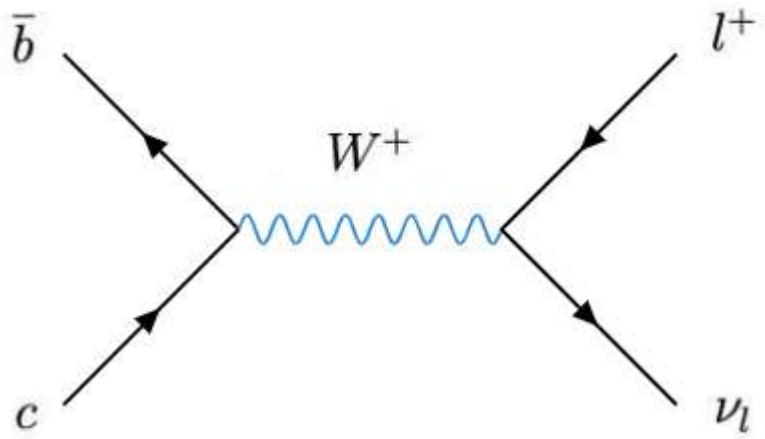
Modelling the Tau lepton decay

Thijs Rozeboom

$$B_c^+ \longrightarrow \tau^+ \left(\longrightarrow \pi^+ \pi^+ \pi^- \overline{\nu}_\tau \right) \nu_\tau$$



$$\tau^+ \to \bar{\nu}_\tau (a_1^+(1260) \to \pi^+ (\rho^0 \to \pi^+ \pi^-))$$

RapidSim
Tauola
EvtGen

How is the Feasibility study performed

Multivariate analysis (MVA)

- GradientBoostingClassifier (GBC) algorithm
  - Optimization of a loss function

Backgrounds

$$B^+ \to \tau^+ \nu_\tau$$

D cocktail (charm cocktail):

$$D^+ \to \tau^+ \nu_\tau$$

$$D_s^+ \to \tau^+ \nu_\tau$$

B cocktail:

$$B^+ \to \bar{D}^0 \tau^+ \nu_\tau$$

$$B^+ \to \bar{D}^{*0} \tau^+ \nu_\tau$$

$$B^+ \to \bar{D}^0 \pi^+ \pi^+ \pi^-$$

$$B^+ \to \bar{D}^{0*} \pi^+ \pi^+ \pi^-$$

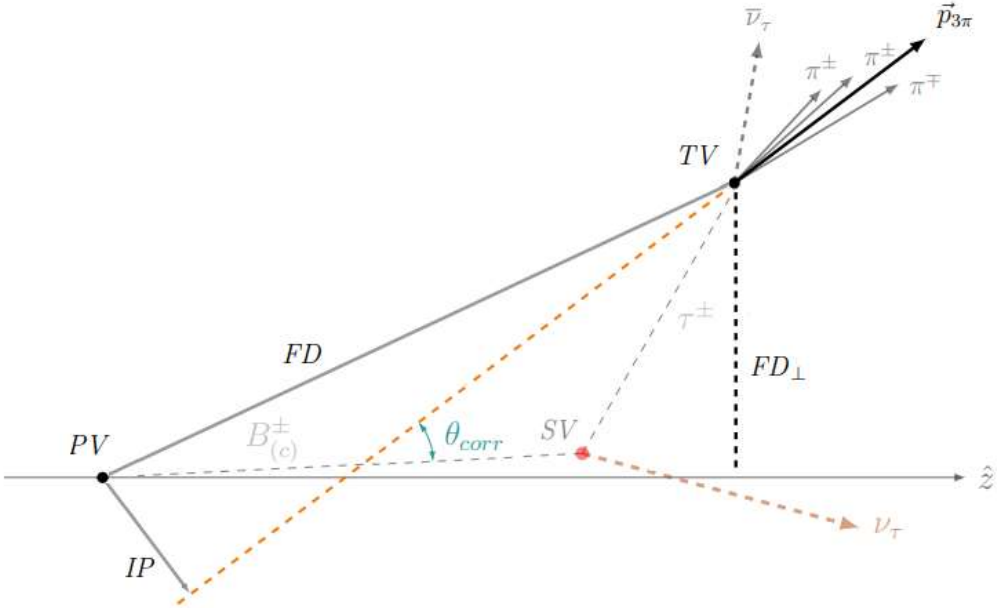
$$B^+ \to \bar{D}^0 (D_s^+ \to \tau^+ \nu_\tau)$$

