
Università degli Studi di Milano
FACOLTÀ DI SCIENZE E TECNOLOGIE
Corso di Laurea in Fisica

*Martino M. L. Pulici*

# Improving Suppression of Jets from Pileup at High Luminosity LHC Using Timing Information from the High Granularity Timing Detector for ATLAS

**Relatore:**
Prof. Leonardo C. Carminati

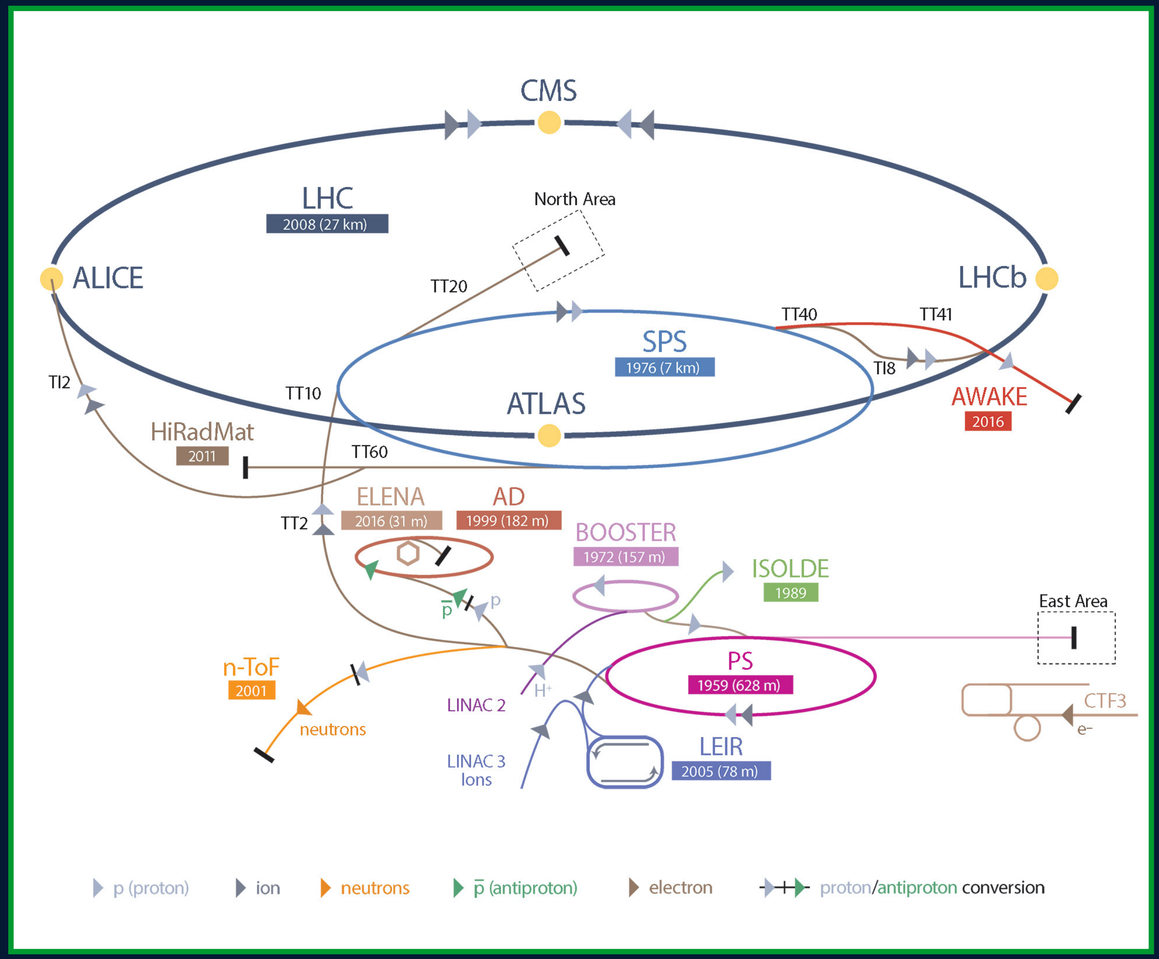
**Correlatori:**
Dott. Silvia Resconi
Dott. Marianna Testa
Dott. Ruggero Turra

ELABORATO FINALE

Anno Accademico 2019–2020

# LHC and collisions

- The Large Hadron Collider
  - World's largest particle accelerator
  - Center of mass energy of 7 TeV
  - Luminosity around $10^{34}$ $cm^{-2}s^{-1}$
  - $R = L\sigma$



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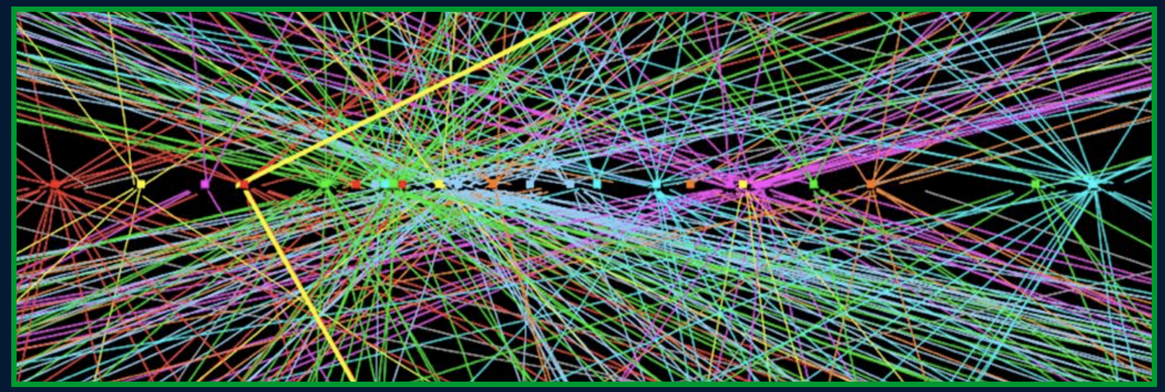
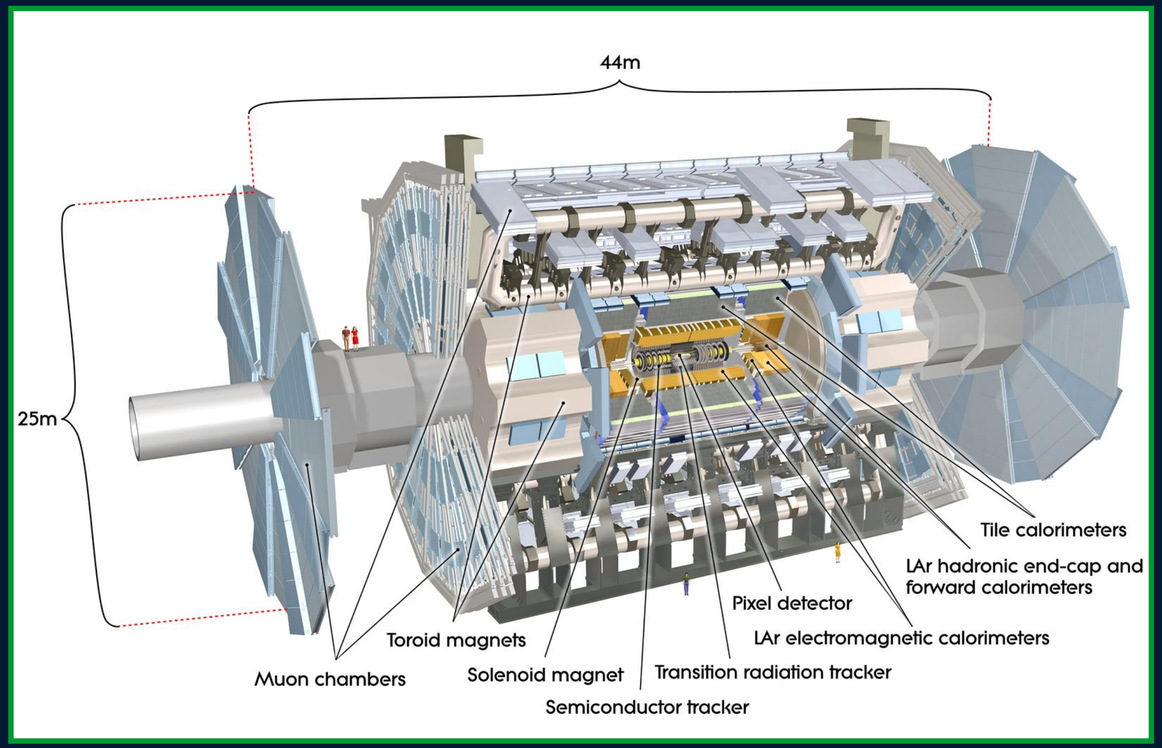
- The Large Hadron Collider
  - World's largest particle accelerator
  - Center of mass energy of 7 TeV
  - Luminosity around $10^{34}$ $cm^{-2}s^{-1}$
  - $R = L\sigma$
- Collisions
  - Hard collisions
  - Soft or pileup collisions

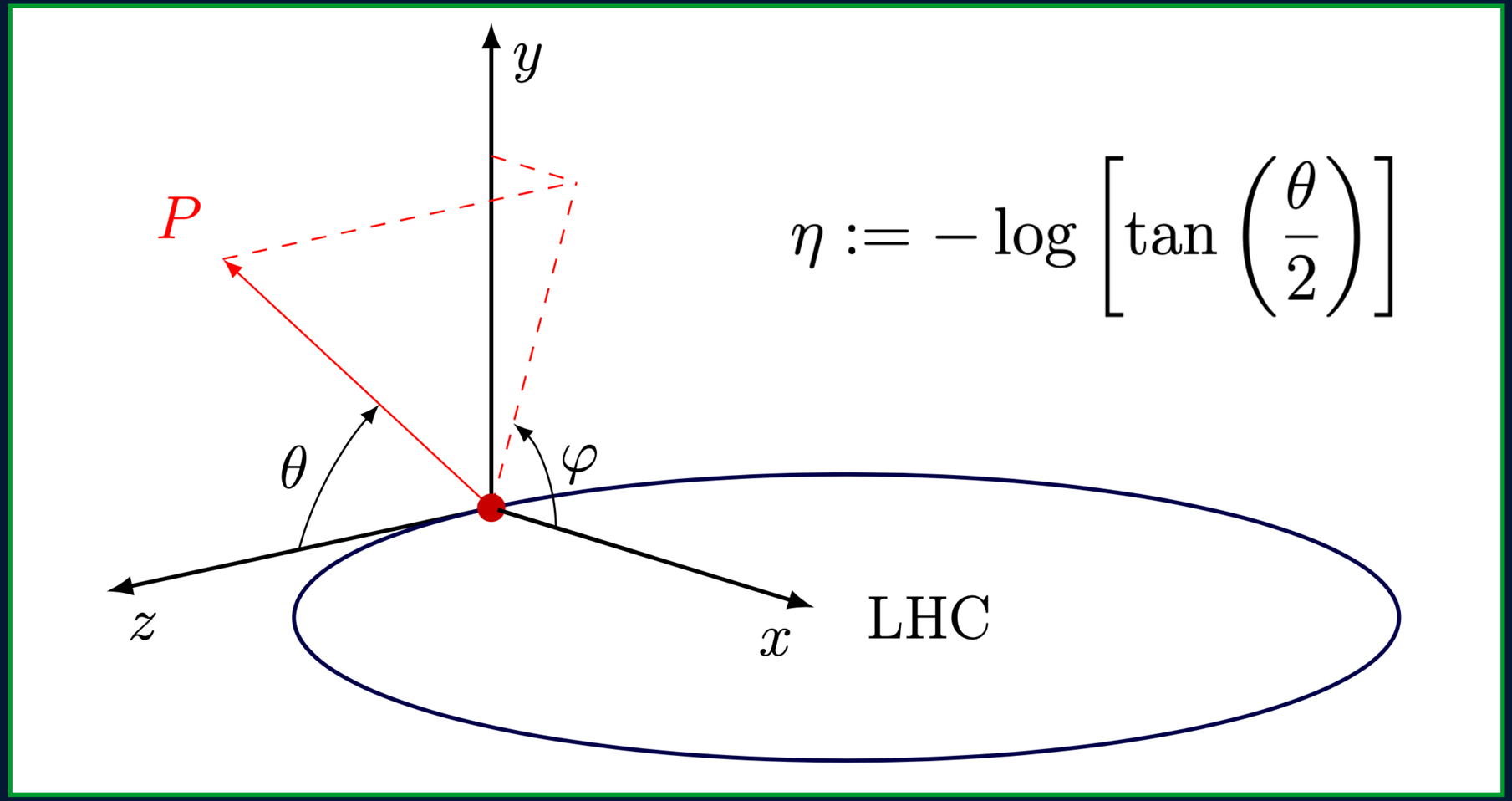


# ATLAS

- A Toroidal LHC ApparatuS
  - Largest detector ever constructed
  - 3000 authors from 181 institutions
  - Inner Detector
  - Calorimeter
  - Muon Spectrometer
  - Magnet System

