

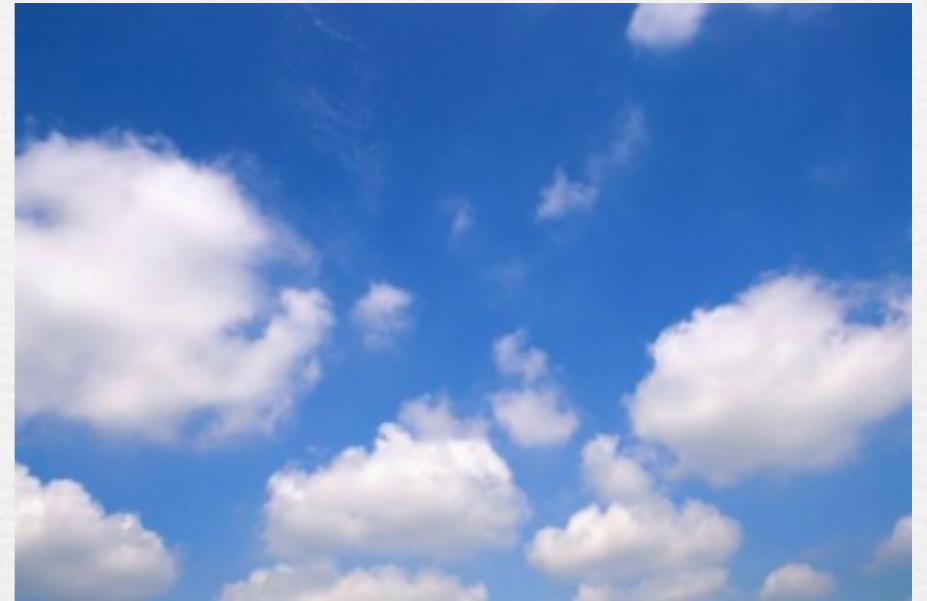
Computing in Particle Physics

ICTP HPC Appointment
30 October 2012



David Grellscheid
IPPP, Durham University

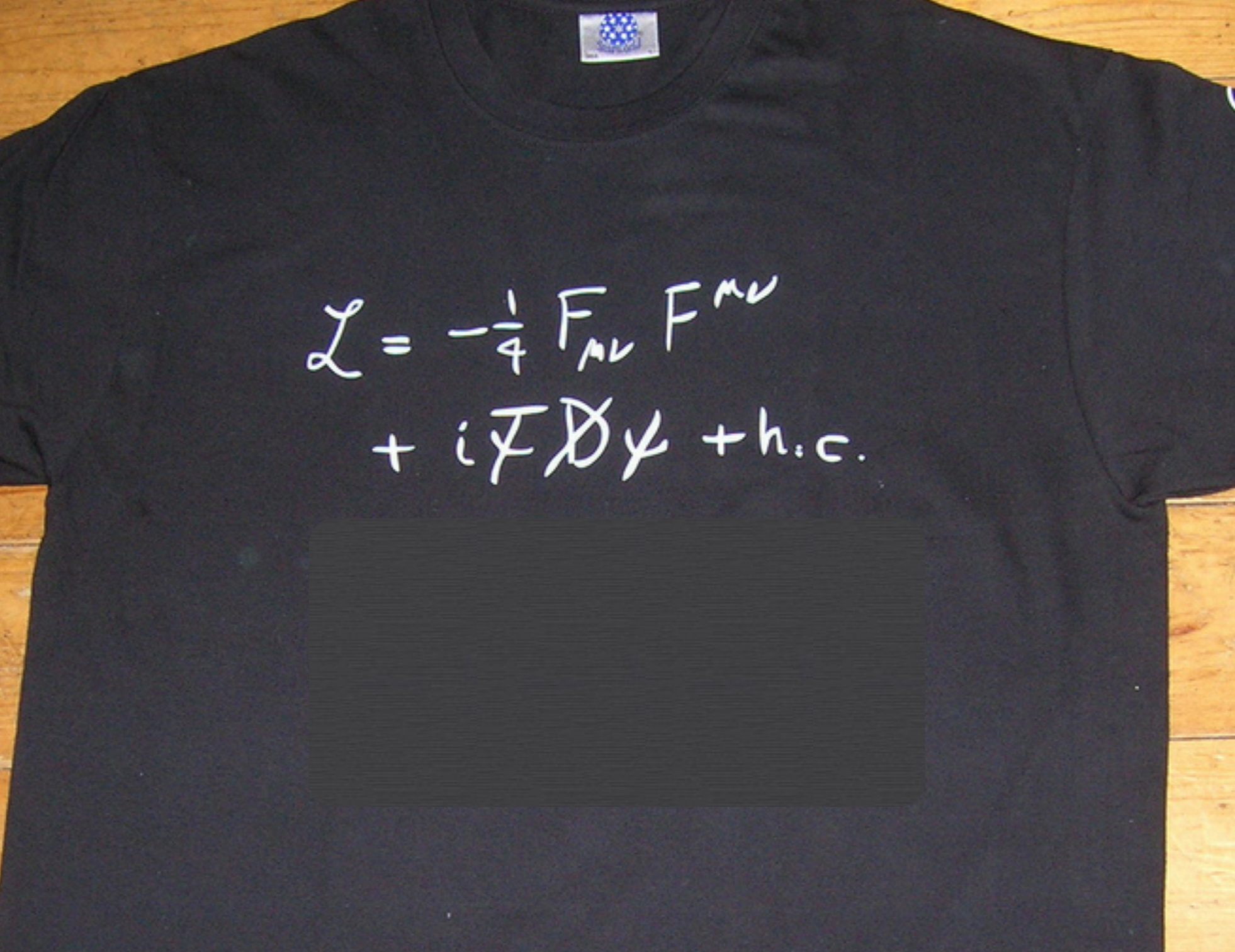




What are the fundamental building blocks of Nature?



Quarks	u up	c charm	t top	γ photon	Force carriers
	d down	s strange	b bottom		
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
	e electron	μ muon	τ tau	g gluon	



A black t-shirt is laid flat on a wooden surface. The t-shirt has a small white tag at the collar with a blue and white logo. The equation is written in white marker on the chest area.

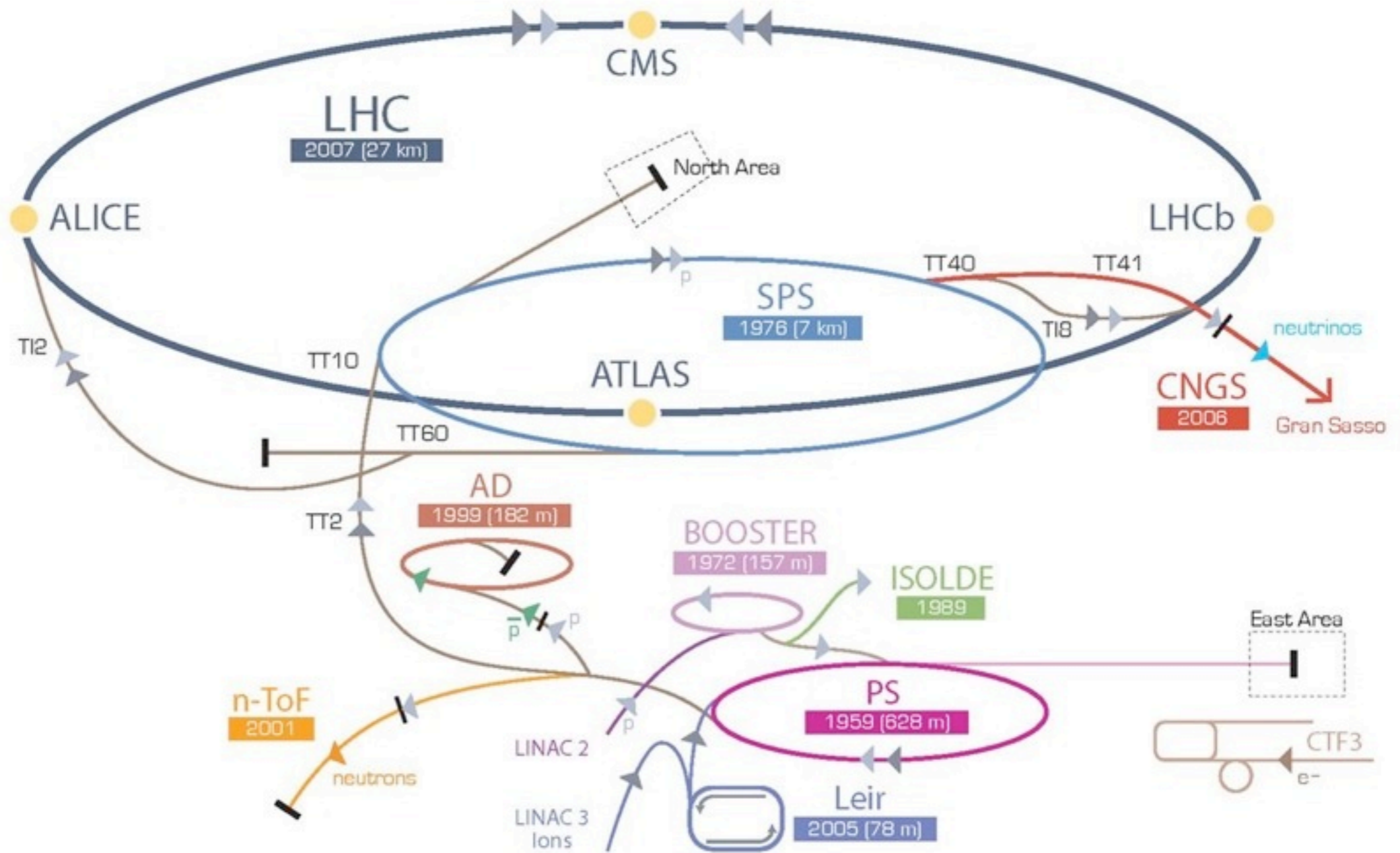
$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \text{h.c.}$$

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





CERN Accelerator Complex



▶ p (proton) ▶ ion ▶ neutrons ▶ \bar{p} (antiproton) ▶ \leftrightarrow proton/antiproton conversion ▶ neutrinos ▶ electron

LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

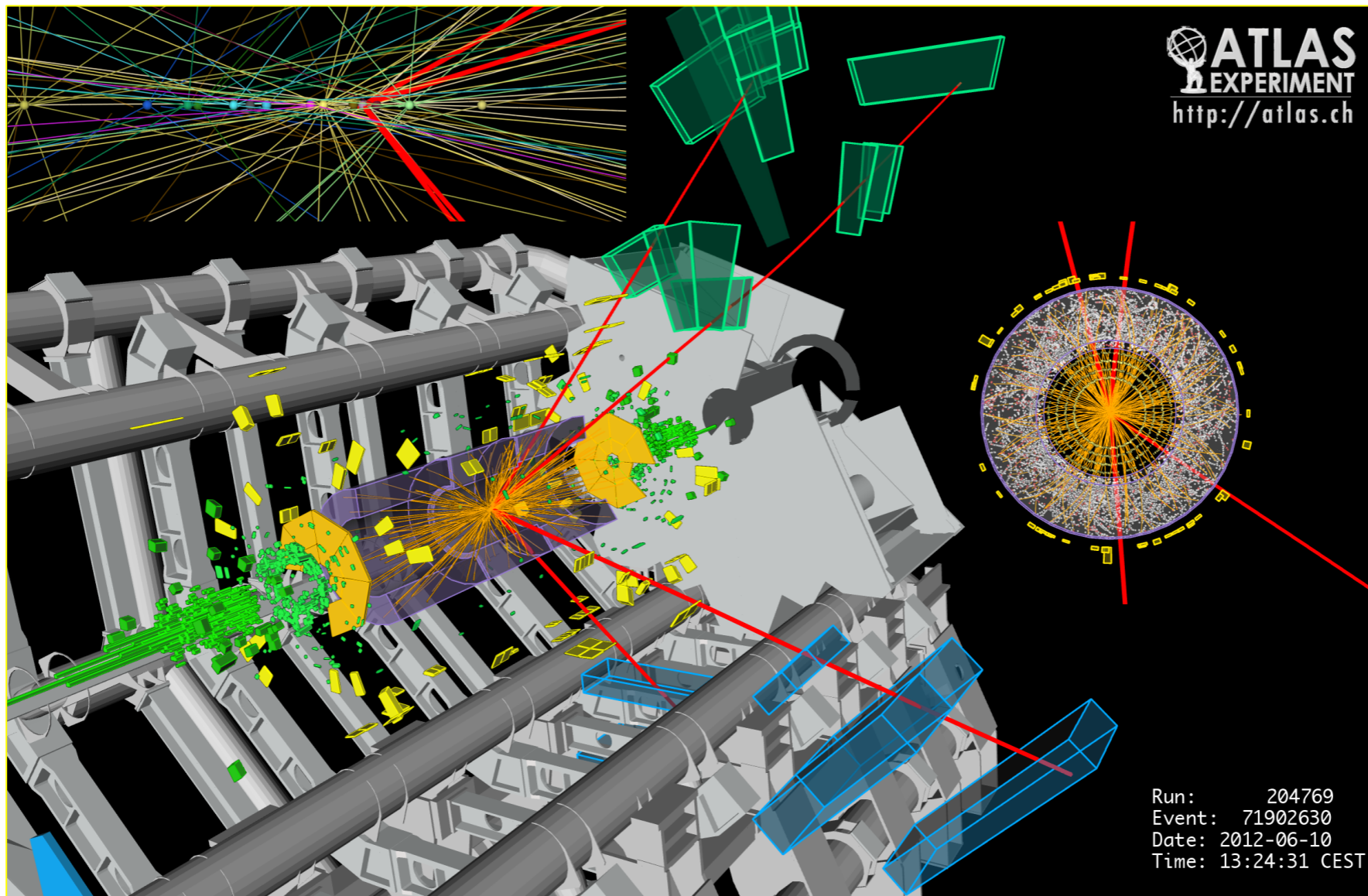
AD Antiproton Decelerator CTF3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice

LEIR Low Energy Ion Ring LINAC LINEar ACcelerator n-ToF Neutrons Time Of Flight



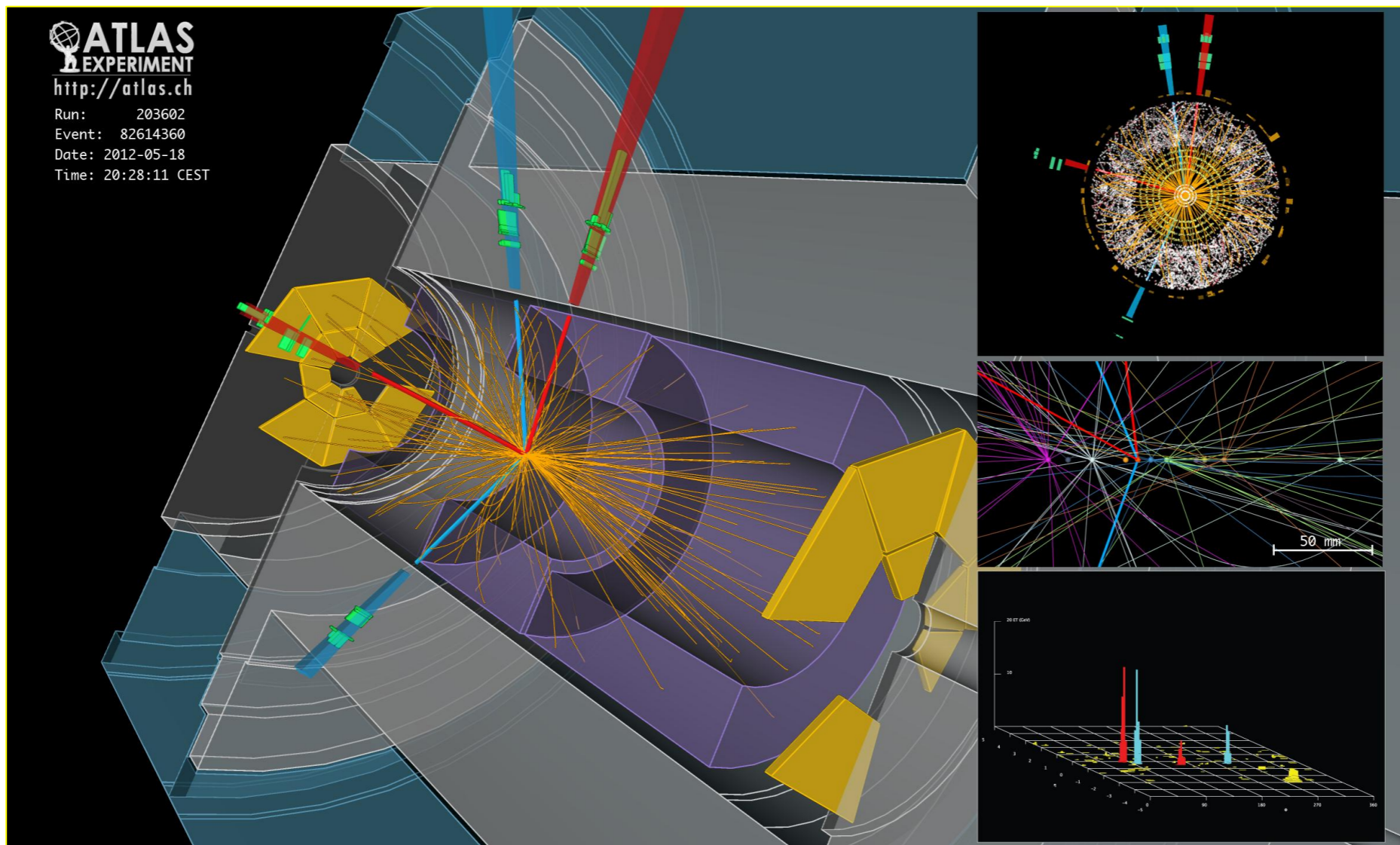
4 μ candidate with $m_{4\mu} = 125.1 \text{ GeV}$

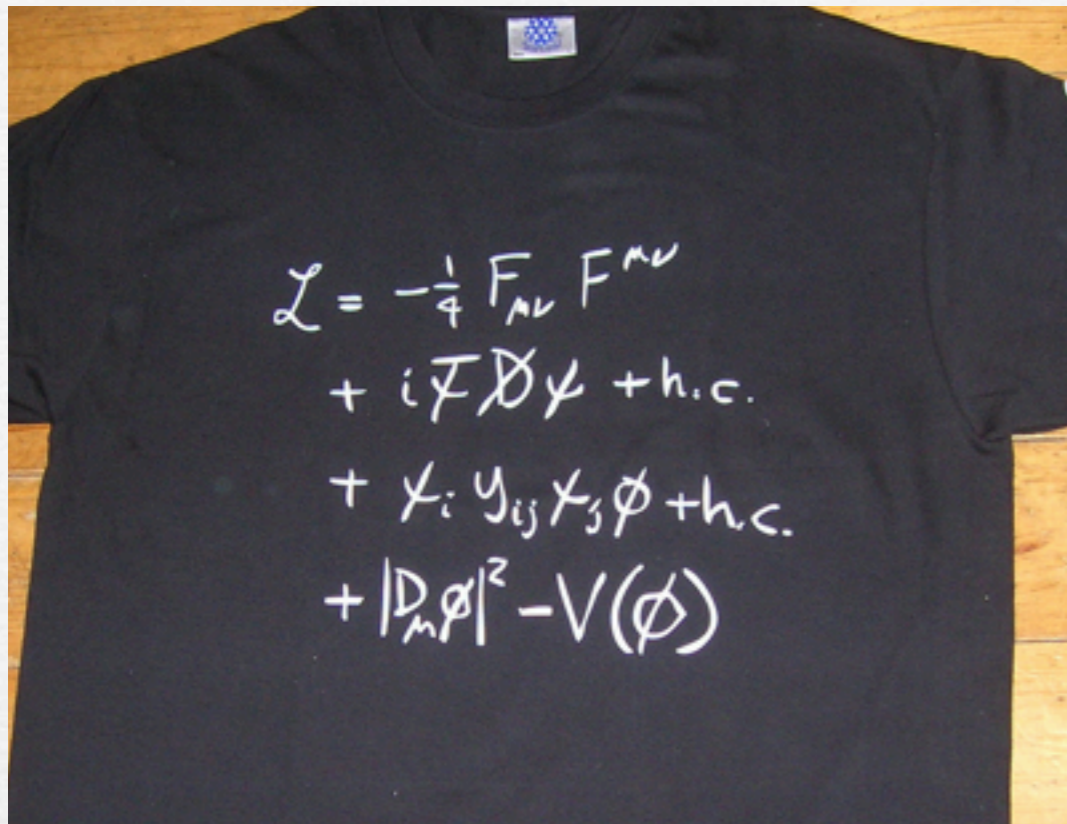
p_T (muons) = 36.1, 47.5, 26.4, 71.7 GeV $m_{12} = 86.3 \text{ GeV}$, $m_{34} = 31.6 \text{ GeV}$
15 reconstructed vertices



