# Belle II Particle Identification

Jake Bennett The University of Mississippi Quarknet workshop - July 2020







## Mt. Tsukuba (877m)

6- 6 St



## KEK Tsukuba Campus



### SuperKEKB and Belle II: 2nd generation "B Factory"



# $c\bar{c}, u\bar{u}, d\bar{d}, \ell^+\ell^- \leftarrow e^+e^- \rightarrow \Upsilon(\mathsf{nS}) \rightarrow B^{(*)}\bar{B}^{(*)}$



З

### SuperKEKB and Belle II: 2nd generation "B Factory"





**New** positron damping ring

7 GeV e-



 $c\bar{c}, u\bar{u}, d\bar{d}, \ell^+\ell^- \leftarrow e^+e^- \rightarrow \Upsilon(\mathsf{nS}) \rightarrow B^{(*)}\bar{B}^{(*)}$ 



Check-in: How are the electrons and positrons "steered" around the rings?

Animat

A. Air pressure
B. Electric fields
C. Magnetic fields
D. Both electric and magnetic fields
E. The Force

## A canonical **BB** Event



The second secon

H





## A canonical **BB** Event



What are some features you notice in this event?





First new particle collider since the LHC (intensity rather than energy frontier; e<sup>+</sup>e<sup>-</sup> rather than pp)

K<sub>L</sub> and muon detector:

Resistive Plate Counter (barrel outer layers) Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

Particle Identification:

Time-of-Propagation counter (barrel) Prox. Focusing Aerogel RICH (fwd)

positron (4 GeV)

Readout (TRG, DAQ):

Max. 30kHz L1 trigger ~100% efficient for hadronic events. 1MB (PXD) + 100kB (others) per event - over 30GB/sec to record

Offline computing:

Distributed over the world via the GRID

arXiv:1011.0352 [physics.ins-det]







First new particle collider since the LHC (intensity rather than energy frontier; e<sup>+</sup>e<sup>-</sup> rather than pp)

K<sub>L</sub> and m Resistive Scintillato

#### Central Drift Chamber

positron (4 GeV)

#### Readout (TRG, DAQ):

Max. 30kHz L1 trigger ~100% efficient for hadronic events. 1MB (PXD) + 100kB (others) per event - over 30GB/sec to record

Offline computing:

Distributed over the world via the GRID

arXiv:1011.0352 [physics.ins-det]





- CDC layers alternate between "field layers" and "sense layers" •
  - Sense wires held at a large potential (anode)
  - Grounded field wires help to shape the electric field -





- CDC layers alternate between "field layers" and "sense layers"  $\bullet$ 
  - Sense wires held at a large potential (anode) —
  - Grounded field wires help to shape the electric field -

 $F_B = q \overrightarrow{v} \times B'$ 

#### B into the page







- CDC layers alternate between "field layers" and "sense layers"  $\bullet$ 
  - Sense wires held at a large potential (anode) —
  - Grounded field wires help to shape the electric field -

 $F_B = q \overrightarrow{v} \times B$ 

#### B into the page





- CDC layers alternate between "field layers" and "sense layers"
  - Sense wires held at a large potential (anode)
  - Grounded field wires help to shape the electric field
- Electrons liberated by ionization drift toward the sense wires



 $F_B = q \overrightarrow{v} \times \overrightarrow{B}$ 





- CDC layers alternate between "field layers" and "sense layers"
  - Sense wires held at a large potential (anode)
  - Grounded field wires help to shape the electric field
- Electrons liberated by ionization drift toward the sense wires



 $F_B = q \overrightarrow{v} \times \overrightarrow{B}$ 





- CDC layers alternate between "field layers" and "sense layers"
  - Sense wires held at a large potential (anode)
  - Grounded field wires help to shape the electric field
- Electrons liberated by ionization drift toward the sense wires
- Near the wires, the large electric field causes the electrons to gain enough energy per mean free path to ionize at the next collision



- CDC layers alternate between "field layers" and "sense layers"
  - Sense wires held at a large potential (anode)
  - Grounded field wires help to shape the electric field
- Electrons liberated by ionization drift toward the sense wires
- Near the wires, the large electric field causes the electrons to gain enough energy per mean free path to ionize at the next collision
- Detectable signal created by avalanche of electrons near sense wires
- Location of the hit and drift time are used to determine the trajectory of the track



- CDC layers alternate between "field layers" and "sense layers"  $\bullet$ 
  - Sense wires held at a large potential (anode)
  - Grounded field wires help to shape the electric field
- Electrons liberated by ionization drift toward the sense wires
- Noar the wires the large electric field causes

Check-in: What important feature are we missing in this picture?

A. Air pressure **B. Electric fields** C. Magnetic fields **D.** Ionization E. The Force







### Drift cells

- Presence of magnetic field causes electron trajectories to curve
  - Changes the shape of isochrones (lines of equal drift time)
  - Lorentz Angle: angle between drift path with and without B-field
  - Also depends on the gas composition
  - Note: B-field can have a big effect on drift time!

