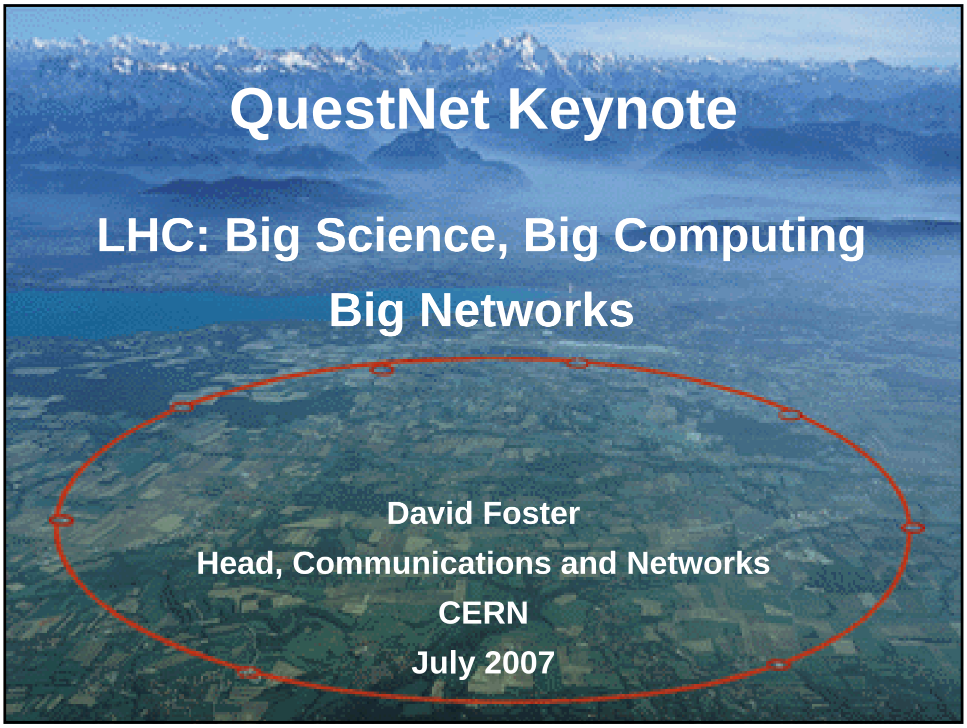
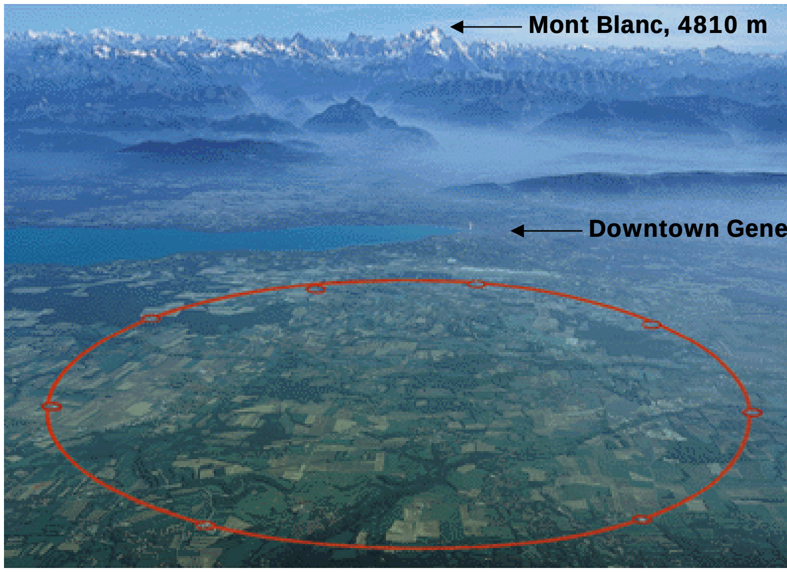


Acknowledgments

- ✓ Many presentations and material in the public domain have contributed to this presentation, too numerous to mention individually.

CERN – March 2007 2

Big Science



David Foster 1/11/04

3

CERN stands for over 50 years of

- fundamental research and discoveries
- technological innovation
- training and education
- bringing the world together

1954 Rebuilding Europe
First meeting of the CERN Council

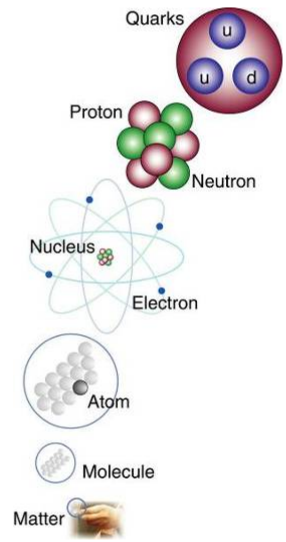
1980 East meets West
Visit of a delegation from Beijing

2004 Global Collaboration
The Large Hadron Collider involves over 80 countries

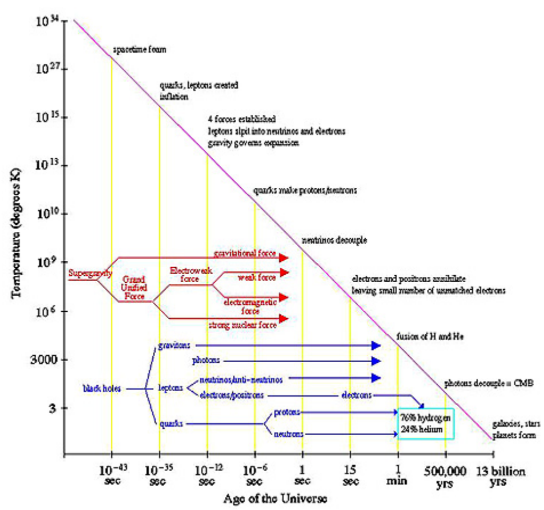
4

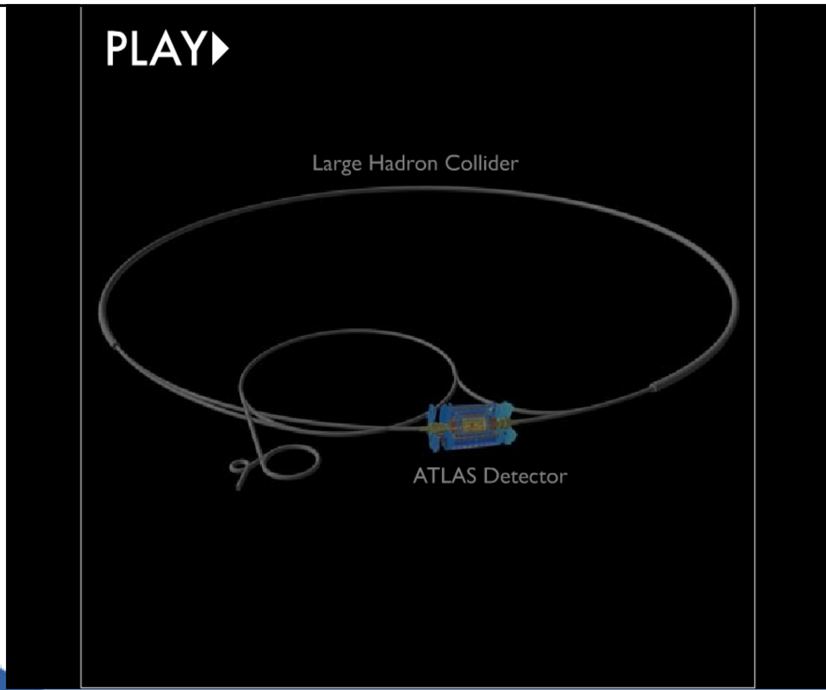
CERN's Mission in Science

- Understand the fundamental laws of nature by studying elementary particles and fields and their interactions
- Provide a world-class laboratory to researchers in Europe and beyond
- Train young scientists



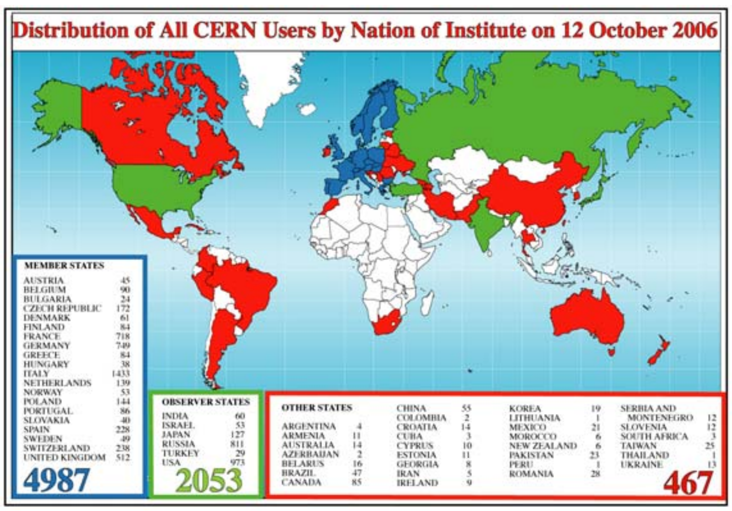
The Origins of Everything





CERN in numbers

- 2600 staff , 650 Fellows and Associates , 7500 users (Oct 2006)



CERN's Tools

- To understand the fundamental laws of nature we accelerate elementary particles and make them collide.
- This requires special tools:
  - **ACCELERATORS**, huge machines able to speed up particles to very high energies before colliding them into other particles
  - **DETECTORS**, massive instruments which register the particles produced when the accelerated particles collide
  - **COMPUTING**, to collect, store, distribute and analyse the vast amount of data produced by the detectors

