Nikhef

THE HIGGS BOSON AND THE MYSTERY OF MATTER-ANTIMATTER ASYMMETRY

Robin Hayes for the ATLAS group

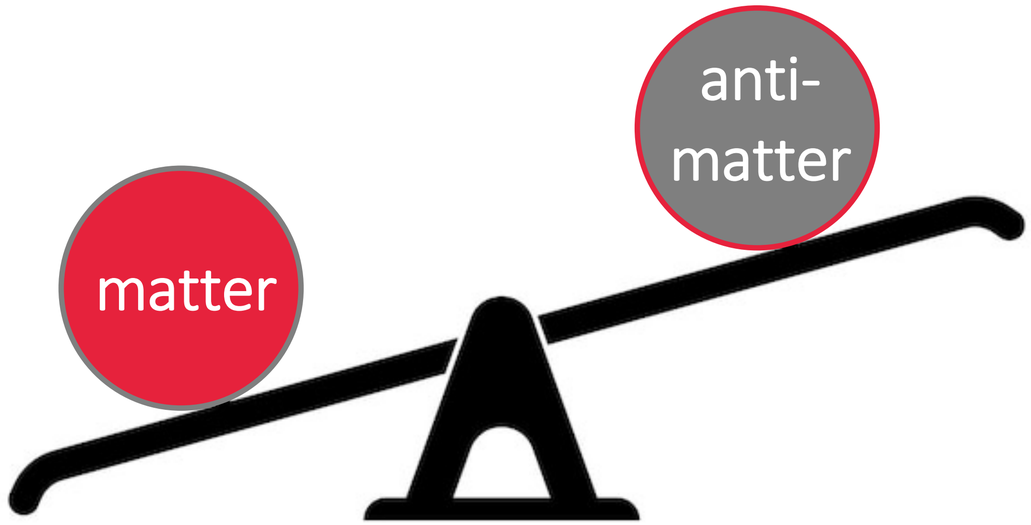
Nikhef Jamboree (May 11-12 2026)

Why is the Universe Mostly Matter?

Following the Big Bang:
for every $\mathbf{10^8}$ matter particles, there were $\mathbf{10^8 - 1}$ anti-matter particles.

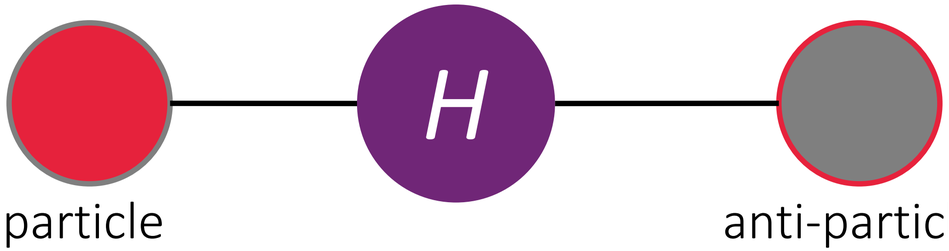
The Standard Model (SM) can't account for this asymmetry!

For answers: the Higgs boson?



For Answers: the Higgs Boson?

Predicted by the SM:

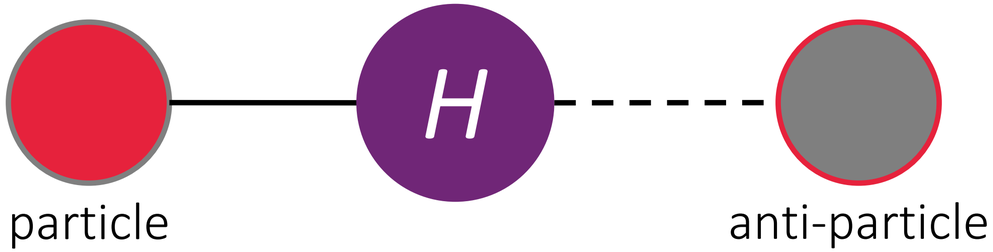


- Higgs interacts identically with particles and antiparticles

  No matter-antimatter asymmetry*

*actually just very small

Predicted by alternate theories:



