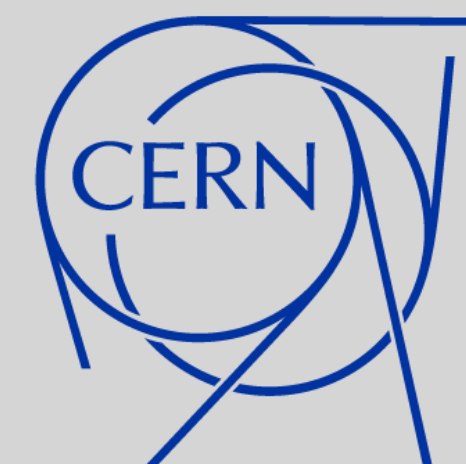


Challenges of Experimental Particle Physics*

*from my very biased point of view.

A. Salzburger (CERN)





from my very **biased** point of view.

Why biased?

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

Theory



Accelerator



Detector



Data Acquisition



Data Reconstruction



Data Analysis



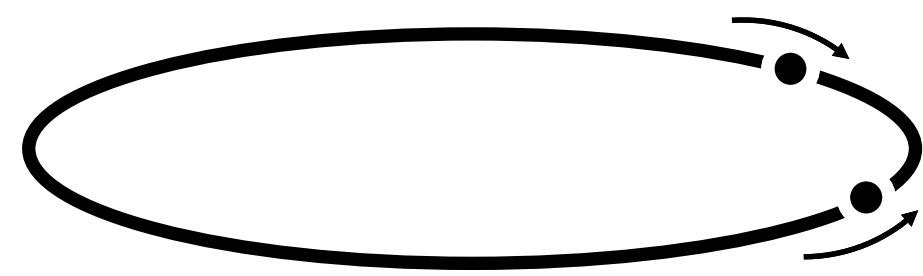
Yeah, I had to study this for university, but I am really NO theoretical physicist!

Worldwide distributed Computing

Why biased?

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

Theory



Accelerator



Detector



Data Acquisition



Data Reconstruction



Data Analysis



How do these guys
even do that?

Seriously?!?

Worldwide distributed
Computing

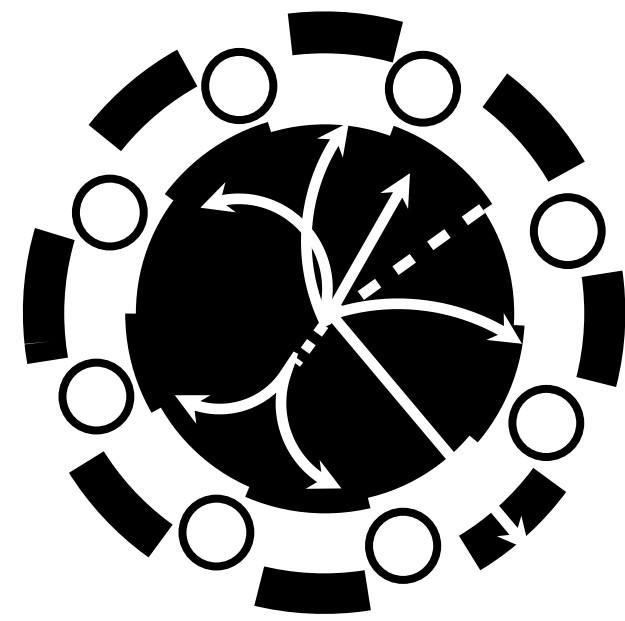
Why biased?

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

Theory



Accelerator



Detector



Hey, I designed one!!

And ok, the engineers
laughed at me ...

Worldwide distributed
Computing



Data Analysis



Data Acquisition



Data Reconstruction

Why biased?

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

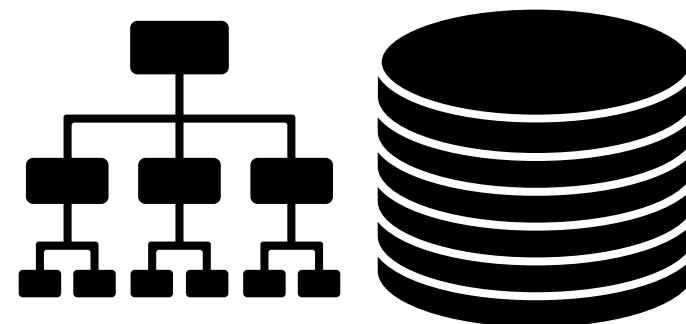
Theory



Accelerator



Detector



Data Acquisition



I know a fair bit of that!

Worldwide distributed Computing



Data Analysis



Data Reconstruction

Why biased?

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

Theory



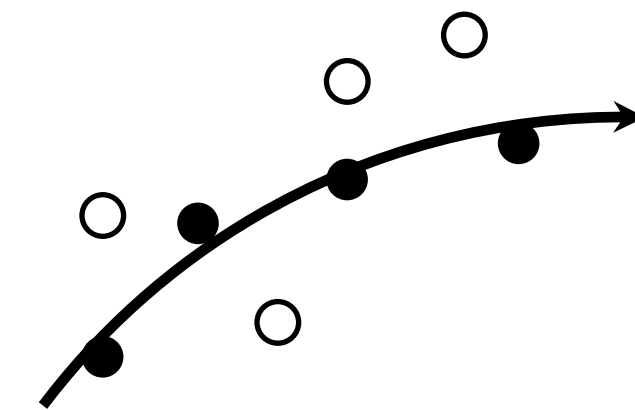
Accelerator



Detector



Data Acquisition



Data Reconstruction



Data Analysis

Worldwide distributed Computing



Now we are talking, I can preach HOURS about that stuff.

Why biased?

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

Theory



Accelerator



Detector



Data Acquisition



Data Reconstruction



Data Analysis



Yup, seen that,
done that.

Worldwide distributed
Computing

Why biased?

I really don't care about the details too much ...
... as long as it WORKS!



Worldwide distributed Computing



Data Analysis



Data Reconstruction



Data Acquisition



Detector



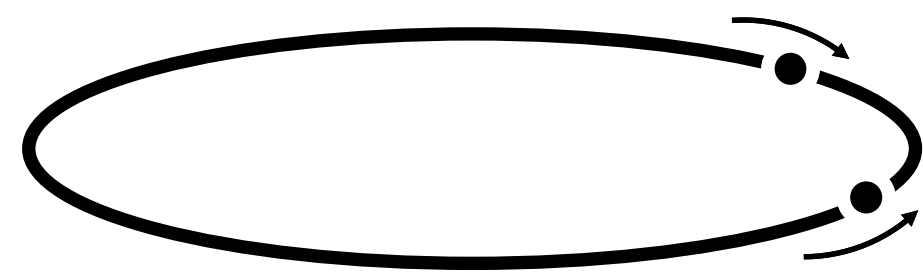
Accelerator

Theory

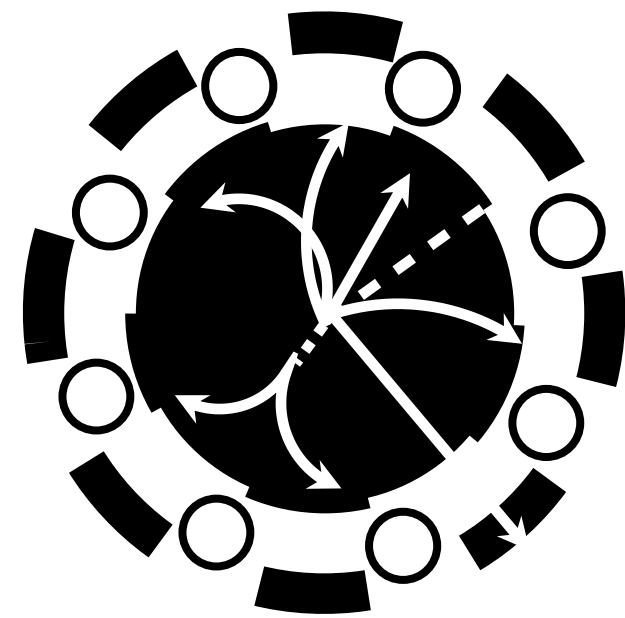
So complex!

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

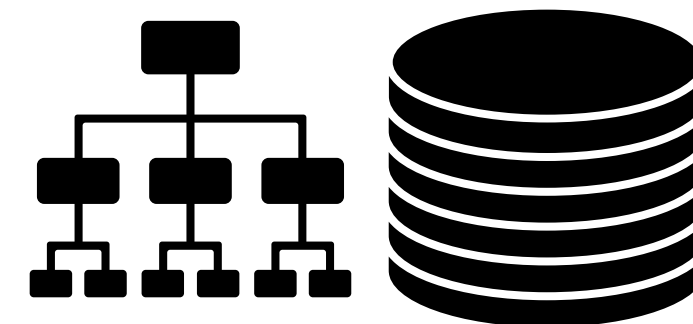
Theory



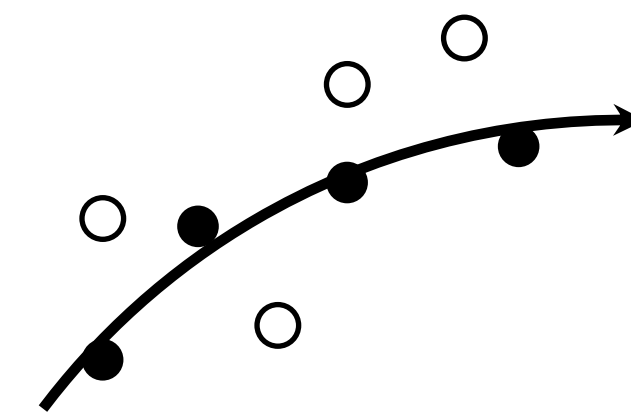
Accelerator



Detector



Data Acquisition



Data Reconstruction



Worldwide distributed Computing

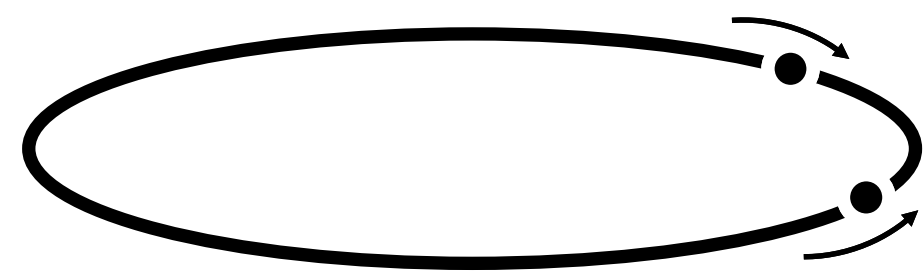


Data Analysis

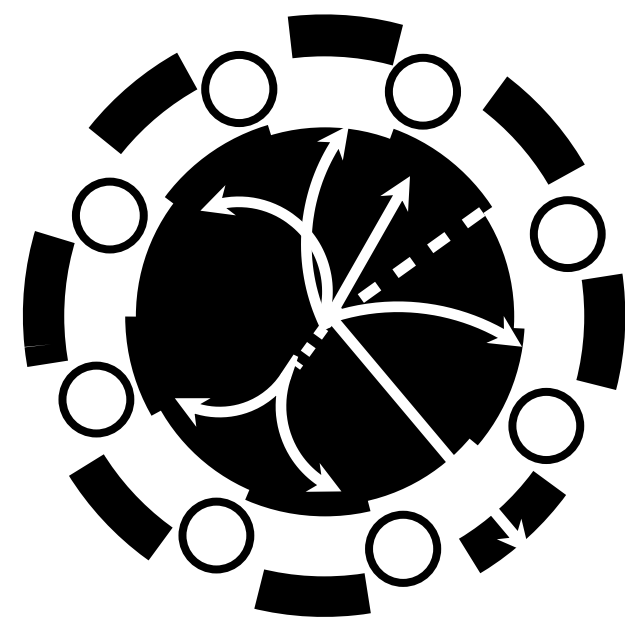
And yet ...

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

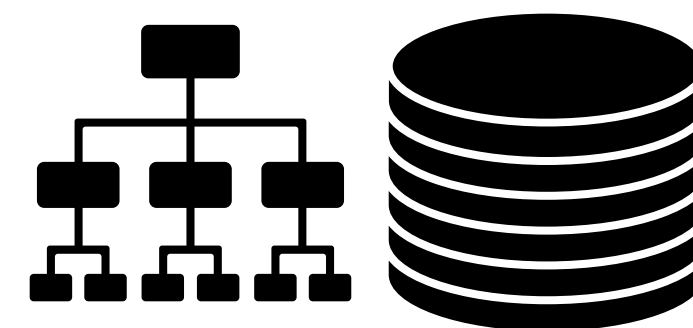
Theory



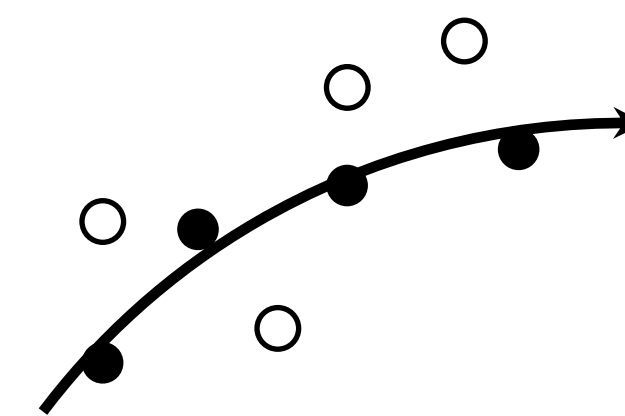
Accelerator



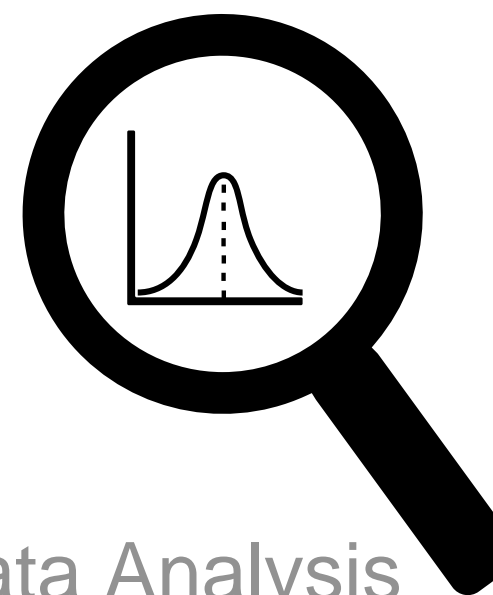
Detector



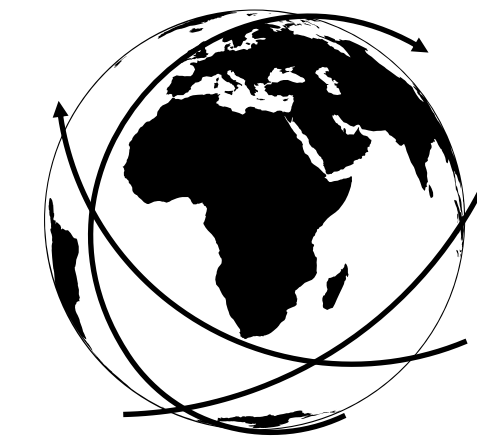
Data Acquisition



Data Reconstruction



Data Analysis



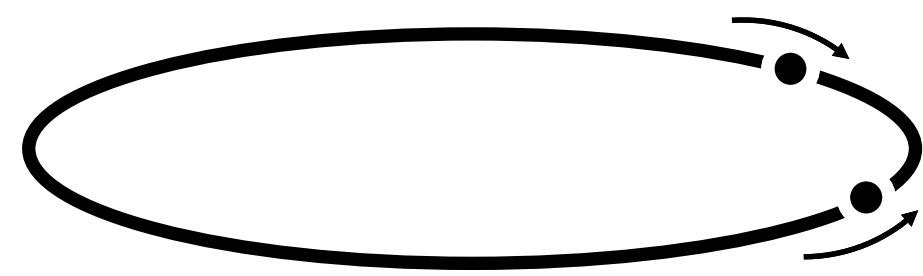
Worldwide distributed Computing

... all of that has
to work together!

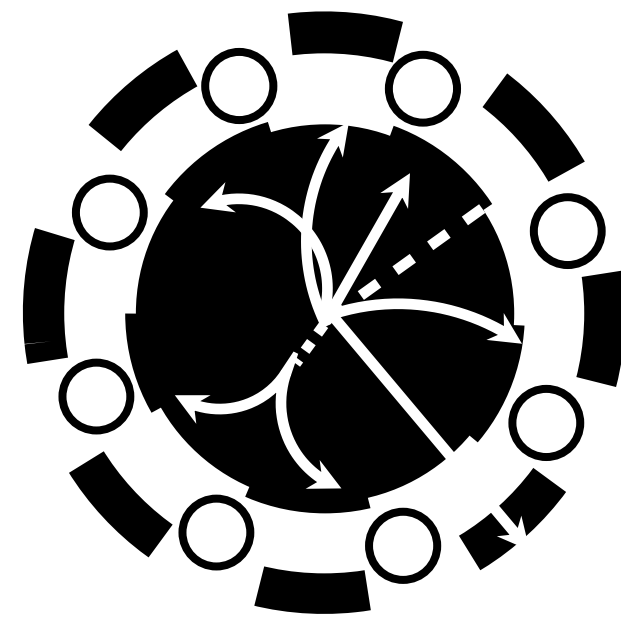
Oh, what ...

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

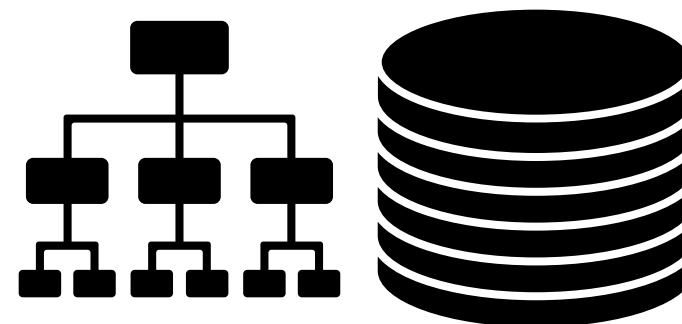
Theory



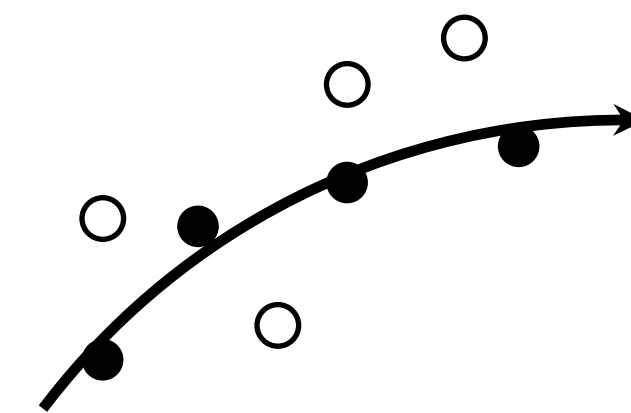
Accelerator



Detector



Data Acquisition



Data Reconstruction



Data Analysis



Laboratory



Worldwide distributed Computing

YOU

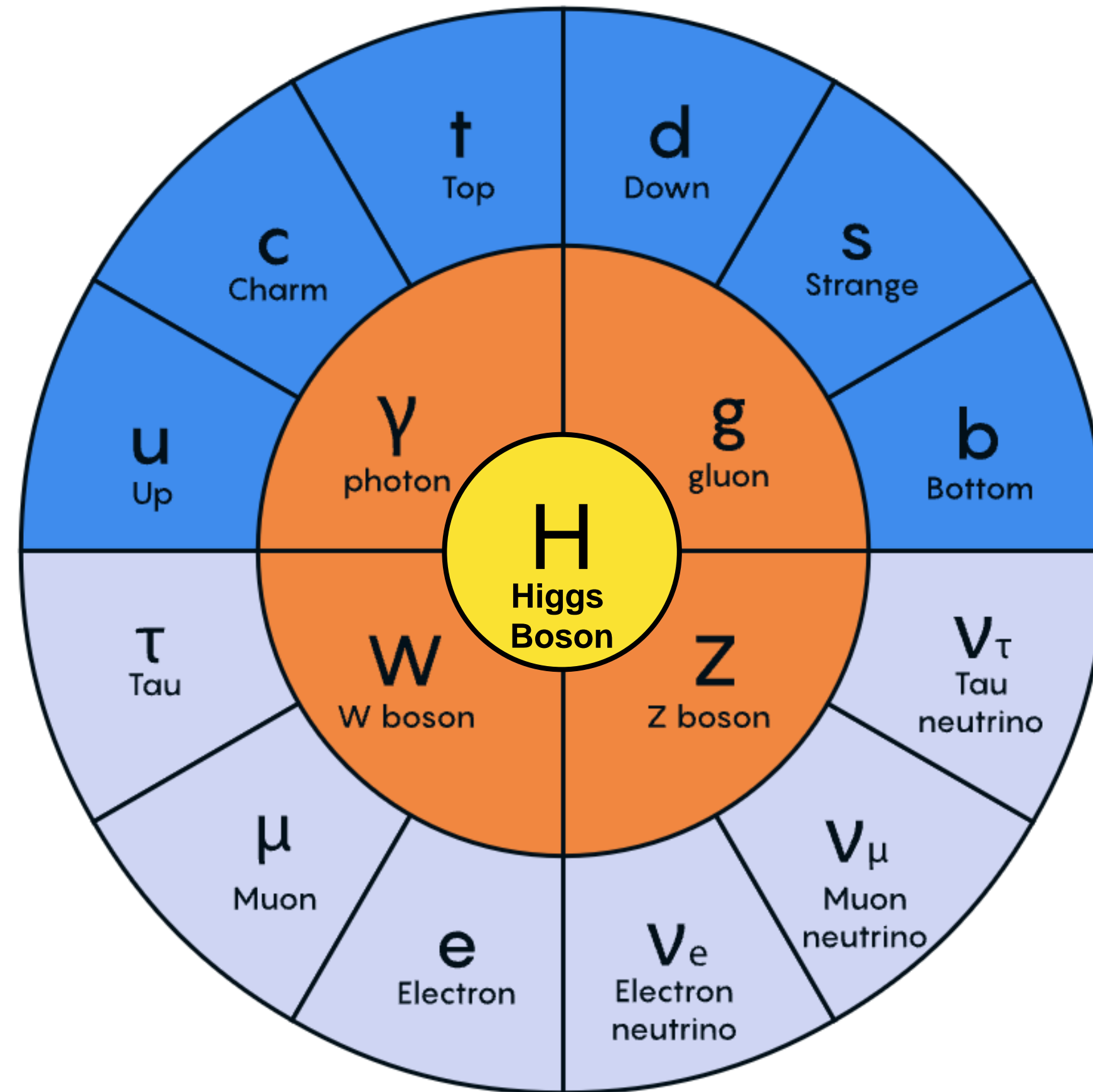
The theory

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

The Lagrangian of the Standard Model:

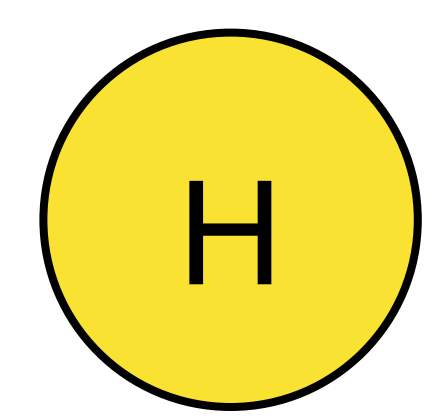
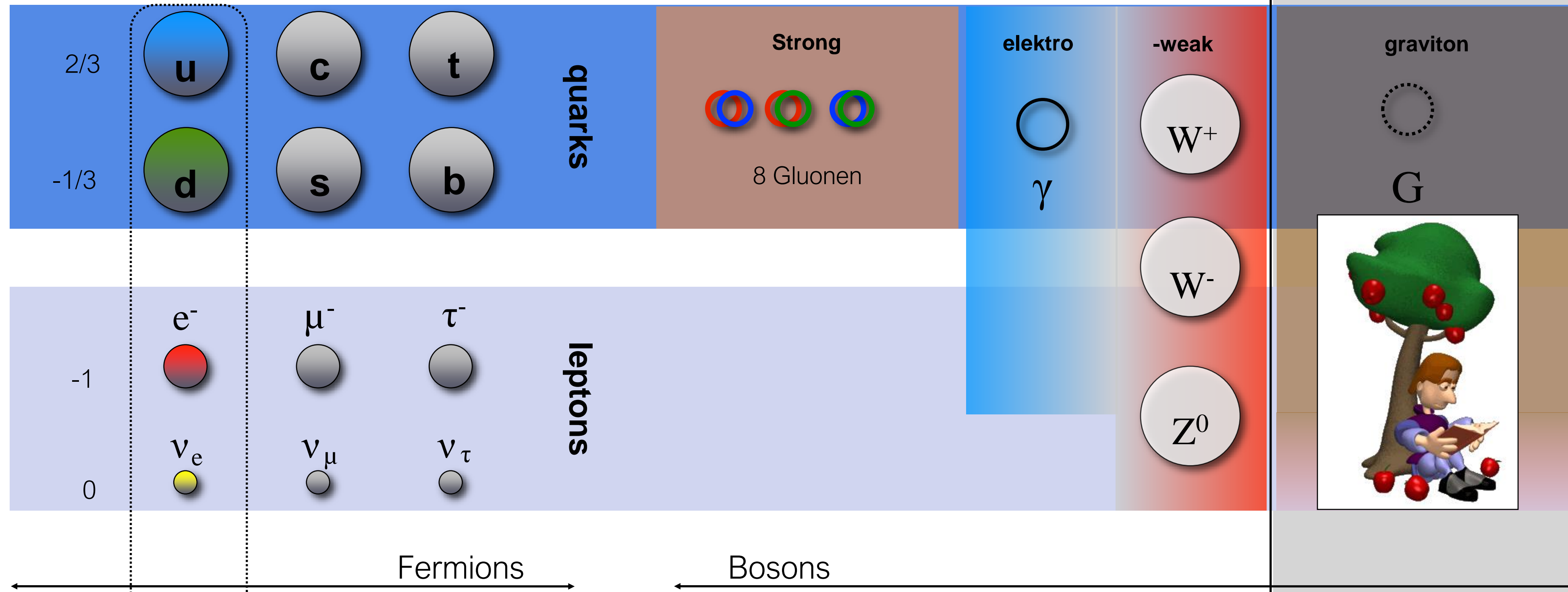
It describes the particles, and how they interact with another

The particles?



Particles and mediators

Not described by the Standard Model

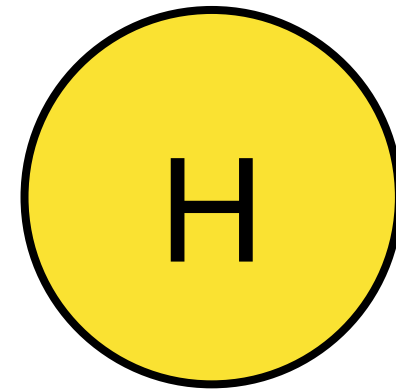


+ Higgs Boson

Finding the Higgs Boson

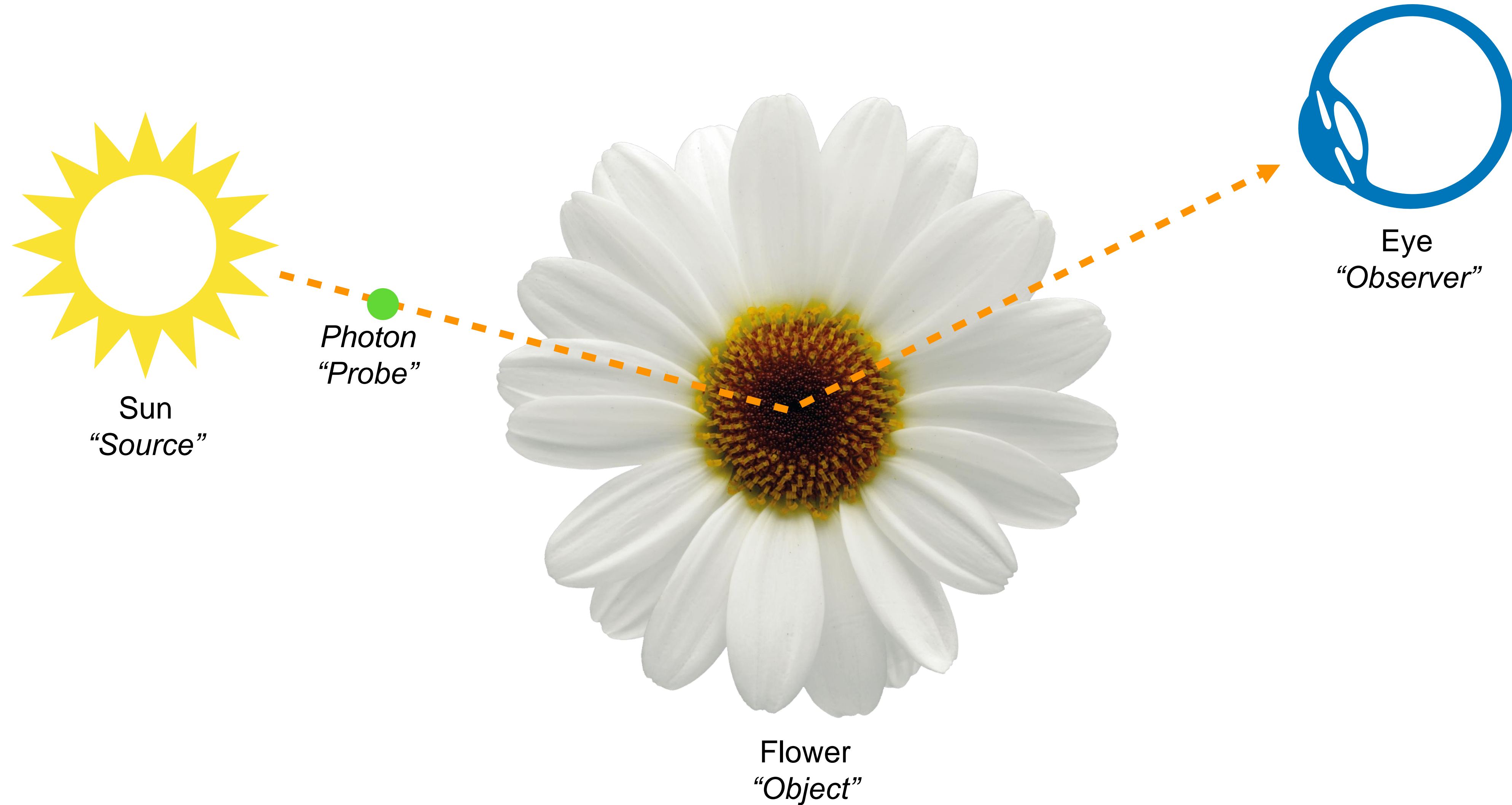


I wait until a

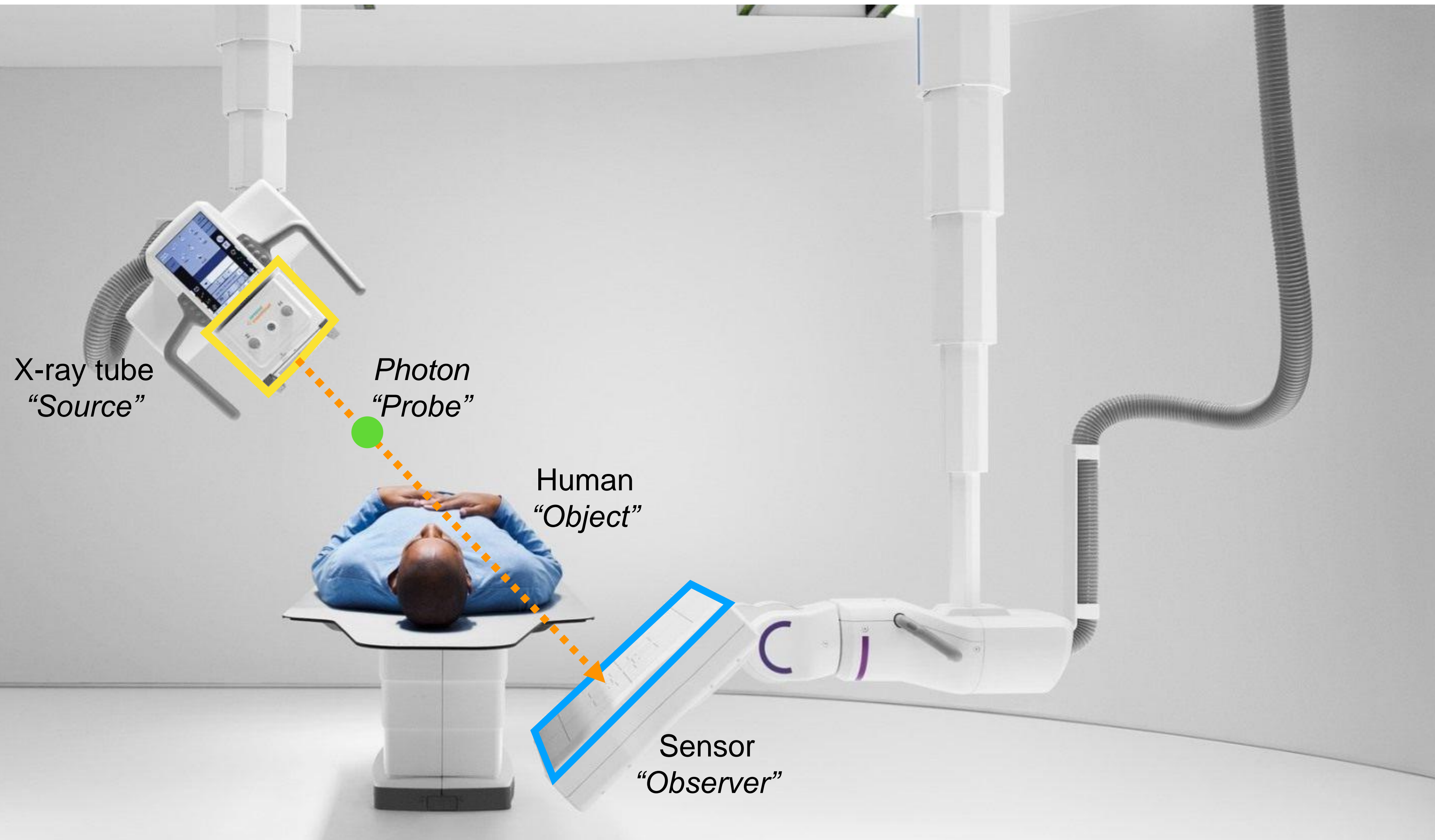


comes around,
and then I
look at it.