$$B^+ \to \bar{D}^{0*} (D_s^+ \to \tau^+ \nu_\tau)$$

$$B^+ \to \bar{D}^{0*} (D_s^{*+} \to \gamma (D_s^+ \to \tau^+ \nu_\tau))$$

Observables

Corrected mass
Missing mass
Opening angle
Impact parameter
(Transverse) Flight distance
(Transverse) Momentum



$$m_{corr} = \sqrt{m_{3\pi}^2 + |\vec{p}_\perp(3\pi)|^2} + |\vec{p}_\perp(3\pi)|$$

$$m^2_{miss} = (p^\mu_B - p^\mu_{3\pi})^2 = m^2_B + m^2_{3\pi} - 2p^\mu_B p^\mu_{3\pi}$$

How is the Feasibility study performed

Multivariate analysis (MVA)

- GradientBoostingClassifier (GBC) algorithm
  - Optimization of a loss function

  Area under the Curve (AUC)

Toy Monte Carlo study 2000

- Signal yield
- Likelihood fit
- Probability density function (PDF)

$$\mathrm{N}(B_c^+ \to \tau^+ \nu_\tau) = 1065 = 0.02\% \text{ of PDF}$$

$$\mathrm{N}(B^+ \to \tau^+ \nu_\tau) = 18811 = 0.40\% \text{ of PDF}$$