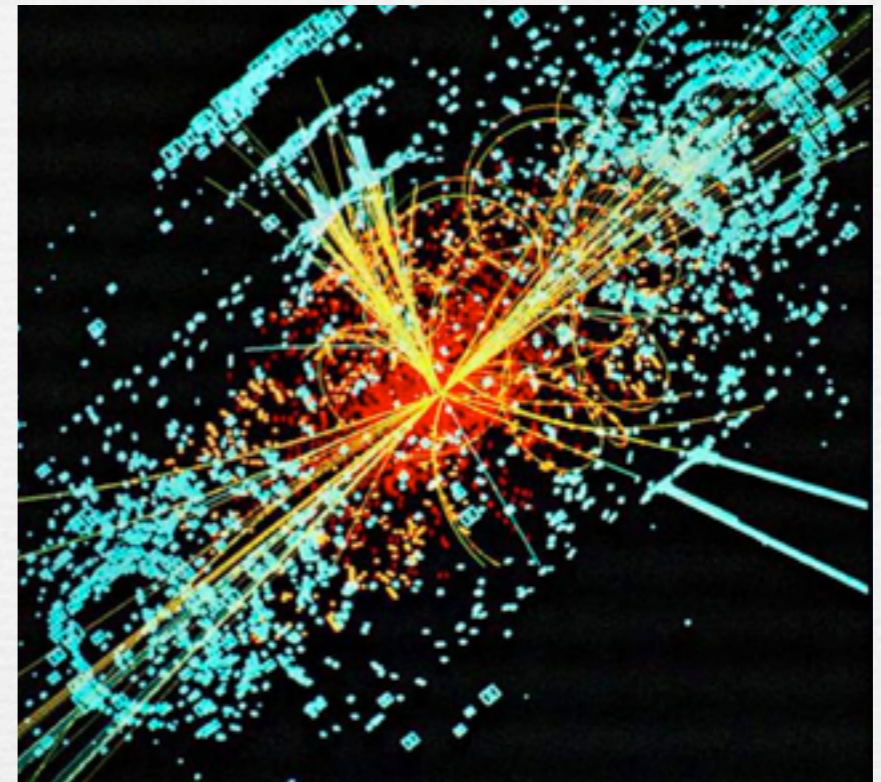
4e candidate with $m_{4e} = 124.6 \text{ GeV}$

p_T (electrons) = 24.9, 53.9, 61.9, 17.8 GeV $m_{12} = 70.6 \text{ GeV}$, $m_{34} = 44.7 \text{ GeV}$
12 reconstructed vertices



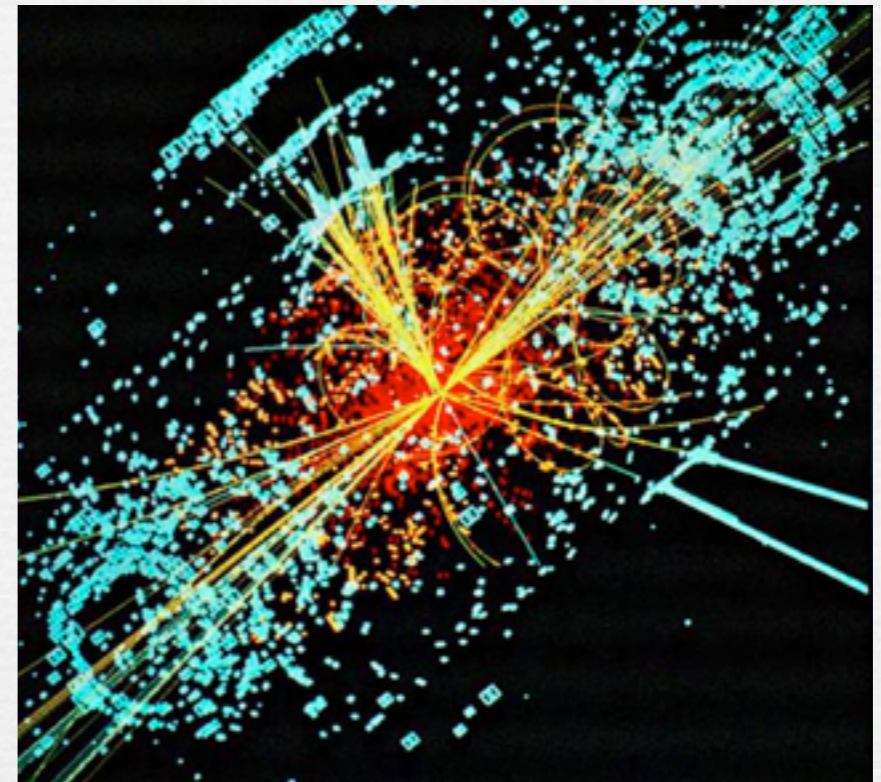
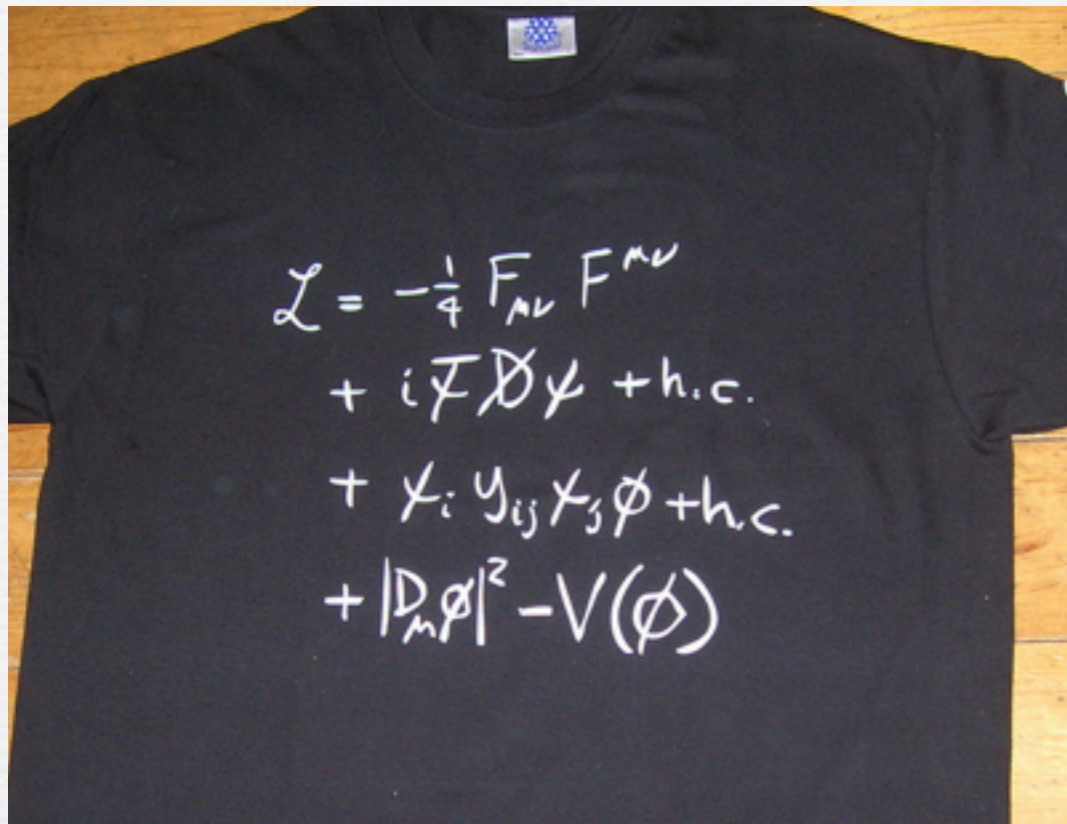


