

After the Higgs Discovery:

Accelerators for Higgs Factories

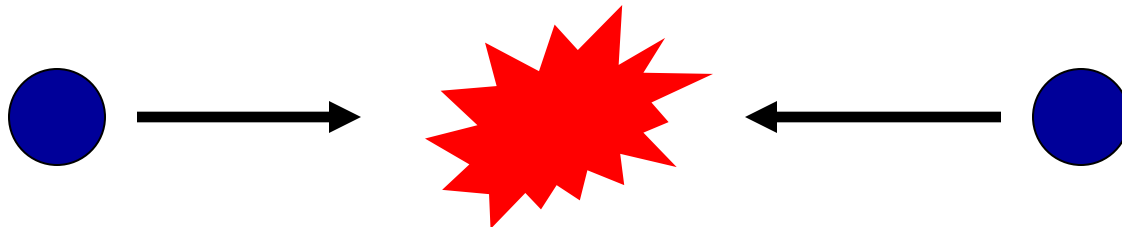
Philip Burrows

John Adams Institute for Accelerator Science

Oxford University

Smashing matter apart

- **Want to see what matter is made of**
- **Smash matter apart and look for the building blocks**
- **Take small pieces of matter:
accelerate them to very high energy
crash them into one another**



- **LHC: protons crashing into protons head-on**

Scientific importance of accelerators

- **30% of physics Nobel Prizes awarded for work based on accelerators**
- **Increasing number of non-physics Nobel Prizes being awarded for work reliant on accelerators!**



Accelerator-related Physics Nobel Prizes

- 1901 Roentgen: X rays
- 1905 Lenard: cathode rays
- 1906 JJ Thomson: electron
- 1914 von Laue: X-ray diffraction
- 1915 WH+WL Bragg: X-ray crystallography
- 1925 Franck, Hertz: laws of impact of e on atoms
- 1927 Compton: X-ray scattering
- 1937 Davission, Germer: diffraction of electrons
- 1939 Lawrence: cyclotron
- 1943 Stern: magnetic moment of proton
- 1951 Cockcroft, Walton: artificial acceleration
- 1959 Segre, Chamberlain: antiproton discovery
- 1961 Hofstadter: structure of nucleons
- 1968 Alvarez: discovery of particle resonances
- 1969 Gell-Mann: classification of el. particles
- 1976 Richter, Ting: charmed quark
- 1979 Glashow, Salam, Weinberg: Standard Model
- 1980 Cronin, Fitch: symmetry violation in kaons
- 1984 Rubbia, van der Meer: W + Z particles
- 1986 Ruska: electron microscope
- 1988 Ledermann, Schwartz, Steinberger: mu nu
- 1990 Friedmann, Kendall, Taylor: quarks
- 1992 Charpak: multi-wire proportional chamber
- 1994 Brockhouse, Shull: neutron scattering
- 1995 Perl: tau lepton discovery
- 2004 Gross, Pollitzer, Wilczek: asymptotic freedom
- 2008 Nambu, Kobayashi, Maskawa: broken symmetries