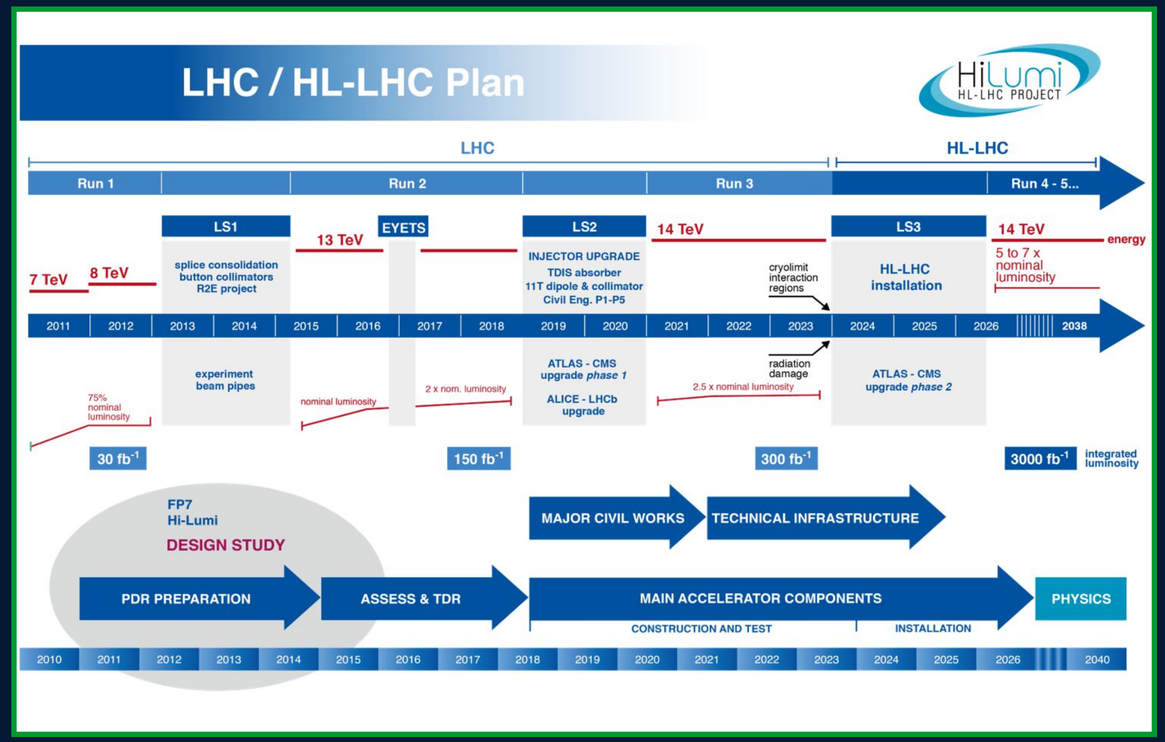


# ATLAS



# High Luminosity LHC and the HGTD detector

- High Luminosity LHC
  - Increased statistics
  - Instantaneous luminosity of $7.5 \times 10^{34}$ $cm^{-2}s^{-1}$ (4 times the current one)
  - Integrated luminosity of 4000 $fb^{-1}$ (30 times the current one)
  - Increased pileup (from 36 to 200 pileup collisions per bunch crossing)



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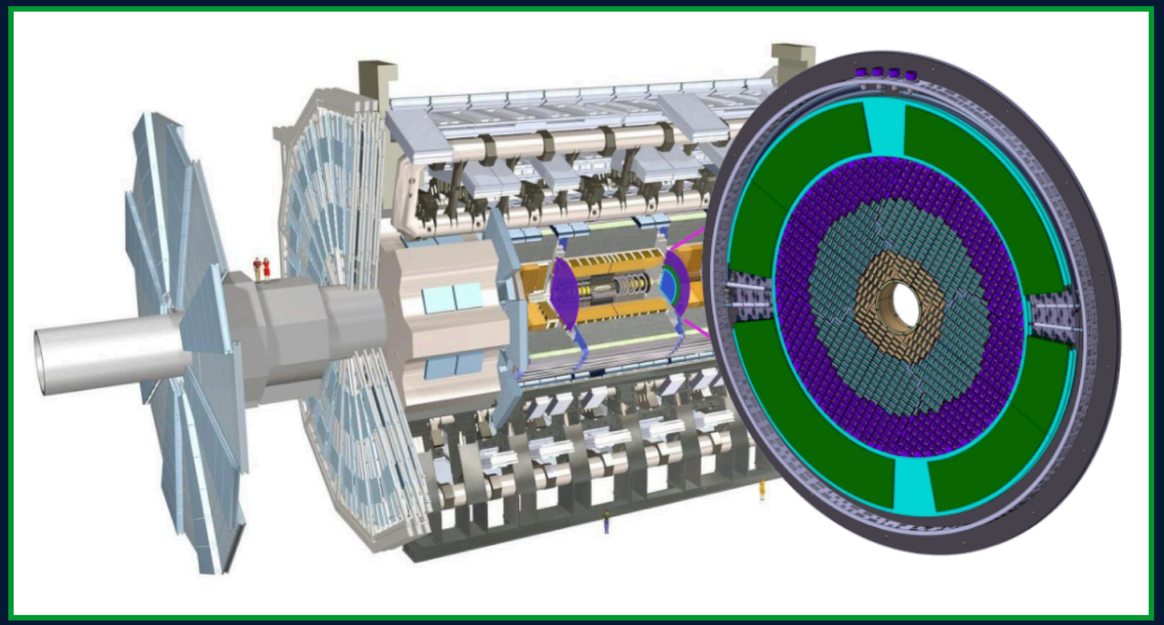
- The High Granularity Timing Detector



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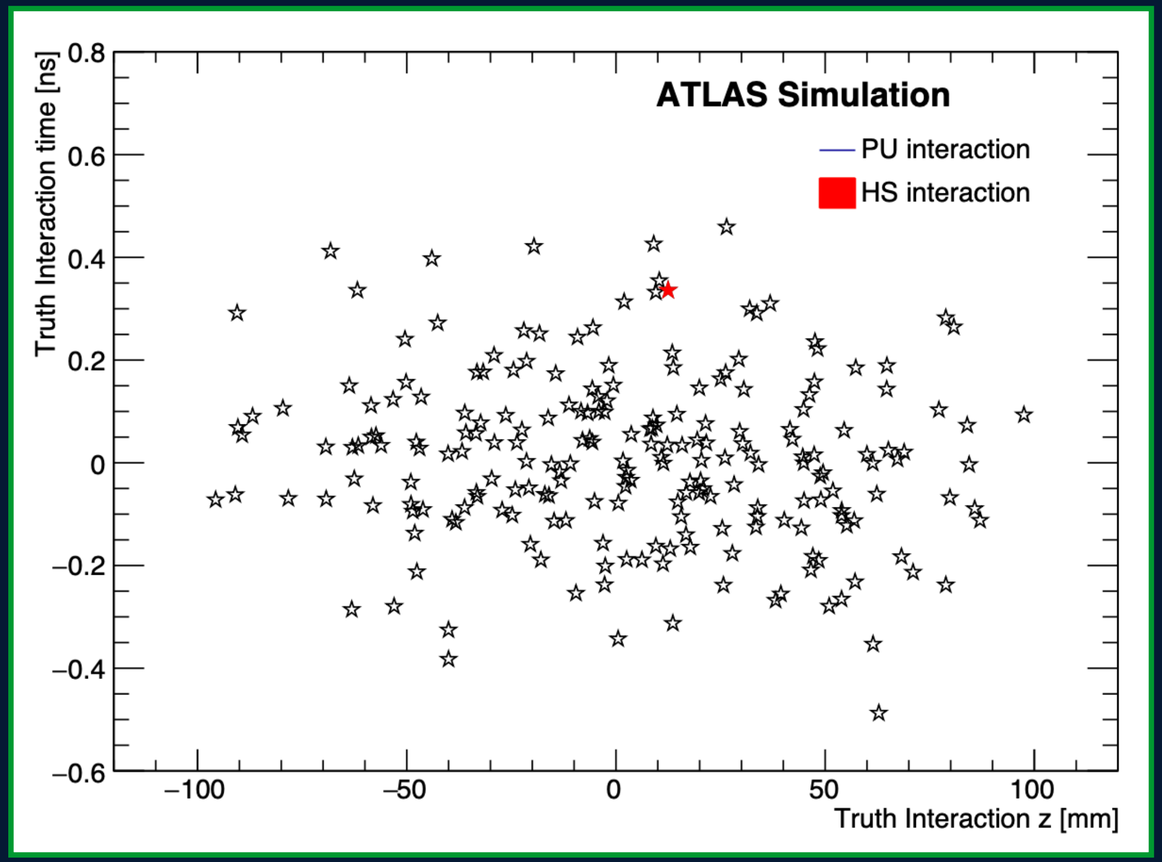
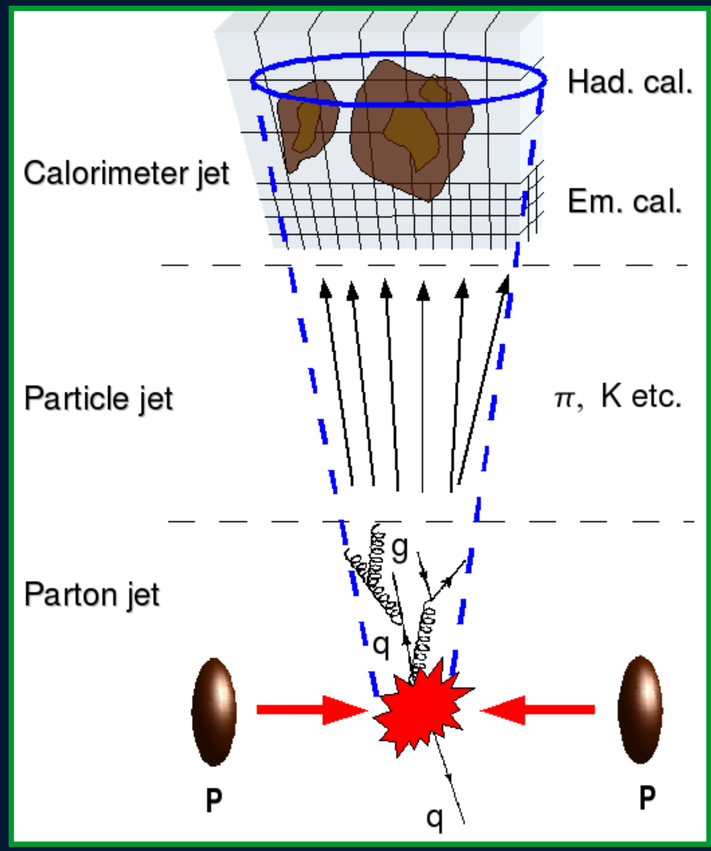
  - Increased pileup (from 36 to 200 pileup collisions per bunch crossing)
- The High Granularity Timing Detector
  - Timing information
  - Resolution of 30 ps



