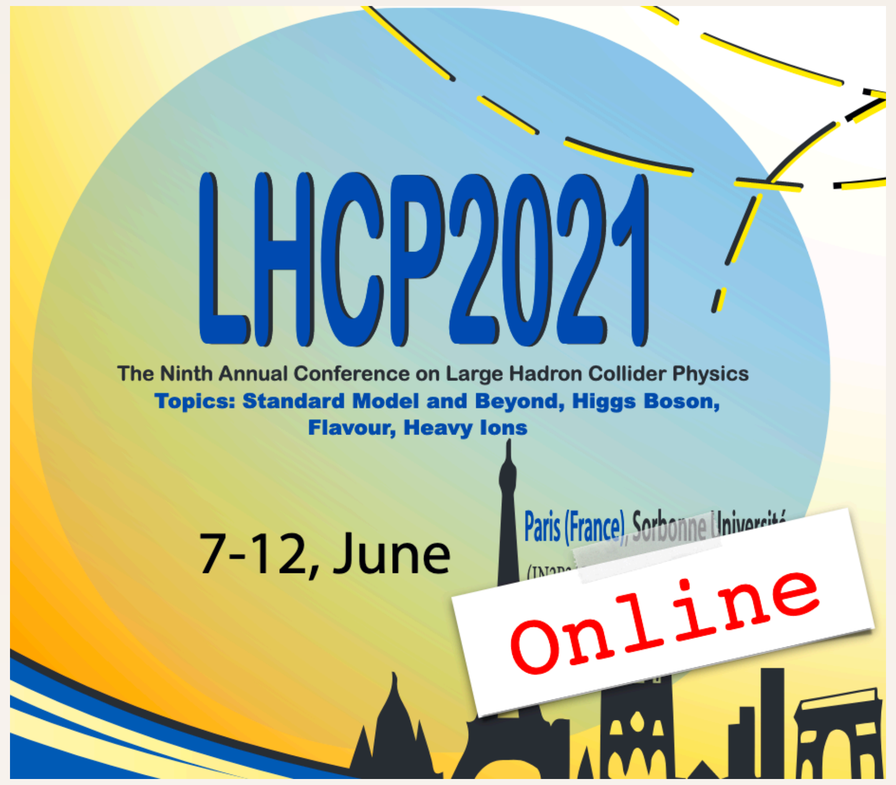

Implementation of machine learning techniques to predict impact parameter and transverse spherocity in heavy-ion collisions at the LHC

