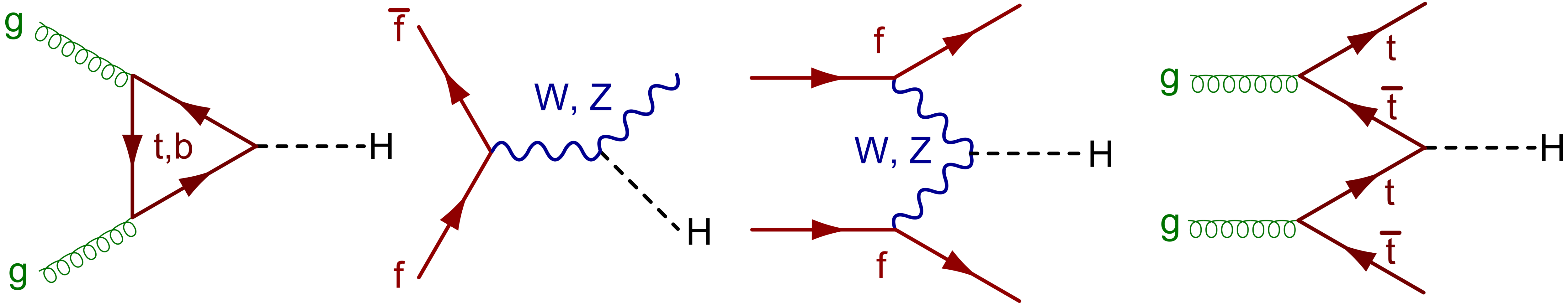
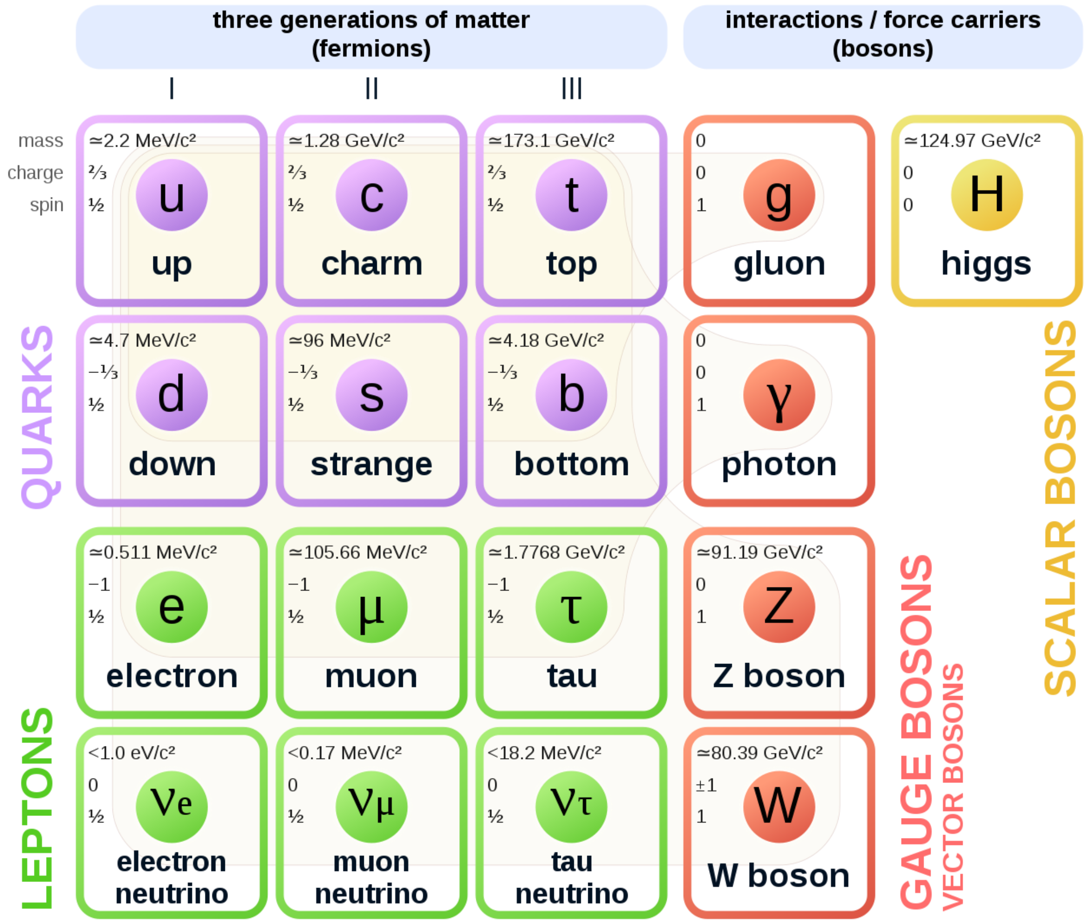


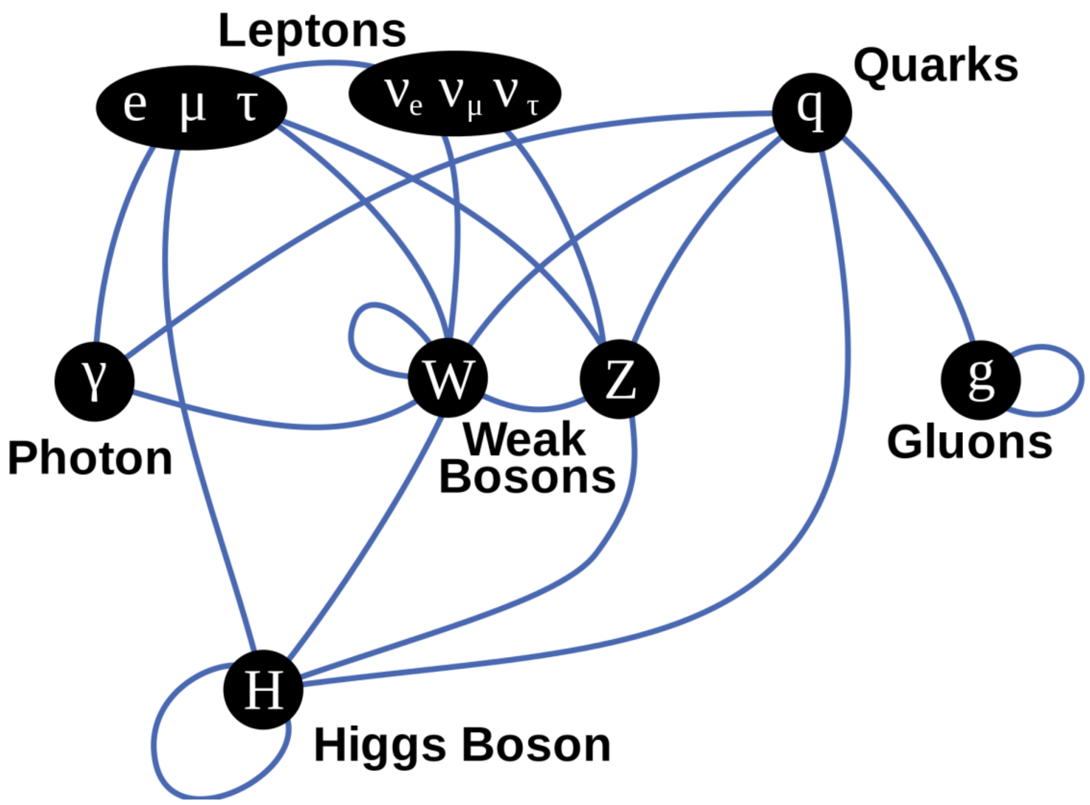
Analysis of Higgs boson production at ATLAS experiment

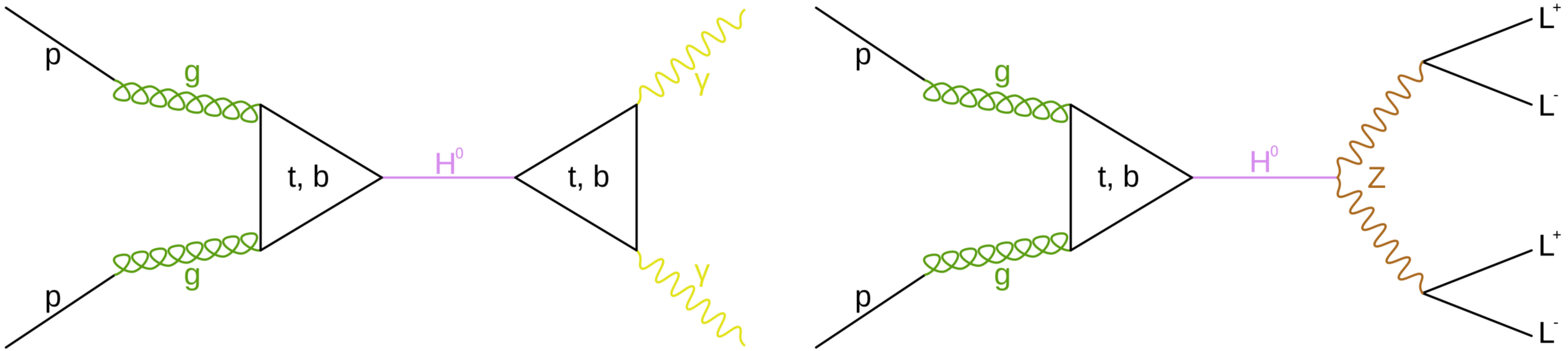
Sára Bánovská, Anna Mária Sodomková, Jakub Šťavina

$$
\begin{aligned}
\mathcal{L} = &-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} \\
&+ i\bar{\psi}\not{D}\psi \\
&+ \psi_i y_{ij}\psi_j\phi + h.c. \\
&+ |D_n\phi|^2 - V(\phi)
\end{aligned}
$$

