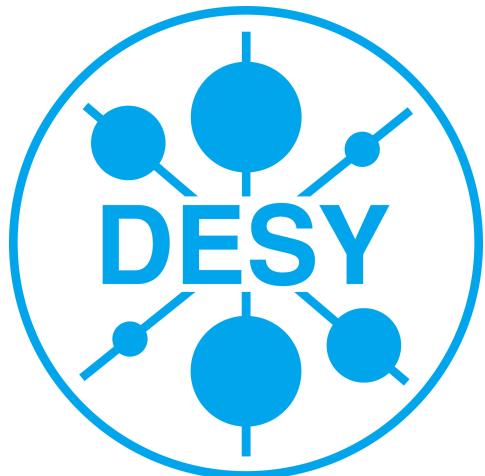


Training a machine to find the rare decay $B^0 \rightarrow K^*(892)^0 \ell^+ \ell^-$ at the Belle experiment

Cyrille Praz & Margarete Kattau (Summer Students)

Supervised by Dr. Simon Wehle

07.09.2017



Outlines

- ▶ The Belle experiment and the rare decay $B^0 \rightarrow K^*(892)^0 e^+ e^-$
- ▶ Monte Carlo simulated background and signal
- ▶ Background suppression strategy based on classifiers
- ▶ Results

The Belle experiment and the rare decay $B^0 \rightarrow K^*(892)^0 e^+ e^-$

$$B^0 \rightarrow K^*(892)^0 e^+ e^-$$

$$\mathcal{B}(B^0 \rightarrow K^*(892)^0 e^+ e^-) = (1.03^{+0.19}_{-0.17}) \times 10^{-6} \quad [3]$$

The Belle experiment and the rare decay $B^0 \rightarrow K^*(892)^0 e^+ e^-$

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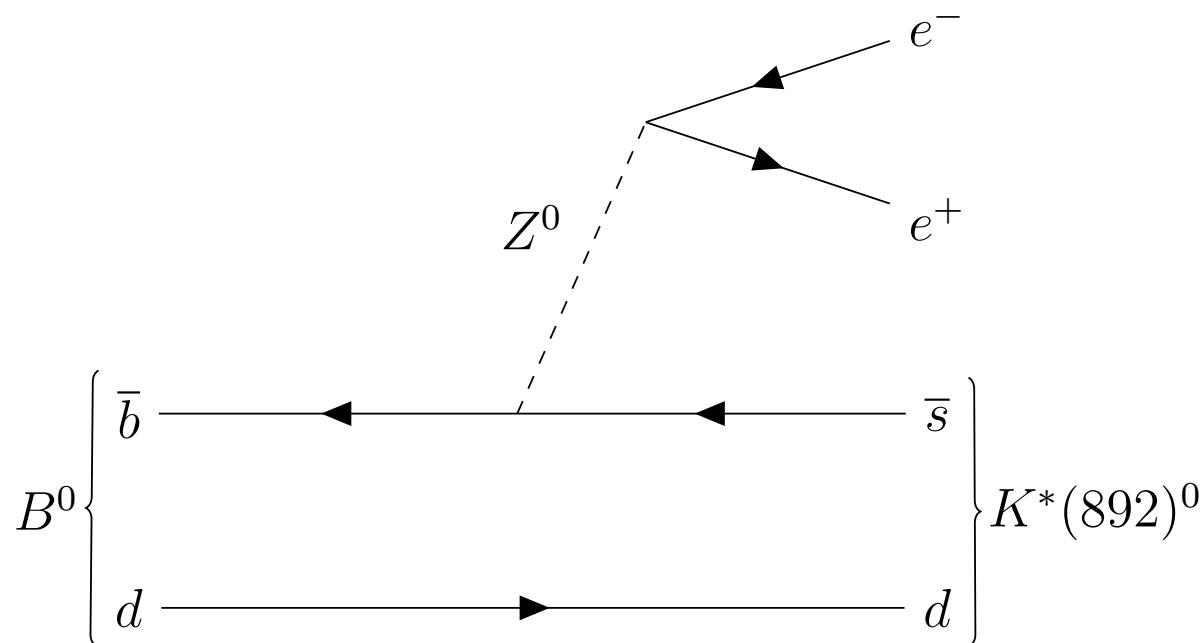


Figure : **Forbidden** flavour changing neutral current.

The Belle experiment and the rare decay $B^0 \rightarrow K^*(892)^0 e^+ e^-$

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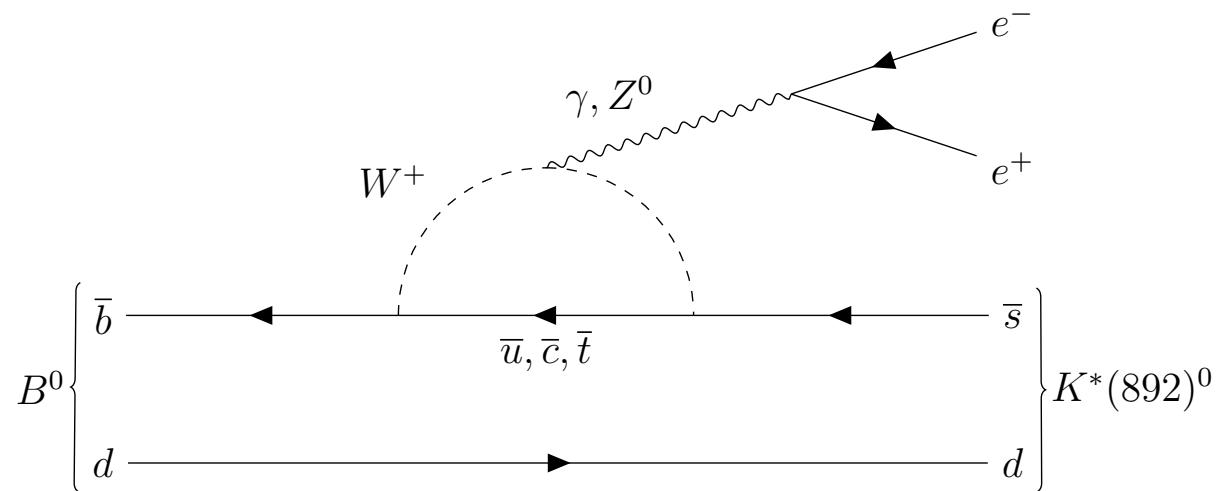


Figure : **Allowed** flavour changing neutral current.

The Belle experiment and the rare decay $B^0 \rightarrow K^*(892)^0 e^+ e^-$

$$B^0 \rightarrow K^*(892)^0 e^+ e^-$$

$$\mathcal{B}(B^0 \rightarrow K^*(892)^0 e^+ e^-) = (1.03^{+0.19}_{-0.17}) \times 10^{-6} \quad [3]$$

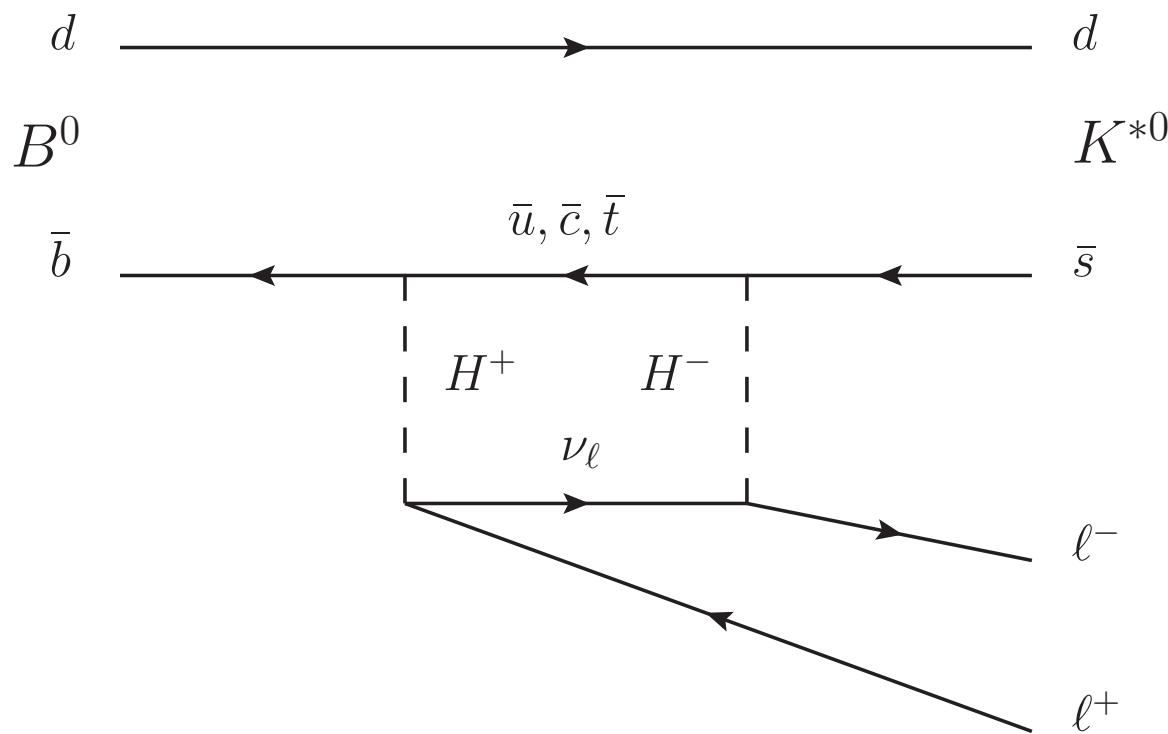


Figure : **Hypothetical** charged Higgs contribution.

The Belle experiment and the rare decay $B^0 \rightarrow K^*(892)^0 e^+ e^-$

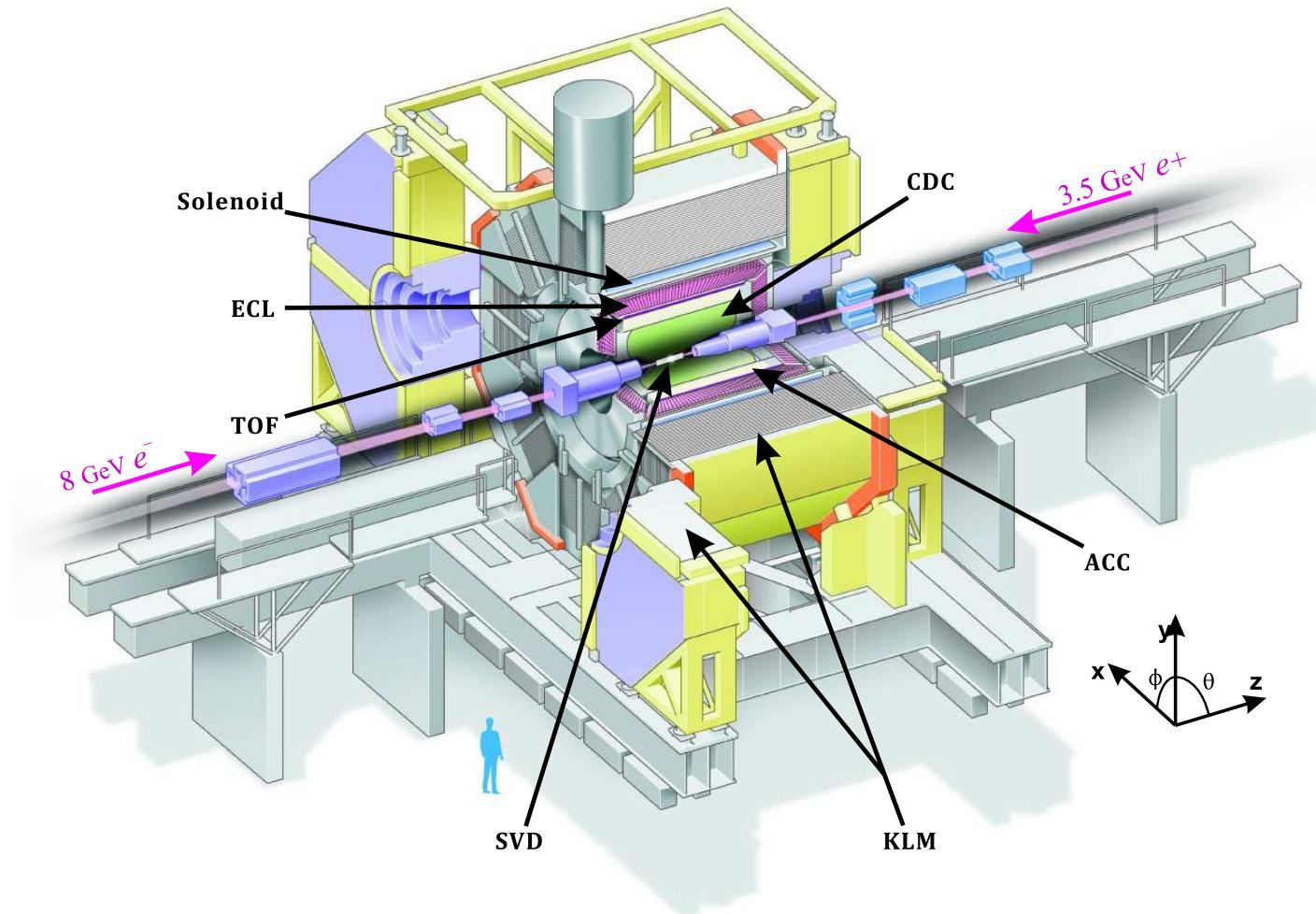


Figure : The Belle detector. [4]

The Belle experiment and the rare decay $B^0 \rightarrow K^*(892)^0 e^+ e^-$

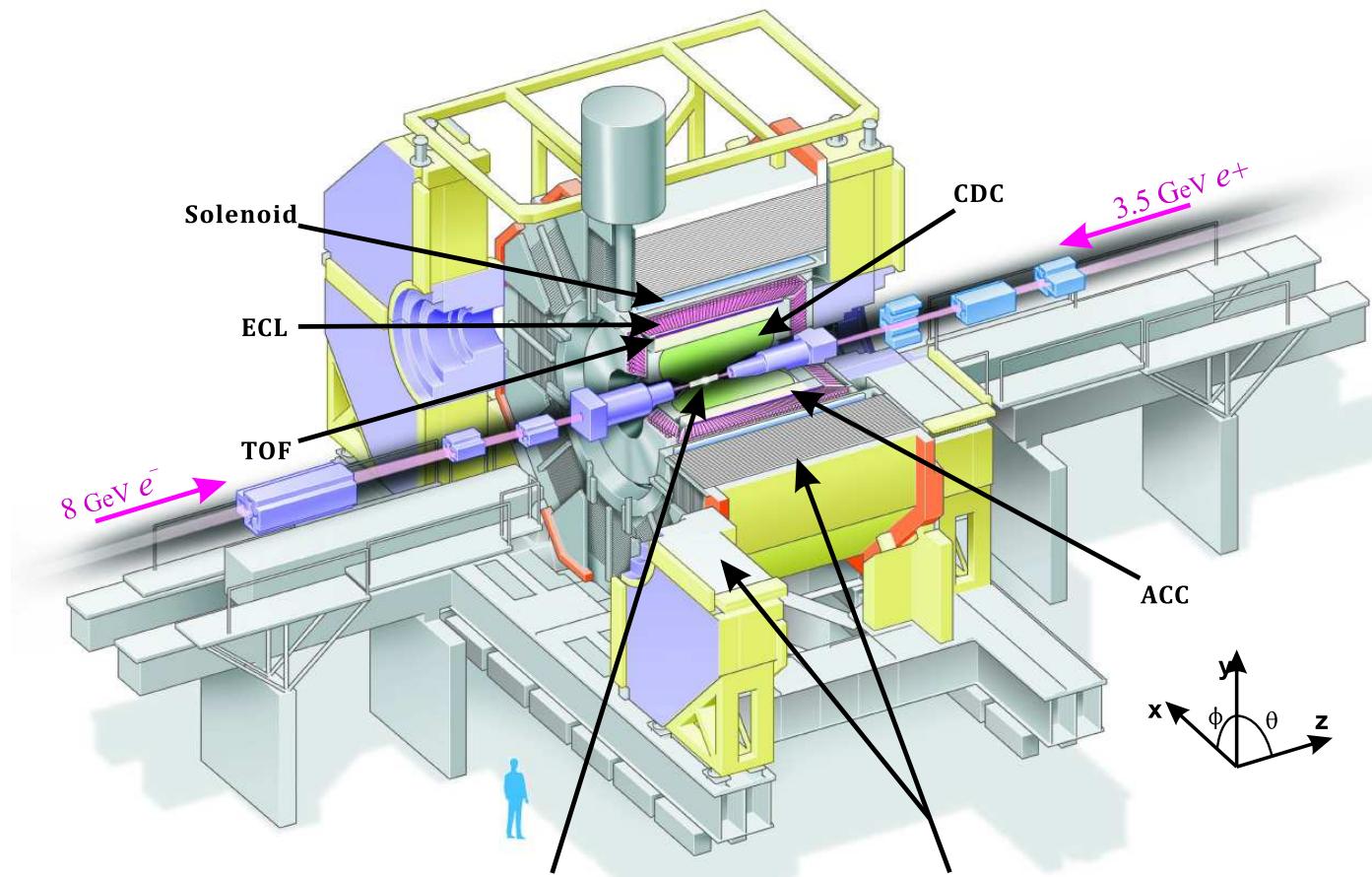


Figure : The Belle detector. [4]

$$M_{\Upsilon(4S)} = (10.5794 \pm 0.0012) \text{ GeV} \approx \sqrt{s} = 2\sqrt{8 \cdot 3.5} \text{ GeV} \quad (1)$$

