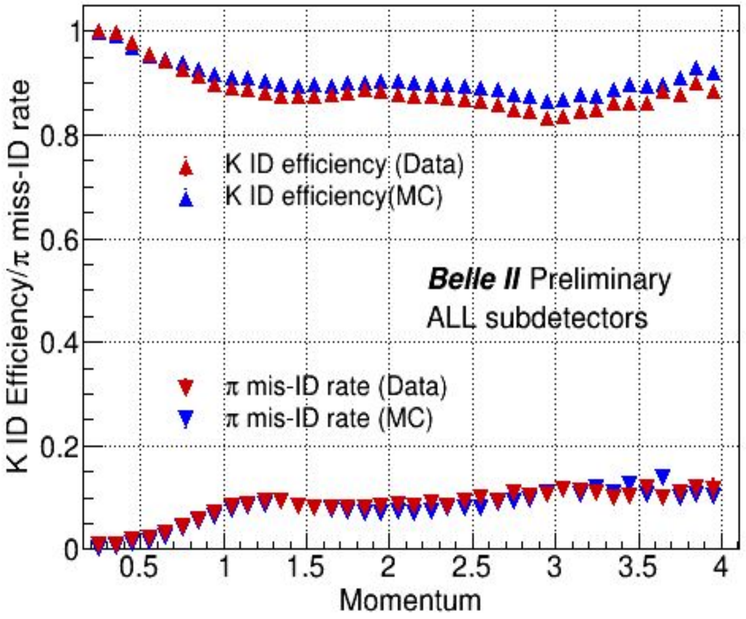
**π mis-id rate (data) : 5.08 ± 0.02%**

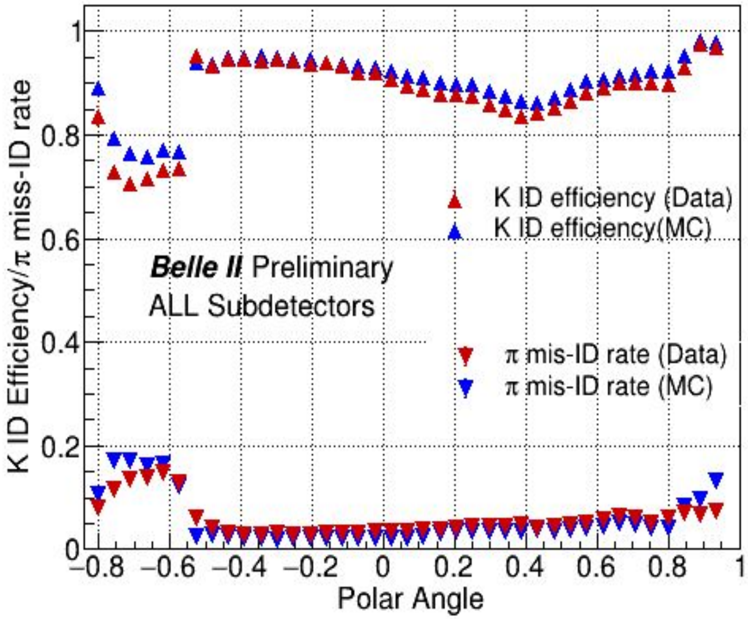
**π mis-id rate (MC) : 4.60 ± 0.02%**

There is minor data-MC disagreement

# Performance

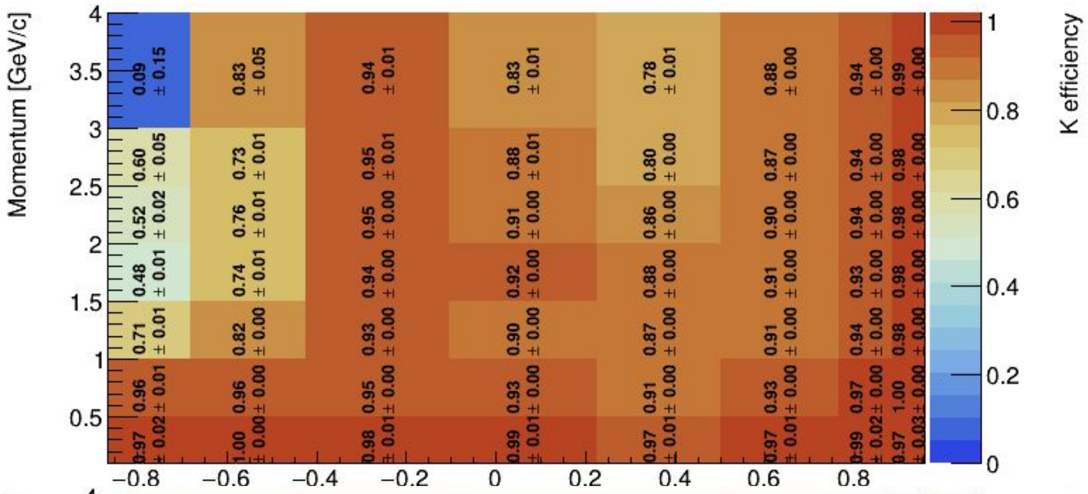
- Kaon efficiency and π mis-identification in bins of momentum and polar angle for $R_{[K/\pi]} > 0.5$



