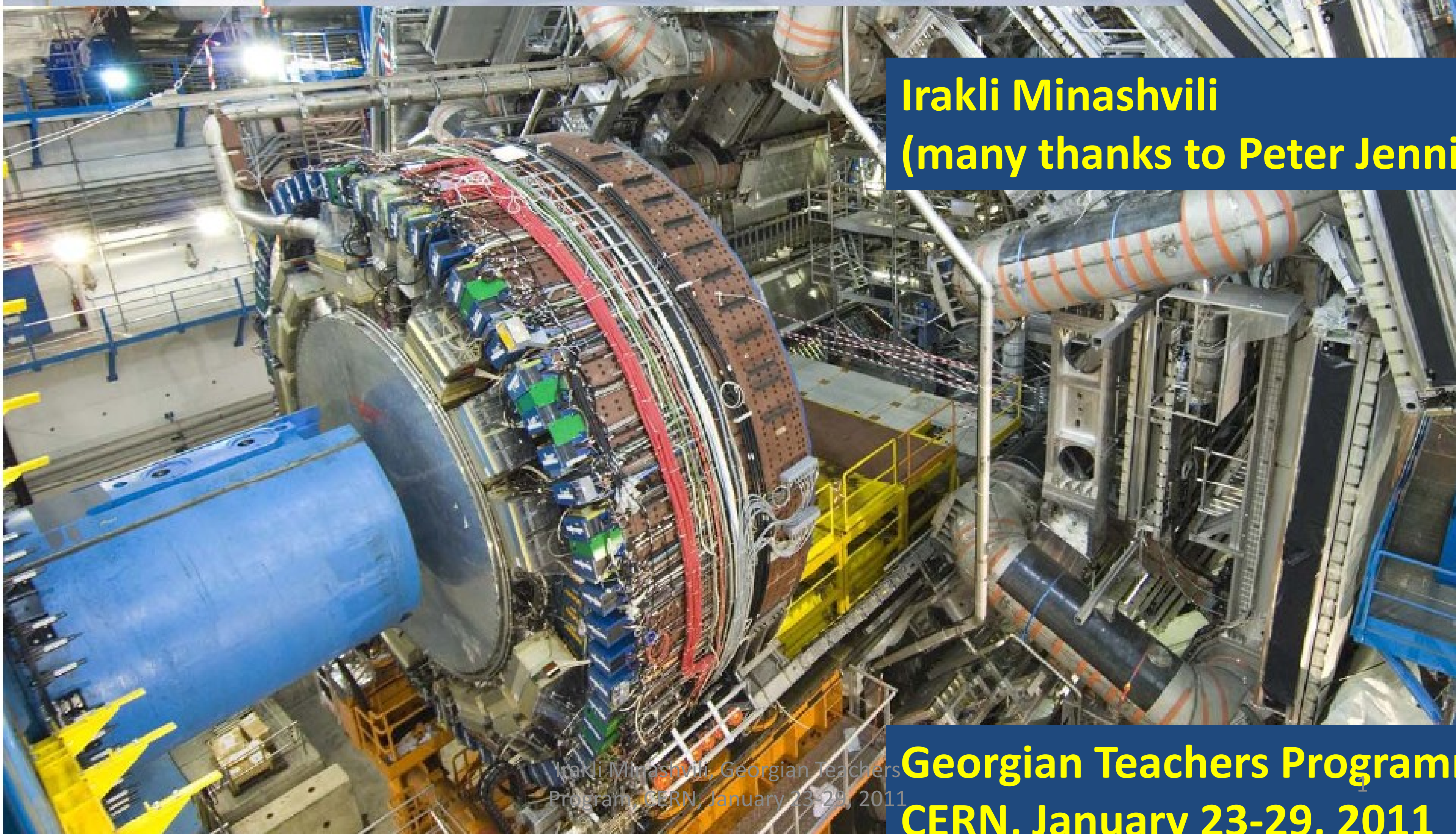
THE ATLAS EXPERIMENT

Mapping the Secrets of the Universe

Aanarekli samyaros saidumloebisa



Irakli Minashvili
(many thanks to Peter Jenni

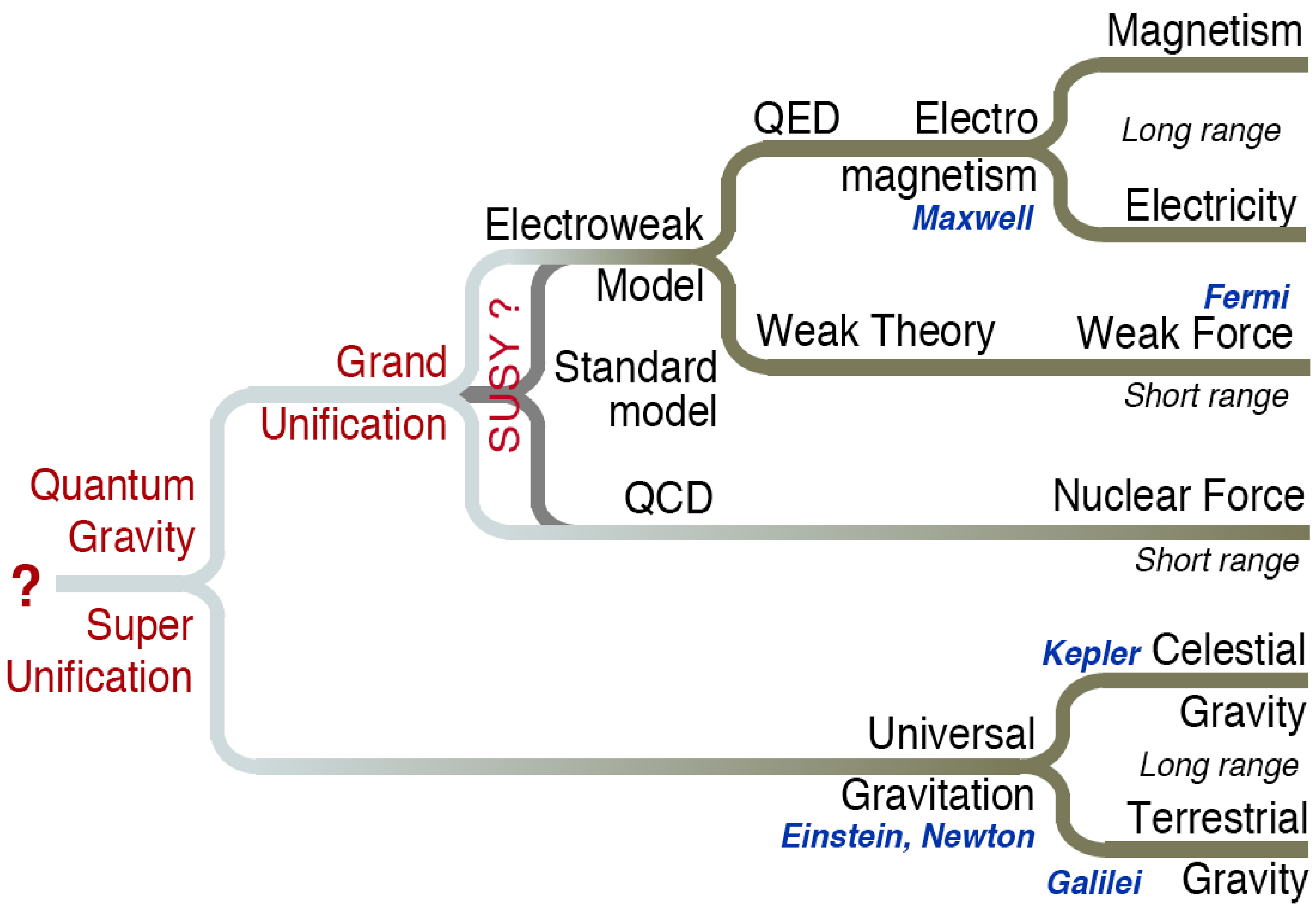
Georgian Teachers Programm
CERN, January 23-29, 2011


Large Hadron Collider
Lake of Gene
CMS
LHCb
ALICE
ATLAS

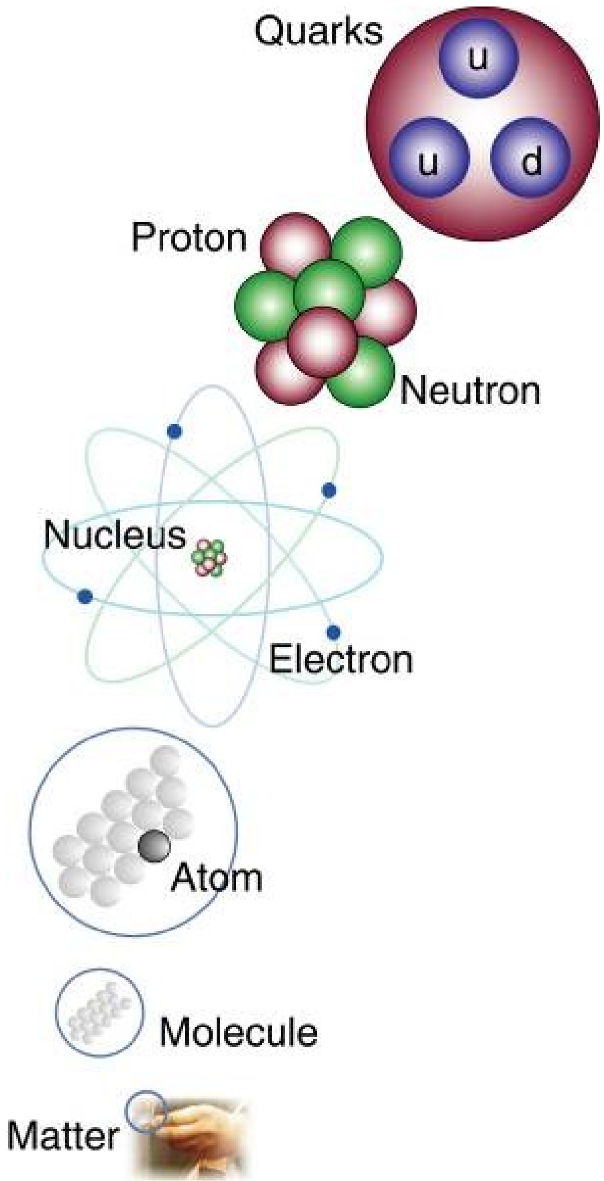
ra aris fundametaluri fizikaSikis ZiriTadi amocanebi da ras velodebiT LHeqsperimetebidan
(Zalian mokled)

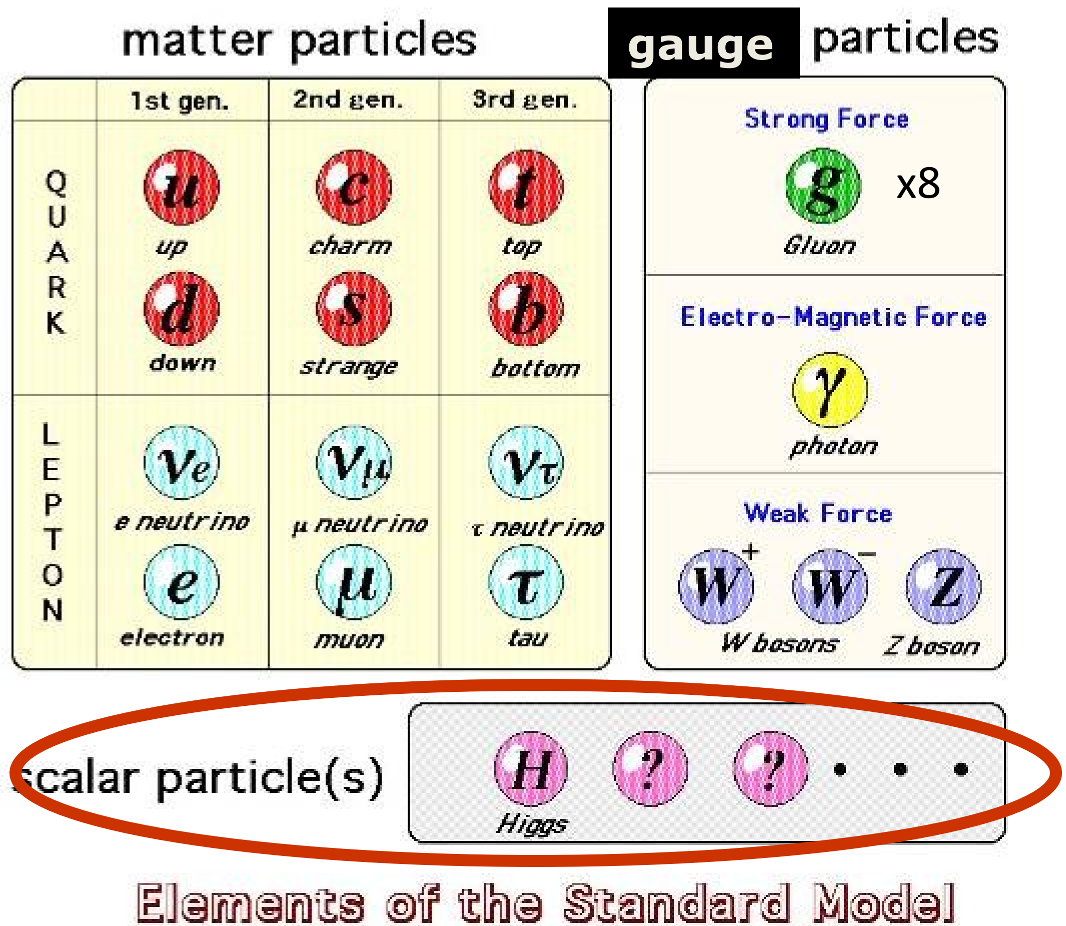
- masis warmoqmnis meqanizmi
- sad aris anti materia
- sad da ra mdgomareobaSia damaluli samyaros 96% energiisa (Savi materia, bneli energia)
- aris Tu ara ganzomileba 4-ze meti
- sruliad axali aRmoCenebi
- ☺

Unification of Forces



The study of elementary particles and fields and their interactions

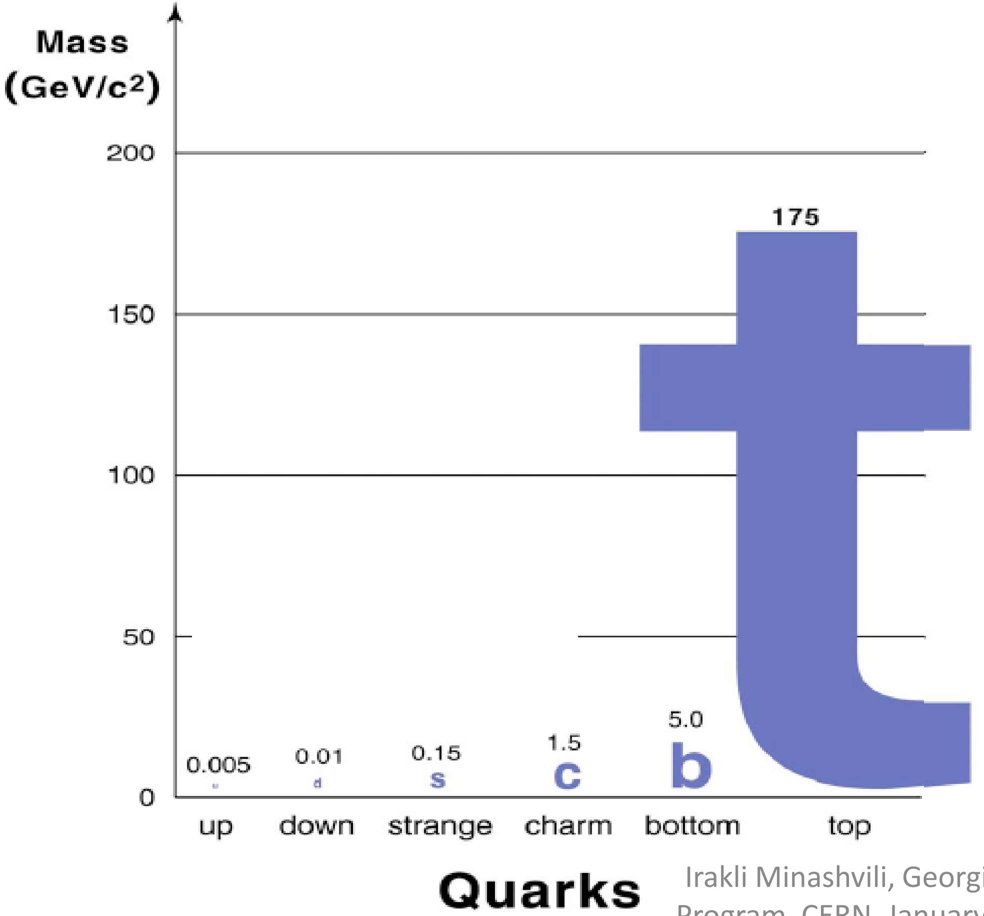




A most basic question is why particles (and matter) have masses (and so different masses)

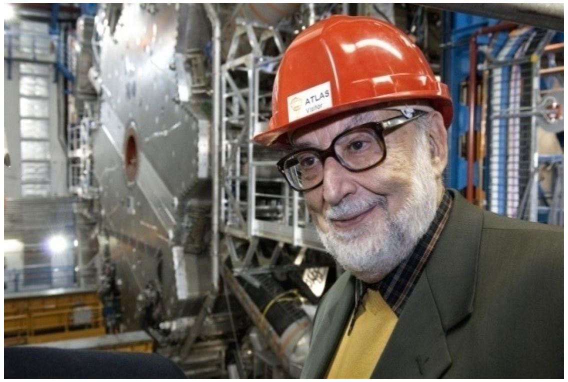
The mass mystery could be solved with the 'Higgs mechanism' which predicts the existence of a new elementary particle, the 'Higgs' particle (theory 1964, P. Higgs, R. Brout and F. Englert)

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



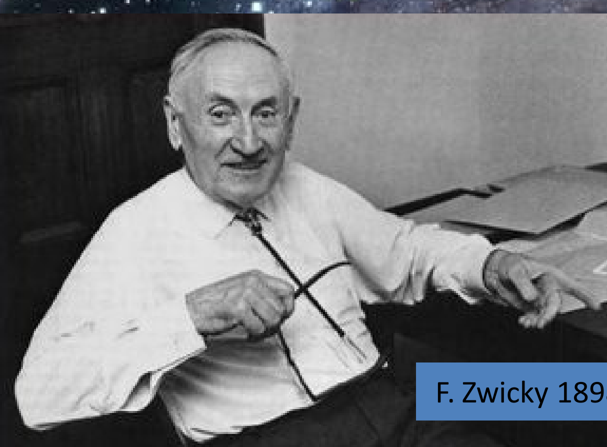
Francois Englert

Dark Matter in the Universe

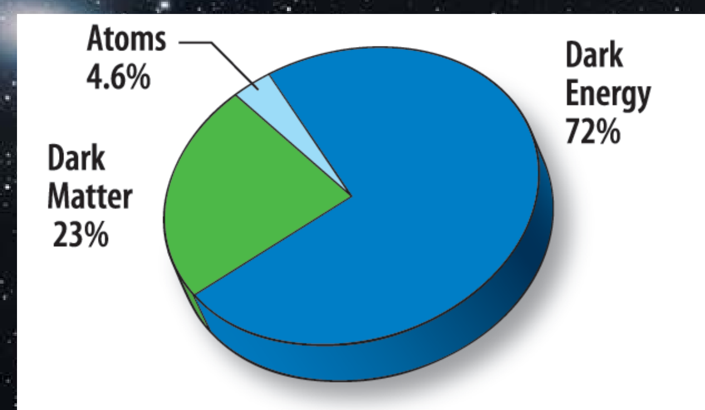
Astronomers found that most of the matter in the Universe must be invisible Dark Matter

Vera Rubin ~ 1970

'Supersymmetric' particles ?



F. Zwicky 1898-1974



Supersymmetry (SUSY)

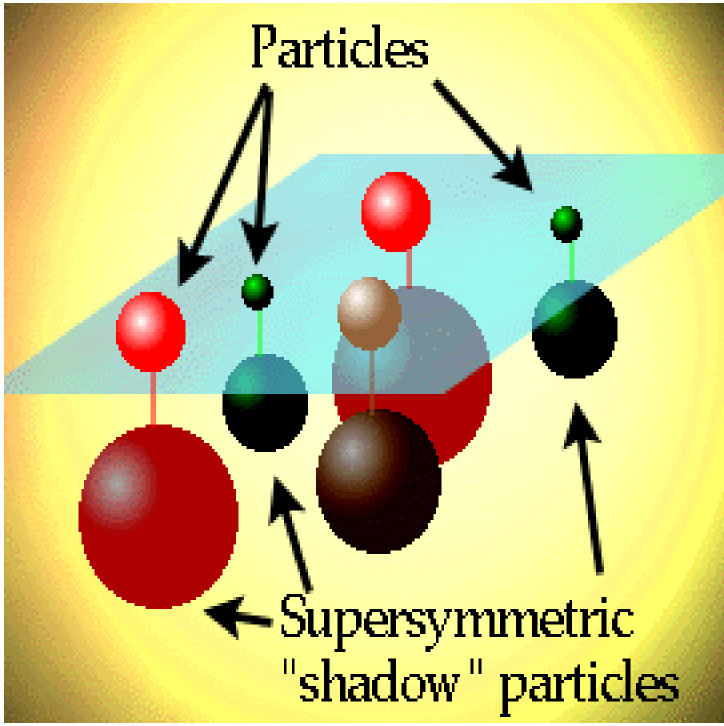
(Julius Wess and Bruno Zumino, 1974)

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

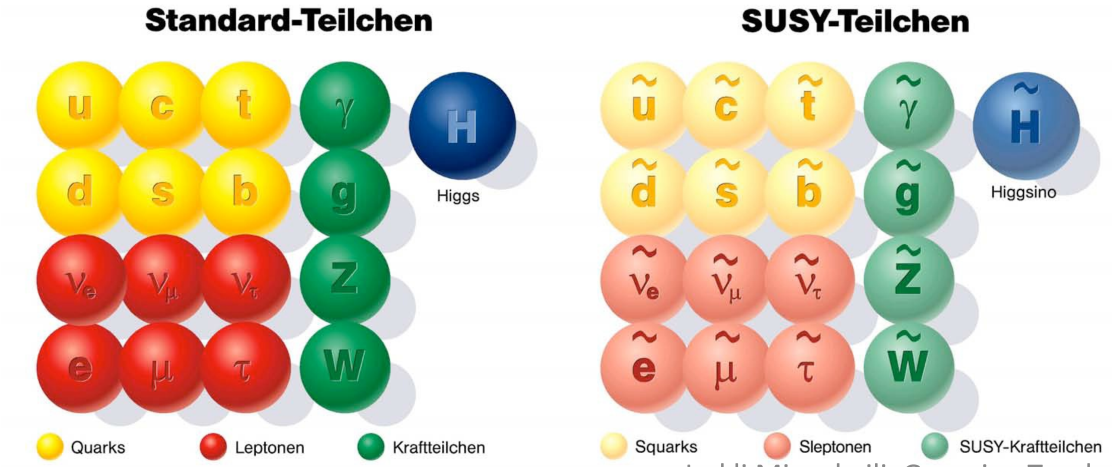
- Each particle p with spin s has a SUSY partner $\tilde{p}$ with spin s -1/2

