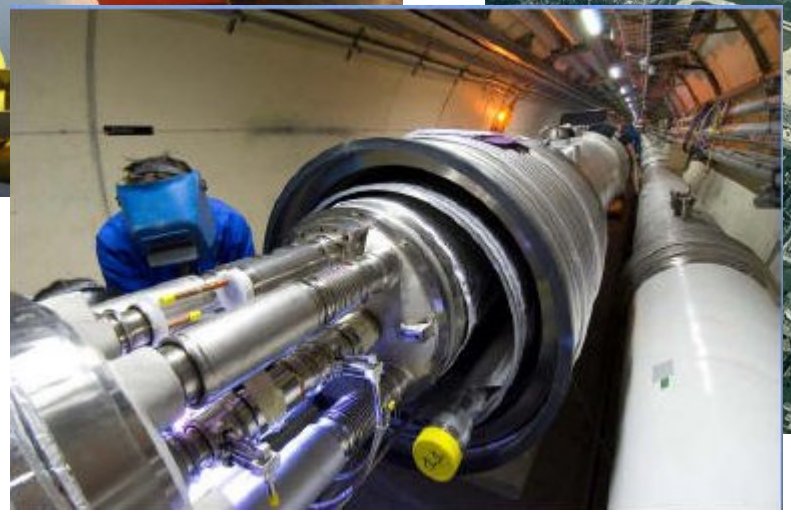
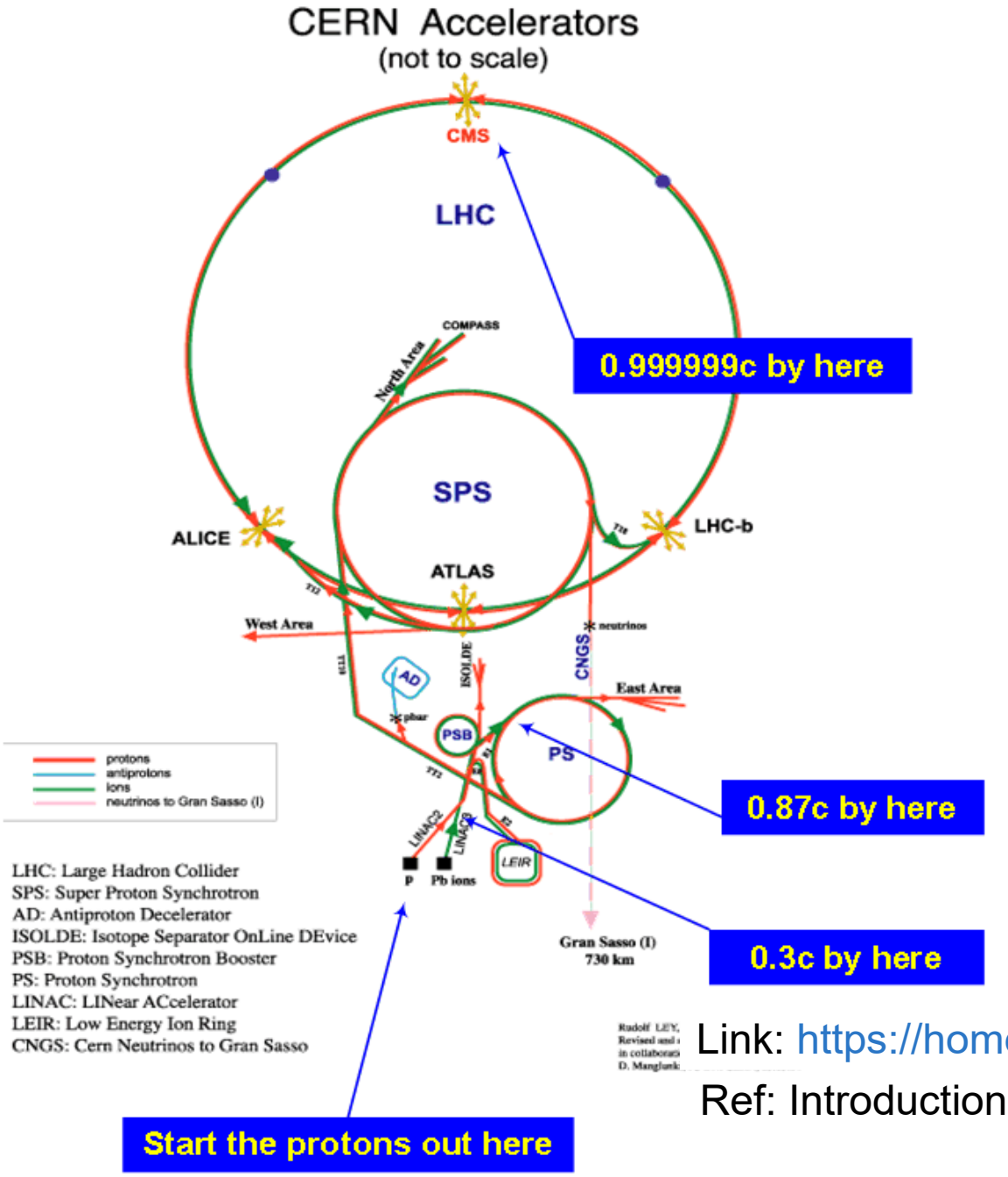
CERN's Large Hadron Collider



Ref: www.cern.ch

Large Hadron Collider (LHC)



Energies:

Linac 50 MeV

PSB 1.4 GeV

PS 28 GeV

SPS 450 GeV

LHC 6.5 TeV

Link: https://home.cern/topics/large-hadron-collider

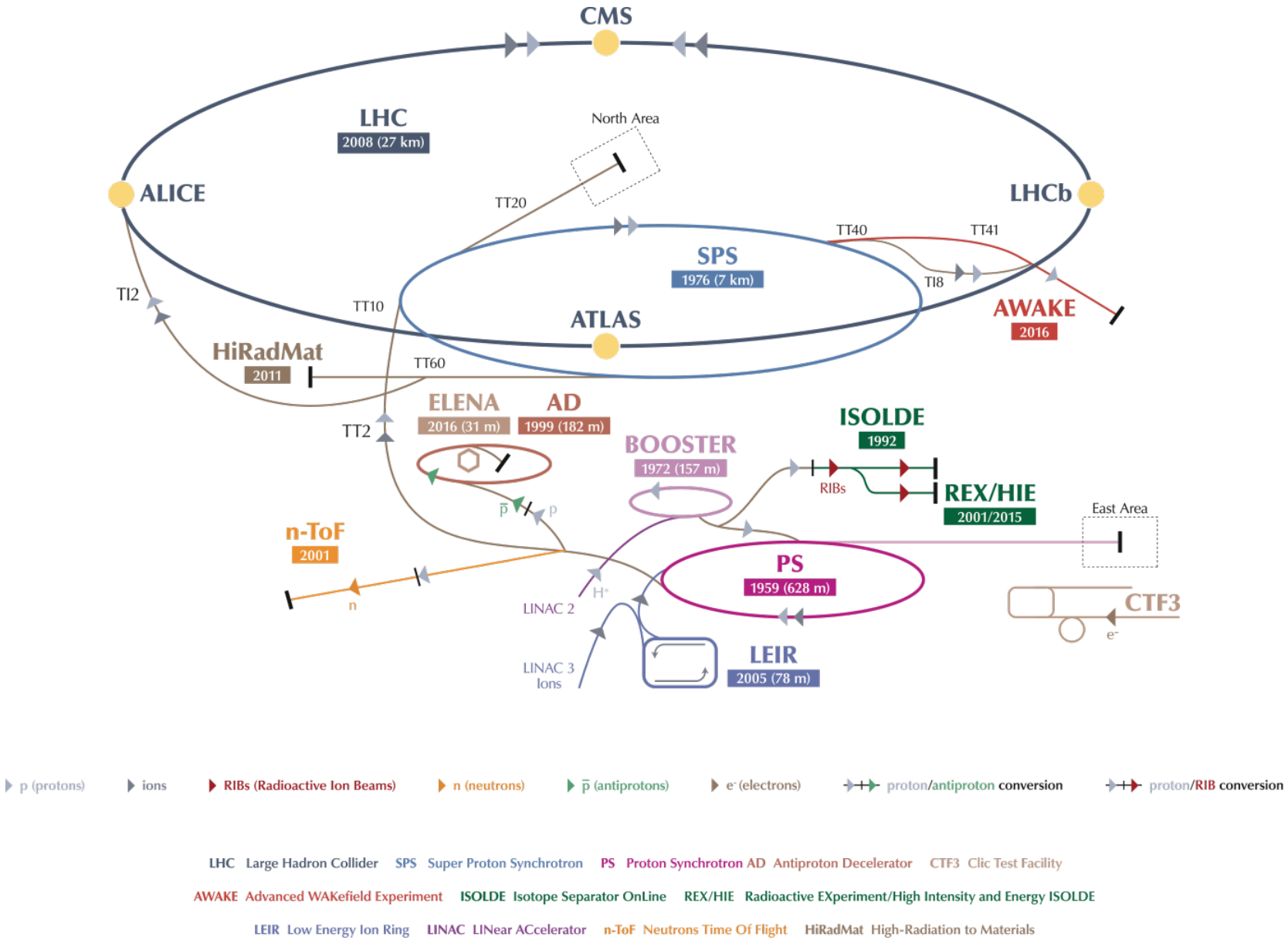
Ref: Introduction to Accelerators, Elena Wildner, CERN

LHCParameters

Circumference	26659 m
Dipole operating temp	1.9 deg K
Main RF frequency	400.8 MHz
“Bucket,” 1/frequency	2.5 ns
Energy per beam	6.5 TeV, operating
Dipole Magnetic Field	7.7 T
Ions Energy per nucleon	2.56 TeV/n = 6.5*82/208 (Pb-208)
no. of protons	1.2e11 per bunch
no. of bunches	<= 2604/2748
bunch length, 4sigma	1-1.25 ns
bunch size, x & y at IP, 1 sigma	52 x 66 microns

