

Breaking Baryons

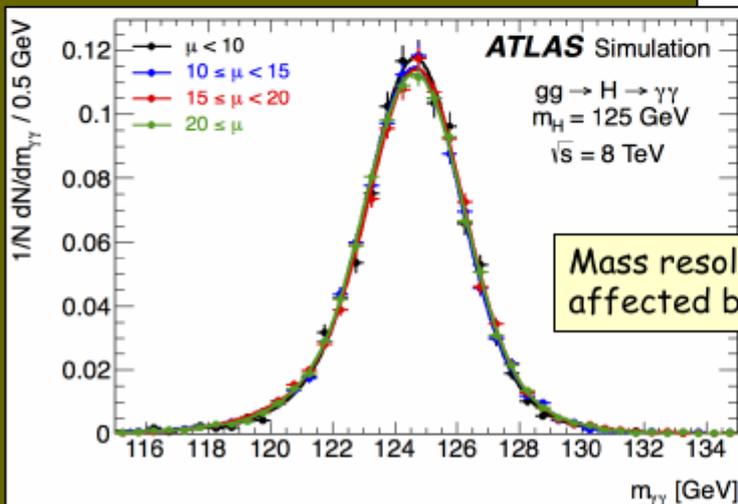
On the Awesomeness of
Particle Accelerators and Colliders

Mass resolution

$$m_{\gamma\gamma}^2 = 2(E_1 E_2 (1 - \cos\alpha))$$

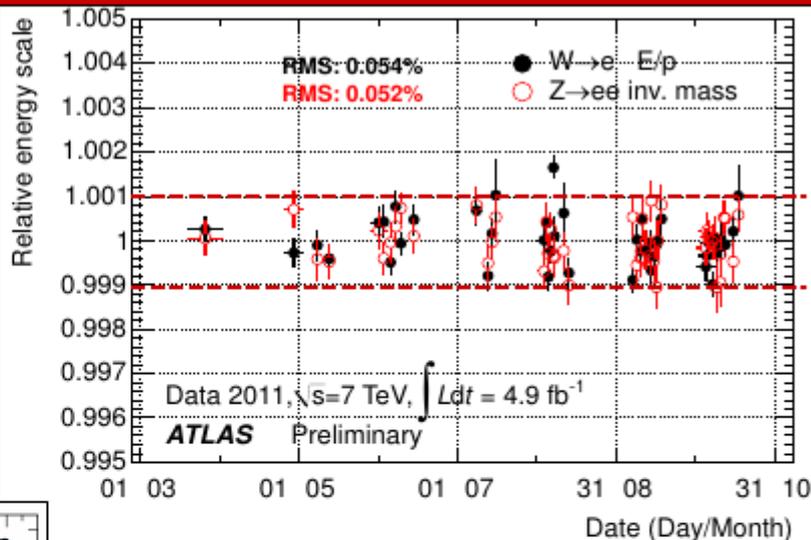
Present understanding of calorimeter E response (from Z, J/ψ → ee, W → ev data and MC):

- E-scale at m_Z known to ~ 0.3%
- Linearity better than 1% (few-100 GeV)
- "Uniformity" (constant term of resolution): ~ 1% (2.5% for $1.37 < |\eta| < 1.8$)



Mass resolution not affected by pile-up

Stability of EM calorimeter response vs time (and pile-up) during full 2011 run better than 0.1%



Electron scale transported to photons using MC (small systematics from material effects)

Mass resolution of inclusive sample: 1.6 GeV
Fraction of events in $\pm 2\sigma$: ~90%

BREAKING BARYONS

On the Awesomeness of Particle Accelerators and Colliders

- Title inspired by Carlos Garcia Prado's "How I Met Your Pointer" at 29C3
--> tinyurl.com/howimetyourpointer
- Goes well with "Desperately Seeking Susy" by atdotde:
Tomorrow (Day 2), 20:30h, Saal 6

ACCELERATORS AND COLLIDERS

What are we doing?

Why are we doing it?

What stuff do we use?

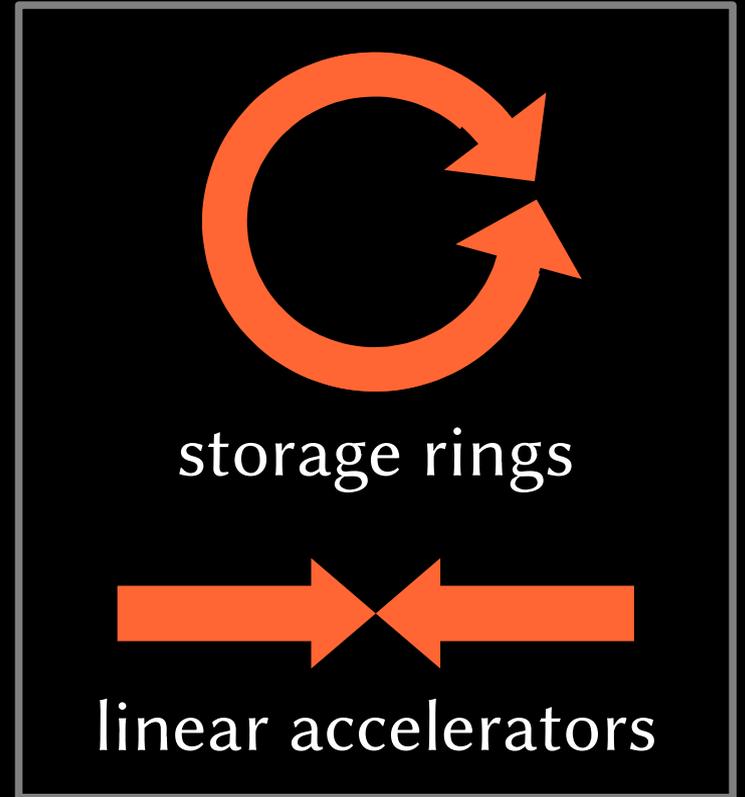
ACCELERATORS AND COLLIDERS

What are we doing?

--> give high energies to particles
by making them 'fast' (accelerating)

--> make them collide

--> see what happens



ACCELERATORS AND COLLIDERS

Why are we doing it?

$$E = m \cdot c^2$$

ACCELERATORS AND COLLIDERS

Why are we doing it?

parts = device

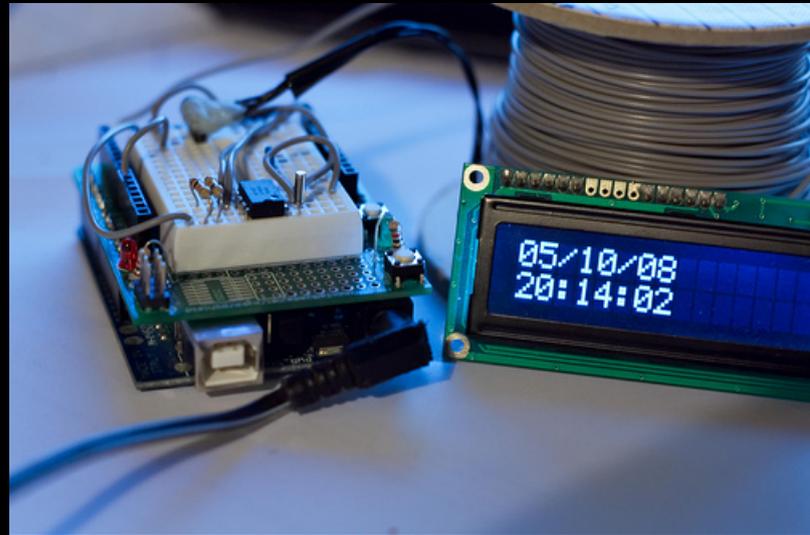
ACCELERATORS AND COLLIDERS

Why are we doing it?

parts = device



=



30C3: BREAKING BARYONS (BY EMTIU)

ACCELERATORS AND COLLIDERS

Why are we doing it?



IMAGE: CC BY-NC 2.0, flickr.com/laughingsquid

30C3: BREAKING BARYONS (BY EMTIU)

ACCELERATORS AND COLLIDERS

Why are we doing it?



IMAGE: CC BY-SA 2.0, flickr.com/viriyincy

IMAGE: CC BY-NC 2.0, flickr.com/laughingsquid

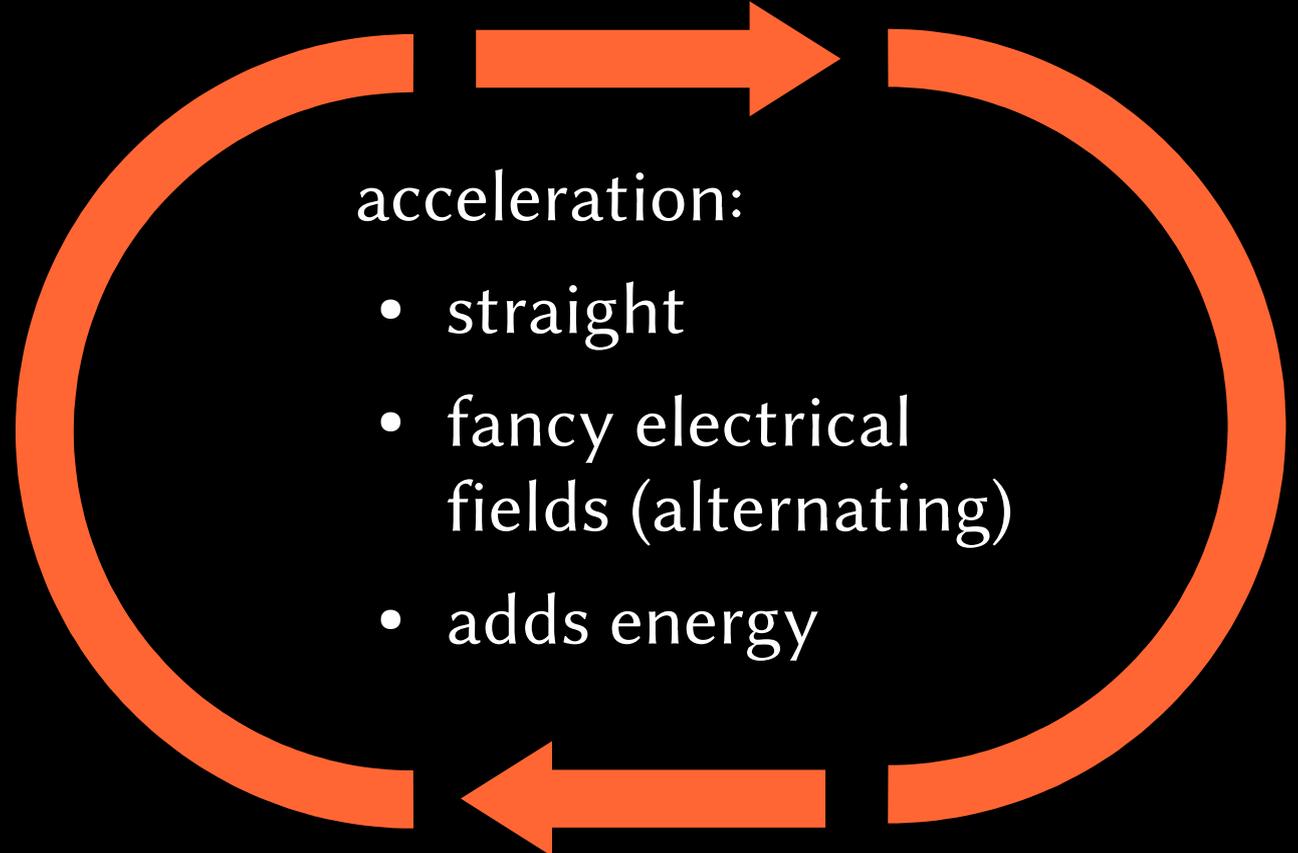
30C3: BREAKING BARYONS (BY EMTIU)

ACCELERATORS AND COLLIDERS

What stuff do we use?

We use **storage rings**
to **produce collisions**
which are analyzed by
enormous experiments

STORAGE RING



curve:

- curved
- strong magnetic fields (constant)
- adds no energy

acceleration:

- straight
- fancy electrical fields (alternating)
- adds energy

STORAGE RING: ACCELERATION

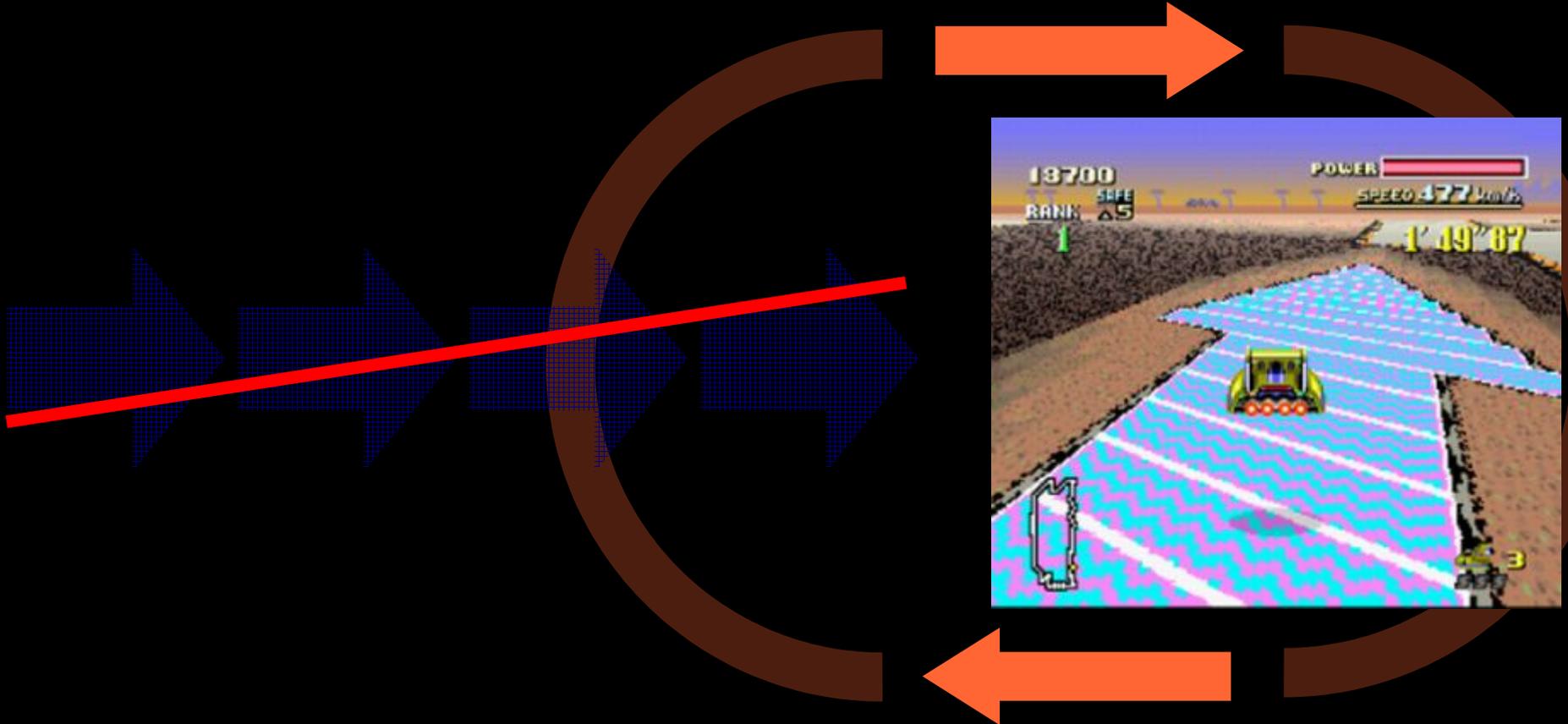


IMAGE: NINTENDO EAD/F-ZERO

30C3: BREAKING BARYONS (BY EMTIU)

