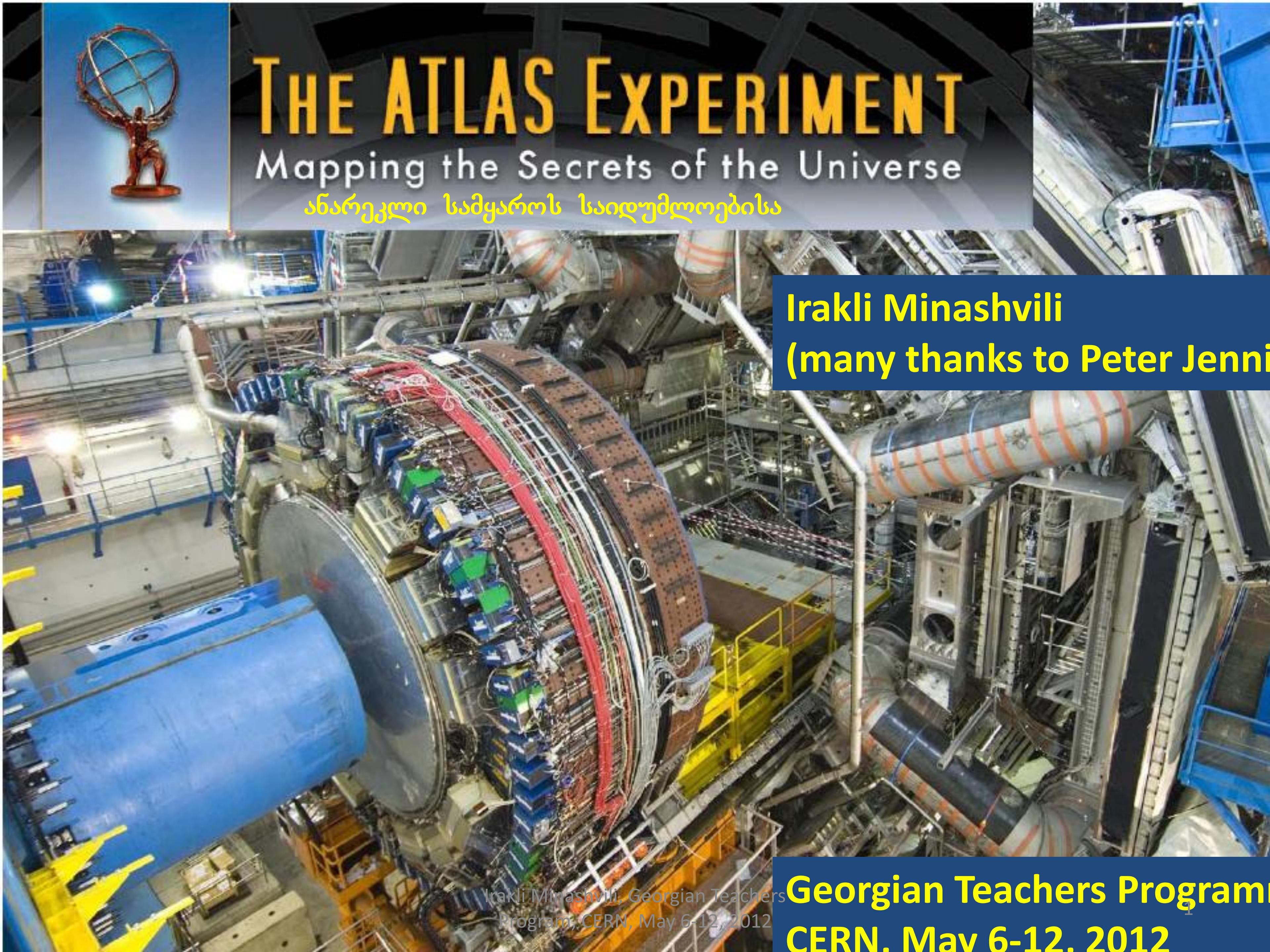
THE ATLAS EXPERIMENT

Mapping the Secrets of the Universe

ანარეკლი სამყაროს საიდუმლოებისა



Irakli Minashvili
(many thanks to Peter Jenni

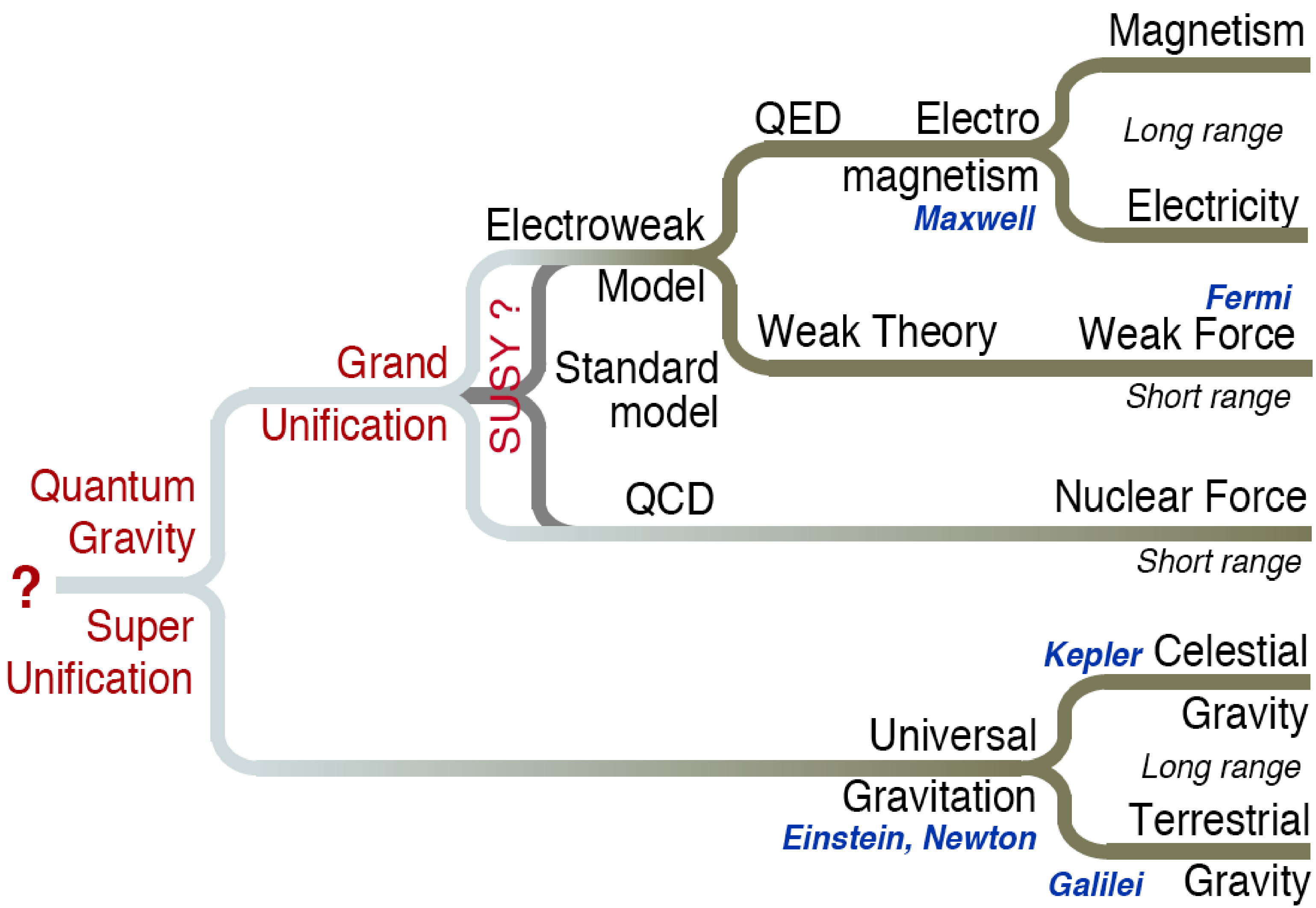
Georgian Teachers Programm
CERN, May 6-12, 2012

Large Hadron Collider დიდი ადრონული ამაჩქარებელი

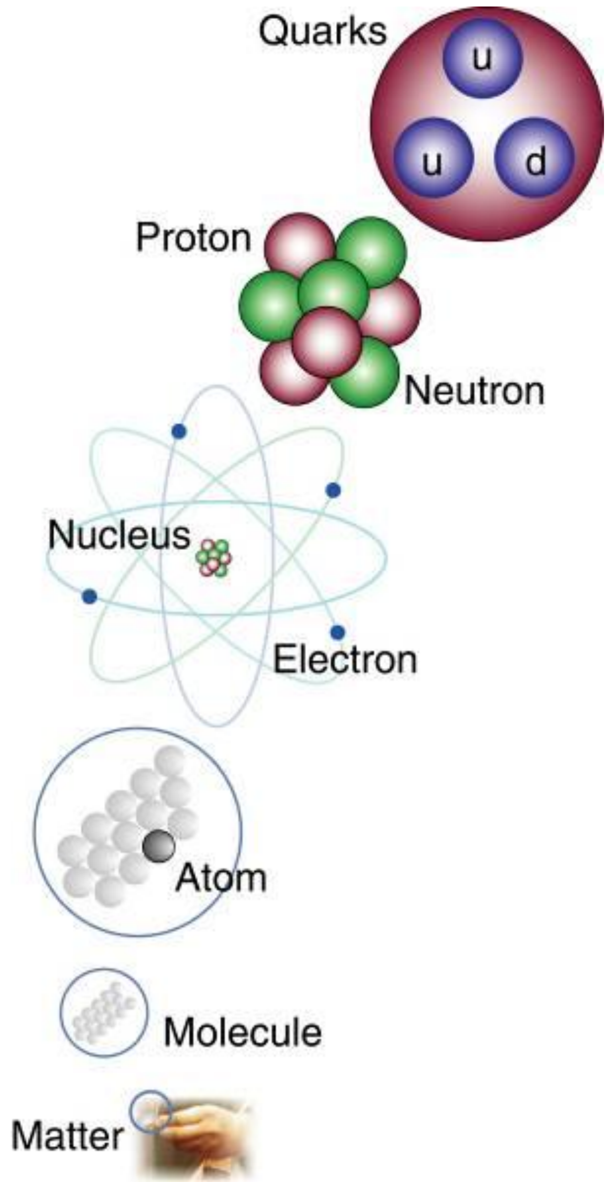
რა არის ფუნდამეტალური ფიზიკაშიკის ძირითადი ამოცანები და რას ველოდებით ექსპერიმეტებიდან (ძალიან მოკლედ)

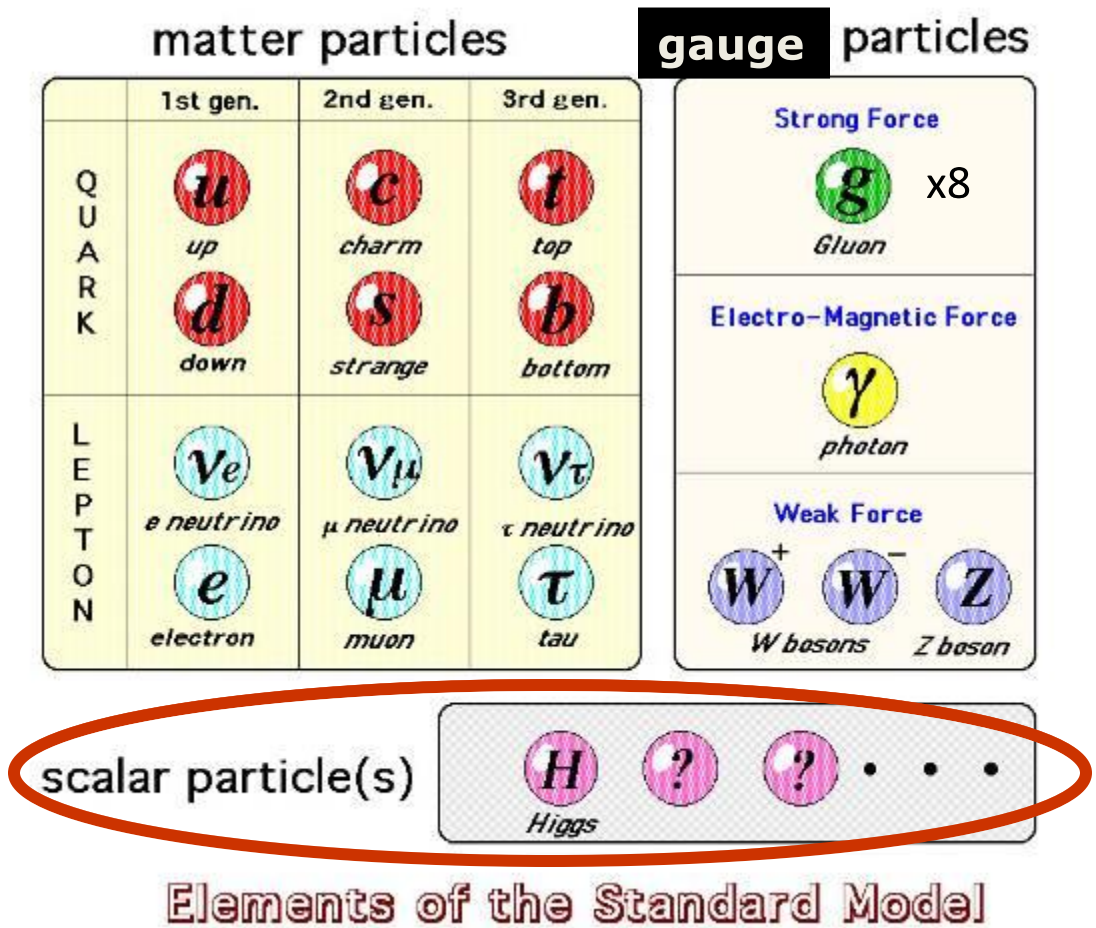
- მასის წარმოქმნის მექანიზმი
- სად არის ანტი მატერია
- სად და რა მდგომარეობაშია დამალული სამყაროს 96% ენერგიისა (შავი მატერია, ბნელი ენერგია)
- არის თუ არა განზომილება 4-ზე მეტი
- სრულიად ახალი აღმოჩენები ☺

ძალების უნიფიცირება



ელემენტარული ნაწილაკებისა და ველების ურთიერთქმედებების შესწავლა

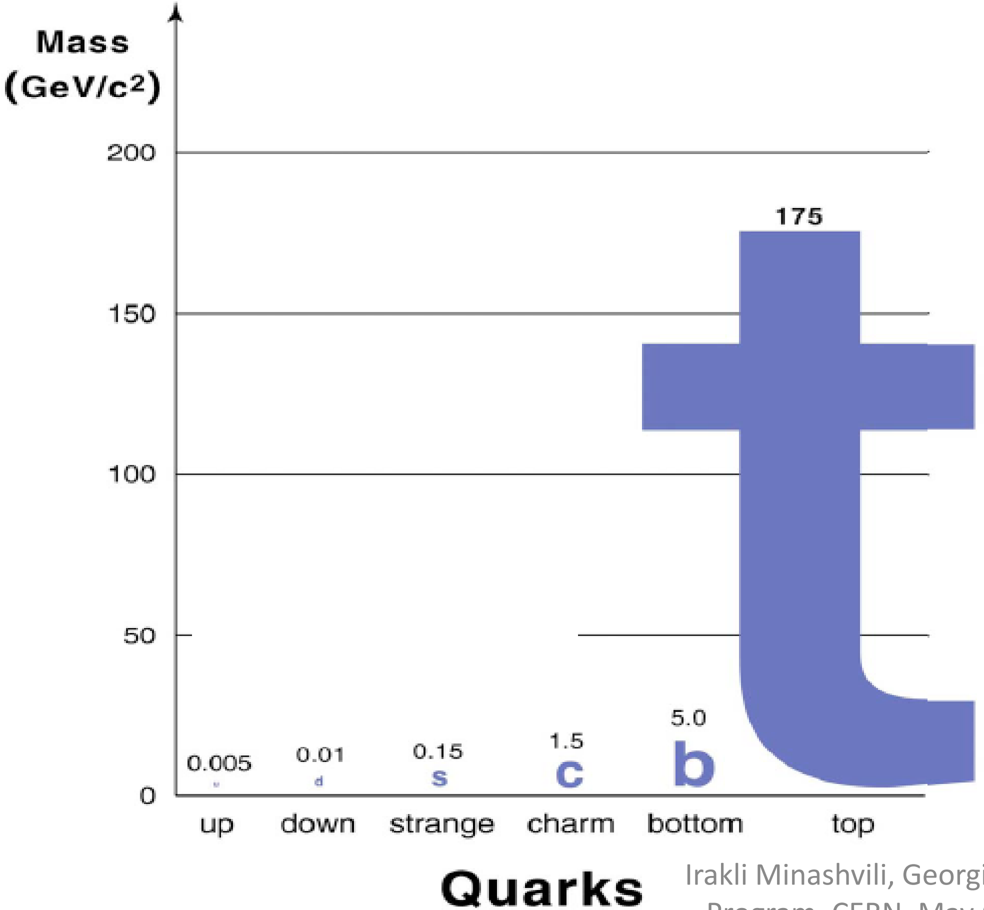




A most basic question is why particles (and matter) have masses (and so different masses)

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

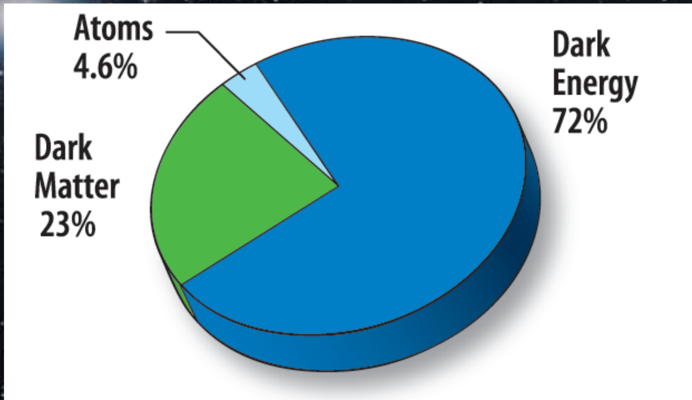
Dark Matter in the Universe

Astronomers found that most of the matter in the Universe must be invisible Dark Matter

Vera Rubin ~ 1970

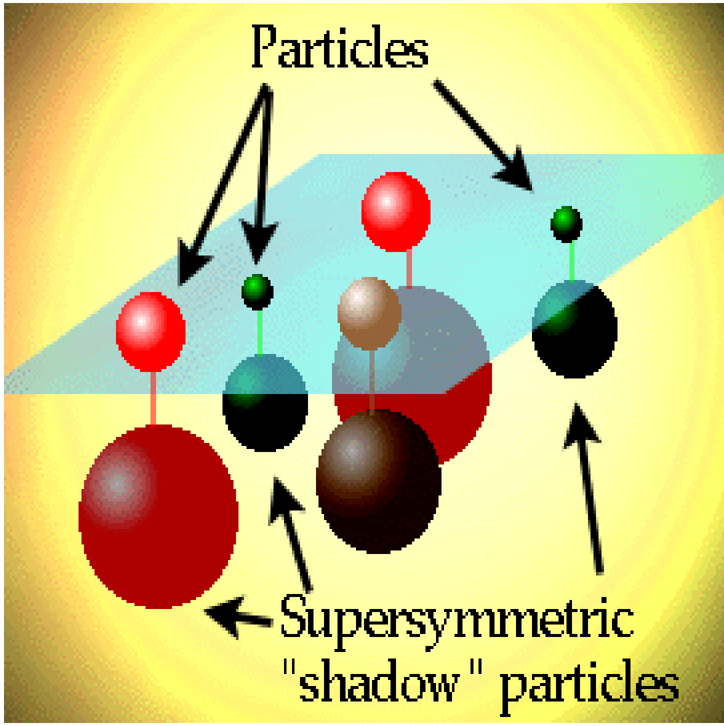
'Supersymmetric' particles ?

