The Future of Particle Physics
The High Energy Frontier

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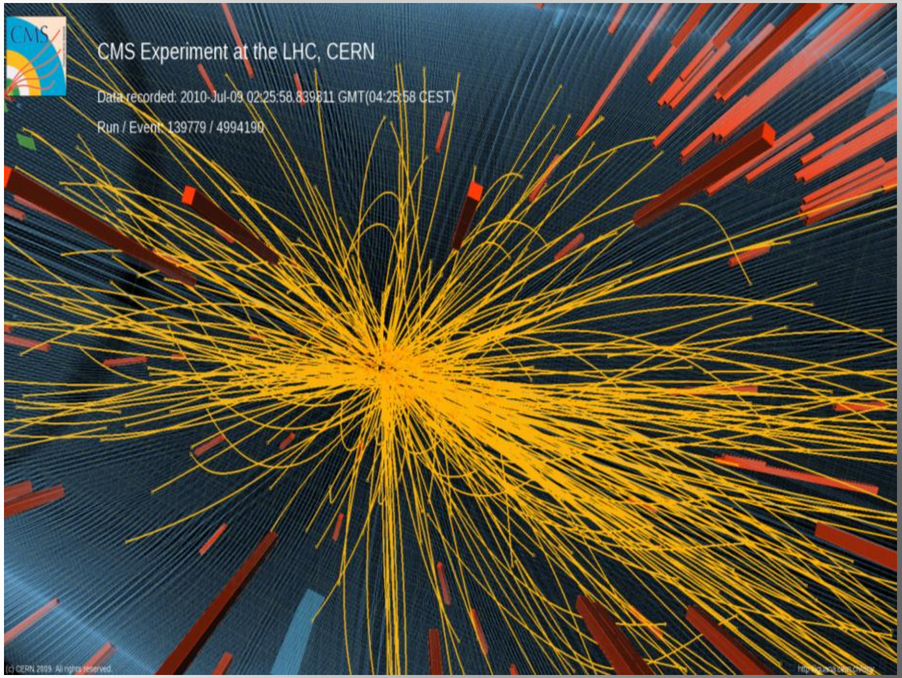
The African School of Fundamental Physics and its Applications 2012

Outline



A proton-proton collision at 7 TeV

- Introduction
- The Large Hadron Collider and the experiments
- Physics results from the LHC and impact on the field
    - Searches for Physics Beyond the Standard Model
    - The Discovery of a Higgs-Like Boson
- Future Colliders in HEP

What is the world made of?
What holds the world together?
Where did we come from?

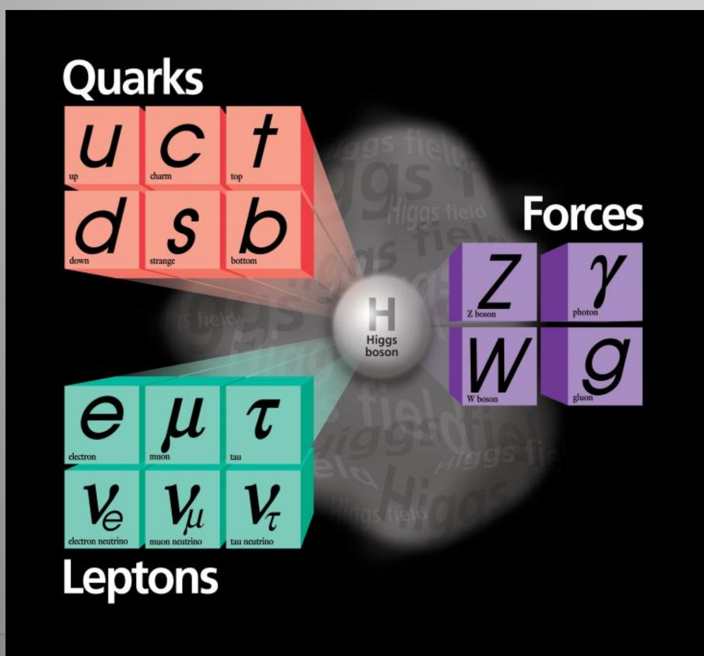
Particle physics is a modern name for centuries old effort to understand the laws of Nature

E. Witten (String Theorist)

The "Standard Model"

Over the last 100 years: combination of
Quantum Mechanics and Special Theory of relativity
along with all new particles discovered has led to the
Standard Model of Particle Physics.
The new (final?) "Periodic Table" of fundamental elements

Matter particles



Force particles

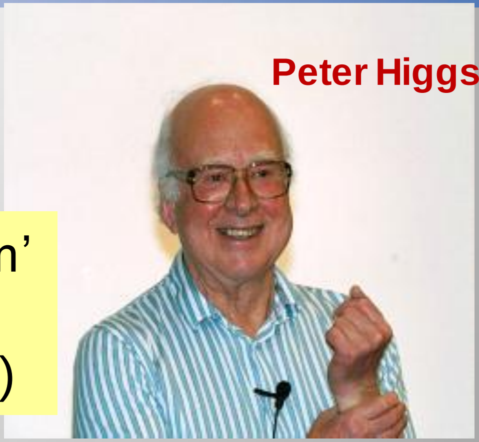
A crowning achievement of 20th Century Science

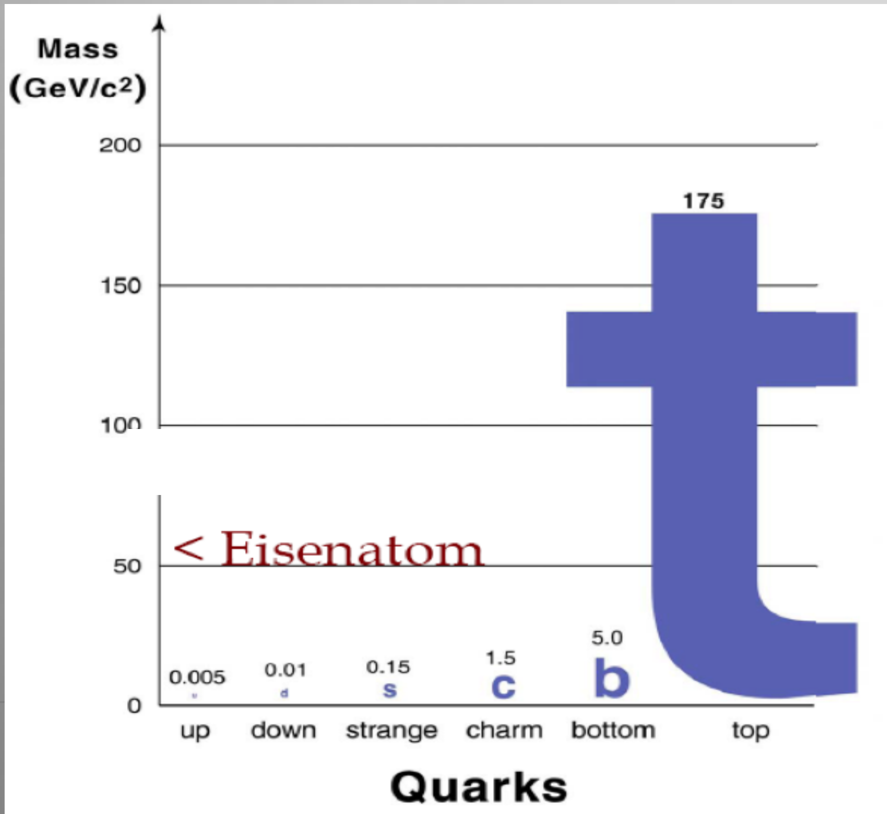
The SM has been tested thousands of times, to excellent precision. Yet, its most basic mechanism, that of granting mass to particles
A major step forward was made this month with the discovery of a particle that could be the long-sought Higgs boson!!

The Origin of Particle Masses

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.

The LHC was always considered THE machine to solve this question!

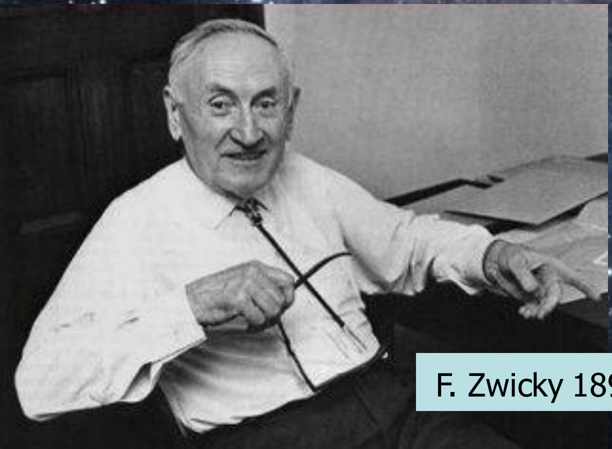

Francois Englert

Dark Matter in the Universe

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

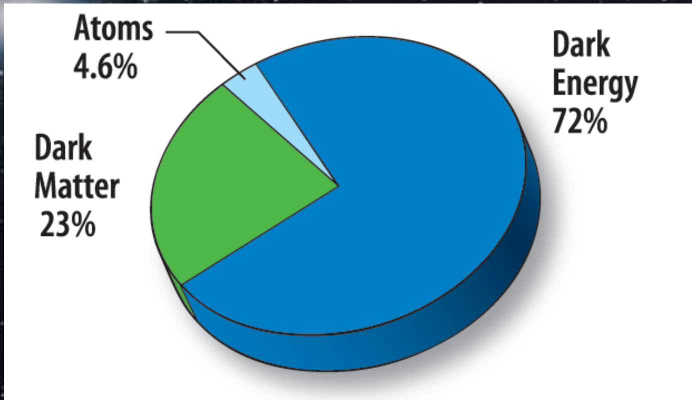
Vera Rubin ~ 1970

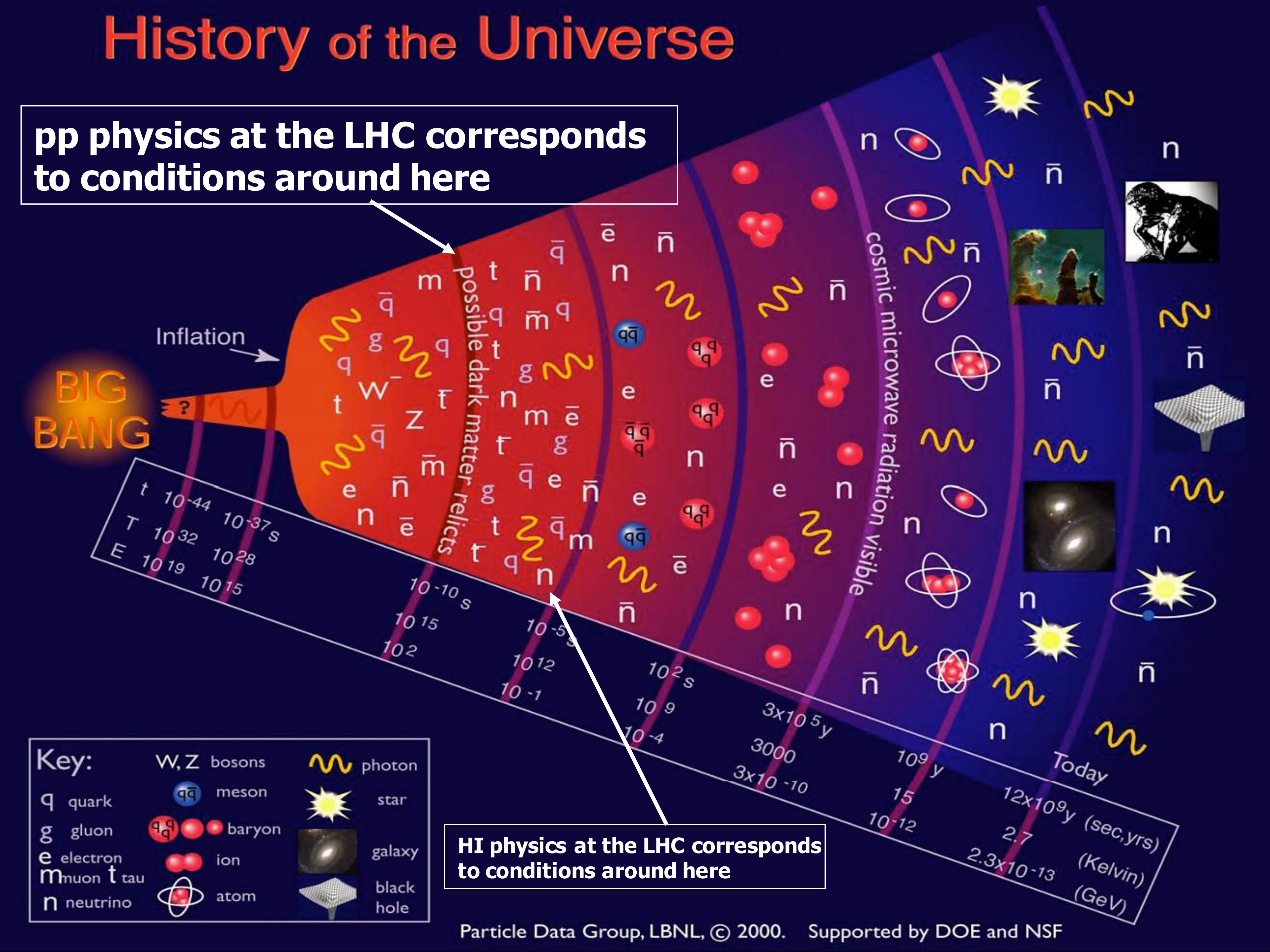
'Supersymmetric' particles ?



F. Zwicky 1898-1974

We are looking for them with the LHC!!




History of the Universe
pp physics at the LHC corresponds to conditions around here
HI physics at the LHC corresponds to conditions around here
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10^{-44} 10^{-37} s 10^{-10} s 10^{-5} s 10^{2} s 3×10^{5} y 10^{9} y Today (sec,yrs)
T 10^{32} 10^{28} 10^{15} 10^{12} 10^{9} 3000 15 2.7 (Kelvin)
E 10^{19} 10^{15} 10^{2} 10^{-1} 10^{-4} 3×10^{-10} 10^{-12} 2.3×10^{-13} (GeV)
Key:
W, Z bosons
q quark
g gluon
e electron
m muon
t tau
n neutrino
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

This Study Requires…….

1. Accelerators : powerful machines that accelerate particles to extremely high energies and bring them into collision with other particles

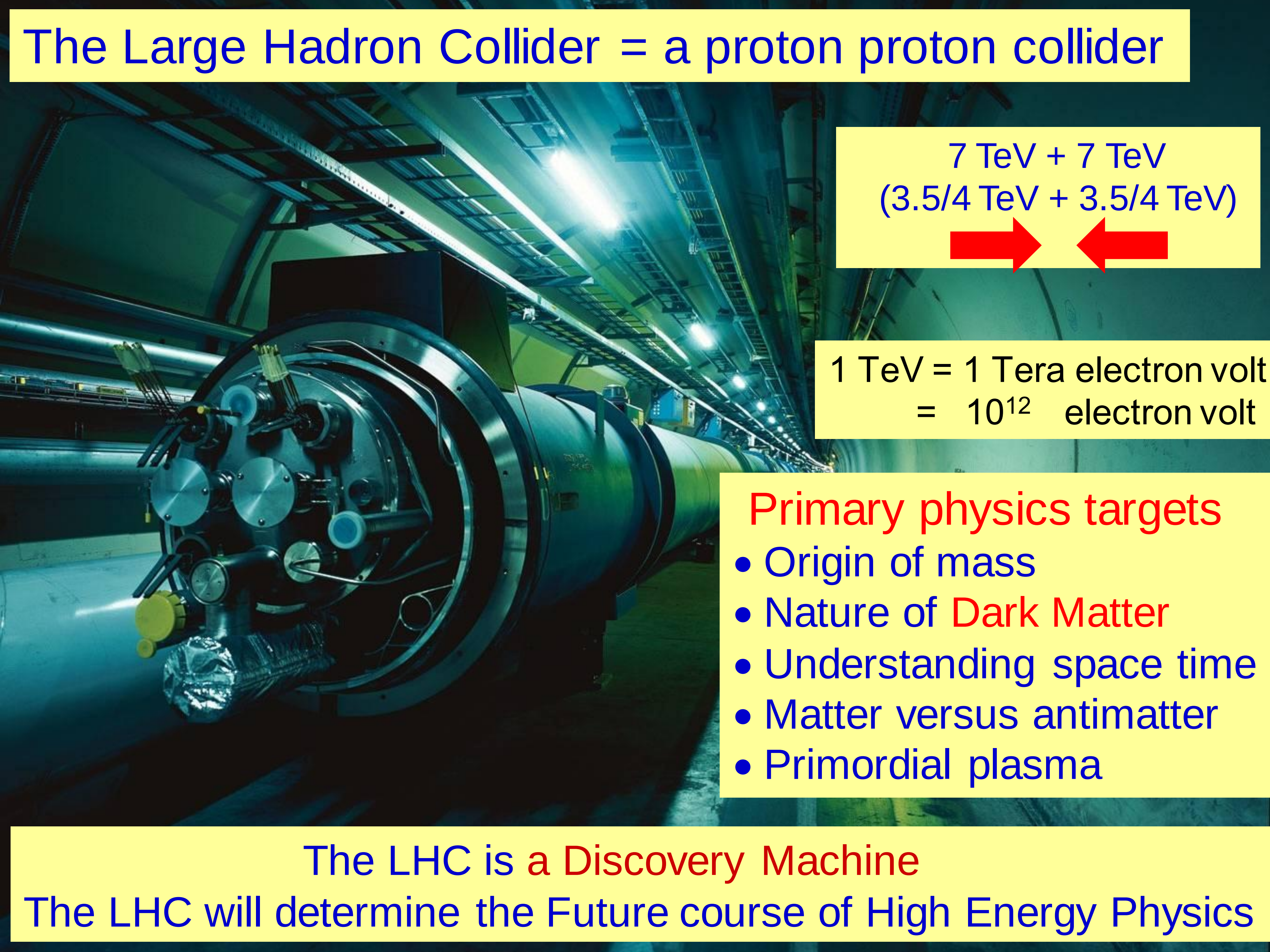
2. Detectors : gigantic instruments that record the resulting particles as they "stream" out from the point of collision.

3. Computing : to collect, store, distribute and analyse the vast amount of data produced by these detectors

4. Collaborative Science on Worldwide scale : thousands of scientists, engineers, technicians and support staff to design, build and operate these complex "machines".

The Large Hadron Collider LHC
The Future Begins!

The Large Hadron Collider = a proton proton collider



7 TeV + 7 TeV
(3.5/4 TeV + 3.5/4 TeV)

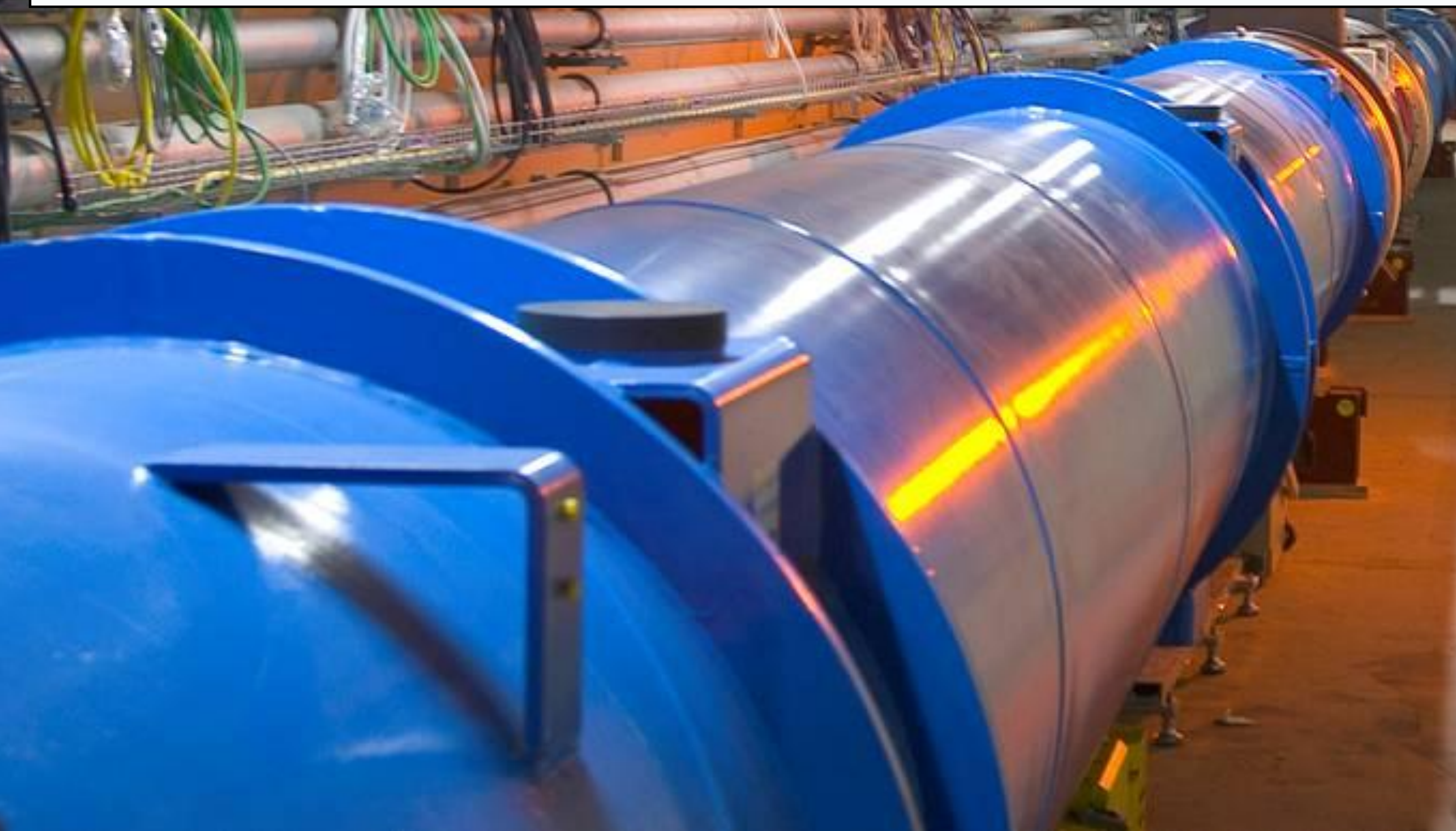
1 TeV = 1 Tera electron volt
= 10^{12} electron volt

