

Please prepare to interact!

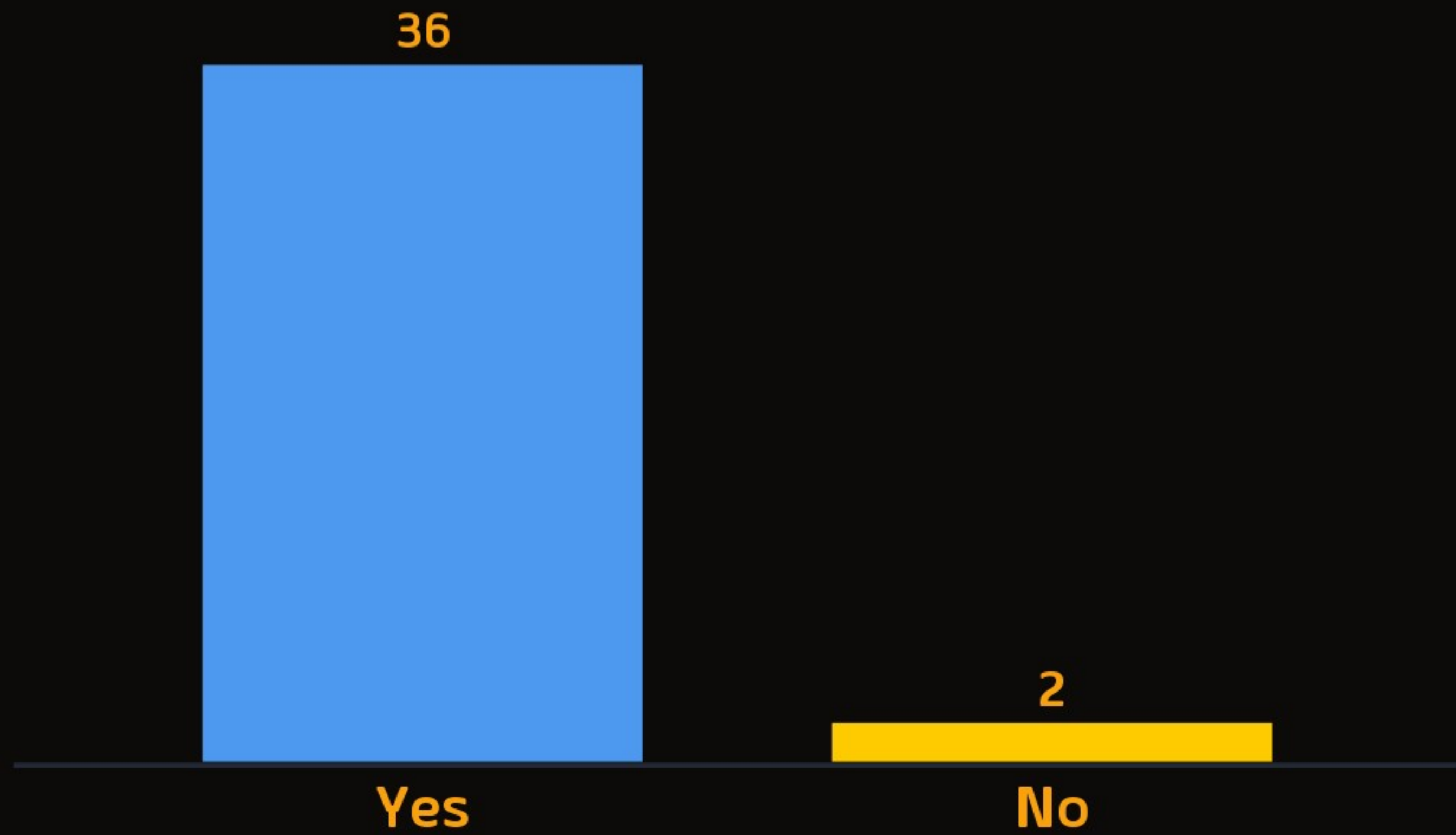


HASCO 2023: AN INTRODUCTION TO

hadron collider physics

by Lene Kristian Bryngemark (they/them), Lund University

I am here



How did you sleep last night?

10	Hardly any sleep
17	It was ok
11	Very well, thanks!

my goal: preparing you in a state to learn

OUTLINE

overall flow of the session



positioning
ourselves

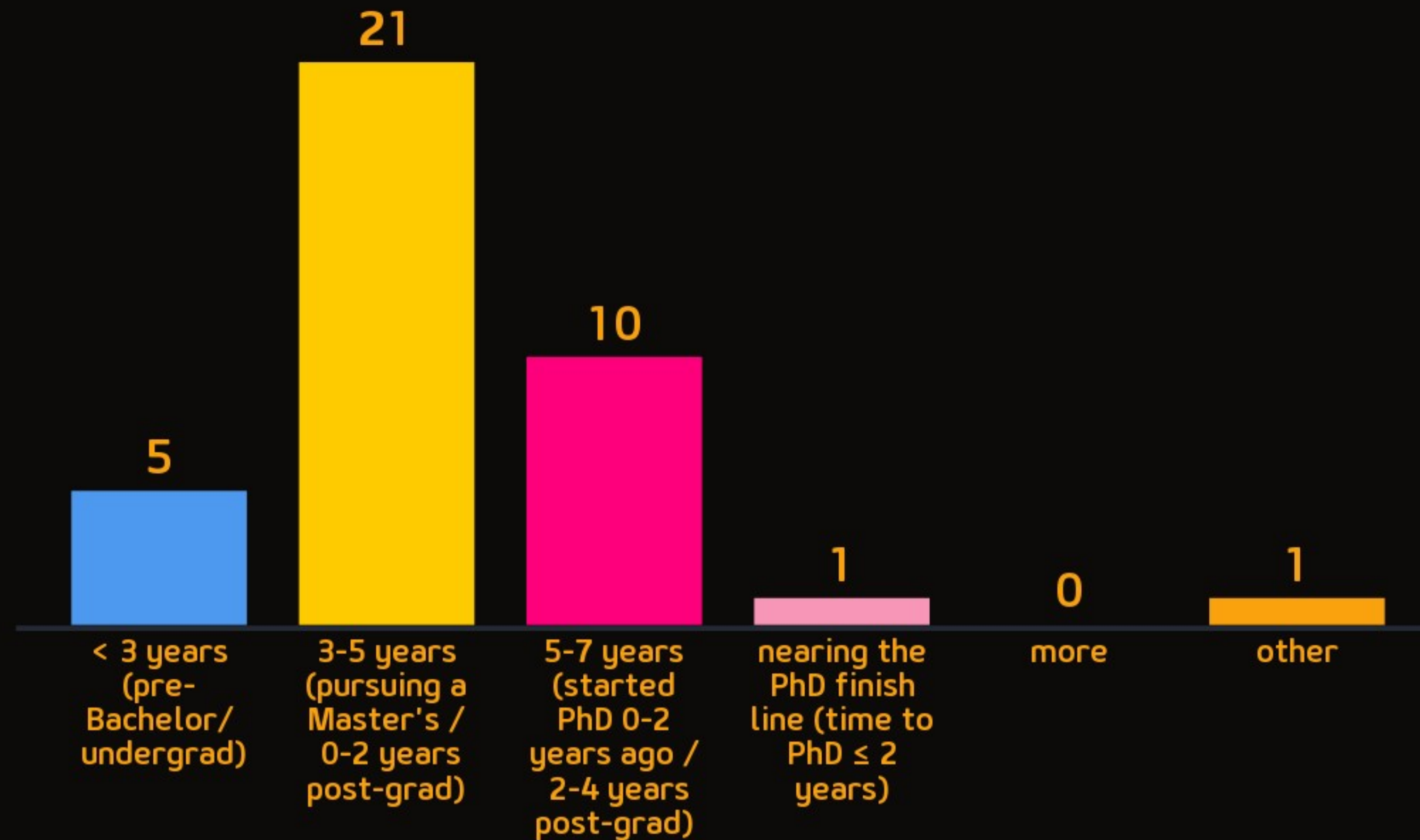
context of the
school

basics of
experiments

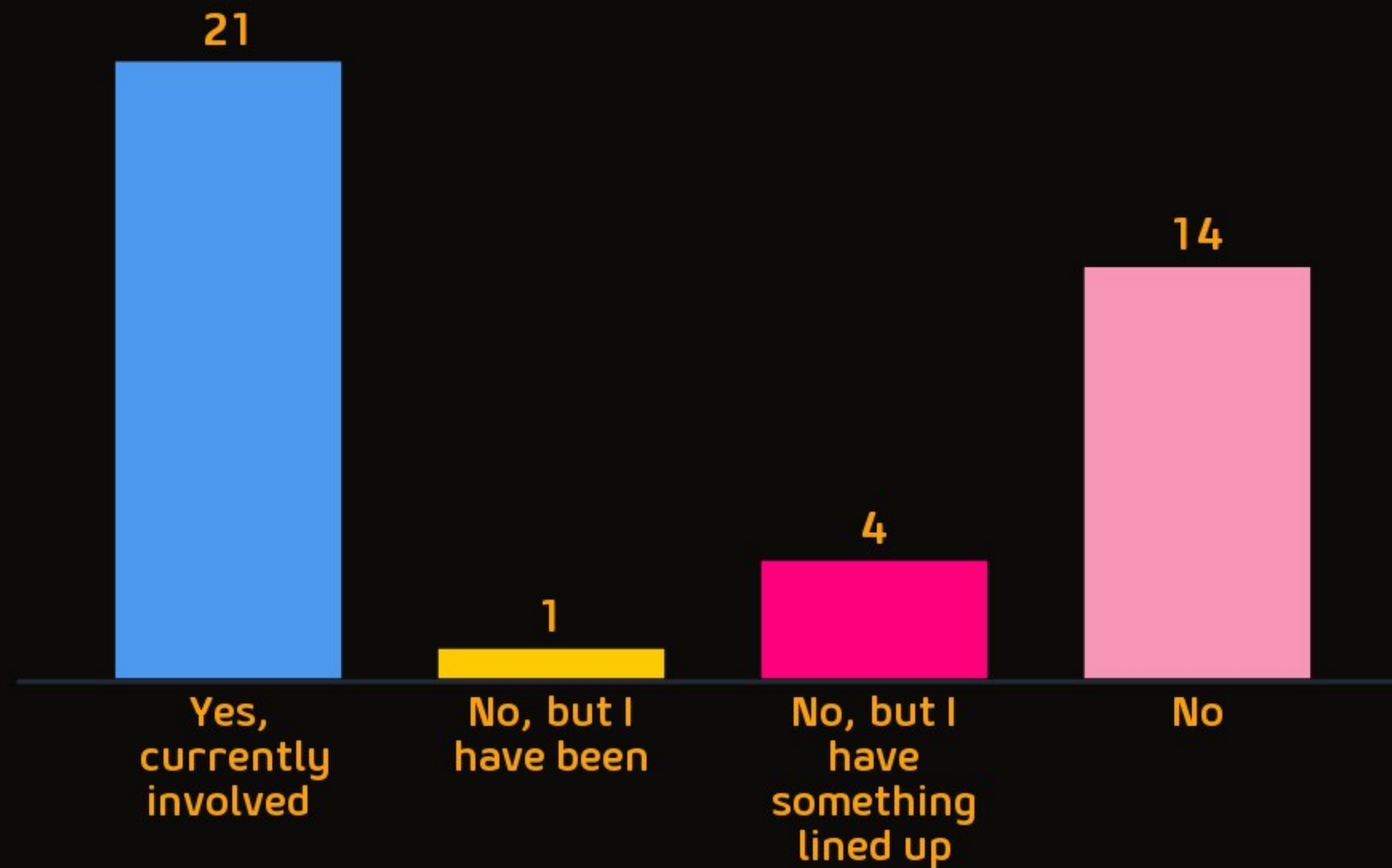
something
about theory

some more
about
experiments

My current level of physics training is...



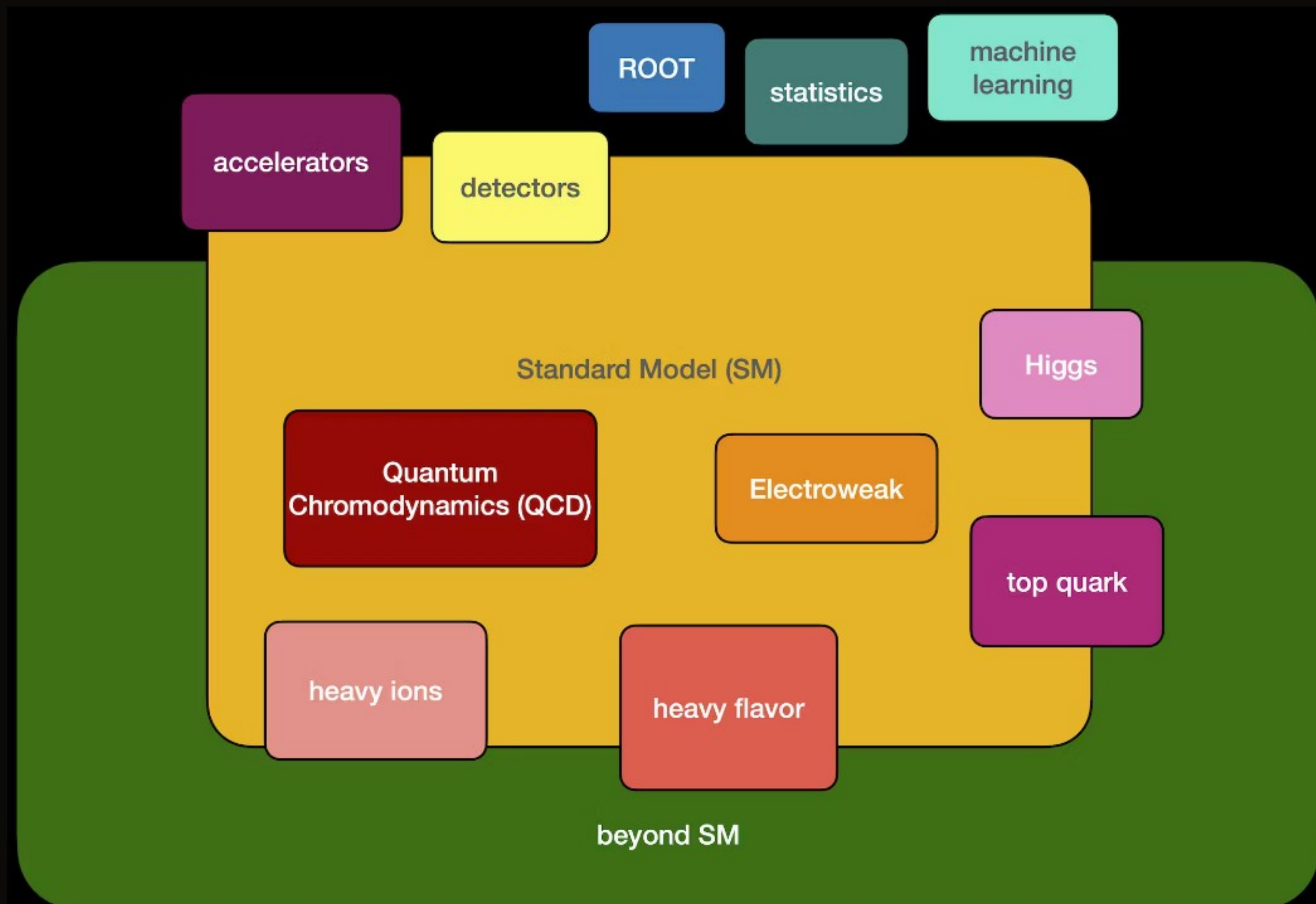
Are you involved in research with a hadron collider experiment?



SHARE WITH THE GROUP, HIT THUMBS UP WHEN YOU'RE DONE!

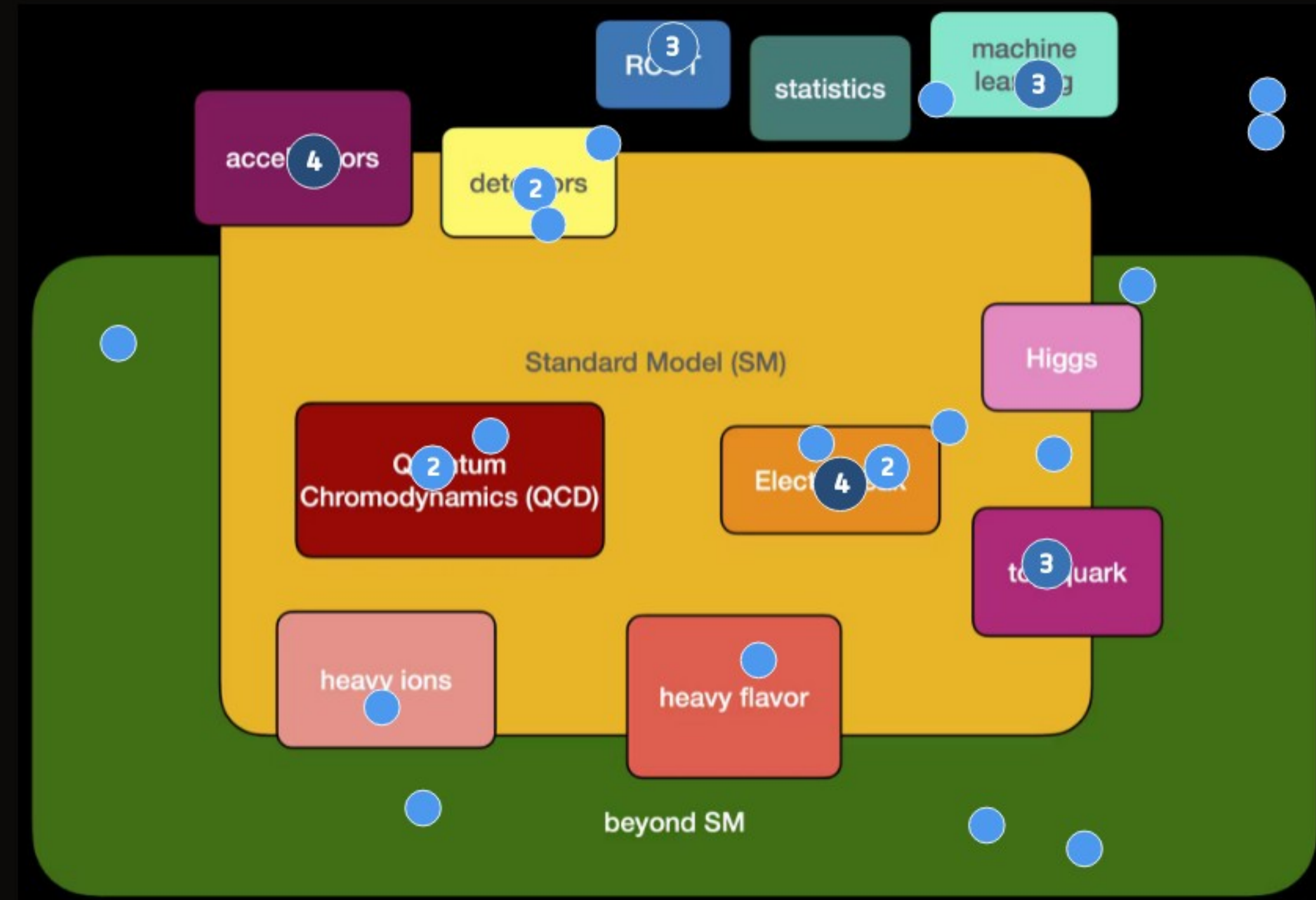
Please name the experiment(s) you are or have been doing research on

alice
atlas
cms
darkside
both atlas and cms



topics at HASCO 2023

Pin something in your approximate comfort zone

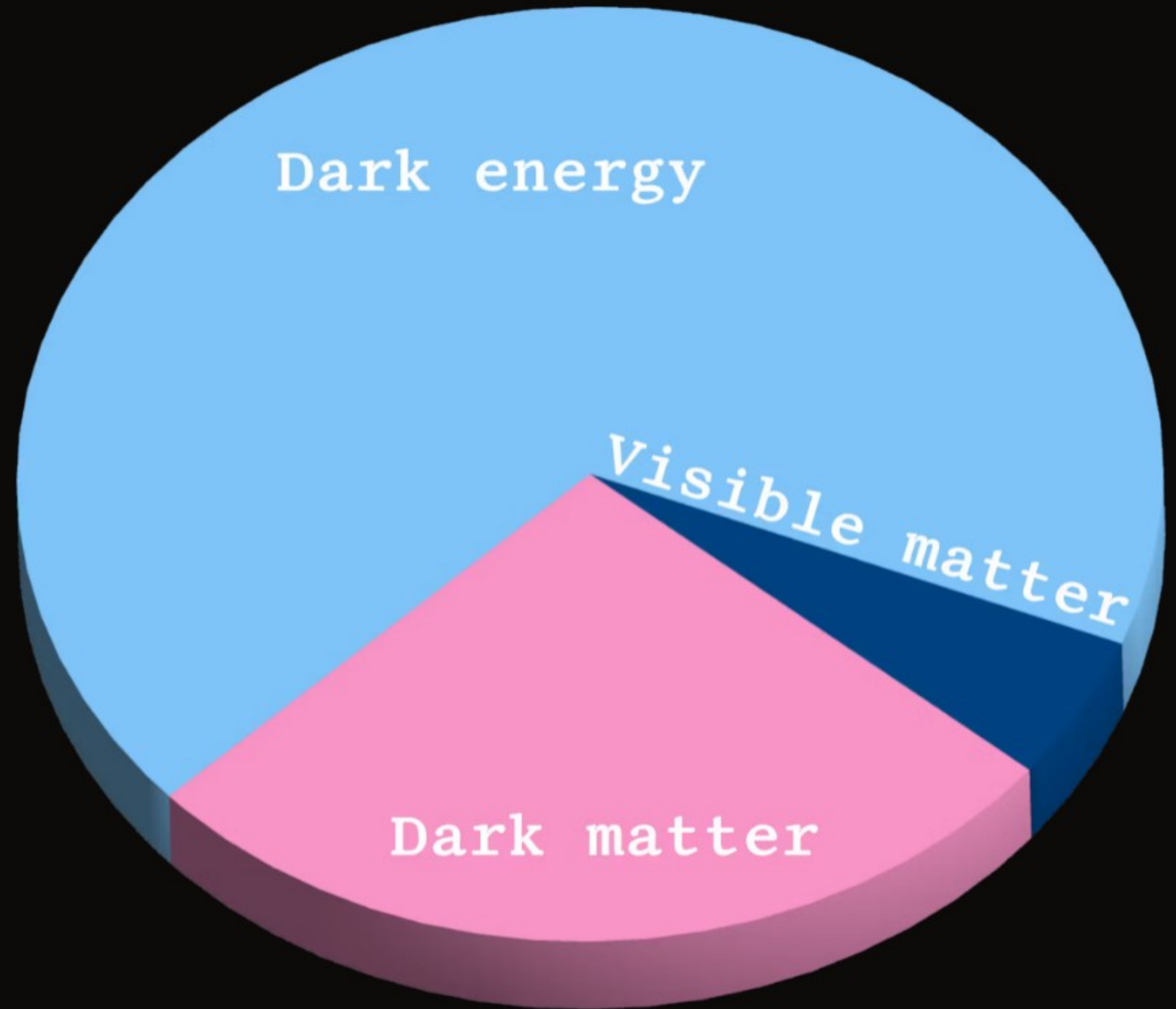


my background

- Bachelor's project (detector development) with (I)LCTPC
- Master's project (charged particle identification) with ALICE
- PhD (jets, pileup, "new physics" searches) and a post doc with ATLAS

current interest

- dark matter search (LDMX)
- fixed-target experiment
- electron beam



Something during the time of this school that you're excited about

45 Responses

Root	Stats	Learning more physics
Electroweak interactions	Beer	Root
Statistics	Statistics	Physics

Something during the time of this school that you're excited about

45

Responses

SUSY

More physics

QCD

Pubs

Bowling

Detectors

detectors

Machine learning

ROOT

32



34



Something during the time of this school that you're excited about

45 Responses

QCD	Standard model	BSM
Stats	Dark photons	Physics BSM
QCD	QCD	QCD, ML

Something during the time of this school that you're excited about

45

Responses

Long Lived Particles

SM Theory

Also beer

SM and ML

root

Sunshine

Qcd

Diverse countries

Stop pretending to understand physicist convos

32



34



Something during the time of this school that you're excited about

45 Responses

QCD

Top quark physics

Even more physics

I am very curious about SUSY lectures and the exams at the end. I am too curious about international lectures, its my first experience

Long Lived Particles

No chalk

qcd

History tour of the city

No chalk

about me

Comfort zone:

in physics: jets

in general: karaoke

Excited about
this week:

to kick off your summer
school

upcoming vacation in
the woods

Nervous:

introducing a large
variety of topics

large social settings

THINK AND FORMULATE ON YOUR OWN

Why are you at this school?

01

minutes

00

seconds

Some ground rules

- We are here to learn for the long run: think, ask, discuss!
- Nobody knows everything but everybody knows something
- Be mindful of "air time" – make space, and take space

One thing that would keep me from participating fully is: 28 Responses

Scared of saying something dumb	No sleep	Karaoke
Nothing	yeah sleep	The food in the hostel
No sleep	Lack of coffee	Show-offs

One thing that would keep me from participating fully is: **28** Responses

Expecting everyone to have the same background

Upcoming Exams

Magic of HASCO

to be bored about some topics

No coffeine

Caffeine deficit (wink wink)

I'm shy

Fear of being judged

Someone making me feel dumb

24



25



One thing that would keep me from participating fully is: 28 Responses

Rain	Not enough time to get used to	Closed conversations
Participating Fully	fear of asking something	Sleep and coffee
No coffee	My supervisor giving me extra work	Asking a dumb question

One thing that would keep me from participating fully is: **28** Responses

Lack of chalkboards

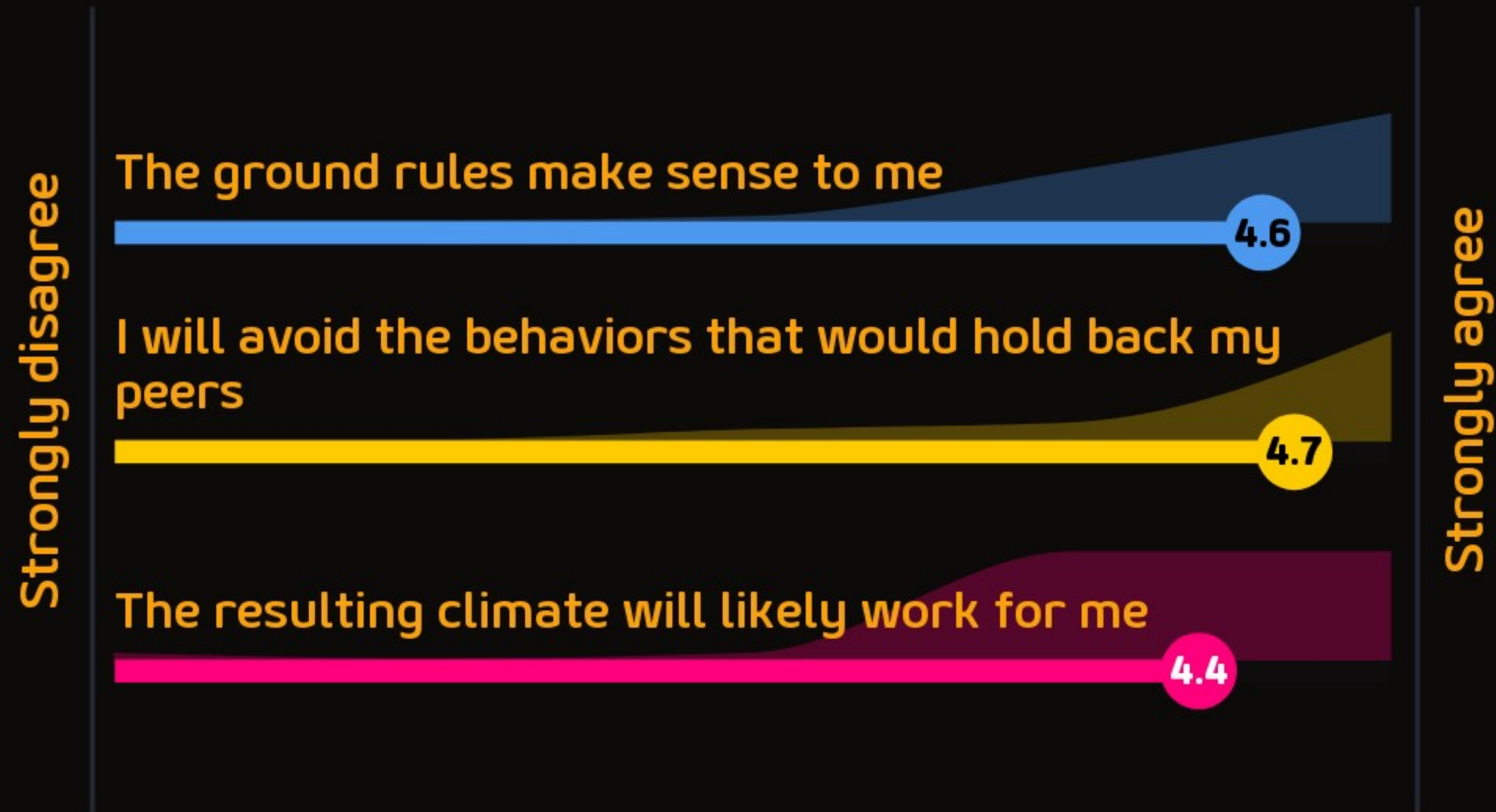
24



25



Towards an agreement on classroom climate



Why do I bother making this so clear?

- physics is a skewed population – needs to be named, and small interactions matter
- don't want you to waste cognitive power on "fitting in" – you are here to bring yourself
- learning in community enhances knowledge retention
- this will be your community for years to come
- you already made it, you belong here, you are welcome here.

Goal setting

As a way to ground ourselves and focus
our attention for the school

SMART goals – Specific, Measurable, Achievable, Relevant, Timely



Make "I want to be a better person" a SMART goal 21 Responses

Patience	Scheduled sleeping	Study harder
be less judgy	scheduled caffee break	Be fitter
Don't be arrogant	Stay away from me	Hike more

Make "I want to be a better person" a SMART goal 21 Responses

I want to be fully present at the lectures, trying to understand the most I can and ask for questions when in doubt

finishing task before deadline

Find Girlfriend

I would like to become more sociable

Spent at maximum 30 minutes daily on social media averaged per week.

knowing ourselves

Obtain a wider overview on physics at colliders and create bounds with potentially future colleagues

Make one person laugh by the end of the day

Appreciate your surroundings

Make "I want to be a better person" a SMART goal 21 Responses

be honest, have open mind

People here are interesting and cool.