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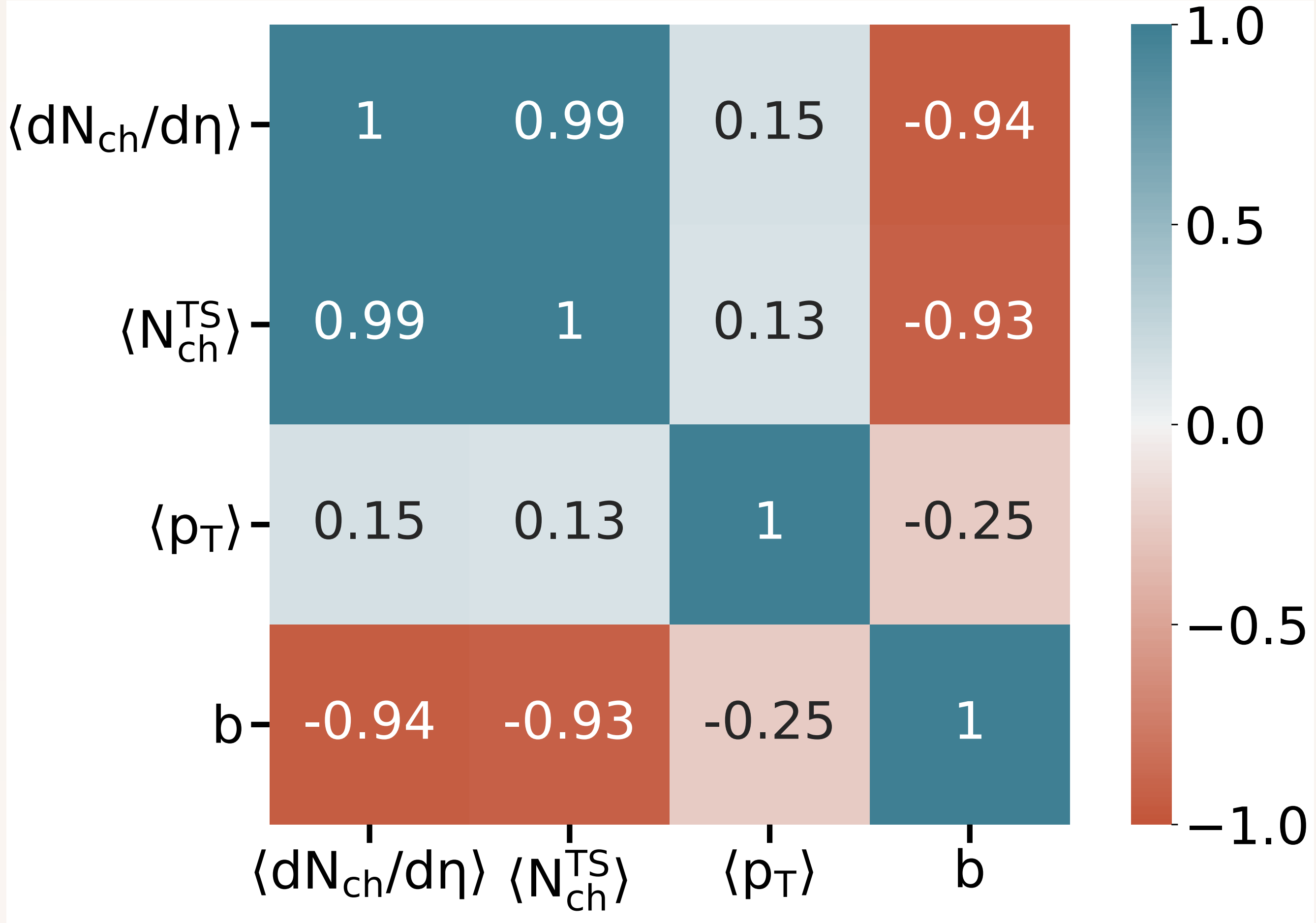
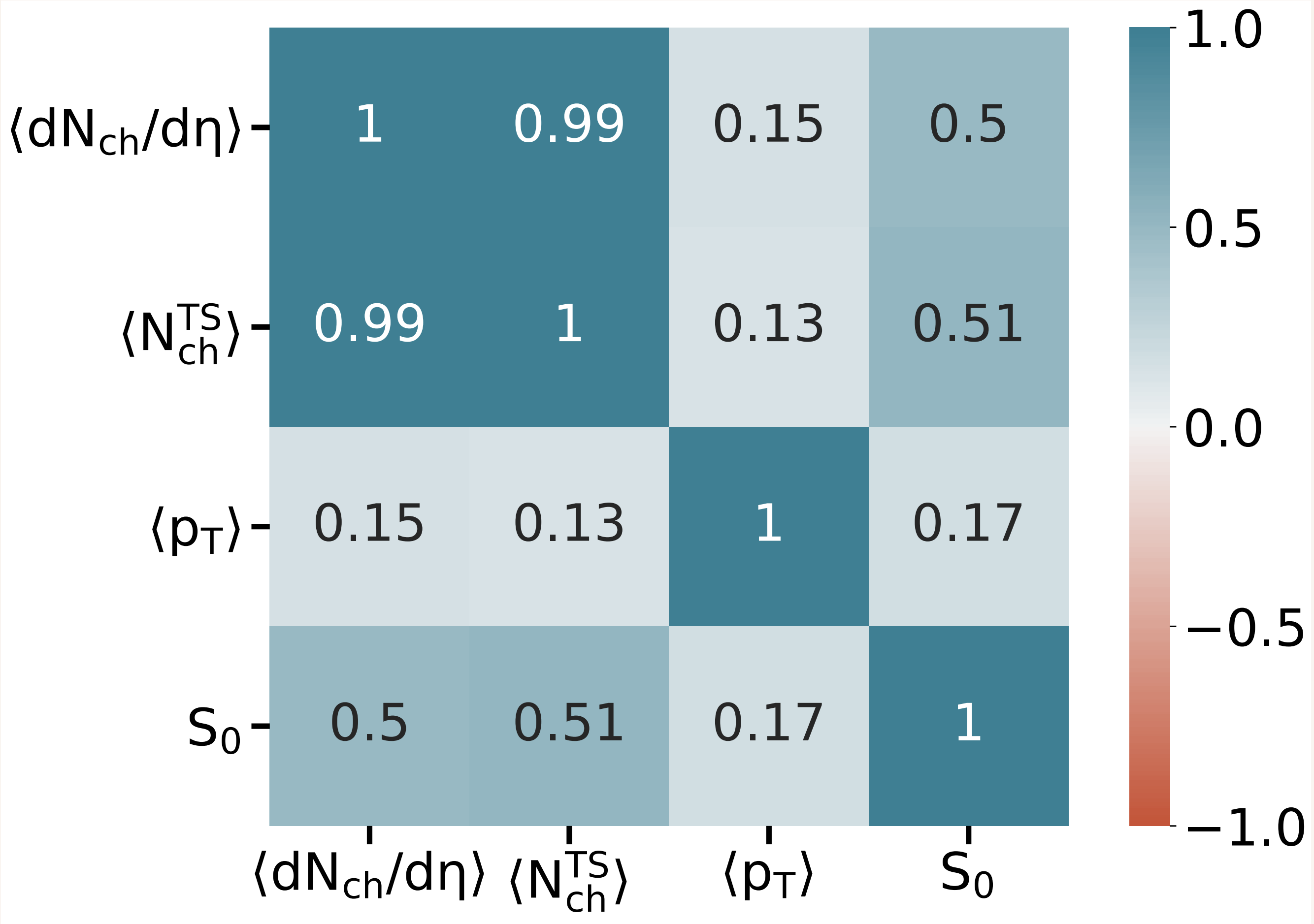
1. Introduction

- Machine learning is being used in various classification and regression problems
- ML gives ability to the machine to predict an outcome without being explicitly programmed
- A multi-phase transport (AMPT) model is used for data generation
- Impact parameter is a crucial observable in heavy-ion collisions yet almost impossible to predict in experiments
- Transverse spherocity, an event shape observable, has recently been introduced in heavy-ion collisions to study azimuthal anisotropy [1]
- In the absence of any experimental exploration, ML could be used to estimate spherocity