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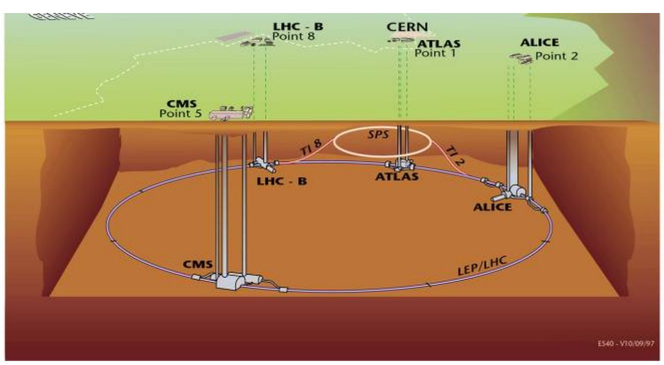
CERN's LHC

- CERN is building the Large Hadron Collider (LHC), the most powerful instrument ever built to investigate elementary particles
- Its results will determine the future course of High Energy Physics



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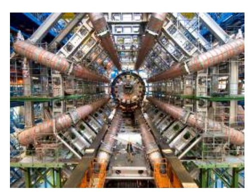
CERN’s Detectors

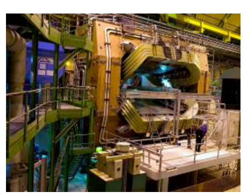
- To observe the collisions, collaborators from around the world are building four huge experiments: ALICE, ATLAS, CMS, LHCb
- Detector components are constructed all over the world
- Funding comes mostly from the participating institutes, less than 20% from CERN

