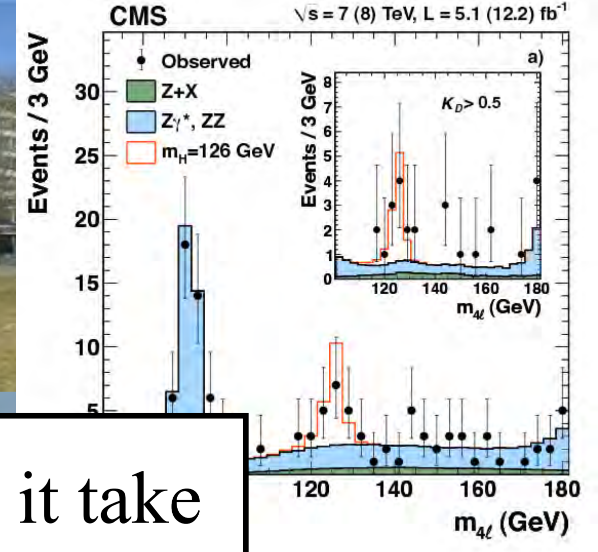

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The Higgs Boson and Big Science

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4 July 2012

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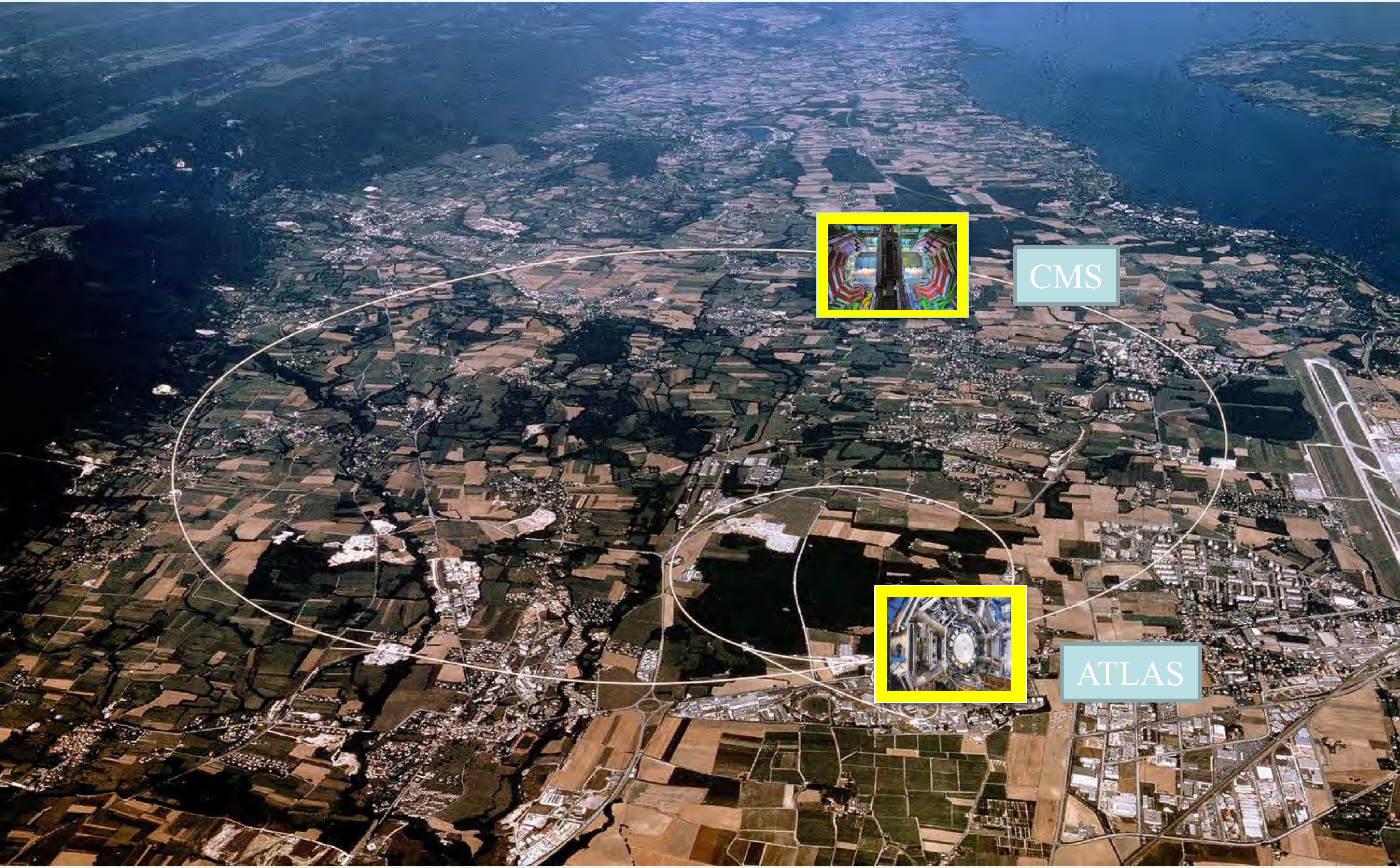
Two Experiments



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CERN-PH-EP/2012-220
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CMS-HIG-12-028

Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC

The CMS Collaboration

Abstract

Results are presented from searches for the standard model Higgs boson in proton-proton collisions at $\sqrt{s} = 7$ and 8 TeV in the Compact Muon Solenoid experiment at the LHC, using data samples corresponding to integrated luminosities of up to 5.1 fb^{-1} at 7 TeV and 5.3 fb^{-1} at 8 TeV. The search is performed in five decay modes: $\gamma\gamma$, ZZ, W^+W^-, $\tau^+\tau^-$, and $b\bar{b}$. An excess of events is observed above the expected background, with a local significance of 5.0 standard deviations, at a mass near 125 GeV, signalling the production of a new particle. The expected significance for a standard model Higgs boson of that mass is 5.8 standard deviations. The excess is most significant in the two decay modes with the best mass resolution, $\gamma\gamma$ and ZZ; a fit to these signals gives a mass of $125.3 \pm 0.4\,(\text{stat.}) \pm 0.5\,(\text{syst.})$ GeV. The decay to two photons indicates that the new particle is a boson with spin different from one.

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Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

ATLAS Collaboration *

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

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ABSTRACT

A search for the Standard Model Higgs boson in proton–proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012. Individual searches in the channels $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of $126.0 \pm 0.4\,(\text{stat}) \pm 0.4\,(\text{sys})$ GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.

1. Introduction

The Standard Model (SM) of particle physics [1–4] has been tested by many experiments over the last four decades and has

120–135 GeV; using the existing LHC constraints, the observed local significances for $m_H = 125$ GeV are 2.7σ for CDF [14], 1.1σ for DØ [15] and 2.8σ for their combination [16].

The previous ATLAS searches in 4.6–4.8 fb^{-1} of data at $\sqrt{s} =$

Discoveries are made by people, not by detectors.

CMS: Discovery courtesy of:

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Texas Tech University, Lubbock, USA

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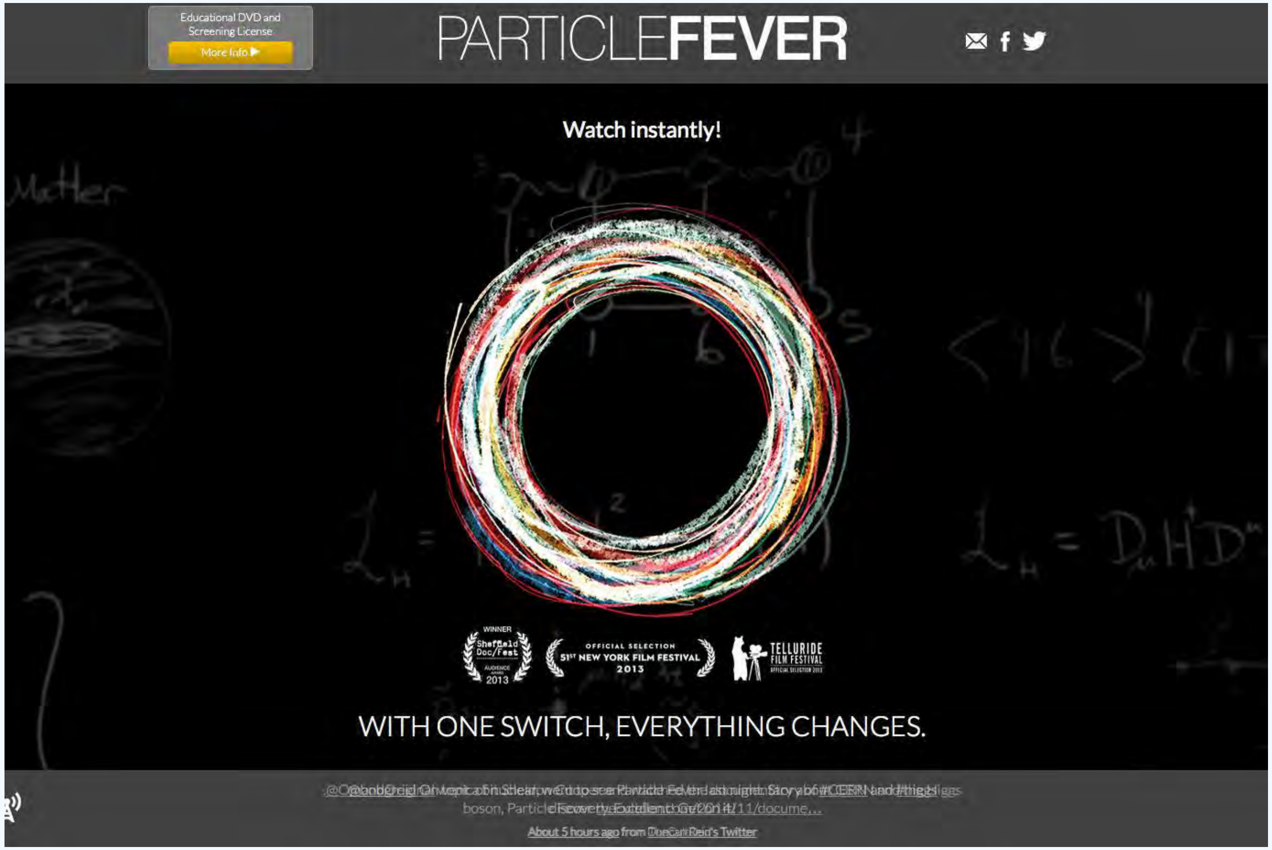
2892 authors from 168 institutions
This is just the CMS paper. There is a similar list for ATLAS.

Outline

- What is the Higgs boson?
- How do we know that it was created in proton-proton collisions at the Large Hadron Collider
- What do all those people actually do?

Particle Fever



Assistant Professor Alberto Belloni

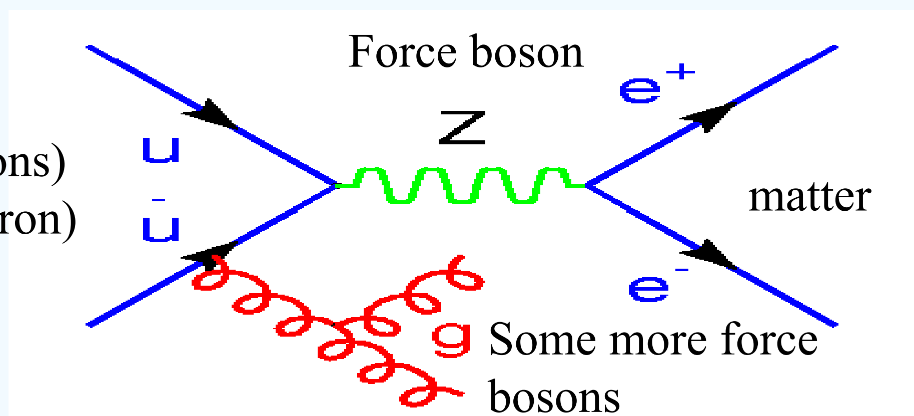
What is a Higgs Boson?

Before we talk about the Higgs, let's think about forces

Is it this?

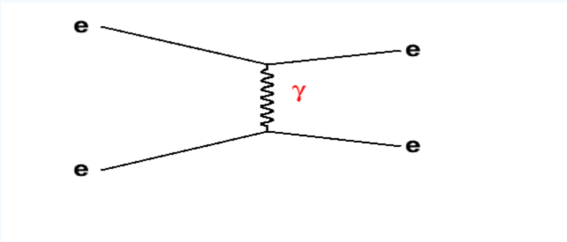
Particle physicists think of it as this:

Matter:
Quarks (protons)
leptons (electron)



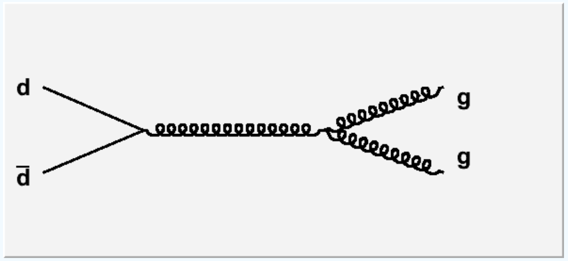
Only four of them, each with a "boson"

Electricity and Magnetism (QED)

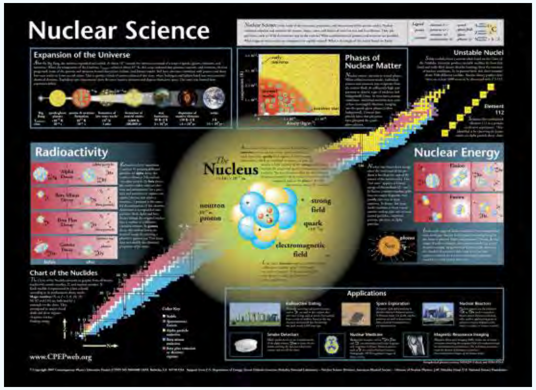


photon

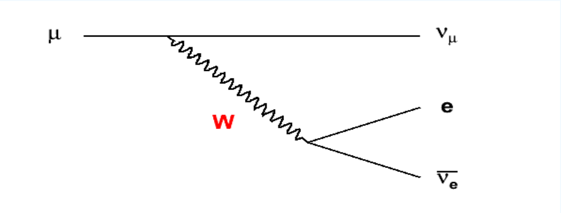
Strong Force (QCD)



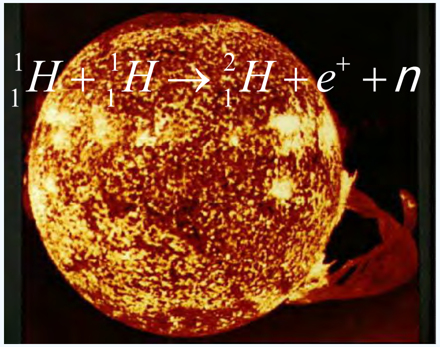
gluon



Weak Force



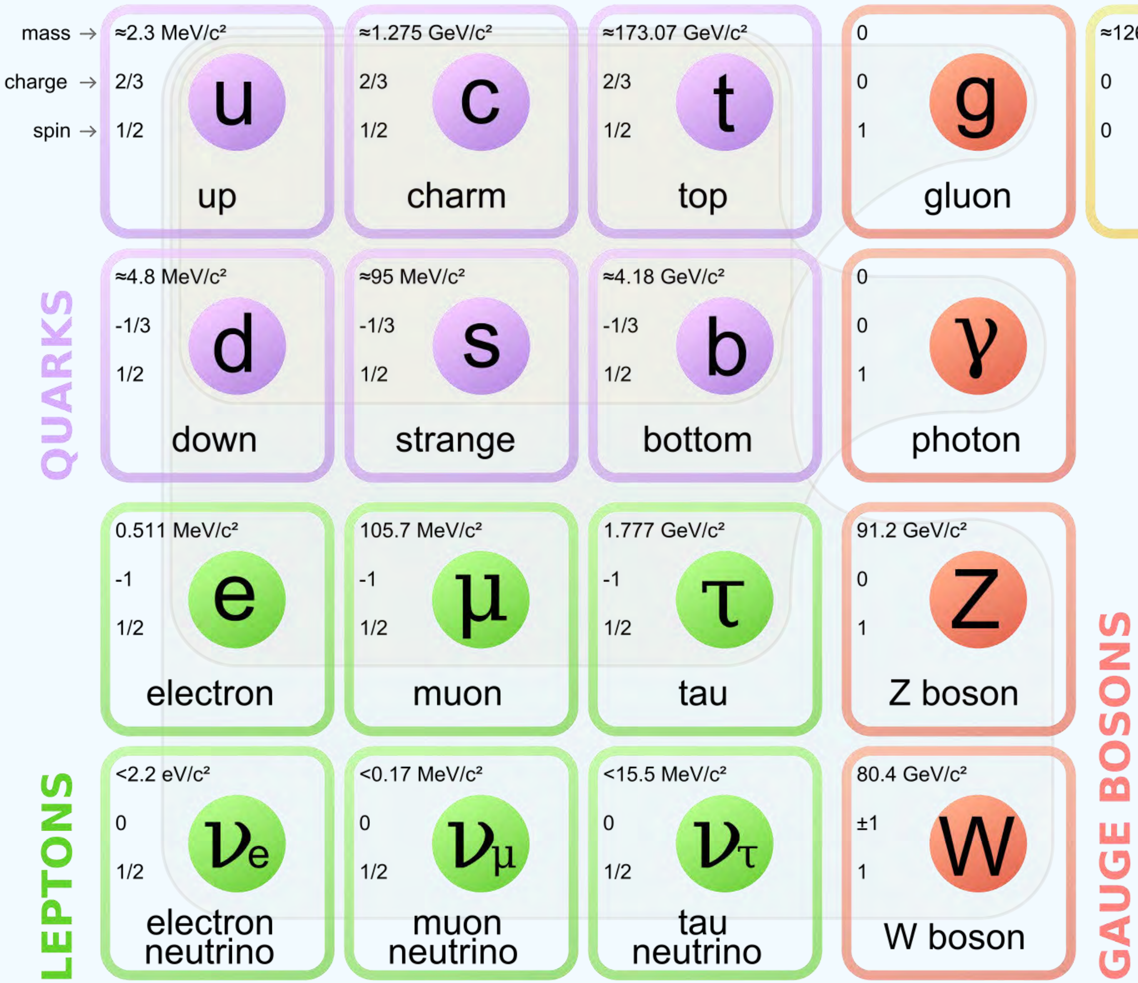
W&Z bosons



http://www.dreamstime.com/powerplant-infrastructure-stock-photo-imagefree242420

Fourth is gravity, but since its effects are negligible when considering particle collisions at accelerators, I'll ignore it.

1970's: Standard Model



A few fundamental particles and a mathematical theory that describes their interactions called a "gauge invariant quantum field theory".

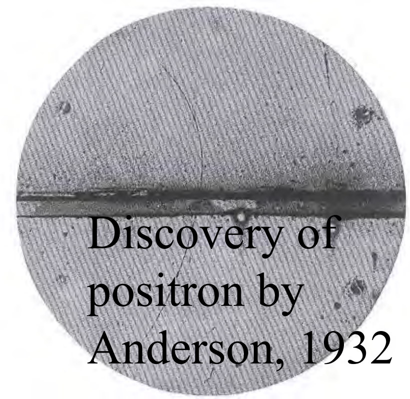
First generation makes up "our world".
Two heavier copies also exist.

To Understand the role of the Higgs, need a little formal theory

Dirac Equation

- 1928 - Electricity and Magnetism and Quantum Mechanics and Relativity
- Predicted anti-matter
- First instance of theory predicting a fundamental particle

$$\left(\beta mc^2 + \sum_{k=1}^{3} \alpha_k p_k \, c\right) \psi(\mathbf{x},t) = i\hbar \frac{\partial \psi(\mathbf{x},t)}{\partial t}$$



Discovery of positron by Anderson, 1932

Gauge-invariant quantum field theory: Fock, London, Pauli in 1940's. Schwinger, Feynman, Dyson, Tomonaga, Wilson and others in 1950's.

Gauge-Invariant Quantum Field Theory

Lagrangian for the strong force in Gauge-Invariant Quantum Field Theory based on a symmetry called SU(3):

$$L_{QCD} = -\frac{1}{4}F^{(a)}_{\mu\nu}F^{(a)\mu\nu} + i\sum_q \bar{\Psi}^i_q \gamma^\mu (D_\mu)_{ij}\Psi^j_q - \sum_q m_q \bar{\Psi}^i_q \Psi_{qi}$$

$$F^{(a)}_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu - g_s f_{abc} A^b_\mu A^c_\nu$$

$$(D_\mu)_{ij} = \delta_{ij}\partial_\mu + i g_s \sum_a \frac{\lambda^a_{i,j}}{2} A^a_\mu$$

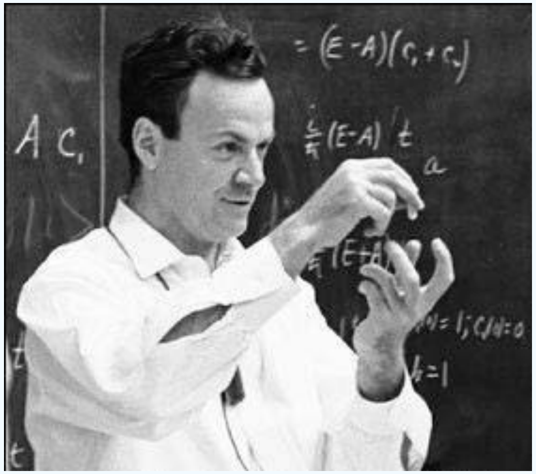
A : gluons

Ψ: quarks with color index i,j running from 1-3

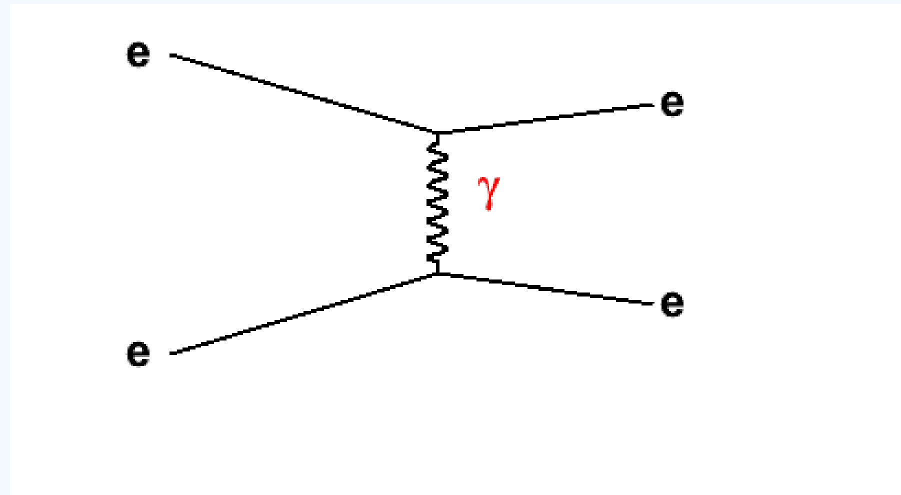
λ_{ij},f_{abc} : SU(3) isoscalar factors and representation matrices

1 parameter theory -> α_s

QED: the theory of electricty

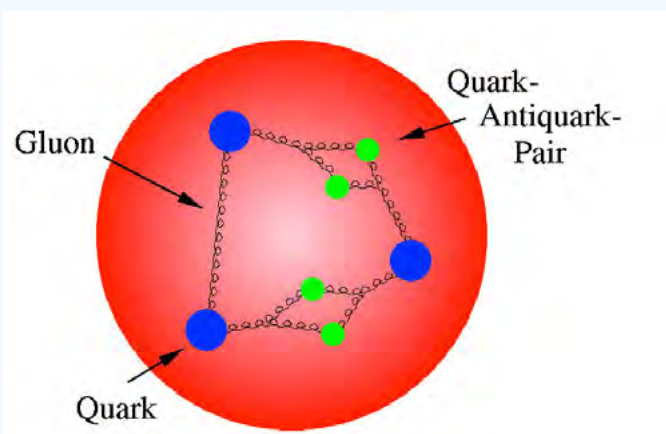


Feynman



QCD: the strong force

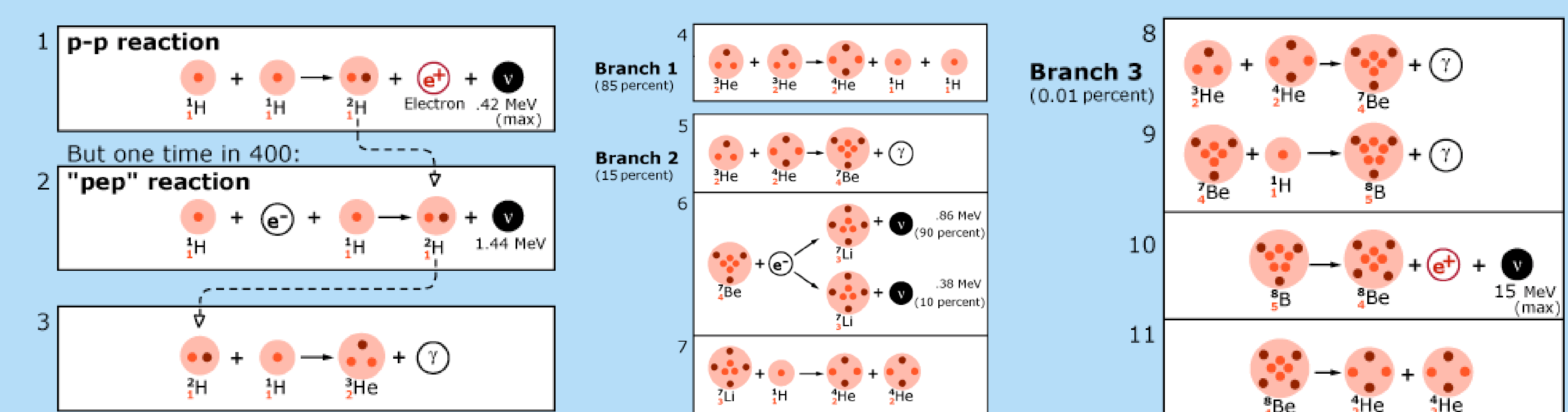
Politzer, Wilczek, Gross



QED and QCD

- Theories are similar.
- And both predict their boson (photon and gluon) are massless.
- The particle responsible for gravity (graviton) also seems to be massless.

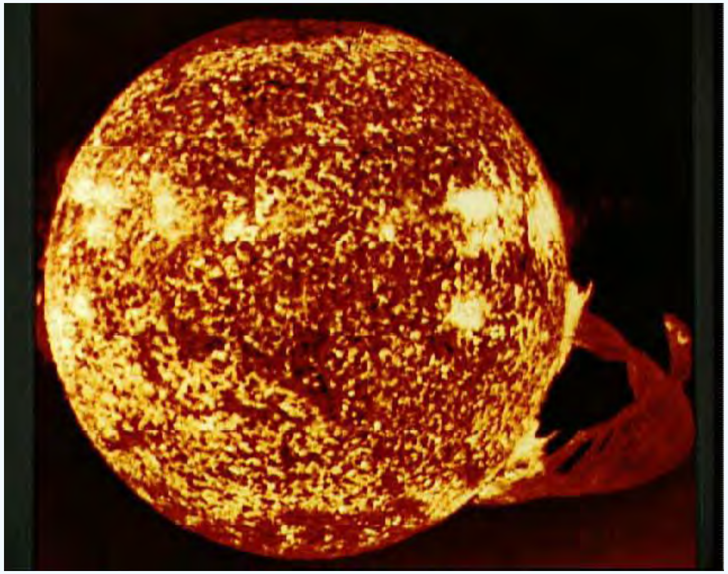
The Sun



http://www.nobelprize.org/nobel_prizes/themes/physics/fusion/

Important to the fusion reaction that powers the sun

$$u \rightarrow Wd \rightarrow dev$$



Weak Force

Predicts W and Z should be massless.

But their weight is 100x that of a proton!

Higgs Boson

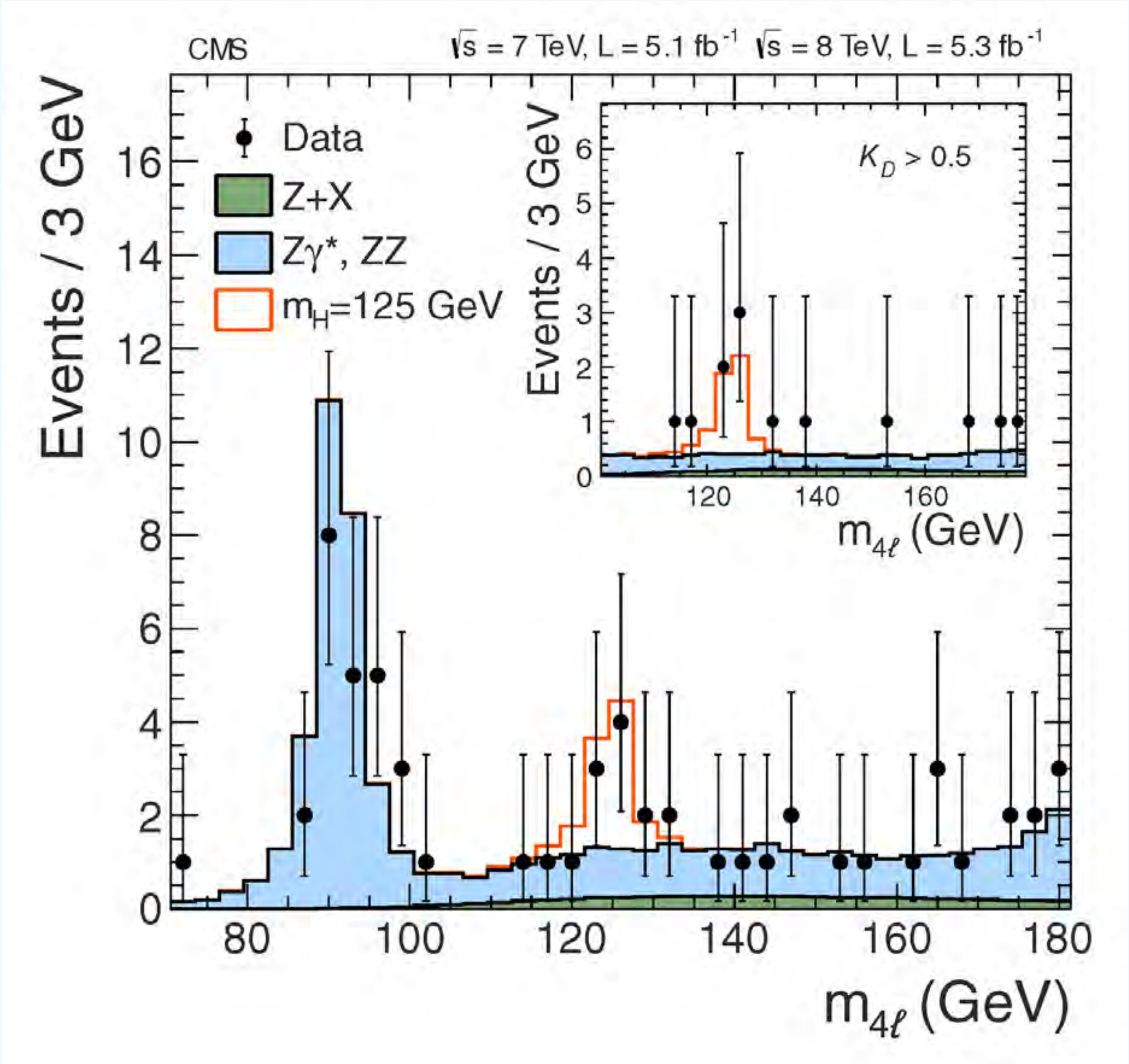
- Higgs boson interacts with fundamental particles that have mass
- Interact more strongly with heavier particles

Higgs and Englert

How do we know that Higgs bosons were produced at the LHC?