STORAGE RING: ACCELERATION



30C3: BREAKING BARYONS (BY EMTIU)

STORAGE RING: ACCELERATION

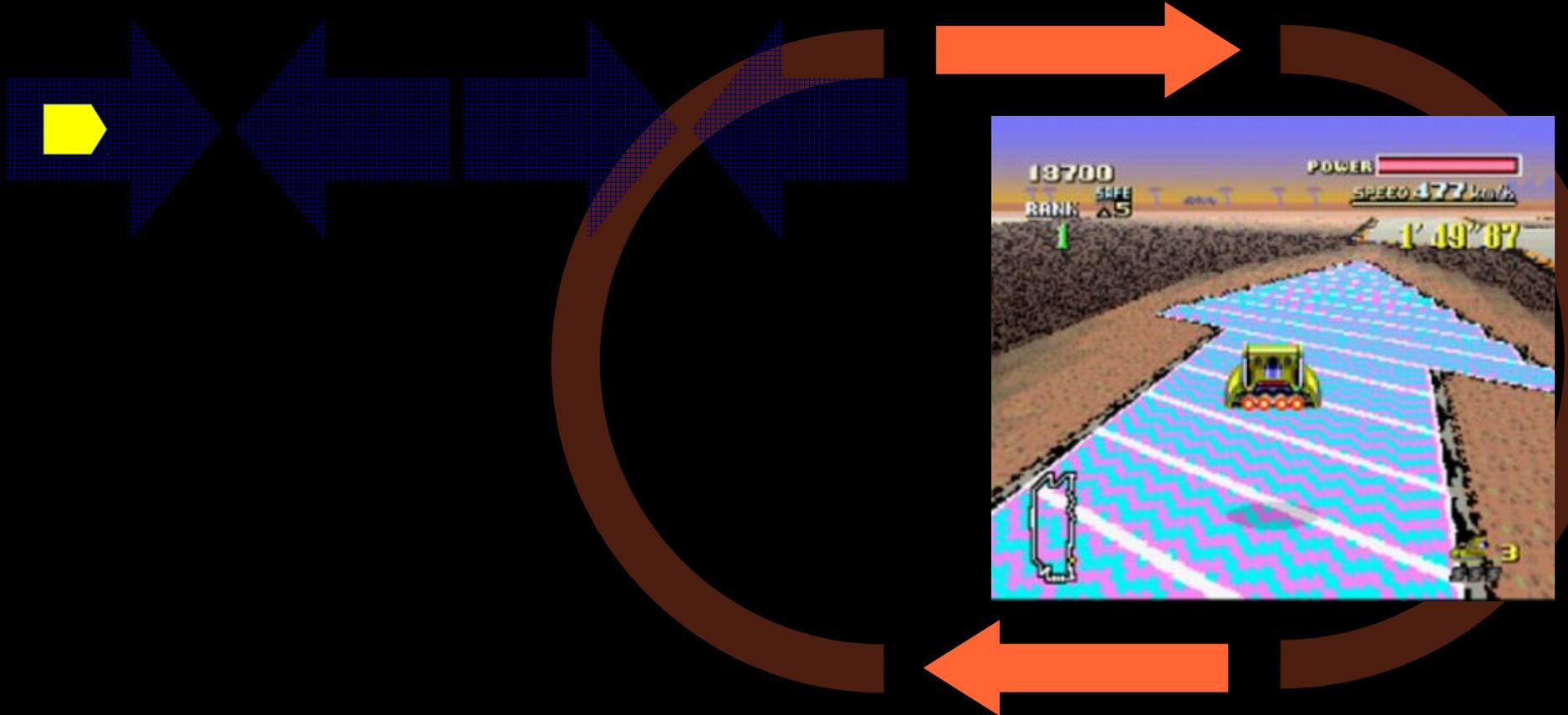


IMAGE: NINTENDO EAD/F-ZERO

30C3: BREAKING BARYONS (BY EMTIU)

STORAGE RING: ACCELERATION

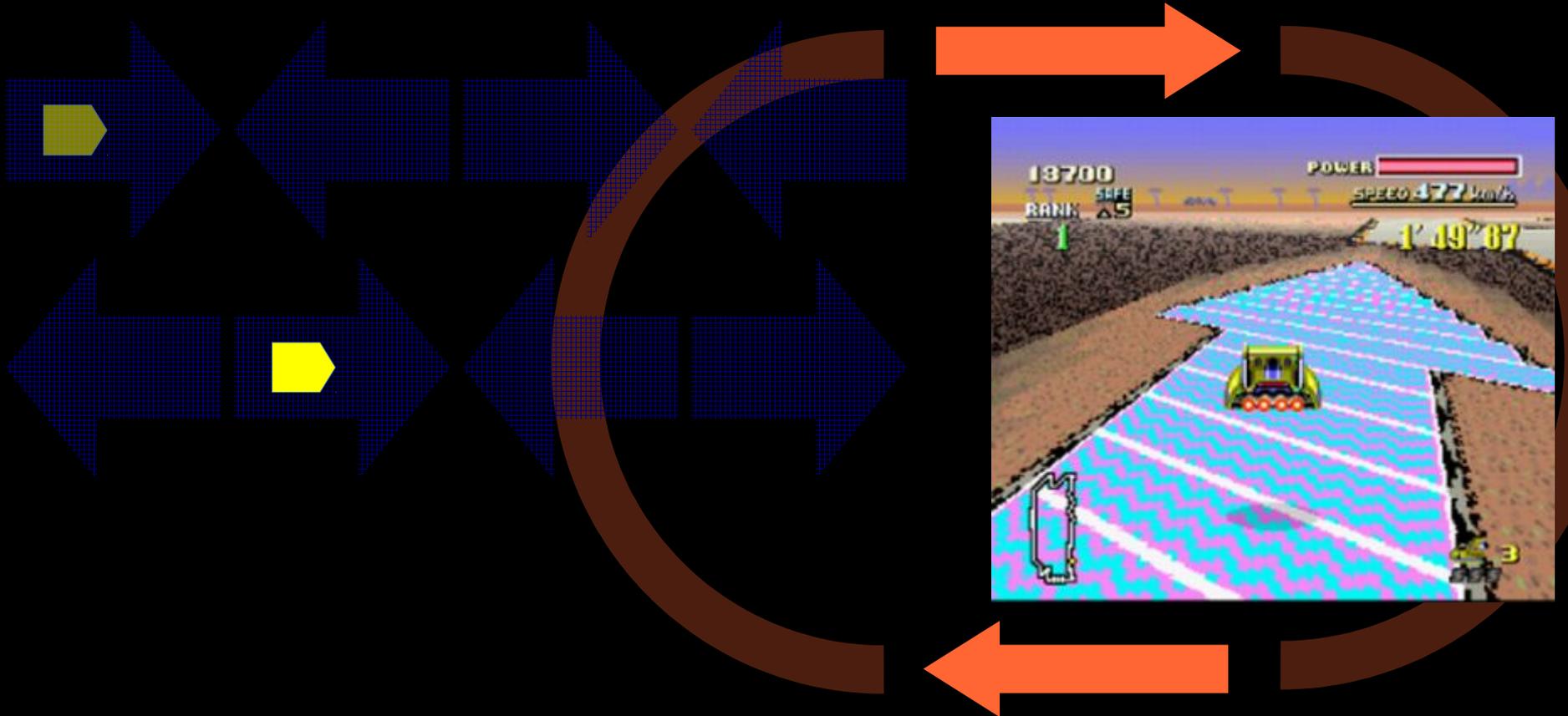


IMAGE: NINTENDO EAD/F-ZERO

30C3: BREAKING BARYONS (BY EMTIU)

STORAGE RING: ACCELERATION

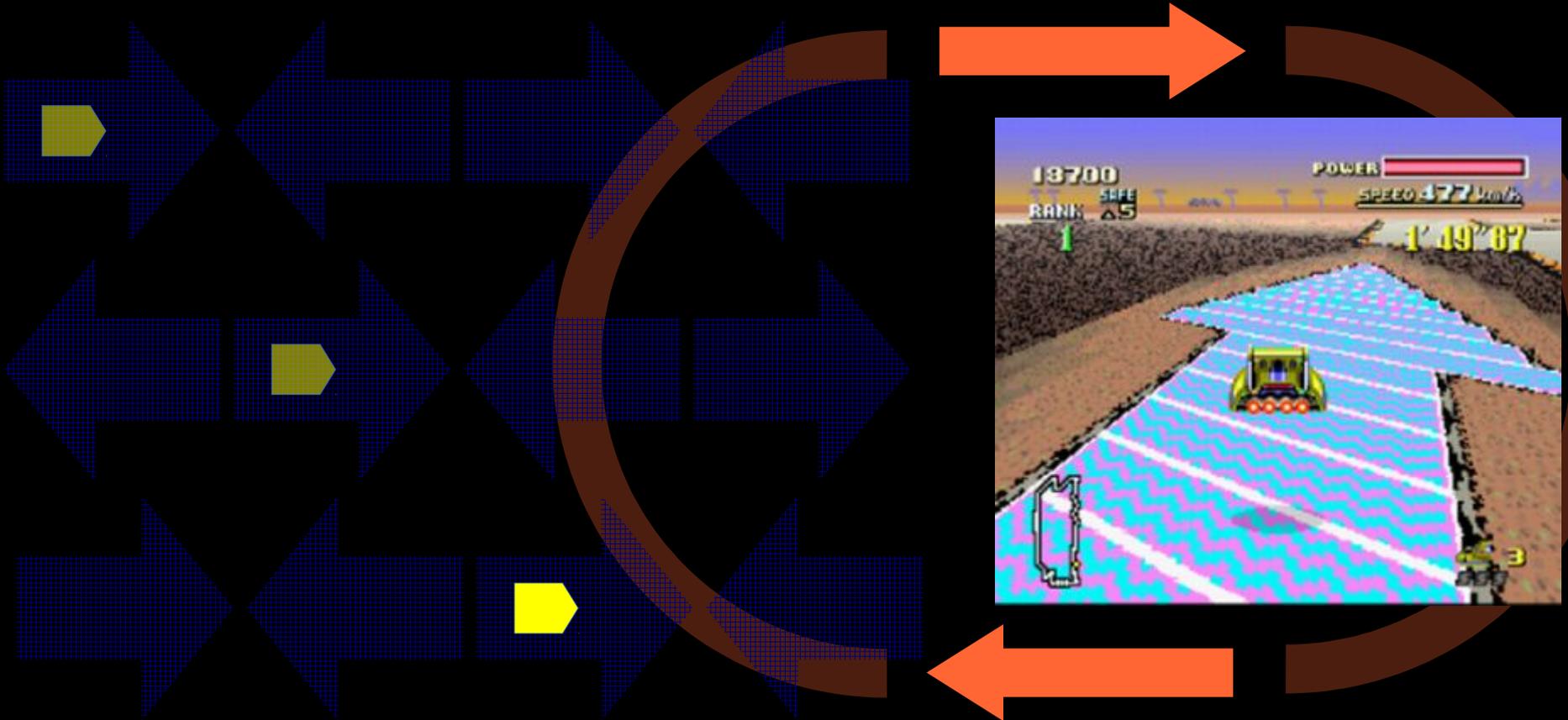


IMAGE: NINTENDO EAD/F-ZERO

30C3: BREAKING BARYONS (BY EMTIU)

STORAGE RING: ACCELERATION

radiofrequency cavity

- several hundred kg
- niobium alloy
(ductile,
superconductive,
not too expensive)
- cooled to ~ 4 K for
superconductivity

