GDR - 2024

Search for lepton flavour violation in $B \to \rho\tau\ell$, at Belle II

Isaac Consigny

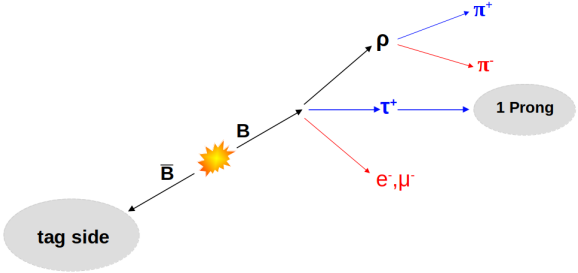
November 7, 2024

$B \to \rho\tau\ell$ - Context

- Search for lepton flavour violation $b \to d\tau\ell$: probe for new physics
- 4 modes to analyse:
  $B \to \rho\tau^+\ell^-$: OSe and OSmu
  $B \to \rho\tau^-\ell^+$: SSe and SSmu
  OS : charge of ℓ opposite sign of the b quark
  SS : charge of ℓ same sign as the b quark

- Upper limits on BR computed by EFT with LHC data in February 2024: link to the paper
  $B \to \rho\tau\mu$: 7×10^{-5}
  $B \to \rho\tau e$: 1.4×10^{-4}

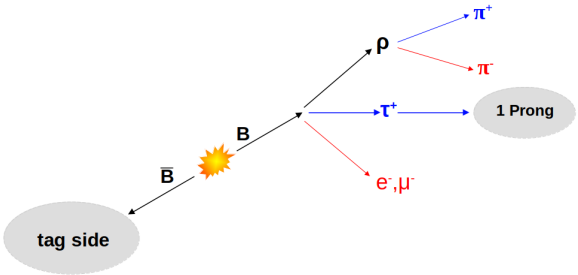
$\to$ This analysis will be the **first direct measurement**



$B \to \rho\tau\ell$ - Tau mass

The signal side is reconstructed as $B \to \rho\ell$ and a track is added for the τ

Recoil mass : $M_\tau = \sqrt{m_B^2 + m_{\rho\ell}^2 - 2(E^*_{Btag}E^*_{\rho\ell} + p^*_{Btag}p^*_{\rho\ell}cos(\theta^*))}$ (***** : center of mass)



$B \to \rho\tau\ell$ - Reconstruction: Two approaches for the reconstruction

Reconstruction using FEI

- Hadronic tagging
- Reconstruction efficiency : $\approx 0.2\%$

$\to$ The constraint comes from the tag

Reconstruction using GraFEI

- **GraFEI** : GNN (graph neural network) trained with MC signal events to recognize it
- The signal side is reconstructed by the GNN
- The tag side is defined with the rest of particles (inclusive tagging)
- Only on the OSe mode for now
- Reconstruction efficency : $\approx 6\%$

$\to$ The constraint comes from the signal

Grafei operation

Input: graph with nodes as track variables (pID, momenta...) and edges as connections between tracks (DOCA, angles...)

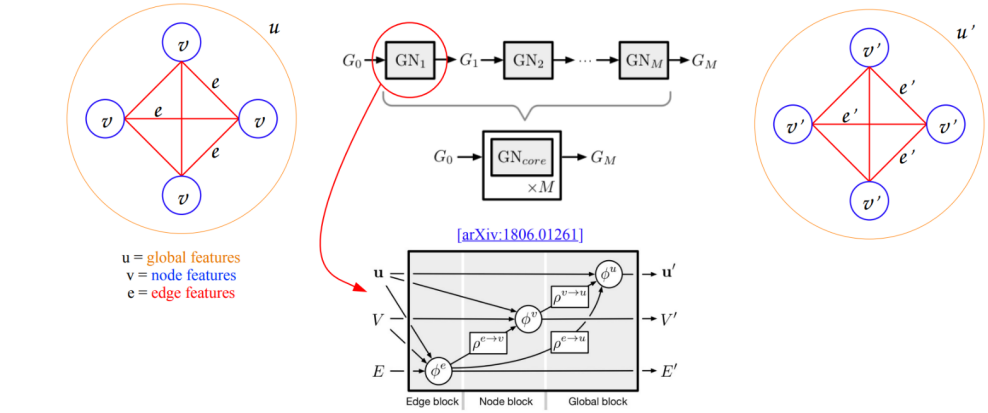


Figure 1: Grafei structure, *J. Cerasoli. slides*

GraFEI : Output

- Nodes = mass hypothesis
- Edges = latest common ancestor
- Nodes and edges are compared to MC truth
- Loss function calculation and GNN parameters update