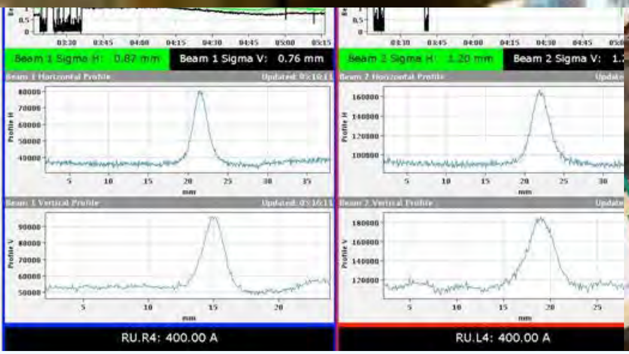
The smoking gun

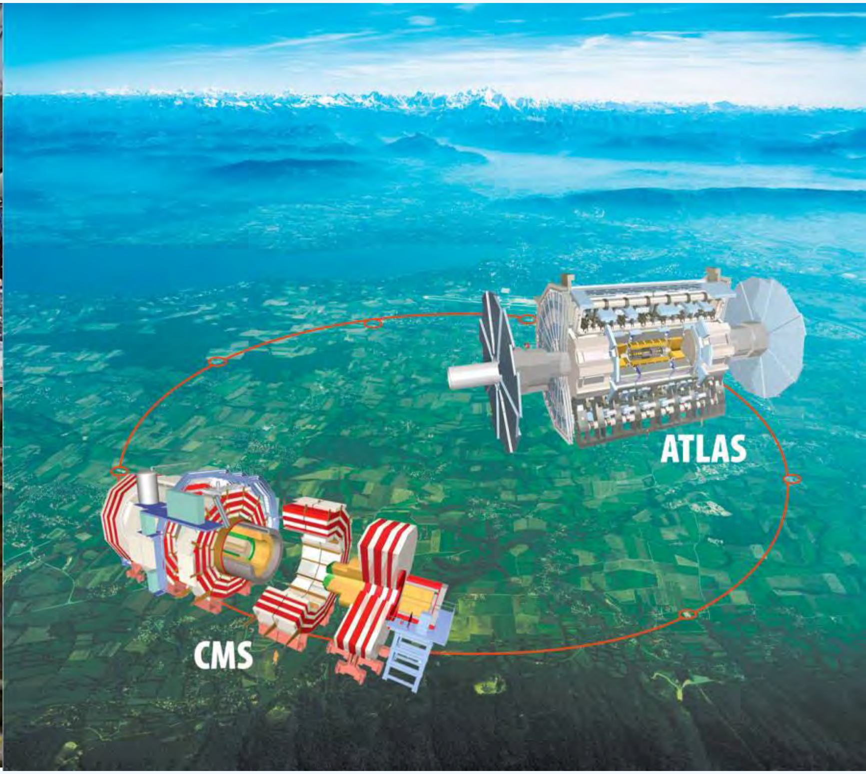
What exactly is shown here?



Higgs Production, Decay and Detection in Proton Collisions

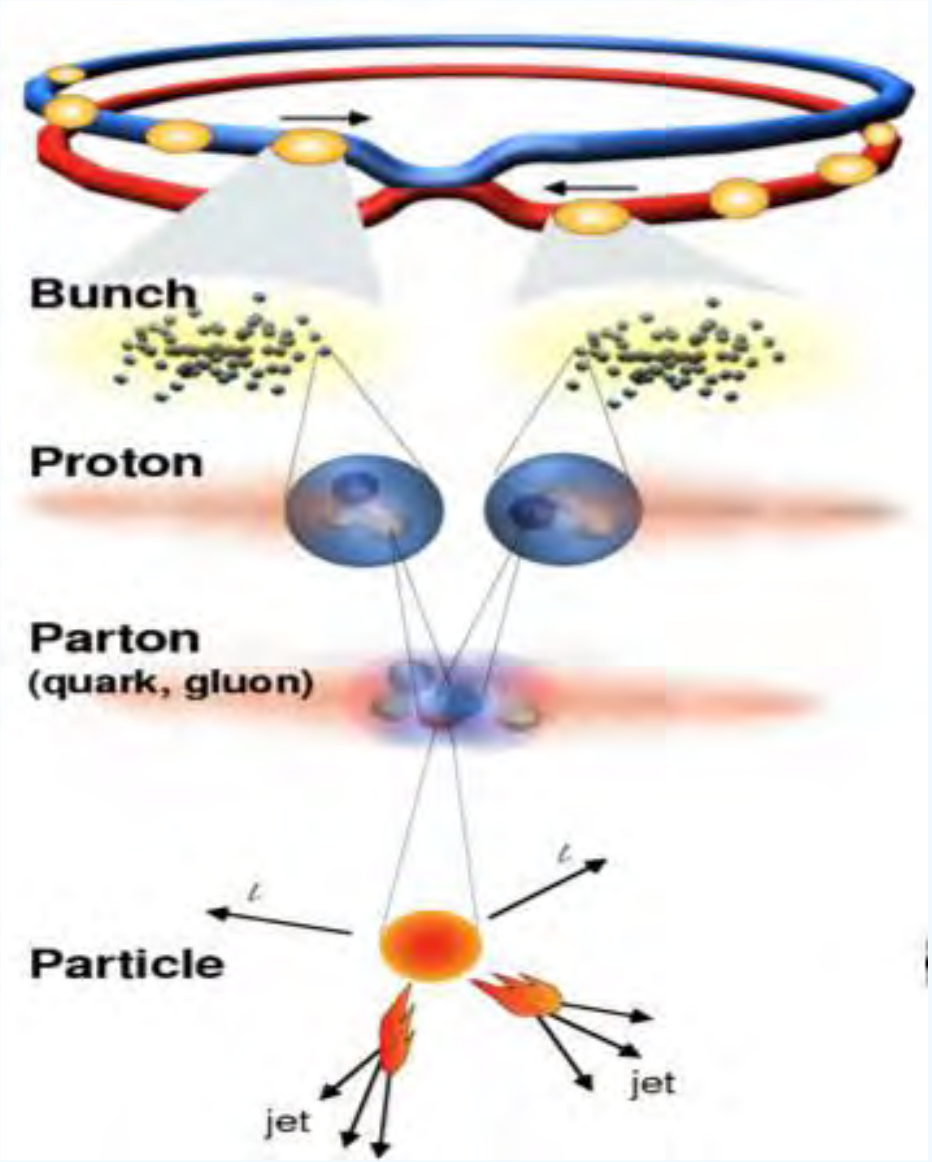
The LHC

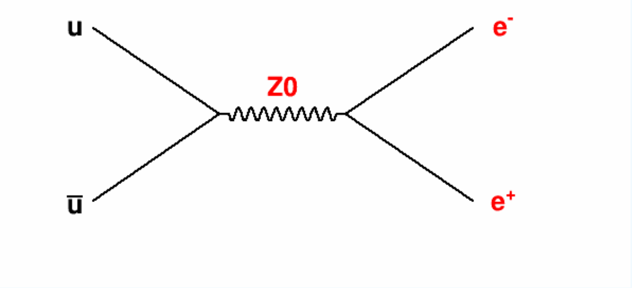




- **proton-proton collider, design center-of-mass energy $\sqrt{s}$ =14 TeV (factor 7x higher than the Tevatron), Higgs discovery data was at 7 and 8 TeV (3.5x Tevatron). Soon to run at 13 TeV**
- **circumference of 27 km (16.8 miles)**
- **cost of about $3B? (depending on accounting method, conversion rate, etc)**

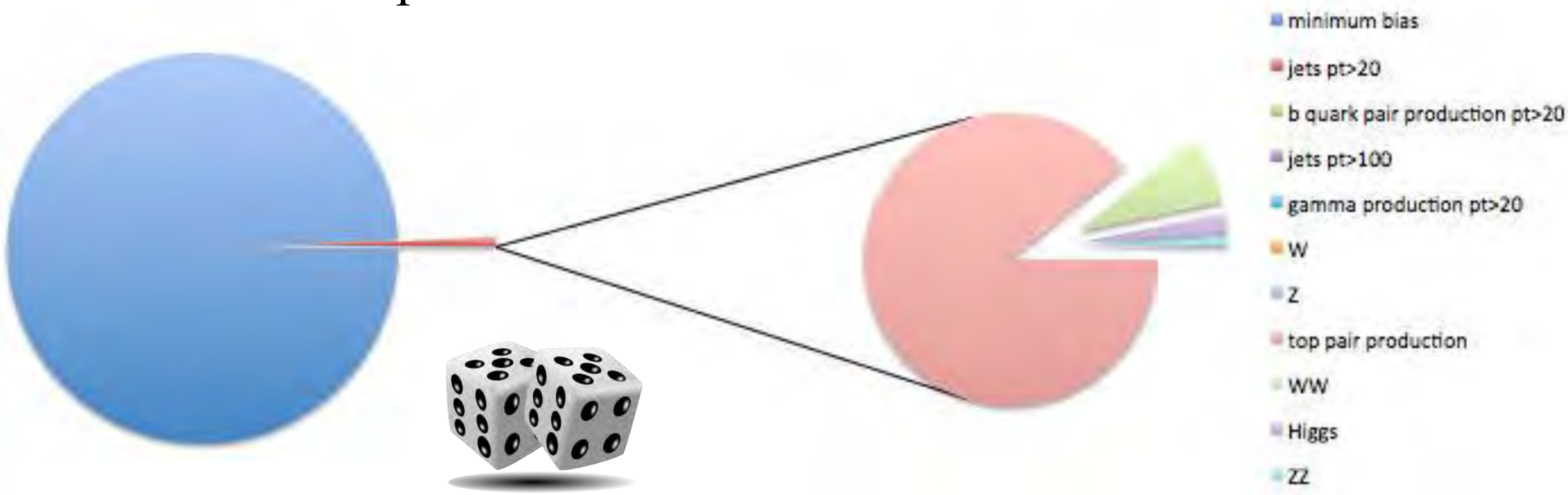
When beams collide…

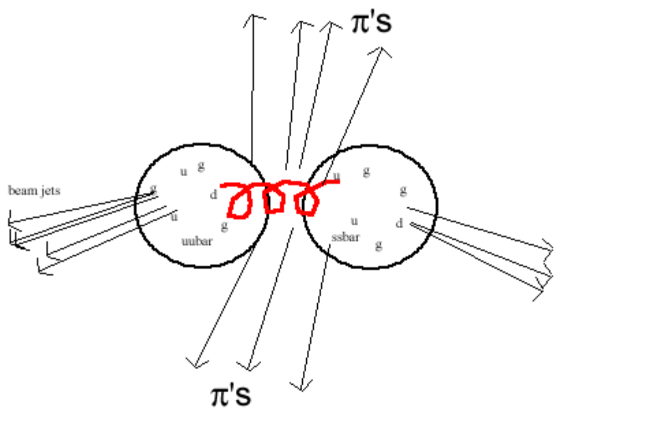




Particle Production

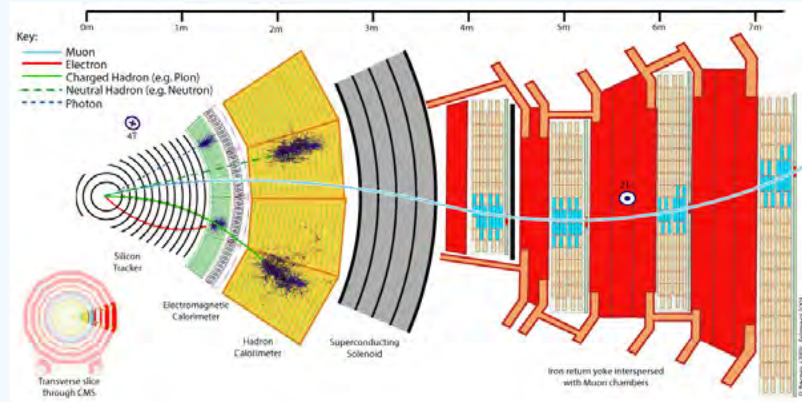
We see all the particles of the standard model.

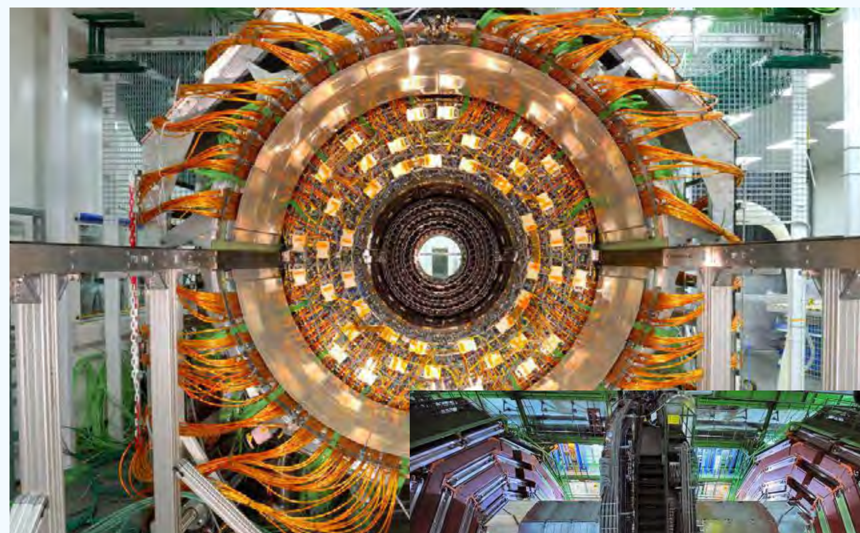




One out every 3,000,000,000 collisions contains a Higgs.

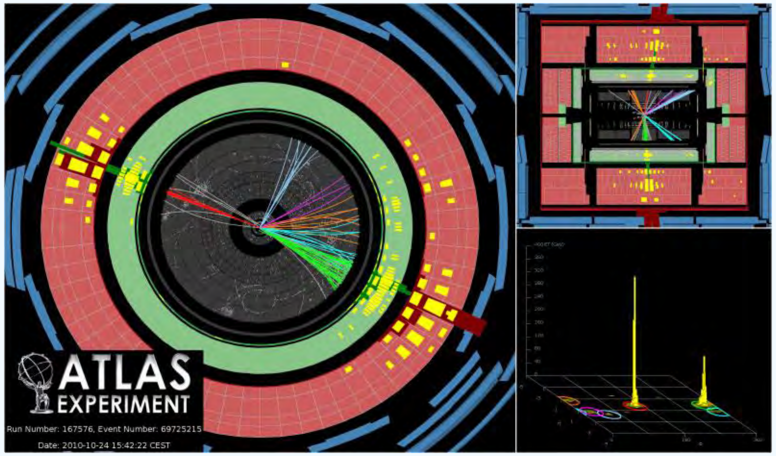
Detected in a detector



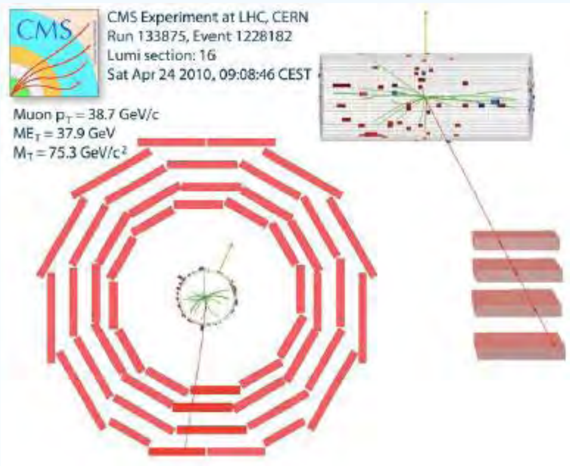


Event Visualization

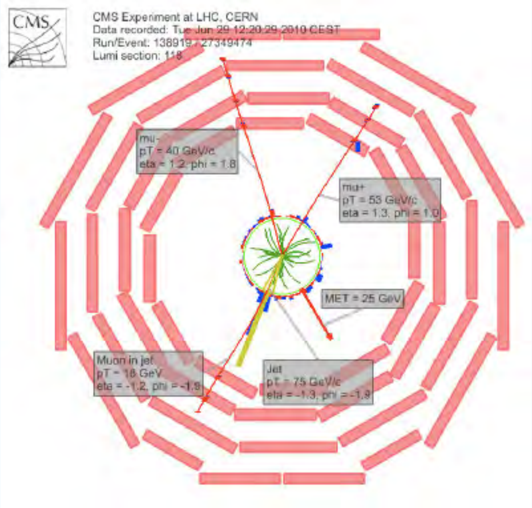
Jets candidate



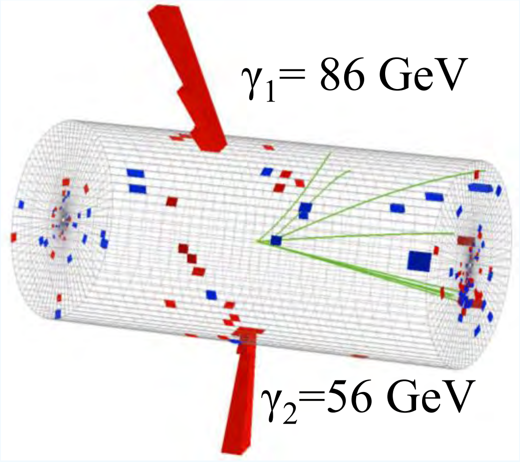
W boson candidate



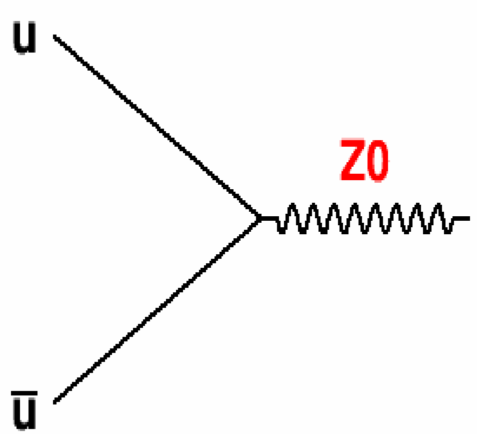
top-antitop candidate

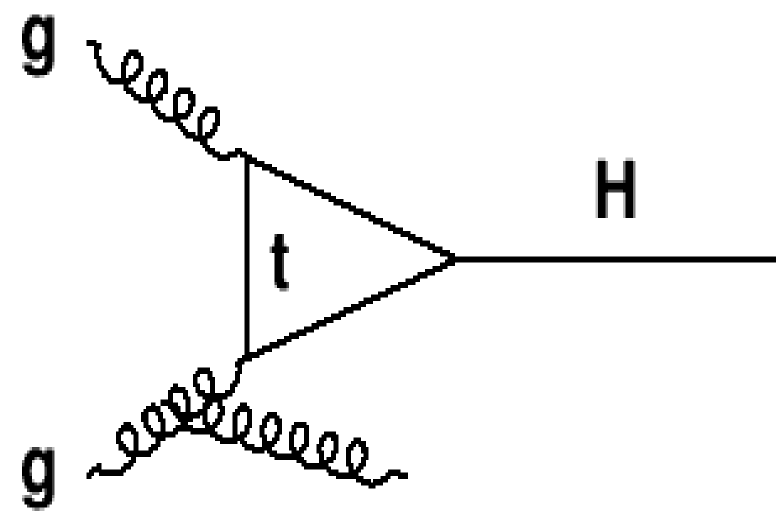


Higgs candidate



How is it made? Why is the production rate so small?



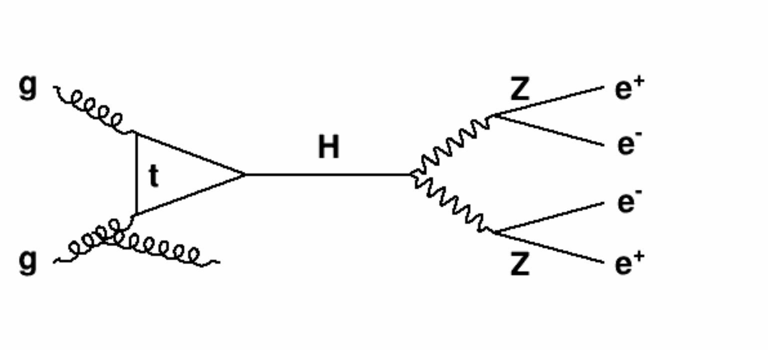


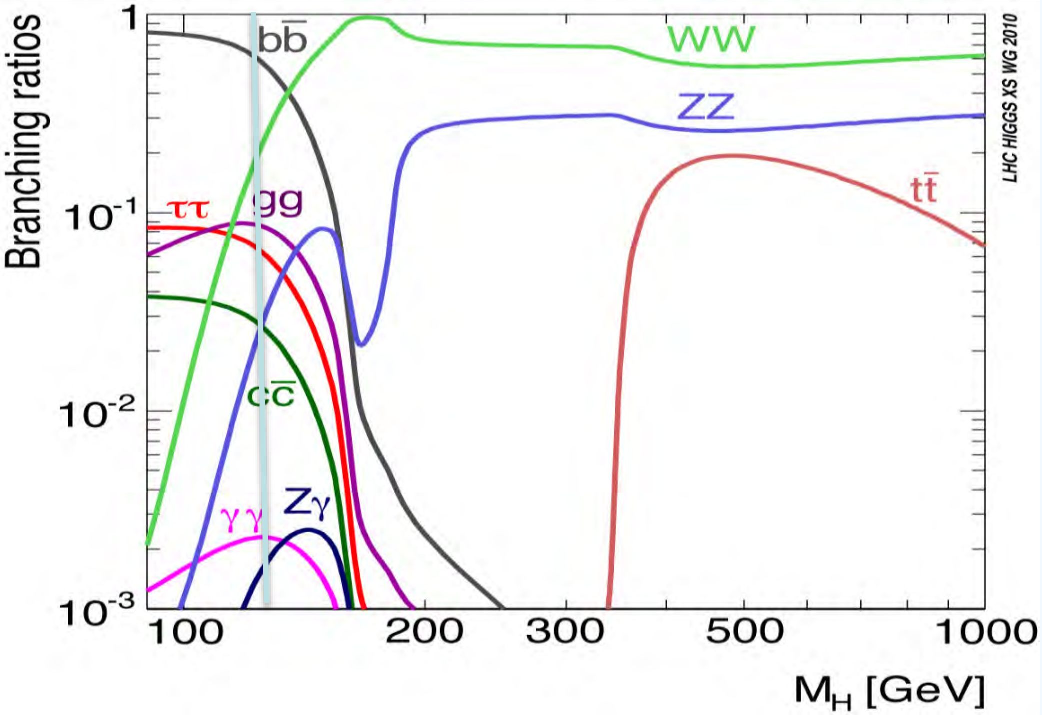
Higgs "couples" to heavy particles. Unfortunately, the proton is full of light particles.

Higgs decay

m(Higgs)=125 GeV

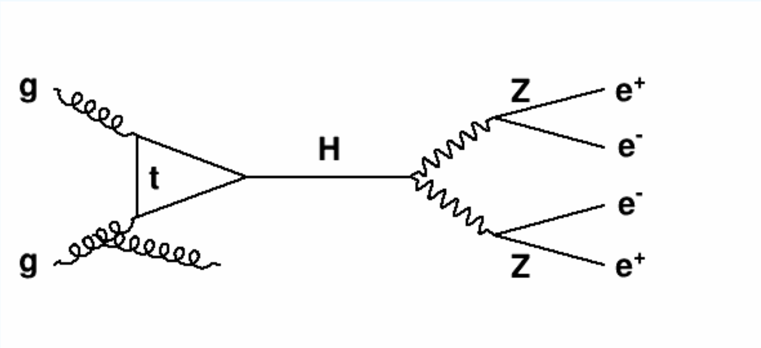
Decay	Particle Mass (GeV)	BR(%)
bb	4.5	57.7
ττ	1.8	6.32
cc	1.3	2.91
μμ	0.1	0.022
WW	80	21.5
gg	0	8.57
ZZ	91	2.64
γγ	0	0.23
Zγ		0.15

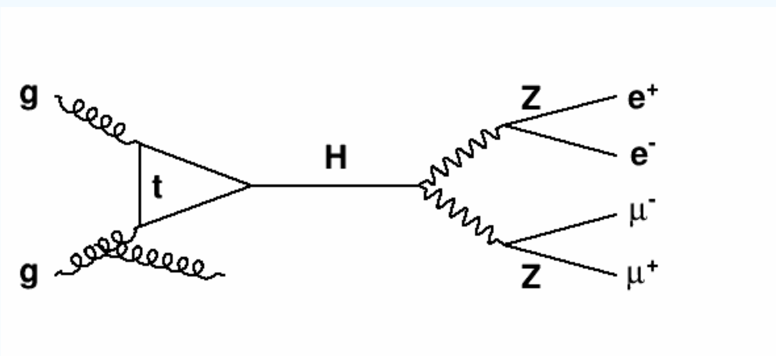


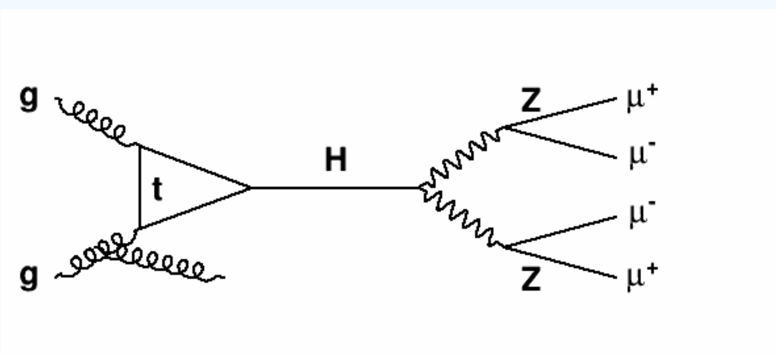


126 GeV is a particularly luck mass.

Higgs to ZZ



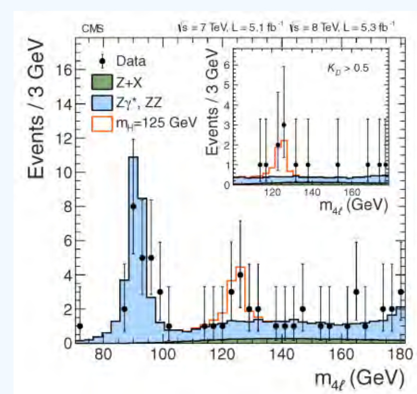




$$M = \sqrt{\sum^{4} E - \left| \sum^{4} \vec{p} \right|}$$

- Look at all the collisions recorded by the detector during the run
- See which ones contain
  - 4 electrons or
  - 4 muons or
  - 2 electrons and 2 muons
- Measure the energy and momenta of each of these particles
- Calculate the variable given above
- Make a histogram of the results

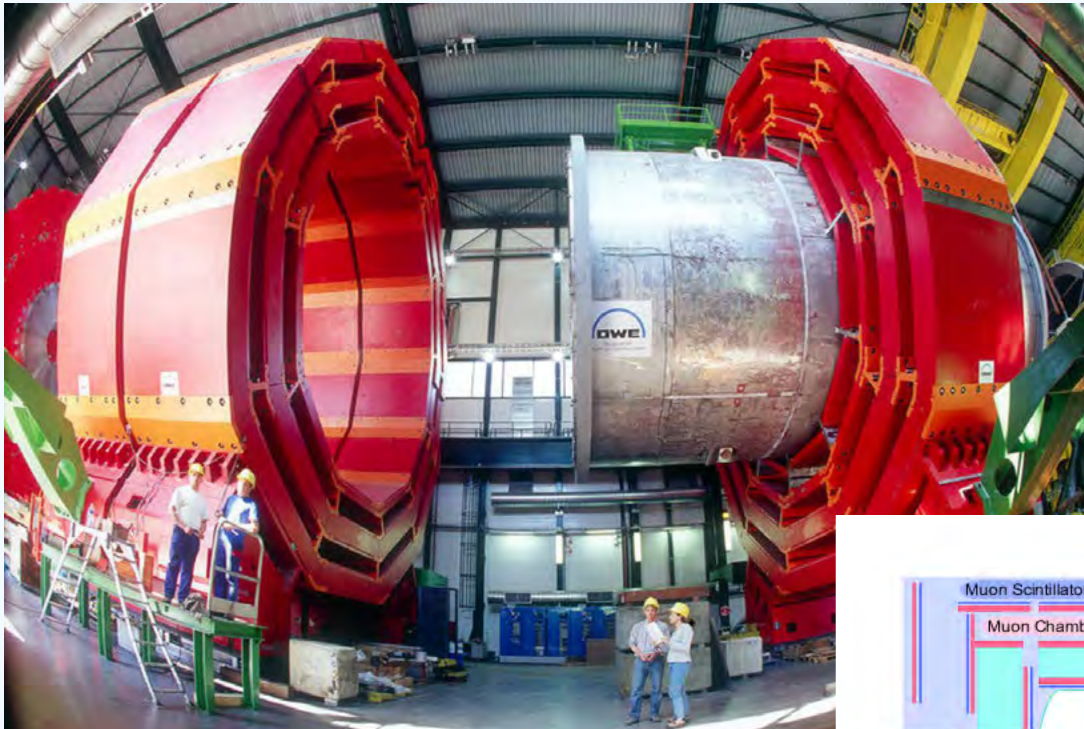
Voilà!



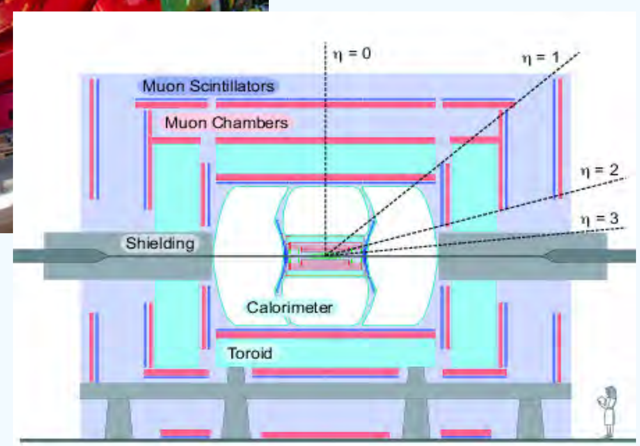
Why are so many needed to make this plot?

It wasn't always like this

I've been on experiments that were looking for the Higgs boson my entire career.

