The Discovery of the Higgs Boson
The Final Missing Piece?

Markus Klute (MIT)
October 11th, 2012

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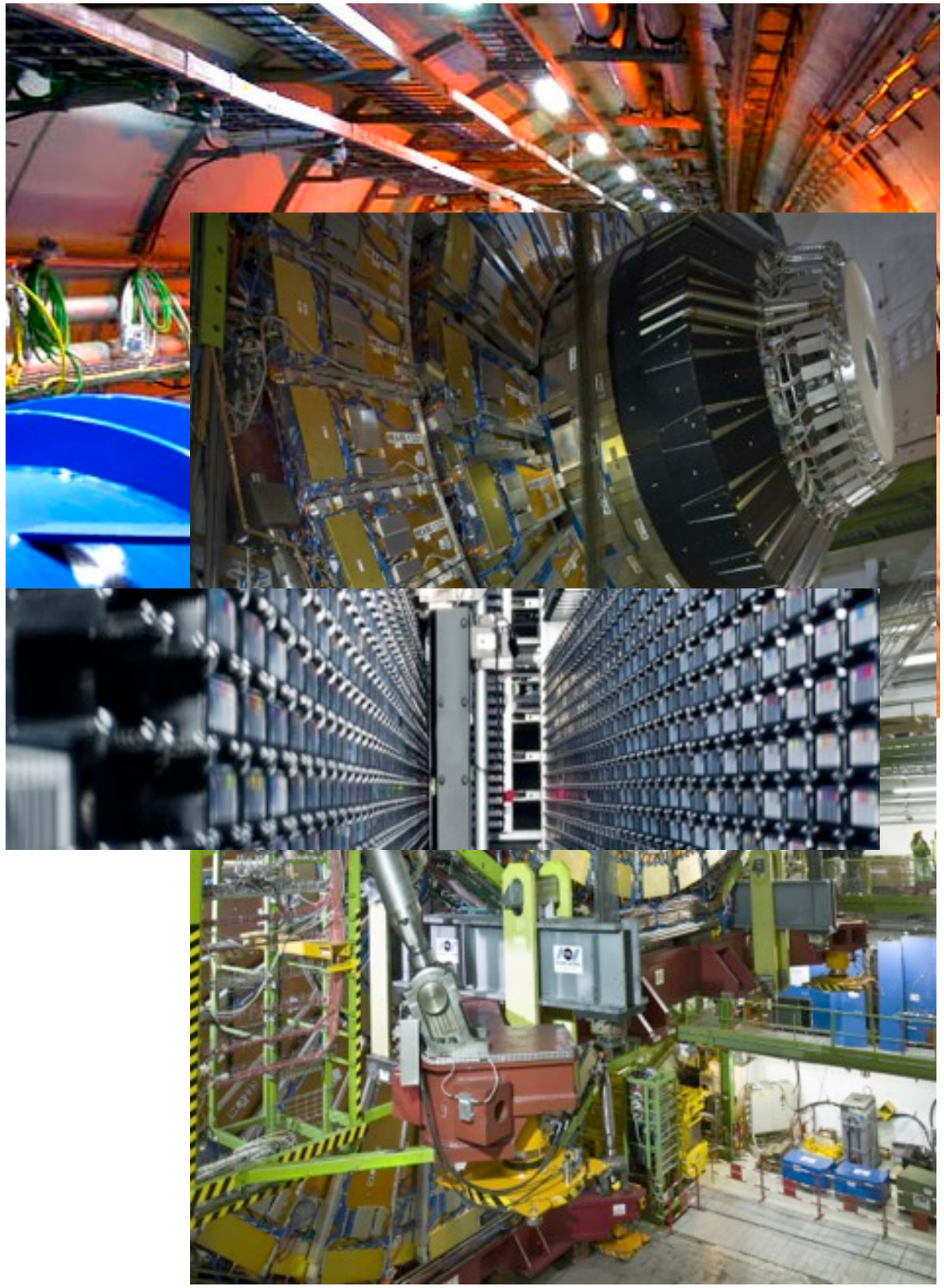

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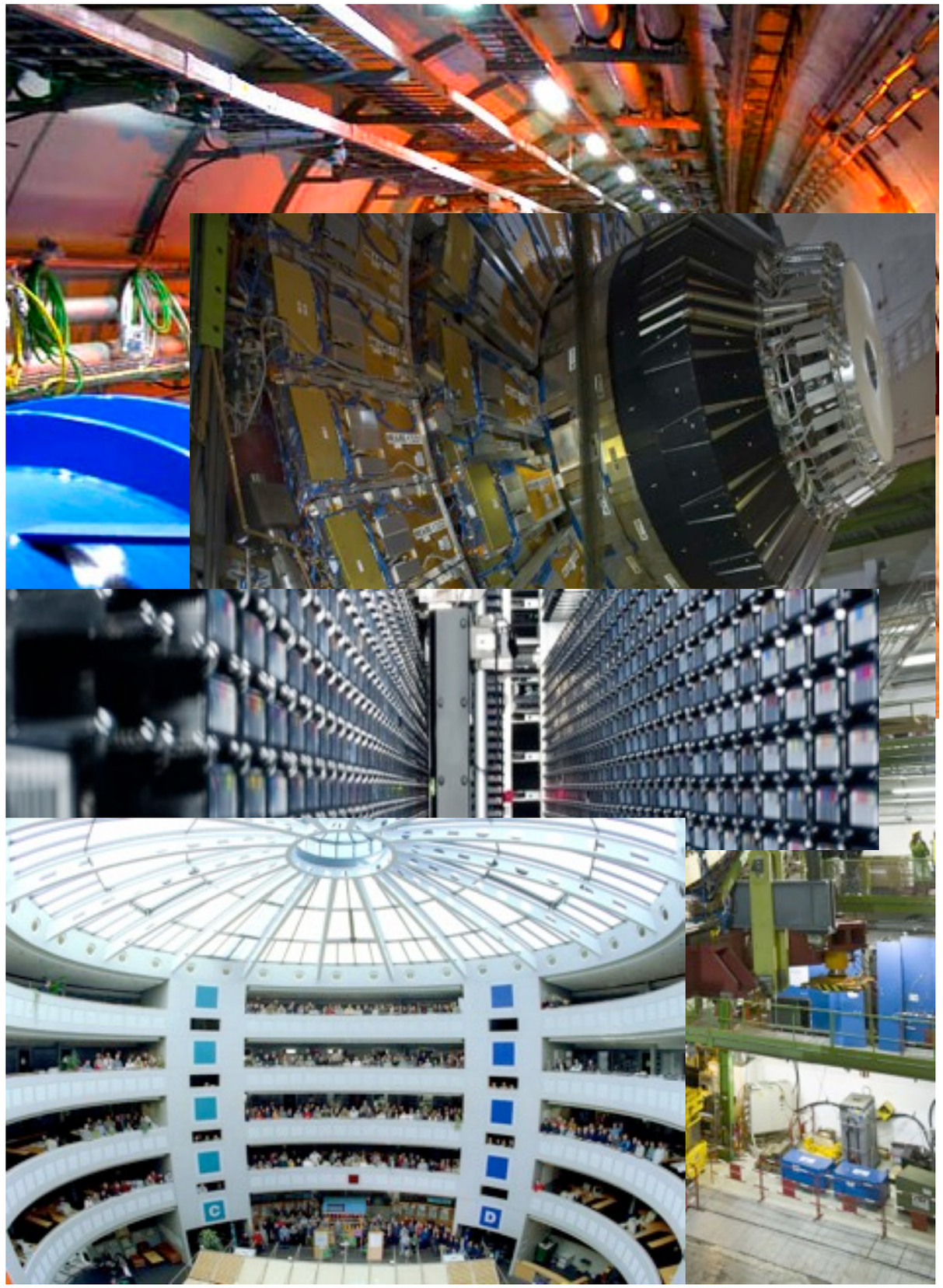
- **Extreme Computing:** to collect, distribute and analyze the vast amount of data produced
- **People:** thousands of scientist, engineers, to design, build and operate the complex machines and to extract physics



Experimental Approach

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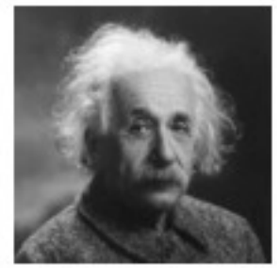
Einstein

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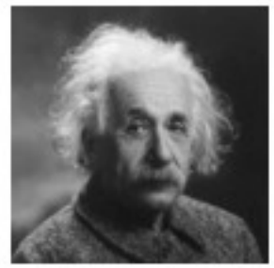
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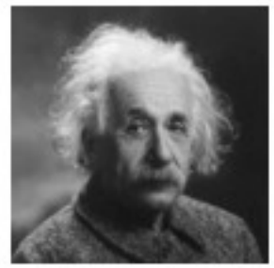

