



THE ATLAS EXPERIMENT

Mapping the Secrets of the Universe

Aanarekli samyaros saidumloebisa

Irakli Minashvili
(many thanks to Peter Jenni)

Irakli Minashvili, Georgian Teachers
Program, CERN, January 23-29, 2011

Georgian Teachers Program
CERN, January 23-29, 2011

Large Hadron Collider

Lake of Geneva

CMS

LHCb

ALICE

ATLAS



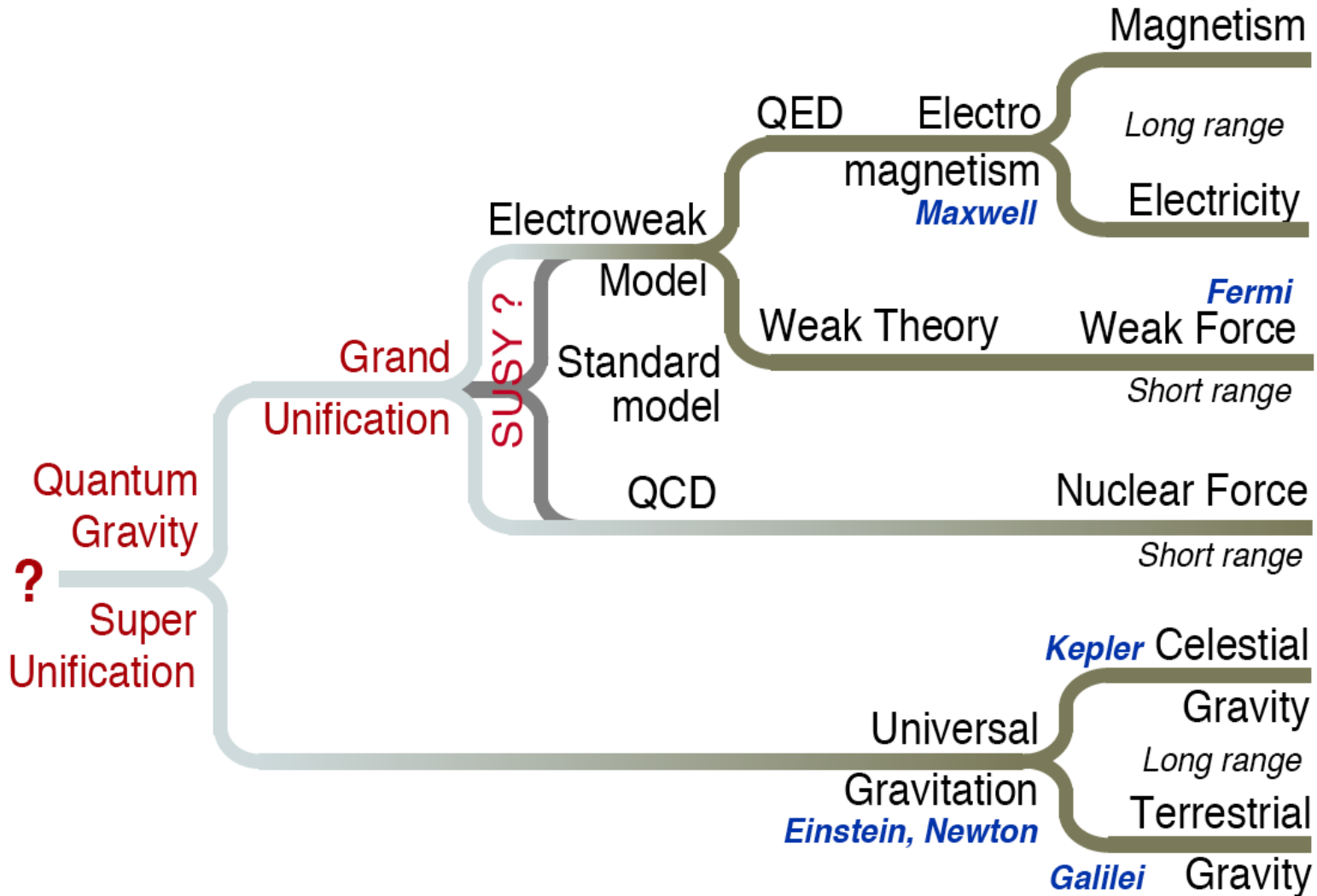
რა არის ფუნდამენტური ფიზიკის პირველი დამატებითი რაოდენობები

ლექსპერიმენტებიდან

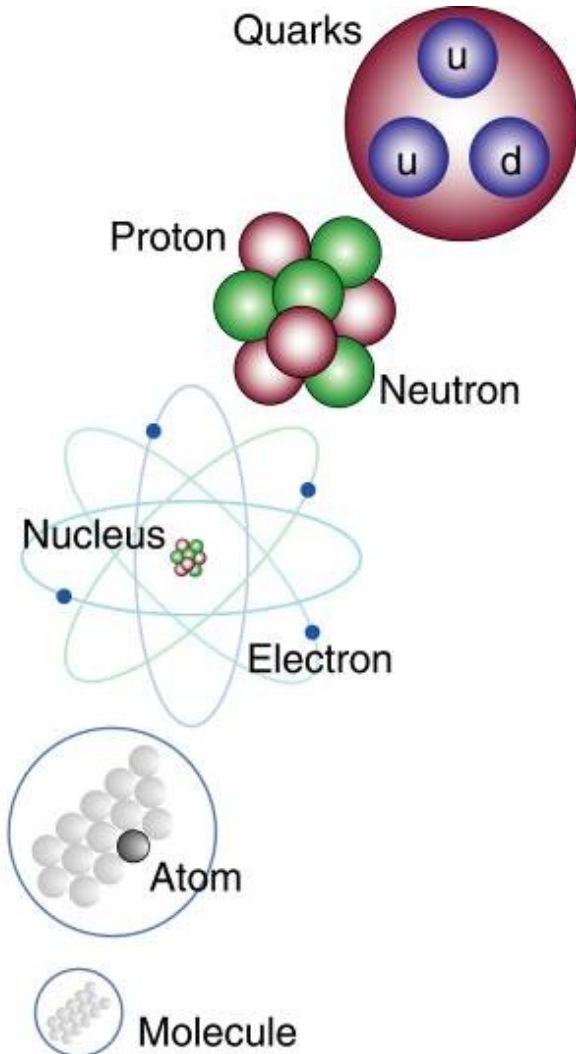
(ზალიანო მკვლედი)

- **მისი თერმული მექანიზმი**
- **სადა არის ანტი მატერია**
- **სადა რა მდგომარეობაშია დამატებული სხვაობა 96% ენერჯია (სადა მატერია, ბნელი ენერჯია)**
- **არის თუ არა განზომილება 4-ზე მეტი**
- **სრულიად ახალი არმოცნობი**
- 😊

Unification of Forces



The study of elementary particles and fields and their interactions



matter particles

gauge particles

| | 1st gen. | 2nd gen. | 3rd gen. | |
|----------------------------|---|---|---|--|
| Q U A R K | <i>u</i> up | <i>c</i> charm | <i>t</i> top | Strong Force <i>g</i> x8 <i>Gluon</i> |
| | <i>d</i> down | <i>s</i> strange | <i>b</i> bottom | |
| L E P T O N | <i>ν_e</i> <i>e neutrino</i> | <i>ν_μ</i> <i>μ neutrino</i> | <i>ν_τ</i> <i>τ neutrino</i> | |
| | | <i>e</i> electron | <i>μ</i> muon | <i>τ</i> tau |

scalar particle(s)

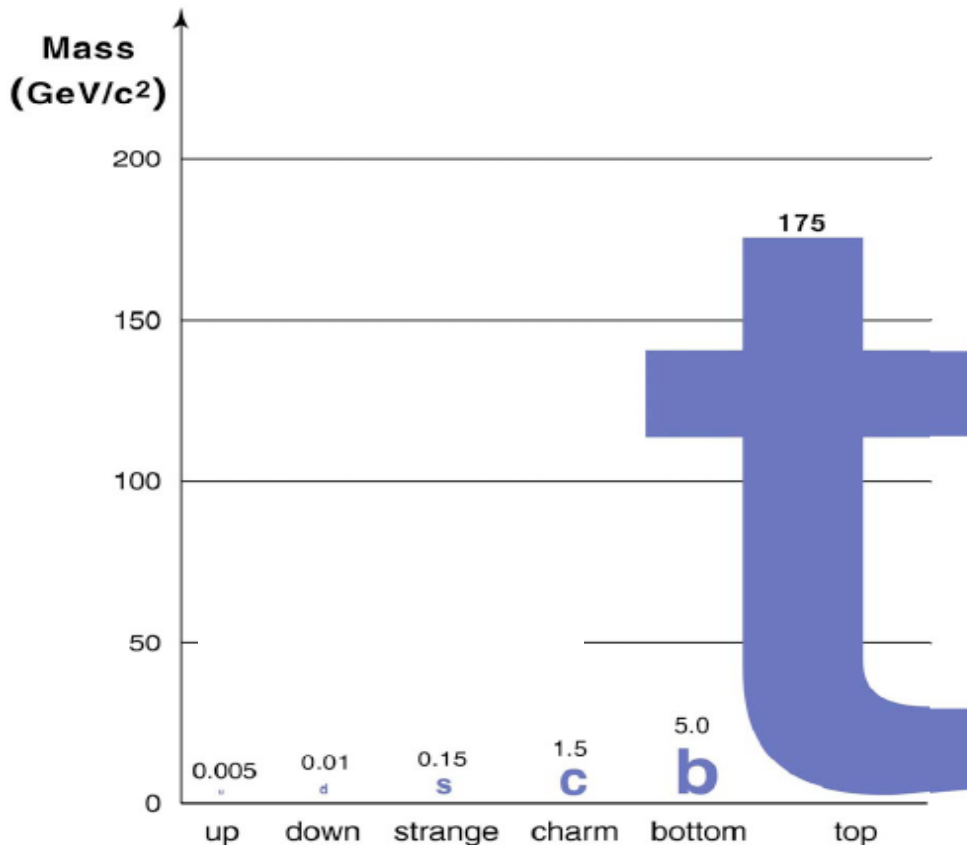
Elements of the Standard Model

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



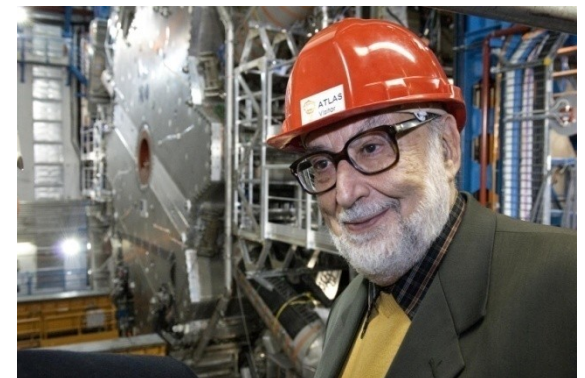
Quarks

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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



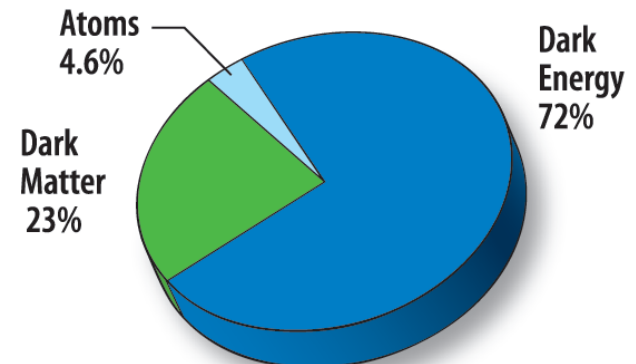
Dark Matter in the Universe

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)

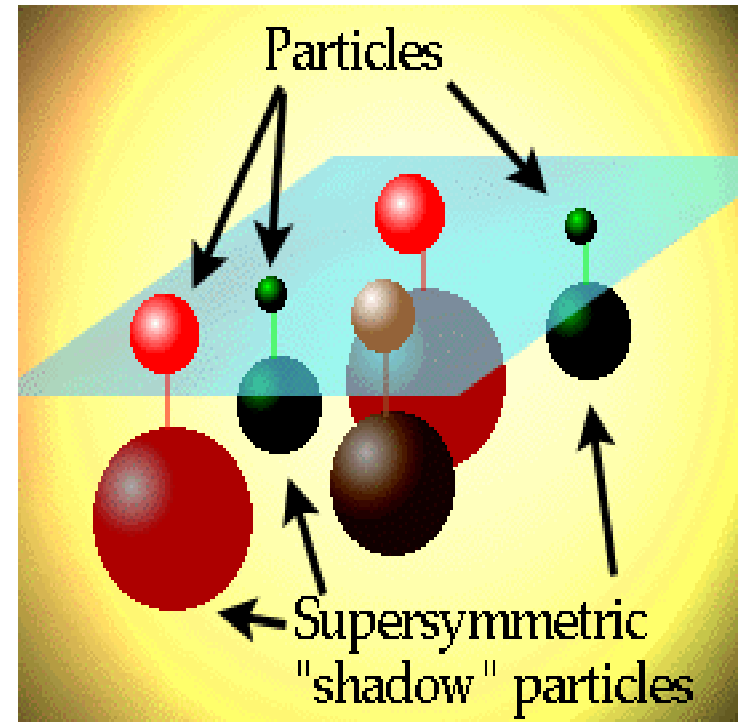
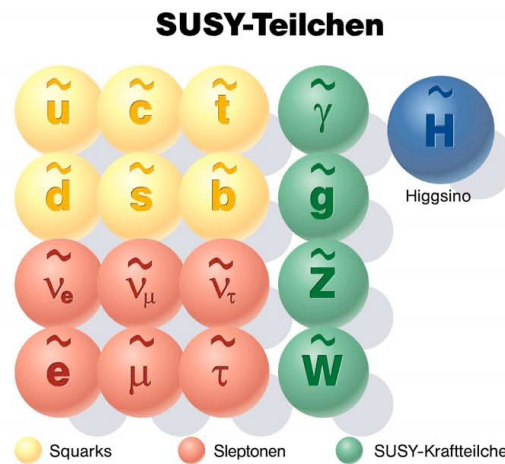
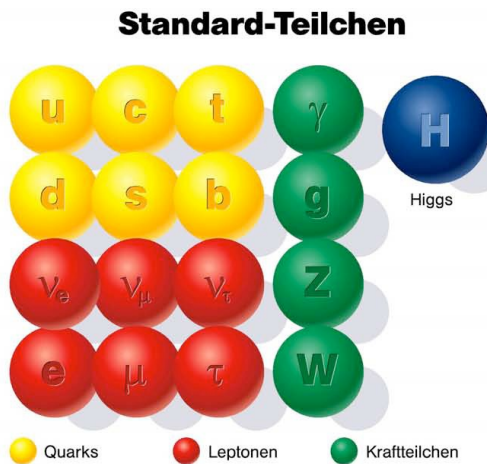
(Julius Wess and Bruno Zumino, 1974)

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

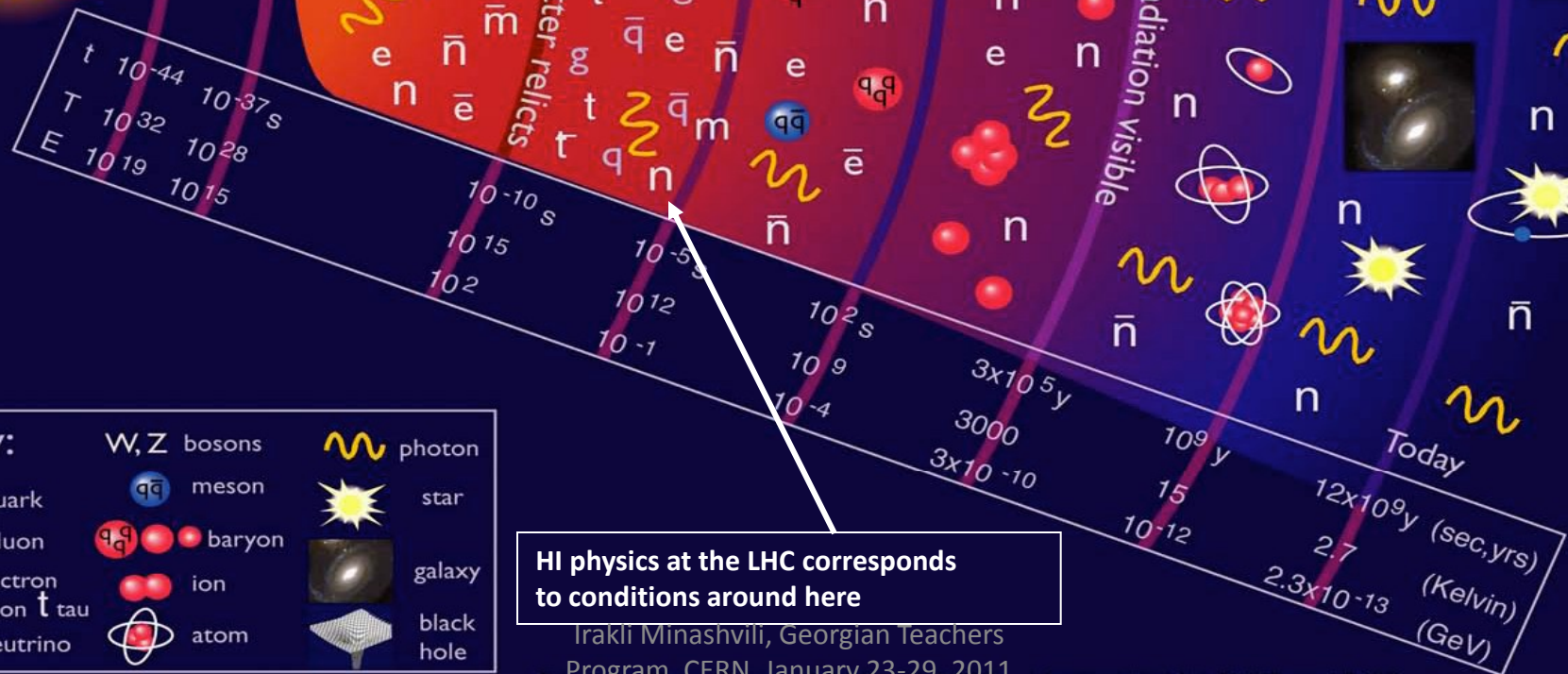
pp physics at the LHC corresponds to conditions around here

BIG BANG

Inflation

possible dark matter relicts

cosmic microwave radiation visible



Key:

- W, Z bosons
- q quark
- g gluon
- e electron
- m muon
- n neutrino
- meson
- baryon
- ion
- atom
- photon
- star
- galaxy
- black hole

HI physics at the LHC corresponds to conditions around here

Understanding the Universe ...



Unification ?

Electroweak
Transition

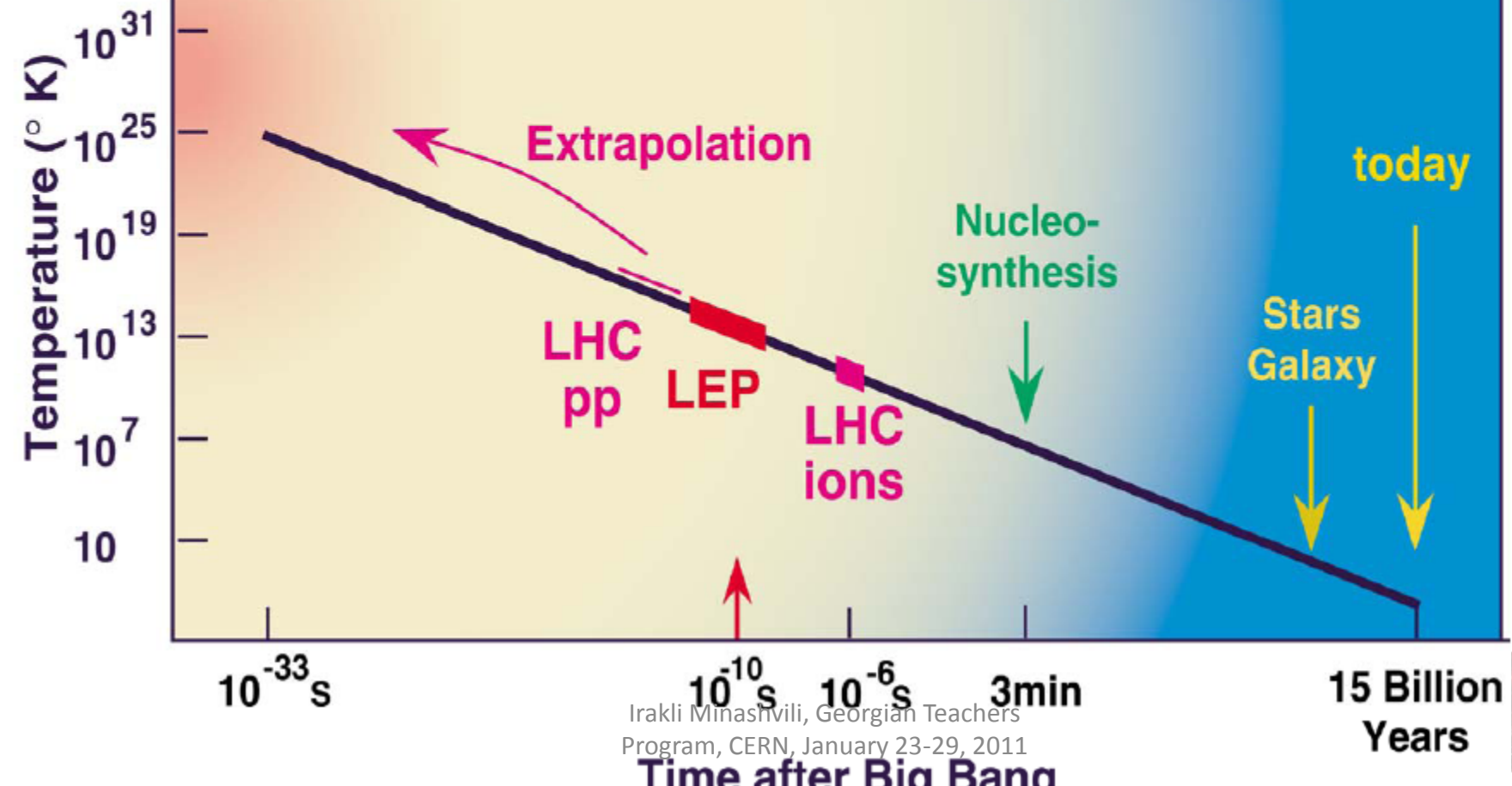


?

