Measurement of the Tau Polarisation in Z Boson Decays

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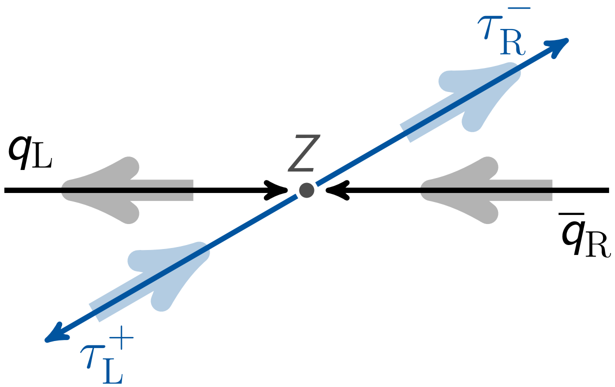
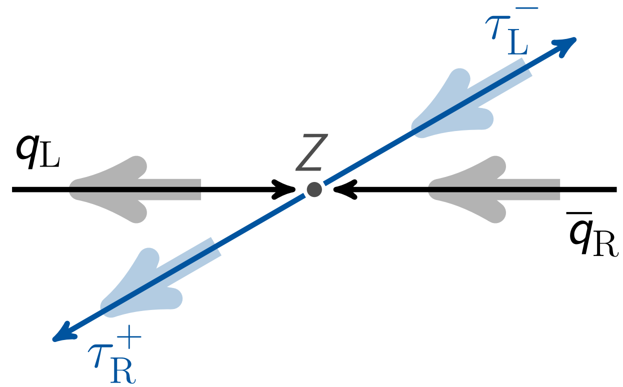
Tau Polarisation





$$\mathrm{N}\left(\tau_R^- \tau_L^+\right) \propto \left(g_R^\tau\right)^2 \left[\left(g_R^q\right)^2 + \left(g_L^q\right)^2\right]$$

$$\mathrm{N}\left(\tau_L^- \tau_R^+\right) \propto \left(g_L^\tau\right)^2 \left[\left(g_R^q\right)^2 + \left(g_L^q\right)^2\right]$$

$$\langle P_\tau \rangle = \frac{\mathrm{N}\left(\tau_R^- \tau_L^+\right) - \mathrm{N}\left(\tau_L^- \tau_R^+\right)}{\mathrm{N}\left(\tau_R^- \tau_L^+\right) + \mathrm{N}\left(\tau_L^- \tau_R^+\right)} \simeq -2\left(1 - 4\sin^2\theta_{\mathrm{eff}}\right)$$

Event Selection

- **Starting point:** $Z/H \to \tau\tau$ analysis of $35.9\mathrm{fb}^{-1}$ of data from 2016
- **Considered decay channel:** $e\tau_h$, $\mu\tau_h$ and $\tau_h\tau_h$
- **Hadronic tau decays:** $\tau_h \to \pi$ and $\tau_h \to \rho \to \pi^{\pm}\pi^{0}$
- **Mass window cut:** $40\,\mathrm{GeV} < \mathrm{m_{vis}} < 80\,\mathrm{GeV}$

MT Channel

- **Trigger:**
  - single muon trigger, $p_{\mathrm{T}} > 24\,\mathrm{GeV}$
- **Muon:**
  - $p_{\mathrm{T}}(\mu) > 25\,\mathrm{GeV}$
- **Hadronic tau:**
  - $p_{\mathrm{T}}(\tau_{\mathrm{had}}) > 20\,\mathrm{GeV}$

ET Channel

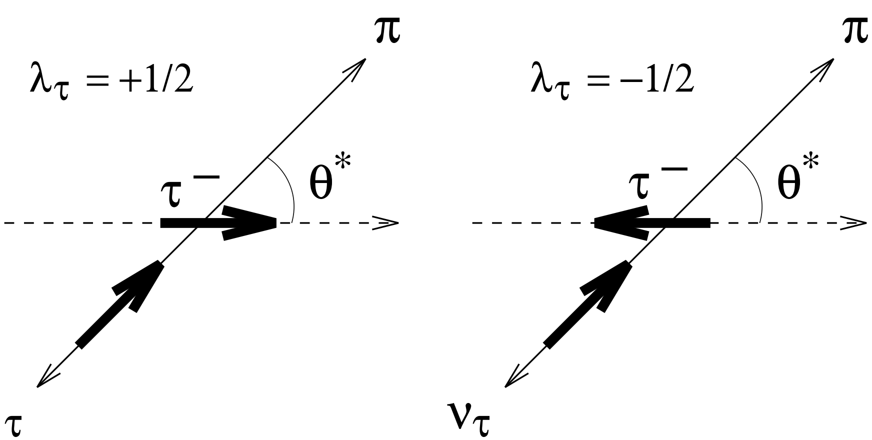
- **Trigger:**
  - single electron trigger, $p_{\mathrm{T}} > 25\,\mathrm{GeV}$
- **Electron:**
  - $p_{\mathrm{T}}(\mathrm{e}) > 26\,\mathrm{GeV}$
- **Hadronic tau:**
  - $p_{\mathrm{T}}(\tau_{\mathrm{had}}) > 20\,\mathrm{GeV}$

TT Channel

- **Trigger:**
  - double tau trigger, $p_{\mathrm{T}} > 35\,\mathrm{GeV}$
- **Hadronic taus:**
  - $p_{\mathrm{T}}(\tau_{\mathrm{had}}) > 40\,\mathrm{GeV}$

Sensitive $\tau_h \rightarrow \pi$ and $\tau_h \rightarrow \rho \rightarrow \pi^{\pm}\pi^{0}$ Quantities