Einstein


Boltzmann

In a controlled environment of a laboratory

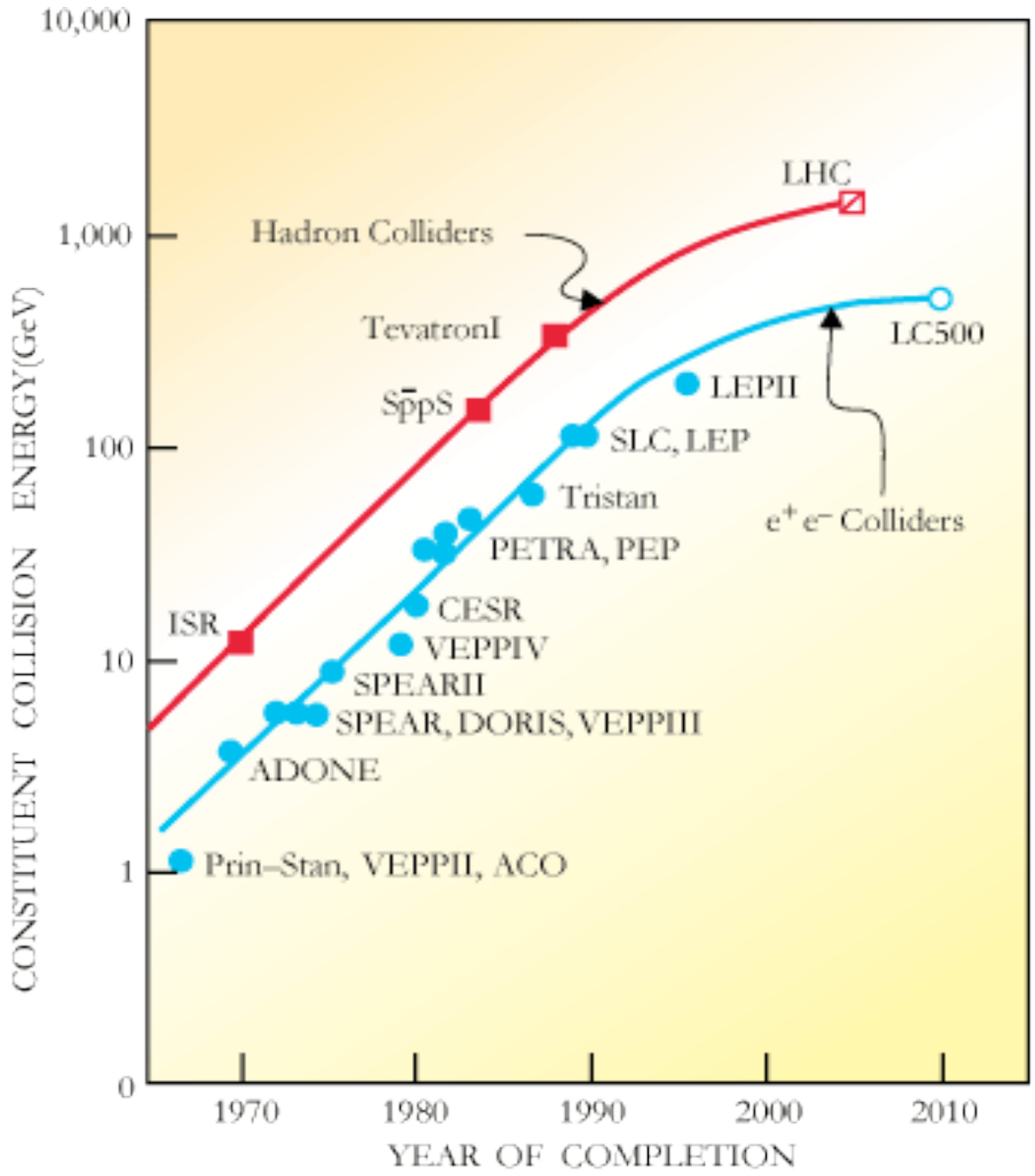
Accelerator Technology

"New directions in science are launched by new tools much more often than by new concepts

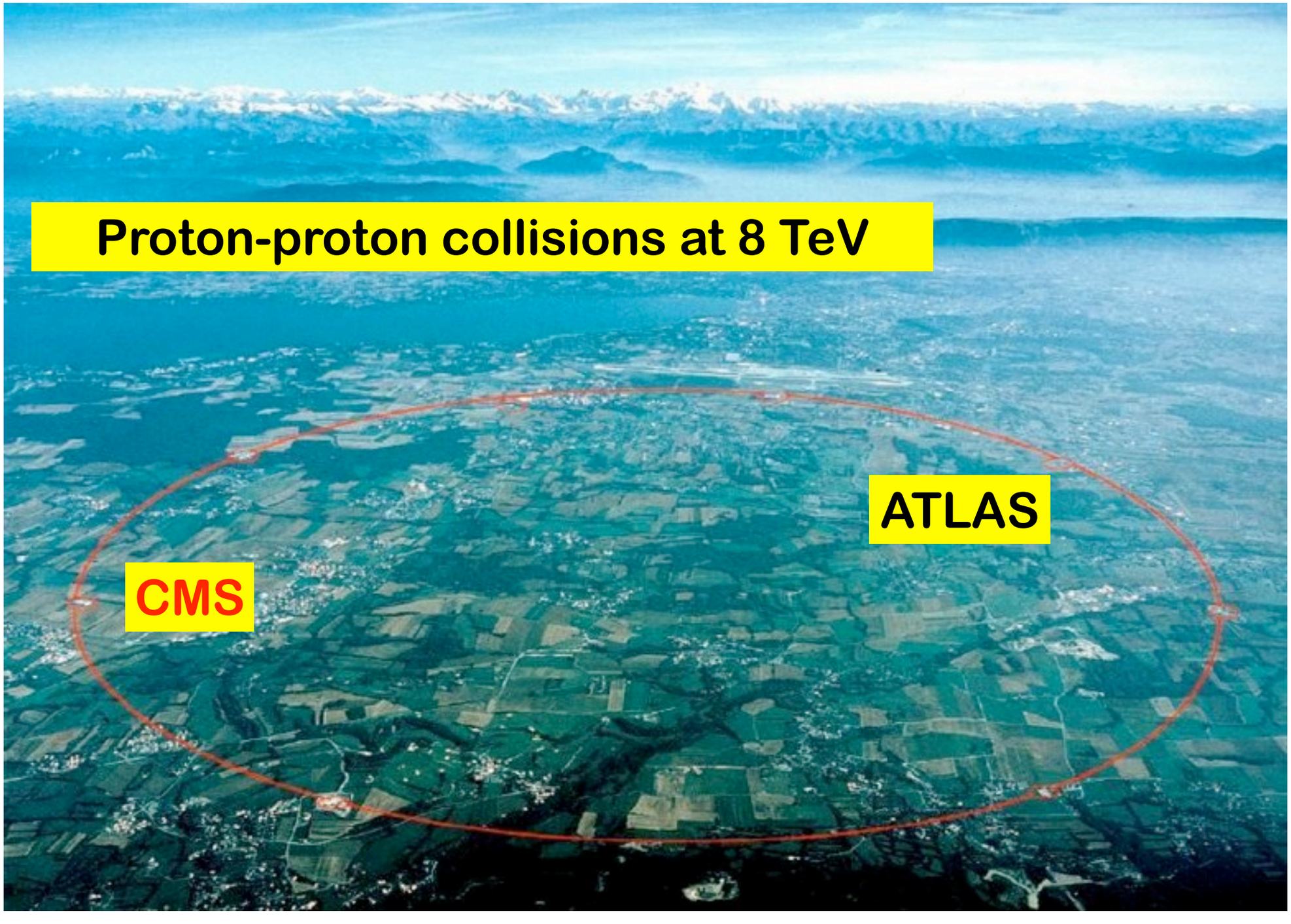
The effect of a concept-driven revolution is to explain old things in new ways

The effect of a tool-driven revolution is to discover new things that have to be explained" - Freeman Dyson

J.J. Thomson discovered the electron with a cathode ray tube (1887)