Quarks and Leptons

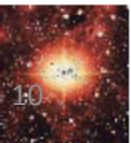
Hadrons

Nuclei Atoms

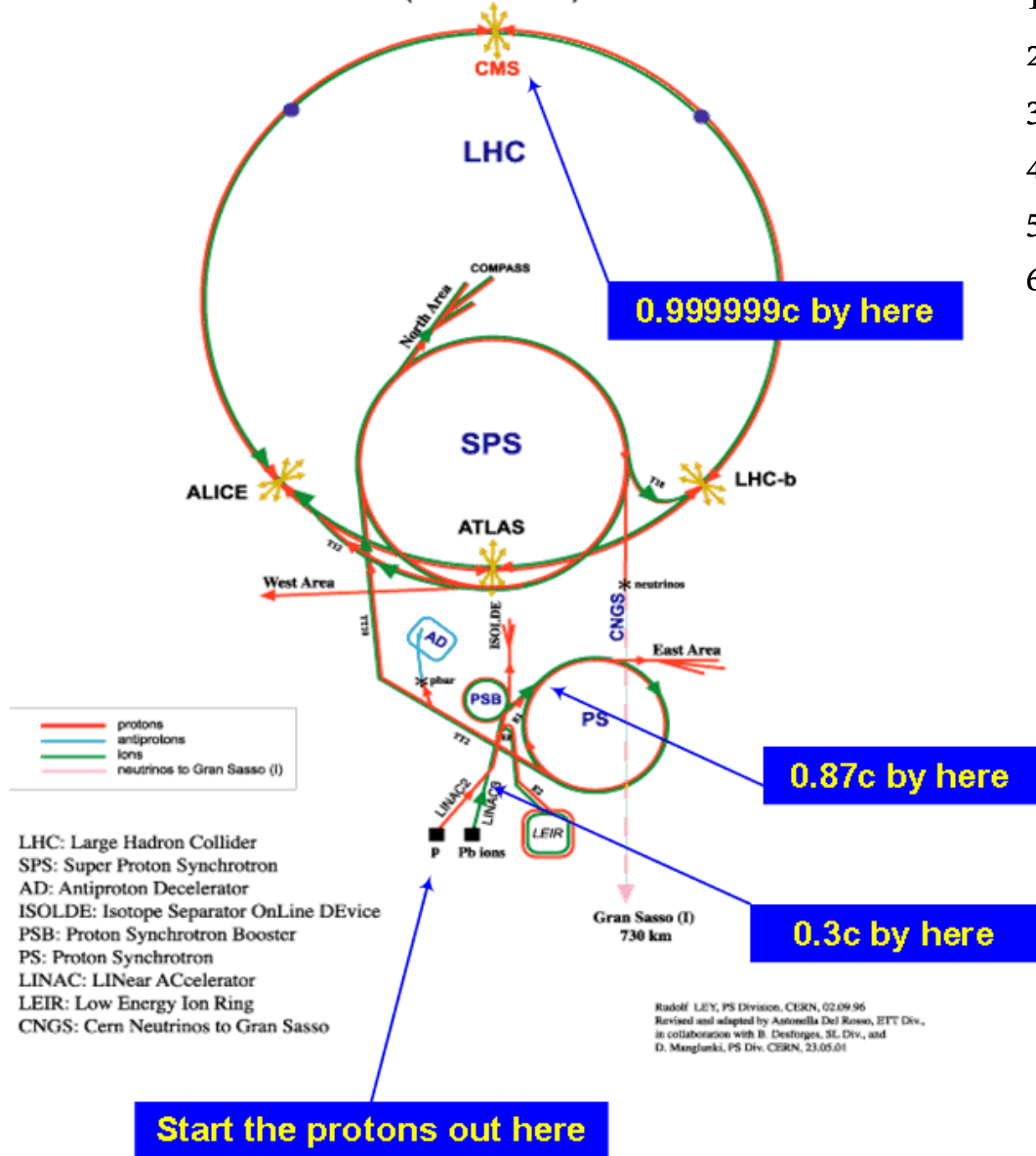


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Time after Big Bang



CERN Accelerators (not to scale)

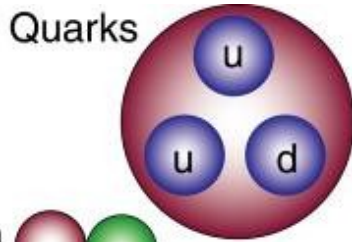


1. Pprotonebis wyaro, 100keV
2. wrfivi amCqarebeli, 50meV
3. Bbusteri, 1,4geV
4. Pprotonuli sinqrotroni, 28geV
5. super Pprotonuli sinqrotroni, 450geV
6. didi adronuli amaCqarebeli Semxvedr nakadebze, 7teV.

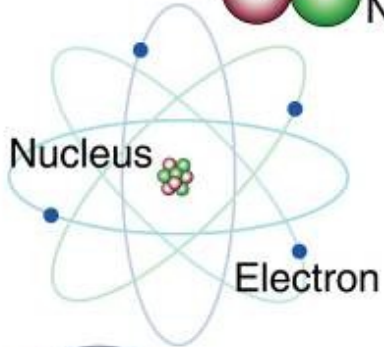
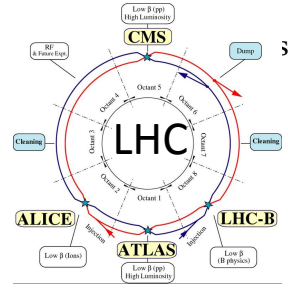
Powerful accelerators and detectors needed

MmaRali energiebi da
intensiuri nakadebi

uaRresad swrafi



$<10^{-16}$ cm



eleqtruli mikroskopi

2 000 000X



Atom



Suqis mikroskopi

2 000X



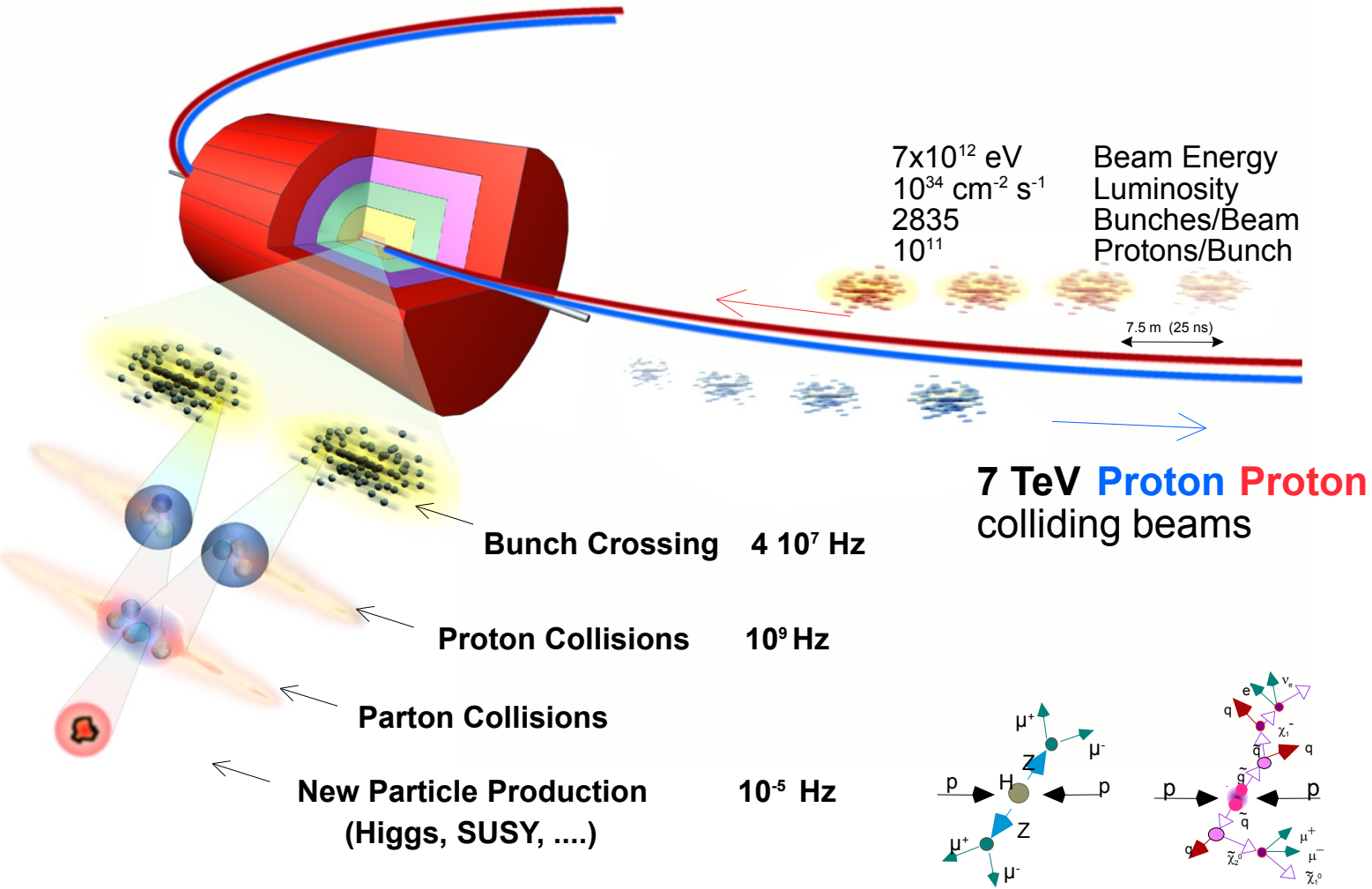
Molecule



Matter

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Collisions at LHC



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

Bunch- yurZnis mtevani protonebiT



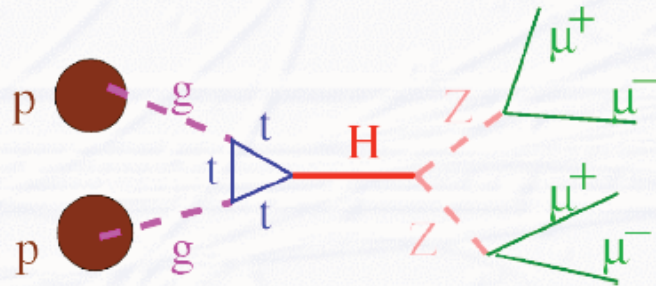
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http://hands-on-cern.physto.se/ani/acc_lhc_atlas/lhc_atlas.swf

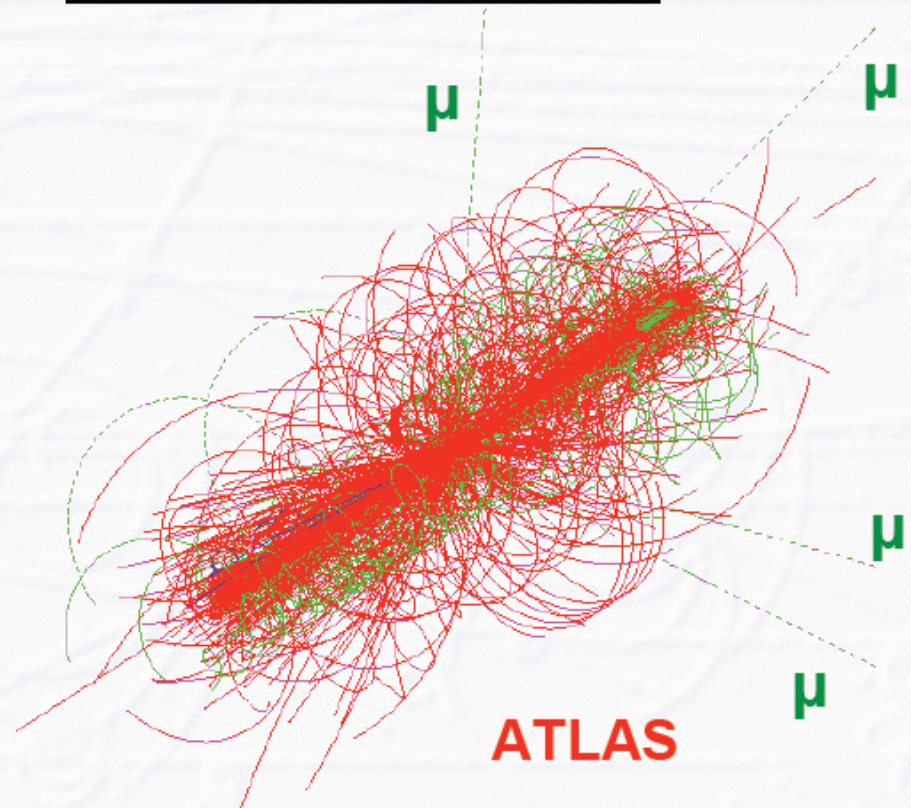
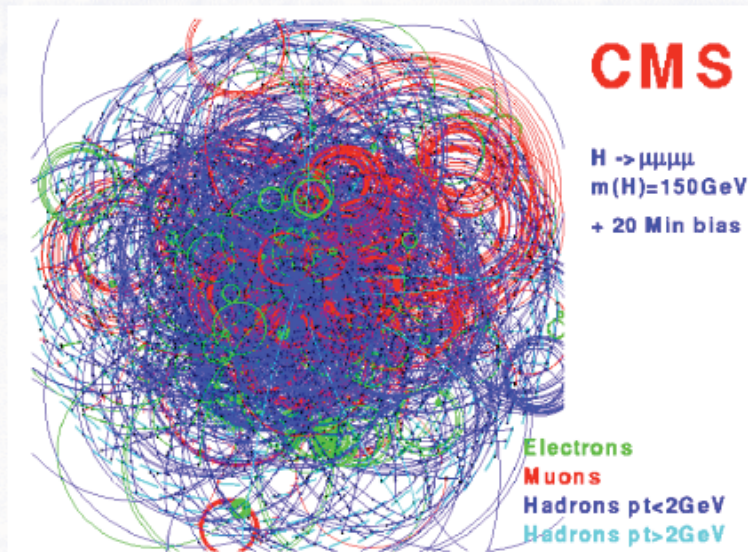
● **One bunch crossing every 25 ns with ~25 interactions**

→ **1000 tracks per bunch crossing = 4×10^{10} tracks per second ...**

→ **... and very often you're interested in a few tracks only!**



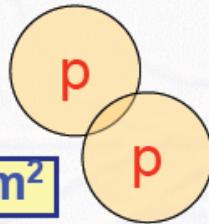
$pp \Rightarrow H \Rightarrow ZZ \Rightarrow 4\mu$



LHC detectors are designed to find "needles in a haystack"

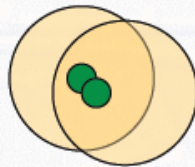
total inelastic cross section

$$\sigma \sim 0.1 \text{ barn} = 10^{-25} \text{ cm}^2$$



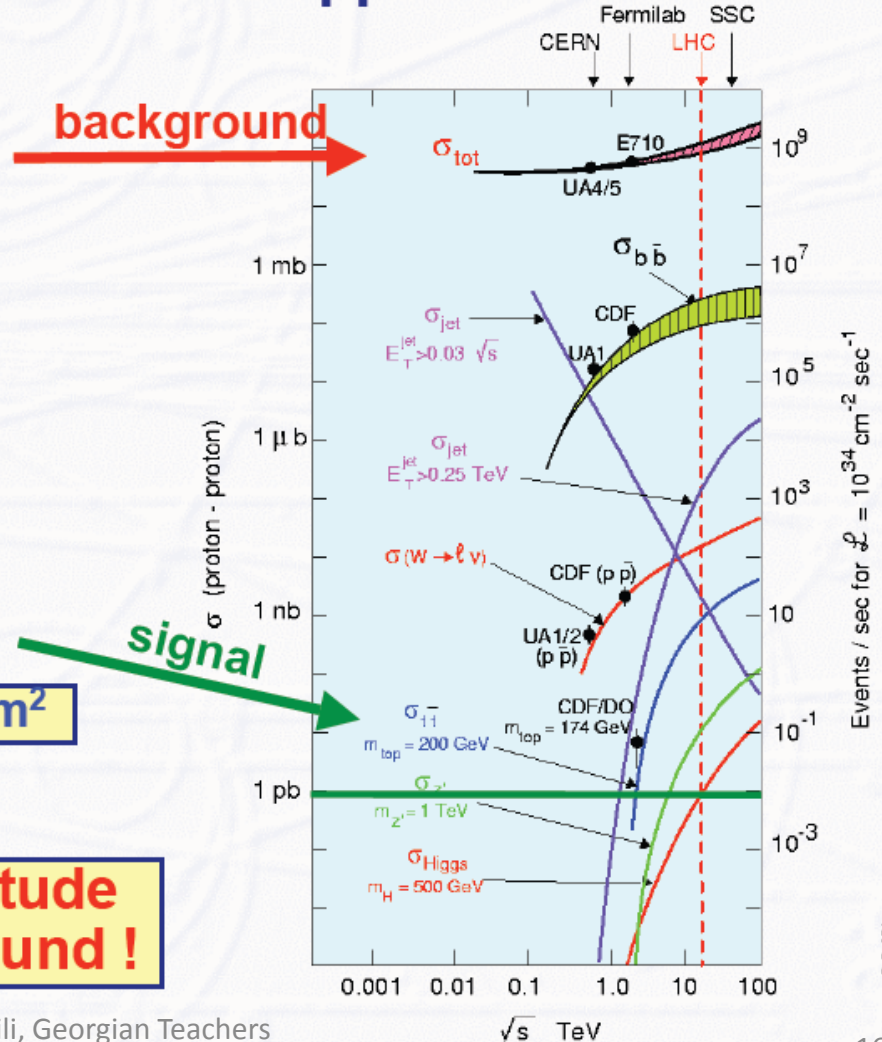
point-like cross section

$$\sigma_H(m_H=500 \text{ GeV}) \sim 1 \text{ pb} = 10^{-36} \text{ cm}^2$$



many many orders of magnitude between signal and background!

pp cross sections



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 Ancey, 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, MEPH 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

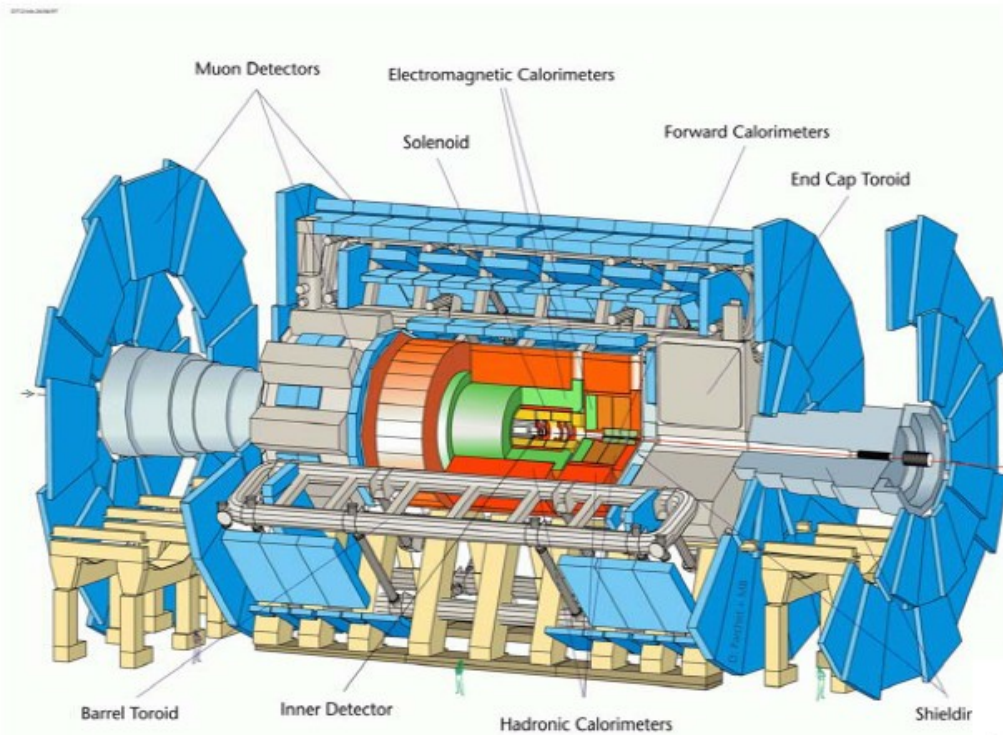


(Across the street from the CERN main entrance)

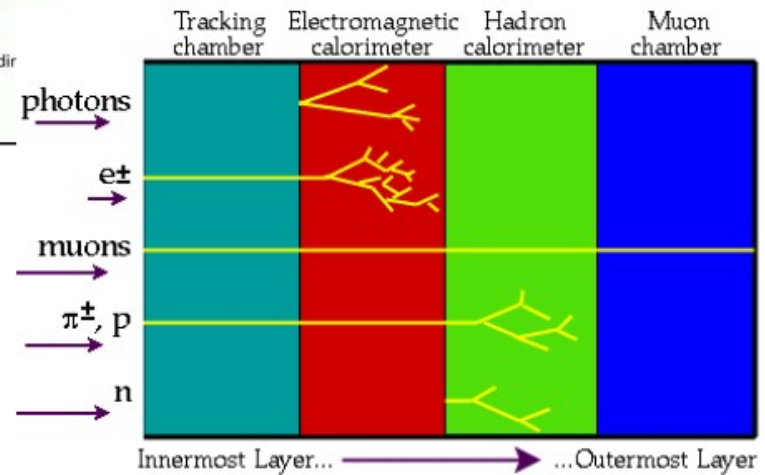


ATLAS

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



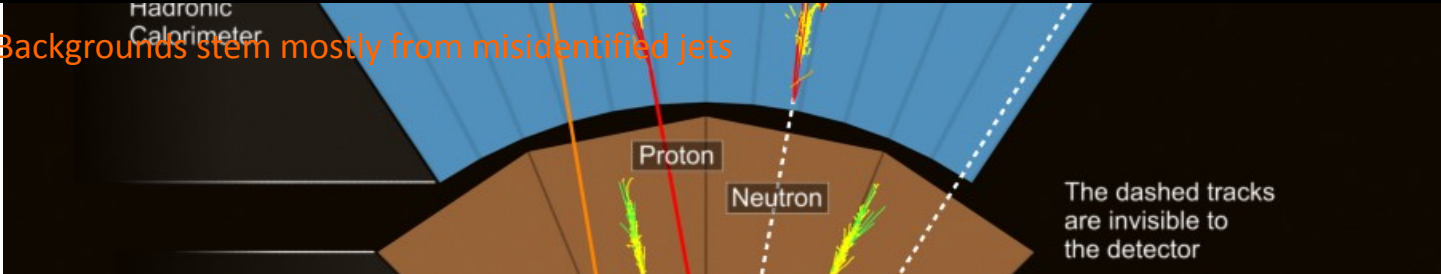
- Tracking ($|\eta| < 2.5$, $B=2T$) :**
 - Si pixels and strips
 - Transition Radiation Detector (e/π separation)
- Calorimetry ($|\eta| < 5$) :**
 - EM : Pb-LAr
 - HAD: Fe/scintillator (central), Cu/W-LAr (fwd)
- Muon Spectrometer ($|\eta| < 2.7$) :**
 air-core toroids with muon chambers