1. N. Mallick, R. Sahoo, S. Tripathy, and A. Ortiz, J. Phys. G 48, 045104 (2021)

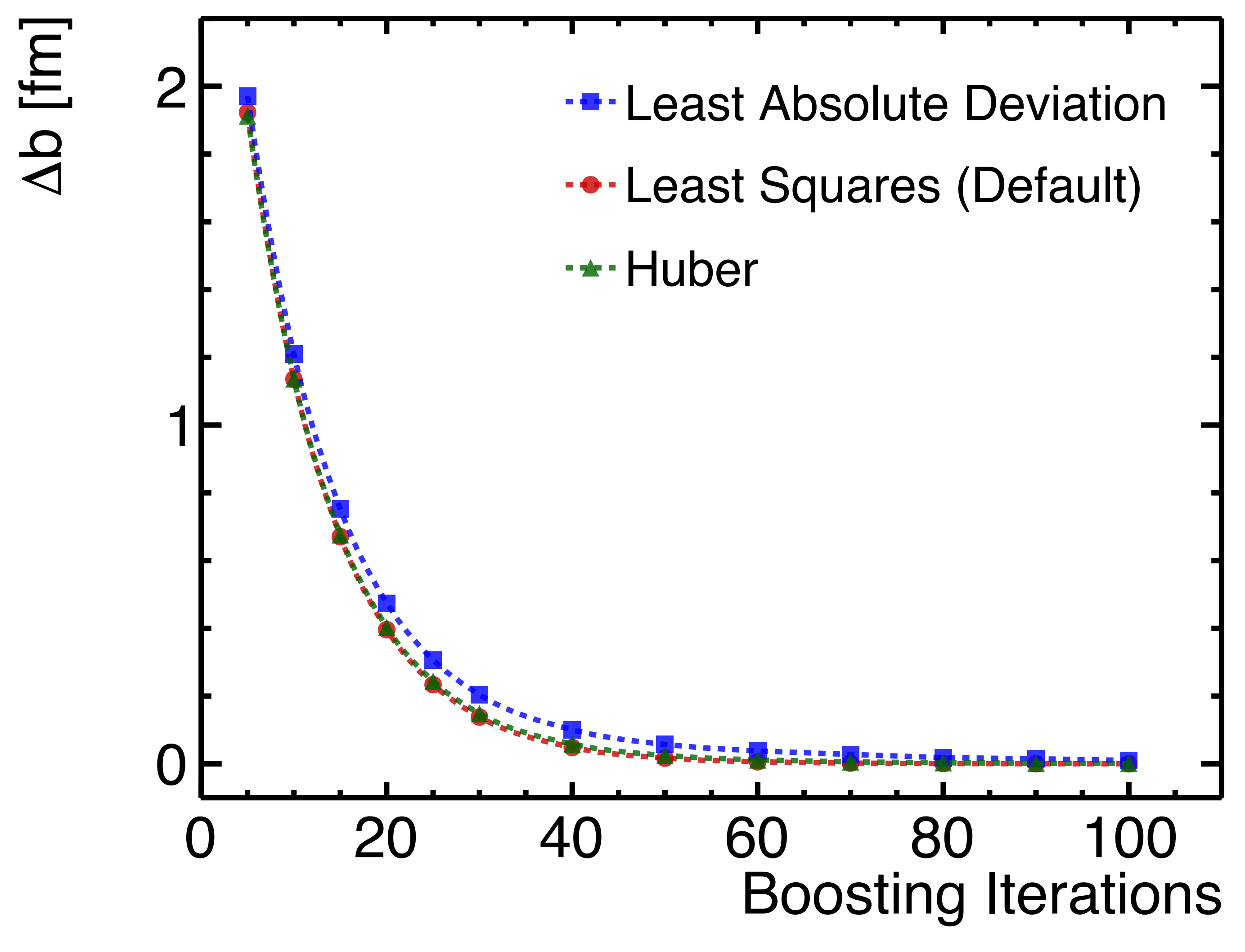
2. Observables

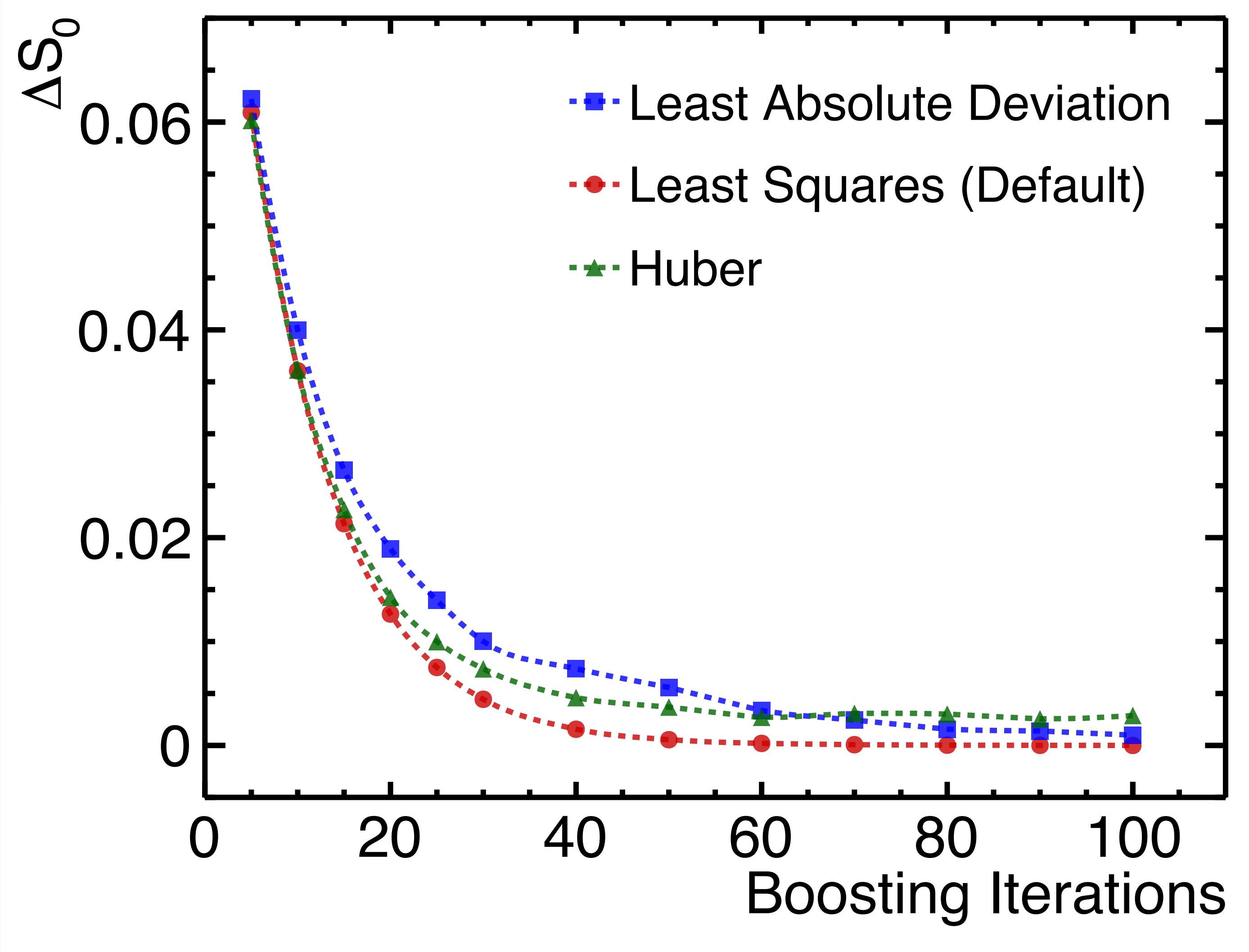




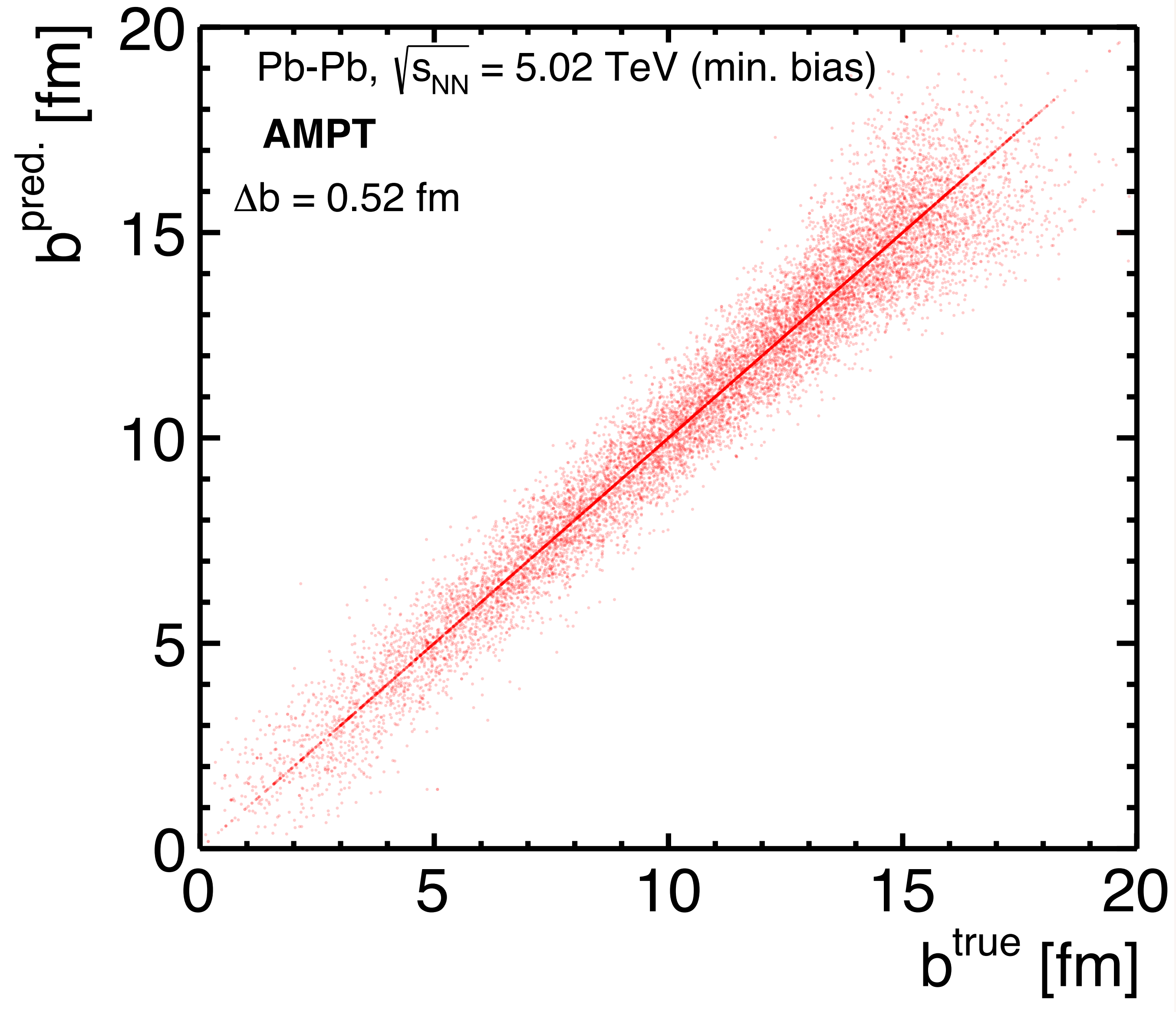
- Final state observables such as charged particle multiplicity, charged particle multiplicity in the transverse region and mean transverse momentum are chosen as the input
- Pearson correlation coefficient indicates strong linear correlation among the chosen input and target observables