The Large Hadron Collider



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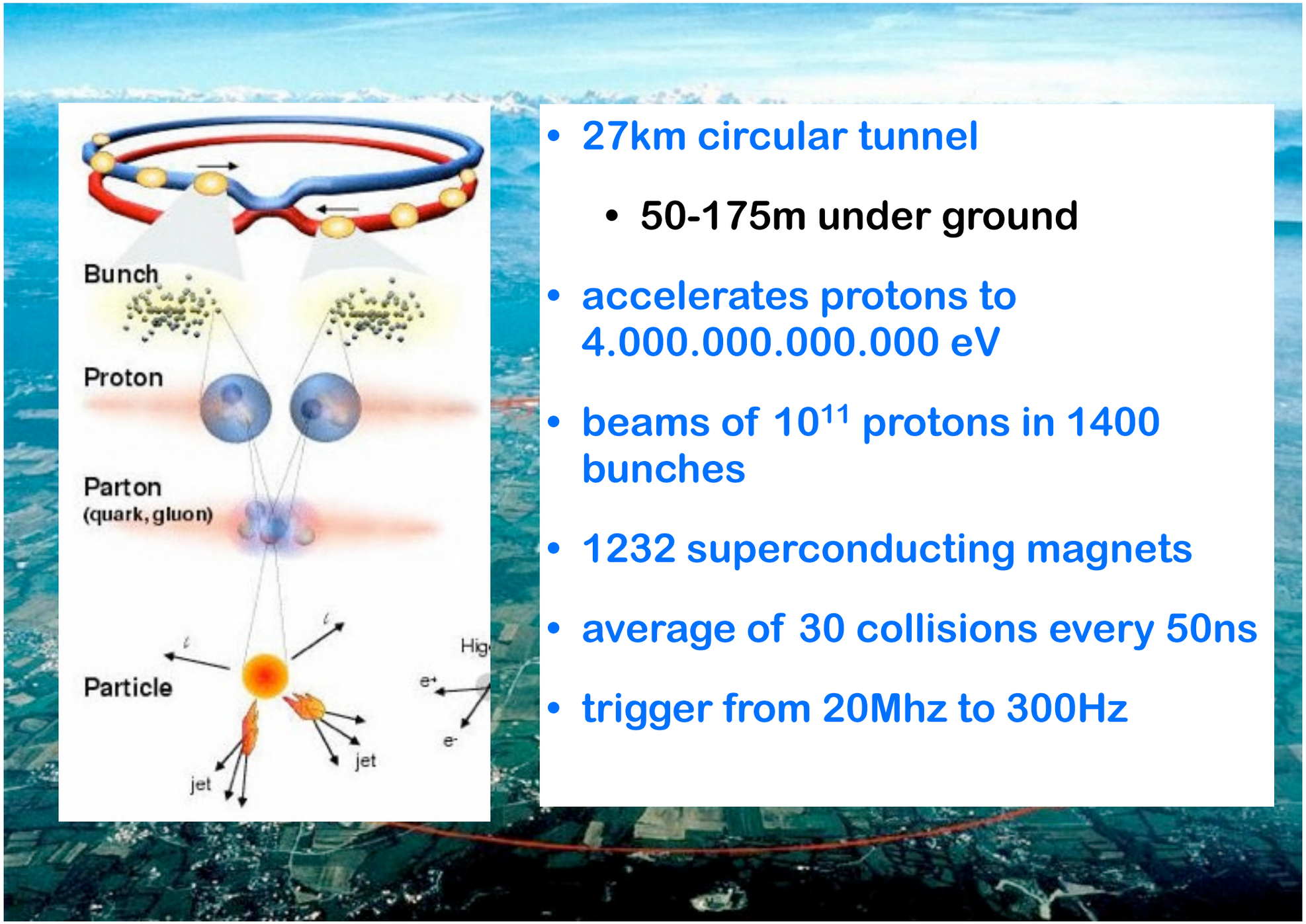
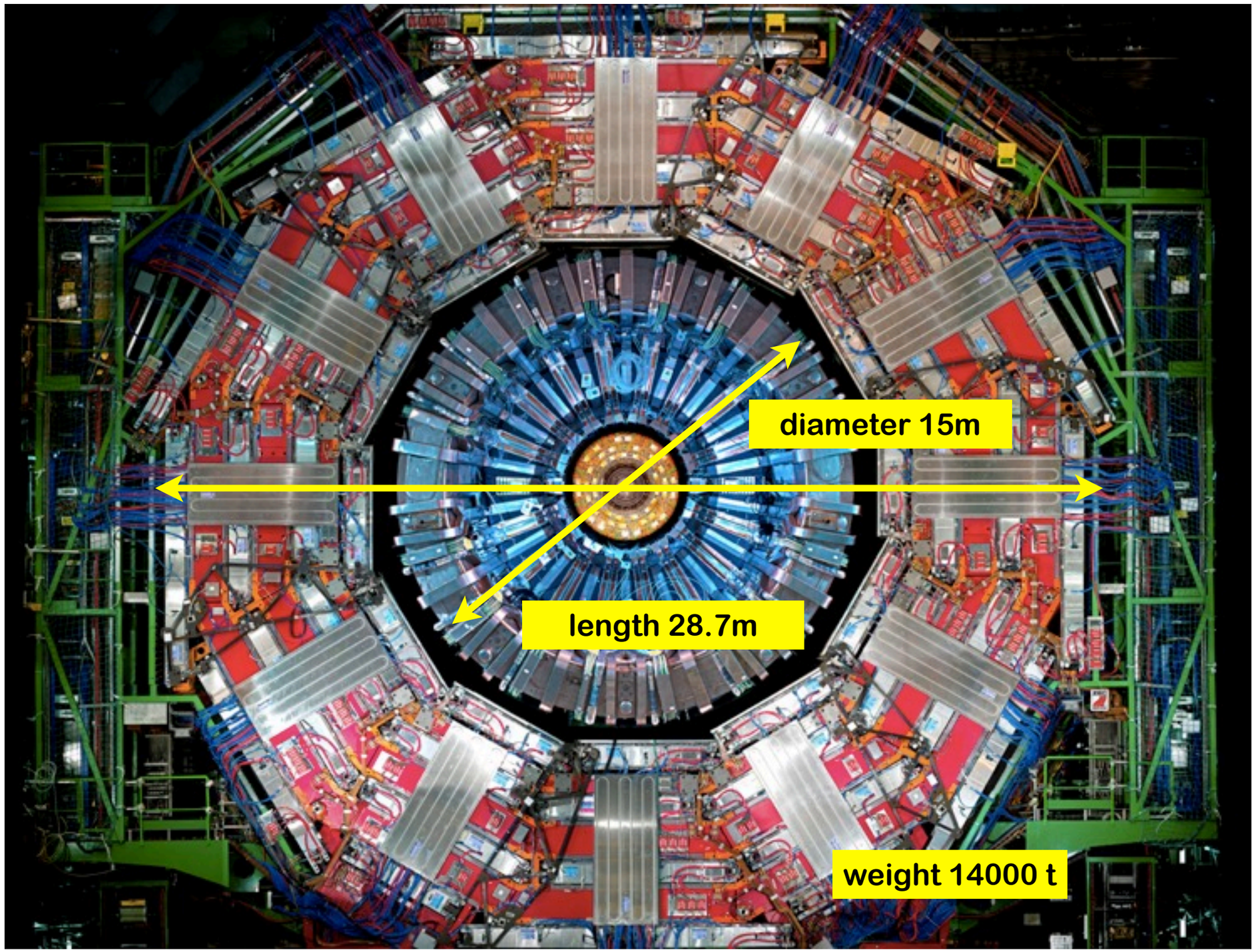
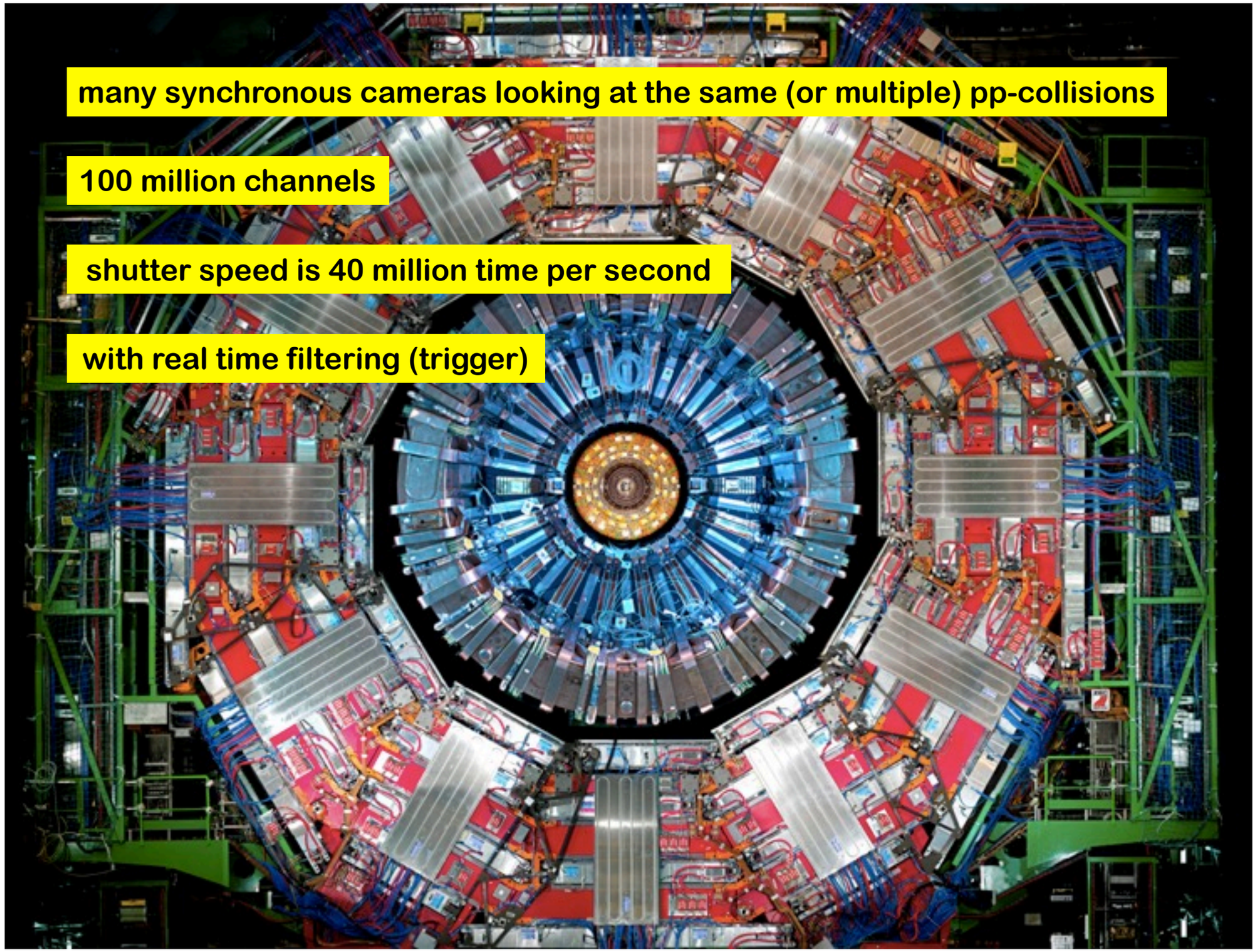


- 27km circular tunnel
  - 50-175m under ground
- accelerates protons to 4.000.000.000.000 eV
- beams of 10^{11} protons in 1400 bunches
- 1232 superconducting magnets
- average of 30 collisions every 50ns
- trigger from 20Mhz to 300Hz