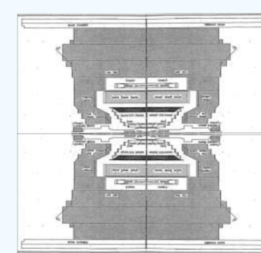


CMS, 2007, 2892 authors, 48 ft high



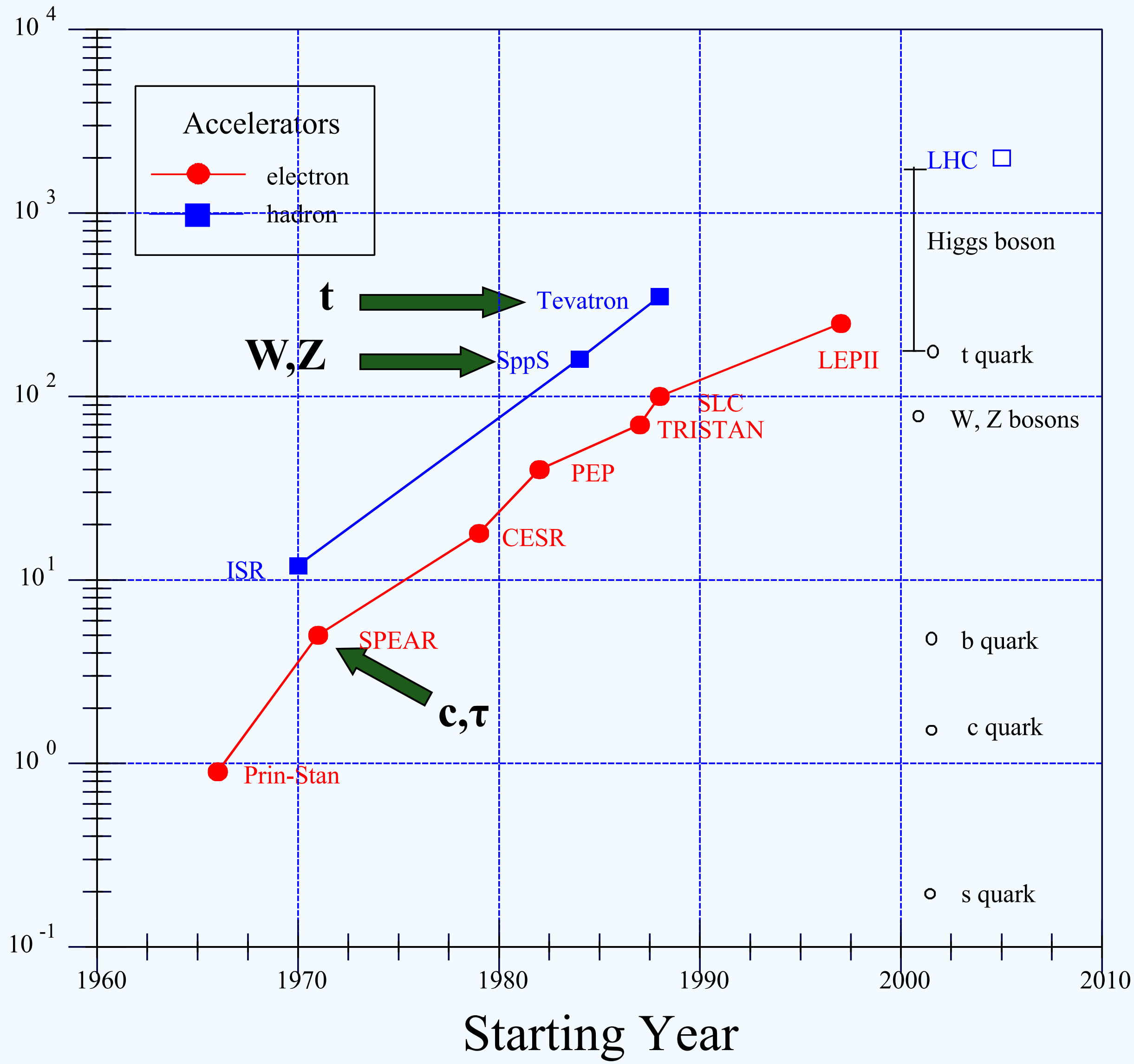
DØ, 1994, 351 authors, 28 ft high

AMY, 1988, 102 Authors, 18 ft high

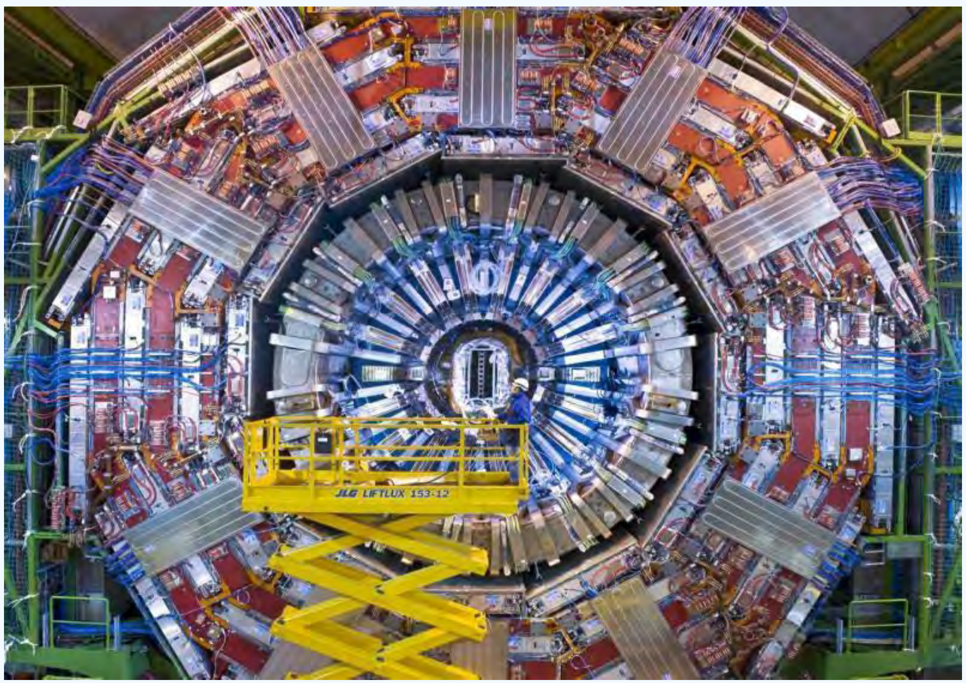


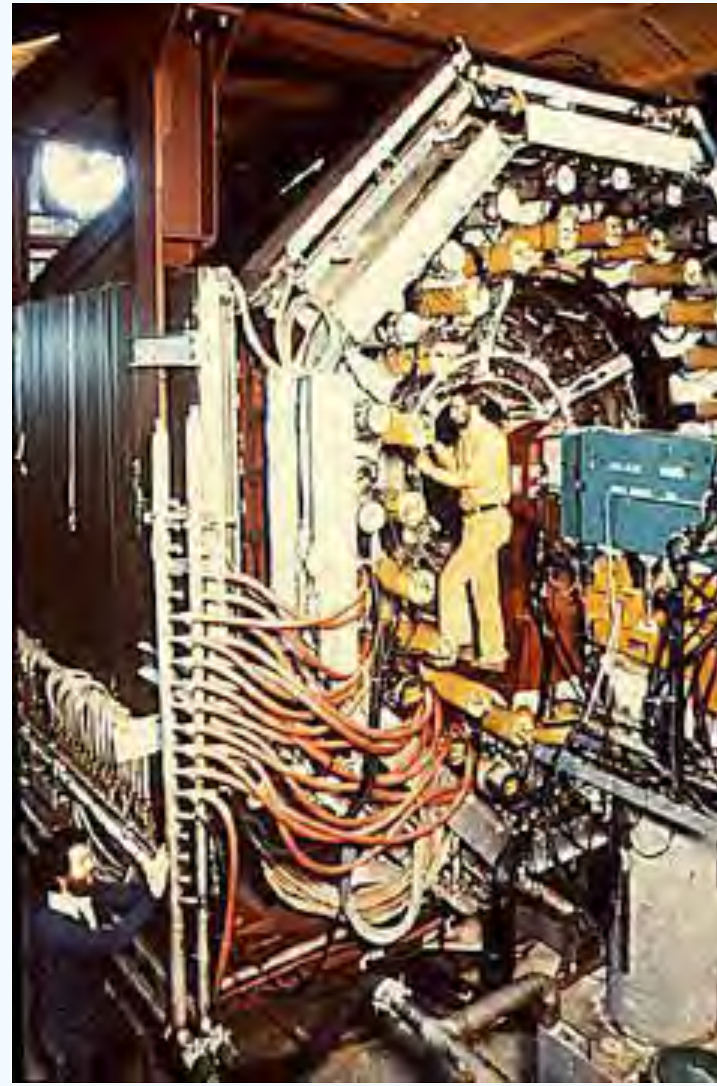
t n e u t i t s n o C

Detectors used for particle discoveries have been similar since the 1970's



Mark I detector at SLAC.
Discovery of charm and tau
(1974): 40 authors, 2 institutions





2892 authors,168 institutions

n.b.: this authorship list is slightly larger than that of a typical paper

- Have been a member for a year
- Institute paid M&O A and B (doctoral students exempt)
- Six months of ESP yourself to qualify
- Your institution must satisfy ESP requirements each year

These obviously were hard to build. Somebody had to carry all those bricks.

However, construction on the LHC and its detectors finished in 2008 and the Higgs was discovered in 2012.

How many people work at CERN?

About half

While it is true that you do can not be on this list until your satisfy "authorship requirements", about half are:

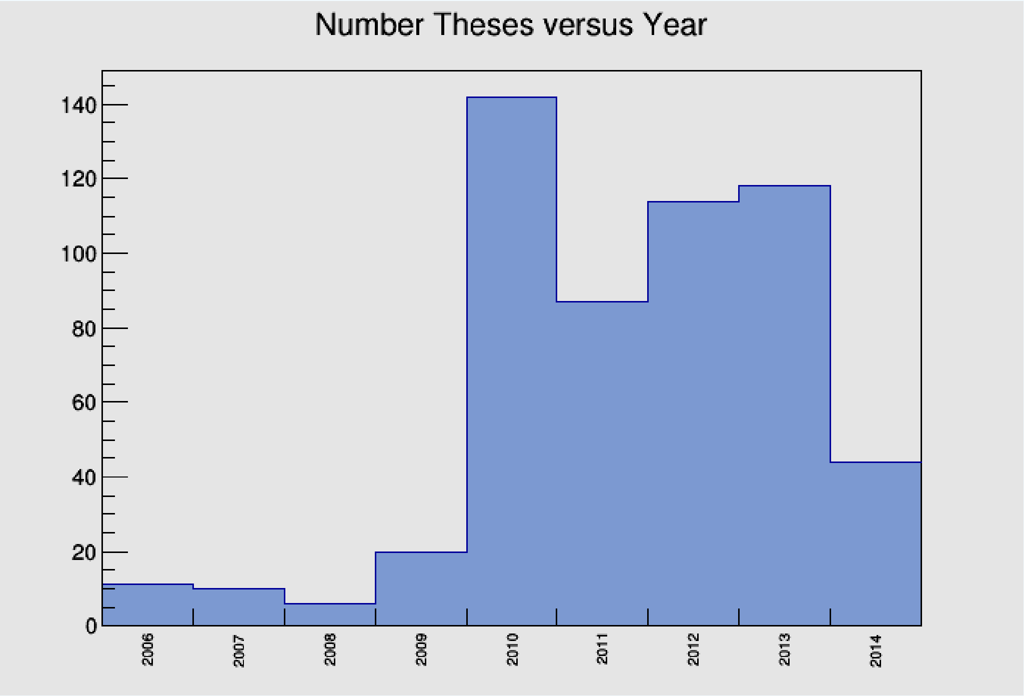
- Students in the writing phase of their thesis
- Students and postdocs have graduated but still get to keep their names on the paper for one year after leaving the collaboration (longer for those who participated in the building of the experiment).
- Formerly active faculty who are now deans, lab directors, etc.
- People who are working on retooling their skill set so they can be active in a different area.

So now we are down to 1400 "active" members.

PhD students

Of these, about 30% are Ph.D. students

- Roughly 400 students, 1000 PhDs. Roughly two supervisors per student.
- Some of what all those authors are doing is training students in a mentor-rich environment. Being in a big collaboration is a bit like being in a small, intense, single-purpose college.
- 400 students distributed over 4 years (first year they are not authors) yields about 100 theses per year)
- Most will get jobs in industry.



Mentor-Rich environment

MD and CMS

Physics Faculty
- Andris Skuja
- Nick Hadley
- Drew Baden
- Sarah Eno

PhDs
- Dick Kellogg
- Ted Kolberg
- Josh Kunkle

Graduate students
- Ellie Lockner
- Malina Kirn
- Ken Rosatto
- Dinko Ferencek
- Brian Calvert
- Kevin Pedro
- Chris Anelli
- Young Ho Shin

Chemistry Faculty
- Alice Mignerey

PhDs
- Marguerite Tonjes

Graduate students
- Ying Lu
- Jaime Gomez
- Chris Ferraioli
- Owen Baron

Big state university built on the cheap

CERN Summer Undergraduate Student Program

Early July – mid-August (13 weeks)
Formally for member-state students, but non-member-state students can attend if sponsored through one of the programs described later.

The U.S. is not a member state.

https://ert.cern.ch/browse_www/wd_pds?p_web_site_id=1&p_web_page_id=5836&p_no_apply=&p_show=N

Famous lecture series

Summer Student Lecture Programme 2009

Keys:
(v): videos
(t): transparencies
(l): web lecture
(b): biography
(q): questionnaire

Time	Monday 29 Jun	Tuesday 30 Jun	Wednesday 01 Jul	Thursday 02 Jul	Friday 03 Jul
09:15 - 10:00			Welcome presentation/ Computer security/ Workshop presentation(t)(v) *Wells, J (Chairman SSLP, CERN)/ Myers, D/ Neufeld, N*	Introduction to Particle Physics (for non particle physicists) (1/4) Introductory Lecture(t)(v)(b)(q) *Close, F (Oxford University)*	Introduction to Particle Physics (for non particle physicists) (3/4)(t)(v) *Close, F (Oxford University)*
10:15 - 11:00			Introduction to CERN(t)(v)(b)(q) *Heuer, R (Director General, CERN)*	Introduction to Particle Physics (for non particle physicists) (2/4)(t)(v) *Close, F (Oxford University)*	Introduction to Particle Physics (for non particle physicists) (4/4)(t)(v) *Close, F (Oxford University)*
11:15 - 12:00			Introduction to CERN Computing Services(t)(v)(b)(q) *Panzer-Steindel, B (CERN)*	Installation, Commissioning and Startup of Atlas & CMS Experiments Experimental Particle Physics - Introductory Lecture(t)(v)(b)(q) *Rolandi, L (CMS, CERN)*	Detectors (1/5) Experimental Particle Physics - Introductory Lecture(t)(v)(b)(q) *Riegler, W (CERN)*
12:00 - 12:30				Discussion Session *Close, F / Rolandi, L*	Discussion Session *Close, F / Riegler, W*

Time	Monday 06 Jul	Tuesday 07 Jul	Wednesday 08 Jul	Thursday 09 Jul	Friday 10 Jul
09:15 - 10:00	Accelerators (1/5) Introductory Lecture(t)(b)(q) *Gilardoni, S (CERN)*	Accelerators (2/5)(t)(v)(b)(q) *Metral, E (CERN)*	Accelerators (3/5)(t)(v) *Metral, E (CERN)*	Accelerators (4/5)(t)(v) *Metral, E (CERN)*	Accelerators (5/5)(t)(v) *Gilardoni, S (CERN)*
10:15 - 11:00	Detectors (2/5)(t)(v) *Riegler, W (CERN)*	Detectors (3/5)(t)(v) *Riegler, W (CERN)*	Detectors (4/5)(t)(v) *Riegler, W (CERN)*	Data Acquisition Systems (1/2) Computing - Introductory Lecture(t)(v)(b)(q) *Neufeld, N (CERN)*	Detectors (5/5)(t)(v) *Riegler, W (CERN)*
11:15 - 12:00	Introduction to Root (1/2)(t)(v)(b)(q) *Rademakers, F (CERN)*	Introduction to Root (2/2)(t)(v)(b)(q) *Grosse-Oetringhaus, J (CERN)*	Antimatter in the Lab (1/2) Experimental Particle Physics - Introductory Lecture(t)(v)(b)(q) *Landua, R (CERN)*	Antimatter in the Lab (2/2)(t)(v) *Landua, R (CERN)*	Data Acquisition Systems (2/2)(t)(v) *Neufeld, N (CERN)*
12:00 -	Discussion Session	Discussion Session	Discussion Session	Discussion Session	Discussion Session

Michigan REU Program

Since 2001 has sent O(15) undergraduates from a variety of US institutions to CERN for the June and July. Currently run by my Ph.D. student Junjie Zhu

http://www.um-cern-reu.org/

ATLAS Calorimeter Commissioning and Missing Transverse Energy
Ticey, Jeremy - Hampton University, Virginia
2009-08-13 10:47:03+02:00
Geneva, Switzerland - CERN - 40-S2-C01
Duration: 00:20:58

UM-CERN REU 2009 Final Student Presentation

http://lecb.physics.lsa.umich.edu/CWIS/browser.php?ResourceI...

ATLAS Live and Higgs Search
Stankowicz, James - University of Florida
2009-08-13 11:11:10+02:00
Geneva, Switzerland - CERN - 40-S2-C01
Duration: 00:21:13

UM-CERN REU 2009 Final Student Presentation

http://lecb.physics.lsa.umich.edu/CWIS/browser.php?ResourceI...

Refinements of Positron Accumulation Technique at ATRAP
Lacy, Monica - University of Dallas
2009-08-13 11:36:23+02:00
Geneva, Switzerland - CERN - 40-S2-C01
Duration: 00:16:38

UM-CERN REU 2009 Final Student Presentation

http://lecb.physics.lsa.umich.edu/CWIS/browser.php?ResourceI...

ATLAS High Level Trigger System
Palmer, Alexander - University of Texas - Dallas
2009-08-13 11:54:44+02:00

Email Print

Discovery

High Energy Physics Center Attracts U.S. Undergrads to Summer in Switzerland

Apprenticeship at the European Laboratory for Particle Physics (CERN) in Geneva, Switzerland

NSF and Ford Motor Company Fund have provided funding for Mr. Kumah and others at CERN.
Credit and Larger Version

January 27, 2005

A semester abroad. In the world of science, the phrase might

Part of the CERN facility.
Credit and Larger Version

"Through the lecture series... I realized that I am, without a doubt, an experimental physicist
Credit and Larger Version

"I believe that this experience will help

NSF, U. Michigan, Ford Motor Co.

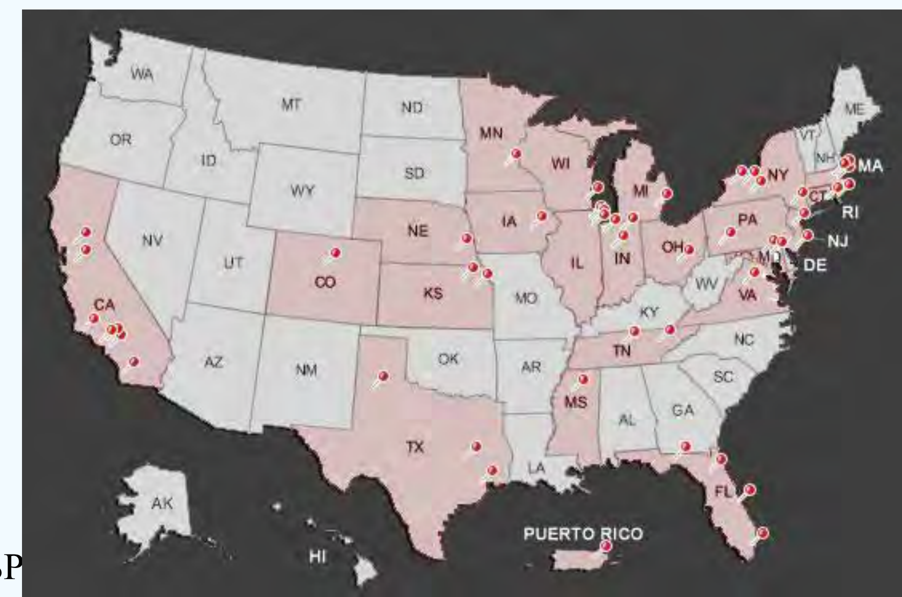
http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=1
&org=NSF

At individual Universities

- all member universities provide research opportunities at their own institution for their own undergraduates
- most participate remotely, from their home institution
- some go to CERN for the summer
- typically 1-5 undergraduates/institution

Map of U.S. institutions associated with ATLAS

Map of U.S. institutions associated with CMS



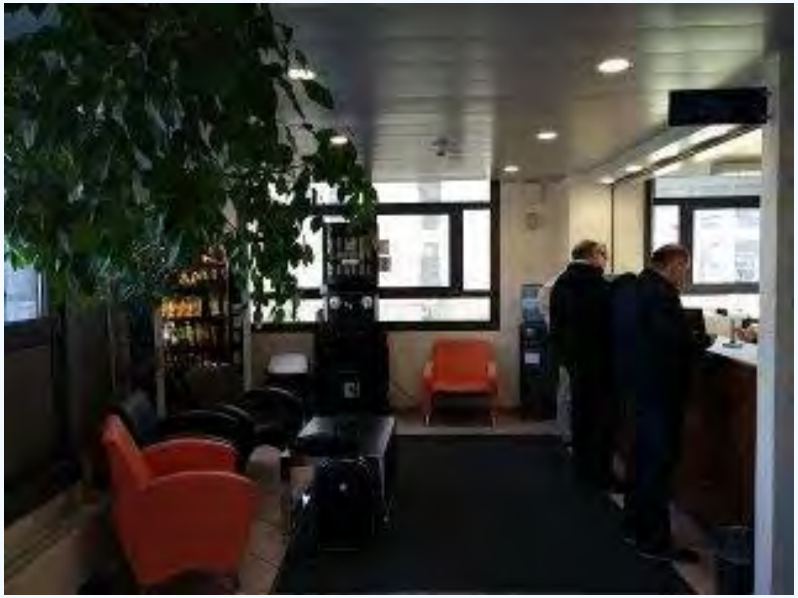
MD Undergraduates

Maryland (especially Physics Chair Drew Baden) has sent many students to CERN during the summer or had them work here in our lab on CMS.



Jeff Calderon
Mahnegar Amouzegar
Julie Schnurr
Zishuo Yang
Guillaume Cheron
Julie Rose
Erin Uhlfelder
Nicholas Zube
Oliver Pierson
Joseph Mariano
Katie Hergenreder
Uchenna Chukwu
Hannalore Gerling-Dunsmore
Noah Mandell
Roland Jeannier
Michael Kossin
Ethan Cowan
Jonathan Wonders
Issac Carruthers

Staying at CERN



All the Ph.D. students have their name on the paper. Did they all write theses on the higgs?

CMS Theses

Search:

All of the words:	higgs	title	AND
All of the words:		any field	AND
All of the words:		any field	Search Browse

Search Tips :: Simple Search

Search collections:

CMS Theses | *** add another collection ***

Sort by: latest first | desc. | - or rank by - **Display results:** 10 results | single list **Output format:** HTML brief

CMS Theses 85 records found 1 - 10 jump to record: 1 Search took 0.88 seconds.

1. **Search For The Higgs Boson Decaying Into τ-Leptons In The Di-Electron Channel** / Salfeld-Nebgen, Jakob
The first dedicated search for Higgs bosons decaying into tau pairs with two electrons and 4 neutrinos in the final state is presented [...]
CERN-THESIS-2014-111 - 186 p.

Fulltext
Detailed record - Similar records

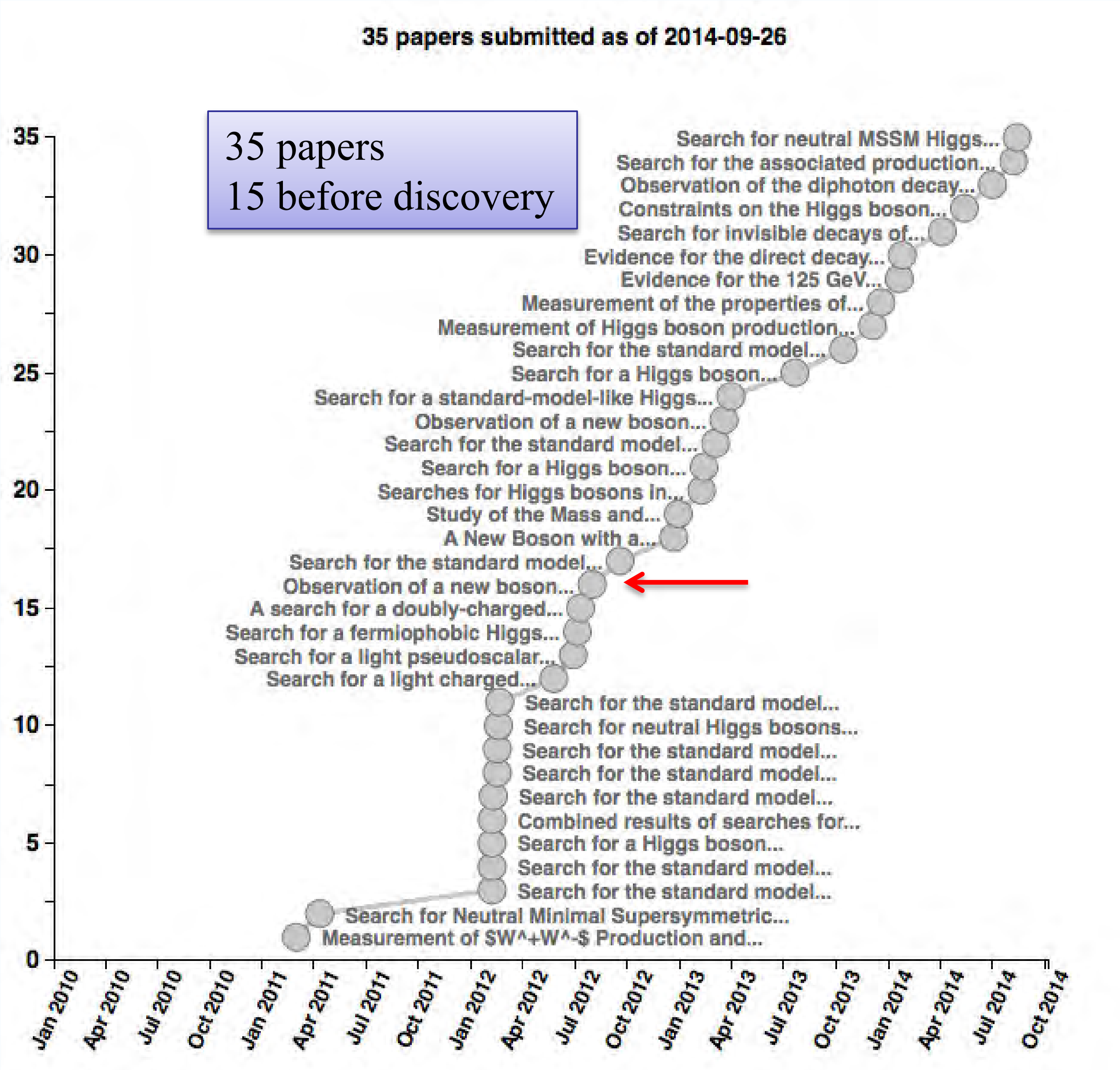
2. **Observation of a Higgs Boson in the H to zz to 4L decay channel and using Z to 4L decays as a calibration tool in studies of the Higgs boson properties** / Snowball, Matthew Alexander (Florida U.) ; Korytov, Andrei (dir.) (Florida U.) ; Aver
(Florida U.)
A search for the Higgs boson in the decay channel H to ZZ to 4 leptons is performed using data from proton-proton collisions corresponding to and integrated luminosity of 5.1 inverse femtobarns at a center-of-mass energy of 7 TeV ar
femtobarns at a center-of-mass energy of 8 TeV data. A new boson is observed as a narrow resonance with a local significance of 6.8 standard deviations, a measured mass of 125.6 0.4(stat.) 0.2(syst.) GeV, and a total width less than or
95% confidence level [...]
CERN-THESIS-2014-107; CMS-TS-2014-023.- 2014 - 261 p. **Fulltext:** *TS2014_023_2* - PDF; *TS2014_023* - PDF;
Detailed record - Similar records

3. **Search for the standard model Higgs boson produced in association with a Z boson with the CMS detector at the LHC** / Bortignon, Pierluigi
A search for the Standard Model Higgs boson produced in association with a Z boson and decaying into bottom quark pairs at the LHC with the CMS detector is presented [...]
CERN-THESIS-2014-095 ETH/21744. - 178 p.

Fulltext
Detailed record - Similar records

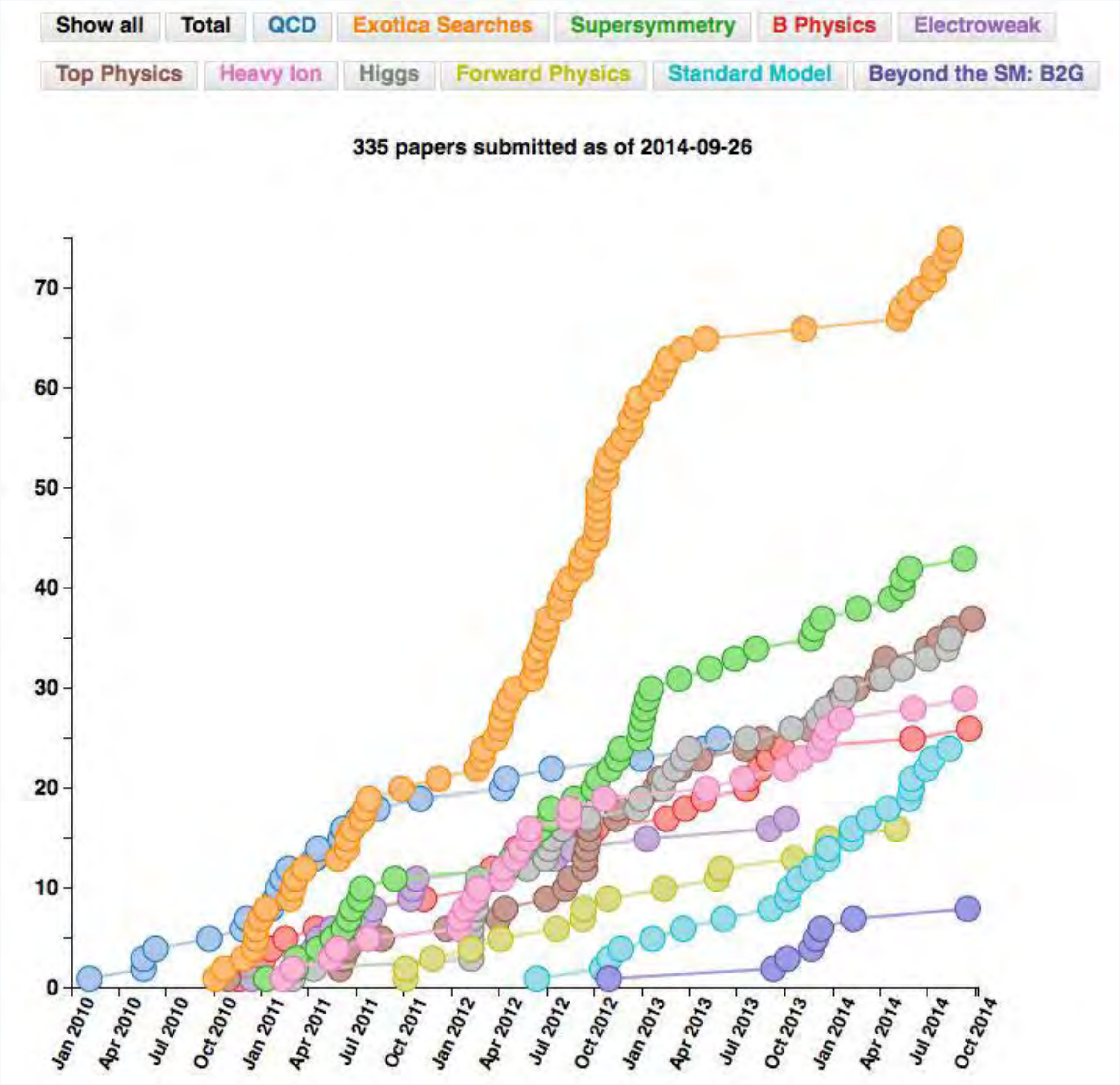
85 Higgs theses; 35 since 2012

Paper with theses



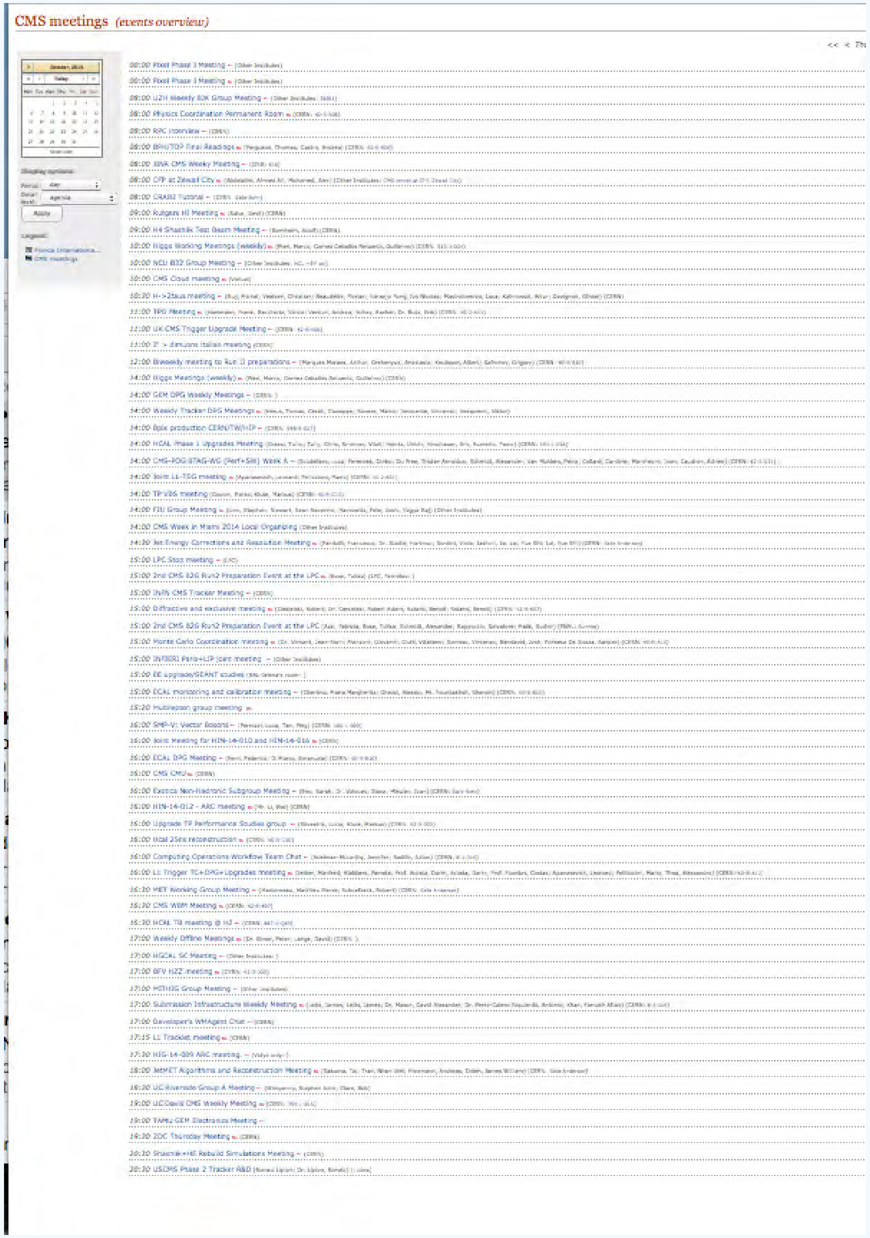
most of our papers aren't on the Higgs

MD works on Exotica, Supersymmetry, Standard Model, and Heavy Ions.