F. Zwicky 1898-1974



Supersymmetry (SUSY)

(Julius Wess and Bruno Zumino, 1974)



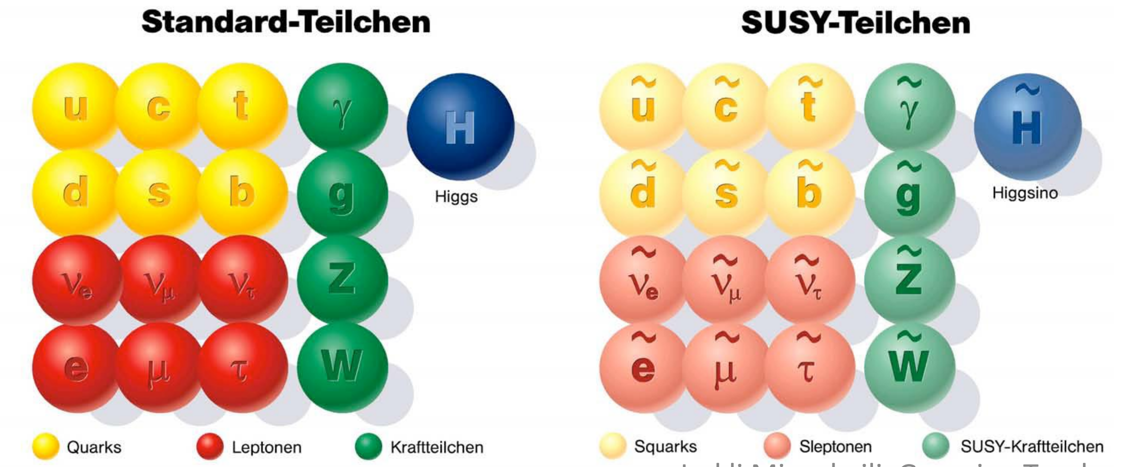
Establishes a symmetry between fermions (matter) and bosons (forces):

- Each particle p with spin s has a SUSY partner $\tilde{p}$ with spin s -1/2

- Examples q (s=1/2) → $\tilde{q}$ (s=0) squark

g (s=1) → $\tilde{g}$ (s=1/2) gluino

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



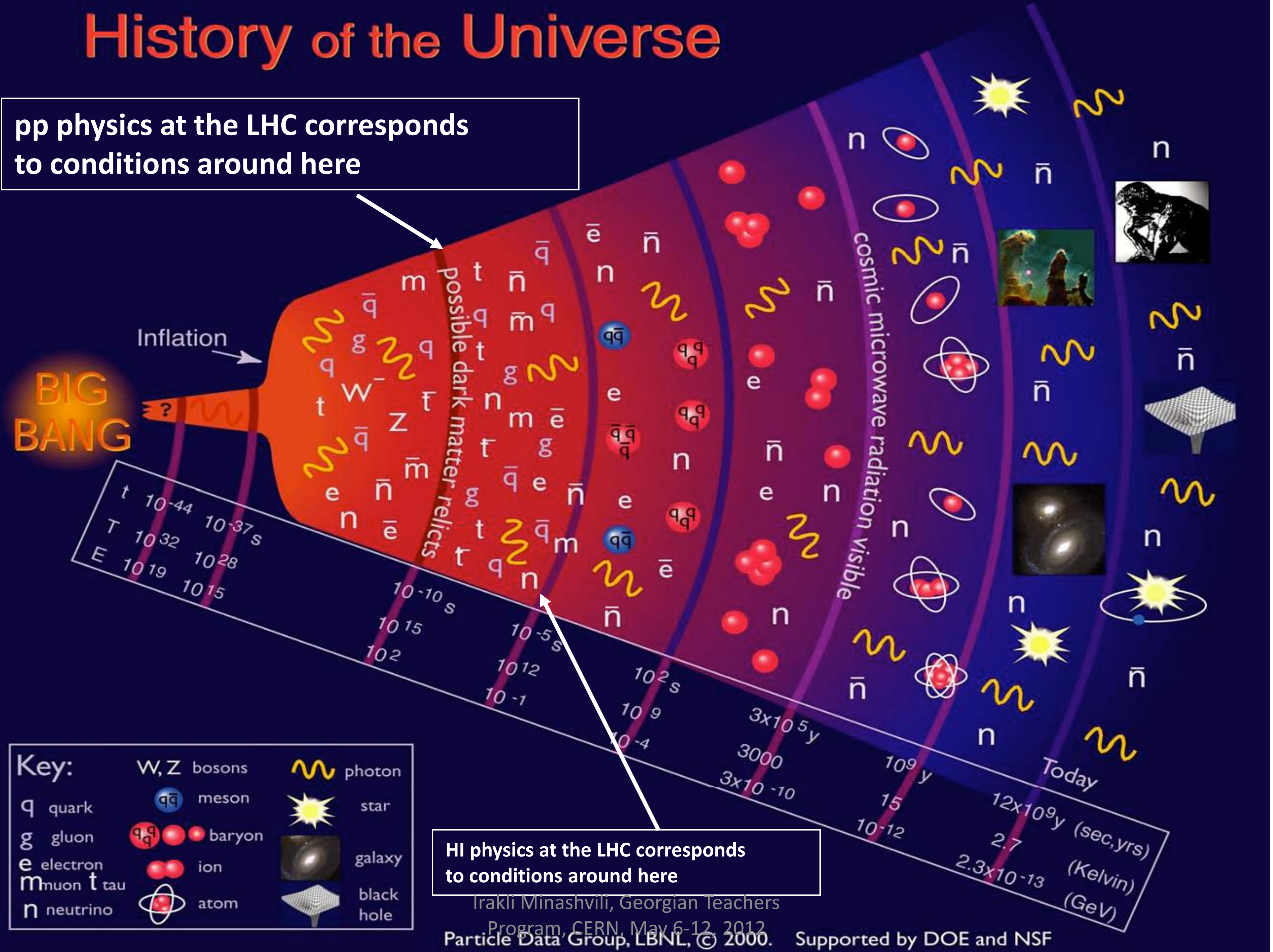
Motivation:

- Unification (fermions-bosons, matter-forces)

- Solves some deep problems of the Standard Model

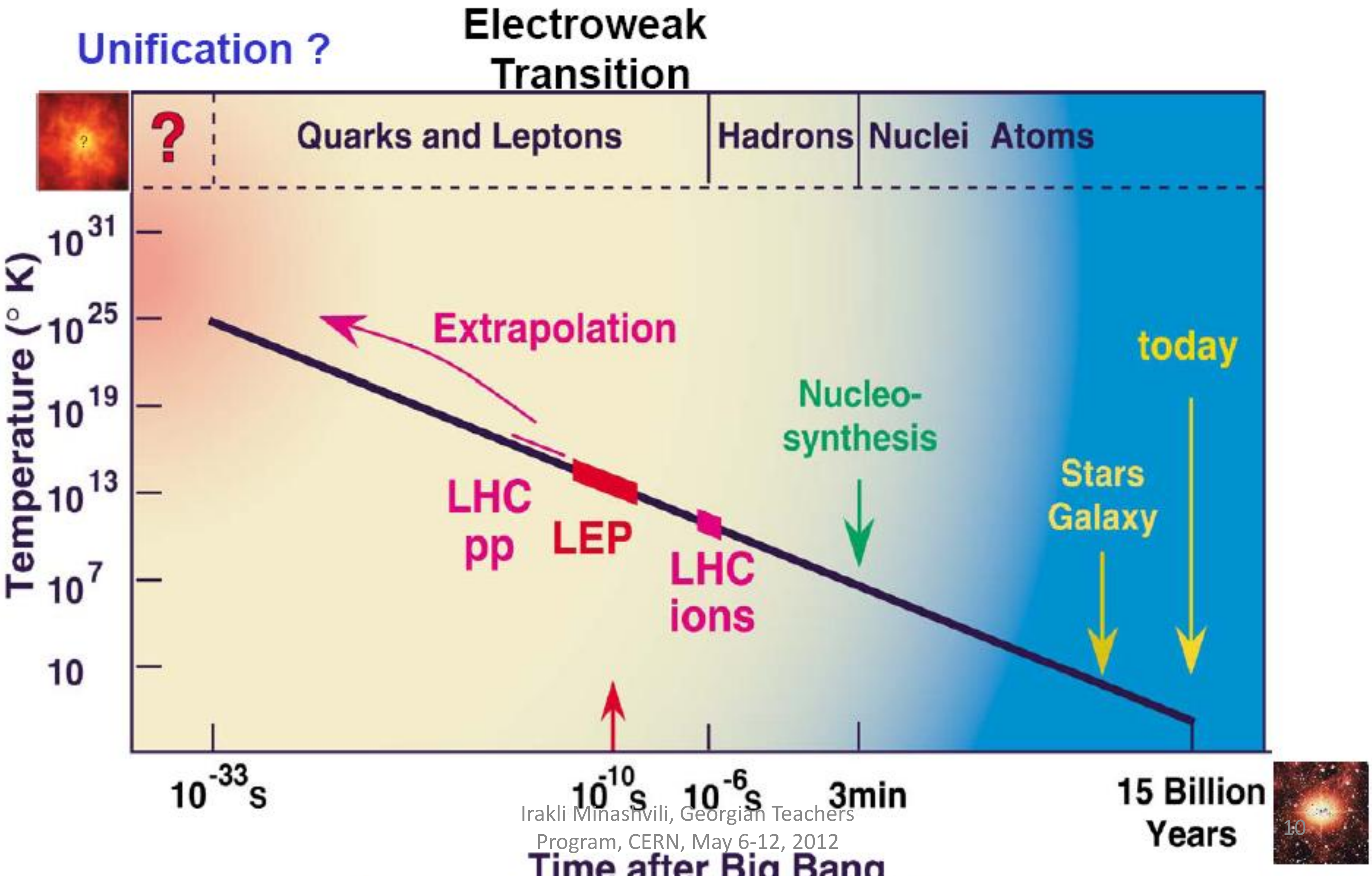
History of the Universe

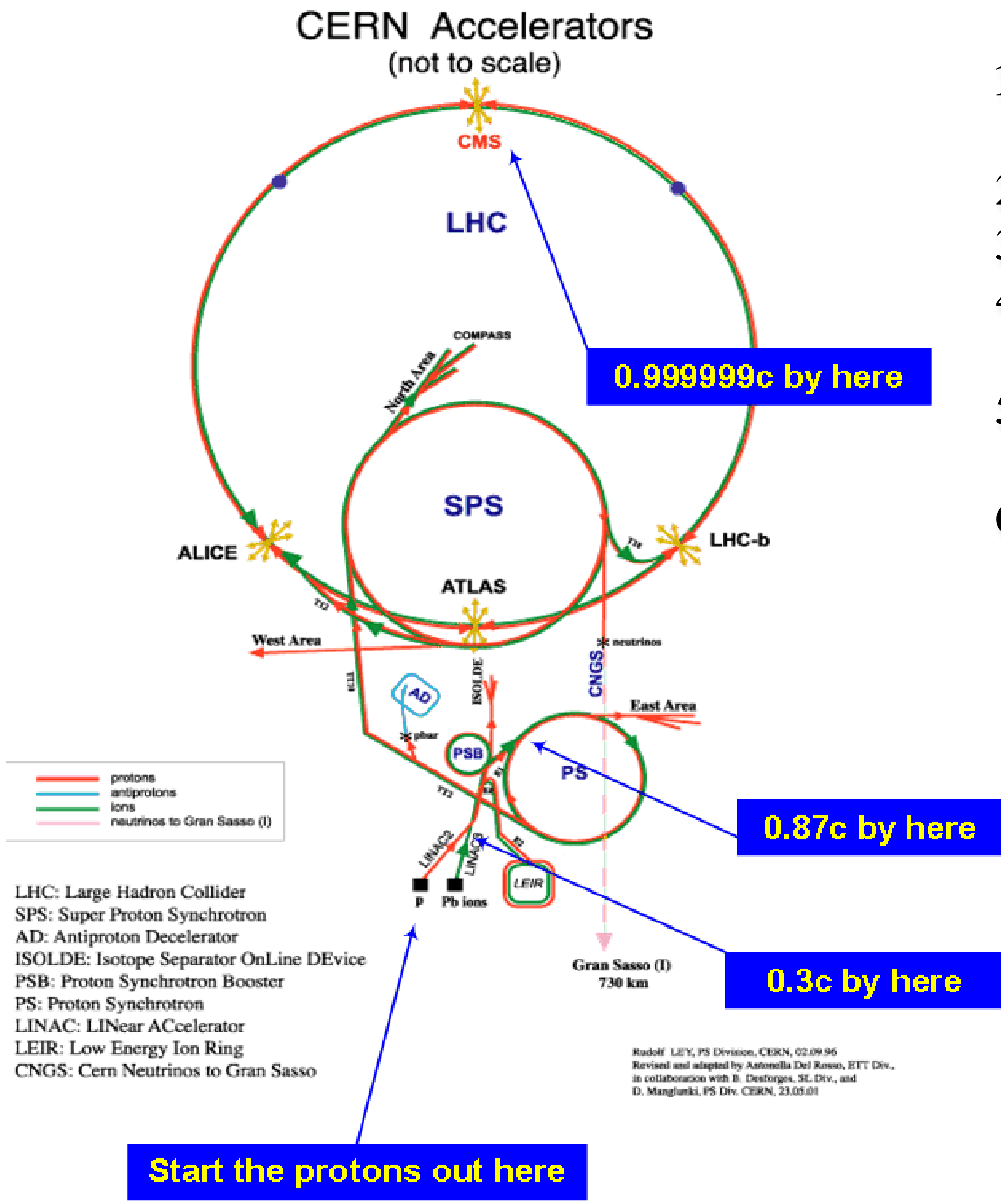
pp physics at the LHC corresponds to conditions around here



HI physics at the LHC corresponds to conditions around here

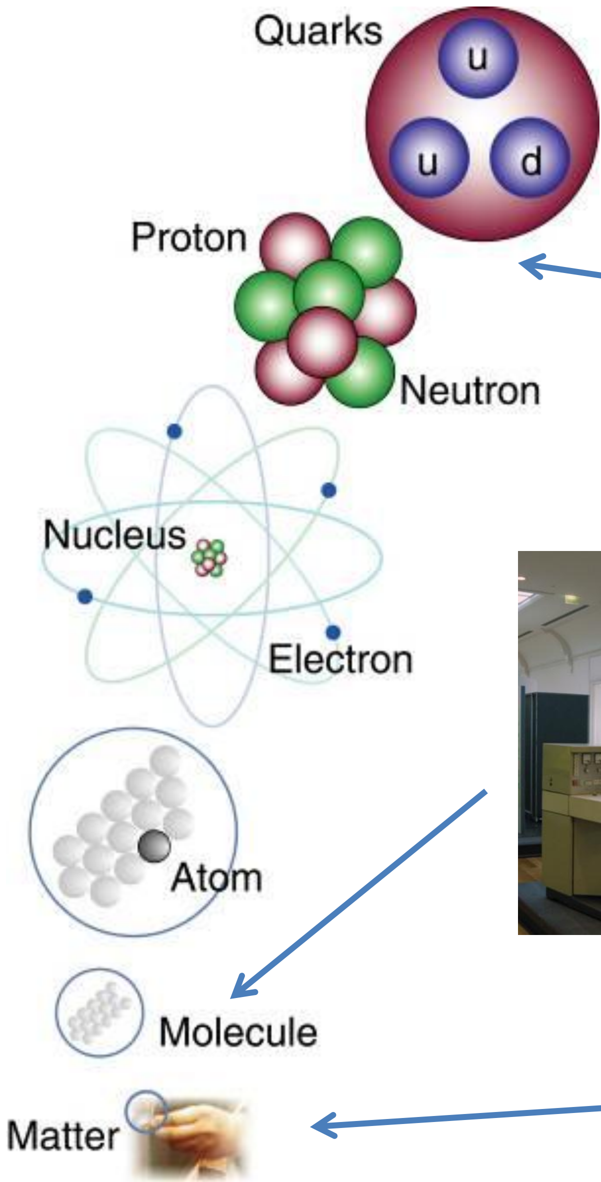
Understanding the Universe …





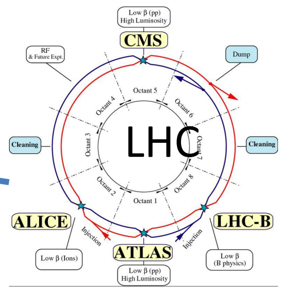
1. პროტონების წყარო, 100კევ
2. წრფივი ამჩქარებელი, 50მევ
3. ბუსტერი, 1,4გევ
4. პროტონული სინქროტრონი, 28გევ
5. სუპერ პროტონული სინქროტრონი, 450გევ
6. დიდი ადრონული ამაჩქარებელი შემხვედრ ნაკადებზე, 7ტევ.