- Higgs interacts differently with particles and antiparticles

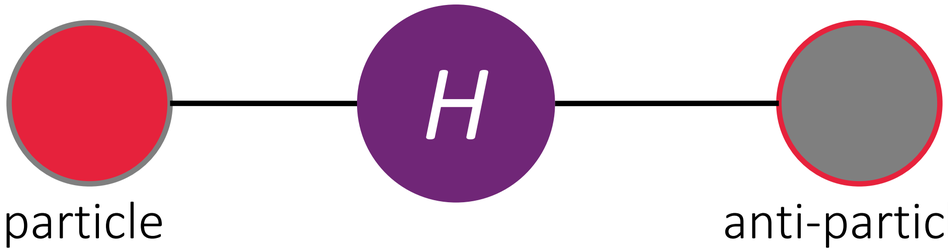
  Matter-antimatter asymmetry*

*if some other conditions are also satisfied

Nikhef

For Answers: the Higgs Boson?

Predicted by the SM:

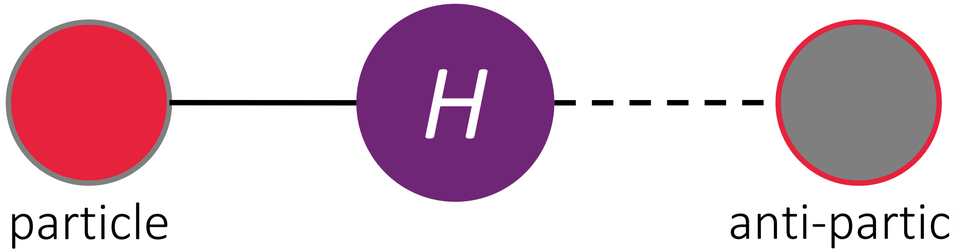


- Higgs interacts identically with particles and antiparticles

  No matter-antimatter asymmetry*

*actually just very small

Predicted by alternate theories:



- Higgs interacts differently with particles and antiparticles

  Matter-antimatter asymmetry*

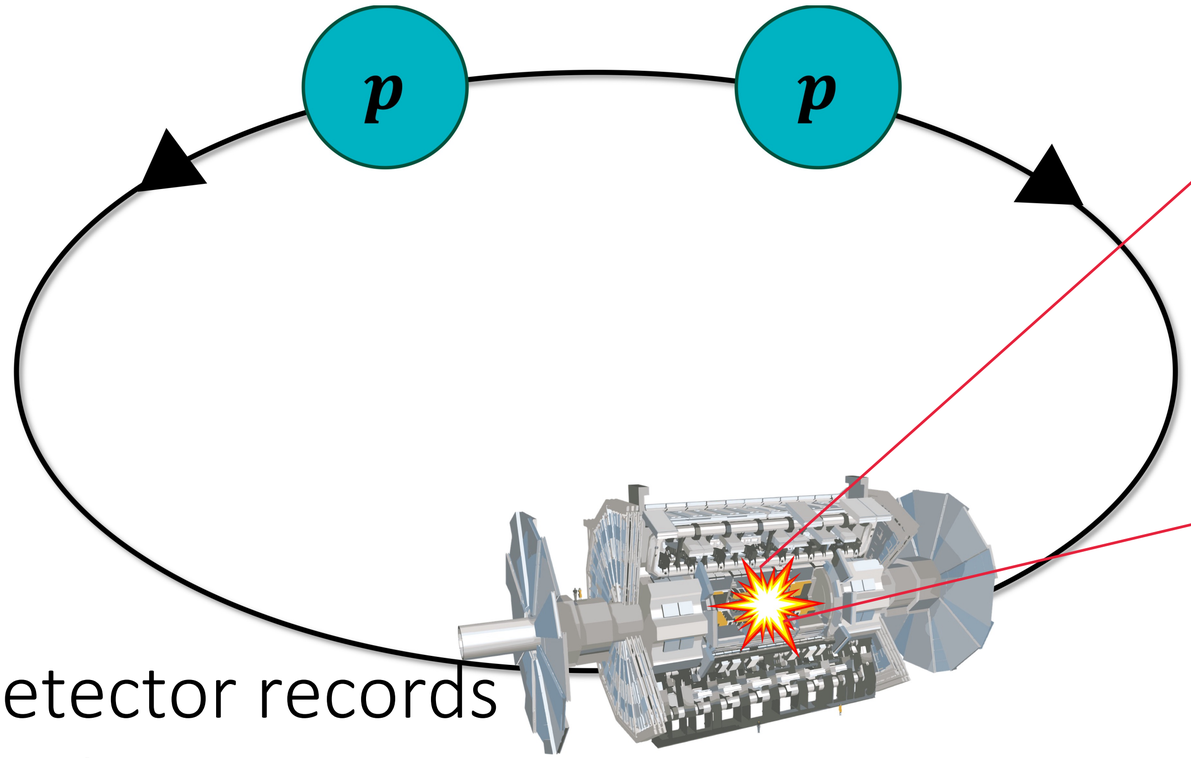
Charge-parity (CP) violation

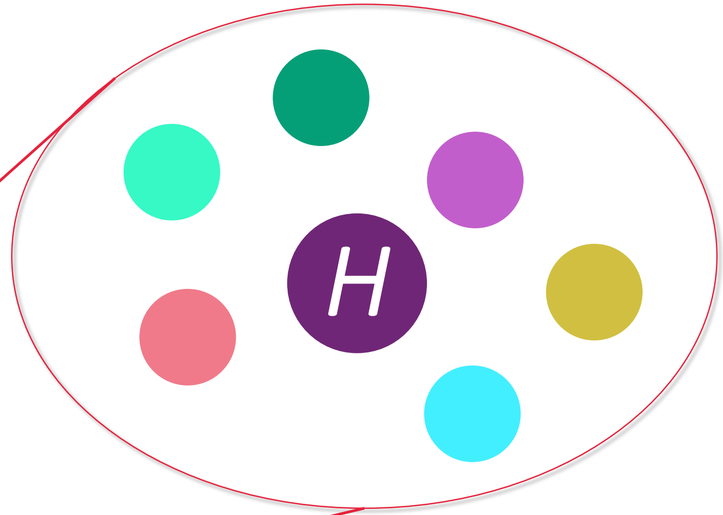
*if some other conditions are also satisfied

Nikhef

Looking for CP Violation at the Large Hadron Collider

1. High-energy proton beams accelerated at the LHC.





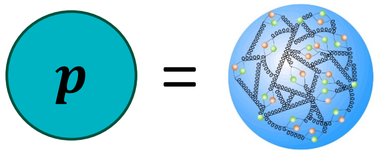
2. ATLAS detector records collision products.