Standard Model of Elementary Particles





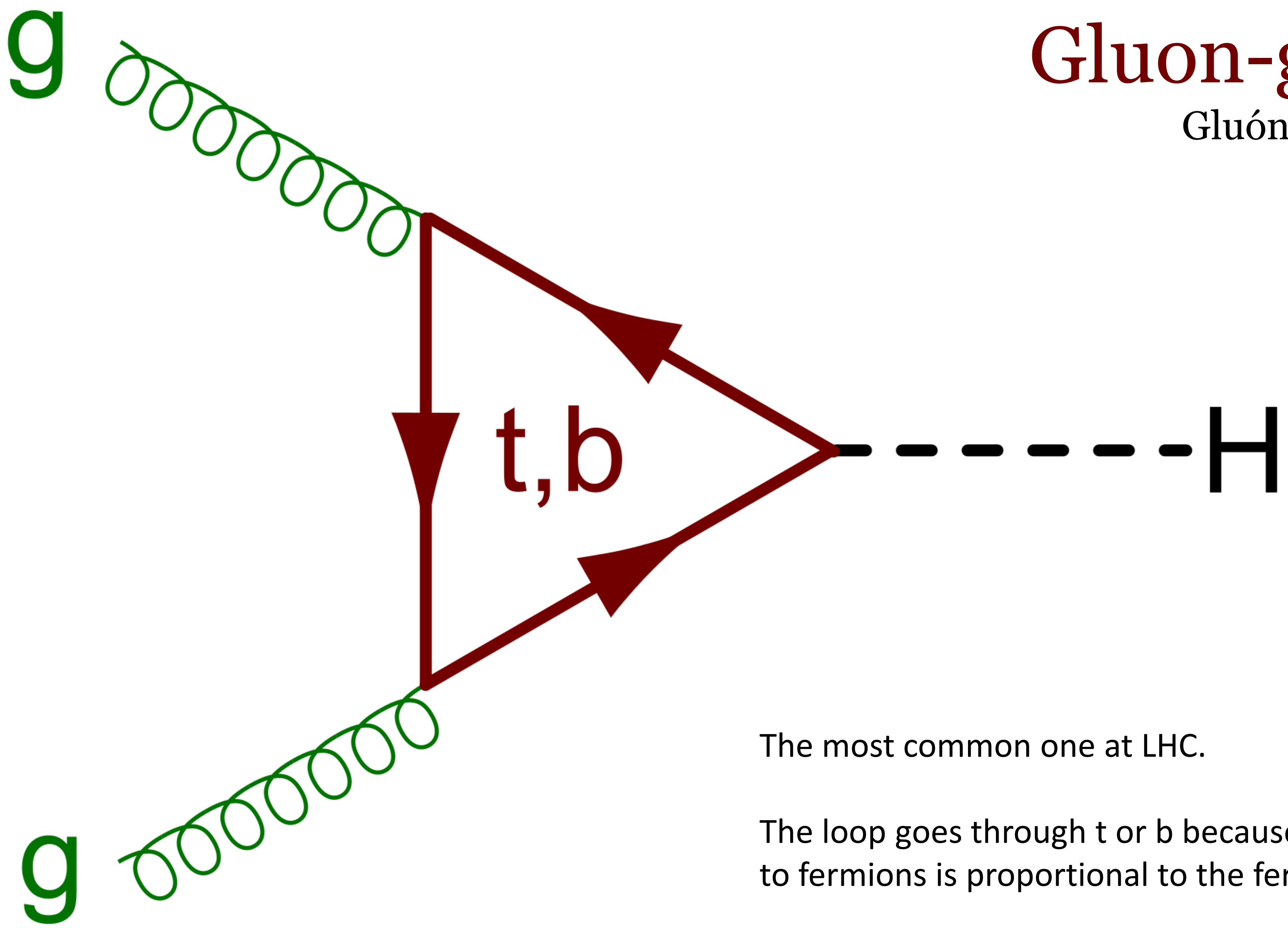


Higgs boson production

The most common expected processes for Higgs boson production

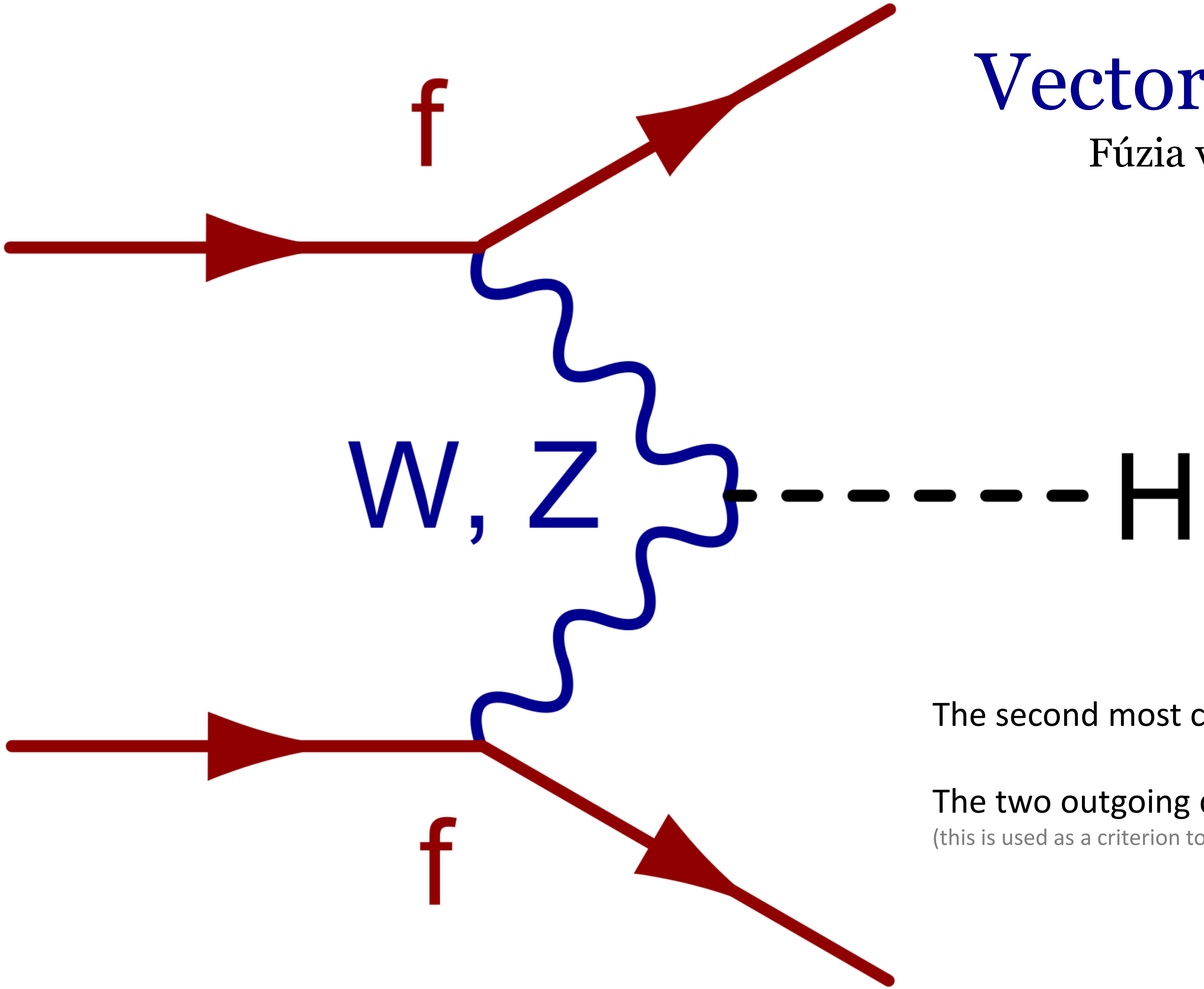
Gluon-gluon fusion

Gluón-gluónová fúzia



The most common one at LHC.

The loop goes through t or b because Higgs's coupling to fermions is proportional to the fermion's mass.



Vector boson fusion

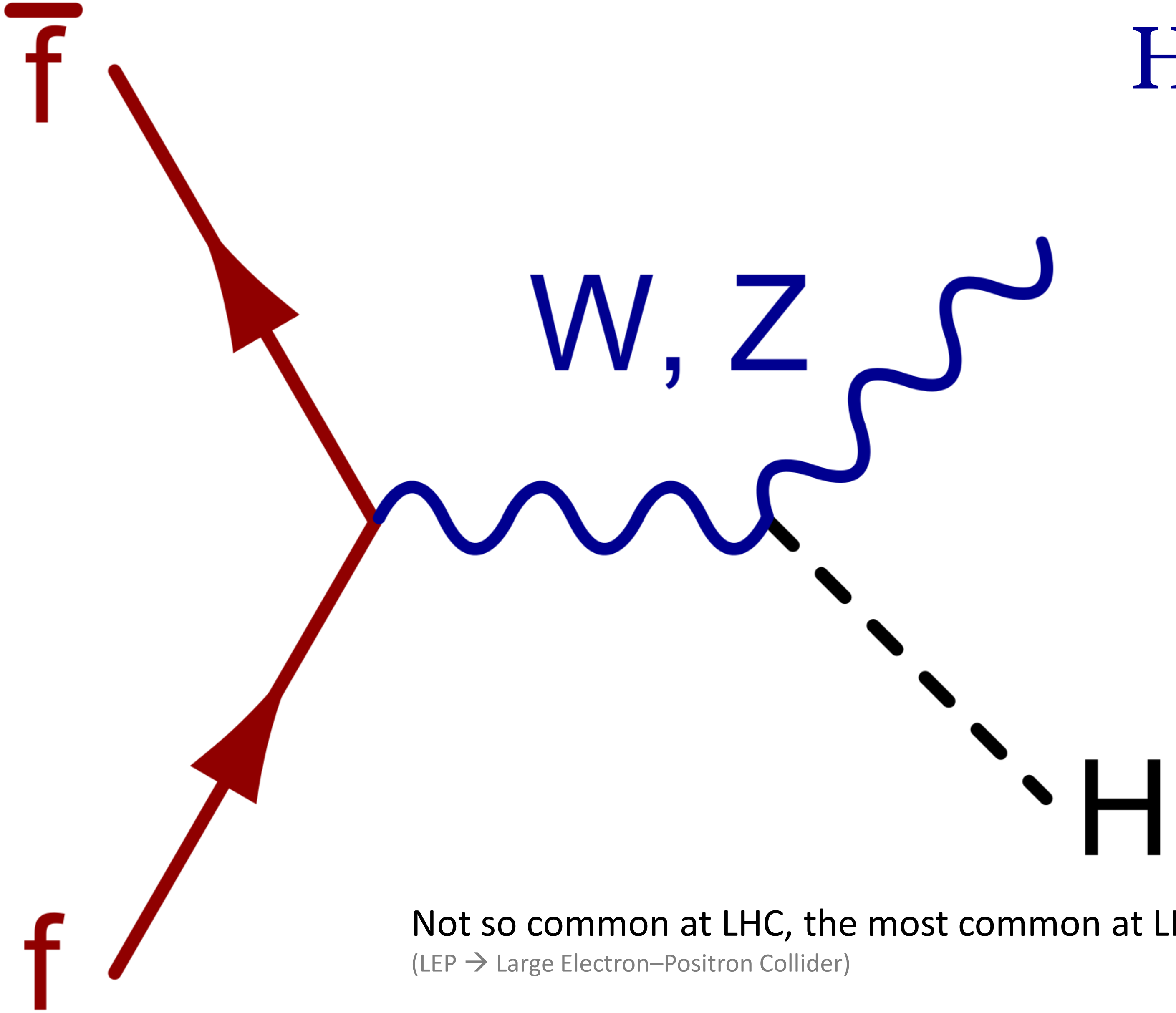
Fúzia vektorových bozónov

The second most common at LHC.

The two outgoing quarks produce jets in the detector.
(this is used as a criterion to select VBF events)

Higgs Strahlung

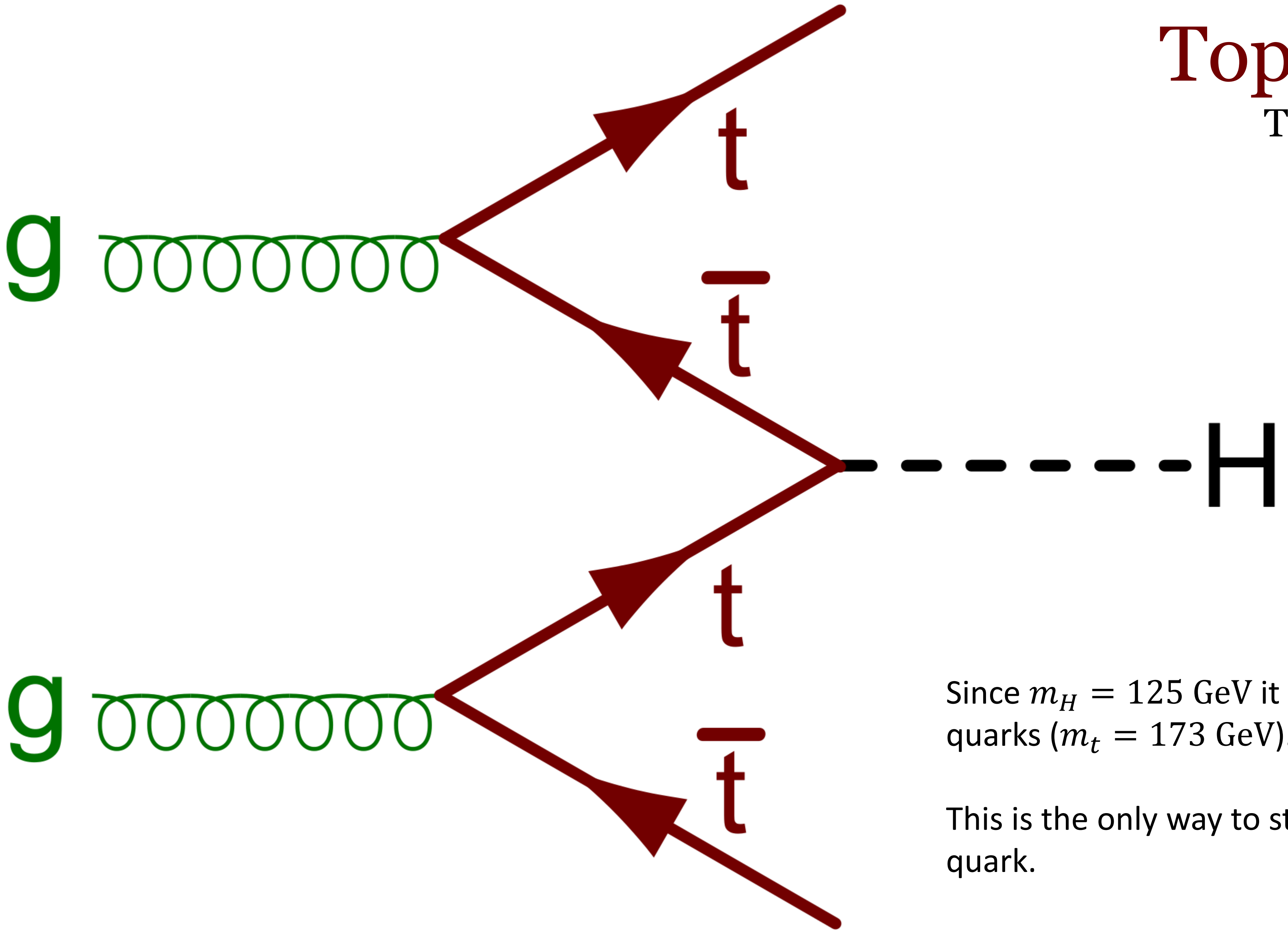
Higgs Strahlung



Not so common at LHC, the most common at LEP.

(LEP → Large Electron–Positron Collider)

However LEP did not detect Higgs due to insufficient energies.

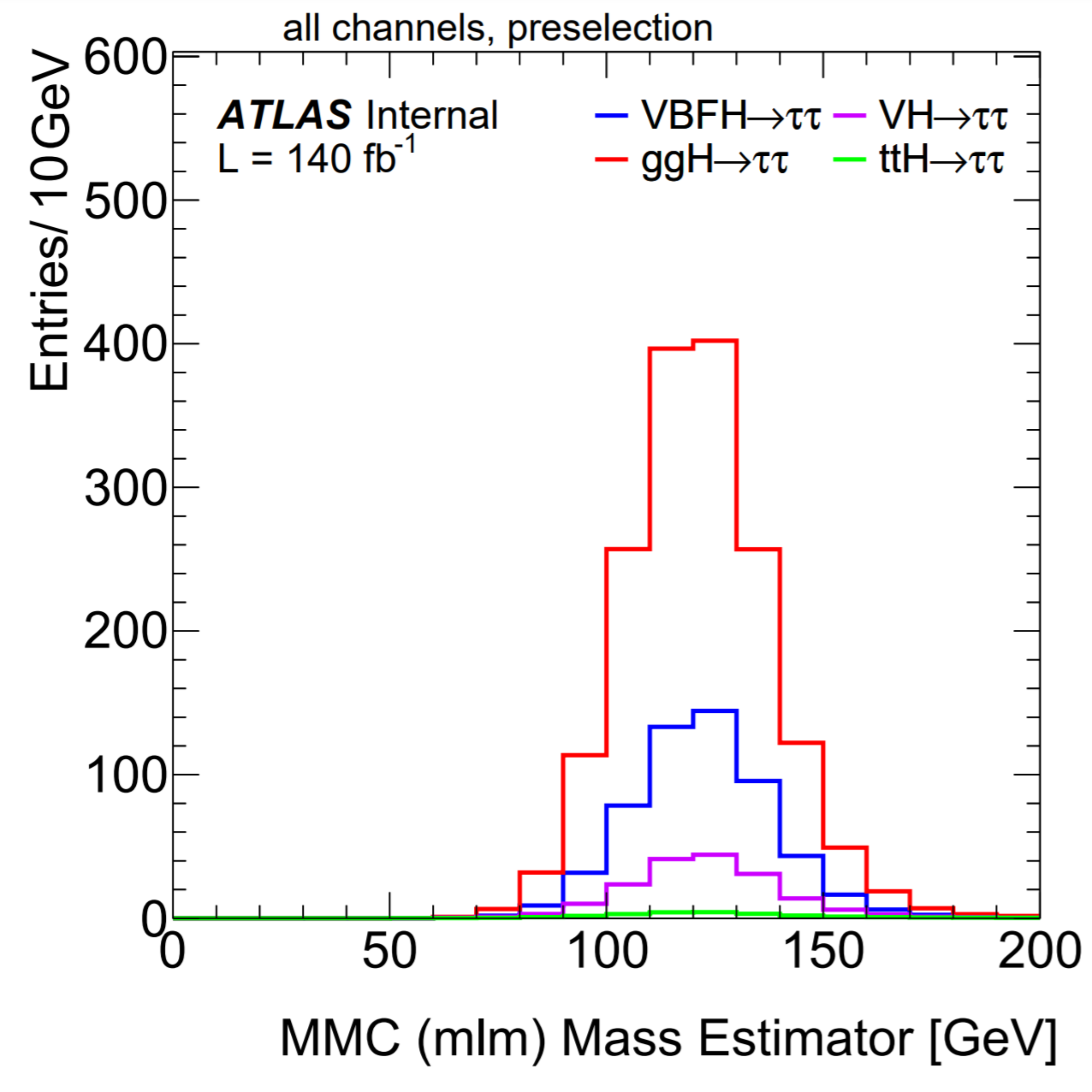


Top fusion

Top fúzia

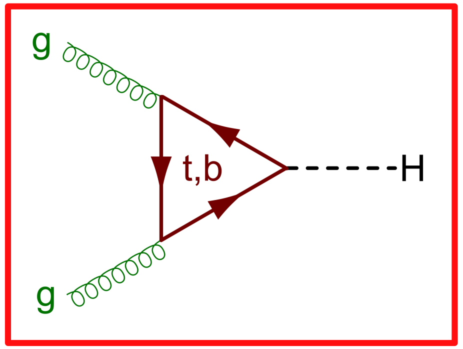
Since $m_H = 125$ GeV it cannot decay to a pair of top quarks ($m_t = 173$ GeV).