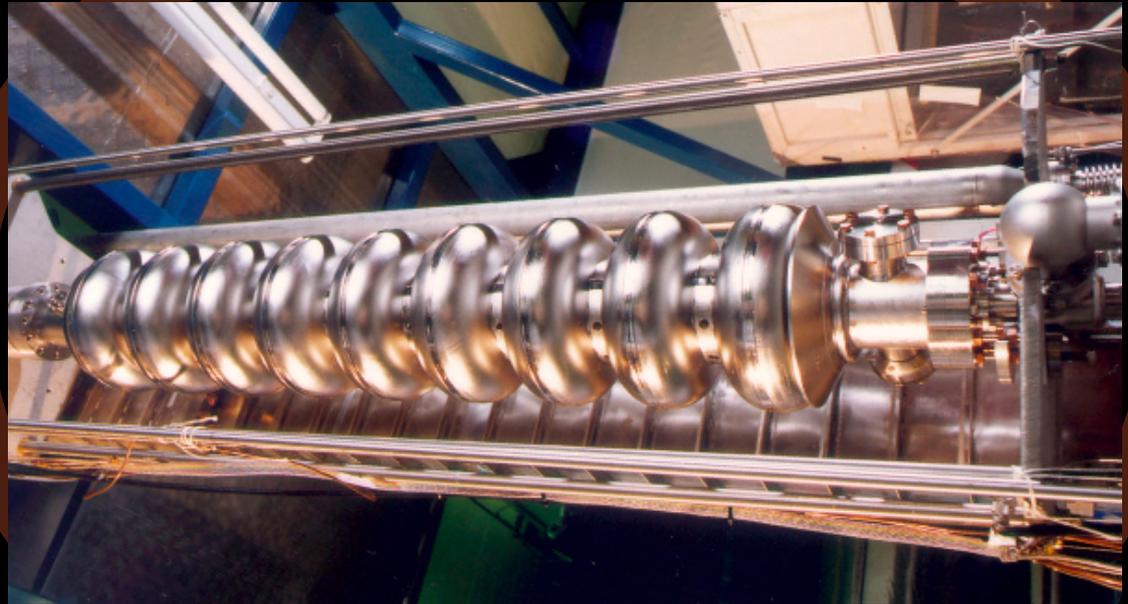


IMAGE: DESY

30C3: BREAKING BARYONS (BY EMTIU)

STORAGE RING: ACCELERATION

klystron

- ~100 MHz radio –
~2 GHz microwave
- uses waveguides,
not cables
- LHC: 16 klystrons of
300 kW/400 MHz



IMAGE: ANL/US DOE

30C3: BREAKING BARYONS (BY EMTIU)

STORAGE RING: CURVES

LHC: 1,232 cryodipoles

- 14 meters, 35 tons, 500,000 CHF each
- ~12,000 A current, ~8.5 T magnetic field
- 600 t niobium wire (25 % world / 5 yr)
- stored energy: 11 GJ (15,000 t @ 150 km/h)



30C3: BREAKING BARYONS (BY EMTIU)

STORAGE RING: ~~CURVES~~ OUCH (2008)

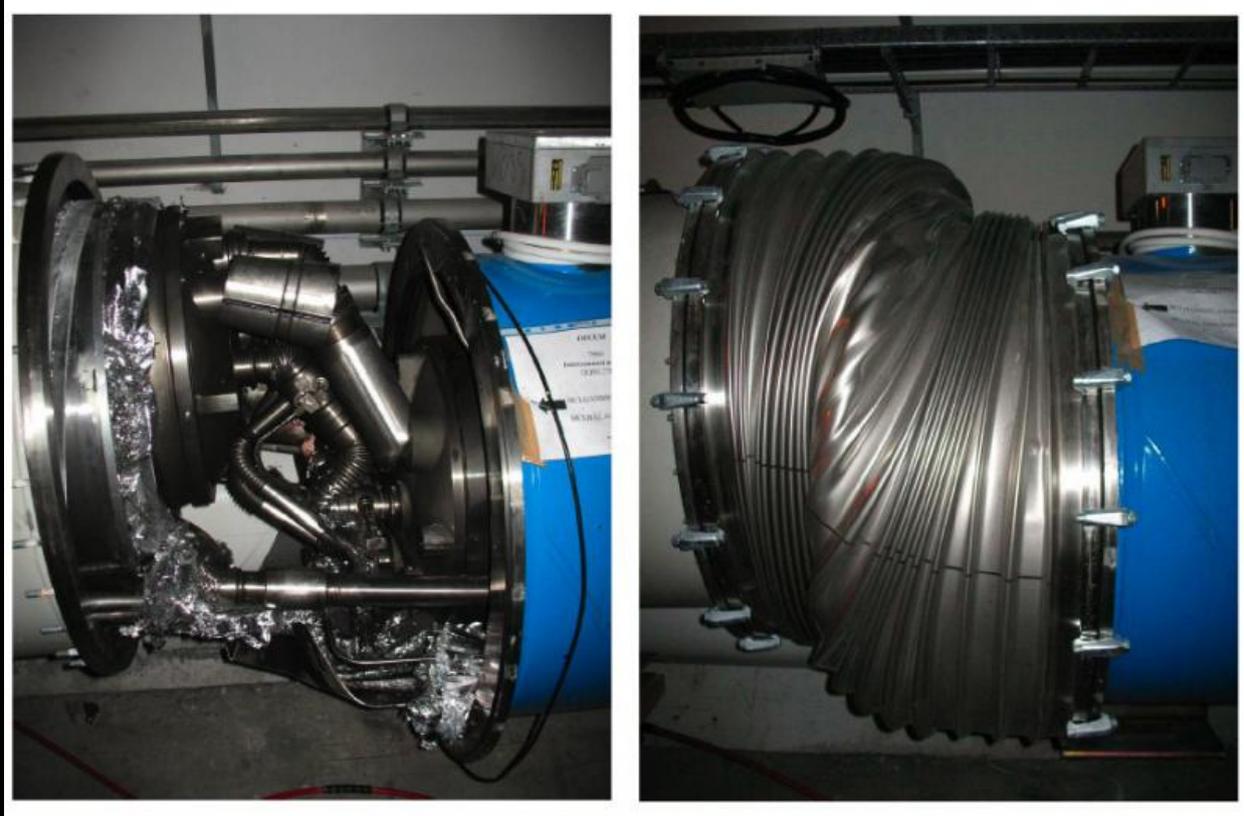
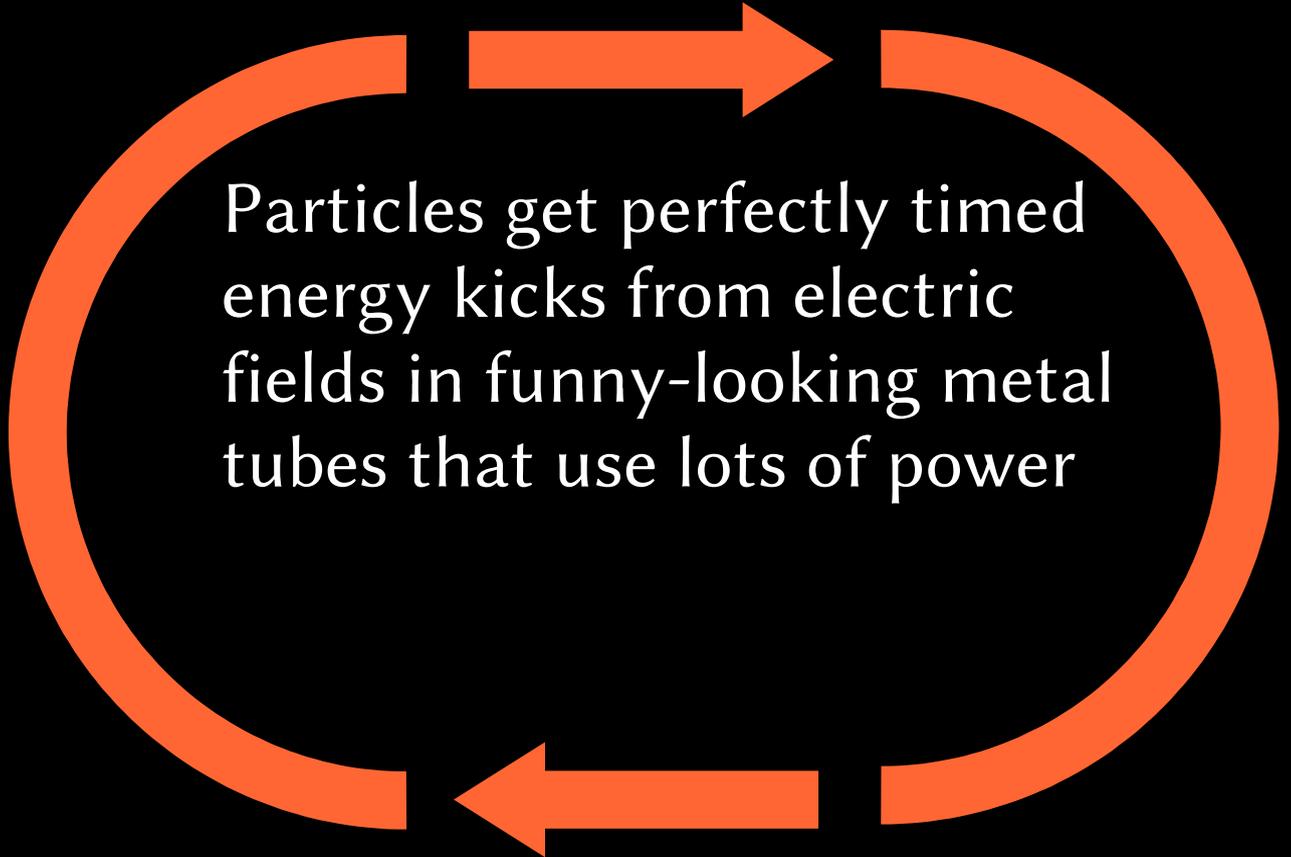


IMAGE: CERN

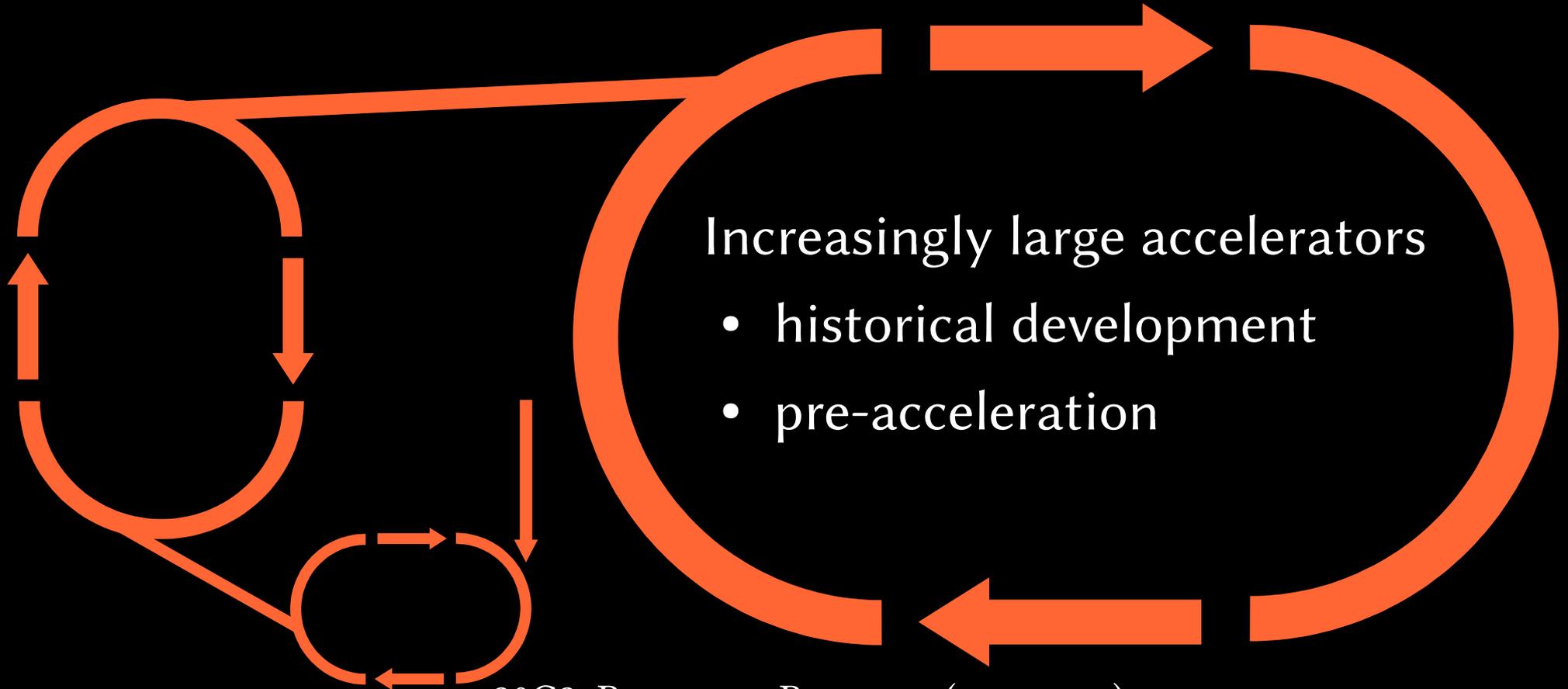
30C3: BREAKING BARYONS (BY EMTIU)

STORAGE RING: SUMMARY

Huge-ass
superconducting
magnets keep the
particles in a circle
so they get a kick
tens of thousands
of times per second



STORAGE RING: MACHINE LAYOUT



30C3: BREAKING BARYONS (BY EMTIU)

