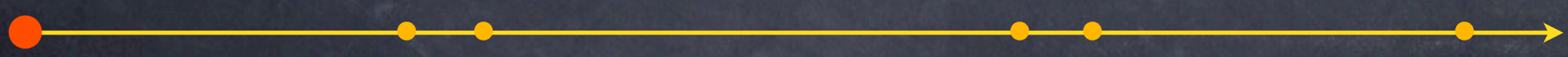
Masterclasses

The structure of the Proton & The search for the Higgs boson

Konrad Jende, HST2014

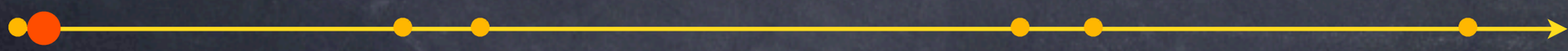
Outline

- Wrap-up 30’ (09:00)
- Technical Intro 15’
- Intro to the Event Display Programme 15’
- Exercises 75’ (10:00)
- Break 15’ (11:15)
- Measurement 60’ (11:30)
- Combination of Data 15’ (12:30)
- Discussion 30’ (12:45)



Part 1 - Introduction

Aims of the workshop



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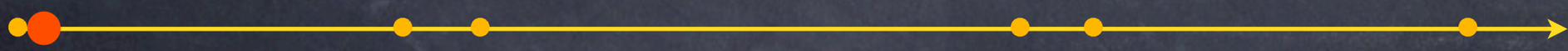
- You will get to know a measurement, which enables us to reveal the inner structure of the proton.



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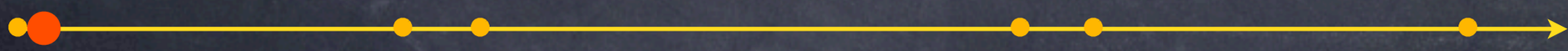
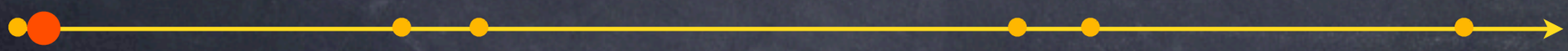
- You will get to know a measurement, which enables us to reveal the inner structure of the proton.
- You will better understand how data analysis is done in practice even though you will only analyze data in a comparable model.



Aims of the workshop

- You will get to know a measurement, which enables us to reveal the inner structure of the proton.
- You will better understand how data analysis is done in practice even though you will only analyze data in a comparable model.
- You can identify particles and proton-proton collision events recorded with the LHC experiment ATLAS by their visual representation in event display programmes.



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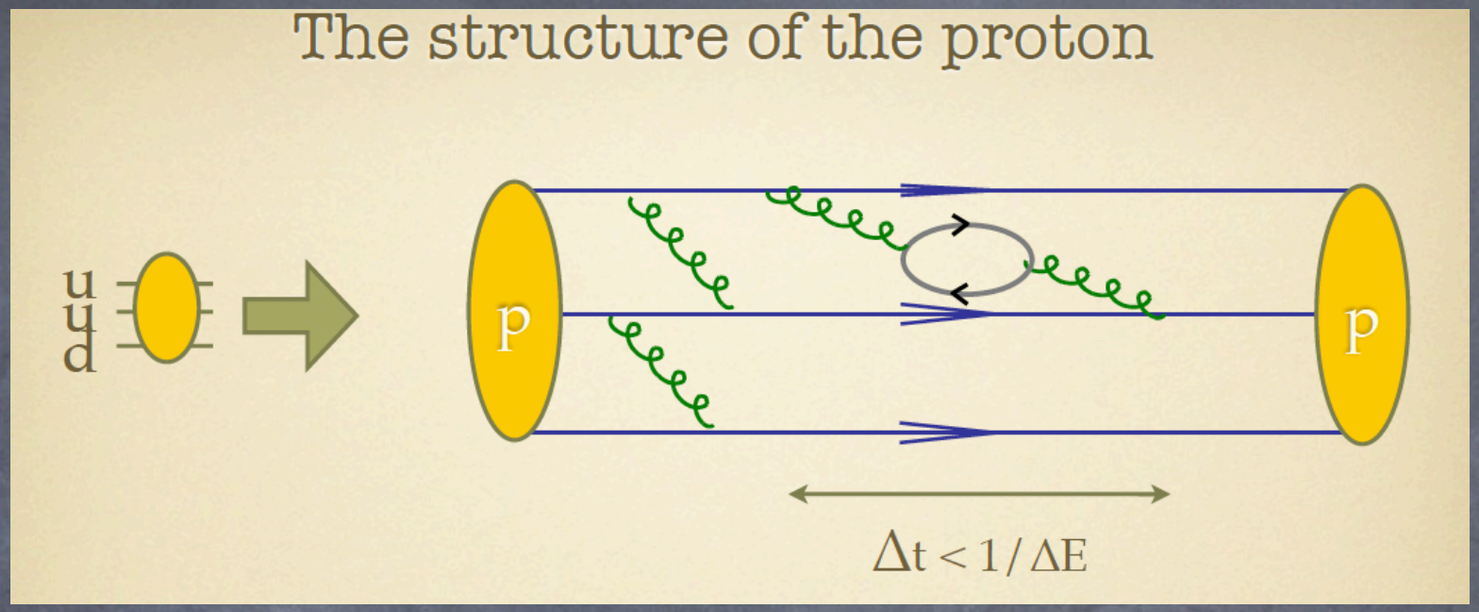
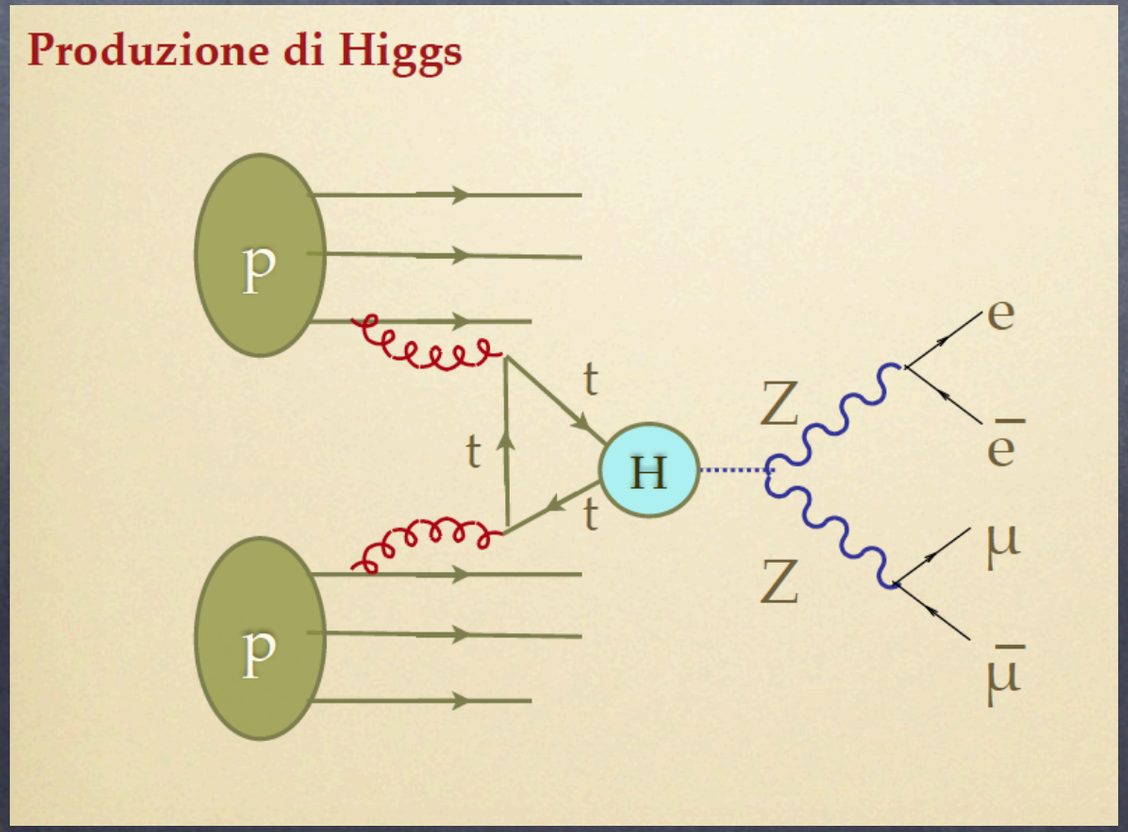
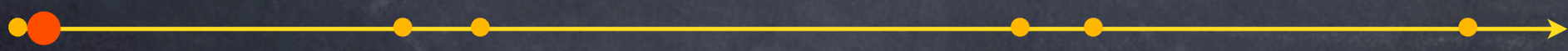




Part 1 - Introduction

Starter



Part 1 - Introduction

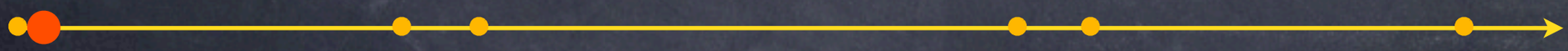
Starter

Work on Task 1!

1. Idea of data analysis (5-10'): Work in groups of 7 teachers. There are 12 visual representations of proton-proton collisions to be lying in front of you:

   a) Find similarities and differences inside the pictures!

   b) Group the events (using the similarities and differences you established beforehand)!



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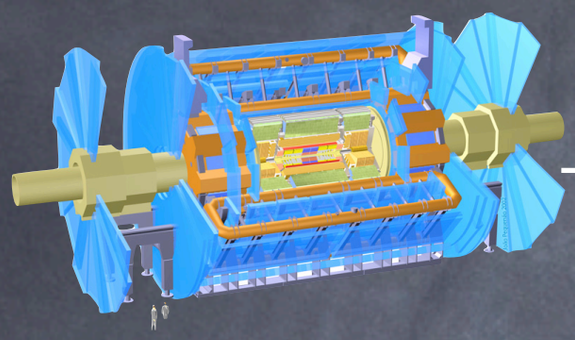
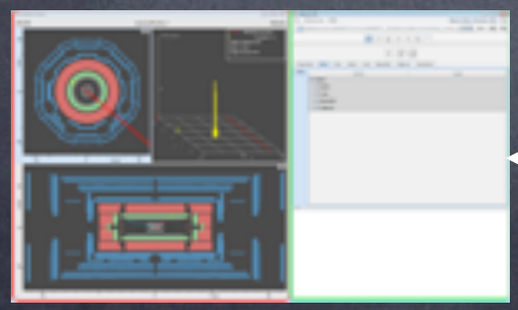


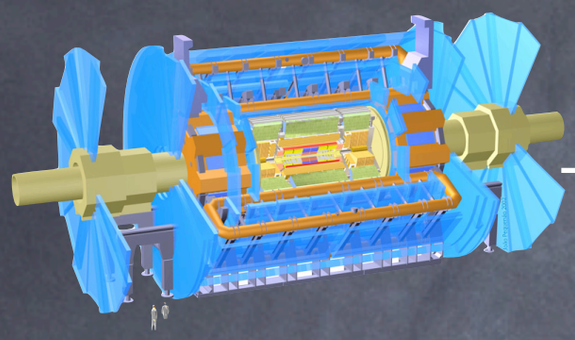
Monte Carlo Simulation

Reconstruction of events

data storage in LHC computing grid

analysis





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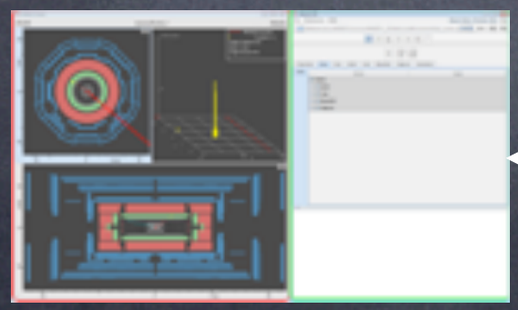
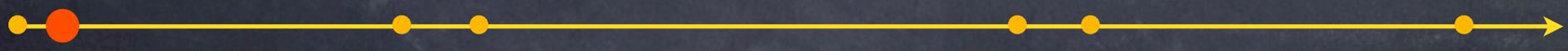


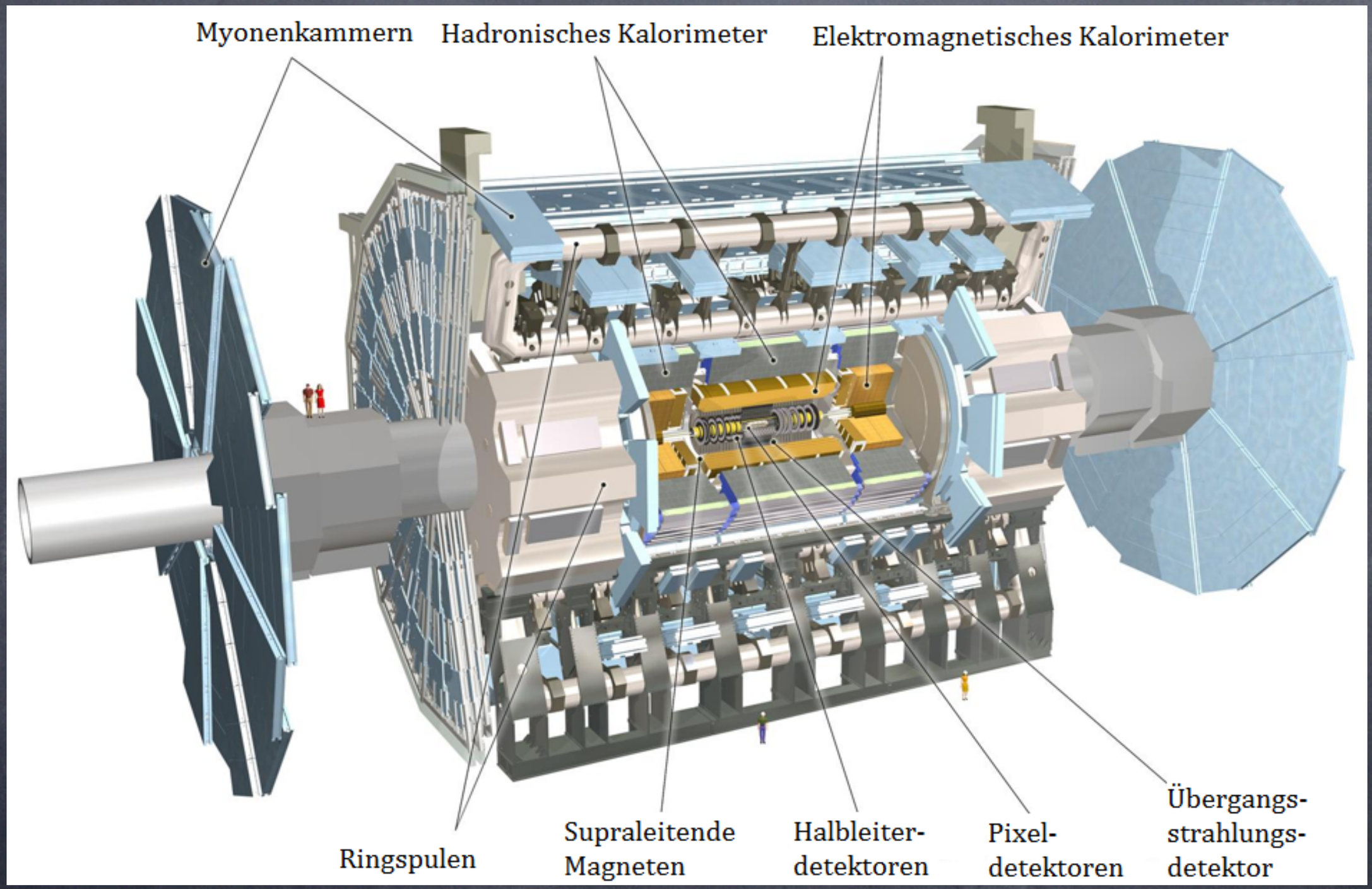
Fig.: Visualization of data flow from the experiment to the event display

Introduction

- ATLAS detector
- Physics
  - W Boson
  - Higgs Boson



particle identification 1



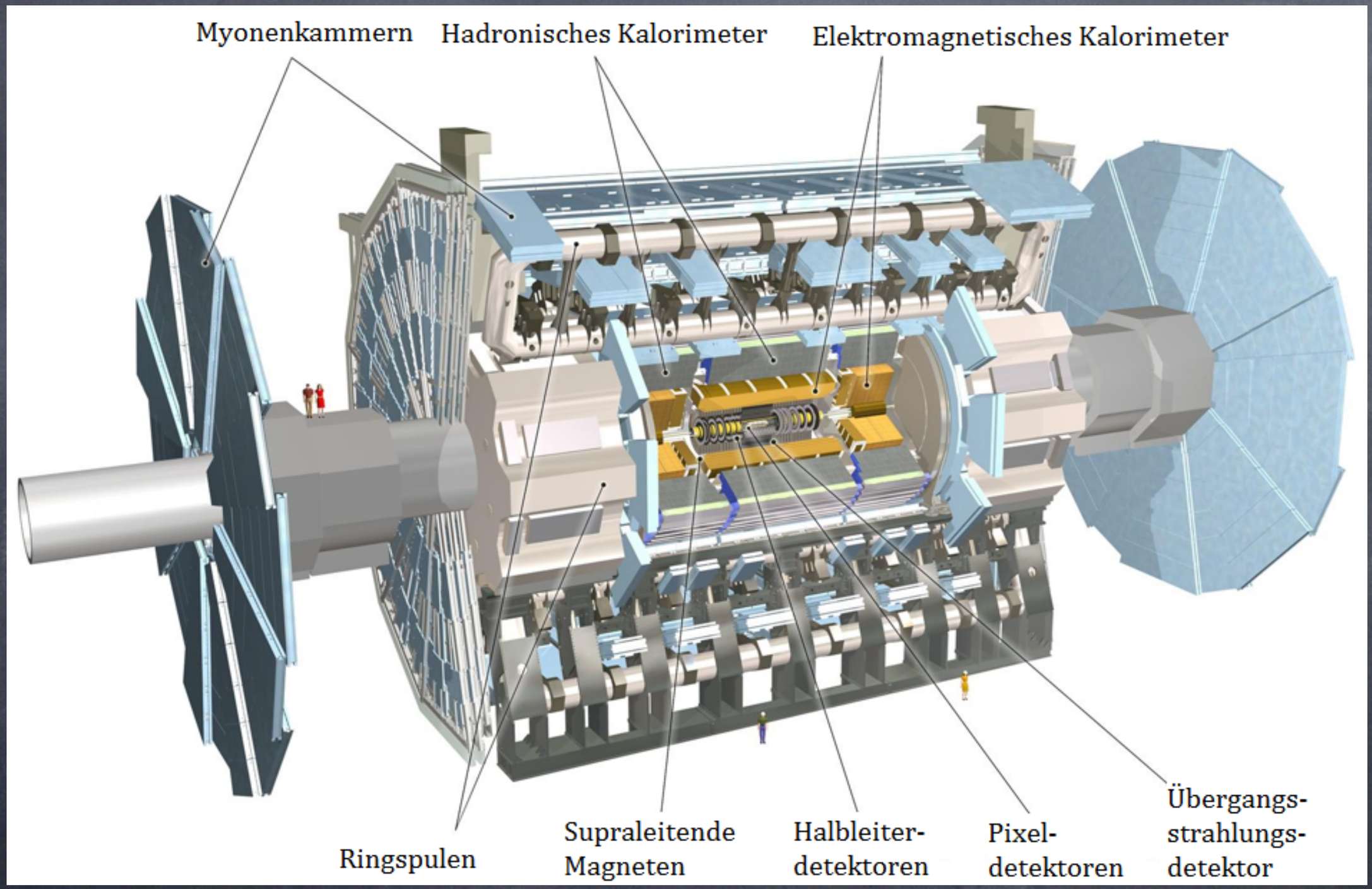
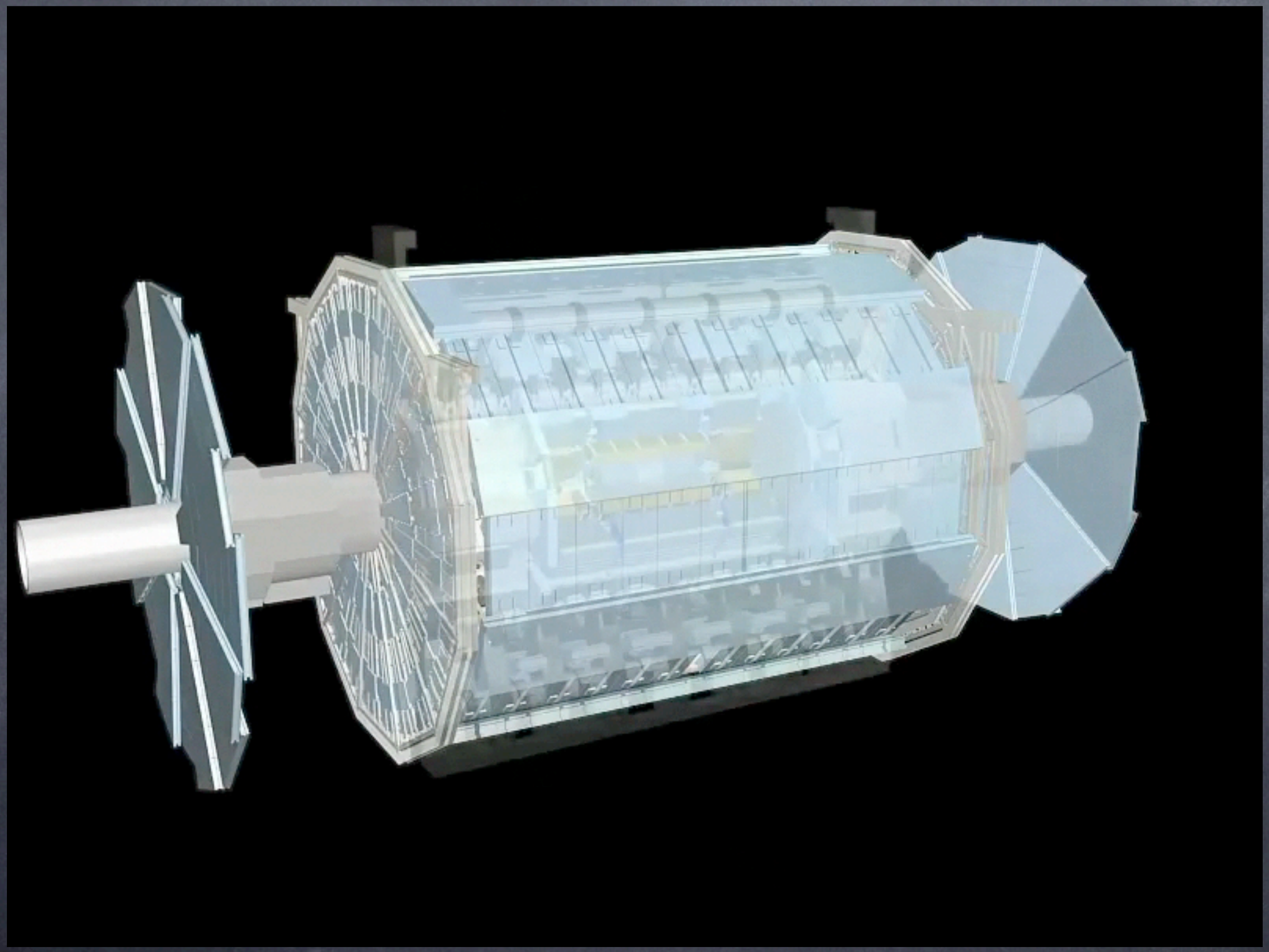
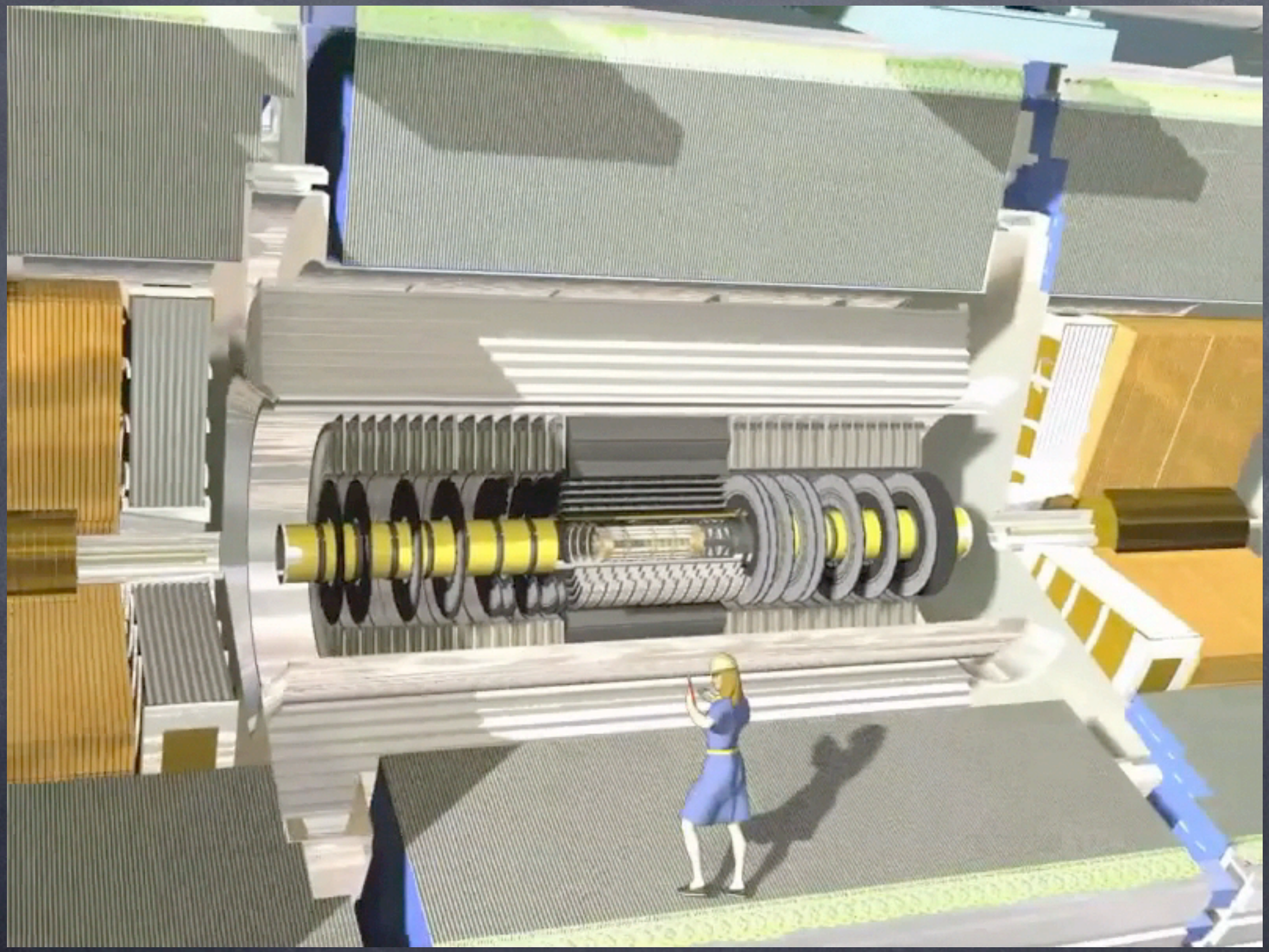
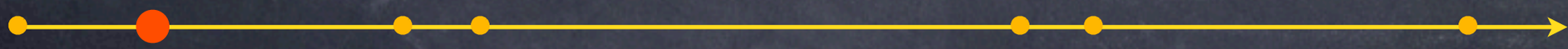


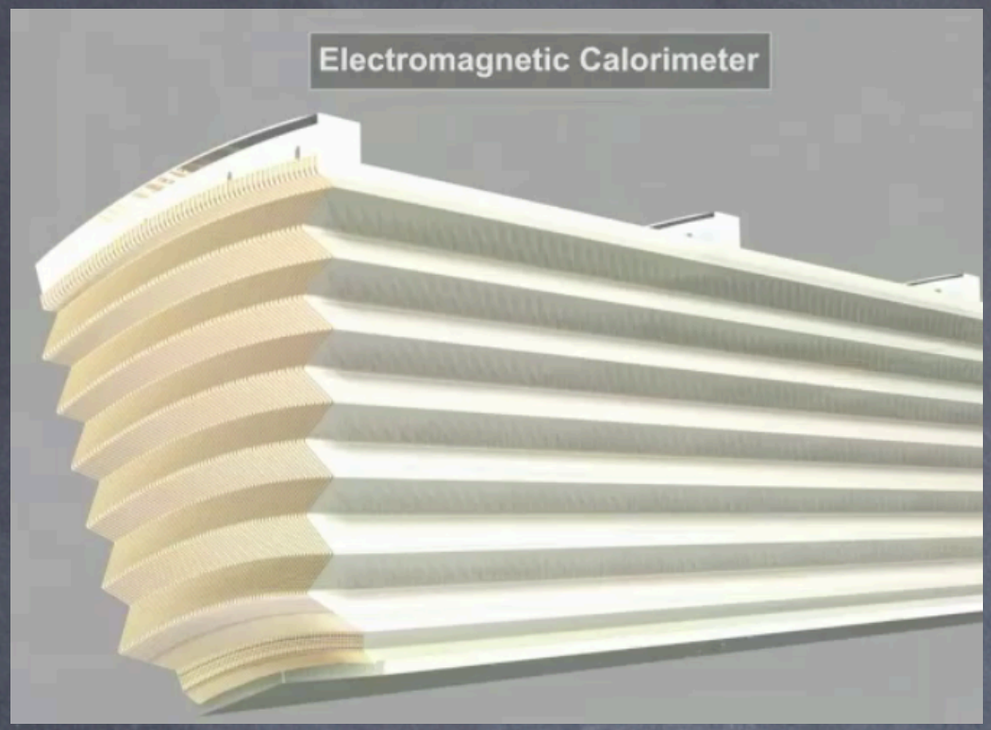
Abb. 2: ATLAS-Detektor mit seinen wichtigsten Komponenten

