

Simulation in Particle Physics

David Grellscheid



What are the fundamental
building blocks of Nature?

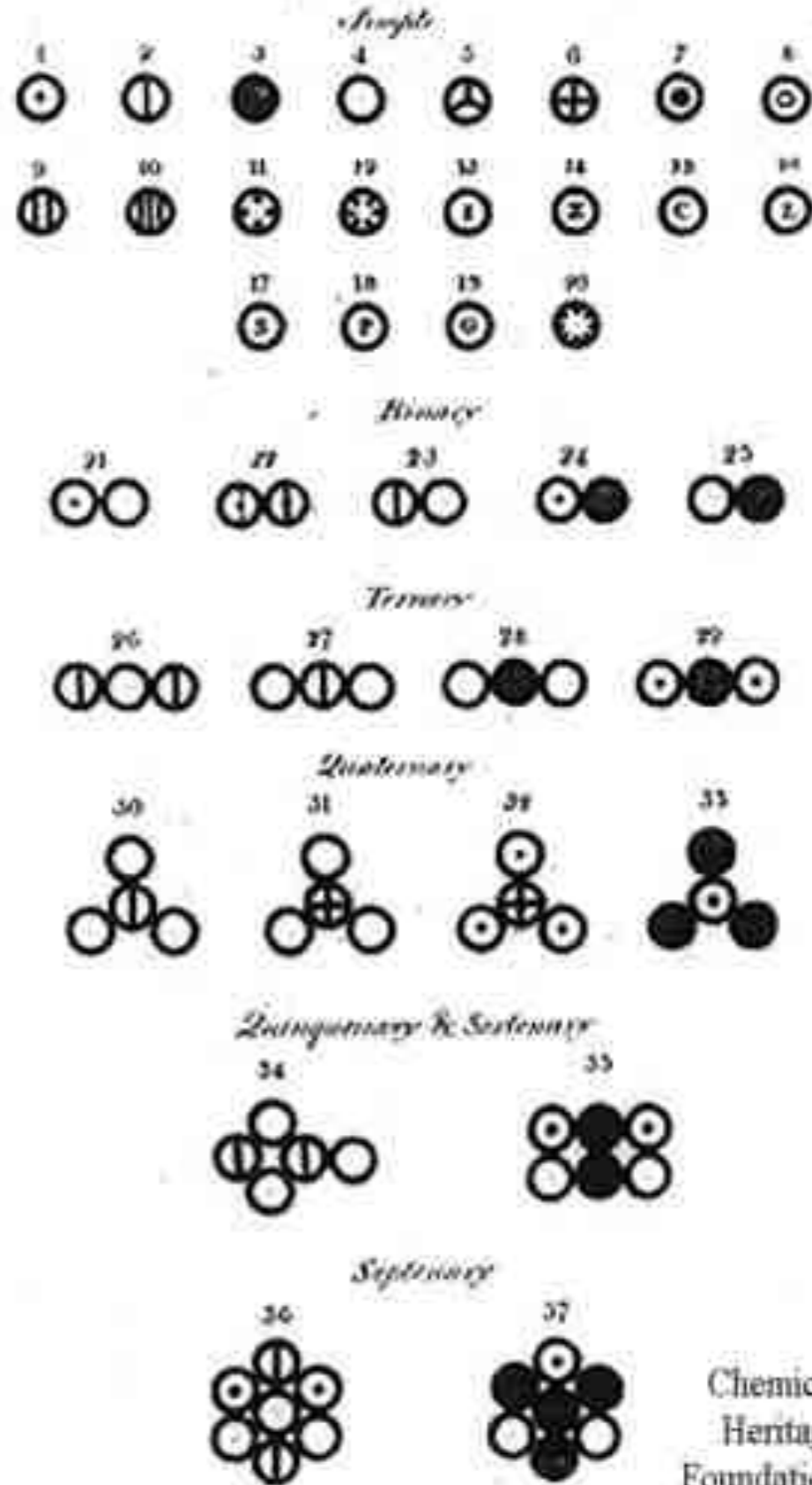


ELEMENTS

	Hydrogen	1		Strontian	46
	Nitrogen	5		Barytes	68
	Carbon	5		Iron	56
	Oxygen	7		Zinc	56
	Phosphorus	9		Copper	56
	Sulphur	13		Lead	90
	Magnesia	20		Silver	190
	Lime	24		Gold	190
	Soda	28		Platina	190
	Potash	42		Mercury	167

ELEMENTS

1789

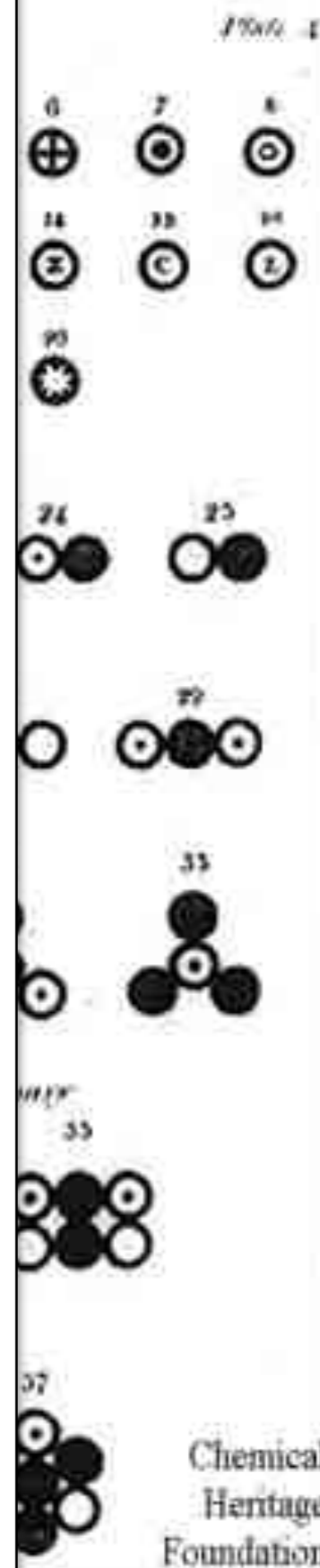


ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ.

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

		Ti = 50	Zr = 90	? = 180.	
		V = 51	Nb = 94	Ta = 182.	
		Cr = 52	Mo = 96	W = 186.	
		Mn = 55	Rh = 104,4	Pt = 197,1.	
		Fe = 56	Ru = 104,4	Ir = 198.	
		Ni = Co = 59	Pd = 106,8	Os = 199.	
H = 1		Cu = 63,4	Ag = 108	Hg = 200.	
	Be = 9,1	Mg = 24	Zn = 65,2	Cd = 112	
	B = 11	Al = 27,1	? = 68	U = 116	Au = 197?
	C = 12	Si = 28	? = 70	Sn = 118	
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?
	O = 16	S = 32	Se = 79,4	Te = 128?	
	F = 19	Cl = 35,5	Br = 80	I = 127	
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204.
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207.
		? = 45	Ce = 92		
		?Er = 56	La = 94		
		?Yt = 60	Di = 95		
		?In = 75,6	Th = 118?		

Д. Менделѣевъ

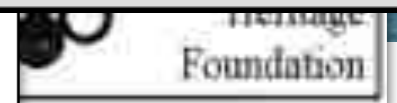


Chemical Heritage Foundation

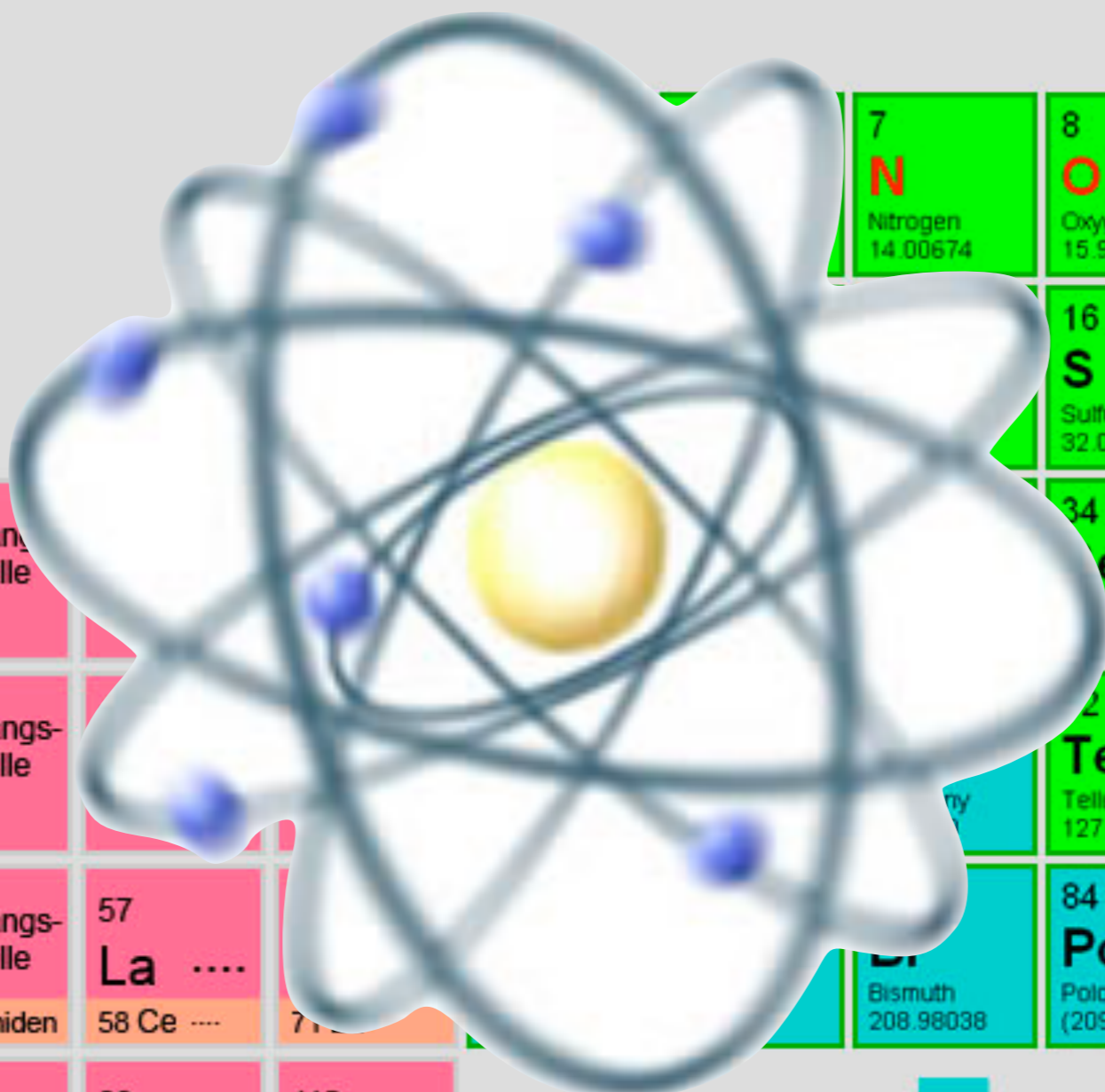
1 IA	2 IIA											13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA	
1 H Hydrogen 1.00794																		2 He Helium 4.002602
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797	
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948	
19 K Potassium 39.0983	20 Ca Calcium 40.078	Übergangs- metalle	21 Sc	30 Zn	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798								
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	Übergangs- metalle	39 Y	48 Cd	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293								
55 Cs Cesium 132.90545	56 Ba Barium 137.327	Übergangs- metalle Lanthaniden	57 La	80 Hg	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)								
87 Fr Francium (223)	88 Ra Radium (226)	Übergangs- metalle Actiniden	89 Ac	112 Uub	90 Th	103 Lr												

 Alkalimetalle	 Metalle	 Nichtmetalle
 Erdalkalimetalle	 Übergangsmetalle	 Edelgase

Д. Менделѣевъ



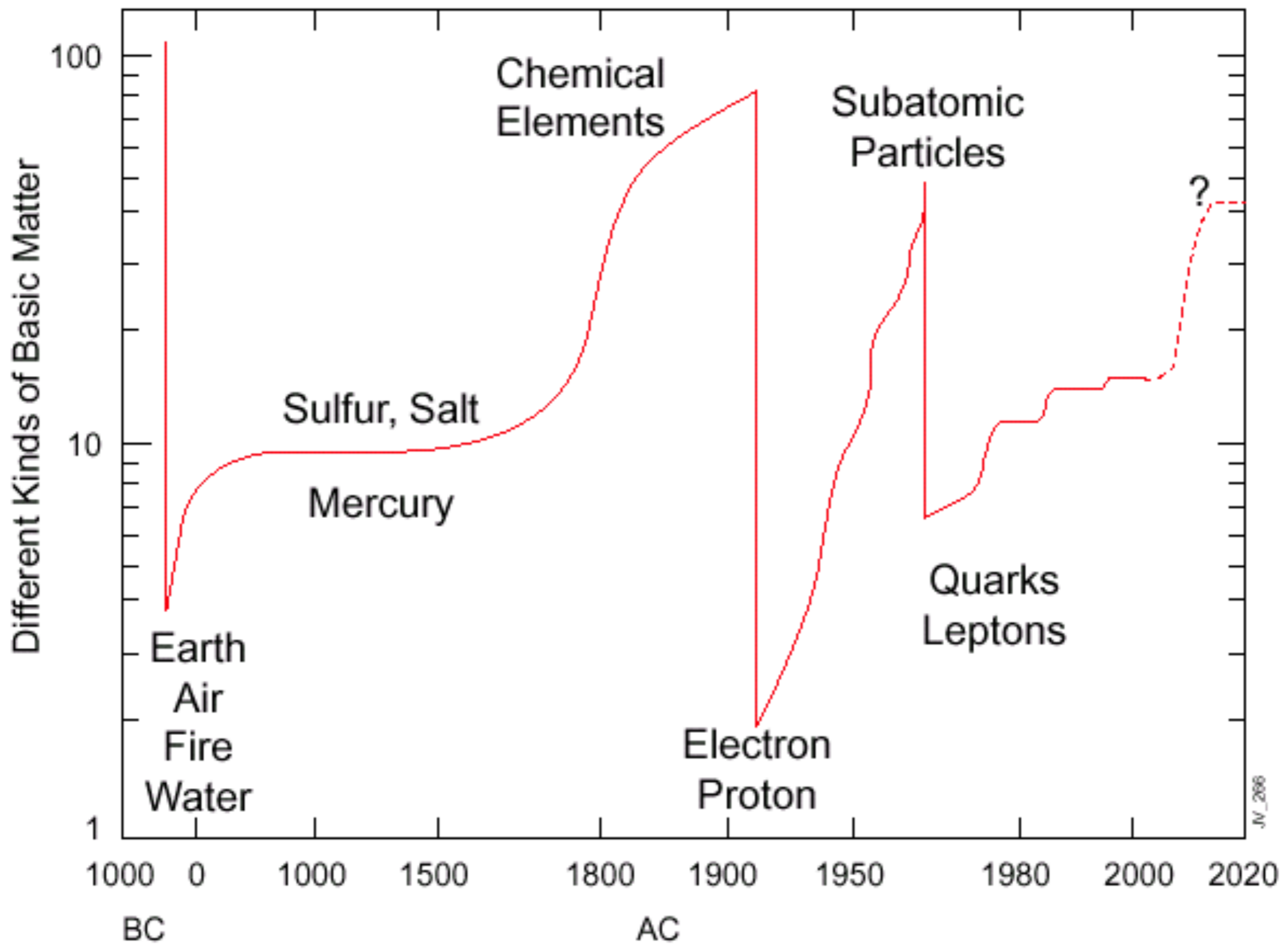
1 IA	2 IIA											13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA														
1 H Hydrogen 1.00794																		2 He Helium 4.002602													
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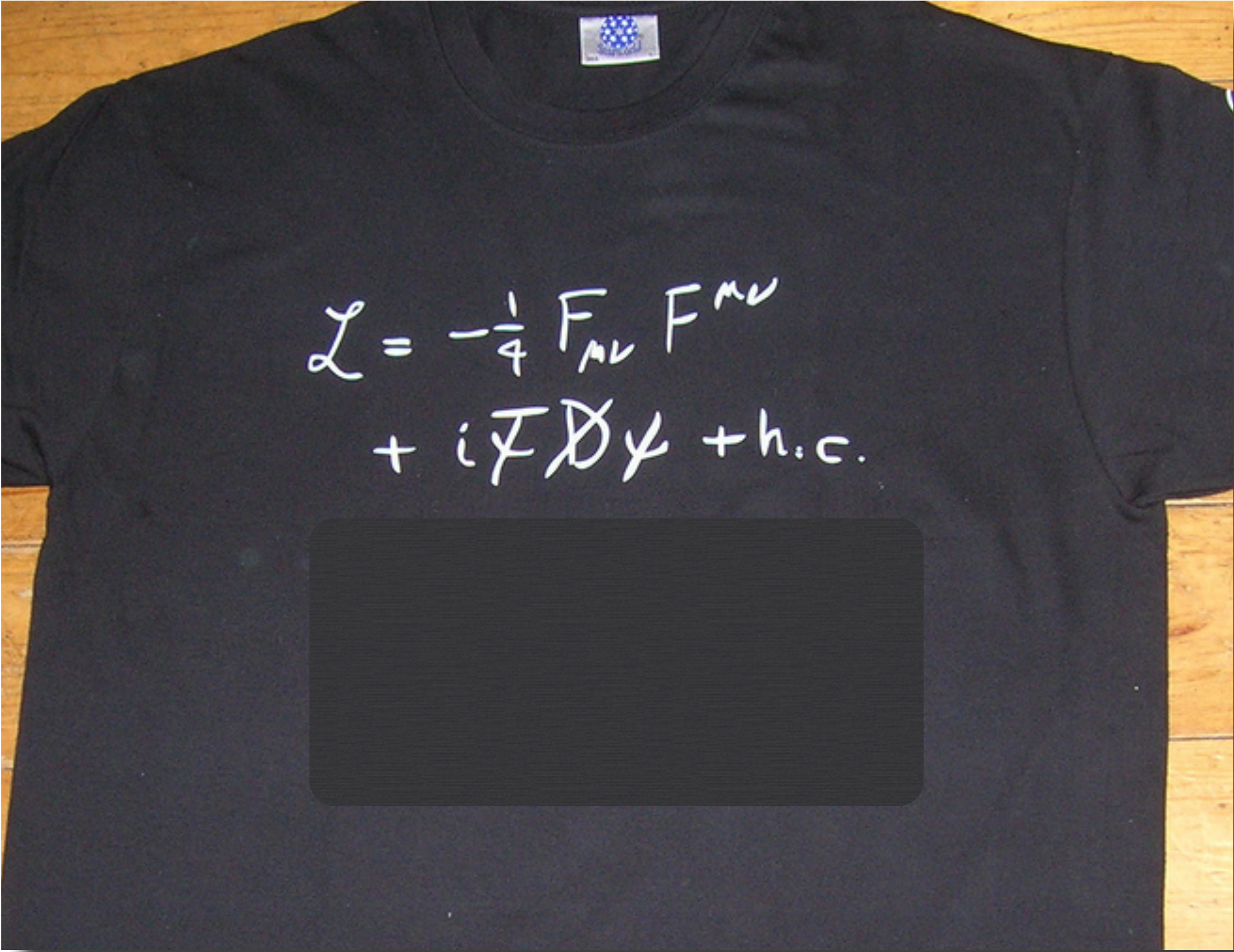
- Alkalimetalle
- Erdalkalimetalle
- Metalle
- Übergangsmetalle
- Nichtmetalle
- Edelgase