The Belle experiment and the rare decay $B^0 \rightarrow K^*(892)^0 e^+ e^-$

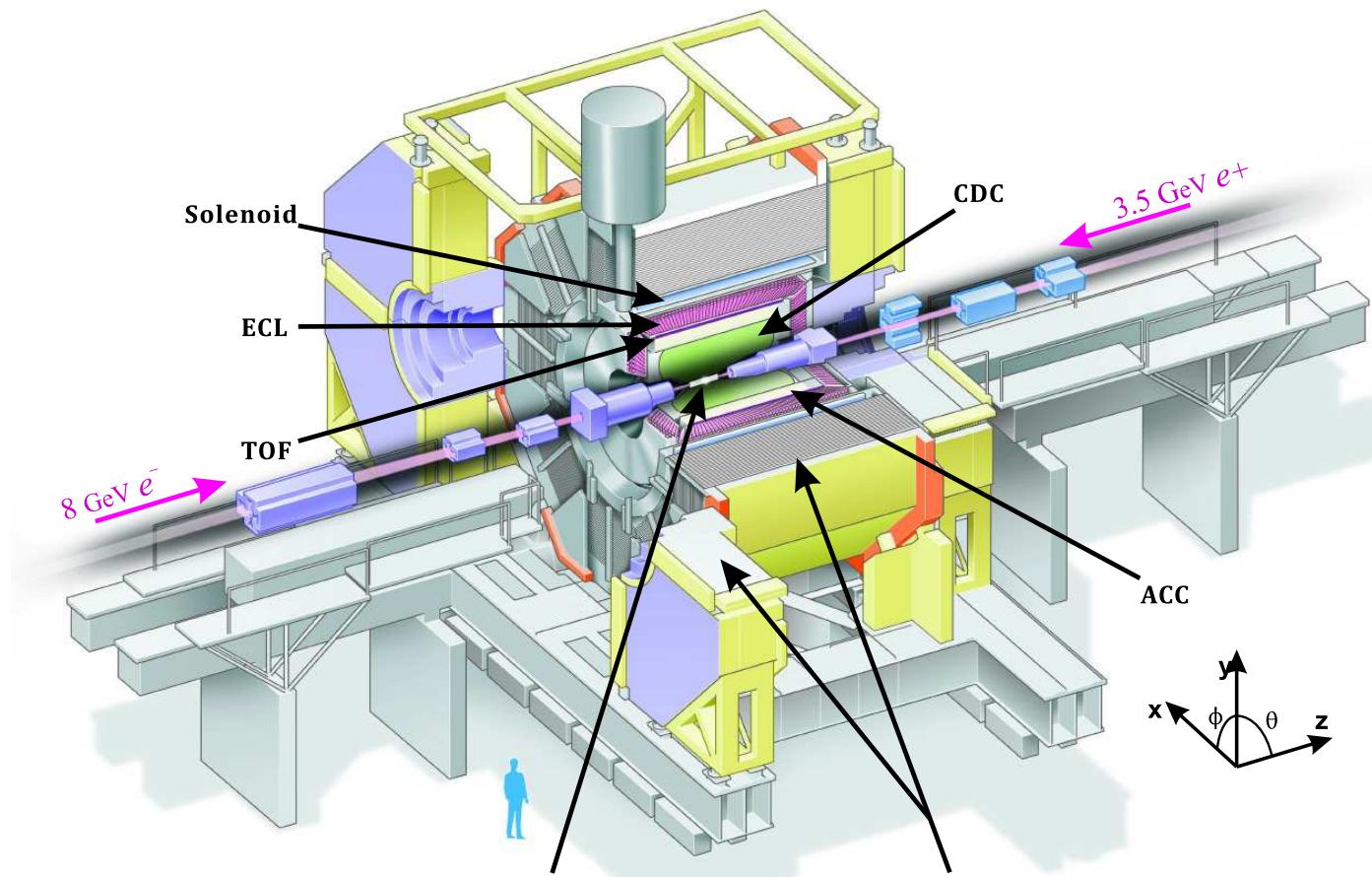


Figure : The Belle detector. [4]

$$M_{\Upsilon(4S)} = (10.5794 \pm 0.0012) \text{ GeV} \approx \sqrt{s} = 2\sqrt{8 \cdot 3.5} \text{ GeV} \quad (1)$$

$$\mathcal{B}(\Upsilon(4S) \rightarrow B^0 \bar{B}^0) \approx 50\% \approx \mathcal{B}(\Upsilon(4S) \rightarrow B^+ B^-) \quad (2)$$

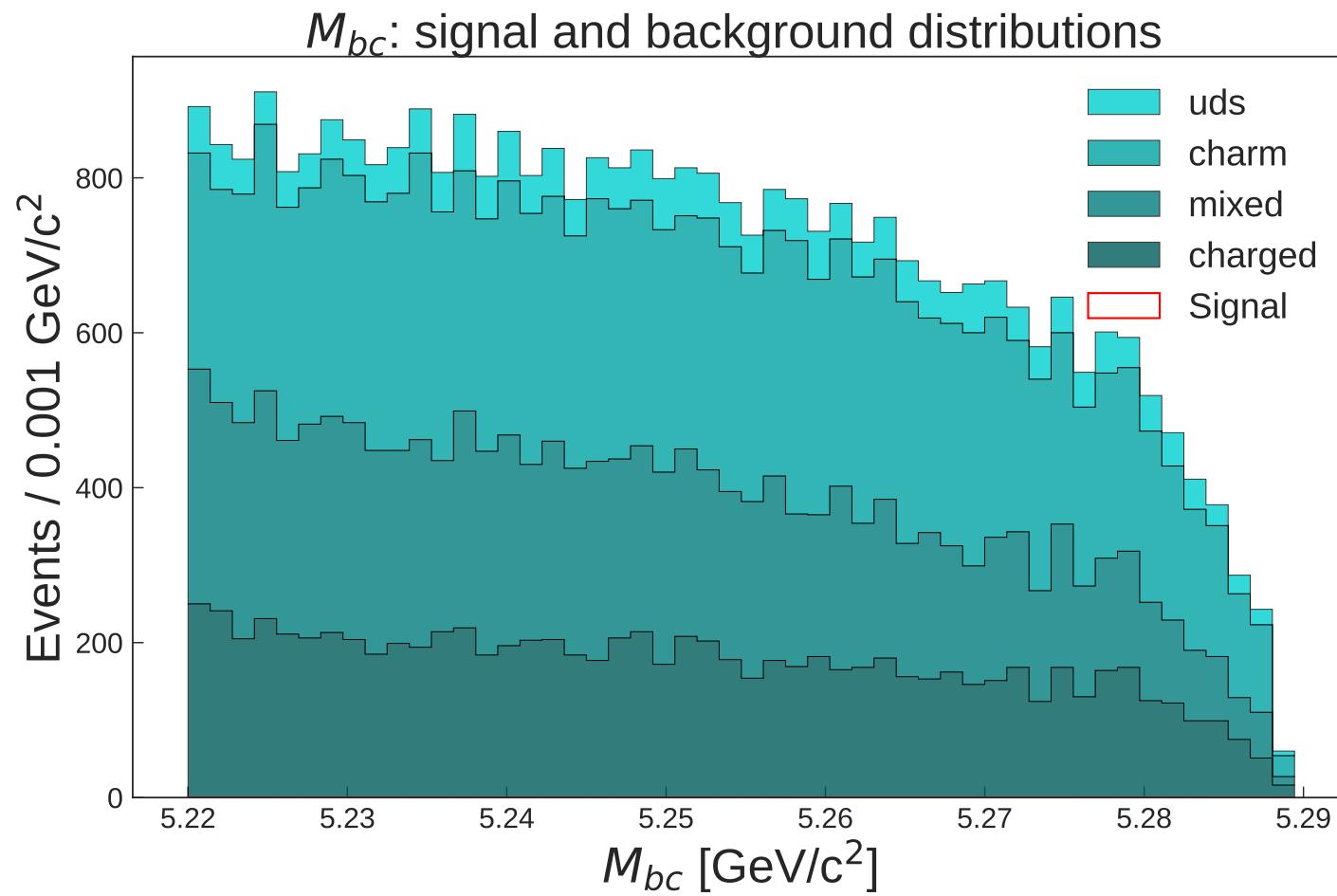
Monte Carlo simulated background

Name	Description
uds	continuum $e^+e^- \rightarrow u\bar{u}, d\bar{d}, s\bar{s}$
charm	continuum $e^+e^- \rightarrow c\bar{c}$
mixed	$\Upsilon(4S) \rightarrow B^0\bar{B}^0$, with generic B^0 decay
charged	$\Upsilon(4S) \rightarrow B^+B^-$, with generic B^+ decay

Table : Description of the background events generated by the Belle generic MC. [1]

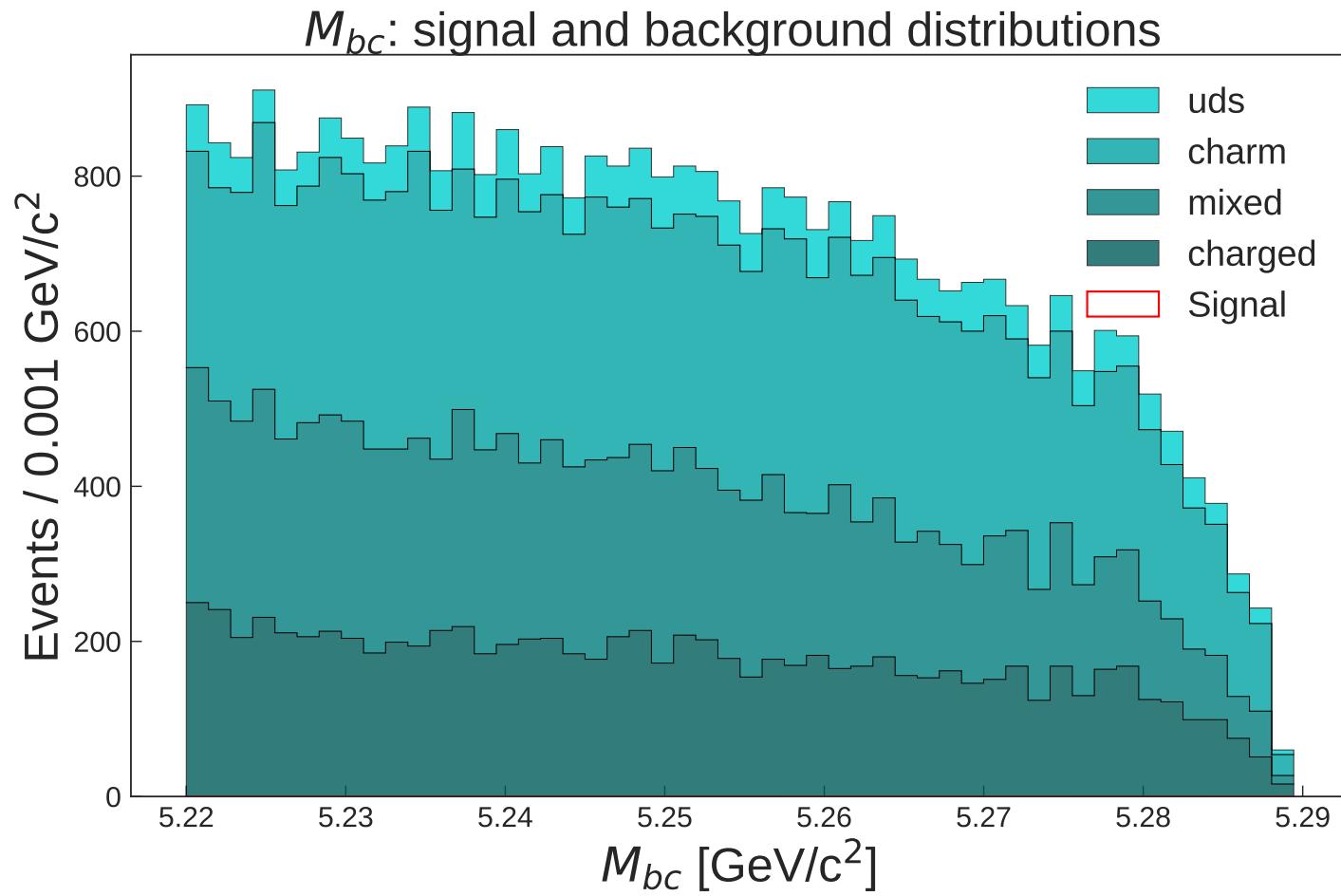
Monte Carlo simulated background and signal

$$\text{Beam constrained mass : } M_{bc} = \sqrt{E_{\text{beam}}^2 - p_B^2} \quad (3)$$



Monte Carlo simulated background and signal

$$\text{Beam constrained mass : } M_{bc} = \sqrt{E_{\text{beam}}^2 - p_B^2} \quad (3)$$



$$\mathcal{B}(B^0 \rightarrow K^*(892)^0 e^+ e^-) = (1.03^{+0.19}_{-0.17}) \times 10^{-6} \quad [3]$$