მძლავრი ამაჩქარებლები და დეტექტორები



მაღალი ენერგიები და ინტენსიური ნაკადები უაღრესად სწრაფი და ზუსტი

$<10^{-16}$cm

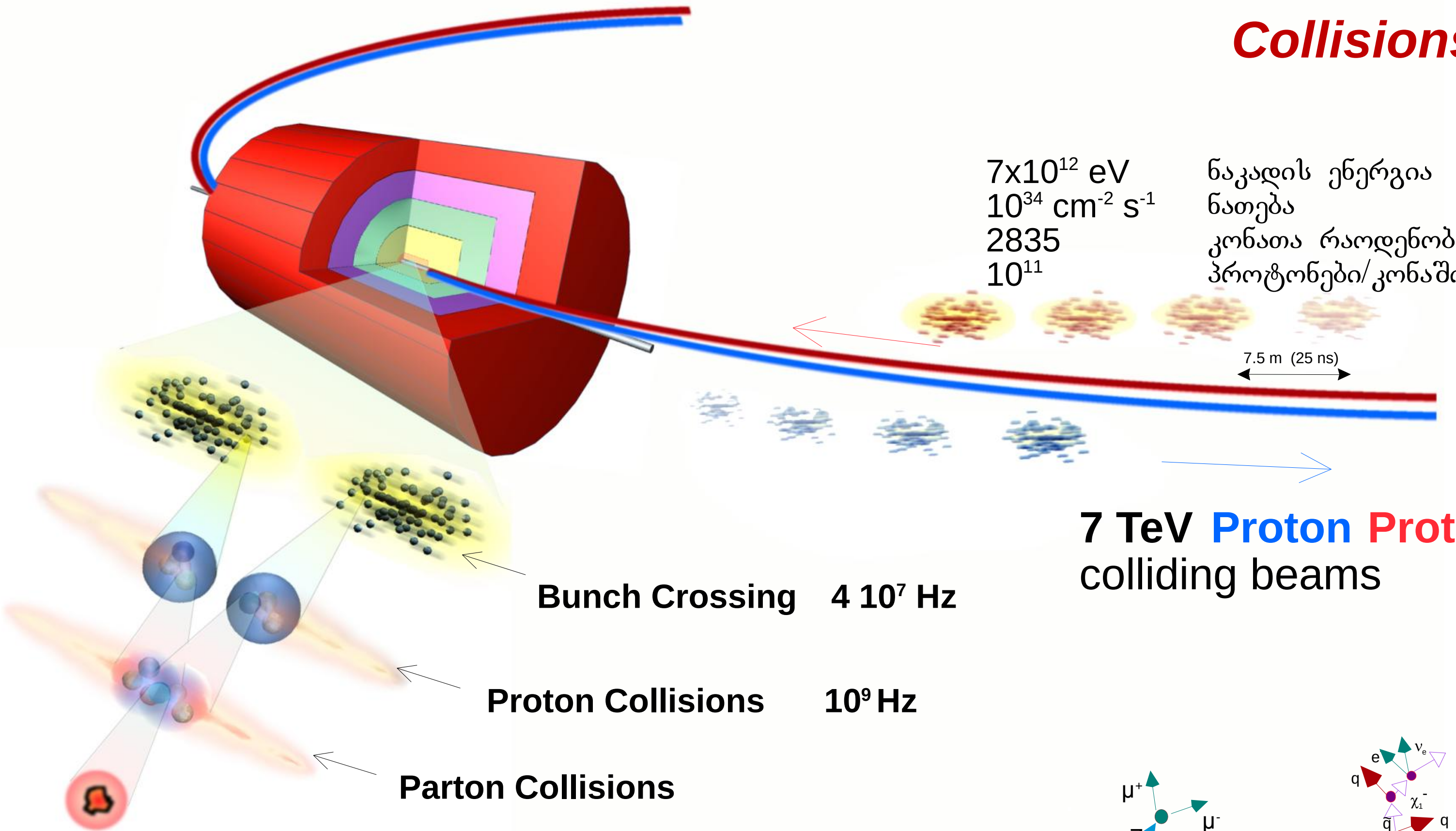


ელექტრული მიკროსკოპი
2 000 000

შუქის მიკროსკოპი
2 000

Collisions at LHC

7×10^{12} eV	ნაკადის ენერგია
10^{34} cm^{-2} s^{-1}	ნათება
2835	კონათა რაოდენობა
10^{11}	პროტონები/კონაში



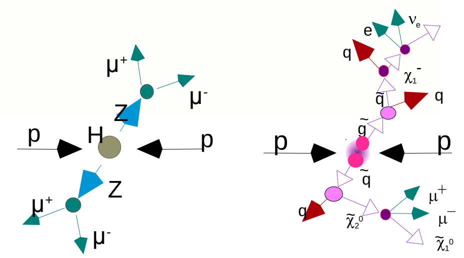
7 TeV Proton Proton
colliding beams

Bunch Crossing **$4\ 10^7$ Hz**

Proton Collisions **10^9 Hz**

Parton Collisions

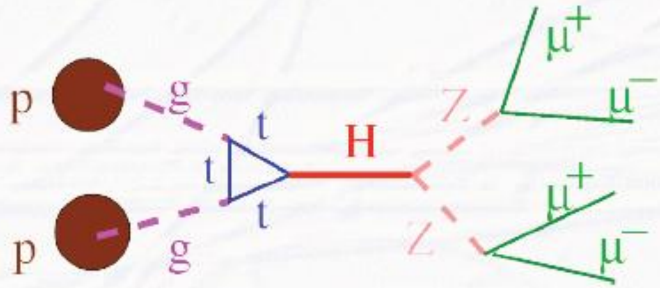
New Particle Production **10^{-5} Hz**
(Higgs, SUSY, ...)



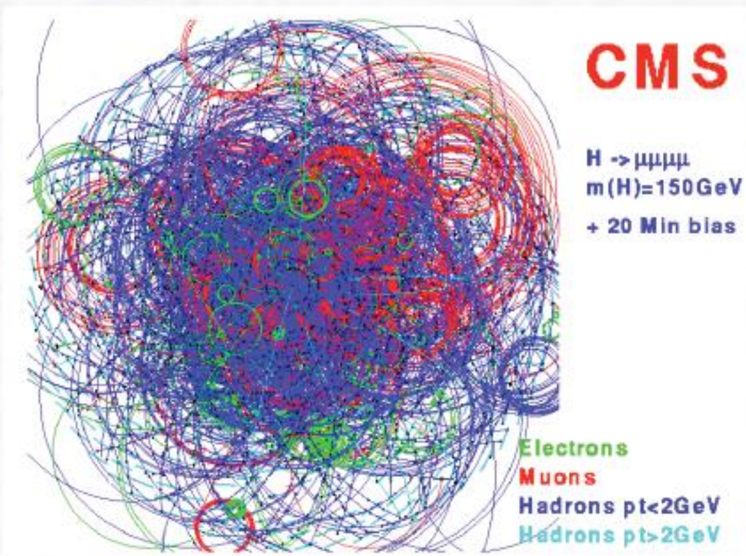
Selection of 1 event in 10,000,000,000,000; 1013**

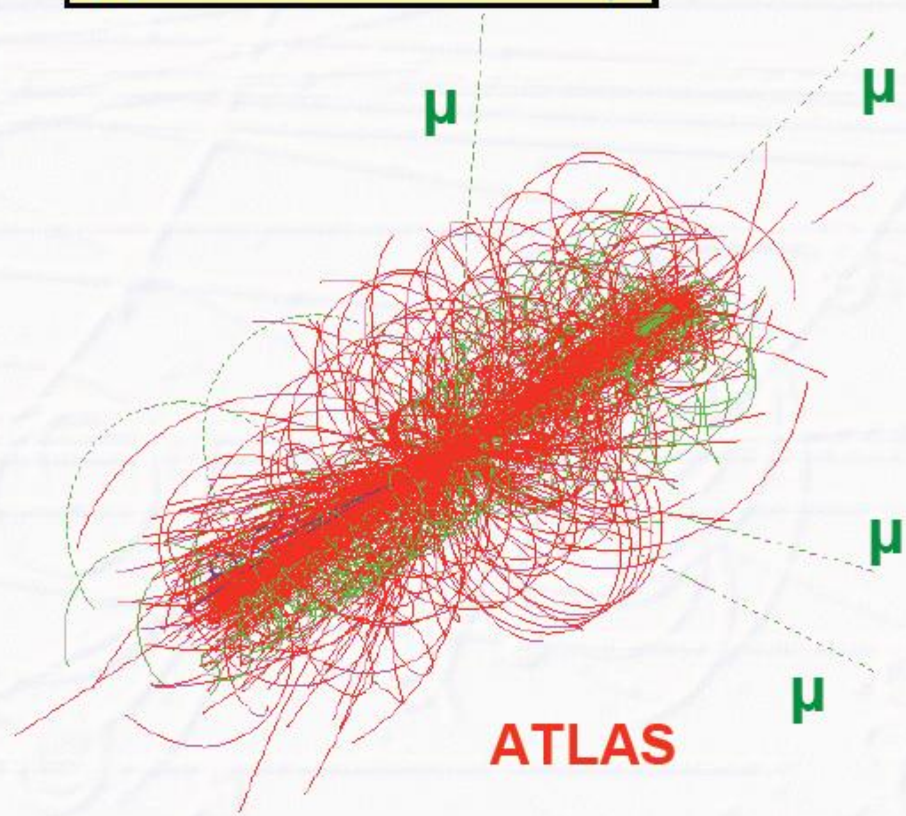
http://hands-on-cern.physto.se/ani/acc_lhc_atlas/lhc_atlas.swf

- **One bunch crossing every 25 ns with ~25 interactions**
  - **1000 tracks per bunch crossing = 4×10^{10} tracks per second …**
  - **… and very often you're interested in a few tracks only!**



$pp \Rightarrow H \Rightarrow ZZ \Rightarrow 4\mu$





ATLAS Collaboration

(As of the April 2007)

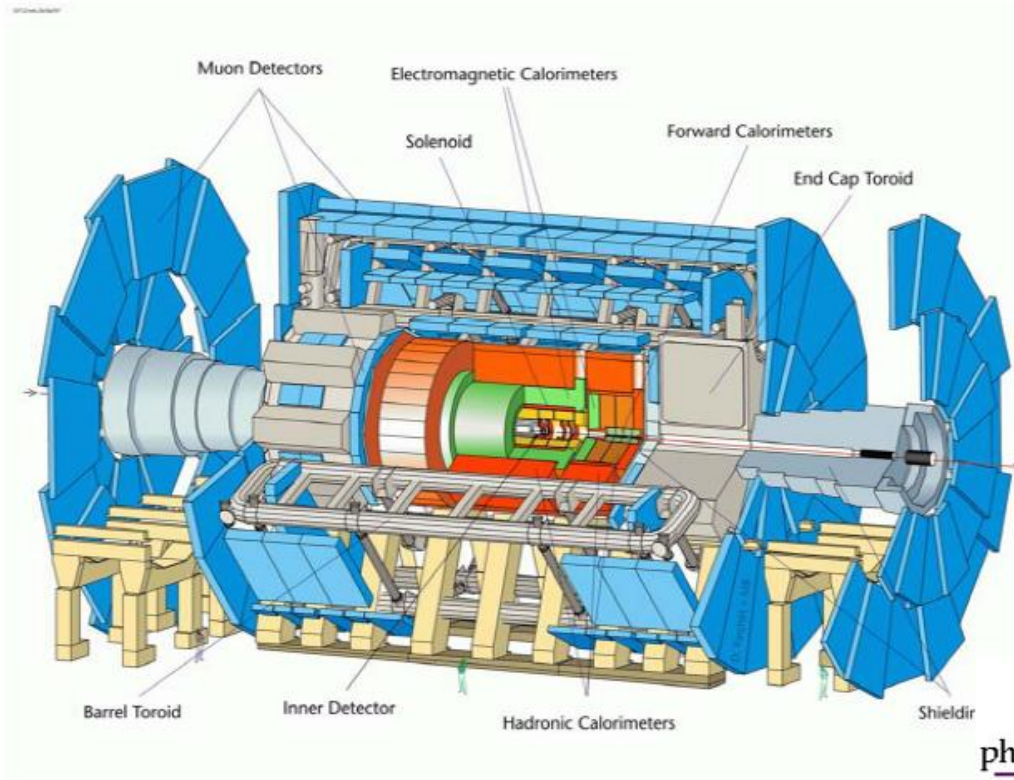
35 Countries
164 Institutions
1900 Scientific Authors total
(400 PhD students)

New Expressions of Interests to join:
Göttingen (Germany)
PUC Santiago, UTFSM Valparaiso (Chile)
UAN Bogota (Colombia)

Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Regina, Ritsumeikan, UFRJ Rio de Janeiro, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Yale, Yerevan

An Aerial View of Point-1

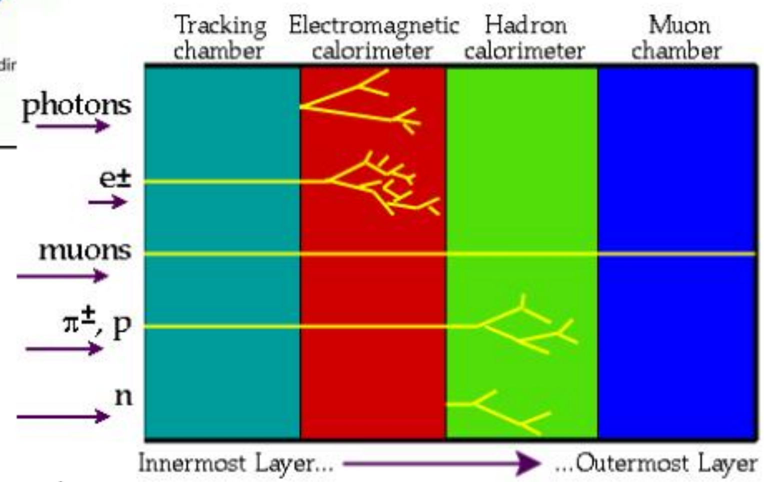
(Across the street from the CERN main entrance)



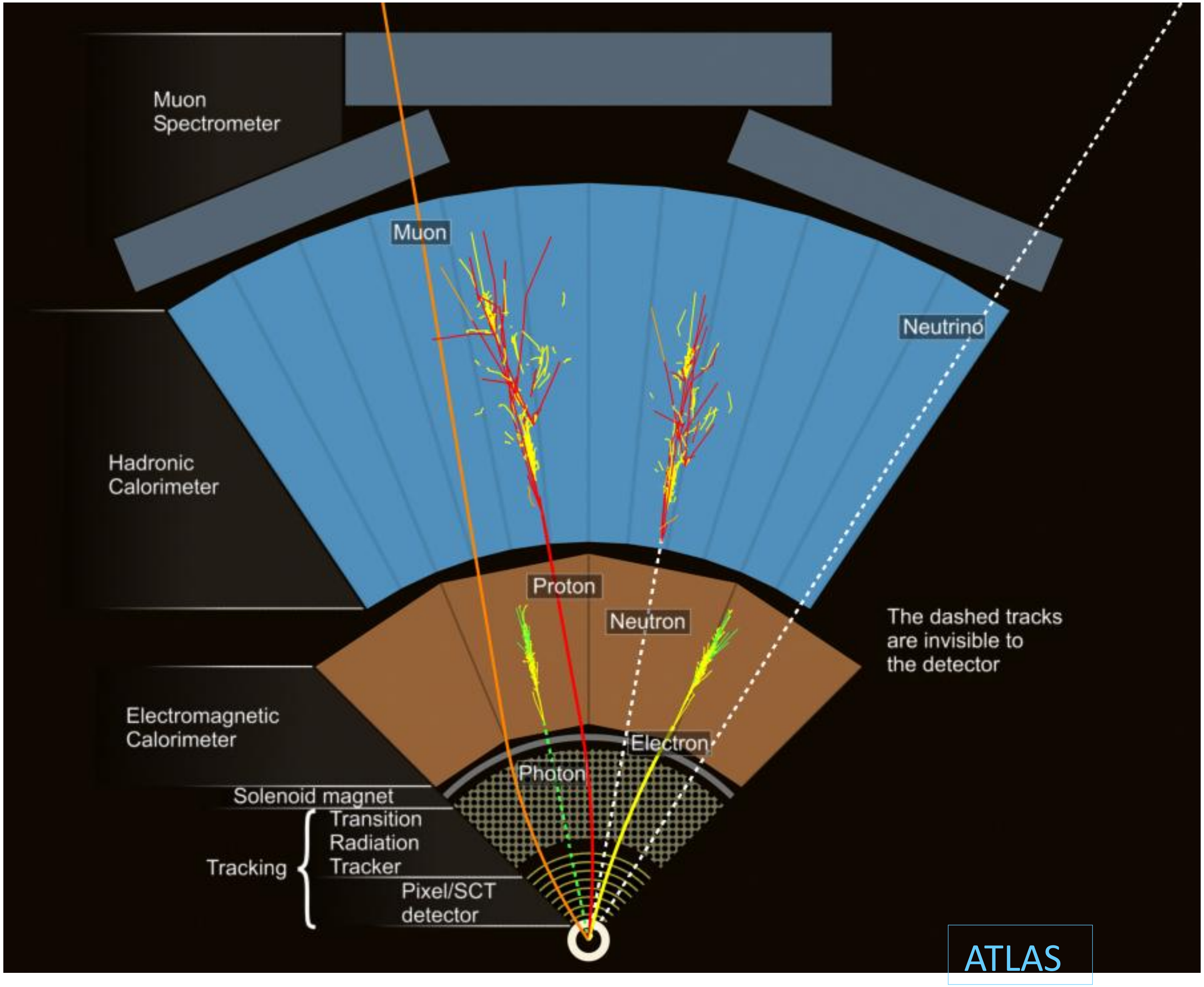
ATLAS

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~ 10^8 electronic channels
~ 3000 km of cables

- **Tracking ($|\eta|<2.5$, B=2T) :**
  - -- Si pixels and strips
  - -- Transition Radiation Detector (e/π separation)
- **Calorimetry ($|\eta|<5$) :**
  - -- EM : Pb-LAr
  - -- HAD: Fe/scintillator (central), Cu/W-LAr (fwd)
- **Muon Spectrometer ($|\eta|<2.7$) :**
  air-core toroids with muon chambers