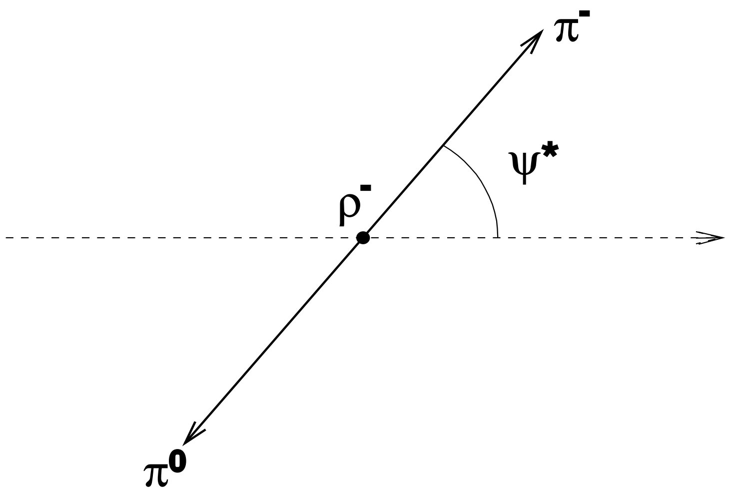
Single Pion:



$$\tau_h \rightarrow \pi : \quad \cos\theta^* \propto \frac{E_{\pi^{\pm}}}{E_{\tau}}$$

$$\tau_h \rightarrow \pi^{\pm}\pi^{0} : \quad \cos\Psi^* \propto \frac{E_{\pi^{\pm}} - E_{\pi^{0}}}{E_{\pi^{\pm}} + E_{\pi^{0}}}$$

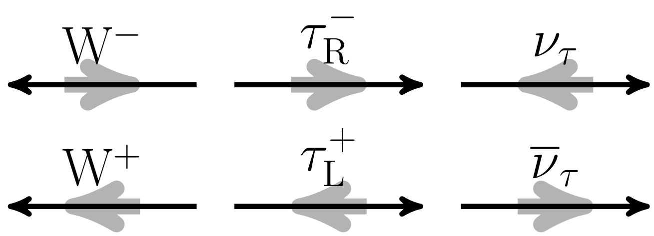
Rho:



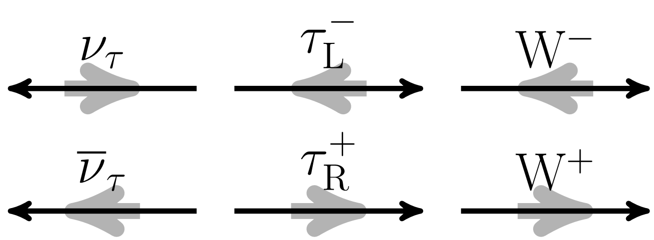
$$\cos\psi^* = \frac{m_\rho}{\sqrt{m_\rho^2 - 4m_\pi^2}} \frac{E_{\pi^-} - E_{\pi^0}}{|\vec{P}_{\pi^-} + \vec{P}_{\pi^0}|}$$

Sensitive Quantity: Visible di-τ Mass

Possible τ decays:

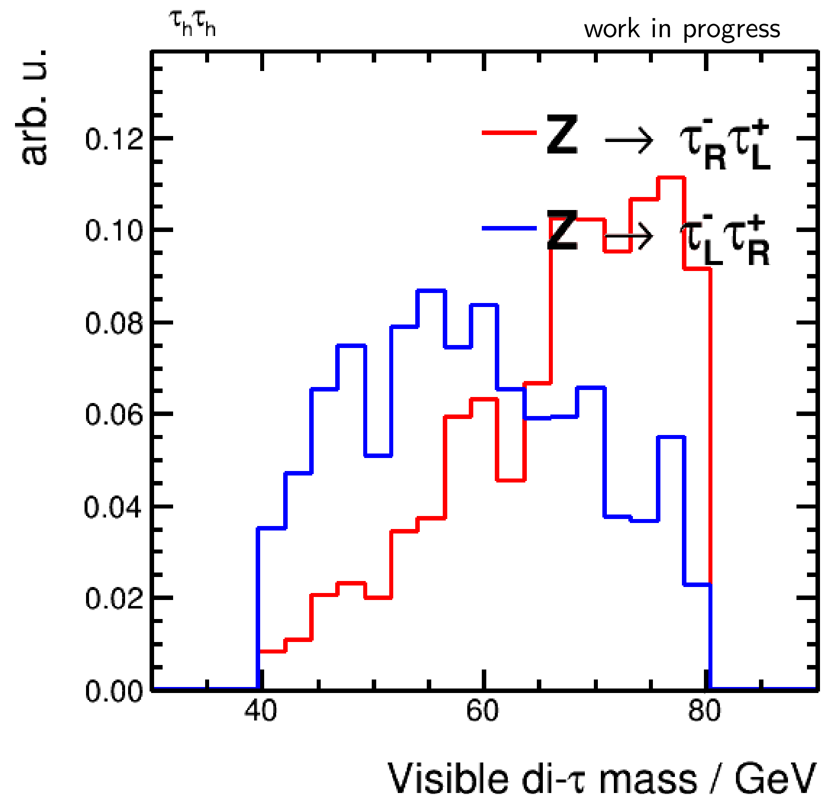


$\Rightarrow Z \to \tau_R^- \tau_L^+$: high m_{vis}



$\Rightarrow Z \to \tau_L^- \tau_R^+$: low m_{vis}

Full hadronic τ decay to single pions:



Analysis Method

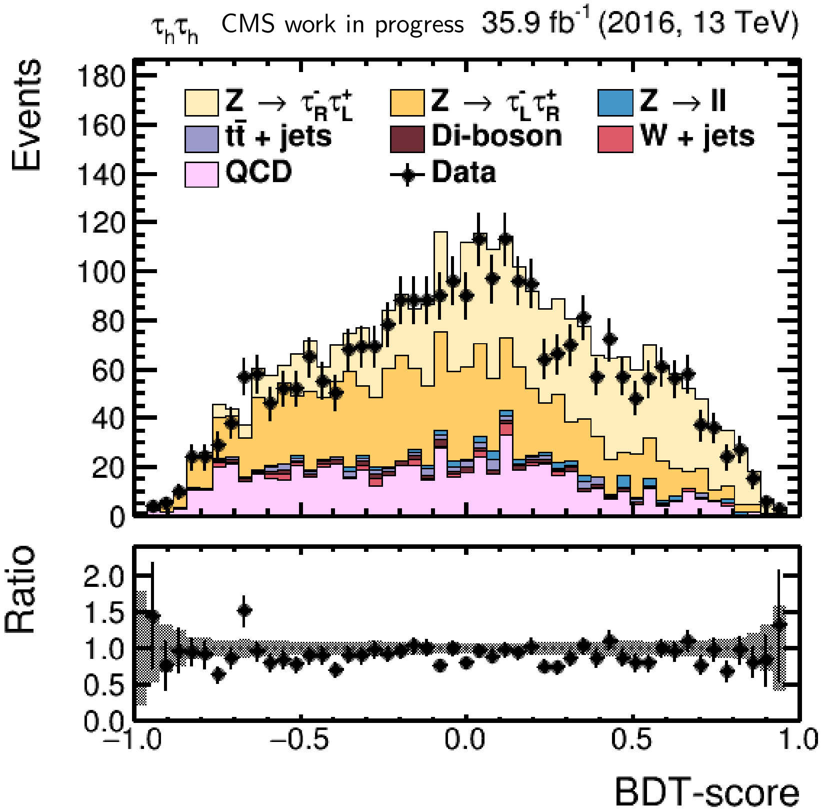
- Separation of two helicity states with BDT
- Input variables:
  - **Single pion** sensitive variable: $(E_{\mathrm{vis}}/E_\tau)$
  - **Angle** ϕ between visible decay products and τ
  - **Rho** sensitive variable: $(E_{\pi^\pm} - E_{\pi^0})/(E_{\pi^\pm} + E_{\pi^0})$
  - τ_h decaymode
  - Transversal momenta p_{T}
  - Visible and fully reconstructed di-τ mass

- Boosting method: AdaBoost
- Hyperparameter optimized with grid search method
- Best set of Hyperparameter:
  - Min events per leaf: 5%
  - Max depth of each tree: 10
  - Number of estimator: 50
  - Learning rate: 0.1

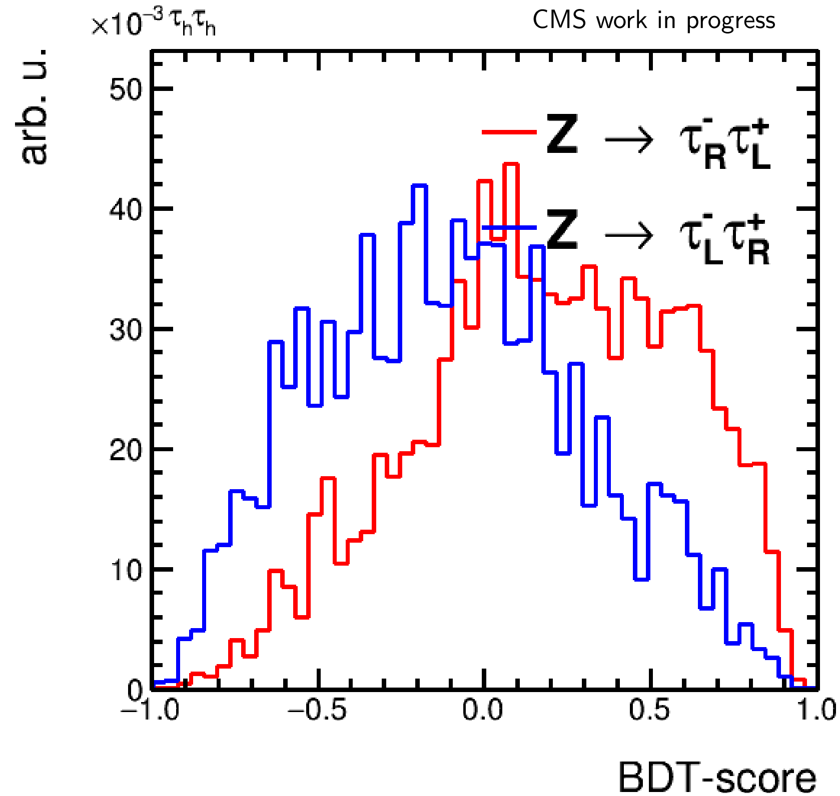
Combine the information of both taus!

BDT Outputs

Data/MC



Shape



Global Fit

- Modelling of samples done consistently with current $Z/H \to \tau\tau$ analysis
- BDT discriminator as input variable
- **Fitting model**
  - Binned Likelihood fit
  - $N_{\mathrm{obs}} = r \cdot \left[N^{+}_{\mathrm{reco}} \left(1 + \langle P_{\tau} \rangle\right) + N^{-}_{\mathrm{reco}} \left(1 - \langle P_{\tau} \rangle\right) \right] + N_{\mathrm{bkg}}$
  - Two fit parameters

    Average τ polarisation $\langle P_{\tau} \rangle$ (parameter of interest)

    Overall $Z \to \tau\tau$ signal strength r (freely floating parameter)
- Fit $e\tau_h$, $\mu\tau_h$ and $\tau_h\tau_h$ channels/categories individually and combined
- Use Asimov dataset with fixed $\langle P_{\tau} \rangle = -15.9\%$