Be understanding

FORMULATE ON YOUR OWN, BE PREPARED TO SHARE ONE. THUMBS UP WHEN DONE

Set 1-3 SMART goals for your participation in HASCO 2023

05

minutes

00

seconds

2 MINUTES PAIR/SHARE: TURN TO YOUR NEIGHBOR

Share one goal with your neighbor

- person with most recent birthday starts sharing
- check in with them if it's ok to share out to the group next
- no grading :) if it's just SMRT, or AT, or... that's fine

my goal: ~~preparing you in a state to learn~~

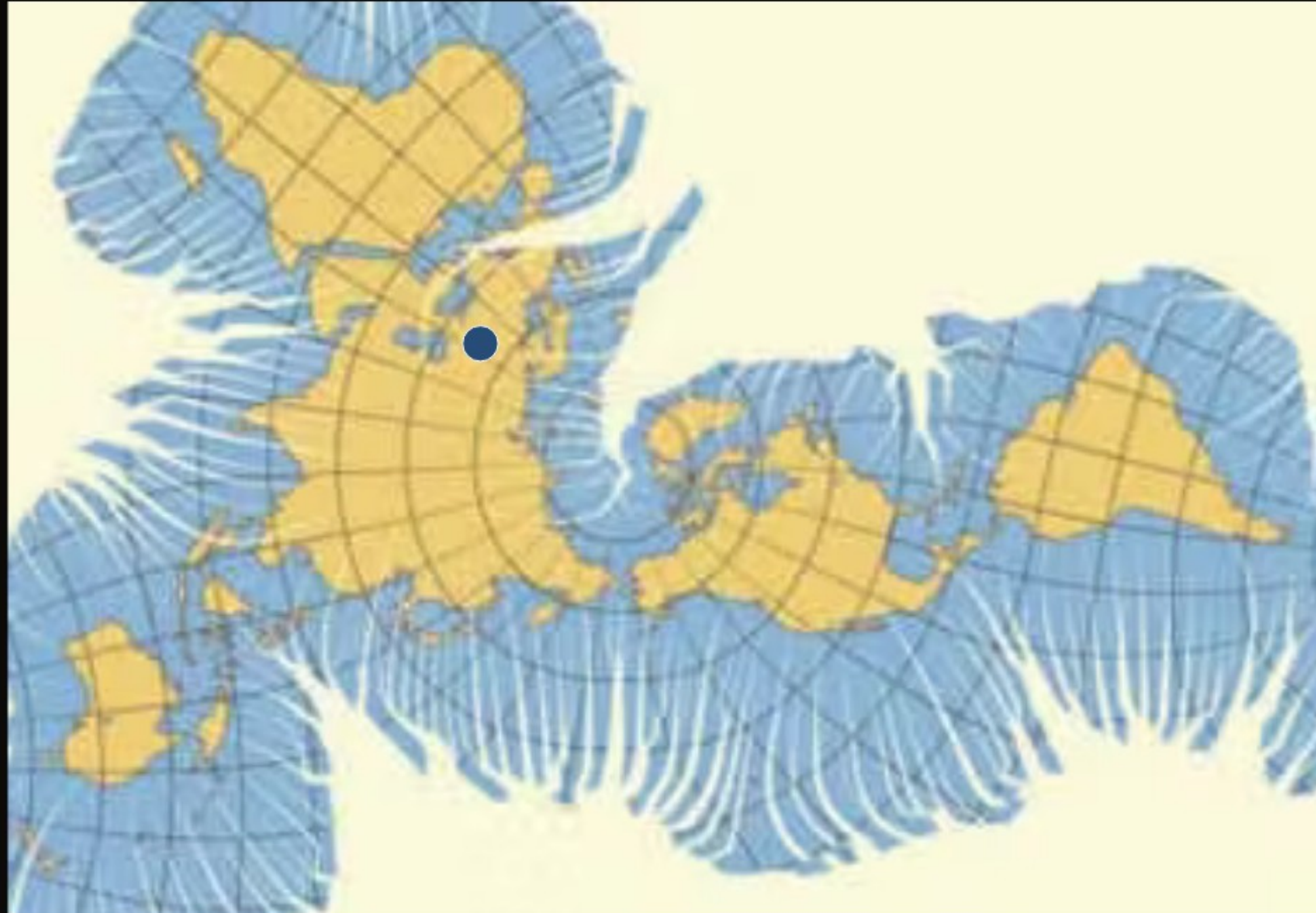
I mean, by lunch you have clarified to
yourself what you want to achieve this week,
you have activated and connected the
school's topics to your preexisting
knowledge,
you are active and curious,
and you are not afraid to speak up
– all of which I measure by how much
everyone is sharing insights and asking
questions

time for a bio break

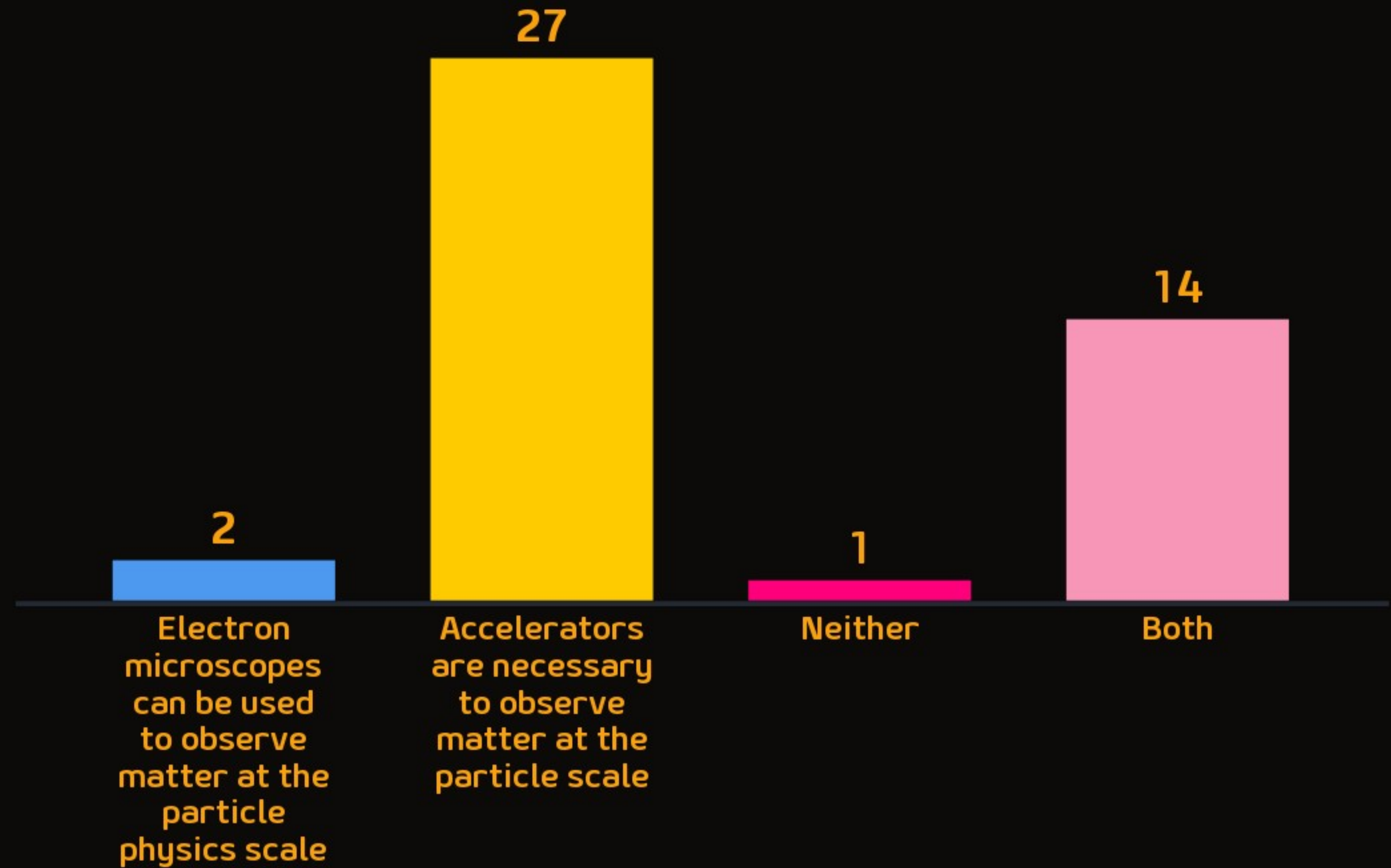
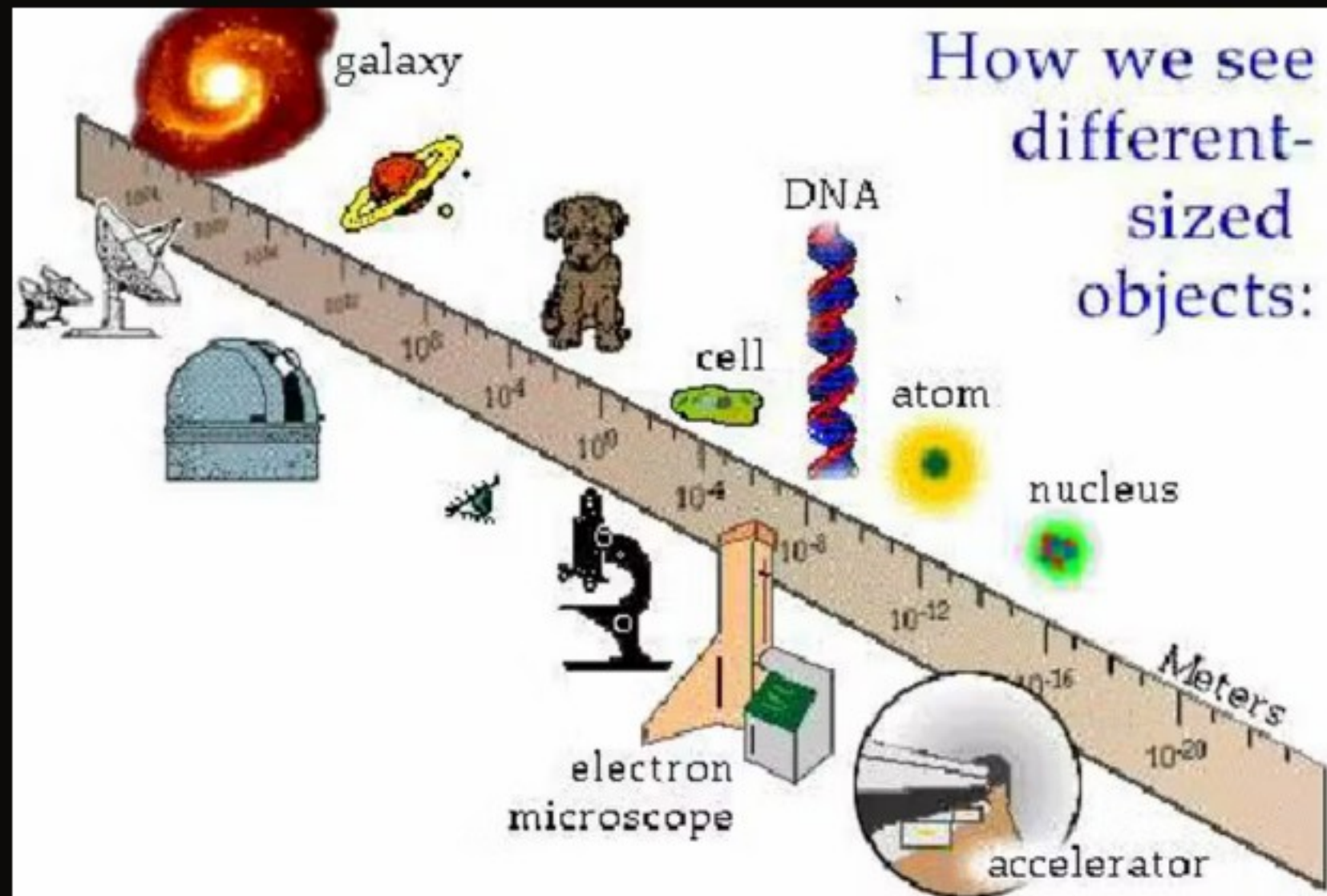
- stretch your legs, get some air, ...
- ask questions
- reshuffle! find a new place to sit (if possible/comfortable)

OPTIONAL DURING BREAK TIME

Pin where you're studying on the map



Observation in particle physics



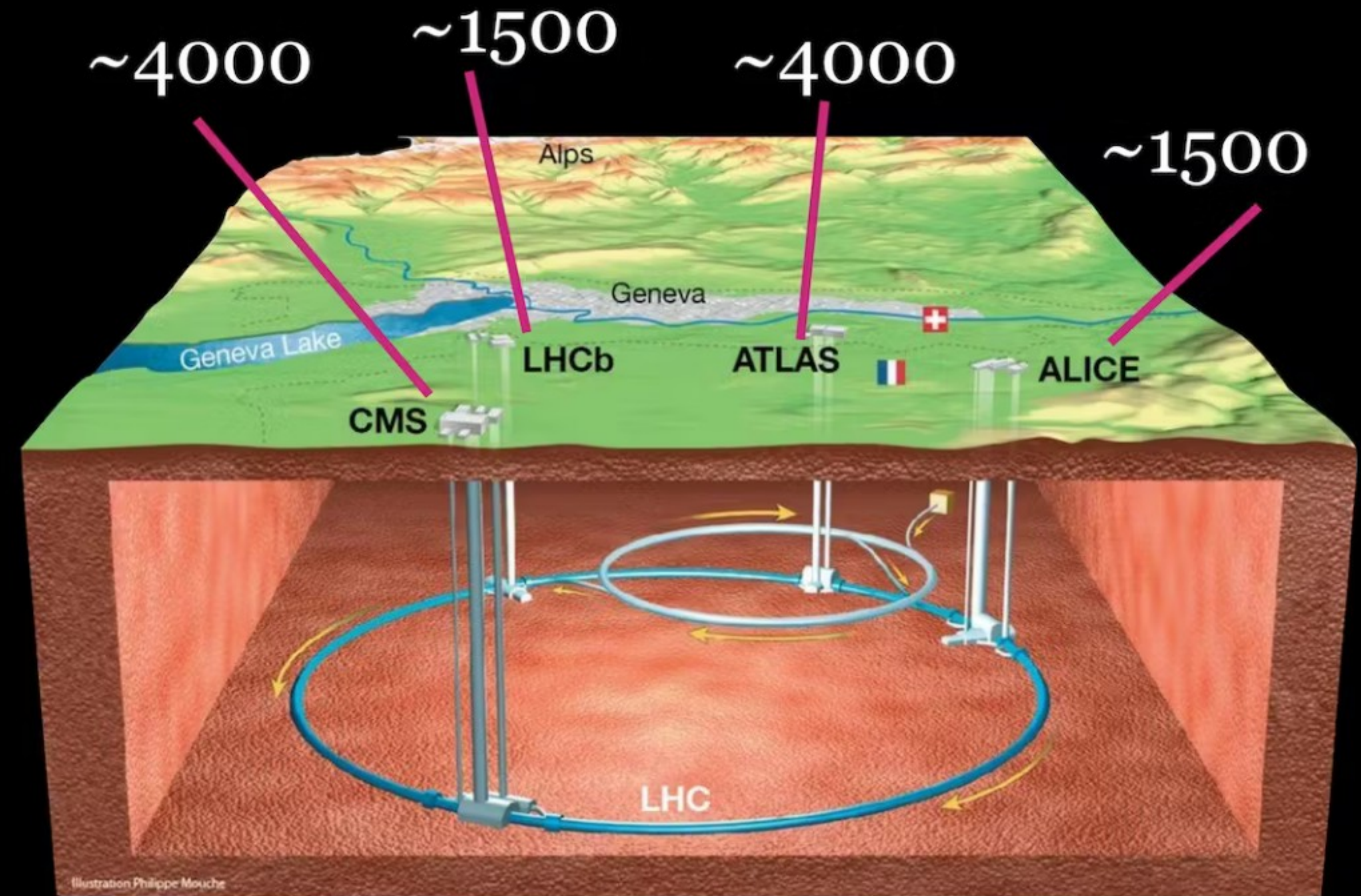
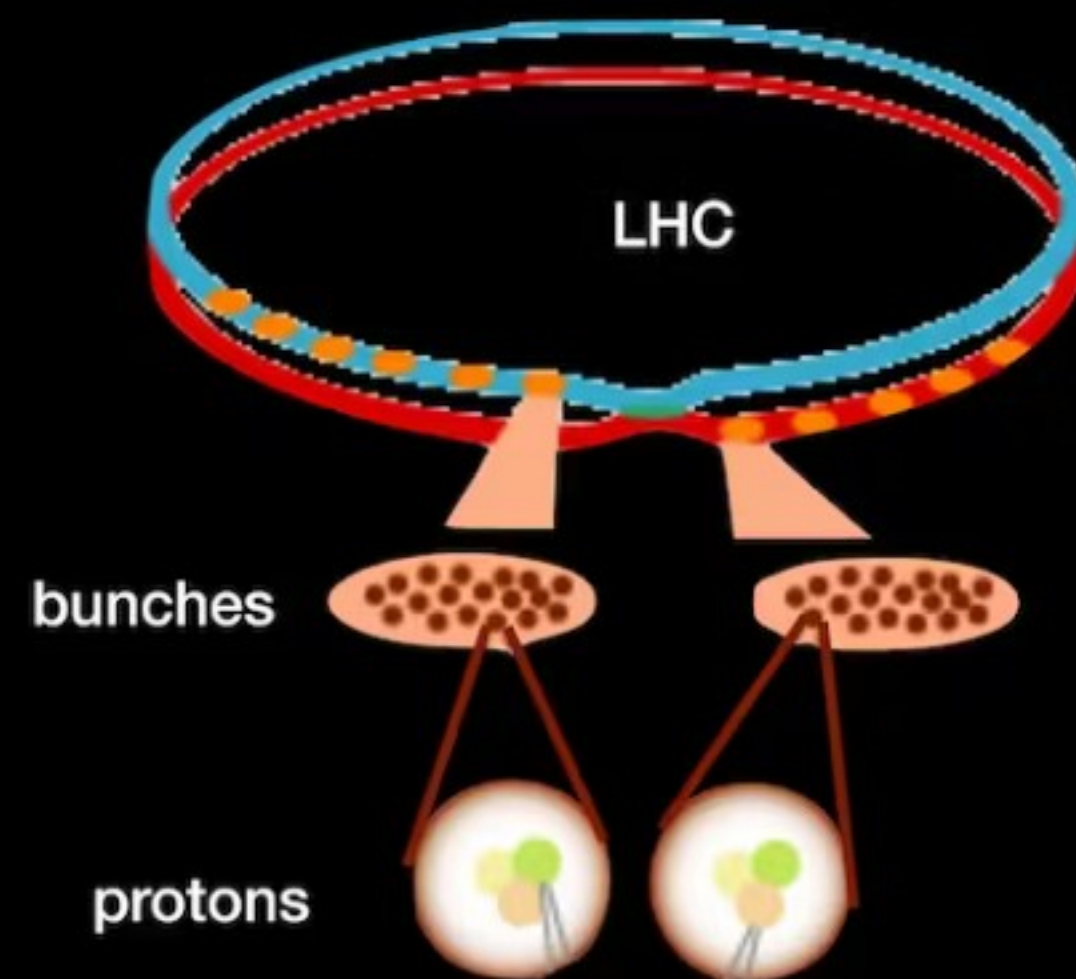
Guiding question: why hadron colliders?

let's introduce a hadron collider

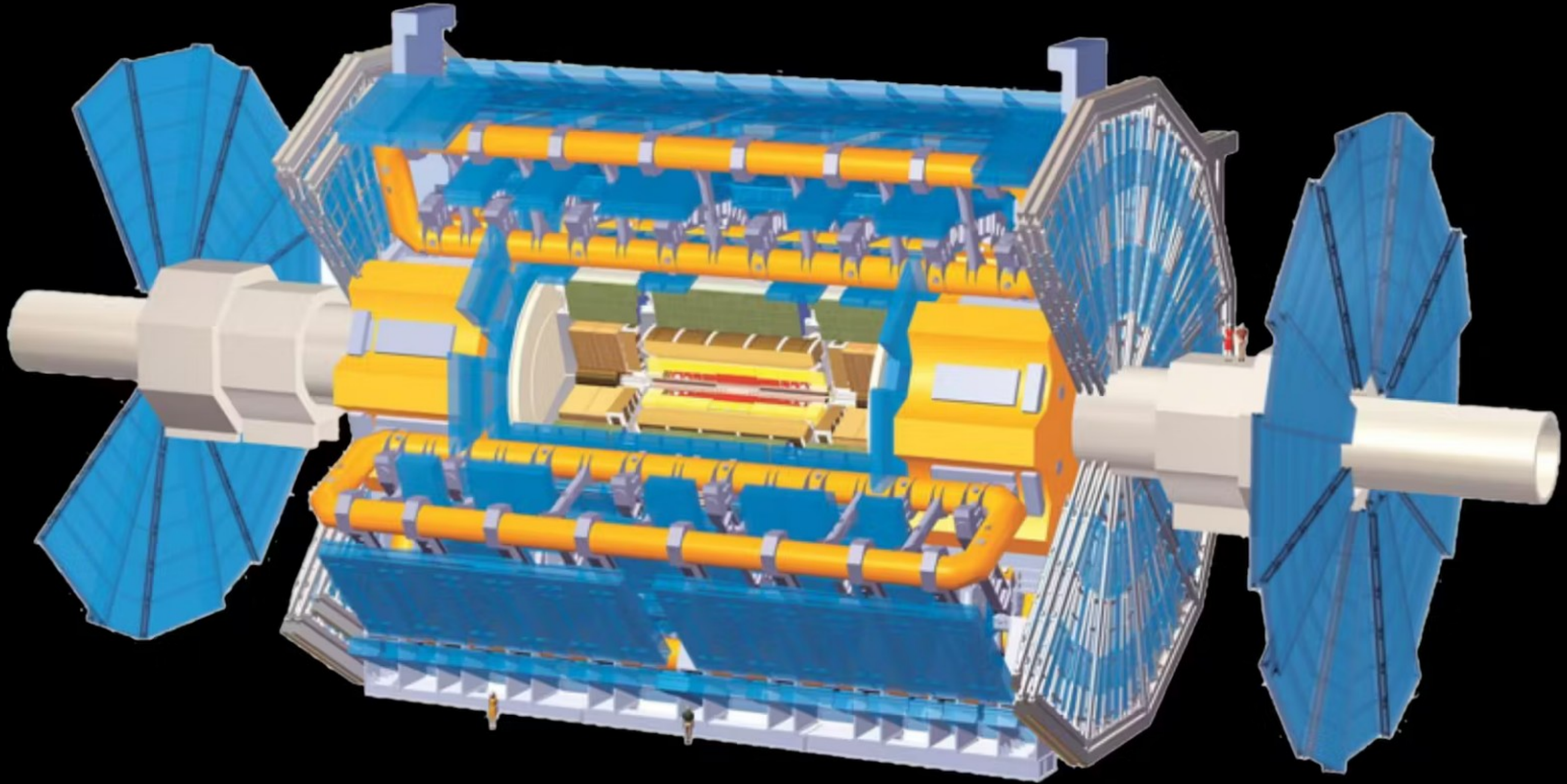


~12000 people work on the LHC and its experiments

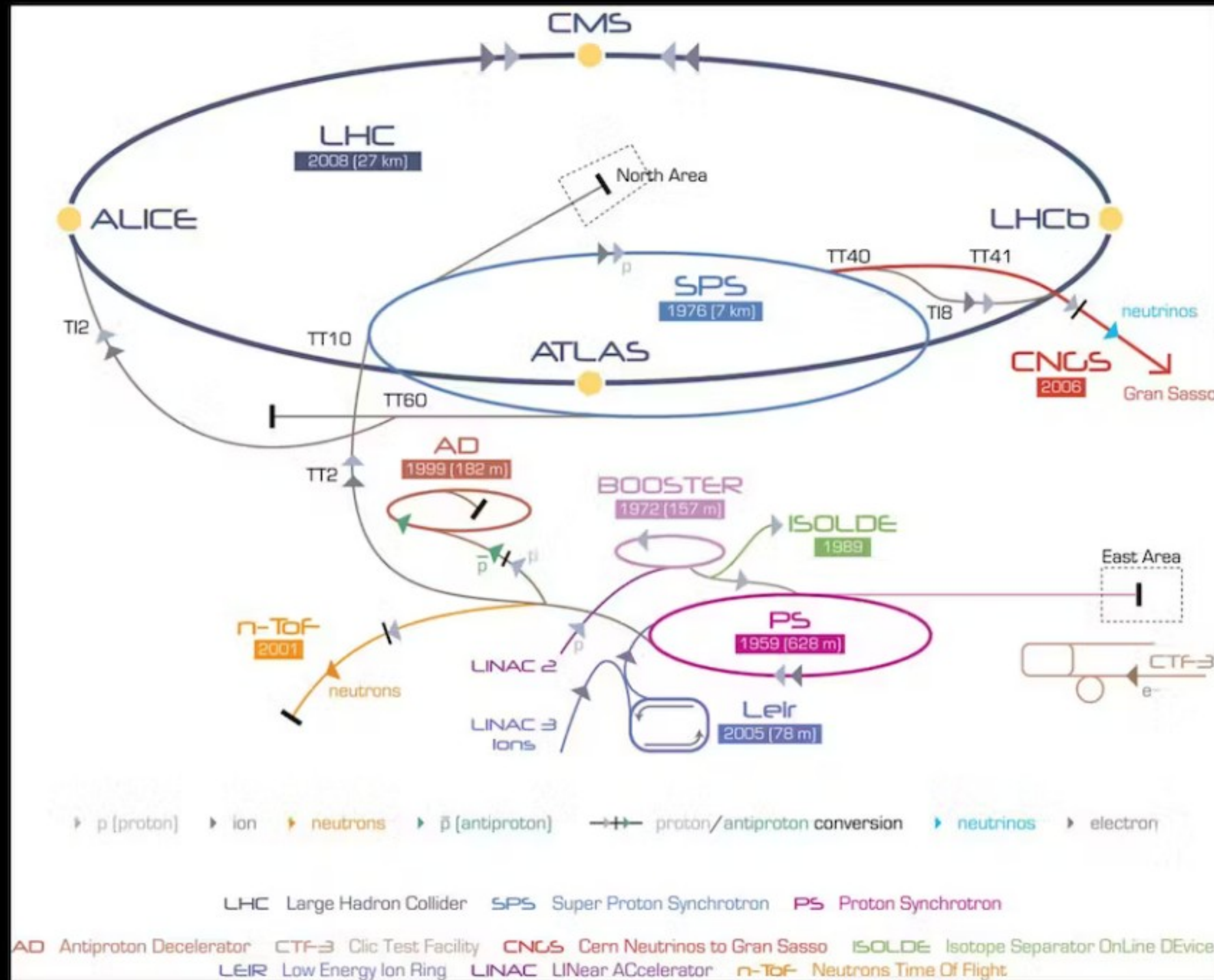
let's introduce a hadron collider



ATLAS for scale

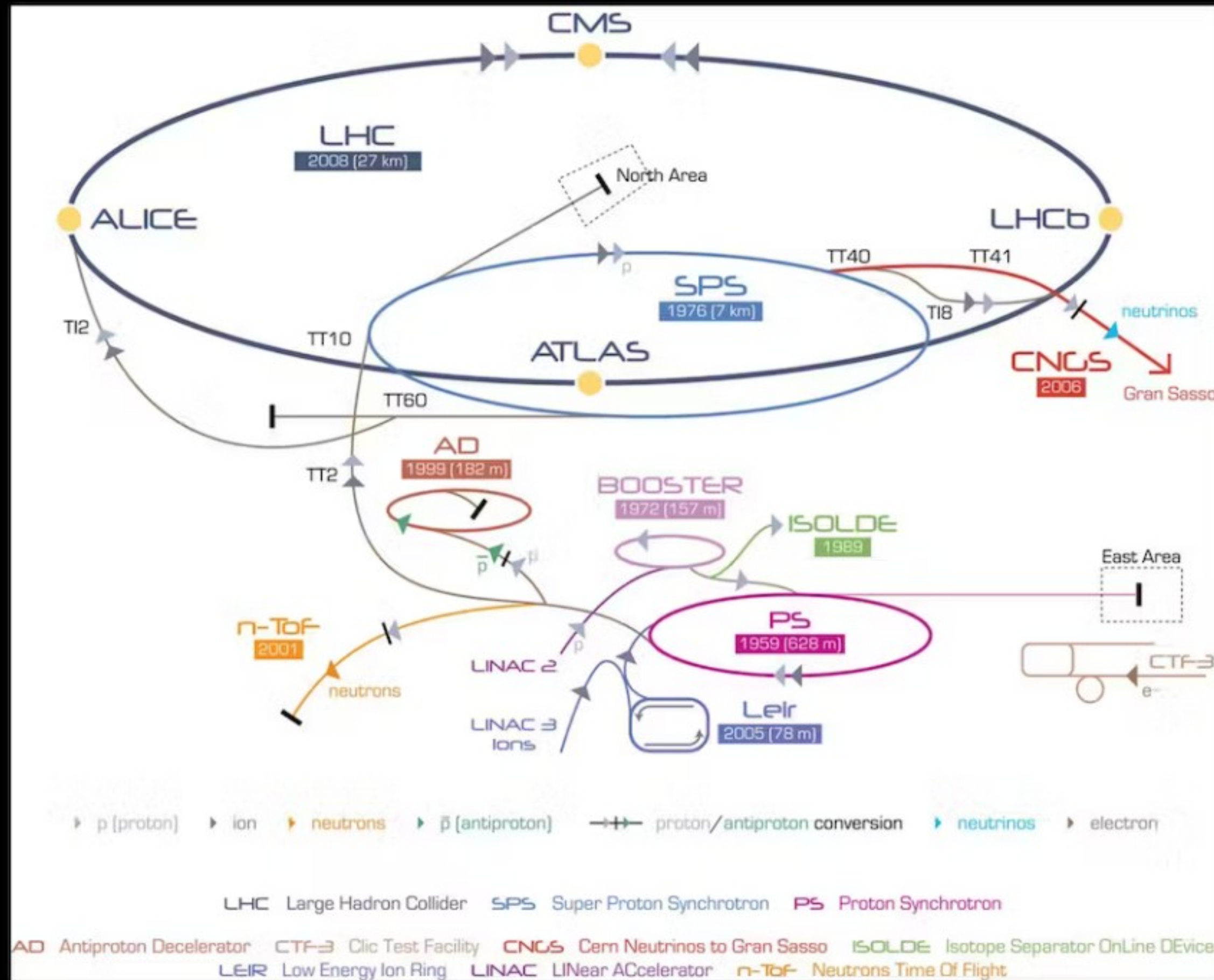


the LHC: the last step in an accelerator chain



... and CERN has more than hadron collider experiments

the LHC: the last step in an accelerator chain



... and CERN has more than hadron collider experiments

*a hadron collider physics school
≠
an all-of-experimental-
particle-physics school*

but a hadron collider physics school is

an opportunity to think about
Why hadron colliders?