Electron, Photon and Muon Identification

- **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
- $e (\gamma)$ 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

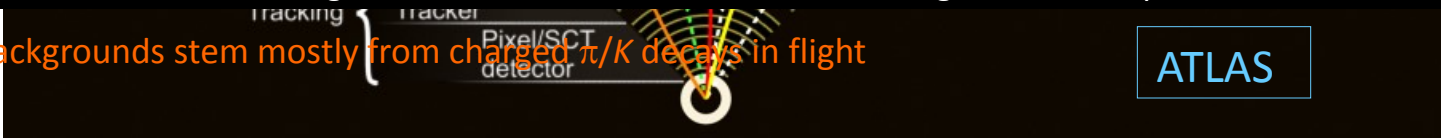


■ Backgrounds stem mostly from misidentified jets

- **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



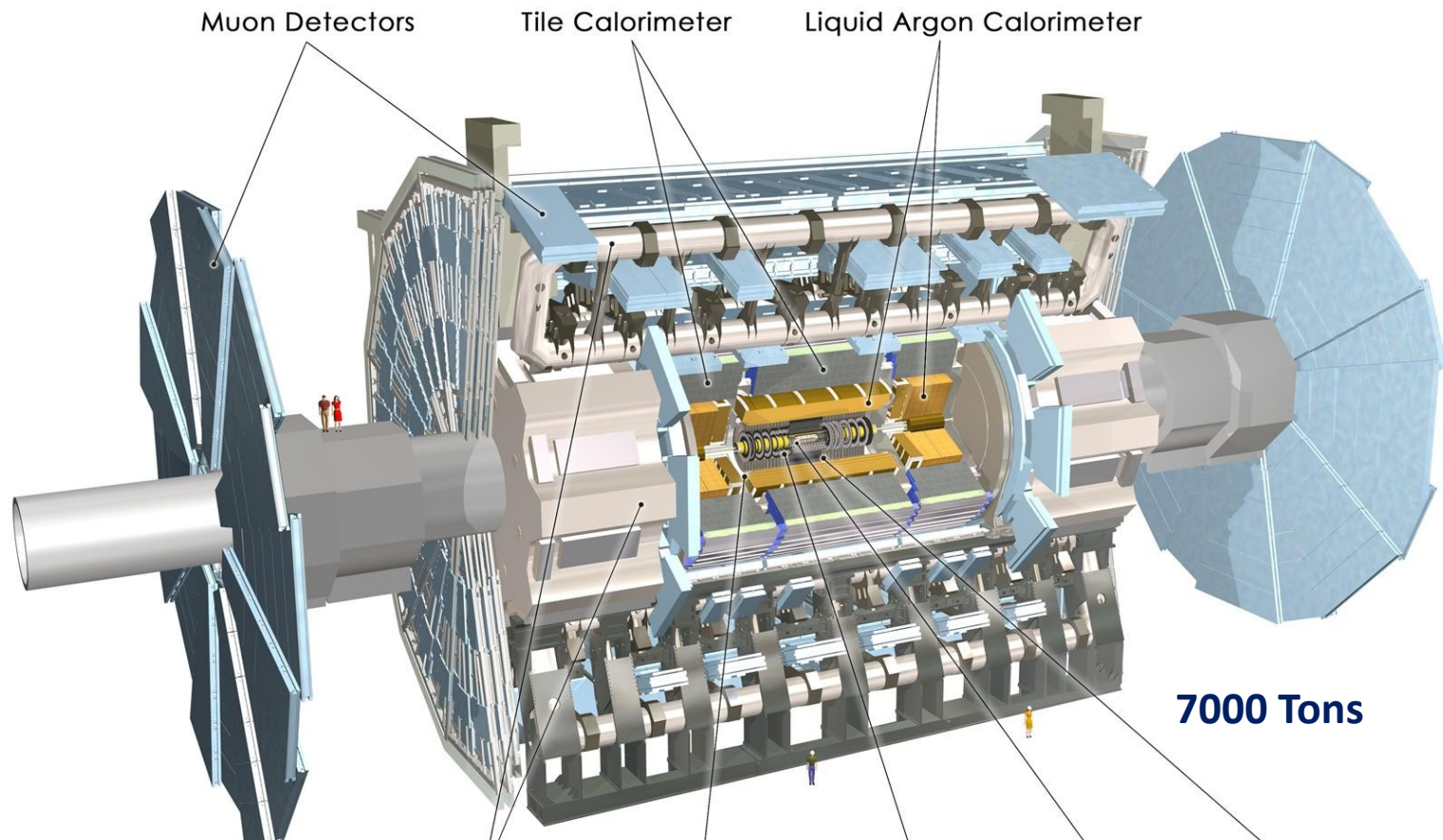
ATLAS Detector



ATLAS superimposed to the 5 floors of building 40

45 m

24 m



7000 Tons

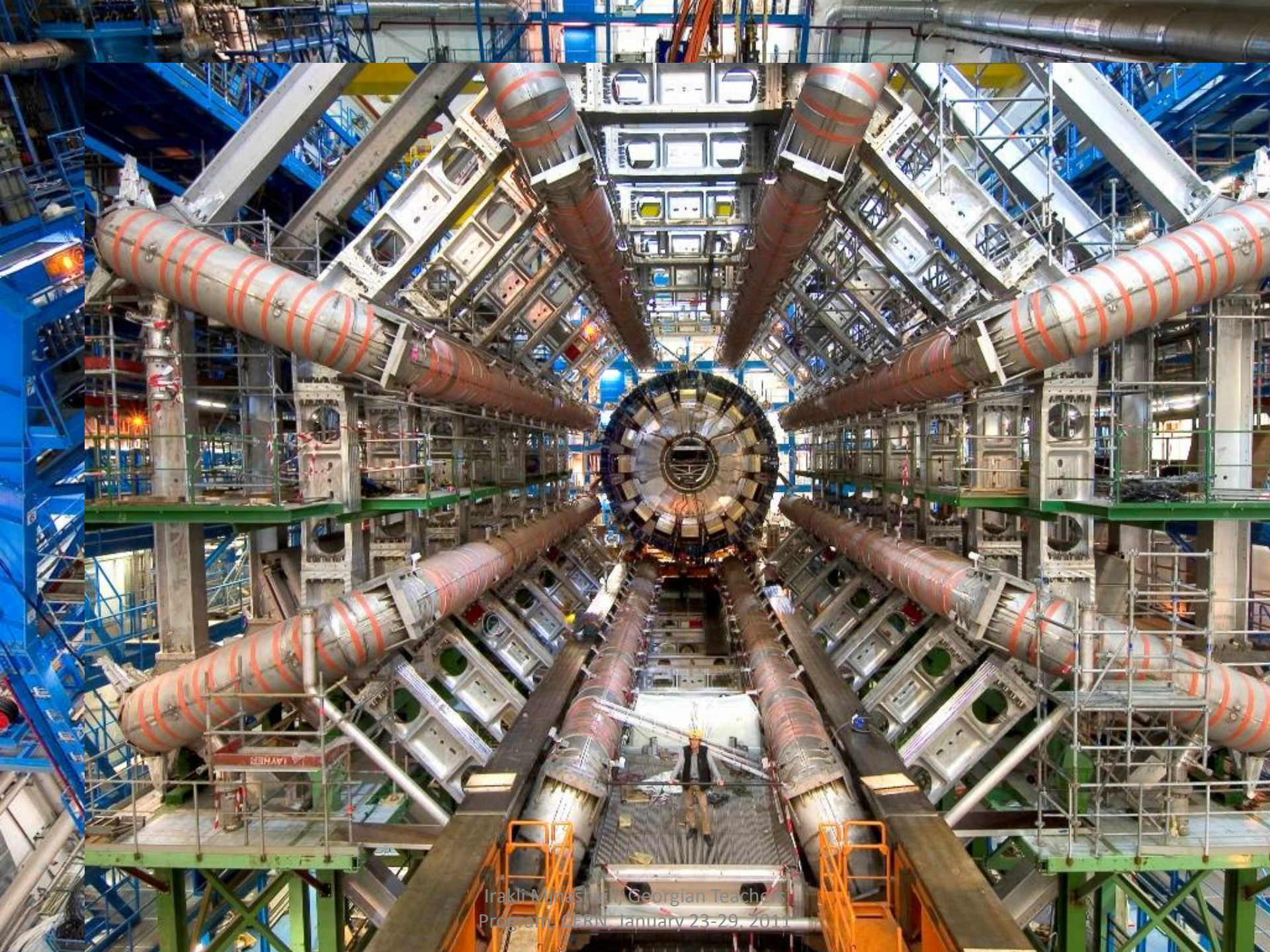
Irakli Minashvili, Georgian Teachers

Project Manager, Science 2.0

SCT Tracker

Pixel Detector

TRT Tracker



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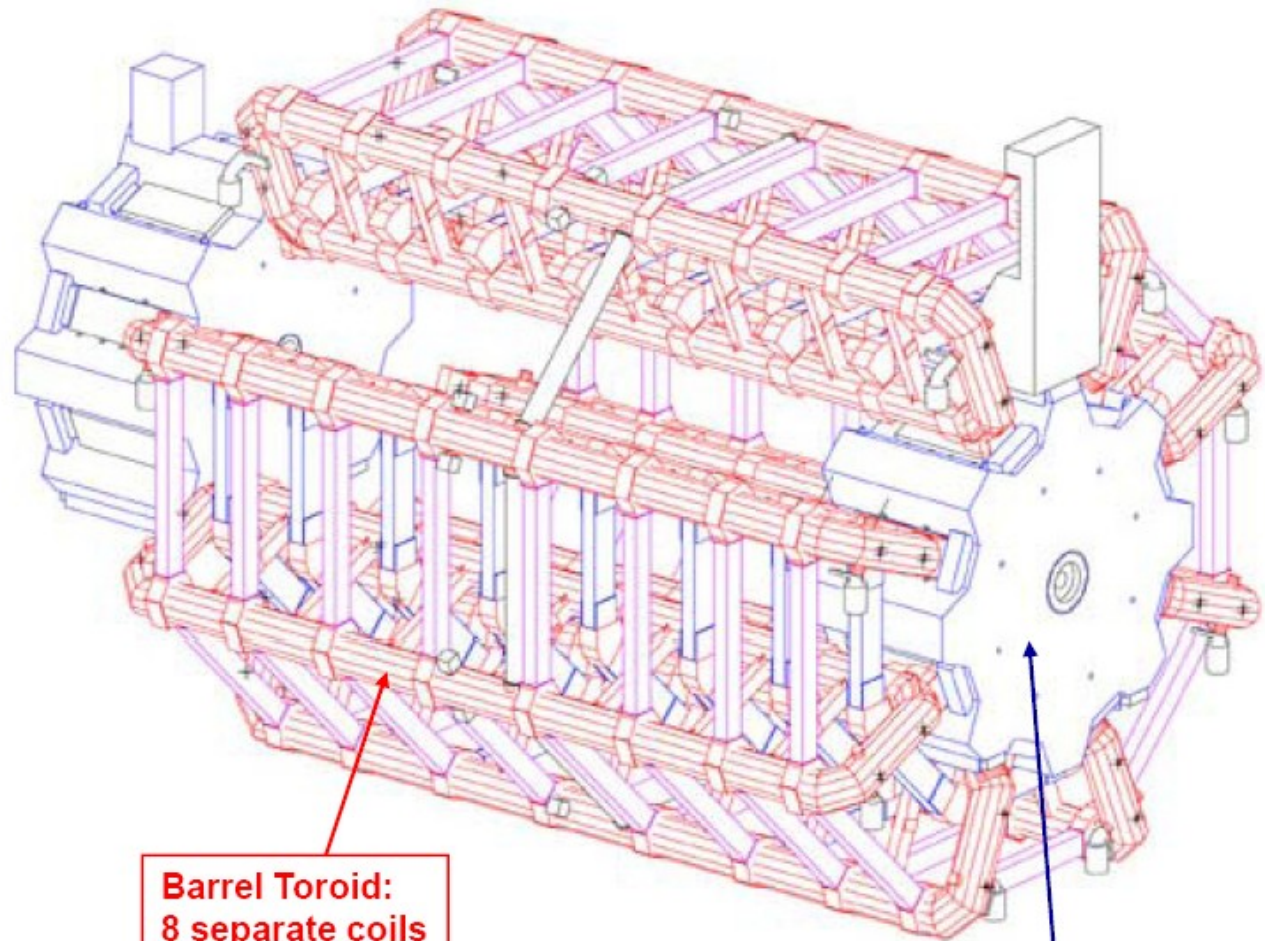
Toroid system

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



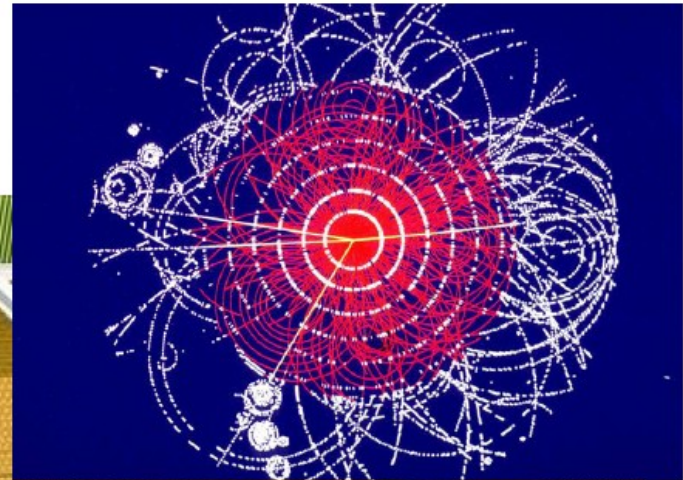
**Barrel Toroid:
8 separate coils**

**End-Cap Toroid:
8 coils in a common cryostat**



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ATLAS Tracking Detectors



~ 6m long, 1.1 m radius

Beam Pipe

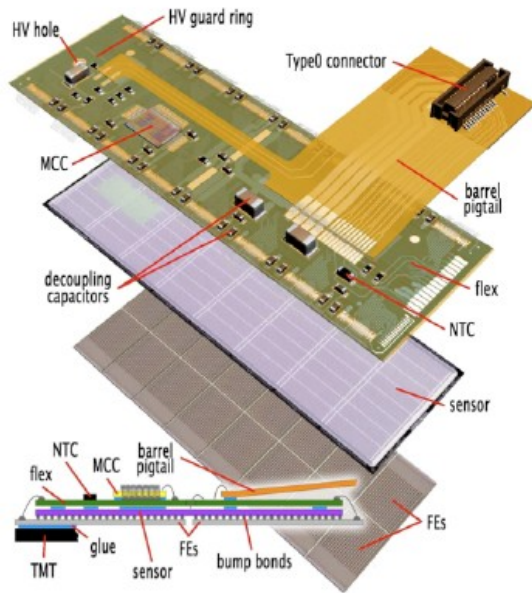
Transition Radiation Tracker (TRT)
($4 \cdot 10^5$ channels)

Pixels
($0.8 \cdot 10^8$ channels)

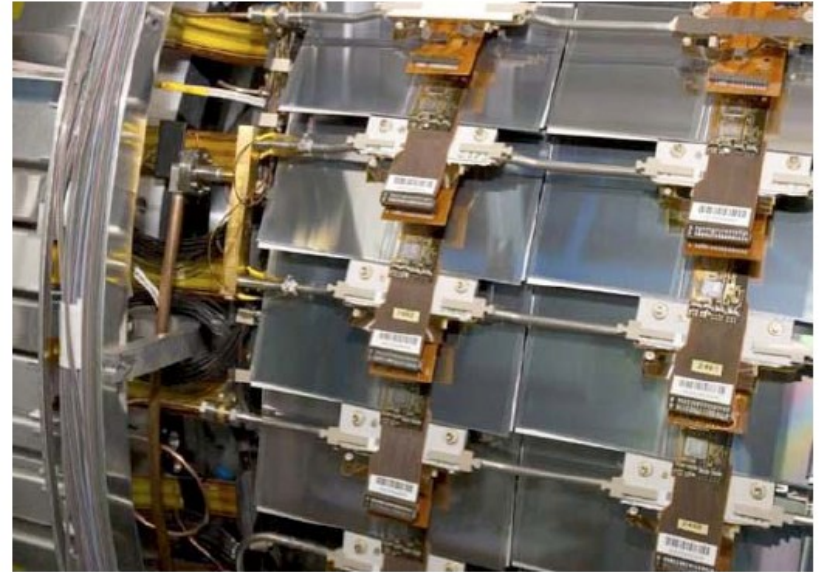
Si Strips Tracker (SCT)
($6 \cdot 10^6$ channels)

59

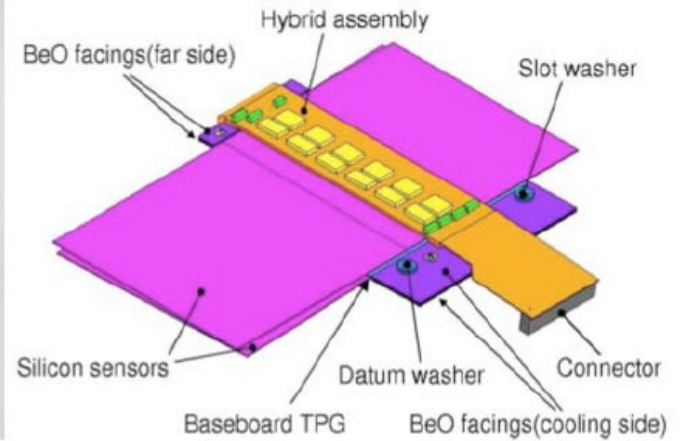
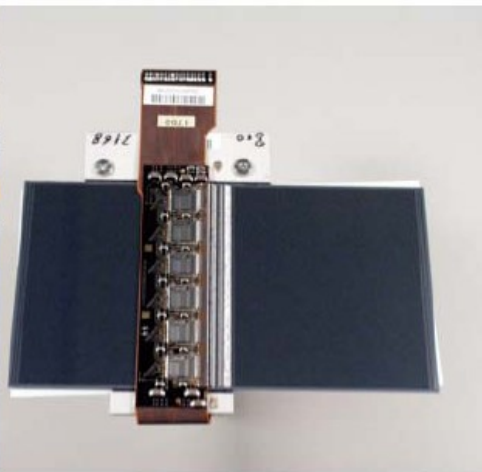
Detector Silicon-sensors