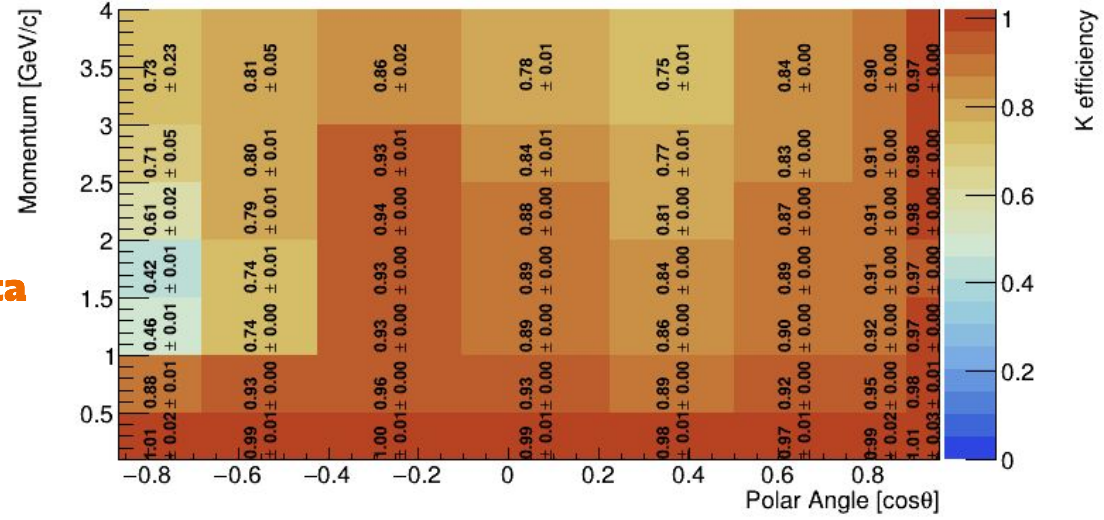



# K efficiency in 2D bins

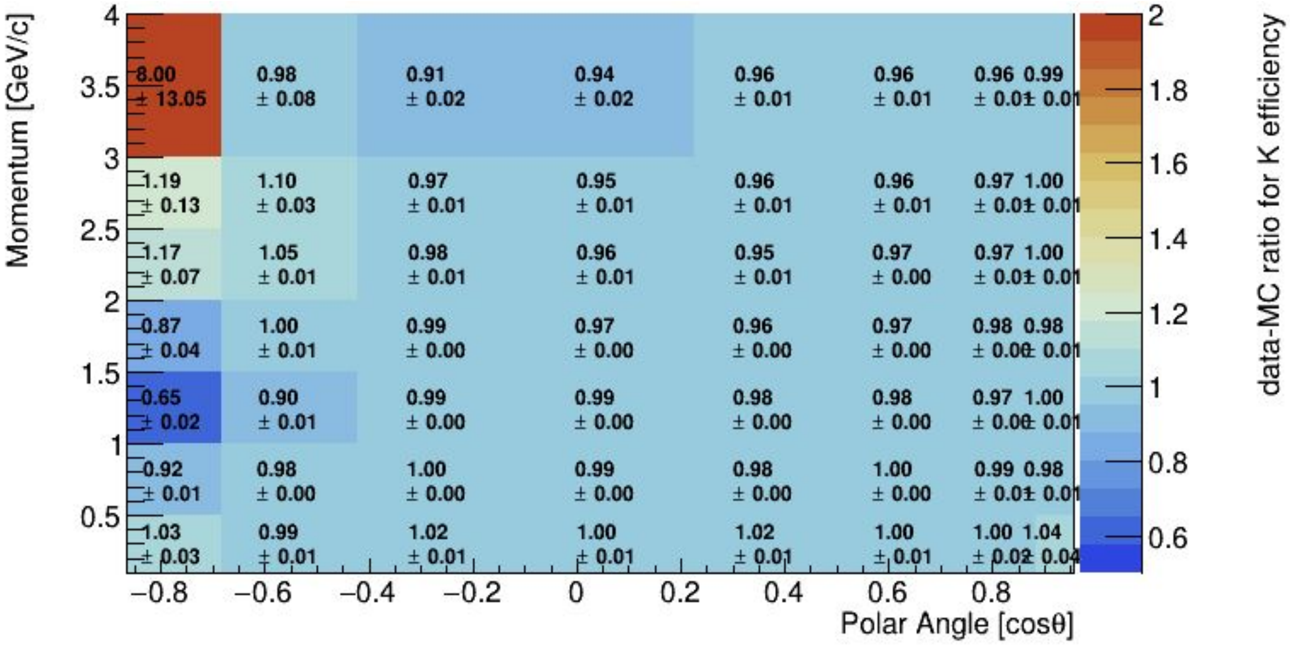
MC




Data



# Data/MC ratio




minor data-MC disagreement

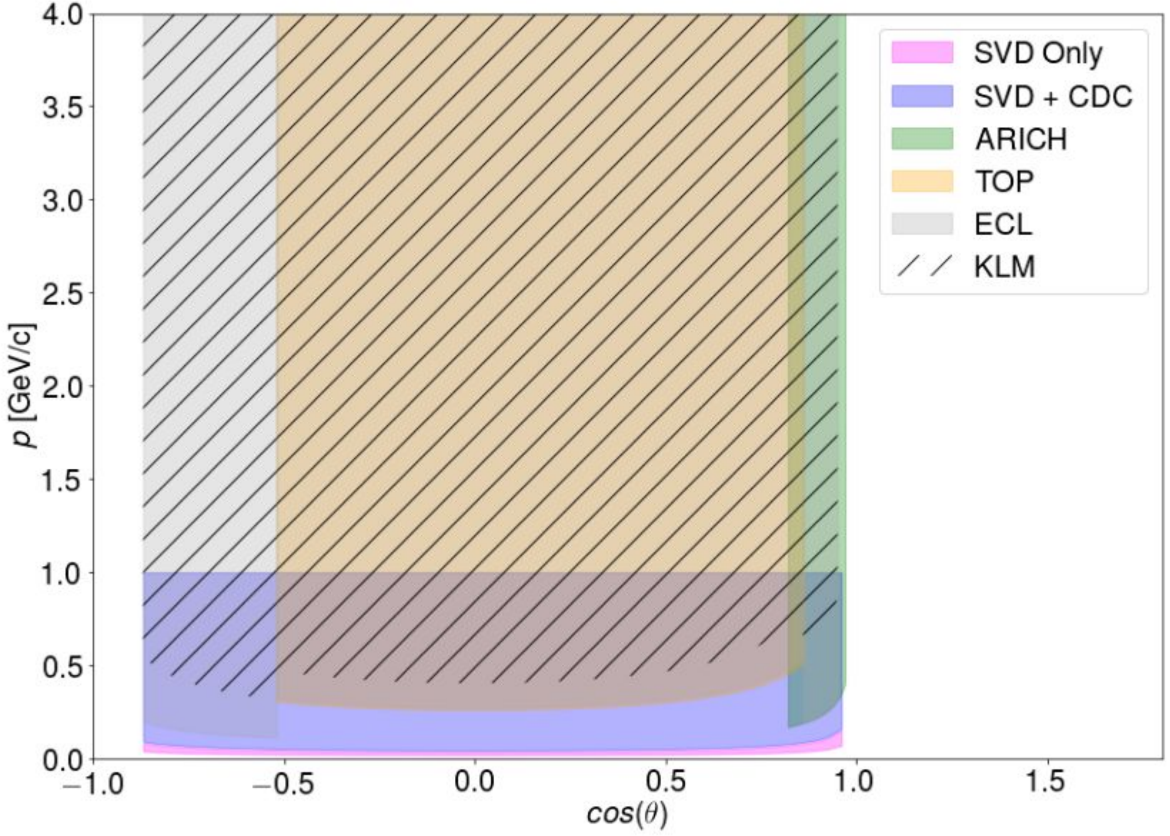
# Summary

- PID is essential as Belle II deals with a larger background.
- CDC along with PID( TOP, ARICH) plays role in K/π separation.
- $D^* \to D^0[K^-\pi^+\pi^0]\pi^+$ allows to probe the performance in lower momentum region.
- There exists a slight discrepancy between data and MC.
- Kaon identification efficiency in data is around 89% with pion fake rate as low as 5% .