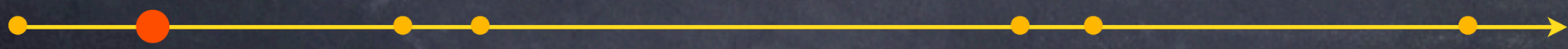


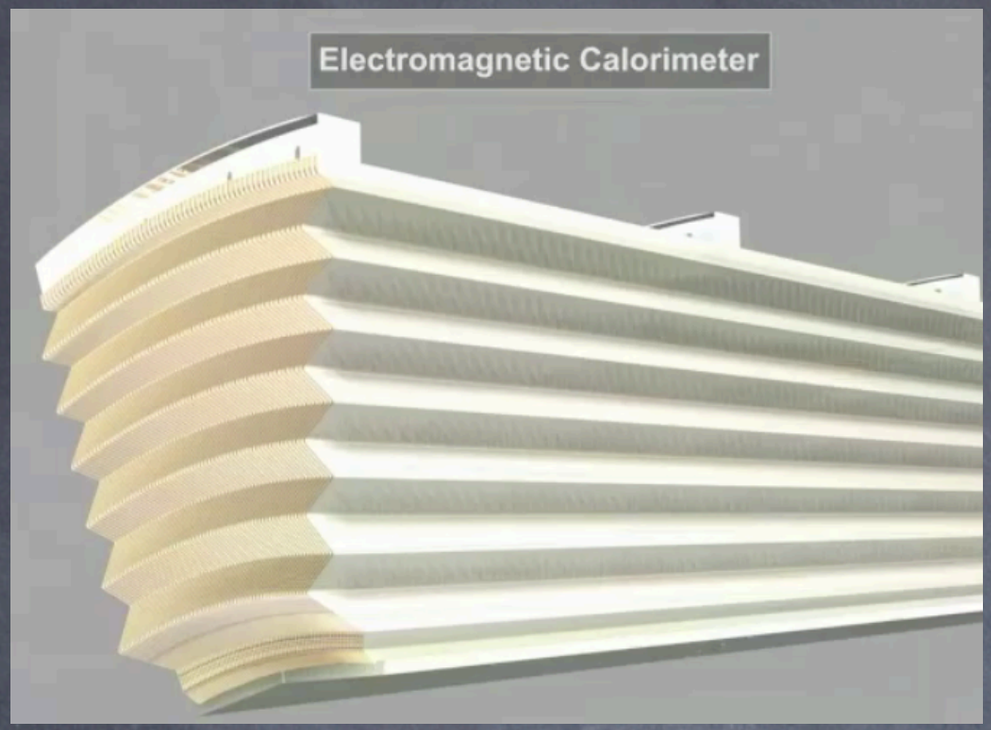
particle identification 4

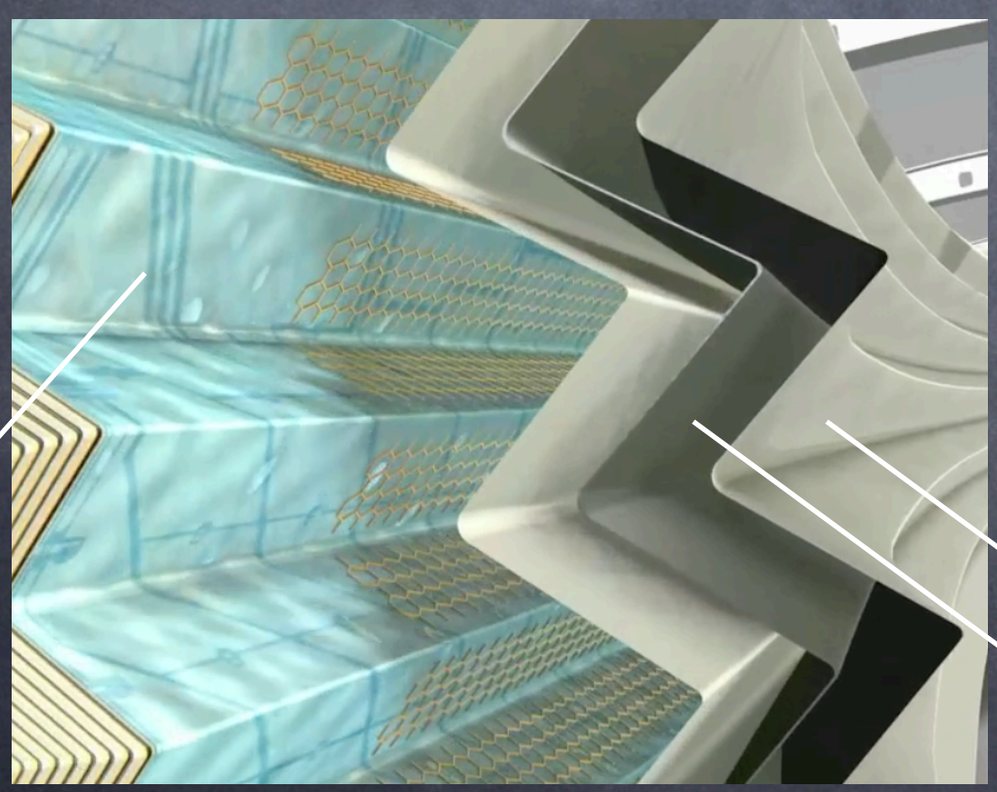





Electromagnetic Calorimeter





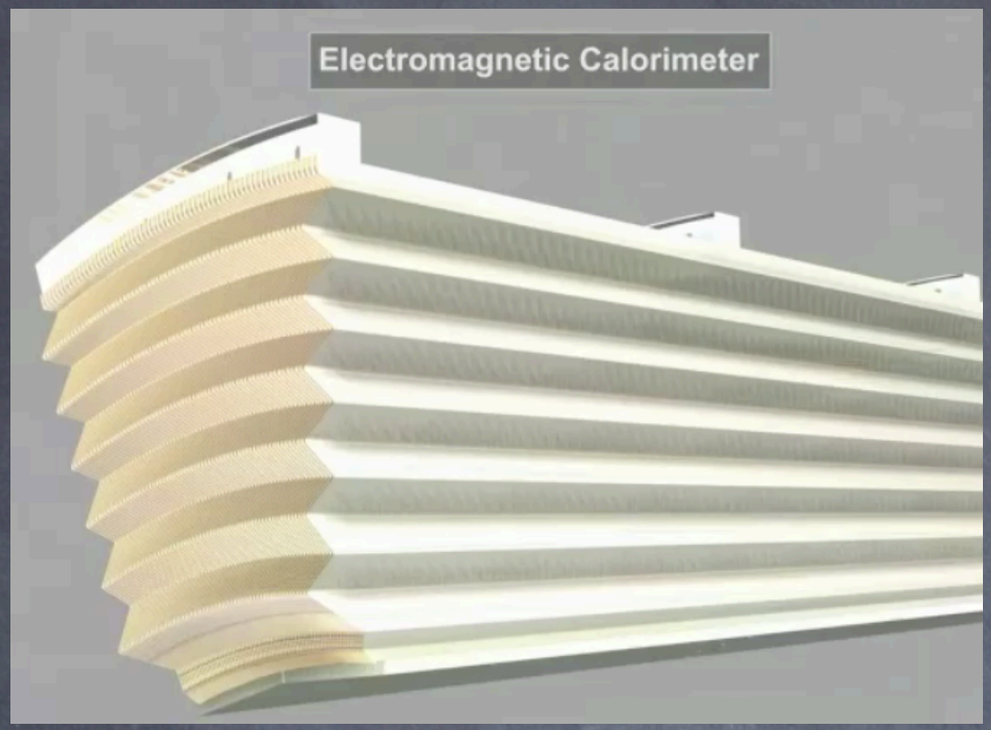


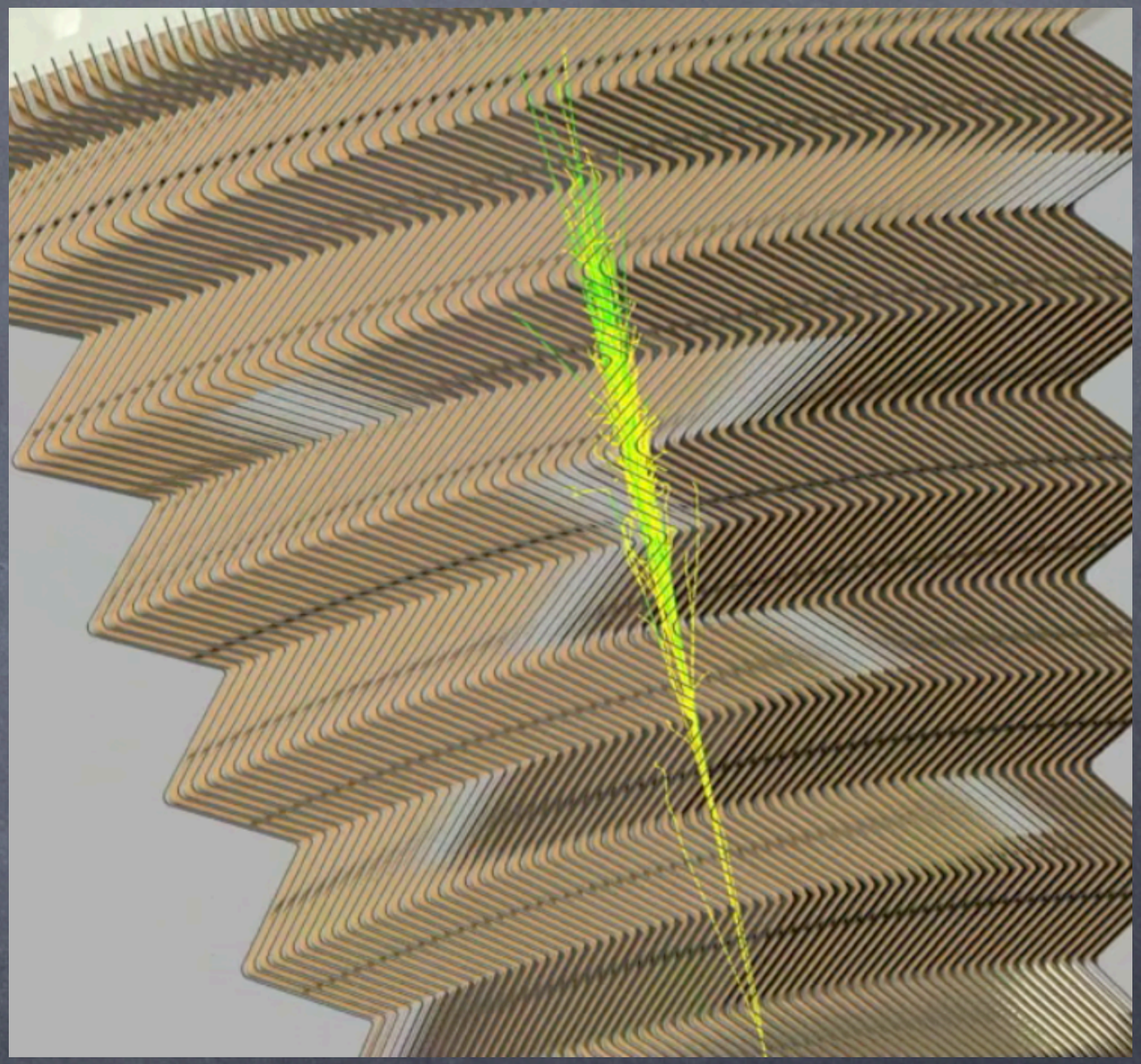
liquid argon (-185°)

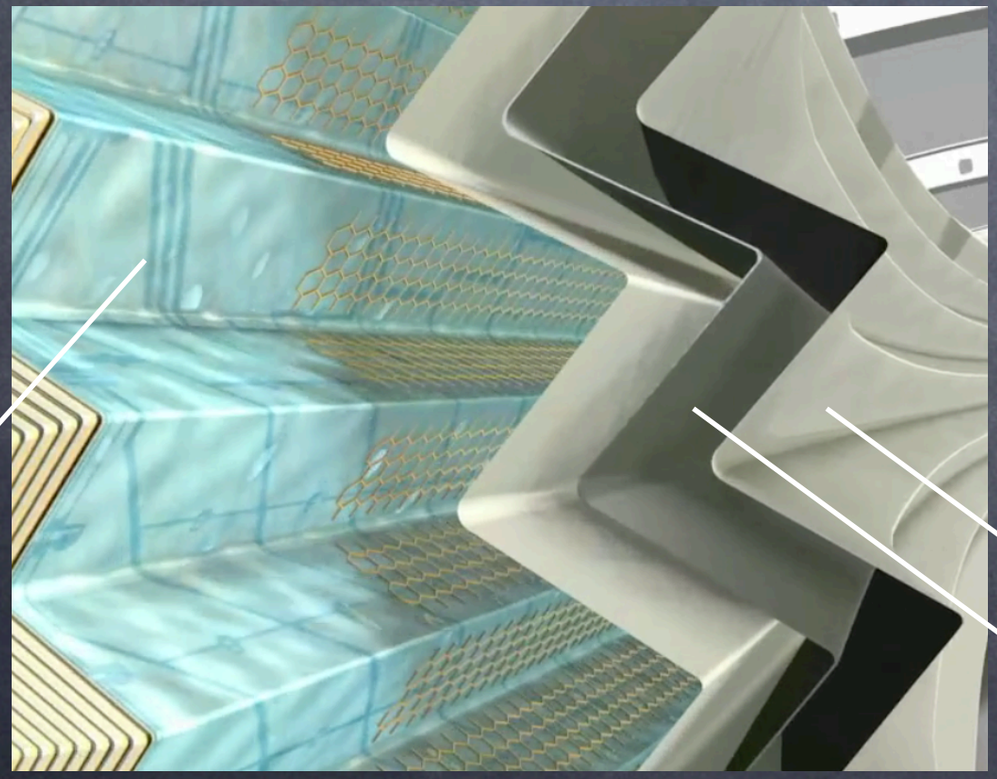
Lead, steal

Part 1 - Introduction

particle identification 5







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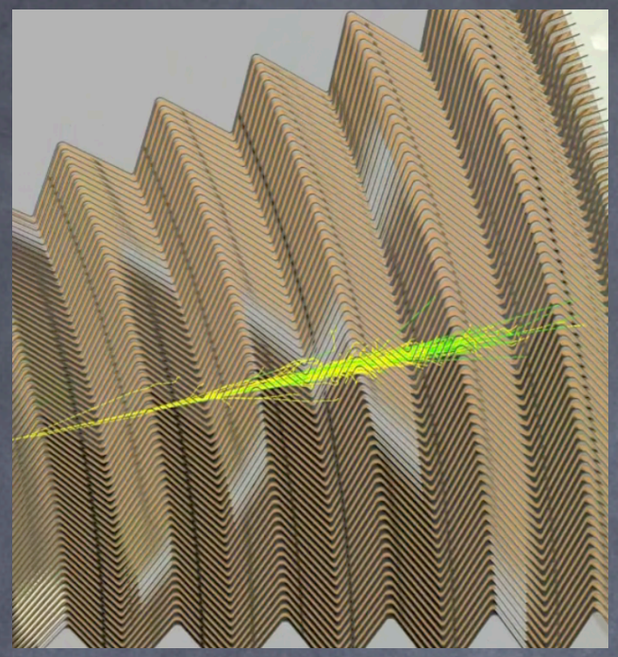
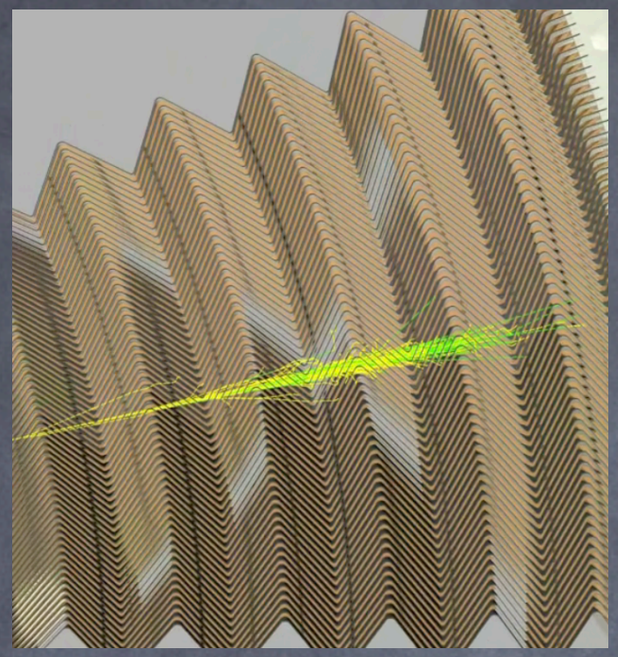
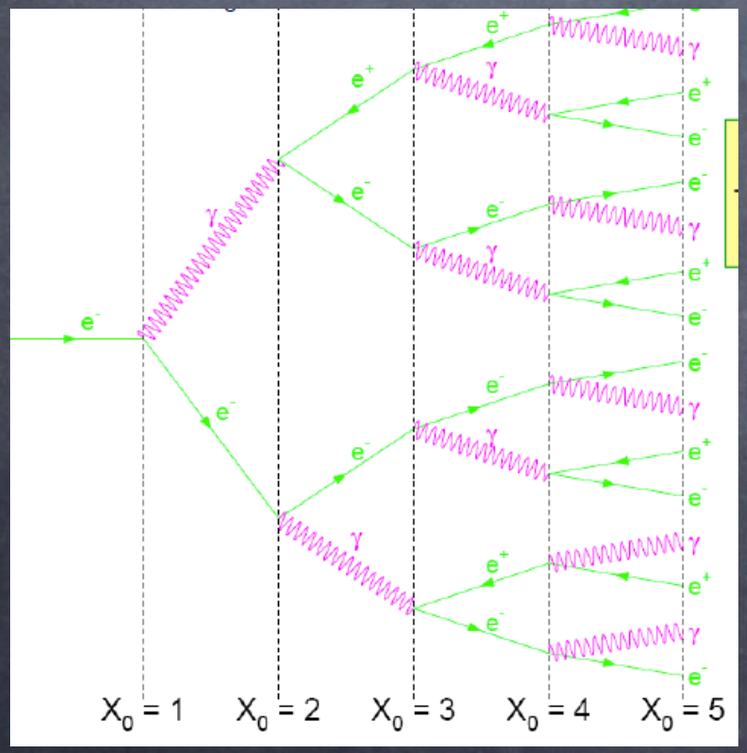


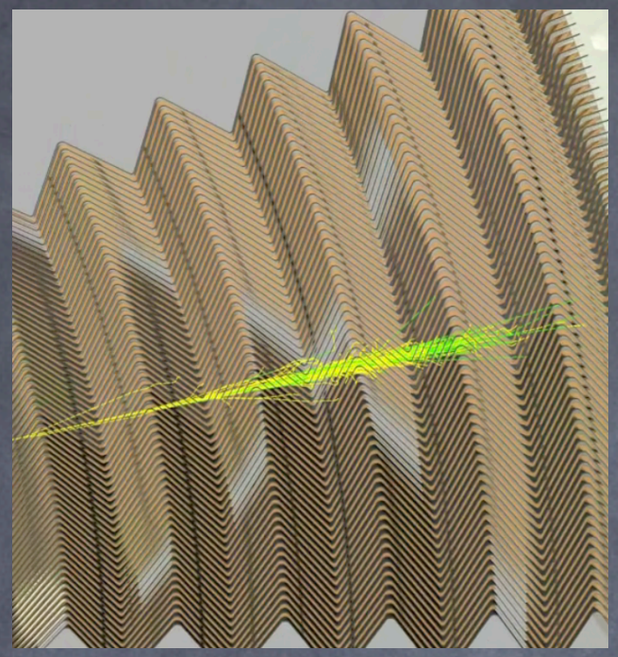




particle identification 6

electrons interact by:
Bremsstrahlung in priestley field $\sim Z^2E/m^2$

muons interact by: ionisation
photons interact by: pair creation



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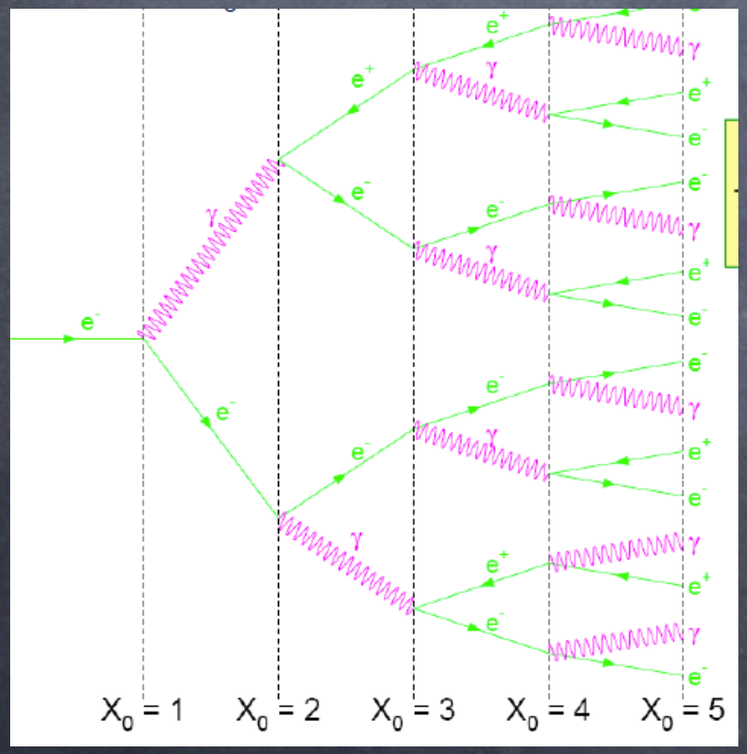
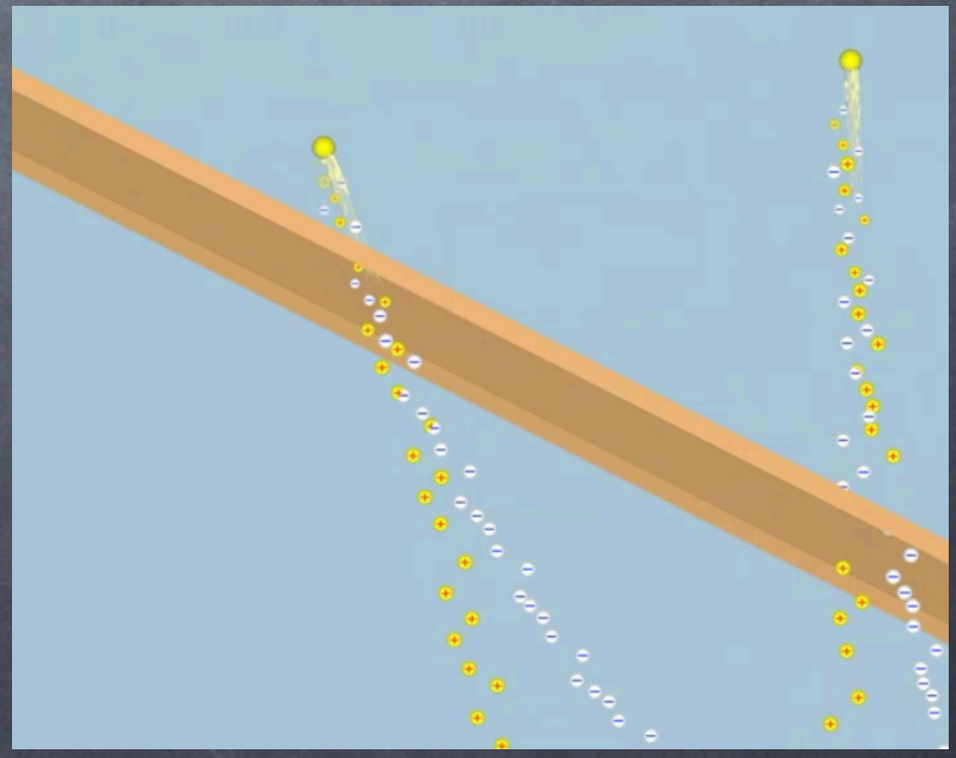
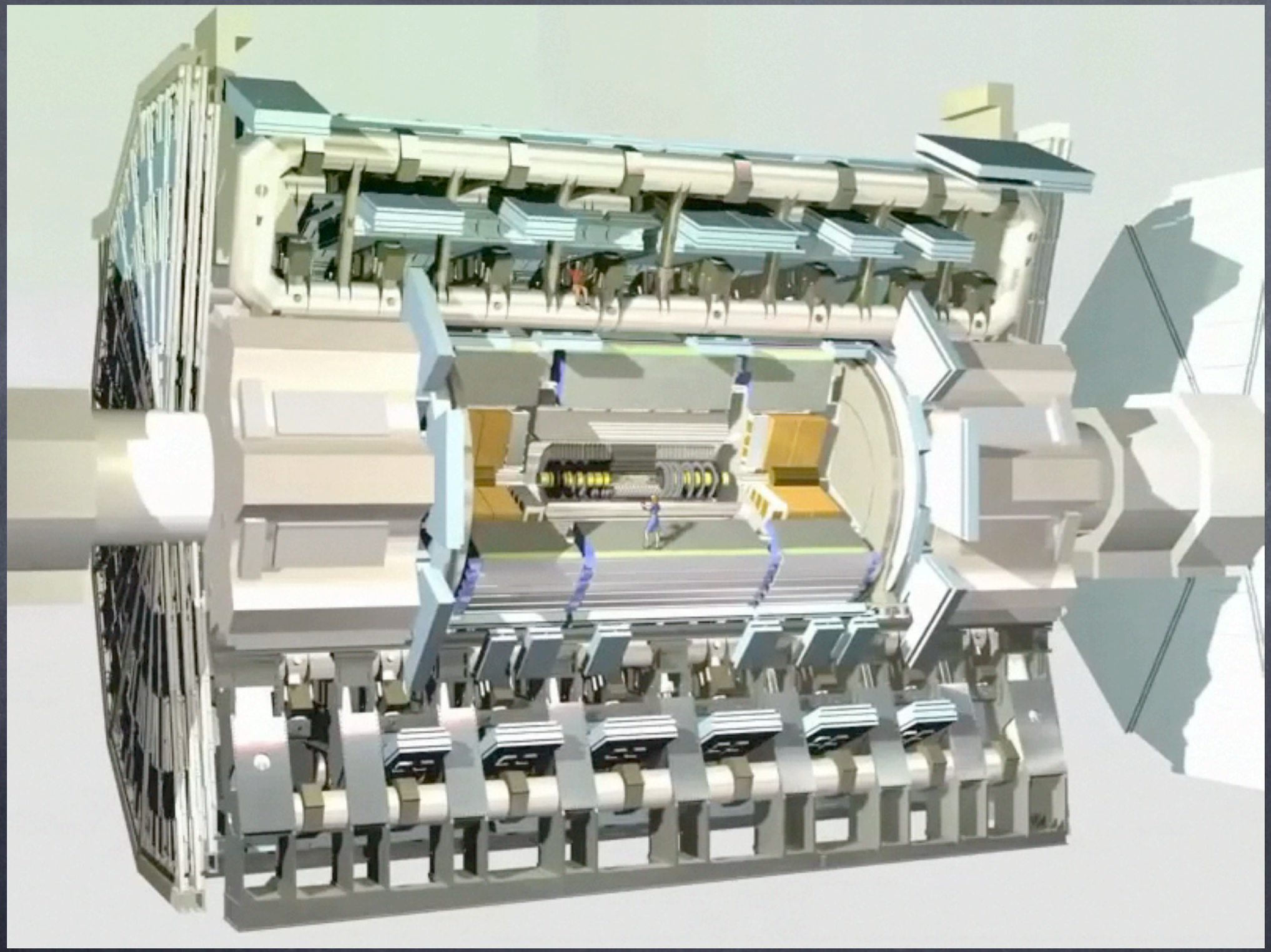
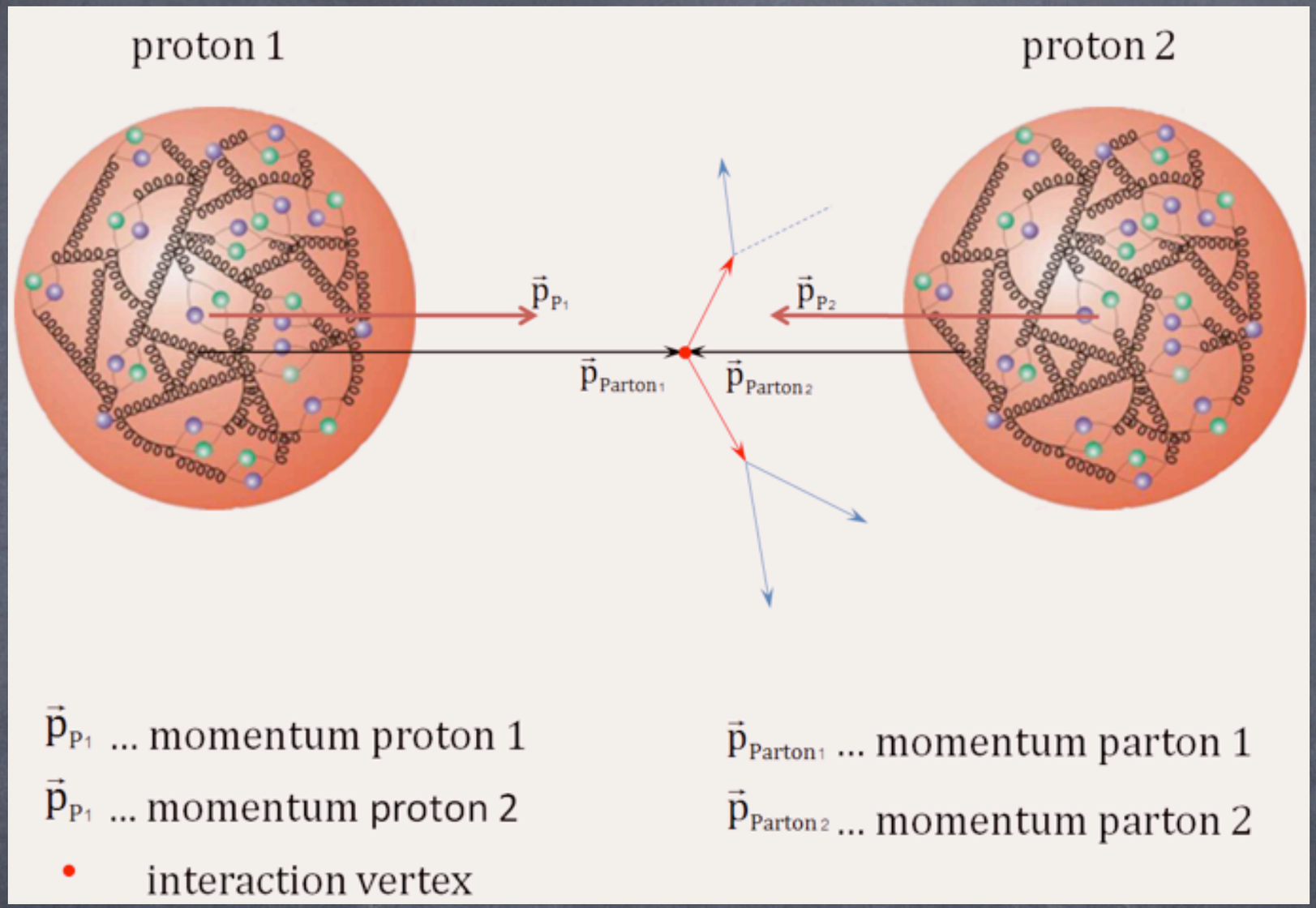







proton 1
proton 2
$\vec{p}_{P_1}$
$\vec{p}_{P_2}$
$\vec{p}_{Parton_1}$
$\vec{p}_{Parton_2}$
$\vec{p}_{P_1}$ ... momentum proton 1
$\vec{p}_{P_1}$ ... momentum proton 2
interaction vertex
$\vec{p}_{Parton_1}$ ... momentum parton 1
$\vec{p}_{Parton_2}$ ... momentum parton 2

