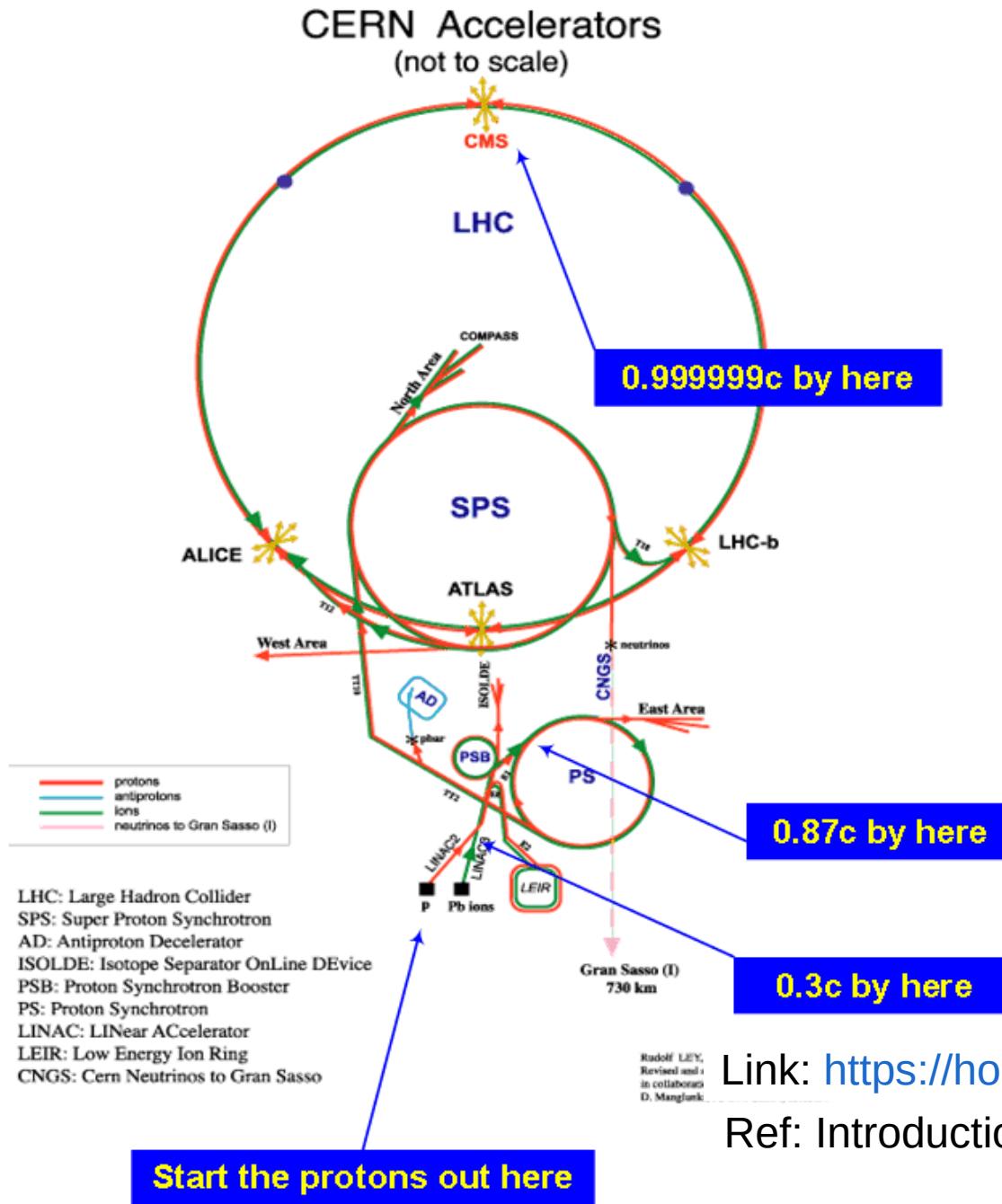


CERN's Large Hadron Collider



Ref: www.cern.ch

Large Hadron Collider (LHC)



Energies:

Linac 50 MeV

PSB 1.4 GeV

PS 28 GeV

SPS 450 GeV

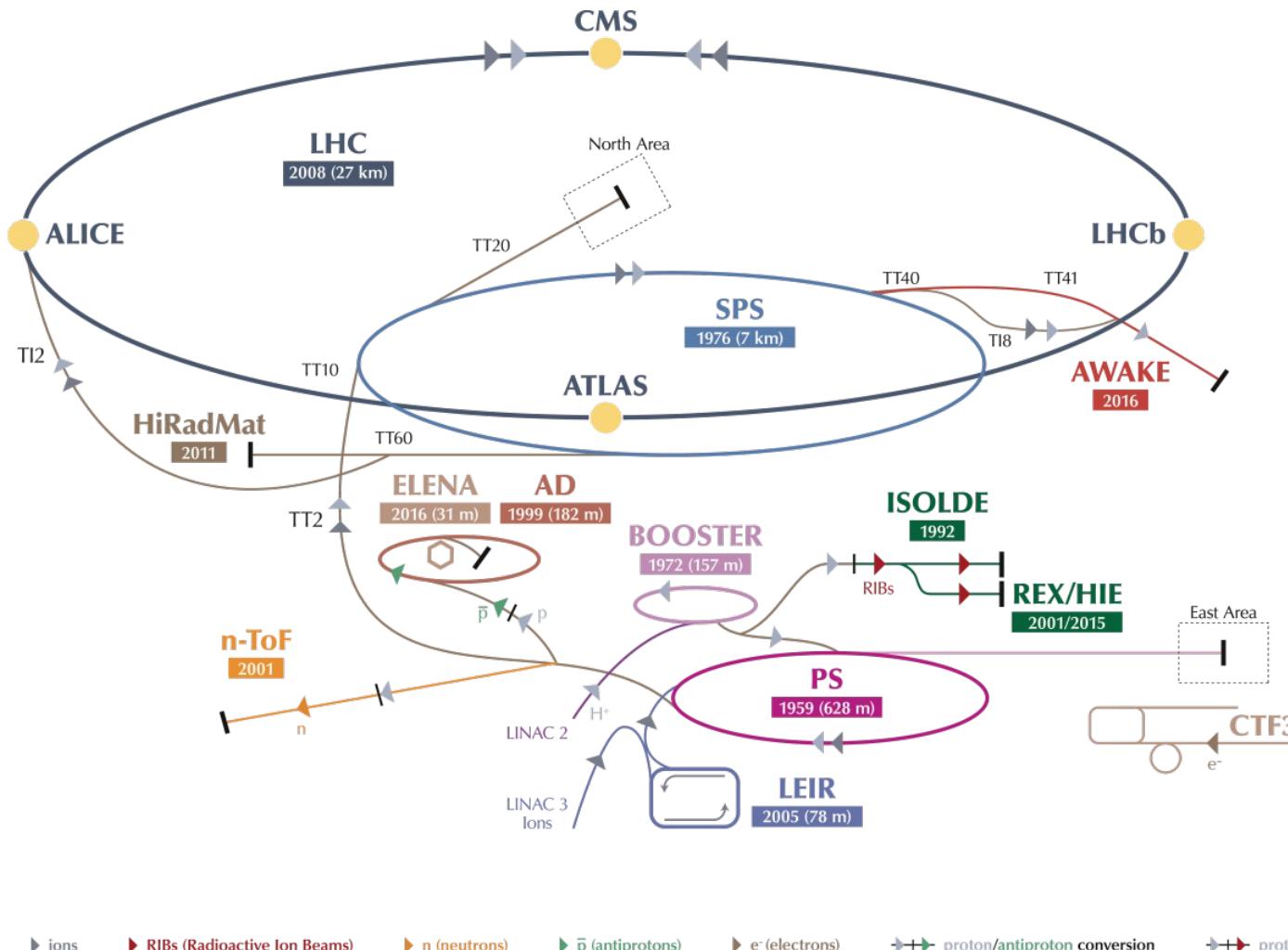
LHC 6.5 TeV



LHC Parameters

| | |
|----------------------------------|---|
| 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 | $2.56 \text{ TeV}/n = 6.5*82/208$ (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 |

Large Hadron Collider (LHC)