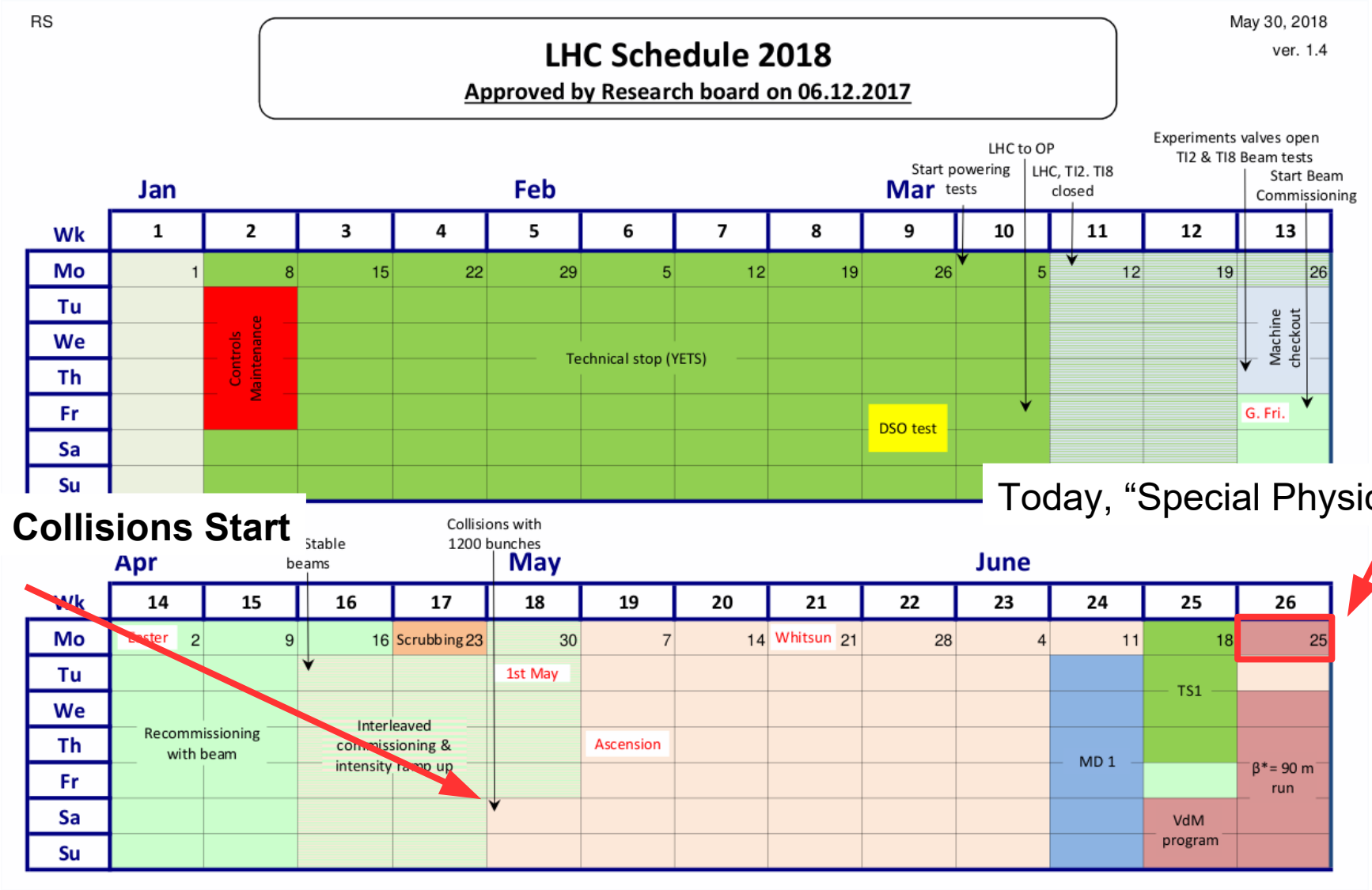
Ref: www.cern.ch

Large Hadron Collider (LHC)



Link https://beams.web.cern.ch/content/accelerators-schedules

LHC Schedule 2018, Jan-June



Proton Collisions Start

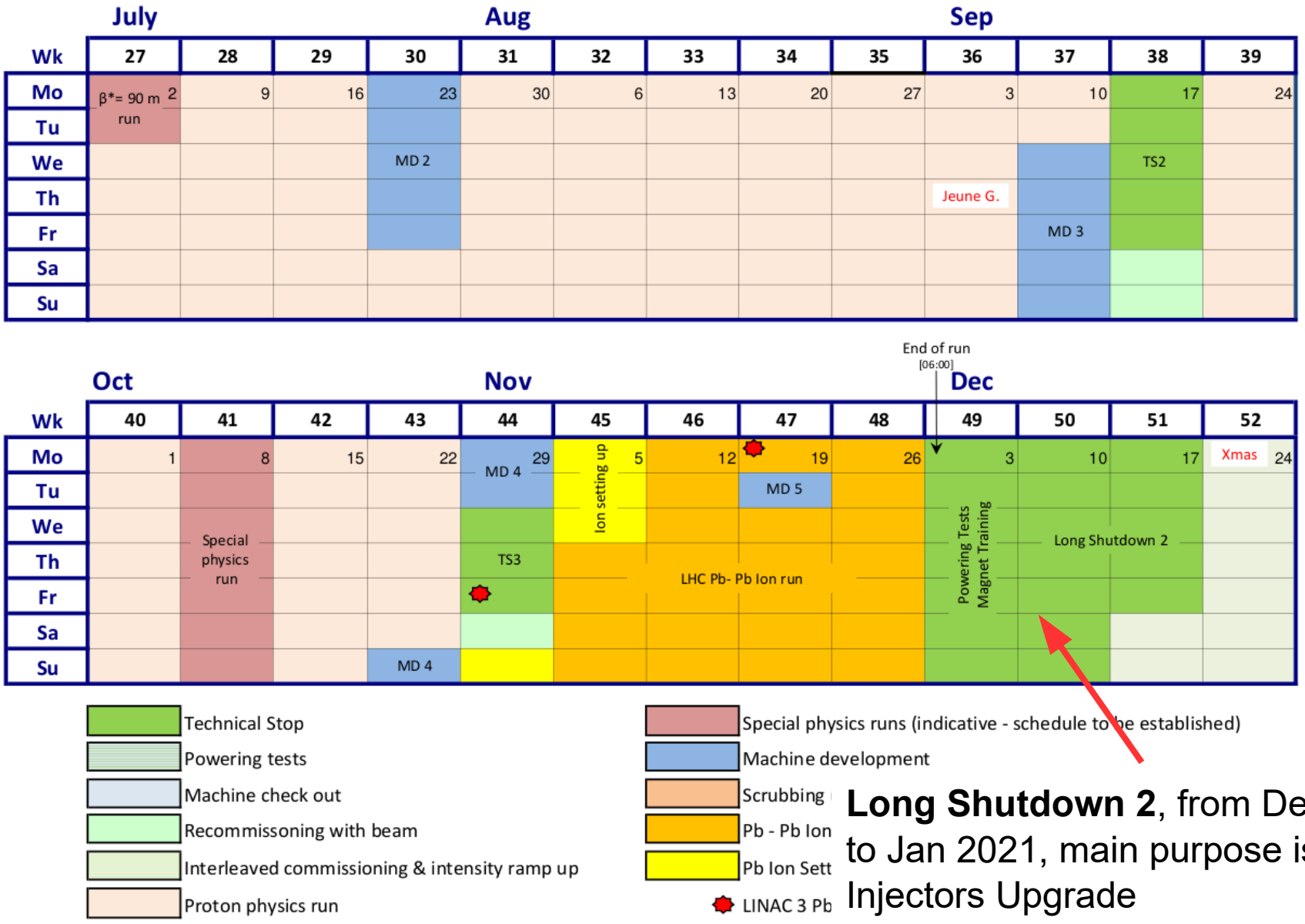
Today, "Special Physics runs"

Link https://beams.web.cern.ch/content/accelerators-schedules

Long term schedule

https://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/LHC-long-term.htm

LHC Schedule 2018, July-Dec

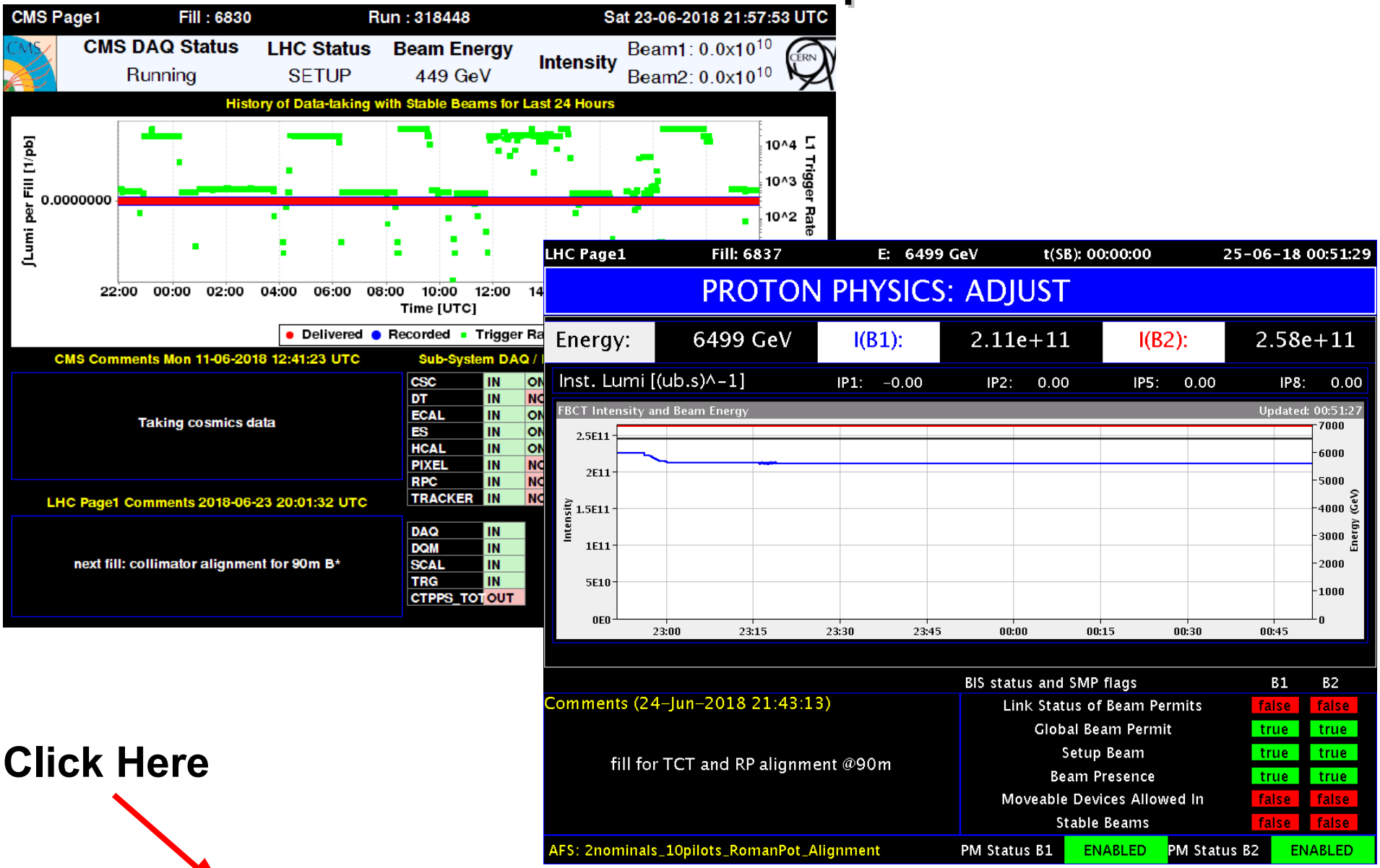


Long Shutdown 2, from Dec 2018 to Jan 2021, main purpose is LHC Injectors Upgrade

Long Shutdown 2 Goals...

