GridPP

UK Computing for Particle Physics

Grid Computing for the Large Hadron Collider



Tony Doyle

British Computer Society

Edinburgh, 8 July 2009

UNIVERSITY of GLASGOW

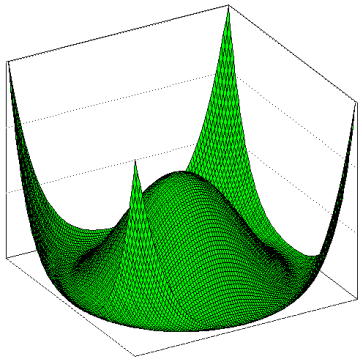
OUTLINE

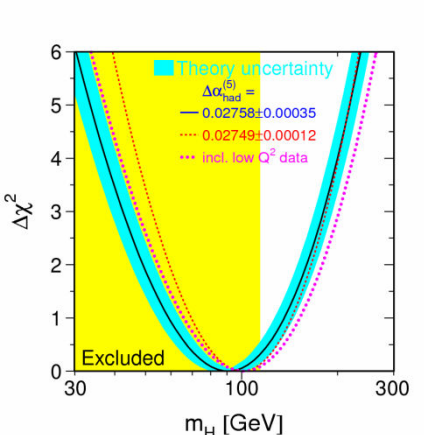
- Introduction

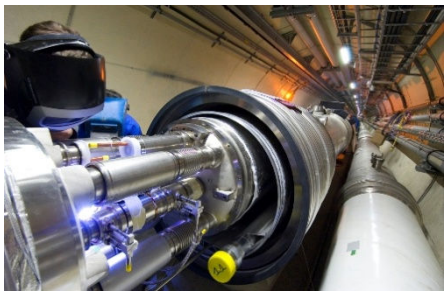
1. Theory
2. Machine
3. Experiment
4. Grid

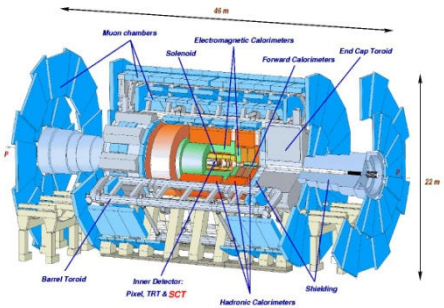
- Epilogue:

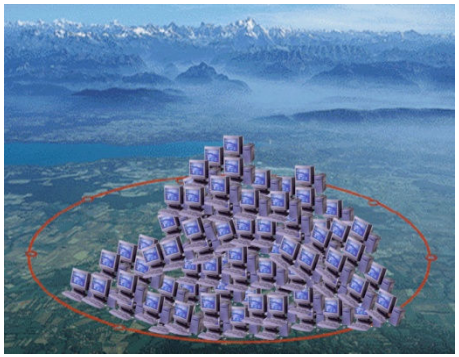
  beyond the Grid?

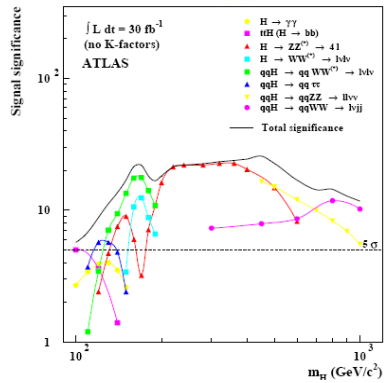














•INTRODUCTION

What? Why? Where? When?

₩ HAT?

The Large Hadron Collider (LHC) is the world's largest and highest-energy particle accelerator

₩ HY?

Built to search for the Higgs boson and new particles predicted by e.g. supersymmetry

₩ HERE?

CERN. In a tunnel 27 kilometres (17 mi) in circumference near Geneva, Switzerland

₩HEN?

10 September 2008: proton beams successfully circulated in the main ring for the first time

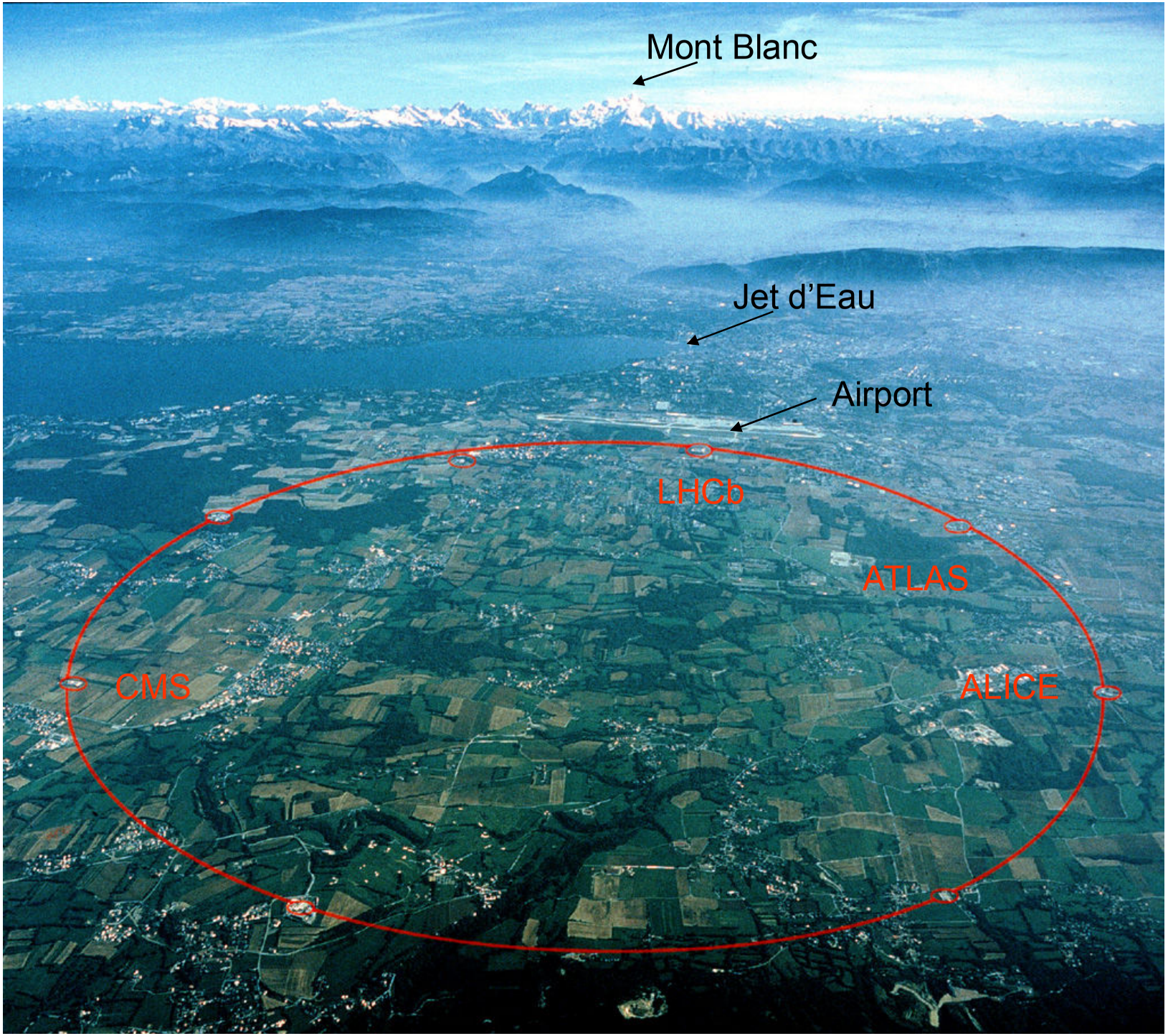
19 September 2008: operations halted due to a faulty weld between two magnets

* (Please detail description)

REASON FOR EXPENSE CLAIM: Please specify clearly

WHAT		**WHERE**	
WHEN		**WHY**	

ESTABLISHMENT REFERENCE - AGRESSO DESCRIPTION FIELD


Mont Blanc
Jet d'Eau
Airport
LHCb
ATLAS
CMS
ALICE

September 10th 2008 Worldwide News

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Scientists send first beam round particle-smasher

Wed Sep 10, 2008 2:28pm IST

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1 of 1 Full Size

By Robert Evans

GENEVA (Reuters) - Scientists at the European Organisation for Nuclear Research (CERN) started up a huge particle-smashing machine on Wednesday, aiming to re-enact the conditions of the "Big Bang" that created the universe.

The Large Hadron Collider (LHC) is the largest and most complex machine ever made and the platform for what experts say is the largest scientific experiment in human history.

Tests conducted inside the tightly-sealed chamber, buried under the Swiss-French border, could unlock the remaining secrets of modern physics and answer questions about the universe and its origins.

The 10 billion Swiss franc ($9 billion) machine's debut came as a blip on a screen in CERN's control room, with a particle beam the size of a human hair appearing in the tightly-sealed 27-km circular tunnel.

"We've got a beam on the LHC," project leader Lyn Evans told his colleagues, who burst into applause at the news.

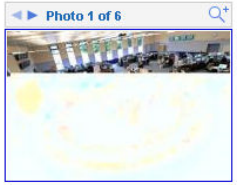
The several hundred physicists and technicians huddled in the control room later celebrated loudly again when a particle beam completed a trajectory of the accelerator in one direction, a key step a CERN spokeswoman described as "fantastic."

Scientists will next send a beam around the LHC in the other direction to test that the path is clear.

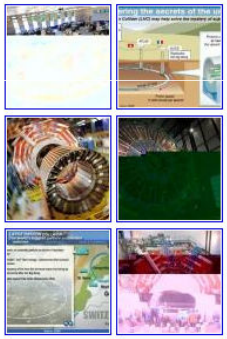
Once that is established, it will be possible to send beams in both directions simultaneously to create high-energy collisions at close to the speed of light. Continued...

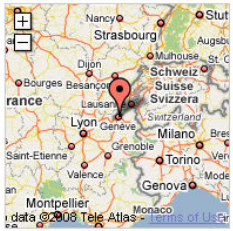
AFP

Go to Google News



European Organisation for Nuclear Research (CERN) scientists work at the Large Hadron Collider (LHC) control center





World's mightiest atom-smasher starts operations

1 hour ago

GENEVA (AFP) — Particle physicists fired up the world's biggest atom-smasher on Wednesday in a mission to answer some of the most perplexing questions about the nature of the Universe.

Built in a tunnel 100 metres (325 feet) below ground in a complex straddling the French-Swiss border, the Large Hadron Collider (LHC) is designed to accelerate sub-atomic particles to nearly the speed of light and then smash them together.

The collisions will briefly stoke temperatures 100,000 times hotter than the Sun, fleetingly replicating conditions which prevailed in split-seconds after the "Big Bang" that created the Universe 13.7 billion years ago.

In this seething primordial soup, novel particles may lurk.

Discovering them could resolve mysteries clouding our understanding of how matter is constituted and came into being, scientists say.

"It's about acquiring knowledge for humanity about the behaviour of fundamental matter," physicist Daniel Denegri told AFP.

"We expect to make discoveries that could be rather spectacular."

Shortly after 9:30 a.m. (0730 GMT), the first protons were injected into the 27-kilometre (16.9-mile) ring-shaped tunnel at the headquarters of the European Organisation for Nuclear Research (CERN).

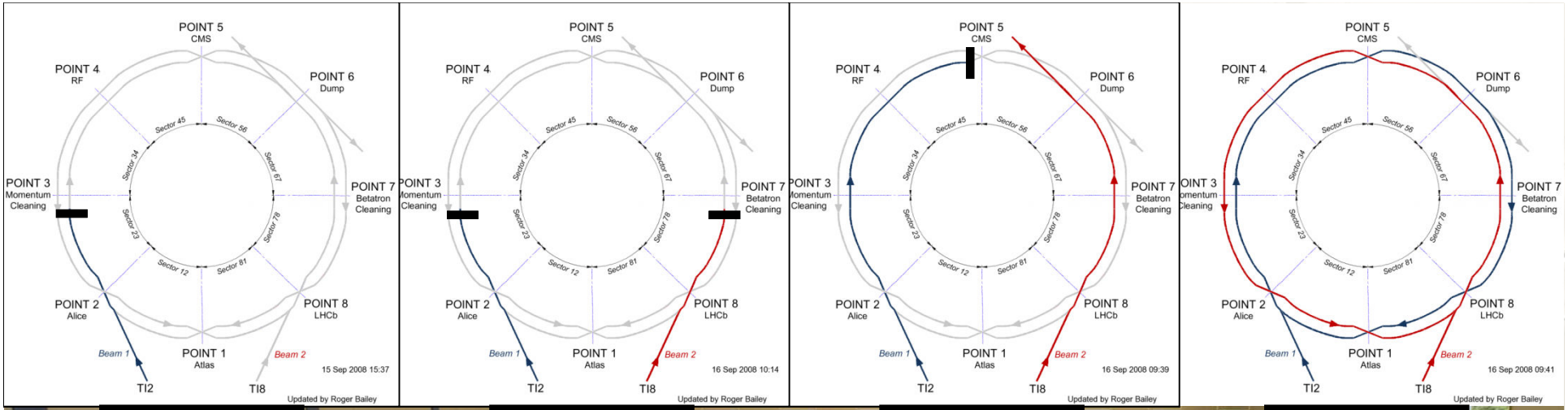
It has required nearly two decades, six billion Swiss francs (3.76 billion euros, 5.46 billion dollars) and 5,000 scientists, engineers and technicians from nearly three dozen countries to bring the LHC to fruition.

Wednesday's operation began a long and cautious commissioning process, testing equipment and procedures, before starting experiments a matter of weeks from now.

In the LHC control room, relieved scientists cheered and clapped when the first particles completed a maiden, clockwise lap around the ring. The protons' progress had been slowed down to ensure that systems were working properly.

When all is ready, the LHC will whizz two parallel beams, one clockwise and the other anticlockwise, around the tunnel.

Superconducting magnets cooled close to absolute zero -- the chill of deep space -- will then steer the beams so that they converge inside four chambers whose walls are swathed with detectors.



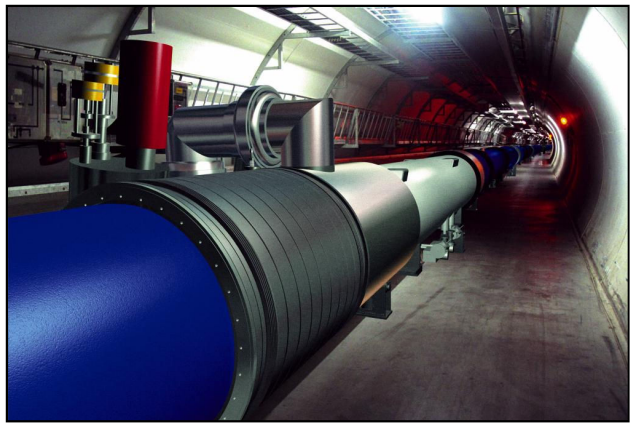
August 08-10 | August 22-24 | September 5-7 | September 10

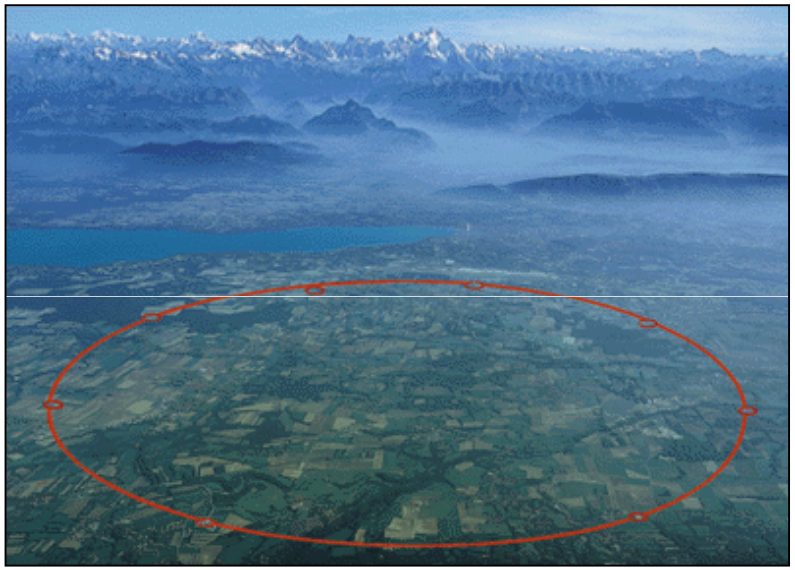


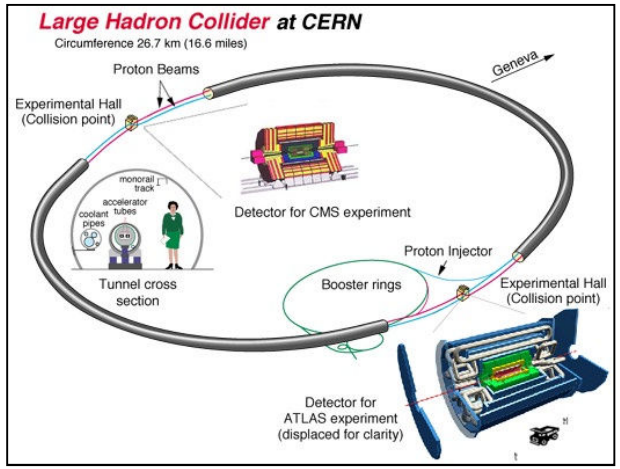
Why do particle physicists need the Grid?

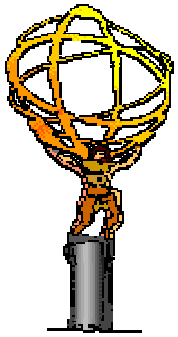
CERN LHC

The world's most powerful particle accelerator





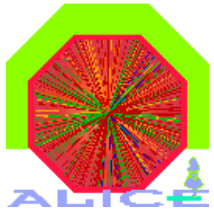




4 Large Experiments

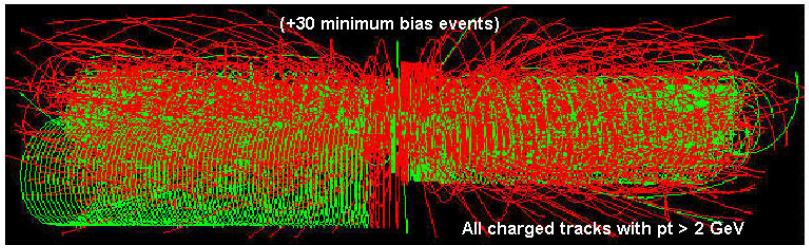




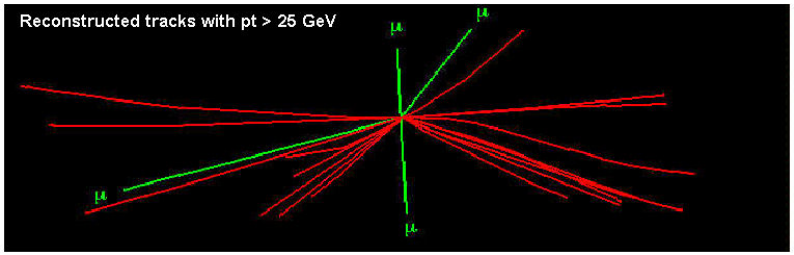


Why do particle physicists need the Grid?

Example from LHC:
starting from this event



We are looking for this "signature"

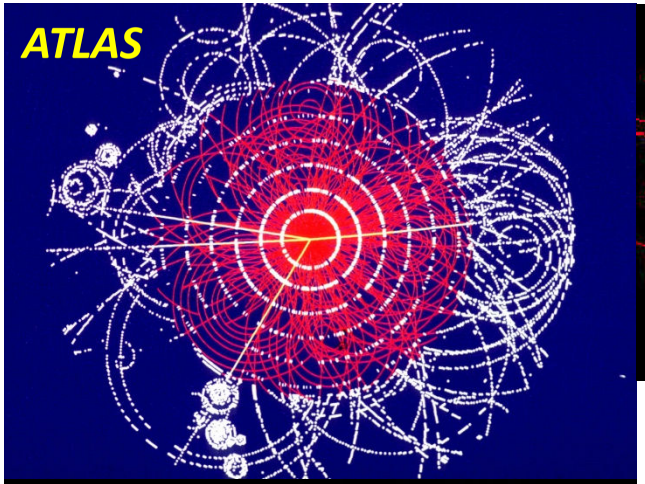


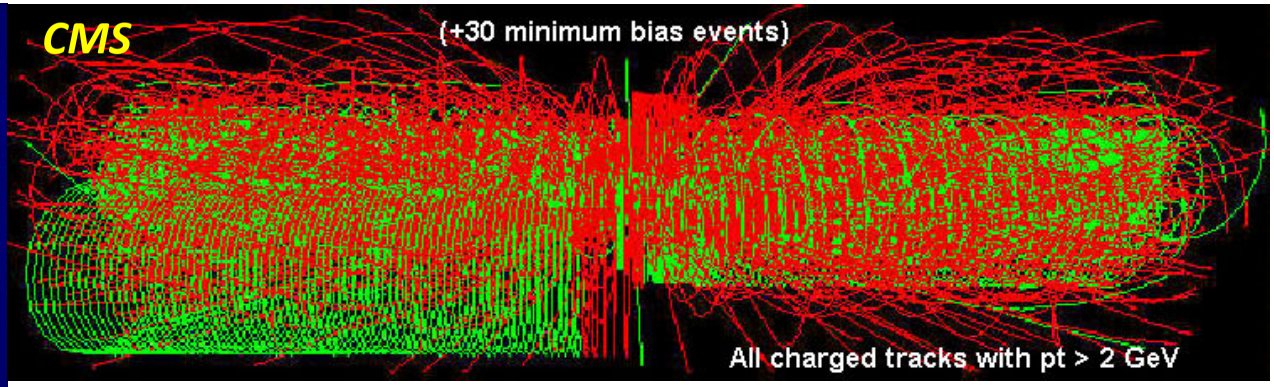
Selectivity: 1 in 10^{13}
Like looking for 1 person in a thousand world populations
Or for a needle in 20 million haystacks!

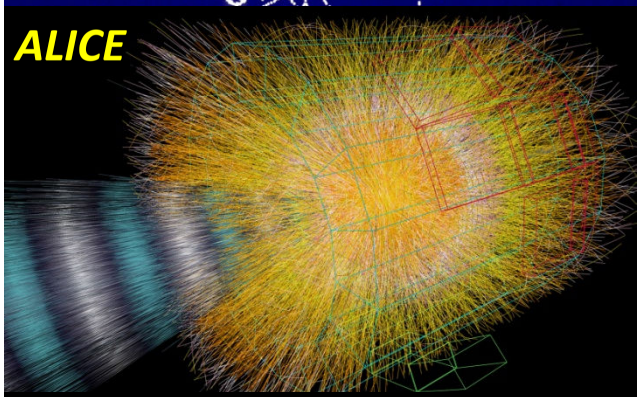


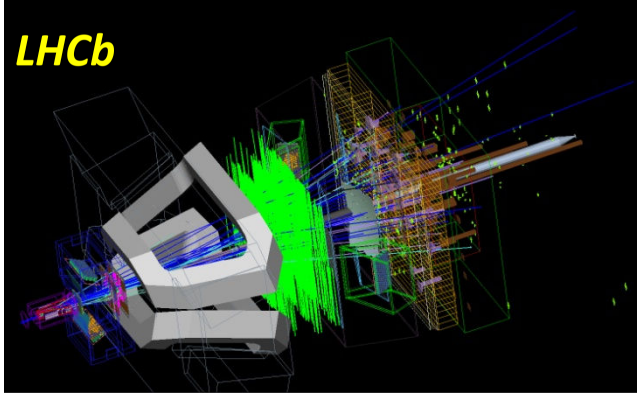
- ~100,000,000 electronic channels
- 800,000,000 proton-proton interactions per second
- 0.0002 Higgs per second
- 10 PBytes of data a year
- (10 Million GBytes = 14 Million CDs)

Data Driven Grid Computing







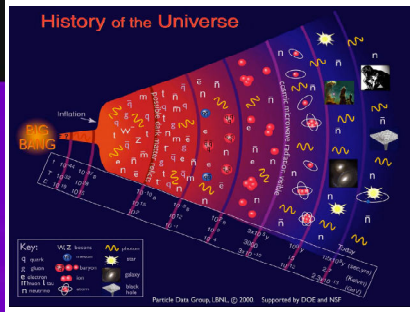


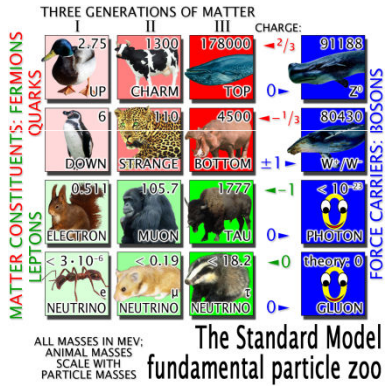
Grid architecture chosen because:

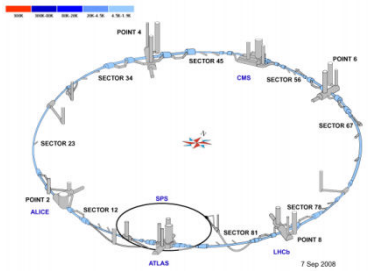
- **Costs** of maintaining and updating resources more easily shared in a distributed environment.
- **Funding bodies** can provide local resources and contribute to global goal.
- More easy to build **redundancy** and **fault tolerance** and minimise risks from single point of failure.
- LHC will operate **around the clock** for 8 months each year. Spanning of time zones means that **monitoring/support** more readily provided.

Universe – Particles – LHC?



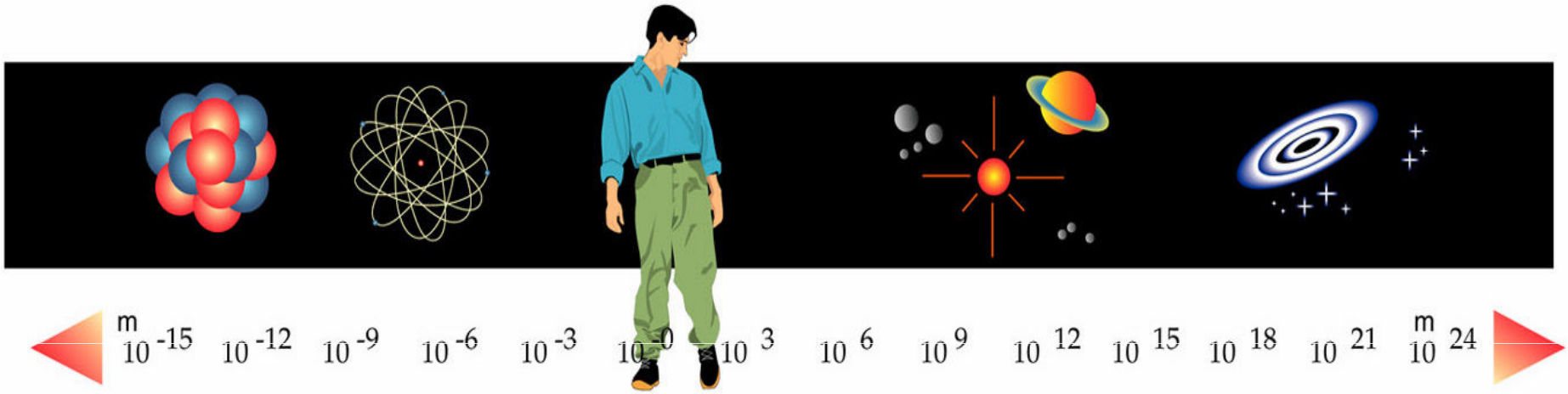






Particle physics looks at matter in its smallest dimensions.

Astrophysics looks at matter in its largest dimensions.



m
10^{-15} 10^{-12} 10^{-9} 10^{-6} 10^{-3} 10^{0} 10^{3} 10^{6} 10^{9} 10^{12} 10^{15} 10^{18} 10^{21} m 10^{24}

Microscopes

Binoculars

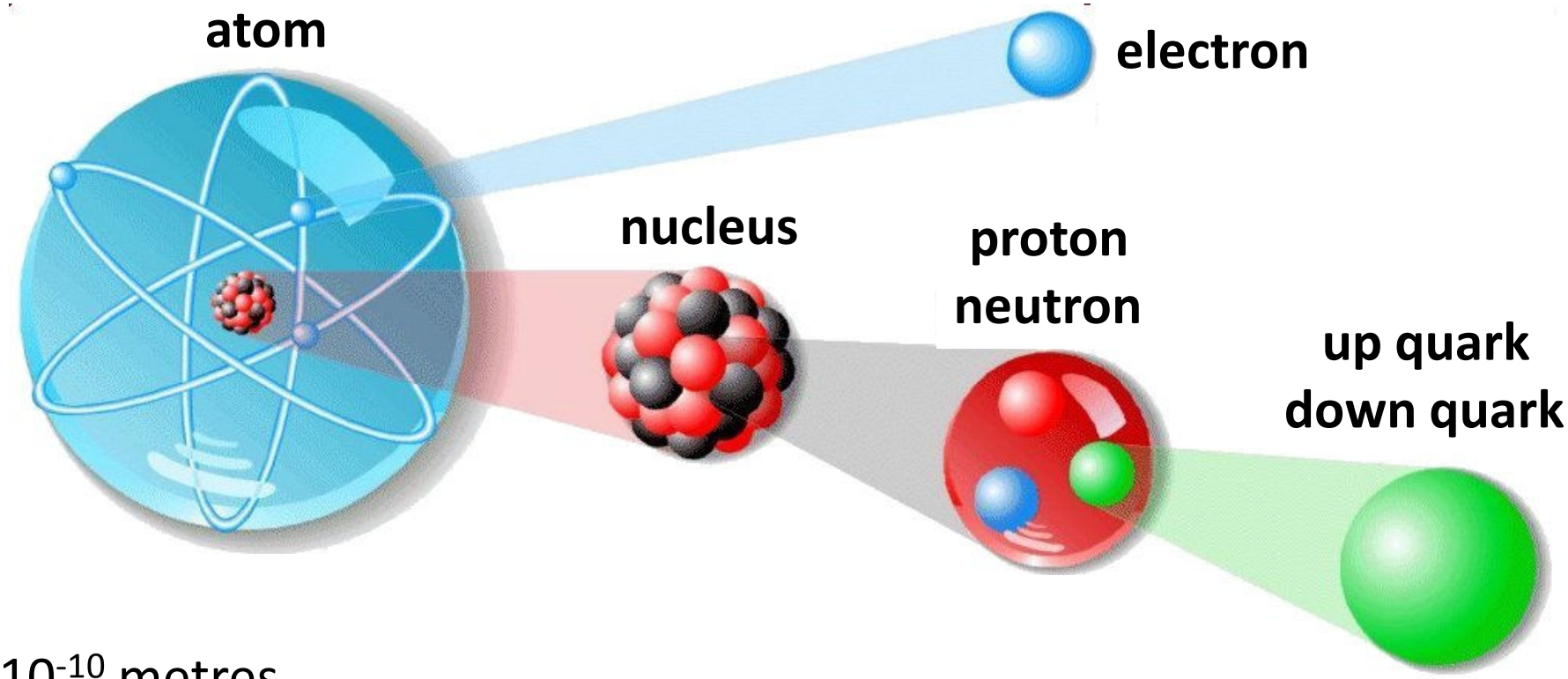
Optical & radio telescopes

Naked eye

Accelerators and detectors

THE TWO FRONTIERS OF PHYSICS

small



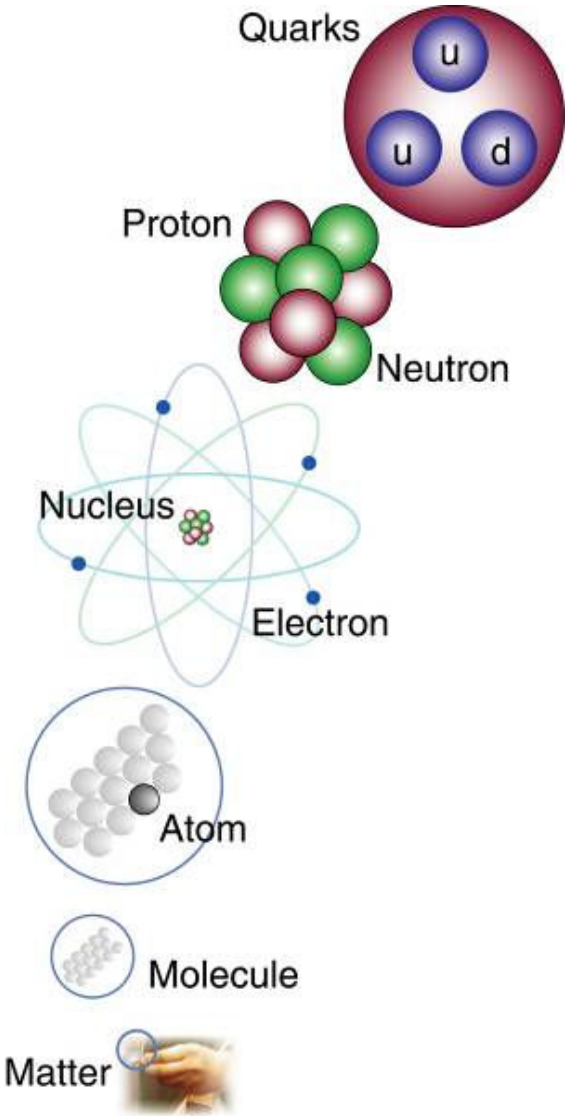
10^{-10} metres (thickness of human hair ~ 10^{-5} m)