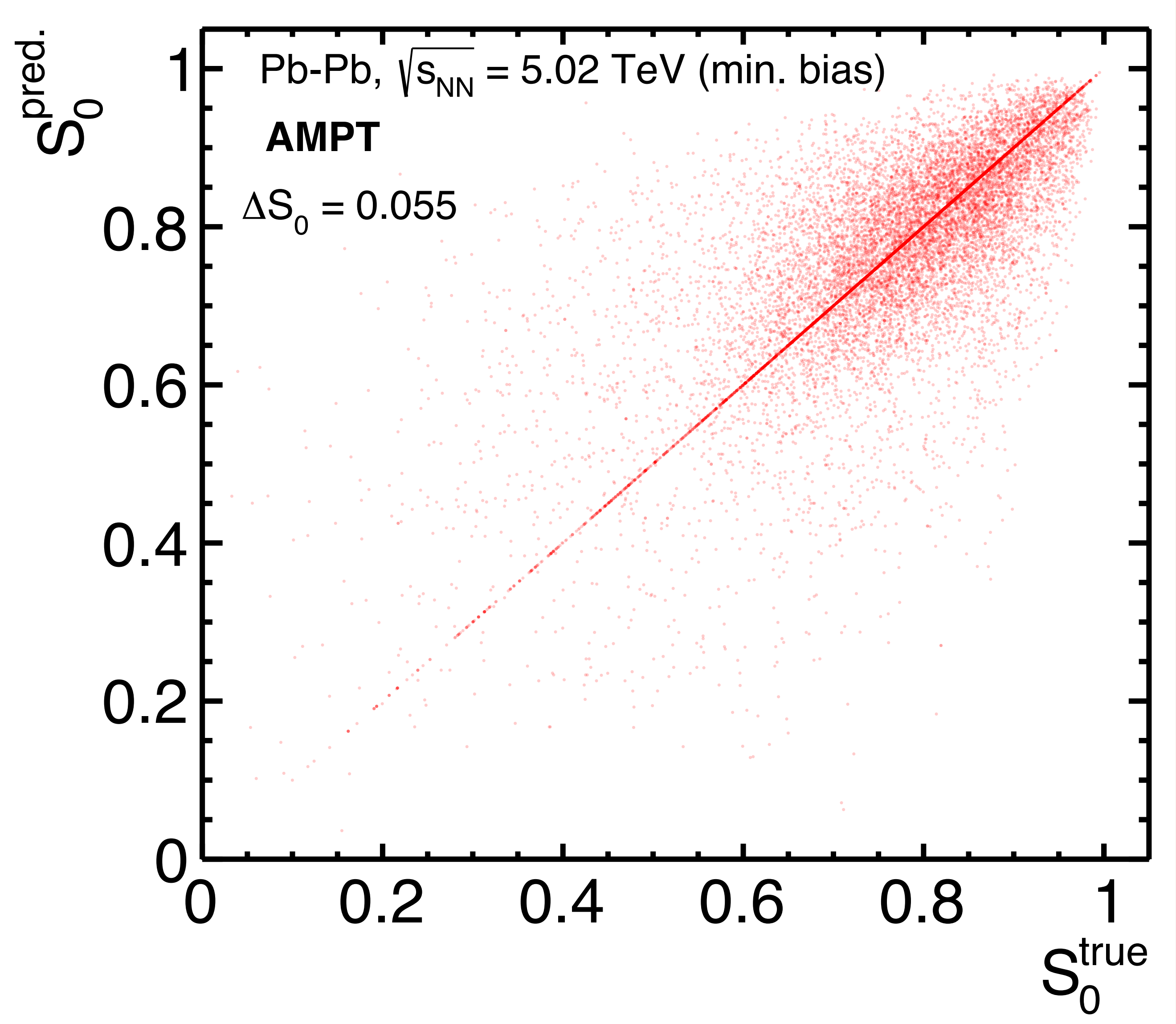
2. Method





$$\Delta b = \frac{1}{N_{\text{events}}} \sum_{n=1}^{N_{\text{events}}} |b_n^{true} - b_n^{pred.}|$$