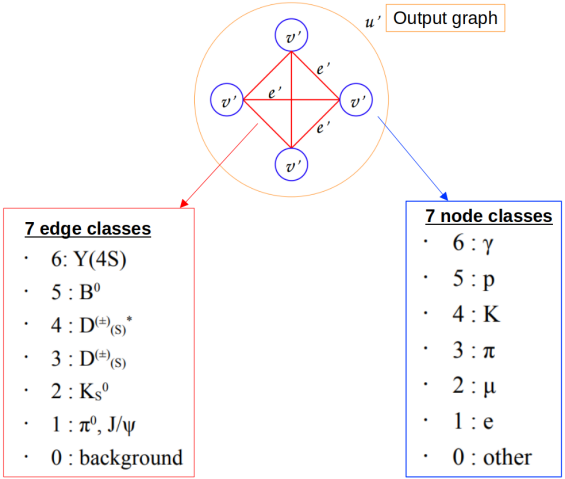
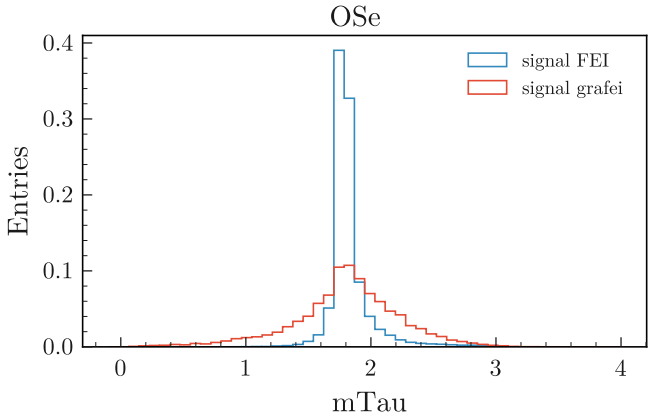


Figure 2: Grafei output

$B \to \rho\tau\ell$ - Reconstruction: FEI and GraFEI, M_τ

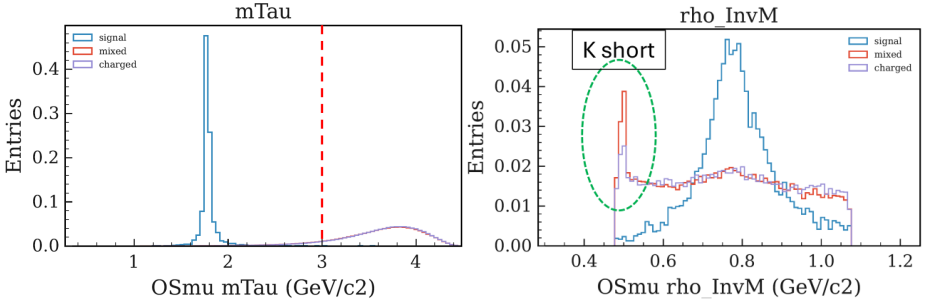
The fei (hadronic) reconstruction has a better resolution than the grafei (inclusive) reconstruction

MC matching signal side for comparison



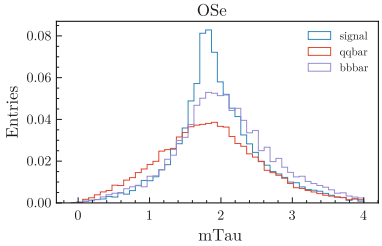
$B \to \rho\tau\ell$ - Background rejection - preselection - FEI

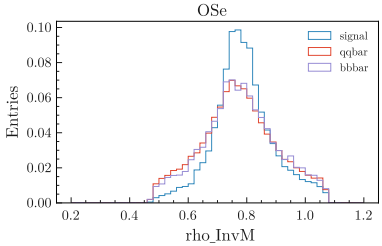
The cut-based preselection is applied **only for the FEI reconstruction**
Variables used for the preselection: M_τ, M_{bc} of tag side B, **invariant masses** of "rho - lepton" and "lepton - tau prong" , number of **charged tracks** in the **ROE**, number of **clusters** in the **ROE**

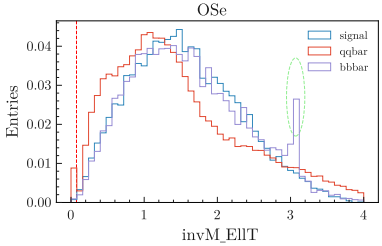


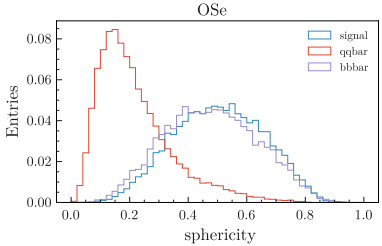
Cut - based selection for the grafei samples ?