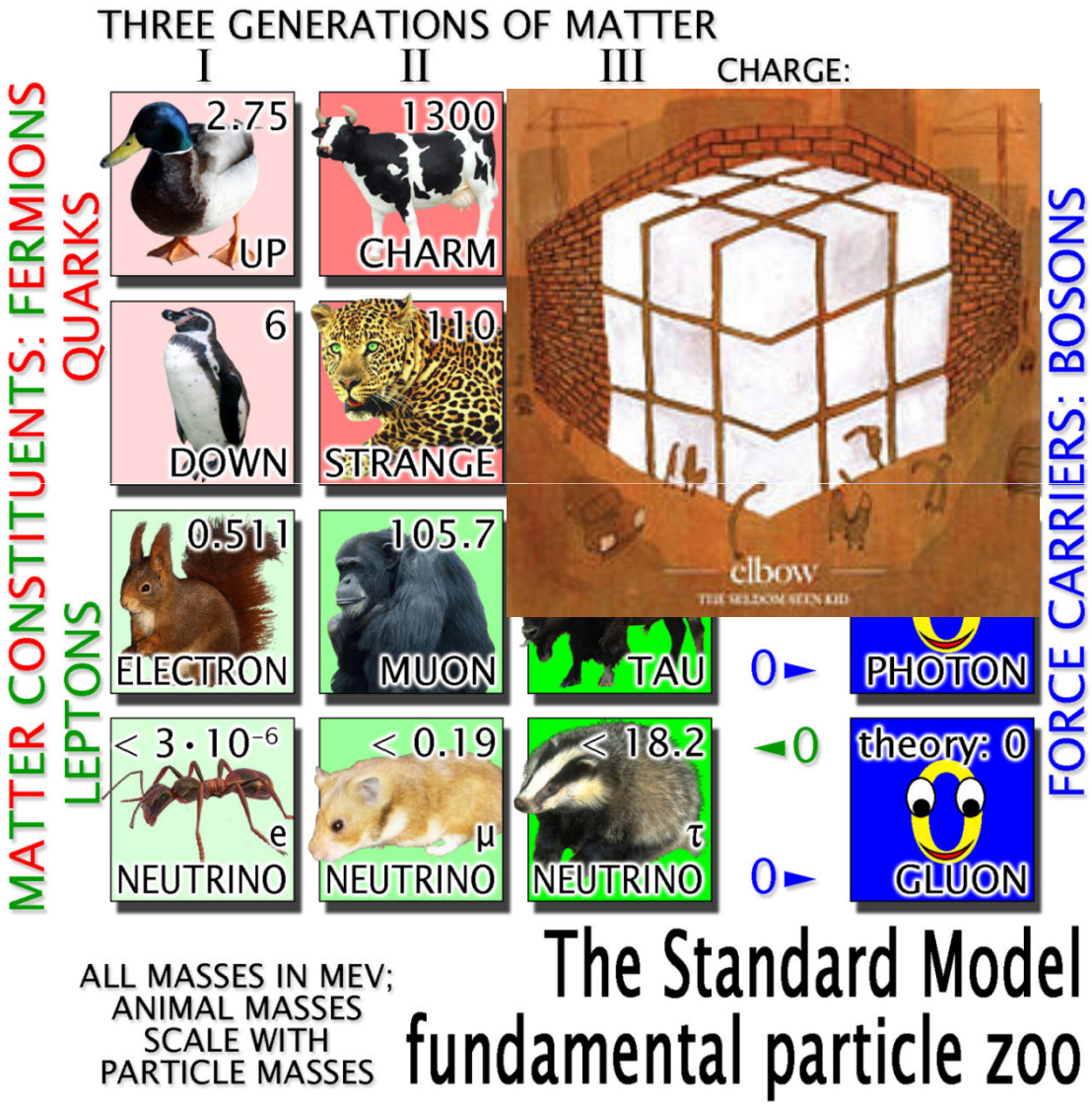
10^{-14} metres

10^{-15} metres

$< 10^{-18}$ metres

The Standard Model

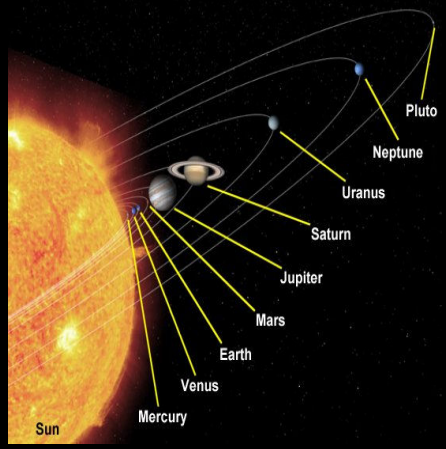




BIG

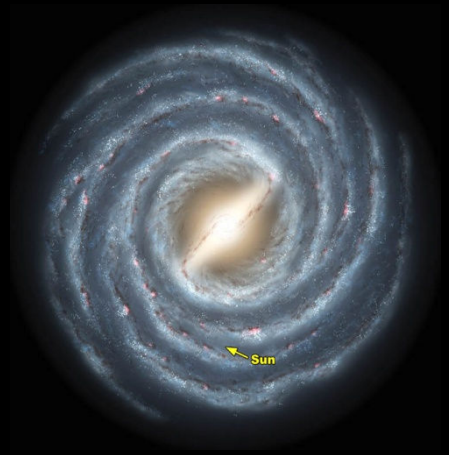
On the largest distance scales the Universe appears smooth with small fluctuations

solar system



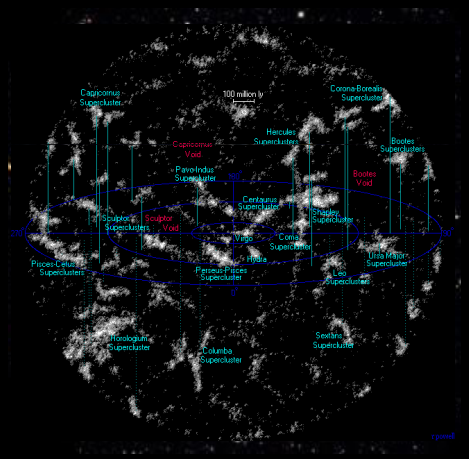
10^{12} metres

galaxy



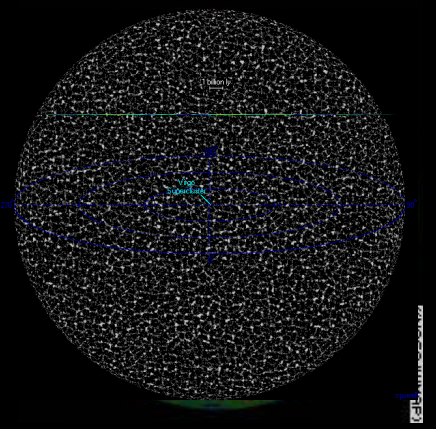
10^{17} metres

galactic super-cluster



10^{23} metres

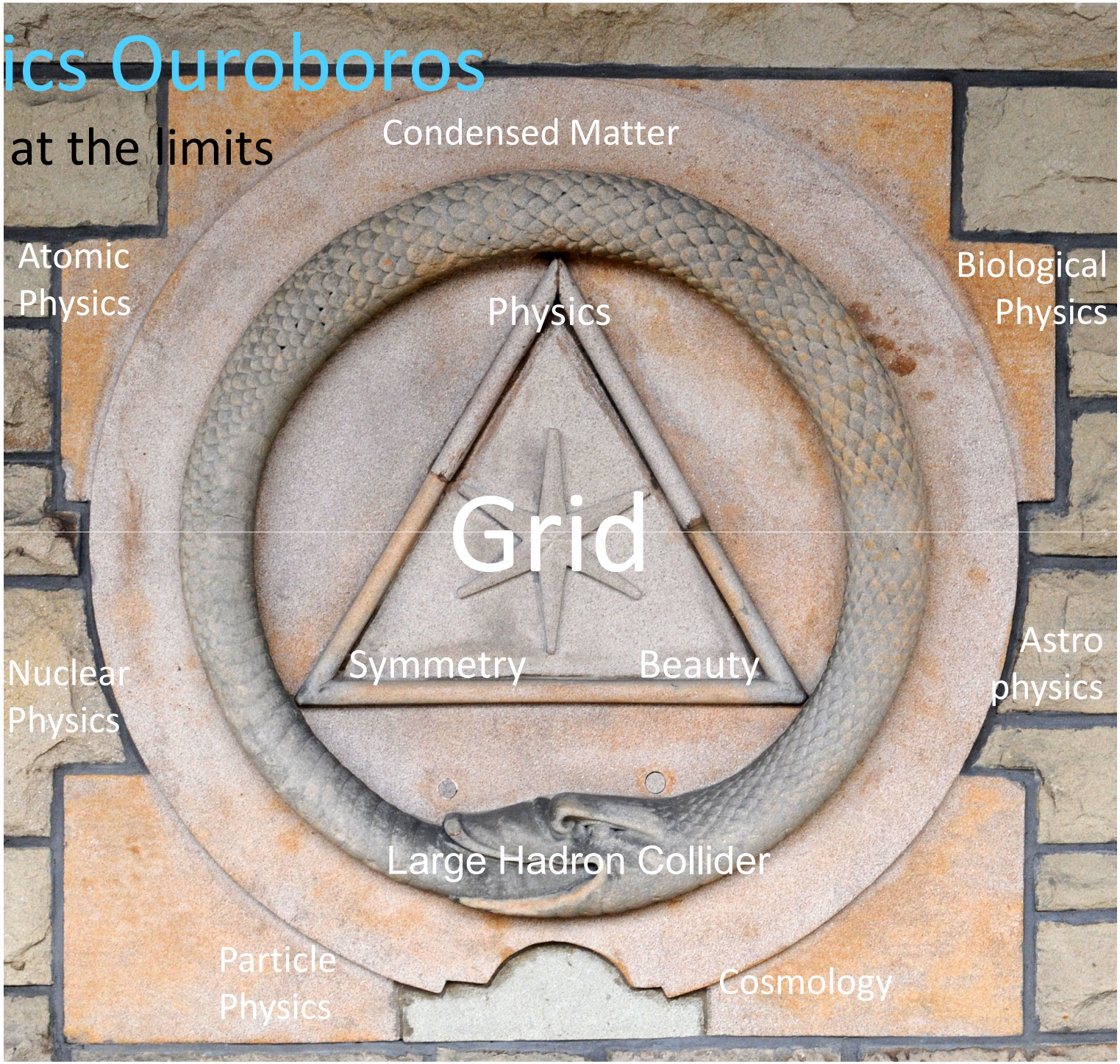
universe



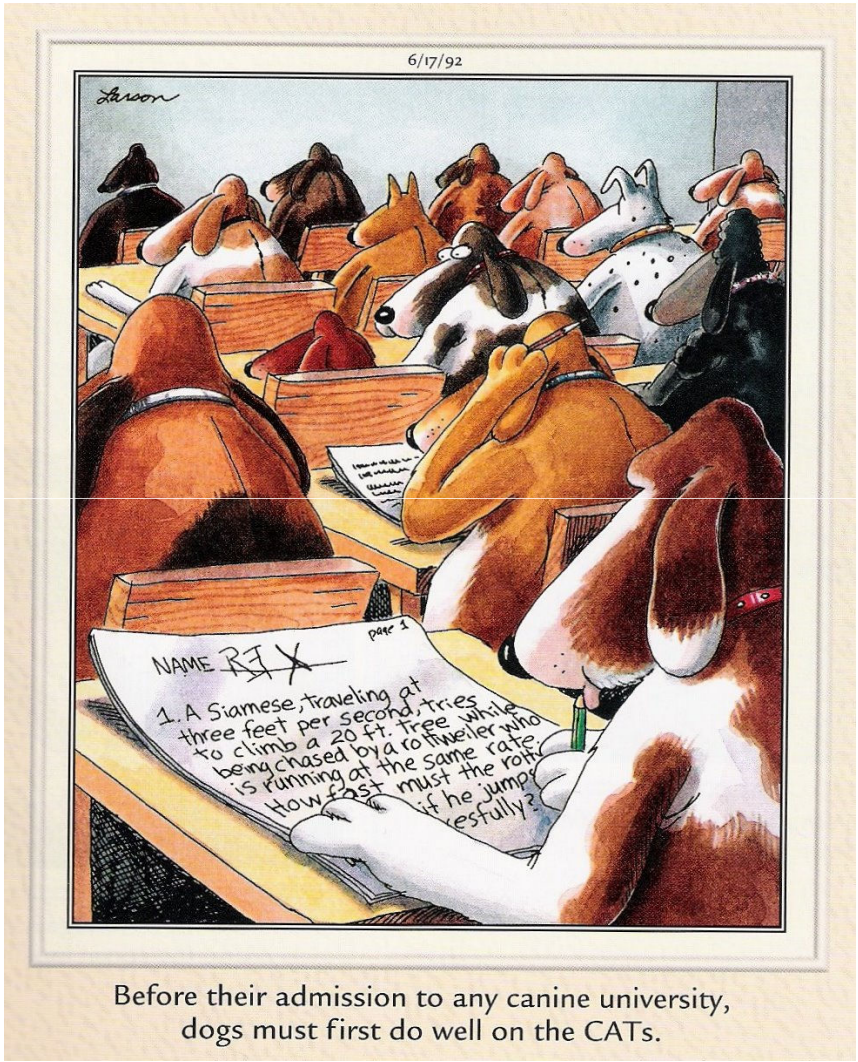
$> 10^{26}$ metres

Physics Ouroboros

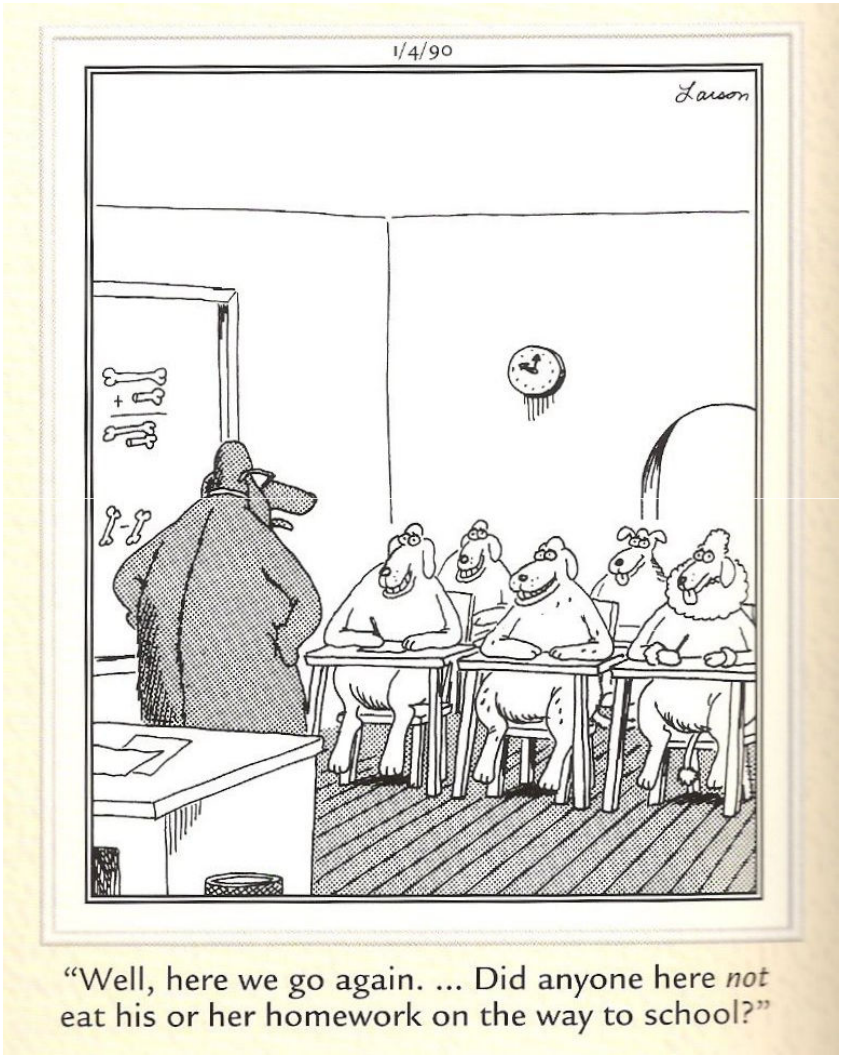
Physics at the limits



1. THEORY



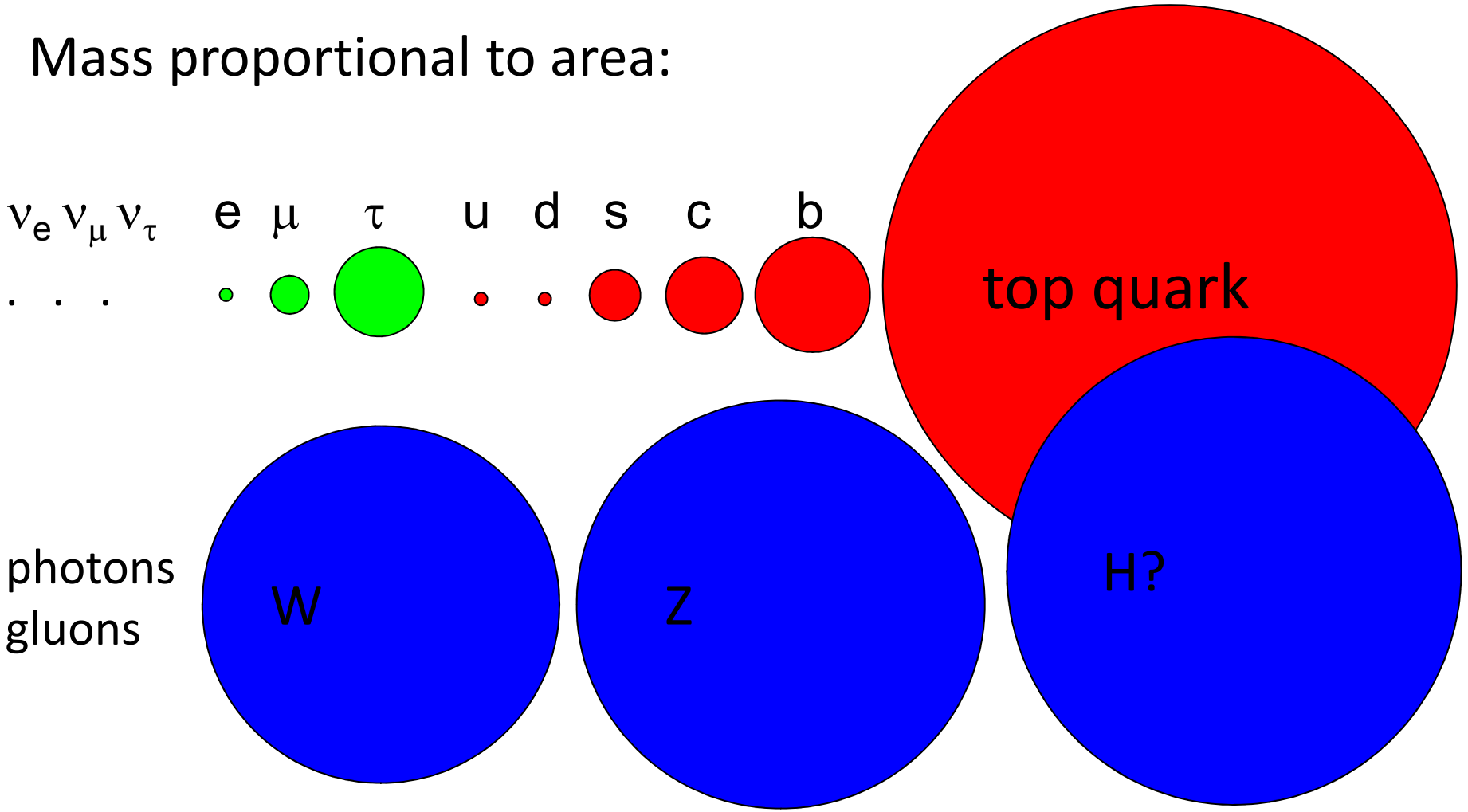
Before their admission to any canine university, dogs must first do well on the CATs.



"Well, here we go again. ... Did anyone here *not* eat his or her homework on the way to school?"

ELEMENTARY PARTICLE MASSES

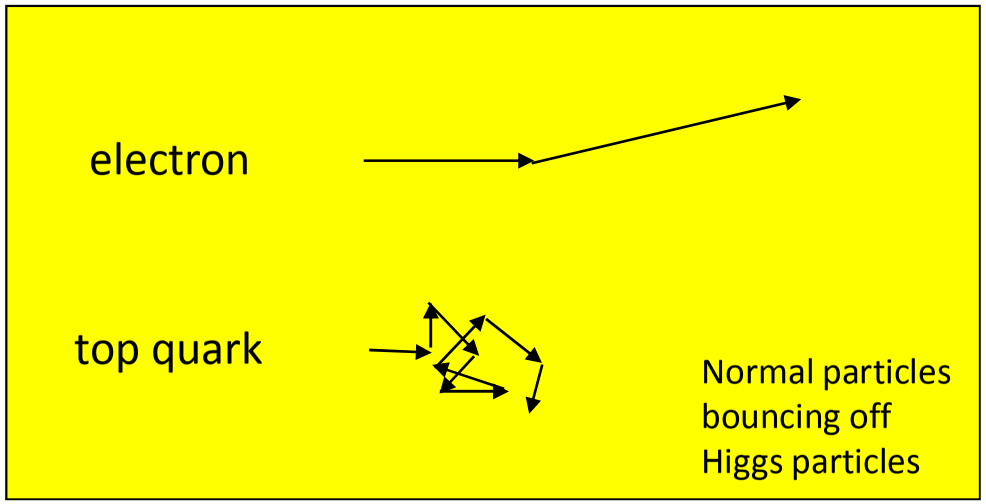
Mass proportional to area:



Are these made of something else? Are there more quark-, neutrino-,and electron-like particles?

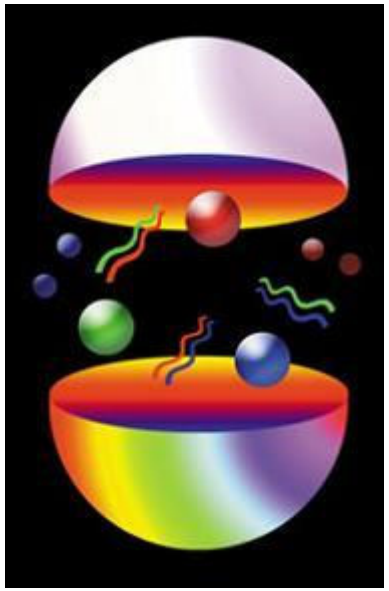
THE HIGGS BOSON

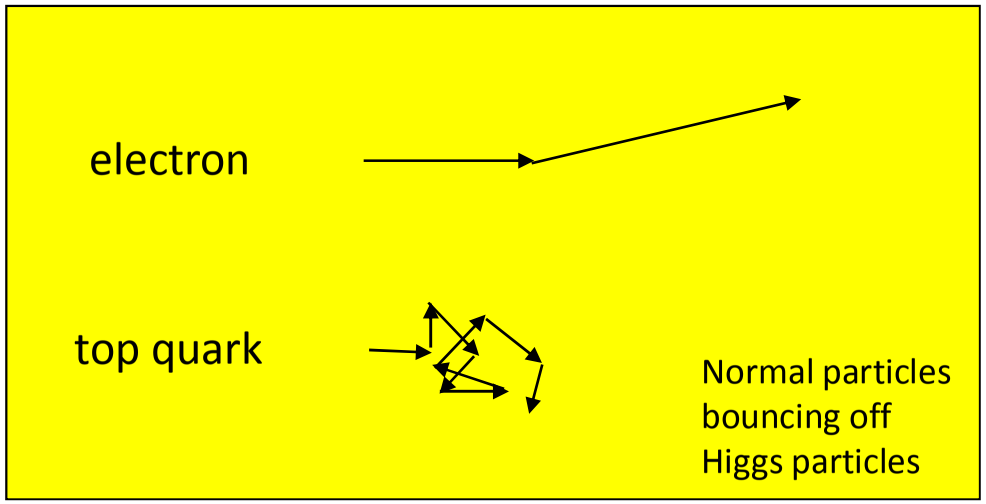
- With only the known particles, the current theory is incomplete: it predicts that all particles are massless and travel at the speed of light
- A hypothetical particle, the Higgs boson, fixes this problem, but we've yet to find it



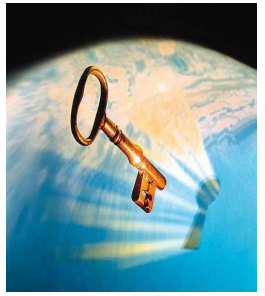
ASIDE: ORIGIN OF MASS
but not the source of all mass

- Higgs allows self-consistent standard model (preserves gauge symmetry)
- Need a Yukawa interaction to incorporate individual fermion masses
- Need QCD to generate massive nucleons from light u, d quarks





THE HIGGS MECHANISM

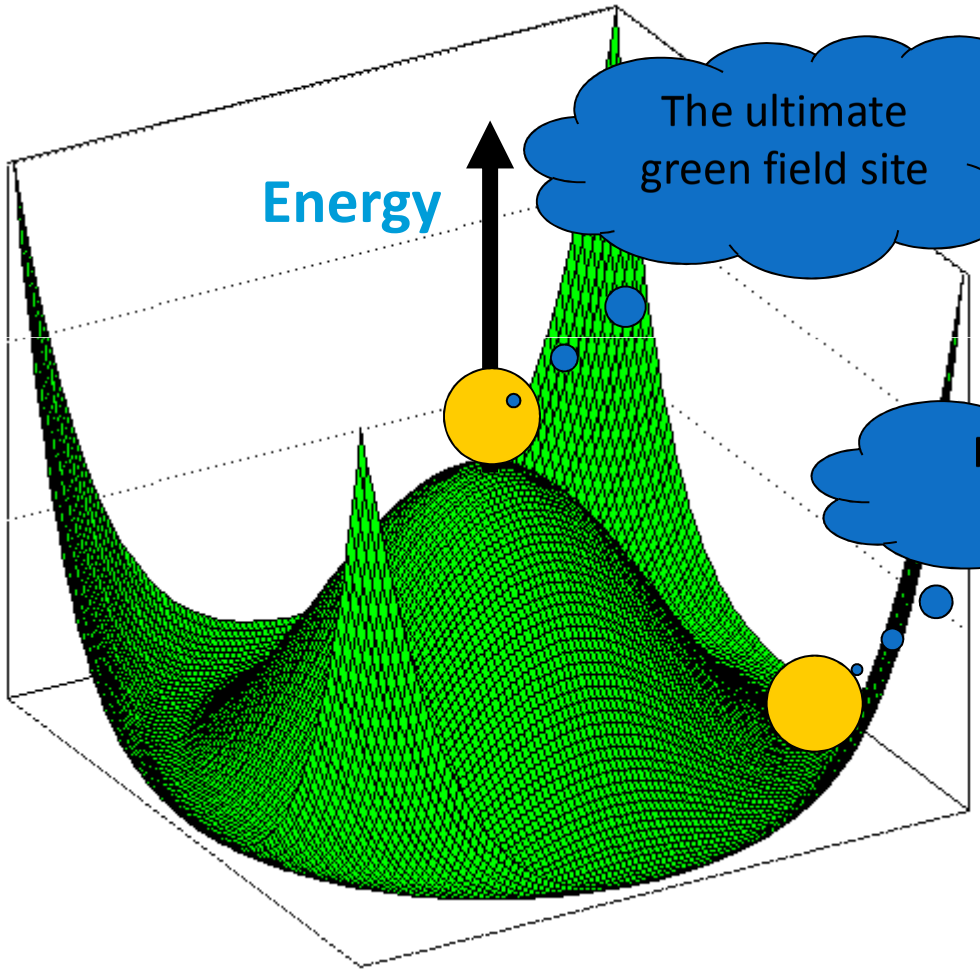


Theory: vacuum potential

Higgs potential:

$V(\underline{\Phi}) = -\mu^2 \underline{\Phi}^+ \underline{\Phi} + \lambda(\underline{\Phi}^+ \underline{\Phi})^2$

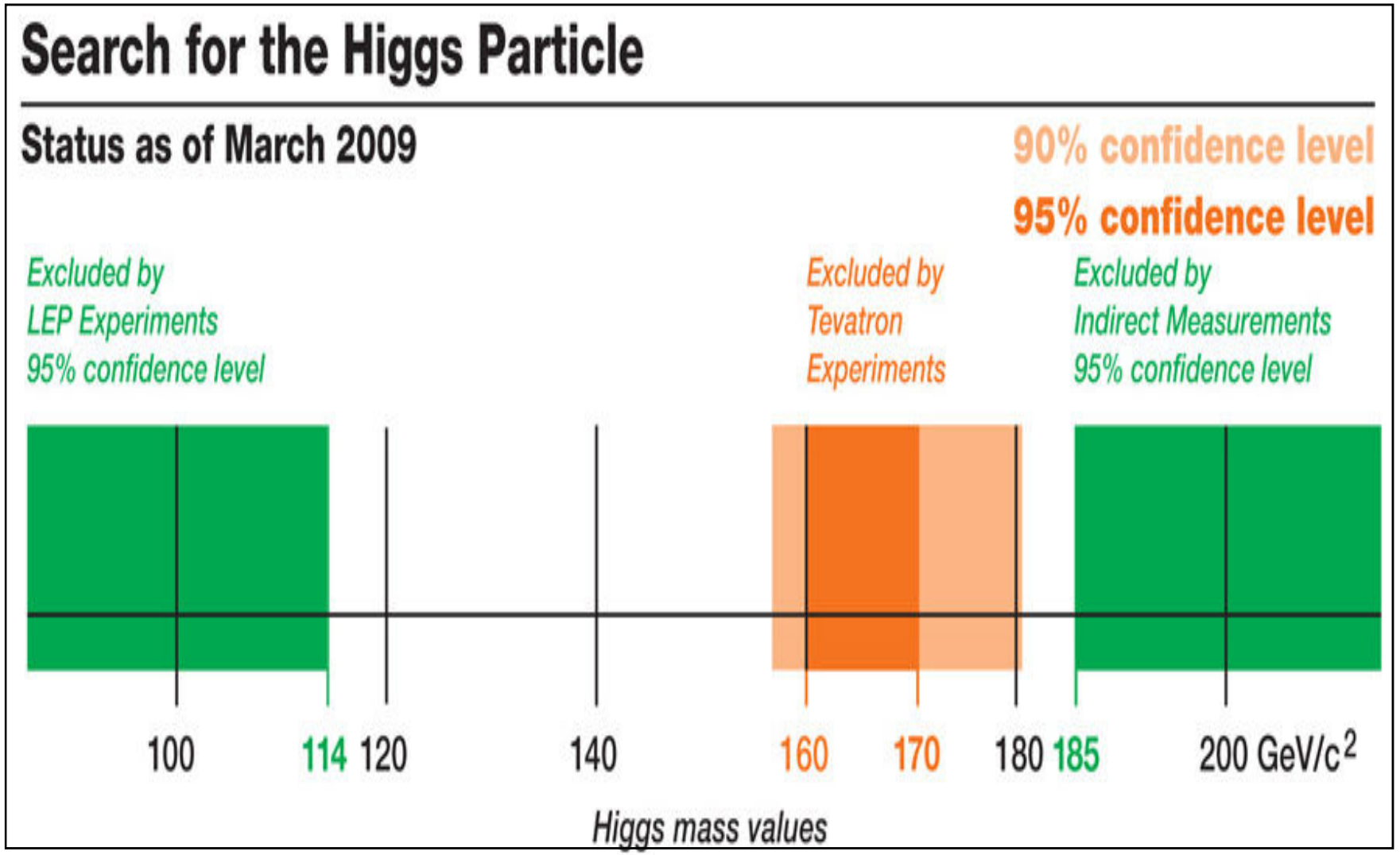
$(\lambda > 0)$



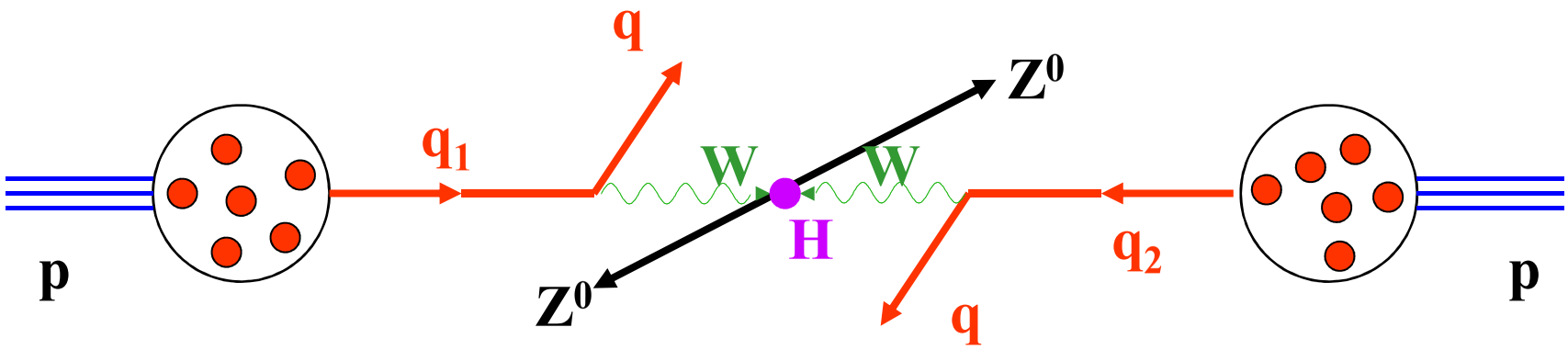
$\underline{\Phi} = exp(i\theta^a(x)\, \underline{T}''^a)\ |_{\underline{\Phi}_0} . (\underline{\Phi}_0 + H(x))$

$m_H = \mu\sqrt{2}$ (a free parameter)

THE HIGGS: WHERE ARE WE NOW?