This is the only way to study Higgs's coupling to top quark.

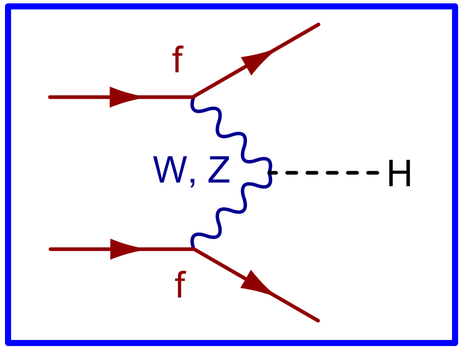


Expected event count for Higgs production mechanisms at LHC

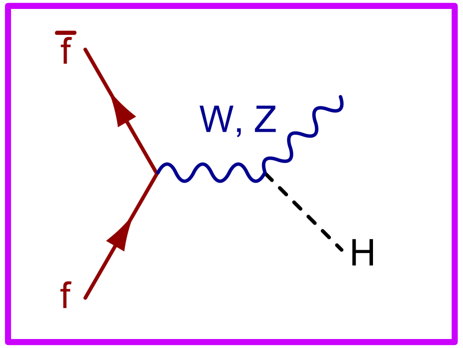
(with a full Run2 dataset)



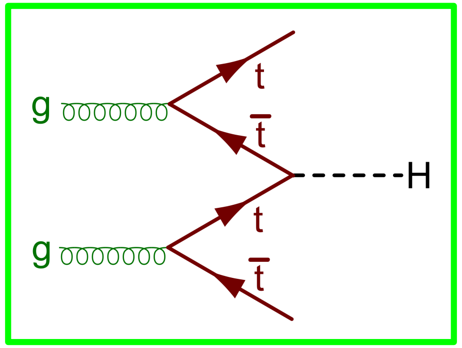
Gluon fusion



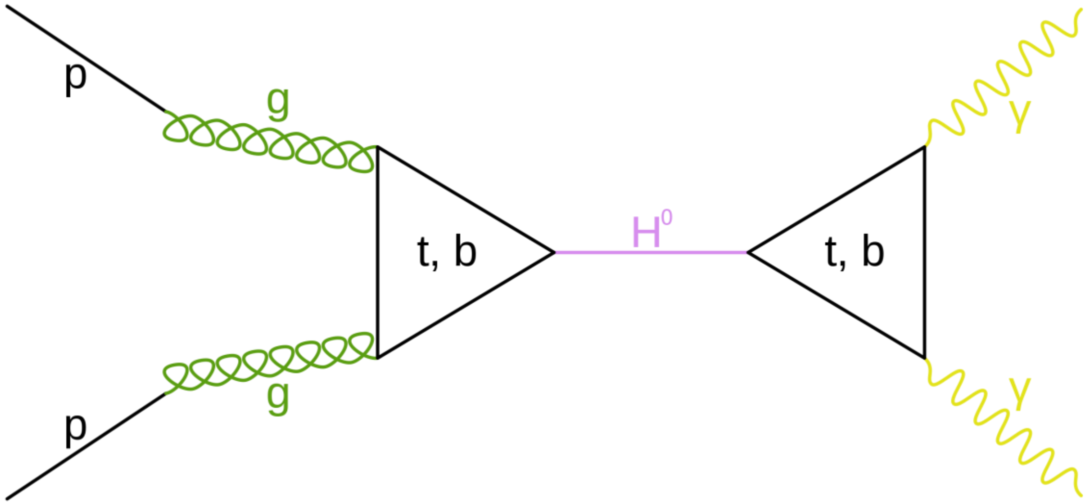
Vector boson fusion

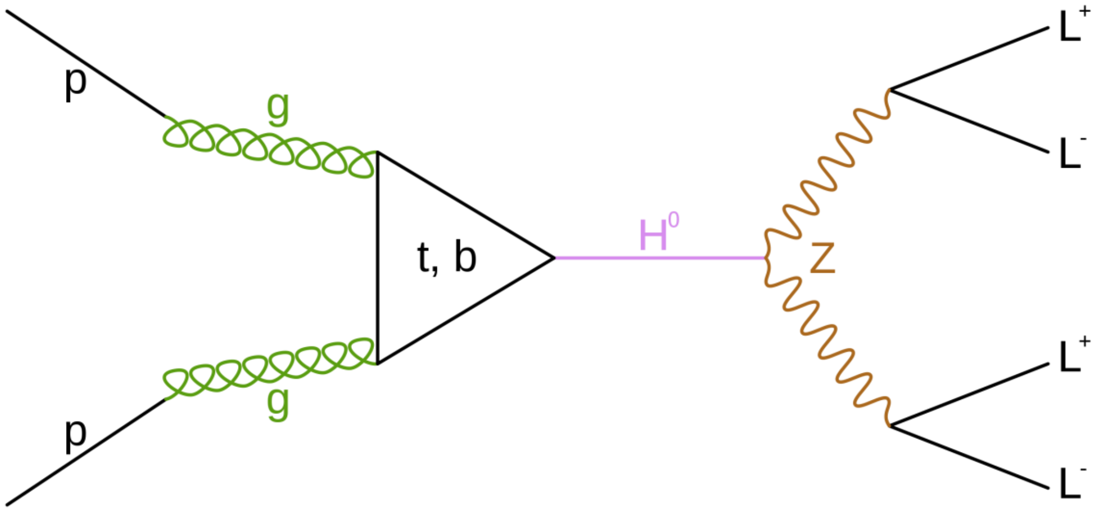


Higgs Strahlung



Top fusion





Higgs boson decay

We cannot detect Higgs boson directly; we study its decay only!

The most common decays at 125 GeV

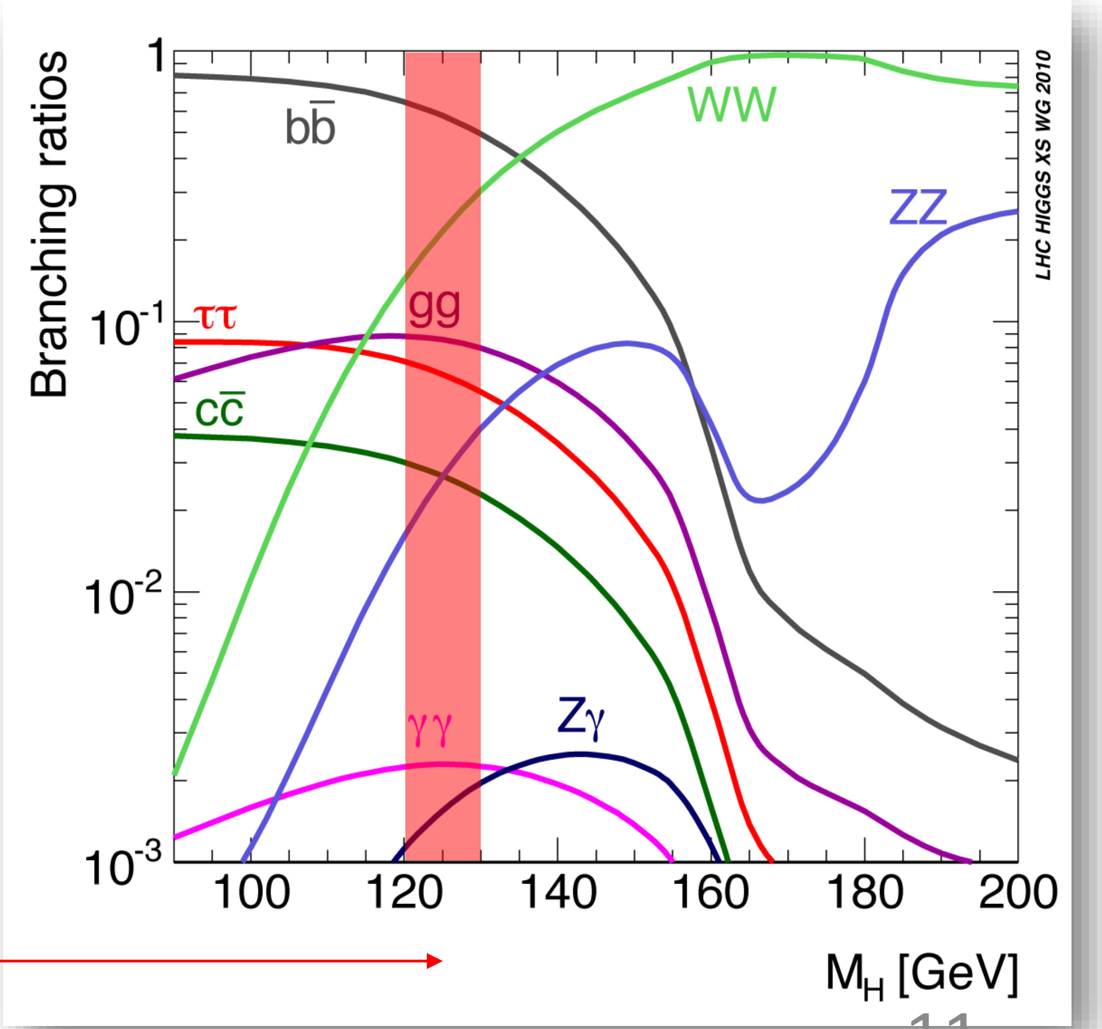
$Higgs \rightarrow \gamma + \gamma$ (two photons)

$Higgs \rightarrow Z^0 + Z^0$ (two Z bosons)

$Higgs \rightarrow W^+ + W^-$ (W boson and its antiparticle)

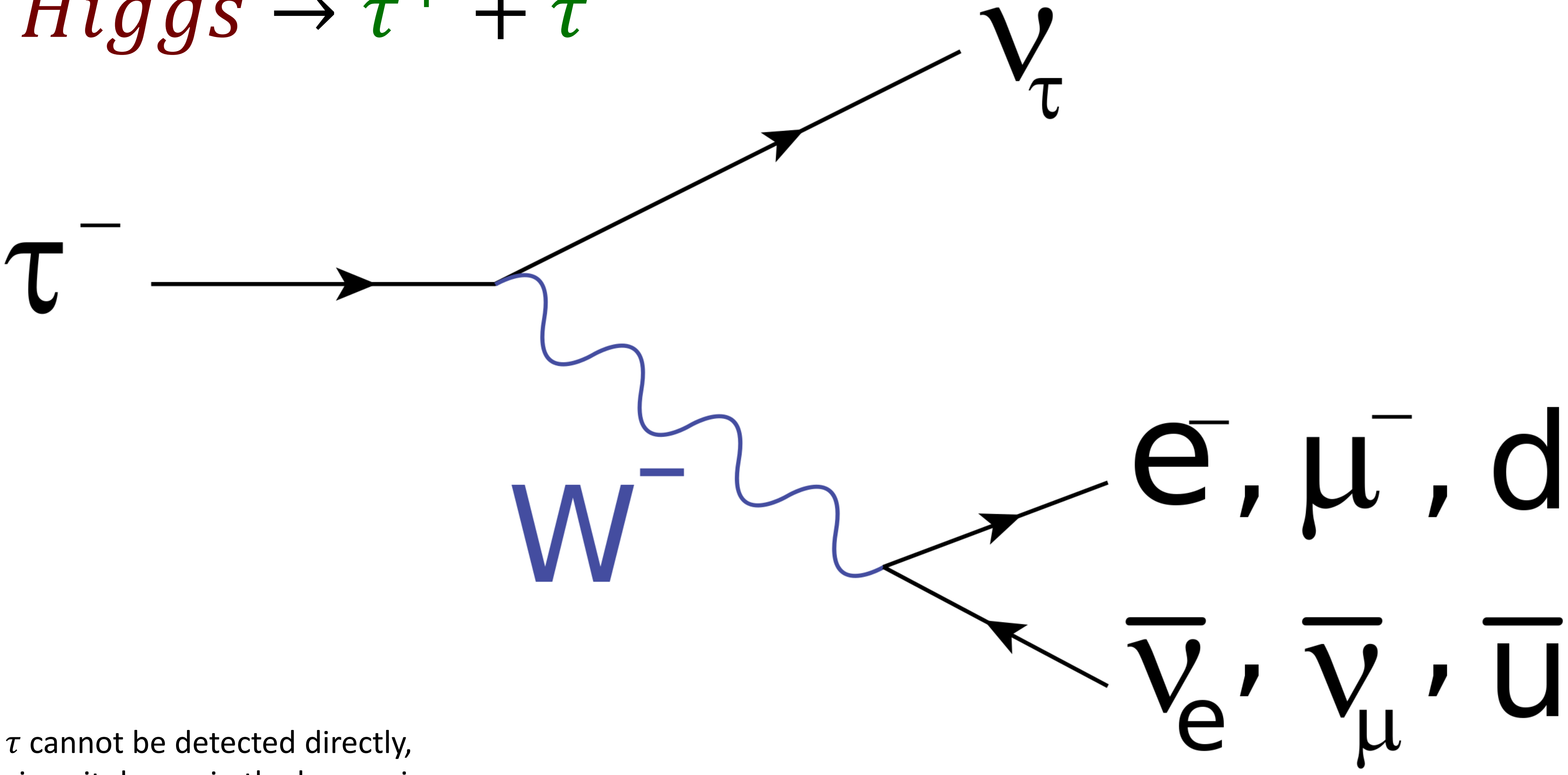
$Higgs \rightarrow \tau^+ + \tau^-$ (τ lepton and its antiparticle)

$Higgs \rightarrow \mathrm{b} + \bar{\mathrm{b}}$ (b quark and its antiquark)



Higgs mass of 125 GeV →

$$Higgs \rightarrow \tau^{+} + \tau^{-}$$



τ cannot be detected directly,
since it decays in the beam pipe.