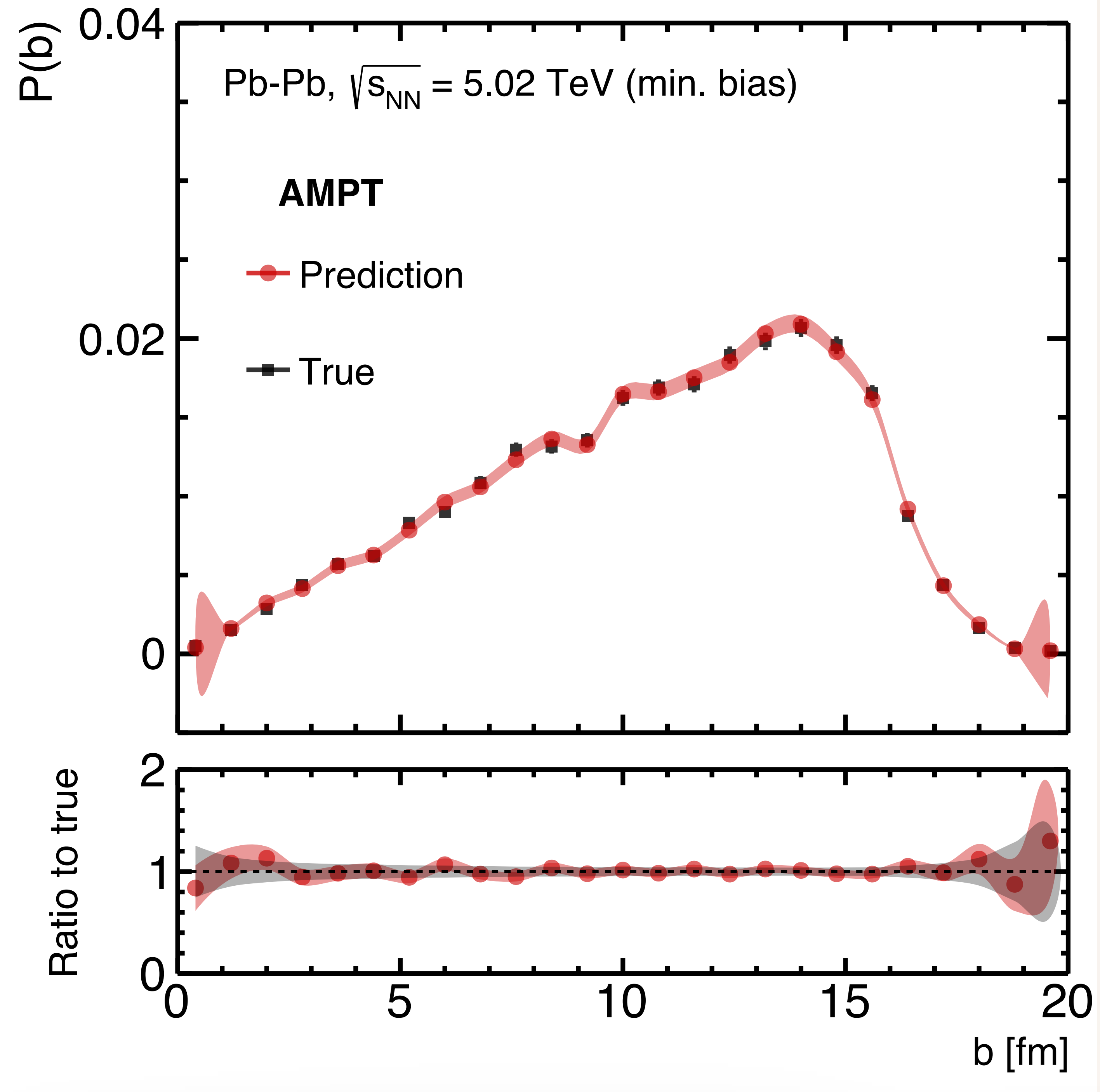
- **Gradient boosting decision trees (GBDTs)** for regression [2,3]
- Loss function: Least squares, Least absolute deviation and Huber function
- Maximum number of trees: 100
- Learning rate: 0.1, Maximum depth: 40
- Training sample size: 60,000 events
- The least difference in Δb and ΔS_0 among the different loss functions are taken as the systematic uncertainty

