LeptonID challenges

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Belle II physics week

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Introduction

Lepton ID is an important item for high precision measurement

- Require good performance → less fake backgrounds ($\pi \to \ell, K \to \ell$)
- Require corrections (Data/MC) with small uncertainties

Eg. Semi-Leptonic WG meeting in B2GM

[$B \to \tau\nu$ (M. Aversano)]

Systematic Uncertainties

Source	Sys. Unc. estimation
$n_{B\bar{B}}$	1.5 %
$BR(\Upsilon(4S) \to B^+B^-)$	1 %
Tracking efficiency	0.24 %
Particle Identification	2.6 %
π^0 reconstruction efficiency	0.6 %
Tag B reconstruction efficiency	0.2 %
E_{extra} PDF	$^{+15.7\%}_{-13.7\%}$
Total	$^{+16\%}_{-14.1\%}$

E_{extra} PDF	Sys. Unc. estimation
MC Statistics	11.4%
Continuum Reweighting	3.6 %
Multiplicity Corr.	$^{+10.2\%}_{-6.7\%}$
Total	$^{+15.7\%}_{-13.7\%}$

[$B \to D^*\ell\nu$ (D.Domer)]

Systematics estimate for $w[1, 1.05]$

- Four systematics missing: fake rate, luminosity, continuum shape, track momentum scaling
- Will be added when rerunning with MC15rd
- Turning on all systematics yields same result as the sum

$d^2\Gamma/dwd\cos_\ell$ rel. err [%]

	bin1	bin2	bin3	bin4	bin5	bin6	bin7
tracking	0.70	0.70	0.70	0.70	0.70	0.70	0.70
lepID eff	1.10	1.30	1.30	1.30	1.10	0.90	0.60
slowPions	2.60	2.60	2.60	2.50	2.60	2.60	2.70
XcEllNuWeight	2.30	2.60	2.30	2.30	2.60	3.50	2.20
Form Factors	2.80	2.20	2.10	2.10	2.30	2.00	2.00
nbb	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Dst_BR	0.70	0.70	0.70	0.70	0.70	0.70	0.70
D_BR	0.70	0.70	0.70	0.70	0.70	0.70	0.70
lifetime	0.30	0.30	0.30	0.30	0.30	0.30	0.30
MC_unc	3.99	5.66	6.74	6.05	5.83	5.42	5.22
data_stat	6.63	9.40	11.20	10.06	9.68	9.01	8.68
all	9.20	12.10	13.90	12.70	12.40	11.80	11.20

D. Dorner (HEPHY) $B \to D^*\ell\nu$ 46th B2GM 11 / 13

<u>**Lepton ID would give a large impact on several analysis**</u>

Let’s discuss some items to improve the performance!

LID efficiency calibration

Evaluate LID efficiency/fake rate using several channels

Electron ID

- $ee \to (ee)ee$: momentum coverage is $p < 2.5$ GeV/c
- J/$\psi \to ee$: momentum coverage is $1.0 < p < 3.0$ GeV/c
- $ee \to ee(\gamma)$: momentum coverage is $1.0 < p$ GeV/c

Possible to cover full p range

Muon ID

- $ee \to (ee)\mu\mu$: momentum coverage is $p < 2.5$ GeV/c
- J/$\psi \to \mu\mu$: momentum coverage is $1.0 < p < 3.0$ GeV/c
- $ee \to \mu\mu$: momentum coverage is $1.0 < p$ GeV/c

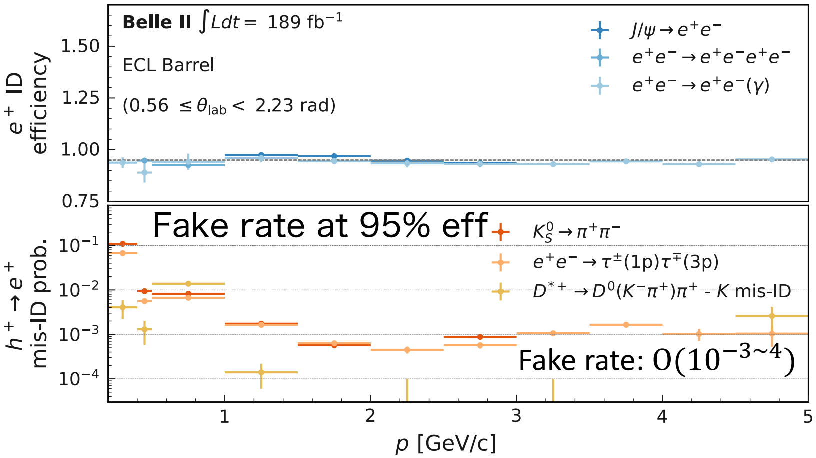
Possible to cover full p range

$\boldsymbol{\pi \to \ell, K \to \ell}$ mis-ID

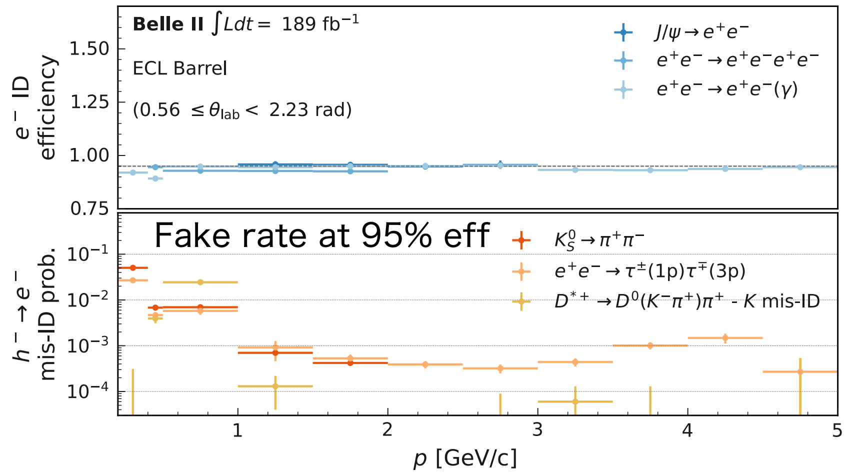
- $\mathrm{K_S^0} \to \pi\pi$: momentum coverage is $p < 1.0$ GeV/c
- $ee \to \tau(1p)\tau(3p)$: momentum coverage is $p < 1.0$ GeV/c
- $\mathrm{D}^{*+} \to (D^0 \to K^-\pi^+)\pi^+$ for $K \to \ell$ fake rates