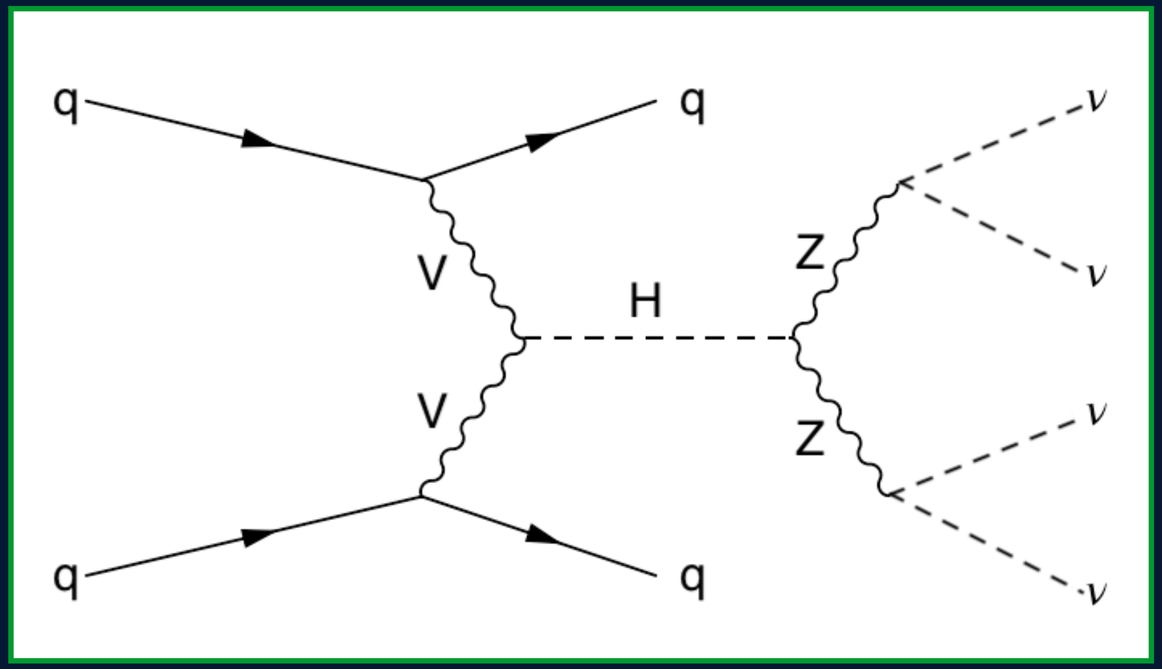
# Jet reconstruction and dataset

- Jet reconstruction



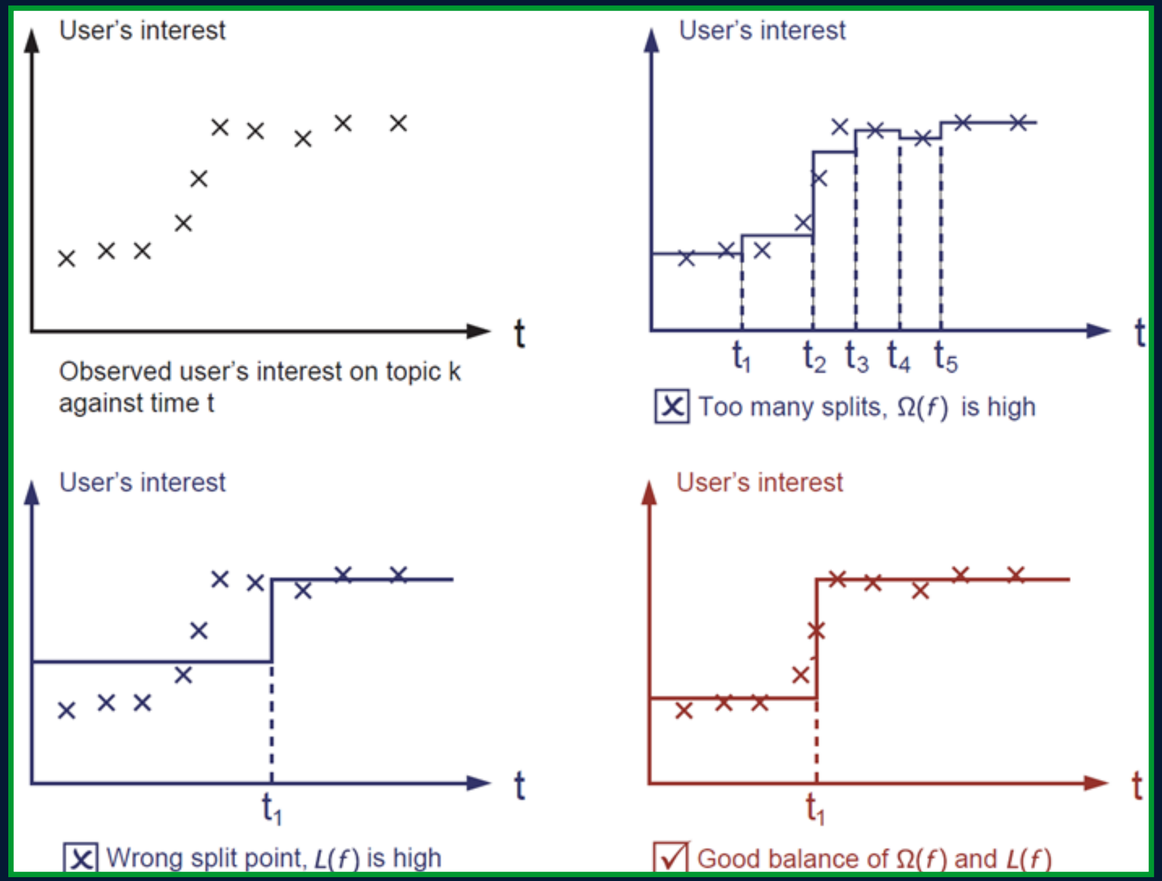
# Jet reconstruction and dataset

- Jet reconstruction
- Dataset
  - Higgs decaying into four neutrinos
  - 90 695 jets with $p_T < 50$ GeV
  - 51 732 jets with $p_T > 50$ GeV



# Boosted Decision Trees

- Supervised learning
  - $\text{Obj}(\boldsymbol{\theta}) = L(\boldsymbol{\theta}) + \Omega(\boldsymbol{\theta})$



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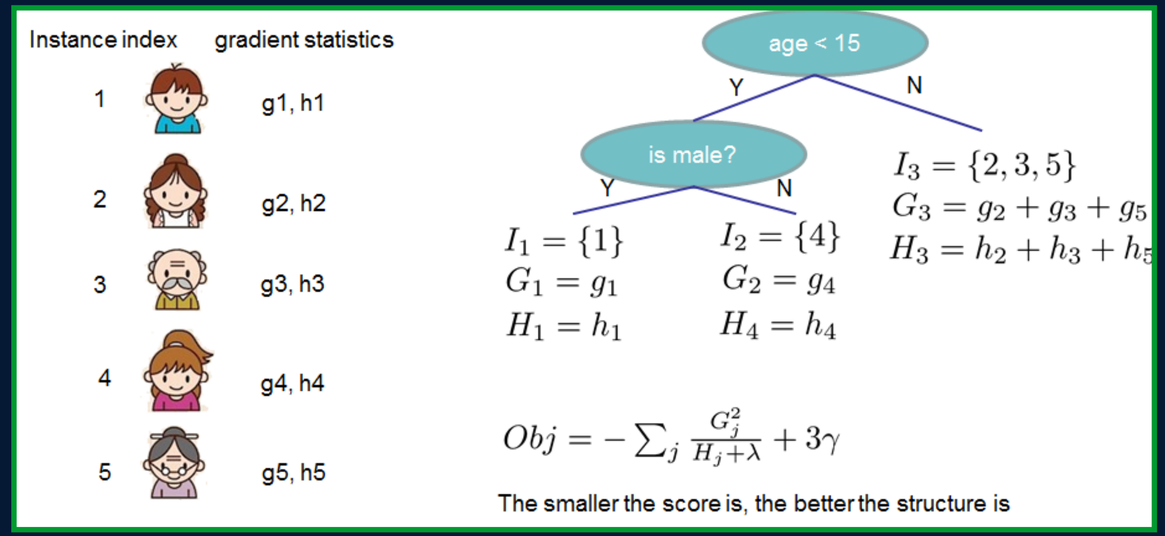
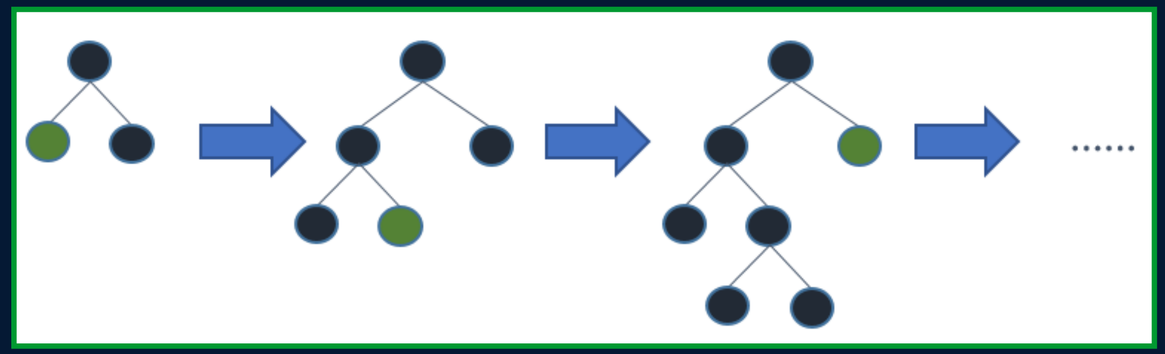
  - Classification And Regression Trees



# Boosted Decision Trees

- Supervised learning
  - Obj $(\boldsymbol{\theta}) = L(\boldsymbol{\theta}) + \Omega(\boldsymbol{\theta})$
  - Classification And Regression Trees
  - Tree boosting
  - Hyperparameters



# Boosted Decision Trees

- Supervised learning
  - Obj $(\theta) = L(\theta) + \Omega(\theta)$
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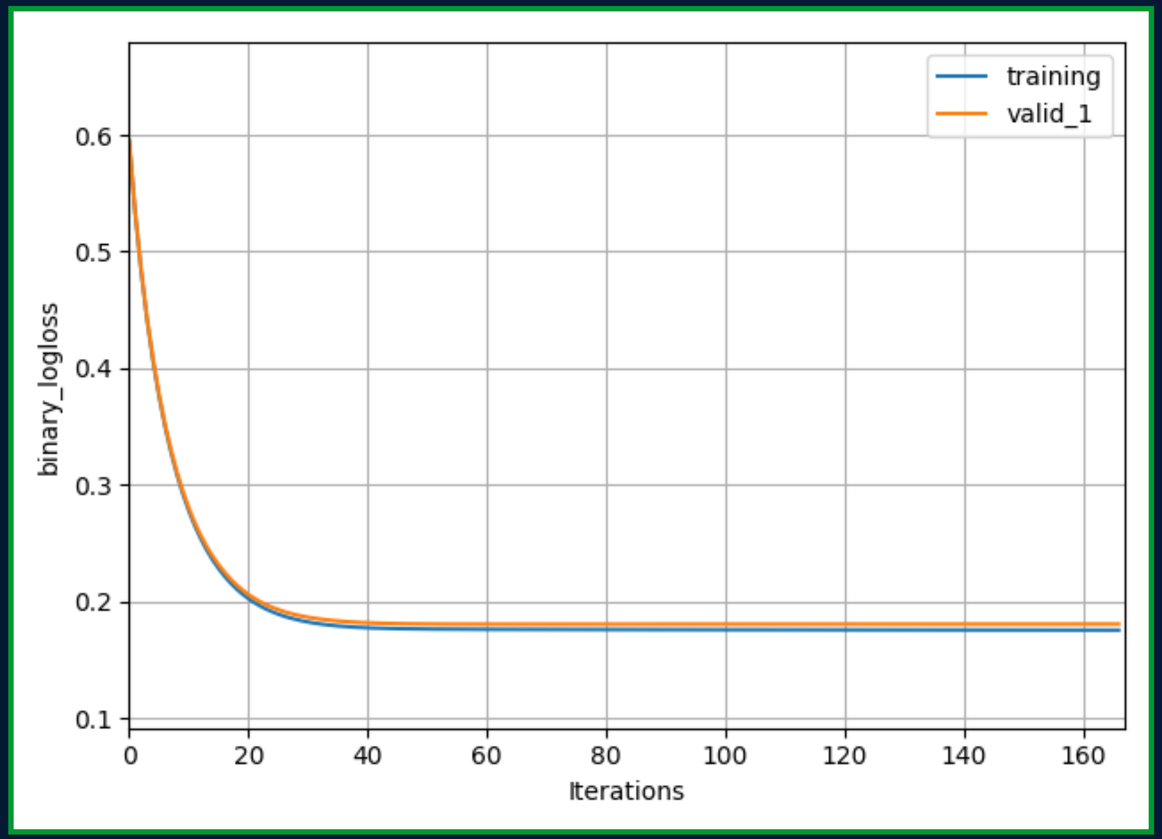
- Training
  - Training loss