CMS

ATLAS

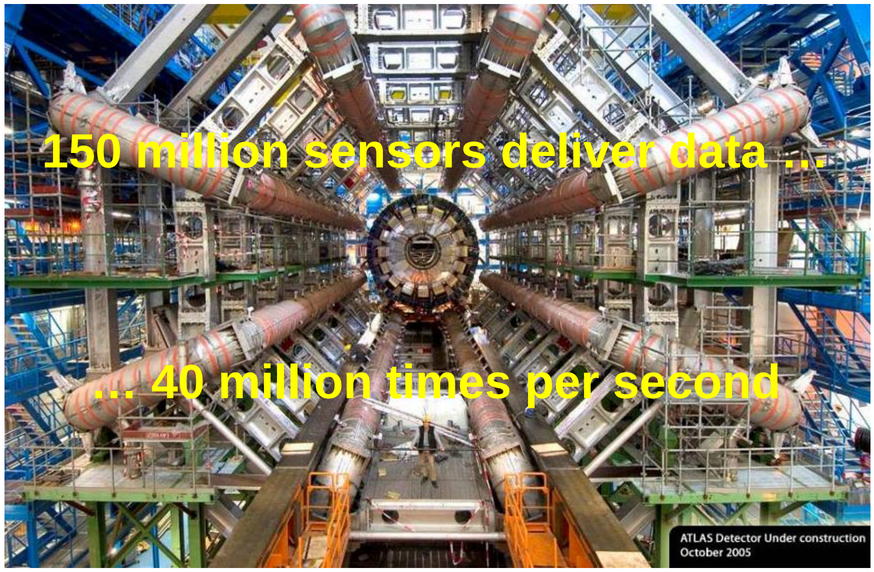


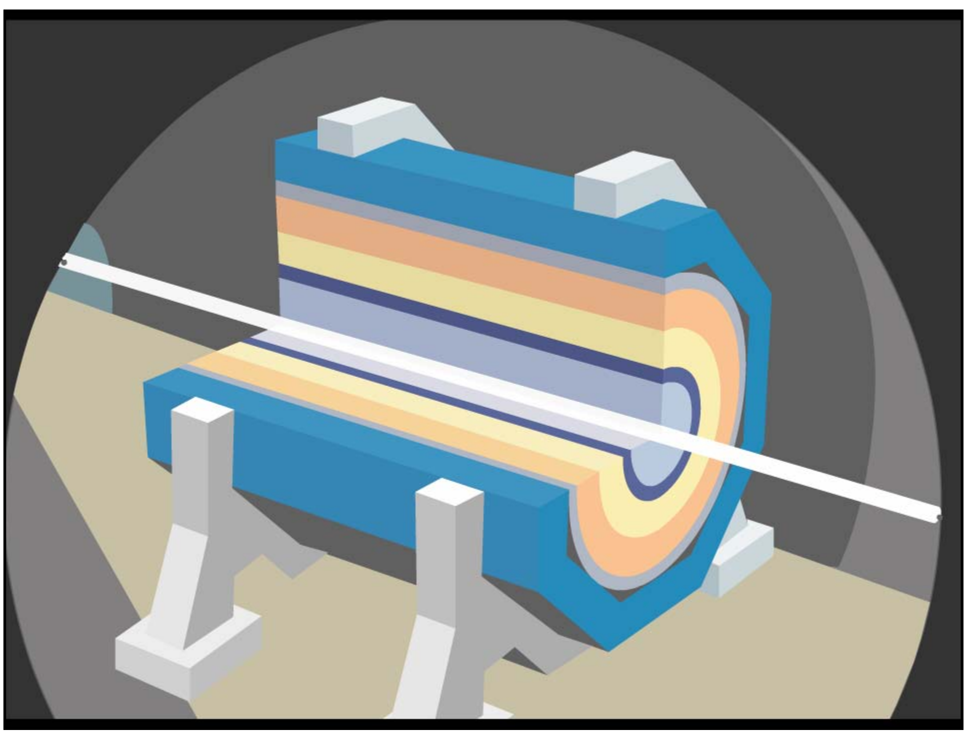
LHCb

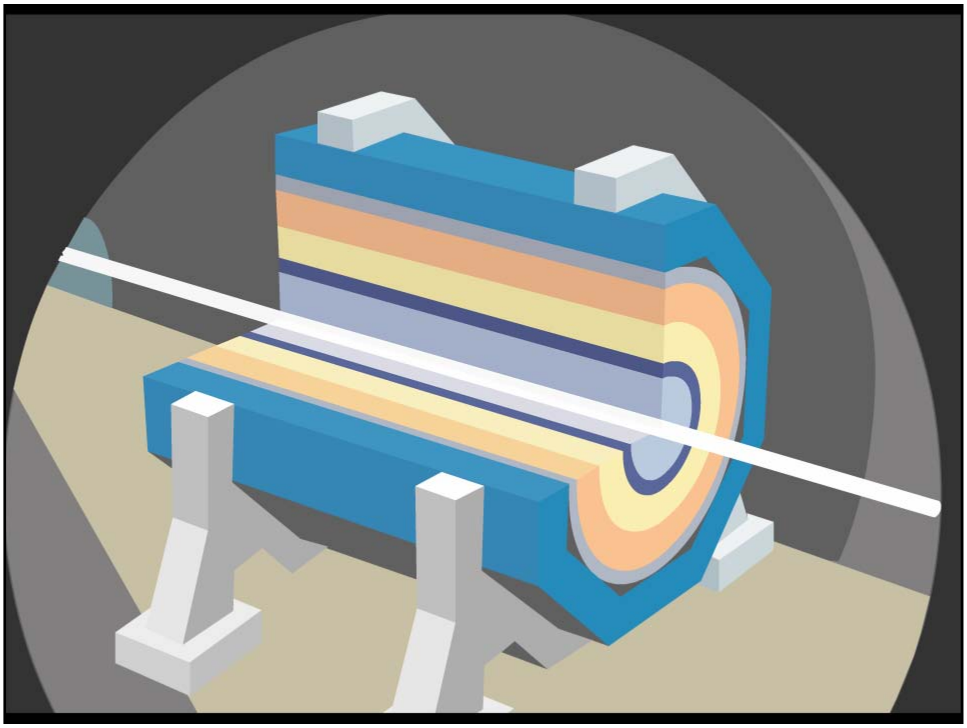


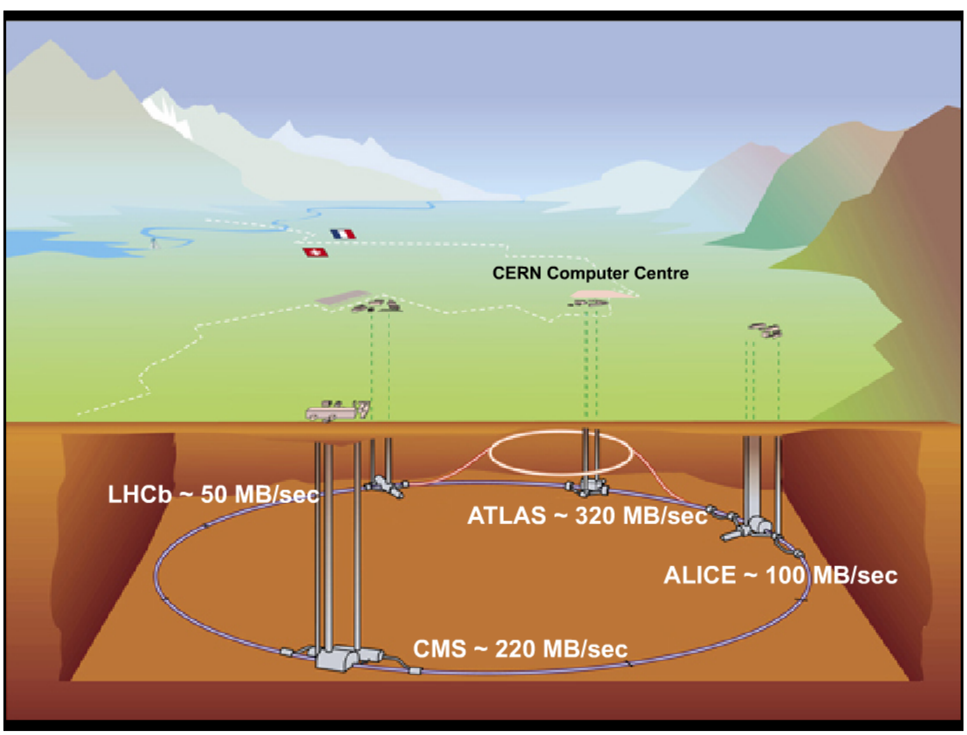
ALICE

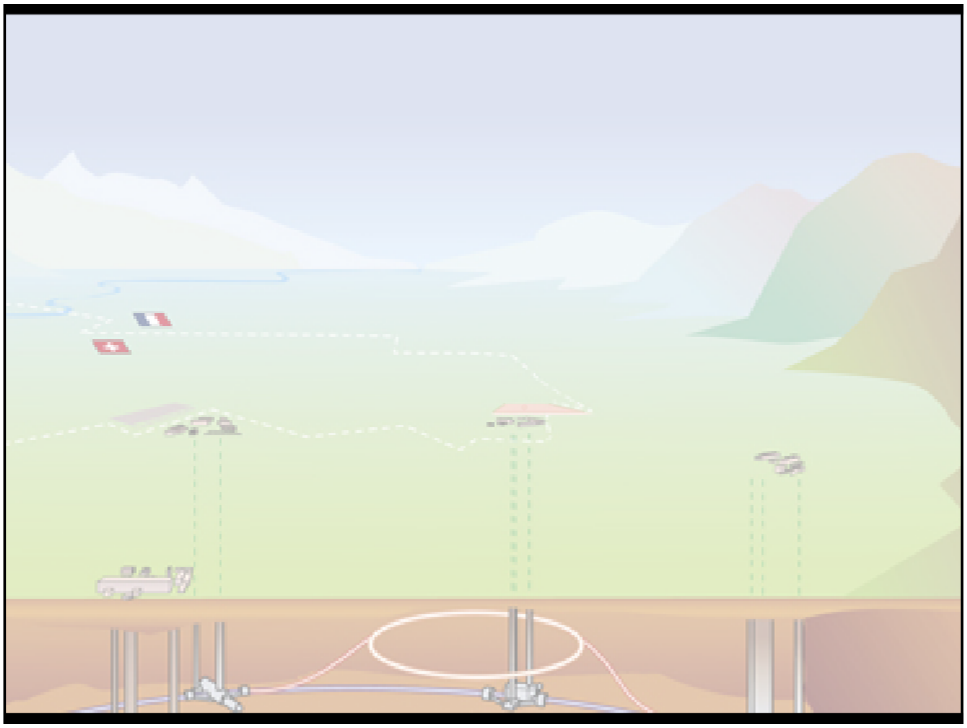
View of the ATLAS detector (under construction)



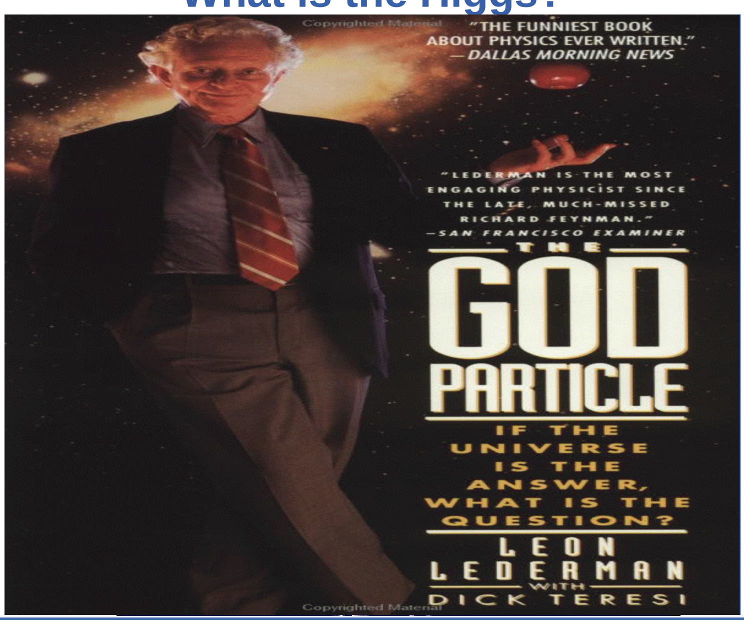





CERN Computer Centre
LHCb ~ 50 MB/sec
ATLAS ~ 320 MB/sec
ALICE ~ 100 MB/sec
CMS ~ 220 MB/sec



What is the Higgs?



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LHC Stakes *1.49 million furlongs per second.*
Purse: Nobel Prize for long-sought particles, well-motivated theoretical concepts, and speculative guesses.

DISCOVERY	COMMENTS	ODDS*
Standard Model Higgs	As good as discovered, some say	2–1
Big surprises	Expect the unexpected	2–1
Supersymmetry	Too beautiful to be wrong?	5–1
Extra dimensions	More an inspired guess than a prediction	14–1
Composite electrons, etc.	Bigger fleas have littler fleas …	14–1
Leptoquarks	Weird particles hinted at by another collider	49–1
Nothing	Be careful what you wish for	7–1

* Based on survey of roughly 300 grad students, postdocs, and professors at Fermilab, as reported in the January/February issue of *Symmetry* Magazine. Respondents could choose more than one prediction.

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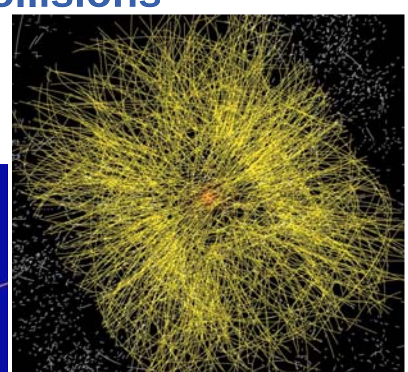
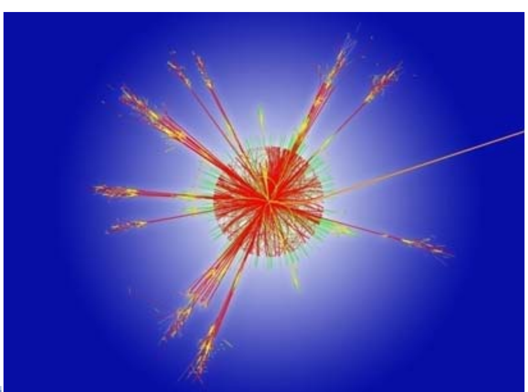
Simulated Collisions



Pb-Pb



Proton-Proton

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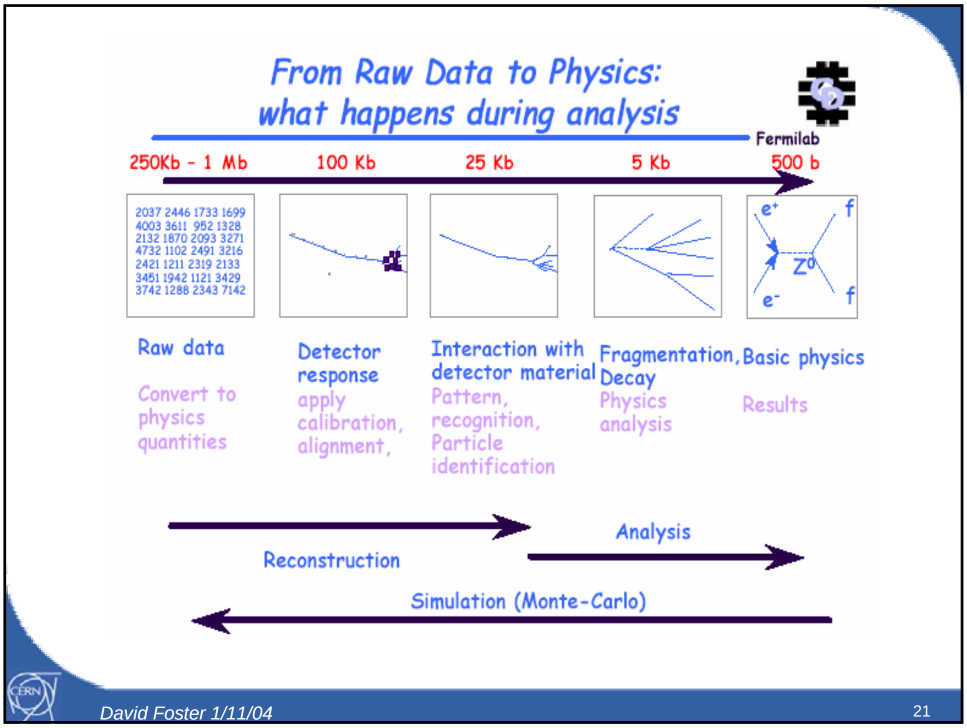
From Raw Data to Physics:
what happens during analysis
Fermilab
250Kb - 1 Mb
100 Kb
25 Kb
5 Kb
500 b
2037 2446 1733 1699
4003 3611 952 1328
2132 1870 2093 3271
4732 1102 2491 3216
2421 1211 2319 2133
3451 1942 1121 3429
3742 1288 2343 7142
e+
f
Z0
e-
f
Raw data
Convert to physics quantities
Detector response
apply calibration, alignment,
Interaction with detector material
Pattern, recognition, Particle identification
Fragmentation, Decay
Physics analysis
Basic physics
Results
Analysis
Reconstruction
Simulation (Monte-Carlo)
David Foster 1/11/04
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Big Computing
CERN – March 2007
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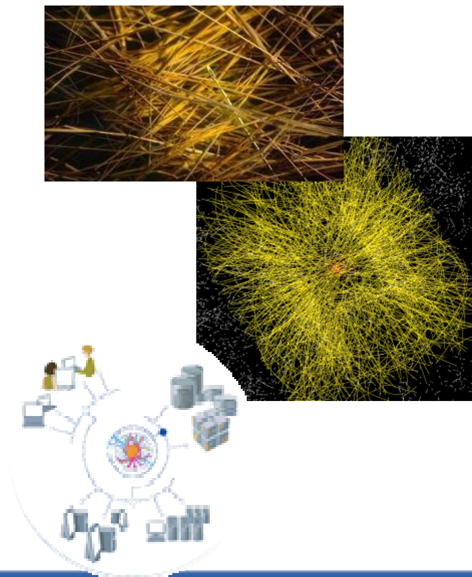
The LHC Computing Challenge