3. Proton collisions produce new particles... including Higgs bosons!

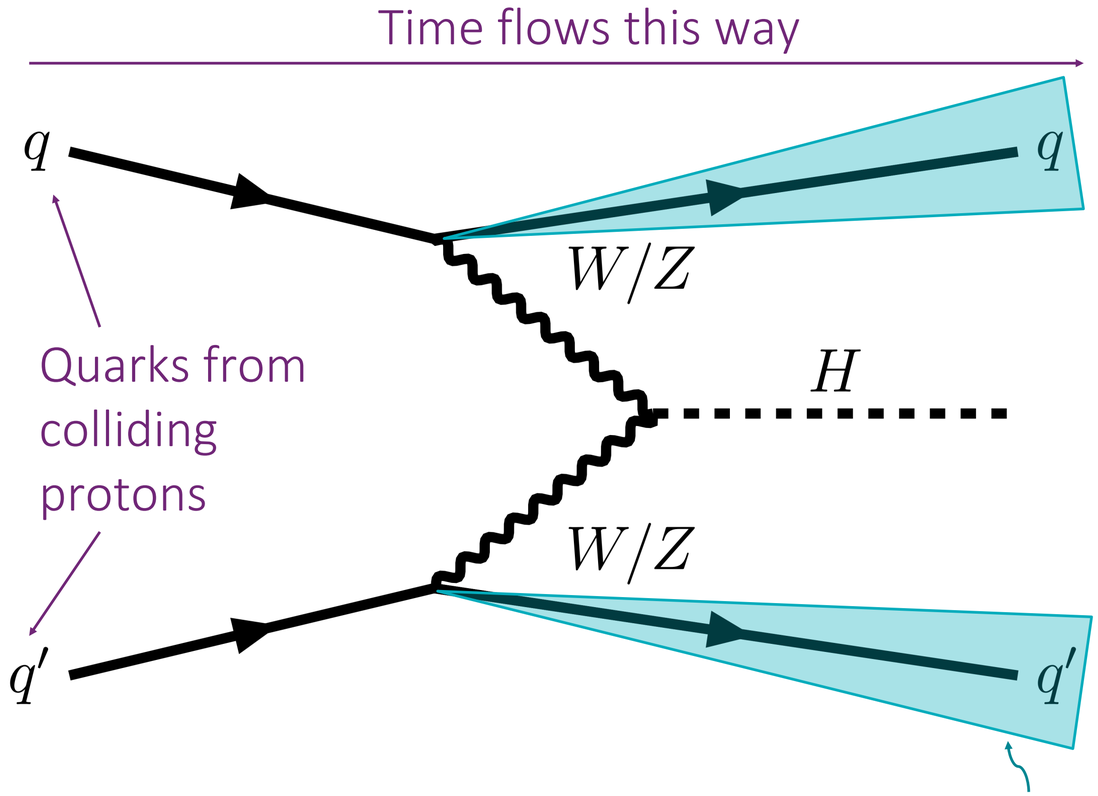
Nikhef

Looking for CP Violation at the Large Hadron Collider

Higgs produced by interaction of quarks and gluons in the proton.



One mechanism:
vector boson fusion (VBF).

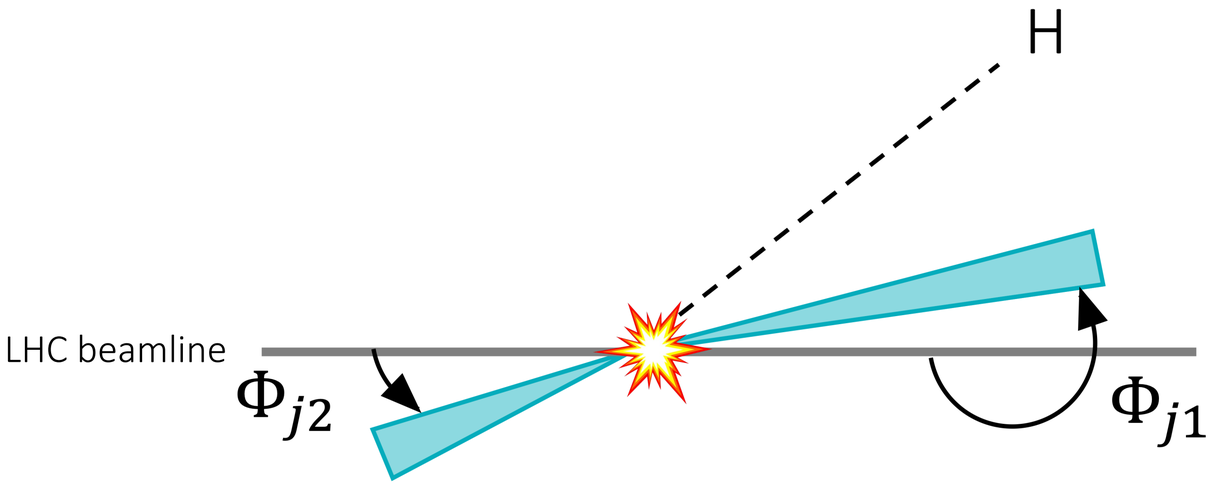


CP violation would change angular distributions of the jets.

CP Violation in Vector Boson Fusion

Variable sensitive to CP violation: $\Delta\Phi_{jj}$.