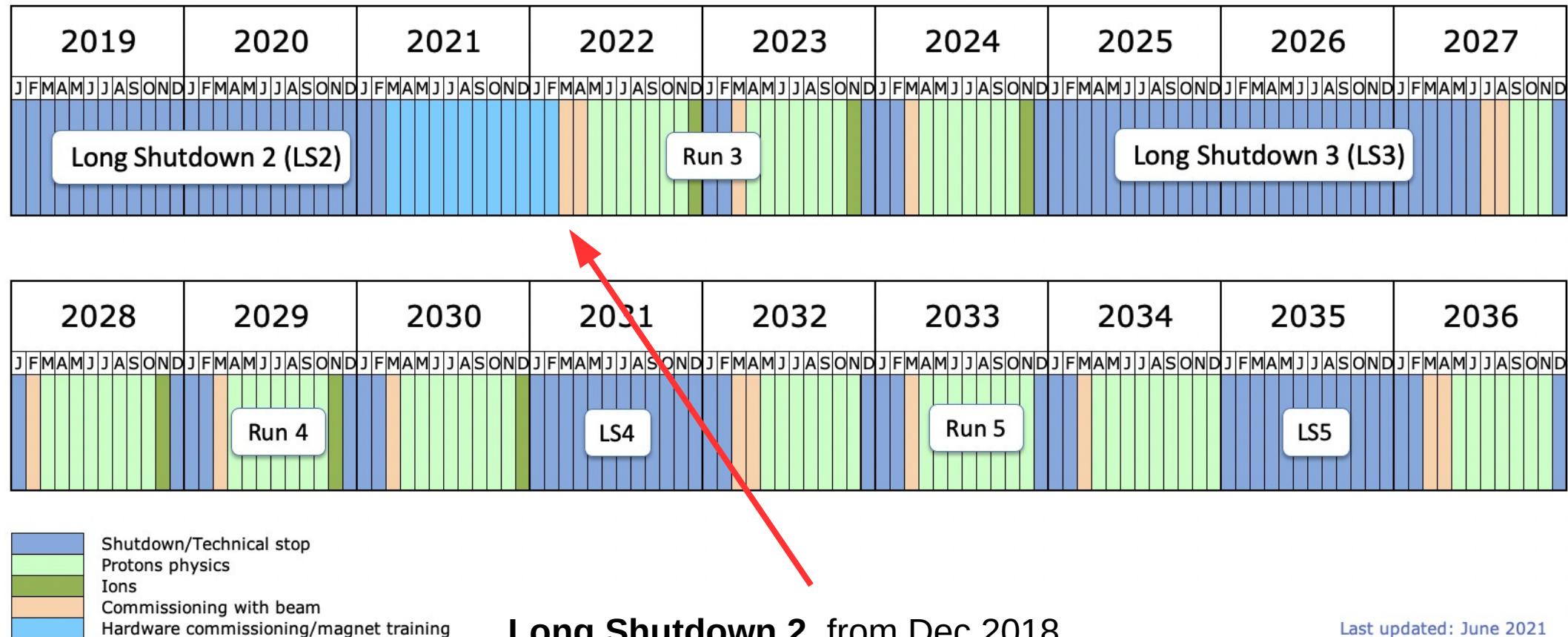


LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron AD Antiproton Decelerator CTF3 Clic Test Facility

AWAKE Advanced WAKEfield Experiment ISOLDE Isotope Separator OnLine REX/HIE Radioactive EXperiment/High Intensity and Energy ISOLDE

LEIR Low Energy Ion Ring LINAC LiNeAR ACcelerator n-ToF Neutrons Time Of Flight HiRadMat High-Radiation to Materials

LHC Long-Term Schedule, June 2021



-  Shutdown/Technical stop
-  Protons physics
-  Ions
-  Commissioning with beam
-  Hardware commissioning/magnet training

Long Shutdown 2, from Dec 2018

to ~~Jan 2021~~ **Mar 2022**, main purpose is LHC
Injectors Upgrade

Last updated: June 2021

<https://lhcc-commissioning.web.cern.ch/schedule/LHC-long-term.htm>



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 Dec 2024 and runs 2.5 years until mid-2027.

Current Status Op Vistar

CMS Page1 Fill : 6830 Run : 318448 Sat 23-06-2018 21:57:53 UTC

CMS DAQ Status CMS DAQ Status LHC Status Beam Energy Intensity Beam1: 0.0x10¹⁰ Beam2: 0.0x10¹⁰

Running SETUP 449 GeV CERN

History of Data-taking with Stable Beams for Last 24 Hours

LHC Page1 Fill: 7501 E: 450 GeV t(SB): 00:00:00 19-06-21 21:18:58

LHC Page1 Fill: 6837 E: 6499 GeV t(SB): 00:00:00

SHUTDOWN: NO BEAM

PROTON PHYSICS: ADJUST

Energy: 6499 GeV I(B1): 2.11e+11 I(B2):

Inst. Lumi [(ub.s)⁻¹] IP1: -0.00 IP2: 0.00 IP5:

FBCT Intensity and Beam Energy

Intensity 2.5E11
2E11
1.5E11
1E11
5E10
0E0

23:00 23:15 23:30 23:45 00:00 00:15 00:30

BIS status and SMP flags

| | B1 | B2 |
|------------------------------------|-----------------------------|----|
| Comments (16-Jun-2021 18:18:51) | W24 powering in all points | |
| | Magnet training in S56 | |
| Comments (24-Jun-2018 21:43:13) | Link Status of Beam Permits | |
| fill for TCT and RP alignment @90m | Global Beam Permit | |
| | Setup Beam | |
| | Beam Presence | |
| | Moveable Devices Allowed In | |
| | Stable Beams | |

AFS: 8b4e_1972b_1967_1178_1886_224bpi_12inj PM Status B1 ENABLED PM Status B2 ENABLED

AFS: 2nominals_10pilots_RomanPot_Alignment PM Status B1 ENABLED PM Status B2 ENABLED