Background suppression strategy based on classifiers

Classifiers

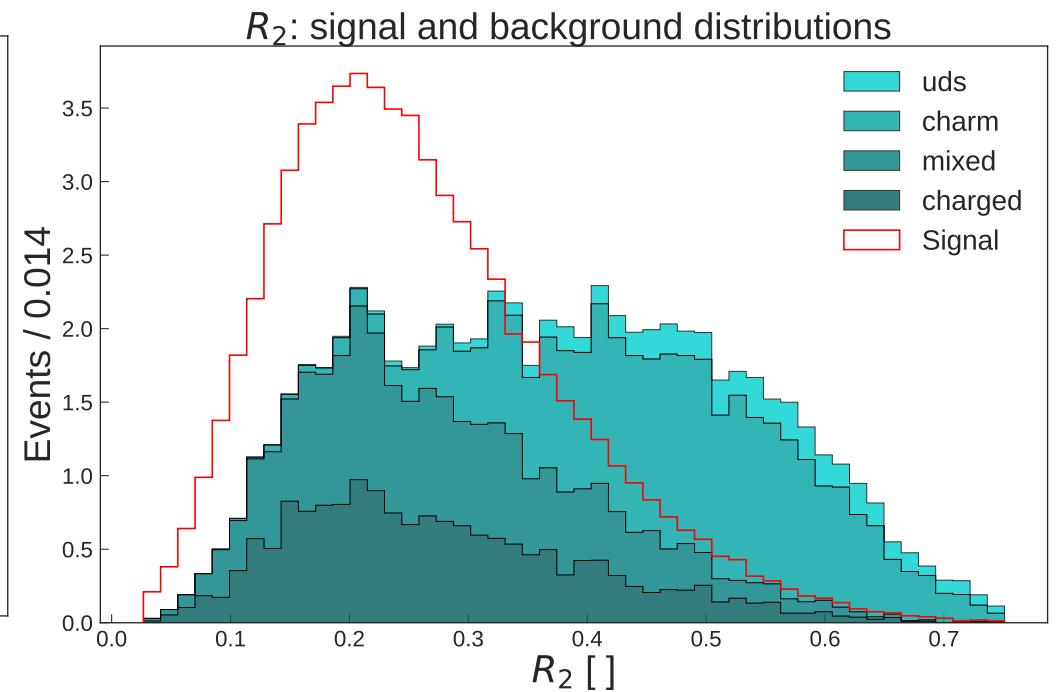
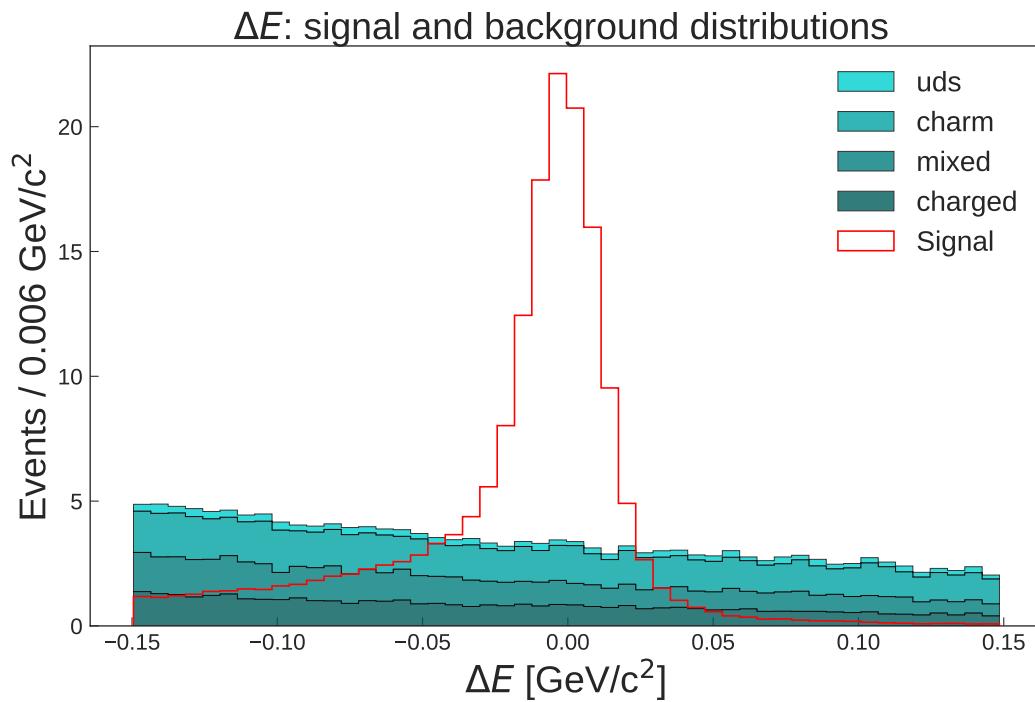
Classifiers in Python: scikit-learn library

Background suppression strategy based on classifiers

Training variables

$$\Delta E = E_{B^0} - E_{\text{beam}}$$

$$R_2 = \frac{\sum_{i,j=1}^N \frac{|\vec{p}_i||\vec{p}_j|P_2(\cos \theta_{ij})}{E_{\text{visible}}^2}}{\sum_{i,j=1}^N \frac{|\vec{p}_i||\vec{p}_j|P_0(\cos \theta_{ij})}{E_{\text{visible}}^2}}$$



In total, 40 variables are used for the training.

Background suppression strategy based on classifiers

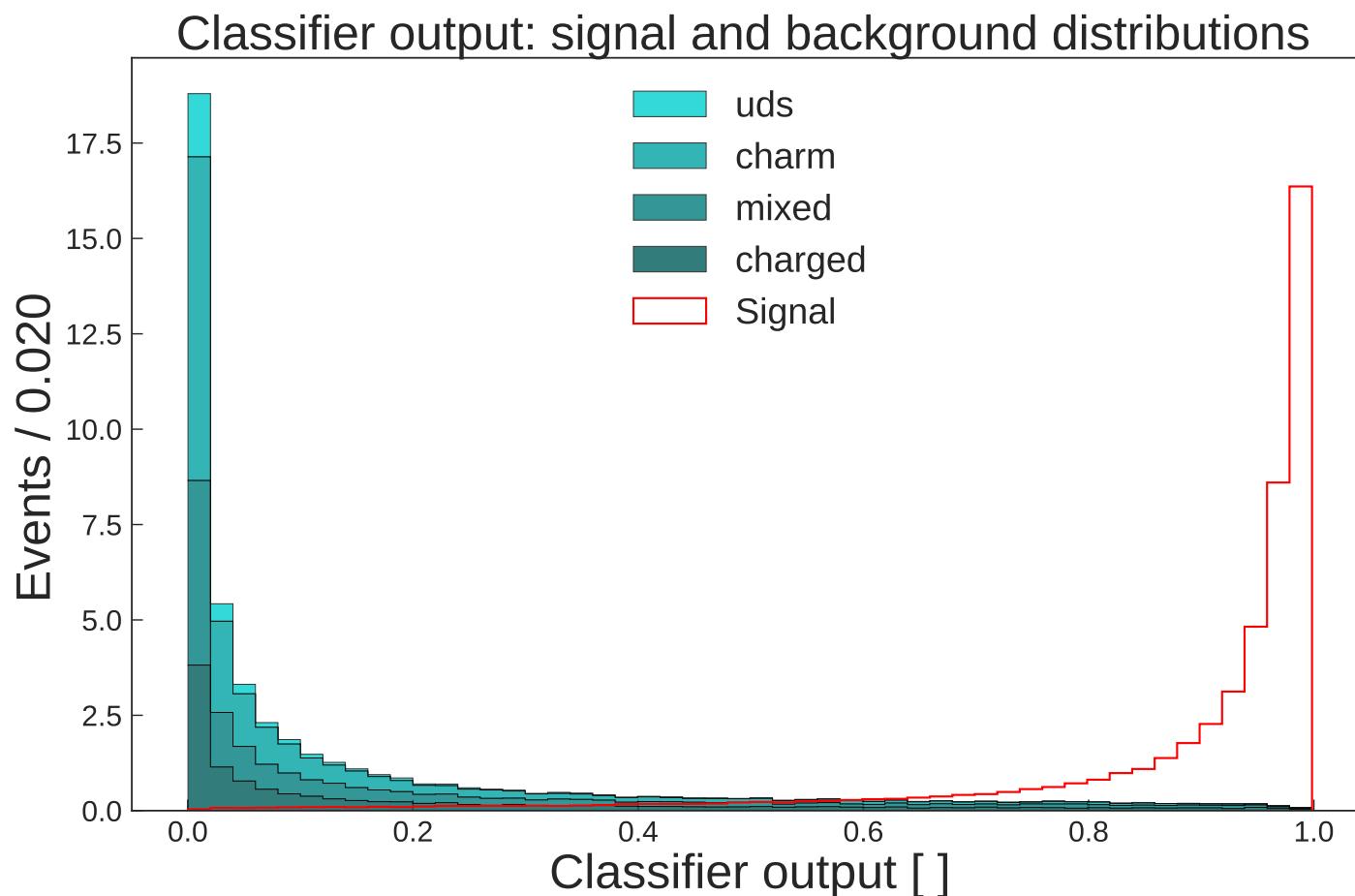
Purity and Efficiency

$$\text{efficiency} = \frac{N_{(\text{true}|\text{selected})}}{N_{(\text{true})}} \quad \text{purity} = \frac{N_{(\text{true}|\text{selected})}}{N_{(\text{true}|\text{selected})} + N_{(\text{false}|\text{selected})}} \quad (4)$$

Background suppression strategy based on classifiers

Purity and Efficiency

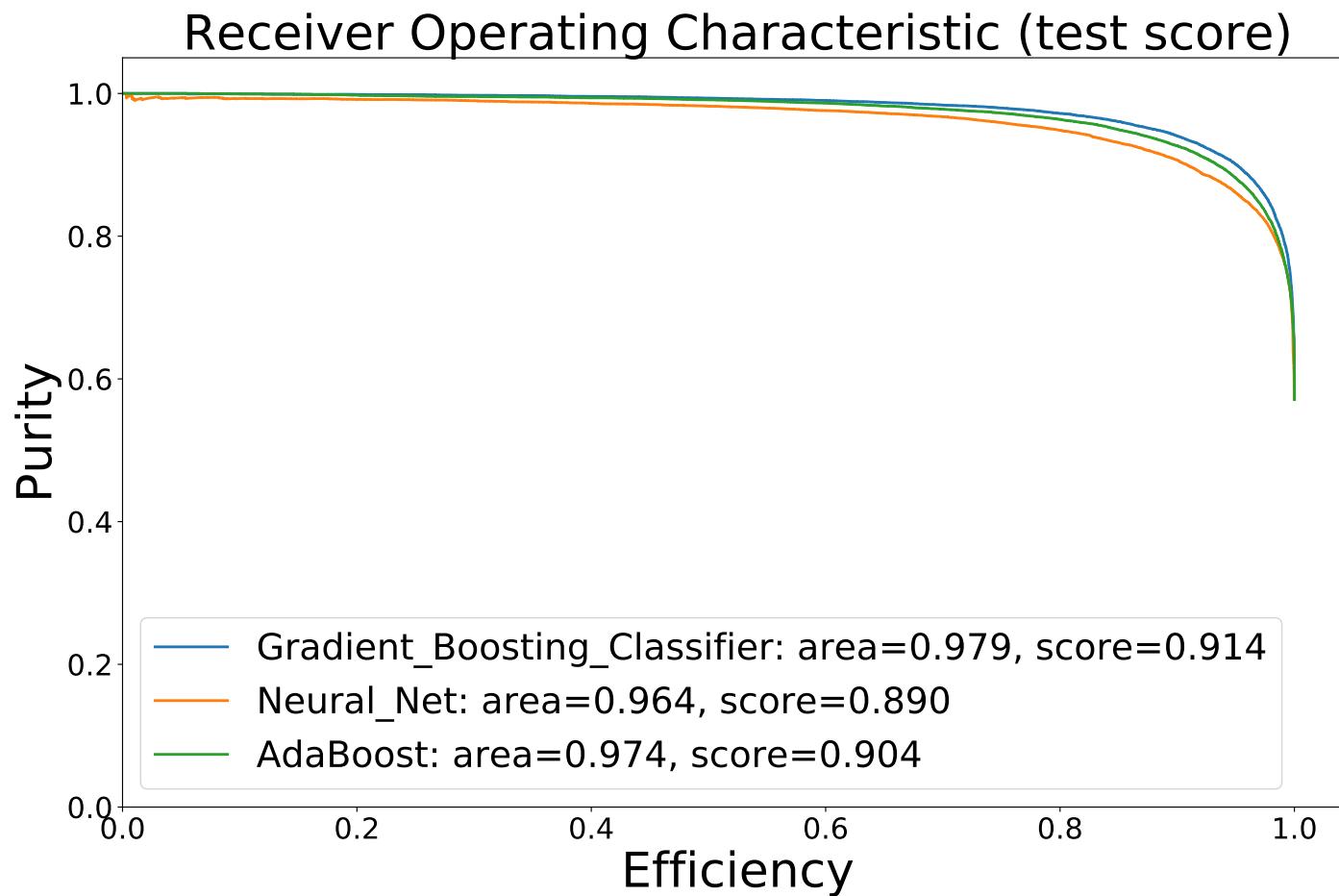
$$\text{efficiency} = \frac{N_{(\text{true}|\text{selected})}}{N_{(\text{true})}} \quad \text{purity} = \frac{N_{(\text{true}|\text{selected})}}{N_{(\text{true}|\text{selected})} + N_{(\text{false}|\text{selected})}} \quad (4)$$



Background suppression strategy based on classifiers

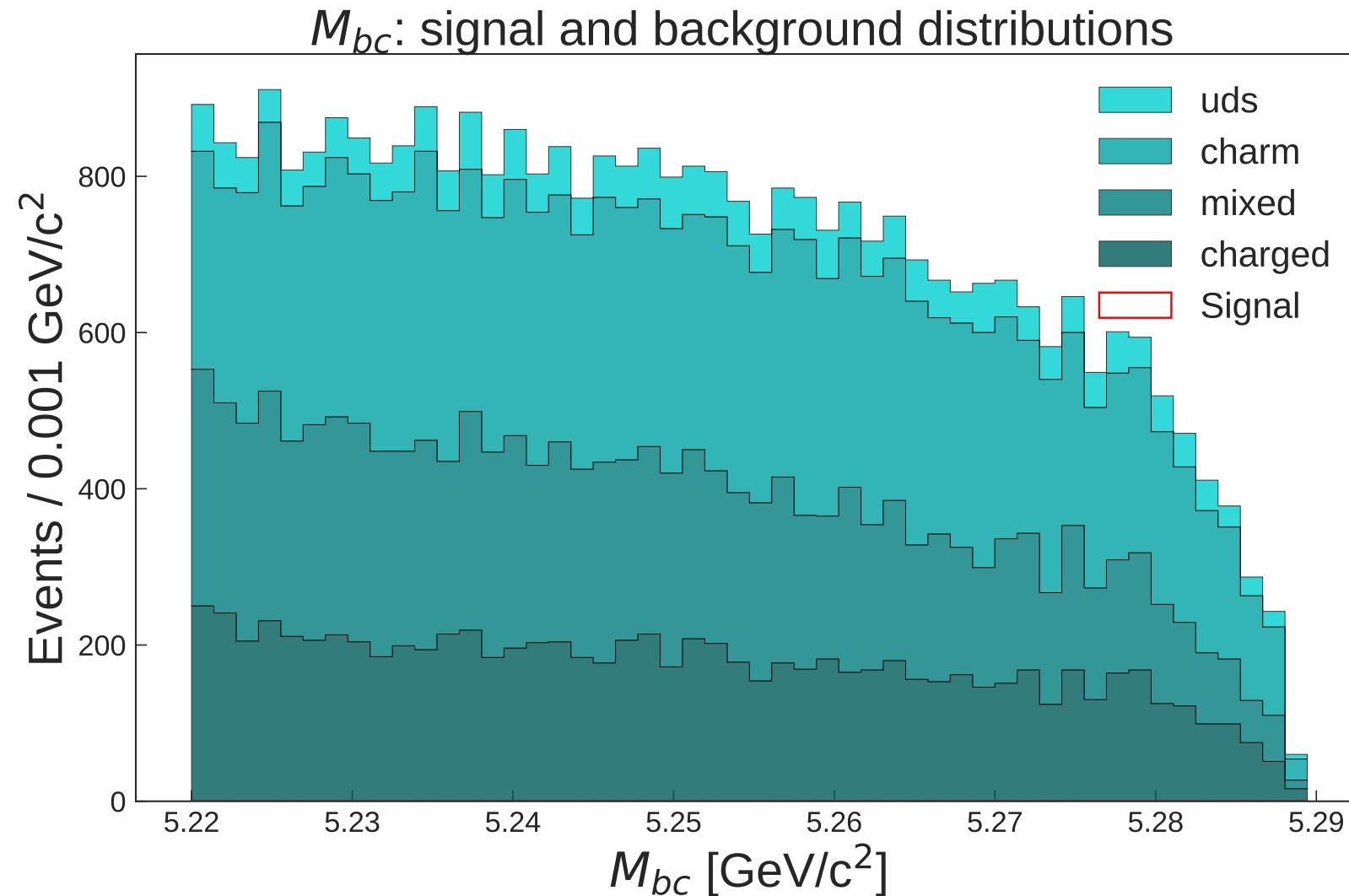
Purity vs Efficiency

$$\text{efficiency} = \frac{N_{(\text{true}|\text{selected})}}{N_{(\text{true})}} \quad \text{purity} = \frac{N_{(\text{true}|\text{selected})}}{N_{(\text{true}|\text{selected})} + N_{(\text{false}|\text{selected})}} \quad (5)$$



