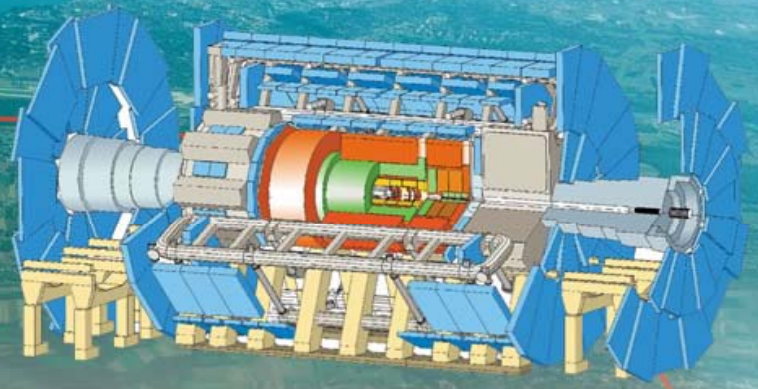
Lecture 1

# Computing for HEP experiments

# Eksperyment ATLAS
# na Wielkim Koliderze Hadronowym



***Czyli Wielka Przygoda z Fizyką i nie tylko……***

# LHC a brief history

The most ambitious project in high-energy physics ever, and one of the most ambitious in science more generally

1983 : W±/Z detected at SPS proton-antiproton collider
Tevatron becomes operational

**1984 : First studies for a high-energy pp collider in the LEP tunnel**

1989 : Start of SLC and LEP e+e- colliders

1993 : SSC is cancelled

**1994 : LHC approved by the CERN Council**

1995 : Top-quark discovery at the Tevatron

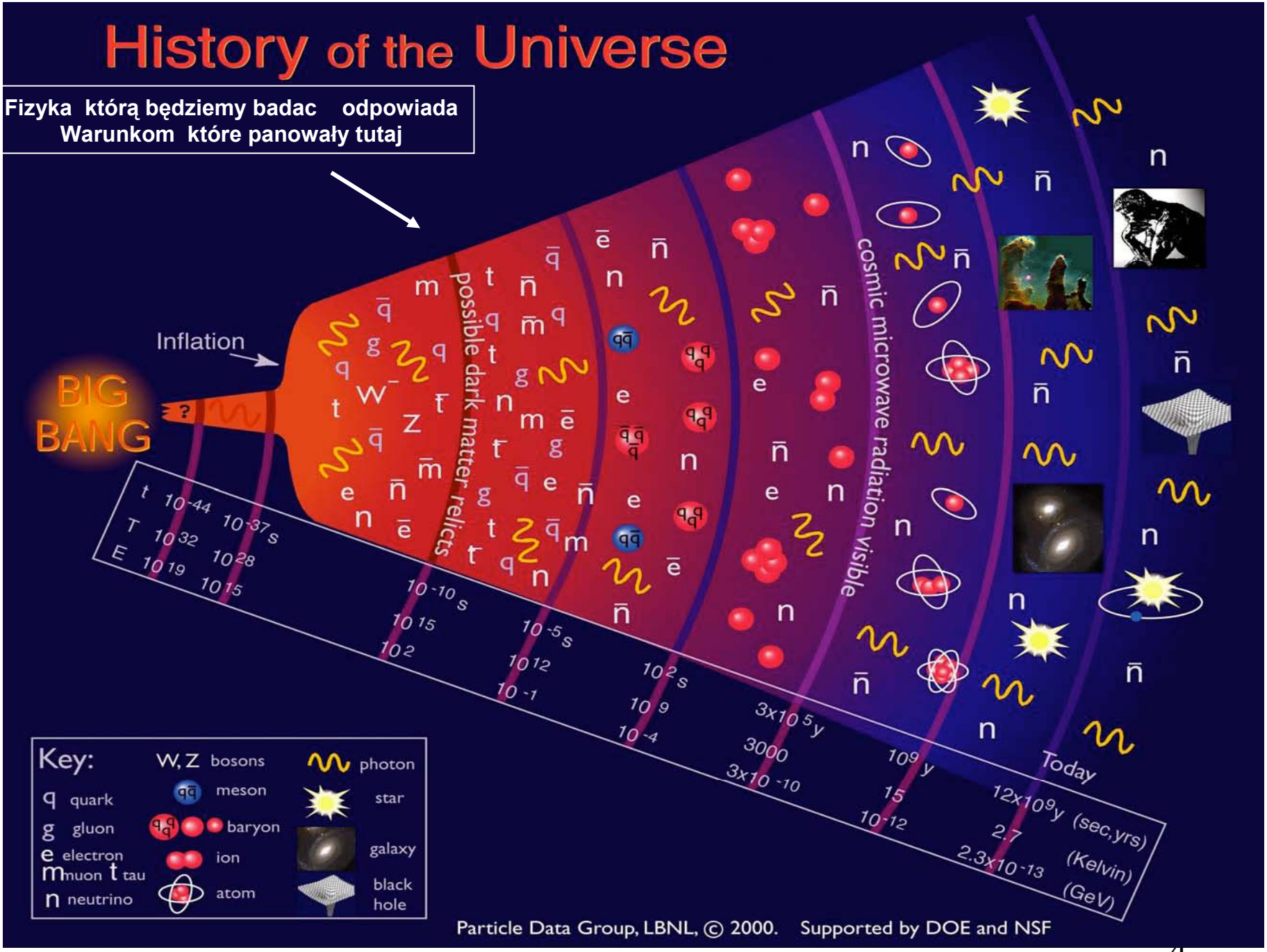
**1996 : Construction of LHC machine and experiments start**

2000 : End of LEP2

**2003 : Start of the accelerator and experiments installatio**

**Summer 2008: start of the operation**

A 40-year project !!


History of the Universe
Fizyka którą będziemy badac odpowiada
Warunkom które panowały tutaj
BIG BANG
Inflation
possible dark matter relicts
cosmic microwave radiation visible
Today
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

## ***Several open questions and mysteries ….***

What is the origin of the particle masses ?

What is the nature of the Universe dark matter ?

What is the origin of the Universe
matter-antimatter asymmetry ?

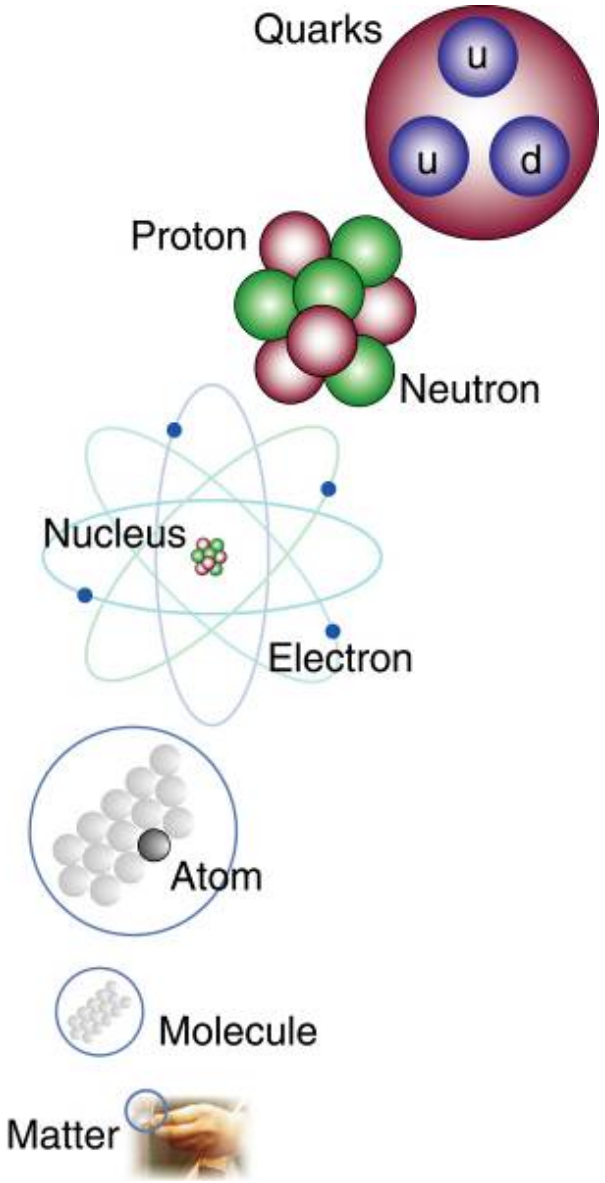
What are the constituents of the Universe
primordial plasma ~10 μs after the Big Bang ?

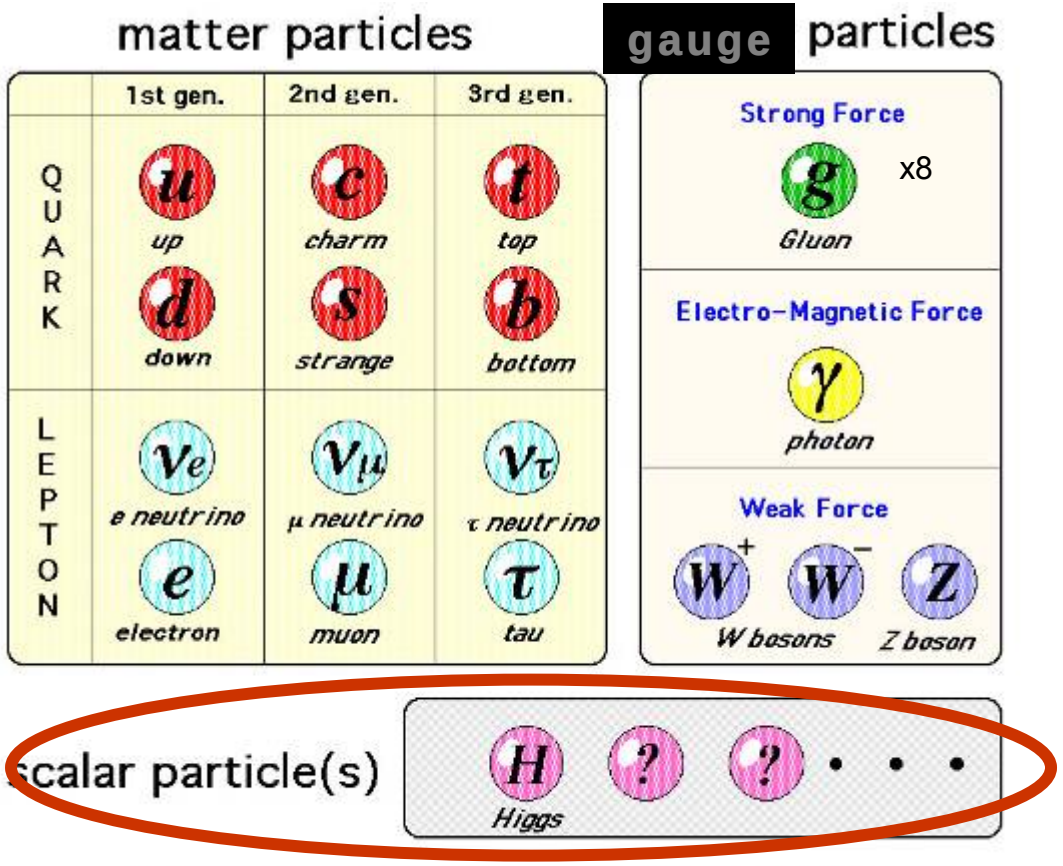
What happened in the first instants of the Universe
life ($10^{-10}$ s after the Big Bang) ?

Etc. etc.

**The LHC will help solve these and other mysteries …**

# The study of elementary particles and fields and their interactions

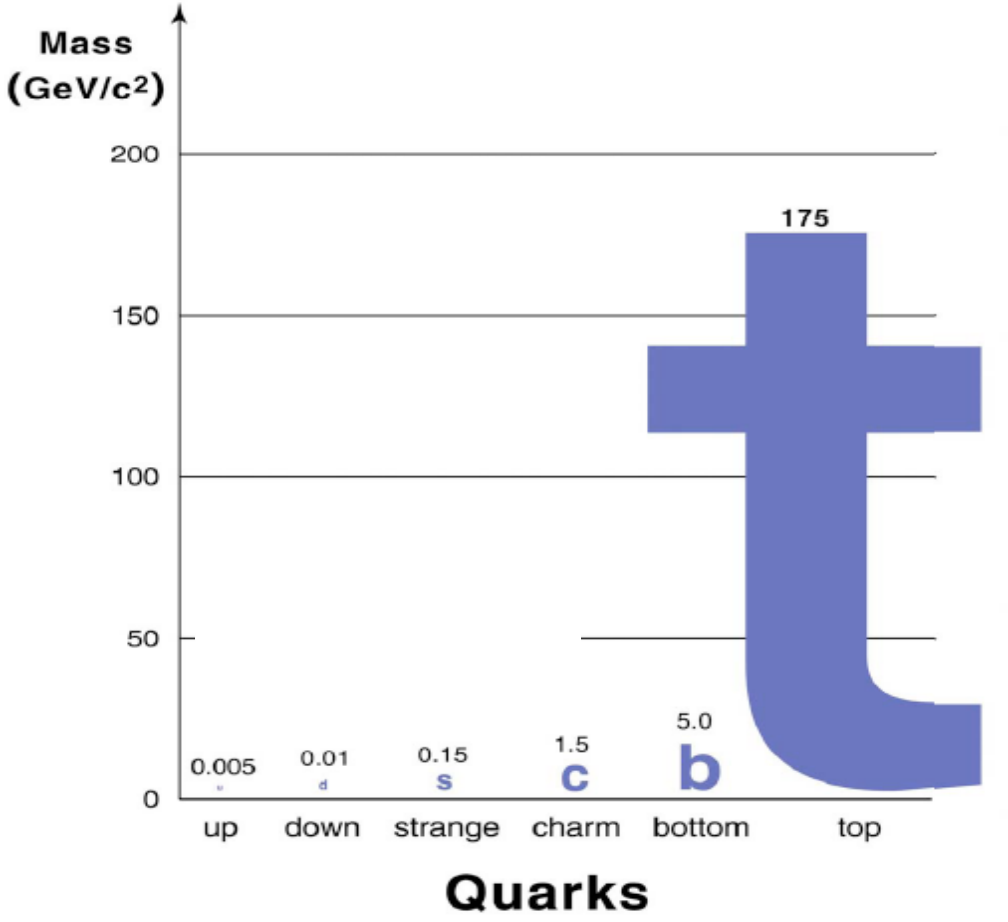


***A most basic question is why particles (and matter) have masses (and so different masses)***

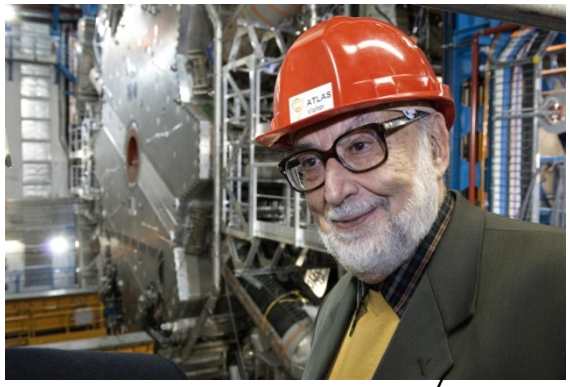
**The mass mystery could be solved with the 'Higgs mechanism' which predicts the existence of a new elementary particle, the 'Higgs' particle (theory 1964, P. Higgs, R. Brout and F. Englert)**

Peter Higgs




**The Higgs (H) particle has been searched for since decades at accelerators, but not yet found…**

**The LHC will have sufficient energy to produce it for sure, if it exists**



Francois Englert

## ***What is the origin of the particle masses ?***

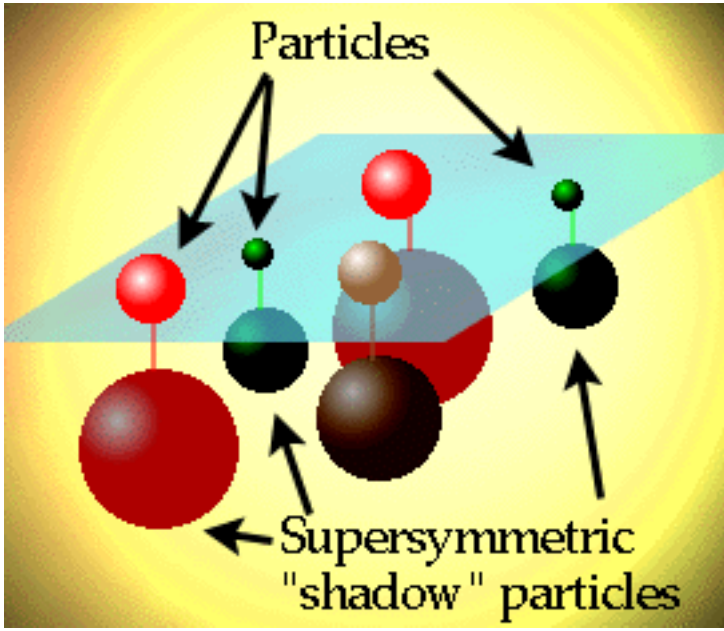
Mass of top quark (heaviest elementary particle observed) ≈ mass of Gold atom
Electron mass is 300 000 times smaller than top-quark mass
WHY ???