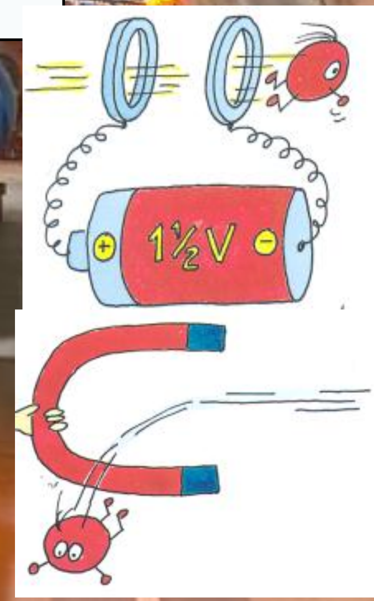
Primary physics targets

- Origin of mass
- Nature of Dark Matter
- Understanding space time
- Matter versus antimatter
- Primordial plasma

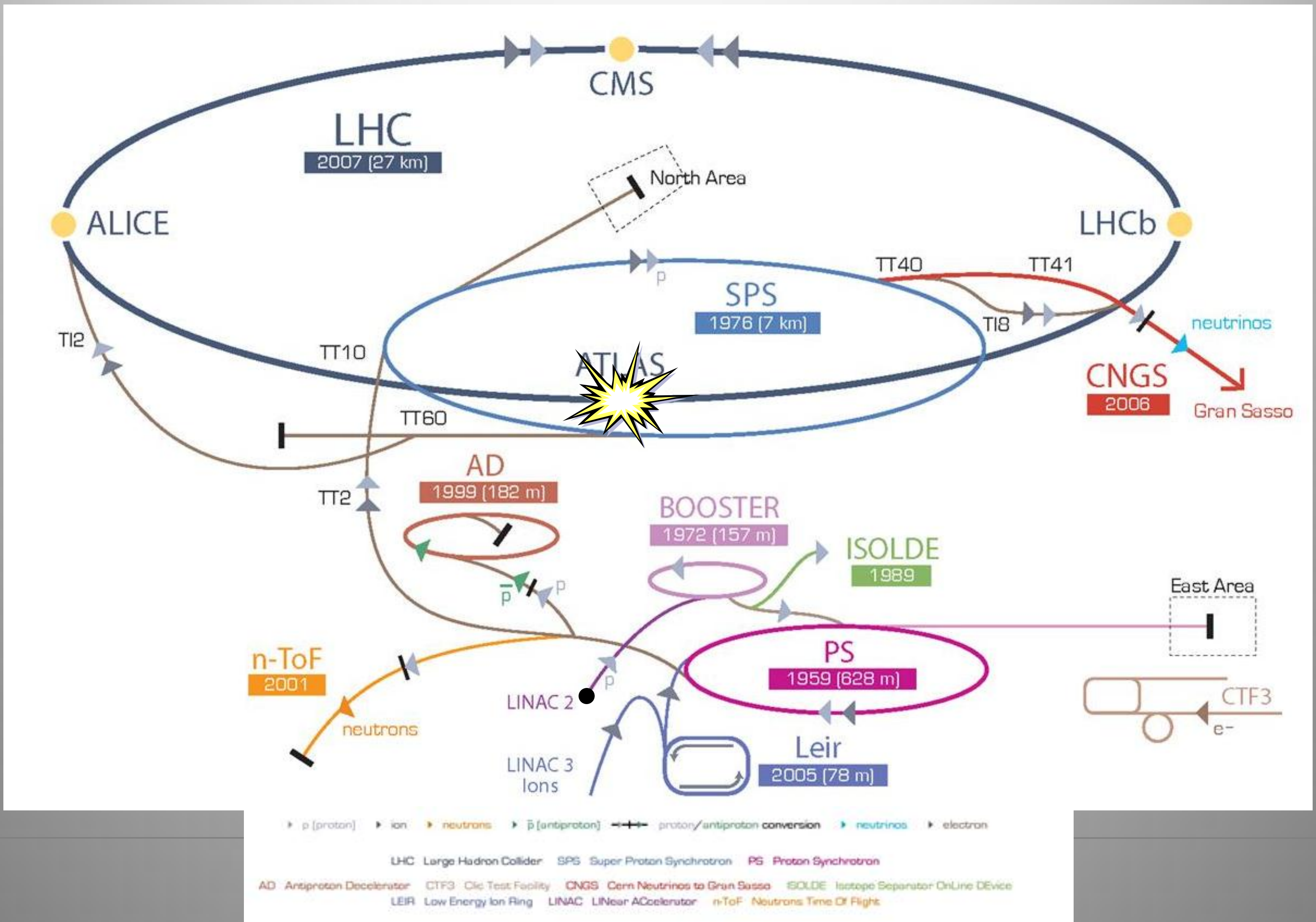
The LHC is a Discovery Machine
The LHC will determine the Future course of High Energy Physics

- Several thousand billion protons
- Each with the energy of a fly
- 99.9999991% of light speed
- They orbit a 27km ring 11 000 times/second
- The machine/experiments are 100m underground
- A billion collisions a second in the experiments





CERN's Particle Accelerator Chain



Accelerators are Powerful Microscopes

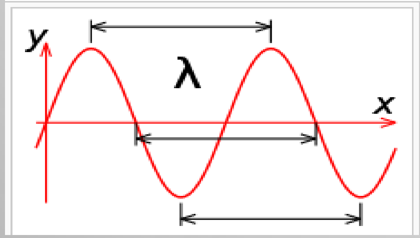
They make high energy particle beams that allow us to see small things.

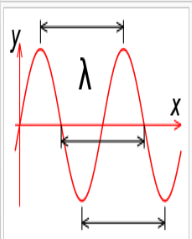
$$\lambda = \frac{h}{p}$$

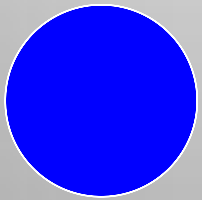
Planck constant

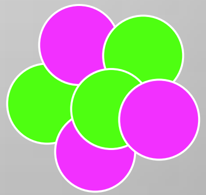
wavelength

momentum ~ energy





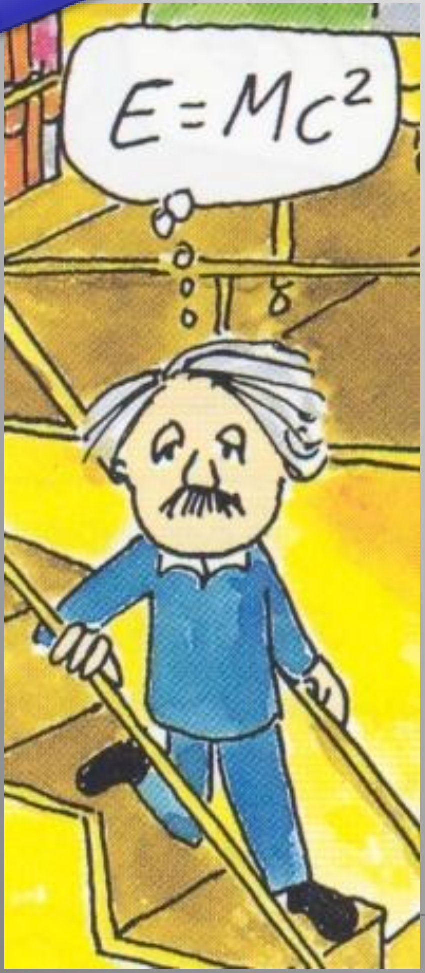


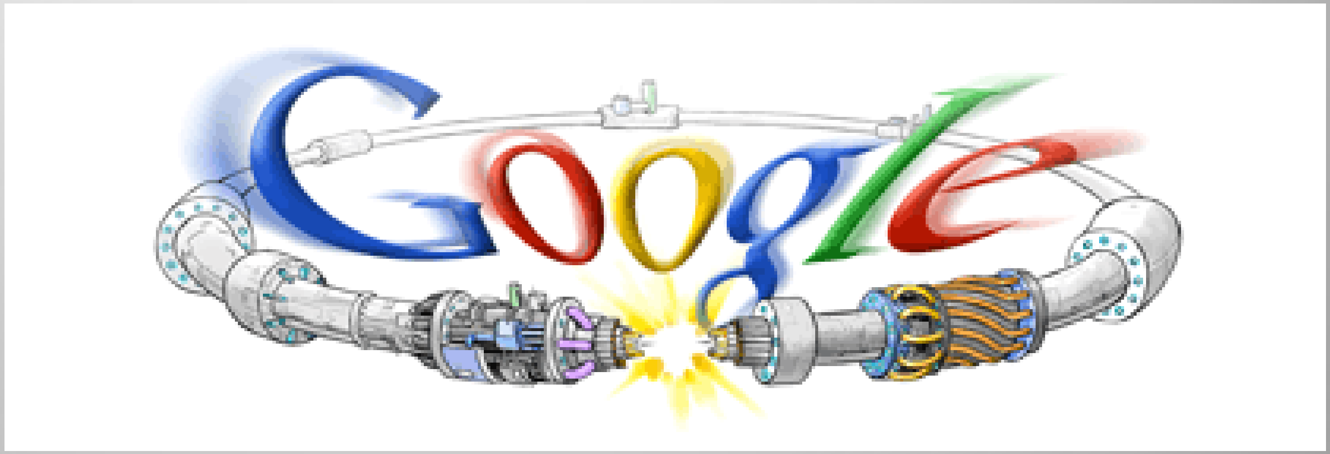


seen by low energy beam of particles (poorer resolution)

seen by high energy beam of particles (better resolution)

We can create particles from energy

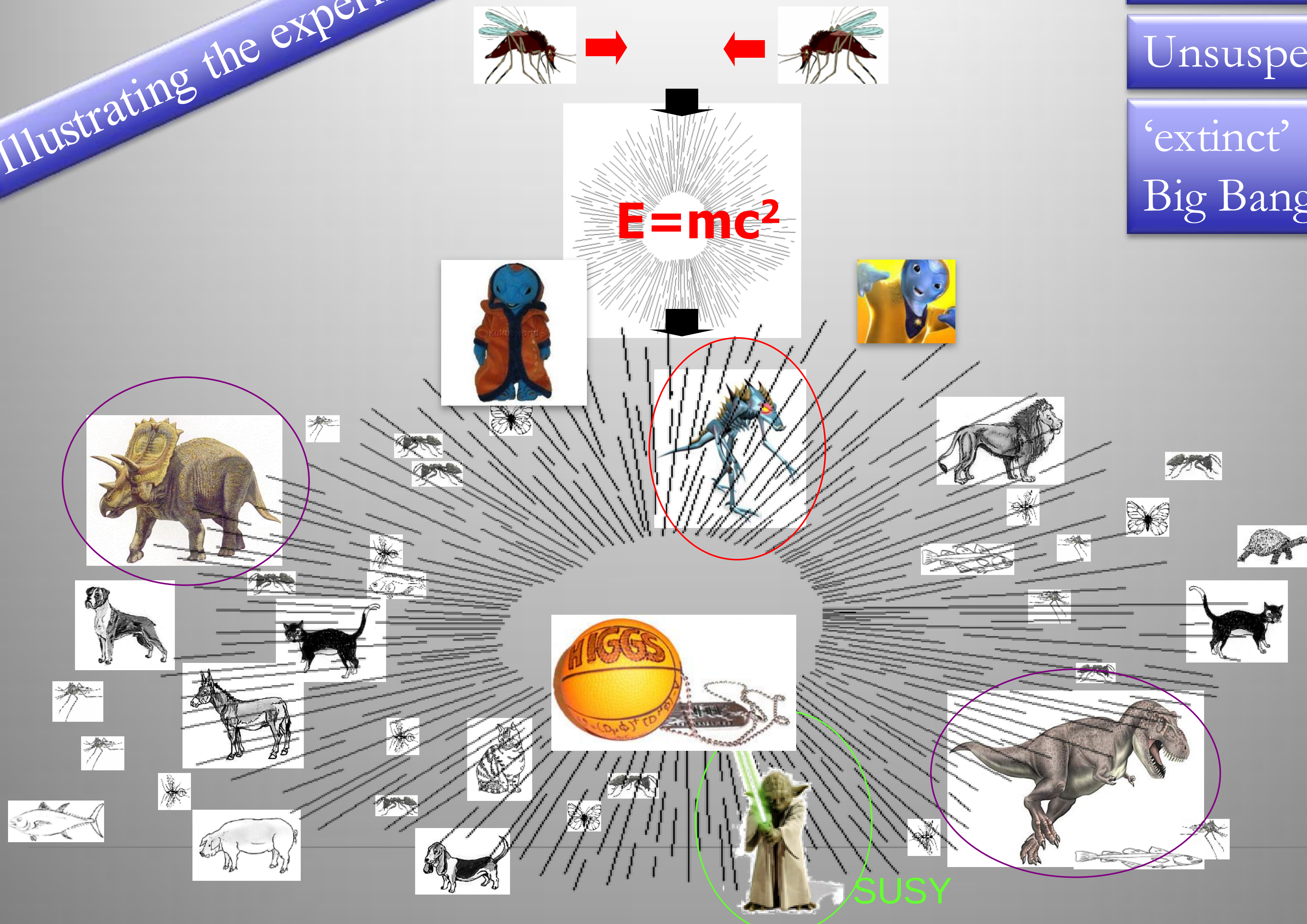




Two beams of protons collide and generate, in a very tiny space, temperatures over a billion times higher than those prevailing at the center of the Sun.

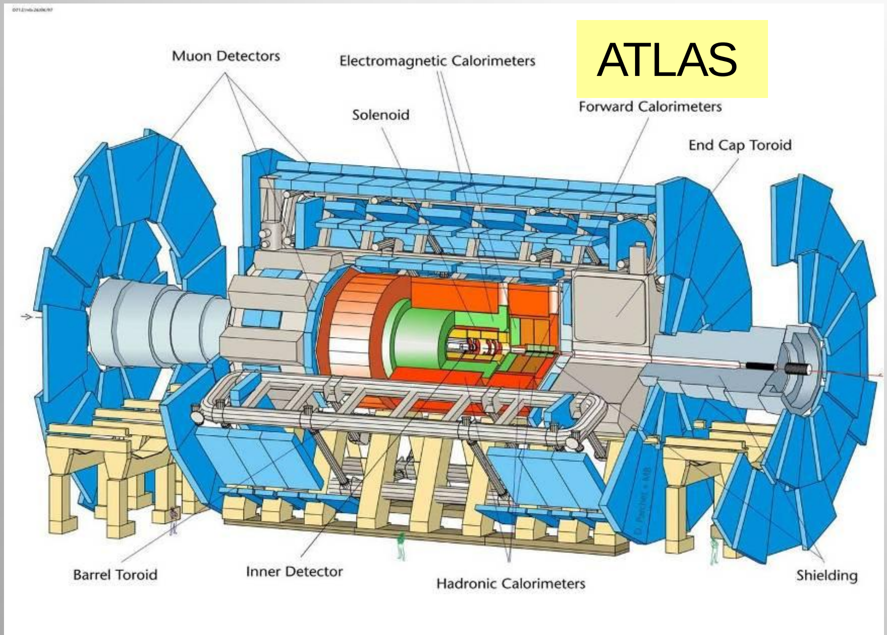
Illustrating the experiment

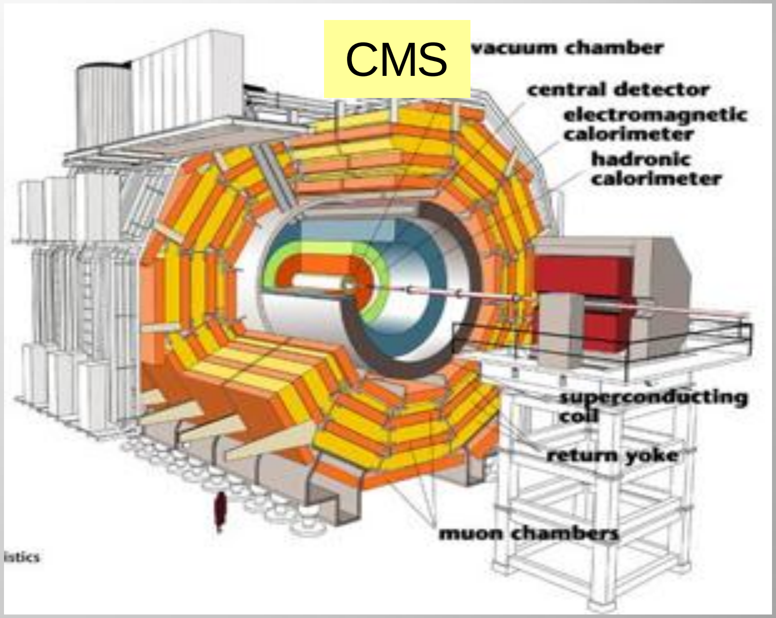
- Highly Expected
- Hypothetical
- Unsuspected ?
- ‘extinct’ since Big Bang

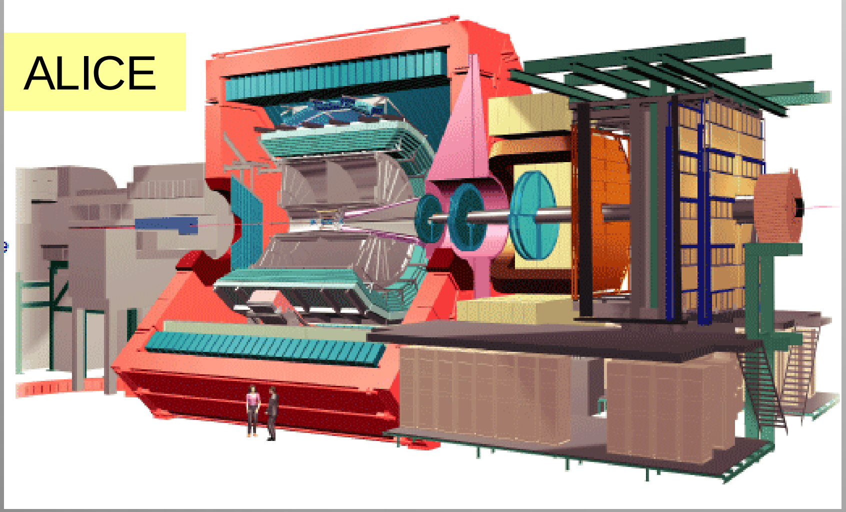


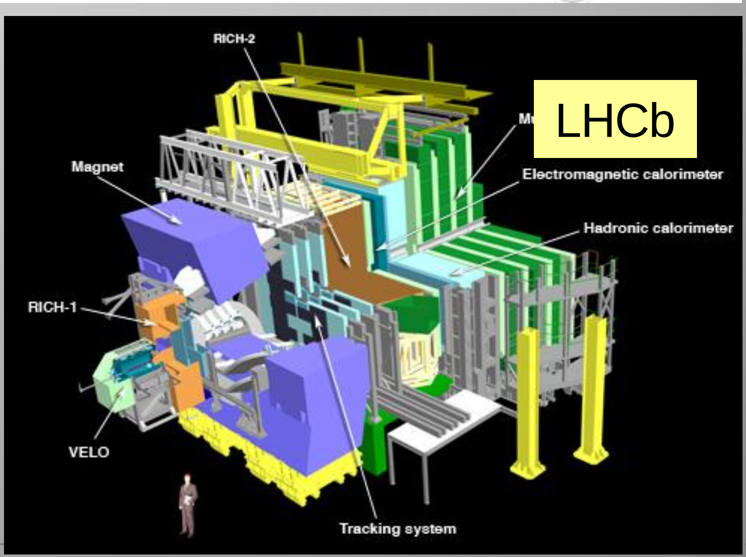
Experiments at the LHC

The Four Central Experiments







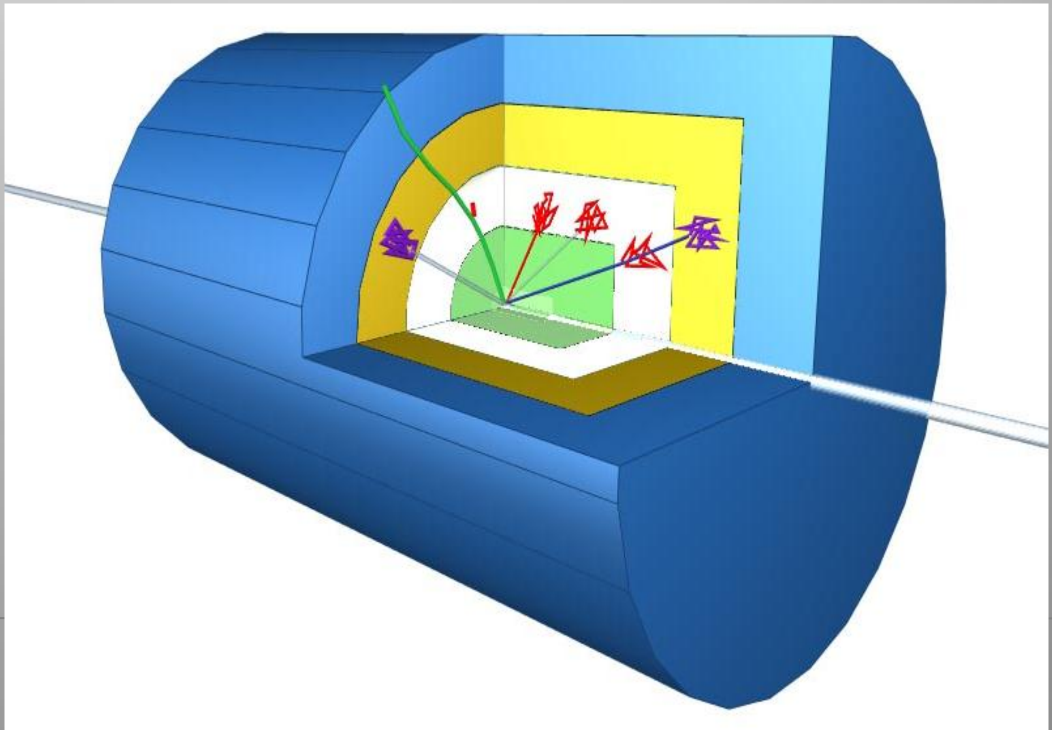


Schematic of a LHC Detector

Physics requirements drive the design!

Analogy with a cylindrical onion:

Technologically advanced detectors comprising many layers, each designed to perform a specific task.
Together these layers allow us to identify and precisely measure the energies and directions of all the particles produced in collisions.



Such an experiment has ~ 100 Million read-out channels!!

CMS Collaboration June 27, 2012

The CMS Collaboration: >3200 scientists and engineers, >800 students from ~190 Institutions in 41 countries .