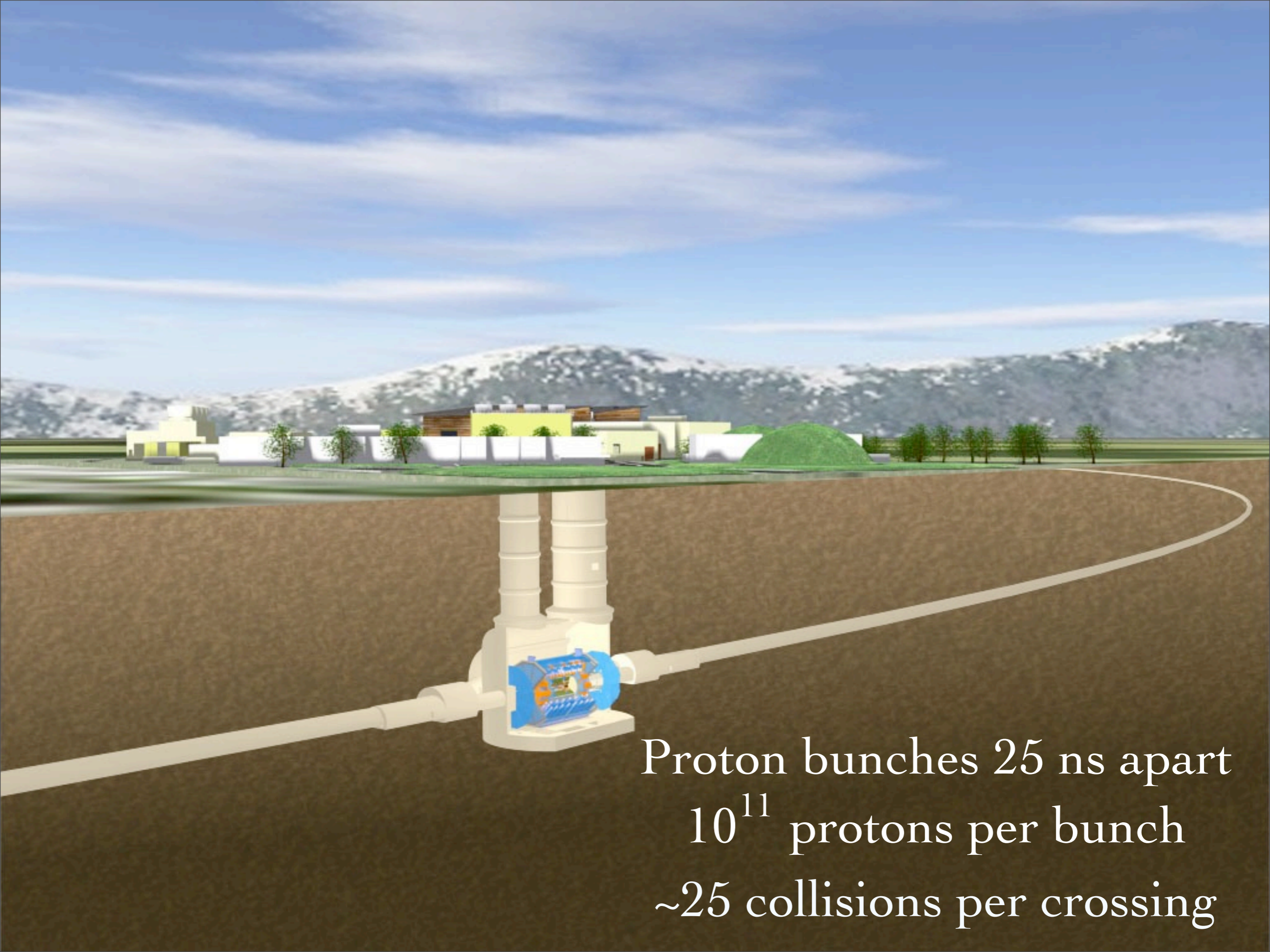
Theory



Experiment

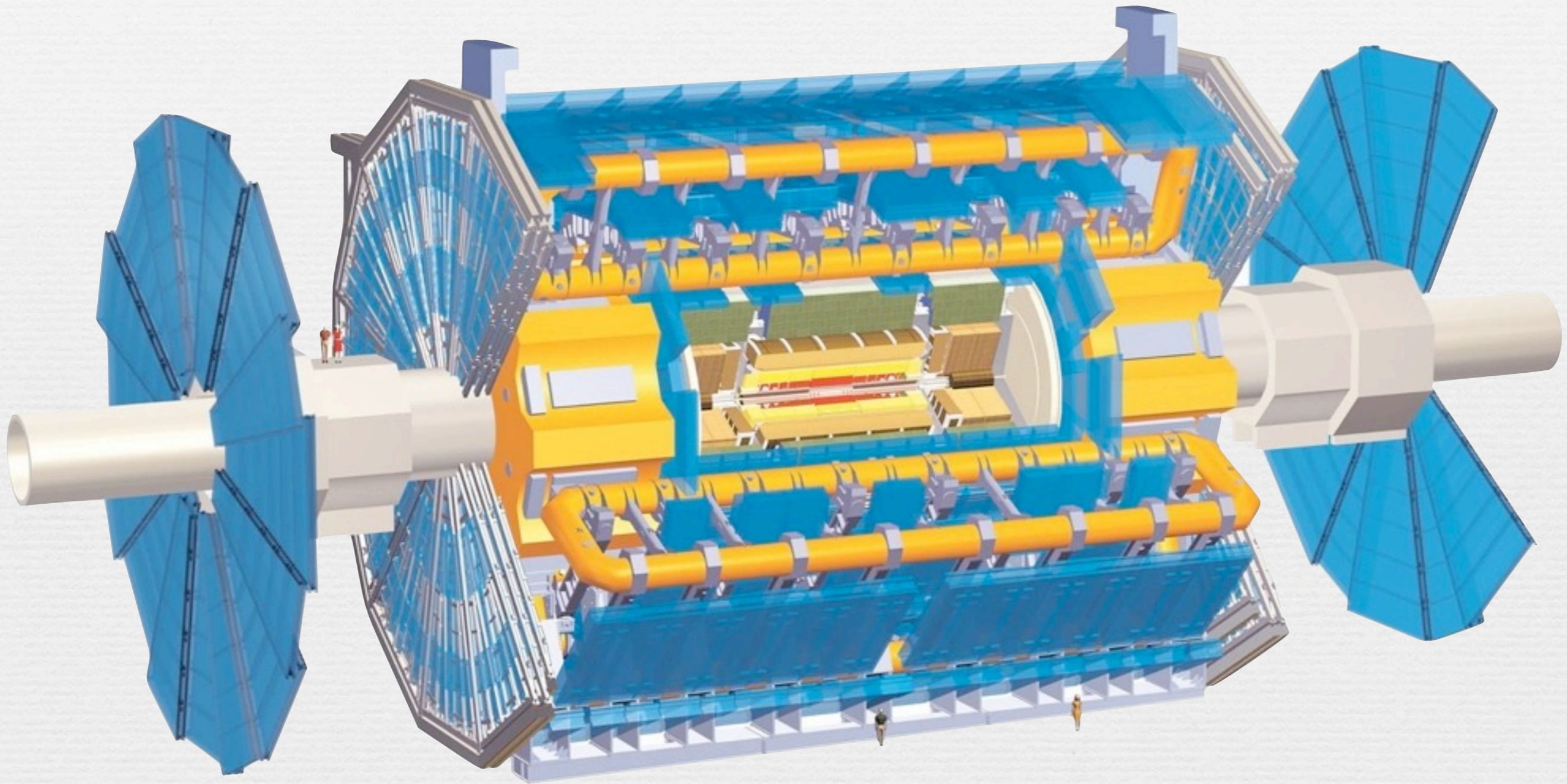


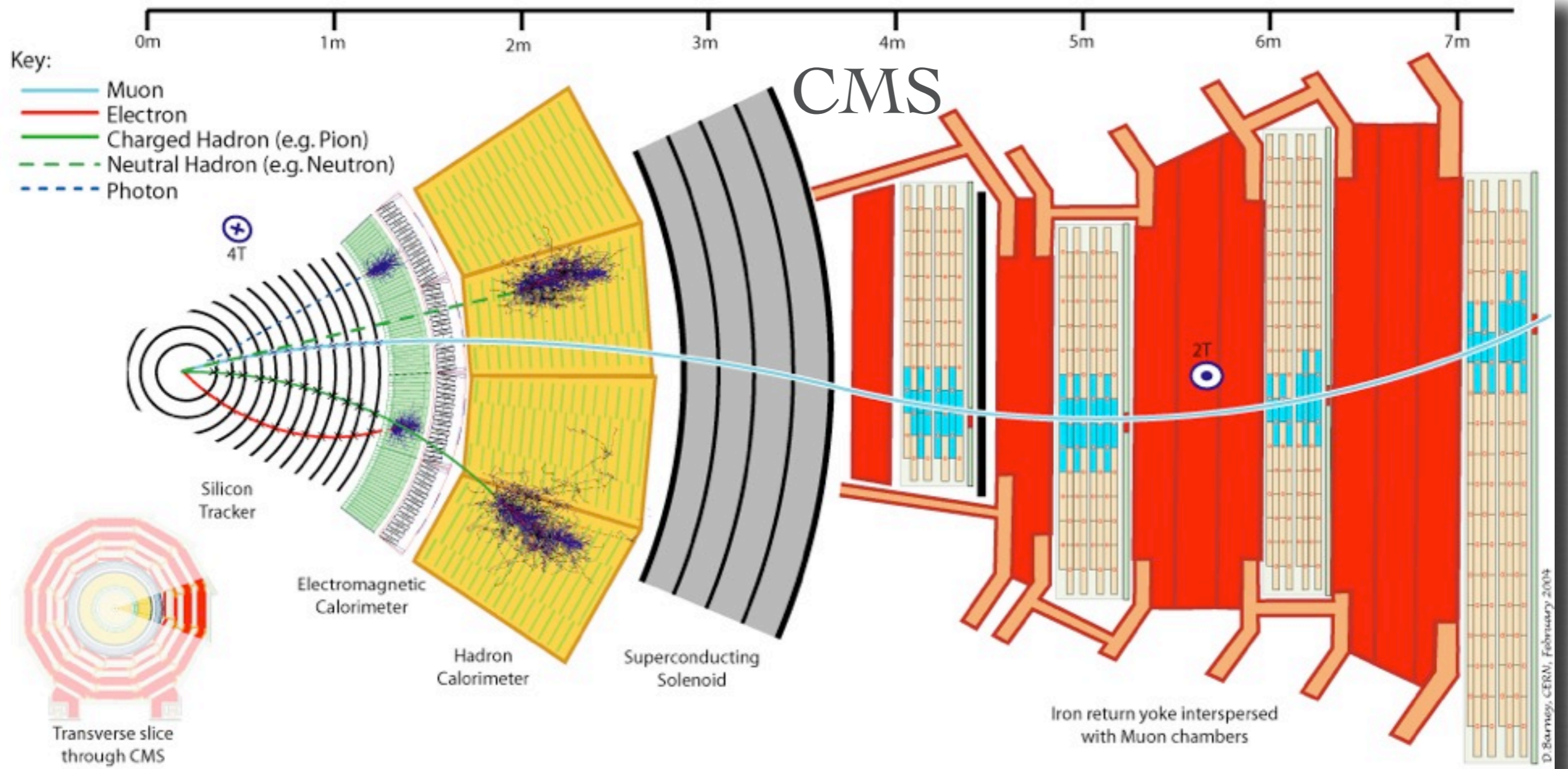


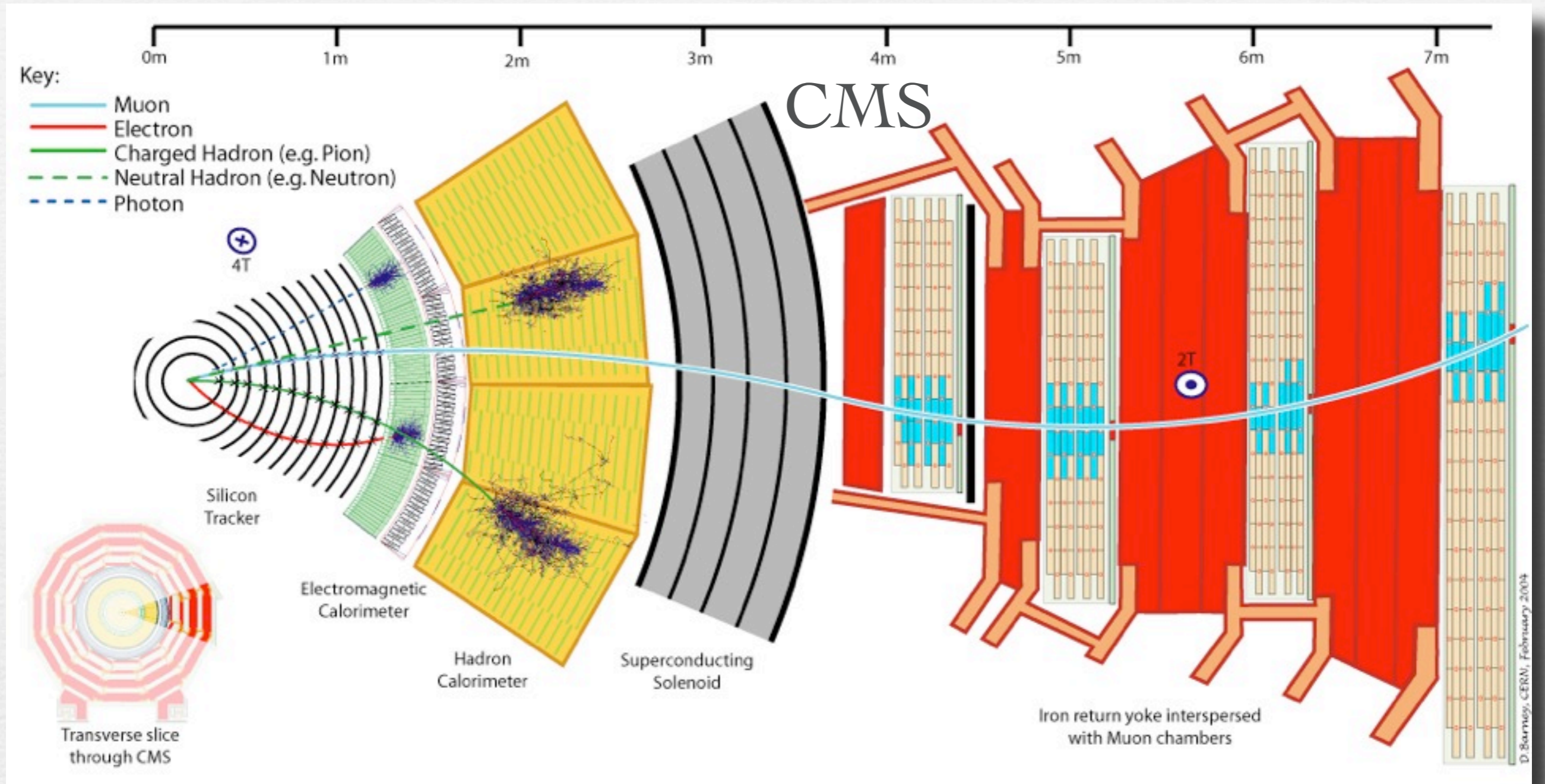


Proton bunches 25 ns apart
 10^{11} protons per bunch
~25 collisions per crossing

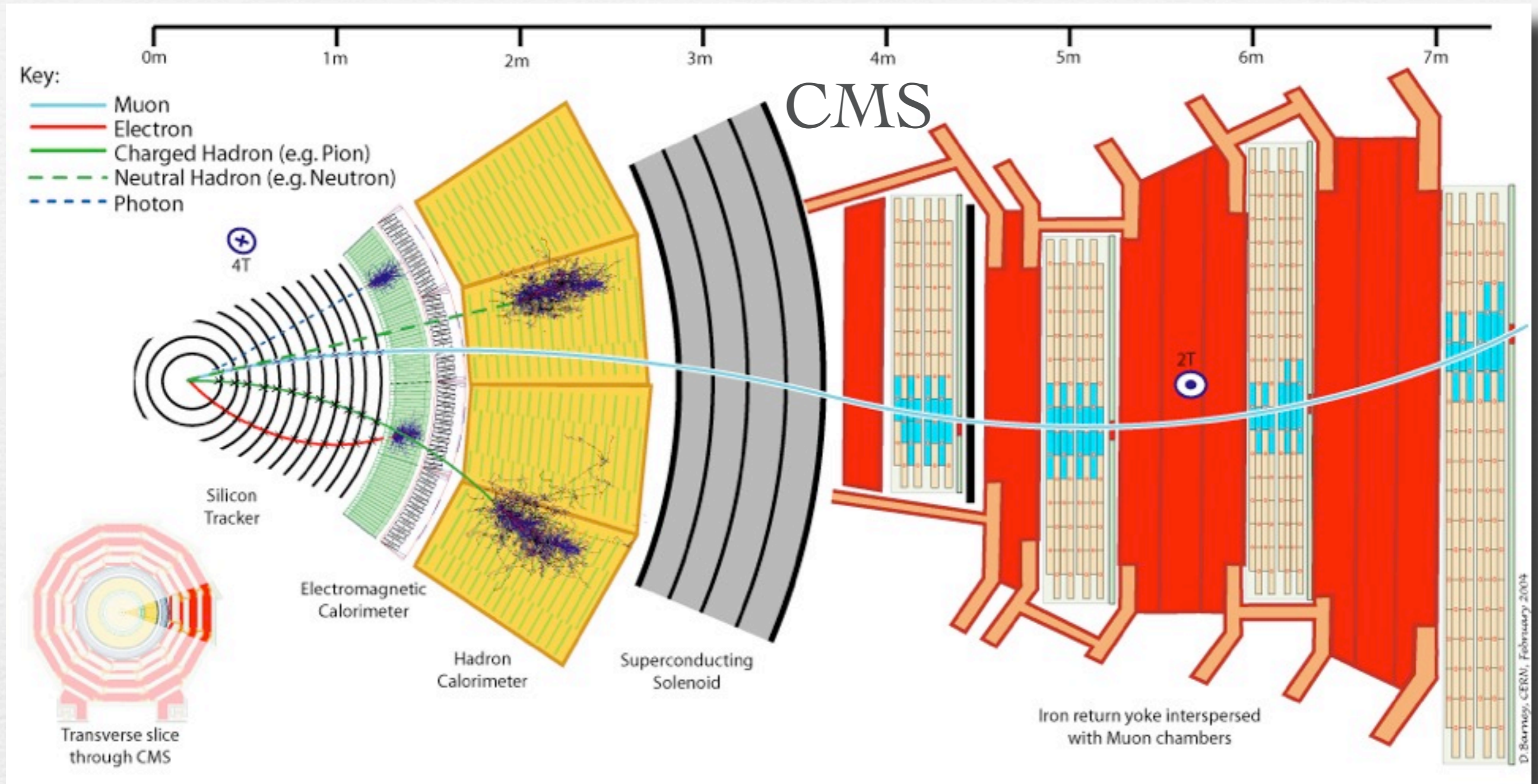
~100 million readout channels, every 25 ns





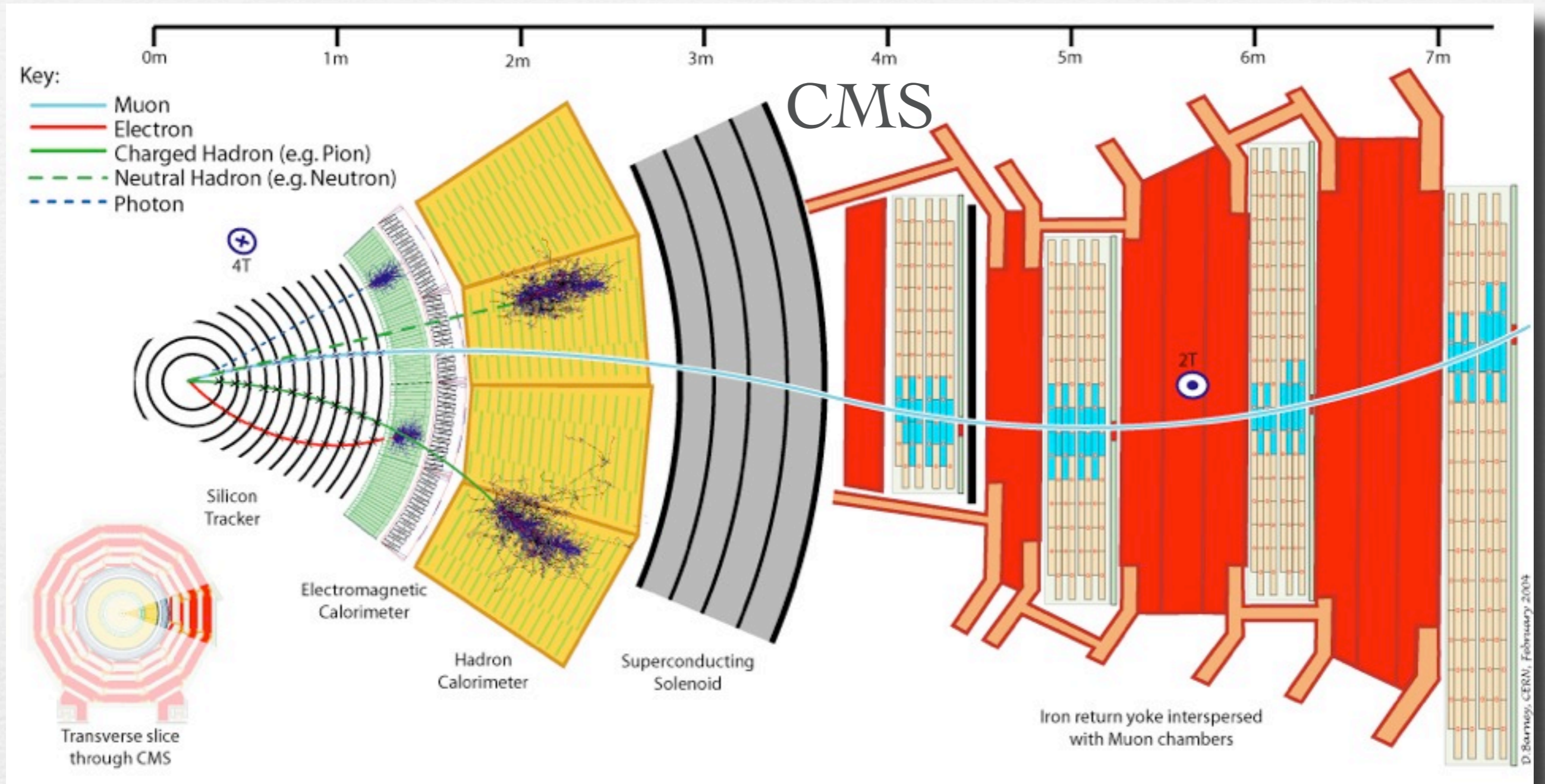


After zeroes removed, 1.6 MB / event



After zeroes removed, 1.6 MB / event

* 40 M events / s = 64 TB / s ?



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* 40 M events / s = 64 TB / s ?

Can't save everything

Trigger system to keep only interesting events

	Incoming event rate per second	Outgoing event rate per second	Reduction factor
Level 1	40 000 000	100 000	400
Level 2	100 000	3 000	30
Level 3	3 000	200	15

Trigger system to keep only interesting events

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$$200 \text{ events / s} * 1.6 \text{ MB / event} = 320 \text{ MB / s}$$

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$$= \sim 3200 \text{ TB / year raw data}$$

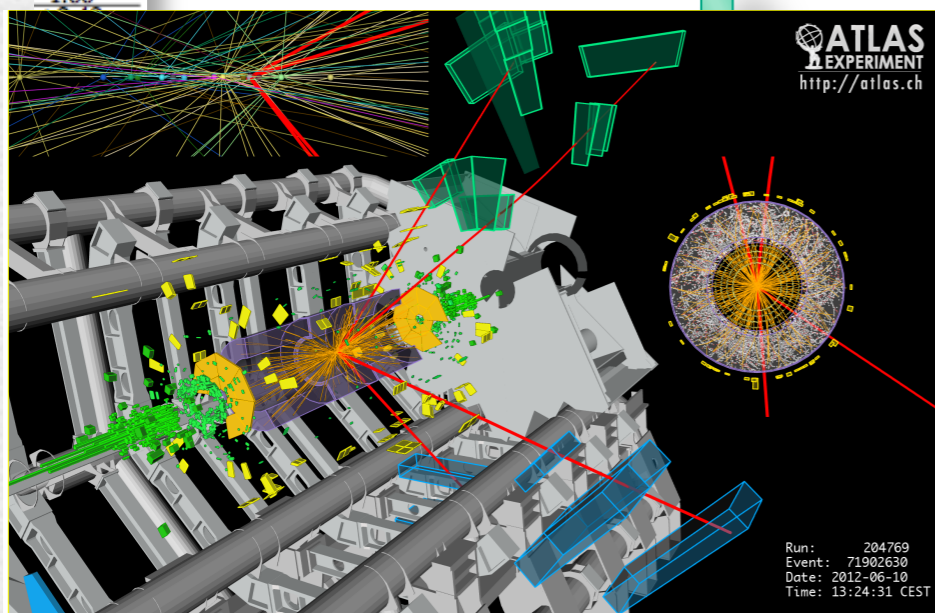
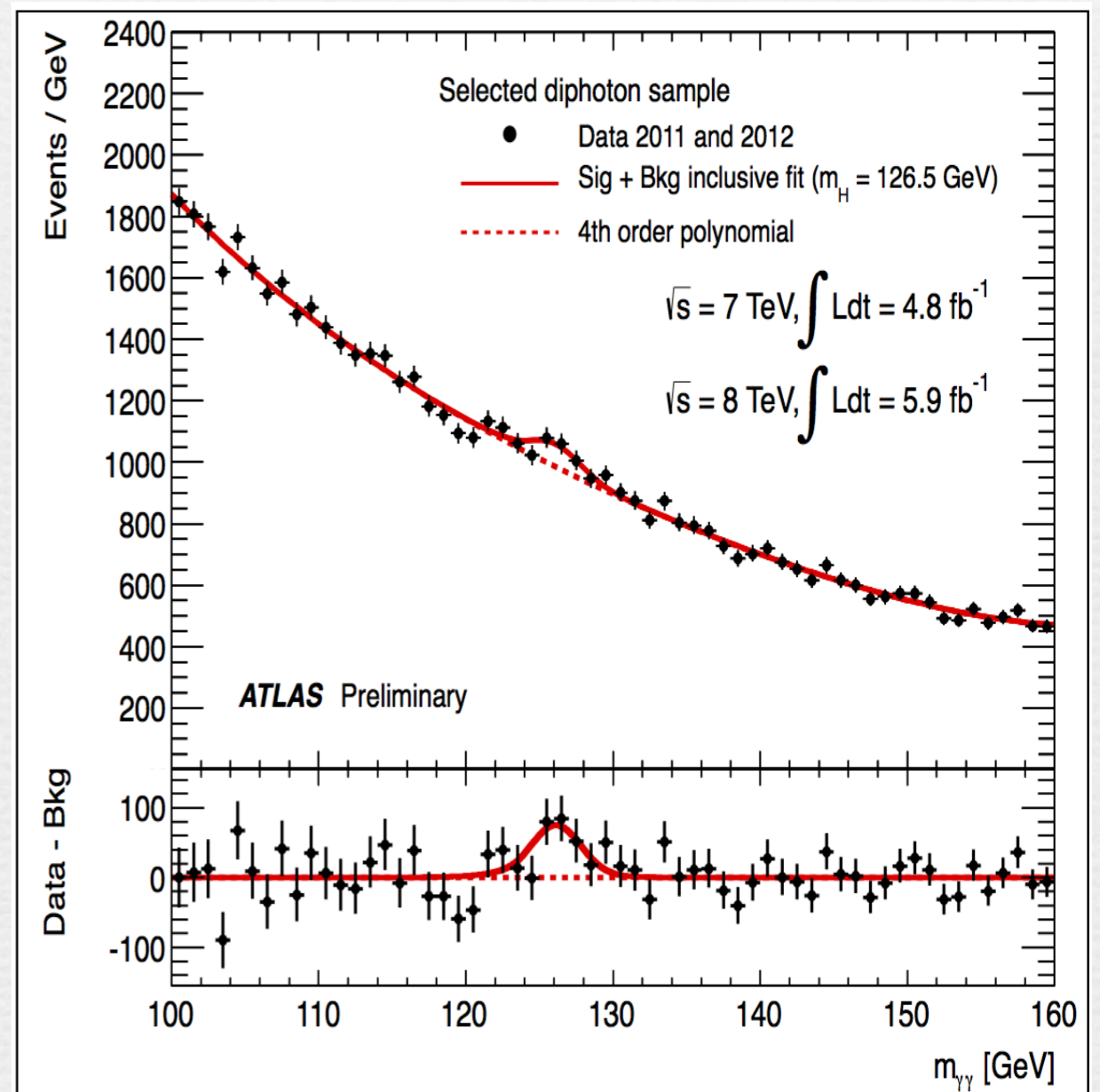
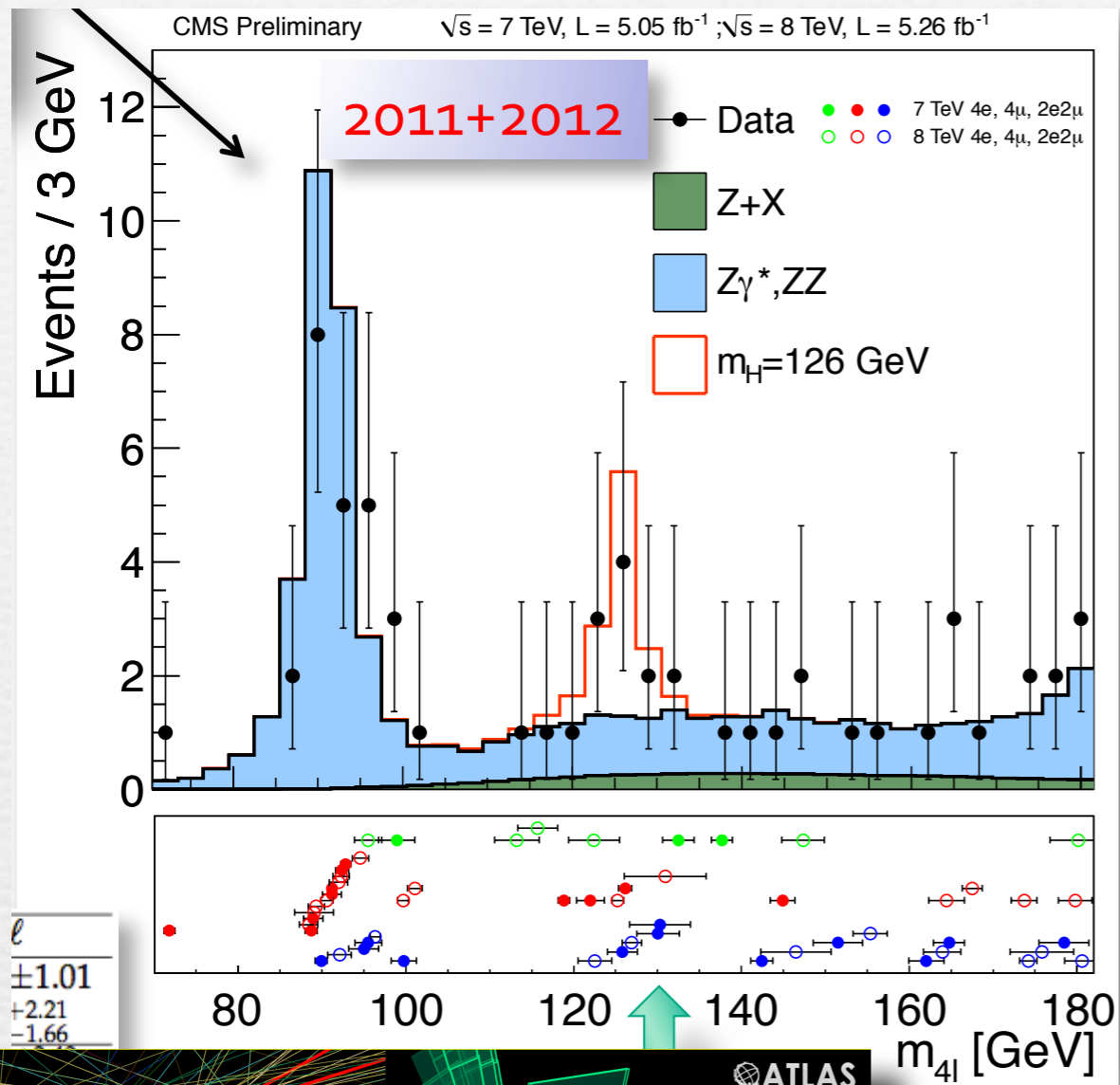
Trigger system to keep only interesting events