A daily observation

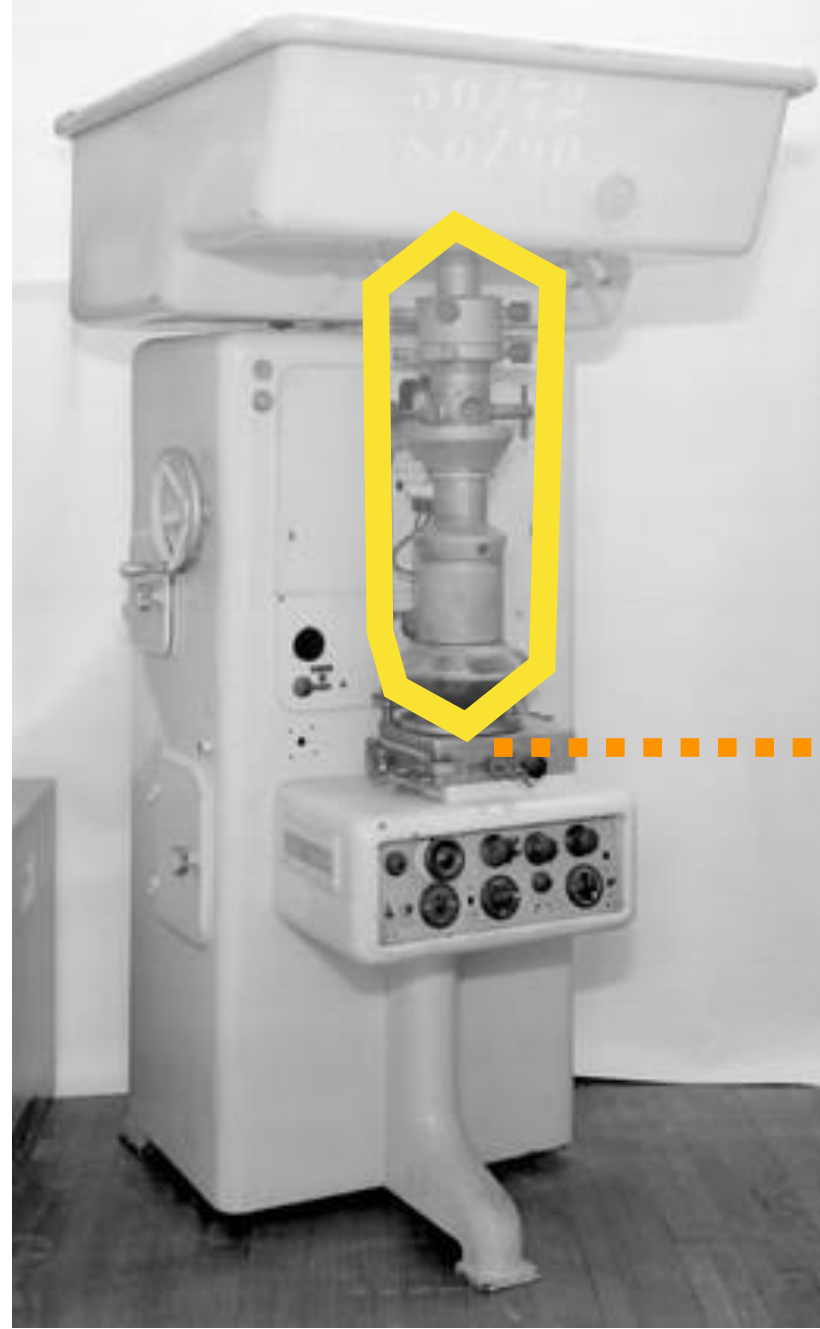


A good microscope



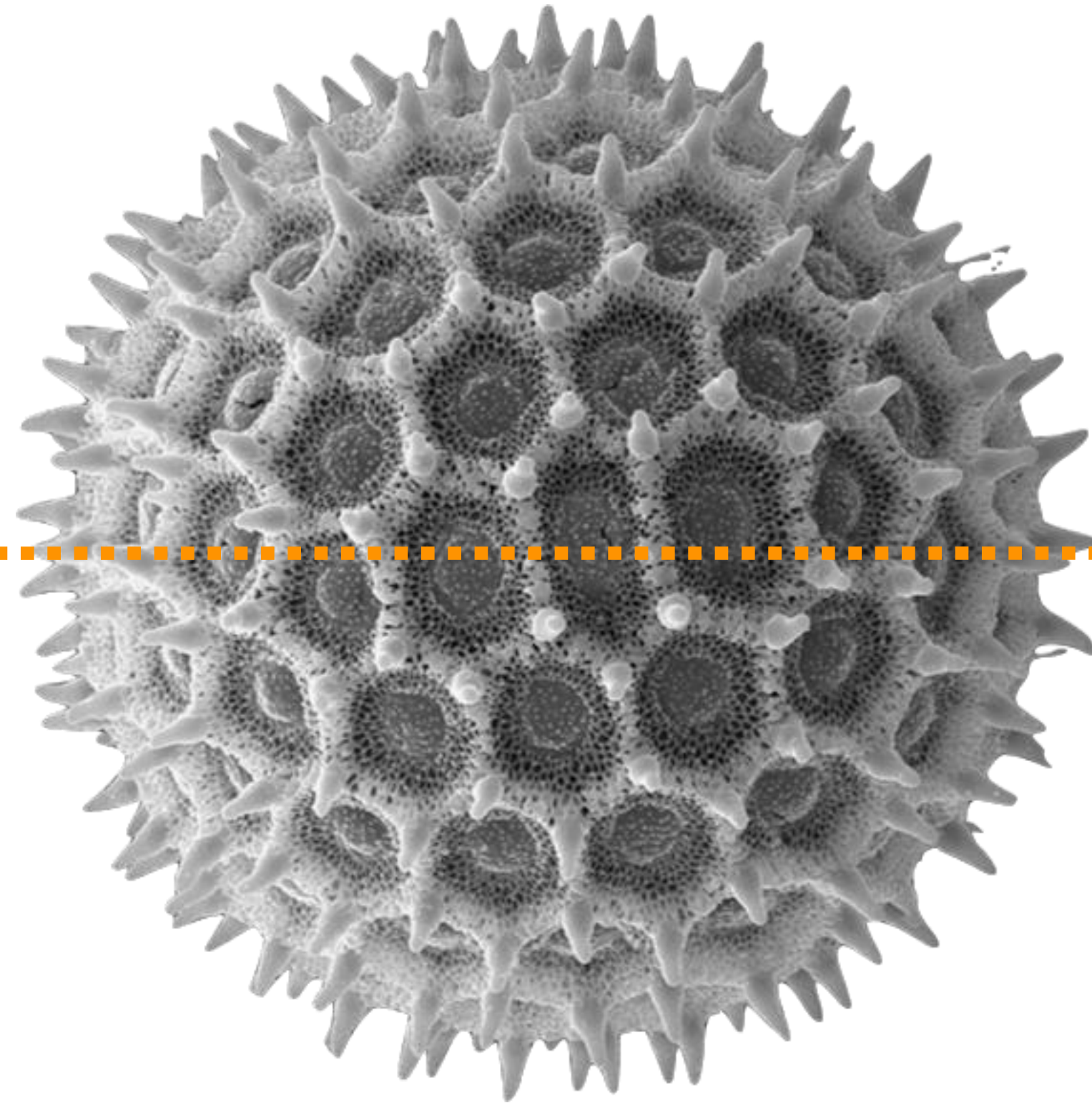
A very good microscope

Electron microscope Siemens, 1943



Cathode
"Source"

Electron
"Probe"

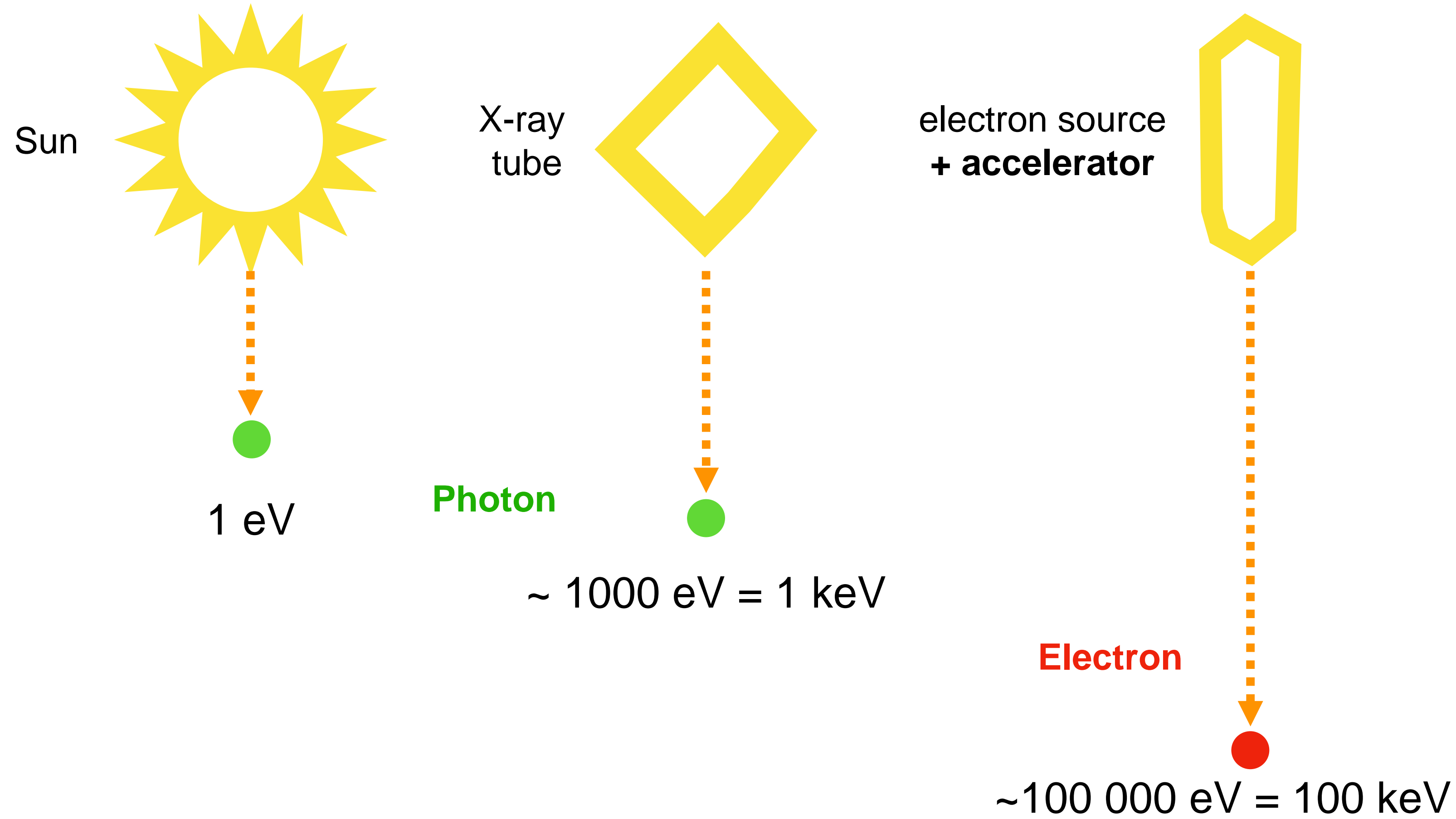


Pollen
"Object"

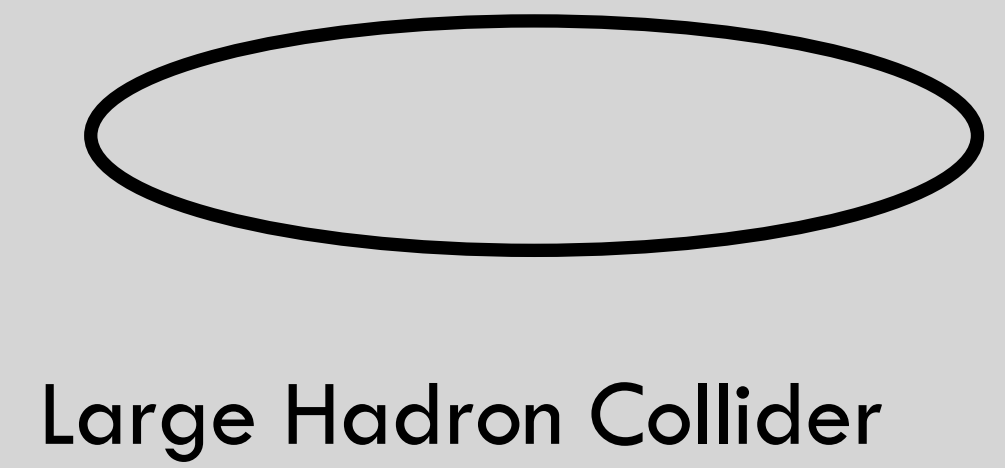
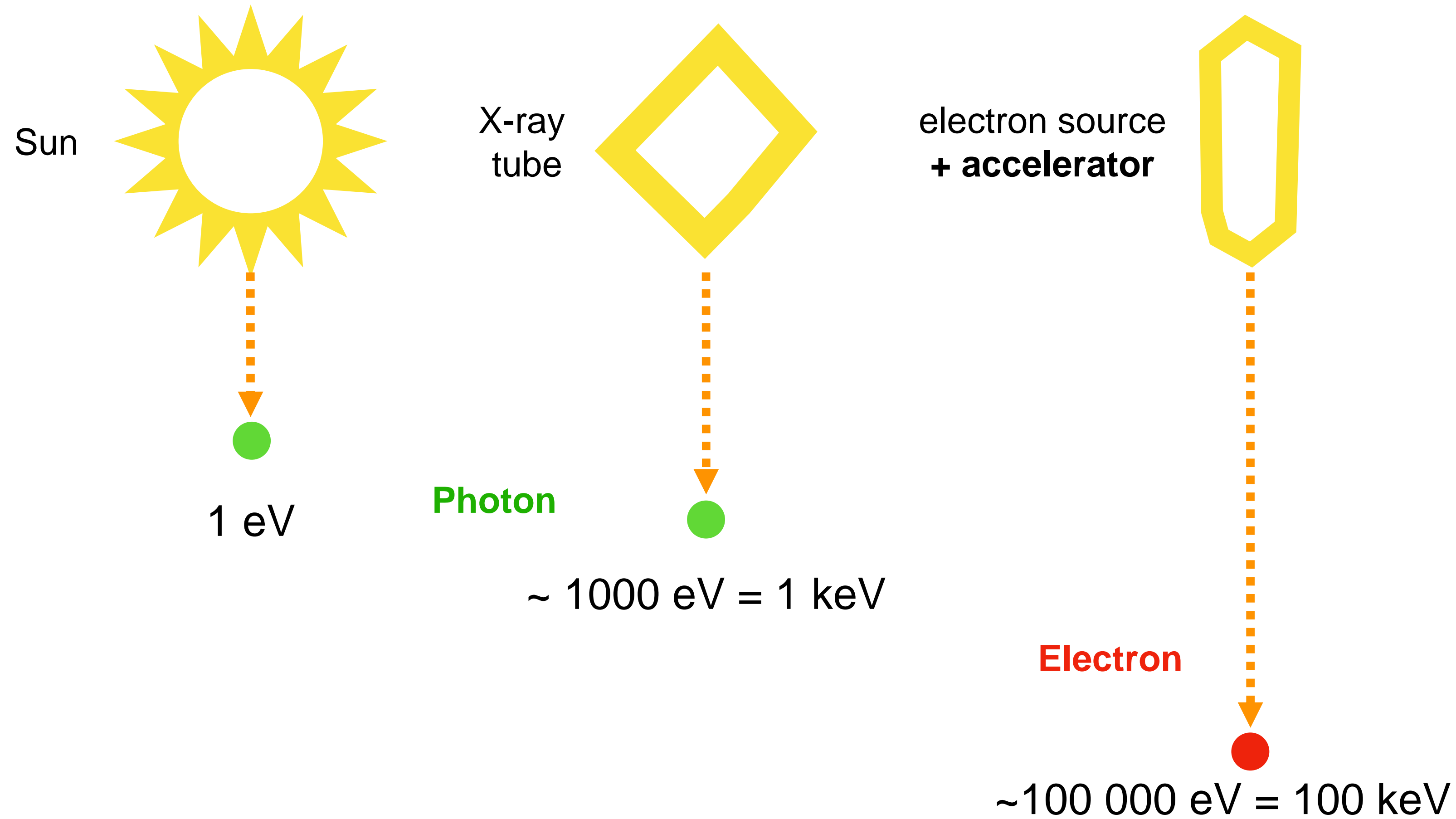


Detector
"Observer"

My experiments so far ...

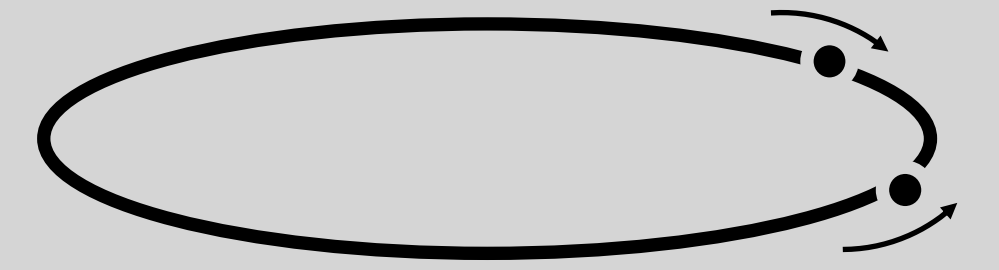
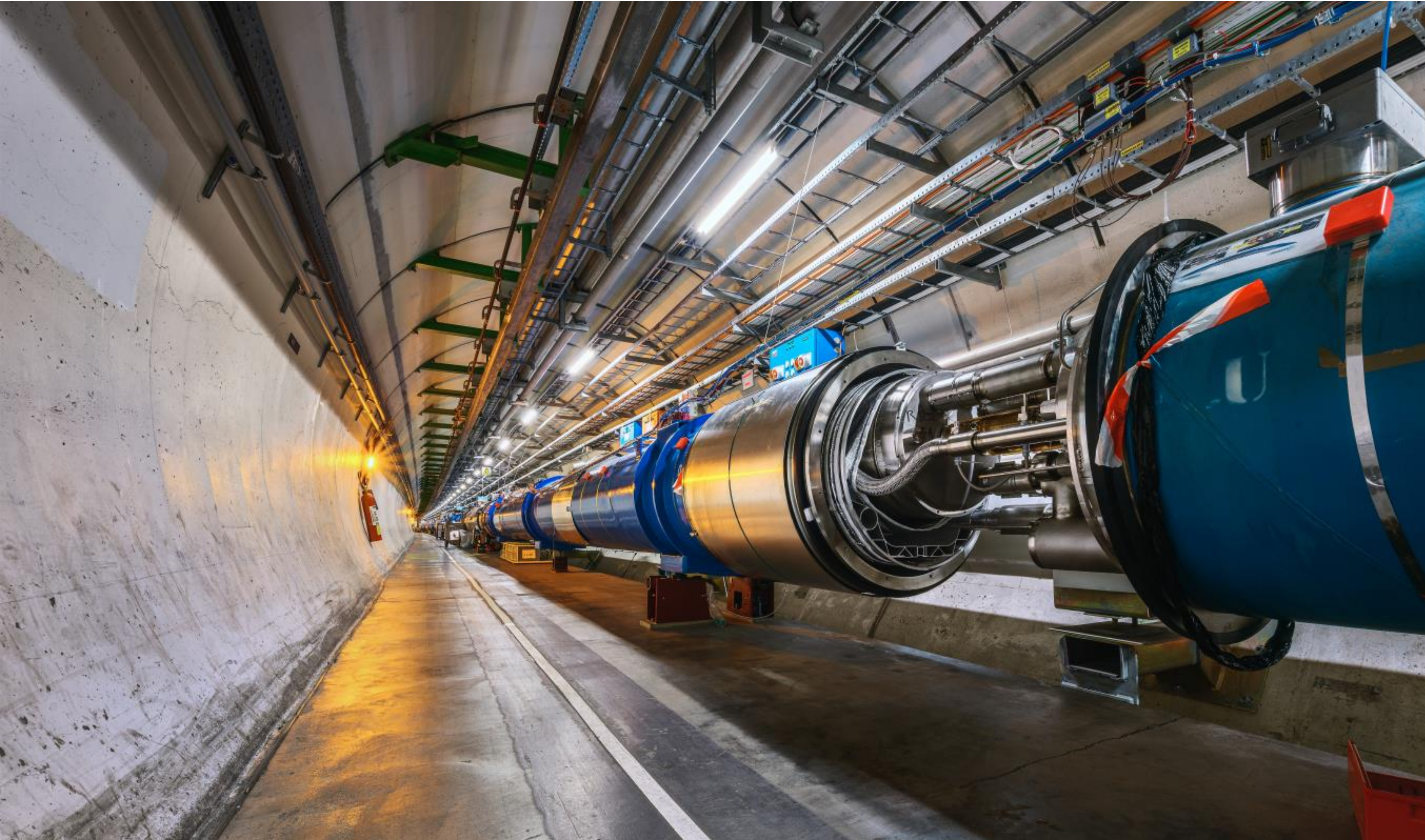


My experiments so far ...



$\sqrt{s} = 14 \text{ TeV (design)}$

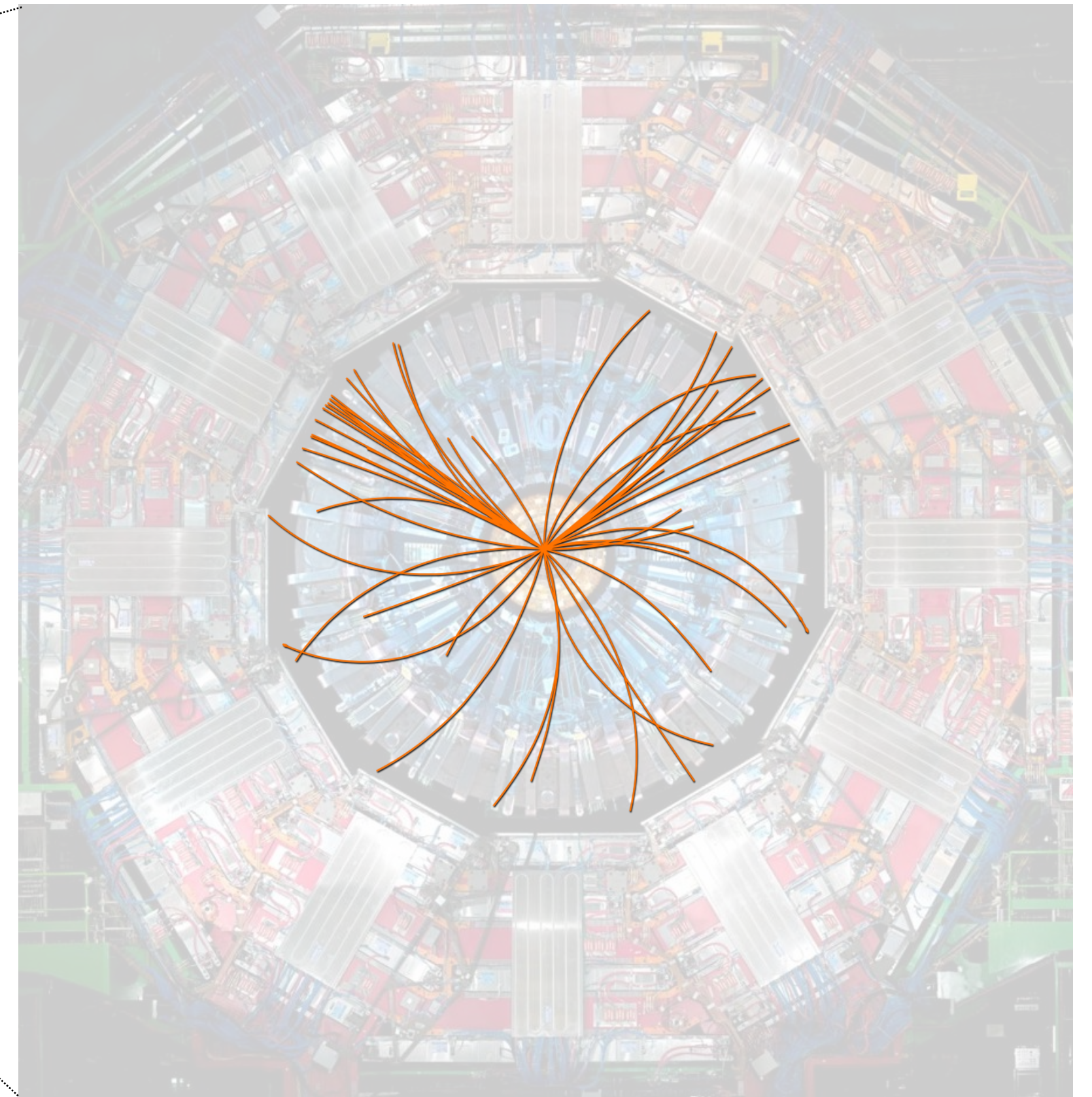
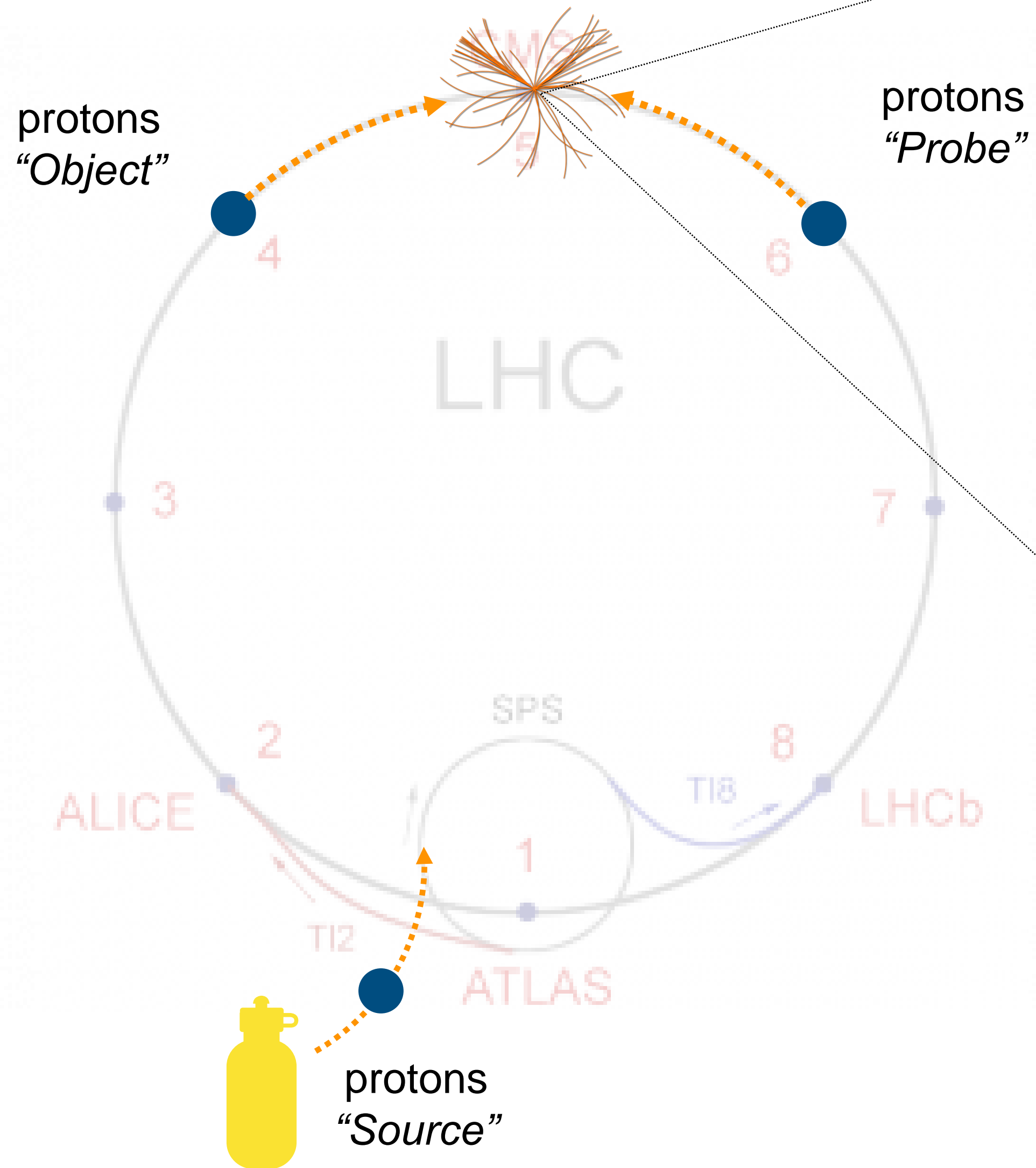
The collider



Large Hadron Collider

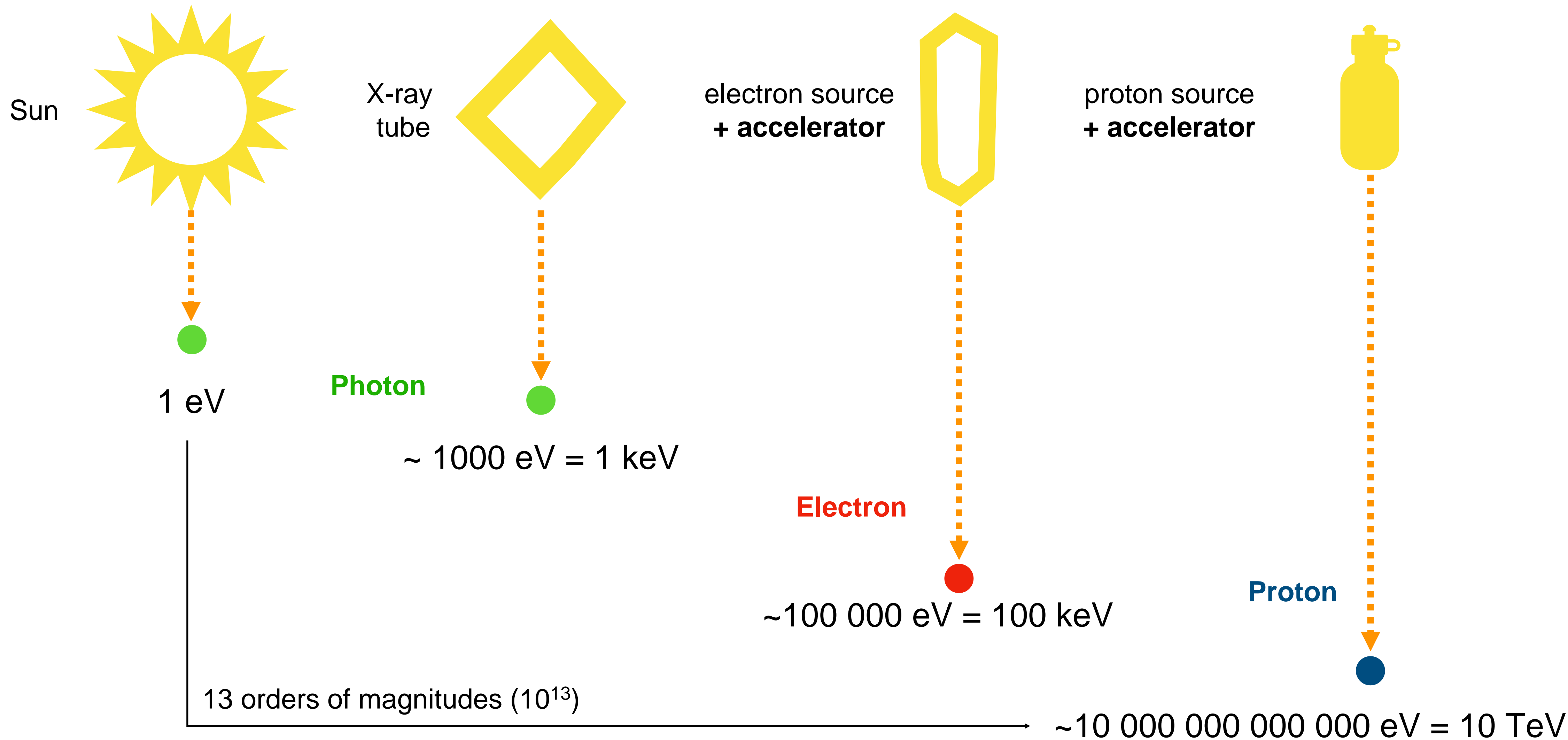
$\sqrt{s} = 14 \text{ TeV (design)}$

A very large microscope




Detector
"Observer"

eV



eV ... and what you can see

1 eV  Photon

eye




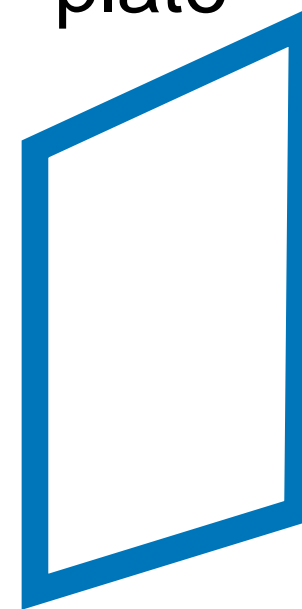

1 keV  Photon

photo plate

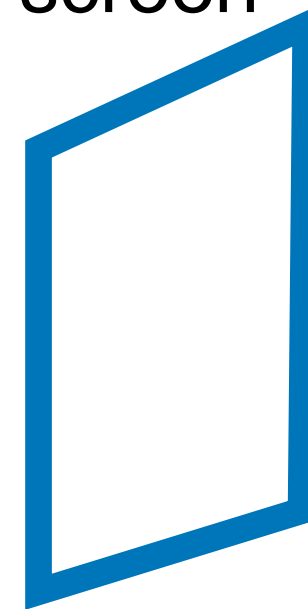


low energy sensor

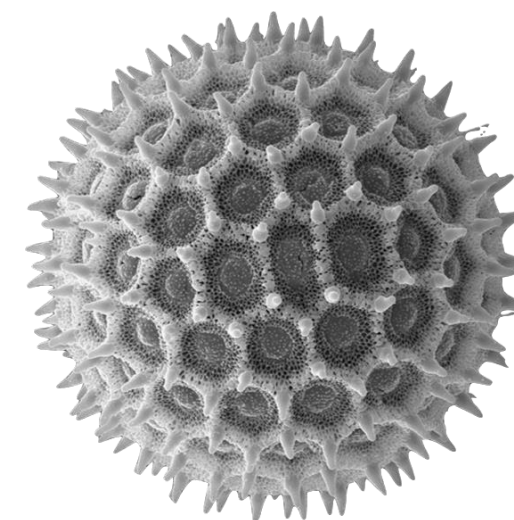
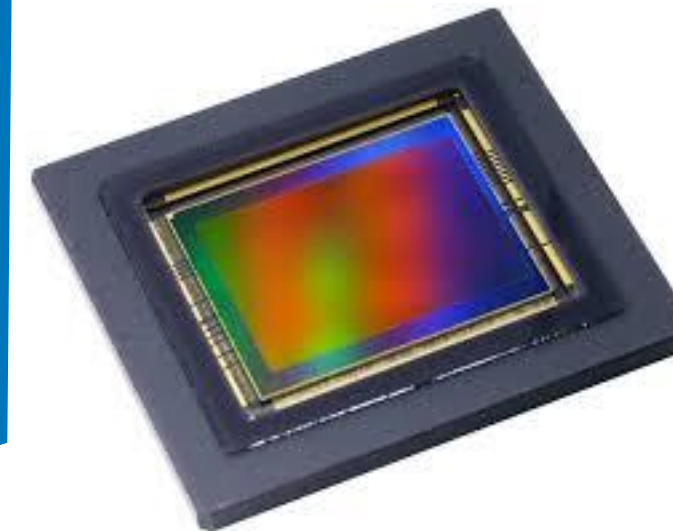



100 keV  Electron

fluorescent screen

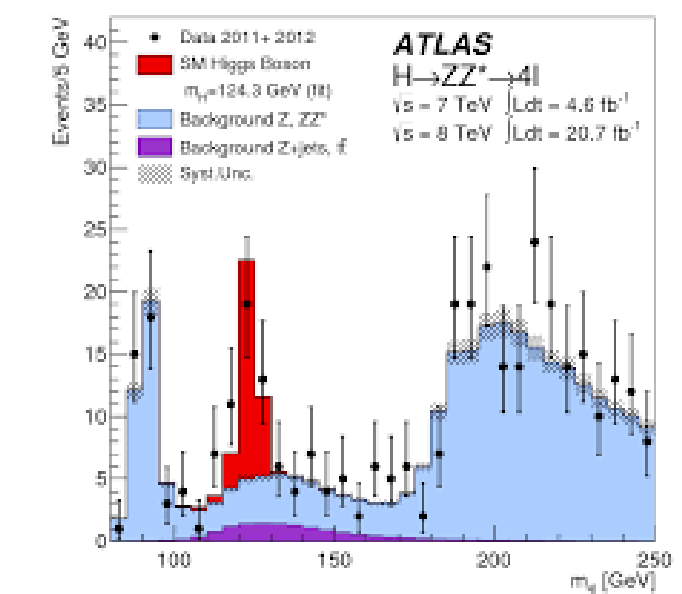
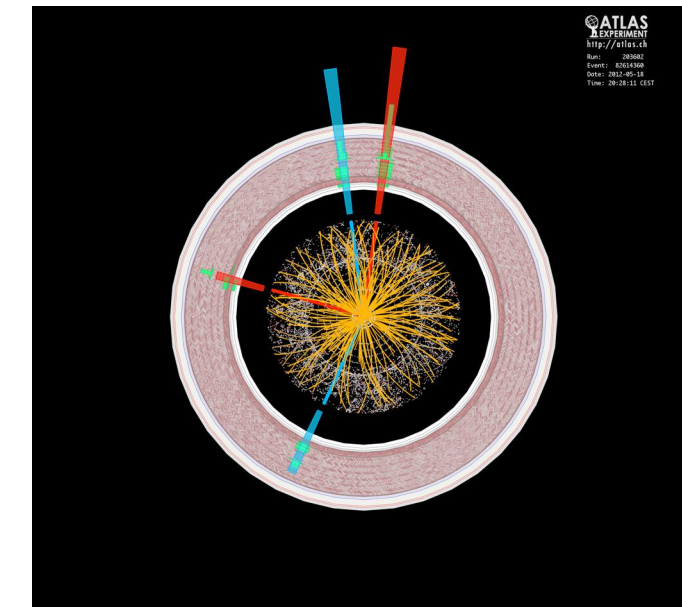


electron detector

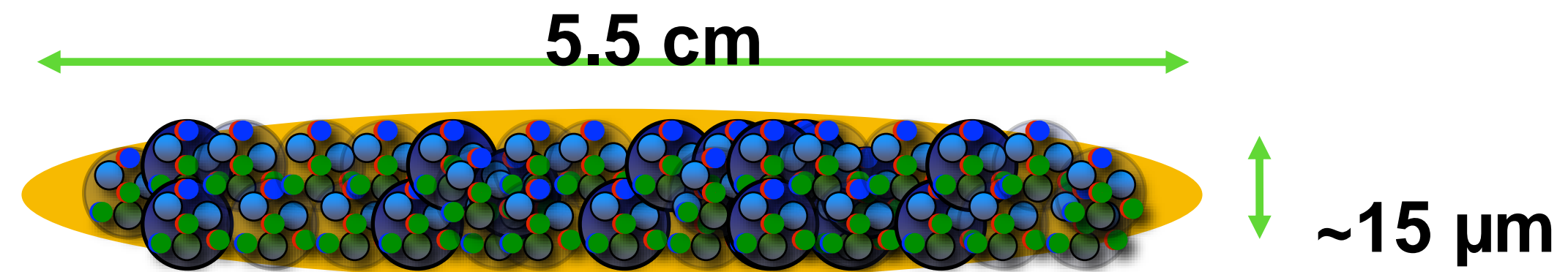


10 TeV  Proton

particle detector

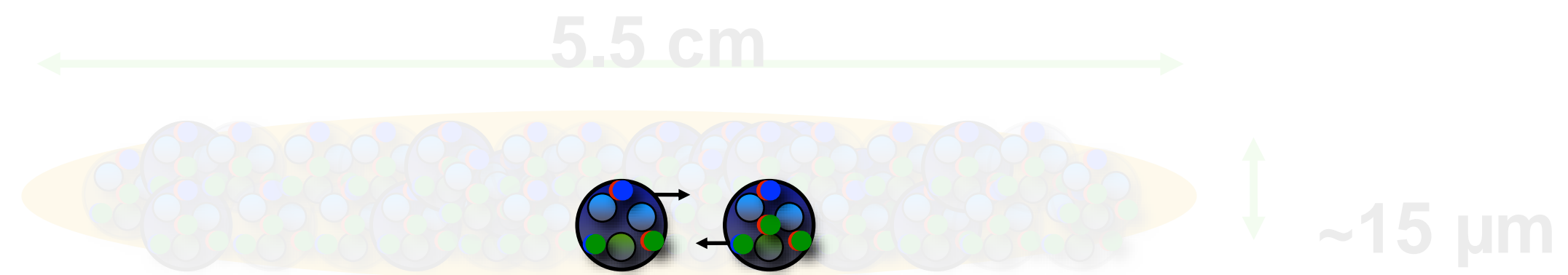
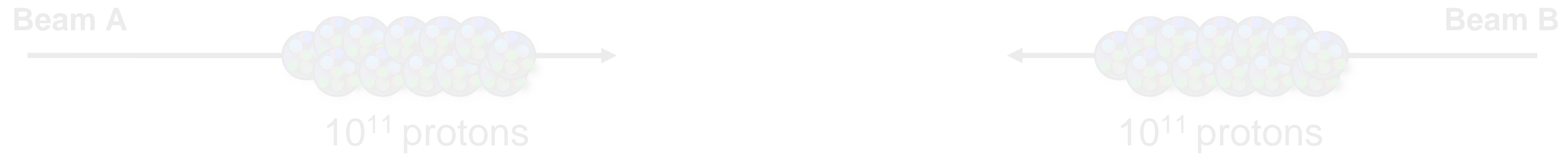


Creating the Higgs Boson



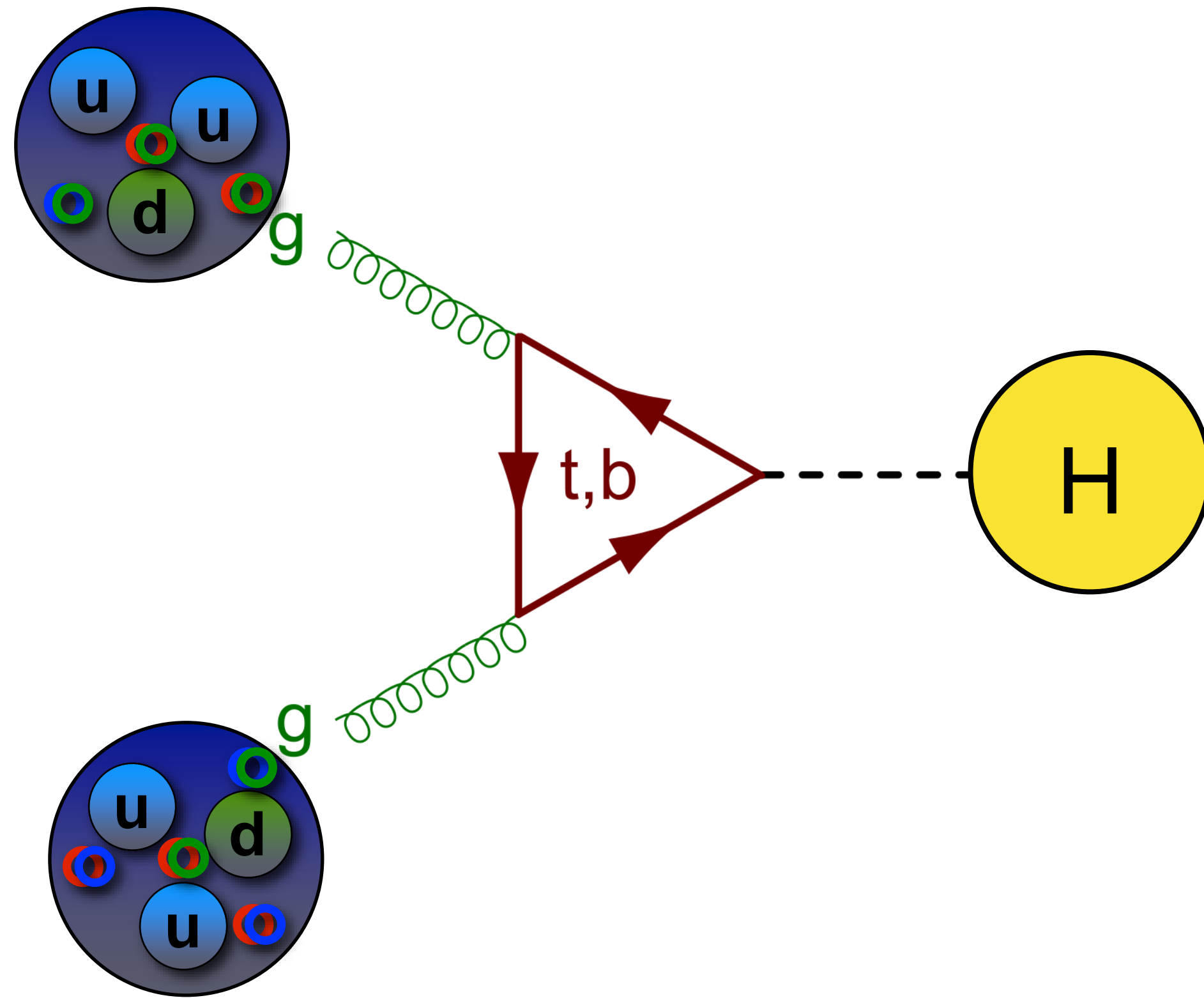
~ 60 individual proton-proton interactions

Creating the Higgs Boson



individual proton-proton interactions

Creating the Higgs Boson



Unfortunately ... this does not happen often.