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

g (s=1) → $\tilde{g}$ (s=1/2) gluino

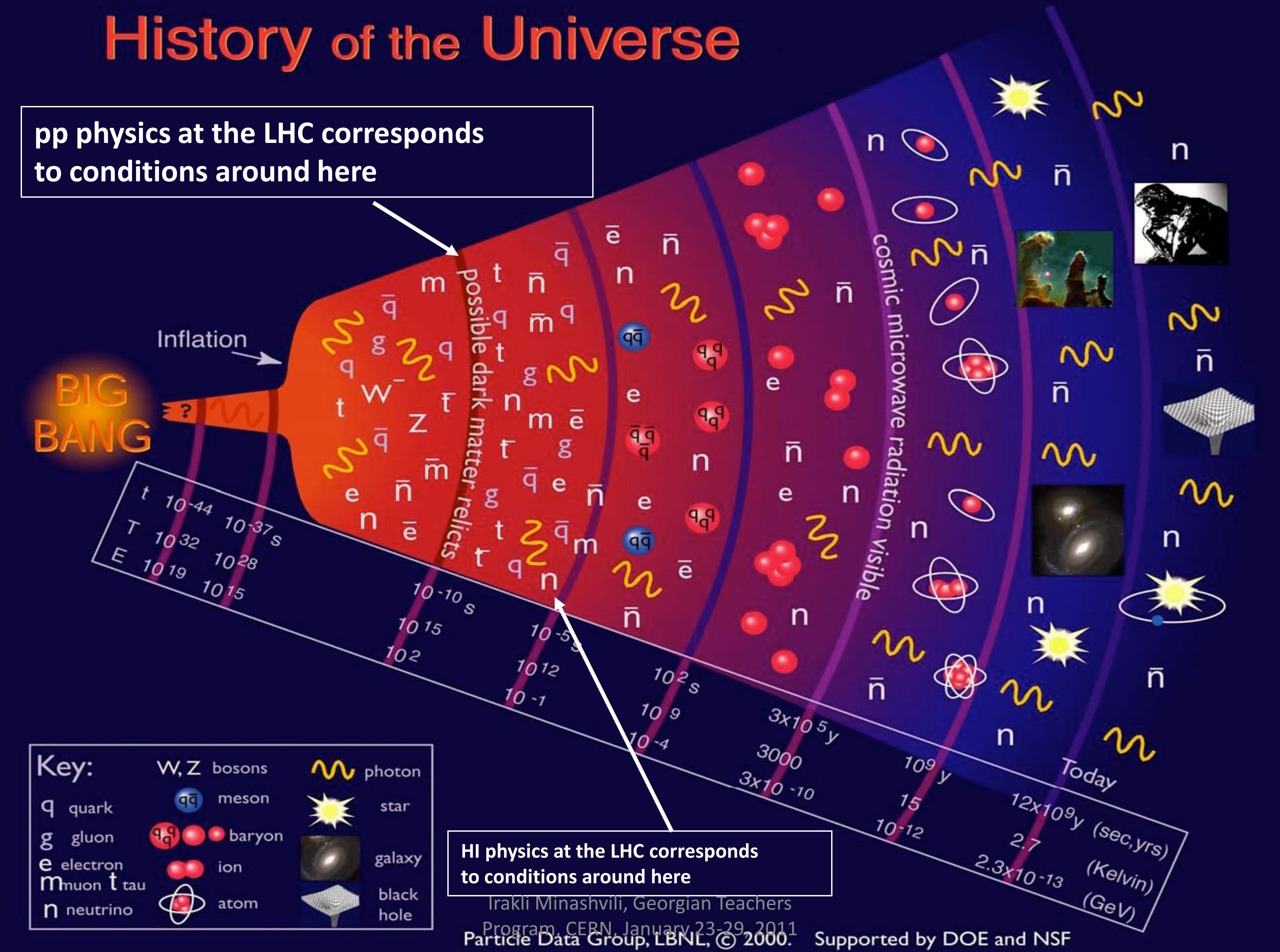


Our known world **Maybe a new world?**



Motivation:

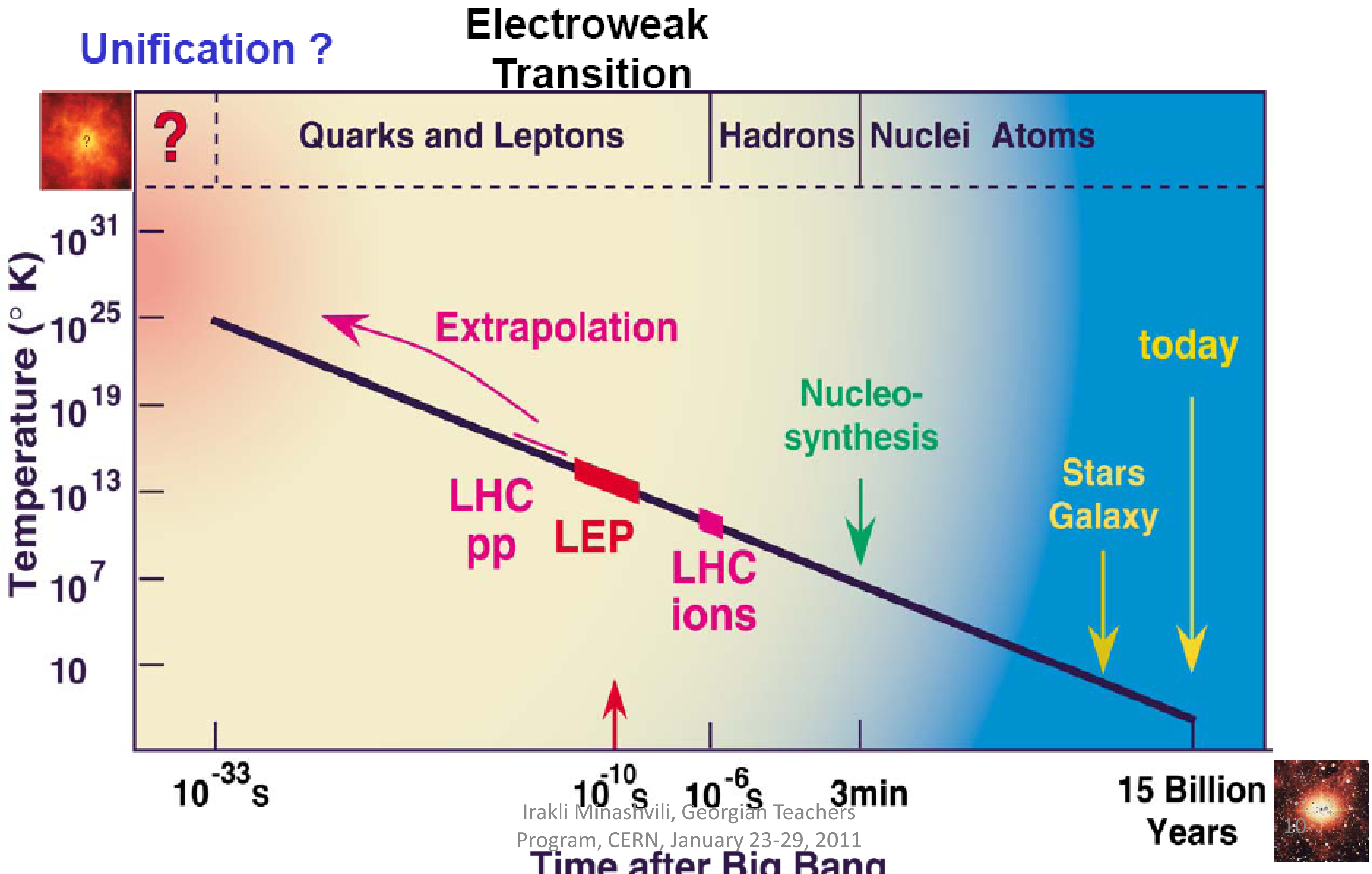
- Unification (fermions-bosons, matter-forces)
- Solves some deep problems of the Standard Model

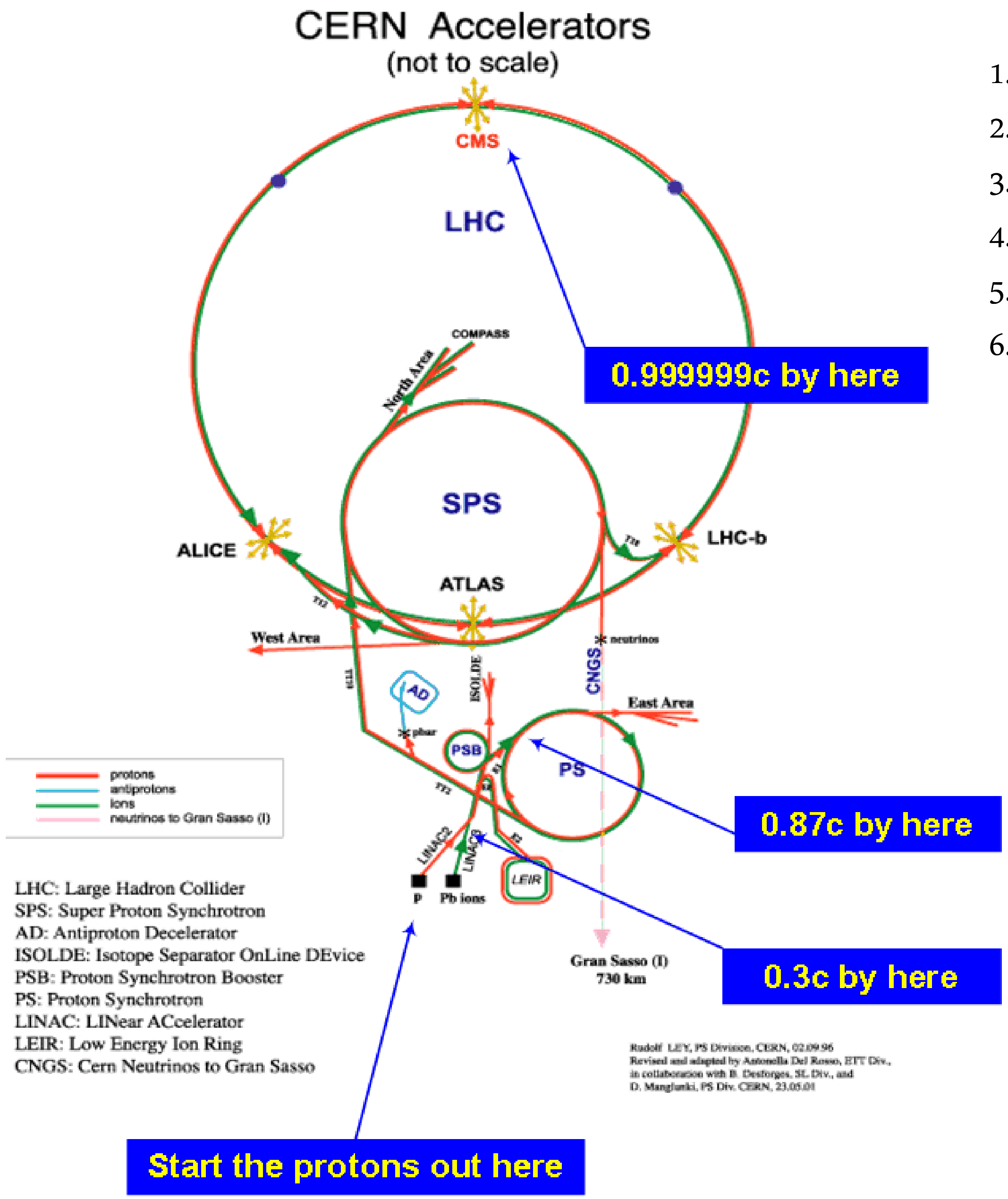


pp physics at the LHC corresponds to conditions around here

HI physics at the LHC corresponds to conditions around here

Understanding the Universe …





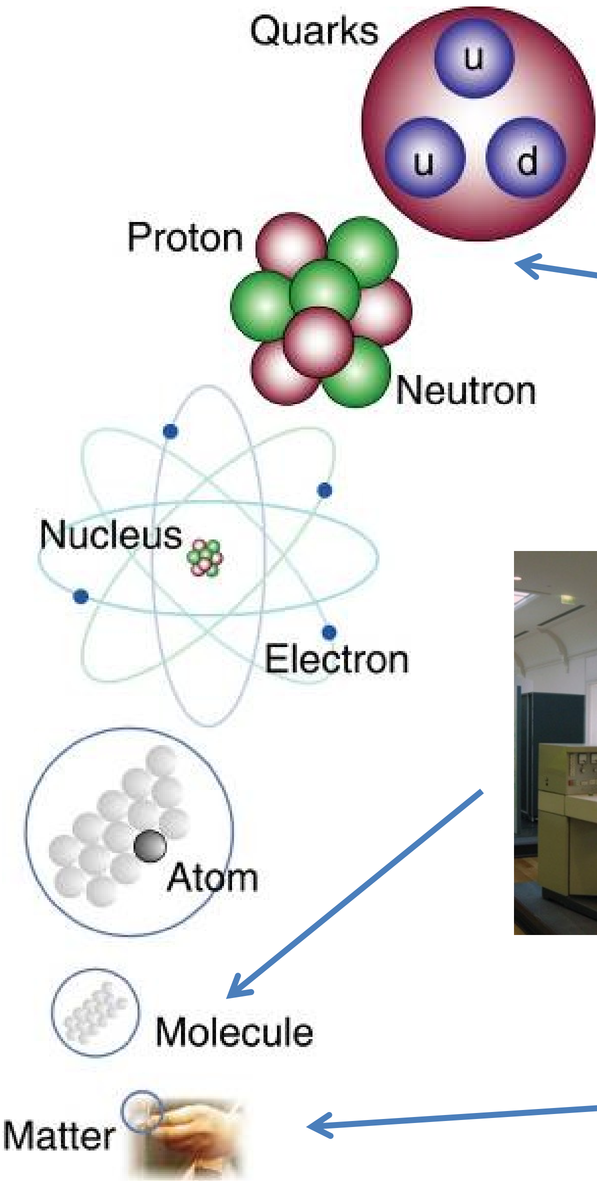
1. Pprotonebis wyaro, 100kev
2. wrfivi amCqarebeli, 50mev
3. Bbusteri, 1,4gev
4. Pprotonuli sinqrotroni, 28gev
5. super Pprotonuli sinqrotroni, 450gev
6. didi adronuli amaCqarebeli Semxvedr nakadebze, 7tev.

Powerful accelerators and detectors needed

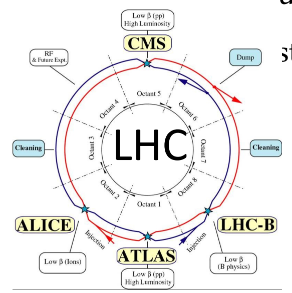
MmaRali energiebi da intensiuri nakadebi

uaRresad swrafi

sti



<10^{-16}cm



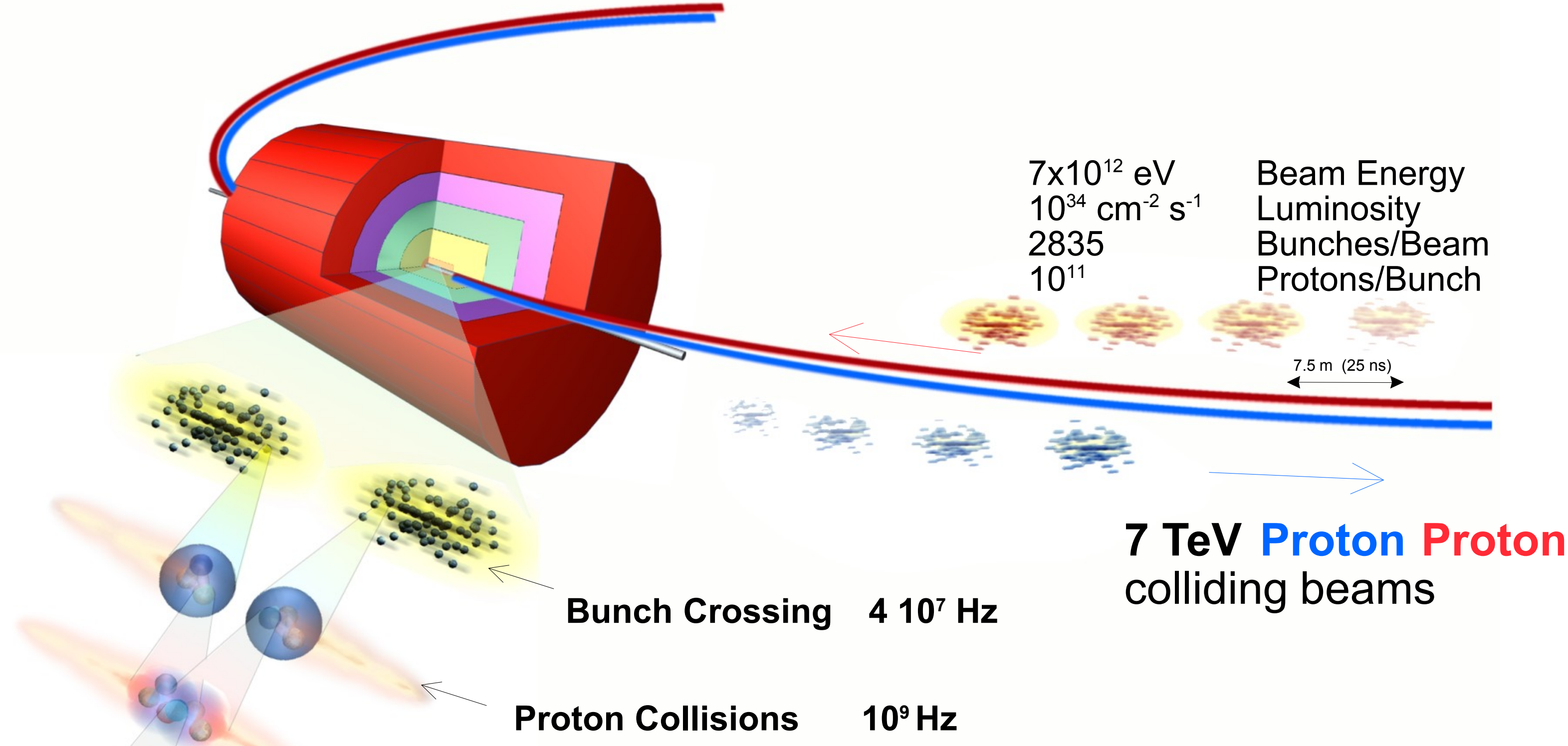
eleqtruli mikroskopi

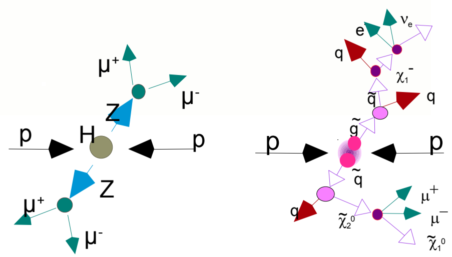
2 000 000X

Suqis mikroskopi

2 000X

Collisions at LHC



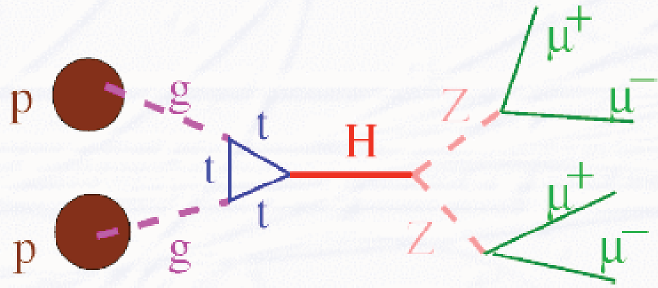


Selection of 1 event in 10,000,000,000,000

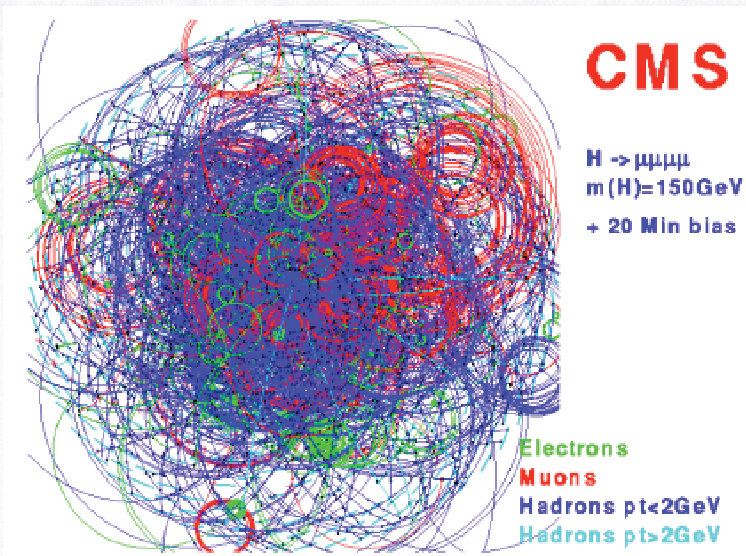
Bunch- yurZnis mtevani protonebiT

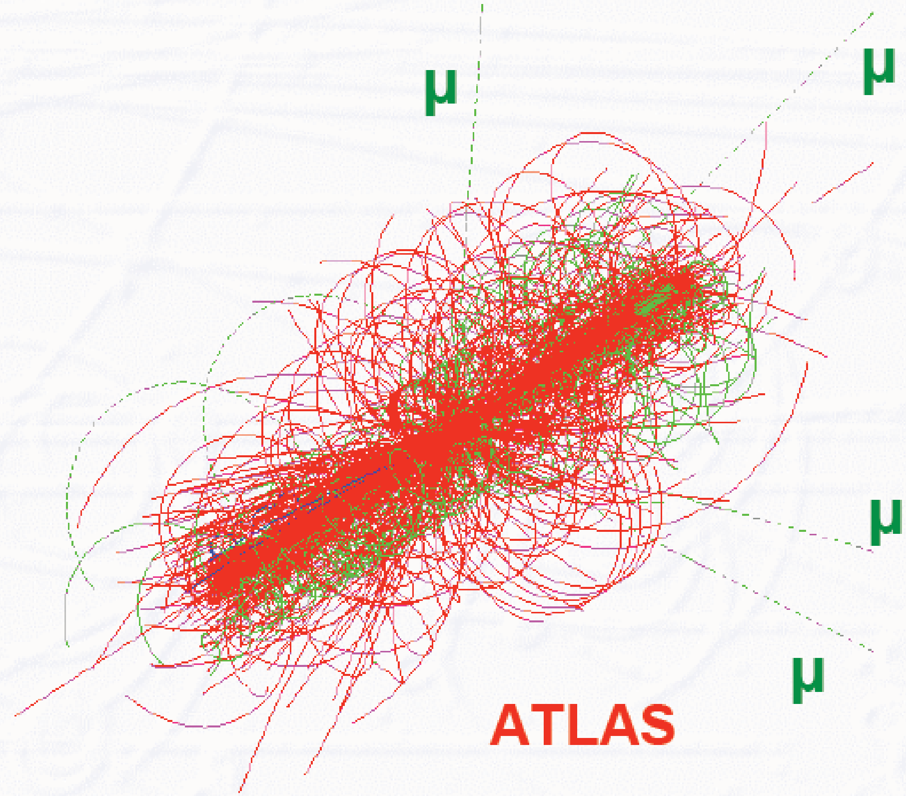
http://hands-on-cern.physto.se/ani/acc_lhc_atlas/lhc_atlas.swf

- **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!**



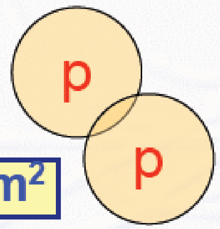
$pp \Rightarrow H \Rightarrow ZZ \Rightarrow 4\mu$





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

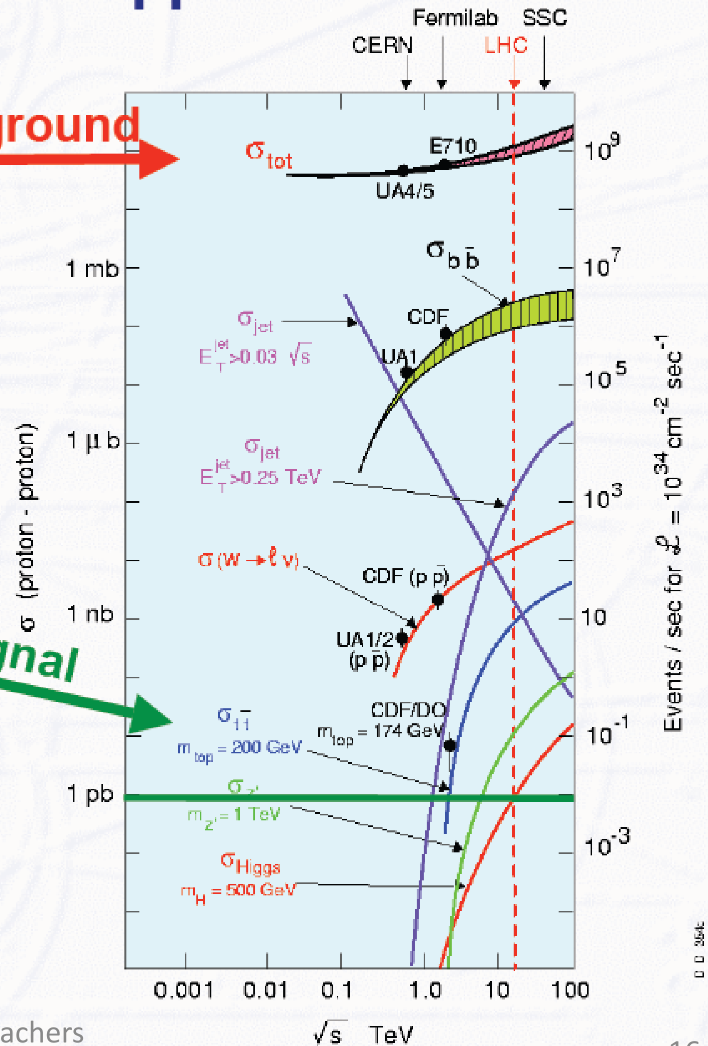
total inelastic cross section



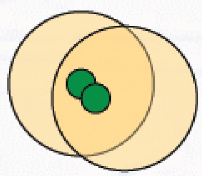
$\sigma \sim 0.1$ barn = 10^{-25} cm^2

background

pp cross sections



point-like cross section



signal

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

many many orders of magnitude between signal and background !