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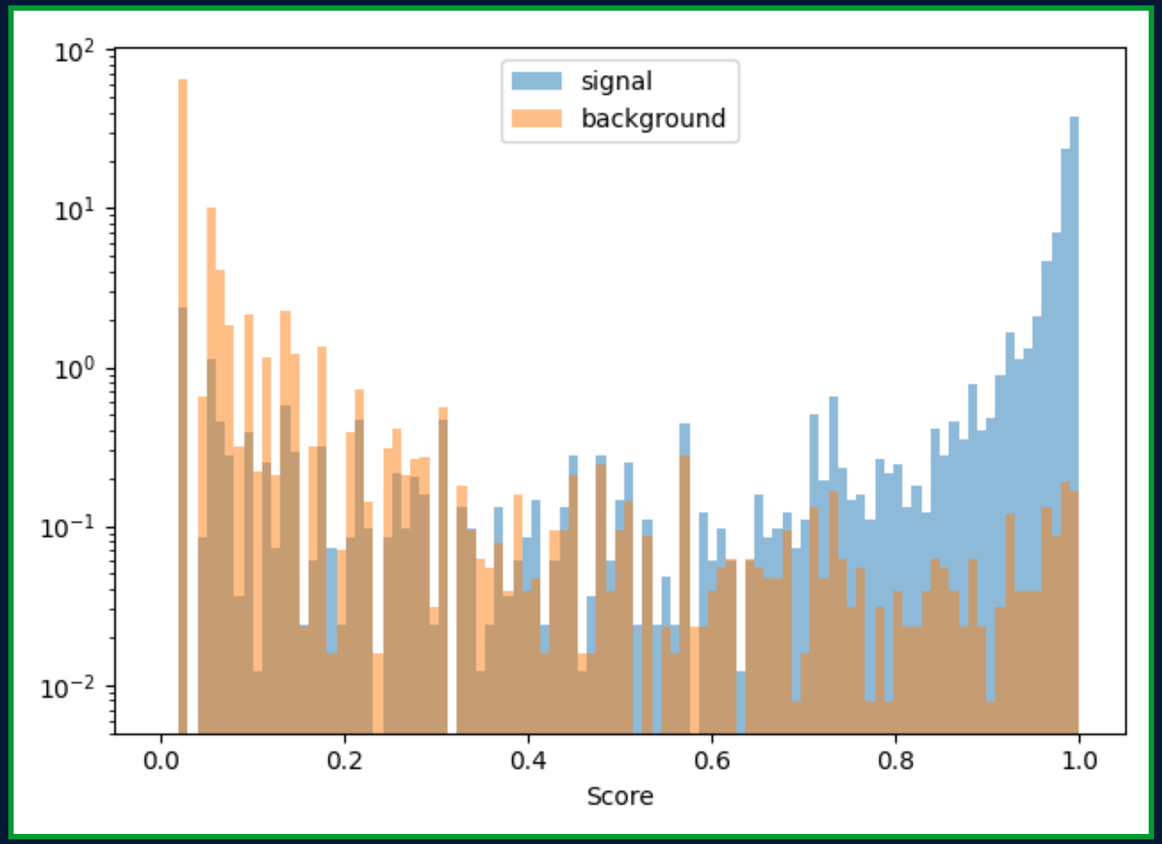
  - Prediction distribution



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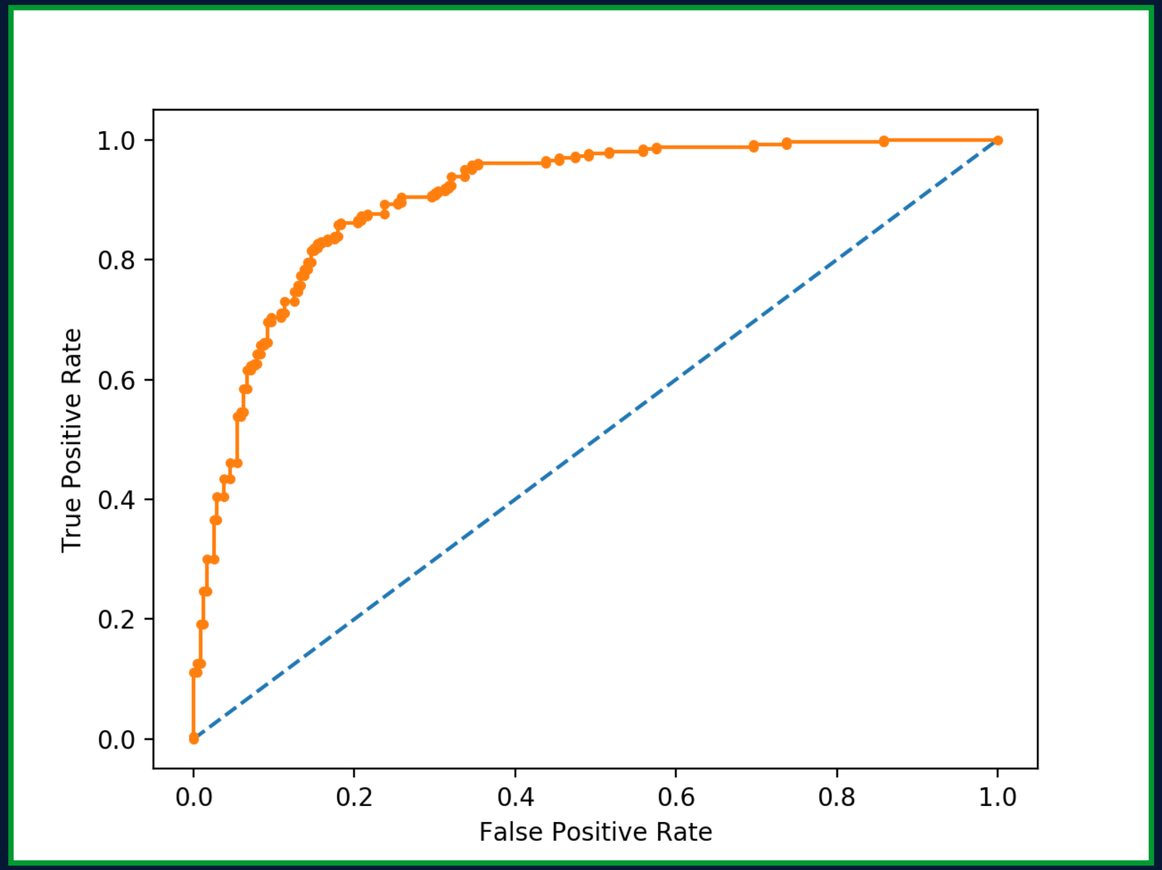
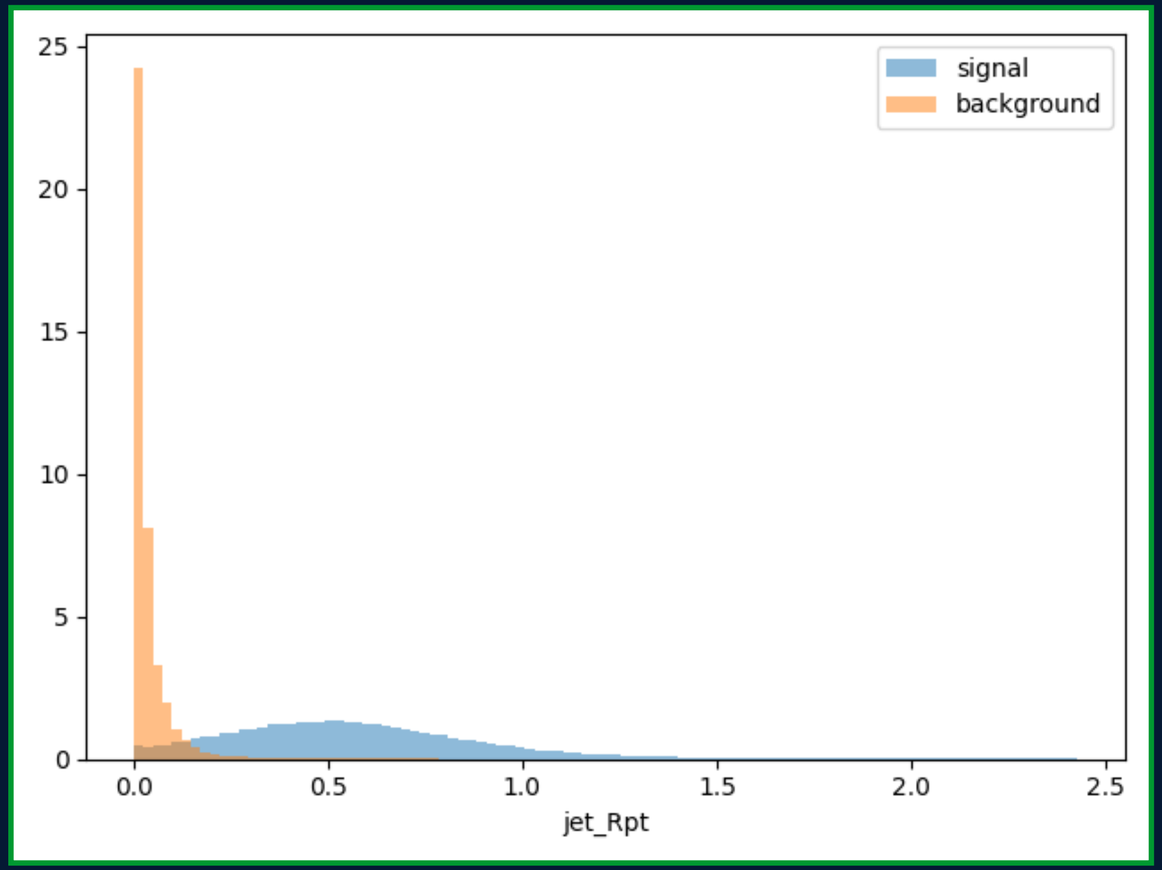
  - Prediction distribution
  - ROC curve and AUC score



# High-level variables

- jet_Rpt = $\frac{\sum p_{\mathrm{T}}^{\mathrm{trk}}\left(\mathrm{PV}_0\right)}{p_{\mathrm{T}}^{\mathrm{jet}}}$