- Data volume
  - High rate x large number of channels x 4 experiments
  - ➔ **15 PetaBytes of new data each year**
- Compute power
  - Event complexity x Nb. events x thousands users
  - ➔ **100 k of today's fastest CPUs**
- Worldwide analysis & funding
  - Computing funding locally in major regions & countries
  - Efficient analysis everywhere
  - ➔ **GRID technology**



WLCG Collaboration

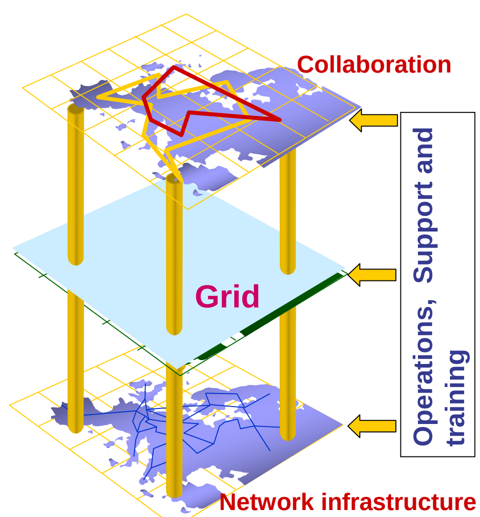
- The Collaboration
  - 4 LHC experiments
  - ~200 computing centres
  - 12 large centres (Tier-0, Tier-1)
  - 38 *federations* of smaller “Tier-2” centres
  - Growing to ~40 countries
  - Grids: EGEE, OSG, Nordugrid
- Technical Design Reports
  - WLCG, 4 Experiments: June 2005
- Memorandum of Understanding
  - Agreed in October 2005
- Resources
  - 5-year forward look

Centers around the world form a Supercomputer

- The EGEE and OSG projects are the basis of the Worldwide LHC Computing Grid Project WLCG

Inter-operation between Grids is working!

The Grid

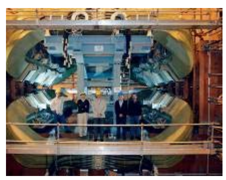


Virtual Organizations (VOs)

- Associated with LHC experiment
  - ALICE ⇨ ALICE experiment
  - ATLAS ⇨ ATLAS experiment
  - CMS ⇨ CMS experiment
  - DTEAM ⇨ Grid (LCG) Deployment Group
  - LHCB ⇨ LHCB experiment
  - SixTrack ⇨ Single Particle Tracking Code

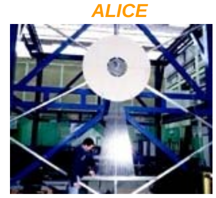
CMS

LHCb



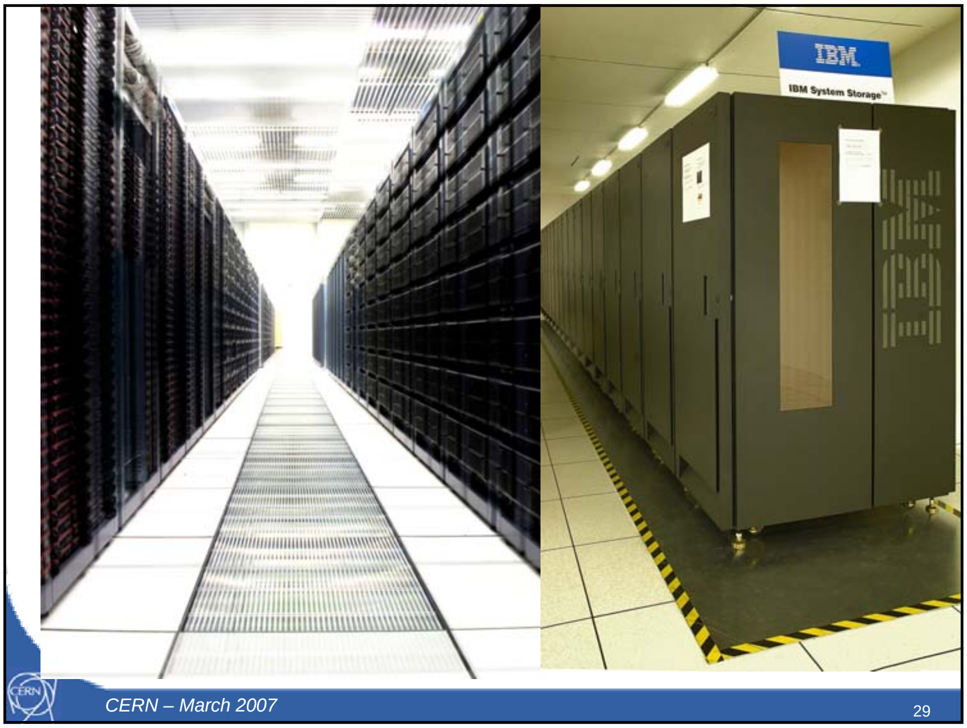
ATLAS

ALICE



Virtual Organizations (VOs)

- Not associated with LHC experiment
  - Babar ⇨ Babar experiment
  - D0 ⇨ D0 experiment
  - H1 ⇨ H1 experiment
  - Zeus ⇨ Zeus experiment
  - ILC ⇨ ILC Community
  - Biomed ⇨ EGEE Biomedical Activity
  - ESR ⇨ Earth Science Research
  - EGEODE ⇨ Expanding GEOsciences on Demand
  - PhenoGrid ⇨ Particle Physics Phenomenology
  - CompChem ⇨ Computational Chemistry
  - SEE-VO ⇨ South Eastern Europe VO


