

Physics at the Large Hadron Collider (LHC)

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THE STANDARD MODEL

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

Higgs^{*}
boson

*Yet to be confirmed

Source: AAAS

Electroweak

Large Hadron Collider (LHC)

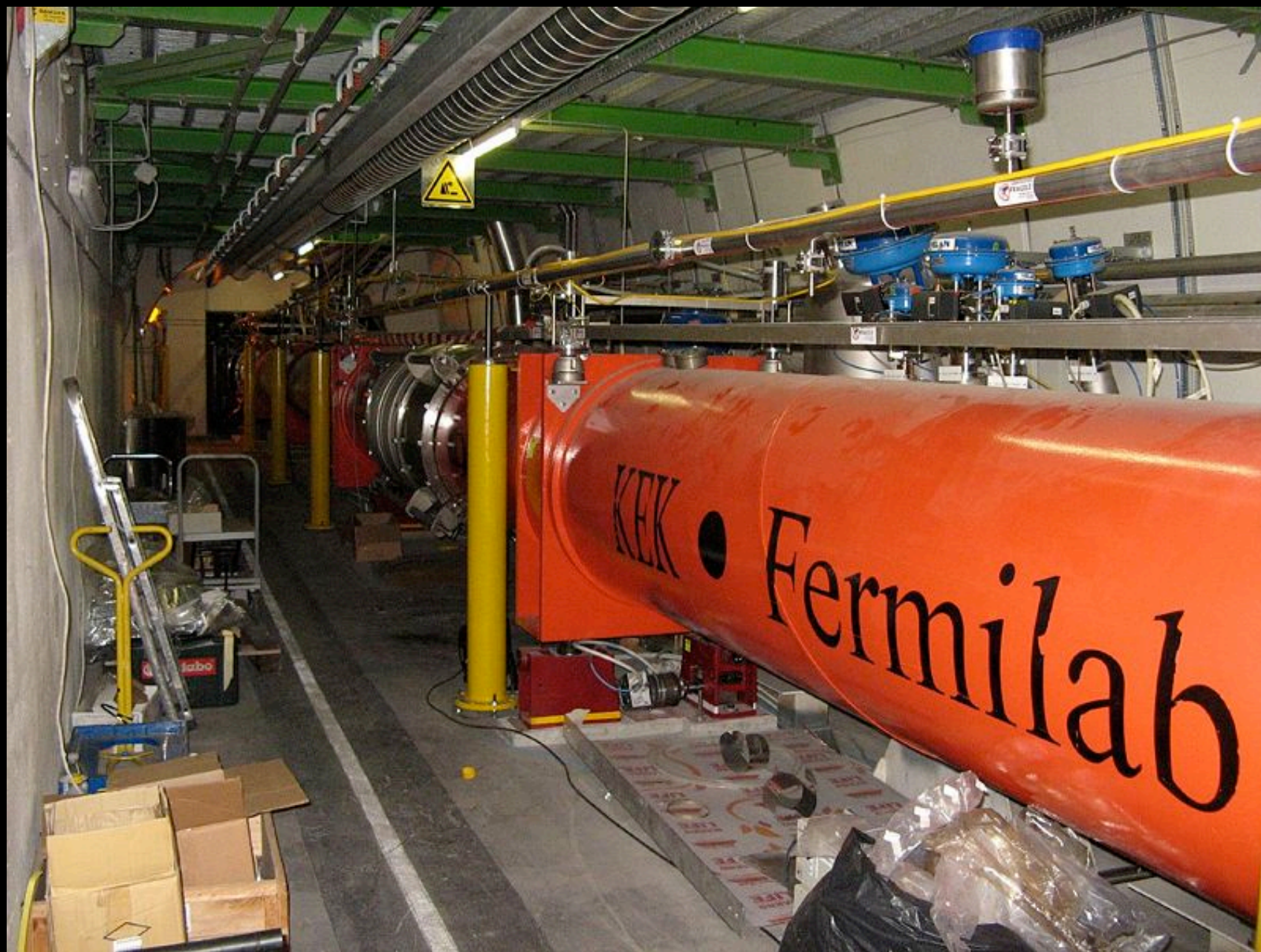
- A 14 TeV proton-proton collider
 - 1 TeV = 10^{12} eV
 - A factor of 7 more energy than the Fermilab Tevatron
- 27 Km long tunnel, 100 m below ground
- 9300 superconducting magnets (1232 dipoles)
 - 60 tons of liquid helium
 - 11,000 tons of liquid nitrogen
- Energy stored in magnets = 10 GJ

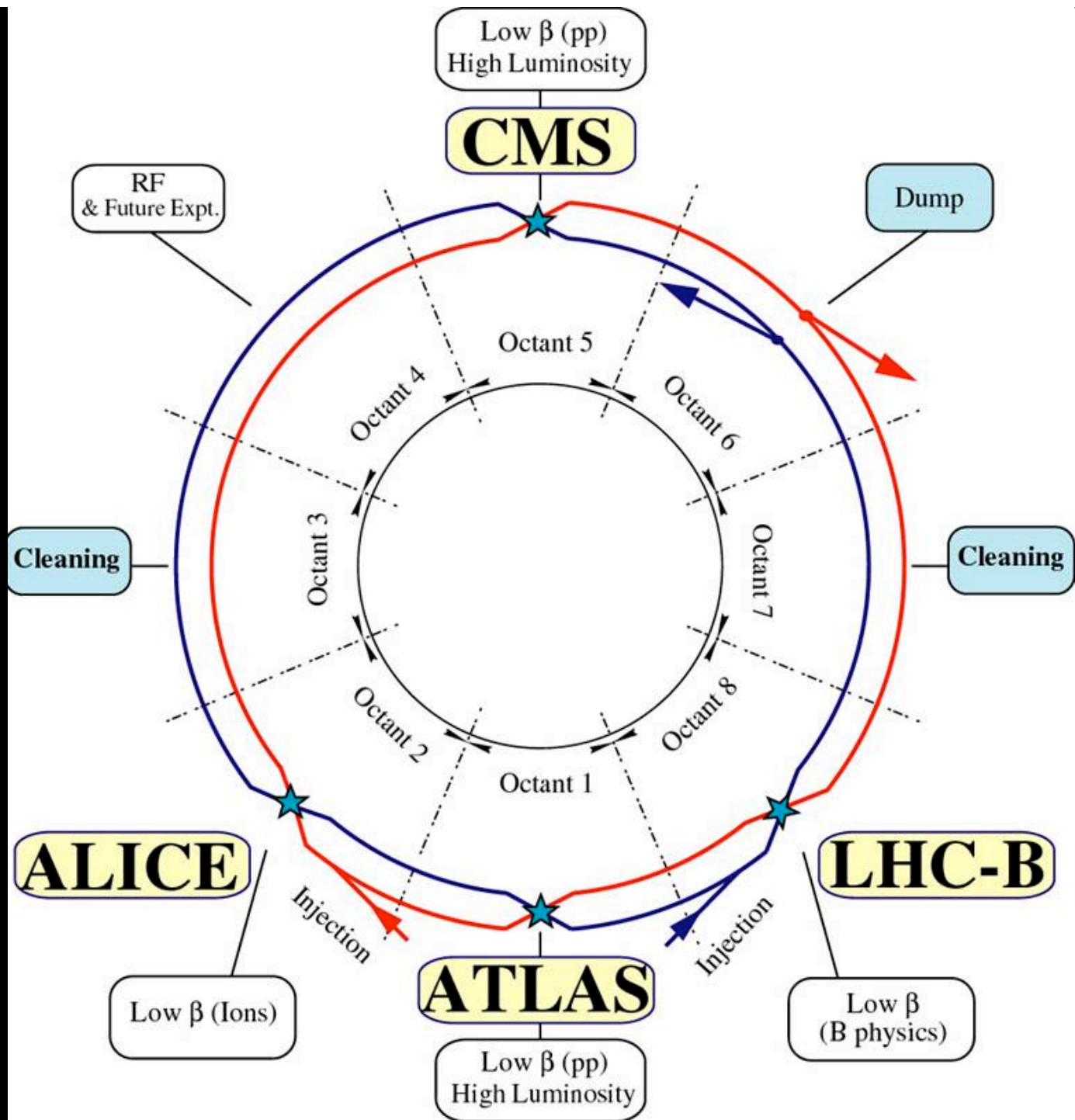
- Each of the 1232 dipoles....
 - is 15 m long
 - carries 11.8 kA of current
 - provides a field of 8.3 T
- There are 2808 "bunches" of protons in each beam
 - 10^{11} protons per bunch
 - 11,245 turn
- When brought into collision the transverse size of the bunches is of order $10\ \mu\text{m}$