Д. Менделѣевъ

Heritage
Foundation



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	

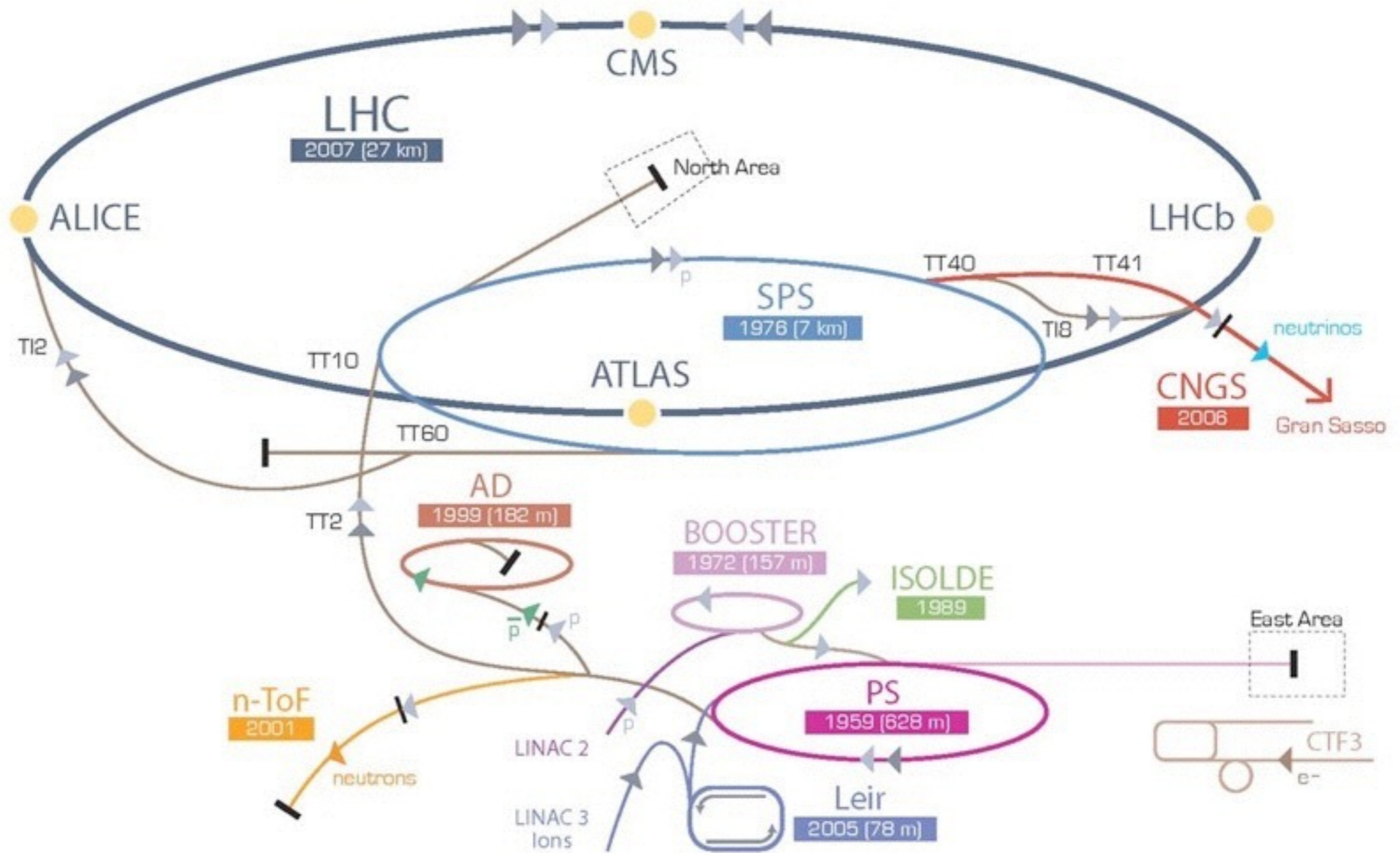

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \text{h.c.}$$

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





CERN Accelerator Complex



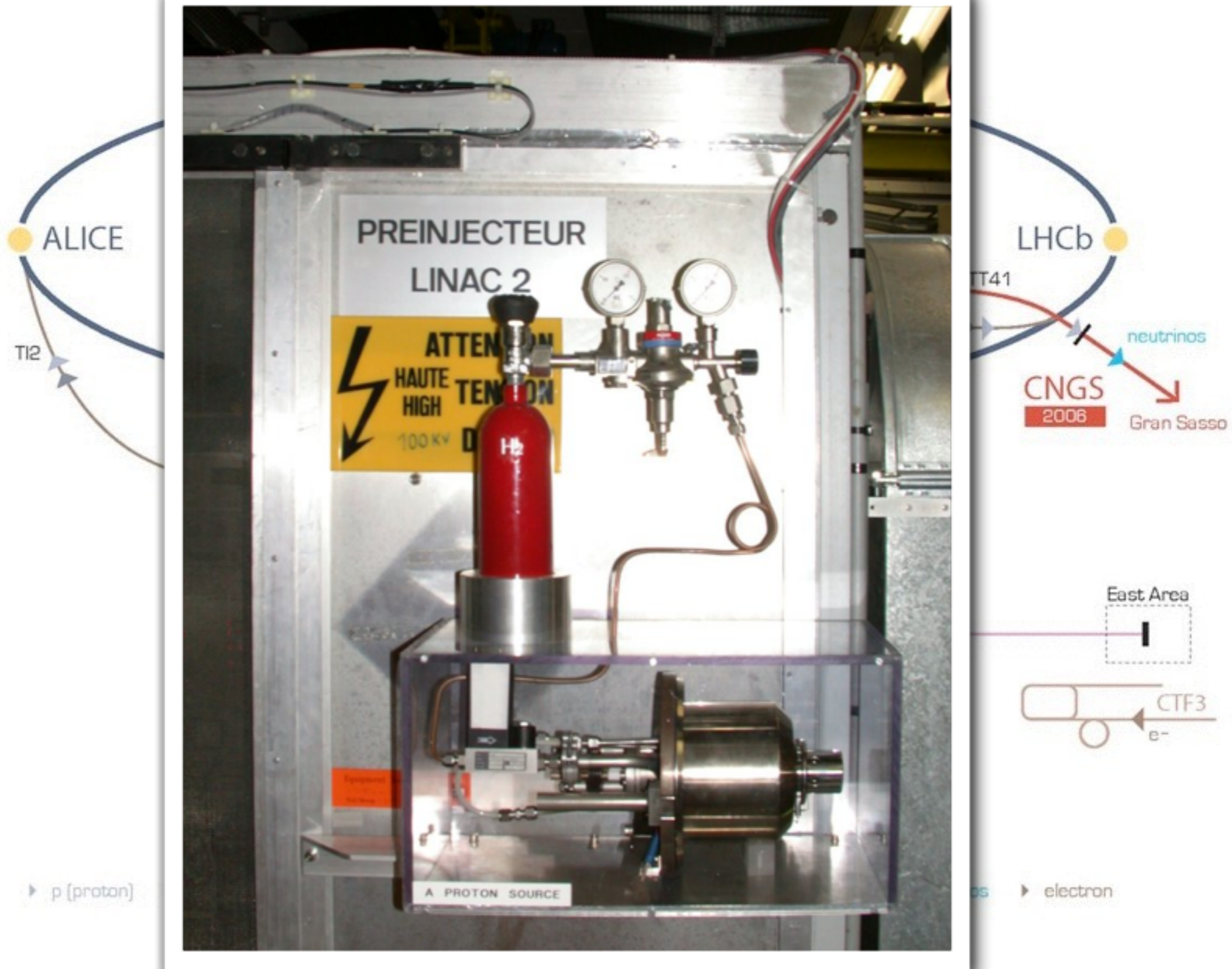
▶ p (proton) ▶ ion ▶ neutrons ▶ \bar{p} (antiproton) \leftrightarrow proton/antiproton conversion ▶ neutrinos ▶ electron

LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

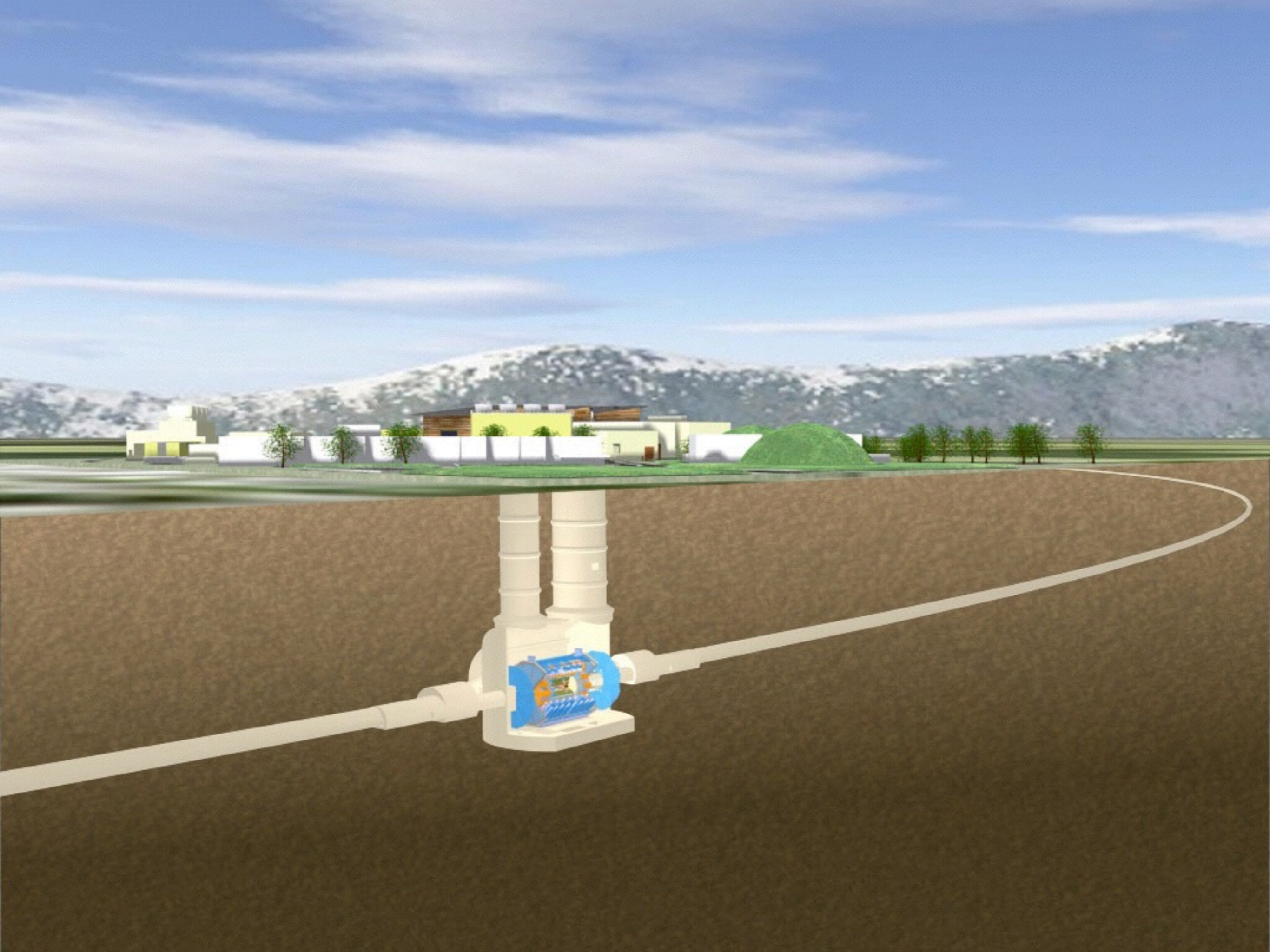
AD Antiproton Decelerator CTF3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice

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

CERN Accelerator Complex

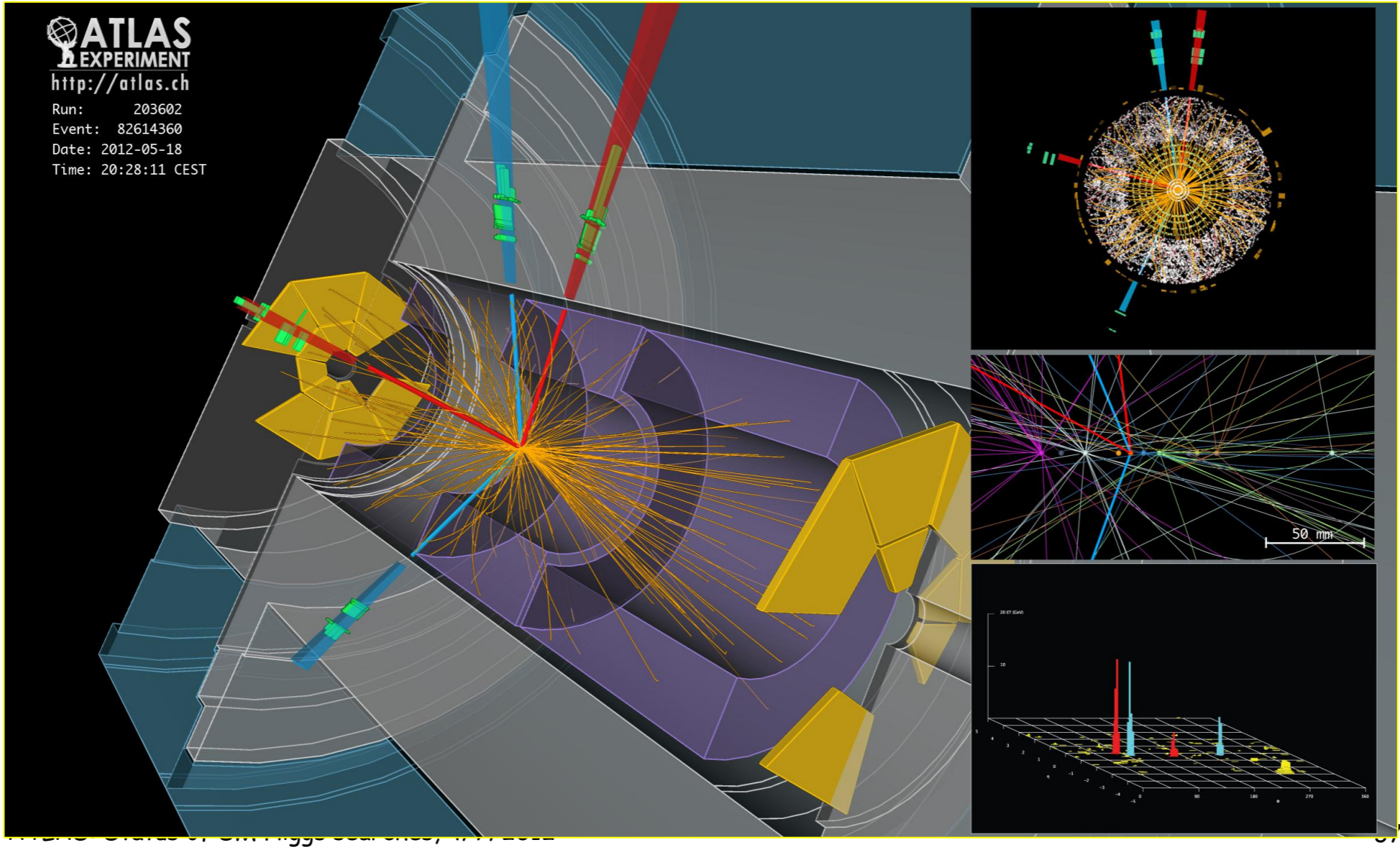


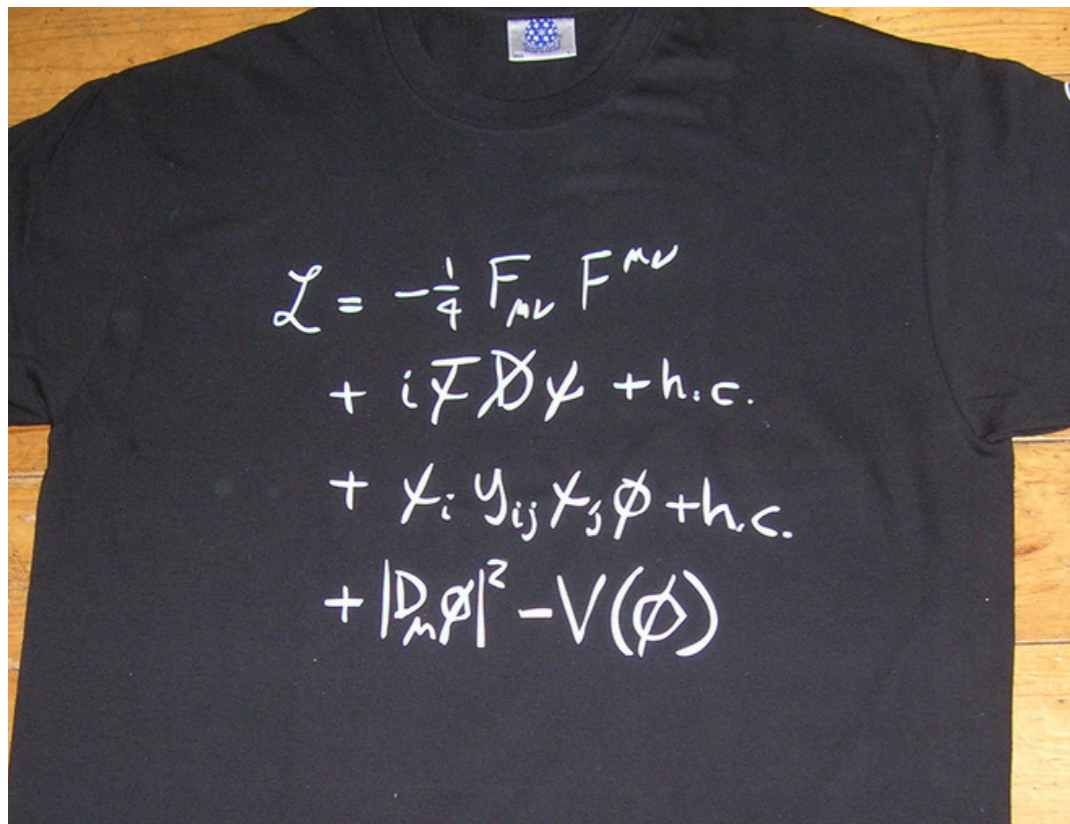
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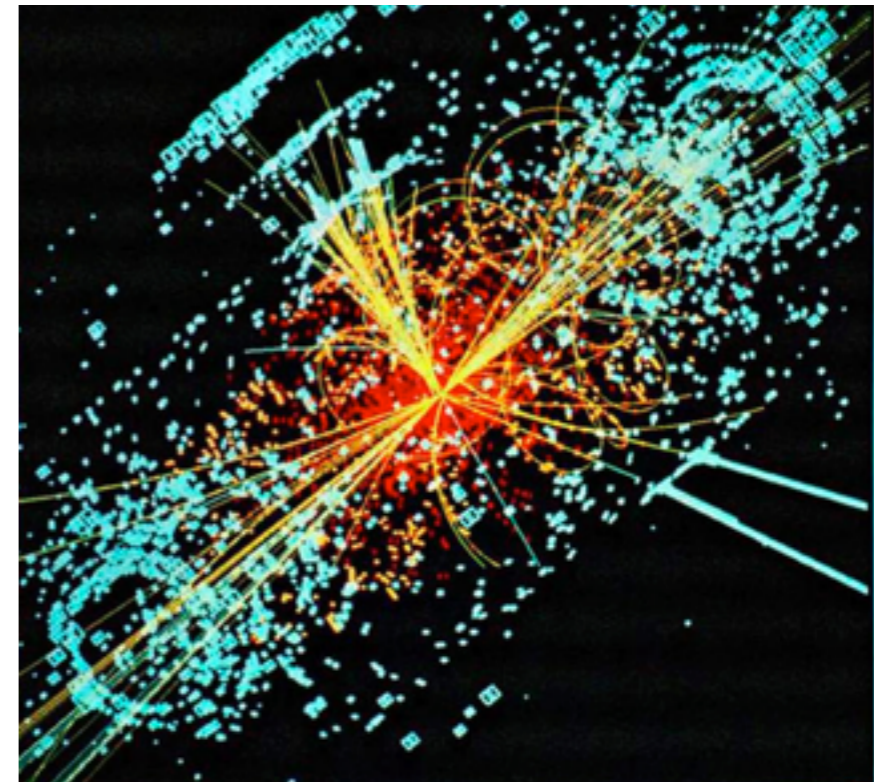
4e candidate with $m_{4e} = 124.6 \text{ GeV}$

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

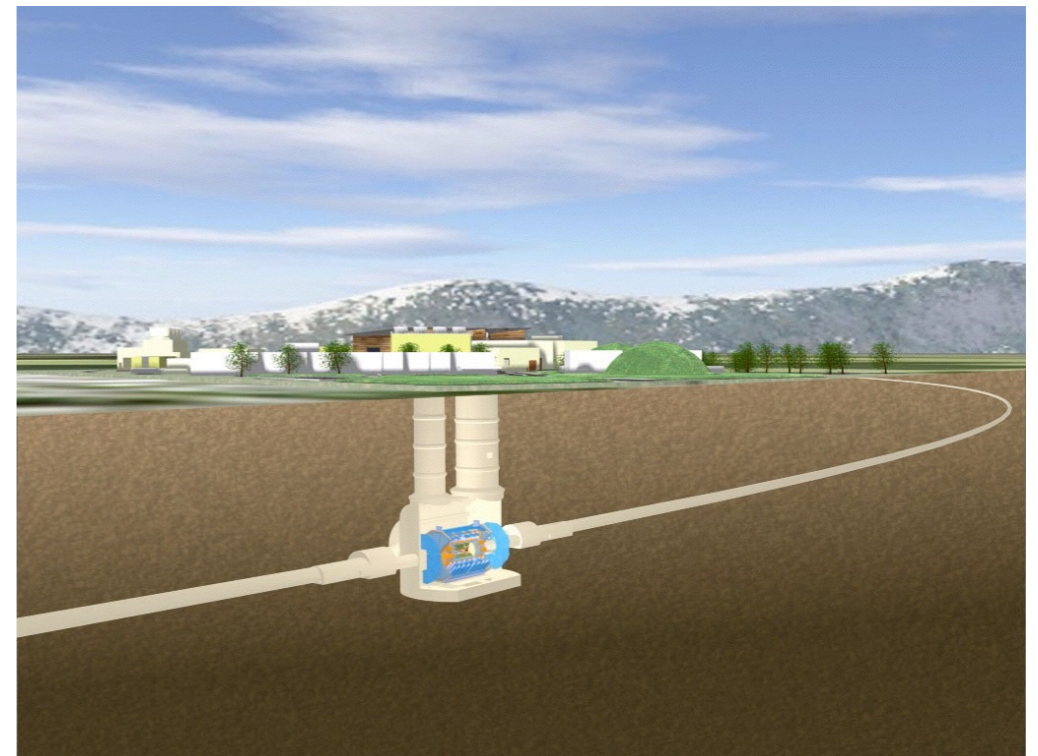


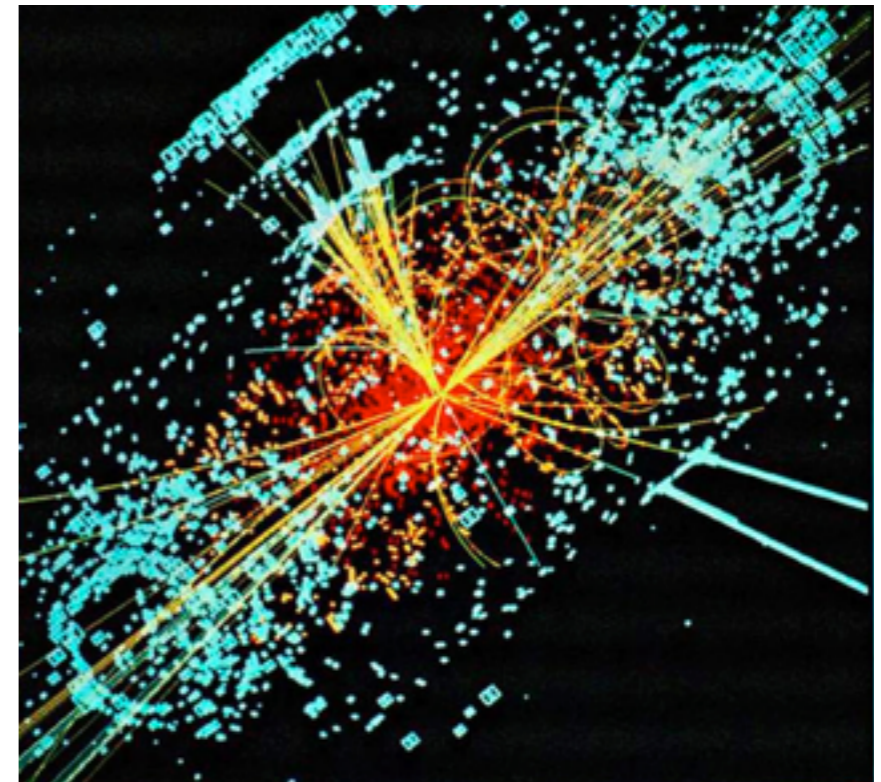
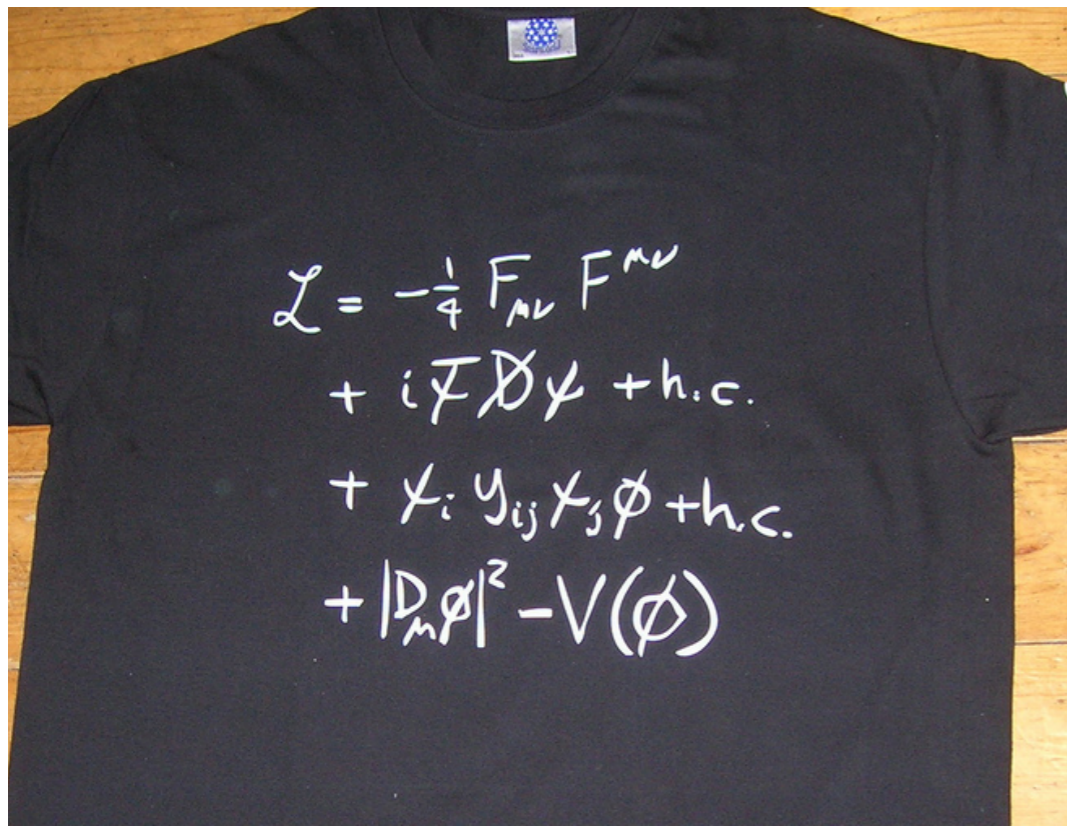


Theory



Experiment



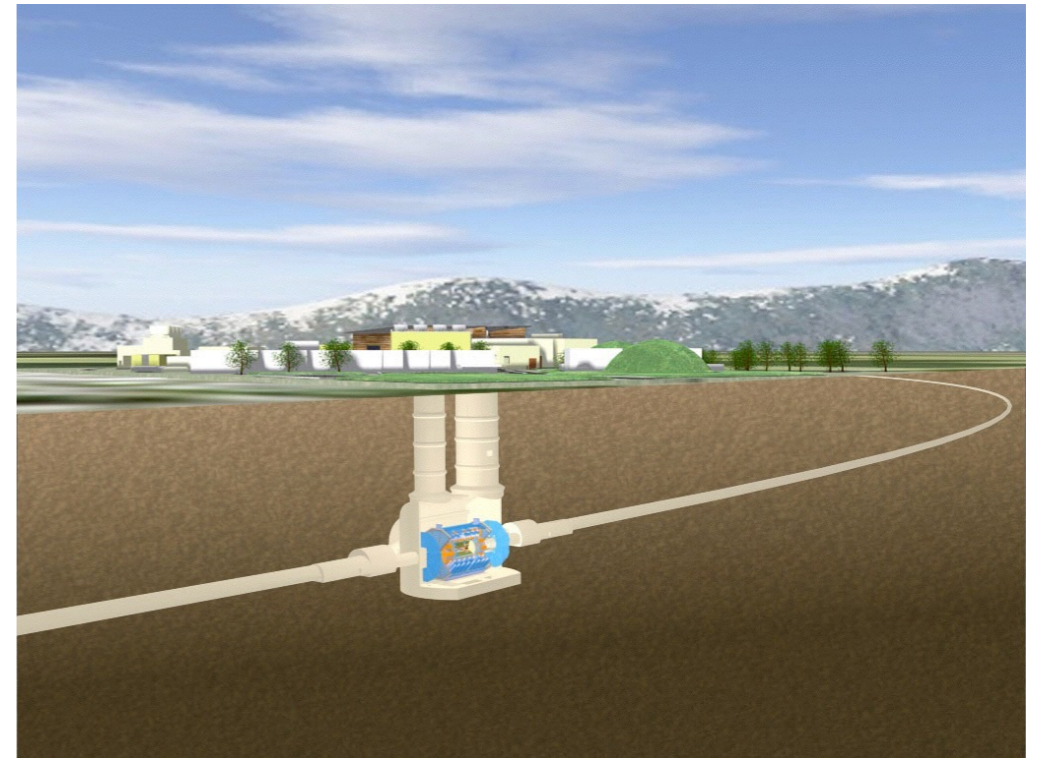


?