IBM
IBM System Storage
CERN – March 2007
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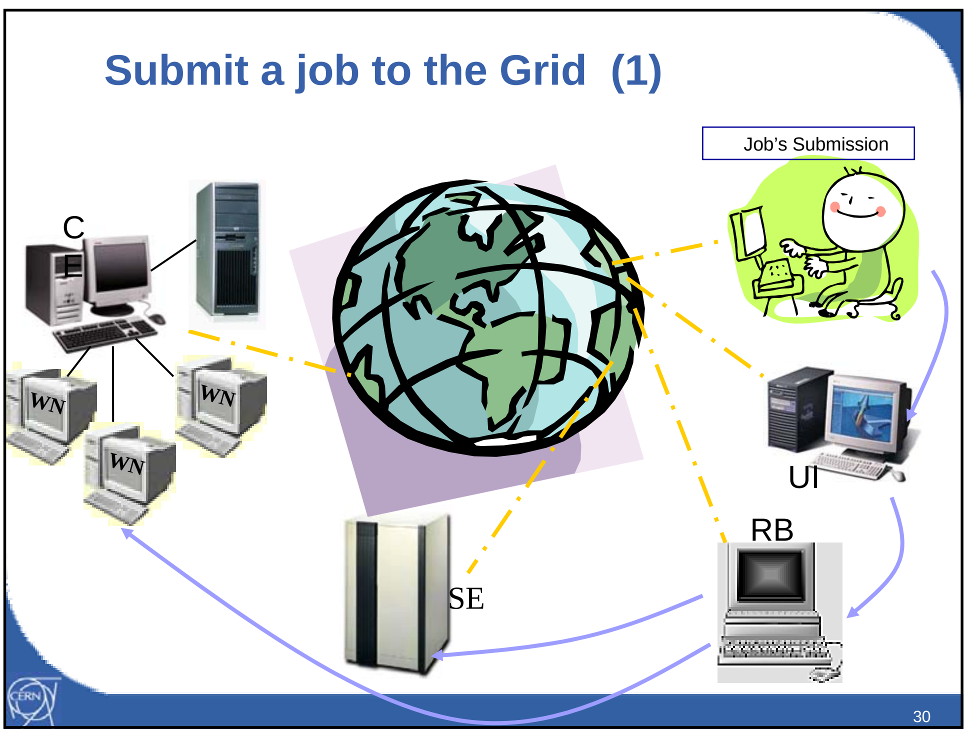
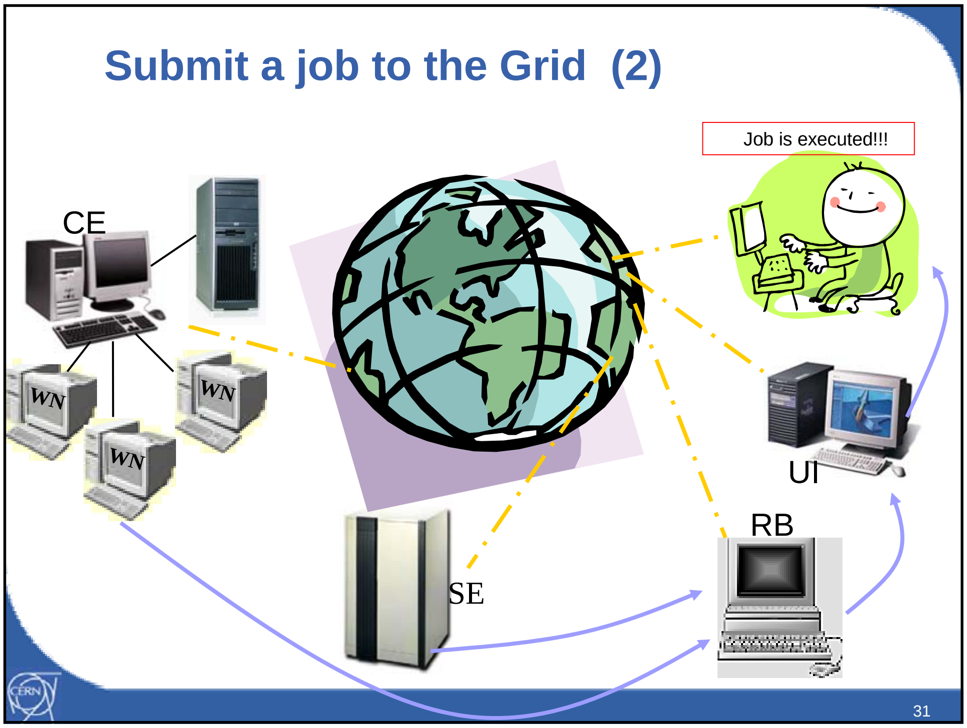
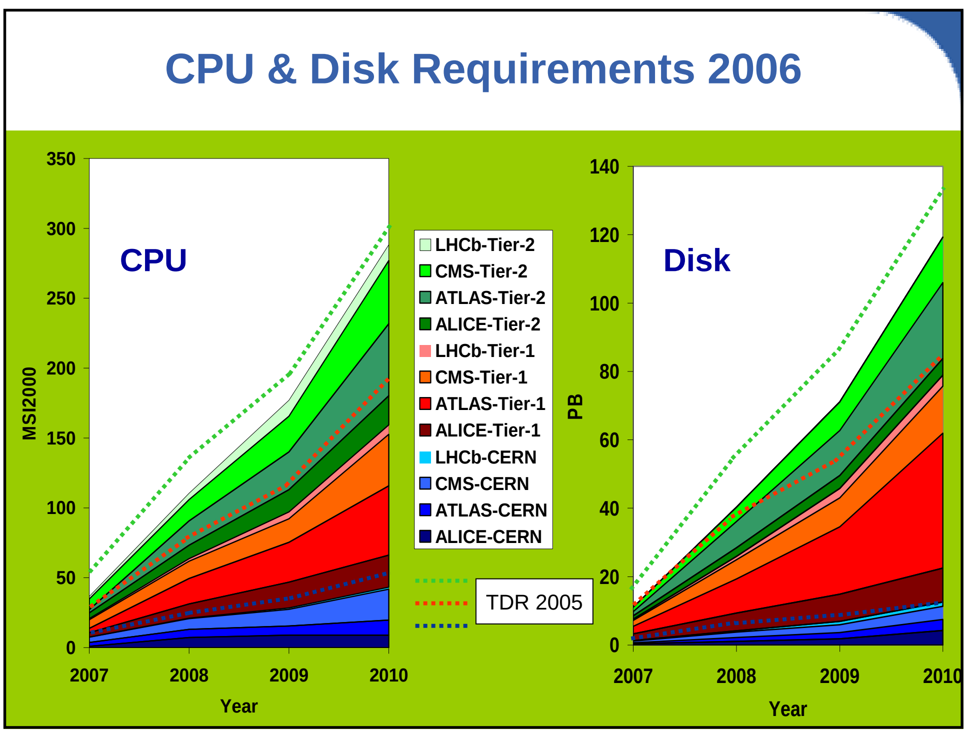
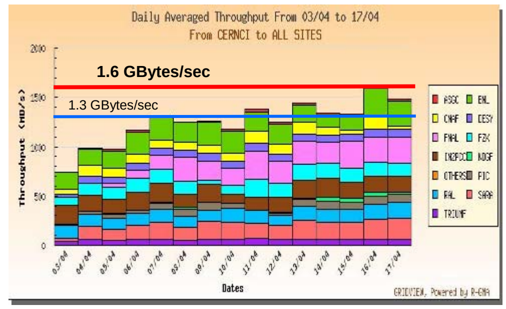

Submit a job to the Grid (1)
Job's Submission
C
E
WN
WN
WN
UI
RB
SE
30

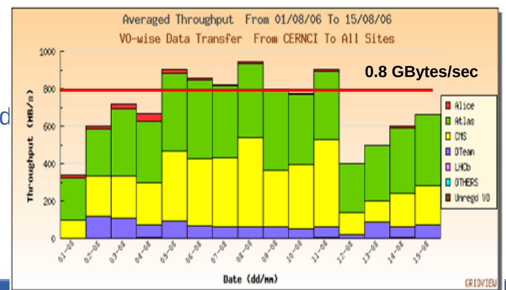

Submit a job to the Grid (2)
Job is executed!!!
CE
WN
WN
WN
SE
RB
UI
31


CPU & Disk Requirements 2006
CPU
Disk
MSI2000
PB
Year
Year
LHCb-Tier-2
CMS-Tier-2
ATLAS-Tier-2
ALICE-Tier-2
LHCb-Tier-1
CMS-Tier-1
ATLAS-Tier-1
ALICE-Tier-1
LHCb-CERN
CMS-CERN
ATLAS-CERN
ALICE-CERN
TDR 2005

Data Distribution

- Pre-SC4 April tests CERN → T1s –
  - SC4 target 1.6 GB/s reached – but only for one day
  - Sustained data rate 80% of the target
- But – experiment-driven transfers (ATLAS and CMS) sustained 50% of the SC4 target under *much more realistic conditions*
- CMS transferred a steady 1 PByte/month between Tier-1s & Tier-2s during a 90 day period
- ATLAS distributed 1.25 PBytes from CERN during a 6-week period





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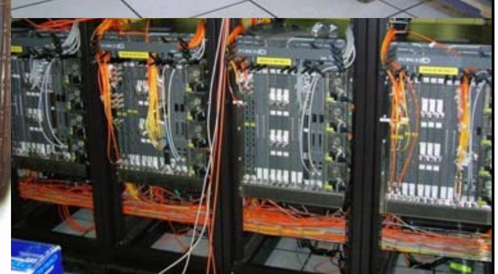
Big Networks



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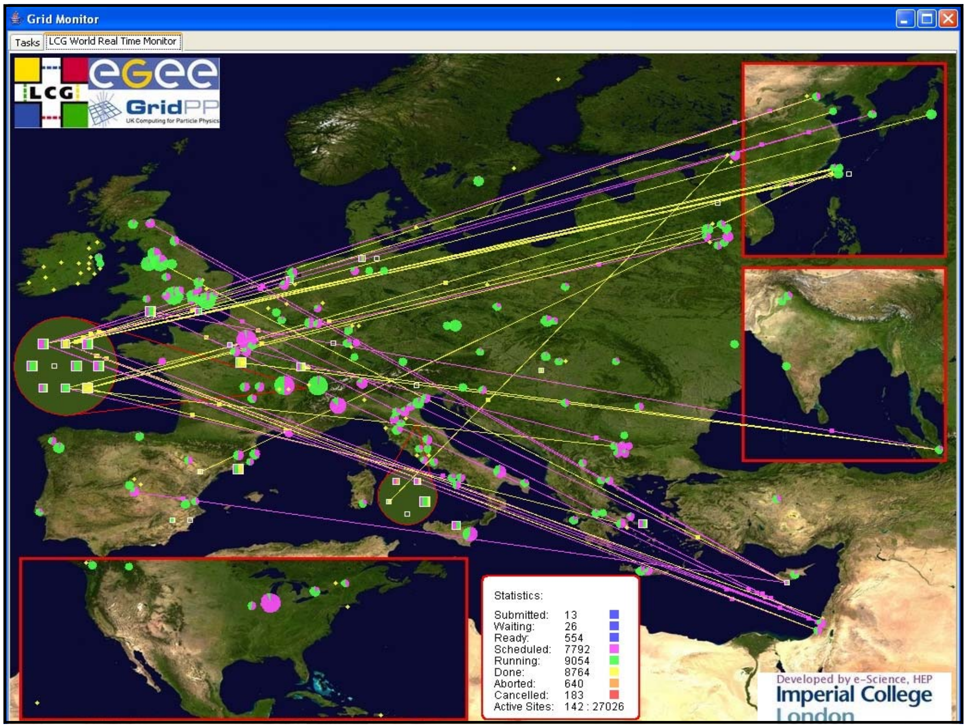
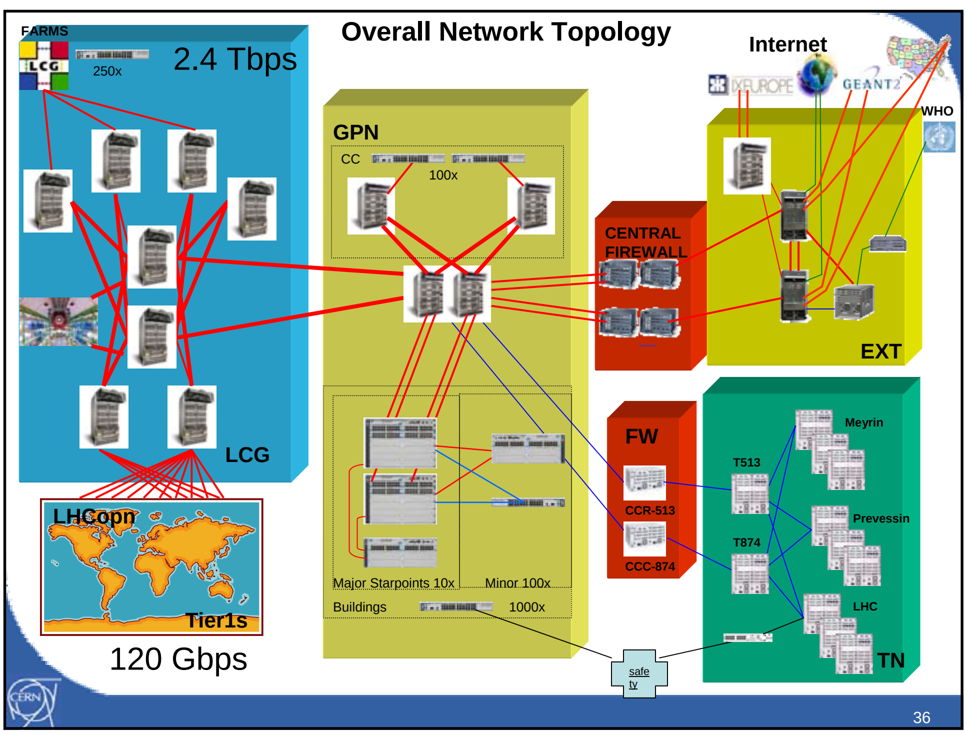