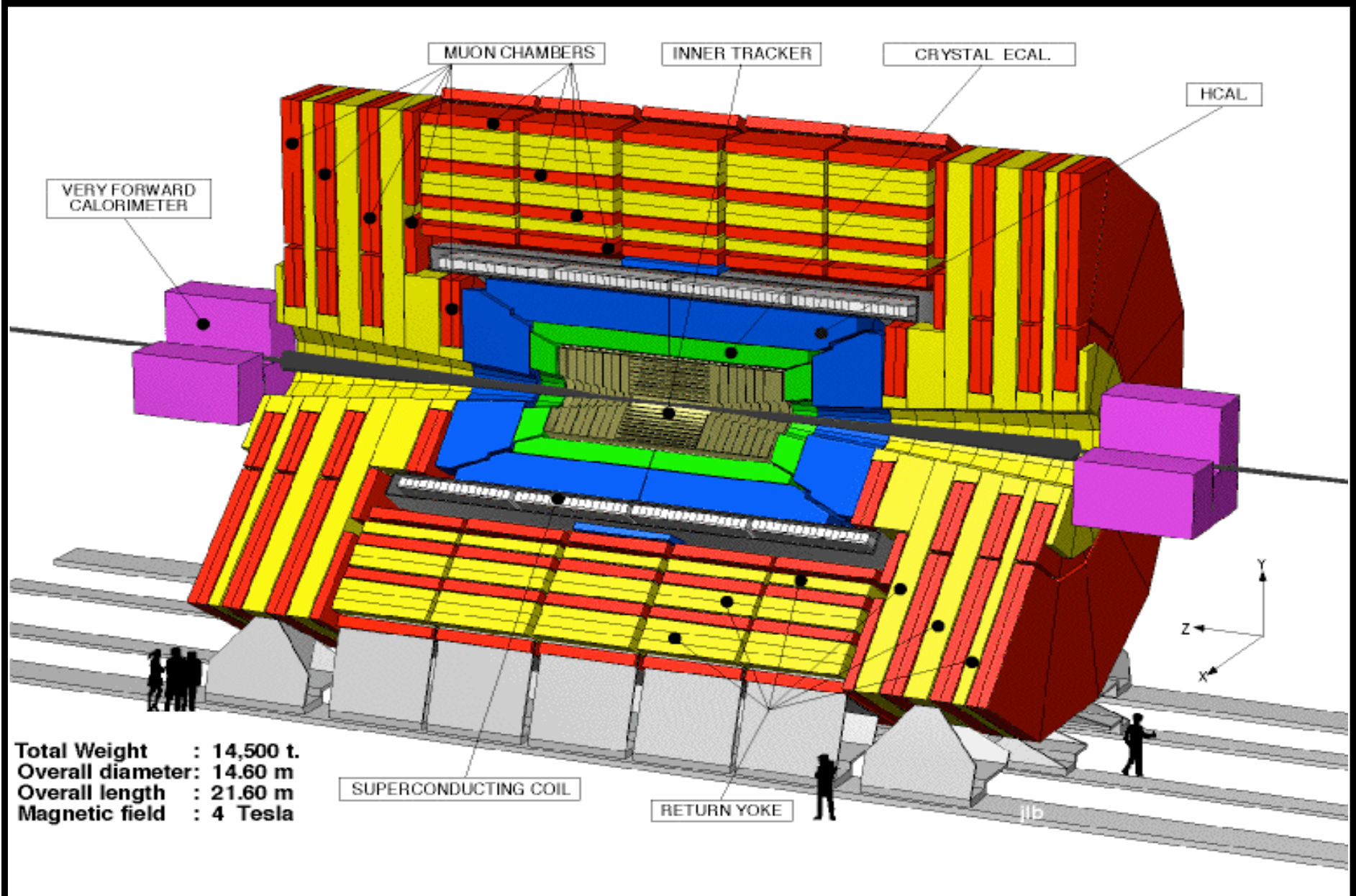


Picture of the tunnel

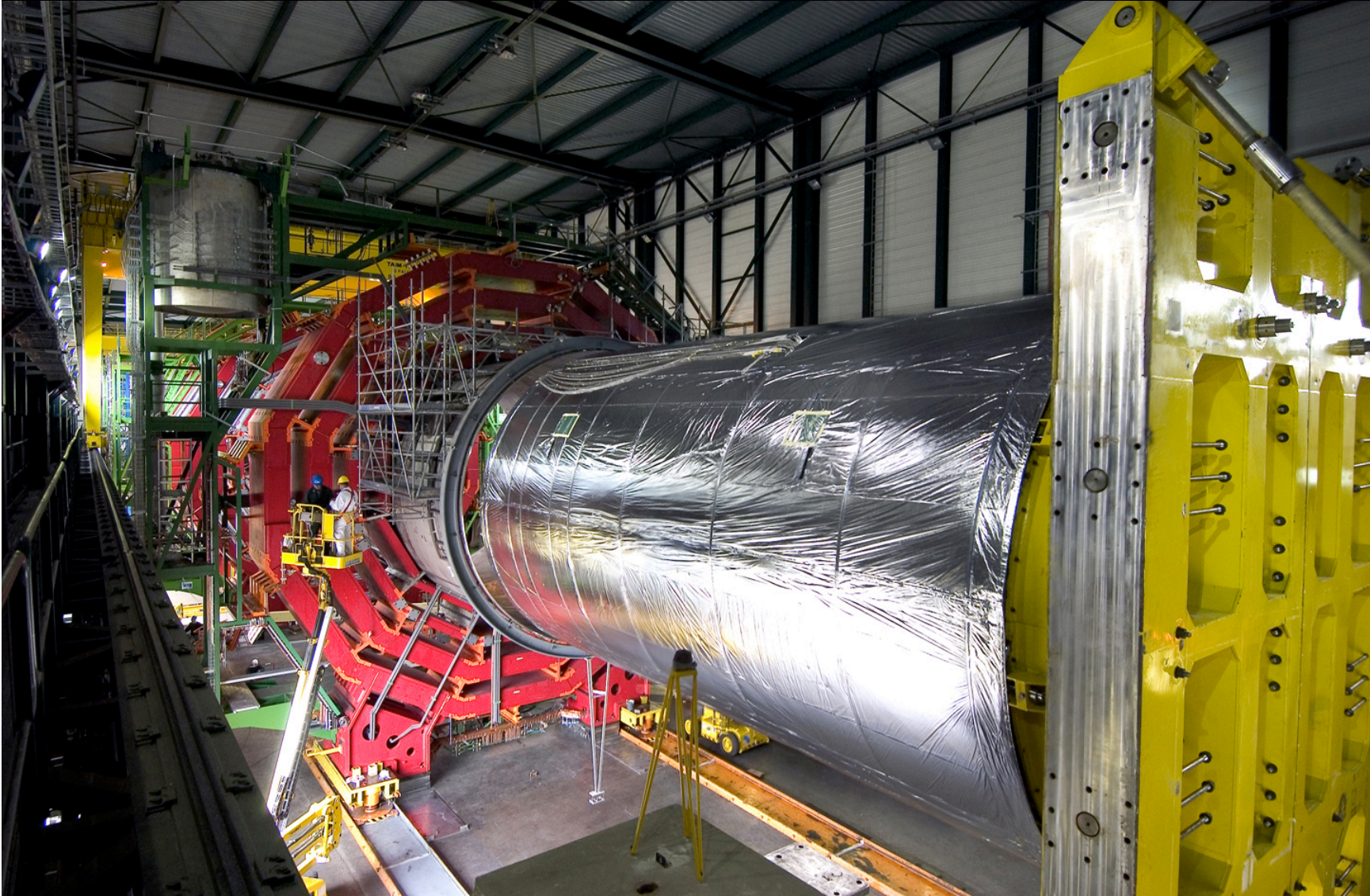






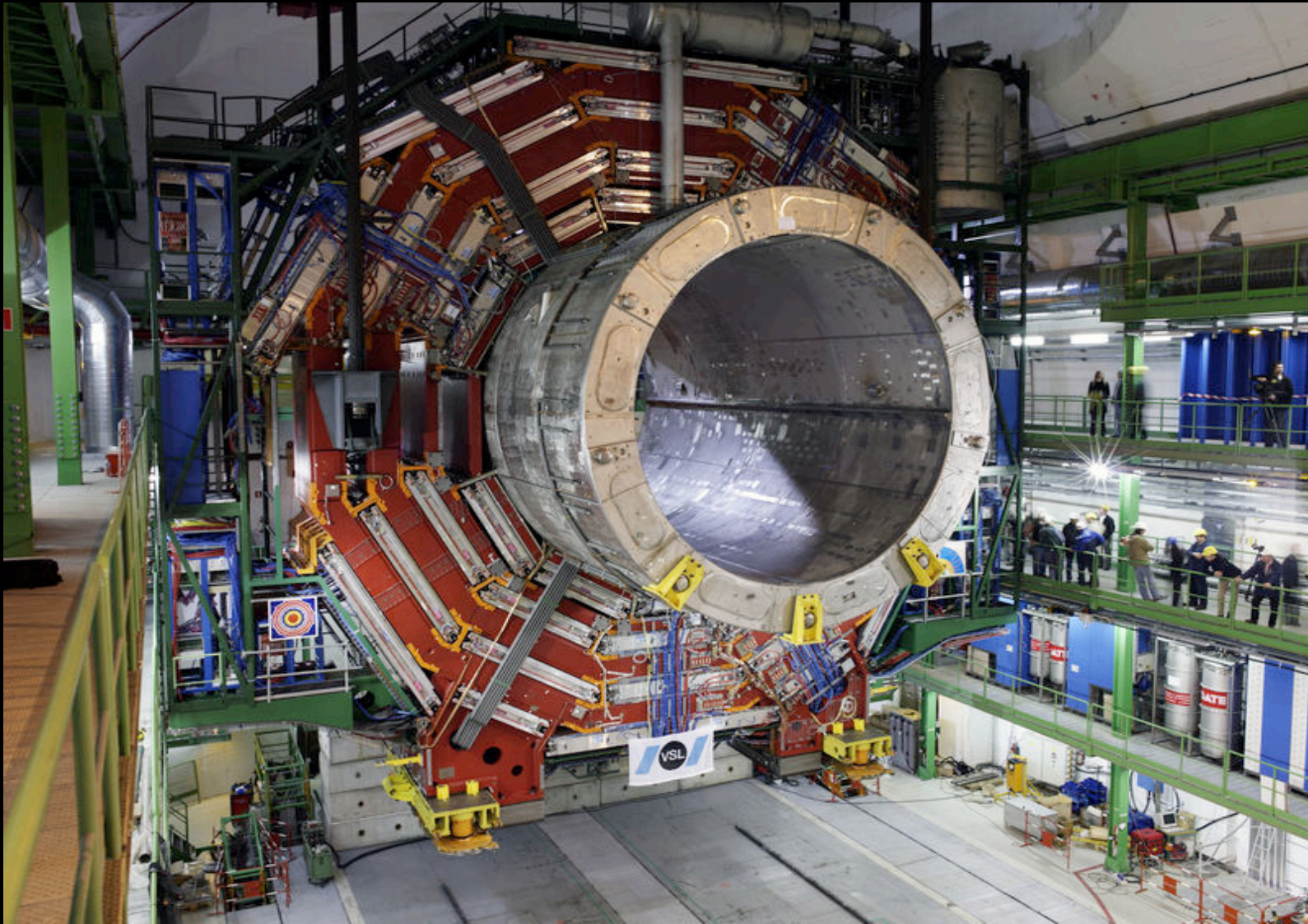


Coil insertion. 4T superconducting solenoid

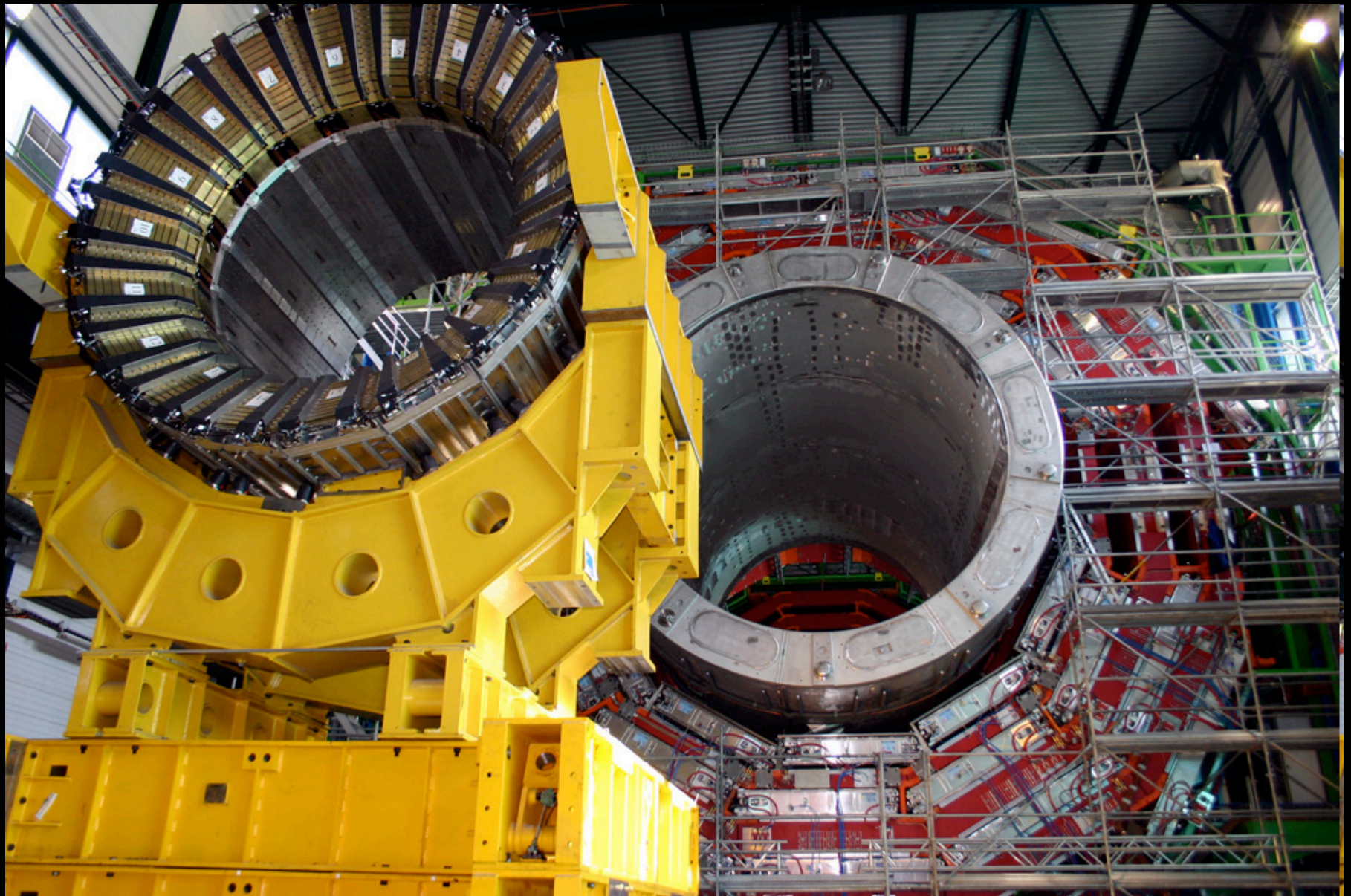


Magnet is 12,000 tons. Stores enough energy to melt 18 tons of gold. 10

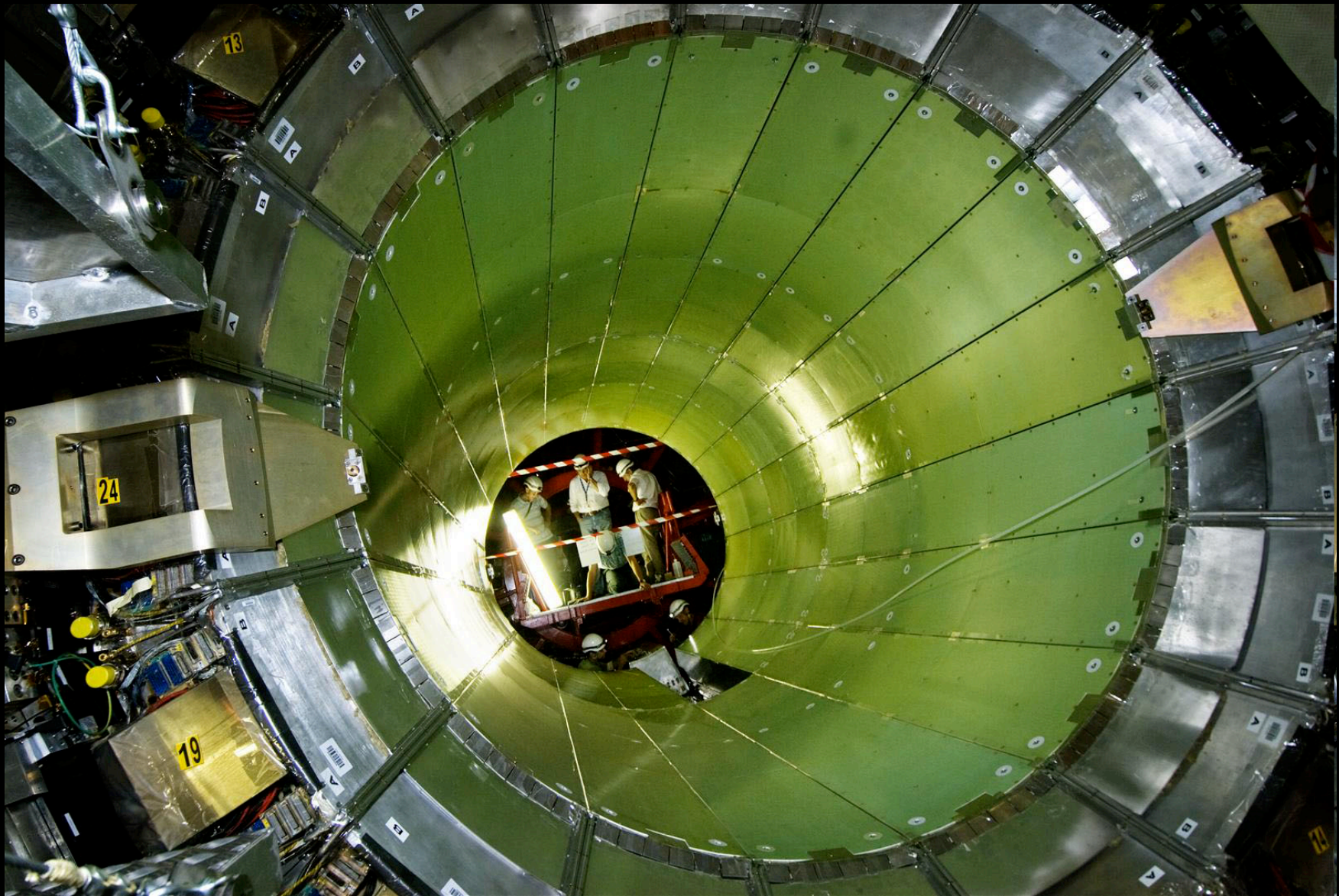




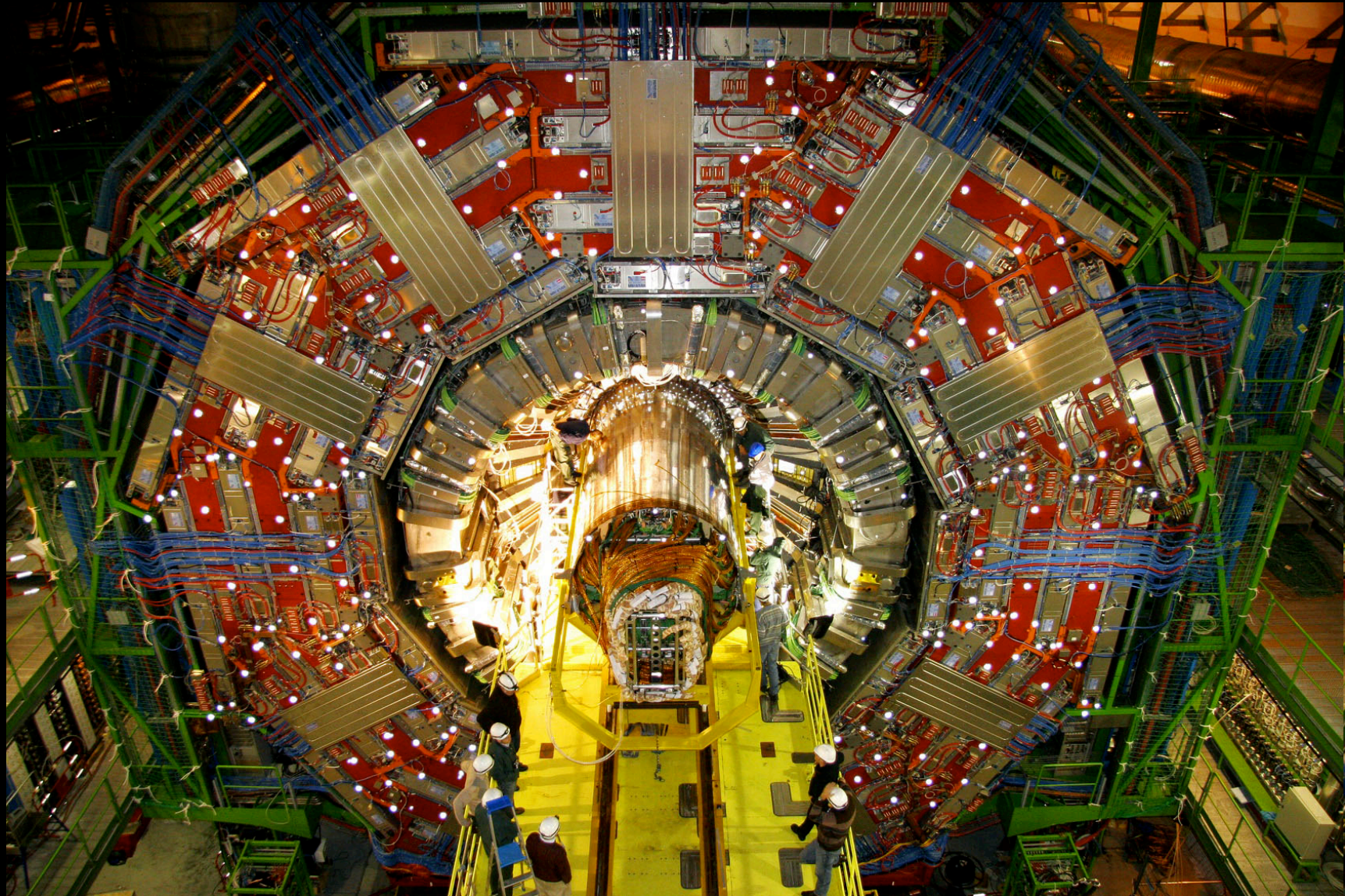
Insertion of HCAL



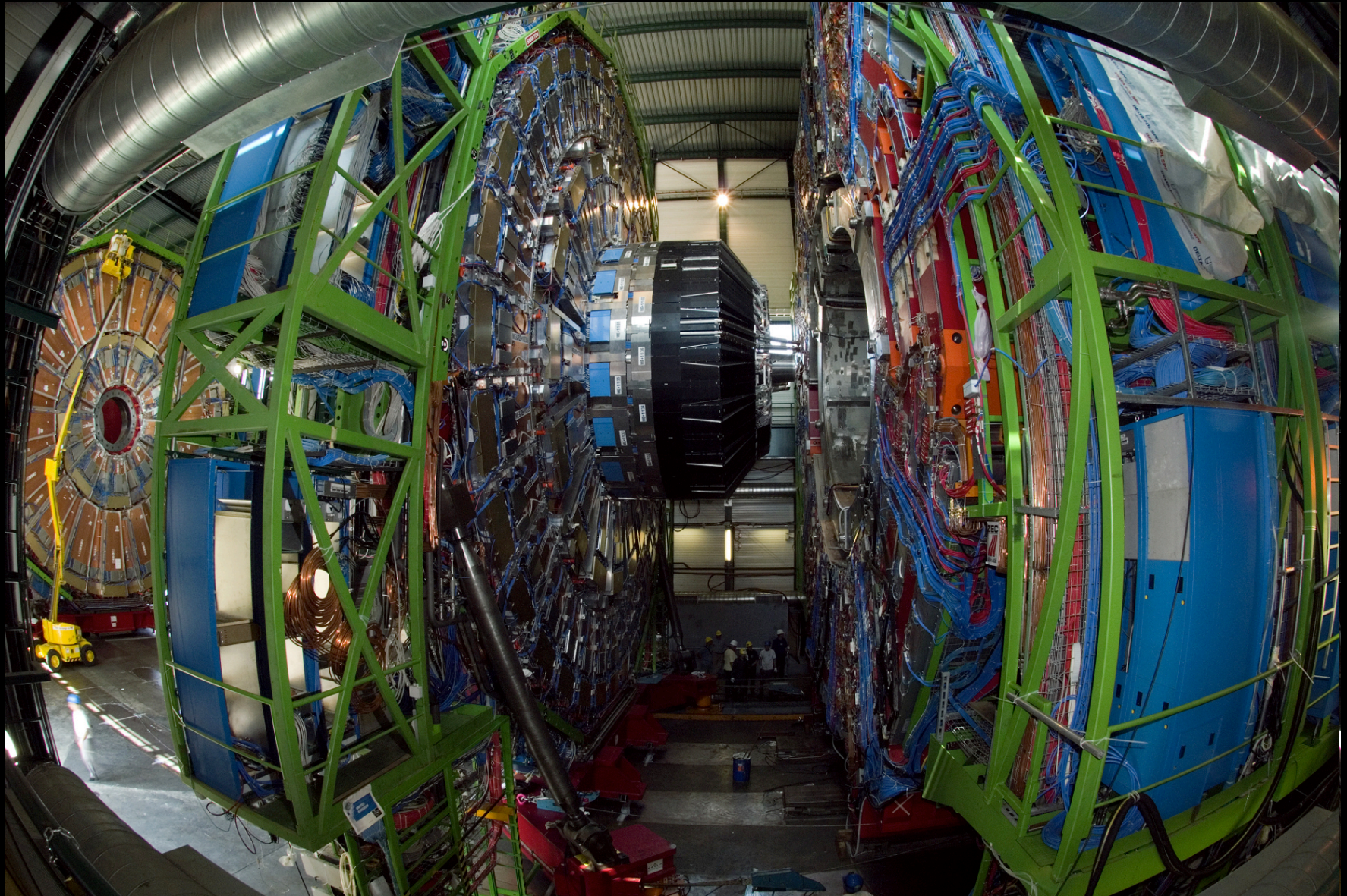
Insertion of ECAL super modules



Insertion of tracker