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

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

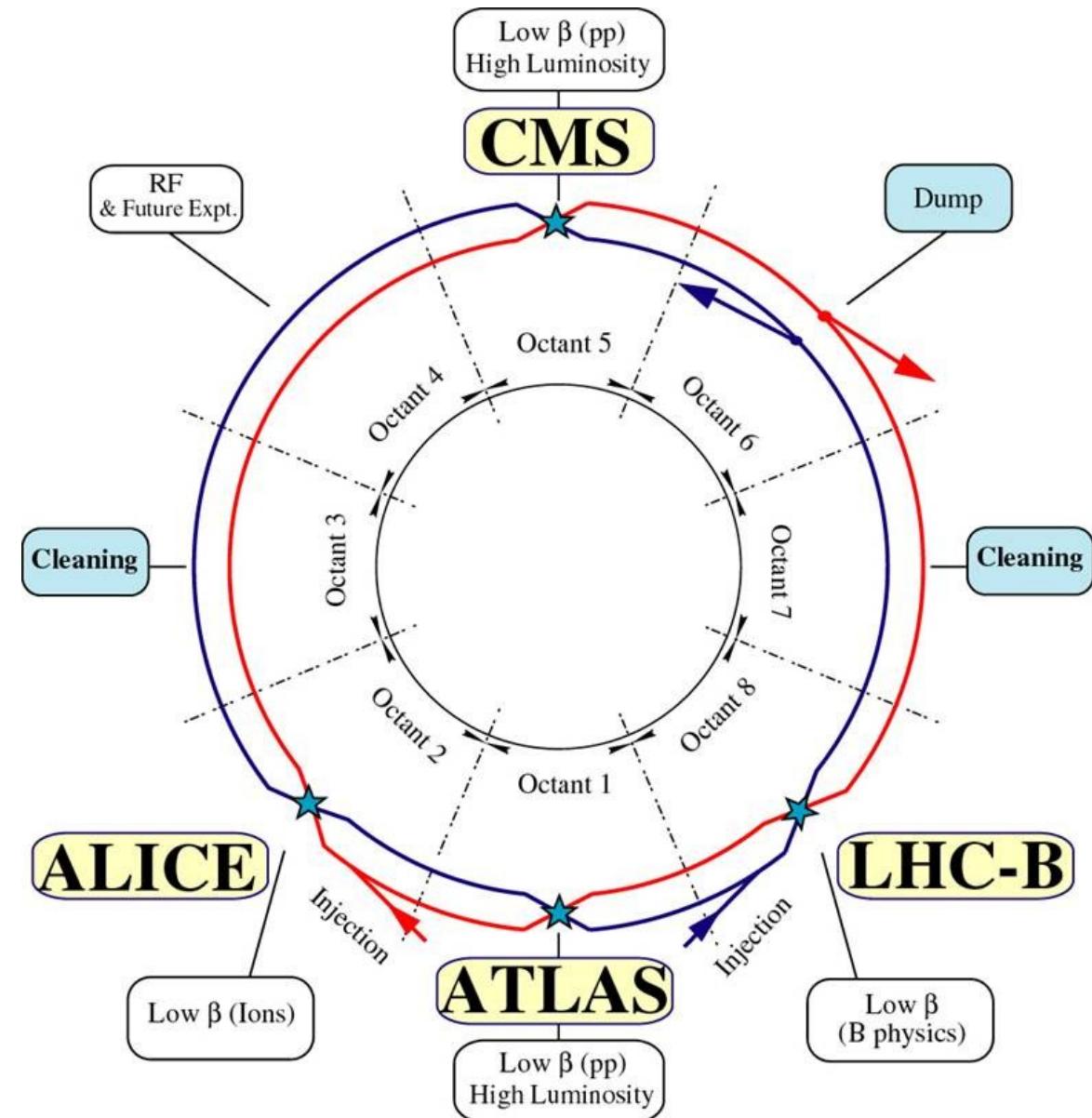
2013 5.02 TeV/u

338 on 338 bunches

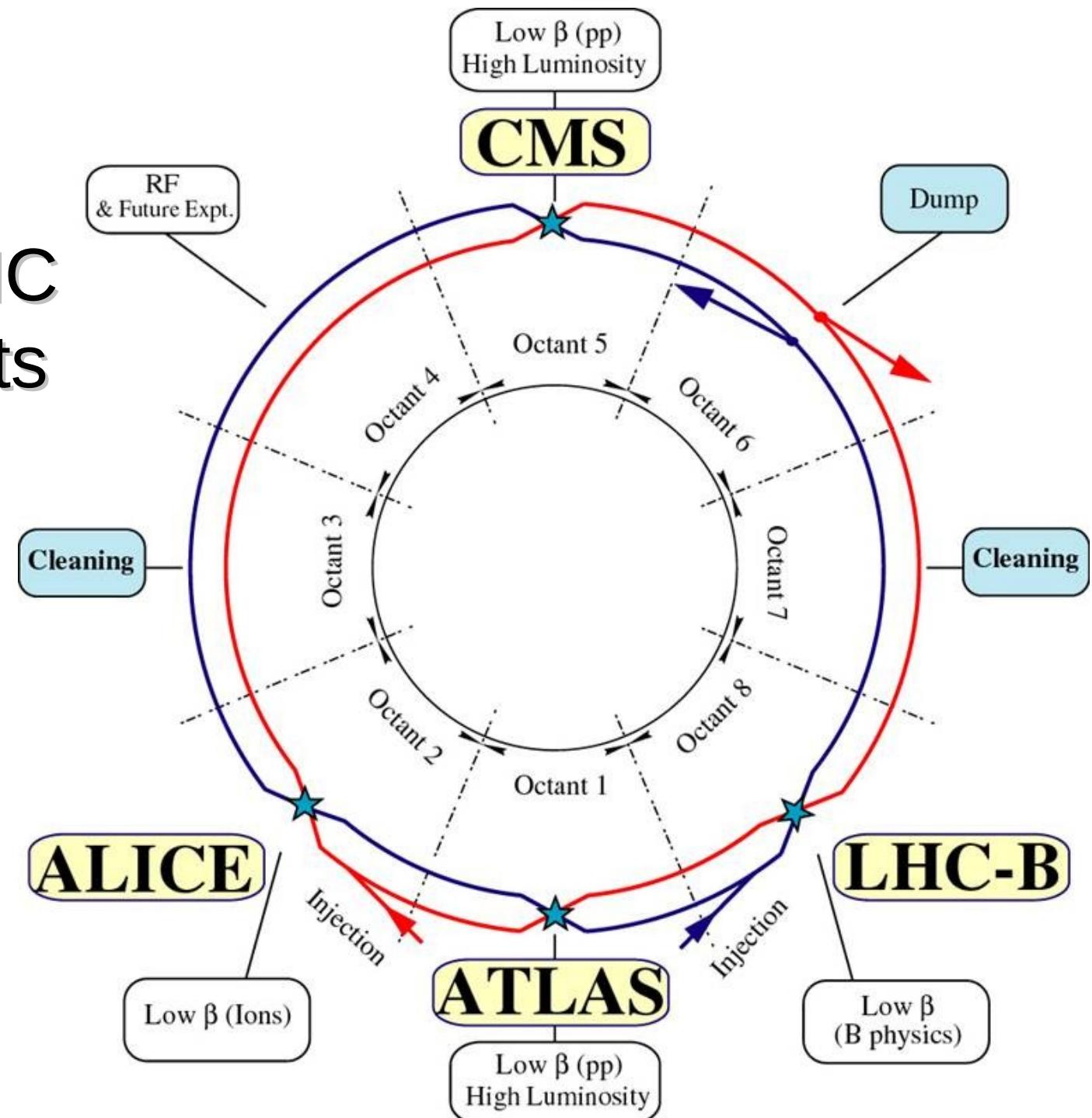
2016 5.02 TeV/u

2016 8.16 TeV/u

What has the LHC done?



CERN's LHC Experiments



Compact Muon Solenoid (CMS) Detector

CMS DETECTOR

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel ($100 \times 150 \mu\text{m}$) $\sim 16\text{m}^2 \sim 66\text{M}$ channels
Microstrips ($80 \times 180 \mu\text{m}$) $\sim 200\text{m}^2 \sim 9.6\text{M}$ channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying $\sim 18,000\text{A}$

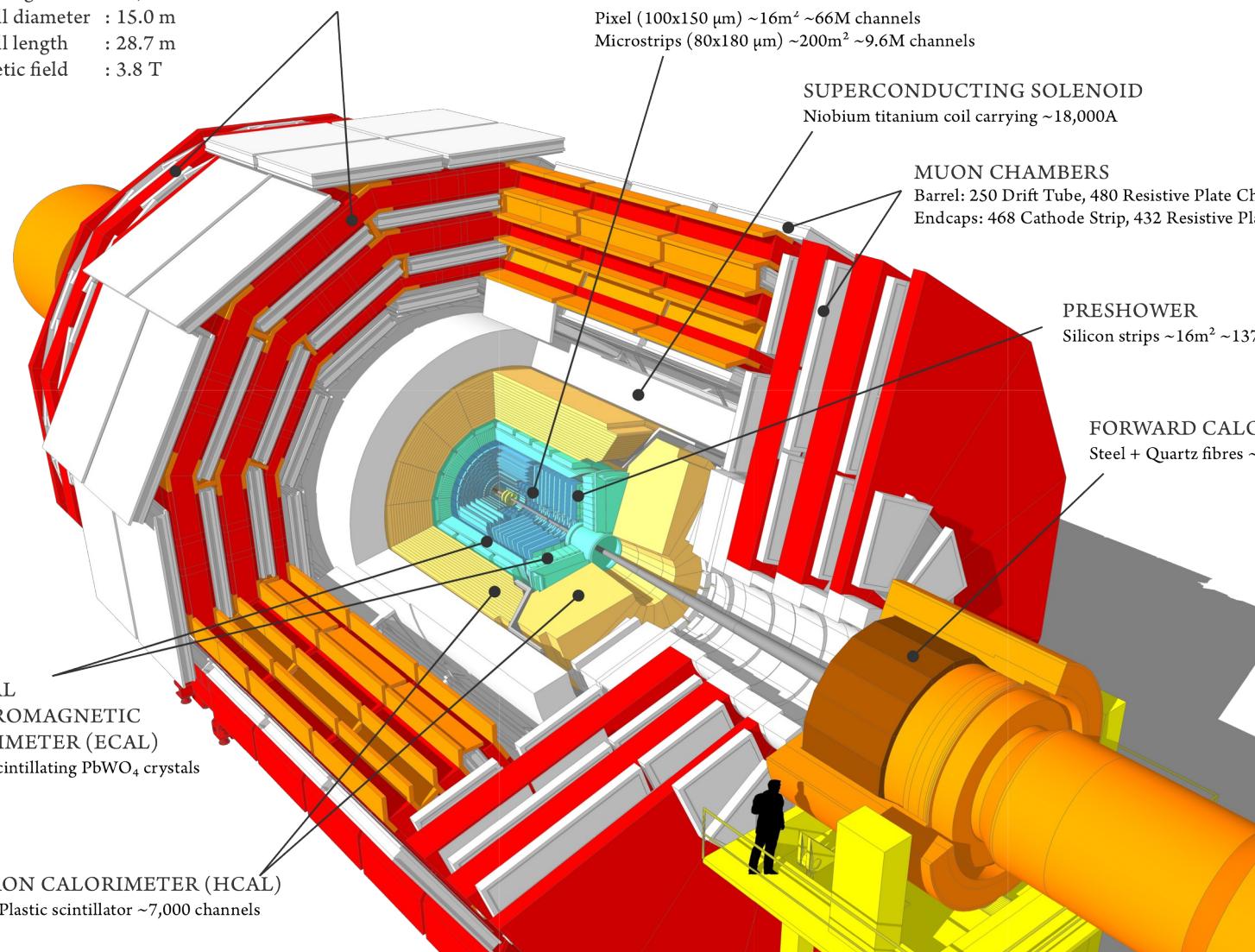
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
Silicon strips $\sim 16\text{m}^2 \sim 137,000$ channels

FORWARD CALORIMETER
Steel + Quartz fibres $\sim 2,000$ Channels

CRYSTAL
ELECTROMAGNETIC
CALORIMETER (ECAL)
 $\sim 76,000$ scintillating PbWO_4 crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator $\sim 7,000$ channels