STORAGE RING: MACHINE LAYOUT

IMAGE: CERN

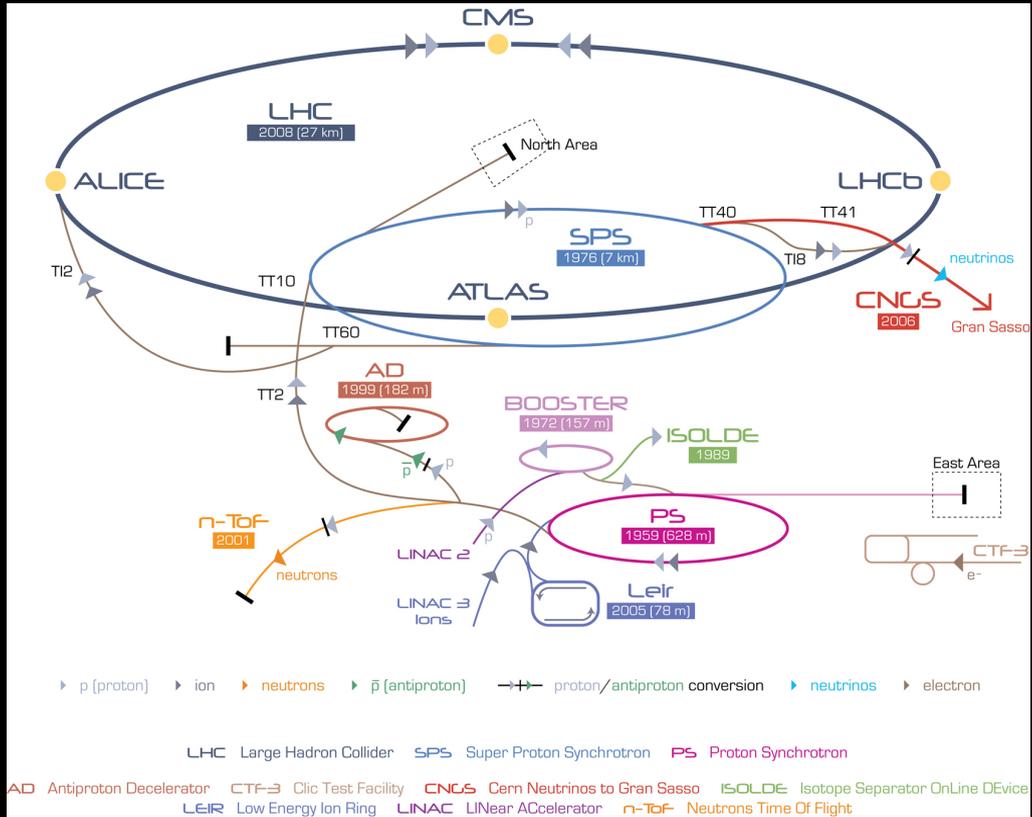
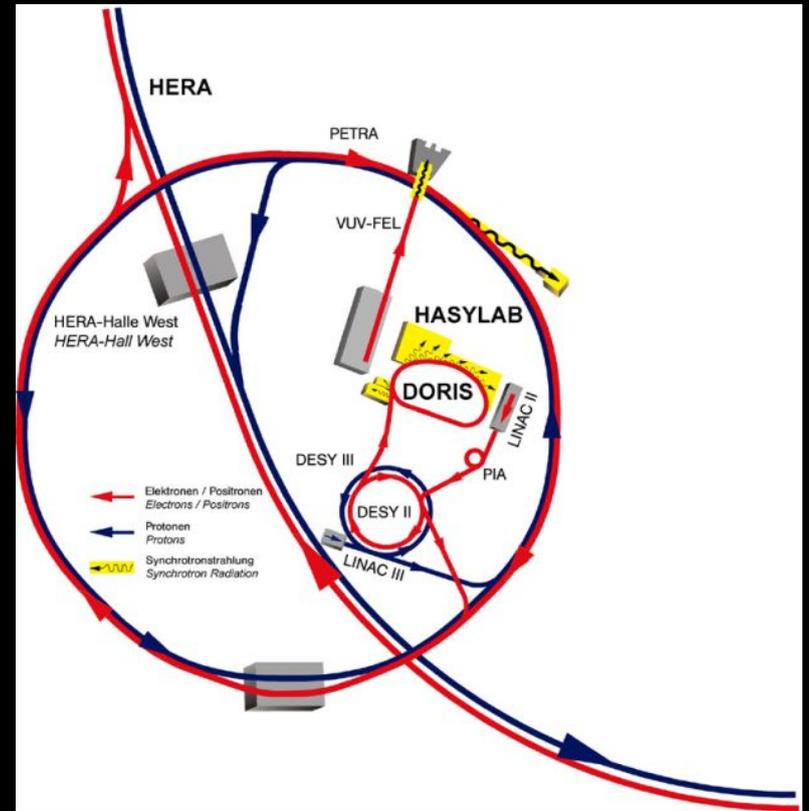


IMAGE: DESY



COLLISIONS

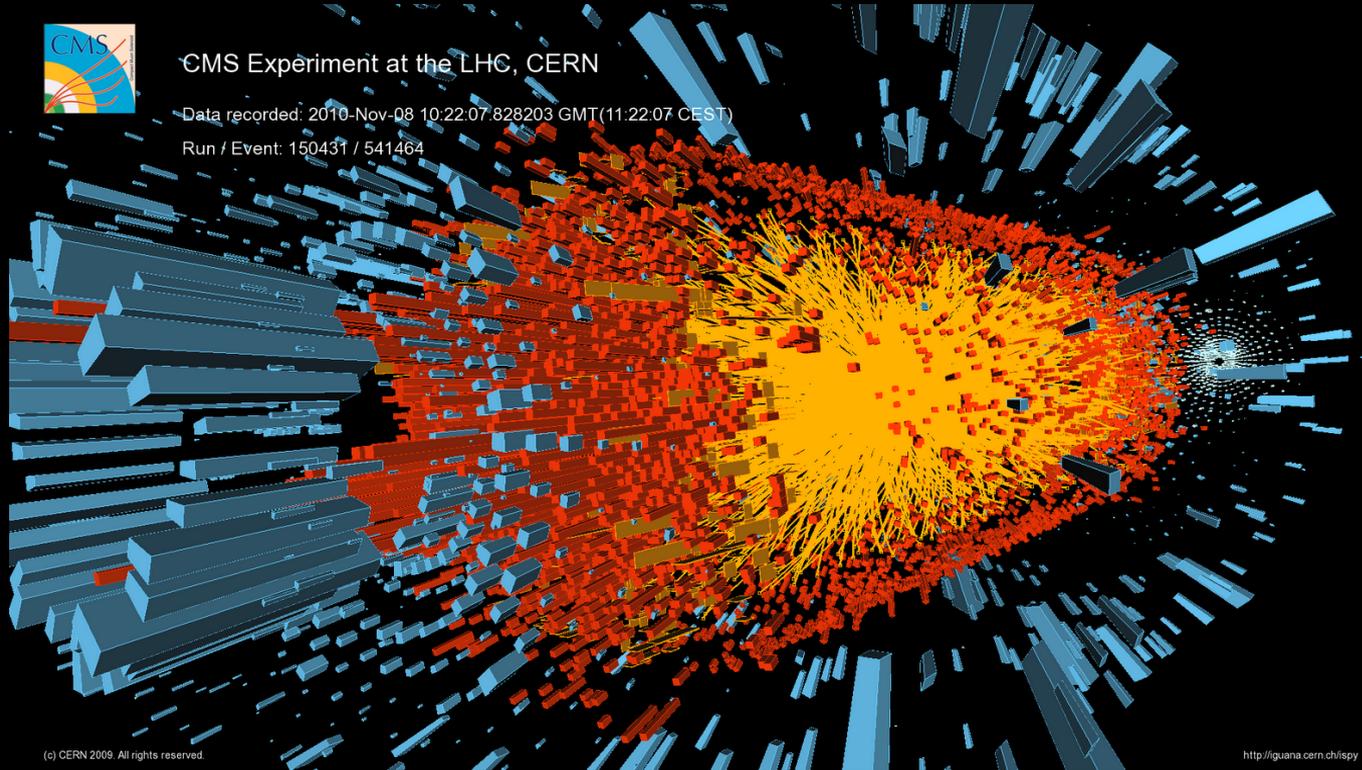
1. They are very hard to produce
2. We produce an enormous number of them



CMS Experiment at the LHC, CERN

Data recorded: 2010-Nov-08 10:22:07.828203 GMT(11:22:07 CEST)

Run / Event: 150431 / 541464



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<http://guana.cern.ch/ispy>

IMAGE: CMS Experiment/CERN

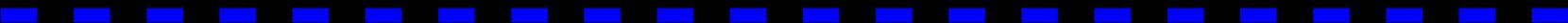
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COLLISIONS: BEAM SHAPE

1. continuous stream: nope



2. packets of single particles: nope

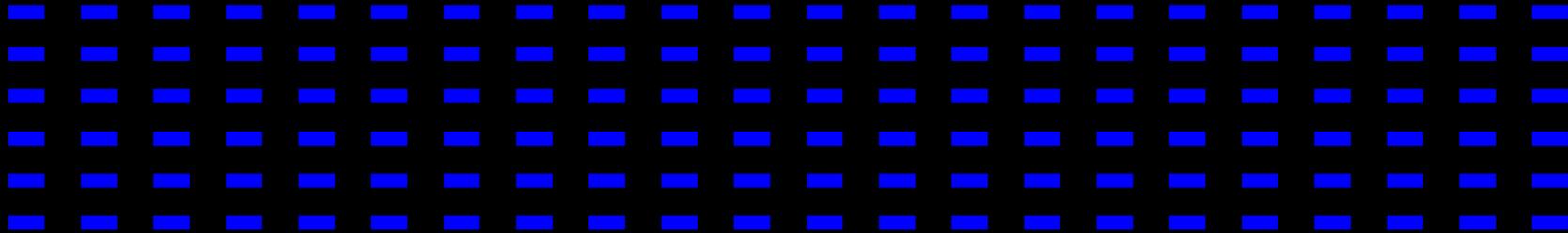


Why? Because:

1. High-frequency acceleration makes bunches
2. Making one-proton-wide beams intersect is unfeasible

COLLISIONS: BEAM SHAPE

packets of enormous bunches



LHC:

100,000,000,000 (10^{11}) protons per bunch

COLLISIONS: BUNCHES

If you stand next to the LHC:

- A bunch flies by every 25 nanoseconds.
- There's about 7,50 meters of space between two bunches.
- You are passed by 2,808 different bunches. Per direction.
- In each direction, you could measure a current of 0.6 mA.

COLLISIONS: INTERACTION

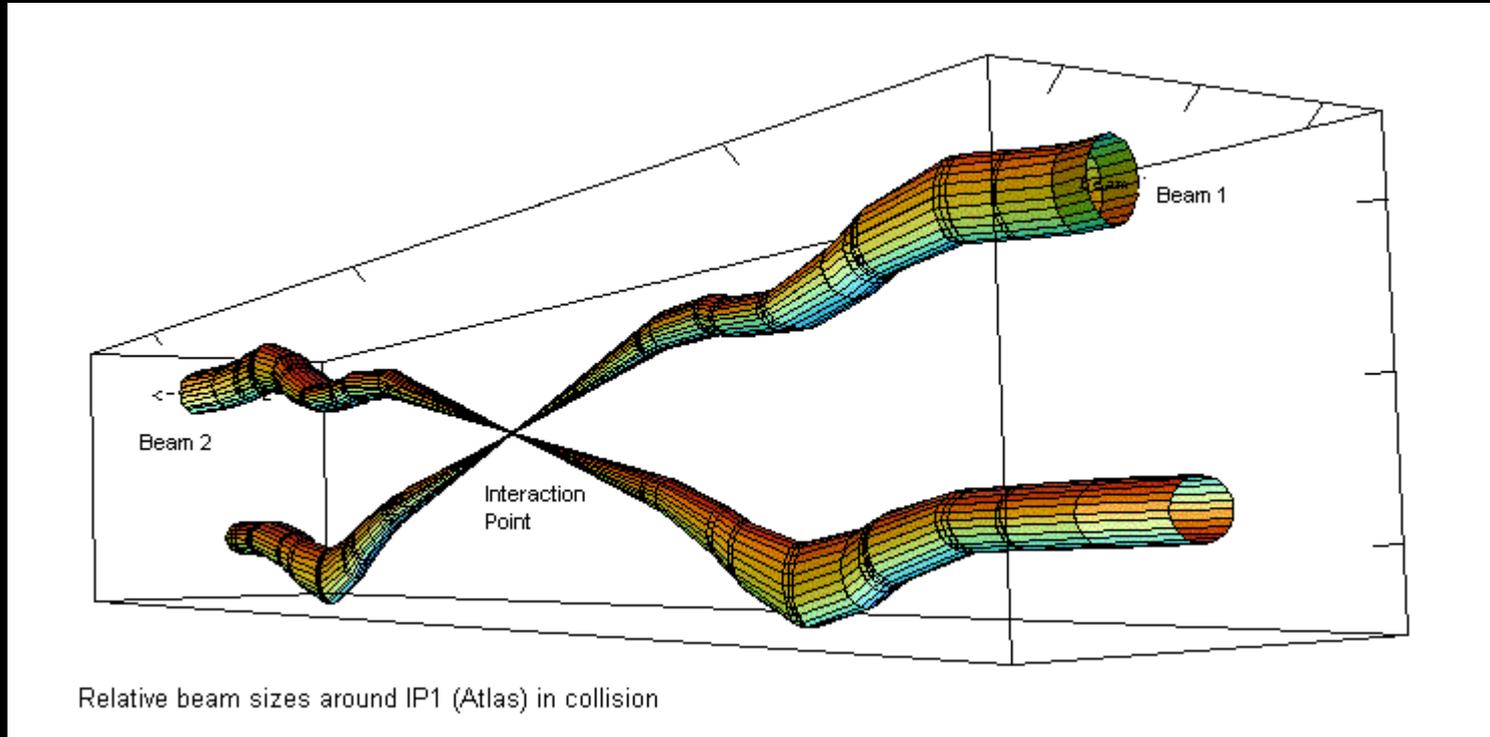


IMAGE: CERN

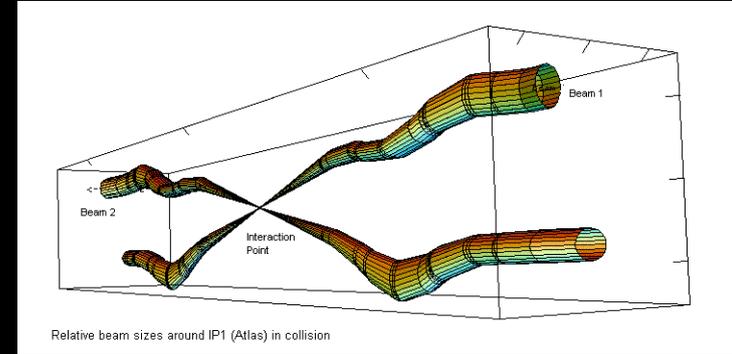
30C3: BREAKING BARYONS (BY EMTIU)

COLLISIONS: INTERACTION

A packet of 100 billion protons
collides head-on with
a packet of 100 billion protons
squeezed into

the cross sectional area of a human hair ($\sim 0.01 \text{ mm}^2$).

