Performance of hadron identification in Belle II

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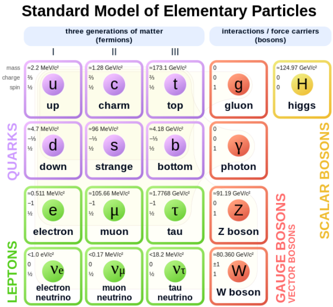
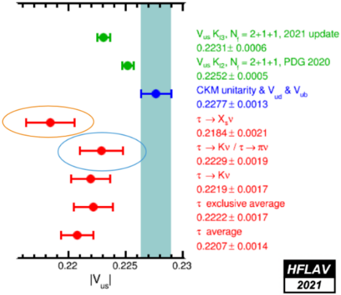
Introduction

- Motivation: hadron identification performance.
- For example: useful to extract the CKM element $|V_{us}|$ from τ leptons.
- For τ decays is important to determine $\ell \to$ *hadron*.

$$|V_{us}|_{\tau s} = \sqrt{R_s / \left[\frac{R_{VA}}{|V_{ud}|^2} - \delta R_{\text{theory}} \right]}$$

$$\frac{B(\tau \to K^- \nu_\tau)}{B(\tau \to \pi^- \nu_\tau)} = \frac{f_K^2 |V_{us}|^2}{f_\pi^2 |V_{ud}|^2} \frac{(1 - m_K^2/m_\tau^2)^2}{(1 - m_\pi^2/m_\tau^2)^2} R_{\tau K/\tau\pi}$$





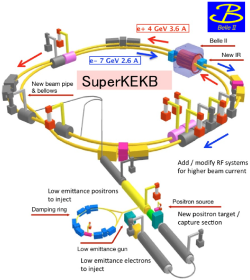
Objective

By applying tag and probe method with J/Ψ decays, calculate the following fake rates:

- $\mu^- \rightarrow \pi^-$
- $\mu^- \rightarrow K^-$
- $e^- \rightarrow \pi^-$
- $e^- \rightarrow K^-$

Belle II experiment

(c) Location of the SuperKEKB in Tsukuba.



(d) Scheme of the different components of the SuperKEKB accelerator.

- B-factory.
- World record of the instantaneous luminosity: $4.7 \times 10^{34} cm^{-2} s^{-1}$.
- Next goal: to reach a luminosity of 50 ab^{-1} operating with an instantaneous luminosity of $6 \times 10^{35} cm^{-2} s^{-1}$.

Belle II collaboration

- 1100 members.
- 123 institutions.
- 26 countries.

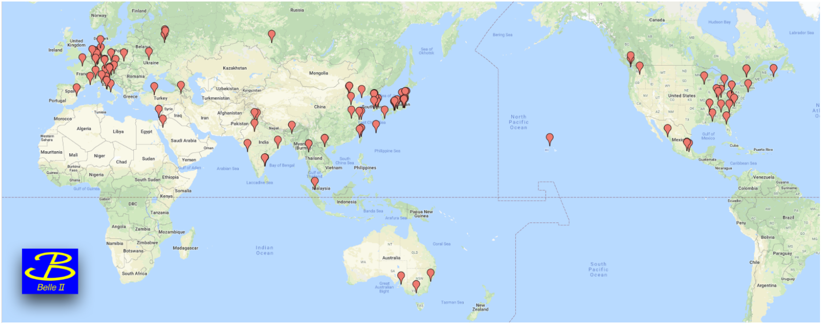


Figure: Relation of the different institution locations collaborating in Belle II.

Belle II subdetectors

- **Tracking detectors**: VerteX Detector (VXD), which is composed by the PiXel Detector (PXD) and the Silicon Vertex Detector (SVD).
- **Particle Identification (PID)**: Central Drift Chamber (CDC), Time Of Propagation (TOP), Aerogel Ring-Imaging Cherenkov (ARICH), Electromagnetic CaLorimeter (ECL), Kinematic calorimeter (KLM).

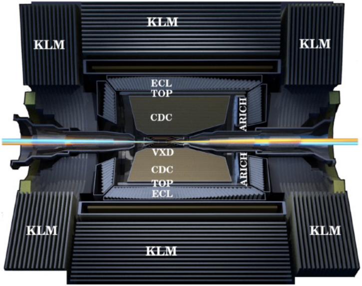


Figure: View of the Belle 2 detector.