ელექტრონის, პროტონის და მიუ-მეზონის იდენტიფიკაცია



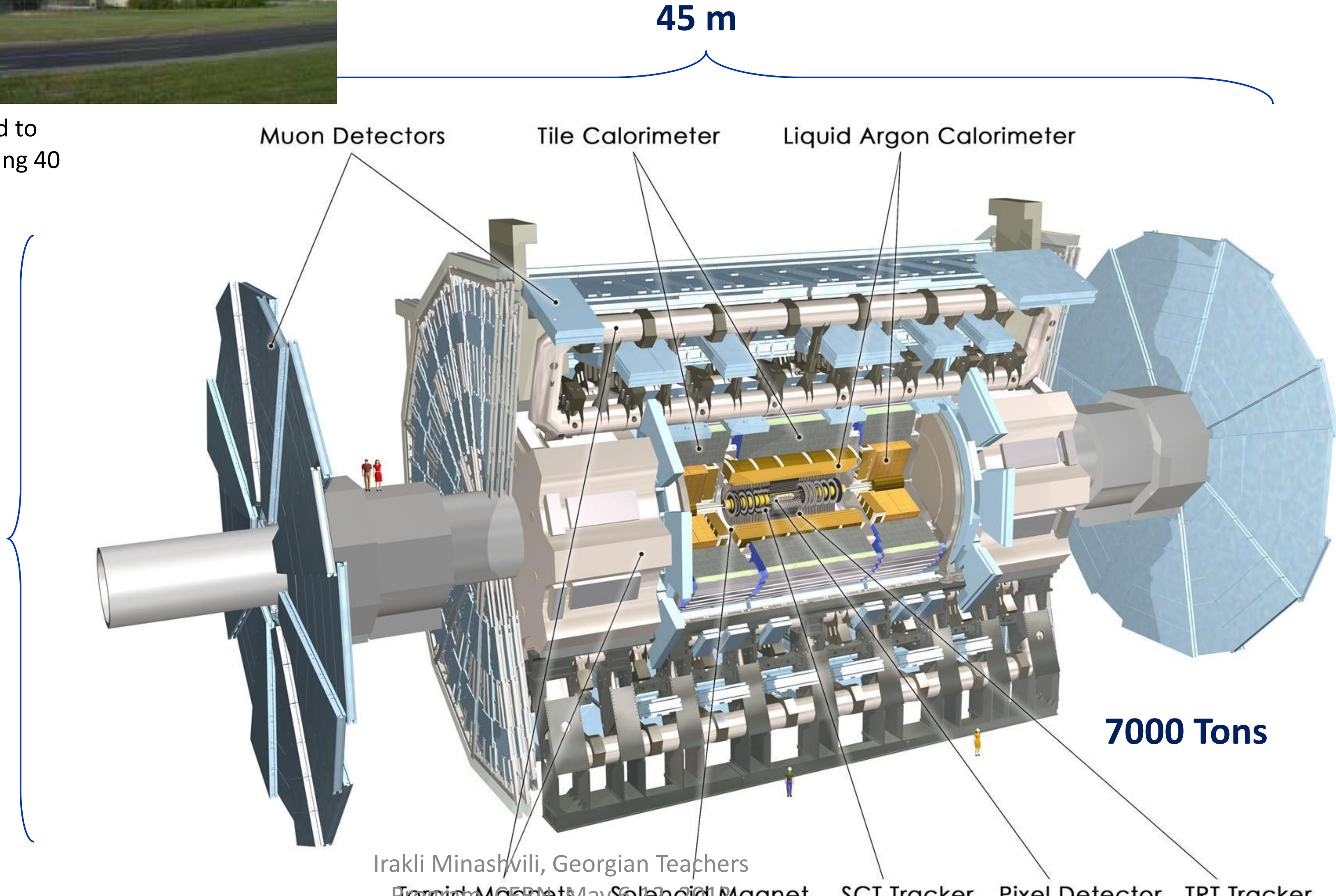
ATLAS

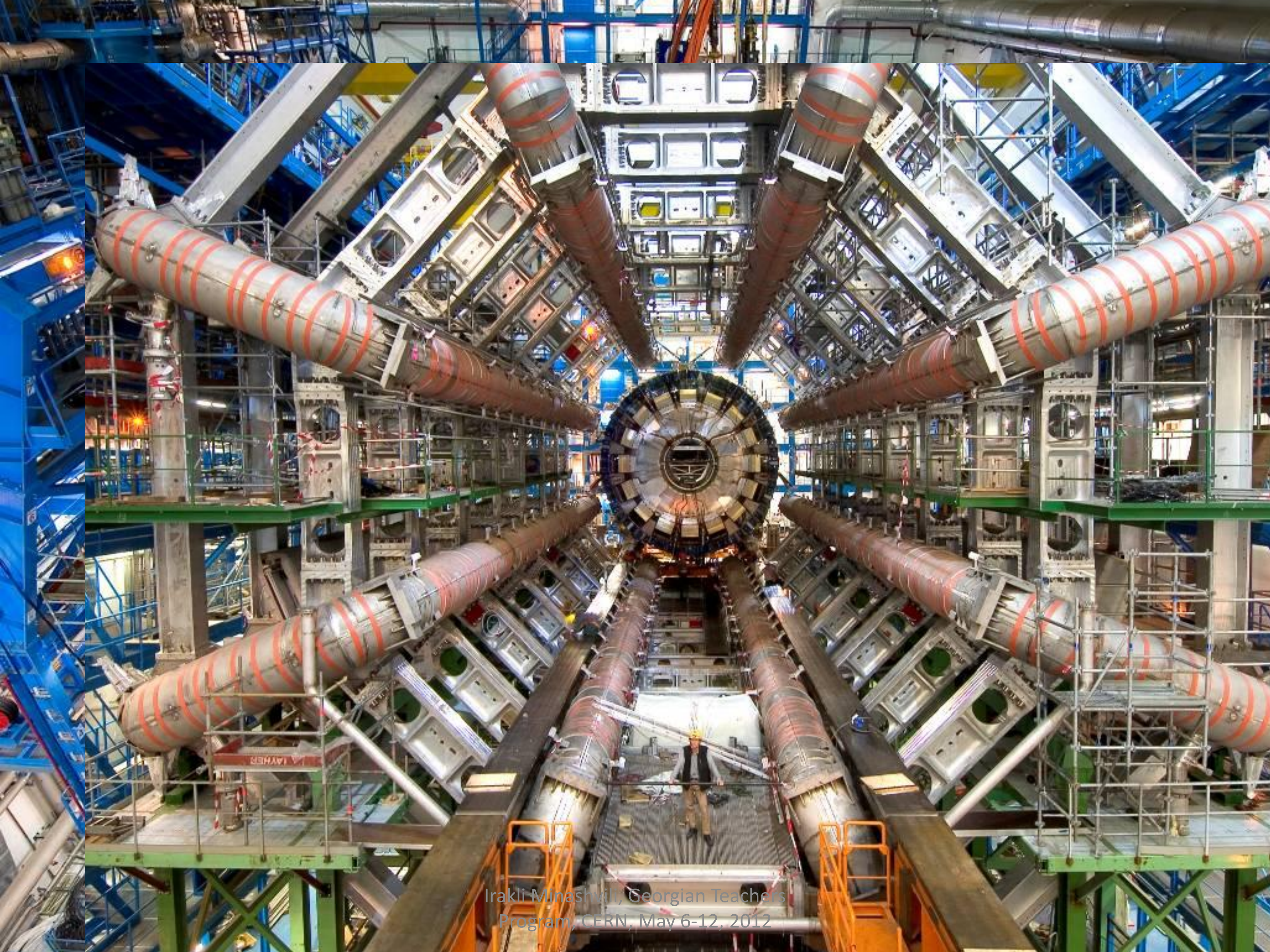
- **Electrons and Photons (e, γ)** – combine information from calorimeters and tracking devices
  - e, γ provide narrow clusters in electromagnetic calorimeter, and deposit all their energy therein
  - e (γ) clusters must (*not*) match with incoming track
  - e can be separated from pions using transition radiation in TRT (ATLAS)
  - For many interesting physics processes e's and γ's are isolated from other particles
  - However, not so for e's from charm and beauty decays and γ's from π^0 decays
  - Backgrounds stem mostly from misidentified jets

- **Muons (μ)** – identified using muon chambers at outer detector (other particles are absorbed)
  - μ momentum and charge can be determined from track bending in B field of μ chambers
  - Backgrounds stem mostly from charged π/K decays in flight

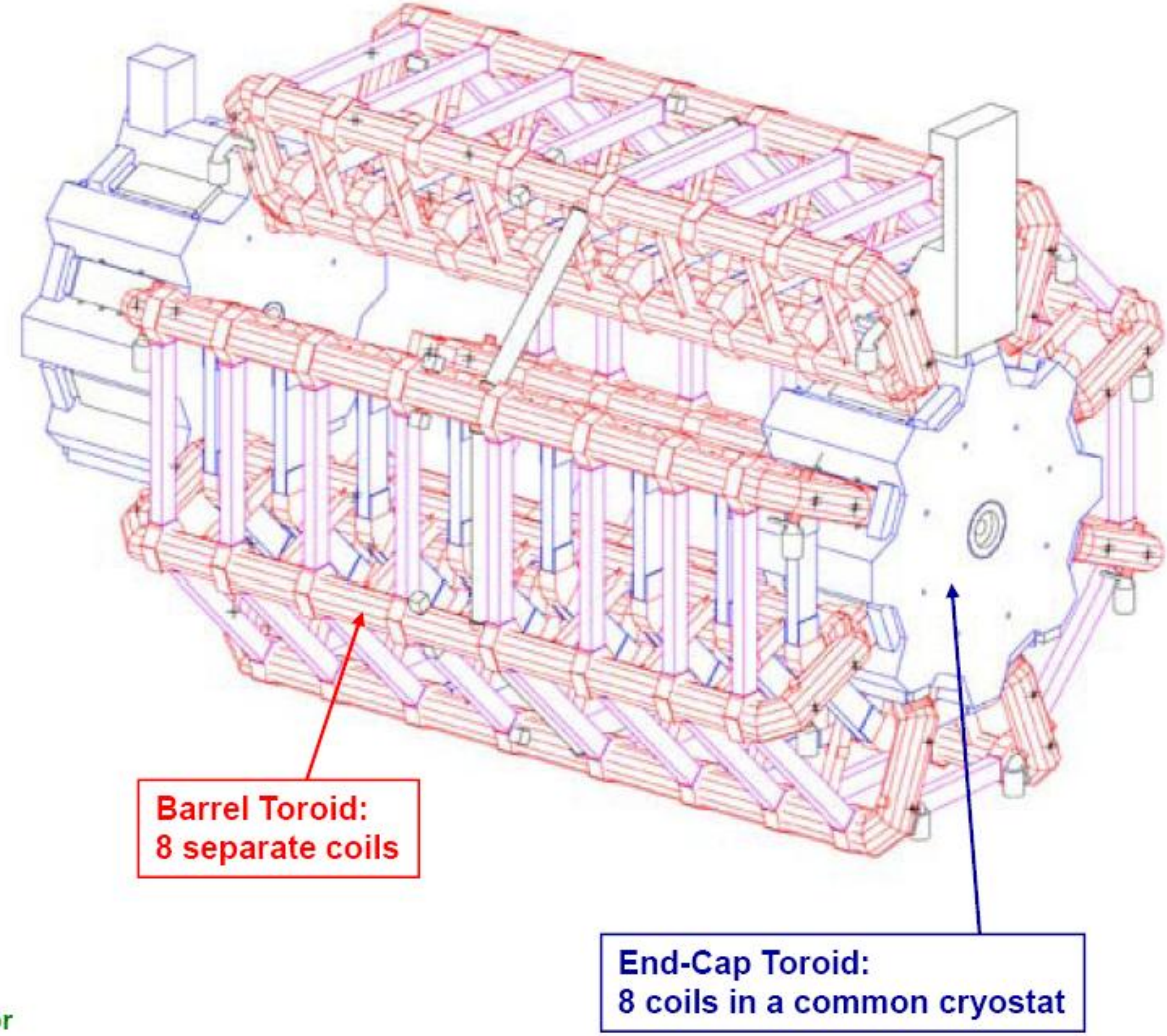
ATLAS Detector

ATLAS superimposed to the 5 floors of building 40





Toroid system

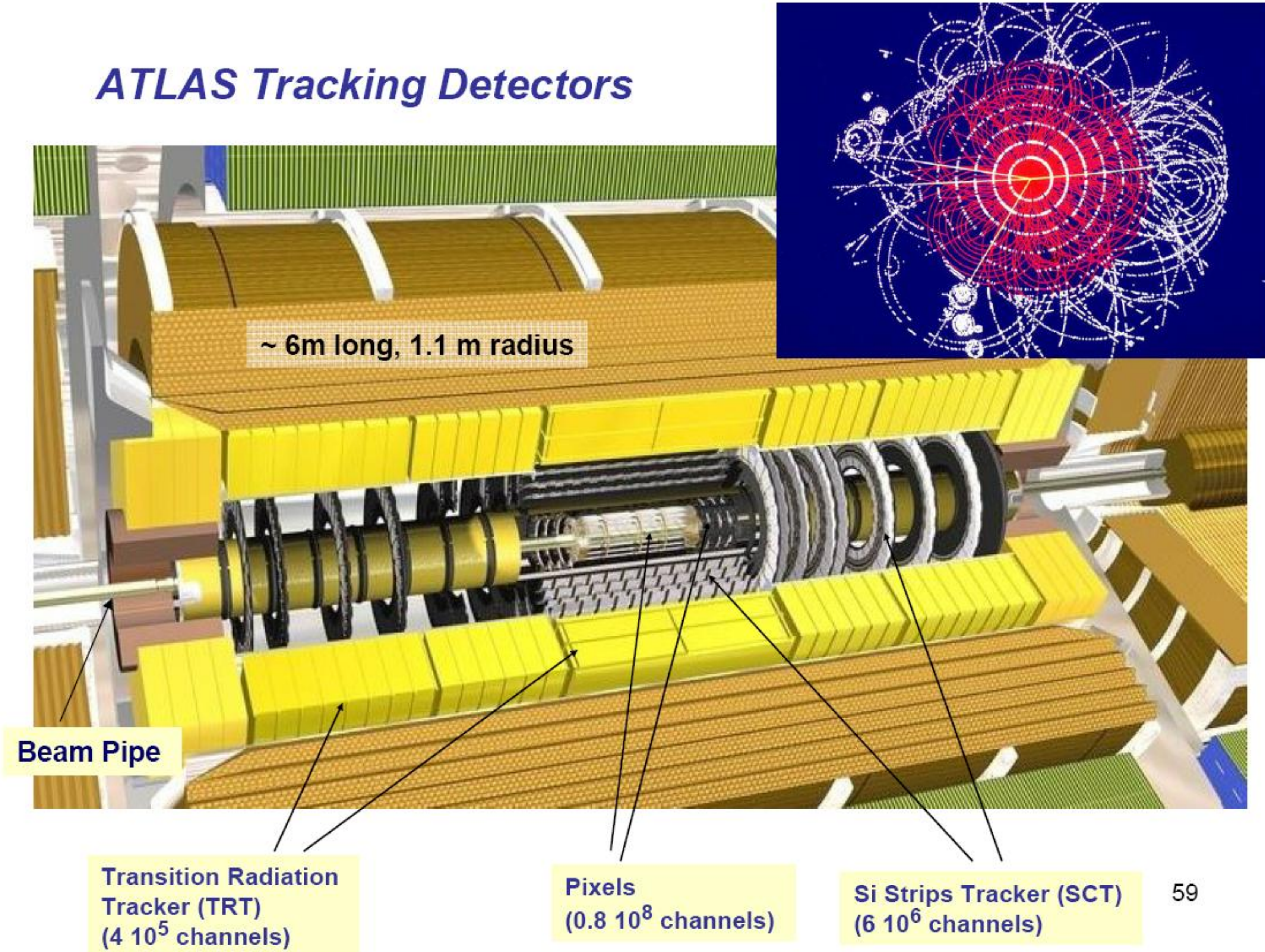


Barrel Toroid parameters
25.3 m length
20.1 m outer diameter
8 coils
1.08 GJ stored energy
370 tons cold mass
830 tons weight
4 T on superconductor
56 km Al/NbTi/Cu conductor
20.5 kA nominal current
4.7 K working point

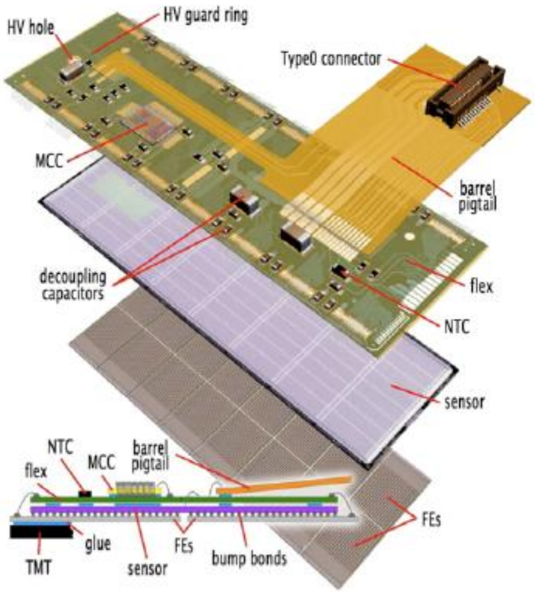
End-Cap Toroid parameters
5.0 m axial length
10.7 m outer diameter
2x8 coils
2x0.25 GJ stored energy
2x160 tons cold mass
2x240 tons weight
4 T on superconductor
2x13 km Al/NbTi/Cu conductor
20.5 kA nominal current
4.7 K working point