ATLAS Collaboration

(As of the April 2007)

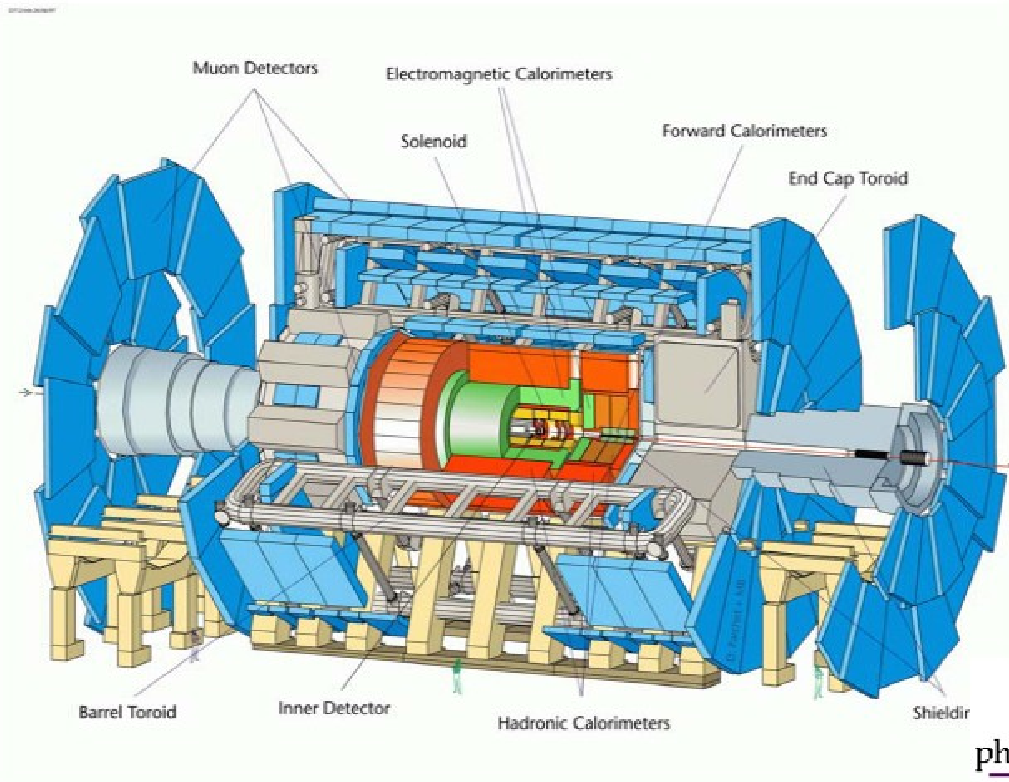
35 Countries
164 Institutions
1900 Scientific Authors total
(400 PhD students)

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

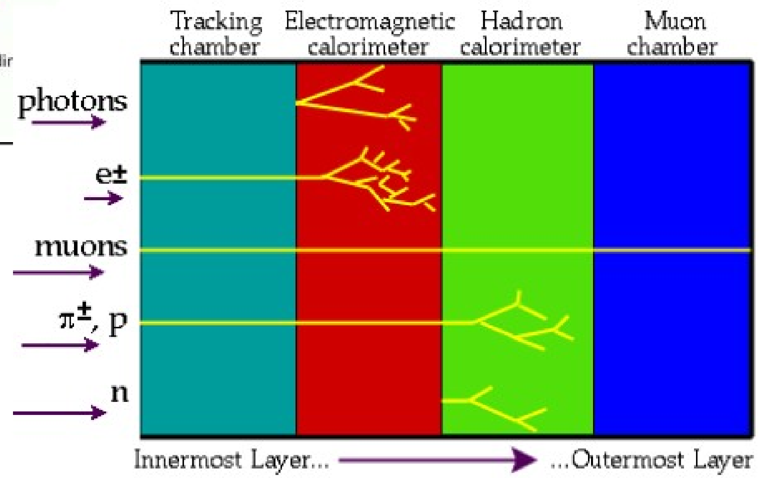
(Across the street from the CERN main entrance)



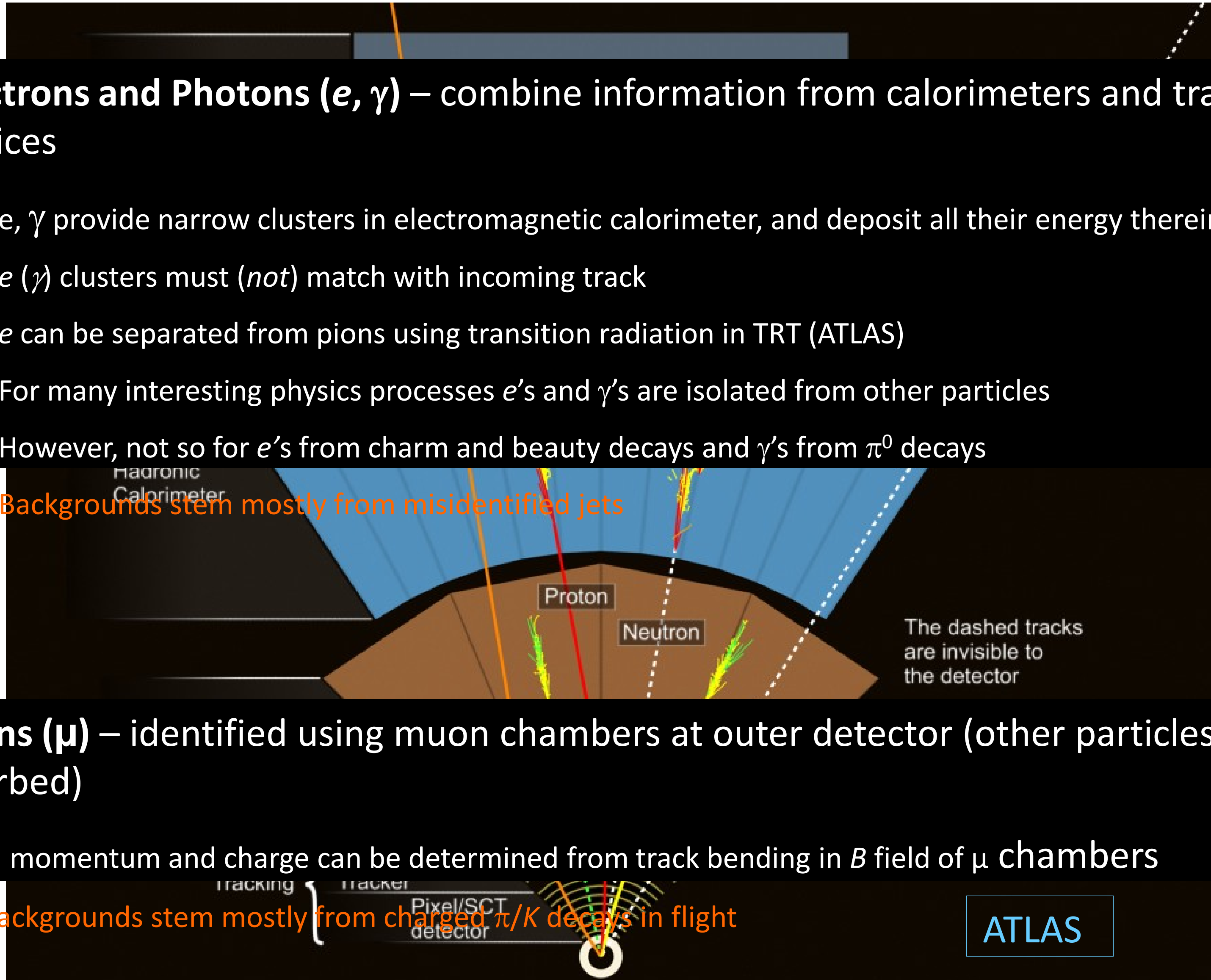
ATLAS

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



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* (*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

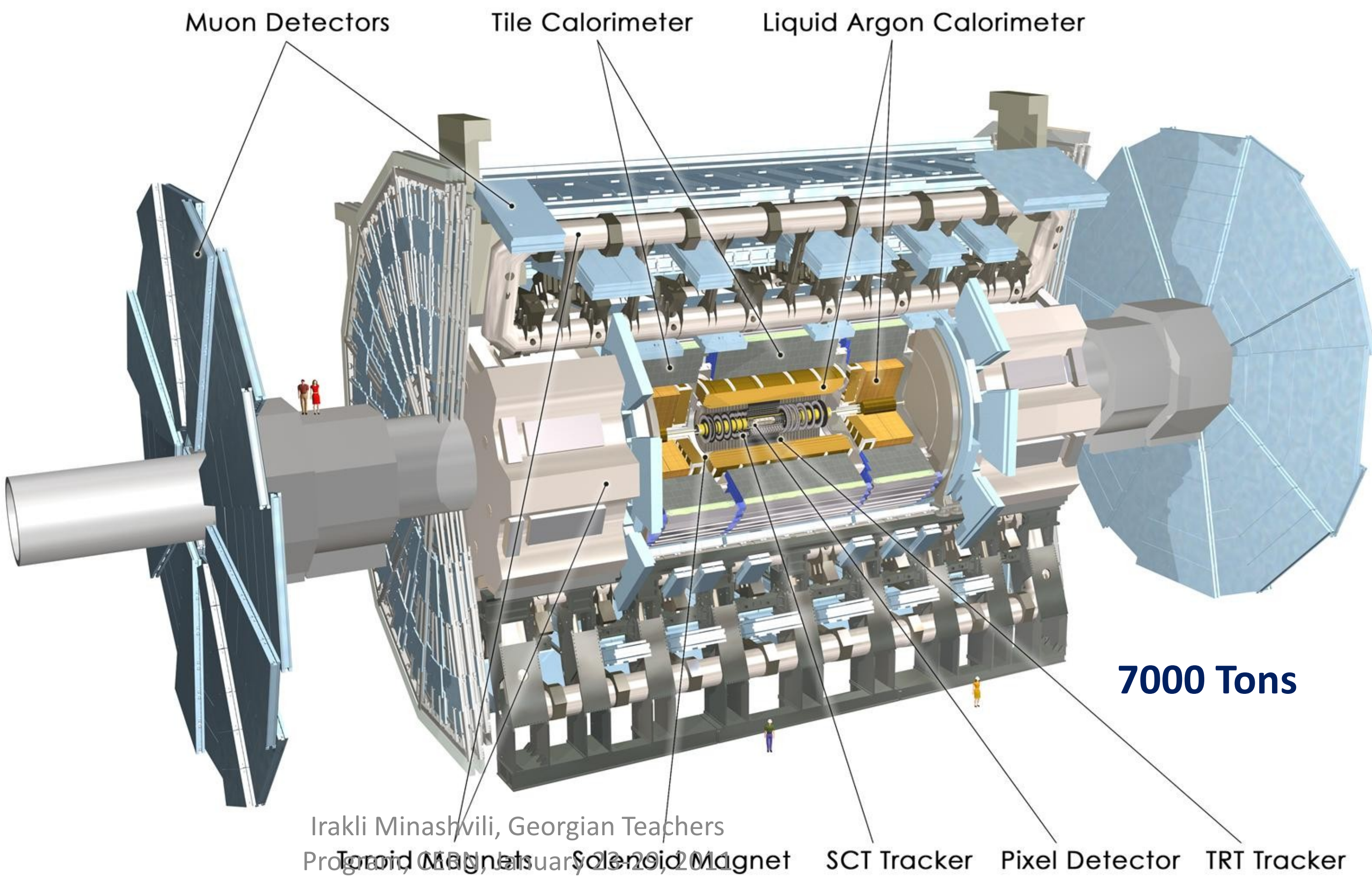
ATLAS

ATLAS Detector

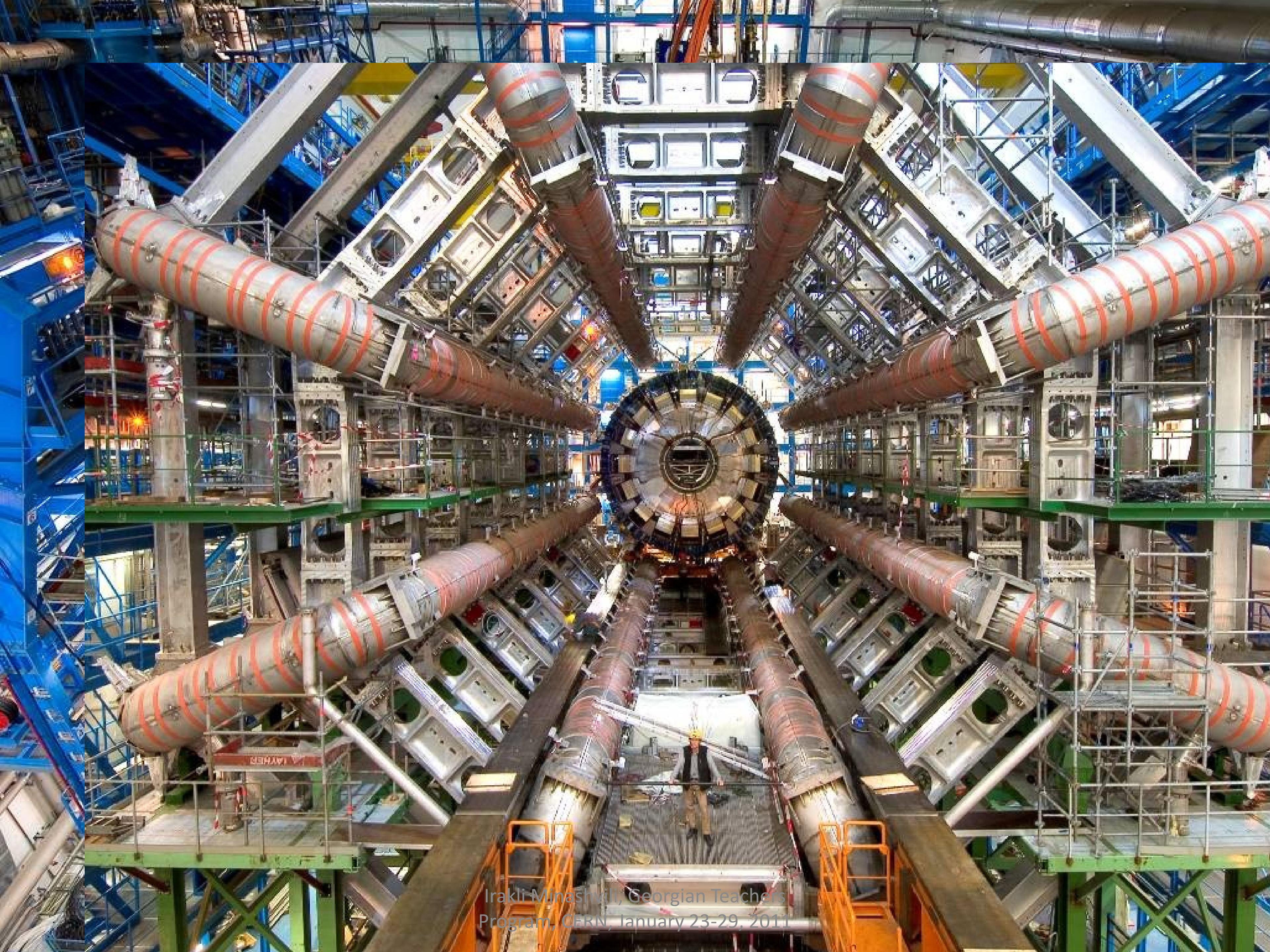
ATLAS superimposed to
the 5 floors of building 40

45 m

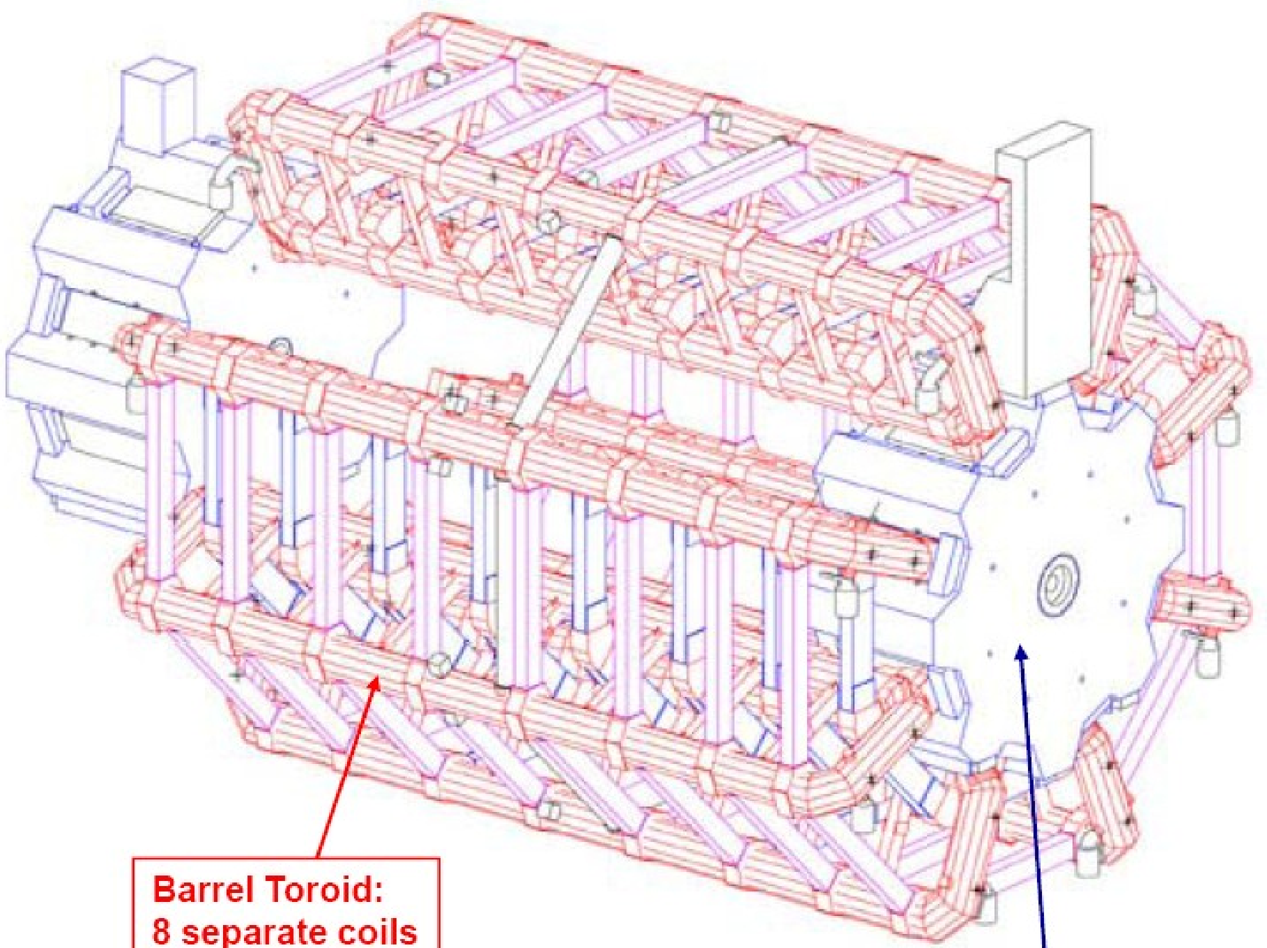
24 m



7000 Tons



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

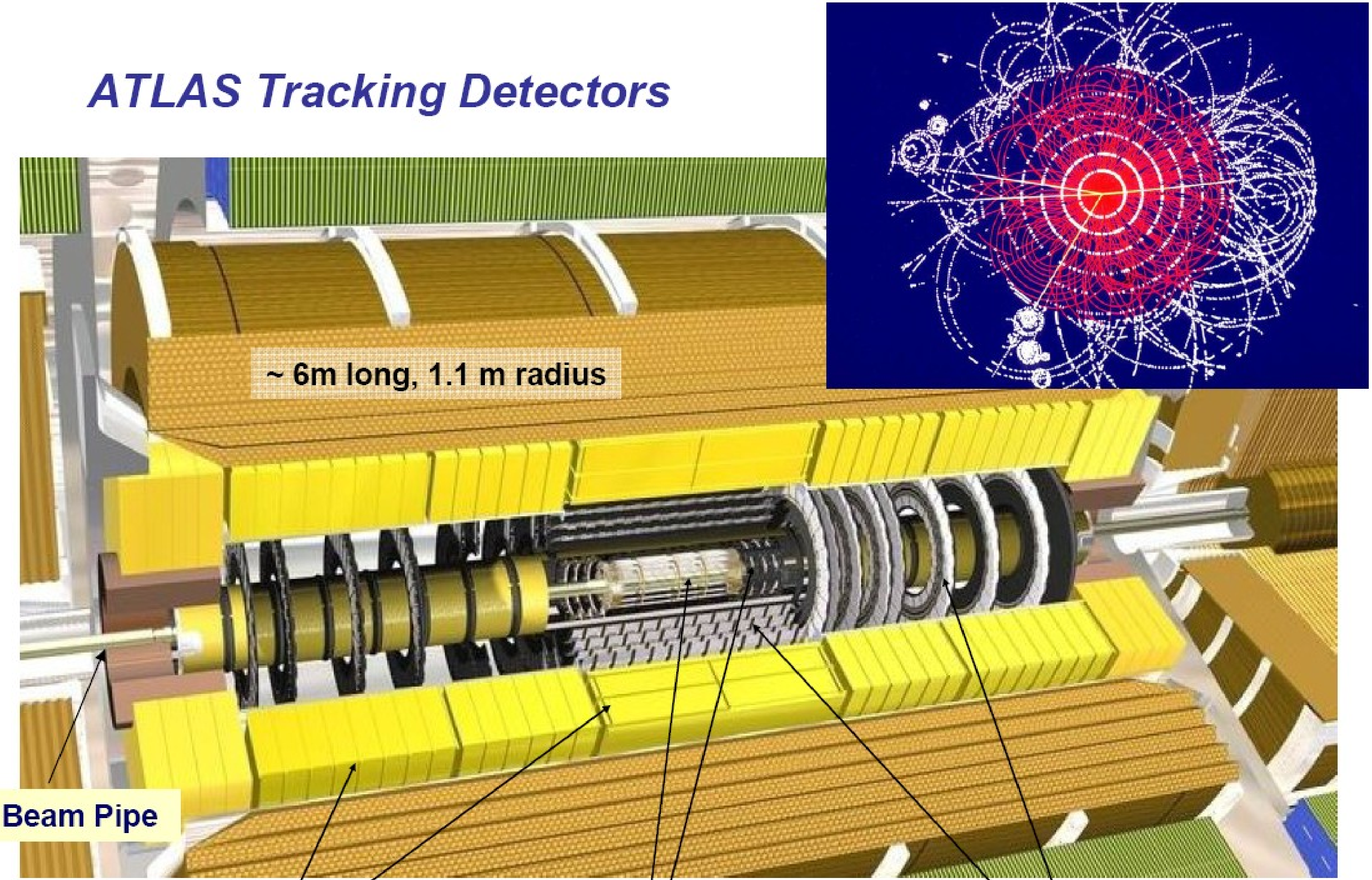
End-Cap Toroid parameters
5.0 m axial length
10.7 m outer diameter
2x8 coils
2x0.25 GJ stored energy
2x160 tons cold mass
2x240 tons weight
4 T on superconductor
2x13 km Al/NbTi/Cu conductor
20.5 kA nominal current
4.7 K working point