How many collisions do you think there are?



COLLISIONS: INTERACTION

20

collisions per bunch crossing

COLLISIONS: INTERACTION

20

collisions per bunch crossing

This is called 'pile-up', and it's considered to be
almost a bit too much.

COLLISIONS: INTERACTION

... because if there's 20 collisions every 25 ns, you get about

600 million

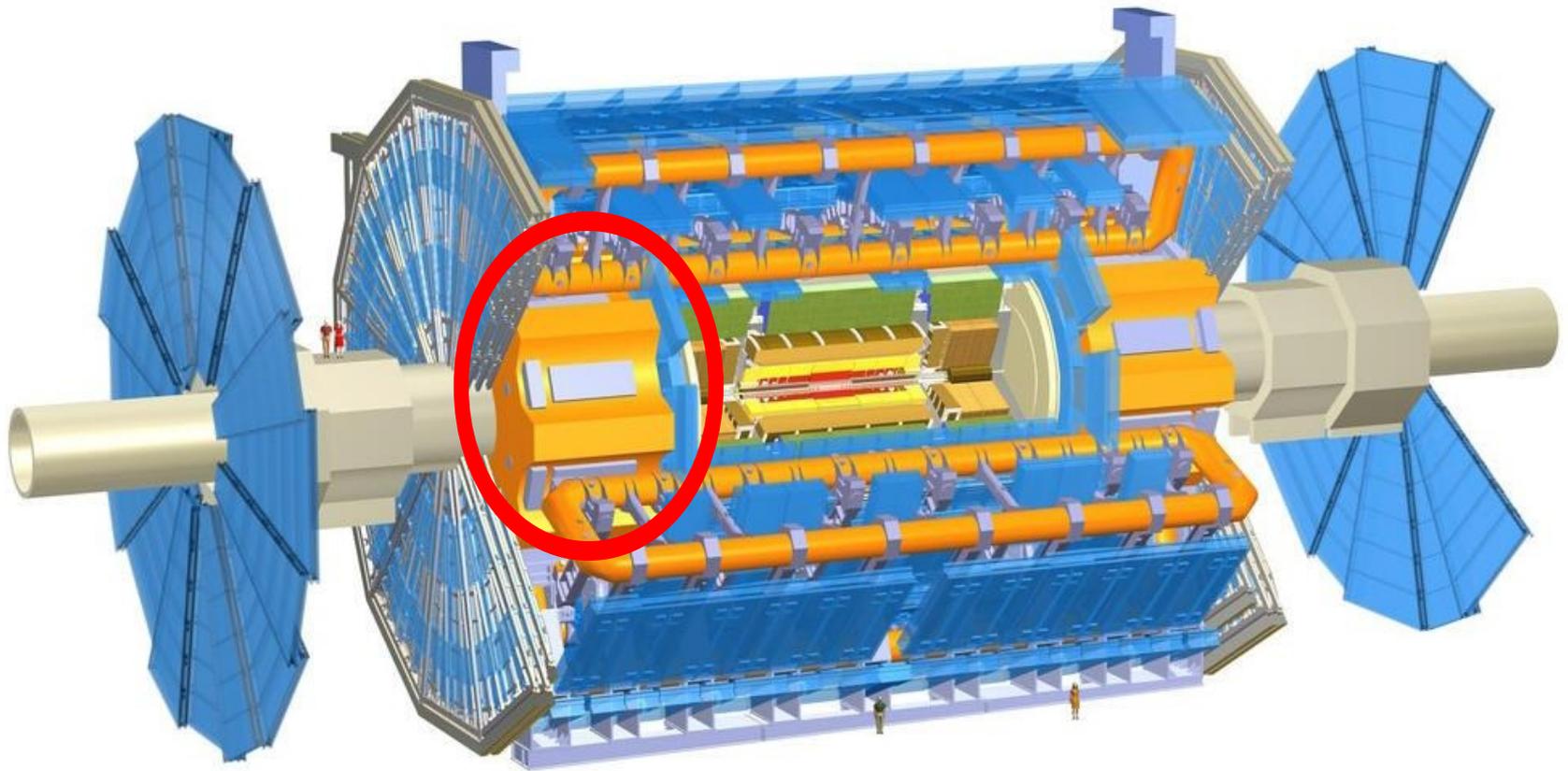
collisions per second (per interaction point).

EXPERIMENTS

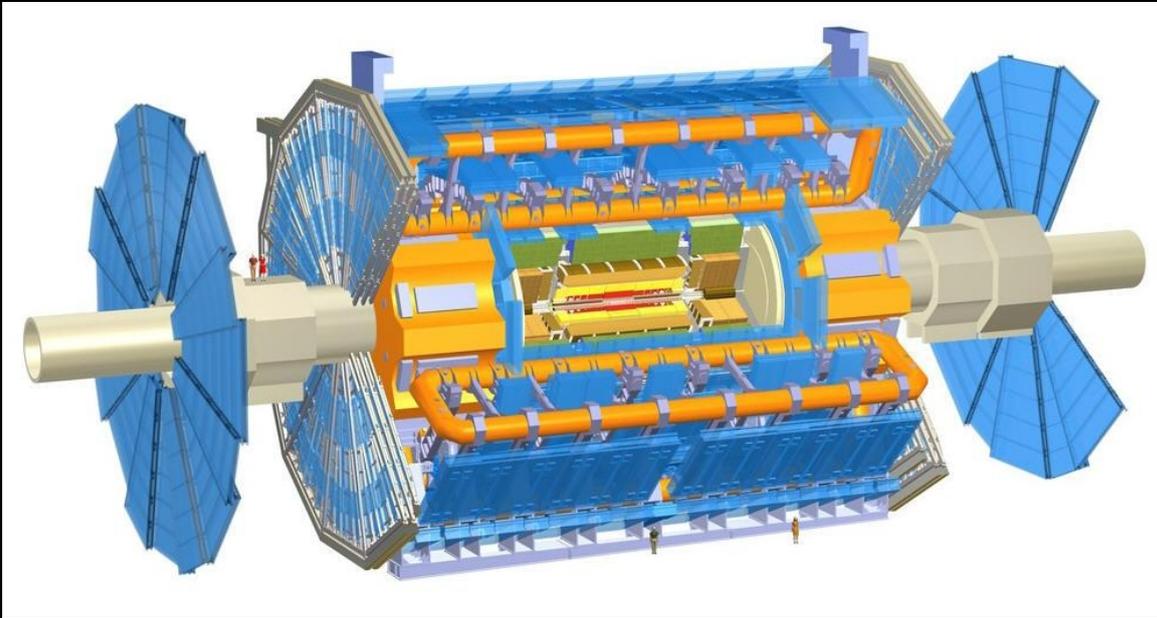


IMAGE: ATLAS Experiment/CERN

EXPERIMENT: LAYOUT



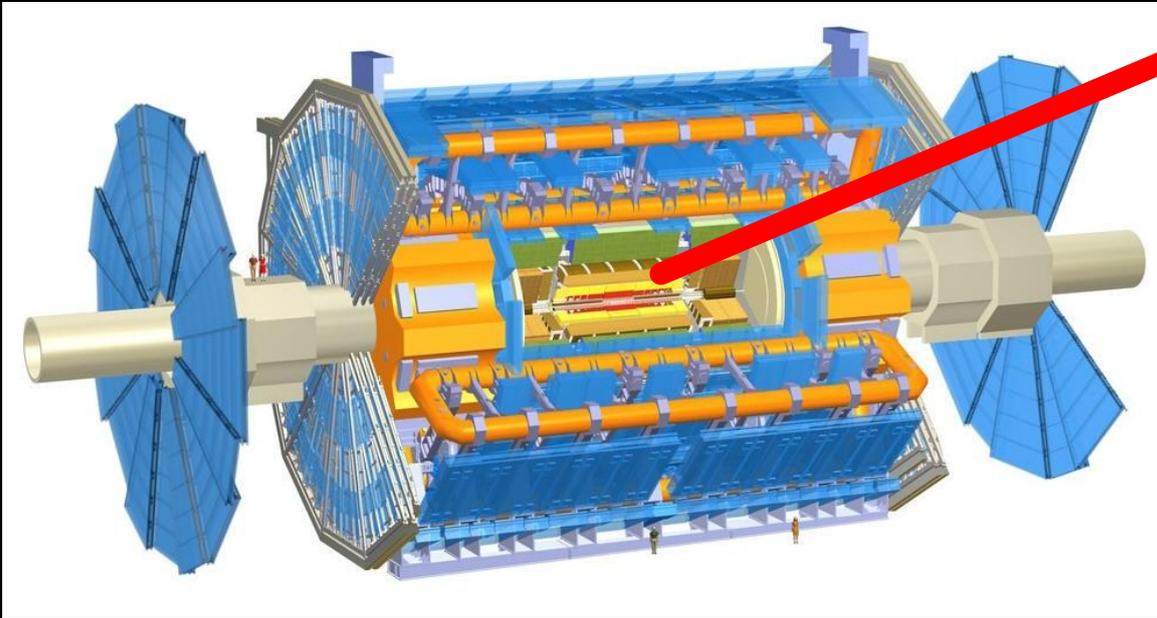
EXPERIMENT: LAYOUT



- interaction point in the center
- ‘onion’ structure
- huge magnetic field for momentum information
- 3,000 km of cables

30C3: BREAKING BARYONS (BY EMTIU)

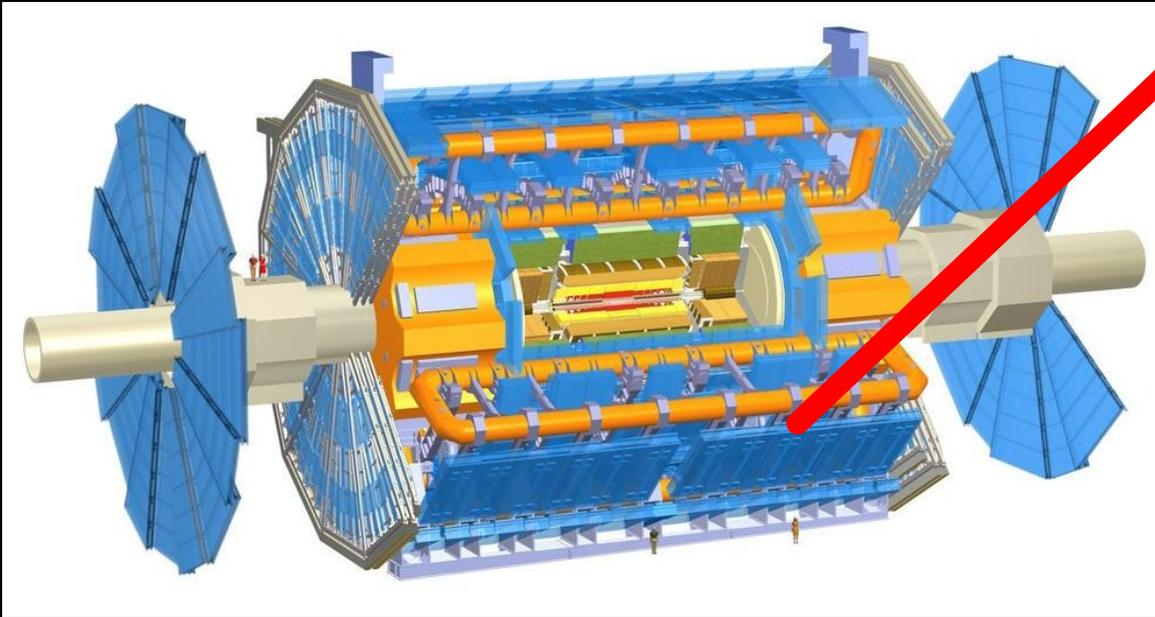
EXPERIMENT: LAYOUT



inner tracking

- located ~centimeters off the beamline
- leaves particles largely undisturbed
- precise location data

EXPERIMENT: LAYOUT

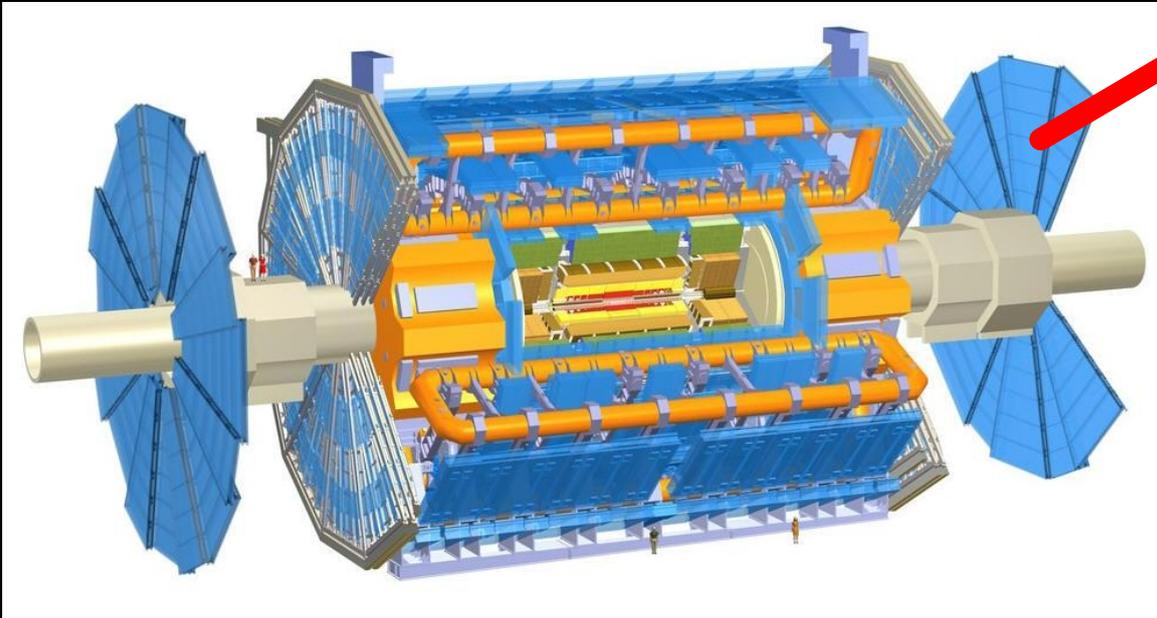


calorimeters

- must be outside of the inner tracking
- stops the particles, has them deposit all their energy
- rough energy data