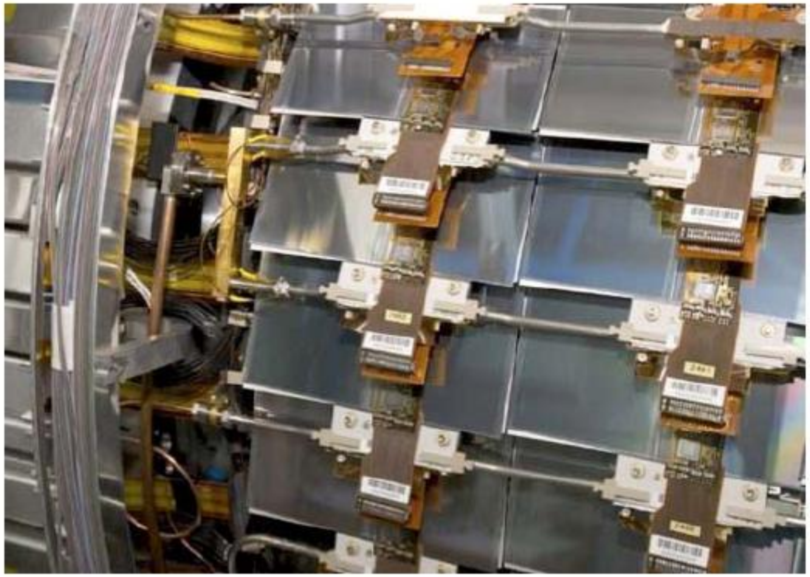

friderici

ATLAS Tracking Detectors



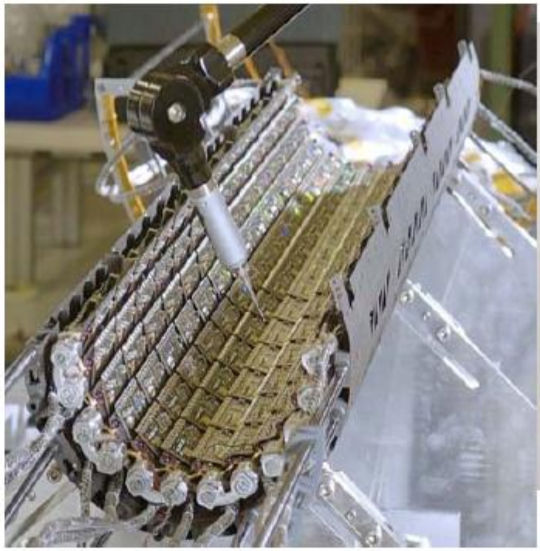
Detector Silicon-sensors

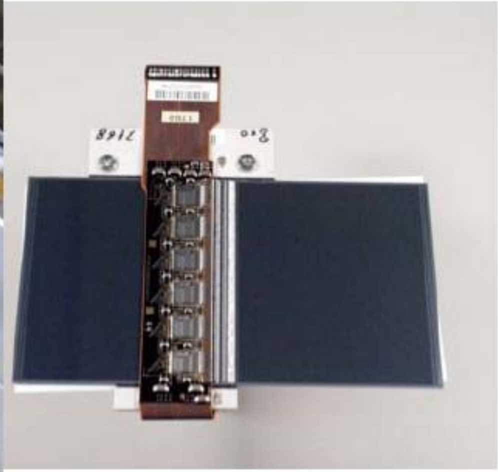


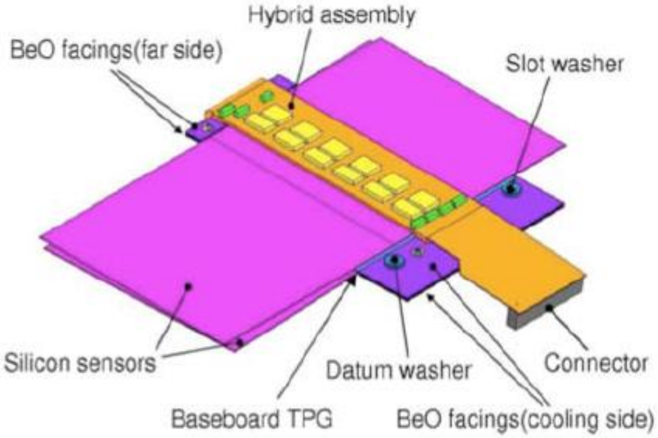


1744 Pixel modules, pixels 50x400 μm^2

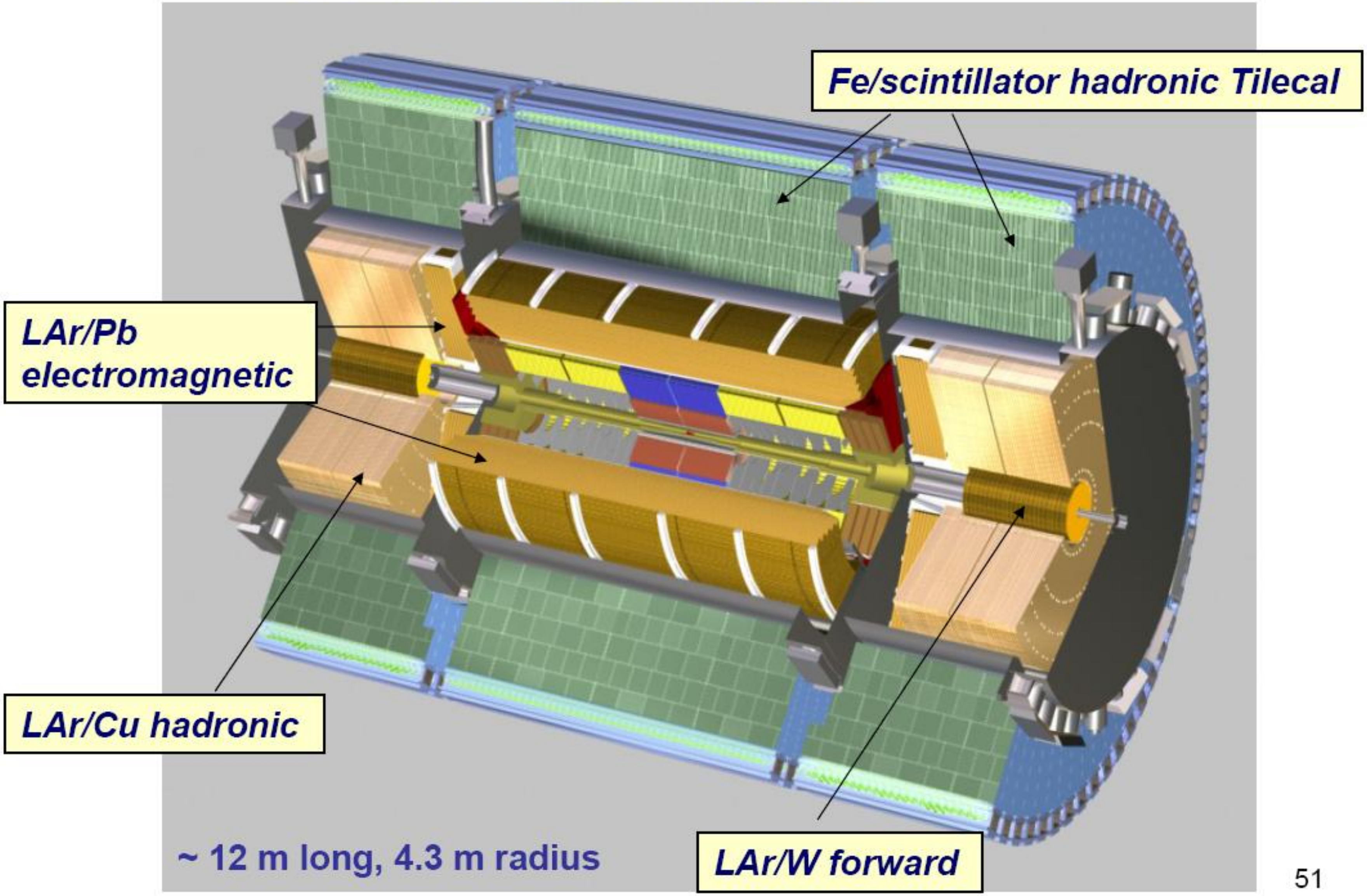
4088 SCT modules, 80 μm micro-strips







ATLAS Calorimeters

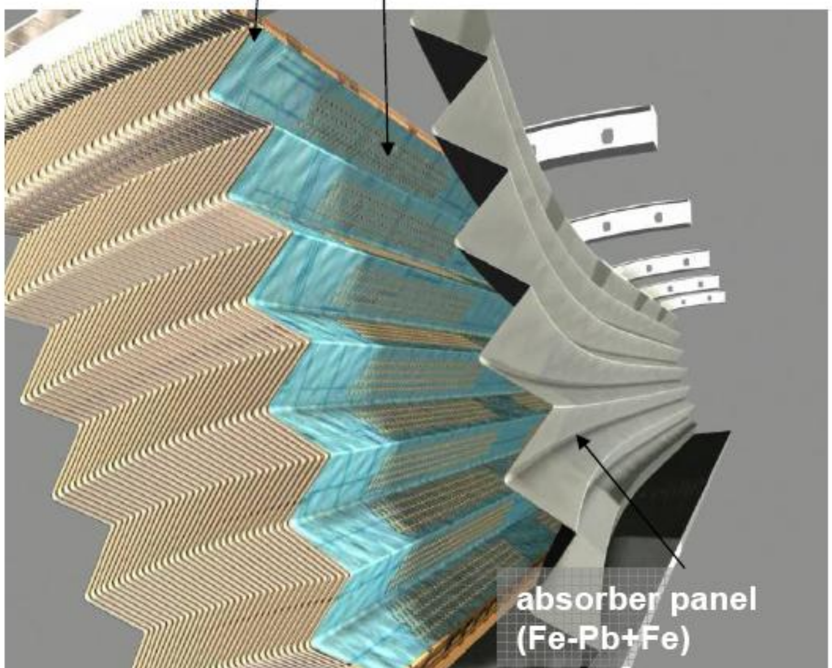


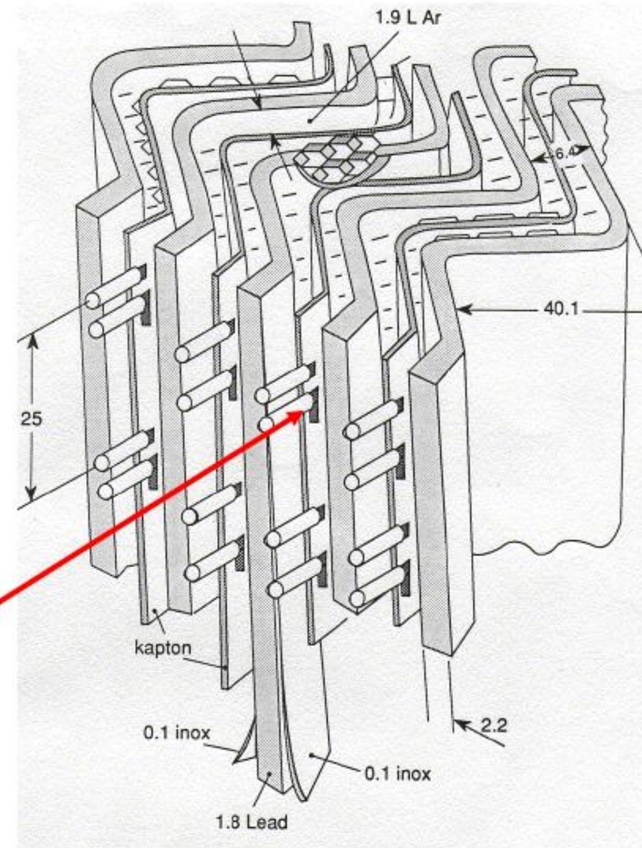
ATLAS Electromagnetic Calorimeters

LAr sampling calorimeter accordion geometry

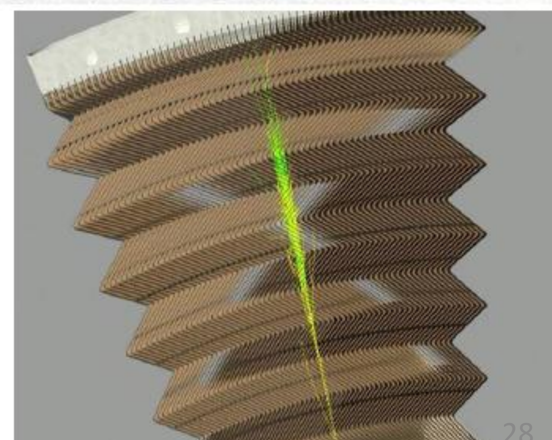
readout panel

LAr gap

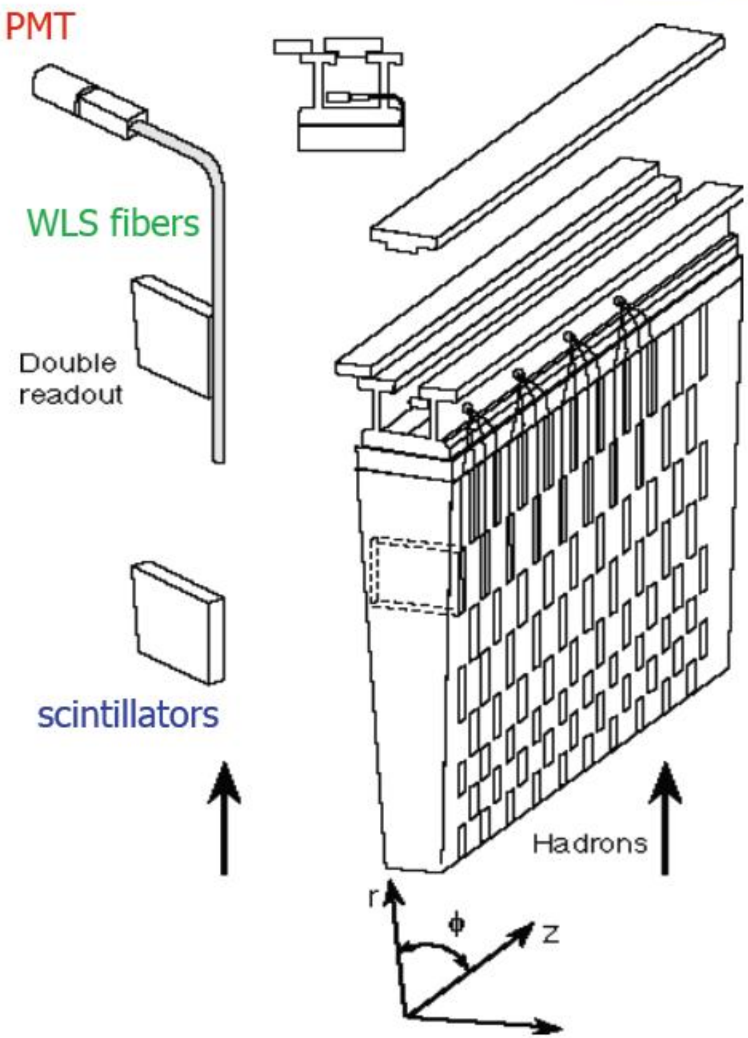




Why ?
- readout speed
- radiation hard
- electronically inter-calibrated
- allows longitudinal segmentation
- hermetic in phi
- good energy and angular resolution



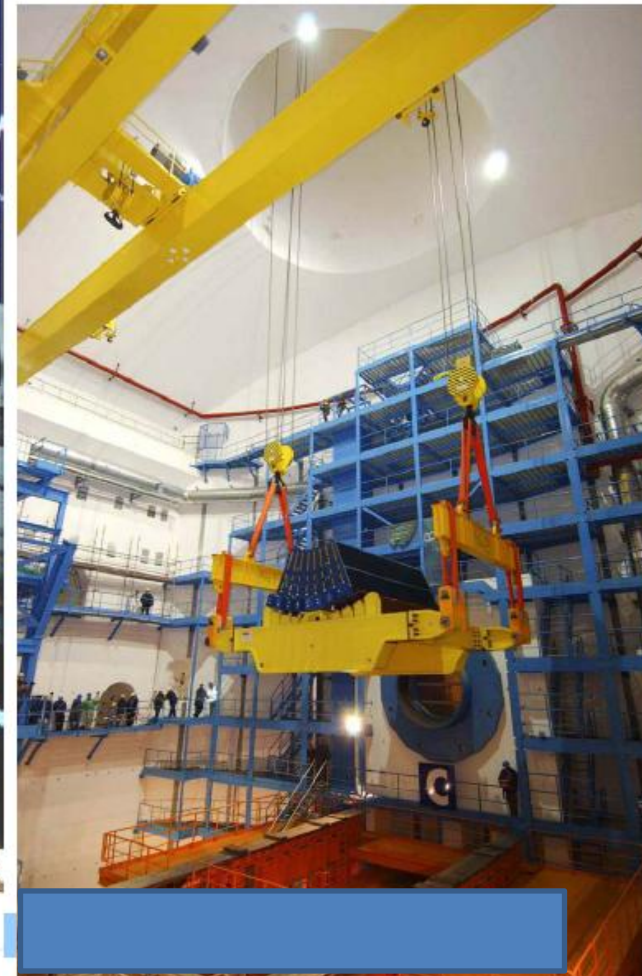
Tile Calorimeter

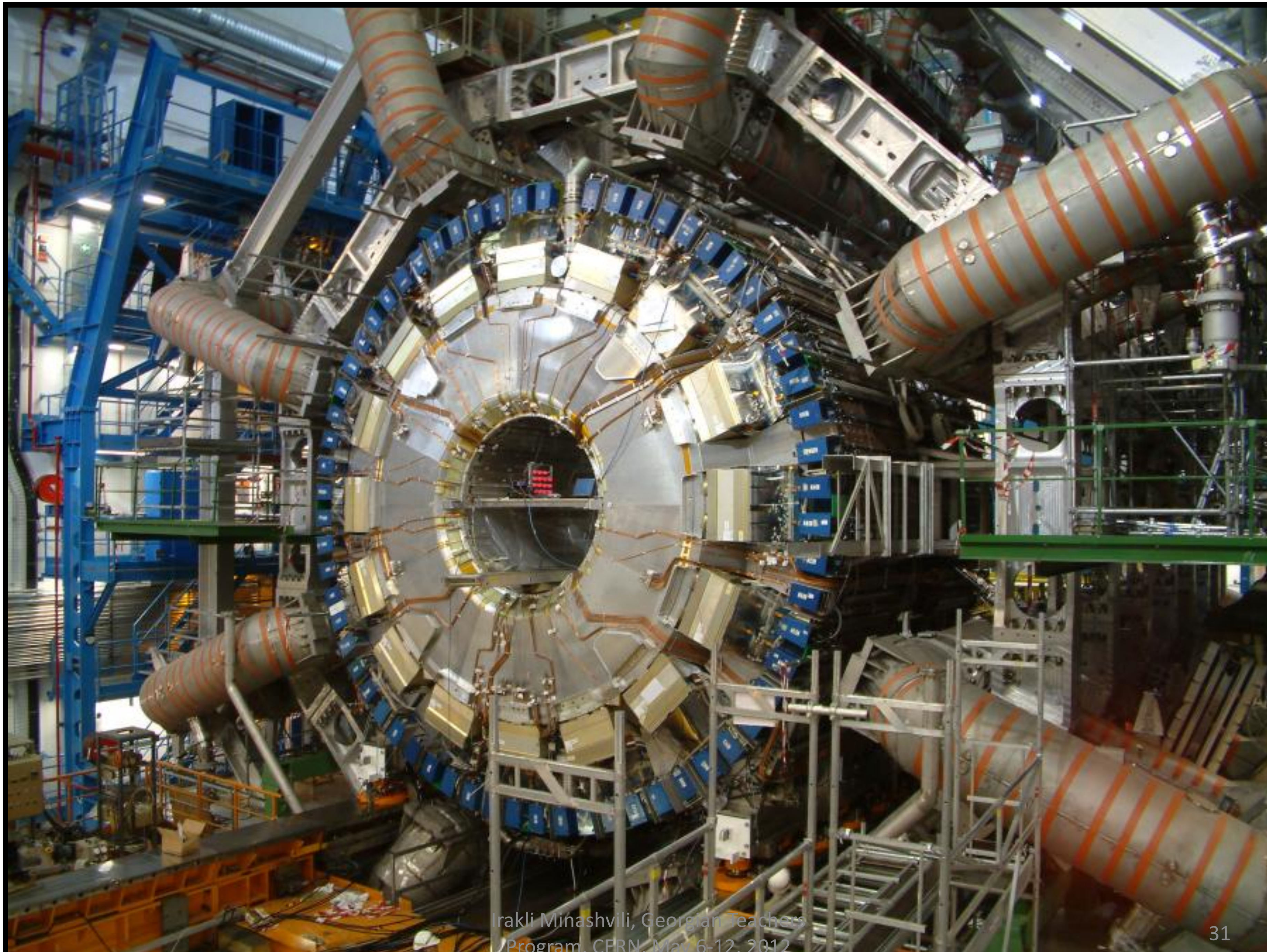


22/05/2006 *HCP2006-2006*

Tile Calorimeter

15 years of fruitful collaboration with our Romanian friends... !

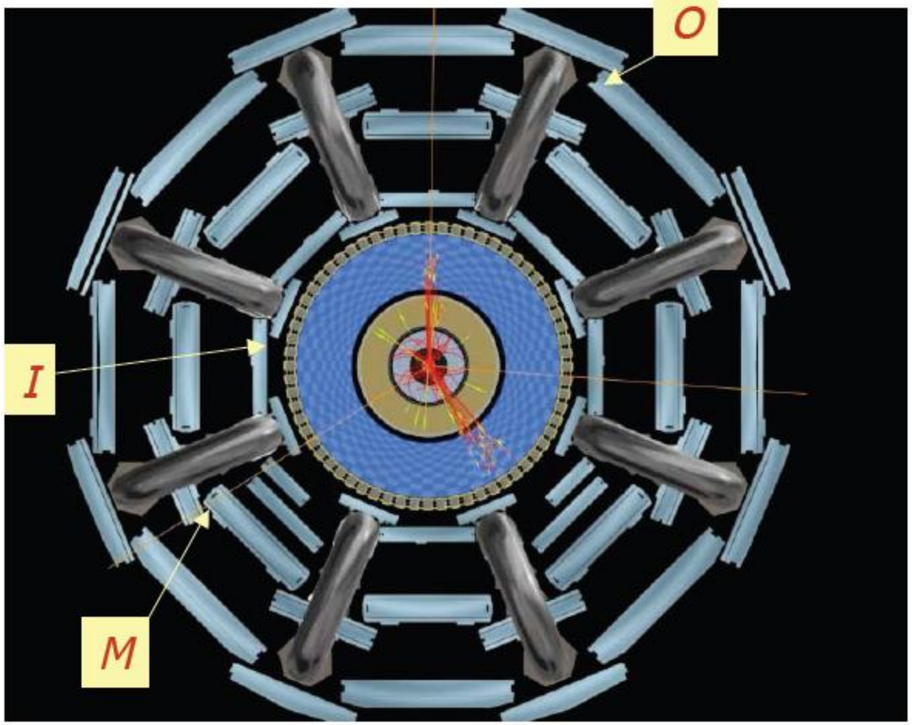


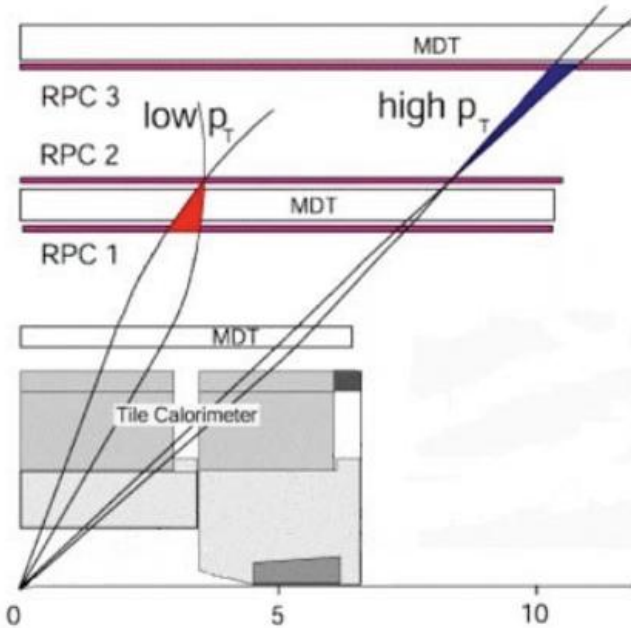


The muon spectrometer (barrel)