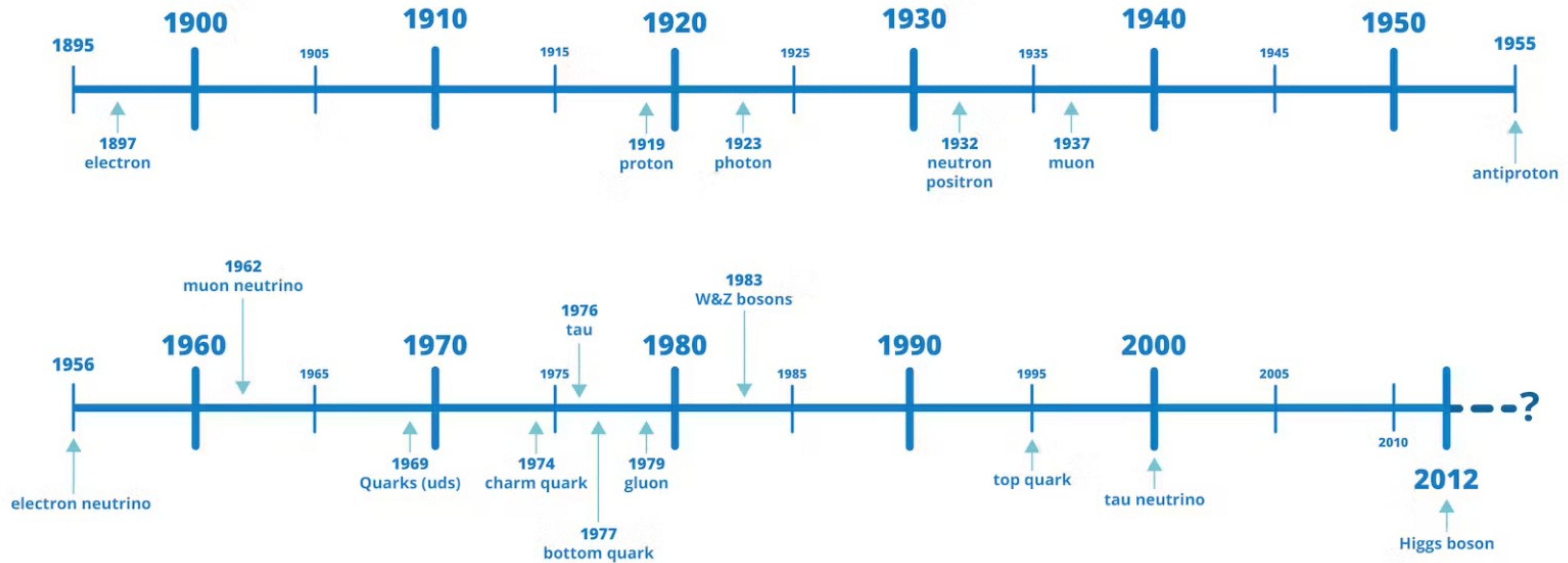
1. an experimental primer

principles of particle detection

a timeline



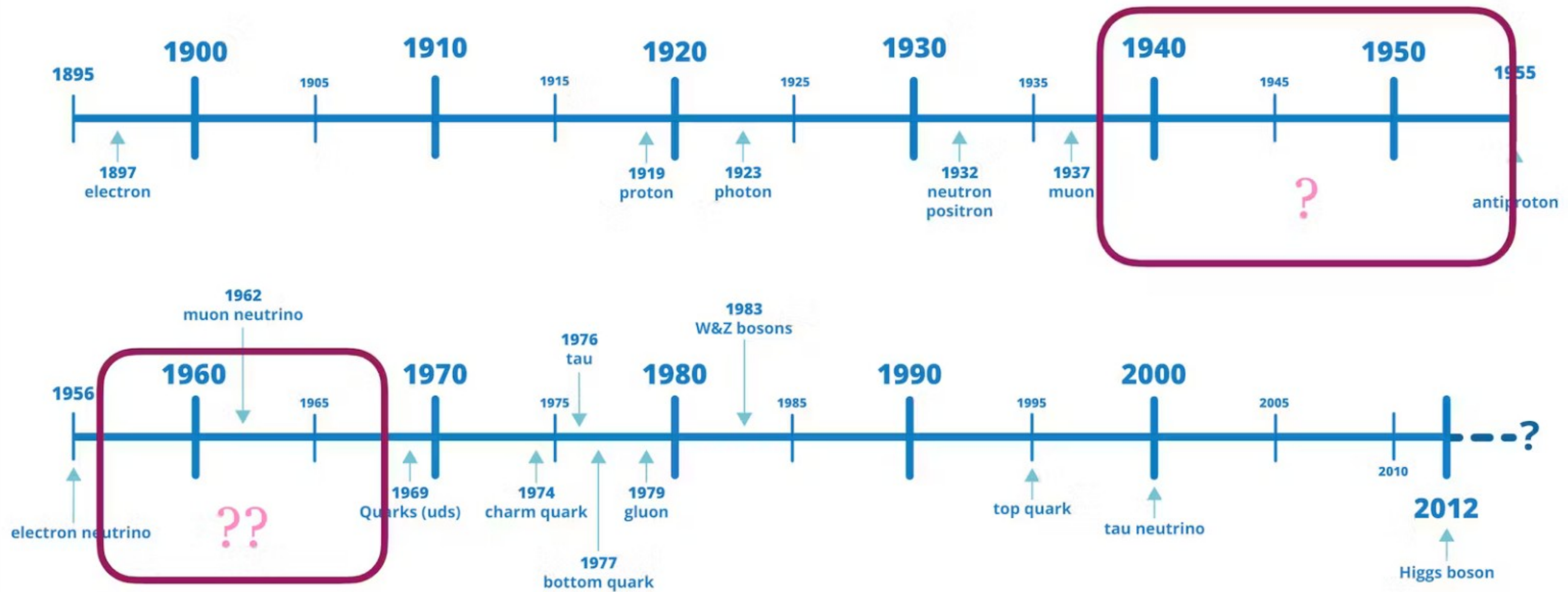
Key particle discoveries



a timeline

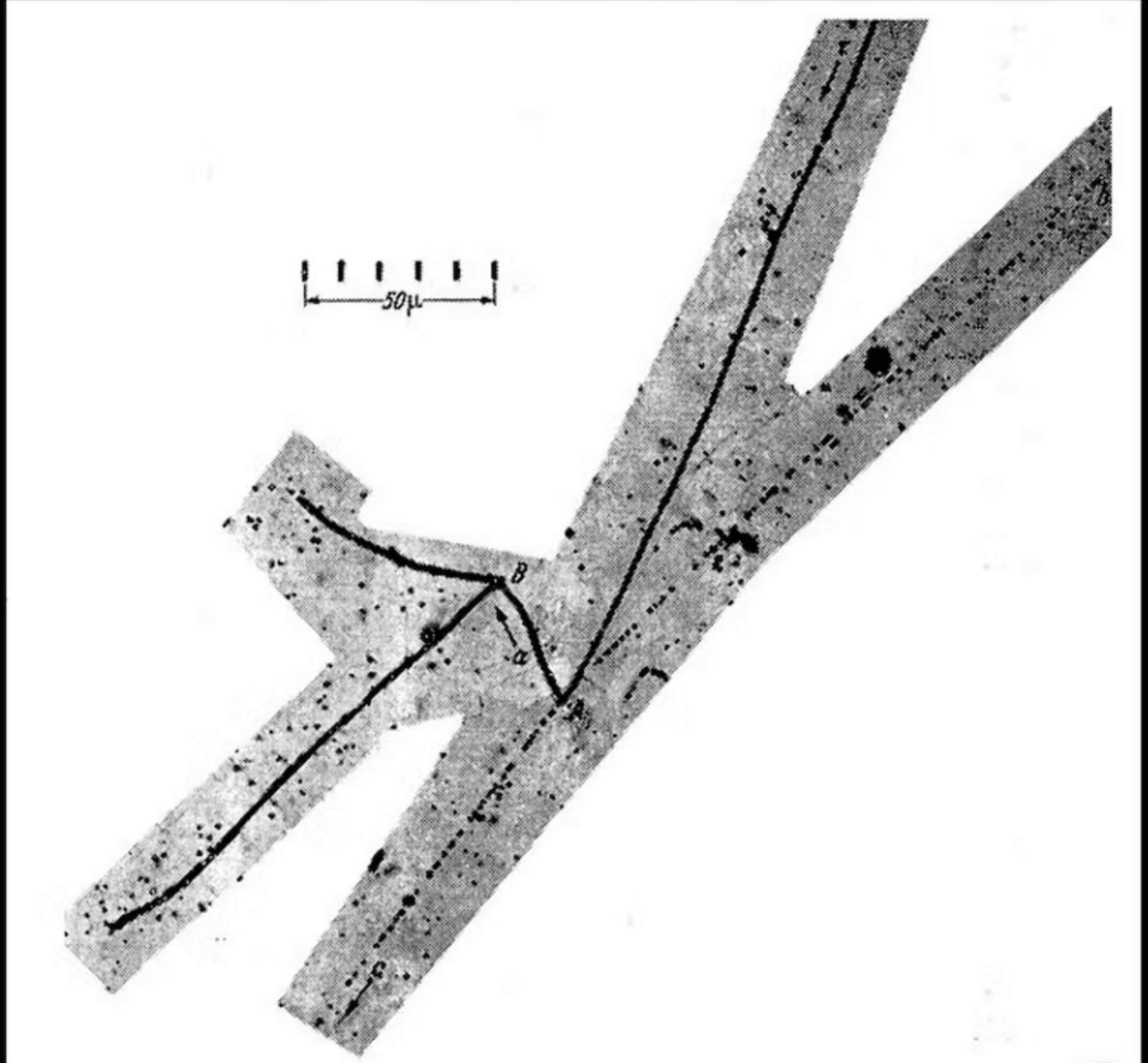


Key particle discoveries

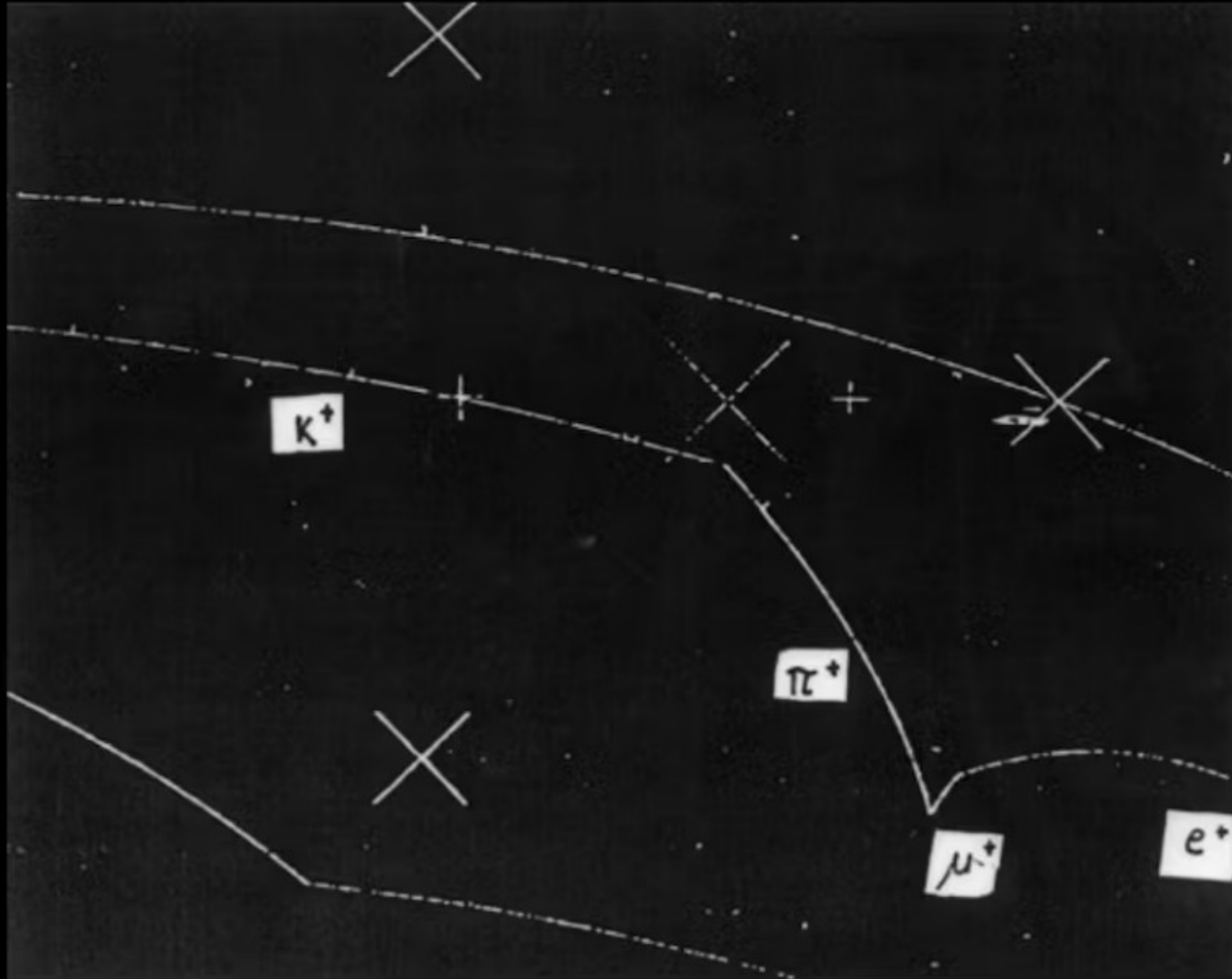


about detectors: nuclear emulsions

- balloon experiments, cosmic rays, etc
- observation of “K meson” (kaon) — strange decays
- still to date about as good spatial resolution *as any detector can get*

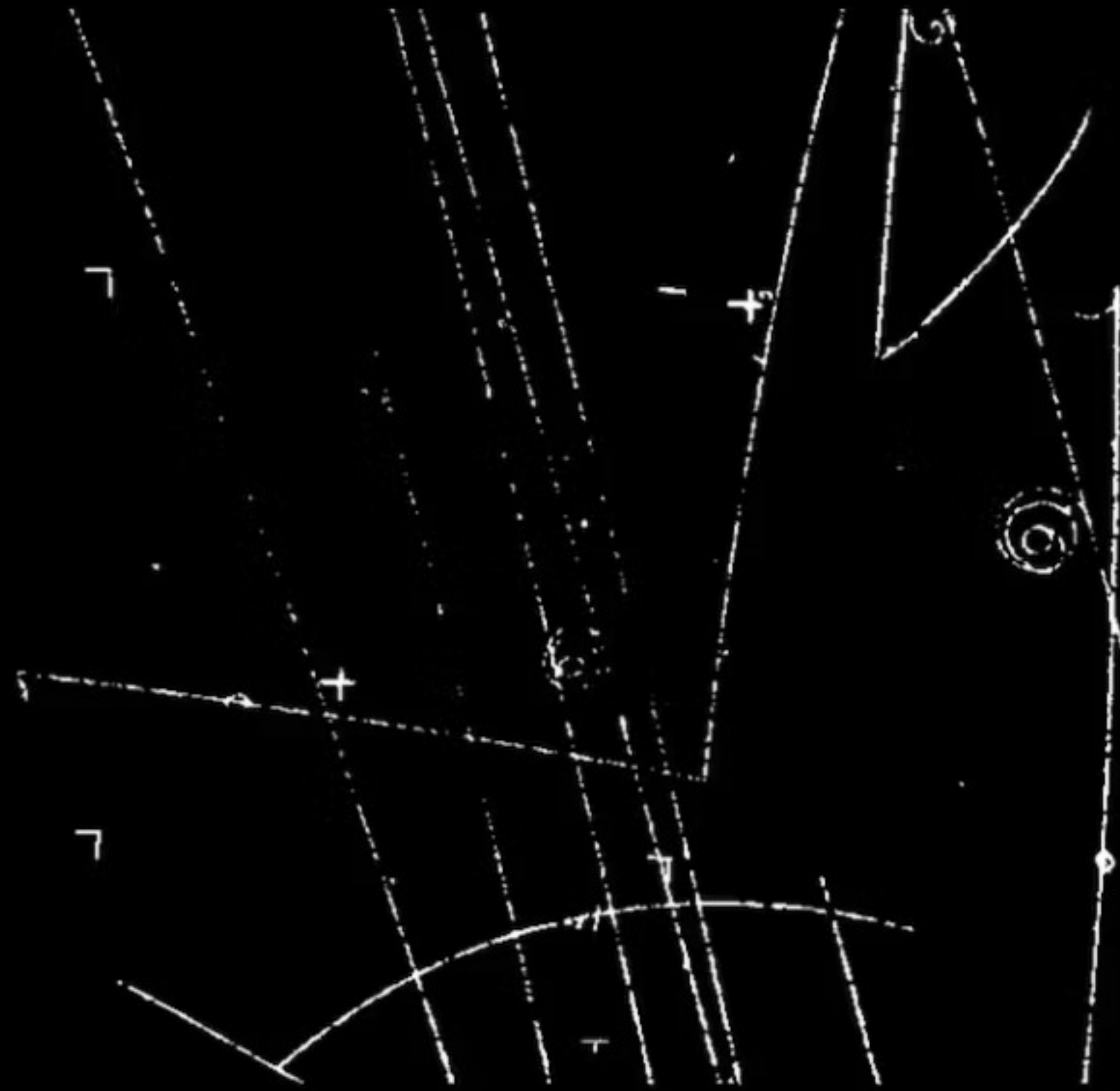


Bubble chambers



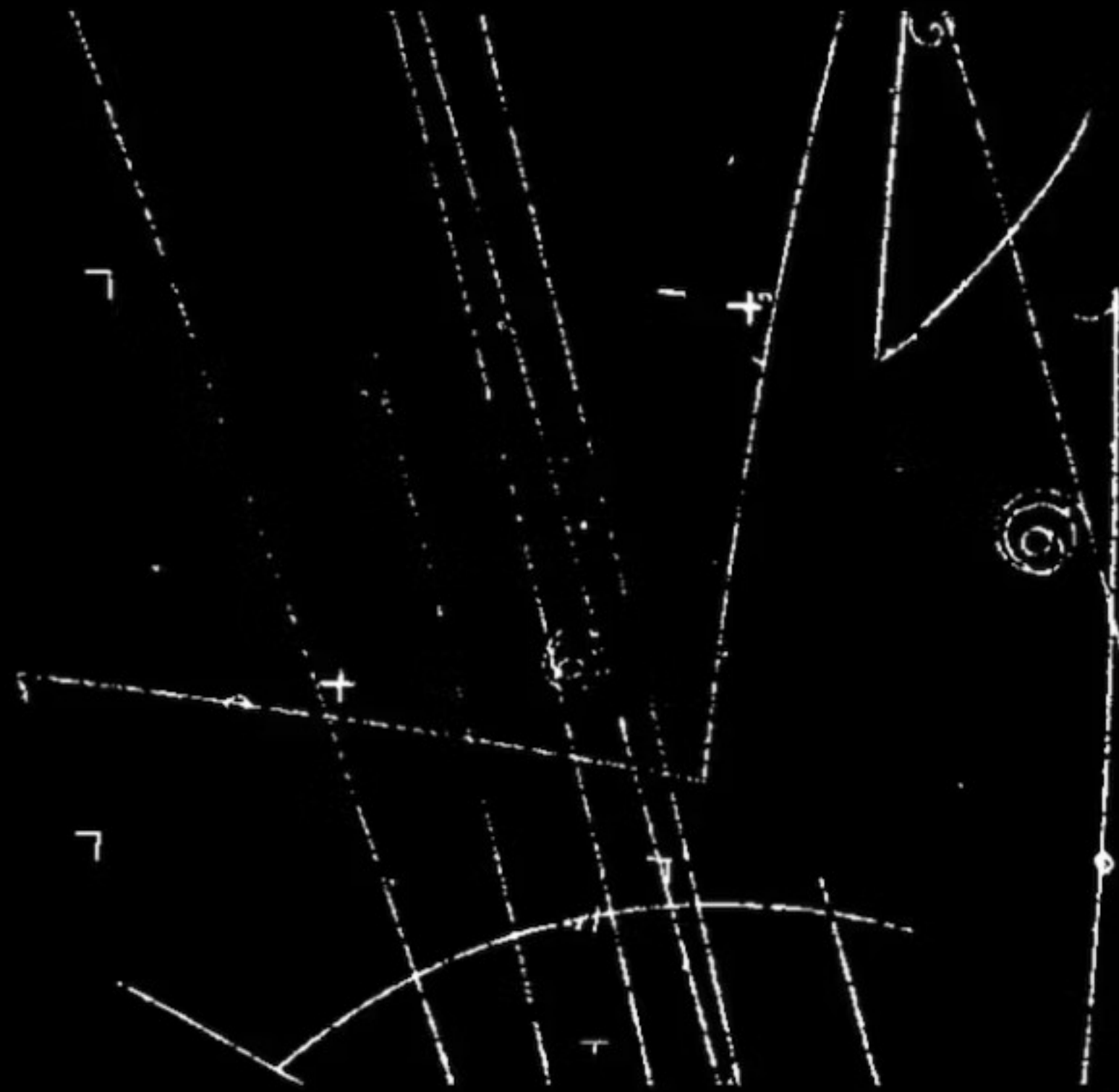
Scanners at work at CERN

π^- beam in liquid-H bubble chamber

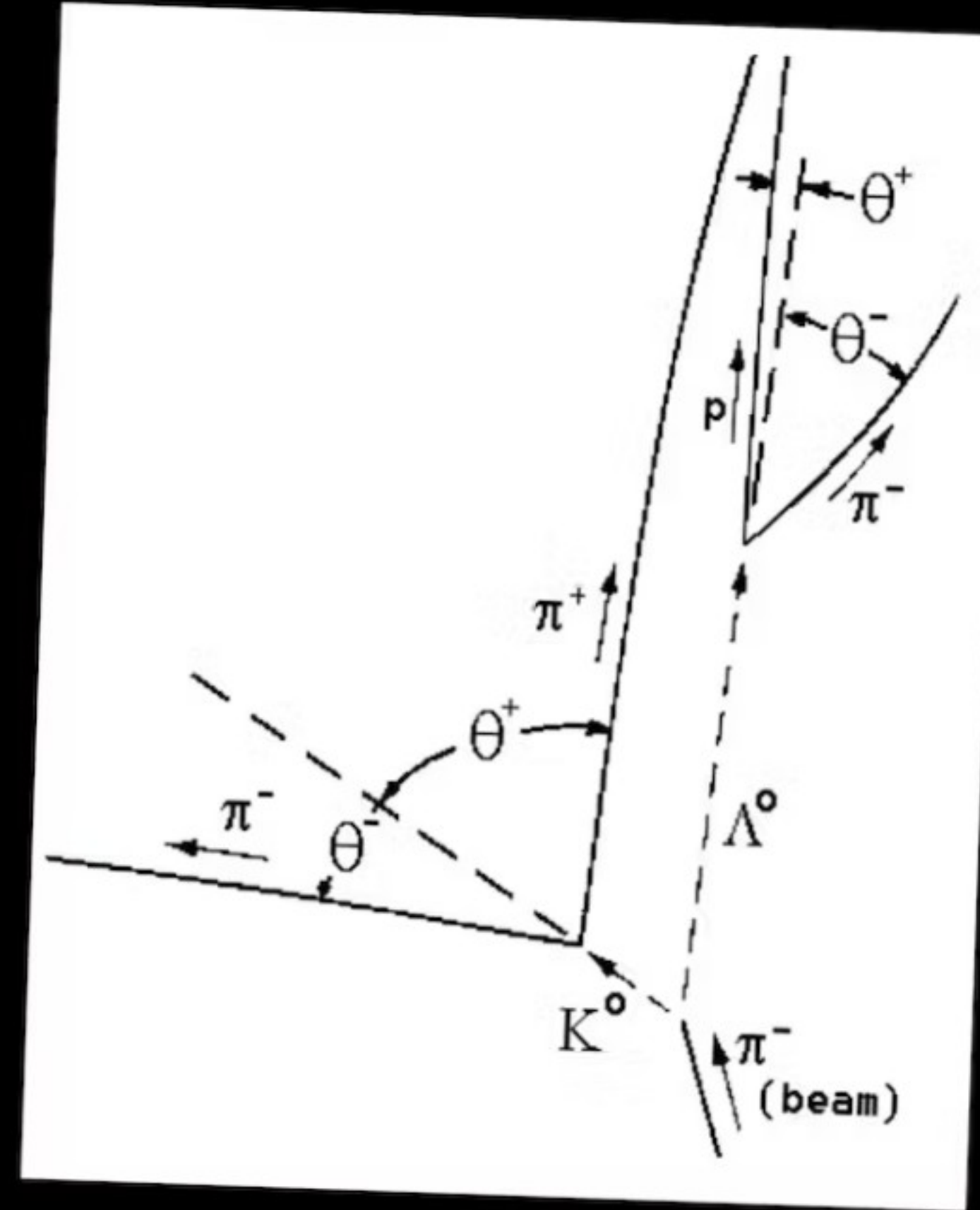


Bevatron, Lawrence Berkeley Lab

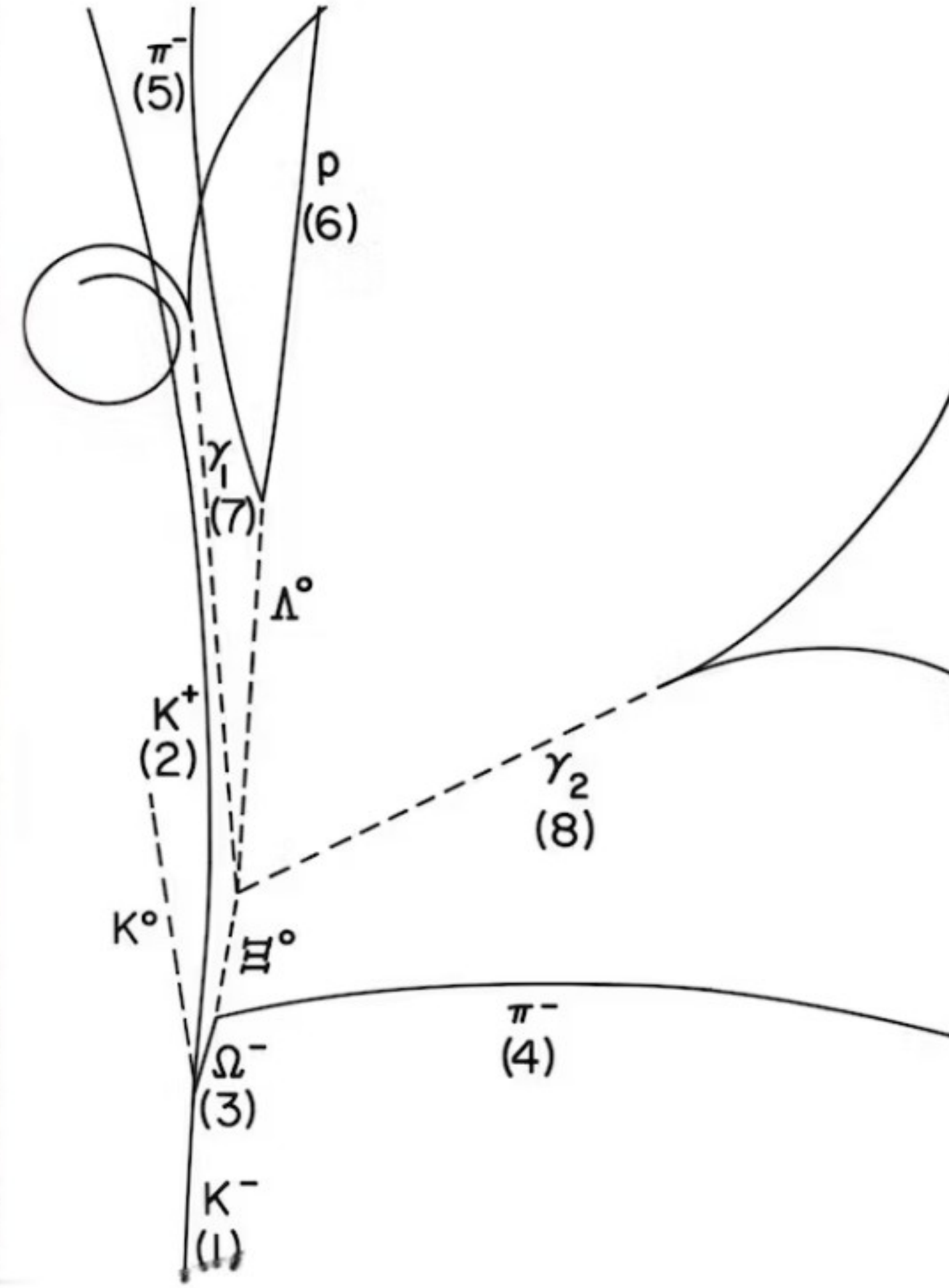
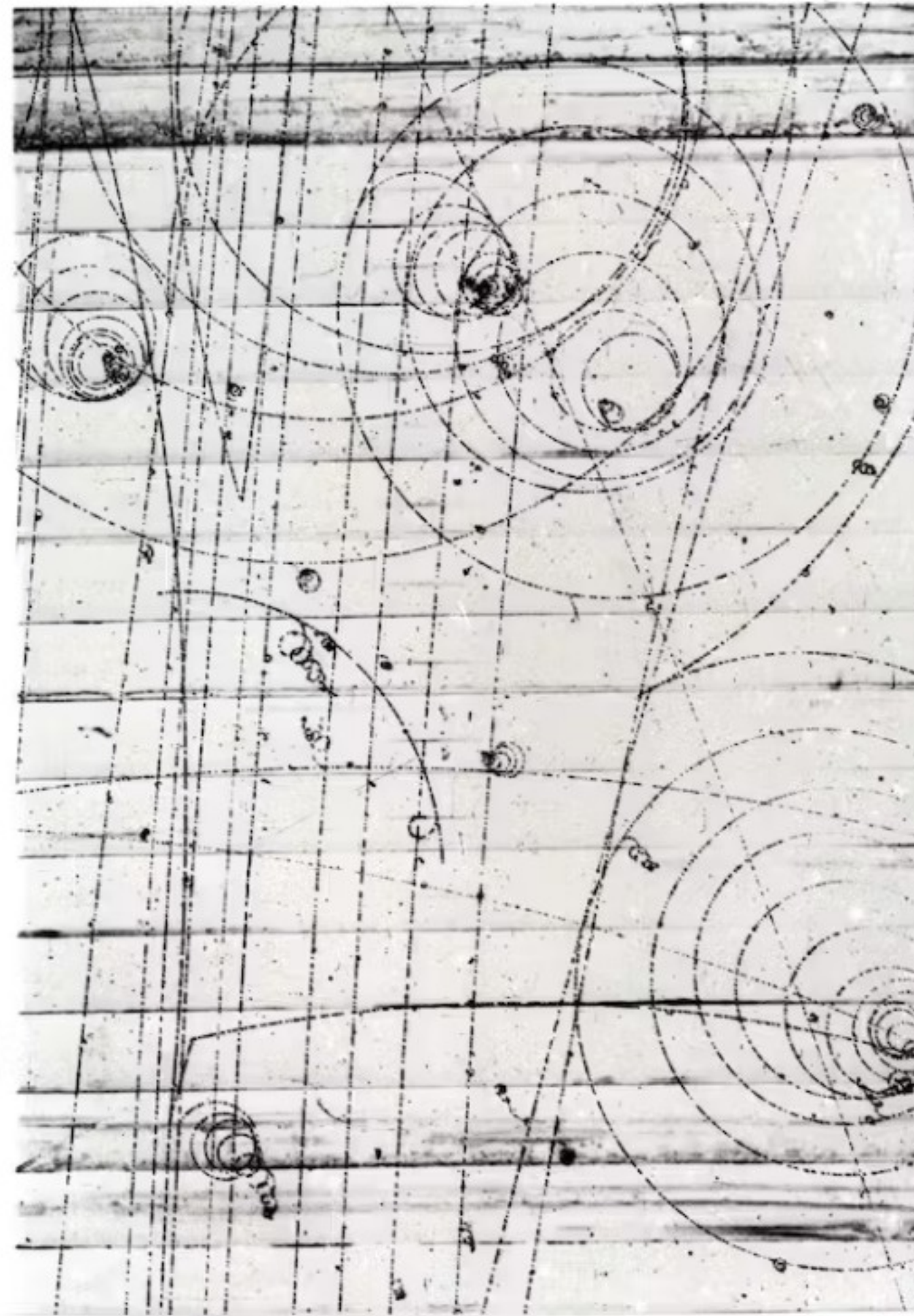
π^- beam in liquid-H bubble chamber