Likelihood performance

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

Figure: Equation for calculating the global likelihood according to the likelihood of each sub-detector.

$$\ell\ \mathrm{ID} = \frac{\mathcal{L}_\ell}{\mathcal{L}_e + \mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K + \mathcal{L}_p}$$

Figure: Global particle ID from likelihoods.

Data sets

- **Data**: data sample corresponds to a integrated luminosity of $\int Ldt =$362 fb^{-1}. It is collected for a nominal CMS beam energy of M(Υ(4S)) $=$ 10.58 GeV$/c^2$.
- **MC**: the integrated luminosity of this data set corresponds to $\int Ldt =$ 1000 fb^{-1}.

$J/\Psi \to \ell^+\ell^-$ selection

- **Lepton (μ or e) candidates**:

$\|dr\|$	< 2.0 cm
$\|dz\|$	< 5.0 cm
p_{lab}	> 0.1 GeV/c

Table: Selection for the good tracks.

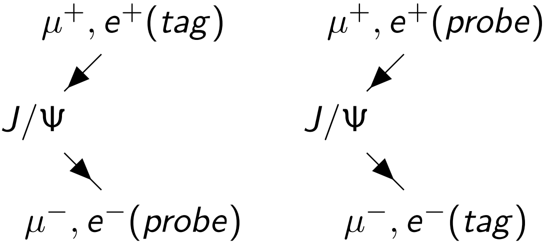
- **Corrections**: tracking scale factor, photon energy and efficiency.
- **Bremsstrahlung** (only for e): angleThreshold$= 0.1$ rad; E < 1 GeV.
- **J/Ψ candidates**:

$2.8 <$ M($J/\psi(\ell^+\ell^-)$) < 3.2 GeV/c^2
daughterSumOf(charge) $== 0$
nGoodTracks $\geqslant 5$
foxWolframR2 < 0.4

Table: Conditions for the selection of the J/Ψ candidates

Tag and probe method

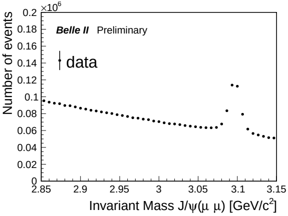
Tag and probe condition:



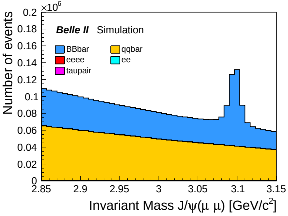
(a) 1^{st} option.   (b) 2^{nd} option.

Figure: Options for the tag and probe method.

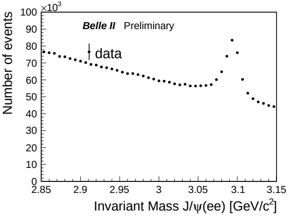
These are the first plots after applying a tag condition



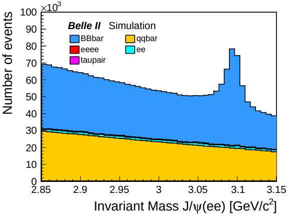
(a) M($J/\Psi \to \mu\mu$) (Data sample).



(b) M($J/\Psi \to \mu\mu$) (MC sample).



(c) M($J/\Psi \to ee$) (Data sample).

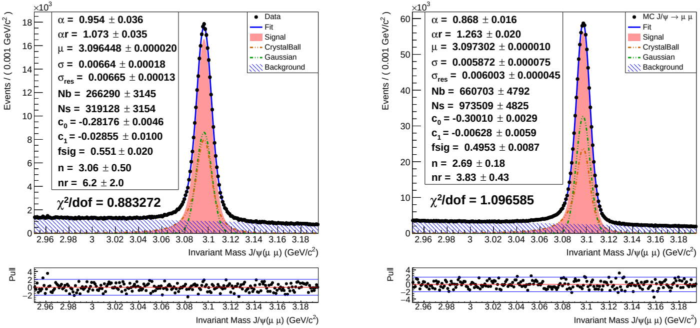


(d) M($J/\Psi \to ee$) (MC sample).