Barrel: precision and trigger chambers in 3 layers (588 stations):
I (inner) - M (middle) - O(outer)

Trigger chambers (RPC) rate capability required ~ 1 kHz/cm^2



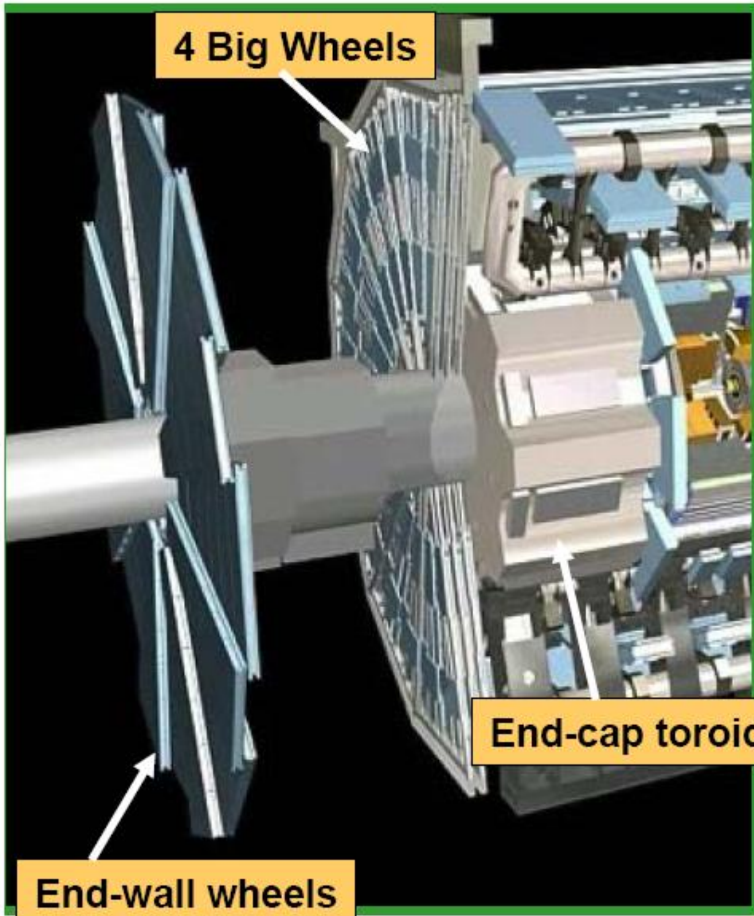


2 technologies:

MDT - *Monitored Drift Tubes (layers: I,O,M)*

RPC - *Resistive Plate Chambers (trigger) (layers M+M,O)*

Forward muon spectrometer
- ‘Big Wheels’ are all installed
- The end-wall wheel installation has started

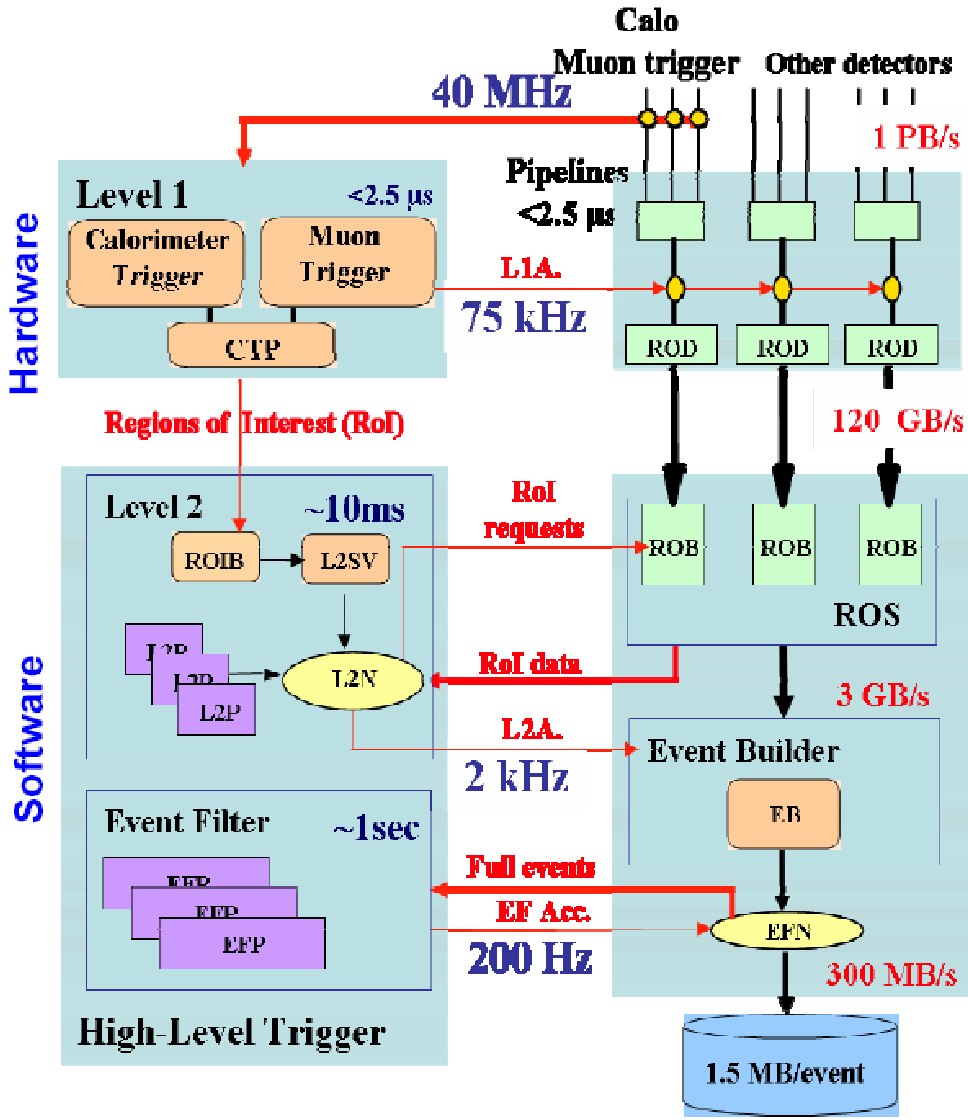


ATLAS Trigger and Data Acquisition

Level 1 decision based on data from calorimeters and muon trigger chambers; synchronous at 40 MHz

Level 2 uses Regions of Interest identified by Level-1 (< 10% of full event) with full granularity from all detectors

Event Filter has access to full event and can perform more refined event reconstruction



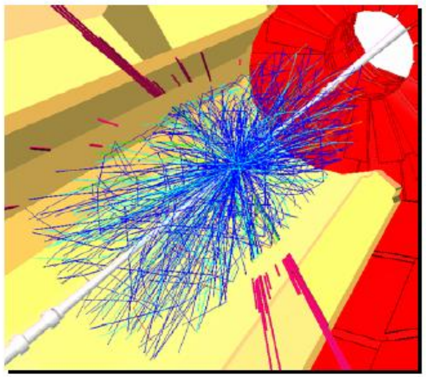
Reduce rate from 40 MHz to 200Hz while retaining the rare, interesting events

66

მონაცემების დაგროვების **ტრიგერის** სისტემა ატლას-ზე დაფუძნებულია საწყისი მონაცემების სამ საფეხურიან შერჩევაზე. ტრიგერის საშუალებით ხდება მონაცემთა არჩევა მანამ ინფორმაცია ჩაიწერება მეხსიერებაში (ინფორმაციის მატარებლებზე).

იმ **10's PetaByte/sec (100 000 CD's/sec)** შემთხვევებიდან რომლებიც წარმოიქმნებიან ატლას-ზე მხოლოდ **100 MetaByte/sec (1 CD's/2sec)** აირჩევა როგორც საჭირო, კარგი შემთხვევა შემდგომი ანალიზისათვის.

Worldwide LHC Computing Grid (WLCG)



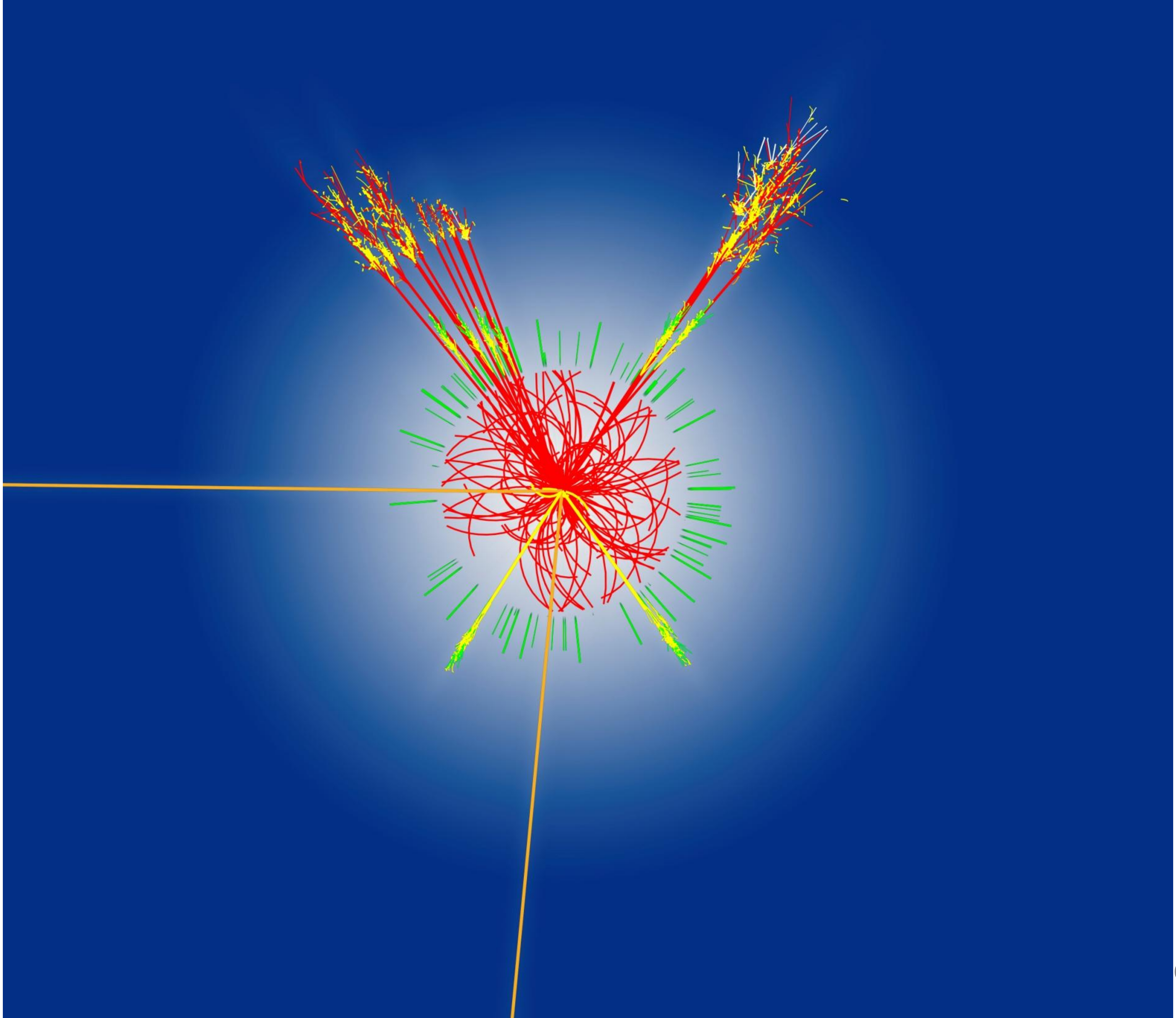
WLCG is a worldwide collaborative effort on an unprecedented scale in terms of storage and CPU requirements, as well as the software project's size

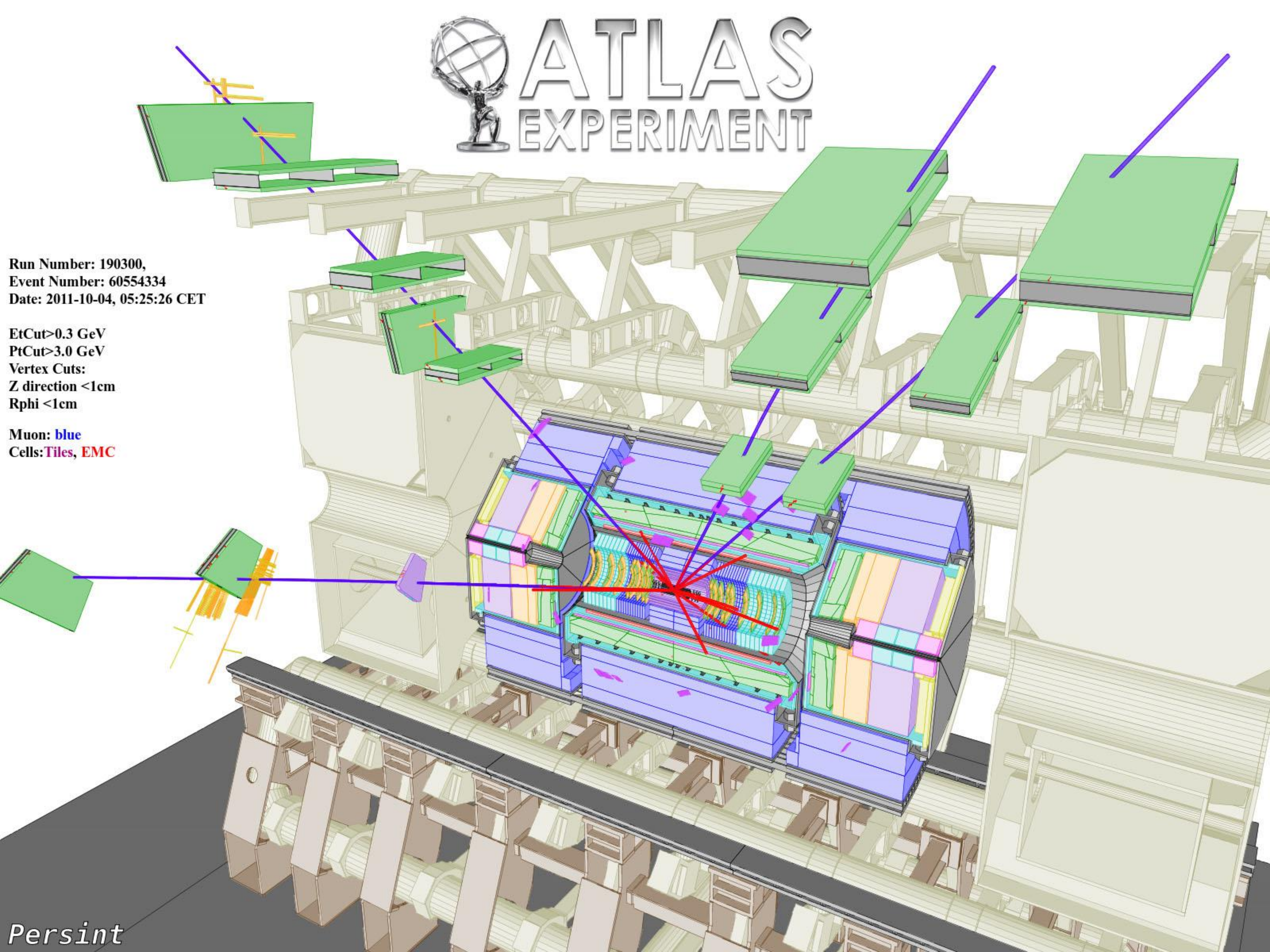
GRID computing developed to solve problem of data storage and analysis

LHC data volume per year:
10-15 Petabytes

One CD has ~ 600 Megabytes
1 Petabyte = 10^9 MB = 10^{15} Byte

(Note: the WWW is from CERN...)




ATLAS
EXPERIMENT
Run Number: 190300,
Event Number: 60554334
Date: 2011-10-04, 05:25:26 CET
EtCut>0.3 GeV
PtCut>3.0 GeV
Vertex Cuts:
Z direction <1cm
Rphi <1cm
Muon: blue
Cells:Tiles, EMC
Persint

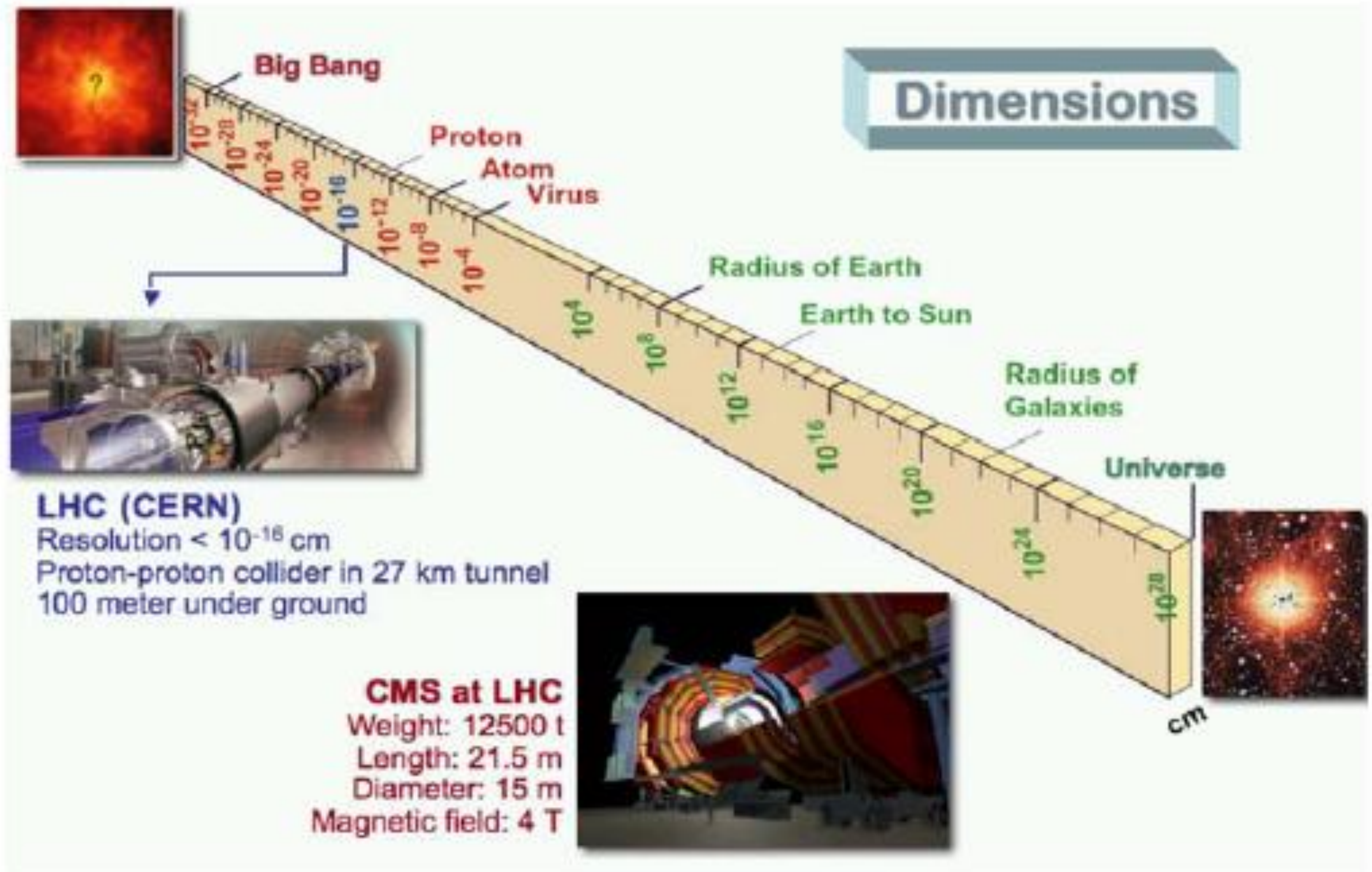
ატლას დეტექტორის მენეჯმენთის თხოვნაა რაც შეიძლება მალე მოამზადოთ ახალი თაობა ფიზიკოსებისა დიდ ადრონულ კოლაიდერზე დასმული ამოცანების გადასაწყვეტად. მხოლოდ მომავალ თაობას შესწევს ასეთი ამბიციური პროექტების წარმატებულად შესრულება.