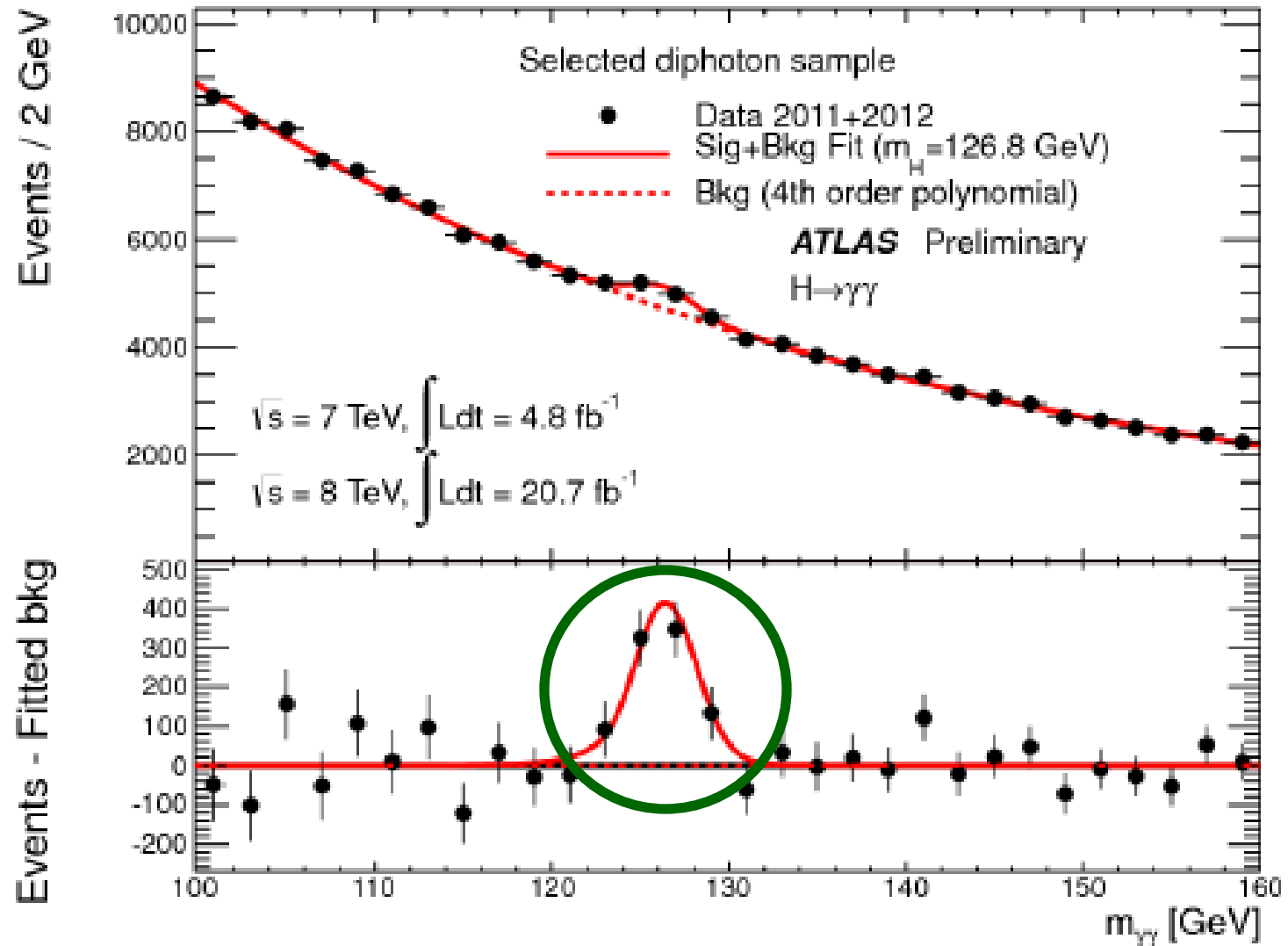


Large Hadron Collider (LHC)