# High-level variables

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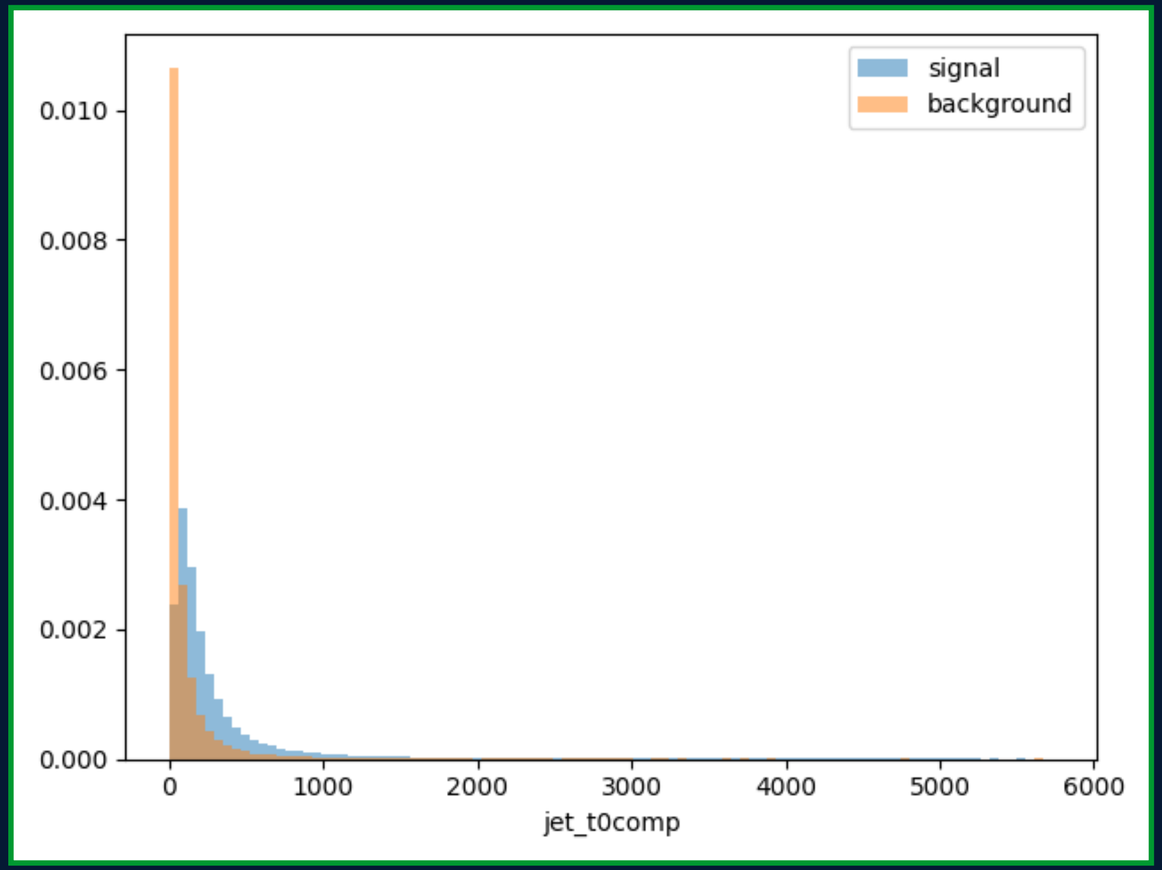
- $\texttt{jet\_t0comp} = \dfrac{\sum_i p_{T,i} \dfrac{\sqrt{\sigma_{\mathrm{lead}}^2 + \sigma_i^2}}{\left|t_{\mathrm{lead}} - t_i\right|}}{\sum_i p_{T,i}}$



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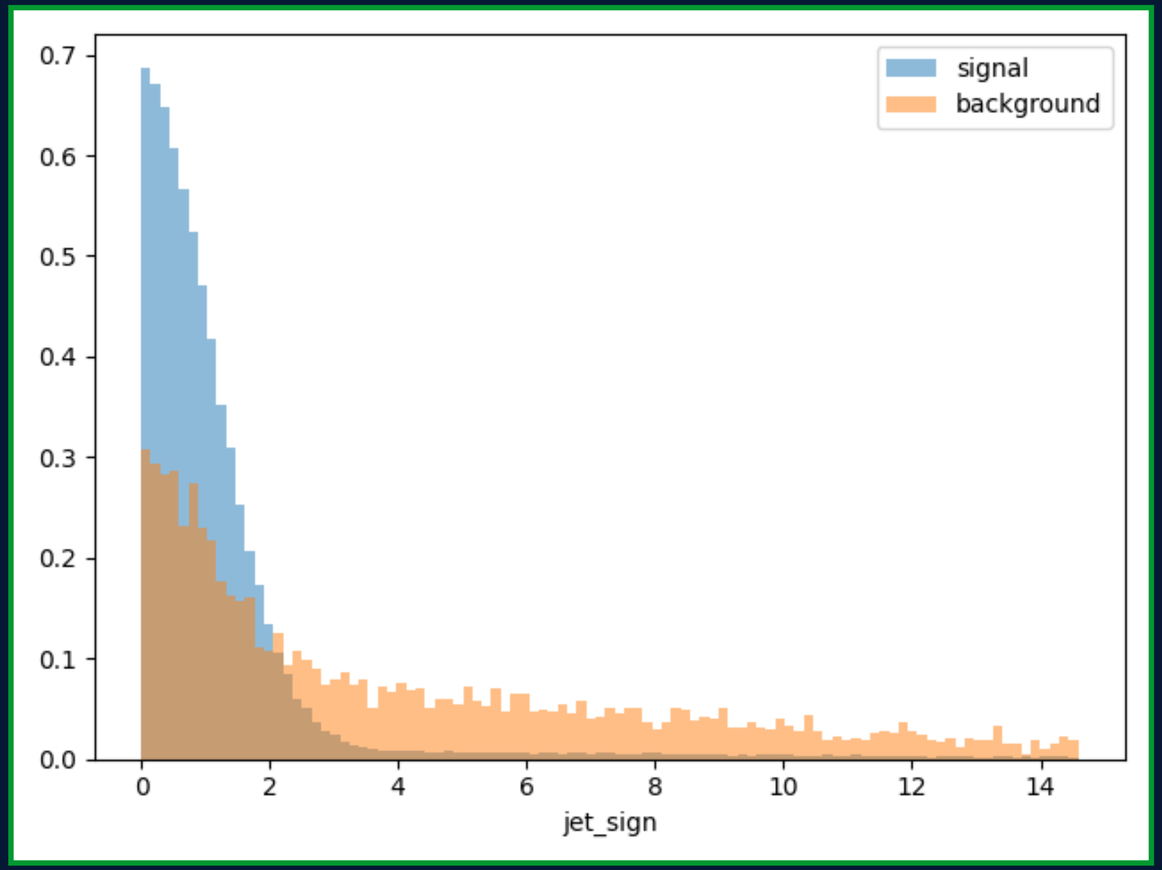