Current performance

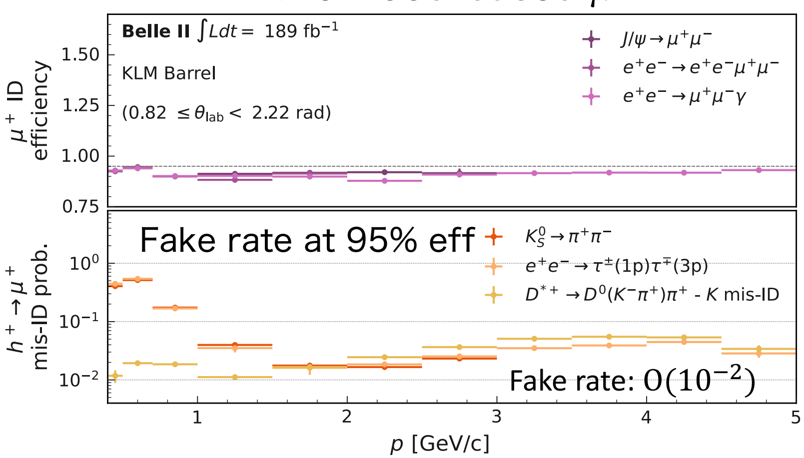
BDT-based eID



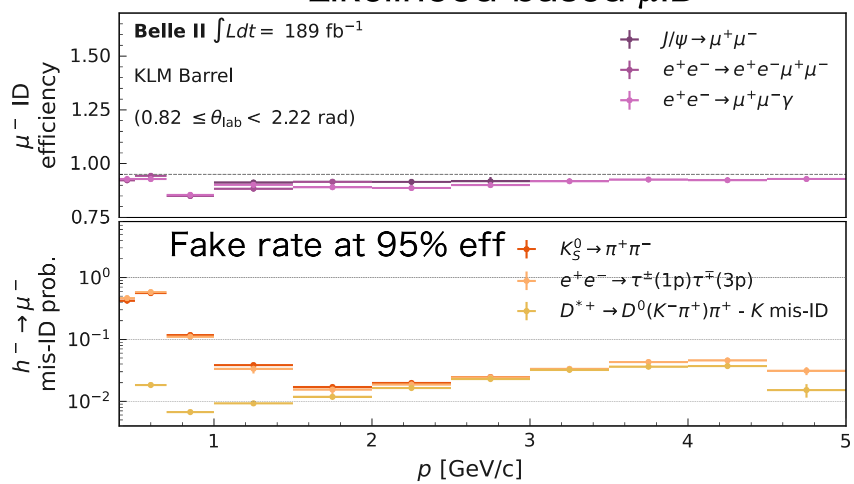
BDT-based eID



Likelihood-based μID

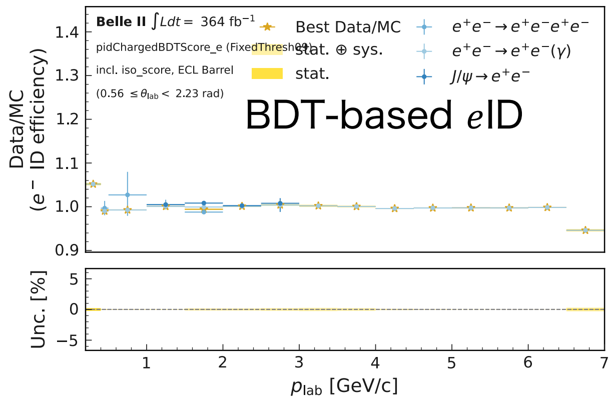


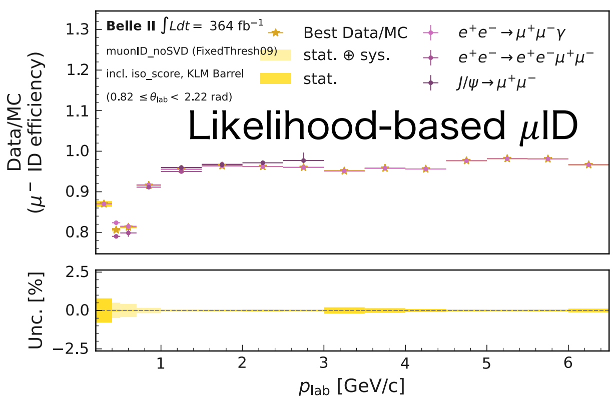
Likelihood-based μID

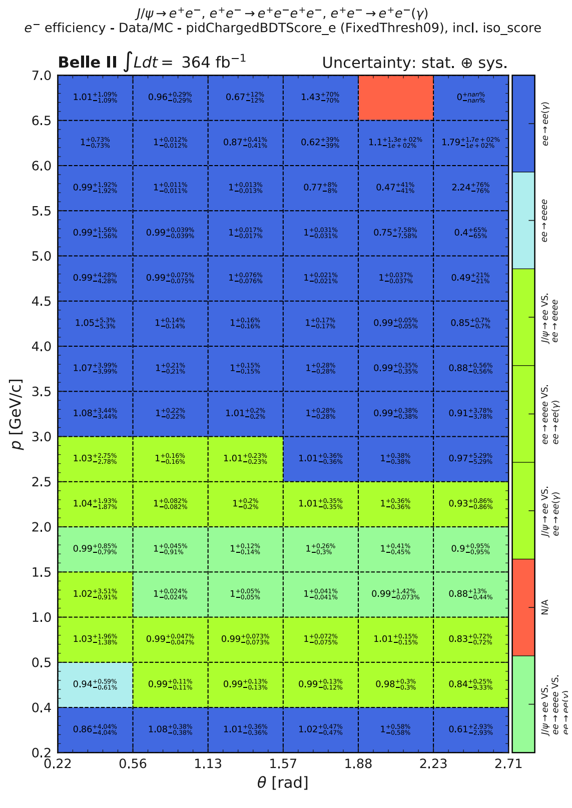


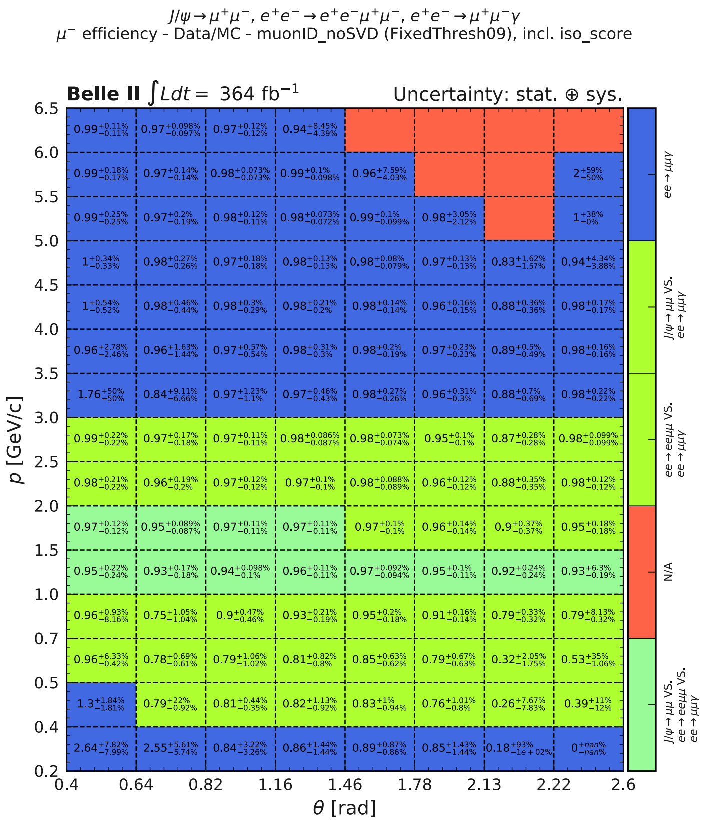
The performance at Belle II is comparable to or better than that at Belle

Current corrections and unc









- Similar corrections in three calibration channels → High reliability
- Calculate corrections and uncertainties in bins of (p, θ, q)
  - Comparable to or better than those at Belle

Next step?

※ my opinion

For high precision measurement, these items should be considered

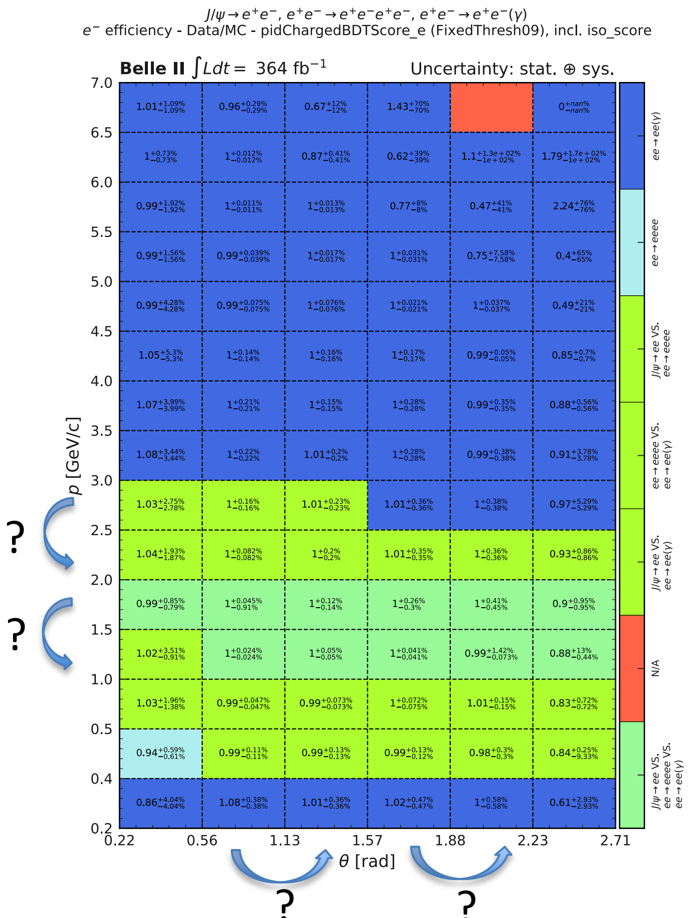
1. Bin-by-bin correlations in Lepton ID
2. Lepton ID considering beam background
3. Effect of event multiplicity

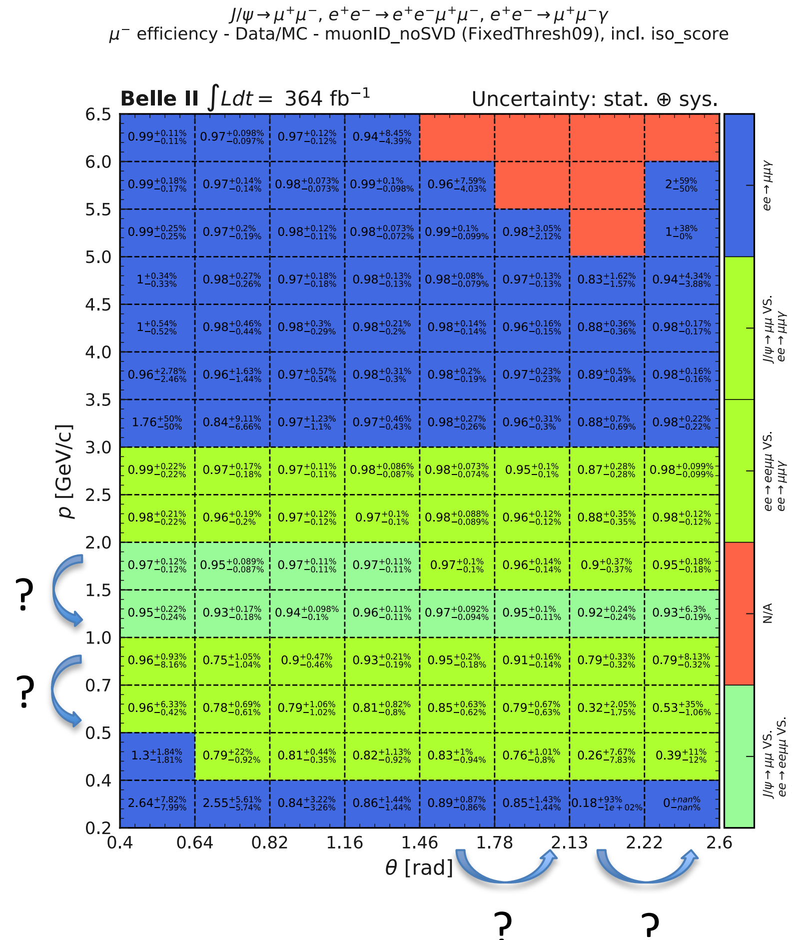
1. bin-by-bin correlations

Currently, provide corrections in bins of (p, θ, q)

- We also estimate both statistical and systematic uncertainties

→ The correlations among the bins are not considered..





Making a covariance matrix is crucial

How to evaluate correlations

We don't have any concreate plan about it..

- One (general?) idea is to apply bootstrapping
  - <u>Need to understand what uncertainties are sensitive for correlations</u>

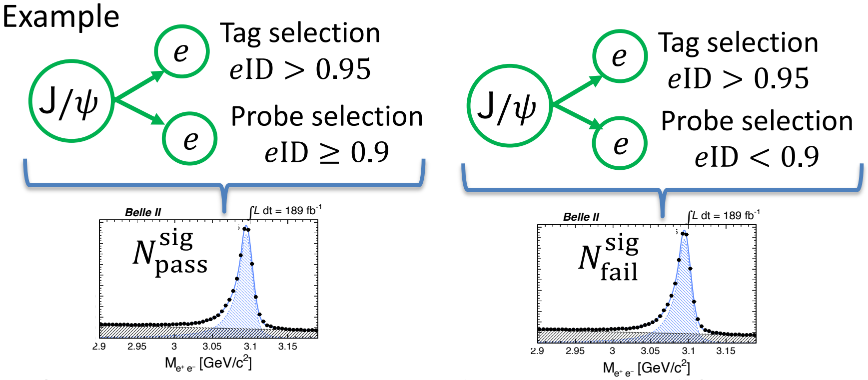
J/ψ channel: perform a binned likelihood fit to $M_{\ell\ell}$ distribution

Tag-and-probe method is used to determine the LID efficiency

LID efficiency (ϵ)

$$\varepsilon = \frac{N_{\text{pass}}^{\text{sig}}}{N_{\text{pass}}^{\text{sig}} + N_{\text{fail}}^{\text{sig}}},$$

Example



- Simultaneous fit is performed over the two "pass" and "fail" sets
- Calculate efficiencies for each (p, θ, q) bin

Systematic uncertainties: signal PDF parameters

Eg. J/$\psi \to \mu\mu$

$$\text{PDF} = N_{\text{sig}}\left[a \times \text{Gauss}(\mu, w\sigma_g) + (1-a) \times \text{Bifur}(\mu, w\sigma_L, w\sigma_R)\right] + N_{\text{bkg}}\text{Cheby}(c_1, c_2).$$

How to evaluate correlations

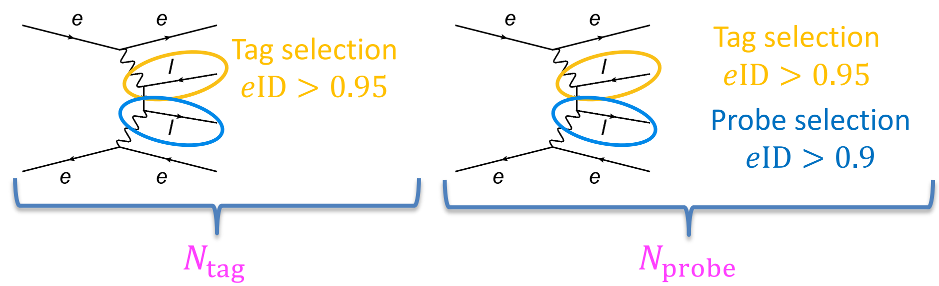
We don’t have any concreate plan about it

- One (general?) idea is to apply bootstrapping
  - <u>Need to understand what uncertainties are sensitive for correlations</u>

$ee \to (ee)\ell\ell, ee(\gamma), \mu\mu$ channels:

Systematic uncertainties

- $\pi \to \ell, K \to \ell$ fake rates
- Trigger selection (on/off)
- Background MC yields



$$\varepsilon_{data} = \frac{N_{\mathrm{probe}} - N_{\mathrm{probe}}^{\mathrm{bkg}}}{N_{\mathrm{tag}} - N_{\mathrm{tag}}^{\mathrm{bkg}}} \qquad \varepsilon_{MC} = \frac{N_{\mathrm{probe}}^{\ell}}{N_{\mathrm{tag}}^{\ell}}$$

Bkg subtraction

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- Can we define a covariant matrix per systematic source, per channel?
- How to combine all these matrices into one?