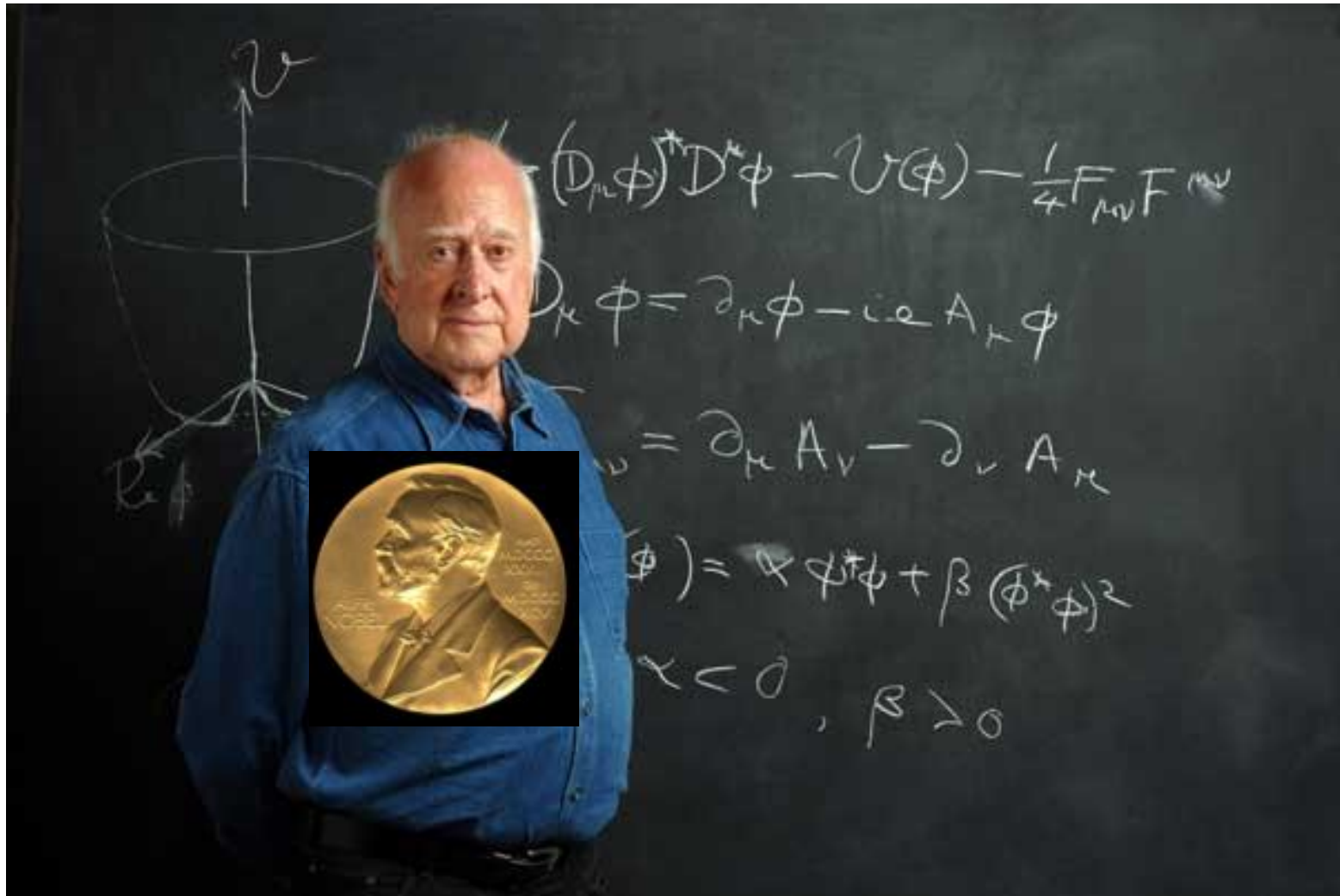
**Best window
we have on
matter in the
universe, at
ultra-early
times and at
ultra-small scales**



The new boson discovered 2012



2013???



After LHC?



LHC:
protons
with energy
 $E = 7000 \text{ GeV}$

Before LHC?

Before LHC



Before LHC



**Large
Electron
Positron
(LEP):**

**c. 100 GeV
electrons +
positrons**

Super Large Electron Positron collider?