- Upgrade the whole LHC injector chain;
- Energy to 7 TeV? 20% higher luminosity?
- Maintenance on the LHC and the Detectors;
- Start on aspects of the *Accelerator Consolidation Project* and
- the *HL-LHC*, aka the High-Luminosity LHC (even more protons per bunch and/or more bunches.
- LS3 starts (maybe) 2024 and runs 2.5 years until mid-2026.

Current Status Op Vistar

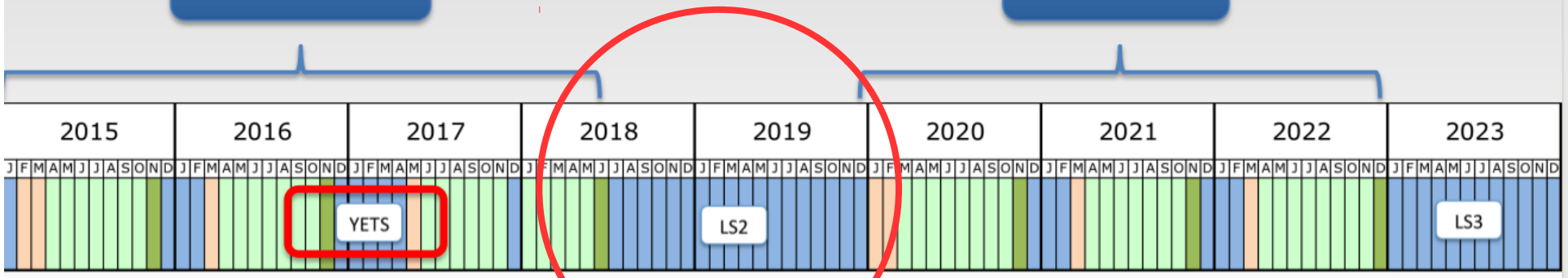


Click Here

https://op-webtools.web.cern.ch/vistar/vistars.php?usr=LHC1

Next 10 years

2015 Plan: LS2 changed, starts later and takes two years



6.5 to 7 TeV
Peak luminosity $1.7 \times 10^{34} cm^{-2} s^{-1}$

7 TeV
Peak luminosity $2.0 \times 10^{34} cm^{-2} s^{-1}$

LIU (Injectors)
ALICE
LHCb

HL-LHC
(Machine
& expts)

1

http://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/LHC-schedule-update.pdf

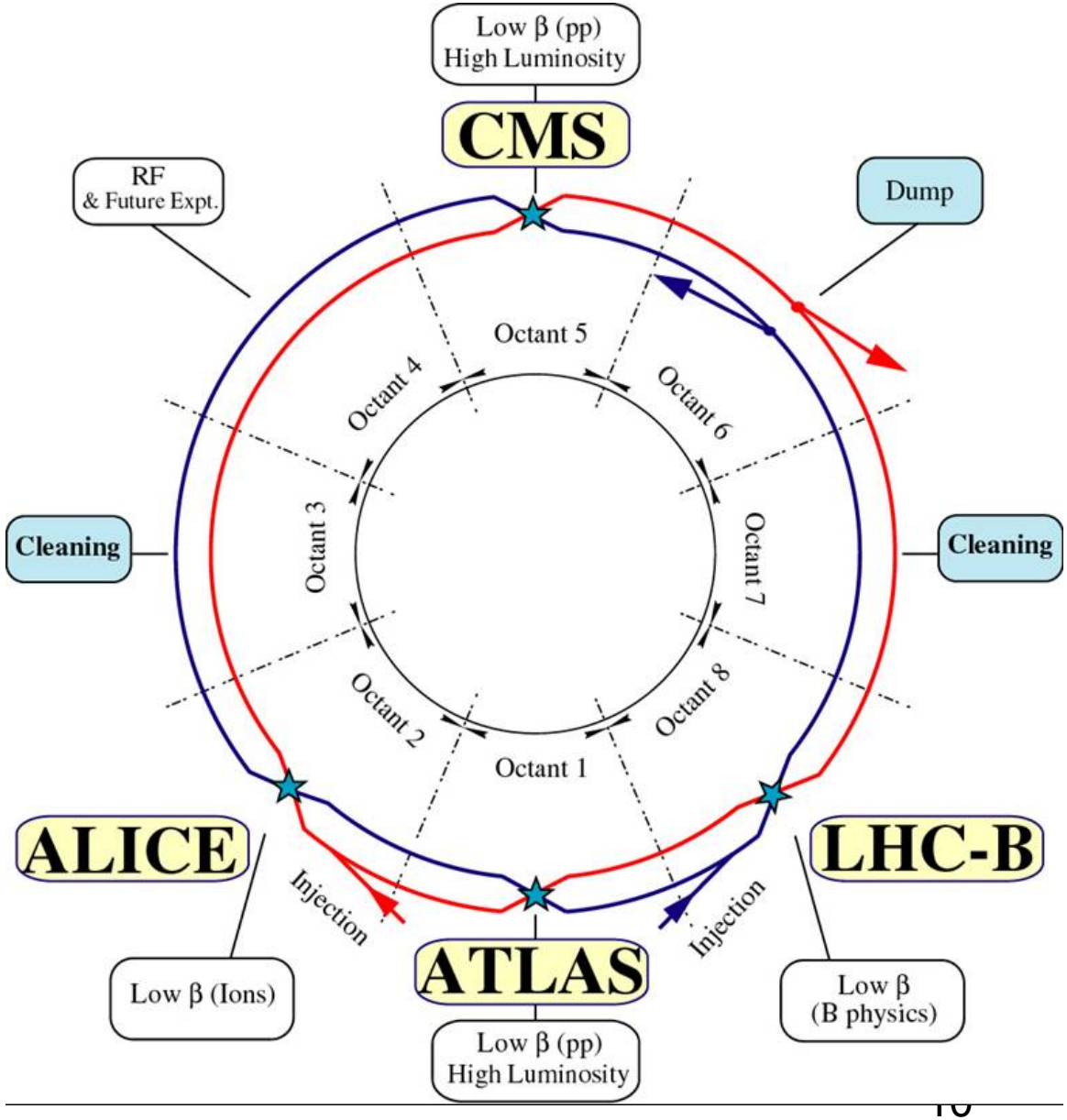
What has the LHC done?

Energies & Modes:

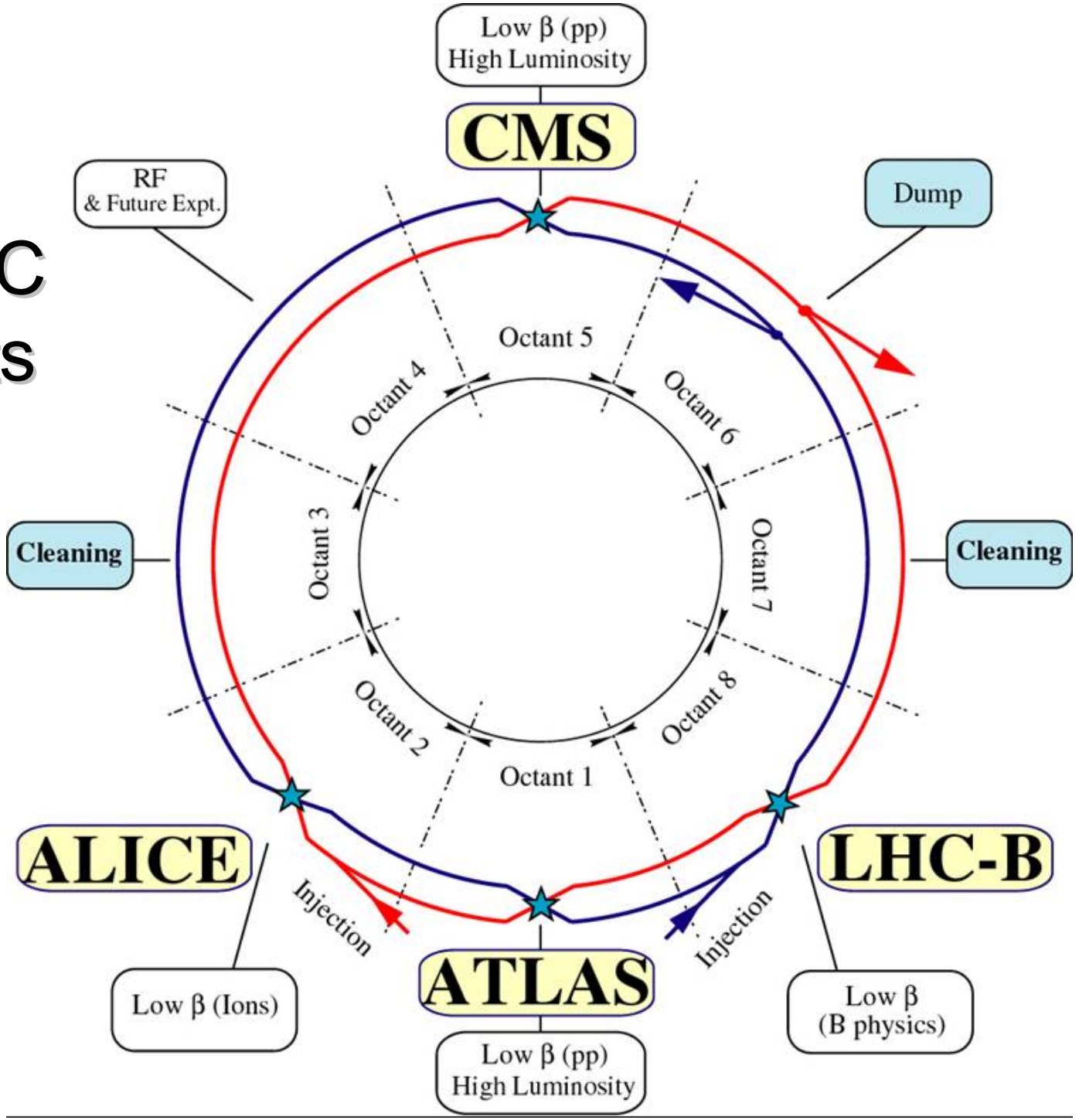
Proton-Proton
2011 3.5+3.5 TeV
2012 4+4 TeV
1380 on 1380 bunches
2013 Long Shutdown 1
2015-8 6.5+6.5 TeV