Bevatron, Lawrence Berkeley Lab



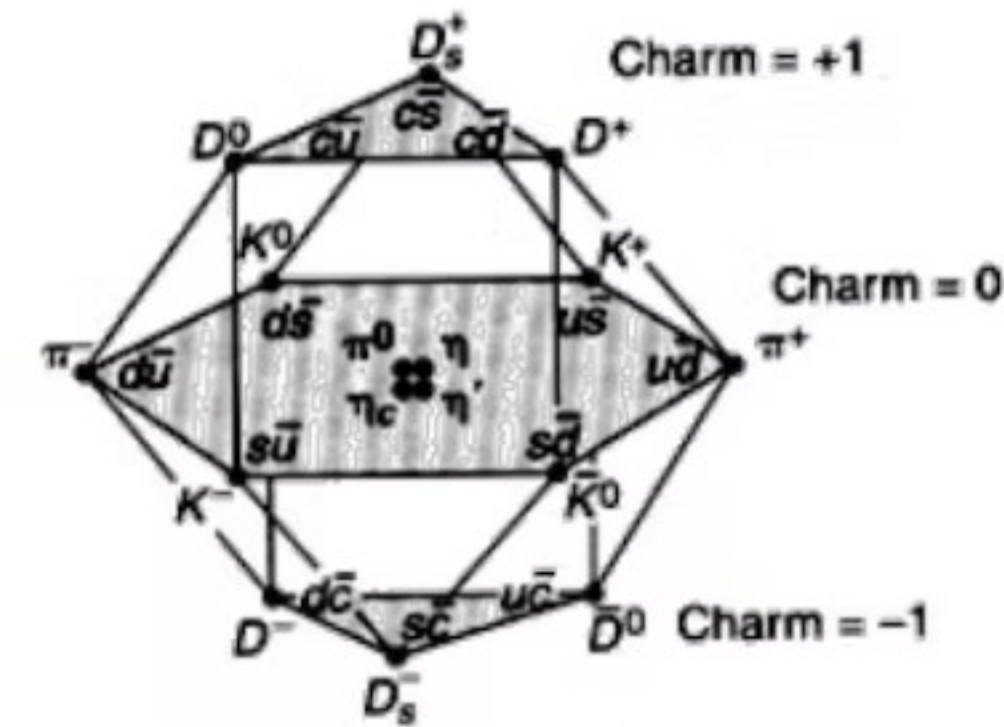
number of fundamental particles exploded



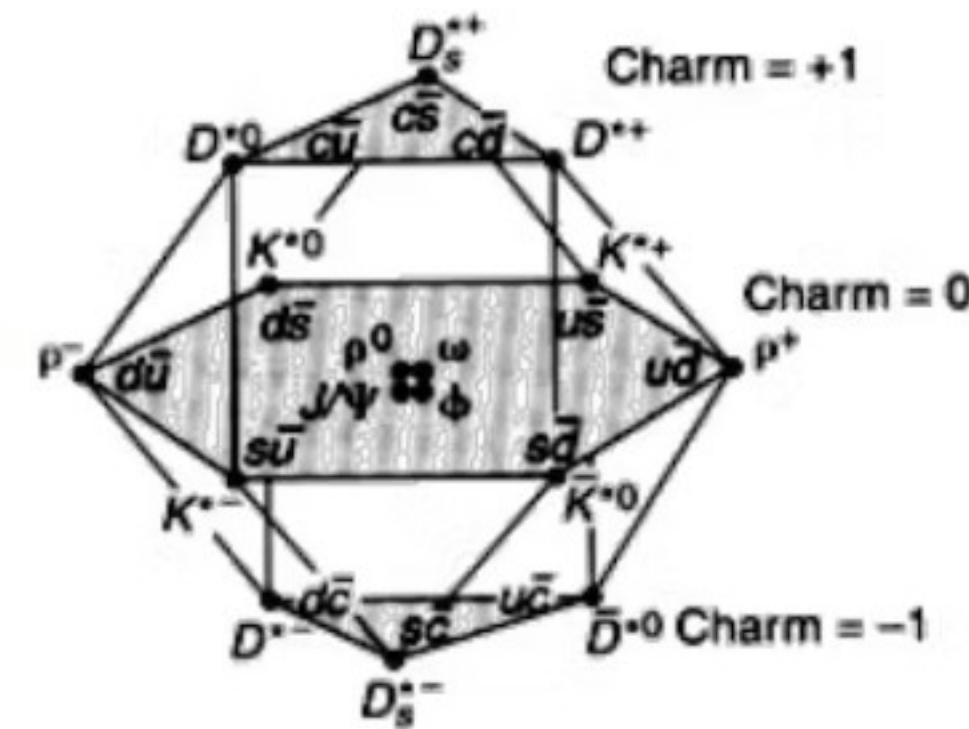
A new system forms

Periodic Table of the Elements

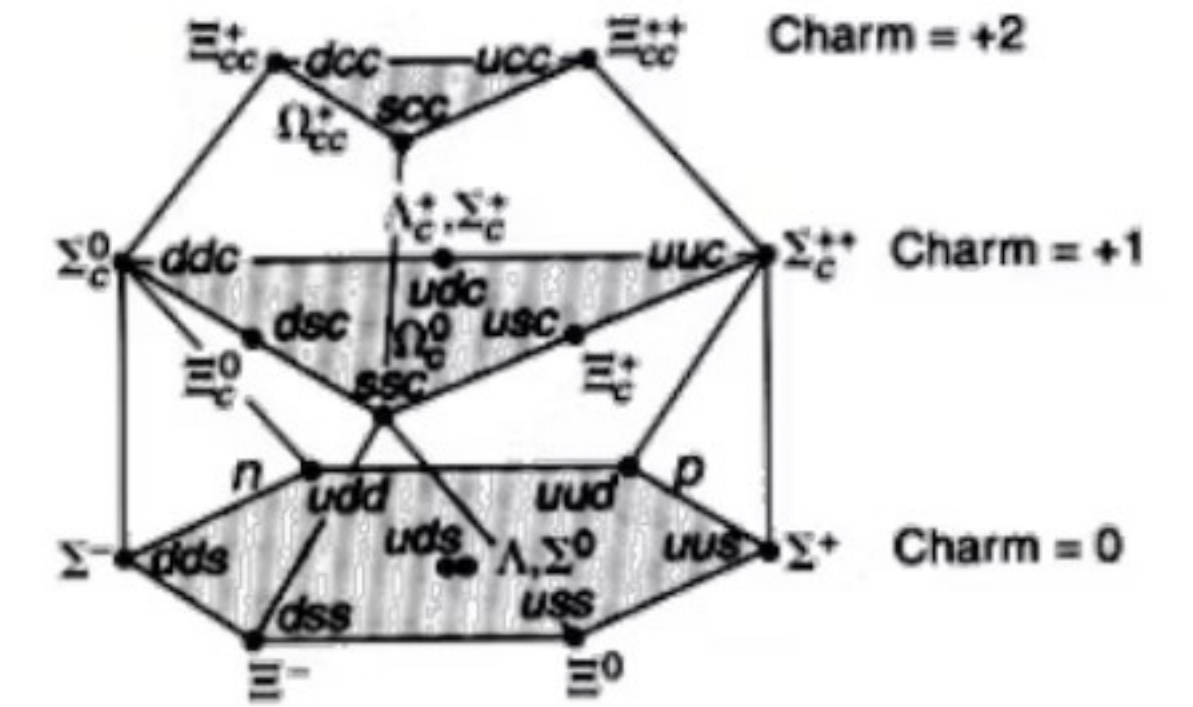
<div><div>Atomic Number →</div><div>← Symbol</div><div>Name →</div><div>Electrons per shell →</div></div> <div><div>13</div><div>Al</div><div>Aluminium</div><div>26.982</div><div>3-3</div></div>																																				<div><div>13</div><div>B</div><div>Boron</div><div>10.81</div><div>2-2</div></div> <div><div>14</div><div>C</div><div>Carbon</div><div>12.011</div><div>2-4</div></div> <div><div>15</div><div>N</div><div>Nitrogen</div><div>14.007</div><div>2-5</div></div> <div><div>16</div><div>O</div><div>Oxygen</div><div>15.999</div><div>2-6</div></div> <div><div>17</div><div>F</div><div>Fluorine</div><div>18.998</div><div>2-7</div></div> <div><div>18</div><div>Ne</div><div>Neon</div><div>20.180</div><div>2-8</div></div>																																																					
<div><div>State of matter (color of name)</div><div>GAS LIQUID SOLID UNKNOWN</div></div> <div><div>Subcategory in the metal-metalloid-nonmetal trend (color of background)</div><div>Alkali metals</div><div>Alkaline earth metals</div><div>Transition metals</div><div>Lanthanides</div><div>Actinides</div><div>Post-transition metals</div><div>Metalloids</div><div>Reactive nonmetals</div><div>Noble gases</div><div>Unknown chemical properties</div></div>																																																																																									
<div><div>1</div><div>IA</div><div>H</div><div>Hydrogen</div><div>1.008</div><div>1</div></div> <div><div>2</div><div>IIA</div><div>Li</div><div>Lithium</div><div>6.94</div><div>2</div></div> <div><div>3</div><div>Be</div><div>Beryllium</div><div>9.012</div><div>2</div></div> <div><div>4</div><div>Na</div><div>Sodium</div><div>22.98976928</div><div>3-1</div></div> <div><div>5</div><div>Mg</div><div>Magnesium</div><div>24.305</div><div>2-8-2</div></div> <div><div>6</div><div>K</div><div>Potassium</div><div>39.0983</div><div>4-1</div></div> <div><div>7</div><div>Ca</div><div>Calcium</div><div>40.078</div><div>2-8-2</div></div> <div><div>8</div><div>Rb</div><div>Rubidium</div><div>85.468</div><div>5-1</div></div> <div><div>9</div><div>Sr</div><div>Strontium</div><div>87.62</div><div>2-8-2</div></div> <div><div>10</div><div>Cs</div><div>Cesium</div><div>132.90545196</div><div>6-1</div></div> <div><div>11</div><div>Ba</div><div>Barium</div><div>137.327</div><div>2-8-2</div></div> <div><div>12</div><div>Fr</div><div>Francium</div><div>223</div><div>2-8-2-18-32-5</div></div> <div><div>13</div><div>Ra</div><div>Radium</div><div>226</div><div>2-8-2-18-32</div></div>																																				<div><div>19</div><div>Sc</div><div>Scandium</div><div>44.955908</div><div>3-2-1</div></div> <div><div>20</div><div>Ti</div><div>Titanium</div><div>47.88</div><div>3-2-2</div></div> <div><div>21</div><div>V</div><div>Vanadium</div><div>50.9415</div><div>3-2-3</div></div> <div><div>22</div><div>Cr</div><div>Chromium</div><div>51.9961</div><div>3-2-3</div></div> <div><div>23</div><div>Mn</div><div>Manganese</div><div>54.938044</div><div>3-2-5</div></div> <div><div>24</div><div>Fe</div><div>Iron</div><div>55.845</div><div>3-2-6</div></div> <div><div>25</div><div>Co</div><div>Cobalt</div><div>58.933</div><div>3-2-6</div></div> <div><div>26</div><div>Ni</div><div>Nickel</div><div>58.693</div><div>3-2-6</div></div> <div><div>27</div><div>Cu</div><div>Copper</div><div>63.546</div><div>3-2-9</div></div> <div><div>28</div><div>Zn</div><div>Zinc</div><div>65.38</div><div>3-2-9</div></div> <div><div>29</div><div>Ga</div><div>Gallium</div><div>69.723</div><div>3-2-9</div></div> <div><div>30</div><div>Ge</div><div>Germanium</div><div>72.63</div><div>3-2-9</div></div> <div><div>31</div><div>As</div><div>Arsenic</div><div>74.922</div><div>3-2-9</div></div> <div><div>32</div><div>Se</div><div>Selenium</div><div>78.971</div><div>3-2-9</div></div> <div><div>33</div><div>Br</div><div>Bromine</div><div>79.904</div><div>3-2-9</div></div> <div><div>34</div><div>Kr</div><div>Krypton</div><div>83.798</div><div>3-2-9</div></div>																																				<div><div>35</div><div>Al</div><div>Aluminium</div><div>26.982</div><div>3-3</div></div> <div><div>36</div><div>Si</div><div>Silicon</div><div>28.086</div><div>3-4</div></div> <div><div>37</div><div>P</div><div>Phosphorus</div><div>30.974</div><div>3-5</div></div> <div><div>38</div><div>S</div><div>Sulfur</div><div>32.06</div><div>3-6</div></div> <div><div>39</div><div>Cl</div><div>Chlorine</div><div>35.45</div><div>3-7</div></div> <div><div>40</div><div>Ar</div><div>Argon</div><div>39.948</div><div>3-8</div></div> <div><div>41</div><div>K</div><div>Potassium</div><div>39.0983</div><div>4-1</div></div> <div><div>42</div><div>Ca</div><div>Calcium</div><div>40.078</div><div>2-8-2</div></div> <div><div>43</div><div>Sc</div><div>Scandium</div><div>44.955908</div><div>3-2-1</div></div> <div><div>44</div><div>Ti</div><div>Titanium</div><div>47.88</div><div>3-2-2</div></div> <div><div>45</div><div>V</div><div>Vanadium</div><div>50.9415</div><div>3-2-3</div></div> <div><div>46</div><div>Cr</div><div>Chromium</div><div>51.9961</div><div>3-2-3</div></div> <div><div>47</div><div>Mn</div><div>Manganese</div><div>54.938044</div><div>3-2-5</div></div> <div><div>48</div><div>Fe</div><div>Iron</div><div>55.845</div><div>3-2-6</div></div> <div><div>49</div><div>Co</div><div>Cobalt</div><div>58.933</div><div>3-2-6</div></div> <div><div>50</div><div>Ni</div><div>Nickel</div><div>58.693</div><div>3-2-6</div></div> <div><div>51</div><div>Cu</div><div>Copper</div><div>63.546</div><div>3-2-9</div></div> <div><div>52</div><div>Zn</div><div>Zinc</div><div>65.38</div><div>3-2-9</div></div> <div><div>53</div><div>Ga</div><div>Gallium</div><div>69.723</div><div>3-2-9</div></div> <div><div>54</div><div>Ge</div><div>Germanium</div><div>72.63</div><div>3-2-9</div></div> <div><div>55</div><div>As</div><div>Arsenic</div><div>74.922</div><div>3-2-9</div></div> <div><div>56</div><div>Se</div><div>Selenium</div><div>78.971</div><div>3-2-9</div></div> <div><div>57</div><div>Br</div><div>Bromine</div><div>79.904</div><div>3-2-9</div></div> <div><div>58</div><div>Kr</div><div>Krypton</div><div>83.798</div><div>3-2-9</div></div>																	
<div><div>3</div><div>IIIB</div><div>Sc</div><div>Scandium</div><div>44.955908</div><div>3-2-1</div></div> <div><div>4</div><div>IVB</div><div>Ti</div><div>Titanium</div><div>47.88</div><div>3-2-2</div></div> <div><div>5</div><div>VB</div><div>V</div><div>Vanadium</div><div>50.9415</div><div>3-2-3</div></div> <div><div>6</div><div>VI B</div><div>Cr</div><div>Chromium</div><div>51.9961</div><div>3-2-3</div></div> <div><div>7</div><div>VIB</div><div>Mn</div><div>Manganese</div><div>54.938044</div><div>3-2-5</div></div> <div><div>8</div><div>VII B</div><div>Fe</div><div>Iron</div><div>55.845</div><div>3-2-6</div></div> <div><div>9</div><div>VII B</div><div>Co</div><div>Cobalt</div><div>58.933</div><div>3-2-6</div></div> <div><div>10</div><div>VIII B</div><div>Ni</div><div>Nickel</div><div>58.693</div><div>3-2-6</div></div> <div><div>11</div><div>IB</div><div>Cu</div><div>Copper</div><div>63.546</div><div>3-2-9</div></div> <div><div>12</div><div>IIB</div><div>Zn</div><div>Zinc</div><div>65.38</div><div>3-2-9</div></div> <div><div>13</div><div>Al</div><div>Aluminium</div><div>26.982</div><div>3-3</div></div> <div><div>14</div><div>Si</div><div>Silicon</div><div>28.086</div><div>3-4</div></div> <div><div>15</div><div>P</div><div>Phosphorus</div><div>30.974</div><div>3-5</div></div> <div><div>16</div><div>S</div><div>Sulfur</div><div>32.06</div><div>3-6</div></div> <div><div>17</div><div>Cl</div><div>Chlorine</div><div>35.45</div><div>3-7</div></div> <div><div>18</div><div>Ar</div><div>Argon</div><div>39.948</div><div>3-8</div></div>																																				<div><div>13</div><div>Al</div><div>Aluminium</div><div>26.982</div><div>3-3</div></div> <div><div>14</div><div>Si</div><div>Silicon</div><div>28.086</div><div>3-4</div></div> <div><div>15</div><div>P</div><div>Phosphorus</div><div>30.974</div><div>3-5</div></div> <div><div>16</div><div>S</div><div>Sulfur</div><div>32.06</div><div>3-6</div></div> <div><div>17</div><div>Cl</div><div>Chlorine</div><div>35.45</div><div>3-7</div></div> <div><div>18</div><div>Ar</div><div>Argon</div><div>39.948</div><div>3-8</div></div> <div><div>19</div><div>K</div><div>Potassium</div><div>39.0983</div><div>4-1</div></div> <div><div>20</div><div>Ca</div><div>Calcium</div><div>40.078</div><div>2-8-2</div></div> <div><div>21</div><div>Sc</div><div>Scandium</div><div>44.955908</div><div>3-2-1</div></div> <div><div>22</div><div>Ti</div><div>Titanium</div><div>47.88</div><div>3-2-2</div></div> <div><div>23</div><div>V</div><div>Vanadium</div><div>50.9415</div><div>3-2-3</div></div> <div><div>24</div><div>Cr</div><div>Chromium</div><div>51.9961</div><div>3-2-3</div></div> <div><div>25</div><div>Mn</div><div>Manganese</div><div>54.938044</div><div>3-2-5</div></div> <div><div>26</div><div>Fe</div><div>Iron</div><div>55.845</div><div>3-2-6</div></div> <div><div>27</div><div>Co</div><div>Cobalt</div><div>58.933</div><div>3-2-6</div></div> <div><div>28</div><div>Ni</div><div>Nickel</div><div>58.693</div><div>3-2-6</div></div> <div><div>29</div><div>Cu</div><div>Copper</div><div>63.546</div><div>3-2-9</div></div> <div><div>30</div><div>Zn</div><div>Zinc</div><div>65.38</div><div>3-2-9</div></div> <div><div>31</div><div>Ga</div><div>Gallium</div><div>69.723</div><div>3-2-9</div></div> <div><div>32</div><div>Ge</div><div>Germanium</div><div>72.63</div><div>3-2-9</div></div> <div><div>33</div><div>As</div><div>Arsenic</div><div>74.922</div><div>3-2-9</div></div> <div><div>34</div><div>Se</div><div>Selenium</div><div>78.971</div><div>3-2-9</div></div> <div><div>35</div><div>Br</div><div>Bromine</div><div>79.904</div><div>3-2-9</div></div> <div><div>36</div><div>Kr</div><div>Krypton</div><div>83.798</div><div>3-2-9</div></div>																																																					
<div><div>19</div><div>K</div><div>Potassium</div><div>39.0983</div><div>4-1</div></div> <div><div>20</div><div>Ca</div><div>Calcium</div><div>40.078</div><div>2-8-2</div></div> <div><div>21</div><div>Sc</div><div>Scandium</div><div>44.955908</div><div>3-2-1</div></div> <div><div>22</div><div>Ti</div><div>Titanium</div><div>47.88</div><div>3-2-2</div></div> <div><div>23</div><div>V</div><div>Vanadium</div><div>50.9415</div><div>3-2-3</div></div> <div><div>24</div><div>Cr</div><div>Chromium</div><div>51.9961</div><div>3-2-3</div></div> <div><div>25</div><div>Mn</div><div>Manganese</div><div>54.938044</div><div>3-2-5</div></div> <div><div>26</div><div>Fe</div><div>Iron</div><div>55.845</div><div>3-2-6</div></div> <div><div>27</div><div>Co</div><div>Cobalt</div><div>58.933</div><div>3-2-6</div></div> <div><div>28</div><div>Ni</div><div>Nickel</div><div>58.693</div><div>3-2-6</div></div> <div><div>29</div><div>Cu</div><div>Copper</div><div>63.546</div><div>3-2-9</div></div> <div><div>30</div><div>Zn</div><div>Zinc</div><div>65.38</div><div>3-2-9</div></div> <div><div>31</div><div>Ga</div><div>Gallium</div><div>69.723</div><div>3-2-9</div></div> <div><div>32</div><div>Ge</div><div>Germanium</div><div>72.63</div><div>3-2-9</div></div> <div><div>33</div><div>As</div><div>Arsenic</div><div>74.922</div><div>3-2-9</div></div> <div><div>34</div><div>Se</div><div>Selenium</div><div>78.971</div><div>3-2-9</div></div> <div><div>35</div><div>Br</div><div>Bromine</div><div>79.904</div><div>3-2-9</div></div> <div><div>36</div><div>Kr</div><div>Krypton</div><div>83.798</div><div>3-2-9</div></div>																																				<div><div>37</div><div>Rb</div><div>Rubidium</div><div>85.468</div><div>5-1</div></div> <div><div>38</div><div>Sr</div><div>Strontium</div><div>87.62</div><div>2-8-2</div></div> <div><div>39</div><div>Y</div><div>Yttrium</div><div>88.906</div><div>3-2-1</div></div> <div><div>40</div><div>Zr</div><div>Zirconium</div><div>91.224</div><div>3-2-2</div></div> <div><div>41</div><div>Nb</div><div>Niobium</div><div>92.906</div><div>3-2-3</div></div> <div><div>42</div><div>Mo</div><div>Molybdenum</div><div>95.94</div><div>3-2-5</div></div> <div><div>43</div><div>Tc</div><div>Technetium</div><div>98</div><div>3-2-5</div></div> <div><div>44</div><div>Ru</div><div>Ruthenium</div><div>101.07</div><div>3-2-6</div></div> <div><div>45</div><div>Rh</div><div>Rhodium</div><div>102.91</div><div>3-2-6</div></div> <div><div>46</div><div>Pd</div><div>Palladium</div><div>106.42</div><div>3-2-8</div></div> <div><div>47</div><div>Ag</div><div>Silver</div><div>107.87</div><div>3-2-9</div></div> <div><div>48</div><div>Cd</div><div>Cadmium</div><div>112.41</div><div>3-2-9</div></div> <div><div>49</div><div>In</div><div>Indium</div><div>114.82</div><div>3-2-9</div></div> <div><div>50</div><div>Sn</div><div>Tin</div><div>118.71</div><div>3-2-9</div></div> <div><div>51</div><div>Sb</div><div>Antimony</div><div>121.76</div><div>3-2-9</div></div> <div><div>52</div><div>Te</div><div>Tellurium</div><div>127.6</div><div>3-2-9</div></div> <div><div>53</div><div>I</div><div>Iodine</div><div>126.905</div><div>3-2-9</div></div> <div><div>54</div><div>Xe</div><div>Xenon</div><div>131.29</div><div>3-2-9</div></div>																																																					
<div><div>55</div><div>Cs</div><div>Cesium</div><div>132.90545196</div><div>6-1</div></div> <div><div>56</div><div>Ba</div><div>Barium</div><div>137.327</div><div>2-8-2</div></div> <div><div>57-71</div><div>Lanthanides</div></div> <div><div>72</div><div>Hf</div><div>Hafnium</div><div>178.49</div><div>3-2-2</div></div> <div><div>73</div><div>Ta</div><div>Tantalum</div><div>180.948</div><div>3-2-3</div></div> <div><div>74</div><div>W</div><div>Tungsten</div><div>183.84</div><div>3-2-3</div></div> <div><div>75</div><div>Re</div><div>Rhenium</div><div>186.21</div><div>3-2-5</div></div> <div><div>76</div><div>Os</div><div>Osmium</div><div>190.23</div><div>3-2-6</div></div> <div><div>77</div><div>Ir</div><div>Iridium</div><div>192.22</div><div>3-2-6</div></div> <div><div>78</div><div>Pt</div><div>Platinum</div><div>195.08</div><div>3-2-8</div></div> <div><div>79</div><div>Au</div><div>Gold</div><div>196.967</div><div>3-2-9</div></div> <div><div>80</div><div>Hg</div><div>Mercury</div><div>200.59</div><div>3-2-9</div></div> <div><div>81</div><div>Tl</div><div>Thallium</div><div>204.38</div><div>3-2-9</div></div> <div><div>82</div><div>Pb</div><div>Lead</div><div>207.2</div><div>3-2-9</div></div> <div><div>83</div><div>Bi</div><div>Bismuth</div><div>208.98</div><div>3-2-9</div></div> <div><div>84</div><div>Po</div><div>Polonium</div><div>209</div><div>3-2-9</div></div> <div><div>85</div><div>At</div><div>Astatine</div><div>210</div><div>3-2-9</div></div> <div><div>86</div><div>Rn</div><div>Radon</div><div>222</div><div>3-2-9</div></div>																																				<div><div>37</div><div>Rb</div><div>Rubidium</div><div>85.468</div><div>5-1</div></div> <div><div>38</div><div>Sr</div><div>Strontium</div><div>87.62</div><div>2-8-2</div></div> <div><div>39</div><div>Y</div><div>Yttrium</div><div>88.906</div><div>3-2-1</div></div> <div><div>40</div><div>Zr</div><div>Zirconium</div><div>91.224</div><div>3-2-2</div></div> <div><div>41</div><div>Nb</div><div>Niobium</div><div>92.906</div><div>3-2-3</div></div> <div><div>42</div><div>Mo</div><div>Molybdenum</div><div>95.94</div><div>3-2-5</div></div> <div><div>43</div><div>Tc</div><div>Technetium</div><div>98</div><div>3-2-5</div></div> <div><div>44</div><div>Ru</div><div>Ruthenium</div><div>101.07</div><div>3-2-6</div></div> <div><div>45</div><div>Rh</div><div>Rhodium</div><div>102.91</div><div>3-2-6</div></div> <div><div>46</div><div>Pd</div><div>Palladium</div><div>106.42</div><div>3-2-8</div></div> <div><div>47</div><div>Ag</div><div>Silver</div><div>107.87</div><div>3-2-9</div></div> <div><div>48</div><div>Cd</div><div>Cadmium</div><div>112.41</div><div>3-2-9</div></div> <div><div>49</div><div>In</div><div>Indium</div><div>114.82</div><div>3-2-9</div></div> <div><div>50</div><div>Sn</div><div>Tin</div><div>118.71</div><div>3-2-9</div></div> <div><div>51</div><div>Sb</div><div>Antimony</div><div>121.76</div><div>3-2-9</div></div> <div><div>52</div><div>Te</div><div>Tellurium</div><div>127.6</div><div>3-2-9</div></div> <div><div>53</div><div>I</div><div>Iodine</div><div>126.905</div><div>3-2-9</div></div> <div><div>54</div><div>Xe</div><div>Xenon</div><div>131.29</div><div>3-2-9</div></div>																																																					
<div><div>55</div><div>Cs</div><div>Cesium</div><div>132.90545196</div><div>6-1</div></div> <div><div>56</div><div>Ba</div><div>Barium</div><div>137.327</div><div>2-8-2</div></div> <div><div>57-71</div><div>Lanthanides</div></div> <div><div>72</div><div>Hf</div><div>Hafnium</div><div>178.49</div><div>3-2-2</div></div> <div><div>73</div><div>Ta</div><div>Tantalum</div><div>180.948</div><div>3-2-3</div></div> <div><div>74</div><div>W</div><div>Tungsten</div><div>183.84</div><div>3-2-3</div></div> <div><div>75</div><div>Re</div><div>Rhenium</div><div>186.21</div><div>3-2-5</div></div> <div><div>76</div><div>Os</div><div>Osmium</div><div>190.23</div><div>3-2-6</div></div> <div><div>77</div><div>Ir</div><div>Iridium</div><div>192.22</div><div>3-2-6</div></div> <div><div>78</div><div>Pt</div><div>Platinum</div><div>195.08</div><div>3-2-8</div></div> <div><div>79</div><div>Au</div><div>Gold</div><div>196.967</div><div>3-2-9</div></div> <div><div>80</div><div>Hg</div><div>Mercury</div><div>200.59</div><div>3-2-9</div></div> <div><div>81</div><div>Tl</div><div>Thallium</div><div>204.38</div><div>3-2-9</div></div> <div><div>82</div><div>Pb</div><div>Lead</div><div>207.2</div><div>3-2-9</div></div> <div><div>83</div><div>Bi</div><div>Bismuth</div><div>208.98</div><div>3-2-9</div></div> <div><div>84</div><div>Po</div><div>Polonium</div><div>209</div><div>3-2-9</div></div> <div><div>85</div><div>At</div><div>Astatine</div><div>210</div><div>3-2-9</div></div> <div><div>86</div><div>Rn</div><div>Radon</div><div>222</div><div>3-2-9</div></div>																																				<div><div>37</div><div>Rb</div><div>Rubidium</div><div>85.468</div><div>5-1</div></div> <div><div>38</div><div>Sr</div><div>Strontium</div><div>87.62</div><div>2-8-2</div></div> <div><div>39</div><div>Y</div><div>Yttrium</div><div>88.906</div><div>3-2-1</div></div> <div><div>40</div><div>Zr</div><div>Zirconium</div><div>91.224</div><div>3-2-2</div></div> <div><div>41</div><div>Nb</div><div>Niobium</div><div>92.906</div><div>3-2-3</div></div> <div><div>42</div><div>Mo</div><div>Molybdenum</div><div>95.94</div><div>3-2-5</div></div> <div><div>43</div><div>Tc</div><div>Technetium</div><div>98</div><div>3-2-5</div></div> <div><div>44</div><div>Ru</div><div>Ruthenium</div><div>101.07</div><div>3-2-6</div></div> <div><div>45</div><div>Rh</div><div>Rhodium</div><div>102.91</div><div>3-2-6</div></div> <div><div>46</div><div>Pd</div><div>Palladium</div><div>106.42</div><div>3-2-8</div></div> <div><div>47</div><div>Ag</div><div>Silver</div><div>107.87</div><div>3-2-9</div></div> <div><div>48</div><div>Cd</div><div>Cadmium</div><div>112.41</div><div>3-2-9</div></div> <div><div>49</div><div>In</div><div>Indium</div><div>114.82</div><div>3-2-9</div></div> <div><div>50</div><div>Sn</div><div>Tin</div><div>118.71</div><div>3-2-9</div></div> <div><div>51</div><div>Sb</div><div>Antimony</div><div>121.76</div><div>3-2-9</div></div> <div><div>52</div><div>Te</div><div>Tellurium</div><div>127.6</div><div>3-2-9</div></div> <div><div>53</div><div>I</div><div>Iodine</div><div>126.905</div><div>3-2-9</div></div> <div><div>54</div><div>Xe</div><div>Xenon</div><div>131.29</div><div>3-2-9</div></div>																																																					
<div><div>57</div><div>La</div><div>Lanthanum</div><div>138.905</div><div>2-8-2-14-1</div></div> <div><div>58</div><div>Ce</div><div>Cerium</div><div>140.12</div><div>2-8-2-14-2</div></div> <div><div>59</div><div>Pr</div><div>Praseodymium</div><div>140.908</div><div>2-8-2-14-3</div></div> <div><div>60</div><div>Nd</div><div>Neodymium</div><div>144.24</div><div>2-8-2-14-4</div></div> <div><div>61</div><div>Pm</div><div>Promethium</div><div>145</div><div>2-8-2-14-4</div></div> <div><div>62</div><div>Sm</div><div>Samarium</div><div>150.36</div><div>2-8-2-14-5</div></div> <div><div>63</div><div>Eu</div><div>Europium</div><div>151.964</div><div>2-8-2-14-6</div></div> <div><div>64</div><div>Gd</div><div>Gadolinium</div><div>157.25</div><div>2-8-2-14-7</div></div> <div><div>65</div><div>Tb</div><div>Terbium</div><div>158.925</div><div>2-8-2-14-8</div></div> <div><div>66</div><div>Dy</div><div>Dysprosium</div><div>162.50</div><div>2-8-2-14-9</div></div> <div><div>67</div><div>Ho</div><div>Holmium</div><div>164.930</div><div>2-8-2-14-10</div></div> <div><div>68</div><div>Er</div><div>Erbium</div><div>167.26</div><div>2-8-2-14-11</div></div> <div><div>69</div><div>Tm</div><div>Thulium</div><div>168.934</div><div>2-8-2-14-12</div></div> <div><div>70</div><div>Yb</div><div>Ytterbium</div><div>173.054</div><div>2-8-2-14-13</div></div> <div><div>71</div><div>Lu</div><div>Lutetium</div><div>174.967</div><div>2-8-2-14-14</div></div>																																				<div><div>13</div><div>B</div><div>Boron</div><div>10.81</div><div>2-2</div></div> <div><div>14</div><div>C</div><div>Carbon</div><div>12.011</div><div>2-4</div></div> <div><div>15</div><div>N</div><div>Nitrogen</div><div>14.007</div><div>2-5</div></div> <div><div>16</div><div>O</div><div>Oxygen</div><div>15.999</div><div>2-6</div></div> <div><div>17</div><div>F</div><div>Fluorine</div><div>18.998</div><div>2-7</div></div> <div><div>18</div><div>Ne</div><div>Neon</div><div>20.180</div><div>2-8</div></div> <div><div>19</div><div>K</div><div>Potassium</div><div>39.0983</div><div>4-1</div></div> <div><div>20</div><div>Ca</div><div>Calcium</div><div>40.078</div><div>2-8-2</div></div> <div><div>21</div><div>Sc</div><div>Scandium</div><div>44.955908</div><div>3-2-1</div></div> <div><div>22</div><div>Ti</div><div>Titanium</div><div>47.88</div><div>3-2-2</div></div> <div><div>23</div><div>V</div><div>Vanadium</div><div>50.9415</div><div>3-2-3</div></div> <div><div>24</div><div>Cr</div><div>Chromium</div><div>51.9961</div><div>3-2-3</div></div> <div><div>25</div><div>Mn</div><div>Manganese</div><div>54.938044</div><div>3-2-5</div></div> <div><div>26</div><div>Fe</div><div>Iron</div><div>55.845</div><div>3-2-6</div></div> <div><div>27</div><div>Co</div><div>Cobalt</div><div>58.933</div><div>3-2-6</div></div> <div><div>28</div><div>Ni</div><div>Nickel</div><div>58.693</div><div>3-2-6</div></div> <div><div>29</div><div>Cu</div><div>Copper</div><div>63.546</div><div>3-2-9</div></div> <div><div>30</div><div>Zn</div><div>Zinc</div><div>65.38</div><div>3-2-9</div></div> <div><div>31</div><div>Ga</div><div>Gallium</div><div>69.723</div><div>3-2-9</div></div> <div><div>32</div><div>Ge</div><div>Germanium</div><div>72.63</div><div>3-2-9</div></div> <div><div>33</div><div>As</div><div>Arsenic</div><div>74.922</div><div>3-2-9</div></div> <div><div>34</div><div>Se</div><div>Selenium</div><div>78.971</div><div>3-2-9</div></div> <div><div>35</div><div>Br</div><div>Bromine</div><div>79.904</div><div>3-2-9</div></div> <div><div>36</div><div>Kr</div><div>Krypton</div><div>83.798</div><div>3-2-9</div></div>																																																					
<div><div>89</div><div>Ac</div><div>Actinium</div><div>227</div><div>2-8-2-14-1</div></div> <div><div>90</div><div>Th</div><div>Thorium</div><div>232.038</div><div>2-8-2-14-2</div></div> <div><div>91</div><div>Pa</div><div>Protactinium</div><div>231.036</div><div>2-8-2-14-3</div></div> <div><div>92</div><div>U</div><div>Uranium</div><div>238.029</div><div>2-8-2-14-4</div></div> <div><div>93</div><div>Np</div><div>Neptunium</div><div>237</div><div>2-8-2-14-4</div></div> <div><div>94</div><div>Pu</div><div>Plutonium</div><div>244</div><div>2-8-2-14-6</div></div> <div><div>95</div><div>Am</div><div>Americium</div><div>243</div><div>2-8-2-14-7</div></div> <div><div>96</div><div>Cm</div><div>Curium</div><div>247</div><div>2-8-2-14-8</div></div> <div><div>97</div><div>Bk</div><div>Berkelium</div><div>247</div><div>2-8-2-14-9</div></div> <div><div>98</div><div>Cf</div><div>Californium</div><div>251</div><div>2-8-2-14-10</div></div> <div><div>99</div><div>Es</div><div>Einsteinium</div><div>252</div><div>2-8-2-14-11</div></div> <div><div>100</div><div>Fm</div><div>Fermium</div><div>257</div><div>2-8-2-14-12</div></div> <div><div>101</div><div>Md</div><div>Mendelevium</div><div>258</div><div>2-8-2-14-13</div></div> <div><div>102</div><div>No</div><div>Nobelium</div><div>259</div><div>2-8-2-14-14</div></div> <div><div>103</div><div>Lr</div><div>Lawrencium</div><div>262</div><div>2-8-2-14-15</div></div>																																				<div><div>13</div><div>B</div><div>Boron</div><div>10.81</div><div>2-2</div></div> <div><div>14</div><div>C</div><div>Carbon</div><div>12.011</div><div>2-4</div></div> <div><div>15</div><div>N</div><div>Nitrogen</div></div>																																																					