LHC MOTIVATION:
HIGGS PRODUCTION IN PP COLLISIONS



$M_H \leq 1$ TeV

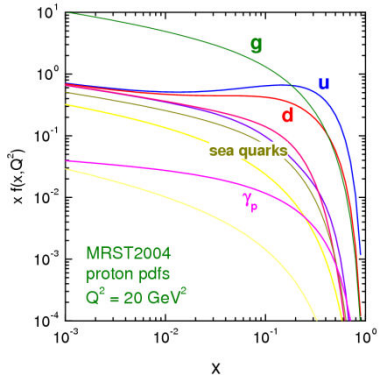
$E_W \geq 0.5$ TeV

$E_1 \geq 1$ TeV

$E_2 >\geq 1$ TeV

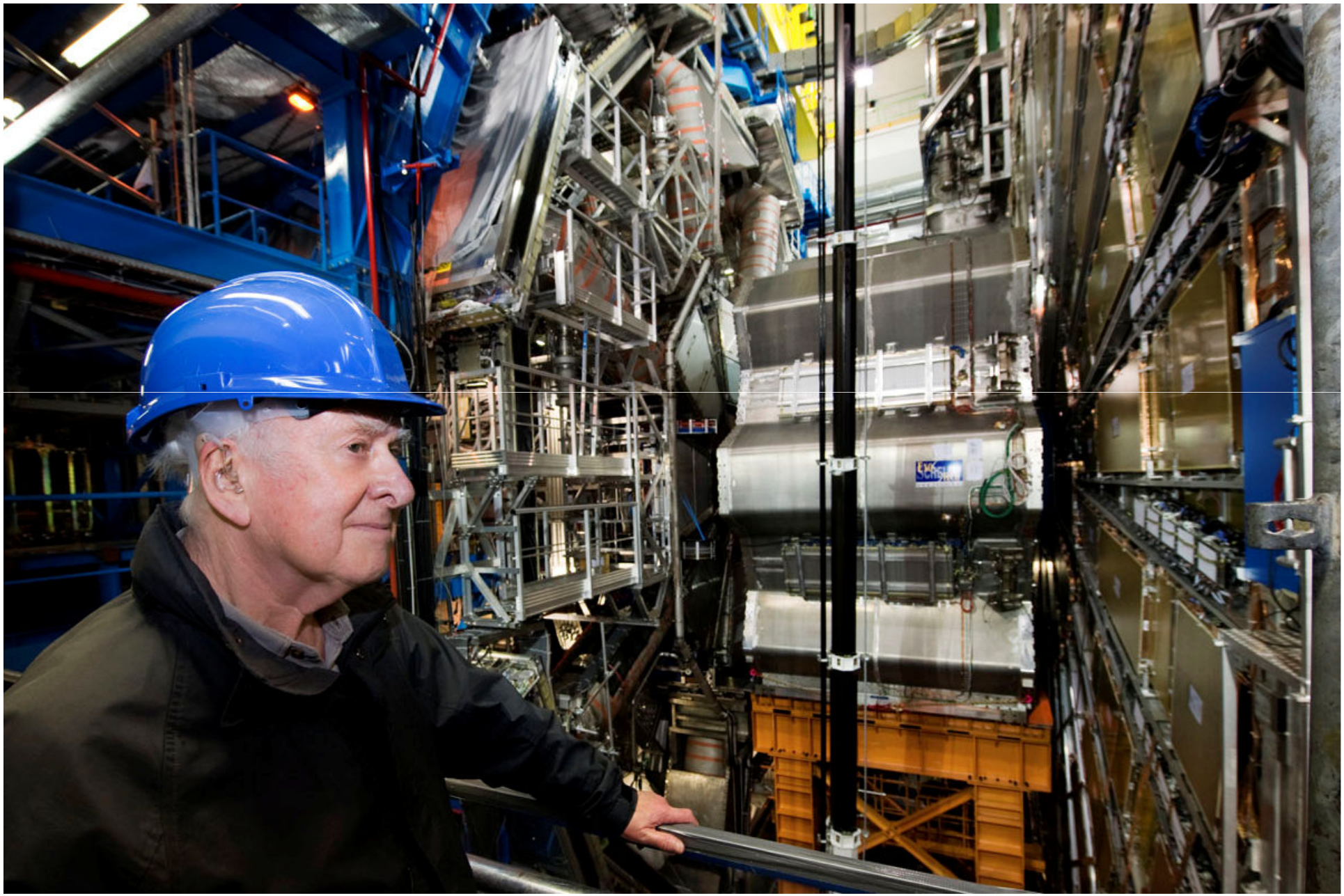
Parton luminosities

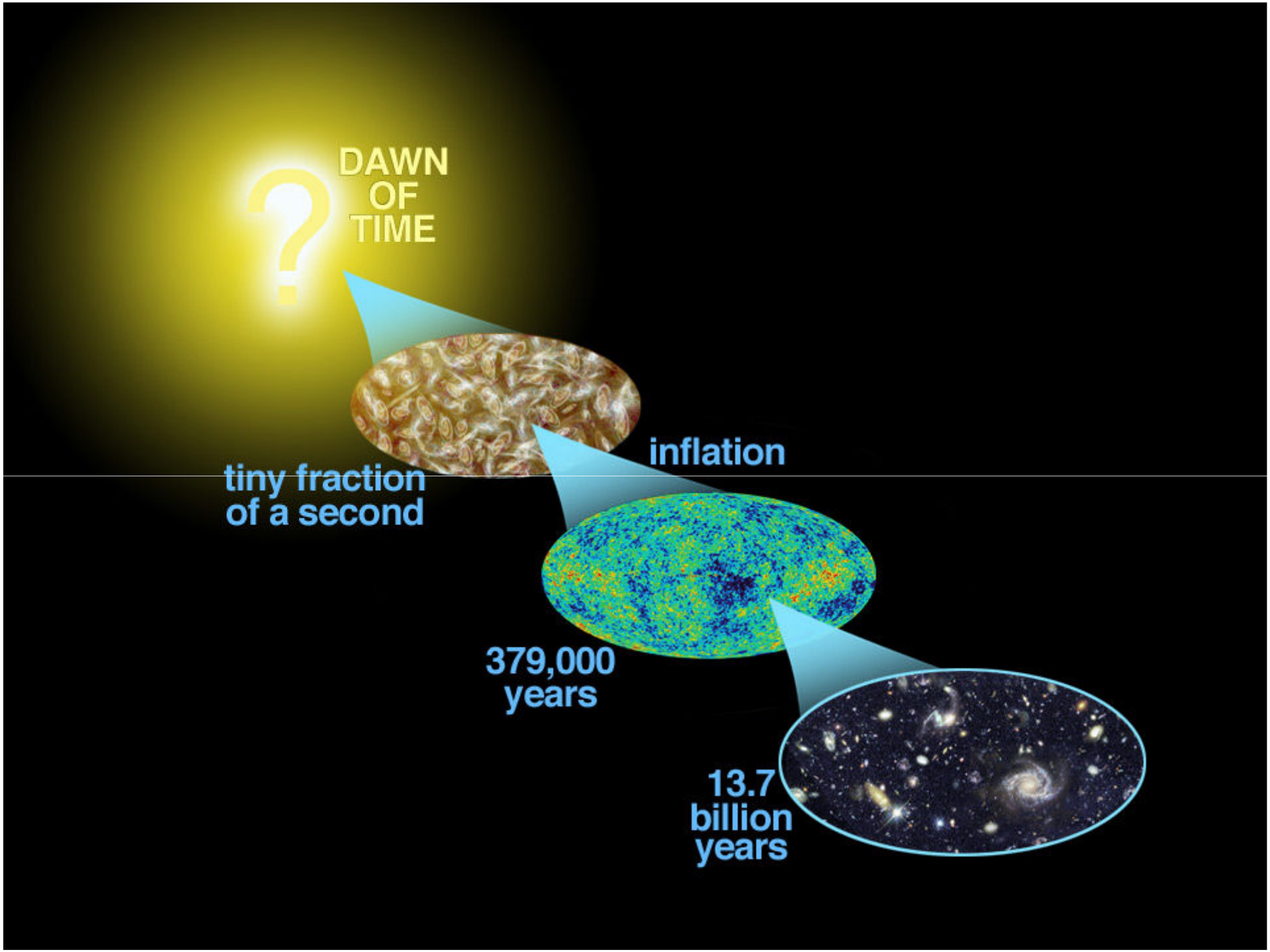
$E_{cm}=\sqrt{(4x_1x_2.E_pE_p)}$

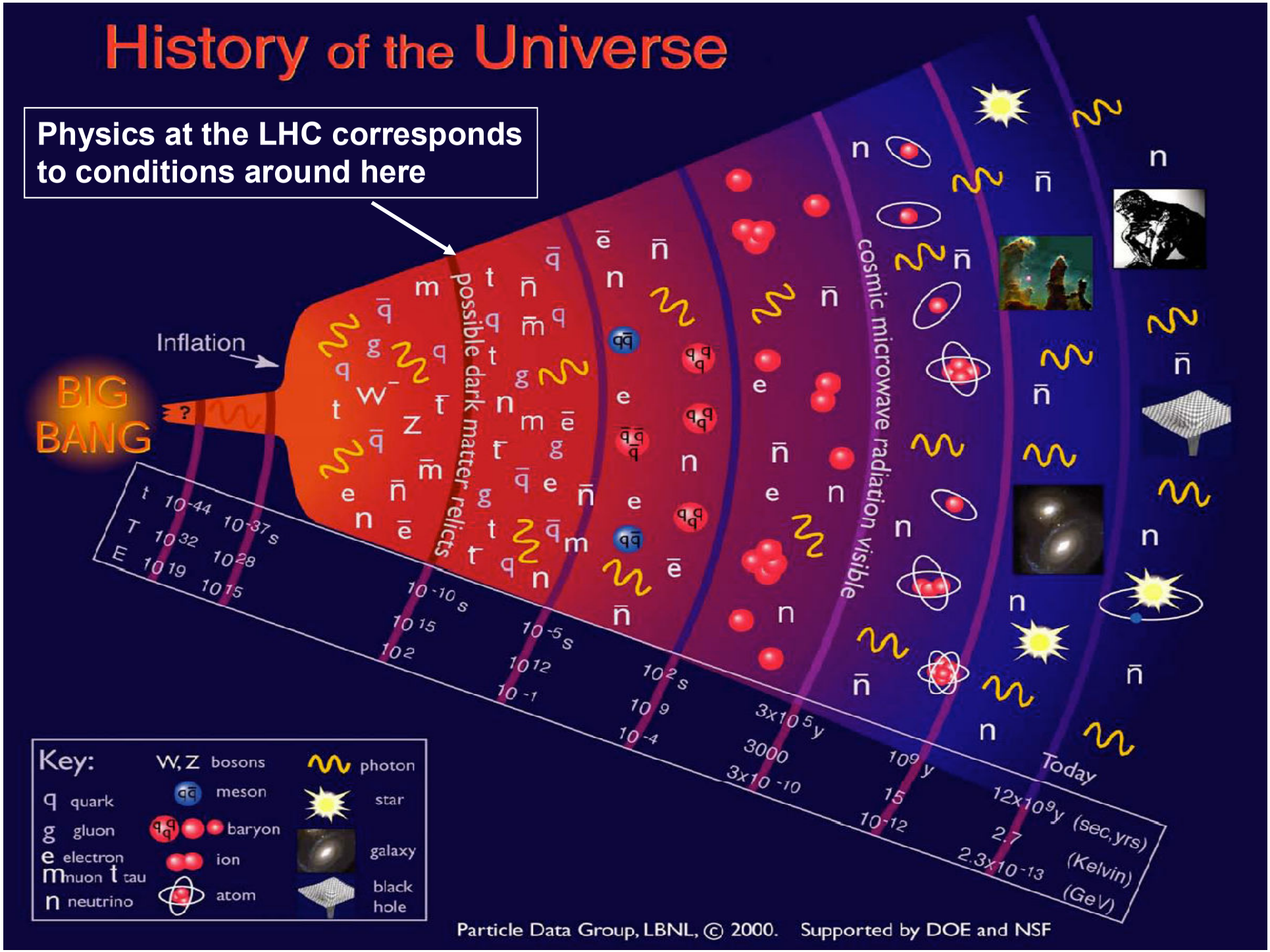


→ Proton Proton Collider with $E_p = 7$ TeV

Where Theory Meets Experiment: 14th April 2008

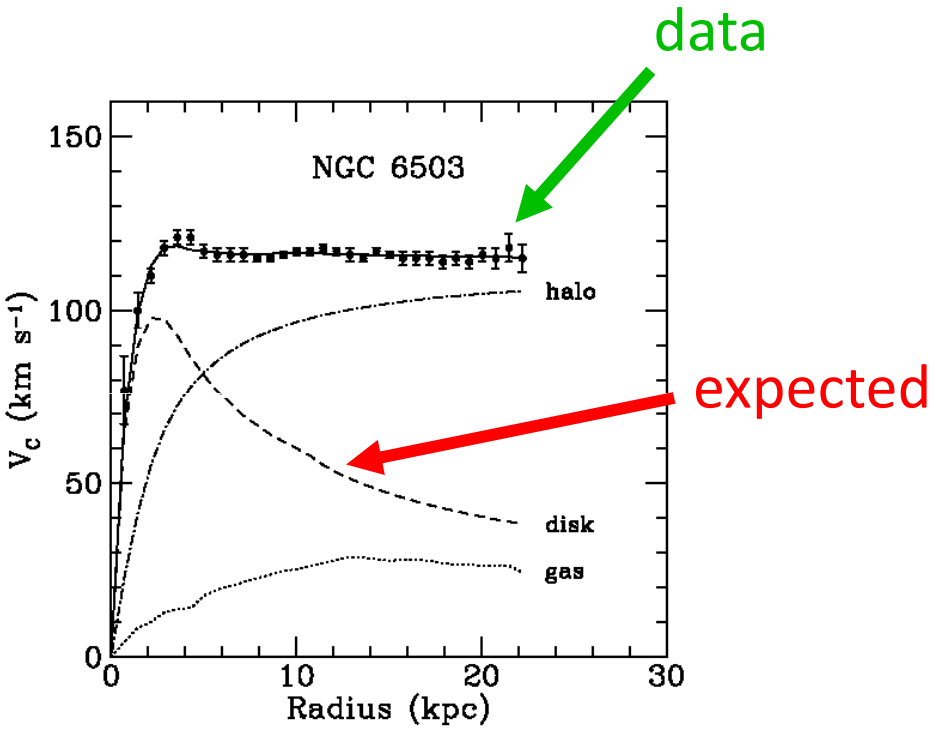



DAWN
OF
TIME
tiny fraction
of a second
inflation
379,000
years
13.7
billion
years


History of the Universe
Physics at the LHC corresponds to conditions around here
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
Today
Key:
W, Z bosons
photon
q quark
meson
star
g gluon
baryon
e electron
galaxy
m muon t tau
ion
n neutrino
atom
black hole
(sec, yrs)
(Kelvin)
(GeV)
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

PUZZLE 1: DARK MATTER



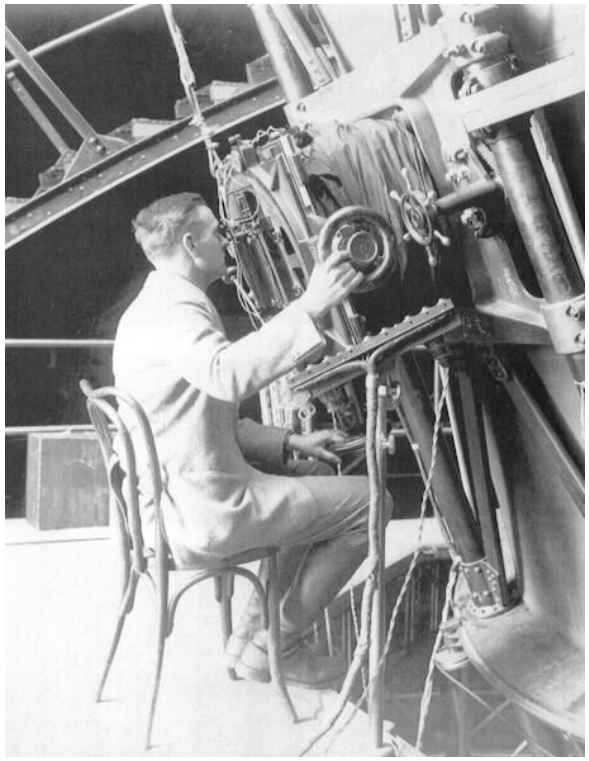


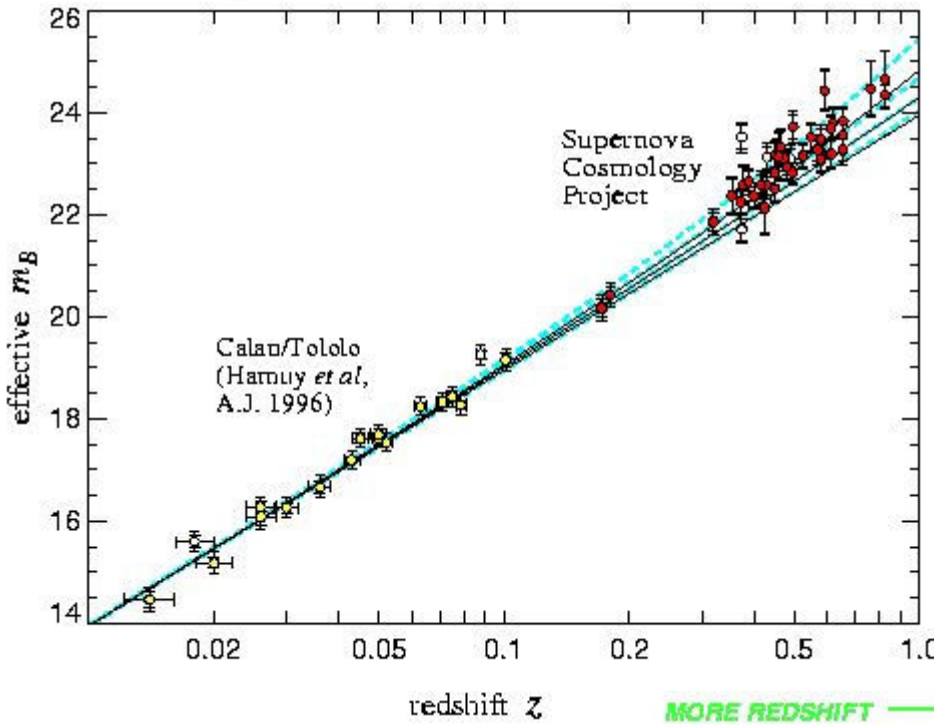
Begeman, Broeils, Sanders (1991)

Galaxies and clusters of galaxies rotate too fast
→ dark matter

$$\frac{Mv^2}{r} = \frac{GMM_{\rm tot}}{r^2} \Rightarrow v \sim r^{-1/2}$$

PUZZLE 2: DARK ENERGY





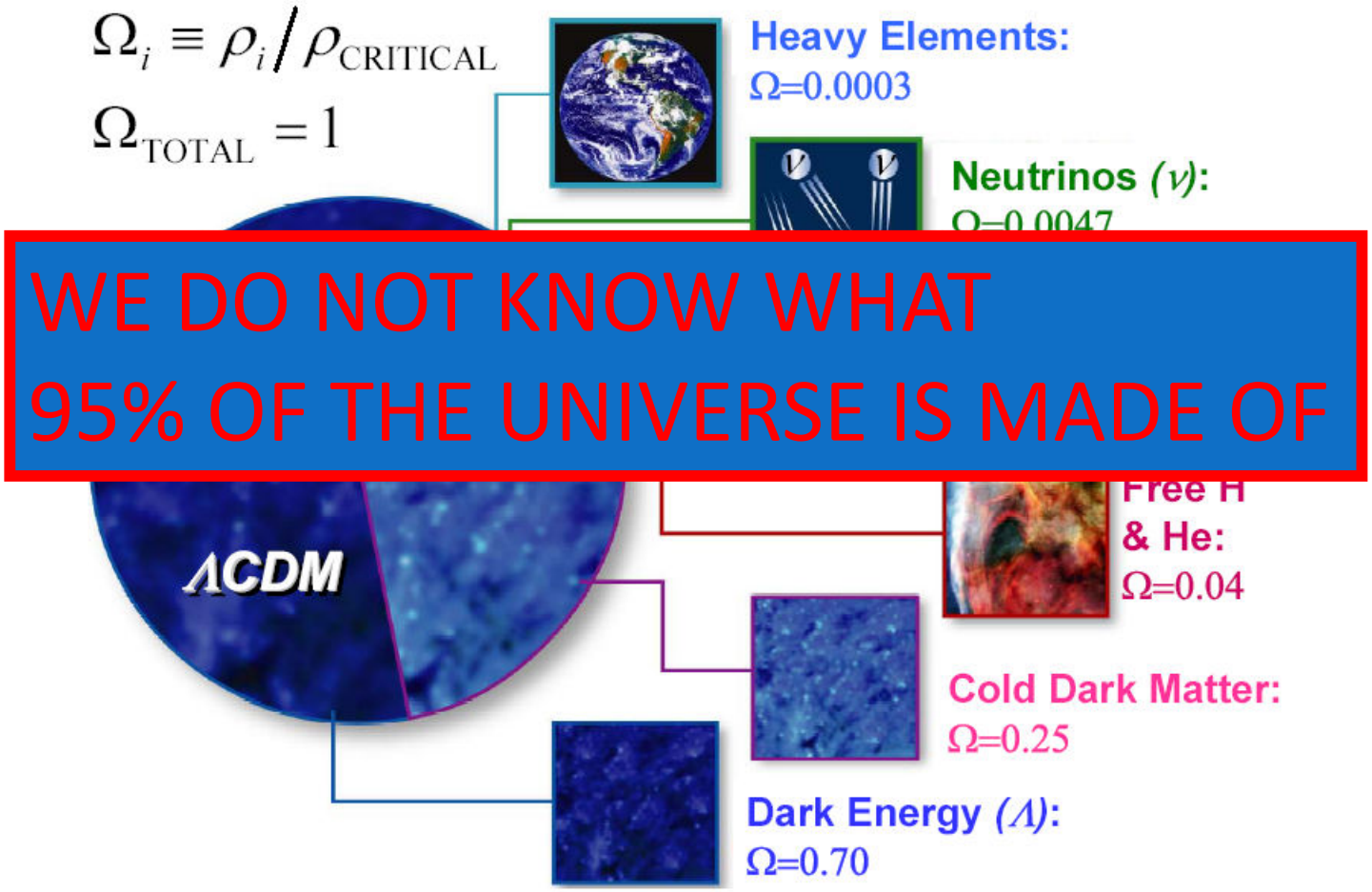
Hubble (1929):

the universe is expanding

Supernovae (1998):

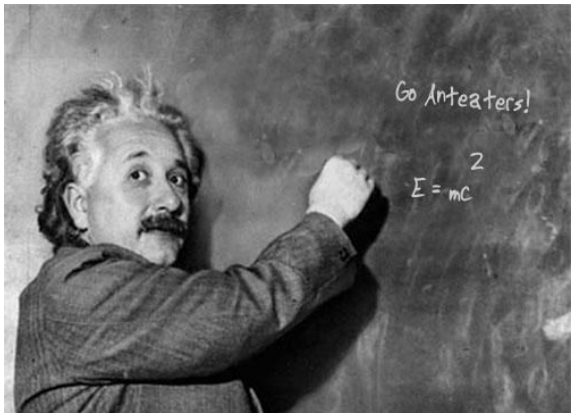
and accelerating → dark energy

(COMBINED) PUZZLE 3: COMPOSITION OF THE UNIVERSE



WE DO NOT KNOW WHAT
95% OF THE UNIVERSE IS MADE OF

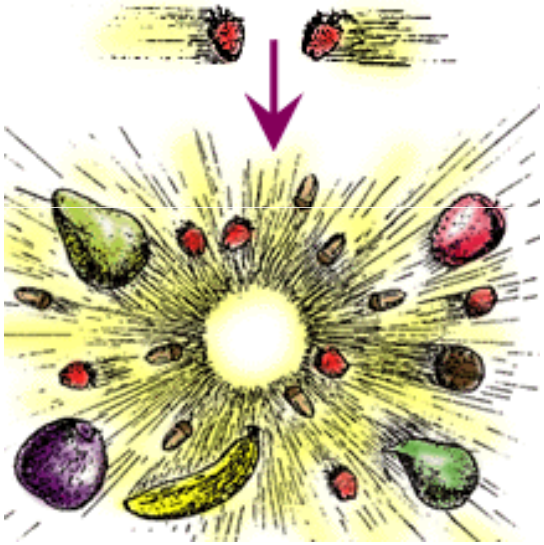
1. $E = mc^2$



- Many of these questions involve hypothetical particles. How can we investigate them?

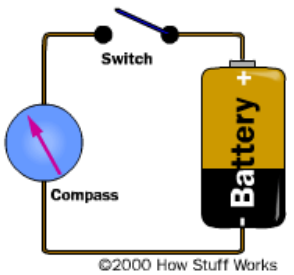
- Einstein: $E = mc^2$. Energy can be transformed into mass.

- To make new, heavy particles, smash together known particles at high energy



The basic unit of energy is the "electron Volt":

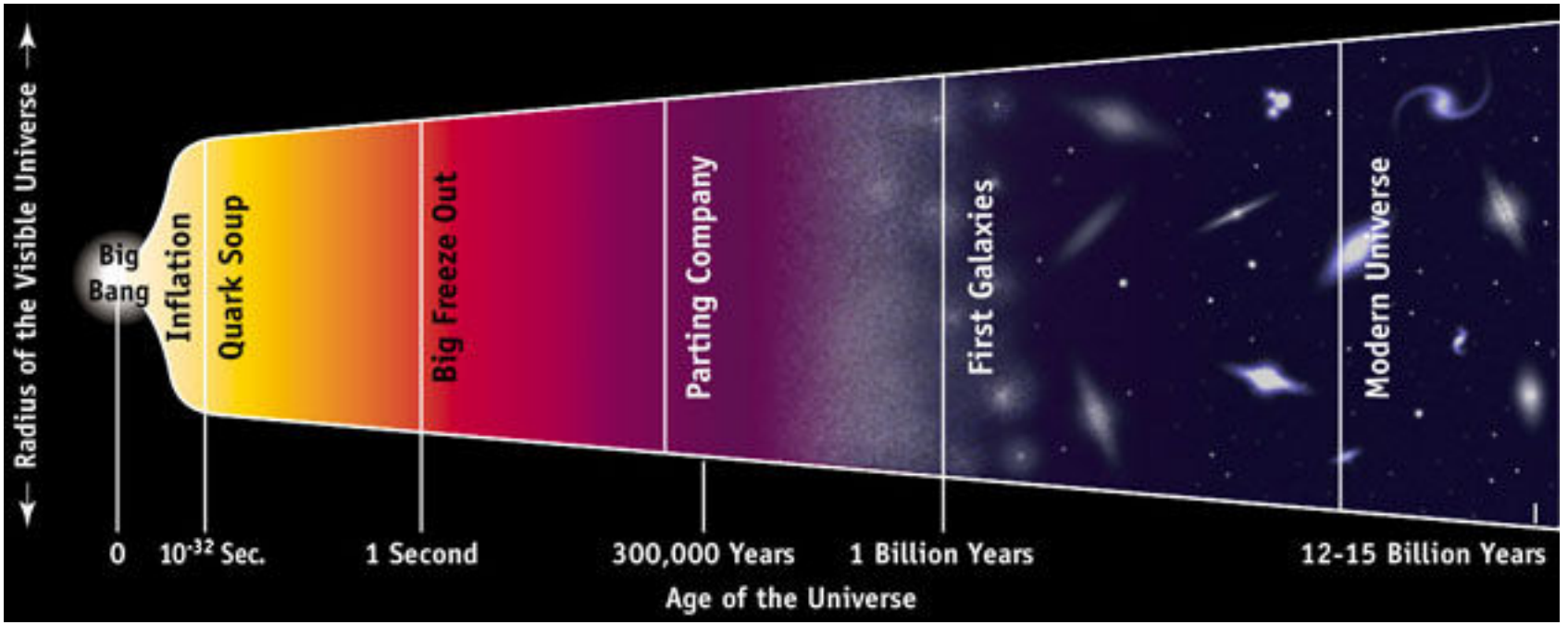
energy that a single electron receives when it passes from negative to positive terminal of a 1 Volt battery



2. E = kT



- Boltzmann: E = kT. Universe just after the Big Bang was very small and very hot. **10^{15} K.** Can go back 13.6 bn years..



Q: how old was the Universe when the physics of the LHC was last probed?

A: t ~ 1ns (E = 100 GeV) - the whole Universe was ~the size of the Solar System

t ~ 0.01ns (E = 1 TeV) - go back two orders of magnitude in time for order of magnitude in energy for the (radiation-dominated) early universe

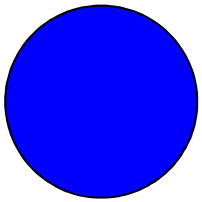
3. E [GeV] ≥ 0.2 / R [fm] MICROSCOPES

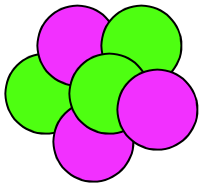
Planck ($\lambda=h/p$) & Heisenberg ($\Delta p \Delta x \geq \hbar$):
Higher energy → improved resolution (quantum limit)











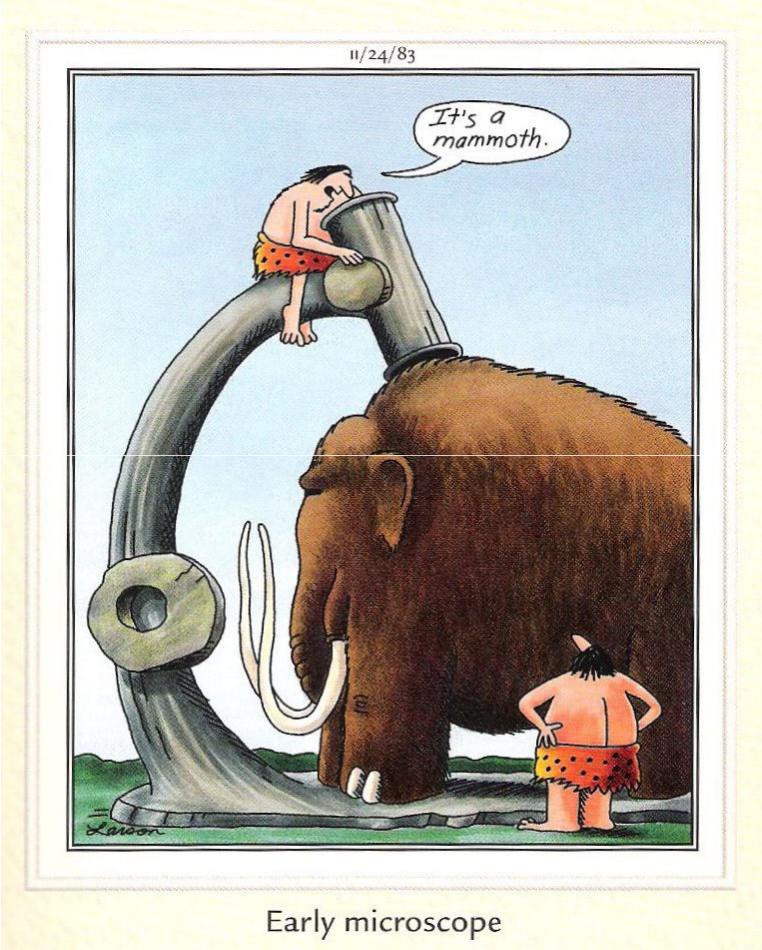
low resolution (R)

high resolution (R)



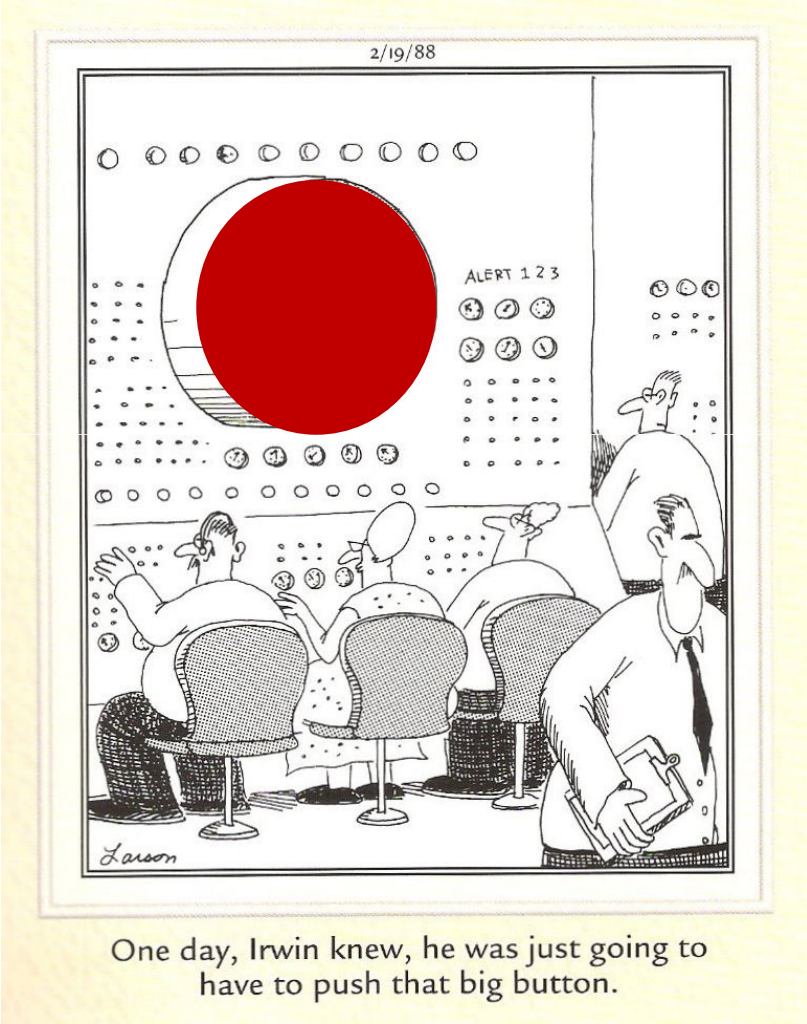
2. MACHINE

Particle Colliders



Early microscope

highest resolution (R)



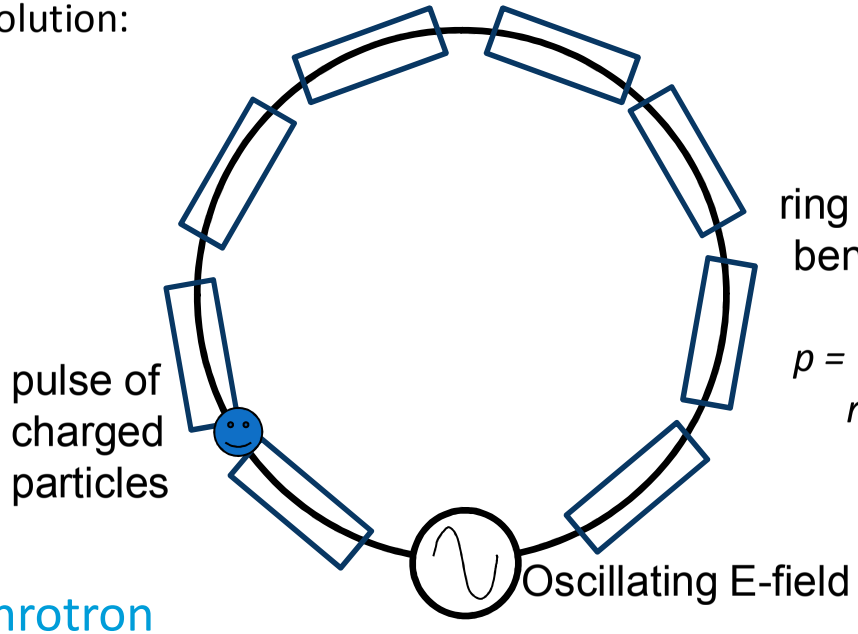
One day, Irwin knew, he was just going to have to push that big button.