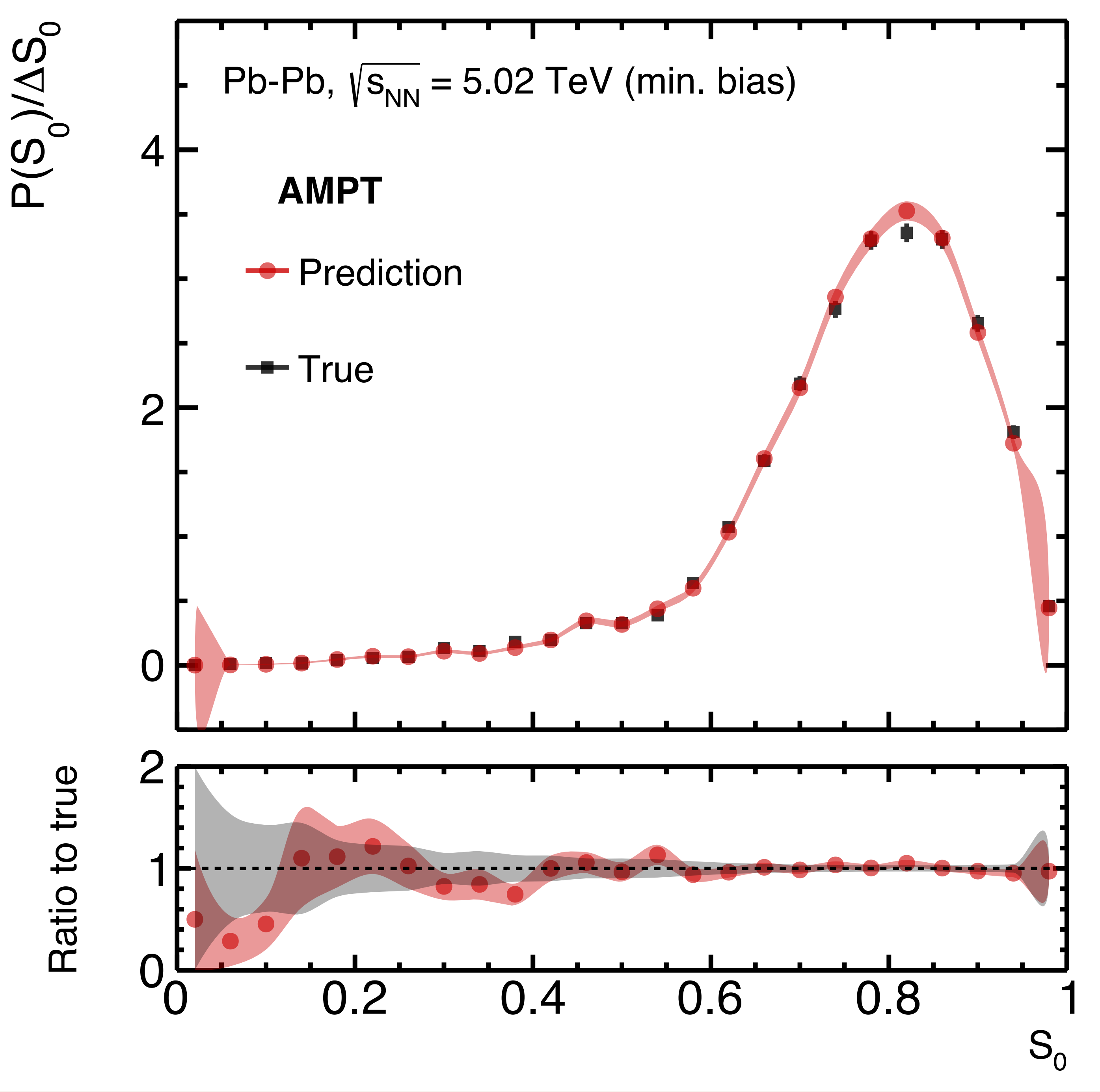
Size of training data	2K	10K	20K	40K	50K	60K
Δb [fm]	0.71	0.62	0.58	0.53	0.52	0.52
ΔS_0	0.079	0.068	0.062	0.058	0.056	0.055

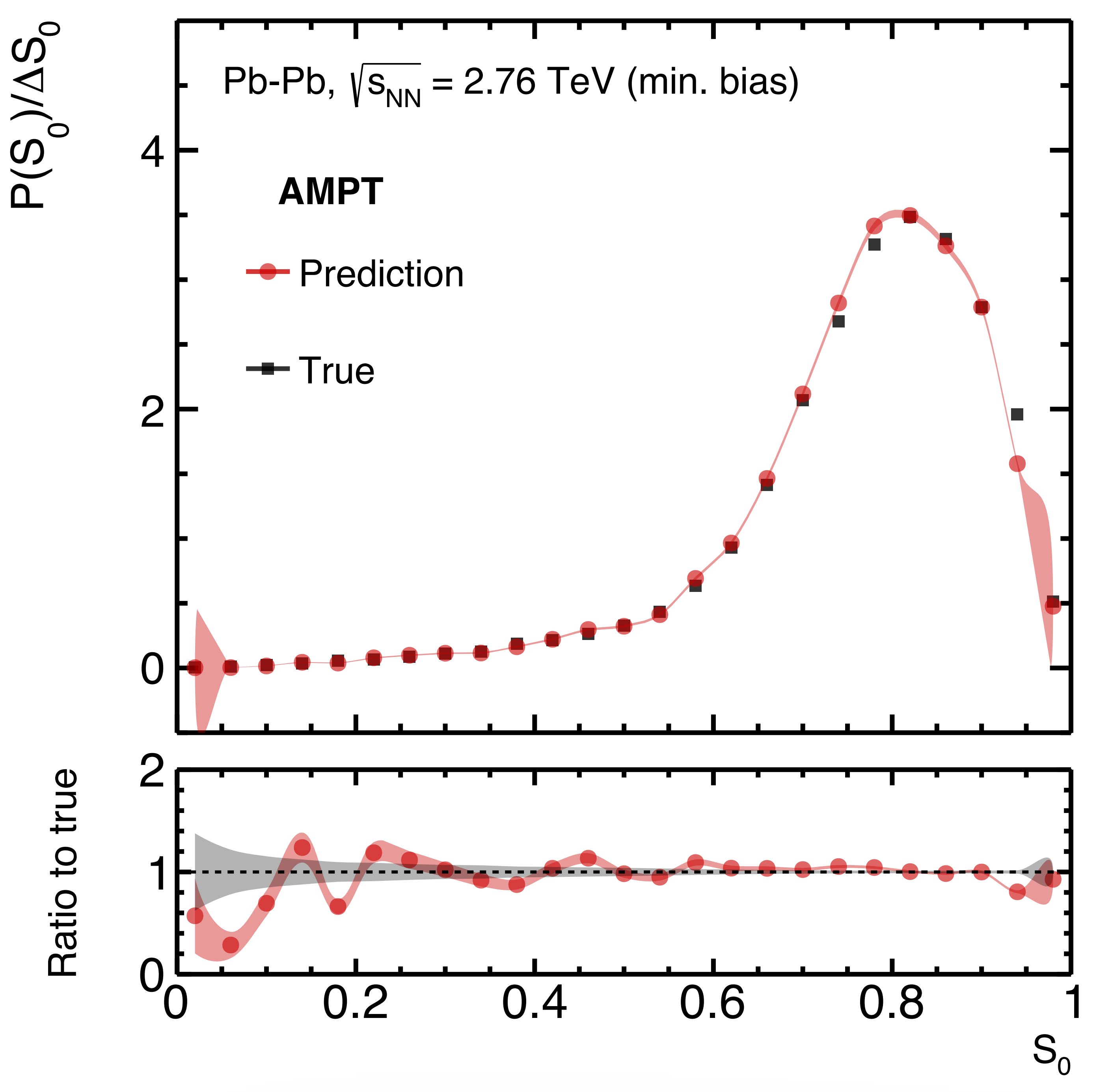
- Least squares loss function gives minimum Δb and ΔS_0
- Training error saturates at 60K events
- Prediction error for $\Delta b = 0.52$ fm and $\Delta S_0 = 0.055$
- Prediction vs. true plot shows a straight line with slope = 1