Lead-208 (82+)-Lead
2011 1.38+1.38 TeV/u
2012 none (?)
358 on 358 bunches

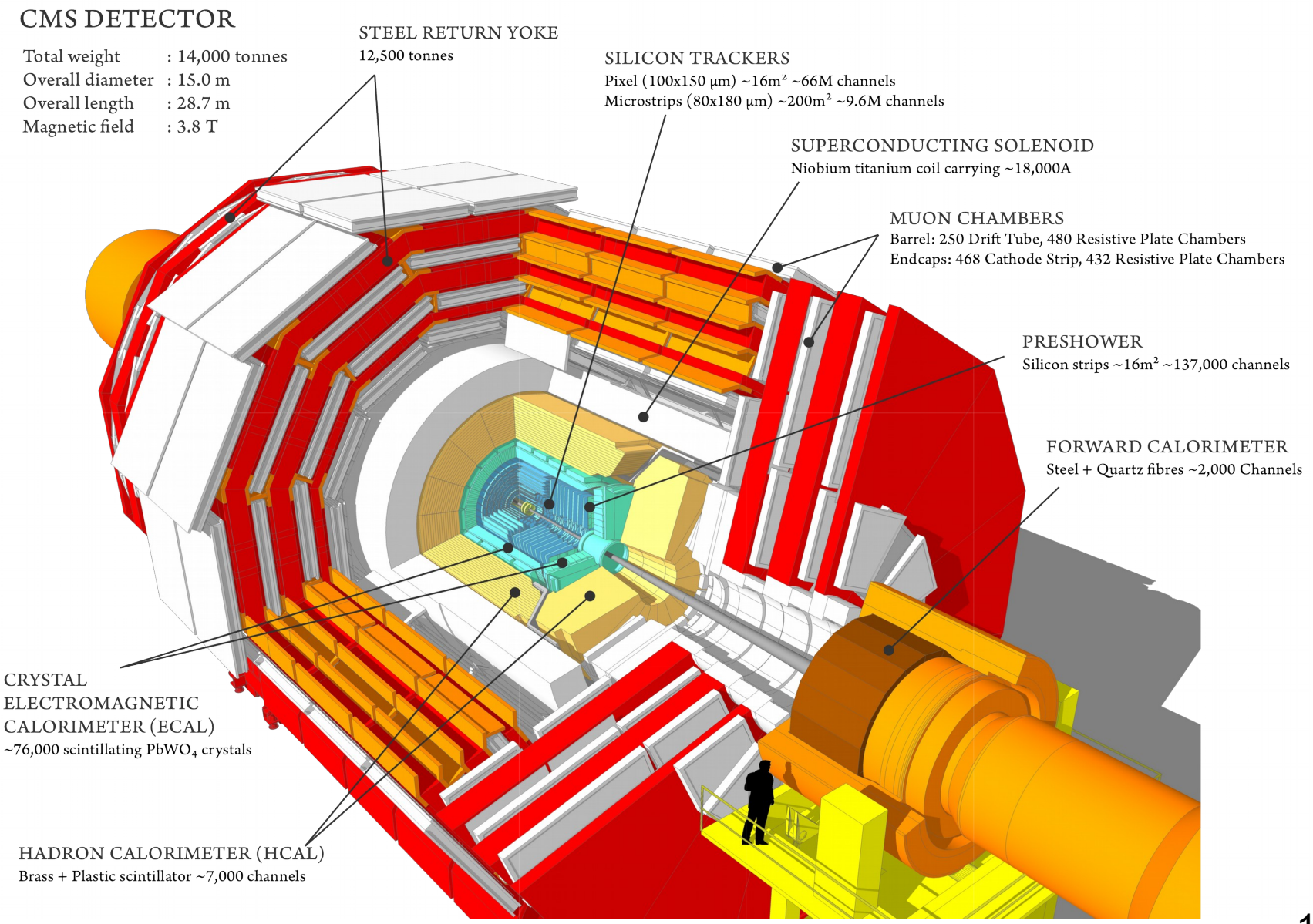
Proton-Lead
2013 5.02 TeV/u
338 on 338 bunches
2016 5.02 TeV/u
2016 8.16 TeV/u



CERN's LHC Experiments



Compact Muon Solenoid (CMS) Detector



CMS Data Taking Status

CMS Page 1 for status...(login required)
https://cmswbm.cern.ch/cmsdb/servlet/Page1

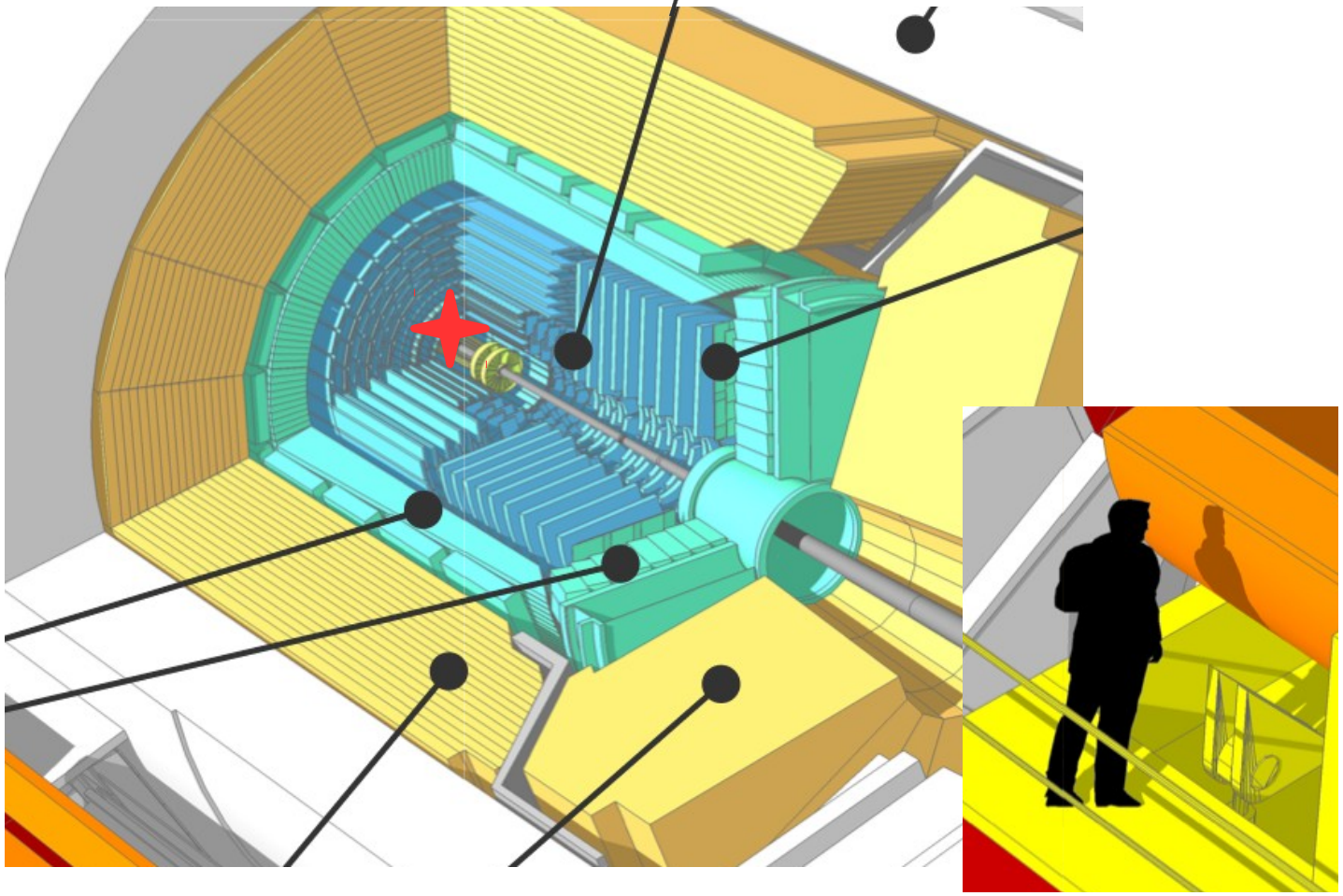
CMS Online Web Based Monitoring...(login required)
https://cmswbm.cern.ch/

Pixel (sub)Detector Wraps around the collision point.