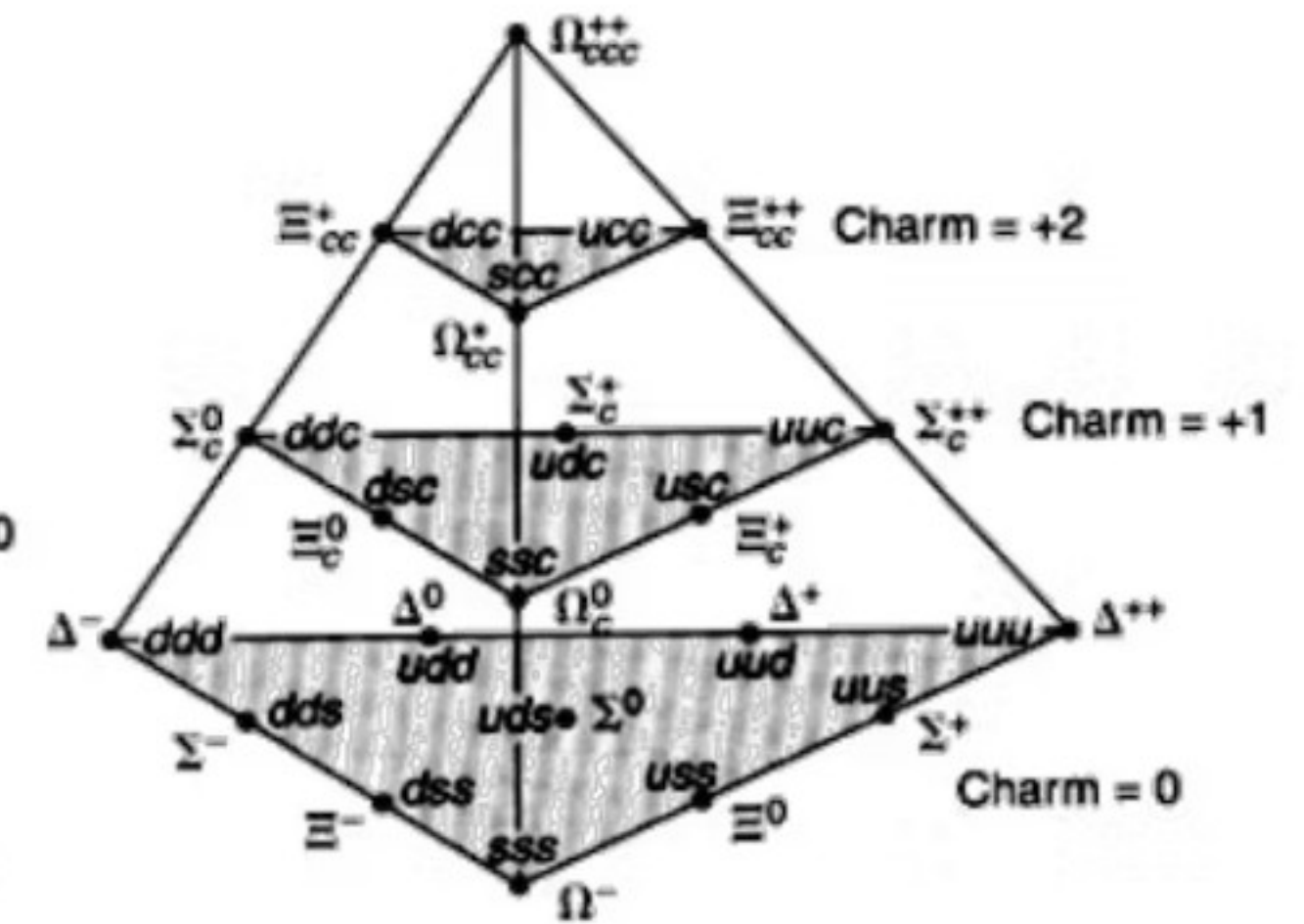
0- Mesons
(a)



1- Mesons
(b)



$\frac{1}{2}^+$ Baryons
(c)



$\frac{3}{2}^+$ Baryons
(d)

... skipping many crucial steps...

Periodic Table of the Elements

Callout for Aluminum (Al):

- Atomic Number: 13
- Symbol: Al
- Name: Aluminium
- Atomic Weight: 26.982
- Electrons per shell: 2-8-3

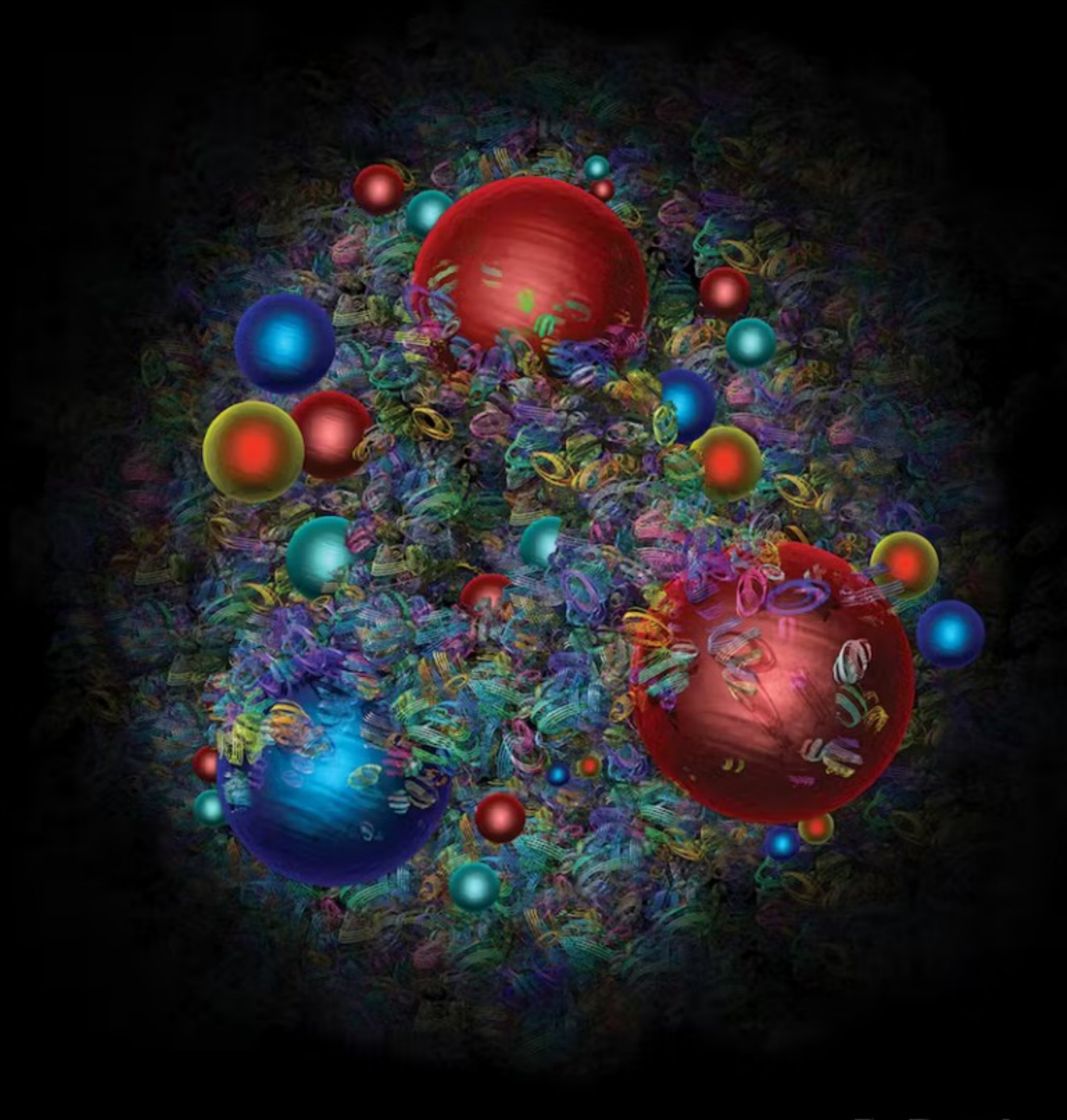
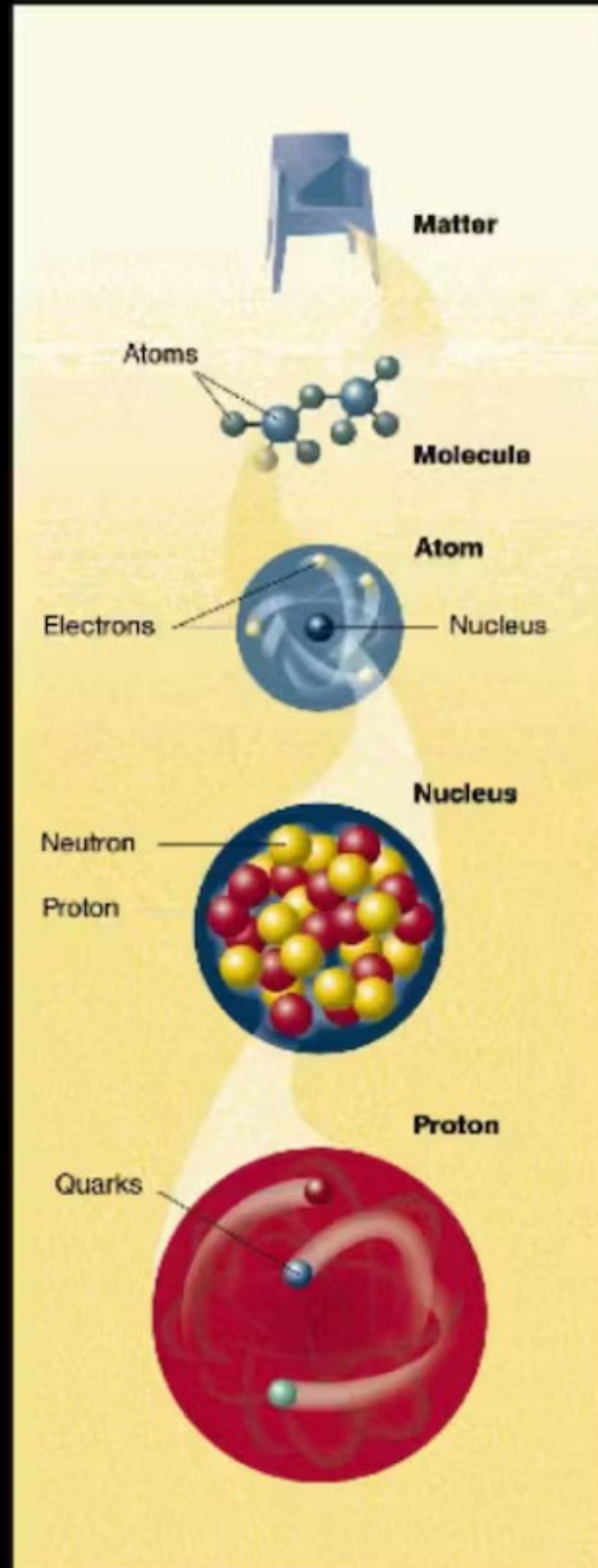
Legend:

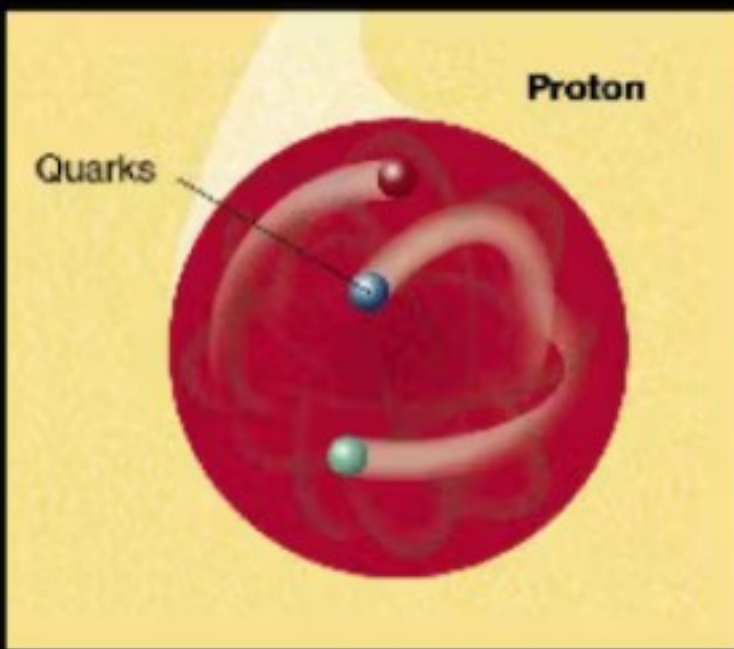
- State of matter (color of name):** GAS (red), LIQUID (orange), SOLID (blue), UNKNOWN (green).
- Subcategory in the metal-metalloid-nonmetal trend (color of background):**
 - Alkali metals (red)
 - Alkaline earth metals (orange)
 - Transition metals (blue)
 - Lanthanides (dark blue)
 - Actinides (teal)
 - Post-transition metals (light blue)
 - Metalloids (yellow)
 - Reactive nonmetals (green)
 - Noble gases (pink)
 - Unknown chemical properties (grey)

The periodic table displays elements from Hydrogen (1) to Oganesson (118), with Lanthanide and Actinide series shown below the main body.

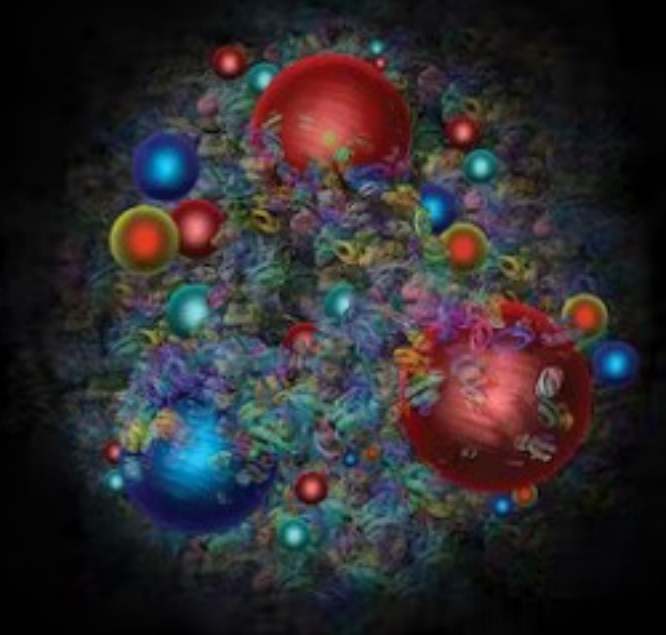
	QUARKS	GAUGE BOSONS			
mass →	≈2.3 MeV/c ²	≈1.275 GeV/c ²	≈173.07 GeV/c ²	0	≈126 GeV/c ²
charge →	2/3	2/3	2/3	0	0
spin →	1/2	1/2	1/2	1	0
	u up	c charm	t top	g gluon	H Higgs boson
	≈4.8 MeV/c ²	≈95 MeV/c ²	≈4.18 GeV/c ²	0	
	-1/3	-1/3	-1/3	0	
	1/2	1/2	1/2	1	
	d down	s strange	b bottom	γ photon	
	0.511 MeV/c ²	105.7 MeV/c ²	1.777 GeV/c ²	91.2 GeV/c ²	
	-1	-1	-1	0	
	1/2	1/2	1/2	1	
	e electron	μ muon	τ tau	Z Z boson	
	<2.2 eV/c ²	<0.17 MeV/c ²	<15.5 MeV/c ²	80.4 GeV/c ²	
	0	0	0	±1	
	1/2	1/2	1/2	1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	

hadrons: made of quarks&gluons

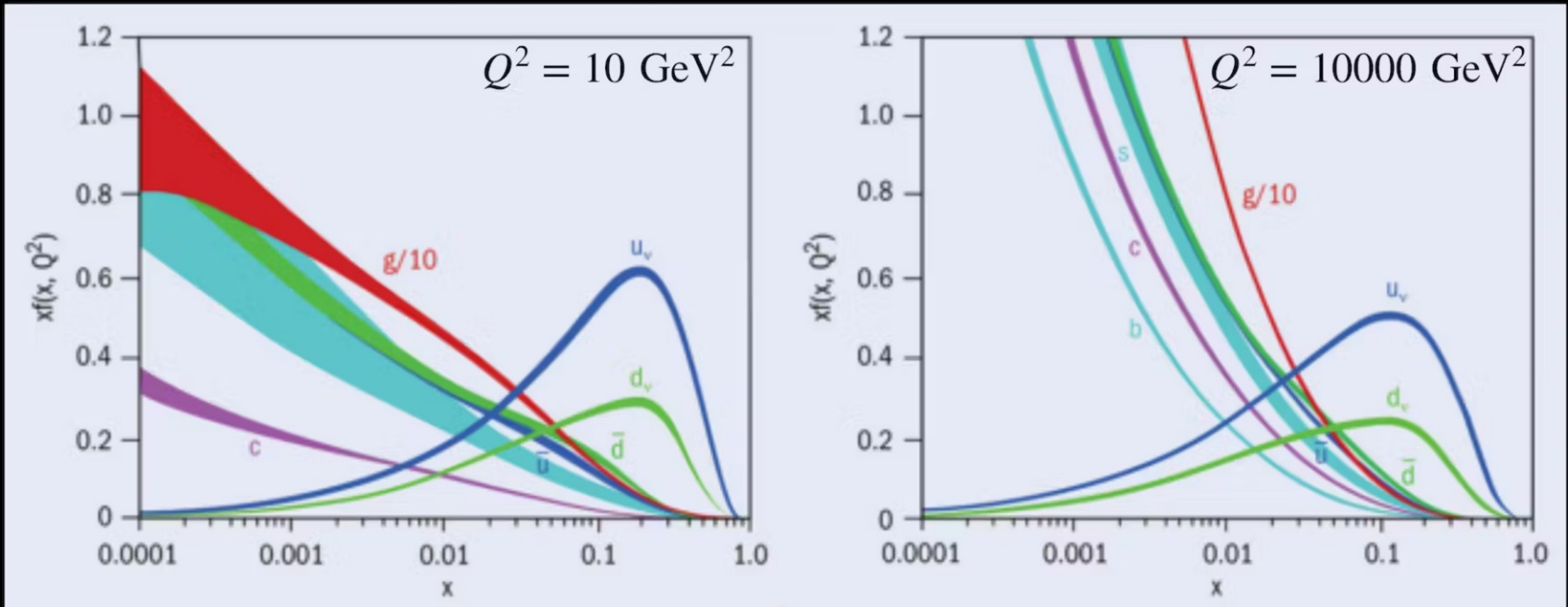




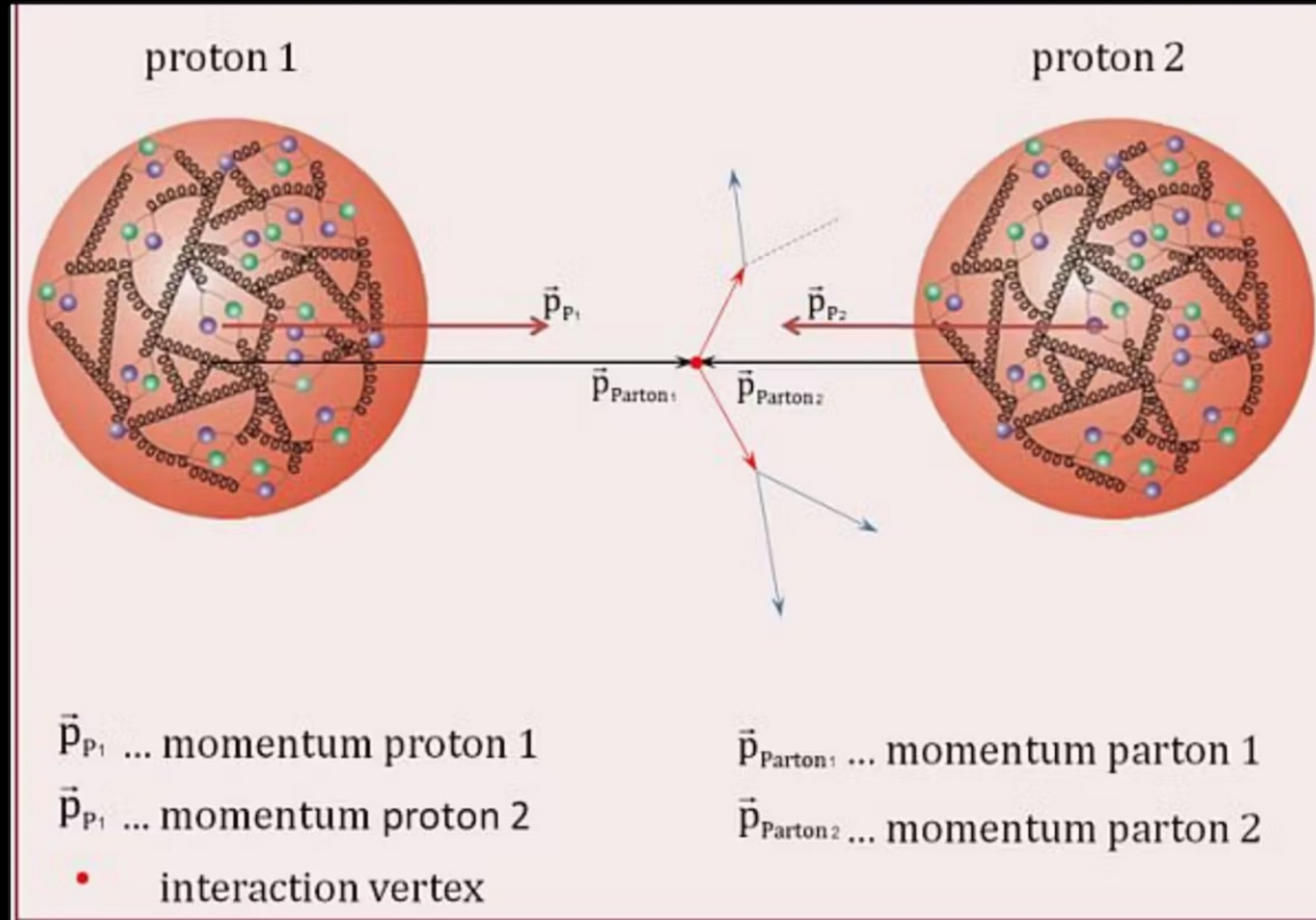
what are we colliding?