Grid Monitor
Tasks
LCG World Real Time Monitor
LCG
eGee
GridPP
UK Computing for Particle Physics
Statistics:
Submitted: 13
Waiting: 26
Ready: 554
Scheduled: 7792
Running: 9054
Done: 8764
Aborted: 640
Cancelled: 183
Active Sites: 142 : 27026
Developed by e-Science, HEP
Imperial College
London


Overall Network Topology
FARMS
LCG
250x
2.4 Tbps
LCG
LHCopn
Tier1s
120 Gbps
GPN
CC
100x
Major Starpoints 10x
Minor 100x
Buildings
1000x
Internet
IXEUROPE
GEANT2
WHO
CENTRAL
FIREWALL
EXT
FW
CCR-513
CCC-874
T513
T874
Meyrin
Prevessin
LHC
TN
safe
ty
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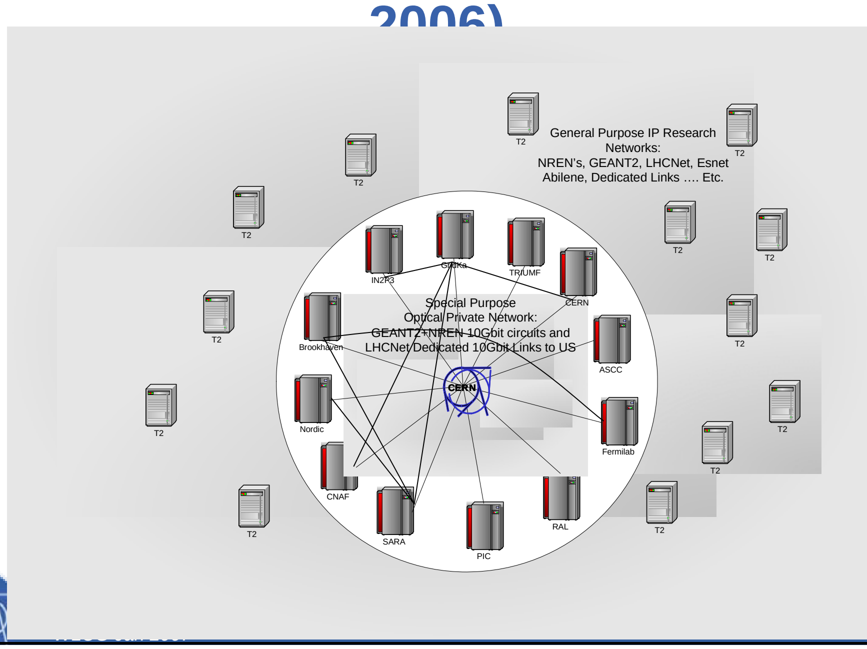
Context

- Wide Area Networking used for all the aspects of the LHC is composed of many different, and separately managed, infrastructures
  - National Research Networks (NRENS) Worldwide (NRENS, I2, ESNet, CANARIE etc.)
  - Interconnection of NRENS in Europe (GEANT-2)
  - Transatlantic Connectivity (USLHCNet)
  - LHC Optical Private Network (LHCOPN)
- No centralised funding, no centralised management.
  - Independent domains of infrastructure and responsibility.

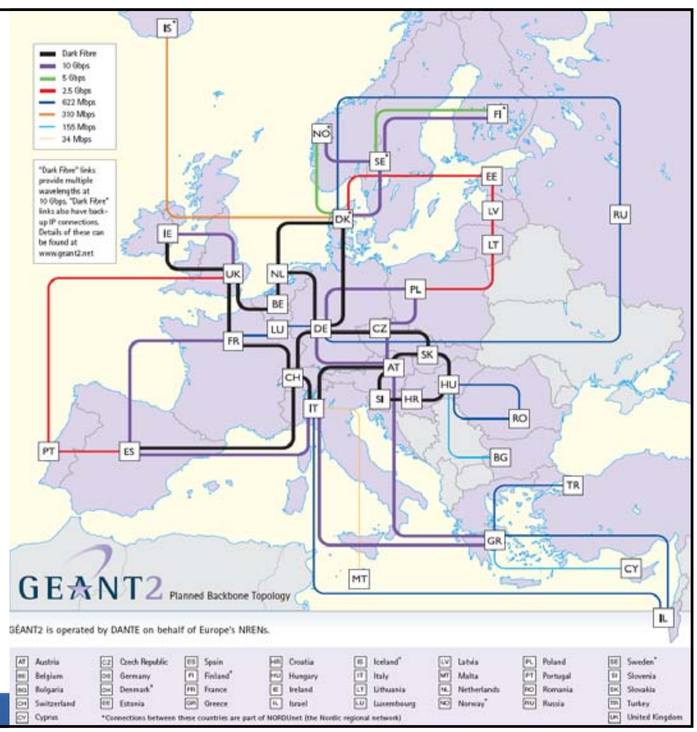
LHCOPN Mission

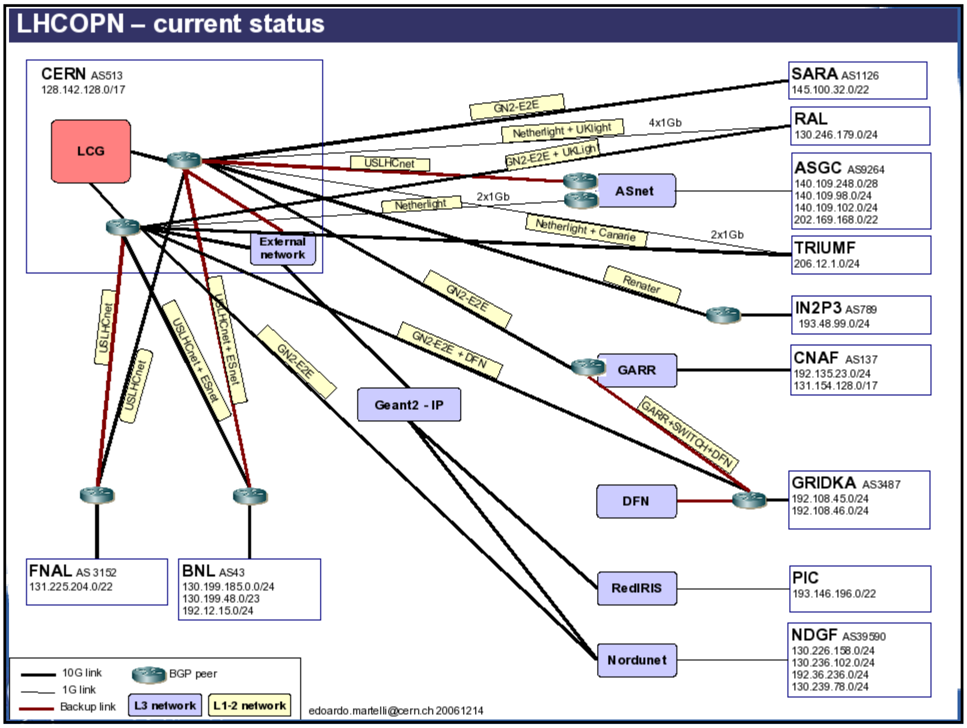
- Started in 2004 to address at least one of the identifiable problems: Getting data from CERN (T0) to the T1's with a predictable performance.
- GEANT-2 Infrastructure was evolved with the LHCOPN requirements in mind.
  - Was important to have this vision in 2004 to have an infrastructure in 2007!
  - LHCOPN was identified as a "considerable achievement" at the last EU review of GEANT
- 10Gbit circuit was/is the unit level of connectivity that matches requirements and motivates development.