(for example)

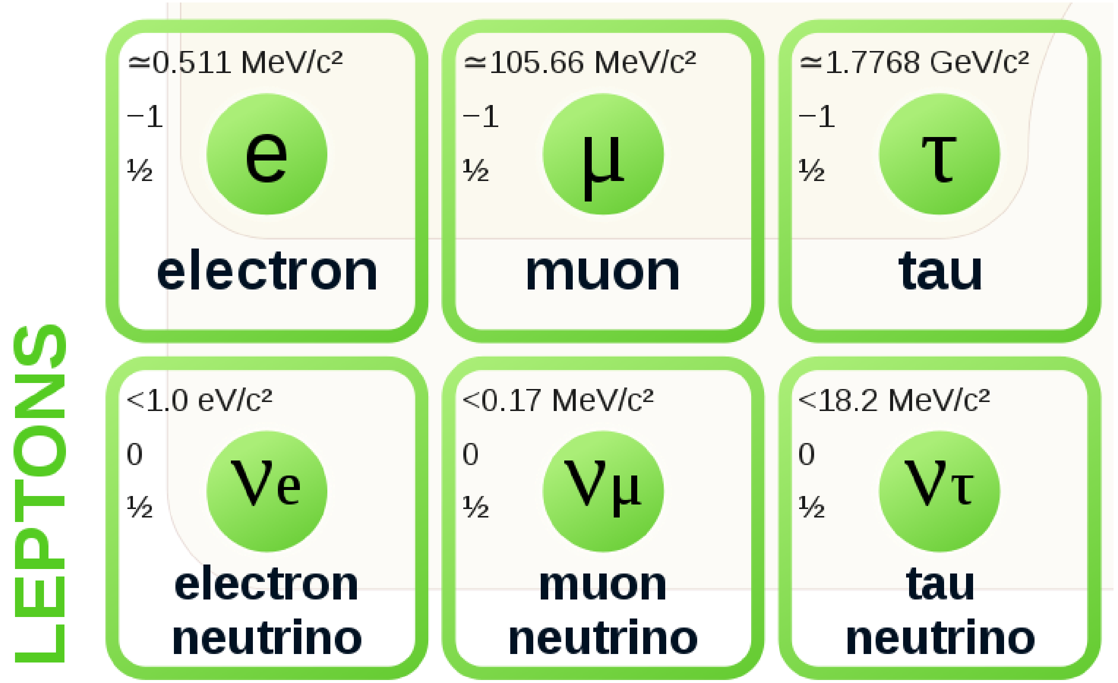
$$Higgs \rightarrow \tau^+ + \tau^- \rightarrow$$

1) $lep\ lep:\ \tau^-\tau^+ \rightarrow e^+\nu_e\bar{\nu}_\tau e^-\bar{\nu}_e\nu_\tau$

2) $lep\ had:\ \tau^-\tau^+ \rightarrow \bar{\mu}\bar{\nu}_\mu\nu_\mu\pi^+\bar{\nu}_\tau$

3) $had\ had:\ \tau^-\tau^+ \rightarrow \pi^-\nu_\tau\pi^+\bar{\nu}_\tau$

From the standard model:



We can detect these only!

We reconstruct these as missing transverse energy.

(for example)

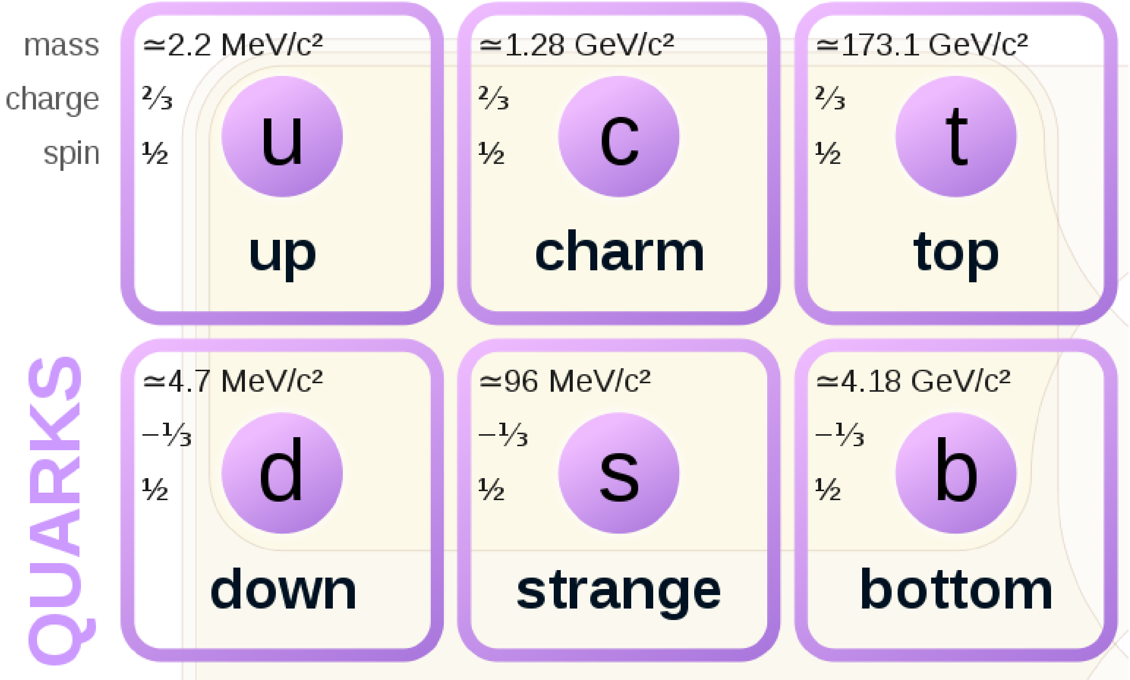
$$Higgs \rightarrow \tau^{+} + \tau^{-} \rightarrow$$

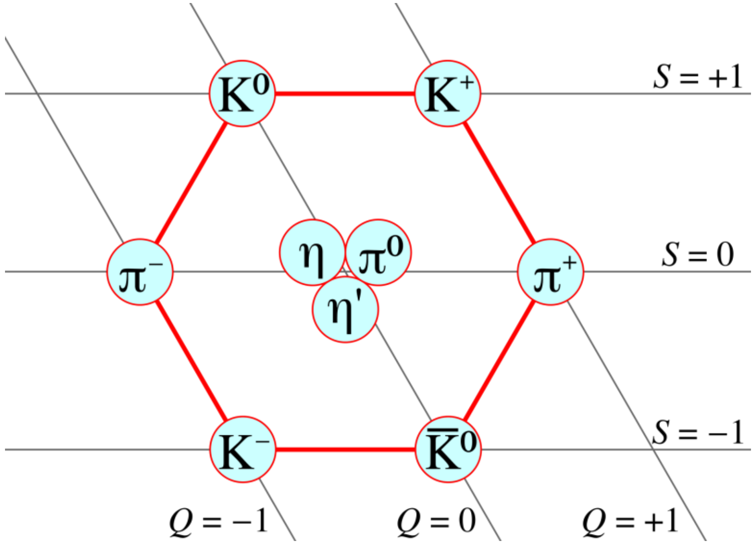
1) $lep\ lep$: $\tau^{-}\tau^{+} \rightarrow e^{+}\nu_{e}\bar{\nu}_{\tau}e^{-}\bar{\nu}_{e}\nu_{\tau}$

2) $lep\ had$: $\tau^{-}\tau^{+} \rightarrow \bar{\mu}\bar{\nu}_{\mu}\nu_{\mu}\pi^{+}\bar{\nu}_{\tau}$

3) $had\ had$: $\tau^{-}\tau^{+} \rightarrow \pi^{-}\nu_{\tau}\pi^{+}\bar{\nu}_{\tau}$

From the standard model:

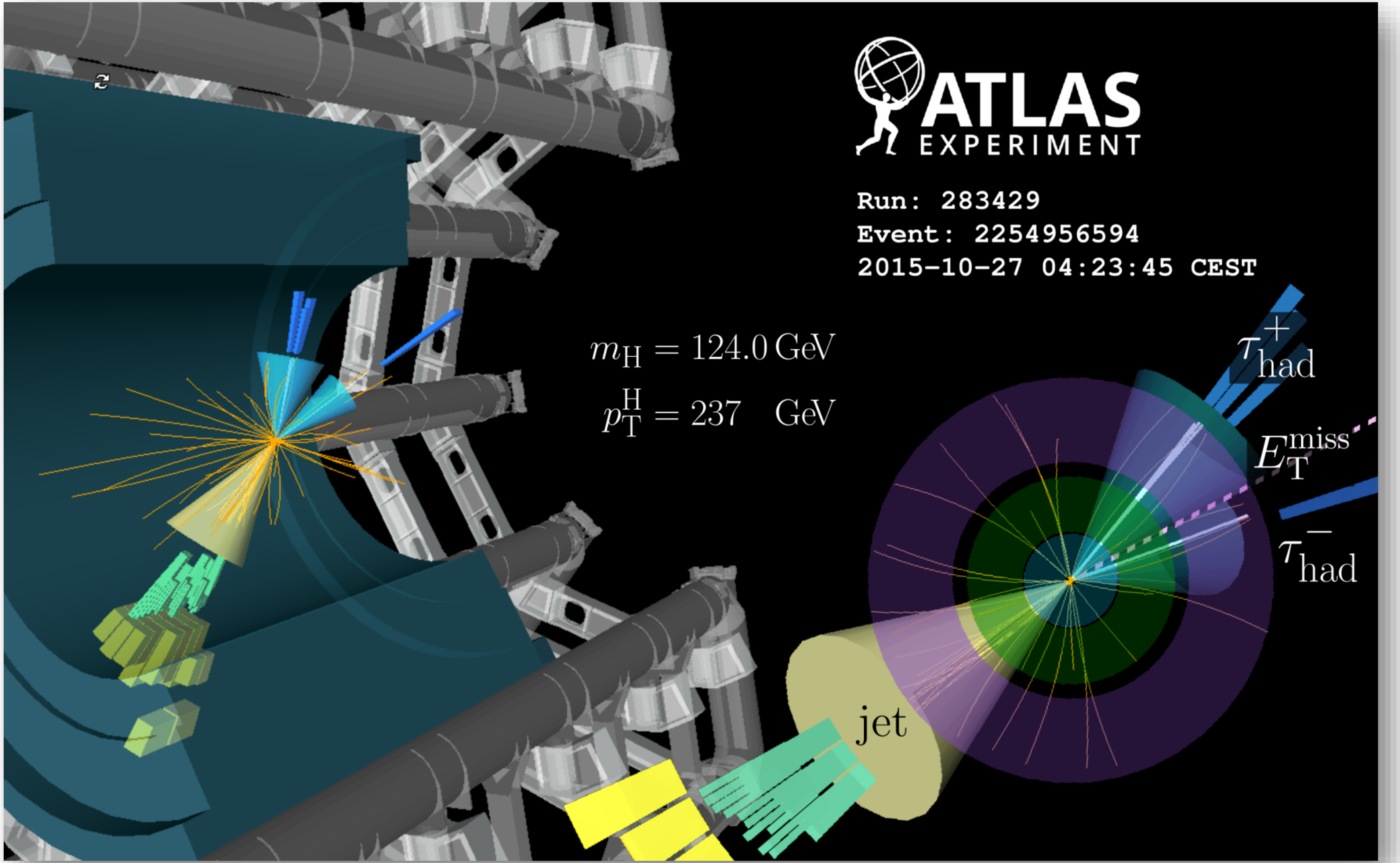


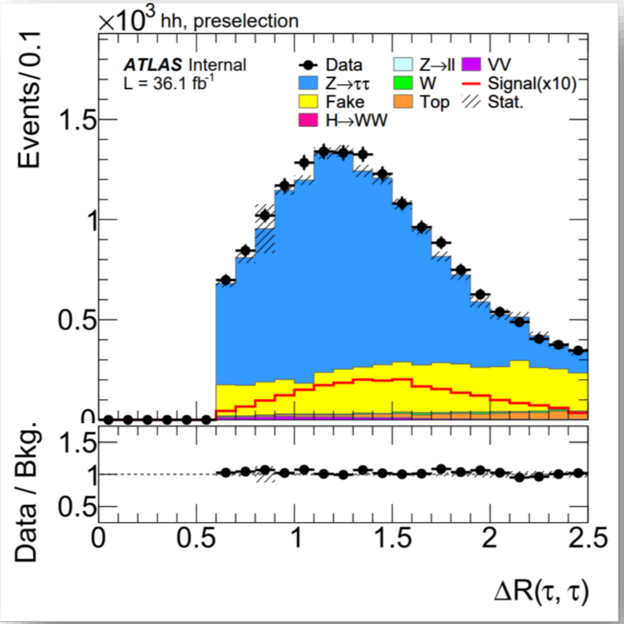


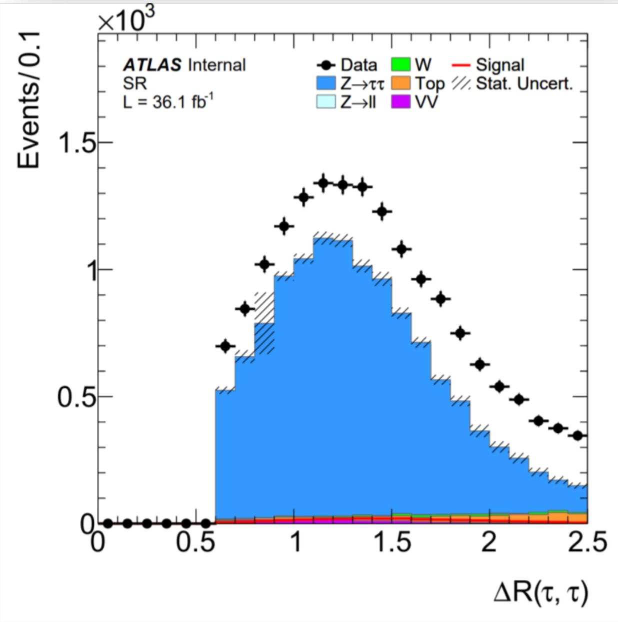
(and many more)