The boring regime:

“probability” of any interaction

10^{10}

The exciting regime:

“probability” of a Higgs boson production

Standard Model Total Production Cross Section Measurements Status: July 2017

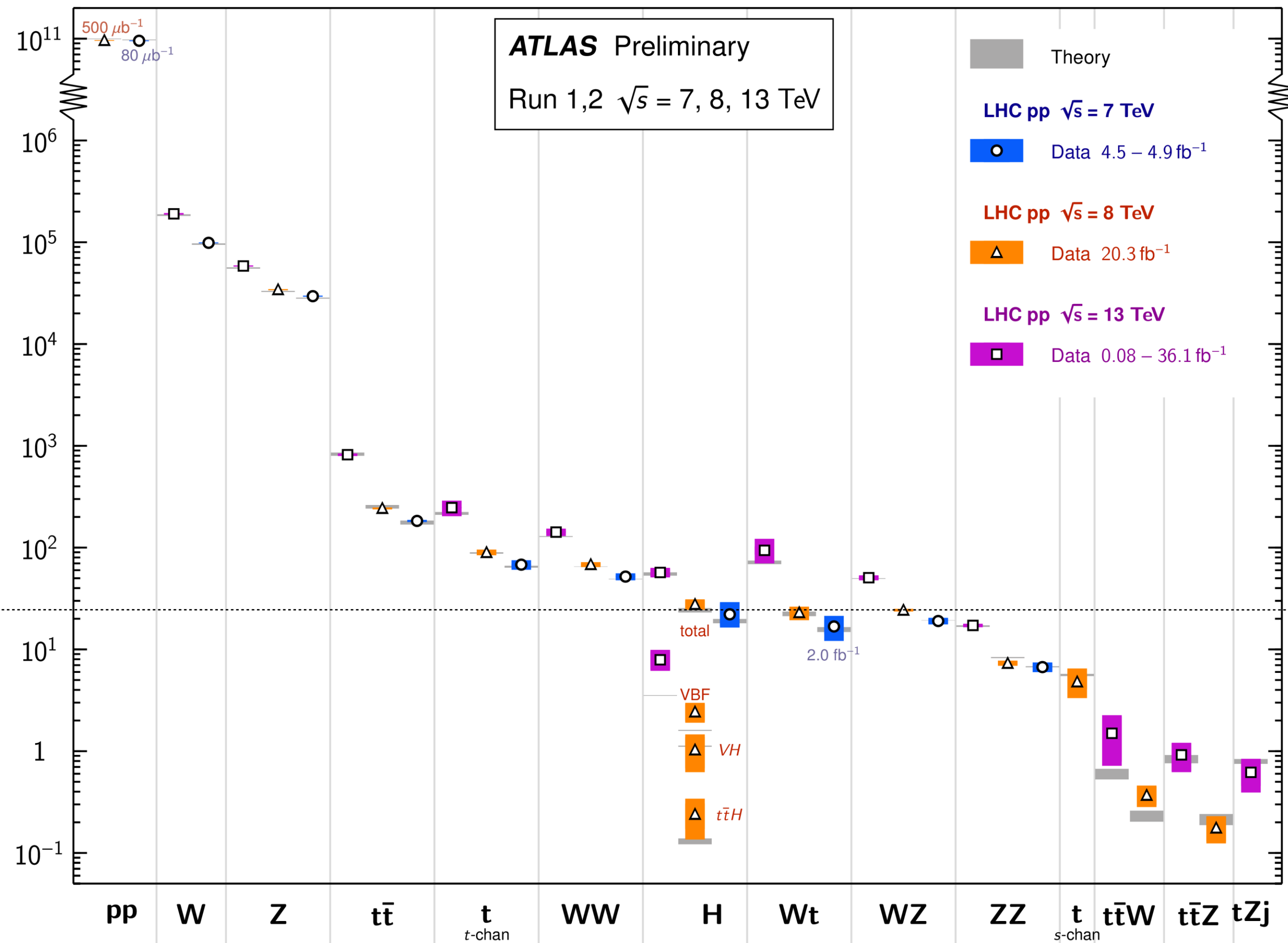
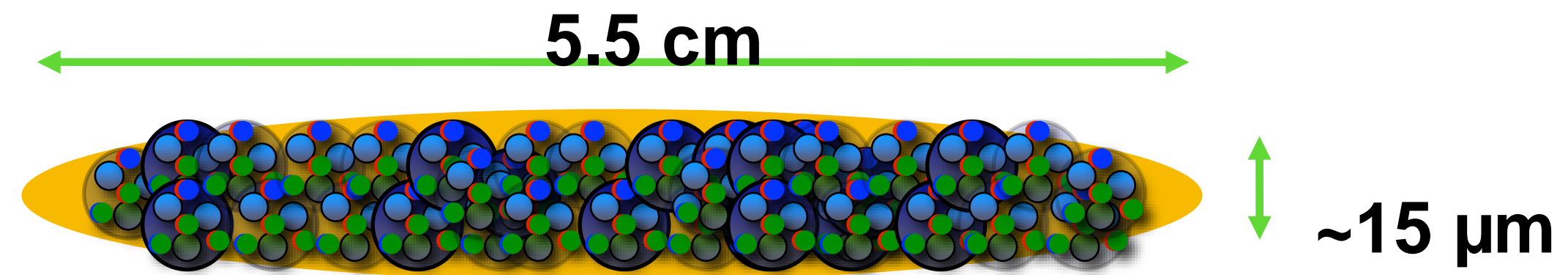


Figure:

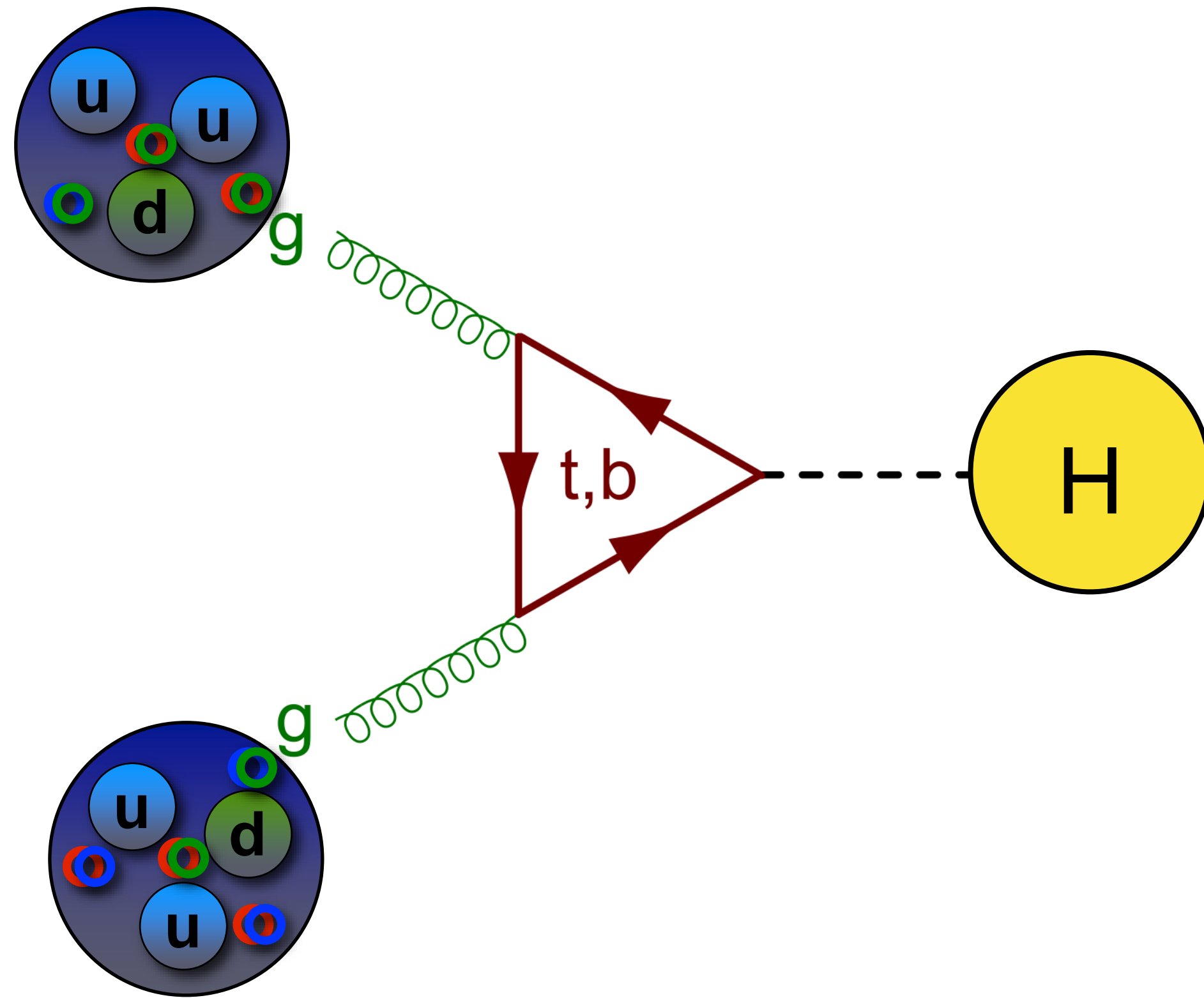
Standard Model cross sections measured with the ATLAS experiment and compared to theoretical predictions, July 2017

This is why we do this every 25 nanoseconds!

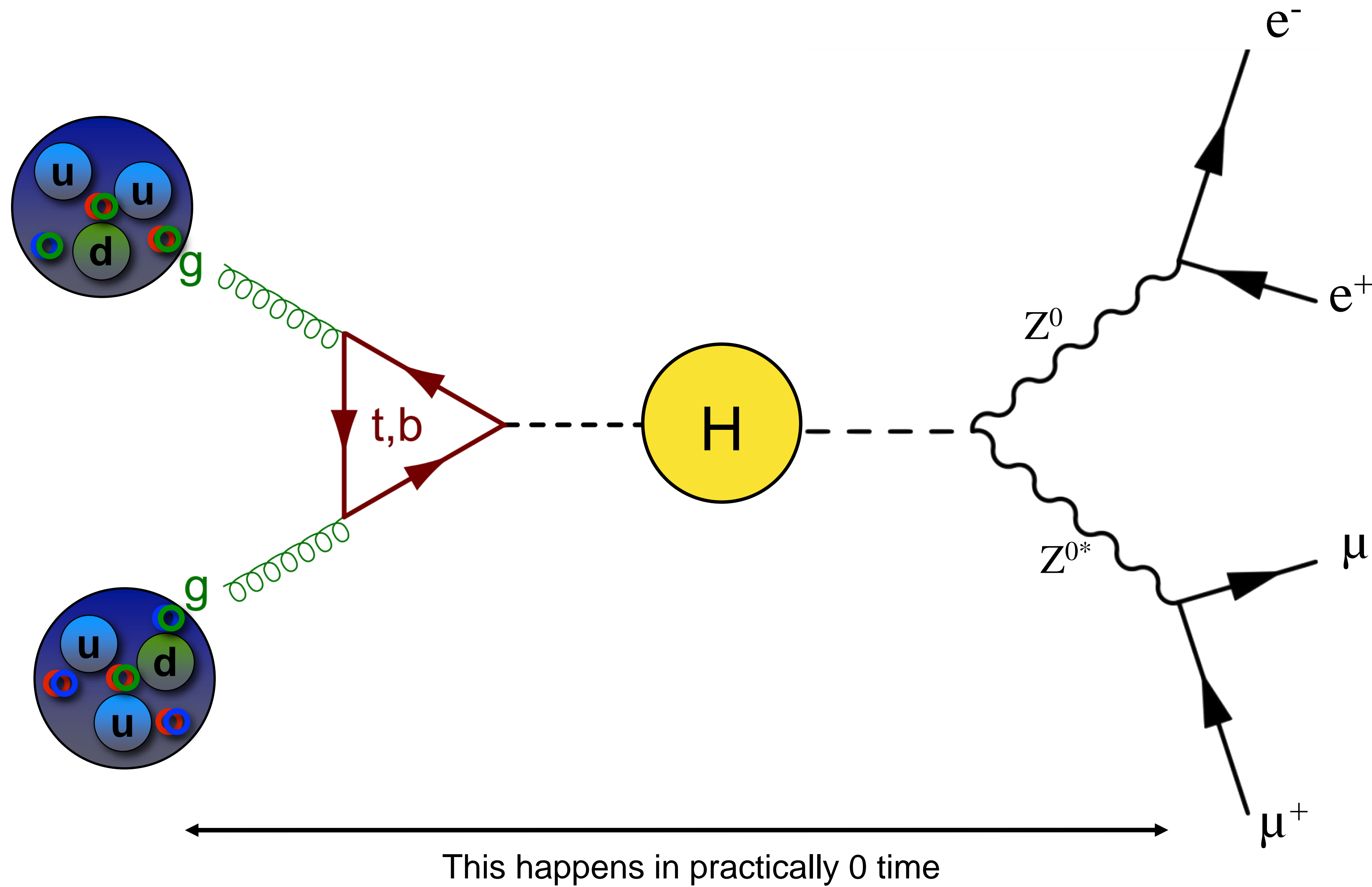


~ 60 individual proton-proton interactions

... and when it happens ...

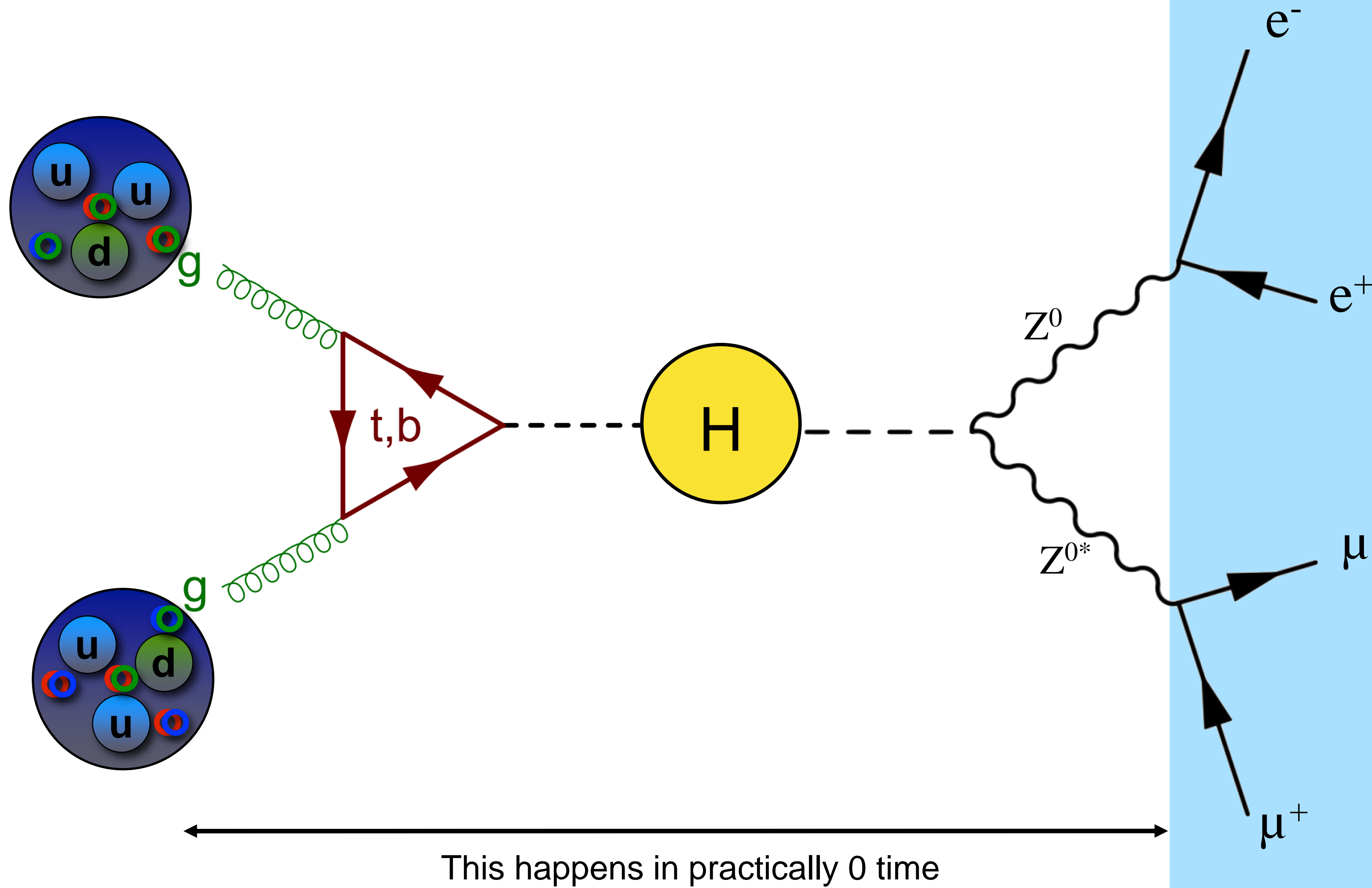


... it decays immediately

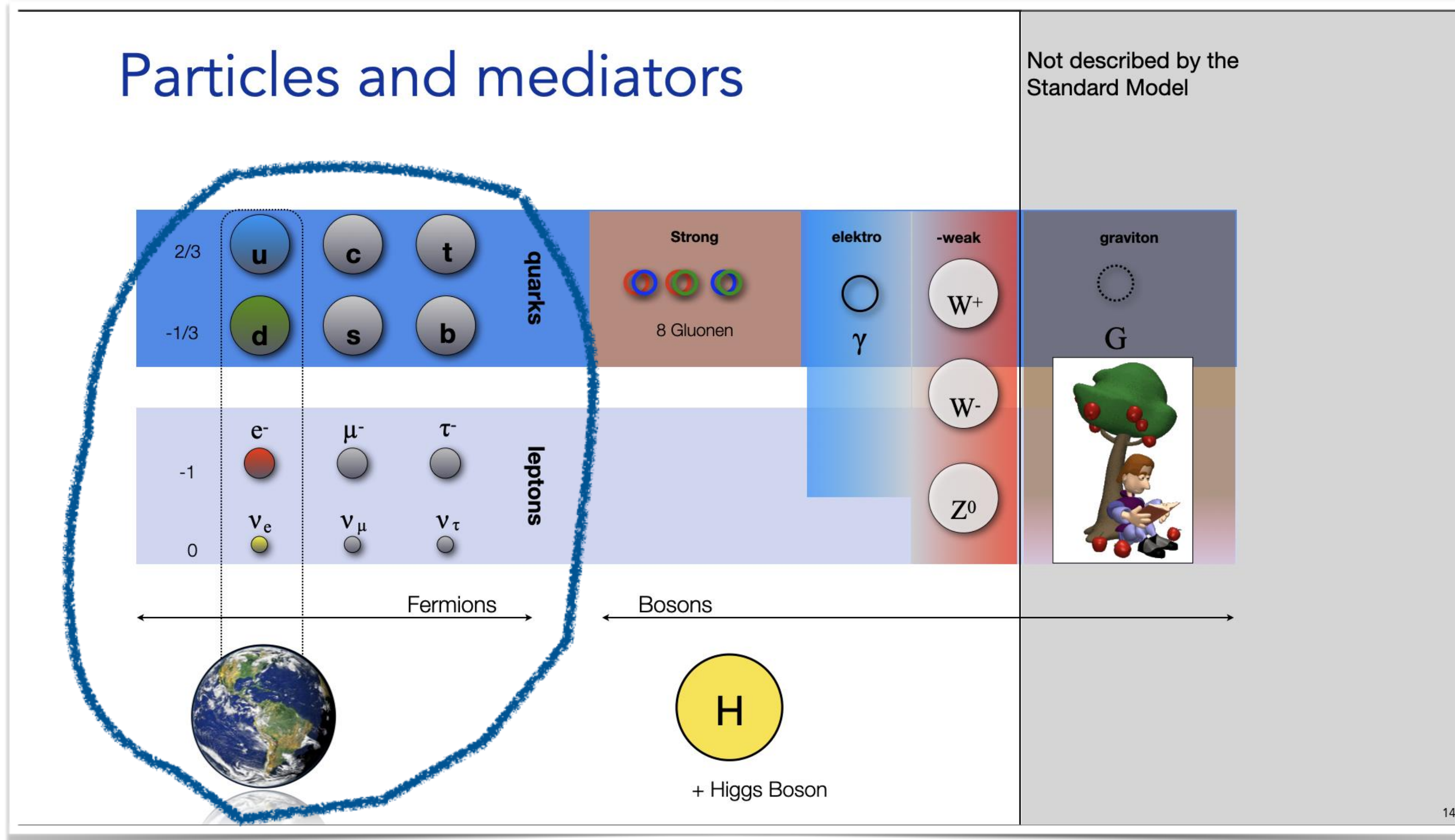


... it decays immediately

Detector

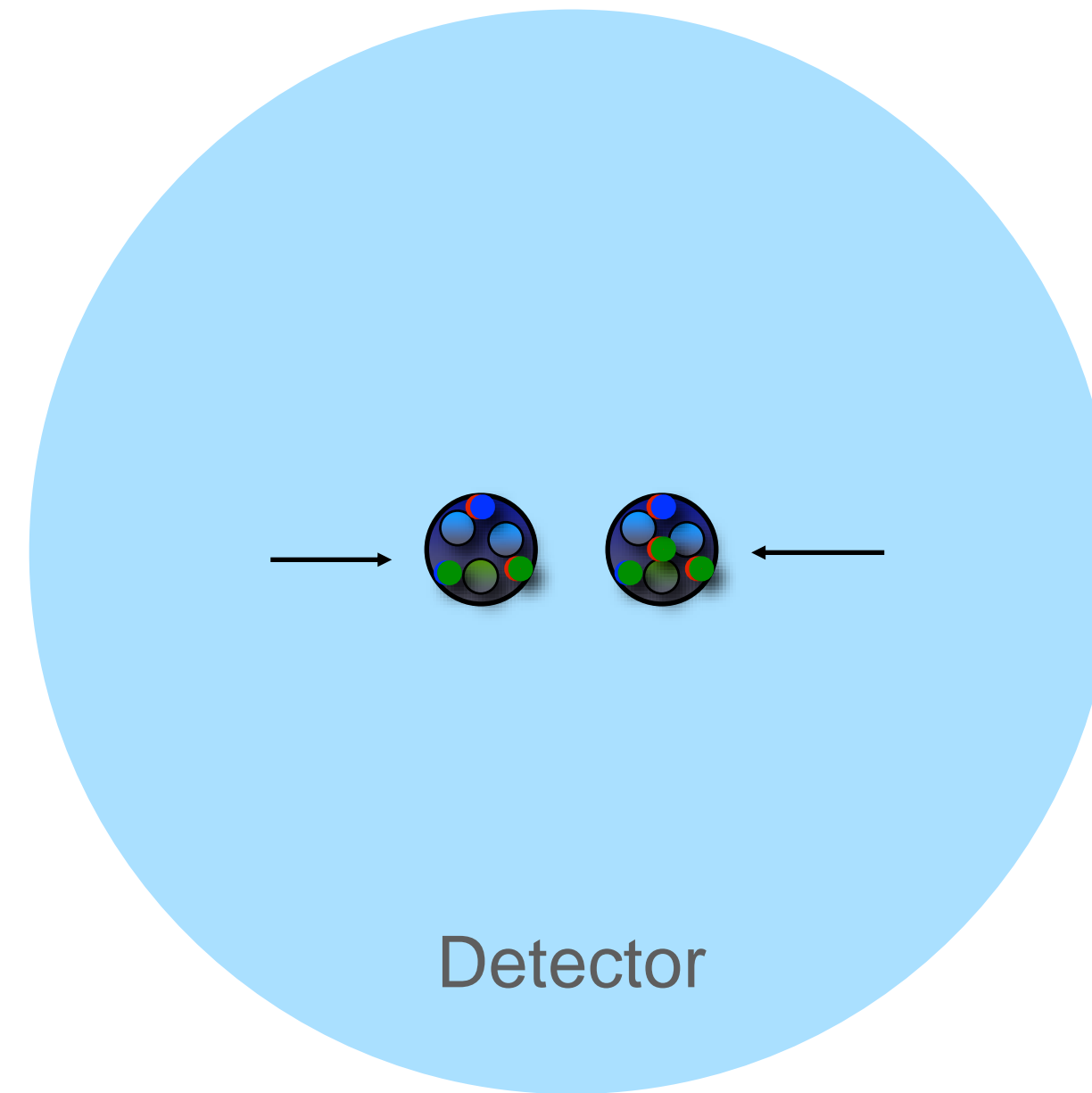


... anti-what?

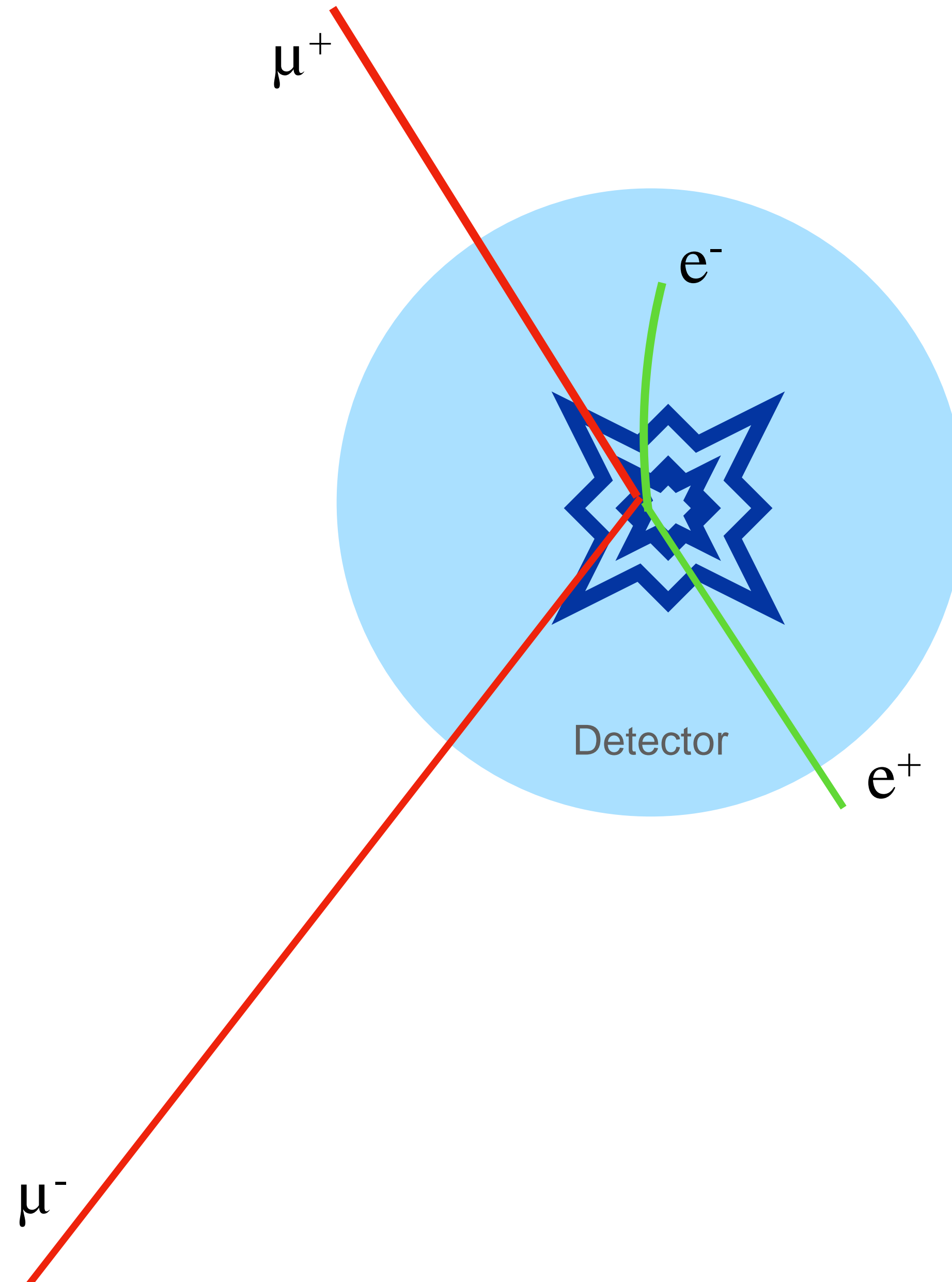


These particles also exist in their anti-matter form ...