Synchrotron Particle Accelerators

Lorentz force $\boldsymbol{F} = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B})$ note $\boldsymbol{v} = d\boldsymbol{r}/dt$

Energy gain = $\int \boldsymbol{F}.d\boldsymbol{r} = q \int \boldsymbol{E}.d\boldsymbol{r} + d\boldsymbol{r}/dt \times \boldsymbol{B} \,.\, \boldsymbol{dr} = qV$ add energy by voltage drop

Economic solution:

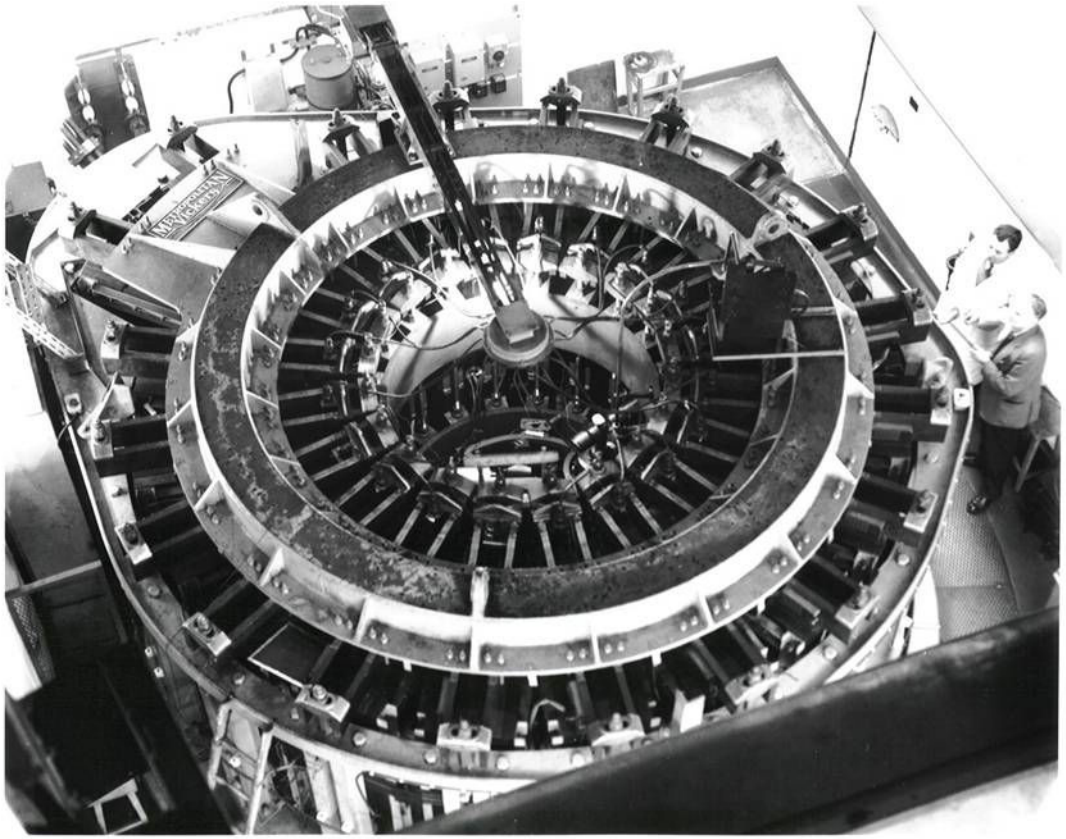


from
$F_B = qvB = mv^2/r$
$qB = mv/r$
$qB = p/r$

The synchrotron

- pulse of particles accelerated by *E*-field
- bend round circle. Accelerate again (get the phase right!!)
- keep radius constant. Increase *B* a little each pass as *p* increases
- when required energy reached, reduce *E*, hold *B* constant – storage ring

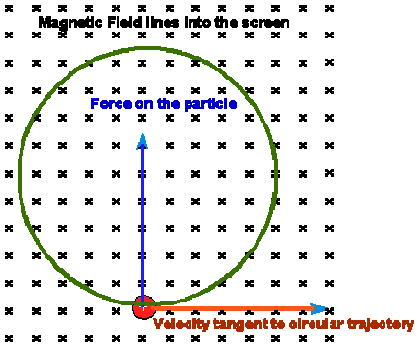
Heritage - Past

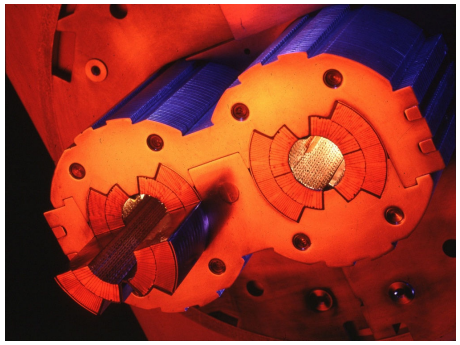


- The first electron synchrotron in Europe was constructed in Glasgow in the 1950s
- E = 300 MeV

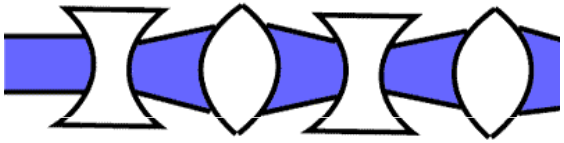
The LHC is a Synchrotron

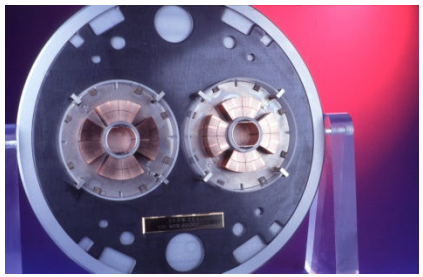
- Magnets
  - Dipoles
    - Keep particles on circular orbit

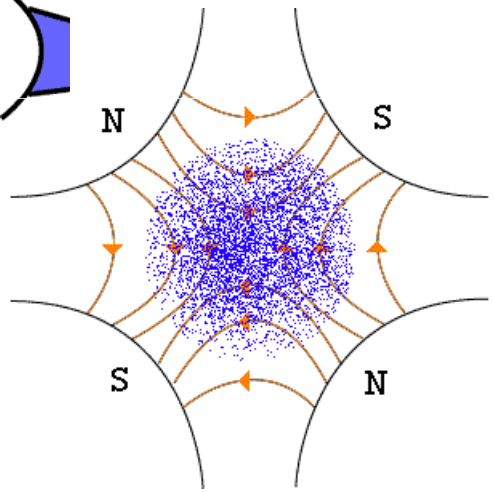




  - Quadrupoles
    - Limit the divergence of the beam (beam stability)
    - Focus beams on interaction points to obtain high luminosities



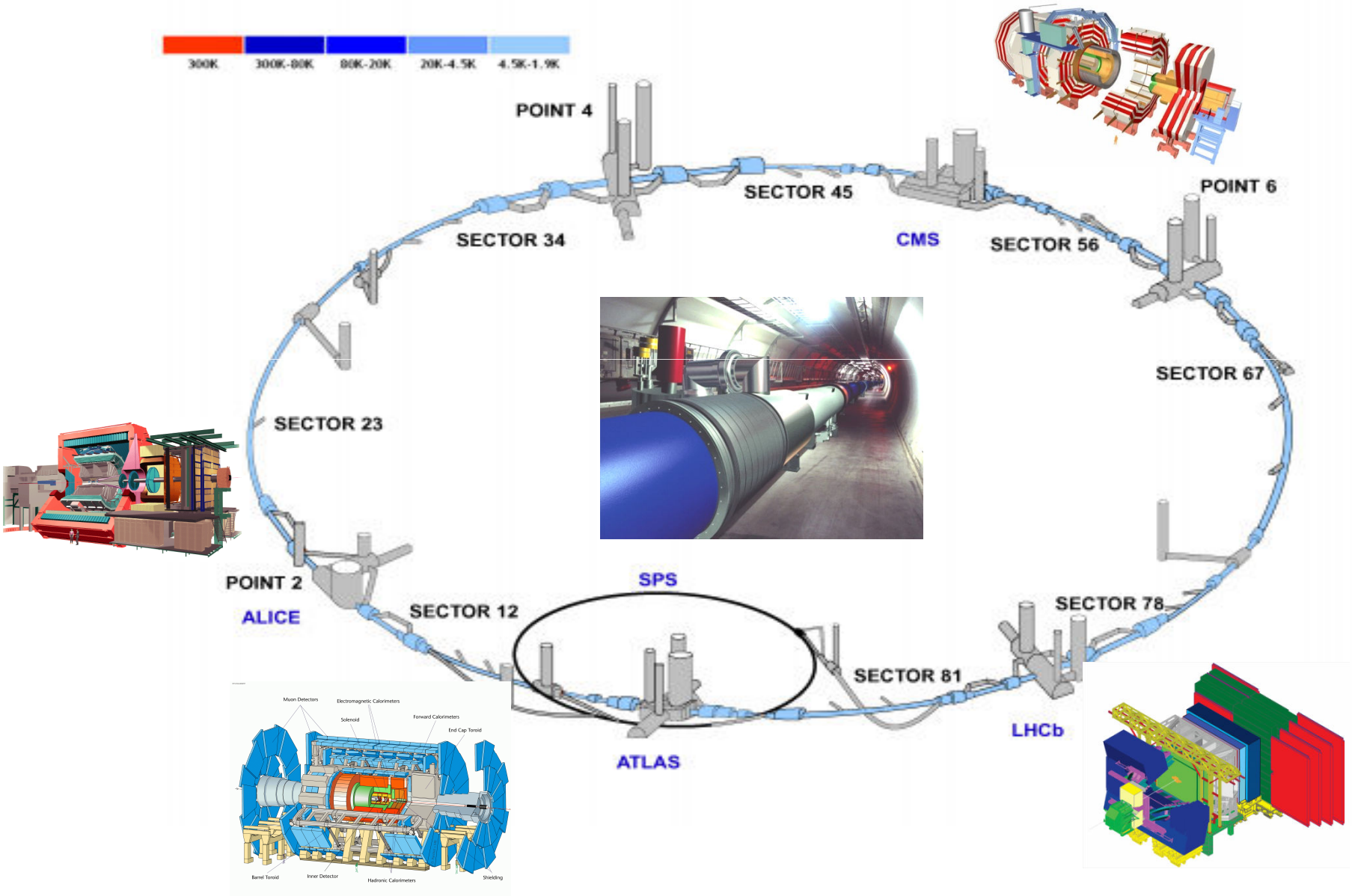


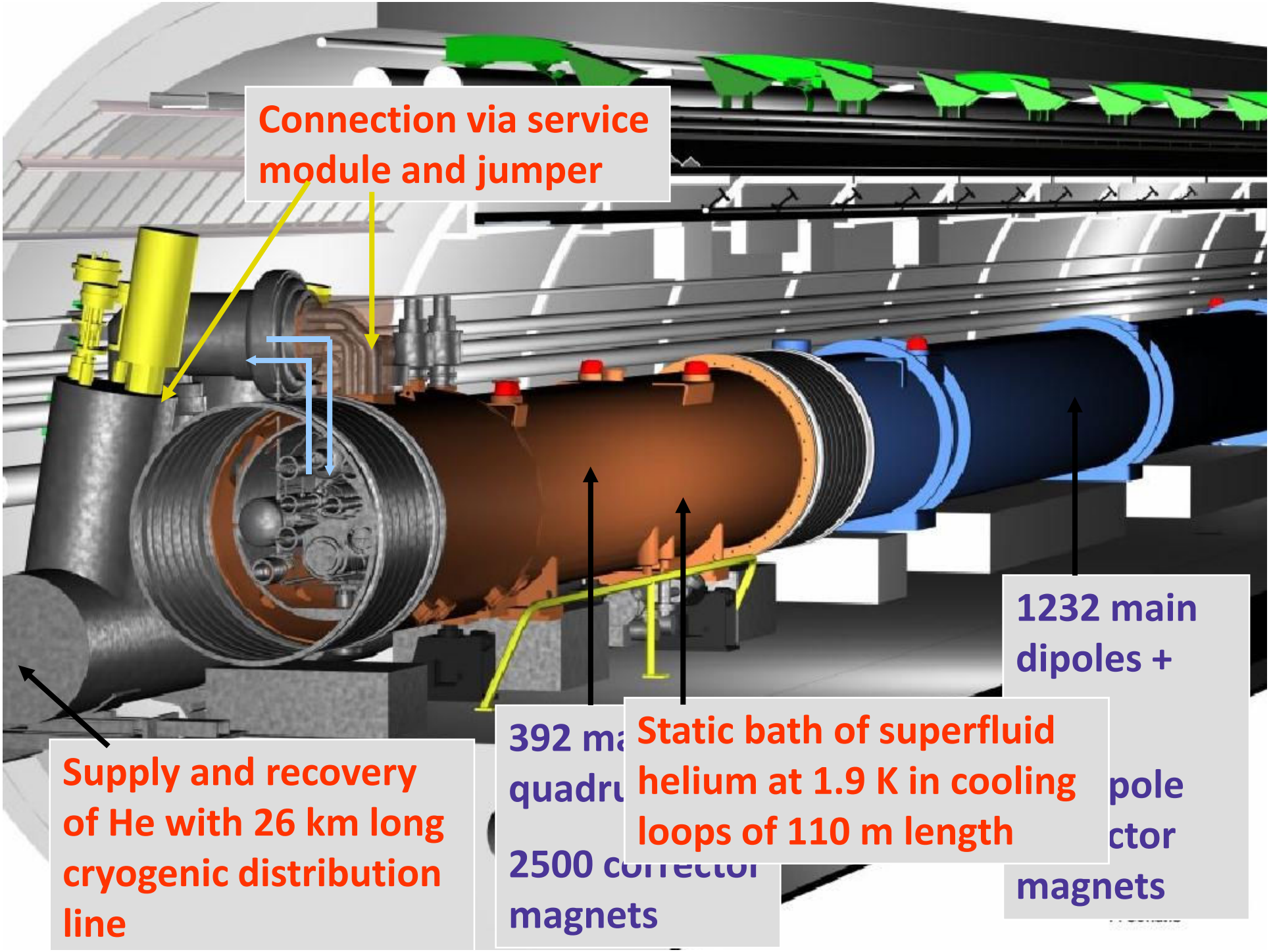


- RF Cavities
  - Boost particles at each turn (0.45 → 7 TeV)



LHC Switches On



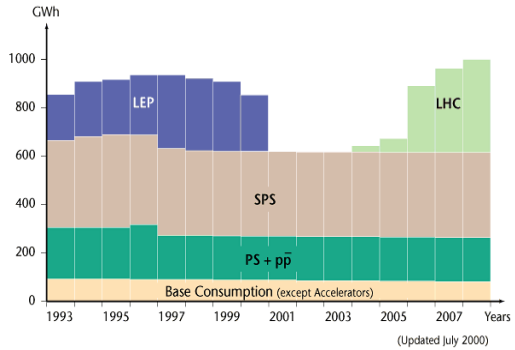

Connection via service module and jumper
Supply and recovery of He with 26 km long cryogenic distribution line
392 ma
quadru
2500 corrector magnets
Static bath of superfluid helium at 1.9 K in cooling loops of 110 m length
1232 main dipoles +
pole
ctor
magnets

LHC statistics

- Collides two 7 TeV proton beams with beam currents of 600mA

  Using $E=mc^2$ we get 14TeV = 0.15g (a fly)

  Total energy stored in each beam is 350MJ
- 1232 superconducting NbTi dipole magnets
- Beam pipe has vacuum of 10^{-13} atmospheres
- Total power required to run LHC is 120MW

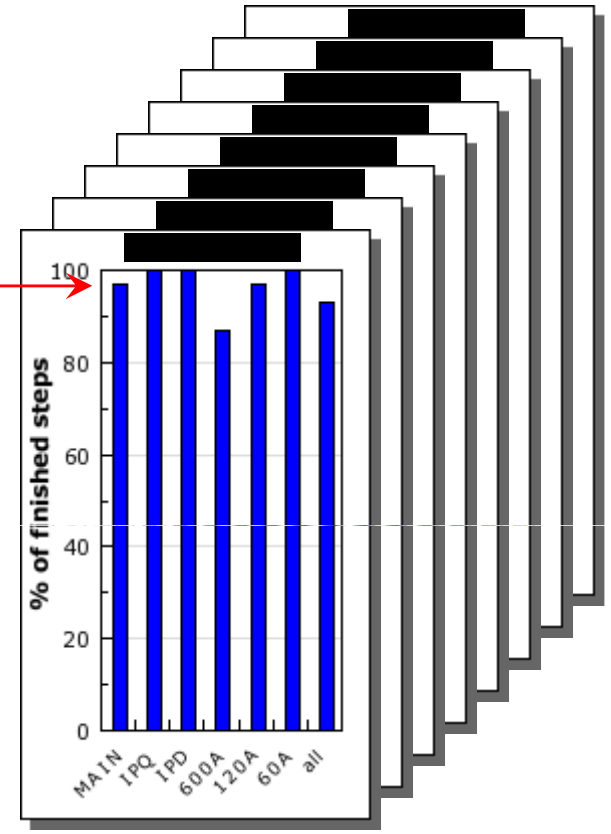




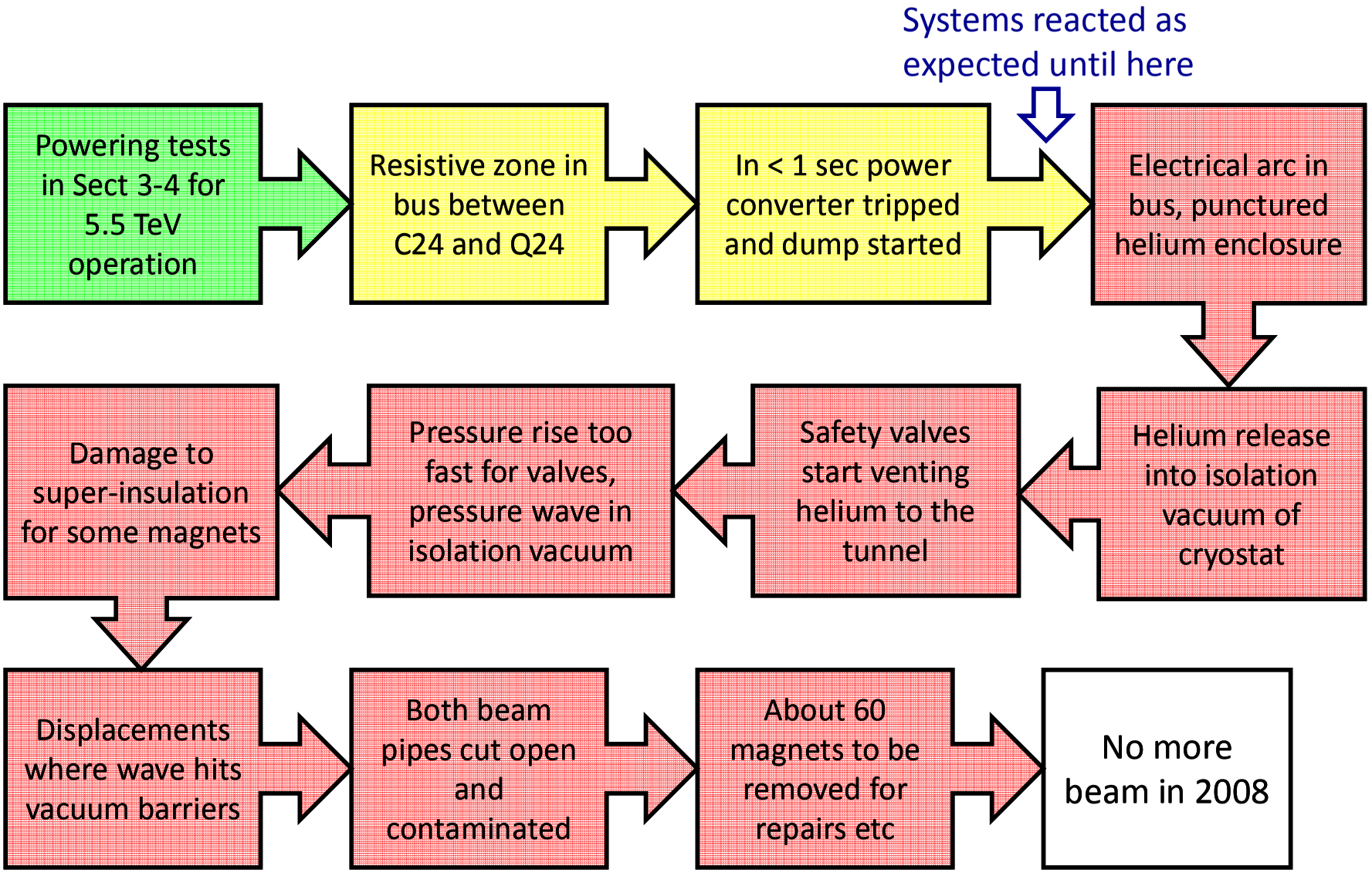
More details at http://lhc.web.cern.ch/lhc/

LHC incident on Sept 19th

- During a few days period without beam while recovering from transformer failure
- Making the last step of the dipole circuit in sector 34, to 9.3kA
- At 8.7kA, development of resistive zone in the dipole bus bar splice between Q24 R3 and the neighbouring dipole
  - Later estimated (from cryogenic data on heat deposition) to be 220nΩ
- Electrical arc developed which punctured the helium enclosure, allowing helium release into the insulating vacuum
- Large pressure wave travelled along the accelerator in both directions

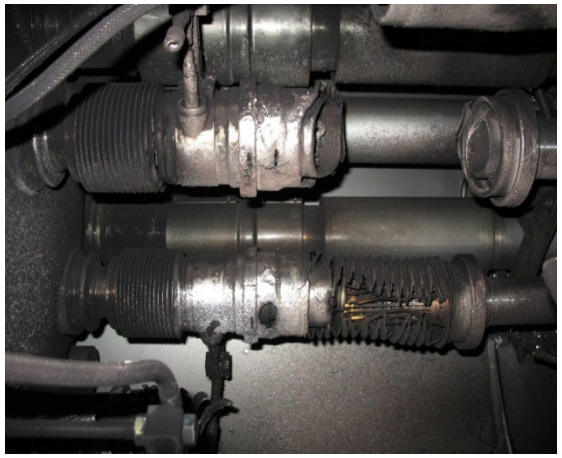


LHC incident on Sept 19th



Consequential Damage

Multi kA electrical arc

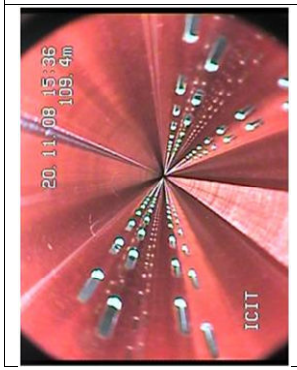
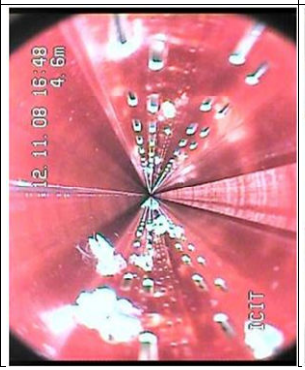
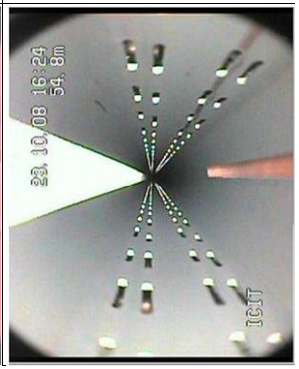


Magnets Displaced



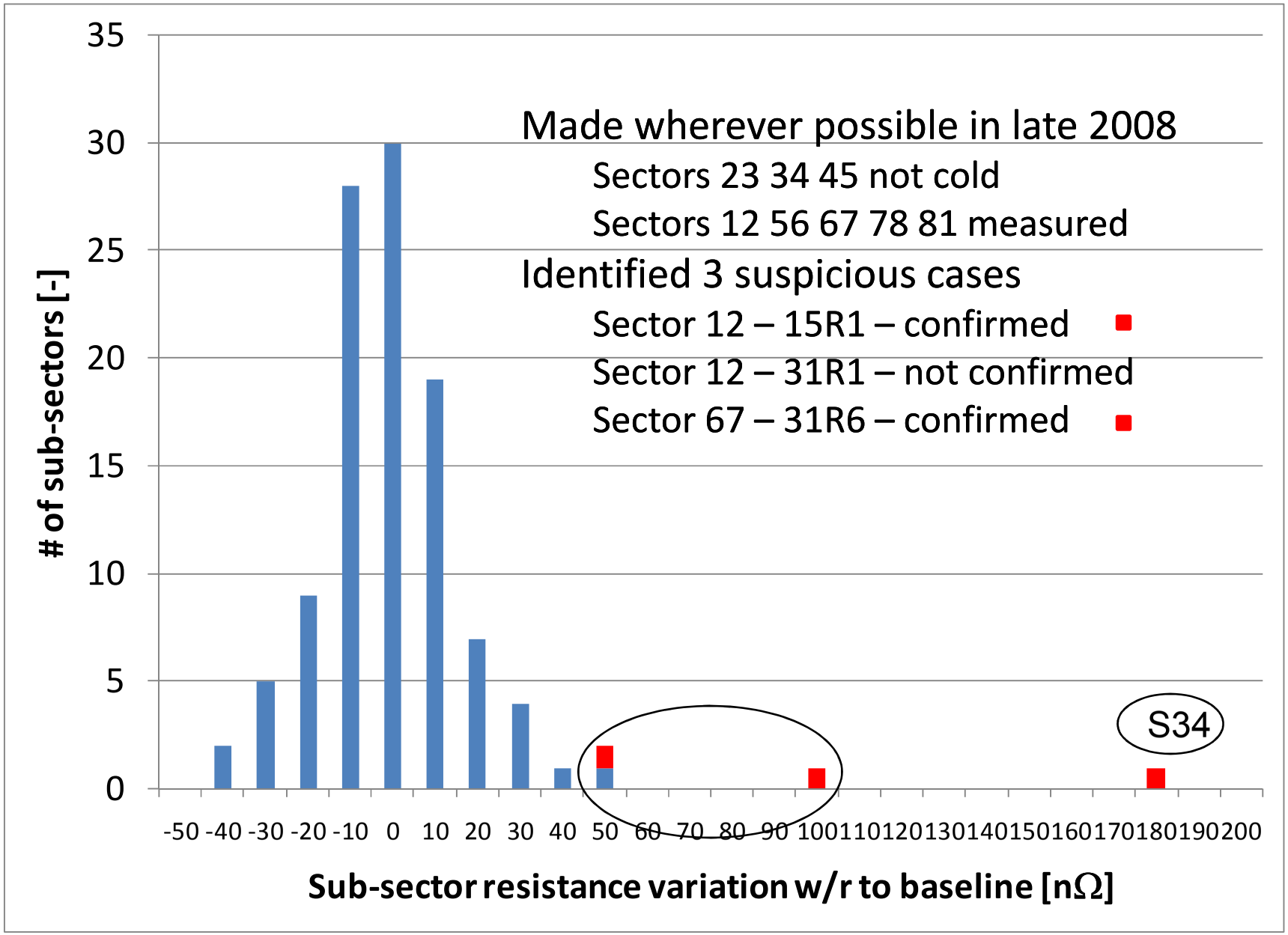




Beam Screen (BS) : The red color is characteristic of a clean copper surface	BS with some contamination by super-isolation (MLI multi layer insulation)	BS with soot contamination. The grey color varies depending on the thickness of the soot, from grey to dark.
		

Vacuum Chamber Contamination

Calorimetric and electrical resistance measurements



Magnet removal



Underground logistics tricky at best

Special tooling needed for safe transport of damaged magnets



Surface activities



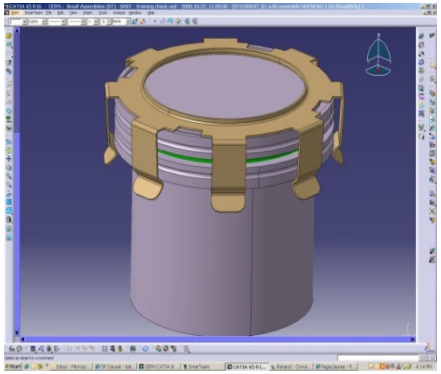






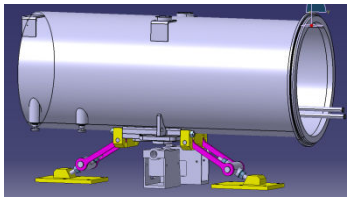
Ongoing Work

Add pressure release valves



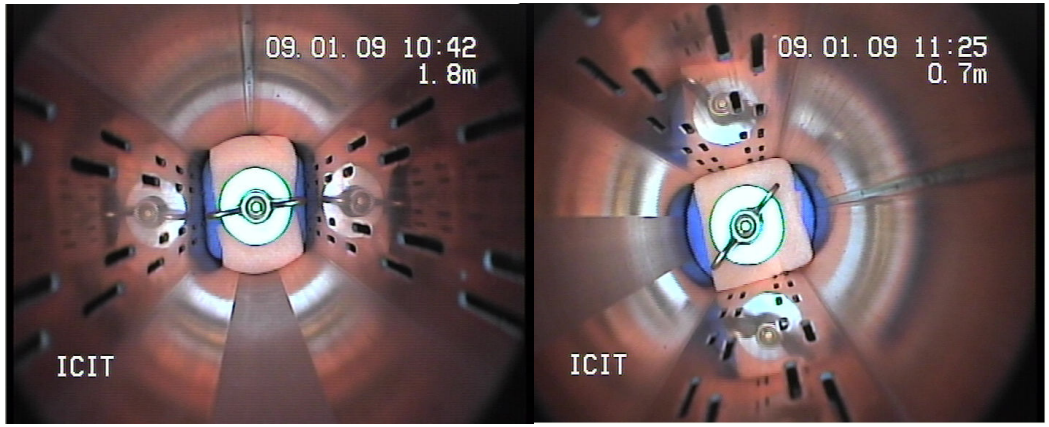
Magnet Stand Improvements





Use of a foam plug wet with alcohol

Up to 50 passages in each direction



Clean Contaminated Vacuum Chamber

Quench Protection System Upgrade

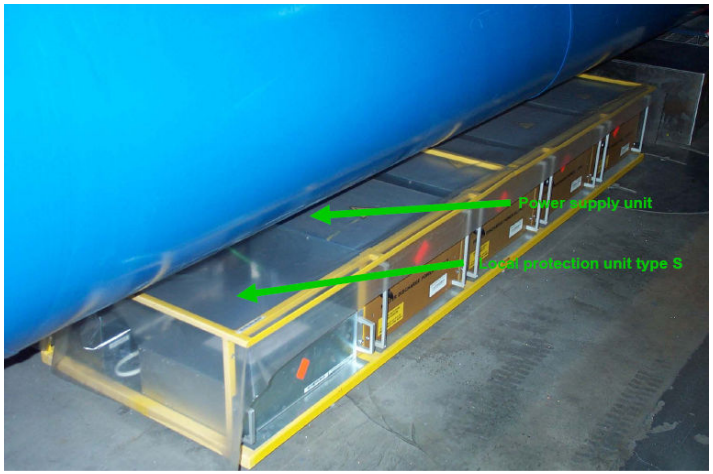
- New QPS to provide
  - Protection against symmetric quenches (problem noticed in summer 08)
  - Local bus bar measurements capable of detecting bad splices
- Huge task
  - Has to be working before repowering (recommendation of external review)
  - On the critical path for restart
  - Will require extensive testing

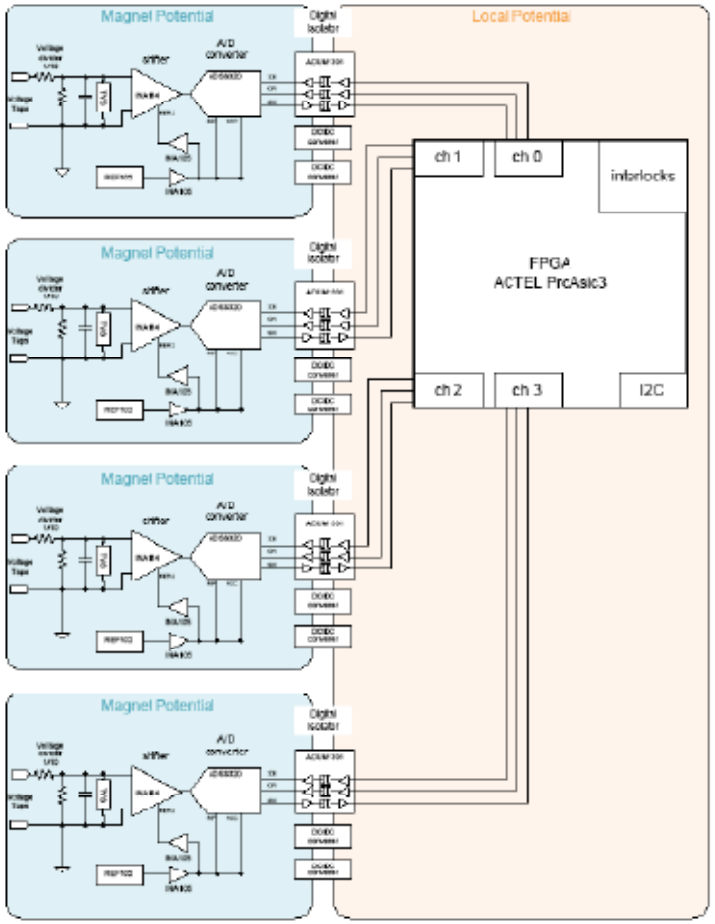
5500 new electronic modules

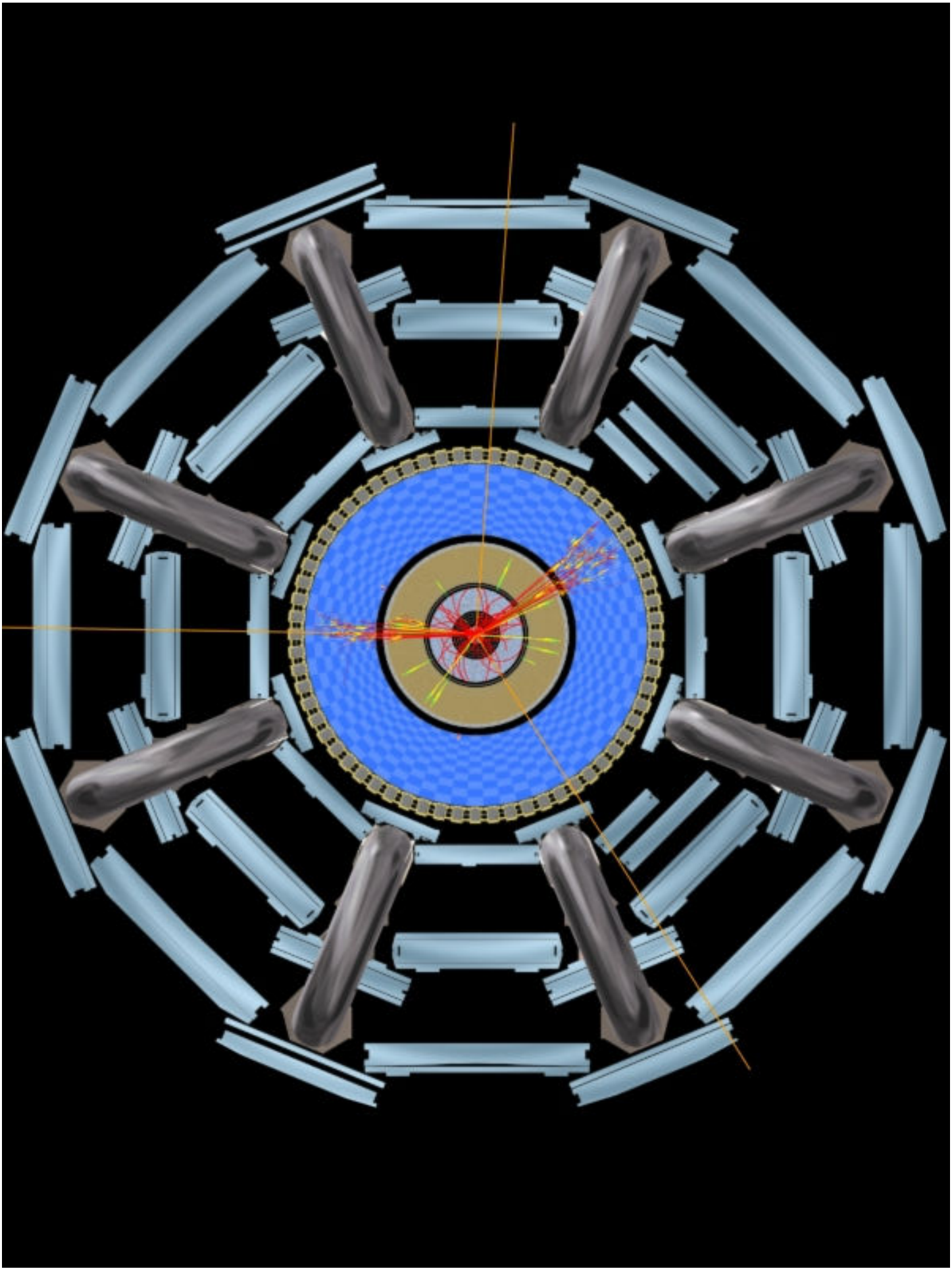
4400 cables of 3 different types
240km of cable
7800 connectors







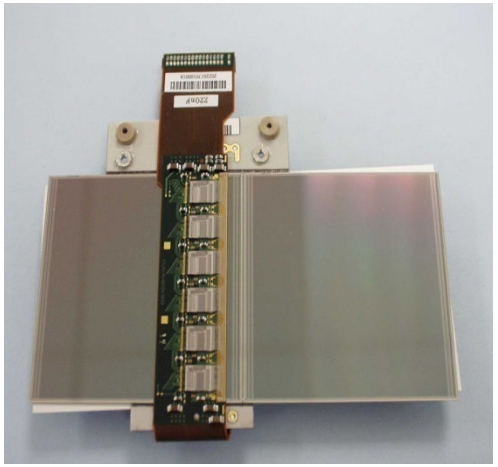


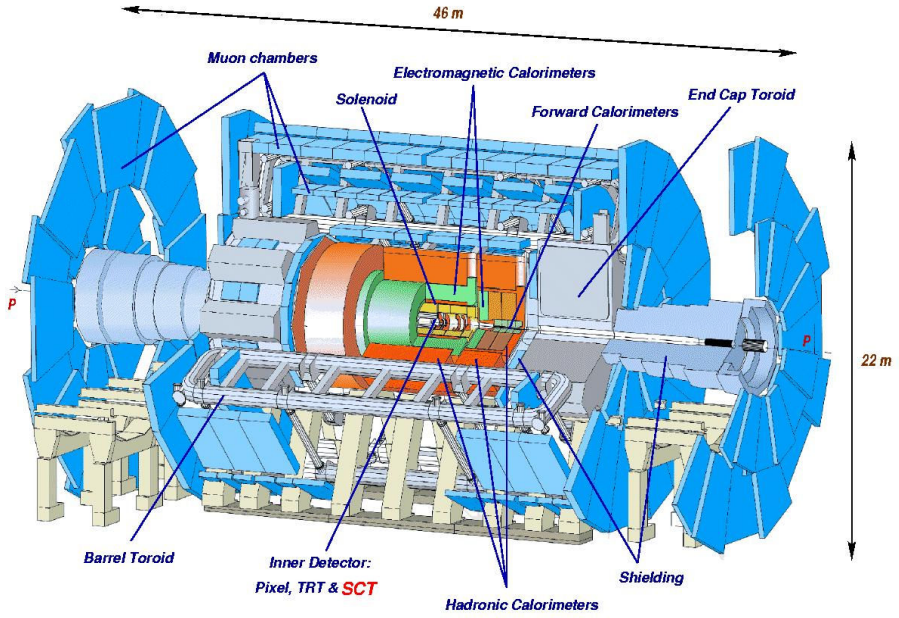


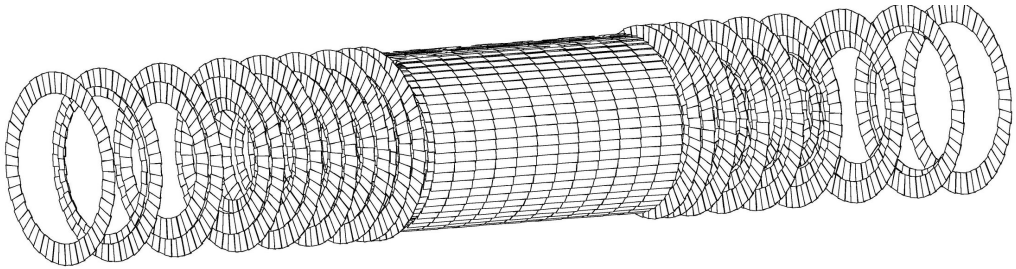
The ATLAS Detector

ATLAS = large international collaboration to find the Higgs (and much more) in the range 0.1TeV < m_H < 1TeV