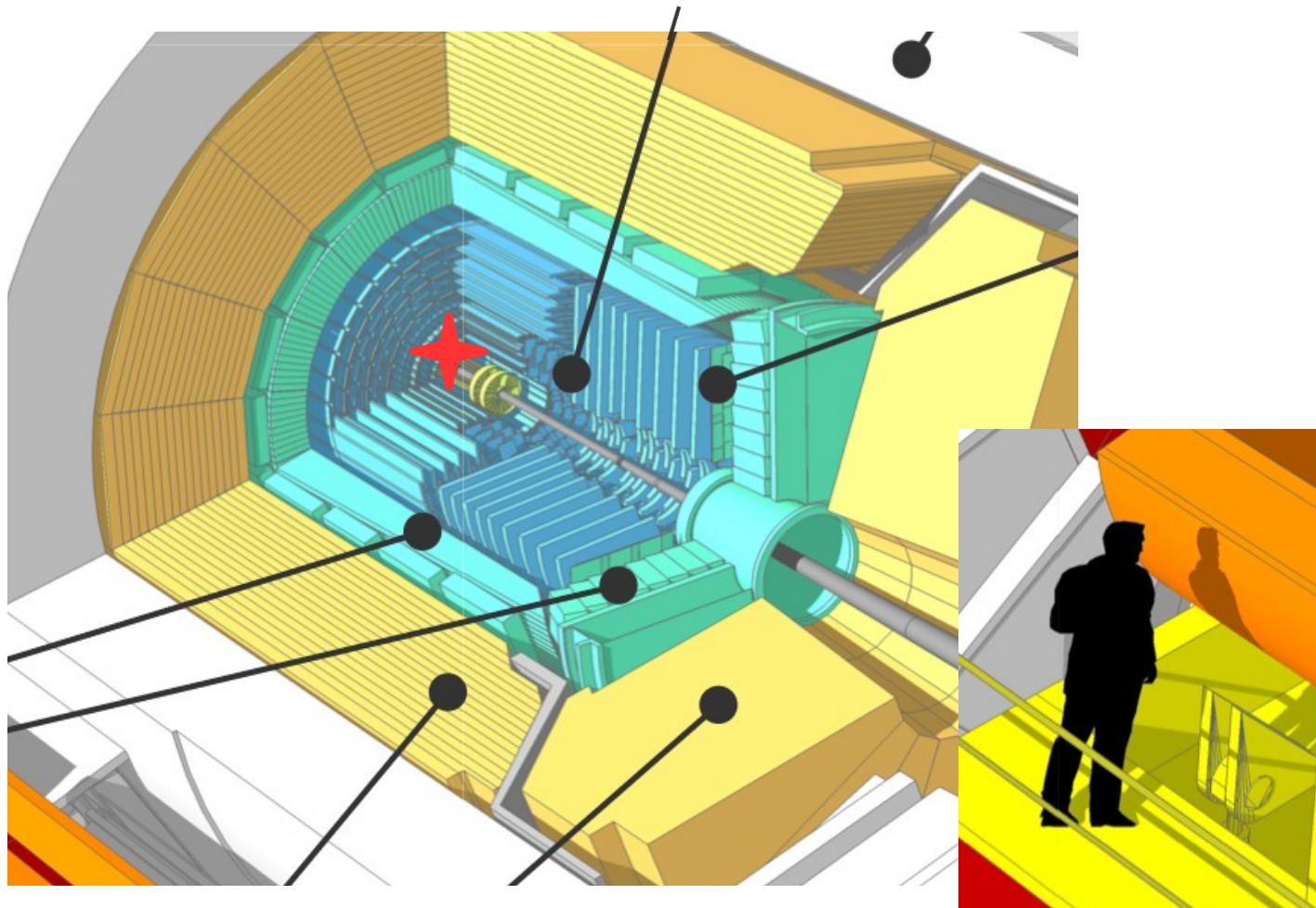


Pixel (sub)Detector Wraps around the collision point.

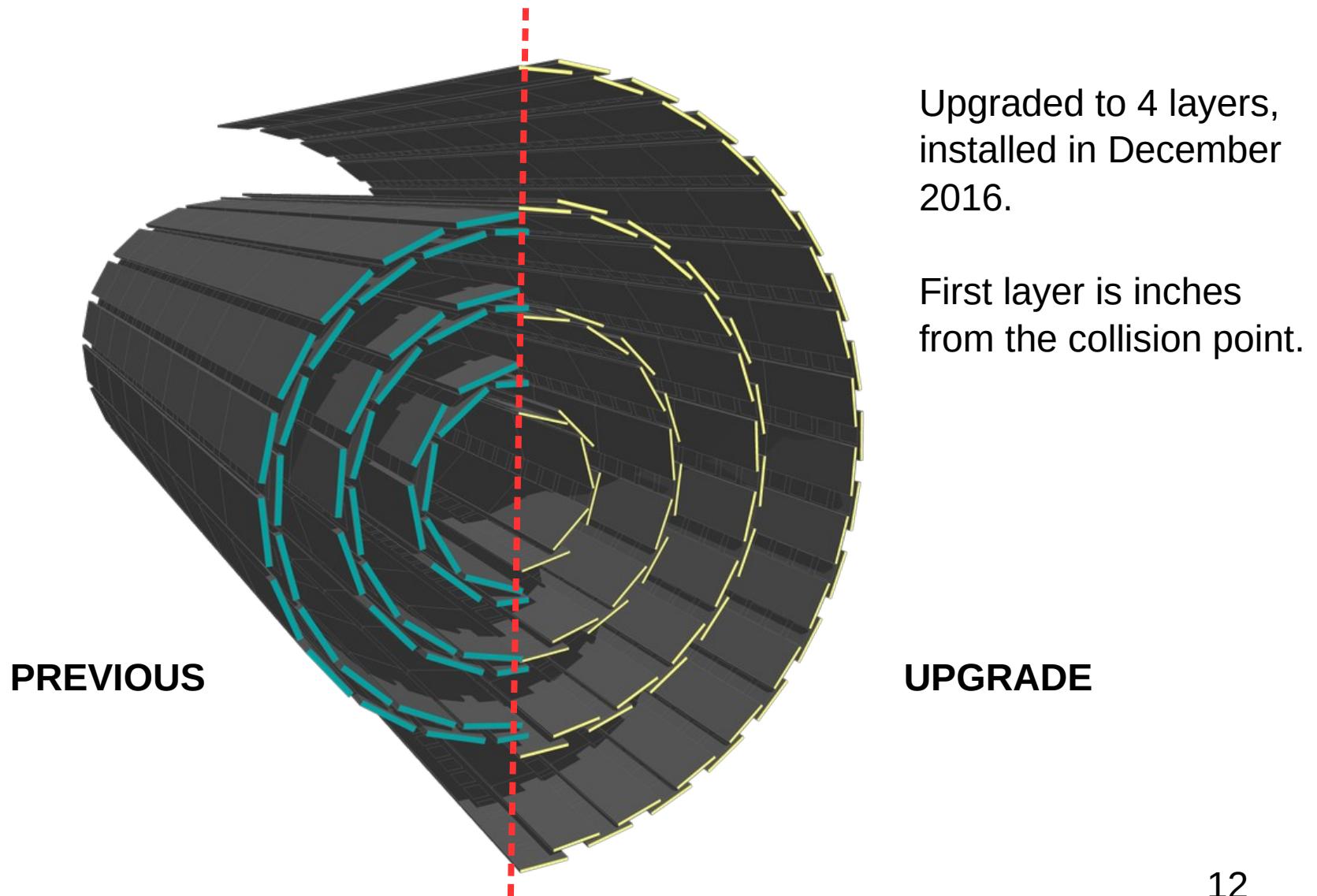
SILICON TRACKERS

Pixel ($100 \times 150 \mu\text{m}$) $\sim 16\text{m}^2 \sim 66\text{M}$ channels