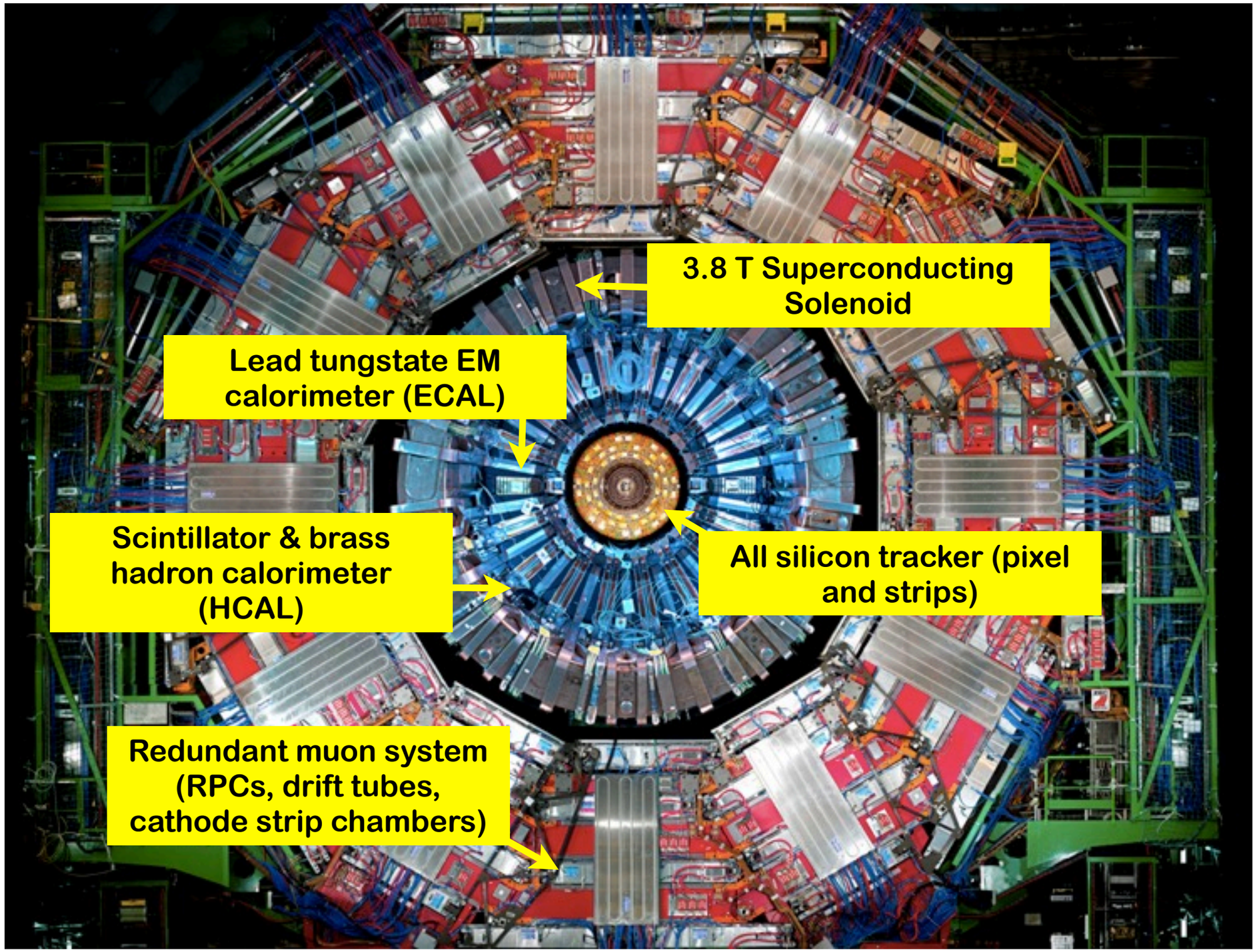
The CMS detector - dimensions



The CMS detector - 100 mega pixel camera



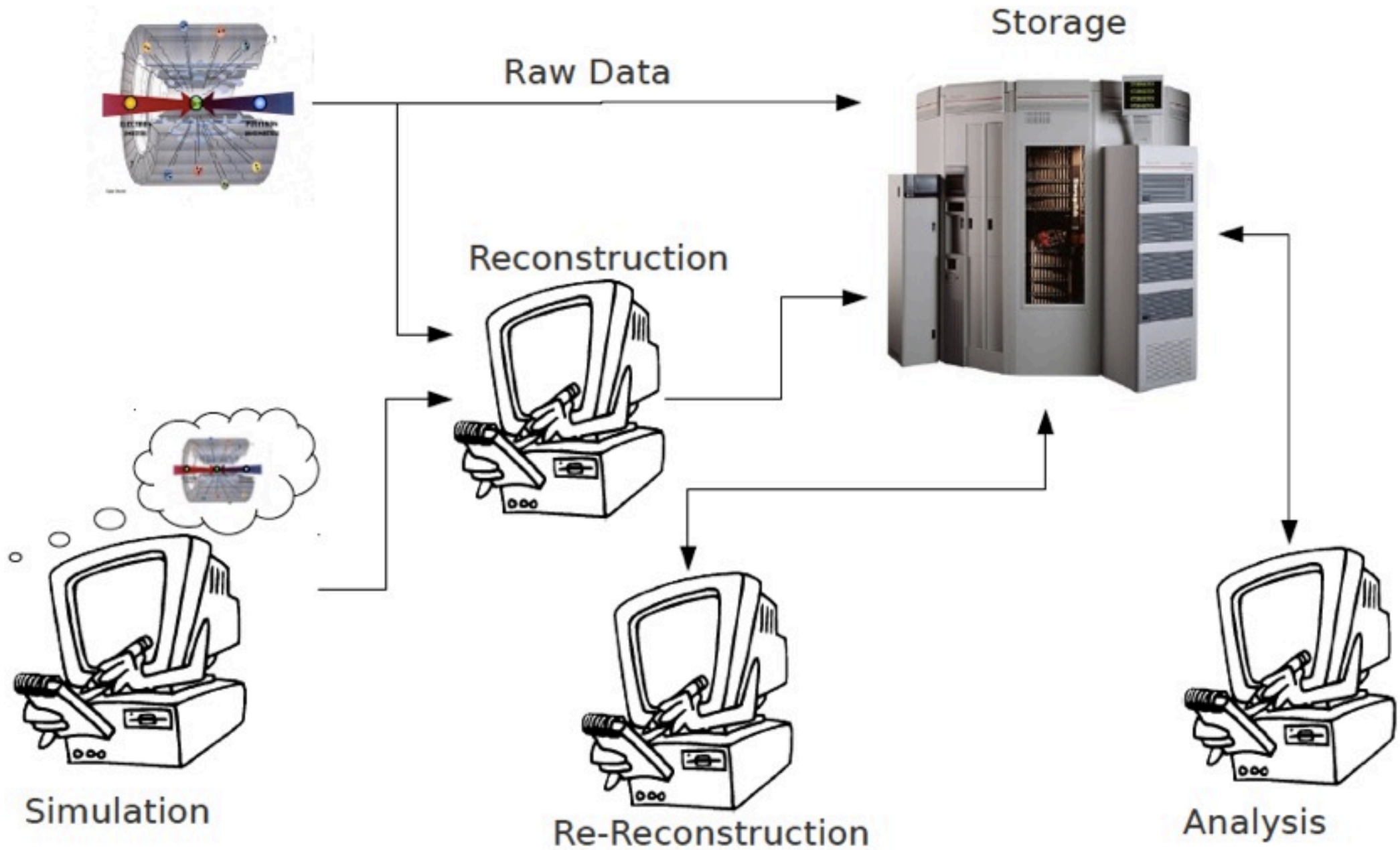
The CMS detector - components



CMS detector - construction (2000)

CMS detector - cathedral of science (2004)

Computing - data flow



People

- 3200 scientists and engineers
- 39 countries*
- 420 PhD physicists
- 800 graduate students
- MIT is among the largest university groups

the sun never sets on CMS

MIT Higgs Group (PPC)

Faculty


Christoph Paus


Steve Nahn


Markus Klute

Research Scientist & PostDoc









now faculty at
North Western

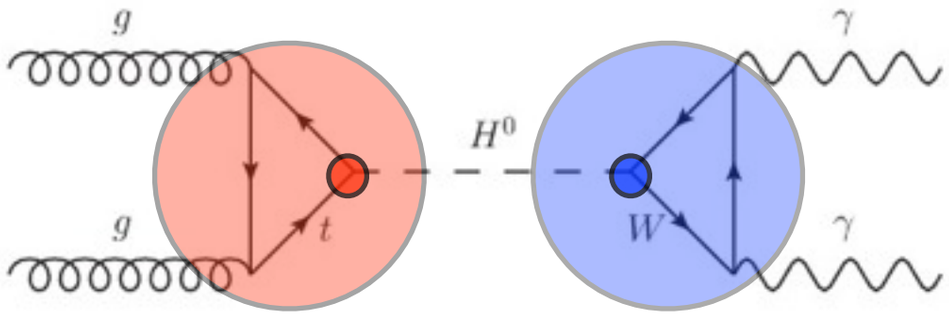
Graduate Students

•	Phil Harris CERN fellow	2005-2011	•	Josh Bendavid Marie-Curie fellow at CERN	2007-2012
•	Matt Rudolph Toronto	2005-2011	•	Valentina Dutta	2007-2013
•	Pieter Everaerts UCLA	2006-2011	•	Matthew Chan	2008-2013
•	Si Xie CalTec	2006-2012	•	Duncan Ralph	2009-2013
•	Kevin Sung North Western	2006-2012	•	Mingming Yang	2009
			•	Aram Apyan	2011
			•	Andrew Levin	2011

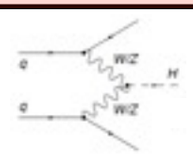
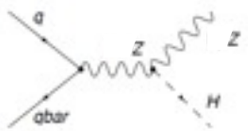
Undergrads

7 MIT undergraduates at CERN Summer 2012. 27 worked with PPC since 2009

SM Higgs boson footprint



m_H = 125 GeV

Process	Diagram	Cross section [fb]	Unc. [%]
gluon-gluon fusion		19520	15
vector boson fusion		1578	3
WH		697	4
ZH		394	5
ttH		130	15

m_H = 125 GeV

Decay	BR [%]	Unc. [%]
bb	57.7	3.3
ττ	6.32	5.7
cc	2.91	12.2
μμ	0.022	6.0
WW	21.5	4.3
gg	8.57	10.2
ZZ	2.64	4.3
γγ	0.23	5.0
Zγ	0.15	9.0
ΓH [MeV]	4.07	4.0

The roadmap to discovery

- from a CMS meeting April 3rd. First 8 TeV collisions April 5th.

Core dates

pre-approval	Jun 4-8
cond. GL until	Jun 18
box opening	Jun 19
approvals	Jun 25-28

Additional dates

physics days	Apr 16-17
analysis review	May 15-16

Data cutoffs

pre-approvals	May 18
approval/reload	Jun 15

April

Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16 phys. days	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

May

Sun	Mon	Tue	Wed	Thu	Fri	Sat
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15 review	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