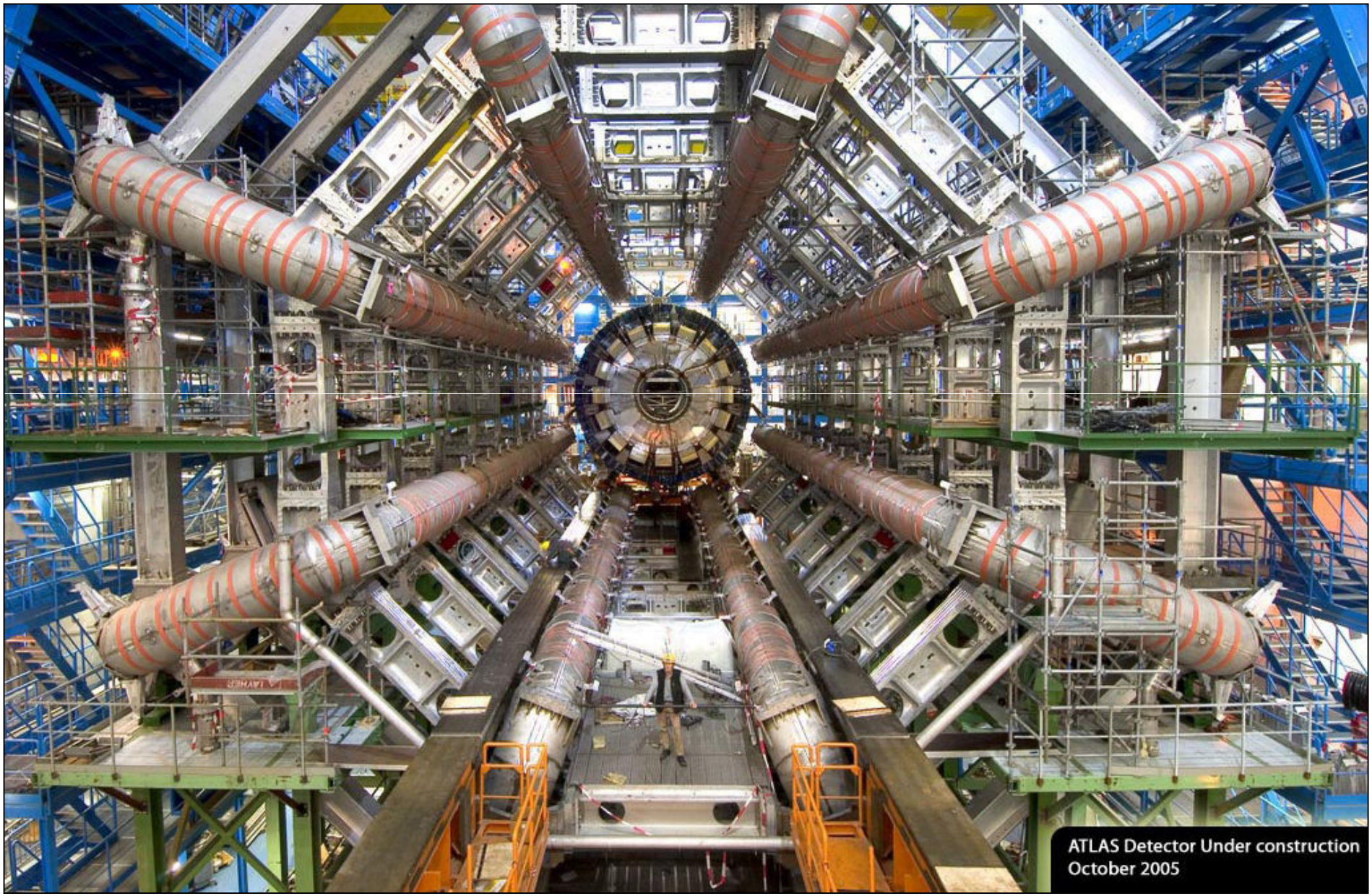
The ATLAS experiment is 26m long, stands 20m high and weighs 7000 tonnes
SCT alone has 6.2 million read-out channels



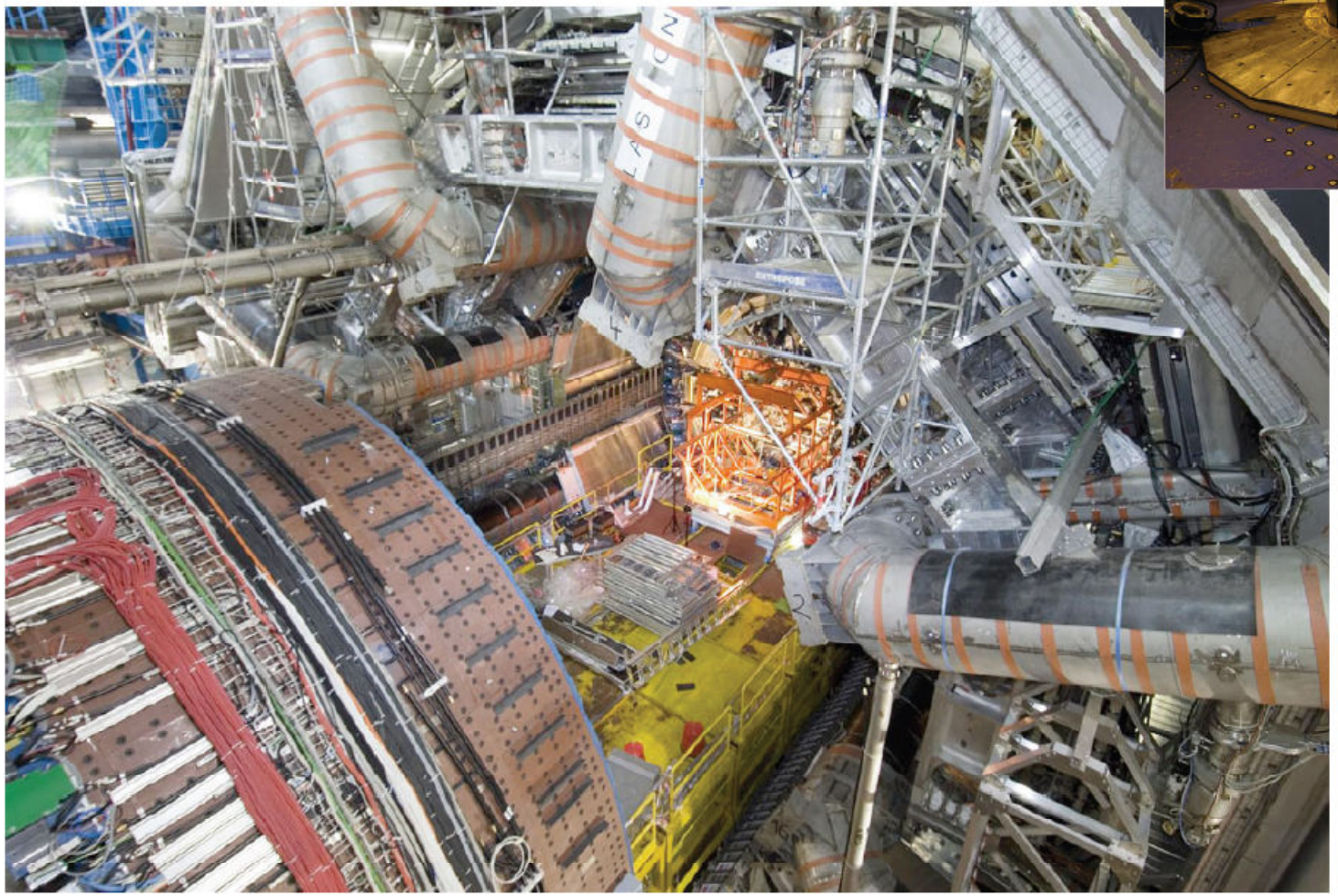


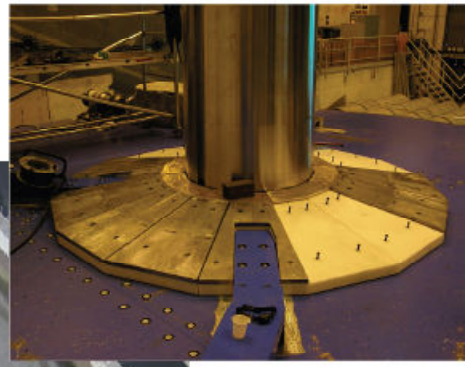


A question of scale



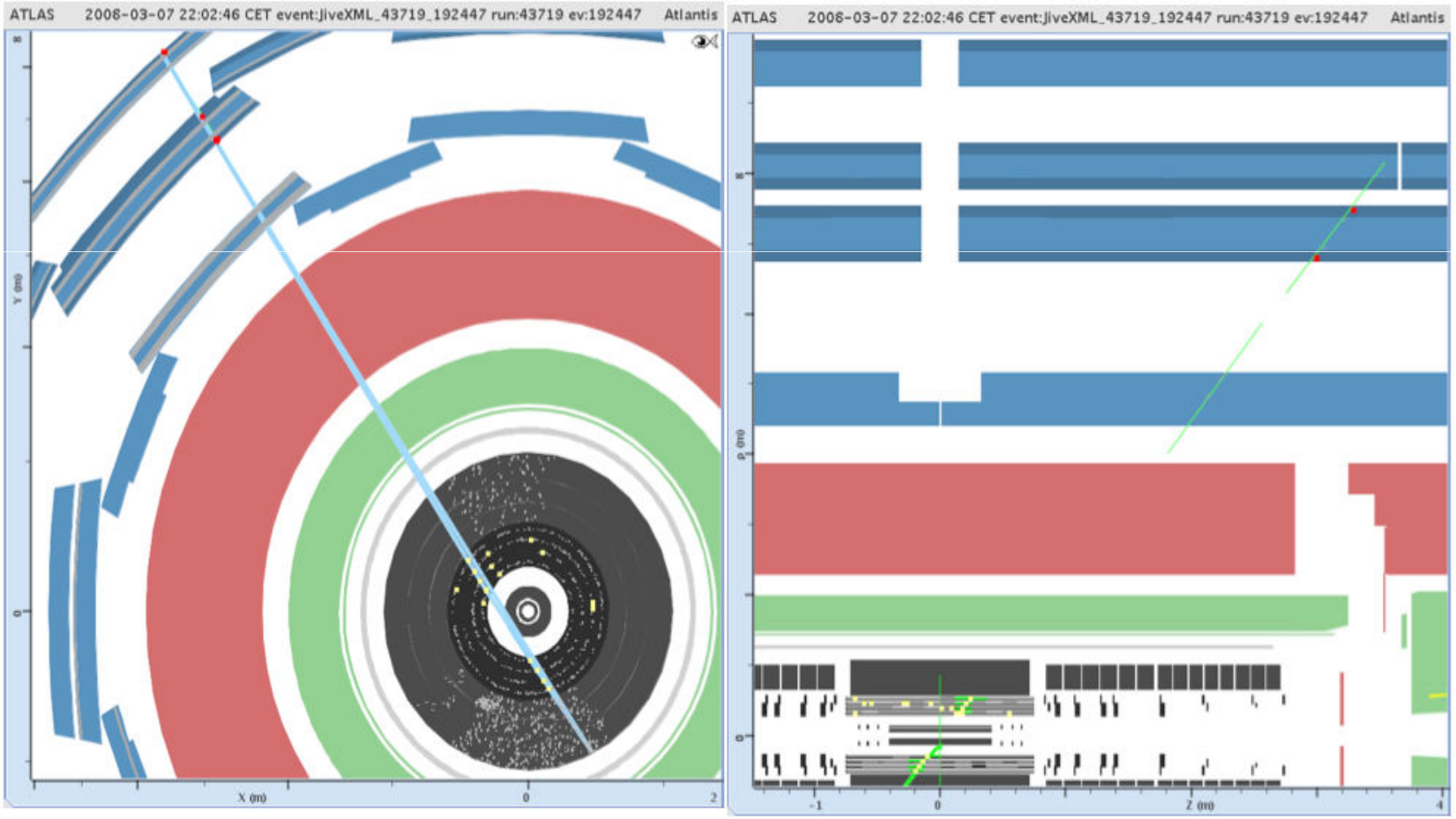
Example: last piece of the puzzle

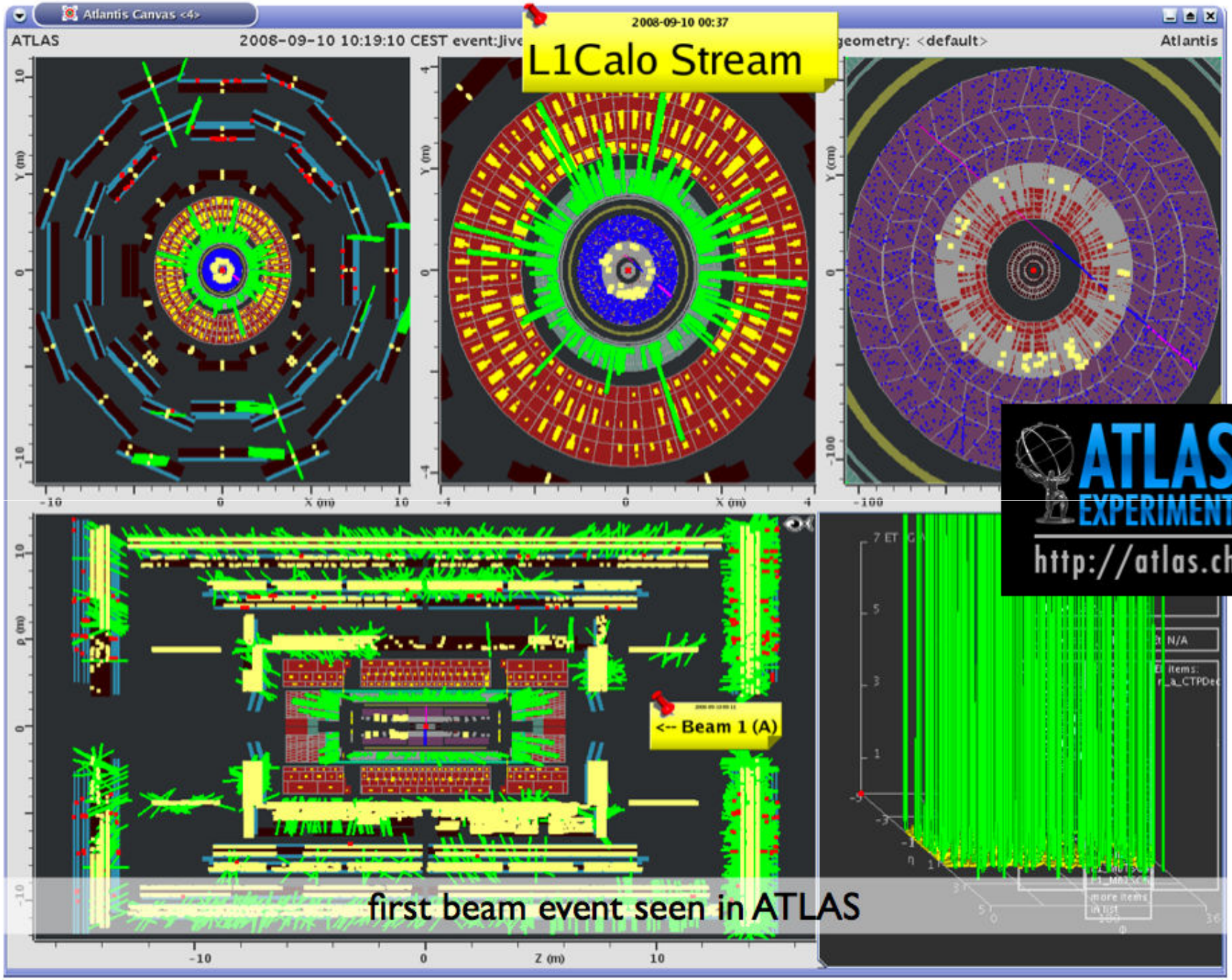




ATLAS commissioning

- Reconstructed cosmics with SCT-TRT-Muon




Atlantis Canvas <4>
ATLAS
2008-09-10 10:19:10 CEST event:Jive
2008-09-10 00:37
L1Calo Stream
geometry: <default>
Atlantis
<-- Beam 1 (A)
ATLAS
EXPERIMENT
http://atlas.ch
first beam event seen in ATLAS

Not just Higgs

- One goal: understand what's going on with "electroweak symmetry breaking"
  - e.g. why are the W and Z heavy when the photon is massless
- Another goal: probe the structure of matter at the smallest possible distance scale
  - Small λ ($=h/p$) means high energy
- Third goal: search for new heavy particles
  - This also means large energy ($E=mc^2$)
- Fourth goal: produce the largest number of previously discovered particles (top & bottom quarks, W's, Z's …) for precision studies



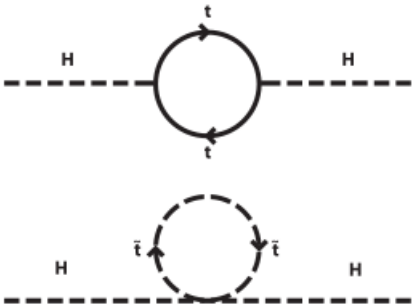
"What is the LHC for?" is a little like "What is the Hubble Space Telescope for?" – the answer depends on who you ask.

A multi-billion dollar instrument really needs to be able to do more than one thing.

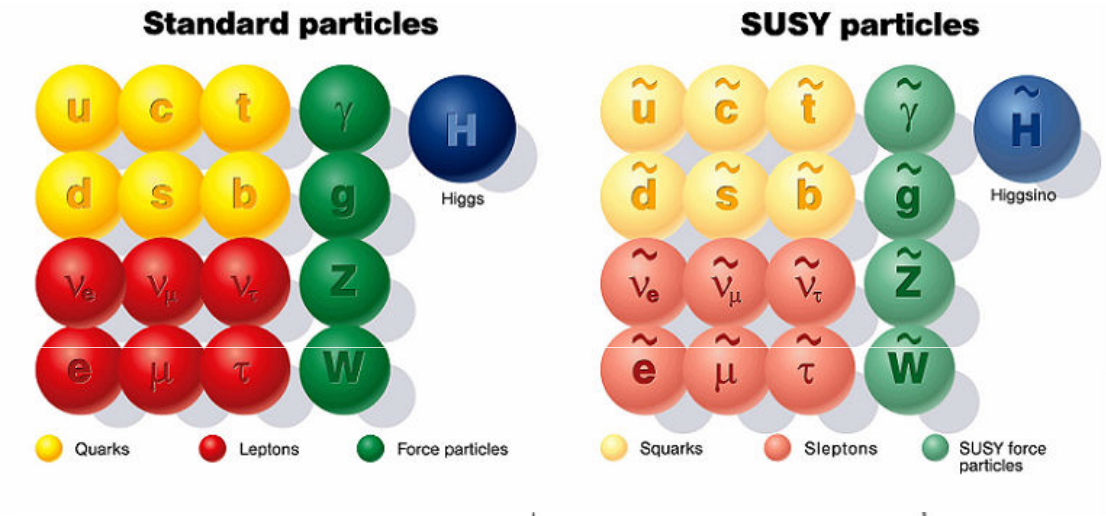
All of these require the highest energy we can achieve

Supersymmetry

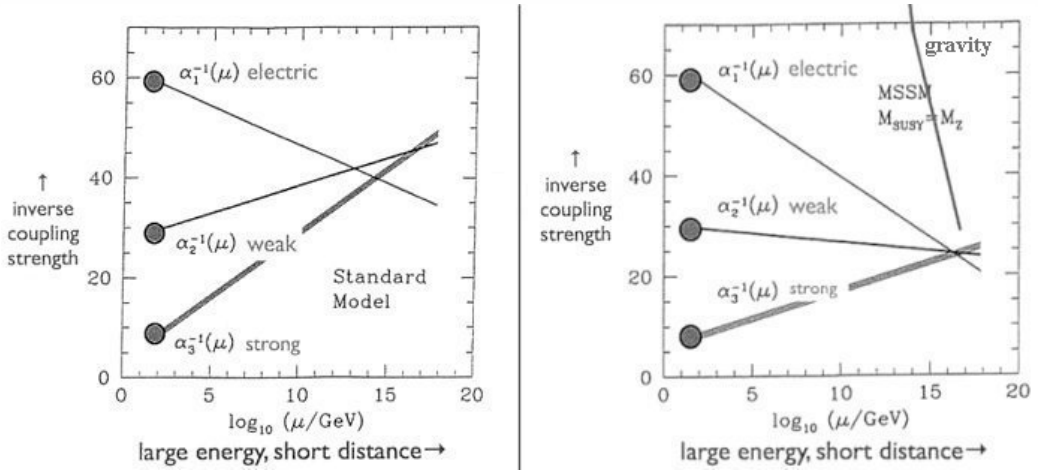
- Conventional method to fix Higgs mass:



- Invoke SUSY
- Double the number of states in model
- Fermion/boson loops cancel



- Can also help to unify forces
- 105 new parameters (MSSM)

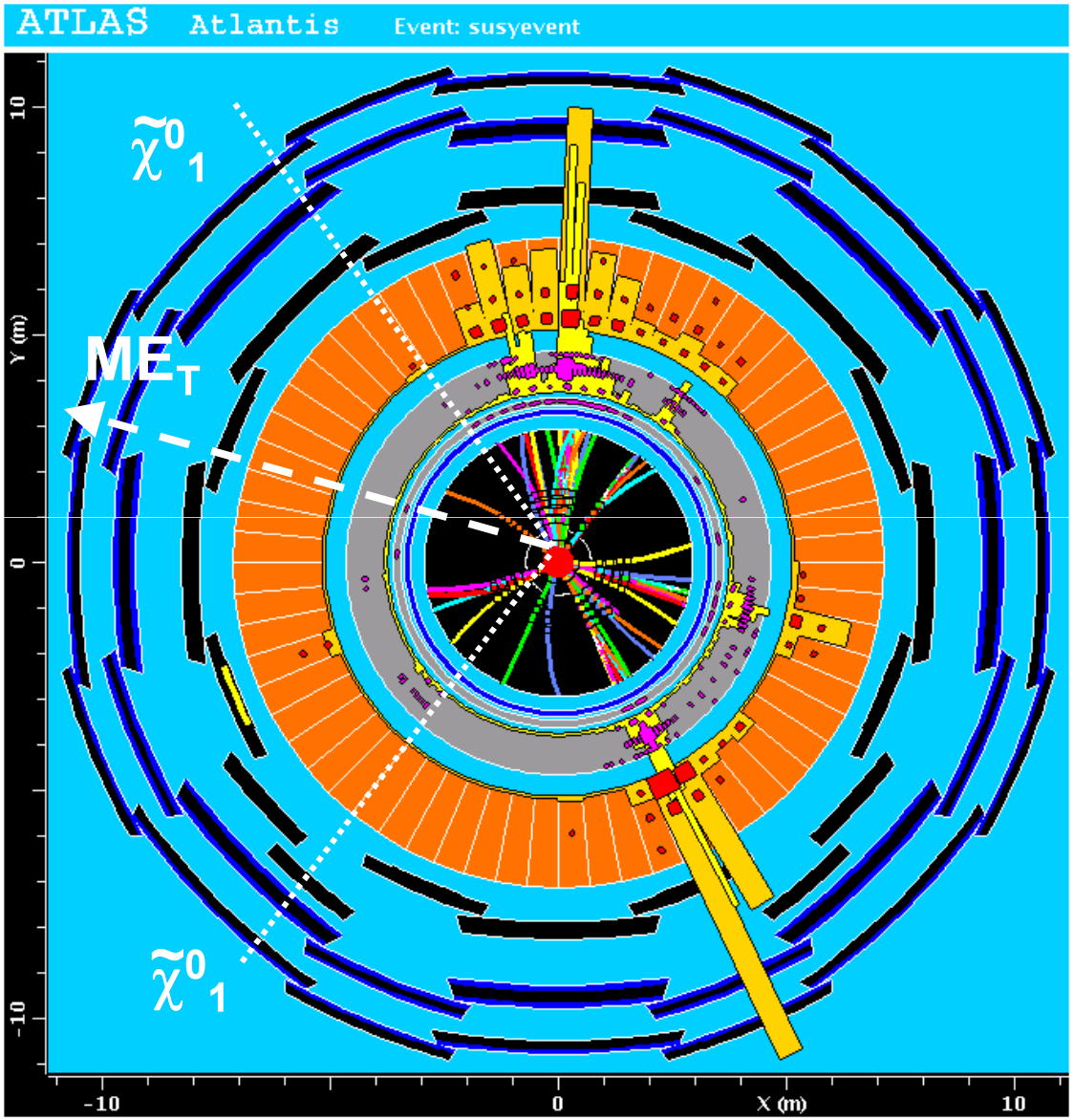


=> SUSY is a good pension plan for experimentalists!

Dark Matter at the LHC?

- Characteristic signature for Dark Matter production at ATLAS:
  Missing Transverse Energy ('ME_T')
- Valid for any DM candidate
  (not just SUSY)
- Observation of ME_T signal *necessary* but not *sufficient* to prove DM signal (DM particle could decay outside detector)

Combine LHC and Astroparticle physics data in order to prove that the neutralino hopefully observed at LHC would be the DM particle…



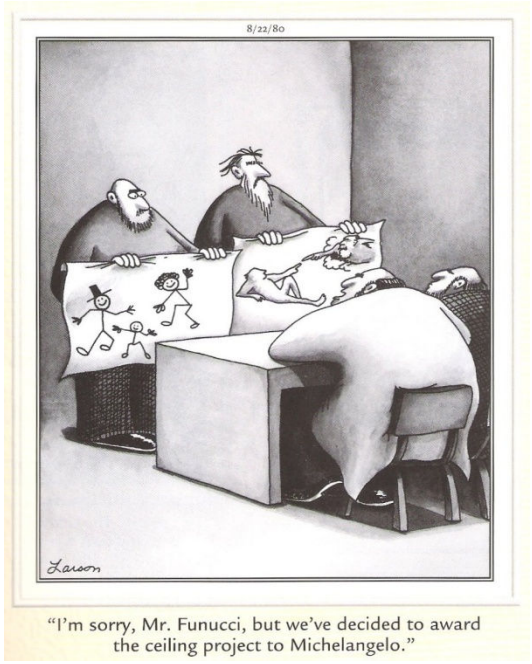
Extra Dimensions

- Hypothesize that there are extra space dimensions
- Volume of bulk space >> volume of 3-D space
- Hypothesize that gravity operates throughout the bulk
- SM fields confined to 3-D

- Then unified field will have “diluted” gravity, as seen in 3-D

- If we choose n-D gravity scale=weak scale then…
- Only one scale -> no hierarchy problem!
- Can experimentally access quantum gravity!

- But extra dimension is different scale from “normal” ones
- -> new scale to explain

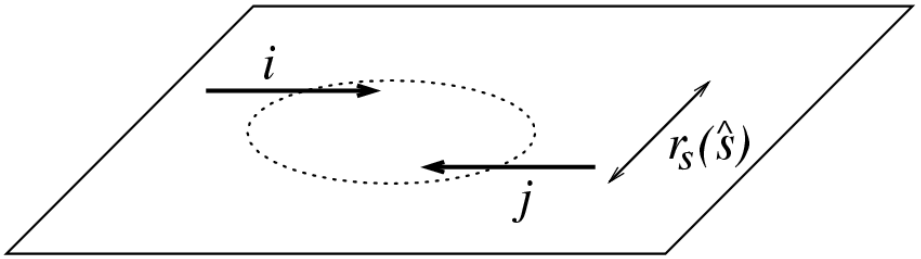


“I’m sorry, Mr. Funucci, but we’ve decided to award the ceiling project to Michelangelo.”

Extra dimensions are more of a lottery bet than a pension plan!

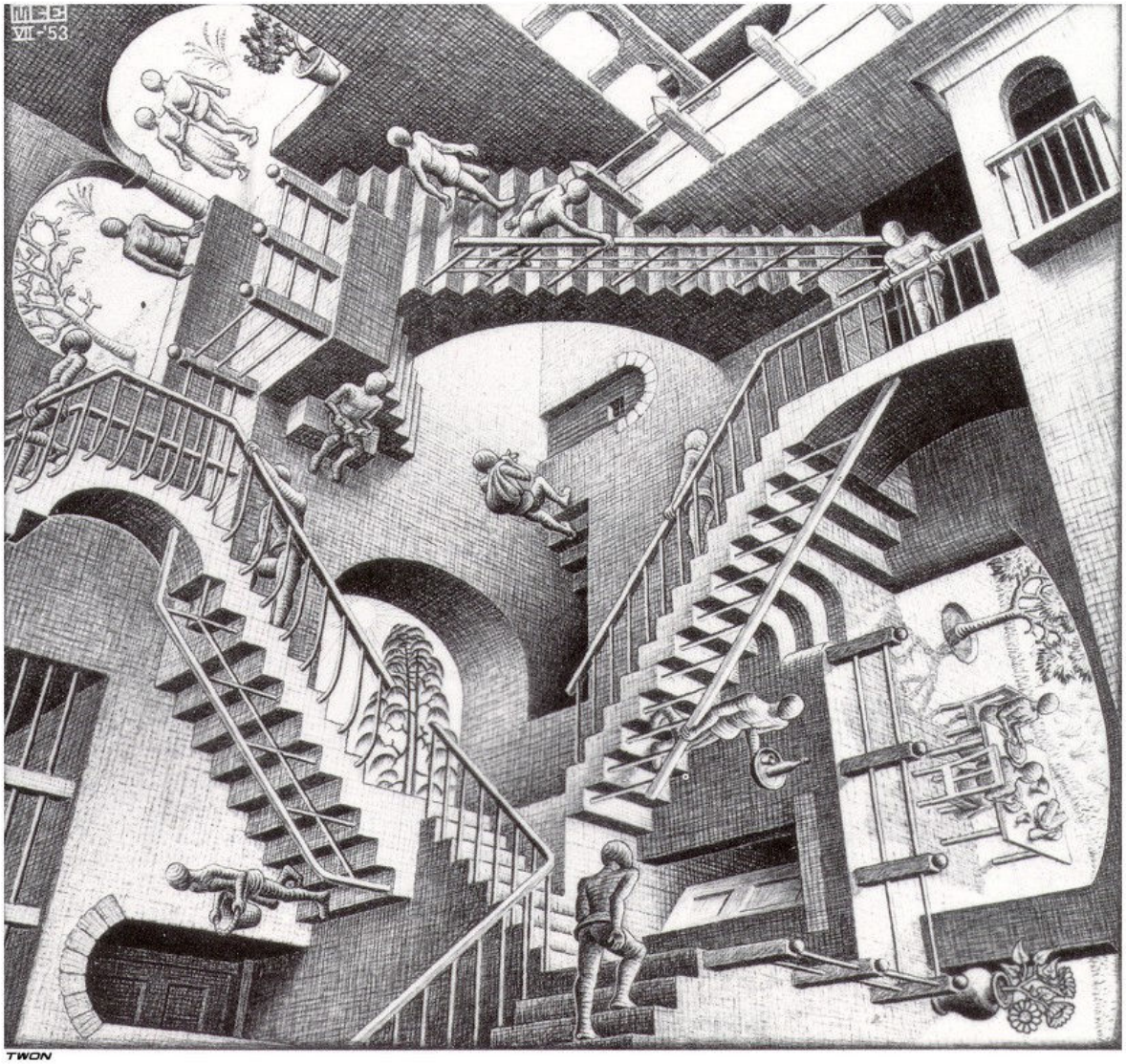
BLACK HOLES AT THE LHC

- If two particles pass close enough with enough energy, they may form a black hole



- For 3 spatial dimensions, this will never happen – gravity is too weak. But with extra dimensions, gravity may become stronger, micro black holes can be created in particle collisions

BLACK HOLES = SEARCH FOR EXTRA DIMENSIONS

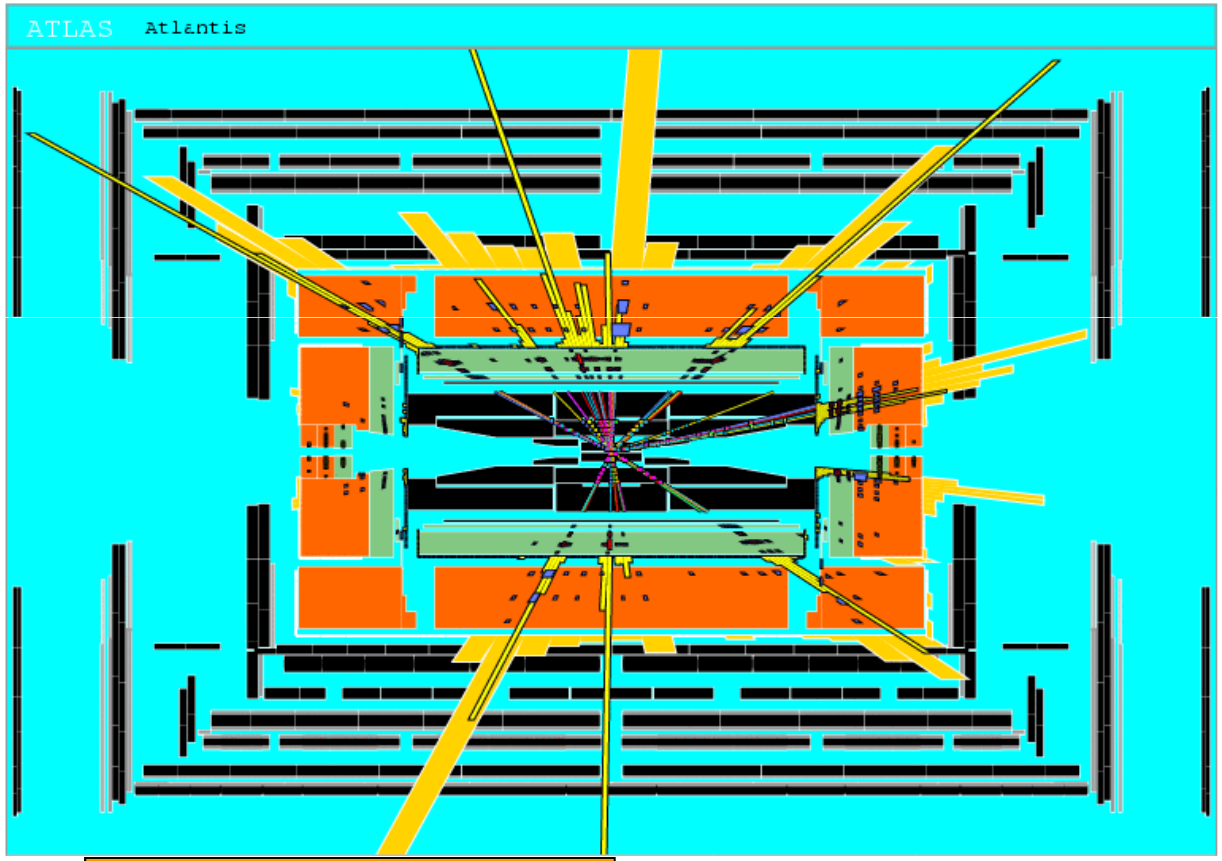


Theories which try to explain why gravity is so much weaker than the other forces