Barrel Toroid:
8 separate coils

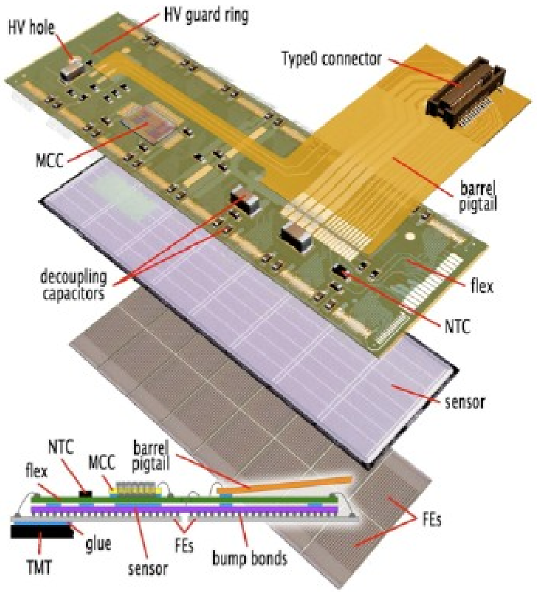
End-Cap Toroid:
8 coils in a common cryostat

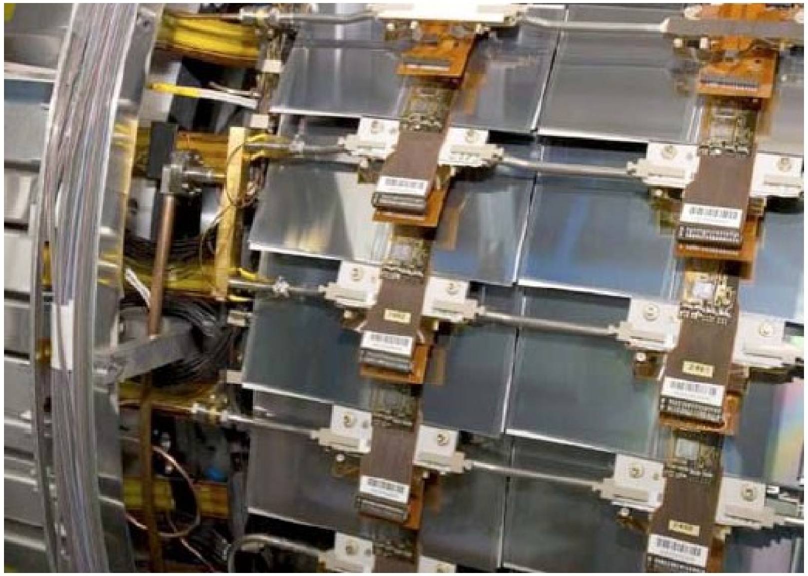

Friderici

ATLAS Tracking Detectors



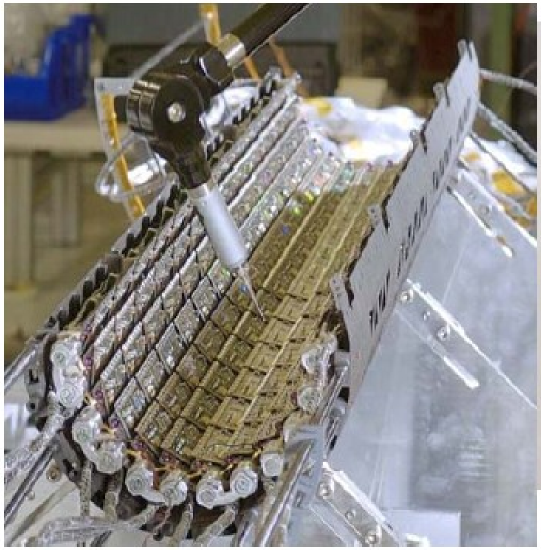
Detector Silicon-sensors

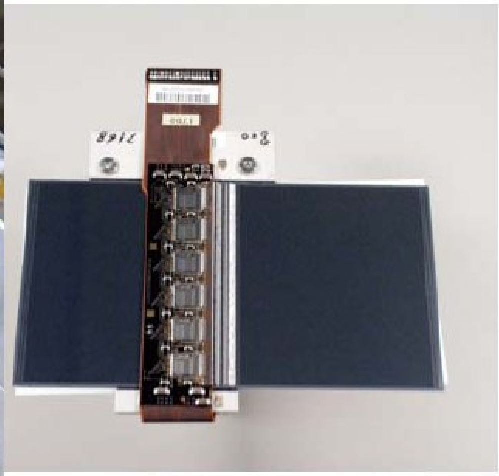


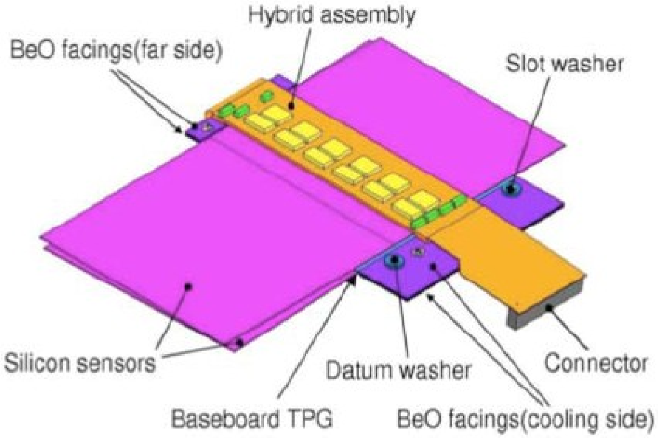


1744 Pixel modules, pixels 50x400 μm^2

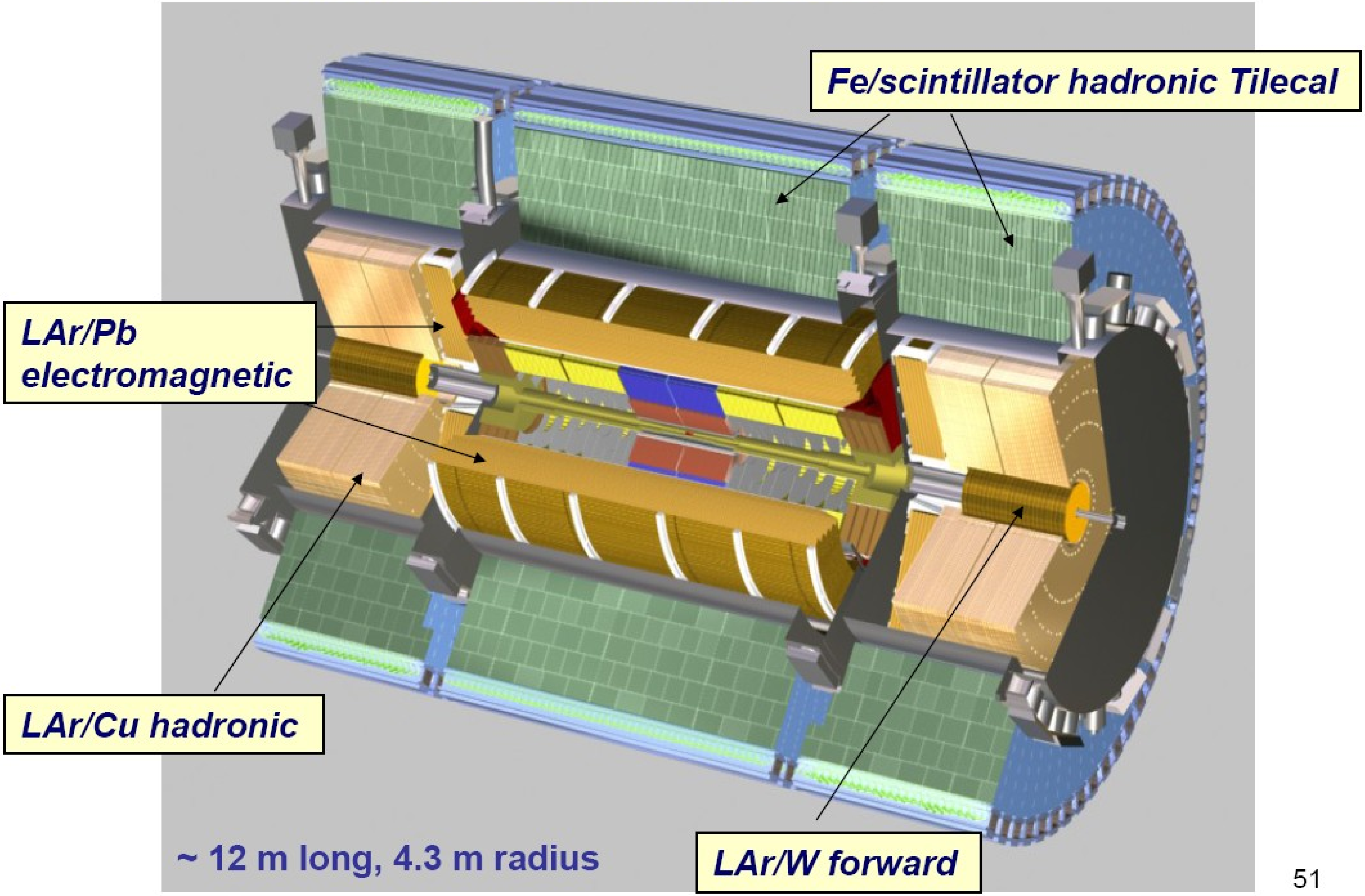
4088 SCT modules, 80 μm micro-strips







ATLAS Calorimeters



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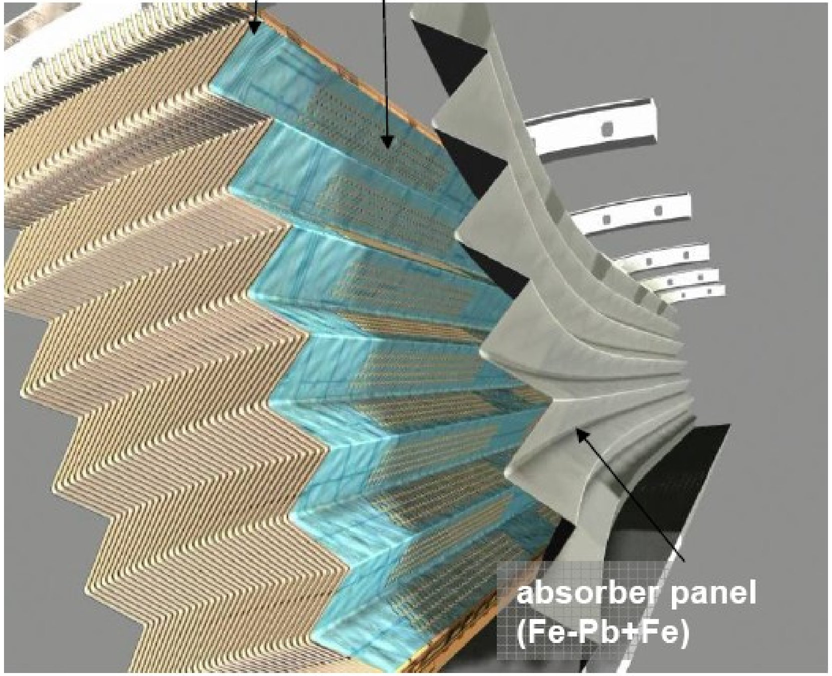
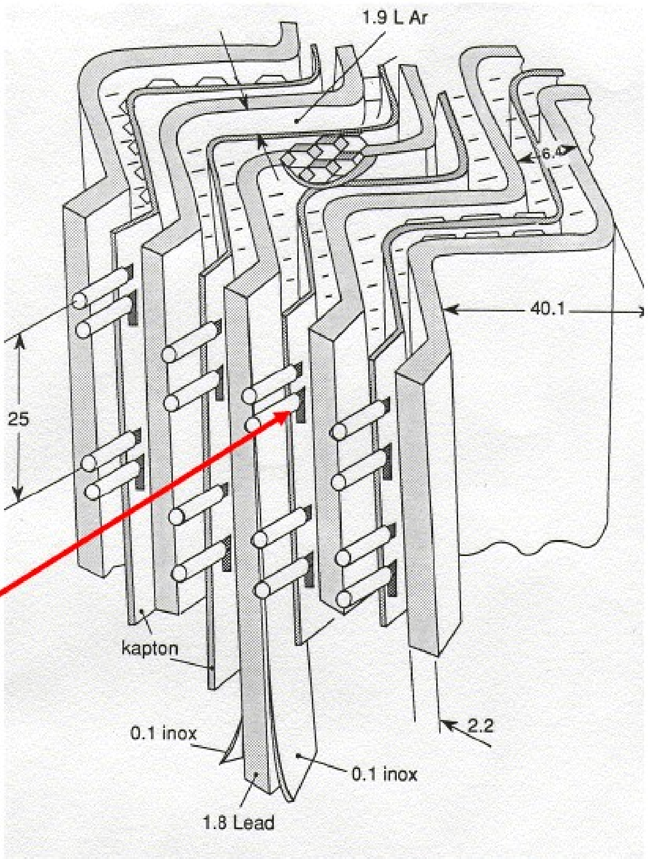
ATLAS Electromagnetic Calorimeters

LAr sampling calorimeter accordion geometry

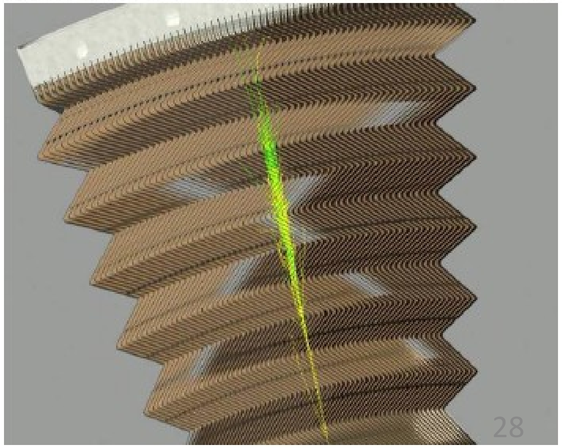
readout panel

LAr gap

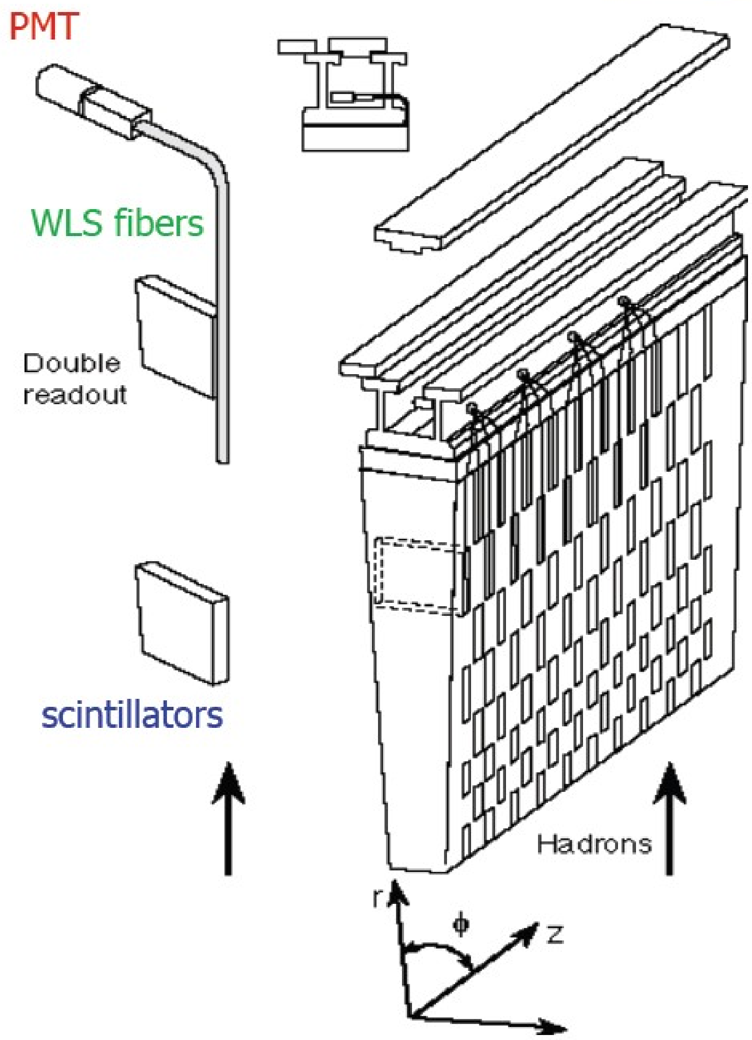


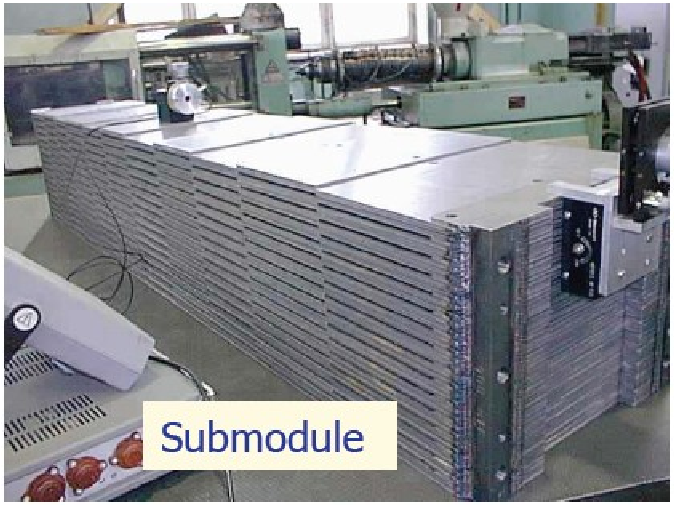


Why ?
- readout speed
- radiation hard
- electronically inter-calibrated
- allows longitudinal segmentation
- hermetic in phi
- good energy and angular resolution