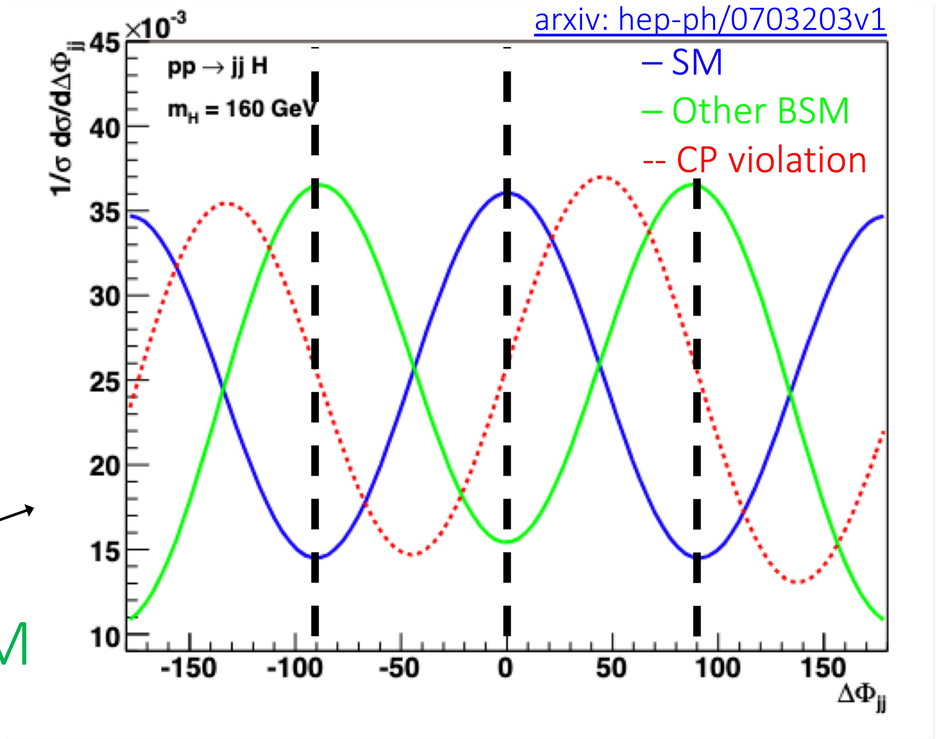
- Azimuthal angle difference b/w the two jets, ordered by their angle wrt the beamline.