- jet_sign $= \dfrac{\left|t_{\mathrm{lead}} - t_{\mathrm{sublead}}\right|}{\sqrt{\sigma_{\mathrm{lead}}^2 + \sigma_{\mathrm{sublead}}^2}}$



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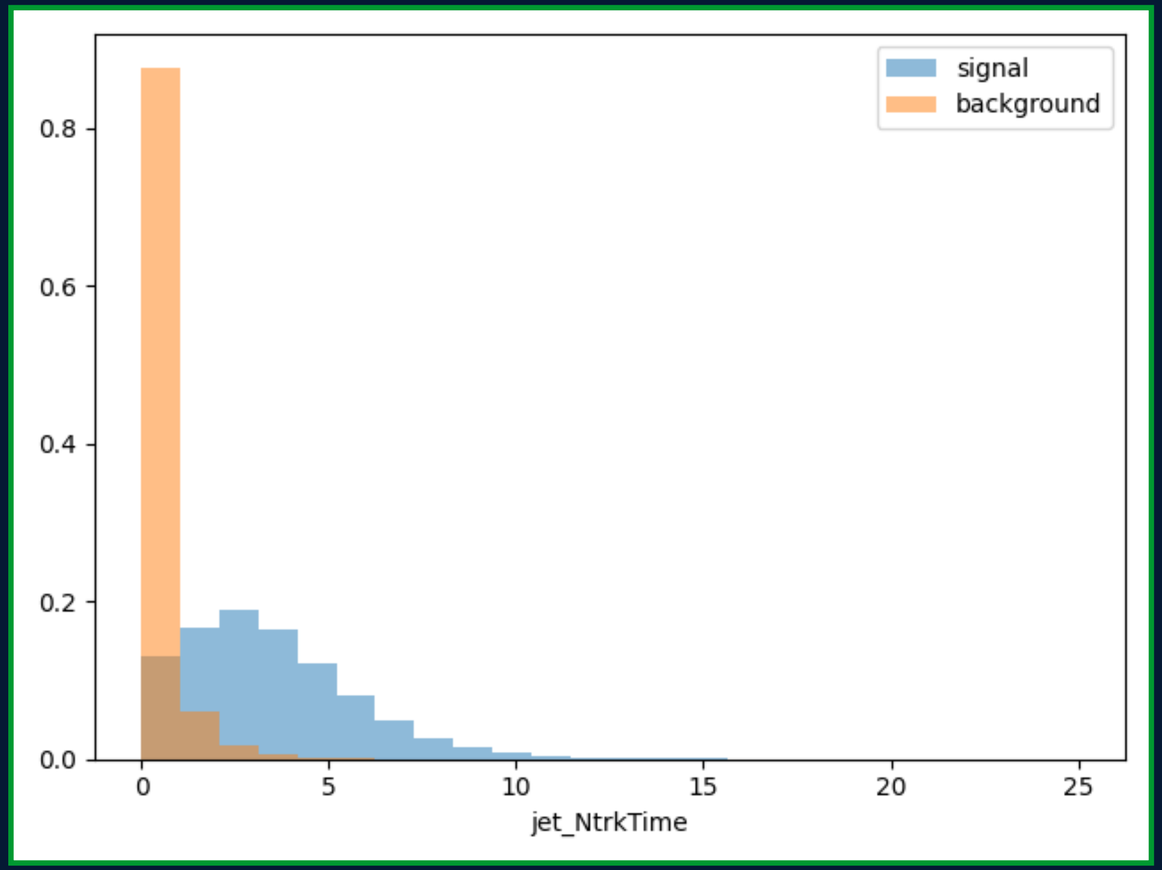
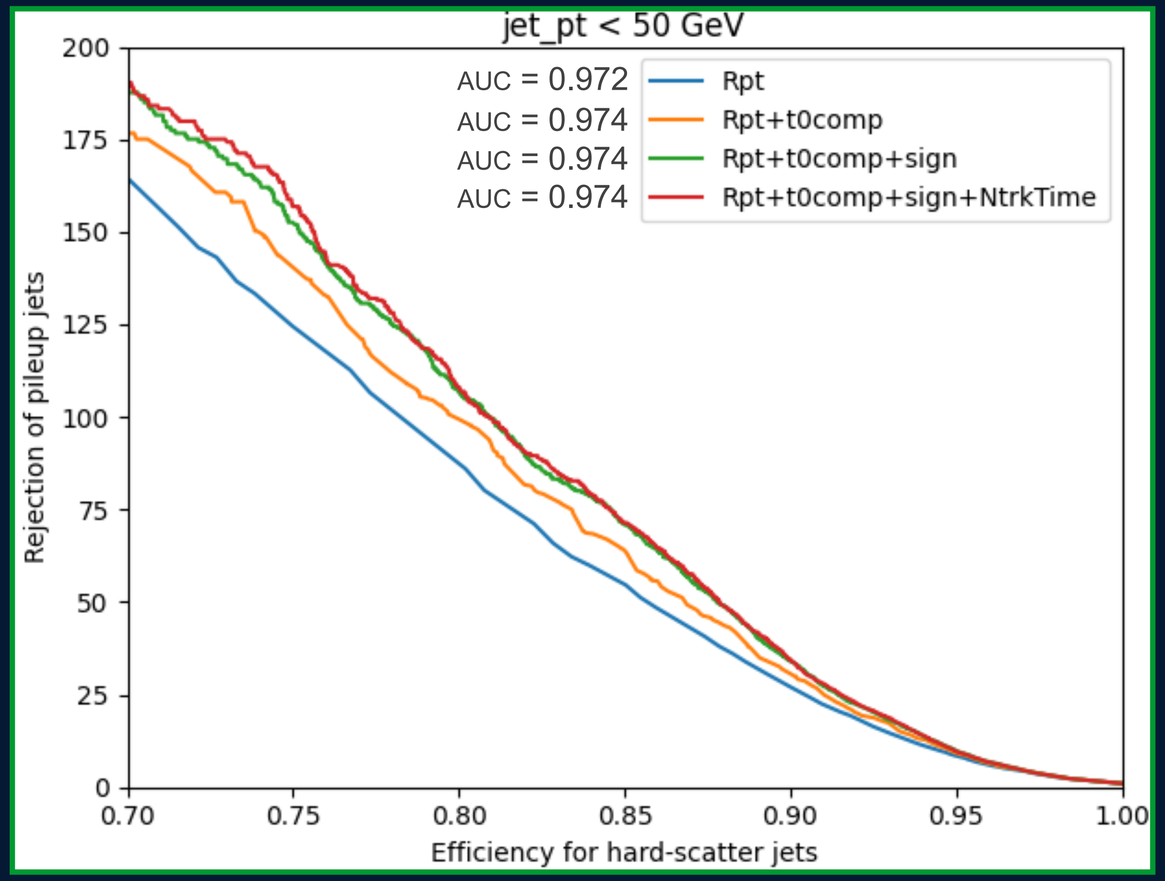
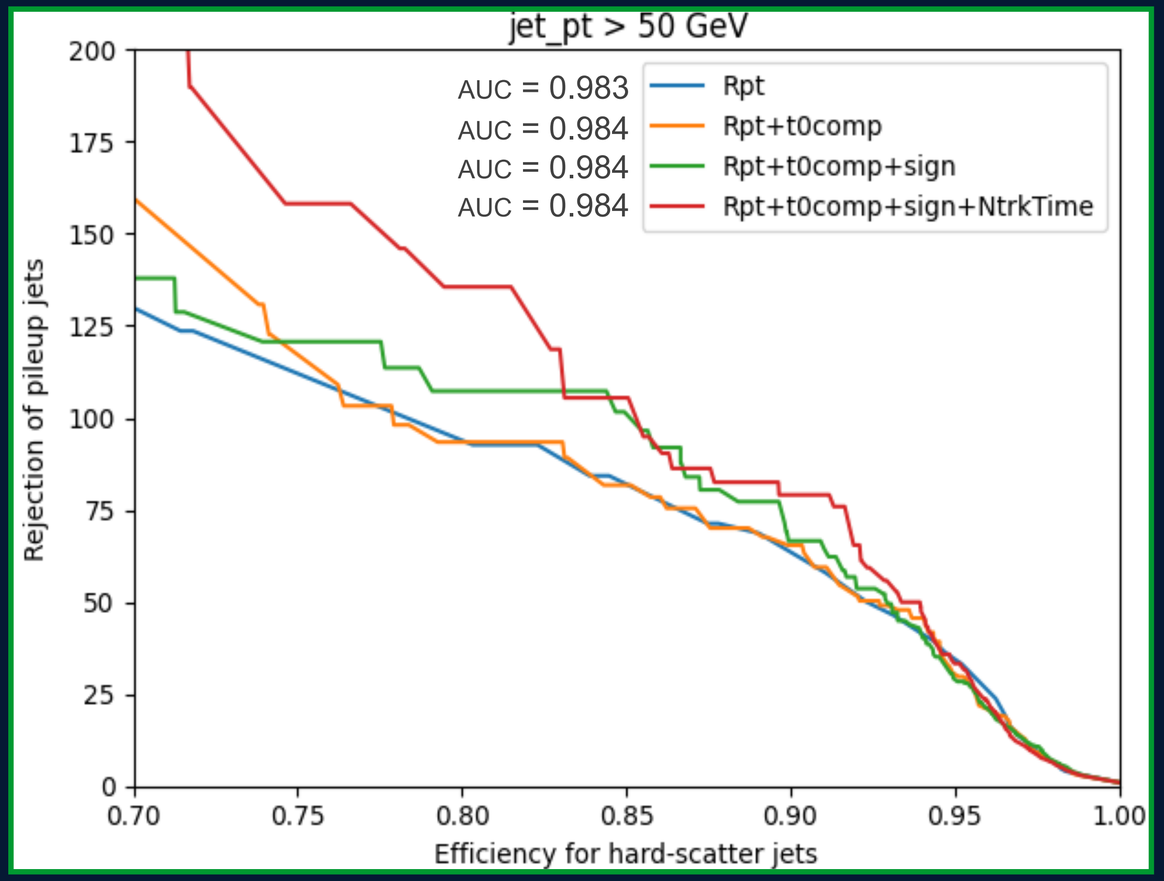
- jet_sign $= \dfrac{\left|t_{\mathrm{lead}} - t_{\mathrm{sublead}}\right|}{\sqrt{\sigma_{\mathrm{lead}}^2 + \sigma_{\mathrm{sublead}}^2}}$
- jet_NtrkTime