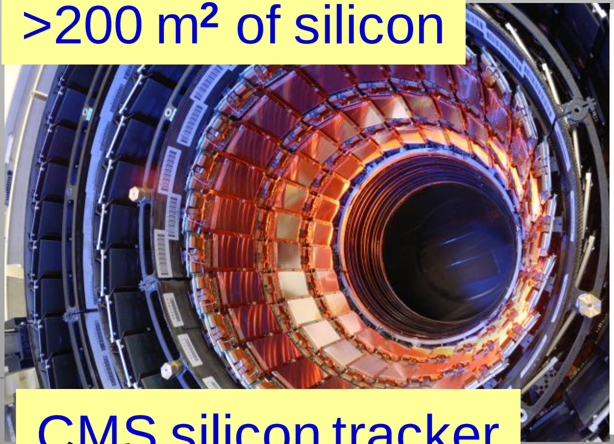
About 1/5th of the collaboration

Latest accepted member: Thailand
Accepted on 29/6/2012

The LHC Detectors are Major Challenges

- CMS/ATLAS detectors have about 100 million read-out channels
- Collisions in the detectors happen every 25 nanoseconds
- ATLAS/CMS uses over 3000 km of cables in the experiment
- The data volume recorded at the front-end in CMS is 1 TB/second which is equivalent to the world wide communication network traffic
- Data recorded during the 10-20 years of LHC life will be about all the words spoken by mankind since its appearance on earth
- A worry for the detectors: the kinetic energy of the beam is that of a small aircraft carrier of 10^4 tons going 20 miles/ hour

ATLAS pixel detector



>200 m² of silicon

CMS silicon tracker

Object	Weight (tons)
Boeing 747 [fully loaded]	200
Endeavor space shuttle	368
ATLAS	7,000
Eiffel Tower	7,300
USS John McCain	8,300
CMS	12,500

Physics Results

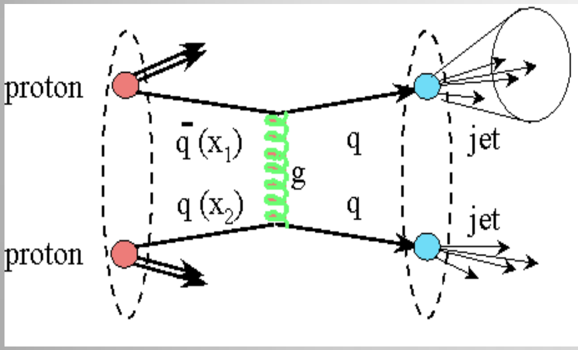
The Physics Program at LHC

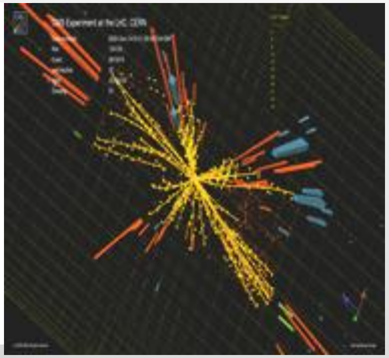
I will give a few examples[(*)] but we have now more than 100 results from LHC

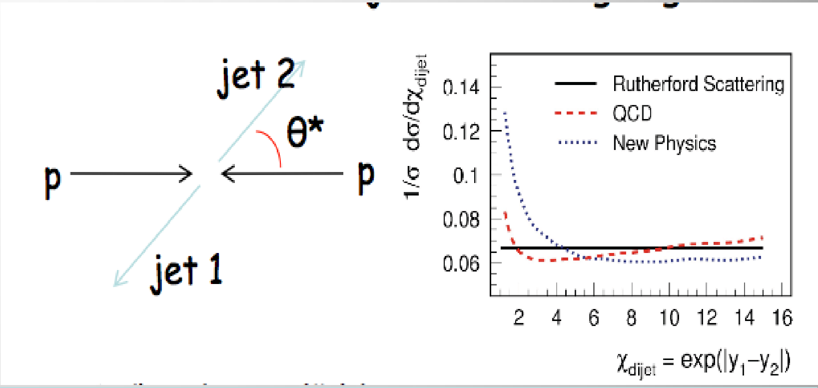
- **-Are quarks the elementary particles?**
- **-Do we see supersymmetric particles?**
- **-Do we see extra space dimensions?**
- **-Do we see micro-black holes?**
- **-The News on the Higgs Boson**

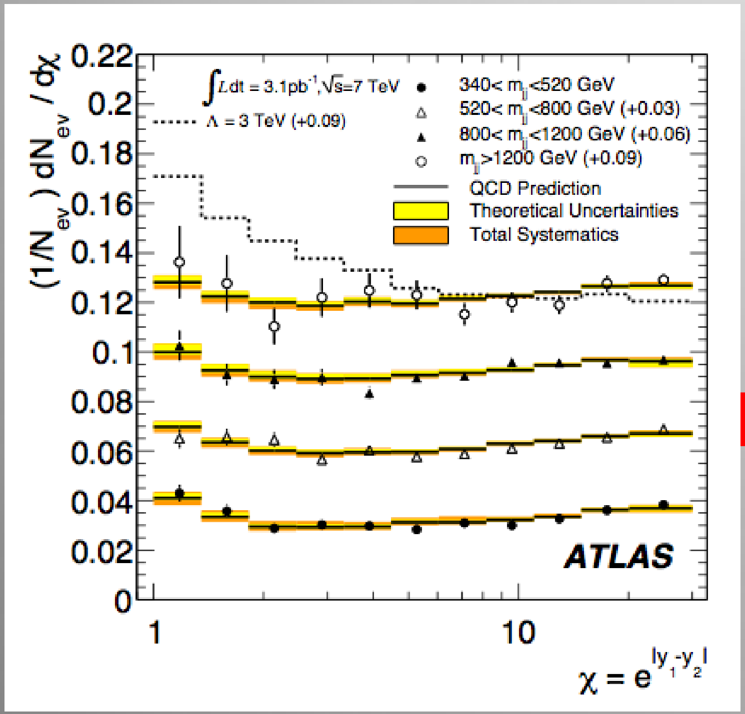
(*) Many papers on measurements of the electroweak and strong force not discussed here

Are Quarks Elementary Particles?

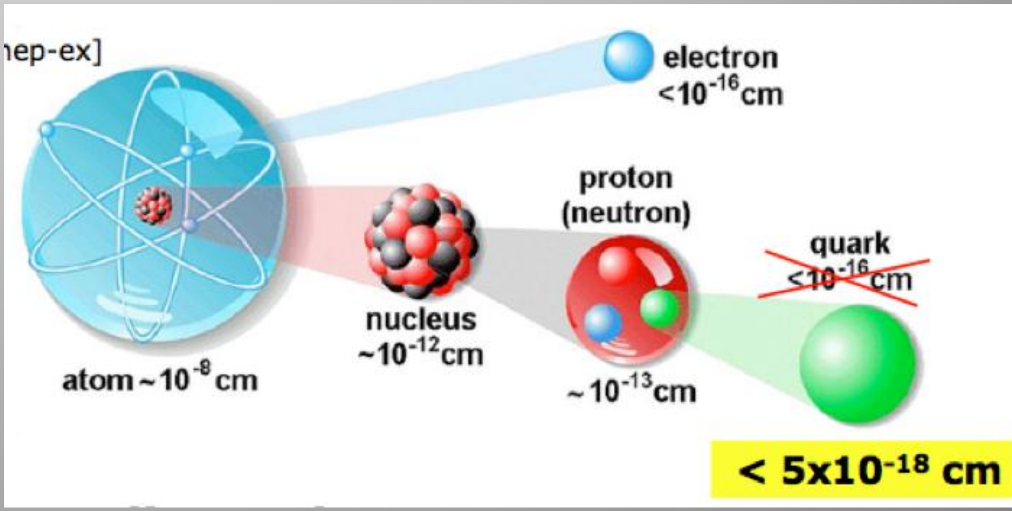






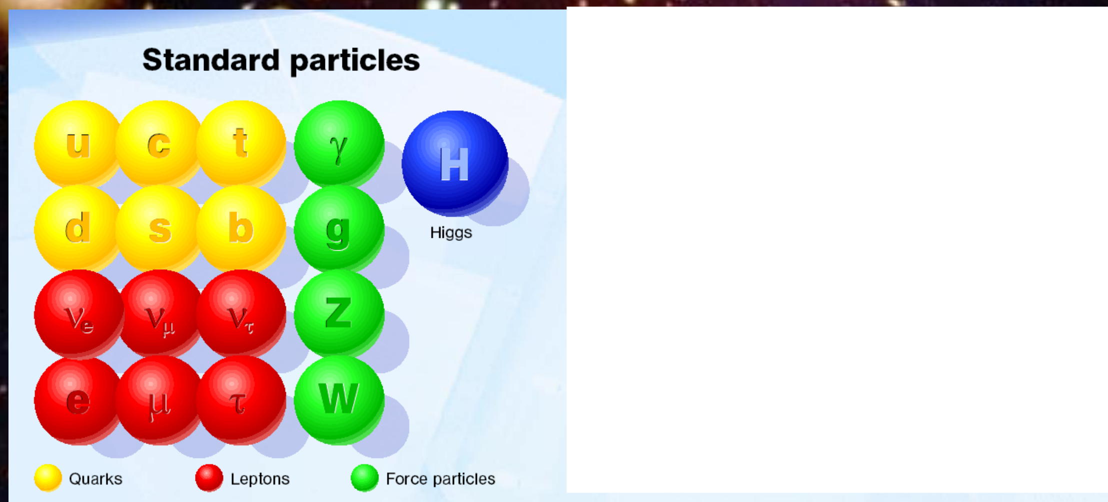


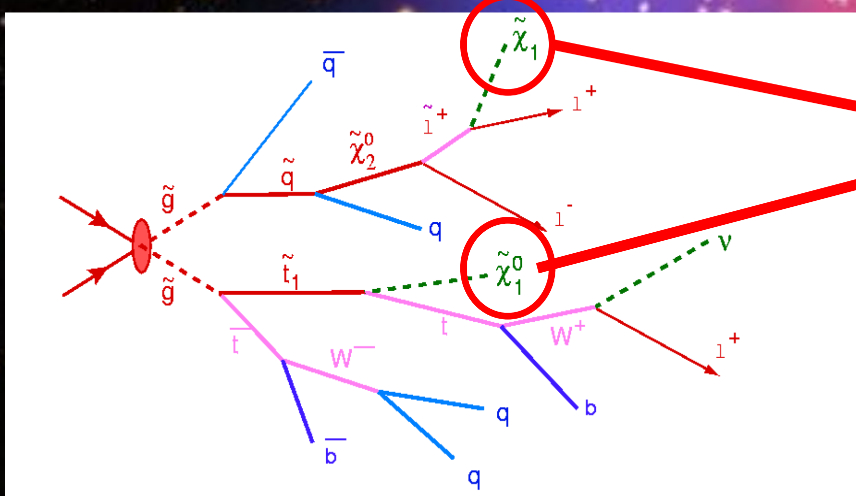
Measurement of the production angle of the jet with respect to the beam
-> High Energy Rutherford Experiment



Quarks remain elementary particles after these first results

Supersymmetry: a new symmetry in Nature?

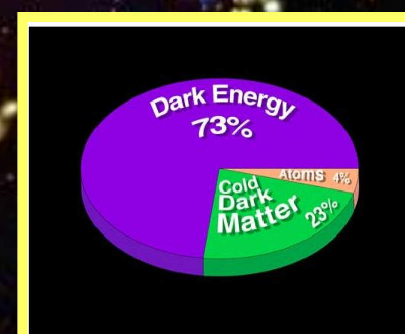




SUSY particle production at the LHC

Candidate particles for Dark Matter

⇒ Produce Dark Matter in the lab



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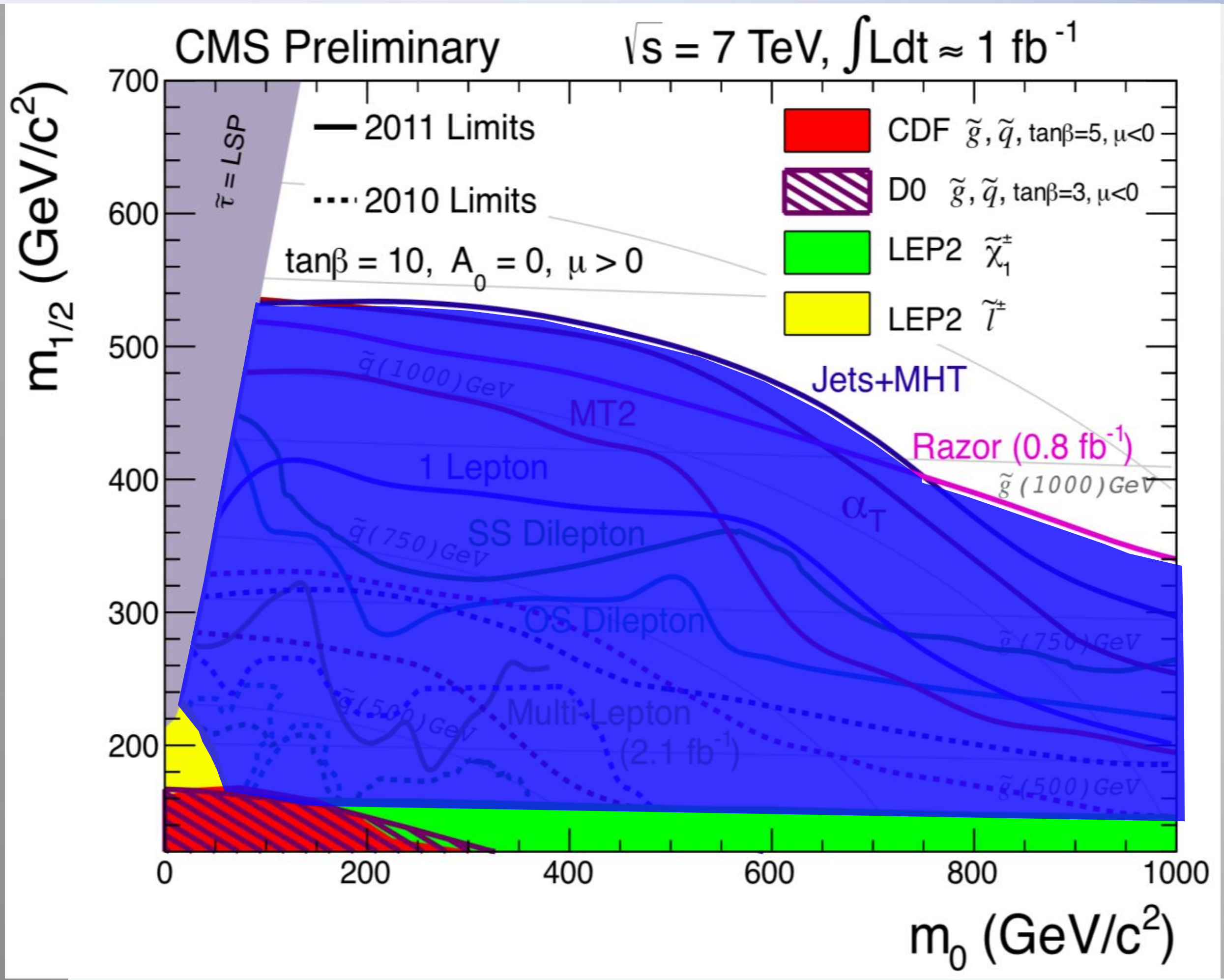
Do we see Supersymmetric Particles?



- So far NO clear signal of supersymmetric particles has been found
- We can exclude regions where the new particles could exist.
- Searches will continue for the next years

m_0 and $m_{1/2}$ are SUSY parameters

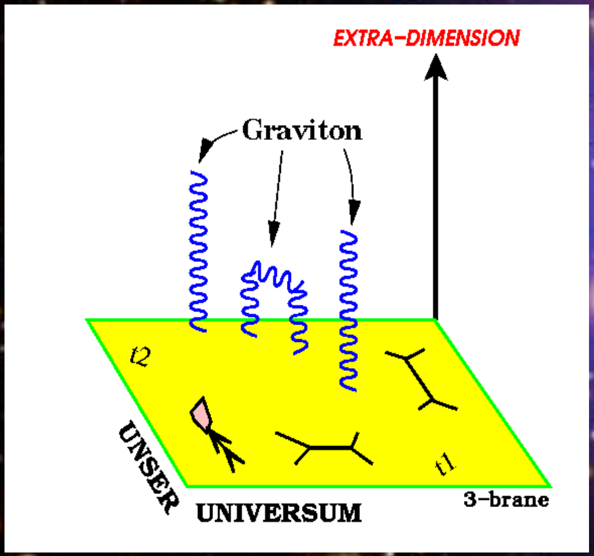
Masses of SUSY particles are larger than 1000 GeV!!!

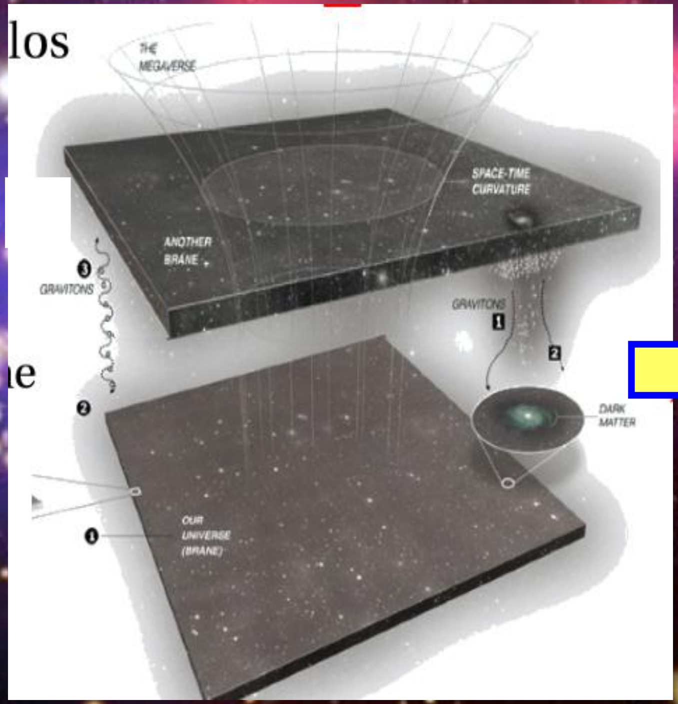
So these particles are heavier than 1000 times the proton

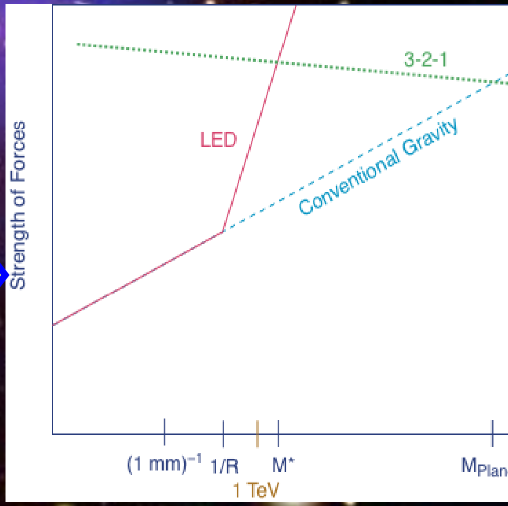
Explore other than the simplest/constrained SUSY models

Extra Space Dimensions

Problem: $m_{EW} = \frac{1}{(G_F \cdot \sqrt{2})^{\frac{1}{2}}} = 246\ \text{GeV}$ ⟷ $M_{Pl} = \frac{1}{\sqrt{G_N}} = 1.2 \cdot 10^{19}\ \text{GeV}$





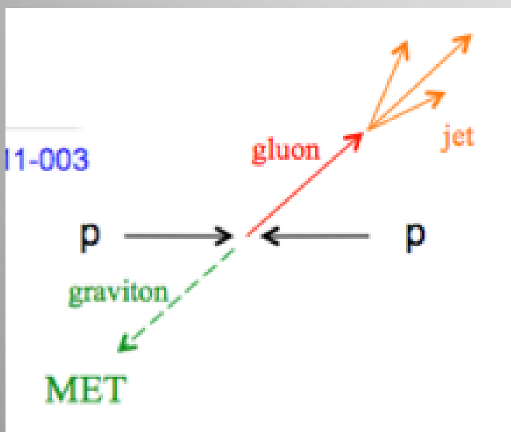


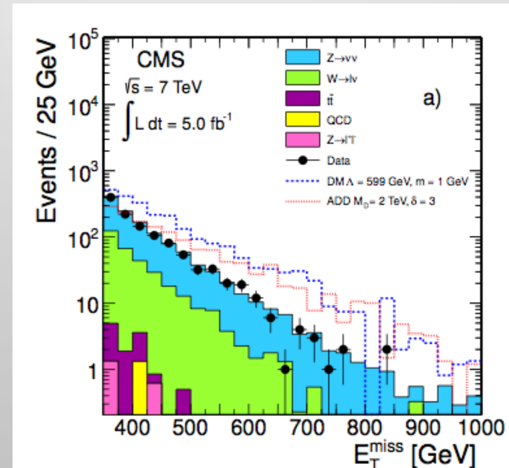
The Gravity force becomes strong!