The mass mystery could be solved by the "Higgs mechanism", which predicts the existence of a new elementary particle : **the Higgs particle**

This particle has been searched for 20 years at accelerators all over the world and has not been observed yet.
The LHC has sufficient energy/intensity to produce it.

Note: a world without "Higgs" would be a very strange one ! Atoms (and thus all of us) would not have the size they have, the neutron could be lighter than the proton, chemistry may not exist, etc.

# *Supersymmetry (SUSY)*



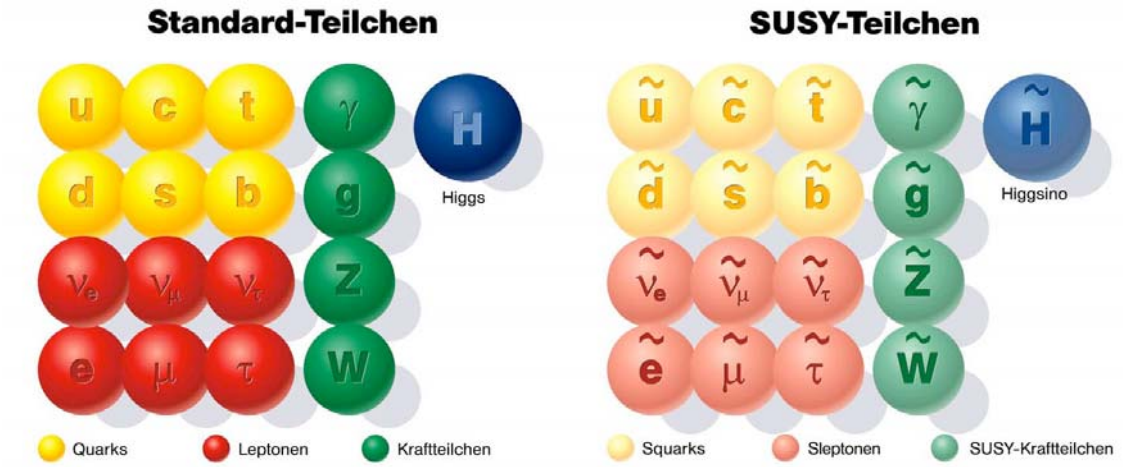

**Establishes a symmetry between fermions (matter) and bosons (forces):**

**- Each particle p with spin s has a SUSY partner p with spin s -1/2**

**- Examples** q (s=1/2) → q (s=0) squark

g (s=1) → g (s=1/2) gluino

**Our known world** **Maybe a new world?**




***Motivation:***

***- Unification (fermions-bosons, matter-forces)***
***- Solves some deep problems of the Standard Model***

# The LHC machine

- pp $\sqrt{s}$ = 14 TeV $L_{design} = 10^{34}$ cm$^{-2}$ s$^{-1}$ (after 2010)

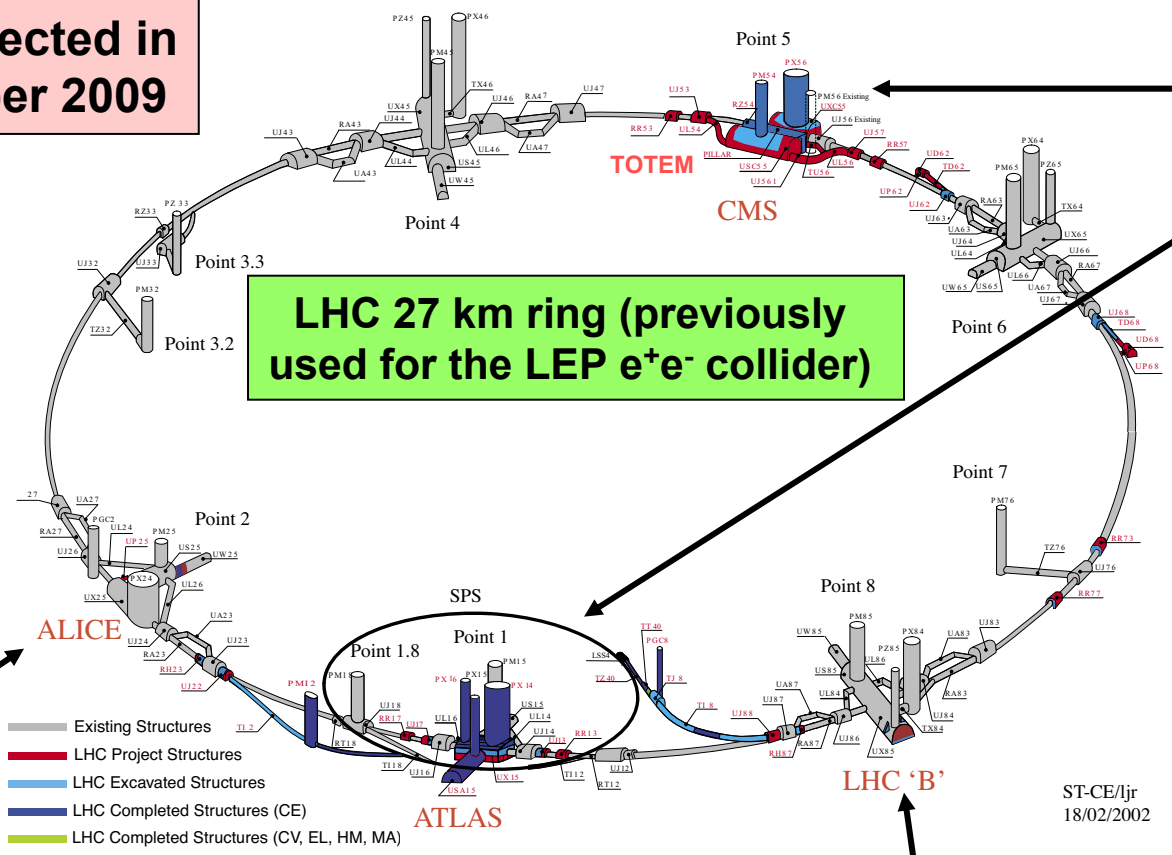
  $L_{initial}$ < few x $10^{33}$ cm$^{-2}$ s$^{-1}$ (before)

**Note: $\sqrt{s}$ is x7 Tevatron, $L_{design}$ is x100 Tevatron**

- Heavy ions (e.g. Pb-Pb at $\sqrt{s}$ ~ 1000 TeV)

**First collisions: now expected in December 2009**

**ATLAS and CMS : pp, general purpose**




**LHC 27 km ring (previously used for the LEP $e^+e^-$ collider)**

**ALICE : ion-ion, p-ion**

**LHCb : pp, B-physics, CP-violation**

**The LHC machine is fully installed and was ready to start operation with single beams on 10th September 2008, but it is now delayed for several months after an incident that happened on 19th September**

# The full LHC accelerator complex

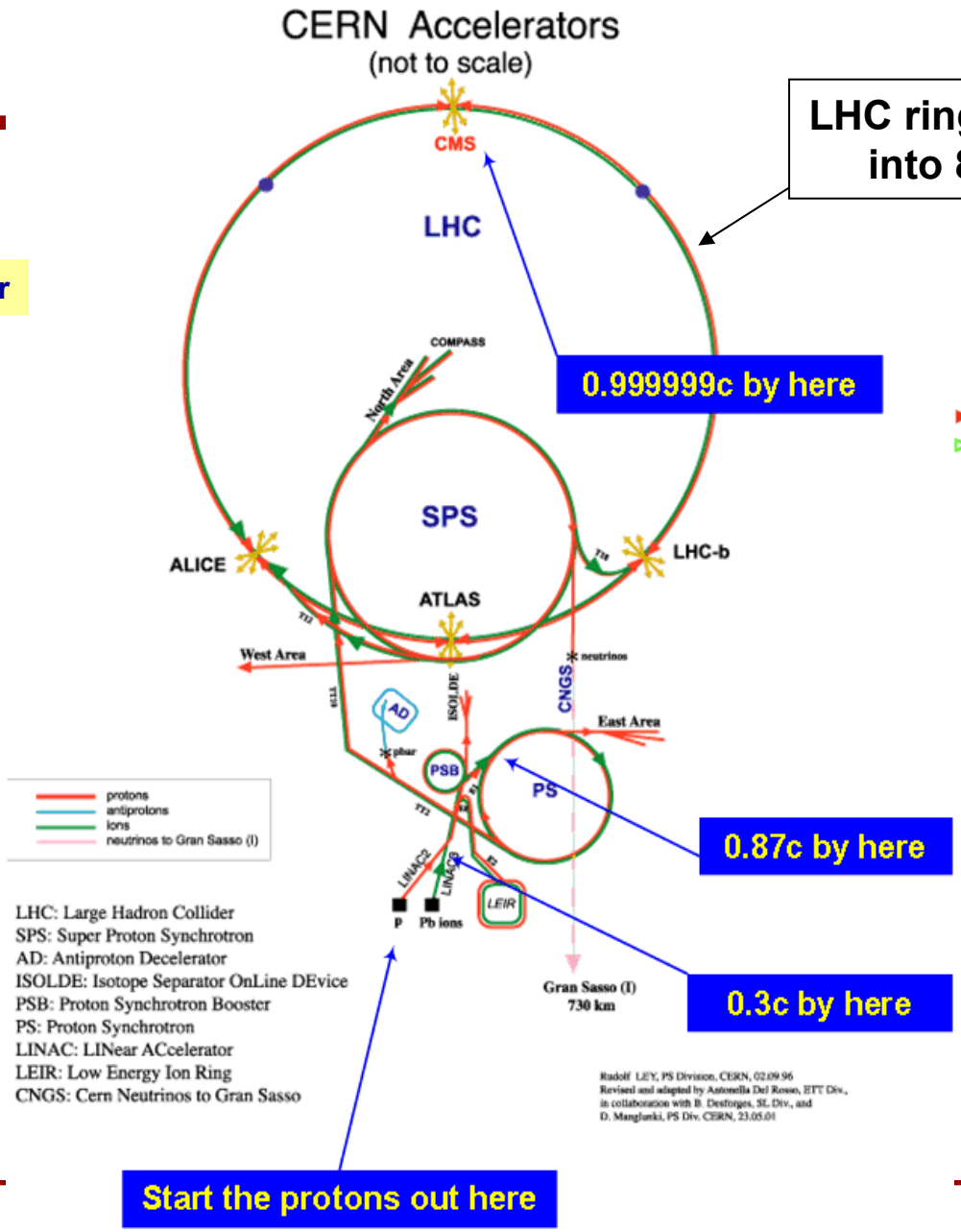
Linac

Booster

PS

SPS

LHC



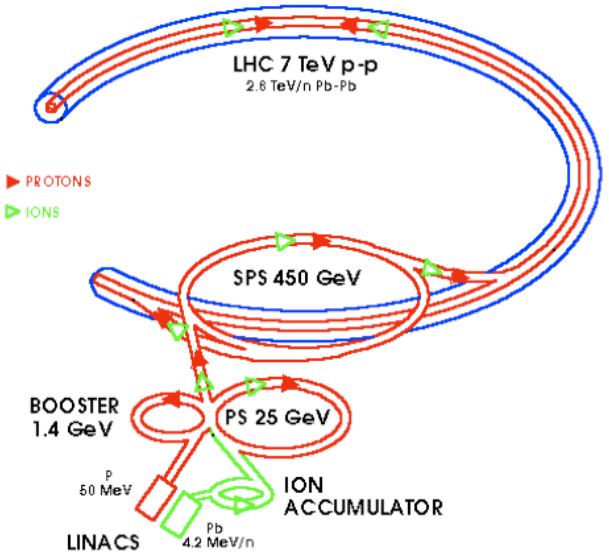

LHC ring is divided into 8 sectors

0.999999c by here

0.87c by here

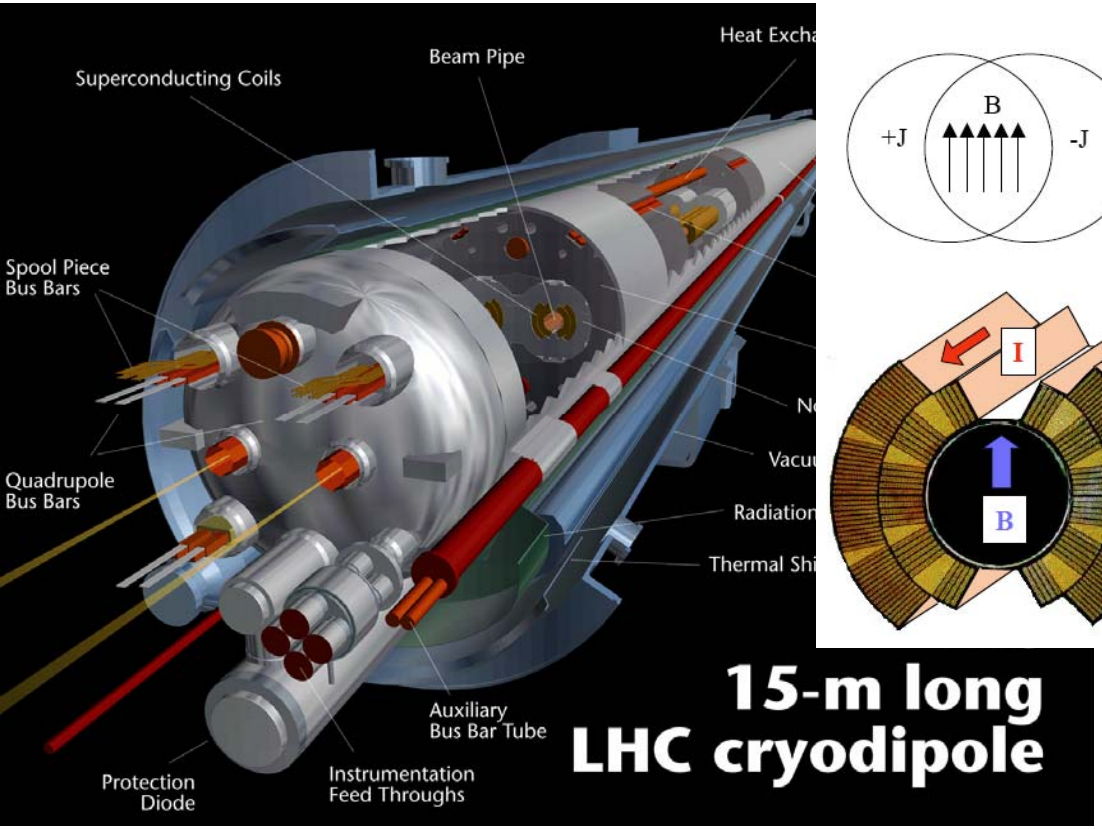
0.3c by here

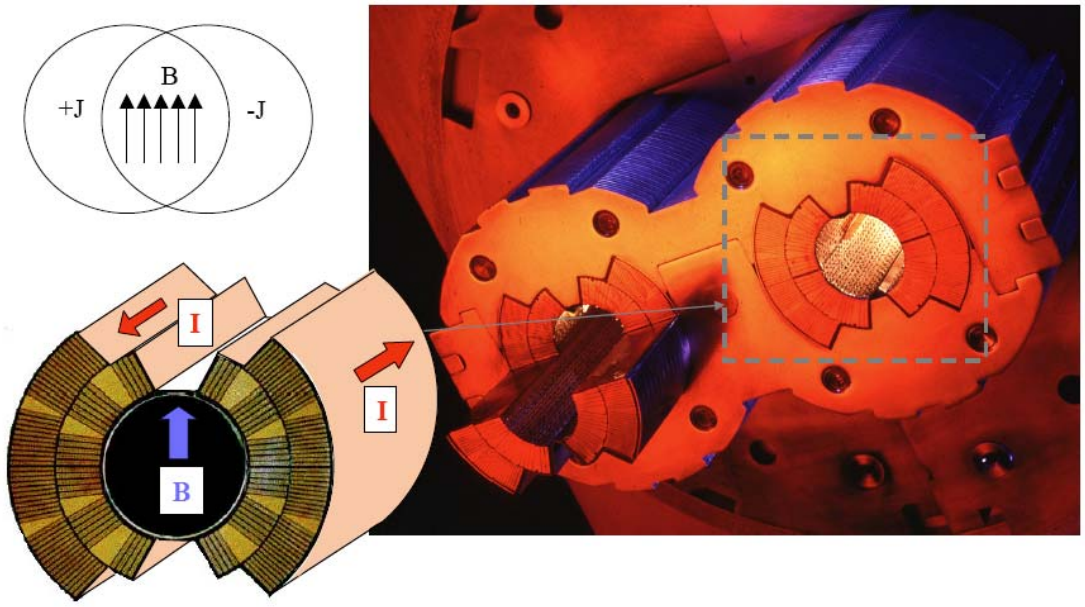
Start the protons out here




> 50 years of CERN history still alive and operational

# LHC Accelerator Challenge: Dipole Magnets




**Magnetic Field for Dipoles**
**p (TeV) = 0.3 B(T) R(km)**

**Coldest Ring in the Universe ?**
1.9 K (CMBR is about 2.7 K)

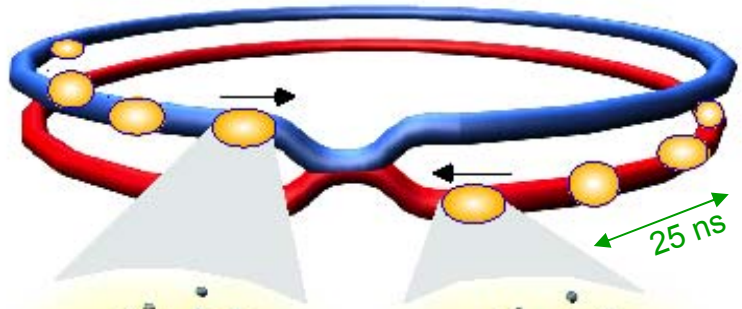
**LHC magnets are cooled with pressurized superfluid helium**