Theory



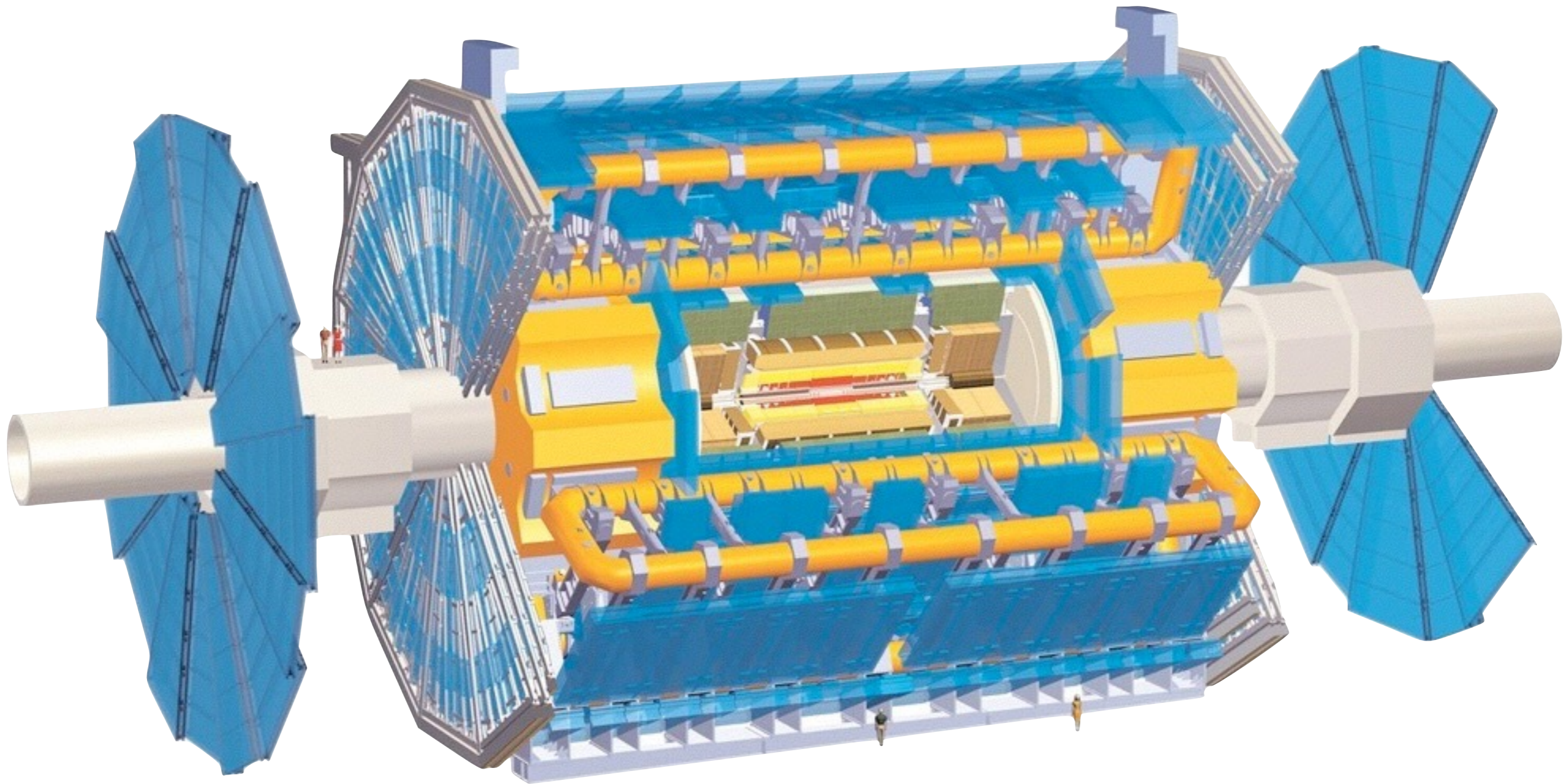
Experiment

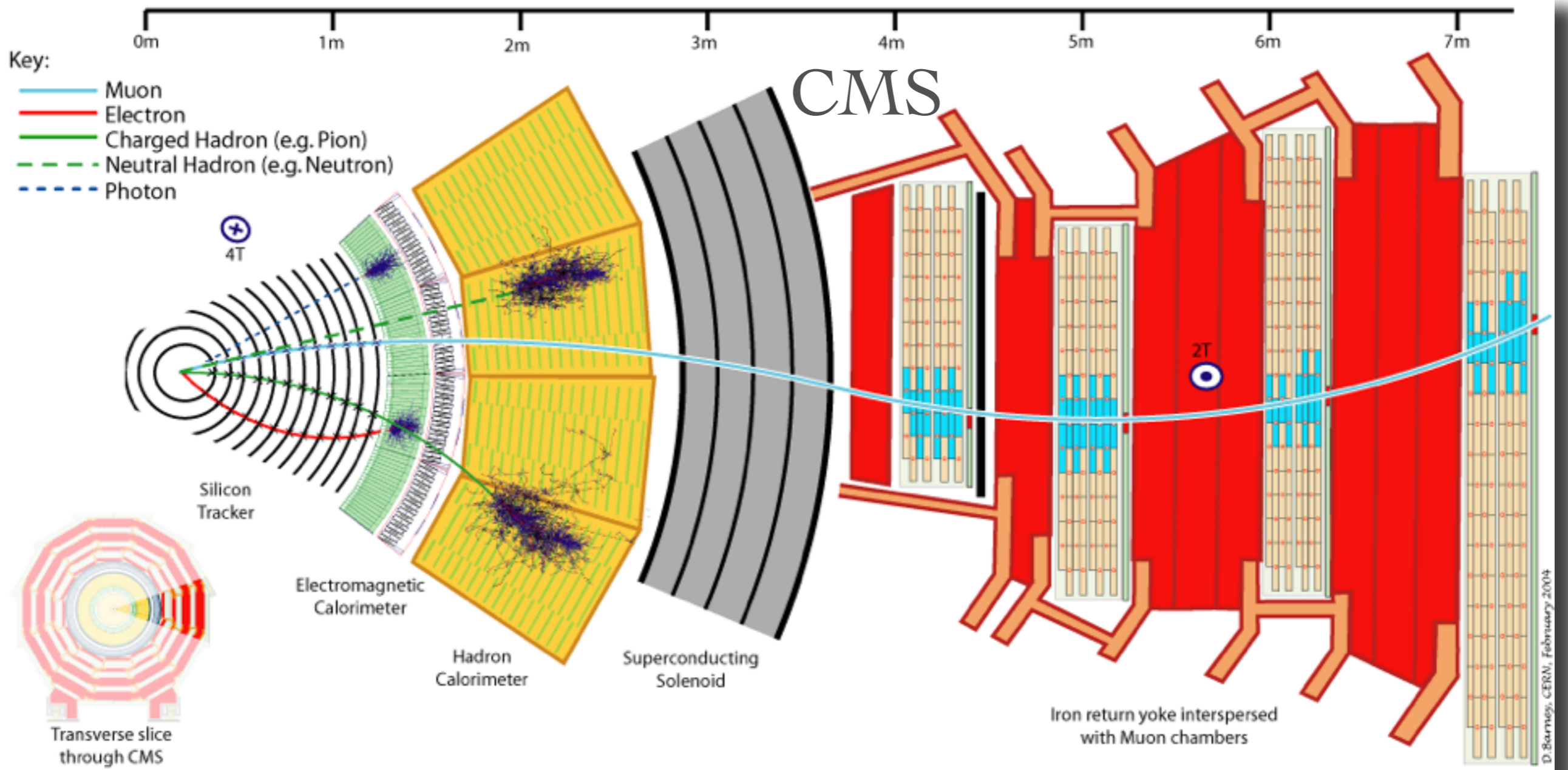


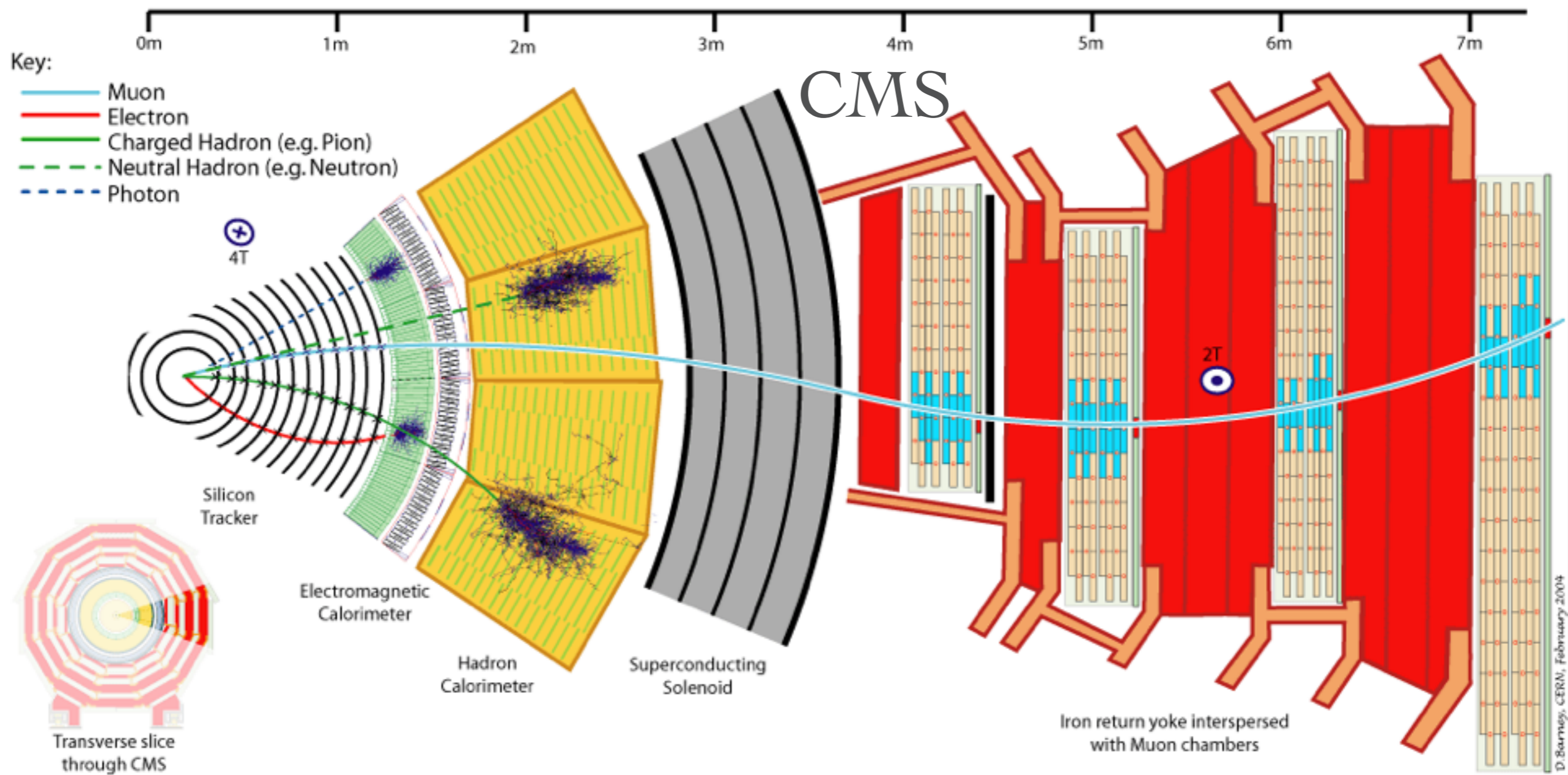


Proton bunches 25 ns apart
 10^{11} protons per bunch
~25 collisions per crossing

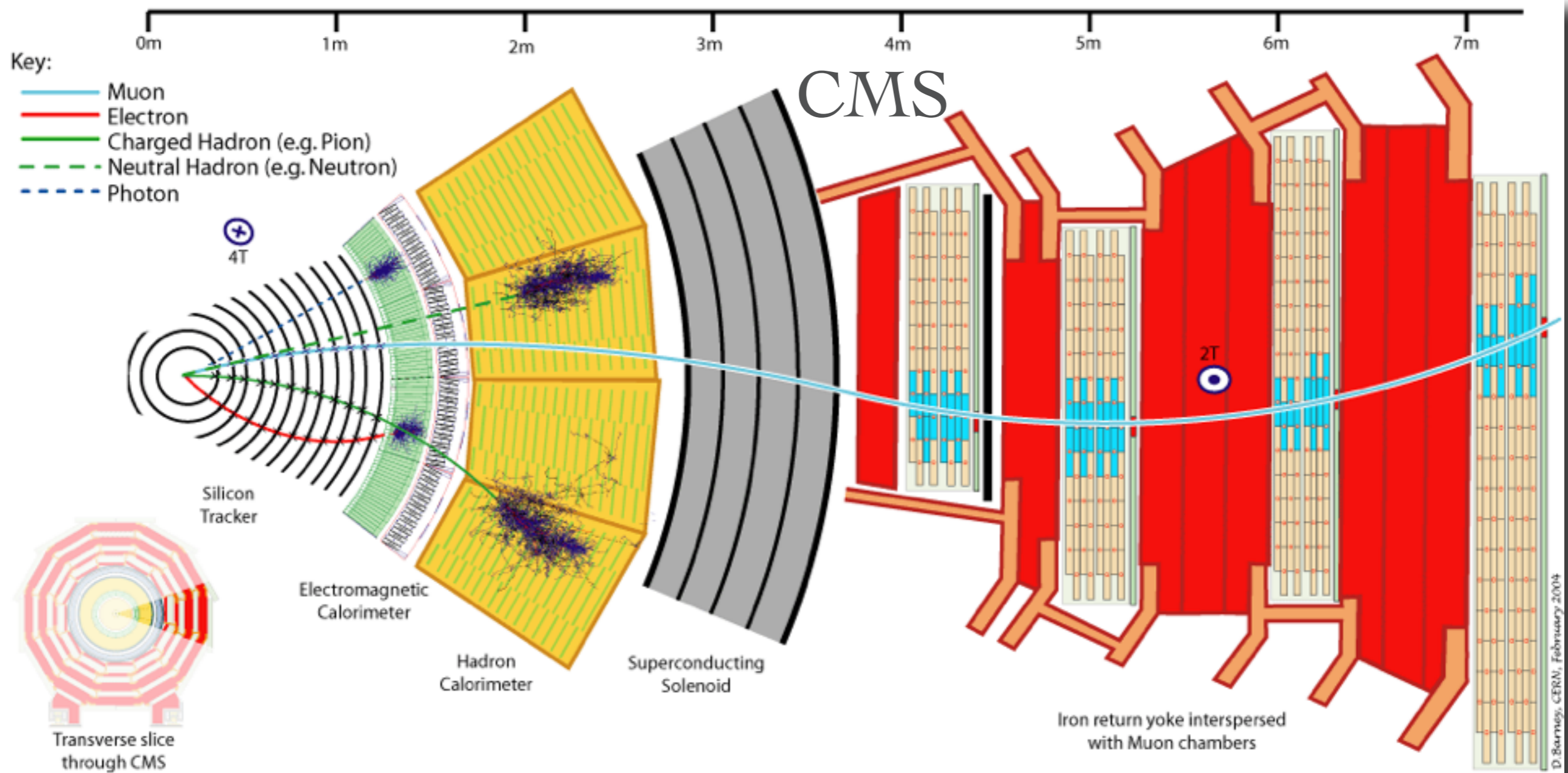
~100 million readout channels, every 25 ns