→ Very "background like" signal (especially BBbar)
→ Only J/Ψ and $\gamma \to e + e-$ vetos applied
→ BDT - based selection needed









$B \to \rho\tau\ell$ - Backgrounds comparison

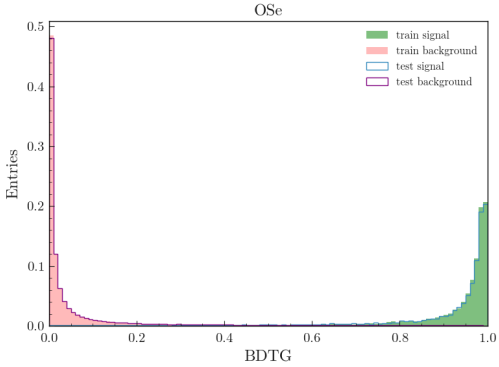
FEI yields are after the cut-based selection.
The inclusive approach reconstruct a lot more background

Background	FEI	GraFEI	ratio GraFEI/FEI
mixed	38777	1017083	26.2
charged	25391	967000	38.1
uubar	93802	3532954	37.7
ddbar	23826	777333	32.6
ccbar	71915	1913478	26.6
ssbar	8192	541521	66.1

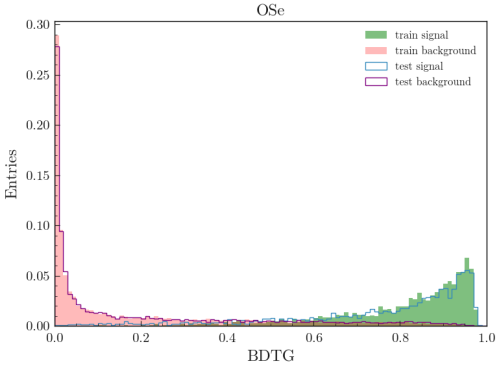
Table 1: Background yield scaled to 1400 fb-1 (mode OSe)

$B \to \rho\tau\ell$ - Background rejection - BDT

FEI samples
Cut at 0.98
Important variables: charged/energy clusters in ROE, sphericity, Btag R2 ...

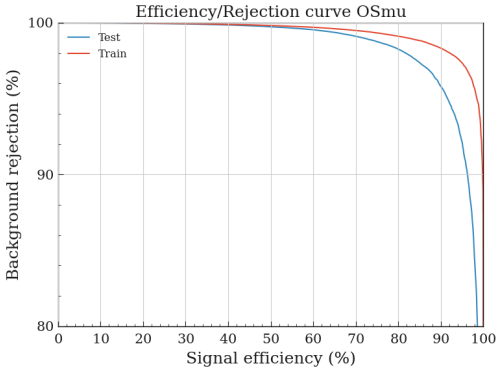


GraFEI samples
Cut at 0.9
Important variables: sphericity, grafei "output", BtagR2 ...