**For p = 7 TeV and R = 4.3 km**
**⇨ B = 8.4 T**
**⇨ Current 12 kA**

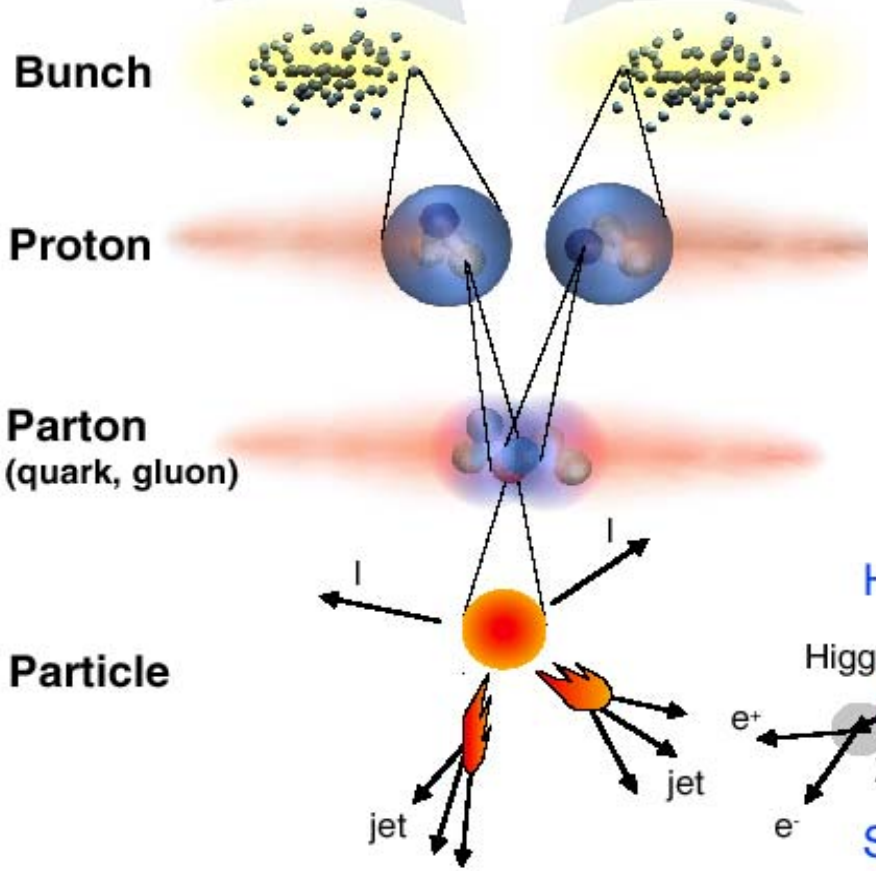
# Descent of the last dipole magnet, 26 April 2007

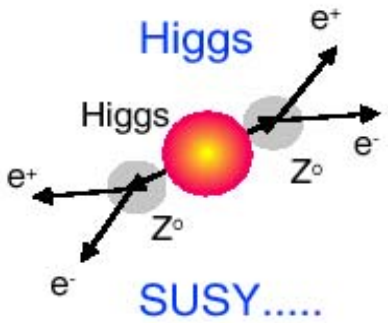
**30’000 km underground transports at a speed of 2 km/h!**

# Collisions at LHC




| | |
|---|---|
| Proton-Proton | 2835 bunch/beam |
| Protons/bunch | $10^{11}$ |
| Beam energy | 7 TeV ($7 \times 10^{12}$ eV) |
| Luminosity | $10^{34}$ cm$^{-2}$ s$^{-1}$ |




In the experiments:

$10^9$ pp interactions per second

~ 1500 particles (p,n, $\pi$) produced in the detectors at each bunch-crossing

**Selection of 1 in**

**10,000,000,000,000**



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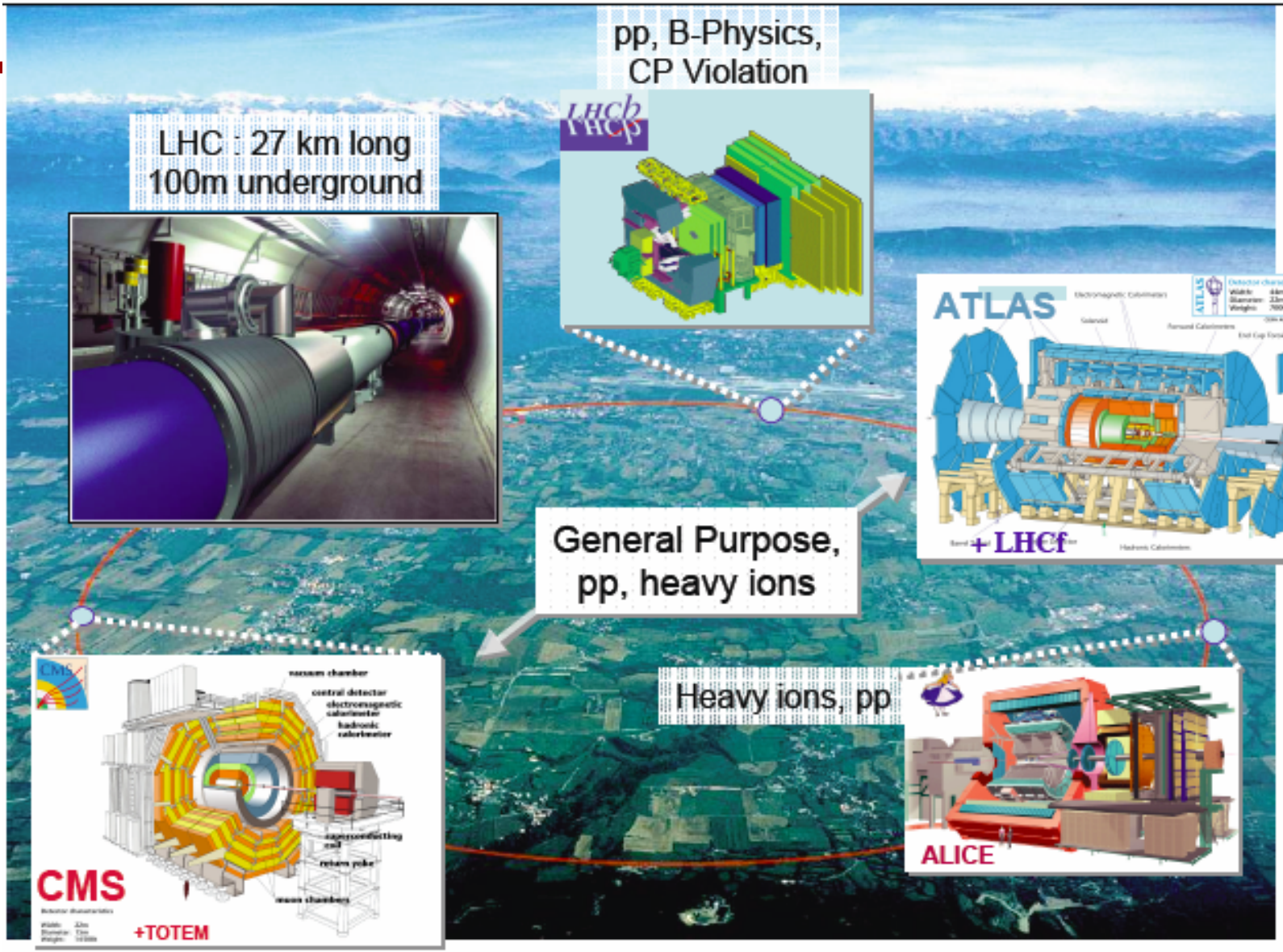
# Large Hadron Collider@CERN



# Detektory eksperymentów fizyki wysokich energii

- **Detektory** pozwalają na obserwację (rejestrację) serii oddziaływań, podjęcie decyzji czy oddziaływanie jest interesujące, identyfikację produkowanych cząstek, pomiar ich energii i pędu.

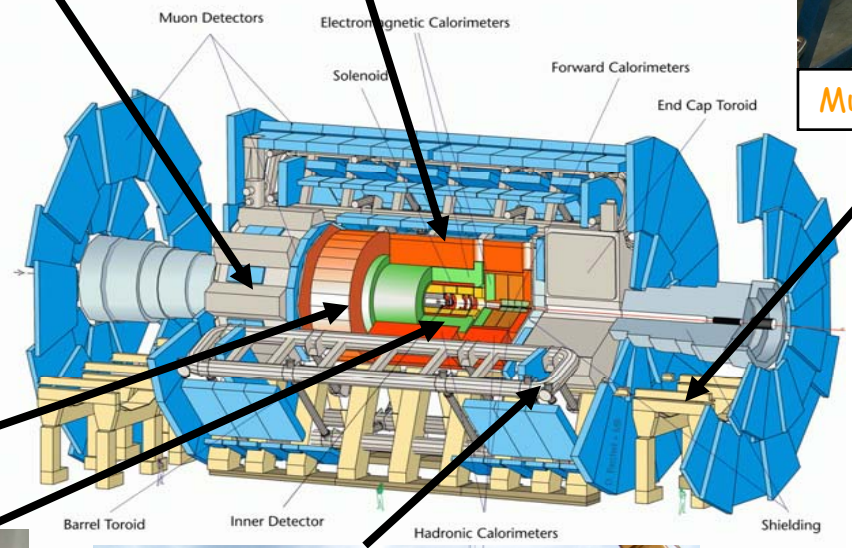
- Detektory dla zderzeń przy wysokich energiach muszą być duże, zbudowane z różnych poddetektorów (każdy dedykowany do rejestracji pewnego określonego typu sygnału). Niektóre poddetektory umieszczone są w polu magnetycznym (aby umożliwić pomiar pędu).

- **Metody pomiarowe** to pomiar absorpcji energii, rekonstrukcja toru na podstawie „śladów” zostawionych w poszczególnych warstwach detektorów, itd. itd...





ATLAS




zdjecia

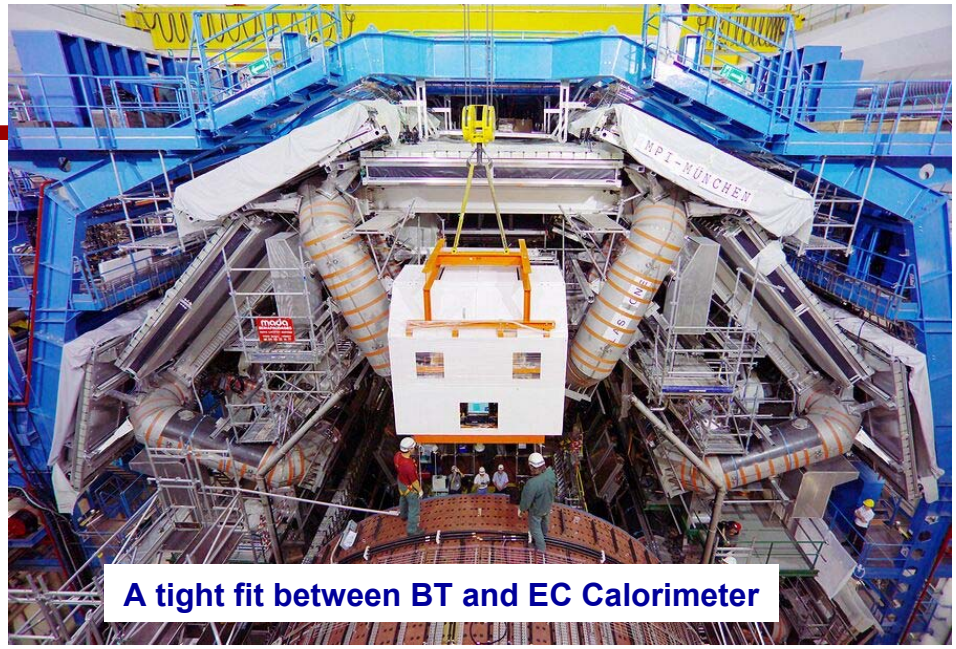
rok 2003



Długość : ~ 40 m
Promień : ~ 10 m
Waga : ~ 7000 ton

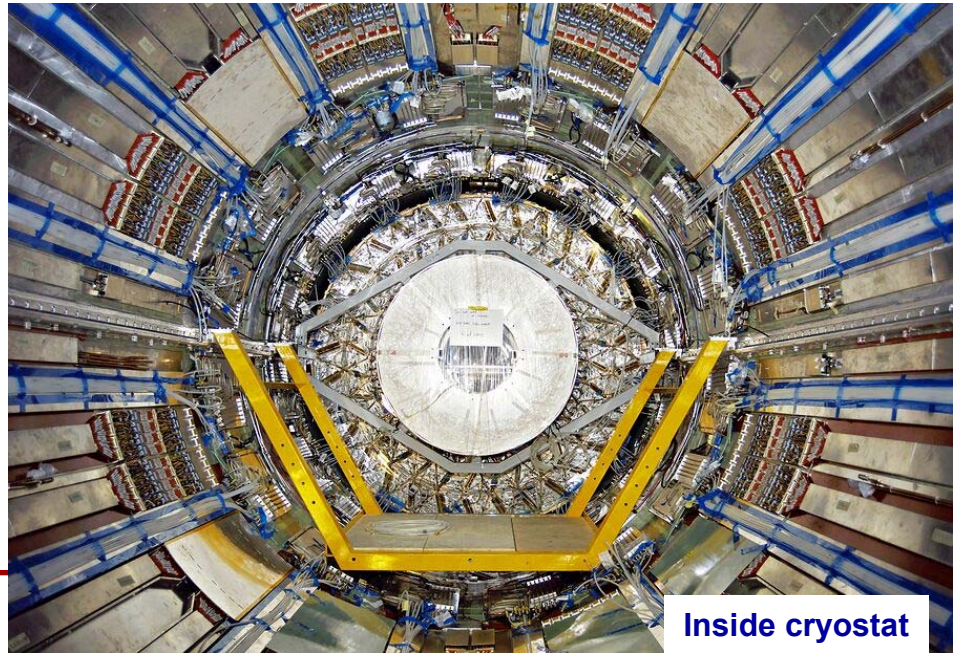
# TRT+SCT barrel travelled to the pit, 24th Aug 2006