30C3: BREAKING BARYONS (BY EMTIU)

EXPERIMENT: LAYOUT



muon detectors

- outside of it all, very large
- only for one special particle: the muon
- energy and direction information

30C3: BREAKING BARYONS (BY EMTIU)

EXPERIMENT: INSTRUMENTS

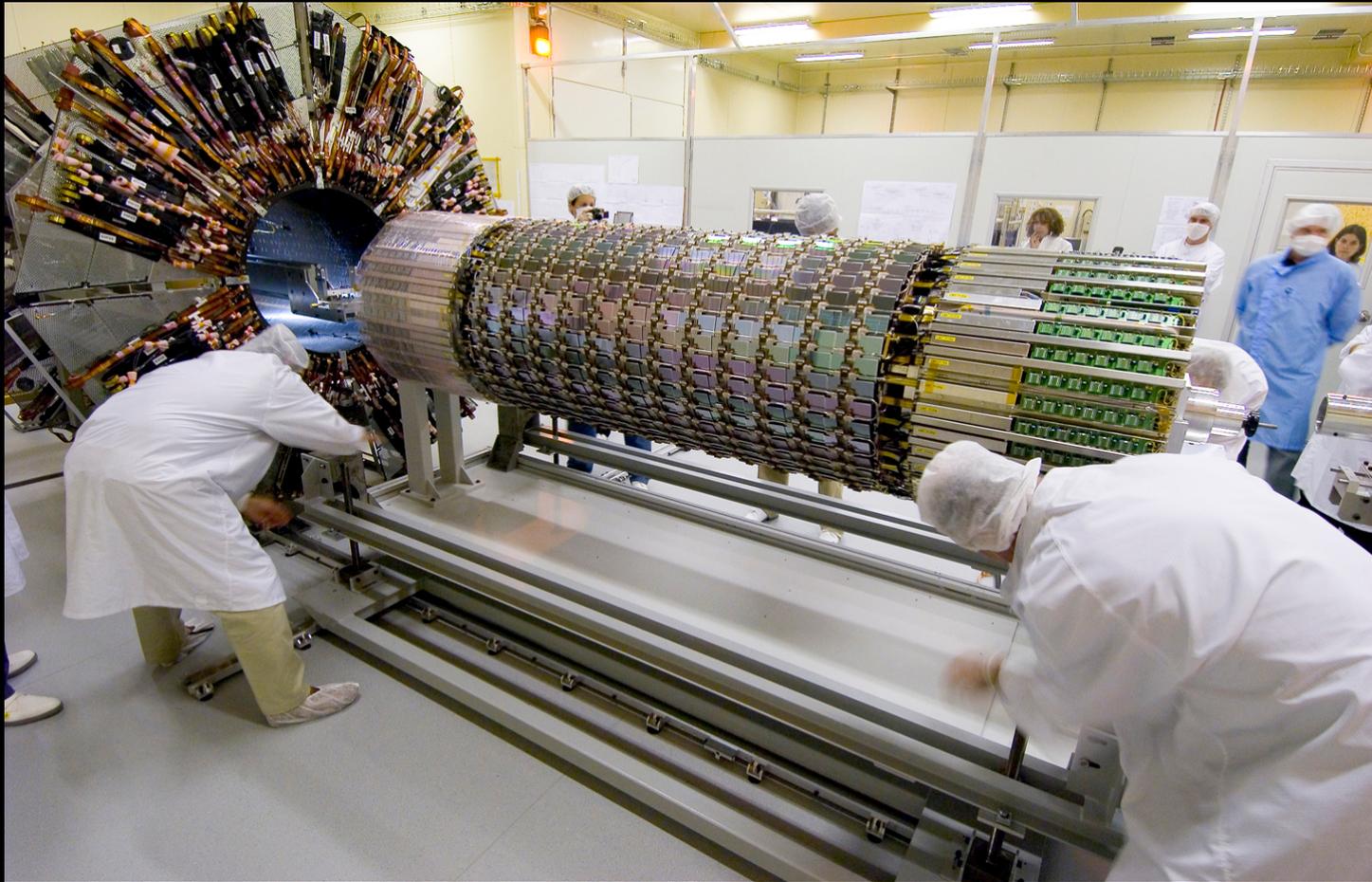
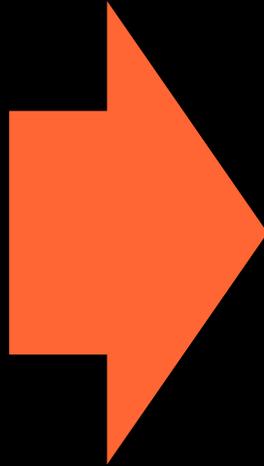


IMAGE: ATLAS EXPERIMENT/CERN

EXPERIMENTS: TRIGGERING

events

- 40 million bunch crossings per second



measurements

- ~100 million channels
- ~1.5 megabytes of raw data per crossing
- ~60 TB/s

EXPERIMENTS: TRIGGERING

events

- 40 million bunch crossings per second



measurements

- ~100 million channels
- ~1.5 megabytes of raw data per crossing
- ~60 TB/s

reconstruction of an event: ~5 million lines of C++ code
simulating 30 million objects in 15 seconds of CPU time
--> 600 million CPUs dedicated to event calculation? Na-uh.

EXPERIMENTS: TRIGGERING

40 million events per second (60 TB/s)

Level 1 trigger

Has 25 ns of time to evaluate
if an event is 'interesting'.

Has to eliminate 99.75 %
of events.

100,000 events per second (150 GB/s)

EXPERIMENTS: TRIGGERING

100,000 events per second (150 GB/s)

Level 2/3 trigger

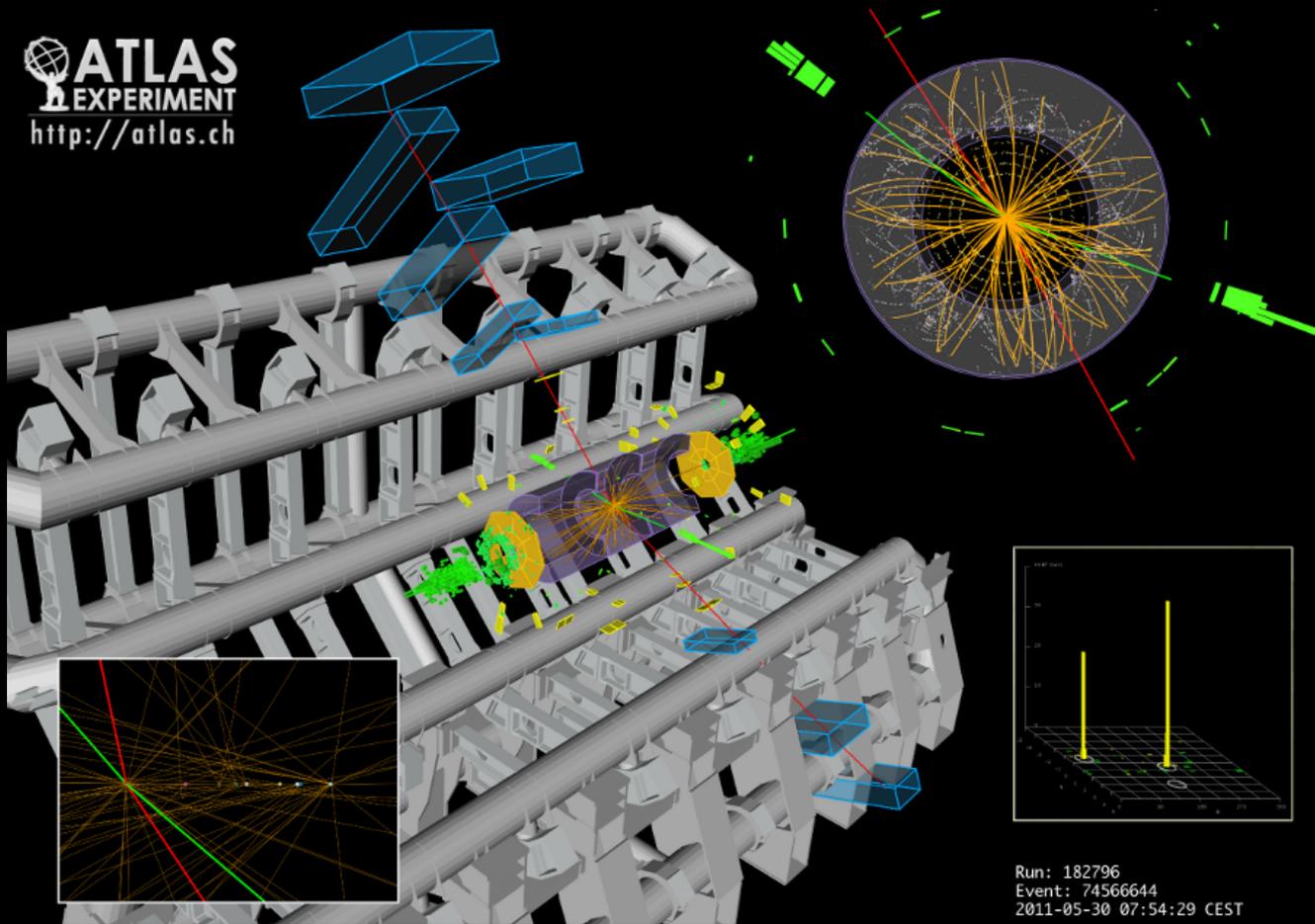
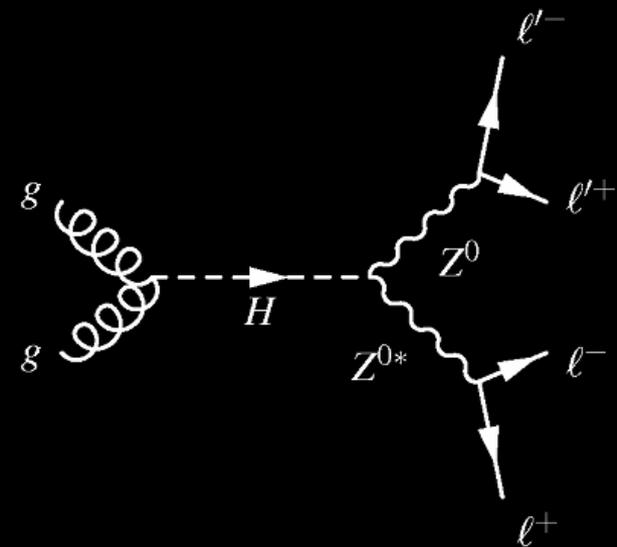
Has 10 μ s of time to evaluate
if an event is 'interesting'.

Has to eliminate 99.87 %
of events (again!).

~150 events per second (~300 MB/s)

EXPERIMENT: EVENT DATA

ATLAS
EXPERIMENT
<http://atlas.ch>



Run: 182796
Event: 74566644
2011-05-30 07:54:29 CEST

IMAGES: CDL/FNAL; ATLAS Experiment/CERN

WORLDWIDE LHC COMPUTING GRID

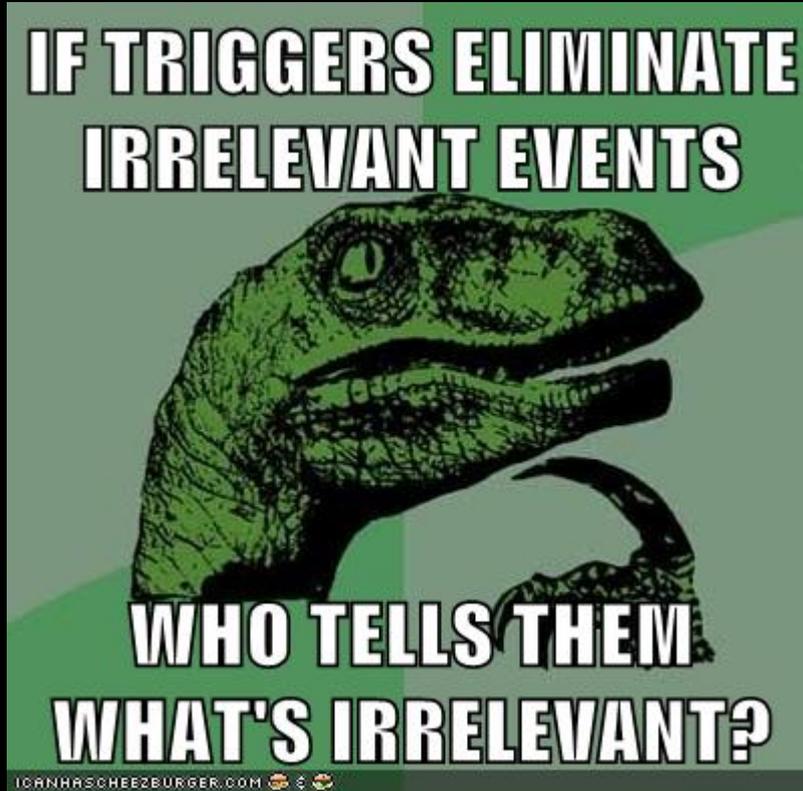
The 4 LHC experiment (CMS, ATLAS, LHCb, ALICE)
produce ~25 PB of data per year.