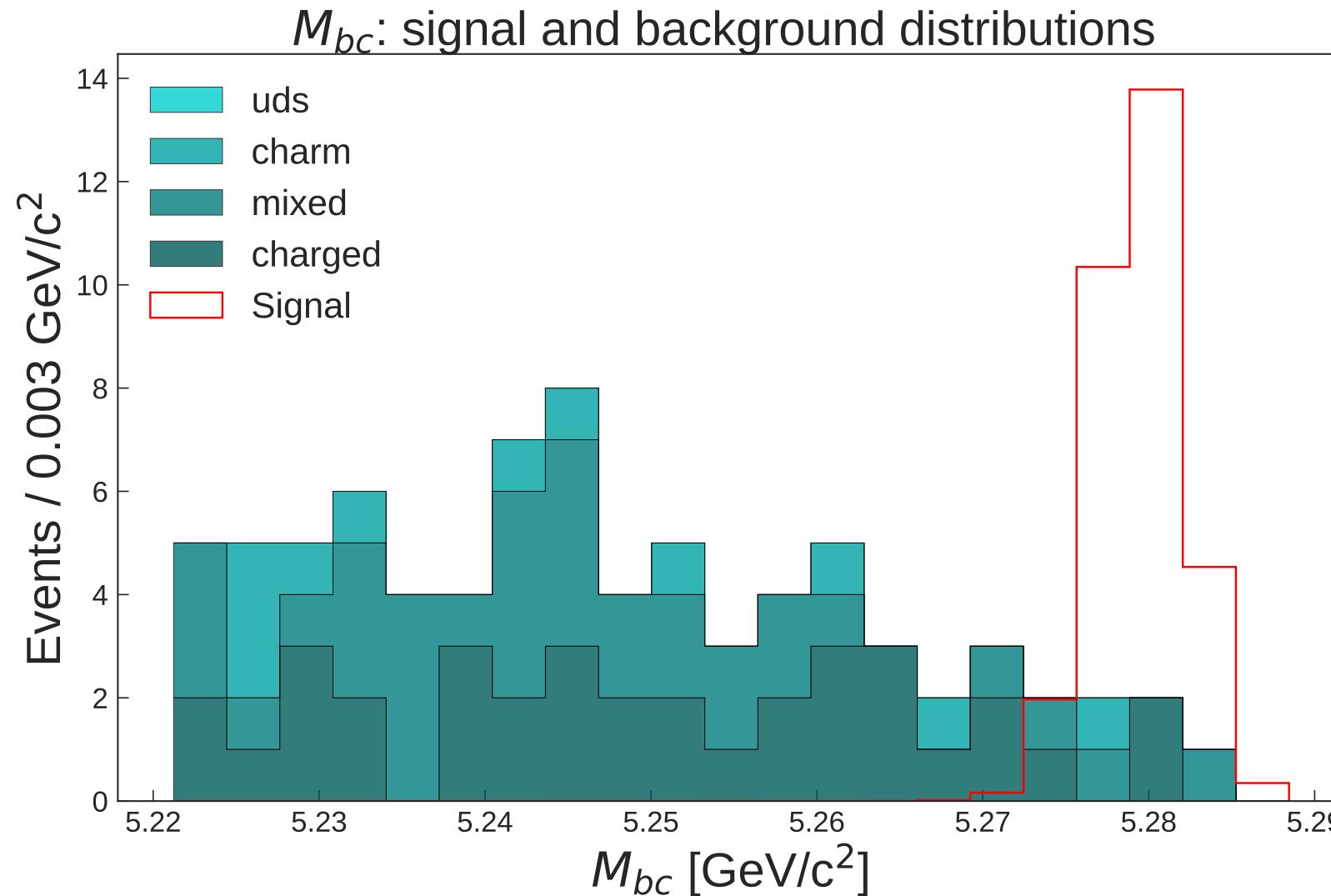
Results

Extraction of $B^0 \rightarrow K^*(892)^0 e^+ e^-$



Results

Extraction of $B^0 \rightarrow K^*(892)^0 e^+ e^-$



References

- S. Wehle, *Angular Analysis of $B \rightarrow K^* ll$ and Search for $B \rightarrow K^* \tau\tau$ at the BELLE Experiment*, DESY-THESIS-2016-025 (2016).
- T. Skwarnicki, *A Study of the radiative cascade transitions between the upsilon-prime and upsilon resonances*, DESY-F31-86-02 (1986).
- C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016).
- A. Abashian *et al.*, *The Belle detector*, Nucl. Instrum. Methods **A479**, 1 (2002).
- Geoffrey C. Fox *et al.*, *Observables for the Analysis of Event Shapes in e^+e^- Annihilation and Other Processes*, Phys. Rev. Lett. **41**, 1581 (1978).
- S. H. Lee *et al.*, *Evidence for $B^0 \rightarrow \pi^0\pi^0$* , Phys. Rev. Lett. **91**, 261801 (2003).
- D. M. Asner *et al.*, *Search for exclusive charmless hadronic B decays*, Phys. Rev. **D53**, 1039 (1996).
- H. Albrecht *et al.*, *Measurement of the polarization in the decay $B \rightarrow J/\psi K^*$* , Phys. Lett. **B340**, 217-220 (1994).
- Pedregosa *et al.*, *Scikit-learn: Machine Learning in Python*, JMLR **12**, 2825-2830 (2011).

Back-up

The Belle experiment and the rare decay $B^0 \rightarrow K^*(892)^0 e^+ e^-$

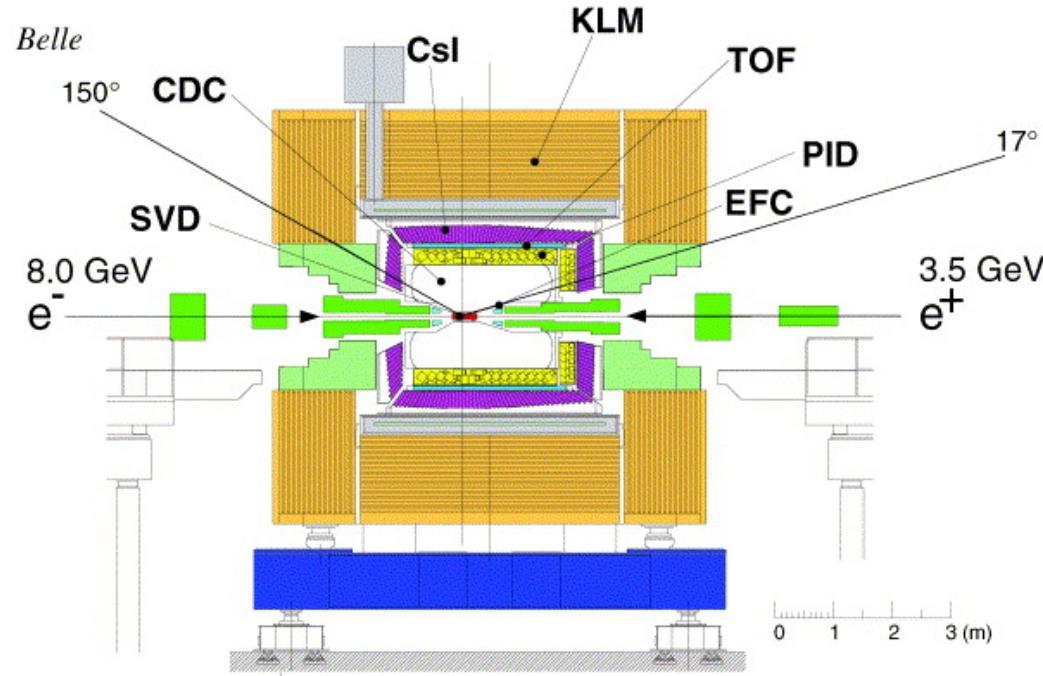


Figure : The Belle detector. [4]

Source	Main purpose
Silicon Vertex Detector (SVD)	tracking, vertex locator
Central Drift Chamber (CDC)	tracking, momentum and energy loss measurement
Time Of Flight counter (TOF)	velocity measurement
Aerogel Cherenkov Counter (ACC)	velocity measurement
Thallium doped Cesium Iodine (CsI)	energy measurement
Extreme Forward Calorimeter (EFC)	energy measurement
K_L^0 and μ detection system (KLM)	particle identification

Background suppression strategy based on classifiers

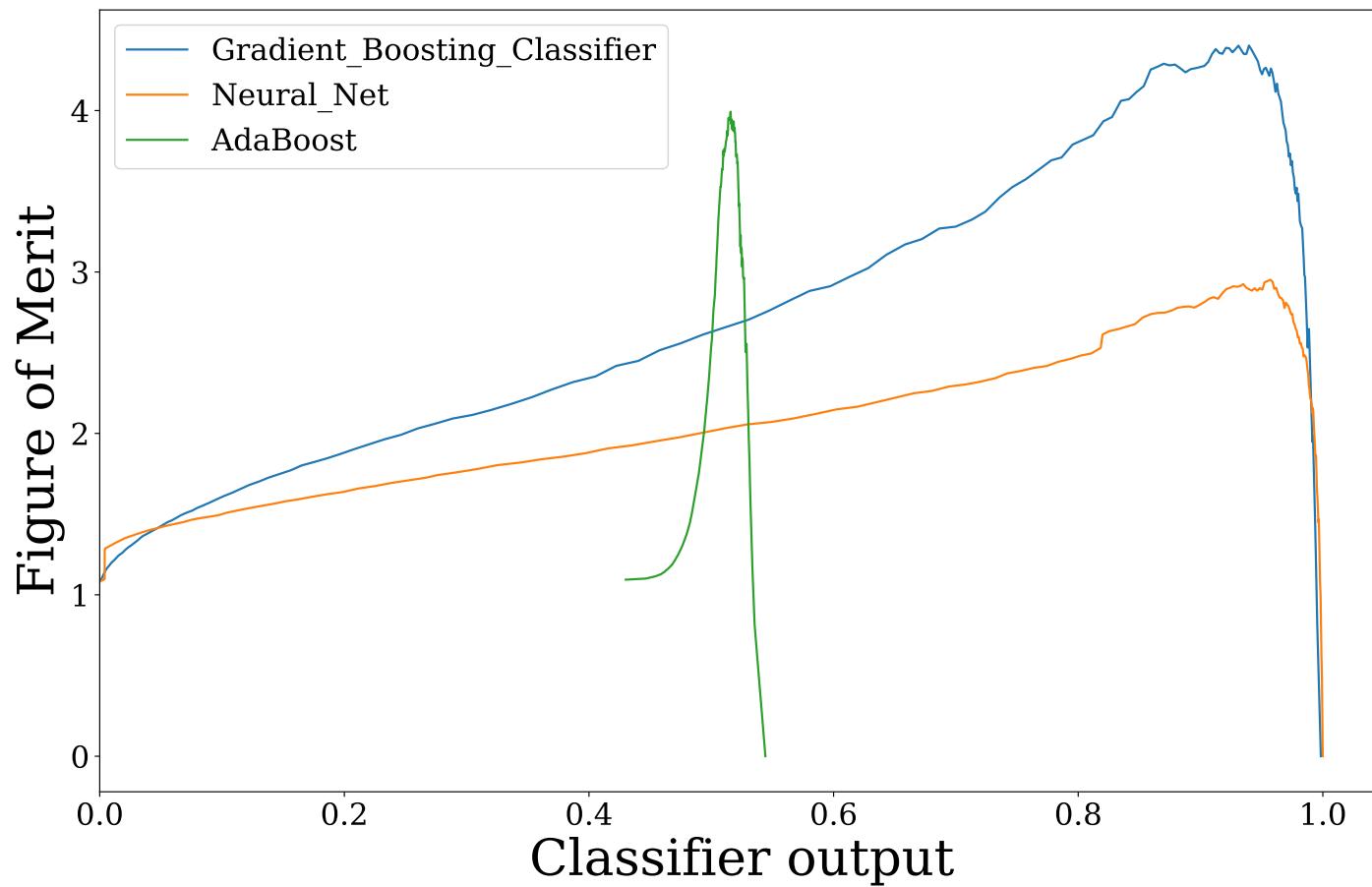
Figure of Merit (FOM)

$$\text{FOM} = \frac{n_{\text{sig}}}{\sqrt{n_{\text{sig}} + n_{\text{bkg}}}} \Big|_{5.27 \text{ GeV} < M_{bc} < 5.29 \text{ GeV}} \quad (6)$$

Background suppression strategy based on classifiers

Figure of Merit (FOM)

$$FOM = \frac{n_{\text{sig}}}{\sqrt{n_{\text{sig}} + n_{\text{bkg}}}} \Big|_{5.27 \text{ GeV} < M_{bc} < 5.29 \text{ GeV}} \quad (6)$$



Results

Highest FOM

Classifier	Classifier output cut(s)	FOM	efficiency [%]	n_{sig}	n_{bkg}
Gradient Boosting	0.95 (ncs) & 0.49 (cs)	4.85	3.89	31	10
Gradient Boosting	0.94	4.32	4.90	39	43
Ada Boosting	0.52	4.11	5.40	43	67
Neural Network	0.95	3.04	4.42	35	100

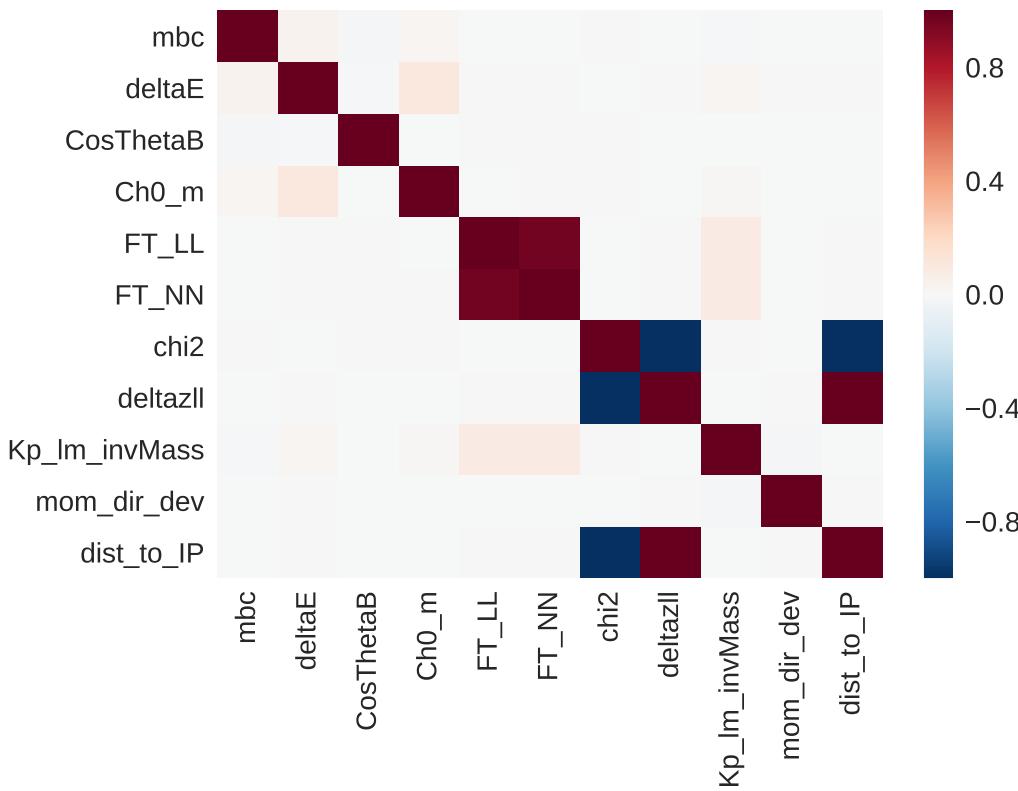


Figure : Linear correlation coefficients among the non continuum suppression variables and M_{bc} .