$$\mathrm{N}(B^+_{cocktail}) = 2955611 = 62.78\% \text{ of PDF}$$

$$\mathrm{N}(D_{cocktail}) = 1732349 = 36.80\% \text{ of PDF}$$

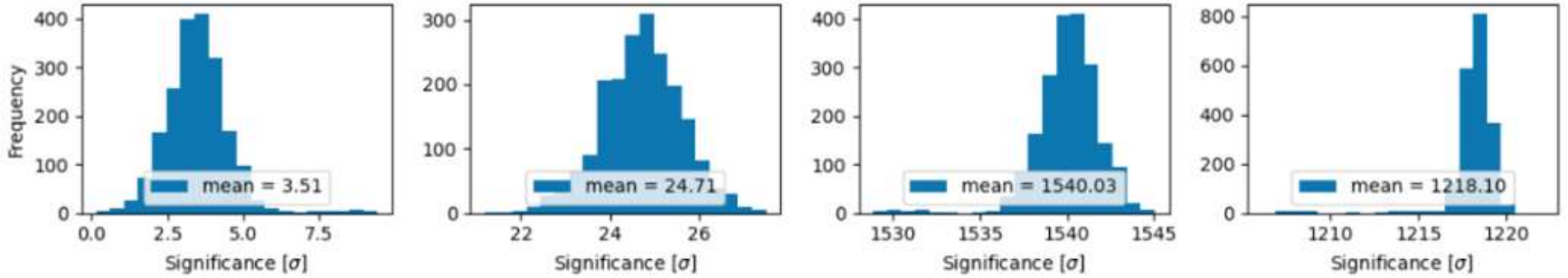
Applying the original MVA

PHSP
- AUC: 0.939

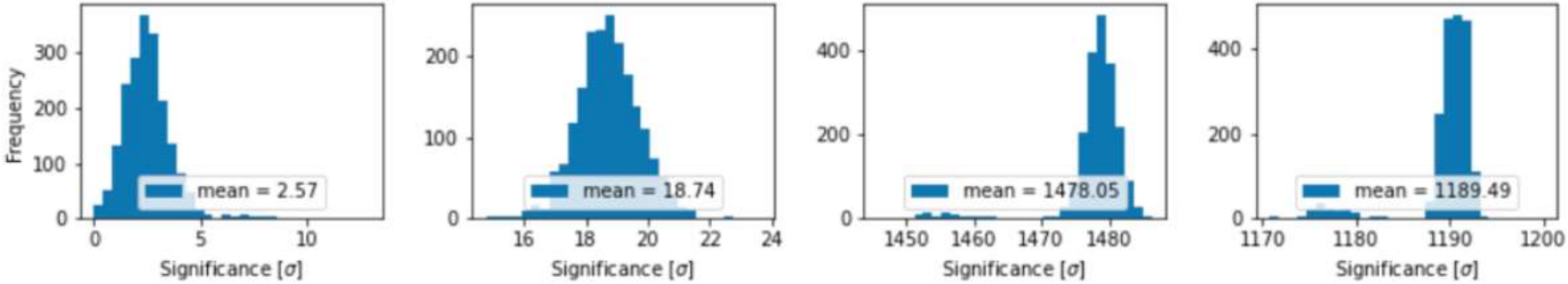
Tauola
- AUC: 0.936

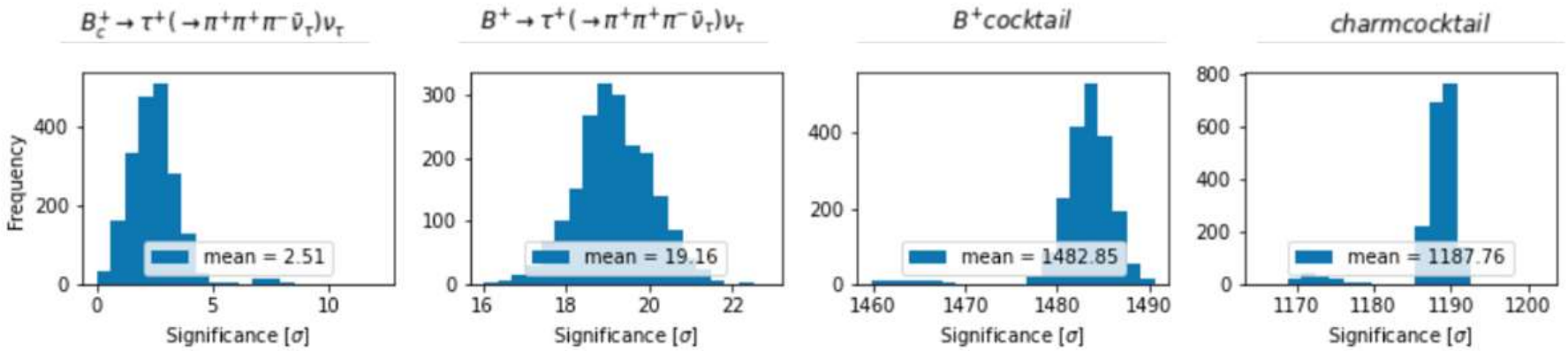
$B_c^+ \to \tau^+(\to \pi^+\pi^+\pi^-\bar{\nu}_\tau)\nu_\tau$	$B^+ \to \tau^+(\to \pi^+\pi^+\pi^-\bar{\nu}_\tau)\nu_\tau$	B^+cocktail	charmcocktail

PHSP



Data with Resonance structure




$B_c^+ \to \tau^+(\to \pi^+\pi^+\pi^-\bar{\nu}_\tau)\nu_\tau$
$B^+ \to \tau^+(\to \pi^+\pi^+\pi^-\bar{\nu}_\tau)\nu_\tau$
B^+cocktail
charmcocktail
Frequency
mean = 2.51
mean = 19.16
mean = 1482.85
mean = 1187.76
Significance [σ]
Significance [σ]
Significance [σ]
Significance [σ]