Tile Calorimeter

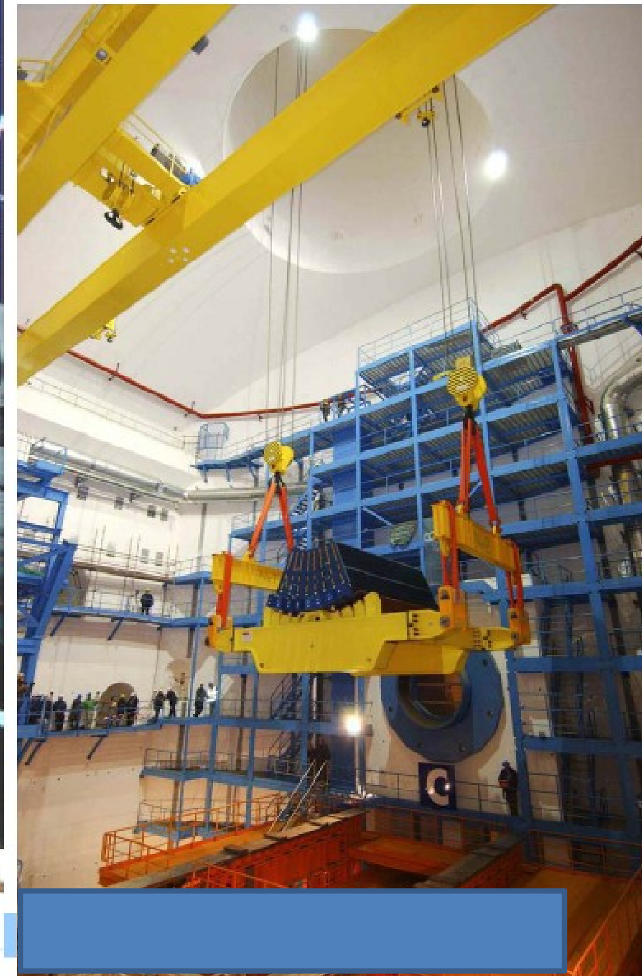


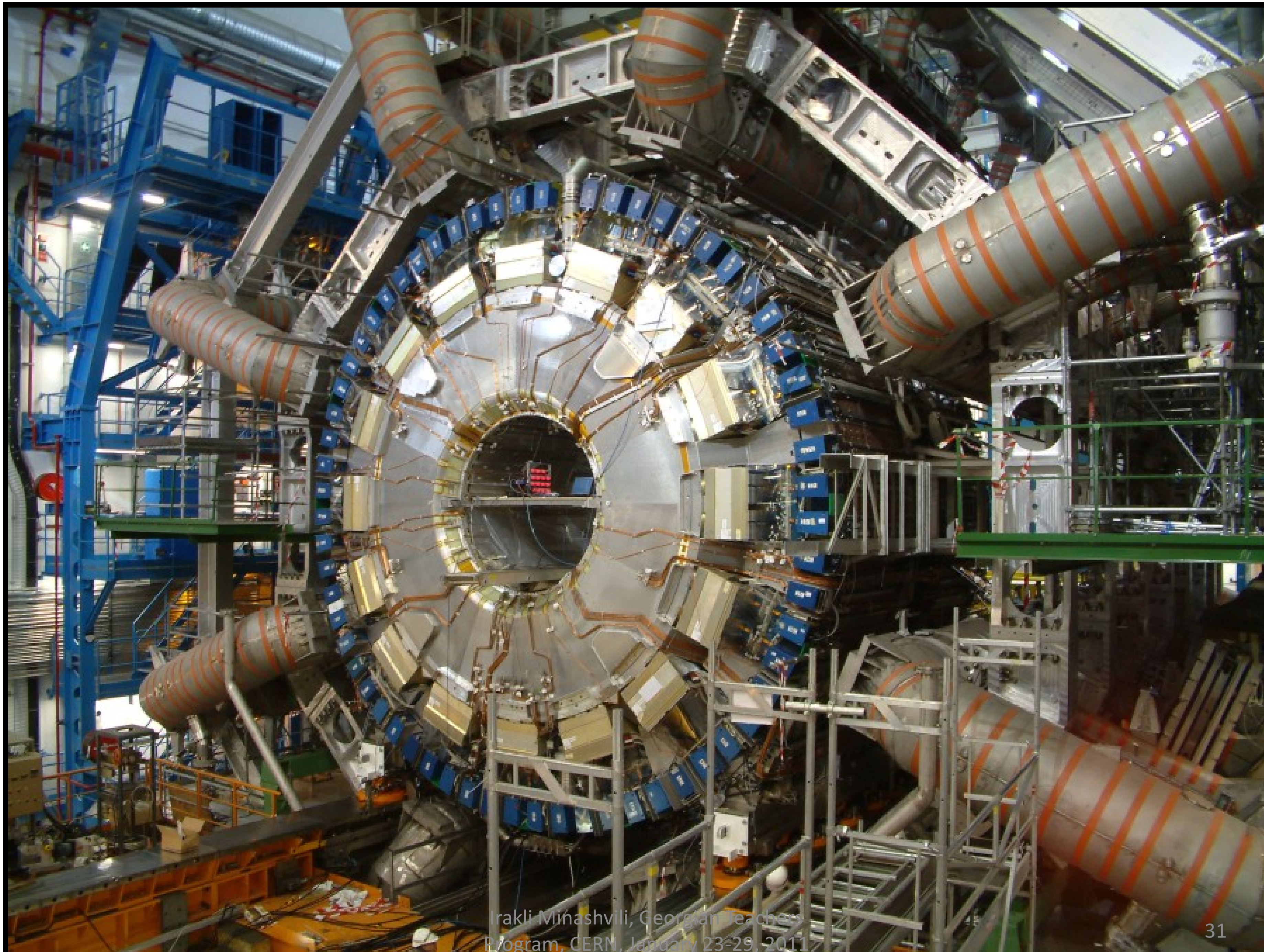


22/05/2006 *HCP2006-2006*

Tile Calorimeter

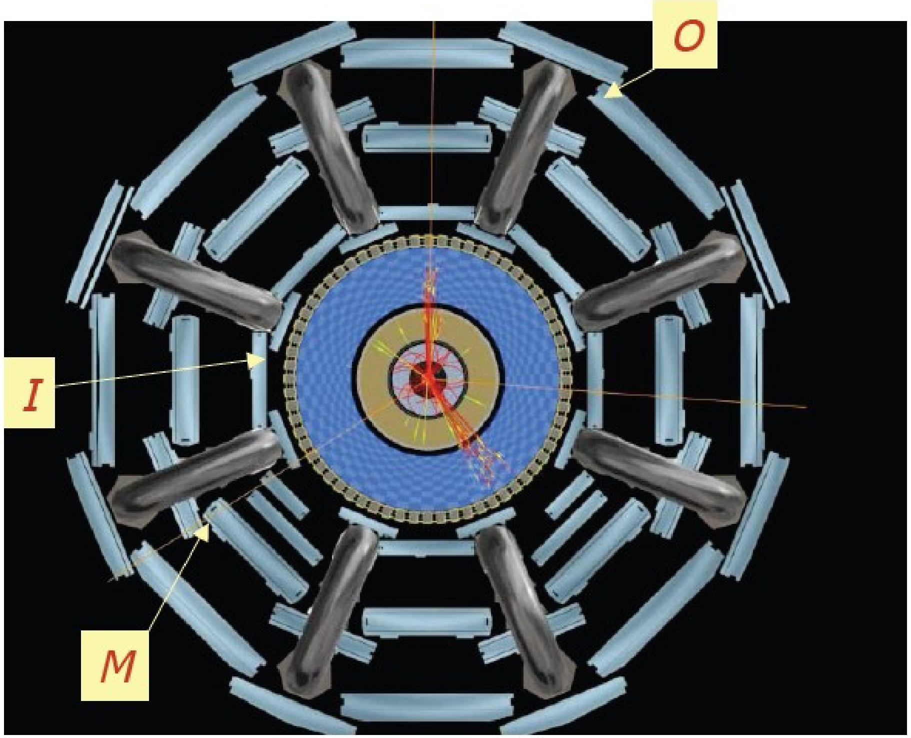
15 years of fruitful collaboration with our Romanian friends... !



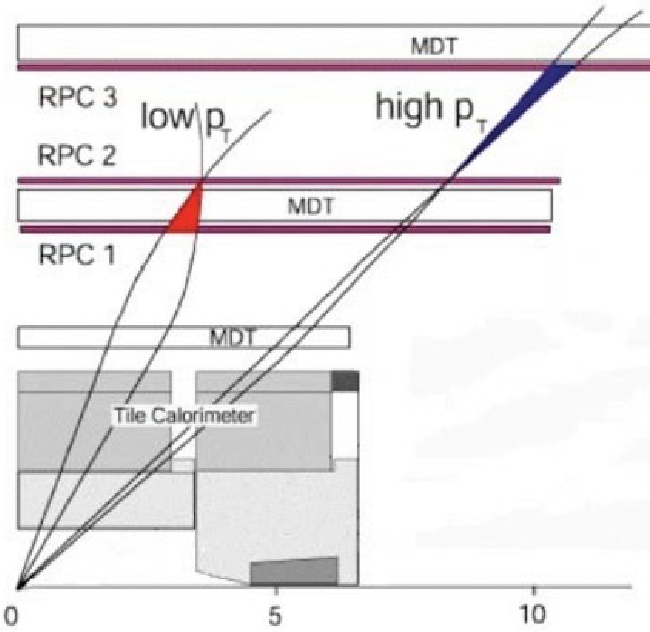


The muon spectrometer (barrel)

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

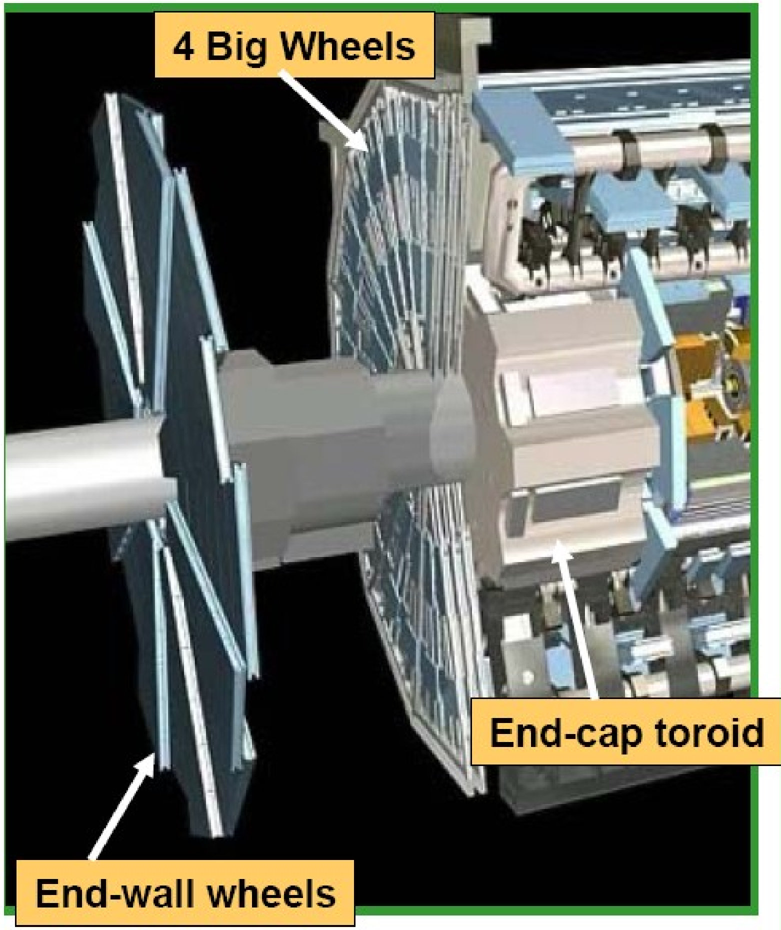


2 technologies:

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**

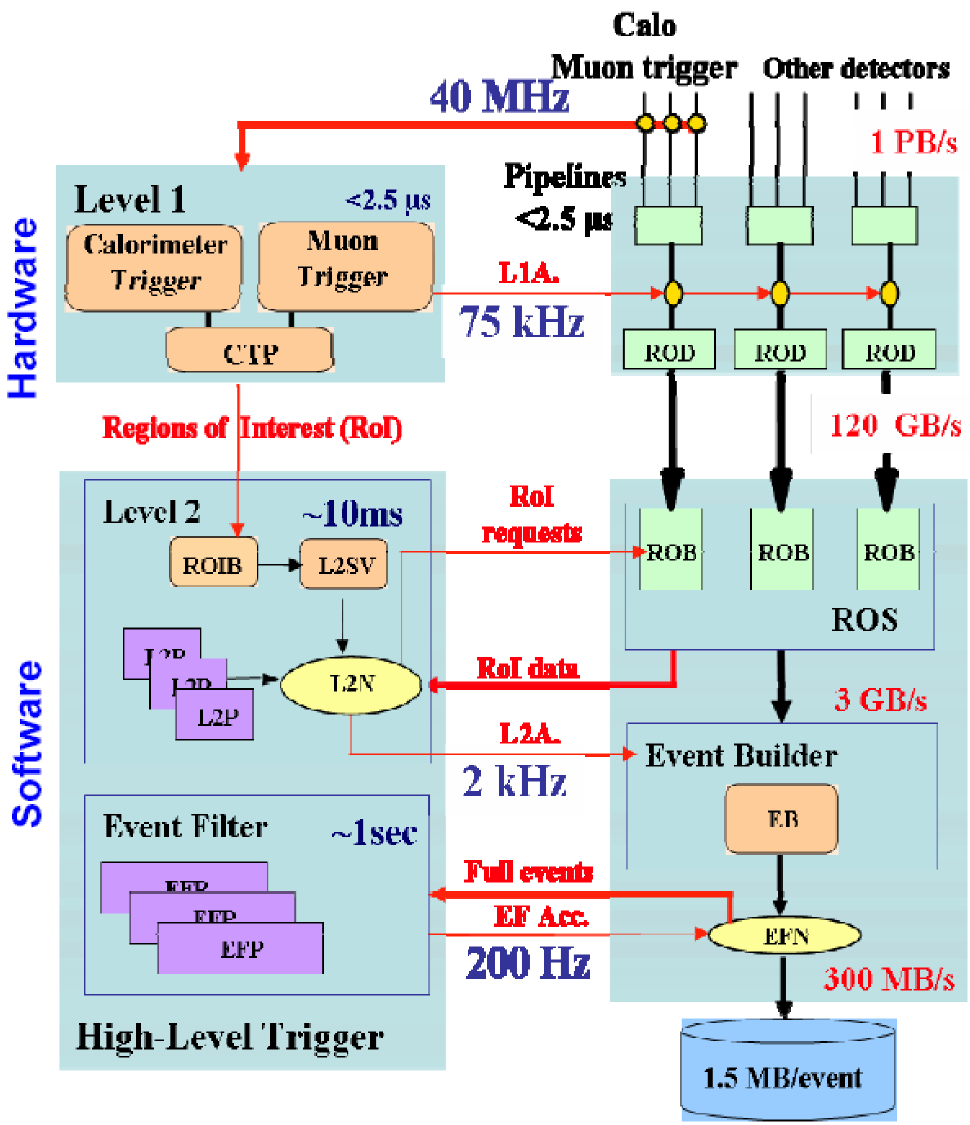


ATLAS Trigger and Data Acquisition

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



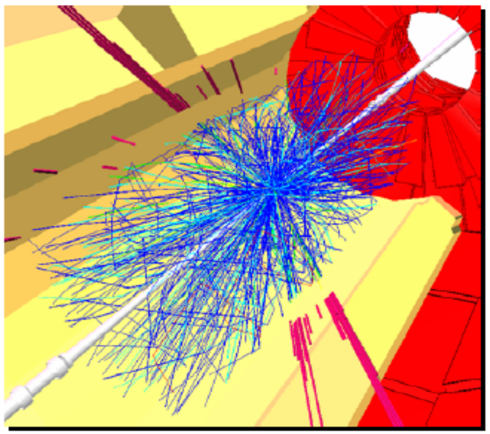
Reduce rate from 40 MHz to 200Hz while retaining the rare, interesting events

66

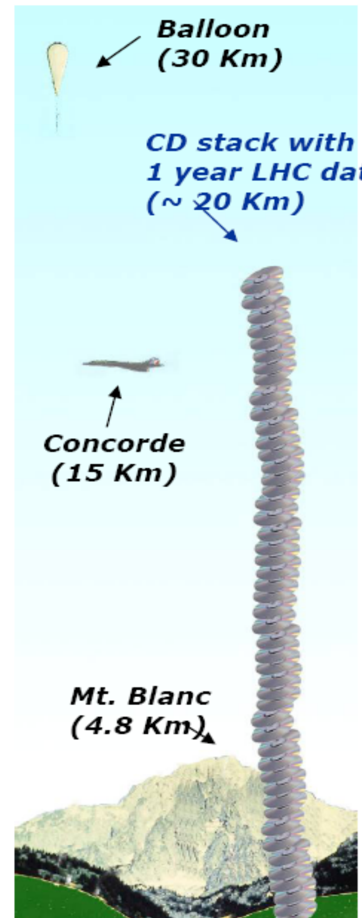
monacemebis dagrovebisa **trigeris** sistema atlas-ze dafuZnebulia sawyisi monacemebis sam safexurian SerCevaze. trigeris saSualebiT xdeba monacemTa arCeva manam informacia Caiwereba mexsierebaSi (informaciis matareblebze).

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 saWiro, 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



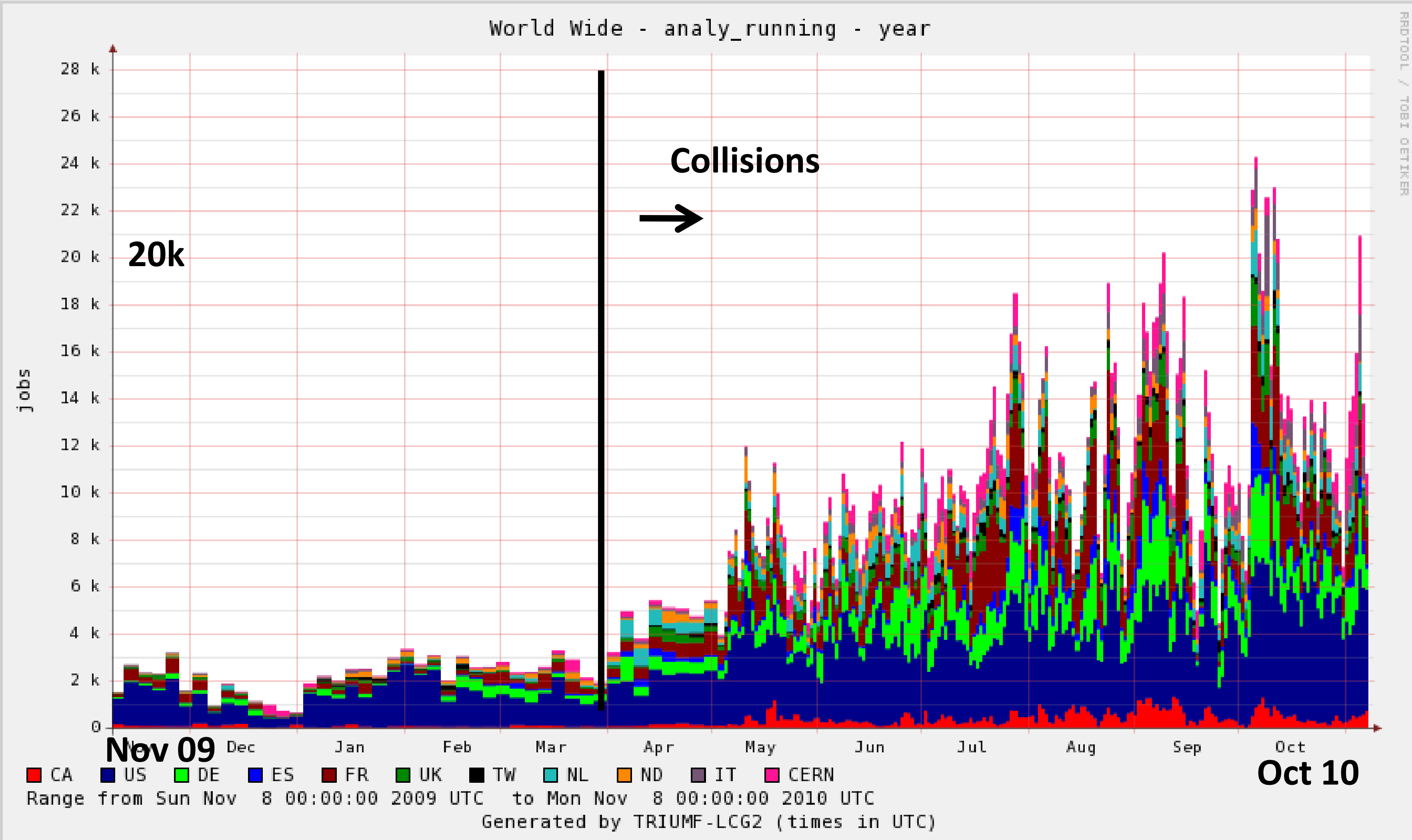
GRID computing developed to solve problem of data storage and analysis

LHC data volume per year:
10-15 Petabytes

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

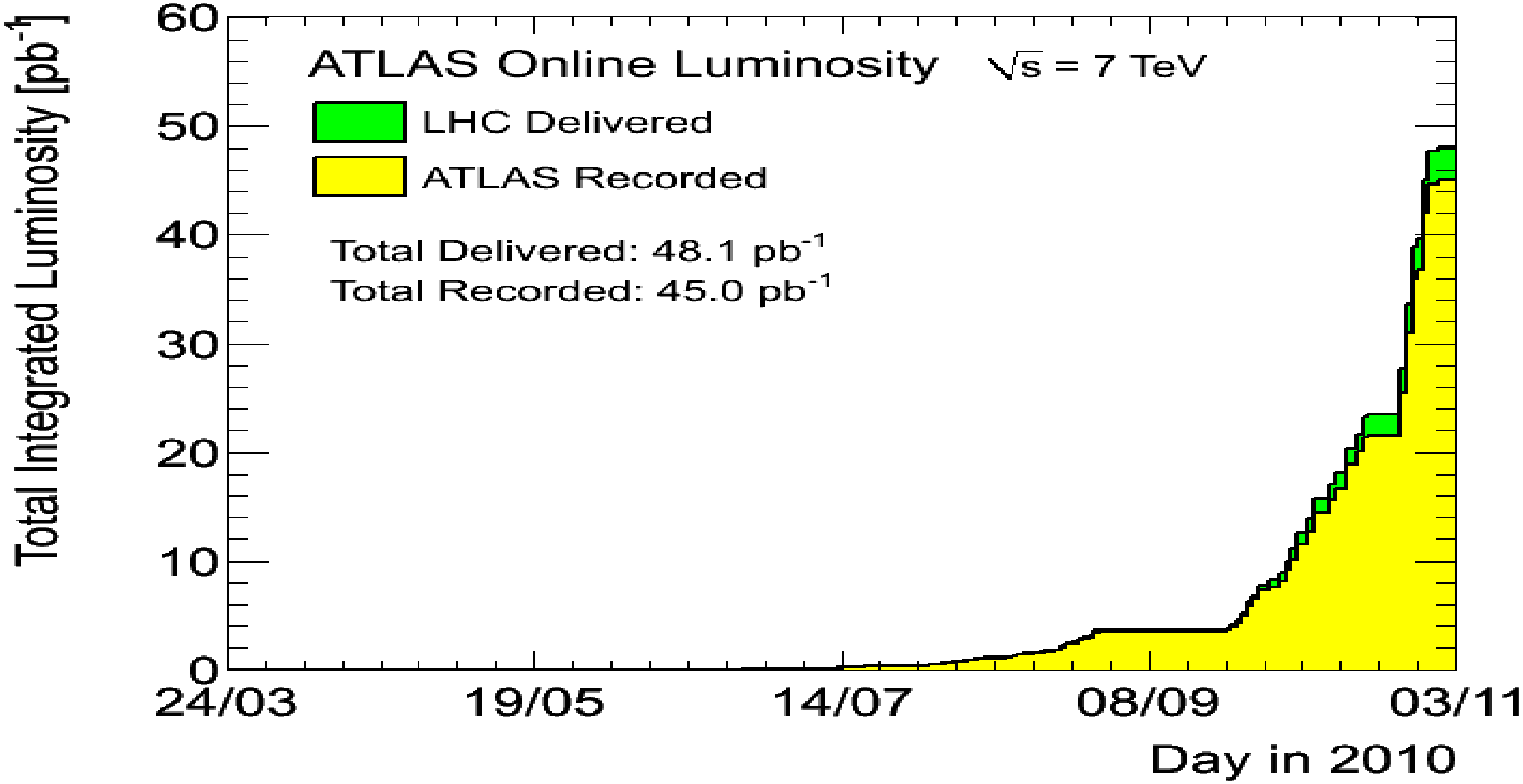
(Note: the WWW is from CERN...)