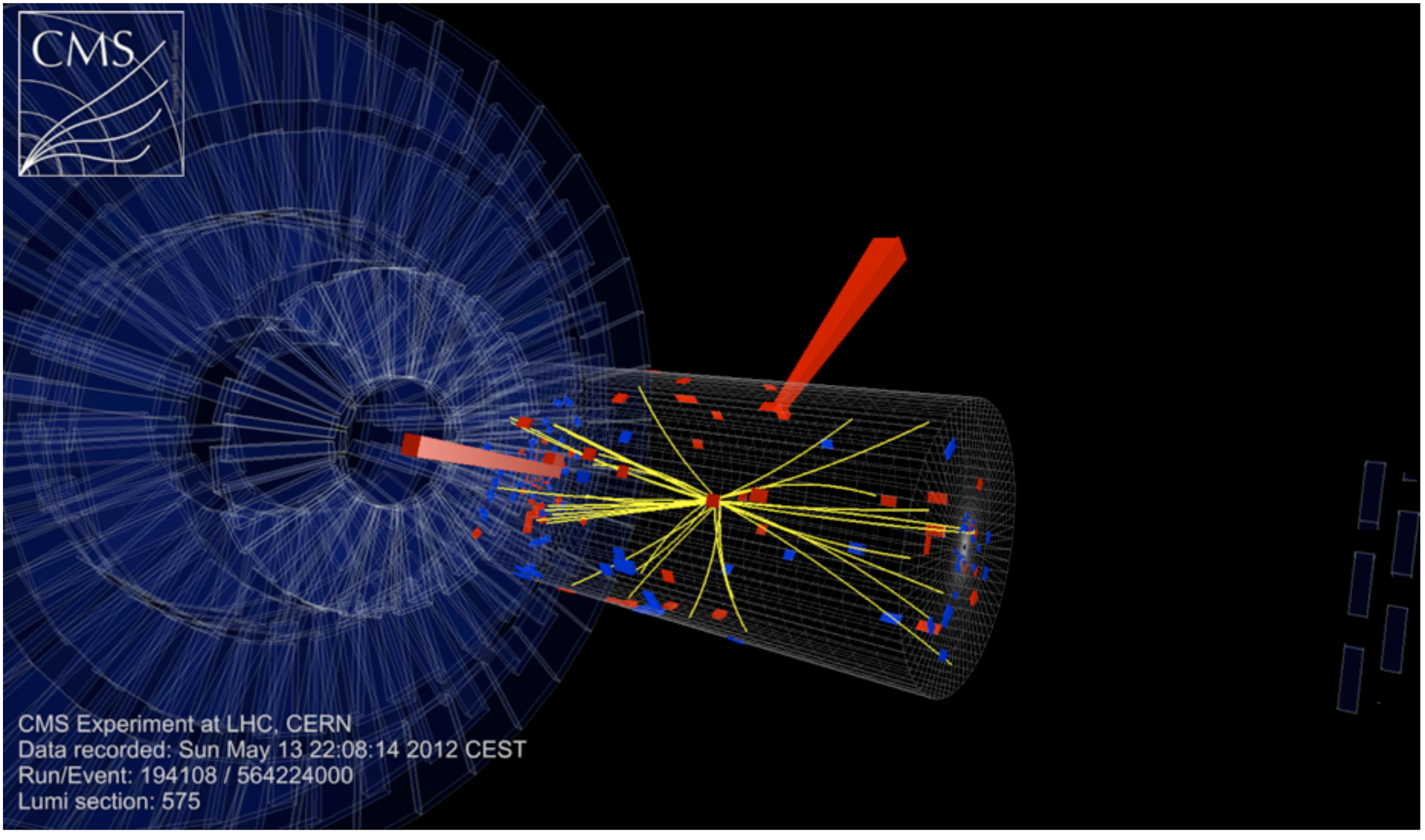
June

Sun	Mon	Tue	Wed	Thu	Fri	Sat
					1	2
3	4 pre-appr.	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25 CMS week	26 approvals	27	28	29	30

July

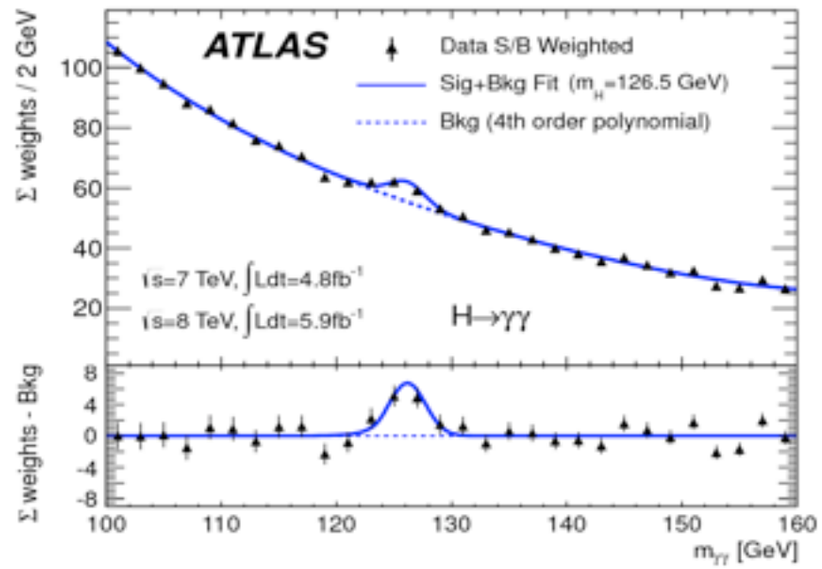
Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	2	3	4 ICHEP	5	6	7
8	9	10	11	12	13	14

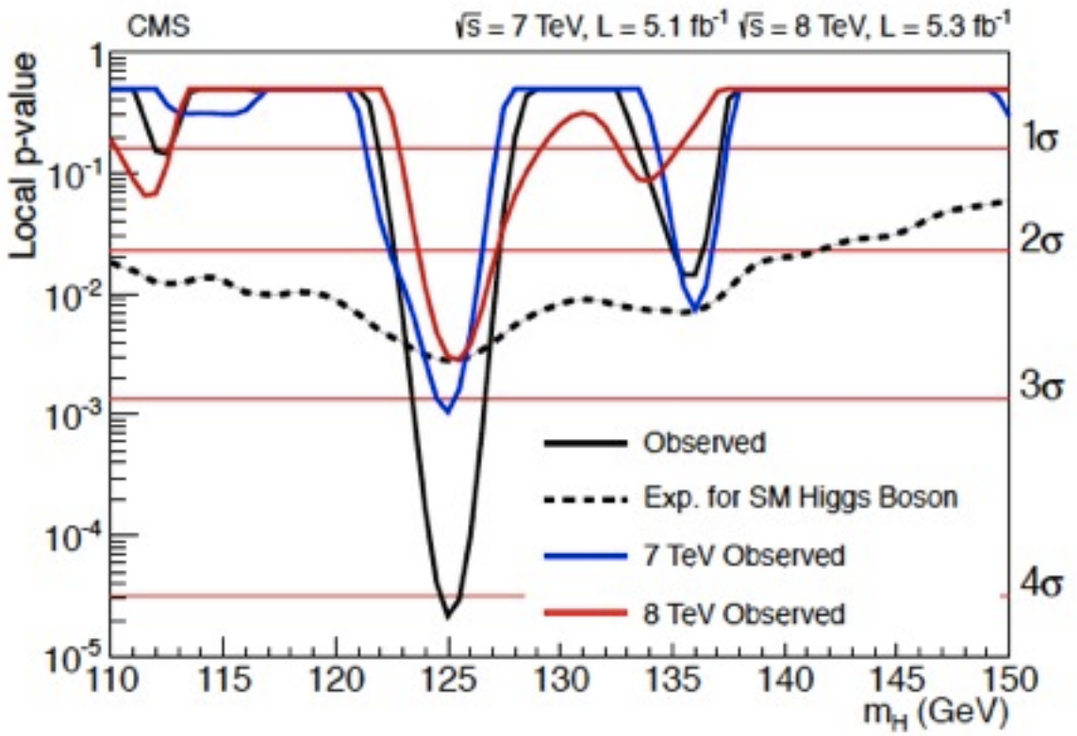
Discovery channel: H → γγ

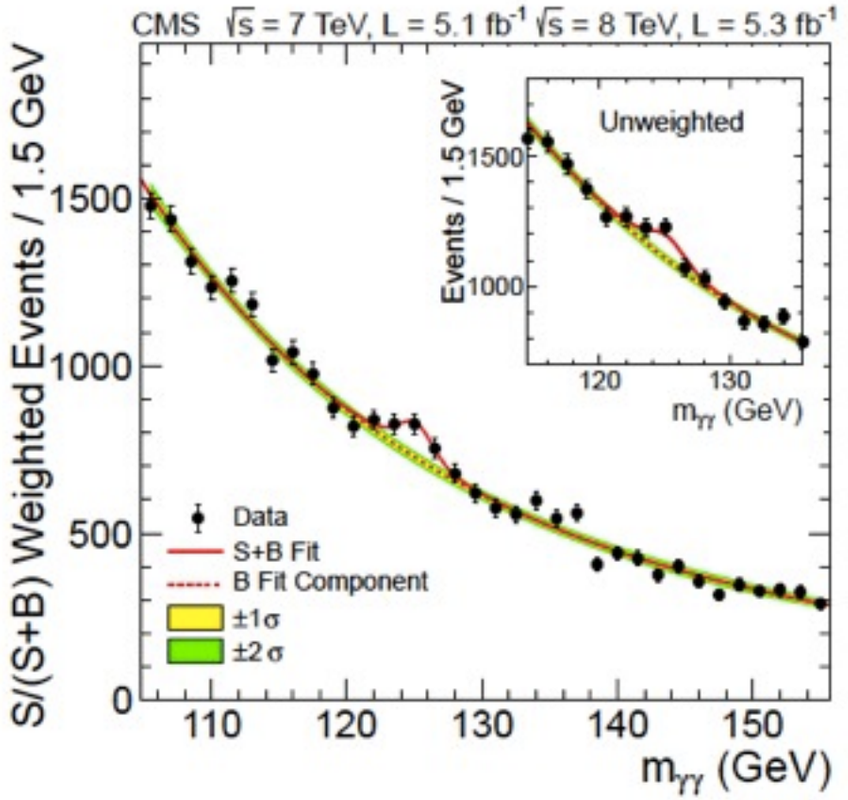


Discovery channel: H → γγ

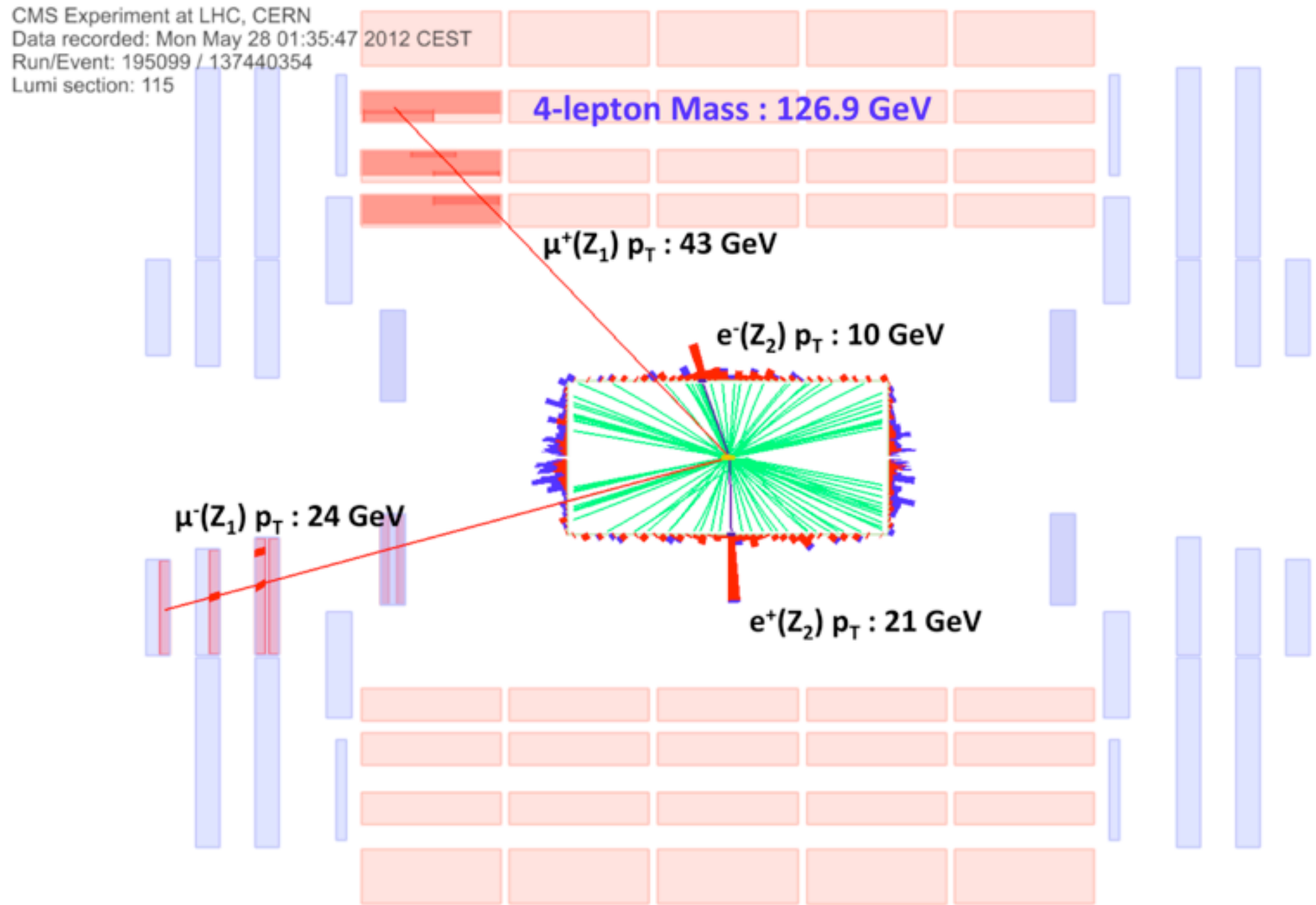
- Search for narrow resonance in di-photon mass spectrum
- Events categorized by mass resolution, event kinematics and primary vertex probability
- Consistent in 7 and 8 TeV data
- Consistent between ATLAS and CMS
- Local significance > 4 σ
- Signal strength 1.9 ± 0.5 (ATLAS) and 1.6 ± 0.4 (CMS)





