GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

HELMHOLTZ ASSOCIATION
Alliance for Astroparticle Physics

Particle Physics Tutorial

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Problem 1: LHC at $\sqrt{s} = 13\,\mathrm{TeV}$

a) Two gluons (of the incoming protons) collide head-on. Each carries 10% of the momentum of its proton. Compute the cm energy of the two gluons.

b) The gluons are scattered by an angle $\theta = 45^\circ$. Compute q^2, the square of the four-momentum transfer.

c) Compute the spatial resolution $\hbar/\sqrt{|q^2|}$ reached in this scattering process. Note:

$$1 = \hbar c = 0.2\,\mathrm{GeV\,fm}$$

d) A proton of one of the LHC beams hits a proton inside a gas molecule left in the (highly evacuated) beam pipe. Compute the cm energy for this collision.

Problem 2: Future circular collider?

The LHC has a circumference of 27 km. With the current superconducting magnets it can reach a maximum cm energy (proton-proton) of 14 TeV with 3×10^{14} protons per beam.

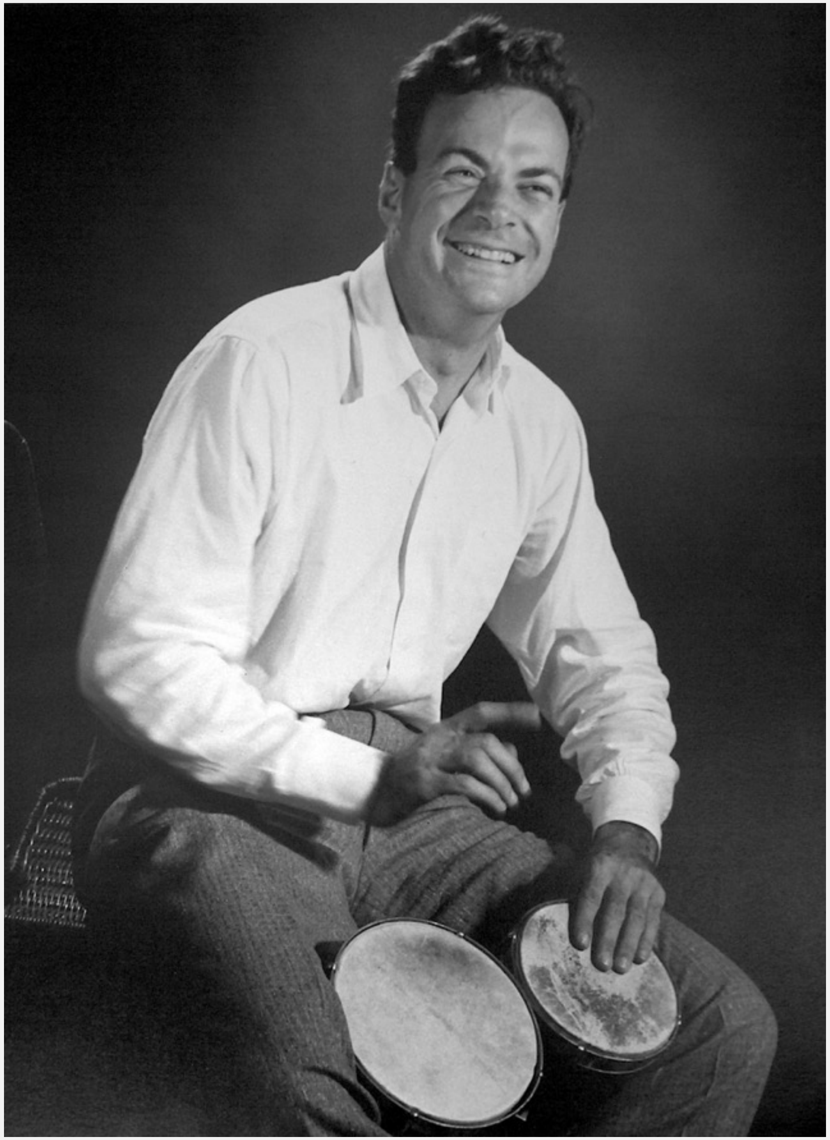
a) Consider a future LHC-like machine with a cm energy of 100 TeV. Assume that by aggressive R&D one can double the field of the magnets. Find the circumference of the ring.

b) The synchrotron radiation power of one LHC beam (at design) is 6 kW. What would be the corresponding power for the new machine assuming the same number of particles per length?

c) Consider now an electron-positron collider in the same tunnel, able to produce top-quark pairs (cm energy 350 GeV). Compute the synchrotron radiation power if 100 bunches, each with 10^{11} particles are stored per beam.