Gravity may propagate in 4+n dimensions, but we could see strong effects only at very small distances, reachable in pp LHC collisions

SEARCH FOR EXTRA DIMENSIONS

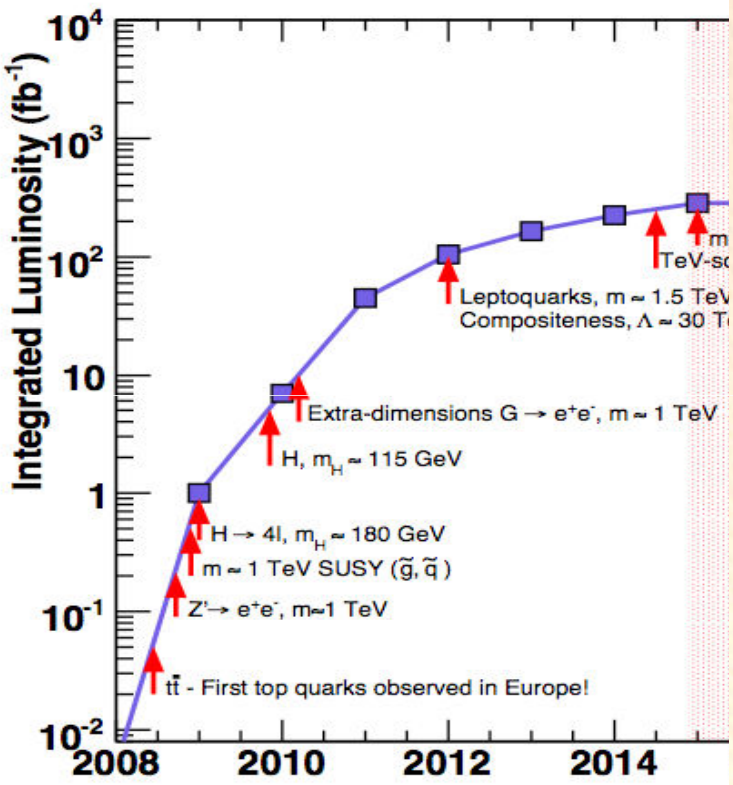
If theories with Extra Dimensions are true, microscopic black holes could be abundantly produced and observed at the LHC



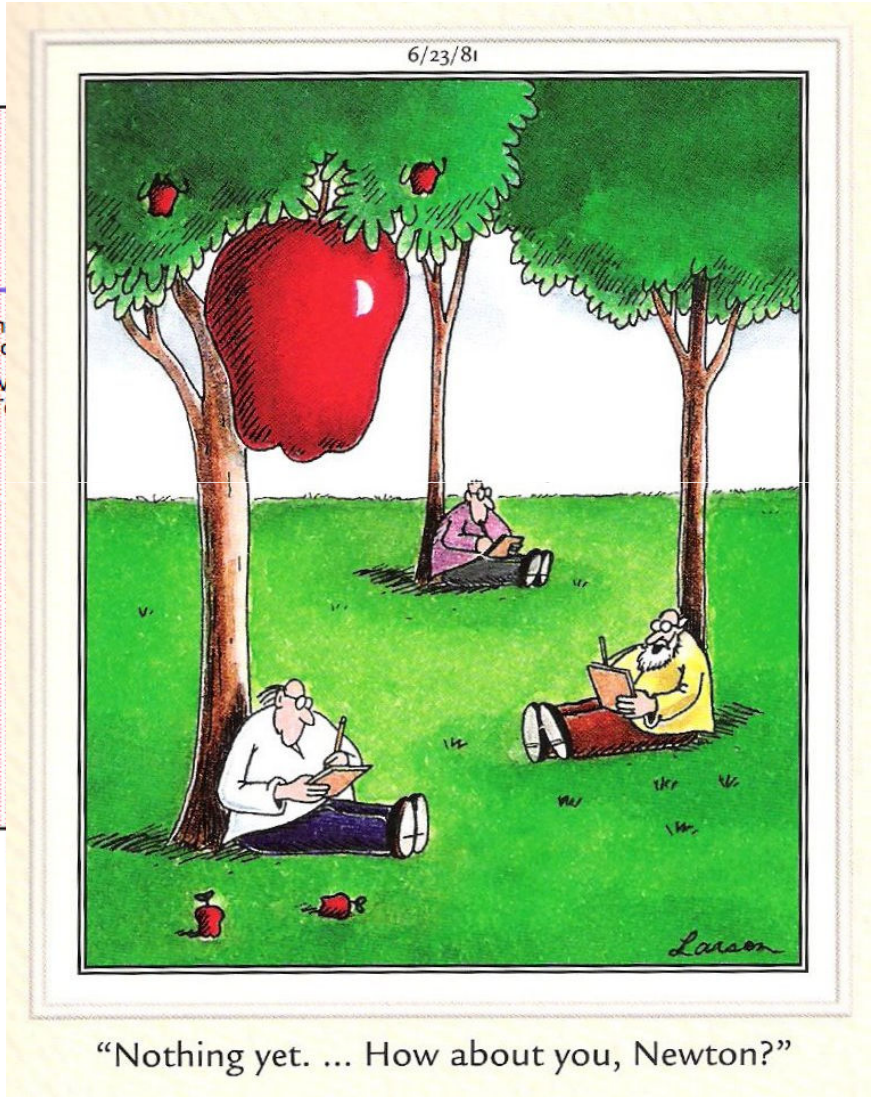
Simulation of a black hole event with M_{BH} ~ 8 TeV in ATLAS



Voyage of Discovery



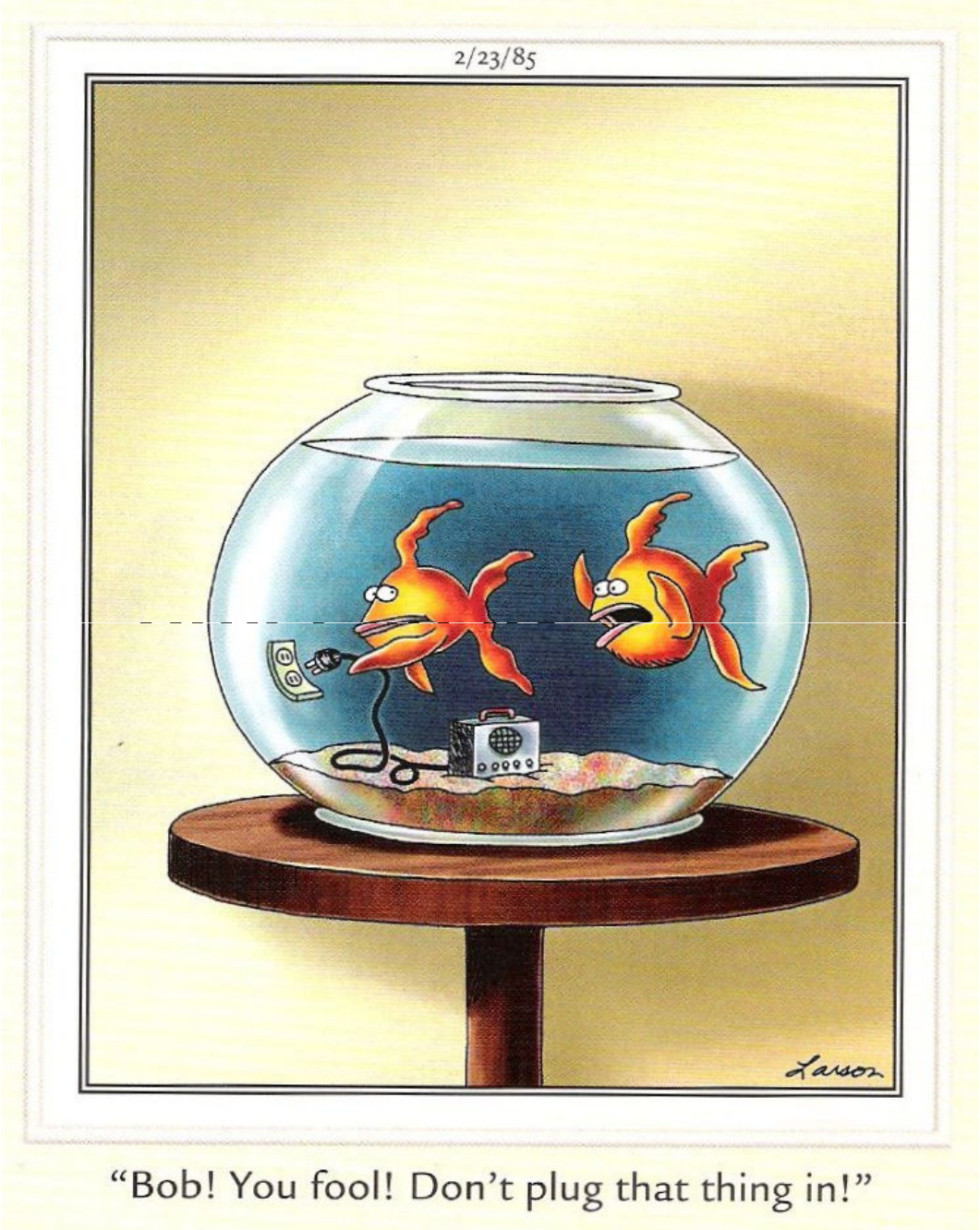
The decade to come will be exciting for fundamental physics and will shape our understanding of Nature



"Nothing yet. ... How about you, Newton?"

4. Th

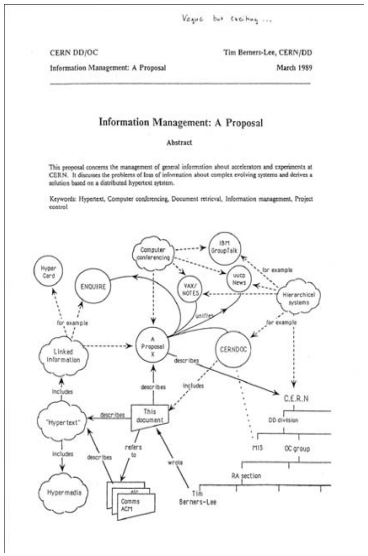
- **The Grid enables us to analyse all the data that comes from the LHC**
- **Petabytes**
- **100,000 CPUs**







- The World Wide Web
- a global information system which users can read and write via computers connected to the Internet
- “born” on March 13th 1989:
- A proposal was submitted
- “information Management”
- Tim Berners-Lee
- CERN



CERN DD/OC — Tim Berners-Lee, CERN/DD

Information Management: A Proposal — March 1989

Information Management: A Proposal

Abstract

This proposal concerns the management of general information about accelerators and experiments at CERN. It discusses the problems of loss of information about complex evolving systems and derives a solution based on a distributed hypertext system.

Keywords: Hypertext, Computer conferencing, Document retrieval, Information management, Project control

Historical Perspective

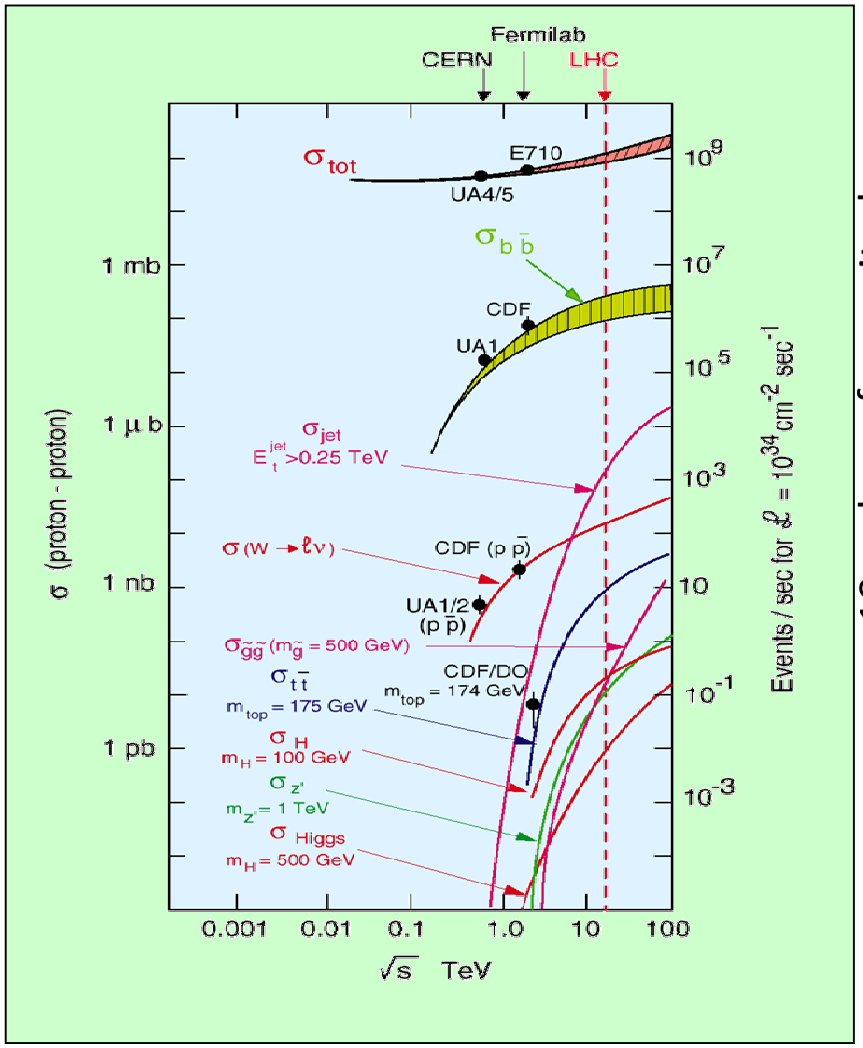
- 1989-91: Development
  - The first three years were a phase of persuasion to get the Web adopted…
- 1992-1995: Growth
  - the load on the first Web server ("info.cern.ch") rose steadily by a factor of 10 every year…
- 1996-1998: Commercialisation
  - Google and other search engines
- 1999-2001: "Dot-com" boom
- (and bust)
- 2002-Present: The ubiquitous Web
  - Web 2.0: blogs and RSS



CERN

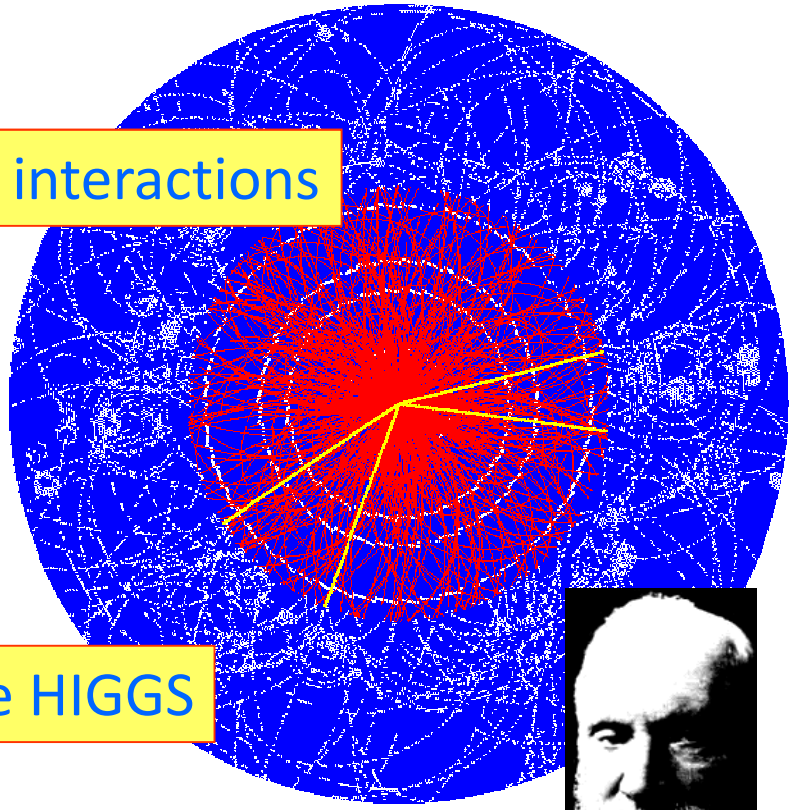
Why (particularly) the LHC?

- Huge Background

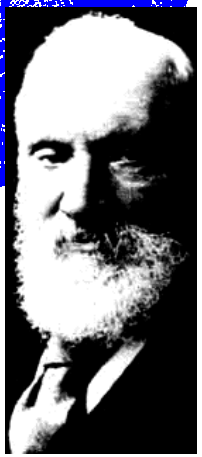


10 orders of magnitude

All interactions



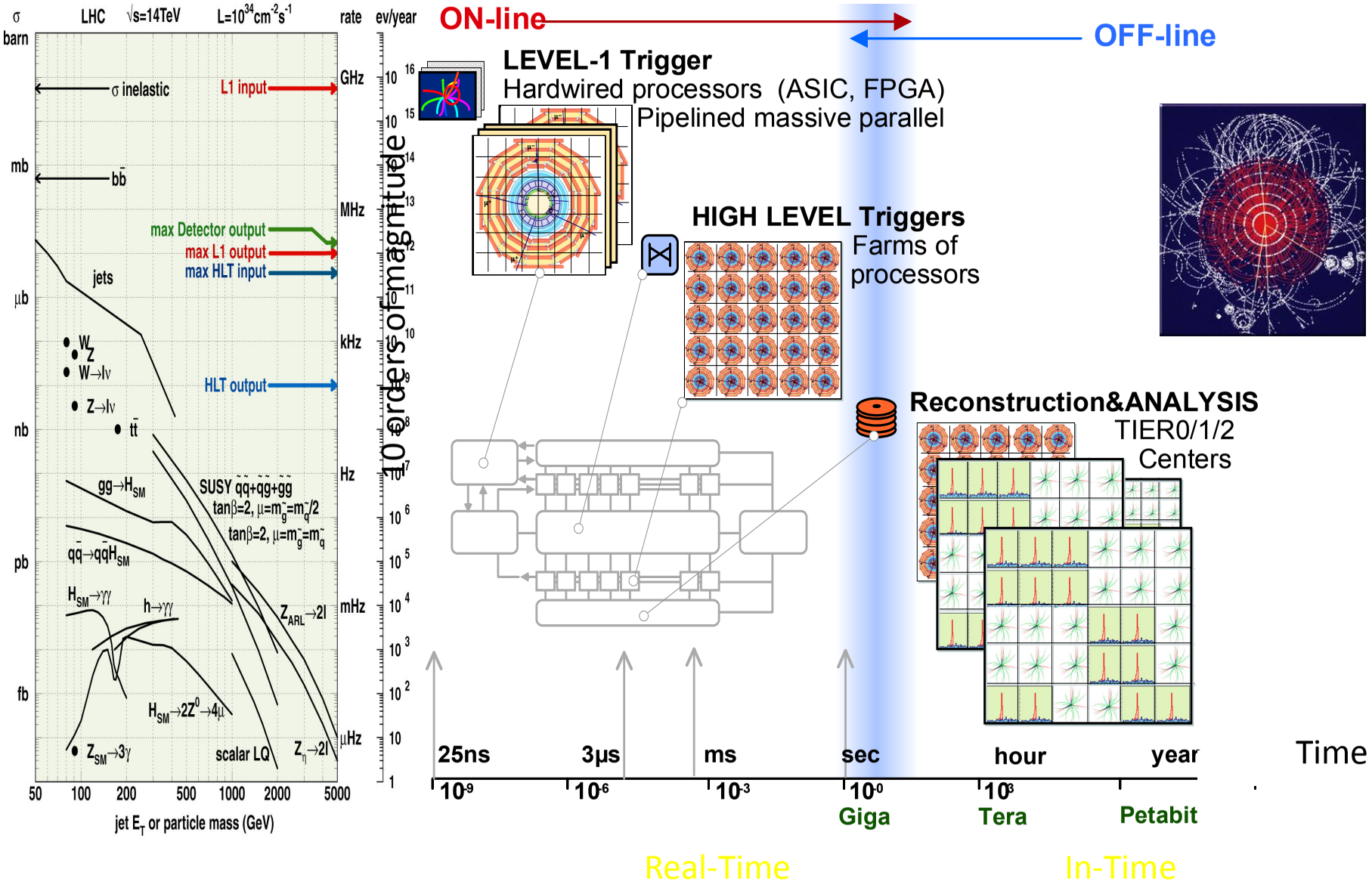
The HIGGS



"When you are face to face with a difficulty you are up against a discovery" Lord Kelvin

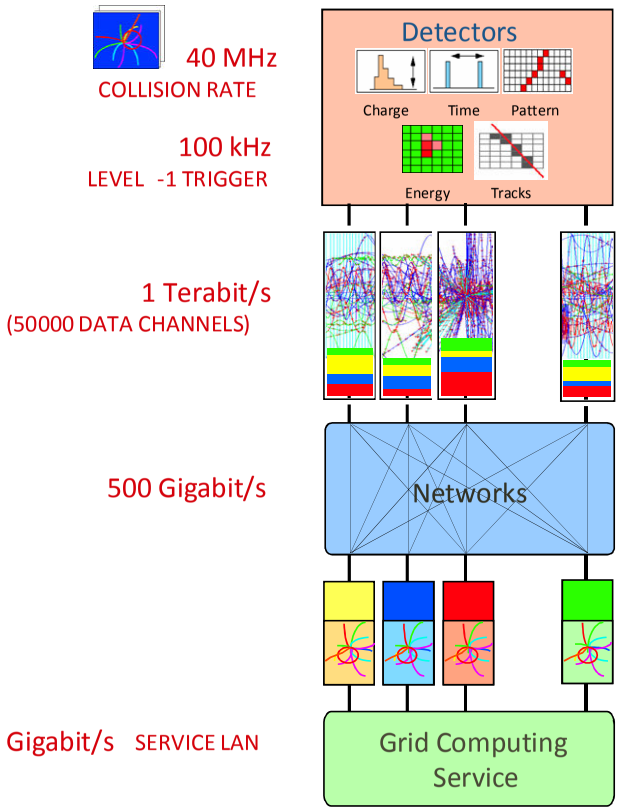
The Challenges

I: Real-Time Event Selection



The Challenges

II: Real-Time Complexity

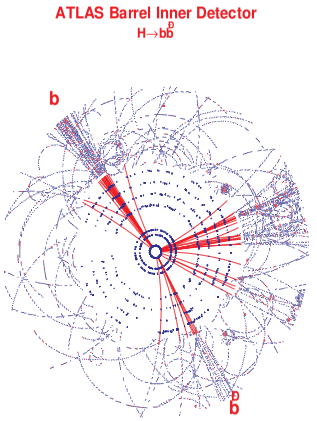


- Many events
  - ~10^9 events/experiment/year
  - >~1 MB/event raw data
  - several passes required

→ Worldwide Grid computing requirement (2008):

~300 TeraIPS

(100,000 of today's fastest processors connected via a Grid)

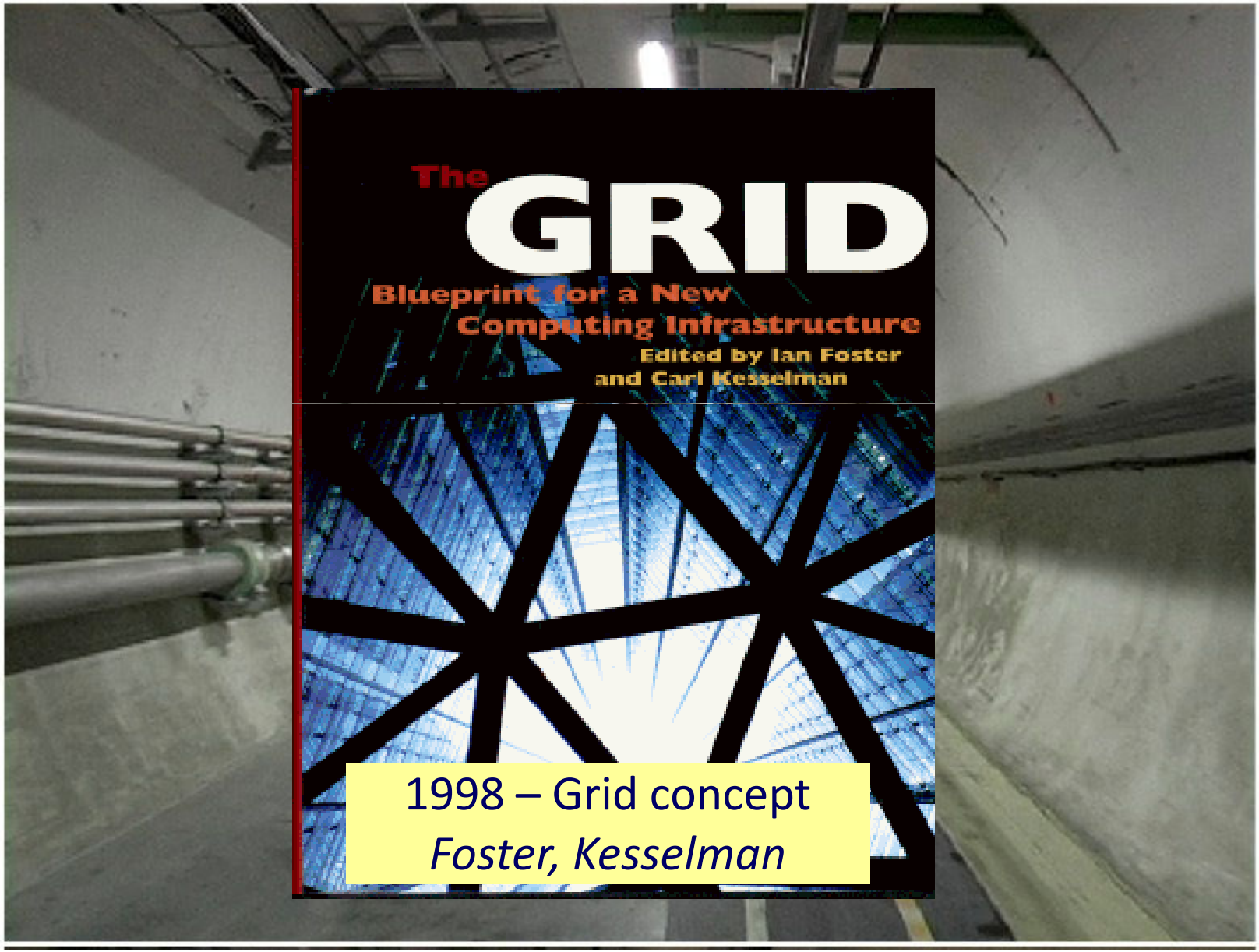


Understand/interpret data via numerically intensive simulations:

- e.g. ATLAS Monte Carlo (gg → H → bb)

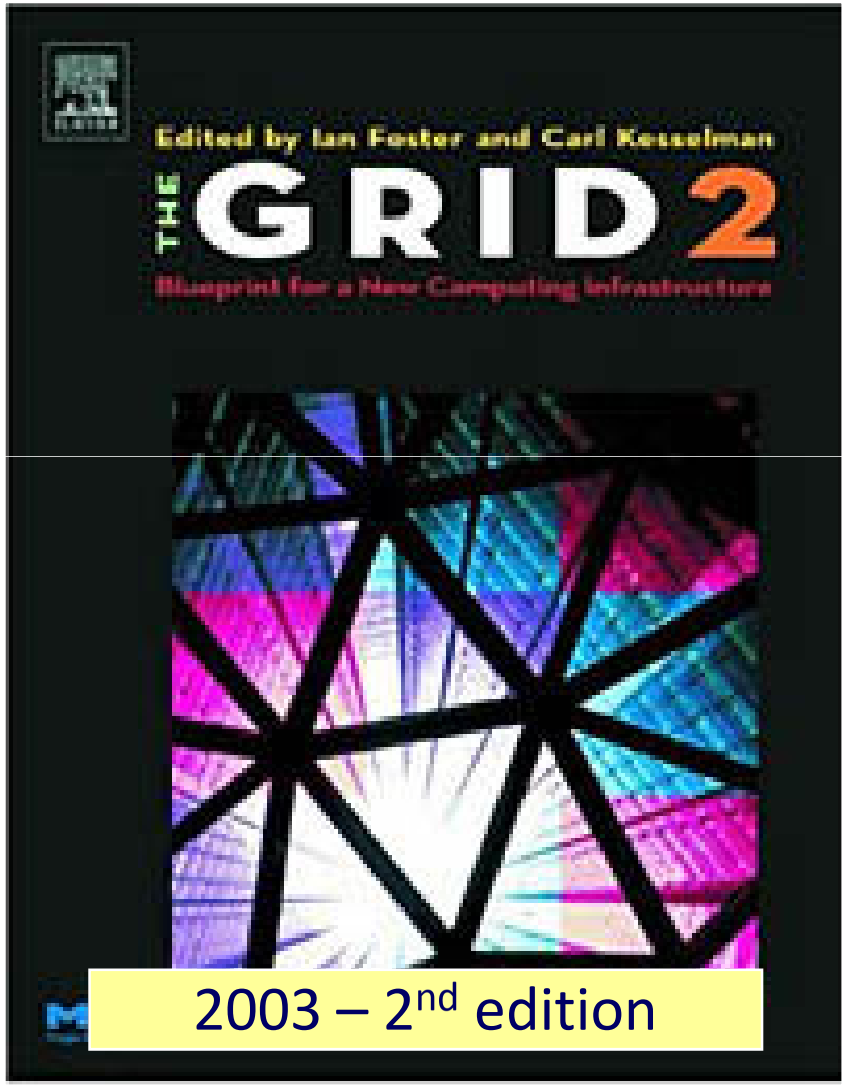
  60 sec/3.5 MB event on 3 GHz linux CPU

In the beginning…



1998 – Grid concept
Foster, Kesselman

What is a Grid?



"A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities".
Ian Foster & Carl Kesselman, 1998

Grid Checklist (2002):

1. Co-ordinates resources that are not subject to centralized control.
2. ... using standard, open, general-purpose protocols and interfaces.
3. … to deliver non-trivial qualities of service.

Electricity Grid

Analogy with the Electricity Power Grid

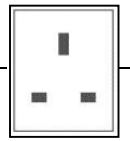
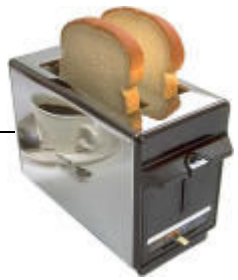




Power Stations



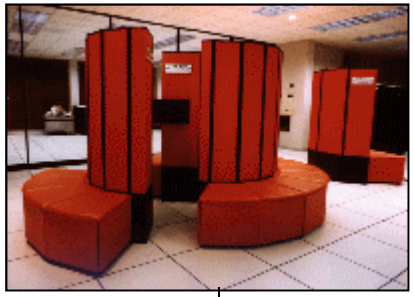
Distribution Infrastructure

'Standard Interface'

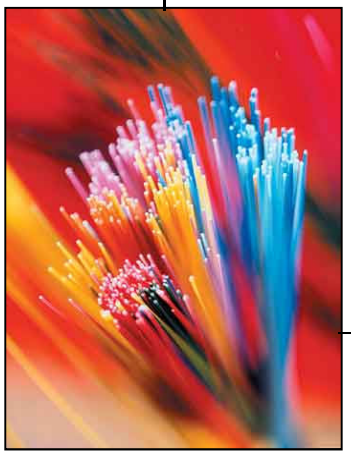
Computing Grid







Computing and Data Centres



Fibre Optics of
the Internet





Solution – Build a Grid

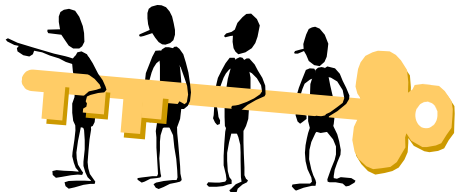


- Share more than information
- Efficient use of resources at many institutes
- Leverage over other sources of funding
- Data, computing power, applications
- Join local communities

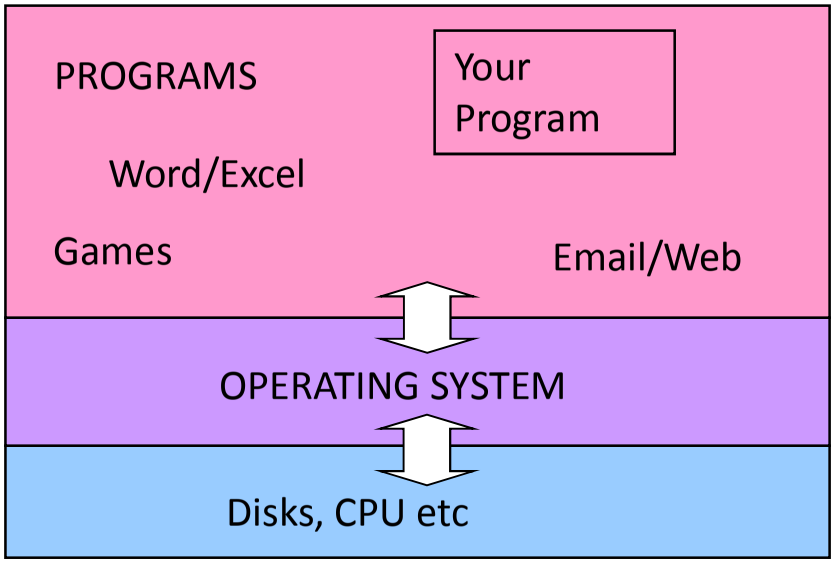
Challenges:

- share data between thousands of scientists with multiple interests
- link major and minor computer centres
- ensure all data accessible anywhere, anytime
- grow rapidly, yet remain reliable for more than a decade
- cope with different management policies of different centres
- ensure data security
- be up and running routinely