Through the parking area



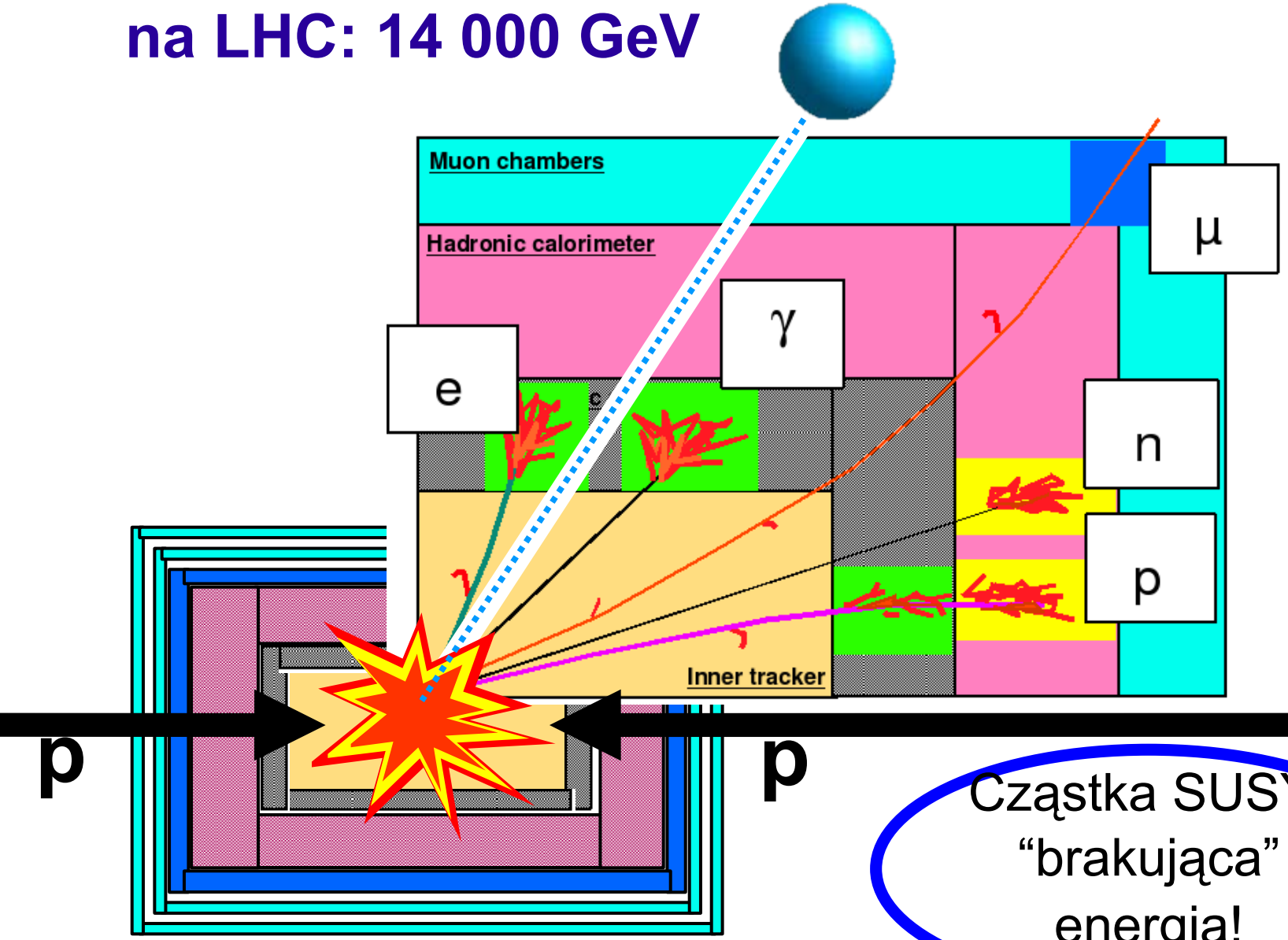

A tight fit between BT and EC Calorimeter

From the trolley to the support rails



Inside cryostat

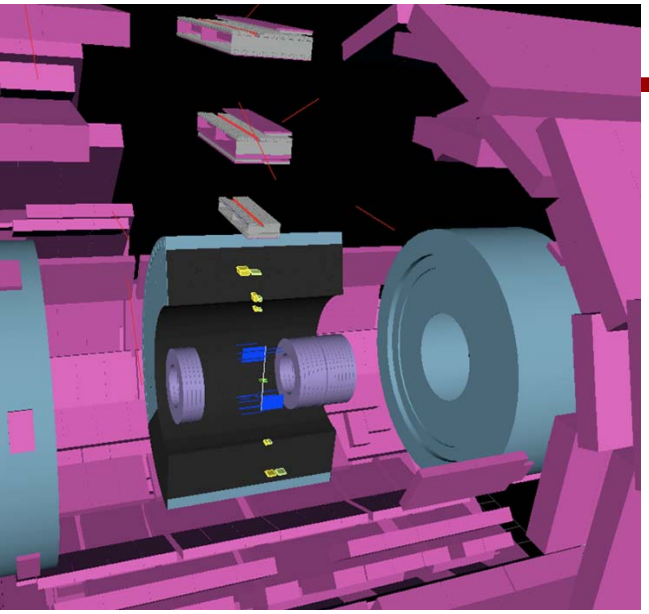
# zderzenie proton-proton na LHC: 14 000 GeV



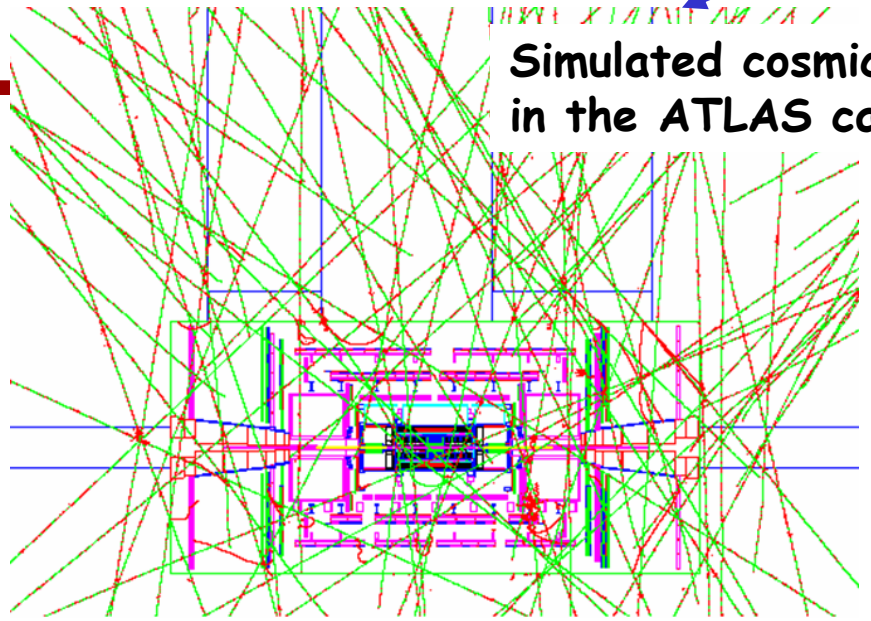

Cząstka SUSY: "brakująca" energia!

# Towards data-taking: Cosmic Muons

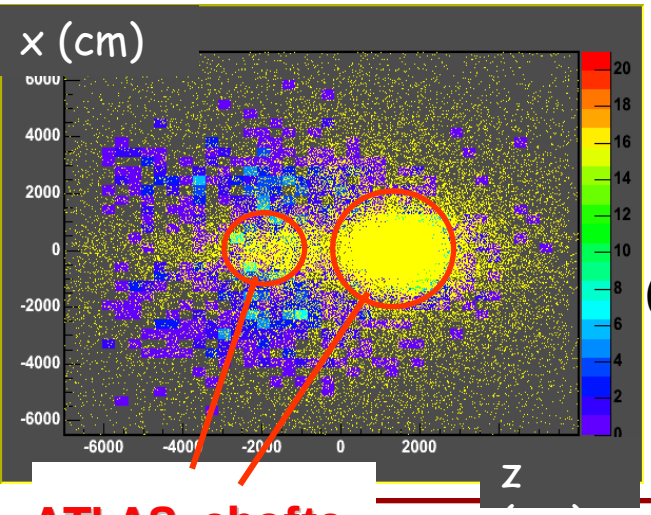
10 ms



Real Cosmic Event



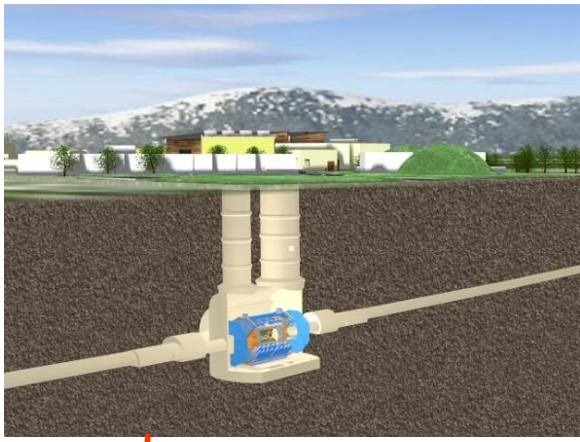
Simulated cosmics flux in the ATLAS cavern




ATLAS shafts

Muon impact points extrapolated to surface as measured by Muon Trigger chambers (RPC)

(Calorimeter trigger also available)

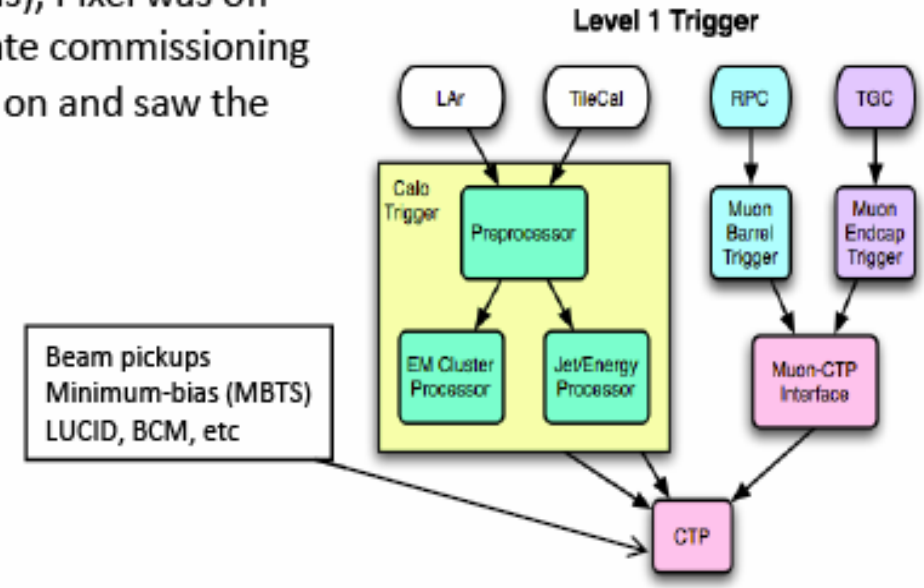


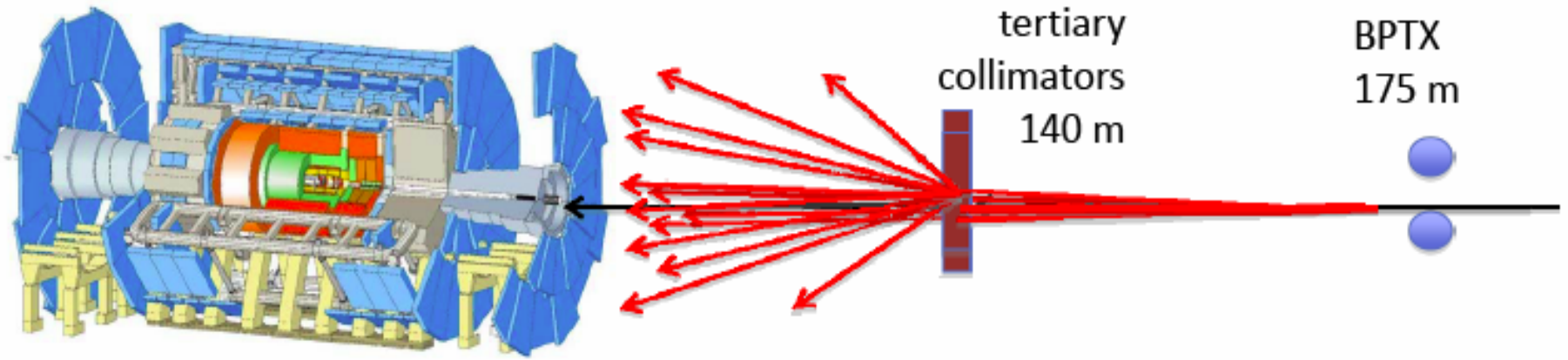
Rate ~100 m below ground:
~ O(15 Hz) crossing Inner Detector

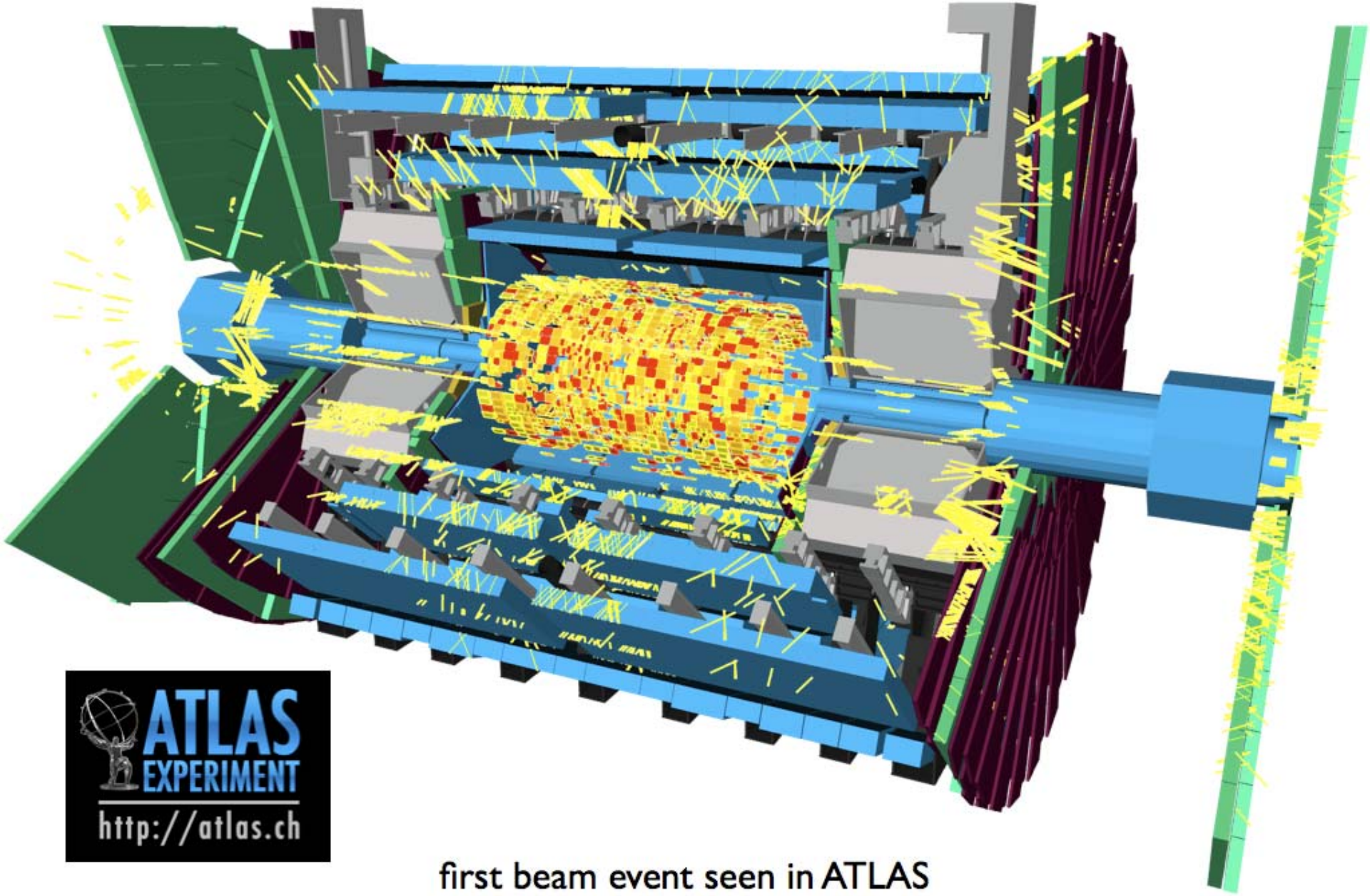
# Detector and trigger for first LHC beams

ATLAS was "on" on Sep. 10, although many components operated with reduced HV (e.g.: SCT/barrel at very low bias), Pixel was off (safety and late commissioning), CSC were off (late commissioning or read-out), the luminosity detector LUCID was on and saw the beam. The three toroid systems were on.

