Exploring CP symmetry in the interaction of Higgs boson with top quark at the ATLAS experiment

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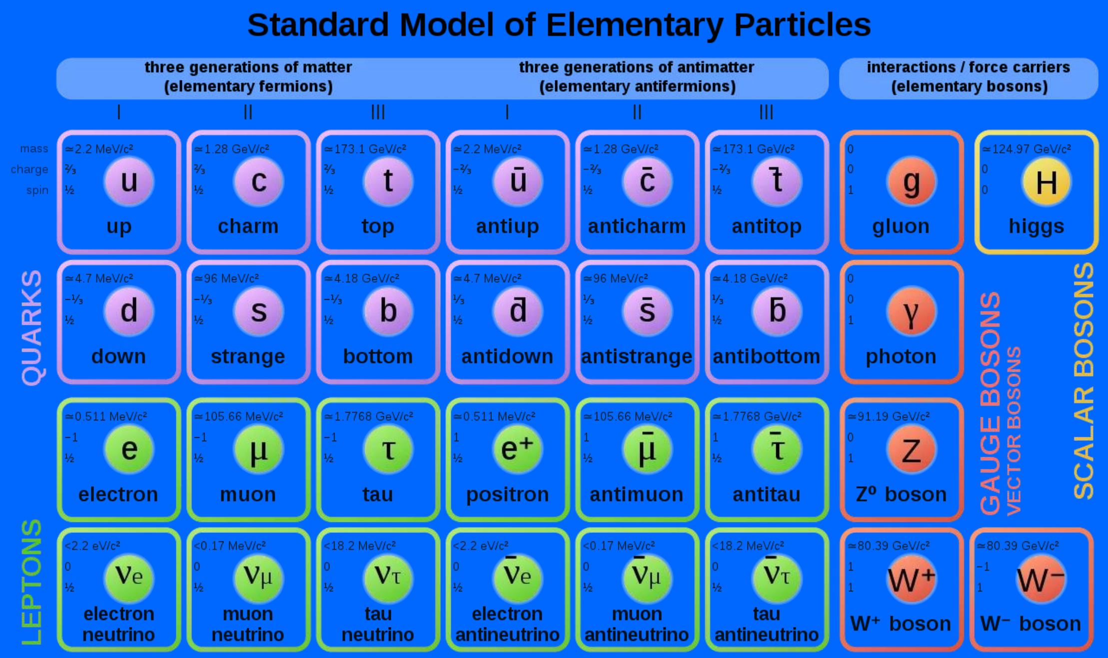
HSSIP CERN 2022.

Overview

- Introduction to CP violation
- Search for the CP violation in the Higgs sector
- Measurement of the CP properties of the Higgs-top coupling - our project;
  - Search for observables sensitive to CP properties
  - Projection of the current ATLAS results for LHC Run3 and HL-LHC
- Discussion of the result.

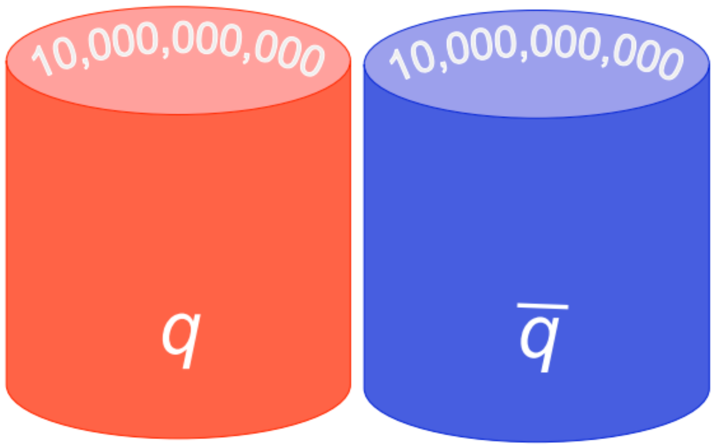
Antimatter and antiparticles

- Negative energy solution to Dirac's equation
- Seen in detectors using magnetic fields
- Different charge
- Annihilates with matter



Matter-Antimatter asymmetry

- Much more matter than antimatter
- After the Big Bang: same amount
- Nbaryons/Nphotons $\cong 6*10^{-10}$