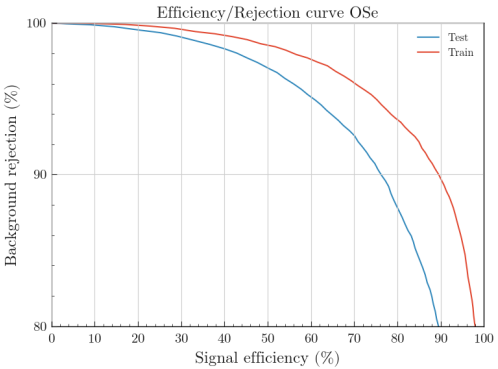


$B \to \rho\tau\ell$ - Background rejection - BDT

FEI samples



GraFEI samples

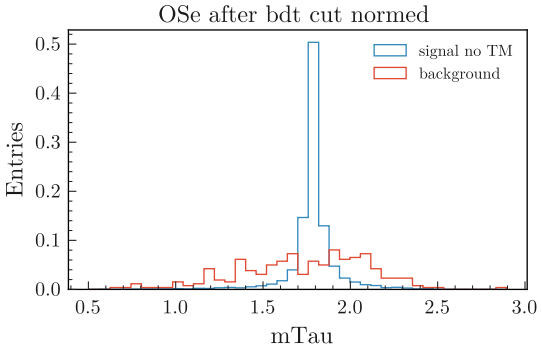


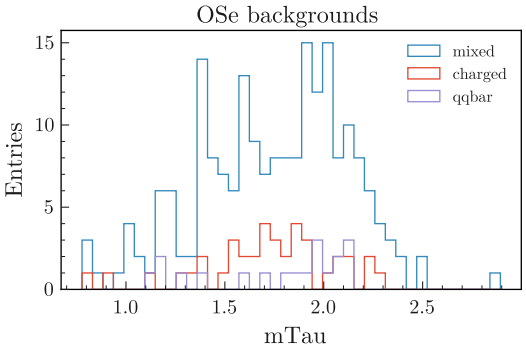
Efficiencies after BDT cut : **FEI** : 0.047 % and **GraFEI** : 1.85%

Remaining background, FEI samples

FEI

- Remaining peak close to the D^* mass (ongoing investigation)
- Possibility to perform a fit

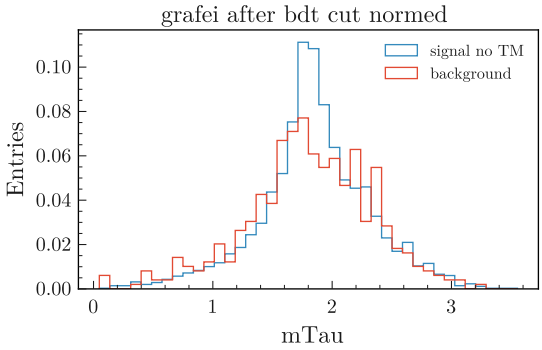


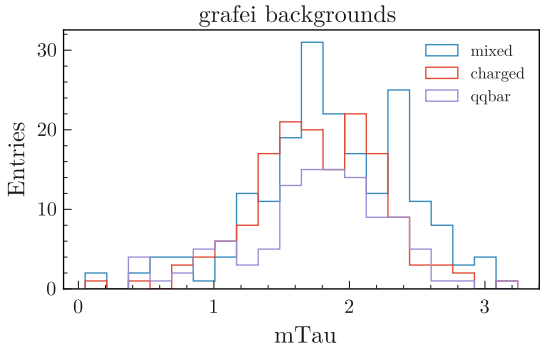


Remaining background, Grafei samples

Grafei

- The signal is still very "background like"
- The reconstruction needs to be improved (better selection of the particles involved in the Btag)





Background yields comparison after the BDT selection

Background	FEI	GraFEI	ratio GraFEI/FEI
mixed	215	42916	199.6
charged	162	32400	200.0
uubar	69	11136	161.4
ddbar	15	2444	162.9
ccbar	57	12391	217.3
ssbar	9	1739	193.2

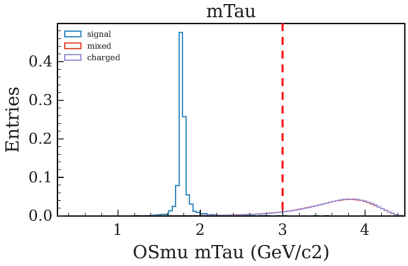
Table 2: Background yield after BDT (scaled to 1400 fb-1 mode OSe)

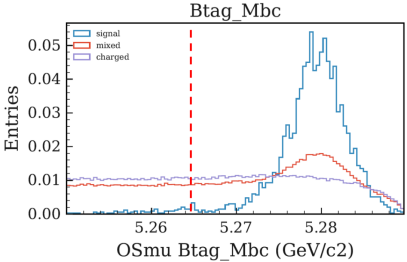
Summary and next steps

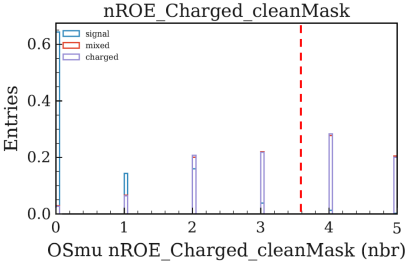
- **FEI** (exclusive) signal efficiency ≈ 0.047 % with good background rejection
  $\rightarrow$ next steps : fit of the M_τ, upper limits...
- **GraFEI** (inclusive approach) signal efficiency ≈ 1.85 %
  $\rightarrow$ background still very high and under the signal
  $\rightarrow$ next steps : improve the reconstruction by selecting the particles involved in the Btag
  $\rightarrow$ improve the selection