So, if only 35 students and their "70 mentors" worked on the Higgs why do all those people get to be on the paper?

Maybe if we look at a list of meetings

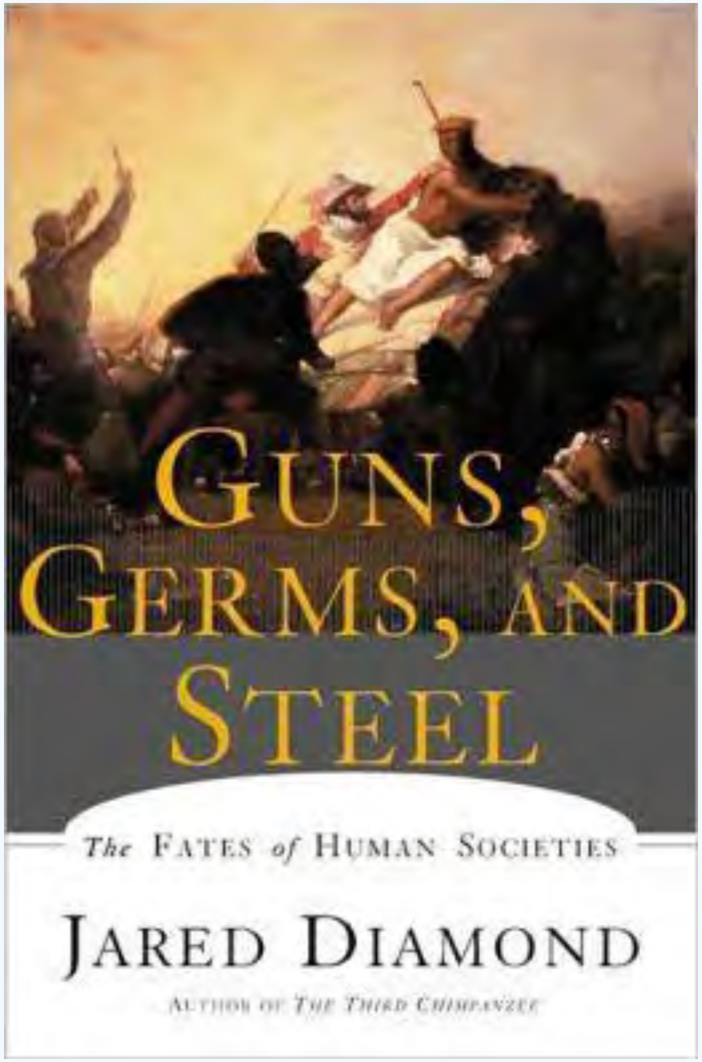


Maybe the org chart will help?

- The organization of a large physics collaboration is fairly byzantine.
- It is related to the large number of nationalities and funding sources.
- There tend to be parallel structures.
  - To organize work
  - To discuss money with national funding agencies
  - To discuss cooperation between those with money
  - To do "good deeds" (unfunded work that would be nice to get done and that helps nobody get promotions)
- Somehow, despite its baroque-ness, in the end, it manages fairly well.

We rank ourselves by our fancy titles.

Guns, Germs, and Steel



1997

Guns, Germs, and Steel

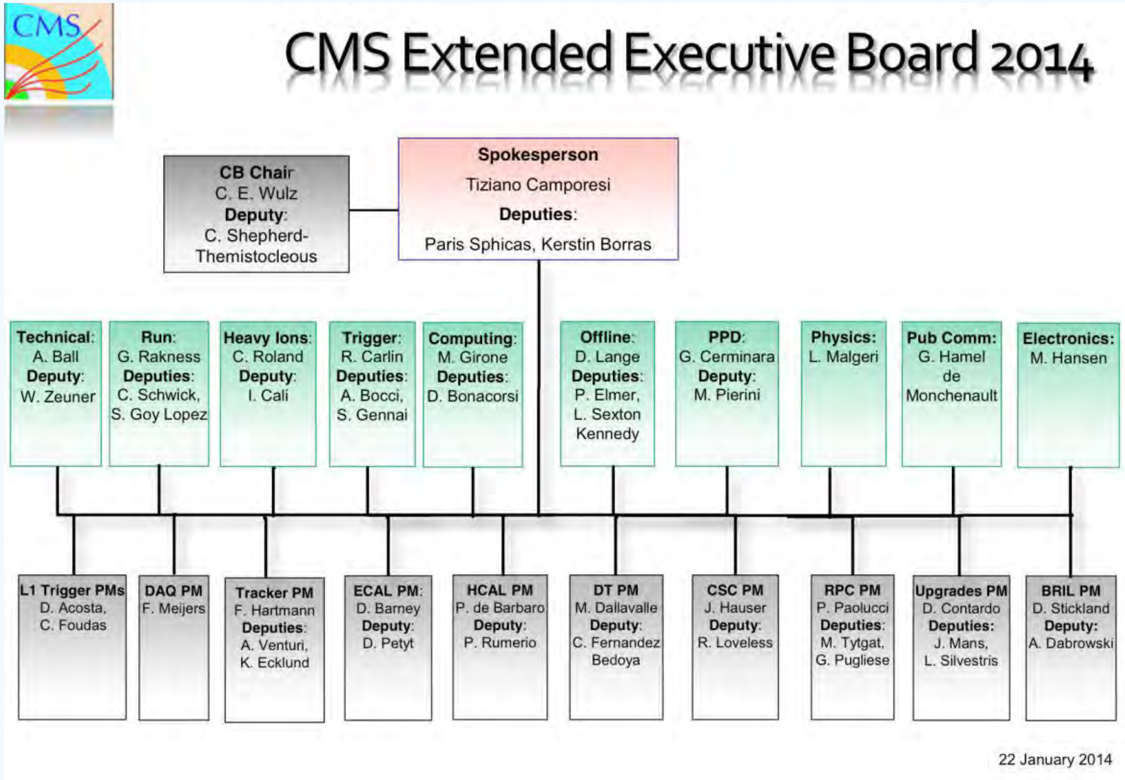
Pages 268-269

Title: Guns, Germs and Steel
Chapter Title: From Egalitarianism to Kleptocracy
Table 14.1 Types of Societies

	Band	***Tribe***	***Chiefdom***	***State***
Membership-	------------------------------------			
Number of People	Dozens	Hundreds	Thousands	Over 500,000
Settlement Pattern	Nomadic	Fixed: 1 Village	Fixed: 1 or more Villages	Fixed: Many Villages
Basis of Relationships	Kin	Kin-based Clans	Class and Residence	Class and Residence
Ethnicities and Languages	1	1	1	1 or more
Government-	------------------------------------			
Decision Making Leadership	"Egalitarian"	"Egalitarian"	Centralized, Hereditary	Centralized
Bureaucracy	None	None	None, or 1 or 2 Levels	Many Levels
Monopoly of Force and Information	No	No	Yes	Yes
Conflict Resolution	Informal	Informal	Centralized	Laws, Judges
Hierarchy of Settlement	No	No	No -> Paramount Village	Capital
Society-	------------------------------------			
Stratified	No	No	Yes, by Kin	Yes, not by Kin
Slavery	No	No	Small-Scale	Large-Scale
Luxury Goods for the Elite	No	No	Yes	Yes
Public Architecture	No	No	No-> Yes	Yes
Indigenous Literacy	No	No	No	Often

AMY D0 CMS

A CMS Org chart



- This one is to organize different kinds of work. Here you can see the lists different kinds of work that need manpower, and who is responsible for organizing that work.
- There is often little contact between these people and those actually "working".
- Only the top person in the red box is elected. The rest are appointed in agreement with the management board. (top grey box)
- All members of CMS also belong to one of the bottom grey boxes. This makes it tough for the green boxes, aside from "physics", to get manpower.

Spokesmen

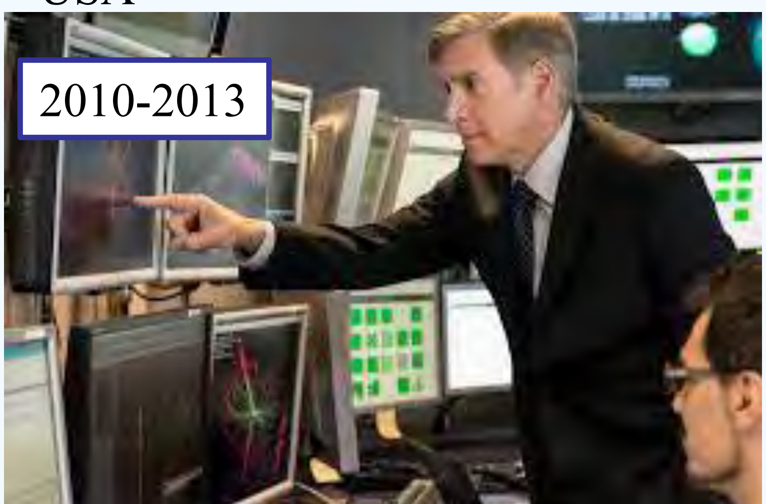
France

Michel Della Negra

Britain

Sir Jim Virdee

USA

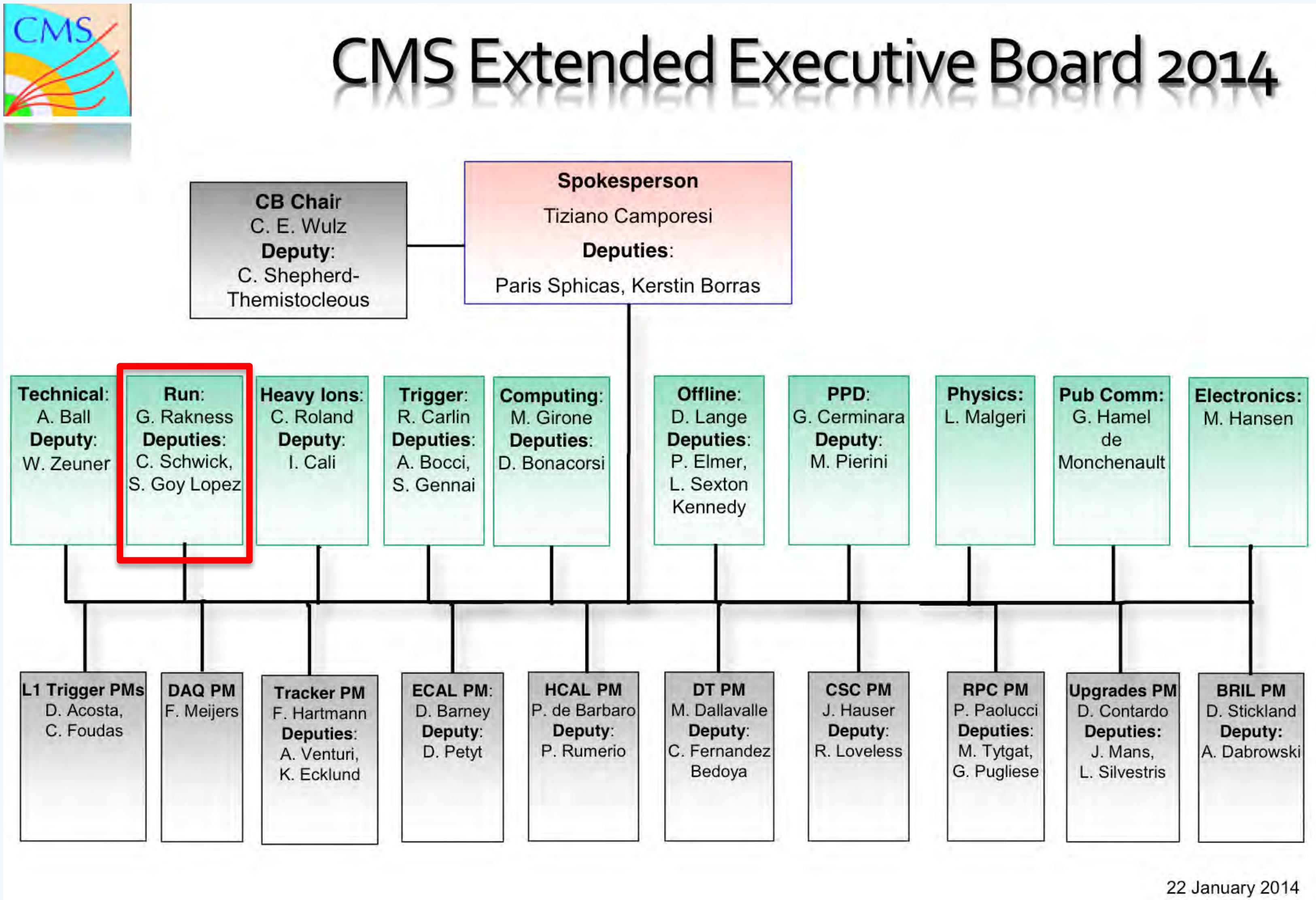


Joe Incandela

Italy

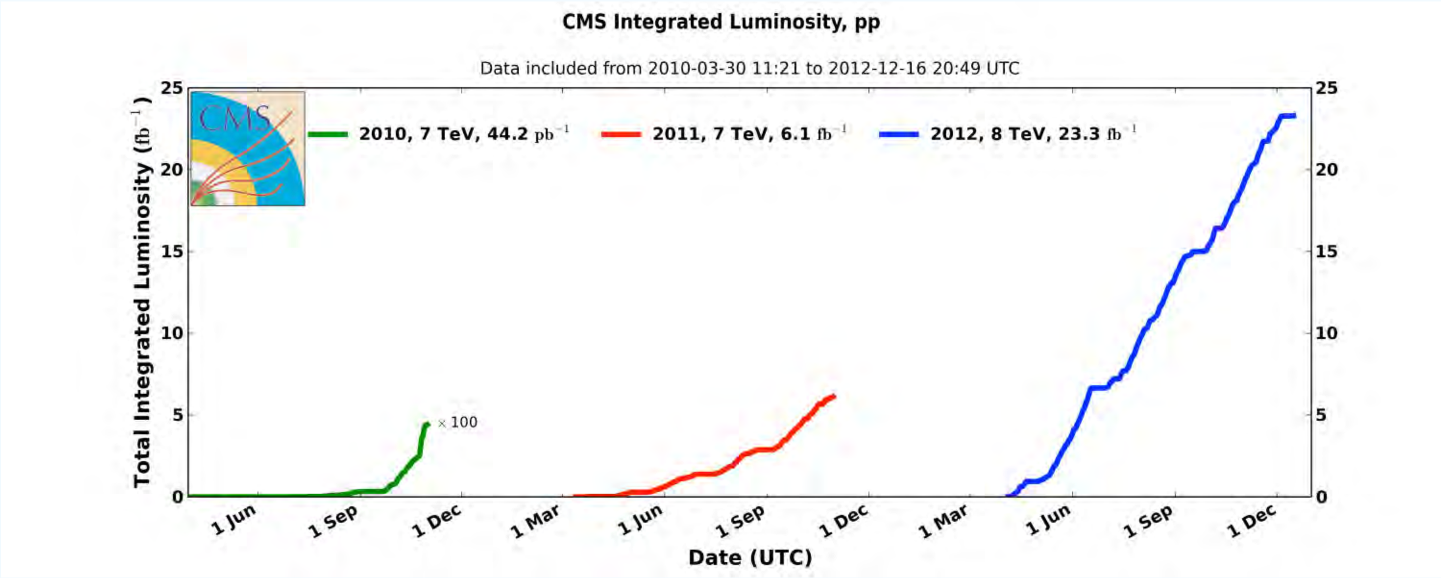
Tiziano Camporesi

Running a big detector



Let’s look at this box

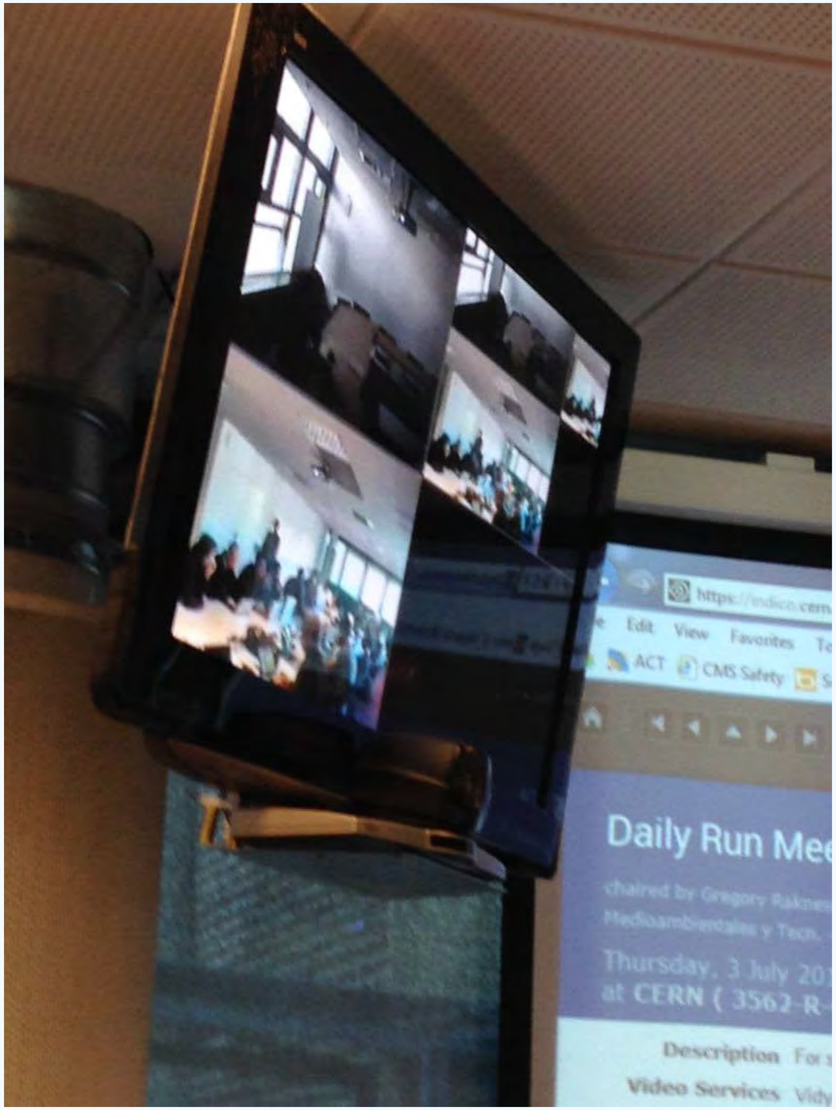
shifts



24/7 (but not past December)

- Check that all subdetectors are operating correcting
- Raise/lower the voltages as appropriate for beam conditions
- Give feedback to accelerator operators on beam conditions at the experiments

shifts



Edit
View
Favorites
ACT
CMS Safety
Daily Run Mee
Thursday, 3 July 20
at CERN (3562-R-
Description
Video Services

Offline

During 2012 run

Common | ECAL | HCAL | RPC | CSC | Tracker | Services

UTC: 23:55:08 5-Oct-14 Home
local: 19:55:08 5-Oct-14 Welcor
page loaded: 19:54:44 5-Oct-14

Daily view | Monthly view | Shift selection | Shift summary

Year: 2012 **Month:** December **Day:** 6 **System:** All Show

main(m) main 2nd(m2) trainee(t) Run field manager: Robert STRINGER

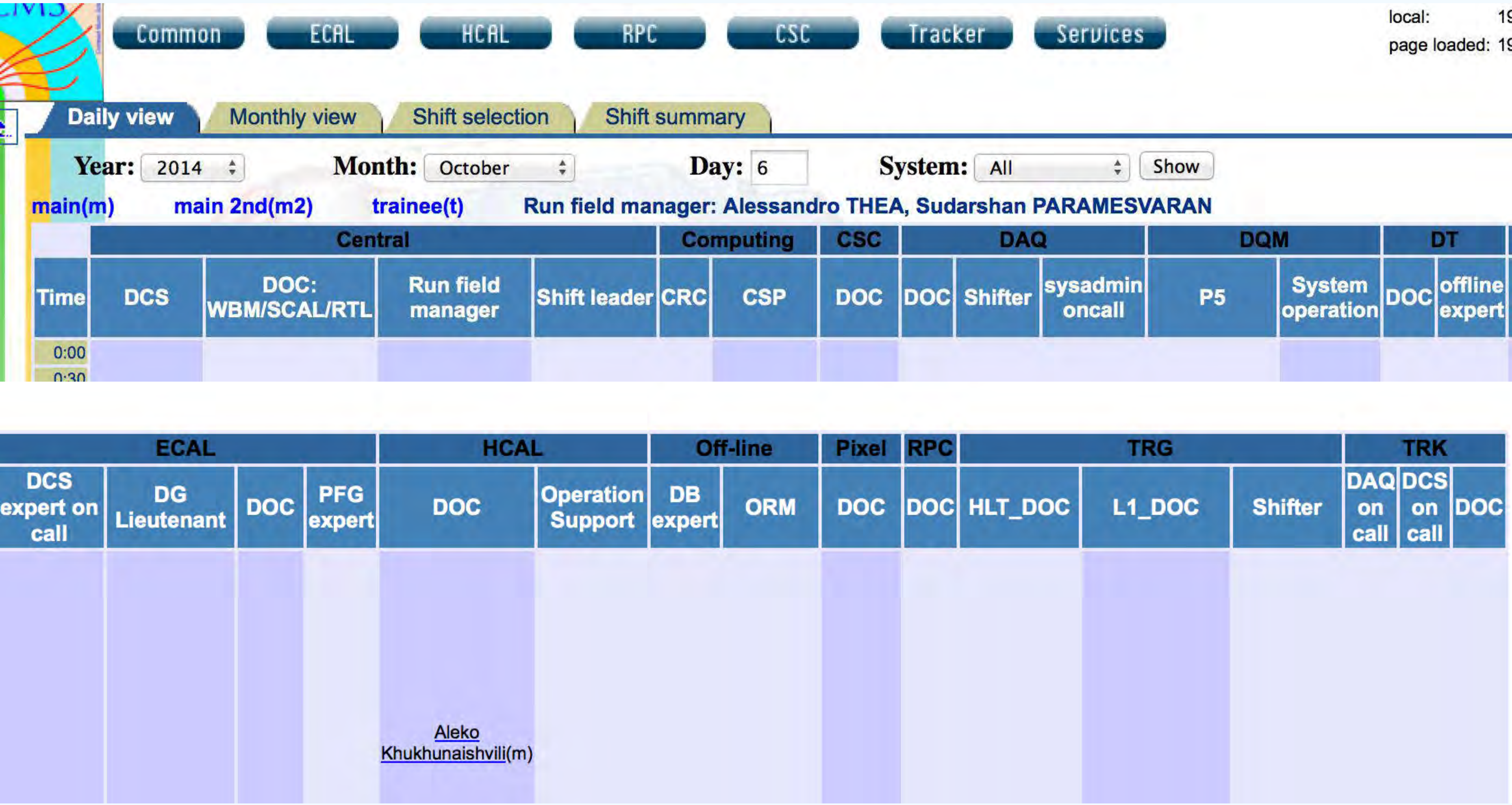
	BRM	Central								Computing		CSC		DAQ		
Time	DOC	DCS	DCS expert	DOC: WBM/SCAL/RTL	DOC: lumi	Run field manager	Safety tour	Shift leader	CRC	CSP	DOC	DQM_Shift	DOC	Shifter	sysadmin oncall
0:00															

DQM			DT		ECAL							HCAL		Off-line		Pixel		
Offline	P5	System operation	DOC	off line	DCS expert on call	DG Lieutenant	DOC	EB+EE DAQ expert on call	ES DAQ expert on call	PFG expert	trigger expert on call	DOC	Off line	DB expert	ORM	DAQ on call	DOC	DQM on call
Rahmat																		

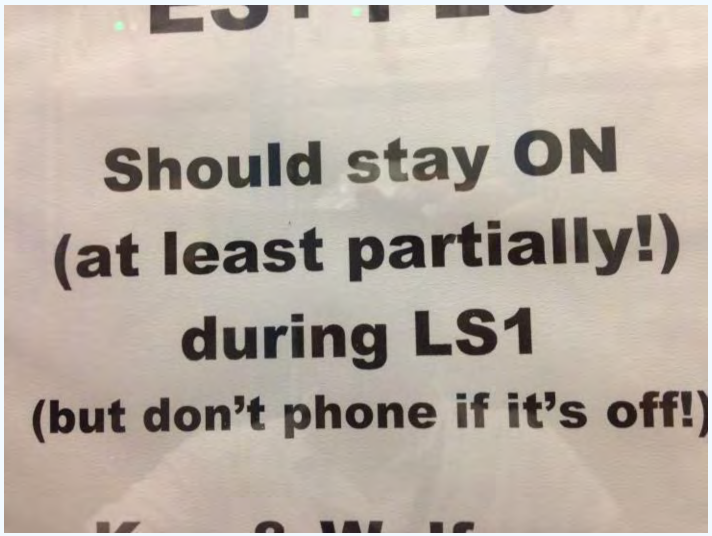
RPC			TC	TRG				TRK						
CAF	DOC	Data Manager	Piquet-patrol	HLT_DOC	L1_DOC	Off line	Shifter	DAQ on call	DCS on call	DOC	DQM on call	Off line	Off line remote	Off line shift leader

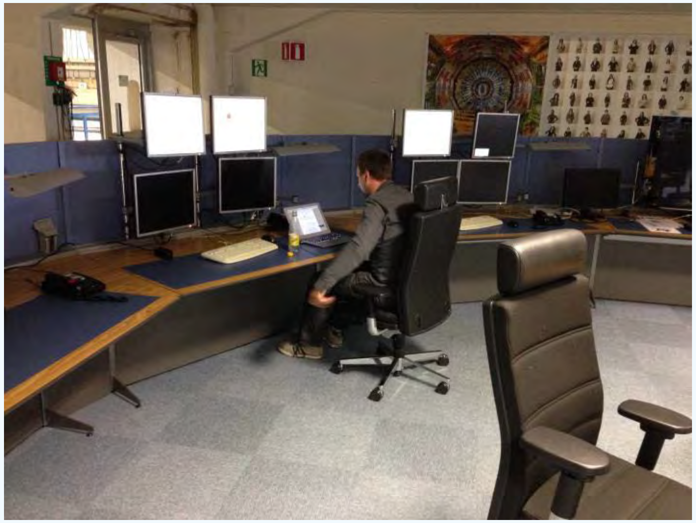
49 shifters/shift x 3 shifts/day = 147 shifters/day

now



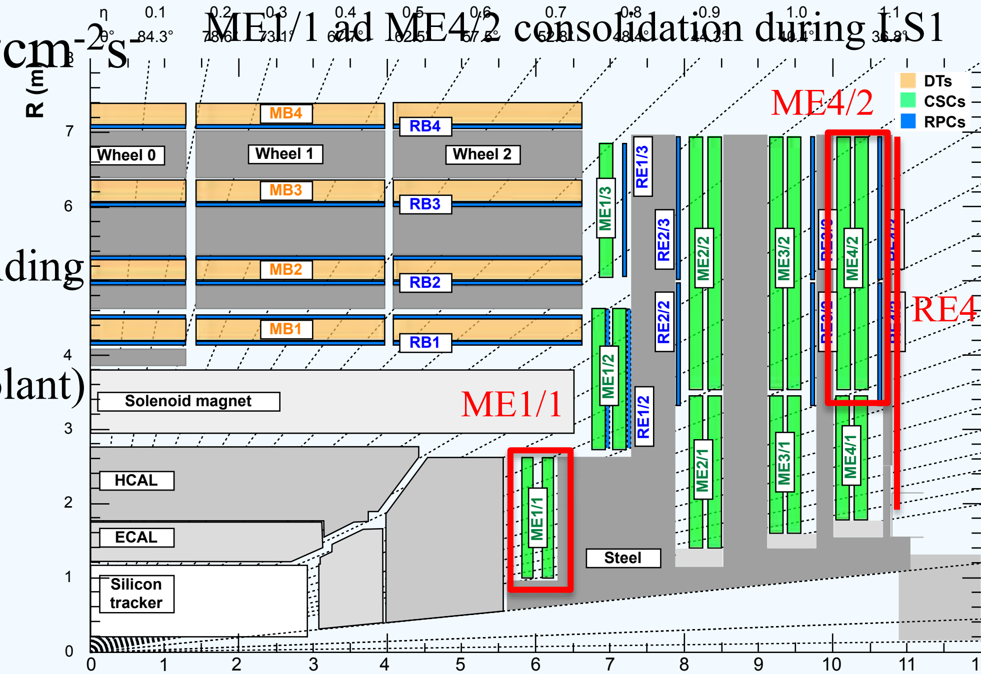
Still have 30x3=90 shifters even though there is no beam.


Should stay ON
(at least partially!)
during LS1
(but don't phone if it's off!)