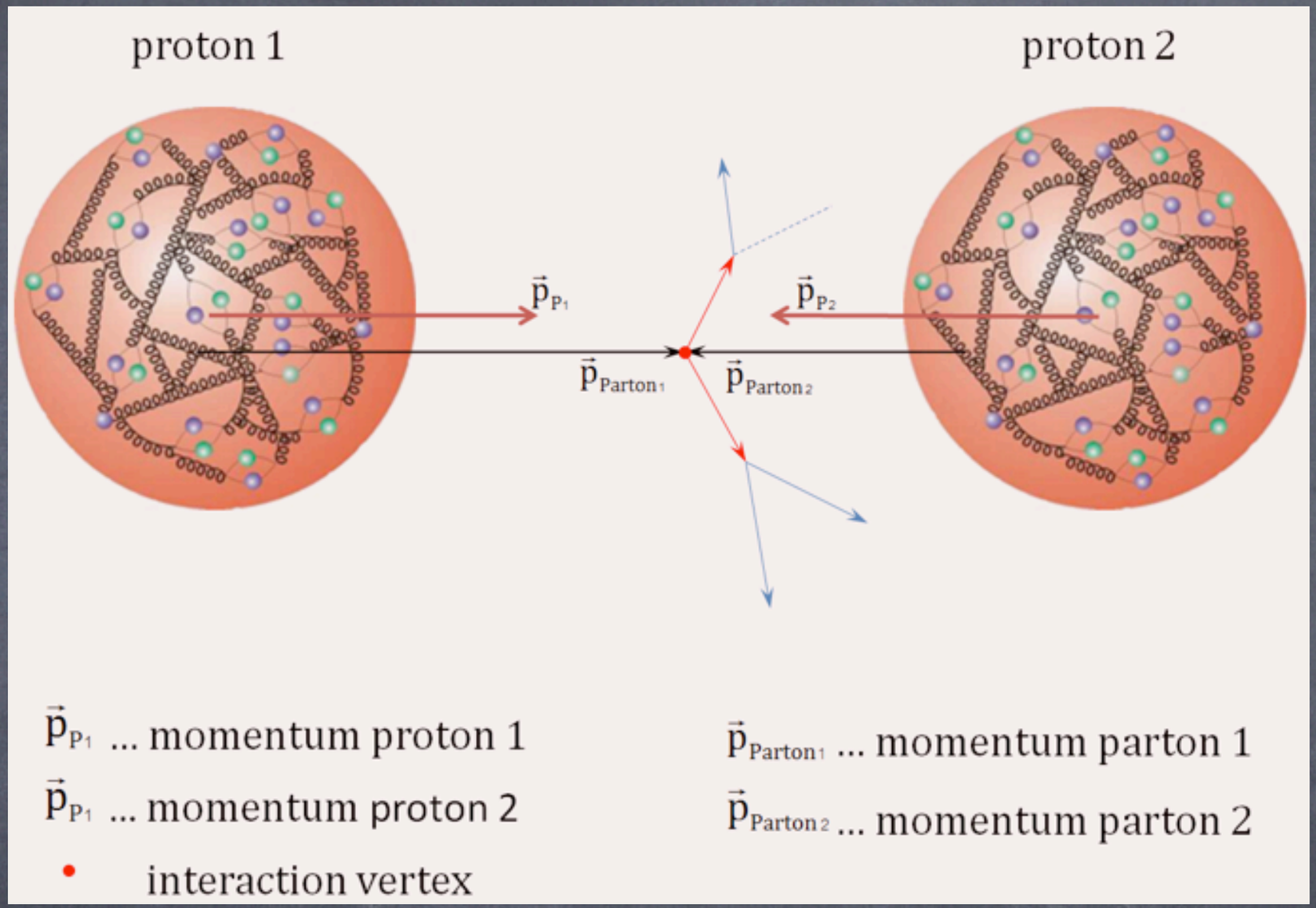
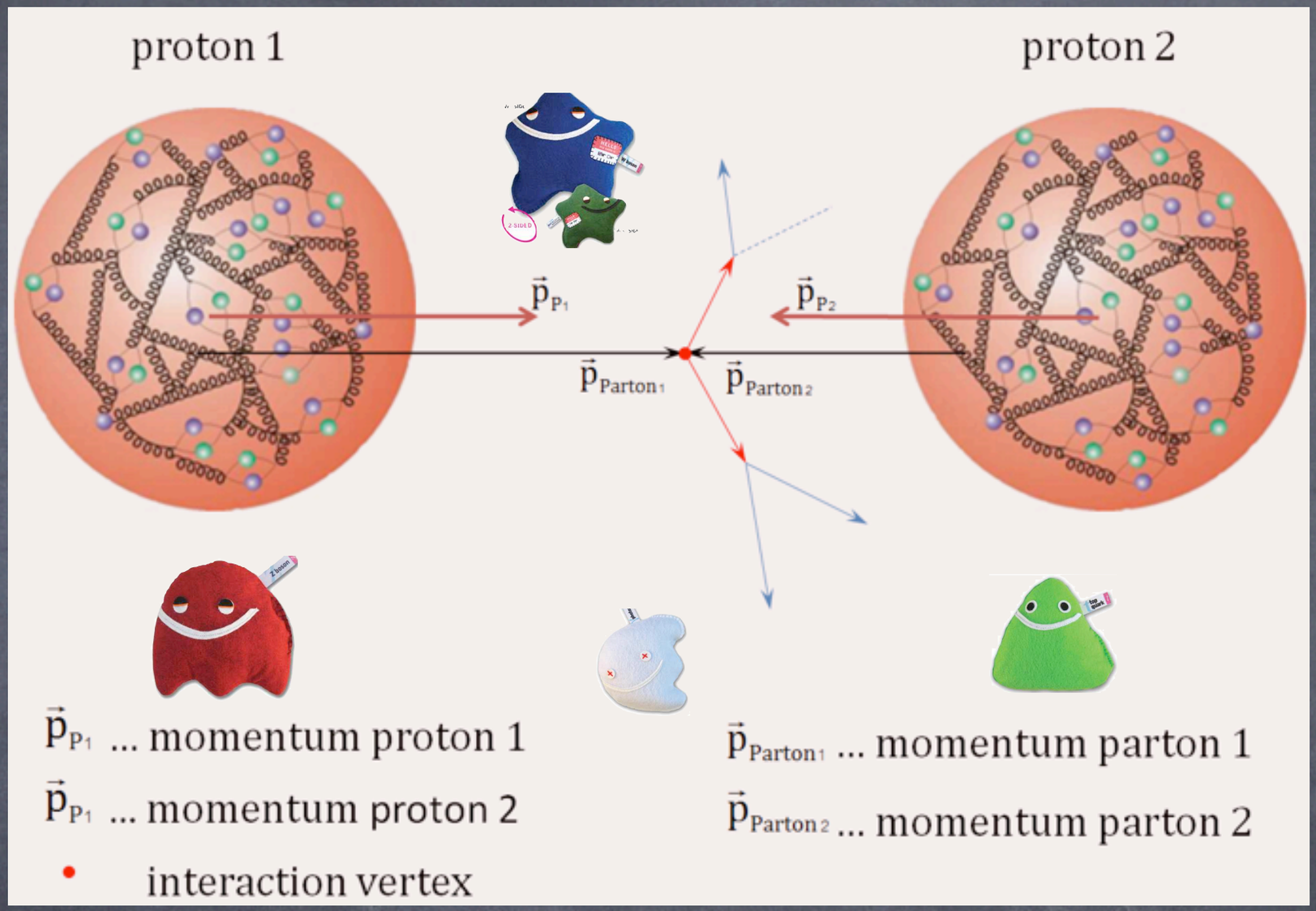


Fig. 3: structure of the proton and considerations of momentum at interaction



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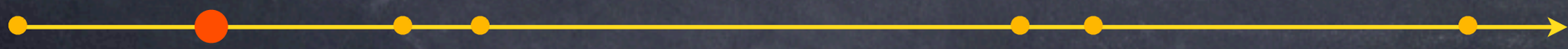
Part 1 - Introduction

physics 2



pick one particle

pick one particle

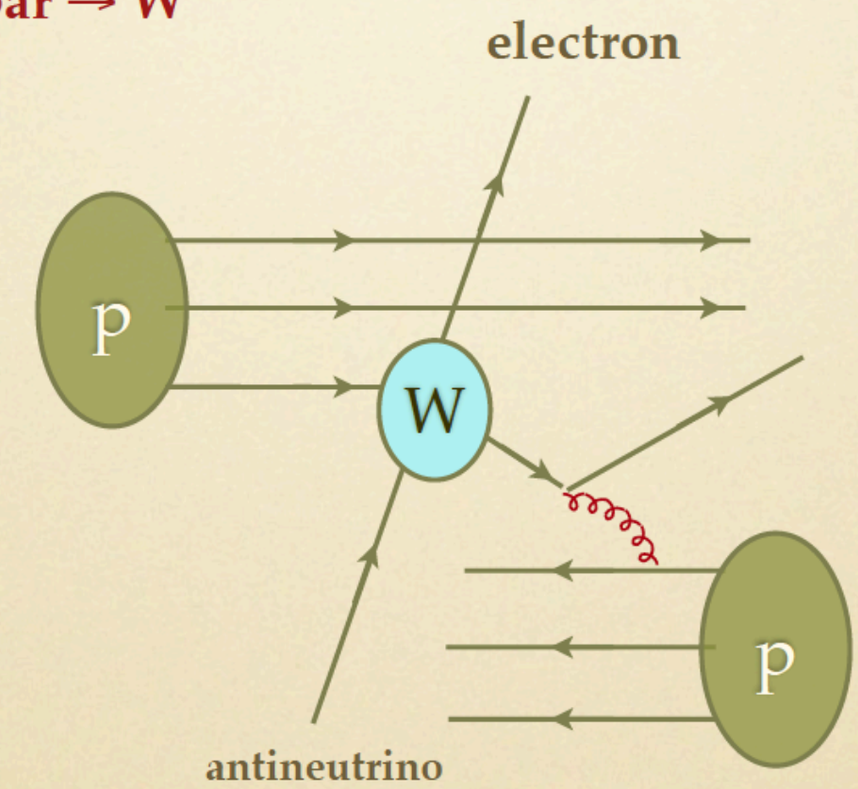
Why is the W particle interesting?

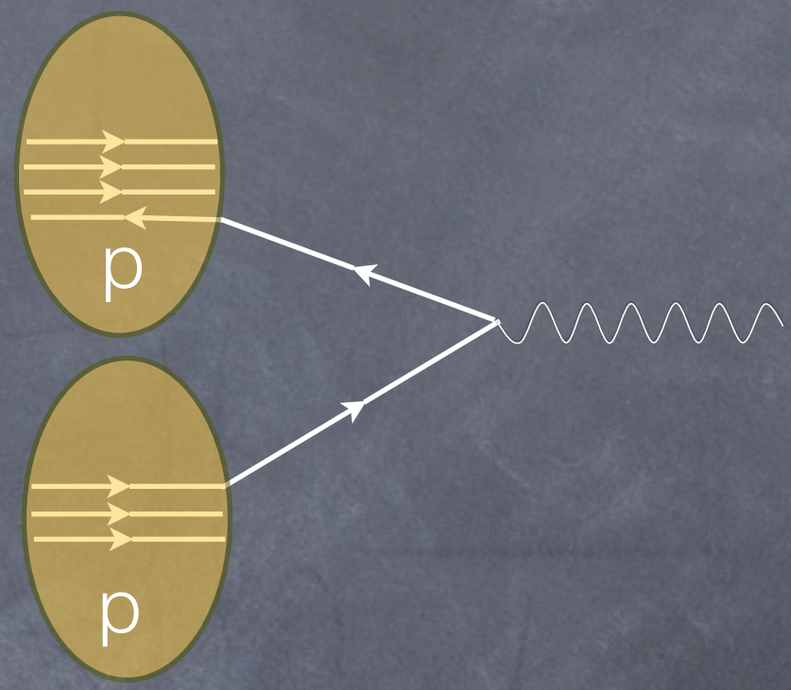
- fusion
- application in radioactivity, medicine, arts and archeology
- weak interaction allows particles to change the family

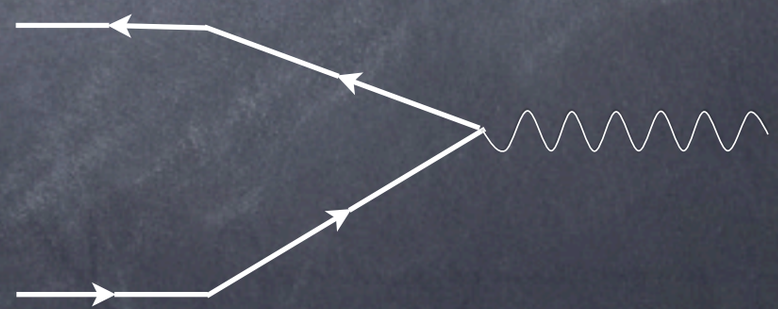
Examples of reactions in proton collisions

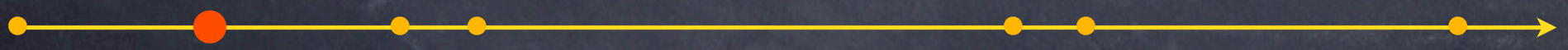
Quark-Antiquark annihilation:

u dbar → W









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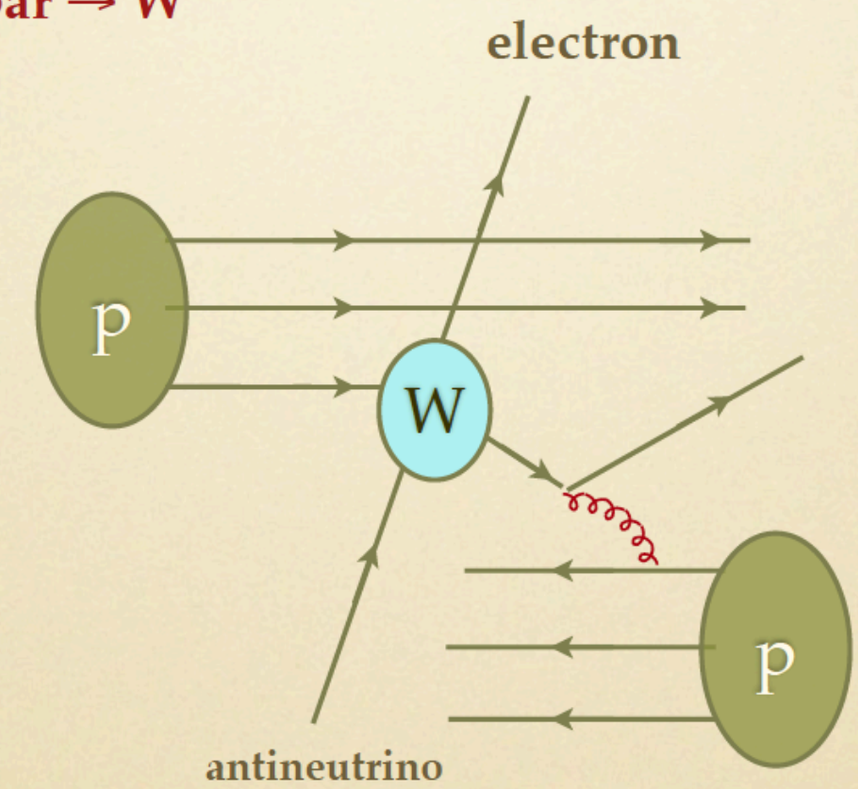
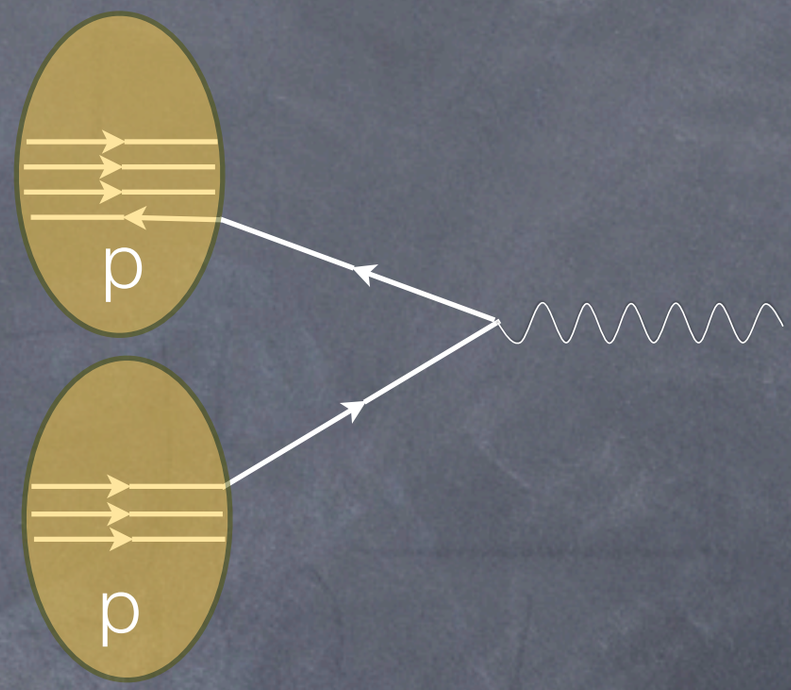




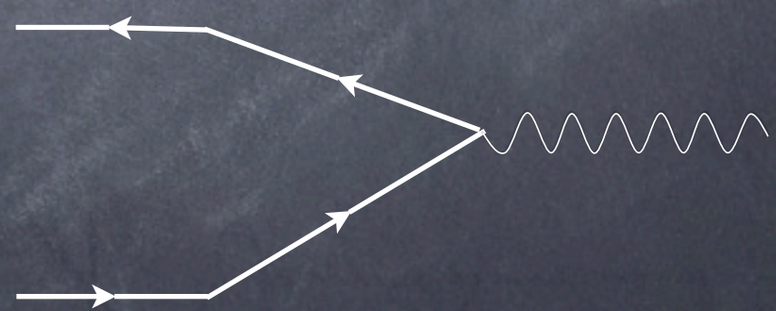
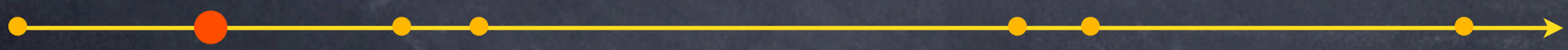
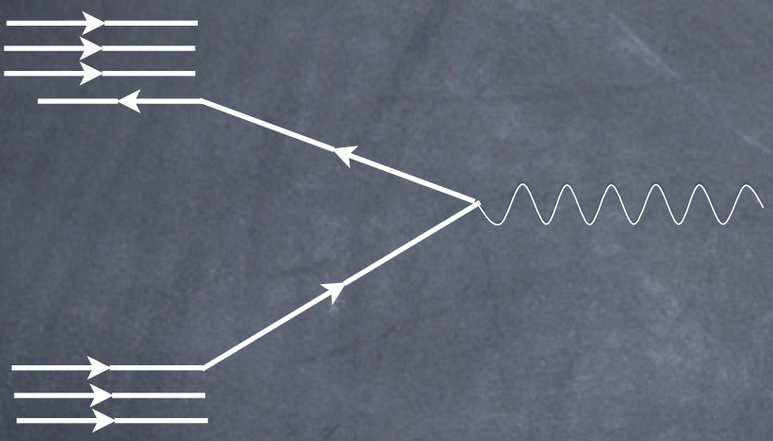


Fig: proton-proton interation - quark-antiquark annihilation and W production



Part 1 - Introduction

production - W Boson



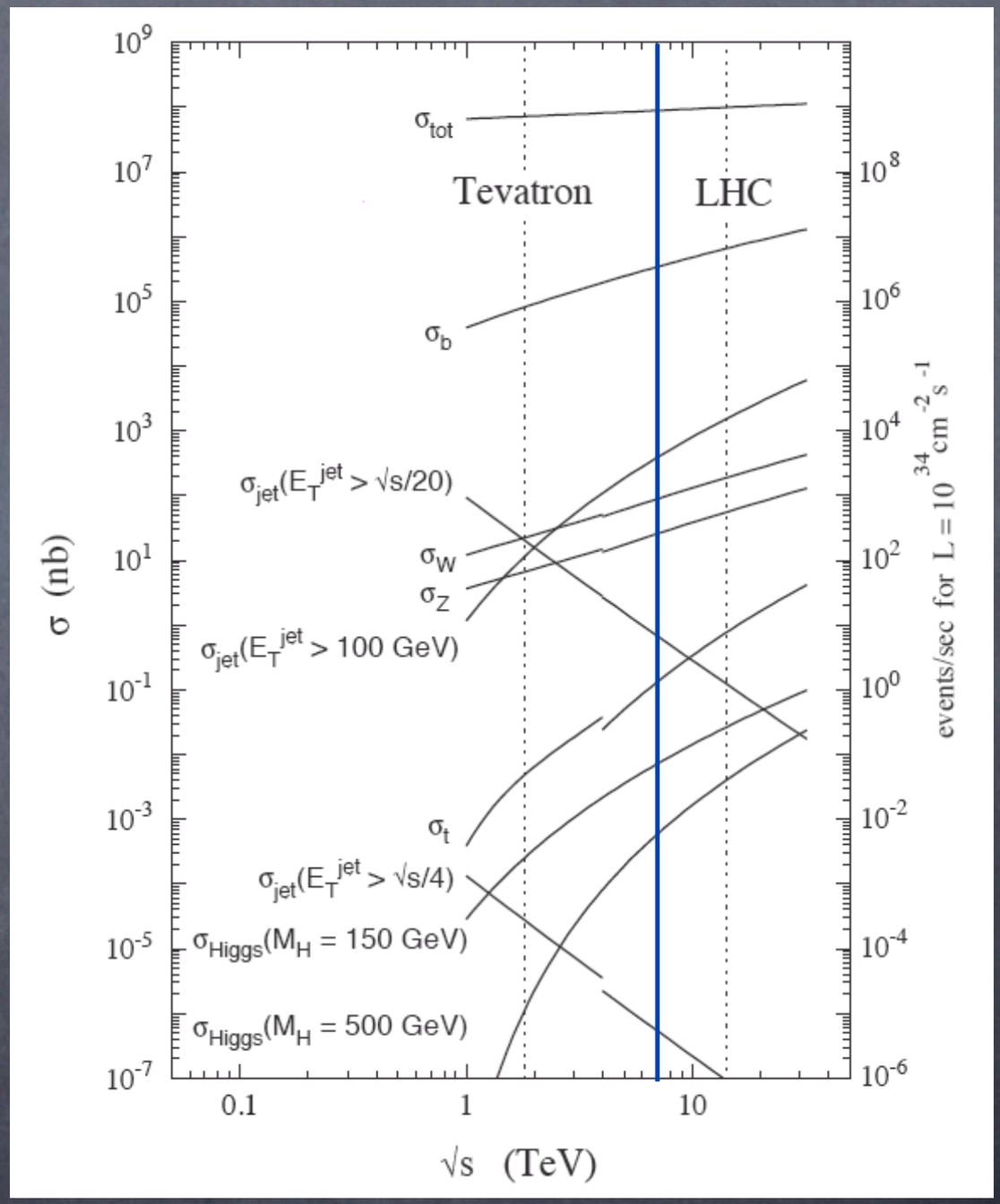
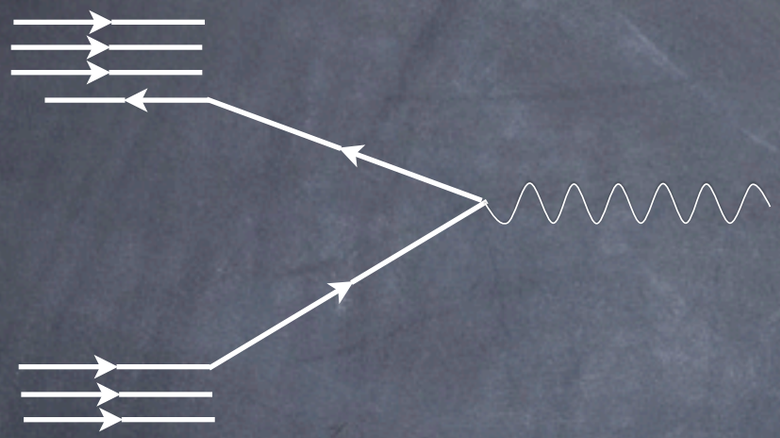


Fig.: production cross section for various particles at various centre of mass energies, from [3]

production - W Boson



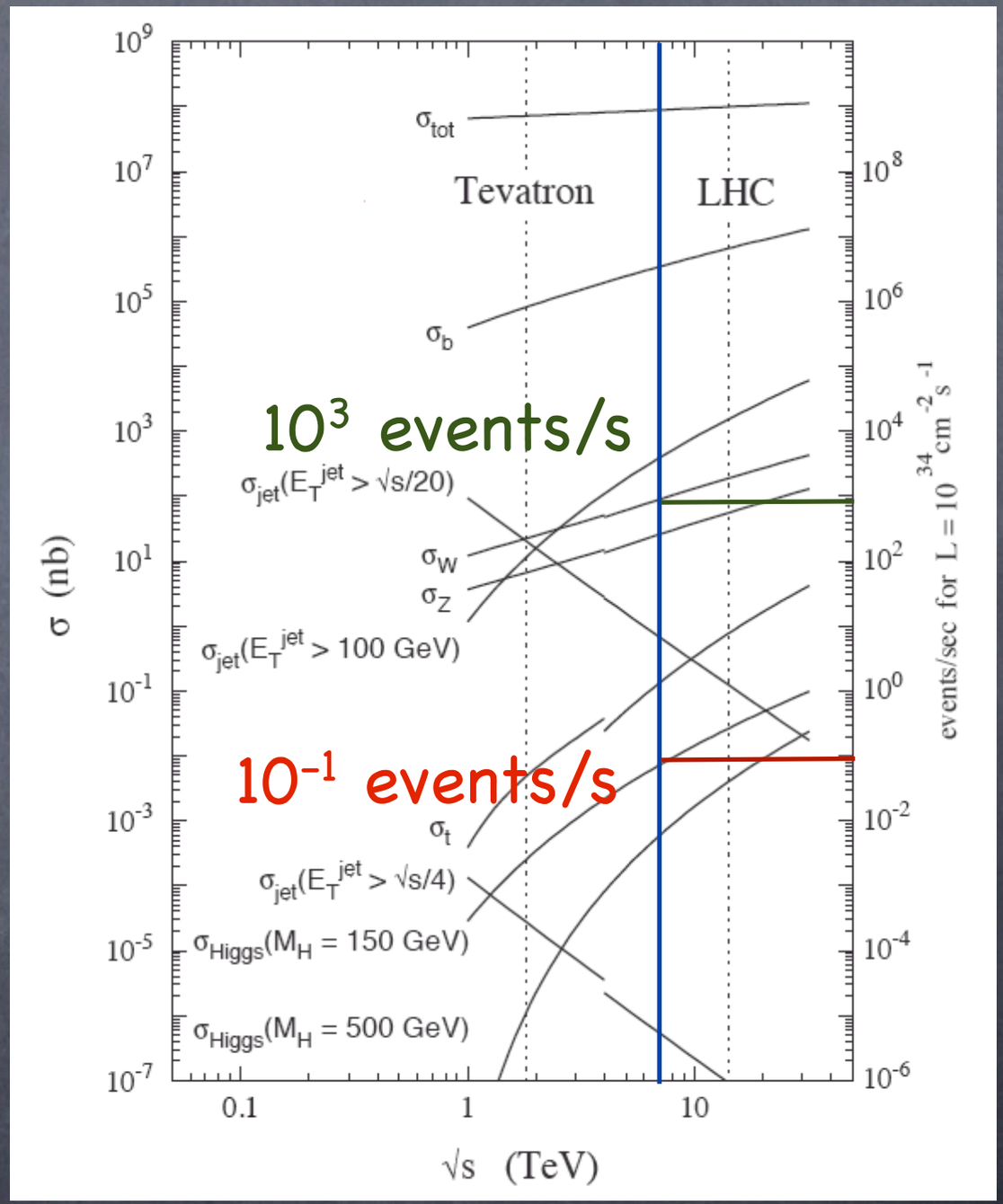


Fig.: production cross section for various particles at various centre of mass energies, from [3]

Part 1 - Introduction

production - W Boson

decay - W Boson

W Boson

life time: $\approx 10^{-25}$ s

mass: 80.39 ± 0.02 GeV/c^2

decay rates (in %):

hadronic: 67.6%

leptonic: 32.4% (from that e,μ: 21.3%)

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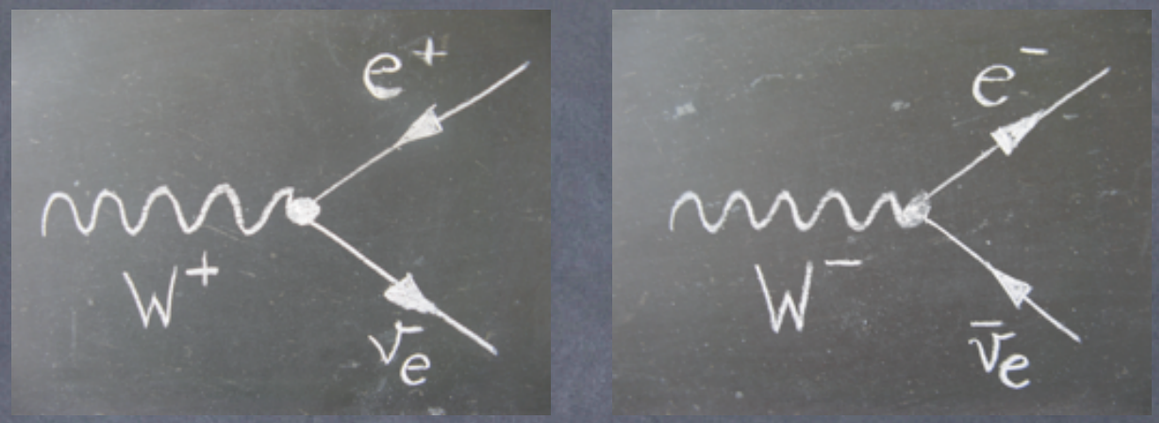

Fig.: Feynman diagrams of leptonic decays of the W boson

Produktion und Zerfall - W-Boson

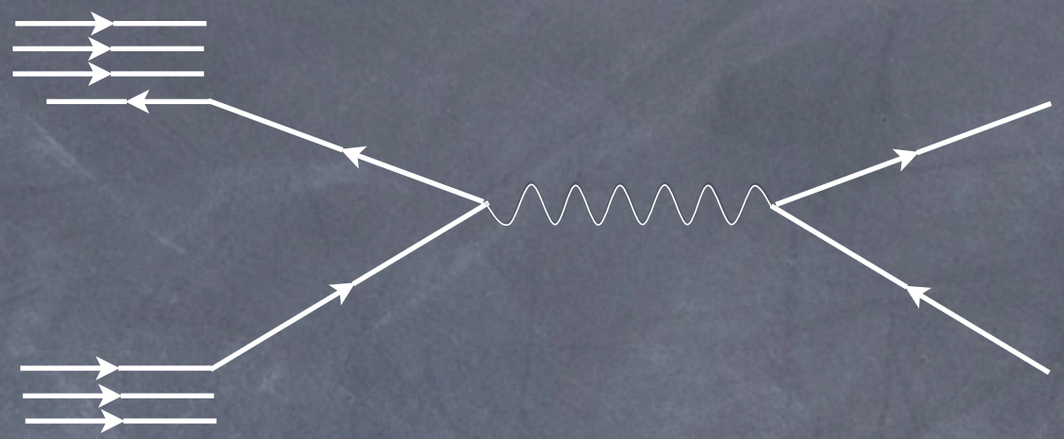

Fig.: quarka-antiquark annihilation, production and decay of W particle

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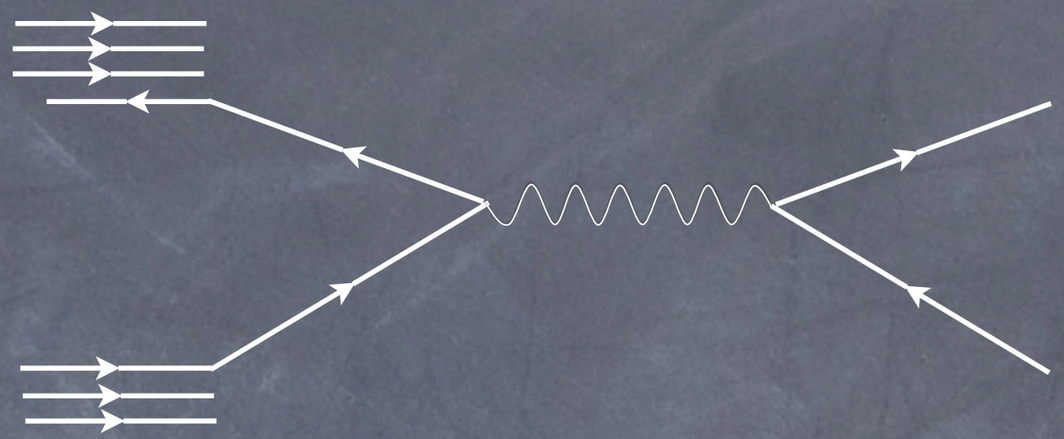