2. J. H. Friedman, Ann. Stat. 29, 1189 (2001).
3. L. Breiman, J. H. Friedman, R. A. Olshen, and C. J. Stone, Classification and Regression Trees (Wadsworth & Brooks/ Cole Advanced Books & Software, Monterey, CA, 1984), p. 358, https://doi.org/10.1002/cyto.990080516.

3. Results and discussions

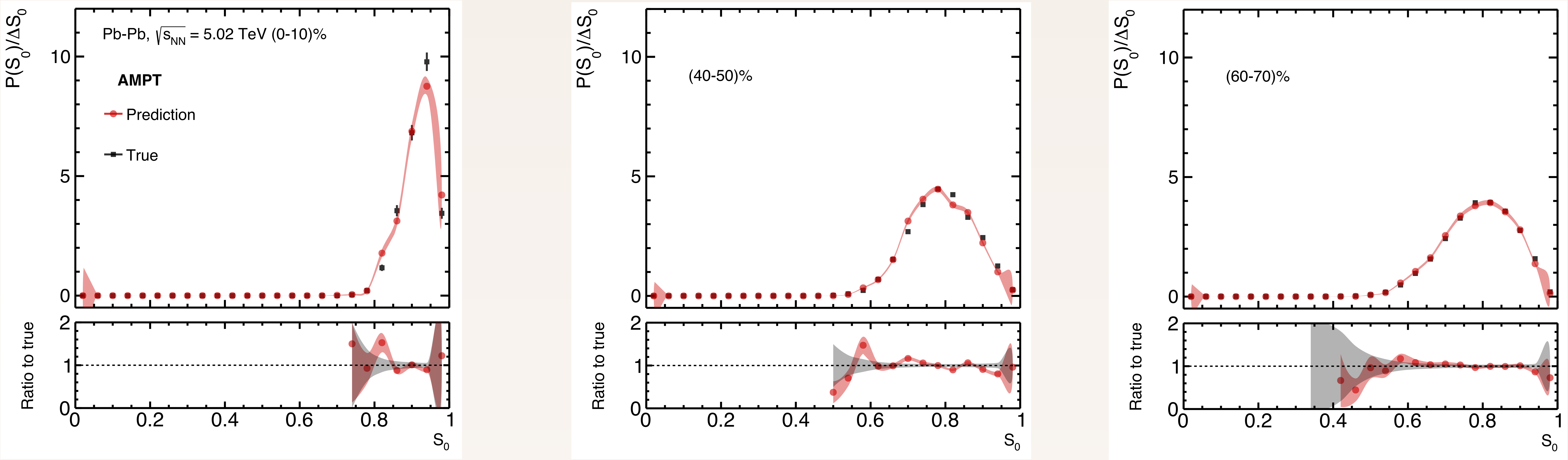






- Training for impact parameter and transverse spherocity is done on Pb-Pb collisions, $\sqrt{s_{\rm NN}} = 5.02$ TeV (min. bias) data from AMPT
- Black band denotes **statistical uncertainty** in simulated (true) values
- Red band denotes the **quadratic sum of statistical and systematic uncertainty** in the predicted values from the ML-model
- The predictions for impact parameter and transverse spherocity in Pb-Pb collisions, $\sqrt{s_{\rm NN}} = 5.02$ TeV (min. bias) are in **good agreement with the true values**
- ML-model trained on Pb-Pb collisions, $\sqrt{s_{\rm NN}} = 5.02$ TeV (min. bias) data **successfully predicts** transverse spherocity distribution for Pb-Pb collisions, $\sqrt{s_{\rm NN}} = 2.76$ TeV (min. bias)

4. N. Mallick, S. Tripathy, A. N. Mishra, S. Deb, and R. Sahoo, Phys. Rev. D 103, 094031 (2021)



- Training for transverse spherocity is done on **Pb-Pb collisions, $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV (min. bias)** data from AMPT
- Black band denotes **statistical uncertainty** in simulated (true) values
- Red band denotes the **quadratic sum of statistical and systematic uncertainty** in the predicted values from the ML-model
- ML-model trained on Pb-Pb collisions, $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV (min. bias) data **successfully predicts** the transverse spherocity distributions at various centralities such as (0-10)%, (40-50)% and (60-70)%

4. N. Mallick, S. Tripathy, A. N. Mishra, S. Deb, and R. Sahoo, Phys. Rev. D 103, 094031 (2021)