Level-1 triggers had been set-up using cosmic rays.
In addition, we had ready a beam-pick-up trigger (BPTX), and a dedicated scintillator hodoscope trigger (MBTS), from a device installed against the front face of the end-cap calorimeters.






first beam event seen in ATLAS

10.09.2008

# Jak w ciągu 1 sekundy wybrać 1 spośród $10^7$ ?

LHC (Large Hadron Collider) będzie zderzał przeciwbieżne wiązki protonów z energią środka masy 14 TeV. (Ta energia wystarczałaby na produkcję 15 000 protonów!)

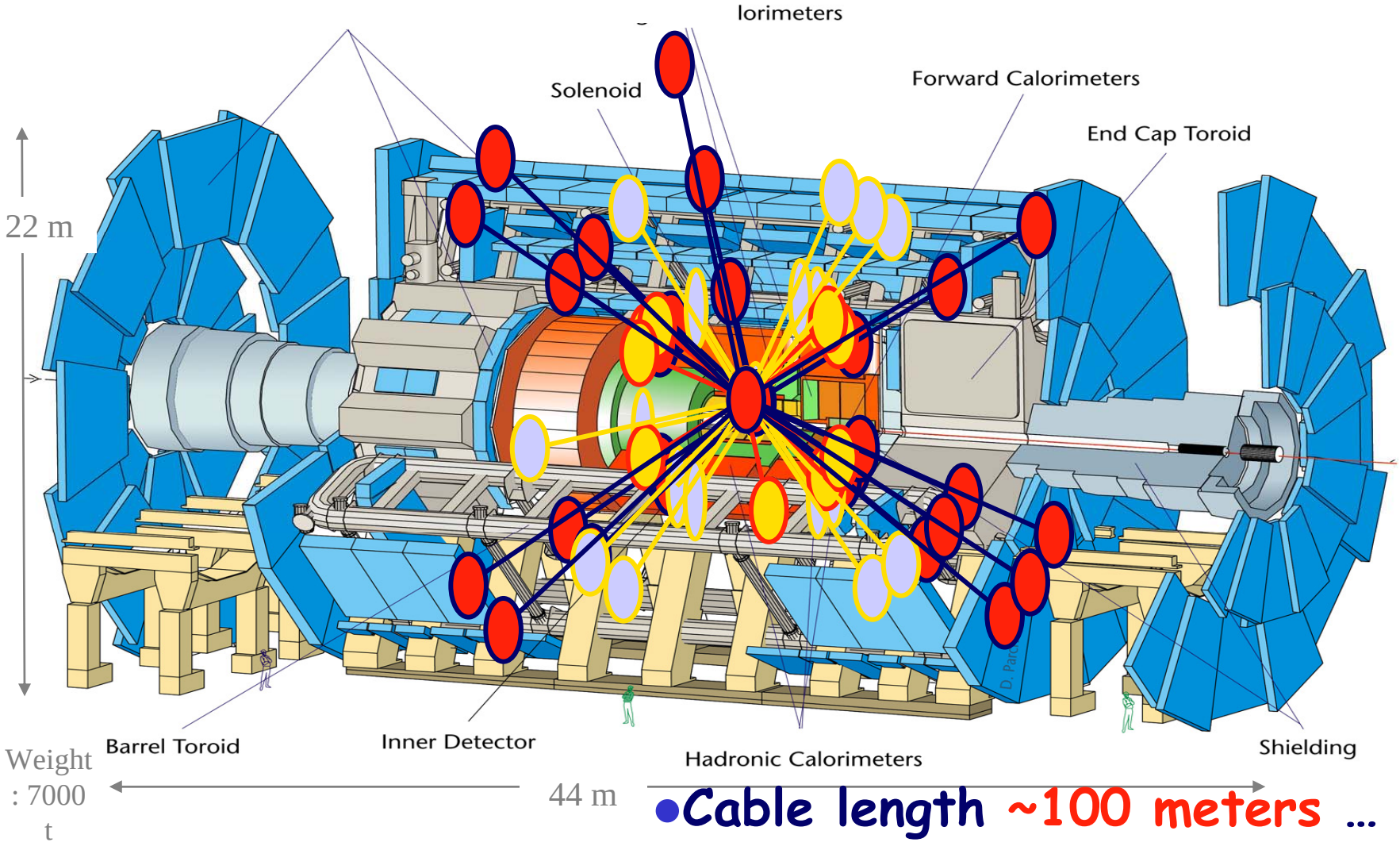
Wiązki protonów będą oddziaływały co 25 ns wewnątrz ogromnego detektora wypełnionego milionami kanałów odczytu elektronicznego.

Każde zderzenie wiązek to ~ 23 pp oddziaływań, każde produkujące strugę (~ $10^3$) wychodzących cząstek.

Odstęp pomiędzy kolejnymi zderzeniami wiązek to tylko **25ns**

- 25ns to odległość 8m dla cząstek poruszających się z prędkością światła (to jest mniej niż promień detektora)
- Na raz w detektorze „fale cząstek” od 3 kolejnych zderzeń
- Tylko niewielka cześć tych oddziaływań może zostać zapisana „na taśmie” . System który podejmuje decyzje nazywa się TRIGGER.

- Interactions every 25 ns …
  - In 25 ns particles travel 7.5 m




- Cable length ~100 meters …
  - In 25 ns signals travel 5 m

# Jak w ciągu 1 sekundy wybrać 1 spośród $10^7$ ?

Co to znaczy niewielka część?

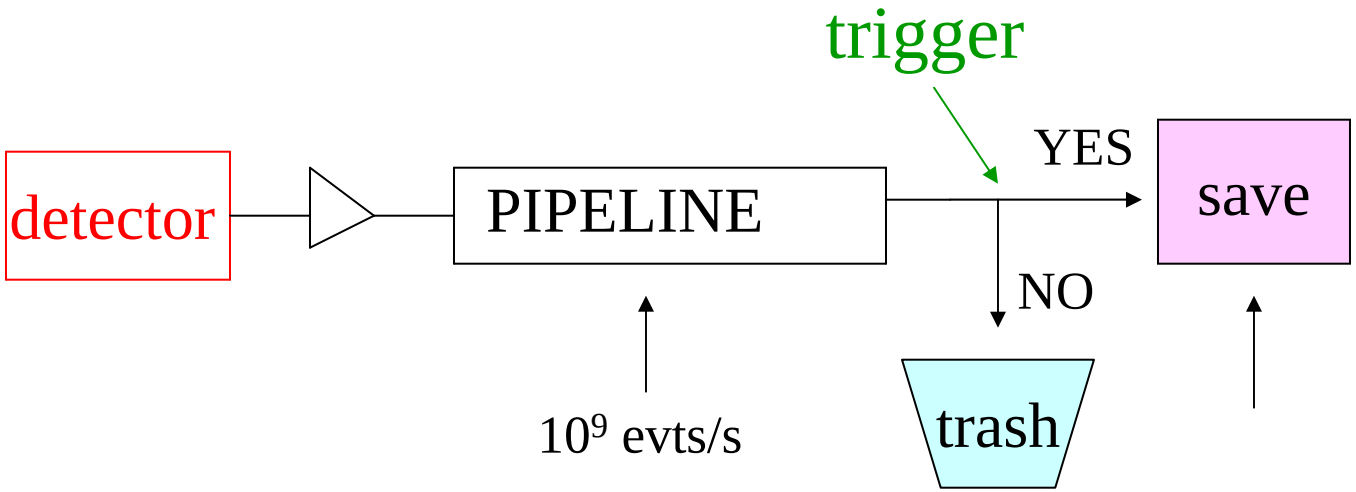
- 25ns $\Rightarrow$ 40 x $10^6$/s zderzeń
- 23 oddział/zderzenie $\Rightarrow$ 23 x 40 x 106 /sek ~ $10^9$ /sek oddział
- możemy zarejestrować tylko ~ 100/sek zderzeń $\Rightarrow$ **redukcja $10^7$**

Ile informacji trzeba przetworzyć?

trigger elektron: 8bit x 40MHz x 7500 ~ 3 000 Gbit/sek

Czy można podjąć decyzje w 25ns?

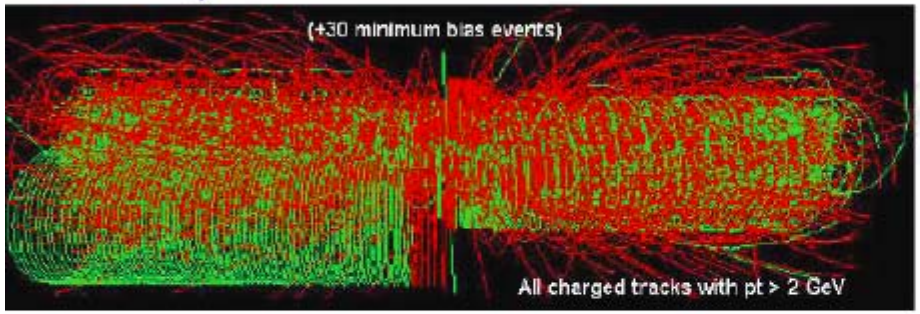
nie można: czas rejestracji w detektorze dłuższy (ok. 50 x 25ns)
informacje trzeba wysłać do procesora (ok. 15 x 25ns)
informacje trzeba przetworzyć (ok. 10 x 25ns)



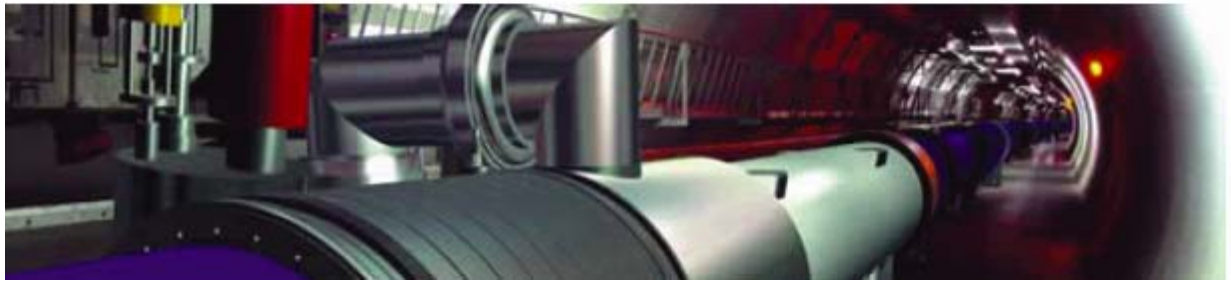
CERN openlab

# LHC DATA

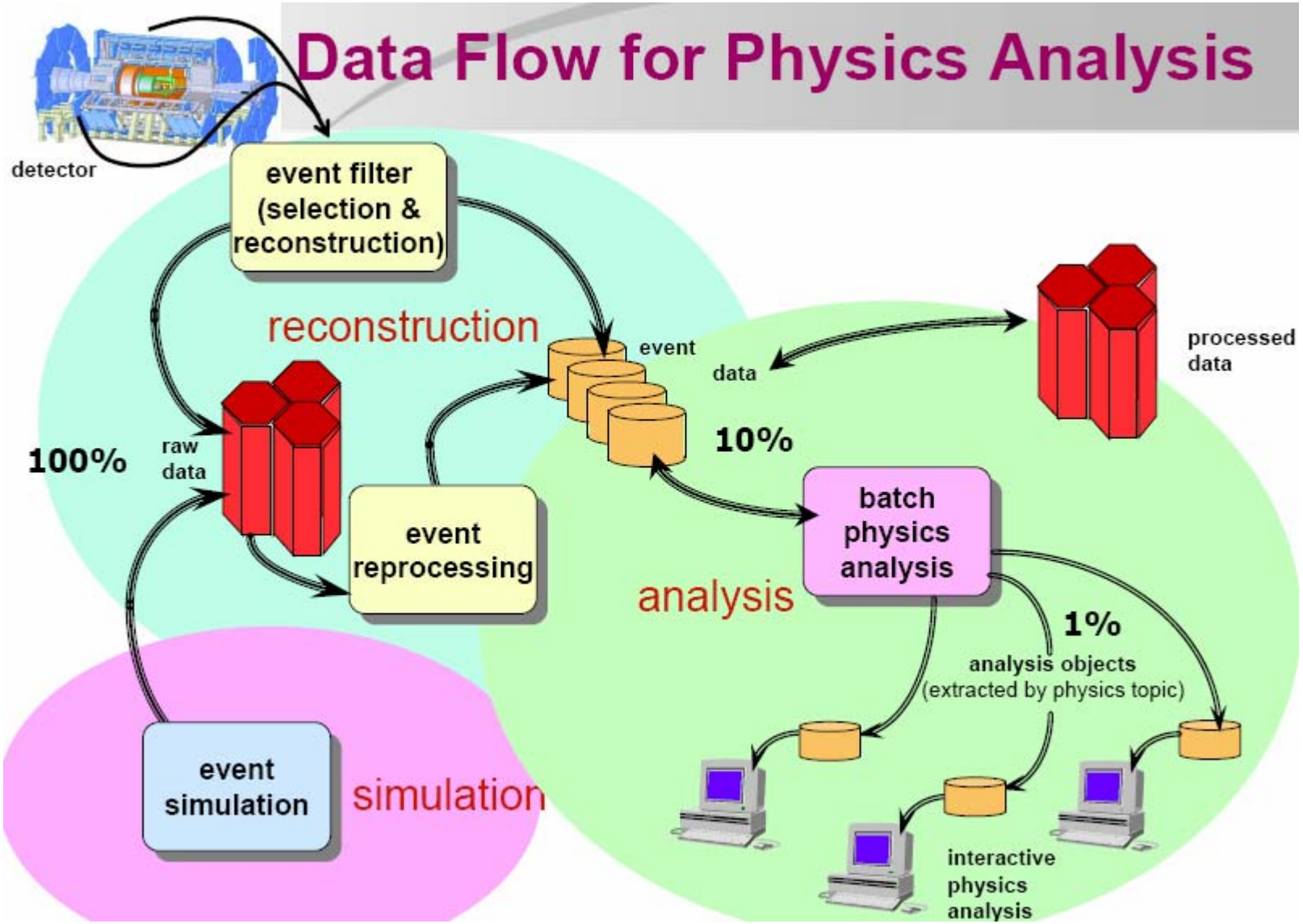
Online computers filter out a few hundred "good" events per sec. Each event is ~1 MB.




Which are recorded on disk and magnetic tape at 100-1,000 Megabytes/sec → ~15 Petabytes per year for all four experiments



# Data Flow for Physics Analysis



# „Off-line computing model" dla eksperymentów LHC

Definiuje ogólną architekturę czyli sposób w jaki planuje się używać dostępnych mocy obliczeniowych

- Jak duże moce są potrzebne aby zanalizować informację zebraną w detektorze?
- Jaki system zapisu danych (media, technologia)?
- Jaki system networku? itd...