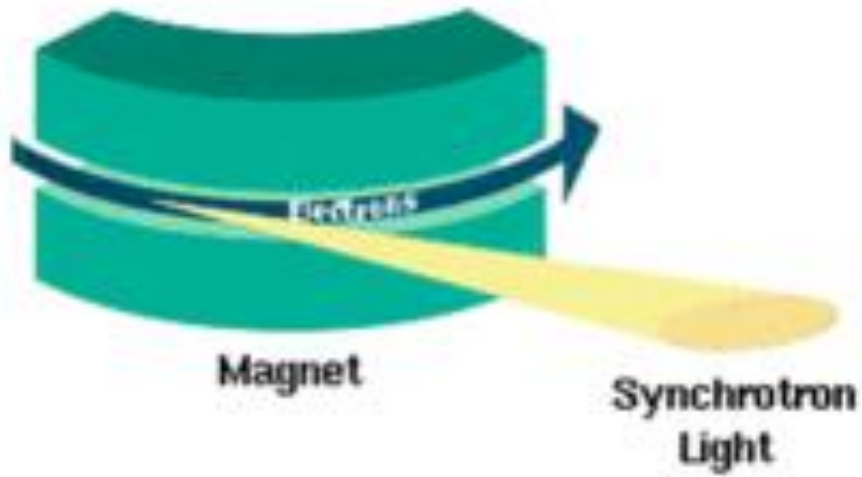


500 GeV

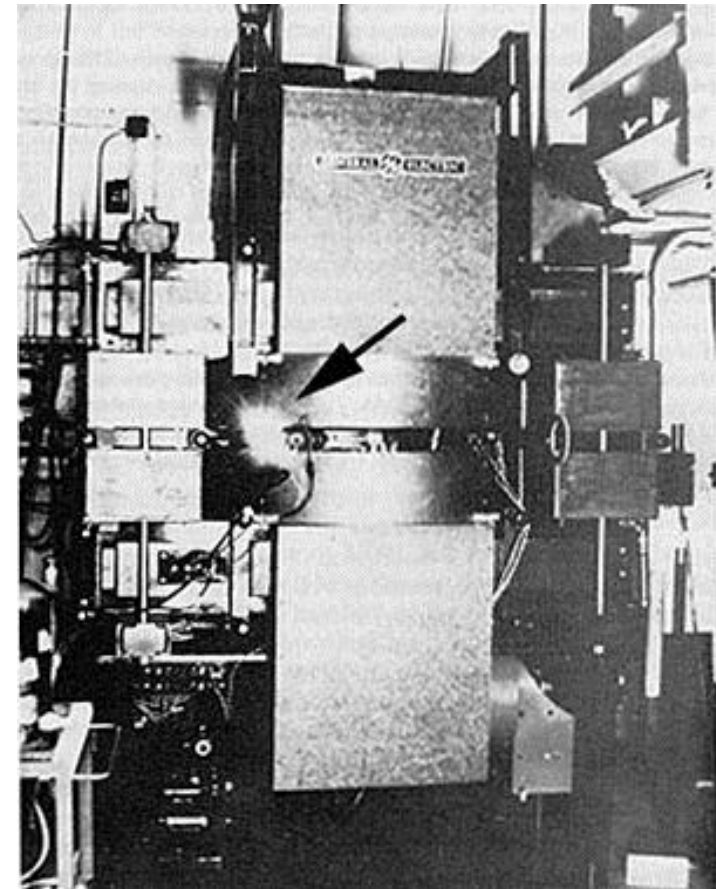
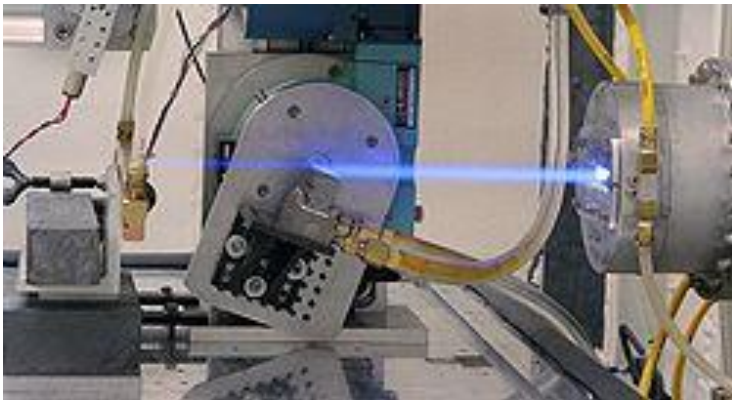
beams?