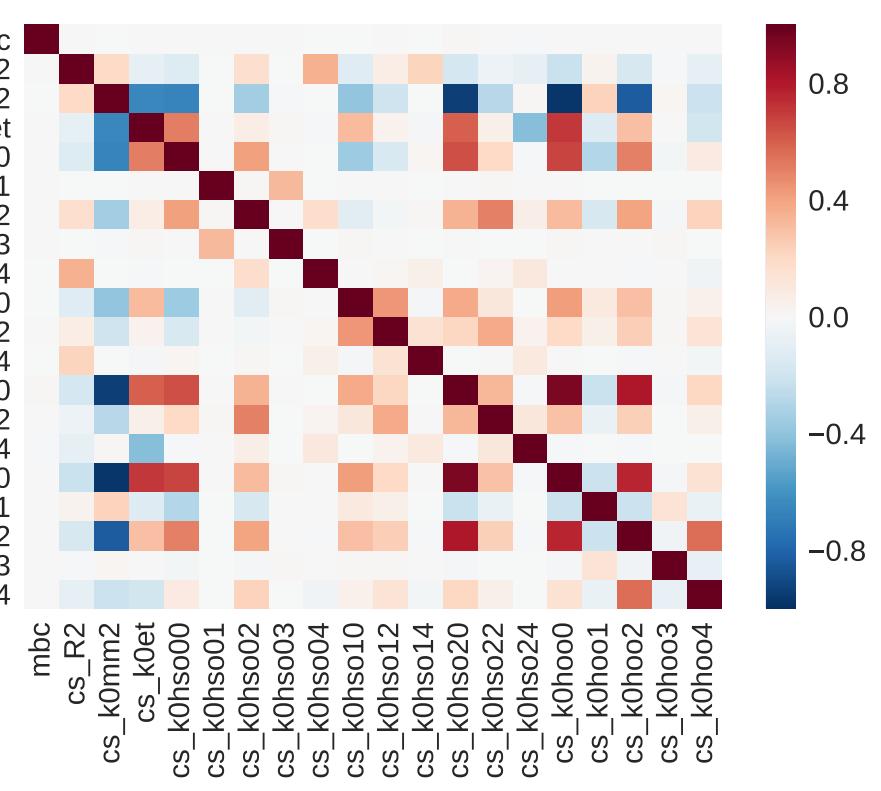
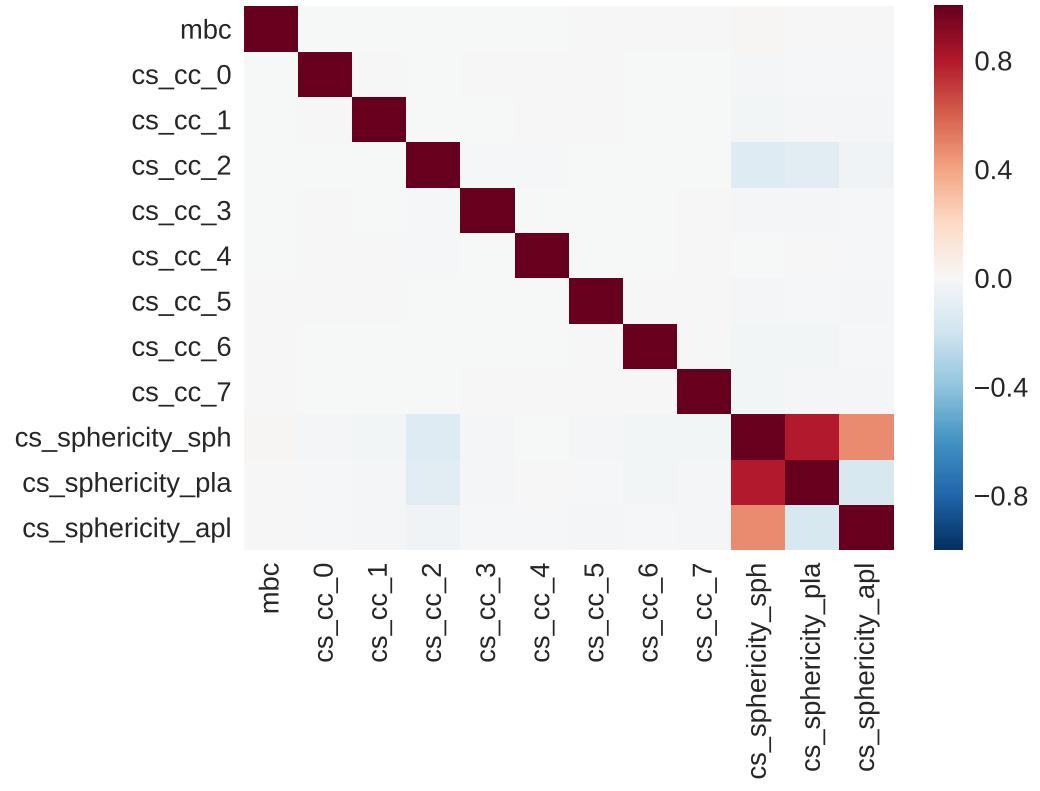


Figure : Linear correlation coefficients among the continuum suppression variables and M_{bc} .

Background source	Selection
$B^0 \rightarrow K^{(*)0}(J/\psi \rightarrow e^+e^-)$	$-0.45 < M_{e^+e^-(\gamma)} - M_{J/\psi} < +0.08 \text{ GeV}/c^2$
$B^0 \rightarrow K^{(*)0}(\Upsilon(2S) \rightarrow e^+e^-)$	$-0.20 < M_{e^+e^-(\gamma)} - M_{\Upsilon(2S)} < +0.08 \text{ GeV}/c^2$
$\gamma \rightarrow e^+e^-$ and $\pi^0 \rightarrow e^+e^- \gamma$	$M_{e^+e^-} > +0.14 \text{ GeV}/c^2$

Table : Background sources and corresponding selections. The values for $M_{J/\psi}$ and $M_{\Upsilon(2S)}$ are given by the PDG [3].

Variable	Selection
M_{bc}	$5.22 < M_{bc} < 5.89 \text{ GeV}/c^2$
ΔE	$-0.15 < \Delta E < +0.15 \text{ GeV}/c^2$

Table : Beam constrained variables and corresponding cuts.

Name	Description
uds	continuum $e^+e^- \rightarrow u\bar{u}, d\bar{d}, s\bar{s}$
charm	continuum $e^+e^- \rightarrow c\bar{c}$
mixed	$\Upsilon(4S) \rightarrow B^0\bar{B}^0$, with generic B^0 decay
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Table : Description of the background events generated by the Belle generic MC. [1]

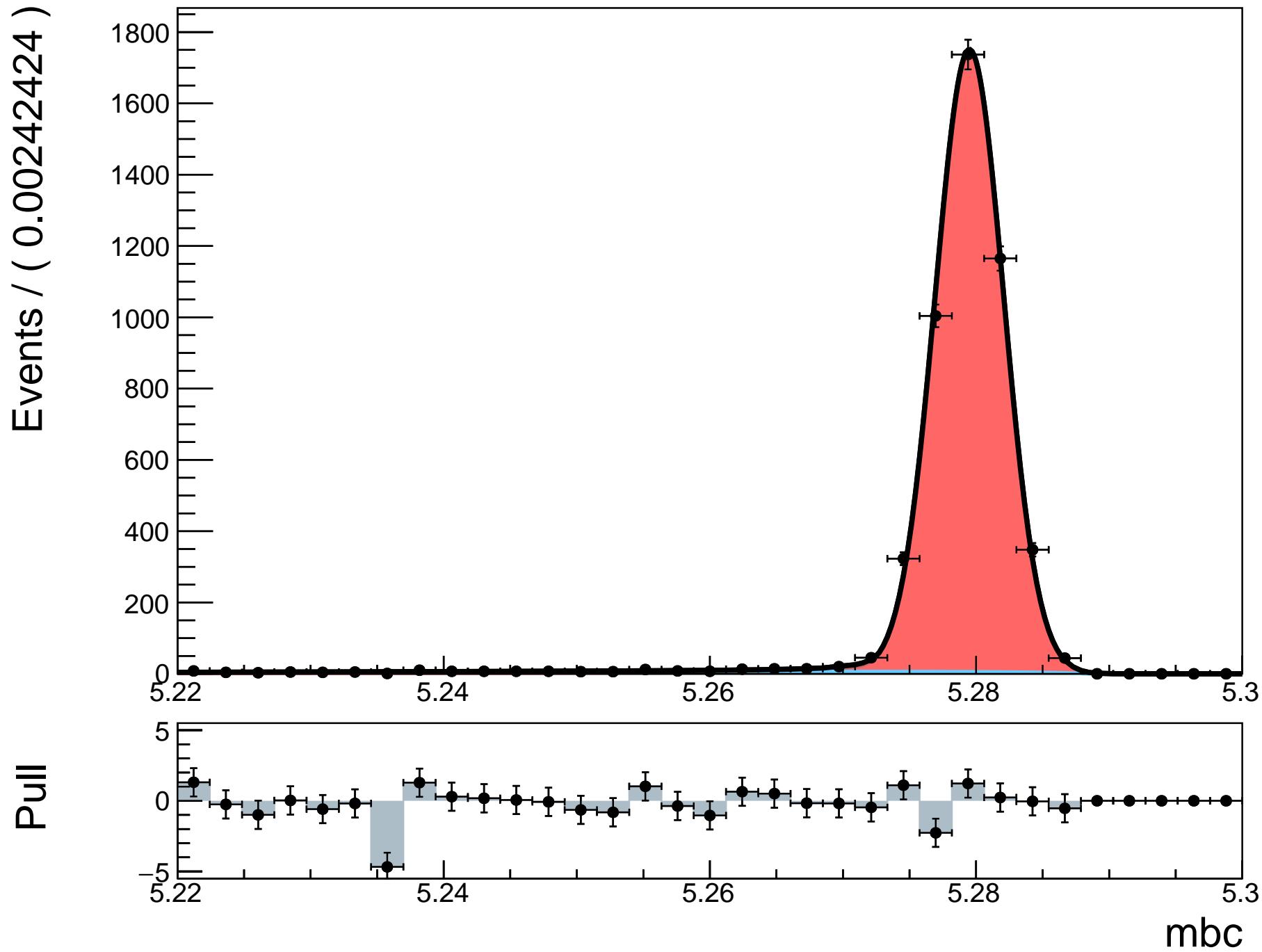


Figure : First data set, $M_{e^+e^-}$ cut around $M_{J/\psi}$, M_{bc} is given in GeV/c^2 .

Background suppression strategy based on classifiers

Classifiers

Machine Learning in Python: scikit-learn

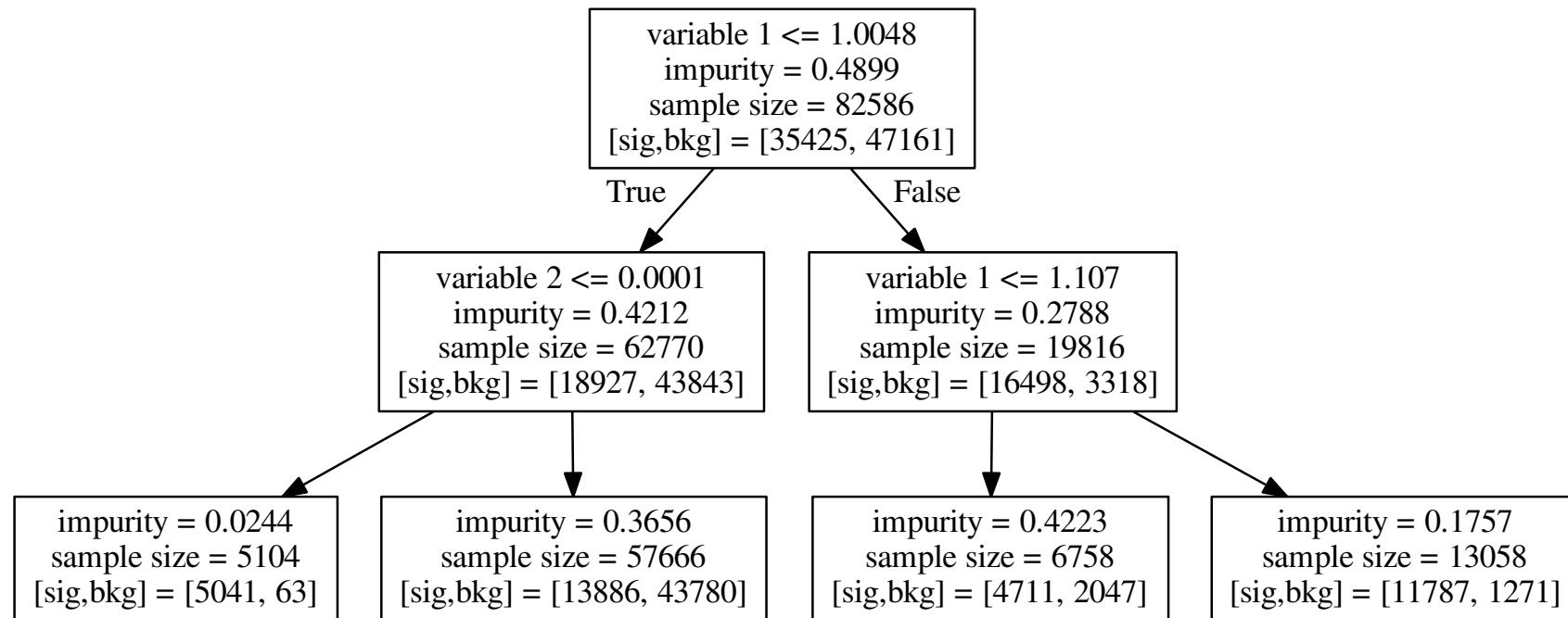
- ▶ GradientBoostingClassifier
- ▶ AdaBoostClassifier
- ▶ MLPClassifier