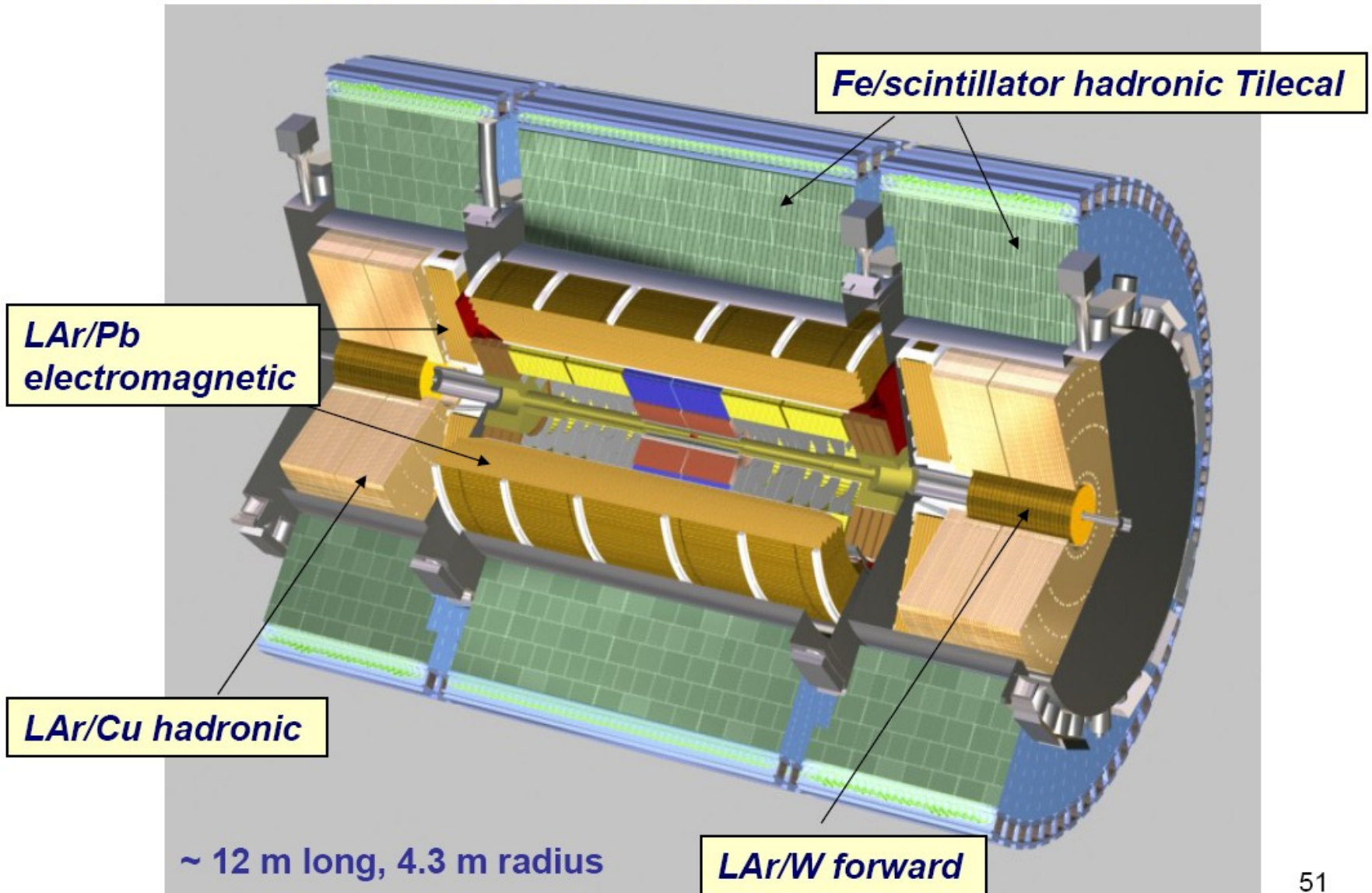
1744 Pixel modules, pixels 50x400 μm^2



4088 SCT modules, 80 μm micro-strips

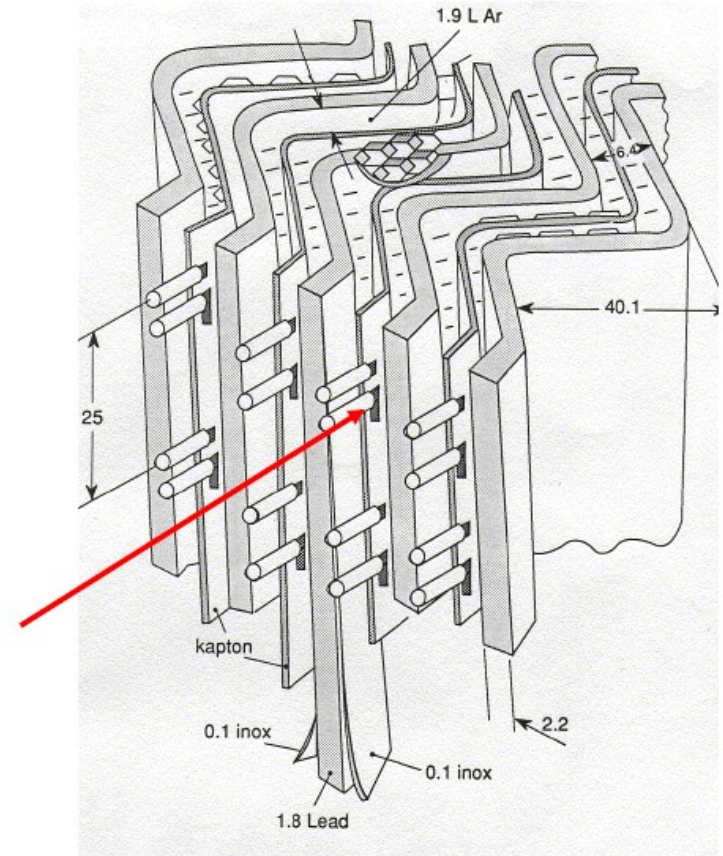
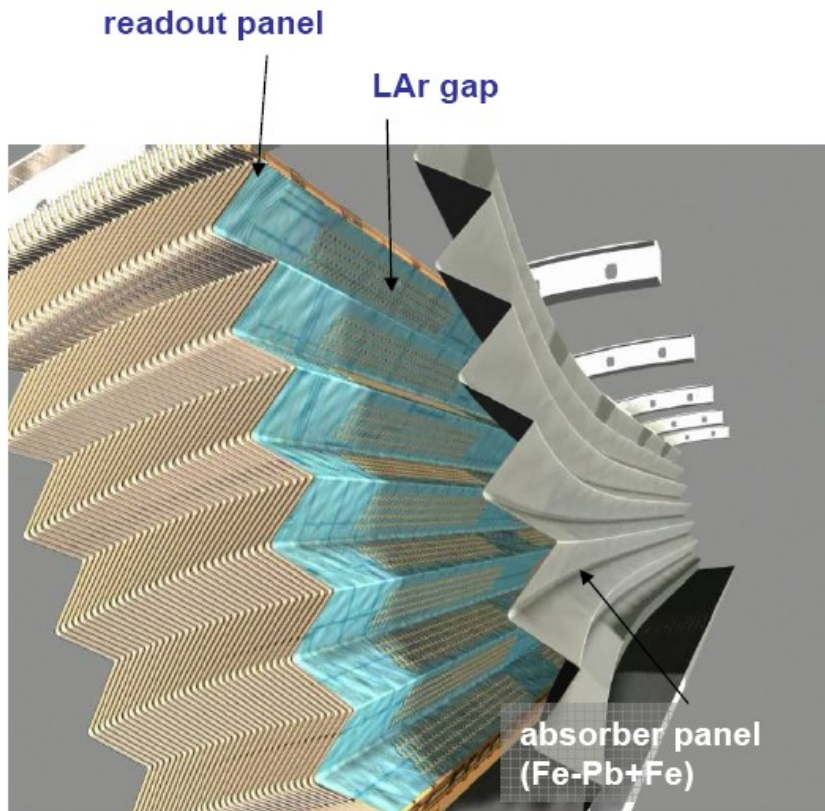


ATLAS Calorimeters



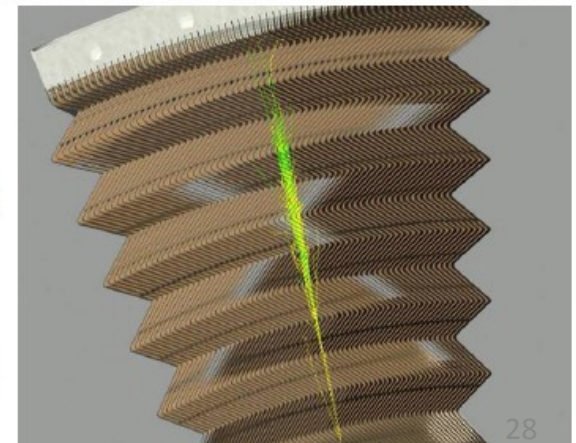
ATLAS Electromagnetic Calorimeters

LAr sampling calorimeter accordion geometry

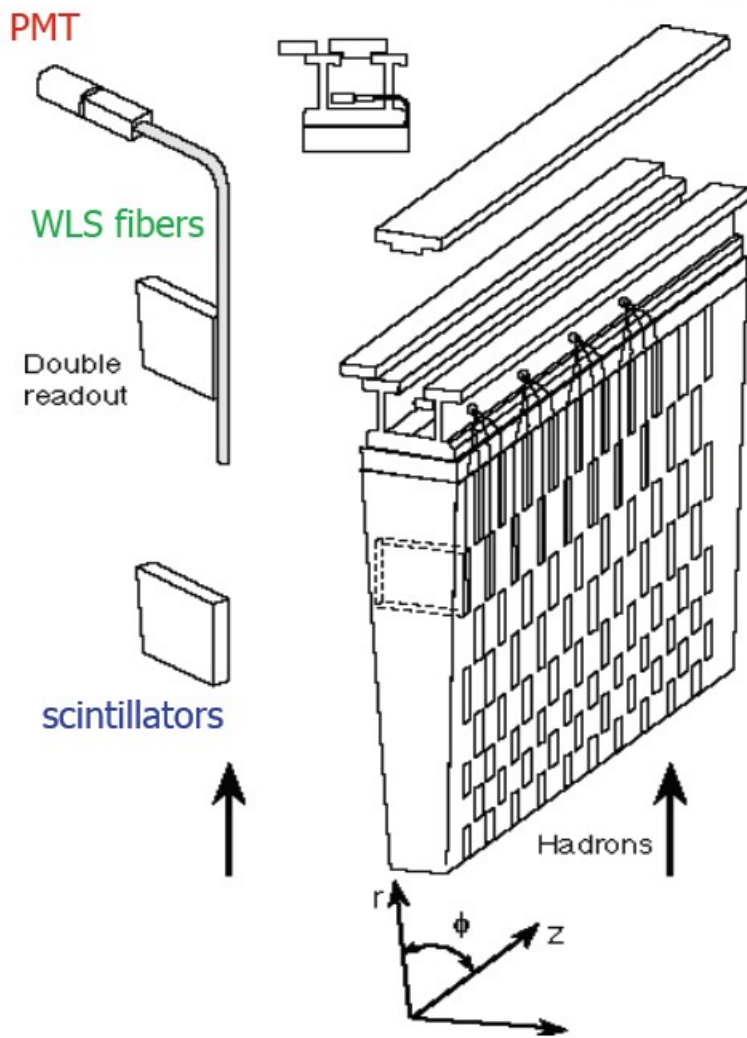


Why ?

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



Tile Calorimeter

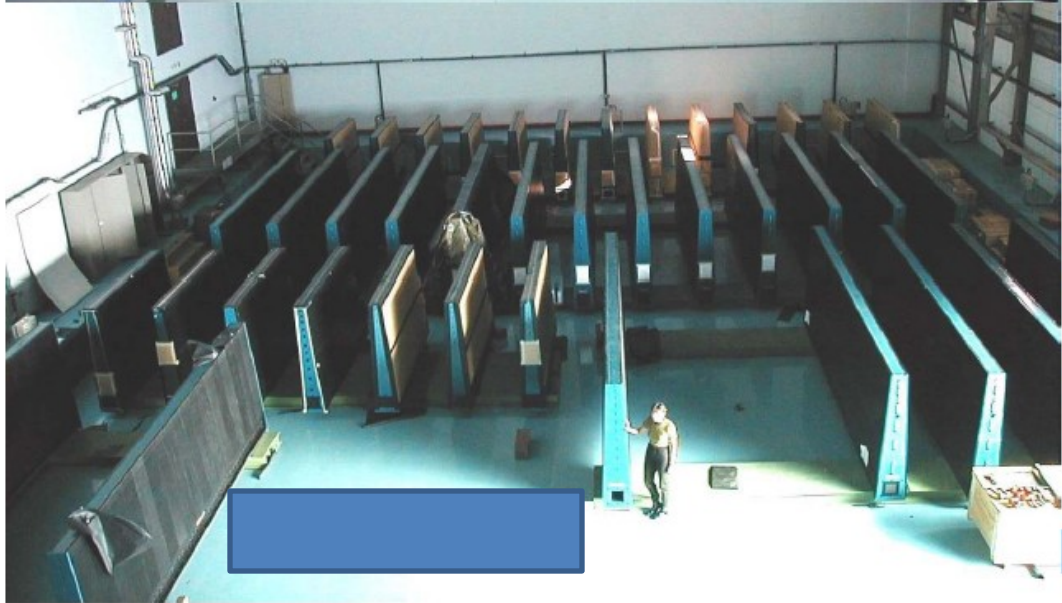


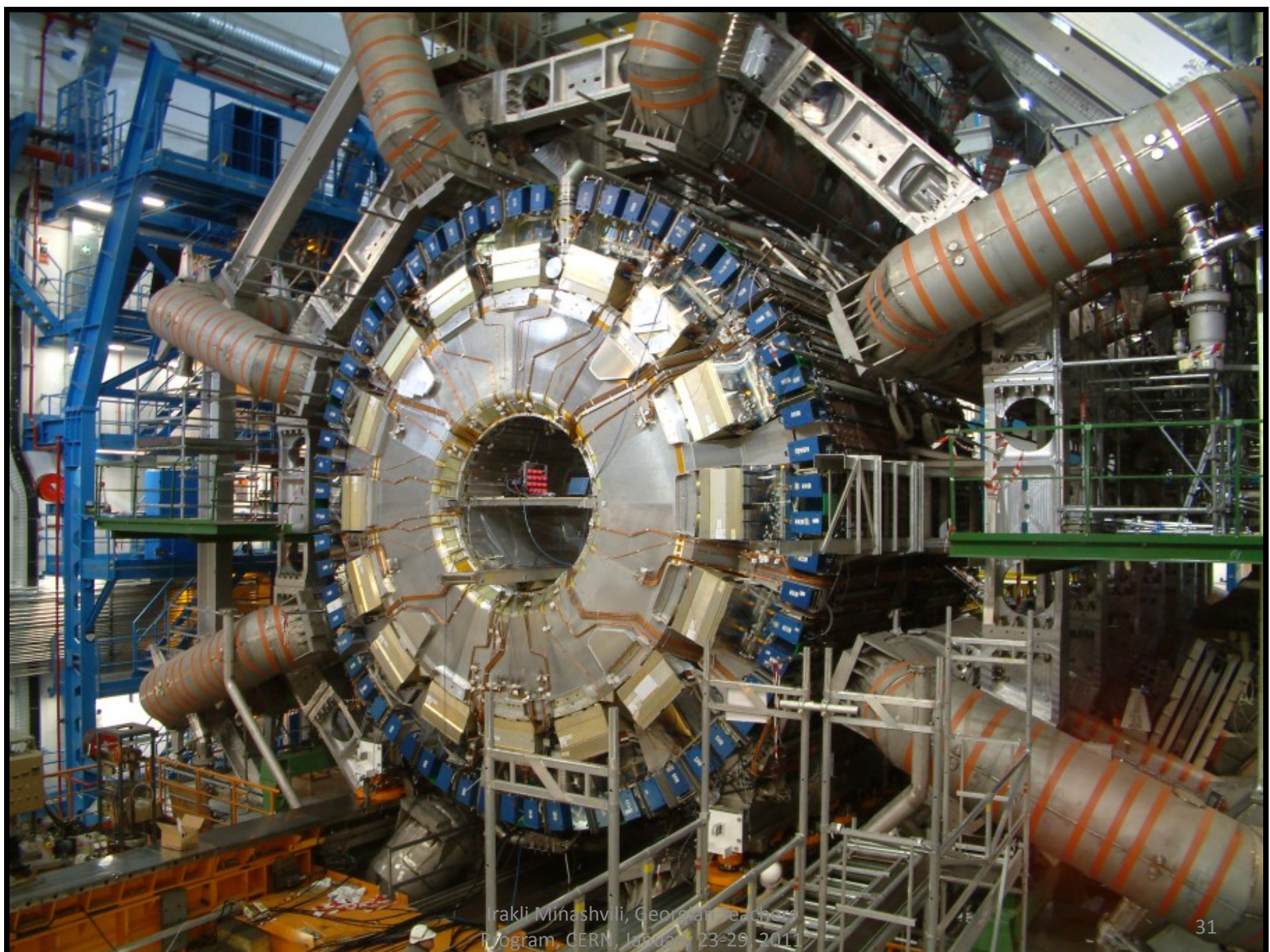


Tile Calorimeter



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





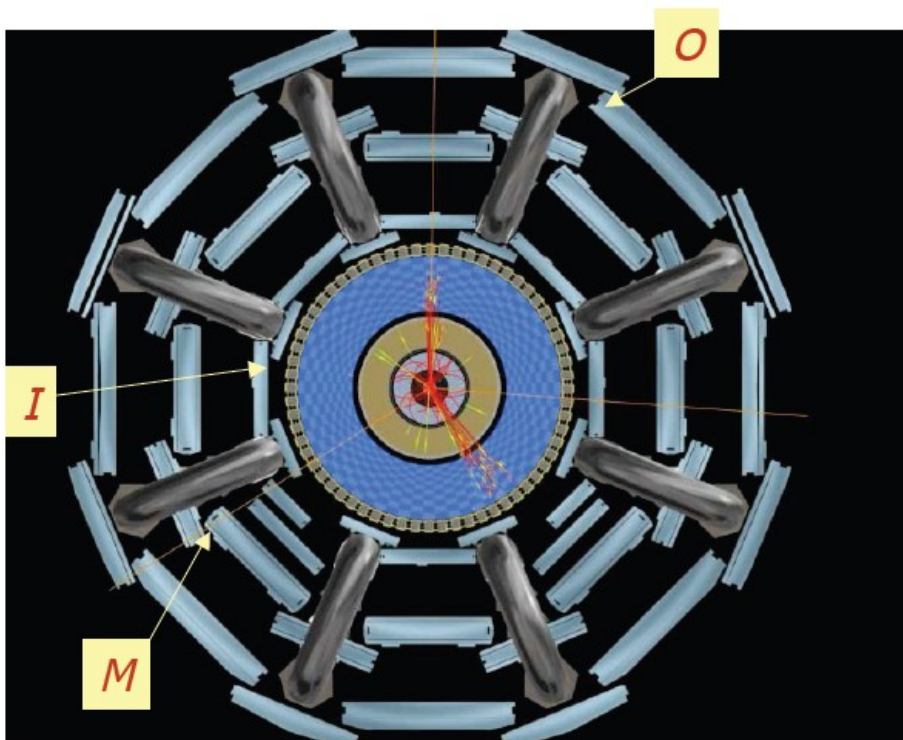
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The muon spectrometer (barrel)

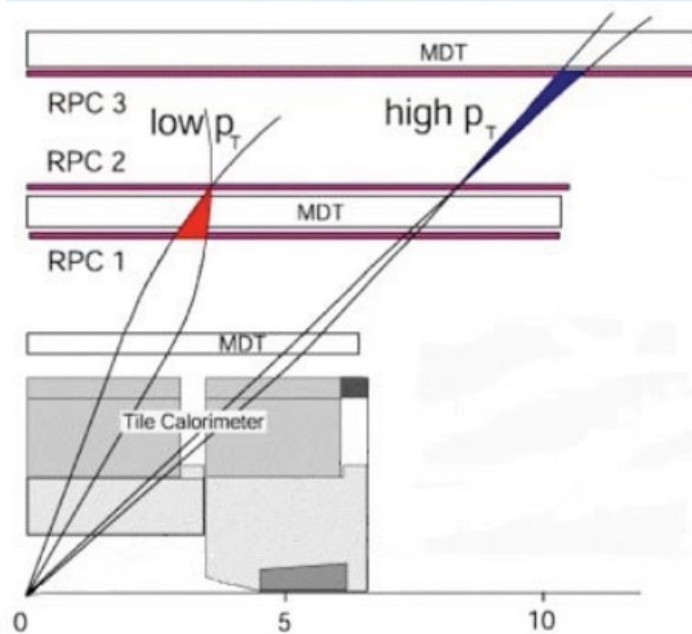


Barrel: precision and trigger chambers in 3 layers (588 stations):

I (inner) - M (middle) - O(outer)



Trigger chambers (RPC) rate capability required $\sim 1 \text{ kHz/cm}^2$

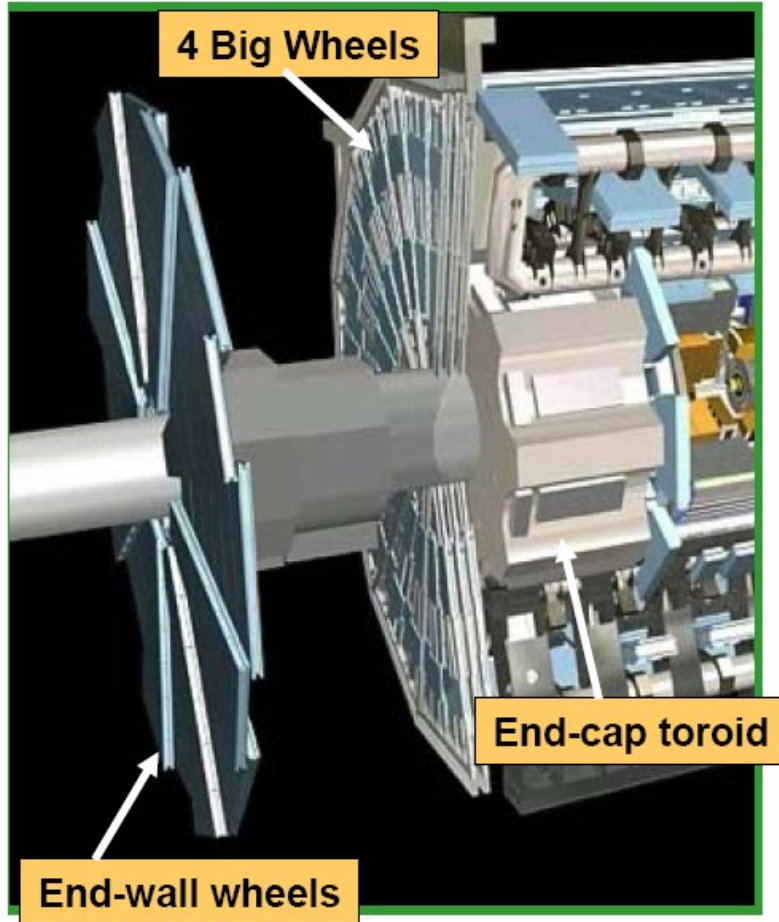


2 technologies:

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

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

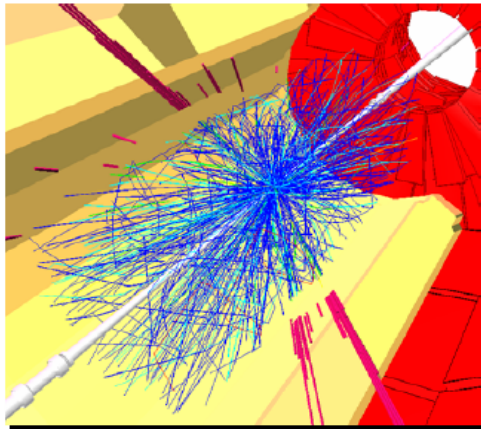
Forward muon spectrometer
- 'Big Wheels' are all installed
- The end-wall wheel installation has started



monacemebis dagrovebisa **trigeris** sistema atlas-ze dafuZnebulia sawyisi monacemebis sam safexurian SerCevaze. trigeris saSualebiT xdeba monacemTa arCeva manam informacia Caiwereba mexsierebaSi (informaciis matareblebze).

im **10's PetaByte/sec (100 000 CD's/sec)** SemTxvevebidan romlebic warmoiqmnebian atlas-ze mxolod **100 MetaByte/sec (1 CD's/2sec)** airCeva rogorc saWiwo, kargi SemTxveva Semdgomi analizisaTvis.