Symmetries

- Continuous/discrete symmetries

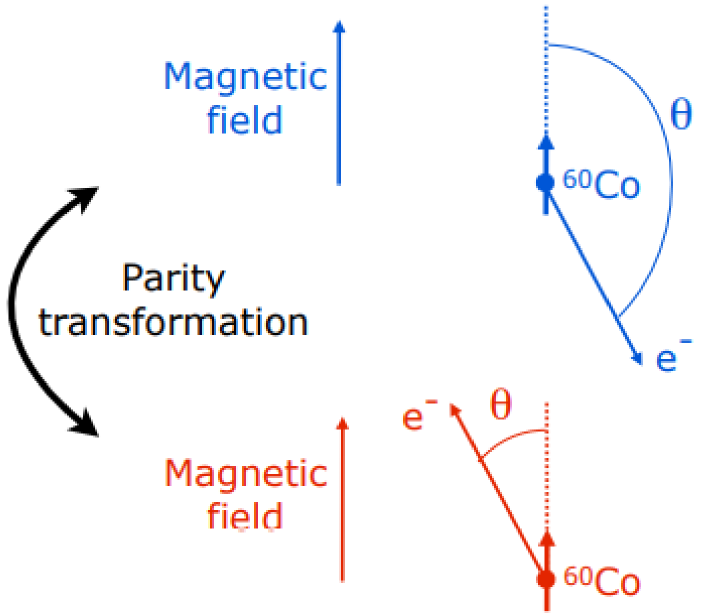
- Space translation, Time shift, Rotation symmetries

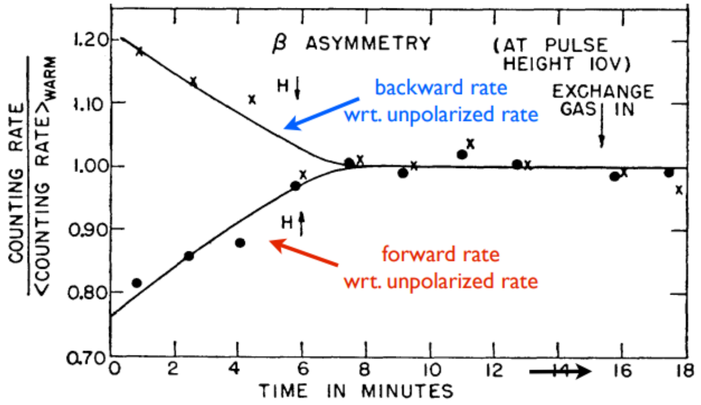
- Discrete symmetries:
  - Spatial sign flip (P)
  - Charge sign flip (C)
  - Time sign flip (T)

Quantity		P	C	T
Space vector	$\mathbf{x}$	$-\mathbf{x}$	$\mathbf{x}$	$\mathbf{x}$
Time	t	t	t	$-t$
Momentum	$\mathbf{p}$	$-\mathbf{p}$	$\mathbf{p}$	$-\mathbf{p}$
Spin	$\mathbf{s}$	$\mathbf{s}$	$\mathbf{s}$	$-\mathbf{s}$
Electrical field	$\mathbf{E}$	$-\mathbf{E}$	$-\mathbf{E}$	$\mathbf{E}$
Magnetic field	$\mathbf{B}$	$\mathbf{B}$	$-\mathbf{B}$	$-\mathbf{B}$