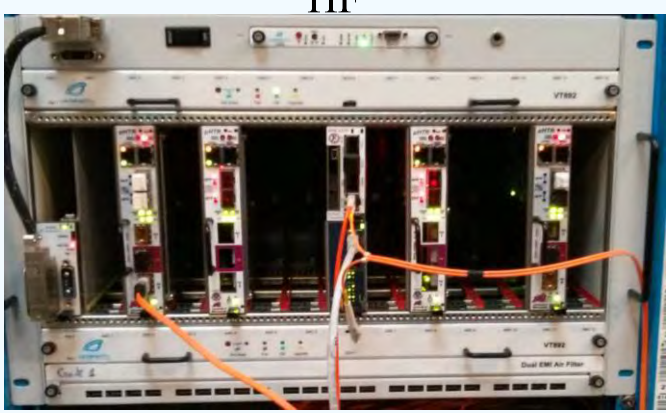


Activity in the pit

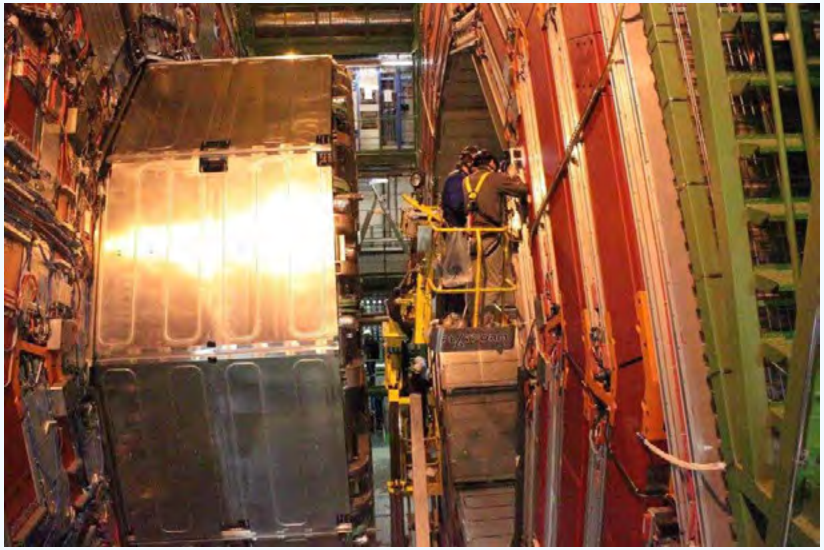
- Completion of the design for 1x10^{34}cm^{-2}s^{-1}
  - Muon endcap system
    - ME1/1 electronics (unganging)
    - ME4/2 completion of stations & shielding
  - Tracker
    - Prepare for cold operation (-20^{o}C coolant)
- Address operational issues in Run 1
  - HF photo-detectors
    - Reduce beam-related background
  - HO photo-detectors
    - operation in return field: replace with Silicon PhotoMultipliers (SiPM)
- Preparatory work for Phase 1 Upgrades
    - New beam pipe and "pilot blade" installation for the Pixel Upgrade
    - New HF backend electronics - ahead of HCAL frontend upgrade
    - Splitting for L1-Trigger inputs to allow commissioning new trigger in parallel with operating present trigger



Slice test: μTCA BE electronics for HF

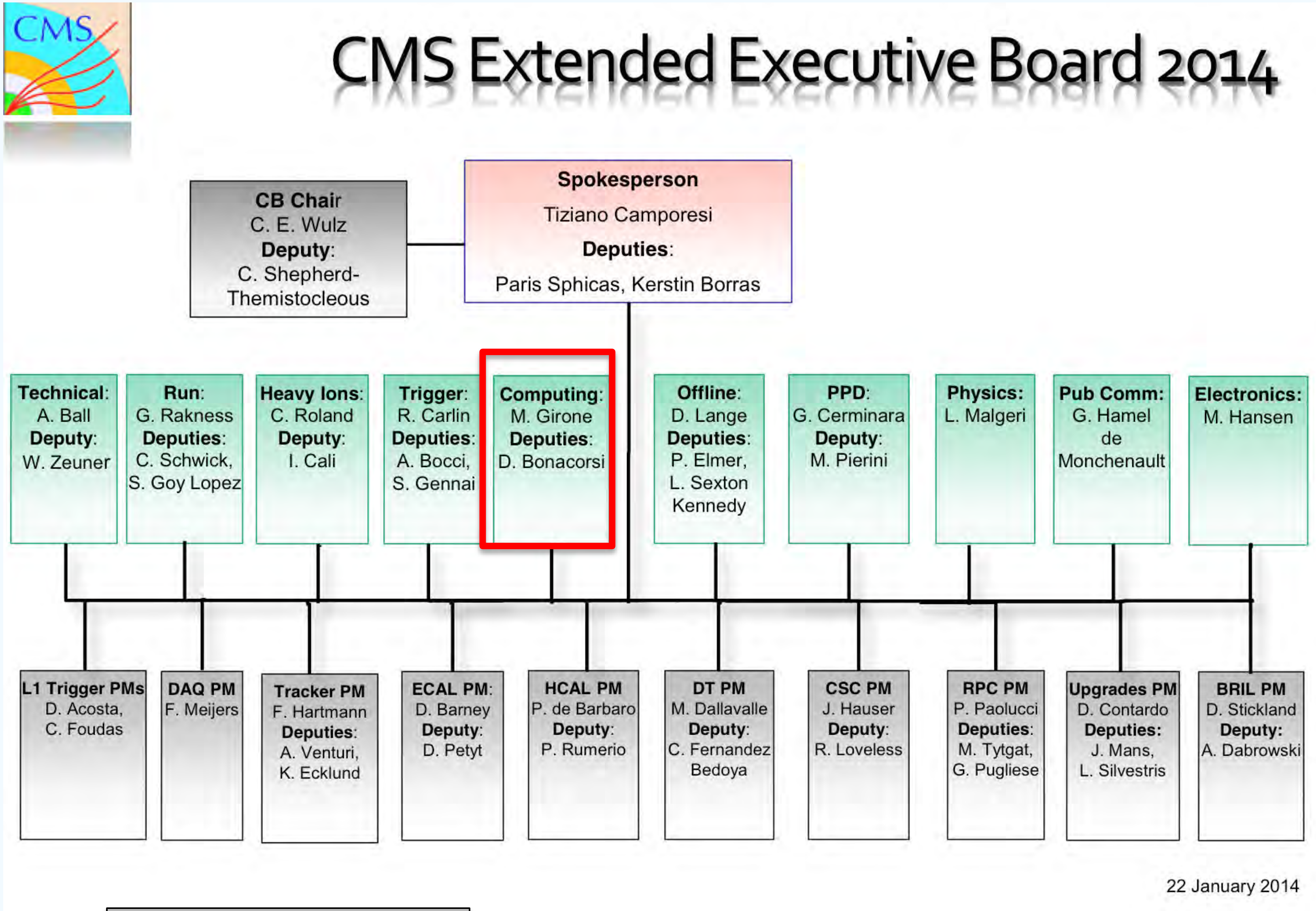


MD during LS1



Assistant Professor Alberto Belloni, Postdoc Josh Kunkle, Graduate student Chris Anelli

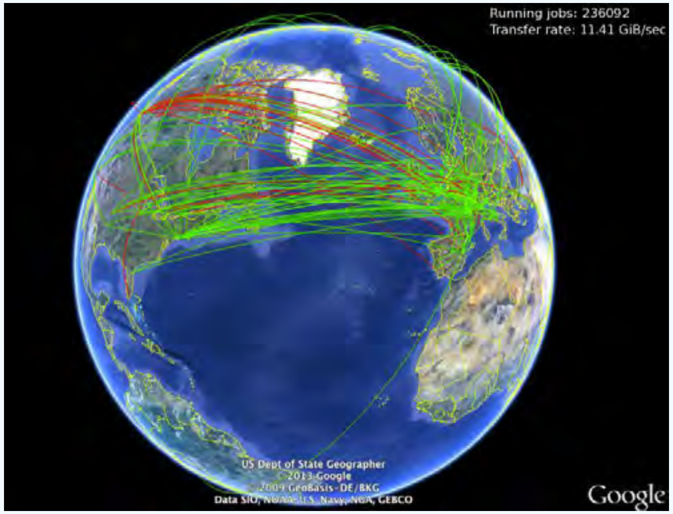
Reconstructing the data

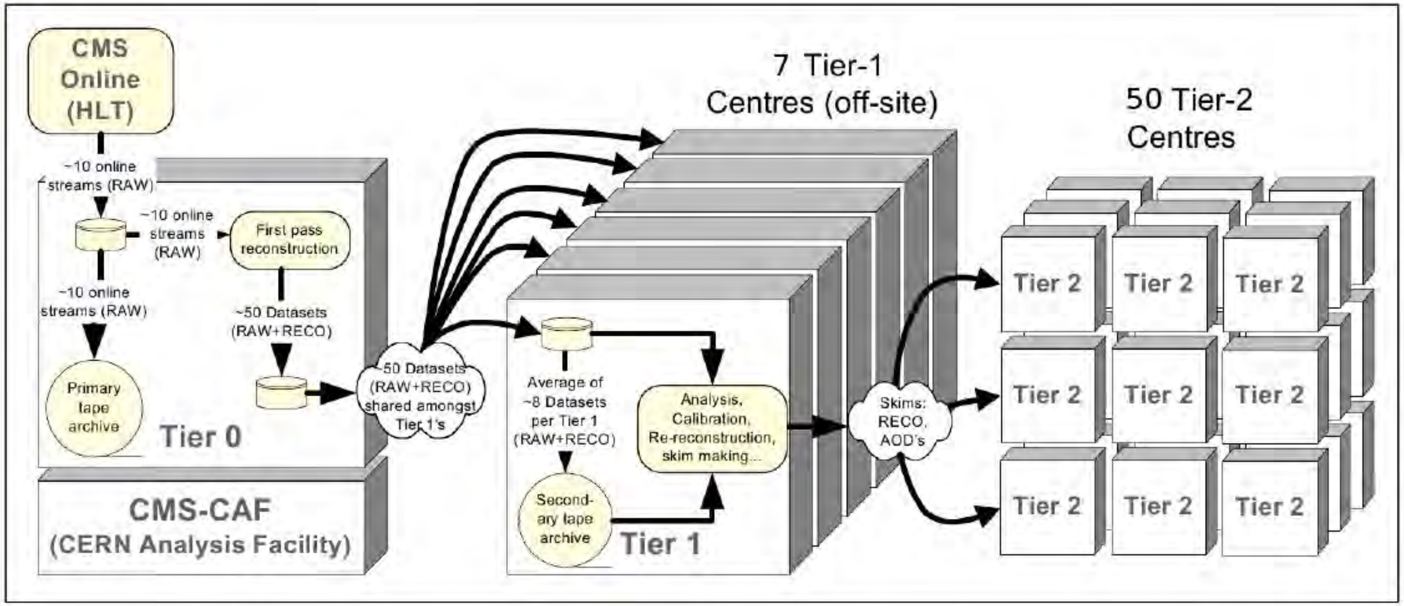


Let's look at this box

LHC Computing

- Billions of recorded collisions to the experiments ~ 100 PB of data stored at CERN
- The Worldwide LHC Computing Grid (WLCG) provides compute and storage resources for data processing, simulation and analysis ~ 300k cores, ~200 PB disk, ~200 PB tape
- The data and simulated data needs to be reprocessed multiple times as new calibrations and algorithm become available.

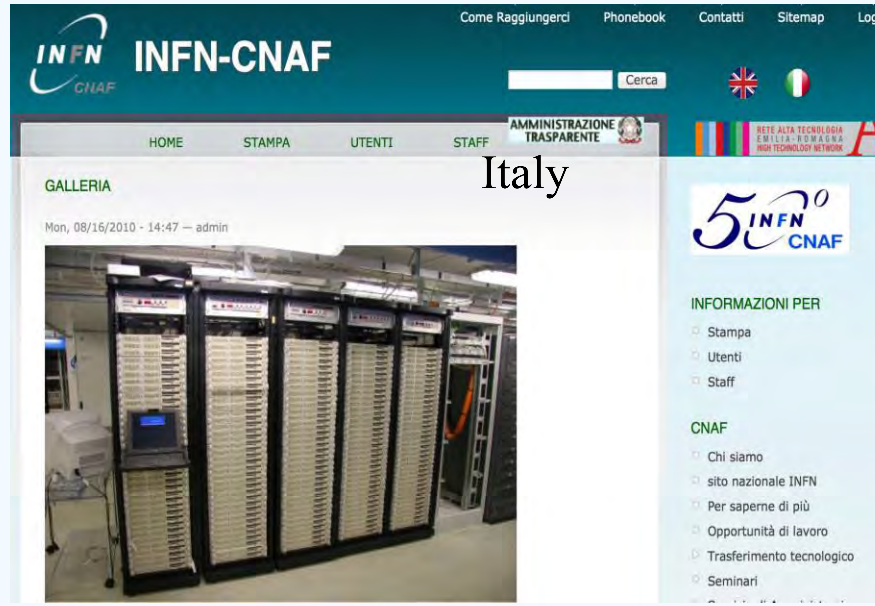




Tier 1 computing

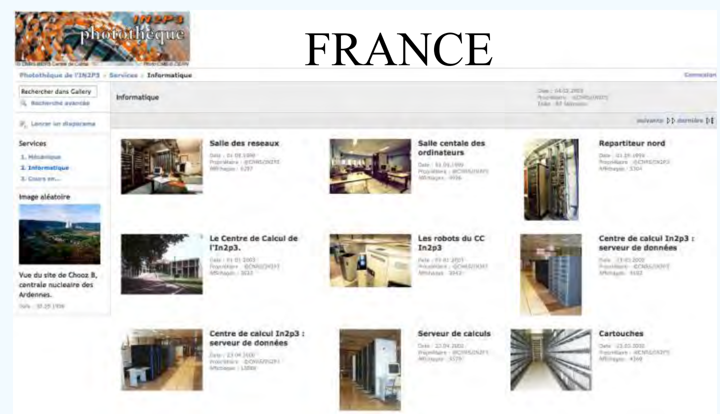
Our computing is spread over the world.
Most of our collaboration is not at CERN.

Tier 1

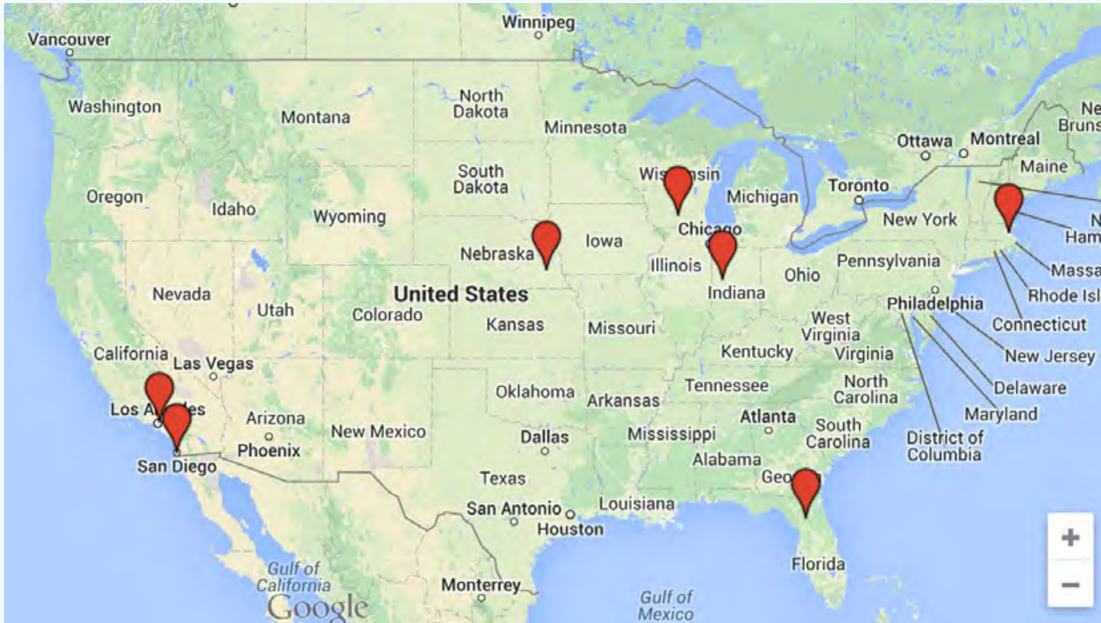


The ASGC team with director Simon Lin (front row, second from right).

The data centre at the ASGC with 400 KSI2K computing capacity.



Tier 2: USA


Vancouver
Winnipeg
Washington
Montana
North Dakota
Minnesota
Oregon
Idaho
Wyoming
South Dakota
Michigan
Ottawa
Montreal
Maine
Toronto
New York
Nebraska
Iowa
Illinois
Indiana
Ohio
Pennsylvania
Nevada
Utah
United States
Colorado
Kansas
Missouri
Philadelphia
Rhode Isla
Connecticut
New Jersey
Delaware
Maryland
District of Columbia
West Virginia
Virginia
Kentucky
North Carolina
Tennessee
California
Las Vegas
Arizona
New Mexico
Oklahoma
Arkansas
Atlanta
South Carolina
Phoenix
San Diego
Dallas
Mississippi
Alabama
Texas
San Antonio
Houston
Louisiana
Florida
Gulf of California
Monterrey
Gulf of Mexico
Google


NEBRASKA

UMD: Tier 3

10 Tbytes/day

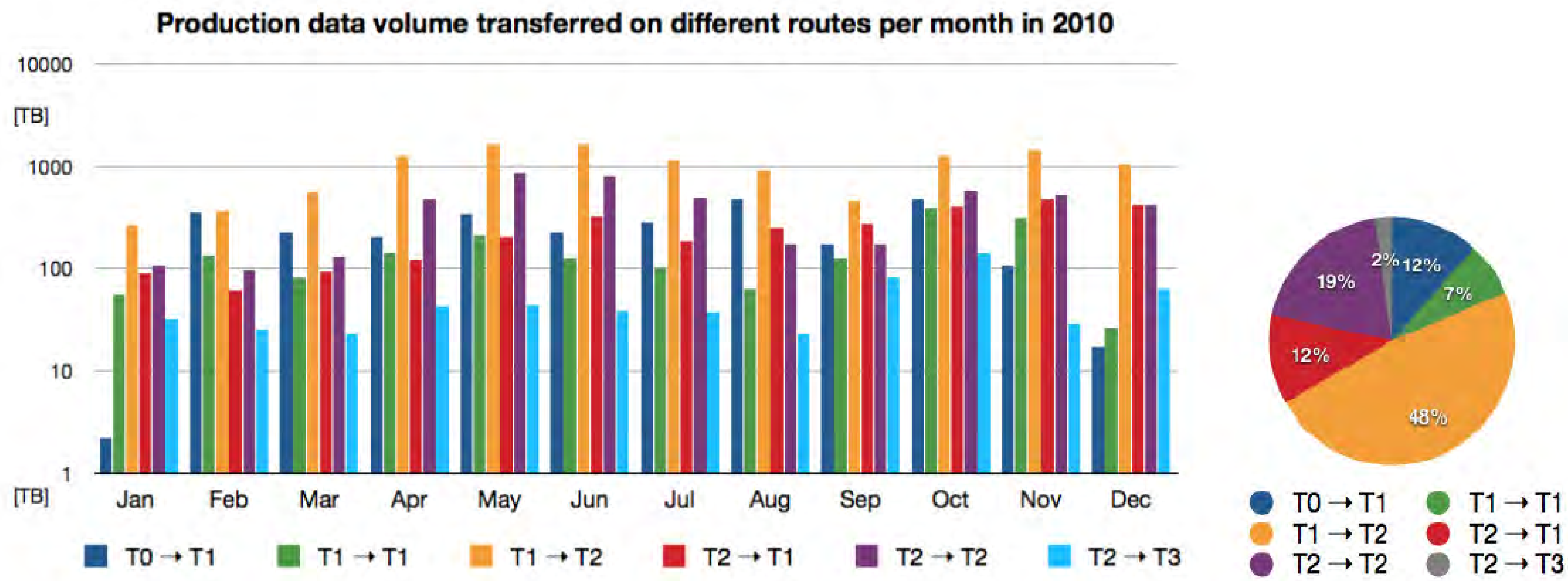
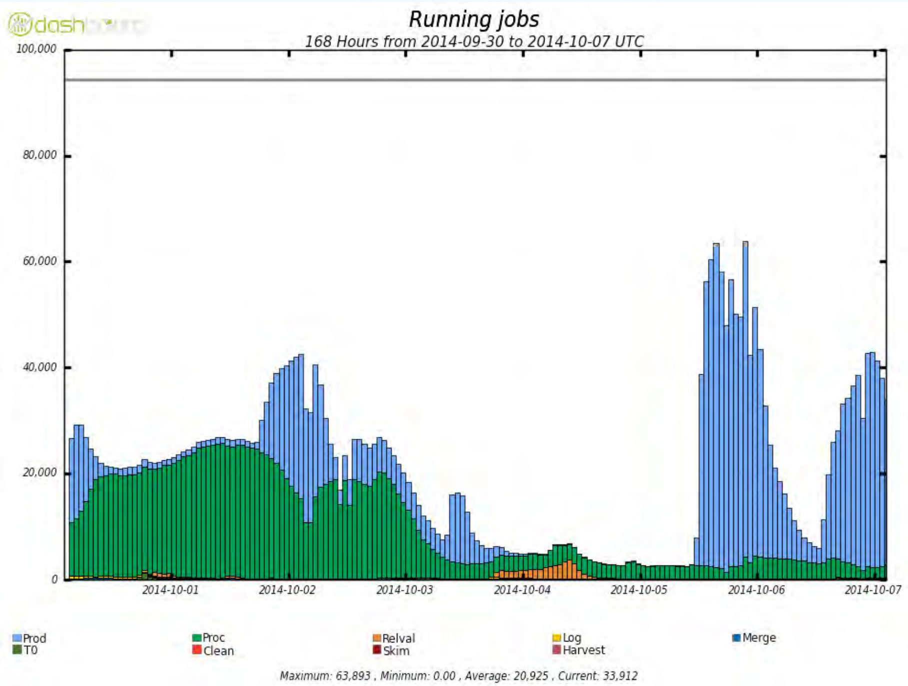
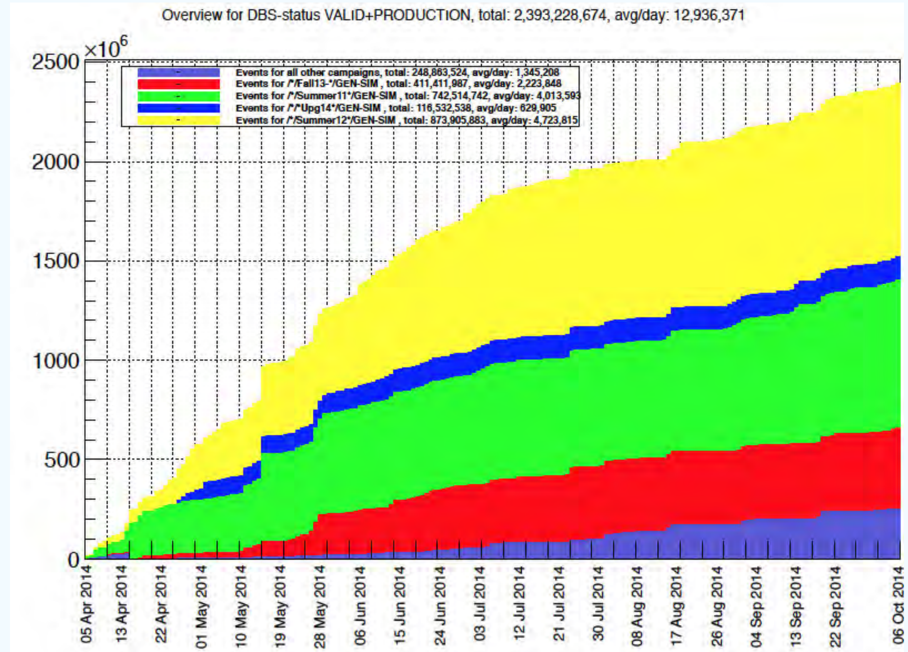


Figure 4: CMS traffic on the different route categories in 2010

Recent jobs

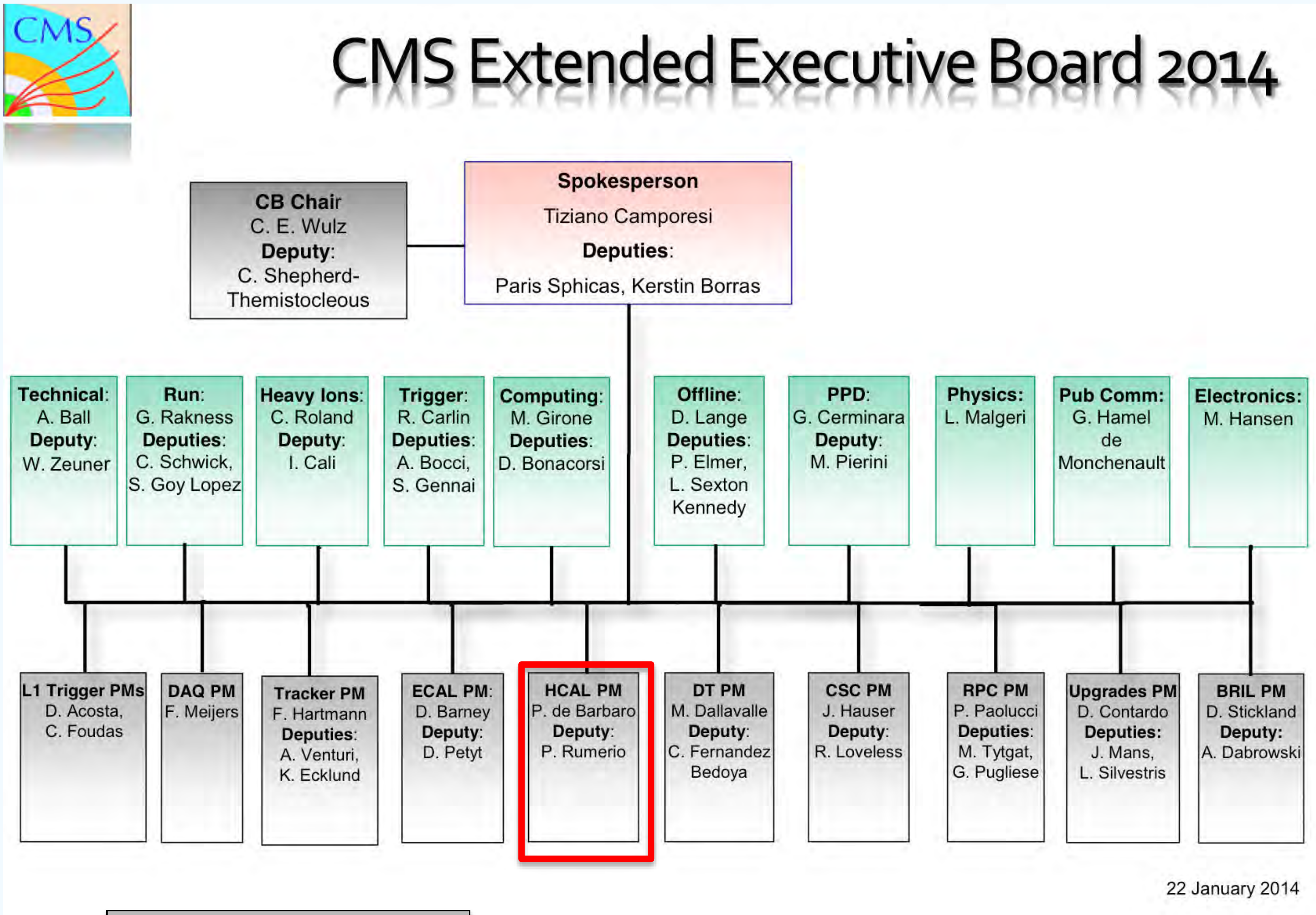




Data reprocessing
Simulations for upgrades
Simulations for run this spring
Physics analysis from last run

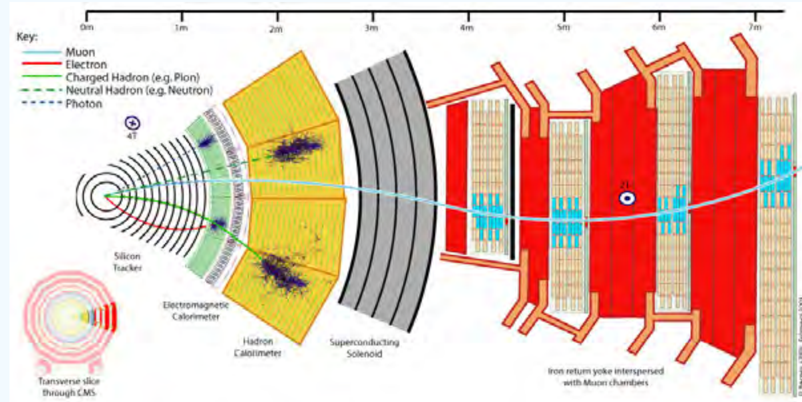
We are preparing the data samples for the upcoming run, which will start in the spring.

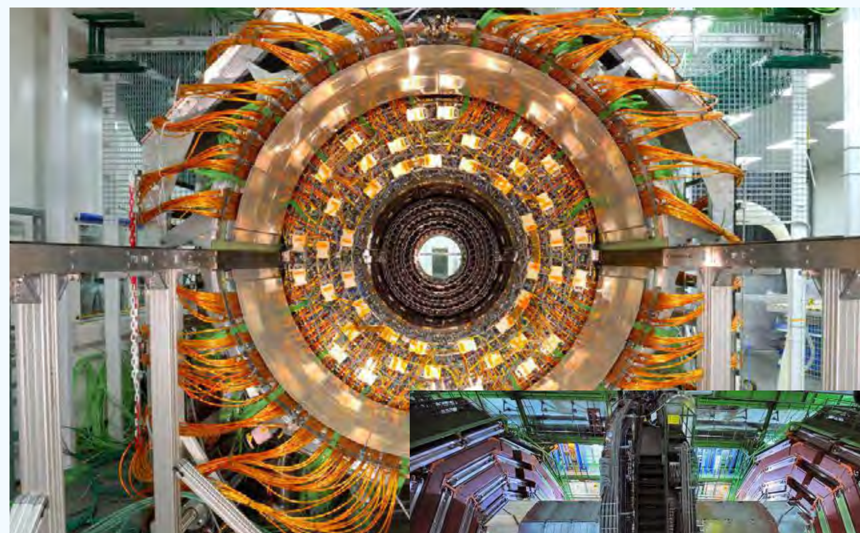
Detector Work



Let's look at this box

Complex Detector





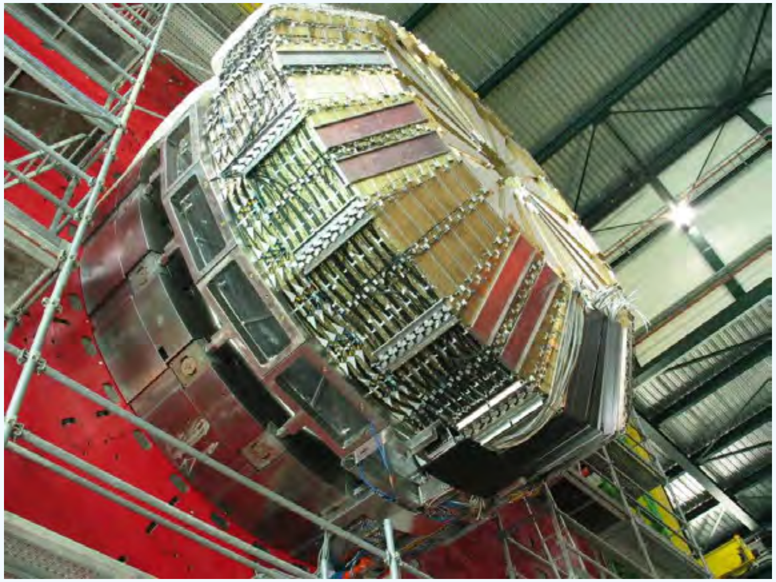
55 million channels

Table 9.1: Sub-detector read-out parameters.

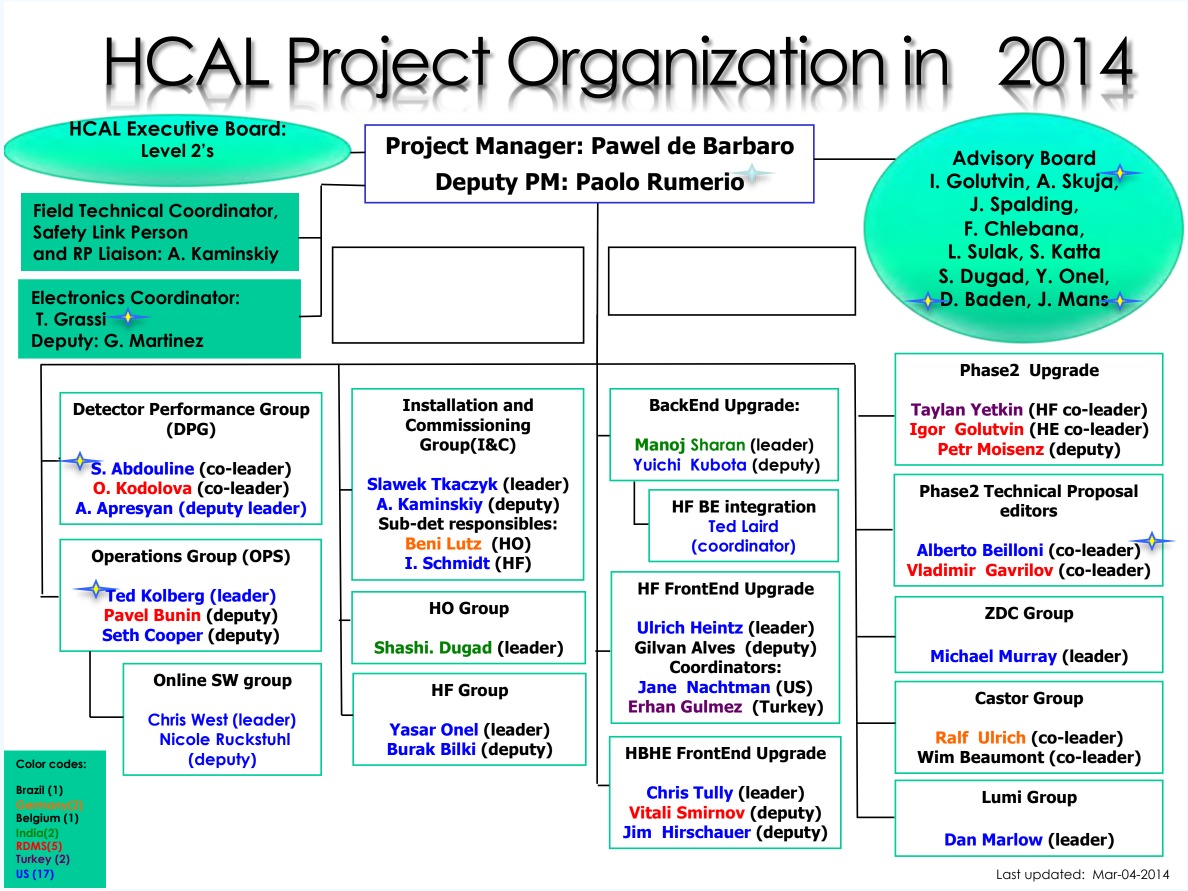
sub-detector	number of channels	number of FE chips	number of detector data links	number of data sources (FEDs)	number of DAQ links (FRLs)
Tracker pixel	≈ 66 M	15840	≈ 1500	40	40
Tracker strips	≈ 9.3 M	≈ 72 k	≈ 36 k	440	250 (merged)
Preshower	144384	4512	1128	56	56
ECAL	75848	≈ 21 k	≈ 9 k	54	54
HCAL	9072	9072	3072	32	32
Muons CSC	≈ 500 k	≈ 76 k	540	8	8
Muons RPC	192 k	≈ 8.6 k	732	3	3
Muons DT	195 k	48820	60	10	10
Global Trigger	n/a	n/a	n/a	3	3
CSC, DT Track Finder	n/a	n/a	n/a	2	2
Total	≈ 55 M			626	458

55,000,000/1400=40,000 channels per active collaborator

HCAL



Detailed Detector Work



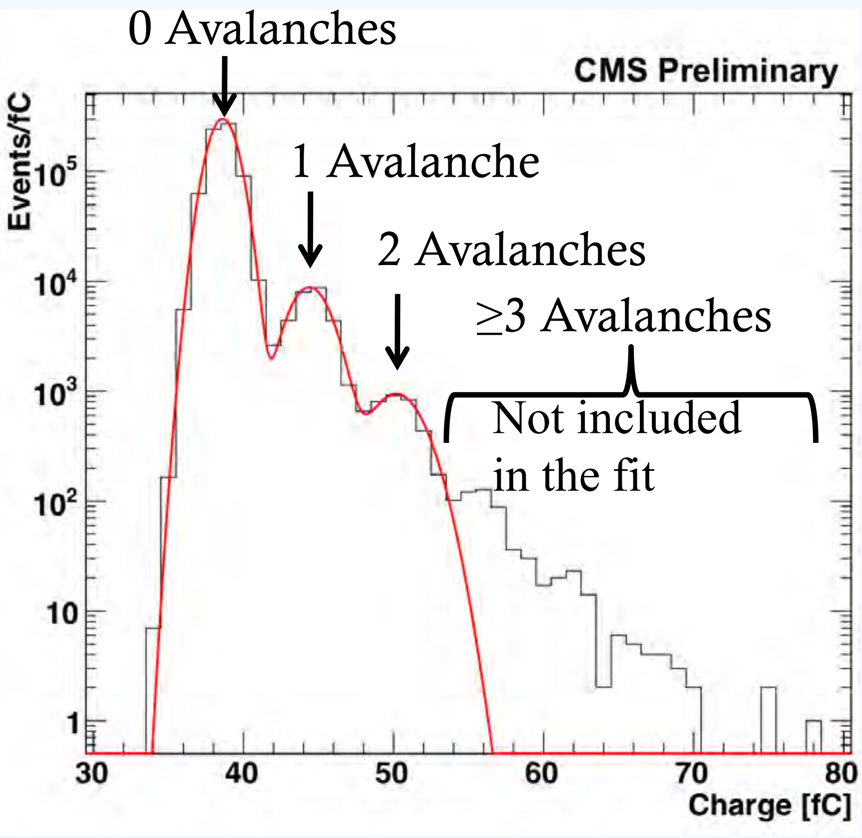
- The lower levels in these boxes actually work directly with workers
- Since this is the HCAL box, many MD or former MD
- You can start to see from these boxes what the people actually do.
- Several hundred people doing something. Strong division by nationality and national effects.