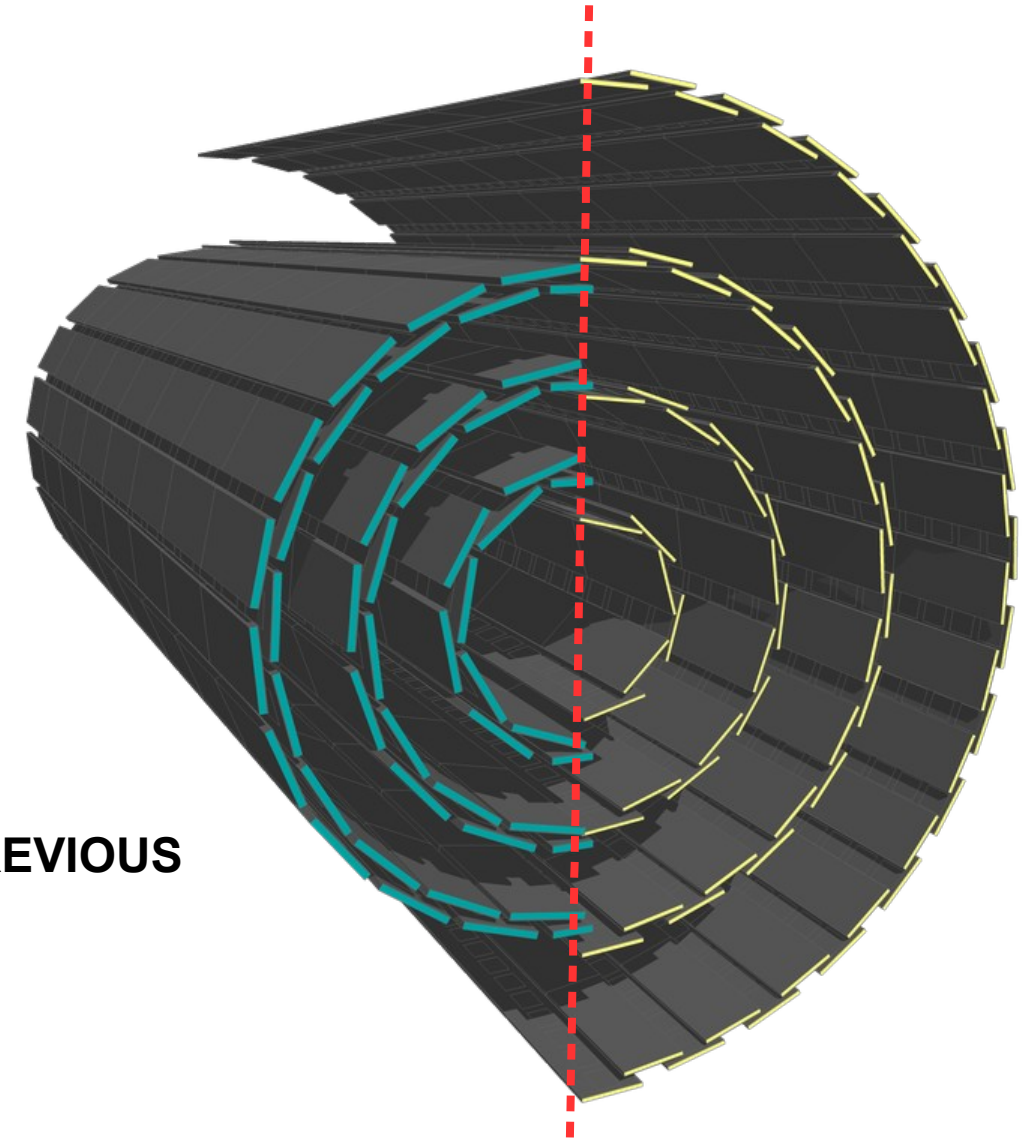
SILICON TRACKERS

Pixel (100x150 μm) ~16m² ~66M channels

Microstrips (80x180 μm) ~200m² ~9.6M channels



The Pixel is made up of the Barrel and the Forward Pixel

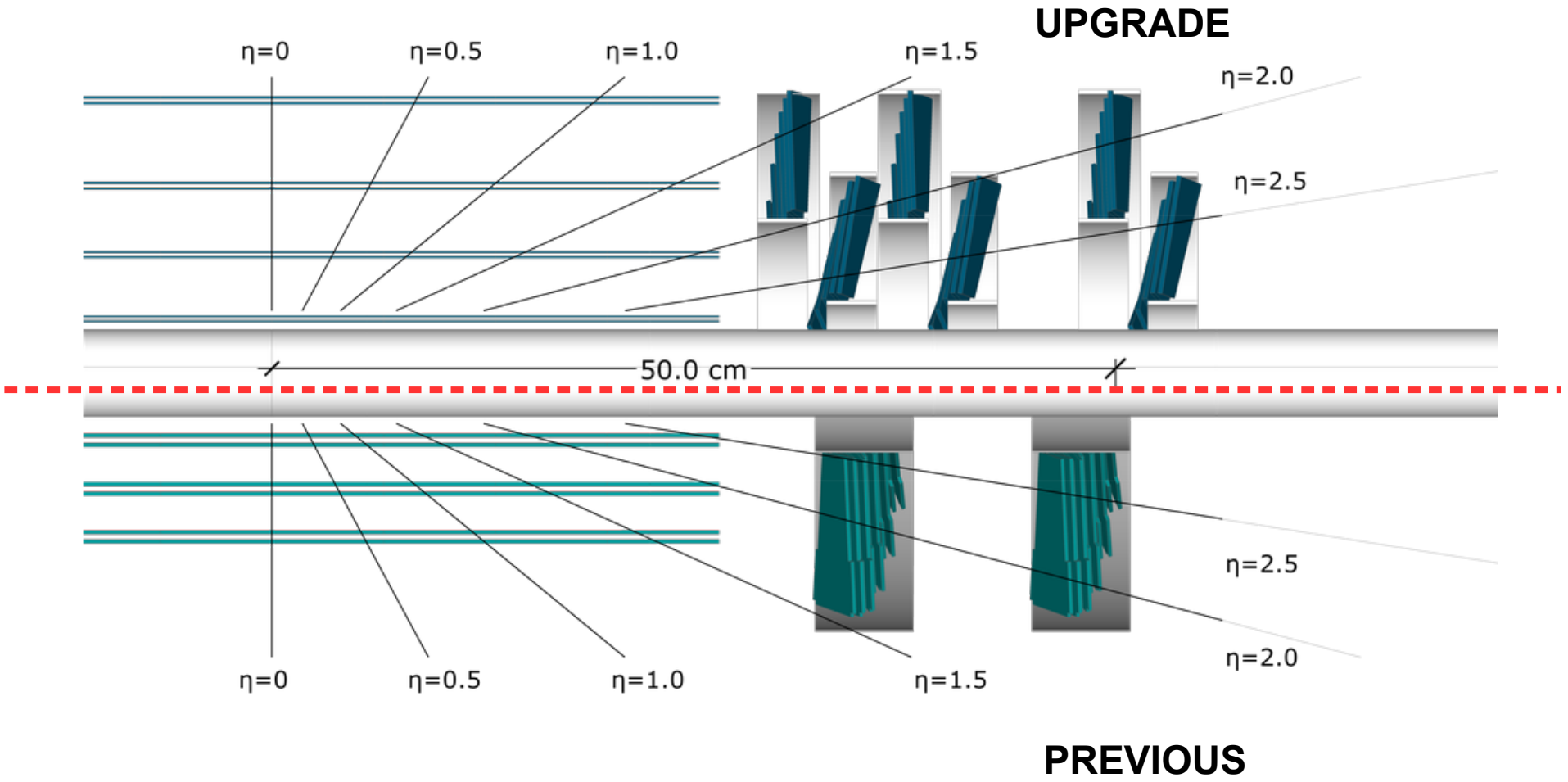


PREVIOUS **UPGRADE**

Upgraded to 4 layers, installed in December 2016.

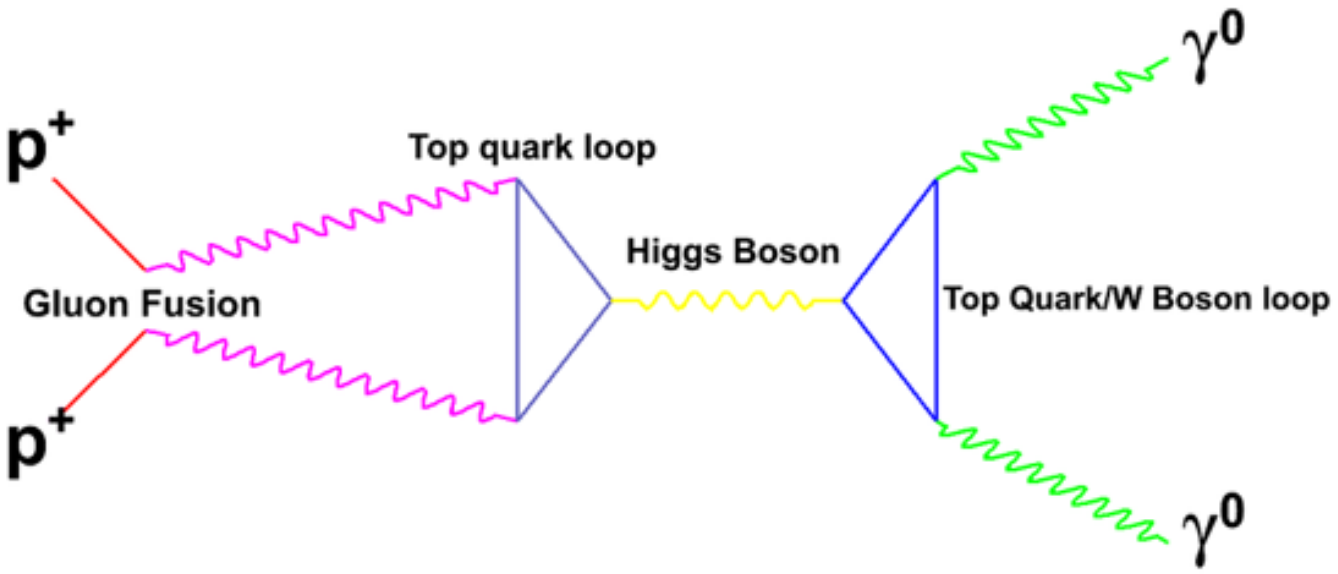
First layer is inches from the collision point.

Vanderbilt (Will Johns) Supports the Forward Pixel (sub)Detector



CMS and Atlas Discovered the Higgs particle

Joint announcement in July 4, 2012, with data from 7 and 8 TeV center of mass energy.