Worldwide LHC Computing Grid (WLCG)



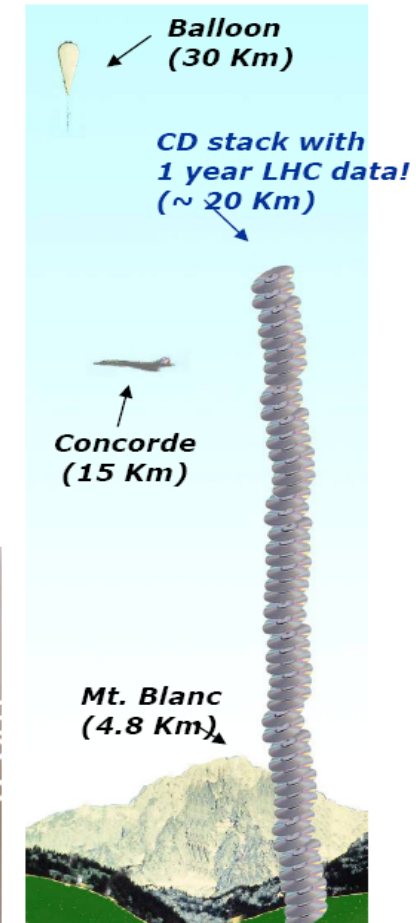
WLCG is a worldwide collaborative effort on an unprecedented scale in terms of storage and CPU requirements, as well as the software project's size

GRID computing developed to solve problem of data storage and analysis

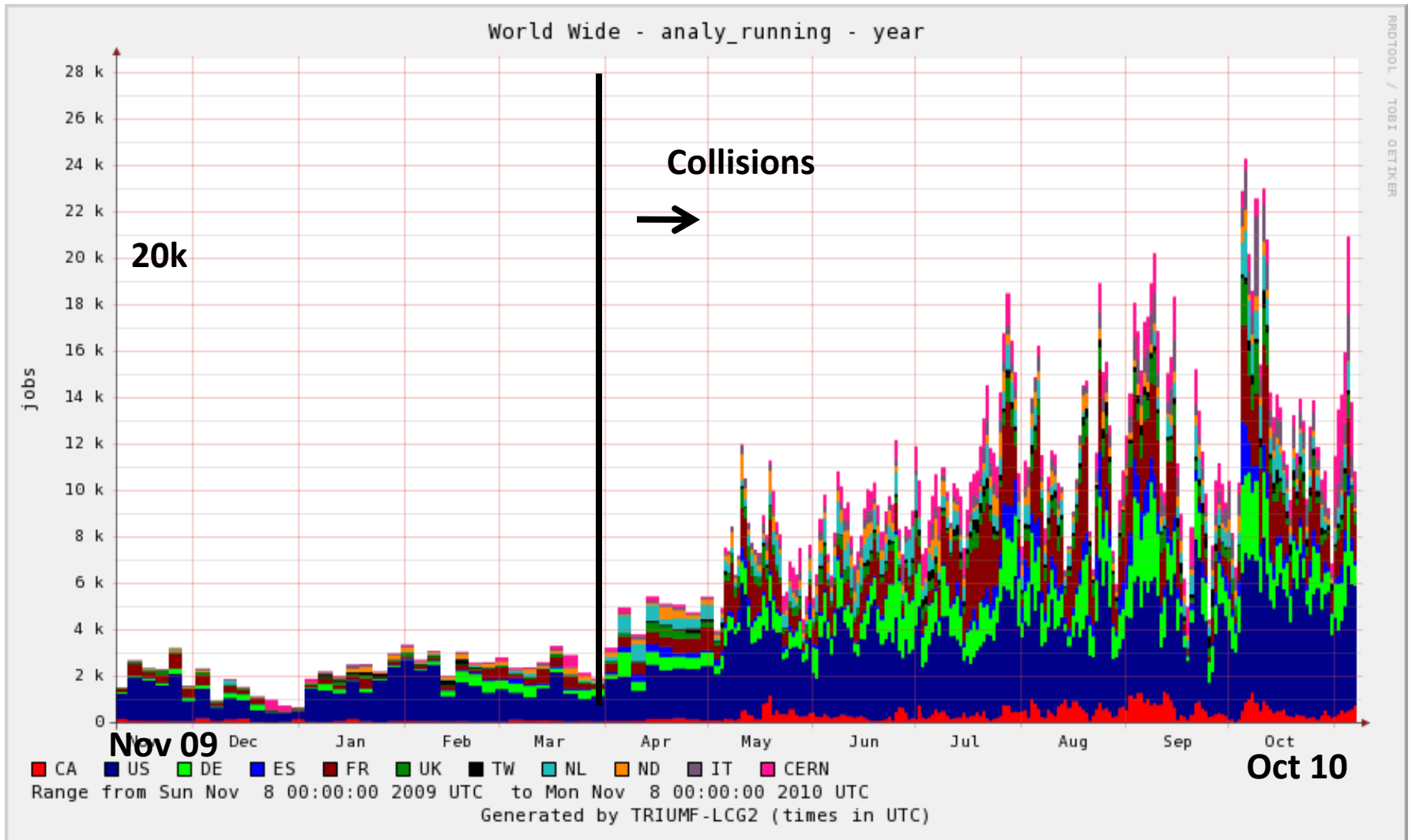
LHC data volume per year:
10-15 Petabytes

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

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



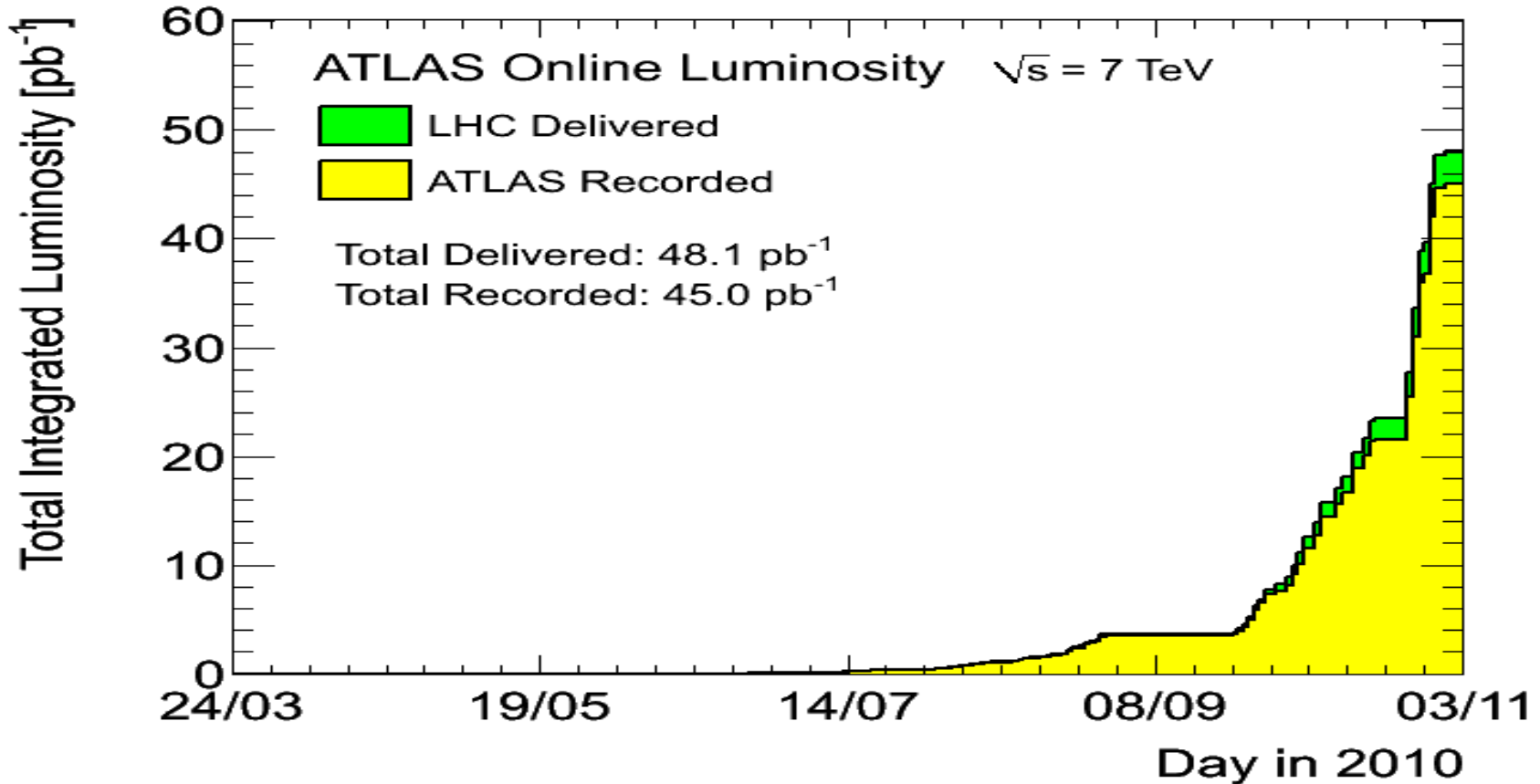
User analysis jobs



More than 1000 users

Irakli Minashvili, Georgian
Teachers Program, CERN,
January 23-29, 2011

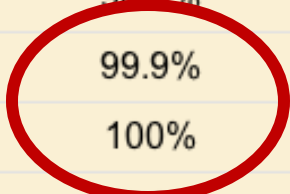
Integrated pp Luminosities 2010 Run



Note that 24 out of 48 pb⁻¹ were delivered in one week of pp running

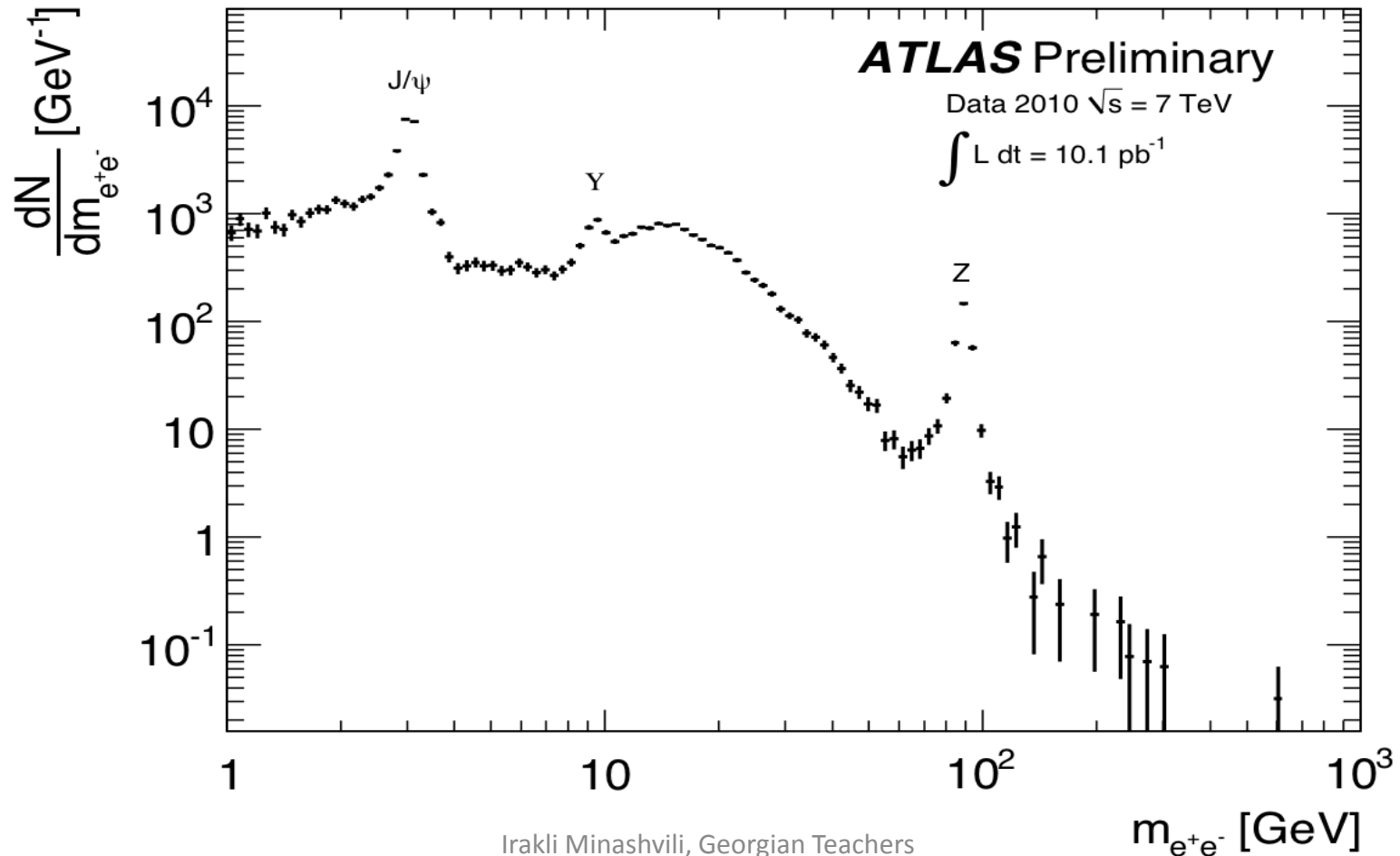
Number of Channels and Operational Fraction of Subsystems

| Subdetector | Number of Channels | Approximate Operational Fraction |
|----------------------------------|--------------------|----------------------------------|
| Pixels | 80 M | 97.3% |
| SCT Silicon Strips | 6.3 M | 99.2% |
| TRT Transition Radiation Tracker | 350 k | 97.1% |
| LAr EM Calorimeter | 170 k | 97.9% |
| Tile calorimeter | 9800 | 96.8% |
| Hadronic endcap LAr calorimeter | 5600 | 99.9% |
| Forward LAr calorimeter | 3500 | 100% |
| LVL1 Calo trigger | 7160 | 99.9% |
| LVL1 Muon RPC trigger | 370 k | 99.5% |
| LVL1 Muon TGC trigger | 320 k | 100% |
| MDT Muon Drift Tubes | 350 k | 99.5% |
| CSC Cathode Strip Chambers | 31 k | 98.5% |
| RPC Barrel Muon Chambers | 370 k | 97.0% |
| TGC Endcap Muon Chambers | 320 k | 98.4% |



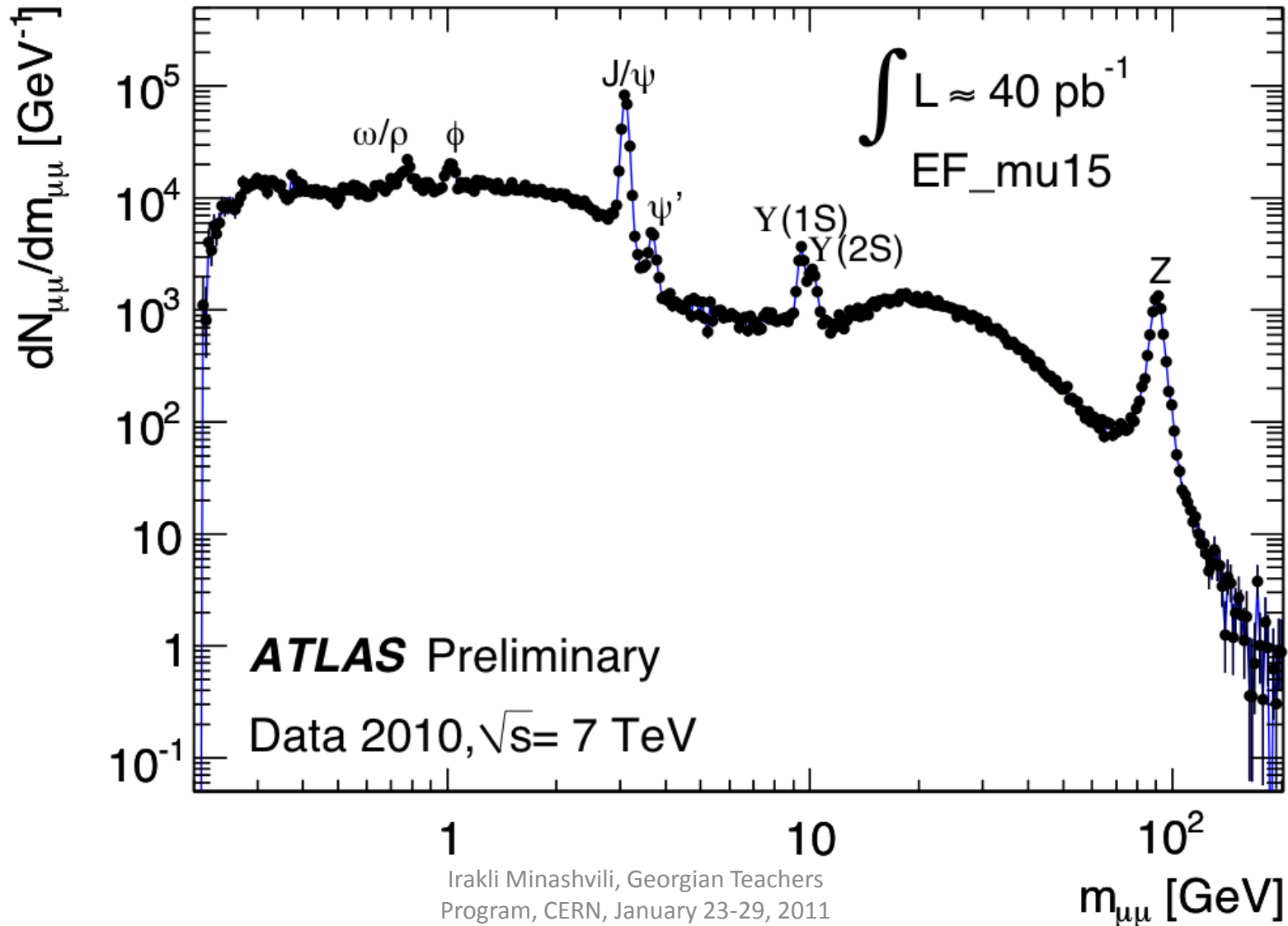
Di-electron invariant mass

Data with 5 GeV E_T di-electron trigger (prescaled in later data)
(Trigger selection produces shoulder around 15 GeV)



Di-muon invariant mass

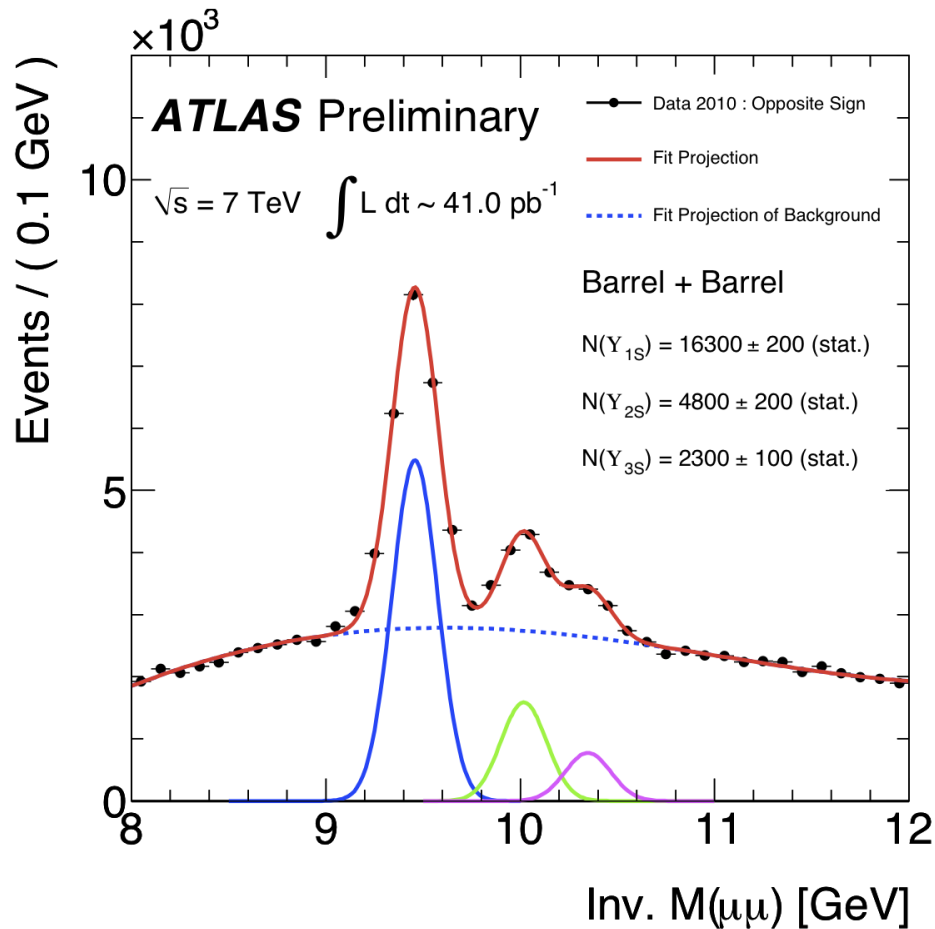
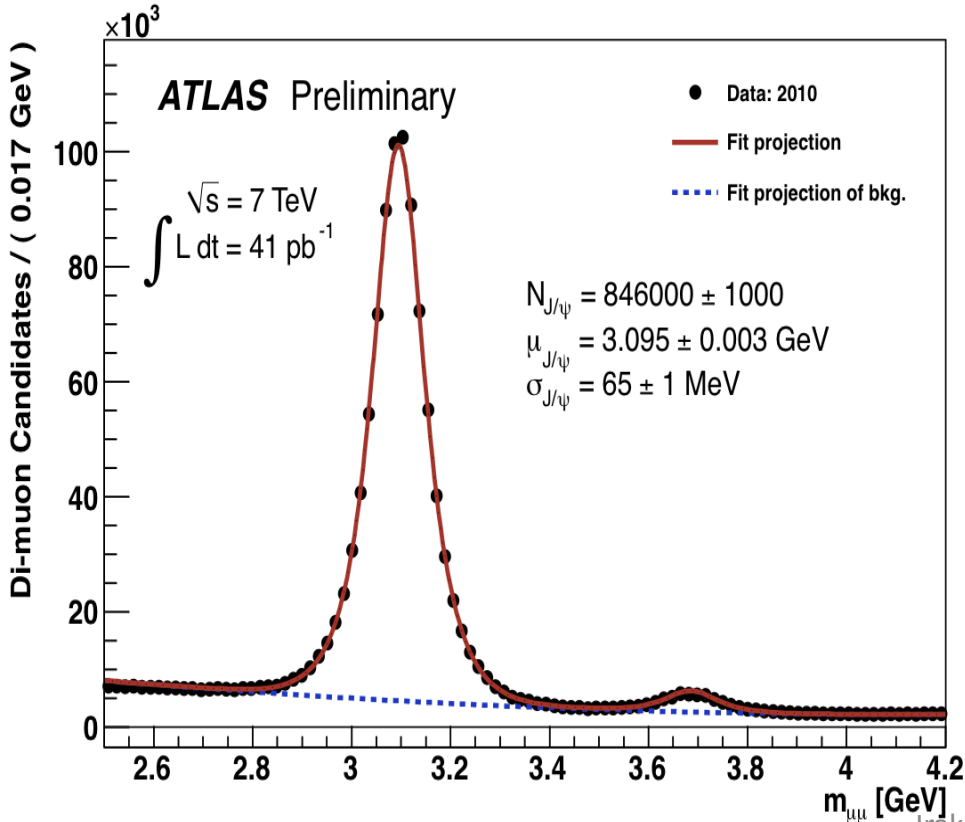
Leading muon, $p_T > 15$ GeV, second muon, $p_T > 2.5$ GeV