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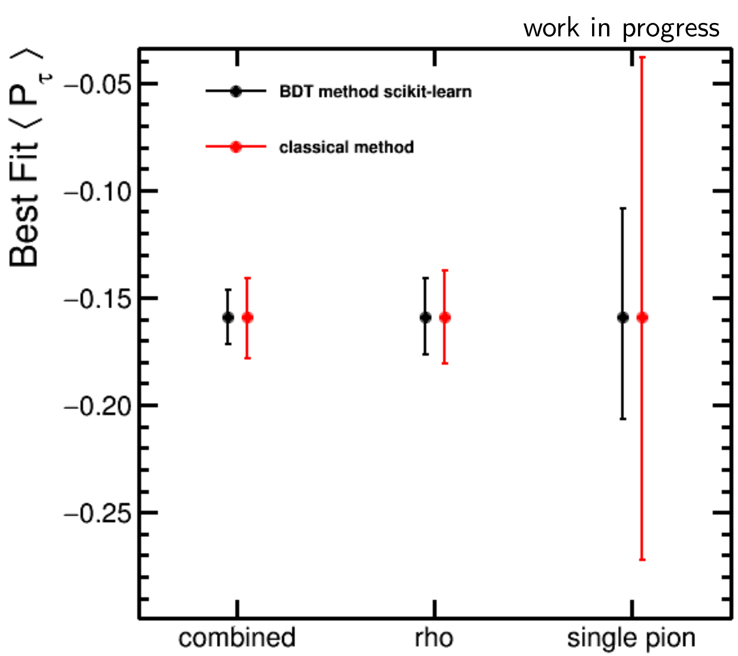
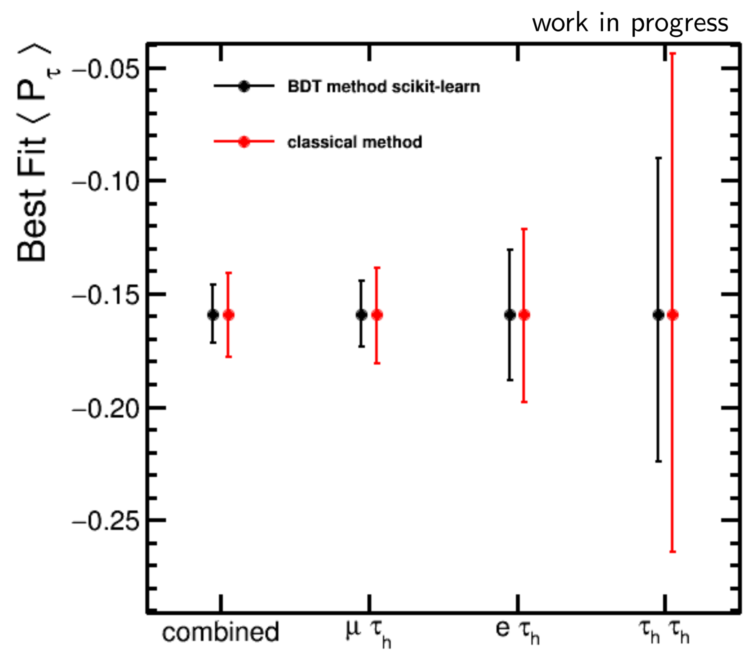
Expected Sensitivity

- Statistical and yield uncertainties shown (no shape uncertainties)
- MVA shows significant improvements, especially in single pion category
- Improvement of $\approx 36.8\%$ by using a BDT in comparison to the classical variable

Categories

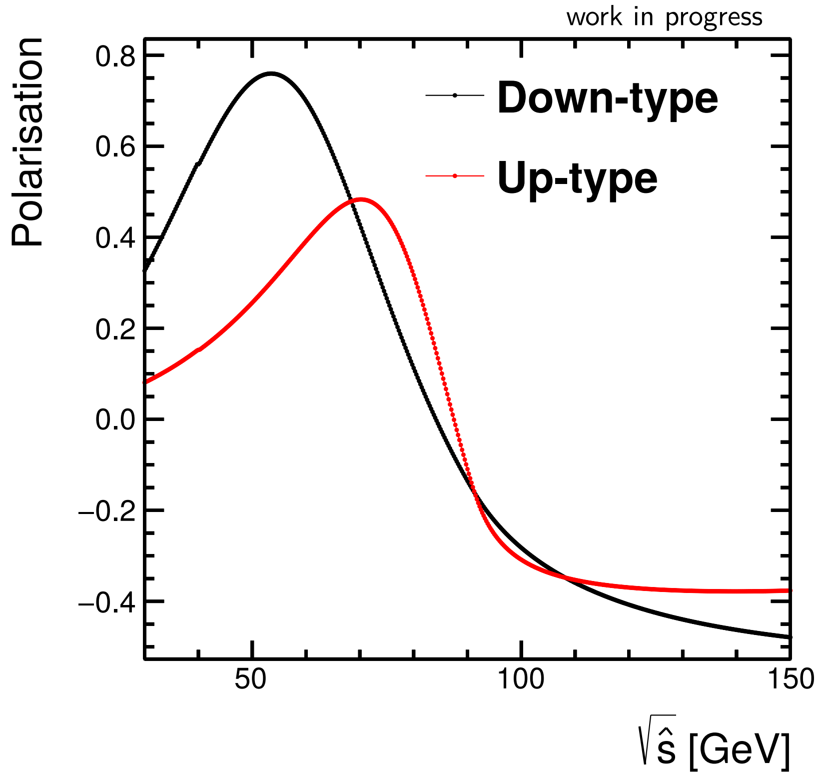


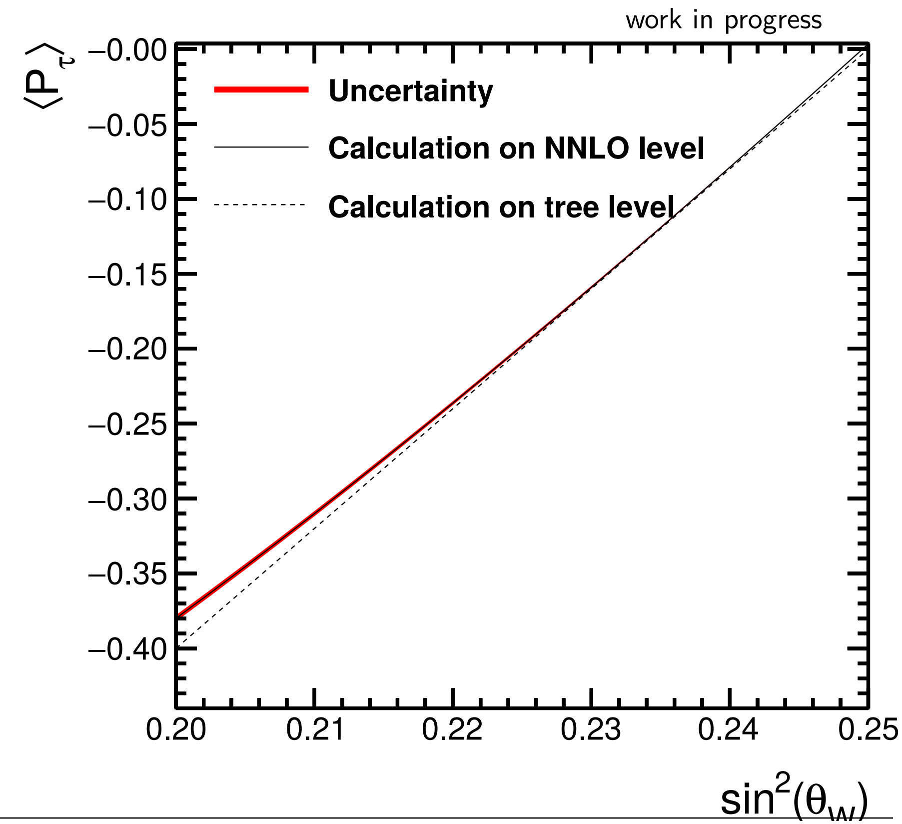
Channel



γ/Z interference

- γ/Z interference needs to be considered near the Z pole
- Polarisation depends on up- or down-type quark collision (weighted average 80 GeV $< m_{\tau\tau} <$ 110 GeV)
- Calibration curve shows only marginal deviations to the simplified linear relation