Gain determination

- The presence of dark counts allows a fit to the pedestal charge distribution to determine:
  - **Gain:** Difference between the charge of the 0 and 1 avalanche peak
  - **Dark Count Rate:** Average number of avalanches per event
  - **Cross-Talk Rate:** Rate that avalanche in one SiPM causes another avalanche in the same SiPM

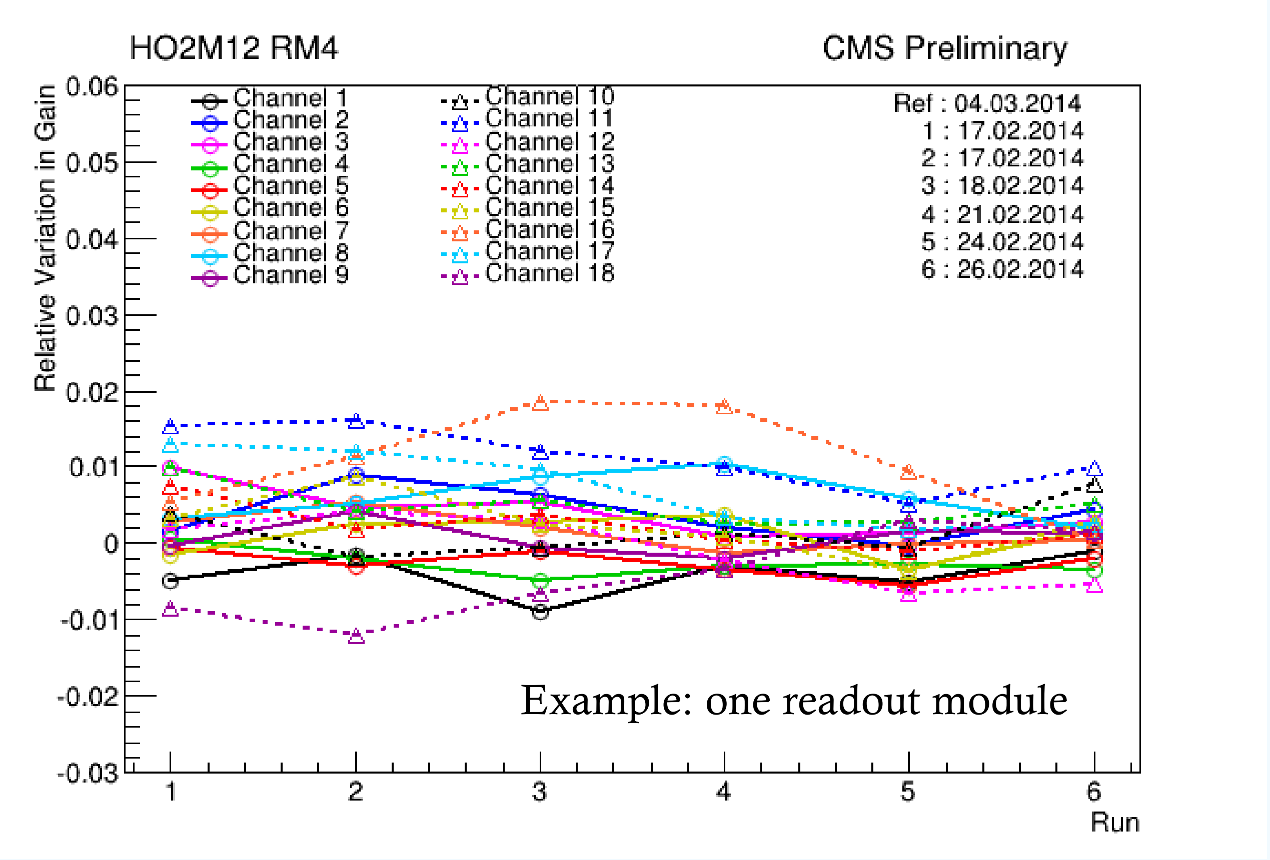
[The fit details can be found in backup]

SiPM Pedestal Charge Distribution



Relative Gain Variation vs. Time

- Stability of gain is monitored over the period of time
  - Example:
    Relative gain variation for 18 channels of one of the readout modules

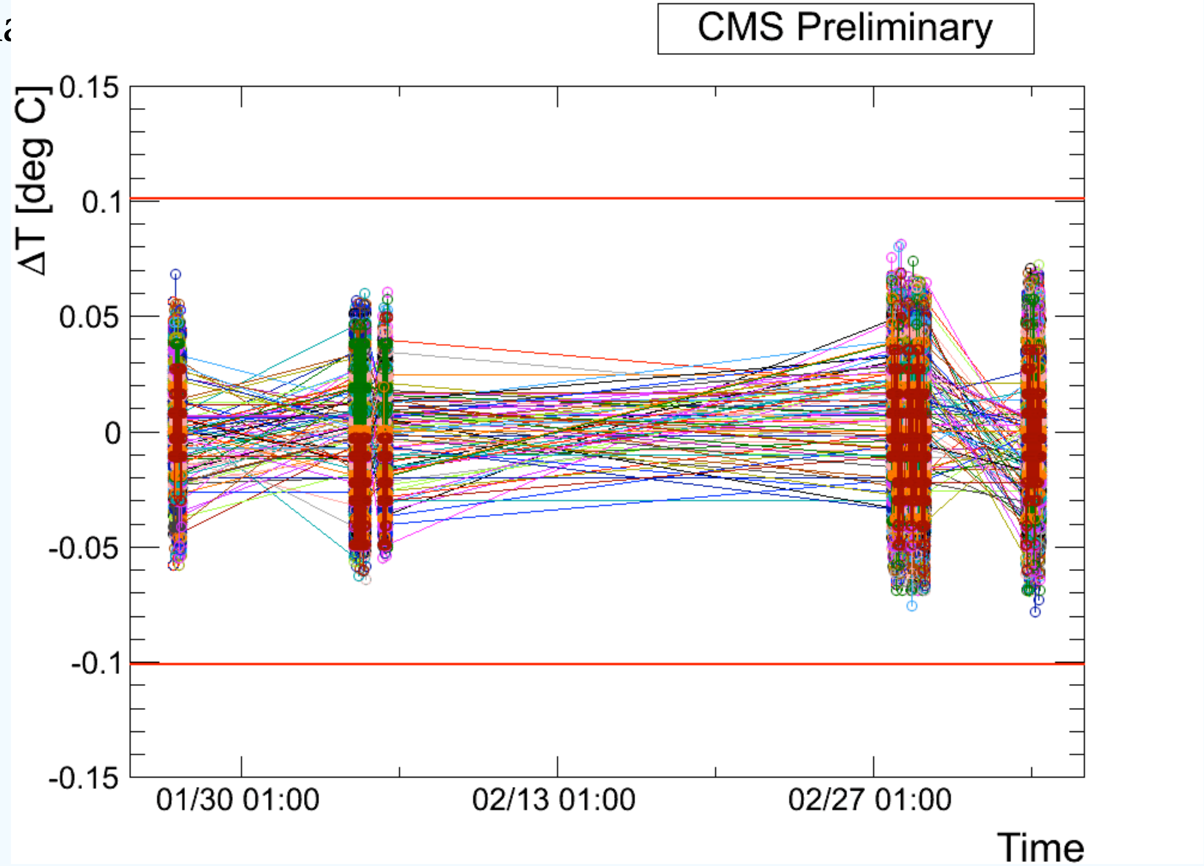


Relative variation in Gain:

$$\frac{Gain - Gain_{ref}}{Gain_{ref}}$$

Temperature Stability

- The SiPM properties are temperature sensitive and Peltier cooling is used to stabilize temperature for each readout module
  - Desired goal for thermal conditions for optimal SiPM operation is achieved: within ±0.1 deg C



What all these people buy

- Speed
- A perfectly calibrated detector on day 1

Run Aug – Oct 92. Some plots from a Nov 92 talk right after D0 startup (Madaras)

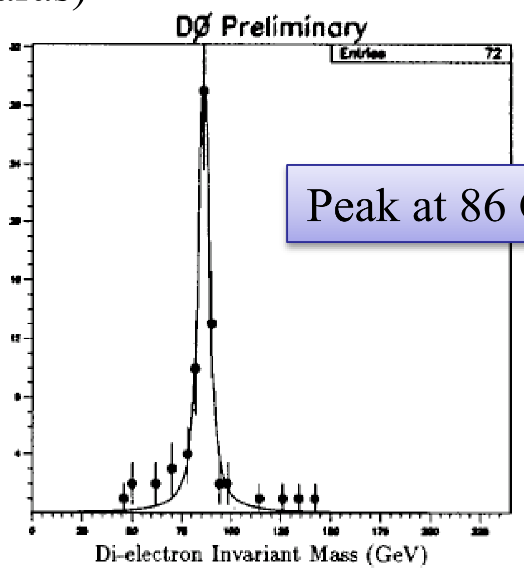
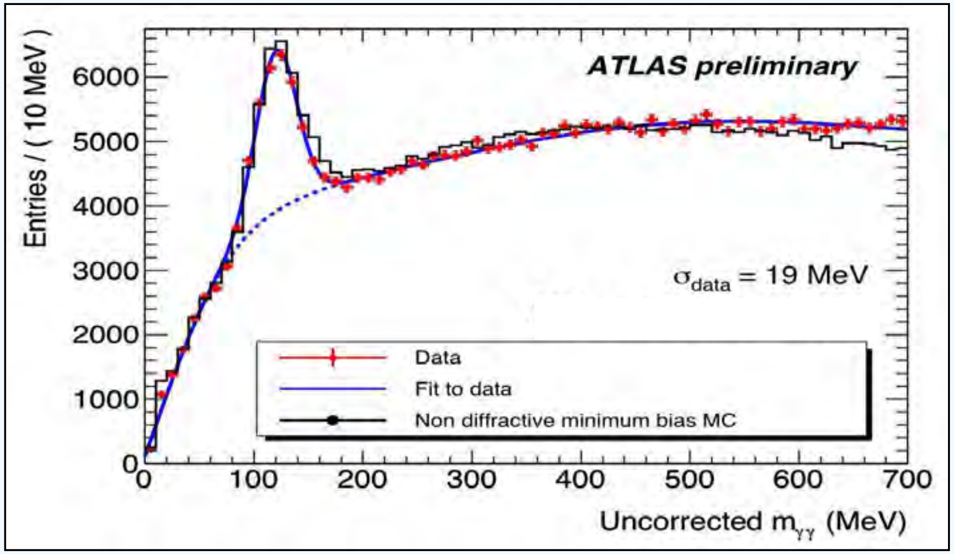
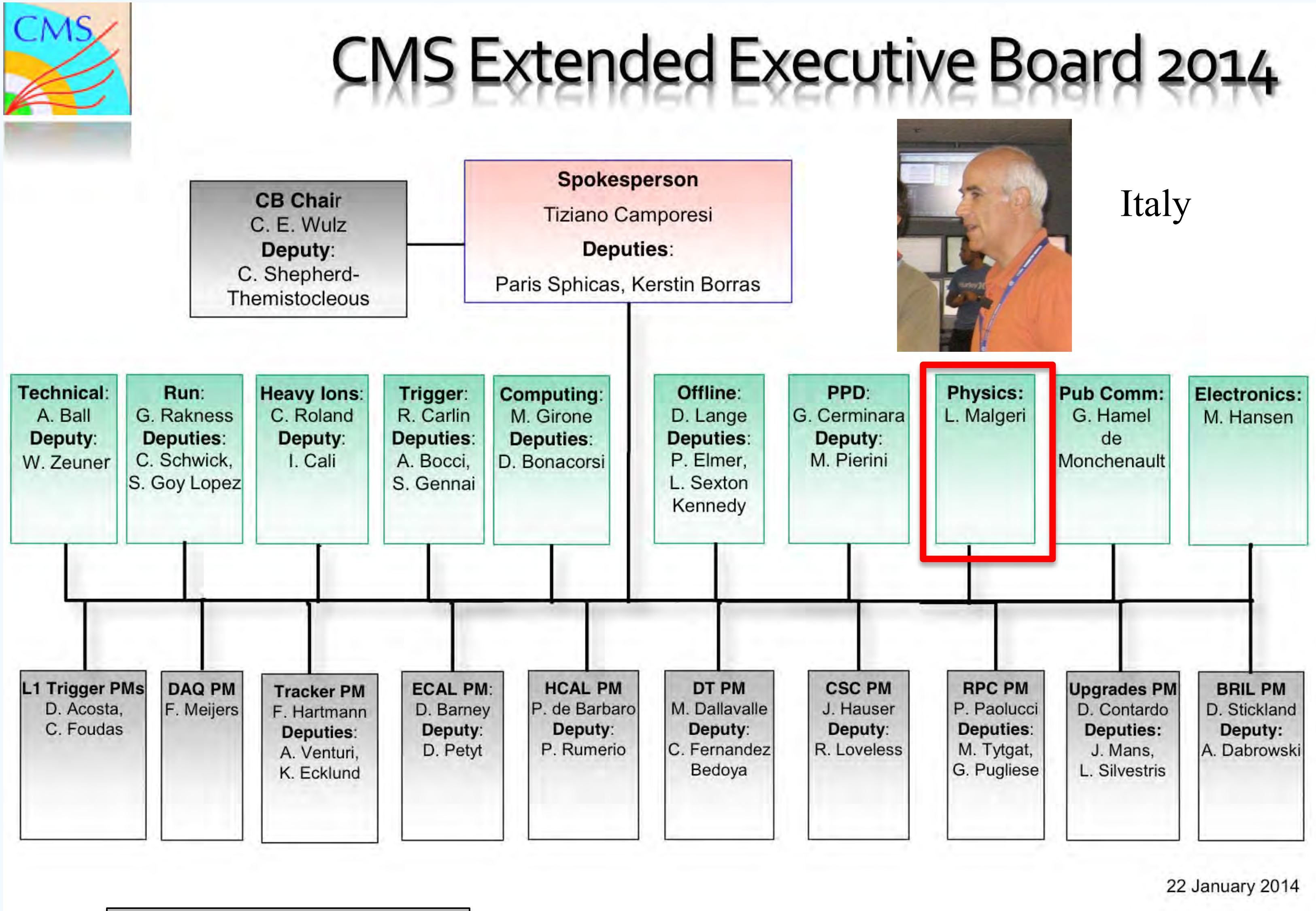


Figure 7: Di-electron invariant mass distribution, with a Breit-Wigner fit.



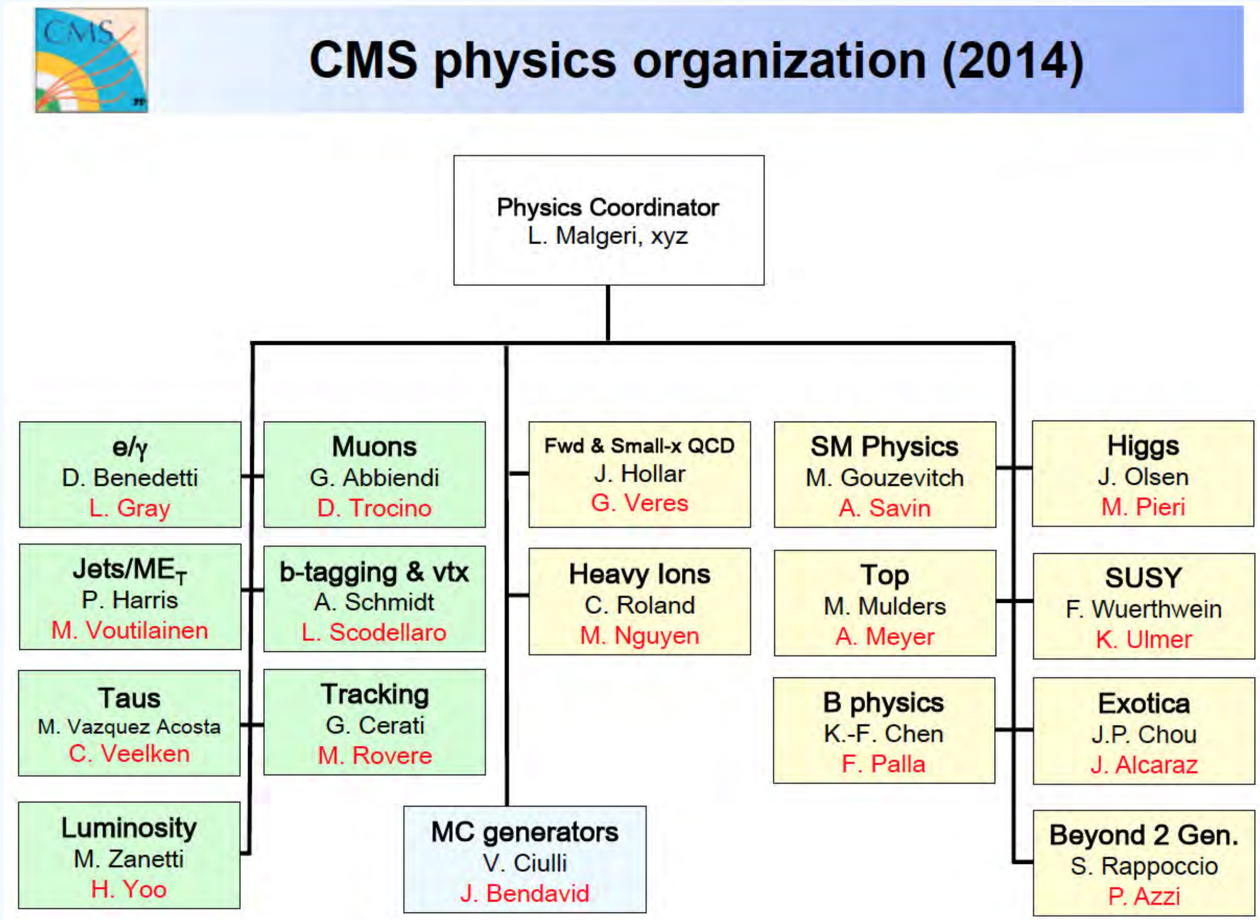
"Physics"



Italy

Let's look at this box

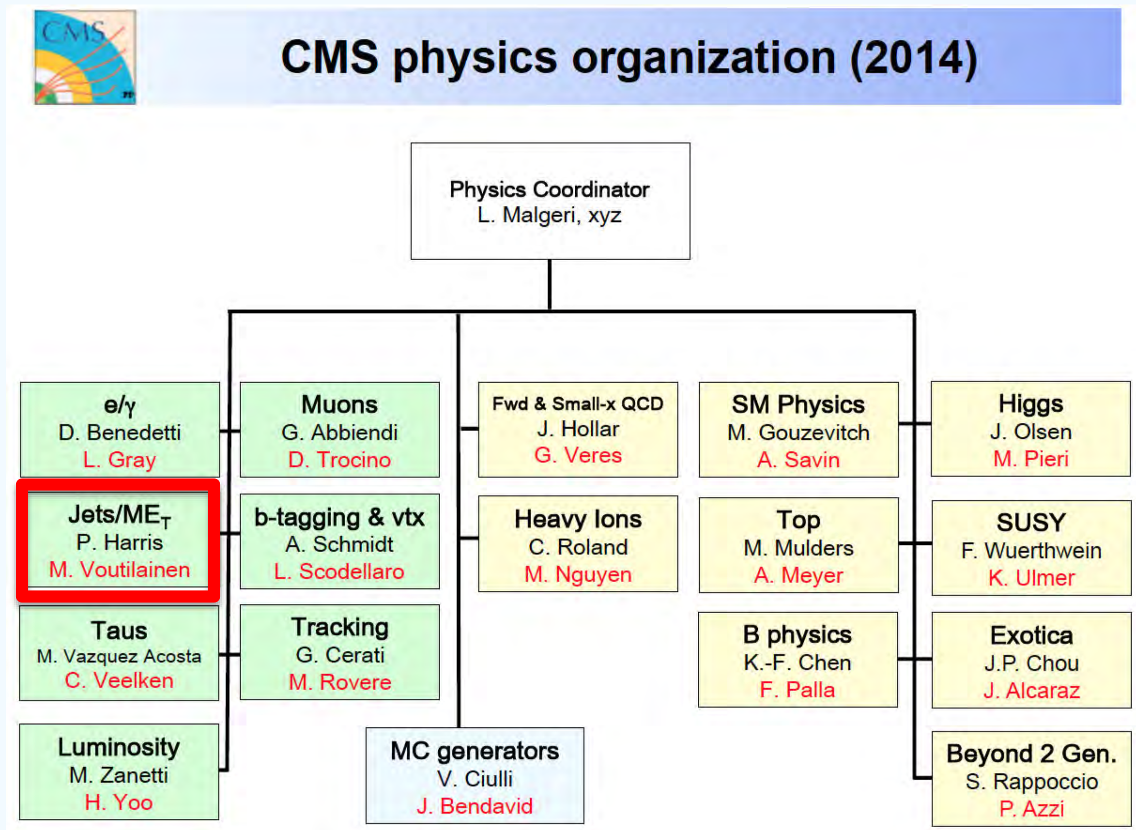
“Physics”



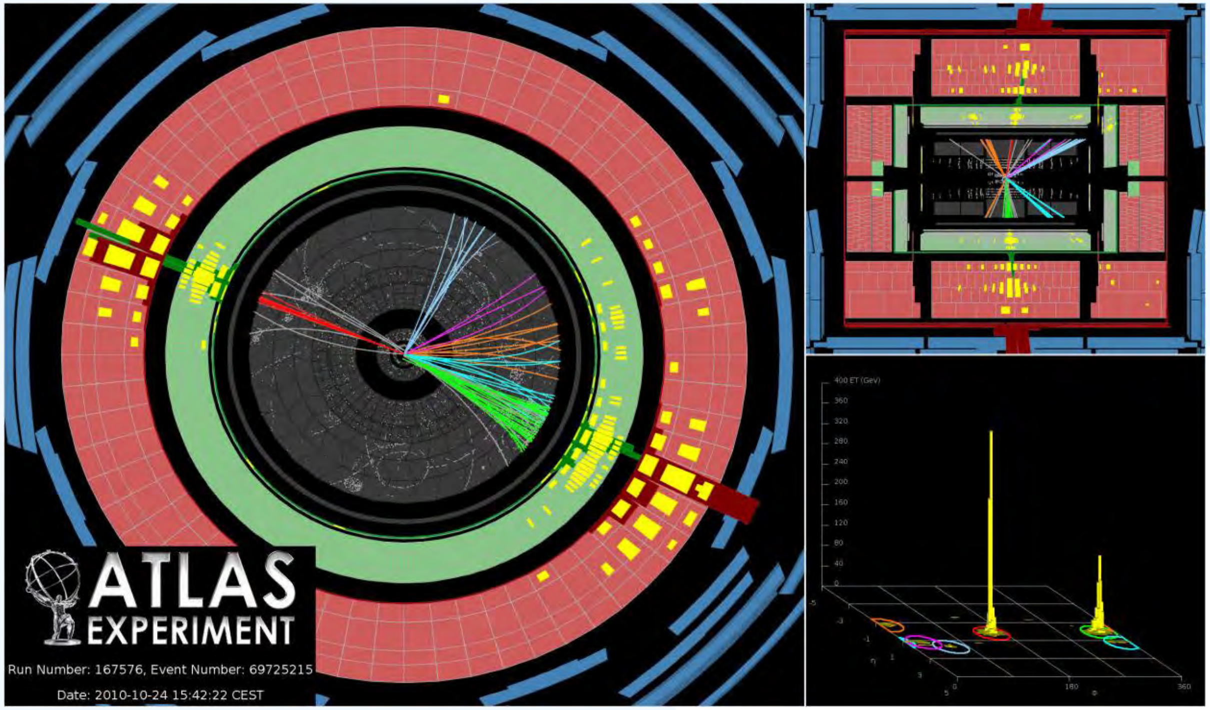
- Physics title is “fancy”, although boxes associated with detectors generally lead to money.
- I used to sit in two of these boxes. I’m now one layer down.
- Let’s look at those two boxes

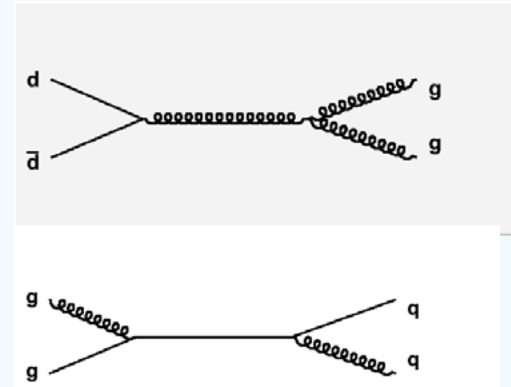
Particle identification, reconstruction, and calibration

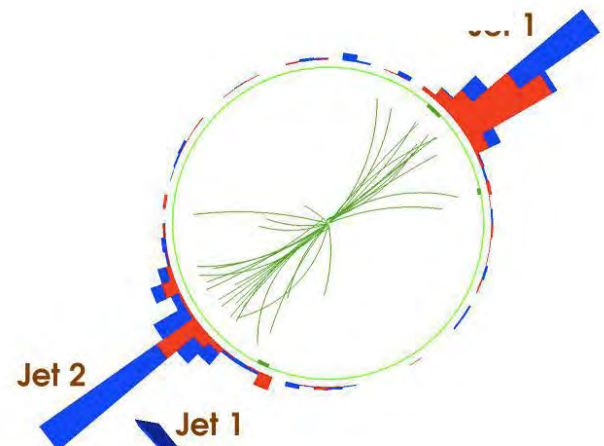
- I ran this group 1999-2002.
- I ran the MET subgroup during 2010, 2011
- Perhaps 100 active people
- Understanding the calibration of jets is one of the most challenging tasks in a hadron collider
- Maryland mostly worked on MET, perhaps 20 active people.