“Bjorken x ” - fraction of proton momentum carried by the parton
 Q is the momentum transfer

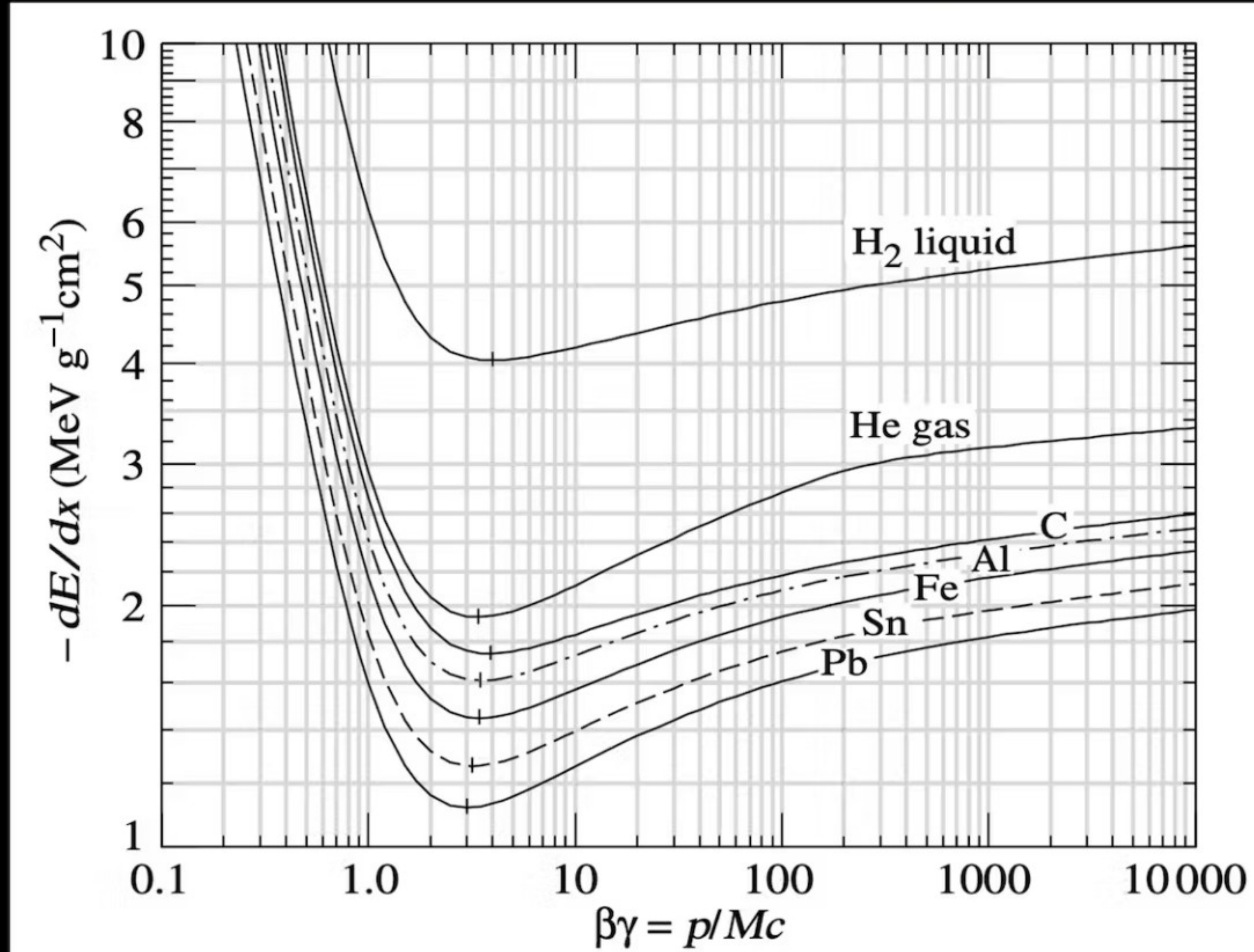


at 13.6 TeV: a ~~hadron~~ parton collider

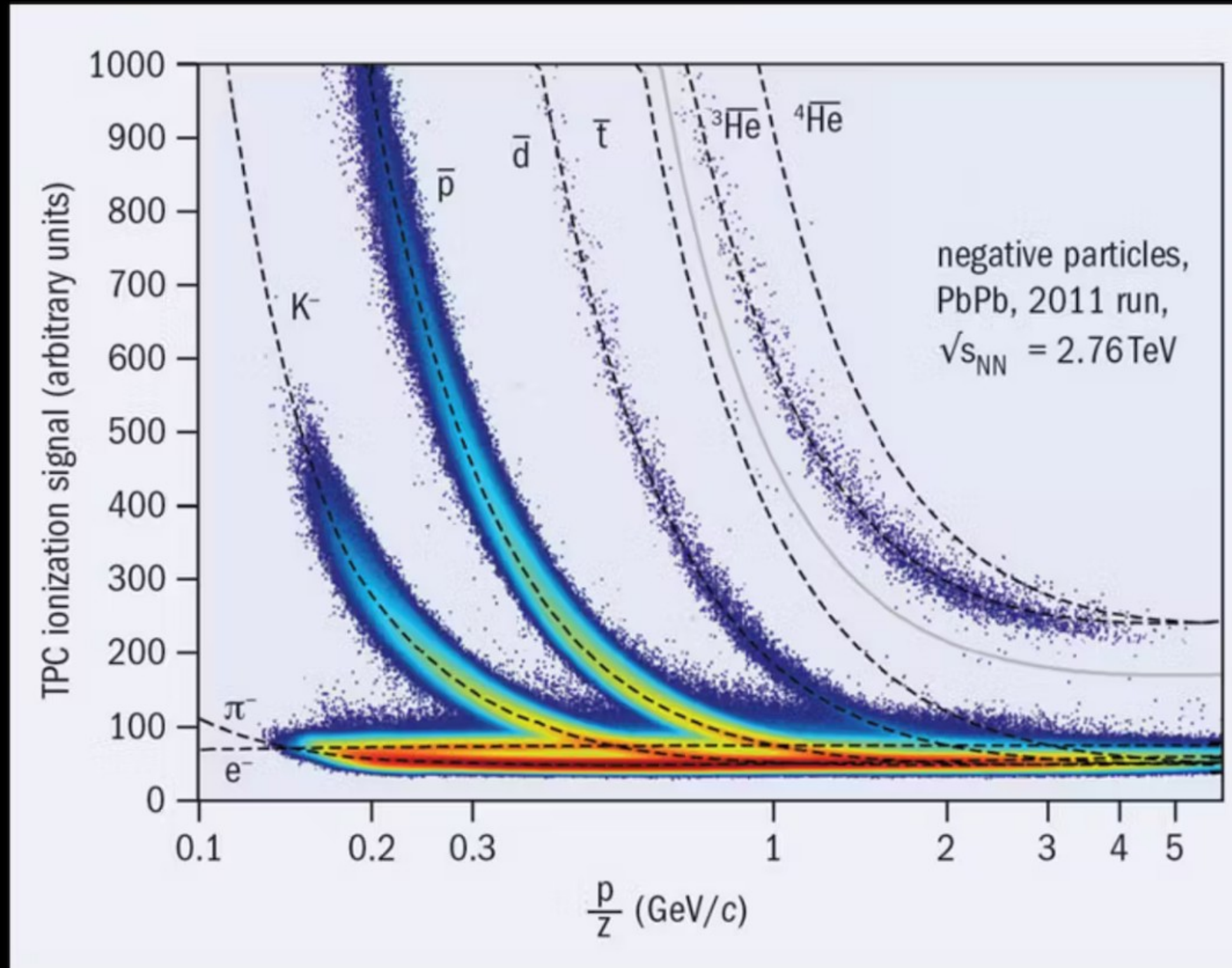


Q: how do we know what
particles made the tracks?

Bethe-Bloch formula for energy loss in material



Measure p — massive particles separate

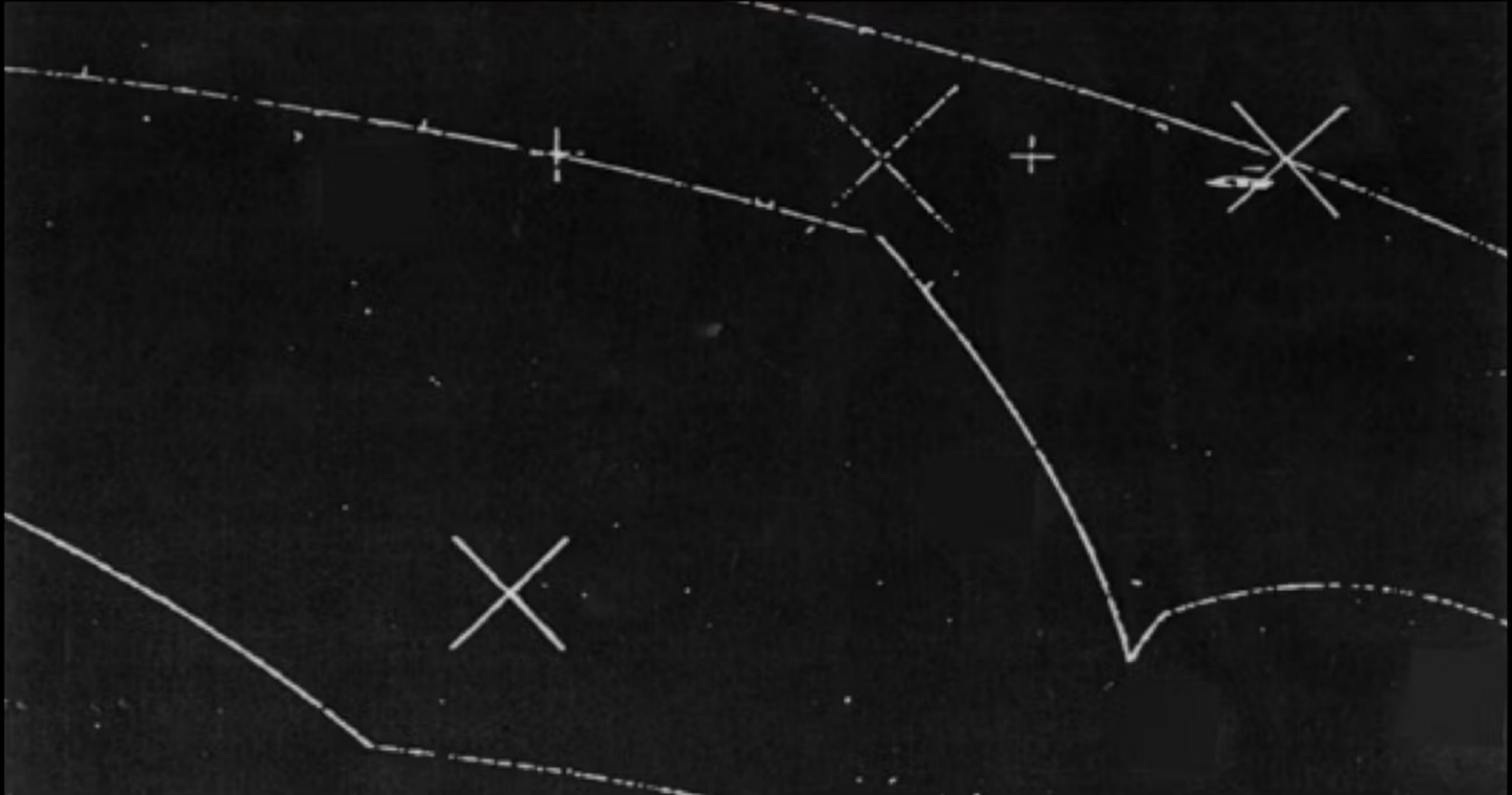


ALICE collaboration



3 min turn to your neighbor:

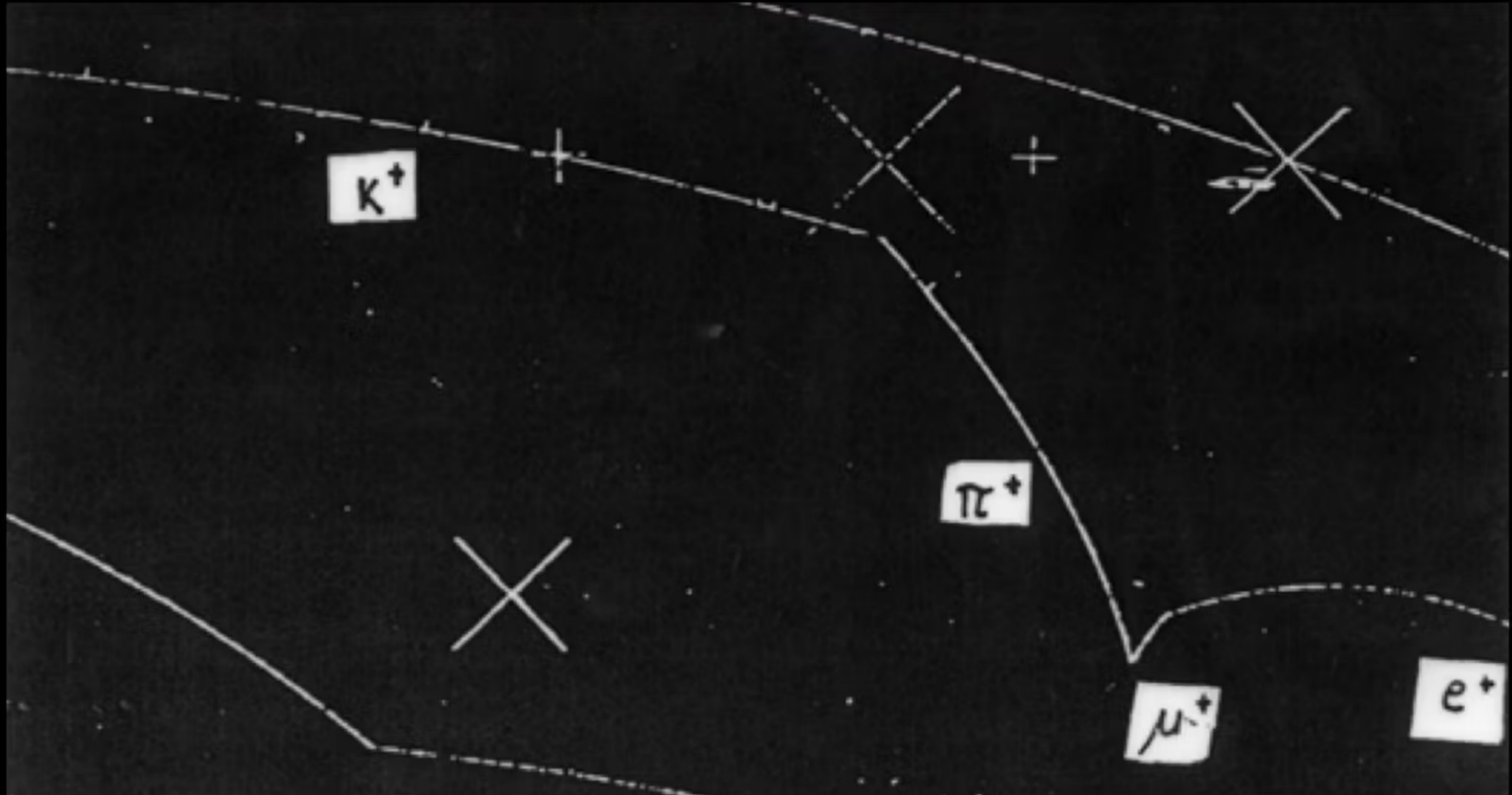
what can be measured here?



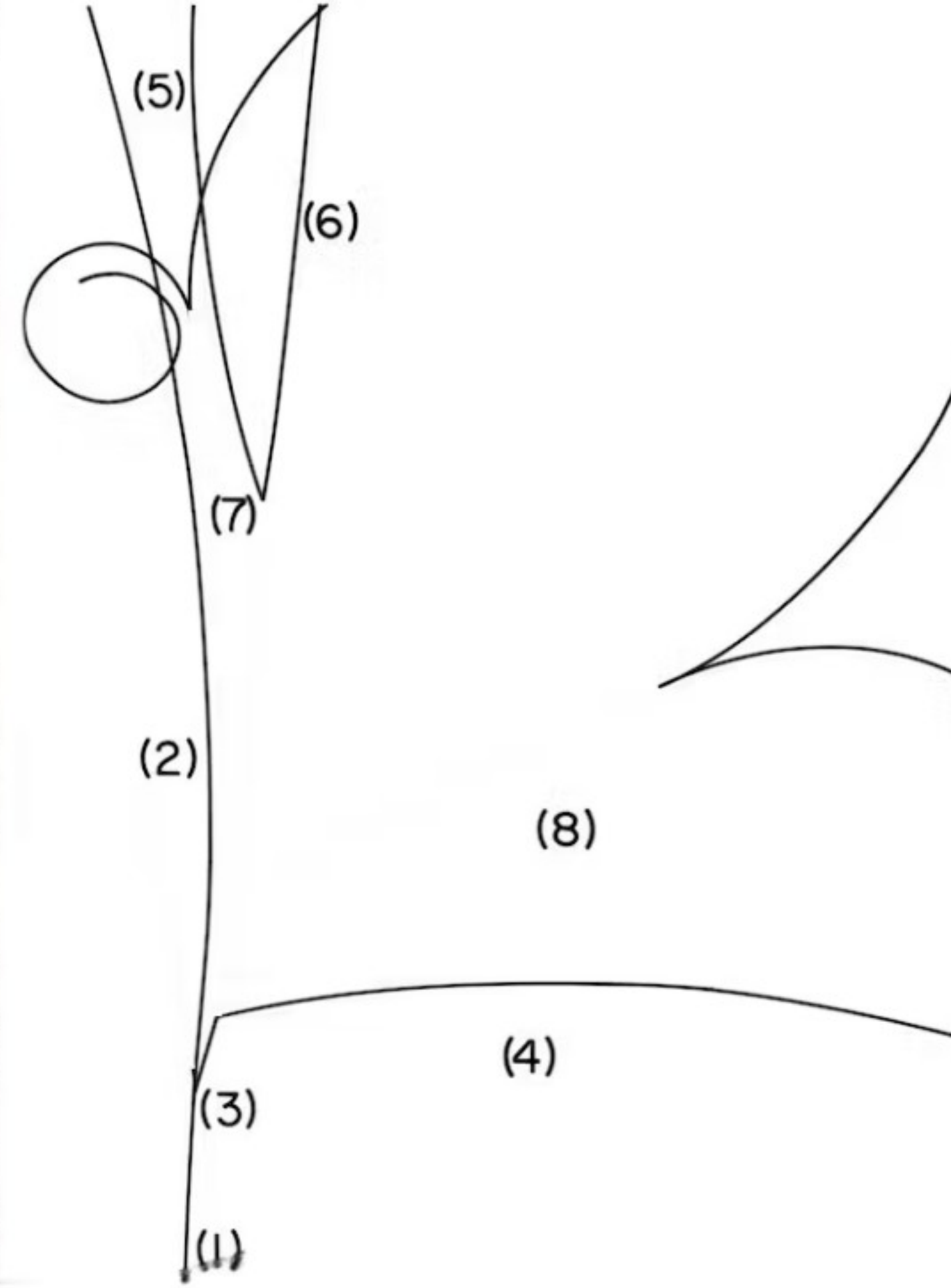
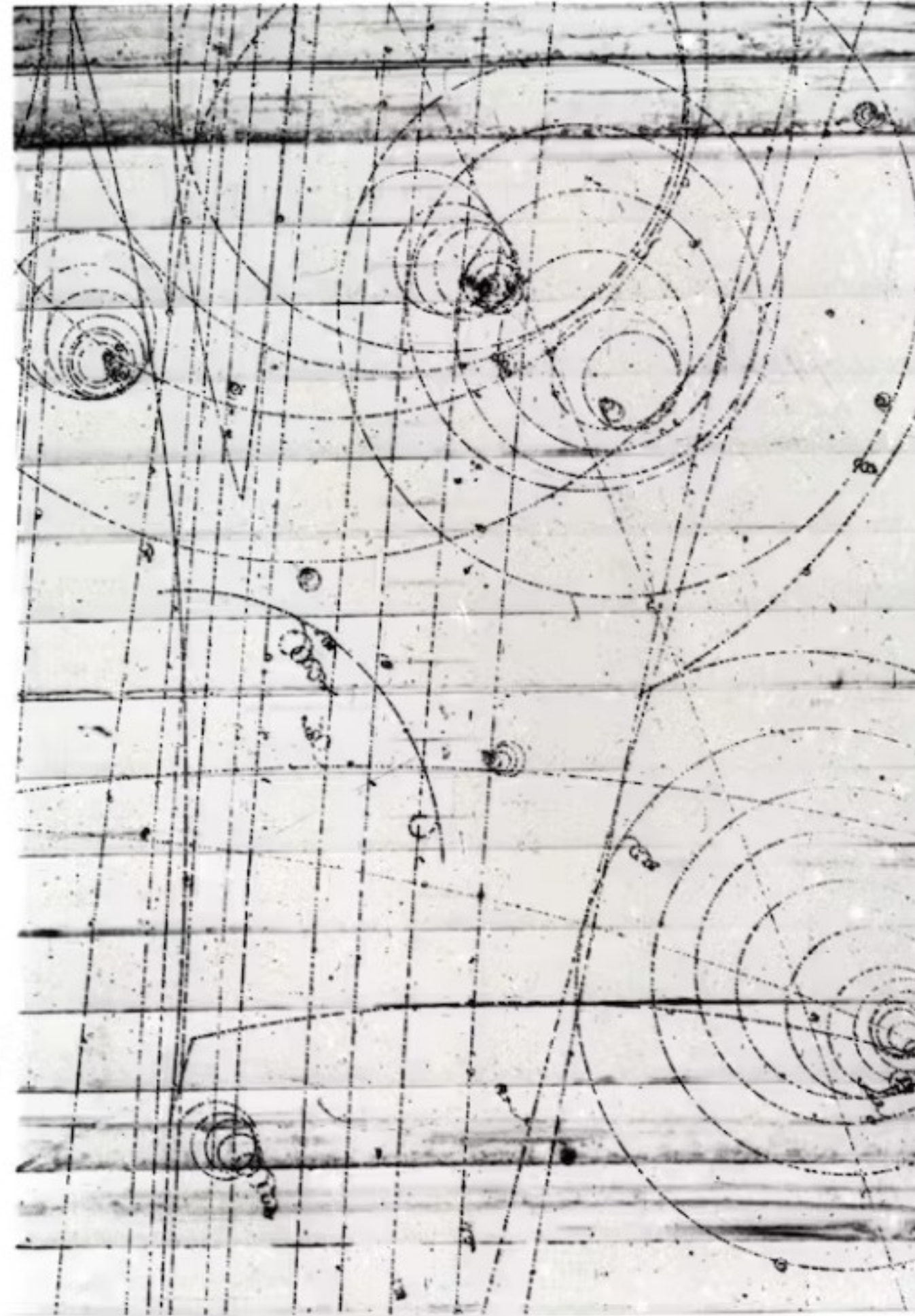


3 min turn to your neighbor:

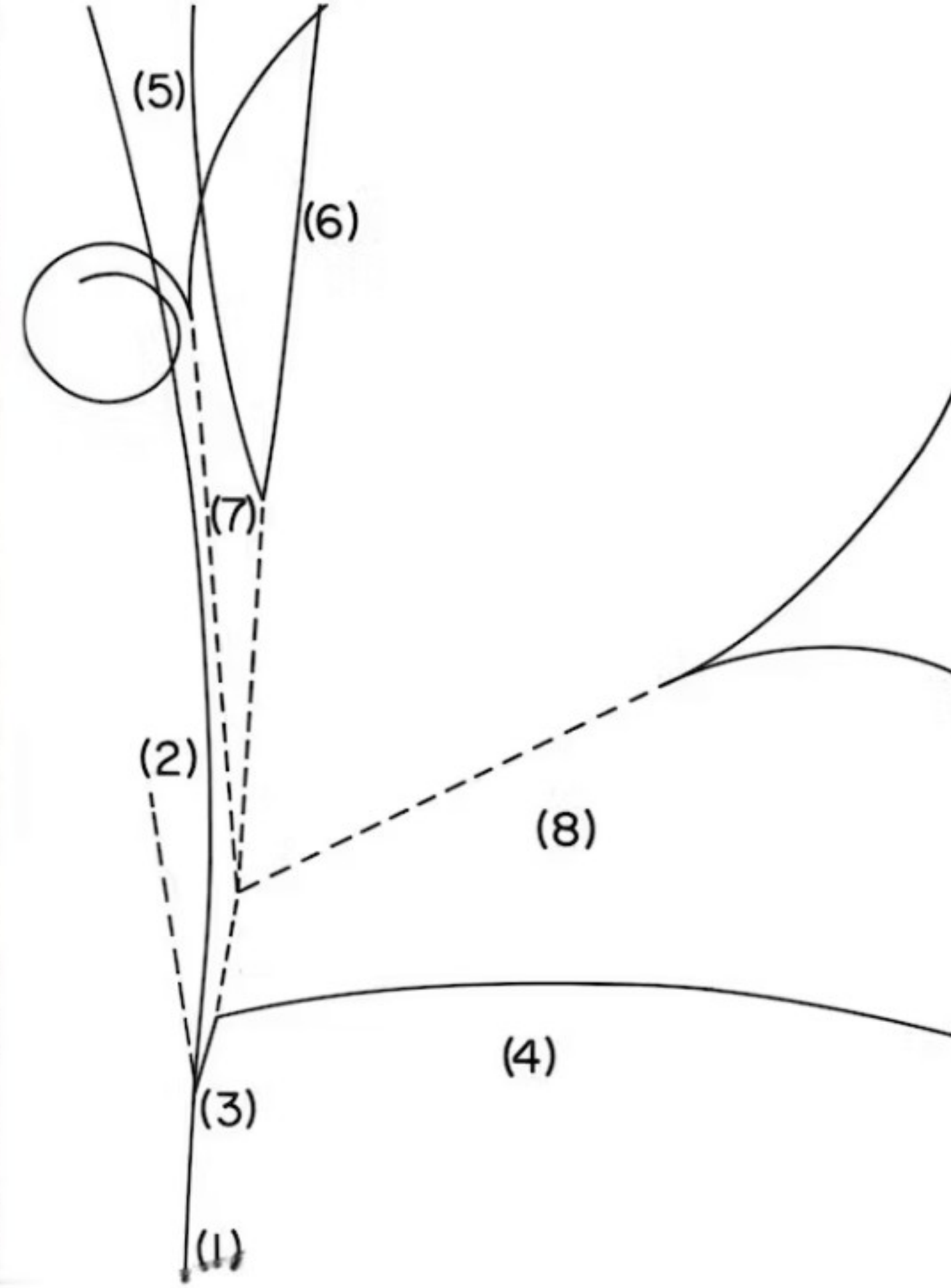
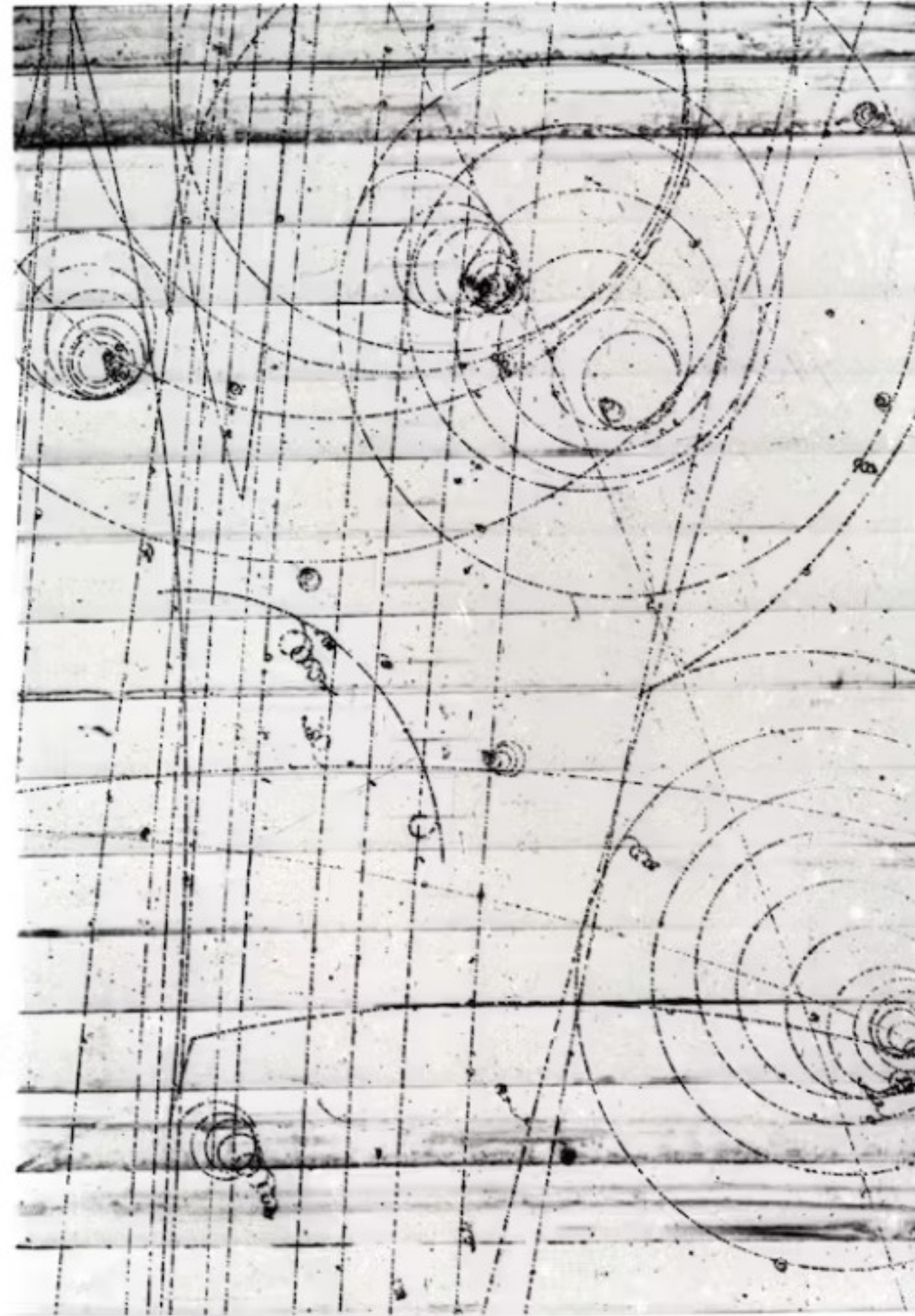
what can be measured here?