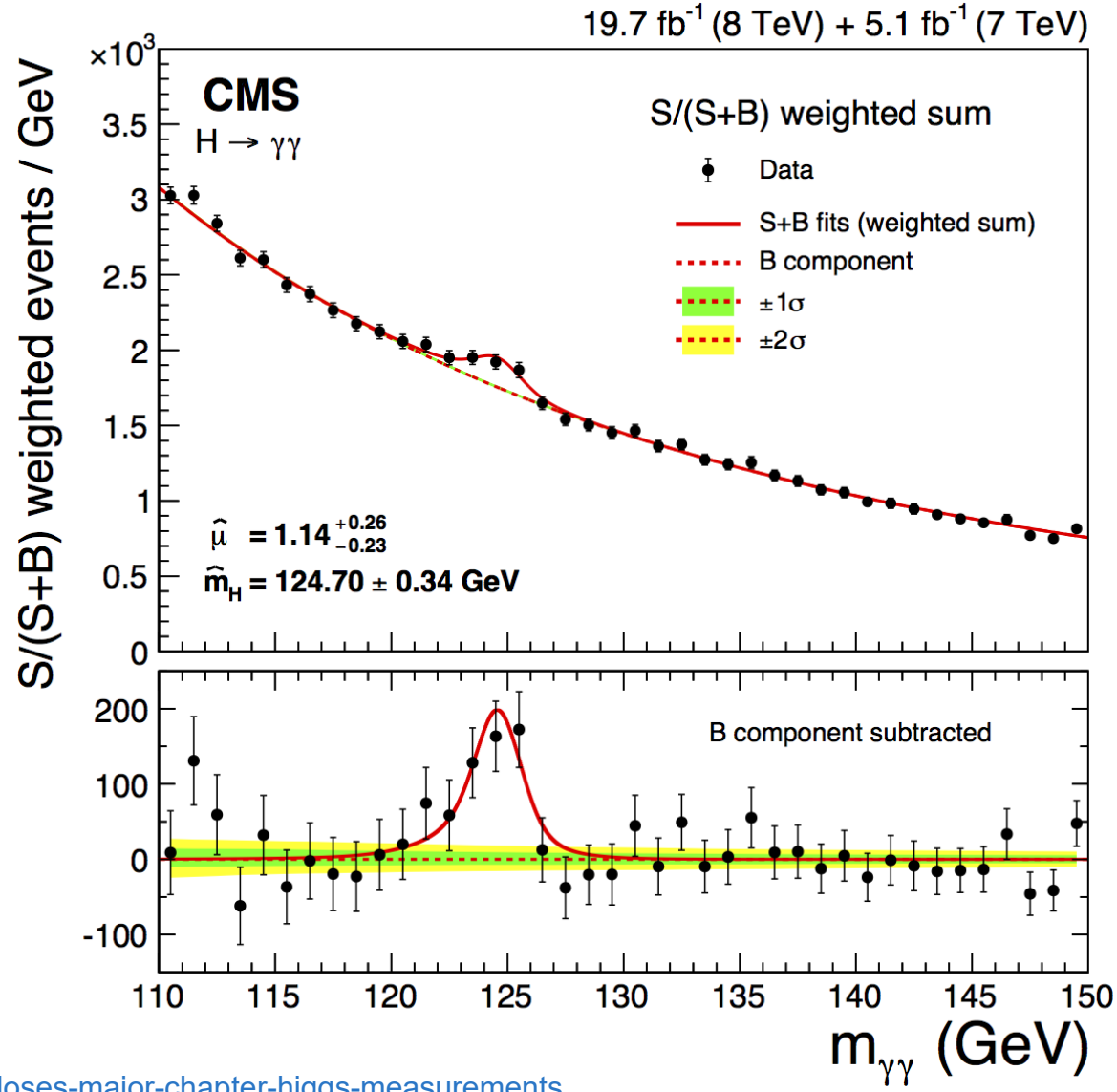


Ref: http://cms.web.cern.ch/news/cms-closes-major-chapter-higgs-measurements
https://biologos.org/blogs/archive/what-is-the-higgs-boson

CMS and Atlas Discovered the Higgs particle

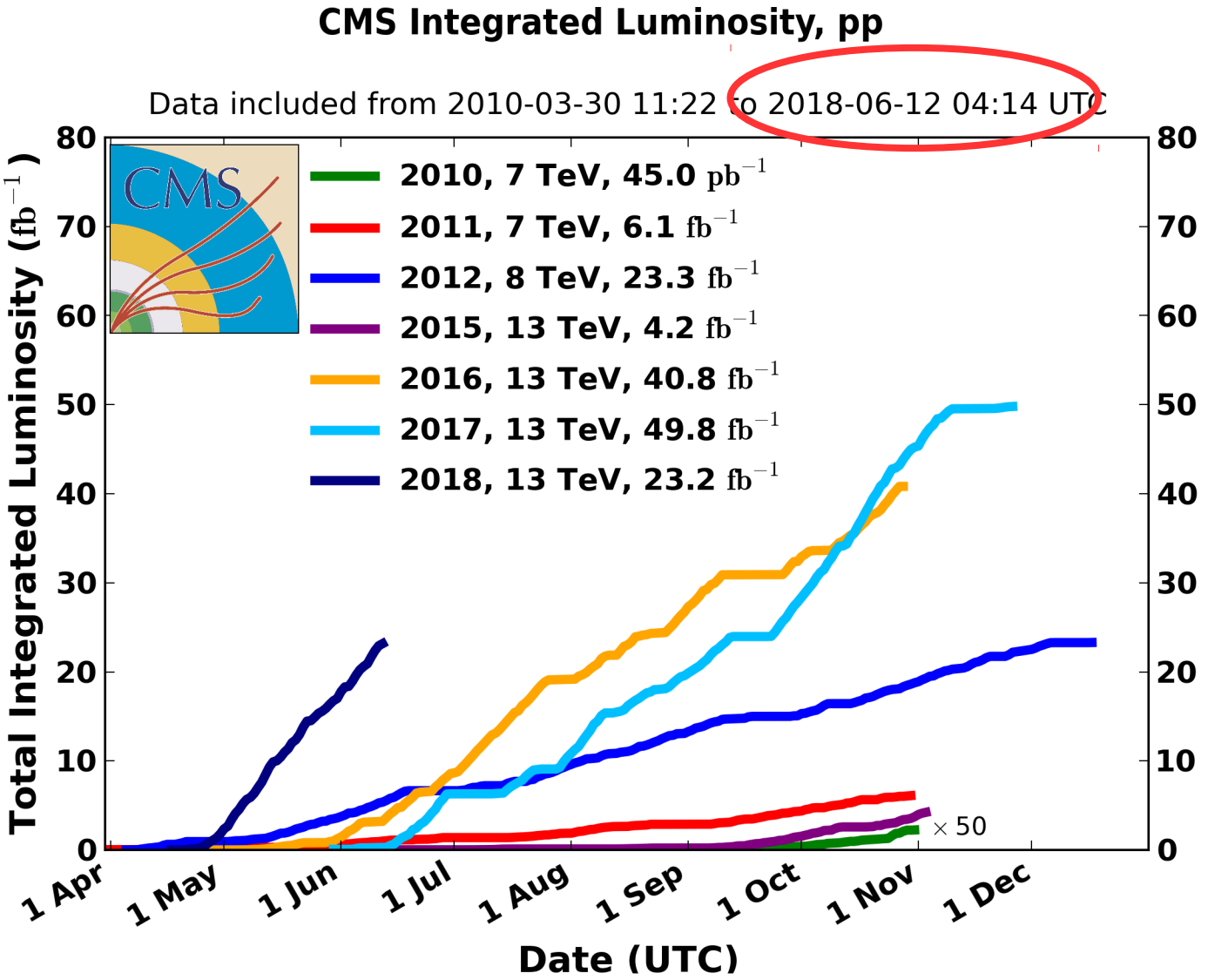
Mass bump, reconstruct the mass if a single particle decayed into the two photons.

Current mass of the Higgs, 125.18+/-0.16 GeV.



Ref: http://cms.web.cern.ch/news/cms-closes-major-chapter-higgs-measurements
https://biologos.org/blogs/archive/what-is-the-higgs-boson

LHC/CMS Integrated Luminosity

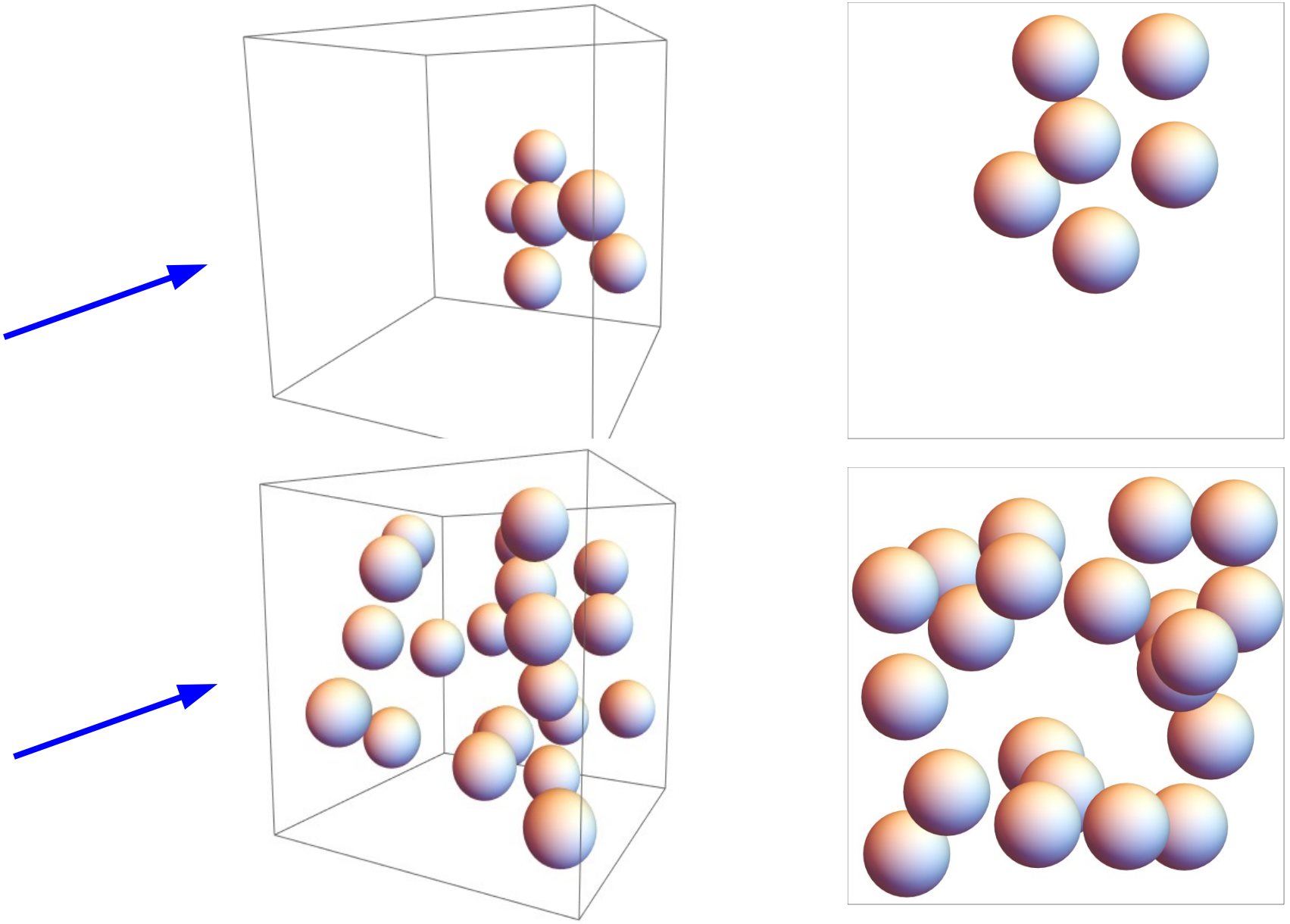


The integrated luminosity indicates the amount of data delivered to the experiments and is measured in inverse femtobarns. One inverse femtobarn corresponds to around **80 million million collisions**.