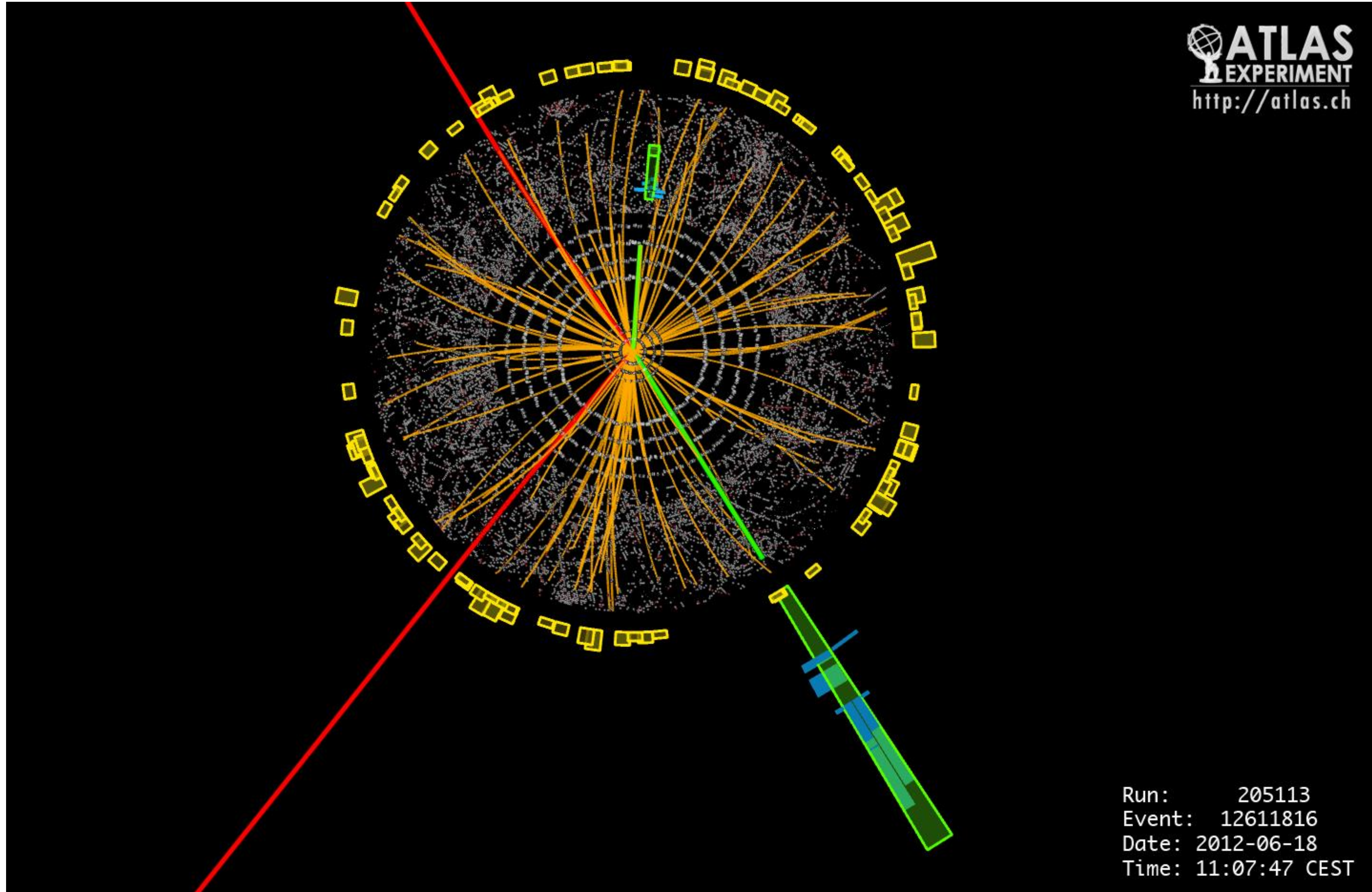
... in our world this looks like



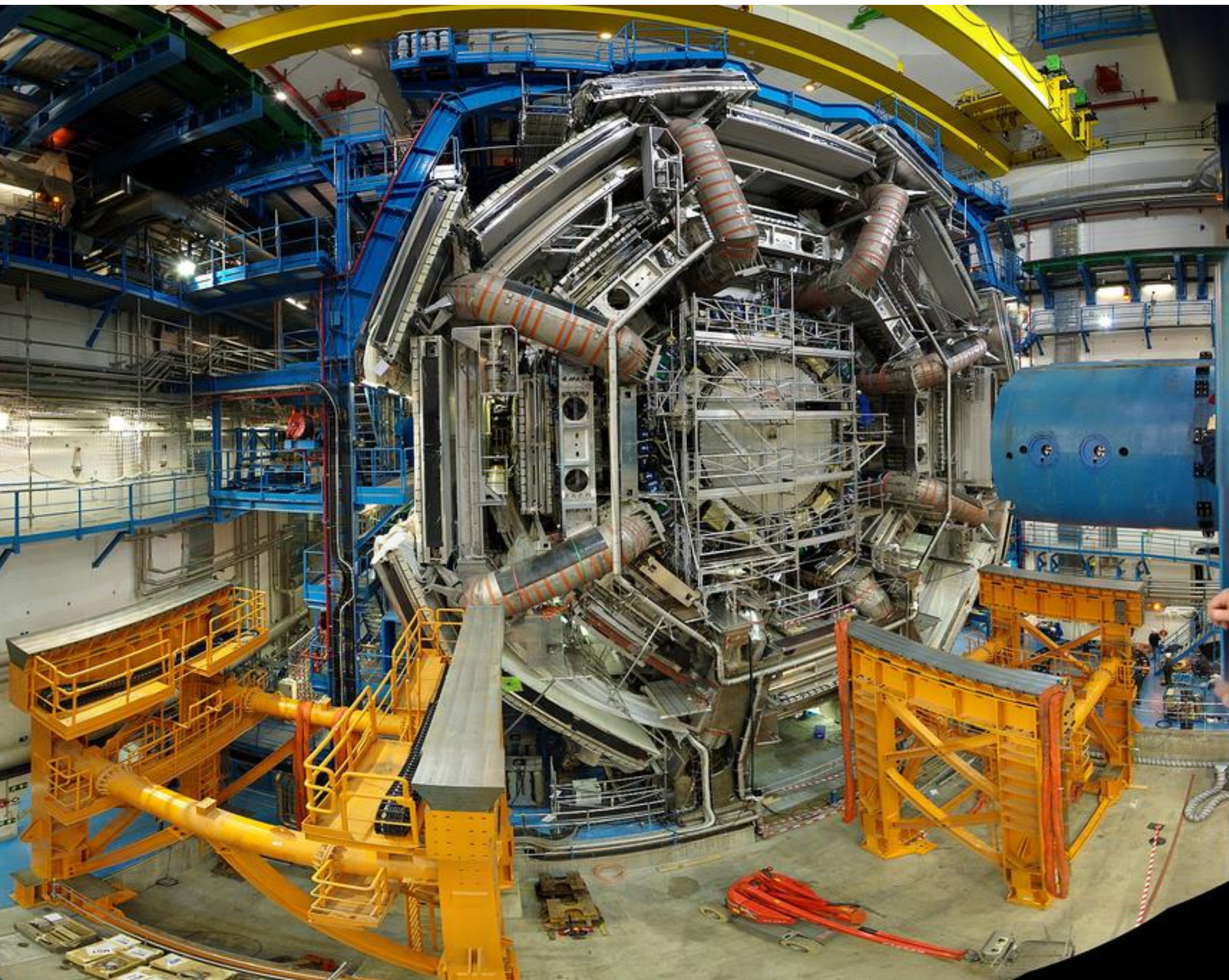
... in our world this looks like



... in our world this looks like

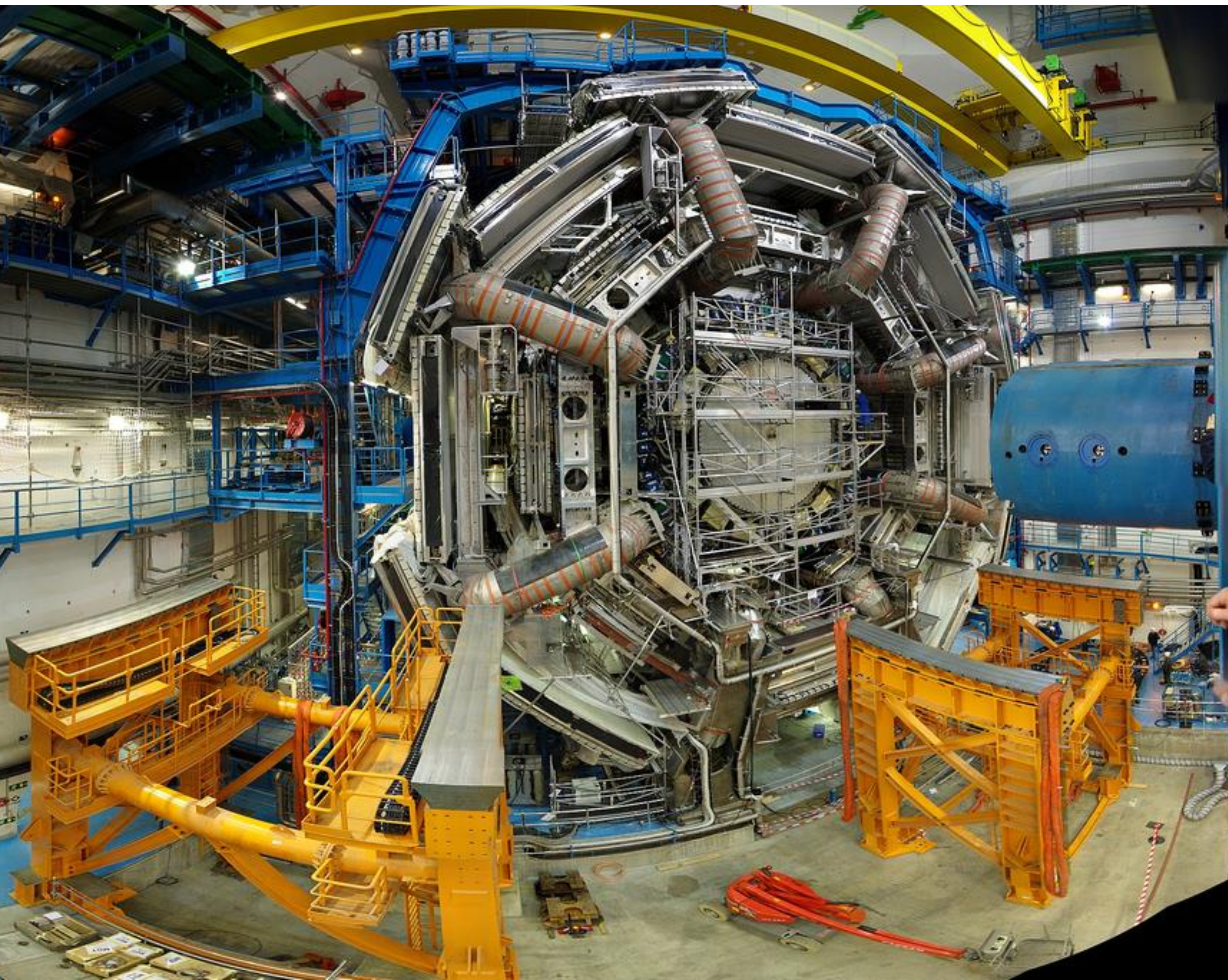


... does it though?

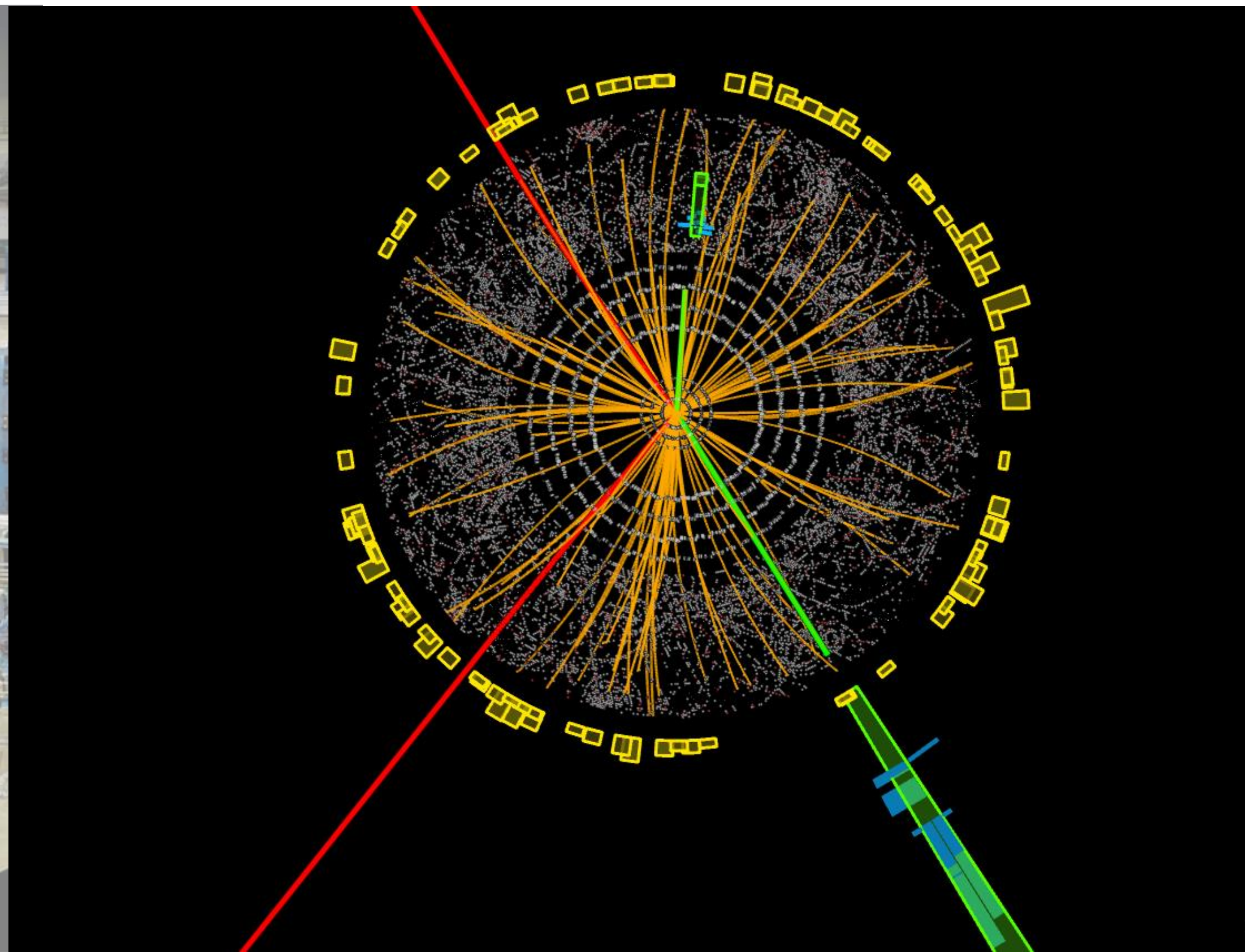
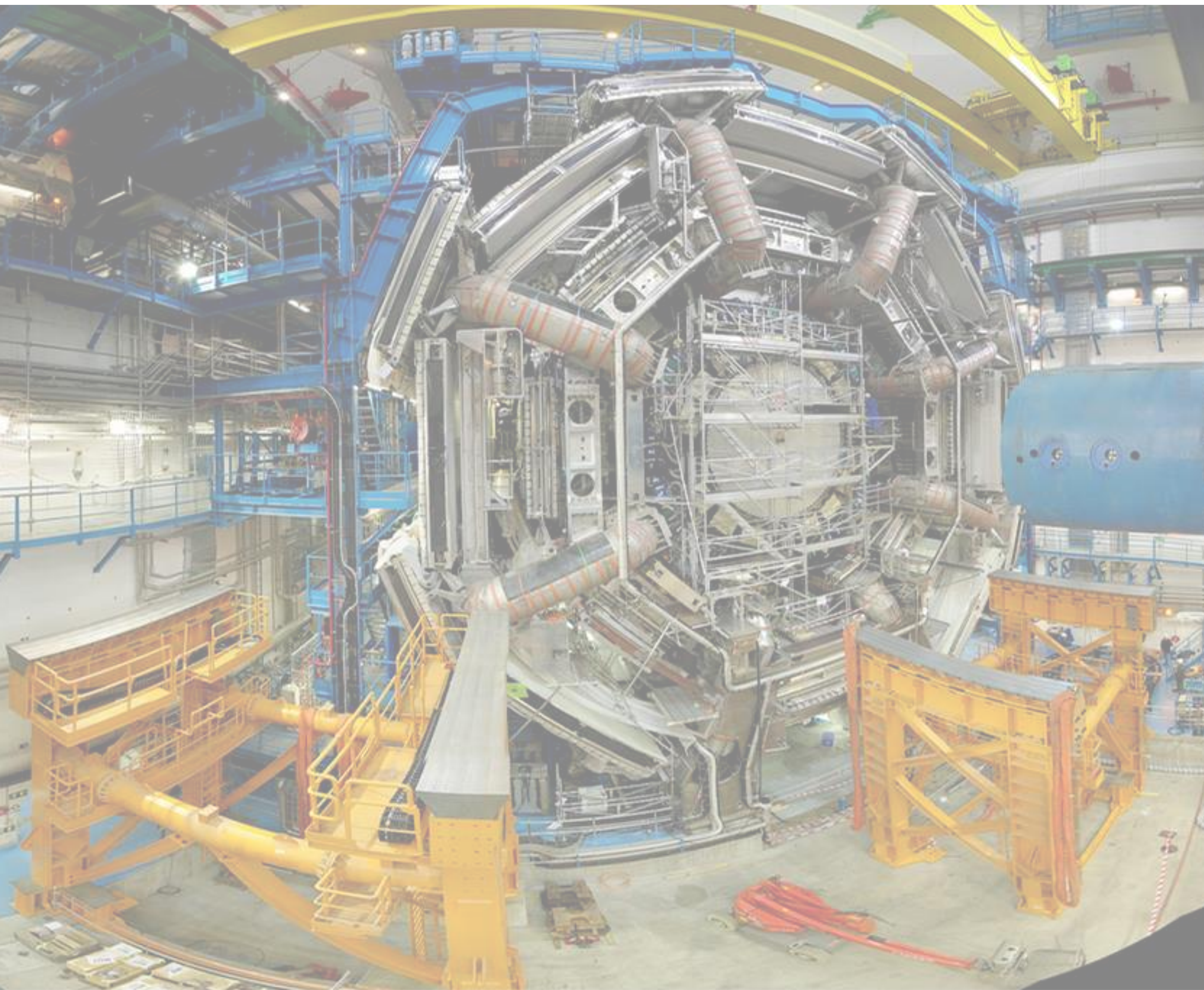


The ATLAS detector

How to get from here ...

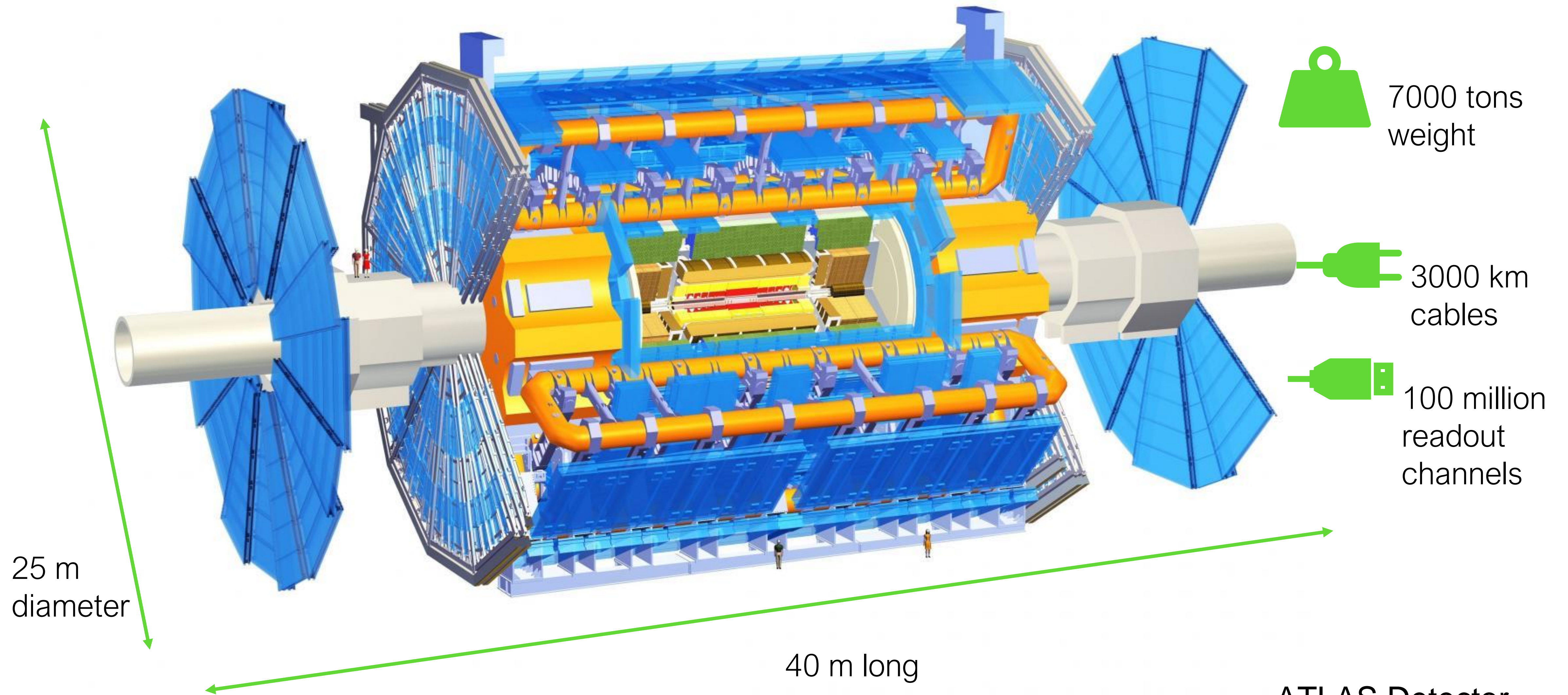


How to get from here ...



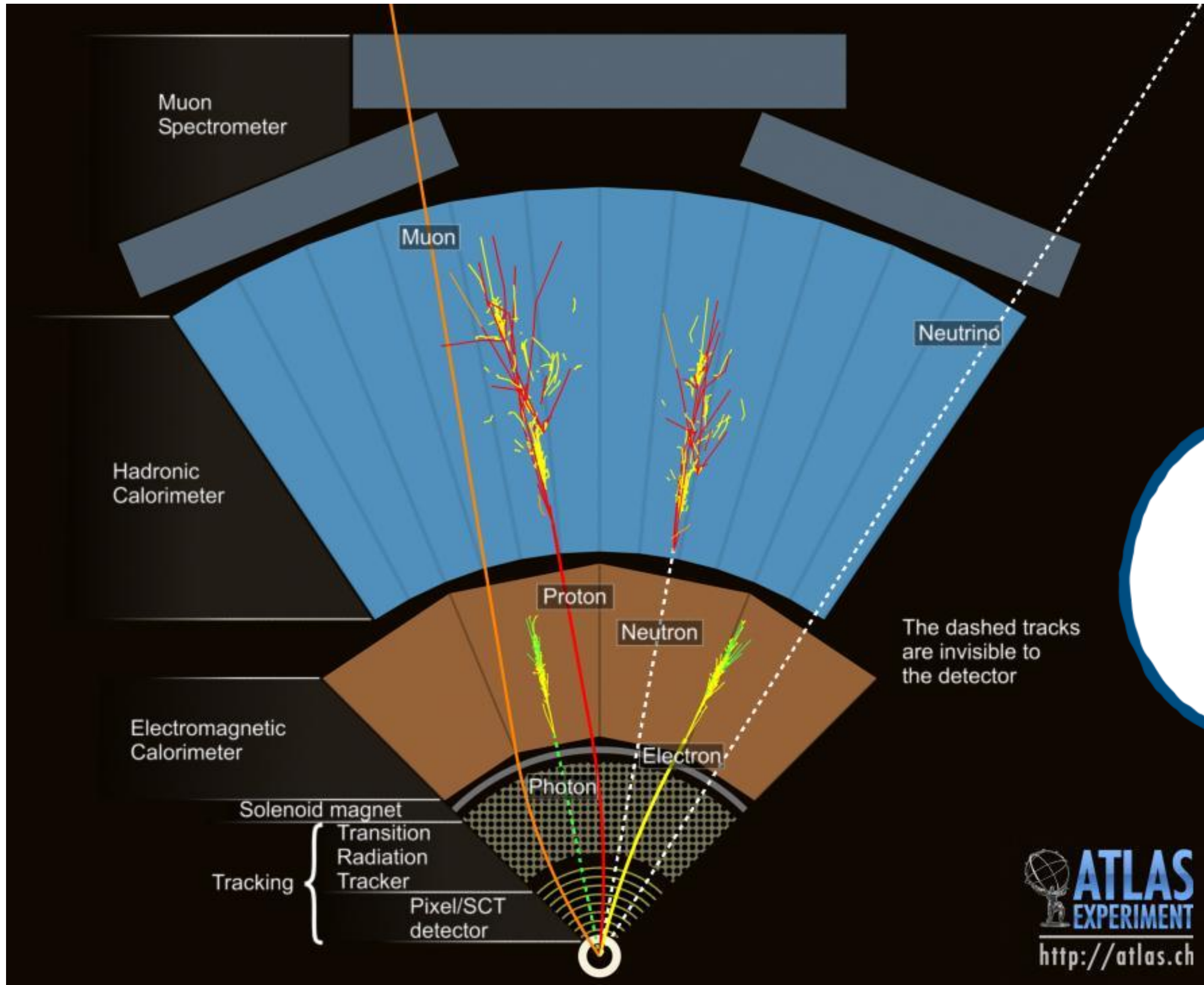
... to here ?

Detector



ATLAS Detector

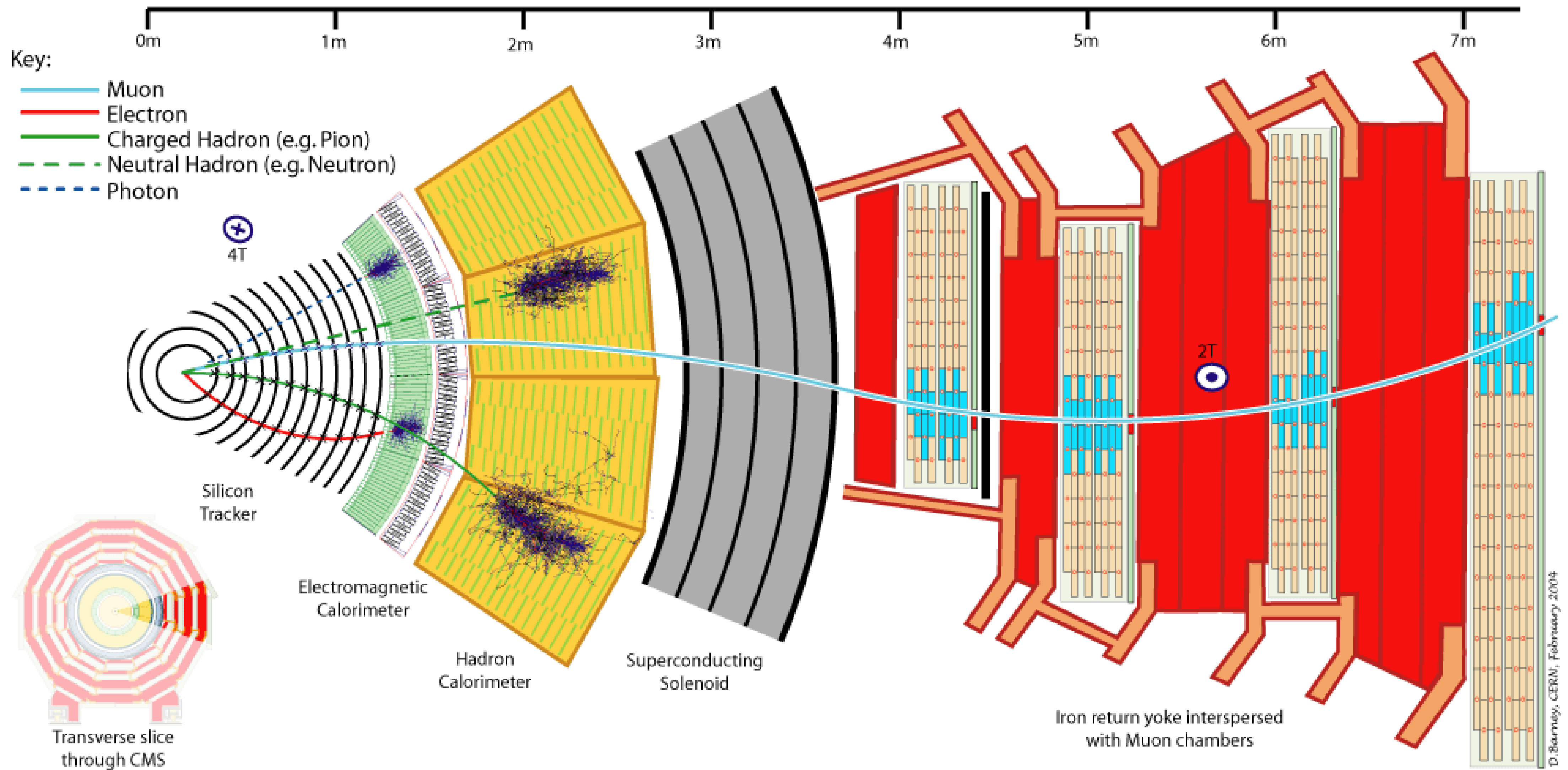
... and it's principle



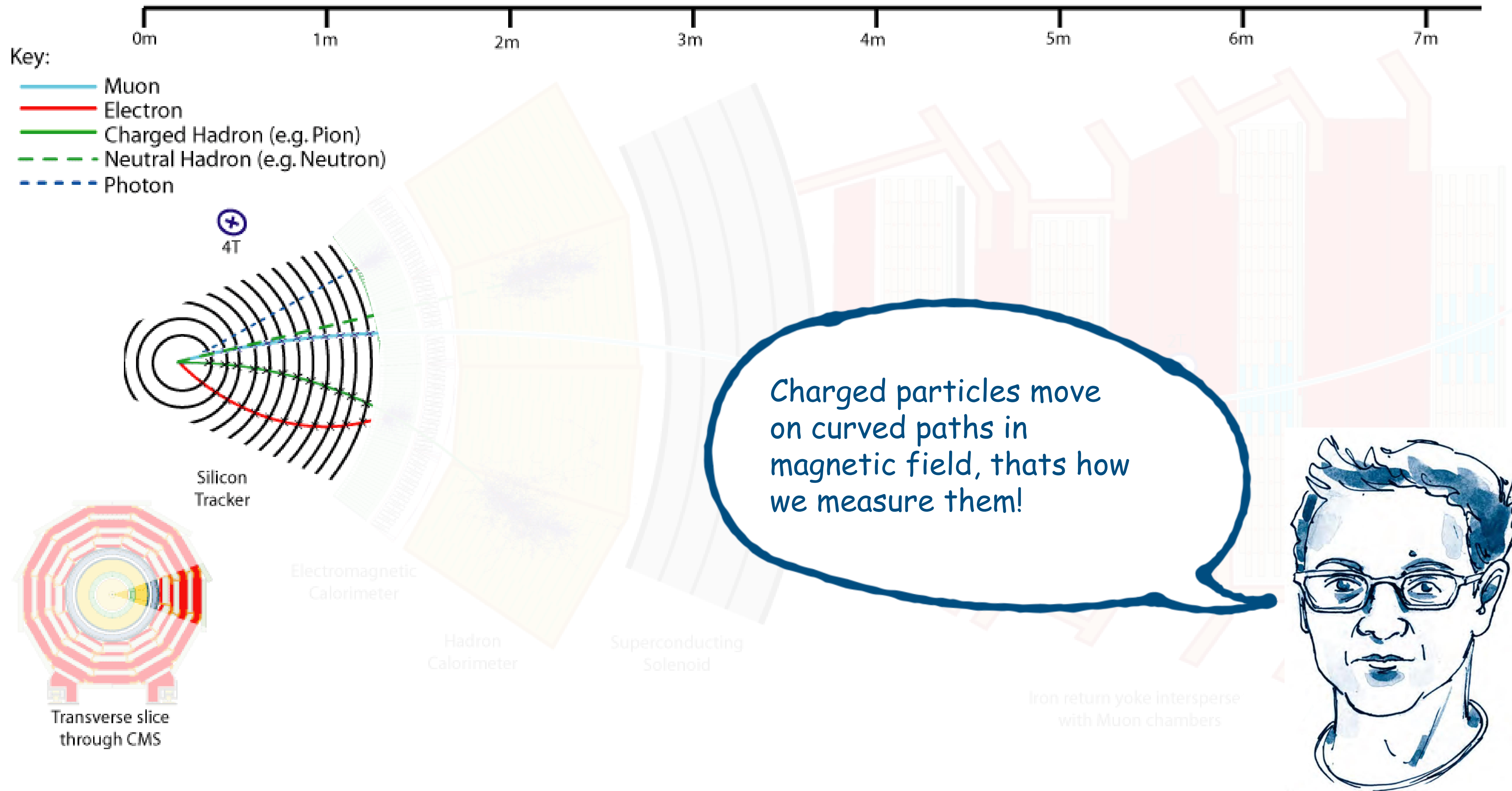
I need to identify each particle and measure its properties.



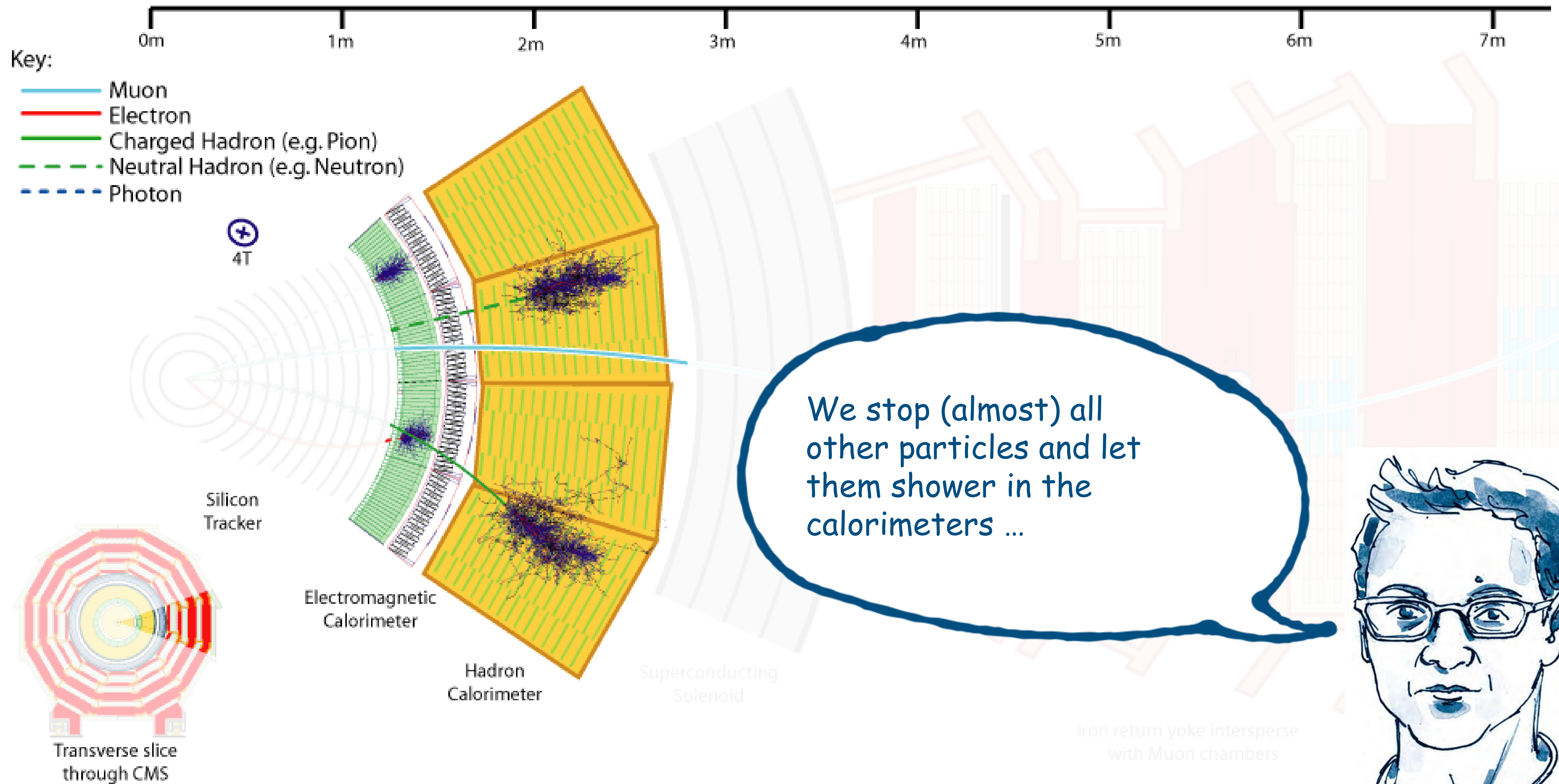
... and it's principle



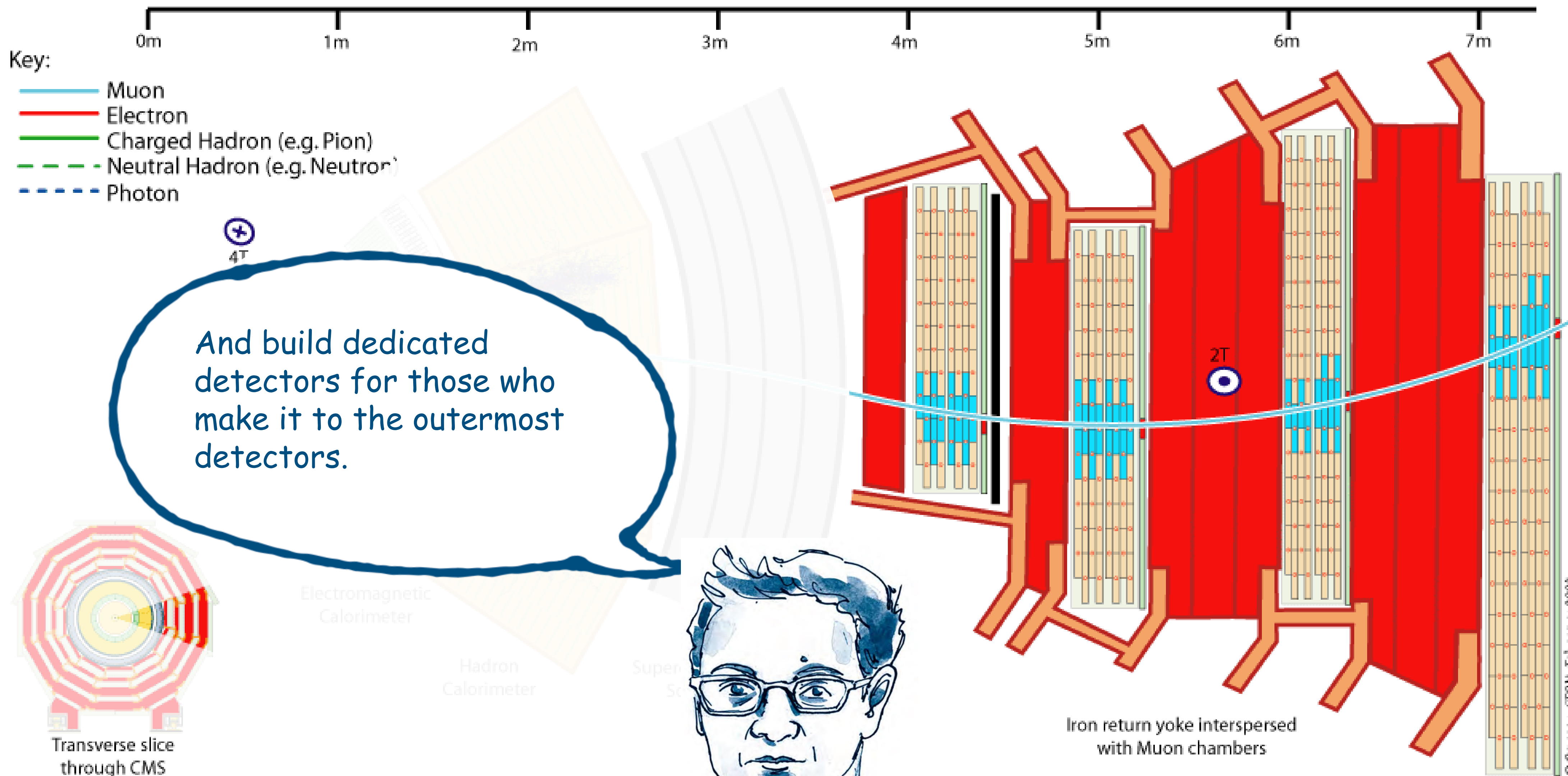
Tracking



Calorimetry



Muon System



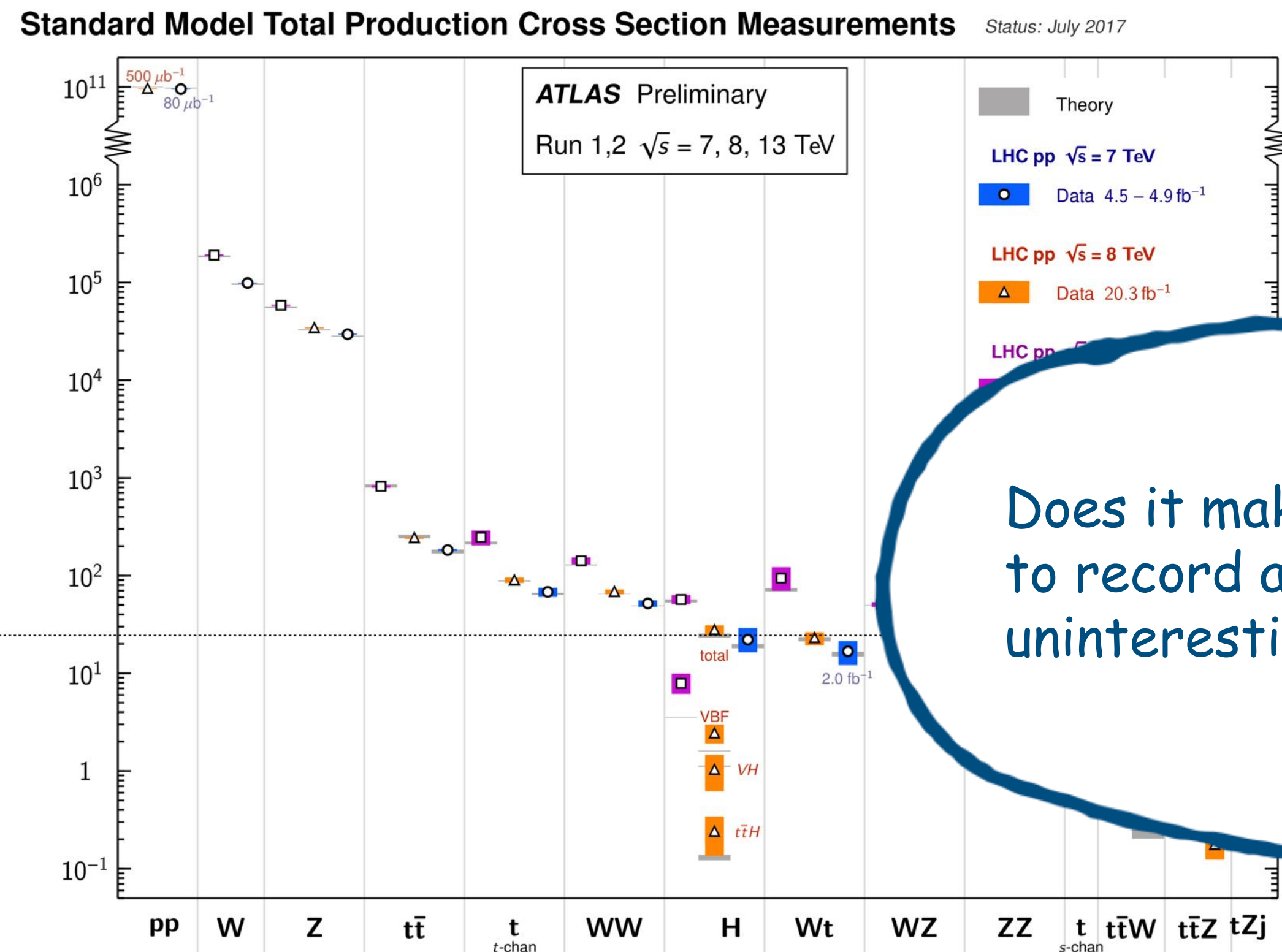
Let's skip back one step ...