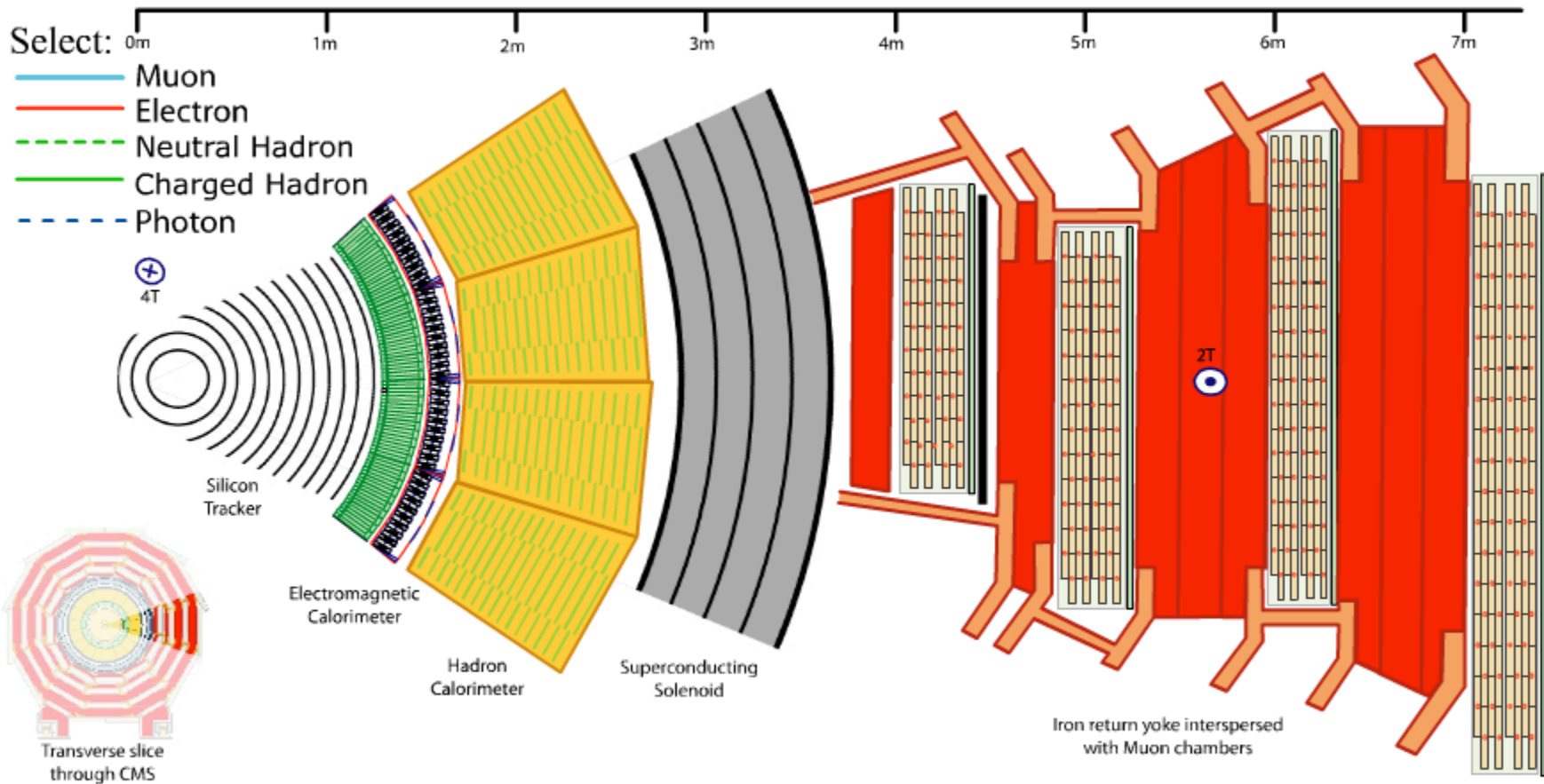


closing of detector for magnet test



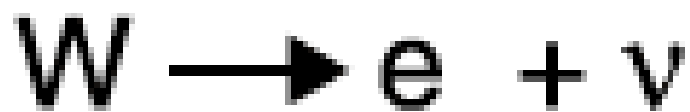
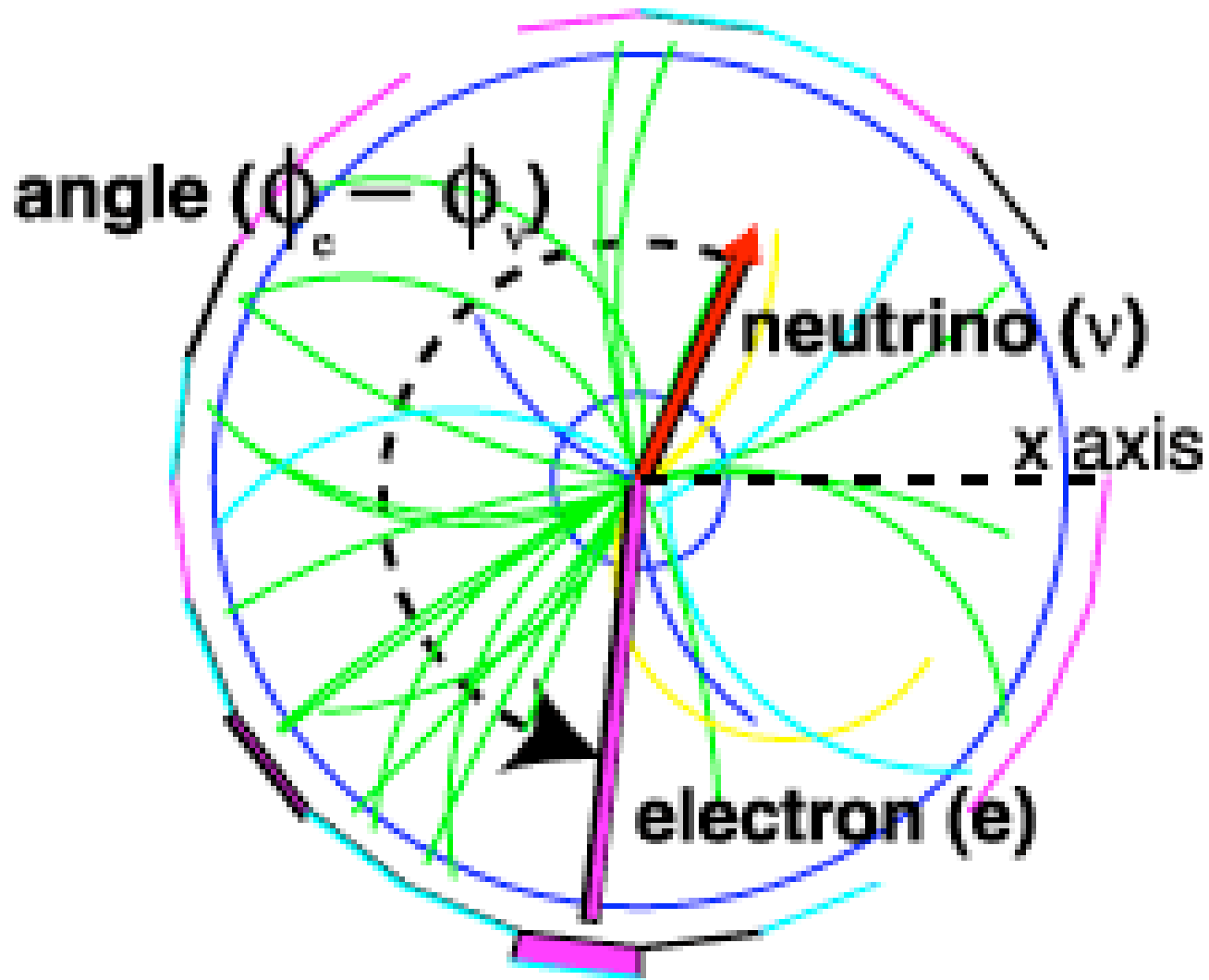
What does the detector do?

- The detector tries to measure the 4-momenta of all particles in a pp collisions
- 3-momenta of charged particles are inferred by reconstructing tracks as it bends in a 4T magnetic field
- For neutrals (γ , neutrons), energy is measured by size of "shower" in instrumented material (calorimeter)
- The interactions patterns of particles with the detector elements allows to "identify" the particle species