8e13 collisions

https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults#Luminosity_versus_week

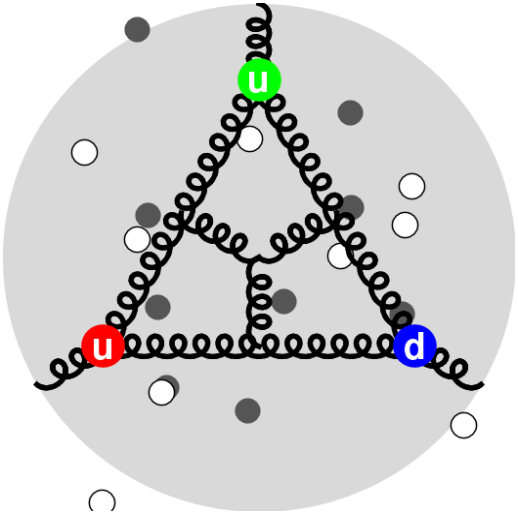
Cross-Section for Interactions

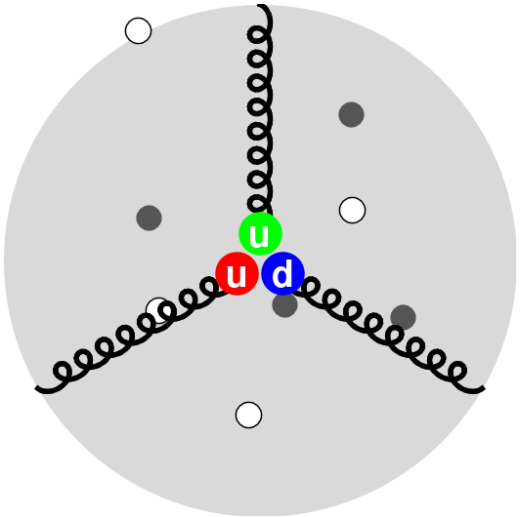


Physical or Effective size and density decide how many times you will interact for each crossing of the box.

Proton is not a simple object.

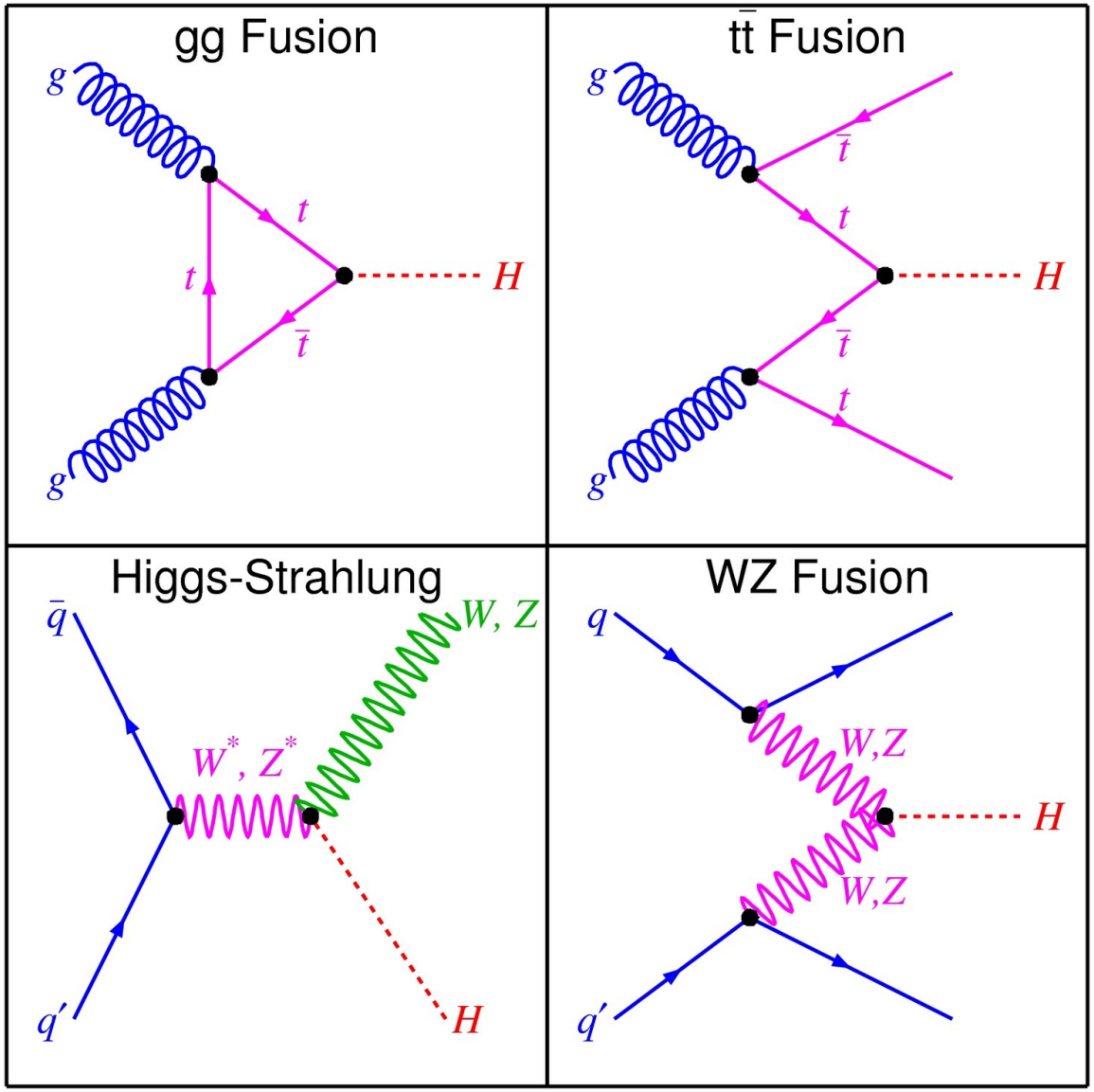
Protons are bags of valence quarks, gluons, and virtual quarks. Proton is a u-u-d valence quark combination, the “intrinsic mass” of the u is 1.9 MeV/c^2 and the d is 4.6 MeV/c^2 (an electron’s rest mass is 0.511 MeV/c^2). Yet the mass of the proton is 940 MeV/c^2 !



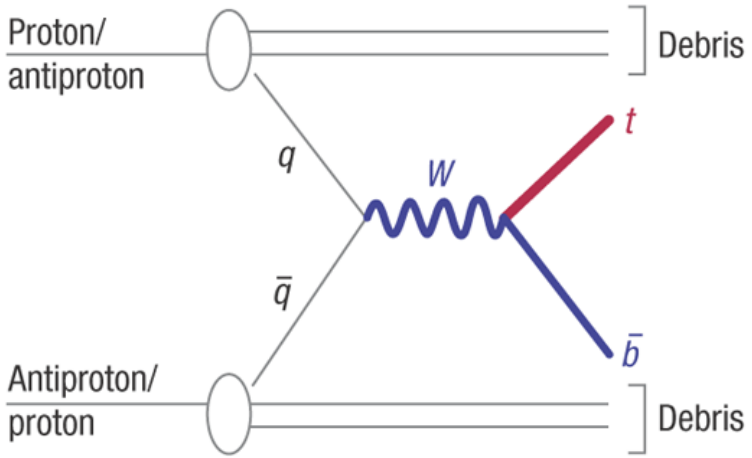


Ref: www.cern.ch

Not so much matter-antimatter but (Vector-Boson) Fusion!



VS



Higgs Production Rate and Cross-section

At 13 TeV and using Higgs mass 125 GeV.

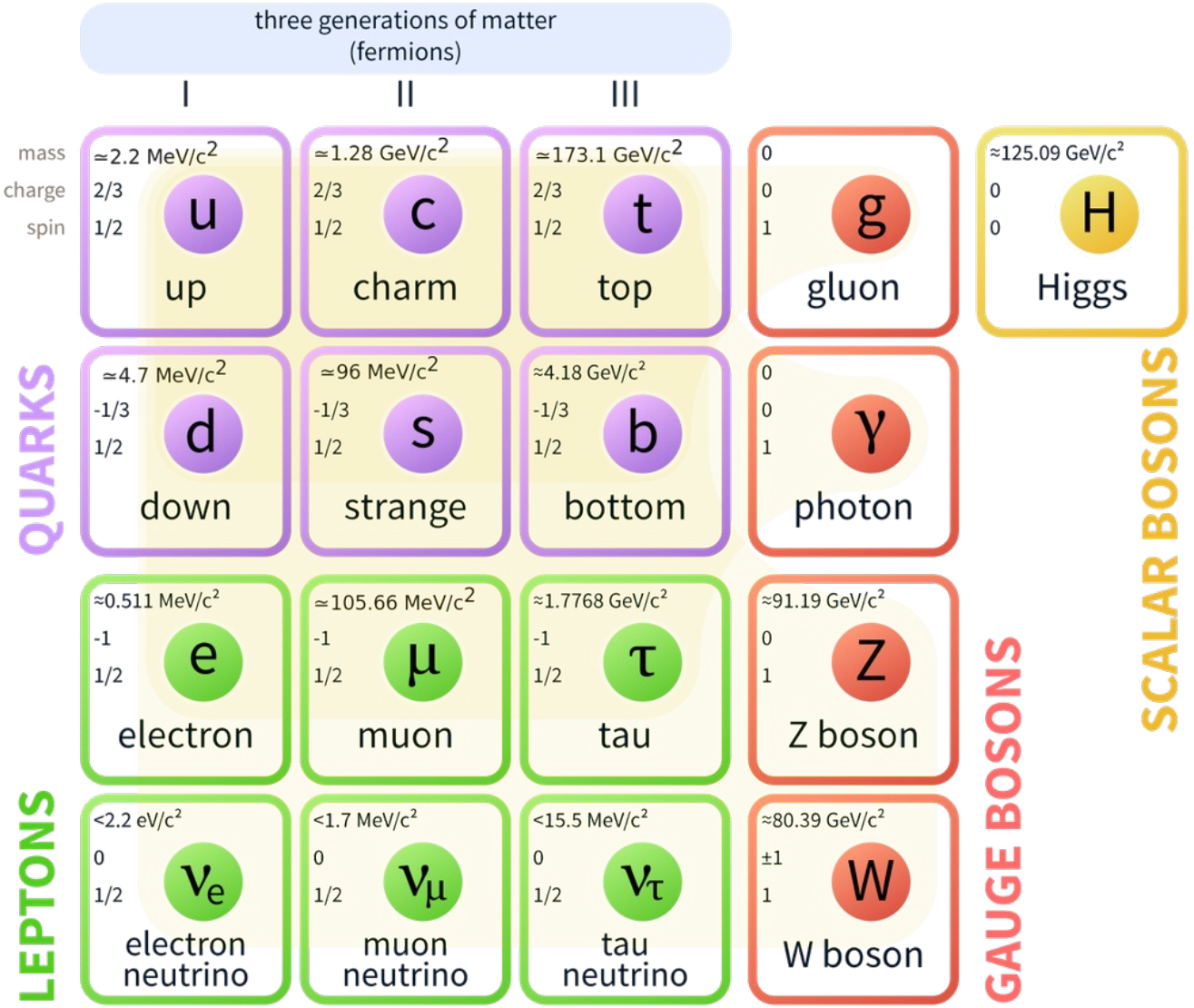
ggF (gluon-gluon fusion)	43.9 pb (picobarns)
VBF (vector boson fusion)	3.75 pb
WH	1.38 pb
ZH	0.870 pb
ttH	0.509 pb
bbH	0.512 pb

Ref: HiggsEuropeanStrategy
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageAt1314TeV2014

Previous slide, making about 6 fb^-1 (inverse femtobarns) of luminosity every week, get the units right, then making Higgs by ggF is 43900 fb * 6 fb^-1 = 263,400 Higgs via that channel every two weeks! **But cannot detect all of them!**

Barn is an (effective area) of 10^-28 m^2 about the physical size of a nucleus. Depending on energy and details, nuclear effects have cross-sections of 10^-3 to 10^6 barns.