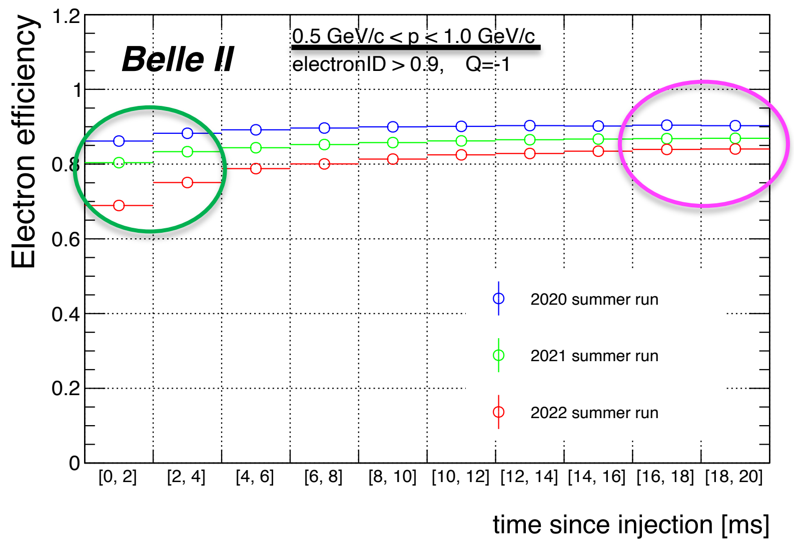
→ Your suggestion is very appreciated!!

2. LID vs beam background

Observe a degradation of LID efficiency due to beam background

- 5-10% degradation of eID efficiency
- 10-15% degradation of eID efficiency

BDT-base eID



Beam bkg gives an impact on detectors

- CDC: gain drop (dE/dx)
- ECL: pedestal shift
- KLM: multi-strip-hit?

Expect larger beam background as the peak luminosity increases

→ We cannot avoid such a degradation for the LID variables.

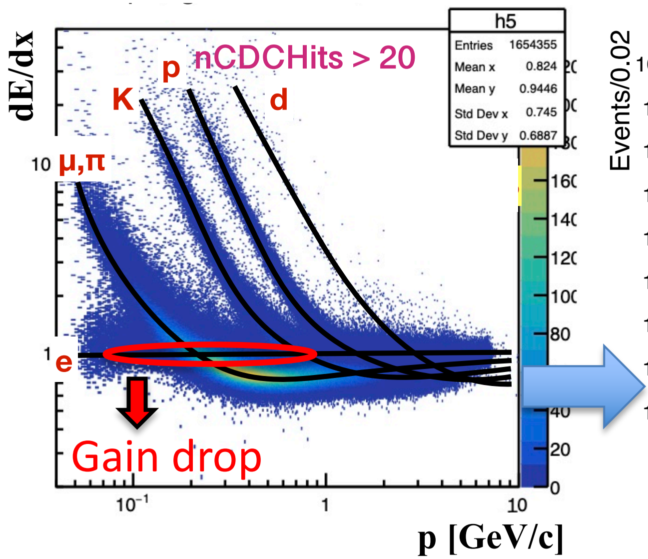
- <u>It would be the limitation of LID performance</u>

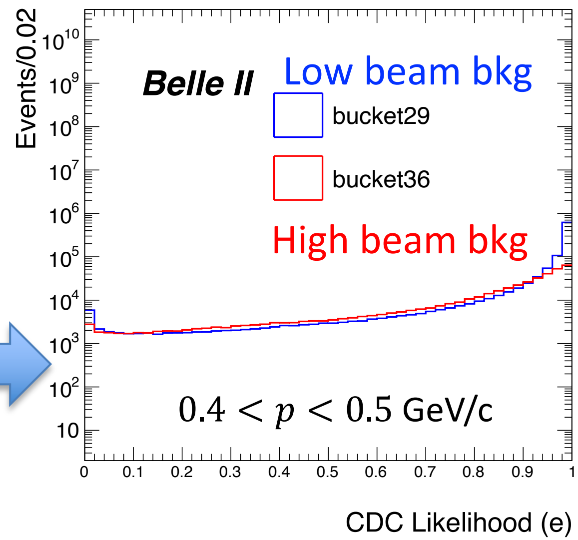
Our approach for beam bkg

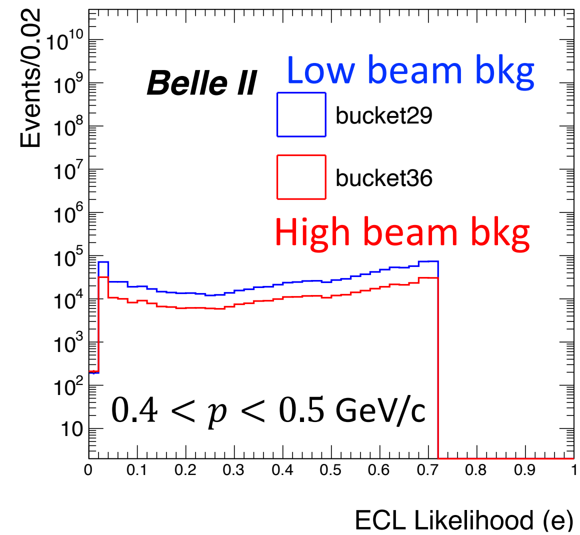
Likelihood-based eID

For low momentum ($p < 1.0$ GeV/c), we rely on CDC info (dE/dx)

- Better to utilize ECL info → more tolerance against beam bkg



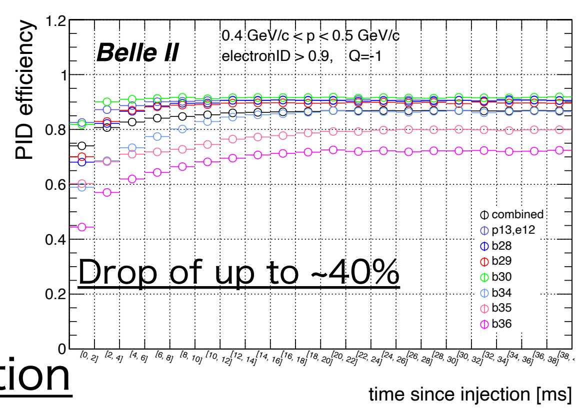




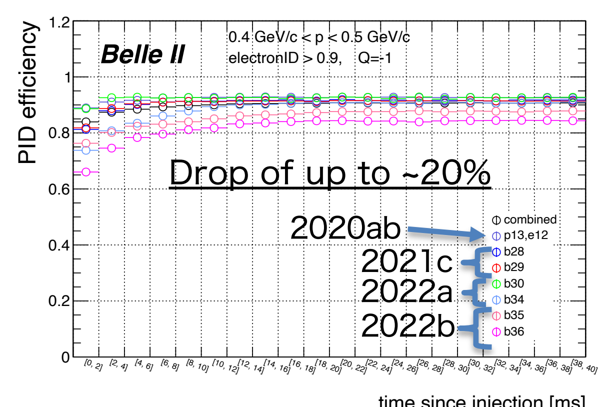
BDT-based eID:

- ECL info as input vars!

→ Smaller drop of eff.!



Likelihood-base eID



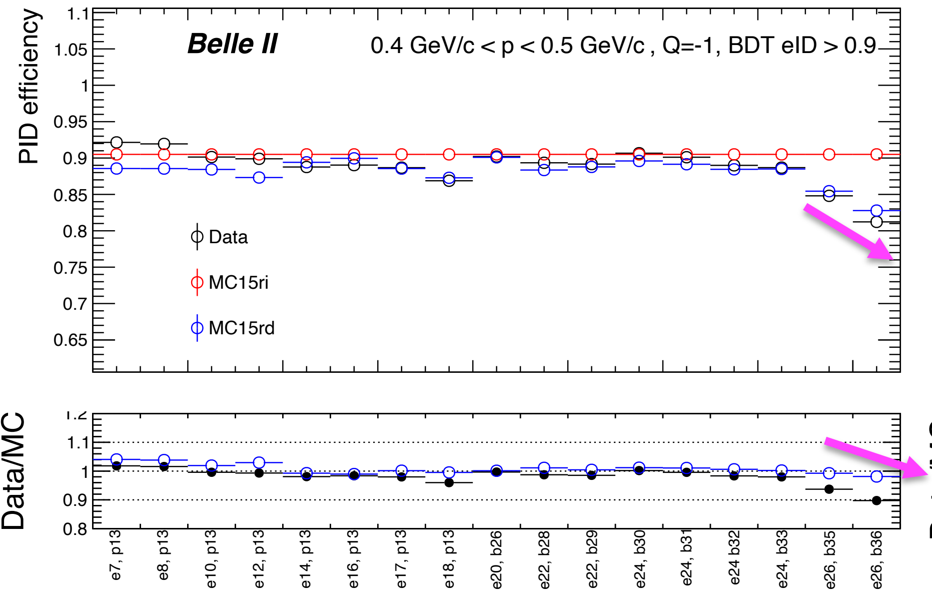
BDT-base eID

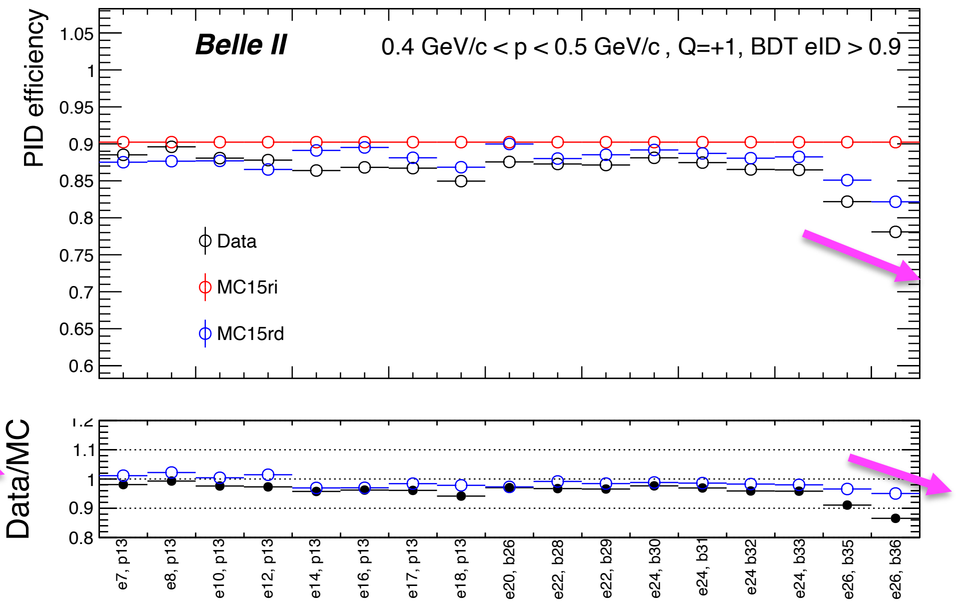
<u>However, we still see degradation</u>

Effect of corrections

Provide corrections in bins of (p, θ, q)

- Assume no run-dependency





Observe run-dependency in LID efficiency

- It appears even though we use run-dependent MC
  - dE/dx calibration is not enough..