 - e.g., electron vs muon vs proton



Neutrinos (or dark matter particles)

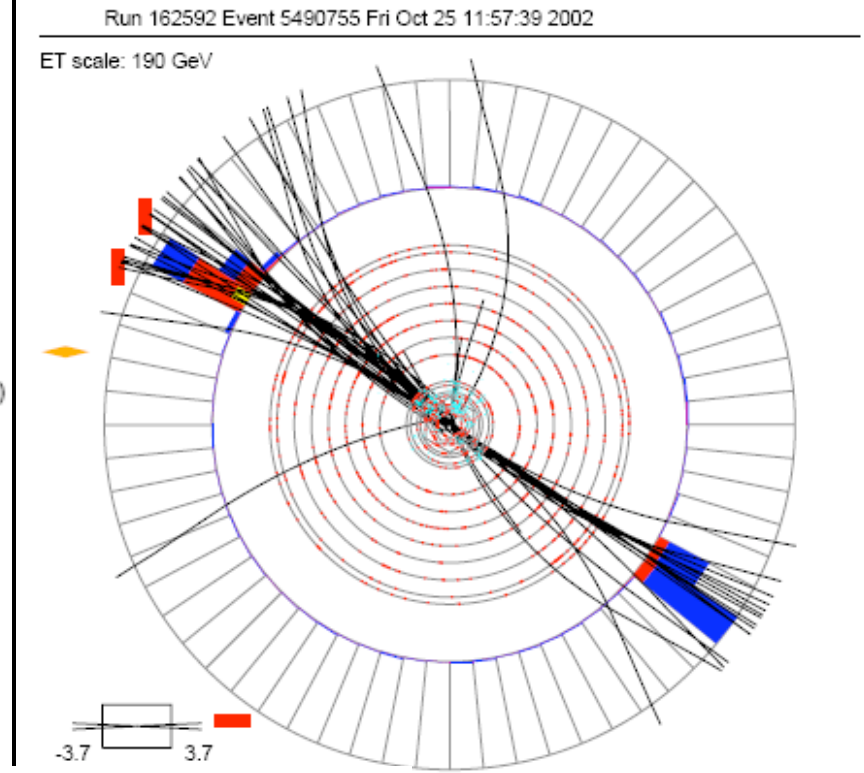
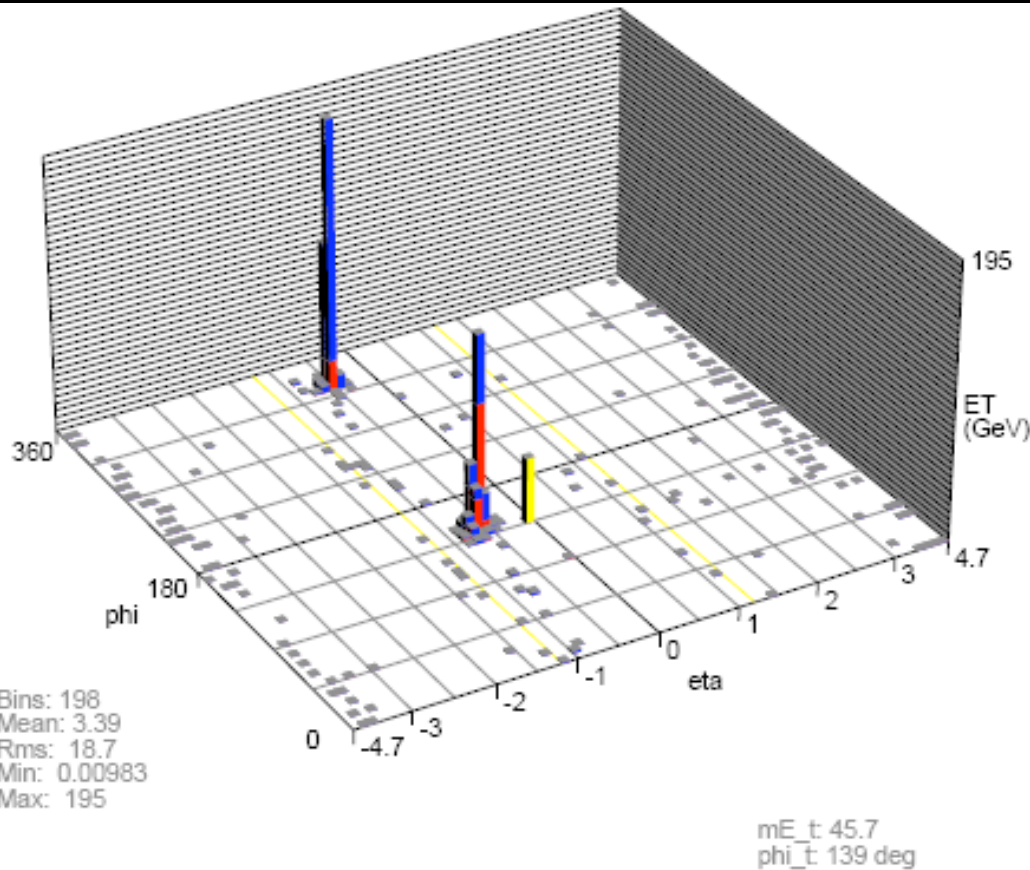
- They do not interact
- Their presence is inferred by conservation of momentum $\sum \vec{P}_\nu = - \sum \vec{P}_{\text{visible}}$
- In practice this can only be done in the plane transverse to the beam direction, since particles escaping down the beampipe are not measured
 - Missing Transverse Momentum, or Missing Transverse Energy