Figure: J/Ψ distributions.

$J/\Psi \to \mu^-\mu^+$: Invariant mass model

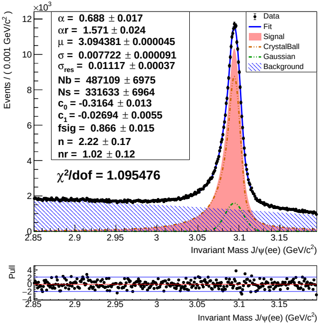
$$PDF = N_{sig}\left[f_{sig} \times Crystal(\mu,\sigma,n,\alpha,n_r,\alpha_r) + (1-f_{sig}) \times Gauss(\mu,\sigma_r)\right] + N_{bkg}\left[Cheb(c_0,c_1)\right]$$



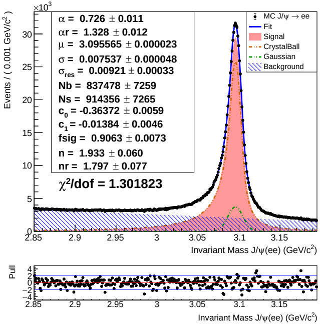
(a) Data sample. (b) MC sample.

Figure: $J/\Psi \to \mu^-\mu^+$ binned fits for Data and MC samples.

$J/\Psi \to e^- e^+$: Invariant mass model



(a) Data sample.



(b) MC sample.

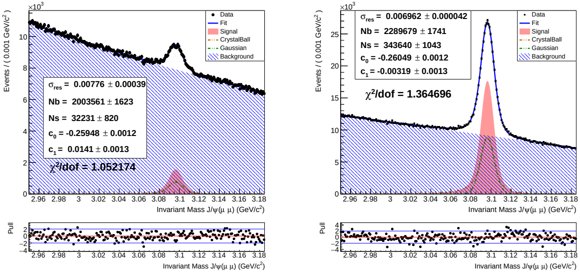
Figure: $J/\Psi \to e^- e^+$ binned fits for Data and MC samples.

Efficiency

The efficiency is calculated by applying the following equation:

$$\epsilon_{ID>x} = \frac{N_s^{pass}}{N_s^{pass} + N_s^{rejected}} \tag{1}$$

Some examples of the fits:



(a) PionID > 0.6 (b) PionID < 0.6

Figure: Examples of the J/Ψ mass distribution by applying tag and probe method

$\mu^- \rightarrow \pi^-$ fake rate

- Integrated for all the (p, θ) phase space of the probe track.

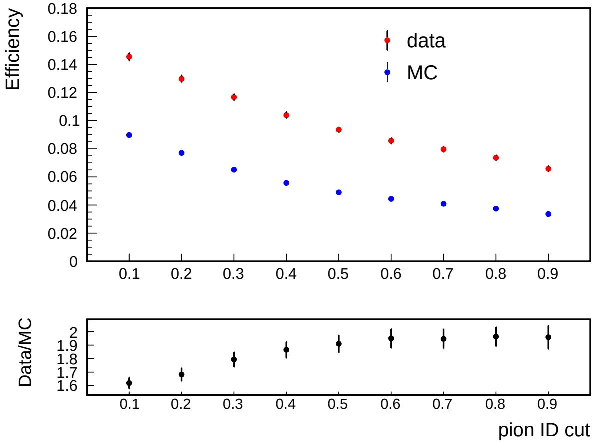


Figure: $\mu^- \rightarrow \pi^-$ fake rate.

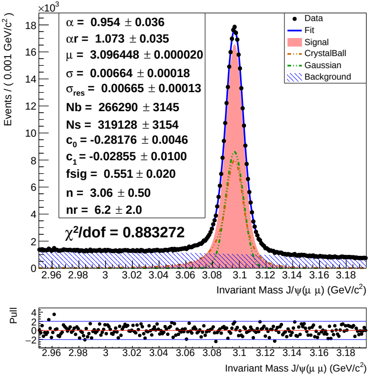
Conclusions

- Procedure using tag and probe method with J/Ψ to determine fake rate on $\ell \rightarrow hadron$.
- Most significant mis-identification comes from $\mu \rightarrow \pi$ (as it was expected because of the similar masses).
- At first look, simulations must be corrected in order to reproduce properly the data.