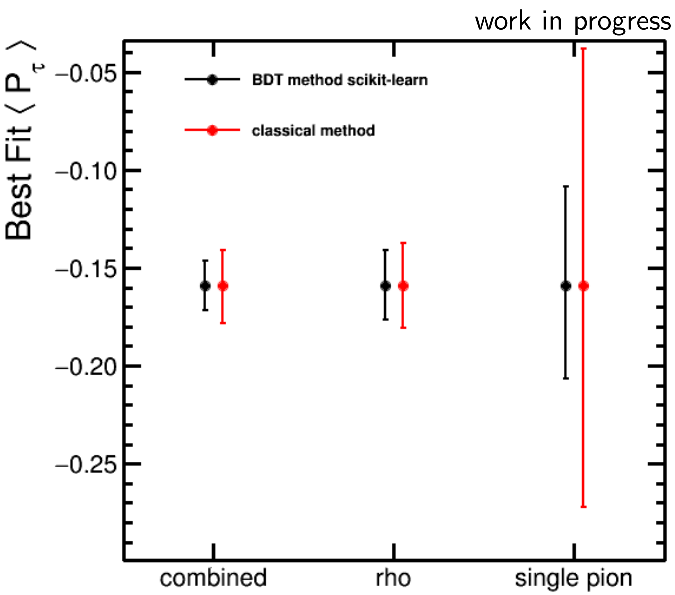


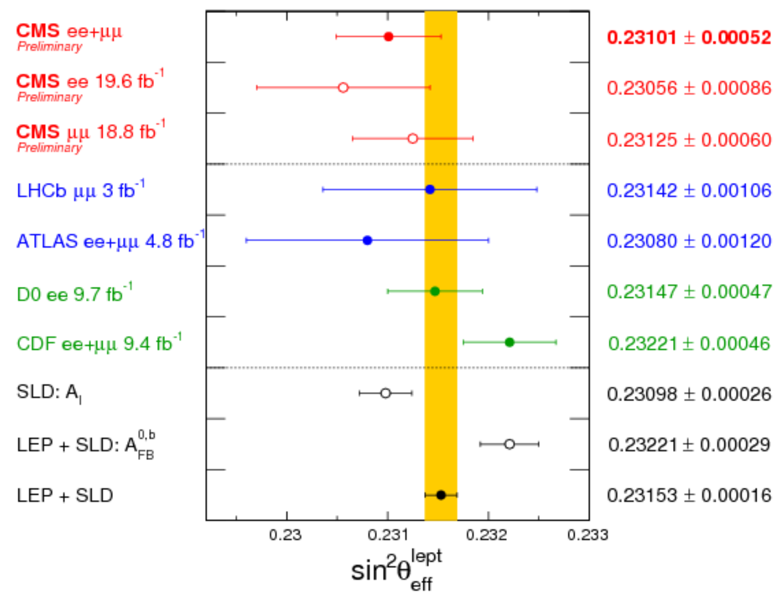
Summary and Outlook

- Expected improvement of the BDT method is $\approx 36.8\%$ (combined)
- Study of shape uncertainties and a_1-channel
- Investigation of radiative and loop corrections
- Calculating calibration curve for all channel and categories

Comparison:

- Classic: $\sin^2\theta_{\text{eff}} = 0.2310 \pm 0.0023$
- MVA: $\sin^2\theta_{\text{eff}} = 0.2310 \pm 0.0015$
- CMS-PAS-SMP-16-007: $\sin^2\theta_{\text{eff}} = 0.23101 \pm 0.00052$

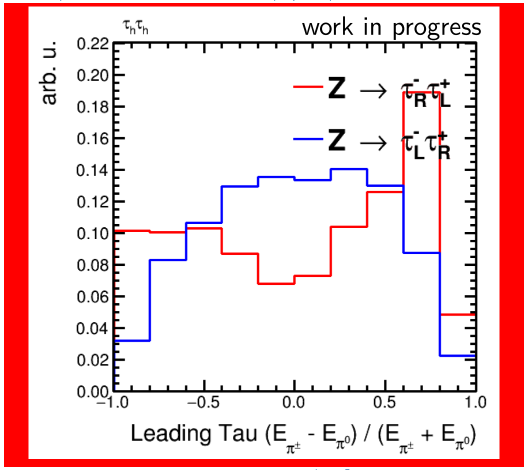




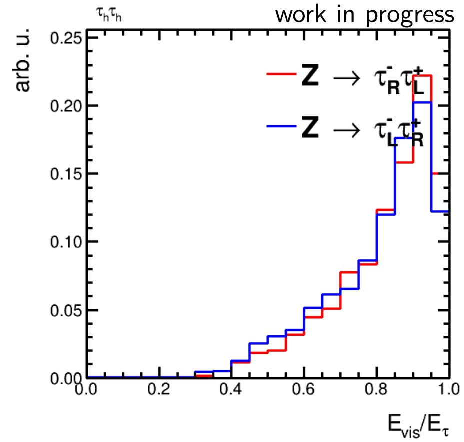
— BACKUP —

Input Variables for rho category in $\tau_h \tau_h$

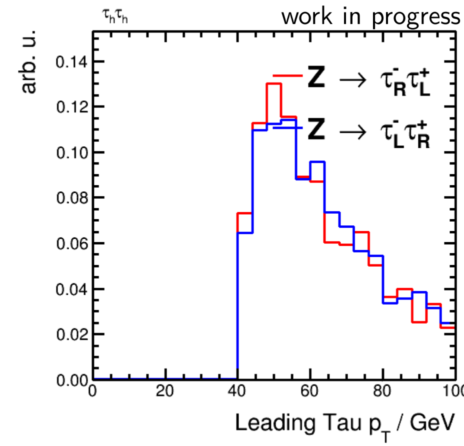
$(E_{\pi^\pm} - E_{\pi^0})/(E_{\pi^\pm} + E_{\pi^0})$