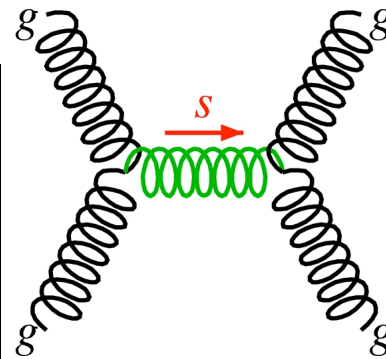
Gluons and quarks → jets

- They do not directly show up in the detector
- Quarks and antiquarks are pulled from the vacuum and bound states are formed (hadrons, eg, pions, protons, etc)
- If the original gluon or quark is energetic enough, the result is a spray of hadrons (jet) that preserves the direction and energy of the original gluon or quark (more or less)

A two jet event from D0 (di-jet)

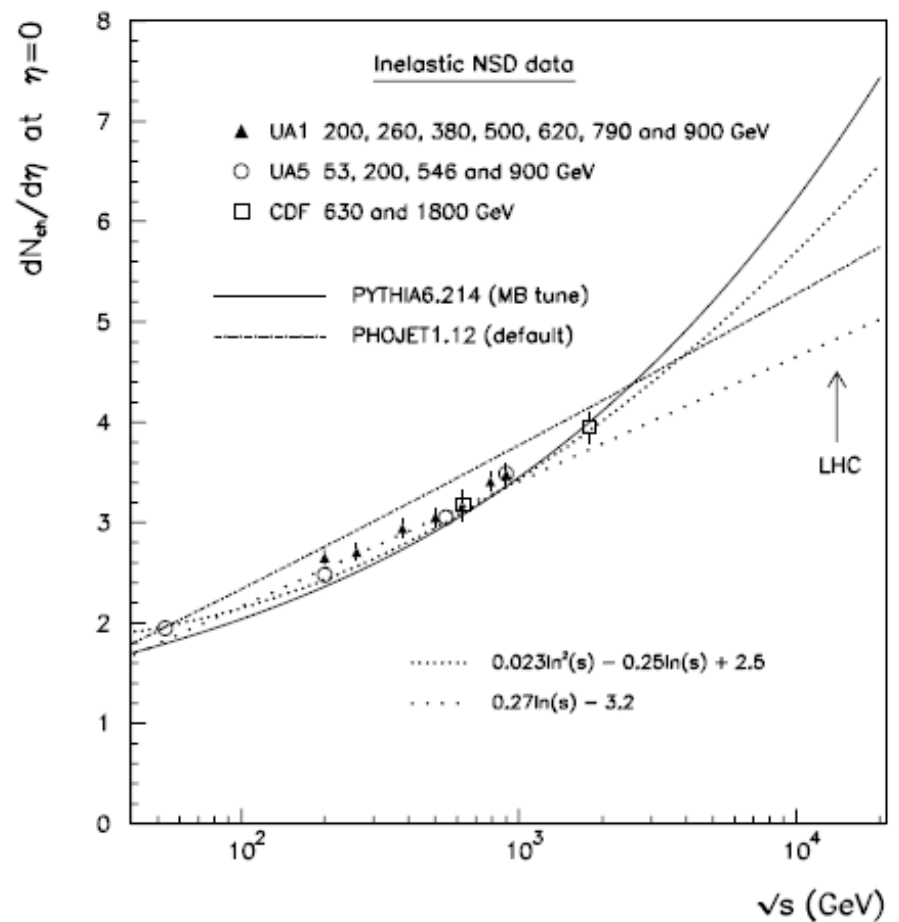
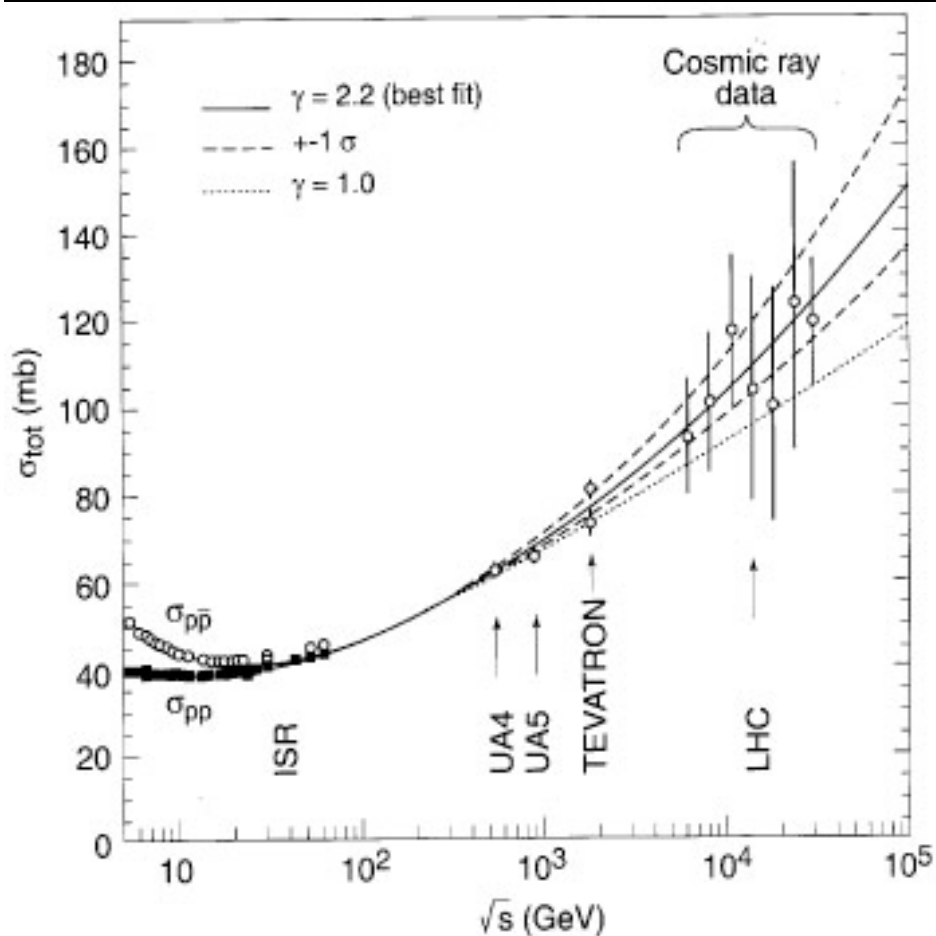


Two jets back-to-back in ϕ
Note: 45 GeV of MET



What happens when two protons collide?

- Most of the times: not very much
- The protons might break up with most daughter particles going down the beampipe. A few (~50-100) particles with small transverse momentum (P_T) show up in the detector

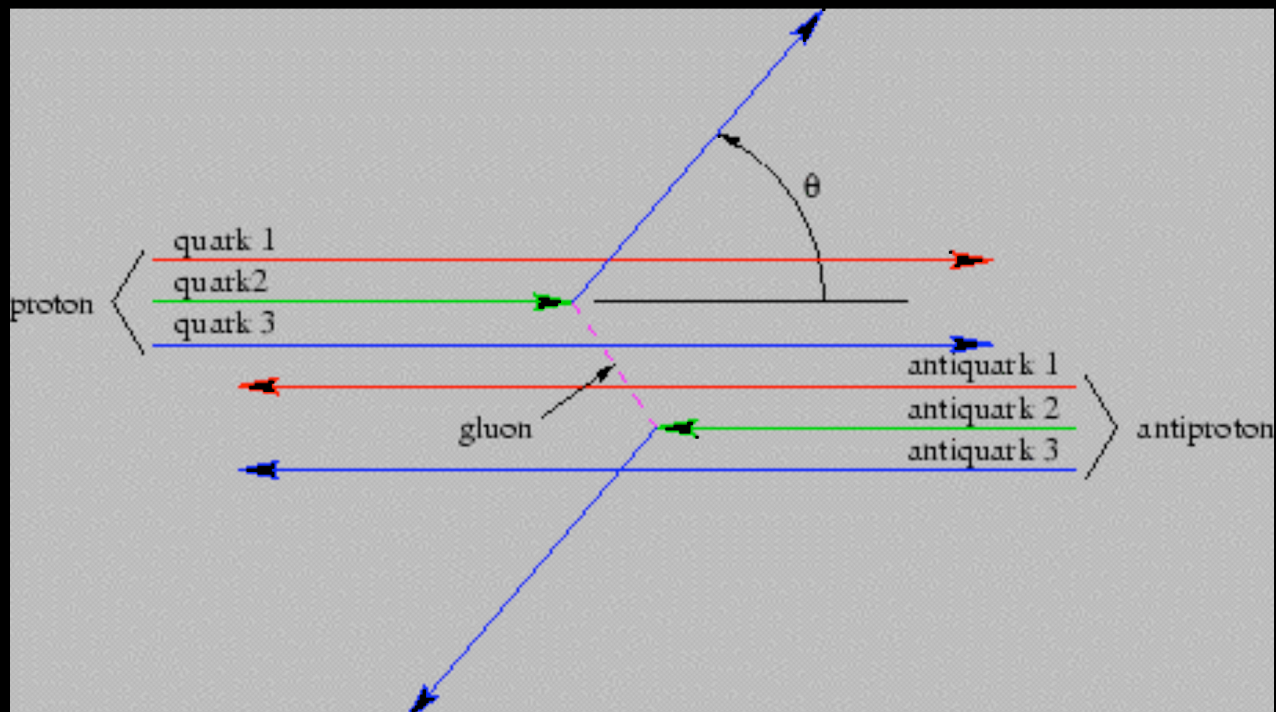


Physics 105B: Billiard ball scattering:

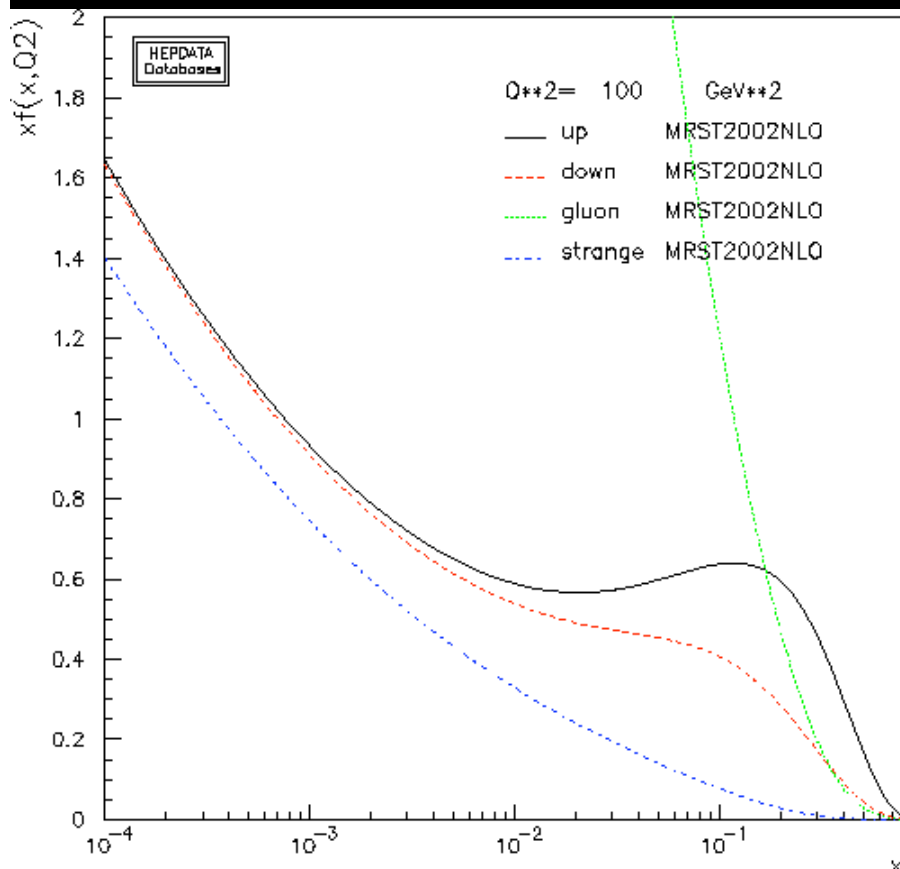
$$\sigma = 4 \pi R^2$$

$$R_{\text{proton}} \sim 10^{-15} \text{ m} \rightarrow \sigma(\text{pp}) \sim 10^{-29} \text{ m}^2 = 100 \text{ mb}$$