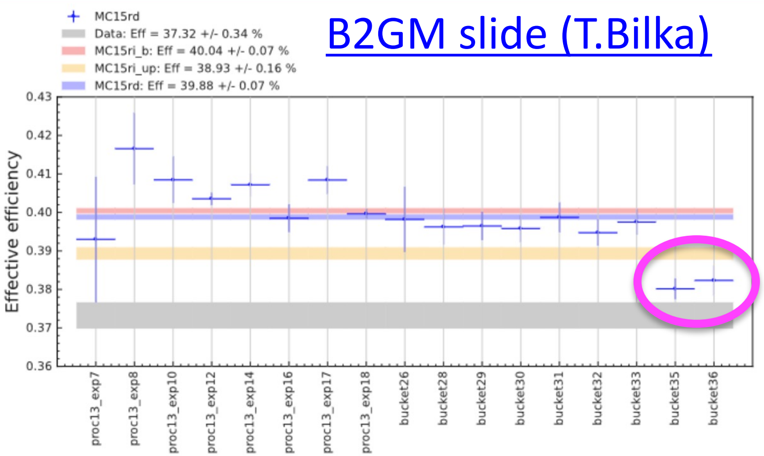
→ Do you want corrections per eg. bucket number?

GNN-based Flavour Tagger

(Just for information):
The LID degradation gives impact on other performance..

Comparison of $\varepsilon_{\mathrm{eff}}$

Belle II



B2GM slide (T.Bilka)

	$\varepsilon_{\mathrm{eff}}$ [%] (only stat)
MC15ri_b	40.04 ± 0.07
MC15ri_up	38.93 ± 0.16
MC15rd	39.88 ± 0.07
(bucket36 only)	38.23 ± 0.38
Data	37.32 ± 0.34

- Results of MC15ri_up and MC15rd are closer to Data than MC15ri.
  - MC15rd (bucket35,36): $\varepsilon_{\mathrm{eff}} \sim 38\%$
- MC15rd vs MC15ri:
  Reconstruction and beam-background condition is more realistic.
- MC15ri_up vs MC15ri:
  Decay model and BR of hadronic B-decay are modified.

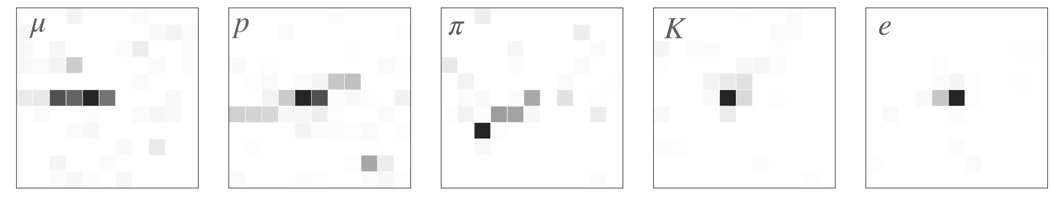
GFlaT performance: consistent run-dependency with LID

PID using Convolutional NN

Anja Novosel's study

Exploit the specific patterns in the ECL crystals

- Utilize the spatial distribution of energy deposition in the ECL



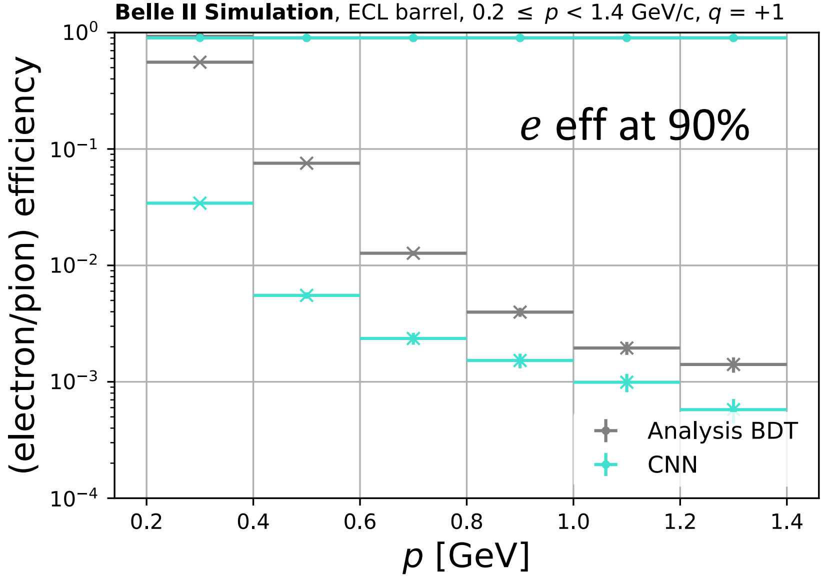
Examples of images for different particle species.

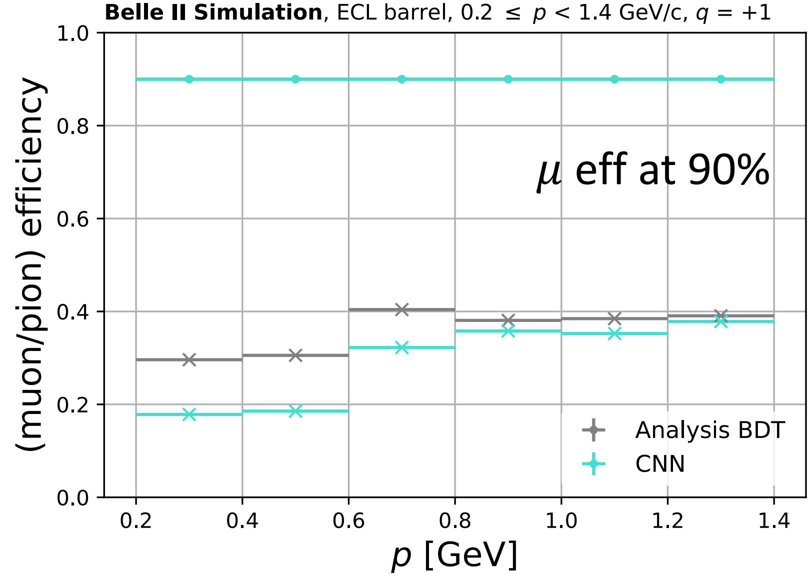
Training sample

- Particle-gun (π, e, μ, K, p)

MC only study

ECL-image: $N \times N$ neighboring crystals





$\pi \rightarrow e, \mu$ fake rate improves at low momentum

Utilize ECL information for low momentum☺

3. Event multiplicity

Other particles in the vicinity of a candidate track

- affect PID of the candidate track

→ Define an "isolation score" per a candidate track

  - The proximity of the track is checked at various cylindrical surfaces.

$$
w = \begin{array}{c} \\ \left(\begin{array}{cccccc} 0.809 & 2.270 & 0.434 & 0.595 & 2.464 & 0.158 \\ 1.363 & 1.958 & 0.429 & 0.611 & 1.962 & 0.483 \\ 1.064 & 1.433 & 0.426 & 0.598 & 2.018 & 0.183 \\ 1.793 & 1.908 & 0.422 & 0.605 & 1.663 & 0.219 \\ 1.719 & 1.866 & 0.414 & 0.646 & 1.963 & 0.221 \\ 1.265 & 2.026 & 0.381 & 0.693 & 4.085 & 0.149 \end{array}\right) \end{array}
\begin{array}{c} e \\ \mu \\ \pi \\ K \\ p \\ d \end{array}
$$

(columns: svd, cdc, top, arich, ecl, klm)

0 0.5 1 1.5 2 2.5 3 3.5 4 4.5

minET2ETIsoScoreAsWeightedAvg(*referenceListName, useHighestProbMassForExt, detectorList*)

Returns a particle's isolation score s based on the weighted average:

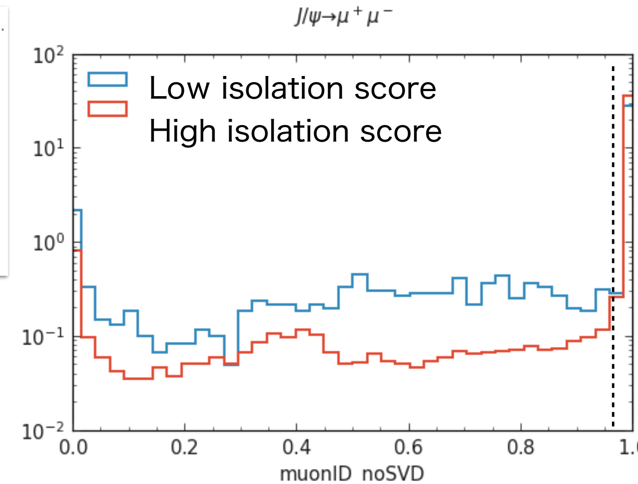
$$s = 1 - \frac{\sum_{\mathrm{det}} \sum_i^{N_{\mathrm{det}}^{\mathrm{layers}}} w_{\mathrm{det}} \cdot \frac{D_{\mathrm{det}}^{\mathrm{thresh}}}{d_i}}{\sum w_{\mathrm{det}}},$$

where d_i is the distance to the closest neighbour at the i-th layer of the given detector (c.f., `minET2ETDist`), $N_{\mathrm{det}}^{\mathrm{layers}}$ is the number of layers of the detector, $D_{\mathrm{det}}^{\mathrm{thresh}}$ is a threshold length related to the detector's granularity defined in the `TrackIsoCalculator` module, and w_{det} are (negative) weights associated to the detector's impact on PID for this particle type, read from a CDB payload.

The score is normalised in [0, 1], where values closer to 1 indicates a well-isolated particle.

```
/**
 * Threshold values for the distance (in [cm]) to closest ext. helix to define isolated particles.
 * One for each detector layer.
 */
std::map<std::pair<std::string, int>, double> m_distThreshPerDetLayer = {
  { {Const::parseDetectors(Const::CDC), 0}, 5.0 },
  { {Const::parseDetectors(Const::CDC), 1}, 5.0 },
  { {Const::parseDetectors(Const::CDC), 2}, 5.0 },
  { {Const::parseDetectors(Const::CDC), 3}, 5.0 },
  { {Const::parseDetectors(Const::CDC), 4}, 5.0 },
  { {Const::parseDetectors(Const::CDC), 5}, 5.0 },
  { {Const::parseDetectors(Const::CDC), 6}, 5.0 },
  { {Const::parseDetectors(Const::CDC), 7}, 5.0 },
  { {Const::parseDetectors(Const::CDC), 8}, 5.0 },
  { {Const::parseDetectors(Const::TOP), 0}, 22.0 },
  { {Const::parseDetectors(Const::ARICH), 0}, 10.0 },
  { {Const::parseDetectors(Const::ECL), 0}, 36.0 },
  { {Const::parseDetectors(Const::ECL), 1}, 36.0 },
  { {Const::parseDetectors(Const::KLM), 0}, 20.0 }
};
```

$D_{\mathrm{det}}^{\mathrm{thresh}}$



- Good agreement of "Data/MC" b.t.w $ee \to \ell\ell, ee\ell\ell$ and J/ψ
- Some difference of "efficiency" b.t.w $ee \to \ell\ell, ee\ell\ell$ and J/ψ

→ Not urgent task, but worth to considering it in the future

Summary

Lepton ID is an important item for high precision measurement

- In the past few years, several improvements have been performed

→ The performance is comparable to or better than that at Belle!