Including the mass of the three pions

Significance signal decay : 2.94 [σ]

$$B^+ \to \bar{D}^0 \pi^+ \pi^+ \pi^-$$

$$B^+ \to \bar{D}^{0*} \pi^+ \pi^+ \pi^-$$

Decay	$\mathcal{BR}$	Yield
$B_c^+ \to \tau^+\nu_\tau$	1.82×10^{-3}	1065
$B^+ \to \tau^+\nu_\tau$	1.015×10^{-5}	18811
$\boldsymbol{D_{cocktail}}$		1732346
$D^+ \to \tau^+\nu_\tau$	1.12×10^{-4}	646382
$D_s^+ \to \tau^+\nu_\tau$	4.95×10^{-3}	1085963
$\boldsymbol{B^+_{cocktail}}$		2955605
$B^+ \to \bar{D}^0\tau^+\nu_\tau$	7.17×10^{-4}	141883
$B^+ \to \bar{D}^{*0}\tau^+\nu_\tau$	1.75×10^{-3}	342555
$B^+ \to \bar{D}^0\pi^+\pi^+\pi^-$	0.0056	850585
$B^+ \to \bar{D}^{0*}\pi^+\pi^+\pi^-$	1.03×10^{-2}	1564469
$B^+ \to \bar{D}^0 D_s^+$	4.45×10^{-5}	15831
$B^+ \to \bar{D}^{0*} D_s^+$	4.06×10^{-5}	14144
$B^+ \to \bar{D}^{0*}(D_s^{*+} \to \gamma D_s^+)$	7.91×10^{-5}	26135

$$B^+ \to \bar{D}^0\pi^+\pi^+\pi^-$$

Decay channel	Branch fraction	Label
$B^+ \to (\bar{D}^0 \to K^+\pi^-)(a_1(1260) \to (\rho^0 \to \pi^+\pi^-)\pi^+)$	0.66	A.0
$B^+ \to (\bar{D}^0 \to K^+\pi^-)(\rho^0 \to \pi^+\pi^-)\pi^+$	0.08	A.1
$B^+ \to (\bar{D}^0 \to K^+\pi^-)(f2 \to \pi^+\pi^-)\pi^+$	0.12	A.2
$B^+ \to (\bar{D}_{10} \to (D^{*+} \to (D^0 \to K^+\pi^-)\pi^+)\pi^-)\pi^+$	0.098	A.3
$B^+ \to (\bar{D}_{10} \to (D^0 \to K^+\pi^-)\pi^-\pi^+)\pi^+$	0.042	A.4

Table 2: Different decay channels for the $B^+ \to \bar{D}^0\pi^+\pi^+\pi^-$ decay.

$B^+ \to \bar{D}^{0*}\pi^+\pi^+\pi^-$

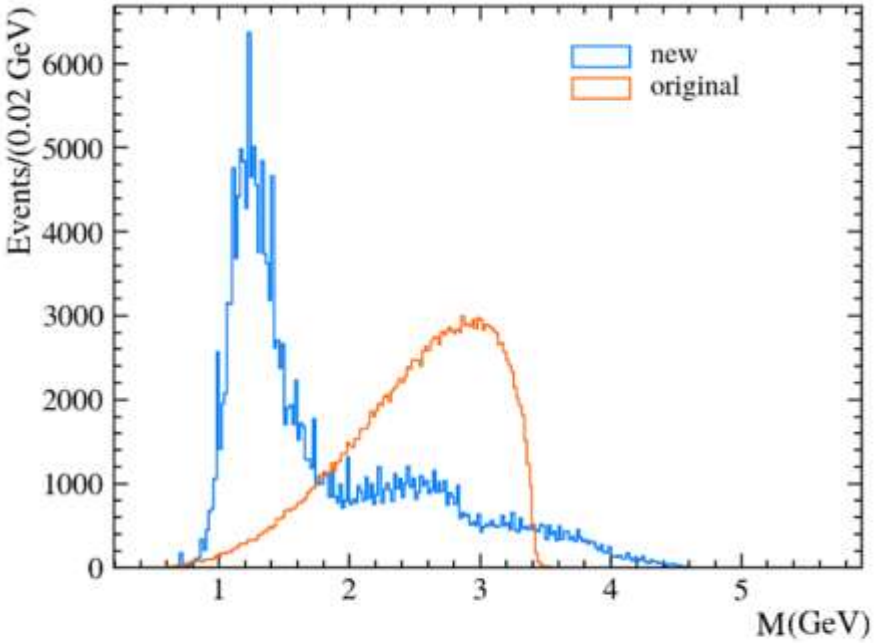
Decay channel	Branch fraction	Label
$B^+ \to (\bar{D}^{0*} \to (D^0 \to K^+\pi^-)\gamma)(a_1(1260) \to (\rho^0 \to \pi^+\pi^-)\pi^+)$	0.70	B.0
$B^+ \to (\bar{D}^{0*} \to (D^0 \to K^+\pi^-)\gamma)(f2 \to \pi^+\pi^-)\pi^+$	0.13	B.1
$B^+ \to (\bar{D}^{0*} \to (D^0 \to K^+\pi^-)\gamma)(\rho^0 \to \pi^+\pi^-)\pi^+$	0.12	B.2
$B^+ \to (\bar{D}^{0*} \to (D^0 \to K^+\pi^-)\gamma)\pi^+\pi^+\pi^-$	0.05	B.3