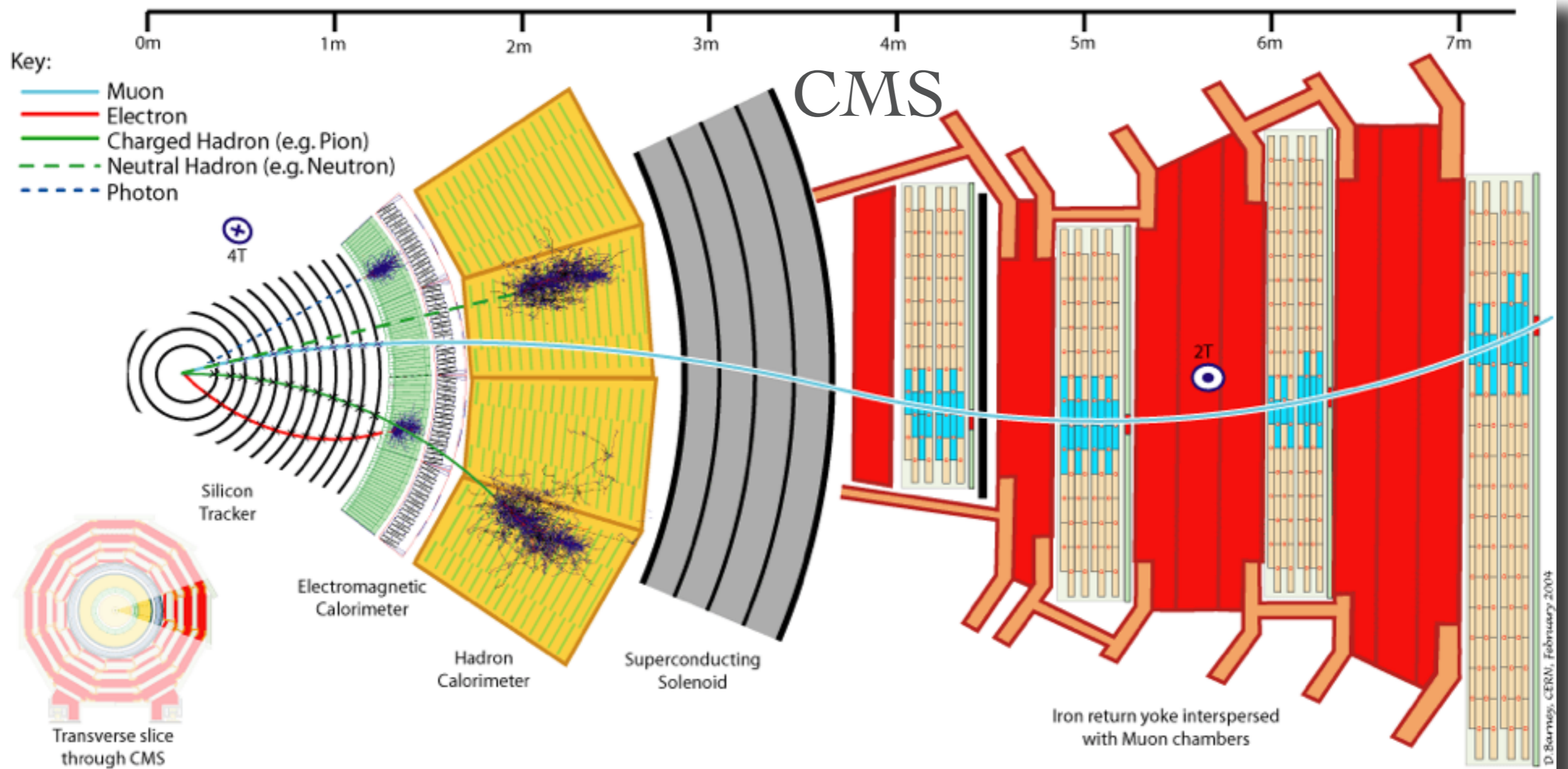


After zeroes removed, 1.6 MB / event



After zeroes removed, 1.6 MB / event

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



After zeroes removed, 1.6 MB / event

* 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

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

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

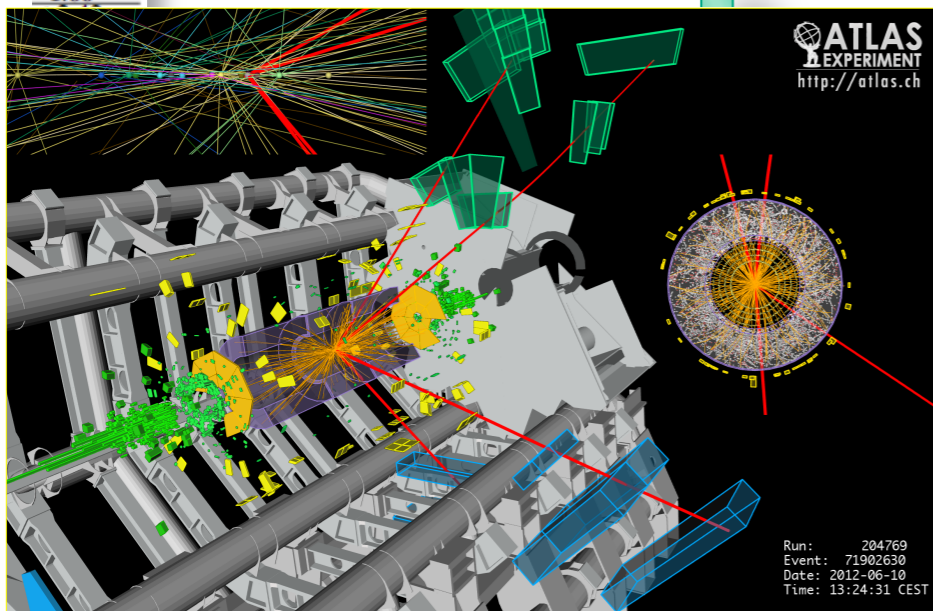
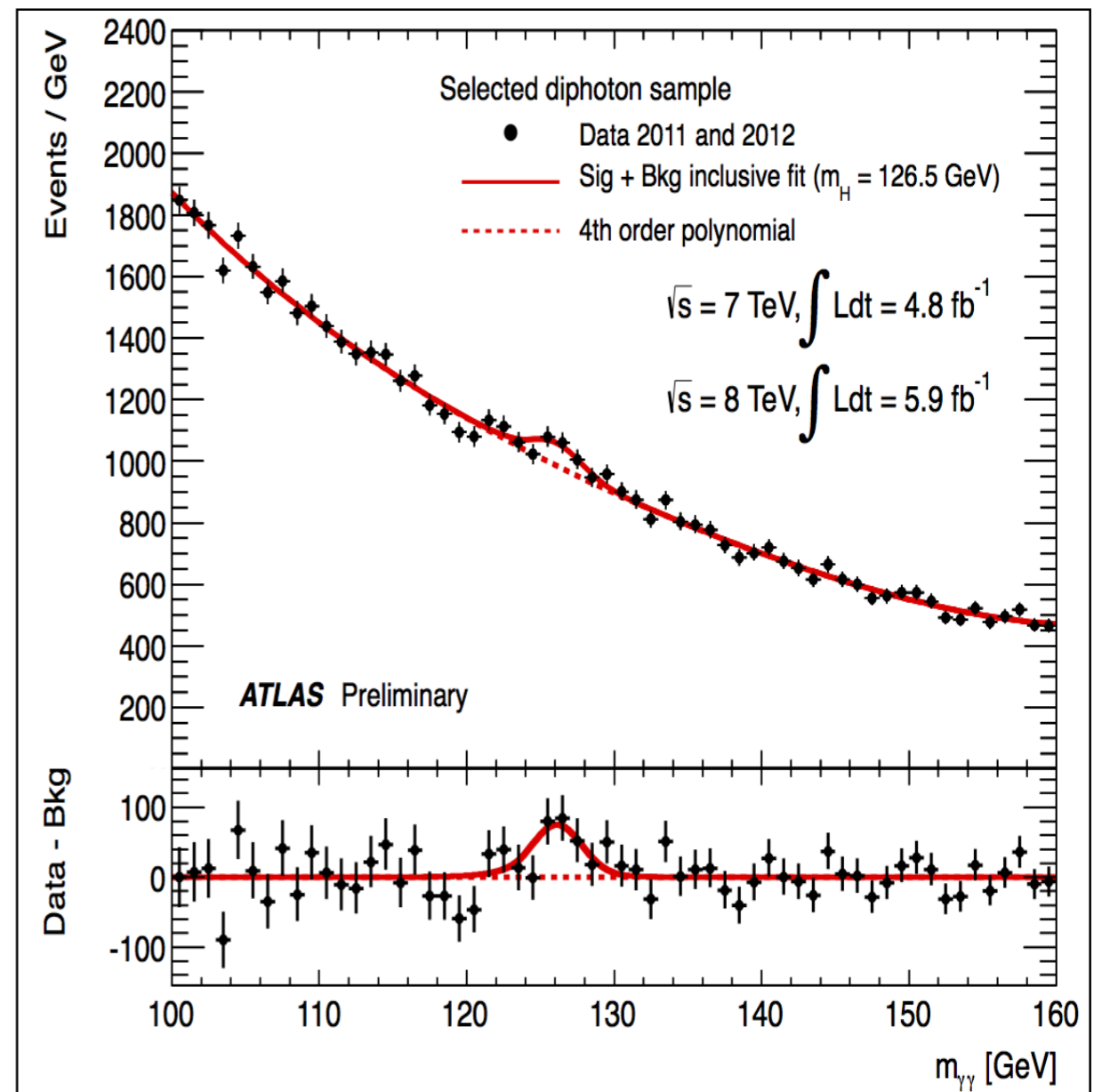
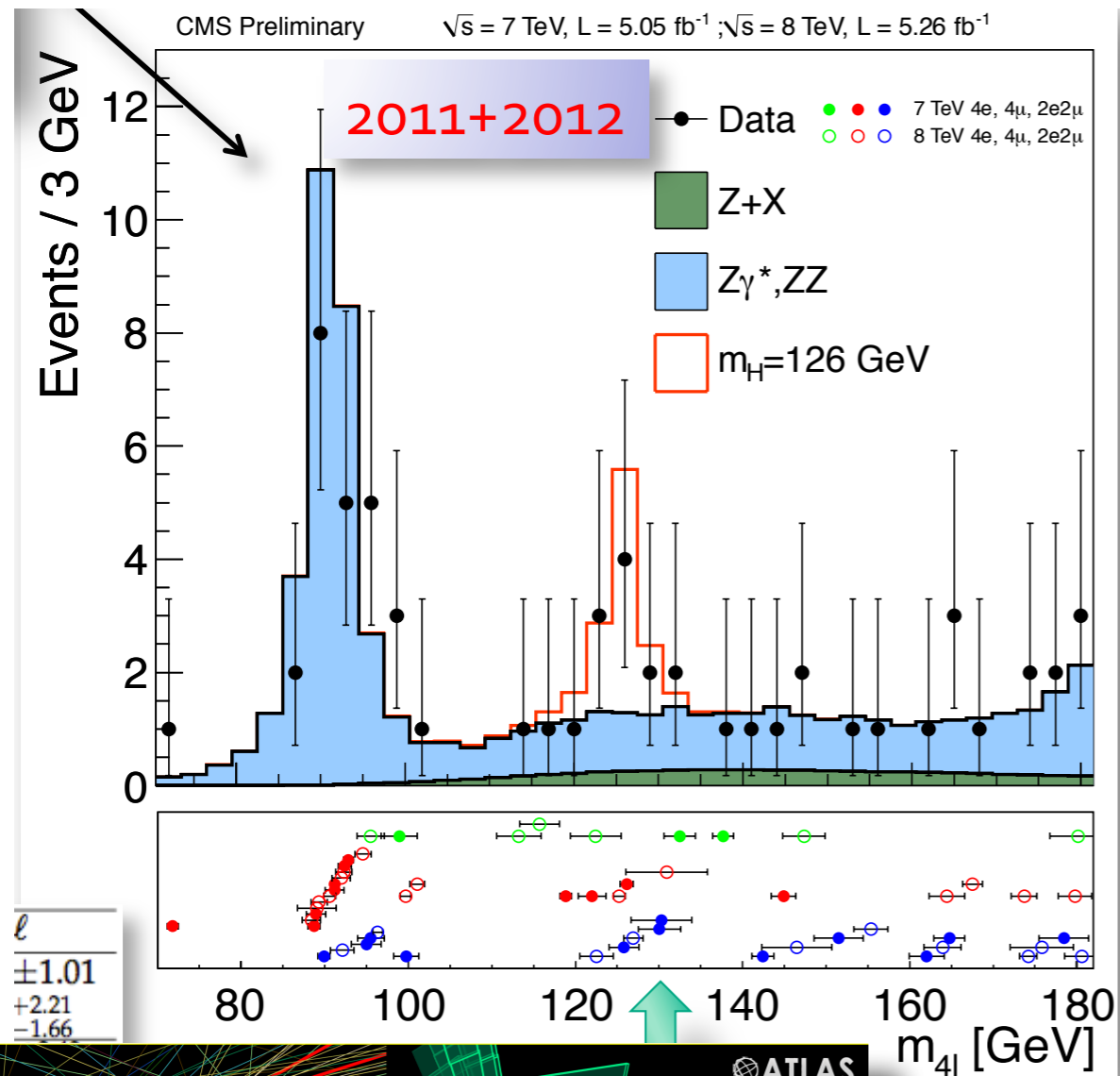
Trigger system to keep only interesting events

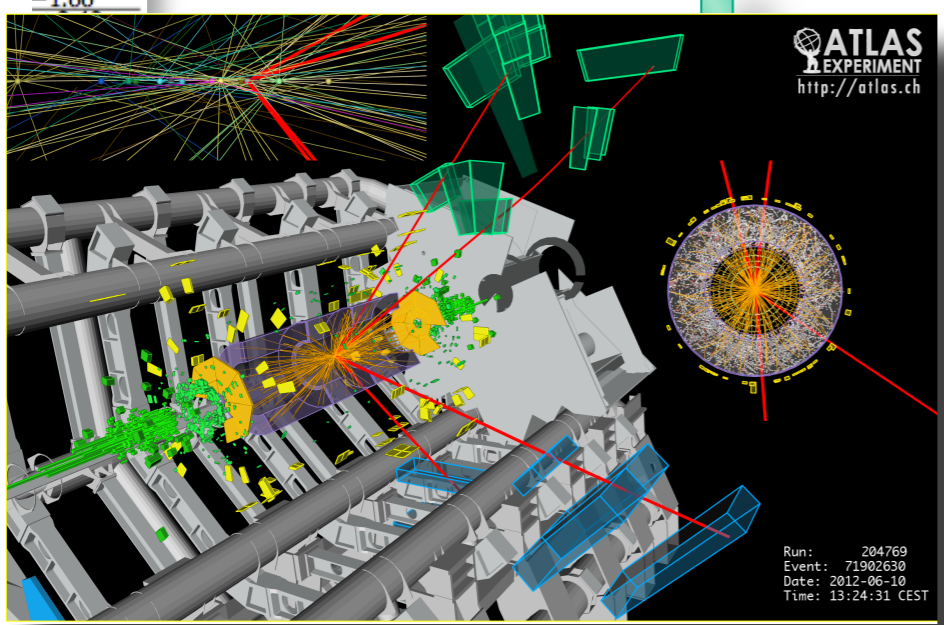
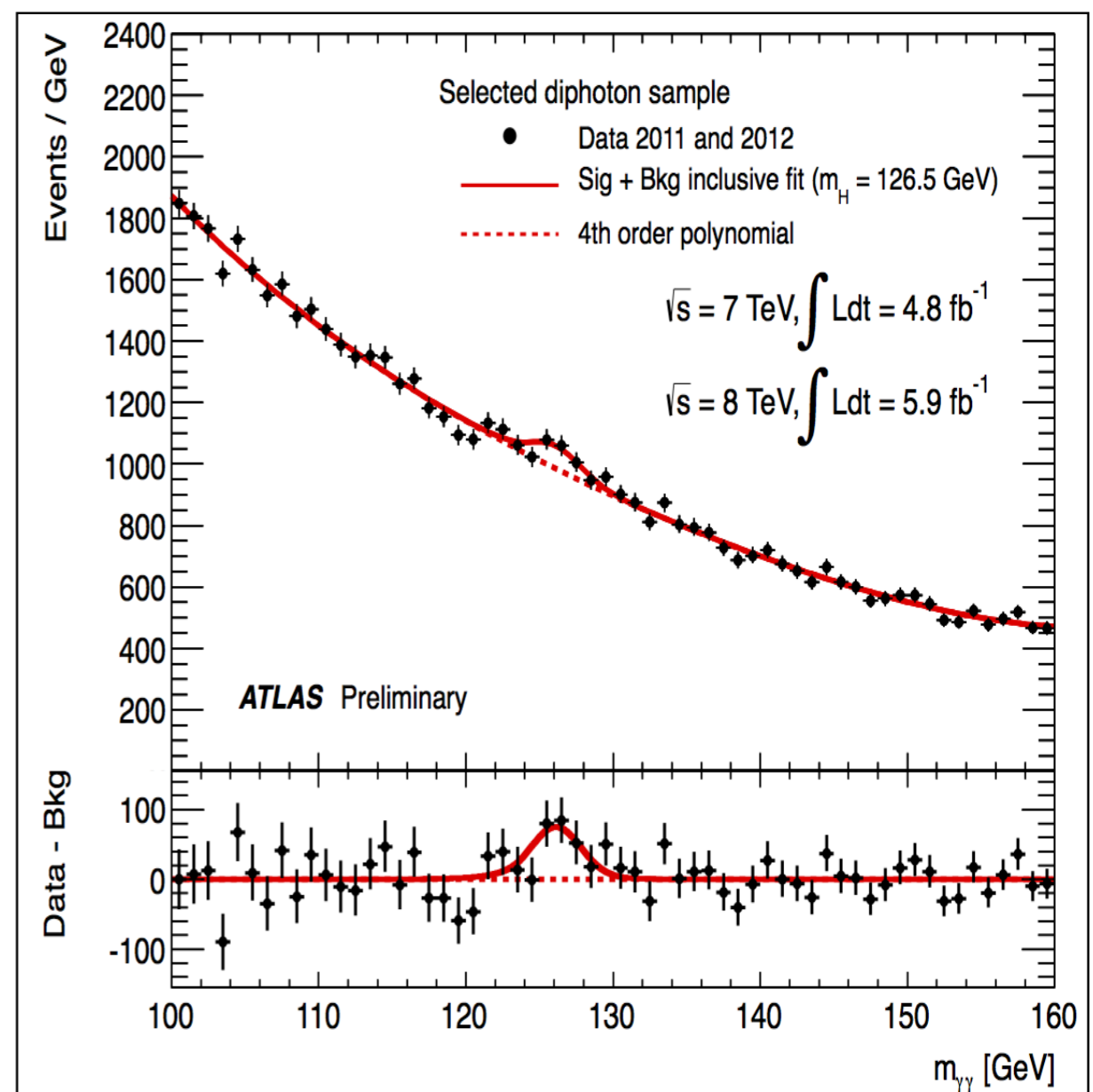
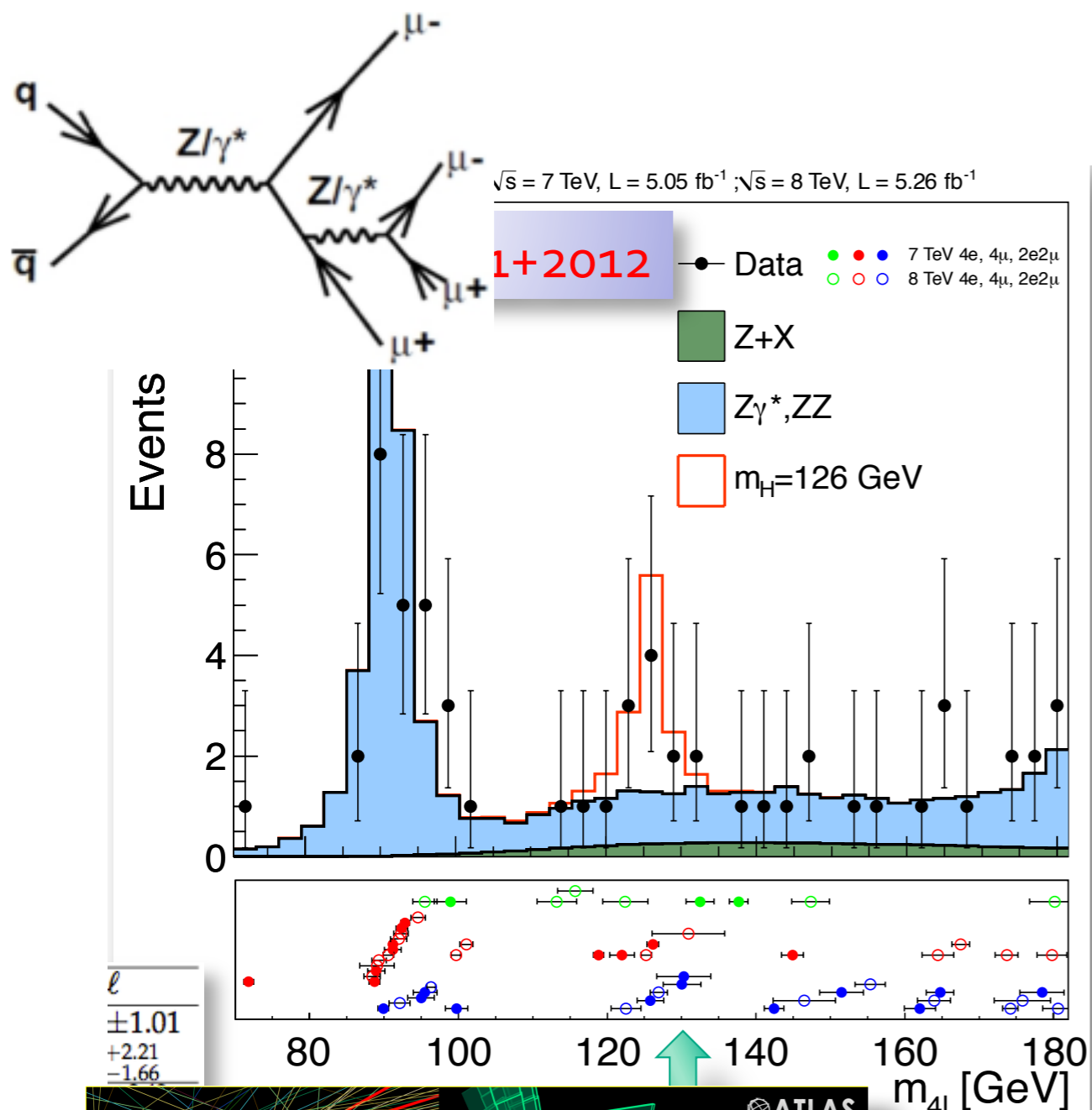
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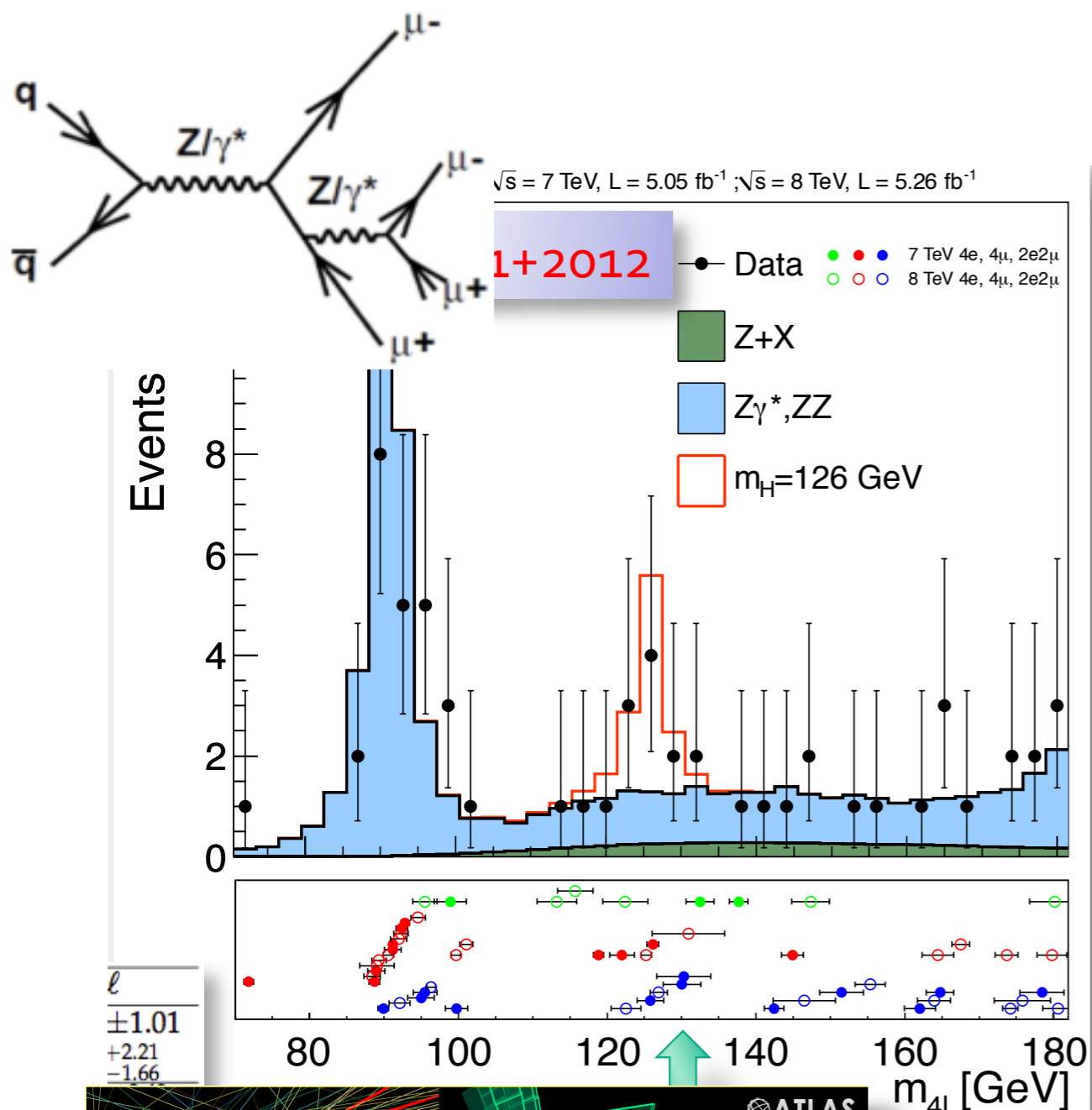
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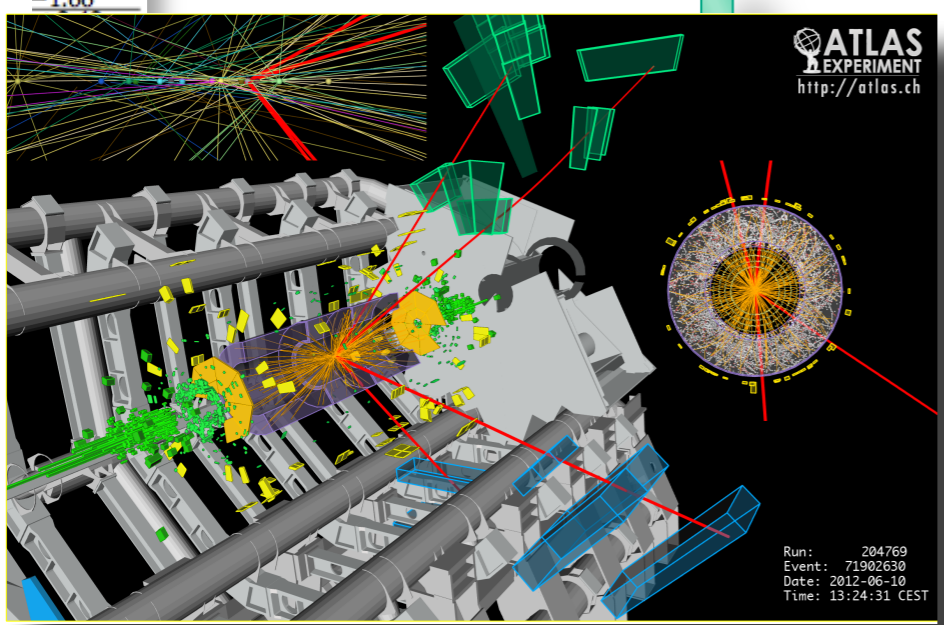
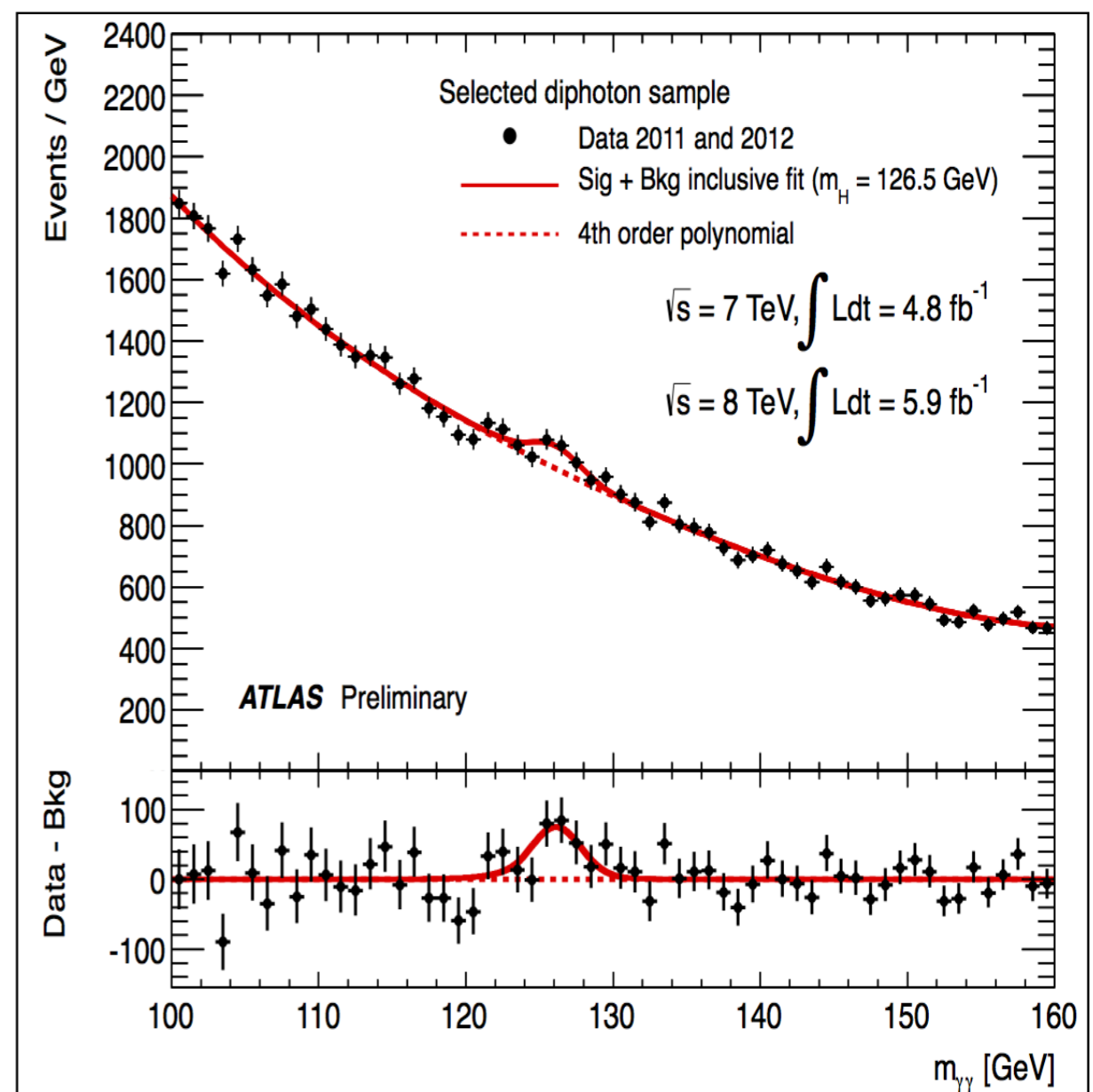
Analysis is done offline,
~3000 collaboration members should have
equal access to data worldwide