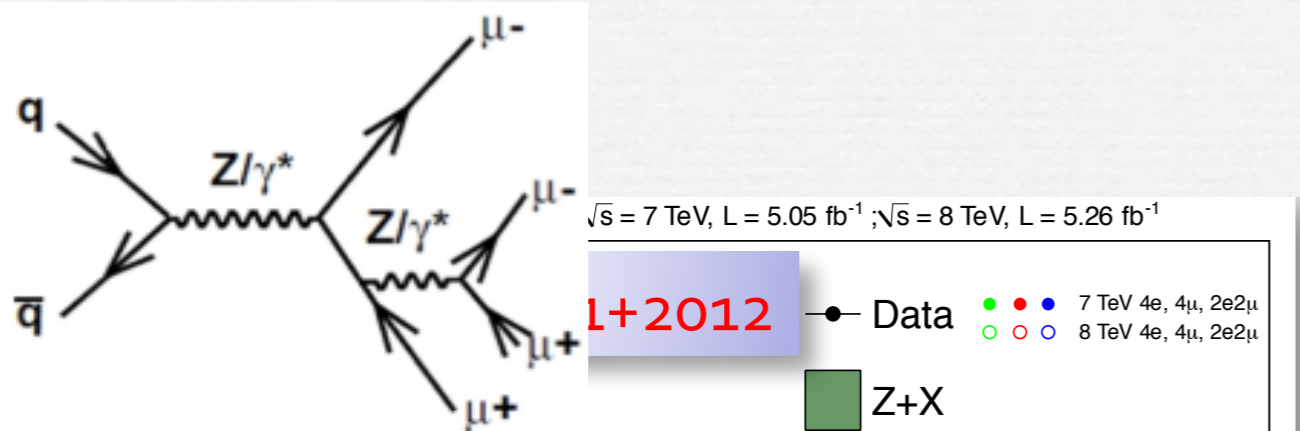
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Analysis is done offline,
~3000 collaboration members should have
equal access to data worldwide

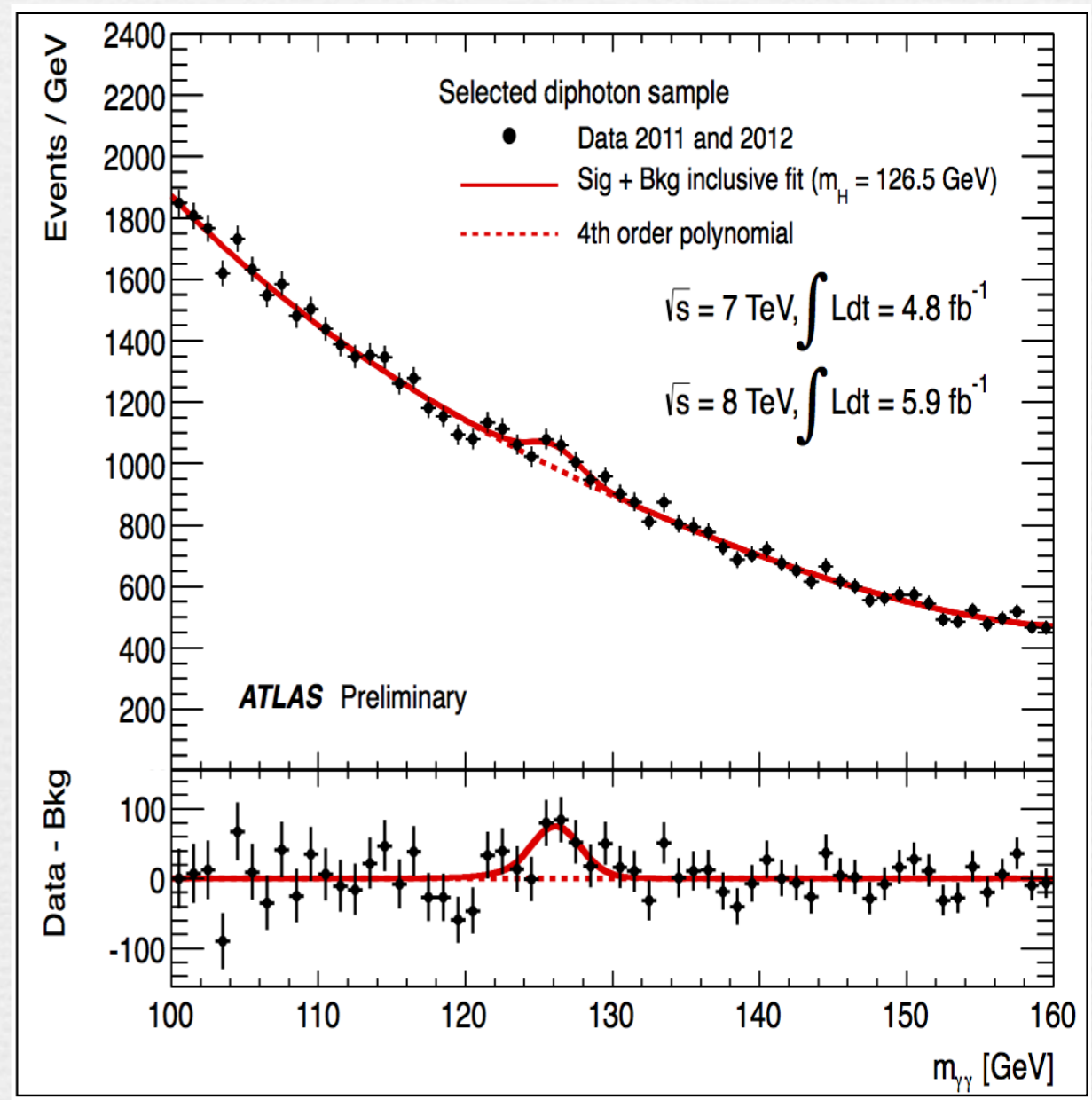
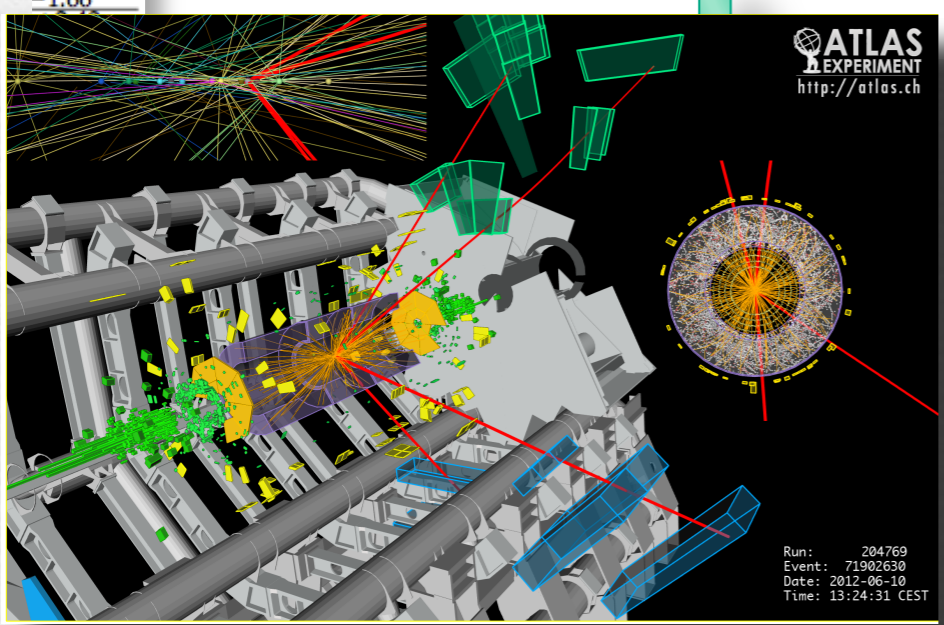
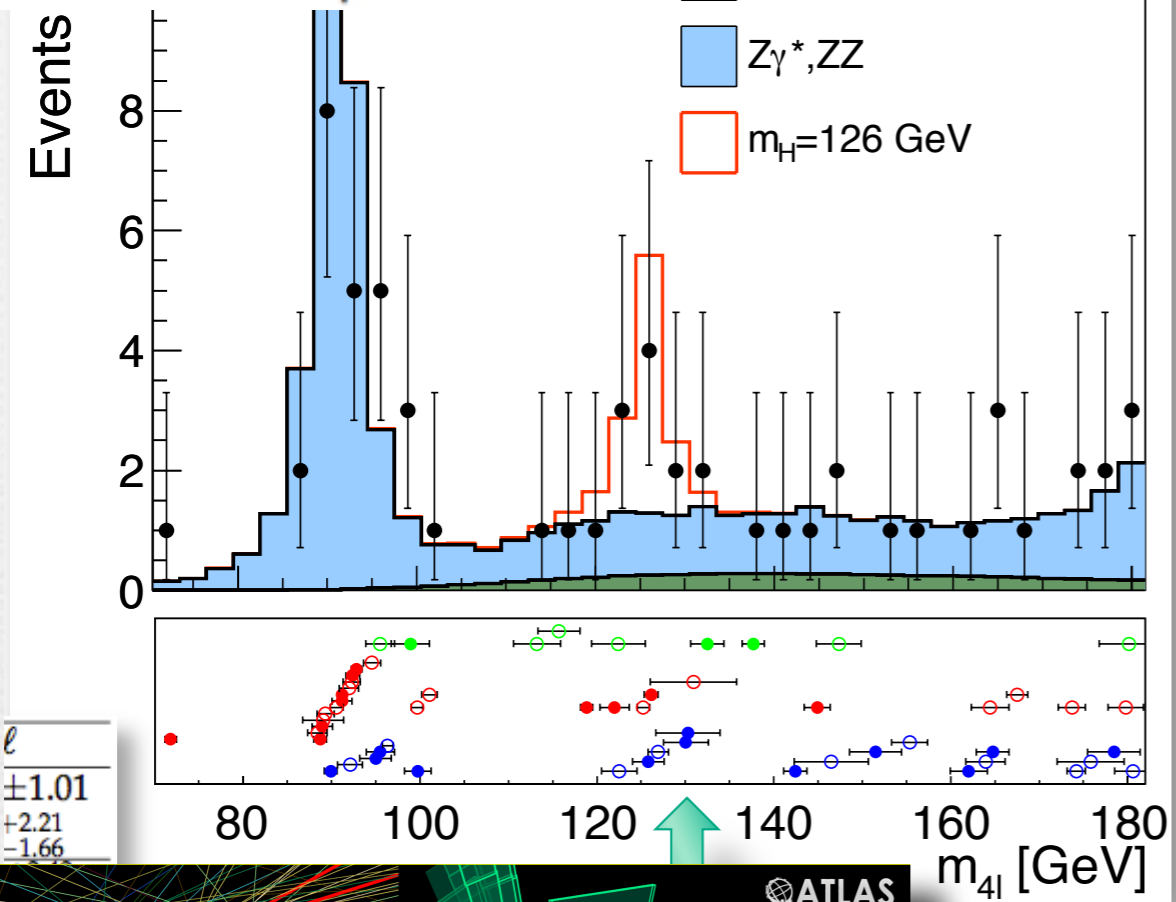