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Your task:

Produktion und Zerfall - W-Boson

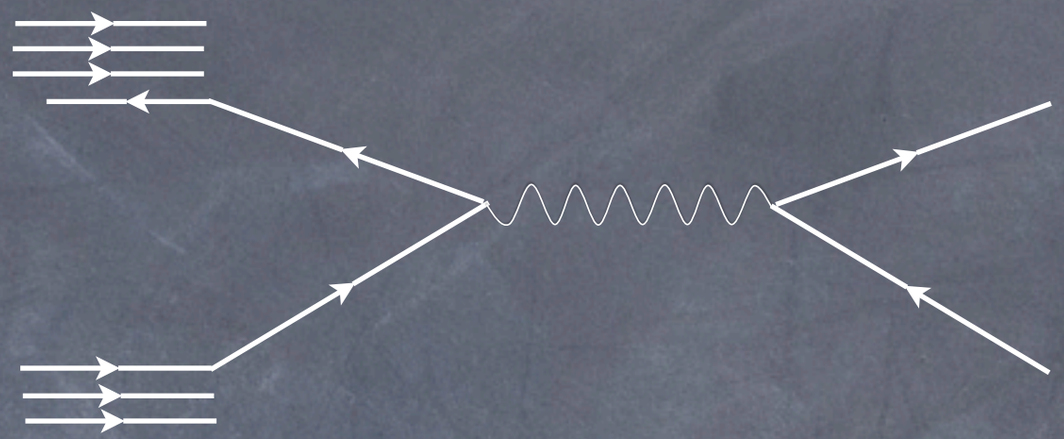

Fig.: quarka-antiquark annihilation, production and decay of W particle

Your task:

1. Find collision events showing production and decay of W particles!

Produktion und Zerfall - W-Boson

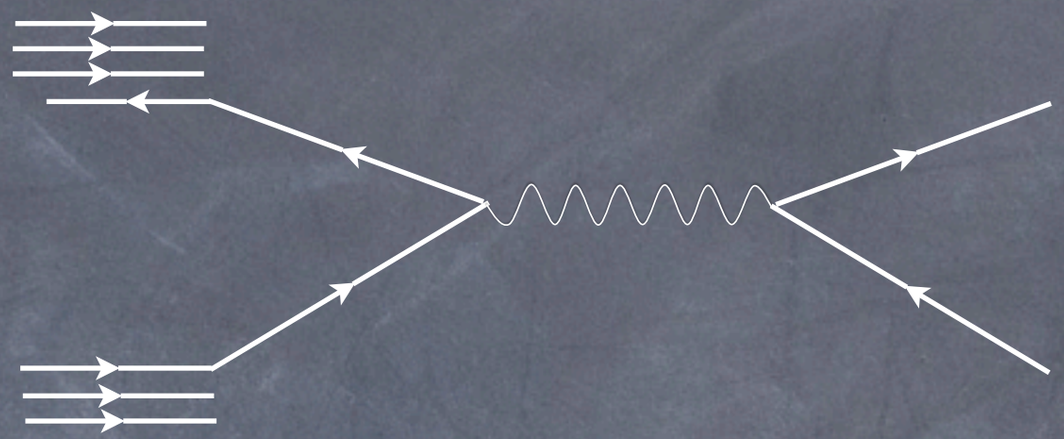

Fig.: quarka-antiquark annihilation, production and decay of W particle

Your task:

1. Find collision events showing production and decay of W particles!
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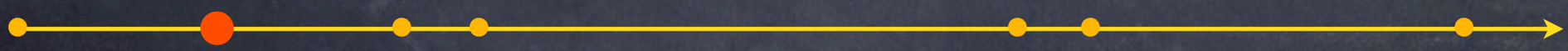

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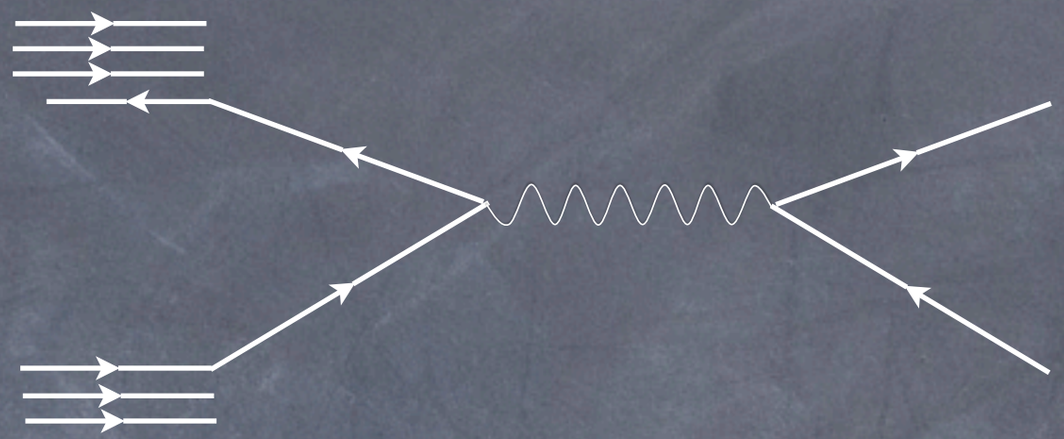

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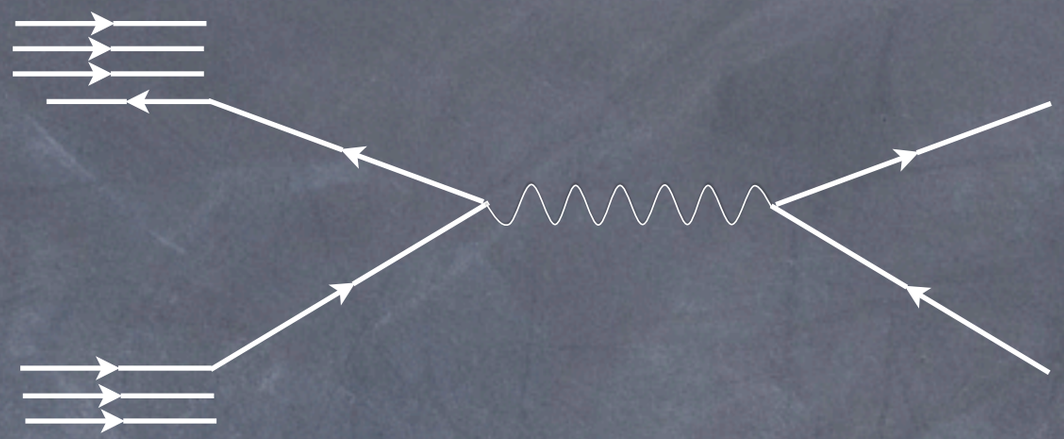
Produktion und Zerfall - W-Boson



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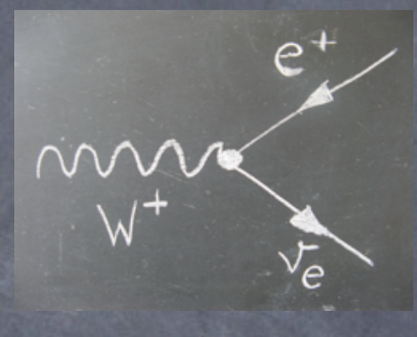
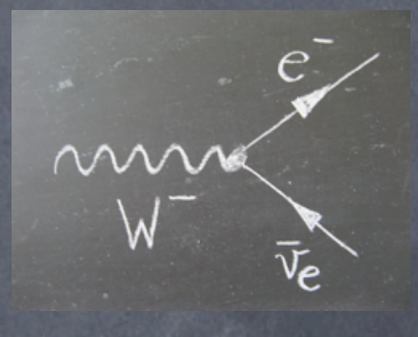
Which value do you expect for R±?

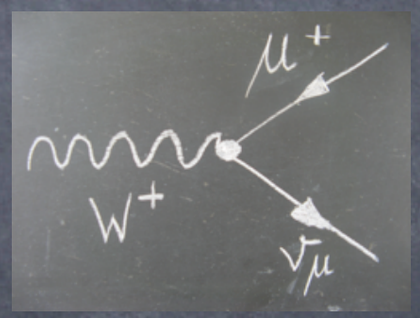
Part 1 - Introduction

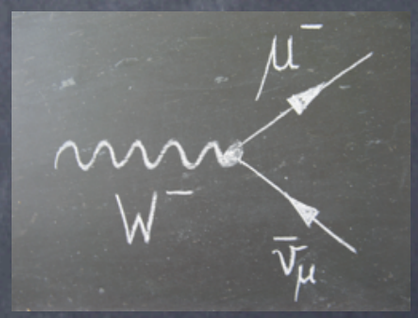
properties of events with
decaying W particle

Zerfall - W-Boson









Part 1 - Introduction

properties of events with
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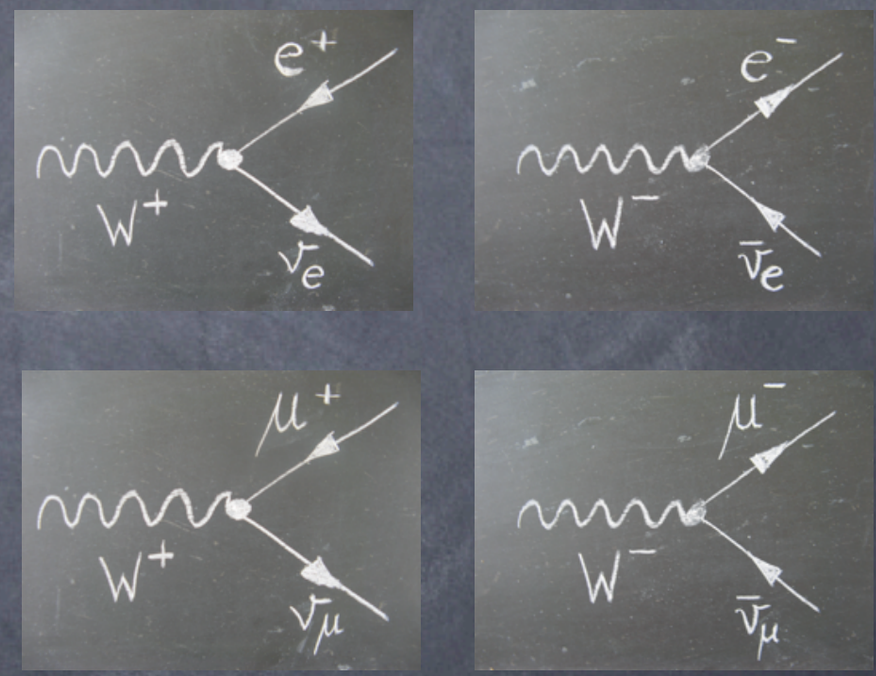
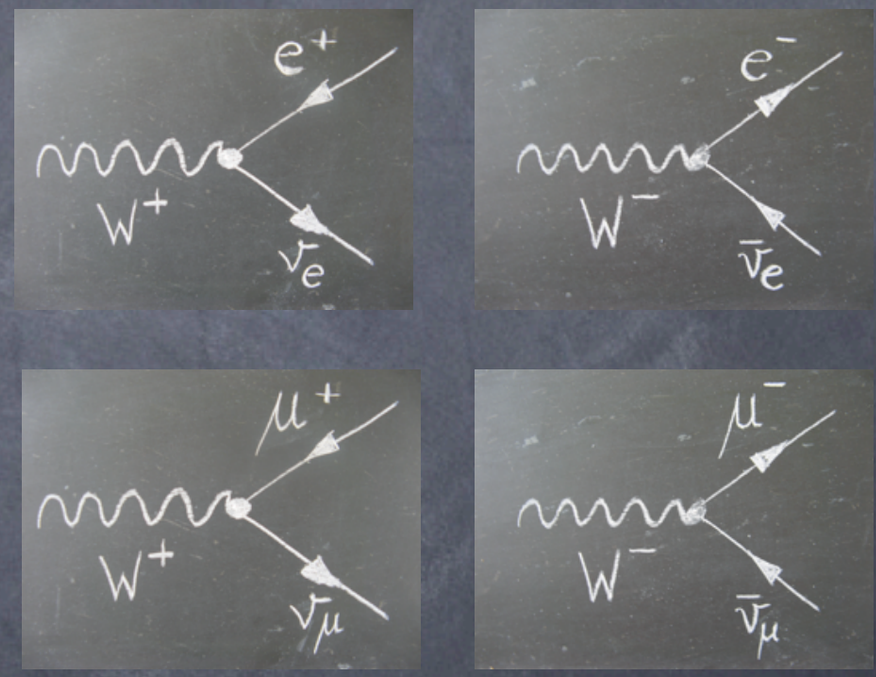


Fig.: Feynman graphs for W decay

properties of events with decaying W particle

- exactly one high energetic, electrically charged lepton [either muon (resp. antimyon) or electron (resp. positron)]

Zerfall - W-Boson



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Part 1 - Introduction

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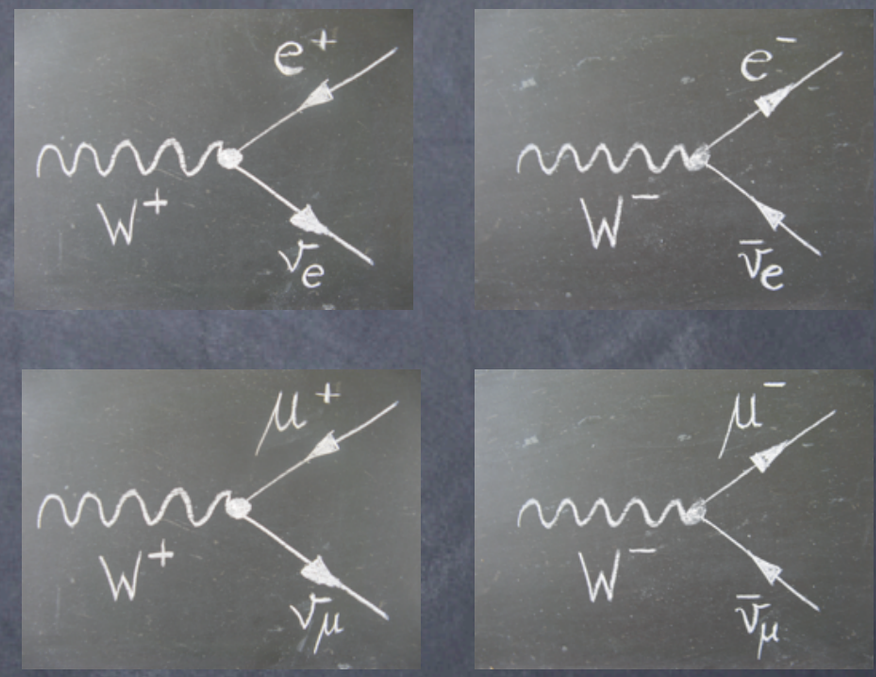

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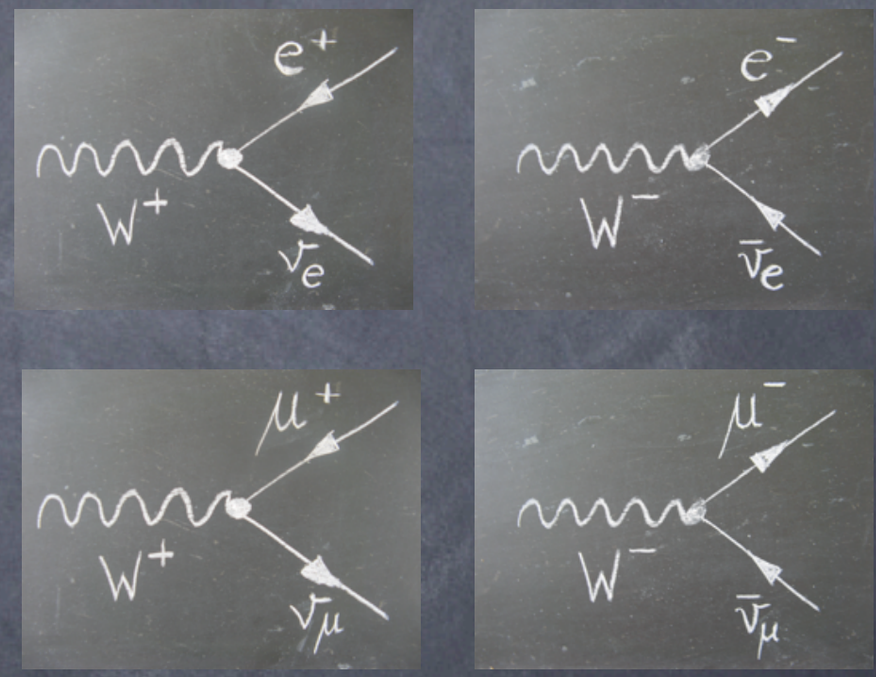

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Part 1 - Introduction

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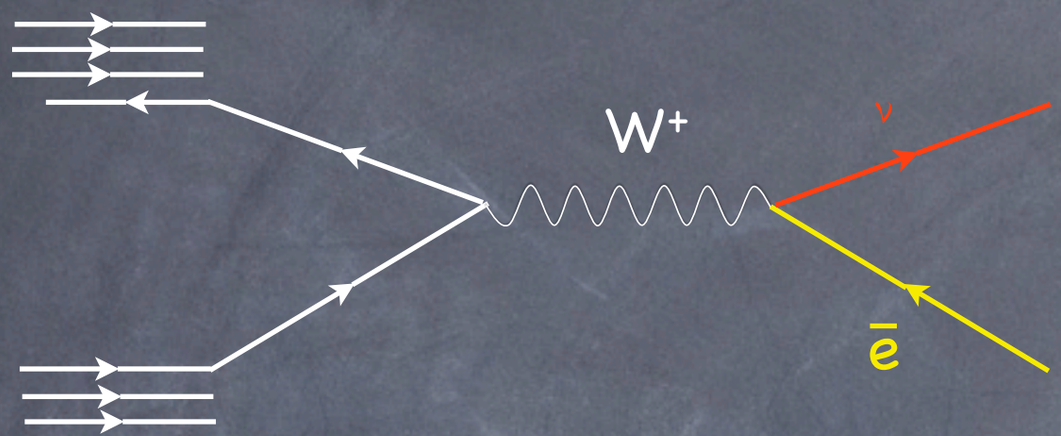
Part 1 - Introduction

Fig.: quark-antiquark annihilation, production and leptonic decay of W particle

signal



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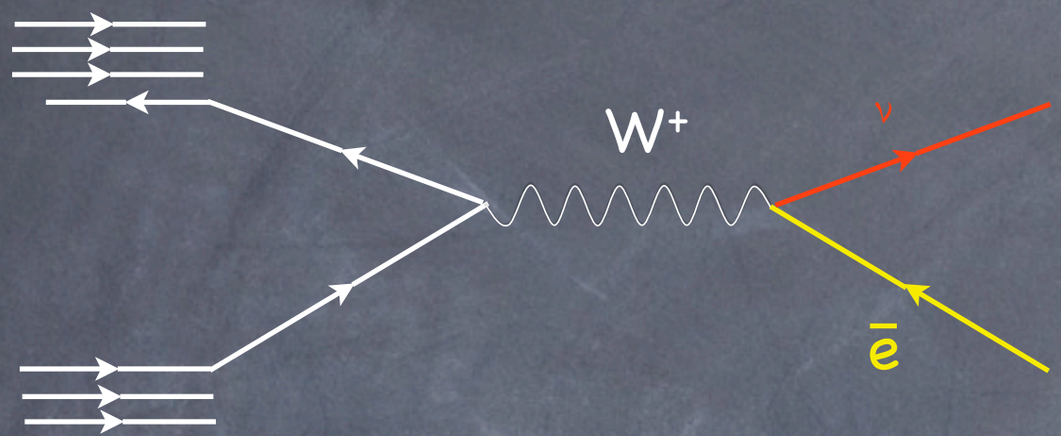

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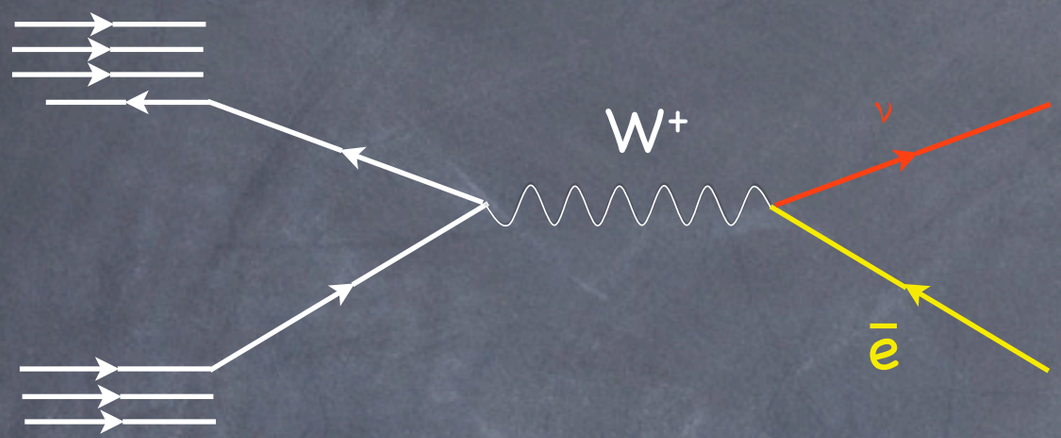
A signal event marks a particular physical process (e.g. production of a W particle)

Another process, who leaves a identical signal in the detector but has originally to be allocated to another process, is called background event.

There is no chance in distinguishing both when looking at a single event!

signal vs. background



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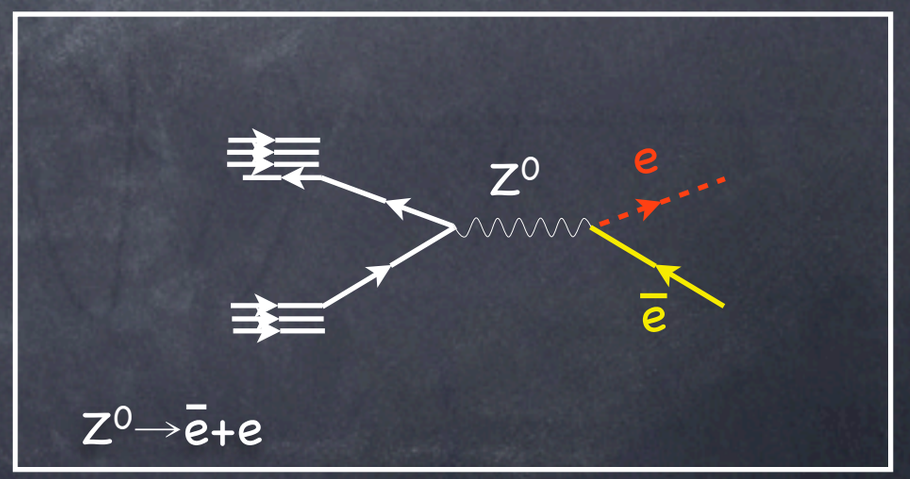

Fig.: Background events to leptonic W decay

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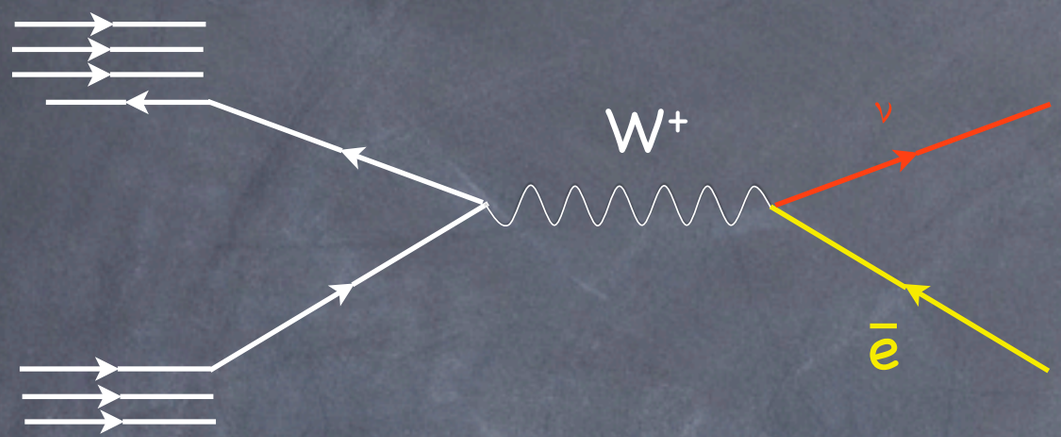

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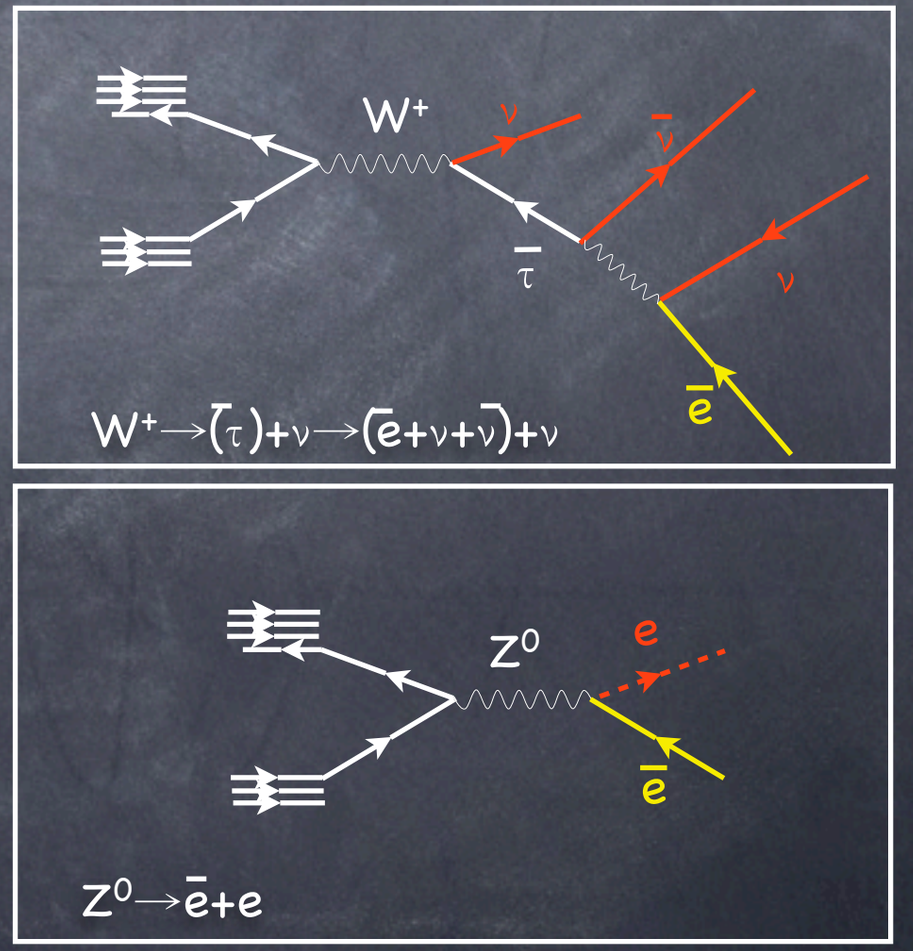

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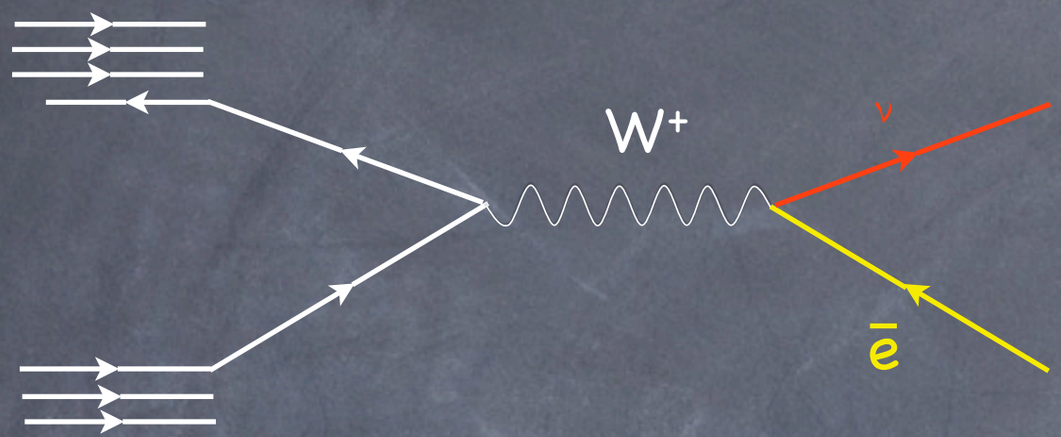

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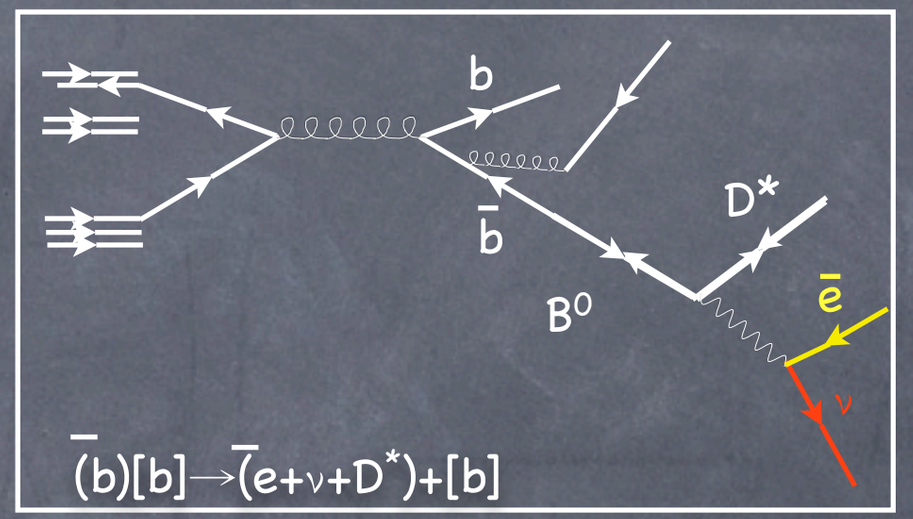