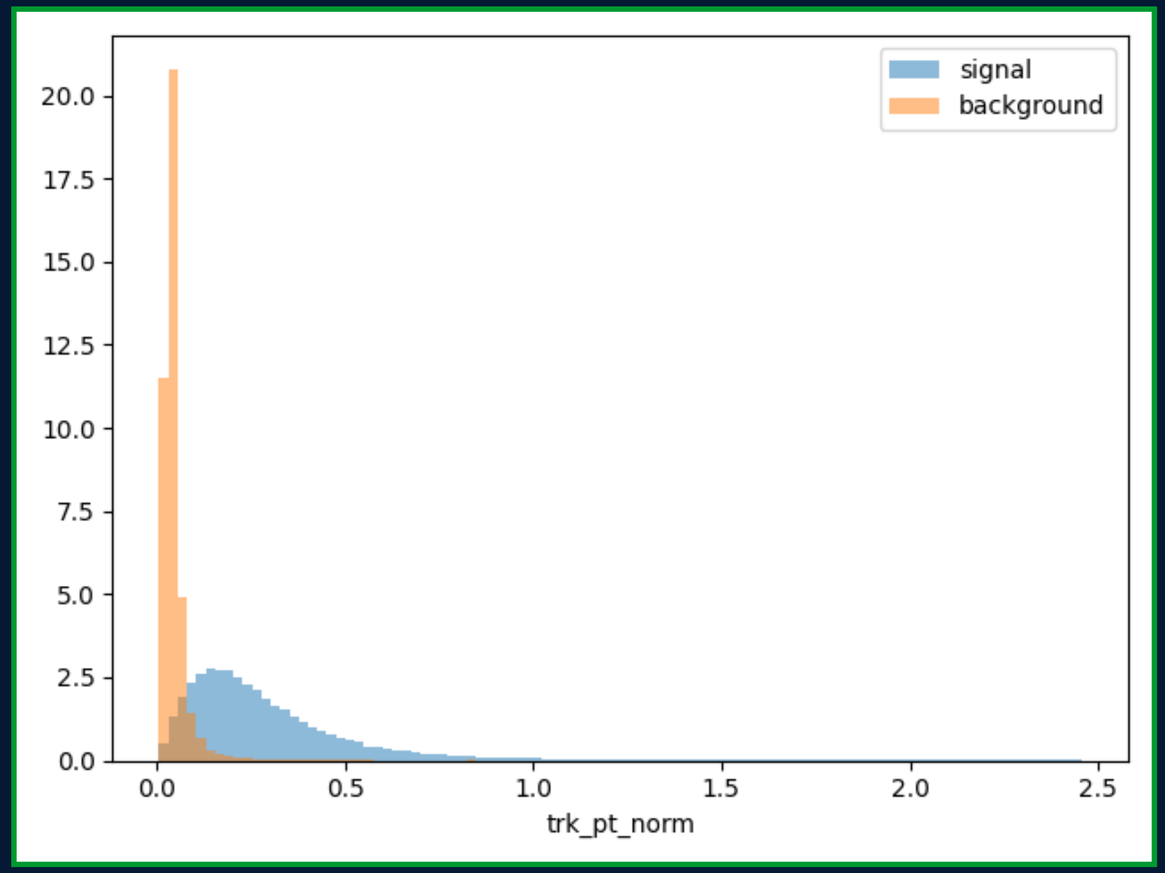
# High-level variable BDT performance



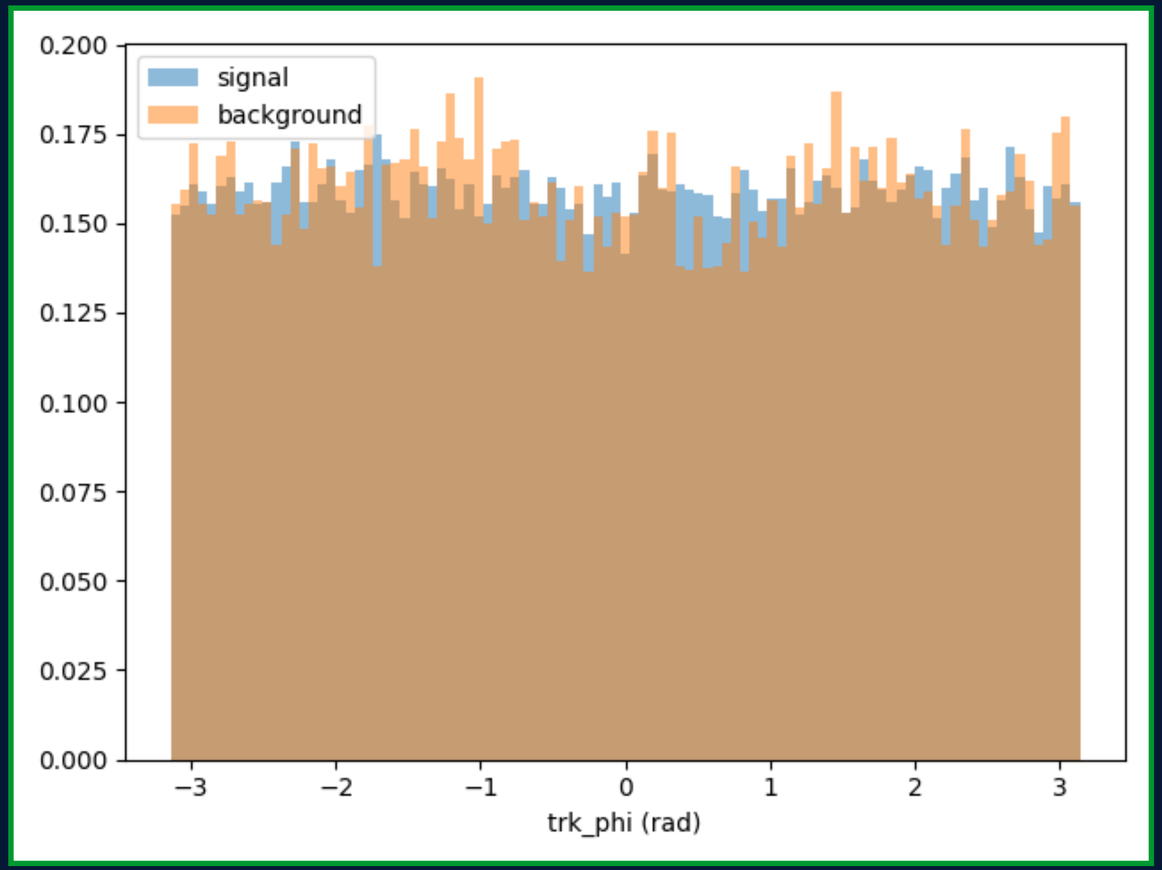
# Low-level variables

- $\texttt{trk\_pt\_norm} = \dfrac{p_T^{\text{track}}}{p_T^{\text{jet}}}$



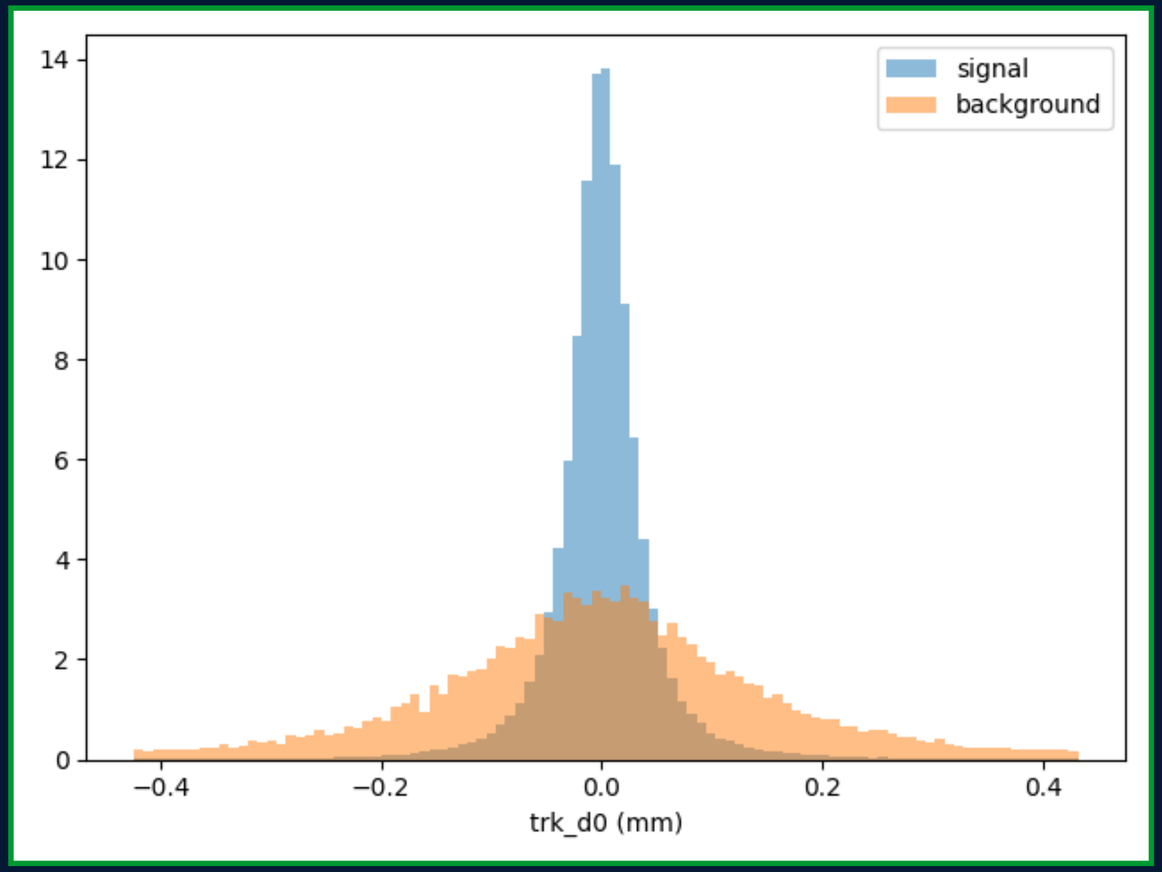
# Low-level variables

- `trk_pt_norm` $= \dfrac{p_T^{\text{track}}}{p_T^{\text{jet}}}$
- `trk_phi`



# Low-level variables

- `trk_pt_norm` $= \dfrac{p_T^{\text{track}}}{p_T^{\text{jet}}}$
- `trk_phi`
- `trk_d0`



# Low-level variables

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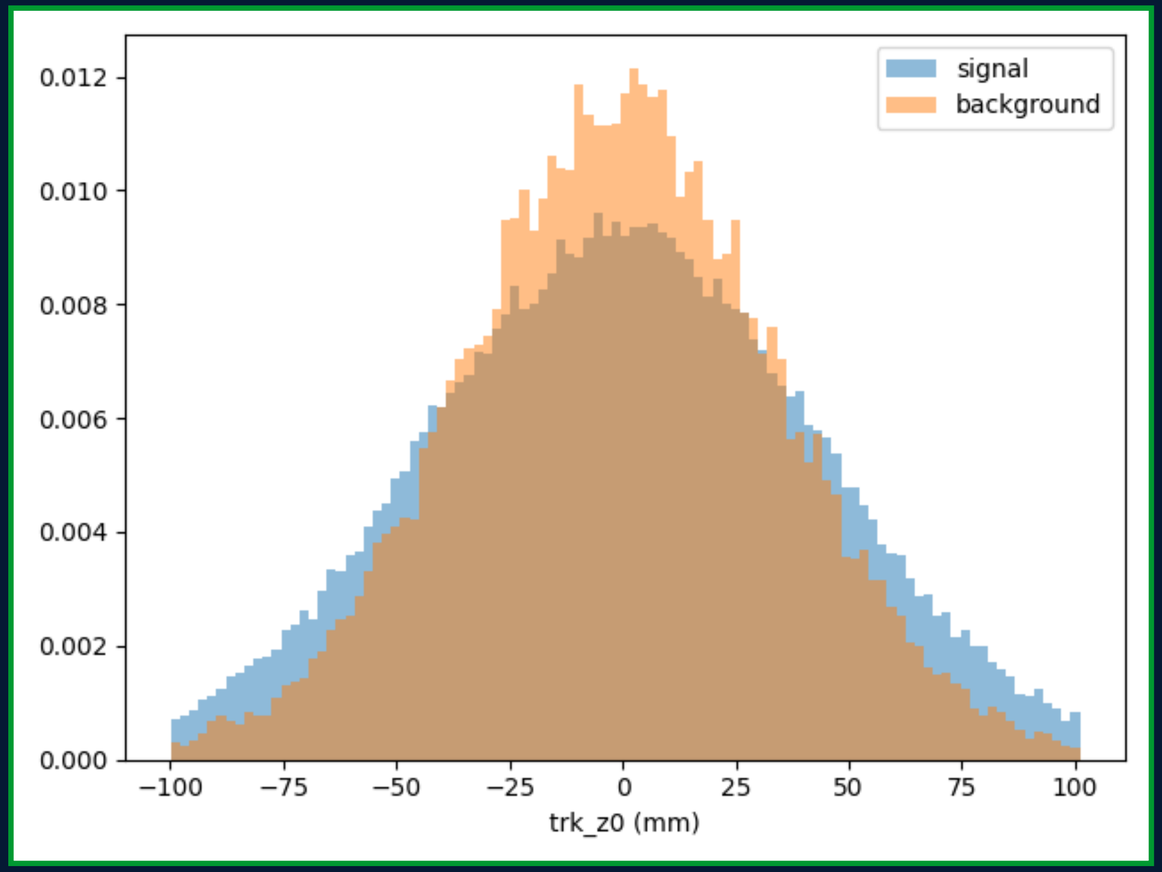
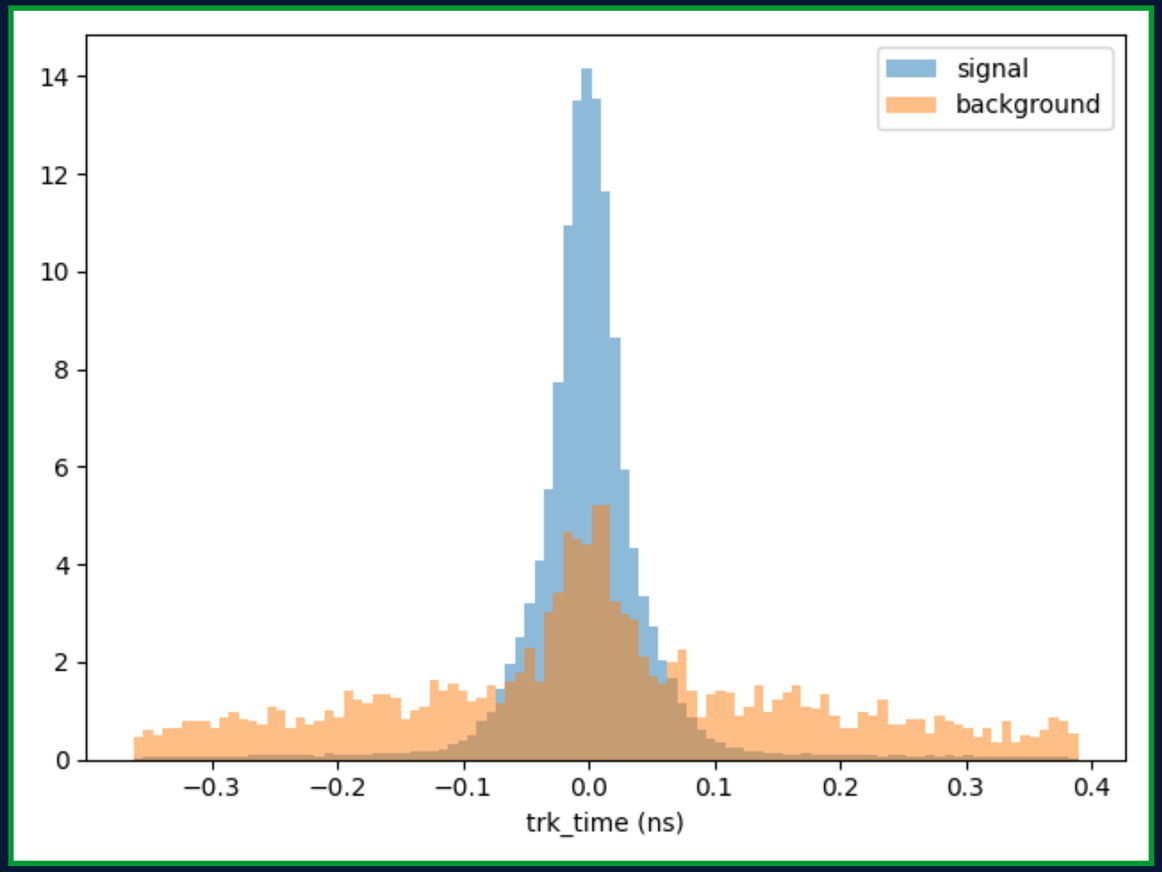
- `trk_phi`
- `trk_d0`
- `trk_z0`