გისურვებთ ამ საქმეში ყოველგვარ წინსვლას.

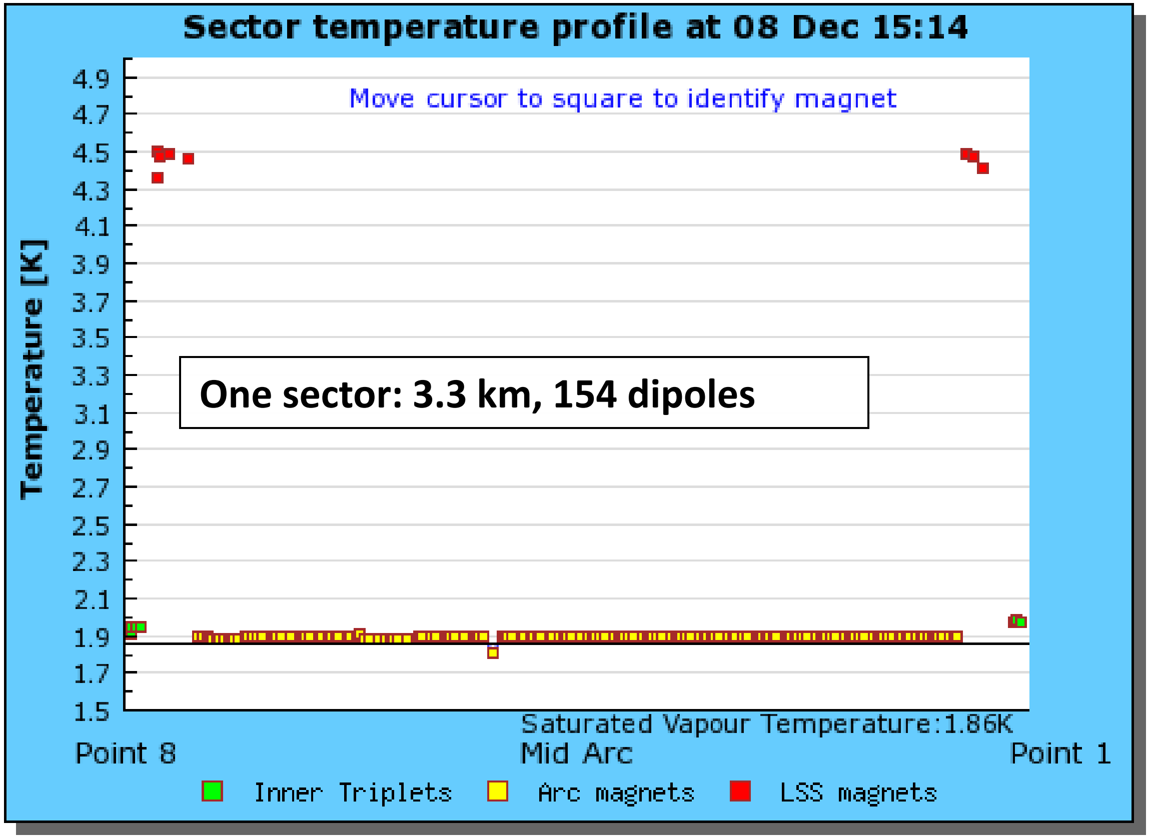
გმადლობთ ყურადღებისათვის და მოთმინებისთვის.

მომავალ შეხვედრამდე.

Back slides

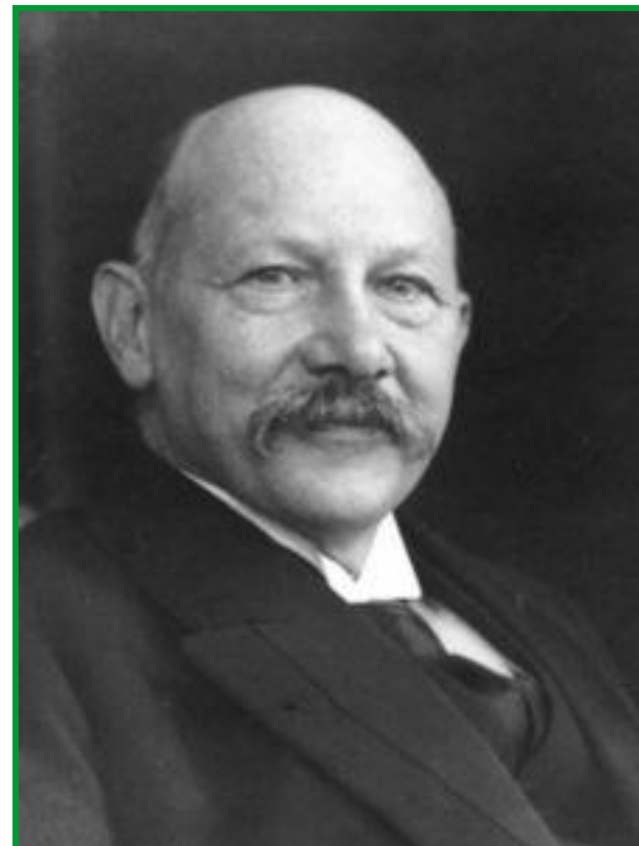

Dimensions
Big Bang
Proton
Atom
Virus
Radius of Earth
Earth to Sun
Radius of Galaxies
Universe
10^{-32}
10^{-28}
10^{-24}
10^{-20}
10^{-16}
10^{-12}
10^{-8}
10^{-4}
10^{4}
10^{8}
10^{12}
10^{16}
10^{20}
10^{24}
10^{28}
cm
LHC (CERN)
Resolution < 10^{-16} cm
Proton-proton collider in 27 km tunnel
100 meter under ground
CMS at LHC
Weight: 12500 t
Length: 21.5 m
Diameter: 15 m
Magnetic field: 4 T

The LHC is the largest cryogenic system on earth, cooler than outer space



Magnets cooled down in a bath of ~120 tons of superfluid Helium (excellent thermal conductor)

H K Onnes
Nobel Prize in Physics 1913

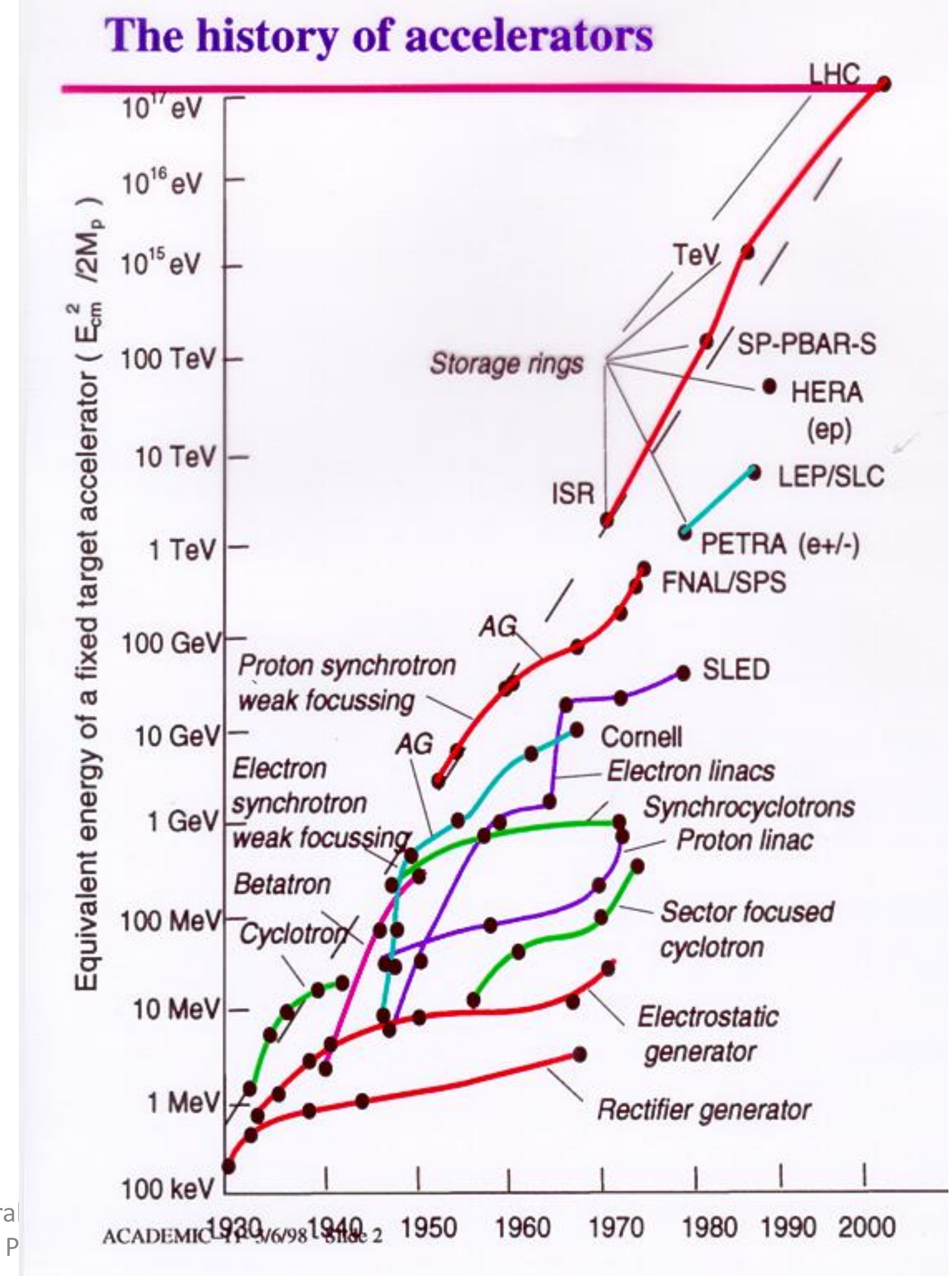


- **~100 years ago, on 10 July 1908: Heike K Onnes first liquefied Helium (60 ml in 1 hour) in Leiden**
- **LHC today: 32000 He liters liquefied per hour by eight big cryogenic plants (the largest refrigerator in the world)**

An exponential development over 70 years,

following emerging technologies,

superconductivity has been the key technology for high energy accelerators since the 1980s.



Main parameters of the machine

Design operation

Beam energy	7	TeV
Instantaneous luminosity L	10^{34}	$cm^{-2}s^{-1}$
Integrated luminosity/year	~ 100	fb^{-1}
Dipole field	8.4	T
Dipole current	11700	A
Circulating current/beam	0.53	A
Number of bunches	2808	
Bunch spacing	25	ns
Protons per bunch	10^{11}	
R.m.s. beam radius at IP1/5	16	μm
R.m.s. bunch length	7.5	cm
Stored beam energy	360	MJ
Crossing angle	300	μrad
Number of events per crossing	20	
Luminosity lifetime	10	hours

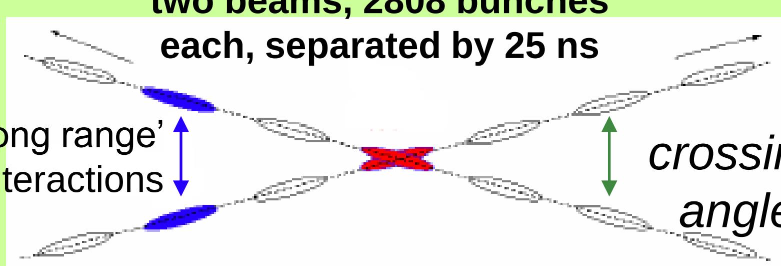
$$L = \frac{N^2 k_b f}{4\pi\sigma_x\sigma_y}$$

n. of protons per bunch (N); n. of bunches (k_b); n. of turns per second (f)

beam size at IP ($\sigma_{x,y}$ = 16 μm)

N = L x σ (pp → X)

two beams, 2808 bunches each, separated by 25 ns



x200 Tevatron

Aircraft carrier at 12 knots

Maximum B-field

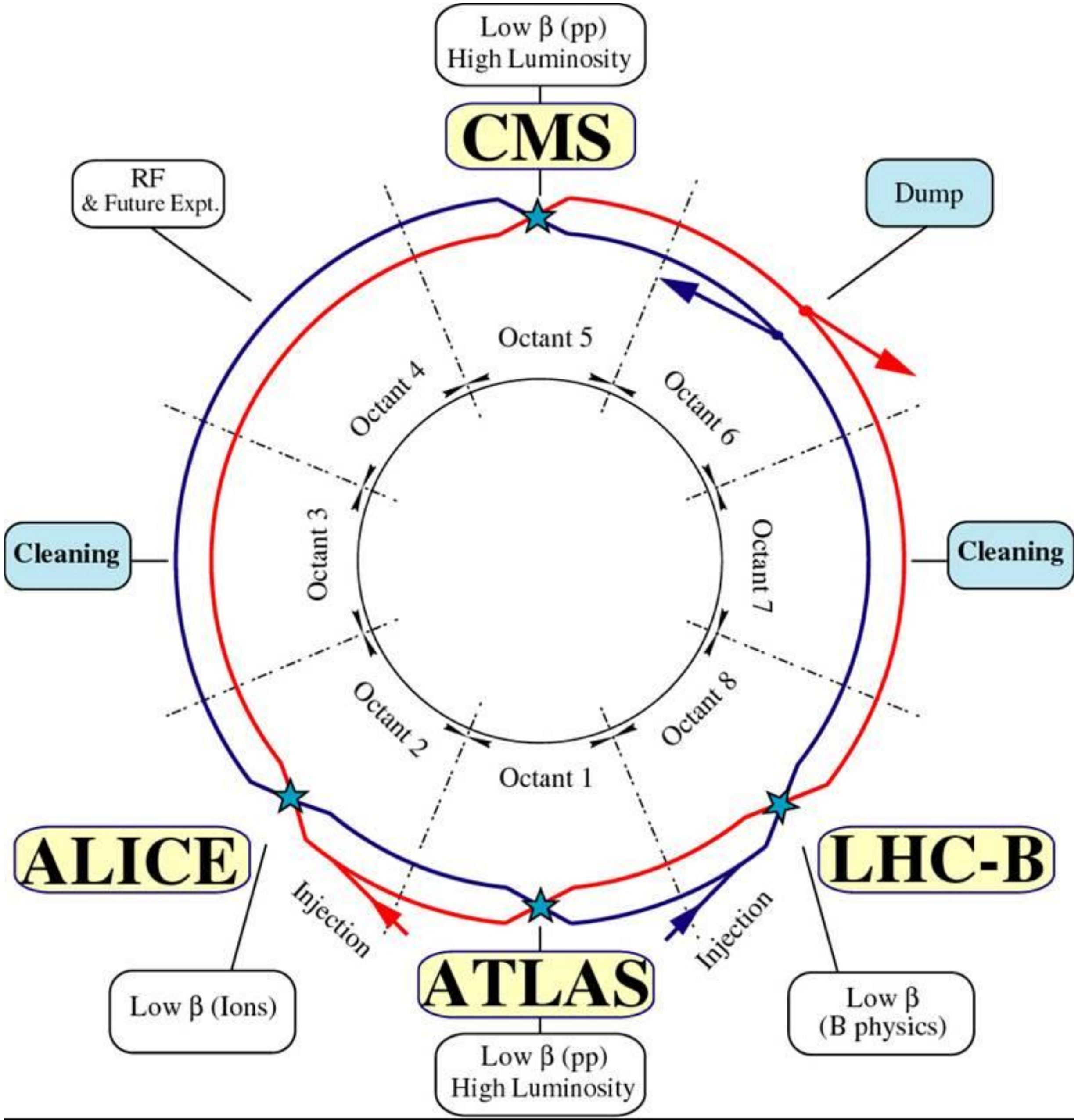
- *required maximum dipole field:*

$B \propto \gamma$

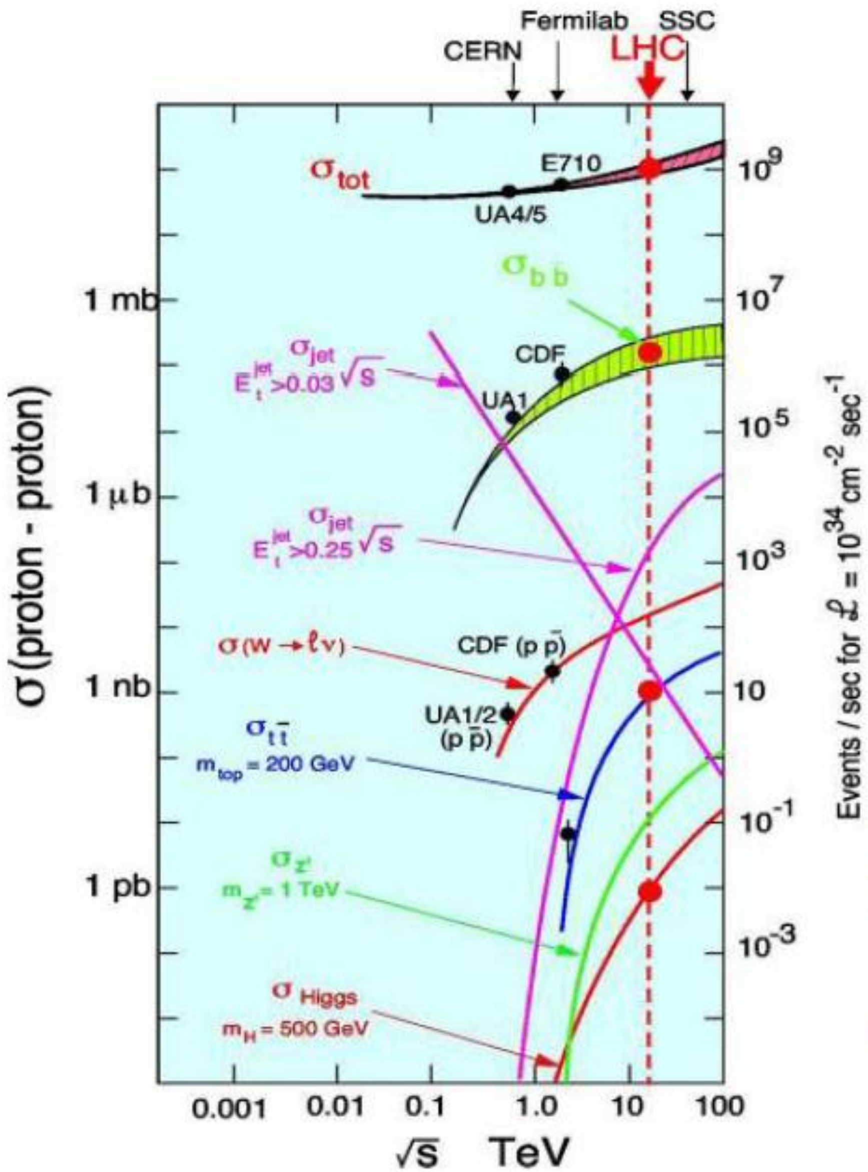
→ $$B[T] = \frac{2\pi}{0.3} \cdot \frac{p[GeV/c]}{F \cdot L[meter]}$$

- *Physics:* → p = 7000 GeV/c
- *LEP tunnel:* L = 27000 meter
- only 80% of the arc are filled with dipoles: → F = 0.