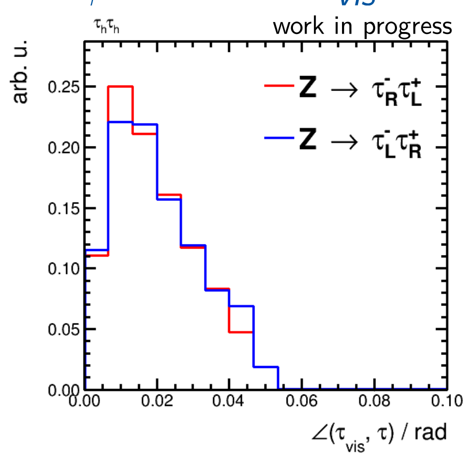
E_{vis}/E_τ



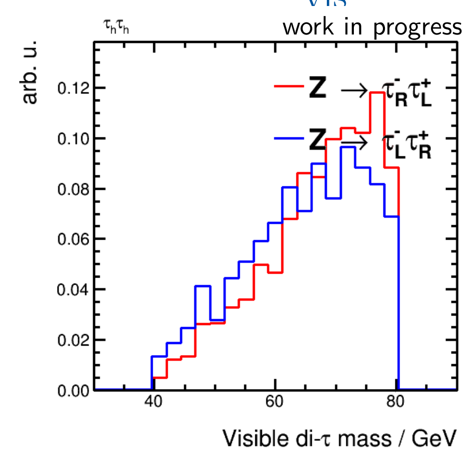
p_T



ϕ between τ_{vis} and τ

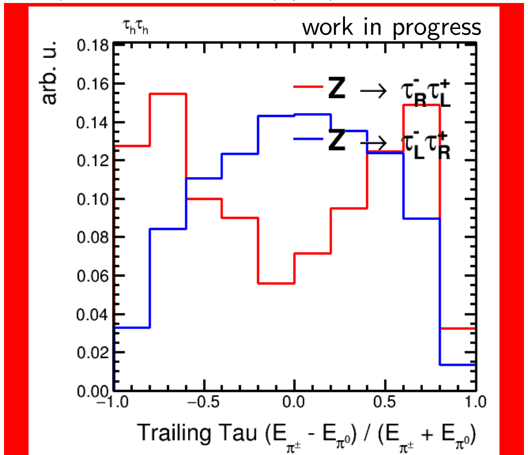


m_vis

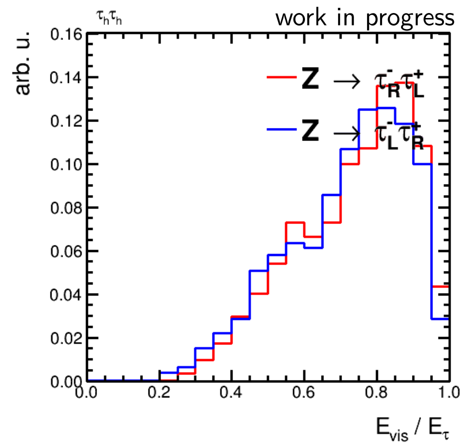


Input Variables for rho category in $\tau_h\tau_h$

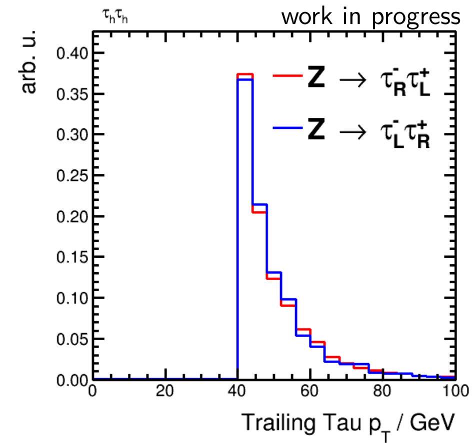
$(E_{\pi^\pm} - E_{\pi^0})/(E_{\pi^\pm} + E_{\pi^0})$