- Mesons are made up of quark-antiquark pairs;
- Baryons (protons and neutrons) are made of 3 quarks.
- Bosons (spin 0 or 1) carry the force.
- Leptons (electrons, muons, ...) do not have the strong nuclear force.



Ref: https://en.wikipedia.org/wiki/Quark

Links

- https://home.cern/topics/large-hadron-collider
- https://timeline.web.cern.ch/timelines/The-Large-Hadron-Collider
- https://op-webtools.web.cern.ch/vistar/vistars.php?usr=LHC1
- http://demonstrations.wolfram.com/HowTheProtonAndNeutronGotTheirMasses/
- http://pdg.lbl.gov/
- http://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/LHC-schedule-update.pdf

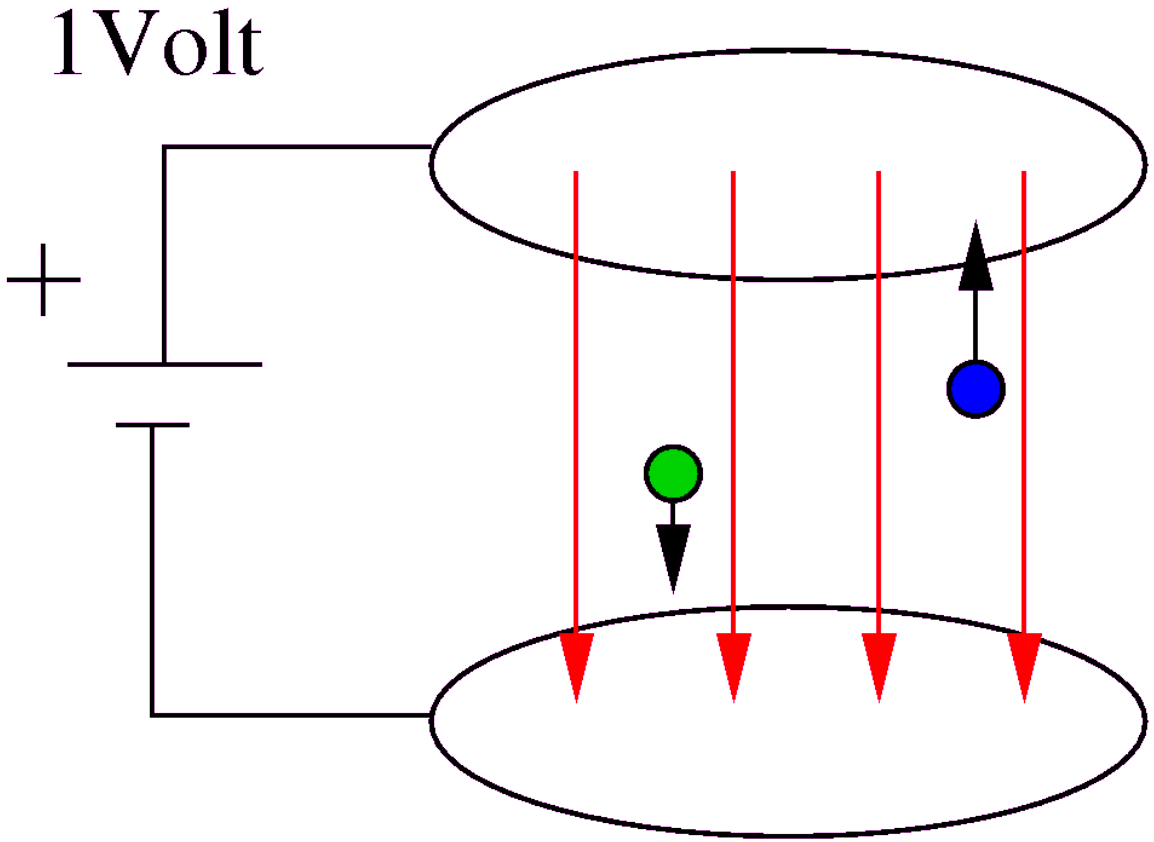
Backup

SI Prefixes

Table 5. SI prefixes

Factor	Name	Symbol	Factor	Name	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deka	da	10^{-24}	yocto	y

Units?



- Proton, heavy, +e
- Electron, light, –e

Speed of Light

Fastest possible speed is the speed of light in vacuum.

Defined as $299792458\,\mathrm{m/s}$

$3.0 \times 10^8\,\mathrm{m/s}$

$30\,cm/ns$

$300\,m/\mu s$

$300\,\mu m/ps$

LHCParameters

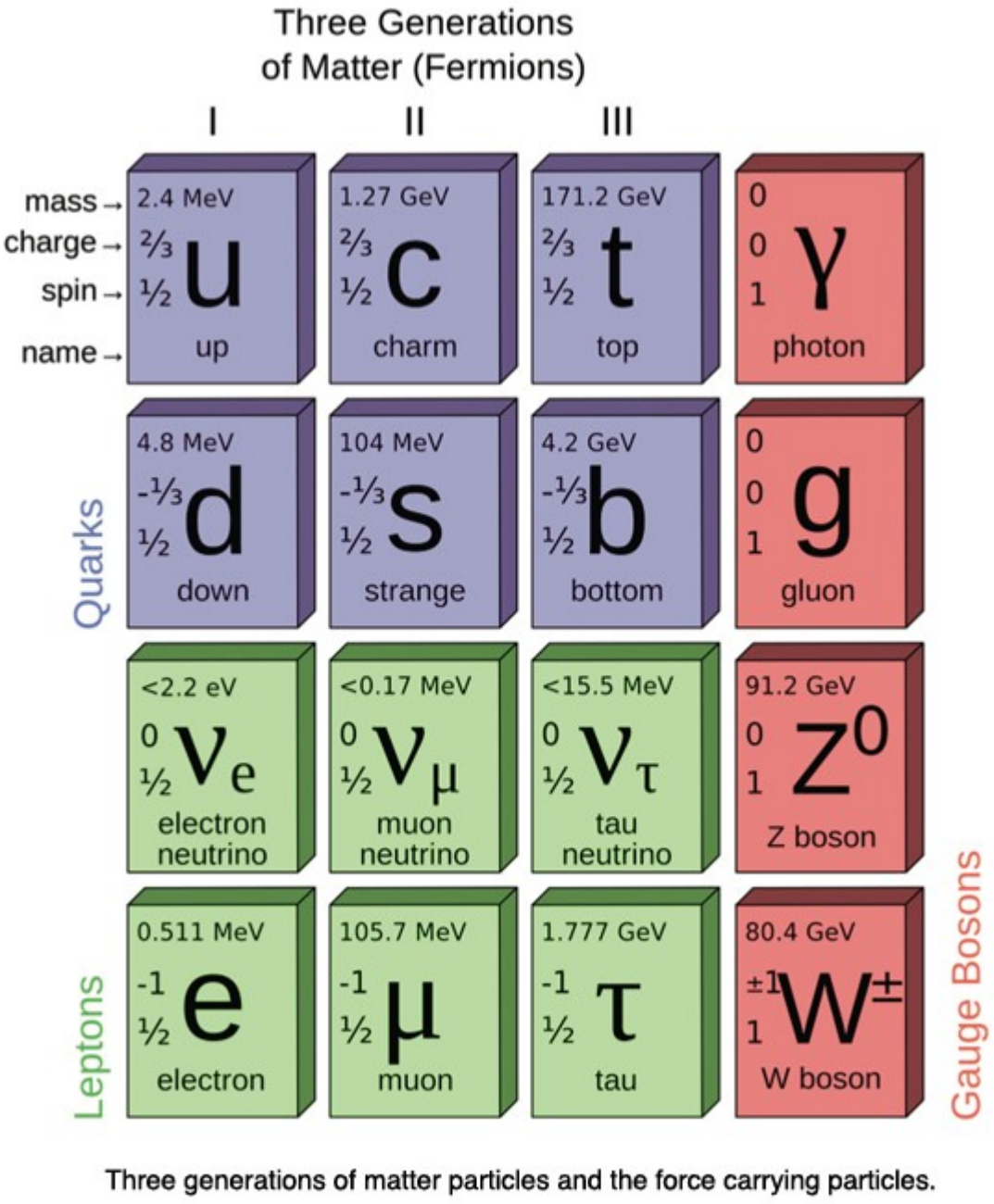
Quantity	number
Circumference	26 659 m
Dipole operating temperature	1.9 K (-271.3°C)
Number of magnets	9593
Number of main dipoles	1232
Number of main quadrupoles	392
Number of RF cavities	8 per direction
Energy, protons*	6.5 TeV
Energy, ions	2.56 TeV/u (**)
Peak magnetic dipole field	7.74 T
Distance between bunches	~7.5 m
Luminosity (protons)	Peak Luminosity: ~ 1.2×10^{34} cm^{-2} s^{-1}
No. of bunches per proton beam (design value)	2808
No. of protons per bunch (at start)	1.2×10^{11}
Number of turns per second	11 245
Number of collisions per second	1 billion

(*) Design value: 7 TeV
(**) Energy per nucleon

Ref: http://cds.cern.ch/record/2255762/files/CERN-Brochure-2017-002-Eng.pdf

Particle Physics in a Page (or two)

- Mesons are made up of quark-antiquark pairs;
- Baryons (protons and neutrons) are made of 3 quarks.
- Bosons (spin 0 or 1) carry the force.



Three generations of matter particles and the force carrying particles.