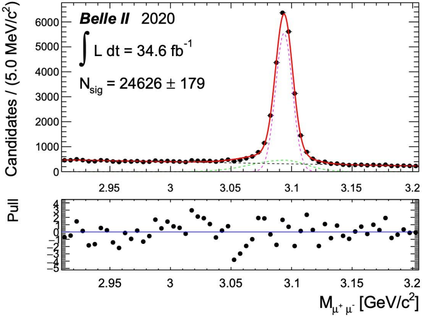
Next steps

- Calculate $e^- \to \pi^-$ and $e^- \to K^-$ fake rates.
- Parametrisation of the corrections in bins of p and θ.
- Determination of the systematics.

$J/\Psi \to \mu^- \mu^+$ comparison



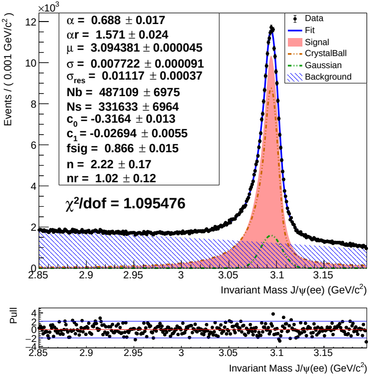
(a) Data sample (Summer Programme).



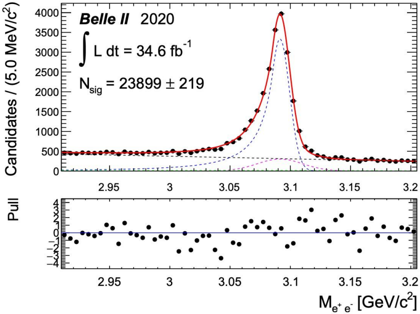
(b) Data sample (2020).

Figure: Comparison between $J/\Psi \to \mu^- \mu^+$ model fits.

$J/\Psi \to e^- e^+$ comparison



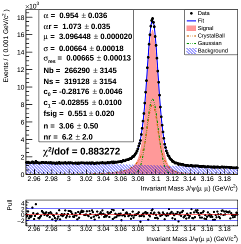
(a) Data sample (Summer Programme).



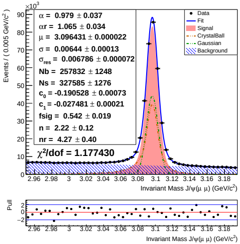
(b) Data sample (2020).

Figure: Comparison between $J/\Psi \to e^- e^+$ model fits.

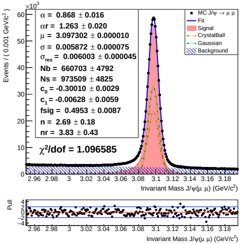
$J/\Psi \rightarrow \mu^-\mu^+$ binned and unbinned fits comparison



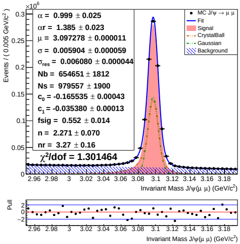
(a) Data binned fit.



(b) Data unbinned fit.

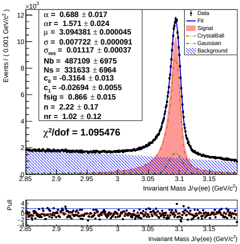


(c) MC binned fit.

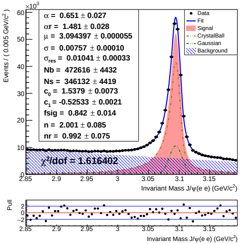


(d) MC unbinned fit.

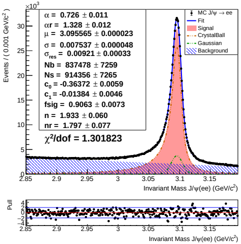
$J/\Psi \to e^- e^+$ binned and unbinned fits comparison



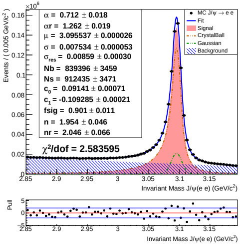
(e) Data binned fit.



(f) Data unbinned fit.



(g) MC binned fit.



(h) MC unbinned fit.