Unfortunately ... this does not happen often.

The boring regime:
"probability" of
any interaction

10^{10}

The exciting regime:
"probability" of
a Higgs boson
production



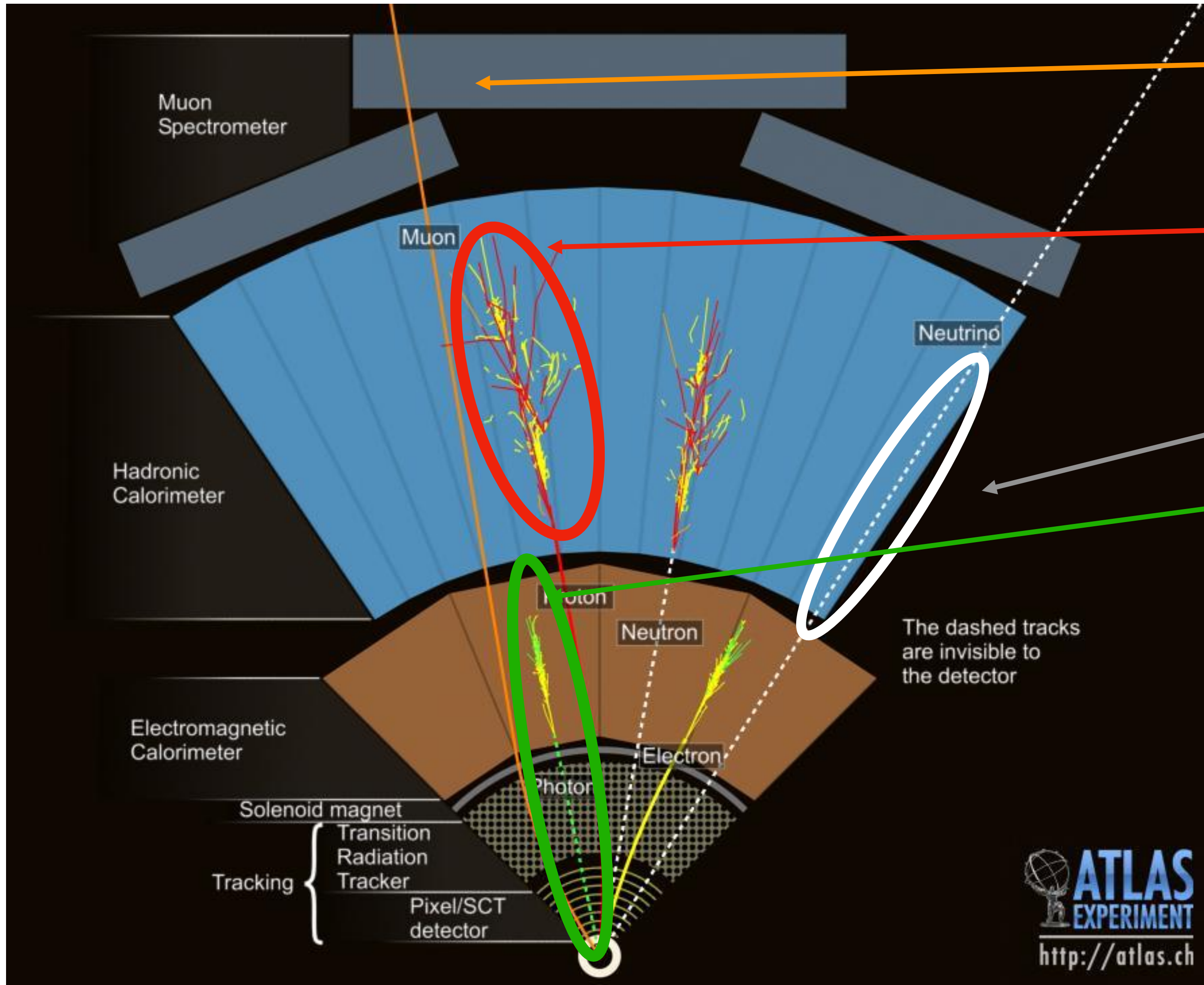
Does it make sense
to record all of those
uninteresting collisions?



Figure:
Standard Model cross sections measured with the ATLAS experiment
and compared to theoretical predictions, July 2017

We need a selection ...

25 ns = 40 MHz



coincidence !

energy !

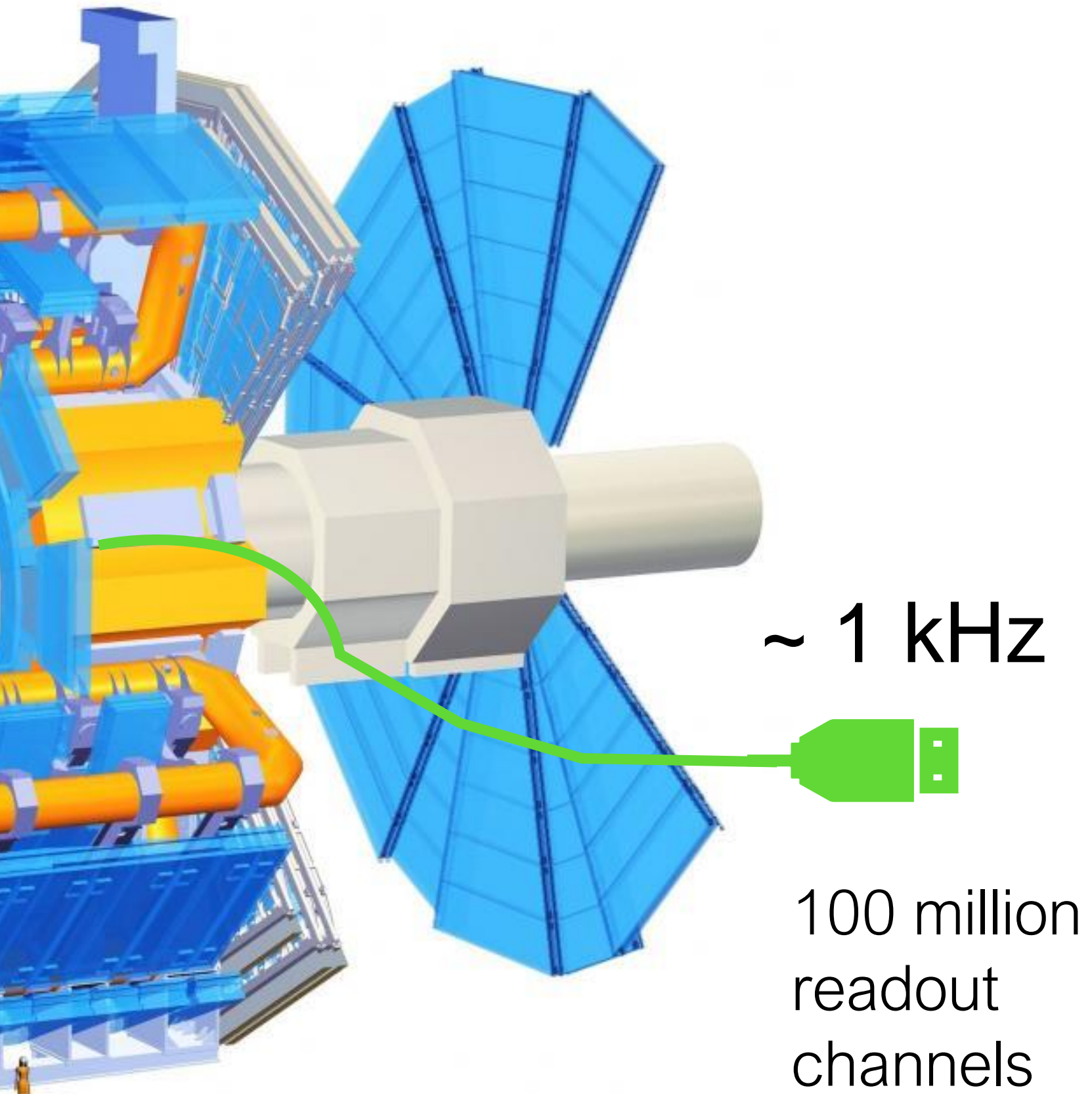
no energy !

energy!

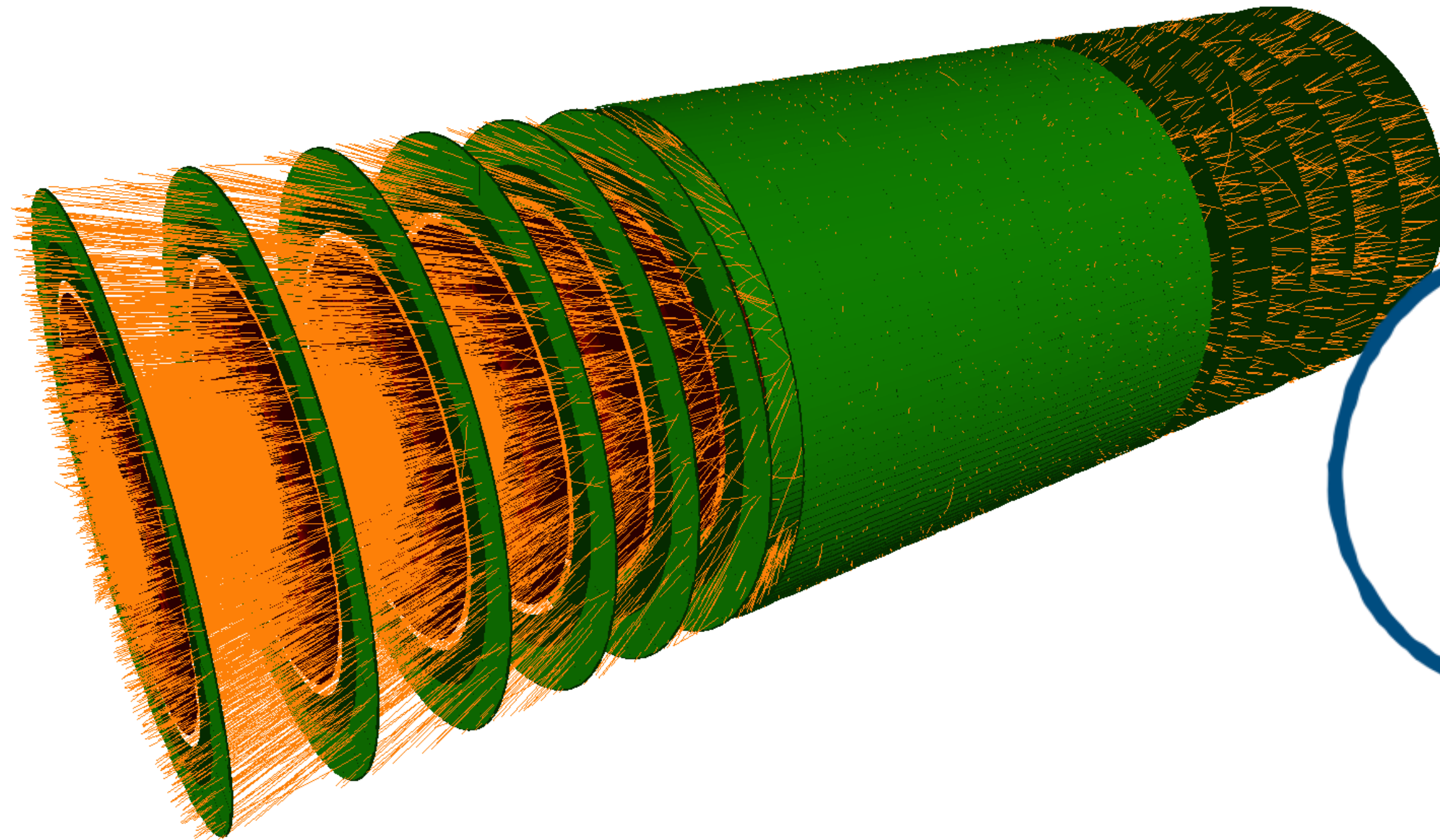


~ 1 kHz

And then read it out ...



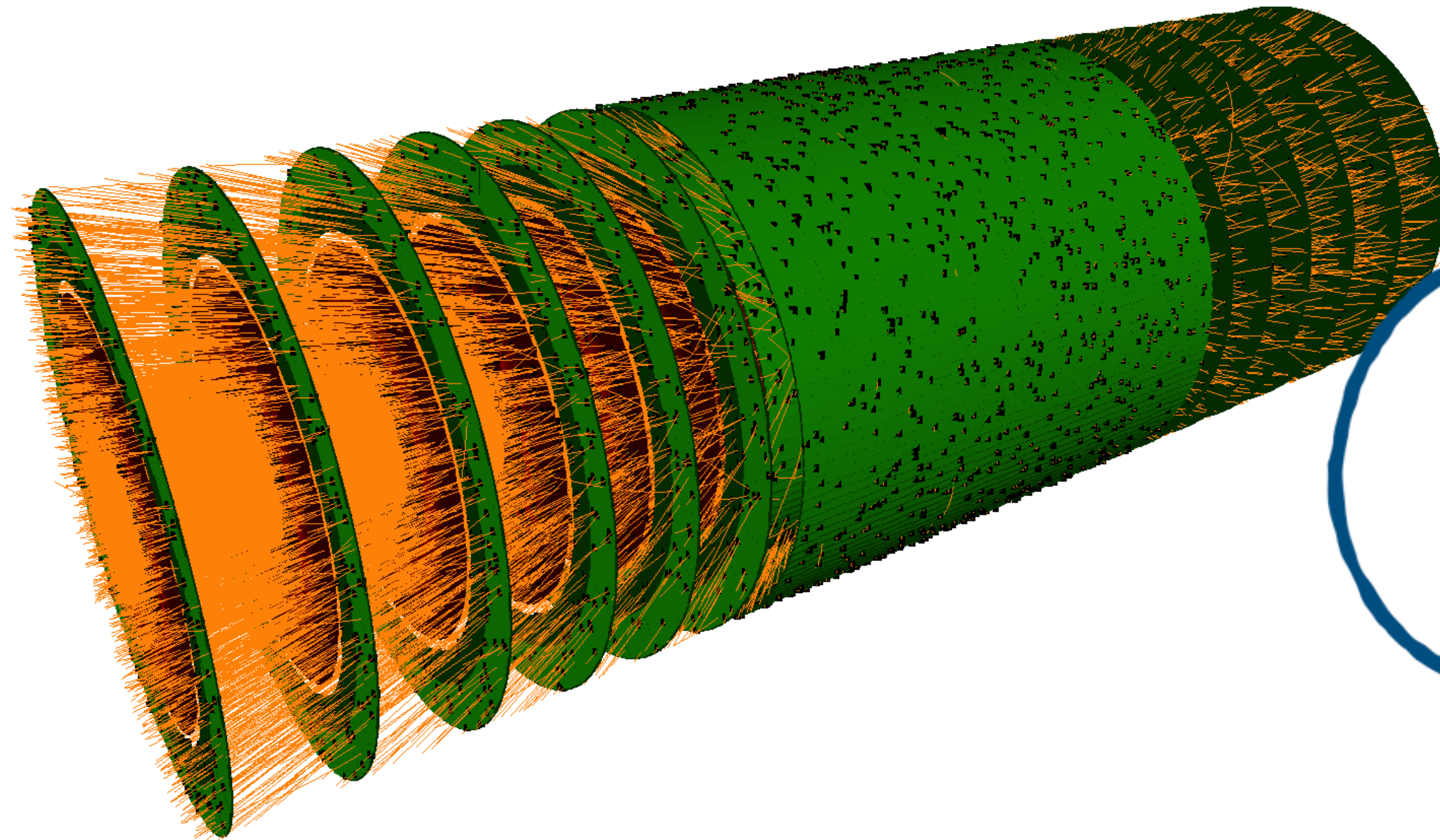
Reconstruct and analyse



This is not what a
experiment looks like ...



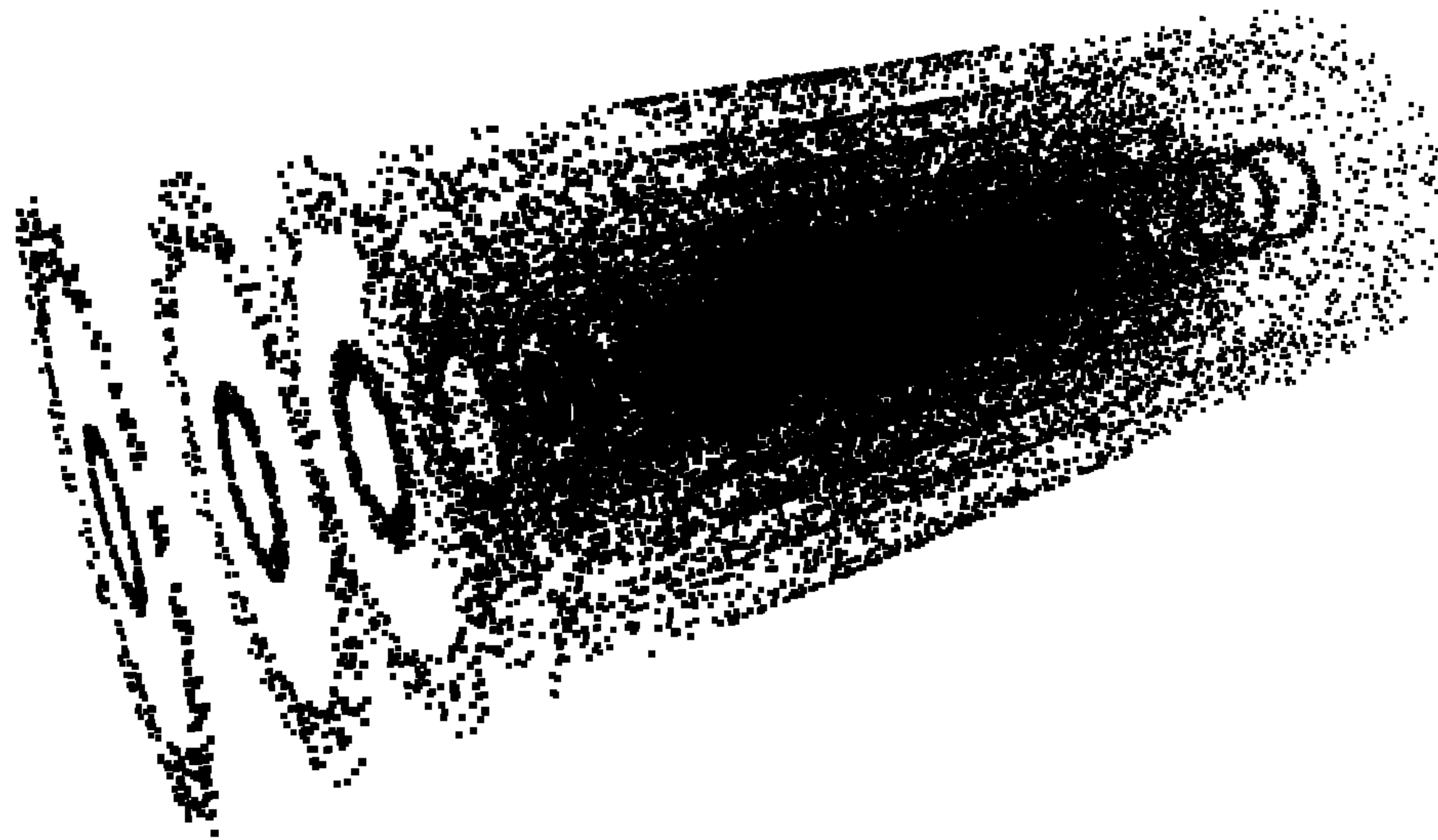
Reconstruct and analyse



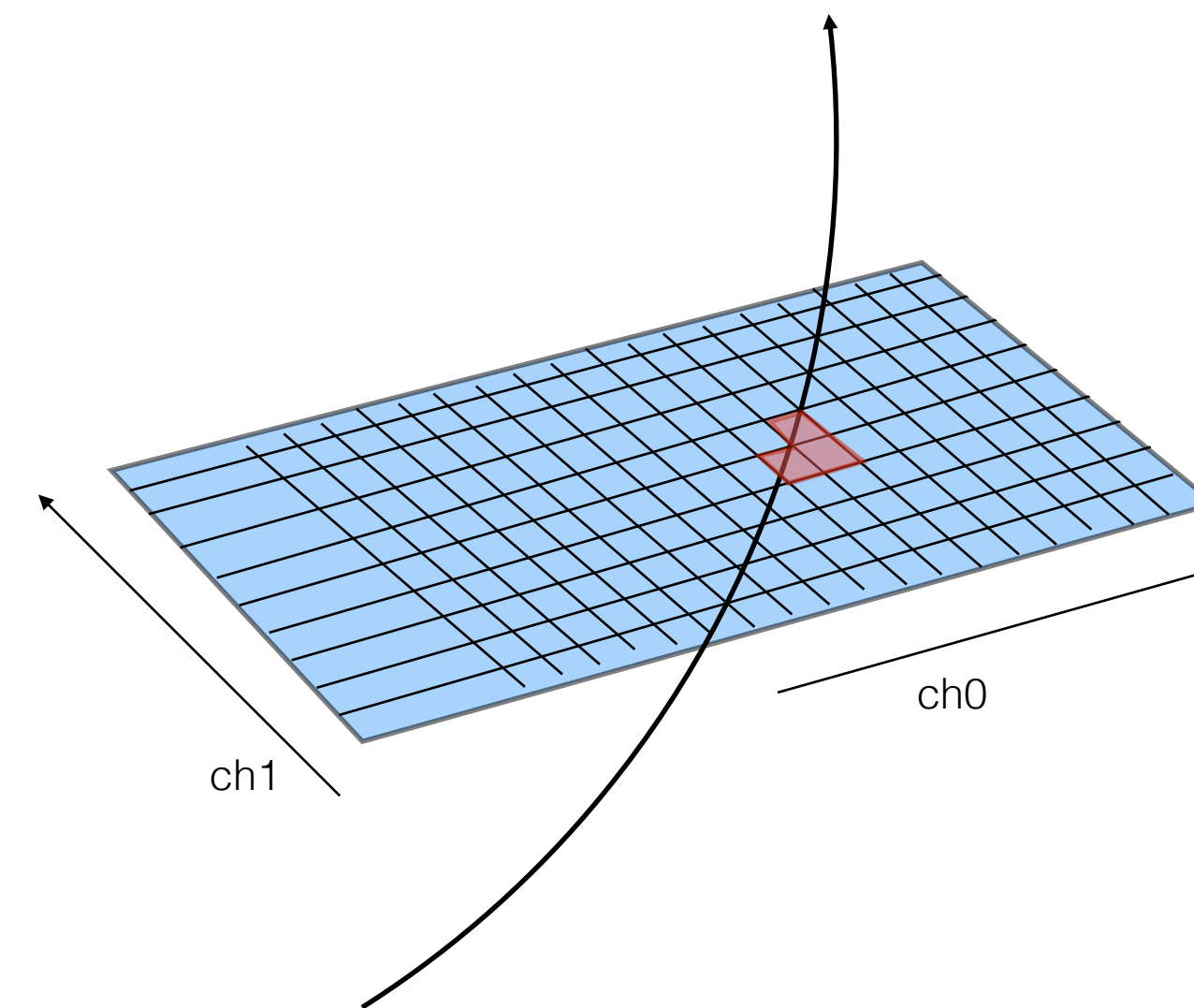
... neither is that ...



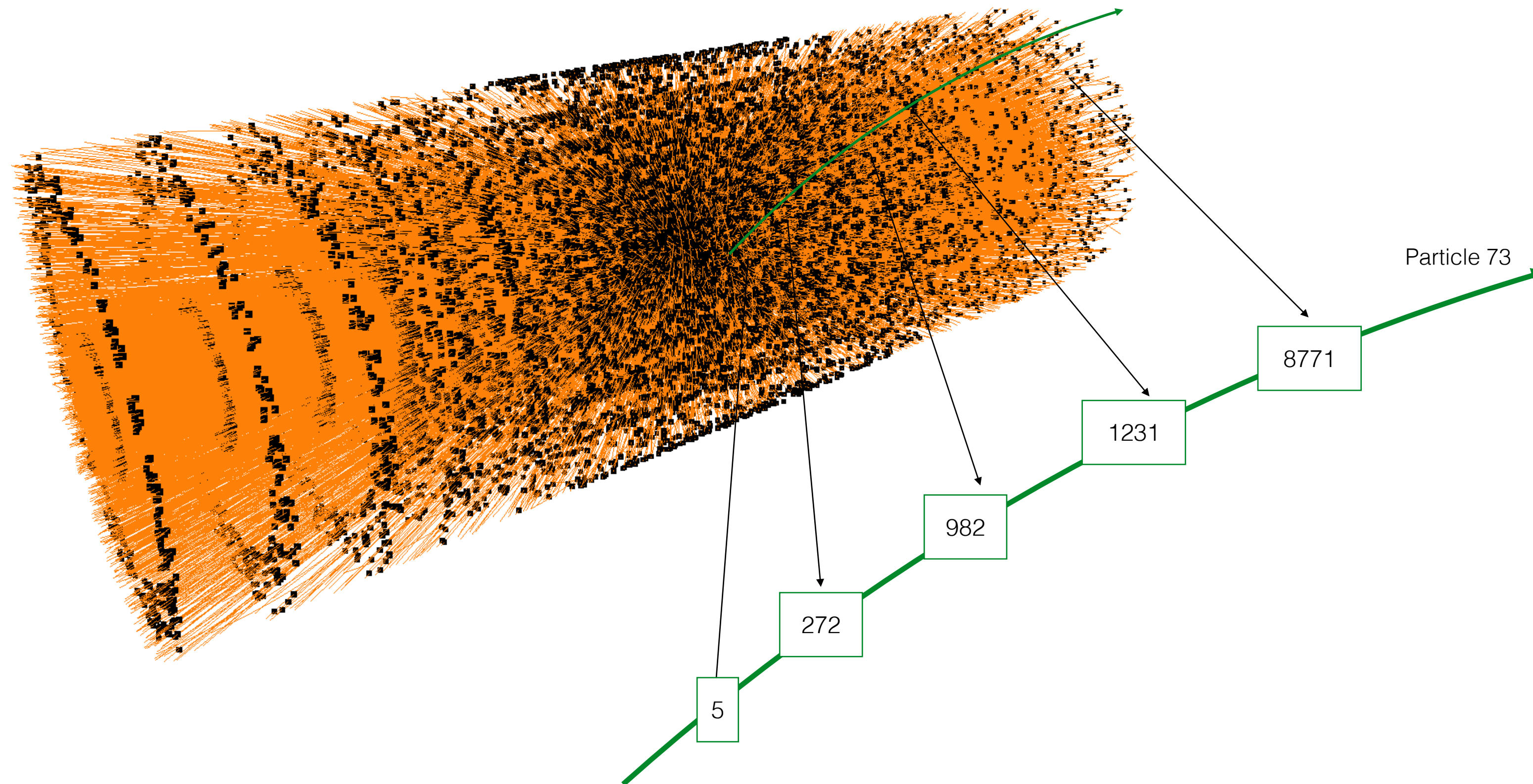
Reconstruct and analyse



Detection devices measure the particle with a given resolution.



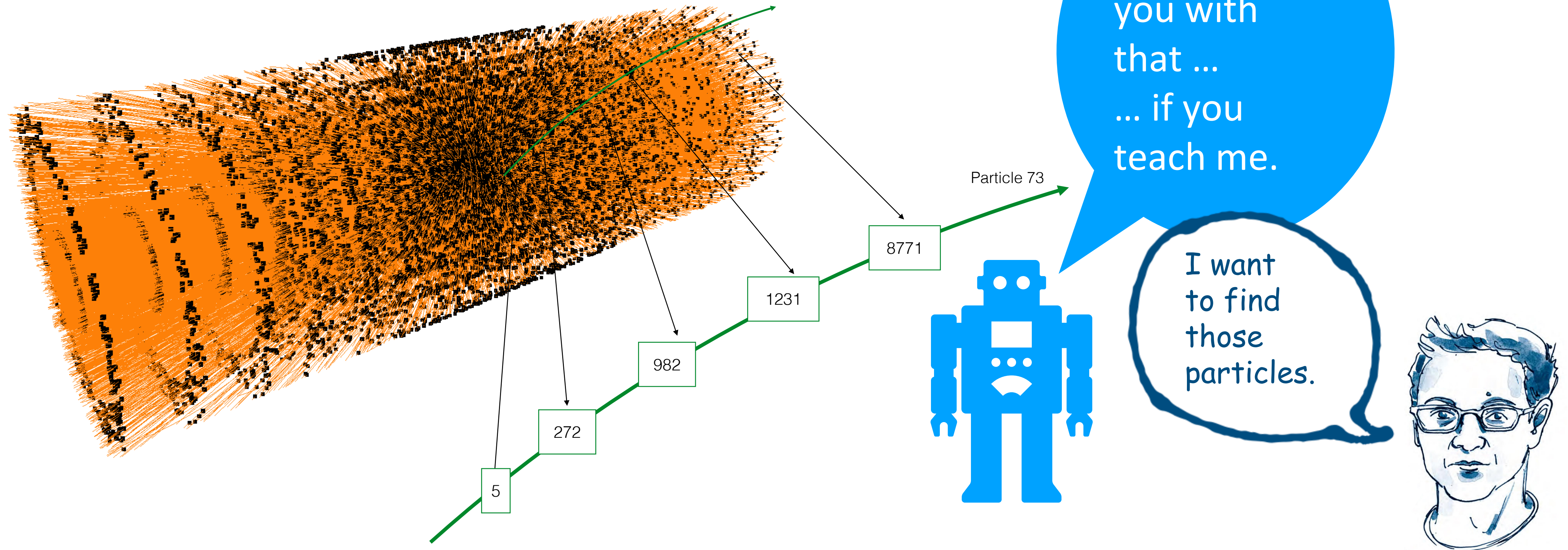
Reconstruct and analyse



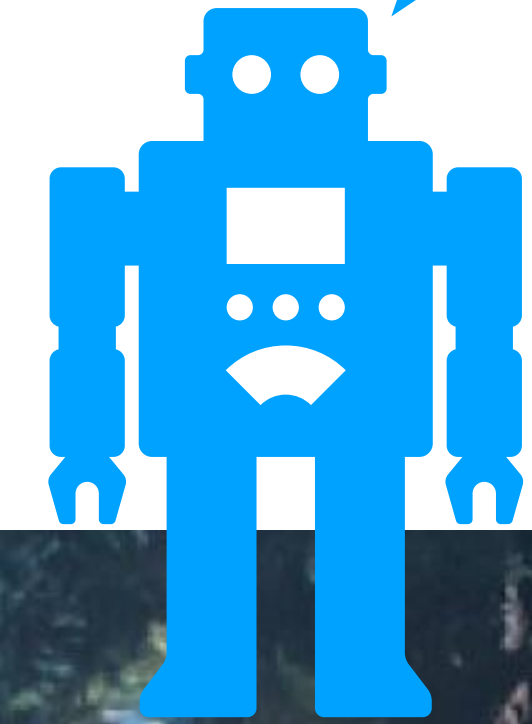
I want to find those particles.



Reconstruct and analyse

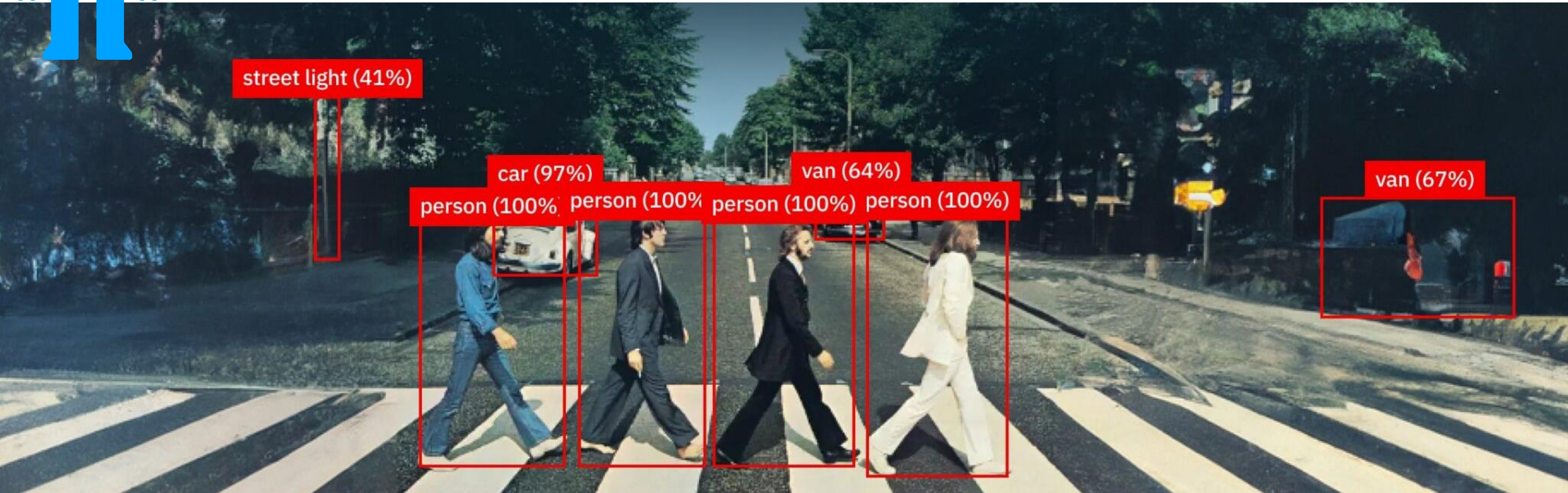


AI detour



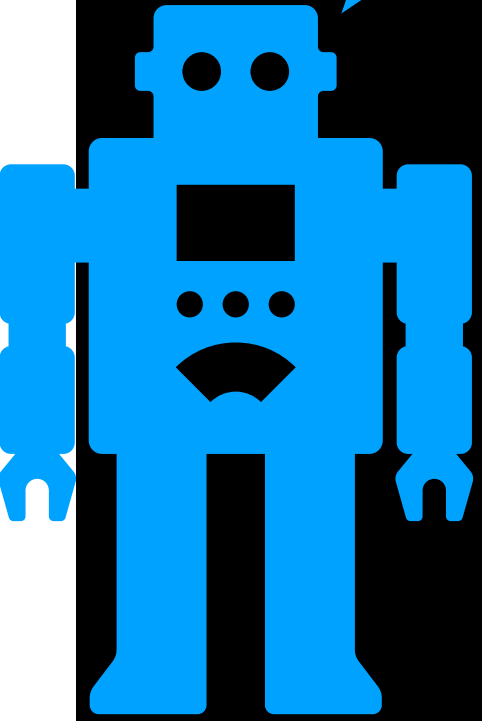
Object detection and recognition is a AI standard problem

- big advances achieved in the last years
- Both in object detection & object classification
- Can we use this for HEP?