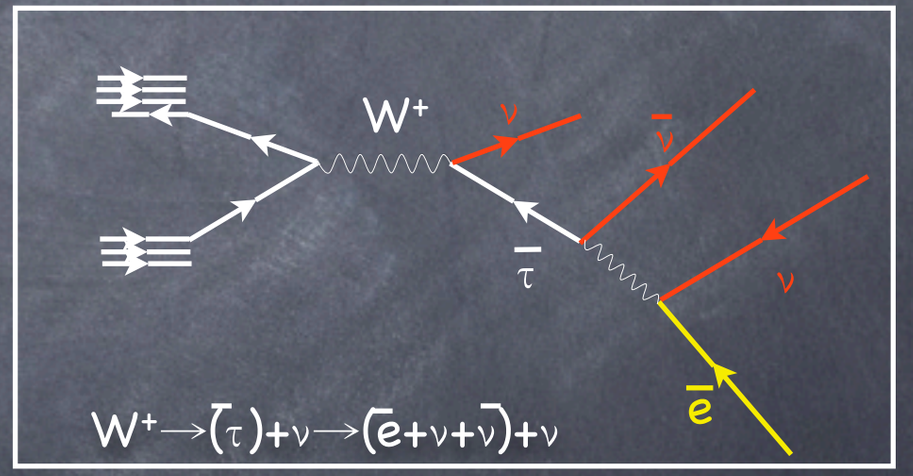

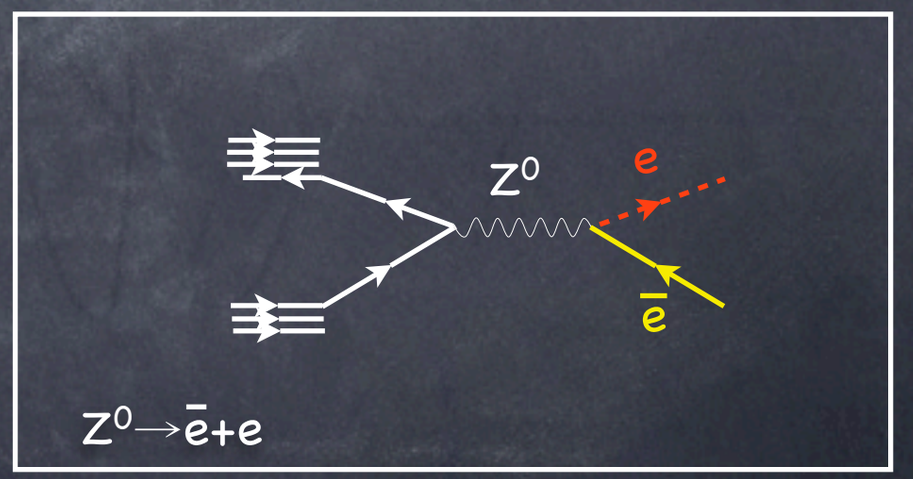

Fig.: Background events to leptonic W decay

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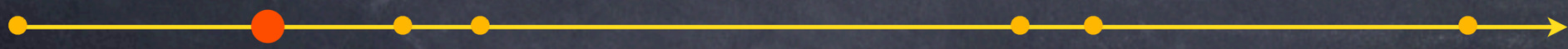
properties of events with
decaying W particle



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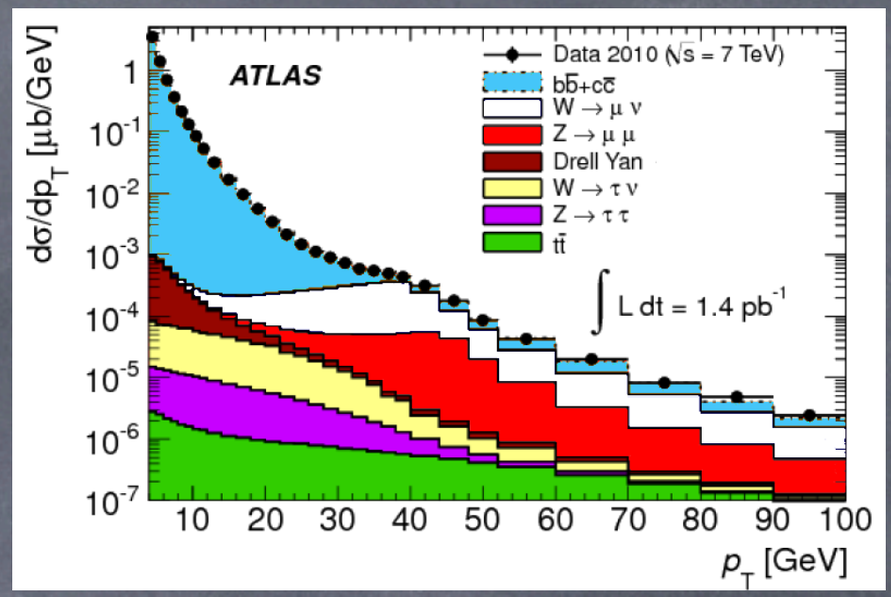

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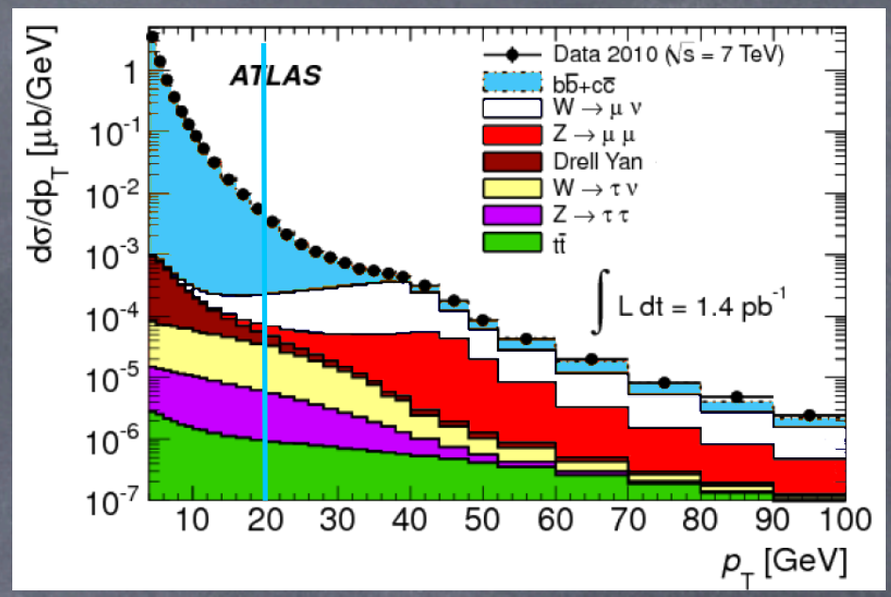

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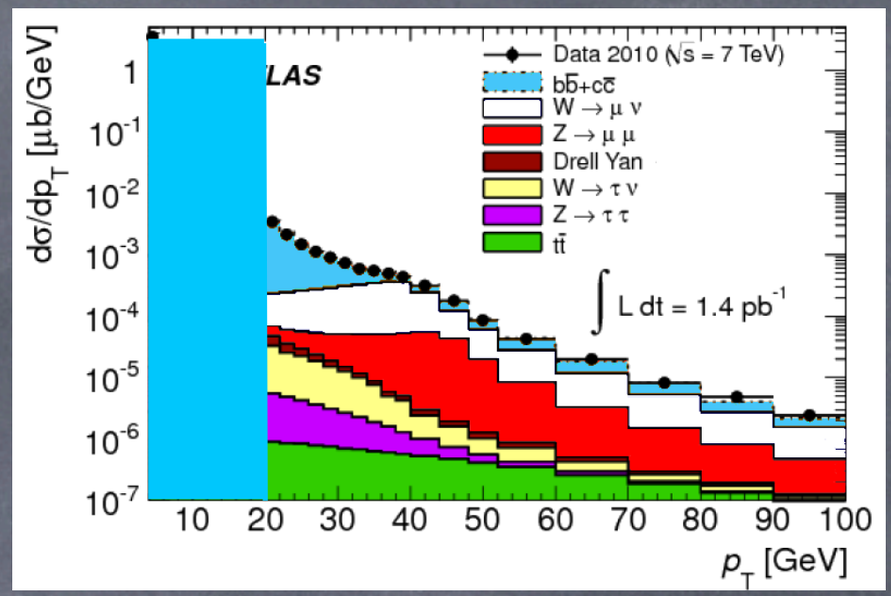

Fig.: production cross section of muons vs transverse momentum, [1]

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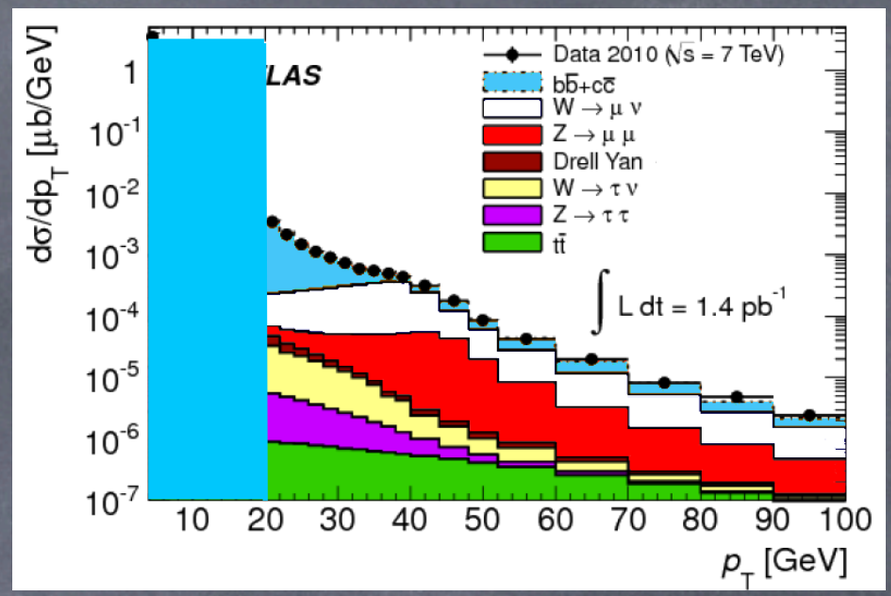

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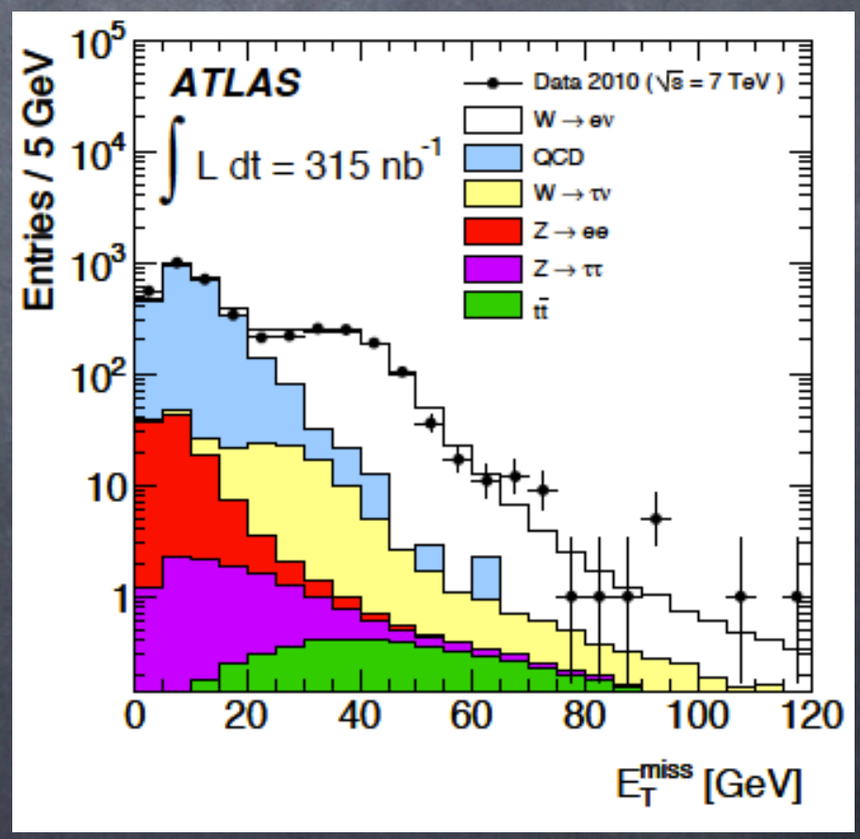

Fig.: Distribution of $E_{T,miss}$ from events with high energetic electrons, [2]

Part 1 - Introduction

properties of events with
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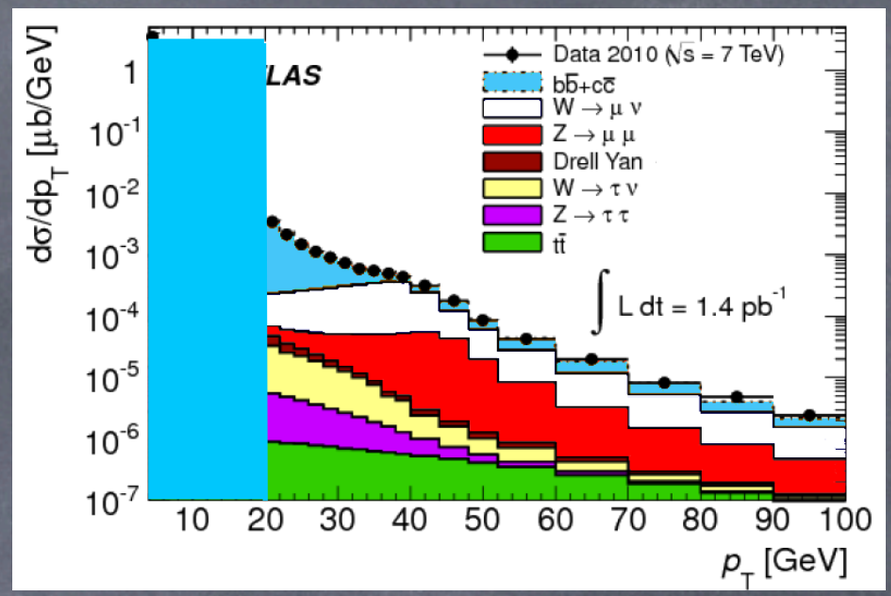

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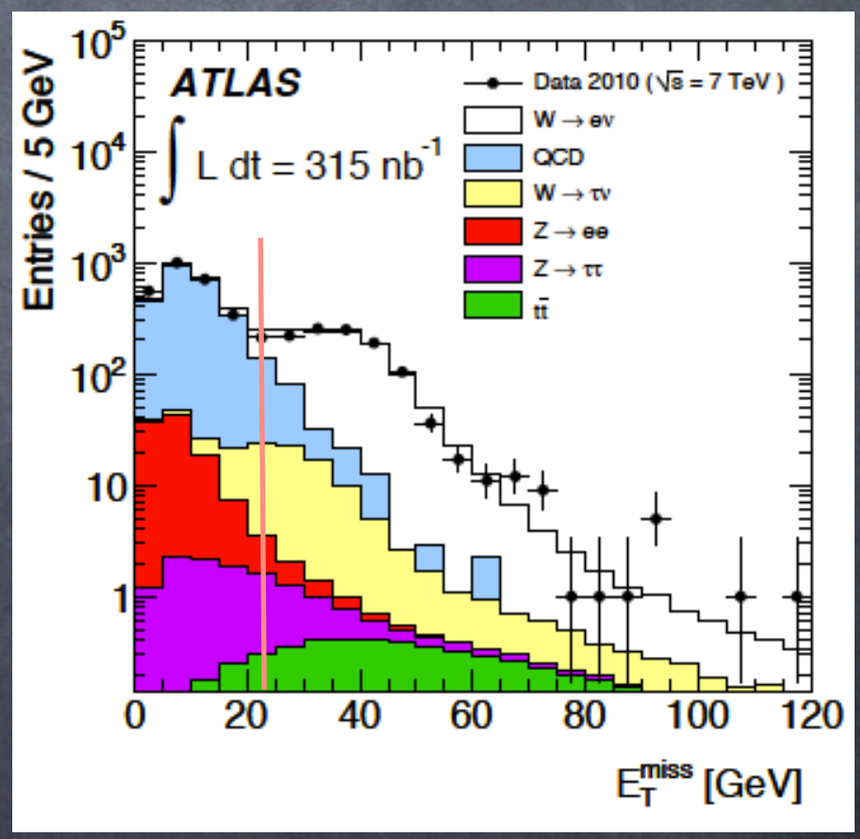

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Part 1 - Introduction

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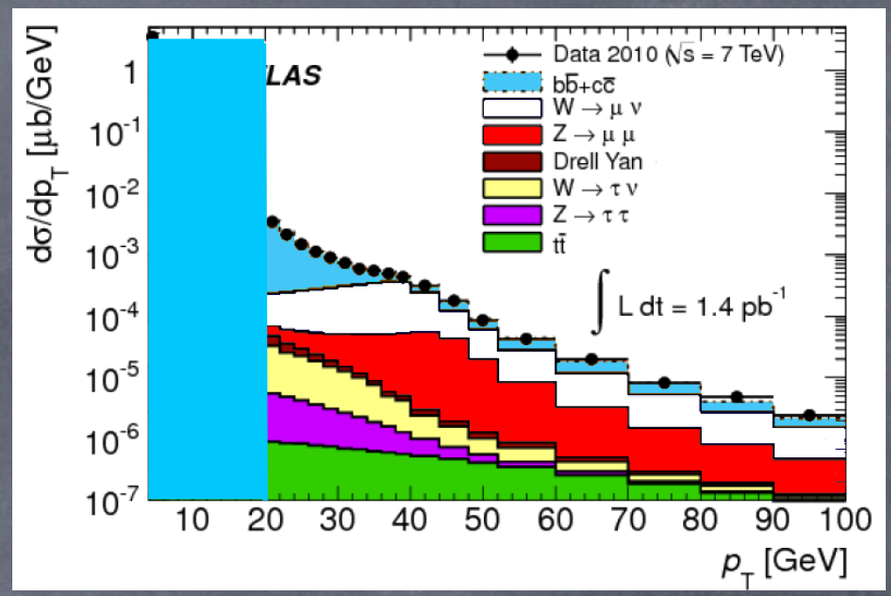

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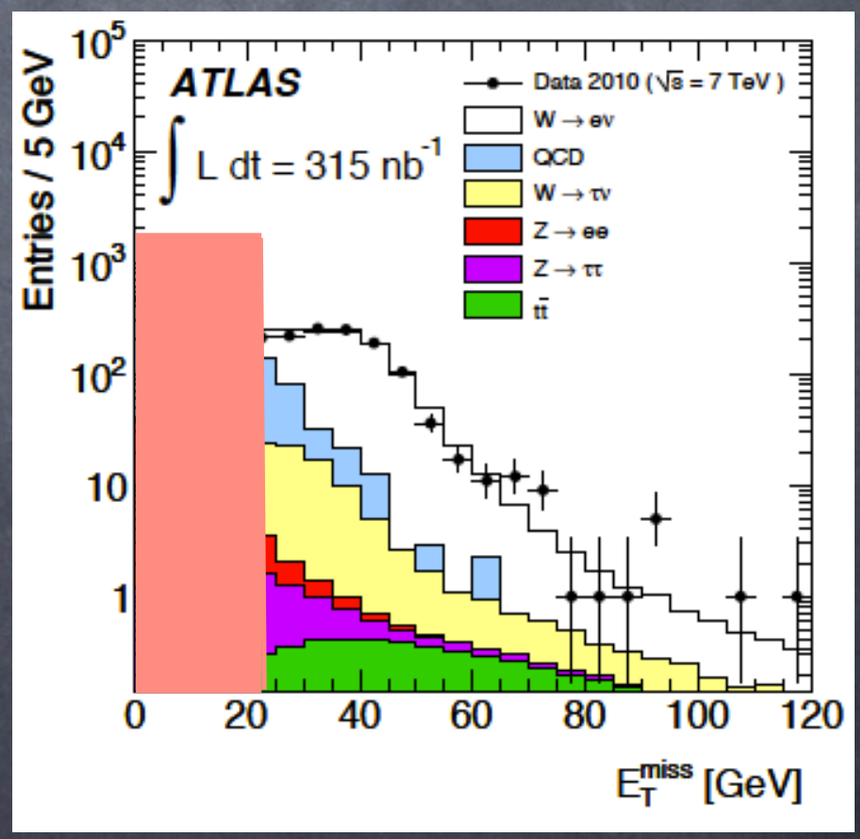

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Part 1 - Introduction

physics 10

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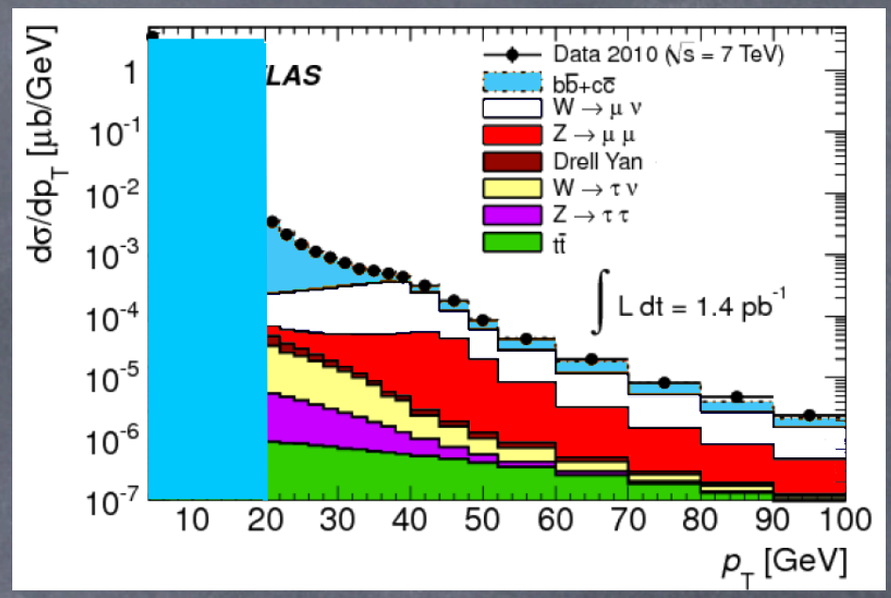

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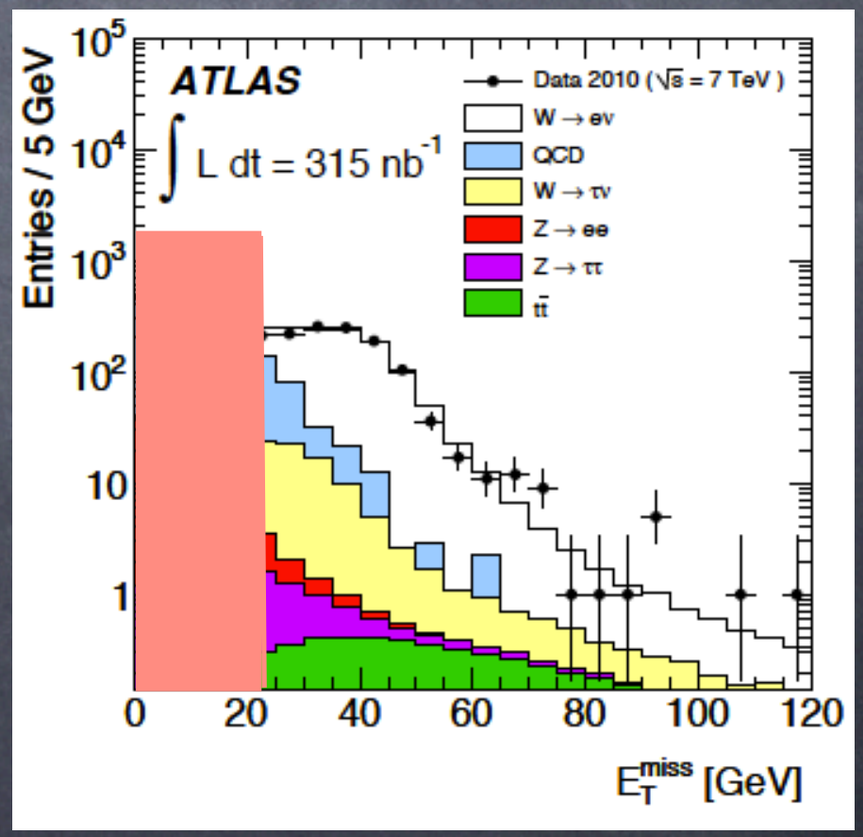

Fig.: Distribution of $E_{T,miss}$ from events with high energetic electrons, [2]

Part 1 - Introduction

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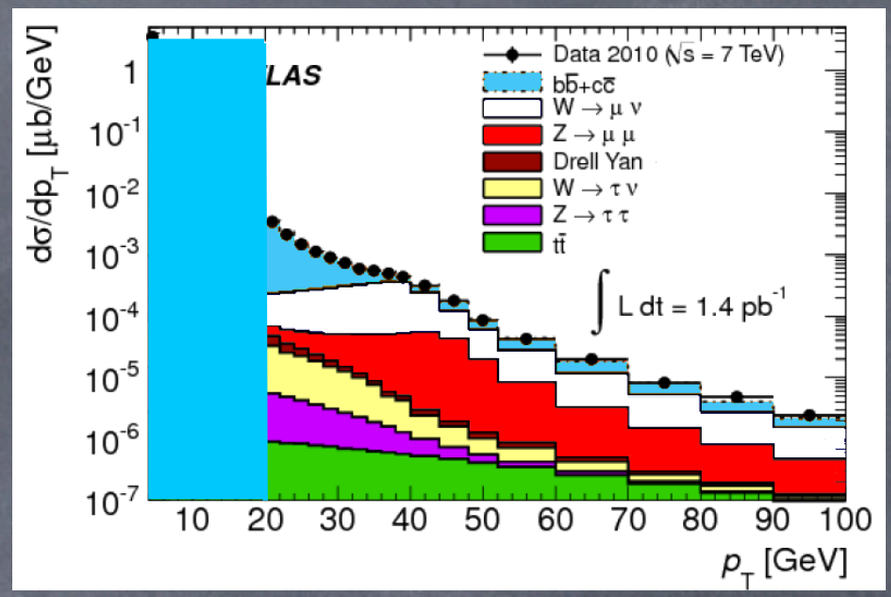
- missing transverse momentum with MET > 20 GeV



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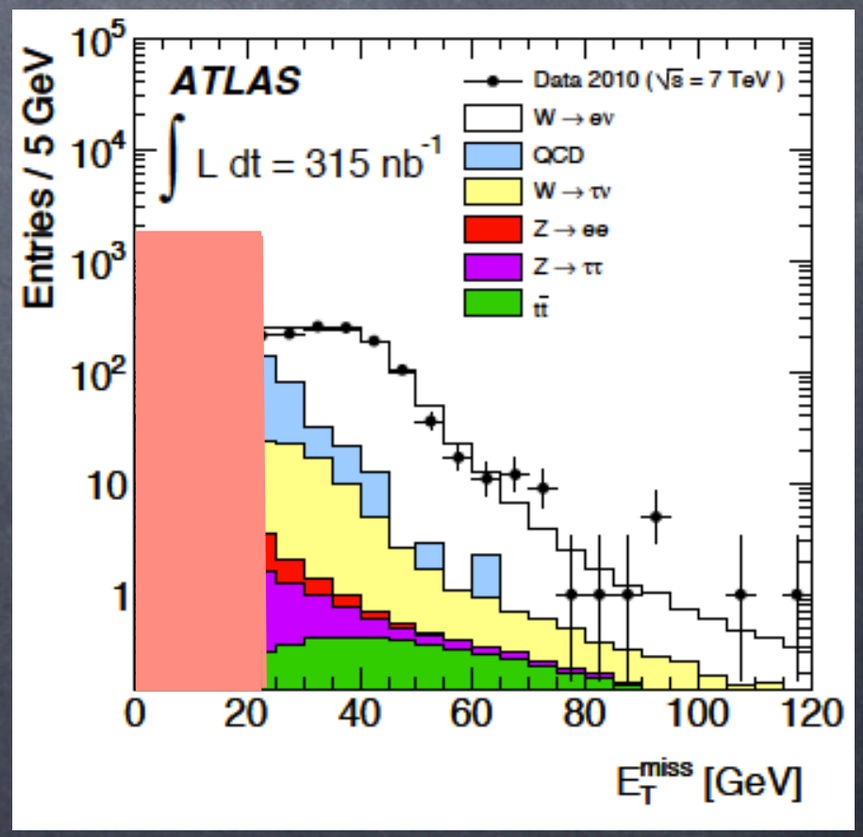

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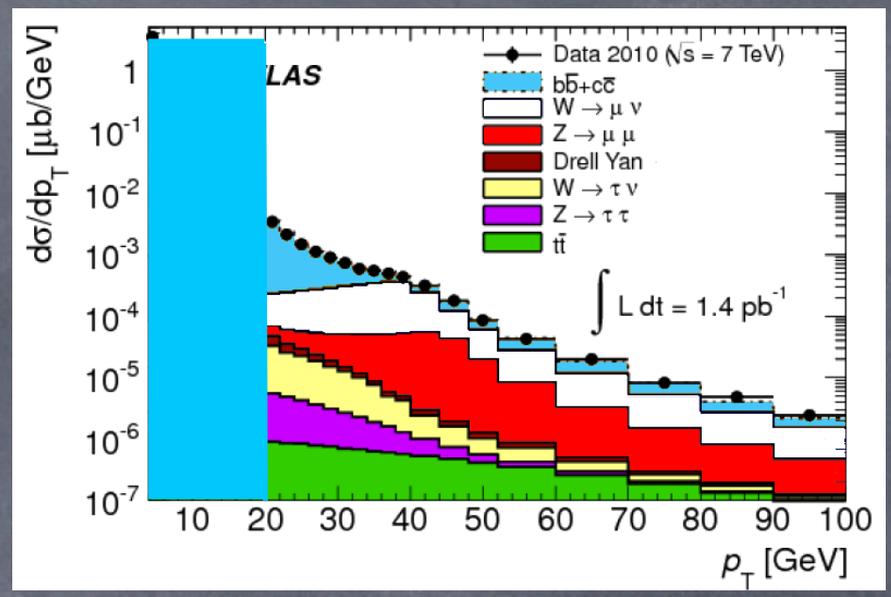

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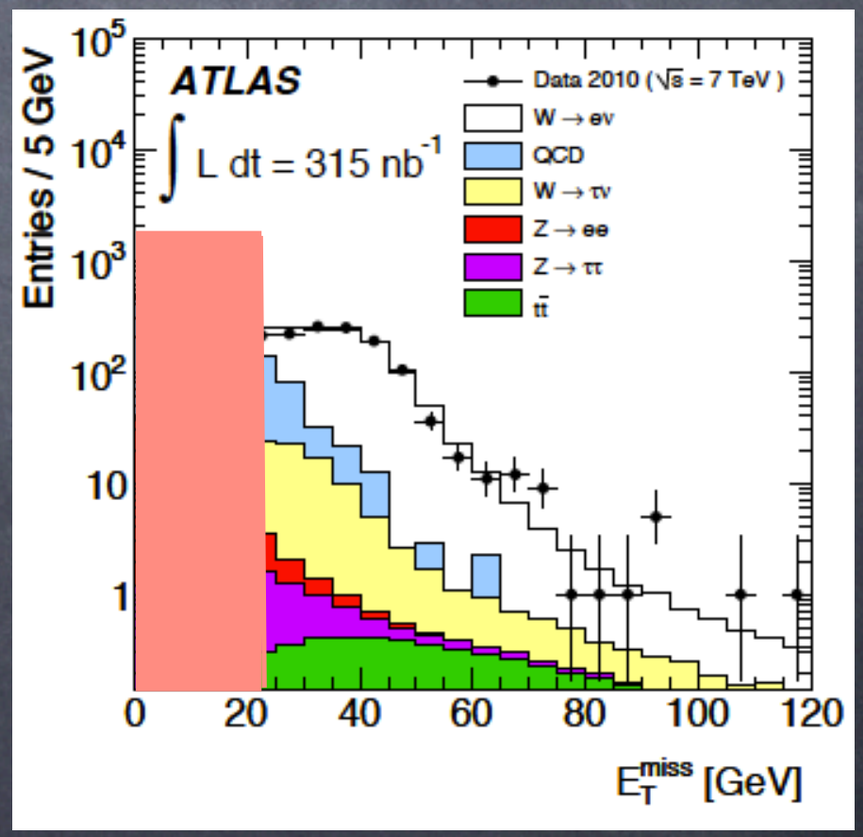