Mme Wu’s Experiment

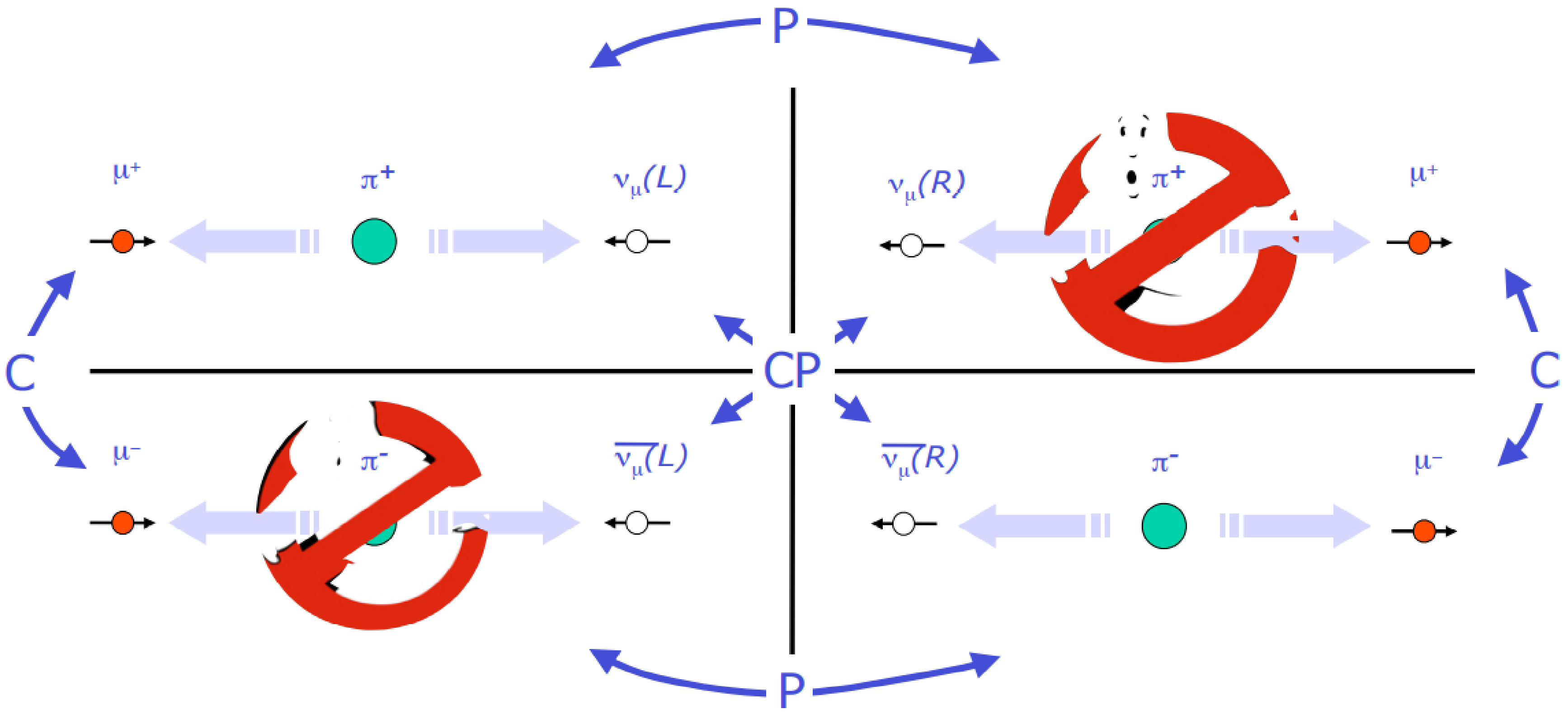
- Parity conserved in QED and QCD, expected to be conserved in weak interactions as well;
- Look at spin of decays products of polarized radioactive nucleus
- Electrons were emitted in the directions opposite the ^{60}Co spin and different was expected





^{60}Co polarization decreases as a function of time as the temperature increases

C, P, CP



CP violation observed with kaons

$$K_s \rightarrow \pi\pi \;\; [CP\ even]$$

$$K_l \rightarrow \pi\pi\pi \;\; [CP\ odd]$$

- Far from a production point of a kaon beam only three pion decays are expected
- However, two pion decays are also observed, but with a low rate