→ $B_{max} = 8.38\ T$ → *iron saturation: 2 Tesla*
earth: $0.3 * 10^{-4}$ Tesla


Low β (pp)
High Luminosity
CMS
RF
& Future Expt.
Dump
Octant 5
Octant 4
Octant 6
Octant 3
Octant 7
Cleaning
Cleaning
Octant 2
Octant 8
Octant 1
ALICE
LHC-B
Injection
Injection
ATLAS
Low β (Ions)
Low β
(B physics)
Low β (pp)
High Luminosity

Cross Sections and Production Rates



Rates for $L = 10^{34}$ cm^{-2} s^{-1}: (LHC)

• Inelastic proton-proton reactions:	10^9 / s
• bb pairs	5 10^6 / s
• tt pairs	8 / s
• W → e ν	150 / s
• Z → e e	15 / s
• Higgs (150 GeV)	0.2 / s
• Gluino, Squarks (1 TeV)	0.03 / s

LHC is a factory for:
top-quarks, b-quarks, W, Z, ……. Higgs, ……

(The challenge: you have to detect them !)

Search for the Standard Model Higgs boson over ~115 < m_H < 1000 GeV

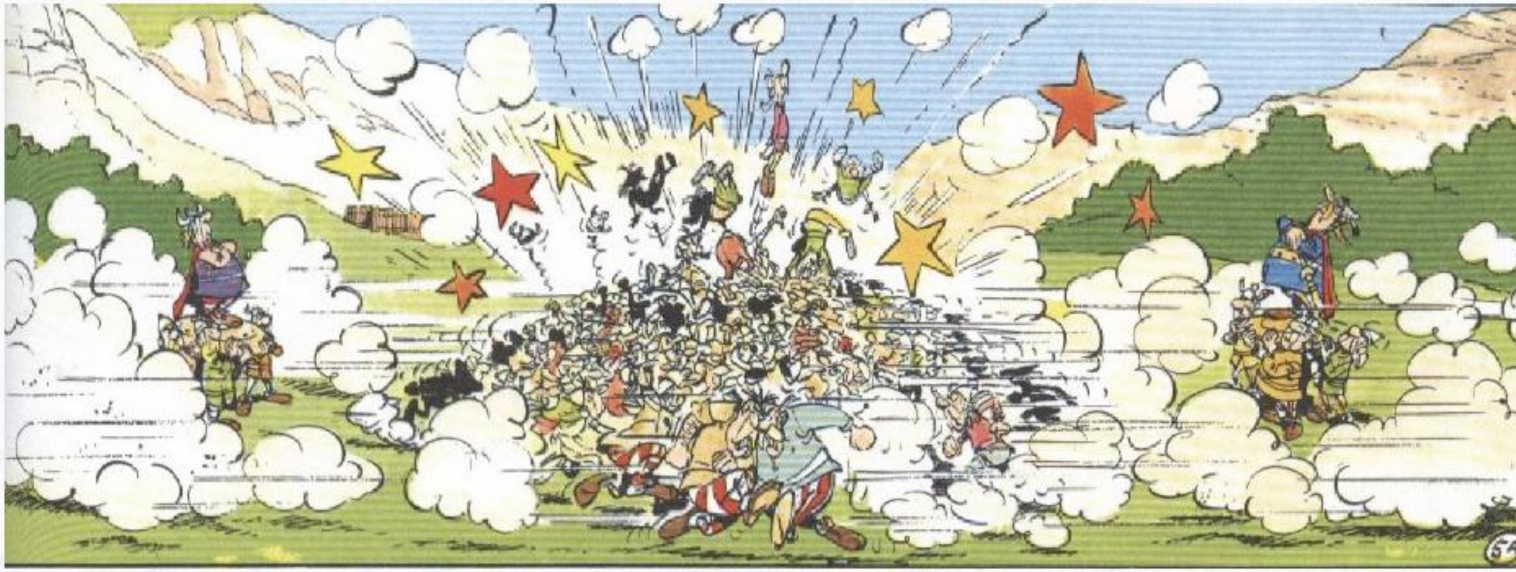
Search for physics beyond the SM (Supersymmetry, q/ℓ compositeness, leptoquarks, W'/Z', heavy q/ℓ, Extra-dimensions, ….) up to the TeV-range

Precise measurements :

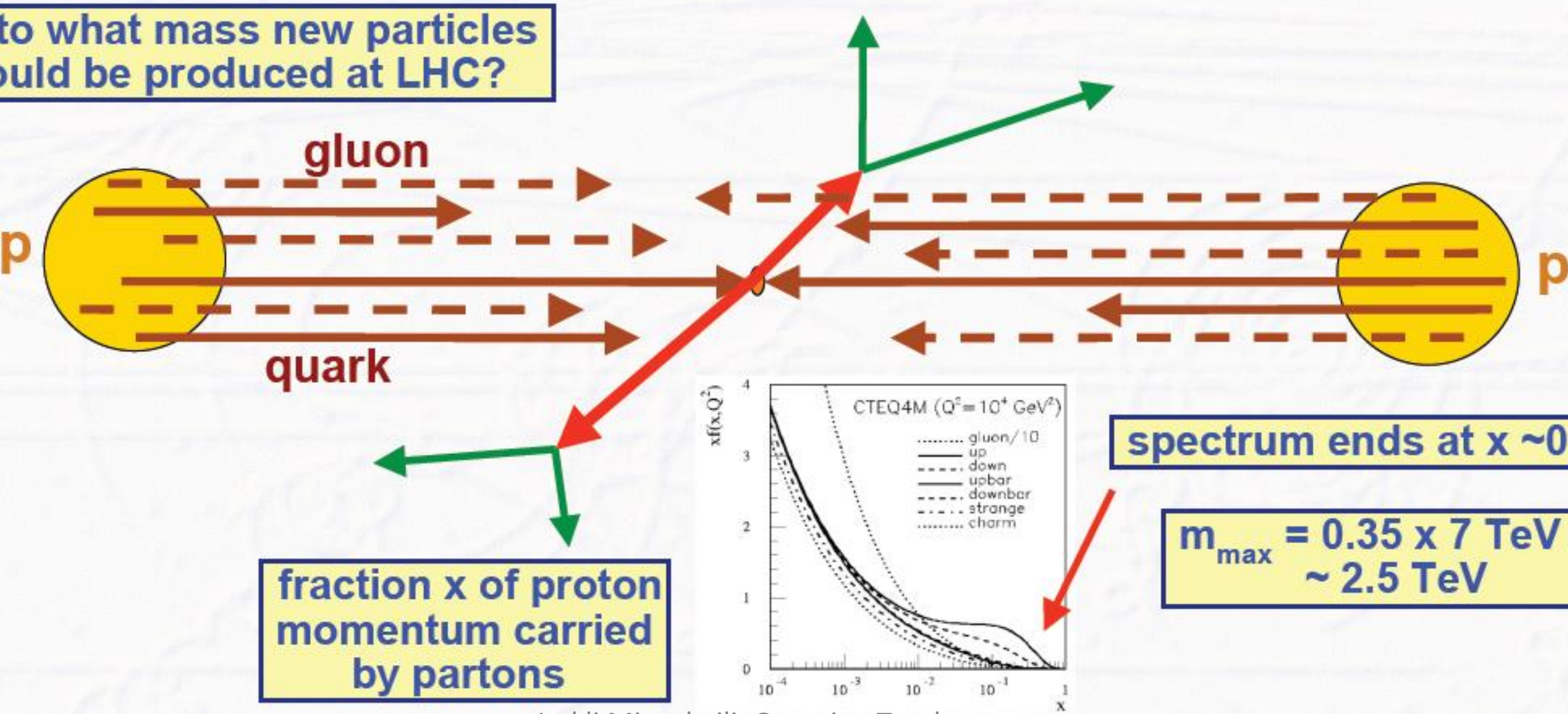
- -- W mass
- -- top mass, couplings and decay properties
- -- Higgs mass, spin, couplings (if Higgs found)
- -- B-physics (complementing LHCb): CP violation, rare decays, B^0 oscillations
- -- QCD jet cross-section and α_s
- -- etc. ….

Study of phase transition at high density from hadronic matter to plasma of deconfined quarks and gluons (complementing ALICE).
Transition plasma $\rightarrow$ hadronic matter happened in universe ~10^{-5} s after Big Bang

Etc. etc. …..



Up to what mass new particles could be produced at LHC?

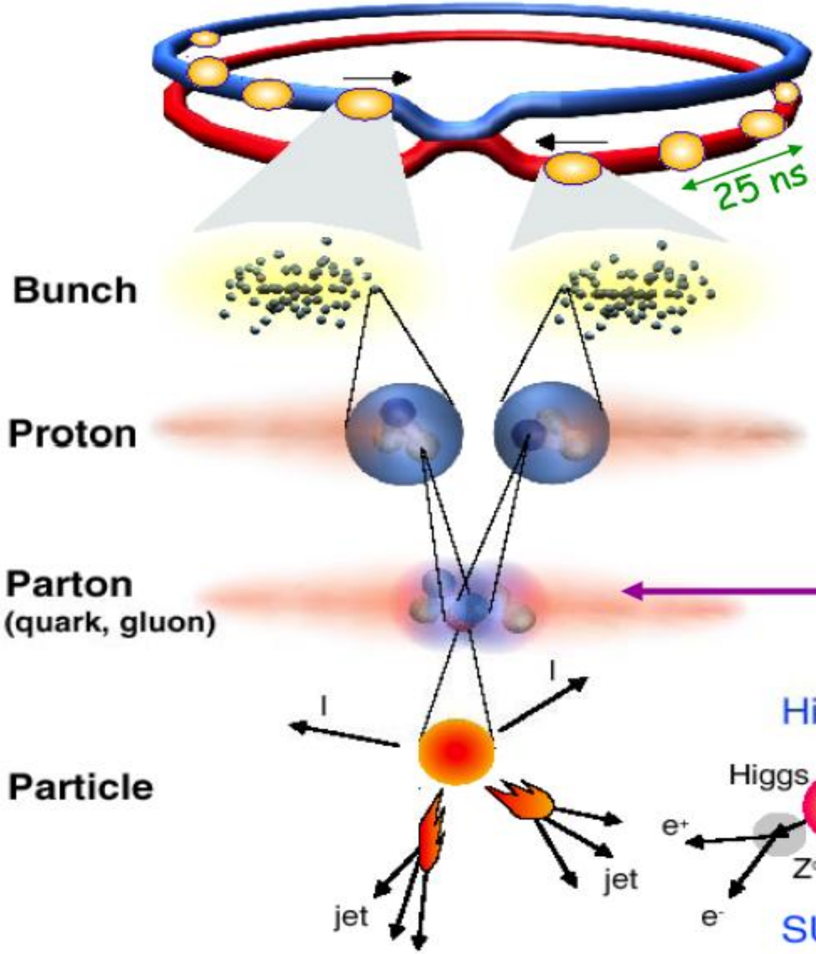


spectrum ends at x ~0.35

m_{max} = 0.35 x 7 TeV (p) ~ 2.5 TeV

fraction x of proton momentum carried by partons

Collisions at LHC



Proton-Proton

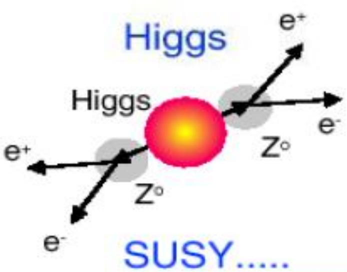
Protons/bunch	10^{11}
Beam energy	7 TeV ($7x10^{12}$ eV)
Luminosity	10^{34} cm^{-2} s^{-1}

Event rate in ATLAS :

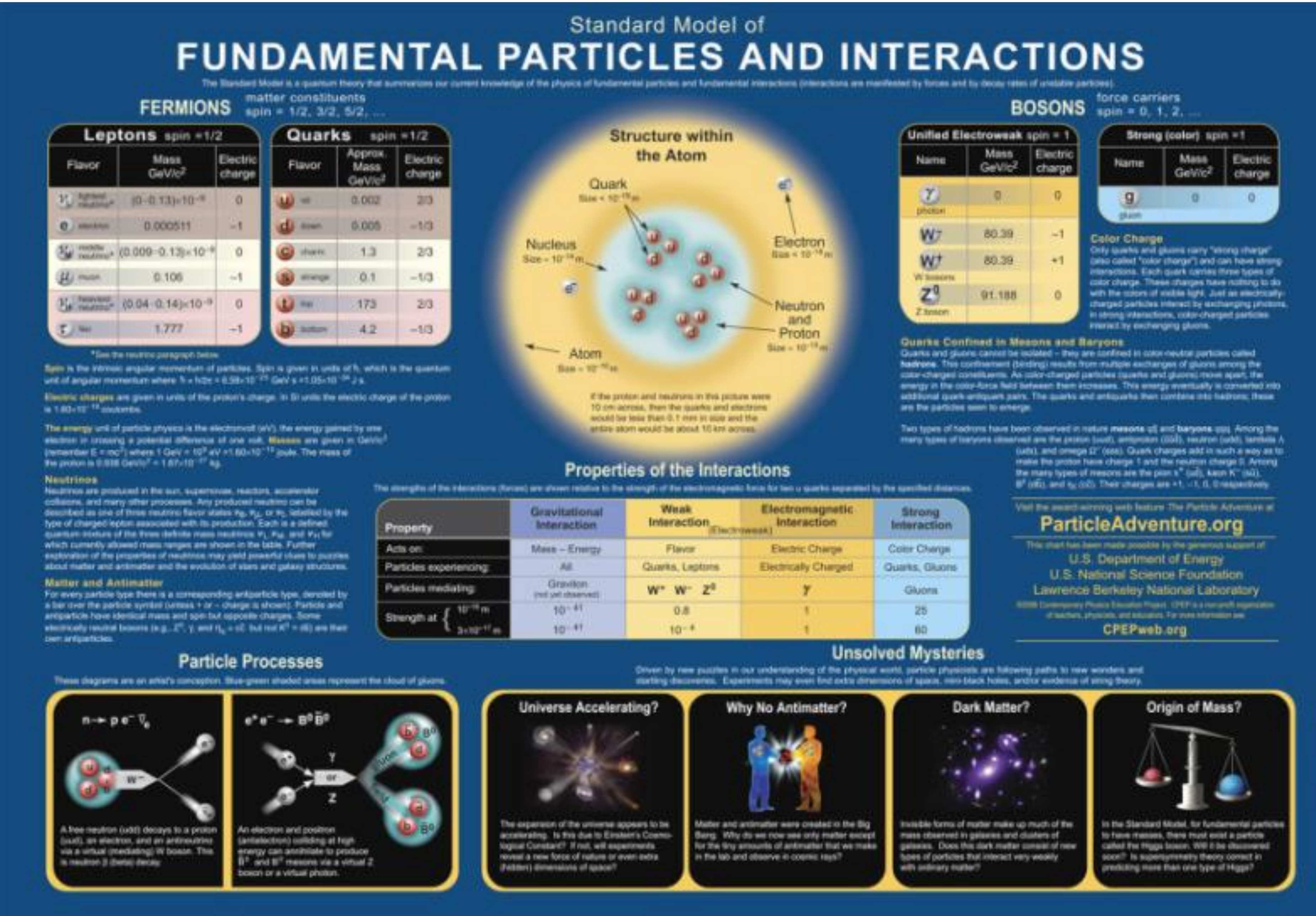
N = L x σ (pp) ≈ 10^9 interactions/s

Mostly soft (low p_T) events

Interesting hard (high-p_T) events are rare



Selection of 1 in 10,000,000,000,000



Standard Model of
FUNDAMENTAL PARTICLES AND INTERACTIONS
FERMIONS
matter constituents
spin = 1/2, 3/2, 5/2, ...
Leptons spin =1/2
Flavor
Mass GeV/c²
Electric charge
Quarks spin =1/2
Flavor
Approx. Mass GeV/c²
Electric charge
BOSONS
force carriers
spin = 0, 1, 2, ...
Unified Electroweak spin = 1
Name
Mass GeV/c²
Electric charge
Strong (color) spin =1
Name
Mass GeV/c²
Electric charge
Structure within the Atom
Quark
Nucleus
Electron
Neutron and Proton
Atom
Color Charge
Properties of the Interactions
Property
Gravitational Interaction
Weak Interaction
Electromagnetic Interaction
Strong Interaction
Acts on:
Particles experiencing:
Particles mediating:
Strength at
Mass – Energy
Flavor
Electric Charge
Color Charge
All
Quarks, Leptons
Electrically Charged
Quarks, Gluons
Graviton
Gluons
ParticleAdventure.org
U.S. Department of Energy
U.S. National Science Foundation
Lawrence Berkeley National Laboratory
CPEPweb.org
Particle Processes
Unsolved Mysteries
Universe Accelerating?
Why No Antimatter?
Dark Matter?
Origin of Mass?

How much do the protons weigh in the LHC at 7Tev?
The energy of a proton is 7 TeV. Via $E = mc^2$ the mass is simply 7 TeV/c^2 - and these are the units usually used.
7 TeV/c^2 divided by the rest mass .938272029 GeV/c^2 gives us 7460.52 times the rest mass
Working in SI units we can do the same thing more explicitly:
At 7 TeV:
Energy = $7 *10^{12} *1.60206 *10^{-19}$ Joules
c= $2.99793\ 10^{8}$ m/s
m = Energy/c^2 = 1.2477^{-23} Kg

At rest (rest mass proton = m_p):
Energy = $m_p\ c^2 = 0.938272029 *10^9*1.60206*10^{-19}$ Joules (or just say m_p = 0.938272029 GeV/c^2)
m_p = Energy/c^2 = 1.672009^{-27} Kg
m/m_p = 7460.52 as before
This number is gamma i.e. 1/square root($1- v^2/c^2$) - from which you can easily calculate the velocity.

CERN- ბირთვული კვლევების ევროპული ცენტრი

Collider -ამაჩქარებელი შემხვედრ ნაკადებზე

LHC- დიდი ადრონული ამაჩქარებელი შემხვედრ ნაკადებზე

LINAC - წრფივი ამჩქარებელი

PS - პროტონული სინქროტრონი

ATLAS – ზოგადი დანიშნულების დეტექტორი

CMS – მიონების კომპაქტური სოლენოიდი

Trigger – პირობა, რომლის შესრულების შემთხვევაში ხდება ფიზიკური მონაცემების ჩაწერა