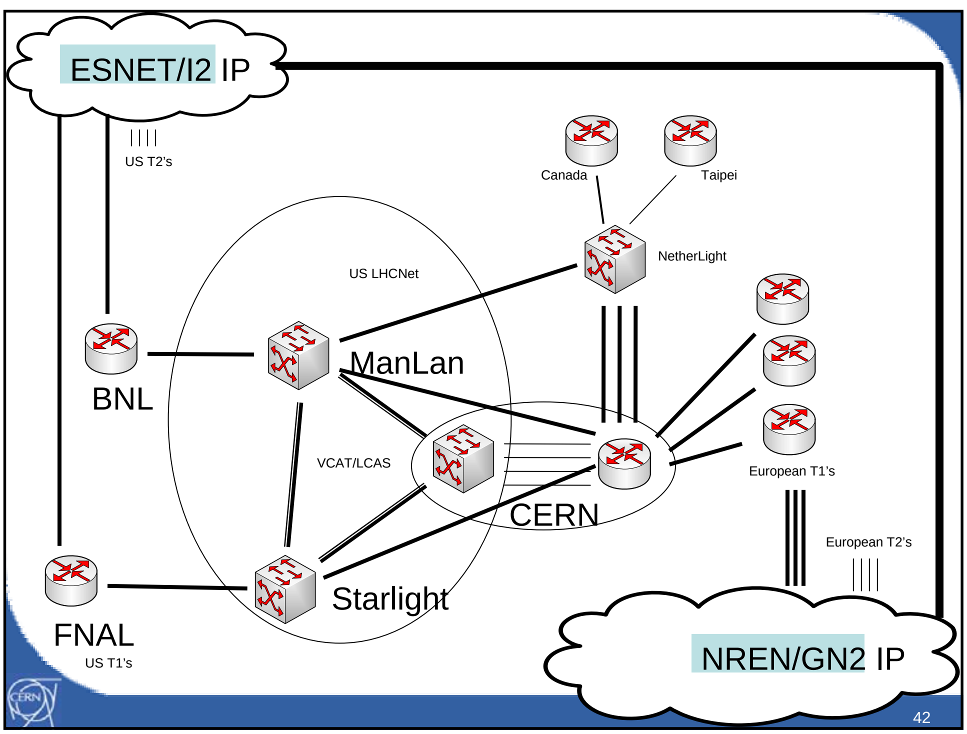
LHCOPN Architecture (2004-2006)



- GEANT2 is an EU project.
- Funding comes from NREN's and the EU
- DANTE is the implementation organisation.
- Policy is decided at the NREN Policy Committee meeting (NREN PC)
- Subgroups work on different aspects. E.g. Global Connectivity Committee (GCC)




LHCOPN – current status
CERN AS513
128.142.128.0/17
LCG
External network
SARA AS1126
145.100.32.0/22
RAL
130.246.179.0/24
ASGC AS9264
140.109.248.0/28
140.109.98.0/24
140.109.102.0/24
202.169.168.0/22
TRIUMF
206.12.1.0/24
IN2P3 AS789
193.48.99.0/24
CNAF AS137
192.135.23.0/24
131.154.128.0/17
GRIDKA AS3487
192.108.45.0/24
192.108.46.0/24
PIC
193.146.196.0/22
NDGF AS39590
130.226.158.0/24
130.236.102.0/24
192.36.236.0/24
130.239.78.0/24
FNAL AS 3152
131.225.204.0/22
BNL AS43
130.199.185.0.0/24
130.199.48.0/23
192.12.15.0/24
ASnet
GARR
DFN
RedIRIS
Nordunet
Geant2 - IP
GN2-E2E
Netherlight + UKlight
GN2-E2E + UKLight
USLHCnet
Netherlight
Netherlight + Canarie
Renater
GN2-E2E + DFN
GARR+SWITCH+DFN
USLHCnet + ESnet
4x1Gb
2x1Gb
10G link
1G link
Backup link
BGP peer
L3 network
L1-2 network
edoardo.martelli@cern.ch 20061214


ESNET/I2 IP
US T2's
Canada
Taipei
NetherLight
US LHCNet
BNL
ManLan
VCAT/LCAS
CERN
European T1's
European T2's
Starlight
FNAL
US T1's
NREN/GN2 IP
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OPN Organisation
"Even simple things are hard"

- LHCOPN Meetings 4 times a year
  - Organised as a sub-activity of the GDB
- Current Working groups
  - Operations (Dante)
  - Monitoring (USA)
  - Routing (CERN)
  - Security (UK)
- Working group evolution
  - Routing will become a long term technical body
  - Monitoring will evolve to become more technical network management including tool selection and deployment
  - Operations will continue to be the problem determination and resolution
  - Security will continue to be an advisory and policy body.

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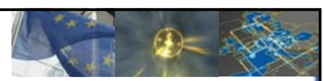
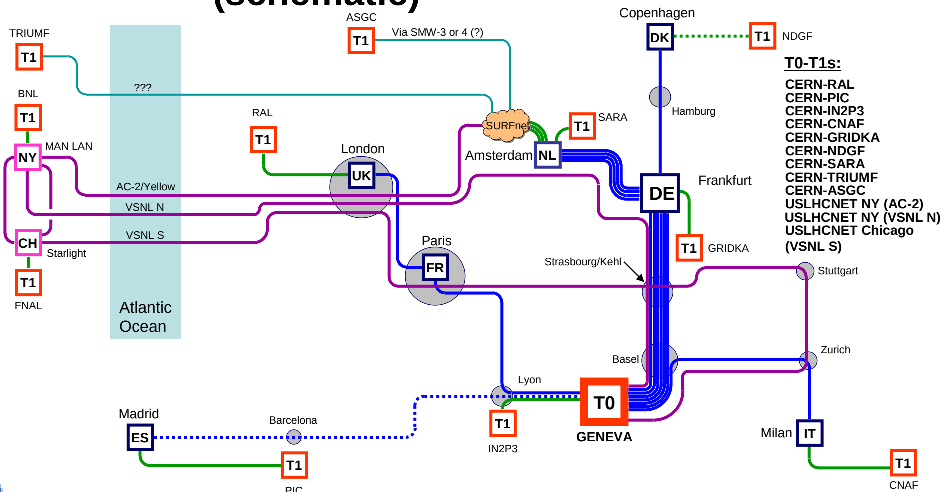


Connect. Communicate. Collaborate

T0-T1 Lambda routing (schematic)



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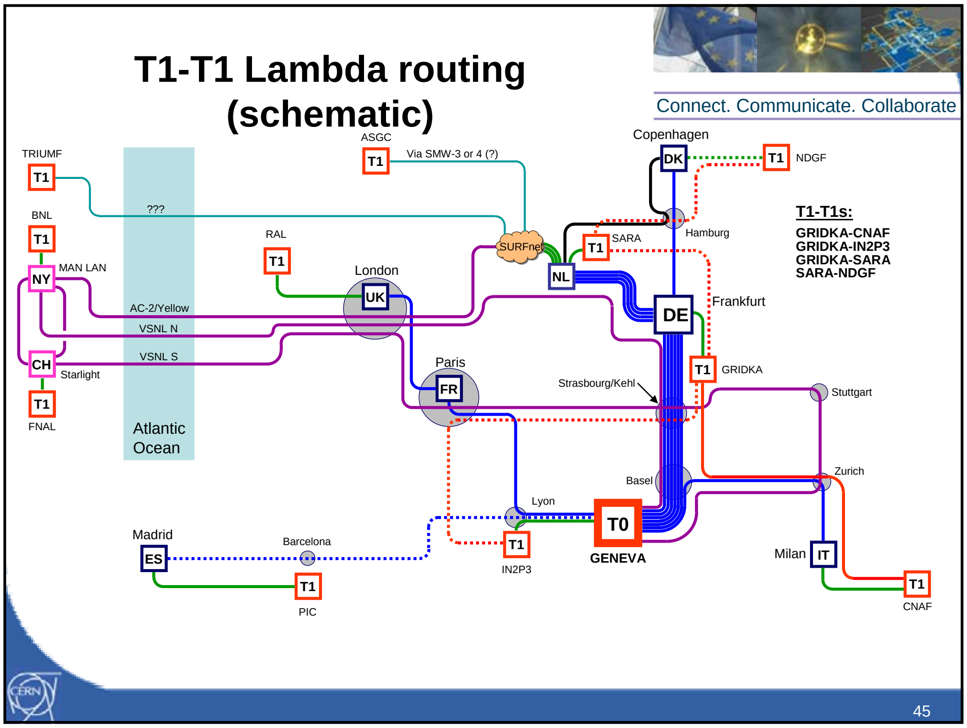
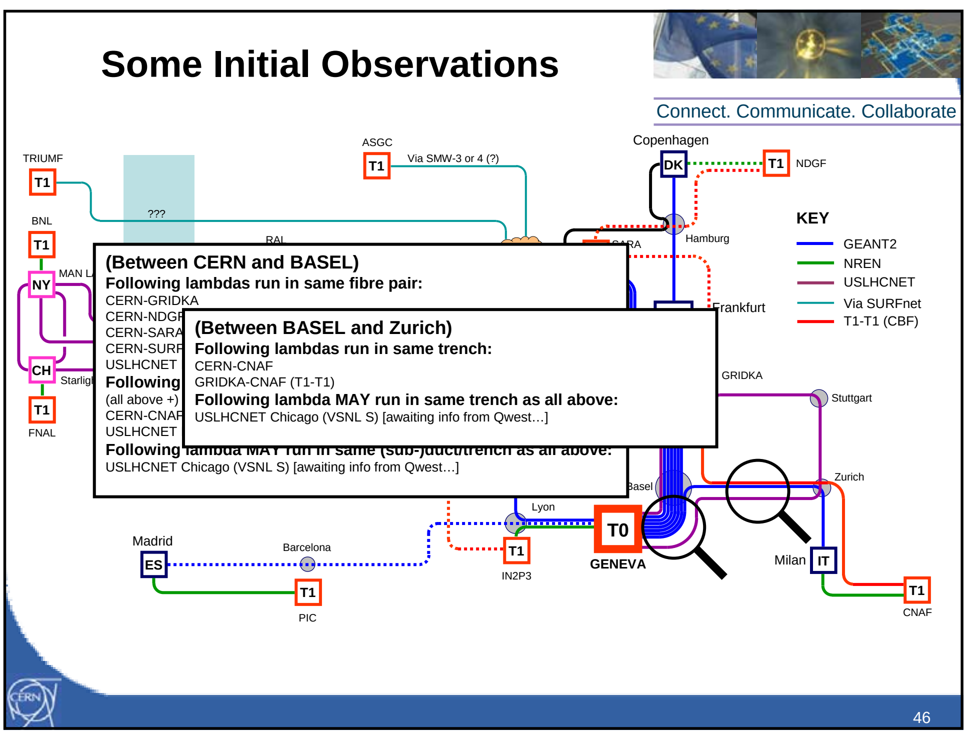