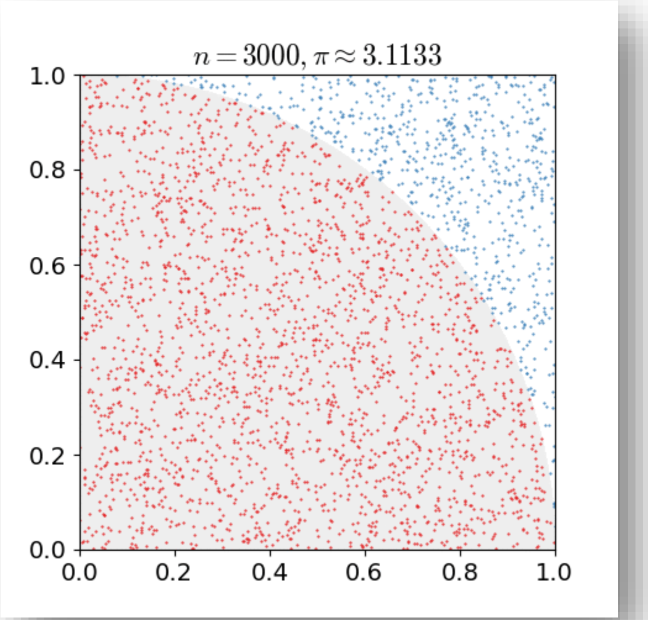
Had-had channel

Jakub Šťavina


ATLAS
EXPERIMENT
Run: 283429
Event: 2254956594
2015-10-27 04:23:45 CEST
$m_H = 124.0$ GeV
$p_T^H = 237$ GeV
τ^+_{had}
E_T^{miss}
τ^-_{had}
jet



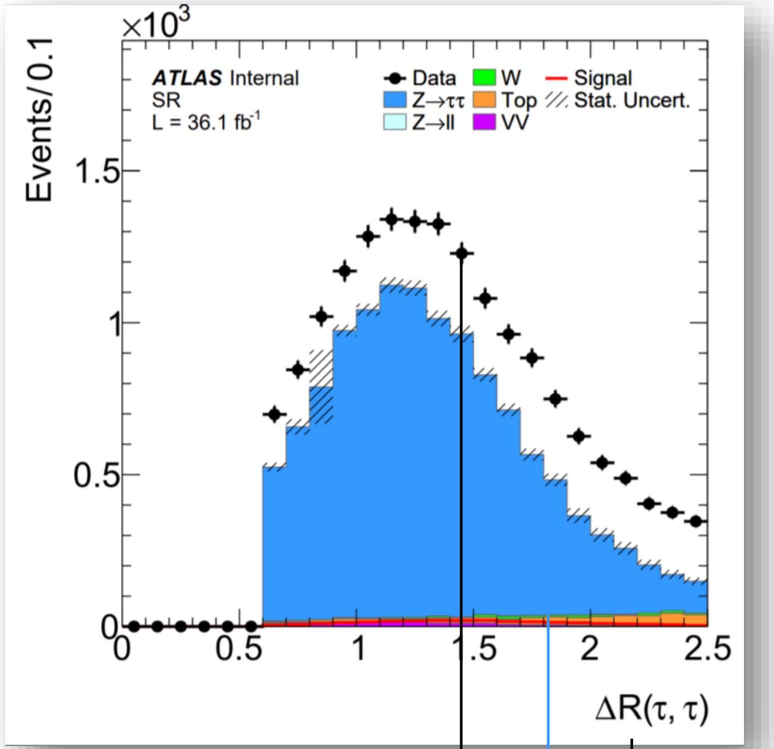




Monte Carlo method

Utilizing randomness to solve problems that are deterministic in principle.

(number of events)

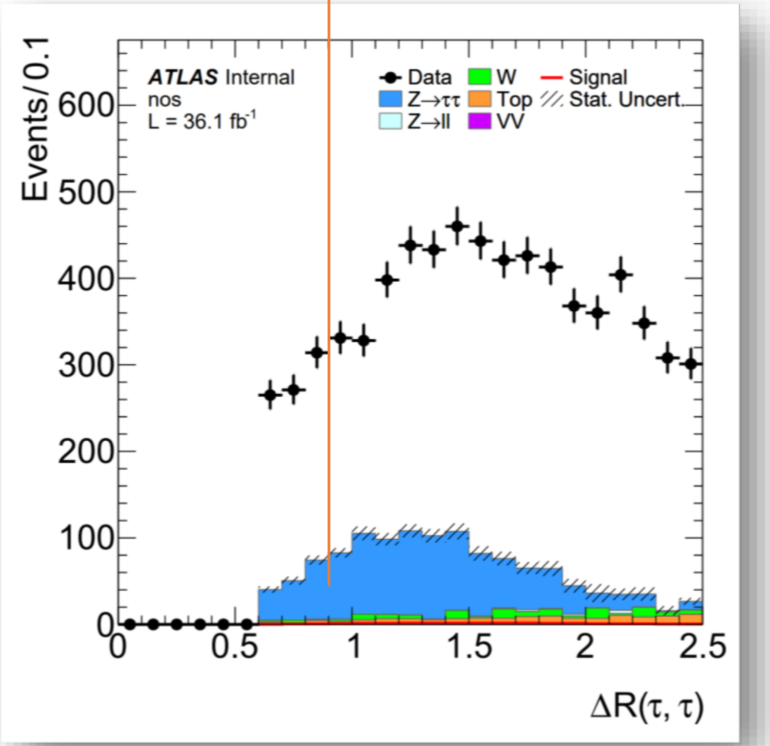


measured data

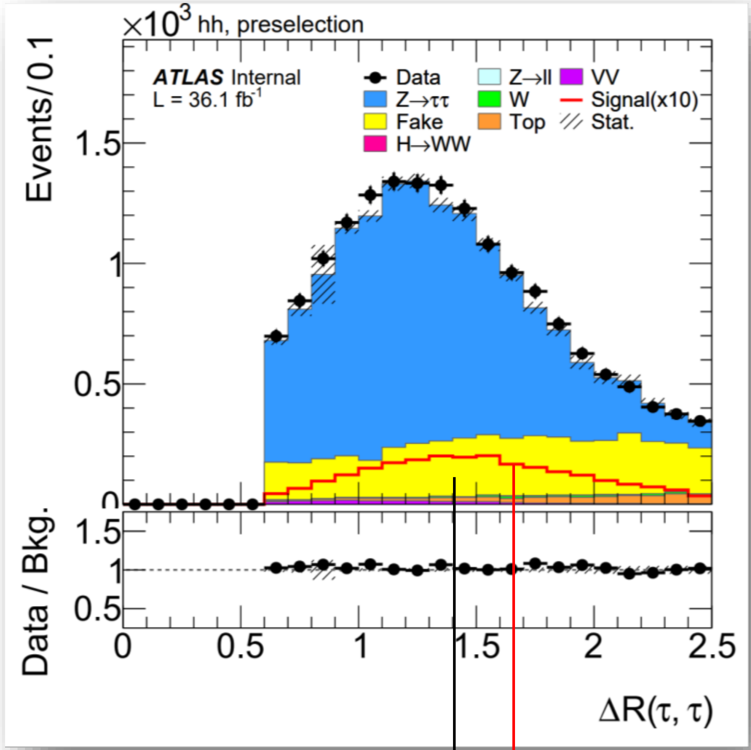
results of Monte Carlo simulation

angle between two particles

Estimating the fakes with data-driven methods based on flawed data with large number of fakes.



$$rQCD = \frac{(DATA - MC)^{presel.}_{OS}}{(DATA - MC)^{presel.}_{nOS}}$$



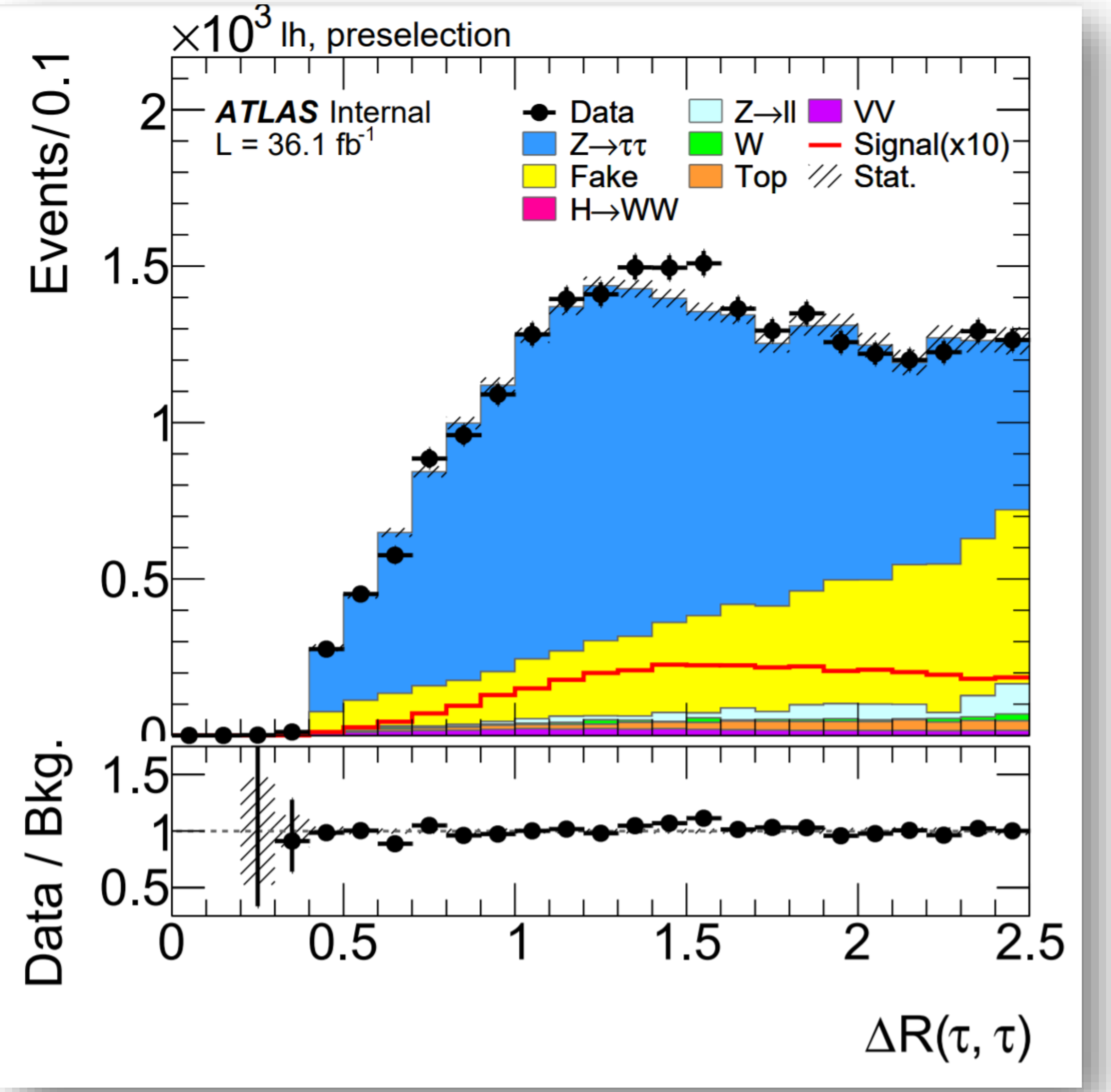
"Fakes"