Table 3: Description of decay channels of $B^+ \to \bar{D}^{0*}\pi^+\pi^+\pi^-$ decay that result in one γ in final state (gamma 1).

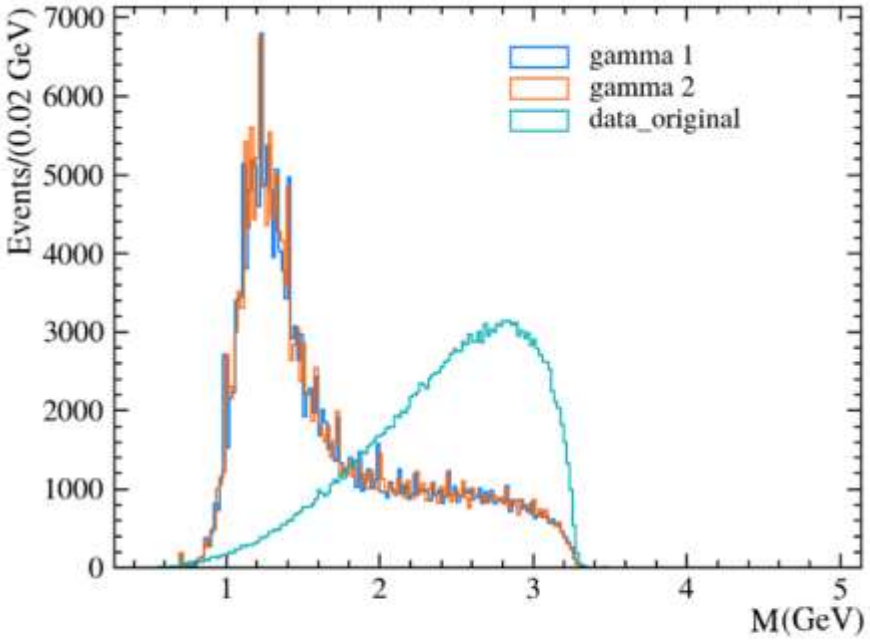
Decay channel	Branch fraction	Label
$B^+ \to (\bar{D}^{0*} \to (D^0 \to K^+\pi^-)(\pi^0 \to \gamma\gamma))(a_1(1260) \to (\rho^0 \to \pi^+\pi^-)\pi^+)$	0.70	C.0
$B^+ \to (\bar{D}^{0*} \to (D^0 \to K^+\pi^-)(\pi^0 \to \gamma\gamma))(f2 \to \pi^+\pi^-)\pi^+$	0.13	C.1
$B^+ \to (\bar{D}^{0*} \to (D^0 \to K^+\pi^-)(\pi^0 \to \gamma\gamma))(\rho^0 \to \pi^+\pi^-)\pi^+$	0.12	C.2
$B^+ \to (\bar{D}^{0*} \to (D^0 \to K^+\pi^-)(\pi^0 \to \gamma\gamma))\pi^+\pi^+\pi^-$	0.05	C.3

Table 4: Description of decay channels of $B^+ \to \bar{D}^{0*}\pi^+\pi^+\pi^-$ decay that result in two γ in final state (gamma 2).