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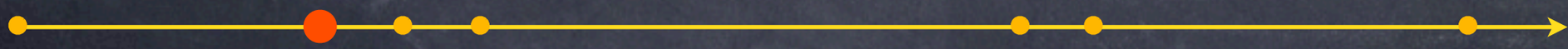
Produktion - H-Boson



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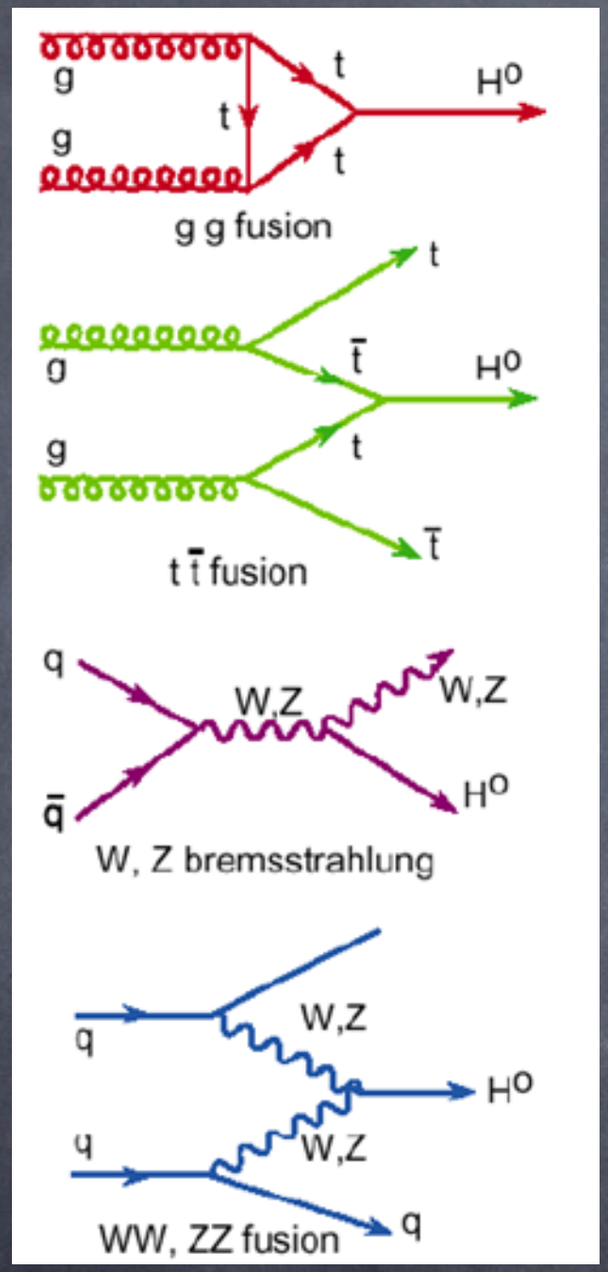
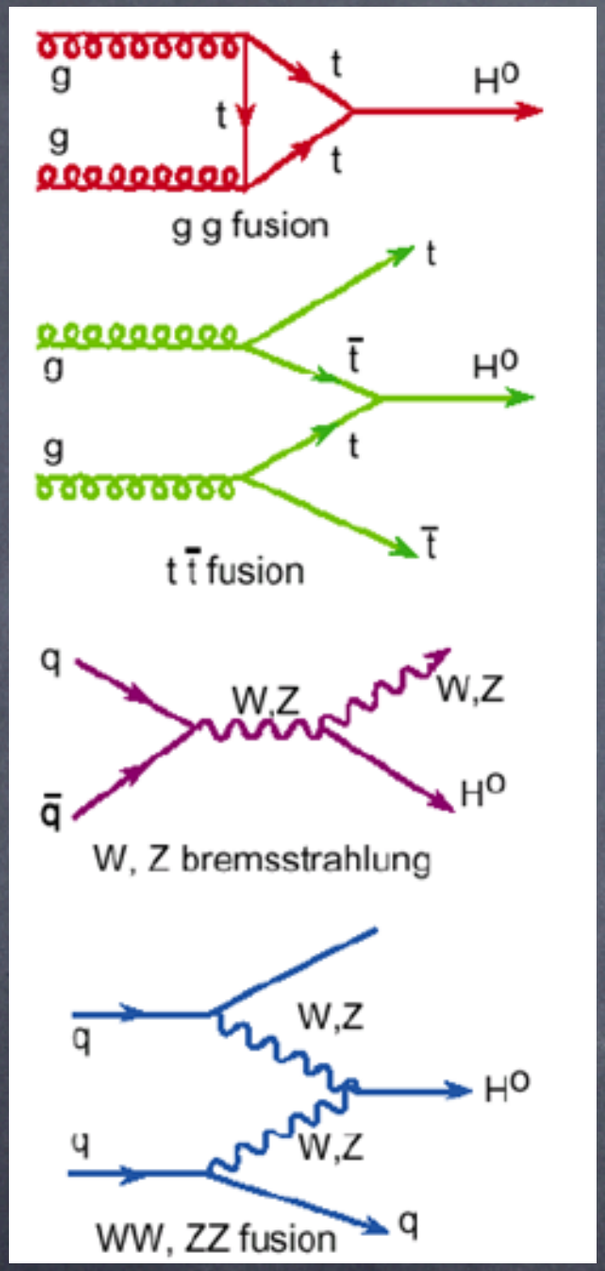


Abb. 14: Feynman-Diagramme zur Erzeugung eines Higgs-Boson

Produktion - H-Boson



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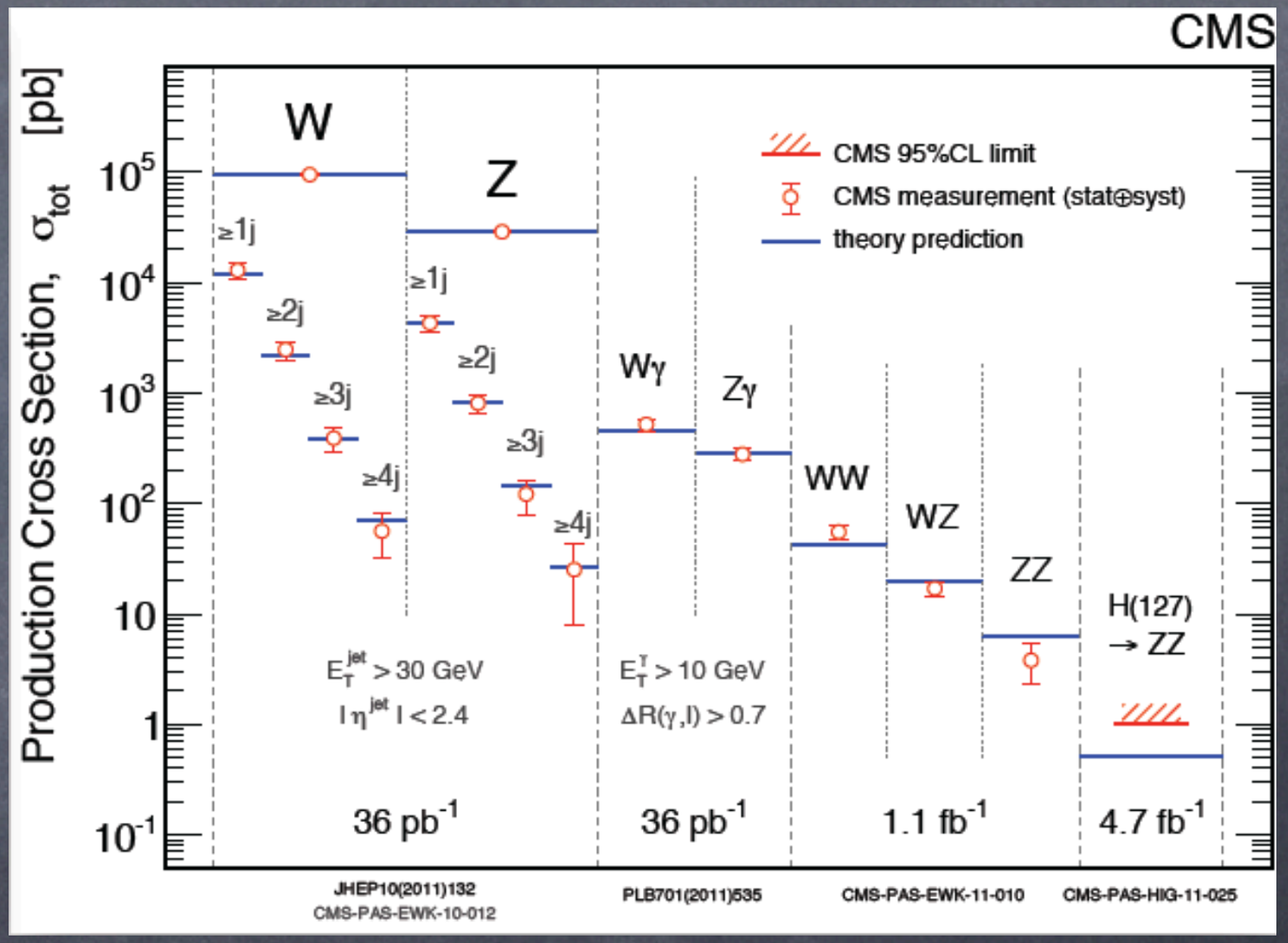

Abb. 15: Wirkungsquerschnitt für die "interessanten" Prozesse der Teilchenproduktionen bei hohen Schwerpunktsenergien, aus [4]

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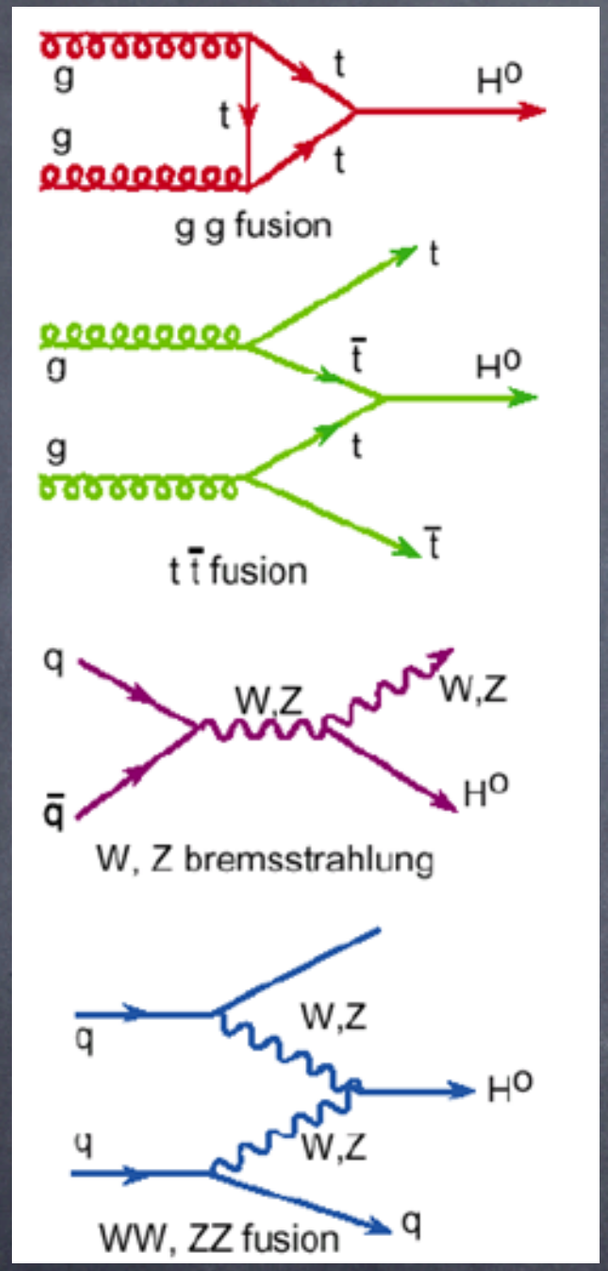

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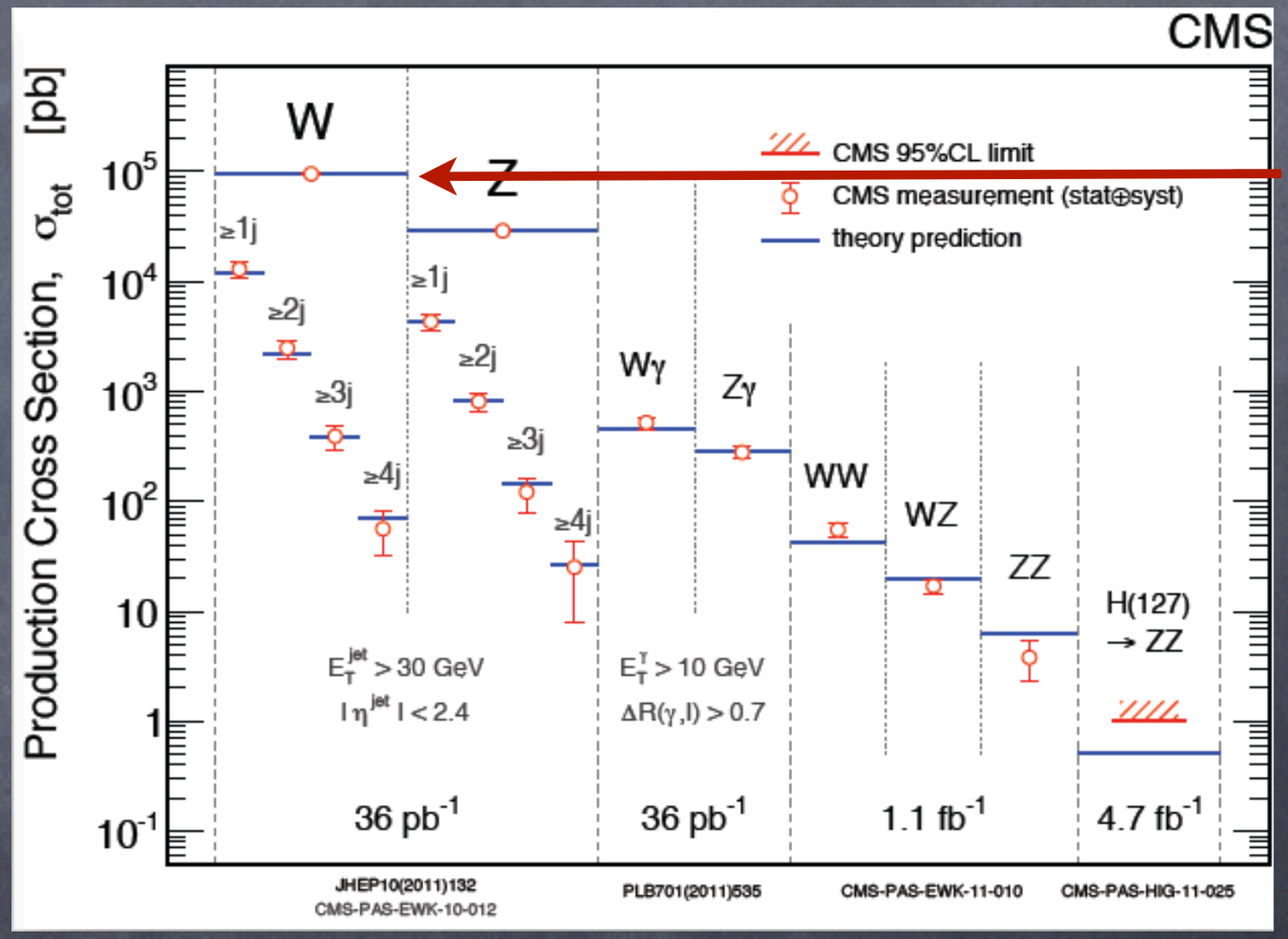

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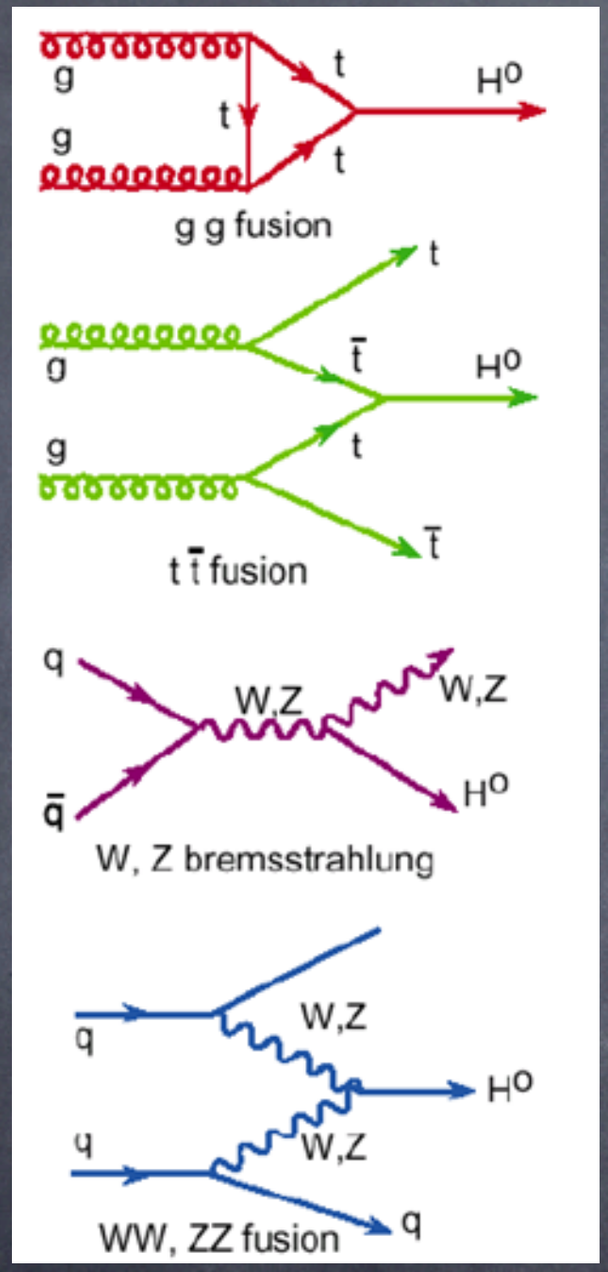

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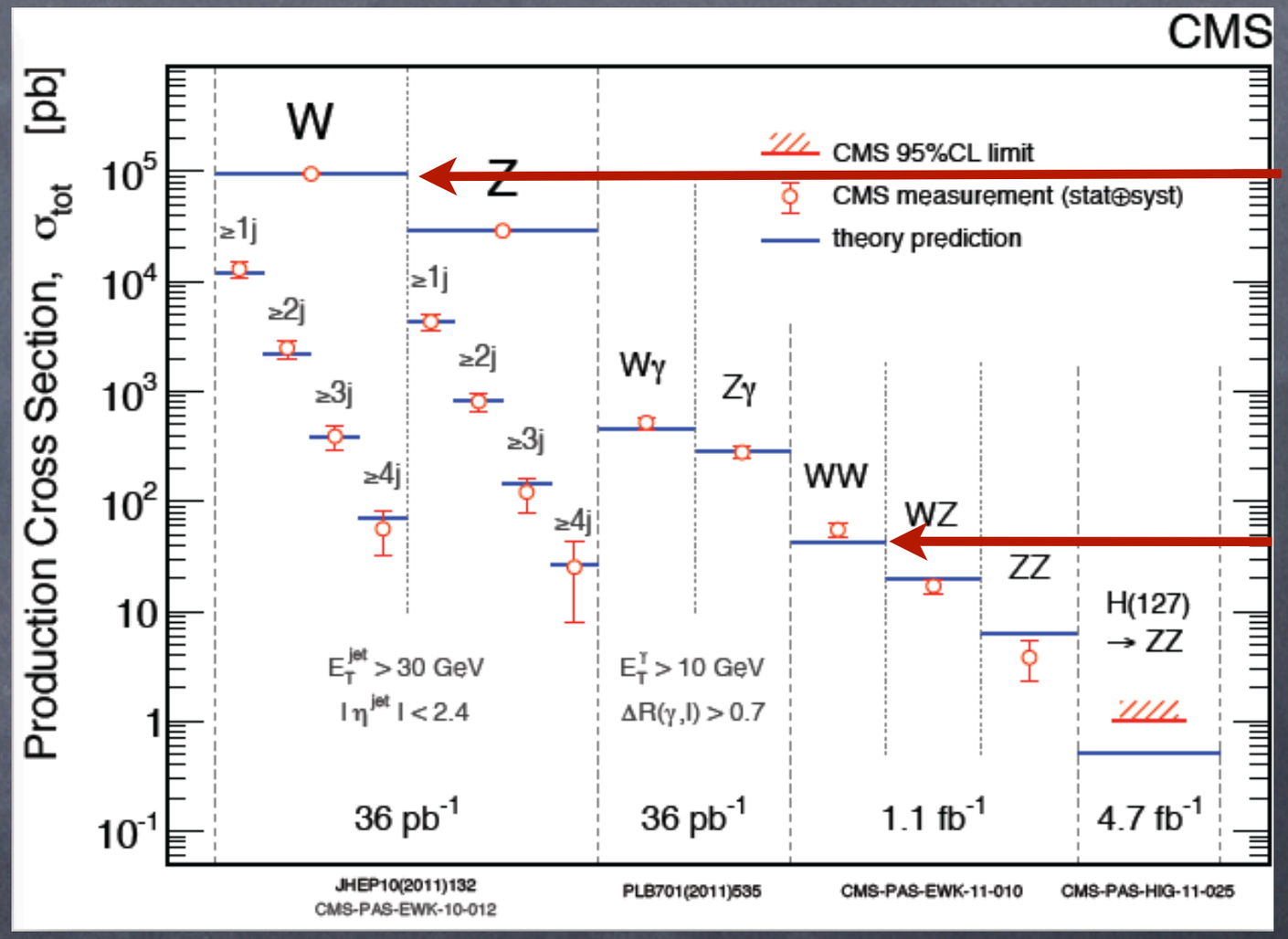

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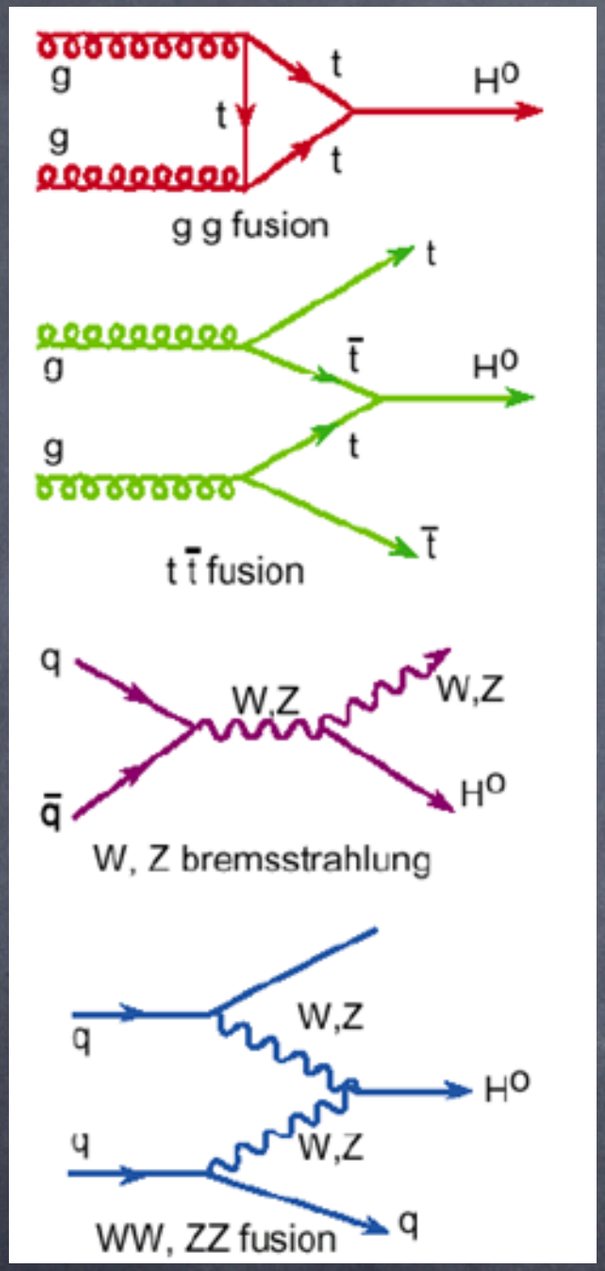


Abb. 14: Feynman-Diagramme zur Erzeugung eines Higgs-Boson

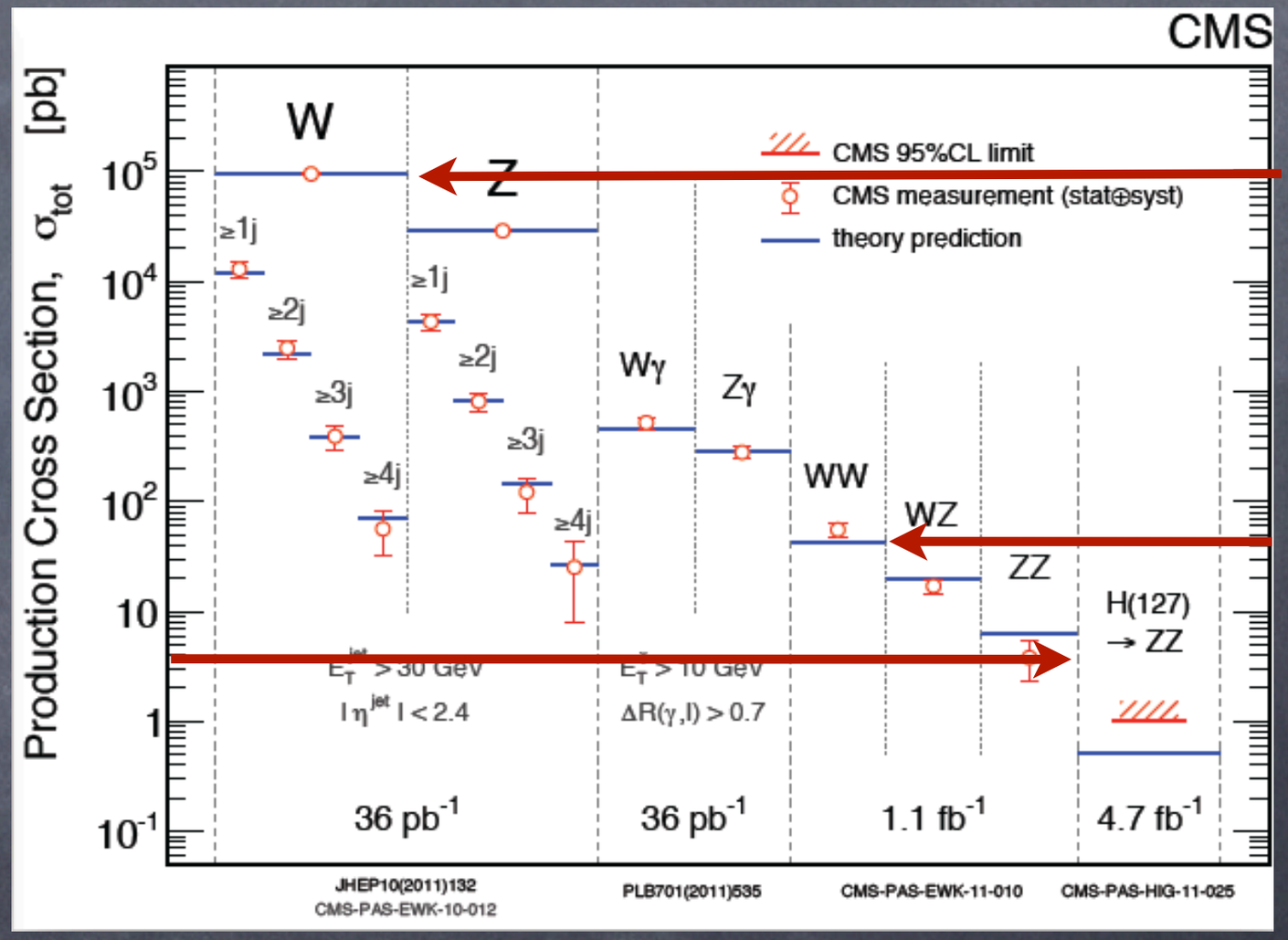
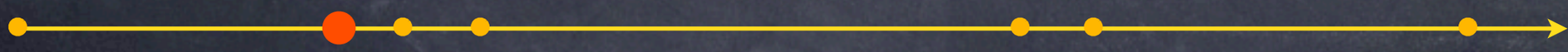


Abb. 15: Wirkungsquerschnitt für die "interessanten" Prozesse der Teilchenproduktionen bei hohen Schwerpunktsenergien, aus [4]

Decay - H Boson

H-Boson
Lebensdauer: $\approx 10^{-25}$s
Masse: 125 GeV/c^2



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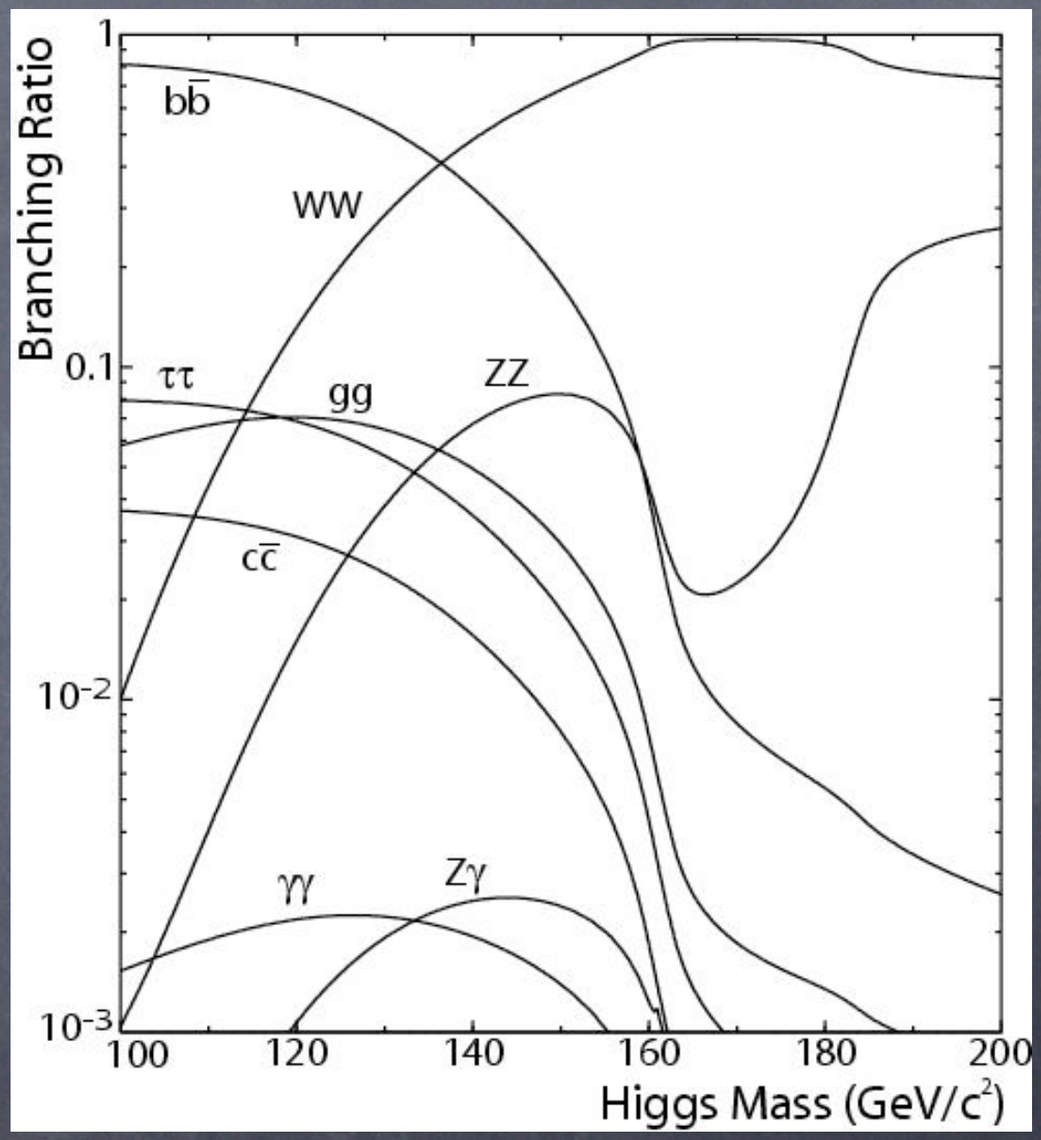