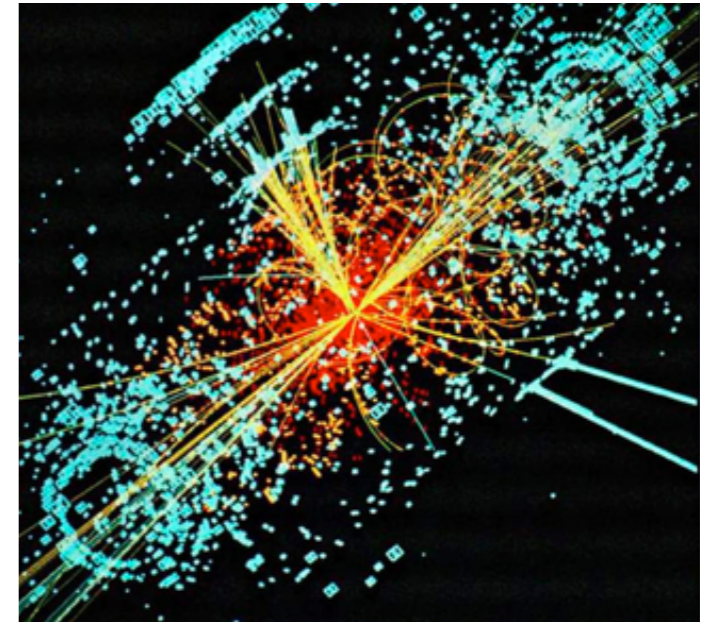
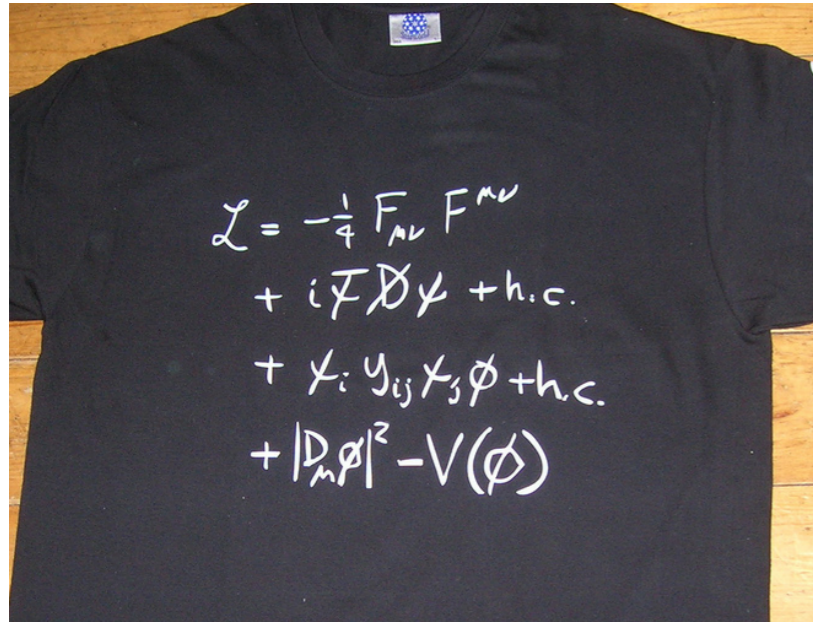


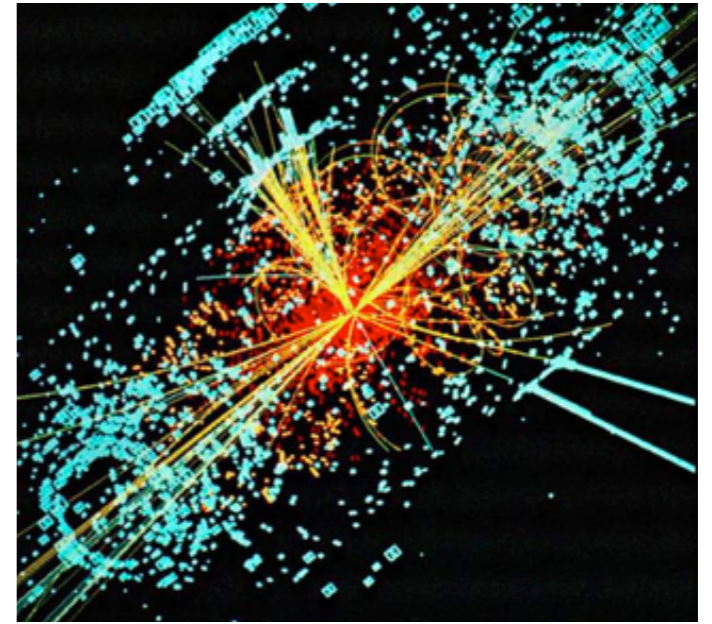
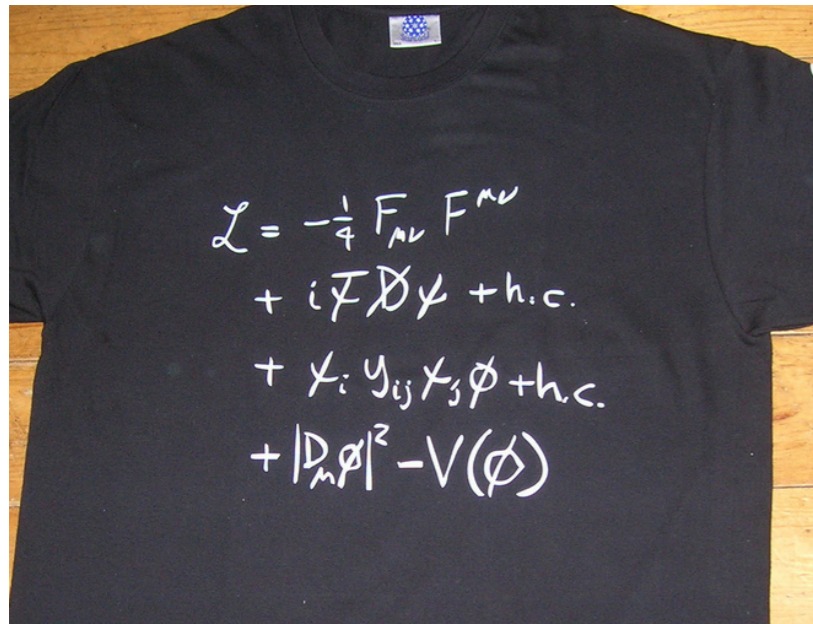


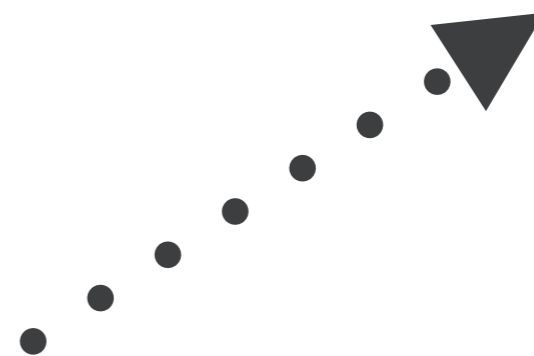
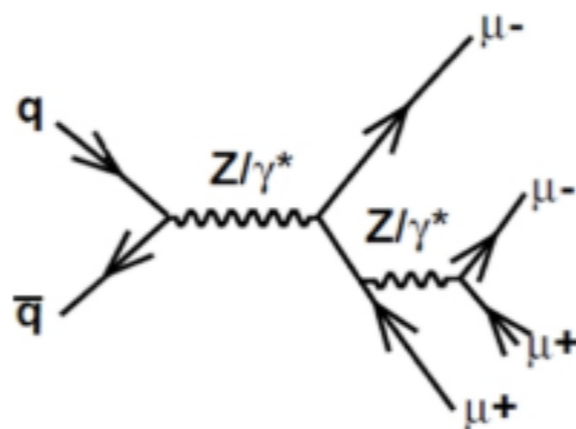
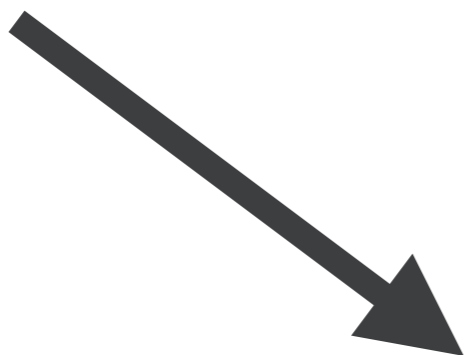
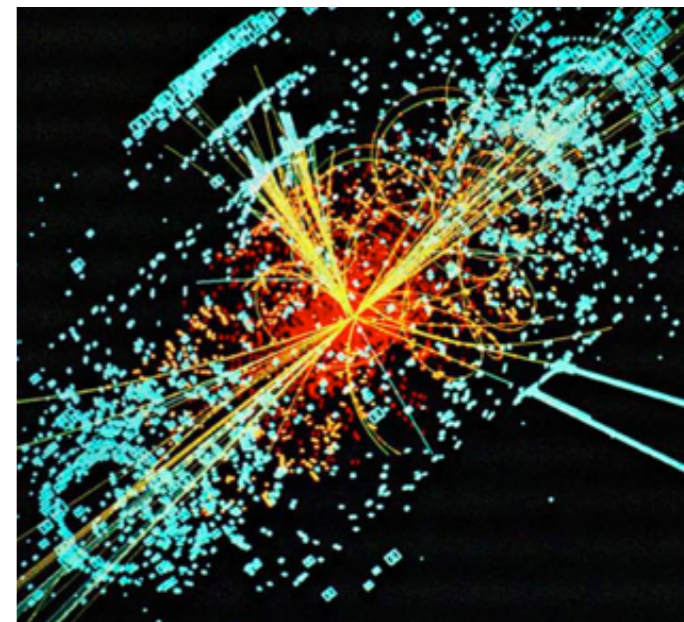
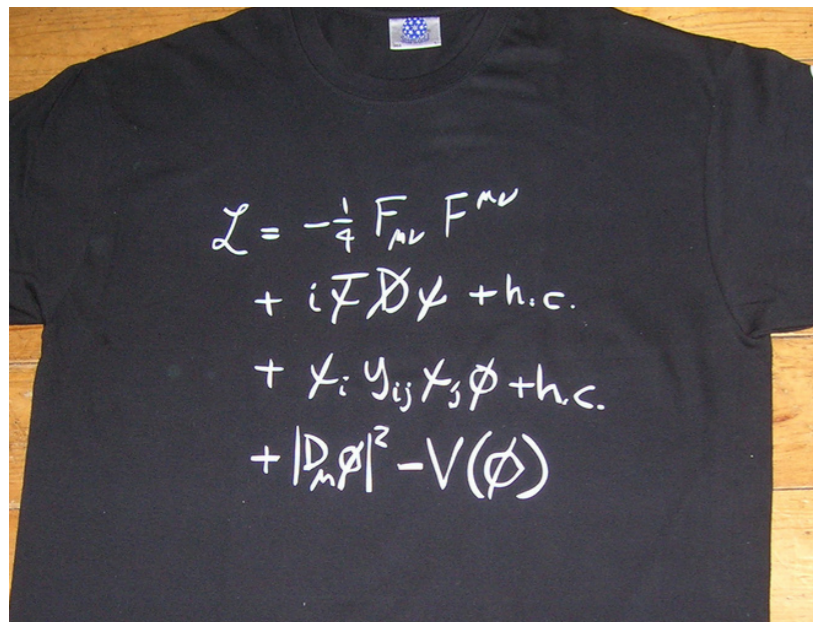


Need to get theory predictions.