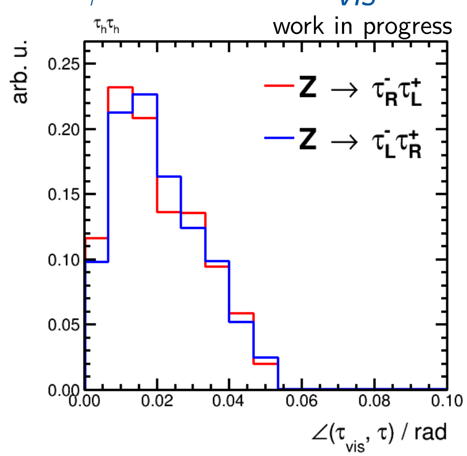
E_{vis}/E_τ



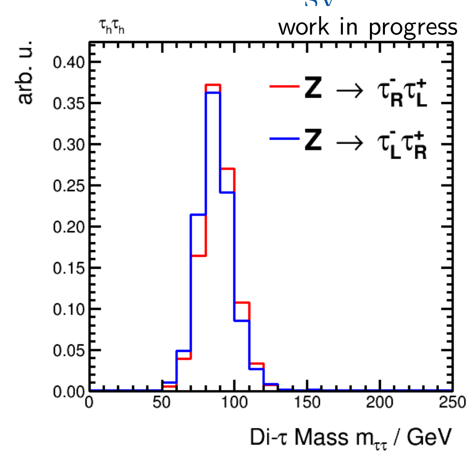
p_{T}



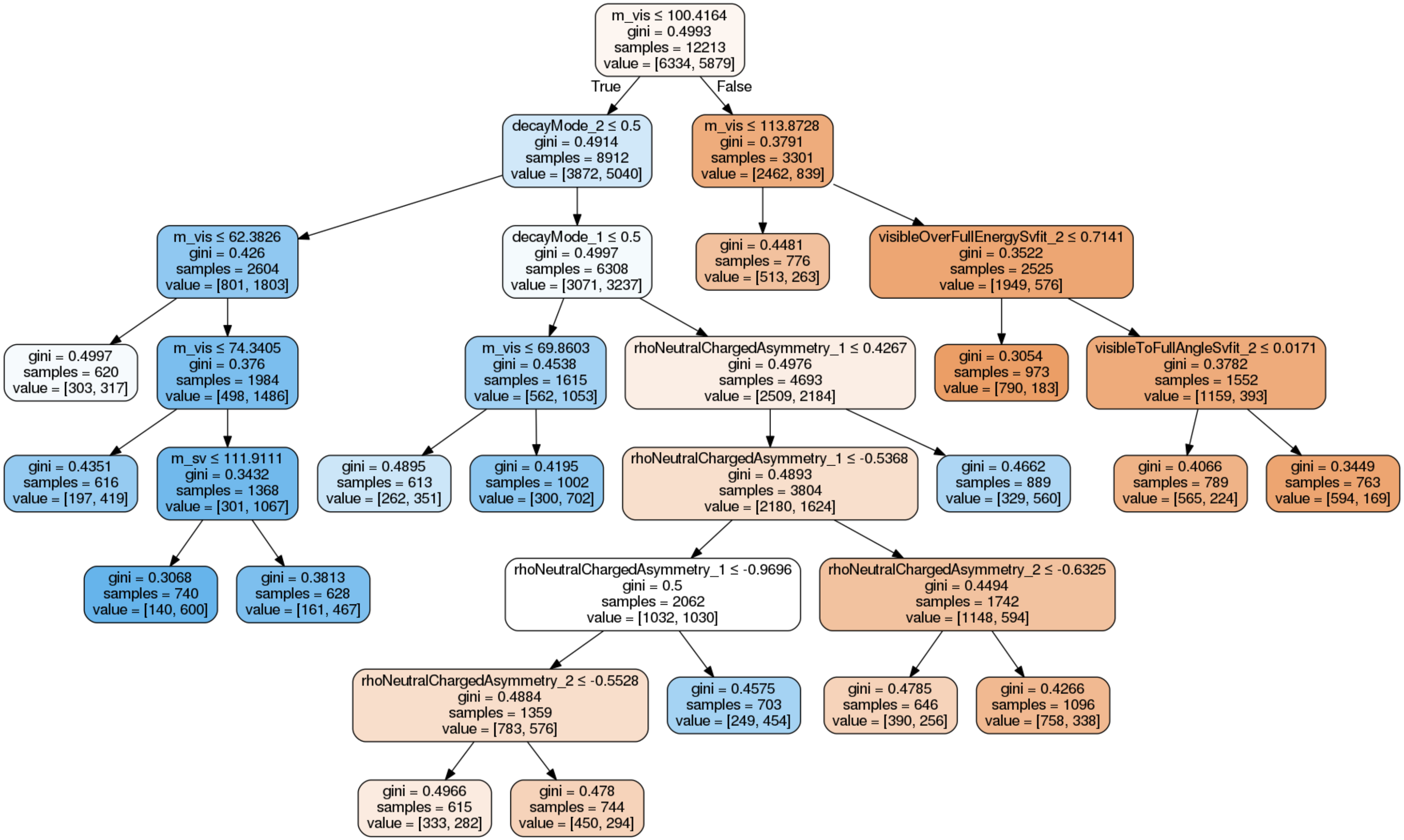
ϕ between τ_{vis} and τ



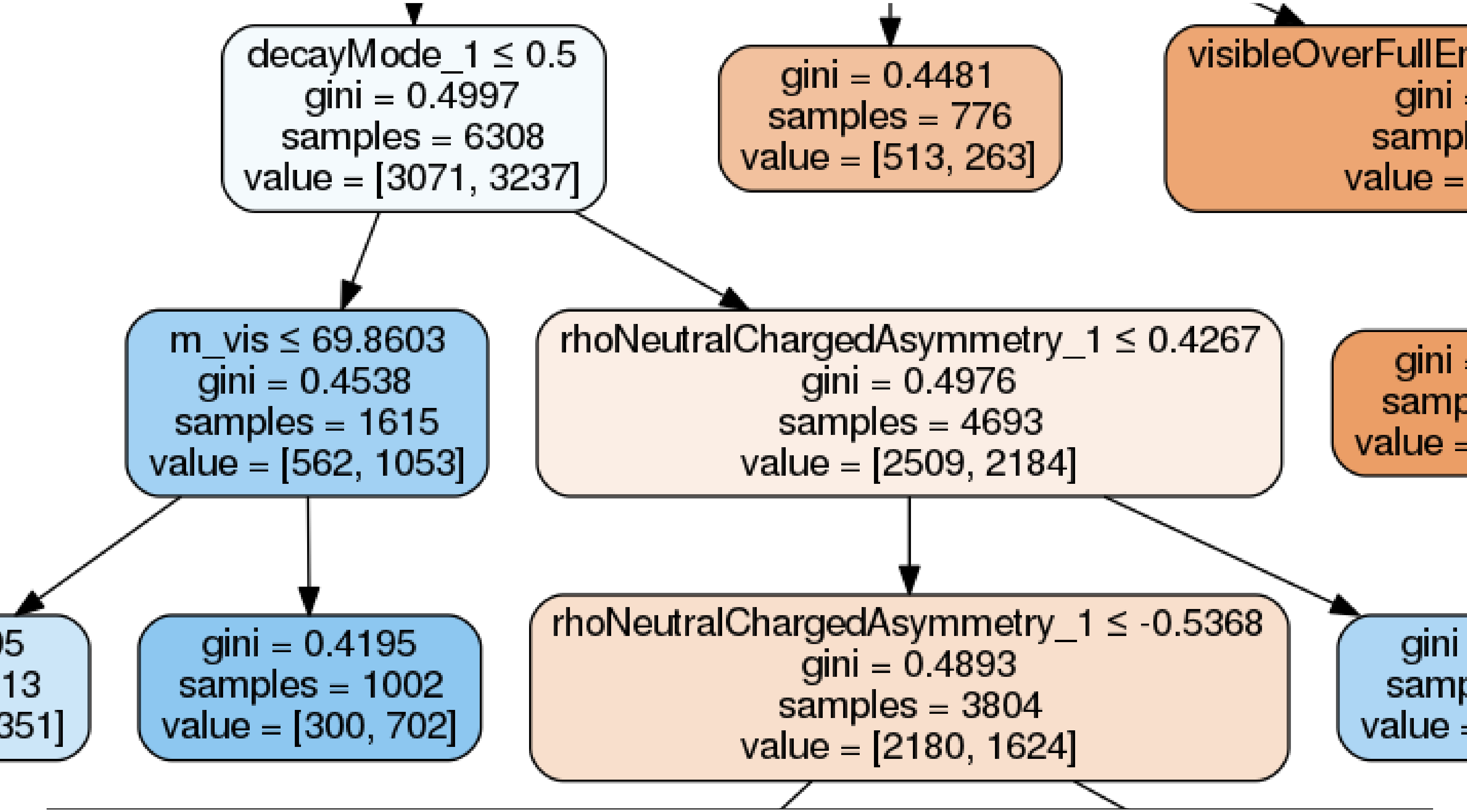
m_{SV}



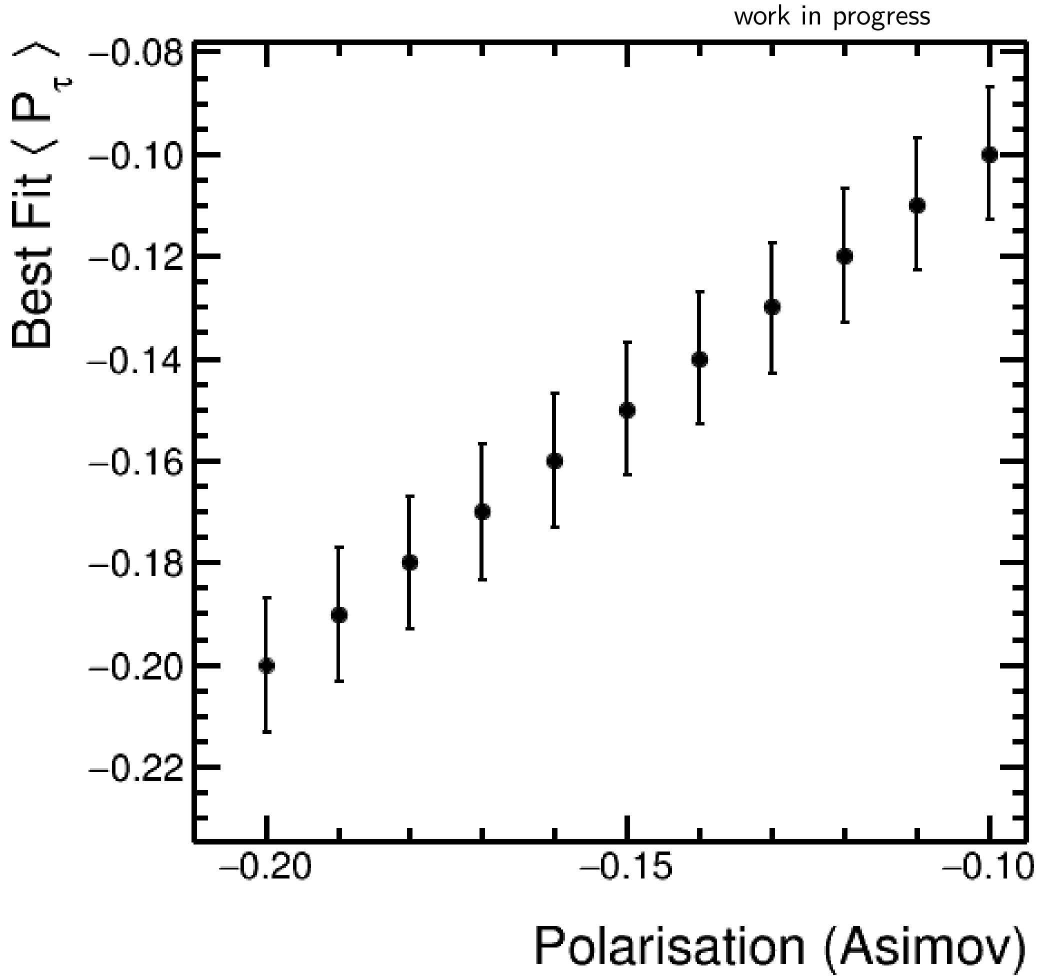
Graphical Example of BDT in TT Channel



Graphical Example of BDT in TT Channel



Bias Check


work in progress
Best Fit ⟨ P_τ ⟩
−0.08
−0.10
−0.12
−0.14
−0.16
−0.18
−0.20
−0.22
−0.20
−0.15
−0.10
Polarisation (Asimov)

Absolute and relative uncertainties

Total absolut uncertainties

- scikit-learn:
  - combined: $\sigma = 0.0125$
  - $\mu\tau_h : \sigma = 0.0144$
  - $e\tau_h : \sigma = 0.029$
  - $\tau_h\tau_h : \sigma \approx 0.067$
- Classic:
  - combined: $\sigma = 0.019$
  - $\mu\tau_h : \sigma = 0.021$
  - $e\tau_h : \sigma = 0.038$
  - $\tau_h\tau_h : \sigma \approx 0.11$

Total relative uncertainties

- scikit-learn:
  - combined: $\sigma_{rel} = 7.8\%$
  - $\mu\tau_h : \sigma_{rel} = 9.1\%$
  - $e\tau_h : \sigma_{rel} = 18.2\%$
  - $\tau_h\tau_h : \sigma_{rel} \approx 42\%$
- Classic:
  - combined: $\sigma_{rel} = 11.9\%$
  - $\mu\tau_h : \sigma_{rel} = 13.2\%$
  - $e\tau_h : \sigma_{rel} = 23.9\%$
  - $\tau_h\tau_h : \sigma_{rel} \approx 69\%$