T1-T1 Lambda routing
(schematic)
Connect. Communicate. Collaborate
TRIUMF
T1
BNL
T1
MAN LAN
NY
CH
Starlight
T1
FNAL
???
AC-2/Yellow
VSNL N
VSNL S
Atlantic
Ocean
ASGC
T1
Via SMW-3 or 4 (?)
RAL
T1
London
UK
Paris
FR
SURFnet
T1
SARA
NL
Copenhagen
DK
T1
NDGF
Hamburg
DE
Frankfurt
T1
GRIDKA
Strasbourg/Kehl
Stuttgart
Zurich
Basel
Lyon
T0
GENEVA
T1
IN2P3
Madrid
ES
Barcelona
T1
PIC
Milan
IT
T1
CNAF
T1-T1s:
GRIDKA-CNAF
GRIDKA-IN2P3
GRIDKA-SARA
SARA-NDGF
45


Some Initial Observations
Connect. Communicate. Collaborate
TRIUMF
T1
BNL
T1
NY
CH
T1
FNAL
ASGC
T1
Via SMW-3 or 4 (?)
Copenhagen
DK
T1
NDGF
Hamburg
Frankfurt
GRIDKA
Stuttgart
Zurich
Lyon
T0
GENEVA
T1
IN2P3
Madrid
ES
Barcelona
T1
PIC
Milan
IT
T1
CNAF
KEY
GEANT2
NREN
USLHCNET
Via SURFnet
T1-T1 (CBF)
(Between CERN and BASEL)
Following lambdas run in same fibre pair:
CERN-GRIDKA
CERN-NDGF
CERN-SARA
CERN-SURF
USLHCNET
Following
(all above +)
CERN-CNAF
USLHCNET
Following lambda MAY run in same (sub-)duct/trench as all above:
USLHCNET Chicago (VSNL S) [awaiting info from Qwest…]
(Between BASEL and Zurich)
Following lambdas run in same trench:
CERN-CNAF
GRIDKA-CNAF (T1-T1)
Following lambda MAY run in same trench as all above:
USLHCNET Chicago (VSNL S) [awaiting info from Qwest…]
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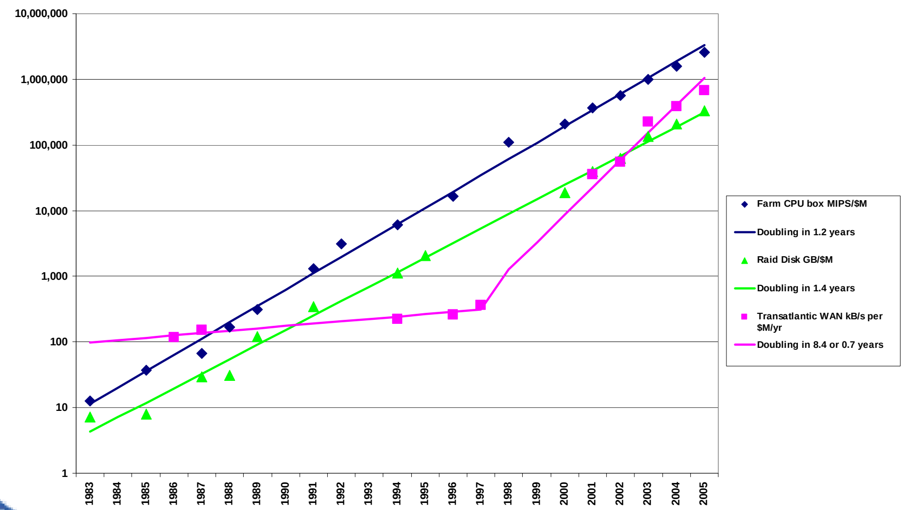
CPU, Disk and Network History

From Richard Mount - SLAC



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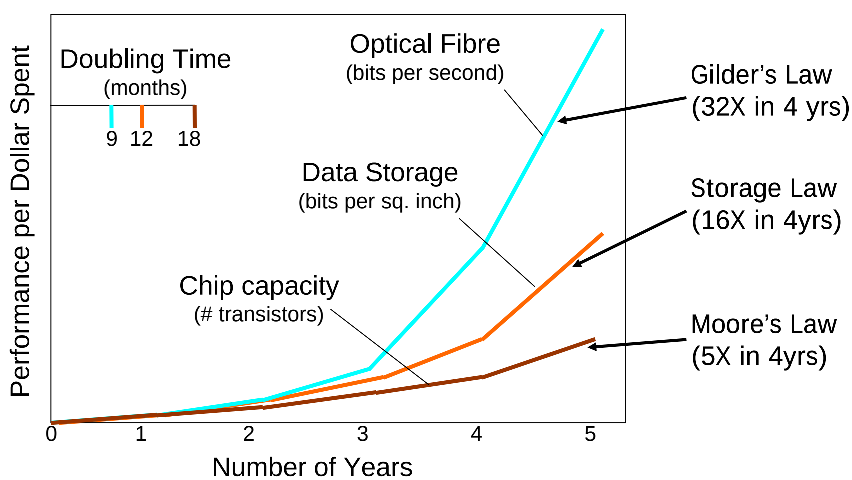
Exponential Growth



Triumph of Light – *Scientific American*. George Stix, January 2001

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Moving Forward

- Hybrid infrastructures are being provided by many R&E networks now.
  - The next generation are networks and not only point-point connections.
  - "Bandwidth on demand" is a concept that is hard to apply out to the edge but may have a significant role in the core of specialised infrastructures.
- Availability of affordable capacity to end users is a key business enabler.
  - New emerging business models (e.g. centralised service delivery)

The emergence of the globalisation of innovation

Globalisation of Innovation

1. Select project sites based on the unique capabilities they will bring to the project rather than resource capability.
2. Allow sites to work together on small projects to build trust and familiarity before launching a large global project
3. Involve all sites in the pre project phase to ensure everyone has a shared vision of what the project will deliver, when and by whom.
4. Project managers should be 'over-informed'. By knowing everything that is happening, they can detect and defuse potential problems before they become serious.
5. Project sites should share common tools, processes and reporting structures.
6. Provide project teams with a wide range of communication tools and channels, including site visits and secondments.

From World Business March 2007

•T1 Sites provide long term data storage

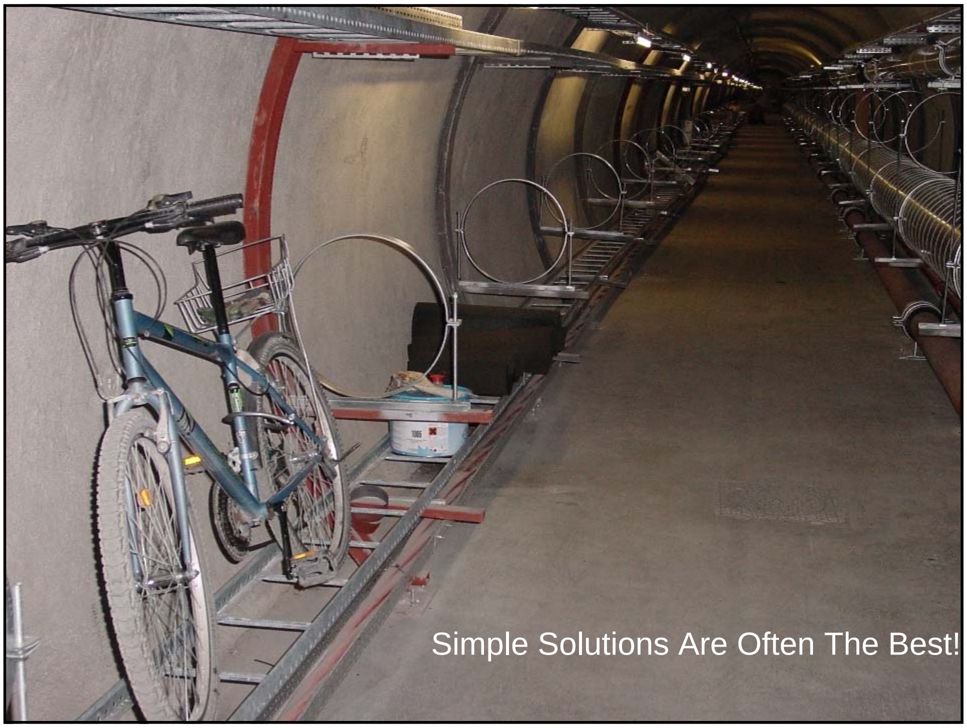
•Grid developments are distributed

•Experiment collaborations
•Grid Development
•HEP Community

•Intensive outreach and dissemination

•Not always so well done!

•Many workshops and site visits



Big Questions?