- The garden-variety collisions are not interesting (to most people)
- The interesting collisions are the "violent" collisions where a lot of transverse momentum is exchanged
- Here we can think of collisions between the components of the proton (quarks, antiquarks, and gluons, aka partons)

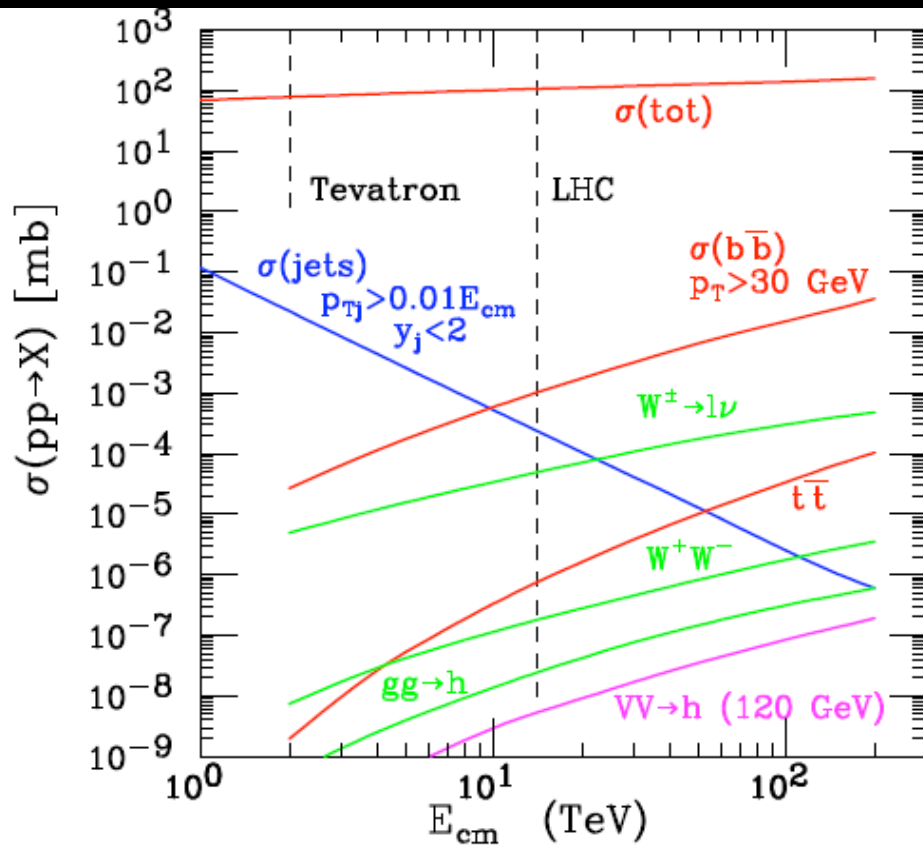


- Think of the LHC as a parton-parton collider
- Broadband collider. Partons in the proton can take any fraction of the proton momentum.
- In a probabilistic way, that we cannot calculate from first principles → measure it



- $f_i(x)$ = prob of parton i having momentum $x \cdot P_{\text{proton}}$
- Parton Distribution Function (pdf)
- Note that there are many many many gluons.
- LHC = gluon collider

Moving on to harder scatters



Note: TeV-scale SUSY, $\sigma \sim 10^{-9}\text{mb}$

- Jets have large cross-sections because they are strong processes, eg, $gg \rightarrow gg$
- To look for "New Physics" require presence of γ or leptons (e, μ, τ) or missing energy
 - Backgrounds are electro-weak processes
 - There are exceptions

Outline

- What and Why?
- The LHC
- A detector (CMS), how we do physics at the LHC
- How to look for "New Physics"
- Status

What Physics should I do at the LHC?

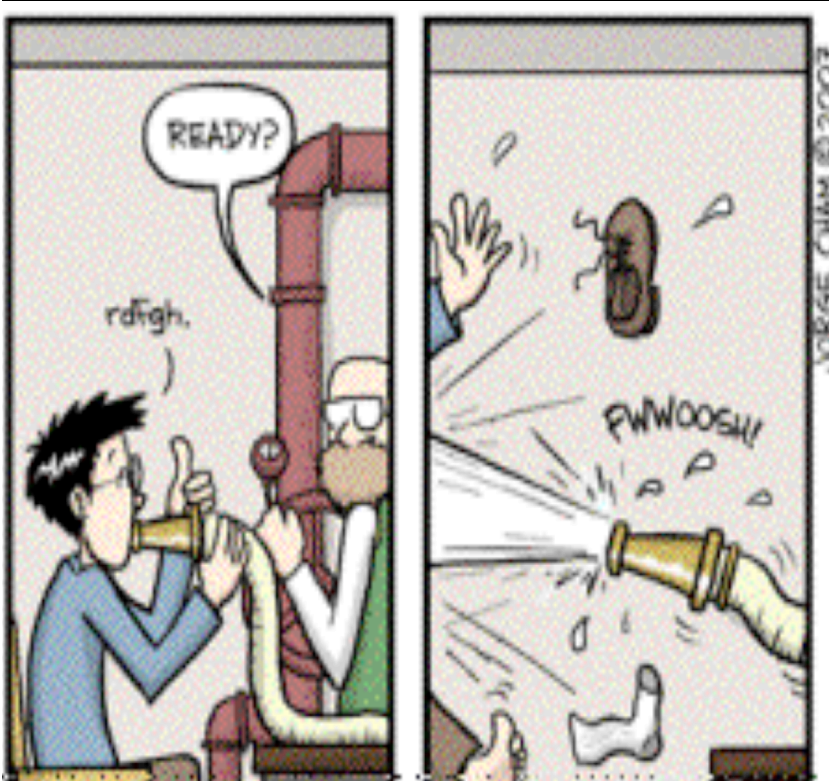
- To Higgs or not to Higgs?
 - Should I look for the Standard Model Higgs, or for "New Physics"?
- Interestingly enough all of us at UCSB have answered "not to Higgs"
- Remainder of the talk on searches for New Physics

3+1 Ingredients for New Physics Discoveries at the LHC

0. Machine/detector: *if they dont work, forget it*
1. Trigger: *if you did not trigger on it, it never happened*
2. Backgrounds: *It's the background, stupid*
 - Need to understand instrumental and Standard Model physics backgrounds
3. Searches: *If you look for something, you may not find it. But if you don't look, you will never find it*

What is the "trigger"?

- $\sigma(pp) \sim 100 \text{ mb}$
- Gives an "event rate" of order 100 MHz
- Each event is $\sim 250 \text{ kb}$
- $250 \text{ kb} \times 100 \text{ MHz} = 25 \text{ Tbytes/second}$



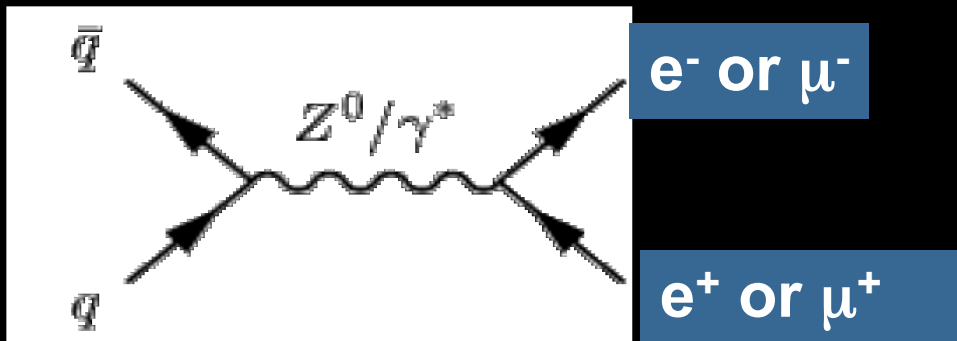
- Trigger is the system that selects the ~ 200 events/second that are saved for further study
- **Most of the events are thrown away!!!!**

CMS "Trigger Menu"

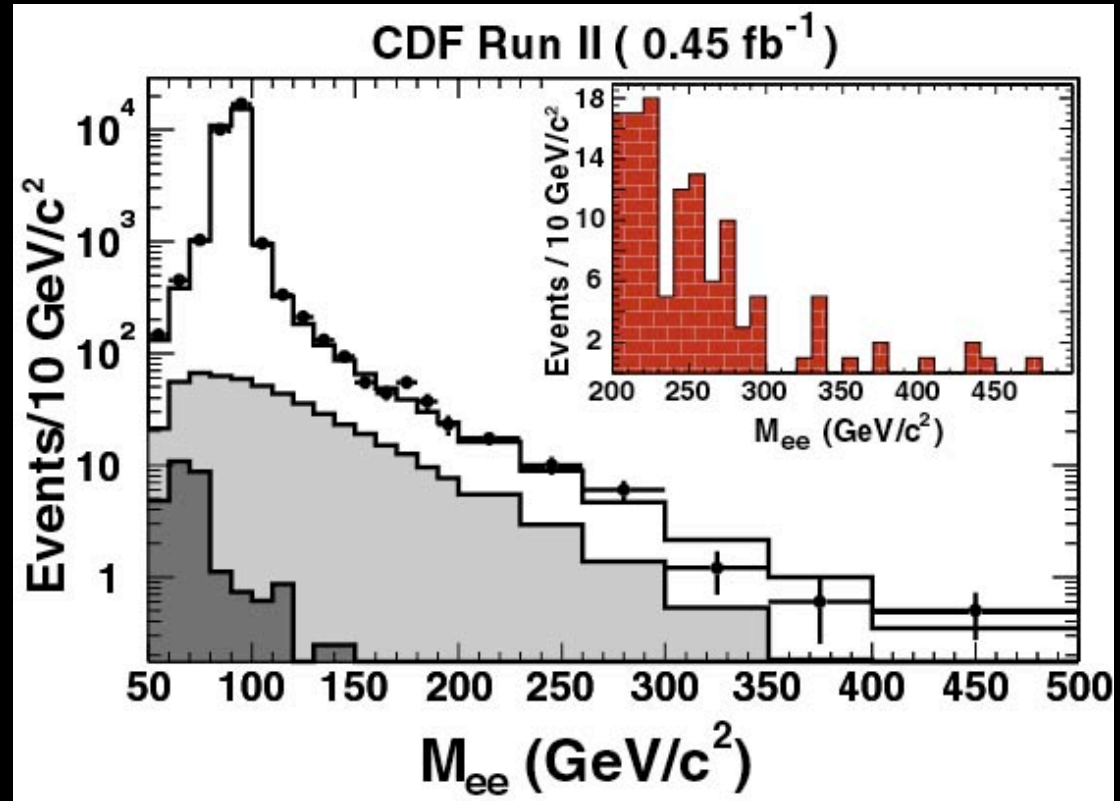
Trigger	Threshold (GeV or GeV/c)	Rate (Hz)	Cumulative Rate (Hz)
Inclusive electron	29	33	33
Di-electrons	17	1	34
Inclusive photons	80	4	38
Di-photons	40, 25	5	43
Inclusive muon	19	25	68
Di-muons	7	4	72
Inclusive τ -jets	86	3	75
Di- τ -jets	59	1	76
1-jet * E_T^{miss}	180 * 123	5	81
1-jet OR 3-jets OR 4-jets	657, 247, 113	9	89
Electron * Jet	19 * 45	2	90
Inclusive b -jets	237	5	95
Calibration and other events (10%)		10	105
TOTAL			105

From the Technical Design Report. Obsolete. There are now close to 100 different triggers in the menu.....