$J/\Psi, \Psi(2S)$ and $\Upsilon \rightarrow \mu\mu$

Use a selection of looser triggers
(Oppositely charged muons with
 $p_T(\mu_1, \mu_2) > (2.5, 4)$ GeV)

For J/Ψ & $\Psi(2S)$ fit tracks to a common
vertex and recalculate mass



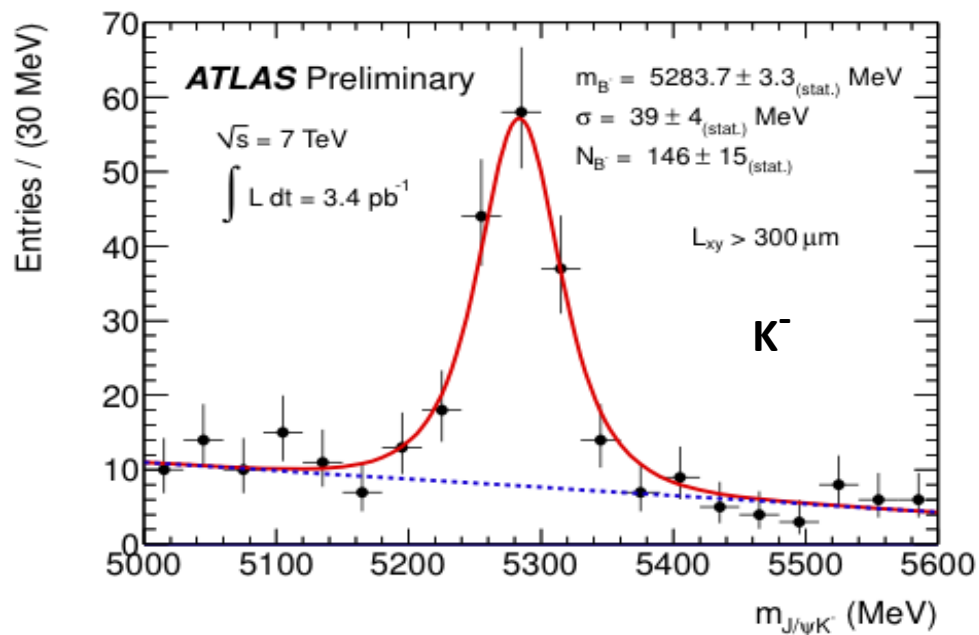
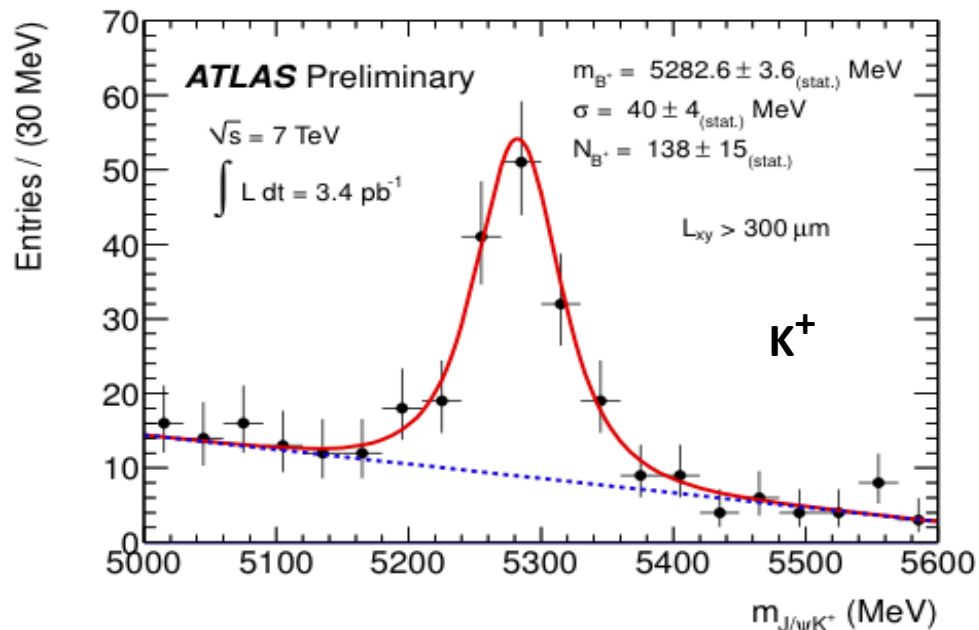
About 60k $\Upsilon(1S, 2S, 3S)$ candidates
over full acceptance

$B \rightarrow J/\Psi(\mu\mu)K$

Signal for $B^\pm \rightarrow J/\Psi(\mu\mu)K^\pm$
require transverse decay
length $> 300 \mu\text{m}$

Unbinned likelihood fit to
signal (with event-by-event
mass uncertainty) and
linear background

Combining K^+ and K^-
 283 ± 22 signal events,
fitted mass 5283 ± 2.5 MeV



Intermediate Vector Bosons W and Z

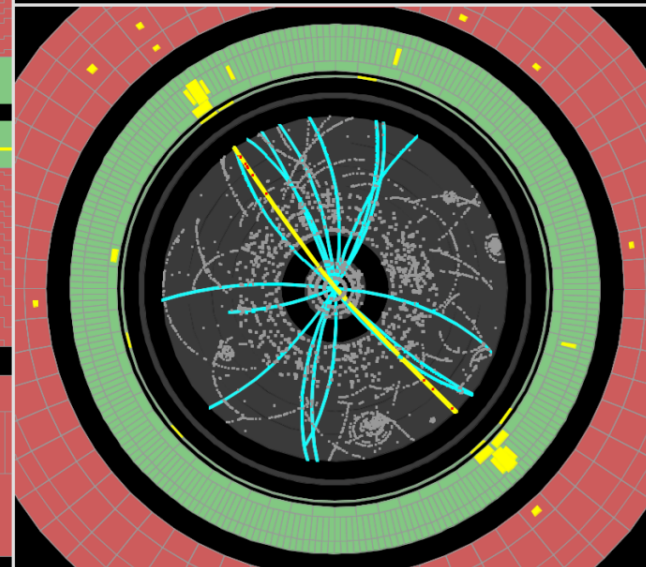
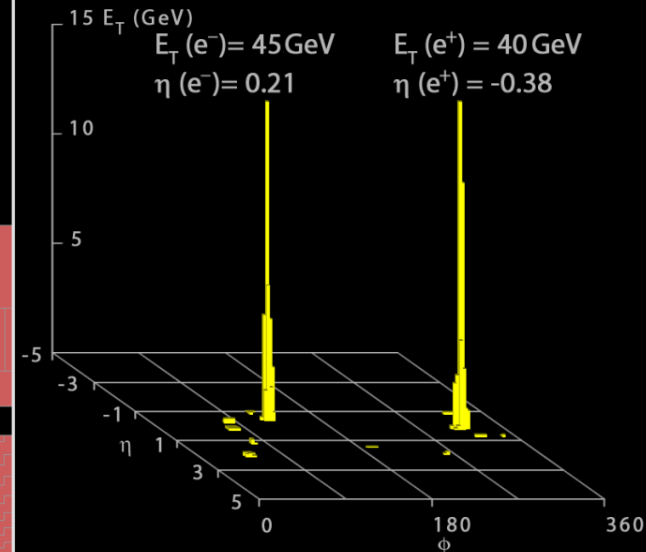
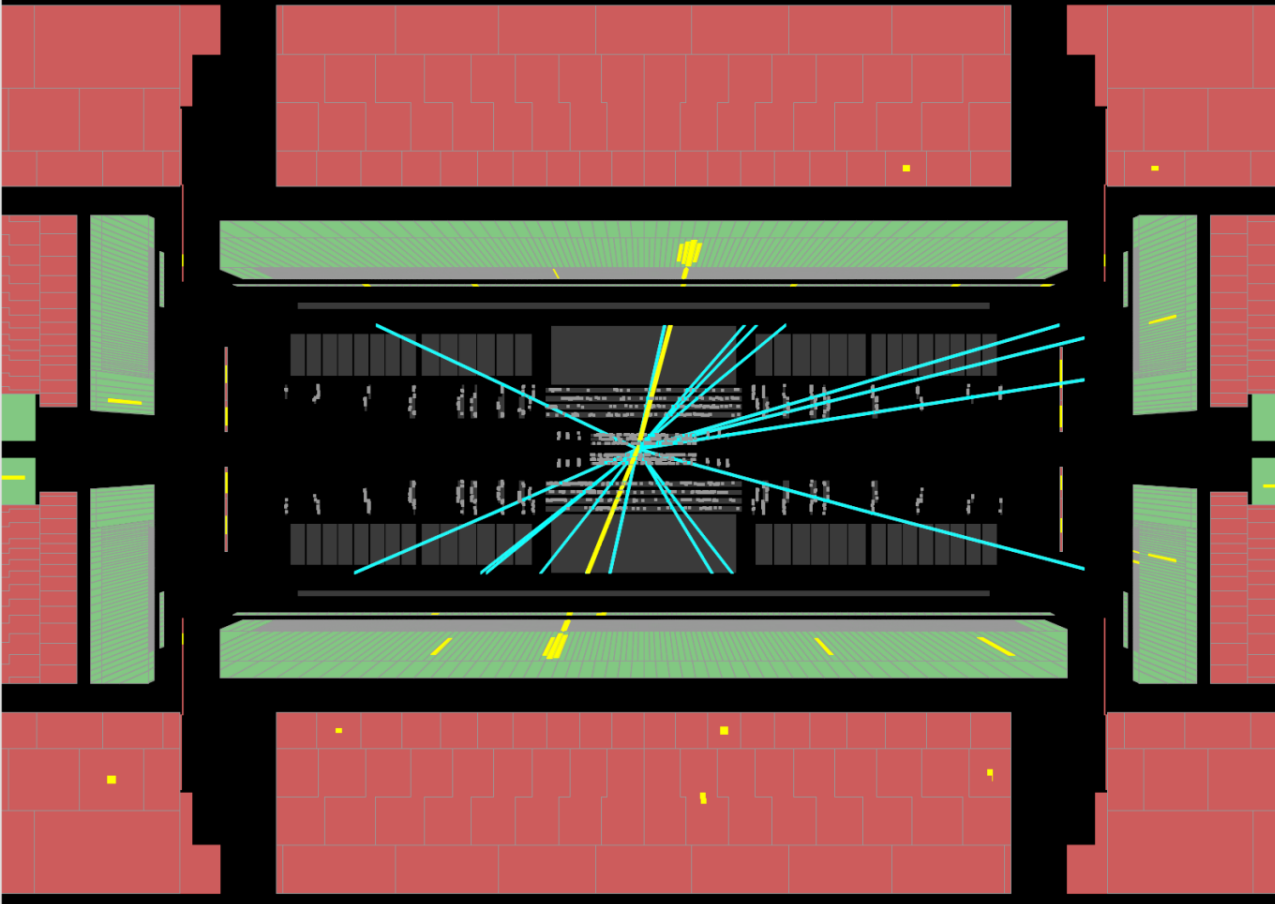


Run Number: 154817, Event Number: 968871

Date: 2010-05-09 09:41:40 CEST

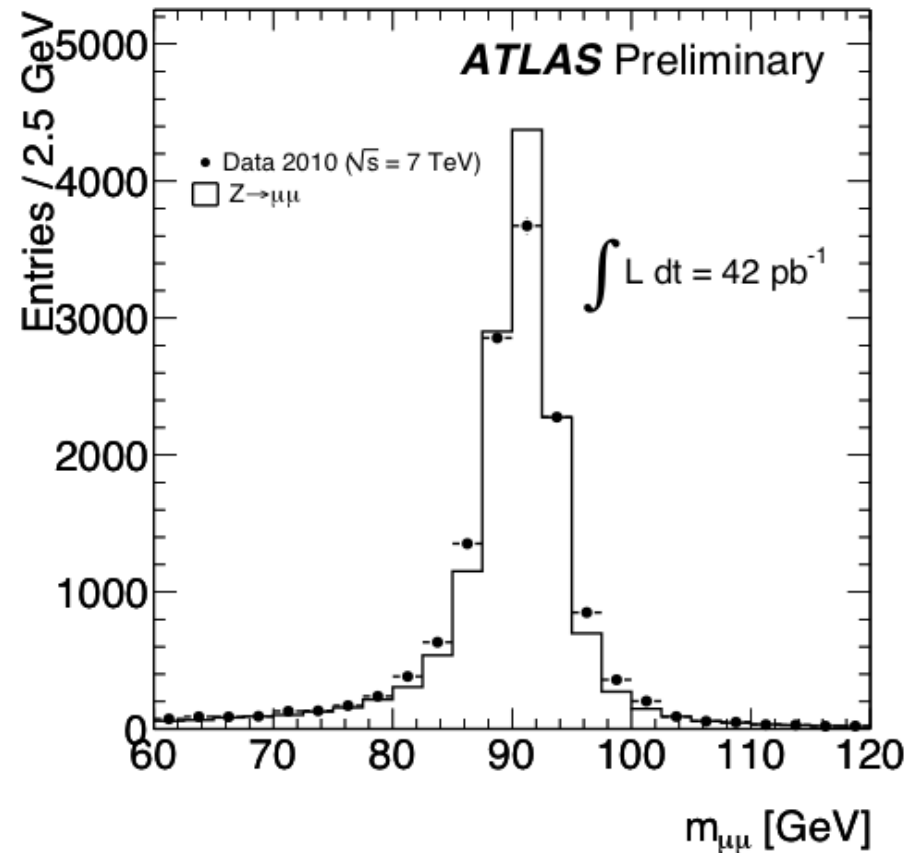
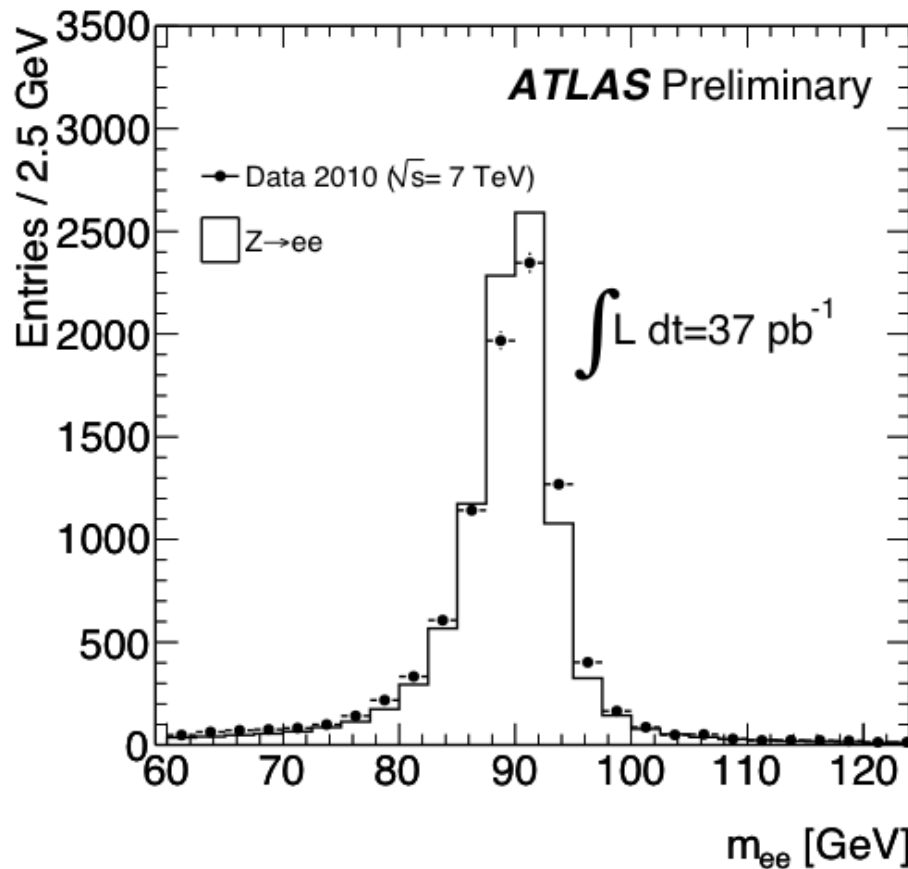
$M_{ee} = 89 \text{ GeV}$

$Z \rightarrow ee$ candidate in 7 TeV collisions



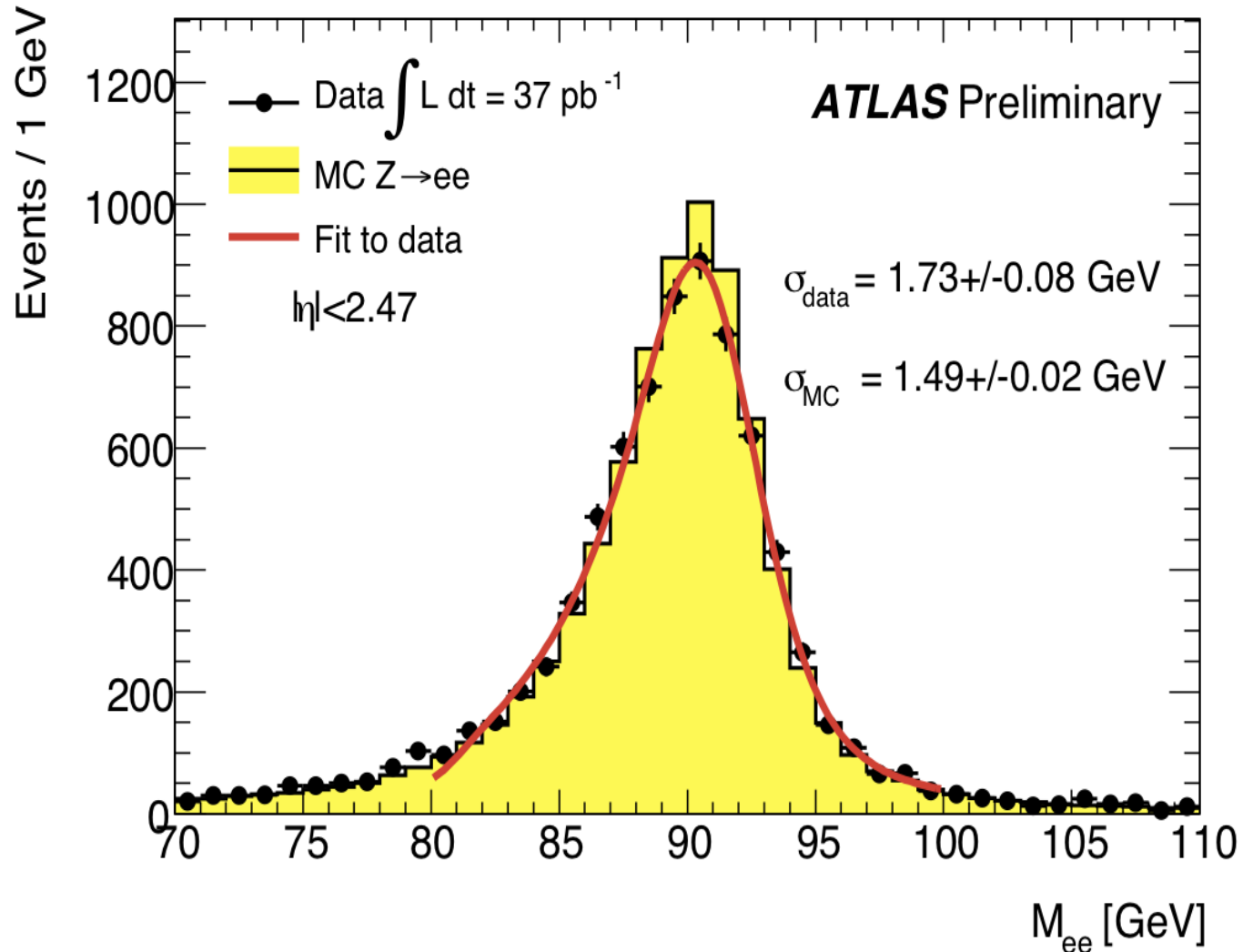
Z mass peaks

- Invariant mass of Z candidates with first pass processing
- MC normalised to data
- **9k electron and 14k muon pair events**



$Z \rightarrow ee$ invariant mass

Used to calibrate the EM scale with constrained fit to the Z lineshape in 28 calorimeter regions: Typical corrections 2%, consistent with precision of cryostat temperature measurement in test beam (this calibration is being applied in the reprocessing)



Fit to a Breit-Wigner convolved with a 'crystal ball' function (statistical errors only)

► The projections for 7/8/9 TeV have been updated to include the luminosity required for discovery

► With 1 fb^{-1} , expect to exclude $129 < M_H < 460 \text{ GeV}$ if LHC runs at 7 TeV. Running at 8 TeV would extend this range down by about 2.5 GeV

► With 5 fb^{-1} at 8 TeV, optimized analysis can lead to 3σ evidence for any allowed $M_H < 500 \text{ GeV}$

► With 10 fb^{-1} at 8 TeV, optimized analysis can lead to 5σ discovery for $120 < M_H < 500 \text{ GeV}$

dReisaTvis dagrovili gvaqvs **45pb-1** raodenoba monacemebisa. xigsis bozonis
aRmosaCenad gWirdeba **10fb-1** anu **>200X** meti monacemi vidre arsebobs.