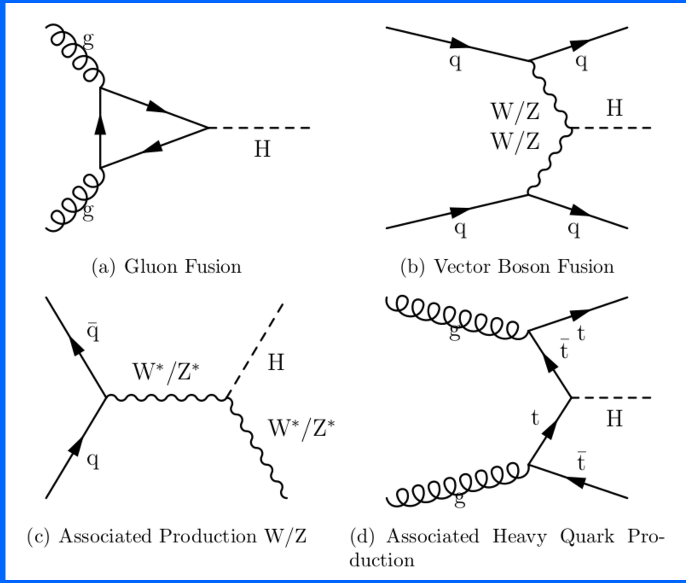
Weak interactions violate CP symmetry

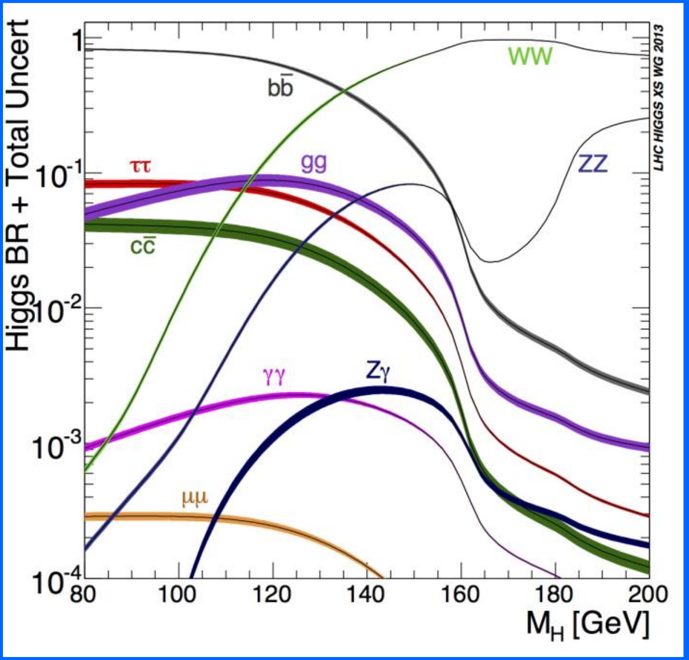
- Violation observed in laboratories don’t fully explain the Baryon asymmetry

Higgs boson CP properties

- The Higgs boson CP properties are measured in the production and decay channels
- The Higgs-top Yukawa coupling is the largest coupling in the SM and any deviation wr.t SM prediction can indicate a presence of new physics -measured only in the production - ttH production.

- We observe ttH production channel because Higgs decay on top quark is very rare
- Only $\gamma\gamma$ and bb decay are fit for studies at ATLAS and CMS experiments





Samples

$$\mathcal{L} = -\frac{m_t}{V}\bar{\Psi}_{\mathrm{T}}K'_{\mathrm{T}}(\cos(\alpha) + i\sin(\alpha)\gamma^5)\Psi_{\mathrm{T}}H$$

- This part of Lagrangian explains Higgs interaction with top quark depending on the angle $\alpha(0° - 90°)$ – mixing angle

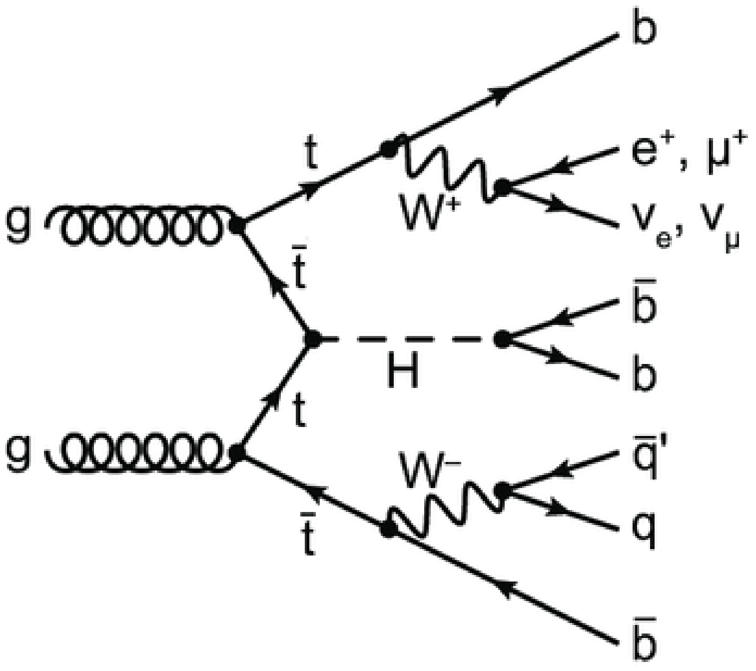
- $\alpha = 0$ – pure CP-even
- $\alpha = 90$ – pure CP-odd (max violation)