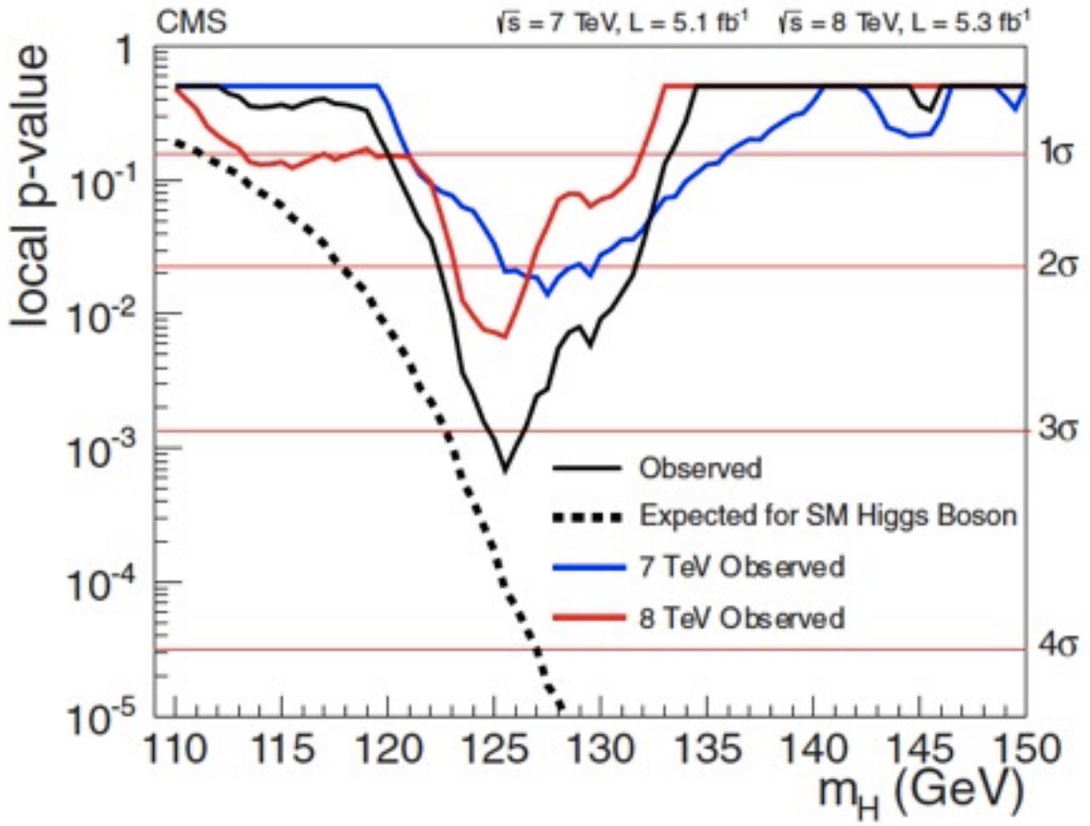


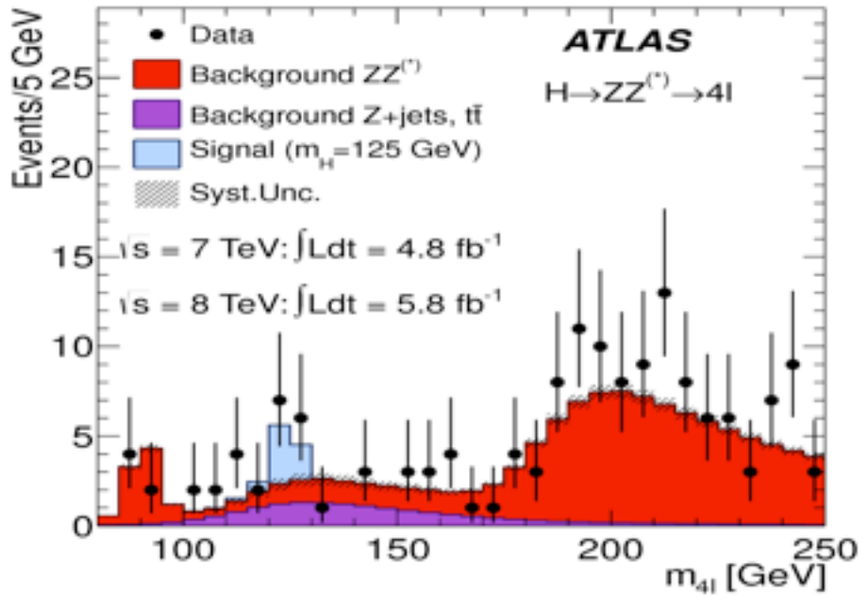
Discovery channel: H → ZZ → 4l

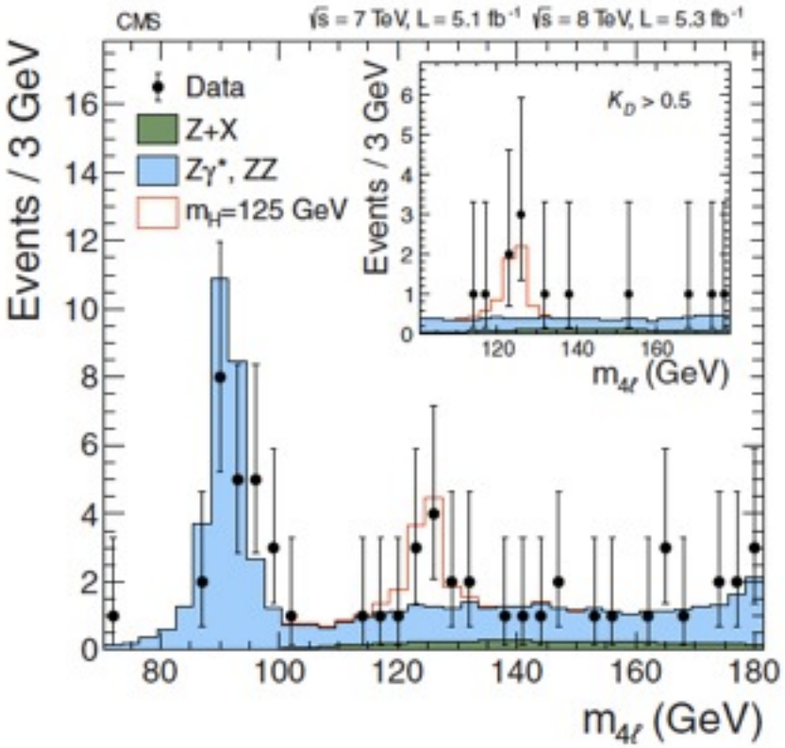


Discovery channel: H → ZZ → 4l

- Search for narrow resonance in 4 lepton mass spectrum
- Consistent in 7 and 8 TeV data
- Consistent between ATLAS and CMS
- Local significance > 3σ