50-50% Argon-Ethane





Example from CLEO

# $F_B = q \overrightarrow{v} \times \overrightarrow{B}$



## Very simplistic overview of tracking

Localize a charged track to be on a ~135 µm resolution drift circle around wire ullet







## Very simplistic overview of tracking

Localize a charged track to be on a ~135 µm resolution drift circle around wire  $\bullet$ 





Superlayer boundaries

CDC Hits (size of circle proportional to drift time)

Hits in axial layers lie along the same trajectory

Offset from stereo layers related to z coordinate of particle trajectory

Charge of track determines sign of bend

Low momentum tracks curl up inside the detector





## Very simplistic overview of tracking

Localize a charged track to be on a  $\sim$ 135 µm resolution drift circle around wire  $\bullet$ 



Superlayer boundaries

CDC Hits (size of circle proportional to drift time)

Hits in axial layers lie along the same trajectory

Offset from stereo layers related to z coordinate of particle trajectory

Charge of track determines sign of bend

Low momentum tracks curl up inside the detector

How can we use this to measure the momentum of a particle?







## Particle IDentification (PID)

- Particle identification is basically measuring mass (measure both p and  $\beta$  simultaneously)
  - π<sup>±</sup> : 140 MeV
  - K±:494 MeV
  - p<sup>±</sup>:938 MeV
  - μ<sup>±</sup> : 106 MeV
- All depends on the interaction
  - Specific energy loss: dE/dx
  - Time of flight (ToF)
  - Cherenkov techniques -

$$\gamma = rac{1}{\sqrt{1-rac{v^2}{c^2}}} = rac{1}{\sqrt{1-eta^2}} \qquad eta\gamma = rac{p}{m}$$



## Particle IDentification (PID)

- Particle identification is basically measuring mass (measure both p and β simultaneously)
  - π<sup>±</sup> : 140 MeV
  - K±:494 MeV
  - p±:938 MeV
  - $\mu^{\pm}$ : 106 MeV
- All depends on the interaction
  - Specific energy loss: dE/dx
  - Time of flight (ToF)
  - Cherenkov techniques





#### Basic philosophy

• dE/dx depends only on  $\beta \gamma = p/m$  (Bethe-Bloch formula)

#### Predict: What will happen if we look at momentum rather than p/m?

dE/dx



βγ



### Basic philosophy

- dE/dx depends only on  $\beta \gamma = p/m$  (Bethe-Bloch formula)
- Measuring dE/dx and the momentum allows us to predict the mass (identity) of the particle





βγ



### Basic philosophy

- dE/dx depends only on  $\beta \gamma = p/m$  (Bethe-Bloch formula)
- Measuring dE/dx and the momentum allows us to predict the mass (identity) of the particle





We artificially set dE/dx to 1 for electrons. Why?

βγ

![](_page_24_Picture_10.jpeg)

![](_page_25_Picture_0.jpeg)

K<sub>L</sub> and muon detector:

Resistive Plate Counter (barrel outer layers) Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

#### **Particle Identification:**

**Time-of-Propagation counter (barrel) Prox. Focusing Aerogel RICH (fwd)** 

#### positron (4 GeV)

![](_page_25_Picture_7.jpeg)

![](_page_25_Picture_8.jpeg)

![](_page_25_Picture_9.jpeg)

#### Cerenkov techniques

Charged particle moving through a dielectric medium •

![](_page_26_Figure_2.jpeg)

![](_page_26_Picture_3.jpeg)

![](_page_26_Picture_4.jpeg)

#### Cerenkov techniques

 Charged particle moving through a dielectric medium with velocity > the propagation speed

![](_page_27_Figure_2.jpeg)

![](_page_27_Picture_3.jpeg)

#### Cerenkov techniques

- Charged particle moving through a dielectric medium  $\bullet$ with velocity > the propagation speed of light in the medium will radiate photons (light)
- Photons are emitted at a fixed angle: ullet
- Emission spectrum is ~1/E: mostly in optical range  $\bullet$

![](_page_28_Picture_4.jpeg)

![](_page_28_Picture_5.jpeg)

![](_page_28_Figure_6.jpeg)

![](_page_28_Picture_7.jpeg)

# **Čerenkov light in the ARICH (endcap Particle ID)**

![](_page_29_Picture_1.jpeg)

# Čerenkov light in the TOP (barrel Particle ID)

![](_page_30_Picture_1.jpeg)

![](_page_31_Picture_0.jpeg)

![](_page_31_Picture_1.jpeg)

#### Belle II @ Ole Miss

![](_page_32_Picture_1.jpeg)

Jake Bennett

![](_page_32_Picture_3.jpeg)

Lucien Cremaldi

![](_page_32_Picture_5.jpeg)

Saroj Pokharel

![](_page_32_Picture_7.jpeg)

Justin Guilliams

![](_page_32_Picture_9.jpeg)

Anil Panta

![](_page_32_Picture_11.jpeg)

![](_page_32_Picture_12.jpeg)

Robert Kroeger

![](_page_32_Picture_14.jpeg)

#### Don Summers

![](_page_32_Picture_16.jpeg)

![](_page_32_Picture_17.jpeg)

Michel Villanueva

![](_page_32_Picture_19.jpeg)

**David Sanders** 

3

Michael Jeandron

![](_page_32_Picture_23.jpeg)

![](_page_32_Picture_24.jpeg)