Mass of three pions



(a) $B^+ \to \bar{D}^0\pi^+\pi^+\pi^-$



(b) $B^+ \to \bar{D}^{0*}\pi^+\pi^+\pi^-$

MVA gamma 1

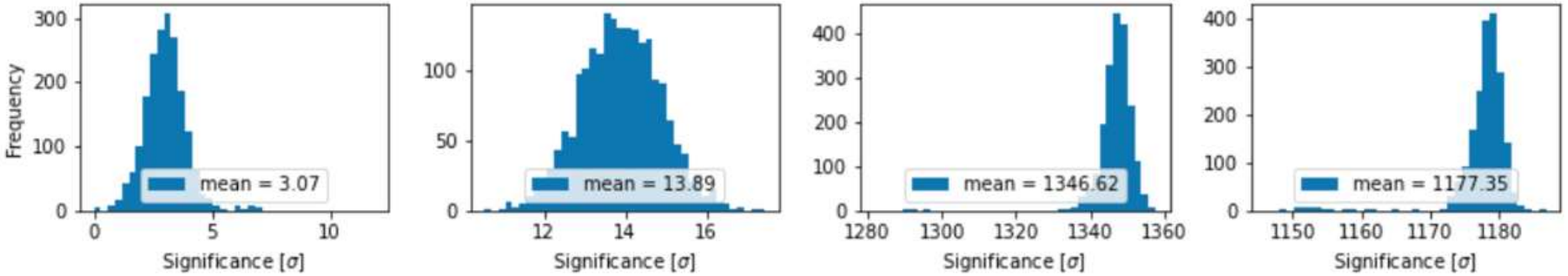
- AUC: 0.927

MVA gamma 2

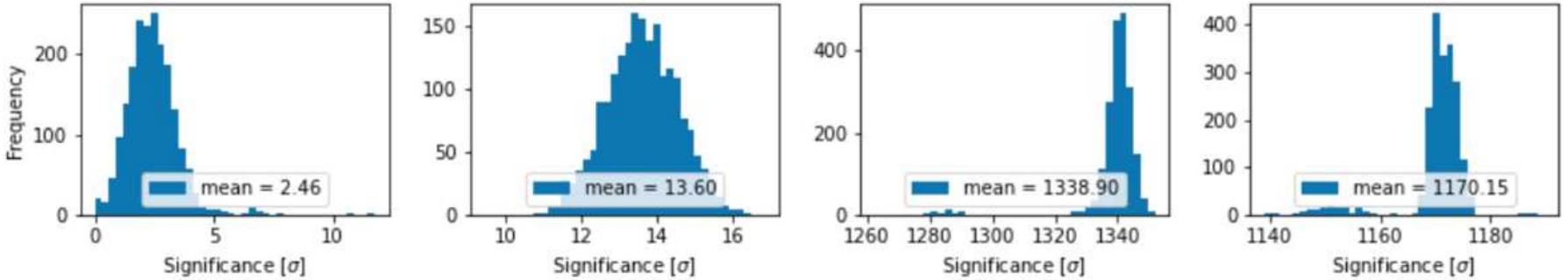
- AUC: 0.927

$B_c^+ \to \tau^+(\to \pi^+\pi^+\pi^-\bar{\nu}_\tau)\nu_\tau$	$B^+ \to \tau^+(\to \pi^+\pi^+\pi^-\bar{\nu}_\tau)\nu_\tau$	B^+cocktail	charmcocktail

MVA gamma 1



MVA gamma 2



Conclusion

Introduction of Tau resonance structure
Improvement description direct decays