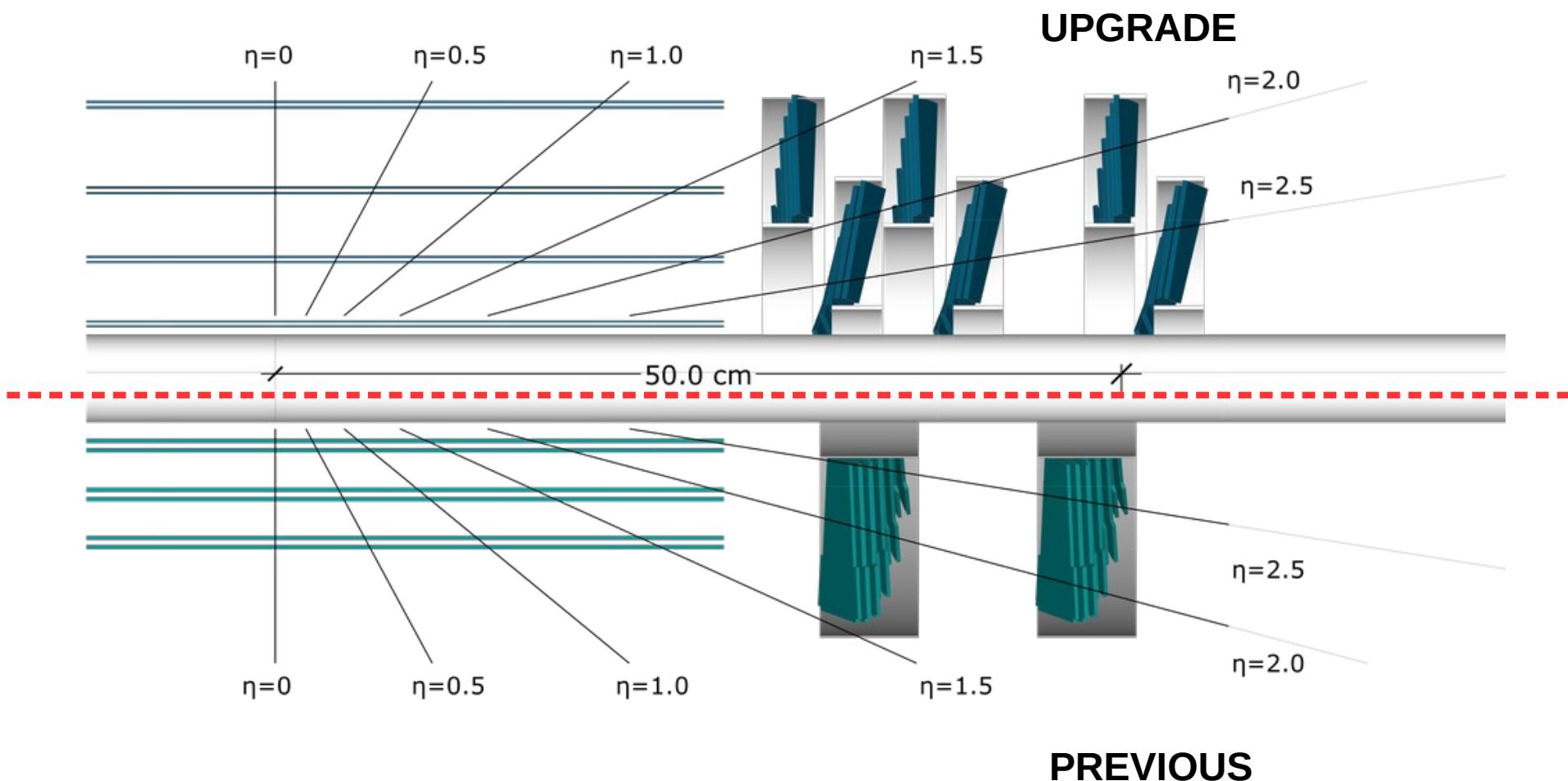
Microstrips ($80 \times 180 \mu\text{m}$) $\sim 200\text{m}^2 \sim 9.6\text{M}$ channels



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

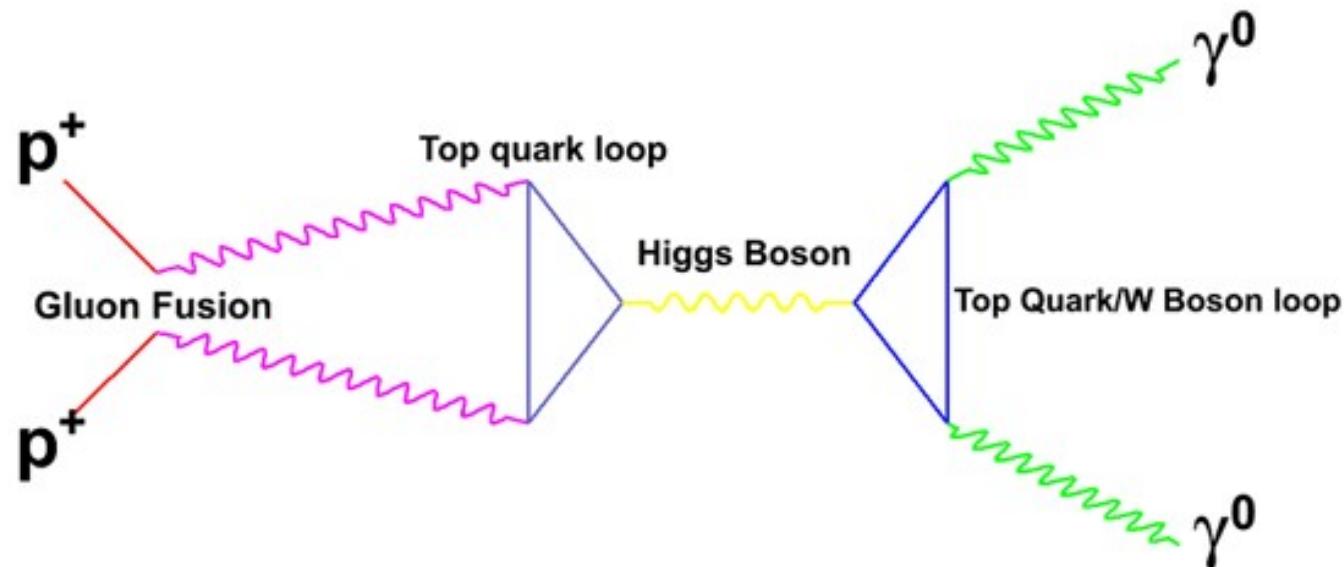


Vanderbilt (Will Johns) Supports the Forward Pixel (sub)Detector



CMS and Atlas Discovered the Higgs particle

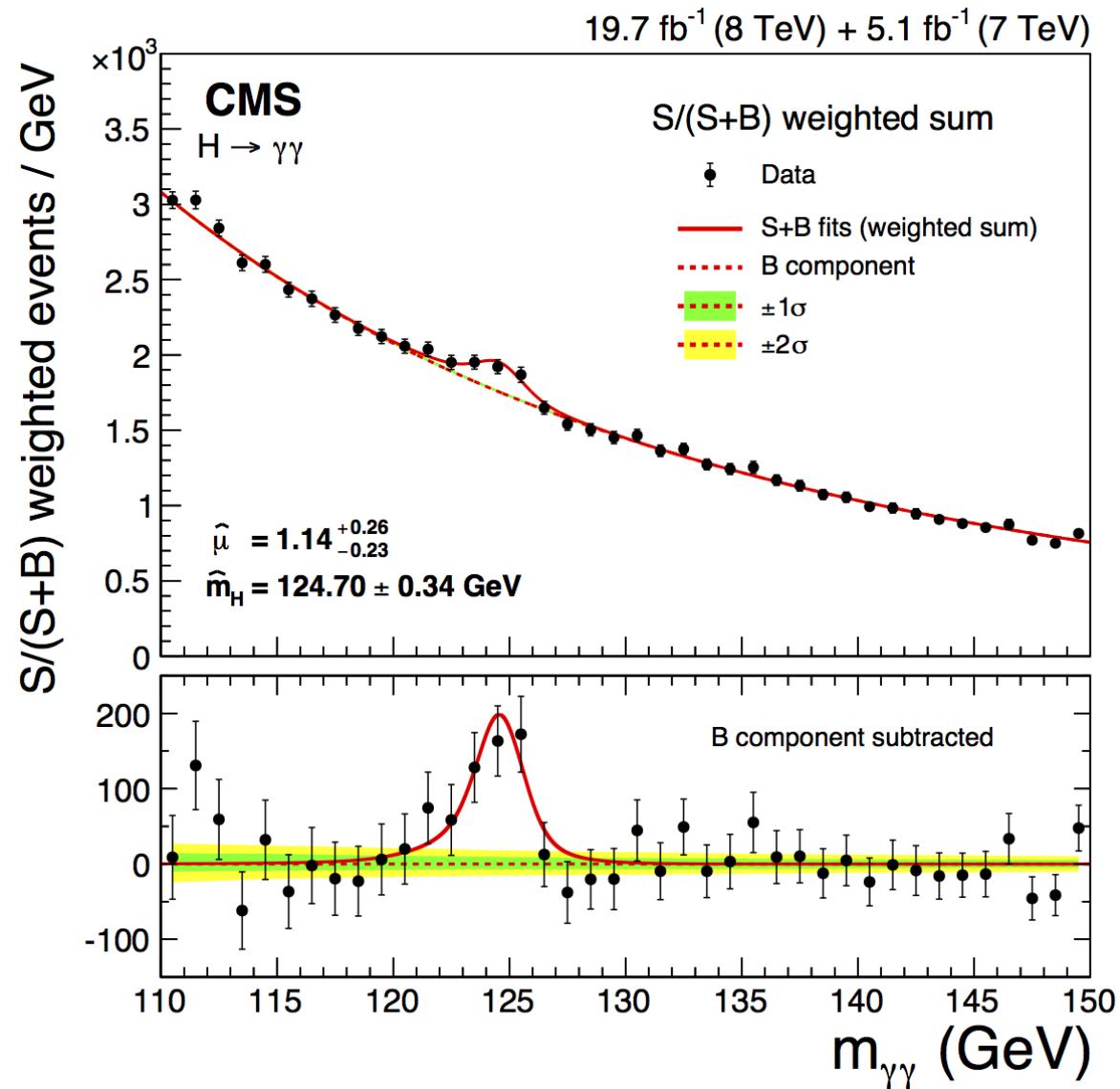
Joint announcement in July 4, 2012, with data from 7 and 8 TeV center of mass energy.