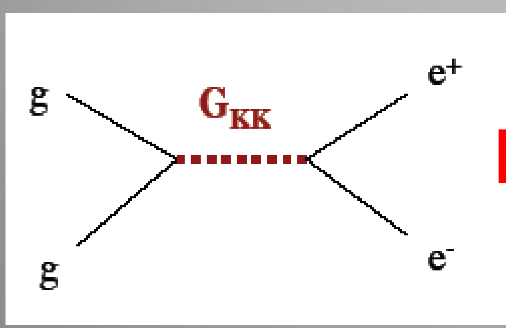
Extra Dimensions at the LHC

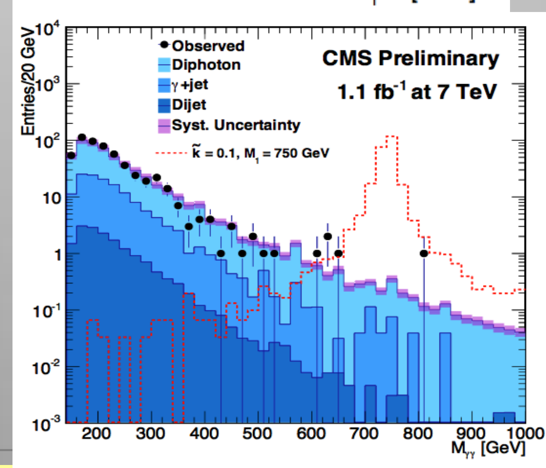
Main detection modes at the experiments

- Collisions with Large missing (transverse) energy
- Resonance production in two particle distributions







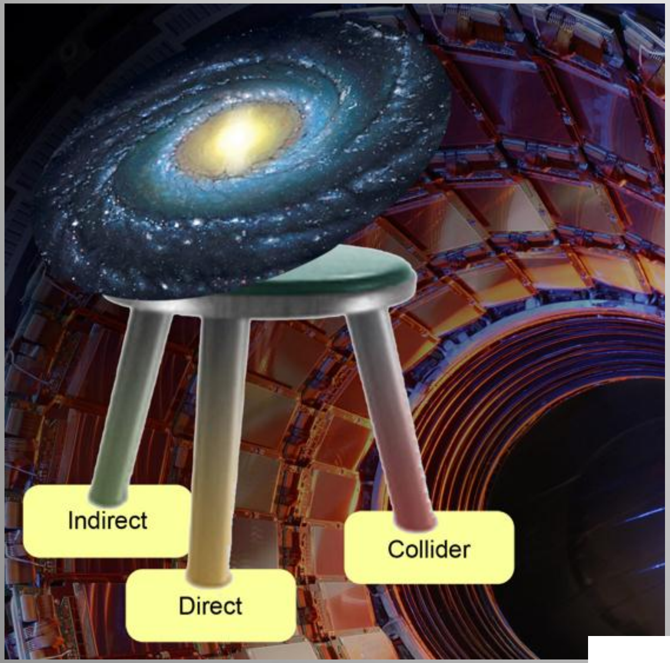


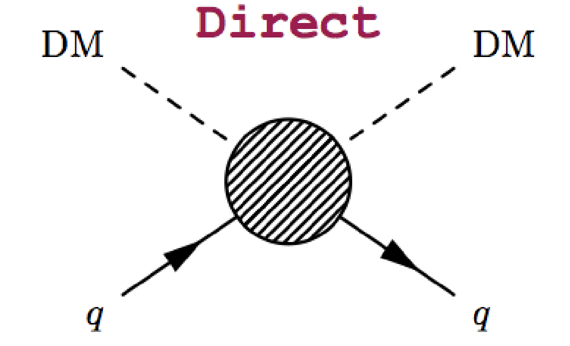
No signal yet
If extra dimensions exist then the Planck scale is larger than 2-3 TeV

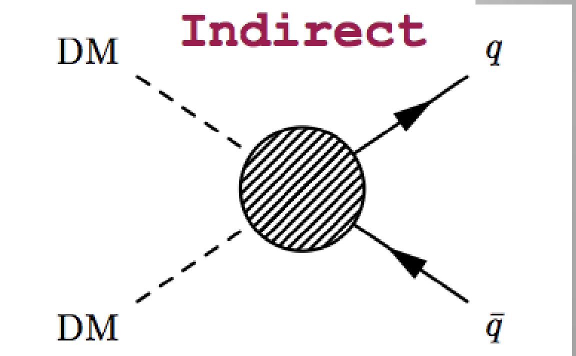
LHC can detect extra dimensions for scales up to 5 to 9 TeV

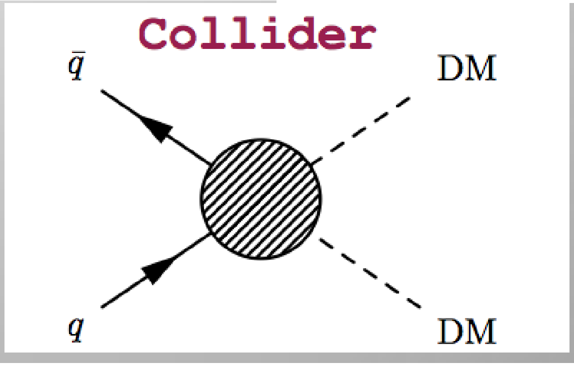
The Dark Matter Connection

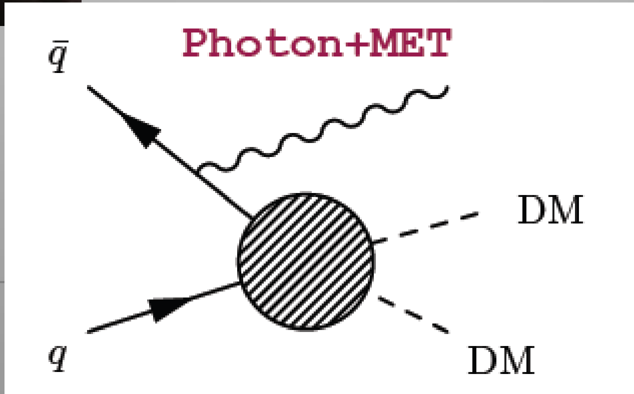
Searches for mono-jets and mono-photons can be used to search for Dark Matter (DM)

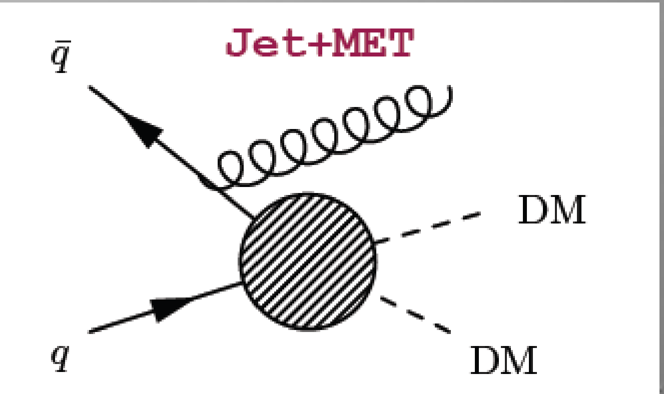






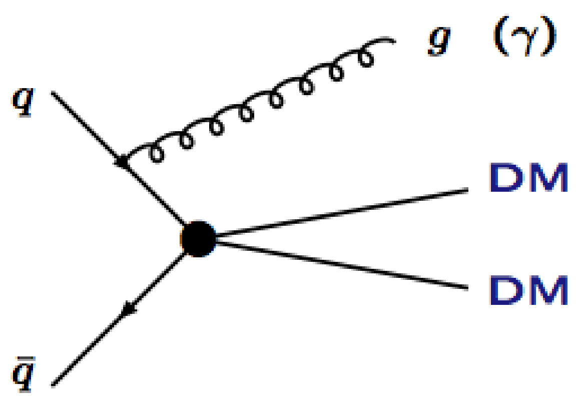


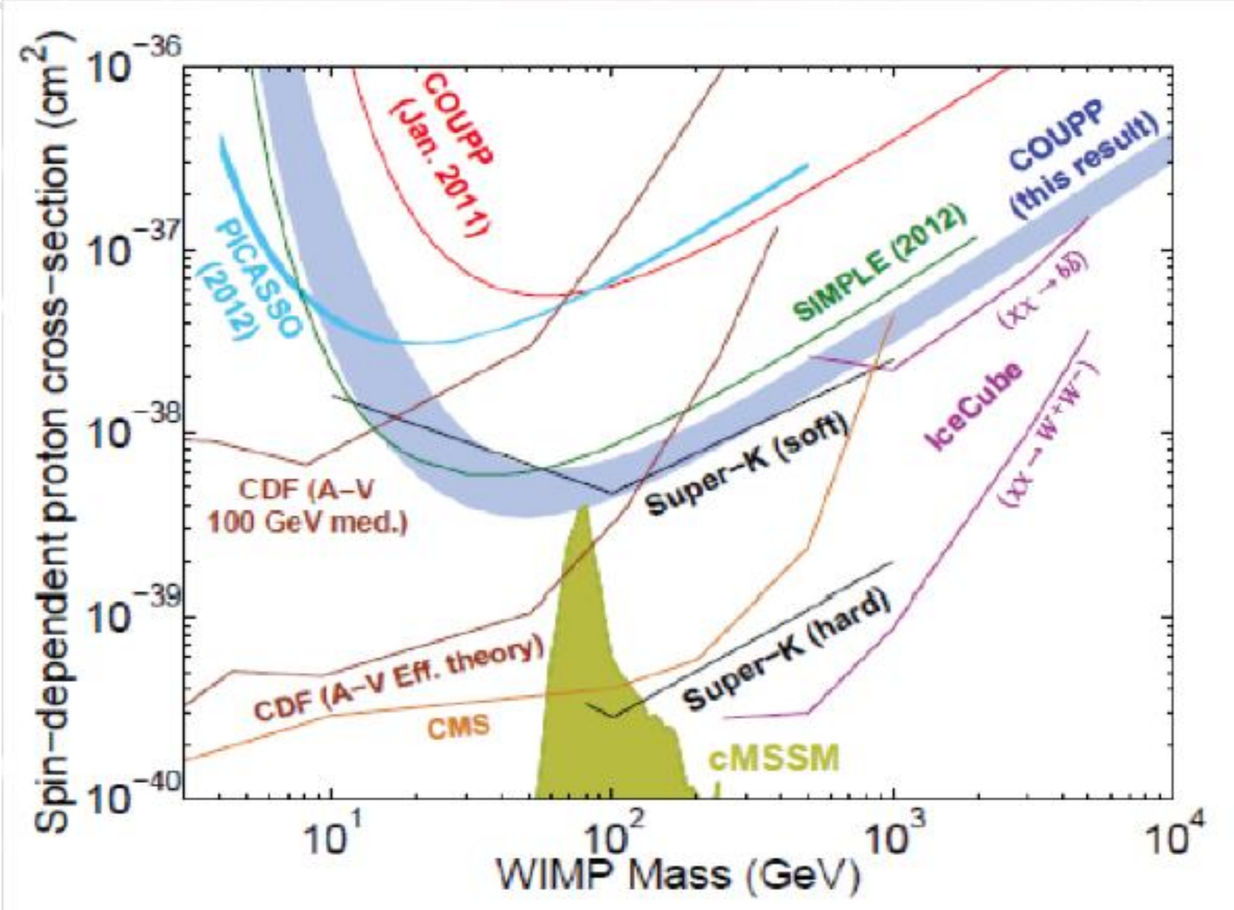




The Dark Matter Connection

Results for direct searches and collider searches for Dark Matter
-> Spin dependent and spin independent cross sections of Dark Matter with ordinary matter

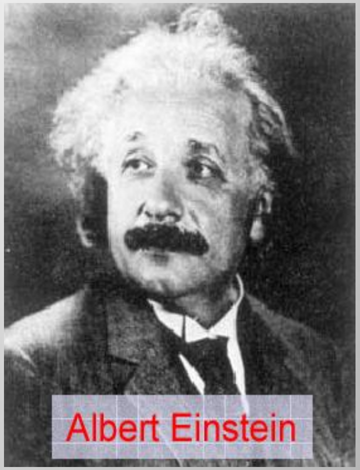




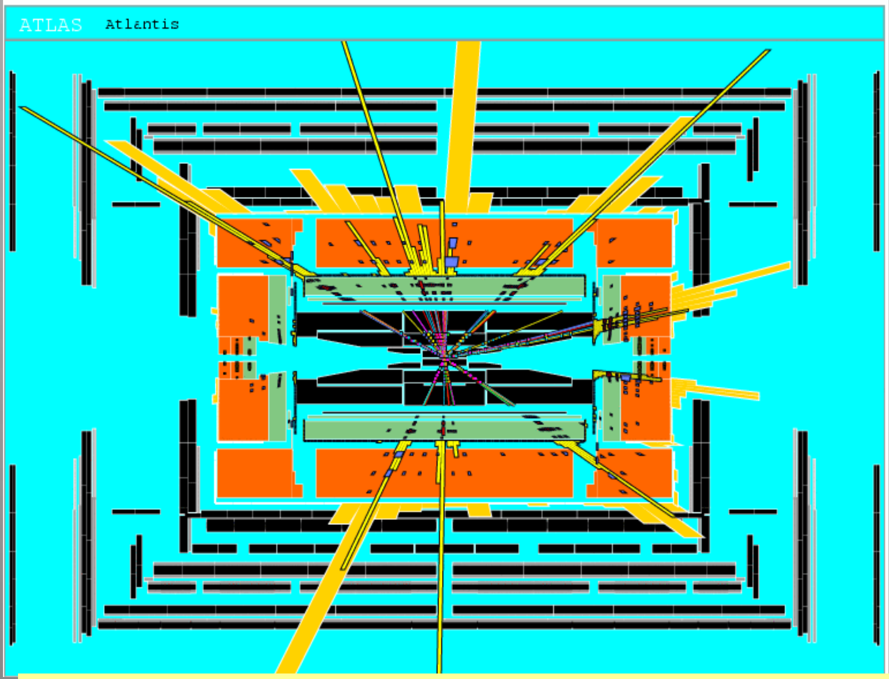
Collider searches are very competitive!!

Quantum Black Holes at the LHC?

Black Holes are a direct prediction of Einstein's general theory on relativity



If the Planck scale is in ~TeV region:
can expect Quantum Black Hole production

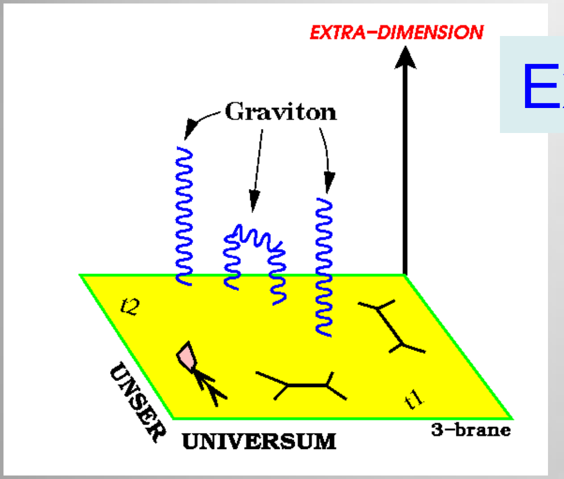


Simulation of a Quantum Black Hole event

Quantum Black Holes are harmless for the environment: they will decay within less than 10^{-27} seconds $\Rightarrow$ SAFE!

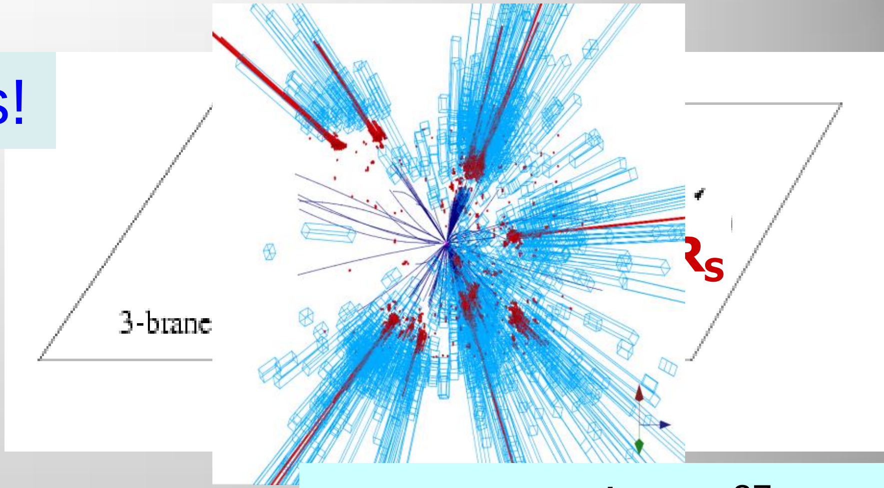
Quantum Black Holes open the exciting perspective to study Quantum Gravity in the lab!

Search for Micro-black Holes



Extra Dimensions!

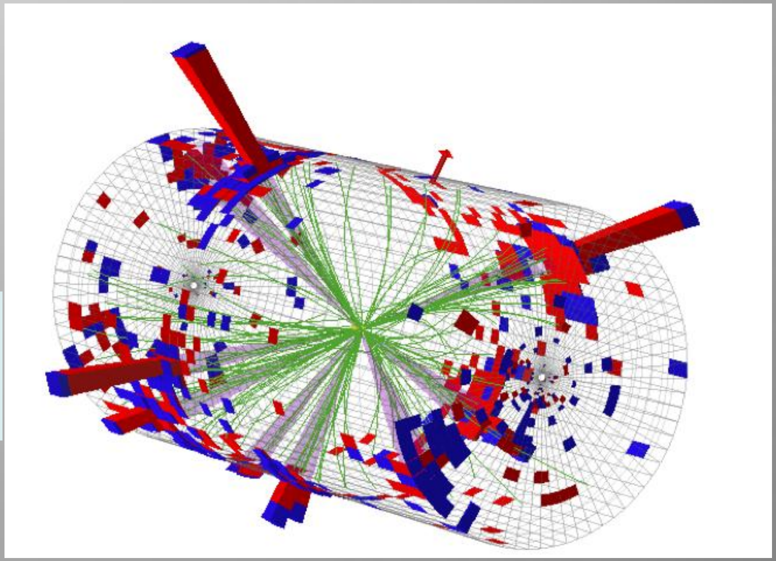
Planck scale a few TeV?



Evaporates in 10^{-27} sec

No evidence for micro black holes was found in the data so far

But some do see some interesting events
These could be background



Black holes with mass of up to 5 TeV are excluded (model dependent)


Black Holes
Hunters
at the LHC…

The Higgs Boson

The Washington Post
NATIONAL

.. A few months ago…

Physicists hope to find the Higgs boson, key to unified field theory, this year

Fabrice Coffrini/Agence France-Presse via Getty Images - A superconducting solenoid magnet, the largest of its kind, is part of the Large Hadron Collider, which is searching for the Higgs boson.

Peter Higgs

Predicted a new kind of particle in 1964, ie 48 years ago

What makes this such a special Particle?

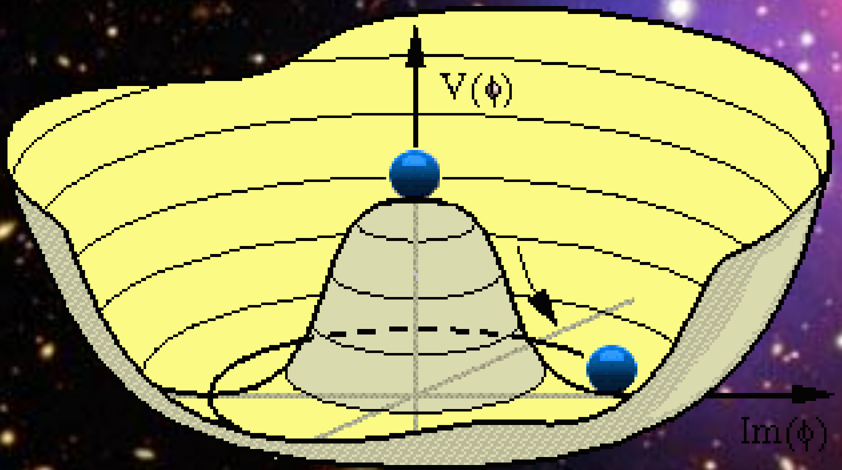
The Hunt for the Higgs

Where do the masses of elementary particles come from?

The key question: Where is the Higgs?

Massless particles move at the speed of light -> no atom formation!!

We do not know the mass of the Higgs Boson



Scalar field with at least one scalar particle

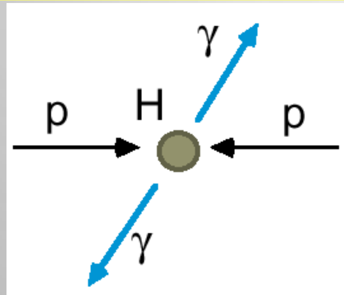
It could be anywhere from 114 to 700 GeV