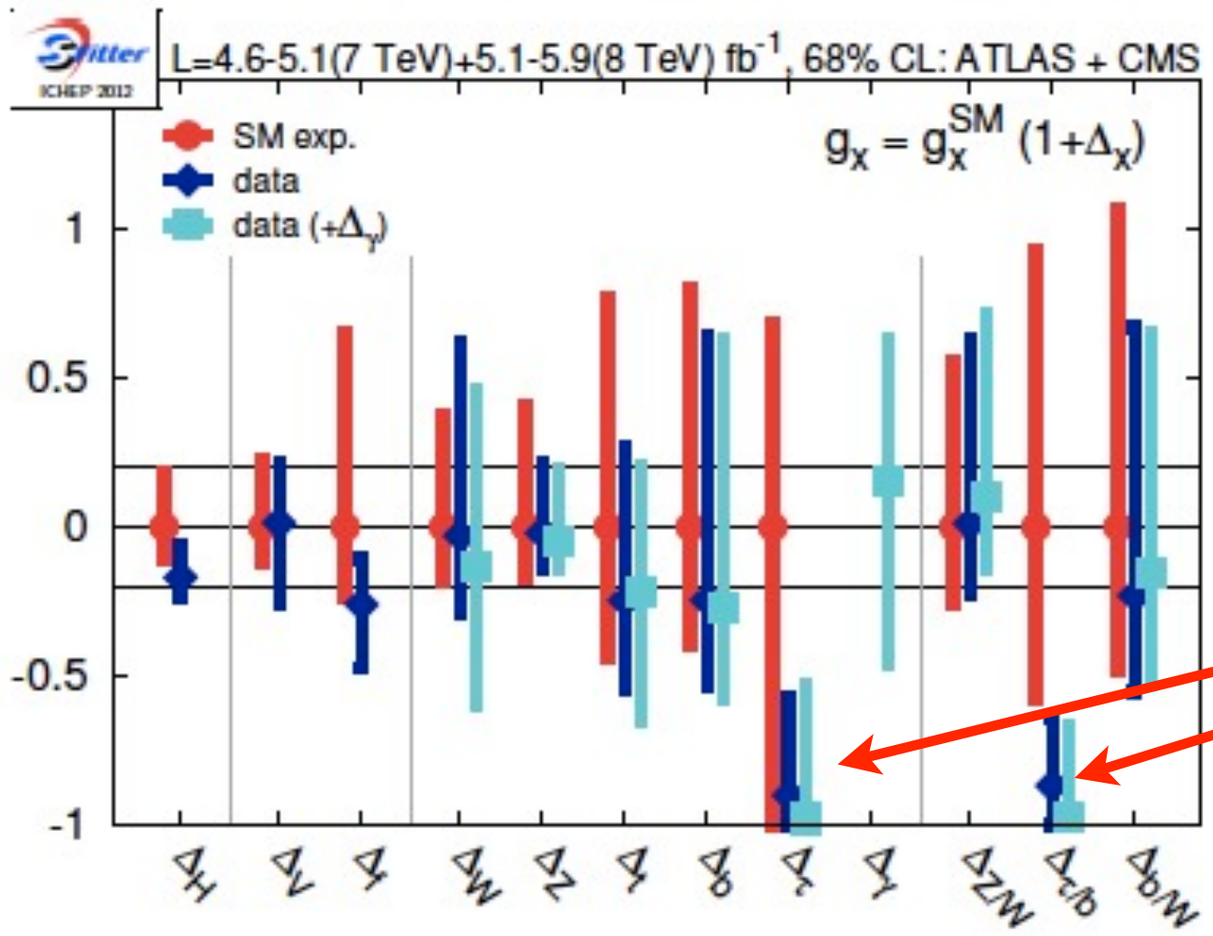






Compatibility with SM Higgs

- **Investigated by serval groups combining ATLAS and CMS results**



Zeppenfeld et al. PRD 62 (2000) 013009
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Giudice, Grojean, Pomarol, Rattazzi, JHEP 0706 (2007) 045
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Carmi, Falkowski, Kuflik, Volansky, JHEP 1207 (2012) 136
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Ellis, You JHEP 1206 (2012) 140
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Low, Lykken, Shaughnessy, arXiv:1207.1093
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Baglio, Djouadi, Godbole, PLB 716 (2012) 203
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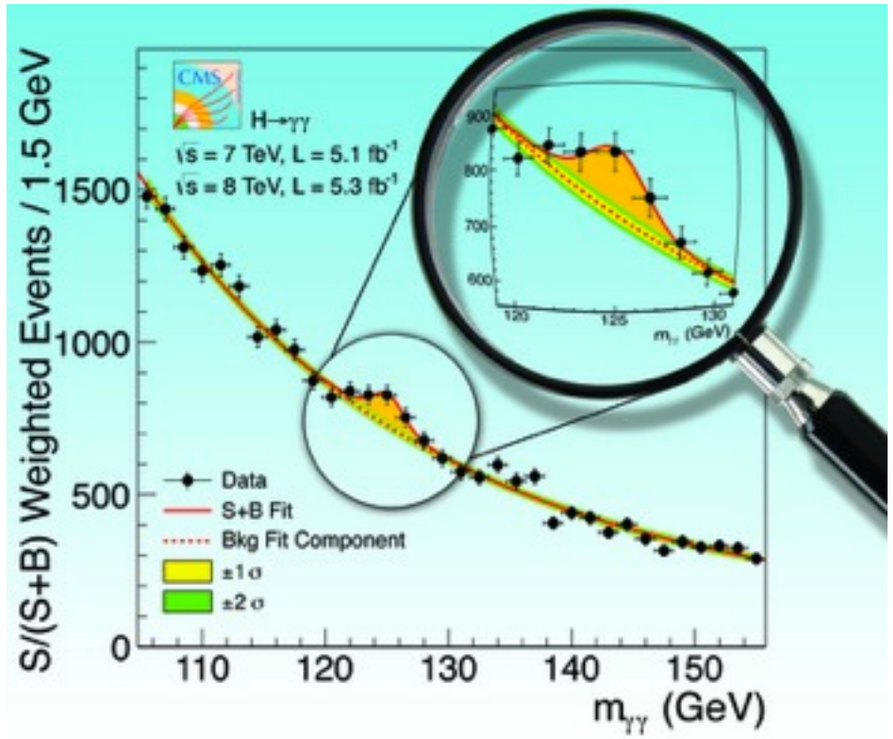
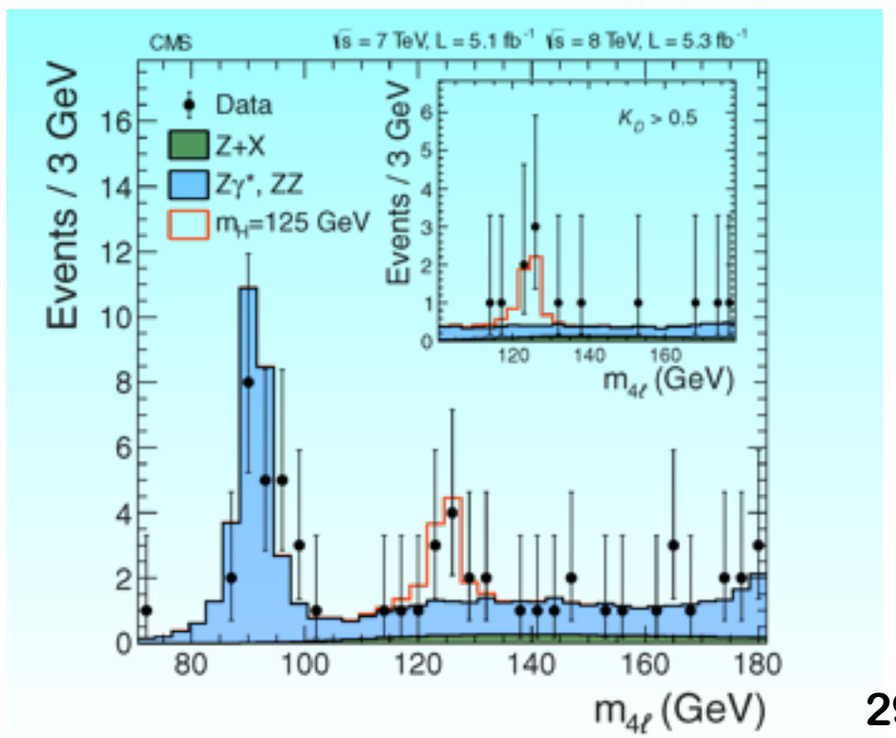
Espinosa, Grojean, Sanz, Trott, arXiv:1207.7355
Djouadi, arXiv:1208.3436

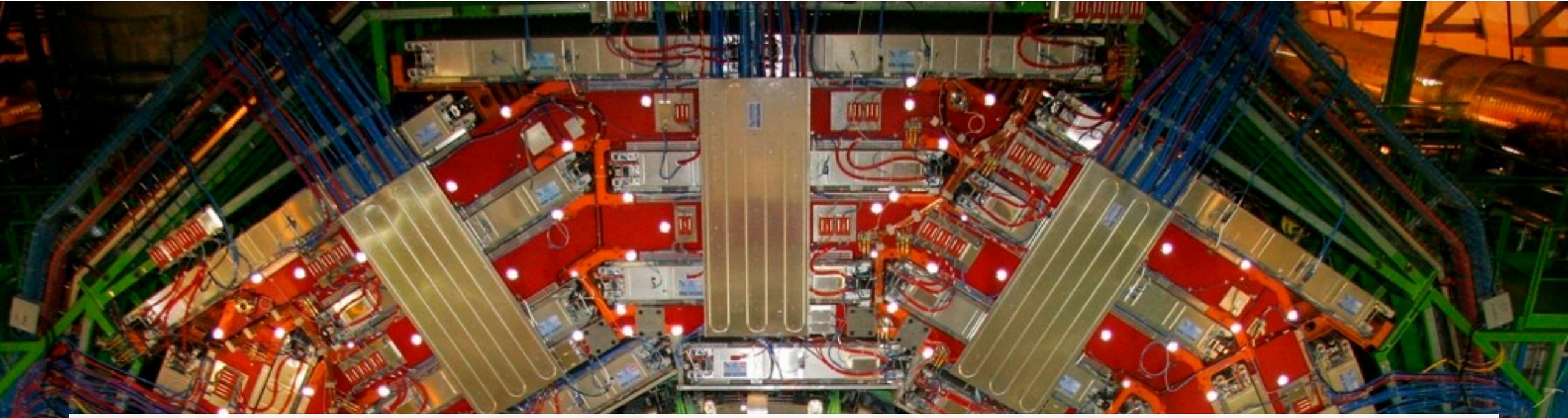
Tension in τ results

Summary

- **Observed new boson near 125 GeV with 5σ significance**
  - **mass: 125.3 ± 0.6 GeV**
  - **evidence in 4l and γγ channels**
  - **confirmed by ATLAS**
  - **consistent with SM Higgs boson**
- **Open question**
  - **is this the final missing piece?**
- **Finding answers**
  - **characterize new state (mass, J^{CP}, couplings)**
  - **continue search for physics beyond the standard model**