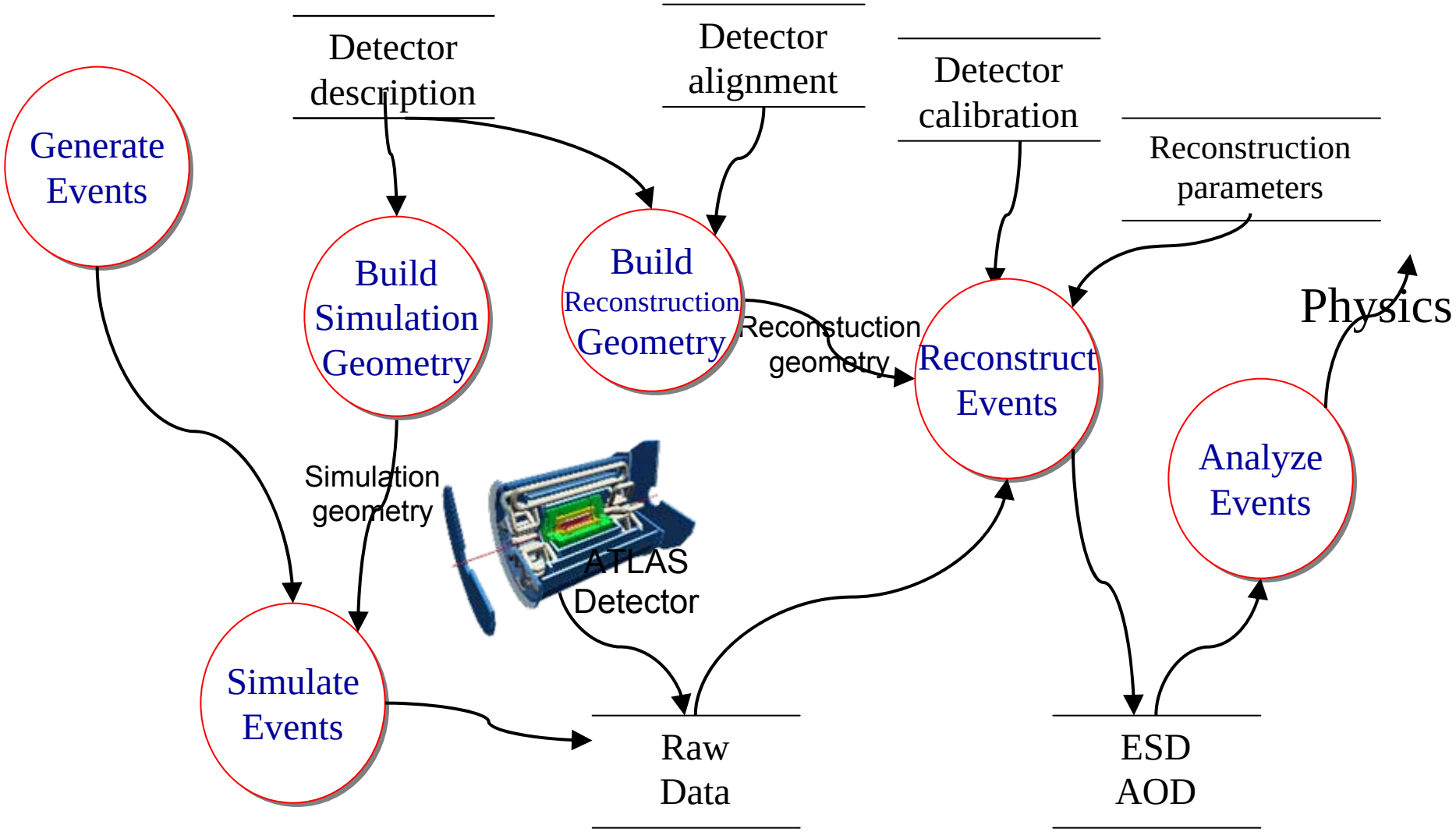
## Założenia wstępne

- długi czas życia ~ 20 lat
- 85% rozwijane w niezależnych grupach na całym świecie
- technologia obiektowa, język C++, aplikacje w java, skrypty w pythonie, pliki xml,....

## Parametry wejściowe

- 100Hz częstość rejestracji ($10^9$ oddziaływań na rok)
- 1 MB rozmiar przypadku
- 1 MB/godz. informacji dodatkowej (kalibracja odczytu)
- 150 równoczesnych użytkowników (dostęp do baz danych)...

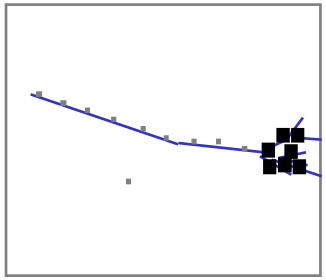
# Co to znaczy analizować dane"?

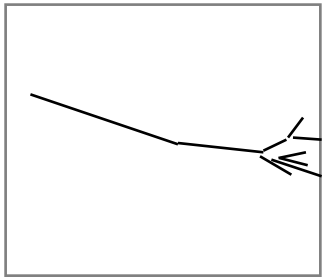


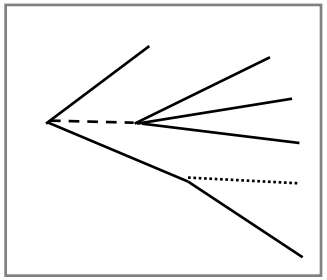
# Od „surowych danych" do fizyki czyli co się dzieje podczas analizy?

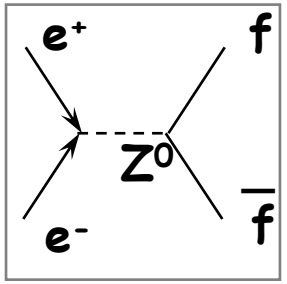
**250Kb – 1 Mb** **100 Kb** **25 Kb** **5 Kb** **500 b**

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










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

**Reconstruction**

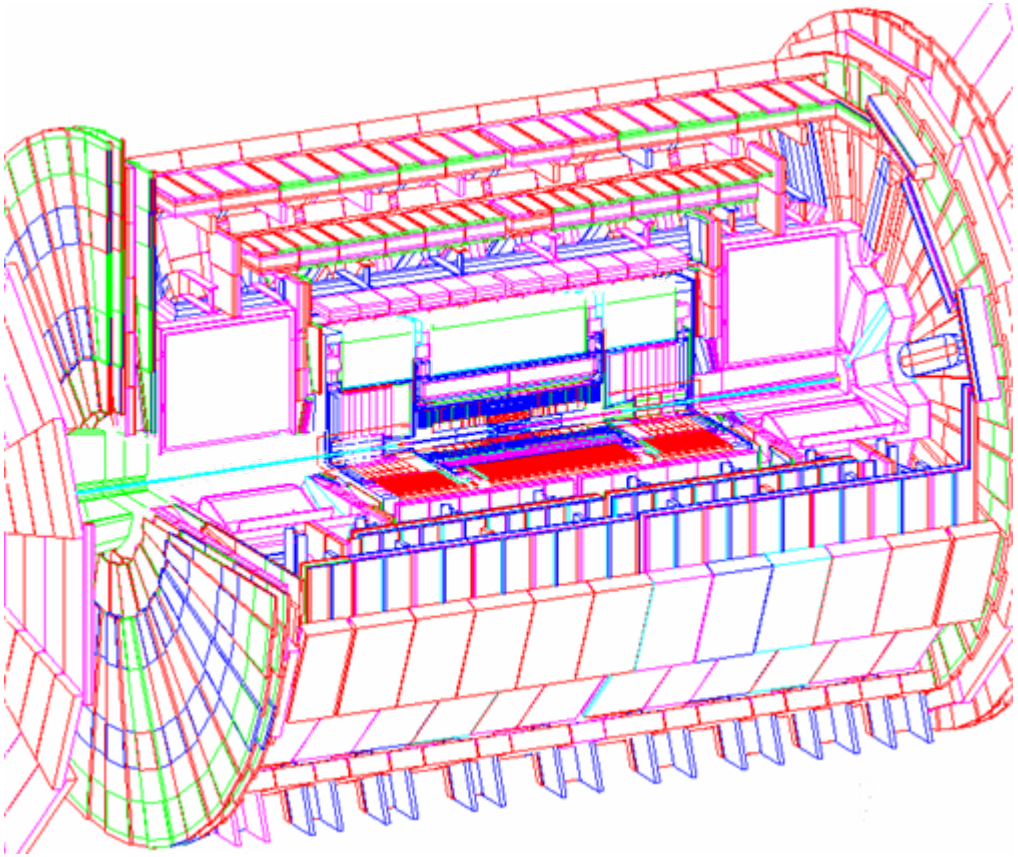
**Analysis**

**Simulation (Monte-Carlo)**

# Co to znaczy „zaprogramować" geometrię?

Jaka jest skala problemu?

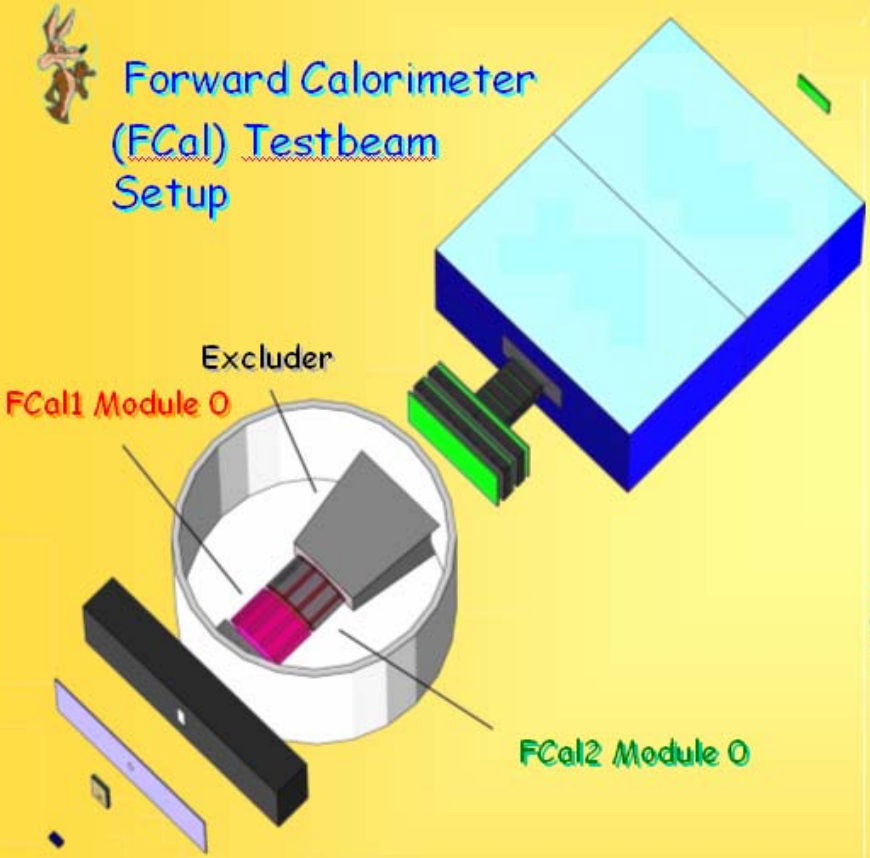
- **25,5 milionów** oddzielnych elementów
- **23 000** różnych obiektów geometrycznych
- **4 673** różnych typów geometrycznych
- kontrolowanie nakładających się na siebie przypadków
- **1 000 000** sygnałów w detektorze na przypadek



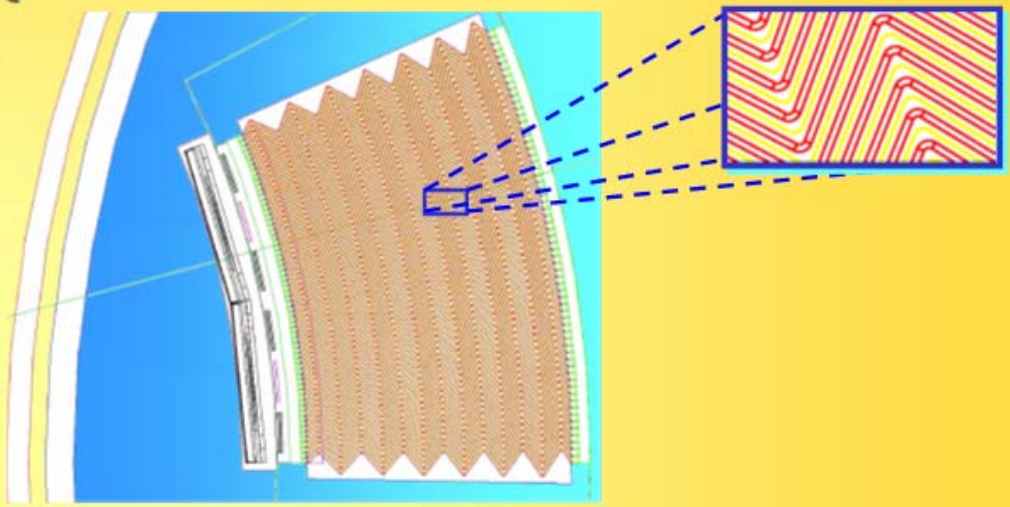
Peter Loch
University of Arizona
Tucson, Arizona 85721

# Geant4 Setups (2)

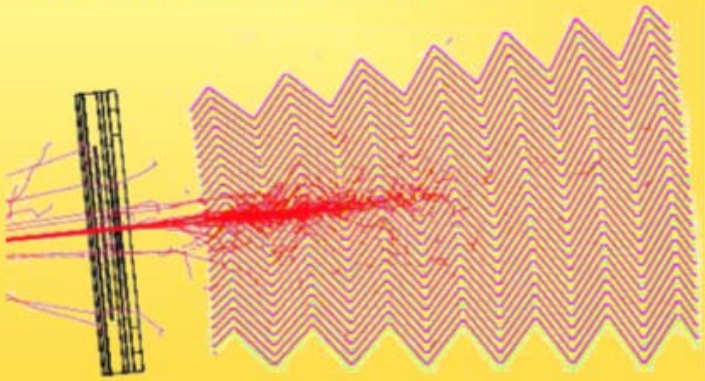
## Forward Calorimeter (FCal) Testbeam Setup



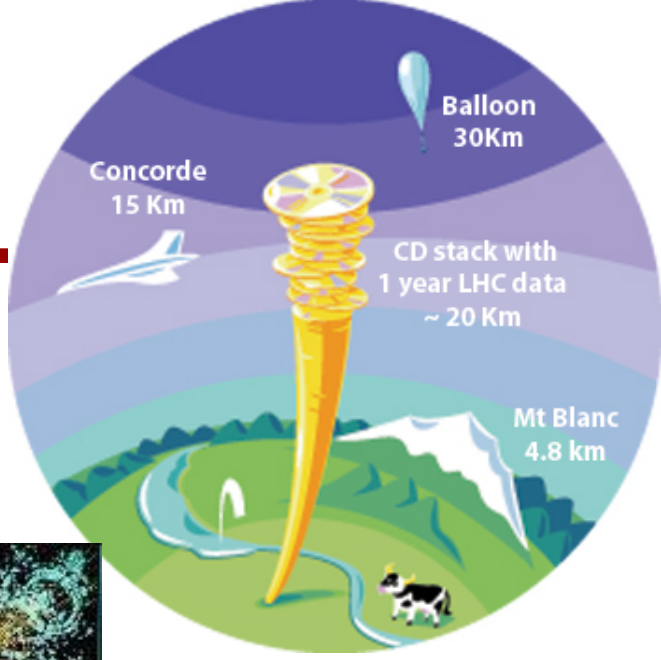

## Electromagnetic Barrel Accordion Calorimeter



## 10 GeV Electron Shower



# Computing




The LHC experiments will produce 10-15 PB of data per year

1 PB=$10^6$ GB

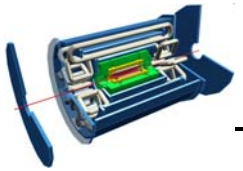
This corresponds to ~ 20 million CD (a 20 km stack …)

Data analysis requires computing power equivalent to ~100 000 today's fastest PC processors.

The experiment international Collaborations are spread all over the world → computing resources must be distributed.