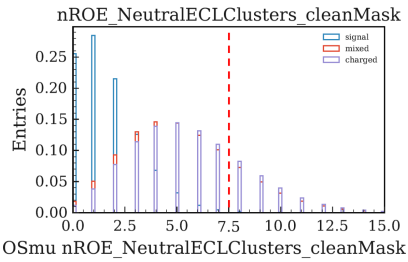
BACK UP

Analyse de $B \to \rho\tau\ell$ - Cut-based selection

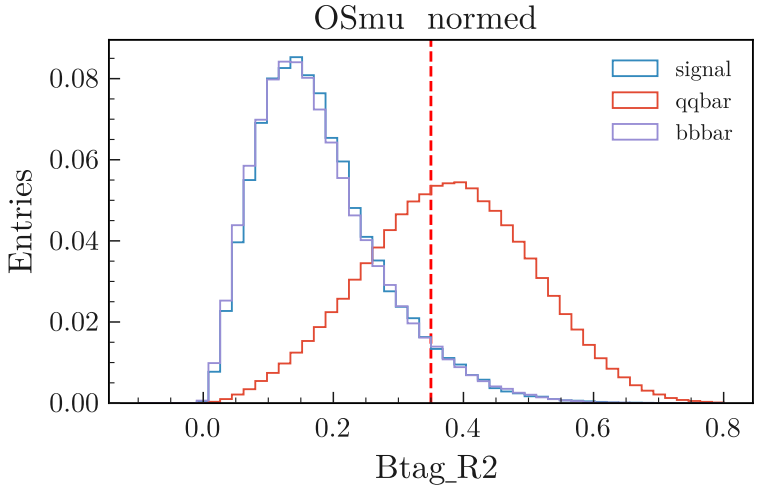




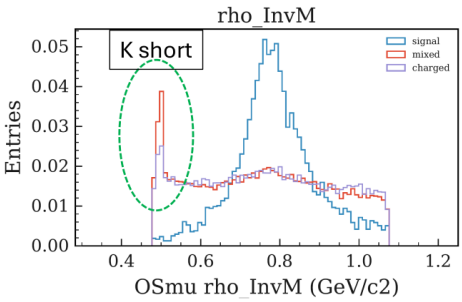


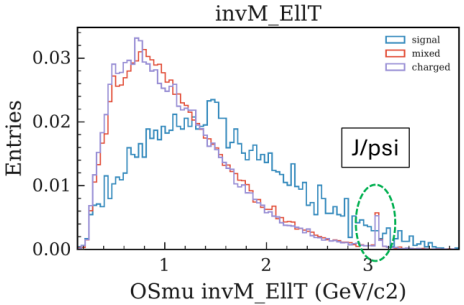


$B \to \rho\tau\ell$ - Selection vs qqbar

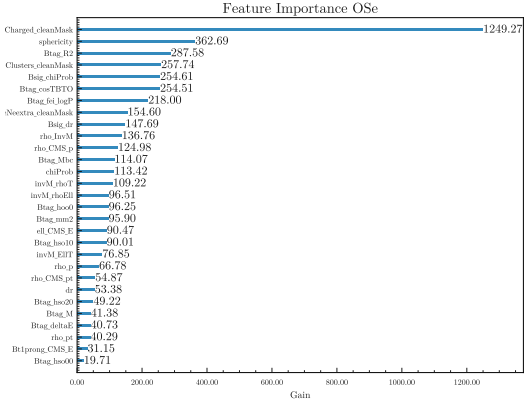


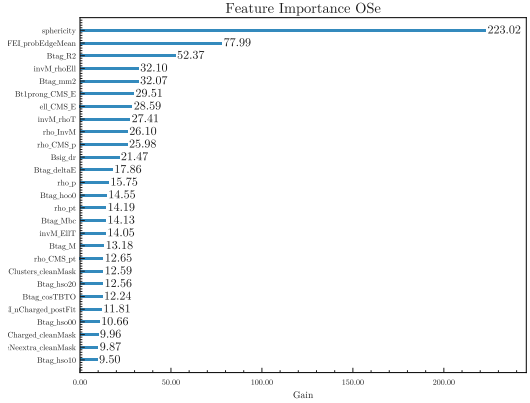
$B \to \rho\tau\ell$ - Vetos





BDT features





7

Figure 3: BDT features importance, FEI (left) and GraFEI (right)