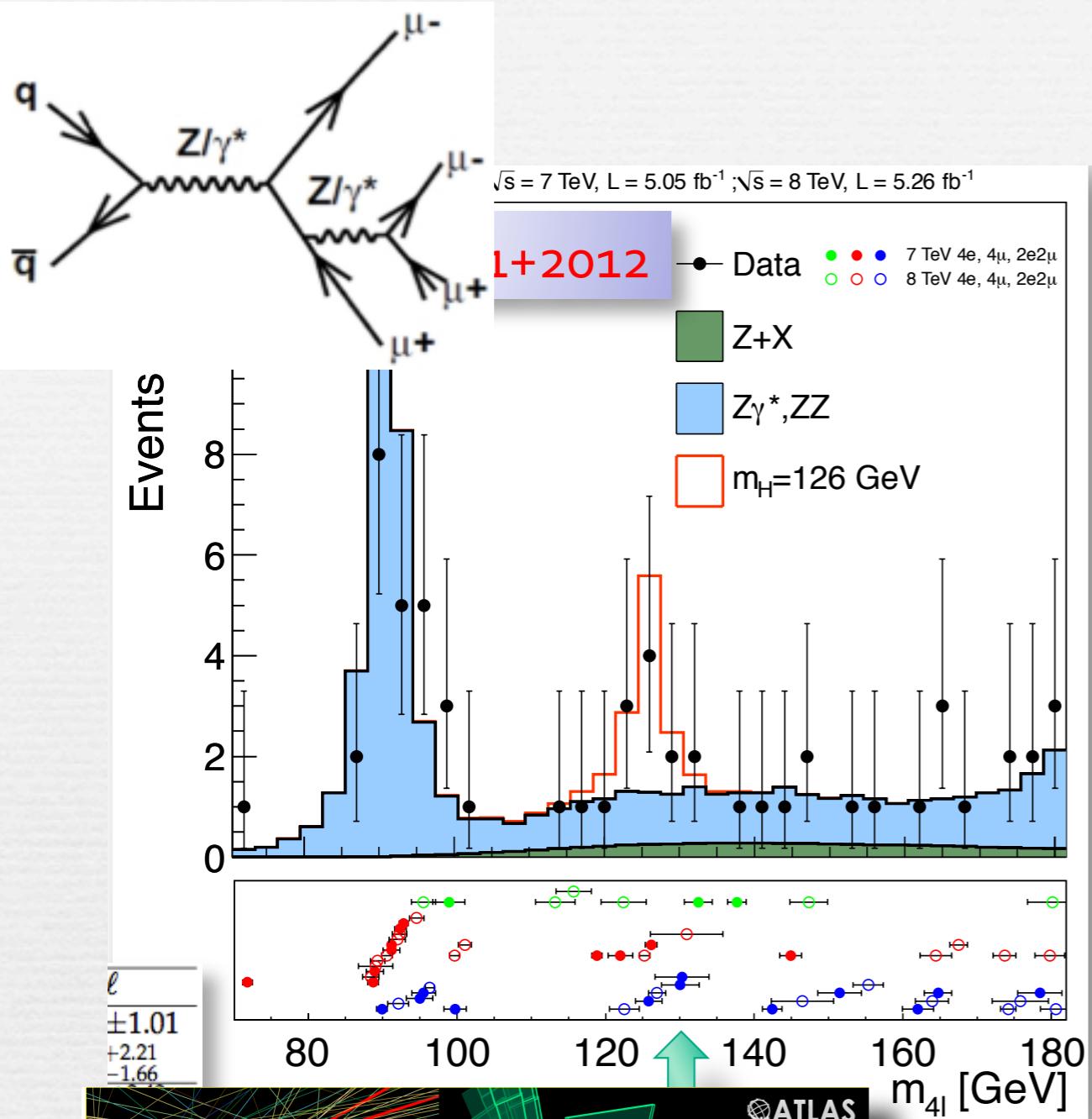


1+2012

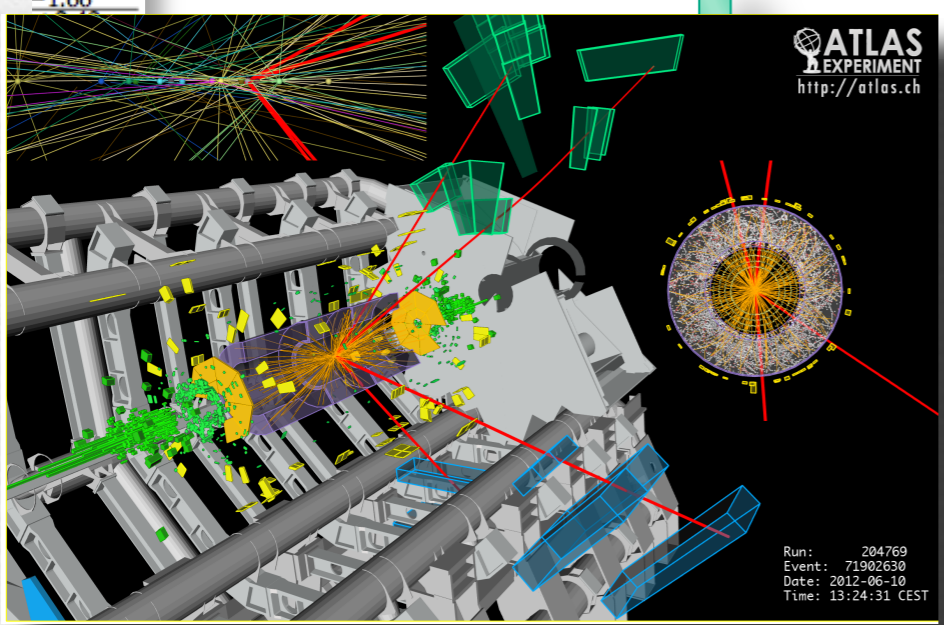
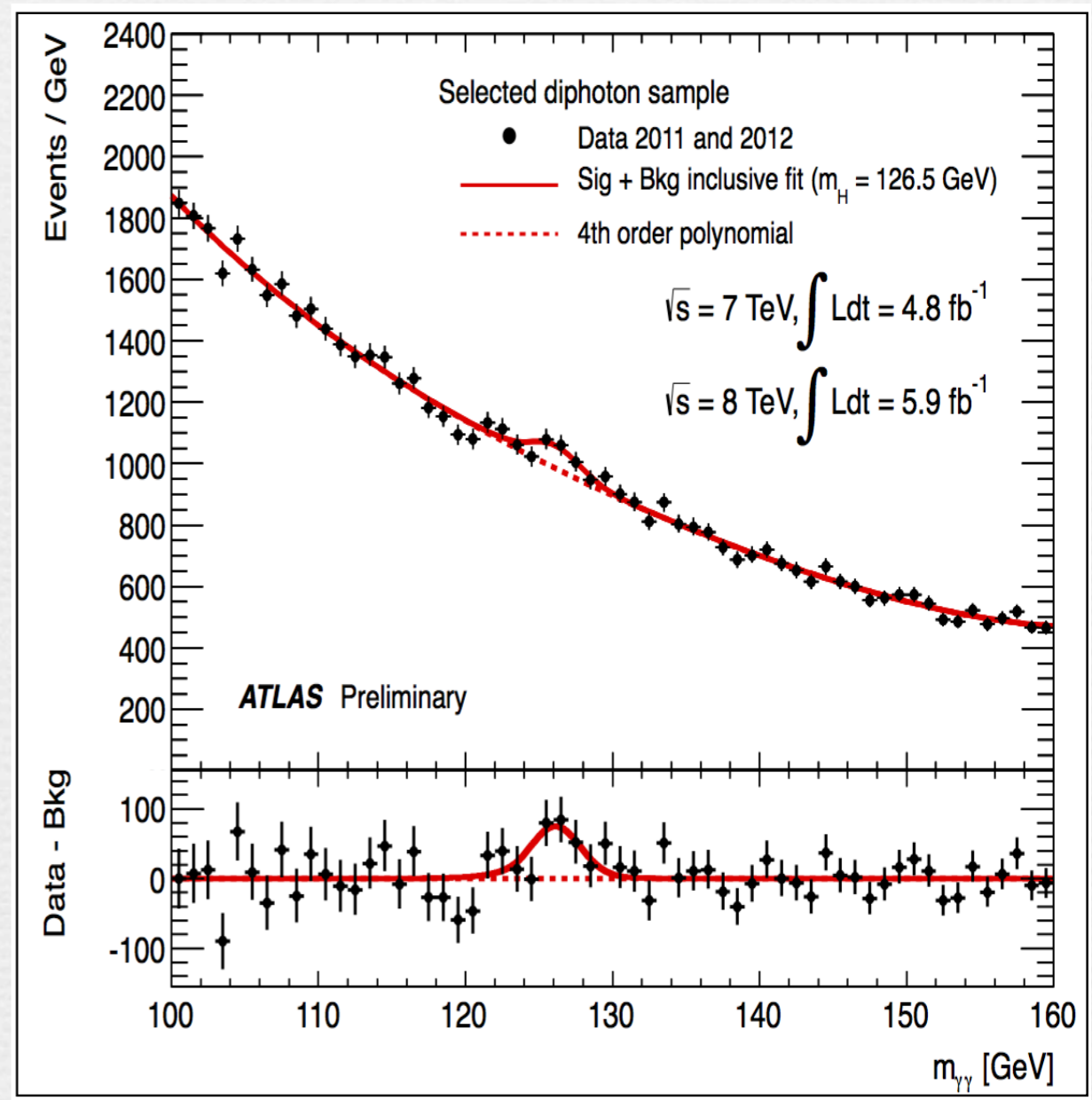
- Data
- 7 TeV 4e, 4\mu, 2e2\mu
- 8 TeV 4e, 4\mu, 2e2\mu

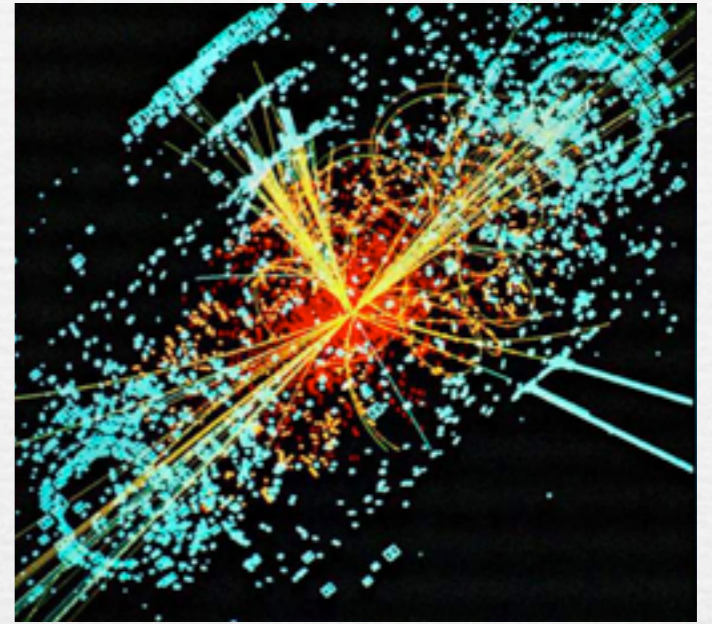
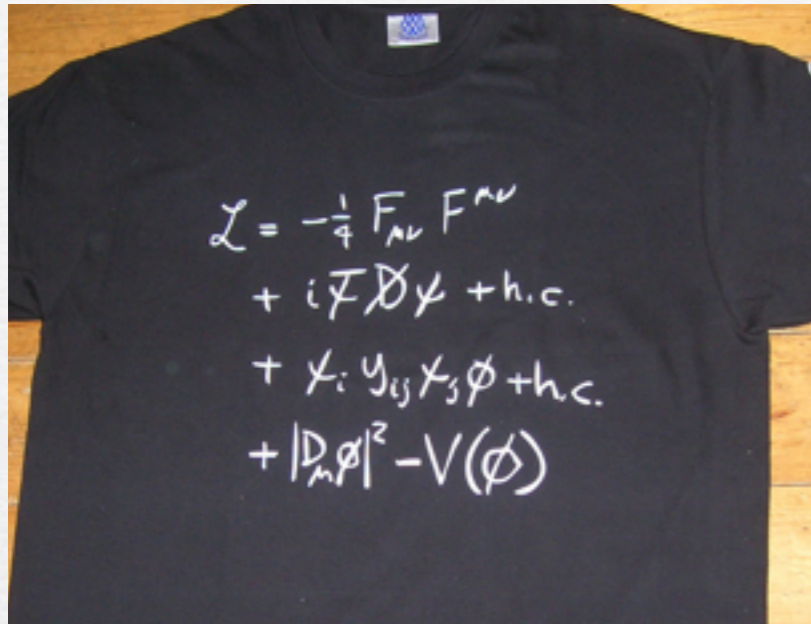
- Z+X
- $Z\gamma^*, ZZ$
- $m_H = 126 \text{ GeV}$

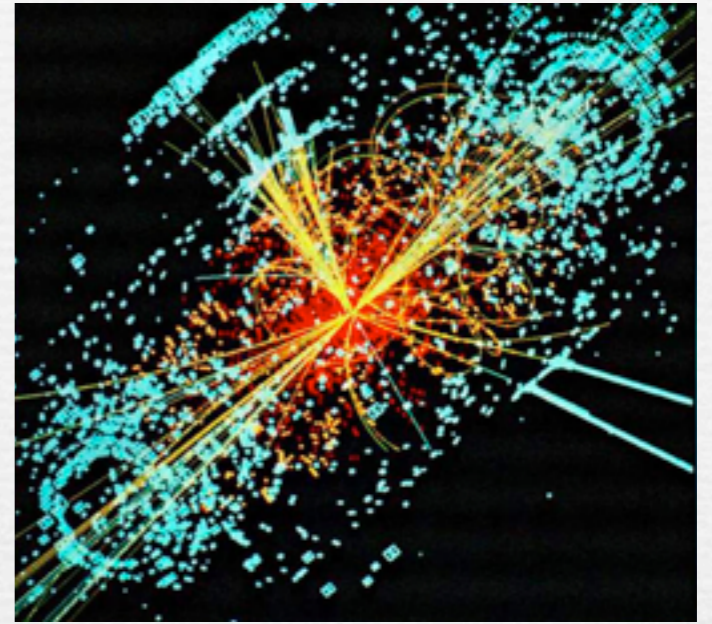
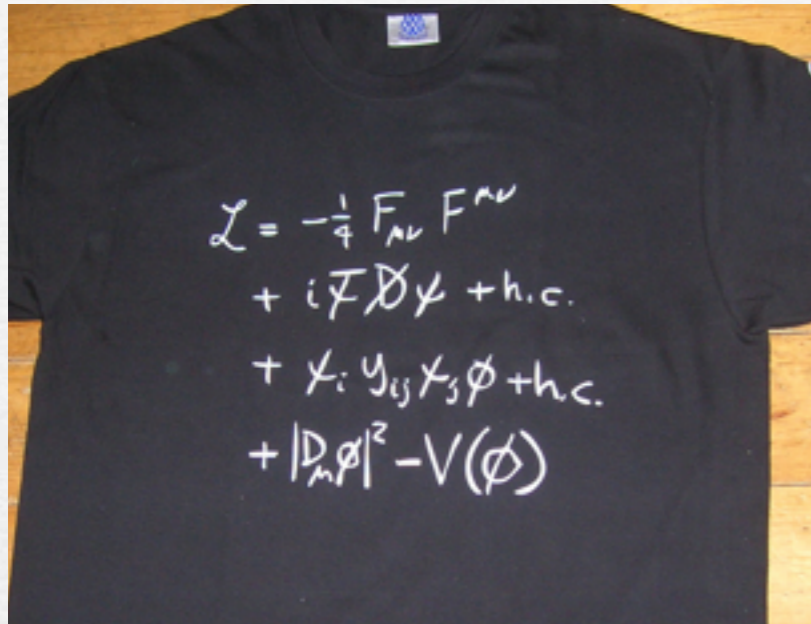


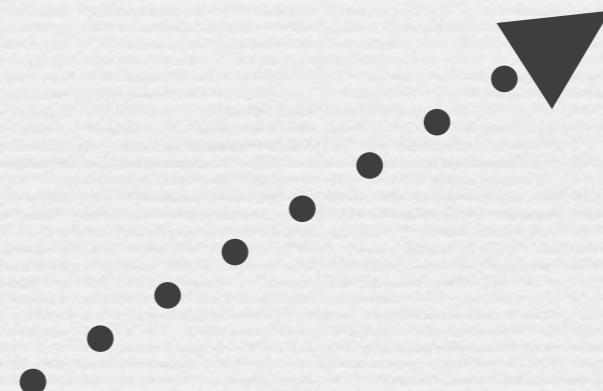
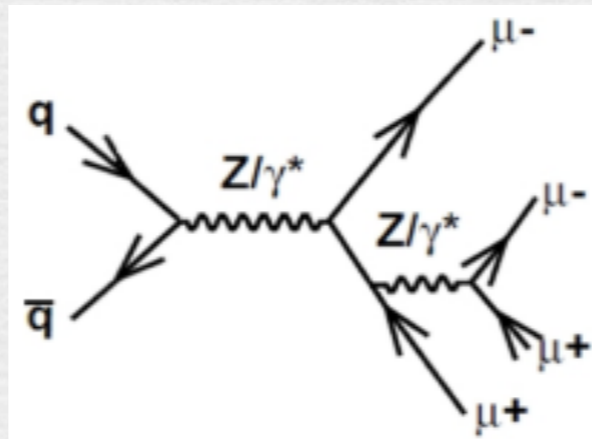
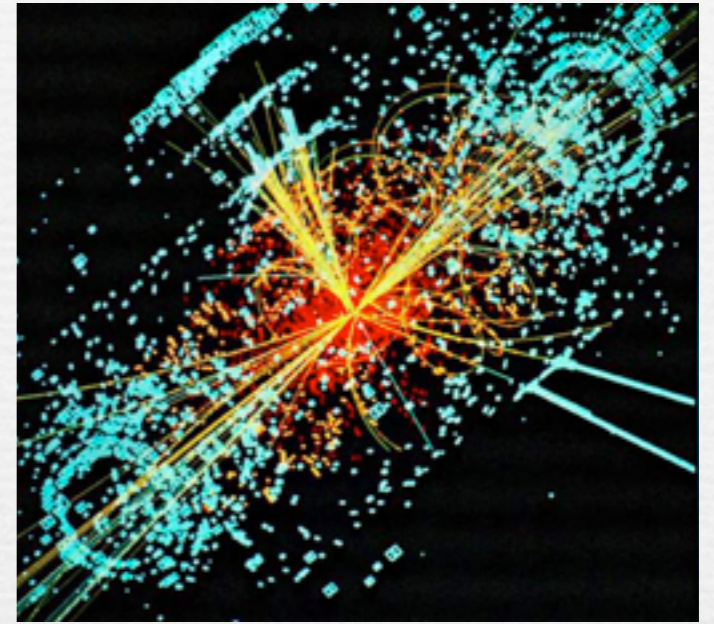
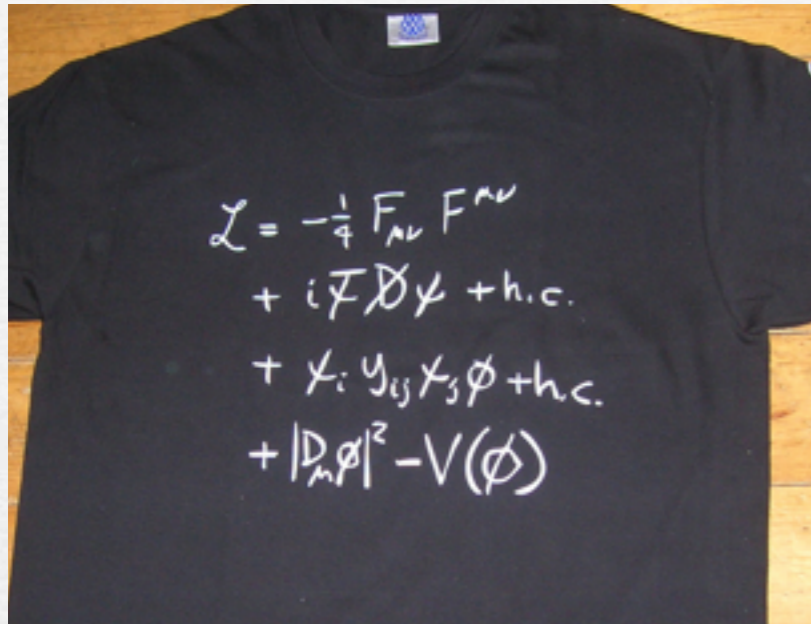


Need to get theory predictions.









Monte Carlo event generators

Nature

Detector

Trigger

Reconstructed
events

Analysis

Theory model

Event generator

Simulated
events

Event generator

Matrix element

Parton shower

Hadronization

Decays

Event generator

Matrix element

Monte-Carlo integration

Parton shower

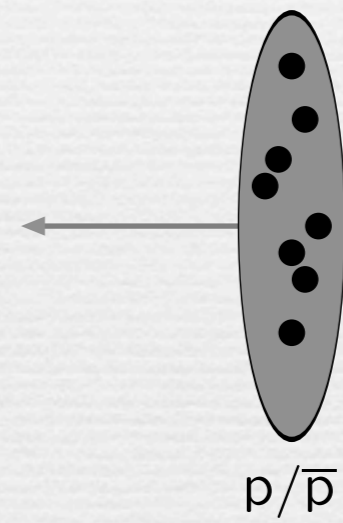
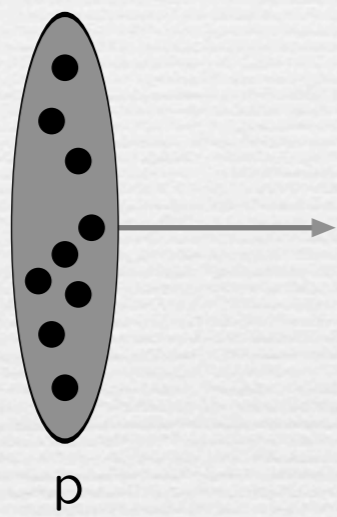
Markov chain