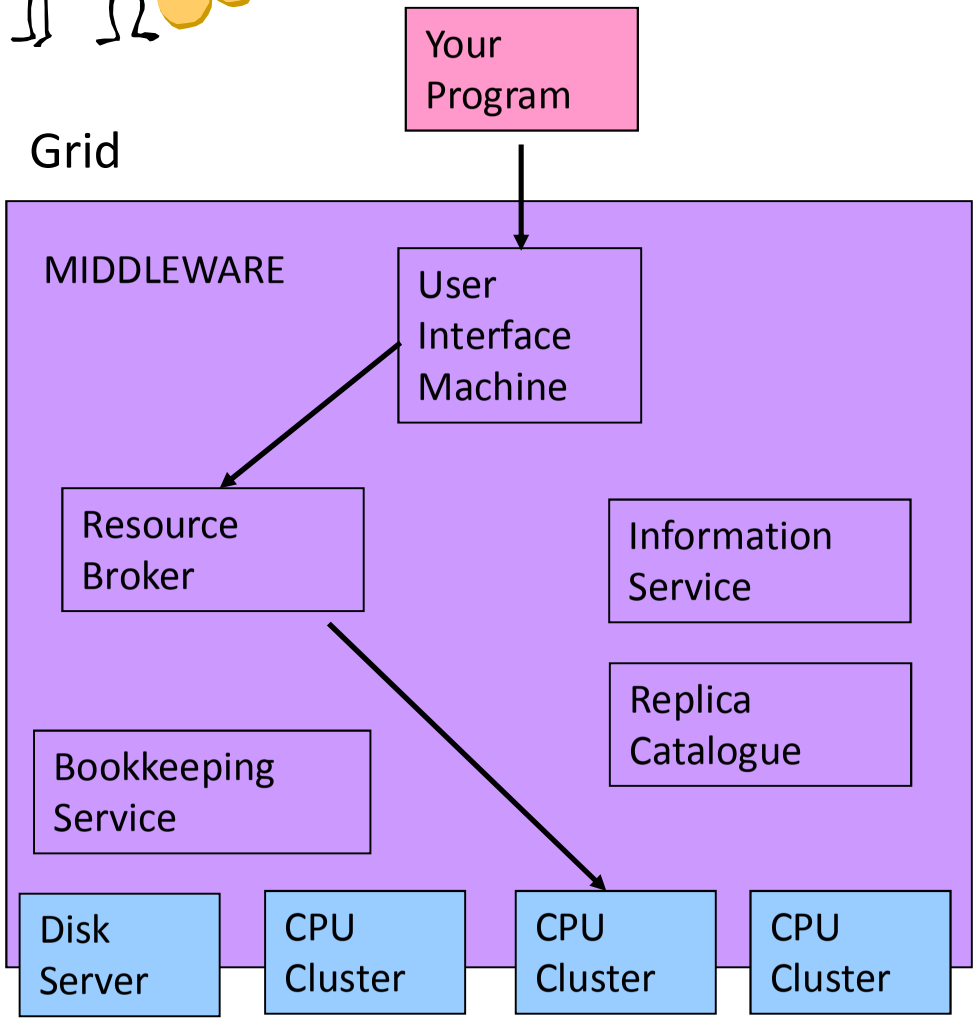
Middleware is the Key



Single PC



Grid

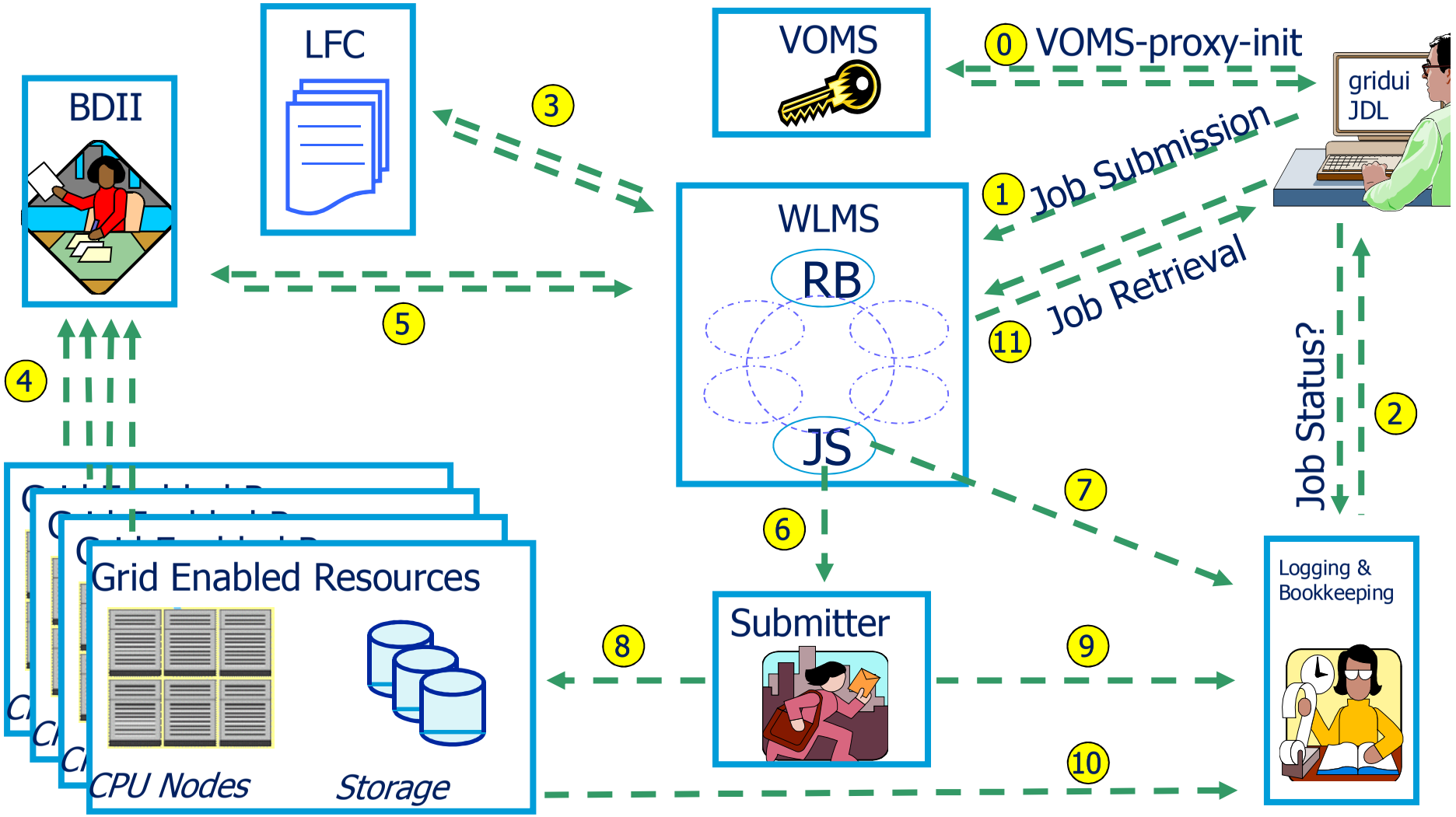


Middleware is the Operating System of a distributed computing system

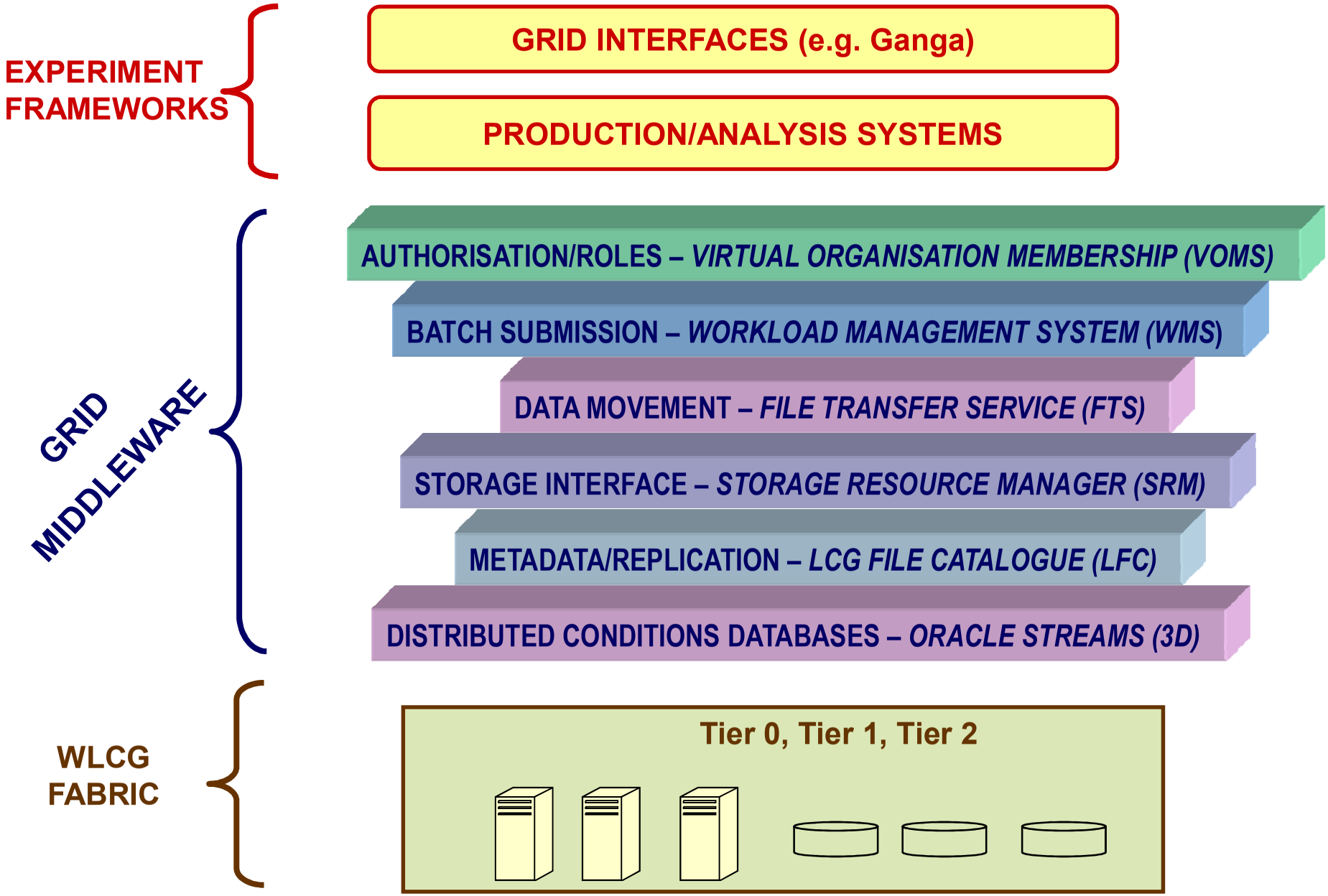
Something like this…



… or this


LFC
VOMS
0 VOMS-proxy-init
gridui
JDL
BDII
3
1 Job Submission
WLMS
RB
Job Retrieval
11
5
Job Status?
2
4
7
6
JS
Logging &
Bookkeeping
Grid Enabled Resources
Submitter
8
9
10
CPU Nodes
Storage

… or this


EXPERIMENT FRAMEWORKS
GRID INTERFACES (e.g. Ganga)
PRODUCTION/ANALYSIS SYSTEMS
GRID MIDDLEWARE
AUTHORISATION/ROLES – VIRTUAL ORGANISATION MEMBERSHIP (VOMS)
BATCH SUBMISSION – WORKLOAD MANAGEMENT SYSTEM (WMS)
DATA MOVEMENT – FILE TRANSFER SERVICE (FTS)
STORAGE INTERFACE – STORAGE RESOURCE MANAGER (SRM)
METADATA/REPLICATION – LCG FILE CATALOGUE (LFC)
DISTRIBUTED CONDITIONS DATABASES – ORACLE STREAMS (3D)
WLCG FABRIC
Tier 0, Tier 1, Tier 2

… or this



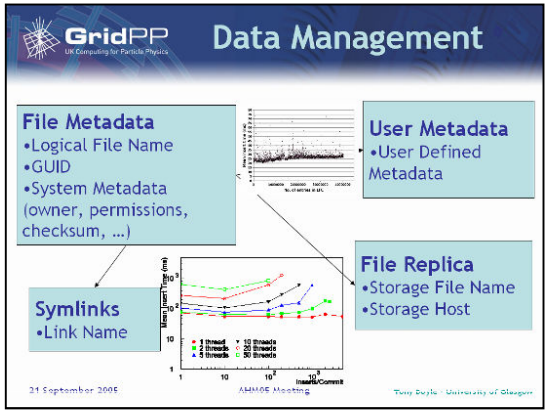


LCG OSG NDG NGS

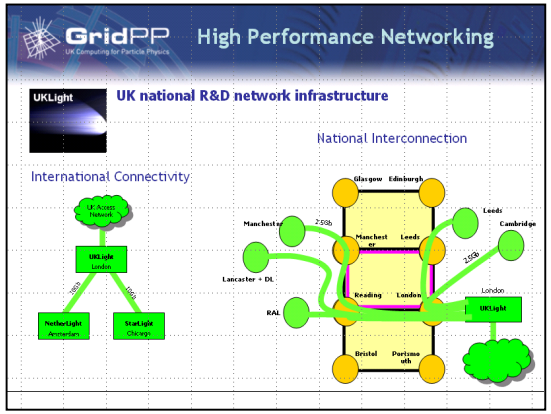
An open operating system does not only have advantages?

GridPP Middleware includes

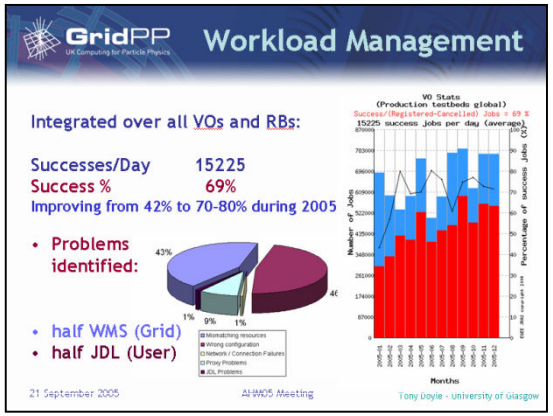
Grid Data Management



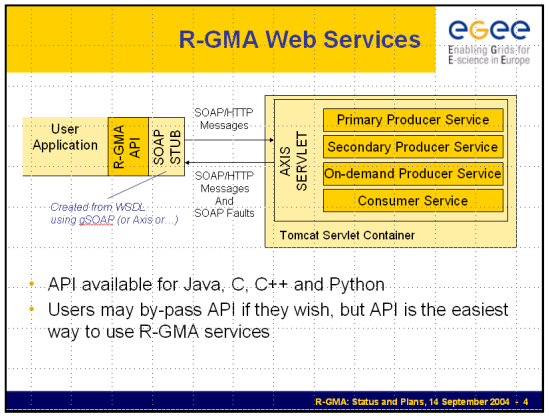
Network Monitoring



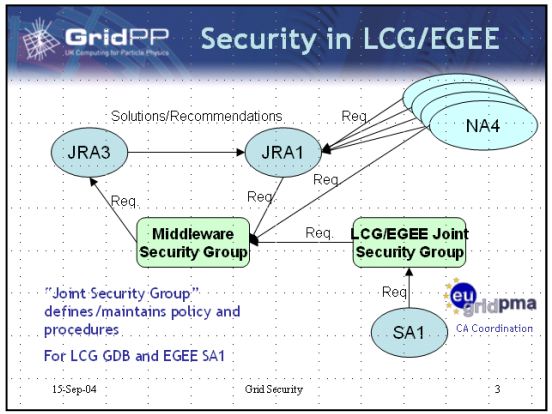
Workload Management



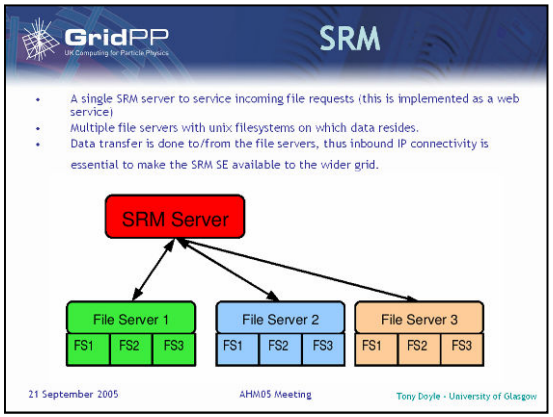
Information Services



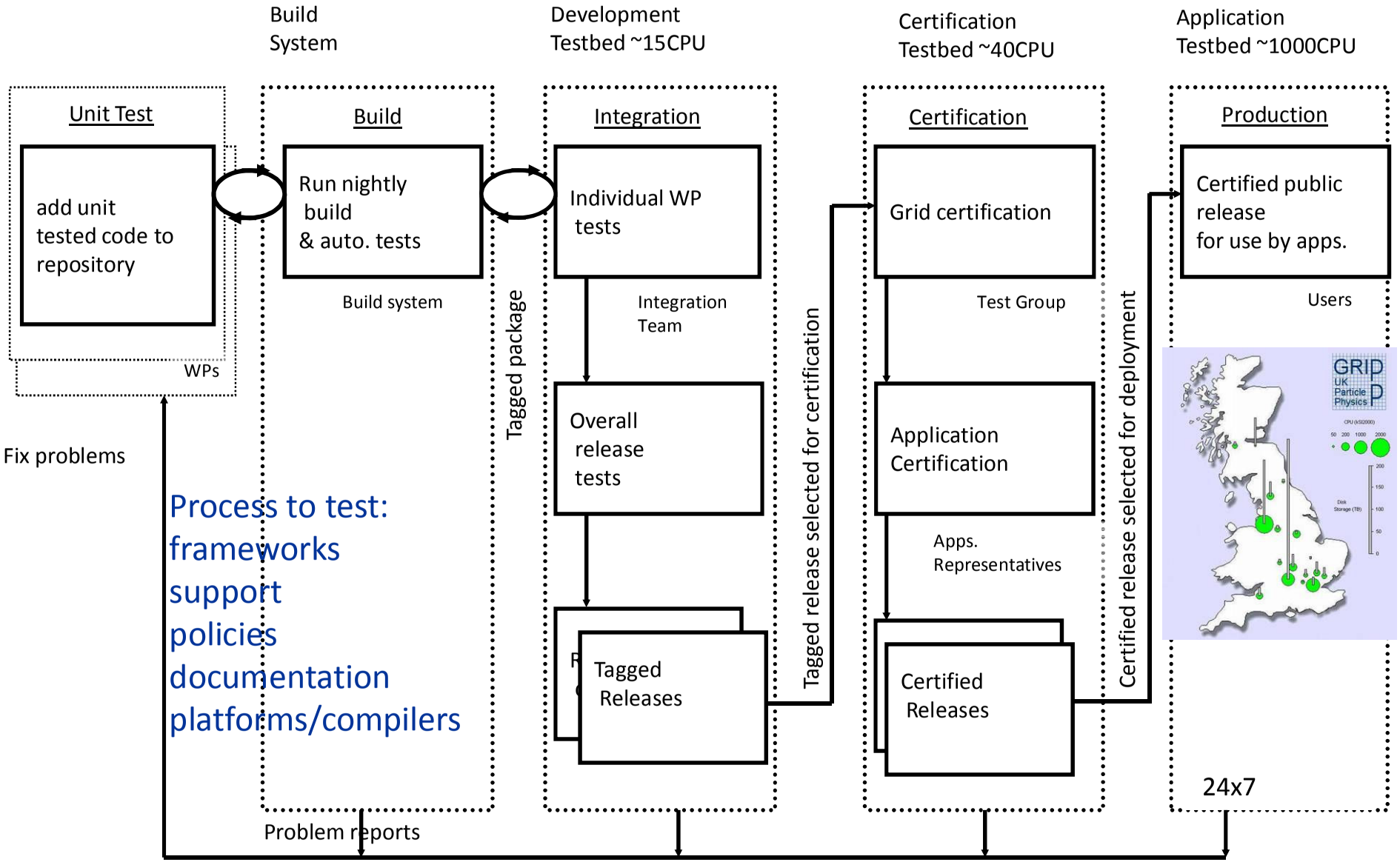
Security



Storage Interfaces

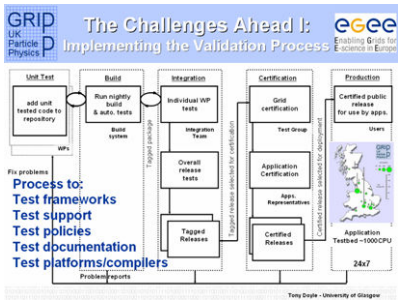


Middleware Validation:
From Testbed to Production

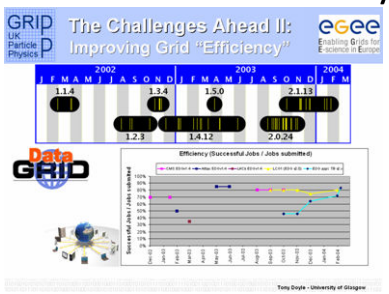


More Challenges?

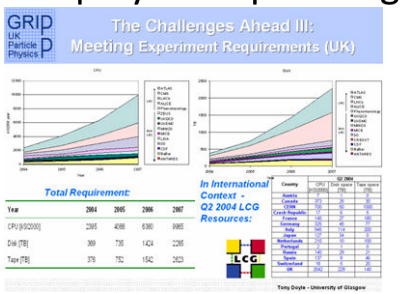
1. Software process



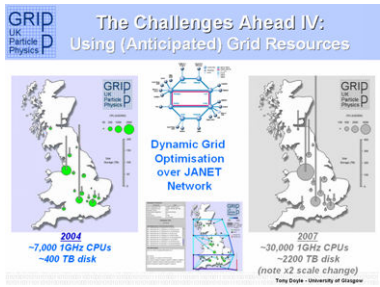
2. Software efficiency



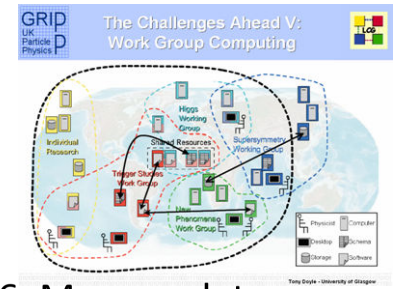
3. Deployment planning



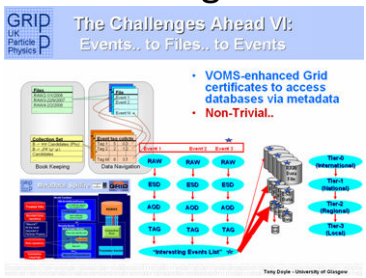
4. Link centres



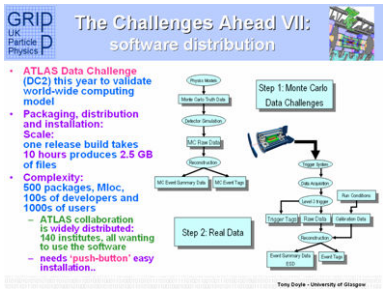
5. Share data



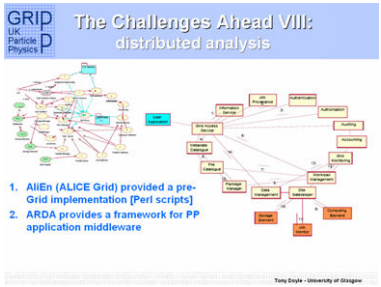
6. Manage data



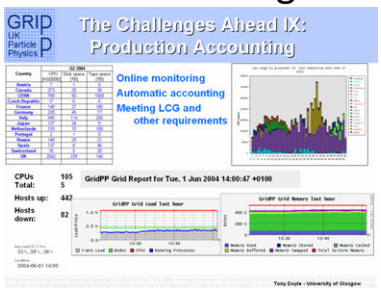
7. Install software



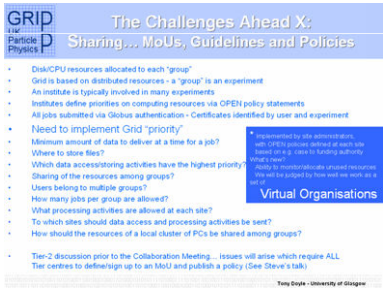
8. Analyse data



9. Accounting

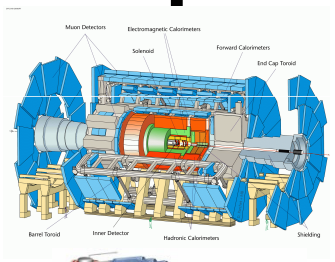


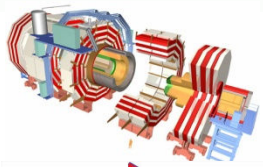
10. Policies

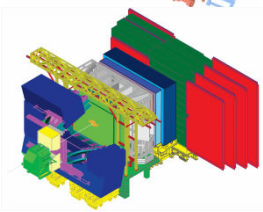


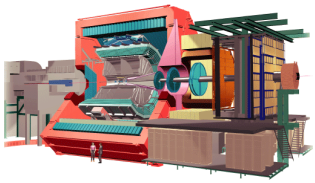
Data Management, Security and Sharing

Physical Tier Structure









Offline farm

Online system

Tier 0

CERN computer centre

11 T1 centres

Tier 1

National centres

RAL,UK

Spain

ermany

Italy

France

Tier 2

Regional groups

ScotGrid

NorthGrid

SouthGrid

London

Institutes

Glasgow

Edinburgh

Durham

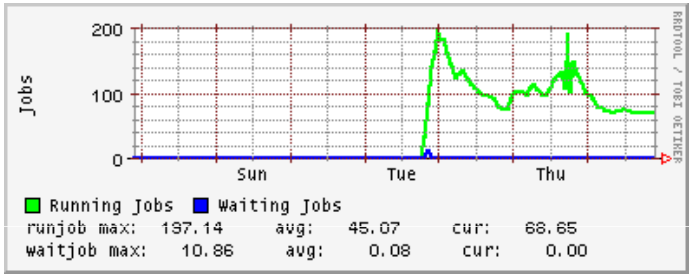
Workstations

Structure chosen for particle physics.
Different for others.

An Example - ScotGrid

ScotGrid

Scottish Grid Service

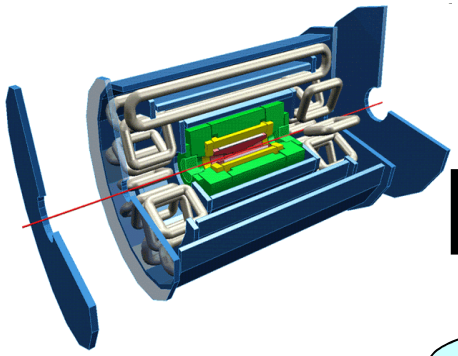


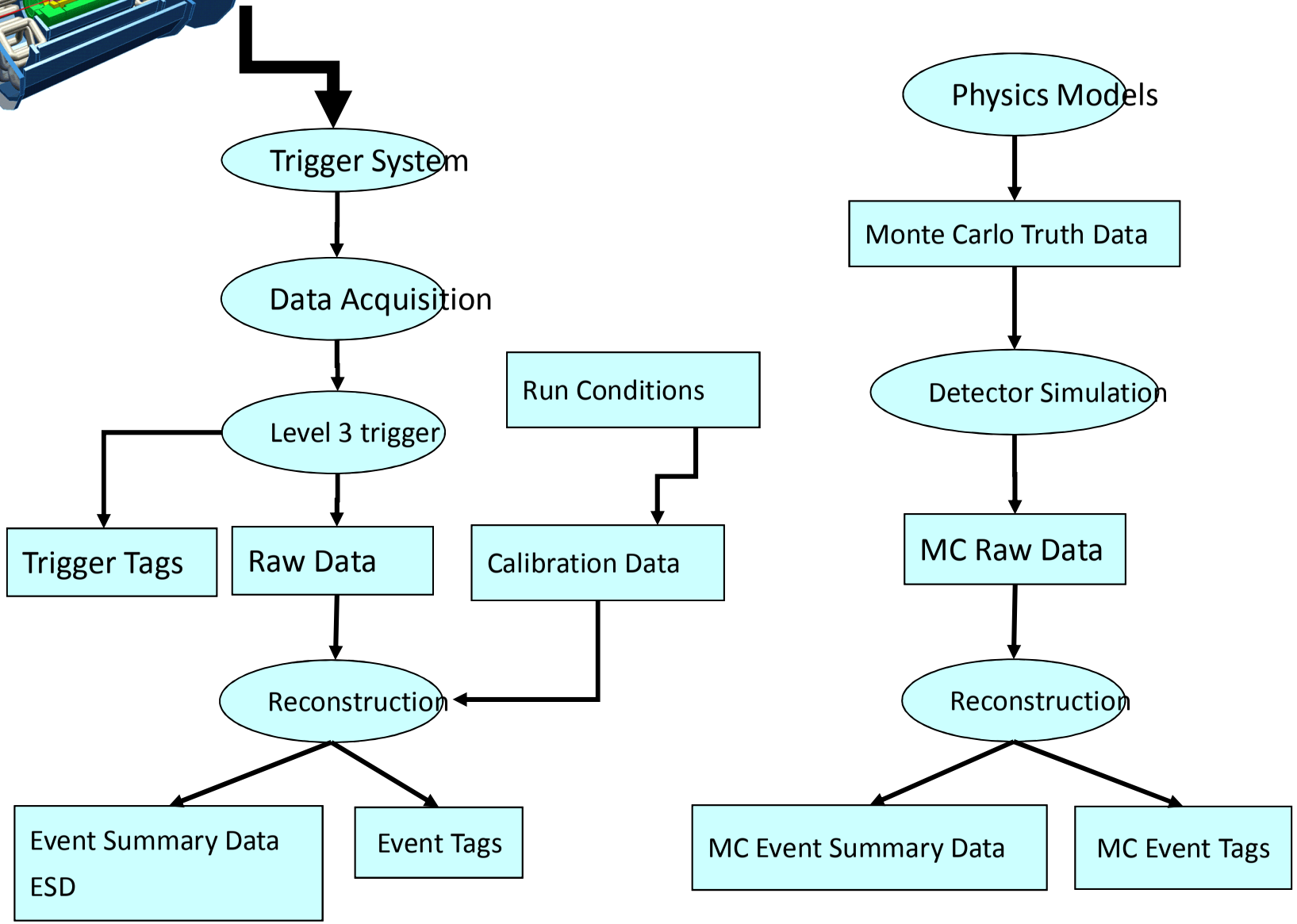
Just in time for the LHC





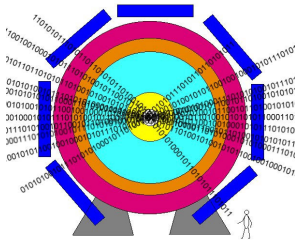
Data Structure





REAL and SIMULATED data

Physics Analysis



INCREASING DATA FLOW

ESD: Data or Monte Carlo

Event Selection

Event Tags

Analysis Object Data
AOD

Calibration Data

Raw Data

Analysis, Skims

Physics Objects

Physics Objects

Physics Objects

Physics Analysis

Tier 0,1

Collaboration wide

Tier 2

Analysis Groups

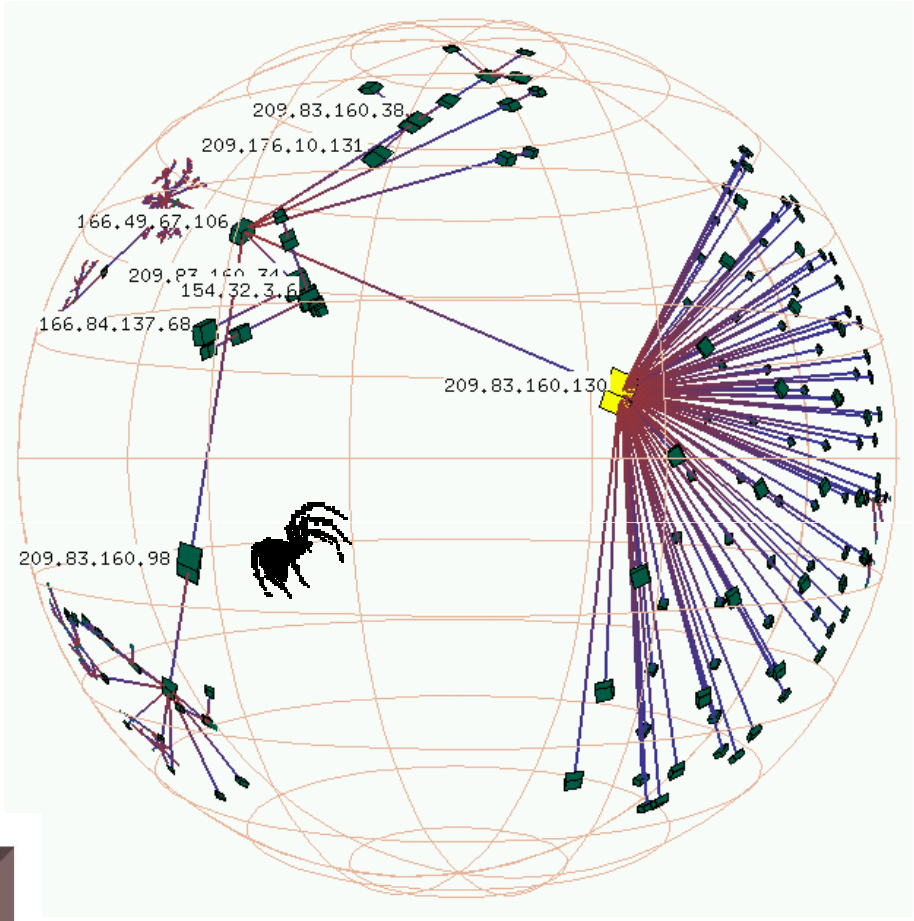
Tier 3, 4

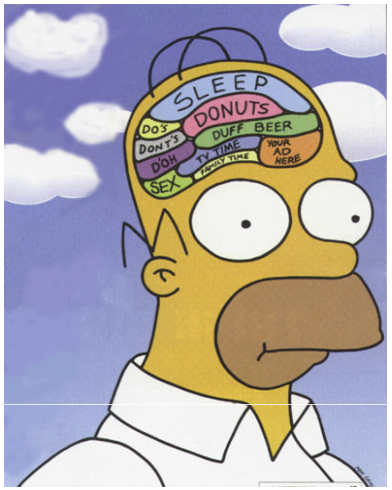
Physicists

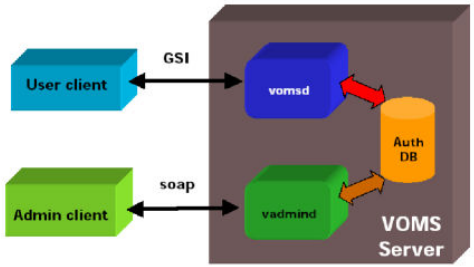
Who do you trust?

No-one?