CMS and Atlas Discovered the Higgs particle

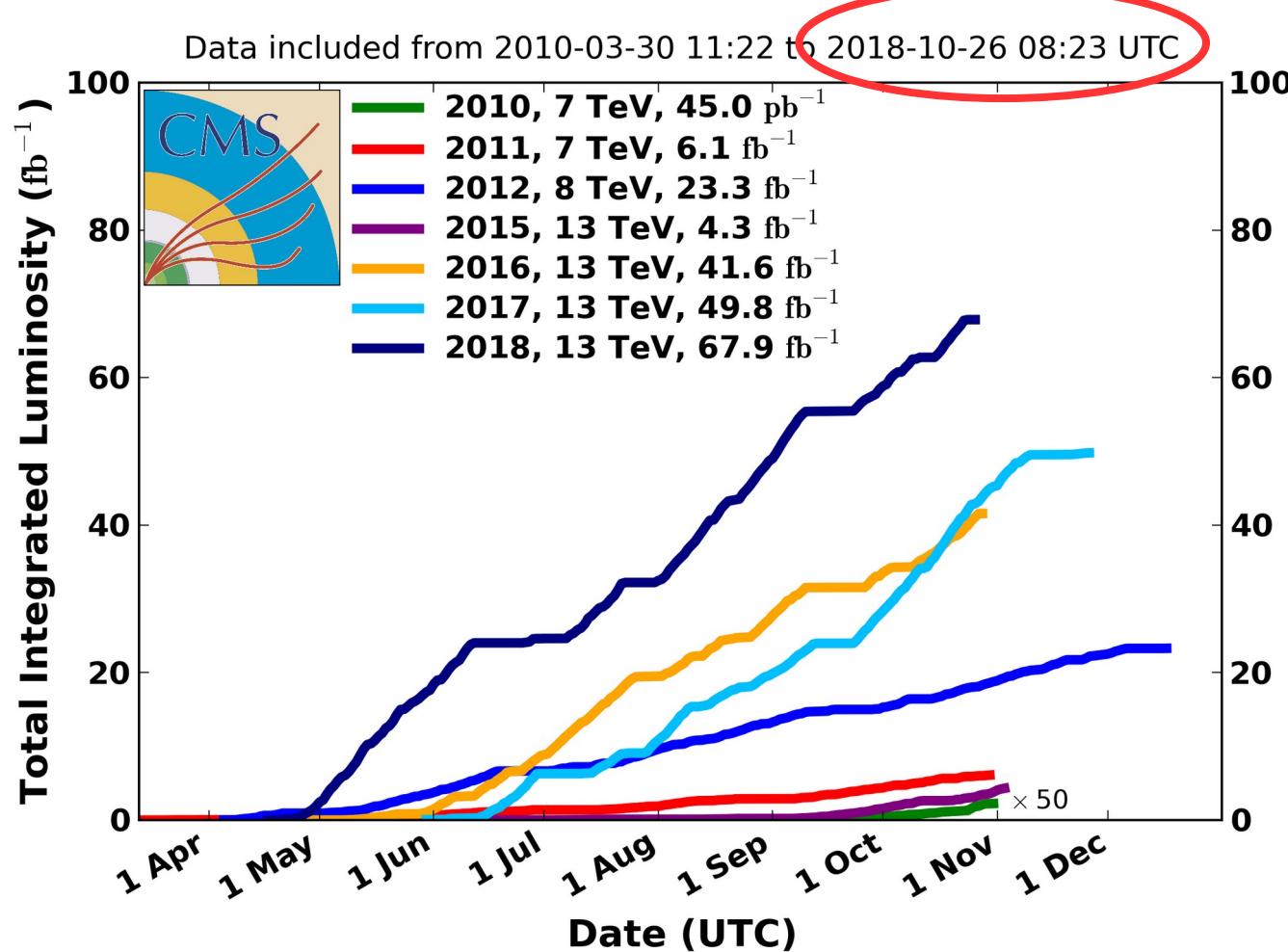
Mass bump,
reconstruct the mass
if a single particle
decayed into the two
photons.

Current mass of the
Higgs, 125.18 ± 0.16
GeV.



LHC/CMS Integrated Luminosity

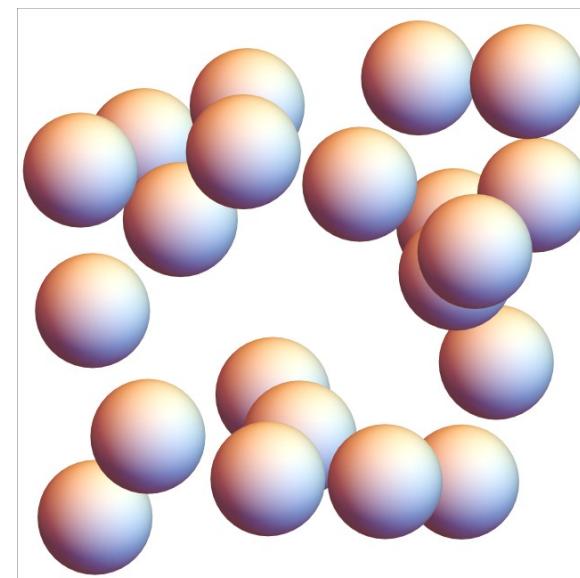
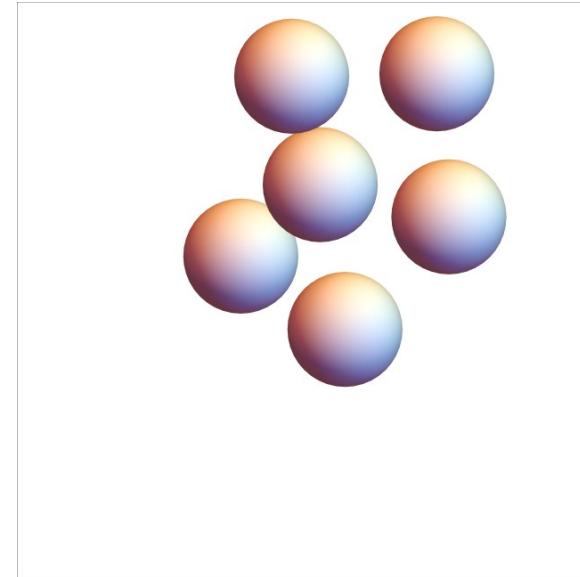
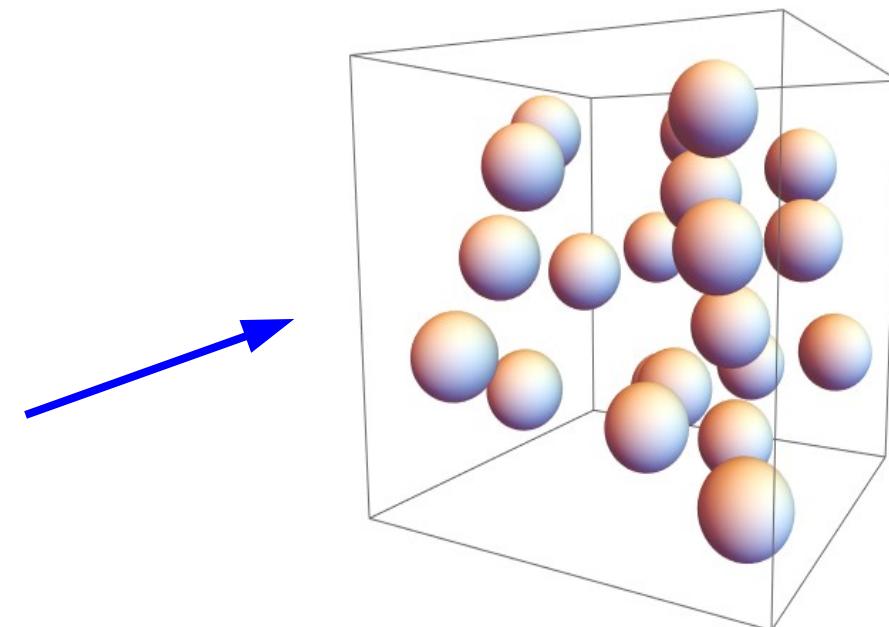
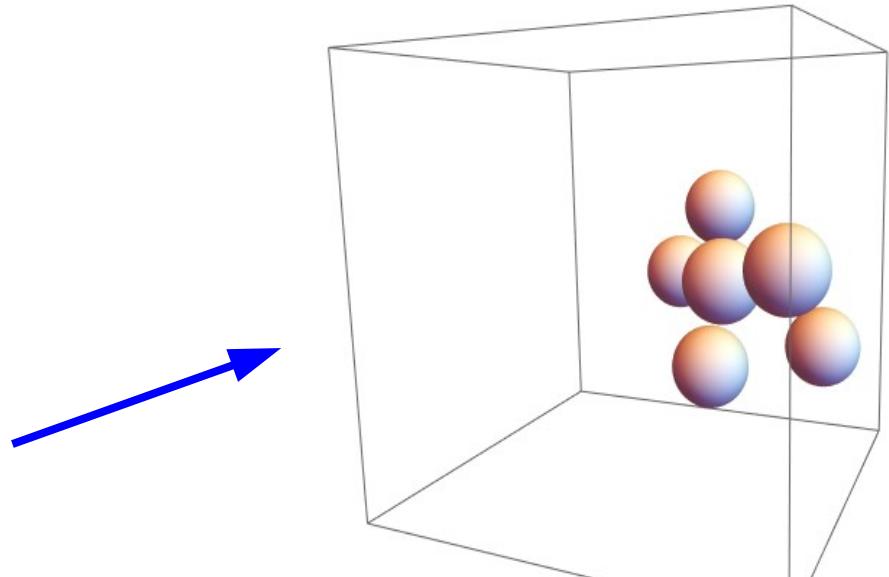
CMS Integrated Luminosity Delivered, pp