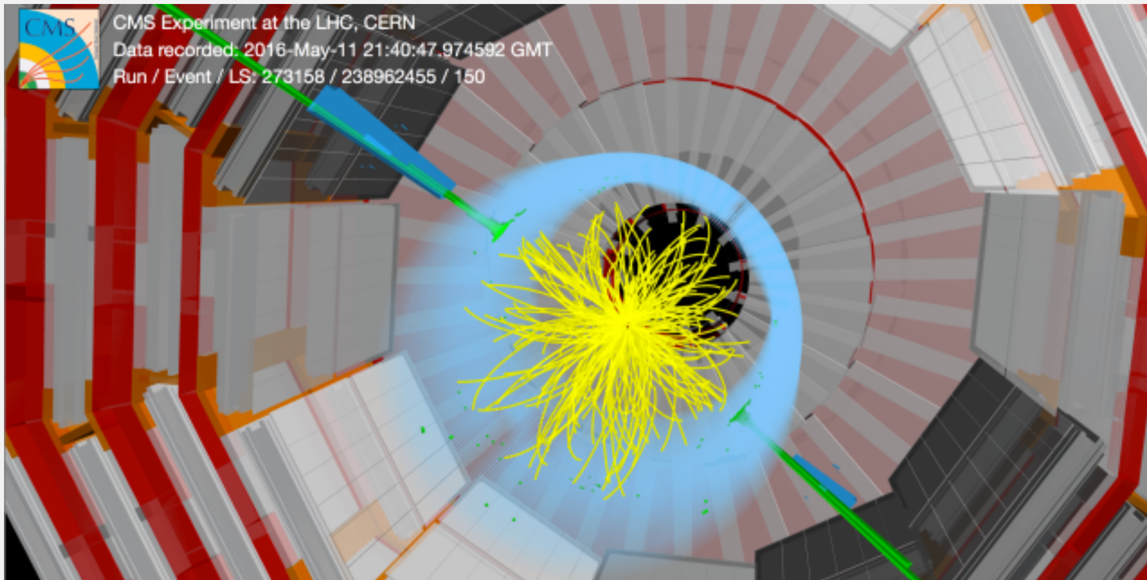
Problem 3: What is the correct pronunciation of:

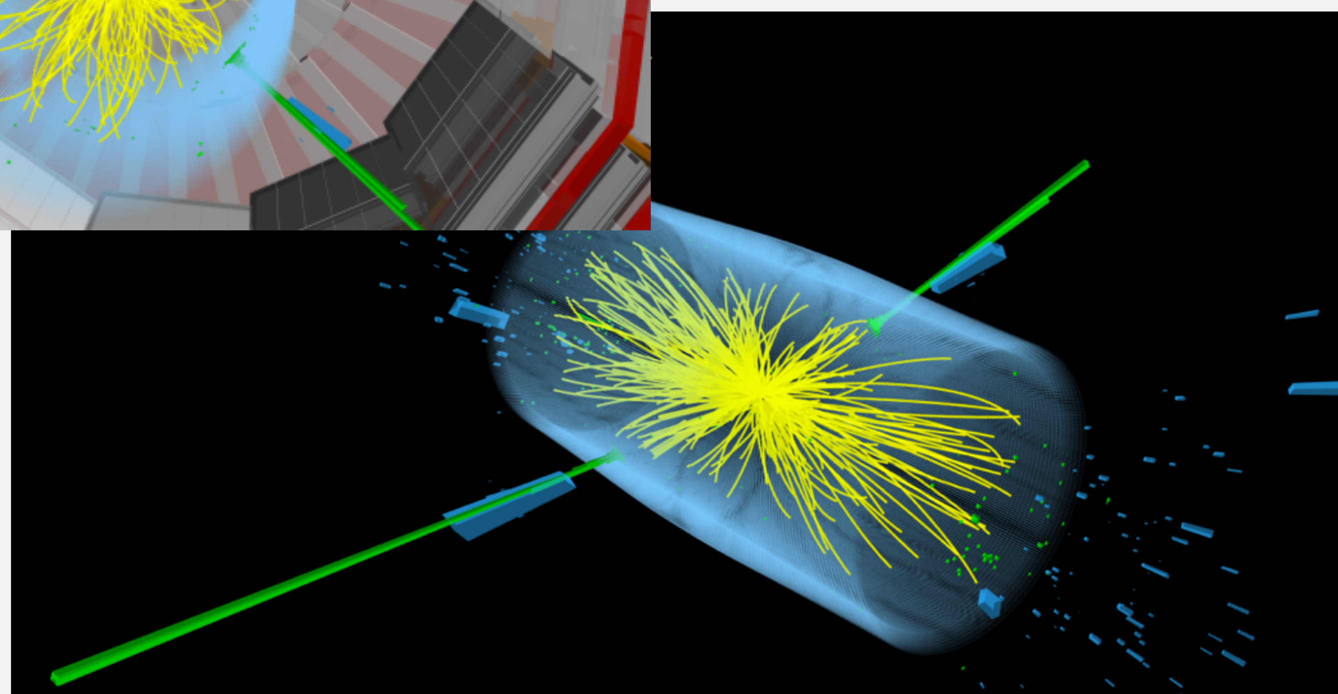
Richard P. Feynman

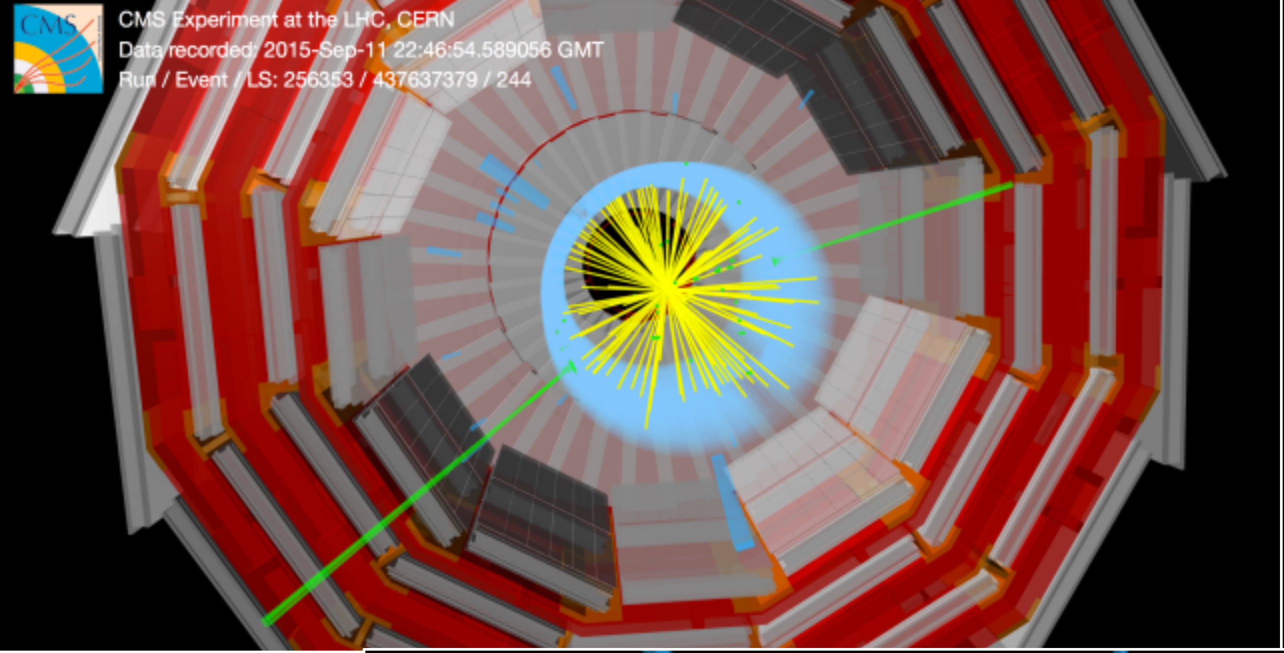


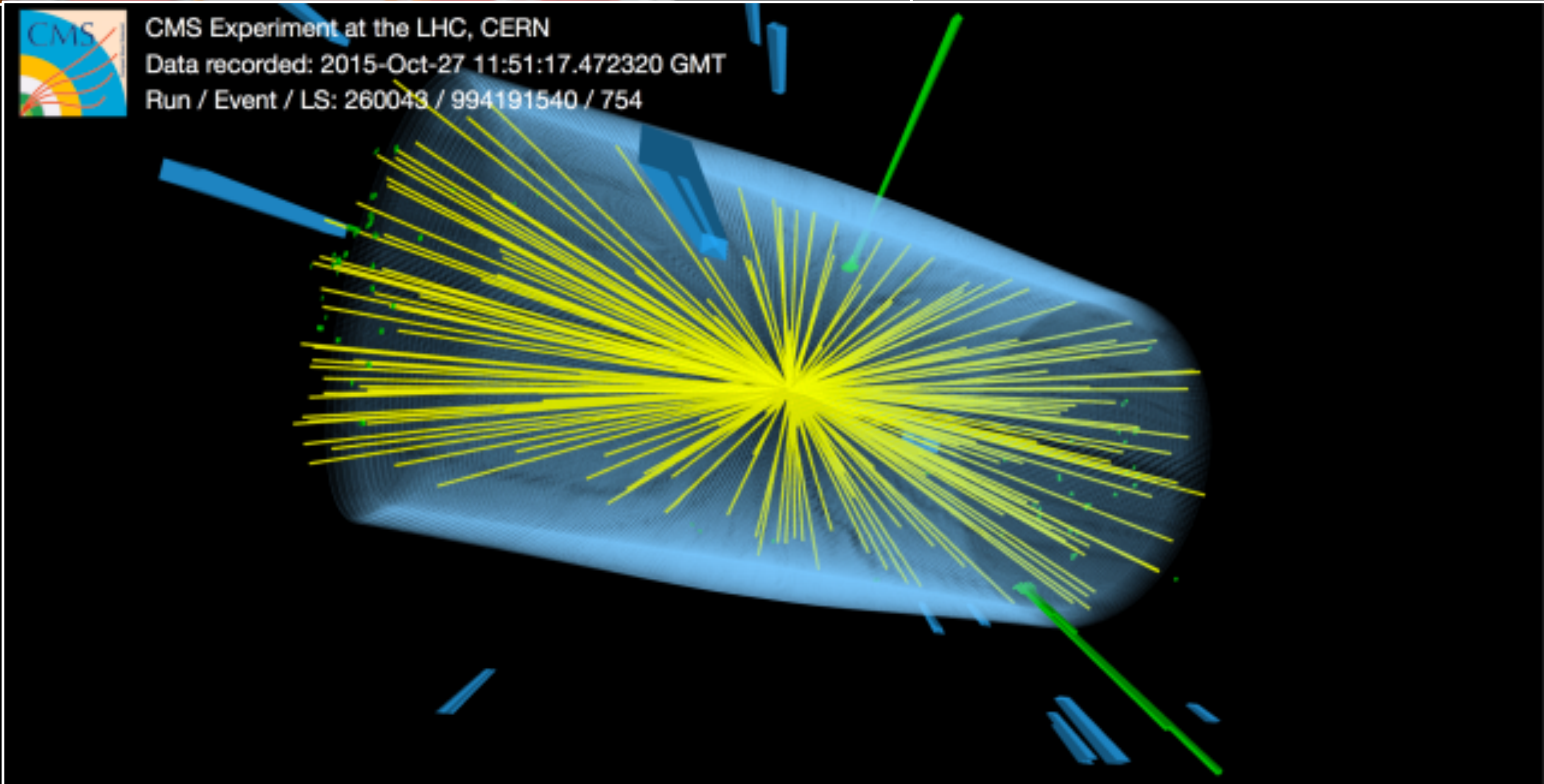