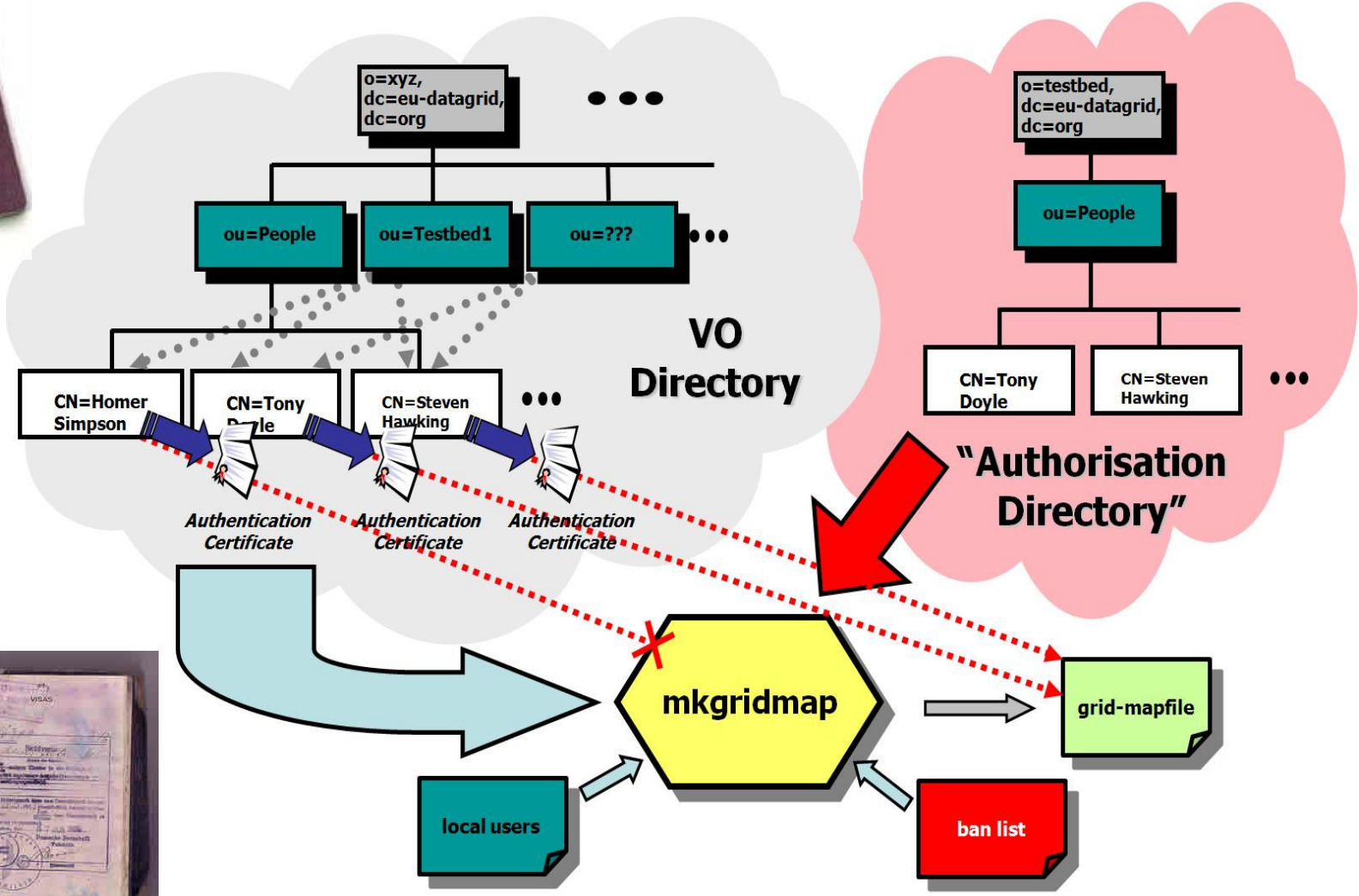
It depends on what you want… (assume its scientific collaboration)



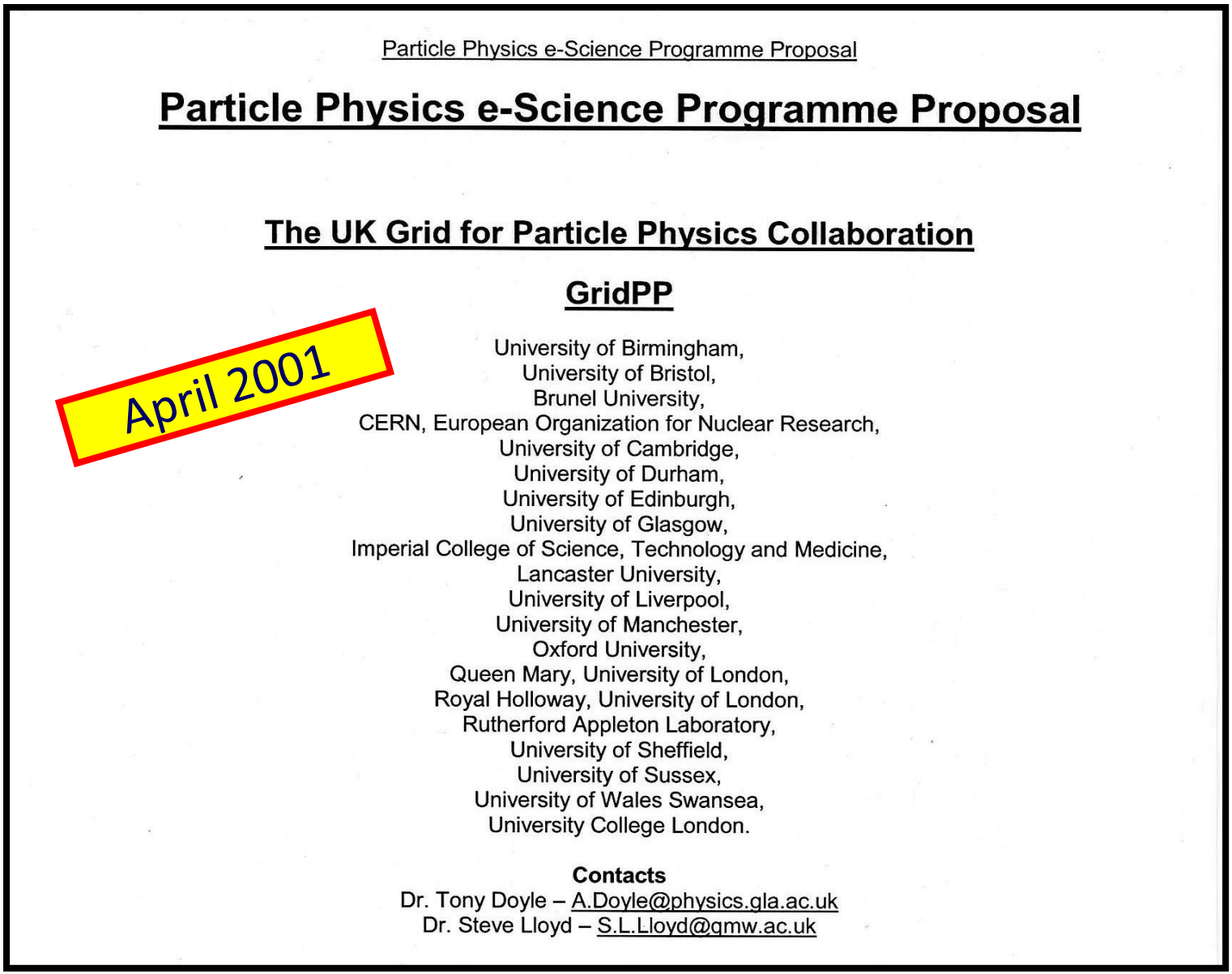
How do I Authorise? Digital Certificates







Rise of the UK Grid



Particle Physics e-Science Programme Proposal

Particle Physics e-Science Programme Proposal

The UK Grid for Particle Physics Collaboration

GridPP

April 2001

University of Birmingham,
University of Bristol,
Brunel University,
CERN, European Organization for Nuclear Research,
University of Cambridge,
University of Durham,
University of Edinburgh,
University of Glasgow,
Imperial College of Science, Technology and Medicine,
Lancaster University,
University of Liverpool,
University of Manchester,
Oxford University,
Queen Mary, University of London,
Royal Holloway, University of London,
Rutherford Appleton Laboratory,
University of Sheffield,
University of Sussex,
University of Wales Swansea,
University College London.

Contacts
Dr. Tony Doyle – A.Doyle@physics.gla.ac.uk
Dr. Steve Lloyd – S.L.Lloyd@qmw.ac.uk

GridPP – UK Grid

UK's contribution to LHC computing:
- 19 UK Universities, STFC and CERN

GridPP1 (2001- 2004) £17M
"From Web to Grid"

GridPP2 (2004 - 2008) £16M
"From Prototype to Production"

GridPP3 (2008 – 2011) ~£30M
"From Production to Exploitation"



CERN
UNIVERSITY OF CAMBRIDGE
THE UNIVERSITY OF BIRMINGHAM
University of Bristol
BRUNEL UNIVERSITY WEST LONDON
University of Durham
THE UNIVERSITY OF EDINBURGH
Imperial College London
LANCASTER UNIVERSITY
UNIVERSITY of GLASGOW
THE UNIVERSITY of MANCHESTER
THE UNIVERSITY of LIVERPOOL
Queen Mary University of London
Royal Holloway University of London
Science & Technology Facilities Council
THE UNIVERSITY OF SHEFFIELD
THE UNIVERSITY OF SUSSEX
UCL
PRIFYSGOL CYMRU ABERTAWE
UNIVERSITY OF WALES SWANSEA
WARWICK

WorldWide Resources



© CERN openlab / EDS

Latest SAM results, Site Status, for 'OPS' VO, 10 Feb 2009 14:19 GMT.
Size of site rectangles is number of CPUs from BDII.
Certified Production sites, grouped by regions.

Worldwide

- 55 Countries
- 283 Sites
- 180,000 CPUs

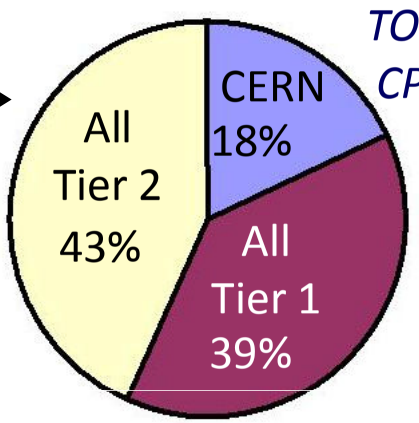
UK

- 23 Sites
- 20,000 CPUs

Worldwide LHC Computing Grid



Computing Technical Design Reports
WLCG + 4 LHC experiments – June 2005



Summary of Computing Resource Requirements

All experiments - 2008

From LCG TDR - June 2005

	CERN	*All Tier-1s*	*All Tier-2s*	*Total*
CPU (MSPECint2000s)	**25**	**56**	**61**	**142**
Disk (PetaBytes)	**7**	**31**	**19**	**57**
Tape (PetaBytes)	**18**	**35**		**53**

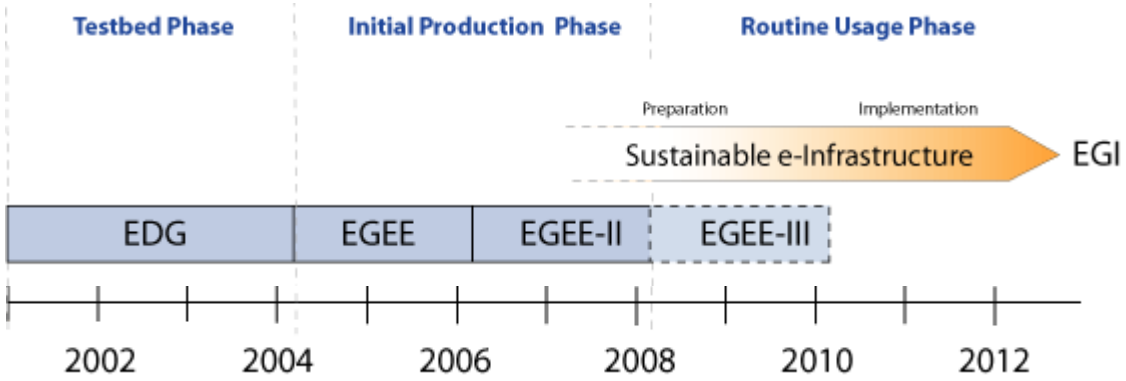
New data will grow at ~15 PetaBytes/year

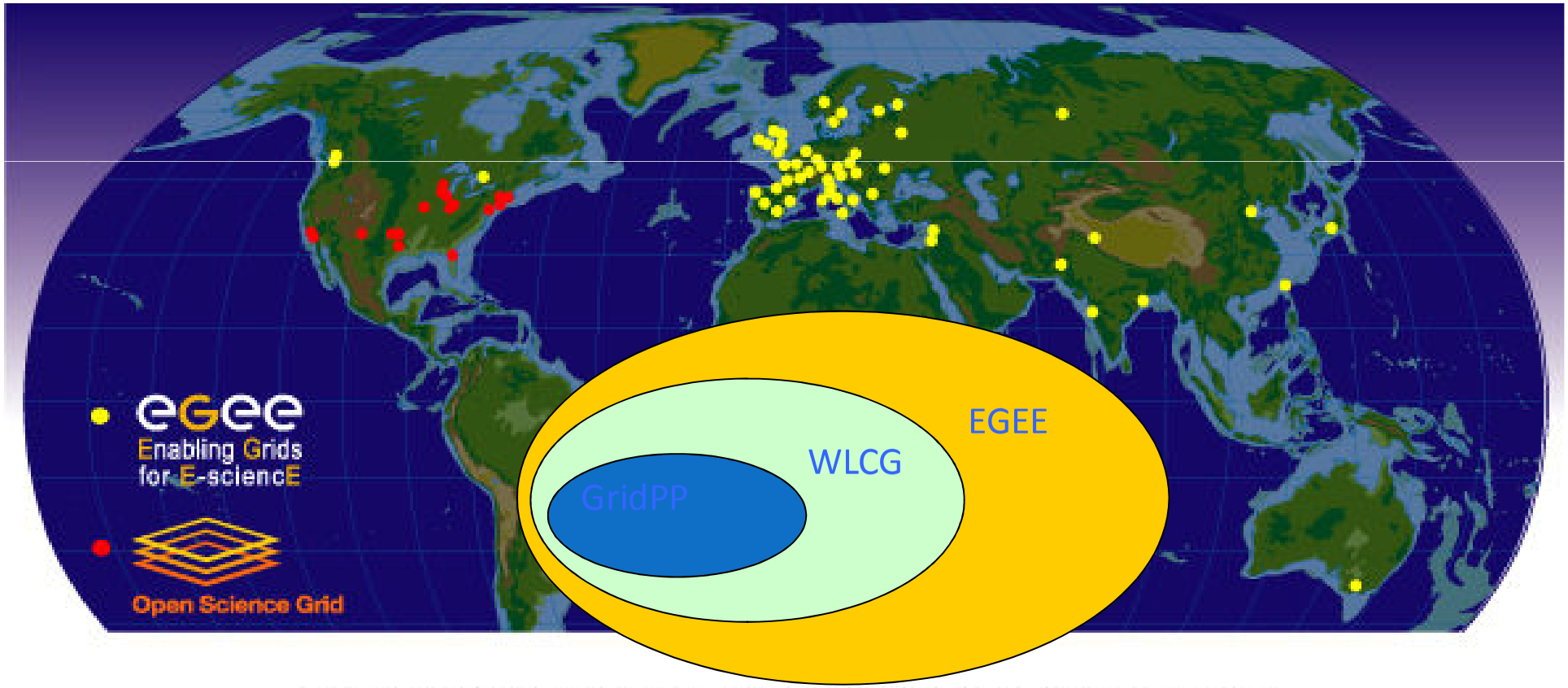
~100,000 fastest CPU cores

Need more than twice as much by 2010

Grid Infrastructure

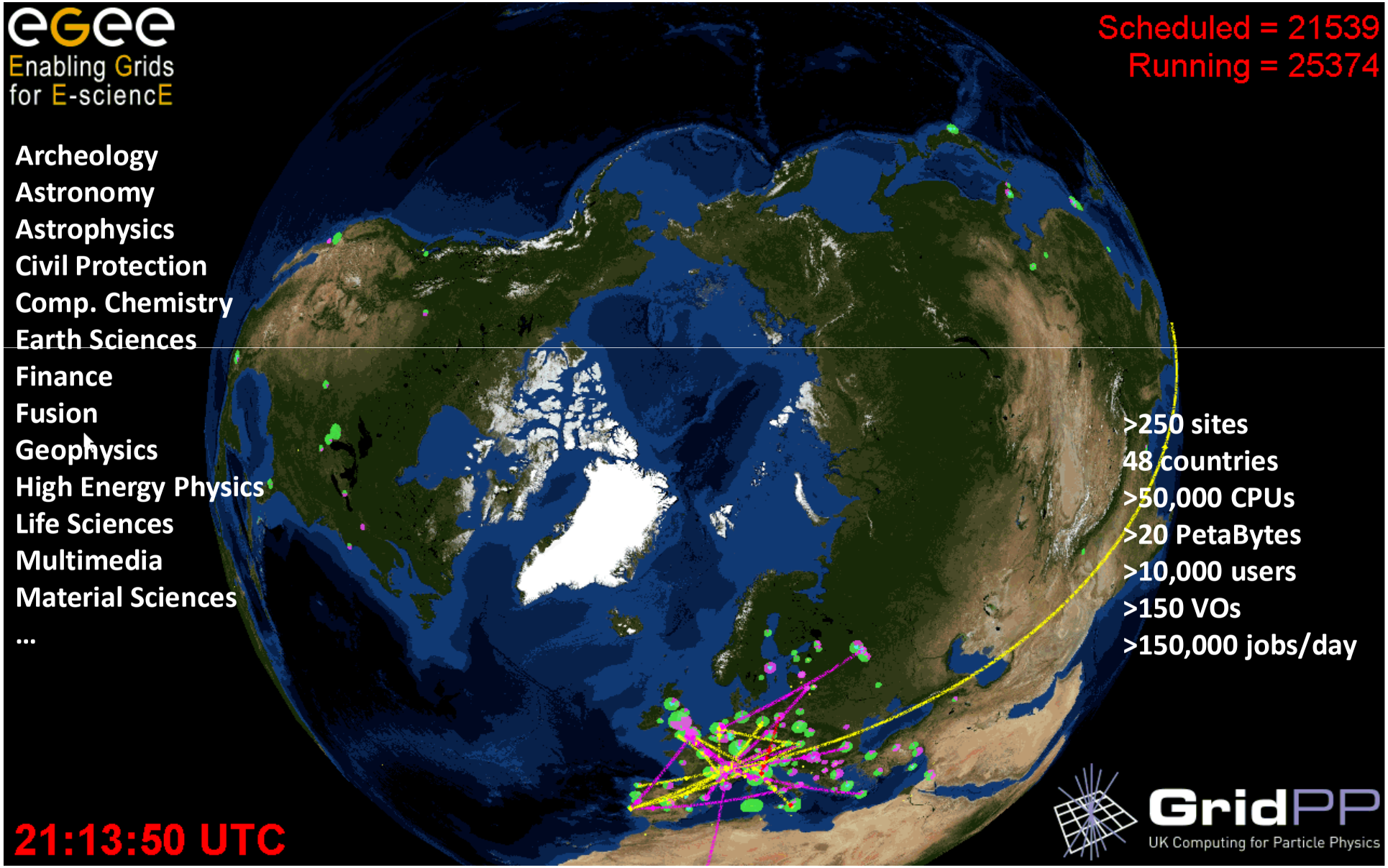
WLCG based on EGEE and OSG Grid infrastructure.



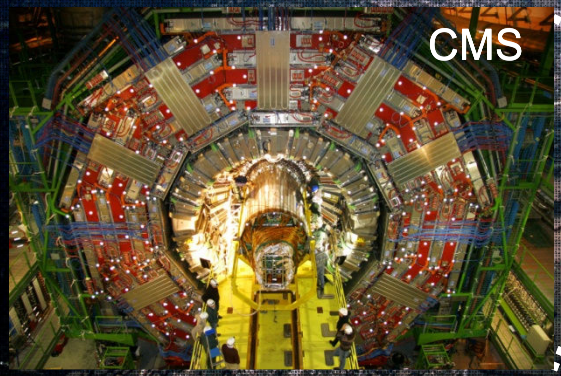


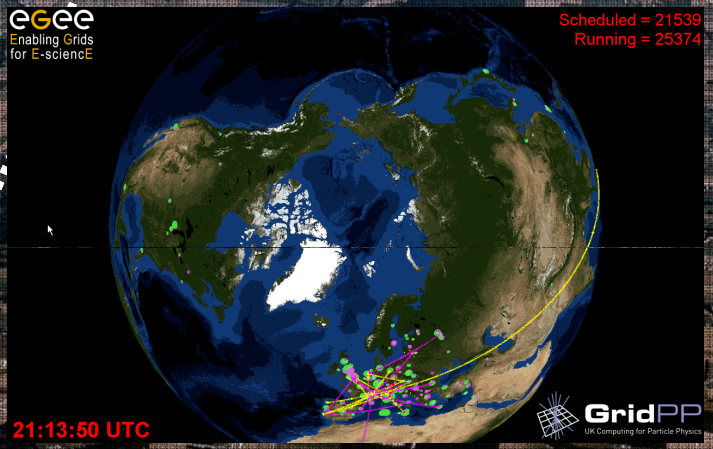
A map of the worldwide LCG infrastructure operated by EGEE and OSG.

The Grid


eGee
Enabling Grids
for E-sciencE
Scheduled = 21539
Running = 25374
Archeology
Astronomy
Astrophysics
Civil Protection
Comp. Chemistry
Earth Sciences
Finance
Fusion
Geophysics
High Energy Physics
Life Sciences
Multimedia
Material Sciences
...
>250 sites
48 countries
>50,000 CPUs
>20 PetaBytes
>10,000 users
>150 VOs
>150,000 jobs/day
21:13:50 UTC
GridPP
UK Computing for Particle Physics

EXCITING YEARS ARE AHEAD

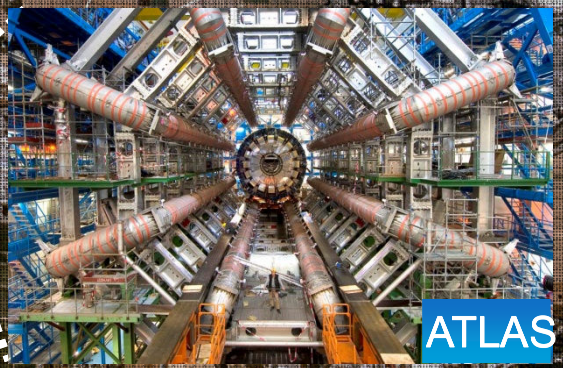


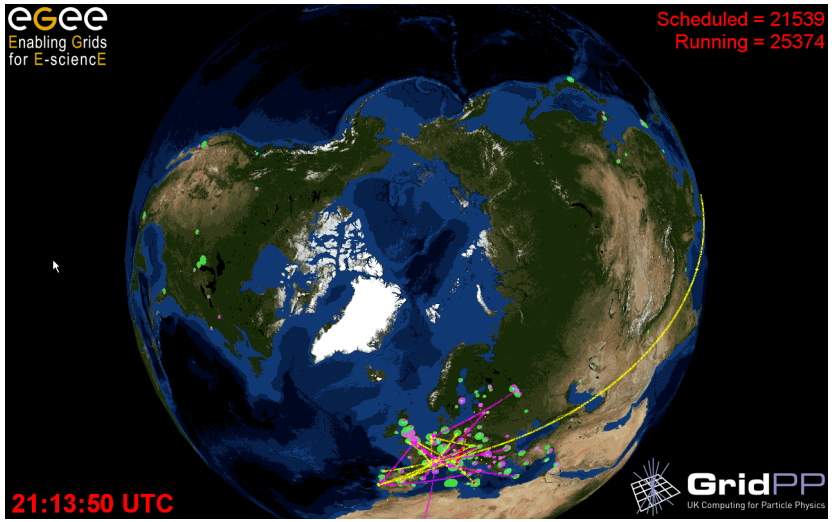




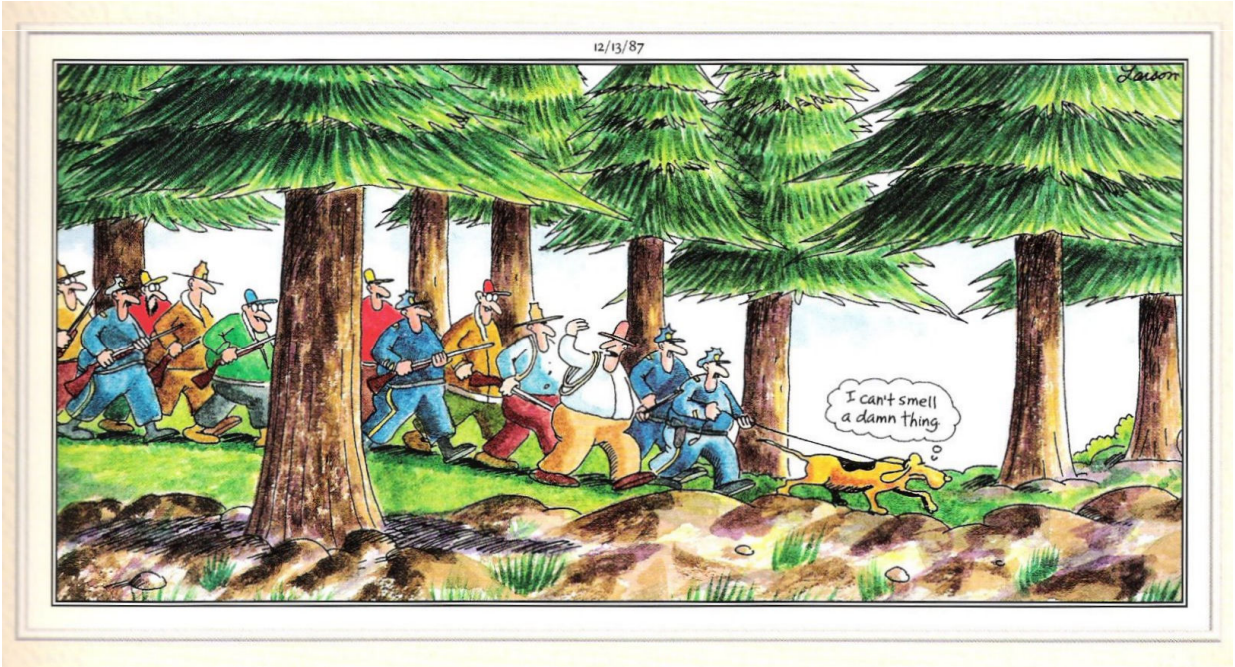






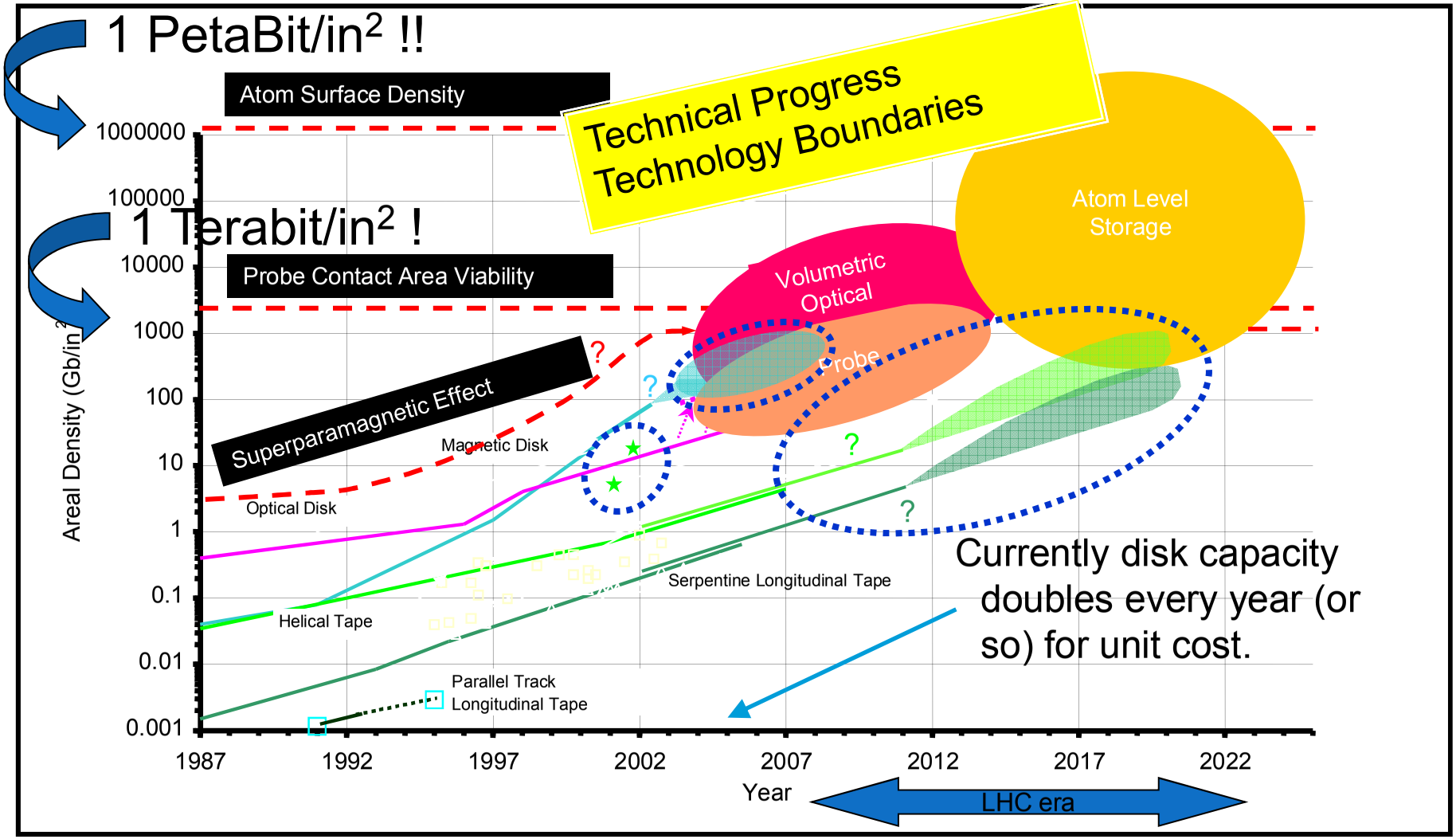


Epilogue:
Beyond The Grid?

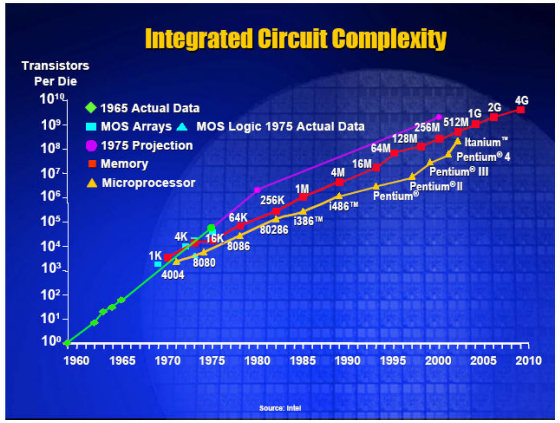


What are the limits on Data?

Advanced Areal Density Trends: Kryder's Law

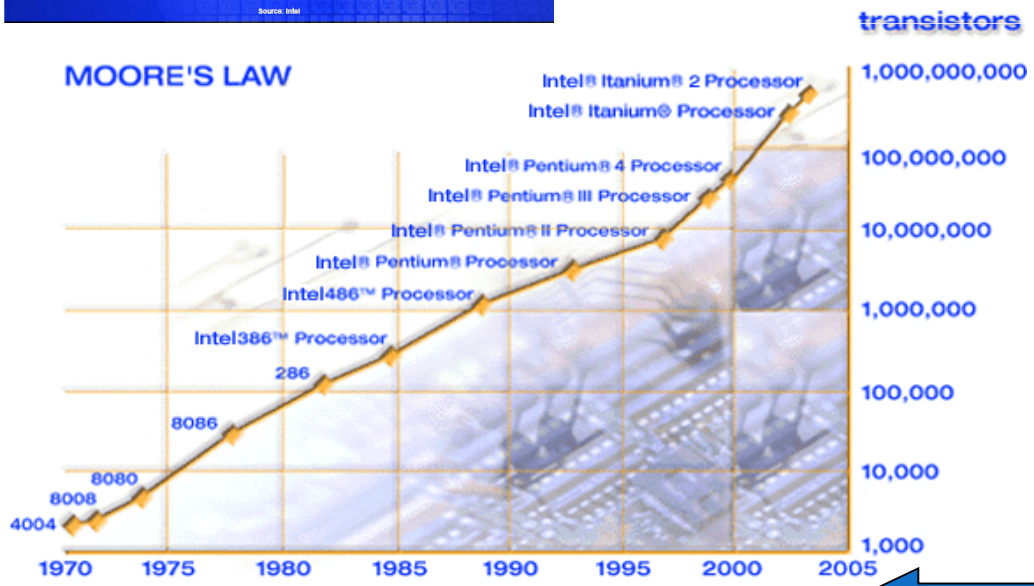


What are the limits on CPU? Moore's Law



No Exponential is Forever … but We Can Delay 'Forever'
ftp://download.intel.com/research/silicon/Gordon_Moore_ISSCC_021003.pdf

Technical Progress Technology Boundaries



Currently CPU performance doubles every two years (or so) for unit cost.

LHC era

16nm manufacturing process to arrive in 2018.. after that?
"We cannot let physics beat us"

Butter's law of photonics: data out of optical fibres doubles every nine months (or so)

Next step beyond electronics? photonics

Step-1	Select Hardware Price Assumptions using the GREEN cells (These are contained in the worksheet called "Assumptions")										
		Calender Year										
	Model	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Disk Doubling	AGGRESSIVE	12	12	15	15	15	18	18	18	18	18	18
CPU Doubling	STANDARD	24	24	24	24	24	24	24	24	24	24	24

Table-1: Moore's Law Assumptions

Step-1..
financial planning

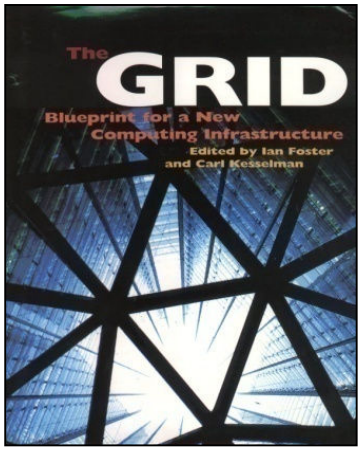
Step-2.. Compare to
(e.g. Tier-1) expt. requirements

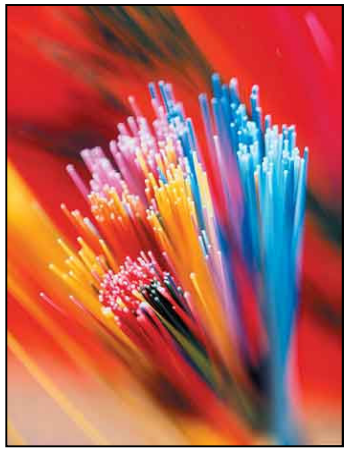
Step-3.. Conclude that more
than one centre is needed

Step-4.. A Grid?

Reqts 2008	ALICE	ATLAS	CMS	LHCb	SUM
CPU (kSI2K)	9100	16600	12600	9500	47800
Disk (Tbytes)	3000	9200	8700	1300	22200
Tape (Pbytes	3.6	6	6.6	0.4	16.6
Number of T1	5	11	7	6	29

Currently network performance doubles every nine months (or so) for unit cost. (Fastest exponential).

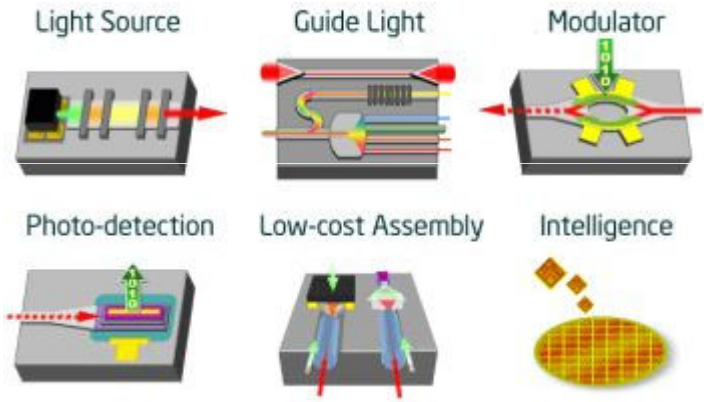




Photonic computers linked via global optical network?

Next step beyond electronics?
(~2020) photonics

Hybrid silicon laser
(Indium phosphide)



Silicon/Germanium
Avalanche Photo Detector
(APD)

Substituting electrons for photons
- overcome heat dissipation and current leakage

Photons and silicon don't marry well (indirect band gap making it a very poor light emitter)

six main development areas:

1. generating the light
2. selectively guiding it
3. encoding light
4. detecting light
5. packaging devices
6. intelligent control

Next steps e.g. 25 lasers on one chip modulated at 40Gbps with 25 detectors on another chip

intel

SUMMARY

1. Theory guides our understanding of the very large and the very small..
2. The LHC machine will re-start soon (but after September 2009)
3. Experiment will tell what lies at the TeV energy scale.. atto-scale Universe
4. The Grid will enable complex LHC and other analyses to be performed

- Exciting next 10 years
- Beyond the Grid? – a new photonics-based computing system??

Top 10 Facts

1. When the 27km long circular tunnel at CERN was excavated, between lake Geneva and the Jura mountain range, the two ends met up with just one centimetre of error.
2. When protons arrive in the LHC they are travelling at 0.999997828 times the speed of light. Each proton goes around the 27km ring over 11 000 times a second.
3. A nominal proton beam in the LHC will have an energy equivalent to a person in a car driving at 1700 kph.
4. The combined strands of the superconducting cable being produced for the LHC would go around the equator 6.8 times.
5. Part of the LHC will be the world's largest fridge. It could hold 150 000 fridges at a temperature colder than deep outer space.
6. The vacuum in the LHC is comparable to outer space, if it were a car tyre with a leak, there are so few gas molecules that it would take 10 000 years to go flat.
7. The ATLAS cavern could hold the nave of Notre Dame cathedral.
8. Understanding all of the different forces of nature within one framework is one of the ultimate goals of physics. Decades of experiments at CERN are working towards this.
9. On 1st October 2003 CERN and the California Institute of Technology set a new Internet Land Speed Record by transferring 1.1 terabytes of data in less than 30 minutes across 7000km of network. The equivalent of transferring a full length DVD movie in 7 seconds.
10. The Grid is a service for sharing computer power and data storage capability over the Internet. Its ultimate aim is to turn the global network of computers into one vast computational resource.