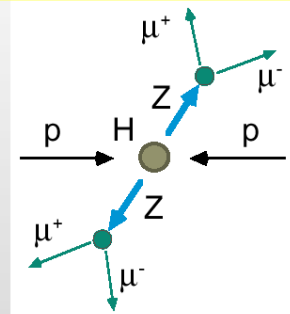
Higgs Boson Searches

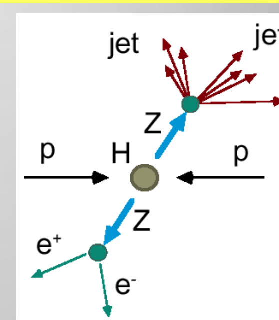
Low M_H < 140 GeV/c²

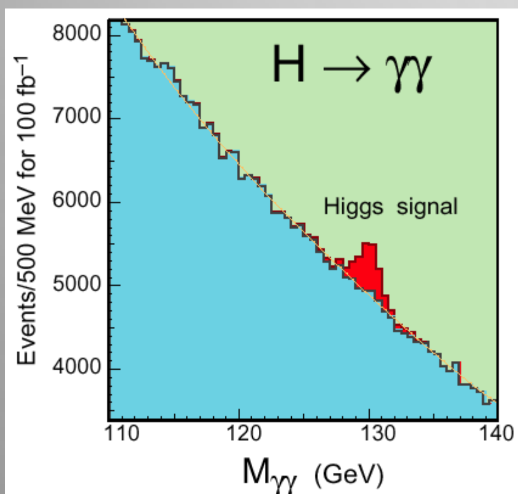
Medium 130<M_H<500 GeV/c²

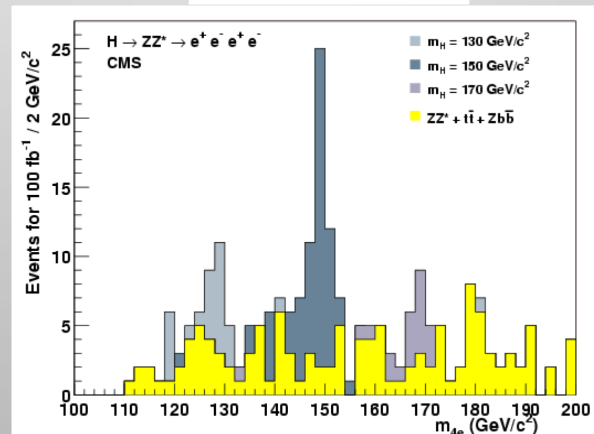
High M_H > ~500 GeV/c²

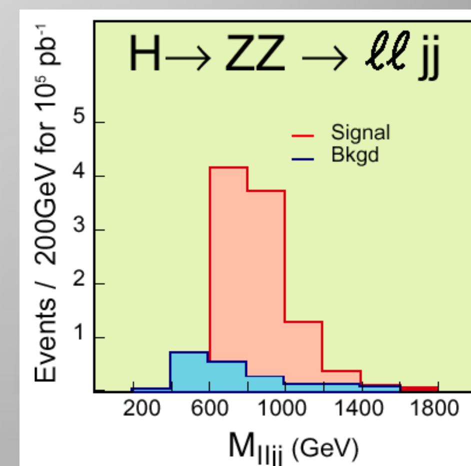


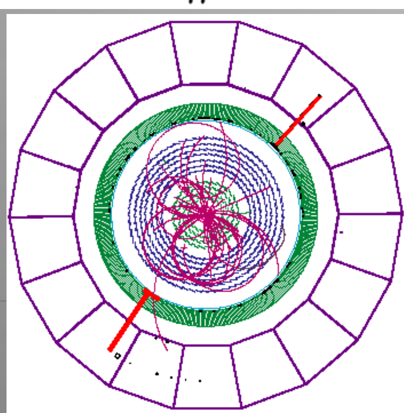


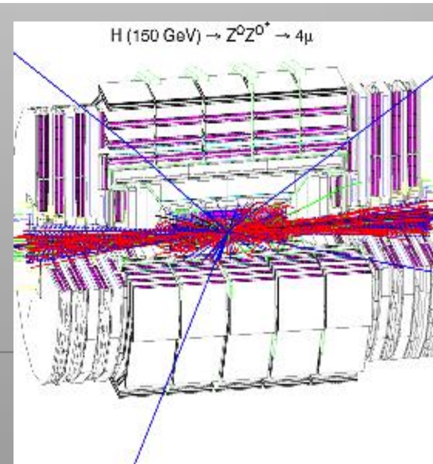


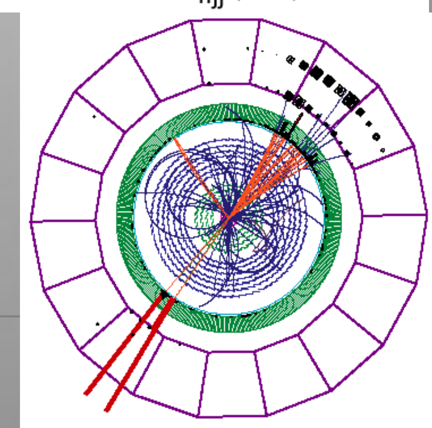












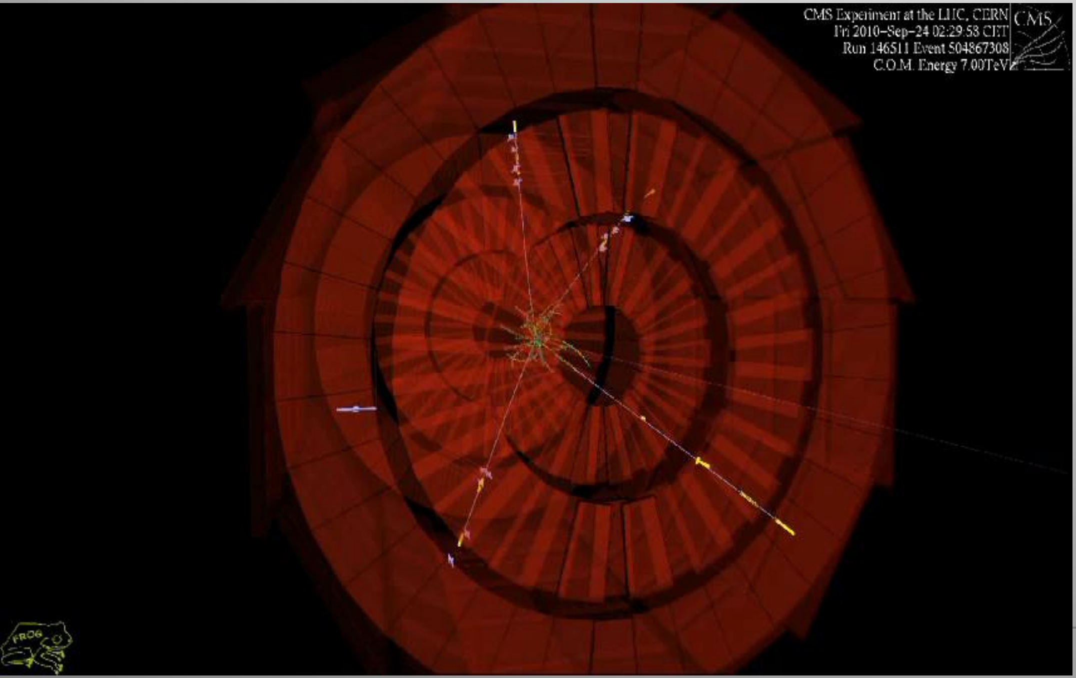
Searches for the Higgs Particle

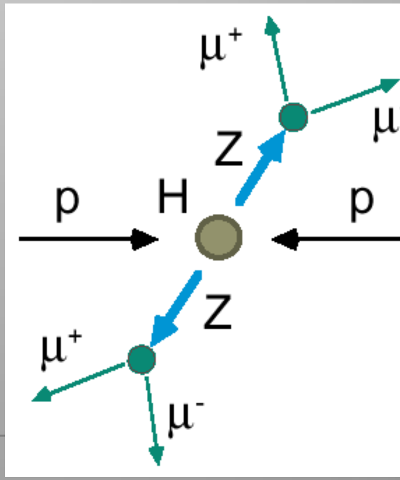
A Higgs particle will decay immediately, eg in two heavy quarks or two heavy (W,Z) bosons

Example: Higgs(?) decays into ZZ and each Z boson decays into μμ

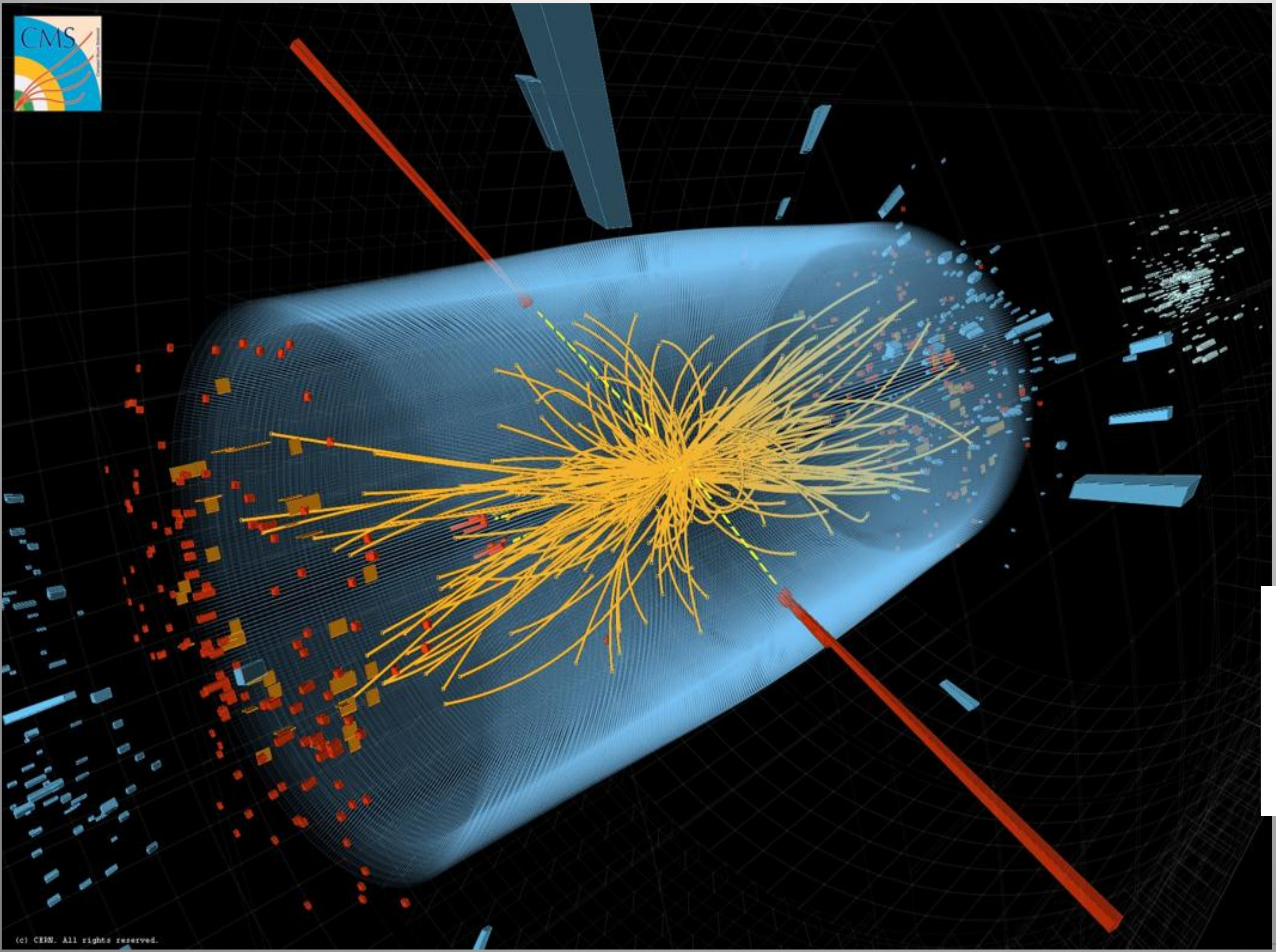
So we look for 4 muons in the detector

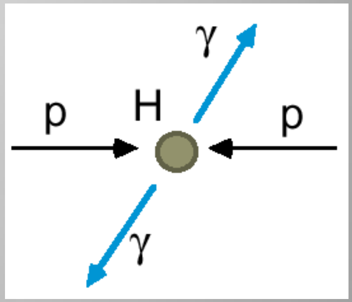
But two Z bosons can also be produced in LHC collisions, without involving a Higgs!
We cannot say for on event by event (we can use the total invariant mass of the 4 muons)





A Collision with two Photons





A Higgs or
a ‘background’
process without
a Higgs?

July 4th 2012

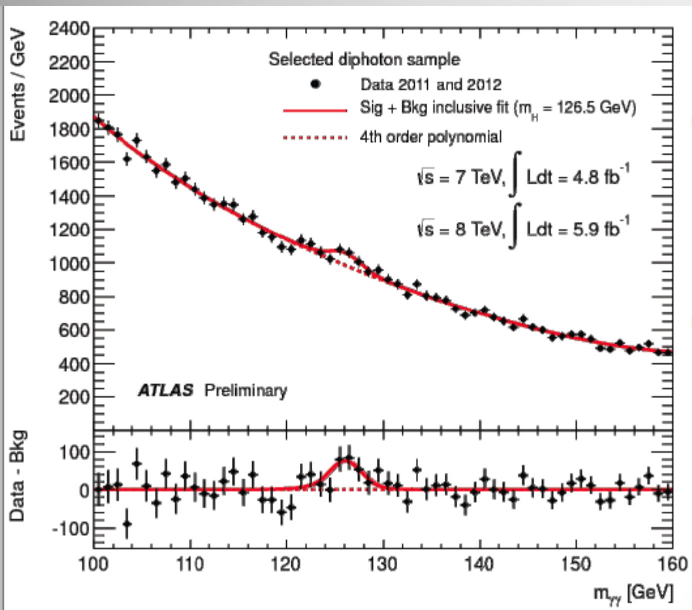
- Official announcement of the discovery of a Higgs-like particle with mass of 125-126 GeV by CMS and ATLAS.
- Historic seminar at CERN with simultaneous transmission and live link at the large particle physics conference of 2012 in Melbourne, Australia

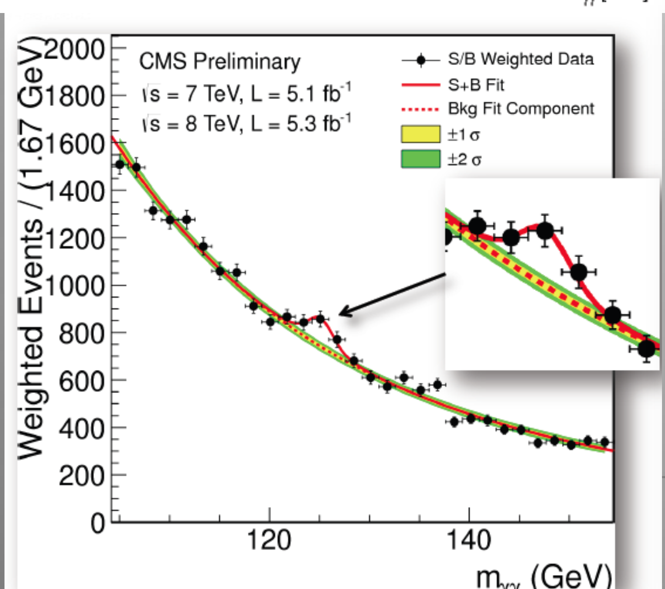
CERN

Melbourne

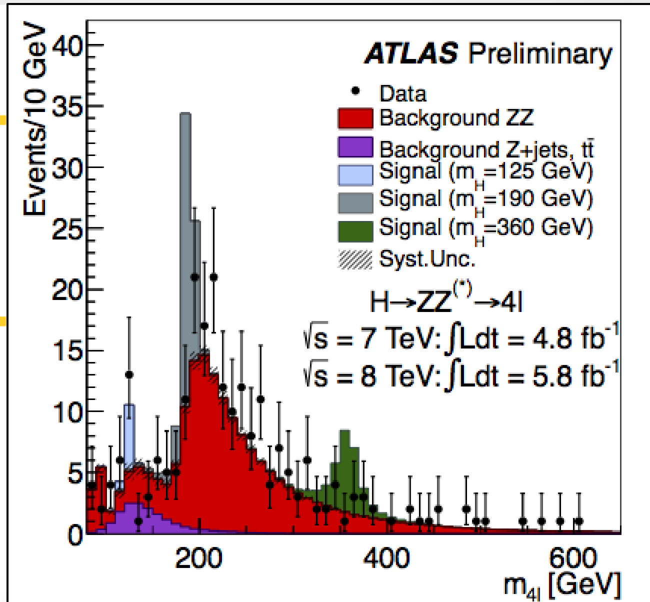
Results from the Experiments

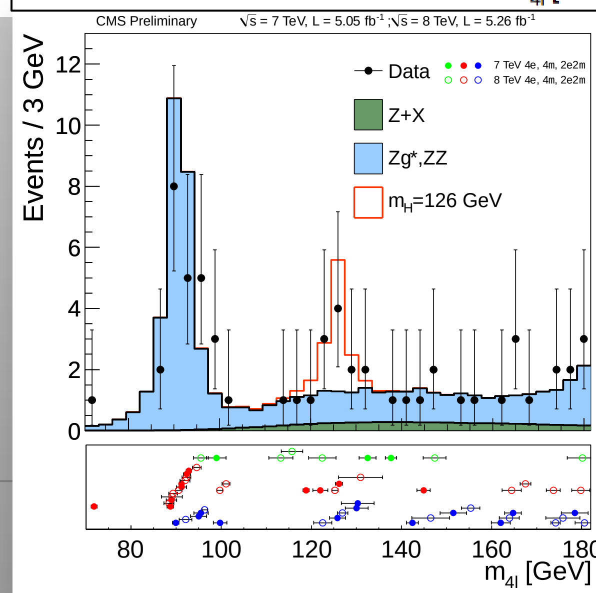
Higgs → 2 photons!!





Higgs → 2 Z →4 leptons!!





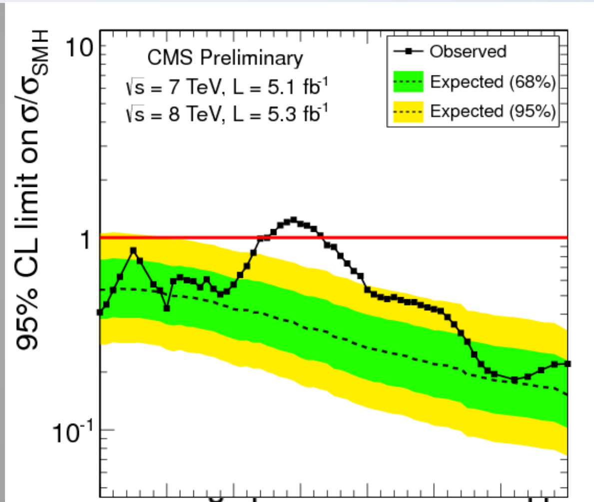
A clear "excess" of events seen in both experiments around 125-126 GeV

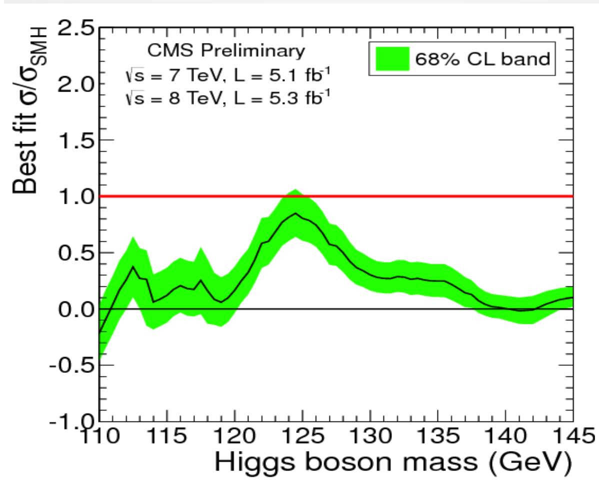
It became very significant in 2012

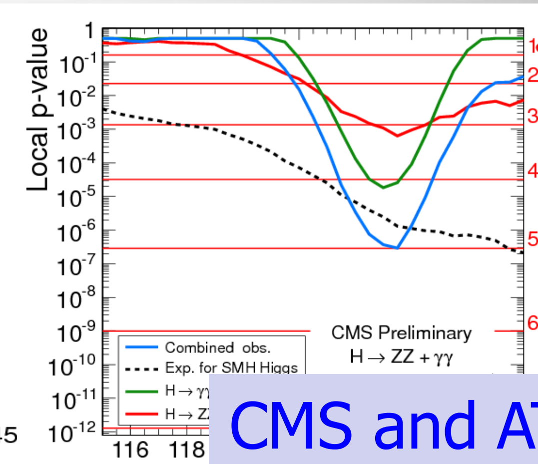
Sophisticated Statistical Methods have used to fully analyse this.

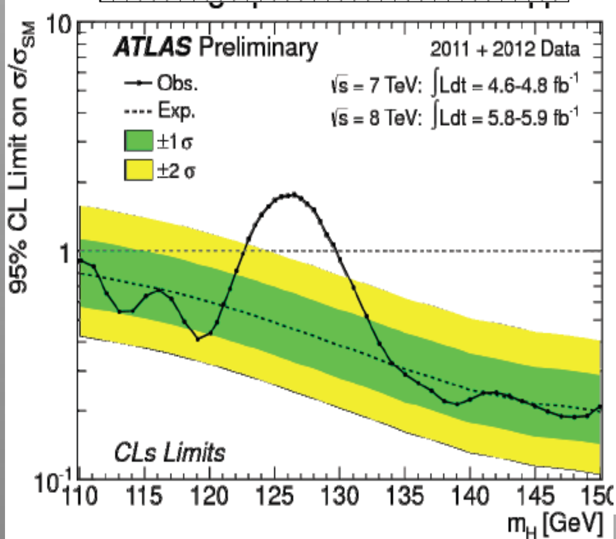
And the result is…→

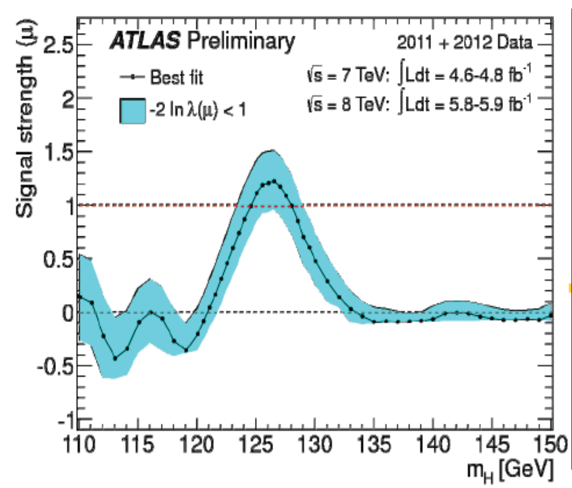
Results from the Experiments

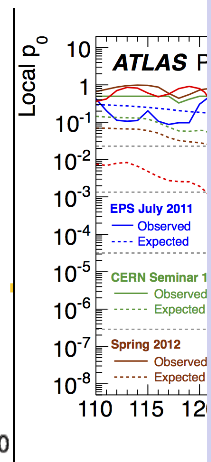












CMS and ATLAS observe a new boson with a significance of about 5 sigma

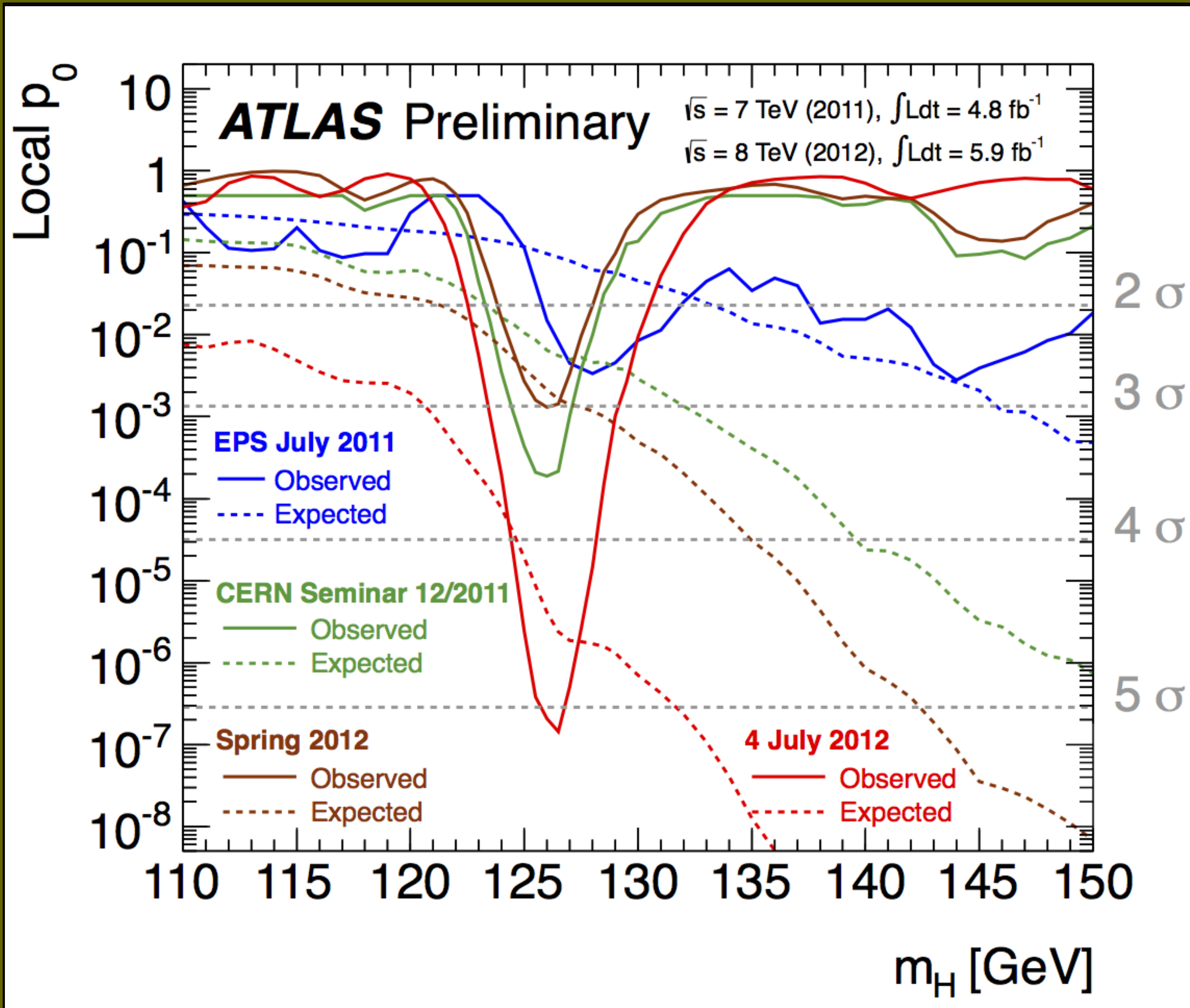
The particle is consistent with a Higgs-like boson

Results

We see an excess of 5 standard deviations (5σ) at 125-126 GeV

-> The observation (Discovery) of a new particle!!!