User analysis jobs



More than 1000 users

Integrated pp Luminosities 2010 Run



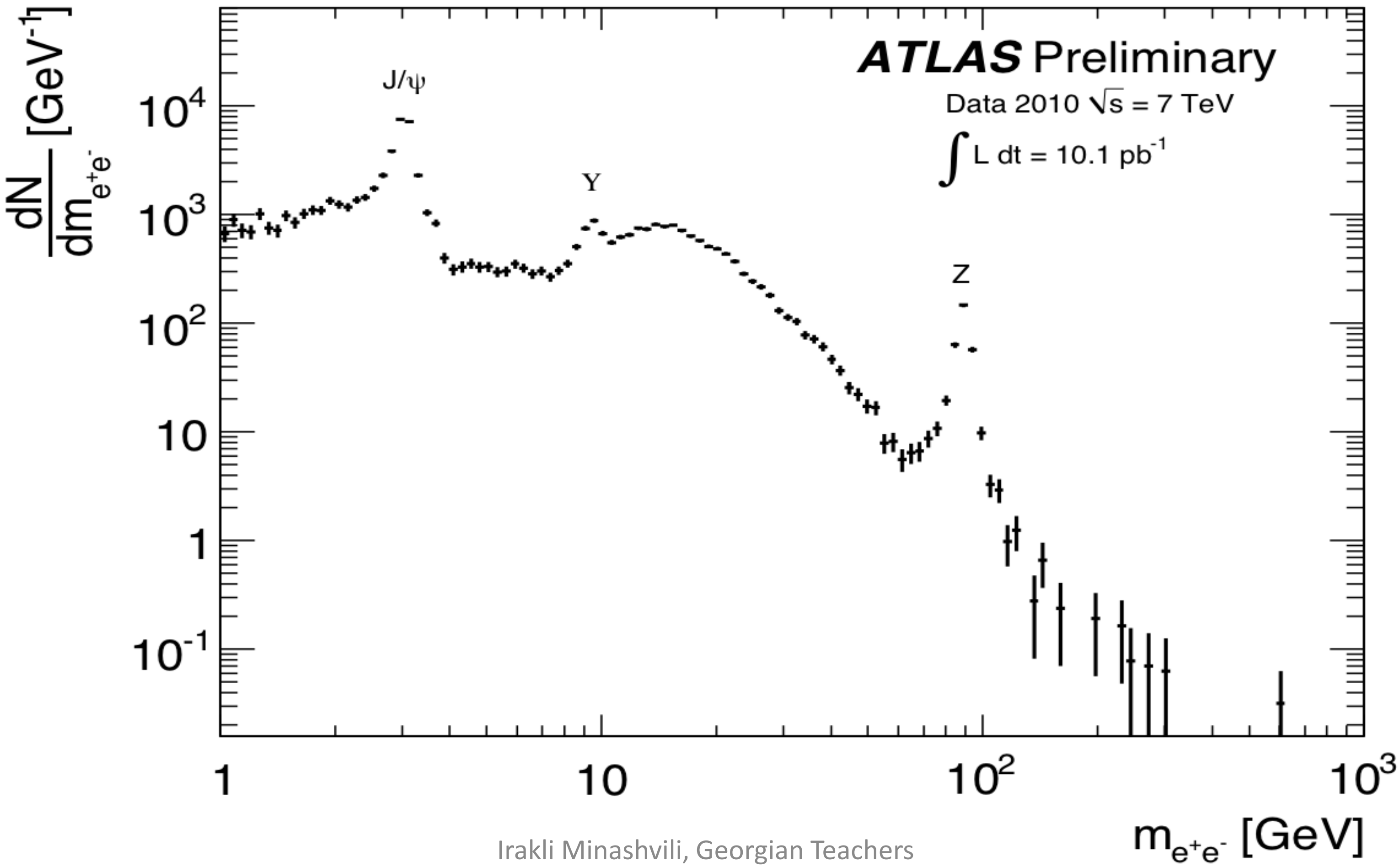
Note that 24 out of 48 pb^{-1} were delivered in one week of pp running

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%

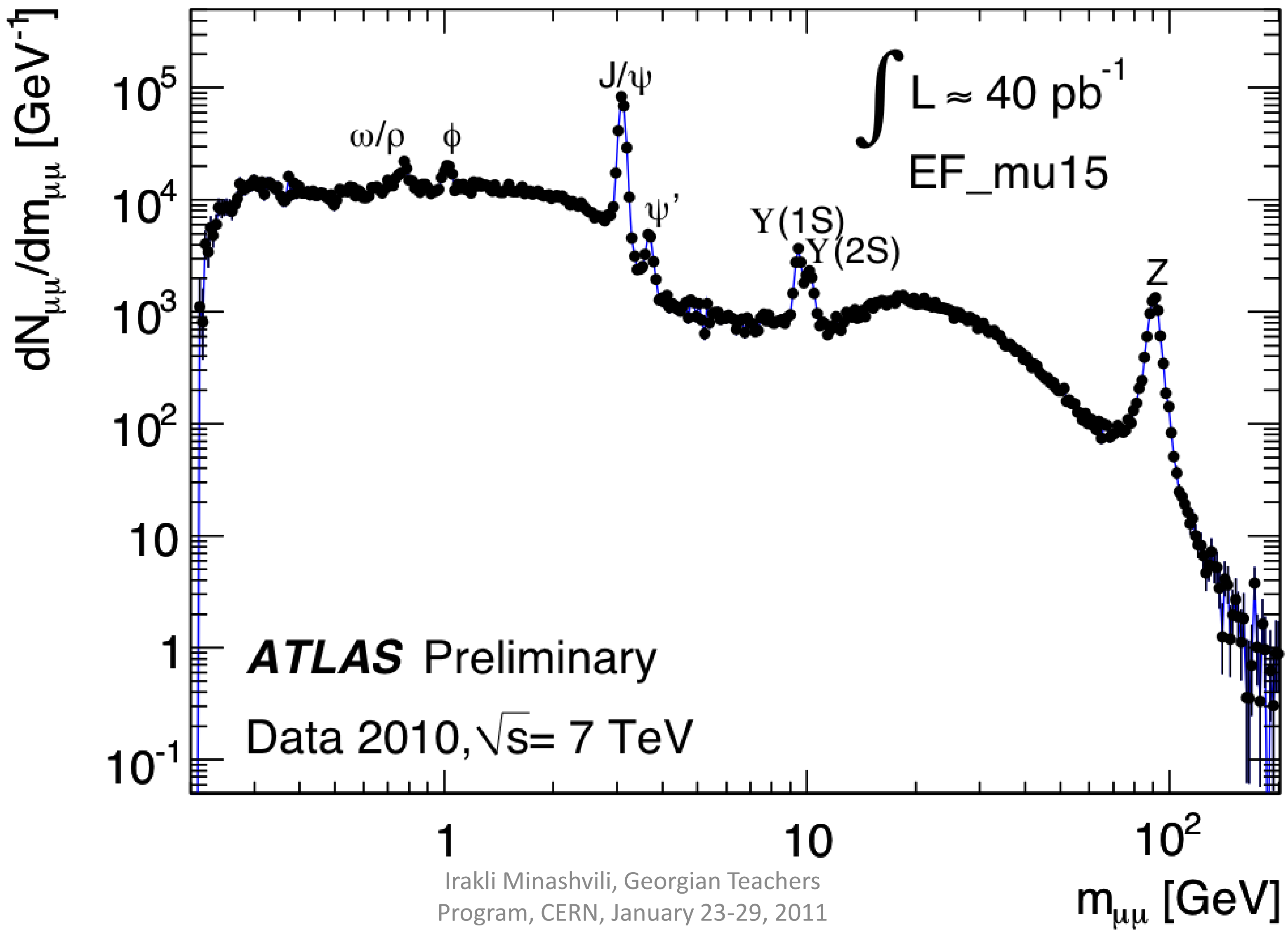
Di-electron invariant mass

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



Di-muon invariant mass

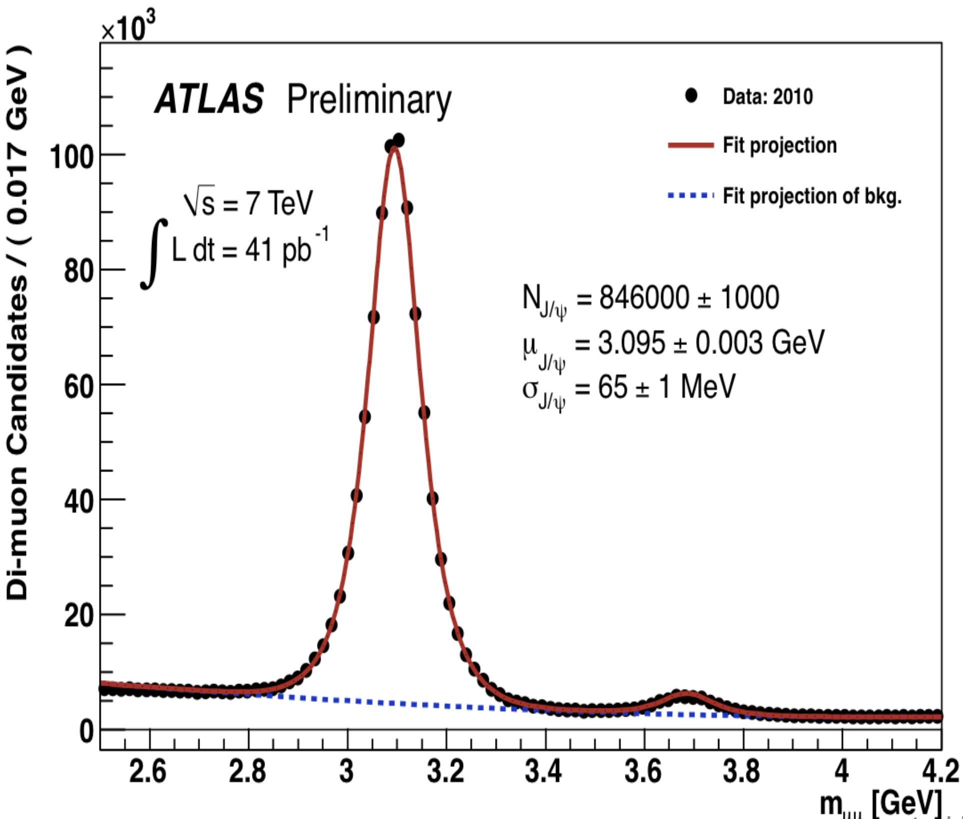
Leading muon, p_T>15 GeV, second muon, p_T>2.5 GeV

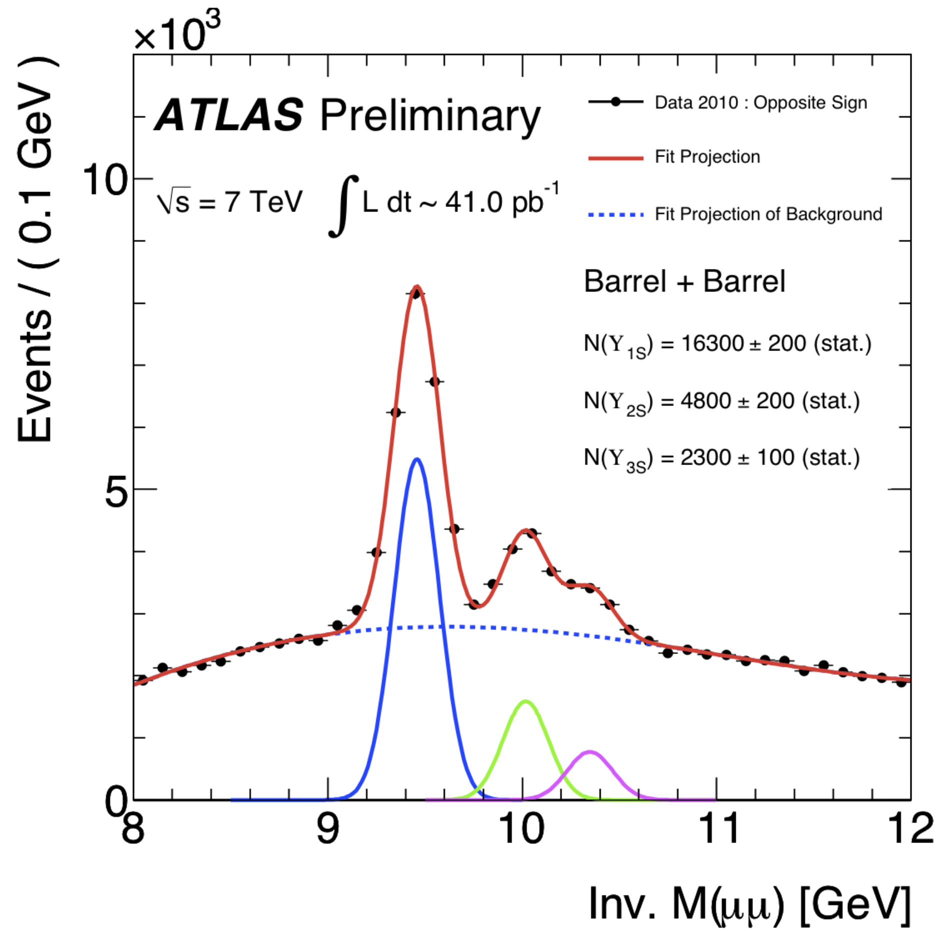


$J/\Psi, \Psi(2S)$ and $\Upsilon \rightarrow \mu\mu$

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





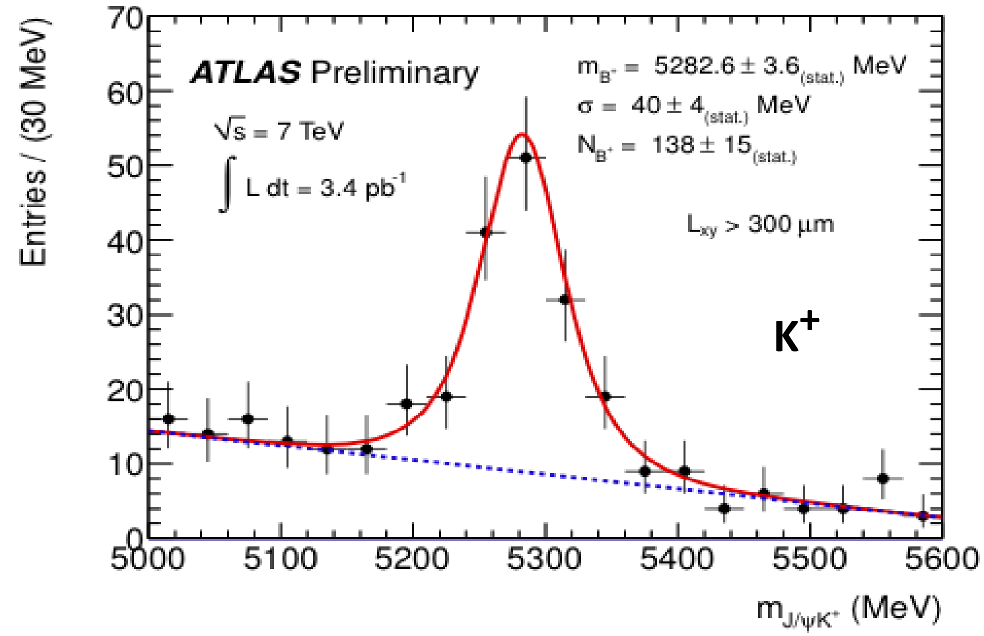
About 60k Υ(1S,2S,3S) candidates over full acceptance

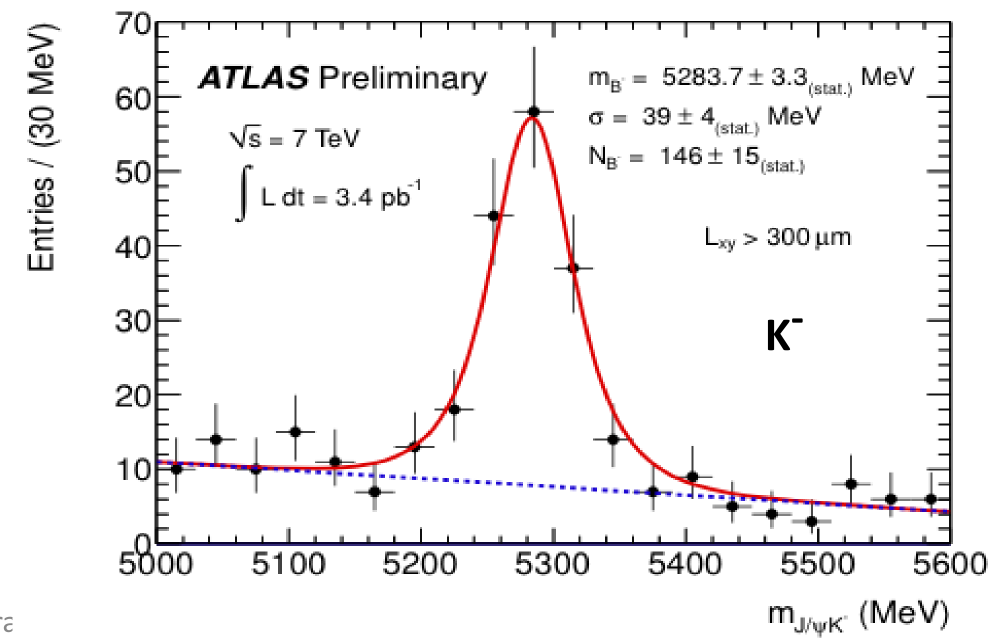
$B \to J/\Psi(\mu\mu)K$

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

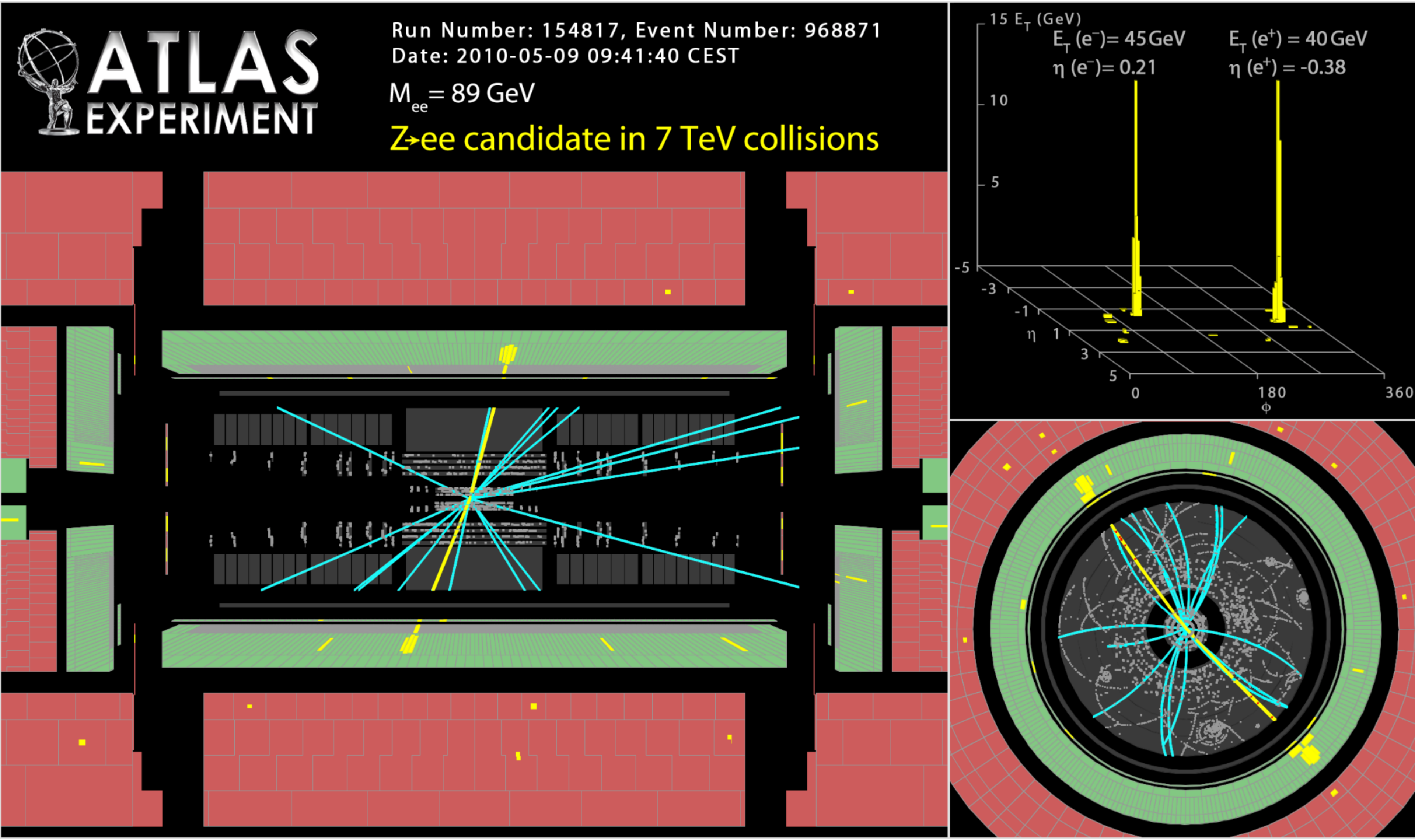
Unbinned likelihood fit to signal (with event-by-event mass uncertainty) and linear background