Problem 4: Event quizz

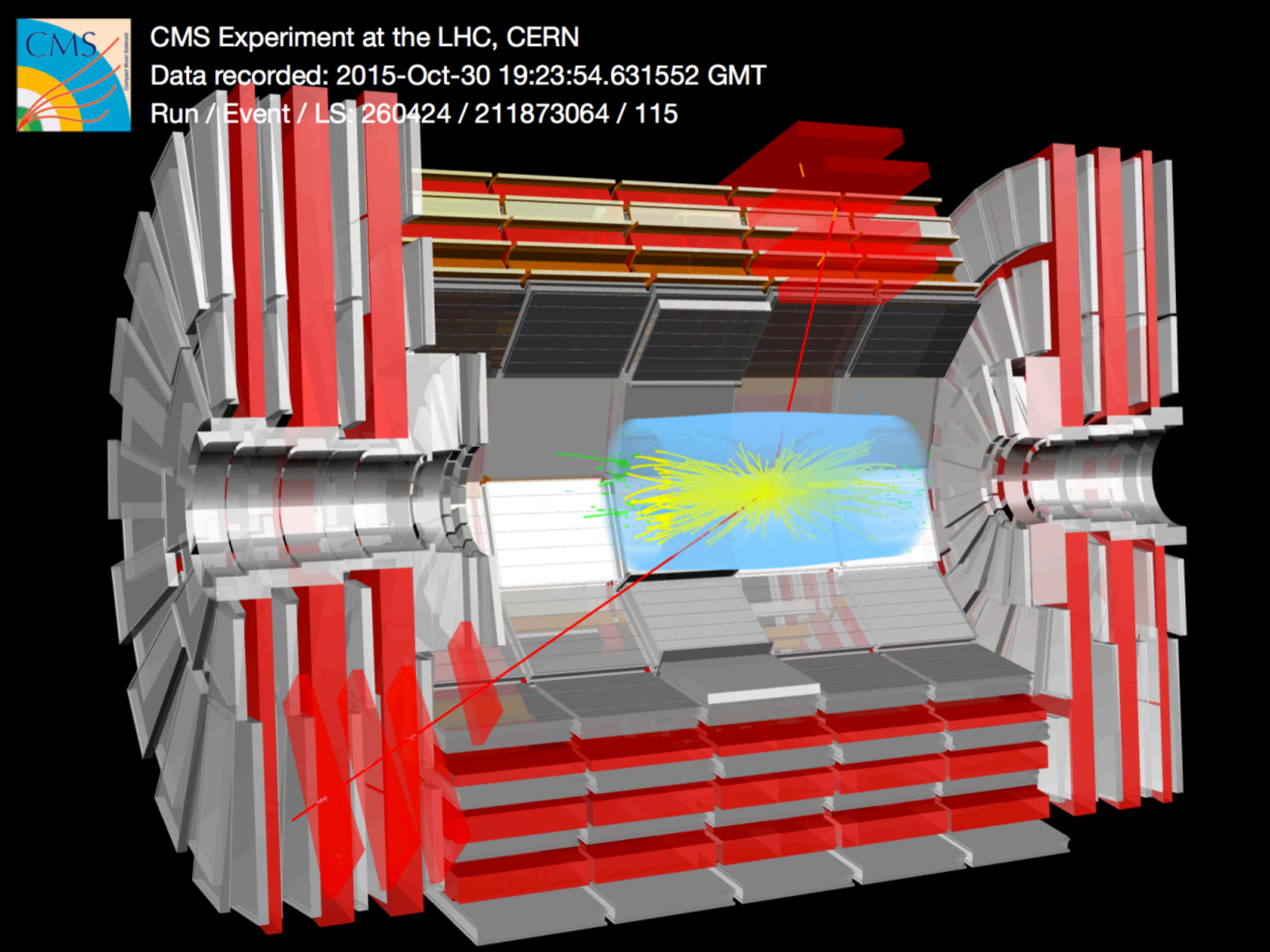
Look at the following event displays and identify final state objects. Can you imagine which process could have taken place? If possible, draw a Feynman diagram.