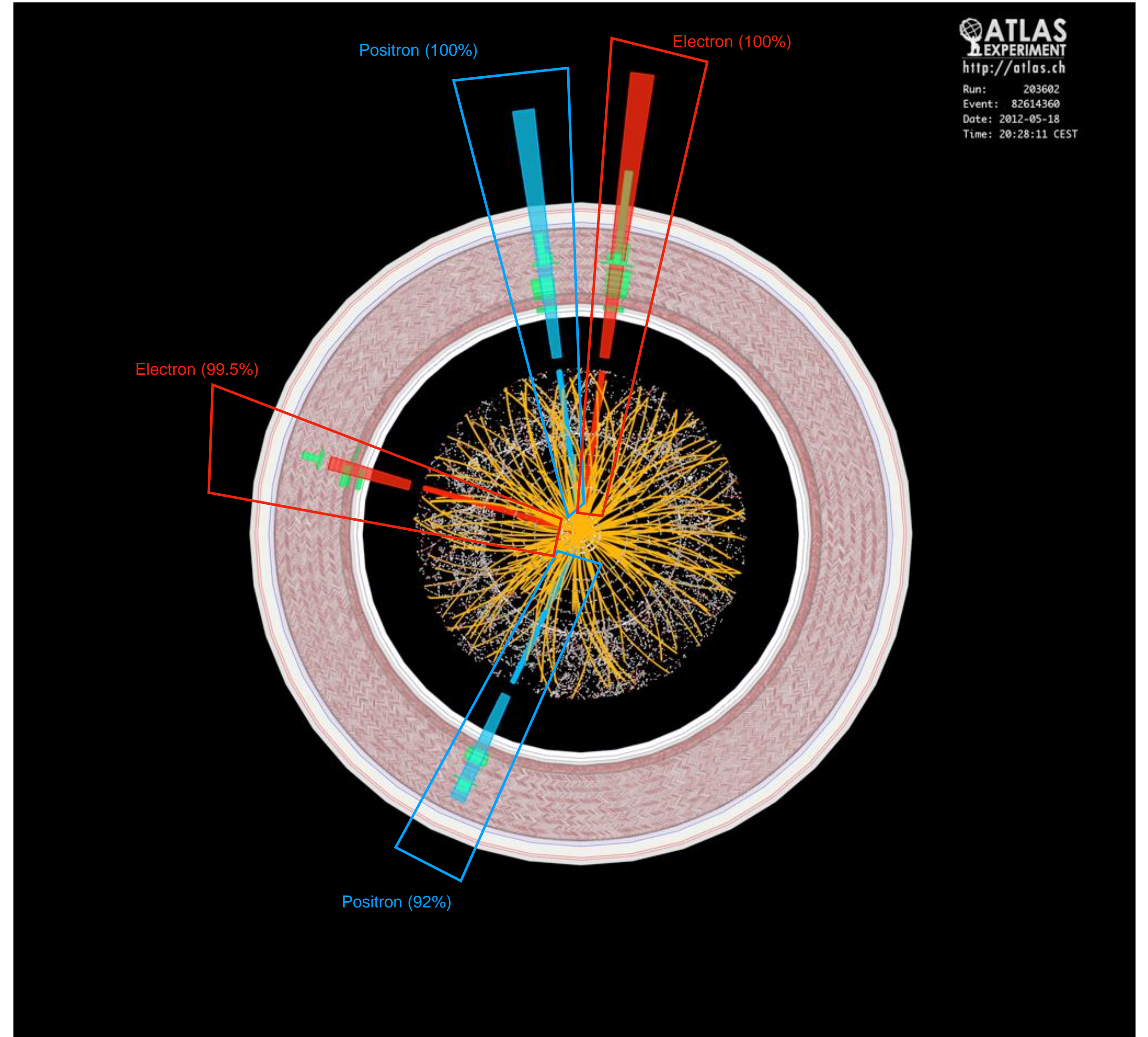
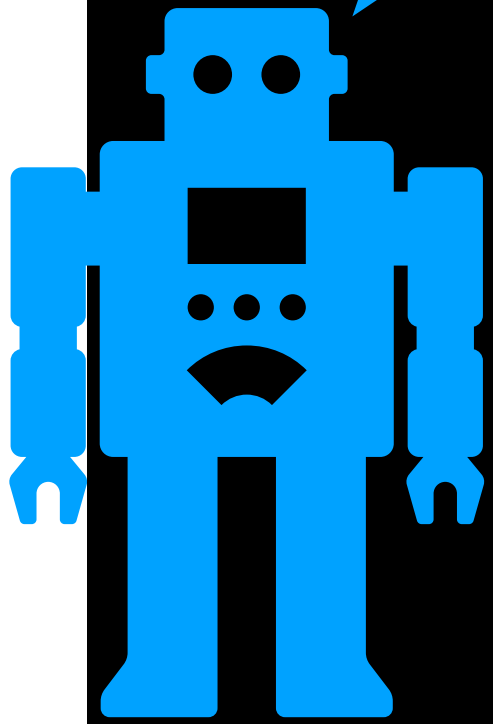


The Beatles, Abbey Road

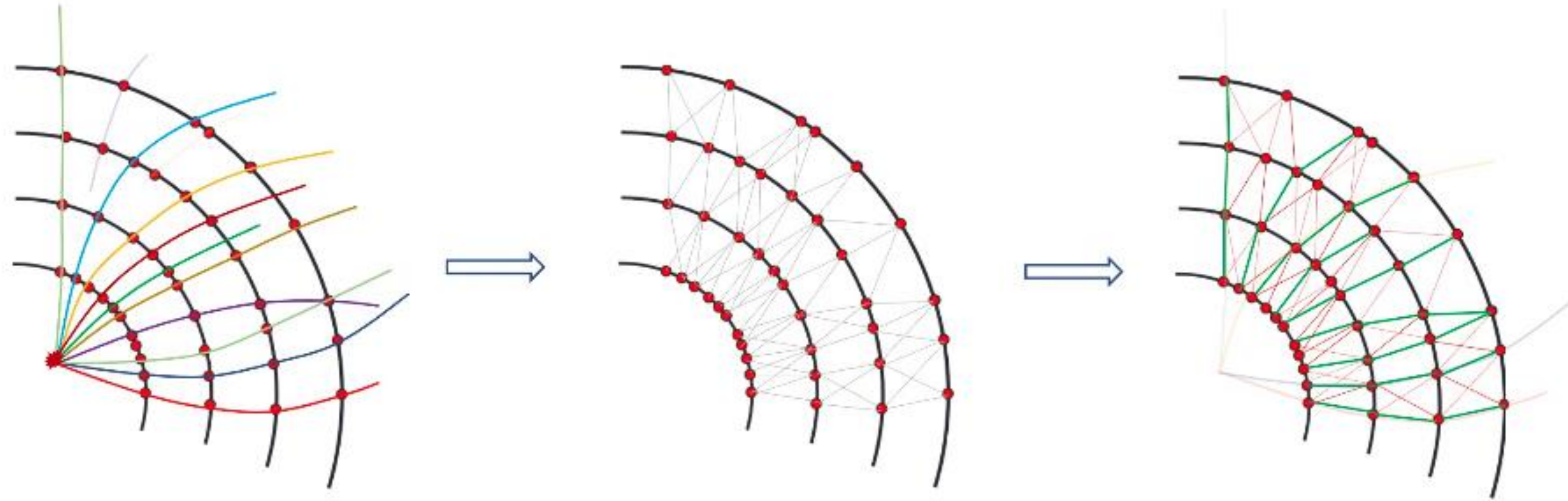
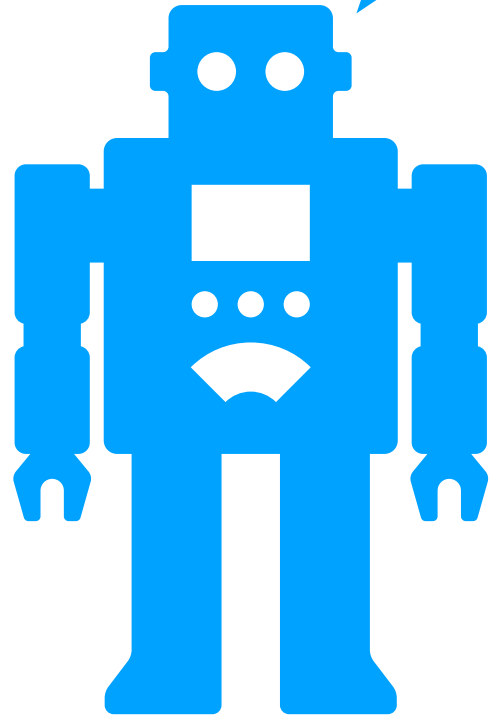
AI detour



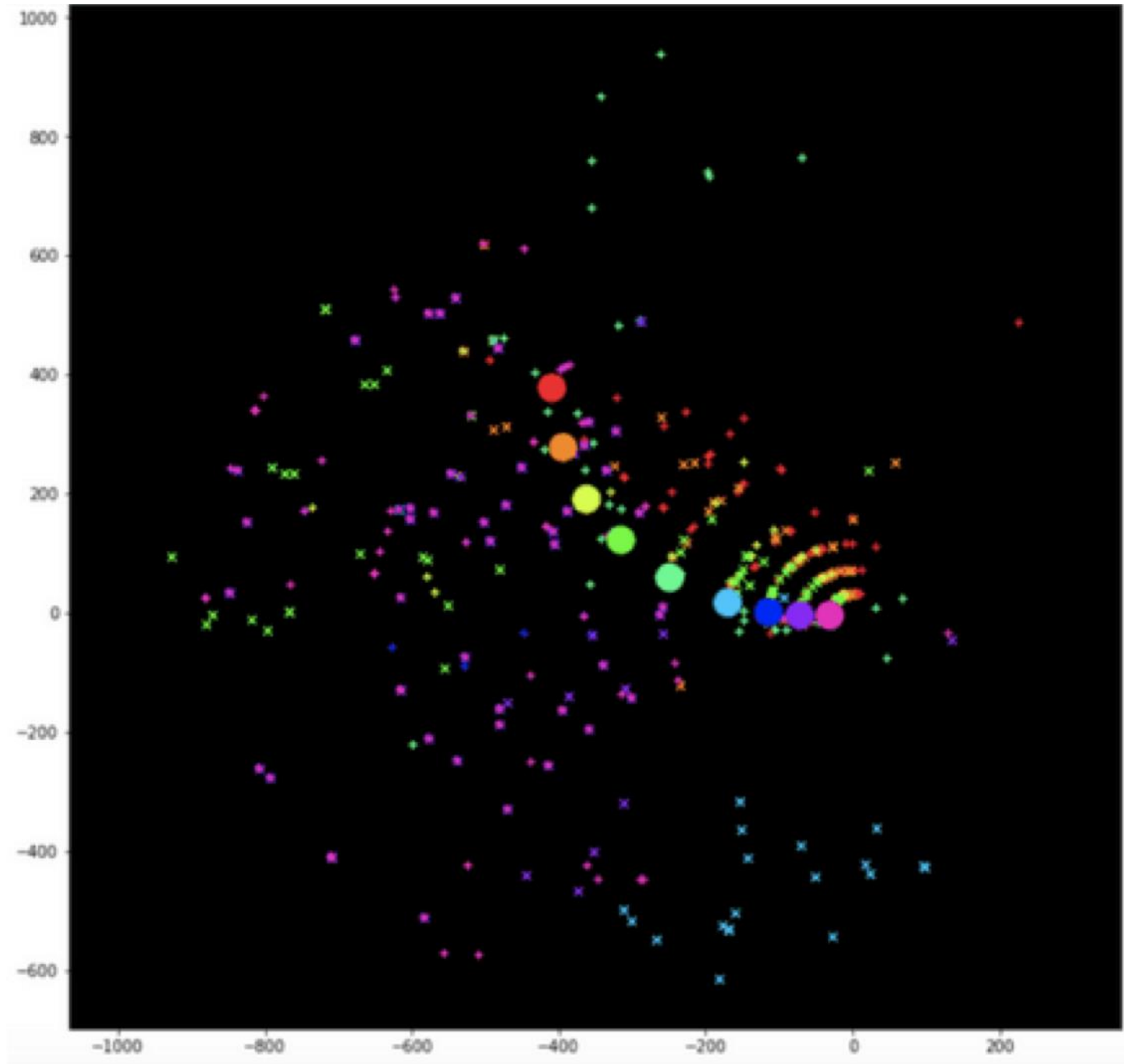
AI detour



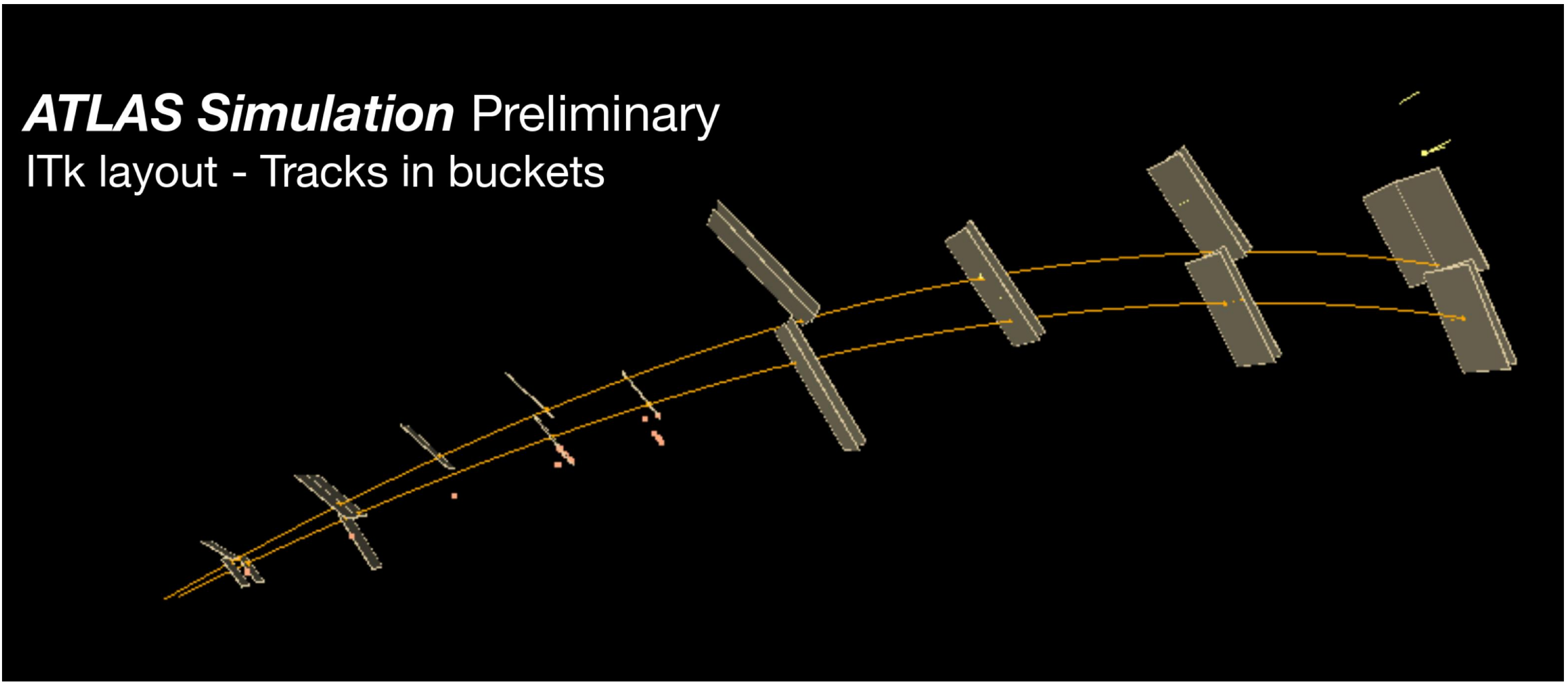
AI detour



Track candidates



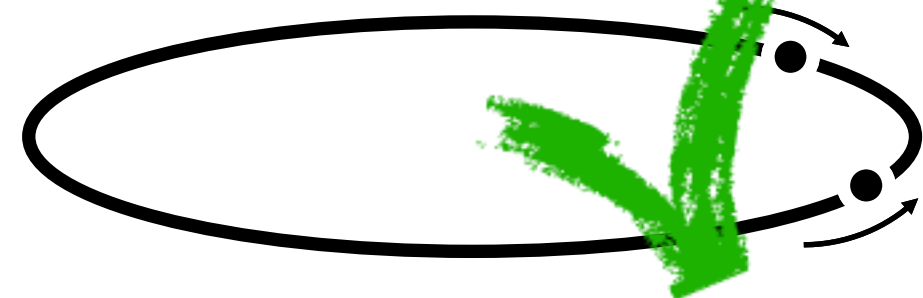
ATLAS Simulation Preliminary
ITk layout - Tracks in buckets



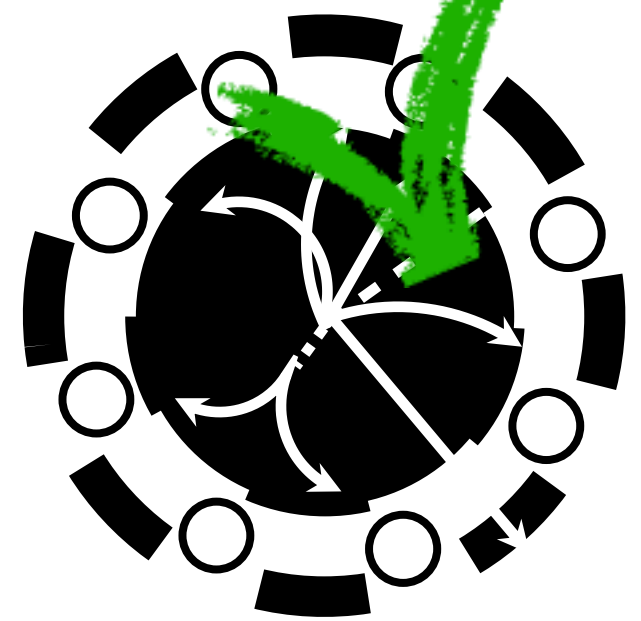
With all ingredients

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

Theory



Accelerator



Detector



Data Acquisition



Data Reconstruction



Laboratory

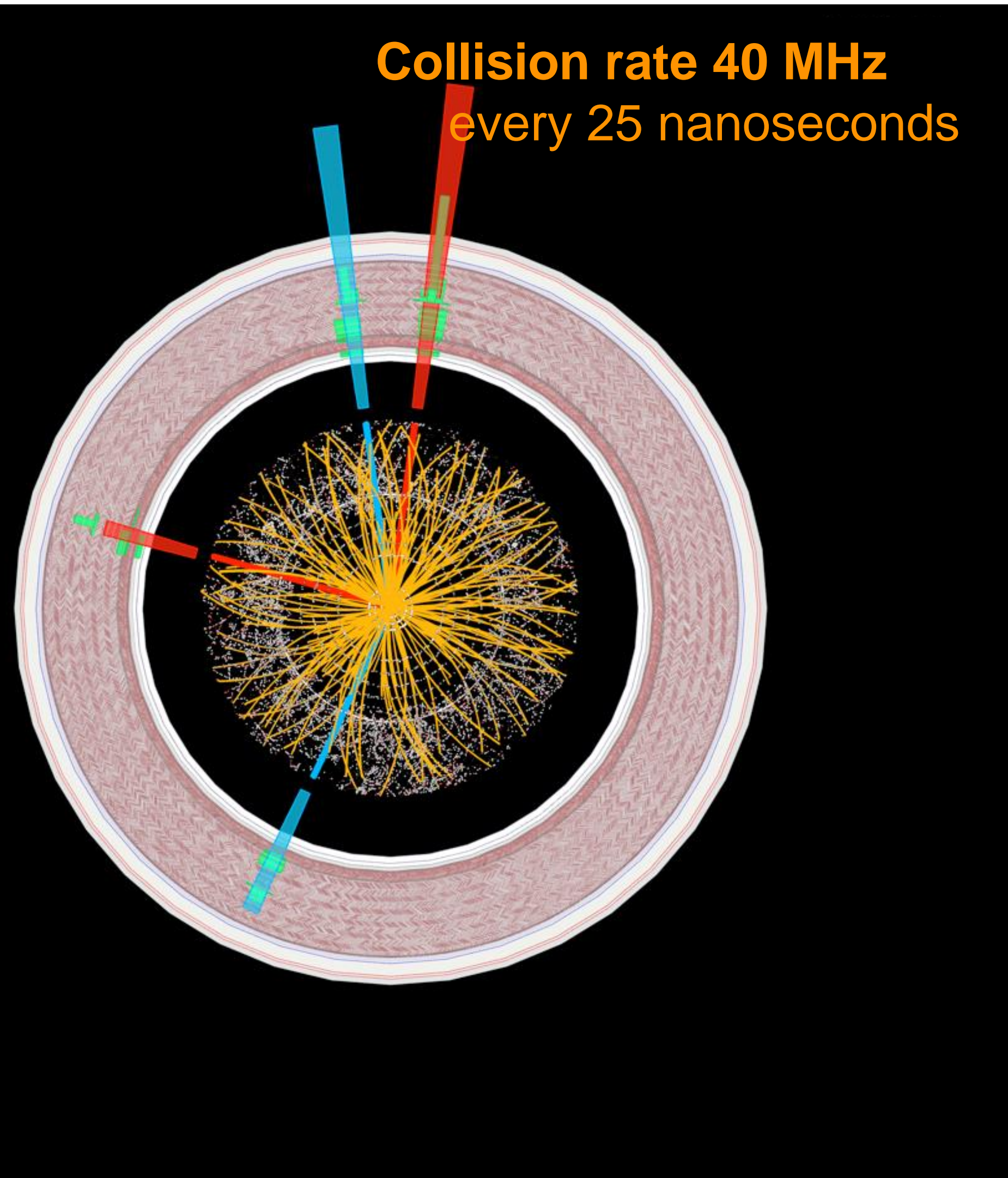


Worldwide distributed
Computing



Data Analysis

Let us run the experiment



Level 1 Trigger to 100 kHz
on detector electronics

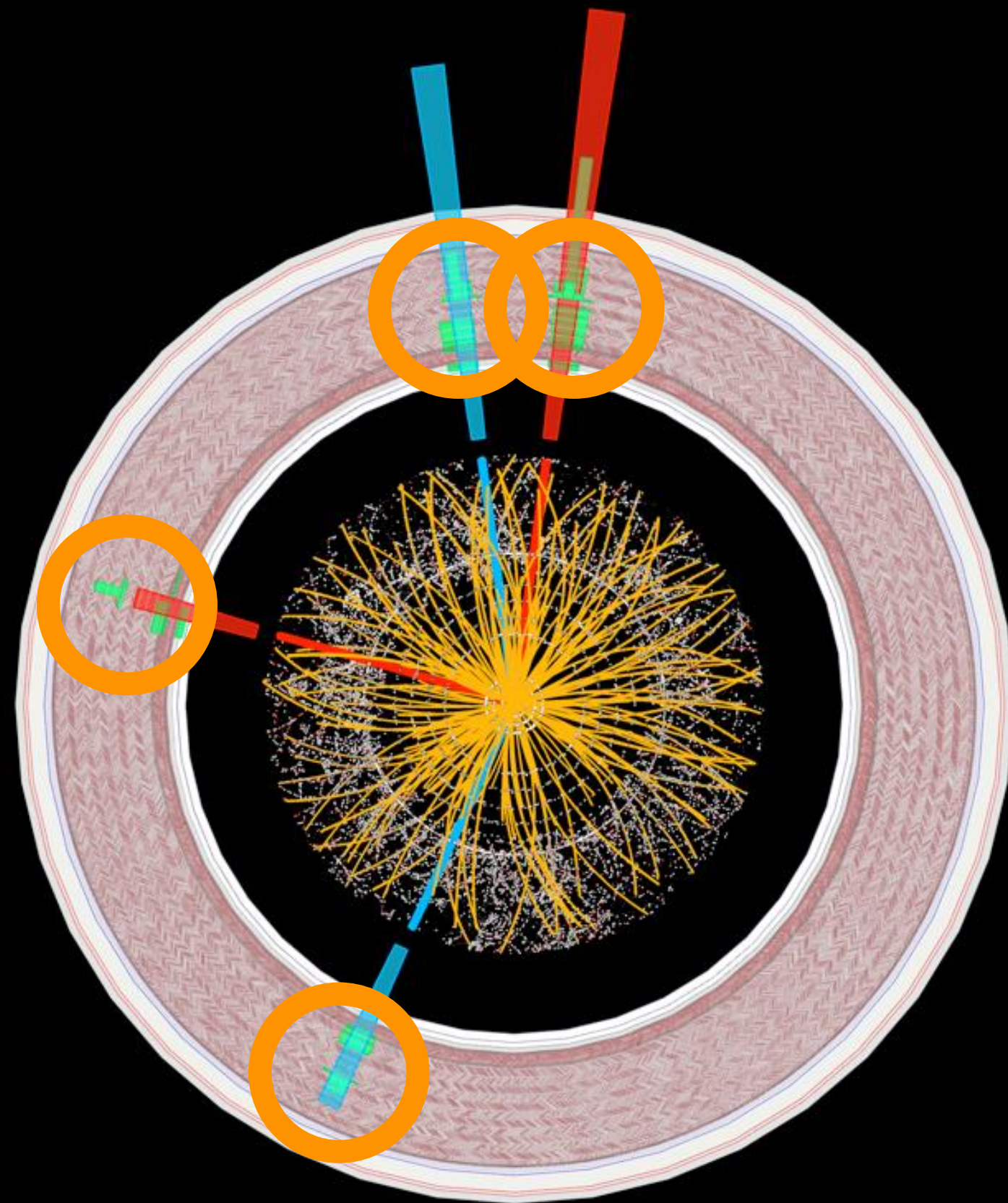
High level trigger ~1kHz
close-by computer farm

Full processing of events
1000 events/second

Data Analysis & publication



Let us run the experiment



Level 1 Trigger to 100 kHz
on detector electronics

4 lepton signals

High level trigger ~1kHz
close-by computer farm

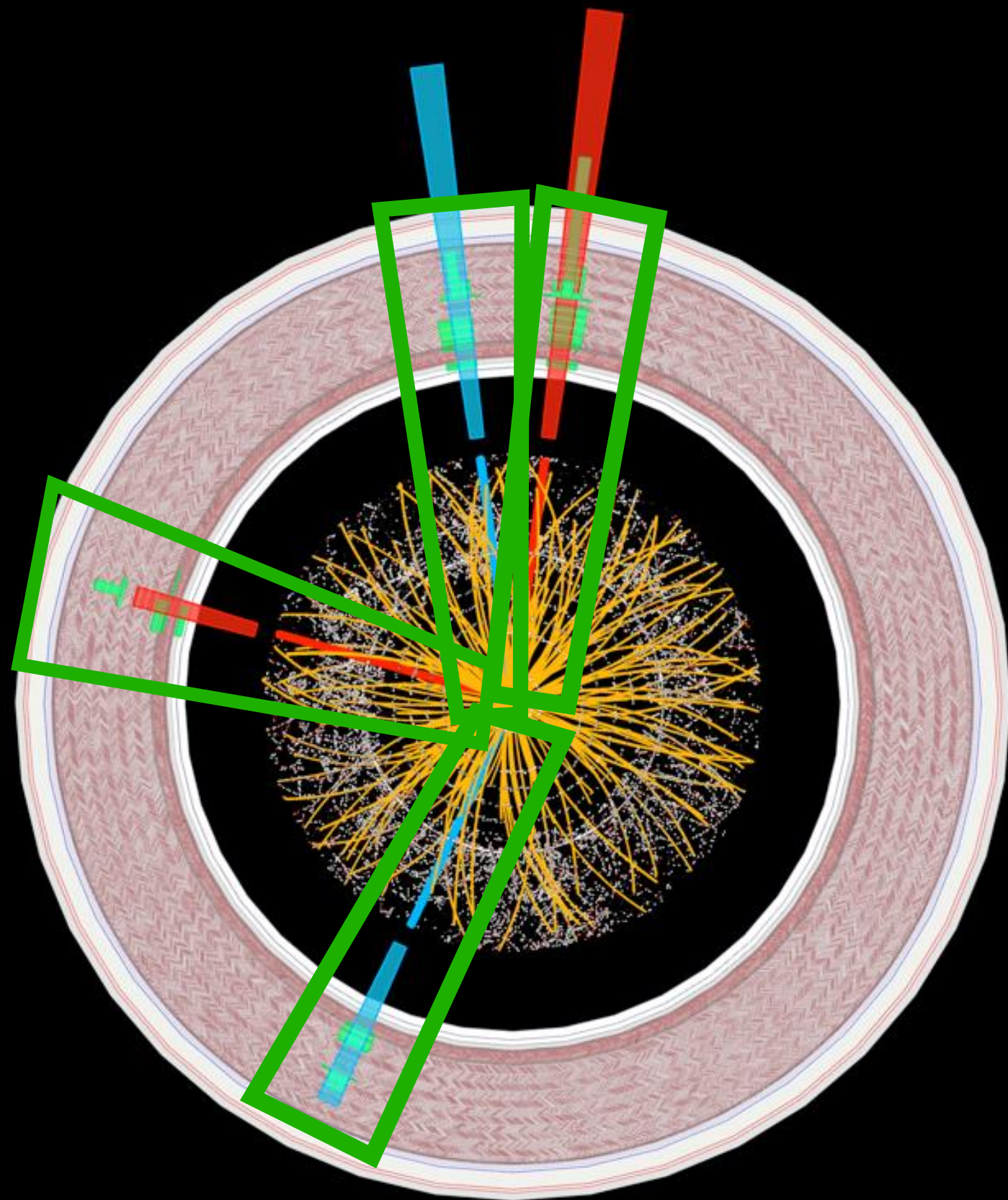
Full processing of events
1000 events/second

Data Analysis & publication



Nobel prize

Let us run the experiment



Level 1 Trigger to 100 kHz
on detector electronics

4 lepton signals

High level trigger ~1kHz
close-by computer farm

4 lepton signals confirmed

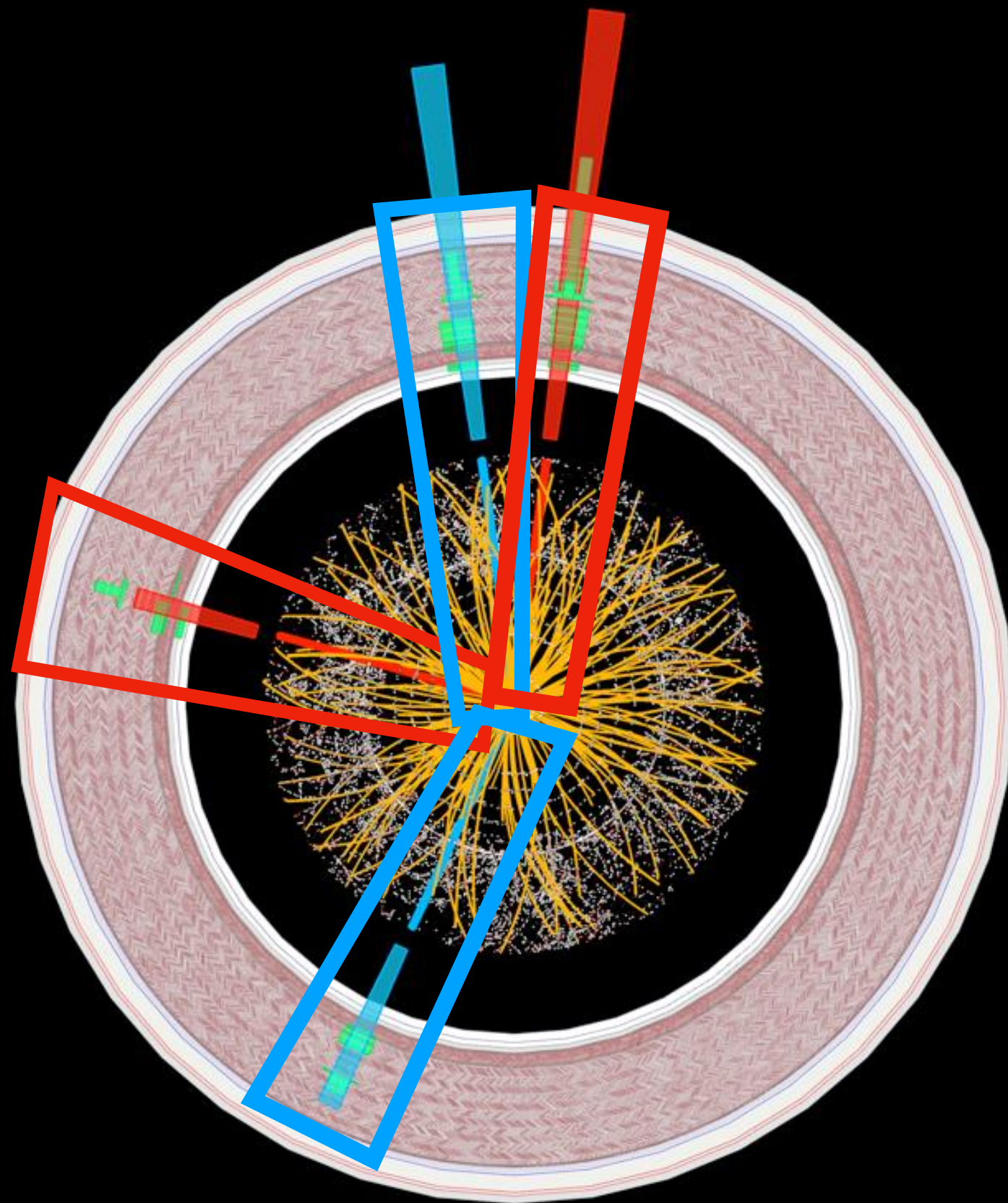
Full processing of events
1000 events/second

Data Analysis & publication



Nobel prize

Let us run the experiment



Level 1 Trigger to 100 kHz
on detector electronics

4 lepton signals

High level trigger ~1kHz
close-by computer farm

4 lepton signals confirmed

Full processing of events
1000 events/second

2 positive leptons
2 negative leptons
and measured

Data Analysis & publication



Nobel prize

Let us run the experiment

Lesson 1 - Minkowski arithmetic

$$p_\mu = (E, p_x, p_y, p_z)$$


energy momentum

Invariant mass:

$$M^2 = E^2 - p_x^2 - p_y^2 - p_z^2$$

Level 1 Trigger to 100 kHz
on detector electronics

4 lepton signals

High level trigger ~1kHz
close-by computer farm

4 lepton signals
confirmed

Full processing of events
1000 events/second

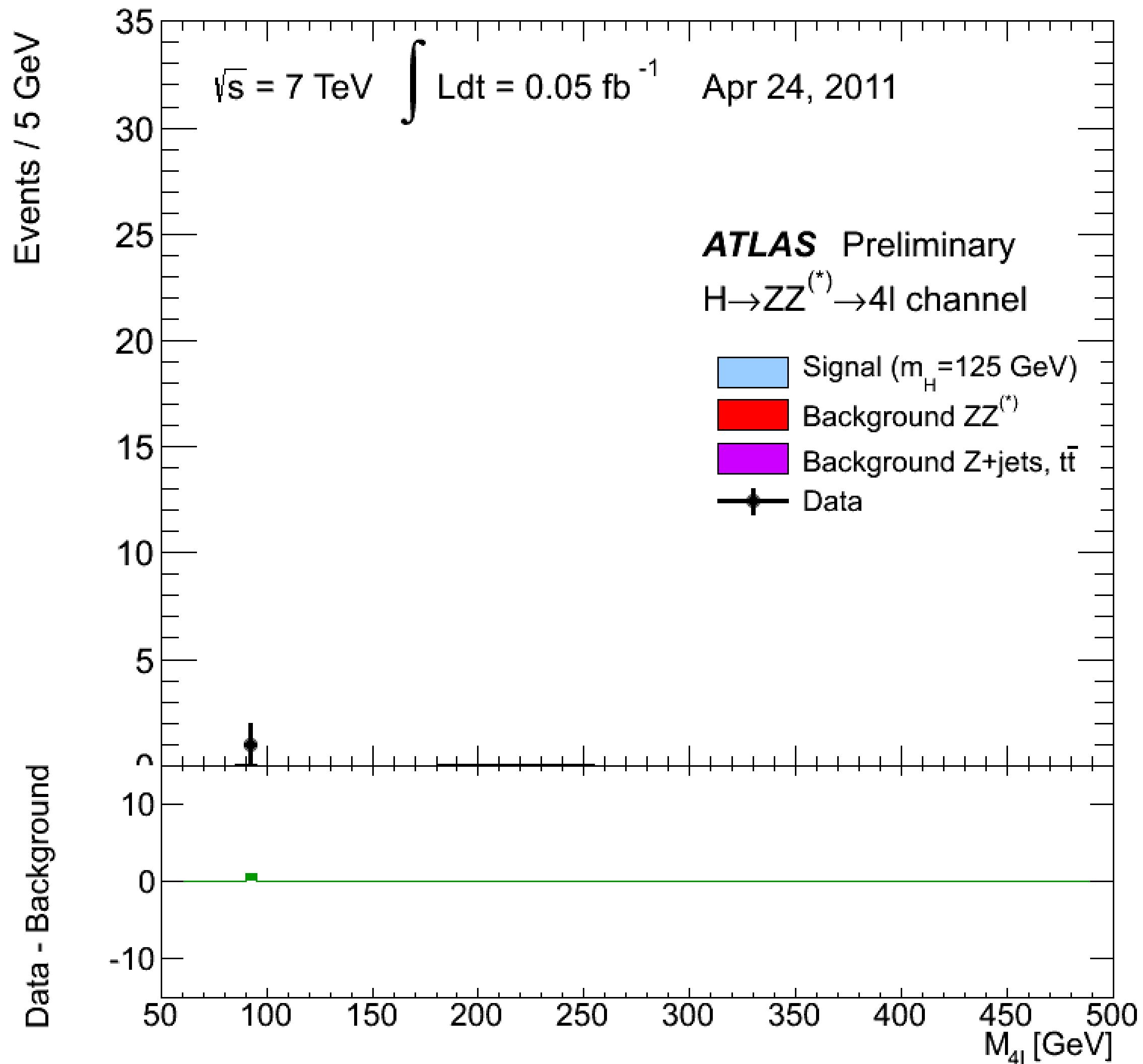
2 positive leptons
2 negative leptons
and measured