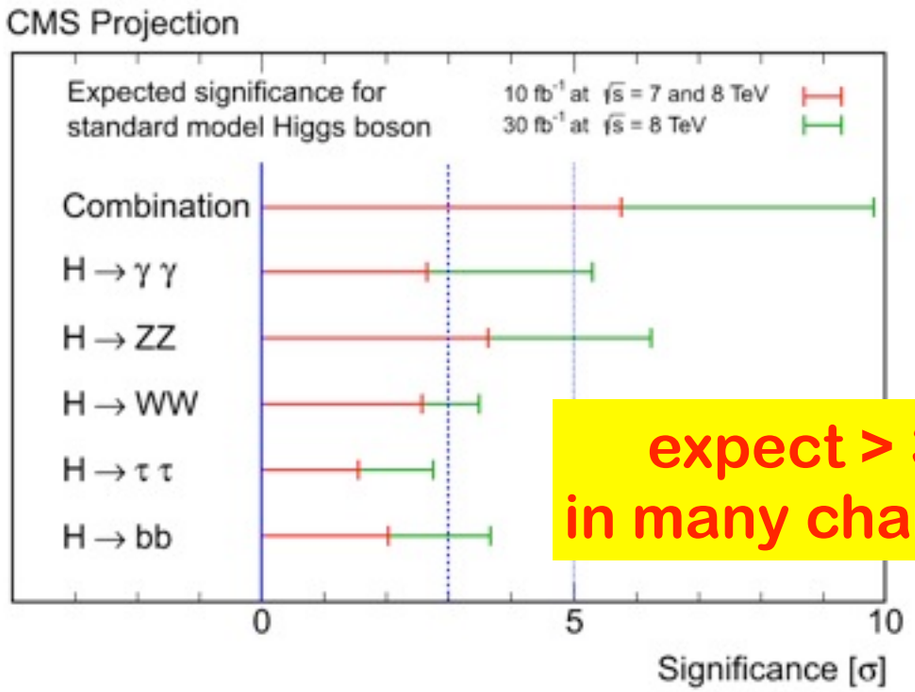




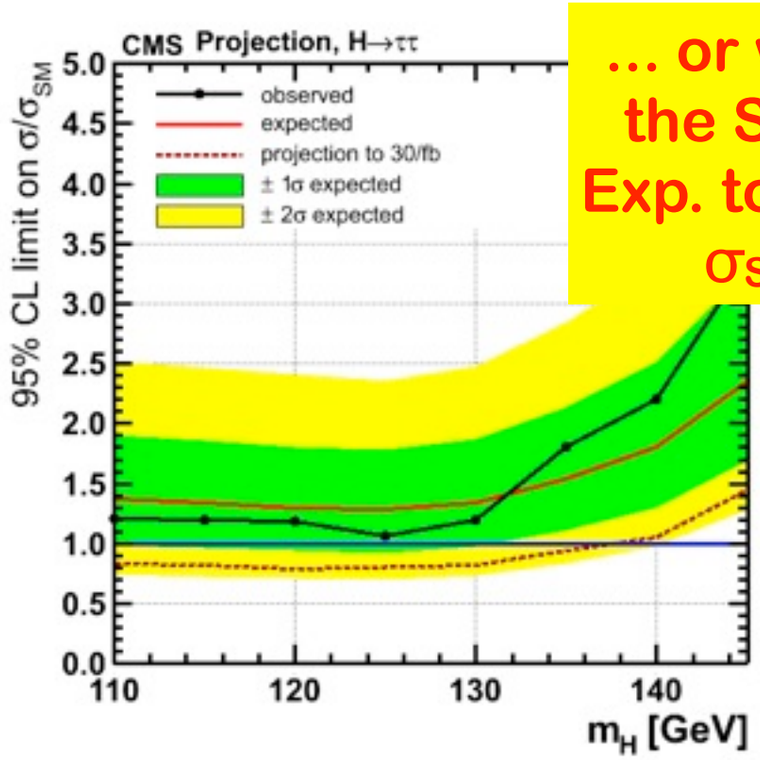
- First historic discovery made at the LHC
  - Observation of new boson near 125 GeV
    - ATLAS and CMS observed it independently
    - It behaves like the Standard Model Higgs boson
- Fantastic experience, for me personally and the MIT team, and a truly great moment for physics

What is next?

- Continue searches (hope for 30/fb at the end of 2012)
  - cover all possible production and decay channels
  - expand mass range
- Measure properties
  - what is the exact mass
  - measure JCP
    - spin-0 vs spin-2 (spin-1 is already excluded)
    - scalar vs pseudoscalar
  - decompose signal strength in coupling measurements
  - ratio measurements
- Beyond the SM Higgs searches
- Use Higgs as probe for new physics
- Combination with ATLAS results in 2013
- Increase of LHC energy to 13 TeV in 2015



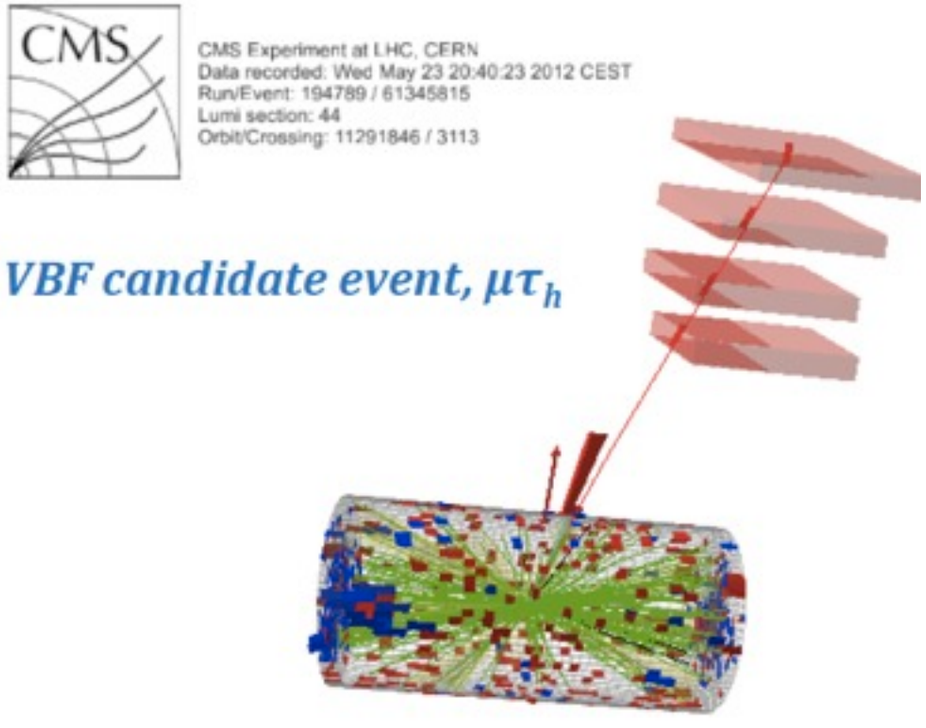
expect > 3σ in many channels



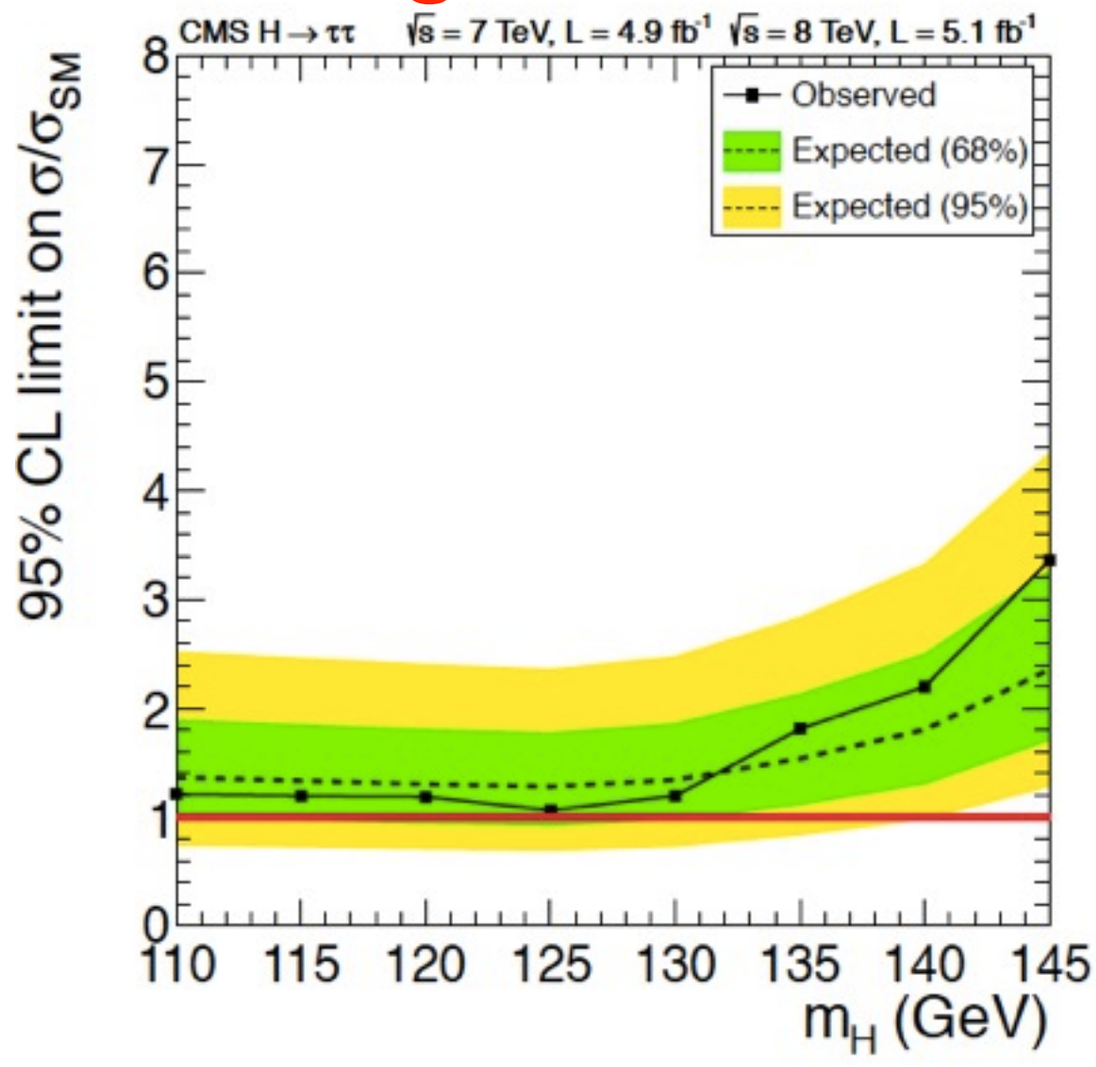
... or we challenge the SM with taus. Exp. to exclude 0.85 σ_{SM} 95% CL

Why is H→ ττ important?

- Large event yield
- Only probe of coupling to leptons
- Along with b-quark the only direct probe of coupling to fermions
- Potential to explore properties of new state: CP, spin, couplings
- Great potential to discover or constrain models beyond the SM: 4th fermion generation, supersymmetric models, etc.



No signal observed



Combination & Mass measurement

- Local significance: 5.0σ
- Best fit result: 0.87 ± 0.23
- Three high mass resolution channels included
  - ZZ → 4l
  - γγ untagged
  - γγ with di-jet tag
- Results are compatible within uncertainties
- Fit of the mass: M = 125.3 ± 0.6 GeV