CMS Experiment at the LHC, CERN
Data recorded: 2015-Sep-11 22:46:54.589056 GMT
Run / Event / LS: 256353 / 437637379 / 244


CMS Experiment at the LHC, CERN
Data recorded: 2015-Oct-27 11:51:17.472320 GMT
Run / Event / LS: 260043 / 994191540 / 754


CMS
CMS Experiment at the LHC, CERN
Data recorded: 2015-Oct-30 19:23:54.631552 GMT
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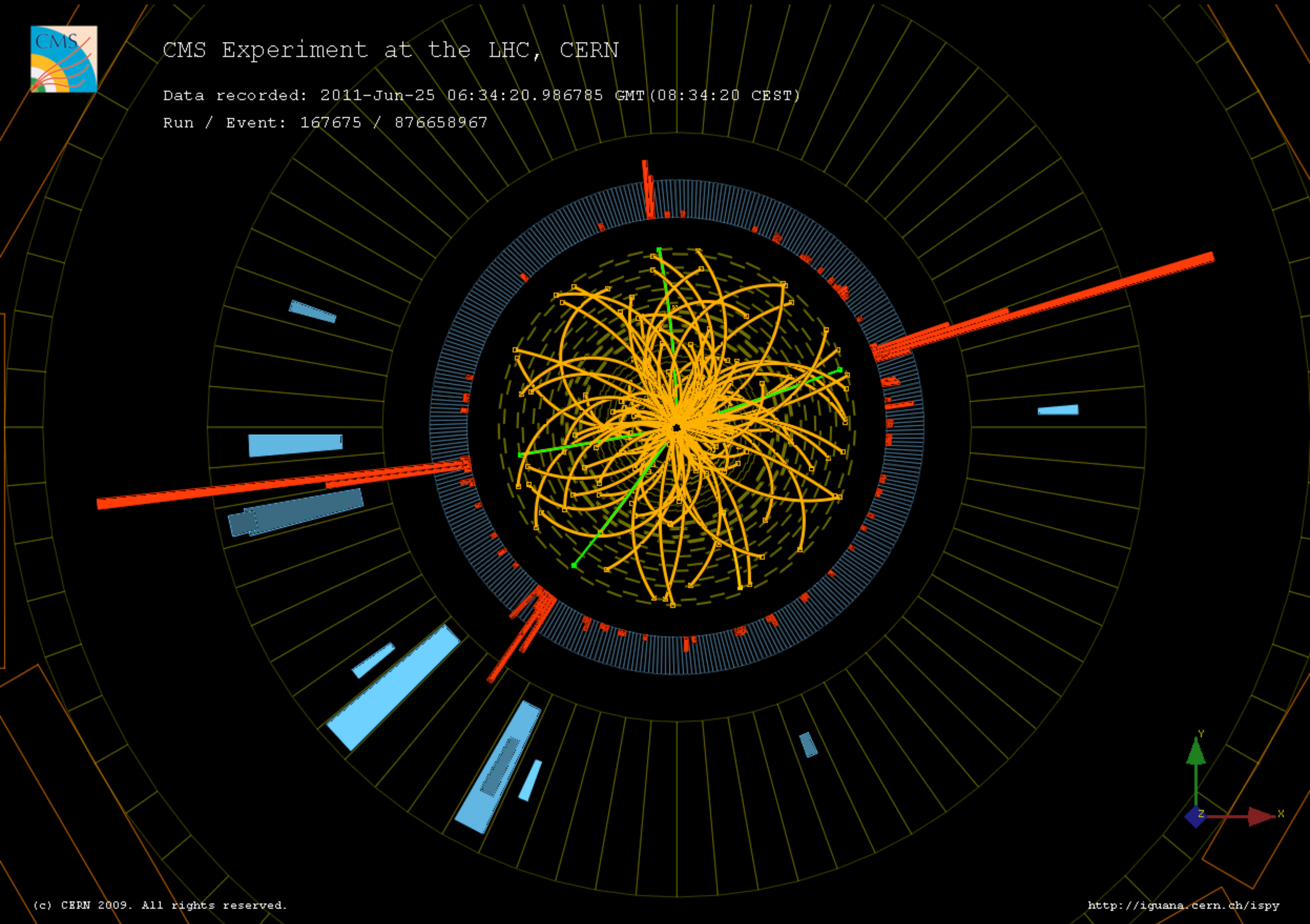
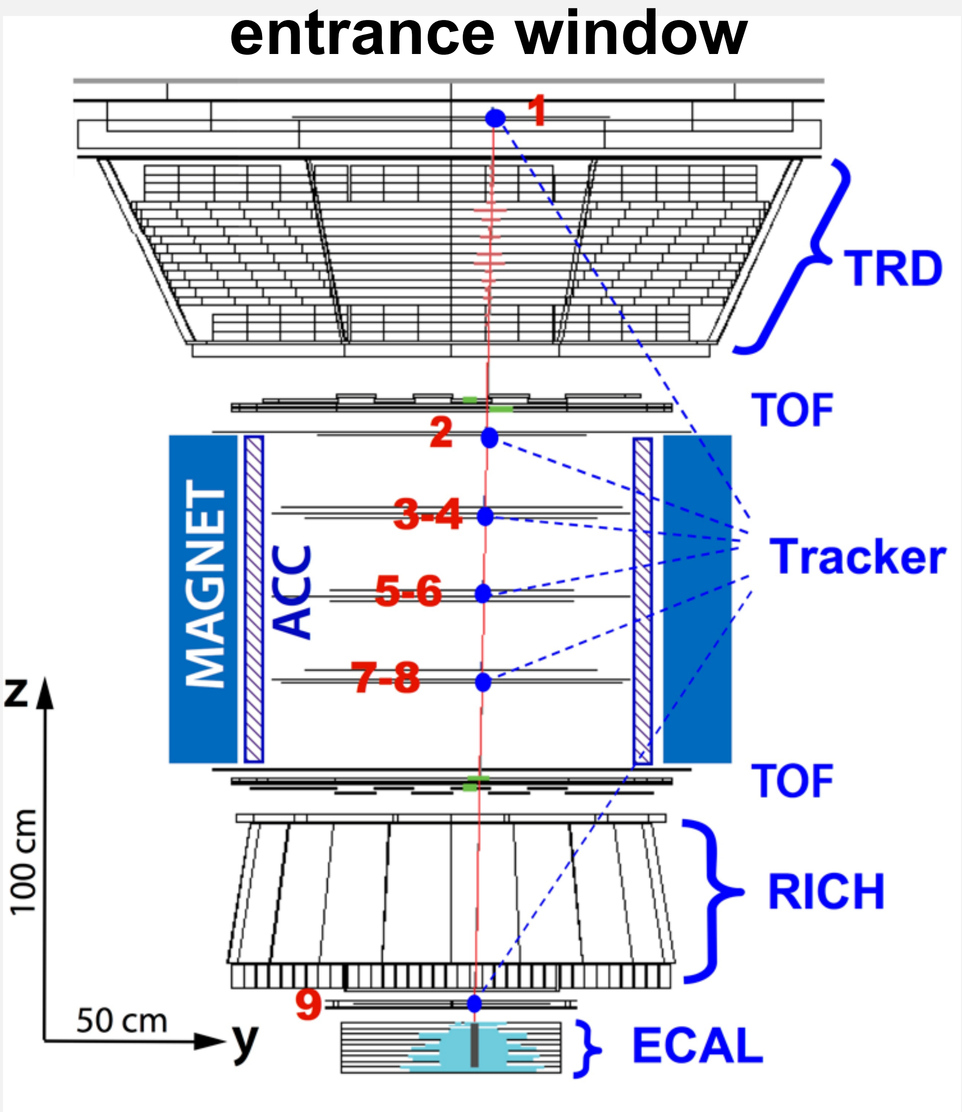