(5 x LEP)

Synchrotron radiation



Discovered Elder et al
1947 (General Electric)



Synchrotron radiation

Power lost due to synchrotron radiation

$$P \sim E^4 / r^2$$

E = beam energy

r = radius of trajectory

Synchrotron radiation

Power lost due to synchrotron radiation

$$P \sim E^4 / r^2$$

E = beam energy

r = radius of trajectory

For LEP each electron lost ~ 3 GeV per turn (3%!)

P = 10⁻⁶ Watts/electron → 18 MW total

→ Must be compensated by accelerating cavities

Synchrotron radiation

Suppose we increase LEP beam energy (100 GeV) by factor 5: $E \rightarrow 500$ GeV, in the same tunnel

$$P \sim E^{**4} / r^{**2}$$

Synchrotron radiation

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this would give $P = 5^{**4} * 18 \text{ MW} = \mathbf{11 \text{ GW!}}$

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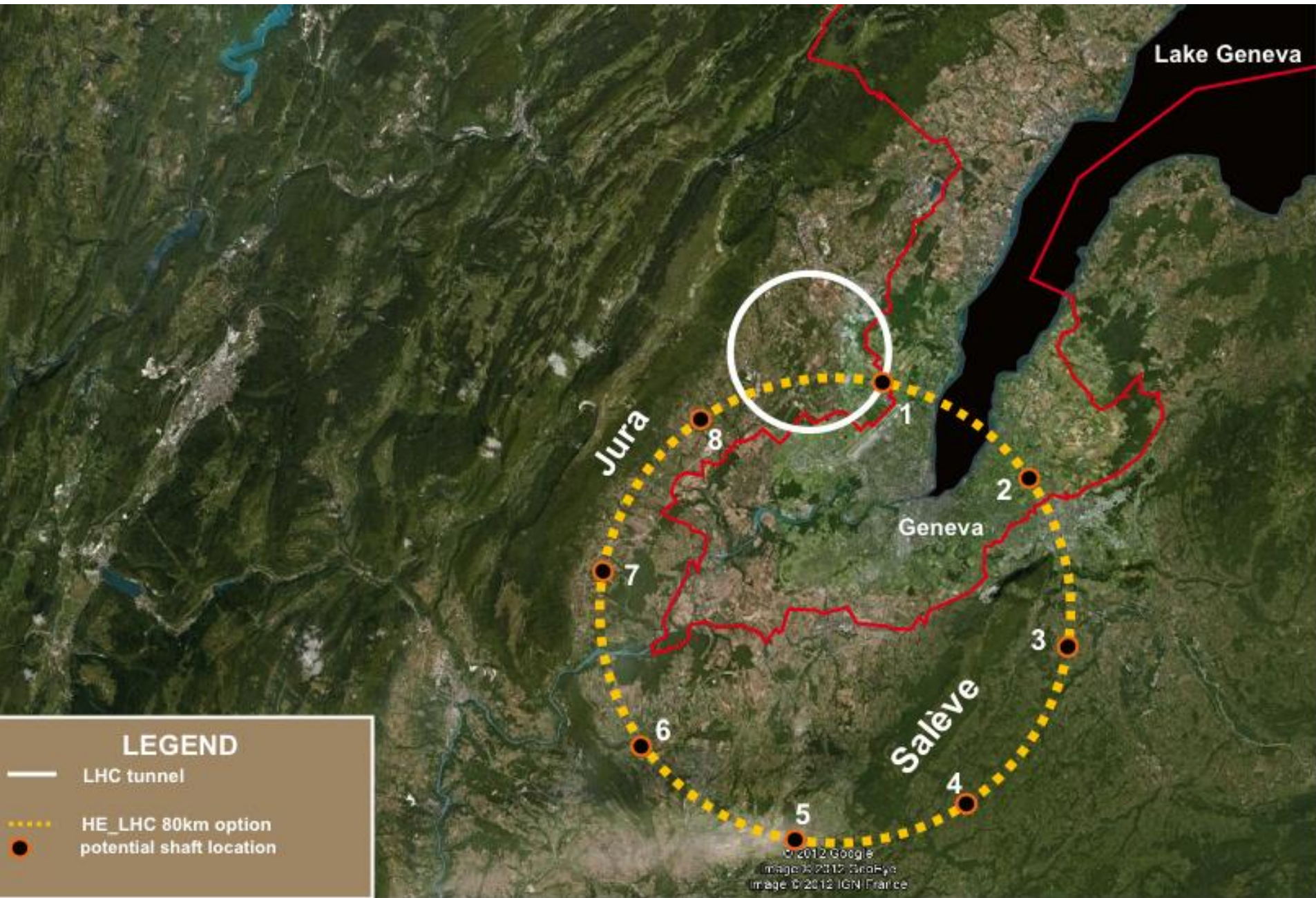
Compensate by increasing radius r?