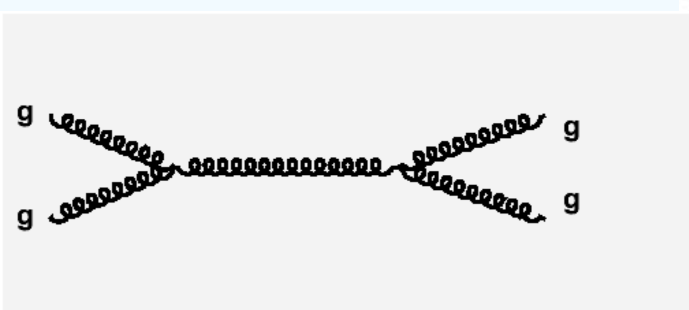


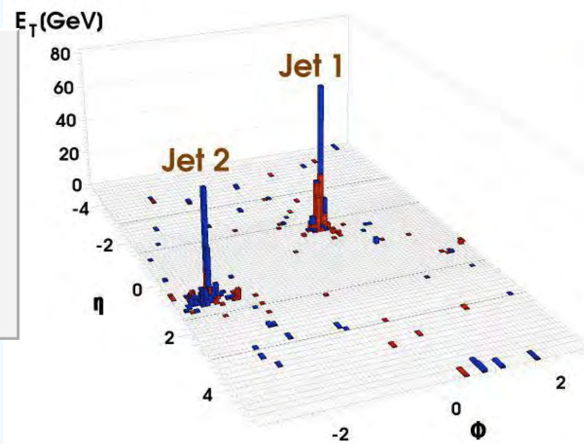
Jets

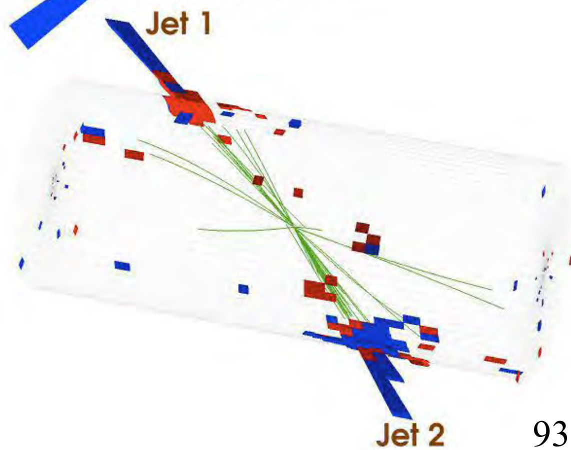

ATLAS EXPERIMENT
Run Number: 167576, Event Number: 69725215
Date: 2010-10-24 15:42:22 CEST


d
d̄
g
g
g
g
q
q

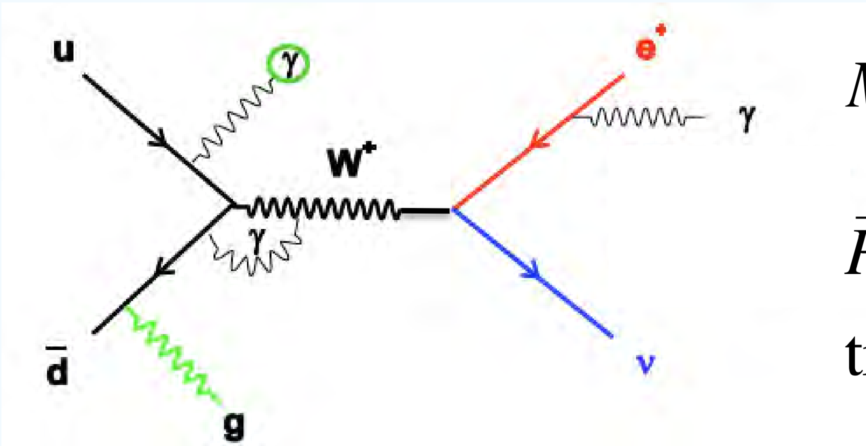

Jet 1
Jet 2


g
g
g
g


E_T(GeV)
80
60
40
20
0
-4
-2
0
2
4
η
Jet 1
Jet 2
-2
0
2
Φ

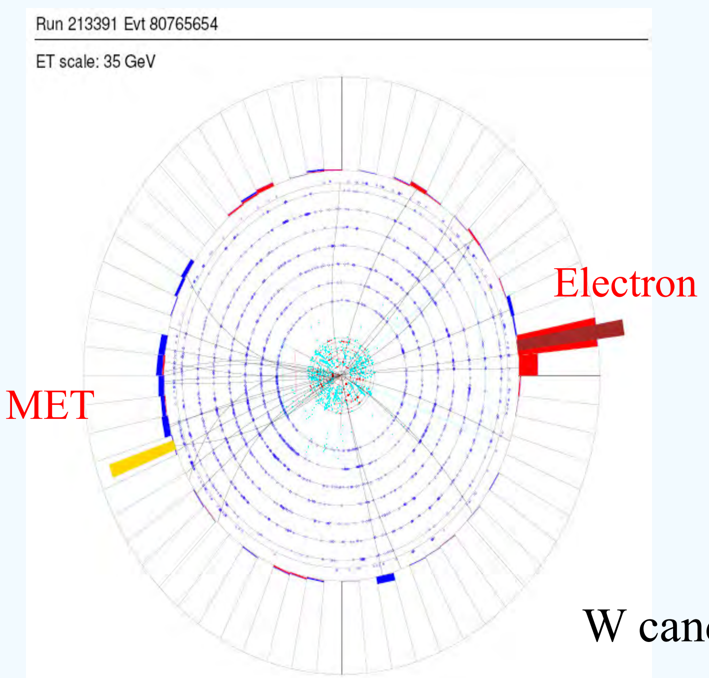

Jet 1
Jet 2

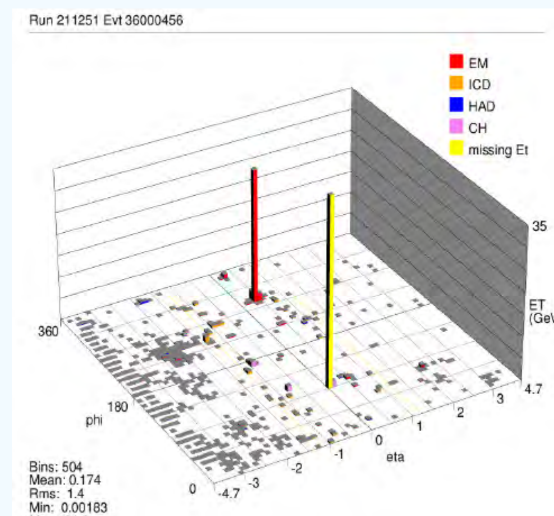
Neutrinos at Hadron Colliders



$$MET \equiv \not{E}_T = -\sum_{\text{all particles}} \vec{P}_T$$

$\vec{P}_T$ is the component of momentum transverse to beam axis





W candidate event from D0 experiment

Particle ID performance

Jinst
PUBLISHED BY IOP PUBLISHING FOR SISSA
RECEIVED: *June 25, 2011*
ACCEPTED: *July 22, 2011*
PUBLISHED: *September 9, 2011*

LHC REFERENCE VOLUME

Missing transverse energy performance of the CMS detector

The CMS collaboration

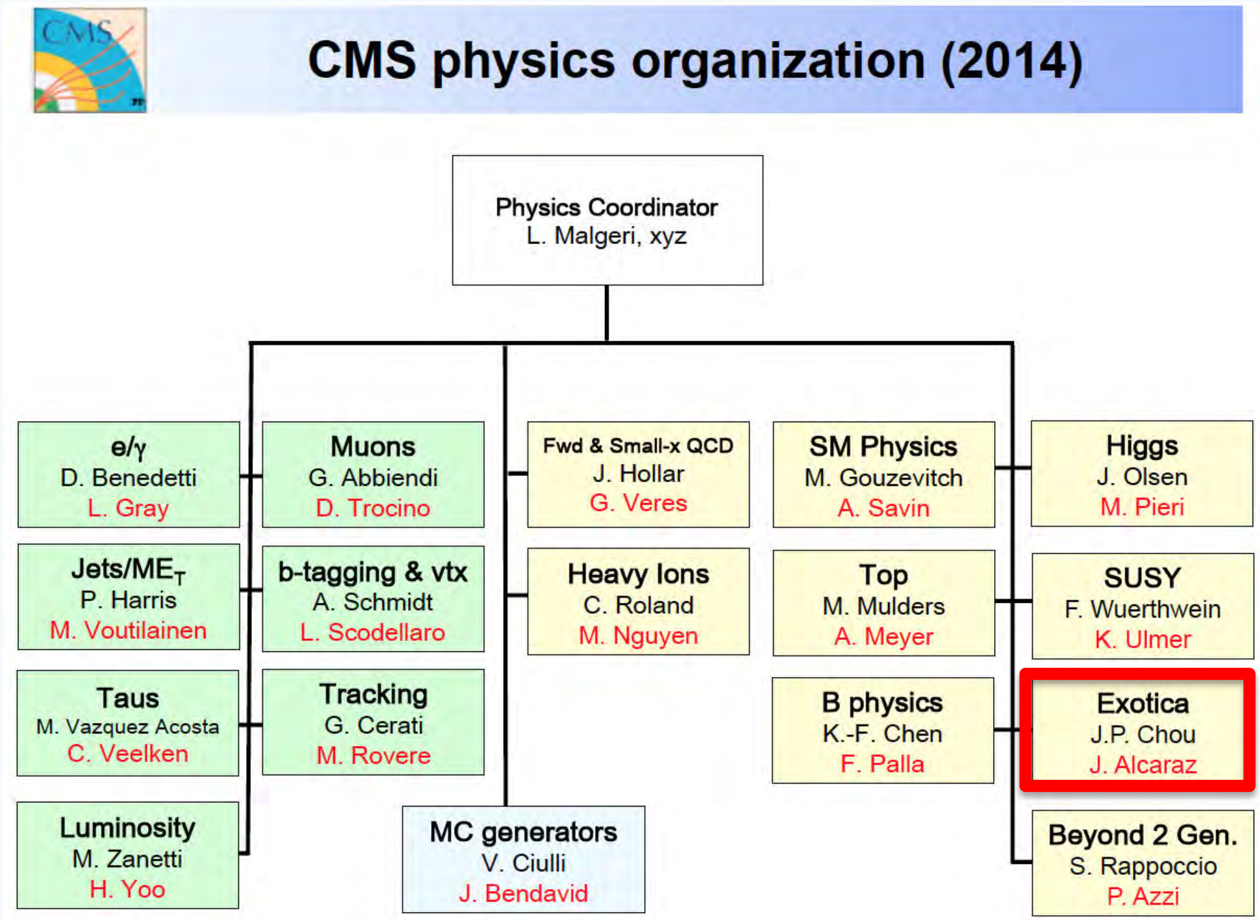
ABSTRACT: During 2010 the LHC delivered pp collisions with a centre-of-mass energy of 7 TeV. In this paper, the results of comprehensive studies of missing transverse energy as measured by the CMS detector are presented. The results cover the measurements of the scale and resolution for missing transverse energy, and the effects of multiple pp interactions within the same bunch crossings on the scale and resolution. Anomalous measurements of missing transverse energy are studied, and algorithms for their identification are described. The performance of several reconstruction algorithms for calculating missing transverse energy are compared. An algorithm, called missing-transverse-energy significance, which estimates the compatibility of the reconstructed missing transverse energy with zero, is described, and its performance is demonstrated.

KEYWORDS: Performance of High Energy Physics detectors; Missing Transverse Energy studies; Calorimeter methods; Detector modelling and simulations (interaction of radiation with matter, interaction of photons with matter, interaction of hadrons with matter, etc)

2011 JINST 6 P09001

Have produced one for the 2011 run and one for the 2012 run (55 pages).

“Physics”



I ran this group 2007 and 2008.

Exotica

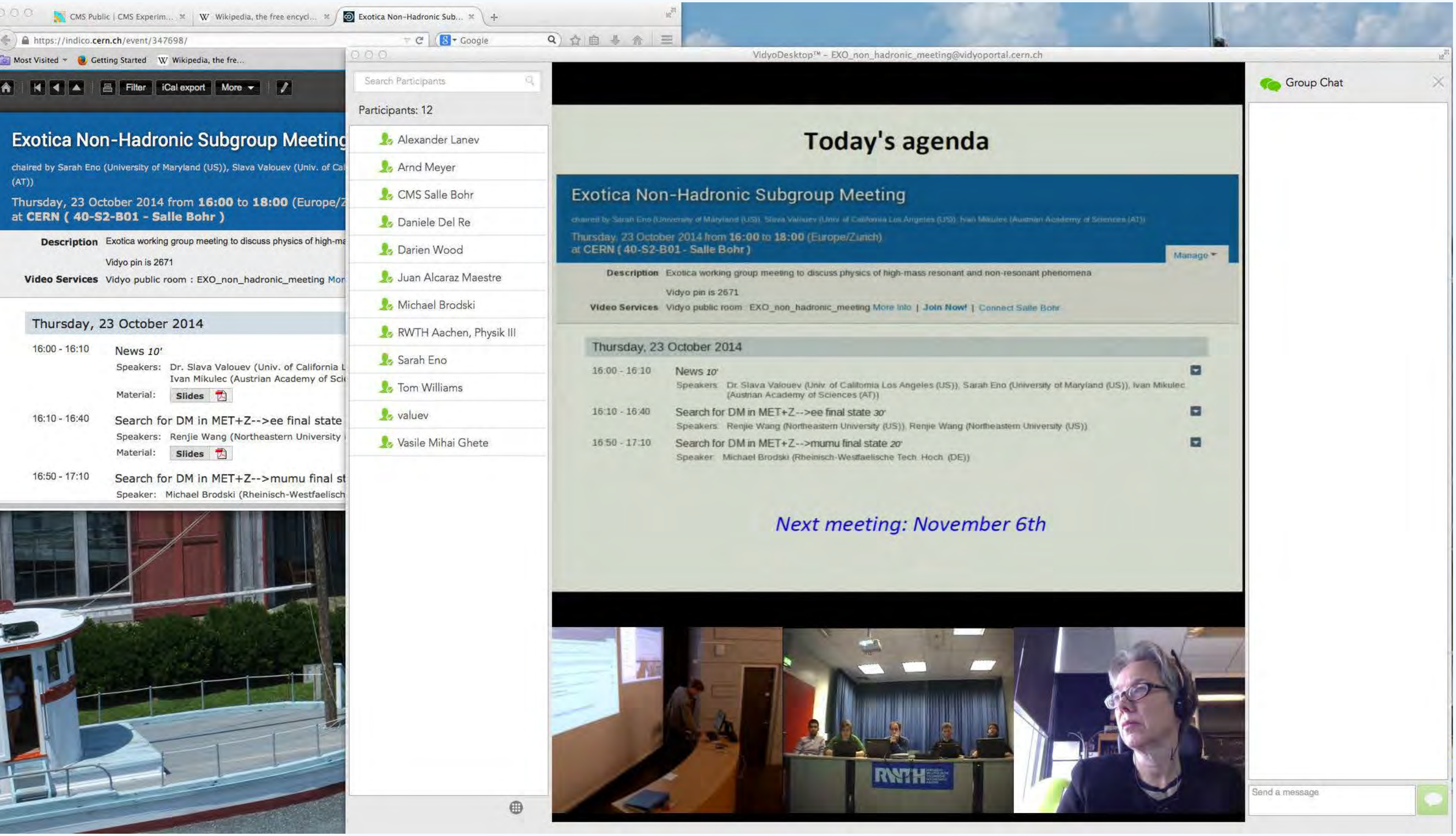
Exotica Analysis Working Groups

- Non-hadronic: Sarah Eno and Slava Valuev
- Lepton + Jet Signatures: Francesco Santanastasio and Ketino Kaadze
- Jet Final States: Andreas Hinzmann and Bryan Dahmes
- Long-lived Particles: Loic Quertenmont and Daniele del Re
- Theory and MC: Stephen Mrenna and Steven Lowette
- Future Physics: Kerstin Hoepfner

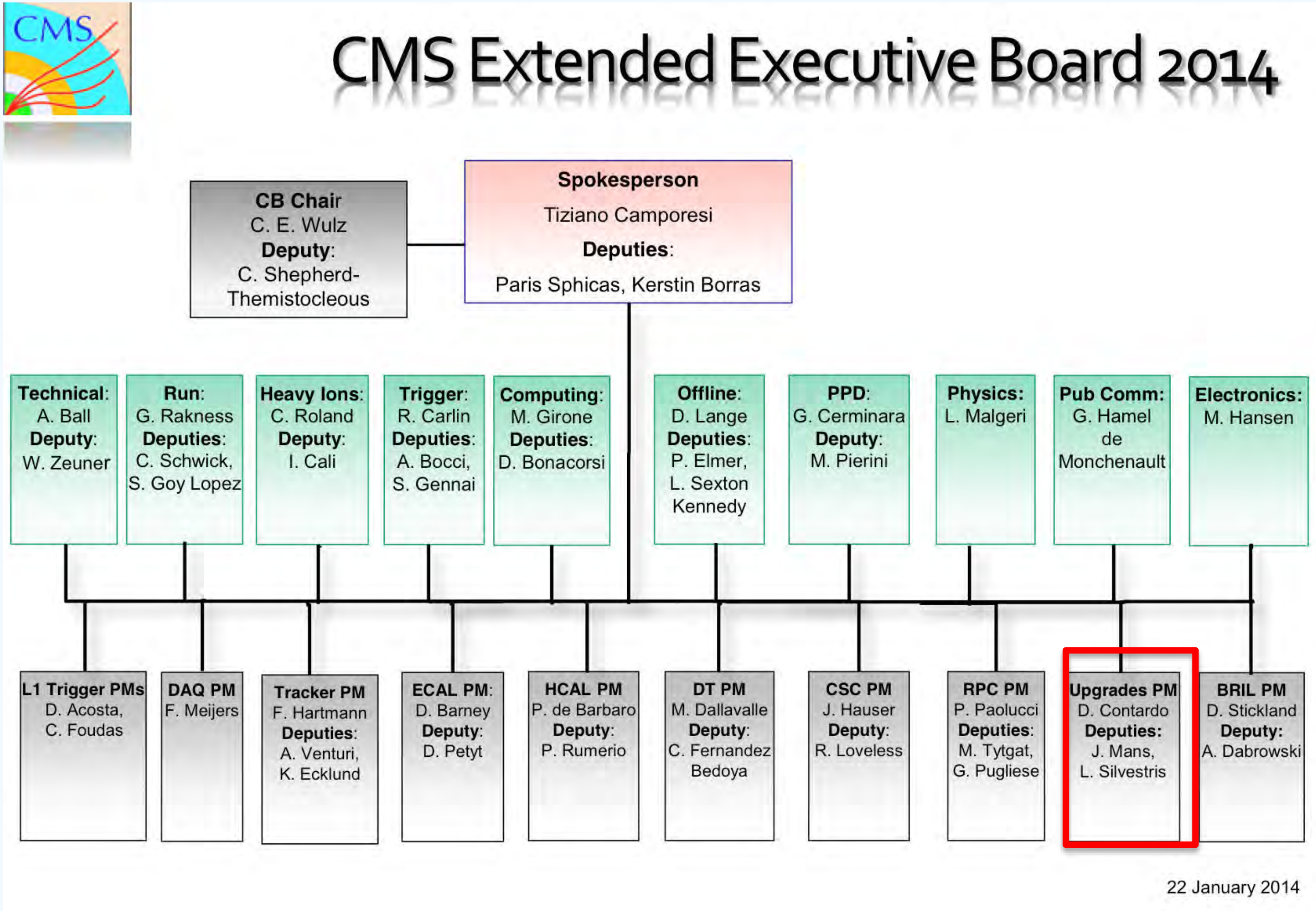
- I’ve run two of these groups.
- Typically 30 students doing their thesis in each group.
- Including students, postdocs, faculty, about 100 active physicists in “my” group.

SUSY subgroup meeting

Exotica nonhadronic subgroup meeting



Reconstructing the data



Let's look at this box

Upgrades

LS1
2013-14

LS1 consolidation: Complete detector & consolidate operation for nominal LHC beam conditions ~13 TeV, 1 x Hz/cm^2, <PU> ~25

- Complete Muon system (4th endcap station), improve RO of CSC ME1/1 & DTs
- Replace HCAL HF and HO photo-detectors and HF backend electronics
- Tracker operation at -20$\circ$C
- Prepare and install slices of Phase 1 upgrades

LS2
2018

Phase 1 upgrades: Prepare detector for 1.6 x 10^{34} Hz/cm^2, <PU> ~40, and up to 200 fb^{-1} by LS2, and 2.5 x 10^{34} Hz/cm^2, <PU> ~ 60, up to 500 fb^{-1} by LS3

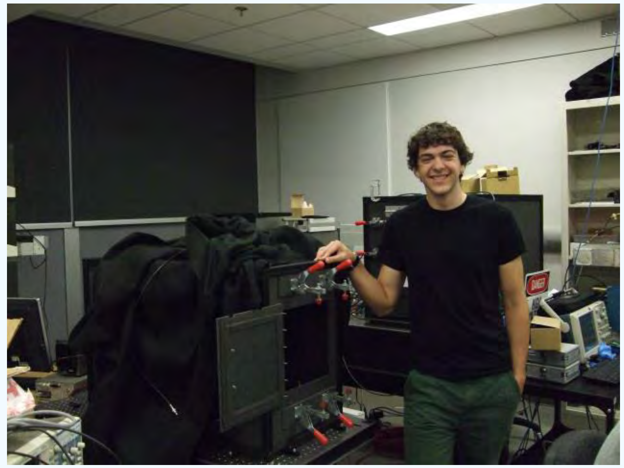
- New L1-trigger systems (Calorimeter - Muons - Global) (ready for 2016 data taking)
- New Pixel detector (ready for installation in 2016/17 Year End Technical Stop)
- HCAL upgrade: photodetectors and electronics (HF 2015/16 YETS, HB/HE LS2)

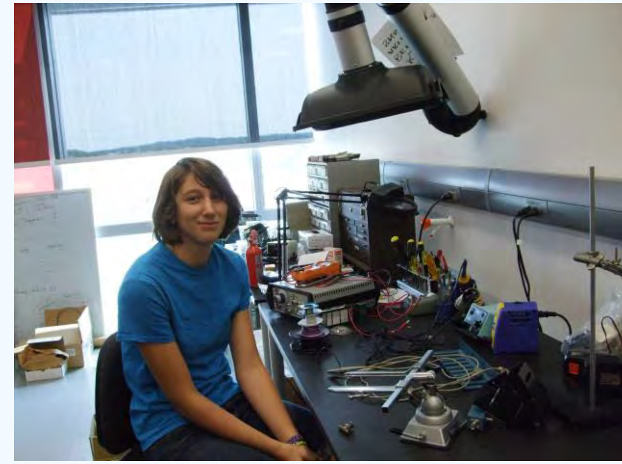
LS3
2022-23

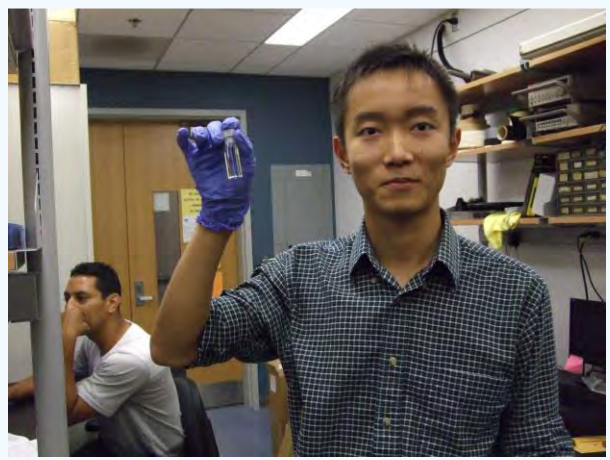
Phase 2 upgrades: $\gtrsim$ 5 x 10^{34} Hz/cm^2 luminosity leveled, <PU> ~128 (simulate 140), reach total of 3000 fb^{-1} in ~10 yrs operation

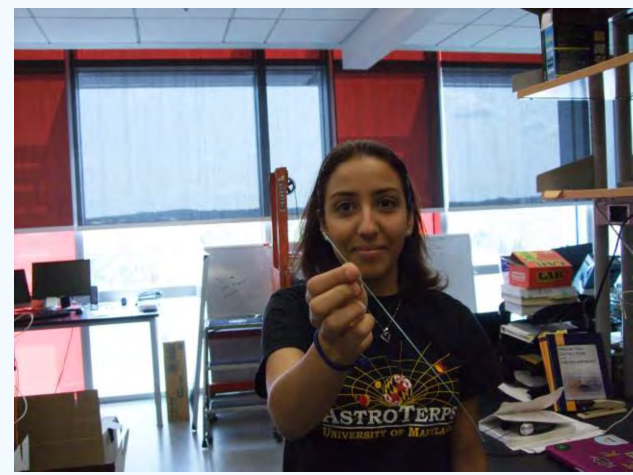
- Replace detector systems whose performance is significantly degrading due to radiation damage
- Maintain physics performance at this very high PU

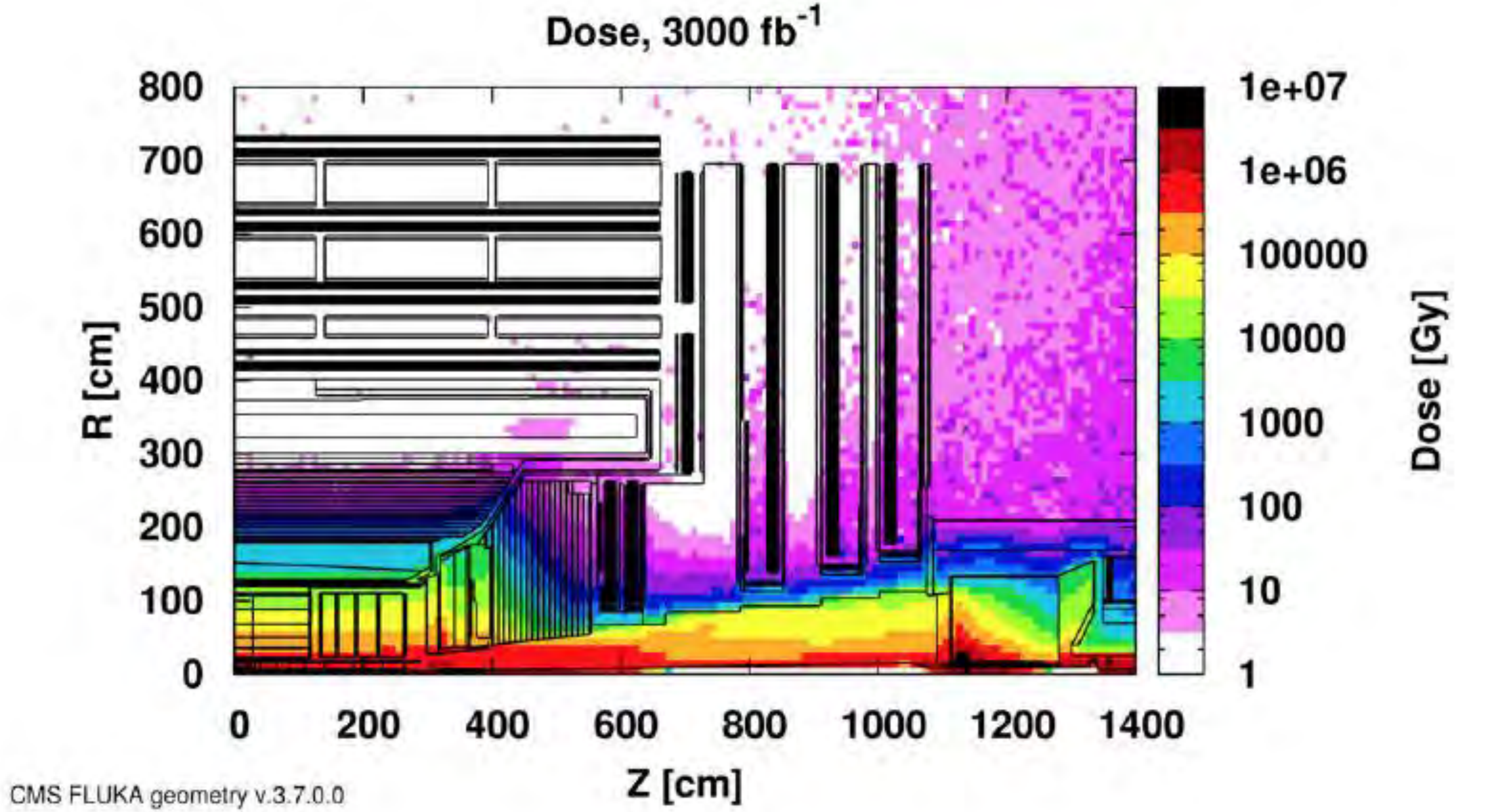
Upgrades and Undergrads







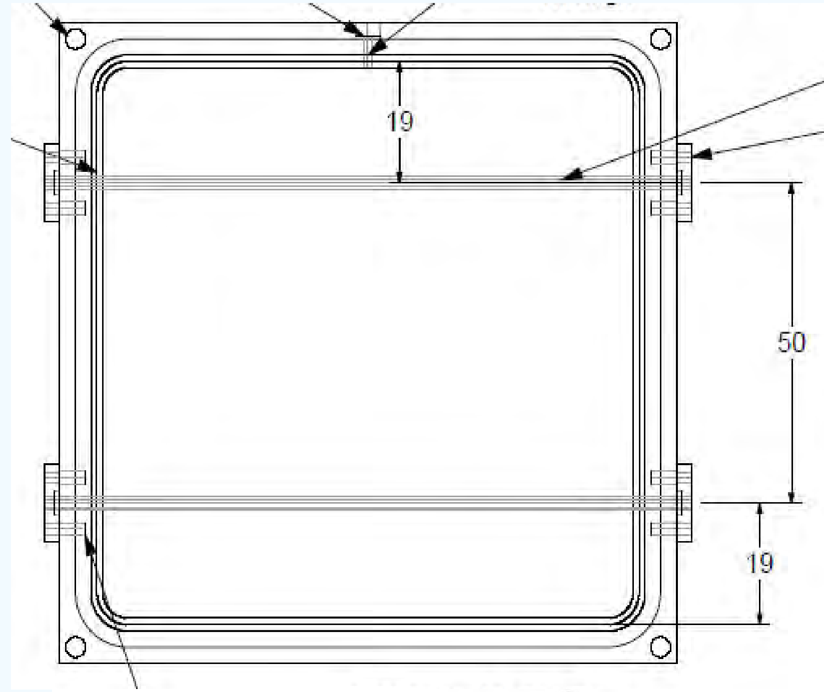


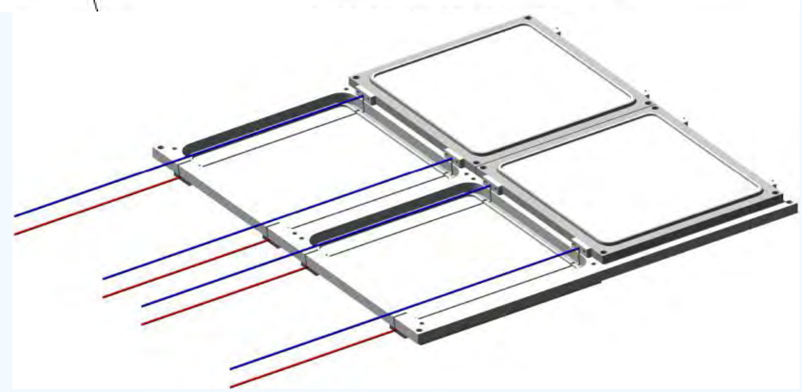


Dose, 3000 fb^{-1}
R [cm]
800
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
1400
Z [cm]
1e+07
1e+06
100000
10000
1000
100
10
1
Dose [Gy]
CMS FLUKA geometry v.3.7.0.0

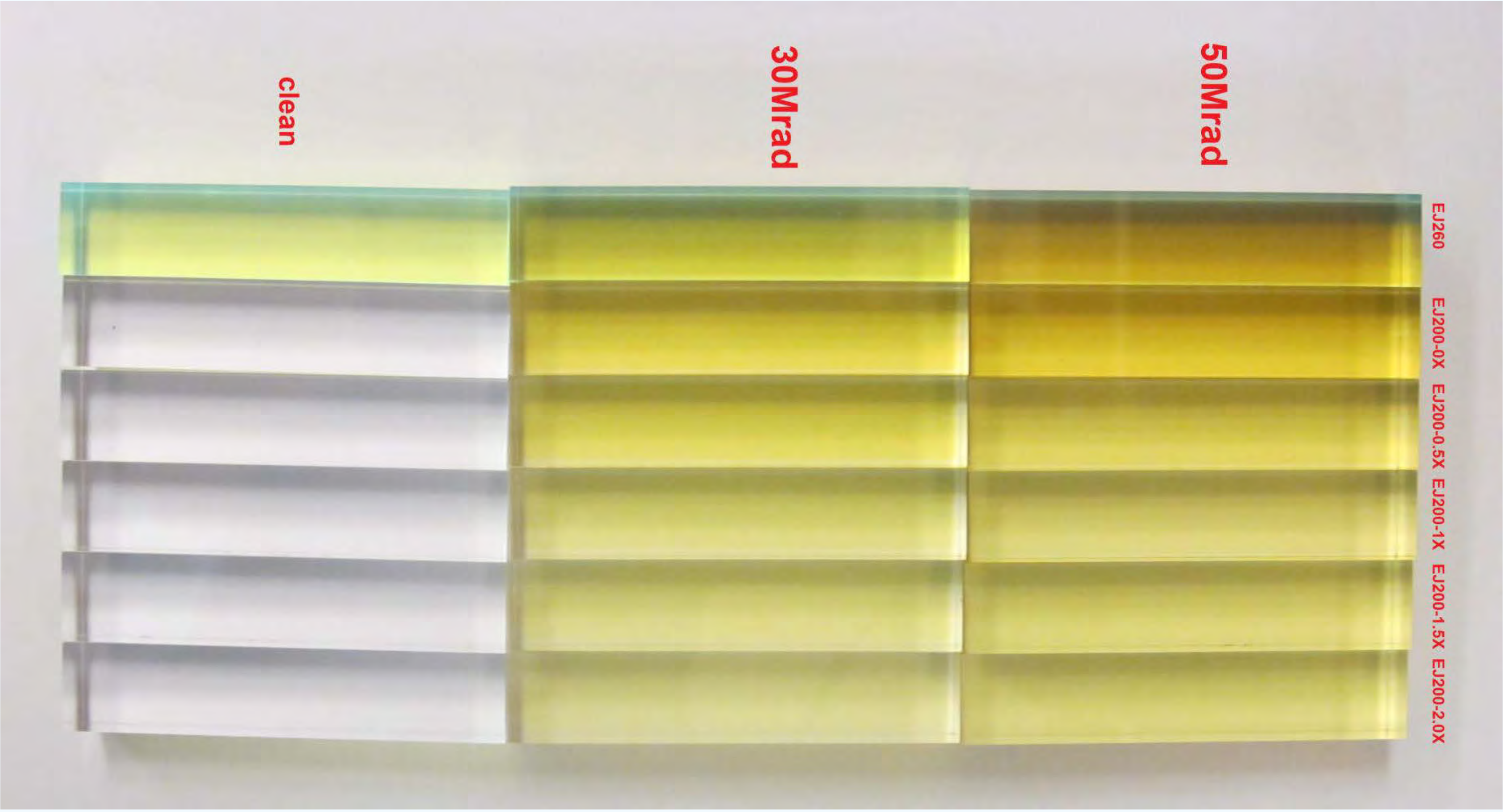
Cell Materials

- Aluminum 6016-T6, 10x10x0.5cm^3
  - No epoxies, welded components
  - Anodized surfaces
- Fused quartz support pipes, Viton O-ring sealers
  - Support pipes: 350μm wall, 1.3mm internal diameter
    - Allow for quick test of alternative readout fiber types and sizes; default: 0.7 or 0.9mm Y11
- 4-cell, 20x20x2cm^3 demonstration unit
  - Plan to gang together the pairs of readout fibers from each cell