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



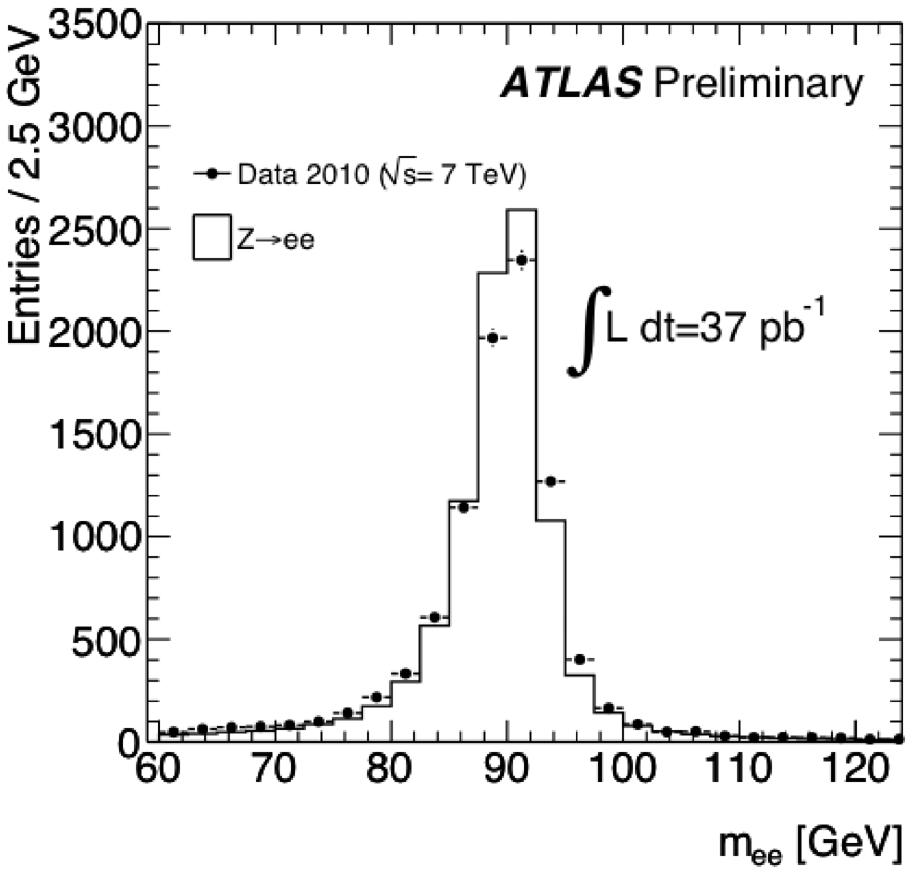


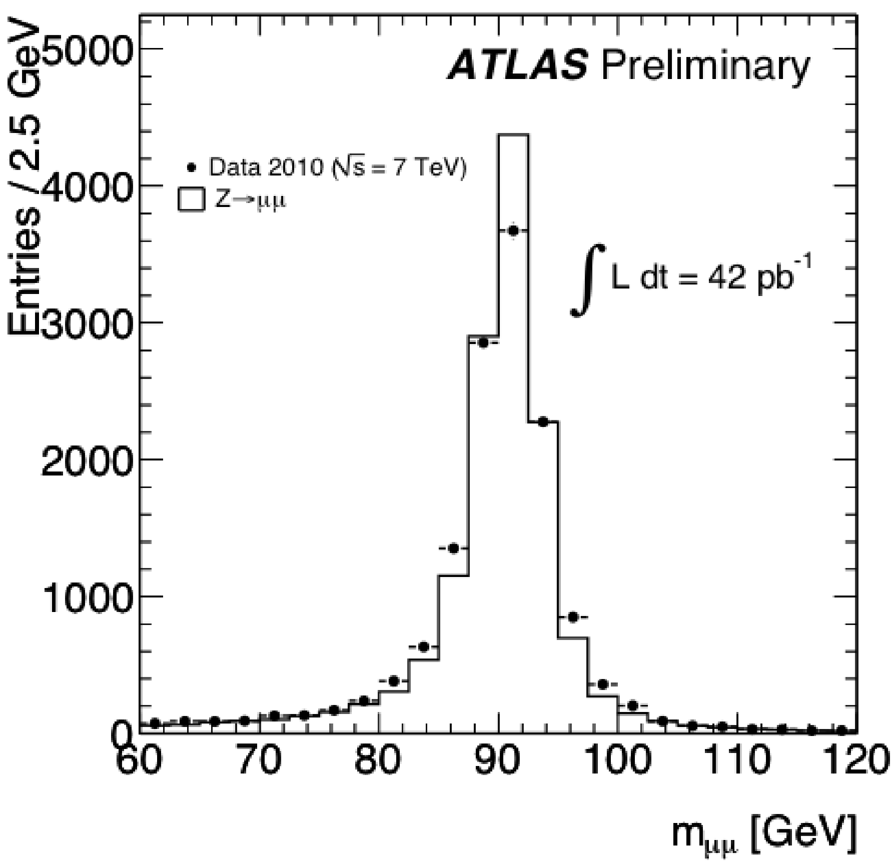
Intermediate Vector Bosons W and Z



Z mass peaks

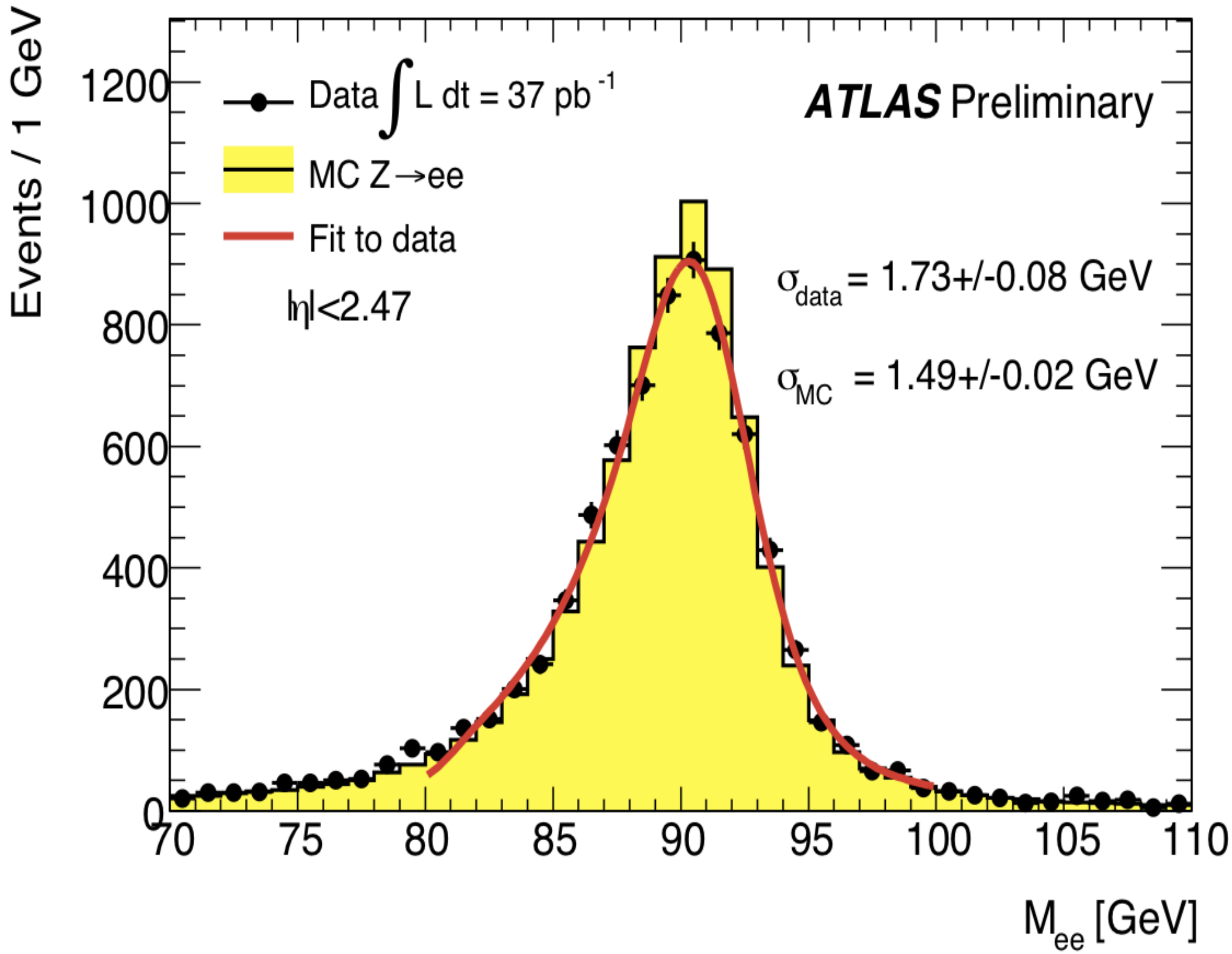
- Invariant mass of Z candidates with first pass processing
- MC normalised to data
- 9k electron and 14k muon pair events





$Z \rightarrow ee$ 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 $129<M_H<460$ 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 $M_H<500$ GeV

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

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

atlas deteqtoris menejmenTis Txovnaa rac SeiZleba male moamzadoT axali Taoba fizikosebisa LHC-ze dasmuli amocanebis gadasawyvetad. Mmxolod momaval Taobas Seswevs aseTi ambiciuri proeqtebis warmatebulad Sesruleba.

gisurvebT am saqmeSi kovelgvar winsvlas.

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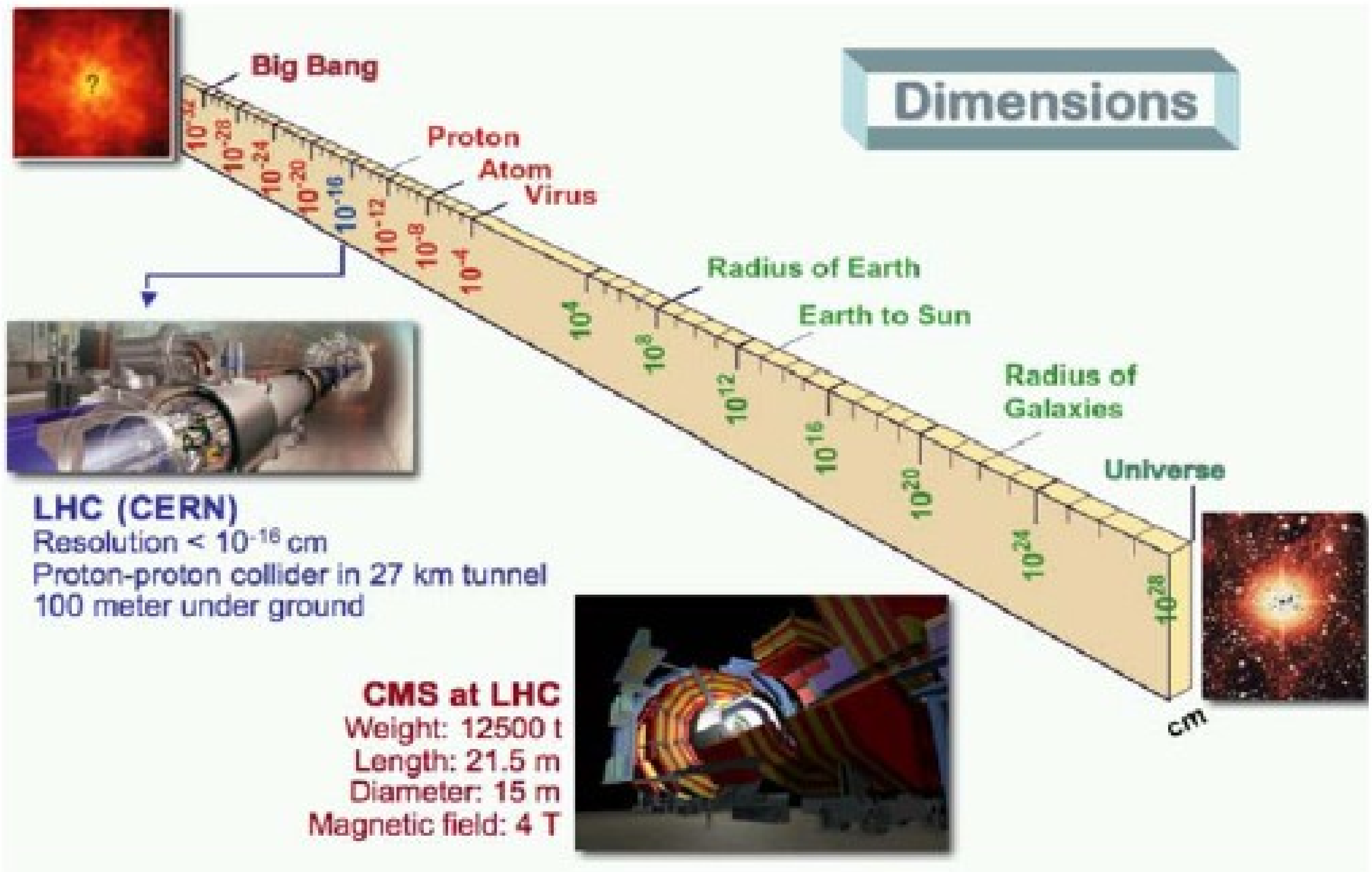
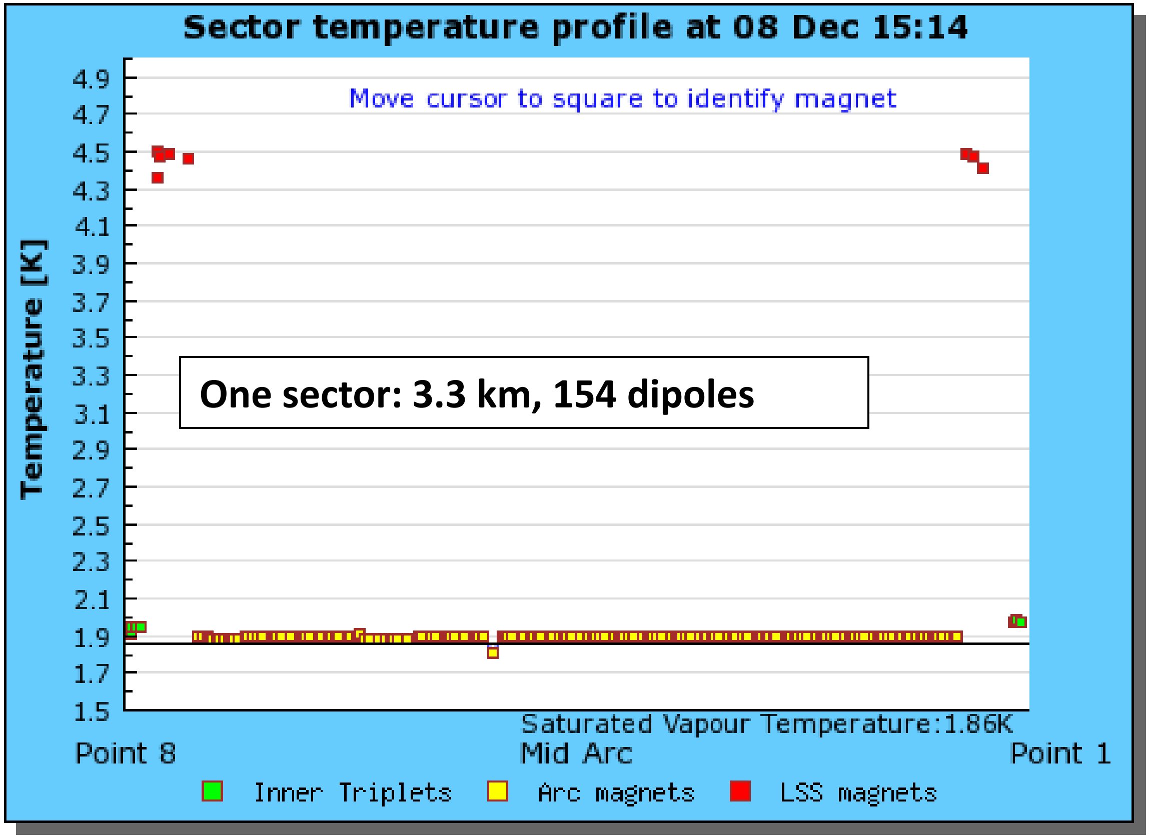
Back slides


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)

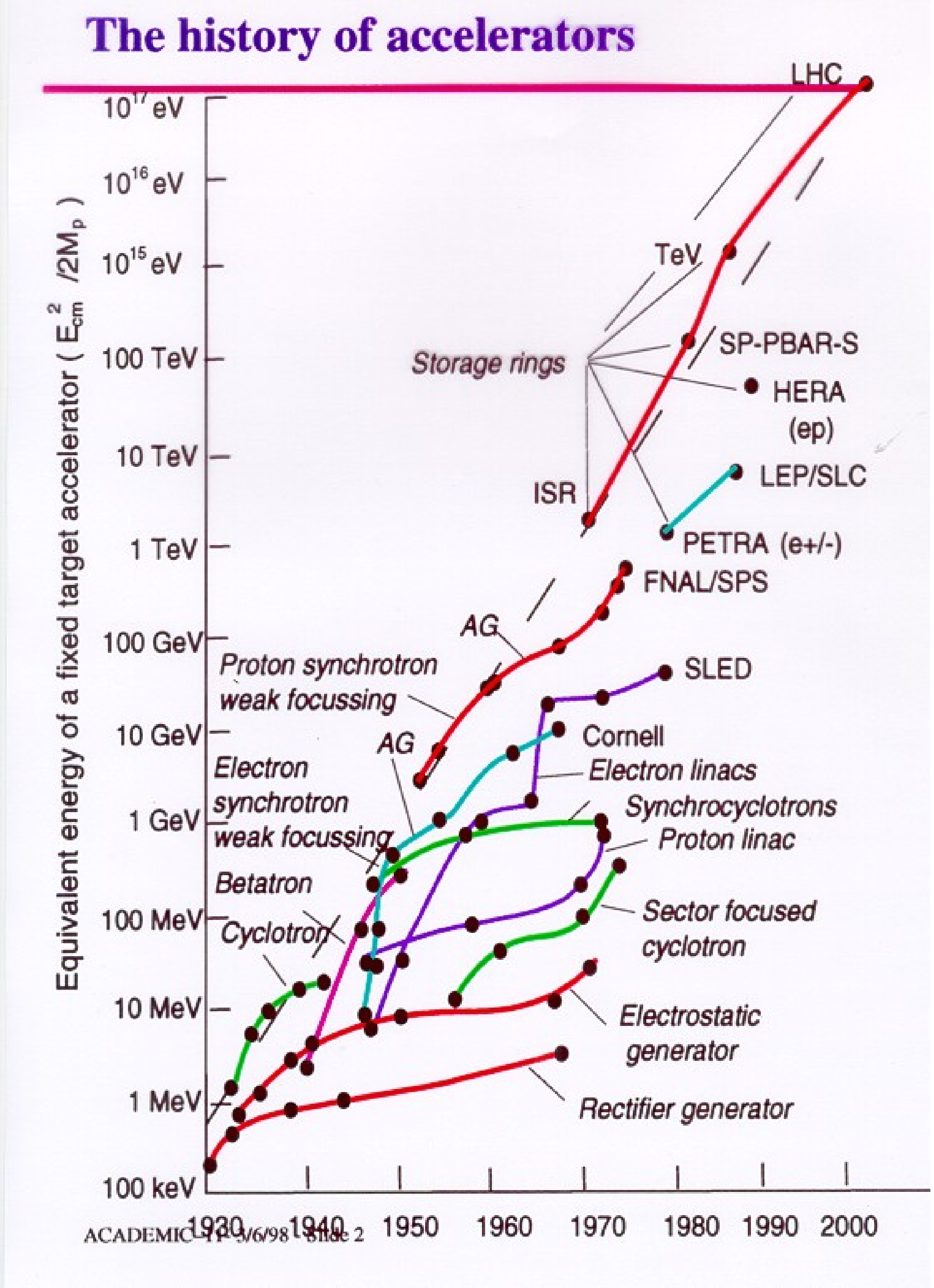
H K Onnes
Nobel Prize in Physics 1913

- **~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.



Iral
Pro

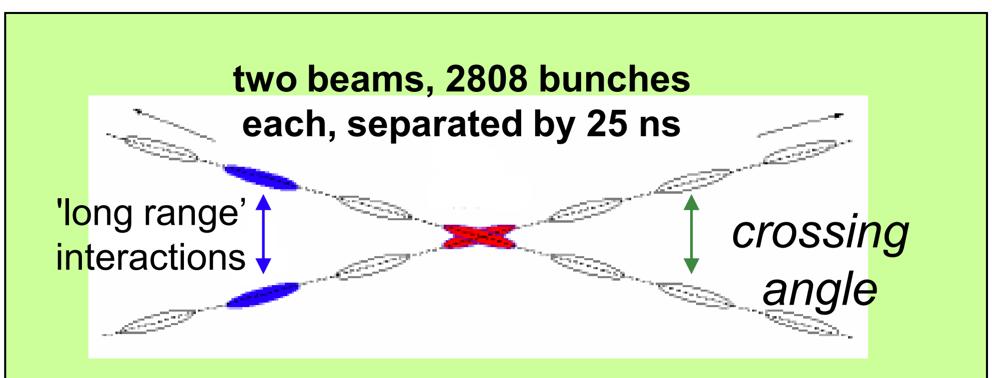
Main parameters of the machine

	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

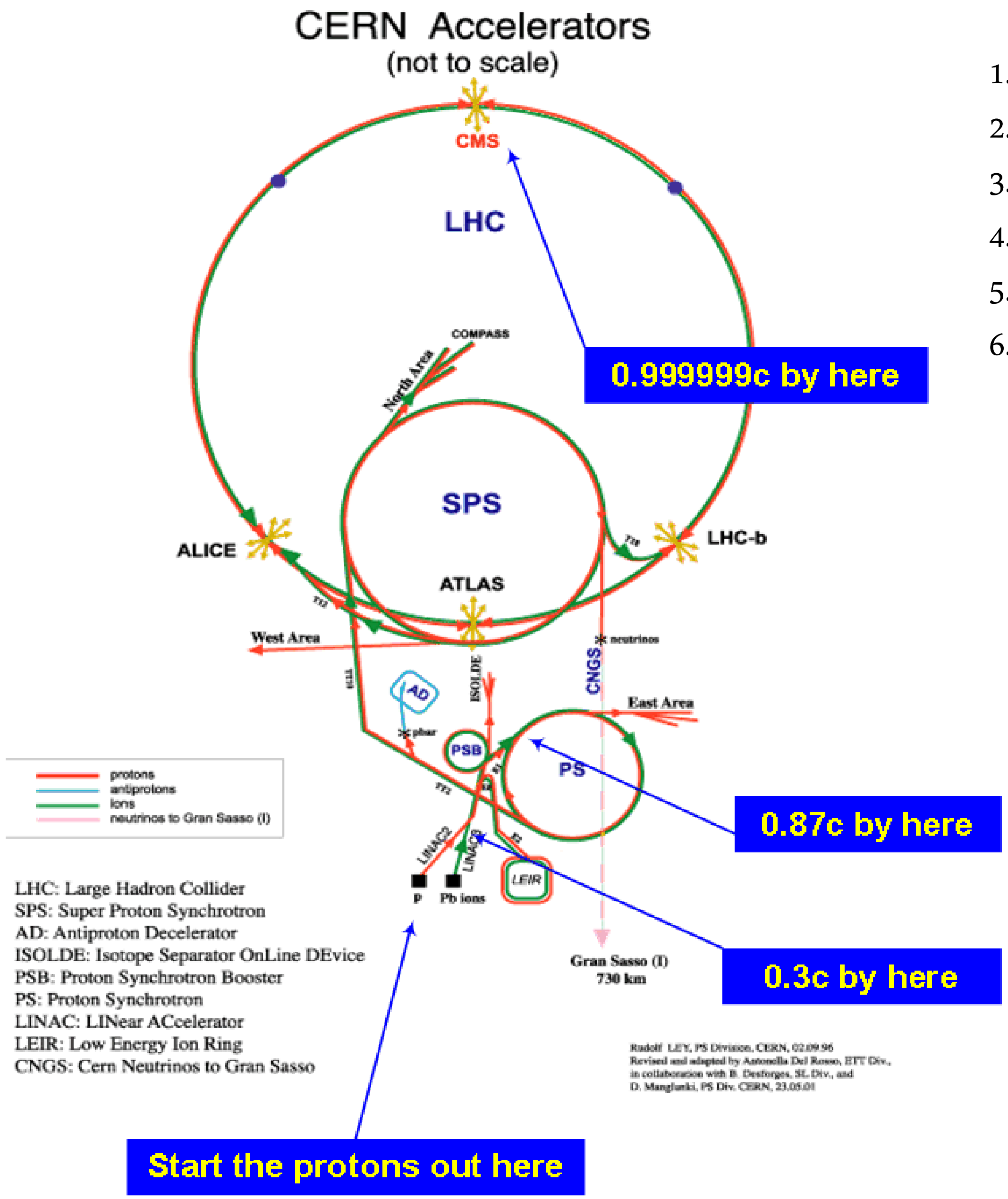
$$L = \frac{N^2 k_b f}{4\pi\sigma_x\sigma_y}$$