Current limitation

- LID correlations
  - How to get one covariant matrix? Your suggestion is welcome.
- LID degradation due to beam background
  - Efficiency drop → Need better PID to avoid losing statistics
  - Data/MC has run-dependency → Need better calibration.
- Event multiplicity (eg. $ee \to ee\ell\ell$ vs J/$\psi \to \ell\ell$)
  - No obvious difference of "Data/MC" b.t.w channels for now
    - It might be worth to considering it in the future

Backup

J/ψ channel

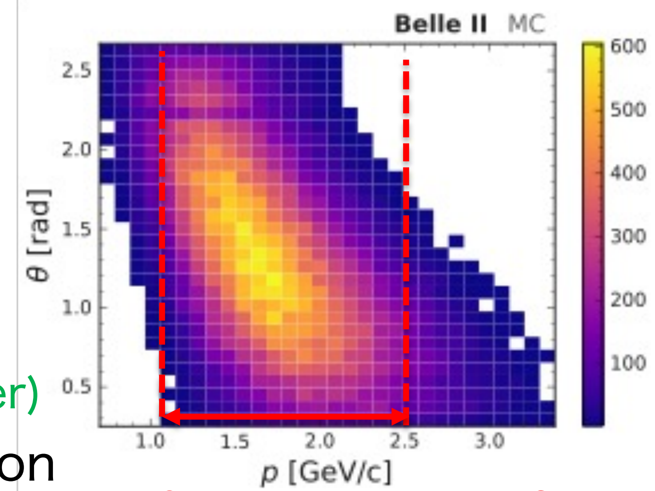
Reconstruct J/ψ candidate from hadronic B decays

- Two tracks as originating from the IP
  - At least one track have a value of ℓID > 0.9
- $2.8 < M_{\ell^+\ell^-} < 3.3$ GeV/c^2
- Some requirements for bkg suppression

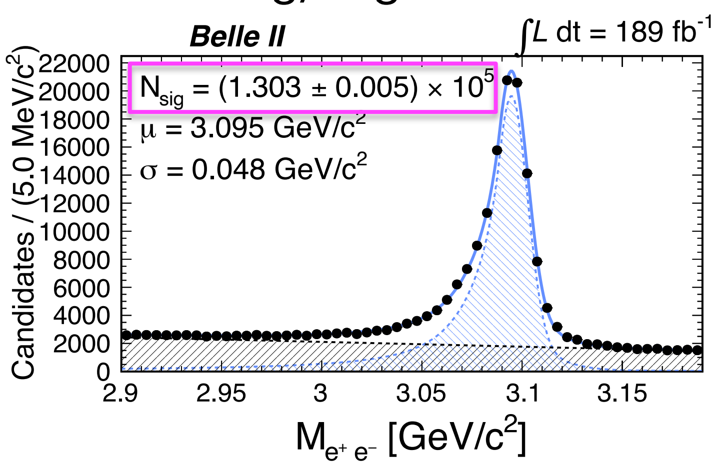
(eg. $R_2 < 0.4$, matching ECL cluster)

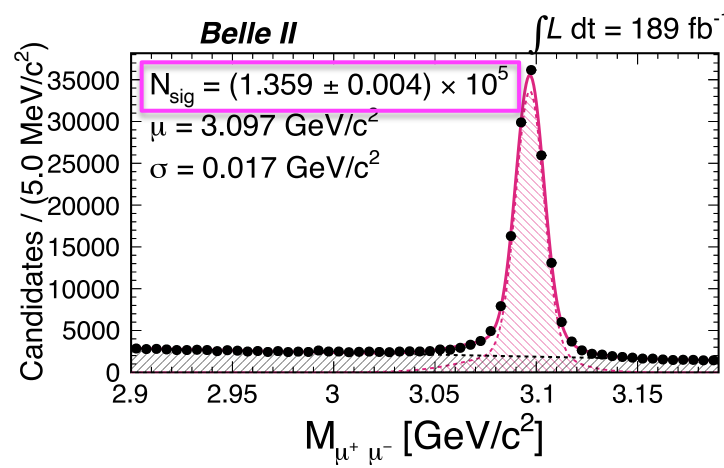
→ Perform a binned likelihood fit to $M_{\ell^+\ell^-}$ distribution

Prepare suitable PDFs for sig/bkg



Coverage: $1.0 < p < 2.5$ GeV/c





Extract the number of of J/ψ candidates based on the fit result

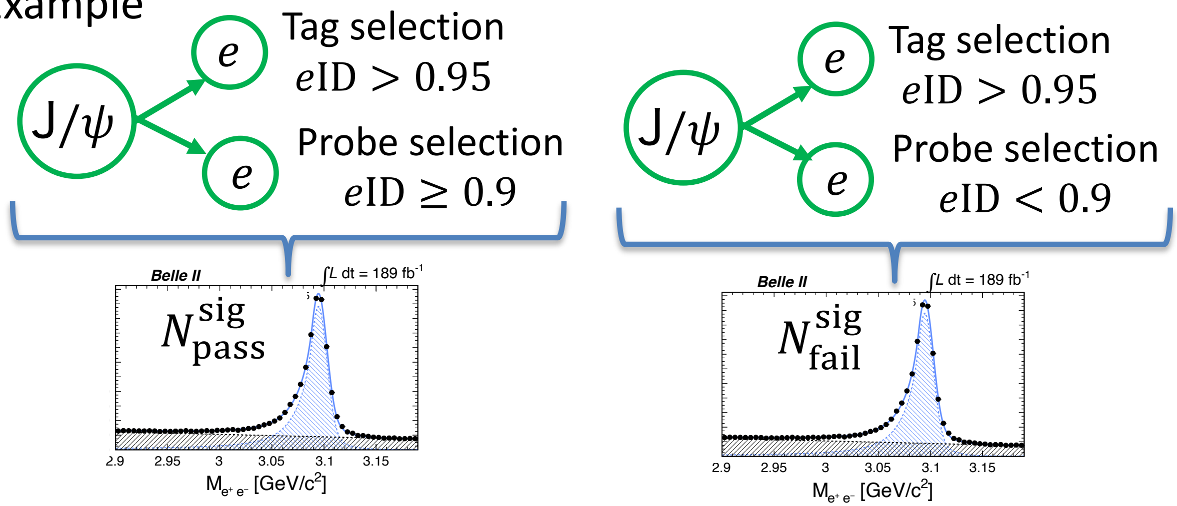
J/ψ channel

Tag-and-probe method is used to determine the LID efficiency

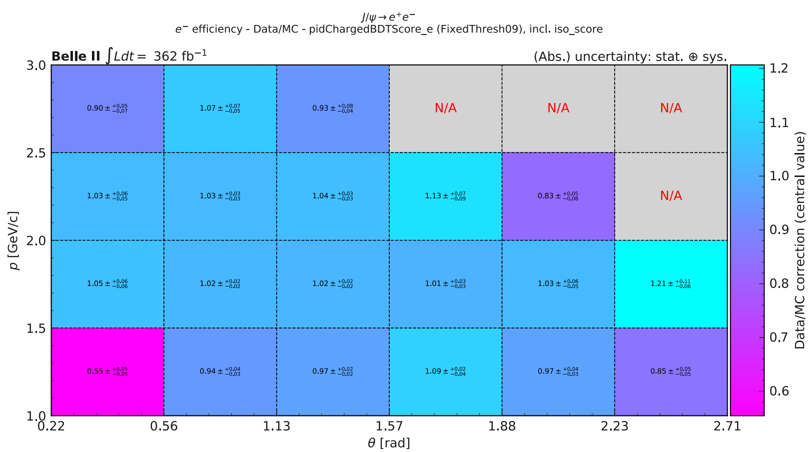
LID efficiency (ϵ)

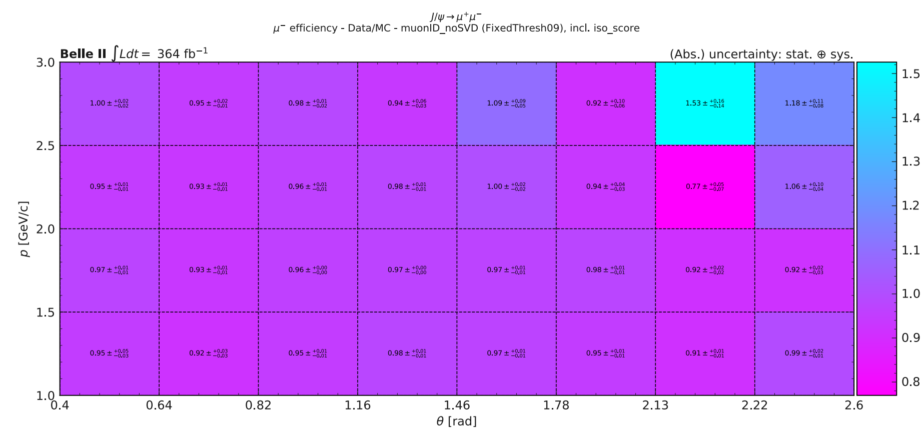
$$\varepsilon = \frac{N^{\mathrm{sig}}_{\mathrm{pass}}}{N^{\mathrm{sig}}_{\mathrm{pass}} + N^{\mathrm{sig}}_{\mathrm{fail}}},$$

Example



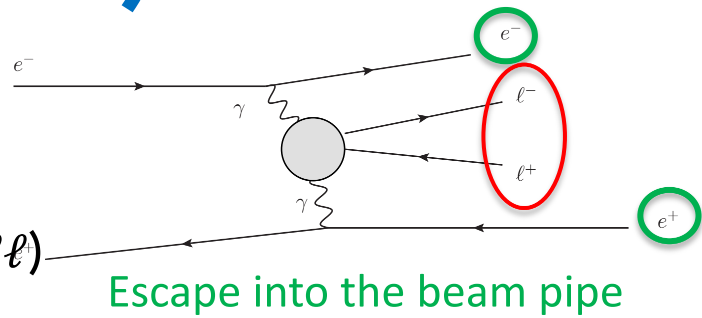
- Simultaneous fit is performed over the two “pass” and “fail” sets
- Calculate efficiencies for each (p, θ, q) bin



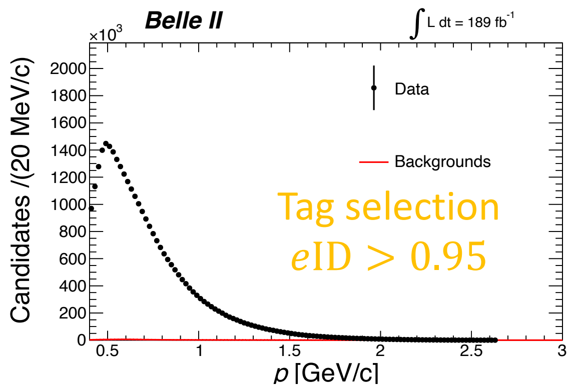


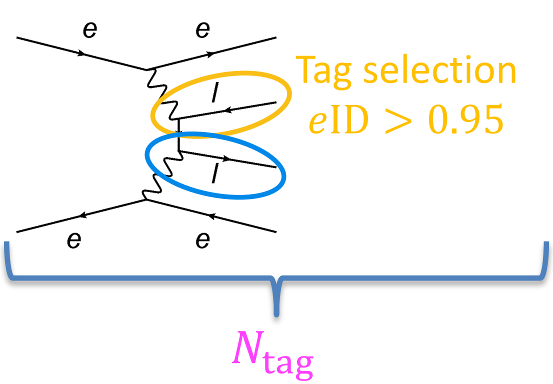
$ee \to (ee)\ell\ell$ (di-photon) channel

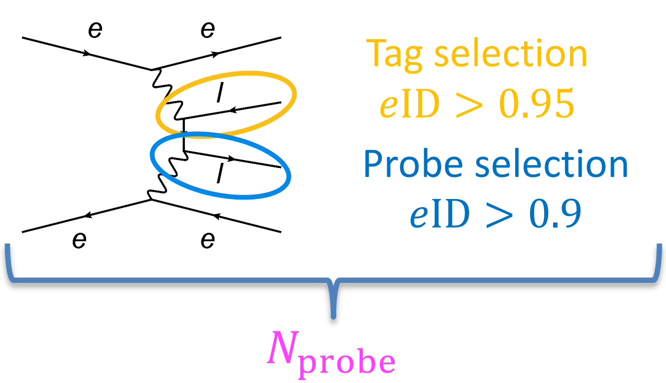
- Enough statistics ($p < 3.0$ GeV/c)
- $\ell^+\ell^-$ within the detector volume acceptance
- Suppress backgrounds ($ee \to qq, \tau\tau, ee\pi\pi, eeKK, \ell\ell$)
  - Eg. Total visible energy, p_T balance