Cooperation of many computer centres all over the world is needed → **Grid**

# Hierarchical View



~PBytes/sec

Online System

~100 MBytes/sec

**1 TIPS = 25,000 SpecInt95**

**PC (1999) = ~15 SpecInt95**

- One bunch crossing per 25 ns
- 100 triggers per second
- Each event is ~1 Mbyte

Offline Farm
~20 TIPS

~100 MBytes/sec

~ Gbits/sec
or Air Freight

Tier 0

CERN Computer
Centre >20 TIPS

HPSS

Tier 1

US Regional Centre

Italian Regional Centre

French Regional Centre

UK Regional Centre (RAL)

Tier 2

Northern Tier
~1 TIPS

Tier2 Centre
~1 TIPS

~Gbits/sec

Tier 3

Lancaster
~0.25TIPS

pool

anchester

Sheffield

Physics data cache

100 - 1000
Mbits/sec

Workstations

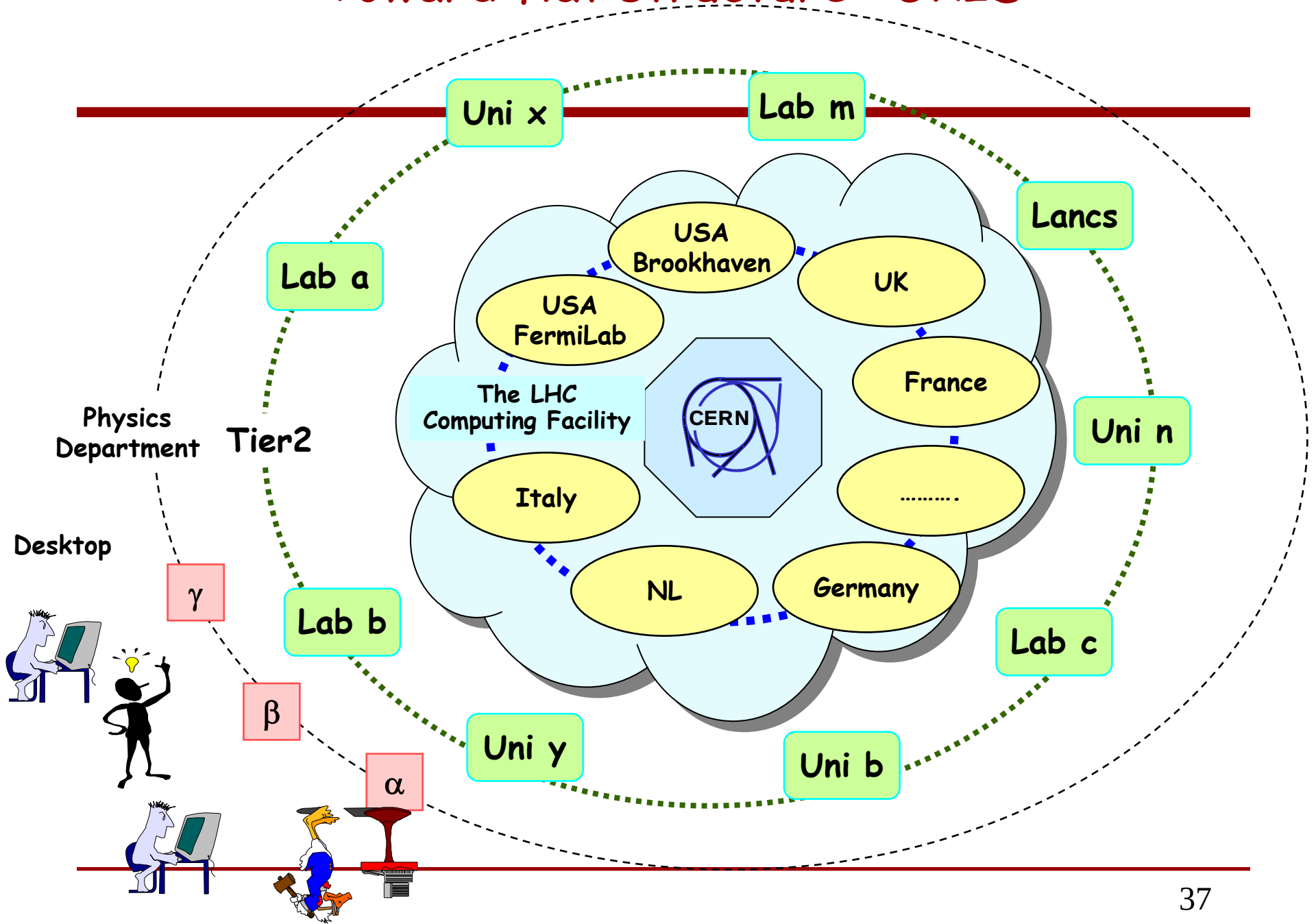
Tier 4

**Physicists work on analysis "channels"**

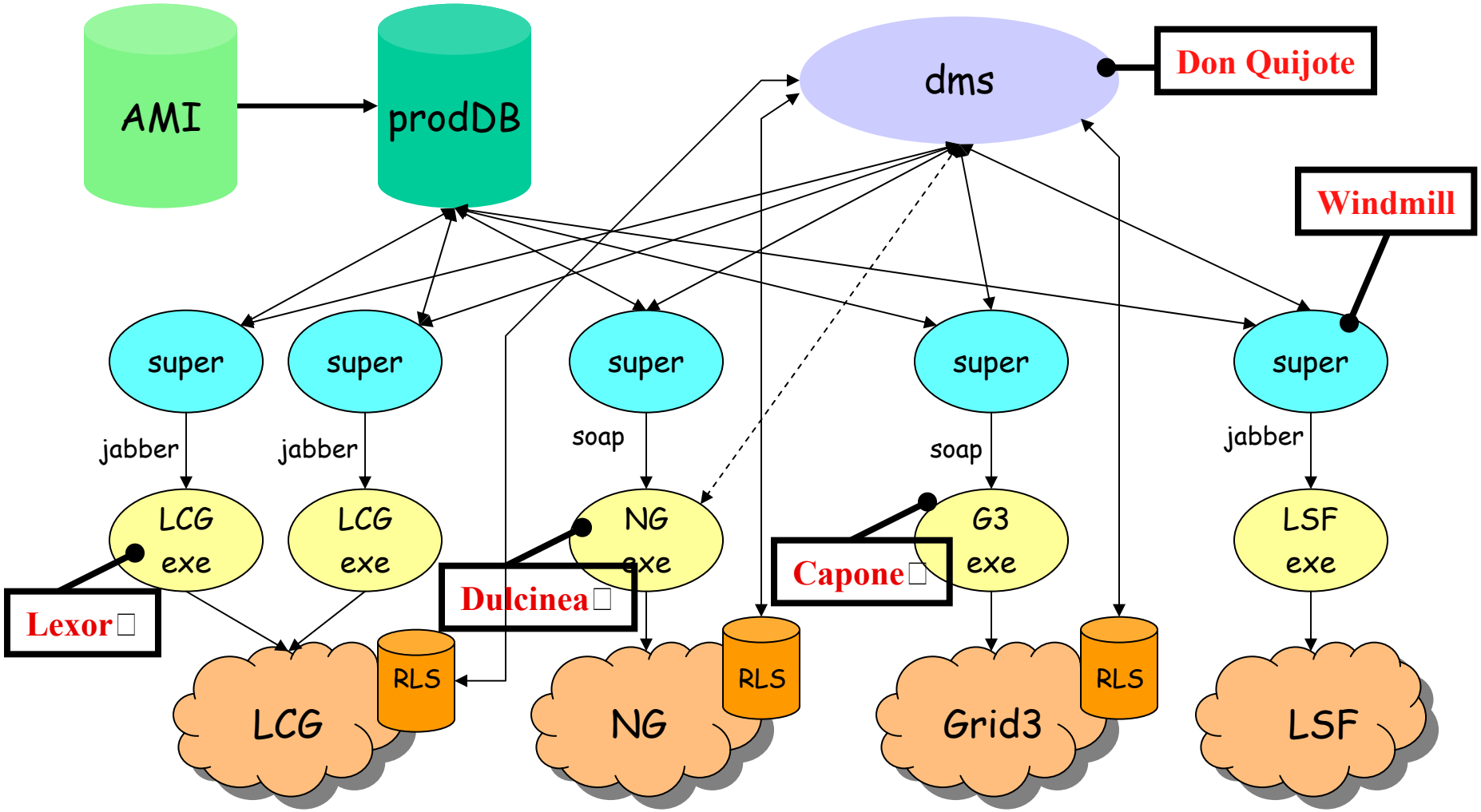
**Each institute has ~10 physicists working on one or more channels**