Evolution of the excess with time



Energy-scale systematics not included

The Press…

The discovery of the Higgs made the headlines worldwide

Hawking lost $100 bet over Higgs boson

What Comes After Higgs Boson?

The Atlantic Wire what matters now

'God Particle' 'Discovered': European Researchers Claim Discovery of Higgs Boson-Like Particle

HOW THE HIGGS COULD BECOME ANNOYING

Yes, the discovery of the Higgs boson is thrilling and game-changing. But it could also introduce some aggravating situations.

Хиггс увидит бозон

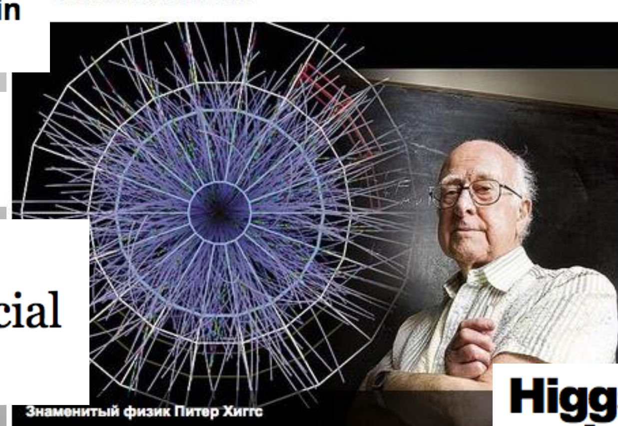
В CERN открыли бозон Хиггса

Текст

— 3.07.12 15:13 —

ТЕКСТ: АЛЕКСАНДРА БОРИСОВА

SCIENCEUNSEEN.COM



Discovery of Higgs Boson Bittersweet News in Texas

Scientists Set The Higgs Boson To Music

3 Ways the Higgs Boson Discovery Will Impact Financial Services

Higgs boson researchers consider move to Cloud computing

"Within another decade the Cloud will be where grid computing is now"

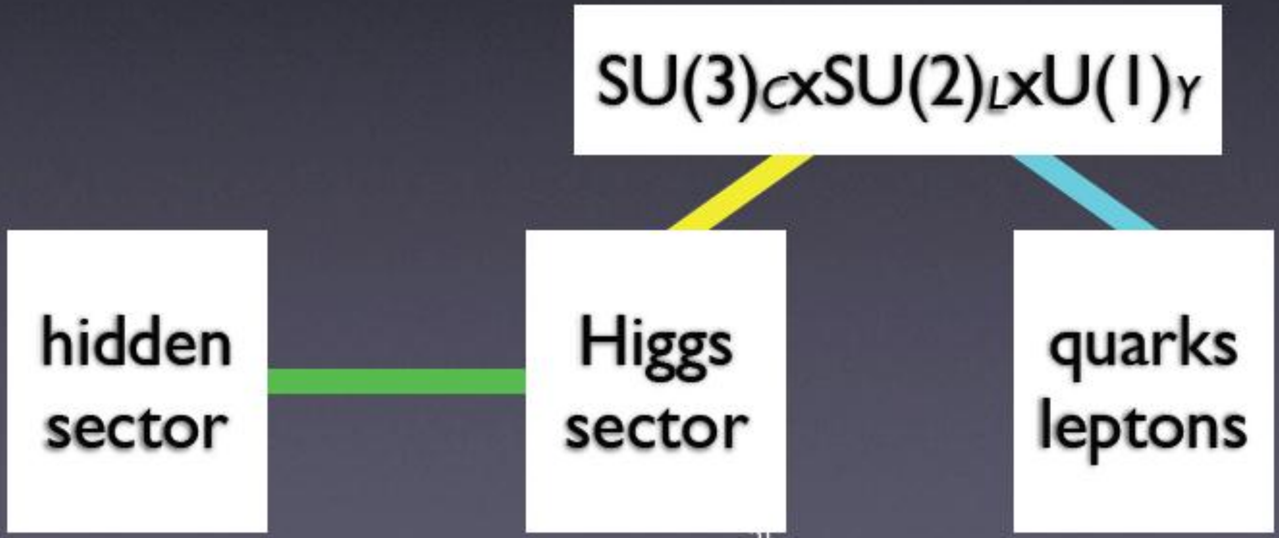
Higgs boson discovery could make science fiction a reality

Discovery of the 'God particle' could make science fiction a reality, and answer one of the most basic questions of our universe: How did light become matter — and us?

The Future…

Higgs as a portal

- having discovered the Higgs?
- Higgs boson may connect the Standard Model to other "sectors"



Discovery of a new Particle at 125 GeV

- CMS (and ATLAS) discovered a brand new heavy particle with a mass of about 125 (126) GeV
- The production rate of the new particle is consistent with that expected for a Higgs-like boson
- It will tell us how elementary particles got there mass and why we are here.
- It may tell us much more, eg what is the physics beyond to the Standard Model.
- This new particle will be important for the future of High Energy Physics!

Quo Vadis: where do we go next?

Now we need more data to study this new particle

-Spin and CP studies?

-Couplings: measure as many production/decay channels?

-Deviations from Standard Model? Composite?

Look also for "non-standard" decays?

-Is it alone or accompanied?

Will it shows us that there is physics beyond the Standar Model?

We have now analysed 10 fb^{-1} of data

Another 10-20 fb^{-1} at 8 TeV will help (by end of 2012)!!

Then we will have 300 fb^{-1} with LHC by end of 2020

Future possible new colliders have a new target: a brand New Particle to study. Maybe the LHC will discover more…


beyond LHC ?

Future Options

- Luminosity and Energy upgrade scenario for the LHC machine and other projects
  - High Luminosity LHC: HL-LHC
  - Higher Energy LHC: HE-LHC
  - Electron–proton LHC: LHeC
  - Special Higgs Factories ("LEP3")
  - Linear e+e- Collider
  - B- physics factories (super-B)
  - Neutrino factories?
  - Muon Colliders?

Right now there are "strategy" meetings in all world regions
Eg: September 2012: The European strategy meeting in Krakow (Poland)

Clearly High Energy Physics has a bright and long future!!

The predictable future: LHC Time-line

2009 — Start of LHC

Run 1: 7 and 8 TeV centre of mass energy, luminosity ramping up to few 10^{33} cm^{-2} s^{-1}, few fb^{-1} delivered

2013/14 — LHC shut-down to prepare machine for design energy and nominal luminosity

Run 2: Ramp up luminosity to nominal (10³… 100 fb^{-1} Energy of the LHC 13-14 TeV

2018 — Injector and LHC Phase-I upgr…

Run 3: Ramp up l… …0 fb^{-1} / year accumu…

~2022 — Phase-I… …g magnets and CRAB cavities fo… …velling

Run 4: Co… 3000 fb^{-1}

2030 — Start Higher Energy LHC?

Study of the properties of the Higgs Boson
or
other ew symmetry breaking mechanism
and
Physics beyond the Standard Model

Physics Studies for the LHC upgrade

- Electroweak Physics
  - Production of multiple gauge bosons ($n_V \geq 3$)
    - triple and quartic gauge boson couplings
  - Top quarks/rare decays
- Higgs physics
  - Rare decay modes
  - Higgs couplings to fermions and bosons
  - Higgs self-couplings
  - Heavy Higgs bosons of the MSSM
- Supersymmetry
- Extra Dimensions
  - Direct graviton production in ADD models
  - Resonance production in Randall-Sundrum models TeV^{-1} scale models
  - Black Hole production
- Quark substructure
- Strongly-coupled vector boson system
  - $W_L Z_L g$ $W_L Z_L$, $Z_L Z_L$ scalar resonance, $W^+_L W^+_L$
- New Gauge Bosons

Examples studied in some detail

CERN-TH/2002-078
hep-ph/0204087
April 1, 2002

PHYSICS POTENTIAL AND EXPERIMENTAL CHALLENGES OF THE LHC LUMINOSITY UPGRADE

Conveners: F. Gianotti [1], M.L. Mangano [2], T. Virdee [1,3]
Contributors: S. Abdullin [4], G. Azuelos [5], A. Ball [1], D. Barberis [6], A. Belyaev [7], P. Bloch [1], M. Bosman [8], L. Casagrande [1], D. Cavalli [9], P. Chumney [10], S. Cittolin [1], S.Dasu [10], A. De Roeck [1], N. Ellis [1], P. Farthouat [1], D. Fournier [11], J.-B. Hansen [1], I. Hinchliffe [12], M. Hohlfeld [13], M. Huhtinen [1], K. Jakobs [13], C. Joram [1], F. Mazzucato [14], G.Mikenberg [15], A. Miagkov[16], M. Moretti[17], S. Moretti [2,18], T. Niinikoski [1], A. Nikitenko[3,†], A. Nisati [19], F. Paige[20], S. Palestini [1], C.G. Papadopoulos[21], F. Piccinini[2,‡], R. Pittau[22], G. Polesello [23], E. Richter-Was[24], P. Sharp [1], S.R. Slabospitsky[16], W.H. Smith [10], S. Stapnes [25], G. Tonelli [26], E. Tsesmelis [1], Z. Usubov[27,28], L. Vacavant [12], J. van der Bij[29], A. Watson [30], M. Wielers [31]

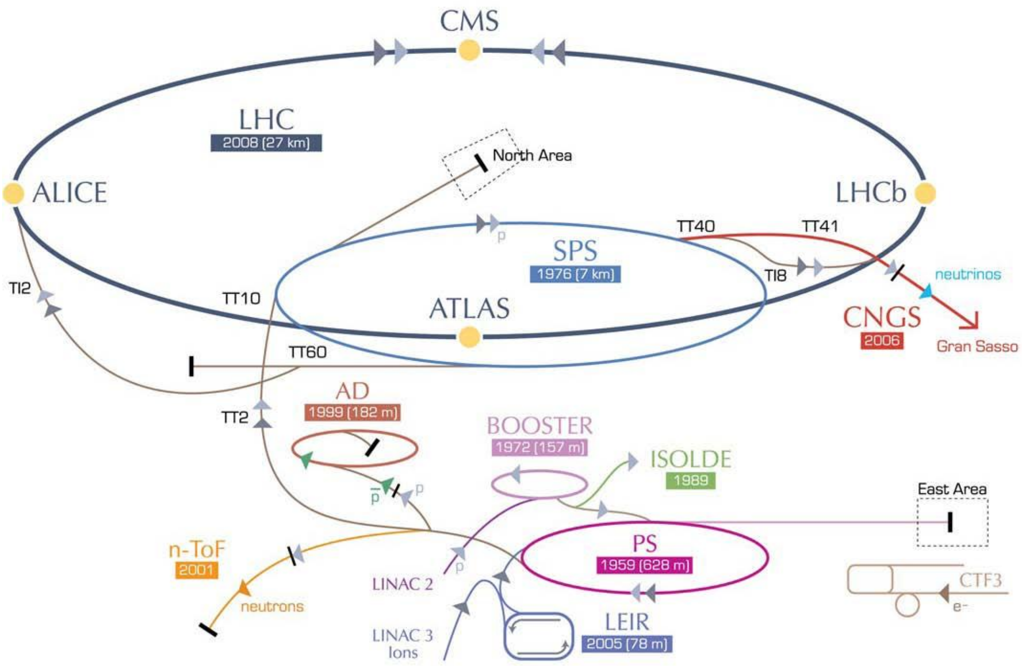
Include pile up, detector…

hep-ph/0204087

10 years already!!!

Long-Term Future: High-Energy LHC

- HE-LHC: The Energy Upgrade

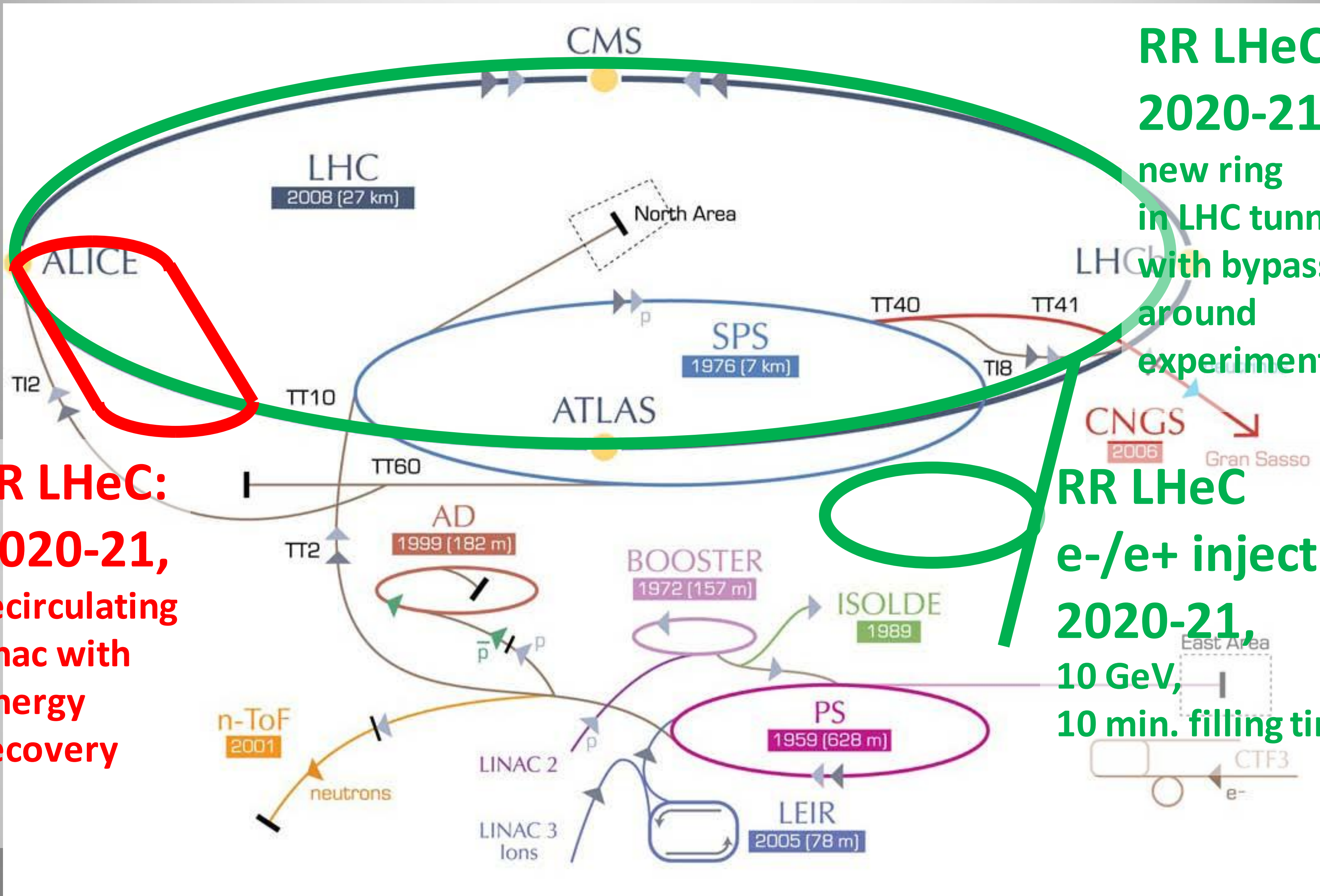


Energy upgrade of the LHC!?!

Collisons at 33 TeV center of mass energy?

- Replace all current LHC magnets with High-field 20T dipole magnets based on Nb_3Sn, Nb_3Al, and High Temperature Super conducters
- Fast cycling Super Conducting magnets for ~1.3 TeV injector (SPS)
- Main work is on research and development of the magnets right now
- A project for 2030 and afterwards (?)

A Hadron electron Collider?



RR LHeC: 2020-21, new ring in LHC tunnel, with bypasses around experiments

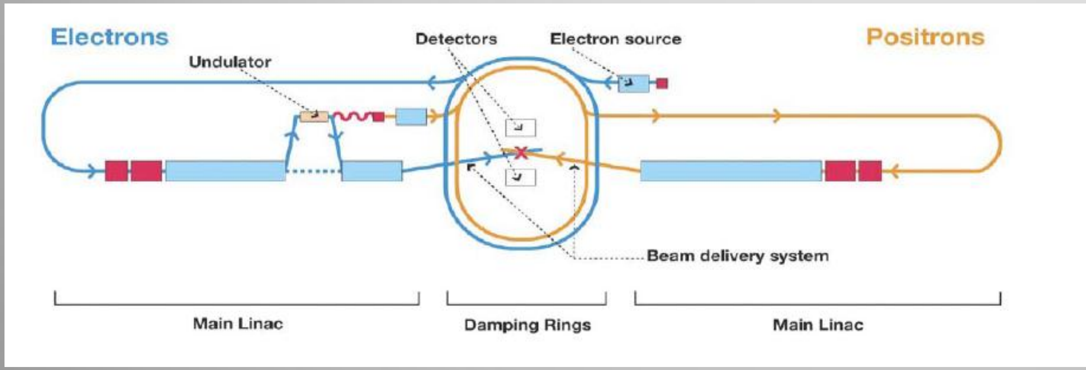
LR LHeC: 2020-21, recirculating linac with energy recovery

RR LHeC e-/e+ injector 2020-21, 10 GeV, 10 min. filling time

Next Accelerator: A Linear e+e- Collider?

Luminosity
~ 2•10^{34} cm^{-2}s^{-1}

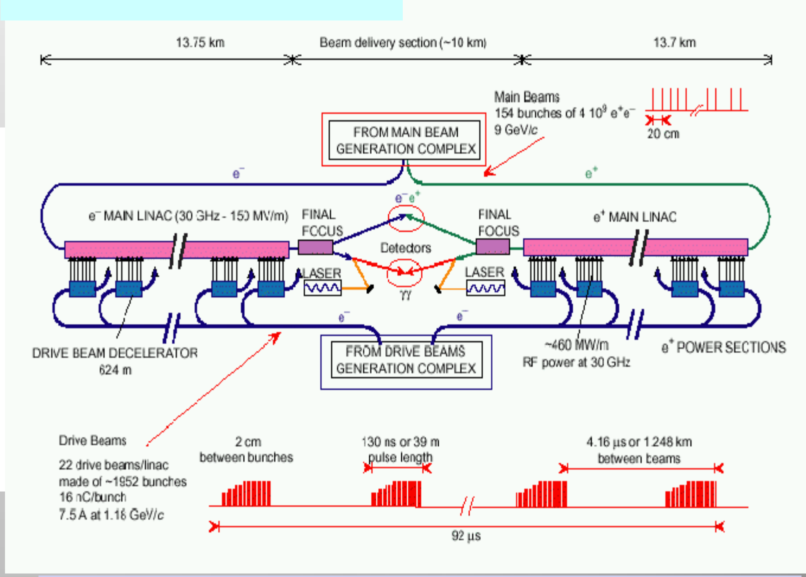
~31 km 500 GeV



TDR under preparation for 2013
Technology essentially ready

Luminosity
~6•10^{34} cm^{-2}s^{-1}

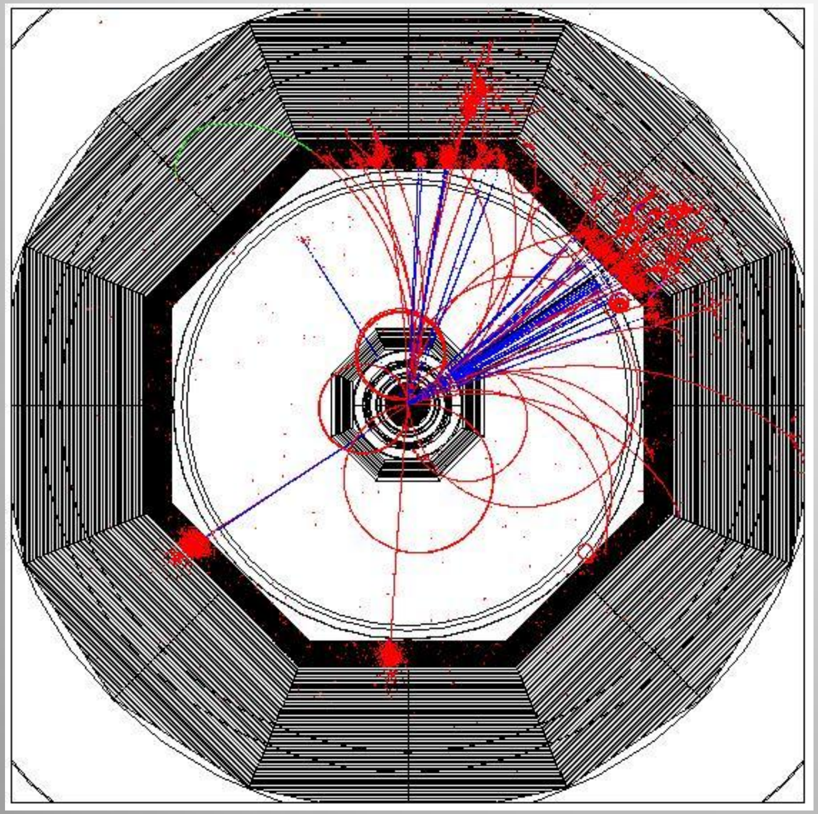
~40 km 3 TeV

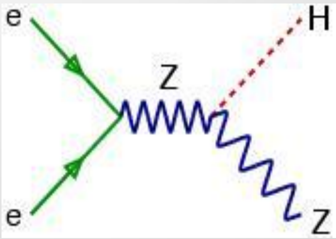


CDR completed (Feb 2012)
Technology still in R&D

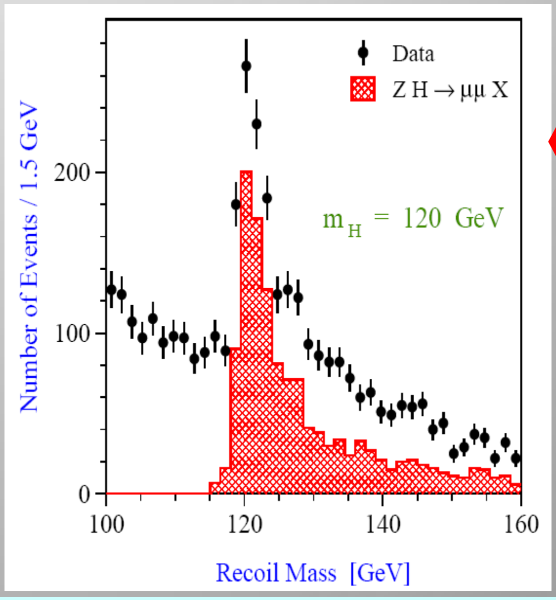
Discussion at the European Strategy Meeting September 2012 (Krakow)

Higgs studies at an e+e- linear Collider





Can detect the Higgs via the recoil to the Z



Fully simulated+reconstructed HZ event
Very clean compared to events at LHC

Precision measurements!