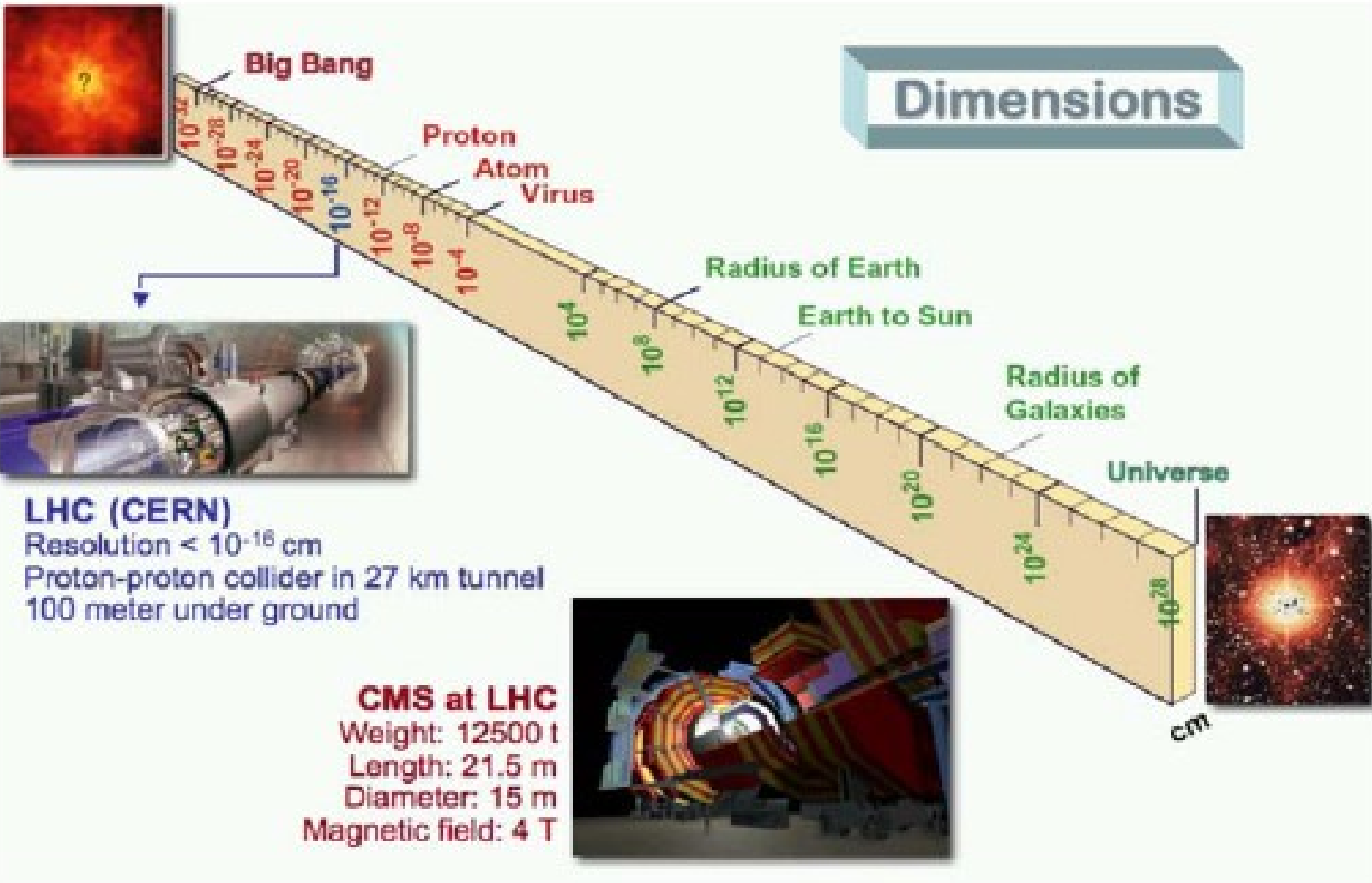
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gisurvebT am saqmeSi kovelgvar winsvlas.

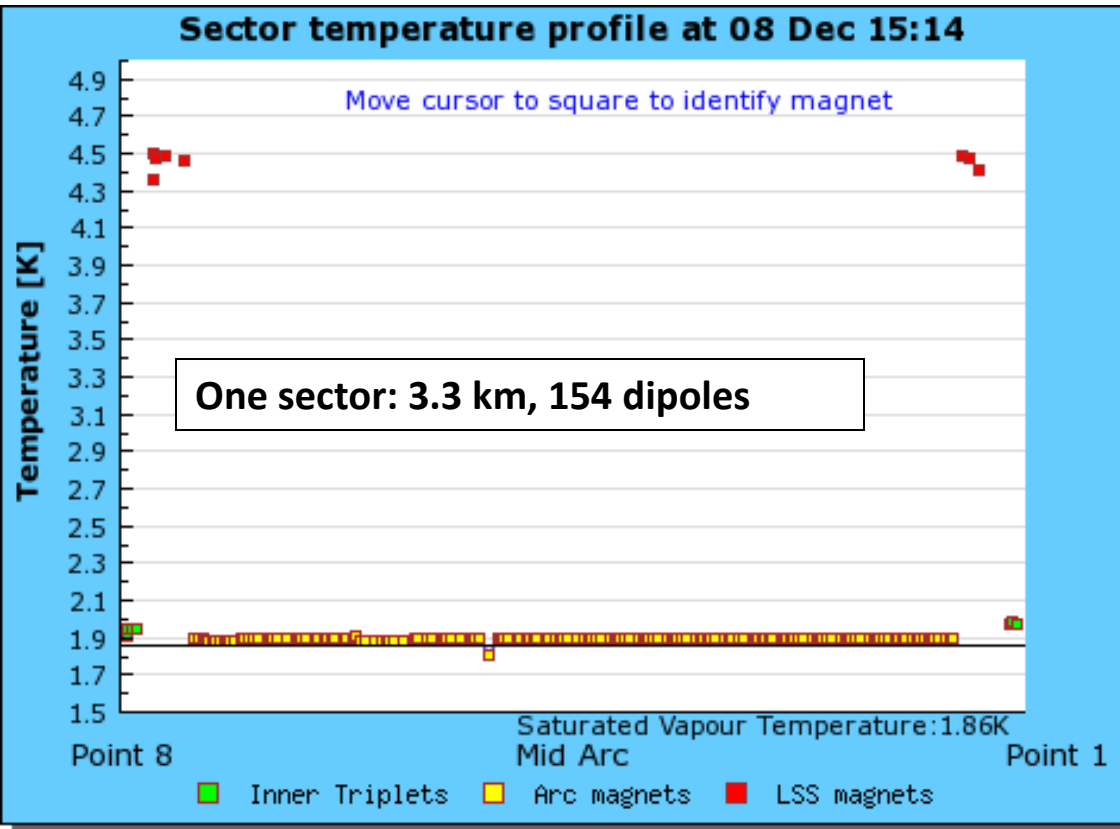
gmadlobT yuradRebisaTvis da moTminebisTvis.

momaval Sexvedramde.

Back slides

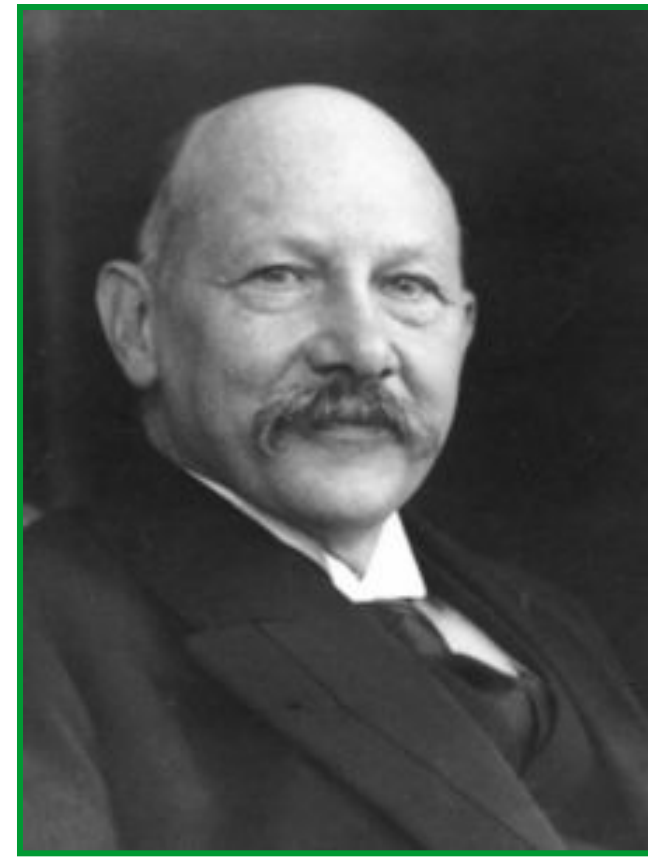


The LHC is the largest cryogenic system on earth, cooler than outer space



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

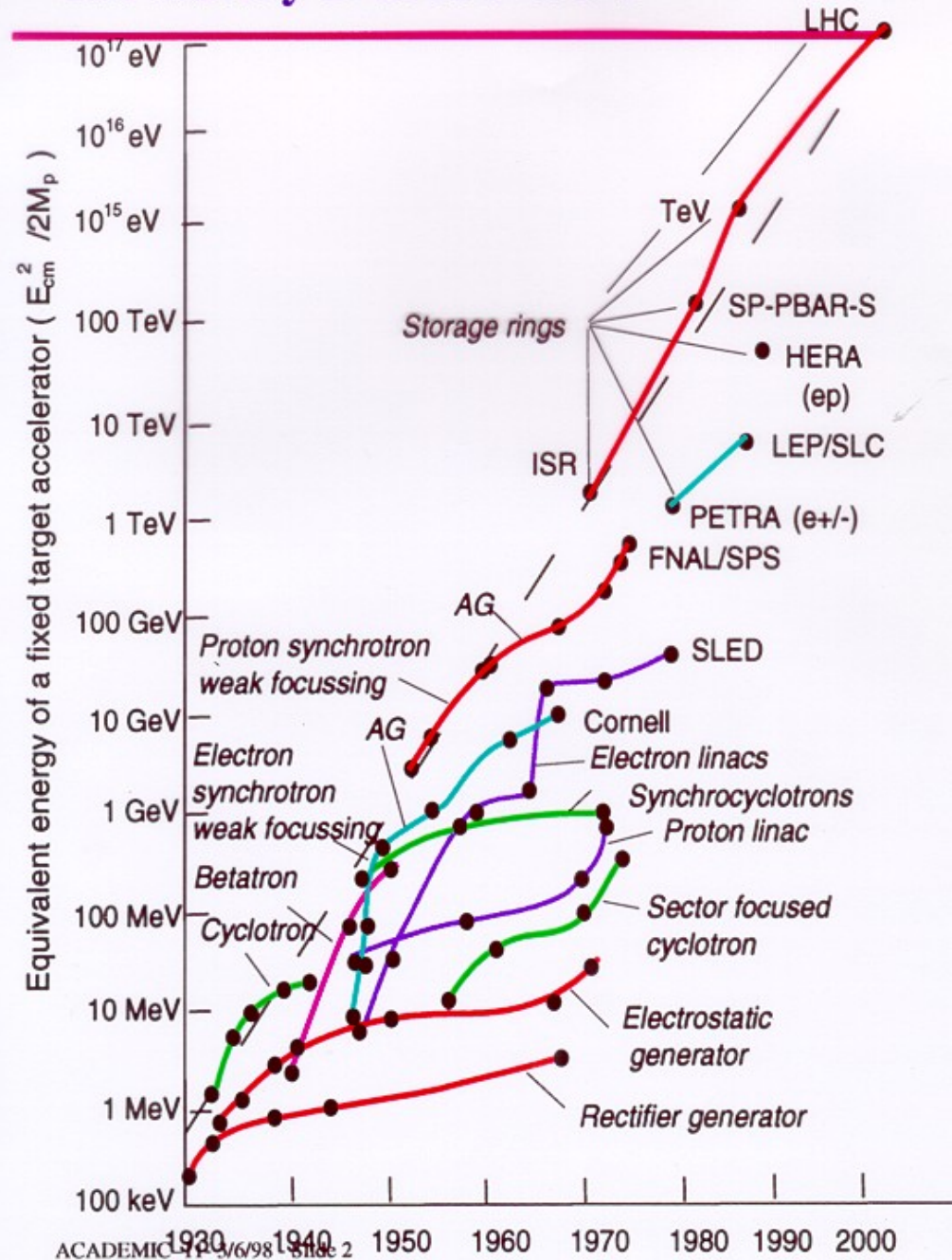
H K Onnes
Nobel Prize in Physics 1913



- ~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)

The history of accelerators

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} | $\text{cm}^{-2}\text{s}^{-1}$ |
| 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 |

n. of protons per bunch n. of bunches

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

n. of turns per second

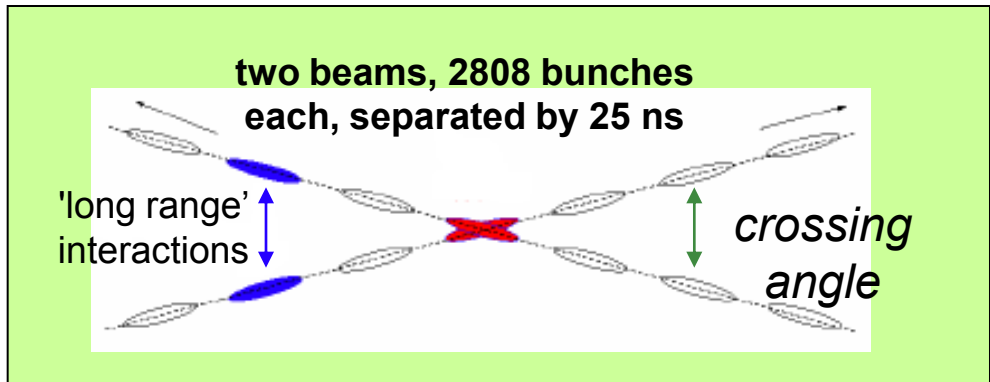
beam size at IP ($\sigma_{x,y} = 16 \mu\text{m}$)

$$N = L \times \sigma \text{ (pp} \rightarrow \text{X)}$$

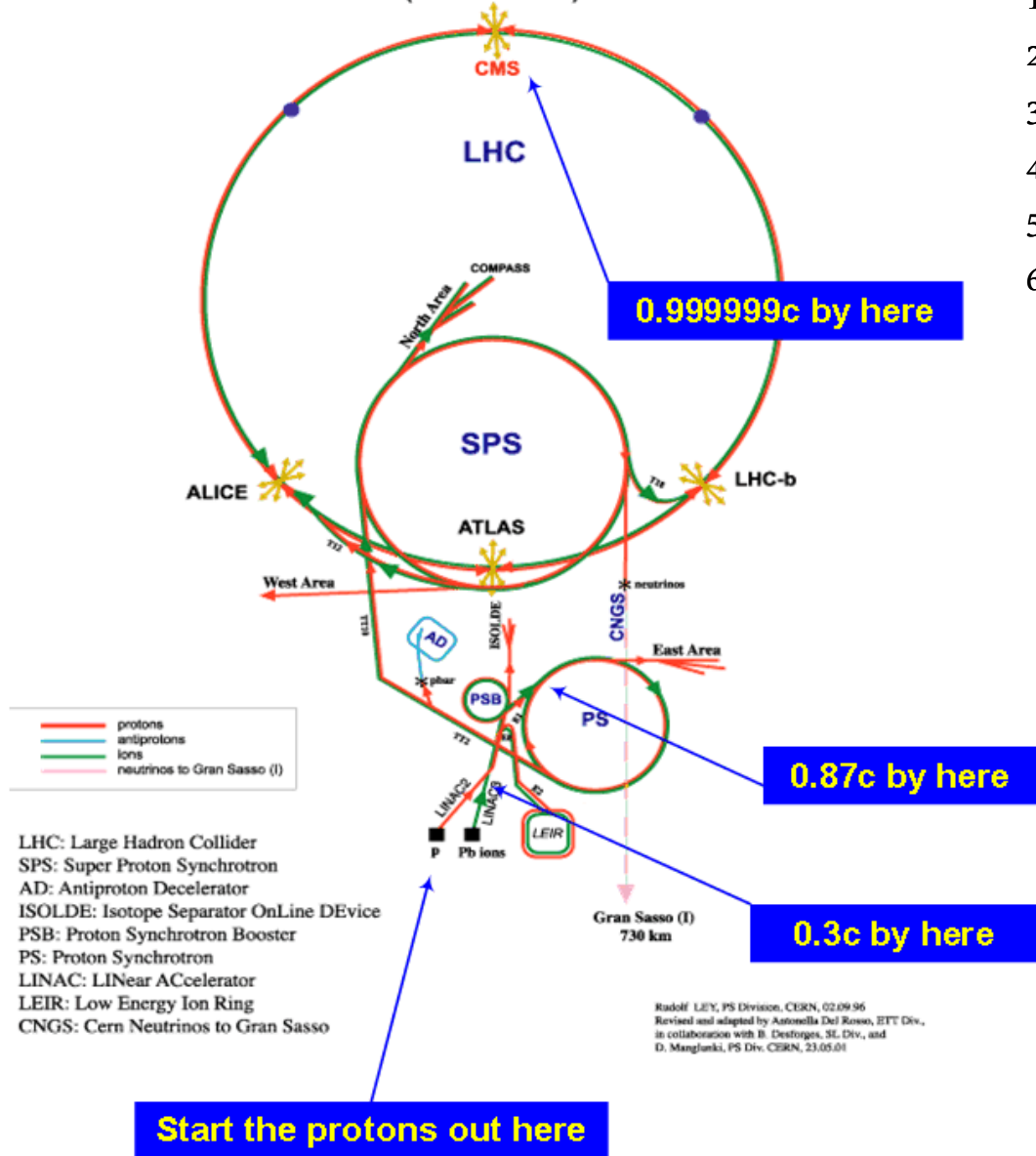
x200 Tevatron



Aircraft carrier at 12 knots



CERN Accelerators (not to scale)



1. Pprotonebis wyaro, 100keV
2. wrfivi amCqarebeli, 50meV
3. Bbusteri, 1,4geV
4. Pprotonuli sinqrotroni, 28geV
5. super Pprotonuli sinqrotroni, 450geV
6. didi adronuli amaCqarebeli Semxvedr nakadebze, 7teV.

Maximum B-field

■ *required maximum dipole field:*

$$B \propto \gamma$$

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

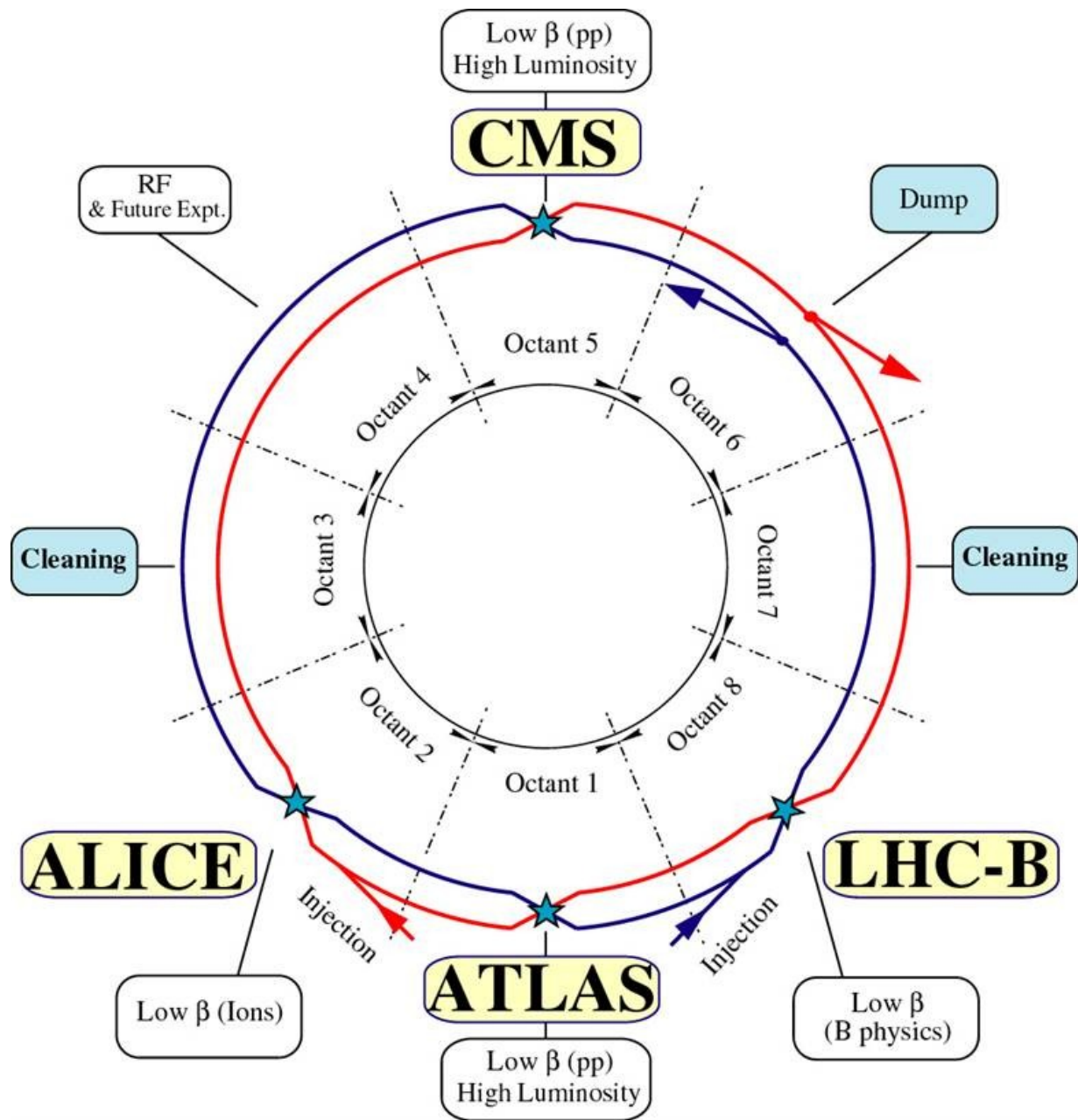
■ *Physics:* $\rightarrow p = 7000 \text{ GeV}/c$