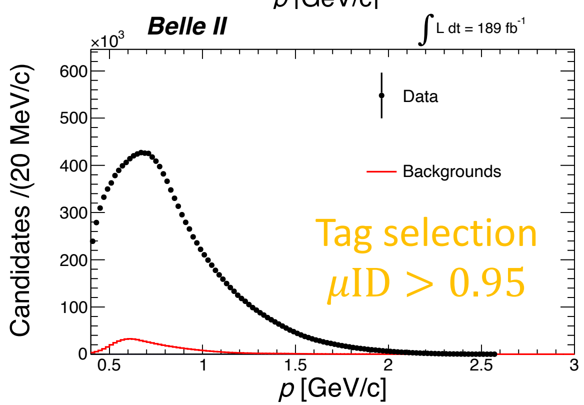


Tag-and-probe method is used to determine the LID efficiency







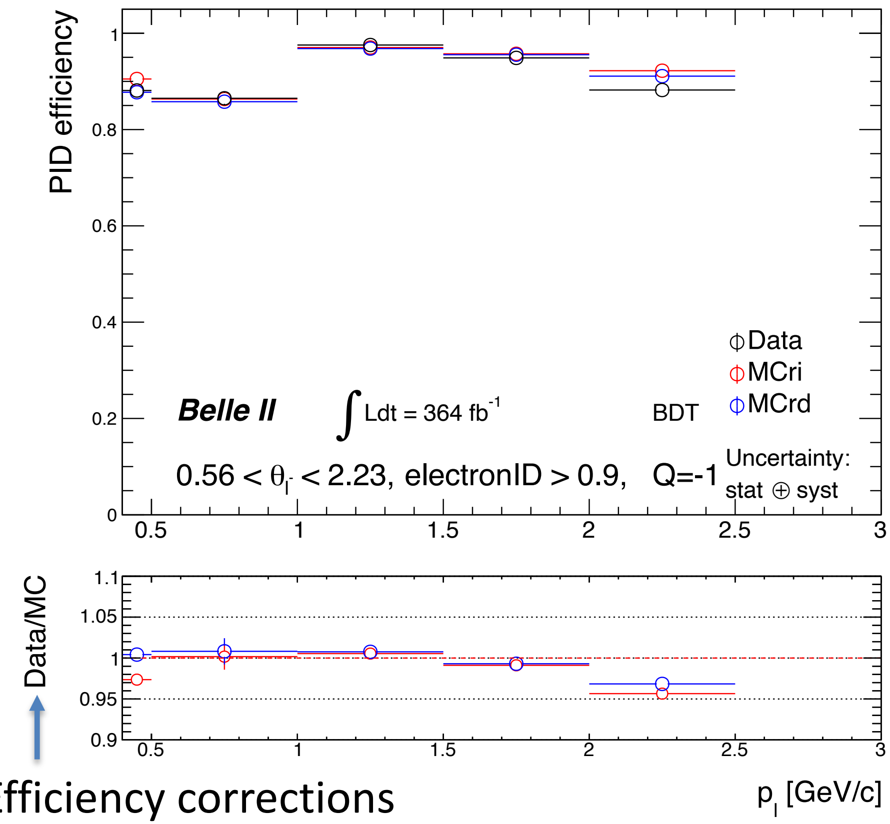


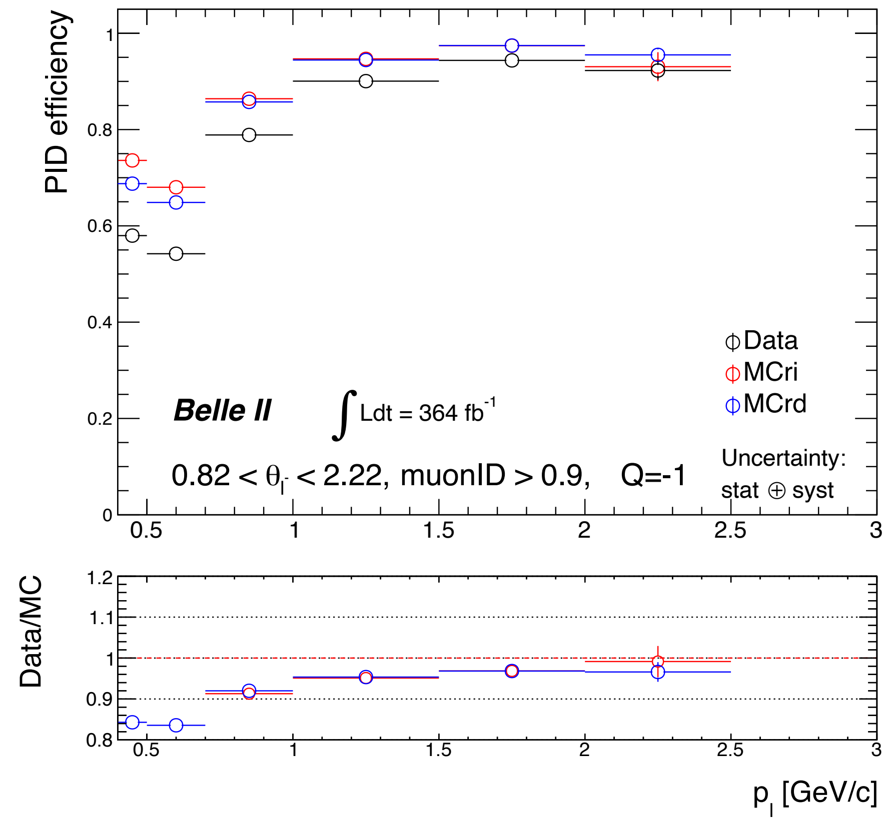
$$\varepsilon_{data} = \frac{N_\mathrm{probe} - N_\mathrm{probe}^\mathrm{bkg}}{N_\mathrm{tag} - N_\mathrm{tag}^\mathrm{bkg}}$$

Bkg subtraction

$$\varepsilon_{MC} = \frac{N_\mathrm{probe}^\ell}{N_\mathrm{tag}^\ell}$$

$ee \to (ee)\ell\ell$ (di-photon) channel



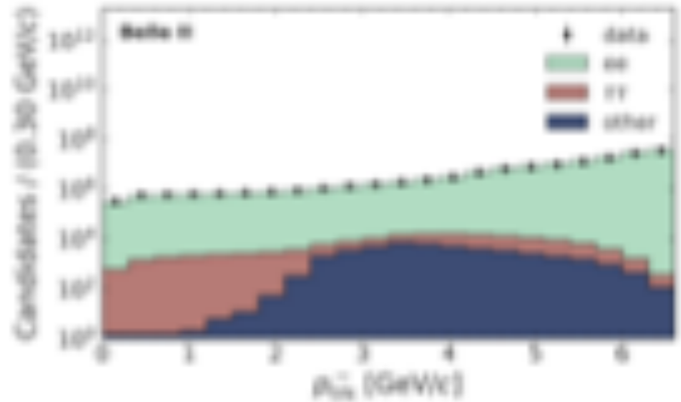


Efficiency corrections

- Electron ID: a good agreement between data and MC15rd
- Muon ID: Some discrepancy between data and MC15rd
  - Low momentum → CDC dE/dx calibration? Still under investigation

$ee \to ee(\gamma)$: Bhabha channel

- Large events across full momentum range
  - High momentum: $ee \to ee$
  - Low momentum: $ee \to ee\gamma$



<u>Event selection</u>

- Use trigger requiring an ECL cluster (>2 GeV)
  - Probe the track, which is not used in the trigger
- Require the recoil mass M^2_{recoil} to suppress backgrounds

e^- Used in the trigger

e^+ Used for the LID eff

Tag-and-probe method

$$\epsilon_{data} = \frac{\rho_{tag+probe}\ N_{probe+tag}}{\rho_{tag}\ N_{tag}} \qquad \epsilon_{MC} = \frac{N_{probe+tag}}{N_{tag}}$$

e^- Tag selection

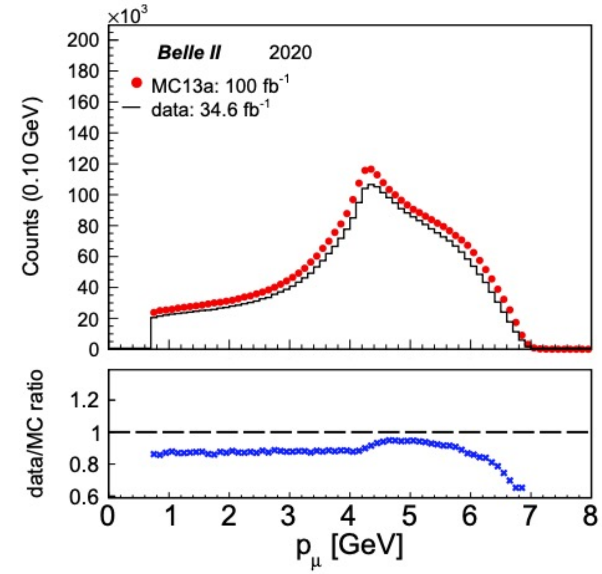
e^+ Probe selection

ρ: purities with $eeee, ee\mu\mu, \mu\mu, \tau\tau$ MC samples

In this B2GM, Phillip reported a recent progress in this channel.
Please check his slide [Link]

ee → $\mu\mu\gamma$: di-muon channel

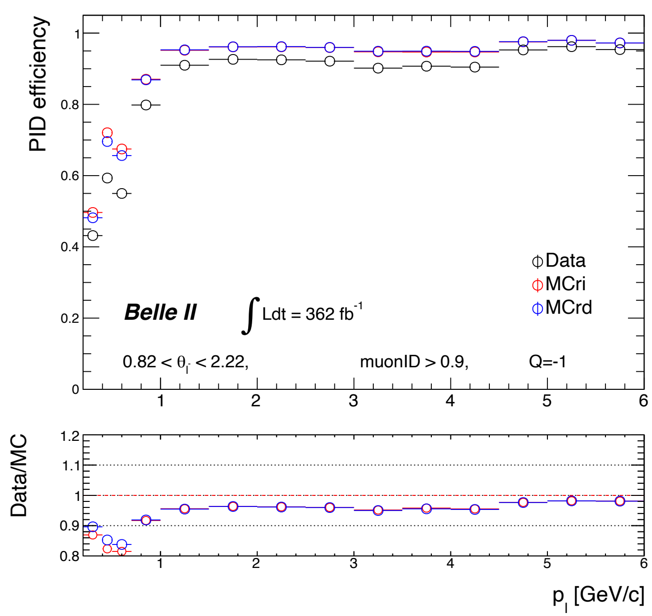
- Large events across full momentum range
- Clean environment
  - (Almost) no backgrounds