Fig.: branching ratio of Higgs decay vs Higgs mass

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Lebensdauer: ≈ 10^{-25}s
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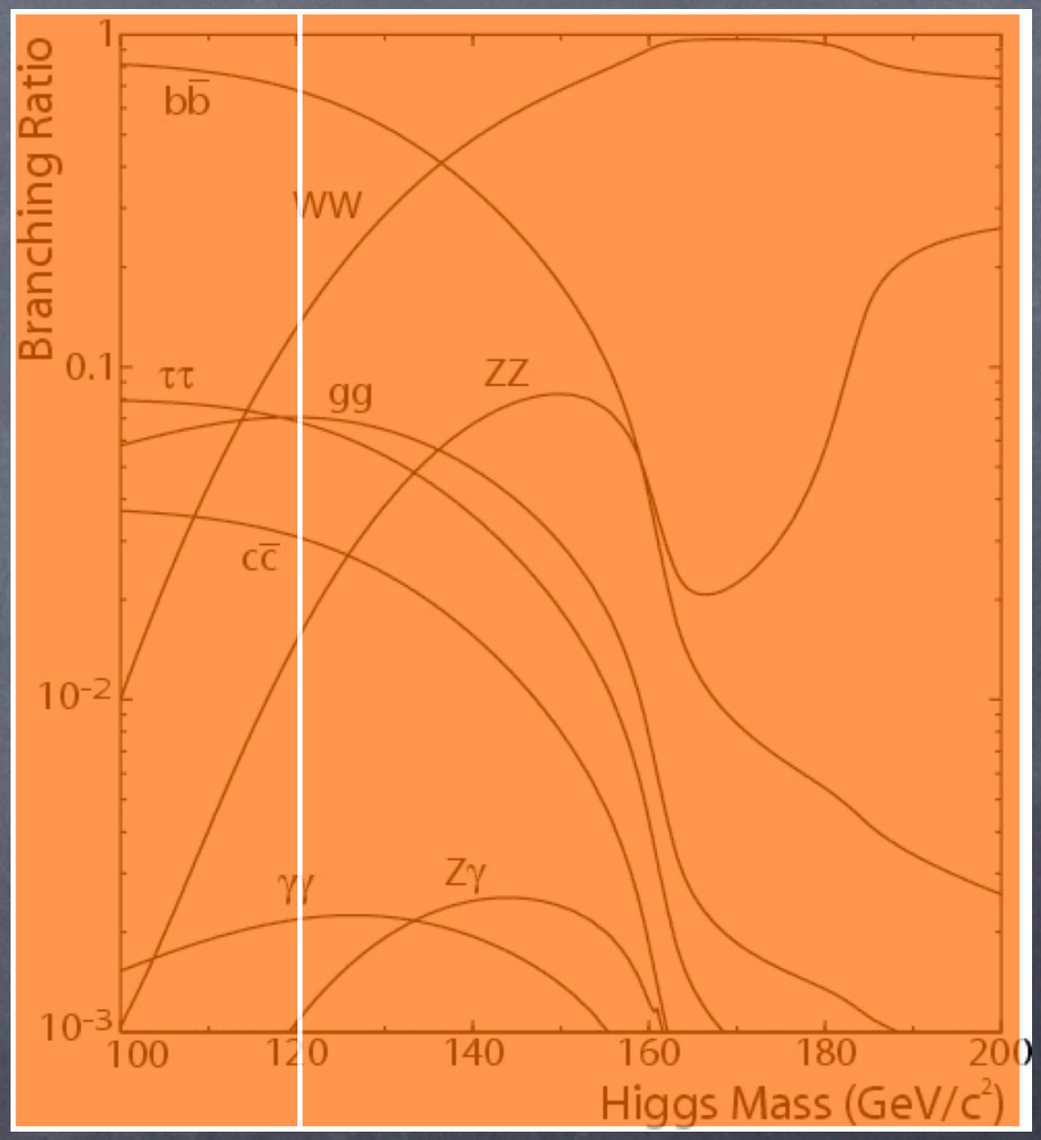

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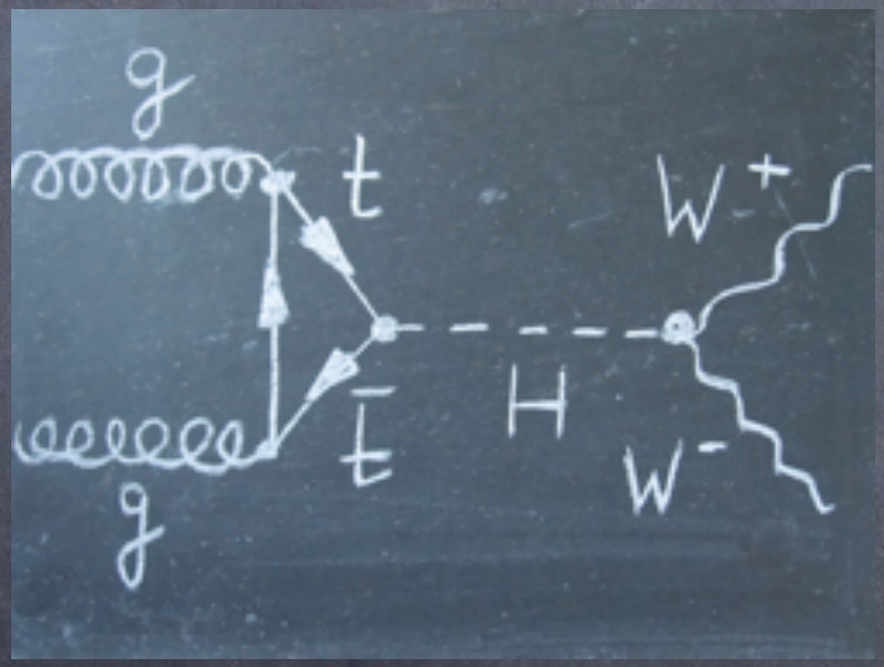


Fig.: Feynman graph of production and decay of Higgs boson

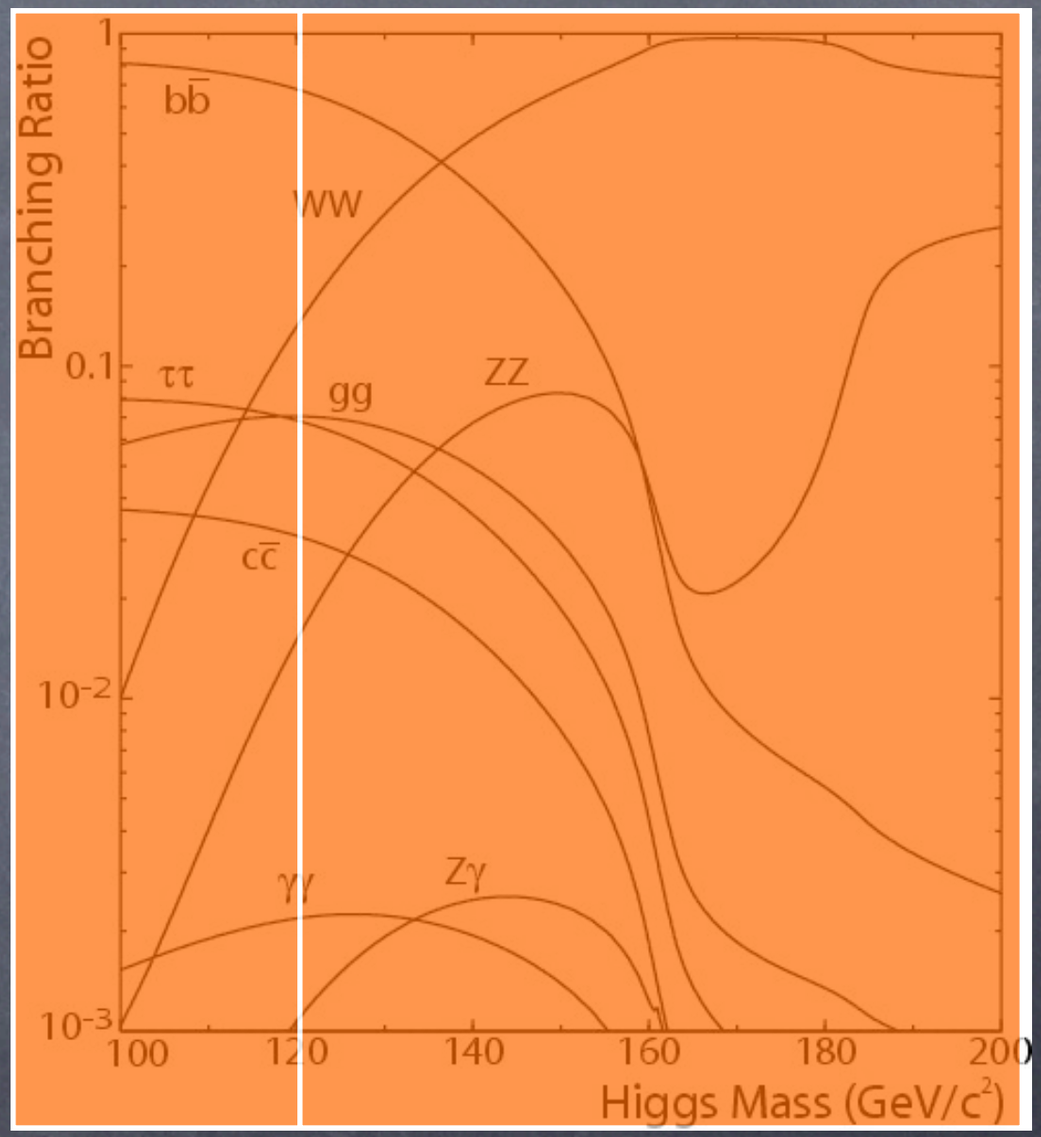
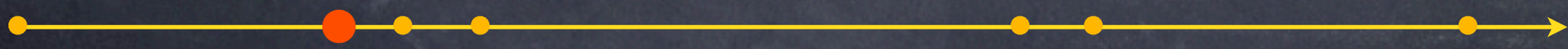


Fig.: branching ratio of Higgs decay vs Higgs mass

Part 1 - Introduction physics 13

Challenges in the search H → ww



Challenges in the search H → ww

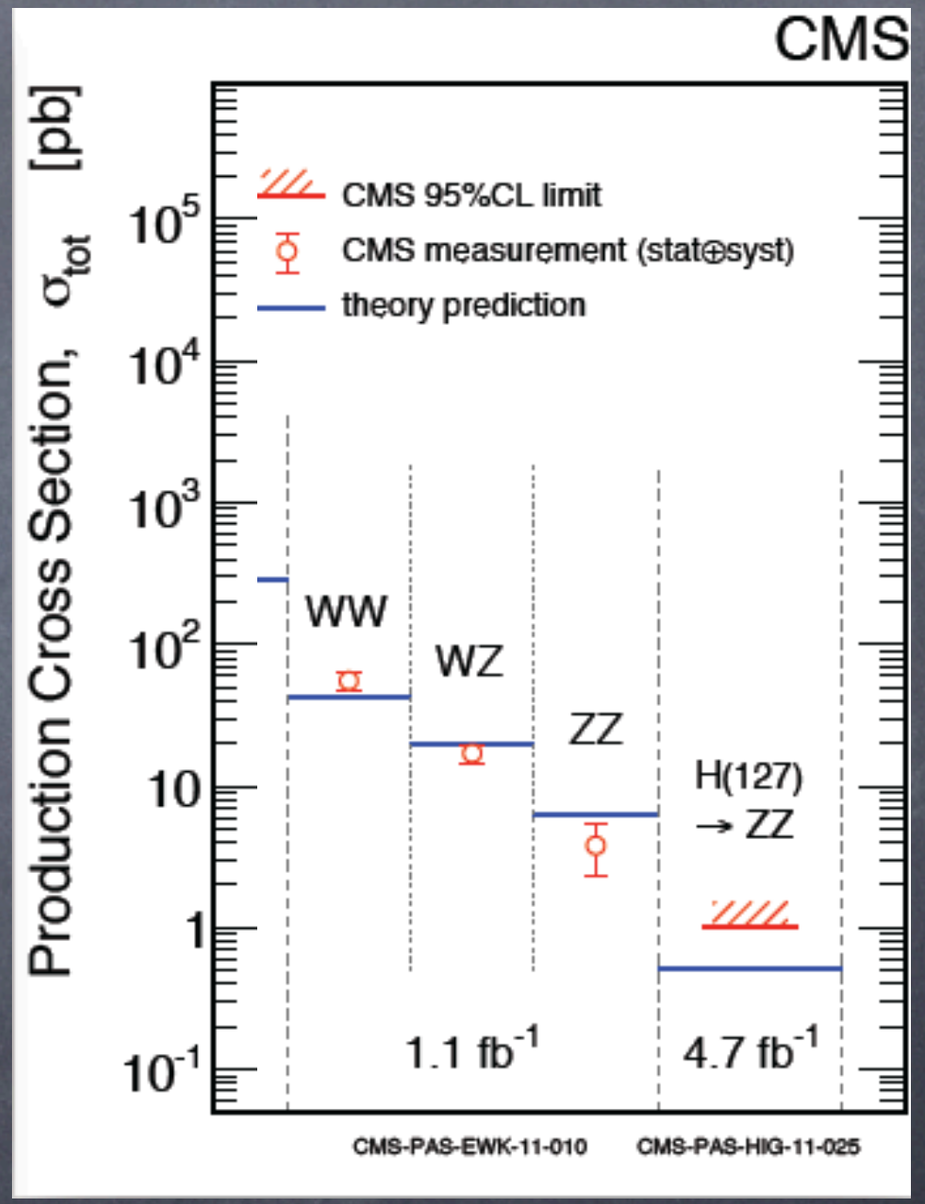
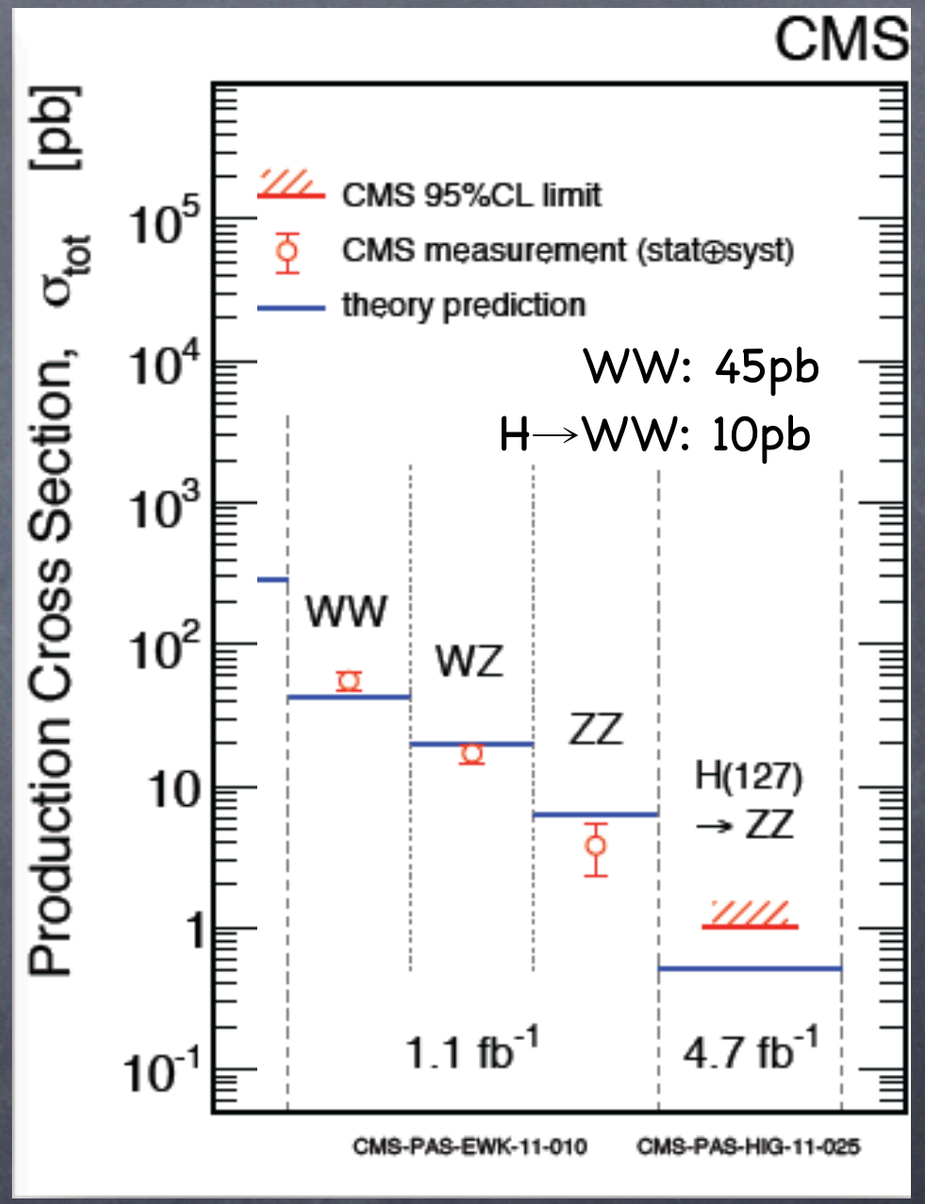


Fig.: production cross section for signal and background events of the Higgs search

Challenges in the search H → ww



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Challenges in the search H → ww

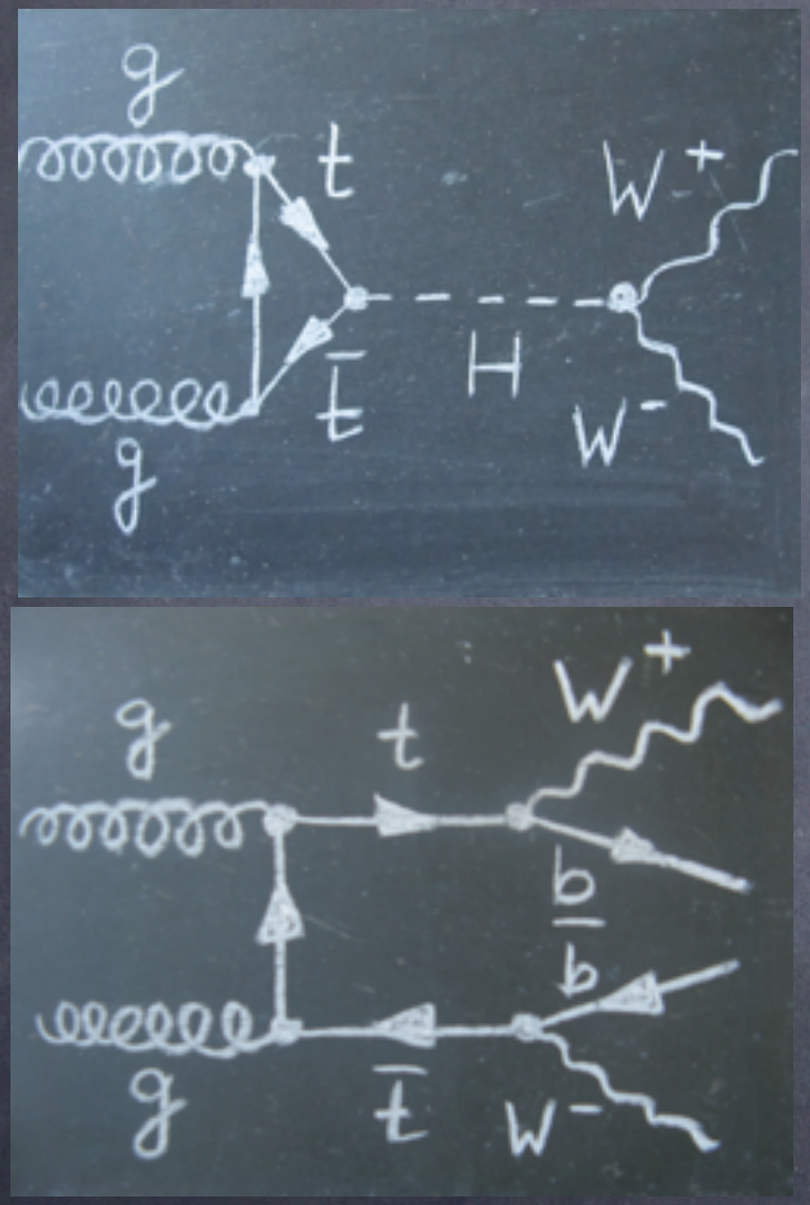


Fig.: Signal (top) vs background (bottom)

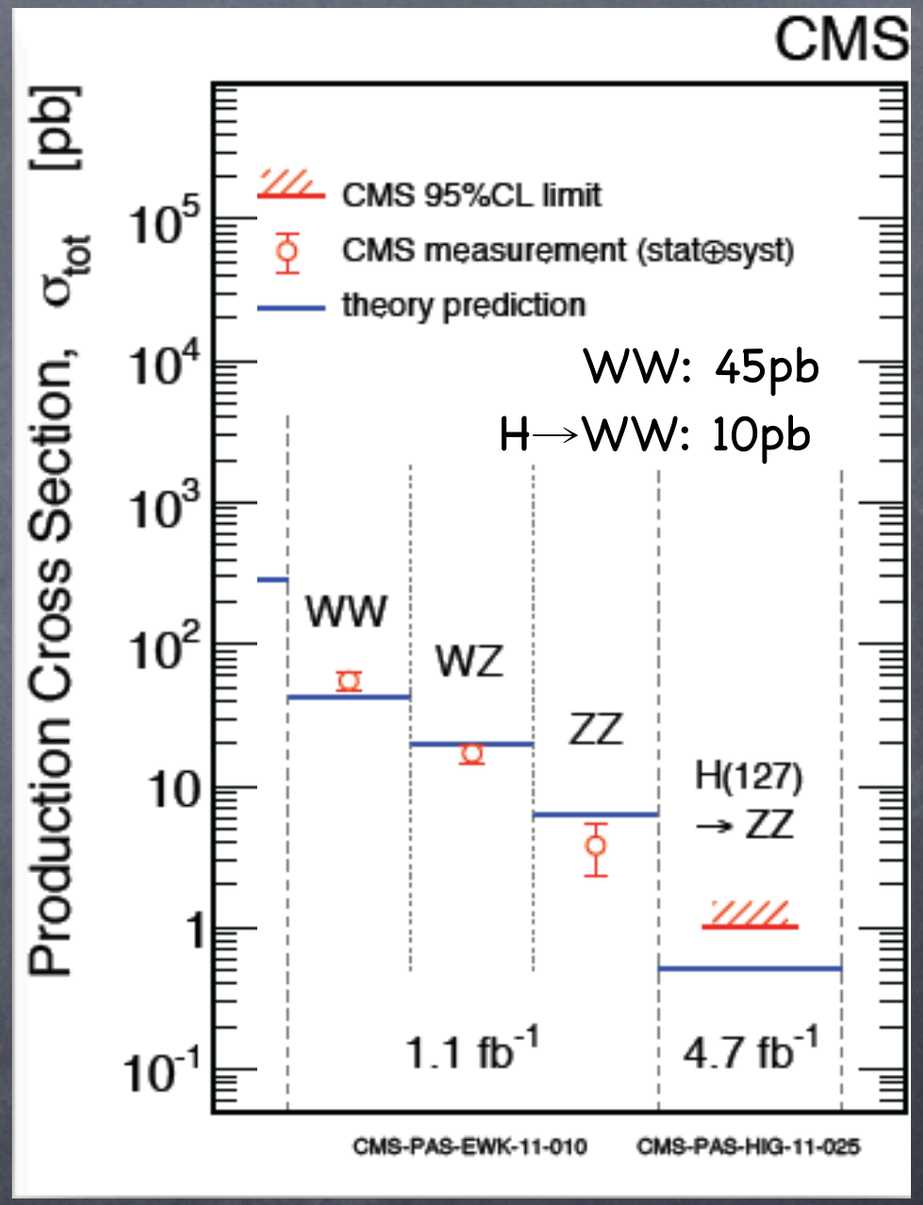
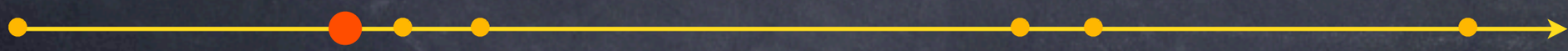


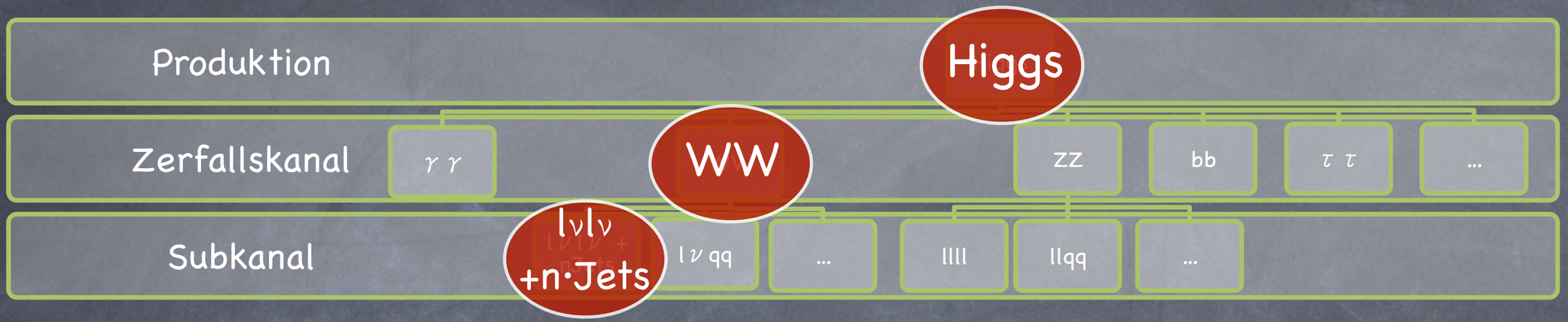
Fig.: production cross section for signal and background events of the Higgs search

Part 1 - Introduction

physics 14




Produktion
Higgs
Zerfallskanal
γ γ
WW
ZZ
bb
τ τ
...
Subkanal
l ν l ν + nJets
l ν qq
...
llll
llqq
...