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**. $8\text{e}13$ collisions

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

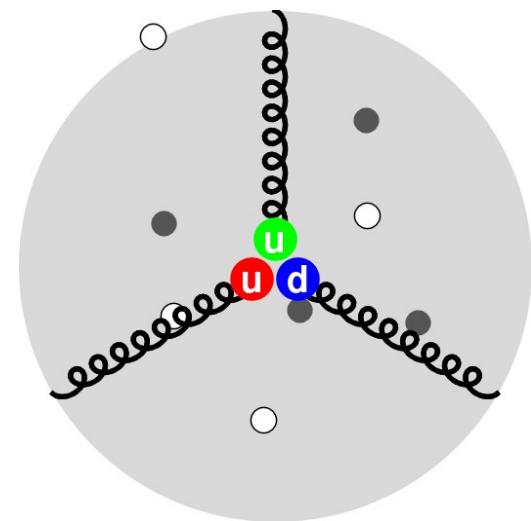
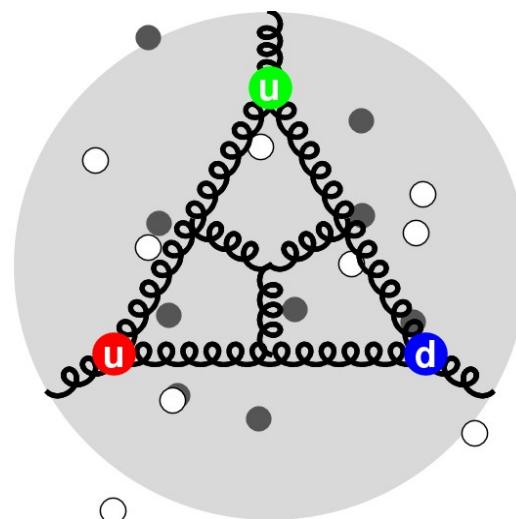
Cross-Section for Interactions



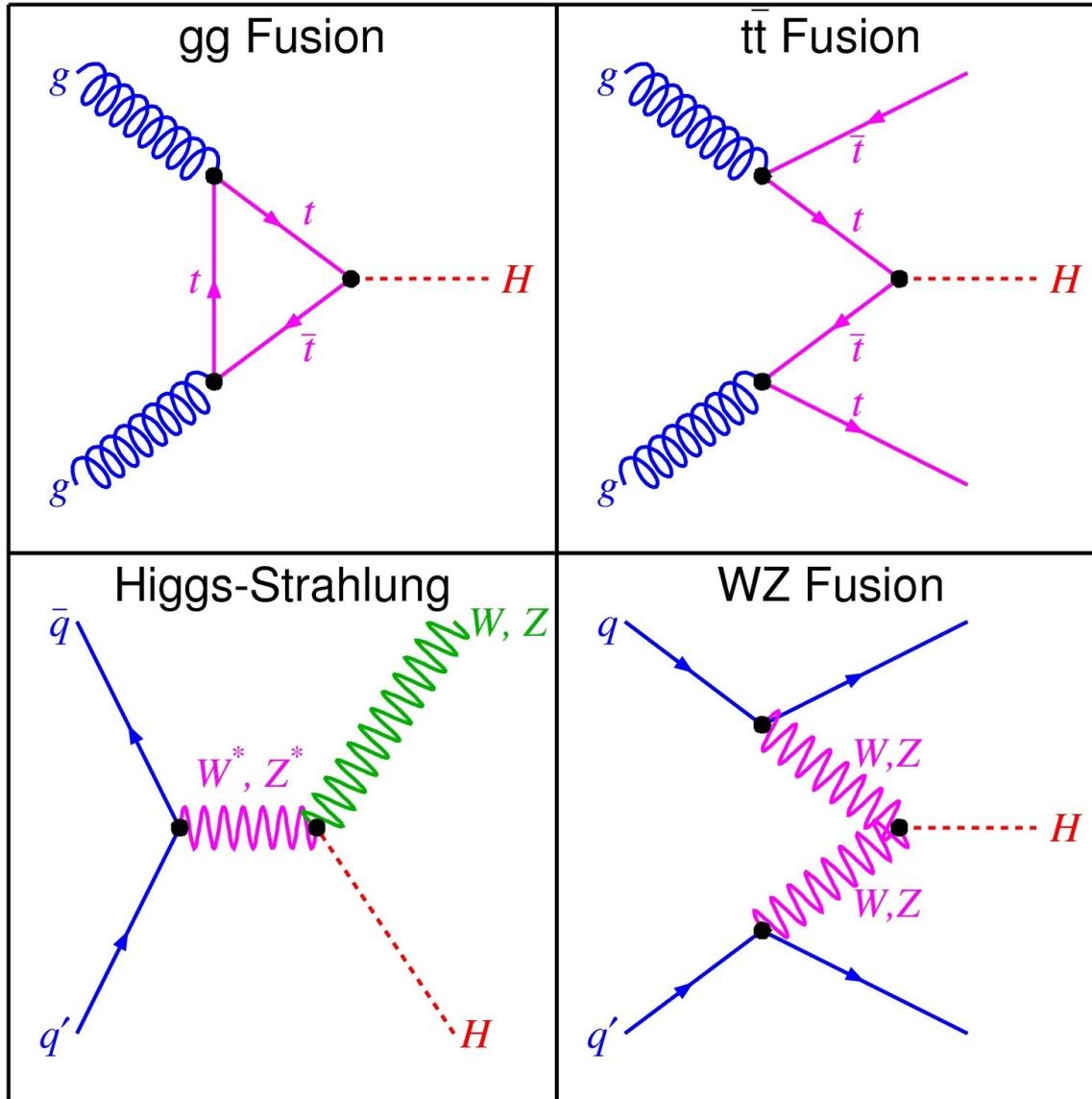
Physical or Effective size and density decide how many times you will interact for each crossing of the box.

Proton is not a simple object.

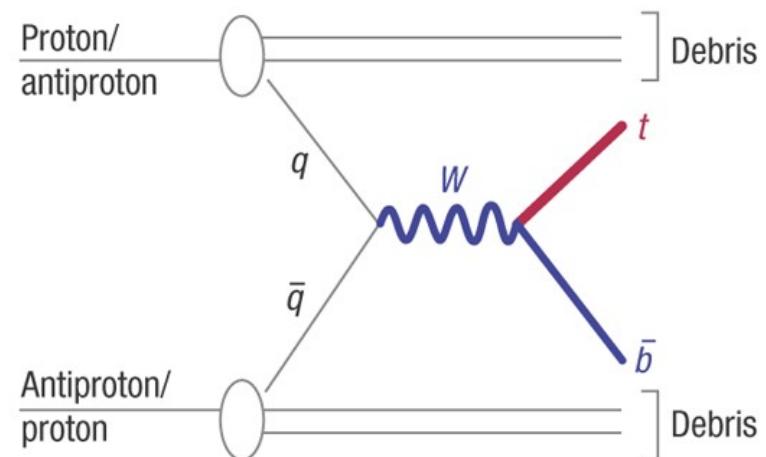
Protons are bags of valence quarks (the three main ones), gluons, and virtual quarks. Proton is a up-up-down valence quark combination, the “intrinsic mass” of the u is 1.9 MeV/c² and the d is 4.6 MeV/c² (an electron’s rest mass is 0.511 MeV/c²). Yet the mass of the proton is 940 MeV/c² !