- Both CP-even and CP-odd processes were generated using MadGraph-aMC@NLO generator https://launchpad.net/mg5amcnlo;

ttH production and event selection

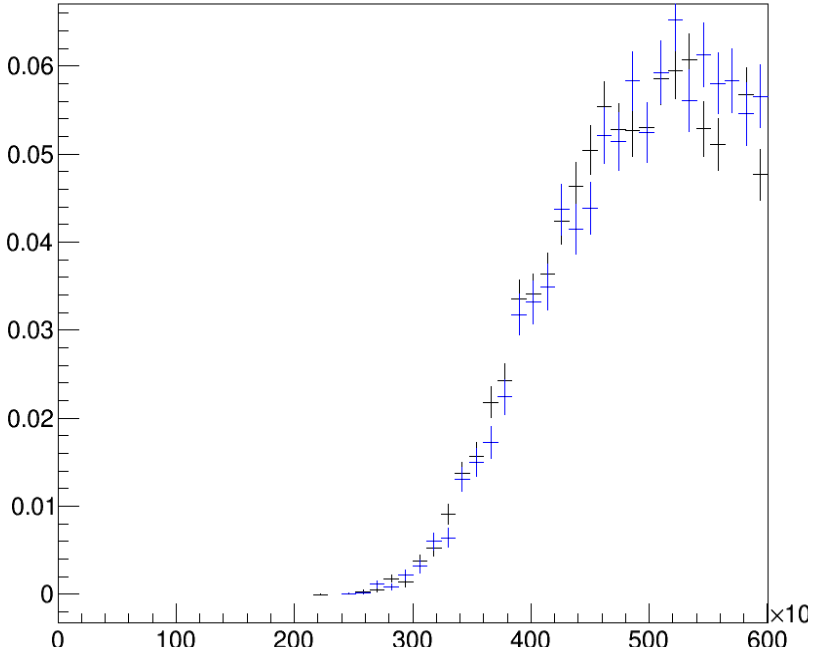
- The idea of our project was to study the CP properties in the ttH.H->bb decay

- Event selection:
- 1 lepton (e or μ)
- 6 jets
- 4 b-tagged jets (originating from b-quarks)