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)



x200 Tevatron



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

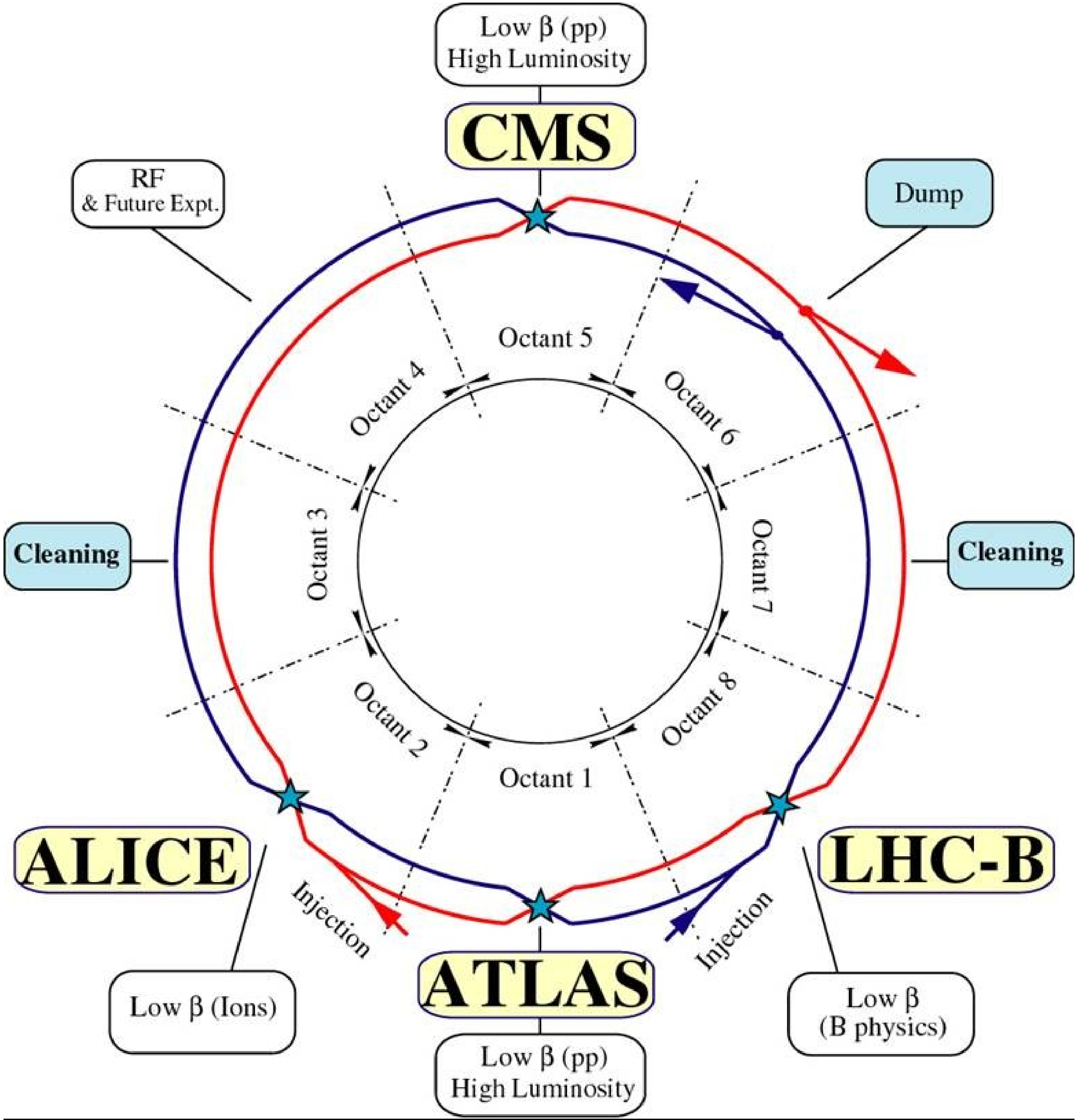
- *required maximum dipole field:*

$B \propto \gamma$

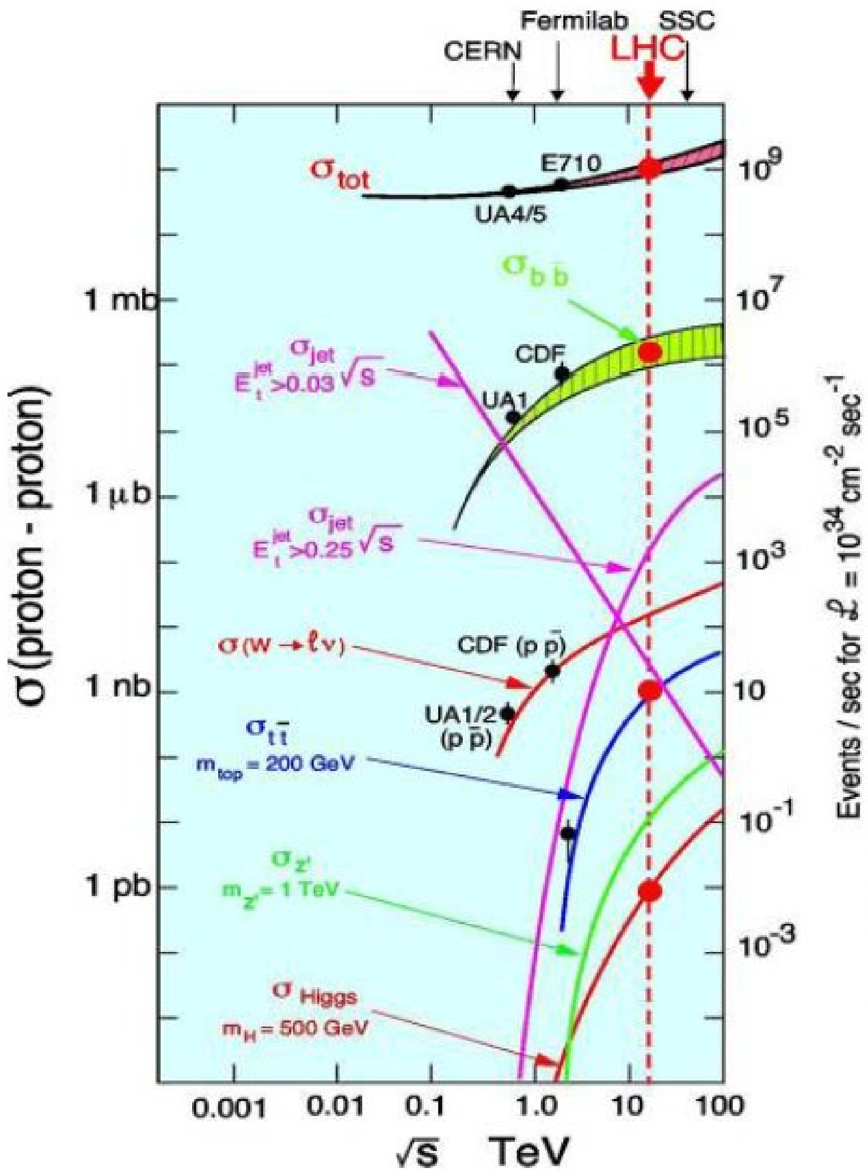
→ $$B[T] = \frac{2\pi}{0.3} \cdot \frac{p[GeV/c]}{F \cdot L[meter]}$$

- *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: $0.3 \cdot 10^{-4}$ 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

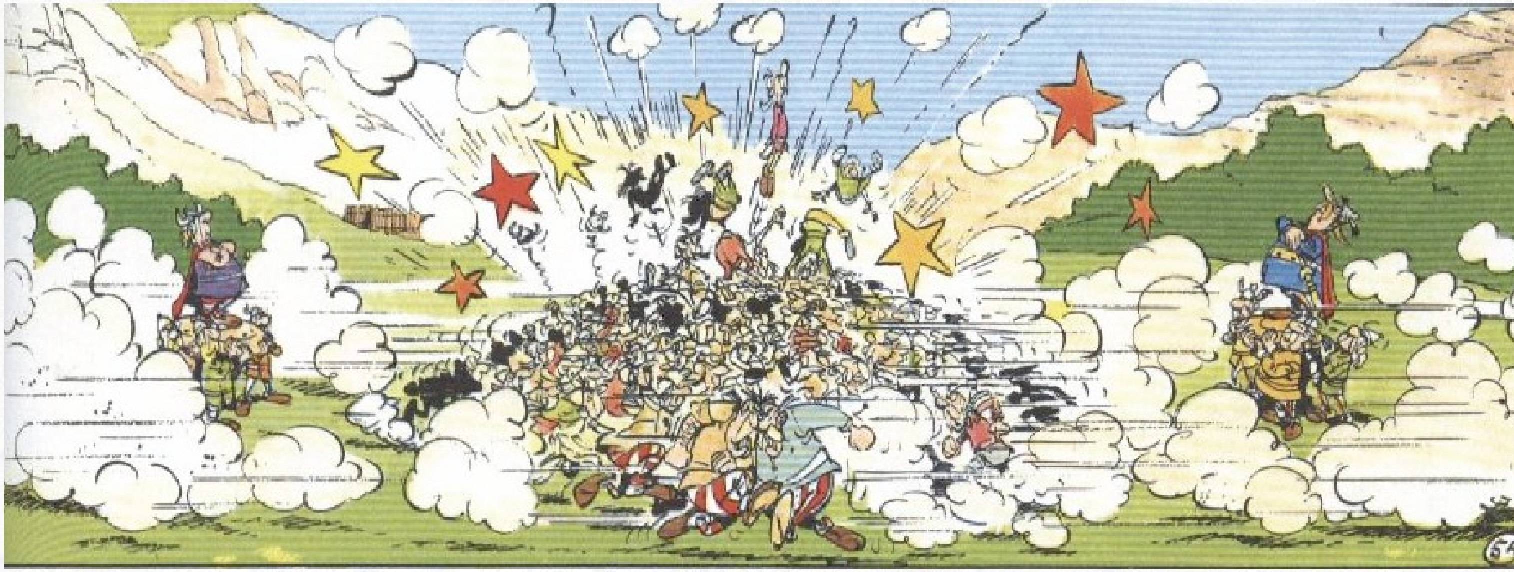
Search for physics beyond the SM (Supersymmetry, q/ℓ compositeness, leptoquarks, W'/Z', heavy q/ℓ, Extra-dimensions, ….) up to the TeV-range

Precise measurements :

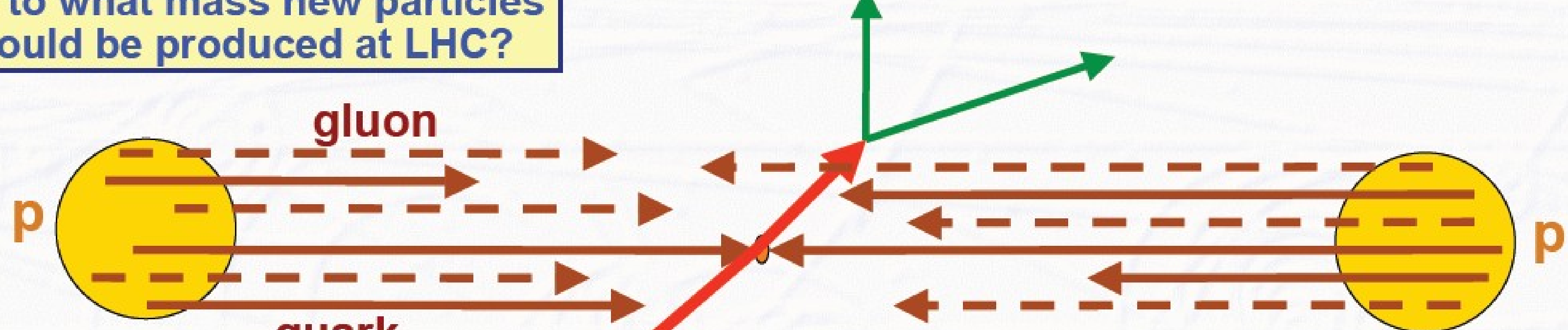
-- W mass
-- top mass, couplings and decay properties
-- Higgs mass, spin, couplings (if Higgs found)
-- B-physics (complementing LHCb): CP violation, rare decays, B^0 oscillations
-- QCD jet cross-section and α_s
-- etc. ….

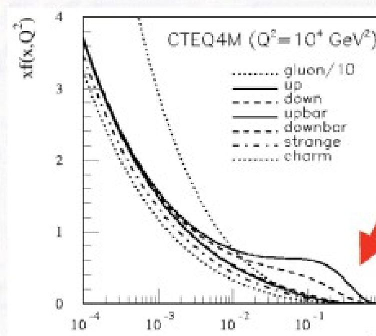
Study of phase transition at high density from hadronic matter to plasma of deconfined quarks and gluons (complementing ALICE).
Transition plasma → hadronic matter happened in universe ~10^{-5} s after Big Bang

Etc. etc. …..



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



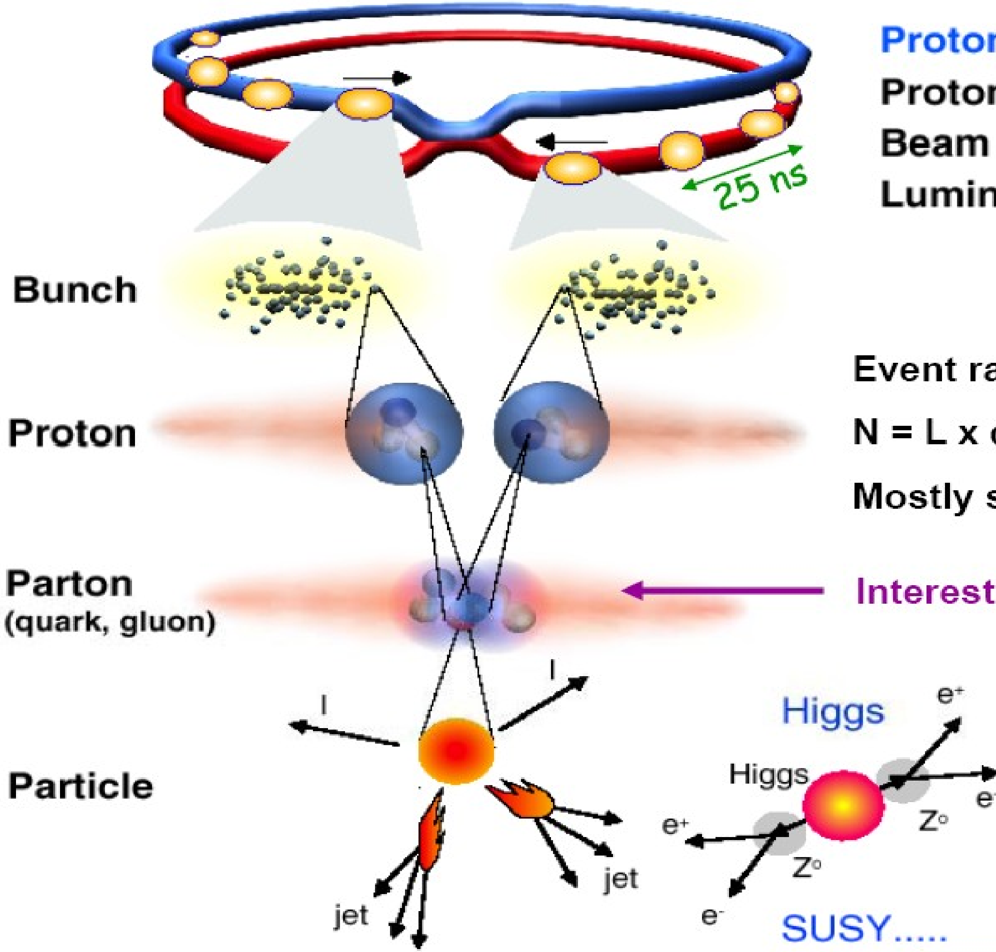


spectrum ends at x ~0.35

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 (7×10^{12} eV)
Luminosity	10^{34} cm^{-2} s^{-1}

Event rate in ATLAS :

$N = L \times \sigma\ (pp) \approx$ 10^9 interactions/s

Mostly soft (low p_T) events

Interesting hard (high-p_T) events are rare

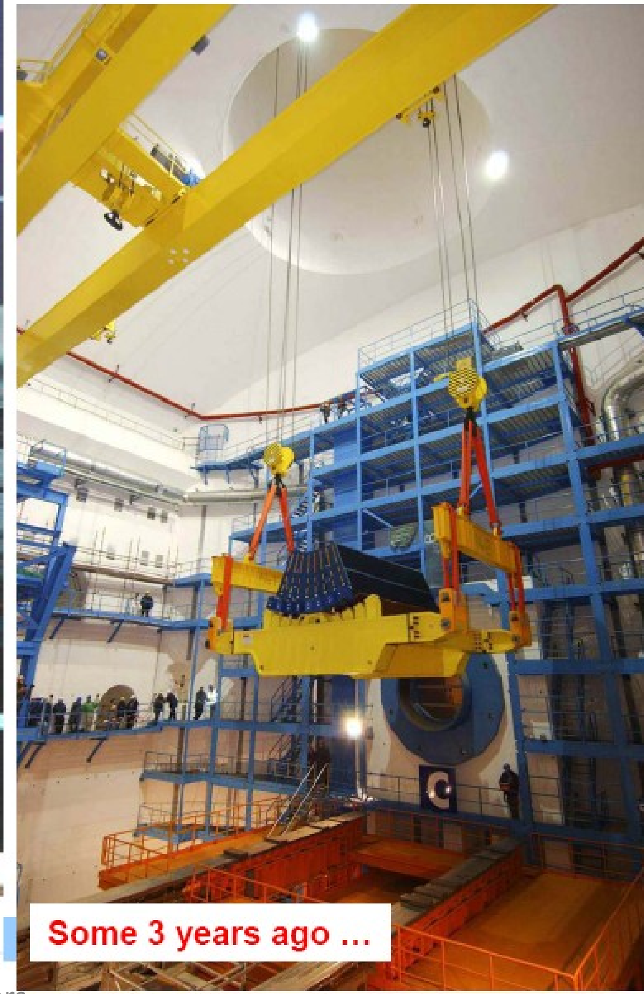
Selection of 1 in 10,000,000,000,000

Tile Calorimeter

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

Some 8 years ago ...

Some 7 years ago ...



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 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

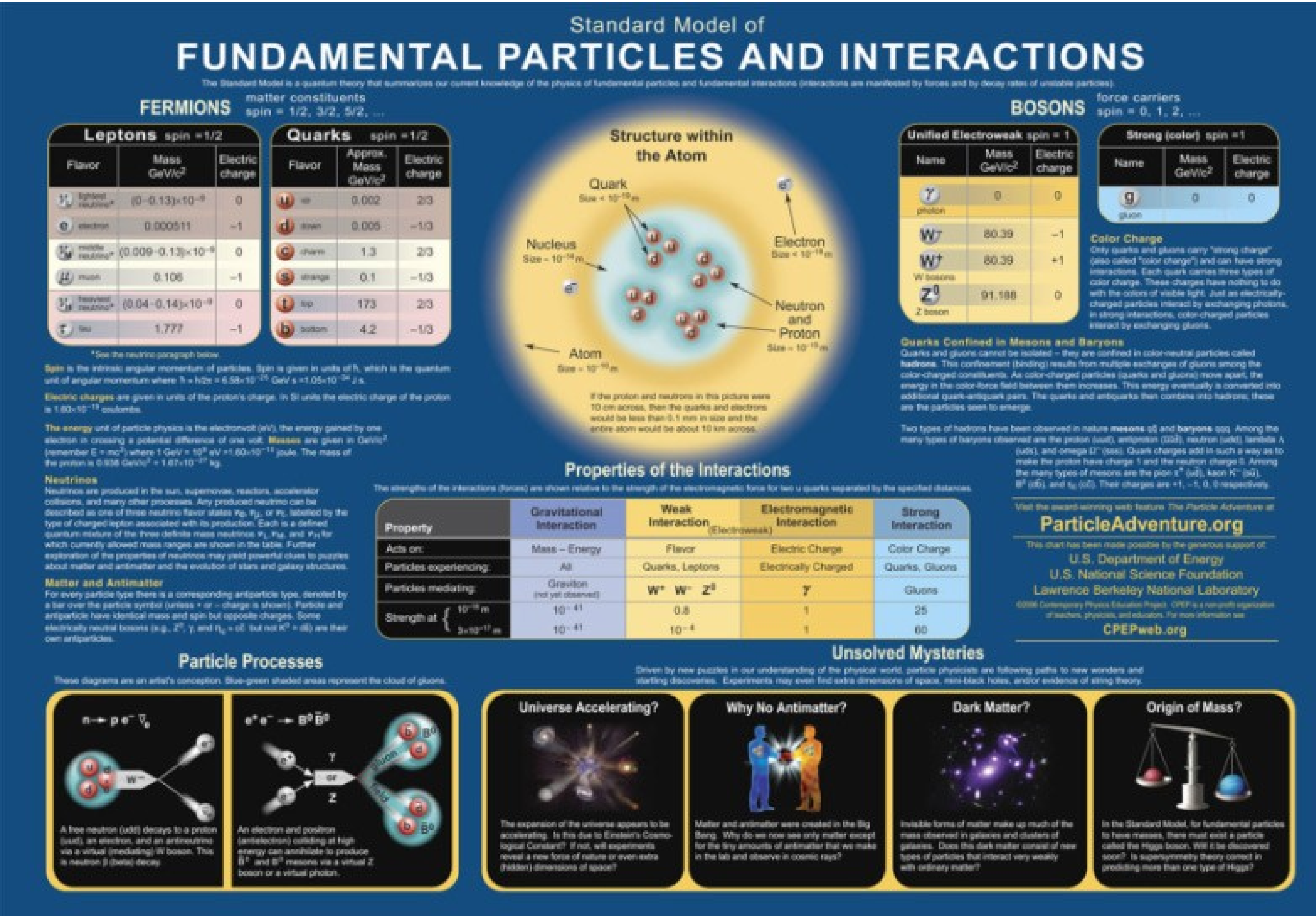
At rest (rest mass proton = m_p):

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.


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
(0-0.13)×10⁻⁹
0
0.000511
−1
(0.009-0.13)×10⁻⁹
0
0.106
−1
(0.04-0.14)×10⁻⁹
0
1.777
−1
Quarks spin =1/2
Flavor
Approx. Mass GeV/c²
Electric charge
0.002
2/3
0.005
−1/3
1.3
2/3
0.1
−1/3
173
2/3
4.2
−1/3
Structure within the Atom
Quark
Nucleus
Electron
Neutron and Proton
Atom
BOSONS
force carriers
spin = 0, 1, 2, ...
Unified Electroweak spin = 1
Name
Mass GeV/c²
Electric charge
0
0
80.39
−1
80.39
+1
91.188
0
Strong (color) spin =1
Name
Mass GeV/c²
Electric charge
0
0
Color Charge
Quarks Confined in Mesons and Baryons
Properties of the Interactions
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
W⁺ W⁻ Z⁰
Gluons
Strength at
0.8
1
25
1
60
Neutrinos
Matter and Antimatter
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?

CERN - birTvuli kvlevebis evropuli centri

Collider -amaCqarebeli Semxvedr nakadebze

LHC - didi adronuli amaCqarebeli Semxvedr nakadebze

LINAC - wrfivi amCqarebeli

PS - Pprotonuli sinqrotroni

ATLAS – zogadi daniSnulebis deteqtori

CMS – mionebis kompaqturi solenoidi

Trigger – piroba, romlis Sesrulebis SemTxvevaSi xdeba fizikuri monacemebis Cawera