Need 10 x r to reduce P by 100 \rightarrow **270km tunnel!**

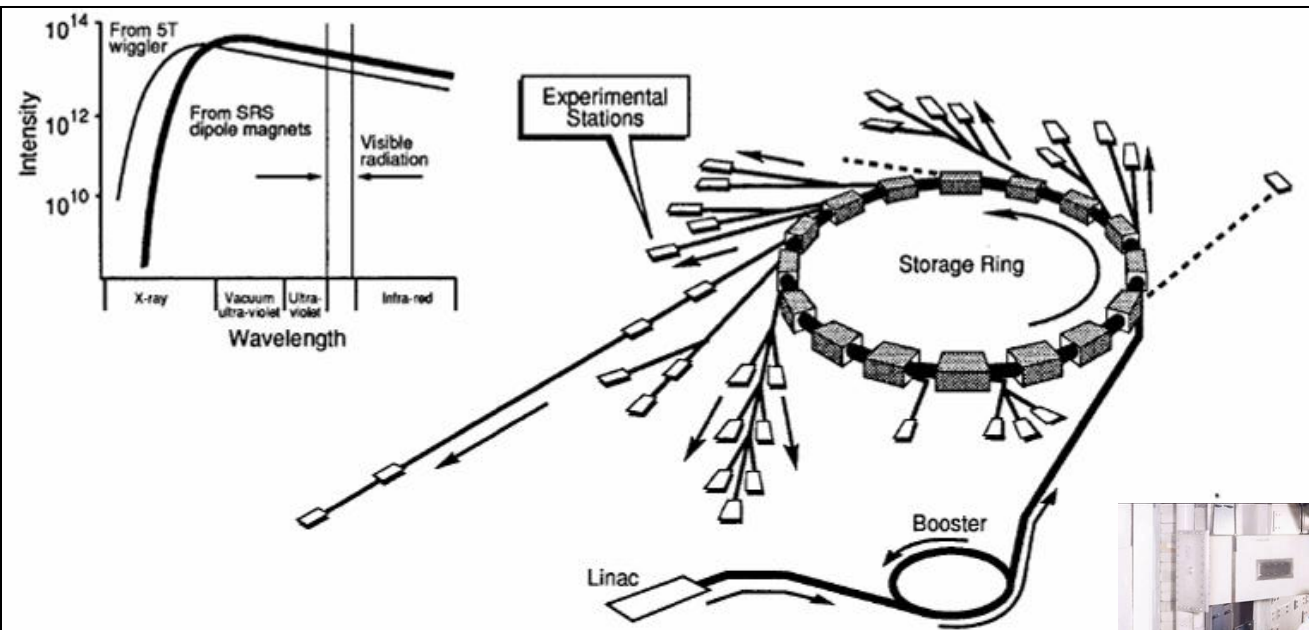
270km tunnel???