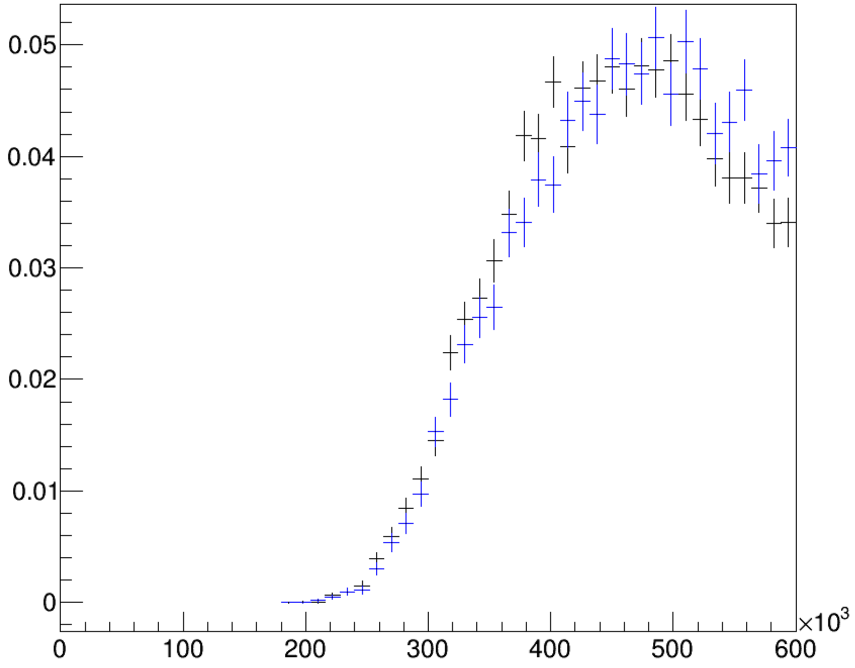
Parameters we've observed

HT all



jets + leptons

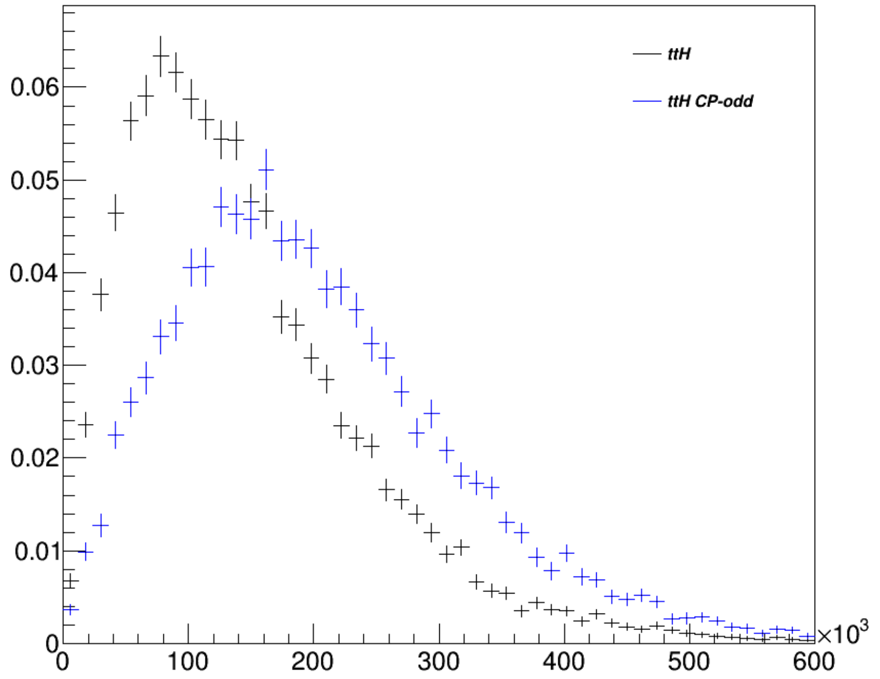
HT jets



jets only

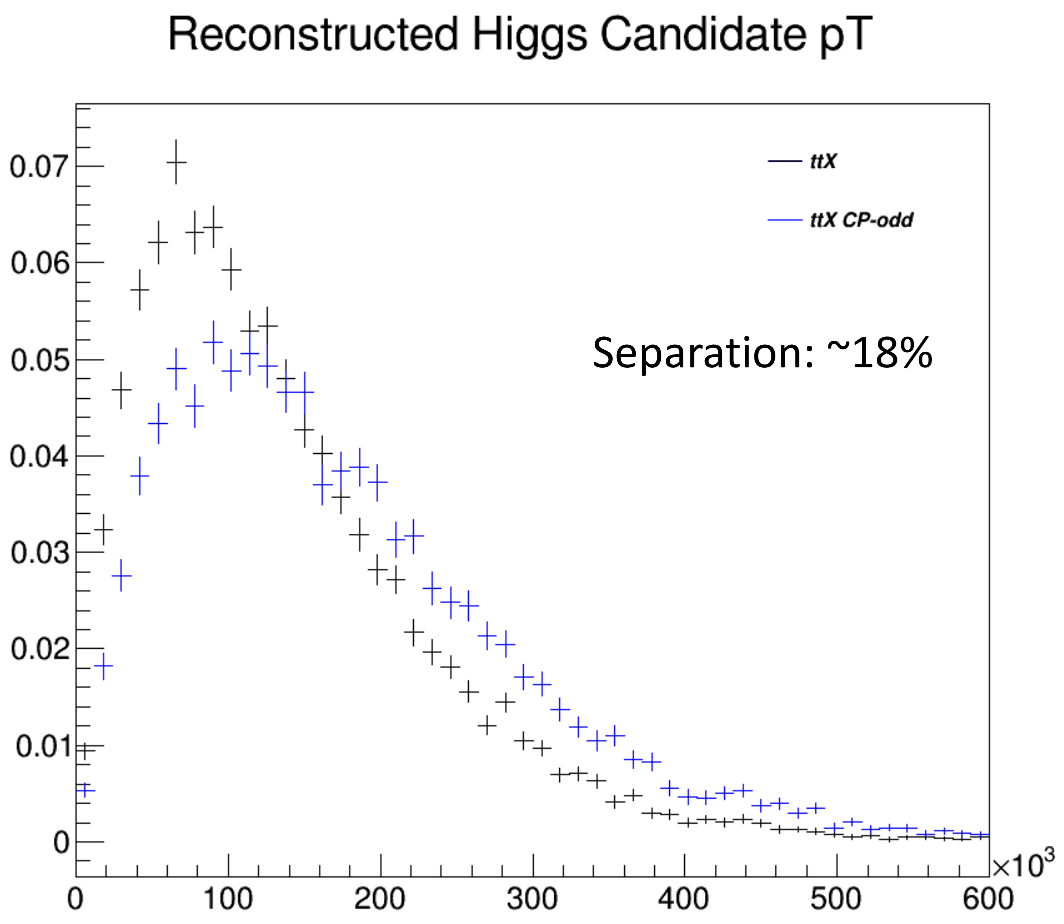
Scalar sum of transverse momentum (p_T)