Background suppression strategy based on classifiers

Classifiers

Machine Learning in Python: scikit-learn

- ▶ GradientBoostingClassifier
- ▶ AdaBoostClassifier
- ▶ MLPClassifier



Monitoring the thermal environment of the PXD in the Belle-II detector

Brian CHAN

Supervisor: Hua YE

07/09/2017

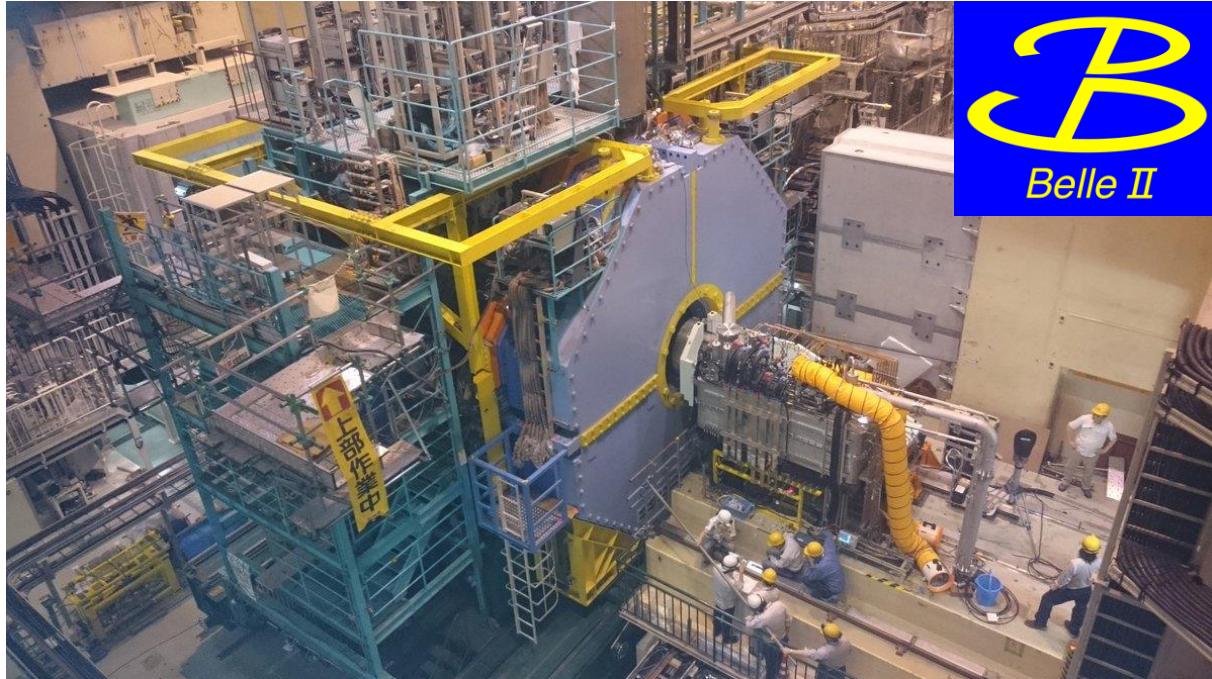


Monitoring the thermal environment of the
PXD in the **Belle-II** detector

World's
highest
instantaneous
luminosity

Table 1: Comparison of Belle and Belle-II luminosities. [1]

Experiment	Instantaneous Luminosity ($\text{cm}^{-2}\text{s}^{-1}$)	Integrated Luminosity (ab^{-1})
Belle	2.1×10^{34} (Actual)	1
Belle-II	8×10^{35} (Designed)	50 (Until 2025)



<https://pbs.twimg.com/media/DA-lmcPVoAEp9Wy.jpg>

Monitoring the thermal environment of the
PXD in the Belle-II detector

Vertex Detector (VXD) Upgrade

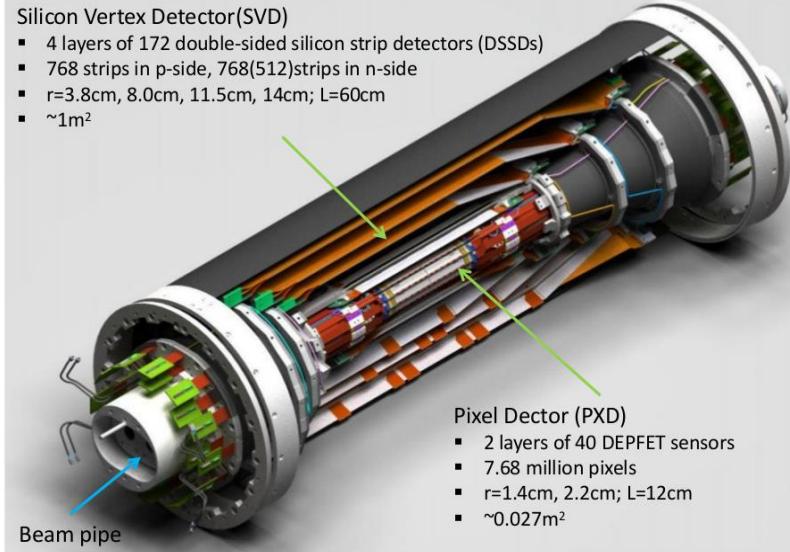
2x PXD + 4x SVD = VXD

- Better vertex and track reconstruction
- Belle-II lower Lorentz boost

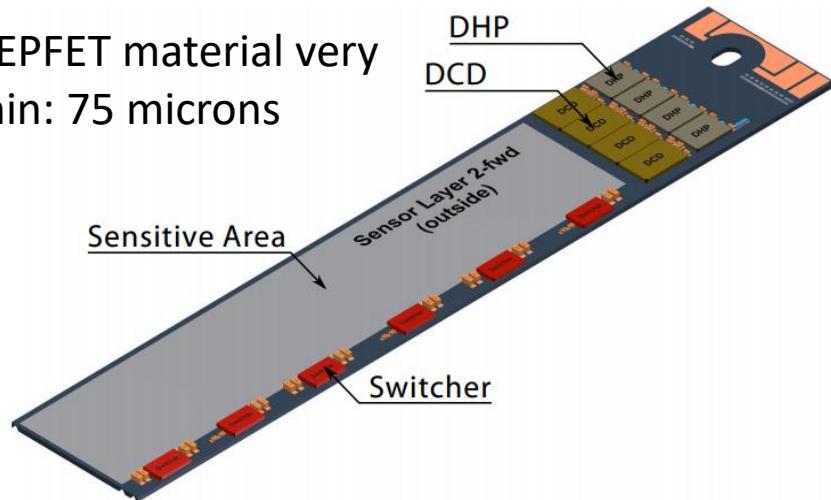
NEW Pixel Vertex Detector (PXD)

- Sensitive area: physics acceptance
(low heat load)
- Readout area: electronics present
(high heat load)

Total Heat Load: 2-3kW



DEPFET material very thin: 75 microns



Monitoring the thermal environment of the
PXD in the Belle-II detector

A cooling solution (for PXD)



Use 2-phase CO₂ (readout) and gaseous N₂ (sensitive):

- CO₂ set temperature target: $\sim -25\text{C}$

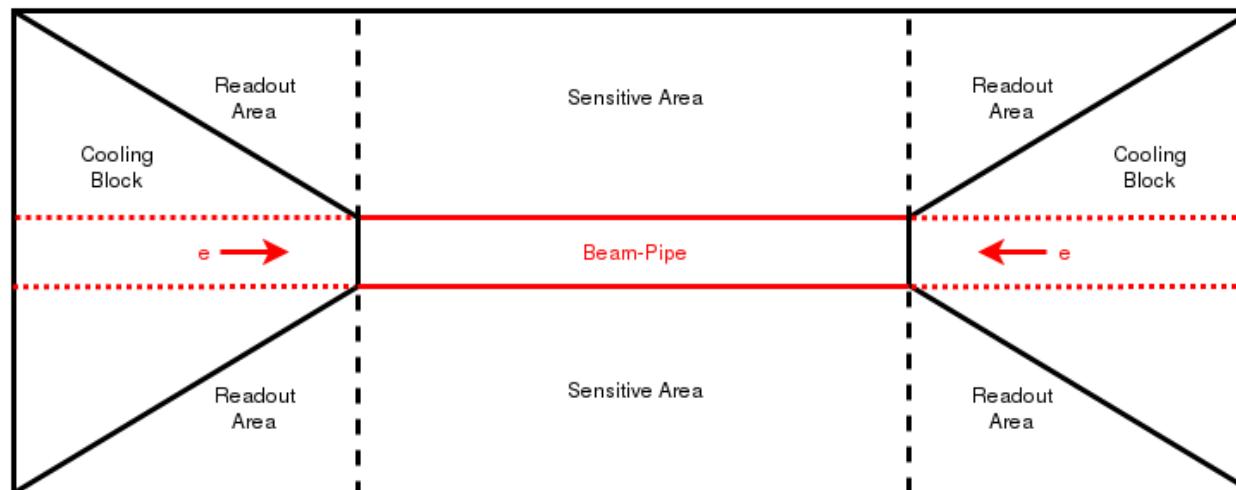
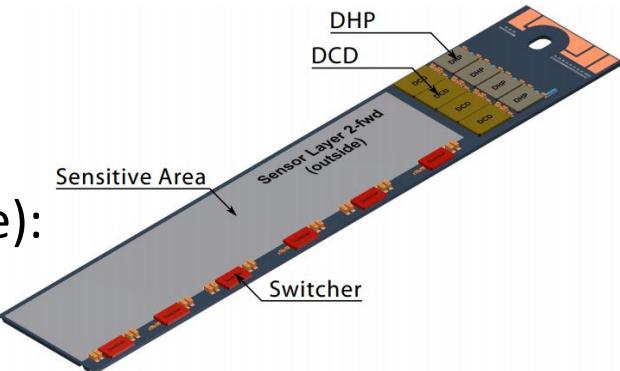


Diagram of the Vertex Detector (VXD) [Artist's (yours truly) Impression]

Condensation Problem

Cooling can cause condensation:

- Water in detectors is not optimum
- Threshold: Dew point temperature
- Condensation when $T < T_{DP}$

Strategy:

- Measure T_{DP} and keep T above that
- Use N_2 for reducing the humidity (thus lowering T_{DP})

$$T_{DP} = \frac{243.12 \left(\ln \left(\frac{H_R}{100} \right) + \frac{17.62T}{243.12+T} \right)}{17.62 - \left(\ln \left(\frac{H_R}{100} \right) + \frac{17.62T}{243.12+T} \right)}$$



VXD Thermal Mock-Up

- Investigating effects of cooling on PXD
- Readout electronics replaced with resistors to simulate heat load

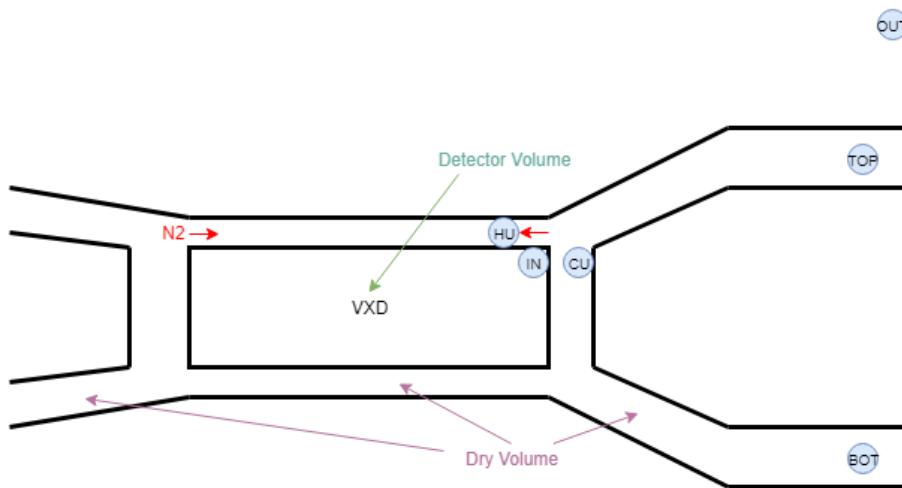


Diagram of the Thermal Mock-Up



Monitoring the thermal environment of the PXD in the Belle-II detector

Monitoring the System

Method: Use SHT21 sensors mounted on Raspberry Pi

Python code features:

- Read temperature, and relative humidity data from SHT21
- Calculate dew point temperature
- Output data to .txt file
- Live-Plot data
- Publish to basic HTTP server on port 8080

<https://github.com/BrianC2/Belle2ThermalMonitor.git>

Example of results on HTTP:

The latest thermal environment of the Thermal Mockup for 151.

Sensor 0 at BOT

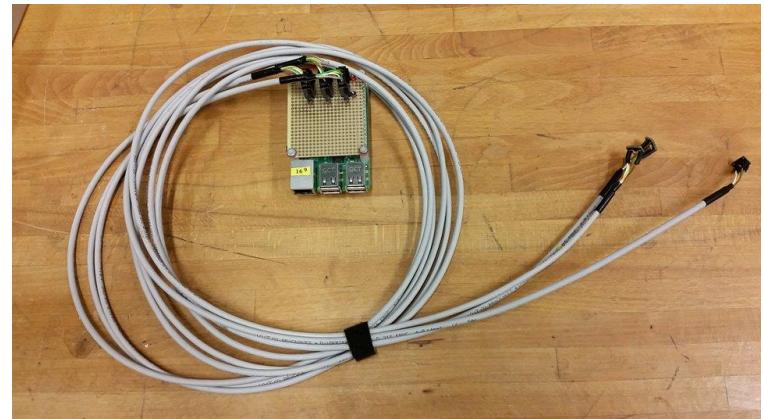
At time: Wed Sep 6 11:54:49 2017
Temperature (C): 25.244106
Humidity (%): 51.441711
Dew Point Temperature (C): 14.515642

Sensor 1 at TOP

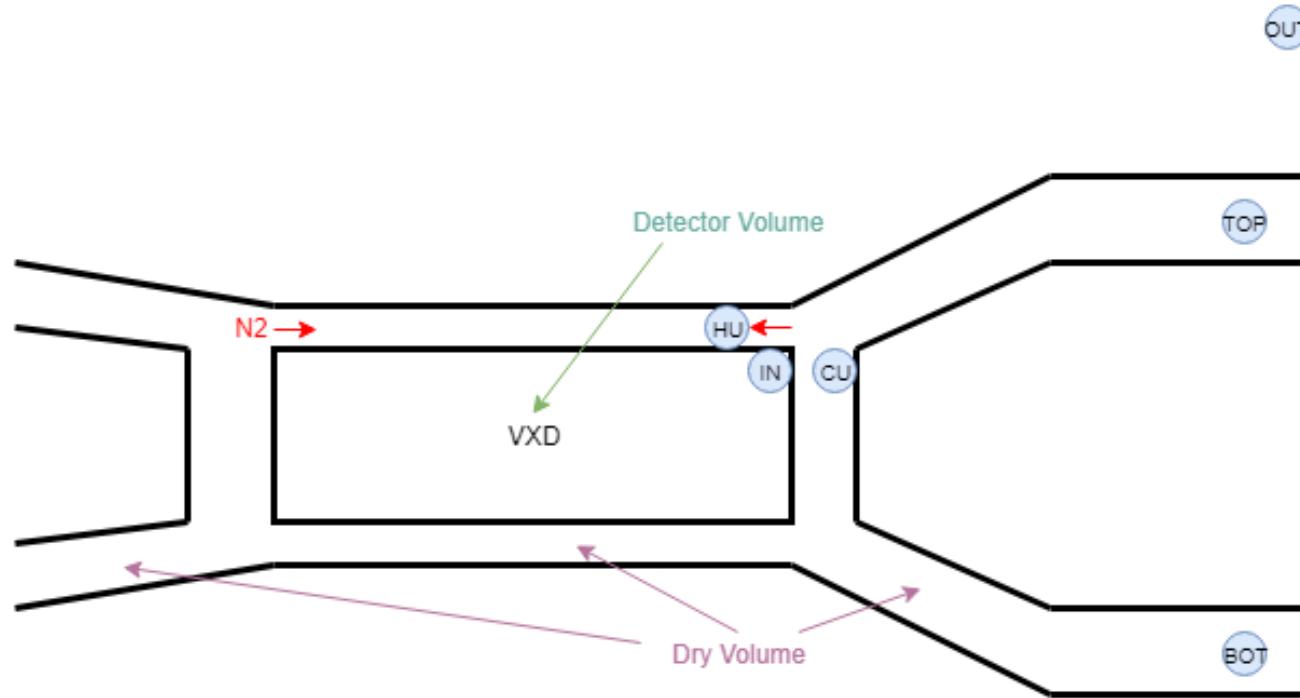
At time: Wed Sep 6 11:54:50 2017
Temperature (C): 25.297732
Humidity (%): 51.640076
Dew Point Temperature (C): 14.624736