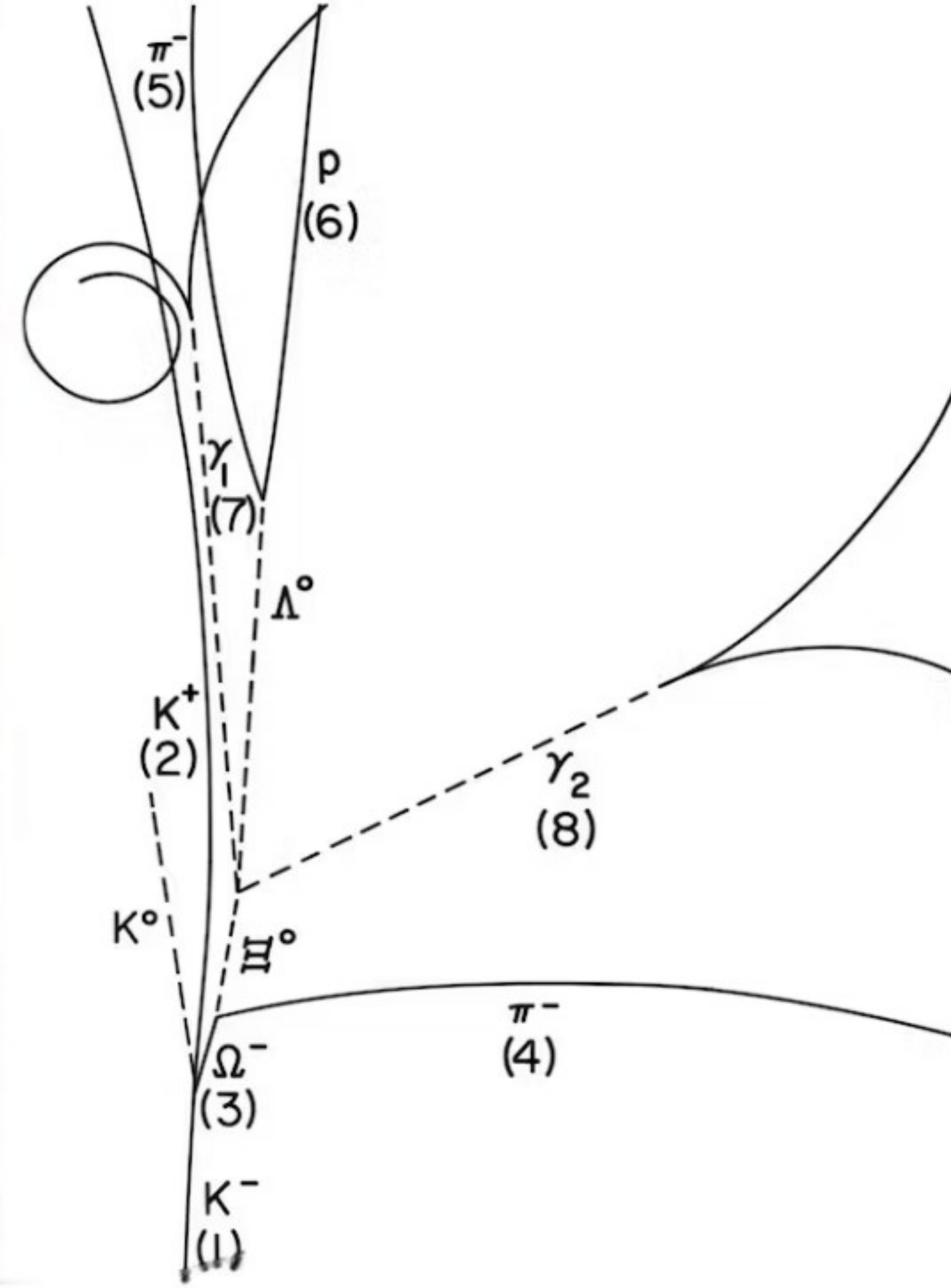
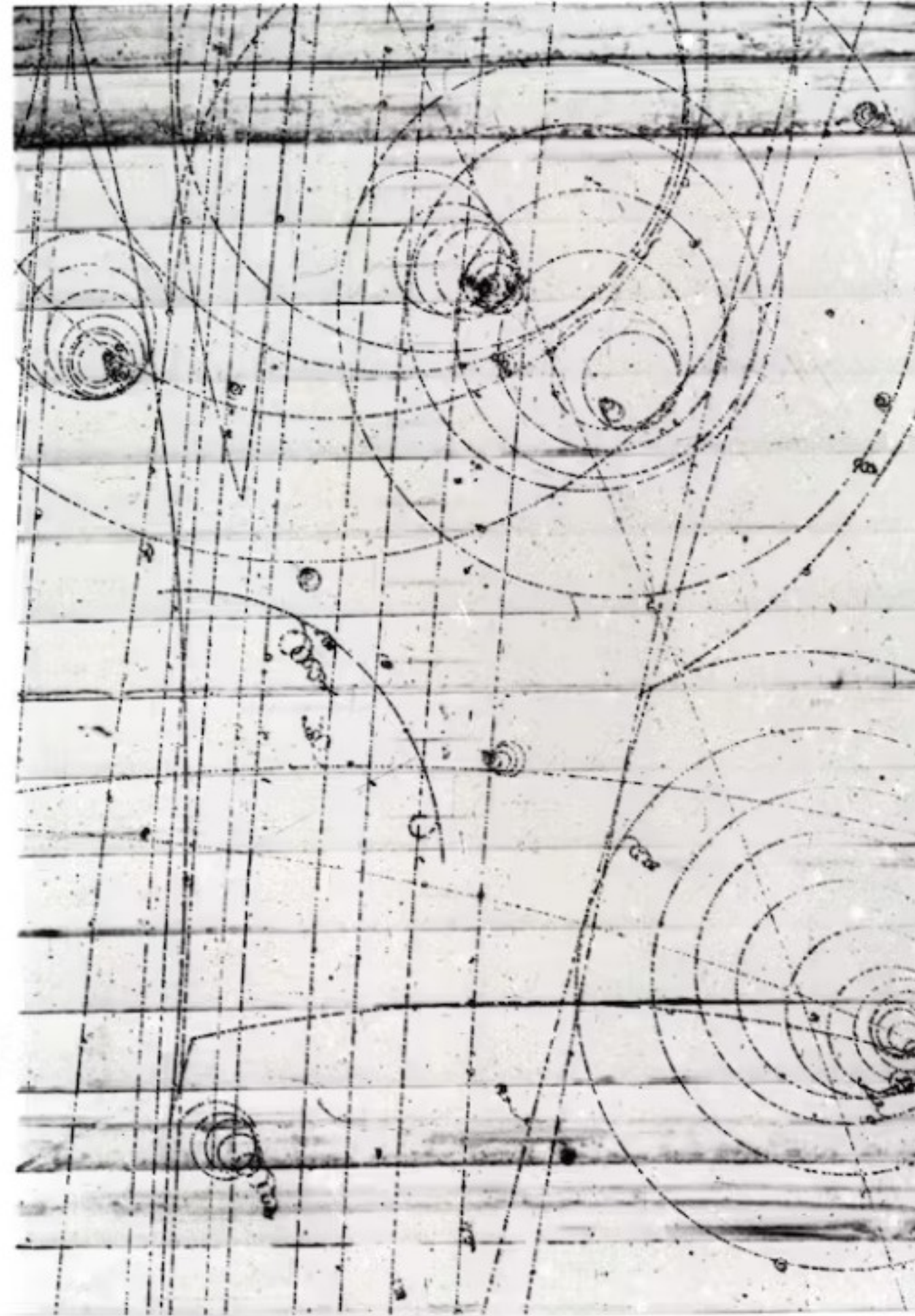
what characteristics are used here?



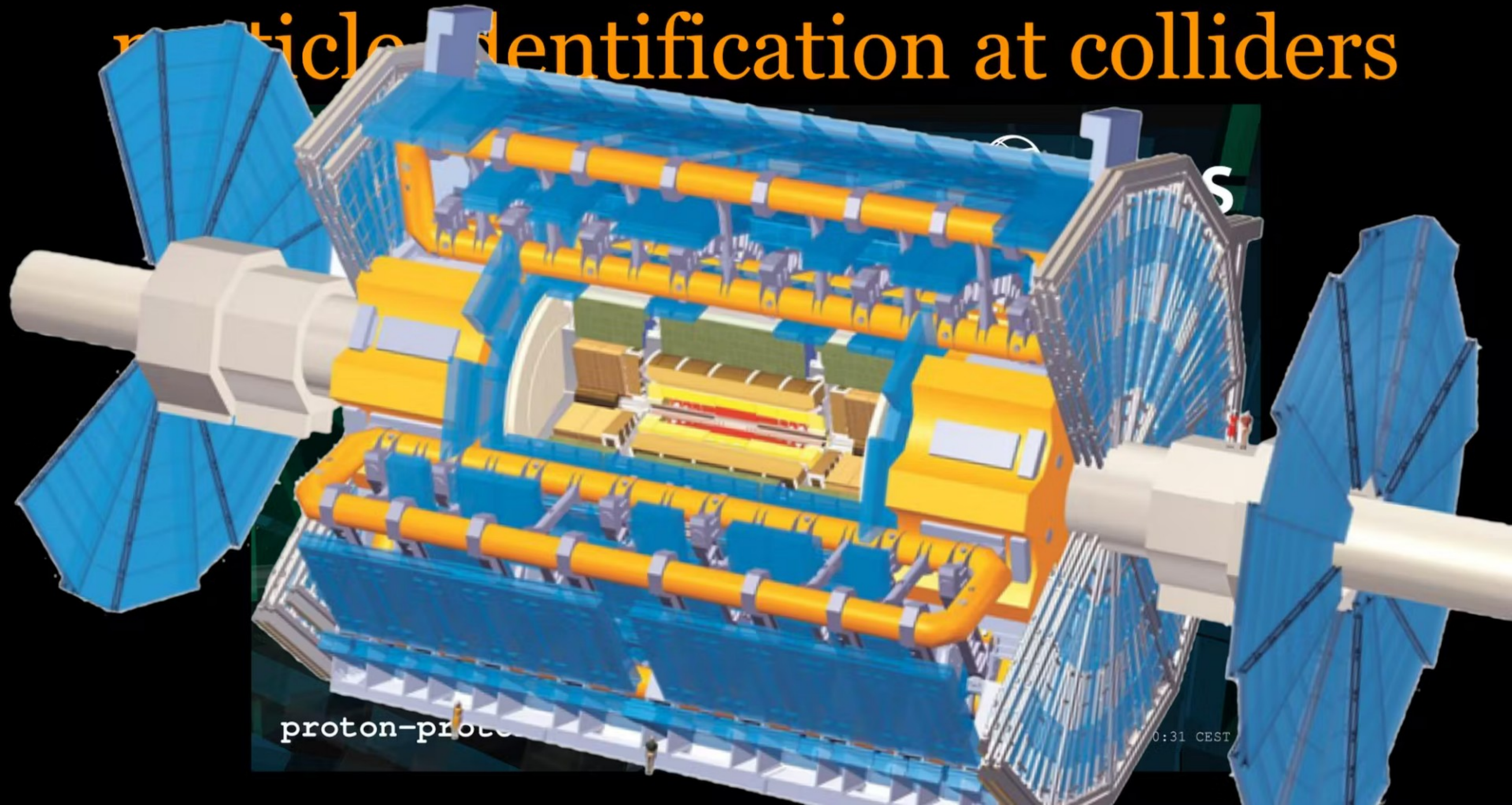
what characteristics are used here?



what characteristics are used here?



particle identification at colliders



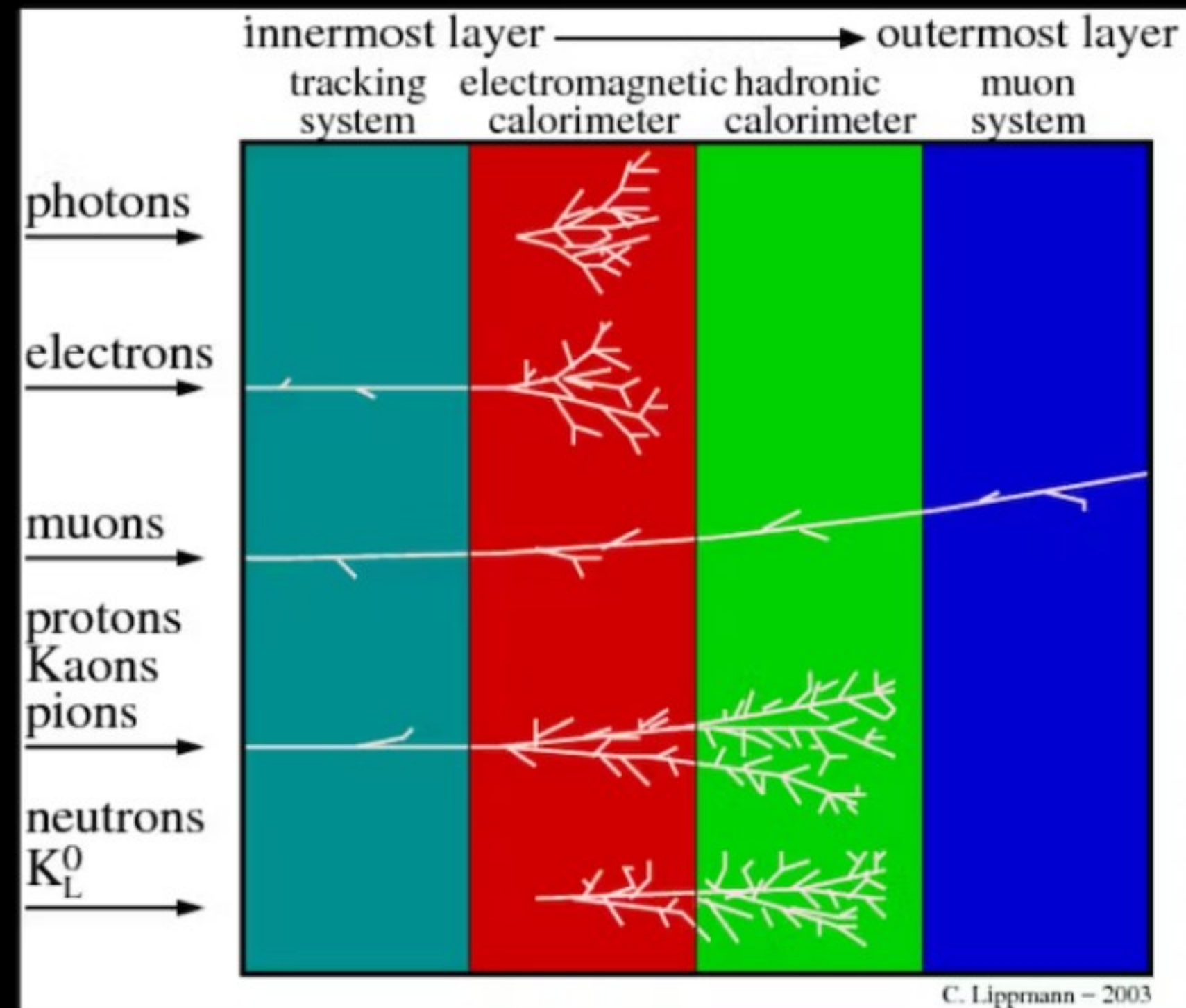
proton-proton

0:31 CEST

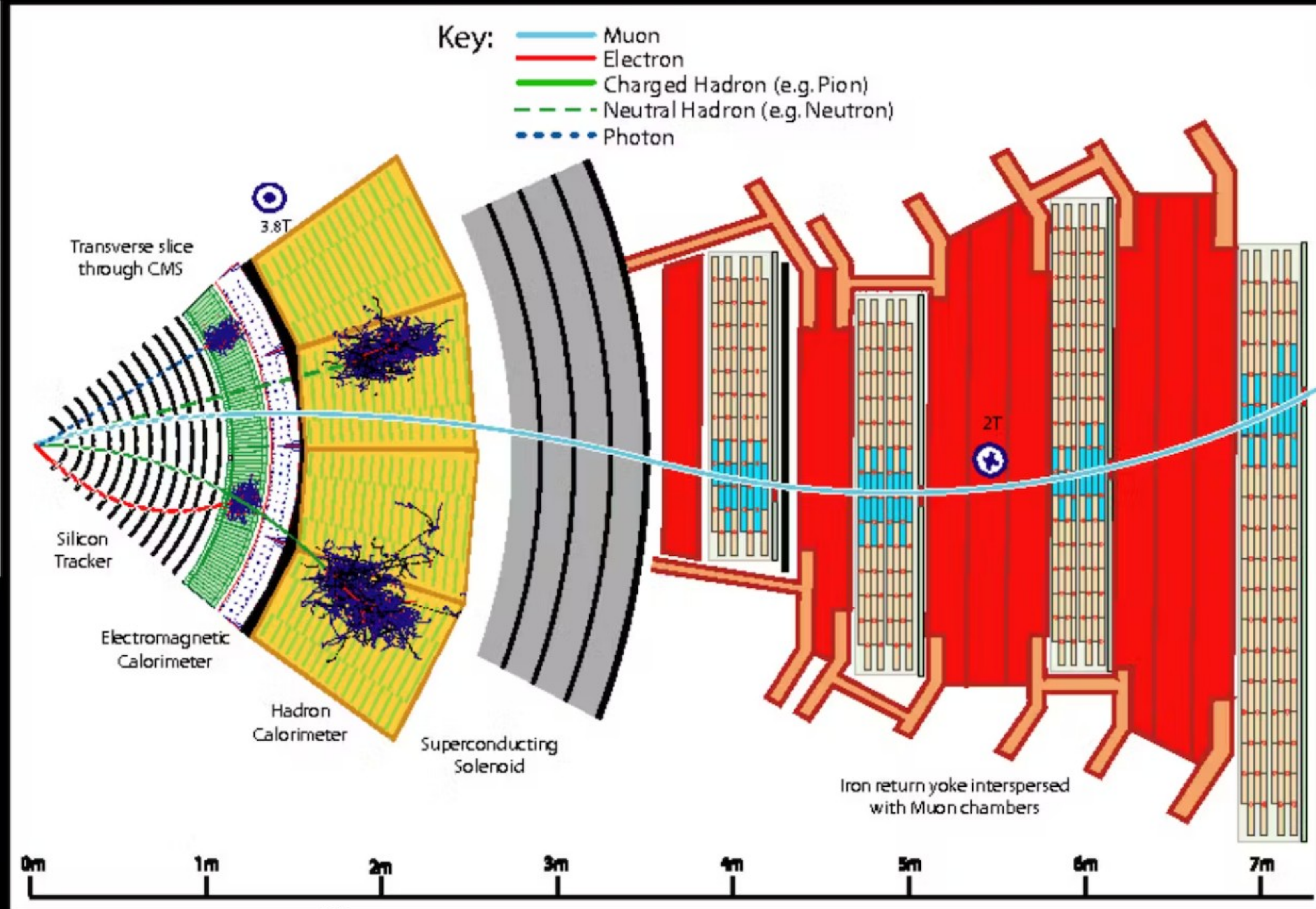
particle identification at colliders



principles of particle detection



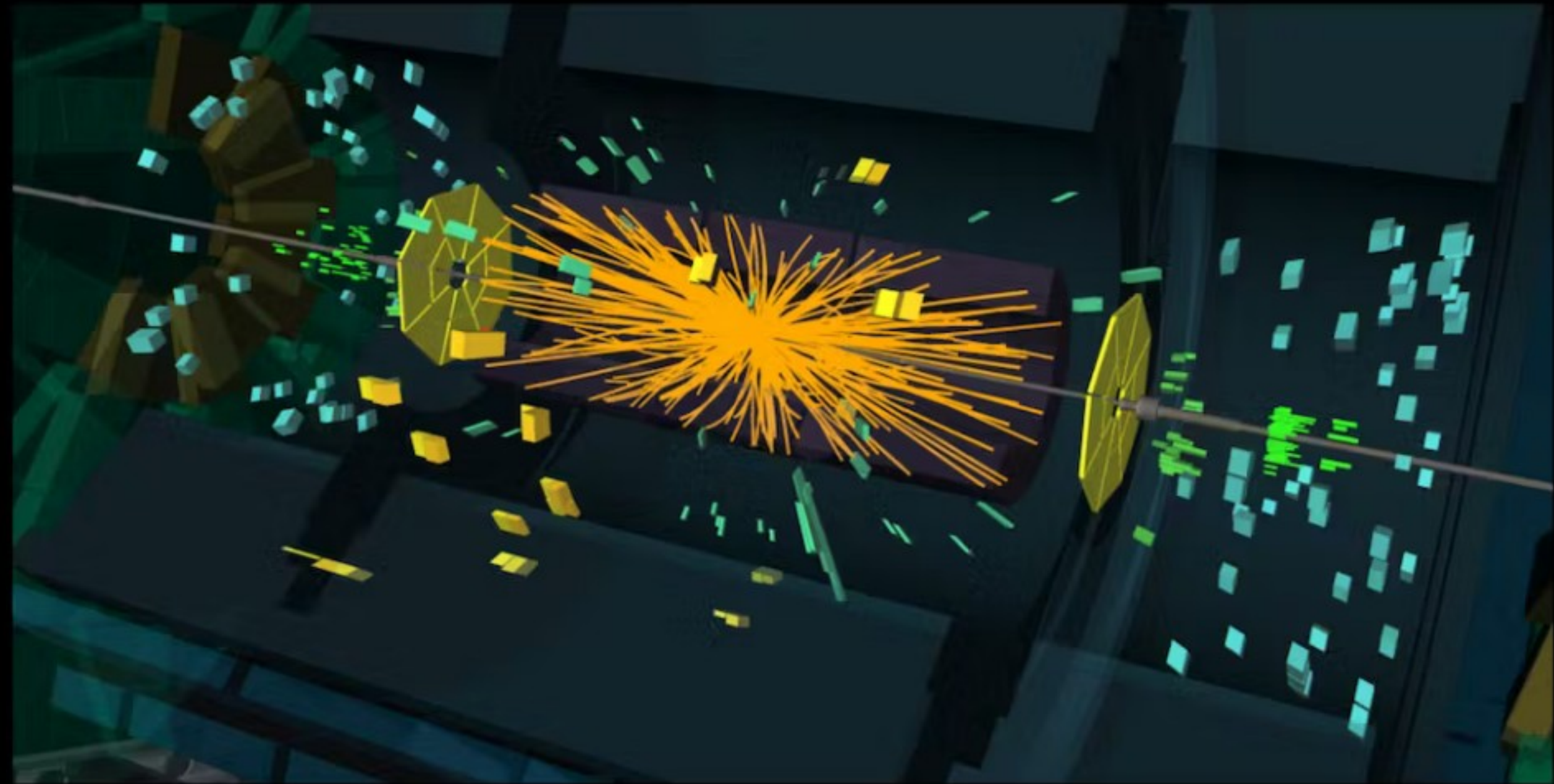
a wedge of CMS



particle identification at colliders

5 min turn to your neighbor

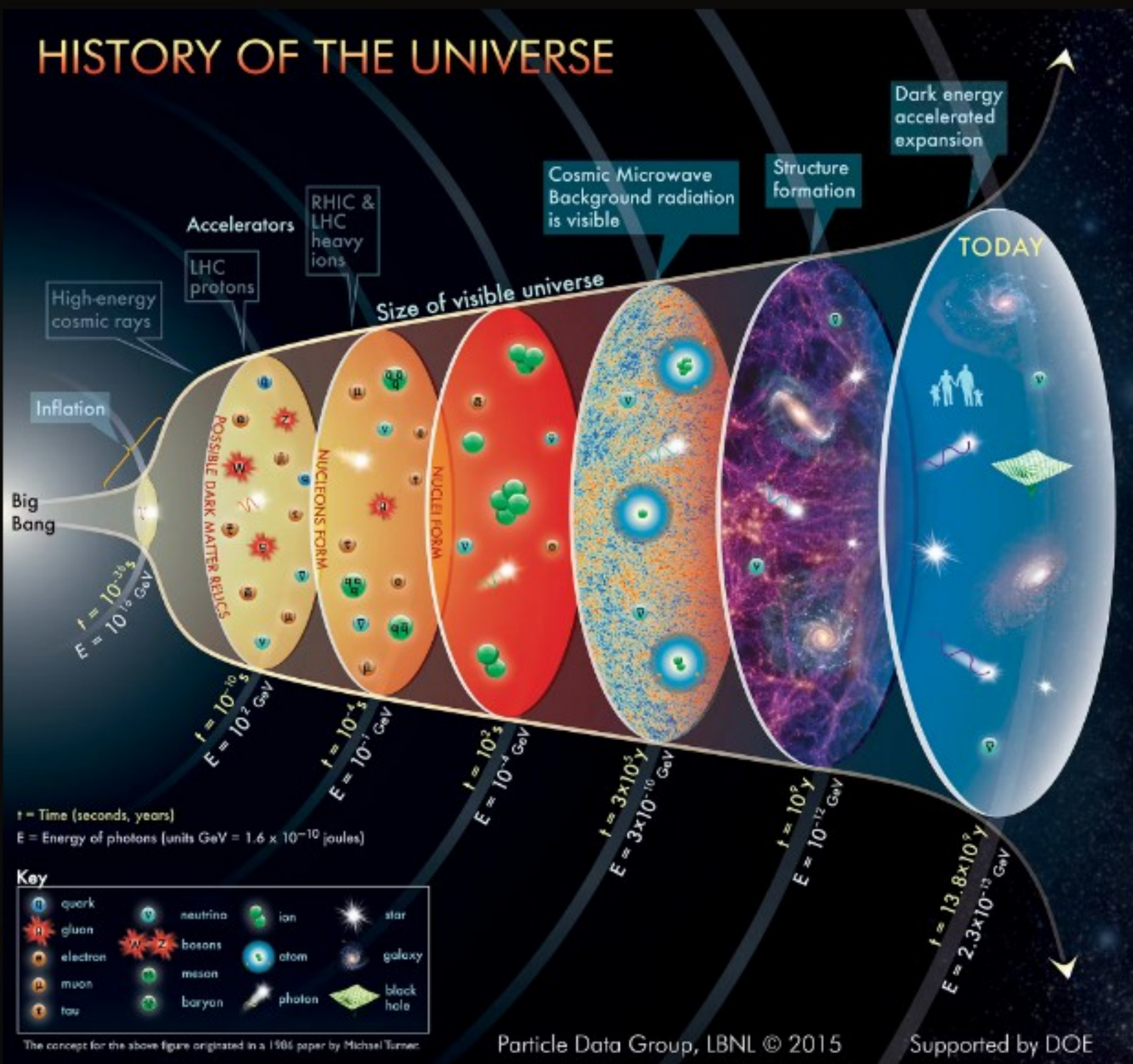
- do we use the same methods?
- what still works and what needs to change?
- why?



time for a bio break

- stretch your legs, get some air, ...
- ask questions
- reshuffle! find a new place to sit (if possible/comfortable)

We learn about the history of the universe mostly from



astronomy

33%

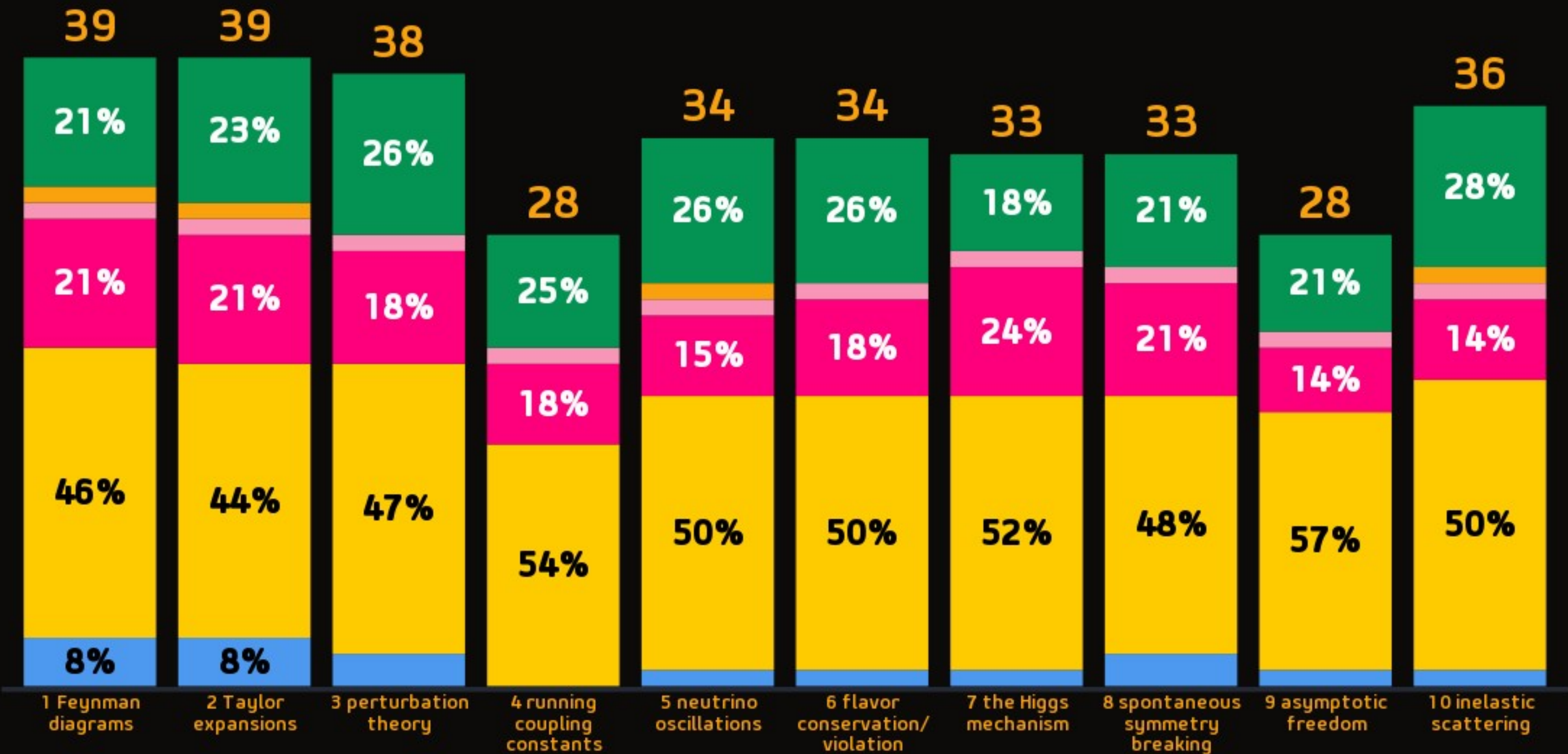
particle physics

67%

2. SM/theory chats

MARK ALL THAT APPLY, THUMBS-UP WHEN DONE

Some SM nice-to-haves: I have heard of



My current level of physics training is...

- < 3 years (pre-Bachelor / undergrad)
- 3-5 years (pursuing a Master's / 0-2 years post-grad)
- 5-7 years (started PhD 0-2 years ago / 2-4 years post-grad)
- nearing the PhD finish line (time to PhD \leq 2 years)
- more
- other
- Unknown

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RANK YOUR CONFIDENCE, THUMBS-UP WHEN DONE

I have a grasp of



20



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hadron collider theory bonanza

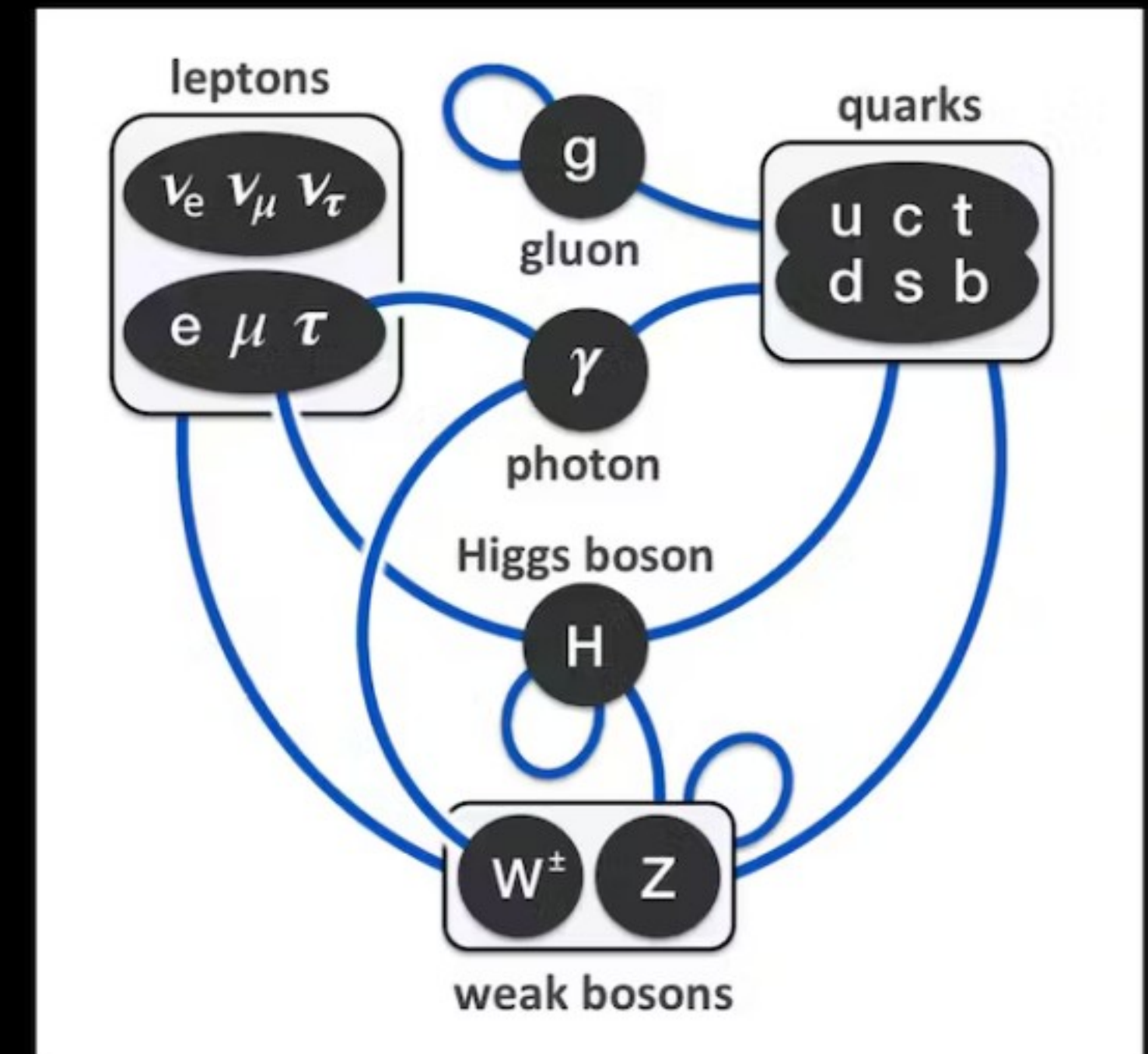
On a piece of paper or similar, make a note of a) 3 topics you could teach, and b) 3 topics you want to learn about — they are all numbered

We will do 3 rounds of:

- hold up the number of fingers matching what you will teach
- pair up with someone who teaches what you want to learn (if possible)
- 2 minute peer instruction per topic, then you will switch roles
- pick a new topic and switch partners.