Produktion
Higgs
Zerfallskanal
γ γ
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...
Subkanal
lνlν
+n·Jets
l ν qq
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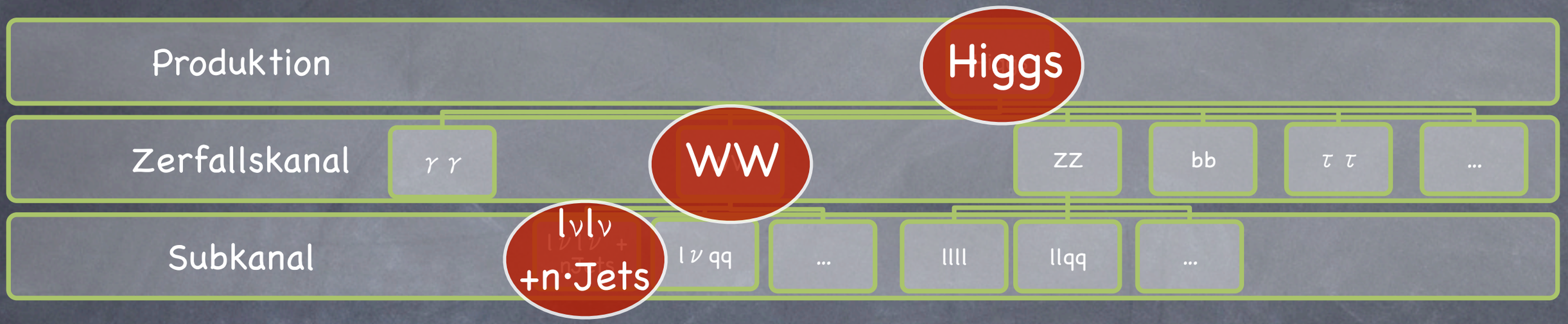
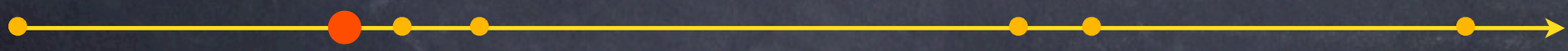
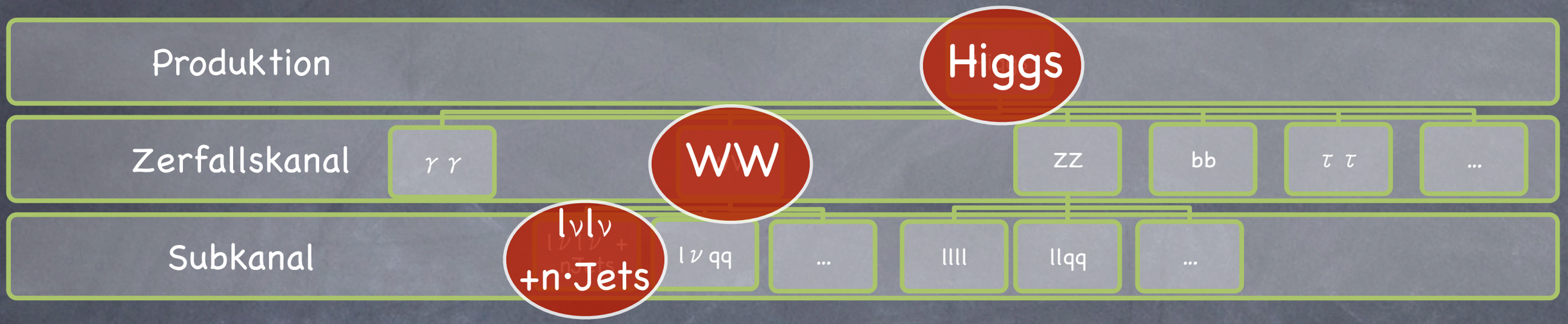


properties of events with decaying Higgs bosons in the decay channel H → WW → lνlν + n·Jets (n=0,1)





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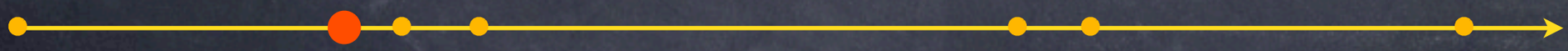
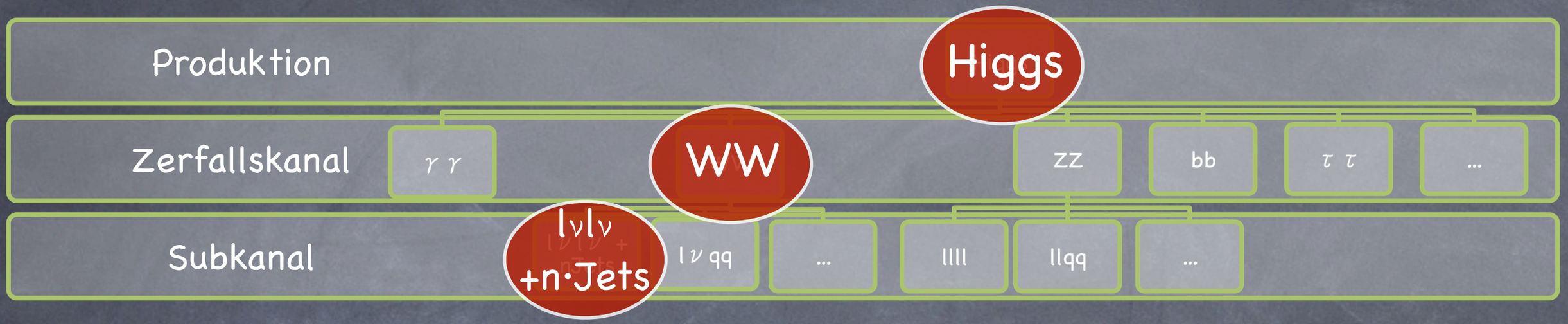
- exactly two high-energetic, opppositely electrically charged leptons [either muon and (or) antimuon or (and) positron and (or) electron)] with $p_{T,lead}$>20 GeV/c and $p_{T,sub}$>10 GeV/c





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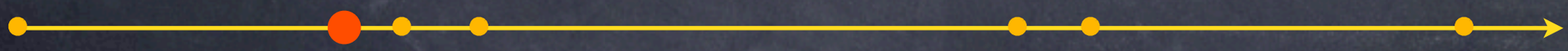
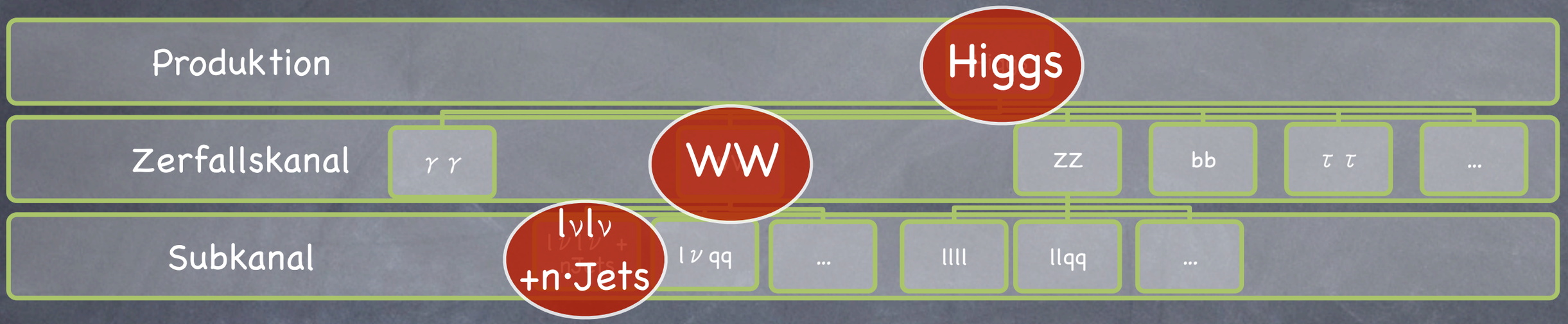
- missing transverse momentum with $E_{T,miss}$>20GeV (if leptons come from different families, e.g. electron and antimyon) or $E_{T,miss}$>40GeV (if leptons come from the same family, e.g. electron and positron)





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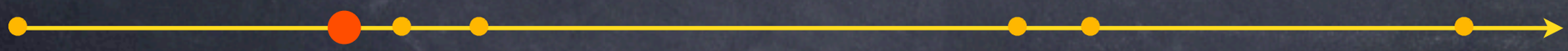
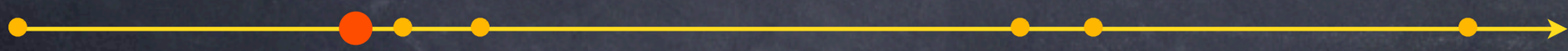
- missing transverse momentum with $E_{T,miss}$>20GeV (if leptons come from different families, e.g. electron and antimyon) or $E_{T,miss}$>40GeV (if leptons come from the same family, e.g. electron and positron)
- leptons are isolated from Jets - but there can be a jet in the event

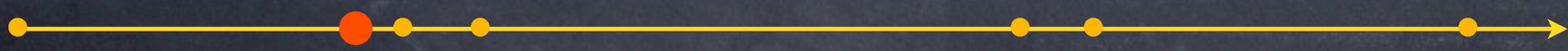


Question: How can one find the Higgs boson in this decay channel when the background is so heavy?



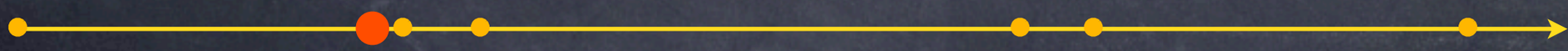
Question: How can one find the Higgs boson in this decay channel when the background is so heavy?

- Measure the angle ($\Delta\phi_{ll}$) between the two electrically charged leptons in transverse plane



Part 1 - Introduction

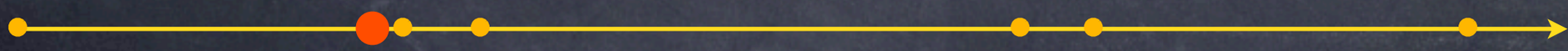
physics sum



Part 1 - Introduction

physics sum

- strategies, methods and tools for searches are very different



Part 1 - Introduction

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- strategies, methods and tools for searches are very different
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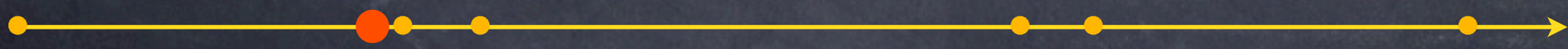

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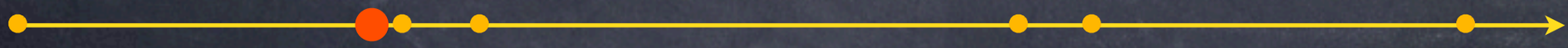

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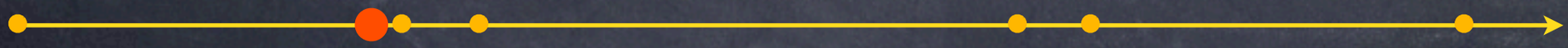

Part 1 - Introduction

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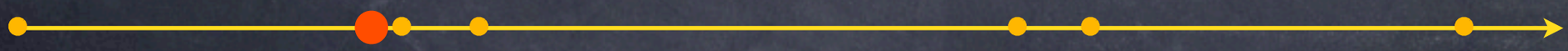
- these come in 10-20% from the Higgs decay



Part 1 - Introduction

physics sum

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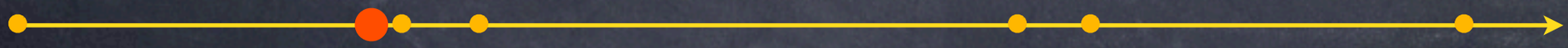
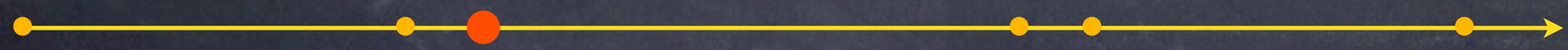
- these come in 10-20% from the Higgs decay
- statistical scrutiny with the help of distinguishing variables (such as the opening angle between the electrically charged leptons) allow discoveries



break

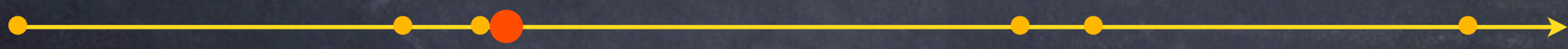
Outline

- Wrap-up 30’ (09:00)
- Technical Intro 15’
- Intro to the Event Display Programme 15’
- Exercises 75’ (10:00)
- Break 15’ (11:15)
- Measurement 60’ (11:30)
- Combination of Data 15’ (12:30)
- Discussion 30’ (12:45)



Part 2 - Exercises

Preparation 1

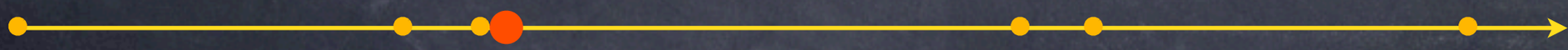


Part 2 - Exercises

Preparation 1

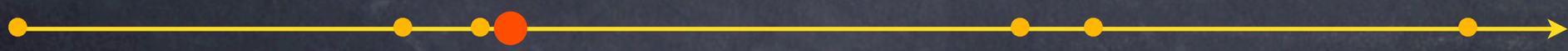
What do you need?

- computer access (CERN laptops):
  - user name: teacherg
  - password: Einstein1879
- Event Display ‘MINERVA’ (application ‘atlantis’ to be started from desktop)



Part 2 - Exercises

Preparation 2

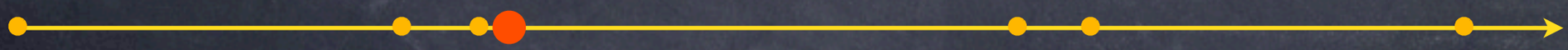


Part 2 - Exercises

Preparation 2

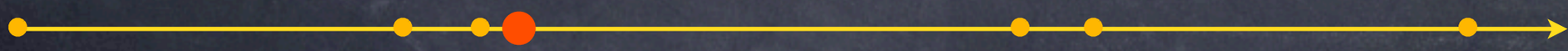
What do you need?

- website: http://www.cern.ch/kjende/en/wpath.htm
- data samples (2A.zip ... 2T.zip)
- tally sheet



Part 2 - Exercises

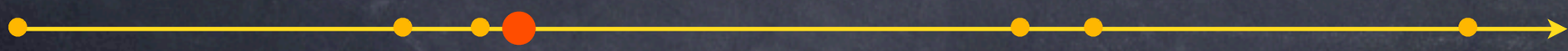
Preparation 3



Part 2 - Exercises

Preparation 3

Preparation of analysis

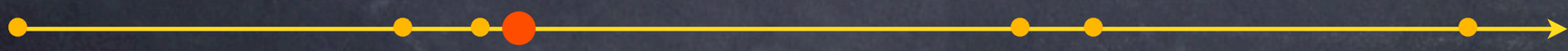


Part 2 - Exercises

Preparation 3

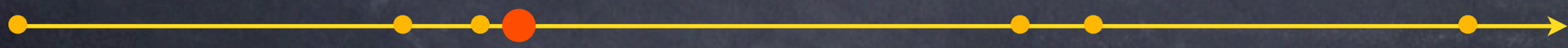
Preparation of analysis

- $1.8 \cdot 10^{15}$ collisions were recorded by ATLAS (28.03.2014)



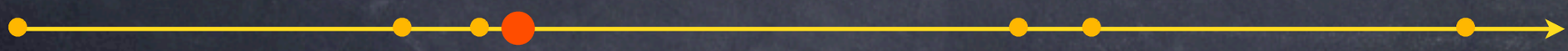
Preparation of analysis

- $1.8 \cdot 10^{15}$ collisions were recorded by ATLAS (28.03.2014)
- events to be analyzed were pre-selected



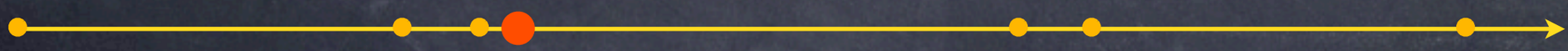
Preparation of analysis

- ✳ $1.8 \cdot 10^{15}$ collisions were recorded by ATLAS (28.03.2014)
- ✳ events to be analyzed were pre-selected
- ✳ time constraints



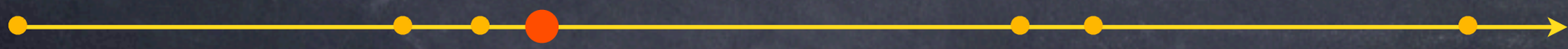
Preparation of analysis

- ✳ $1.8 \cdot 10^{15}$ collisions were recorded by ATLAS (28.03.2014)
- ✳ events to be analyzed were pre-selected
- ✳ time constraints
- ✳ different skills in programming



Part 2 - Exercises

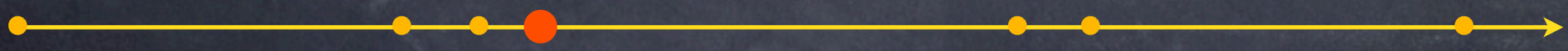
Preparation 4



Part 2 - Exercises

Preparation 4

1. Event Display
2. particle identification with exercise
3. event classification with exercise



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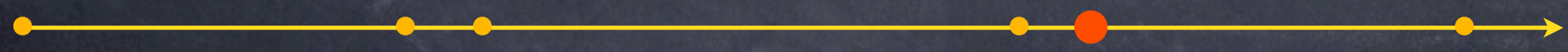
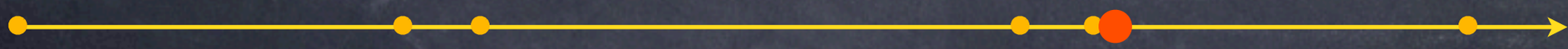
- Discussion 30’ (12:45)



Part 3 - Measurement

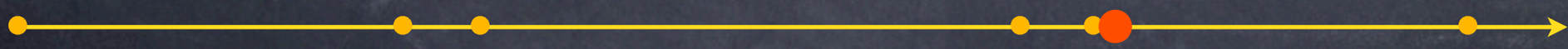
Tasks



Part 3 - Measurement

Tasks

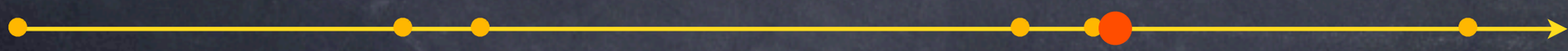
Tasks



Part 3 - Measurement

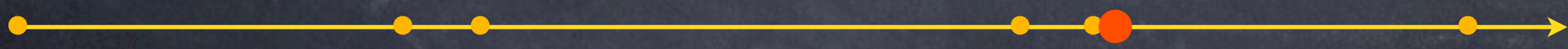
Tasks

1. Measure the ratio of the numbers of events containing a positivly electrically charged W particle to the number of events containing a negatively charged W particle (R±).



Tasks

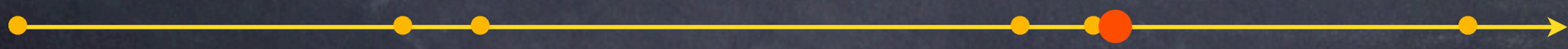
1. Measure the ratio of the numbers of events containing a positivly electrically charged W particle to the number of events containing a negatively charged W particle (R±).
2. What does the result mean for the inner structure of the proton?



Tasks

Tasks

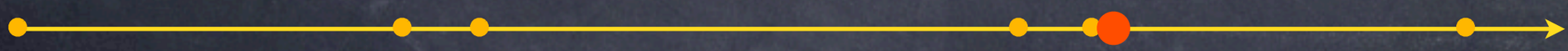
1. Measure the ratio of the numbers of events containing a positivly electrically charged W particle to the number of events containing a negatively charged W particle (R±).
2. What does the result mean for the inner structure of the proton?
3. Pick all events containing two W particles (coming from the same vertex).



Part 3 - Measurement

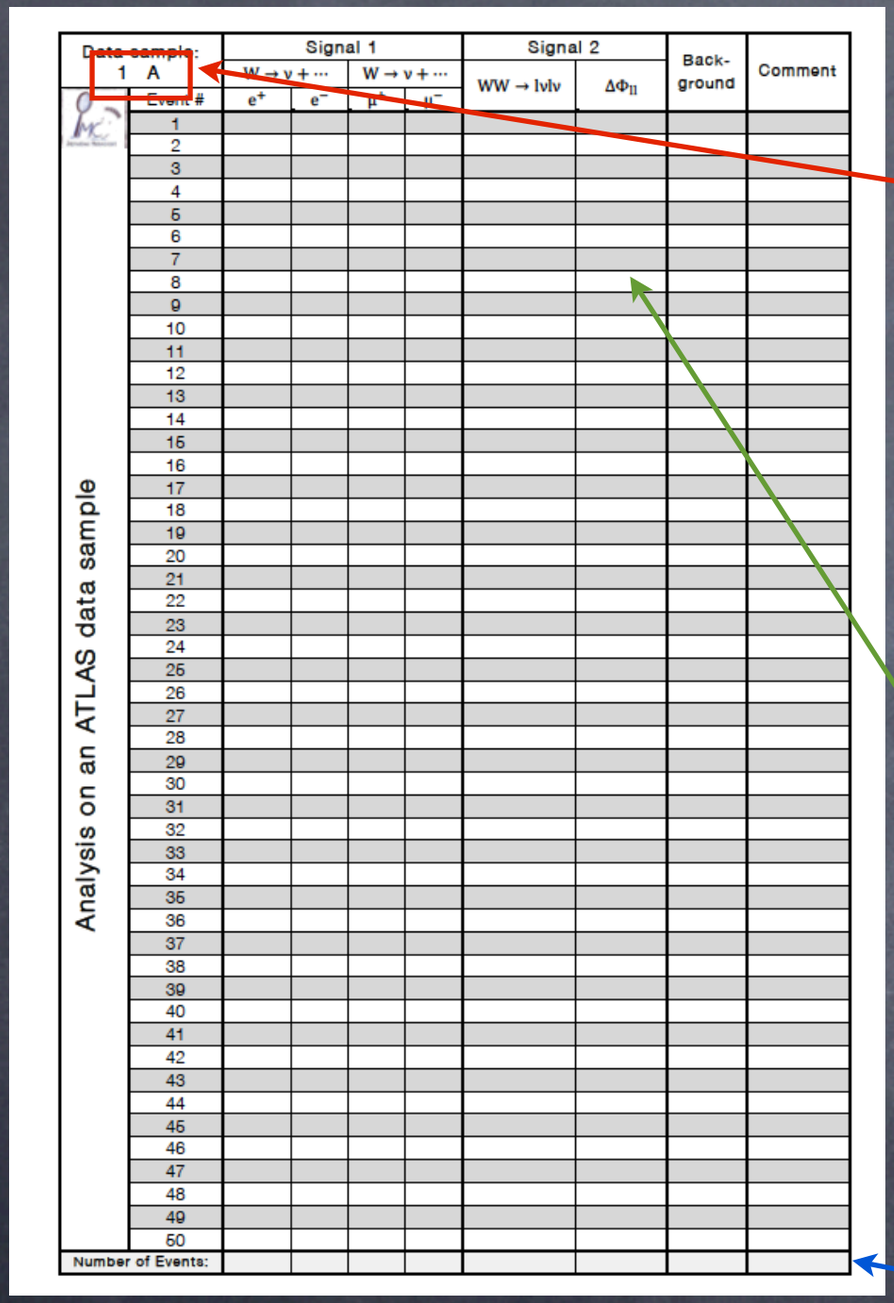
Tasks

1. Measure the ratio of the numbers of events containing a positivly electrically charged W particle to the number of events containing a negatively charged W particle (R±).
2. What does the result mean for the inner structure of the proton?
3. Pick all events containing two W particles (coming from the same vertex).
4. Look at the angular distribution and say something about the discovery potential of your search.



Part 3 - Measurement

Tally sheet



Analysis on an ATLAS data sample

Data sample: 1 A	Signal 1				Signal 2		Back-ground	Comment
	$W \to \nu + \cdots$		$W \to \nu + \cdots$		$WW \to l\nu l\nu$	$\Delta\Phi_{ll}$		
Event #	e^+	e^-	μ^+	μ^-				
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
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36								
37								
38								
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40								
41								
42								
43								
44								
45								
46								
47								
48								
49								
50								
Number of Events:								

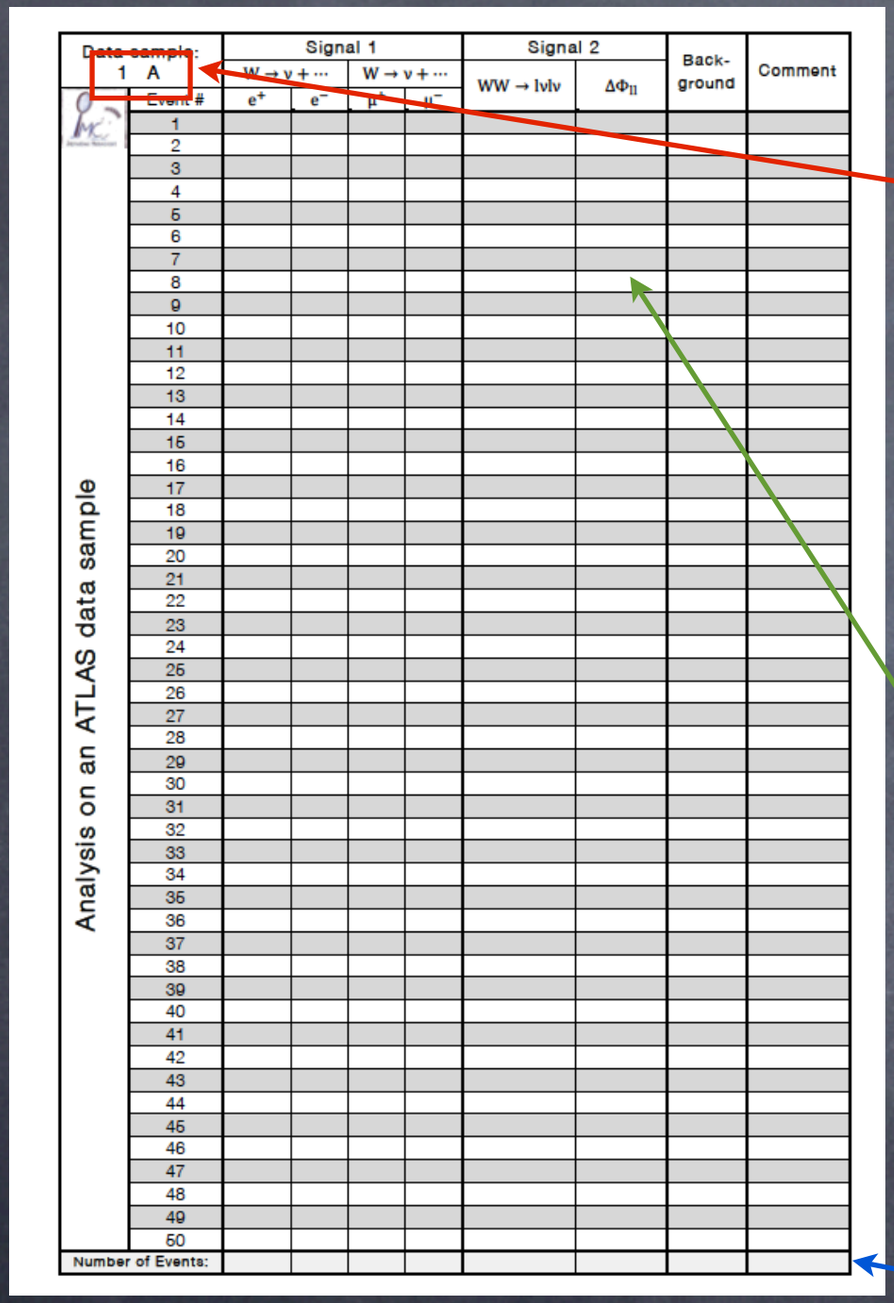
important Code; this is the name of the data sample you are supposed to analyze

If you find a WW candidate please fill in the angle between the electrically charged leptons here

sum up

Part 3 - Measurement

Tally sheet



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Data sample: 1 A	Signal 1				Signal 2		Back-ground	Comment
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47								
48								
49								
50								
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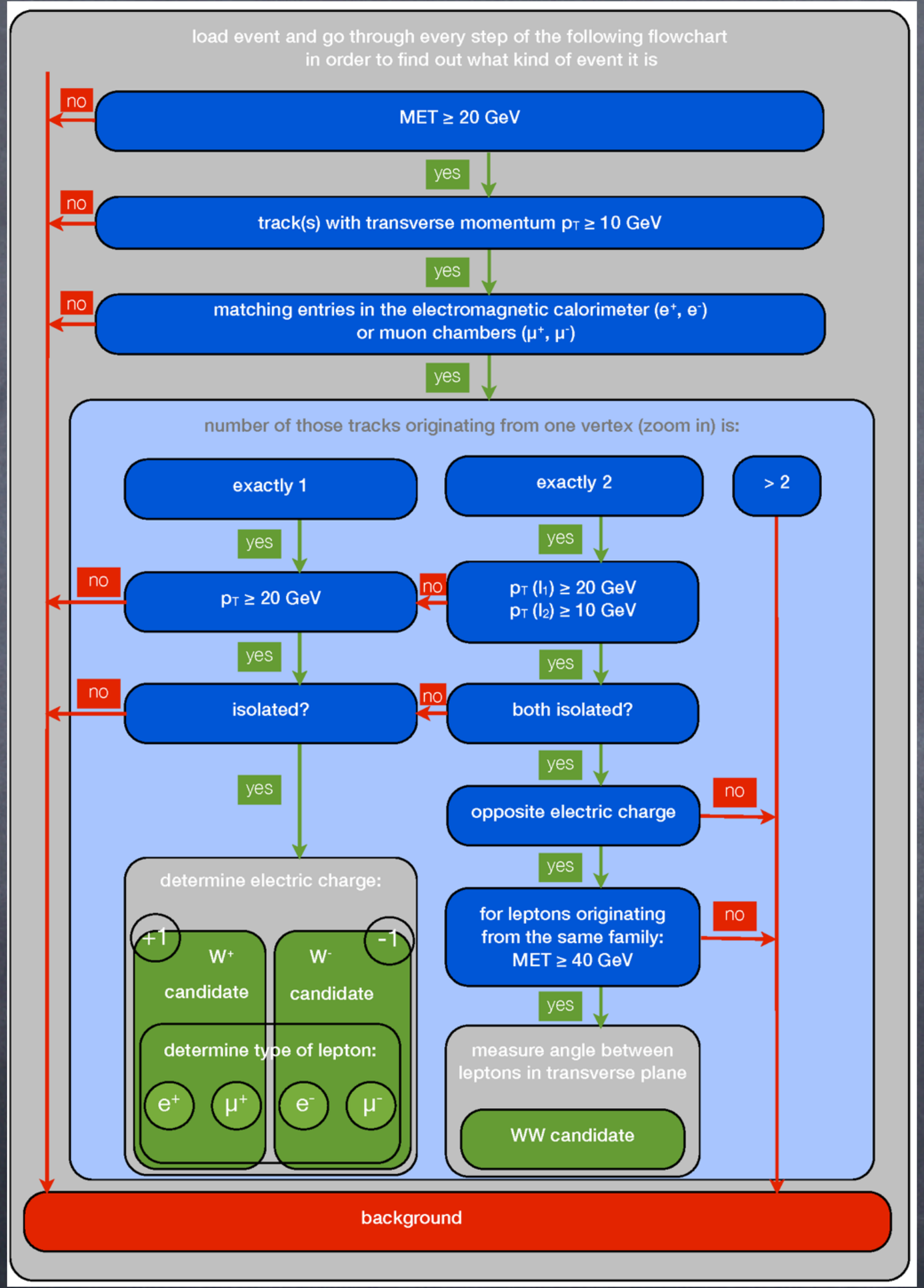
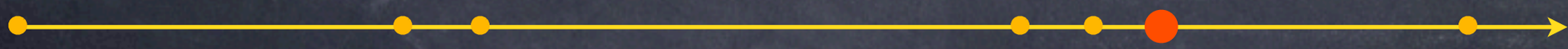
If you find a WW candidate please fill in the angle between the electrically charged leptons here

sum up

Fig. Tally sheet for W measurement

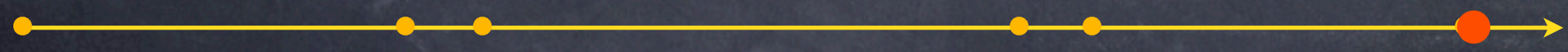

load event and go through every step of the following flowchart
in order to find out what kind of event it is
no
MET ≥ 20 GeV
yes
no
track(s) with transverse momentum $p_T \geq 10$ GeV
yes
no
matching entries in the electromagnetic calorimeter (e^+, e^-)
or muon chambers (μ^+, μ^-)
yes
number of those tracks originating from one vertex (zoom in) is:
exactly 1
exactly 2
> 2
yes
yes
no
$p_T \geq 20$ GeV
no
p_T (l_1) ≥ 20 GeV
p_T (l_2) ≥ 10 GeV
yes
yes
no
isolated?
no
both isolated?
yes
yes
opposite electric charge
no
yes
determine electric charge:
+1
W^+
candidate
W^-
candidate
-1
for leptons originating
from the same family:
MET ≥ 40 GeV
no
yes
determine type of lepton:
e^+
μ^+
e^-
μ^-
measure angle between
leptons in transverse plane
WW candidate
background

Enjoy your first LHC data analysis



Outline

- Wrap-up 30’ (09:00)
- Technical Intro 15’
- Intro to the Event Display Programme 15’
- Exercises 75’ (10:00)
- Break 15’ (11:15)
- Measurement 60’ (11:30)
- Combination of Data 15’ (12:30)
- Discussion 30’ (12:45)



Part 5 - appendix

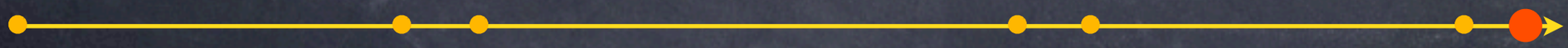
further readings

[1] The ATLAS Collaboration: Measurement of the muon inclusive cross section in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector, 21.11.2011, Link.

[2] The ATLAS Collaboration: Measurement of the W->lnu and Z/gamma*->ll production cross sections in proton-proton collisions at sqrt(s) = 7 TeV with the ATLAS detector, 9.10.2010

[3] The ATLAS Collaboration: ATLAS high-level trigger, data-acquisition and controls : Technical Design Report. Geneva, CERN, 2003.

[4] Joe Incandela on behalf od the CMS Collaboration: Status of the CMS SM Higgs Search. CERN-Seminar, July 4 2012. Link: https://cms-docdb.cern.ch/cgi-bin/PublicDocDB/RetrieveFile?docid=6125&filename=CMS_4July2012_Incandela.pdf



Part 5 - appendix

Webseiten

[www1] http://www.cern.ch/kjende/de/wpath.htm - Webseite zur ATLAS W-Messung bei Masterclasses

[www2] http://www.cern.ch/kjende/de/wpath_teilchenid1.htm - Webseite mit interaktivem Applet zur Teilchenidentifikation in ATLAS

[www3] http://www.cern.ch/kjende/de/downloads/minerva2012.zip - Link zum Herunterladen des Event Display Programms MINERVA

[www4] http://www.atlas.ch - offizielle Webseite des ATLAS-Experimentes mit sehr guter Multimedia-Abteilung

[www5] http://www.physicsmasterclasses.org - Informationen zu den Internationalen Masterclasses

[www6] http://www.teilchenwelt.de - Webseite des deutschen Netzwerk Teilchenwelt mit Informationen zur Beteiligung im Netzwerk, Veranstaltungen (Teilchenwelt-Masterclasses und Cosmic Workshops) auch an Ihrer Schule uvm.