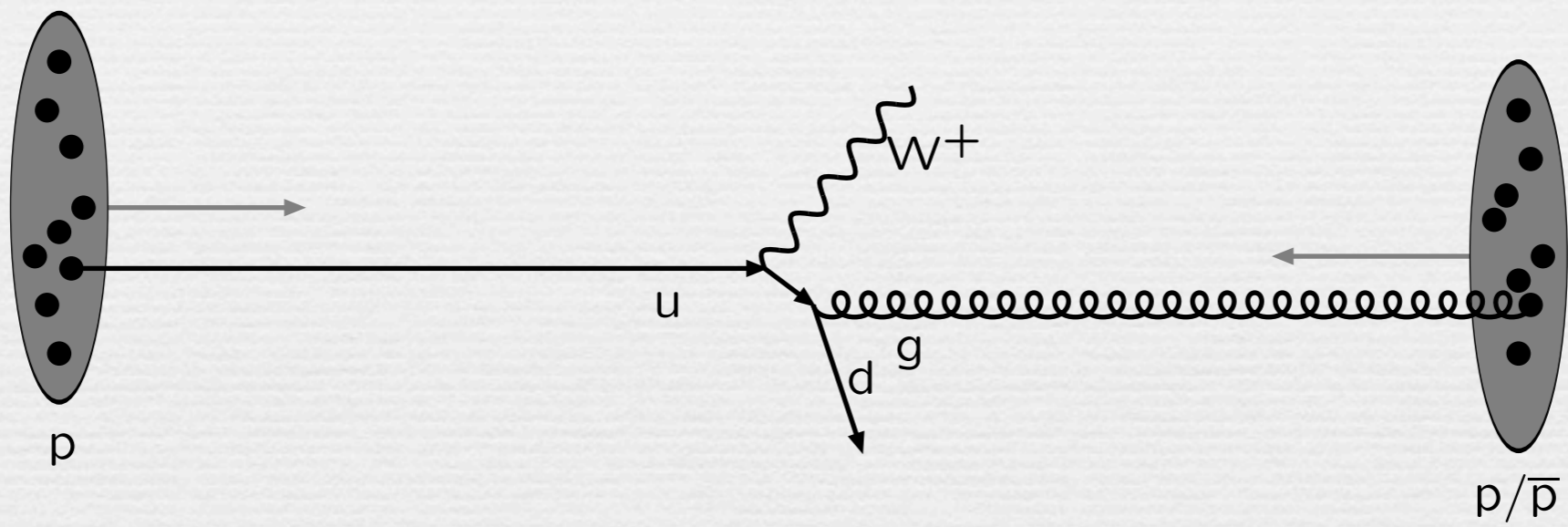
Hadronization

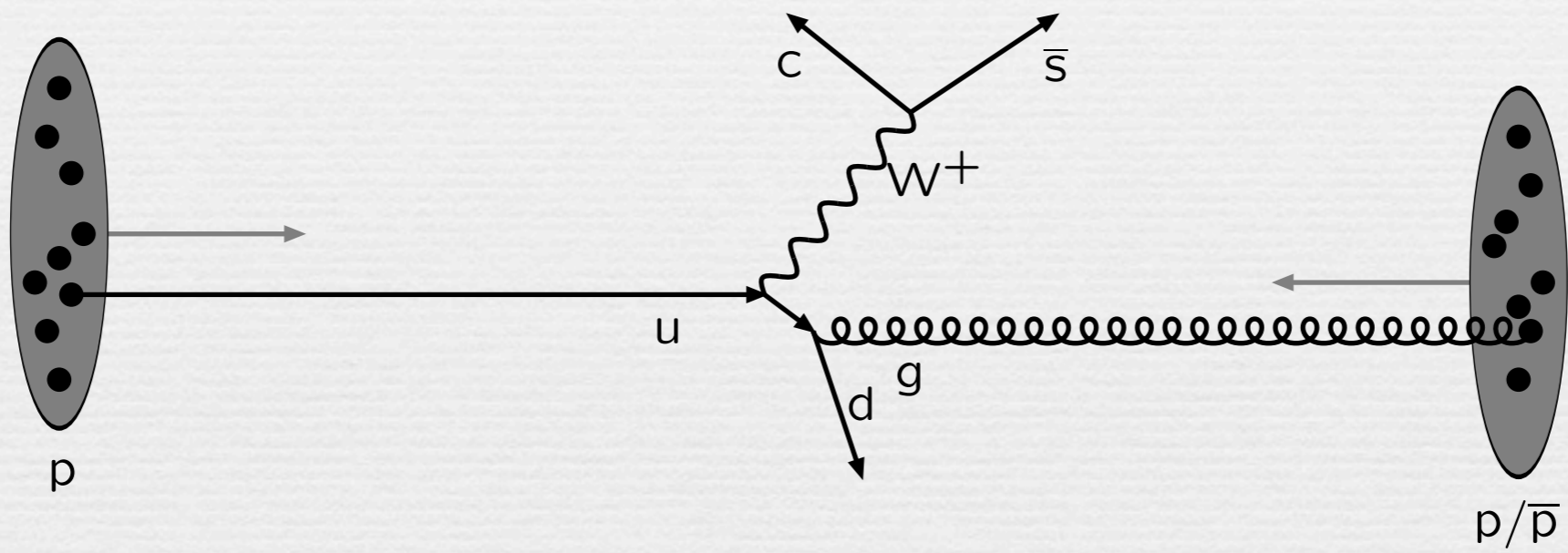
book-keeping

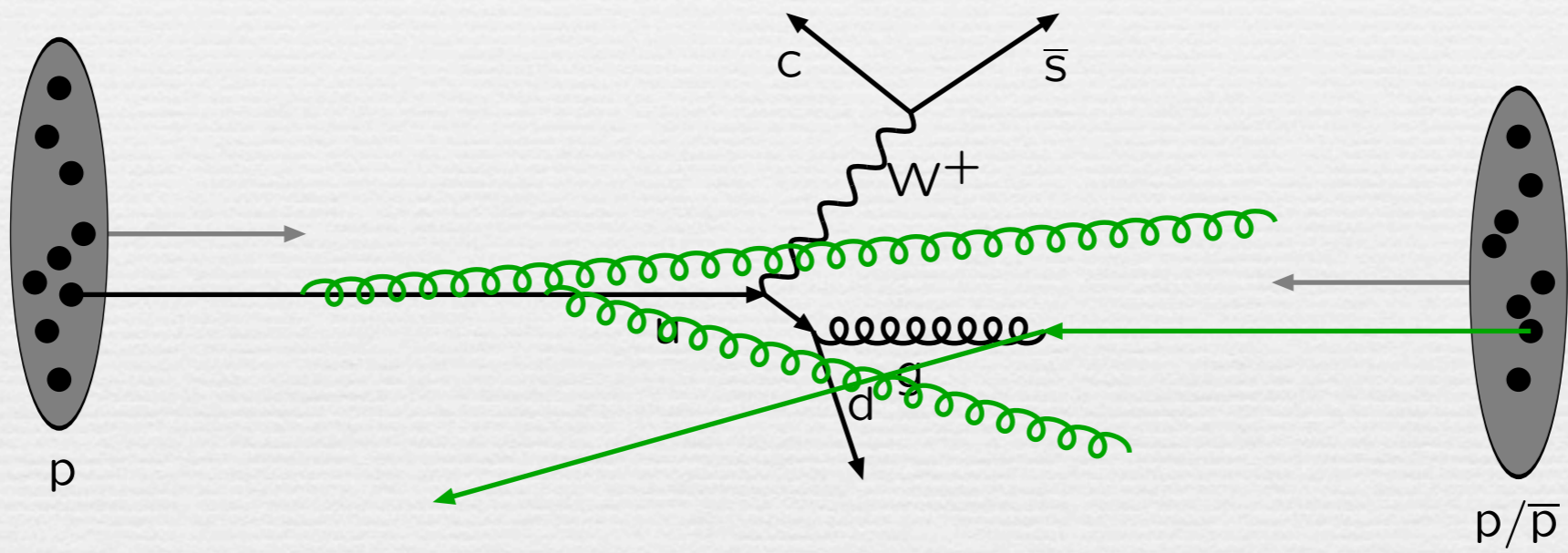
Decays

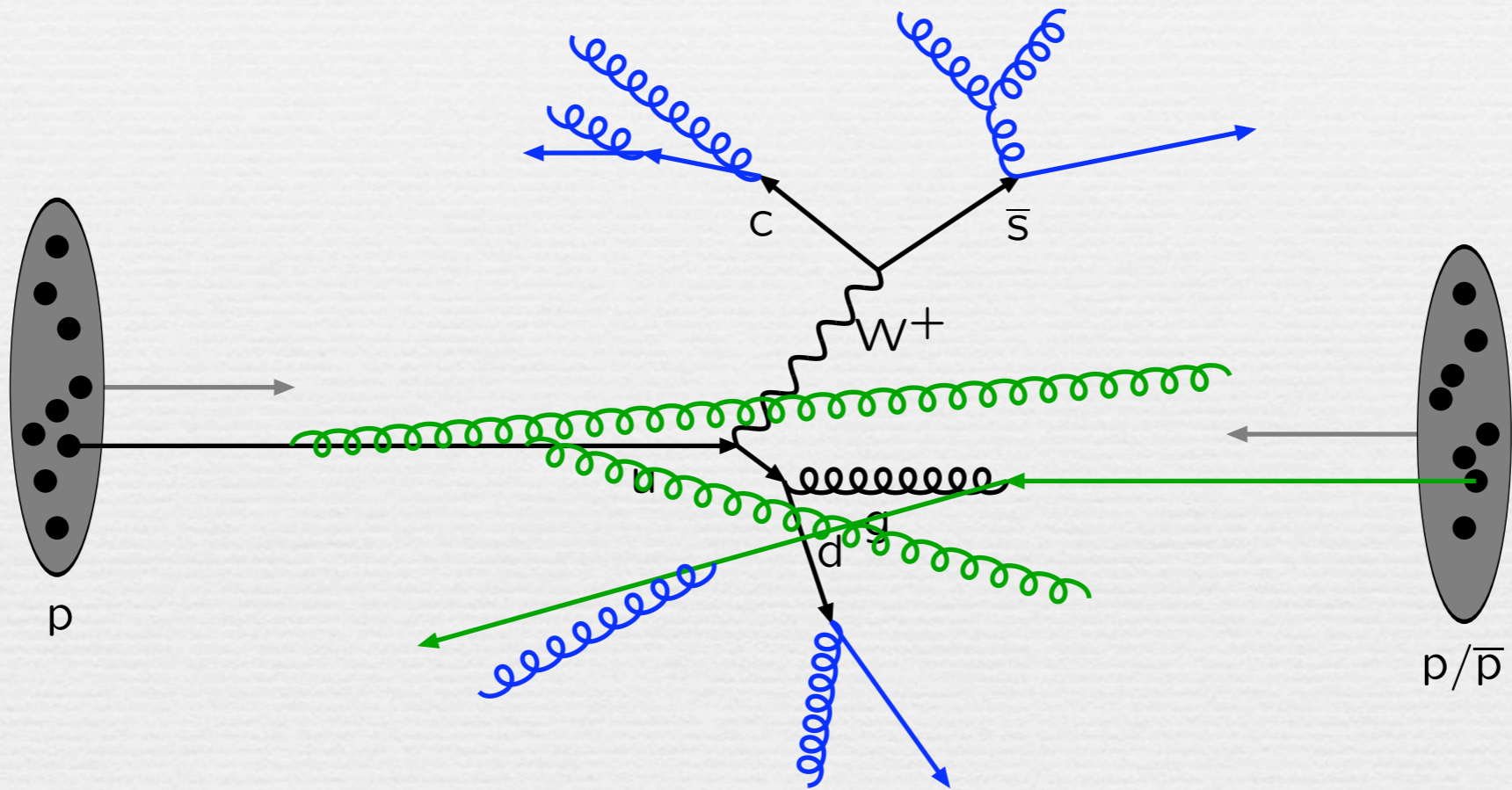
Monte-Carlo integration

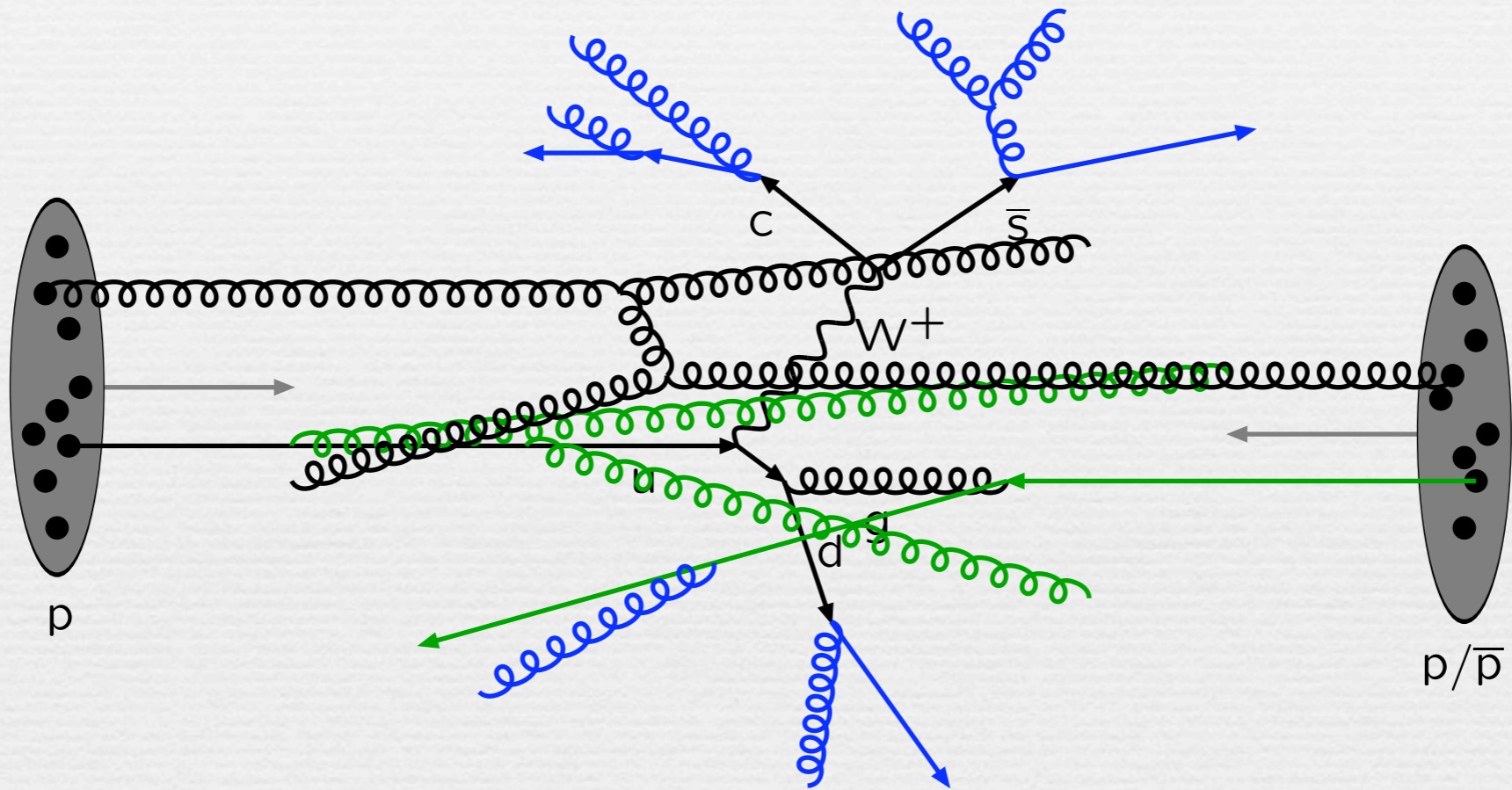


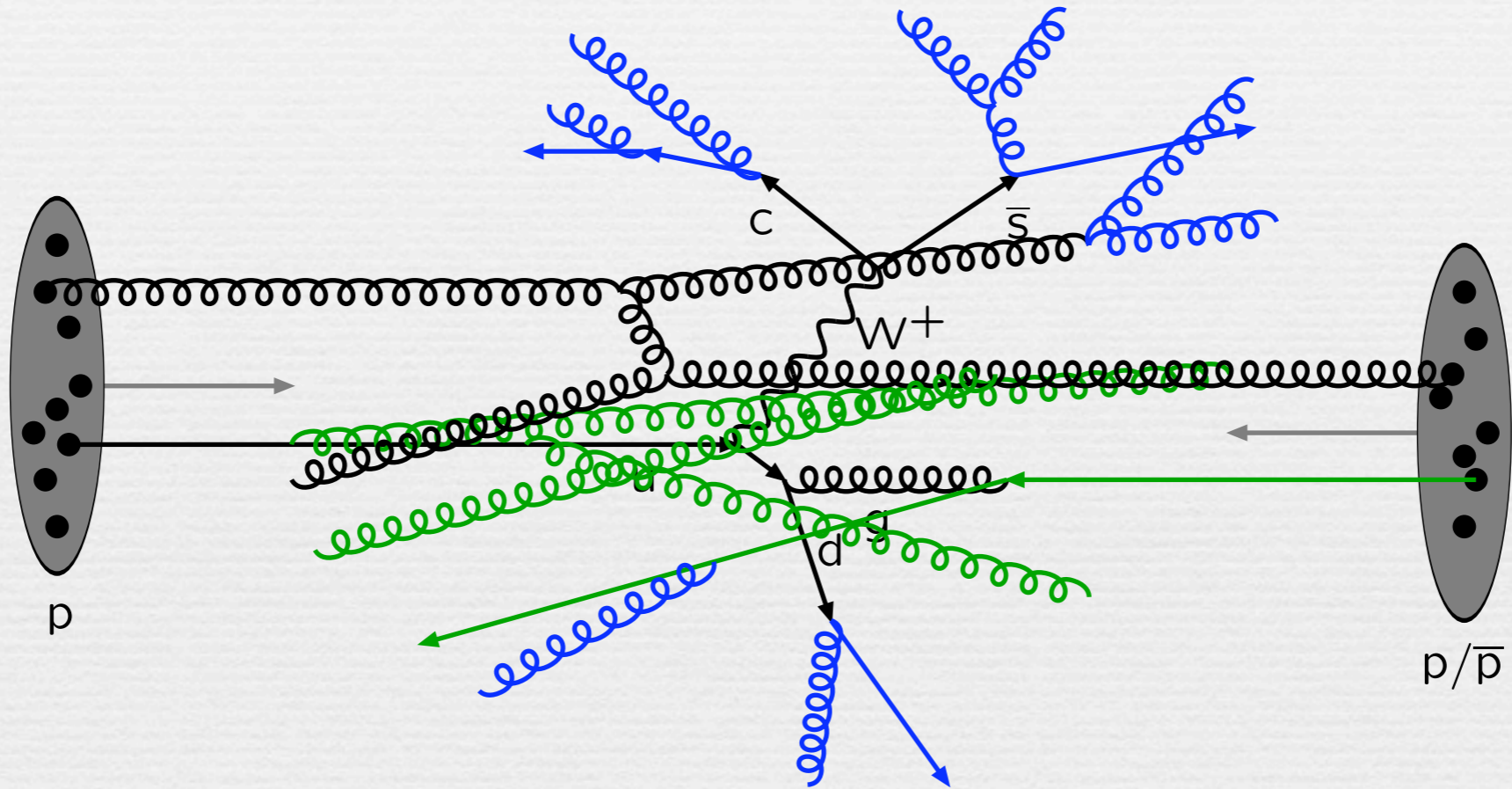


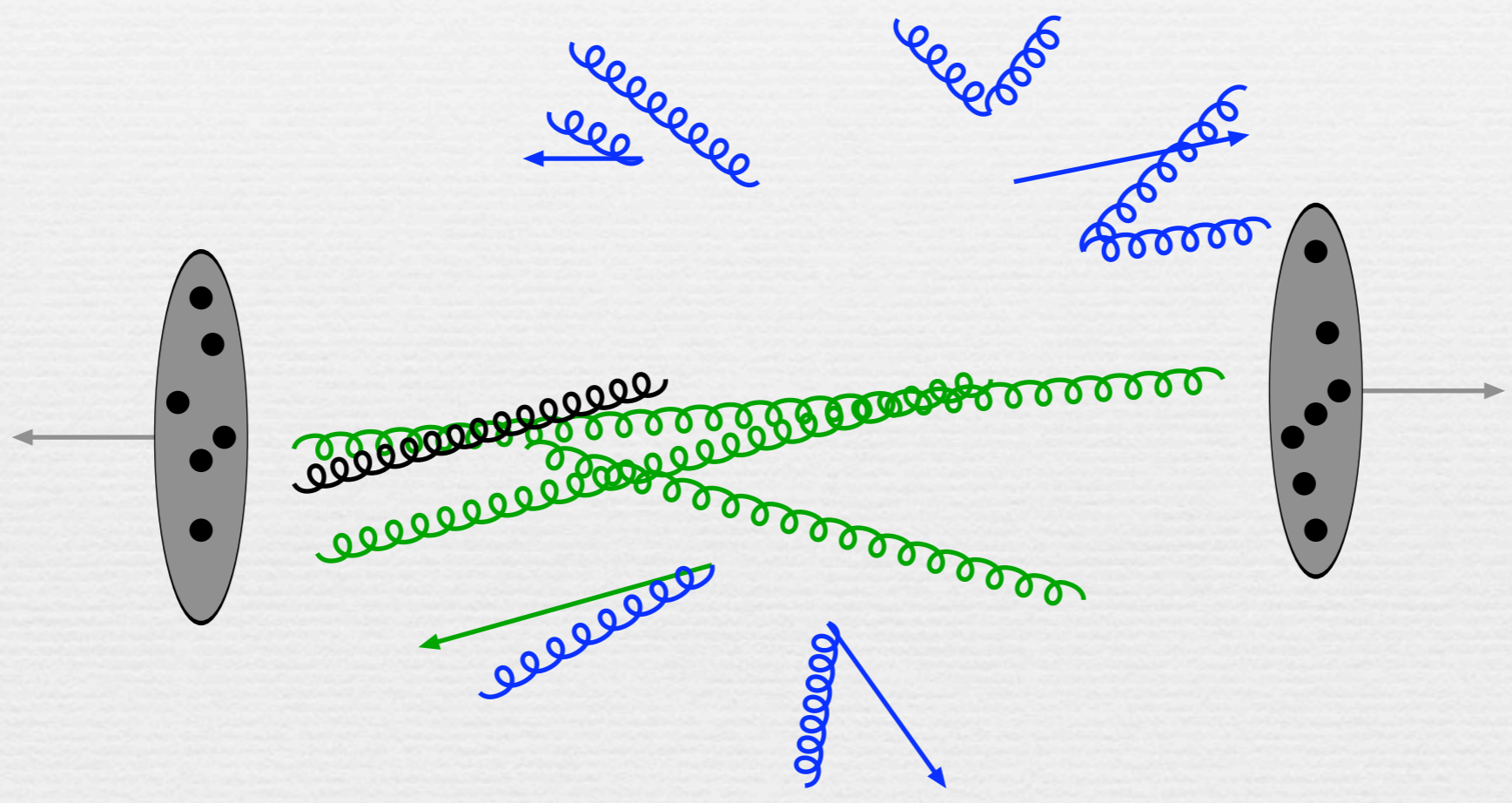