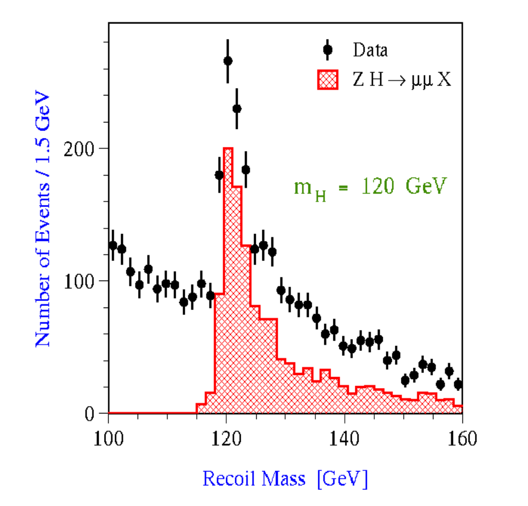
Observation of the Higgs independent of decay modes
Precise determination of couplings

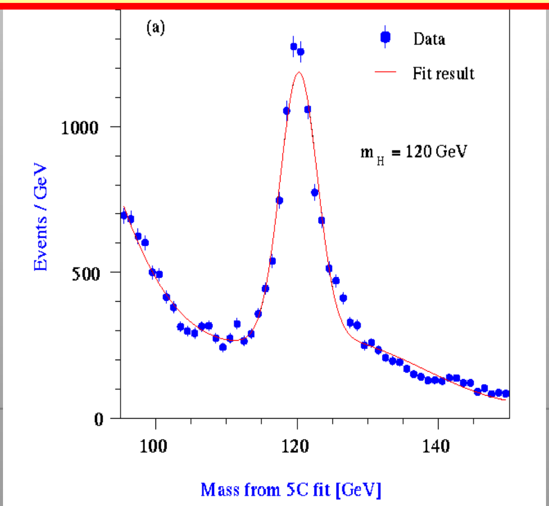
A LC is a Precision Instrument

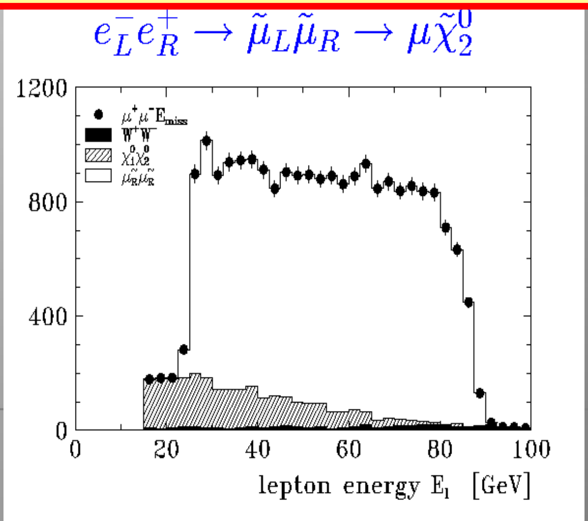
- Clean e+e- (polarized intial state, controllable $\sqrt{s}$ for hard scattering)
- Detailed study of the properties of Higgs particles

  mass to 0.03%, couplings to 1-3%, spin & CP structure, total width (6%) factor 2-5 better than LHC/measure couplings in model indep. way
- Precision measurements of SUSY particles properties, i.e. slepton masses to better than 1%, if within reach
- Precision measurements a la LEP (TGC's, Top and W mass)
- Large indirect sensitivity to new phenomena (eg $W_L W_L$ scattering)

LC could play an important role to disentangle the underlying new theory







Future Collider Proposals

Ellis, Gianotti, ADR
hep-ex/0112004+ few updates

Units are TeV (except $W_L W_L$ reach)
$\int$Ldt correspond to 1 year of running at nominal luminosity for 1 experiment

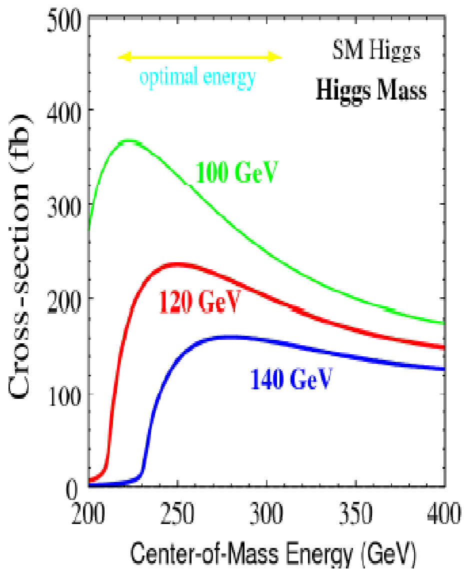
PROCESS	LHC 14 TeV 100 fb^{-1}	HL-LHC 14 TeV 1000 fb^{-1}	HE-LHC 28 TeV 100 fb^{-1}	VLHC 40 TeV 100 fb^{-1}	VLHC 200 TeV 100 fb^{-1}	ILC 0.8 TeV 500 fb^{-1}	CLIC 5 TeV 1000 fb^{-1}
Squarks	2.5	3	4	5	20	0.4	2.5
$W_L W_L$	2σ	4σ	4.5σ	7σ	18σ	6σ	90σ
Z'	5	6	8	11	35	8†	30†
Extra-dim (δ=2)	9	12	15	25	65	5-8.5†	30-55†
q*	6.5	7.5	9.5	13	75	0.8	5
Λcompositeness	30	40	40	50	100	100	400
TGC (λ_γ)	0.0014	0.0006	0.0008		0.0003	0.0004	0.00008

† indirect reach
(from precision measurements)

Approximate mass reach machines:
$\sqrt{s}$ = 14 TeV, L=10^{34} (LHC) : up to ≈ 6.5 TeV
$\sqrt{s}$ = 14 TeV, L=10^{35} (HL-LHC): up to ≈ 8 TeV
$\sqrt{s}$ = 28 TeV, L=10^{34} : up to ≈ 10 TeV

Select your favorit machine!!

LEP3?

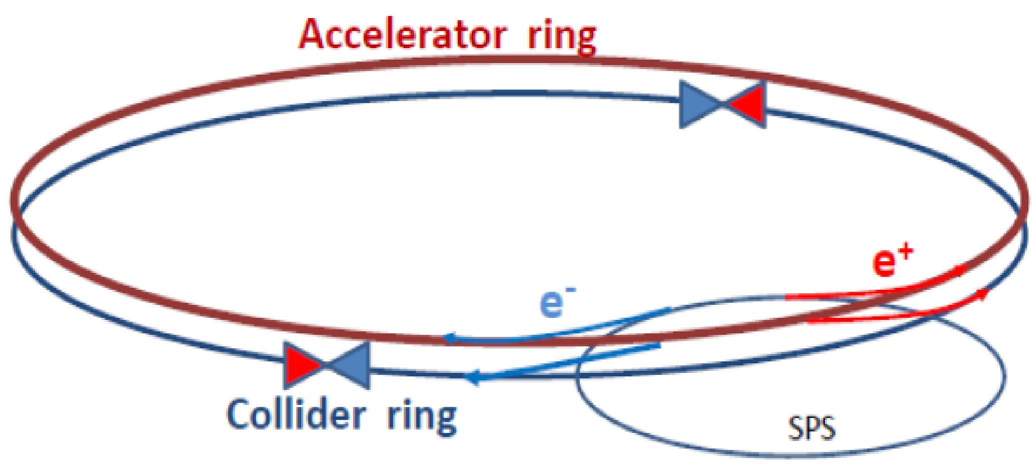


The Higgs-like boson has a mass of 125 GeV?
Do we need a Linear Collider for a Higgs factory?

A. Blondel and F. Zimmerman: LEP3? arXiv:1112.2518v1
Proposal: Reinstall an e+e- collider in the LHC tunnel
With LC RF to make up for the energy loss of 7 GeV for a 120 GeV/beam

Note: beam lifetime ~ 12 minutes. Needs top-up ring

Expected Higgs events ~ 20 K/year



Also mentioned DLEP: a 52 km tunnel nearby CERN?

The LHC operates at an energy and precision that takes us far beyond our current understanding, into a new regime

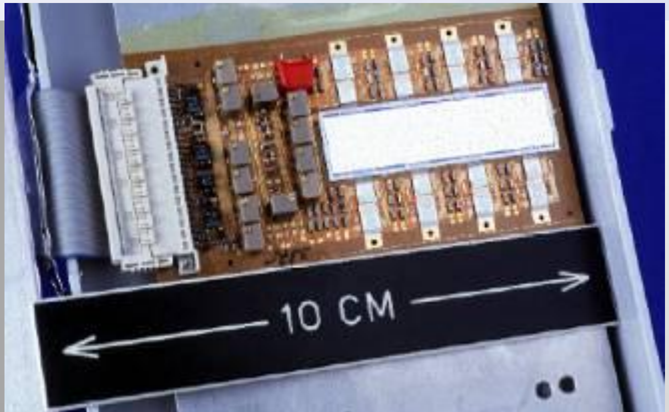
The LHC will reveal the origin of mass of particles. **Two weeks ago discovery of a new particle was announced with properties of a Higgs Boson!!**

LHC will very likely reveal much more ….
There is mounting evidence, from neutrino mass to dark matter and dark matter observations, that there is something profound that we do not yet understand. Is it supersymmetry, extra dimensions, other…? First LHC results do not yet show signatures for new physics but these can come now any day!

The results of the LHC will determine the future of HEP!!!

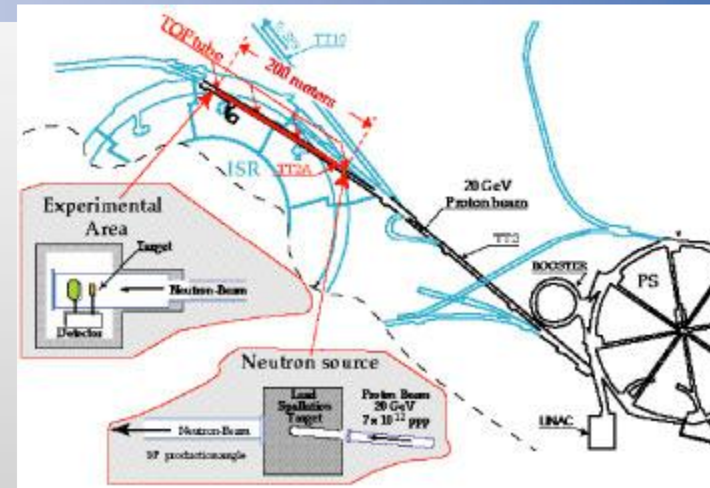
We are on the verge of a revolution in our understanding of the Universe and our place within it. African scientists and students can take part in this science revolution

CERN/HEP is also: Technology Transfer

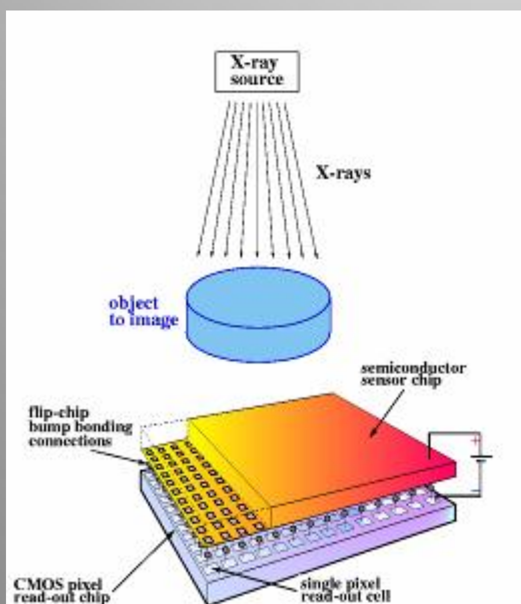


Silicon detector for a Compton camera in nuclear medical imaging

GRID Computing!

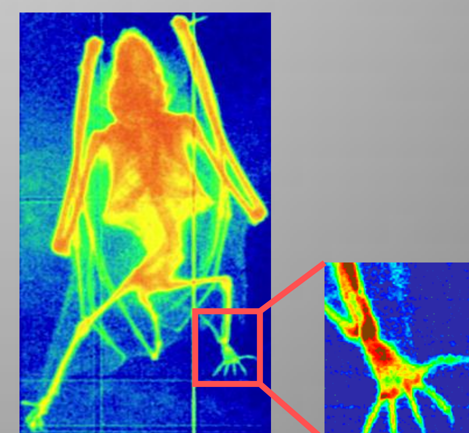


Radio-isotope production for medical applications



Medipix: Medical X-ray diagnosis with contrast enhancement and dose reduction

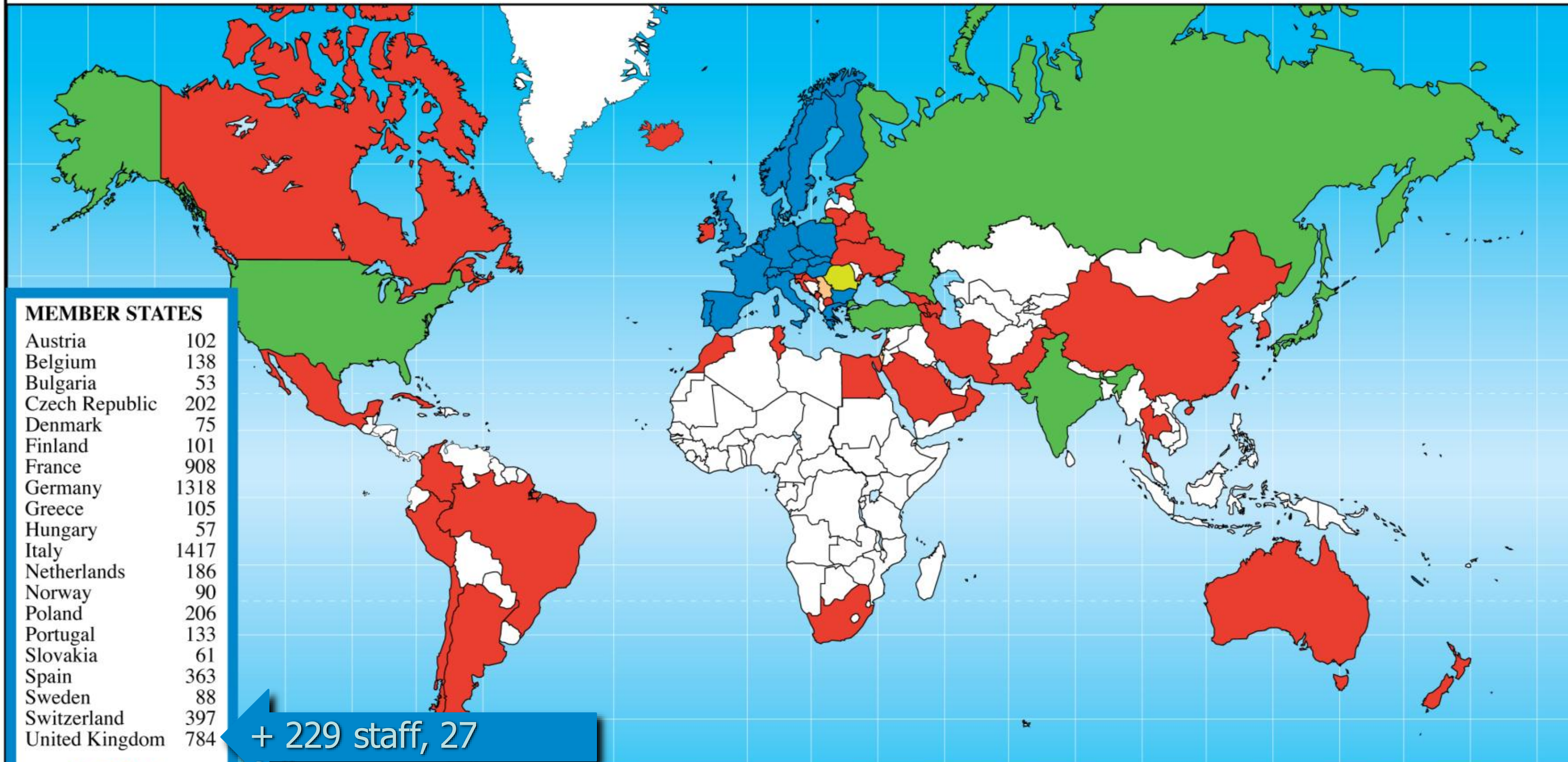
Thin films by sputtering or evaporation



Radiography of a bat, recorded with a GEM detector

Science is getting more and more global

Distribution of All CERN Users by Nation of Institute on 4 April 2012



MEMBER STATES

Austria	102
Belgium	138
Bulgaria	53
Czech Republic	202
Denmark	75
Finland	101
France	908
Germany	1318
Greece	105
Hungary	57
Italy	1417
Netherlands	186
Norway	90
Poland	206
Portugal	133
Slovakia	61
Spain	363
Sweden	88
Switzerland	397
United Kingdom	784

6784

+ 229 staff, 27 fellows

OBSERVERS

India	134
Japan	225
Russia	859
Turkey	83
USA	1749

3050

CANDIDATE FOR ACCESSION

Romania	78

ASSOCIATE MEMBER IN THE PRE-STAGE TO MEMBERSHIP

Israel	67
Serbia	26

OTHERS

Argentina	18
Armenia	13
Australia	28
Azerbaijan	1
Belarus	22
Brazil	102
Canada	170
Chile	4
China	115
China (Taipei)	70
Colombia	10
Croatia	21
Cuba	4
Cyprus	9
Egypt	7
Estonia	17
Georgia	10
Iceland	3
Iran	16
Ireland	10
Korea	91
Lebanon	1
Lithuania	13
Malta	1
Mexico	43
Montenegro	1
Morocco	6
New Zealand	11
Oman	1
Pakistan	22
Peru	2
Qatar	1
Saudi Arabia	3
Slovenia	38
South Africa	21
Thailand	5
T.F.Y.R.O.M.	2
Tunisia	1
Ukraine	21
Uzbekistan	1

934

Bringing the Nations Together

Backup

HE-LHC

High Energy-LHC (HE-LHC)

CERN working group since April 2010

EuCARD AccNet workshop HE-LHC'10 , 14-16 October 2010

key topics

beam energy 16.5 TeV; 20-T magnets

cryogenics: **synchrotron-radiation heat**

radiation damping & emittance control

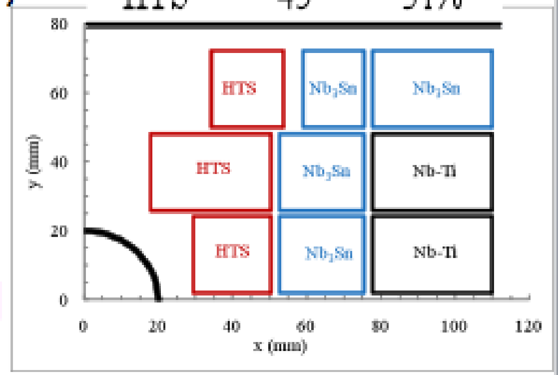
vacuum system: synchrotron radiation

new injector: energy > 1 TeV

parameters

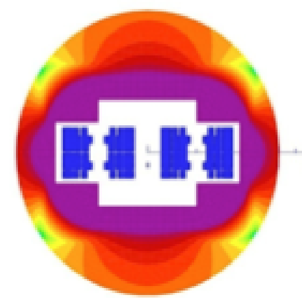
	LHC	HE-LHC
beam energy [TeV]	7	16.5
dipole field [T]	8.33	20
dipole coil aperture [mm]	56	40
#bunches	2808	1404
IP beta function [m]	0.55	1 (x), 0.43 (y)
number of IPs	3	2
beam current [A]	0.584	0.328
SR power per ring [kW]	3.6	65.7
arc SR heat load dW/ds [W/m/ap]	0.21	2.8
peak luminosity [10^{34} cm^{-2}s^{-1}]	1.0	2.0

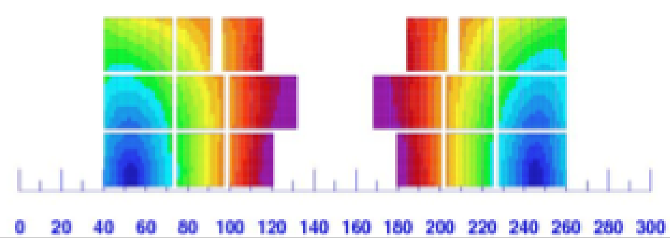
	Turns	%
Nb-Ti	40	28%
Nb_3Sn	58	41%
HTS	45	31%