$\Delta\Phi_{jj}$ is: symmetric for SM

symmetric for non-CP-violating beyond SM

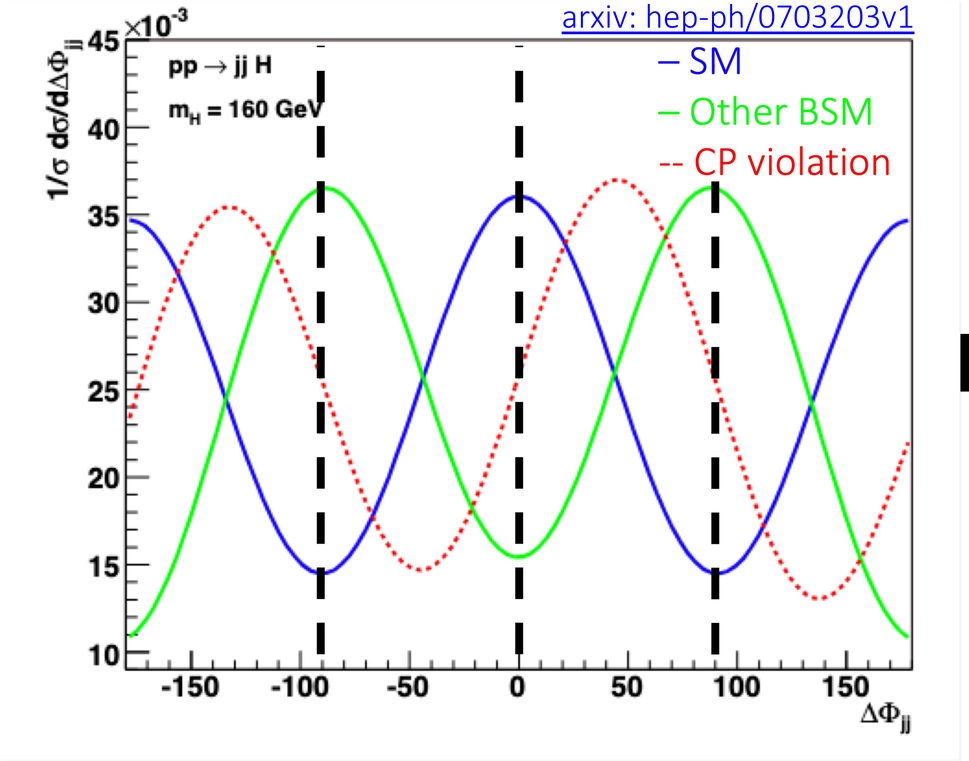
asymmetric for CP violation

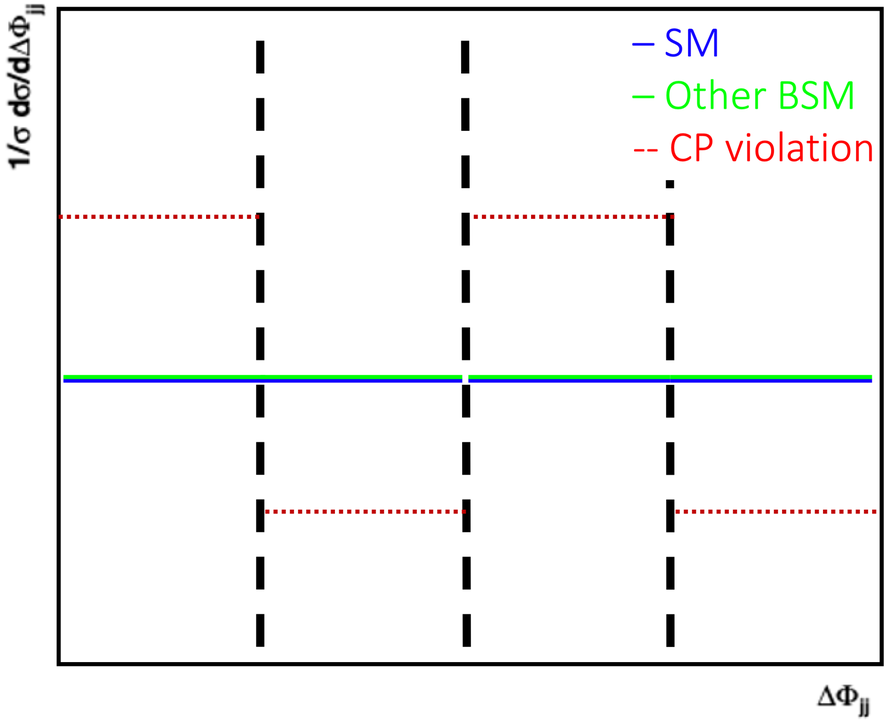


Nikhef

Measurement Strategy

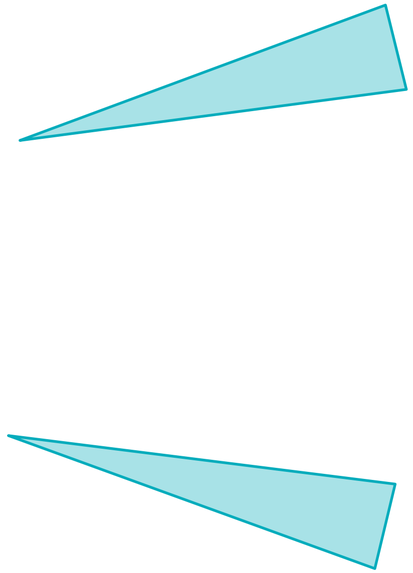
- Four distinct bins capture the major shape effects.