LHC Optical Private Network:

11 dedicated 10 Gbit/s links from CERN outward, 150
secondary links to ~170 datacenters in ~35 countries

250,000 cores and ~100 PB of storage for 8,000 scientists

TRIGGERS: CRITERIA



30C3: BREAKING BARYONS (BY EMTIU)

TRIGGERS: CRITERIA

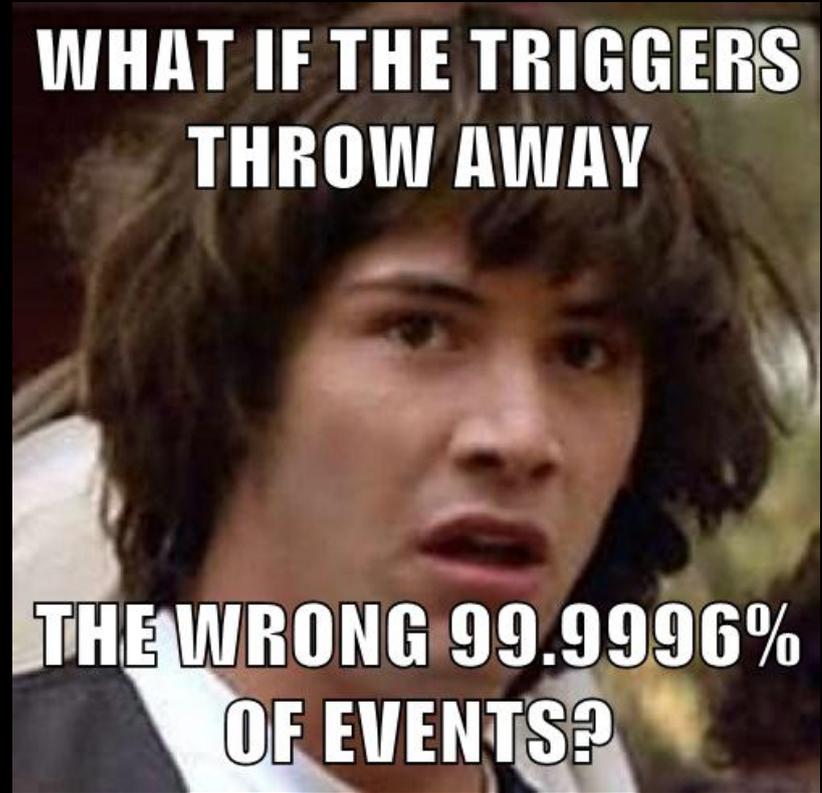
**IF TRIGGERS ELIMINATE
IRRELEVANT EVENTS**



**WHO TELLS THEM
WHAT'S IRRELEVANT?**

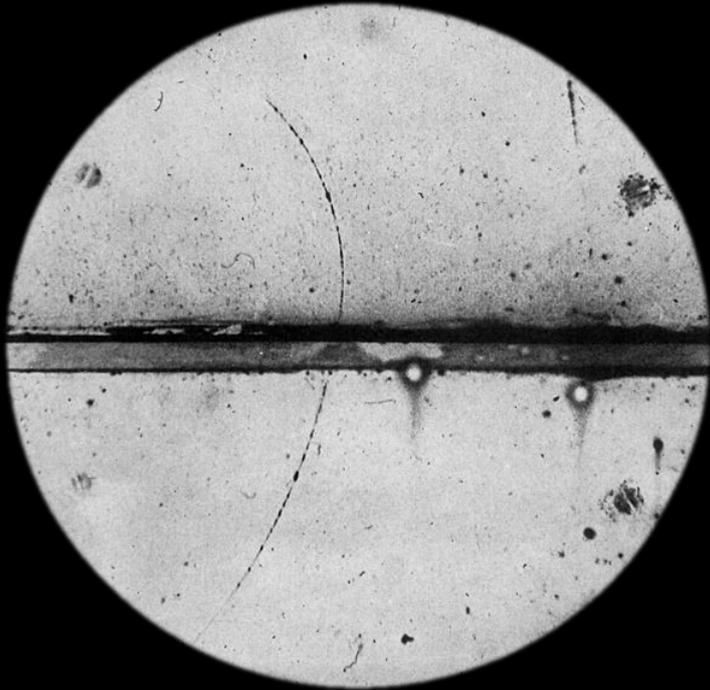
ICANHASCHEEZBURGER.COM

**WHAT IF THE TRIGGERS
THROW AWAY**



**THE WRONG 99.9996%
OF EVENTS?**

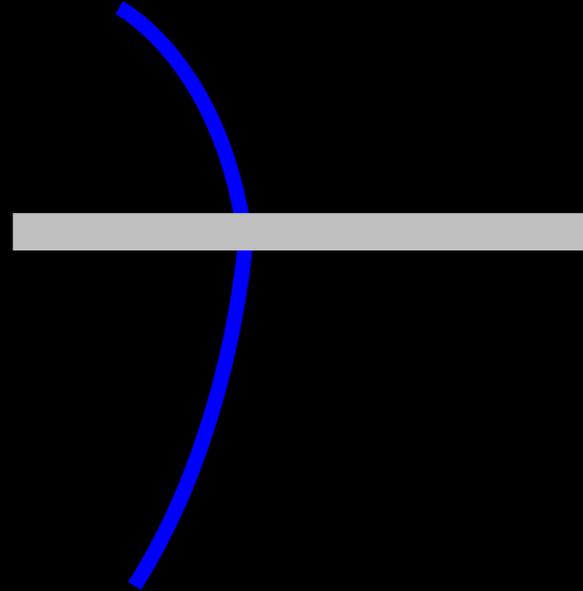
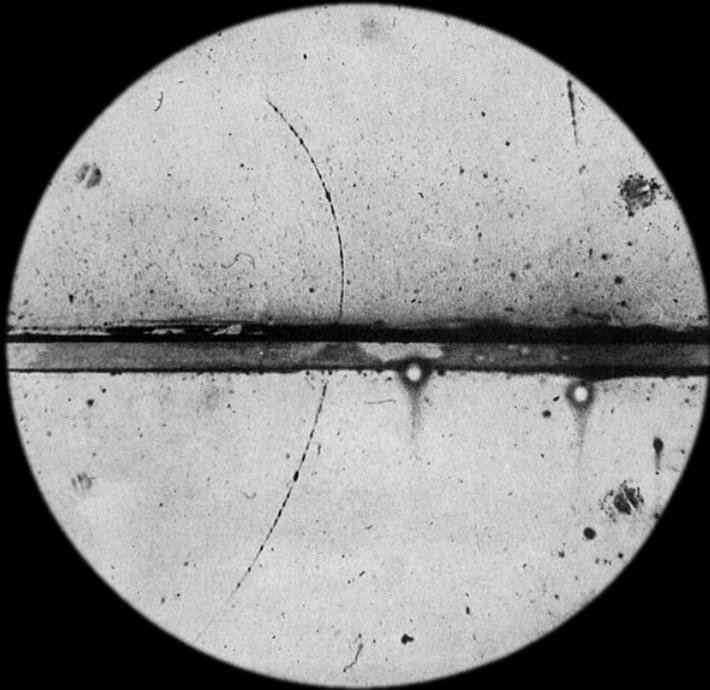
EXAMPLE: POSITRON (~1930)



positron = anti-electron
(positive charge, otherwise identical)

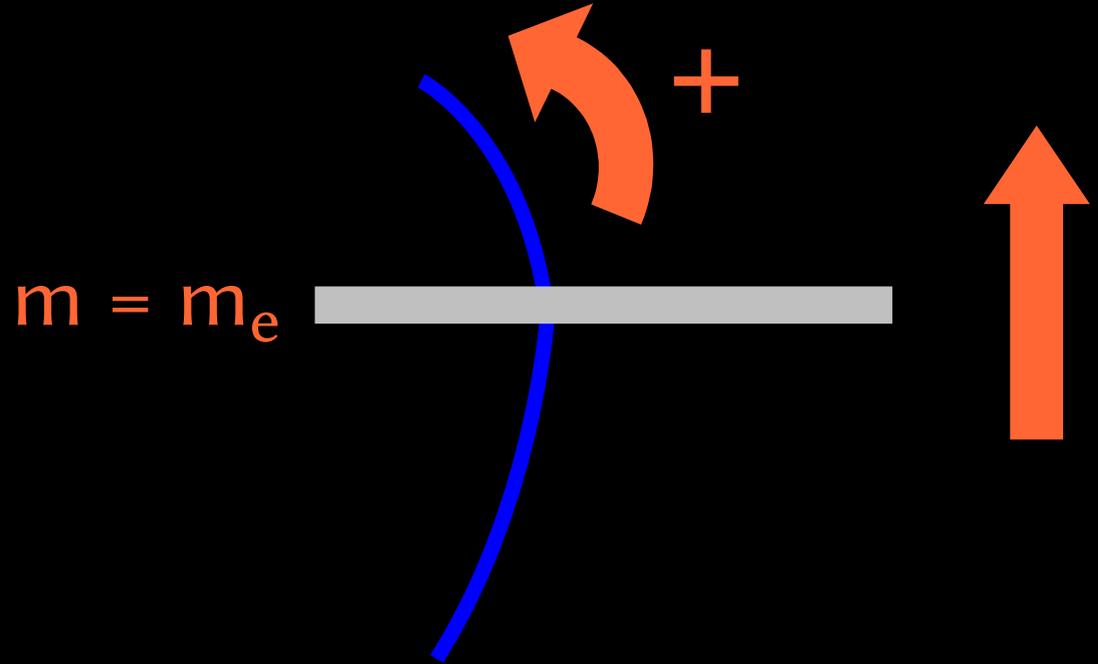
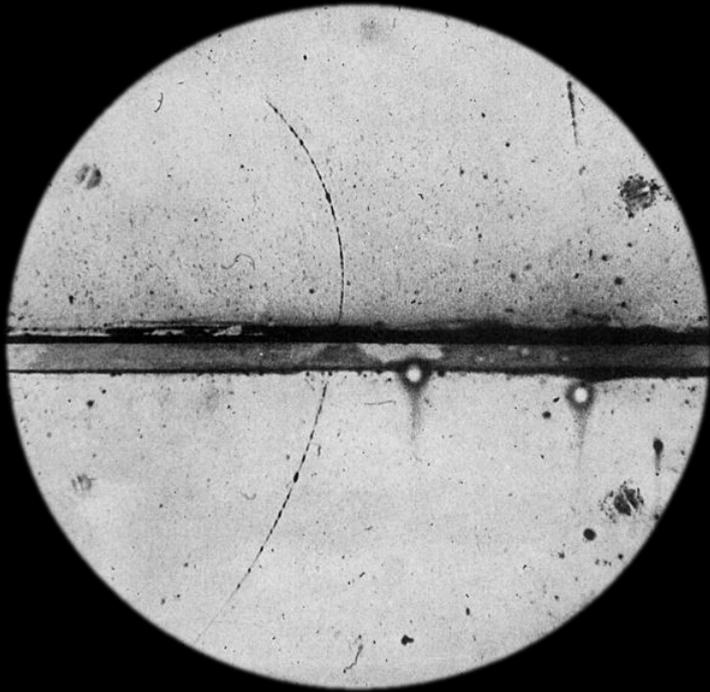
- theorized in 1928 by Dirac
- first identified in 1931

EXAMPLE: POSITRON (~1930)



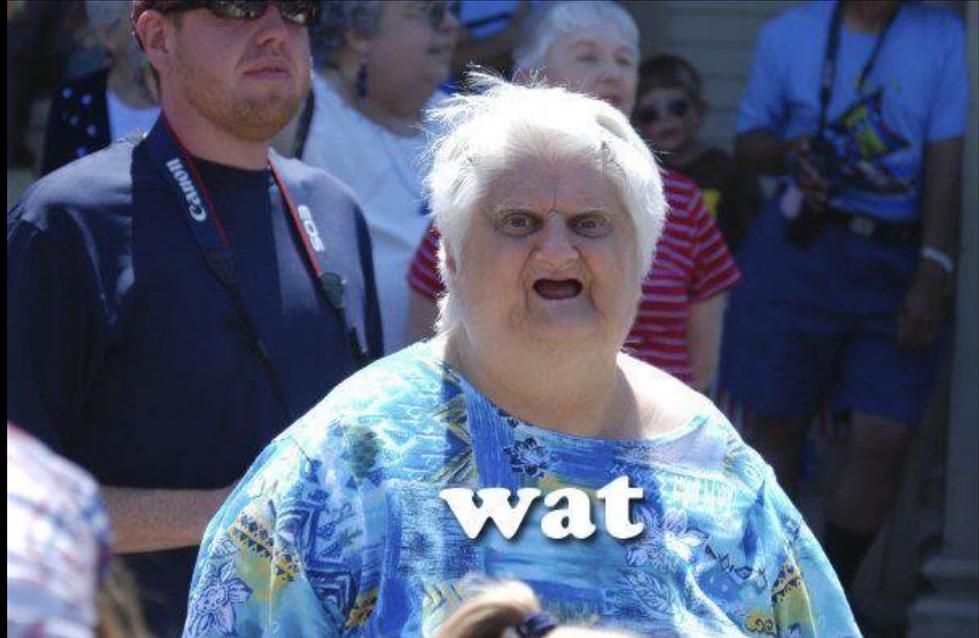
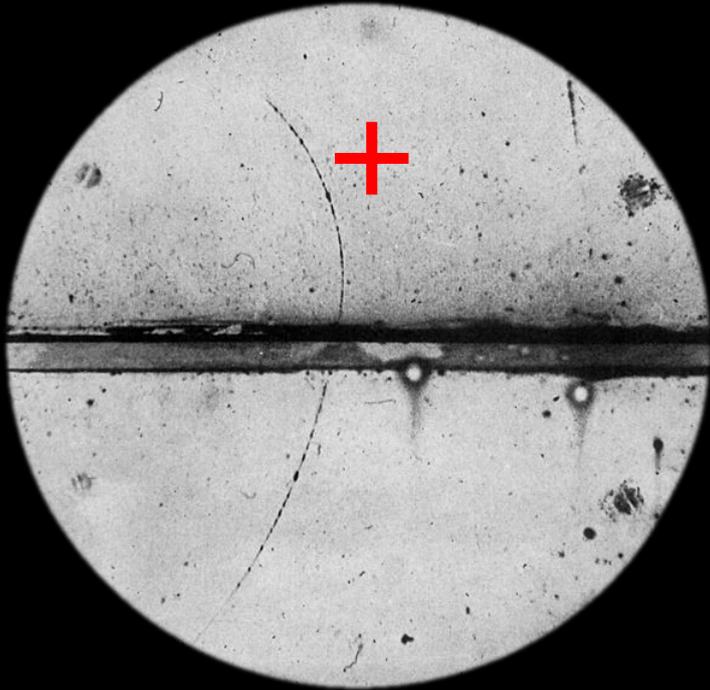
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EXAMPLE: POSITRON (~1930)