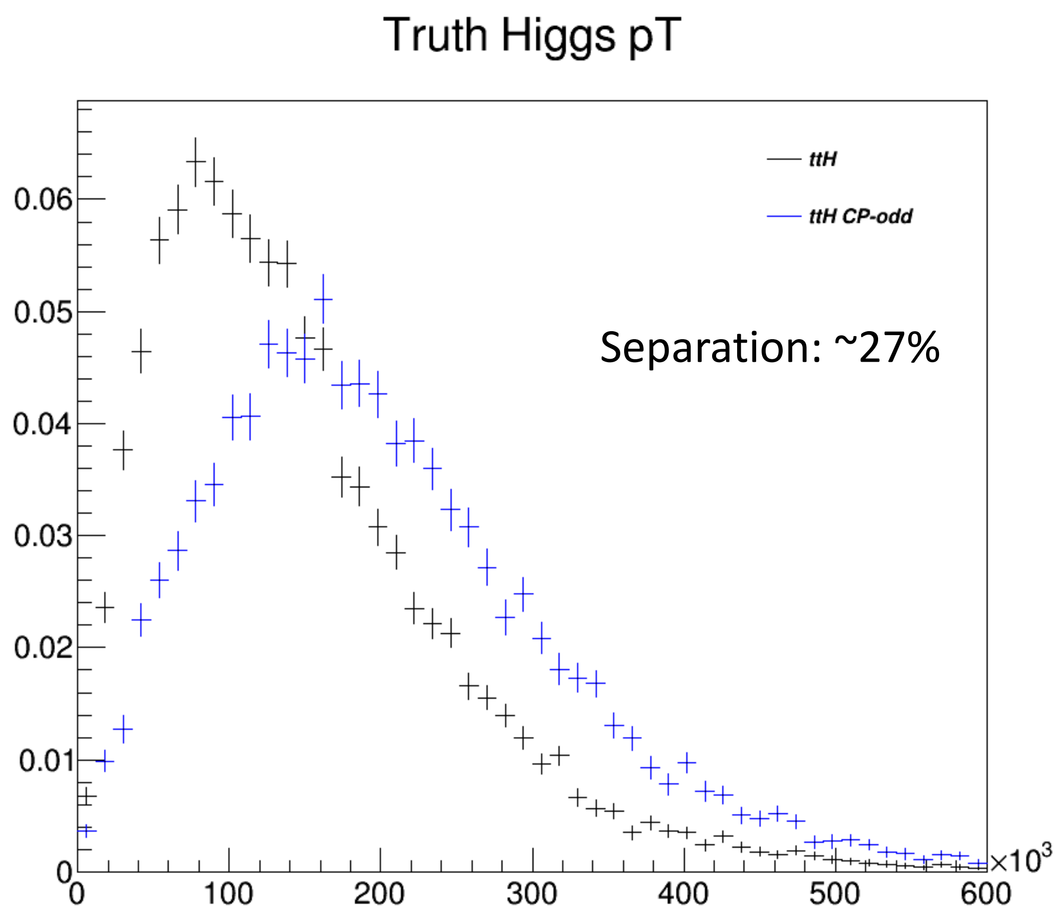
Truth Higgs pT

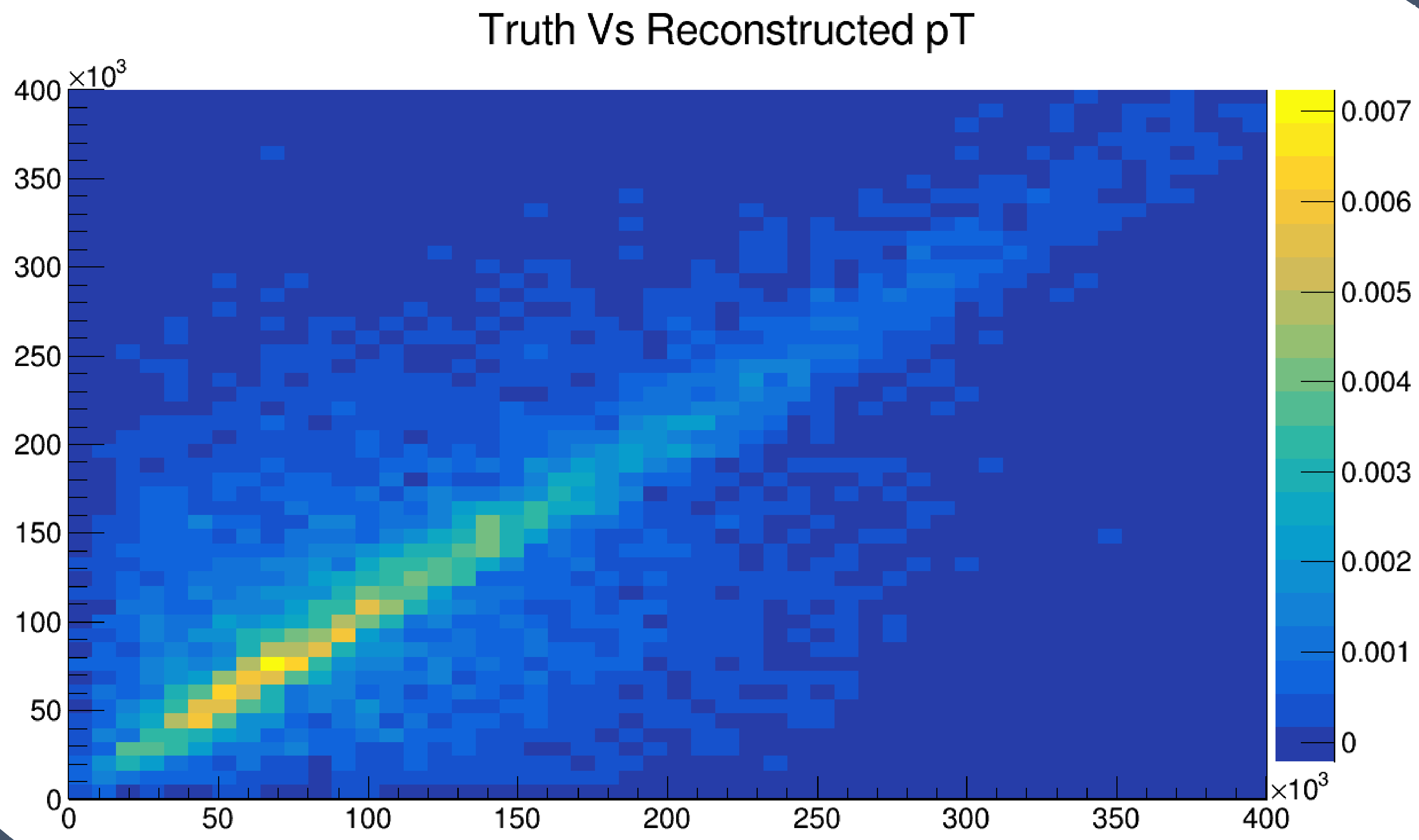


Transversal momentum of Higgs

Reconstructed vs Truth






Truth Vs Reconstructed pT
×10^3
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
×10^3
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0

Latest ATLAS results

New H $\rightarrow b\bar{b}$ result (2022)

Disfavors pure CP odd: 1.2σ

Uncertainty of measurement of the

mixing angle: 38% (28% systematic component)

Using full Run 2 data with 139 fb^-1

Reference: https://cds.cern.ch/record/2805772

H $\rightarrow \gamma\gamma$ result (2020):

Excludes pure CP odd : 3.9σ

Uncertainty of measurement of the

mixing angle: 23%

- negligible component from the

systematic uncertainty.

Reference: https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.125.061802

Projections for the future

- Increasing the amount of data lowers the statistical uncertainty
- Run 3: 300 fb^{-1}
- HL-LHC: 3000 fb^{-1}

Relative uncertainty of	300 fb^{-1} with no systematic improvement	300 fb^{-1} with double systematic improvement	3000 fb^{-1} with no systematic improvement	3000 fb^{-1} with double systematic improvement
bb	30,79%	18,41%	28,53%	14,3%
$\gamma\gamma$	10,67%	10,67%	1,067%	1,067%

Summary

- • The CP-violation that could explain asymmetry between matter and anti-matter has been studies in the particle experiments for decades.
- • Discovery of the Higgs boson opens a new window for the CP violation search - in the Higgs boson interactions;
- • Our project was to study the CP properties in the Higgs-top Yukawa coupling in the ttH. H->bb process using simulated ATLAS samples;
- • We studies several observable and found out that pT(Higgs) is the sensitive observable that can be used in the measurement;
- • Another task of the project was to make projections and estimate the precision ATLAS can achieve with Run 3 data and at HL-LHC.

Thank you for your attention