Measurement Strategy

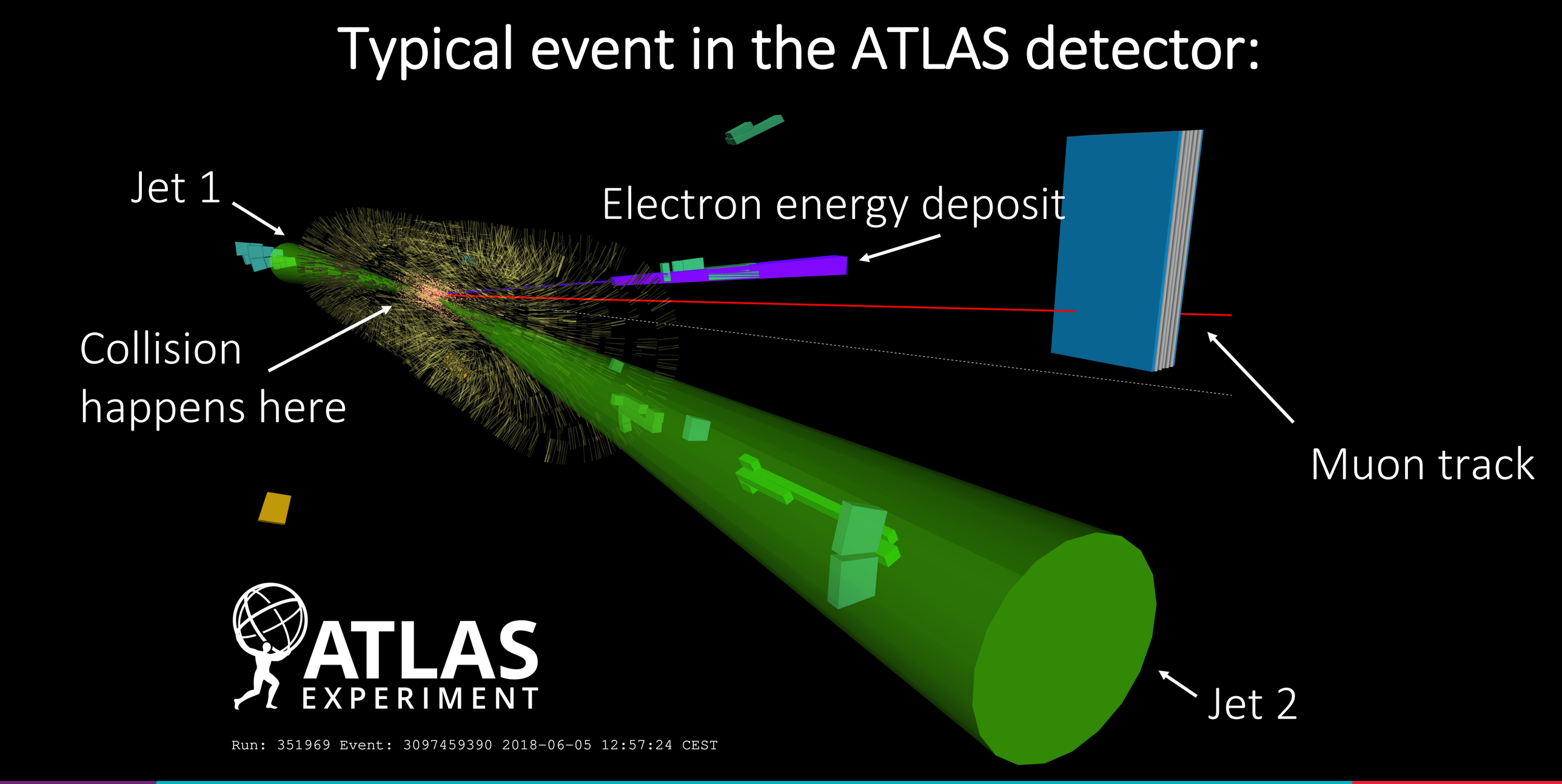
- The Higgs boson lives for 10^{-22} s → look for its decay to W bosons, then to leptons (e/μ) and neutrinos.



Detect:

- 2 jets
- two leptons (e/μ)
- missing energy from neutrinos

Typical event in the ATLAS detector:

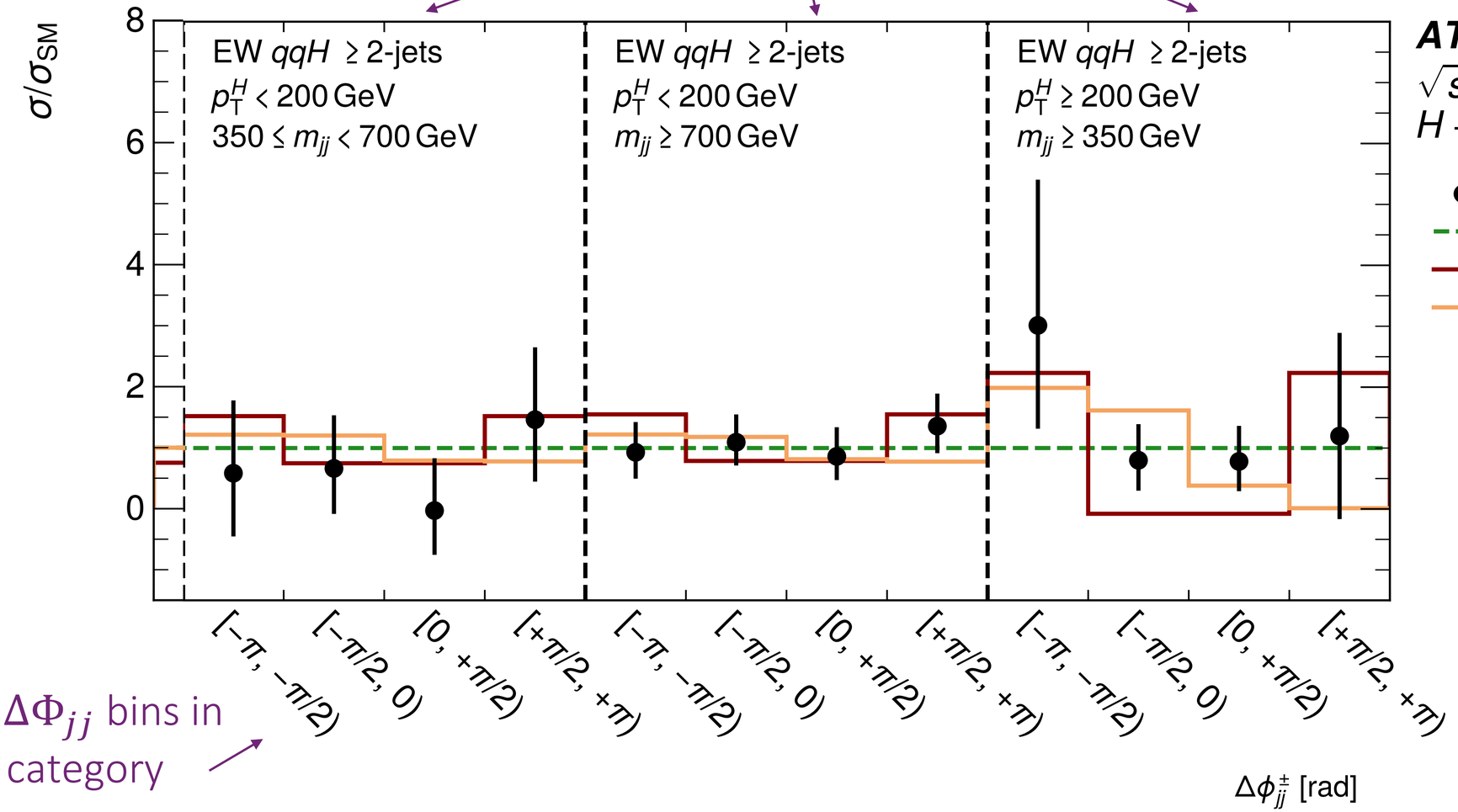


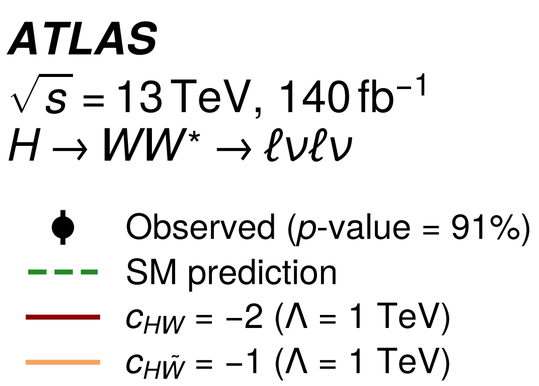
Nikhef

Results

Eur. Phys. J. C 85 (2025) 1403

Three main categories for sensitivity





Four $\Delta\Phi_{jj}$ bins in each category

Measurement is symmetric in $\Delta\Phi_{jj}$ → no CP violation ☹

Nikhef

Conclusion

- First time probing CP violation in VBF $H \rightarrow WW^*$.
- Measurement strategy enables combination with others for stronger results [arXiv:2603.20117].
- No sign of CP violation here yet!