Monte Carlo event generators

Herwig details

- General purpose MC event generator
- 30-year history in its F77 implementation;
Herwig 7 is a complete redesign from ground up in C++, started 2003. (more and more python creeping in)
- currently ~15 collaboration members
in Durham, Karlsruhe, Manchester, Zurich
- Coordination is hard. Technically: Trello / Trac / Jenkins.
Don't have a good model sociologically.
- Main reference: arXiv:0803.0883, 1101.2599
<https://herwig.hepforge.org/>

ThePEG



Toolkit for high energy
physics event generation

[Leif Lönnblad]

Herwig++

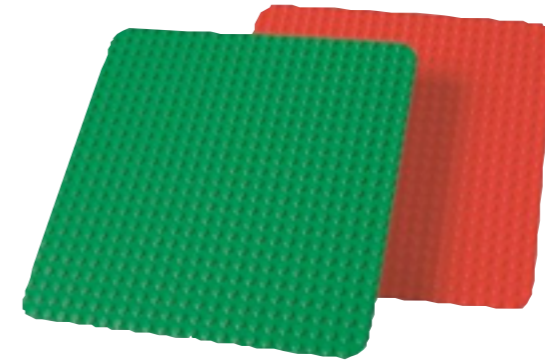


Box of physics implementations

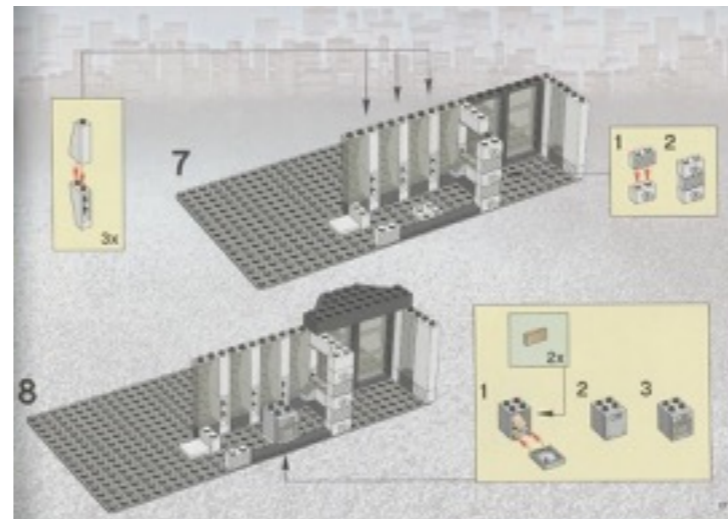
Each building block is
a compiled C++ class



ThePEG Repository

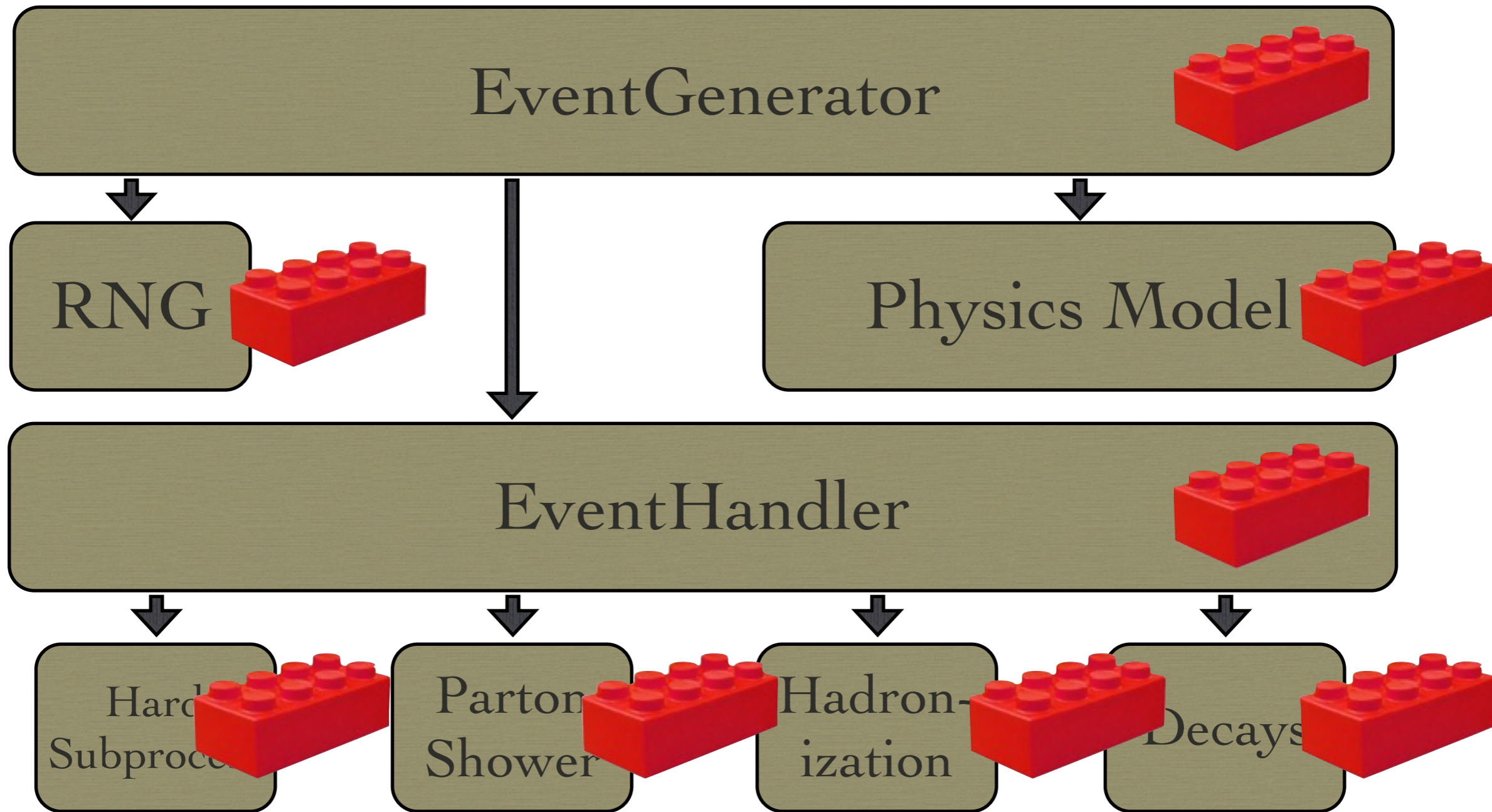


plaintext
setup files



no more compilation needed here

Default Setup



Default Setup

```
create ThePEG::StandardEventHandler /Herwig/LHCHandler
set    LHCHandler:LuminosityFunction FixedLHCLuminosity
```

```
insert LHCHandler:SubProcessHandlers[0] /Herwig/SimpleQCD
set    LHCHandler:CascadeHandler        /Herwig/ShowerHandler
set    LHCHandler:HadronizationHandler  /Herwig/ClusterHadHandler
set    LHCHandler:DecayHandler         /Herwig/DecayHandler
[...]
```

```
create ThePEG::EventGenerator /Herwig/LHCGenerator ThePEG.so
set    LHCGenerator:EventHandler /Herwig/LHCHandler
[...]
```

```
set LHCHandler:BeamA /Herwig/Particles/p+
set LHCHandler:BeamB /Herwig/Particles/p+
set FixedLHCLuminosity:Energy 14000.0
[...]
```


Default Setup

```
create ThePEG::StandardEventHandler /Herwig/LHCHandler
set    LHCHandler:LuminosityFunction FixedLHCLuminosity
```

```
insert LHCHandler:SubProcessHandlers[0] /Herwig/SimpleQCD
set    LHCHandler:CascadeHandler        /Herwig/ShowerHandler
set    LHCHandler:HadronizationHandler  /Herwig/ClusterHadHandler
set    LHCHandler:DecayHandler          /Herwig/DecayHandler
[...]
```

```
create ThePEG::EventGenerator /Herwig/LHCGenerator ThePEG.so
set    LHCGenerator:EventHandler /Herwig/LHCHandler
[...]
```

```
set
set
set
[...]
```

Arbitrary user extensions use dlopen():

```
create DGrell::Myclass /DGrell/Myclass DGrellHwPlugin.so
```

Main code never needs recompilation.

Default Setup

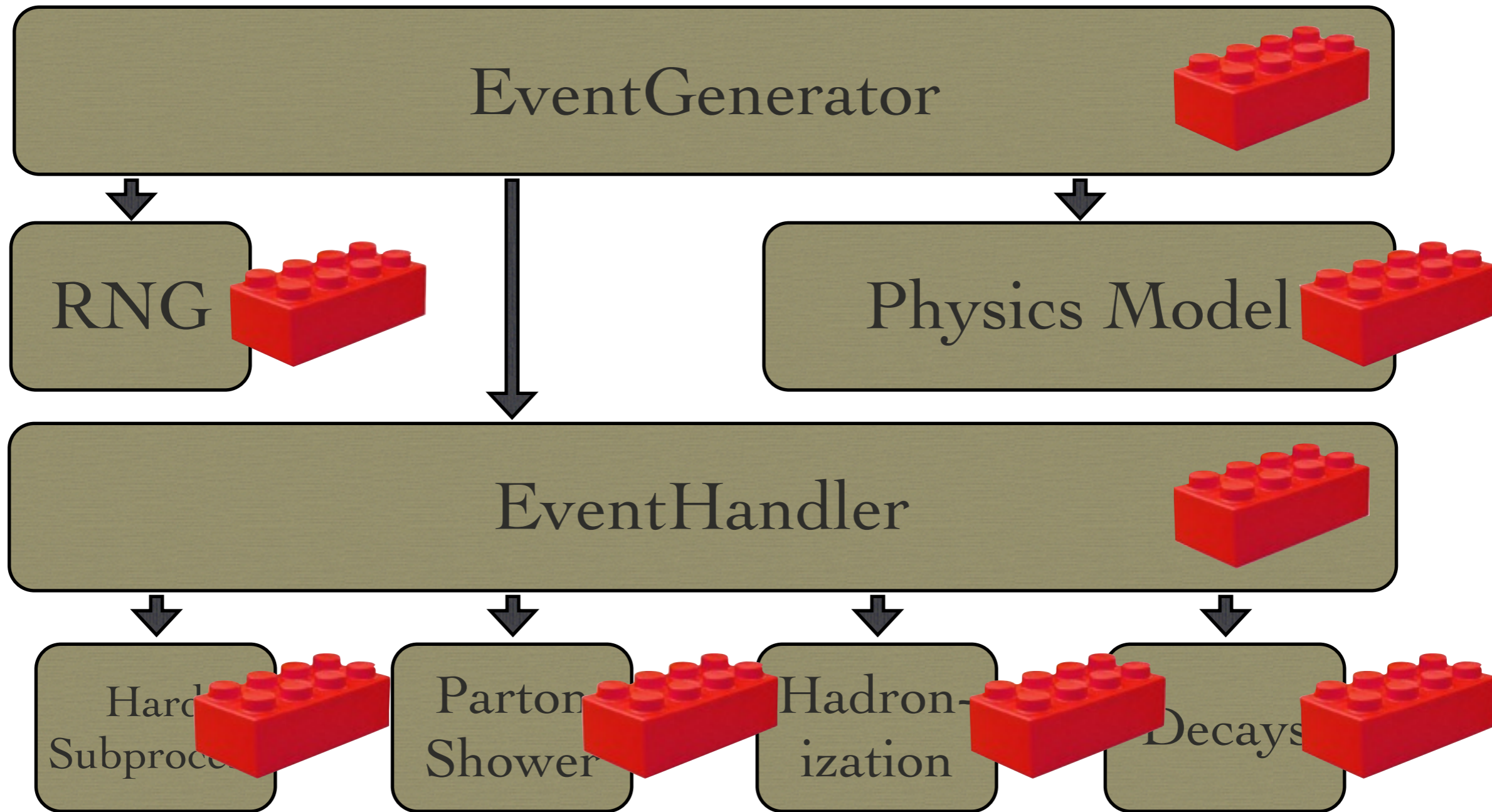
```
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[...]
```

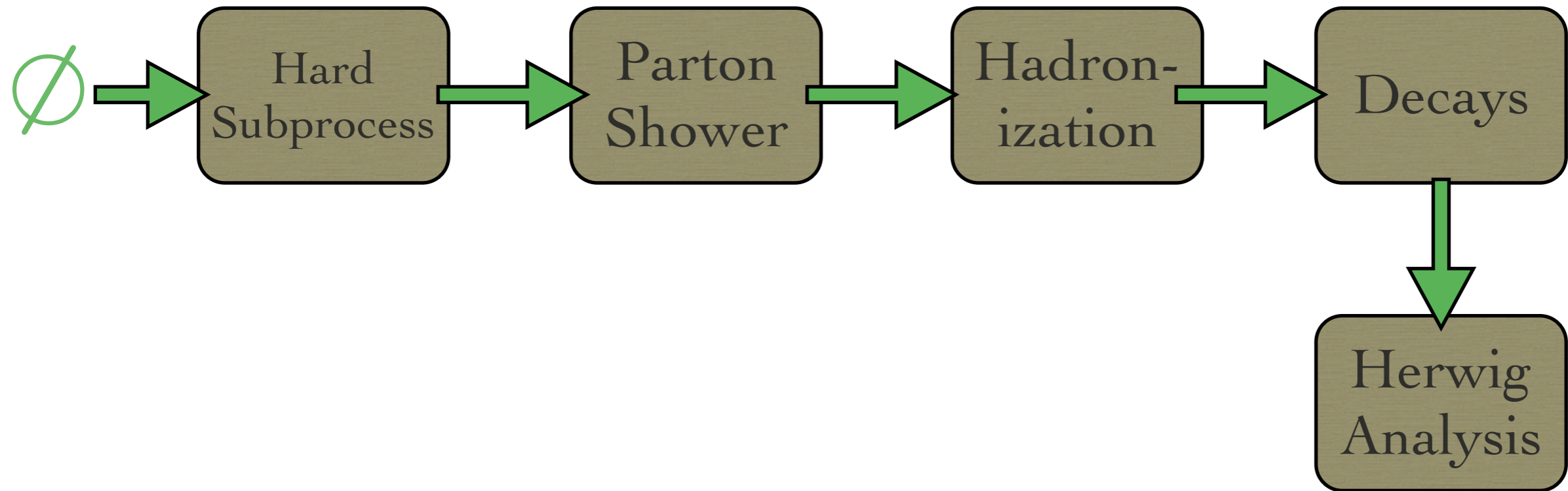
```
create ThePEG::EventGenerator /Herwig/LHCGenerator ThePEG.so  
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[...]
```

```
set LHCHandler:BeamA /Herwig/Particles/p+  
set LHCHandler:BeamB /Herwig/Particles/p+  
set FixedLHCLuminosity:Energy 14000.0  
[...]
```