Signal from Higgs x 10

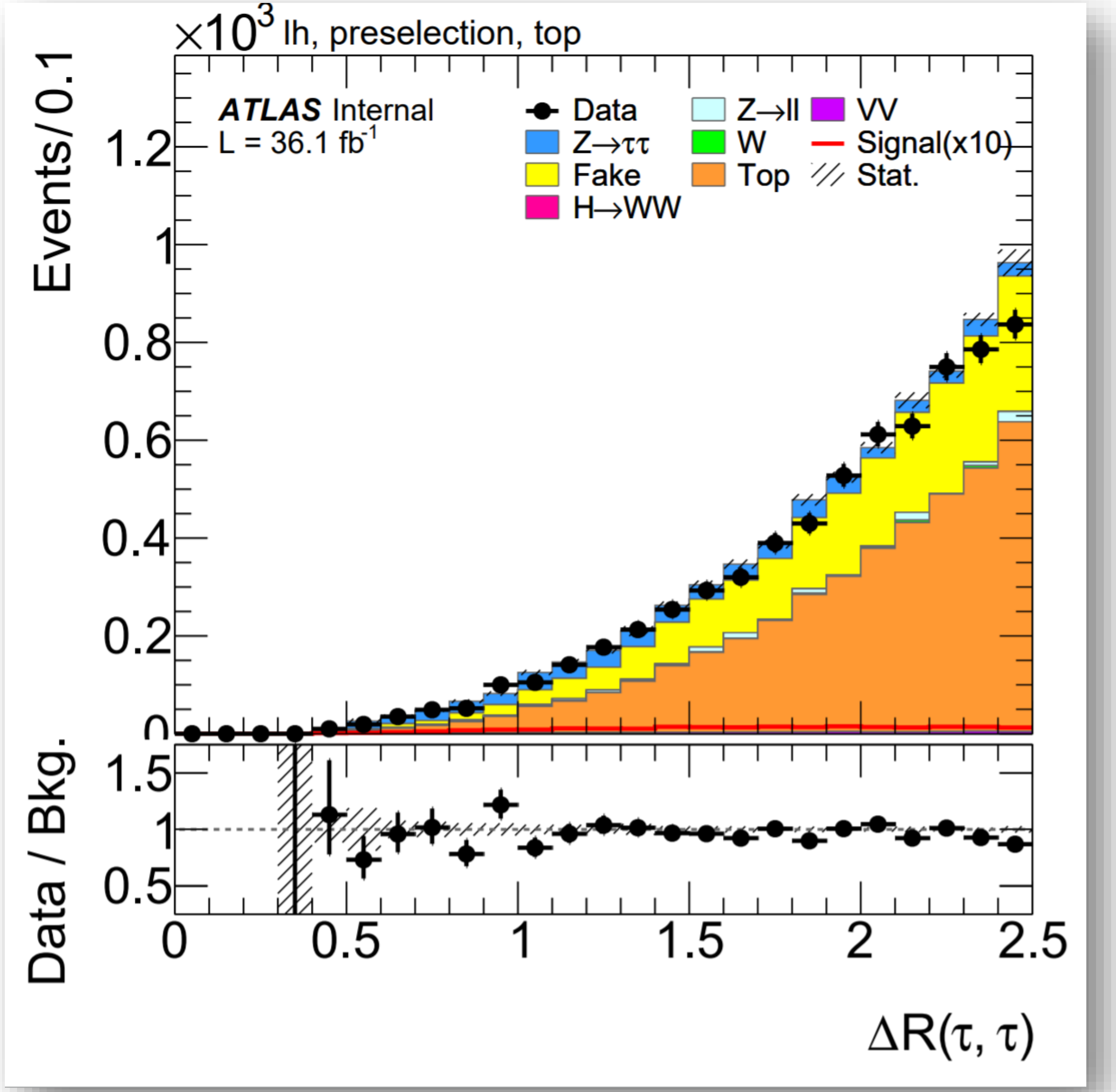
$$FAKE = (DATA - MC) \times rQCD$$

Lep-had channel

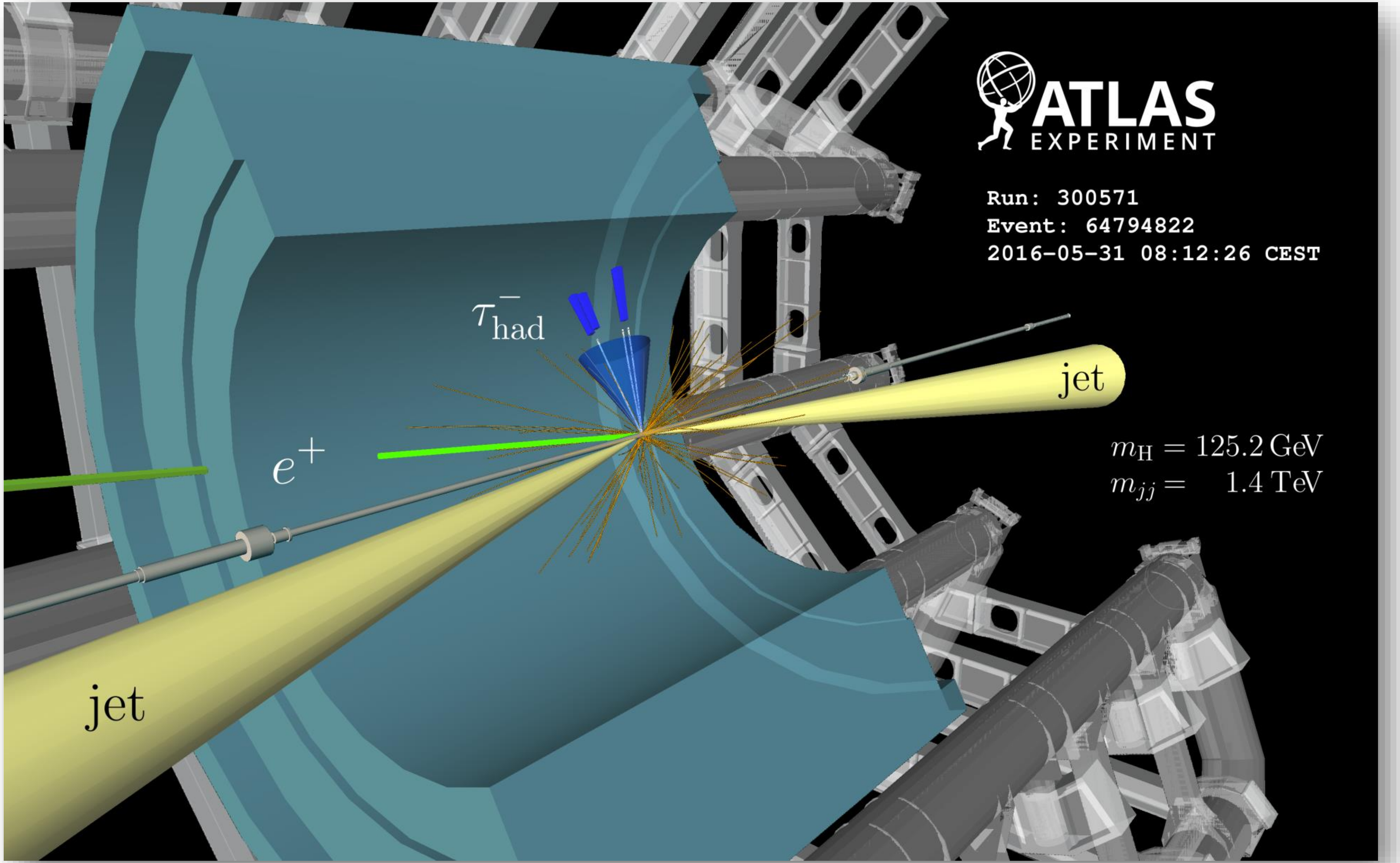
Sára Bánovská

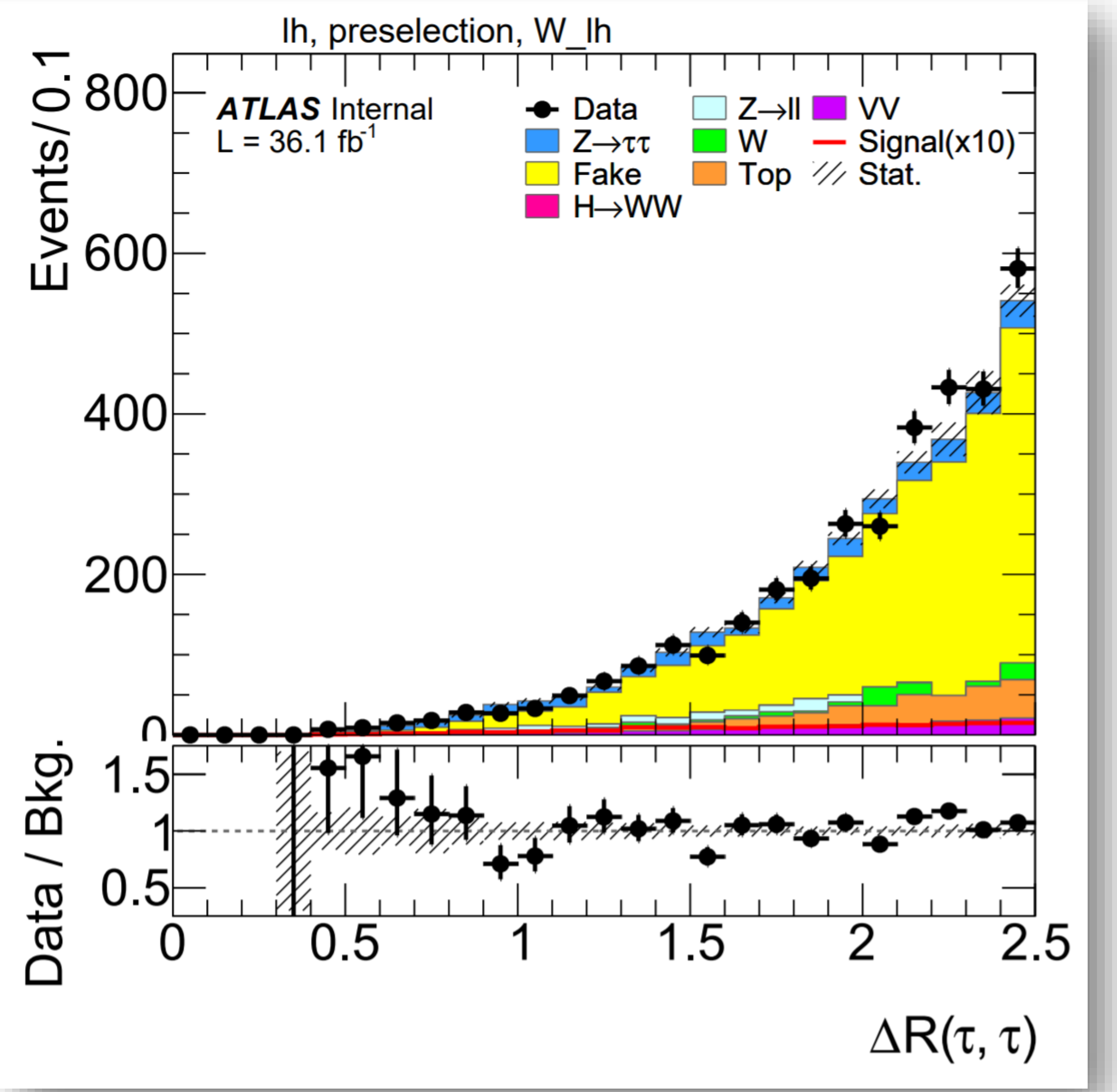


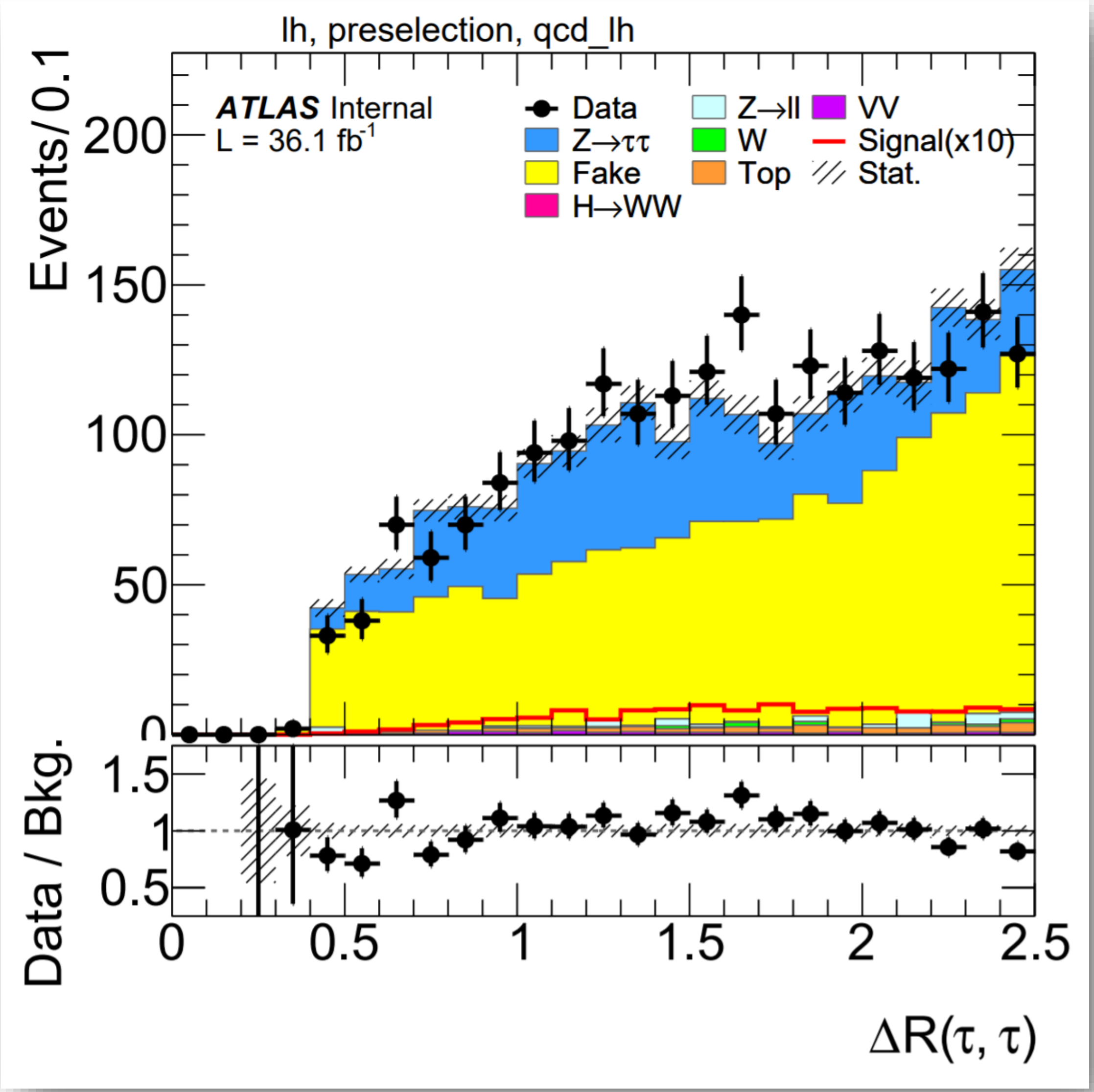
×10³ lh, preselection
ATLAS Internal
L = 36.1 fb⁻¹
Data
Z→ττ
Fake
H→WW
Z→ll
W
Top
VV
Signal(x10)
Stat.
Events/0.1
Data / Bkg.
ΔR(τ, τ)



×10³ lh, preselection, top
ATLAS Internal
L = 36.1 fb⁻¹
Data
Z→ττ
Fake
H→WW
Z→ll
W
Top
VV
Signal(x10)
Stat.
Events/0.1
Data / Bkg.
ΔR(τ, τ)

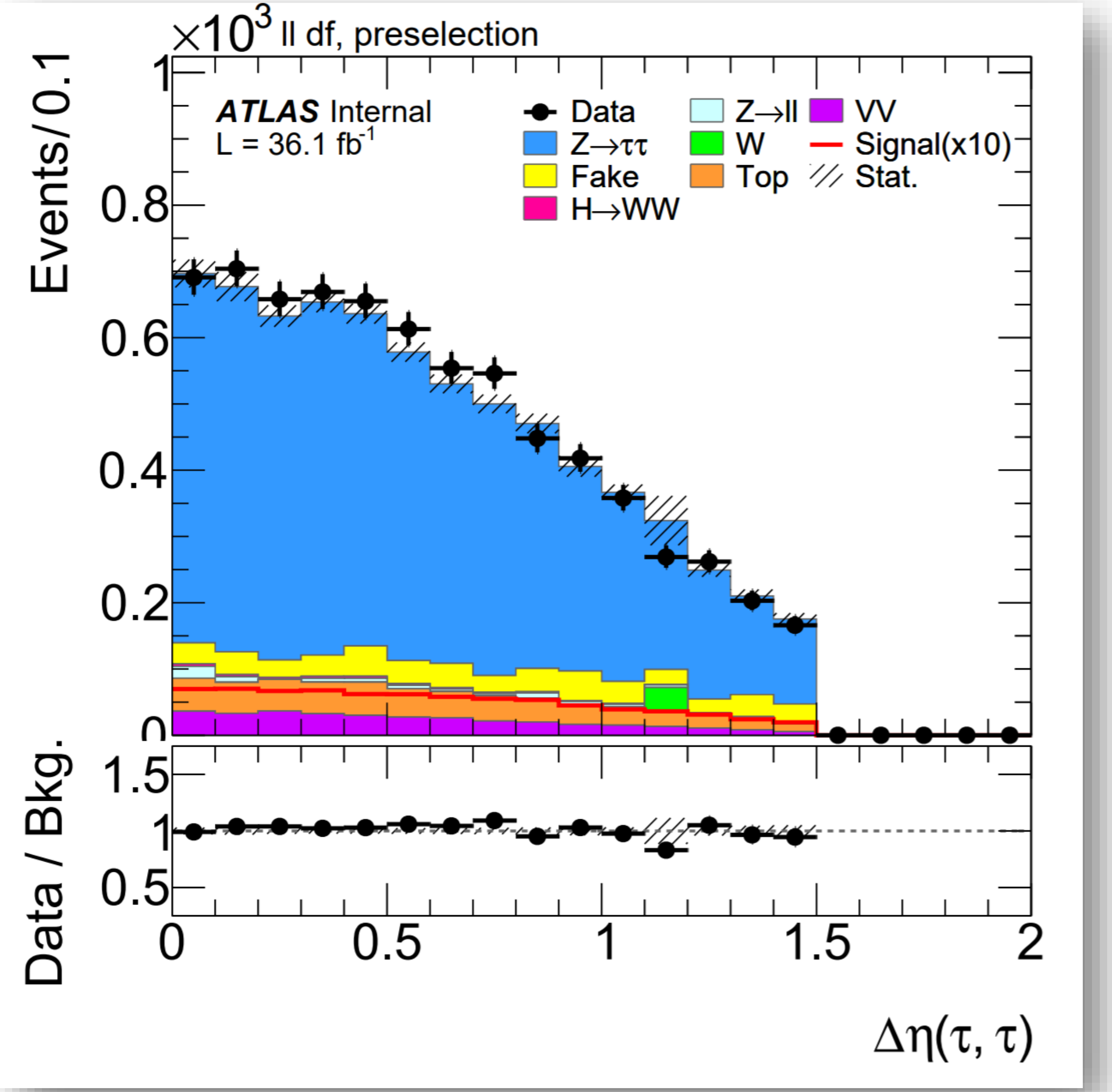

ATLAS EXPERIMENT
Run: 300571
Event: 64794822
2016-05-31 08:12:26 CEST
τ^-_{had}
jet
e^+
$m_{\mathrm{H}} = 125.2$ GeV
$m_{jj} = 1.4$ TeV
jet