E. Todesco

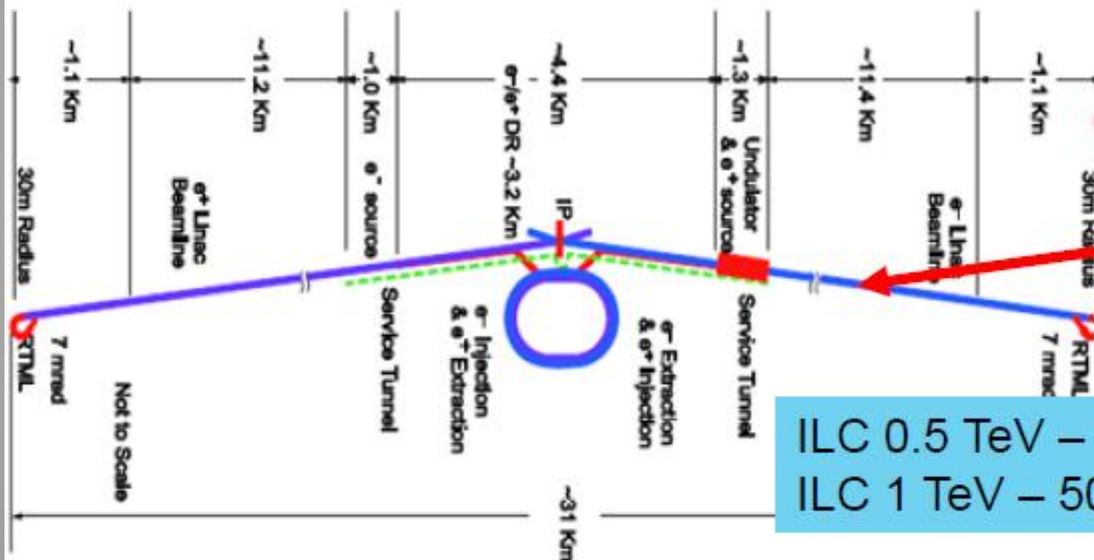
hybrid magnet

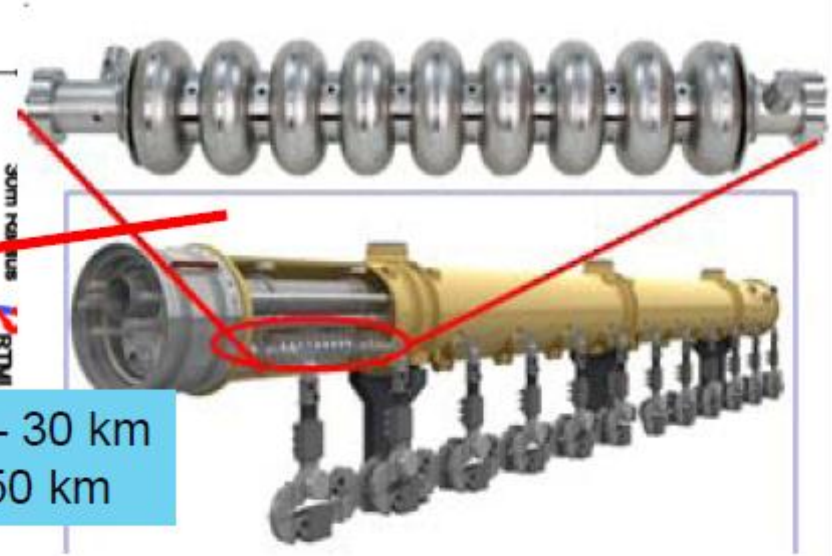




Linear Collider layouts

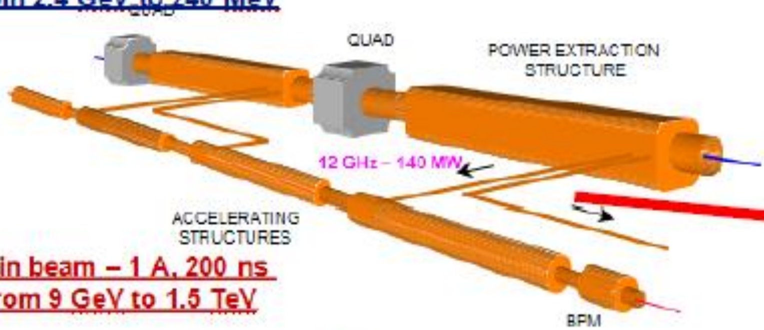
http://www.linearcollider.org/cms   http://clic-study.web.cern.ch/CLIC-Study/



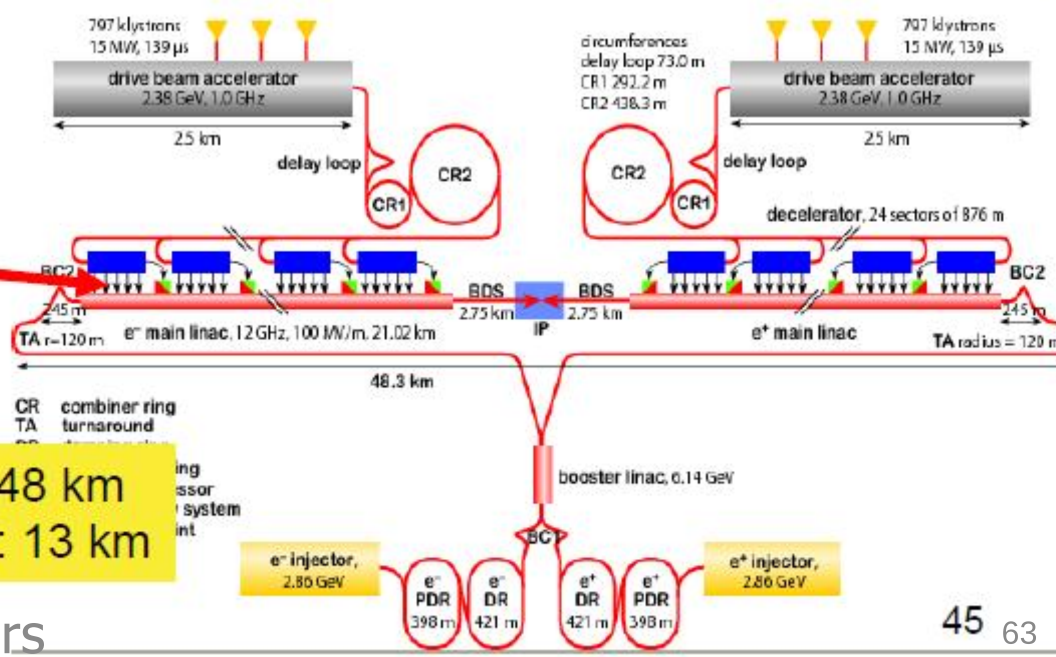


ILC 0.5 TeV – 30 km
ILC 1 TeV – 50 km

Drive beam - 95 A, 300 ns
from 2.4 GeV to 240 MeV



Main beam – 1 A, 200 ns
from 9 GeV to 1.5 TeV



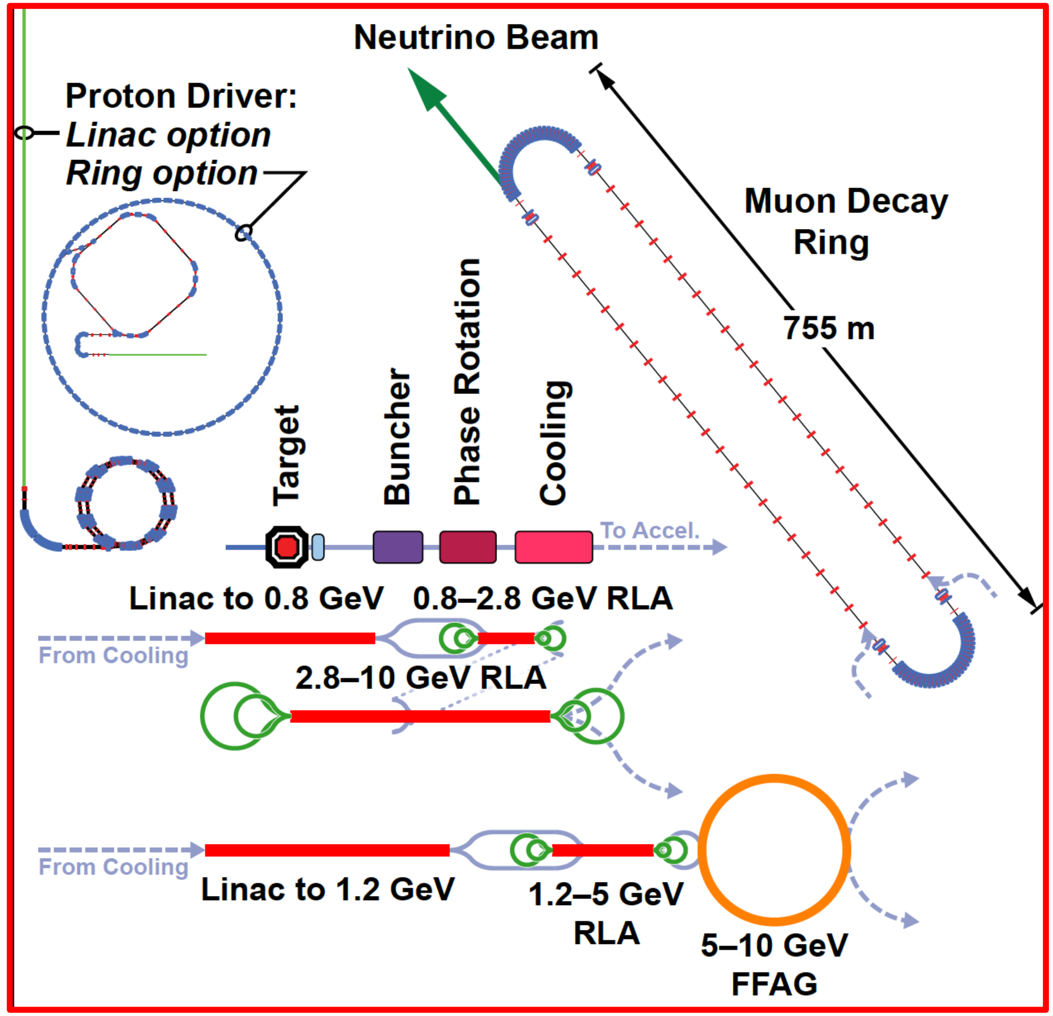
CLIC 3 TeV: 48 km
CLIC 0.5 TeV: 13 km

Options:

- Conventional super-beams:
  - Wide-band, long baseline: e.g. LBNE, LBNO
    - $<E_\mu>$ ~ 2—3 GeV; matched to LAr or magn.Fe calorimeter;
    - Long-baseline allows observation of first and second maximum
    - Near detector exploited to reduce systematic errors
  - Narrow-band, short baseline: e.g. T2HK, SPL
    - $<E_\mu>$ ~ 0.5 GeV; matched to H_20 Cherenkov;
    - Short-baseline allows observation of first maximum
    - Near detector exploited to reduce systematic errors
- Beta-beam, short baseline:
  - $<E_\mu>$ ~ 0.5 GeV; matched to H_20 Cherenkov;
  - Short-baseline allows observation of first maximum
  - Requires short-baseline super-beam to deliver competitive performance

Neutrino Factory:

- Optimise discovery potential for CP and MH:
  - Requirements:
    - Large ν_e ($\bar{\nu}_e$) flux
      - Detailed study of sub-leading effects
- Unique:
  - (Large) high-energy ν_e ($\bar{\nu}_e$) flux
    - Optimise event rate at fixed *L/E*
    - Optimise MH sensitivity
    - Optimise CP sensitivity



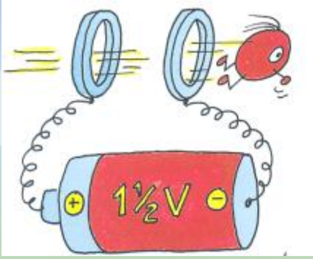
K.Long

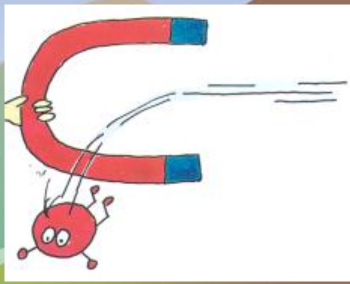
Summary

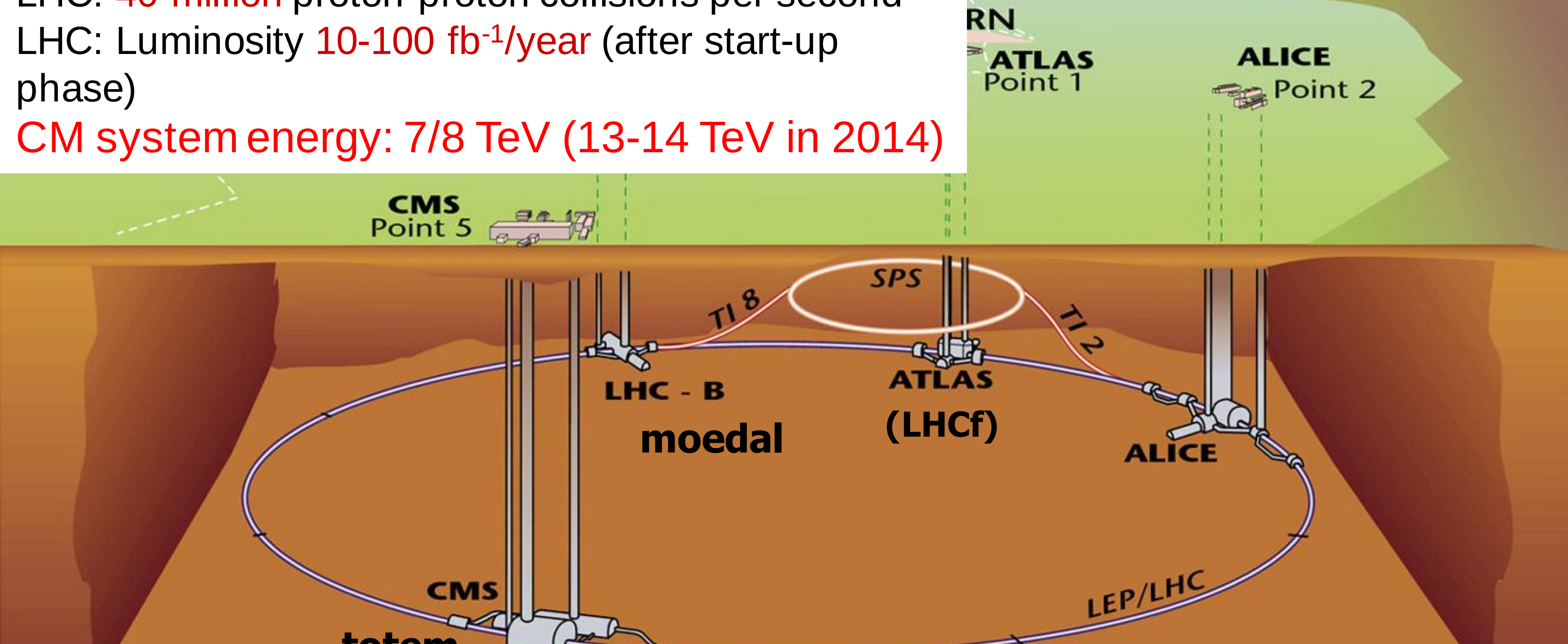
- Detector upgrade preparations in the experiments are well under way, making use of 3 foreseen long shutdowns.
- HL-LHC: High Luminosity operation expected to start around 2022. Expect ~ 3 ab^{-1}/exp or more by 2030.
- HE-LHC: CM Energy discussed now 33 TeV, but magnets still in R&D. Not starting before well into the 2030's, according to present planning...
- LHeC: Technically feasible. CDR in review
- Physics case for the HL-LHC and HE-LHC have not been revisited since quite some time. Maybe something to think about for 2013-14…

The LHC Machine and Experiments

LHC is 100m underground
LHC is 27 km long
Magnet Temperature is 1.9 Kelvin = -271 Celsius
LHC has ~ 9000 magnets
LHC: 40 million proton-proton collisions per second
LHC: Luminosity 10-100 fb^{-1}/year (after start-up phase)
CM system energy: 7/8 TeV (13-14 TeV in 2014)





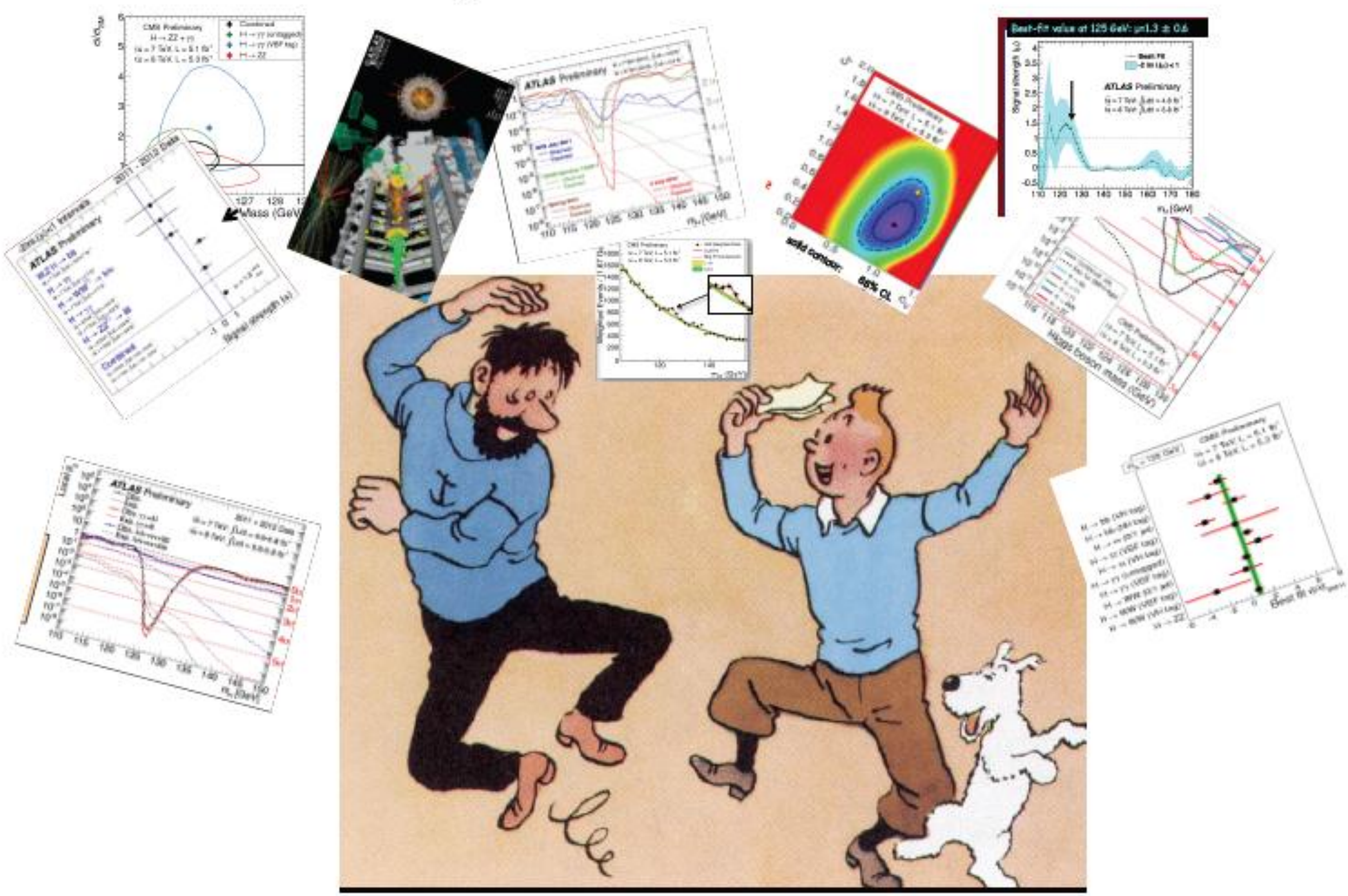


- High Energy ⇒ factor 3.5-7 increase w.r.t. present accelerators
- High Luminosity (# events/cross section/time) ⇒ factor 100 increase

The Theorists…

A. Pomarol ICHEP2012

… and finally plenty of new relevant data has begun to fall over us!



The Community (The day after…)

Confronting the MSSM and the NMSSM with the Discovery of a Signal in the two Photon Channel at the LHC
R. Benbrik, M. Gomez Bock, S. Heinemeyer, O. Stal, G. Weiglein, L. Zeune

Have We Observed the Higgs (Imposter)?
Ian Low, Joseph Lykken, Gabe Shaughnessy

2:1 for Naturalness at the LHC?
Nima Arkani-Hamed, Kfir Blum, Raffaele Tito D'Agnolo, JiJi Fan

The apparent excess in the Higgs to di-photon rate at the LHC: New Physics or QCD uncertainties?
I. Baglio, A. Djouadi, R. M. Godbole

Testing No-Scale F-SU(5): A 125 GeV Higgs Boson and SUSY at the 8 TeV LHC
Tianjun Li, James A. Maxin, Dimitri V. Nanopoulos, Joel W. Walker

Higgs boson of mass 125 GeV in GMSB models with messenger-matter mixing
A. Albaid, K.S. Babu

125 GeV Higgs Boson, Enhanced Di-photon Rate, and Gauged U(1)_PQ-Extended MSSM
Haipeng An, Tao Liu, Lian-Tao Wang

Higgs discovery: the beginning or the end of natural EWSB?
Marc Montull, Francesco Riva

The Social Higgs
Daniele Bertolini, Matthew McCullough

Could two NMSSM Higgs bosons be present near 125 GeV?
John F. Gunion, Yun Jiang, Sabine Kraml

First Glimpses at Higgs' face
J. R. Espinosa, C. Grojean, M. Muhlleitner, M. Trott

Precision Unification in λSUSY with a 125 GeV Higgs
Edward Hardy, John March-Russell, James Unwin

Implications of the Higgs Boson Discovery for mSUGRA
Sujeet Akula, Pran Nath, Gregory Peim

Global Analysis of the Higgs Candidate with Mass ~ 125 GeV
John Ellis, Tevong You

The Higgs sector of the phenomenological MSSM in the light of the Higgs boson discovery
Alexandre Arbey, Marco Battaglia, Abdelhak Djouadi, Farvah Mahmoudi

Is the resonance at 125 GeV the Higgs boson?
Pier Paolo Giardino, Kristjan Kannike, Martti Raidal, Alessandro Strumia

Constraining anomalous Higgs interactions
Tyler Corbett, O. J. P. Eboli, J. Gonzalez-Fraile, M. C. Gonzalez-Garcia

Higgs After the Discovery: A Status Report
Dean Carmi, Adam Falkowski, Eric Kuflik, Tomer Volansky, Jure Zupan

Are There Hints of Light Stops in Recent Higgs Sear
Matthew R. Buckley, Dan Hooper