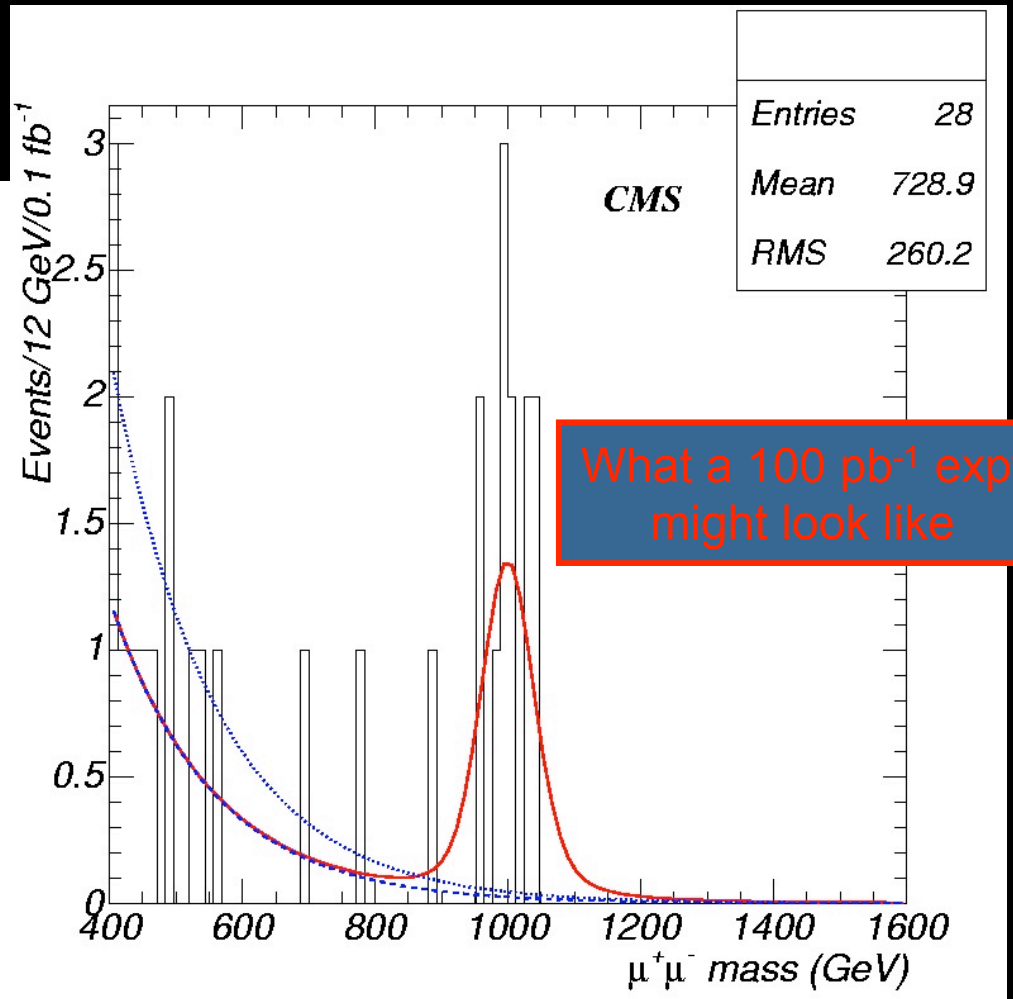
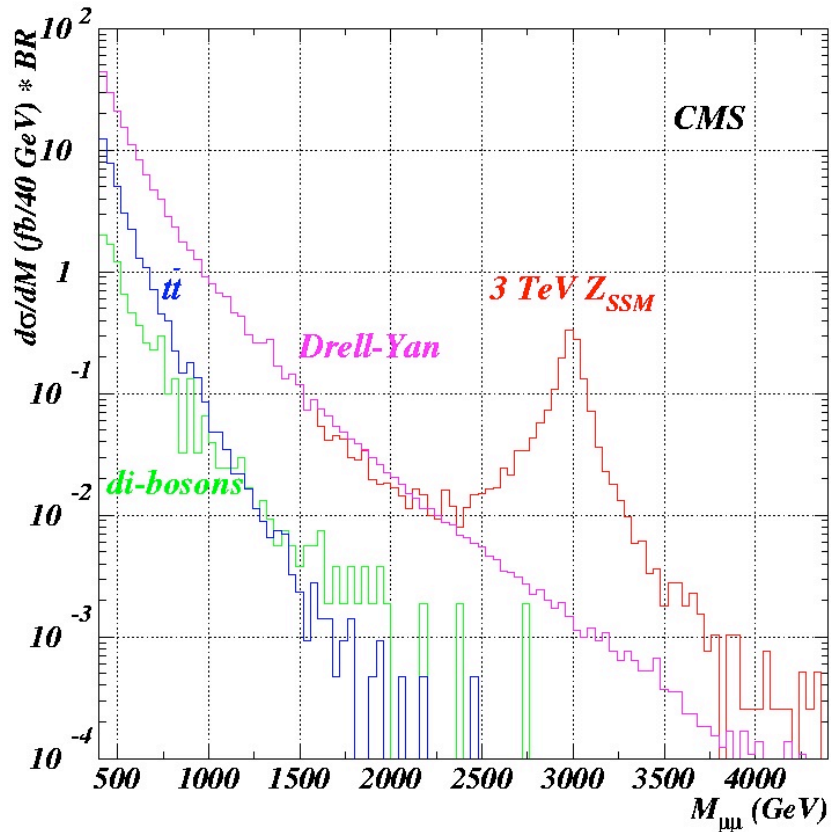
Drell-Yan



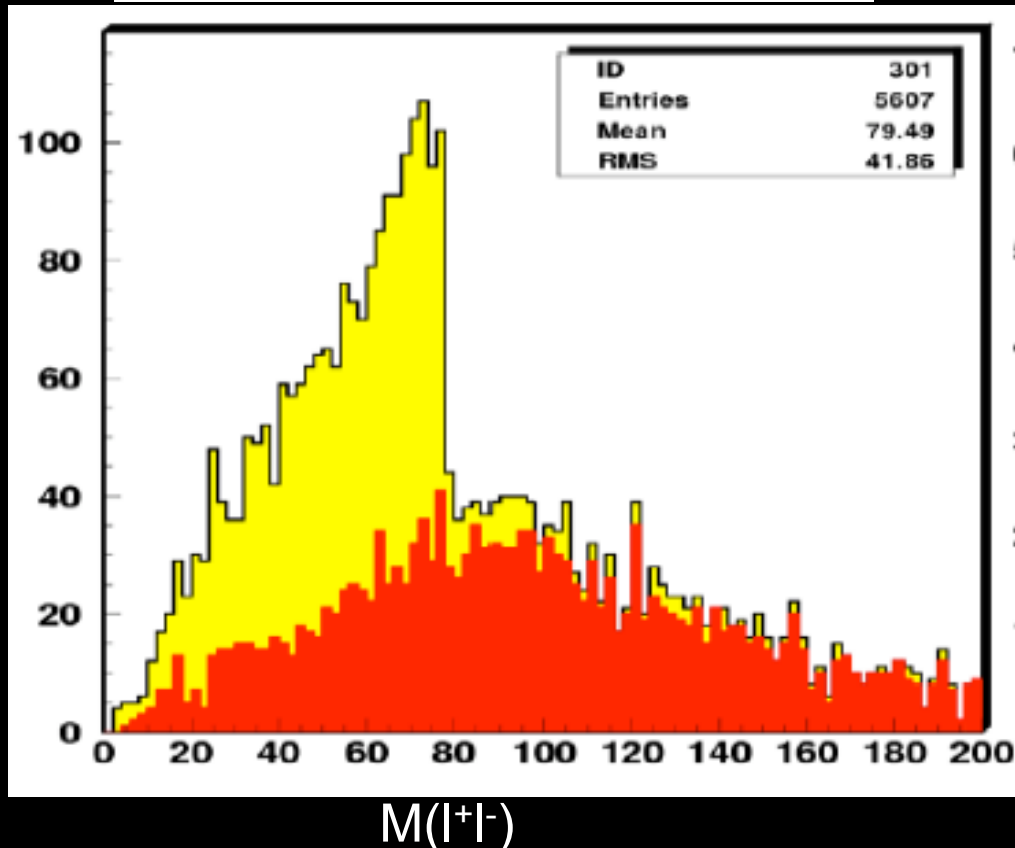
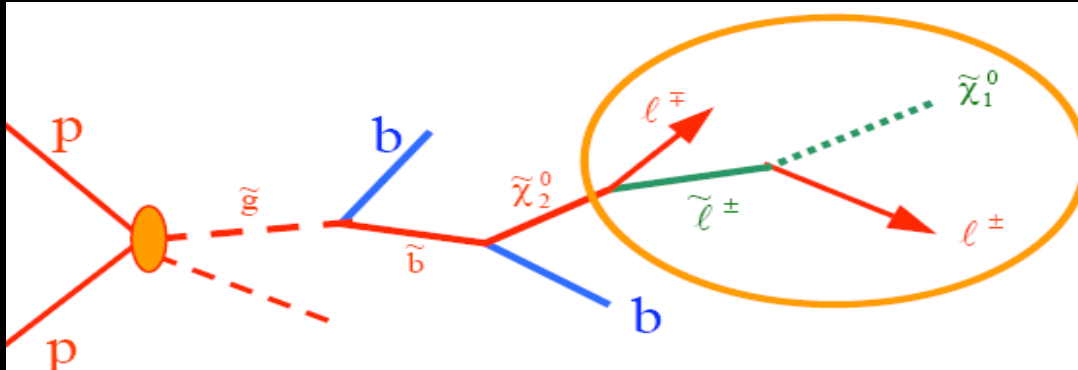
- SM Drell-Yan
- Di-jet background
- WW background



SCS example: $Z' \rightarrow \mu\mu$



SCS: Edges




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Protons and Champagne Mix as New Particle Collider Is Revved Up

By DENNIS OVERBYE
Published: September 10, 2008

BATAVIA, Ill. — Science rode a beam of subatomic particles and a river of Champagne into the future on Wednesday.

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Anja Niedringhaus/Associated Press

The entrance to the CERN laboratory near Geneva. After 14 years of labor, scientists activated their new particle

After 14 years of labor, scientists at the [CERN](#) laboratory outside Geneva successfully activated the [Large Hadron Collider](#), the world's largest, most powerful particle collider and, at \$8 billion, the most expensive scientific experiment to date.

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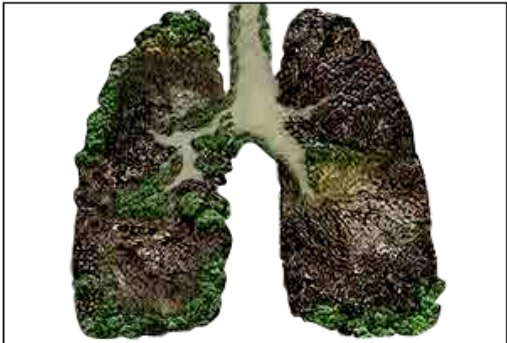
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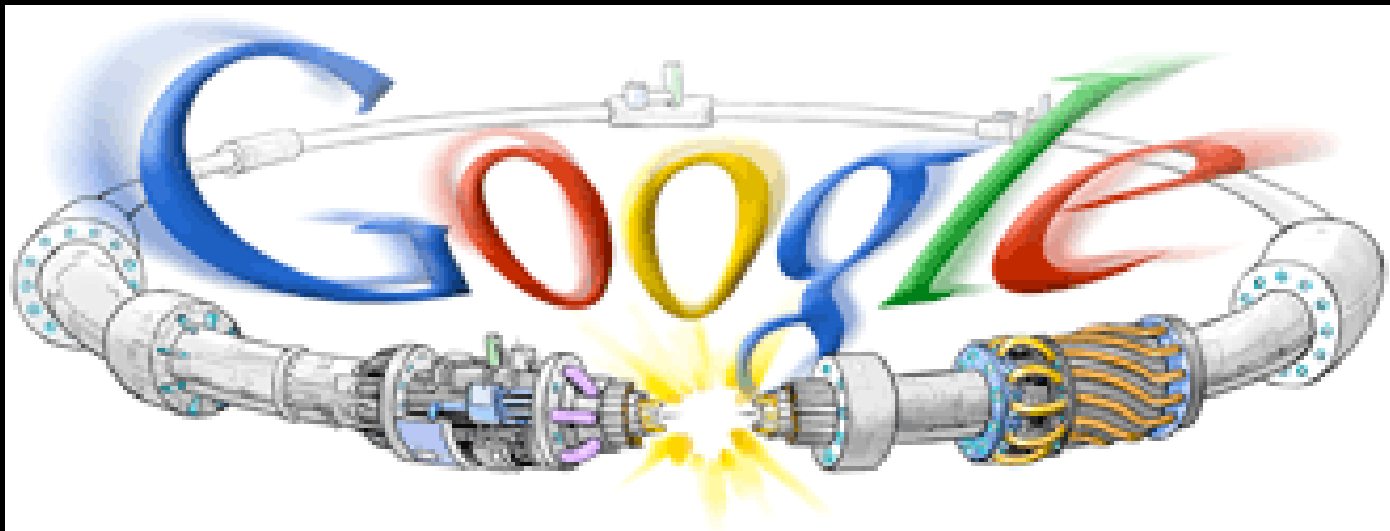
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The Top 10 Everything of 2008