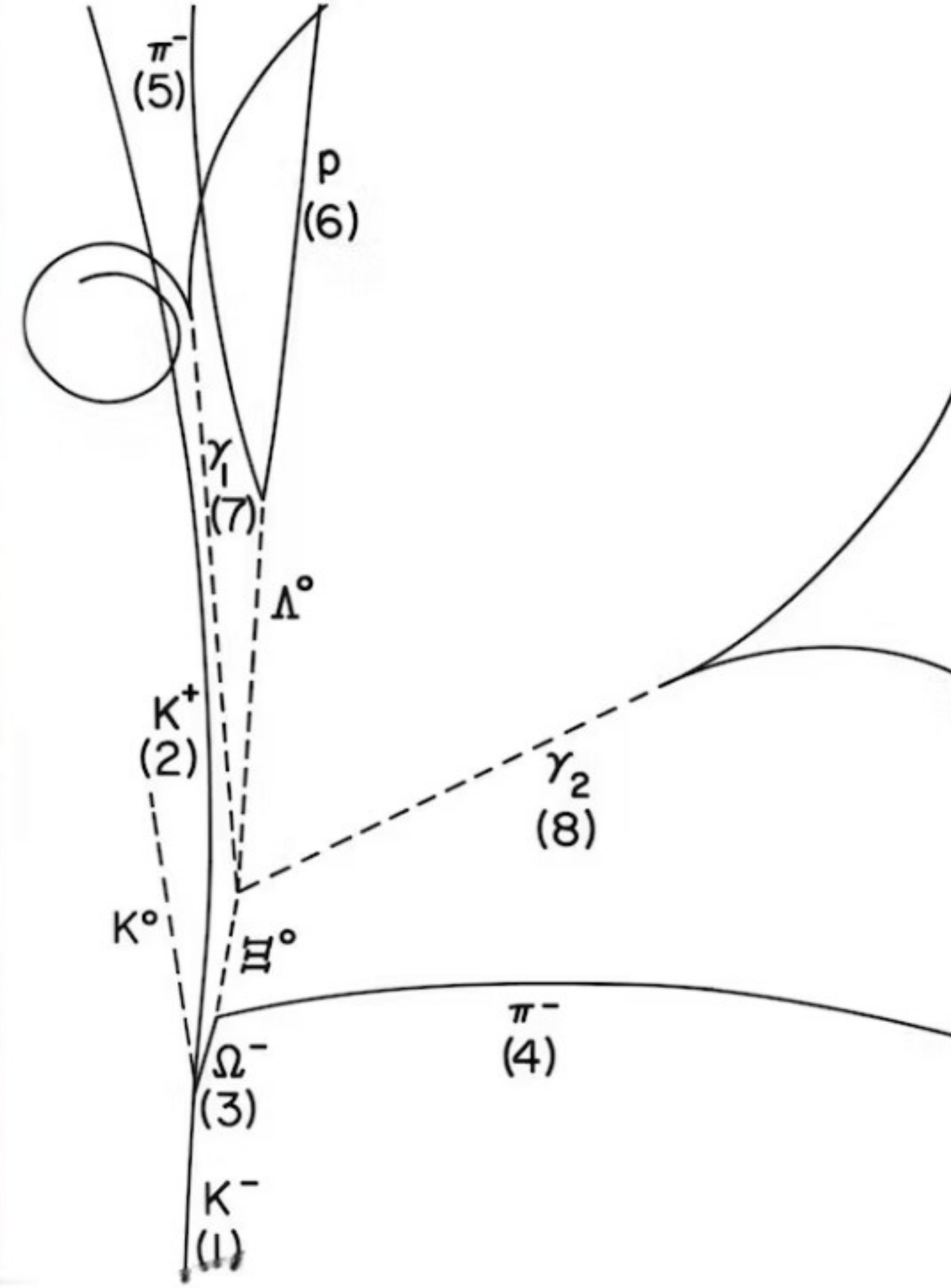
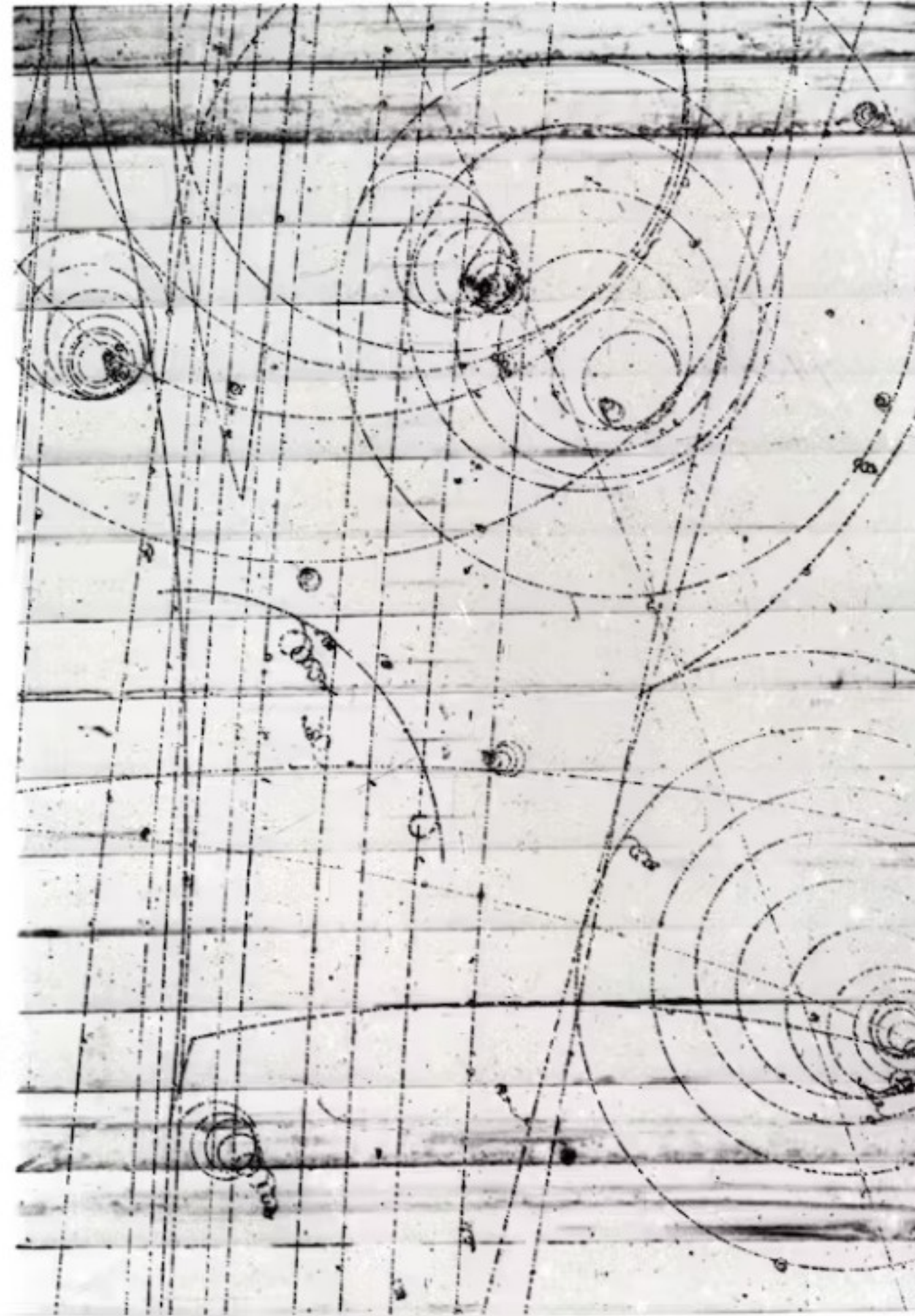
Afterwards, people who learned something share out to the group

- a chance to get clarifications, additions, comments, or give a shout-out to a really interesting explanation



3. accelerators and triggers

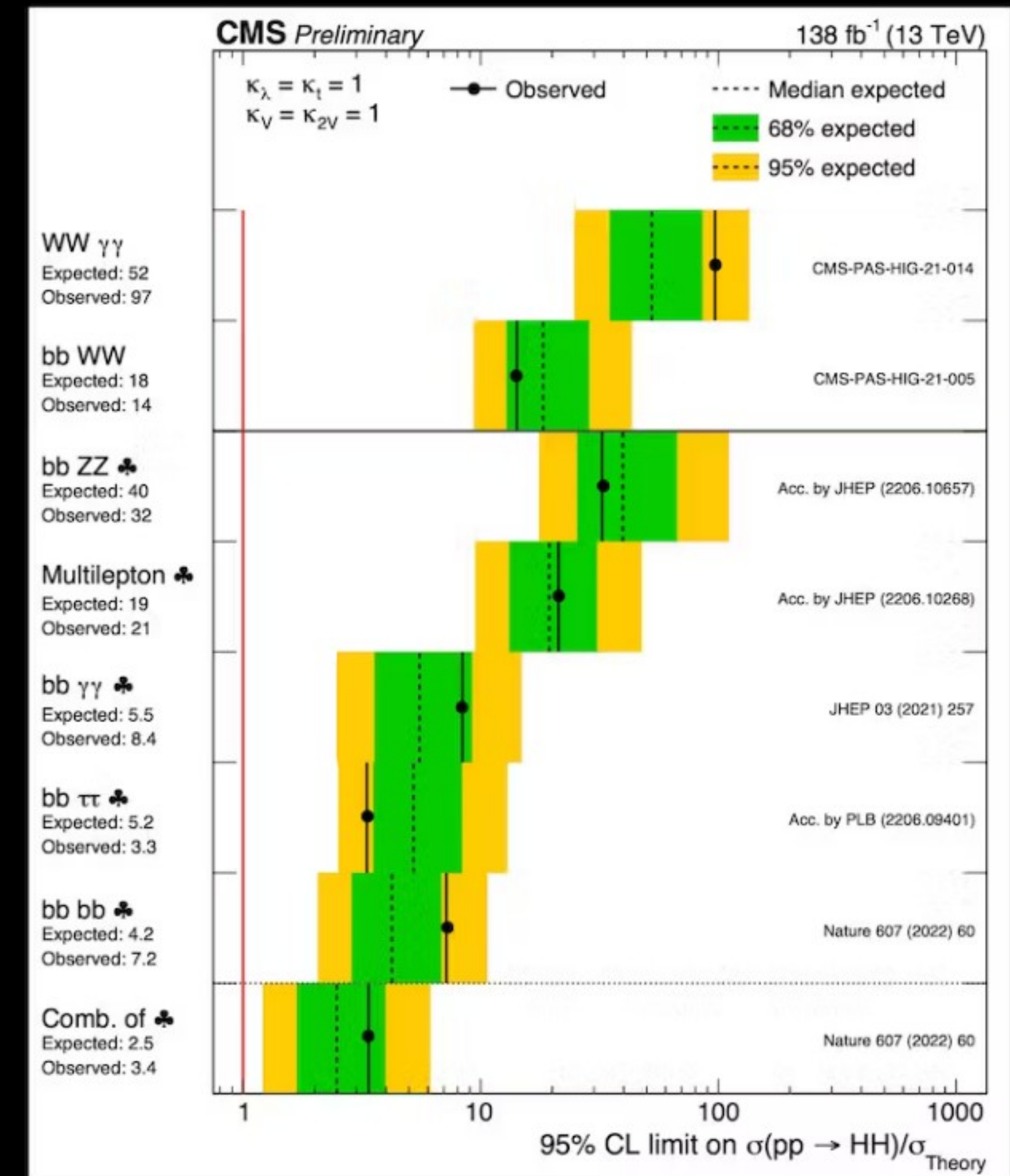
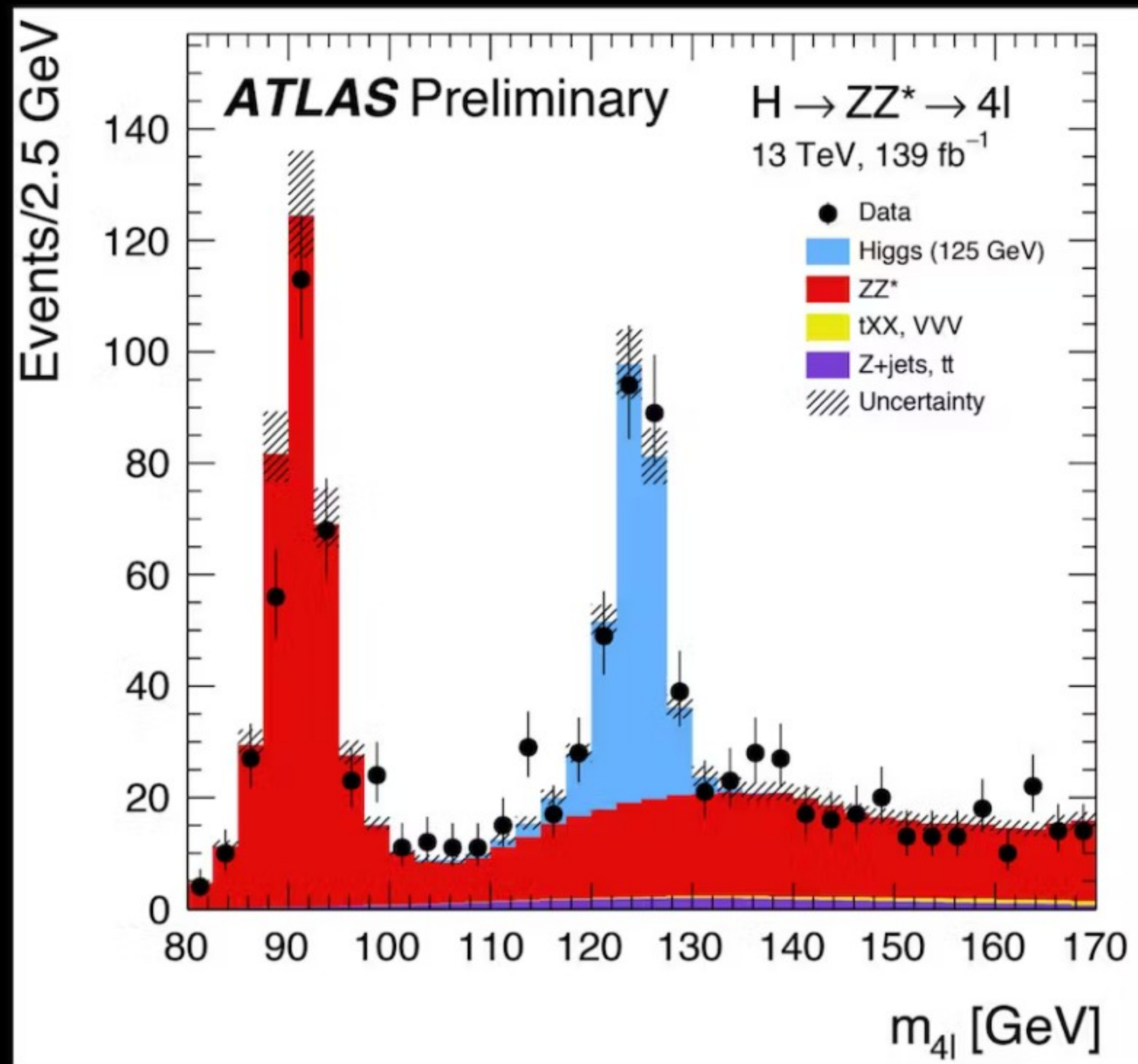
Q: what are all those vertical lines?



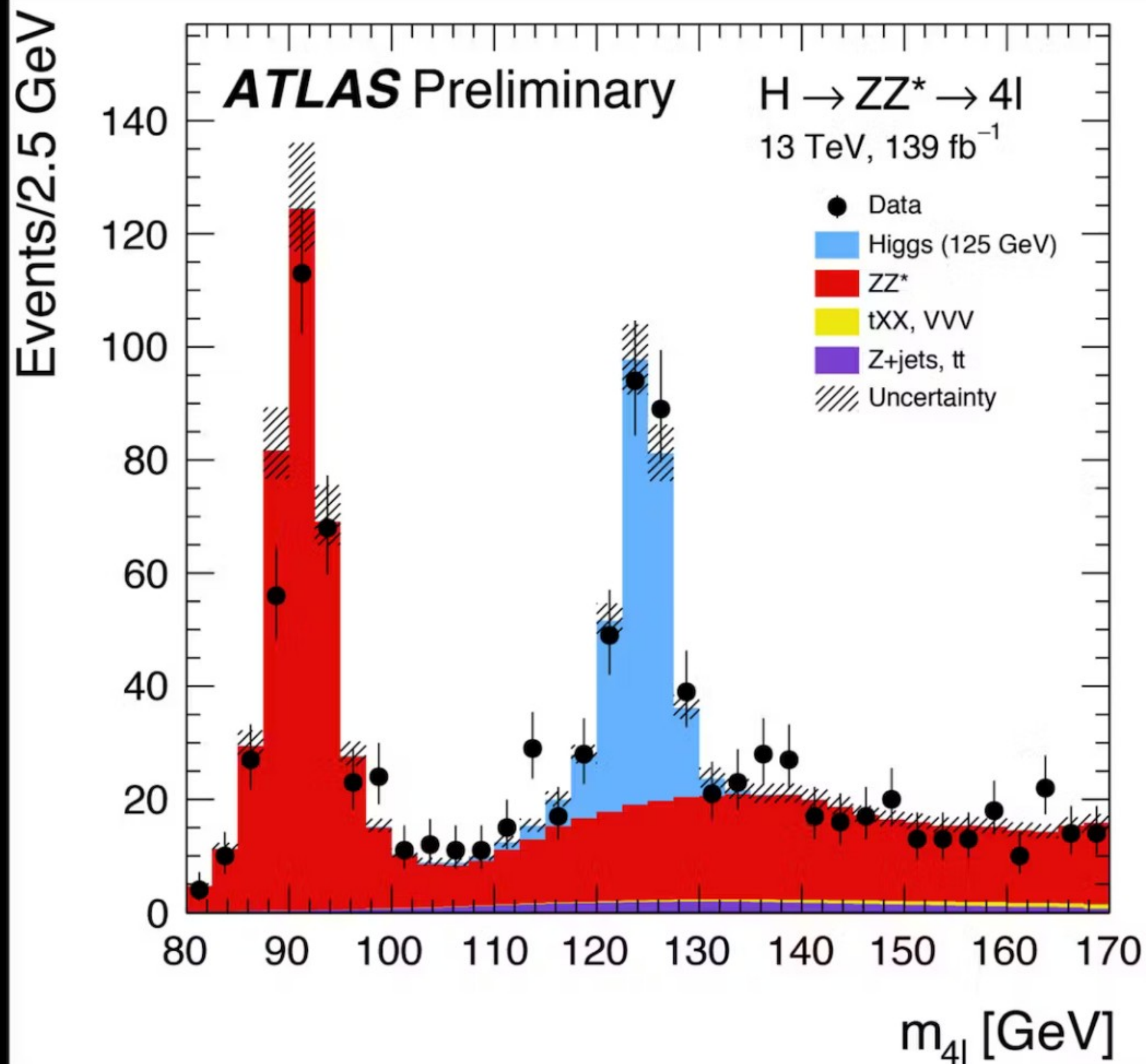
triggers starting from the example
of a cosmic ray experiment

4. what goes into typical plots

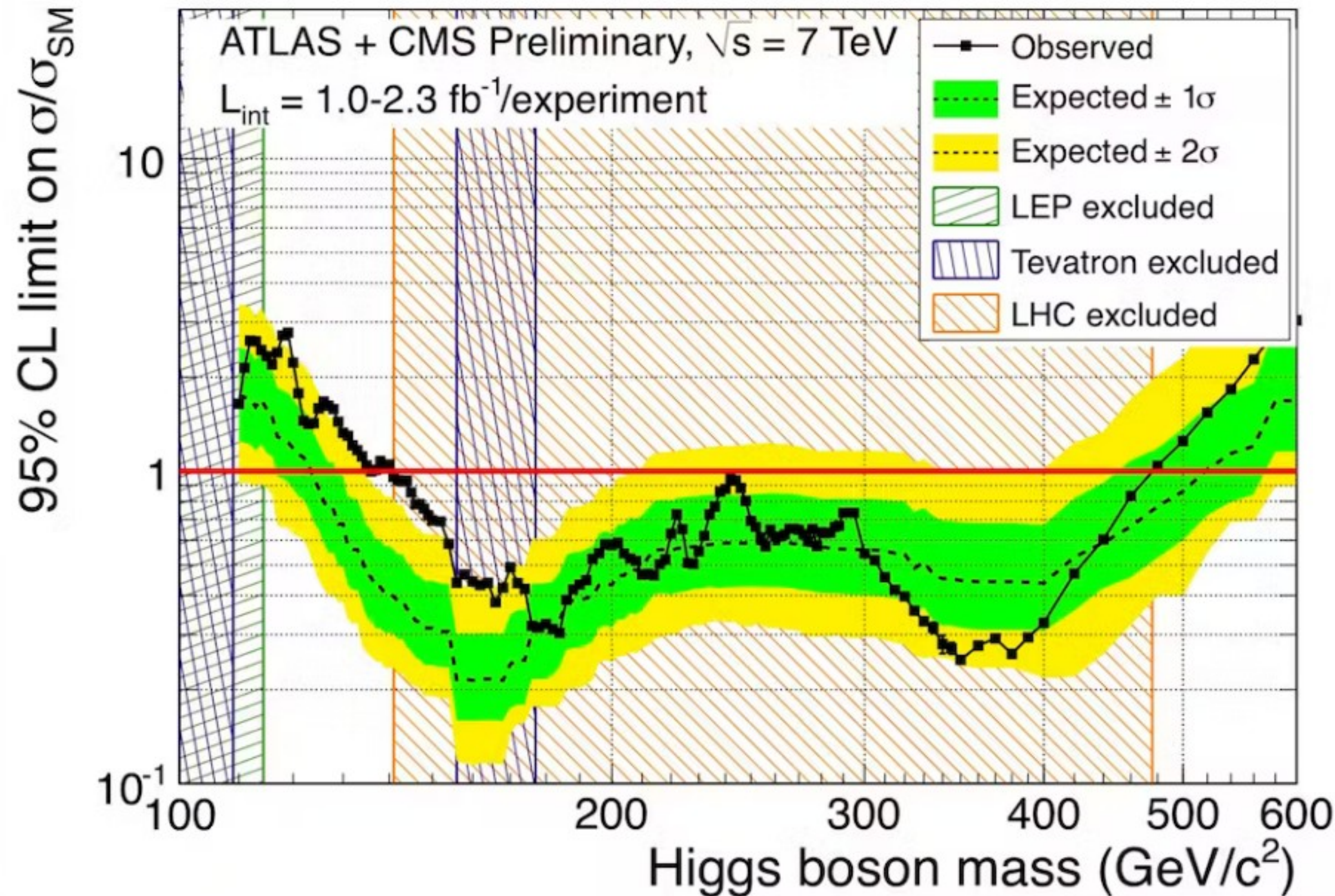
typical conference plots



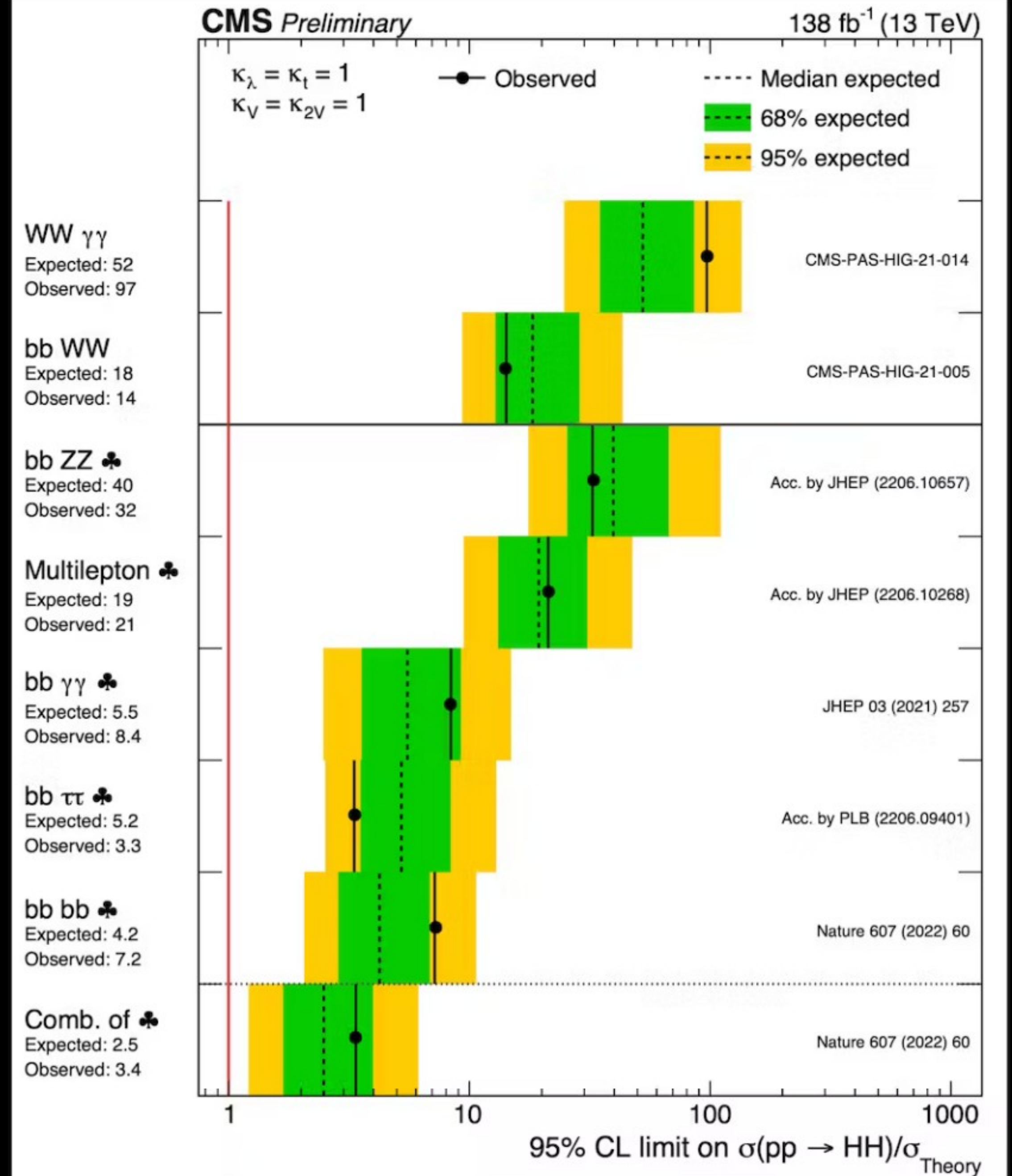
what went
into making
this plot?



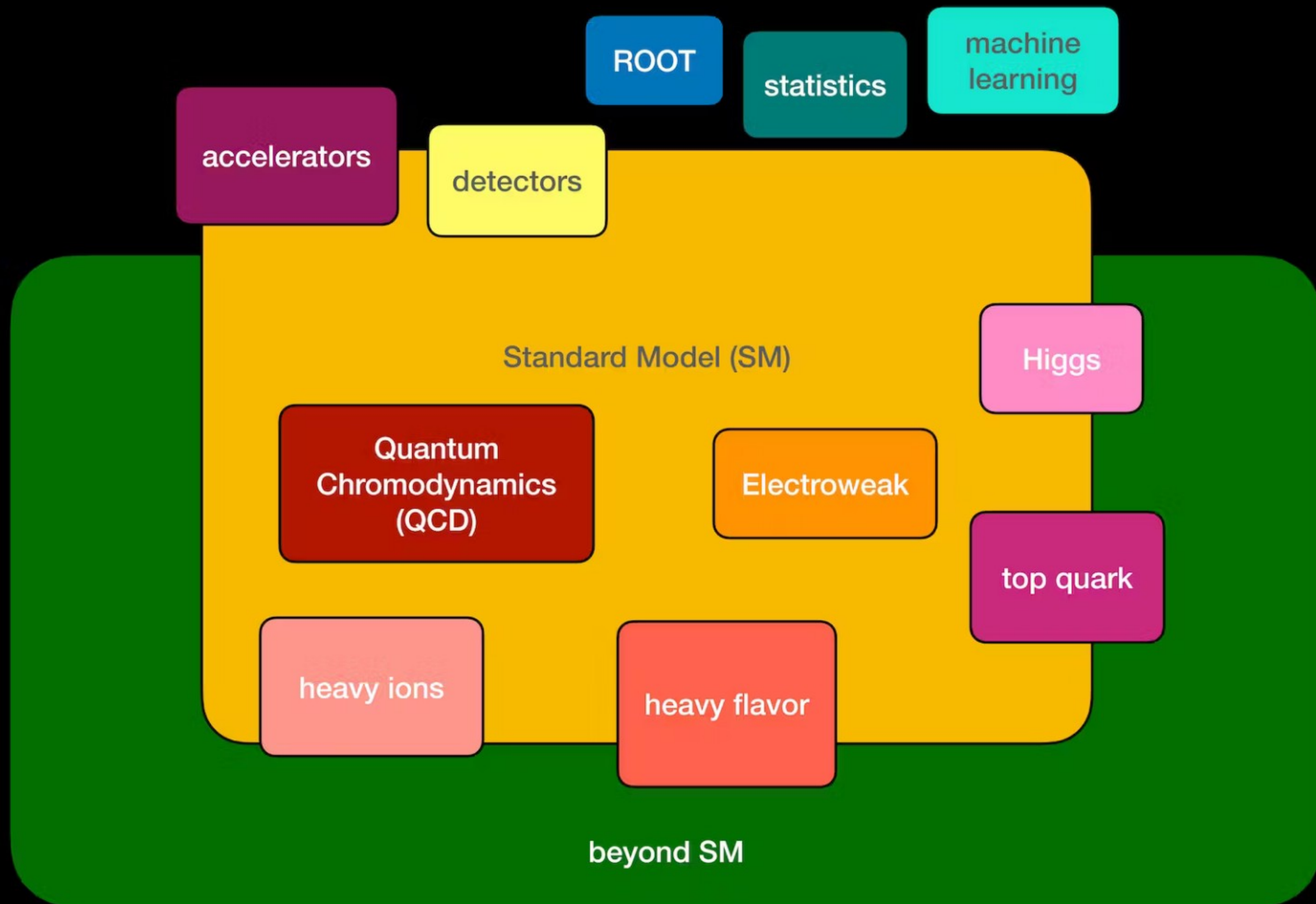
how does one interpret these?



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topics



Other summer schools (or similar) you have attended and would recommend



This is your community

You already made it, you belong here,
you are welcome here.



Before I thought... Now I think...

ANONYMOUS, OPTIONAL AND HIDDEN:

Please give me feedback on my lecture!

the end.