Data Analysis & publication



Nobel prize

Let us run the experiment ... for real



Level 1 Trigger to 100 kHz
on detector electronics

High level trigger ~1kHz
close-by computer farm

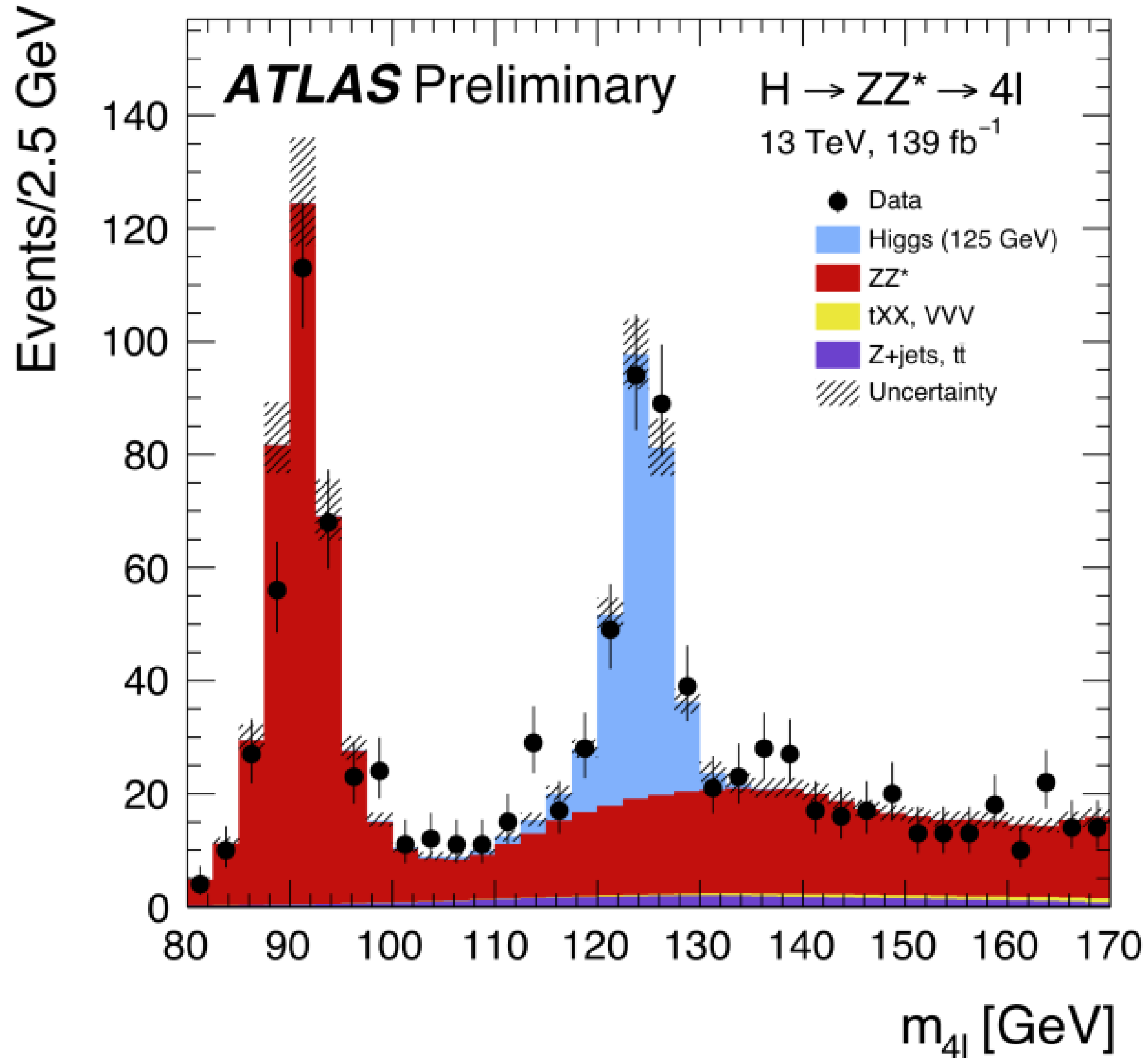
Full processing of events
1000 events/second

Data Analysis & publication



Nobel prize

Let us run the experiment ... for real



Level 1 Trigger to 100 kHz
on detector electronics

High level trigger ~1kHz
close-by computer farm

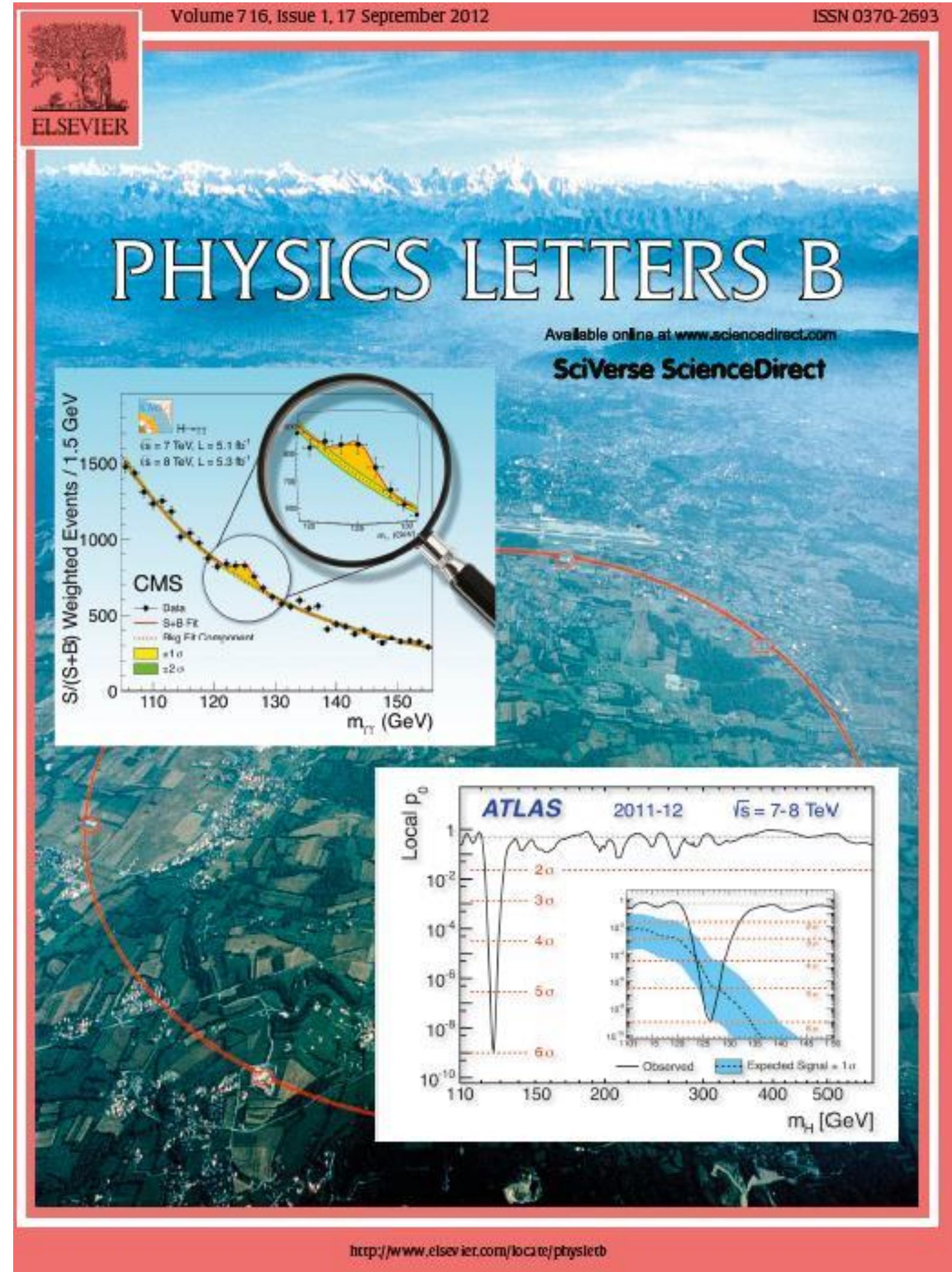
Full processing of events
1000 events/second

Data Analysis & publication



Nobel prize

And so it went ...



Level 1 Trigger to 100 kHz
on detector electronics

High level trigger ~ 1 kHz
close-by computer farm

Full processing of events
1000 events/second

Data Analysis & publication



... and of course the right guys got it.

The Nobel Prize in Physics 2013



© Nobel Media AB. Photo: A. Mahmoud

François Englert

Prize share: 1/2



© Nobel Media AB. Photo: A. Mahmoud

Peter W. Higgs

Prize share: 1/2

Level 1 Trigger to 100 kHz
on detector electronics

High level trigger ~1kHz
close-by computer farm

Full processing of events
1000 events/second

Data Analysis & publication



Nobel prize

scientific information



Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC[☆]

ATLAS Collaboration^{*}

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

ARTICLE INFO

Article history:
Received 31 July 2012
Received in revised form 8 August 2012
Accepted 11 August 2012
Available online 14 August 2012
Editor: W.-D. Schlatter

ABSTRACT

A search for the Standard Model Higgs boson in proton–proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7 \text{ TeV}$ in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8 \text{ TeV}$ in 2012. Individual searches in the channels $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$, $H \rightarrow \gamma\gamma$ and $H \rightarrow WW^{(*)} \rightarrow e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \rightarrow ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of $126.0 \pm 0.4 \text{ (stat)} \pm 0.4 \text{ (sys)} \text{ GeV}$ is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9} , is compatible with the production and decay of the Standard Model Higgs boson.

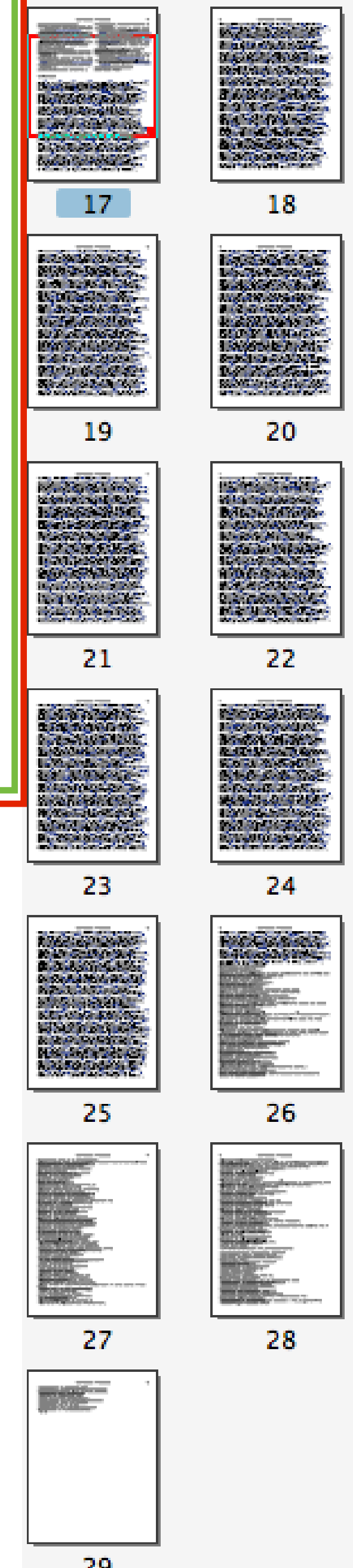
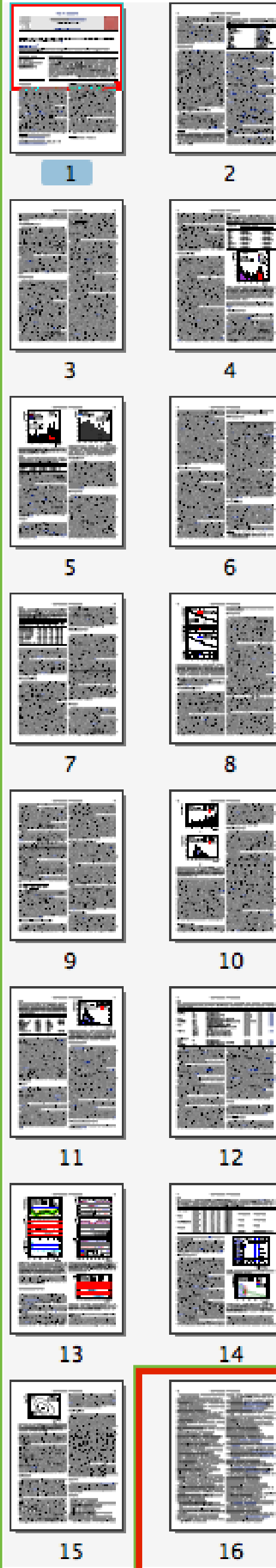
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L. Rummyantsev⁶⁴, Z. Rurikova⁴⁸, N.A. Rusakovich⁶⁴, J.P. Rutherford⁷, P. Ruzicka¹²⁵, Y.F. Ryabov¹²¹, M. Rybar¹²⁶, G. Rybkin¹¹⁵, N.C. Ryder¹¹⁸, A.F. Saavedra¹⁵⁰, I. Sadeh¹⁵³, H.F.-W. Sadrozinski¹³⁷, R. Sadykov⁶⁴, F. Safai Tehrani^{132a}, H. Sakamoto¹⁵⁵, G. Salamanna⁷⁵, A. Salamon^{133a}, M. Saleem¹¹¹, D. Salek³⁰, D. Salihagic⁹⁹, A. Salnikov¹⁴³, J. Salt¹⁶⁷, B.M. Salvachua Ferrando⁶, D. Salvatore^{37a,37b}, F. Salvatore¹⁴⁹, A. Salvucci¹⁰⁴, A. Salzburger³⁰, D. Sampsonidis¹⁵⁴, B.H. Samset¹¹⁷, A. Sanchez^{102a,102b}, V. Sanchez Martinez¹⁶⁷, H. Sandaker¹⁴, H.G. Sander⁸¹, M.P. Sanders⁹⁸, M. Sandhoff¹⁷⁵, T. Sandoval²⁸, C. Sandoval¹⁶², R. Sandstroem⁹⁹, D.P.C. Sankey¹²⁹, A. Sansoni⁴⁷, C. Santamarina Rios⁸⁵, C. Santoni³⁴, R. Santonico^{133a,133b}, H. Santos^{124a}, J.G. Saraiva^{124a}, T. Sarangi¹⁷³, E. Sarkisyan-Grinbaum⁸, F. Sarri^{122a,122b}, G. Sartisohn¹⁷⁵, O. Sasaki⁶⁵, Y. Sasaki¹⁵⁵, N. Sasao⁶⁷, I. Satsounkevitch⁹⁰, G. Sauvage^{5,*}, E. Sauvan⁵, J.B. Sauvan¹¹⁵, P. Savard^{158,d}, V. Savinov¹²³, D.O. Savu³⁰, L. Sawyer^{25,m}, D.H. Saxon⁵³, J. Saxon¹²⁰, C. Sbarra^{20a}, A. Sbrizzi^{20a,20b}, D.A. Scannicchio¹⁶³, M. Scarcella¹⁵⁰, J. Schaarschmidt¹¹⁵, P. Schacht⁹⁹, D. Schaefer¹²⁰, U. Schäfer⁸¹, A. Schaelicke⁴⁶, S. Schaepe²¹, S. Schaelzel^{58b}, A.C. Schaffer¹¹⁵, D. Schaile⁹⁸, R.D. Schamberger¹⁴⁸, A.G. Schamov¹⁰⁷, V. Scharf^{58a}, V.A. Schegelsky¹²¹, D. Scheirich⁸⁷, M. Schernau¹⁶³, M.I. Scherzer³⁵, C. Schiavi^{50a,50b}, J. Schieck⁹⁸, M. Schioppa^{37a,37b}, S. Schlenker³⁰, P. Schmid³⁰, E. Schmidt⁴⁸, K. Schmieden²¹, C. Schmitt⁸¹, S. Schmitt^{58b}, M. Schmitz²¹, B. Schneider¹⁷, U. Schnoor⁴⁴, L. Schoeffel¹³⁶, A. Schoening^{58b}, A.L.S. Schorlemmer⁵⁴, M. Schott³⁰, D. Schouten^{159a}, J. Schovancova¹²⁵, M. Schram⁸⁵, C. Schroeder⁸¹, N. Schroer^{58c}, M.J. Schultens²¹, J. Schultes¹⁷⁵, H.-C. Schultz-Coulon^{58a}, H. Schulz¹⁶, M. Schumacher⁴⁸, B.A. Schumm¹³⁷, Ph. Schune¹³⁶, C. Schwanenberger⁸², A. Schwartzman¹⁴³, Ph. Schwegler⁹⁹,

15 pages scientific context

~ 3000 authors





3000

Scientific authors



182

Institutions



42

Countries



1200

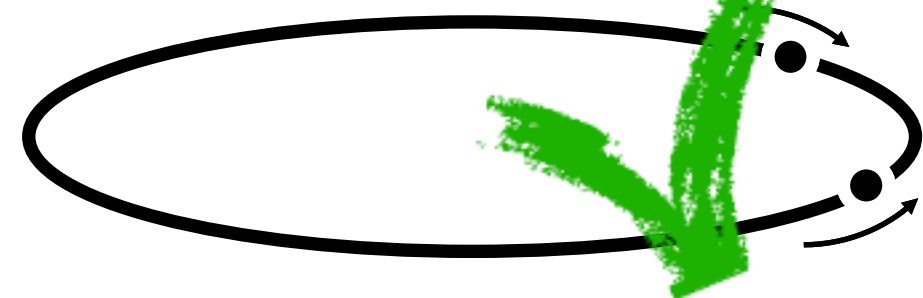
Doctoral students



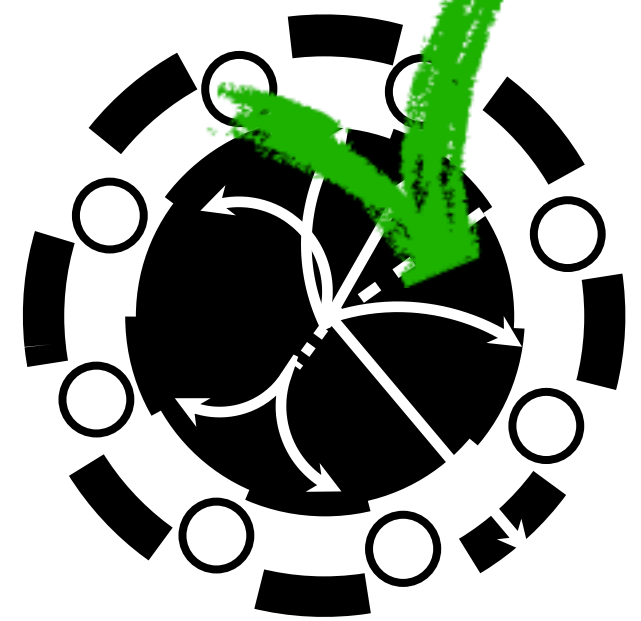
When we all work together ...

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

Theory



Accelerator



Detector



Data Acquisition



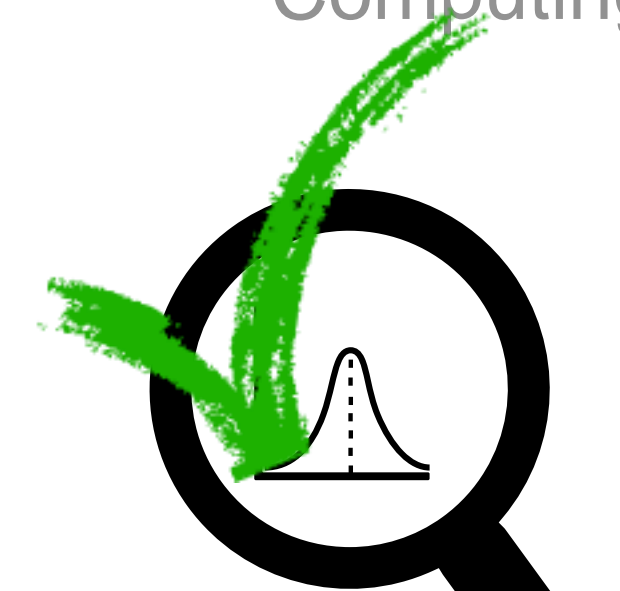
Data Reconstruction



Laboratory

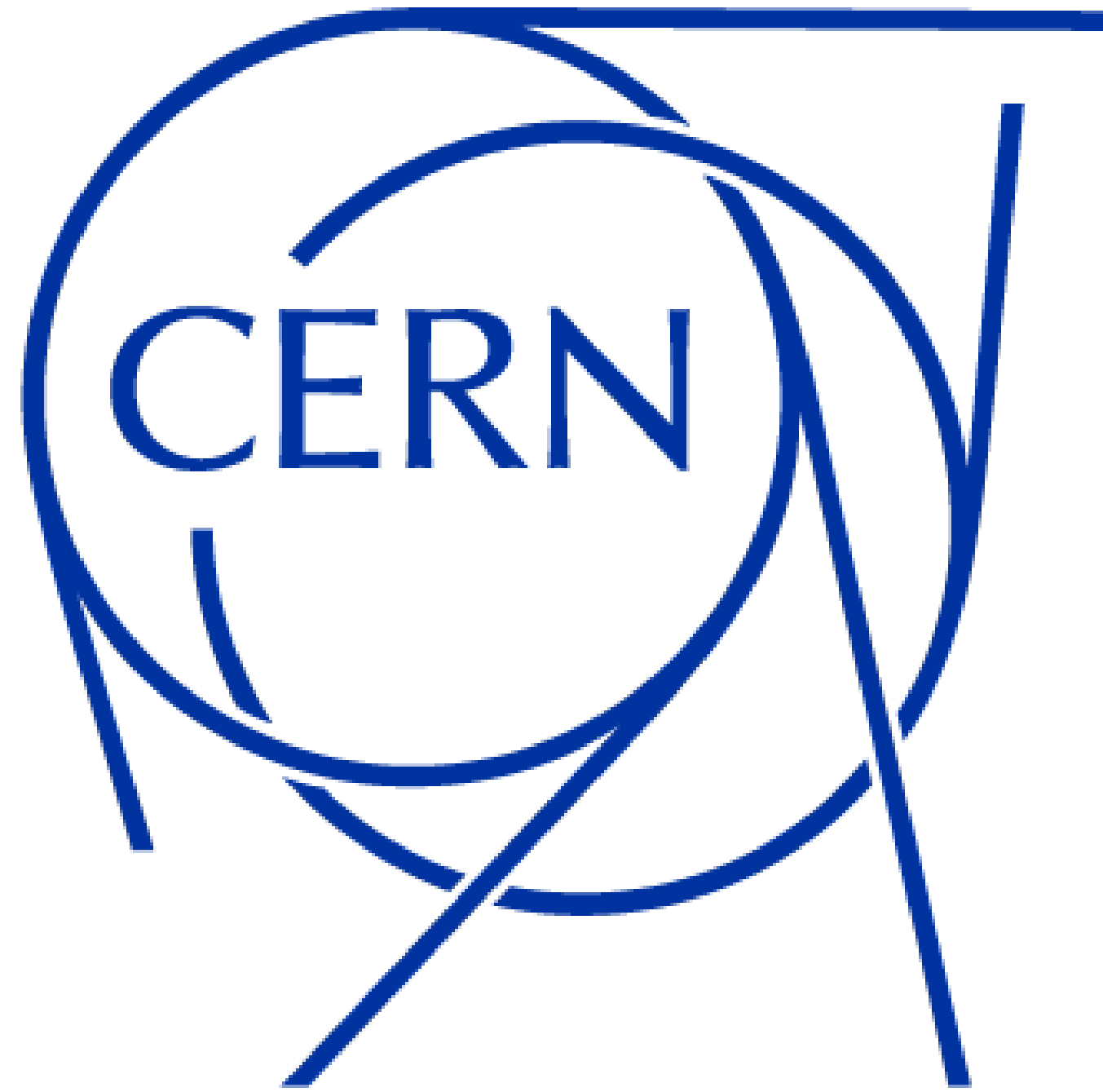


Worldwide distributed
Computing



Data Analysis

When we all work together ...



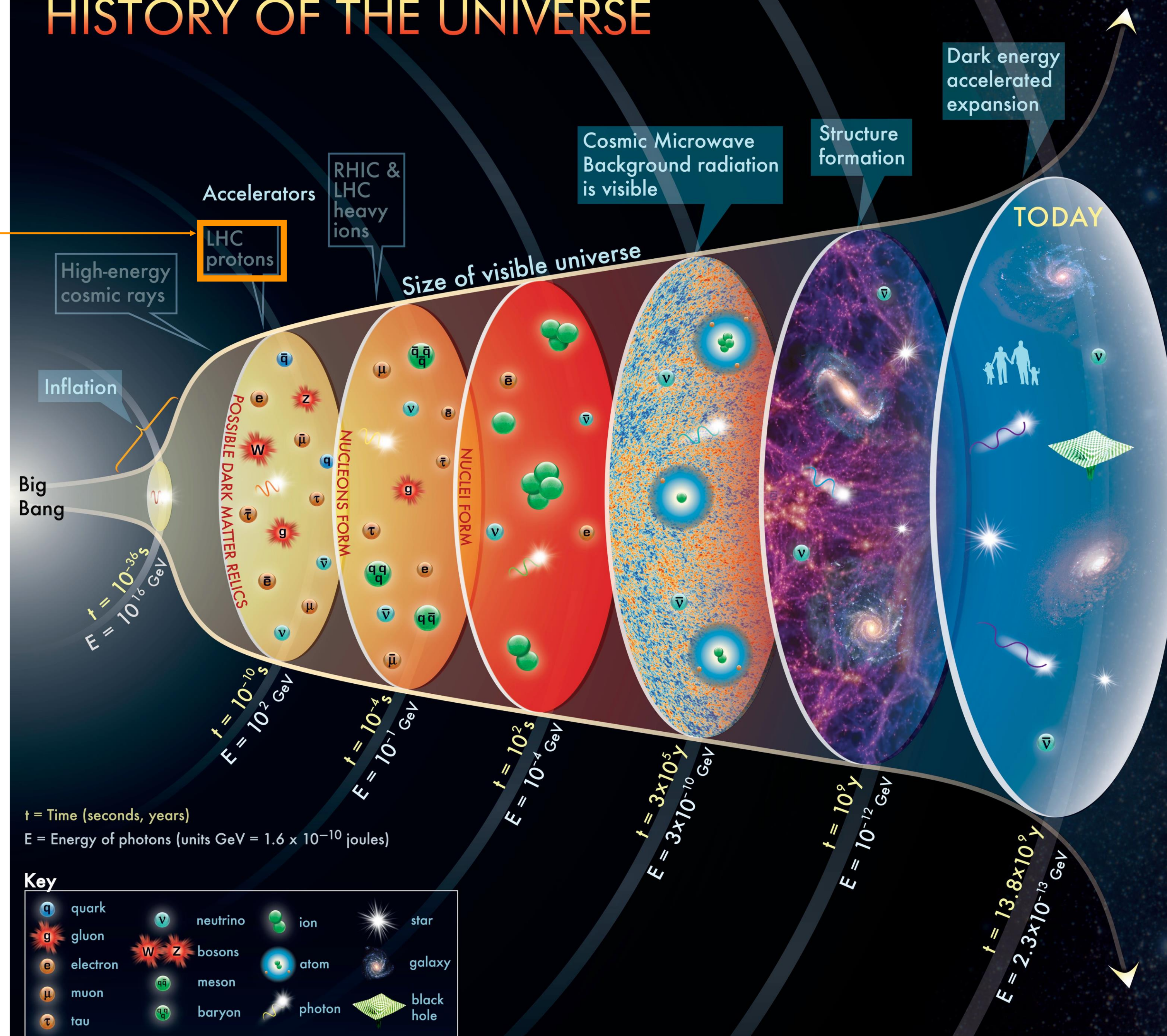
... we can achieve amazing things.

The why

allows us to investigate universe at an age of

10^{-10} s = 0.0000000001 s

HISTORY OF THE UNIVERSE



t = Time (seconds, years)
E = Energy of photons (units GeV = 1.6×10^{-10} joules)

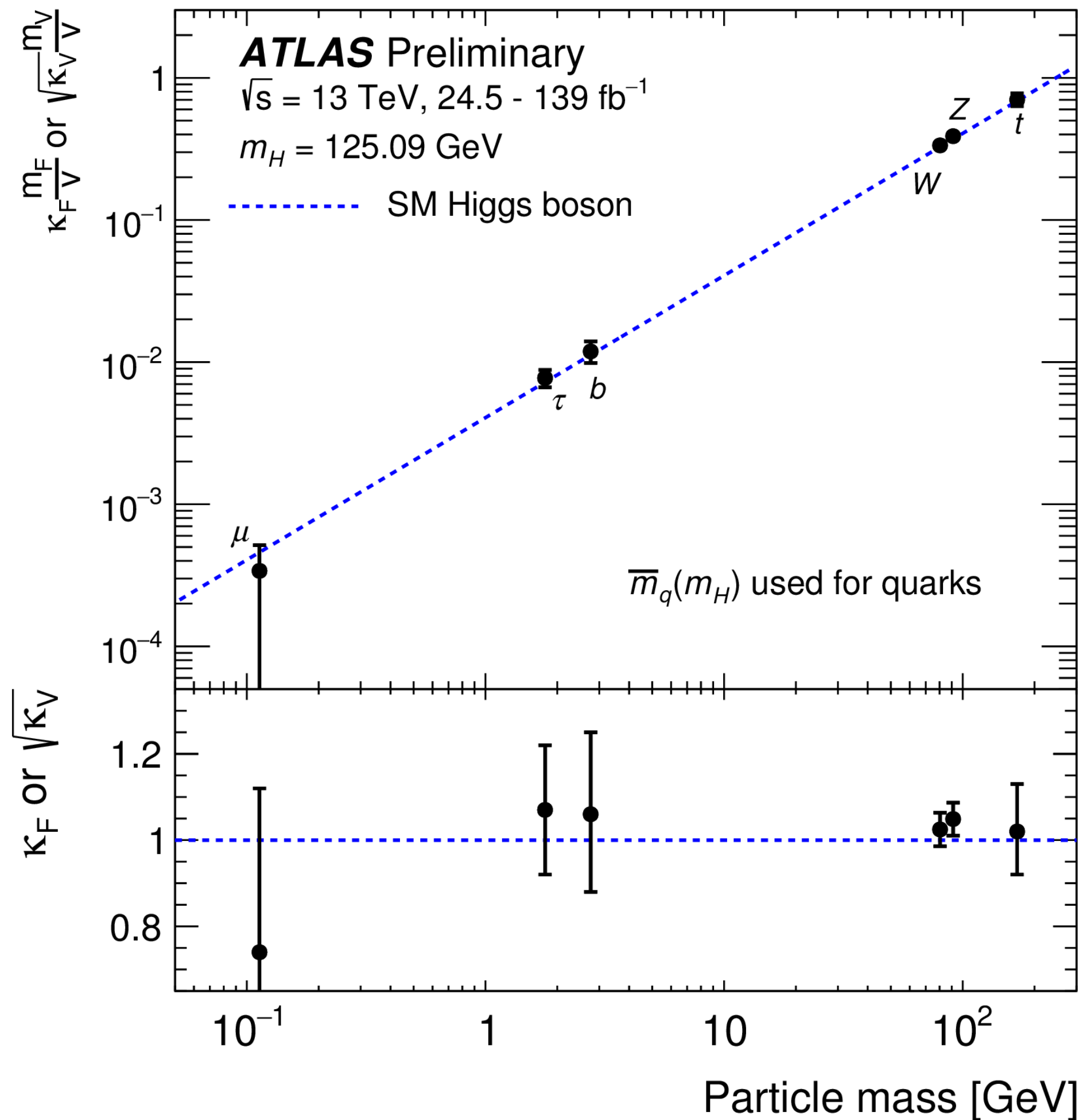
Key

q	quark	v	neutrino	ion	star
g	gluon	W Z	bosons	atom	galaxy
e	electron	qq	meson	photon	black hole
μ	muon	qqq	baryon		
τ	tau				

The concept for the above figure originated in a 1986 paper by Michael Turner.