**Data for these channels should be cached by the institute server**

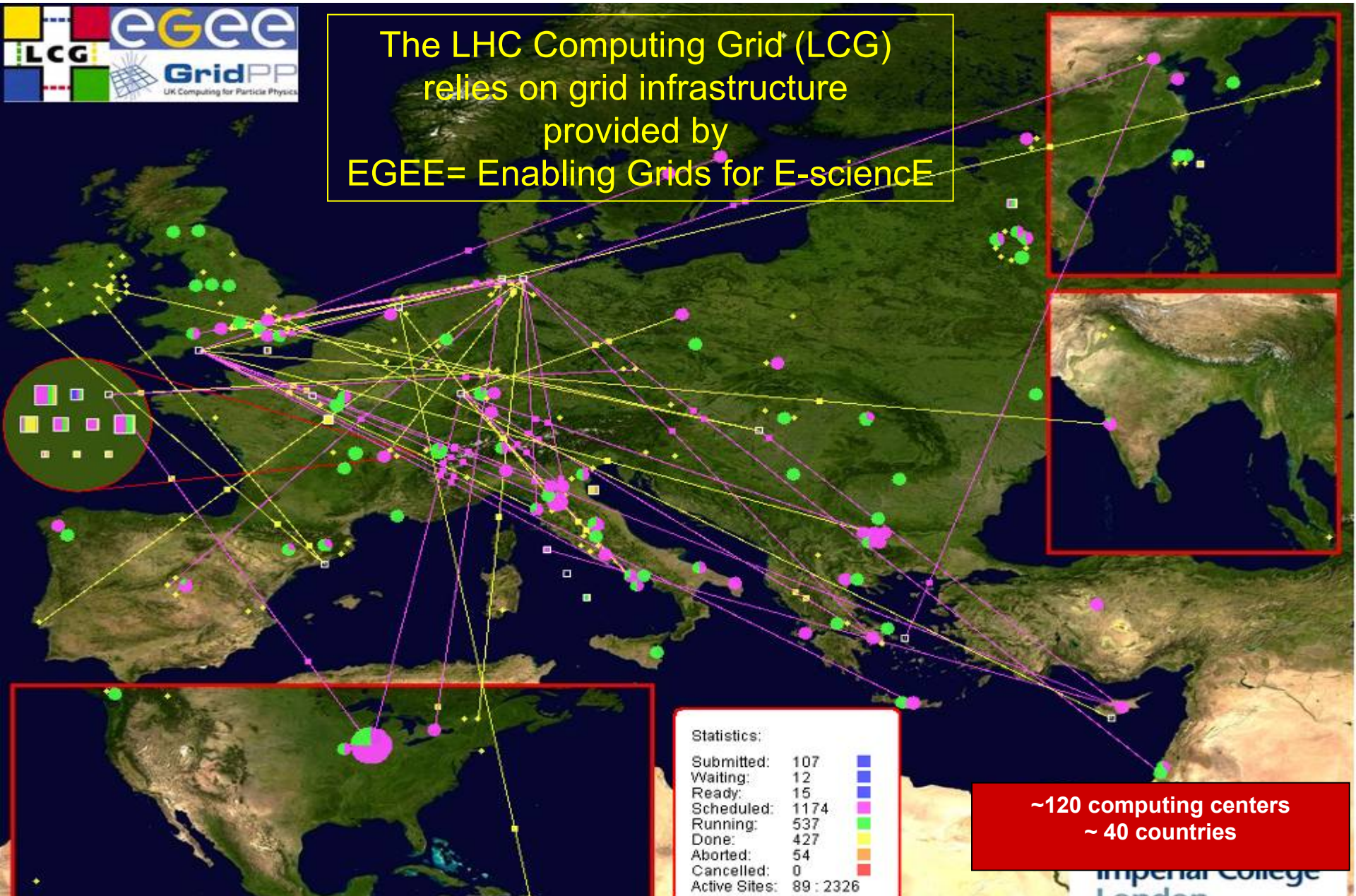
# Toward flat structure: GRID



# ATLAS Production system

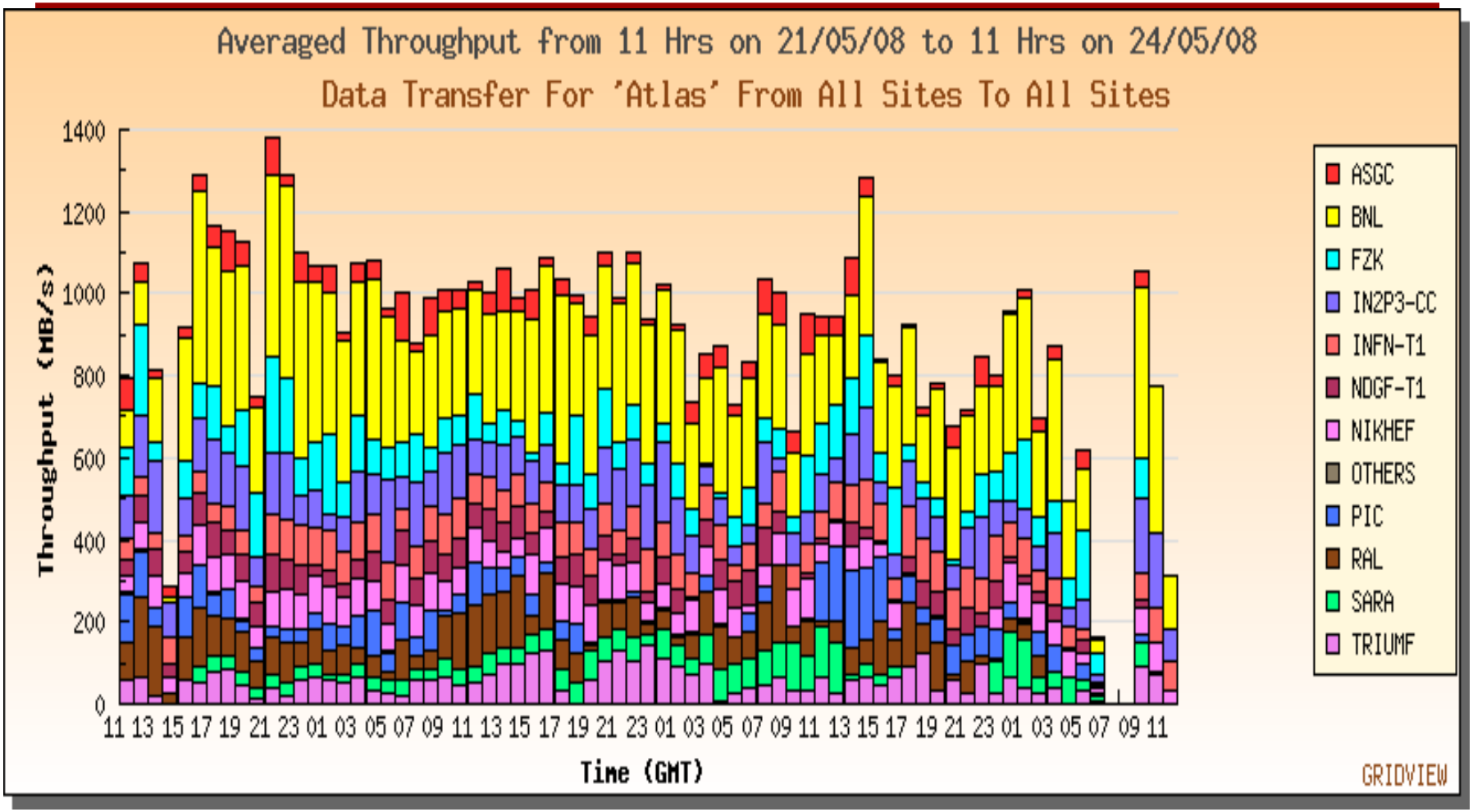


# The Grid provides seamless access to computing power and data storage capacity distributed over the globe



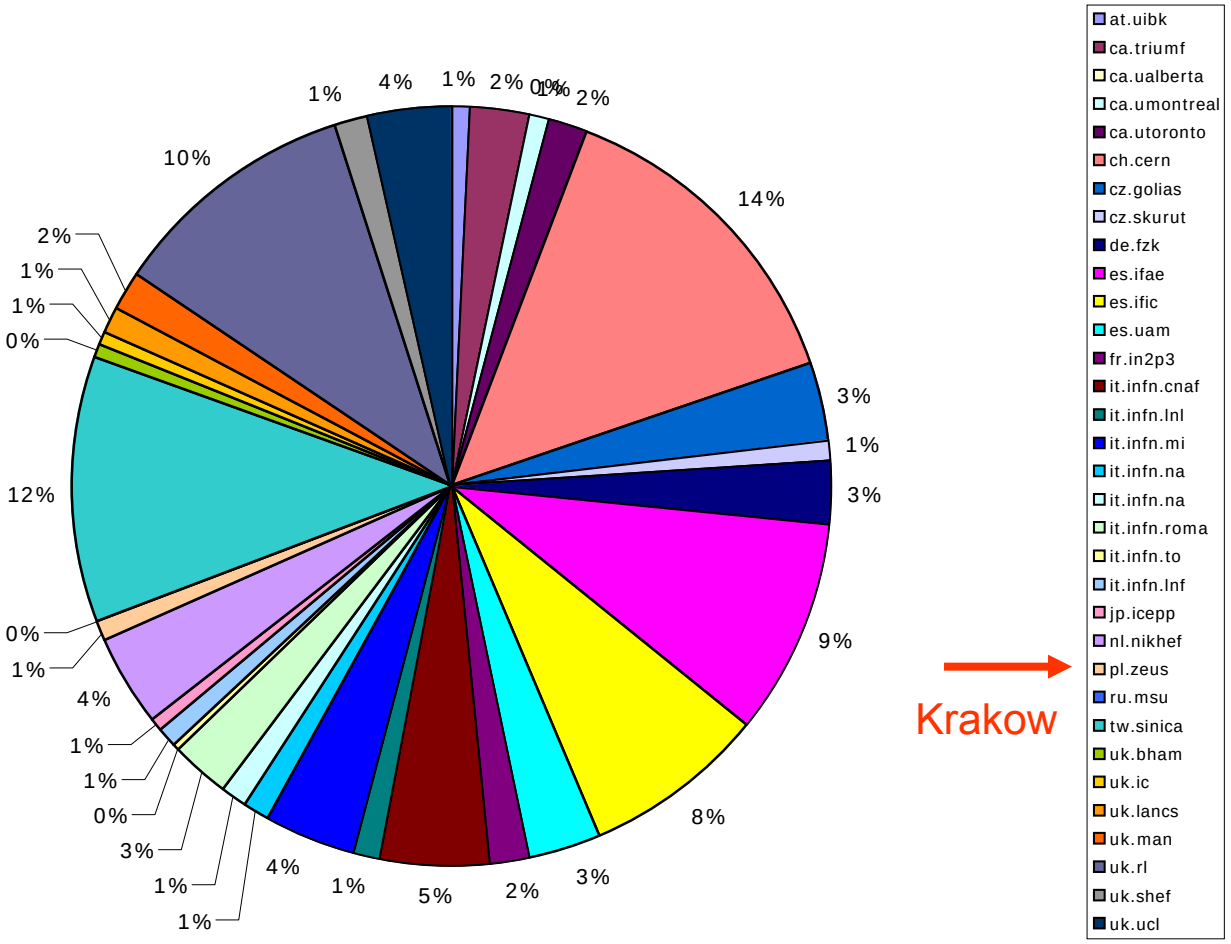
# *ATLAS during the Common Computing Readiness Challenge CCRC Phase 2*

Data transfer Tier0--> Tiers-1



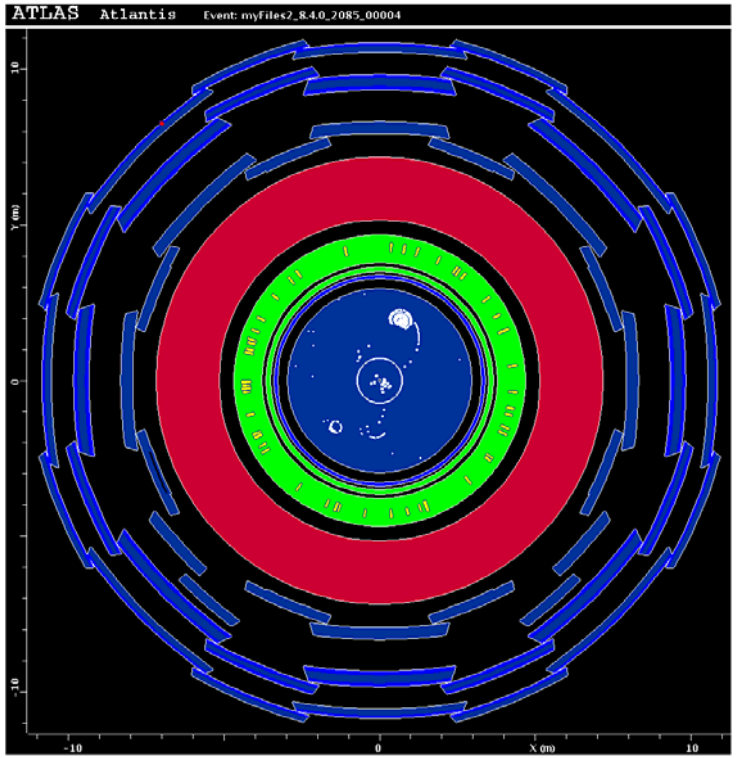

Nominal peak level (~1 GB/s) sustained over 3 days

# Jobs distribution on LCG

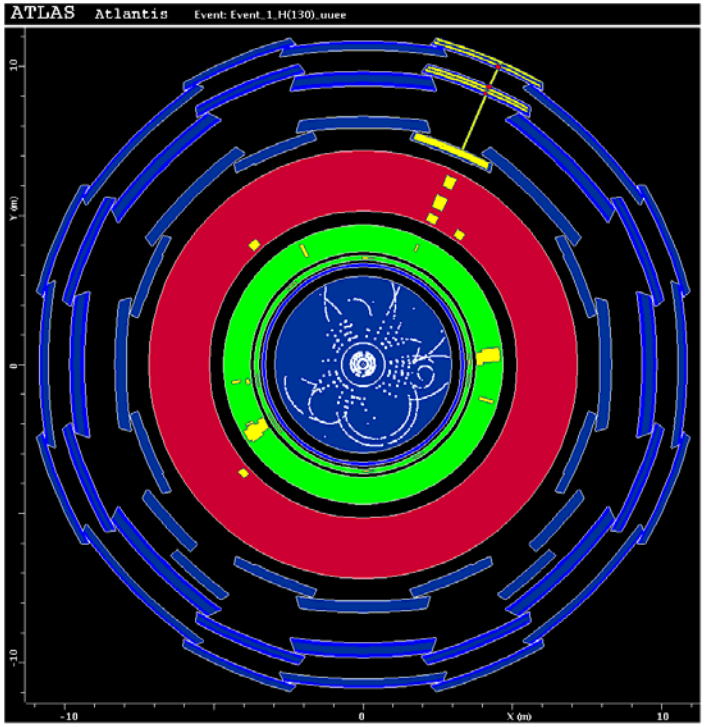


# Physics and Trigger

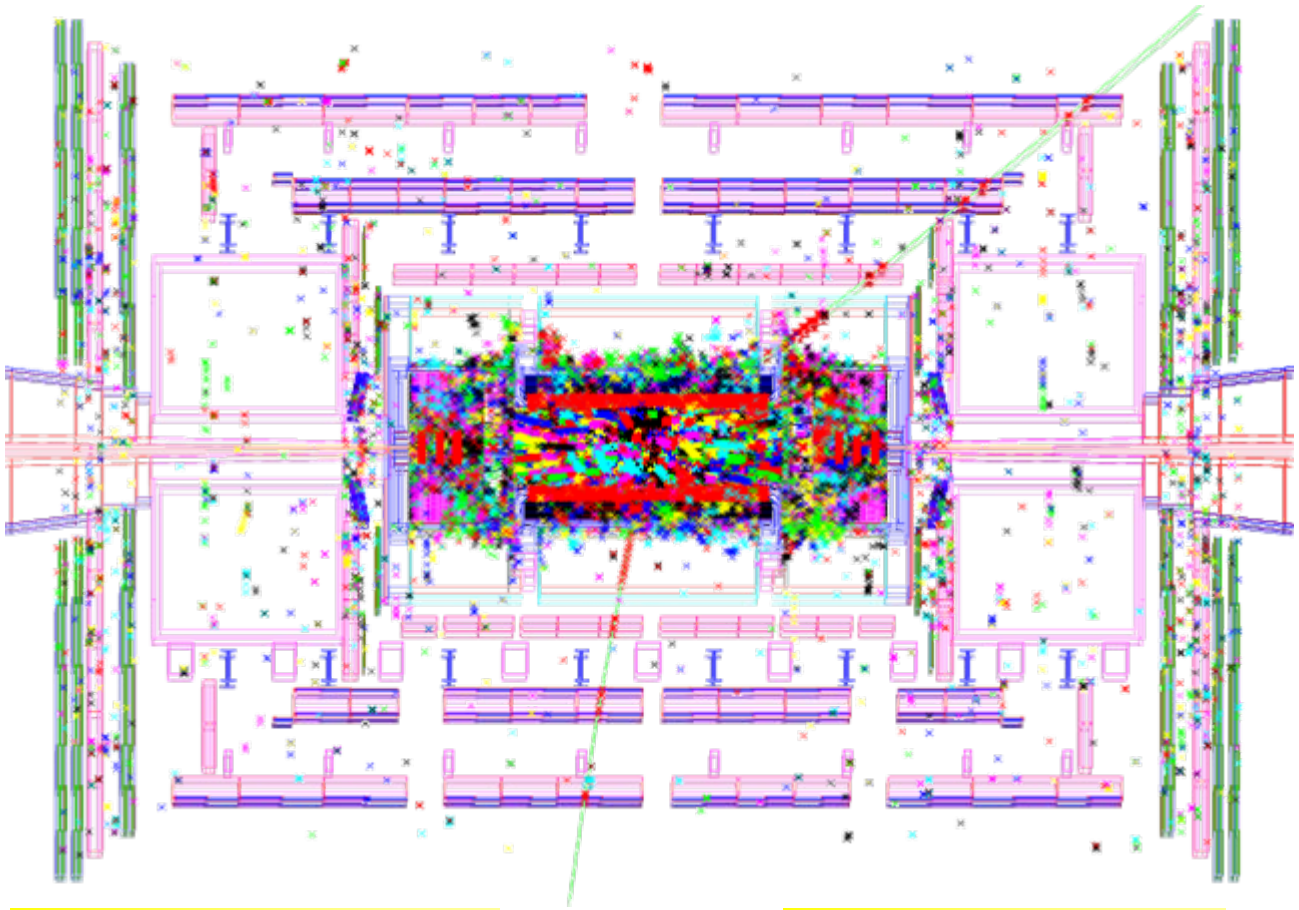
**Minimum Bias**




**$H(130\ GeV) \rightarrow Z^0Z^{0*} \rightarrow \mu^+\mu^-e^+e^-$**



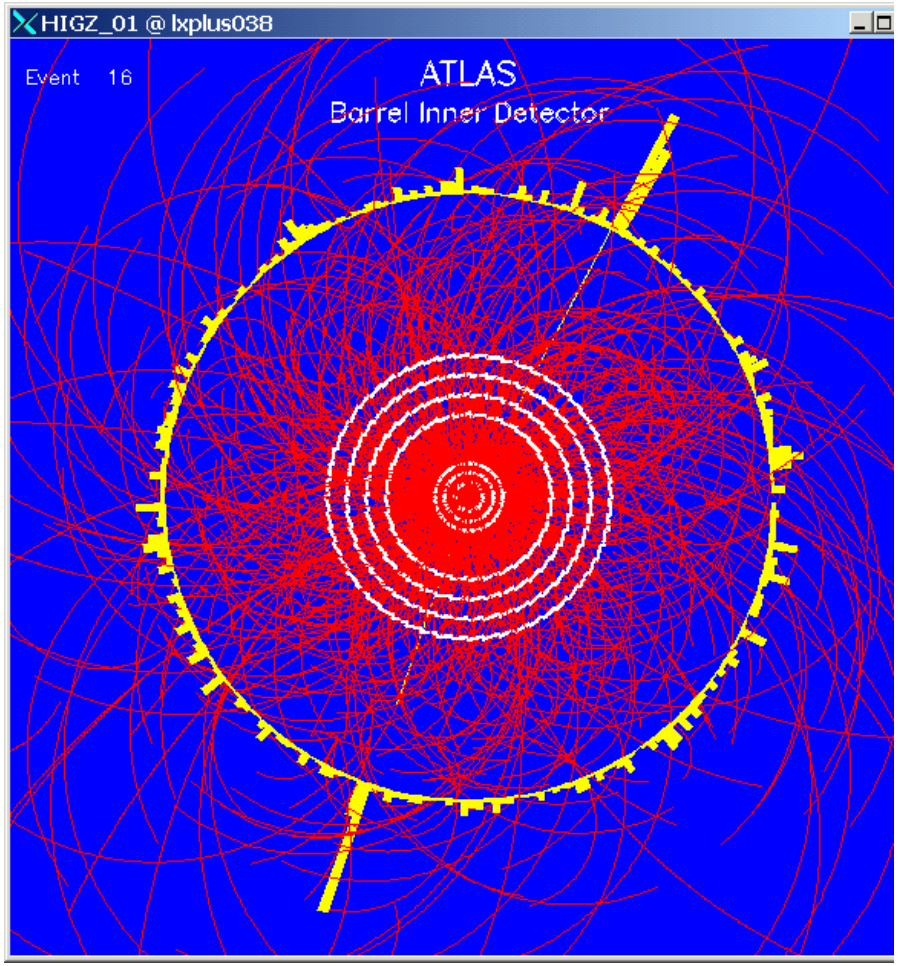
# Looking for interesting event

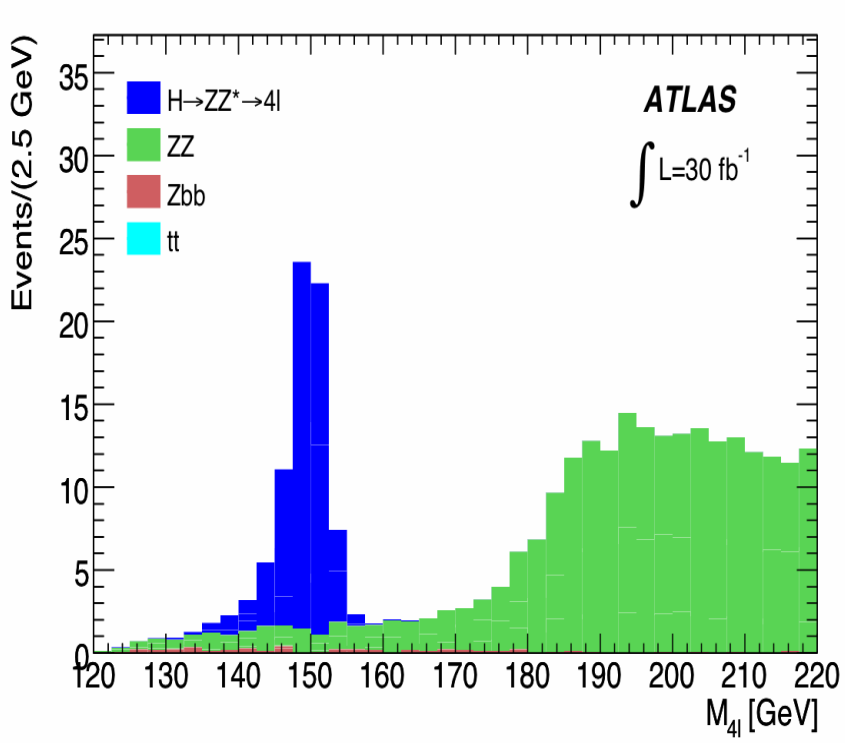


Higgs → ZZ → 2e+2μ

23 min bias events

# Possible discovery channel: H->ZZ*->4l



## ***Collecting few numbers …..***

Number of turns of the LHC ring made by protons in one second: ~ 11000

Number of proton-proton interactions per second : 1 billion

Number of particles produced per collision : more than 1000

Machine temperature : 1.9 K (the largest cryogenic system in the world)

Weight of CMS experiment: ~ 13000 tons (30% more than the Tour Eiffel)

Amount of cables used to transfer the detector signals in ATLAS : ~ 3000 km

Data recorded by experiments in 1 year: 20 km of CD

Number of involved physicists : > 4000 (from the 5 continents !)

Total cost (accelerator plus experiments) : ~ 5000 MCHF

The most ambitious project in particle physics ever and one of the most ambitious in science in general

## Co z tego dzieje się w Krakowie?

- grupa ATLAS, ALICE, LHCb (eksperymenty LHC) w Instytucie Fizyki Jądrowej ul. Radzikowskiego 152
- grupa ATLAS i LHCb w AGH

## Czym się zajmujemy?

- modelowanie triggera (on-line)
- rekonstrukcja i analiza informacji (off-line)
- oprogramowanie dla monitorowania pracy detektora
- projektowanie elementów elektroniki
- procesowanie dużej ilości danych: GRID
- Przygotowywanie analiz fizycznych

*Zapraszamy ....*