Sensor 2 at OUT

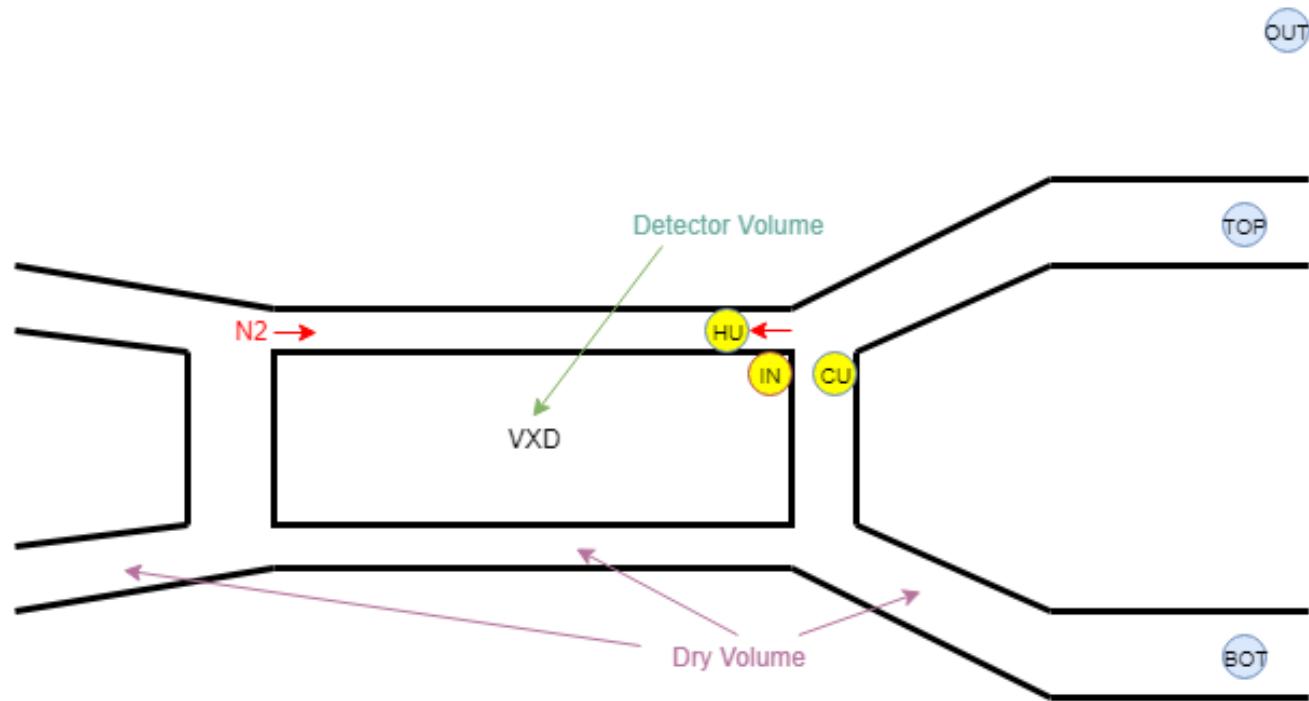
At time: Wed Sep 6 11:54:51 2017
Temperature (C): 25.029604
Humidity (%): 51.197571
Dew Point Temperature (C): 14.244364



1. Thermal Mock-Up: Sensor Placement



1. Thermal Mock-Up: Sensor Placement



1. Thermal Mock-Up:

BAD!!

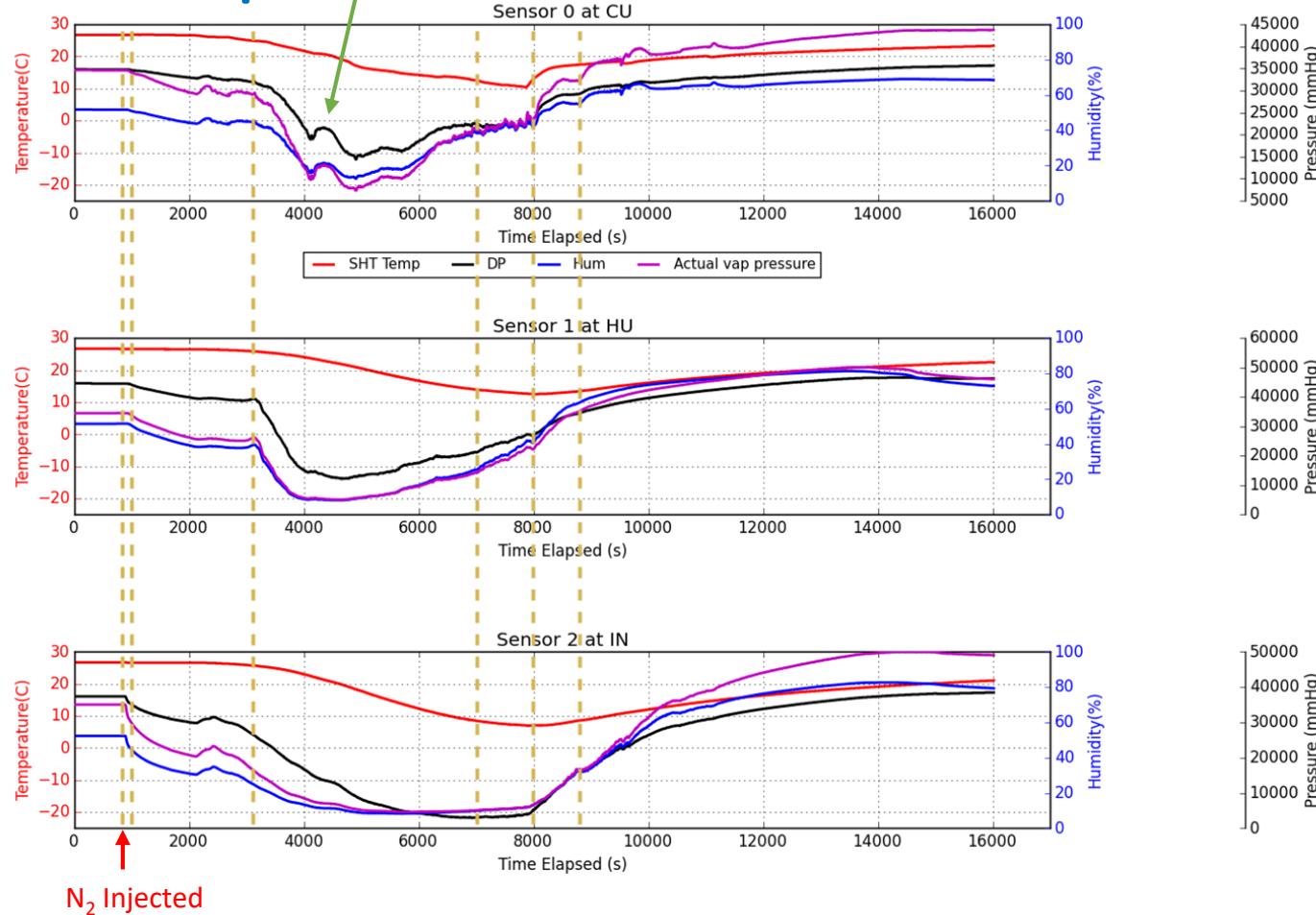
Line Legend:

Sensor Temp

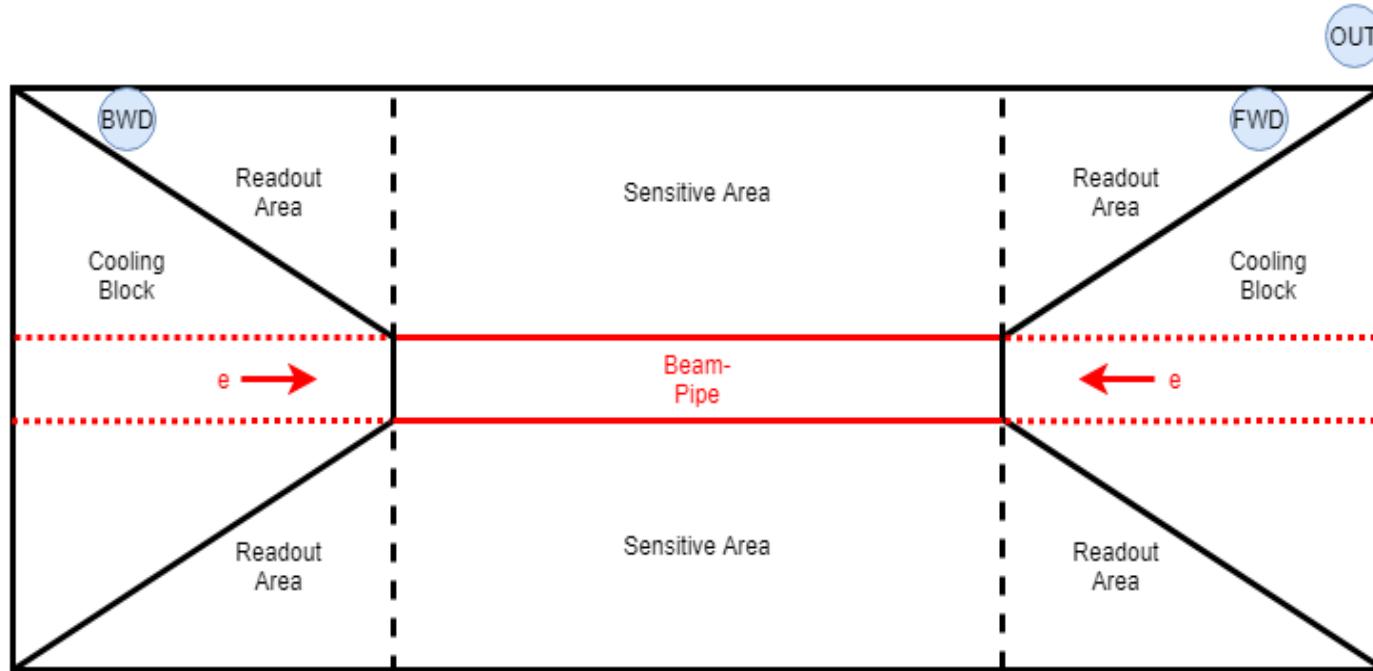
Dew Point Temp

Vapour Pressure

Sensor Humidity

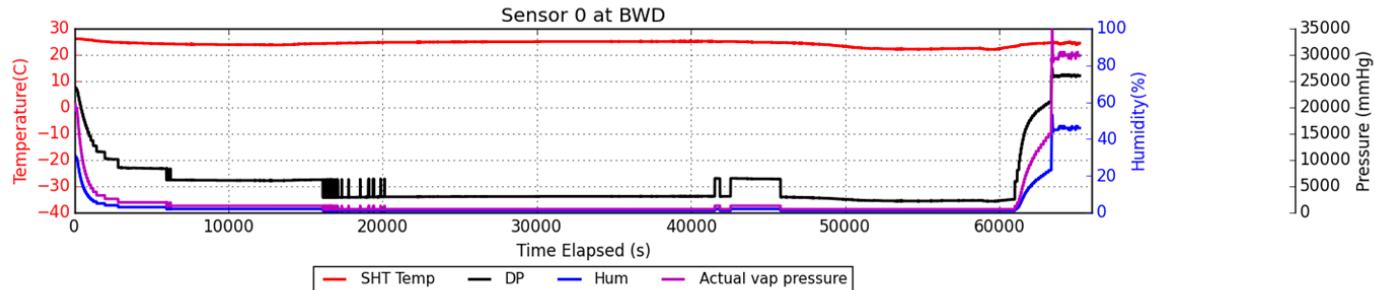


2. Belle-II PXD: Sensor Placement



Detector Volume Run

2. Belle-II PXD:



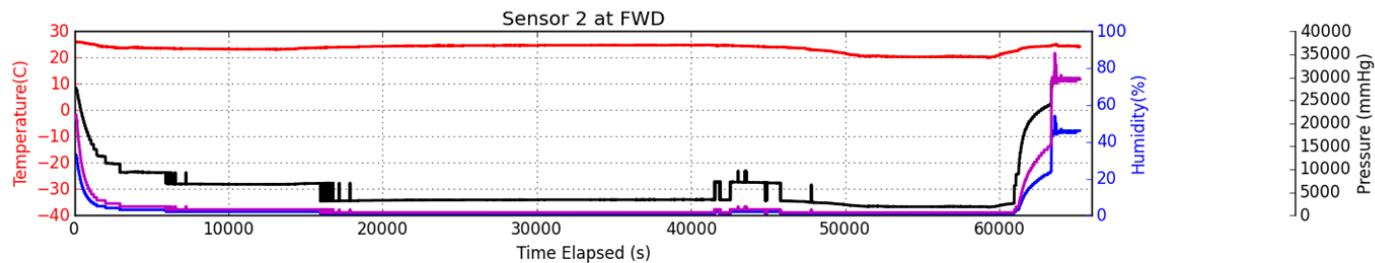
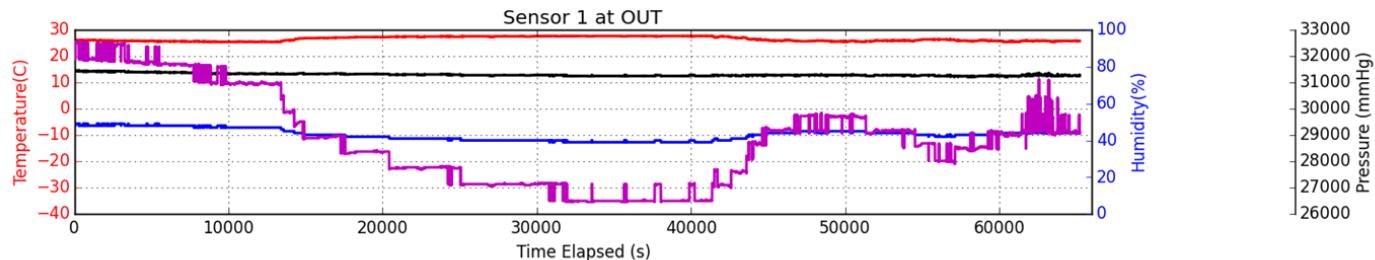
Line Legend:

Sensor Temp

Vapour Pressure

Dew Point Temp

Sensor Humidity



Summary

- Cooling is vital for the operation of a detector (particularly PXD)
- Condensation is a major issue (**water in detector is bad**)
- Created a **methodology** of measuring thermal environment

Future Work:

- SHT21 not radiation-hard – require other monitoring solution for when Belle-II is running

BACKUP

Thermal Mock-Up: Other sensors

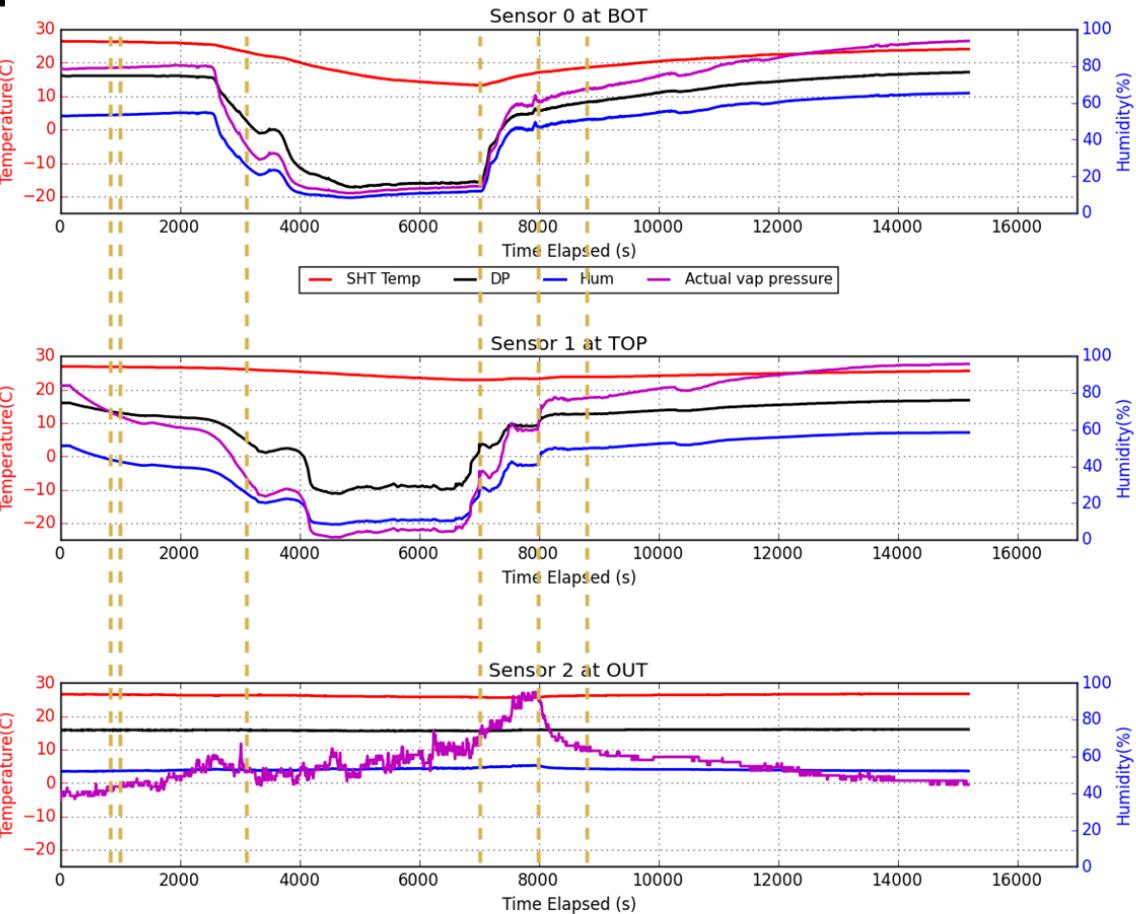
Line Legend:

Sensor Temp

Vapour Pressure

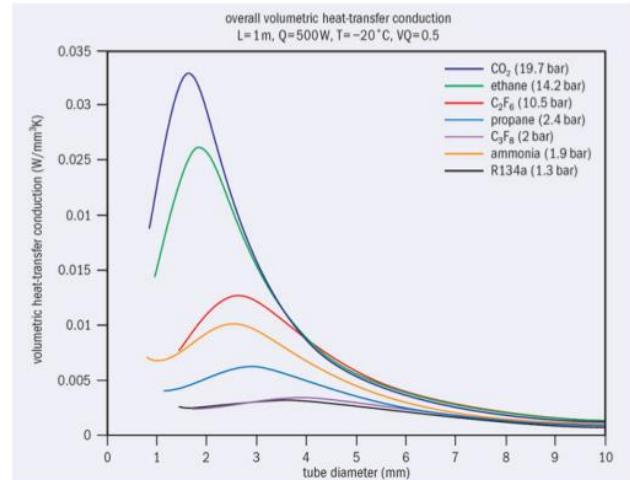
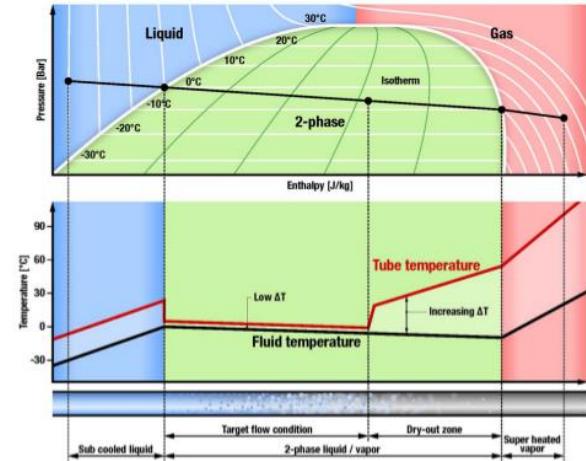
Dew Point Temp

Sensor Humidity

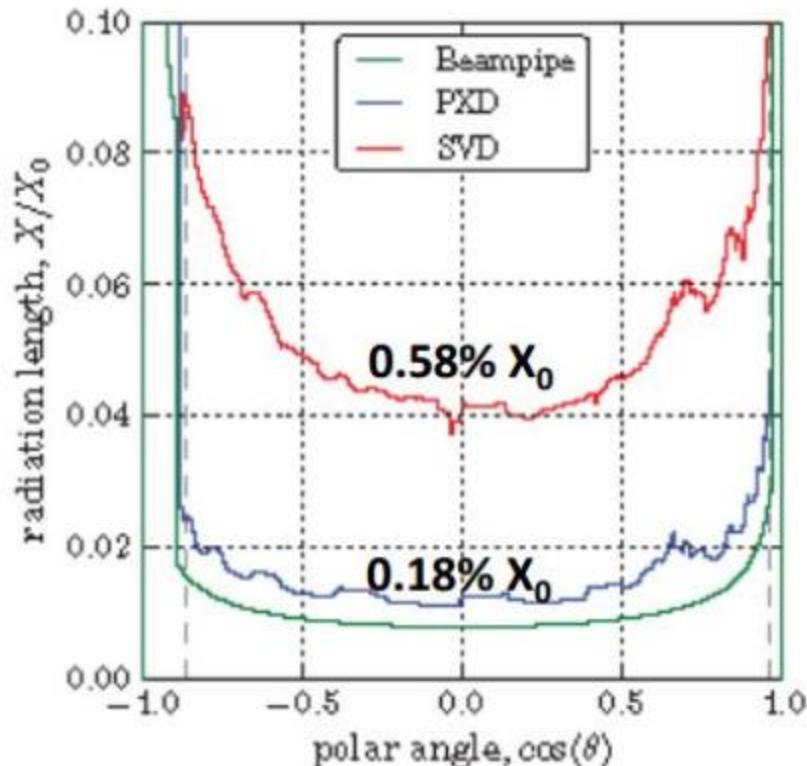
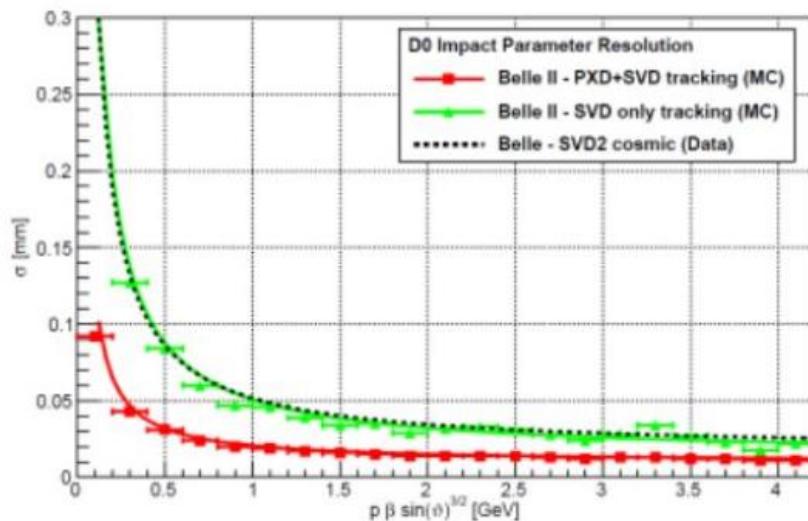


Why 2-phase CO₂

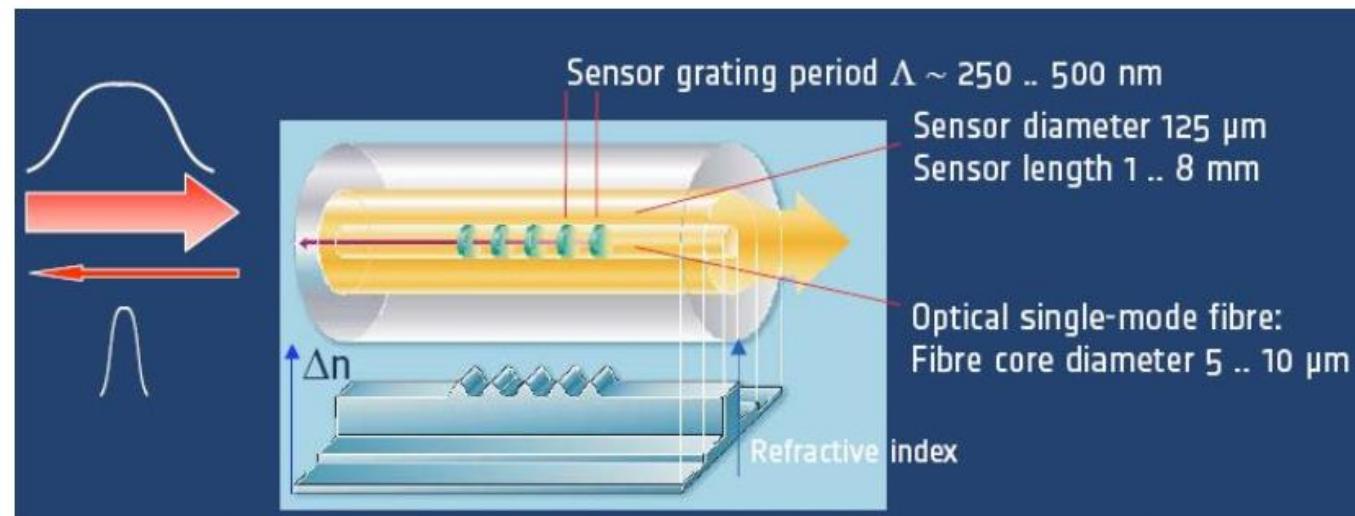
- Safe, stable, relatively inexpensive, radiation hard
- High latent heat (low dT):
 - Temperature can be calculated from pressure
 - Small dT means if you P_in and P_out, you know T_experiment
- High latent heat (low volume):
 - Save space in dry volume
 - Lower material budget as SVD requires active cooling



Improvement to vertex/track detection



Fibre Optics Temperature Measurement



SVD Upgrades

Why PXD is necessary:

- If two particles pass thru SVD matrix, impossible to precisely track location

Upgrades to SVD:

- Smaller strip sizes
- More channels
- Readout upgrade using APV25 (same as CMS) with 100micron

Problem with PXD:

- Lots more data = vital trigger cuts

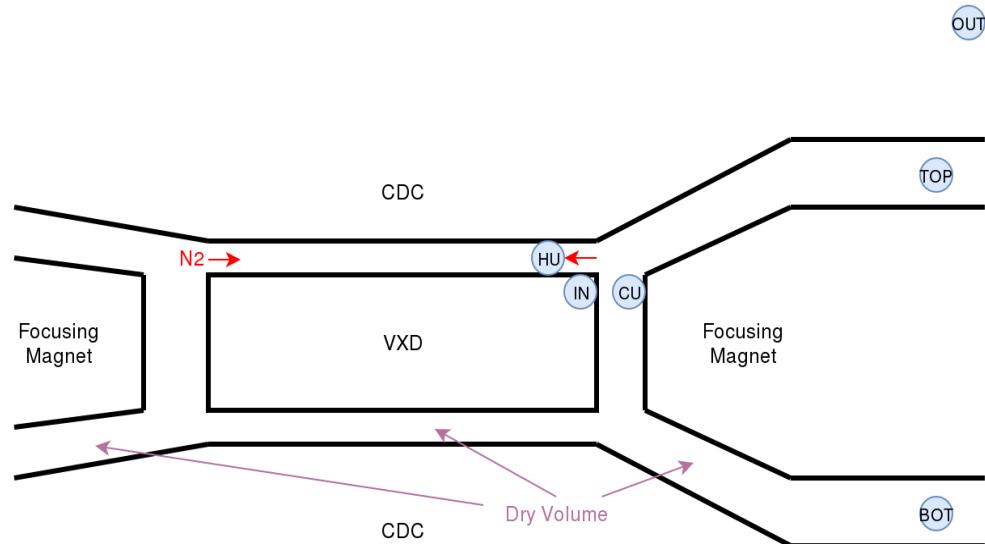
Thermal Requirements

VXD surface:

- CDC: 23C
- Beam pipe (not shown): 15C

VXD volume:

- PXD ASICs: <50C
- PXD sensor: <25C
- SVD ASICs: ~0C



Partial Pressure of Water Vapour

Suppose p_{vapour} is constant:

- If T decreases, H must increase
- If H increases, then T_{DP} must also increase
- Thus if p_{vap} is constant and the peaks happen, the theory is consistent

If p_{vap} is changing, many other factors could affect the T_{DP} since it is a complicated coupled system. Therefore it is difficult to pin-point the cause

$$p_{\text{vapour}} = \frac{H_R}{100} p_{\text{saturation}} = \frac{H_R}{100} 10^{\left(8.07131 - \frac{1730.63}{233.426 + T}\right)}$$

- The **Depleted P- Channel Field Effect Transistor**

References

- [1] T. Abe et al., Belle-II Technical Design Report, KEK Report, 2010-1
- [2] C. Marinas, The Belle II Experiment, [PoS(DIS2016)261] Proceedings of Science, 2016
- [3] H. Ye et al., Thermal mock-up studies of the DEPFET pixel vertex detector for Belle II, 2017 [<http://arxiv.org/abs/1607.00663>]
- [4] B. Verlaat, Evaporative CO₂ cooling for thermal control of scientific equipments, SLAC Advanced Instrumentation Seminars, 2012
[<https://www-group.slac.stanford.edu/ais/publicDocs/presentation152.pdf>]
- [5] SHTxx documentation: http://irtfweb.ifa.hawaii.edu/~tcs3/tcs3/Misc/Dewpoint_Calculation_Humidity_Sensor_E.pdf
- [6] Antoine's formula constants: <http://ddbonline.ddbst.de/AntoineCalculation/AntoineCalculationCGI.exe?component=Water>

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