# References


- Particle Identification at Belle II, Saurabh Sandilya
- Particle ID in Belle II ARICH and TOP, Oskar Hartbrich
- The Belle II PID Detectors, Marko Starič
- From PID detectors to PID variables, Umberto Tamponi

# Thank You




$$\log \mathcal{L}_\pi = \log \mathcal{L}_\pi^{\mathrm{SVD}} + \log \mathcal{L}_\pi^{\mathrm{CDC}} + \log \mathcal{L}_\pi^{\mathrm{TOP}} + \log \mathcal{L}_\pi^{\mathrm{ARICH}} + \log \mathcal{L}_\pi^{\mathrm{ECL}} + \log \mathcal{L}_\pi^{\mathrm{KLM}}$$

# Belle II PID

Each sub detector measures the likelihoods for 6 basic species

- Electron
- Muon
- Pion
- Kaon
- Proton
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Particle ID for a given species is the combination for all detectors:

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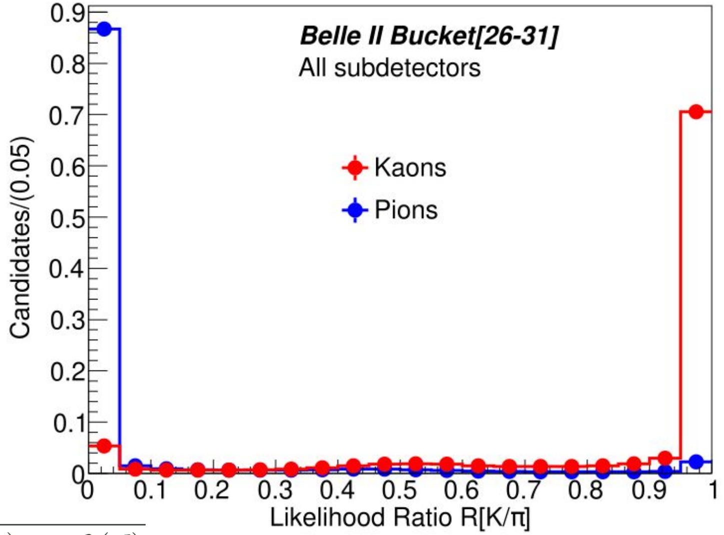
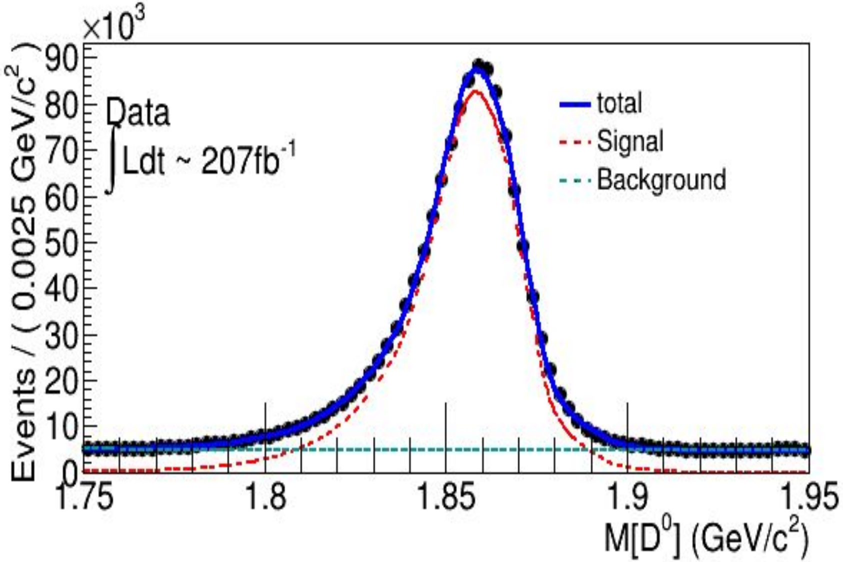
Binary PID likelihood ratio, R[K/π] is given by:

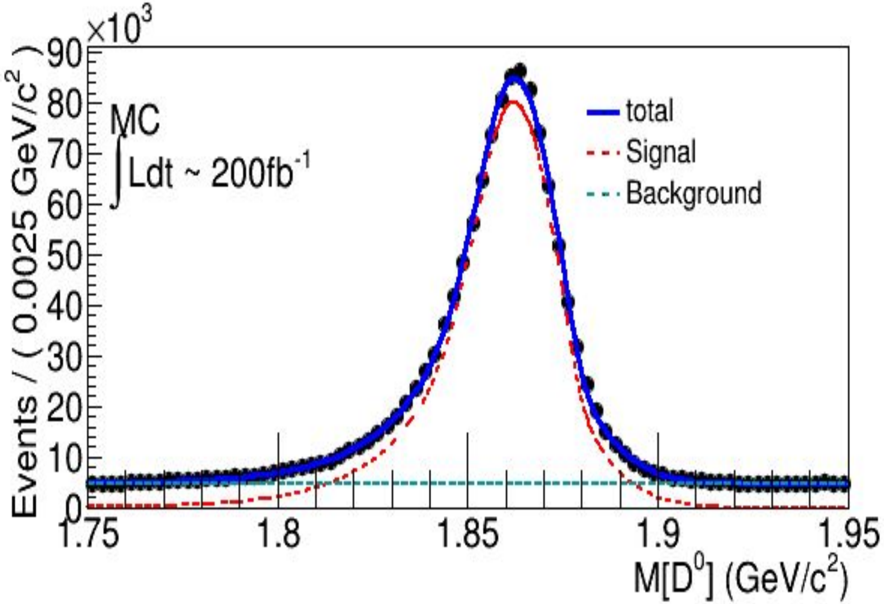
$$R[K/\pi] = \frac{\mathcal{L}(K)}{\mathcal{L}(K) + \mathcal{L}(\pi)}$$

Global PID likelihood ratio, R[K] is given by:

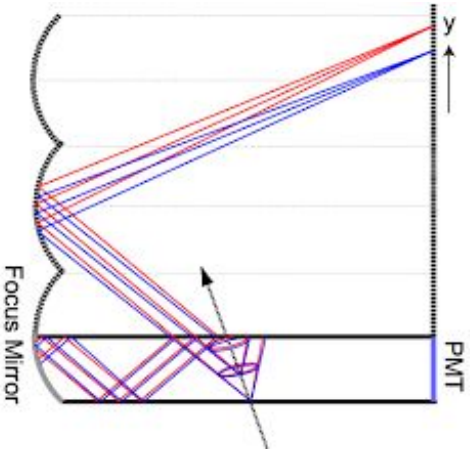
$$R[K] = \frac{\mathcal{L}(K)}{\mathcal{L}(K) + \mathcal{L}(\pi) + \mathcal{L}(e) + \mathcal{L}(\mu) + \mathcal{L}(p) + \mathcal{L}(d)}$$



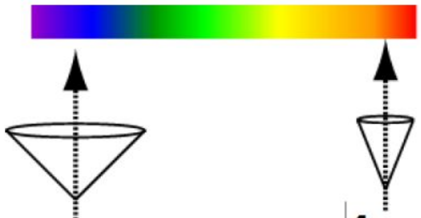

×10^3
Events / ( 0.0025 GeV/c^2 )
Data
∫Ldt ~ 207fb^-1
total
Signal
Background
M[D^0] (GeV/c^2)


×10^3
Events / ( 0.0025 GeV/c^2 )
MC
∫Ldt ~ 200fb^-1
total
Signal
Background
M[D^0] (GeV/c^2)

# Time of Propagation Counter(TOP)

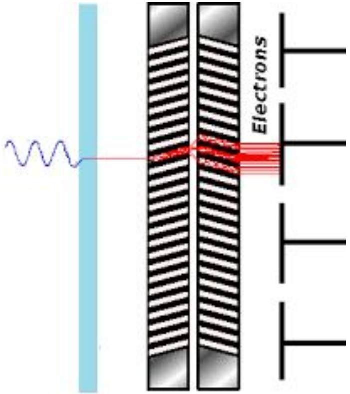



- parallel rays get focused to a single point.
- non-parallel rays are focused to different points(K /π separation).