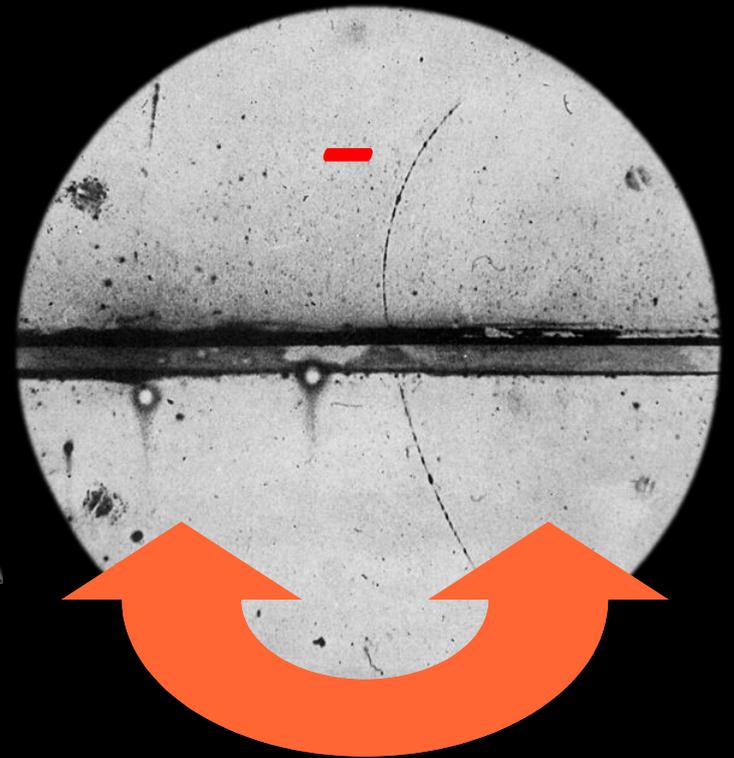
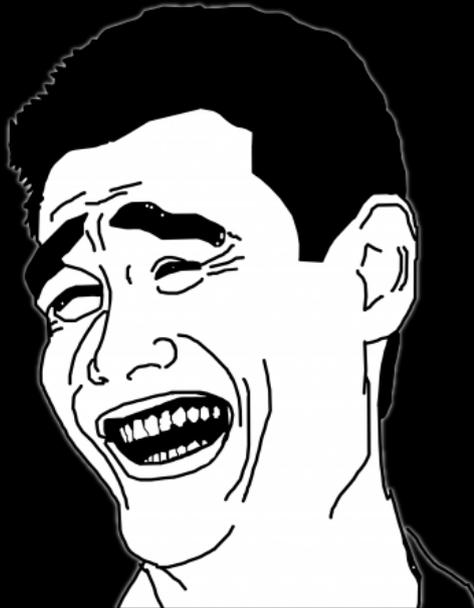
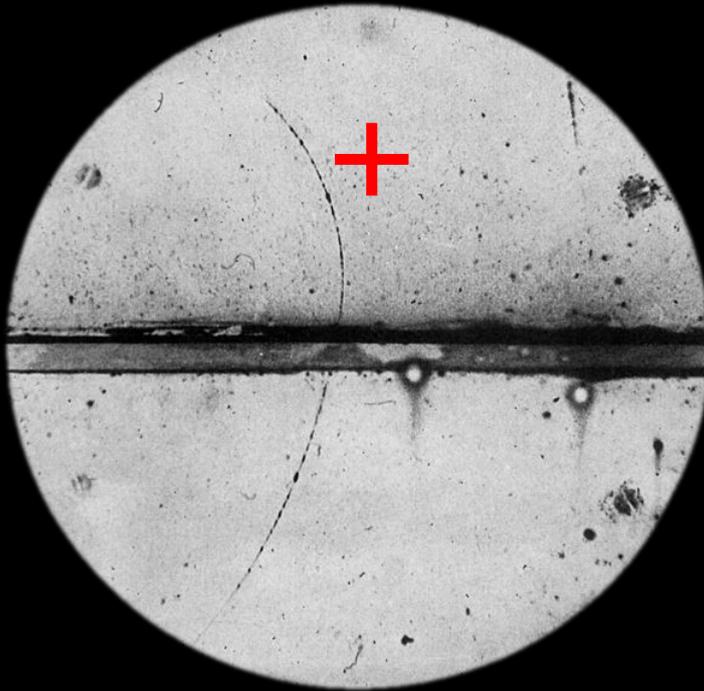
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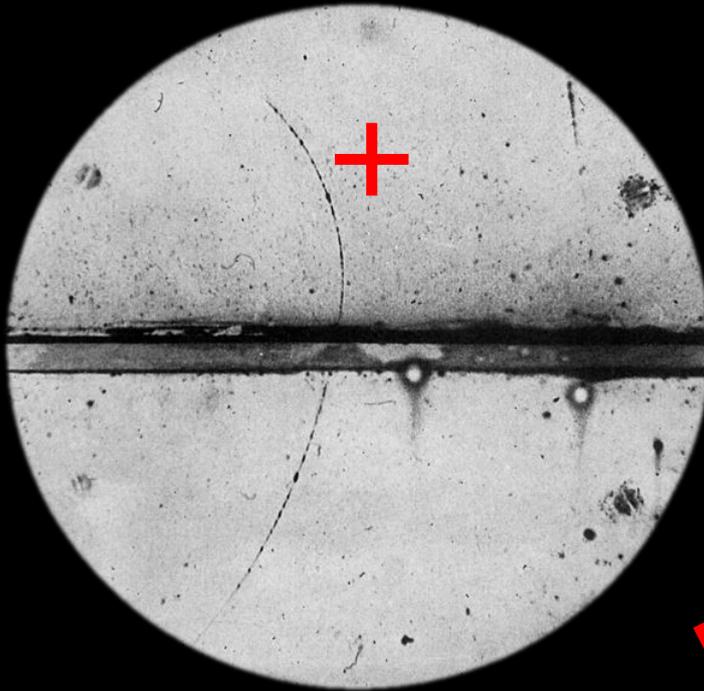
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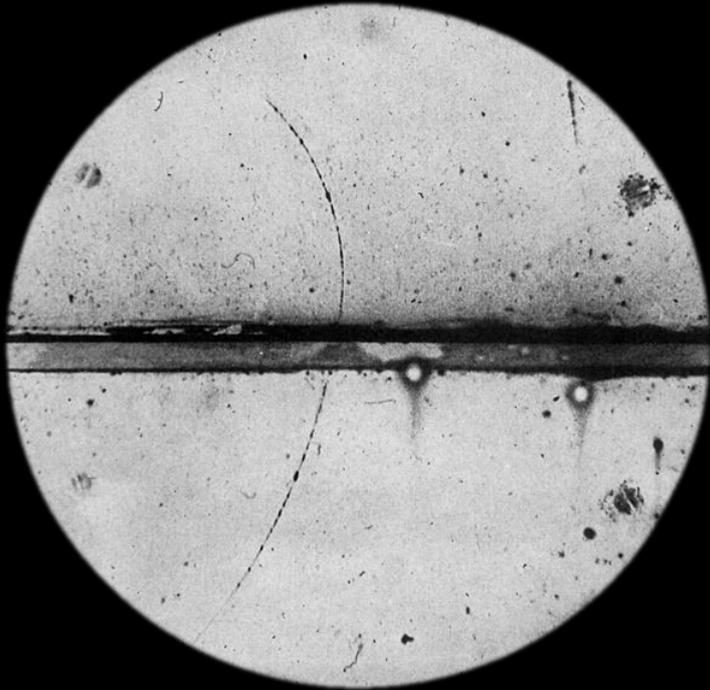
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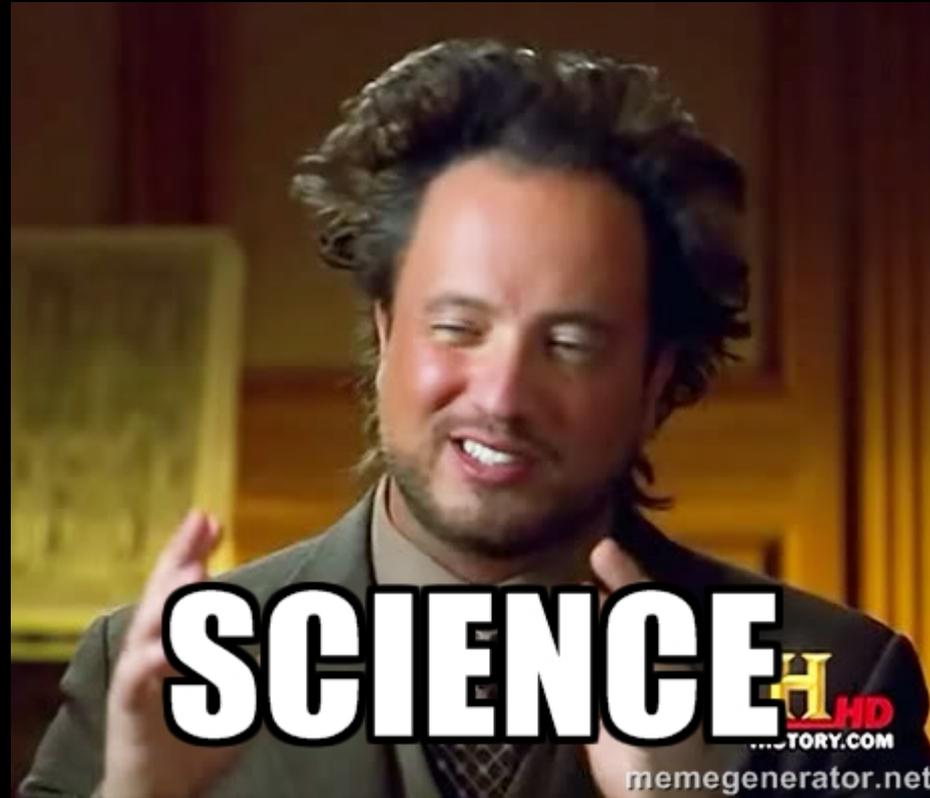
30C3: BREAKING BARYONS (BY EMTIU)

DIE MORAL VON DER GESCHICHT'



You can only discover
that which you can
accept as a result!

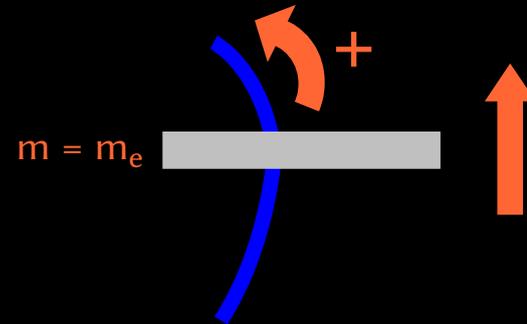
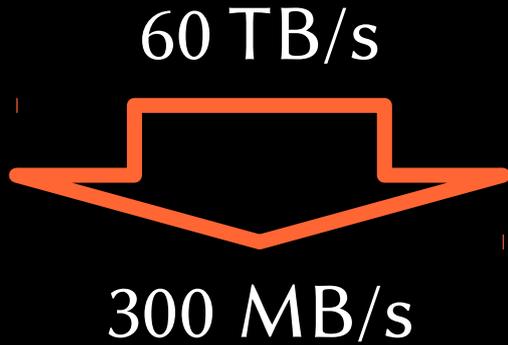
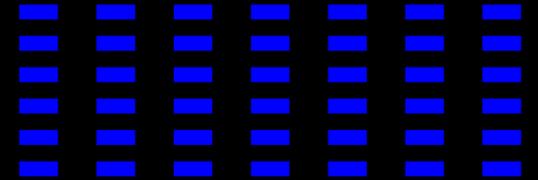
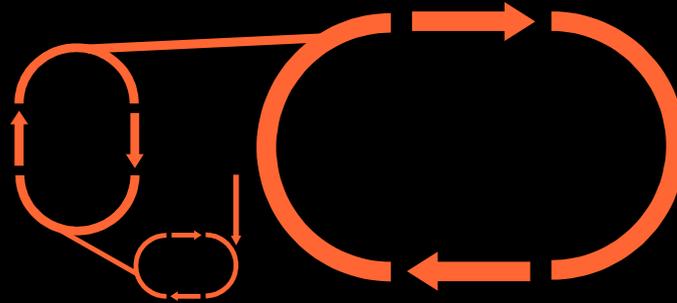
WE CALL IT ...



30C3: BREAKING BARYONS (BY EMTIU)

RECAP

parts = device



FUNDAMENTAL PARTICLE PHYSICS



IMAGES: CERN



30C3: BREAKING BARYONS (BY EMTIU)

DID YOU LIKE IT?

- My name's Michael Büker (@emtiu on Twitter, DECT 7892). I talk about science.
- Find the slides, video link and **please leave feedback!**
--> tinyurl.com/breakingbaryons
- Go watch **Desperately Seeking Susy** by atdotde!
Tomorrow (Day 2), 20:30h in Saal 6