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Top 10 Scientific Discoveries

1. Large Hadron Collider

By JEFFREY KLUGER



Good news! The Large Hadron Collider (LHC) — the massive particle accelerator straddling the Swiss-French border — didn't destroy the world! The bad news: The contraption didn't really work either. In September, the 17-mile collider was switched on for the first time, putting to rest the febrile webchatter that the machine would create an artificial black hole capable of swallowing the planet or at least a sizeable piece of Europe — a bad day no matter what. No lucid observer ever thought that would really happen, but what they did expect was

Good news! The Large Hadron Collider (LHC) — the massive particle accelerator straddling the Swiss-French border — didn't destroy the world! The bad news: The contraption didn't really work either. In

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The Top 10

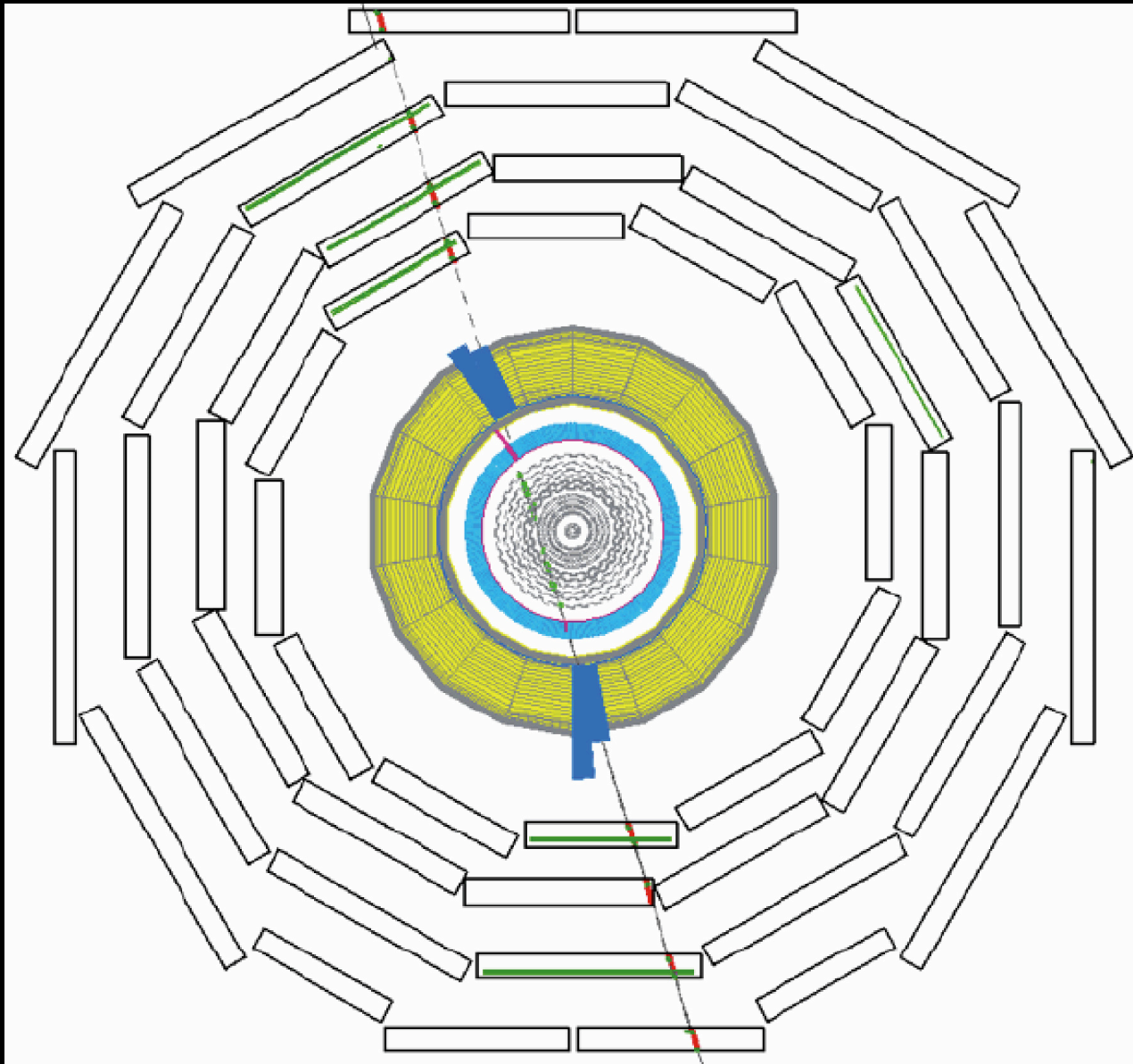


Current Schedule

- After extensive repairs the machine is scheduled to come on line this Fall
- Energy of 10 TeV (design is 14)
- Low intensity to commission

- First results in 2010

**In the meantime the experiments are getting ready for data.
Using cosmic rays to debug detector, align components, etc**



Conclusions

- The LHC era is (finally) about to begin
- We are looking forward to finding out what nature has in store for us

The End

Interim Summary Report on the analysis of the 19th September 2008 incident at the LHC

Incident during powering

The magnet circuits in the seven other sectors of the LHC had been fully commissioned to their nominal currents (corresponding to beam energy of 5.5 TeV) before the first beam injection on 10 September 2008. For the main dipole circuit, this meant a powering in stages up to a current of 9.3 kA. The dipole circuit of sector 3-4, the last one to be commissioned, had only been powered to 7 kA prior to 10 September 2008. After the successful injection and circulation of the first beams at 0.45 TeV, commissioning of this sector up to the 5.5 TeV beam energy level was resumed as planned and according to established procedures.

On 19 September 2008 morning, the current was being ramped up to 9.3 kA in the main dipole circuit at the nominal rate of 10 A/s, when at a value of 8.7 kA, a resistive zone developed in the electrical bus in the region between dipole C24 and quadrupole Q24. The first evidence was the appearance of a voltage of 300 mV detected in the circuit above the noise level: the time was 11:18:36 CEST. No resistive voltage appeared on the dipoles of the circuit, individually equipped with quench detectors with a detection sensitivity of 100 mV each, so that the quench of any magnet can be excluded as initial event. After 0.39 s, the resistive voltage had grown to 1 V and the power converter, unable to maintain the current ramp, tripped off at 0.46 s (slow discharge mode). The current started to decrease in the circuit and at 0.86 s, the energy discharge switch opened, inserting dump resistors in the circuit to produce a fast power abort. In this sequence of events, the quench detection, power converter and energy discharge systems behaved as expected.

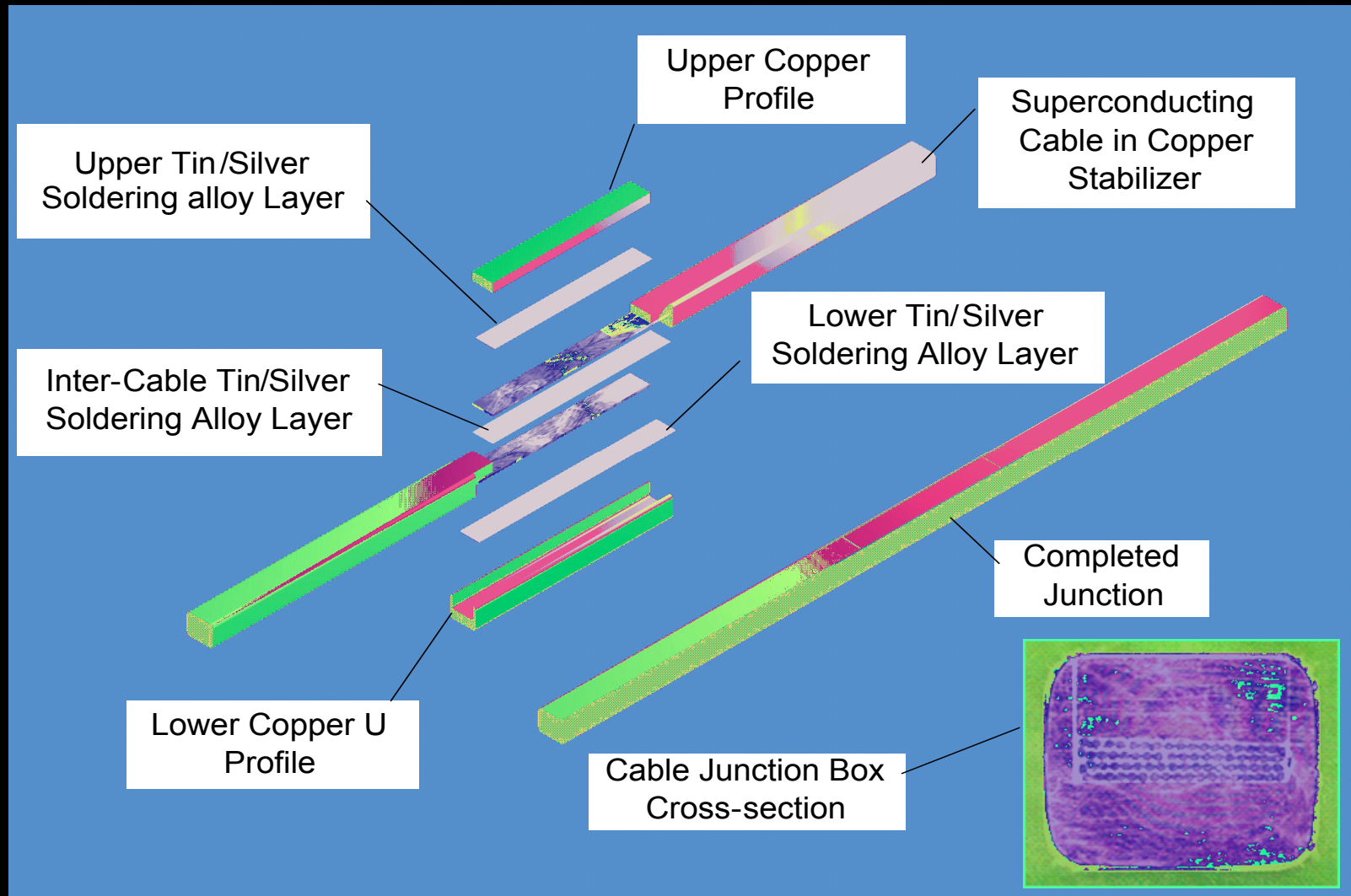
Interim Summary Report on the analysis of the 19th September 2008 incident at the LHC

Sequence of events and consequences

Within the first second, an electrical arc developed and punctured the helium enclosure, leading to release of helium into the insulation vacuum of the cryostat.

The spring-loaded relief discs on the vacuum enclosure opened when the pressure exceeded atmospheric, thus relieving the helium to the tunnel. They were however unable to contain the pressure rise below the nominal 0.15 MPa absolute in the vacuum enclosures of subsector 23-25, thus resulting in large pressure forces acting on the vacuum barriers separating neighboring subsectors, which most probably damaged them. These forces displaced dipoles in the subsectors affected from their cold internal supports, and knocked the Short Straight Section cryostats housing the quadrupoles and vacuum barriers from their external support jacks at positions Q23, Q27 and Q31, in some locations breaking their anchors in the concrete floor of the tunnel. The displacement of the Short Straight Section cryostats also damaged the “jumper” connections to the cryogenic distribution line, but without rupture of the transverse vacuum barriers equipping these jumper connections, so that the insulation vacuum in the cryogenic line did not degrade.

Busbar splice



QQBI.27R3



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