$$\theta_c(\lambda) = \cos^{-1}\left(\frac{1}{n(\lambda)\beta}\right)$$

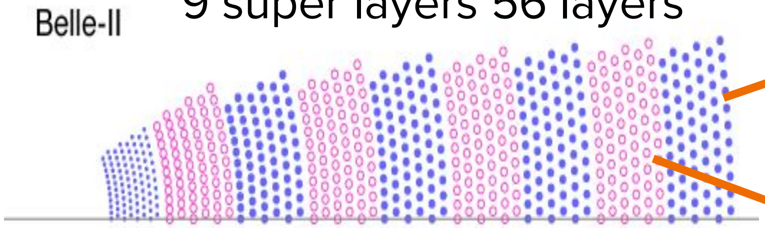
allows to correct for chromatic dispersion.

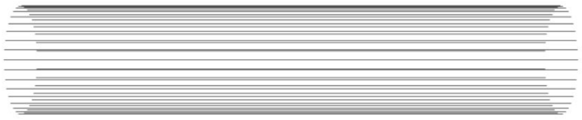



- MCP-PMT : Transit time spread ~30-35ps(required<50ps)
- Quantum efficiency : >24% at 350-400nm

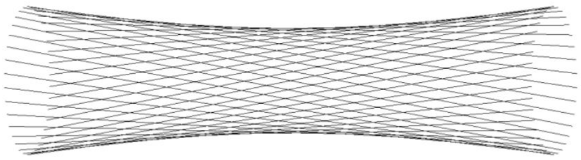
# Central Drift Chamber(CDC)

9 super layers 56 layers



(a) An axial wire layer - sense wires are parallel to the beamline



(b) A stereo wire layer - sense wires are skewed to the beamline (exaggerated)

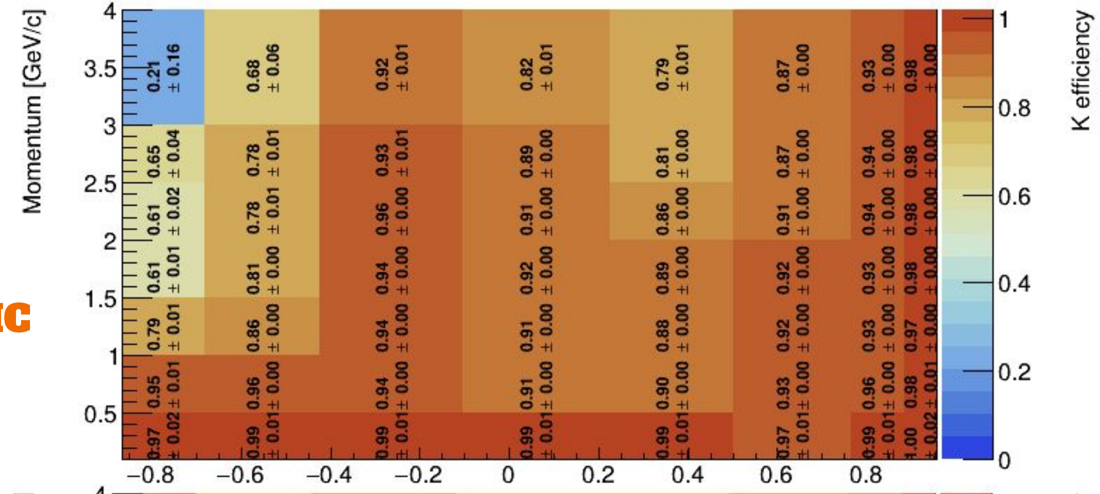

X = field wires
O = sense wires

| | |
|---|---|
| Radius of inner cylinder (mm) | 160 |
| Radius of outer cylinder (mm) | 1130 |
| Radius of innermost sense wire (mm) | 168 |
| Radius of outermost sense wire (mm) | 1111.4 |
| Number of layers | 56 |
| Number of sense wires | 14,336 |
| Gas | $He - C_2H_6$ |
| Diameter of sense wire ($\mu m$) | 30 |

Primary particle ionises gas molecules ⟶ Secondary electrons create avalanches ⟶ electron avalanche reaches the sense wire ⟶ signal is generated(CDC Hit)

# K⁻ efficiency in 2D bins

MC




Data