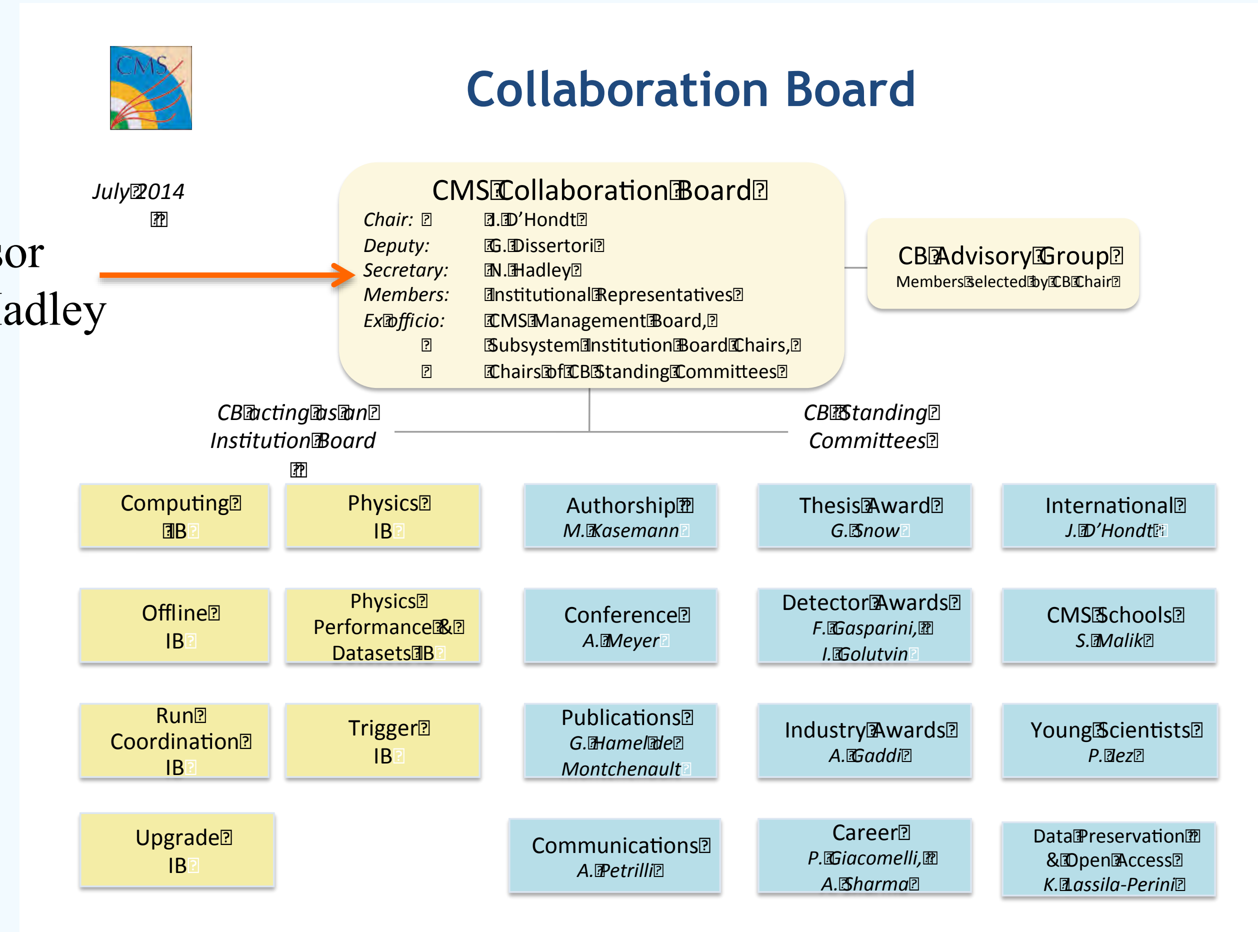
Irradiated samples



Test beam

Collaboration board

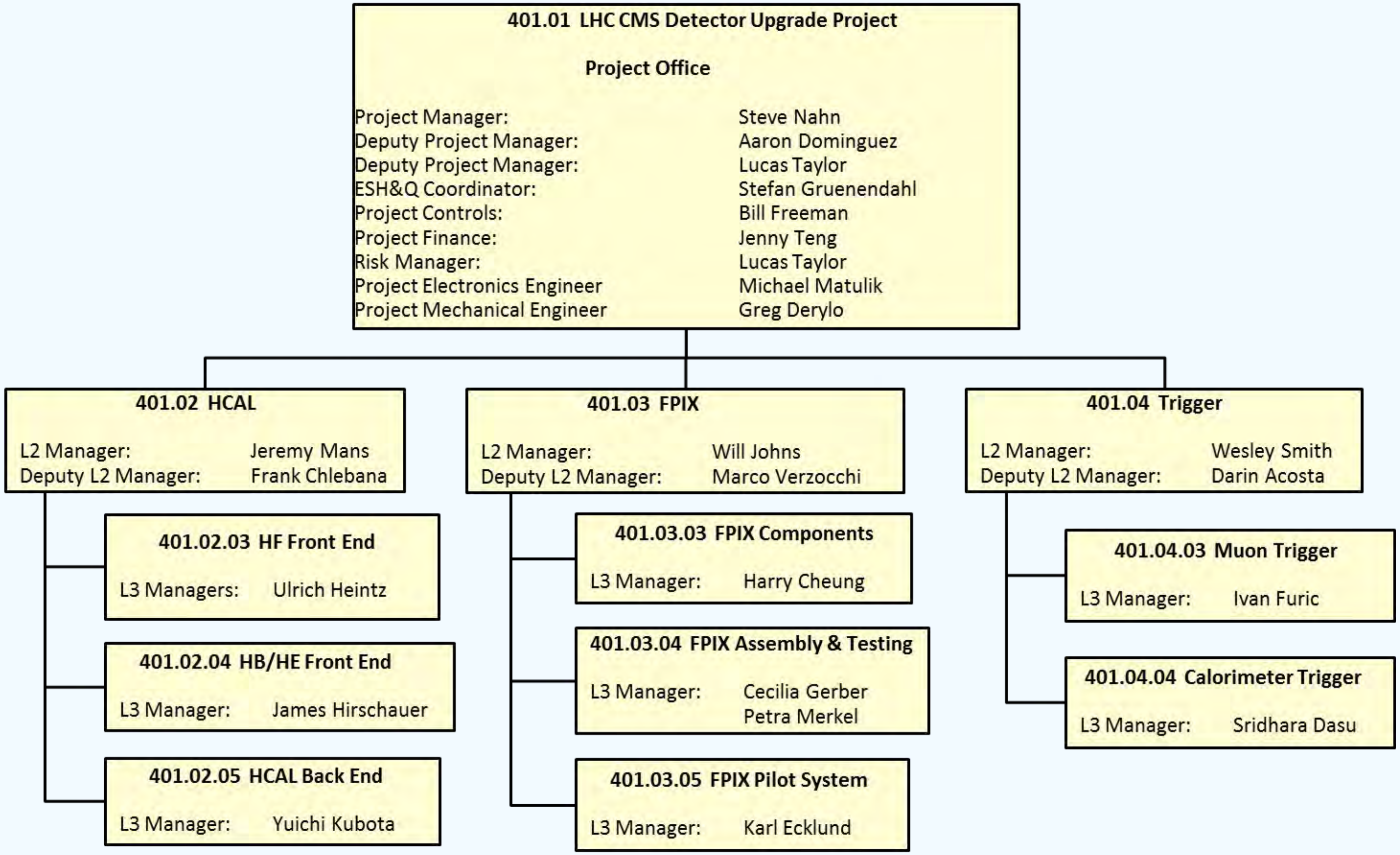
Professor
Nick Hadley



- The full collaboration board has one member/institution (168 members)
- forms a check on the spokesman, handles election and governance issues
- Appointments in previous chart must be ratified by the collaboration board
- Also organizes "good deed" committees

CMS CB Career Committee

National Org Chart follows the money



- Works to check distribution of money by US funding agencies

Acknowledgements

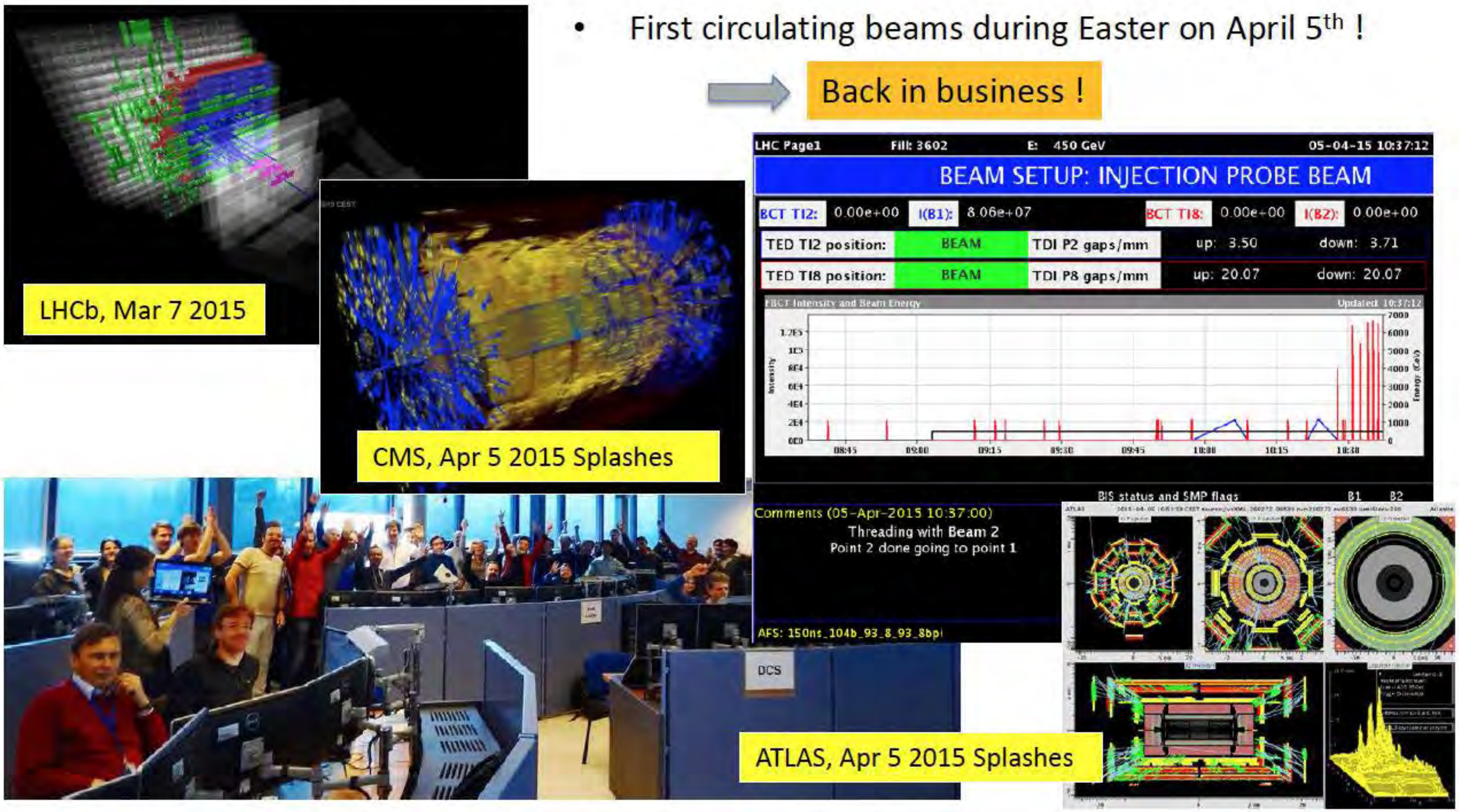
We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC machine. We thank the computing centres in the Worldwide LHC computing Grid for the provisioning and excellent performance of computing infrastructure essential to our analyses. We gratefully acknowledge the contributions of the technical staff at CERN and other CMS institutes. We also thank the administrative staff at CERN and the other CMS institutes and acknowledge support from BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); MEYS (Czech Republic); MoER, SF0690030s09 and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Republic of Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MSI (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MON, RosAtom, RAS and RFBR (Russia); MSTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA). Individuals have received support from the Marie-Curie programme and the European Research Council (European Union); the Leventis Foundation; the A.P. Sloan Foundation; the Alexander von Humboldt Foundation; the Austrian Science Fund (FWF); the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the Council of Science and Industrial Research, India; the Compagnia di San Paolo (Torino); and the HOMING PLUS programme of Foundation for Polish Science, cofinanced from European Union, Regional Development Fund.

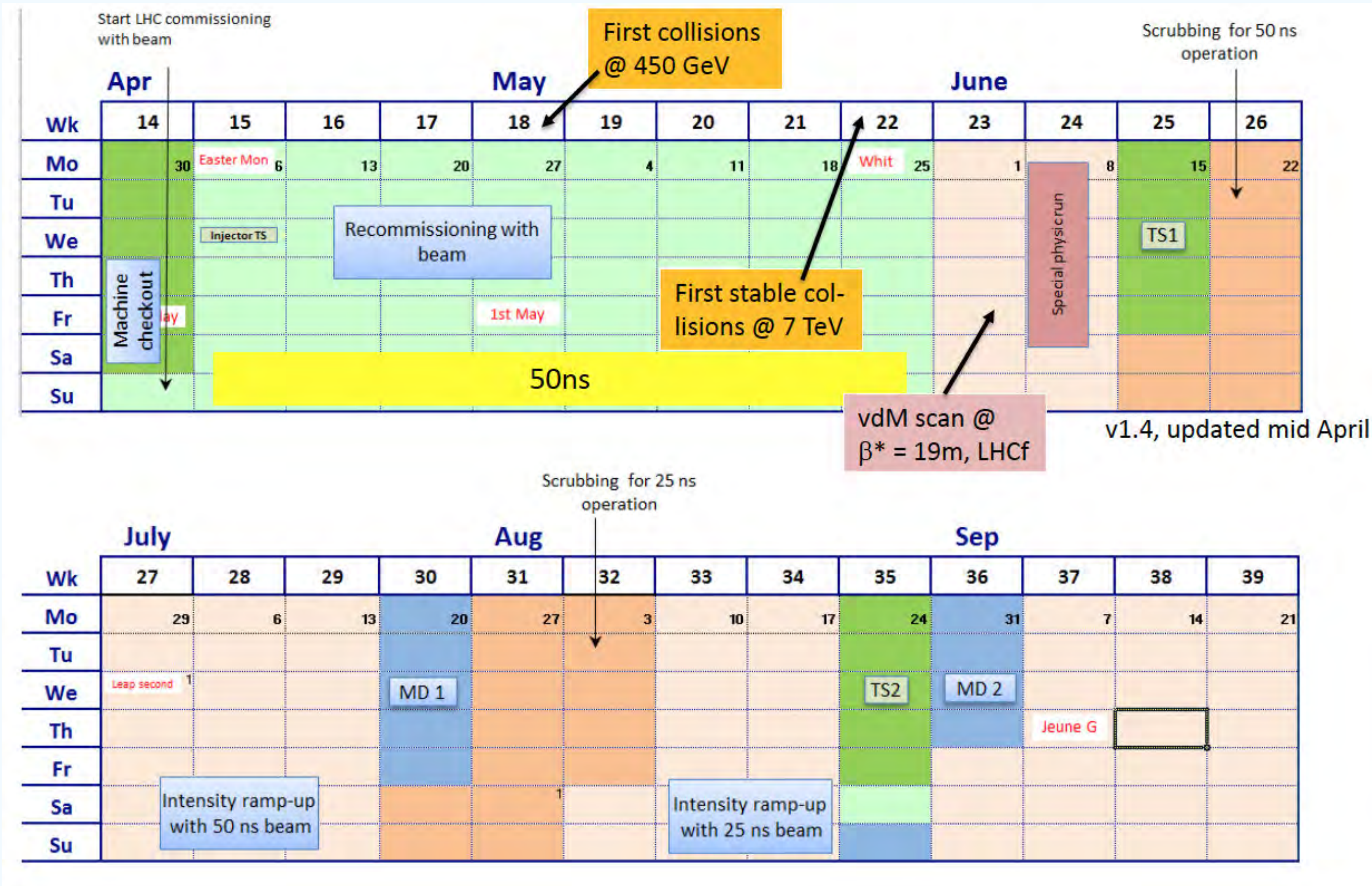
64 funding agencies (not including those that fund individuals instead of groups) in 40 countries

What's next?

- Experiments ready for beam operations from Feb shafts closed → end of LS1 shutdown
- First beam through transfer lines to stopper TDI in front of LHCb on March 7th
- First circulating beams during Easter on April 5th !

→ Back in business !

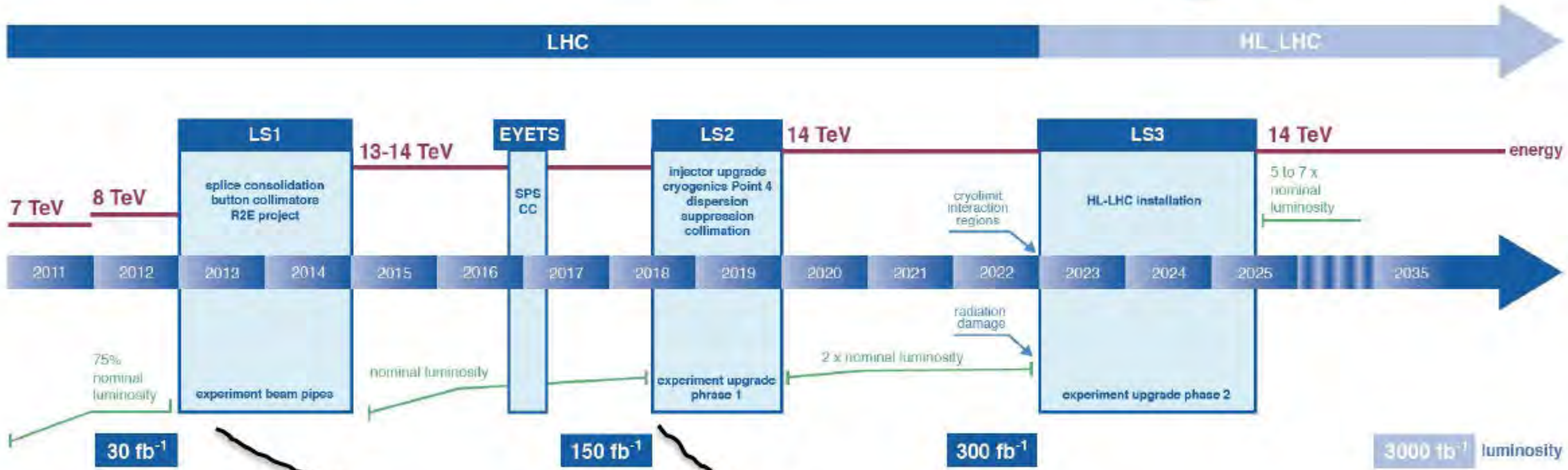




Start LHC commissioning with beam
First collisions @ 450 GeV
Scrubbing for 50 ns operation
Apr
May
June
Wk
14
15
16
17
18
19
20
21
22
23
24
25
26
Mo
Tu
We
Th
Fr
Sa
Su
30
Easter Mon
6
13
20
27
4
11
18
Whit
25
1
8
15
22
Injector TS
Recommissioning with beam
Machine checkout
1st May
First stable collisions @ 7 TeV
Special physics run
TS1
50ns
vdM scan @ β* = 19m, LHCf
v1.4, updated mid April
Scrubbing for 25 ns operation
July
Aug
Sep
27
28
29
30
31
32
33
34
35
36
37
38
39
29
6
13
20
27
3
10
17
24
31
7
14
21
Leap second
MD 1
TS2
MD 2
Jeune G
Intensity ramp-up with 50 ns beam
Intensity ramp-up with 25 ns beam

LHC / HL-LHC Plan

High Luminosity LHC



Run-1

- $\sqrt{s}$ = 7 (8) TeV
- 50ns bunch spacing
- L_{int} ~ 30 fb^{-1}
- L_{peak} ~ $7.5 \cdot 10^{33}$ cm^{-2} s^{-1}
- ~1400 bunches total
- Bunch charge: ~$1.6 \cdot 10^{11}$ p/b
- μ ~ 30
- β^* = 0.6 m

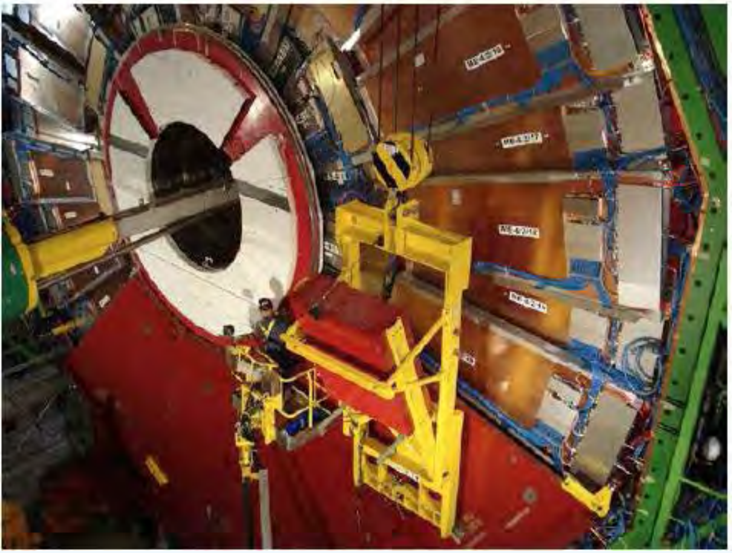
Run-2

- $\sqrt{s}$ = 13 TeV
- 25 ns bunch spacing
- L_{int} ~ 100 – 150 fb^{-1} -- 10 fb^{-1} in 2015
- L_{peak} ~ 1.3 – $1.5 \cdot 10^{34}$ cm^{-2} s^{-1}
- ~ 2800 bunches total
- bunch charge ~ $1.15 \cdot 10^{11}$ p/b
- Small emittance/bright beams with BCMS (batch compression, merging, split) scheme (2.4 → 1.3 μm)
- μ ~ 40
- β^* = 0.55 m nominal, 0.8 m in 2015

(Selected) LS1 Activities:

- Complete maintenance of safety systems, cooling, gas, …

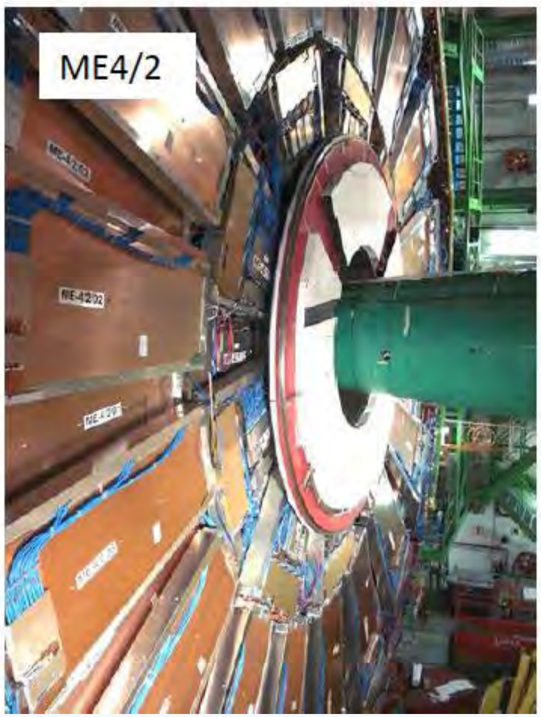
- Installation of new beam pipe
  - Reduced diameter: 45 mm
  - Beryllium material for minimal radiation-length
  - Geometry optimized and ready for new tracker installation in extended end of year shutdown 2016
- Construction and installation of shielding walls in both endcaps to reduce background



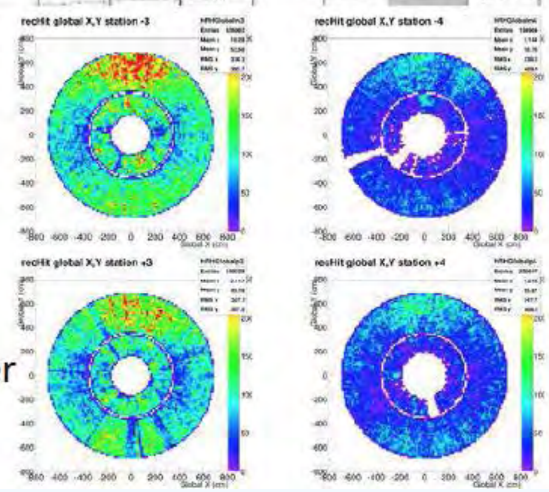
Muon System = Drift Tubes (DT) + Cathode Strip Chambers + Resistive Plate Chambers

Completion of the 4th layer

- Installed 72 new ME4/2 CSC chambers
- Installed 144 new RE4 RPC chambers
- Excellent performance



Summer 2014



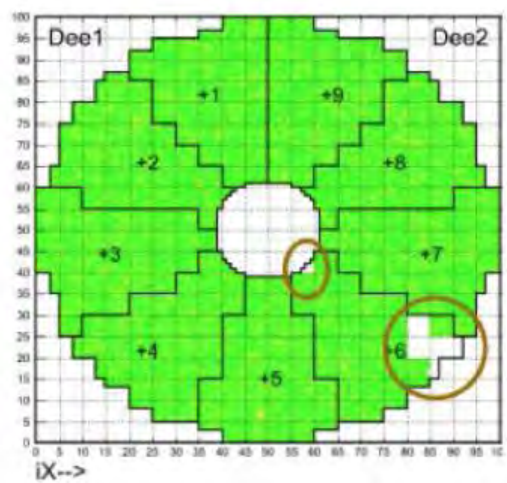
- Recovered dead channels due to LV connector fault in the endcap
  - Both ES disks were de-installed during LS1, moved to the surface, repaired and reinstalled
  - → 99.95% channels operational (from 96.8% at end of run1)

- HV connector repair on the pre-shower detectors
- Moved successfully to operating the pre-shower at -8°C for run-2

- New ECAL local reconstruction algorithm with better out-of-time pileup rejection

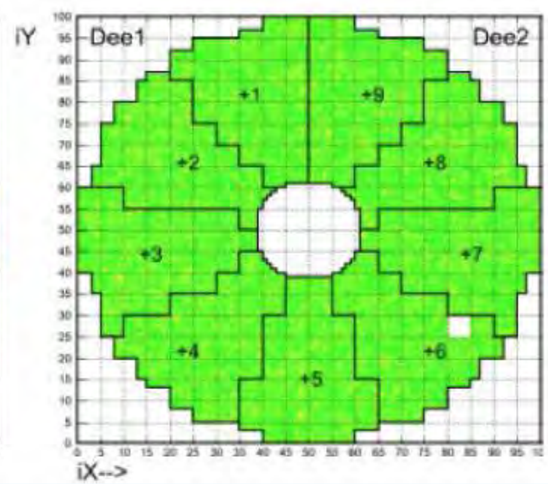
before

EE+ run 214268 11.09.13 B=0.0T



after

EE+ run 215413 21.10.13 B=0.0T

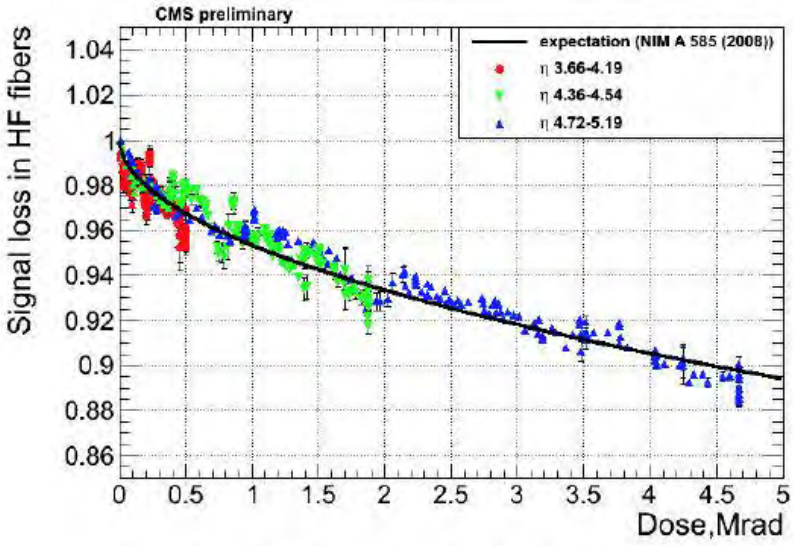


Upgrade/Replacement of photo-detectors

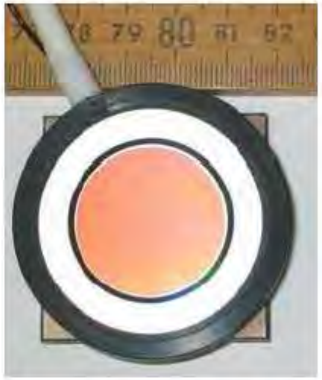
- Magnetic field insensitive, radiation tolerant high-performant SiPMs instead of Hyprid Photo Diodes (HPDs) in all of the HO Barrel
  - Much better identification of MIPs
  - Good for up to 3000 fb-1 integrated lumi, better signal/noise ration than the HPDs
- New thin-window dual-anode readout PMTs in the HF forward region
  - Reduce Cherenkov noise from punch-through muons
  - Reduction of anomalous signals

Other activities

- New back-end electronics for HF installed
- Refurbished and re-established calibration system using radioactive Co-60 sources



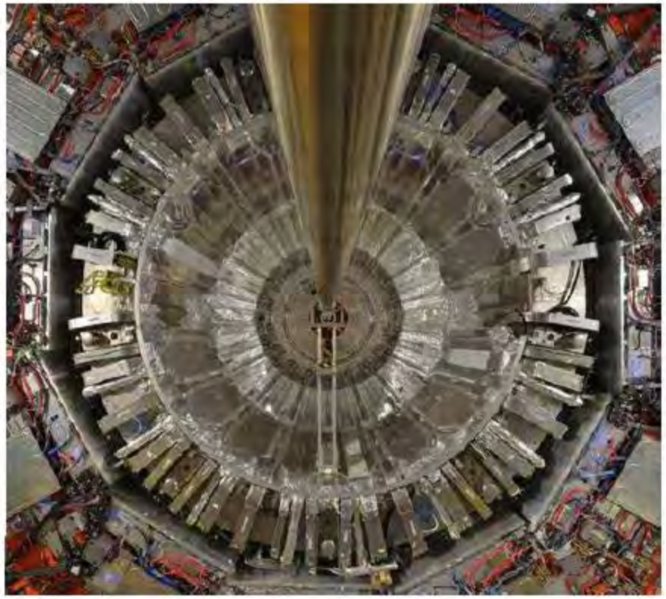
2010-2012 light loss in HCAL HF quartz fibers



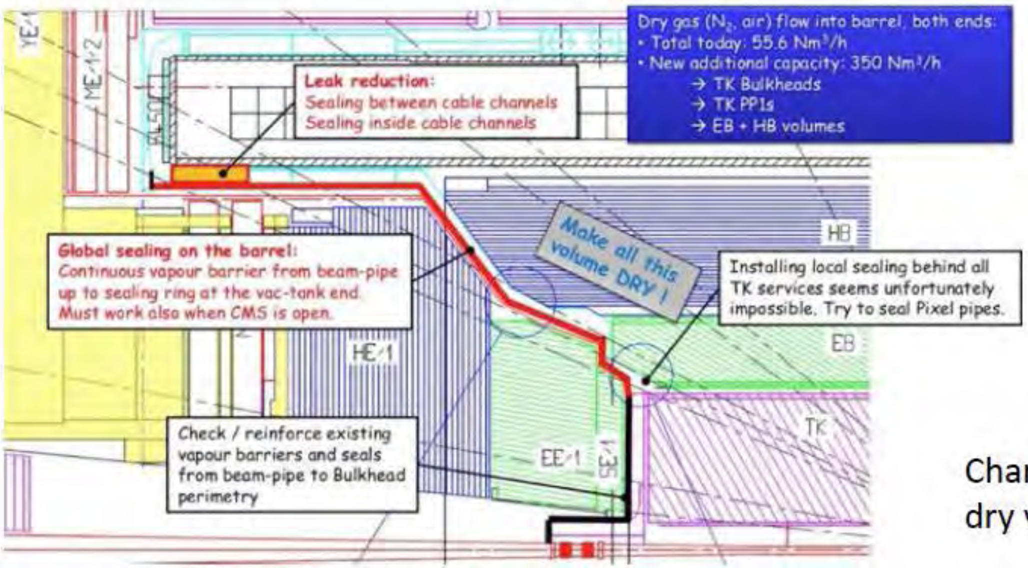
HPD → SiPM

Major difference to run-1: Tracker running "cold" (-10°C .. -20°C) instead of +4°C

- Leakage current doubles every 7°C, plus with increasing radiation dose. Already at ~30% of power supply limit end of 2012 → cold operation ensures efficient performance across run-2
- Dry gas system, new seals, new bulk head panels with heater elements on the outside, dew point sensors and monitoring all working reliably and to specification
- Calibration @ -15 °C completed early this year with cosmics



Si strips with final seal in place



Changes to achieve dry volume

Conclusions

Why does it take so many scientists to discover the Higgs?

- Only a small number make the money plot
- Most are calibrating the detector
- A large number are doing shifts
- A large number are developing particle identification, reconstruction, and calibration methods
- A non-negligible number are developing new detectors for future runs so we can learn more about the Higgs and search for other new particles