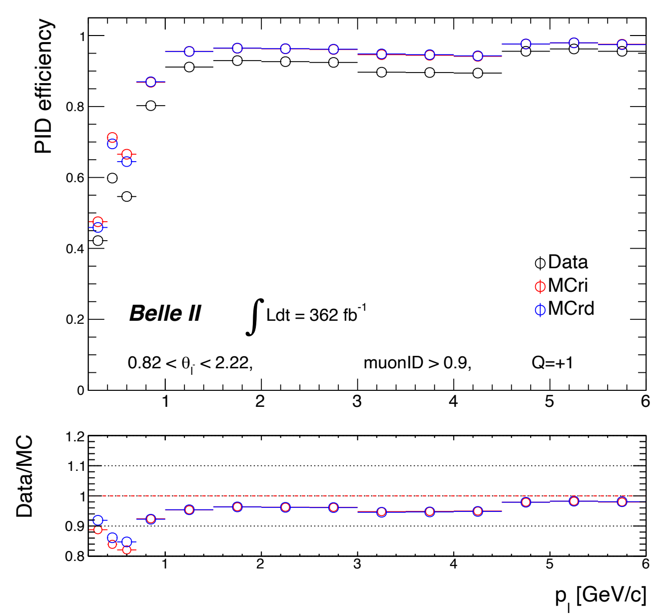


Tag-and-probe method

$$\varepsilon_{data} = \frac{N_{\rm probe} - N_{\rm probe}^{\rm bkg}}{N_{\rm tag} - N_{\rm tag}^{\rm bkg}} \qquad \varepsilon_{MC} = \frac{N_{\rm probe}^{\ell}}{N_{\rm tag}^{\ell}}$$

Bkg subtraction (eg. $ee \rightarrow \pi\pi\gamma, KK\gamma$)





$K_S \to \pi\pi$ channel

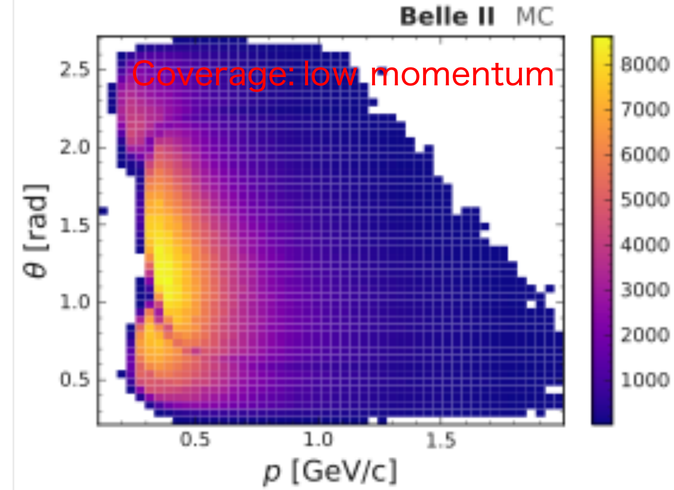
Methodology is similar as $J/\psi \to \ell\ell$

Inclusively reconstructed $K_S \to \pi\pi$ candidates are used

- Two tracks as originating from the IP
- $0.45 < M_{\pi^+\pi^-} < 0.55$ GeV/c^2
- Perform a vertex fit

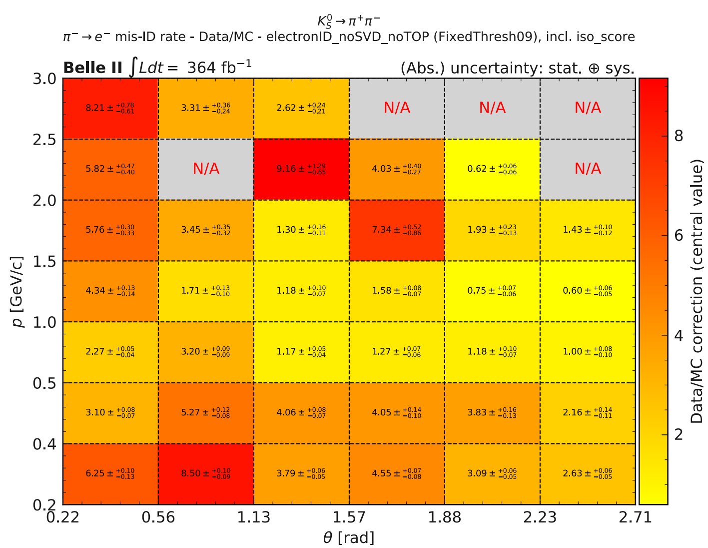
→ High signal purity (99.4%) of this channel

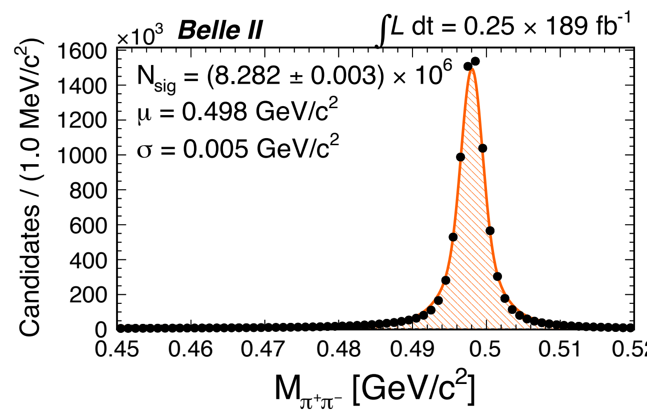
→ No need a tag selection



Misidentification rate: cut-and-count approach

- Compare N_{K_S} yields with and without ℓID cut

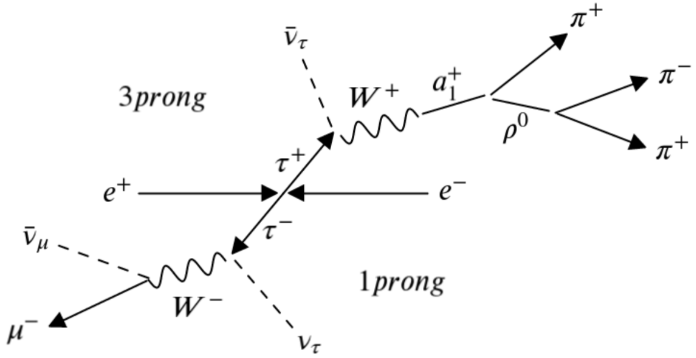




$ee \to \tau(1p)\tau(3p)$ channel

A clean sample of pions to measure pion misidentification probability

- $\tau \to \pi\pi\pi\nu$ (3-prong) and $\tau \to \ell\nu\nu$ (1-prong)
  - 98% of 3-prong tracks: pions (High purity)



<u>Event selection</u>

- Take 1+3 charged track events
- Suppress backgrounds: Thrust, visible energy..

$$\varepsilon_{data} = \frac{N_{\text{probe}} - N_{\text{probe}}^{\text{bkg}}}{N_{\text{tag}} - N_{\text{tag}}^{\text{bkg}}} \qquad \varepsilon_{MC} = \frac{N_{\text{probe}}^{\ell}}{N_{\text{tag}}^{\ell}}$$

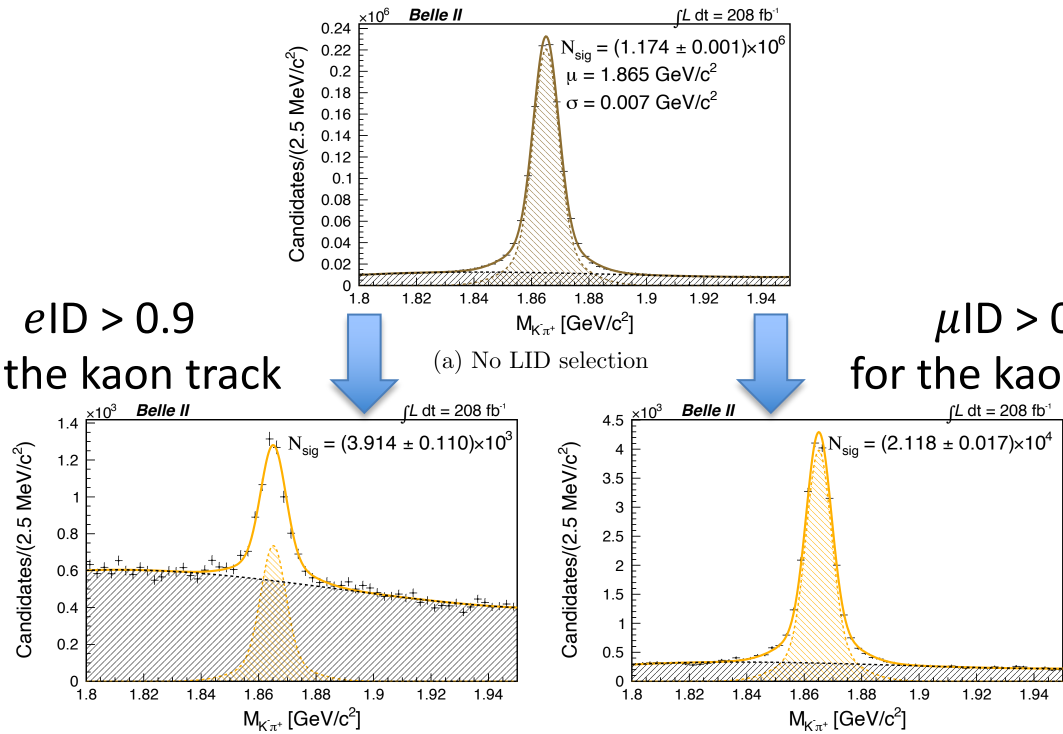
Bkg subtraction

$D^{*+} \to D^0[\to K^-\pi^+]\pi^+$ channel

- Measure kaon-to-lepton misidentification probabilities
- D^{*+} mesons are produced in $e^+e^- \to c\bar{c}$ continuum events
  - Use all the data (on- and –ff-resonance data)

eID > 0.9 for the kaon track

μID > 0.9 for the kaon track



(a) No LID selection

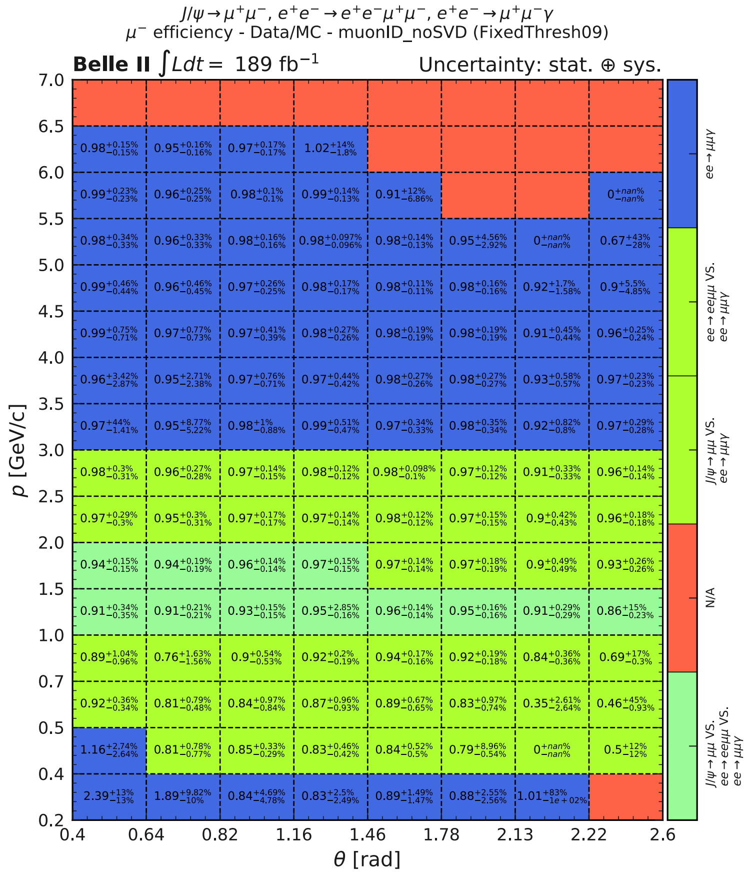
(b) $P_e > 0.9$

(c) $P_\mu > 0.9$

Figure 19: Fit to the M_{D^0} distribution in the $D^{*+} \to D^0[\to K^-\pi^+]\pi^+$ channel without any probe selection criteria (top), with $P_e > 0.9$ for the kaon track (bottom left) and with $P_\mu > 0.9$ for the kaon track (bottom right).