Future 80km tunnel??



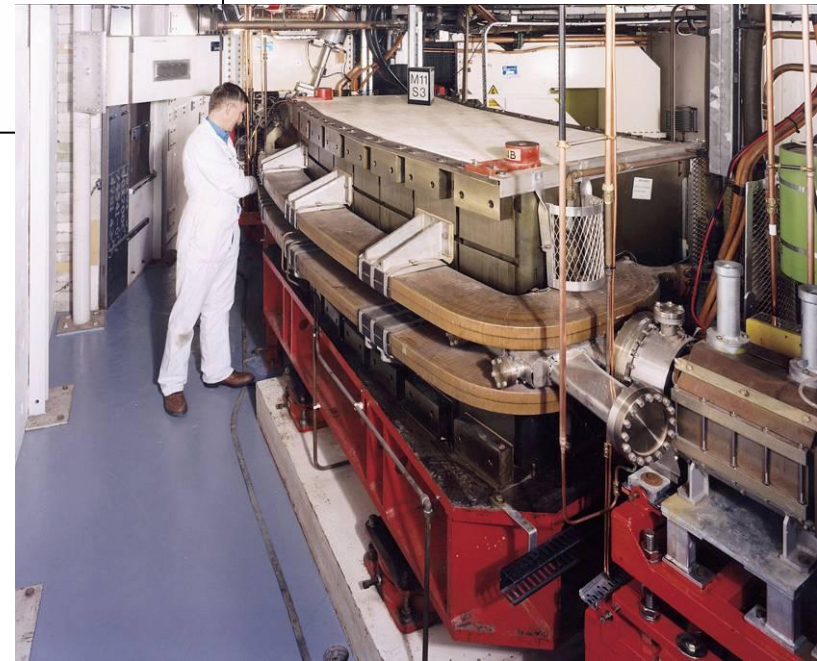
First purpose-built SR source



SRS

Daresbury, UK

1967



Applications of synchrotron radiation

- **Structures of crystalline materials**
- **Protein structures**
- **Phase transitions**
- **Diffusion in solids**
- **Interfaces in solids**
- **Magnetic properties**
- **Polymers**
- **Defect structures (stress + fatigue)**

... ..