Not so much matter-antimatter annihilation 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>

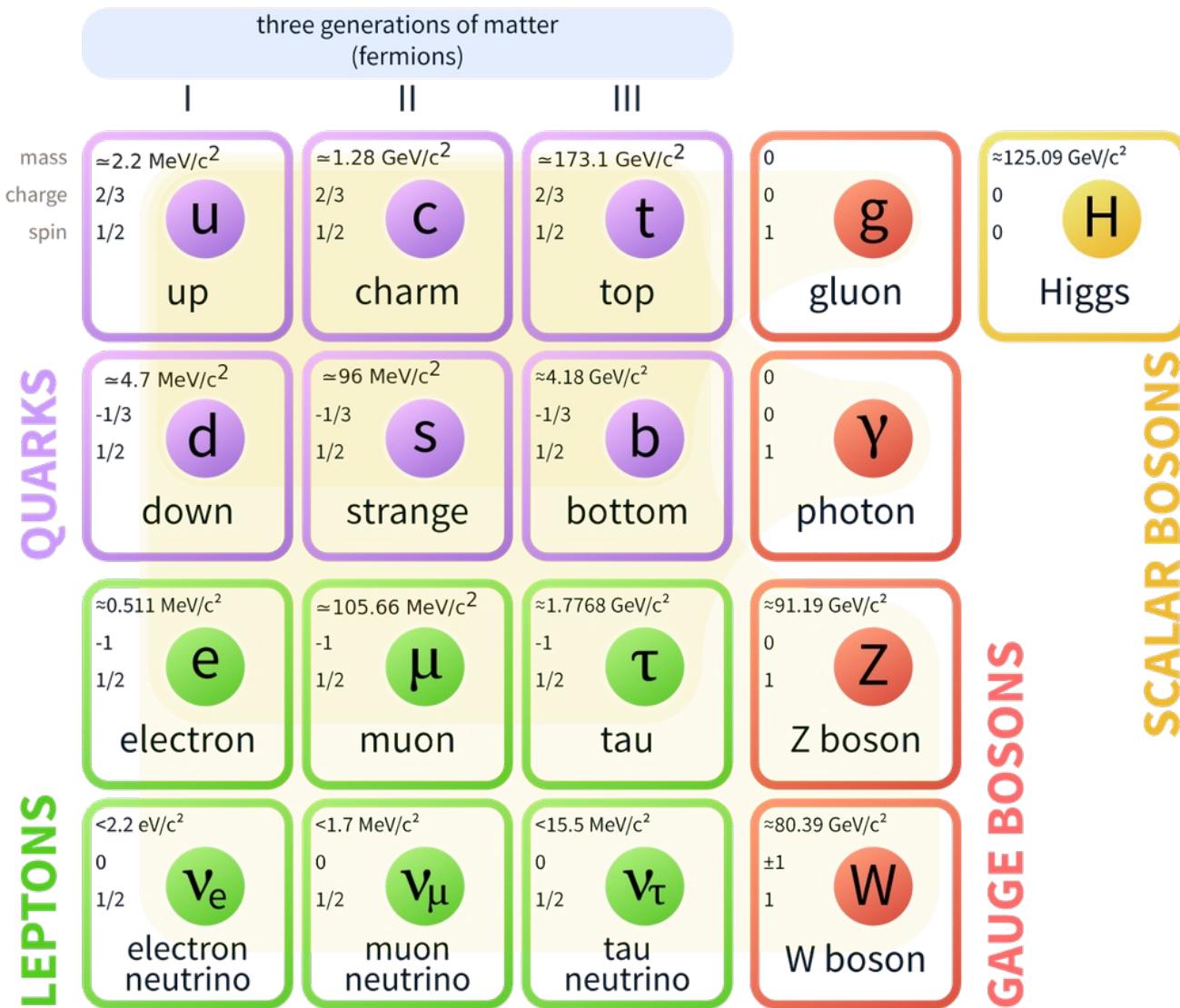
Previous slide, making about 6 fb^{-1} (inverse femtobarns) of luminosity every week, get the units right, then making Higgs by ggF is $43900 \text{ fb} * 6 \text{ fb}^{-1} = 263,400$ Higgs via that channel every two weeks! **But cannot detect all of them!**

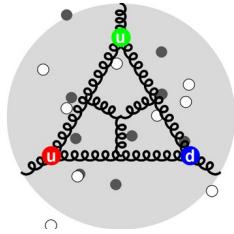
Barn is an (effective area) of 10^{-28} m^2 about the physical size of a nucleus.

Depending on energy and details, nuclear effects have cross-sections of 10^{-3} to 10^6 barns.

Standard Model of Elementary Particles

- 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.





Summary

- LHC starts commissioning in March 2022.
- Run 3 from May 2022 to July 2027.
 - Several “technical stops” in that schedule.



Thank You for your attention!
Any (more) questions?

Links

- <https://home.cern/topics/large-hadron-collider>
- CERN Timeline Large Hadron Collider
- <https://op-webtools.web.cern.ch/vistar/vistars.php?usr=LHC1>
- [http://demonstrations.wolfram.com/HowTheProtonAndNeutronGotTheir Masses/](http://demonstrations.wolfram.com/HowTheProtonAndNeutronGotTheirMasses/)
- <http://pdg.lbl.gov/>
- <http://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/LHC-schedule-update.pdf>
(not up-to-date with changes from Covid-19)



Backup

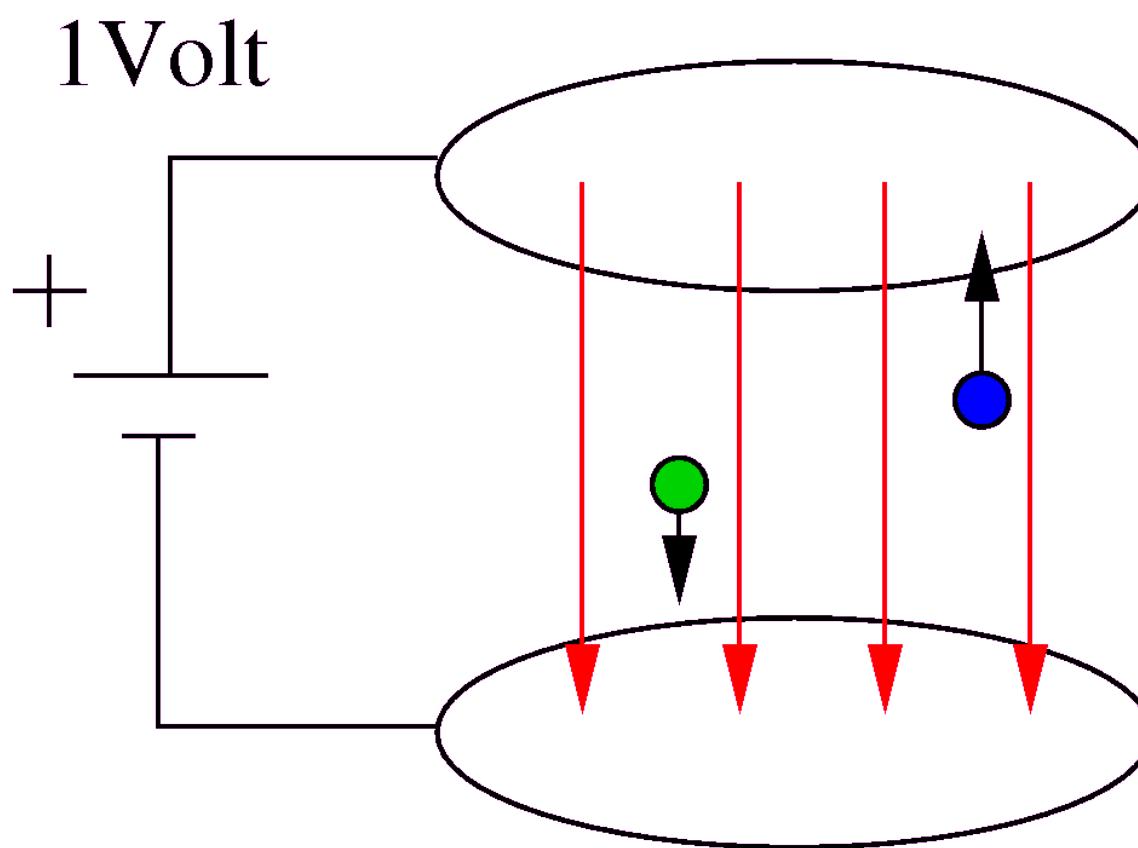


SI Prefixes

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 m/s

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

30 cm/ns

$300 \text{ m/}\mu\text{s}$

$300 \text{ }\mu\text{m/ps}$

LHC Parameters

| 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: $\sim 1.2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ |
| 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

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 (Fermions) | | | | |
|---|-------------------------------------|---------------------------------------|---------------------------------------|--------------------------------|
| | I | II | III | |
| mass → | 2.4 MeV | 1.27 GeV | 171.2 GeV | |
| charge → | $\frac{2}{3}$ | $\frac{2}{3}$ | $\frac{2}{3}$ | |
| spin → | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | |
| name → | u up | c charm | t top | |
| Quarks | d down | s strange | b bottom | |
| | 4.8 MeV | 104 MeV | 4.2 GeV | |
| | $-\frac{1}{3}$ | $-\frac{1}{3}$ | $-\frac{1}{3}$ | |
| | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{2}$ | |
| | g gluon | | | |
| Leptons | <2.2 eV e electron neutrino | <0.17 MeV μ muon neutrino | <15.5 MeV τ tau neutrino | 91.2 GeV Z^0 Z boson |
| | 0.511 MeV e electron | 105.7 MeV μ muon | 1.777 GeV τ tau | ± 1 W^\pm W boson |
| Gauge Bosons | | | | |

Three generations of matter particles and the force carrying particles.

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/>

Neither is working, 20210620, weg.