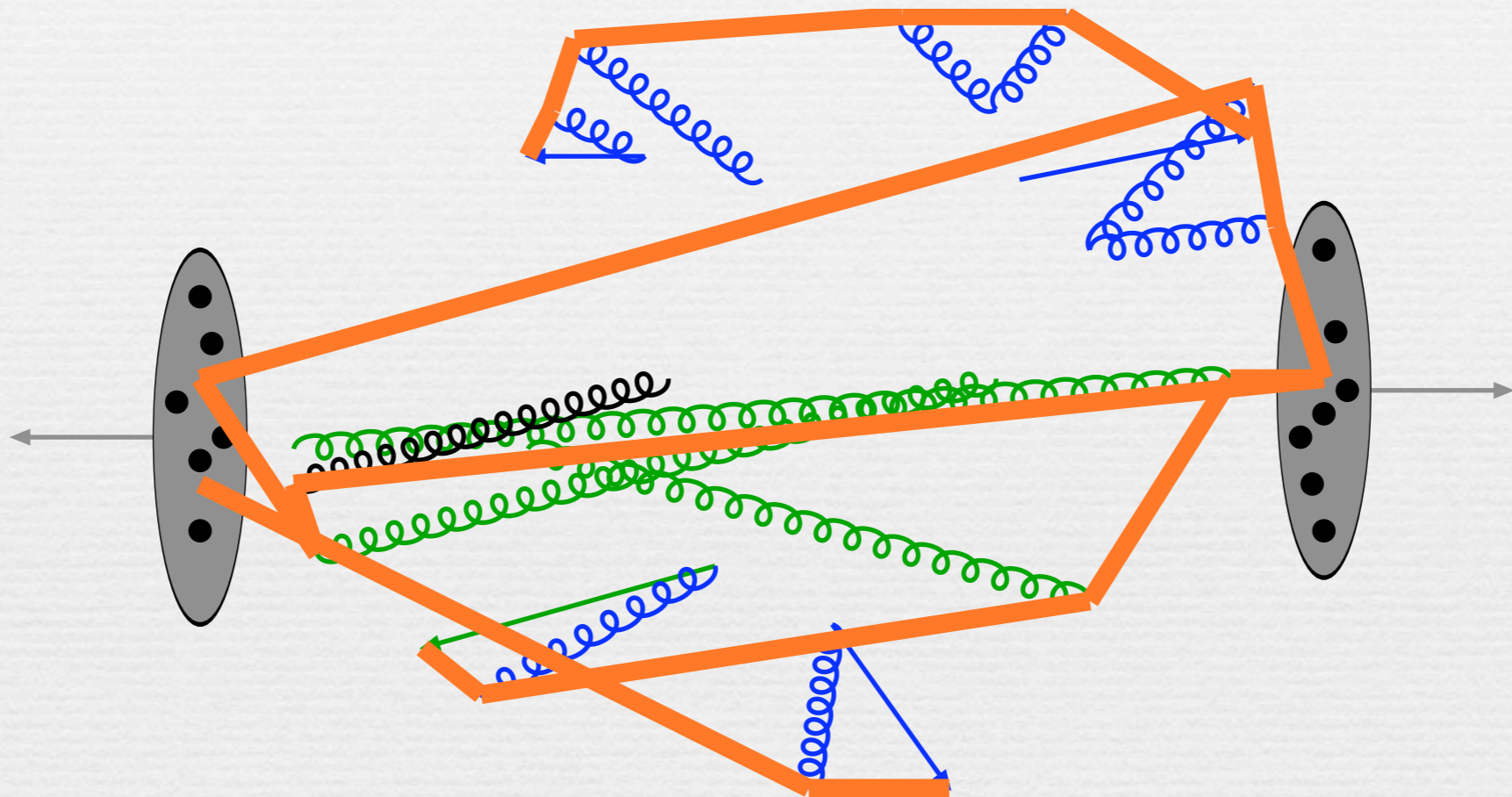


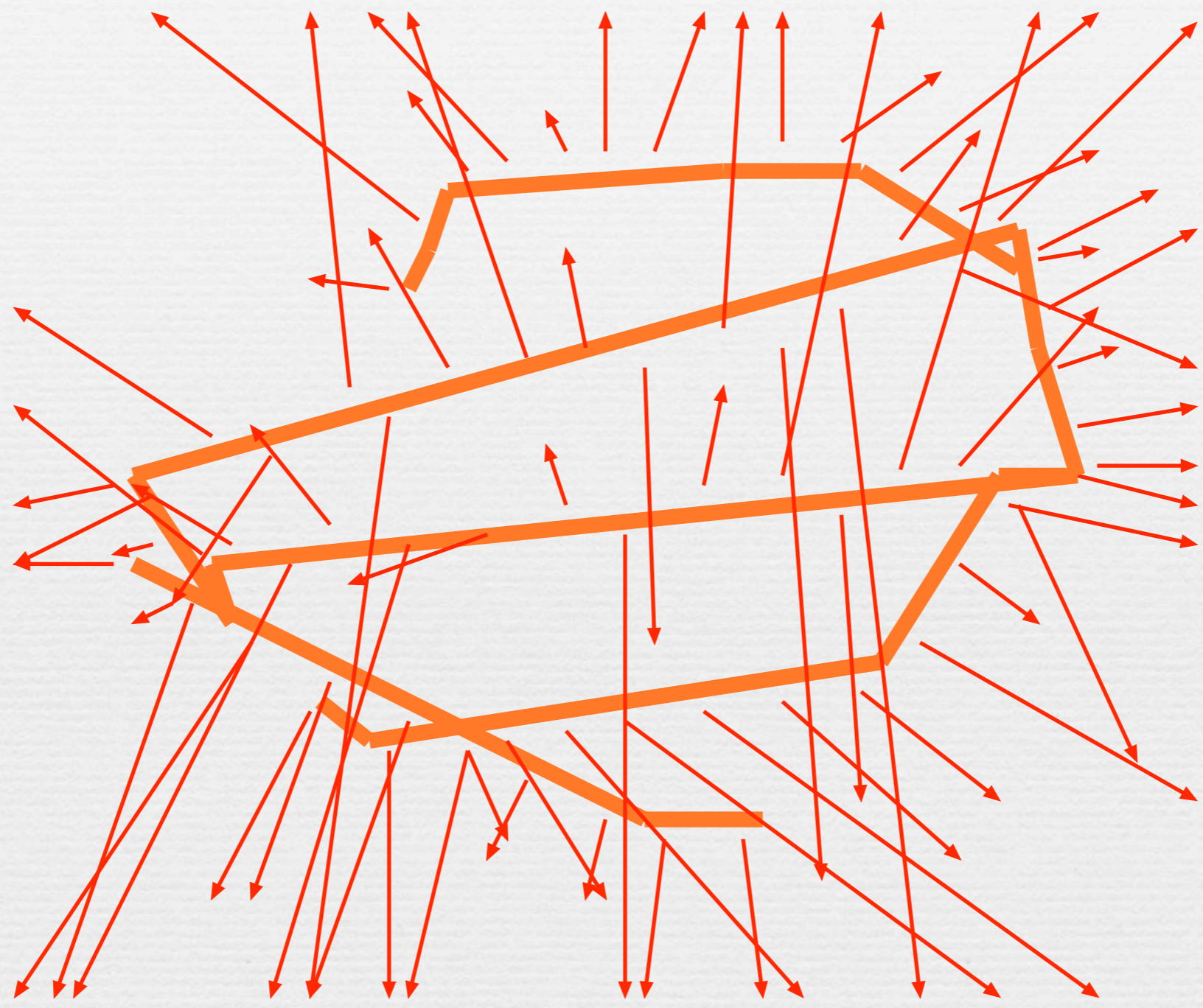


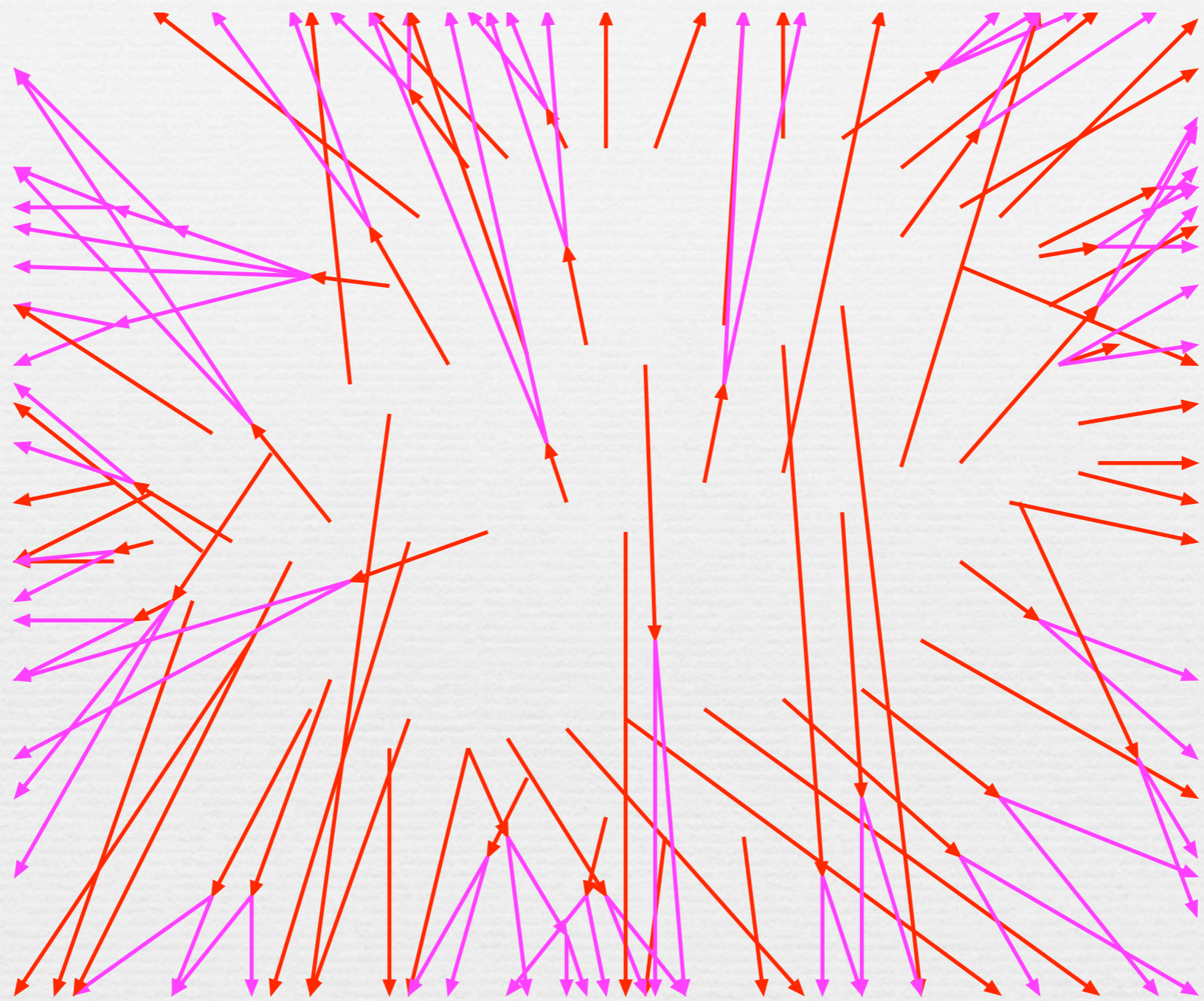


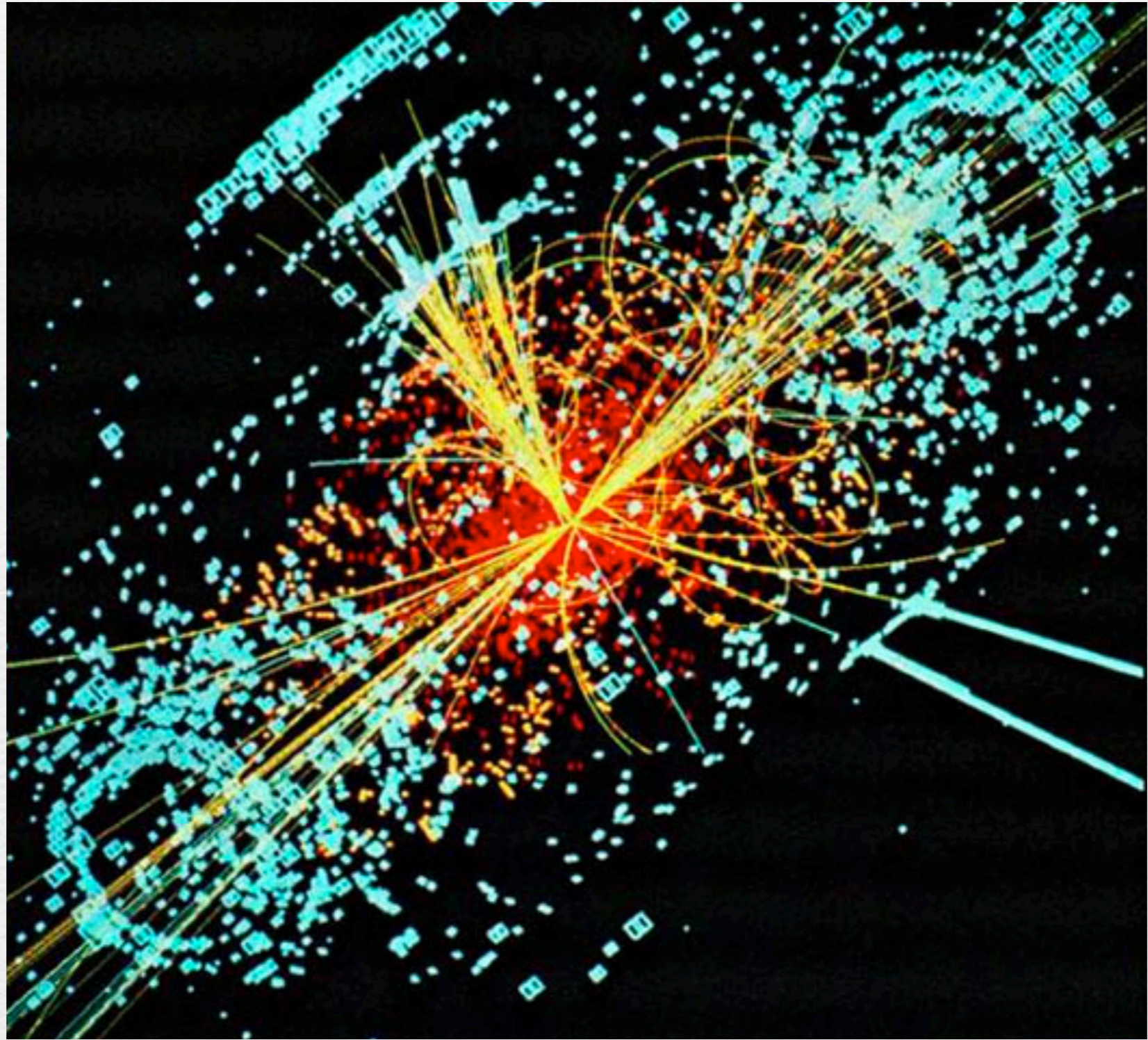


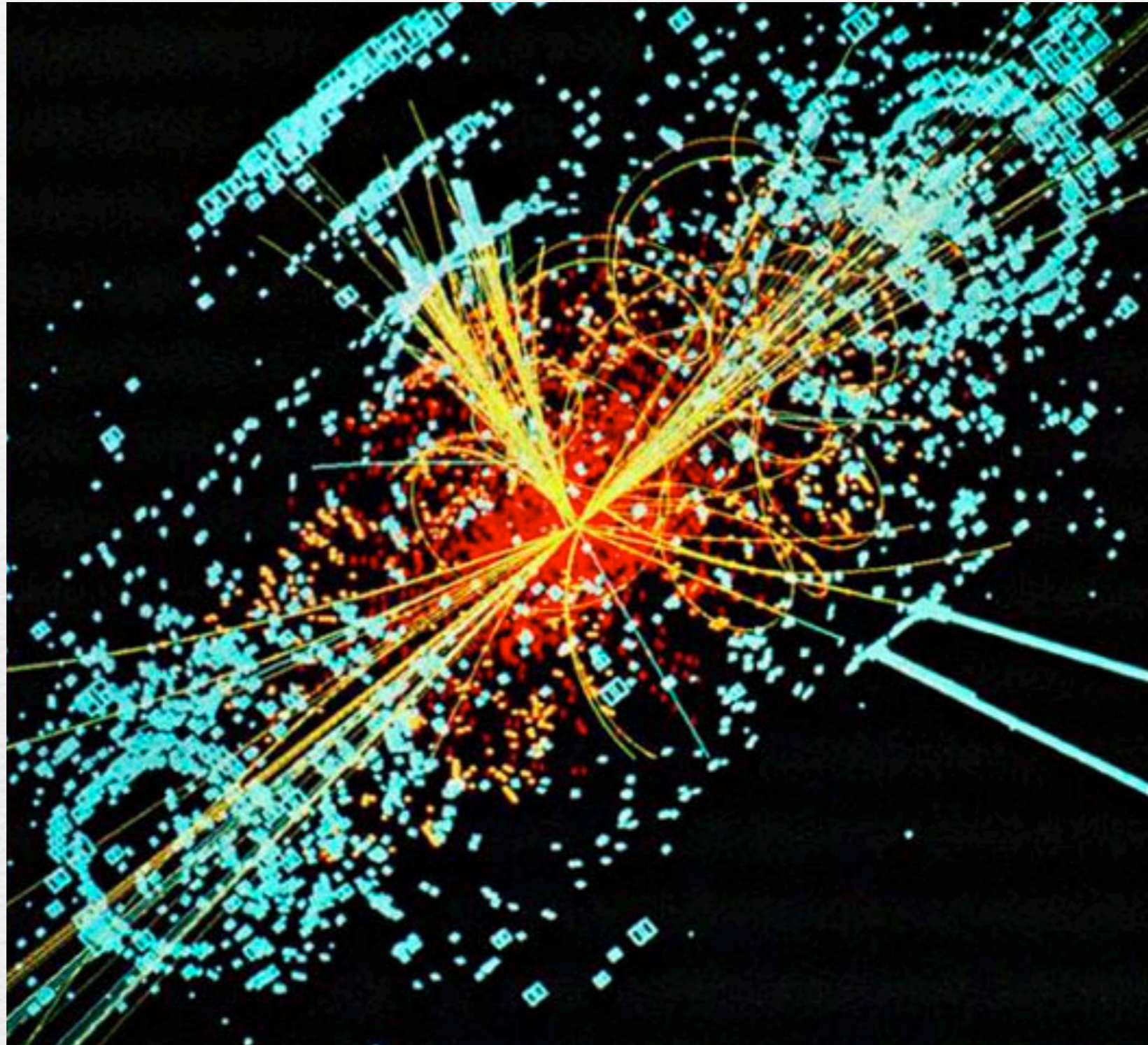












Simulated data sets of millions of events

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need millions!
~15 s per event