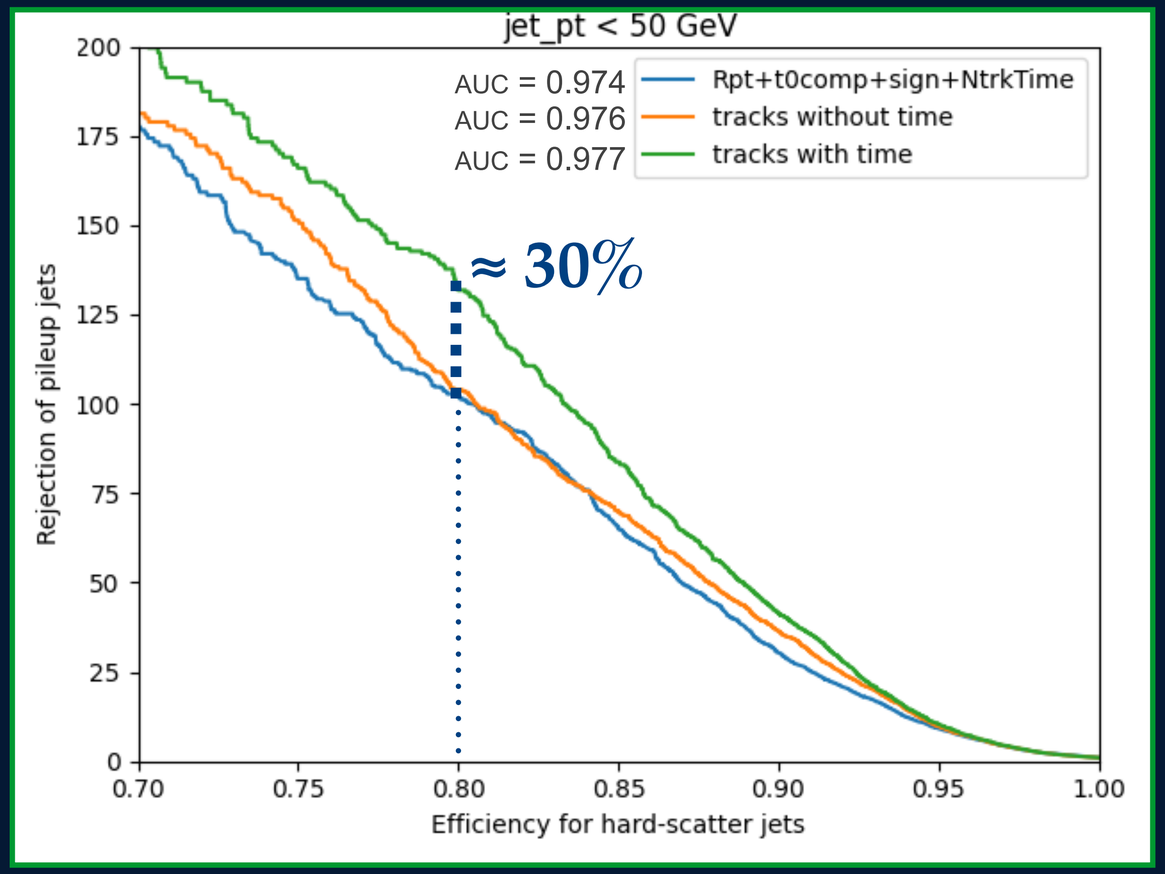


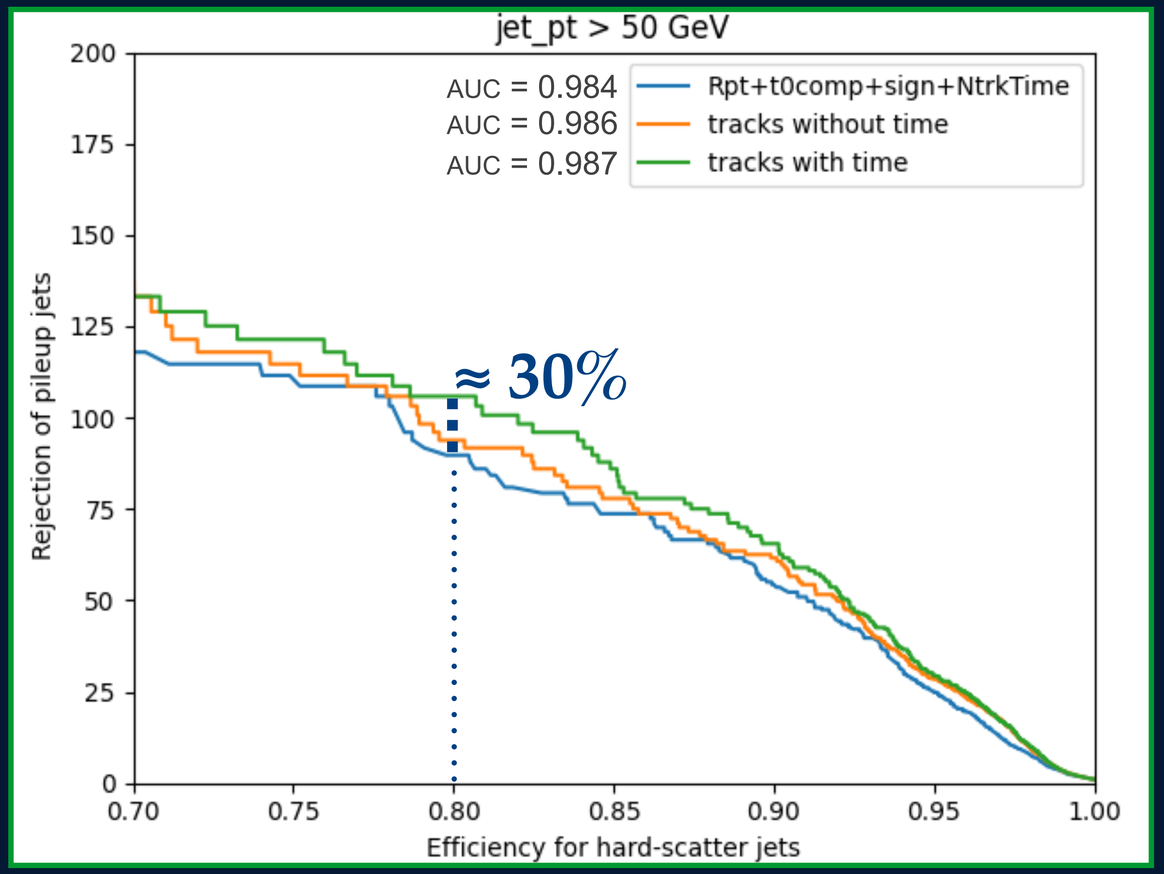
# Low-level variables

- `trk_pt_norm` $= \dfrac{p_T^{\text{track}}}{p_T^{\text{jet}}}$
- `trk_phi`
- `trk_d0`
- `trk_z0`
- `trk_time`



# Conclusion


jet_pt < 50 GeV
AUC = 0.974
AUC = 0.976
AUC = 0.977
Rpt+t0comp+sign+NtrkTime
tracks without time
tracks with time
≈ 30%
Rejection of pileup jets
Efficiency for hard-scatter jets
0
25
50
75
100
125
150
175
200
0.70
0.75
0.80
0.85
0.90
0.95
1.00


jet_pt > 50 GeV
AUC = 0.984
AUC = 0.986
AUC = 0.987
Rpt+t0comp+sign+NtrkTime
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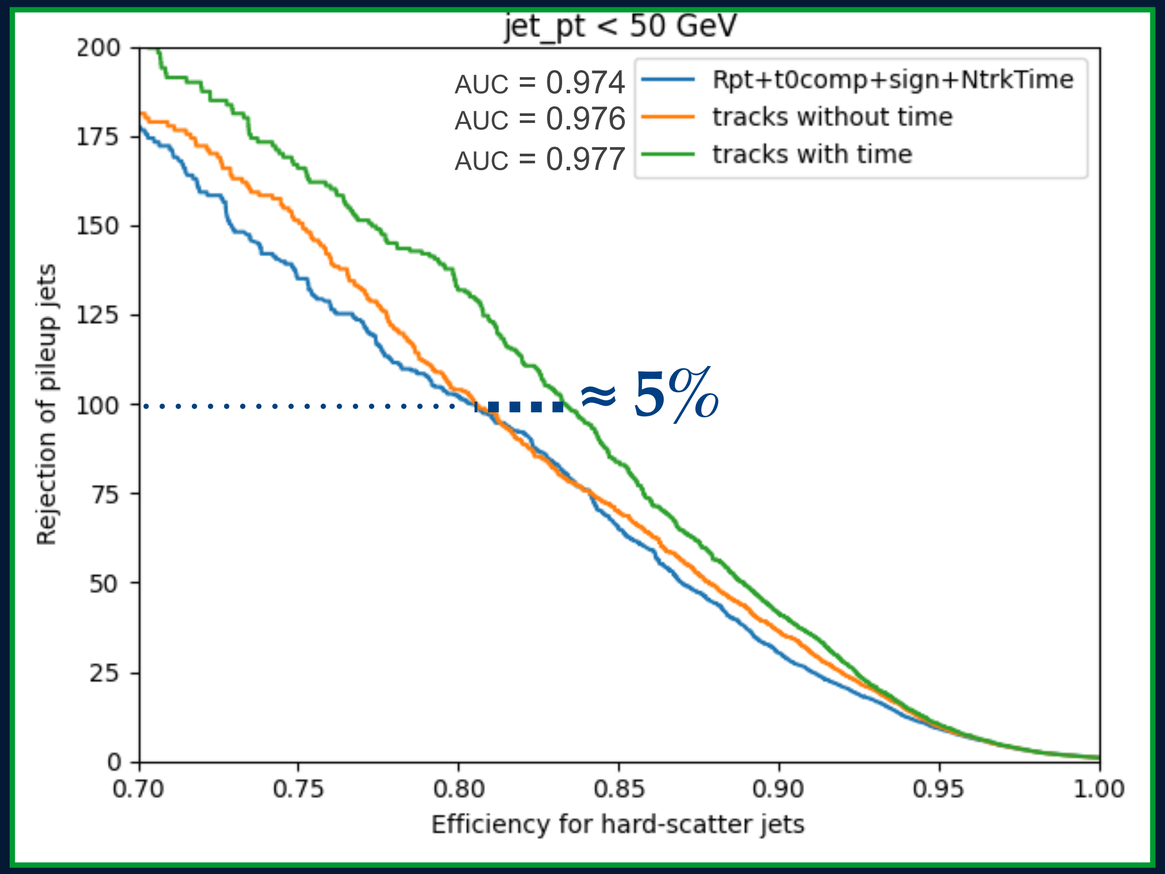
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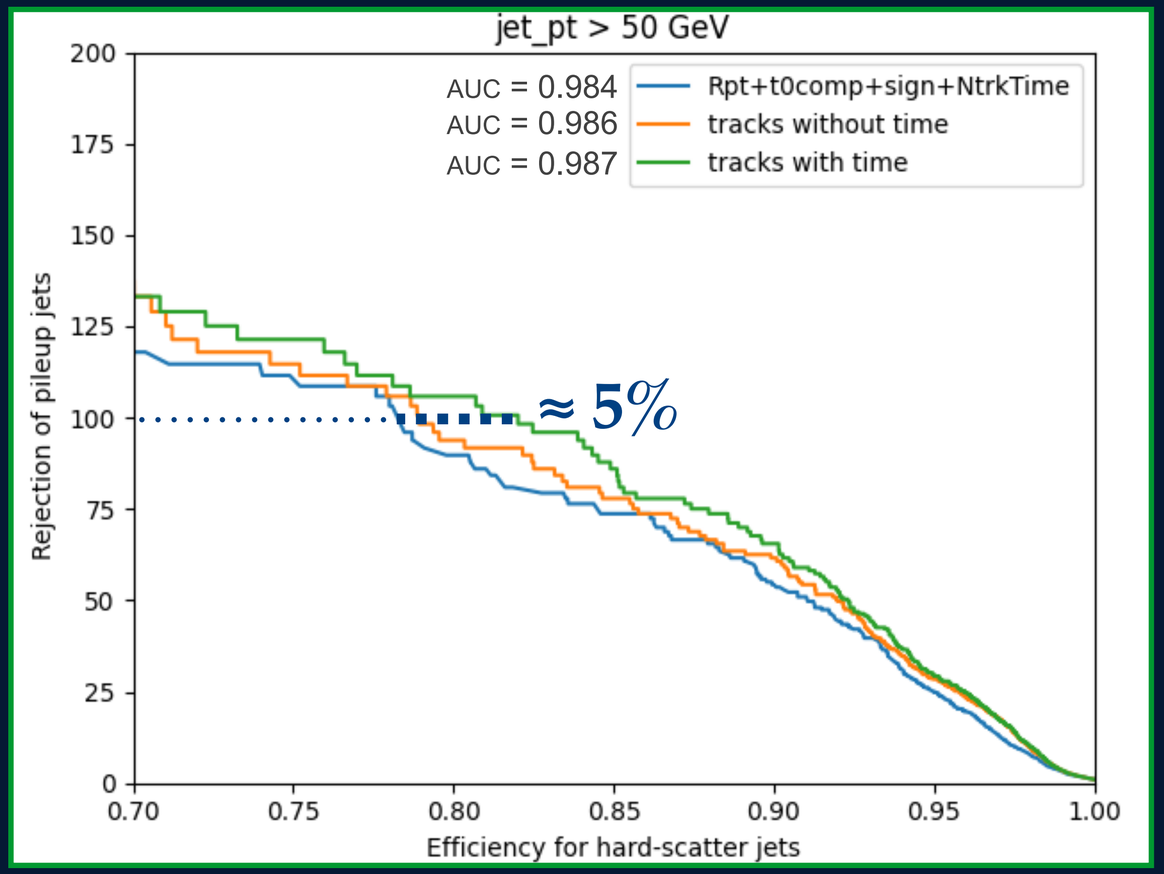
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# Conclusion

- High Luminosity LHC
- High Granularity Timing Detector
- Increased performance using low-level variables
- Increased performance using low-level timing information