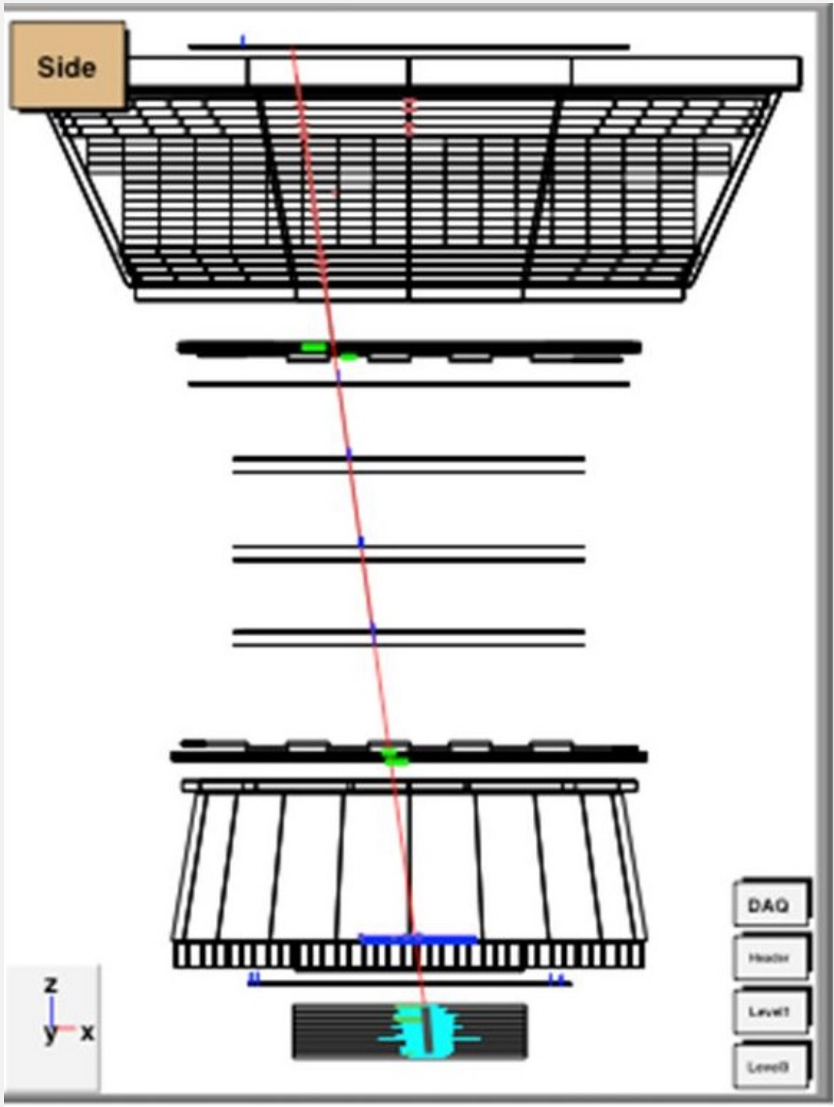

CMS
CMS Experiment at the LHC, CERN
Data recorded: 2011-Jun-25 06:34:20.986785 GMT(08:34:20 CEST)
Run / Event: 167675 / 876658967
Y
Z
X
http://iguana.cern.ch/ispy


entrance window
1
TRD
TOF
2
3-4
5-6
7-8
MAGNET
ACC
Tracker
TOF
RICH
9
ECAL
z
100 cm
50 cm
y


Side
z
y
x
DAQ

Problem 6: Fill all charge numbers (if applicable) into the following table.

particle	Q	I	I_3	Y	colored? y/n
e_L^-					
$\nu_{\mu L}$					
τ_R^-					
t_L					
b_R					
$\nu_{\tau R}$					
γ					
Z					
W^-					
g					

Problem 7: WW scattering

In the lecture we discussed all diagrams (of leading order) contributing to the process:

$$W^+W^- \rightarrow W^+W^-$$

Draw all leading order diagrams contributing to the related process:

$$W^+W^+ \rightarrow W^+W^+$$

Draw a diagram which shows, how this scattering could happen at the LHC in proton-proton collisions.