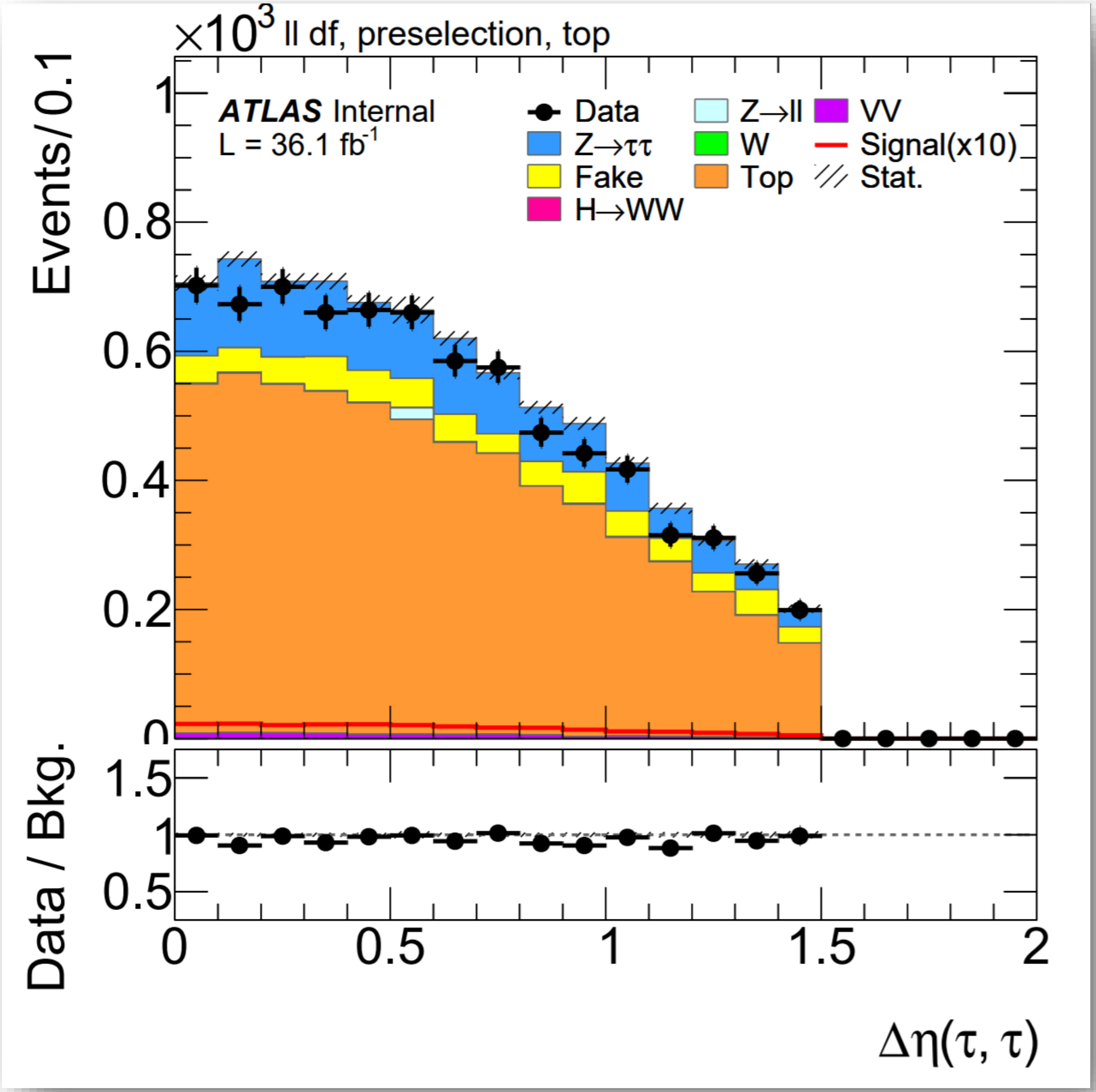

lh, preselection, W_lh
ATLAS Internal
L = 36.1 fb-1
Data
Z→ττ
Fake
H→WW
Z→ll
W
Top
VV
Signal(x10)
Stat.
Events/0.1
Data / Bkg.
ΔR(τ, τ)

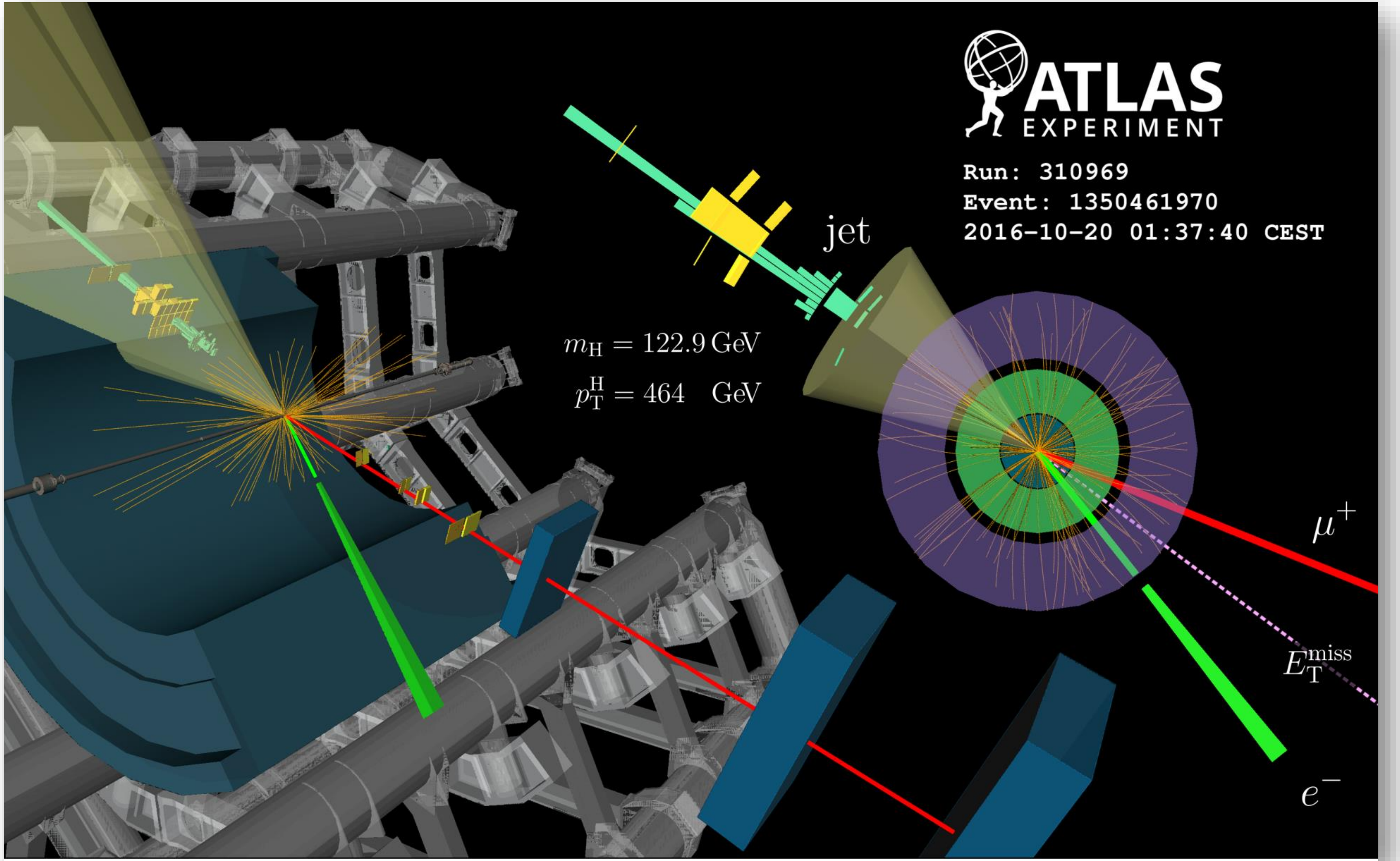

lh, preselection, qcd_lh
ATLAS Internal
L = 36.1 fb-1
Data
Z→ττ
Fake
H→WW
Z→ll
W
Top
VV
Signal(x10)
Stat.
Events/0.1
Data / Bkg.
ΔR(τ, τ)

Lep-lep channel

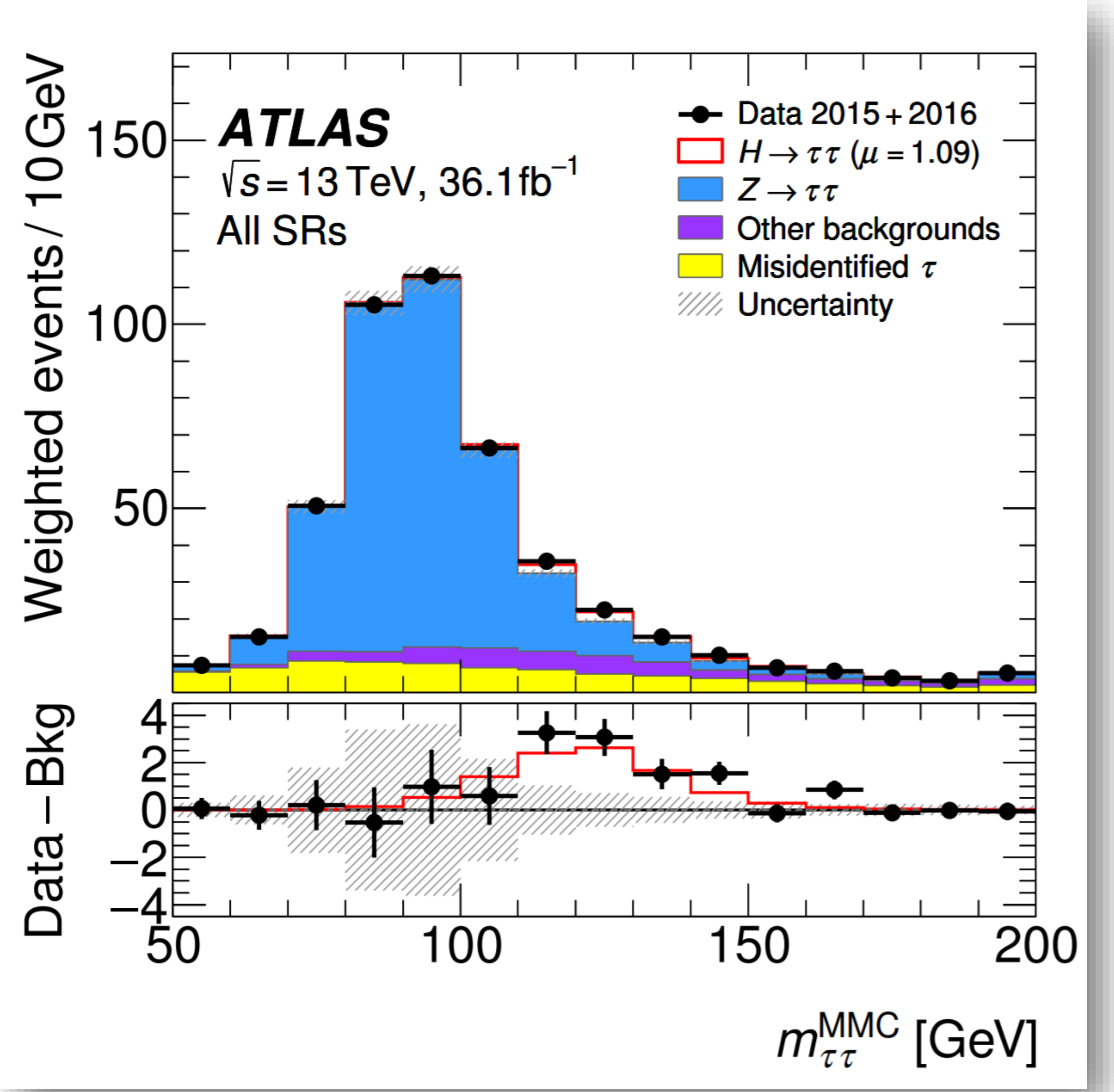
Anna Mária Sodomková


×10^3 ll df, preselection
ATLAS Internal
L = 36.1 fb-1
Data
Z→ττ
Fake
H→WW
Z→ll
W
Top
VV
Signal(x10)
Stat.
Events/0.1
Data / Bkg.
Δη(τ, τ)