Current assumptions for LID corrections

- LID corrections ($c_i = \dfrac{r_i^{\text{data}}}{r_i^{\text{MC}}} \rightarrow$ data/MC eff., fake rate) binned in (p, θ, q) from several calibration channels.



- In each bin, if there's coverage, each channel provides a central value $\pm\, 1\sigma$ stat. $\pm\, 1\sigma$ (combined) syst.

  - Uncertainties can be asymmetric, depending on the source and the prescription.

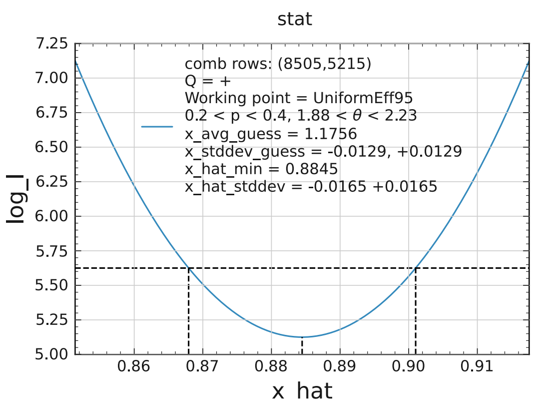
  - Sources of systematic *per channel* are treated as fully independent, thus summed in quadrature.

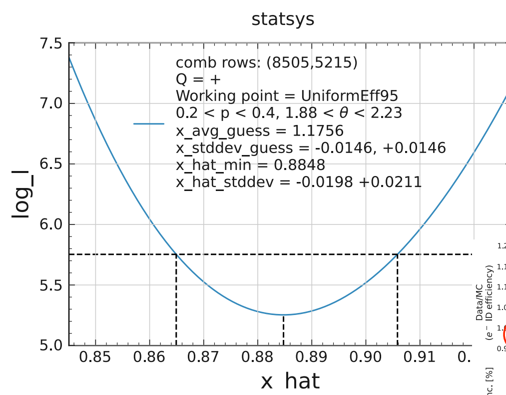
3

Combination of LID corrections, and "distance" systematic unc.

- In each bin, c_i's from available channels $k \in \{J/\psi \to \mu^+\mu^-,\ \mu^+\mu^-\gamma \ldots\}$ are combined via a generalisation of the weighted average in presence of asymmetric errors (c.f. arXiv:physics/0406120).

- Syst. uncertainties of all combined channels are assumed fully independent in each bin.





E.g.: BDT(e), uniform eff. 95% w.p.
$K^0_S \to \pi^+\pi^-, e^+e^- \to \tau^+(1p)\tau^-(3p)$

- After combination, an extra (highly asymmetric) systematic is assigned $\rightarrow$ large channel discrepancies in some bins.

- Analysers are eventually given one (asymmetric) systematic error per bin, summing all in quadrature.

4

Breakdown of sources of systematics

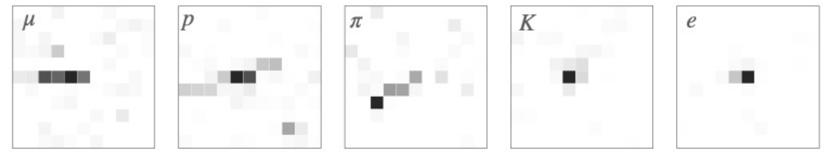
Channel	Source	Correlation [%] between $p_{\rm lab}$ bins	Correlation [%] between $\theta_{\rm lab}$ bins	Correlation [%] between channels	Notes
$J/\psi \to e^+e^-$	1. Signal PDF parameters.	0	0	0	Each $(p_{\rm lab}, \theta_{\rm lab})$ bin fitted individually.
$e^+e^- \to (e^+e^-)e^+e^-$	1. $\pi(K) \to \ell$ data/MC correction.	100	100	0 (*)	(*) Neglected correlation to $K_S^0 \to \pi^+\pi^-$, $e^+e^- \to \tau^\pm(1P)\tau^\mp(3P)$, $D^{*+} \to D^0(\to K^-\pi^+)\pi^+$ channels.
	2. Background MC yield.	100	100	0 (*)	(*) Neglected correlation to $e^+e^- \to e^+e^-(\gamma)$ channel.
$e^+e^- \to e^+e^-(\gamma)$	1. Trigger selection on/off	100	100	0	–
	2. Background MC yield (purity factors).	100	100	0 (*)	(*) Neglected correlation to to $e^+e^- \to (e^+e^-)e^+e^-$ channel.
$J/\psi \to \mu^+\mu^-$	1. Signal PDF parameters.	0	0	0	Each $(p_{\rm lab}, \theta_{\rm lab})$ bin fitted individually.
$e^+e^- \to (e^+e^-)\mu^+\mu^-$	1. $\pi(K) \to \ell$ data/MC correction.	100	100	0 (*)	(*) Neglected correlation to $K_S^0 \to \pi^+\pi^-$, $e^+e^- \to \tau^\pm(1P)\tau^\mp(3P)$, $D^{*+} \to D^0(\to K^-\pi^+)\pi^+$ channels.
	2. Background MC yield.	100	100	0 (*)	(*) Neglected correlation to $e^+e^- \to \mu^+\mu^-\gamma$ channel.
$e^+e^- \to \mu^+\mu^-\gamma$	1. Background MC yield ($M_{\mu^+\mu^-\gamma}$ mismodelling)	100	100	0	
$K_S^0 \to \pi^+\pi^-$	1. Signal PDF parameters.	0	0	0	Each $(p_{\rm lab}, \theta_{\rm lab})$ bin fitted individually.
$e^+e^- \to \tau^\pm(1P)\tau^\mp(3P)$	1. anything $\to \pi$ data/MC corrections.	100	100	0 (*)	(*) Neglected correlation to e, μ eff. channels.
	2. Trigger eff. correction.	100 (?)	100 (?)	0	To be checked
$D^{*+} \to D^0(\to K^-\pi^+)\pi^+$	1. PDF parameters.	0	0	0	Each $(p_{\rm lab}, \theta_{\rm lab})$ bin fitted individually.
post-combination	distance to min/max (if $> 3\sigma$ from weighted avg.)	?	?	–	Largest uncertainty in mid $p_{\rm lab}$ range ([1-2.5] GeV/c). May reduce w/ iso binning.

TABLE V. Description of the source of systematic uncertainty with assumptions on the correlations between bins and channels.

7

ECL image-based classification using Convolutional Neural Network

Improve the identification of low-momentum charged particles by exploiting the specific patterns in the spatial distribution of energy deposition in the ECL crystals using **Convolutional Neural Network (CNN)**.



Examples of images for different particle species.

ECL-image: NxN neighbouring crystals around the entry point of the extrapolated track into the ECL.

pixel intensity
=
energy deposited in the corresponding ECL crystal.

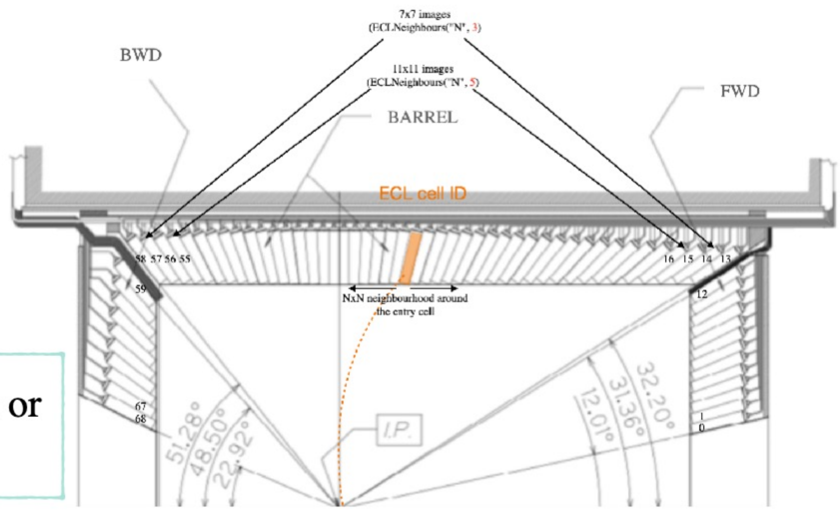
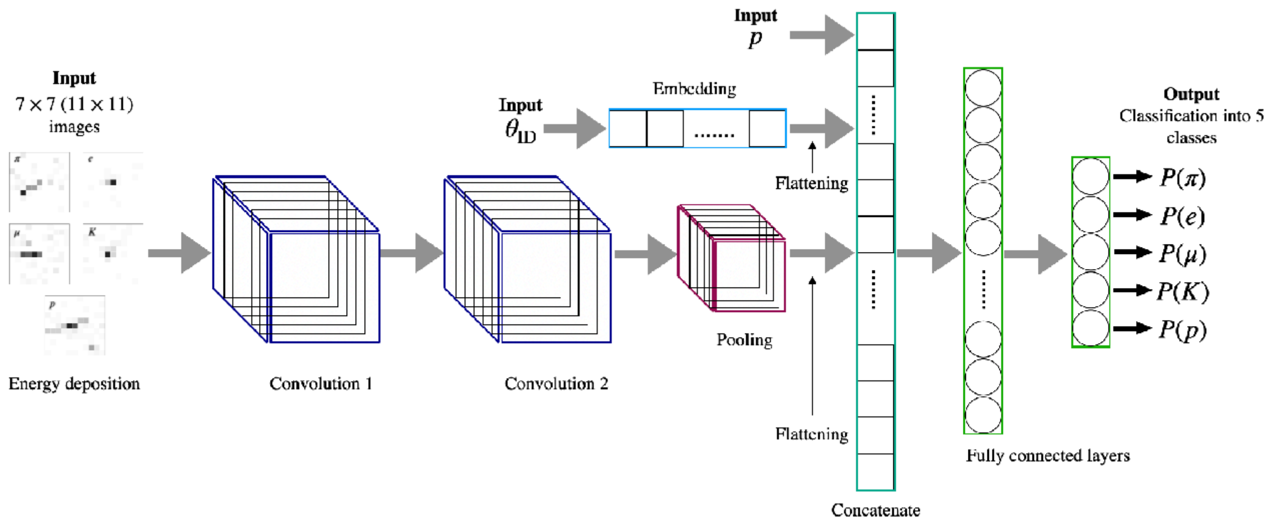


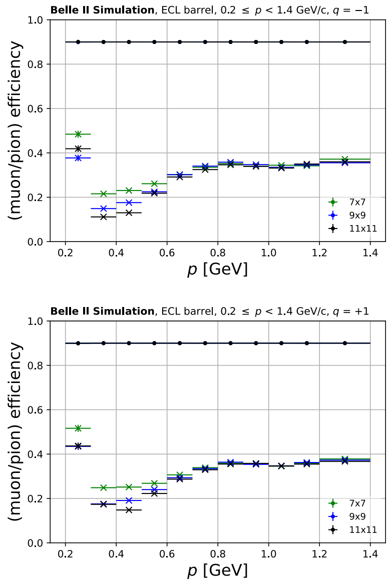
Image production **does not** depend on **cluster reconstruction** or **track-cluster matching**.

Convolutional Neural Network - architecture

Data sample: Particle gun sample with flat $p \in [0.2,0.6], [0.6,1.0], [1.0,1.4]$ GeV/c and $\theta \in [33,131]°$ spectra; +/- charged tracks for each particle hypothesis: π, e, μ, K, p



Convolutional neural network architecture.



$\pi \to \mu$ fake rates at fixed 90% μ efficiency for models using different sized images as an input.