The duck & the wall

SM Higgs coupling to fermions & vector bosons



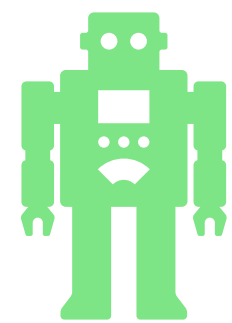
Exclusion limits for various SUSY particles

ATLAS SUSY Searches* - 95% CL Lower Limits
 March 2022

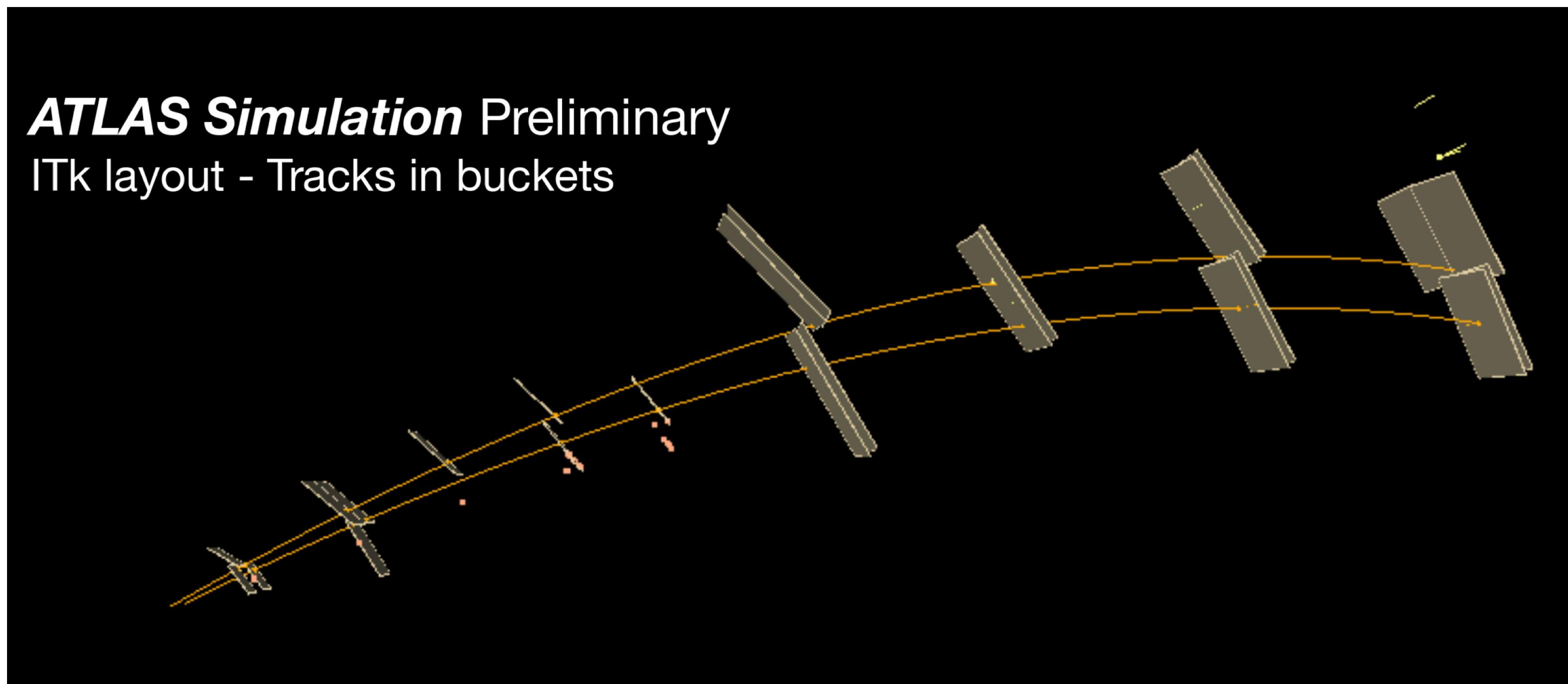
ATLAS Preliminary
 $\sqrt{s} = 13 \text{ TeV}$

Model	Signature	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference		
Inclusive Searches	$\bar{q}q, \bar{q} \rightarrow q\tilde{\chi}_1^0$	0 e, μ	2-6 jets E_T^{miss} 139	\bar{q} [1x, 8x Degen.] 1.0 1.85	$m(\tilde{\chi}_1^0) < 400 \text{ GeV}$	2010.14293
	$\bar{q}q, \bar{q} \rightarrow q\tilde{\chi}_1^0$	mono-jet	1-3 jets E_T^{miss} 139	\bar{q} [8x Degen.] 0.9	$m(\tilde{q}) - m(\tilde{\chi}_1^0) = 5 \text{ GeV}$	2102.10874
	$\bar{g}g, \bar{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$	0 e, μ	2-6 jets E_T^{miss} 139	\bar{g} 2.3	$m(\tilde{\chi}_1^0) = 0 \text{ GeV}$	2010.14293
	$\bar{g}g, \bar{g} \rightarrow q\bar{q}W\tilde{\chi}_1^0$	1 e, μ	2-6 jets 139	\bar{g} Forbidden 1.15-1.95	$m(\tilde{\chi}_1^0) = 1000 \text{ GeV}$	2010.14293
	$\bar{g}g, \bar{g} \rightarrow q\bar{q}\ell\ell\tilde{\chi}_1^0$	$ee, \mu\mu$	2 jets E_T^{miss} 139	\bar{g} 2.2	$m(\tilde{\chi}_1^0) < 600 \text{ GeV}$	2101.01629
	$\bar{g}g, \bar{g} \rightarrow q\bar{q}WZ\tilde{\chi}_1^0$	0 e, μ	7-11 jets E_T^{miss} 139	\bar{g} 2.2	$m(\tilde{\chi}_1^0) < 700 \text{ GeV}$	CERN-EP-2022-014
	$\bar{g}g, \bar{g} \rightarrow q\bar{q}WZ\tilde{\chi}_1^0$	SS e, μ	6 jets 139	\bar{g} 1.97	$m(\tilde{\chi}_1^0) < 600 \text{ GeV}$	2008.06032
	$\bar{g}g, \bar{g} \rightarrow q\bar{q}WZ\tilde{\chi}_1^0$	0 e, μ	6 jets 139	\bar{g} 1.15	$m(\tilde{g}) - m(\tilde{\chi}_1^0) = 200 \text{ GeV}$	1909.08457
	$\bar{g}g, \bar{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b E_T^{miss} 79.8	\bar{g} 2.25	$m(\tilde{\chi}_1^0) < 200 \text{ GeV}$	ATLAS-CONF-2018-041
	$\bar{g}g, \bar{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$	SS e, μ	6 jets 139	\bar{g} 1.25	$m(\tilde{g}) - m(\tilde{\chi}_1^0) = 300 \text{ GeV}$	1909.08457
3 rd gen. squarks direct production	$\bar{b}_1\bar{b}_1$	0 e, μ	2 b E_T^{miss} 139	\bar{b}_1 1.255	$m(\tilde{\chi}_1^0) < 400 \text{ GeV}$	2101.12527
	$\bar{b}_1\bar{b}_1, \bar{b}_1 \rightarrow b\tilde{\chi}_2^0 \rightarrow b\tilde{h}\tilde{\chi}_1^0$	0 e, μ	6 b E_T^{miss} 139	\bar{b}_1 0.68	$10 \text{ GeV} < \Delta m(\bar{b}_1, \tilde{\chi}_1^0) < 20 \text{ GeV}$	2101.12527
	$\bar{b}_1\bar{b}_1, \bar{b}_1 \rightarrow b\tilde{\chi}_2^0 \rightarrow b\tilde{h}\tilde{\chi}_1^0$	2 τ	2 b E_T^{miss} 139	\bar{b}_1 Forbidden 0.13-0.85	$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130 \text{ GeV}, m(\tilde{\chi}_1^0) = 100 \text{ GeV}$	1908.03122
	$\bar{t}_1\bar{t}_1, \bar{t}_1 \rightarrow t\tilde{\chi}_1^0$	0-1 e, μ	≥ 1 jet E_T^{miss} 139	\bar{t}_1 1.25	$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130 \text{ GeV}, m(\tilde{\chi}_1^0) = 0 \text{ GeV}$	2103.08189
	$\bar{t}_1\bar{t}_1, \bar{t}_1 \rightarrow Wb\tilde{\chi}_1^0$	1 e, μ	3 jets/1 b E_T^{miss} 139	\bar{t}_1 Forbidden 1.4	$m(\tilde{\chi}_1^0) = 1 \text{ GeV}$	2004.14060, 2012.03799
	$\bar{t}_1\bar{t}_1, \bar{t}_1 \rightarrow \tilde{\tau}b\nu, \tilde{\tau}_1 \rightarrow \tau\tilde{G}$	1-2 τ	2 jets/1 b E_T^{miss} 139	\bar{t}_1 Forbidden 0.65	$m(\tilde{\chi}_1^0) = 500 \text{ GeV}$	2012.03799
	$\bar{t}_1\bar{t}_1, \bar{t}_1 \rightarrow \tilde{\tau}b\nu, \tilde{\tau}_1 \rightarrow \tau\tilde{G}$	0 e, μ	2 jets/1 b E_T^{miss} 139	\bar{t}_1 Forbidden 1.4	$m(\tilde{\tau}_1) = 800 \text{ GeV}$	2108.07665
	$\bar{t}_1\bar{t}_1, \bar{t}_1 \rightarrow c\tilde{\chi}_1^0 / \tilde{c}\tilde{c}, \tilde{c} \rightarrow c\tilde{\chi}_1^0$	0 e, μ	2 c E_T^{miss} 36.1	\tilde{c} 0.85	$m(\tilde{\chi}_1^0) = 0 \text{ GeV}$	1805.01649
	$\bar{t}_1\bar{t}_1, \bar{t}_1 \rightarrow c\tilde{\chi}_1^0 / \tilde{c}\tilde{c}, \tilde{c} \rightarrow c\tilde{\chi}_1^0$	0 e, μ	mono-jet E_T^{miss} 139	\tilde{t}_1 0.55	$m(\tilde{\tau}_1, \tilde{c}) - m(\tilde{\chi}_1^0) = 5 \text{ GeV}$	2102.10874
	$\bar{t}_1\bar{t}_1, \bar{t}_1 \rightarrow t\tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h\tilde{\chi}_1^0$	1-2 e, μ	1-4 b E_T^{miss} 139	\tilde{t}_1 0.067-1.18	$m(\tilde{\chi}_1^0) = 500 \text{ GeV}$	2006.05880
$\bar{t}_2\bar{t}_2, \bar{t}_2 \rightarrow \tilde{t}_1 + Z$	3 e, μ	1 b E_T^{miss} 139	\tilde{t}_2 0.86	$m(\tilde{\chi}_1^0) = 360 \text{ GeV}, m(\tilde{\tau}_1) - m(\tilde{\chi}_1^0) = 40 \text{ GeV}$	2006.05880	
EW direct	$\tilde{\chi}_1^+\tilde{\chi}_2^0$ via WZ	Multiple ℓ /jets	E_T^{miss} 139	$\tilde{\chi}_1^+\tilde{\chi}_2^0$ 0.96	$m(\tilde{\chi}_1^0) = 0, \text{wino-bino}$	2106.01676, 2108.07586
	$\tilde{\chi}_1^+\tilde{\chi}_2^0$ via WW	$ee, \mu\mu$	≥ 1 jet E_T^{miss} 139	$\tilde{\chi}_1^+\tilde{\chi}_2^0$ 0.205	$m(\tilde{\chi}_1^0) - m(\tilde{\chi}_2^0) = 5 \text{ GeV}, \text{wino-bino}$	1911.12606
	$\tilde{\chi}_1^+\tilde{\chi}_1^+$ via WW	2 e, μ	E_T^{miss} 139	$\tilde{\chi}_1^+\tilde{\chi}_1^+$ 0.42	$m(\tilde{\chi}_1^0) = 0, \text{wino-bino}$	1908.08215
	$\tilde{\chi}_1^+\tilde{\chi}_1^0$ via Wh	Multiple ℓ /jets	E_T^{miss} 139	$\tilde{\chi}_1^+\tilde{\chi}_1^0$ Forbidden 1.06	$m(\tilde{\chi}_1^0) = 70 \text{ GeV}, \text{wino-bino}$	2004.10894, 2108.07586
	$\tilde{\chi}_1^+\tilde{\chi}_1^+$ via $\tilde{\ell}_L/\tilde{\nu}$	2 e, μ	E_T^{miss} 139	$\tilde{\chi}_1^+\tilde{\chi}_1^+$ 1.0	$m(\tilde{\ell}, \tilde{\nu}) = 0.5(m(\tilde{\chi}_1^0) + m(\tilde{\chi}_1^0))$	1908.08215
	$\tilde{\tau}\tilde{\tau}, \tilde{\tau} \rightarrow \tau\tilde{\chi}_1^0$	2 τ	E_T^{miss} 139	$\tilde{\tau}$ [L, R, L] 0.16-0.3 0.12-0.39	$m(\tilde{\chi}_1^0) = 0$	1911.06660
	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$	2 e, μ	0 jets E_T^{miss} 139	$\tilde{\ell}$ 0.7	$m(\tilde{\chi}_1^0) = 0$	1908.08215
	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$	$ee, \mu\mu$	≥ 1 jet E_T^{miss} 139	$\tilde{\ell}$ 0.256	$m(\tilde{\tau}) - m(\tilde{\chi}_1^0) = 10 \text{ GeV}$	1911.12606
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$	0 e, μ	≥ 3 b E_T^{miss} 36.1	\tilde{H} 0.13-0.23	$\text{BR}(\tilde{\chi}_1^0 \rightarrow h\tilde{G}) = 1$	1806.04030
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$	4 e, μ	0 jets E_T^{miss} 139	\tilde{H} 0.55	$\text{BR}(\tilde{\chi}_1^0 \rightarrow Z\tilde{G}) = 1$	2103.11684
$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$	0 e, μ	≥ 2 large jets E_T^{miss} 139	\tilde{H} 0.45-0.93	$\text{BR}(\tilde{\chi}_1^0 \rightarrow Z\tilde{G}) = 1$	2108.07586	
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^+$ prod., long-lived $\tilde{\chi}_1^+$	Disapp. trk	1 jet E_T^{miss} 139	$\tilde{\chi}_1^+$ 0.66	Pure Wino	2201.02472
	Stable \tilde{g} R-hadron	pixel dE/dx	E_T^{miss} 139	\tilde{g} 2.05	Pure higgsino	2201.02472
	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$	pixel dE/dx	E_T^{miss} 139	\tilde{g} [$\tau(\tilde{g}) = 10 \text{ ns}$] 2.2	$m(\tilde{\chi}_1^0) = 100 \text{ GeV}$	CERN-EP-2022-029
	$\tilde{\ell}, \tilde{\ell} \rightarrow \ell\tilde{G}$	Displ. lep	E_T^{miss} 139	$\tilde{\ell}$ 0.7	$\tau(\tilde{\ell}) = 0.1 \text{ ns}$	2011.07812
RPV	$\tilde{\chi}_1^+\tilde{\chi}_1^+/\tilde{\chi}_1^0, \tilde{\chi}_1^+ \rightarrow Z\ell\ell$	3 e, μ	139	$\tilde{\chi}_1^+\tilde{\chi}_1^+/\tilde{\chi}_1^0$ [BR(Z τ)=1, BR(Z e)=1] 0.625 1.05	Pure Wino	2011.10543
	$\tilde{\chi}_1^+\tilde{\chi}_1^+/\tilde{\chi}_1^0 \rightarrow WWZ\ell\ell\nu\nu$	4 e, μ	0 jets E_T^{miss} 139	$\tilde{\chi}_1^+\tilde{\chi}_1^+/\tilde{\chi}_1^0$ [$\lambda_{111} \neq 0, \lambda_{121} \neq 0$] 0.95 1.55	$m(\tilde{\chi}_1^0) = 200 \text{ GeV}$	2103.11684
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow q\bar{q}q$	4-5 large jets	36.1	\tilde{g} [$m(\tilde{\chi}_1^0) = 200 \text{ GeV}, 1100 \text{ GeV}$] 1.3 1.9	Large \mathcal{A}'_{112}	1804.03568
	$\tilde{u}, \tilde{t} \rightarrow t\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow t\bar{b}s$	Multiple	36.1	\tilde{t} [$\lambda'_{211} = 2e-4, 1e-2$] 0.55 1.05	$m(\tilde{\chi}_1^0) = 200 \text{ GeV}, \text{bino-like}$	ATLAS-CONF-2018-003
	$\tilde{u}, \tilde{t} \rightarrow b\tilde{\chi}_1^+, \tilde{\chi}_1^+ \rightarrow b\bar{b}s$	$\geq 4b$	139	\tilde{t} Forbidden 0.95	$m(\tilde{\chi}_1^0) = 500 \text{ GeV}$	2010.01015
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\bar{s}$	2 jets + 2 b	36.1	\tilde{t}_1 [qq, bs] 0.42 0.61	1710.07171	1710.07171
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow q\ell$	2 e, μ	2 b 36.1	\tilde{t}_1 1.0	$\text{BR}(\tilde{t}_1 \rightarrow b\ell/\bar{b}\mu) > 20\%$	1710.05544
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow q\ell$	1 μ	DV 136	\tilde{t}_1 [1e-10 < $\lambda'_{231} < 1e-8, 3e-10 < \lambda'_{231} < 3e-9$] 0.4-1.45	$\text{BR}(\tilde{t}_1 \rightarrow q\mu) = 100\%, \cos\theta = 1$	2003.11956
	$\tilde{\chi}_1^+\tilde{\chi}_2^0/\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow t\bar{b}s, \tilde{\chi}_1^+ \rightarrow b\bar{b}s$	1-2 e, μ	≥ 6 jets 139	$\tilde{\chi}_1^0$ 0.2-0.32	Pure higgsino	2106.09609

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

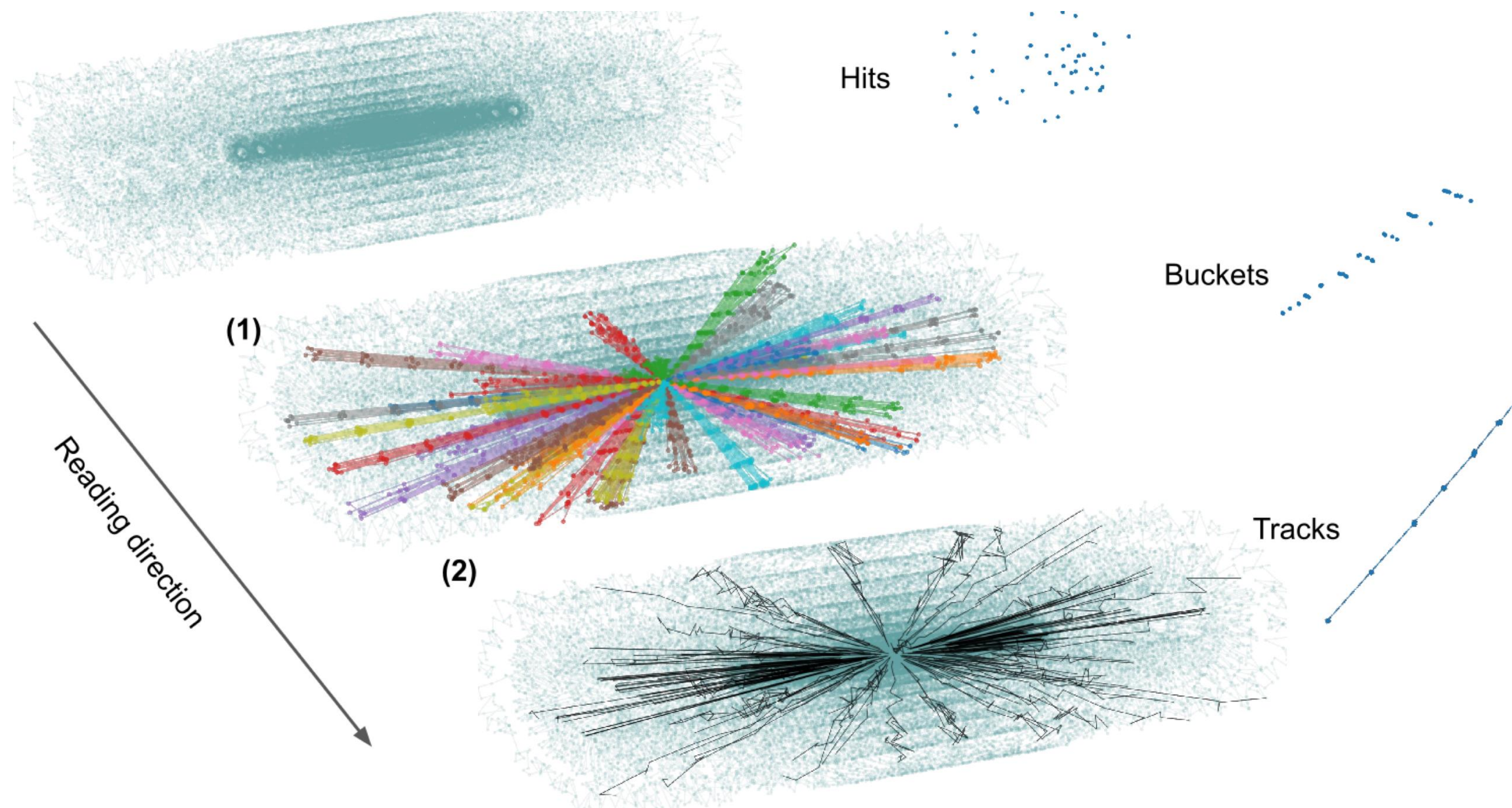


Labelling: Music & eighbours



Trajectories from simulated particles in the ATLAS upgrade tracker, **found** with (the help of) **Spotify**

Labelling: Music & neighbours



Labelling: Music & eighbours

Perfect hash function would solve the tracking problem

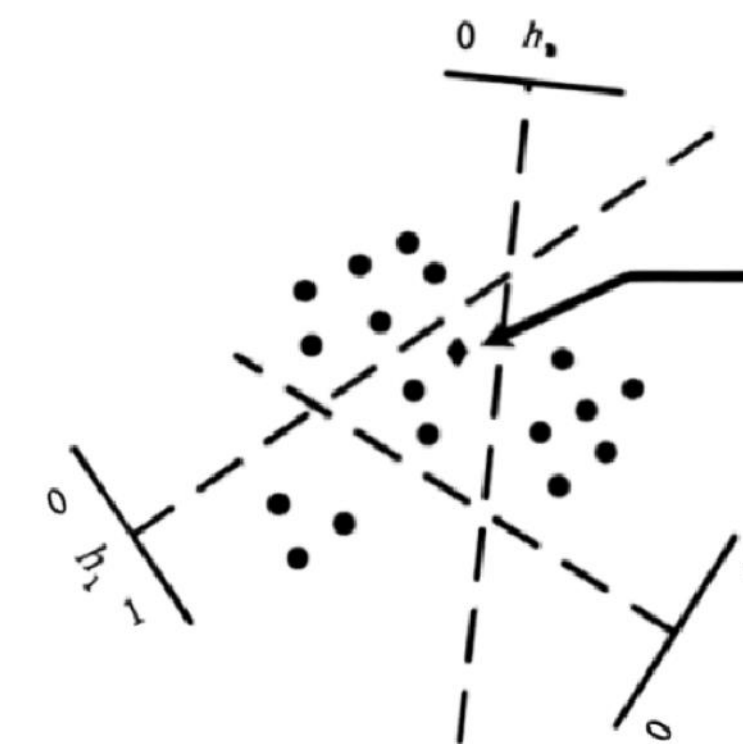
$$h(\text{hit}) = \text{track number}$$

Approximate hashing, however, can be done

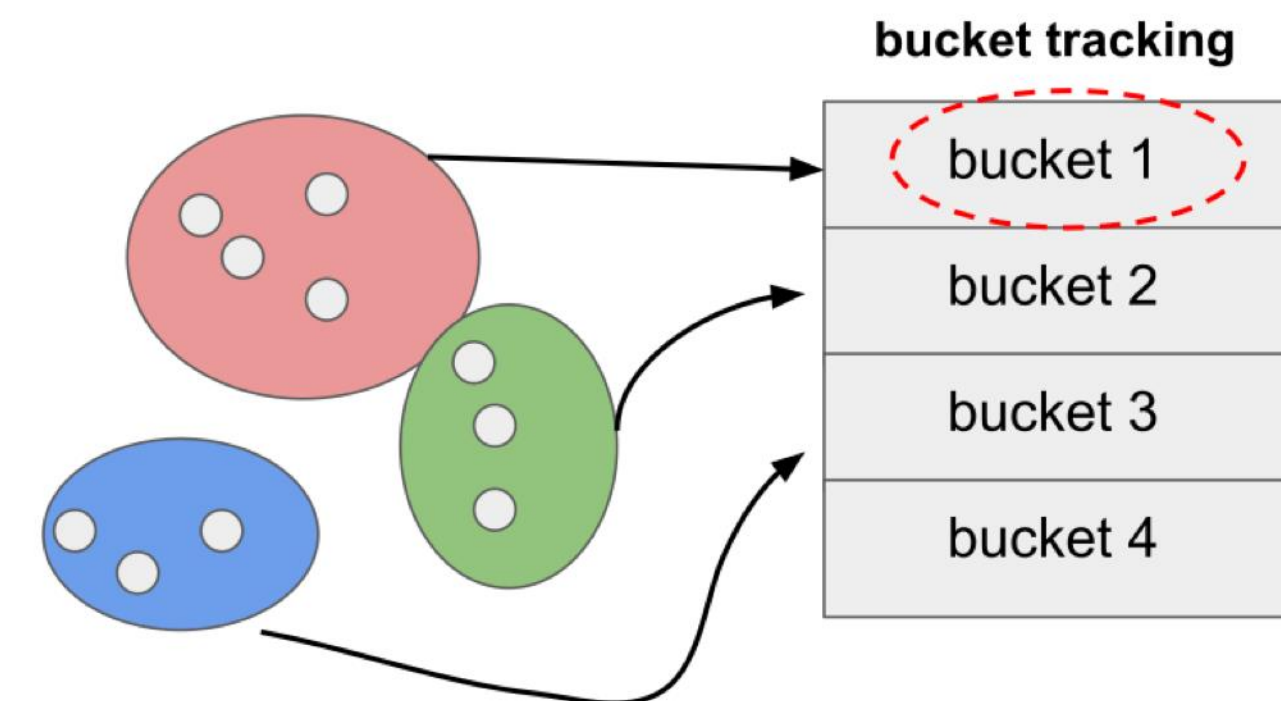
$$h(\text{track 1, hit 0}) = \text{group x}$$

$$h(\text{track 1, hit 1}) = \text{group x}$$

$$h(\text{track 0, hit 1}) = \text{group x}$$

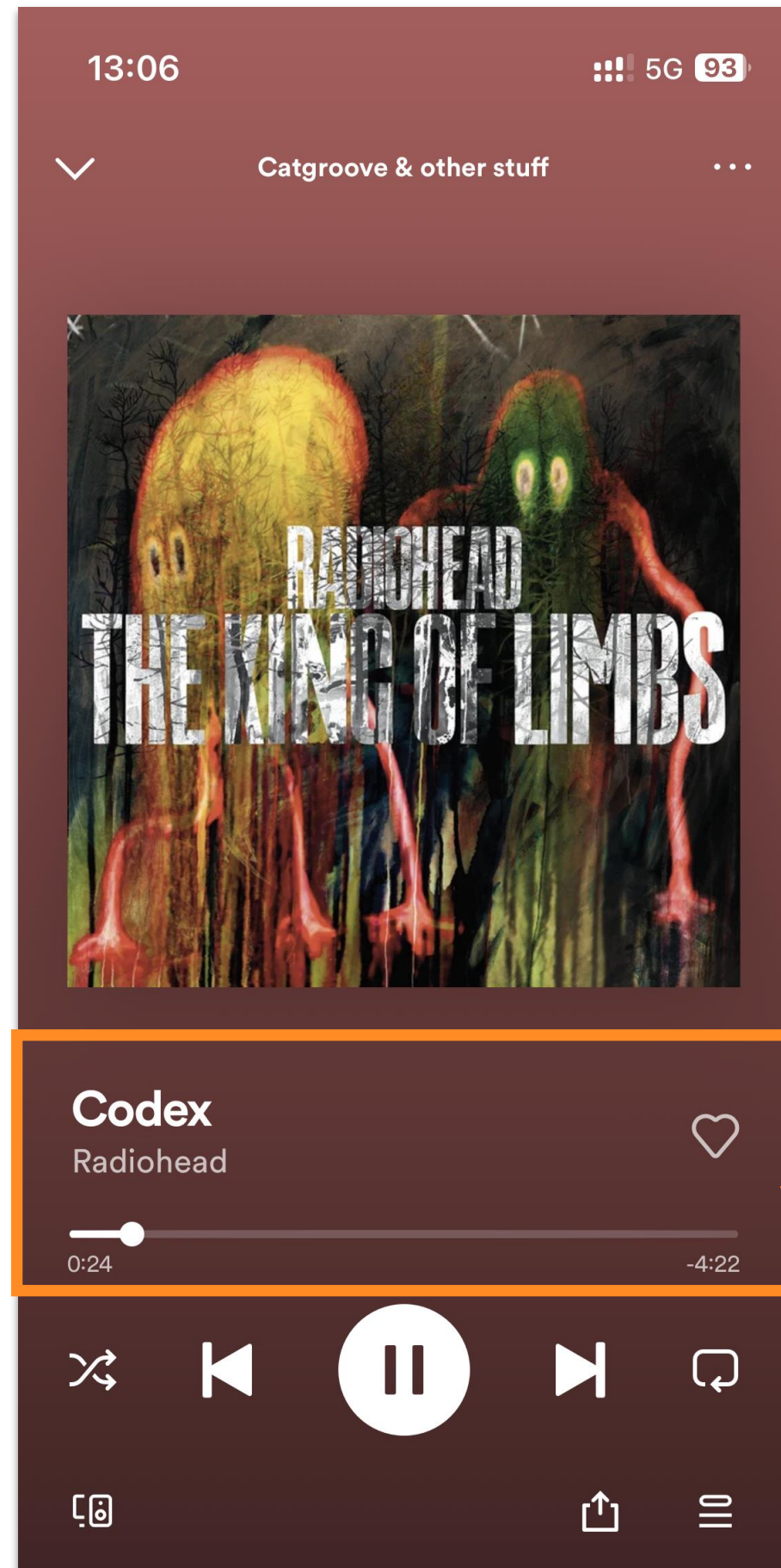


RANDOM PROJECTIONS

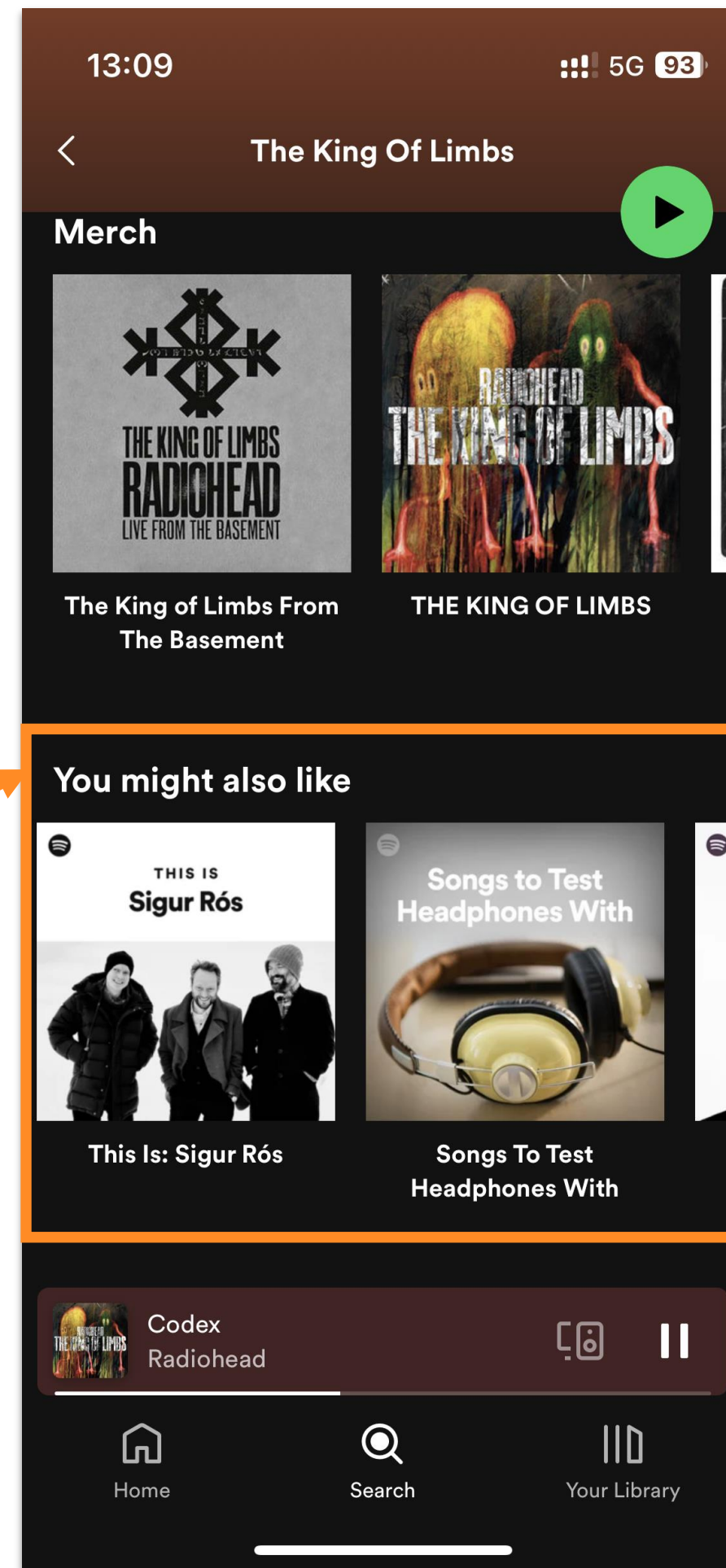


APPROXIMATE NEAREST NEIGHBOURS

Labelling: Music & eighbours



Spotify's approximate nearest neighbourhood library: [\[ANNOY\]](#)



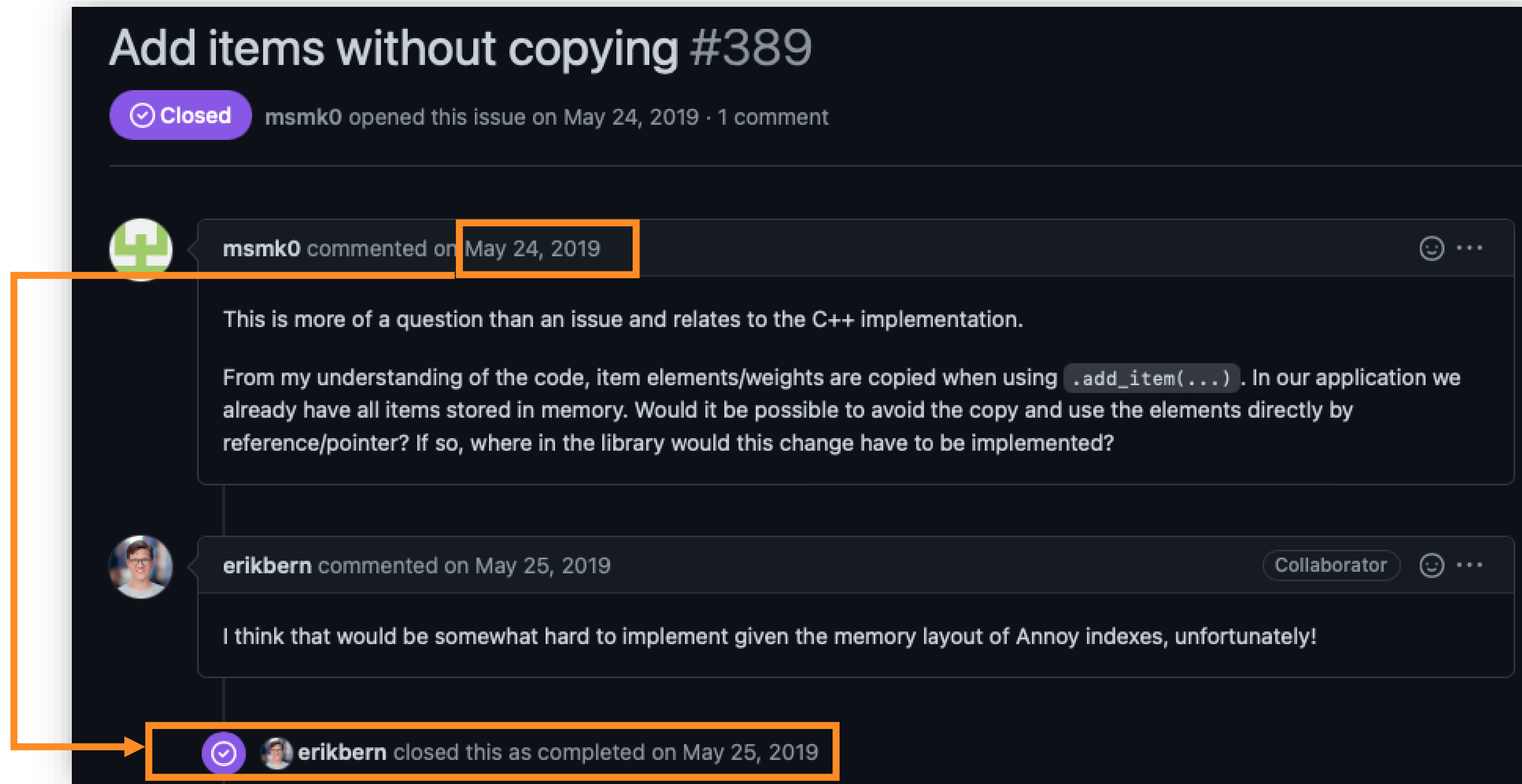
Industry/open source libraries offer quite some potential also for science applications



To find a bucket with at least 4/hits of the track contained (good enough for track seeding)

Labelling: Music & eighbours

Industry/open source libraries offer quite some potential also for science applications, **but ...**



Add items without copying #389
Closed msmk0 opened this issue on May 24, 2019 · 1 comment

msmk0 commented on May 24, 2019

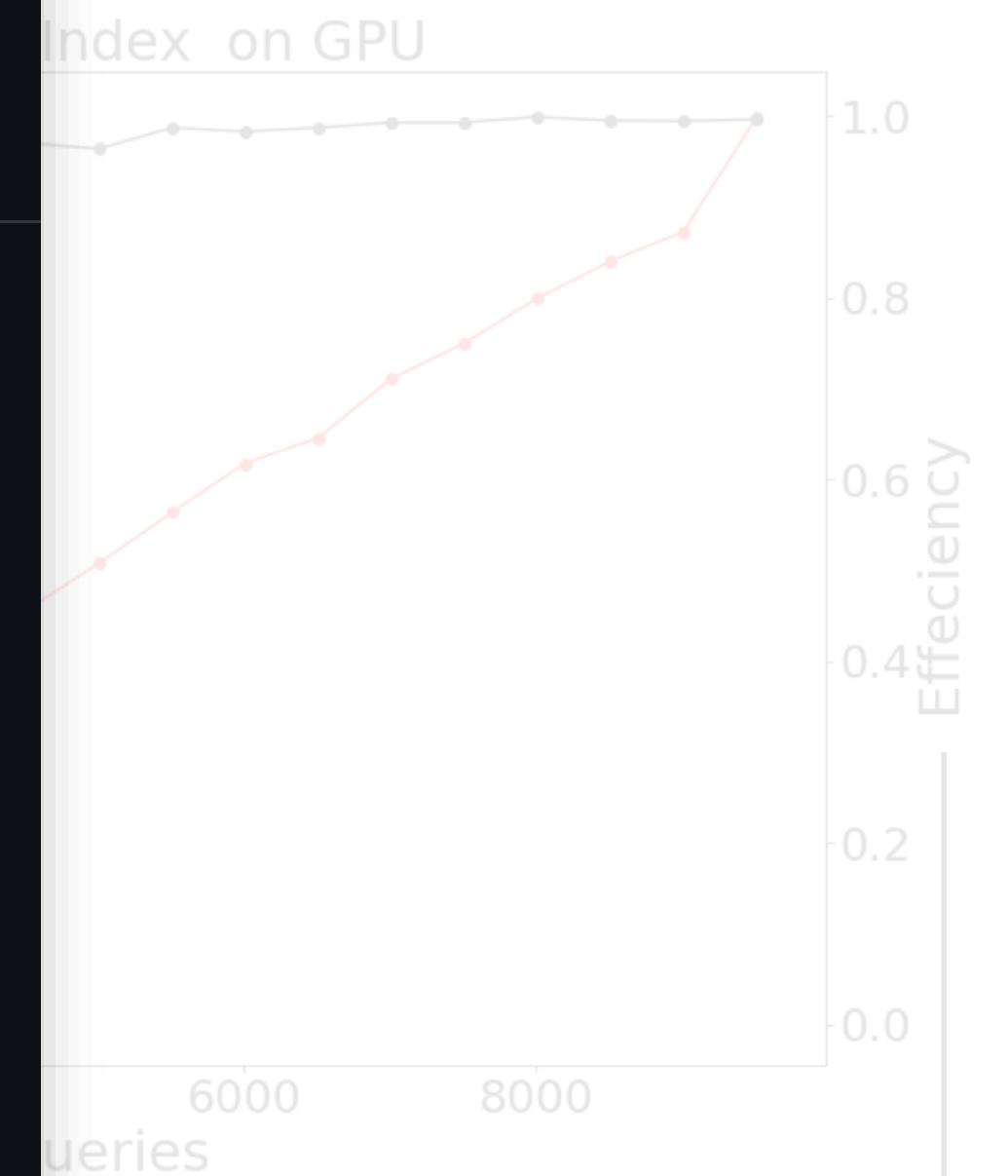
This is more of a question than an issue and relates to the C++ implementation.

From my understanding of the code, item elements/weights are copied when using `.add_item(...)`. In our application we already have all items stored in memory. Would it be possible to avoid the copy and use the elements directly by reference/pointer? If so, where in the library would this change have to be implemented?

erikbern commented on May 25, 2019 Collaborator

I think that would be somewhat hard to implement given the memory layout of Annoy indexes, unfortunately!

erikbern closed this as completed on May 25, 2019



.. no business model!

(In other words)

To find a bucket with at least 4/hits of the track contained (good enough for track seeding)