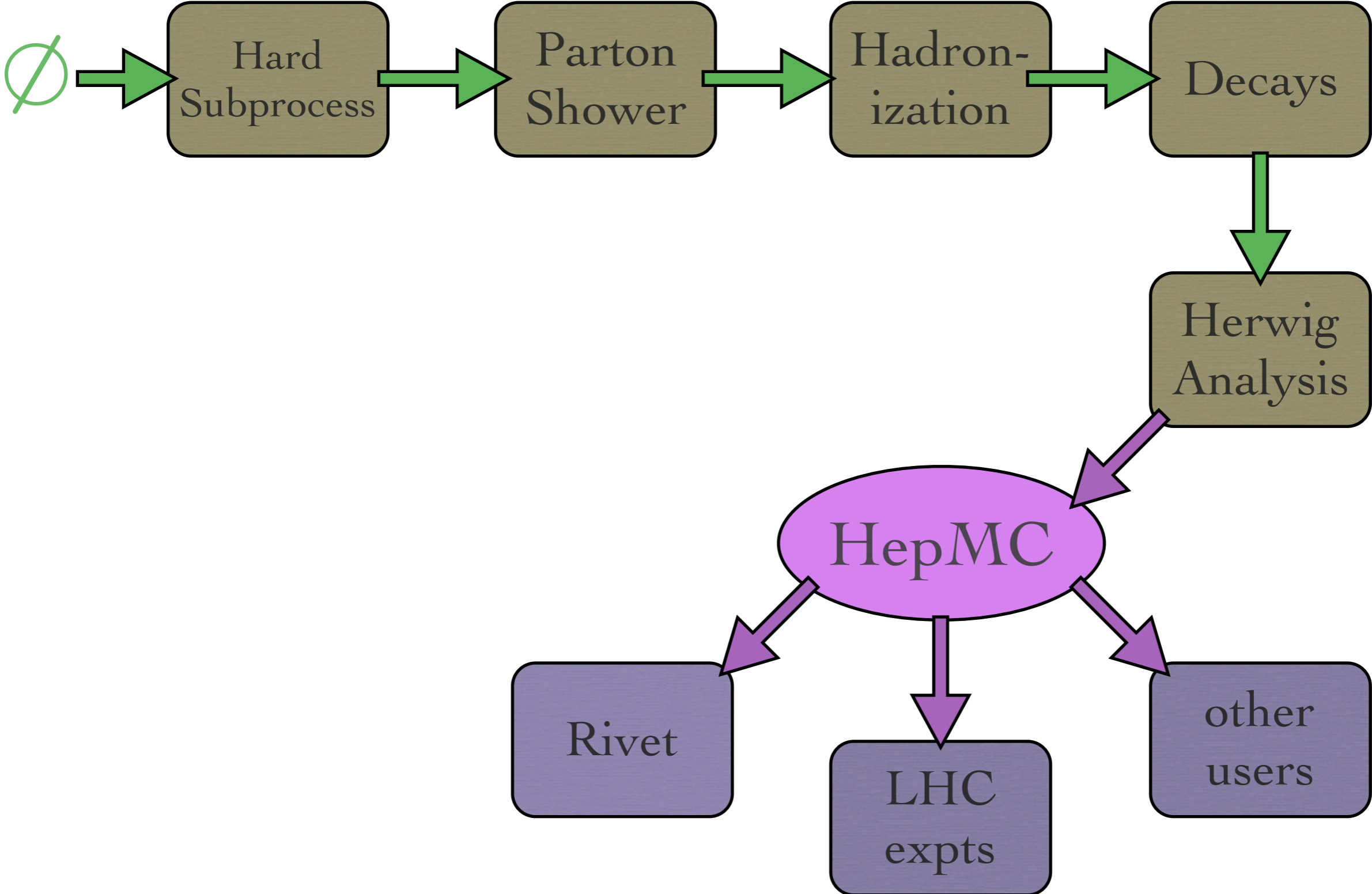
Default Setup



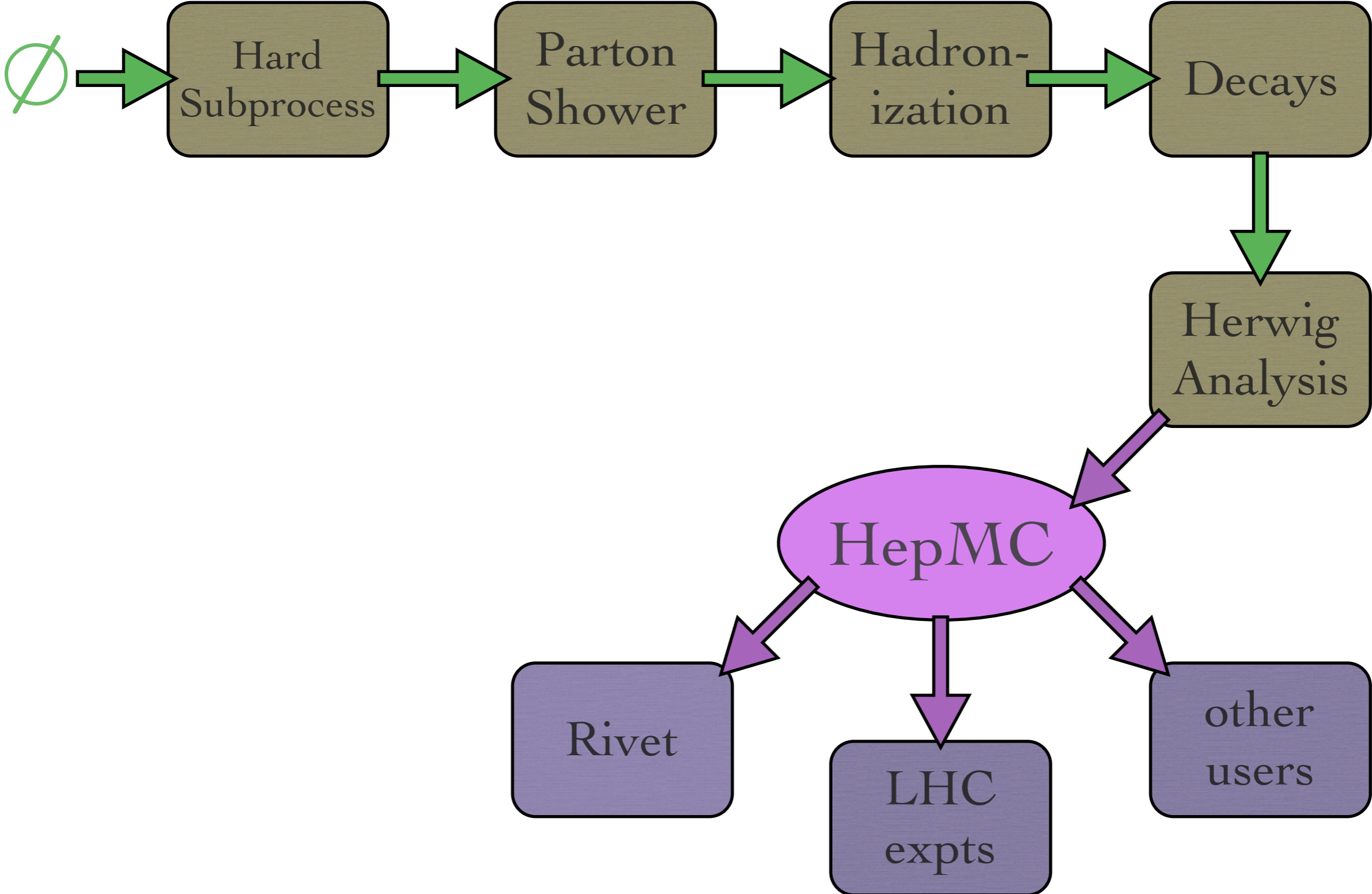
Event record flow



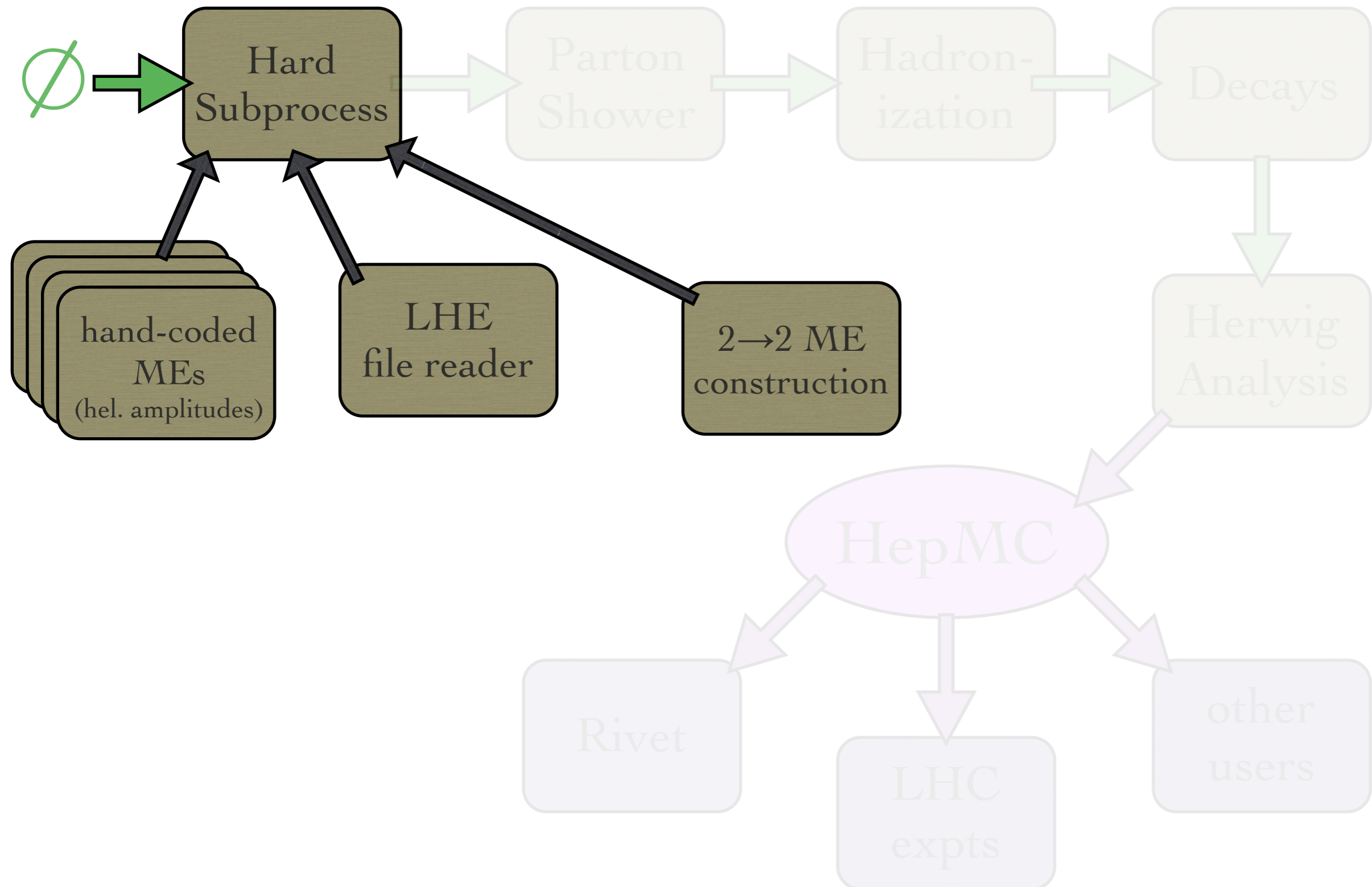
Event record flow



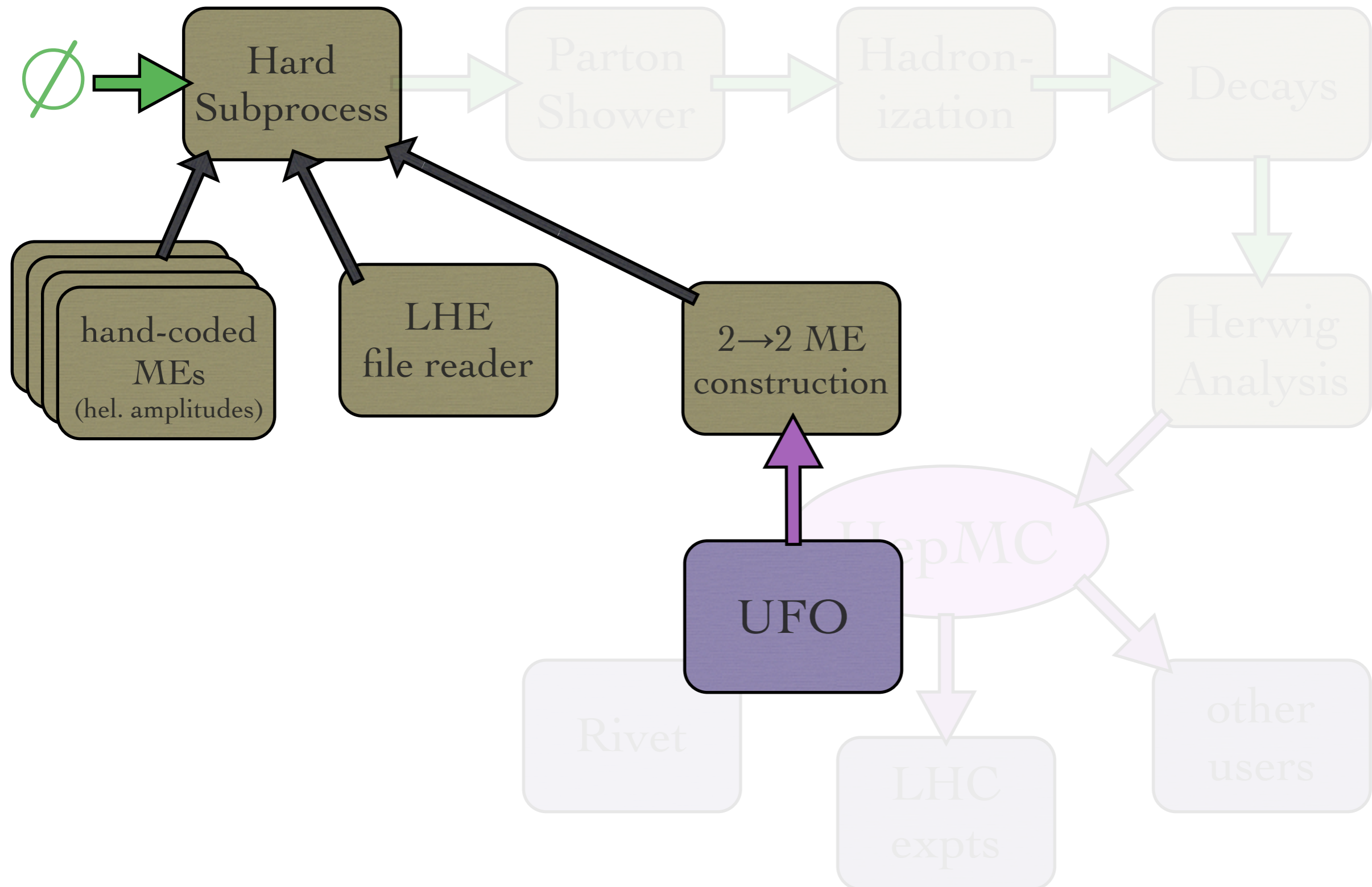
Event record flow

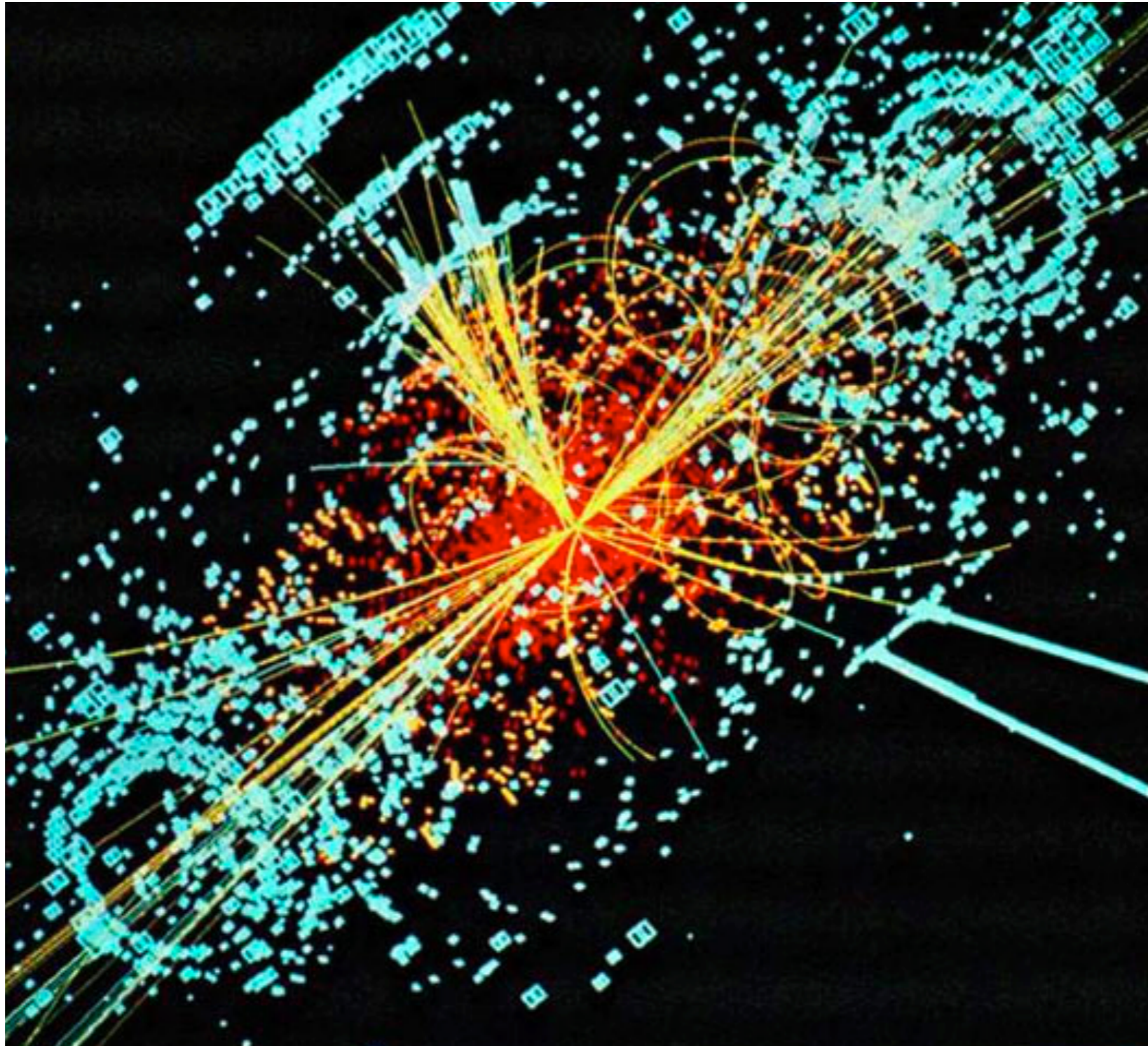


Event record flow



Event record flow





Simulated data sets of millions of events

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](#) .

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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.