■ *LEP tunnel:* $L = 27000 \text{ meter}$

■ *only 80% of the arc are filled with dipoles:* $\rightarrow F = 0.8$

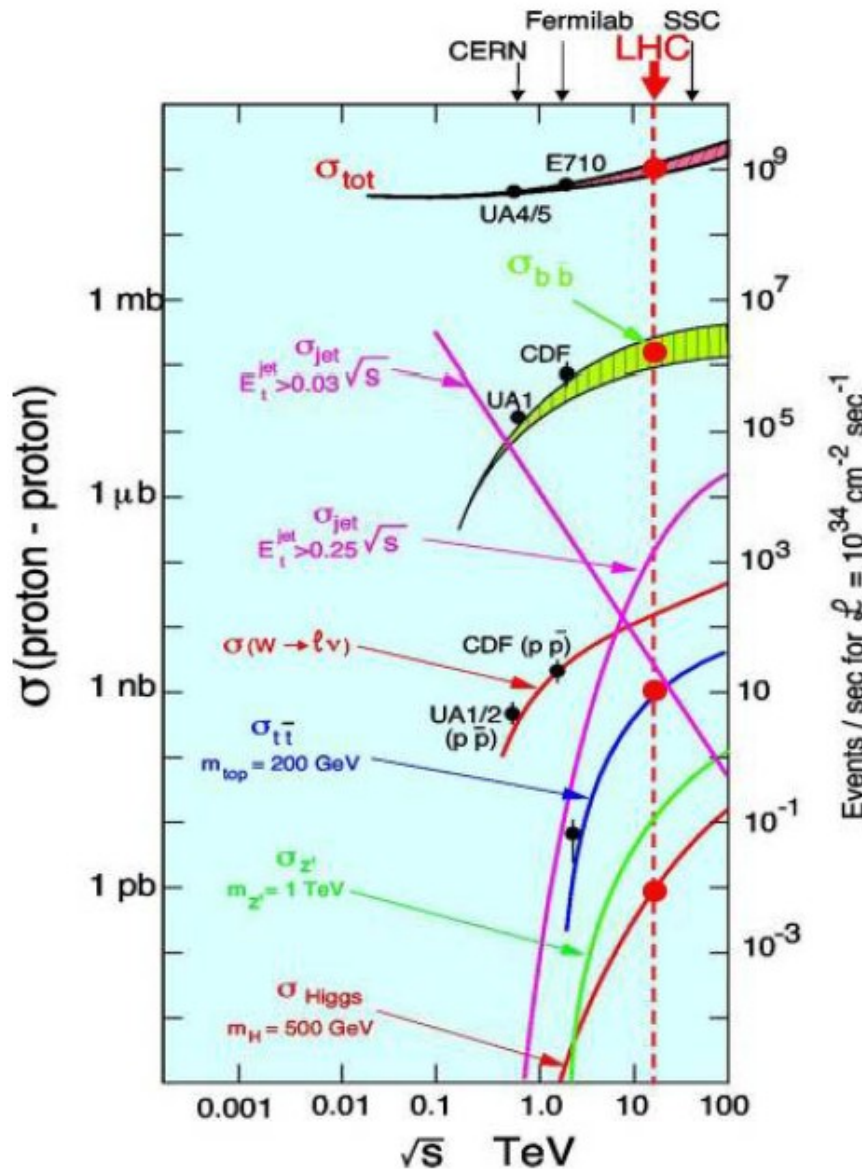
$$\rightarrow B_{\text{max}} = 8.38 \text{ T}$$

iron saturation: 2 Tesla
earth: $0.3 \cdot 10^{-4}$ Tesla





Cross Sections and Production Rates



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

| | |
|--------------------------------------|---------------------------|
| • Inelastic proton-proton reactions: | $10^9 / \text{s}$ |
| • bb pairs | $5 \cdot 10^6 / \text{s}$ |
| • tt pairs | $8 / \text{s}$ |
| • $W \rightarrow e \nu$ | $150 / \text{s}$ |
| • $Z \rightarrow e e$ | $15 / \text{s}$ |
| • Higgs (150 GeV) | $0.2 / \text{s}$ |
| • Gluino, Squarks (1 TeV) | $0.03 / \text{s}$ |

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 $\sim 115 < m_H < 1000 \text{ GeV}$

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.

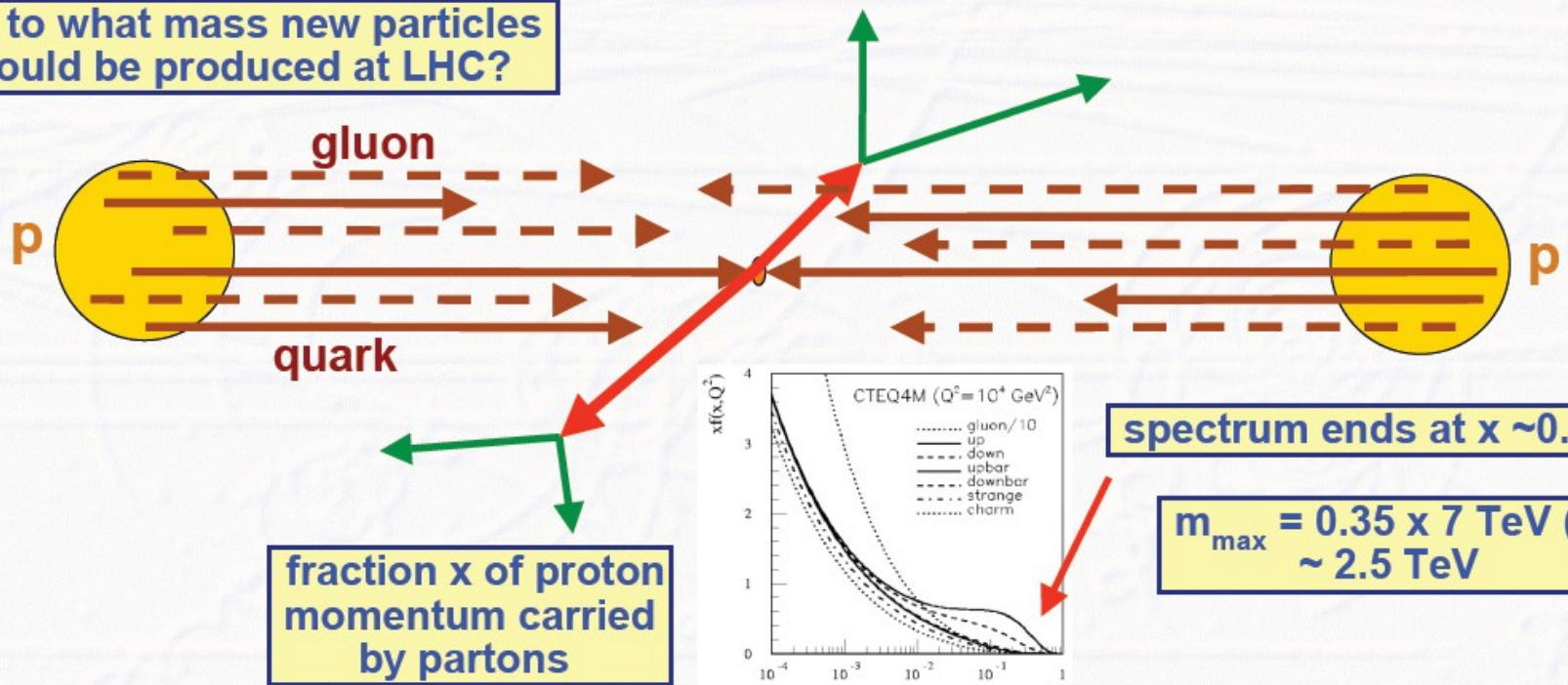
Study of **phase transition** at high density from hadronic matter **to plasma** of deconfined quarks and gluons (complementing **ALICE**).

Transition plasma \rightarrow hadronic matter happened in universe $\sim 10^{-5}$ s after Big Bang

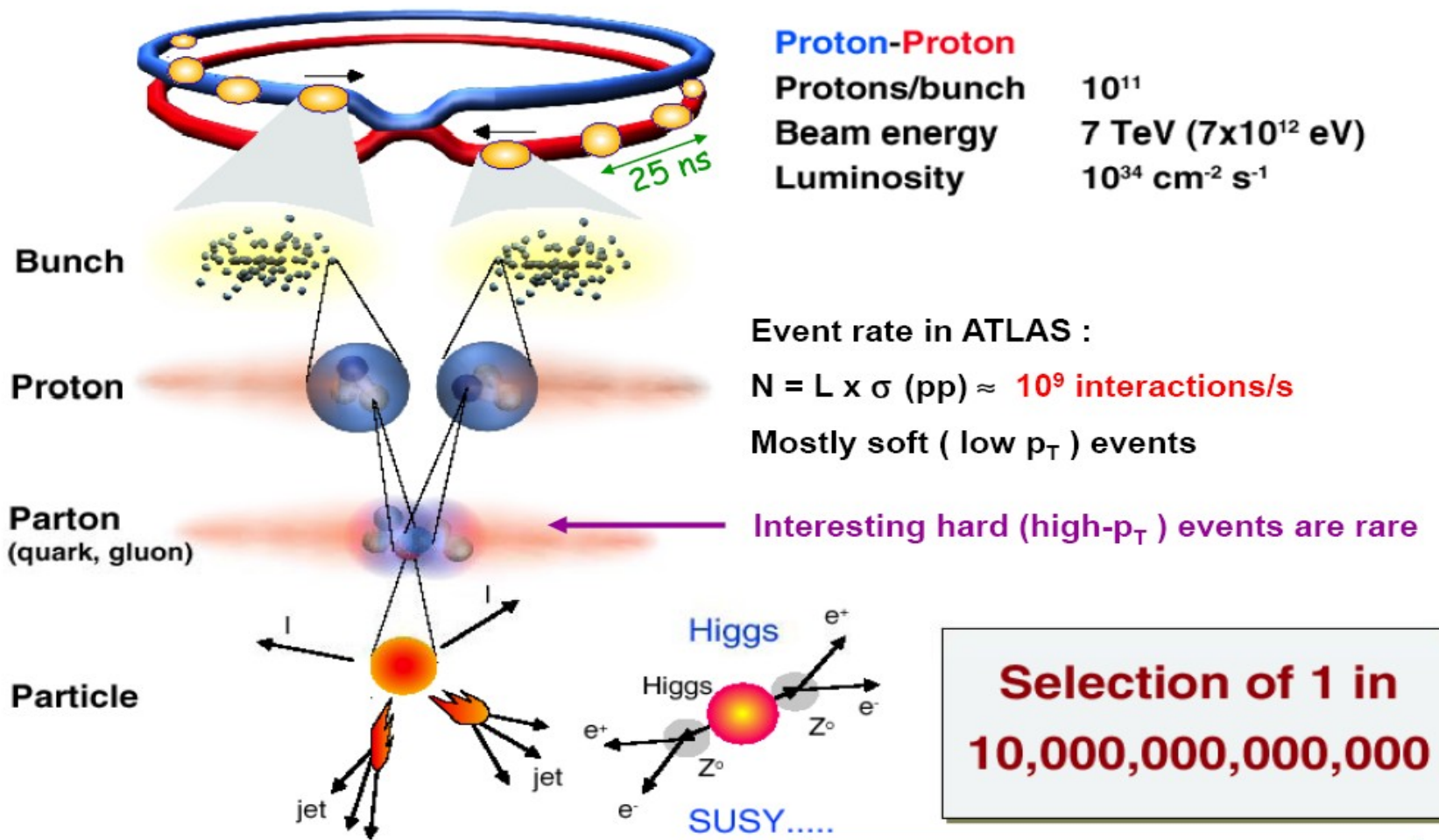
Etc. etc.



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



Collisions at LHC





Some 8 years ago ...

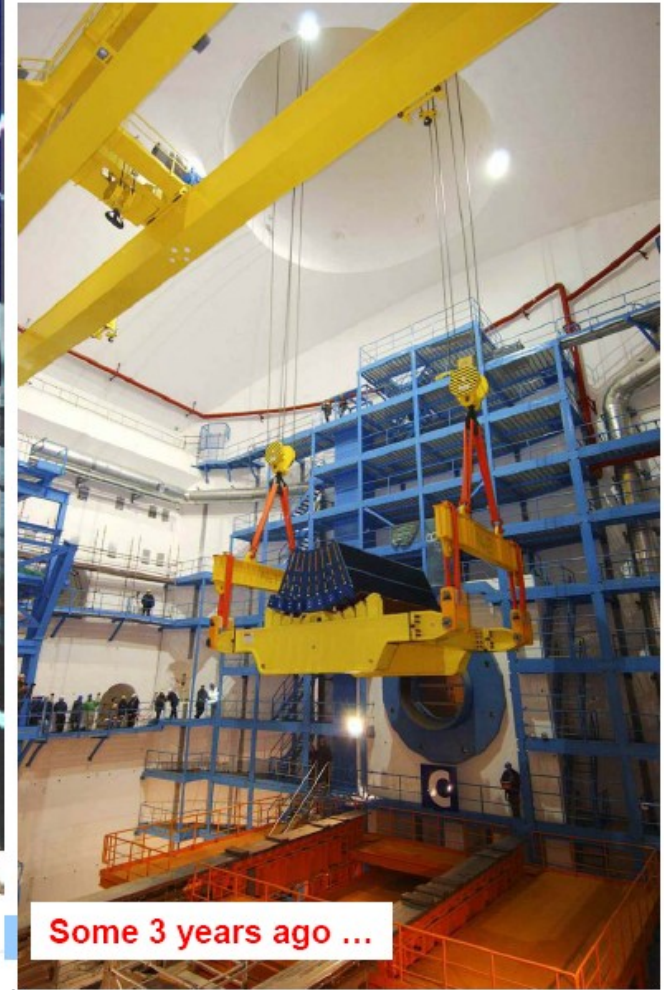


Some 7 years ago ...

Tile Calorimeter



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



Some 3 years ago ...

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 $7 \text{ TeV}/c^2$ - and these are the units usually used.

$7 \text{ TeV}/c^2$ divided by the rest mass $.938272029 \text{ GeV}/c^2$ 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

$c = 2.99793 * 10^8 \text{ m/s}$

$m = \text{Energy}/c^2 = 1.2477 * 10^{-23} \text{ Kg}$

At rest (rest mass proton = m_p):

Energy = $m_p c^2 = 0.938272029 * 10^9 * 1.60206 * 10^{-19}$ Joules (or just say $m_p = 0.938272029 \text{ GeV}/c^2$)

$m_p = \text{Energy}/c^2 = 1.672009 * 10^{-27} \text{ Kg}$

$m/m_p = 7460.52$ as before

This number is gamma i.e. $1/\sqrt{1 - v^2/c^2}$ - from which you can easily calculate the velocity.

Standard Model of FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model is a quantum theory that summarizes our current knowledge of the physics of fundamental particles and fundamental interactions (interactions are manifested by forces and by decay rates of unstable particles).

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

| Leptons spin = 1/2 | | | Quarks spin = 1/2 | | |
|--------------------------------|-------------------------------|-----------------|-------------------|---------------------------------|-----------------|
| Flavor | Mass GeV/c ² | Electric charge | Flavor | Approx. Mass GeV/c ² | Electric charge |
| ν_e "lightest neutrino" | (0-0.13) $\times 10^{-9}$ | 0 | u up | 0.002 | 2/3 |
| e electron | 0.000511 | -1 | d down | 0.005 | -1/3 |
| ν_μ "middle neutrino" | (0.009-0.13) $\times 10^{-9}$ | 0 | c charm | 1.3 | 2/3 |
| μ muon | 0.106 | -1 | s strange | 0.1 | -1/3 |
| ν_τ "heaviest neutrino" | (0.04-0.14) $\times 10^{-9}$ | 0 | t top | 173 | 2/3 |
| τ tau | 1.777 | -1 | b bottom | 4.2 | -1/3 |

*See the neutrino paragraph below.

Spin is the intrinsic angular momentum of particles. Spin is given in units of \hbar , which is the quantum unit of angular momentum where $\hbar = h/2\pi = 6.58 \times 10^{-16}$ GeV s = 1.05×10^{-34} J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The energy unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c² (remember $E = mc^2$) where $1 \text{ GeV} = 10^9 \text{ eV} = 1.60 \times 10^{-10}$ joule. The mass of the proton is $0.938 \text{ GeV}/c^2 = 1.67 \times 10^{-27}$ kg.

Neutrinos

Neutrinos are produced in the sun, supernovae, reactors, accelerator collisions, and many other processes. Any produced neutrino can be described as one of three neutrino flavor states ν_e , ν_μ , or ν_τ , labelled by the type of charged lepton associated with its production. Each is a defined quantum mixture of the three definite mass neutrinos, ν_1 , ν_2 , and ν_3 for which currently allowed mass ranges are shown in the table. Further exploration of the properties of neutrinos may yield powerful clues to puzzles about matter and antimatter and the evolution of stars and galaxy structures.

Matter and Antimatter

For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or - charge is shown). Particles and antiparticles have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0 , γ and $H_0 = h^0$, but not $K^0 = \bar{K}^0$) are their own antiparticles.

Particle Processes

These diagrams are an artist's conception. Blue-green shaded areas represent the cloud of gluons.

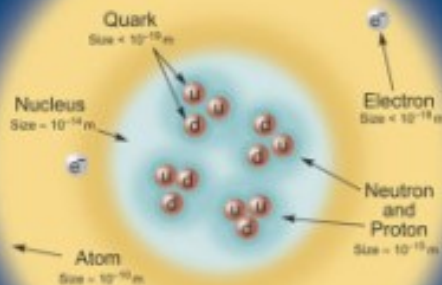
$n \rightarrow p e^- \bar{\nu}_e$

A free neutron (udd) decays to a proton (uud), an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β (beta) decay.

$e^+ e^- \rightarrow B^0 \bar{B}^0$

An electron and positron (antielectron) colliding at high energy can annihilate to produce B^0 and \bar{B}^0 mesons via a virtual Z boson or a virtual photon.

Structure within the Atom



If the proton and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

BOSONS

force carriers
spin = 0, 1, 2, ...

| Unified Electroweak spin = 1 | | | Strong (color) spin = 1 | | |
|------------------------------|-------------------------|-----------------|-------------------------|-------------------------|-----------------|
| Name | Mass GeV/c ² | Electric charge | Name | Mass GeV/c ² | Electric charge |
| γ photon | 0 | 0 | g gluon | 0 | 0 |
| W ⁻ | 80.39 | -1 | | | |
| W ⁺ | 80.39 | +1 | | | |
| Z ⁰ | 91.188 | 0 | | | |

Color Charge

Only quarks and gluons carry "strong charge" (also called "color charge") and can have strong interactions. Each quark carries three types of color charge. These charges have nothing to do with the colors of visible light. Just as electrically-charged particles interact by exchanging photons, in strong interactions, color-charged particles interact by exchanging gluons.

Quarks Confined in Mesons and Baryons

Quarks and gluons cannot be isolated – they are confined in color-neutral particles called hadrons. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs. The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge.

Two types of hadrons have been observed in nature: mesons (qq) and baryons (qqq). Among the many types of baryons observed are the proton (uud), antiproton (\bar{p}), neutron (udd), lambda baryon (Λ), and omega (Ω^-) (sss). Quark charges add in such a way as to make the proton have charge +1 and the neutron charge 0. Among the many types of mesons are the pion π^+ (u \bar{d}), kaon K^+ (u \bar{s}), B^0 (d \bar{s}), and η_c (c \bar{c}). Their charges are +1, -1, 0, 0, respectively.

Visit the award-winning web feature *The Particle Adventure* at ParticleAdventure.org

This chart has been made possible by the generous support of
U.S. Department of Energy
U.S. National Science Foundation
Lawrence Berkeley National Laboratory

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CPEPweb.org

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

| Property | Gravitational Interaction | Weak Interaction (Electroweak) | Electromagnetic Interaction | Strong Interaction |
|-------------------------|---------------------------------------|--|-----------------------------|--------------------|
| Acts on: | Mass – Energy | Flavor | Electric Charge | Color Charge |
| Particles experiencing: | All | Quarks, Leptons | Electrically Charged | Quarks, Gluons |
| Particles mediating: | Graviton (not yet observed) | W ⁺ W ⁻ Z ⁰ | γ | Gluons |
| Strength at: | 10^{-41} m 3×10^{-17} m | 0.8 10^{-4} | 1 1 | 25 60 |

Unsolved Mysteries

Driven by new puzzles in our understanding of the physical world, particle physicists are following paths to new wonders and startling discoveries. Experiments may even find extra dimensions of space, mini-black holes, and/or evidence of string theory.

Universe Accelerating?

The expansion of the universe appears to be accelerating. Is this due to Einstein's Cosmological Constant? If not, will experiments reveal a new force of nature or even extra (hidden) dimensions of space?

Why No Antimatter?

Matter and antimatter were created in the Big Bang. Why do we now see only matter except for the tiny amounts of antimatter that we make in the lab and observe in cosmic rays?

Dark Matter?

Invisible forms of matter make up much of the mass observed in galaxies and clusters of galaxies. Does this dark matter consist of new types of particles that interact very weakly with ordinary matter?

Origin of Mass?

In the Standard Model, for fundamental particles to have masses, there must exist a particle called the Higgs boson. Will it be discovered soon? Is supersymmetry theory correct in predicting more than one type of Higgs?

CERN - ბირთვული კვლევების ევროპული ცენტრი

Collider - ამაწყობელი სემხვედრ ნაკადებზე

LHC - დიდი ადრონული ამაწყობელი სემხვედრ ნაკადებზე

LINAC - ურფივი ამაწყობელი

PS - პროტონული სინკროტრონი

ATLAS – ზოგადი დანიშნულების დეტექტორი

CMS – მიონების კომპაქტური სოლენოიდი

Trigger – პრობა, რომლის შესრულების შემთხვევაშიც ხდება ფიზიკური მონაცემების გადართვა