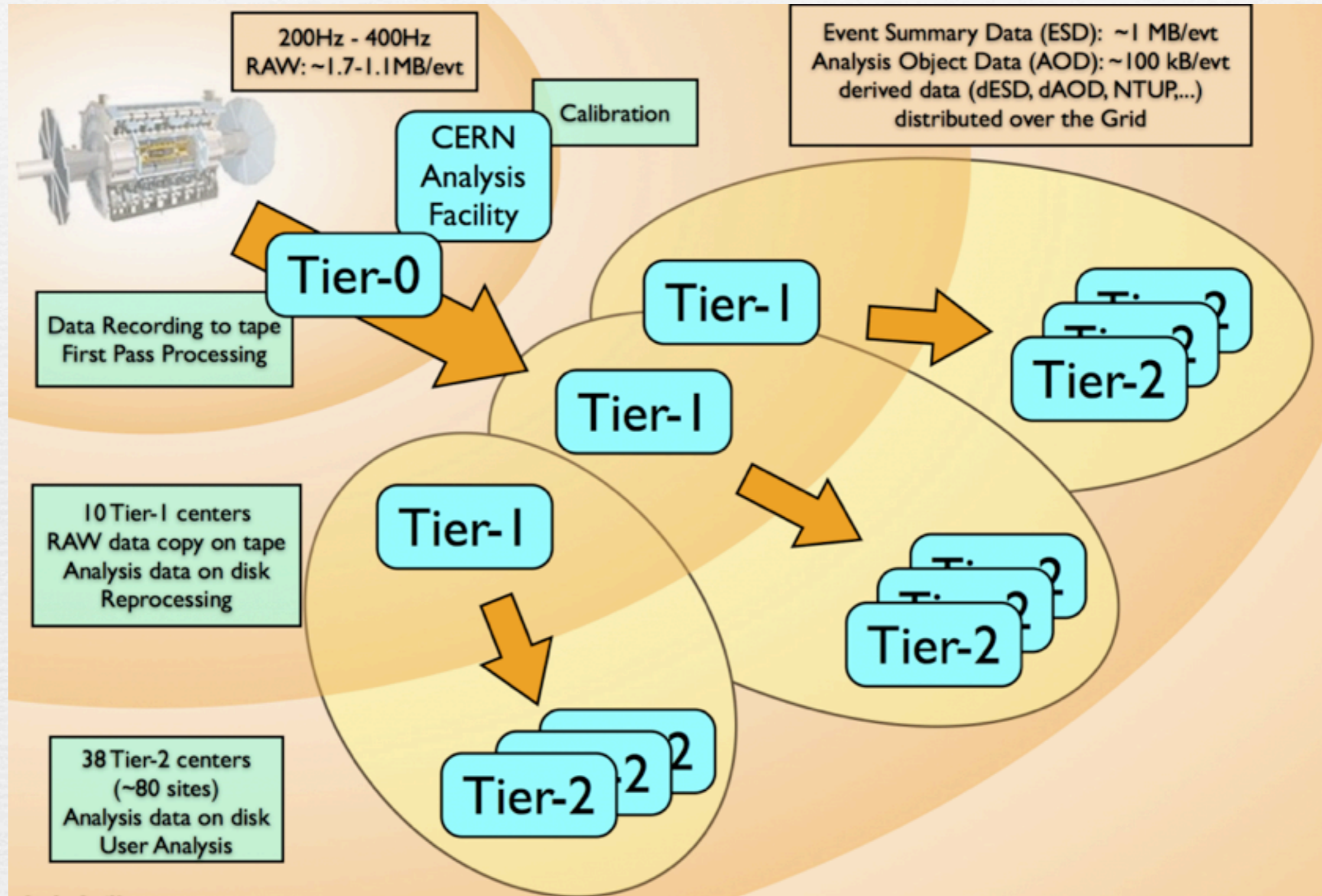
Each event independent

Batch farms are OK, but typical
university clusters not large enough

Connect all participants transparently:

Worldwide LHC Computing Grid

WLCG tiered structure



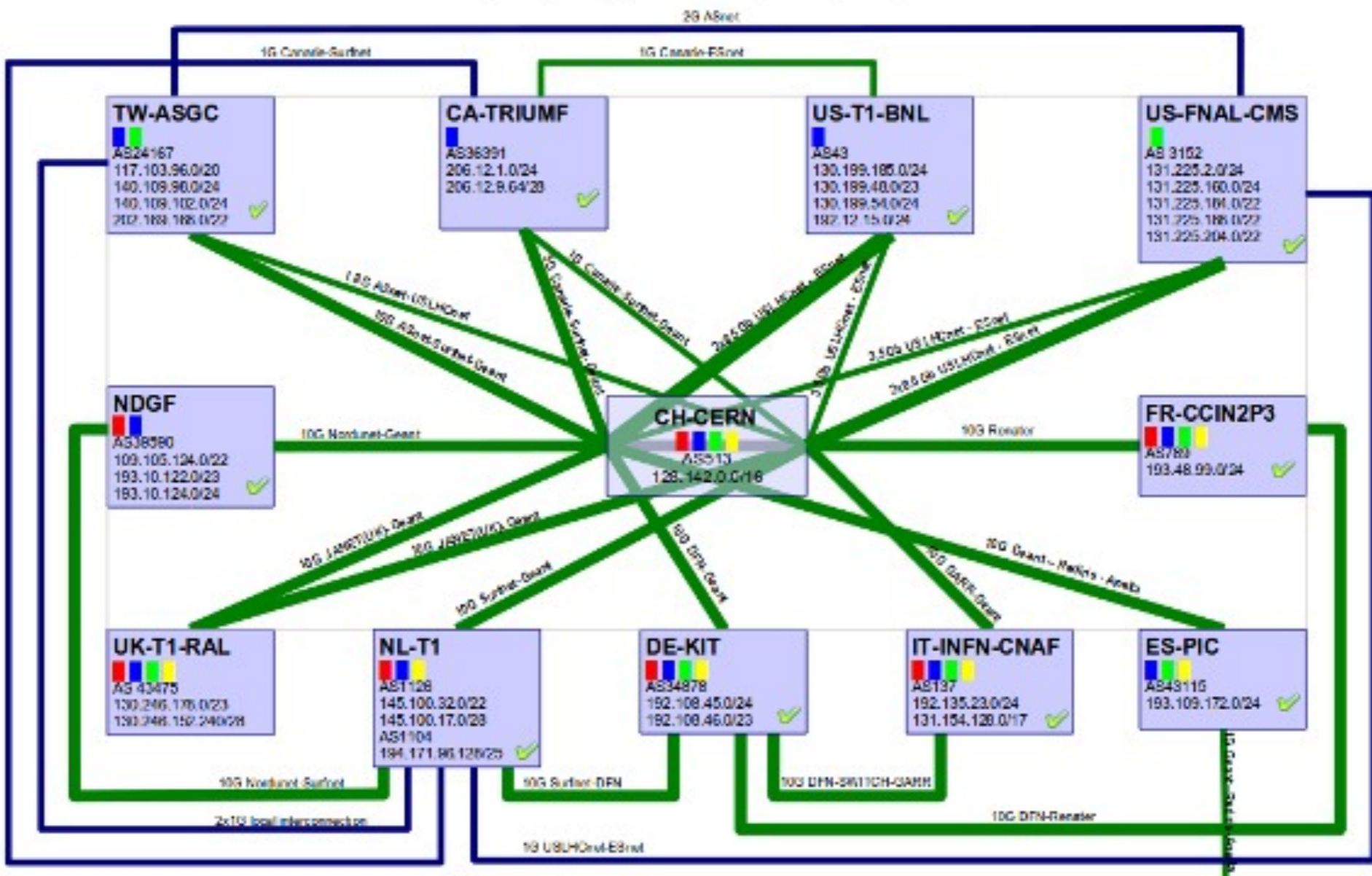
WLCG tiered structure

200Hz - 400Hz

Event Summary Data (ESD): ~1 MB/evt

Analysis Object Data (AOD) ~100 kB/evt

LHCOPN



Data First

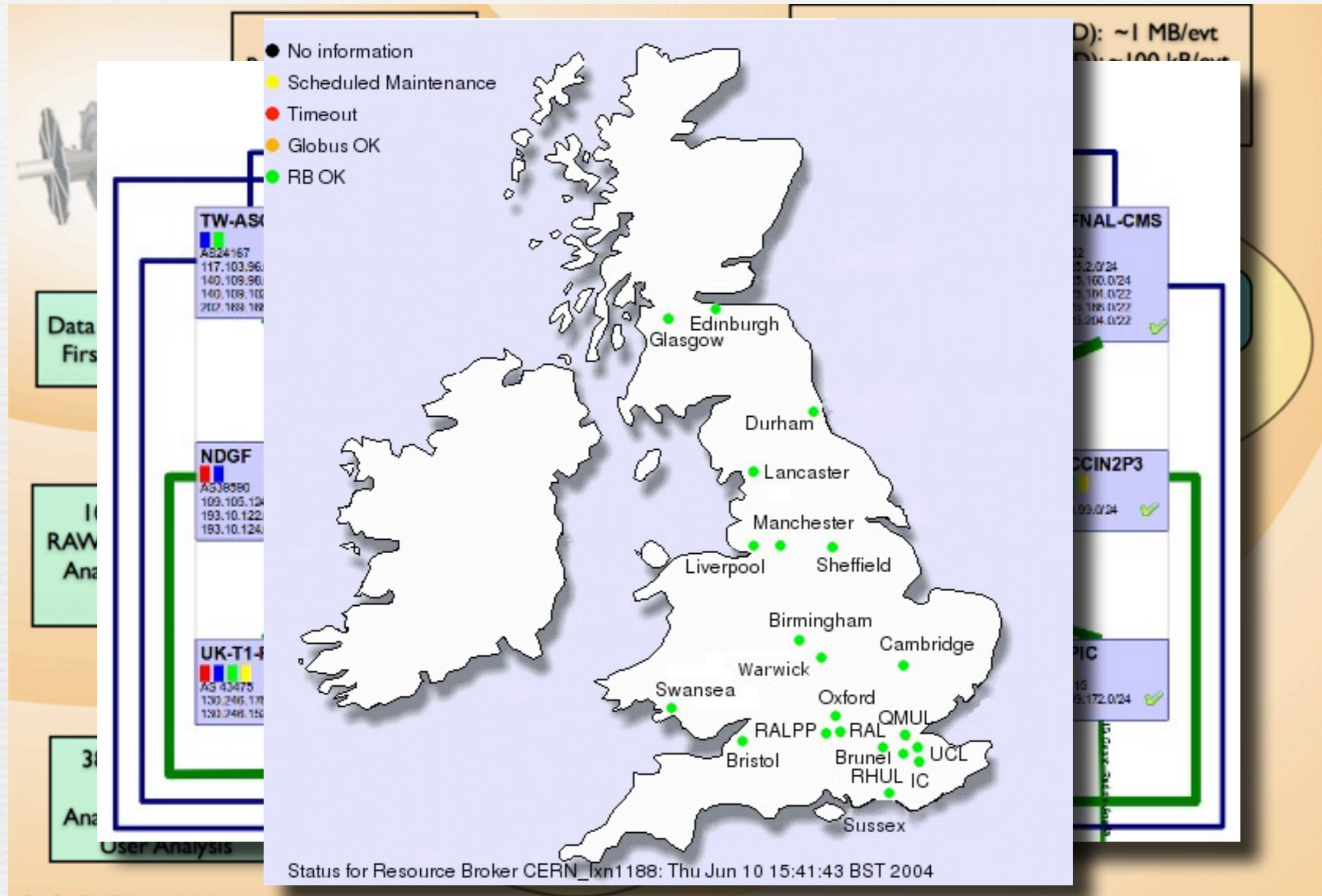
RAW Analysis

30

Analysis

User Analysis

WLCG tiered structure



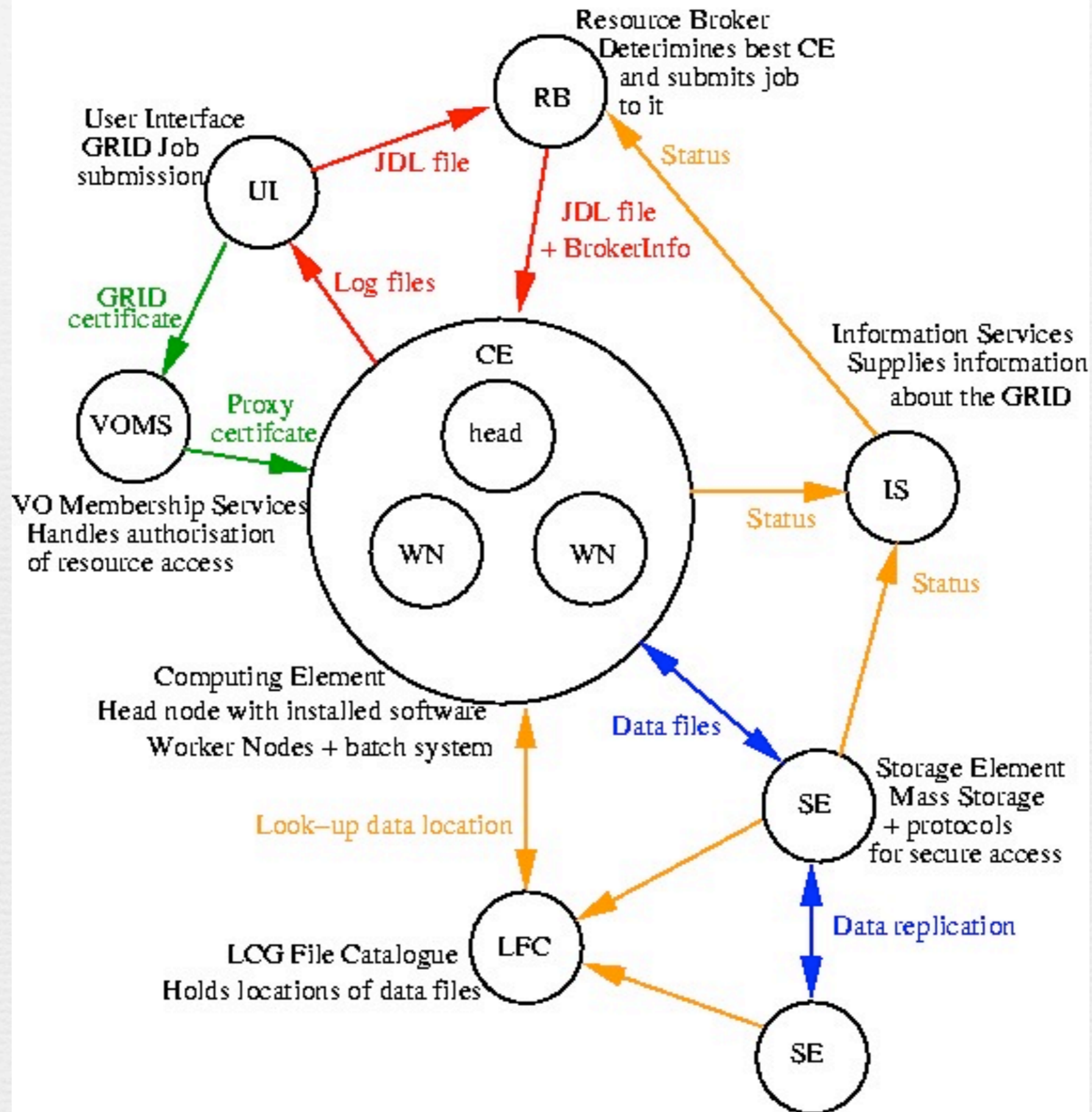
WLCG tiered structure



Main ideas

- Hardware infrastructure supported by “Middleware”
- Allow heterogenous collections of machines to be connected
- End users should not care where data is. Describe job, and “Resource Broker” will find the best location

GRID Key Concepts



Reality

- uniform OS installation needed
- RB bottleneck
- Pilot jobs
- asymmetry between experiments' requirements and WLCG middleware development resources
- Middleware lacks central planning

Would do it differently next time,
but this is what we've got

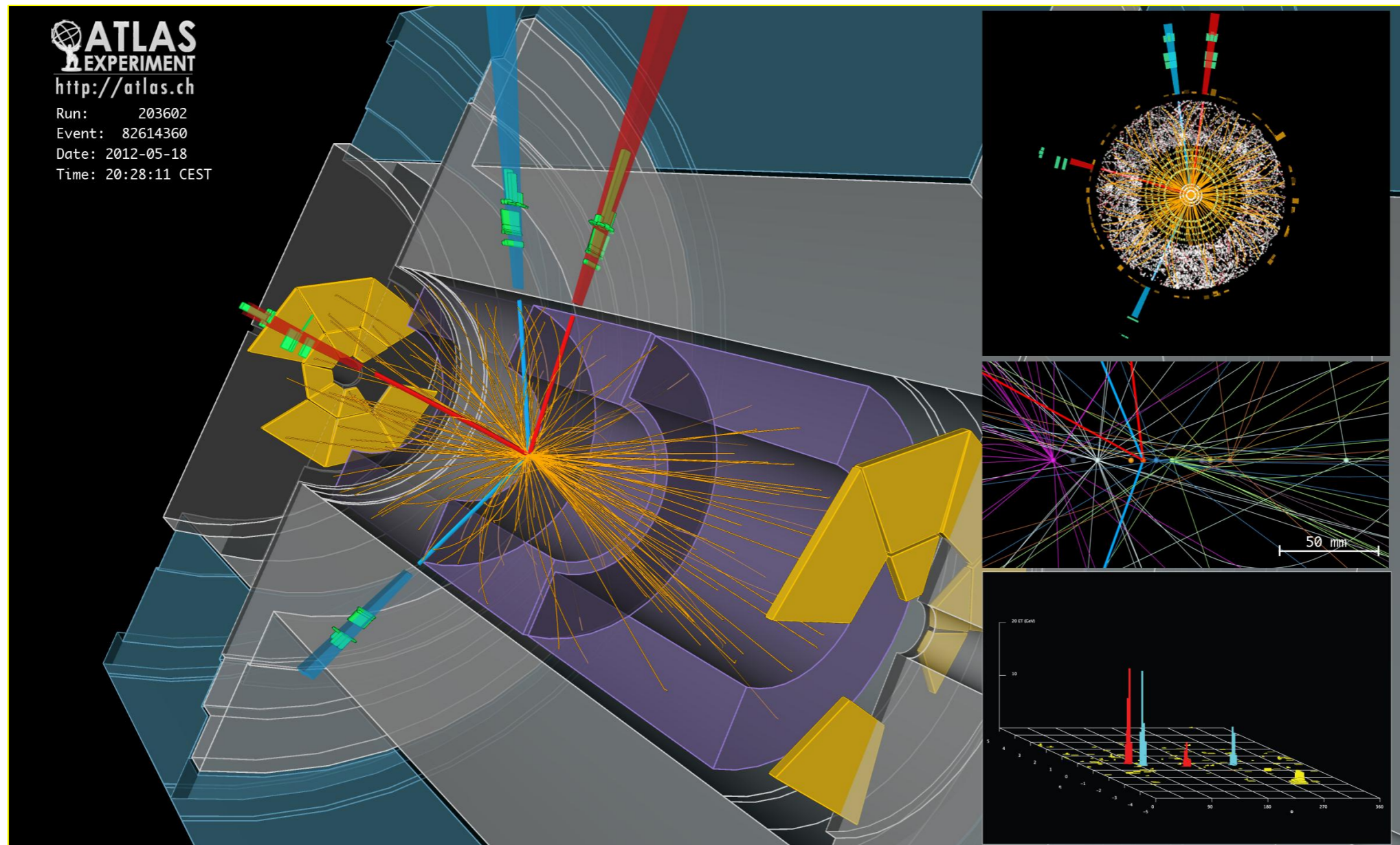
Pragmatic approach seems to work
sufficiently well for the experiments,
problems worked around with lot of effort

Better Monte Carlo tuning

New kinds of theory studies possible

4e candidate with $m_{4e} = 124.6 \text{ GeV}$

p_T (electrons) = 24.9, 53.9, 61.9, 17.8 GeV $m_{12} = 70.6 \text{ GeV}$, $m_{34} = 44.7 \text{ GeV}$
12 reconstructed vertices



World Wide Web

The WorldWideWeb (W3) is a wide-area [hypermedia](#) information retrieval initiative aiming to give universal access to a large universe of documents.

Everything there is online about W3 is linked directly or indirectly to this document, including an [executive summary](#) of the project, [Mailing lists](#), [Policy](#), November's [W3 news](#), [Frequently Asked Questions](#)

[What's out there?](#)

Pointers to the world's online information, [subjects](#), [W3 servers](#), etc.

[Help](#)

on the browser you are using

[Software Products](#)

A list of W3 project components and their current state. (e.g. [Line Mode](#), [X11 Viola](#), [NeXTStep](#), [Servers](#), [Tools](#), [Mail robot](#), [Library](#))

[Technical](#)

Details of protocols, formats, program internals etc

[Bibliography](#)

Paper documentation on W3 and references.

[People](#)

A list of some people involved in the project.

[History](#)

A summary of the history of the project.

[How can I help?](#)

If you would like to support the web.

[Getting code](#)

Getting the code by [anonymous FTP](#), etc.