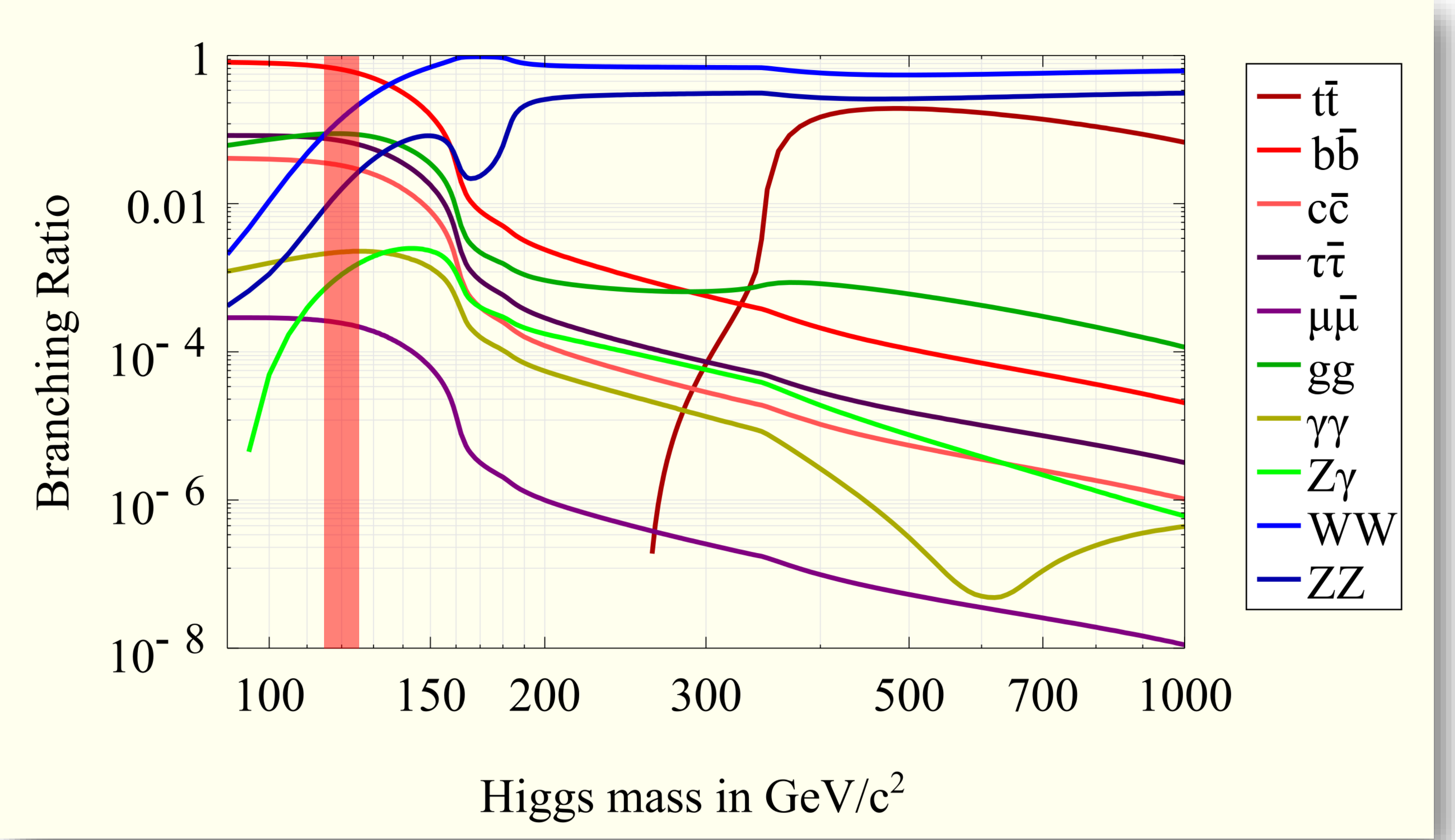

×10^3 ll df, preselection, top
ATLAS Internal
L = 36.1 fb-1
Data
Z→ττ
Fake
H→WW
Z→ll
W
Top
VV
Signal(x10)
Stat.
Events/0.1
Data / Bkg.
Δη(τ, τ)


ATLAS
EXPERIMENT
Run: 310969
Event: 1350461970
2016-10-20 01:37:40 CEST
jet
$m_H = 122.9\,\text{GeV}$
$p_T^H = 464\ \ \text{GeV}$
μ^+
E_T^{miss}
e^-

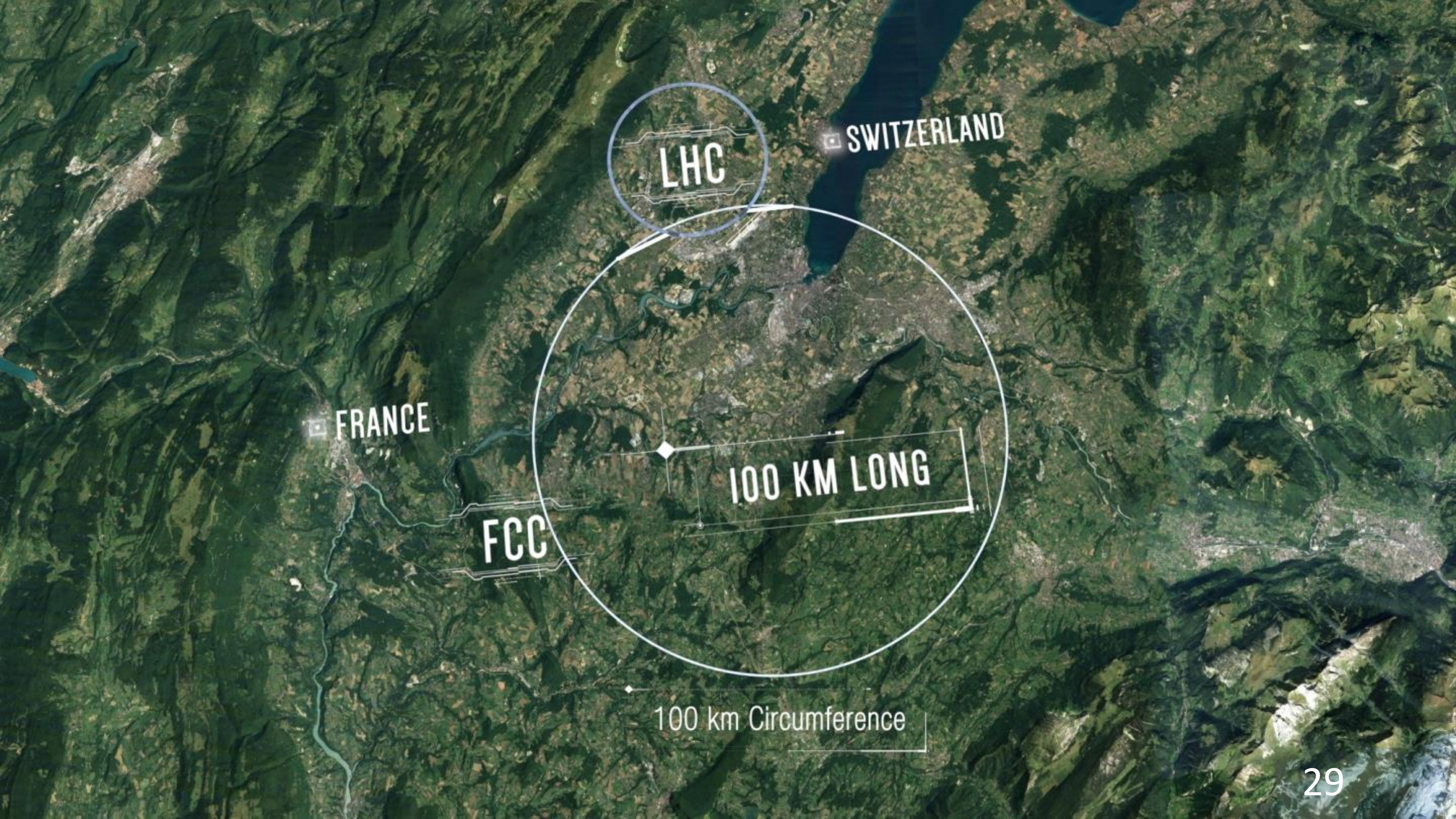
Conclusion

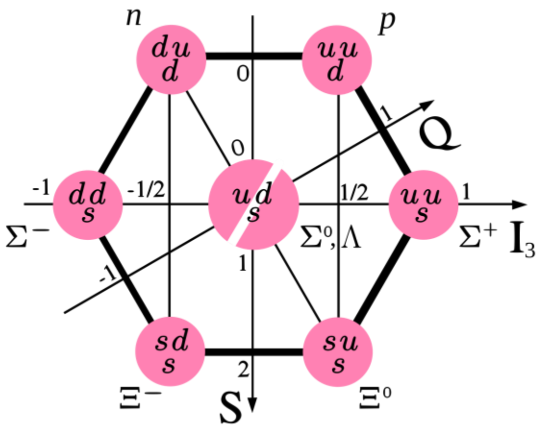


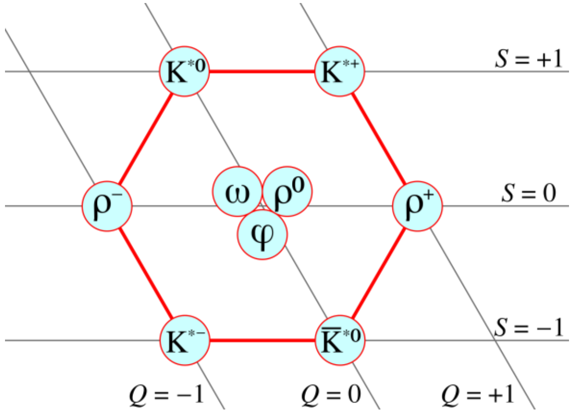
(all channels)

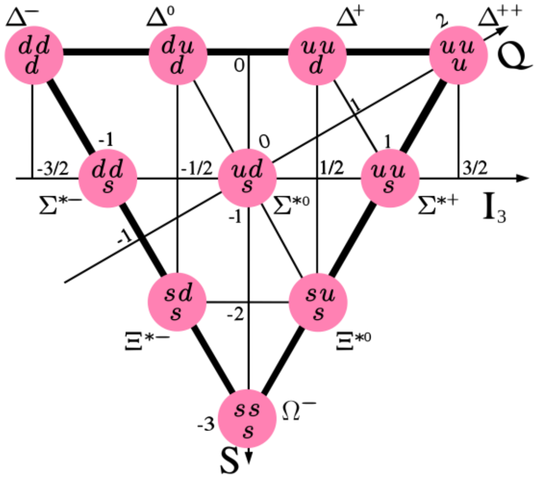


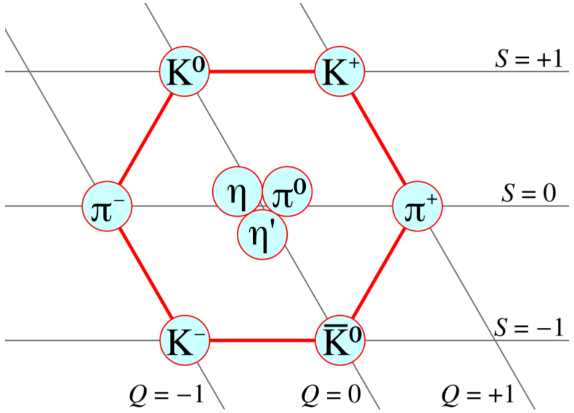
Branching Ratio
1
0.01
10^{-4}
10^{-6}
10^{-8}
100
150
200
300
500
700
1000
Higgs mass in GeV/c^2
$t\bar{t}$
$b\bar{b}$
$c\bar{c}$
$\tau\bar{\tau}$
$\mu\bar{\mu}$
gg
$\gamma\gamma$
$Z\gamma$
WW
ZZ


LHC
SWITZERLAND
FRANCE
100 KM LONG
FCC
100 km Circumference









Thank you for your attention!

Sára Bánovská, Anna Mária Sodomková, Jakub Šťavina

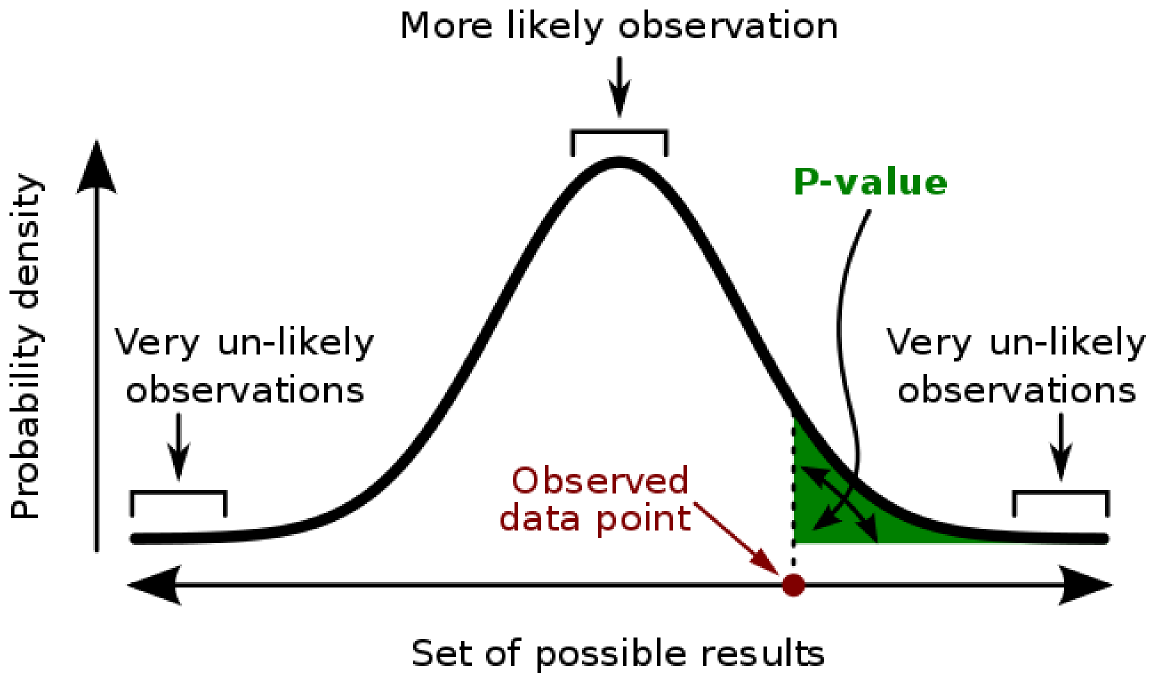
Appendix

Important:

Pr (observation | hypothesis) ≠ Pr (hypothesis | observation)

The probability of observing a result given that some hypothesis is true is *not equivalent* to the probability that a hypothesis is true given that some result has been observed.

Using the p-value as a “score” is committing an egregious logical error:
the transposed conditional fallacy.



A **p-value** (shaded green area) is the probability of an observed (or more extreme) result assuming that the null hypothesis is true.