X-ray diffraction

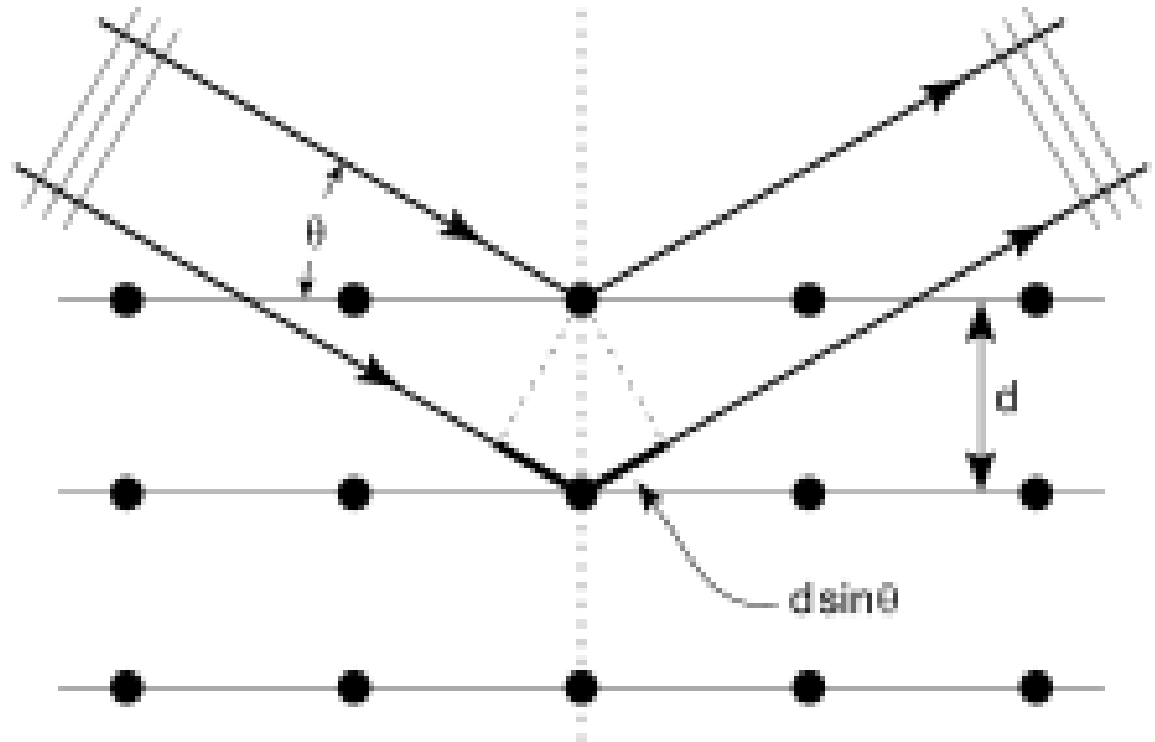


Max von Laue

1914 Nobel Prize:

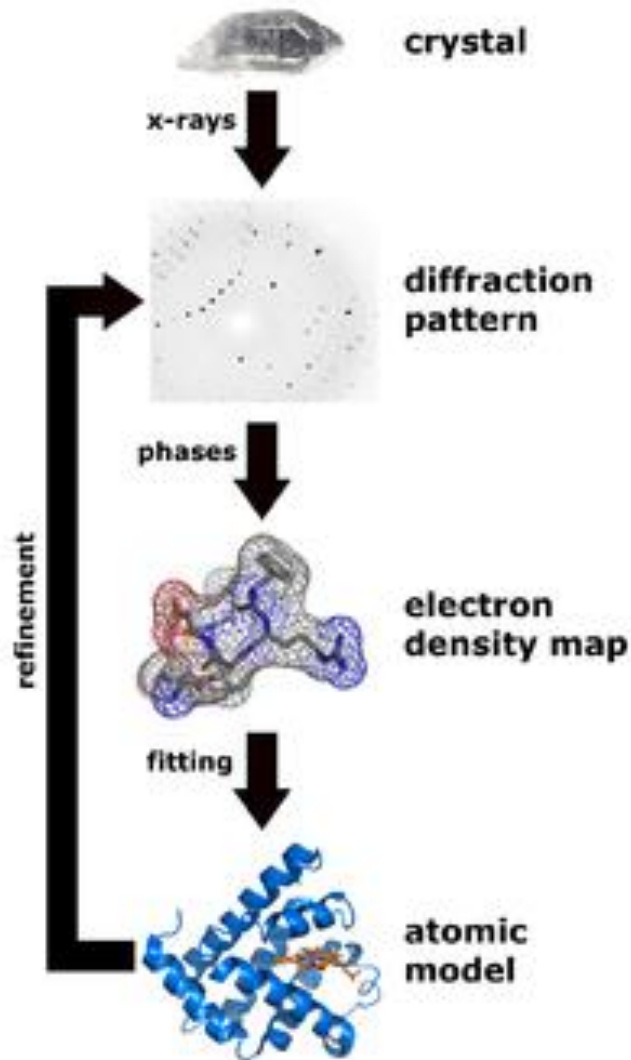
‘For his discovery of the diffraction of X-rays

by crystals’

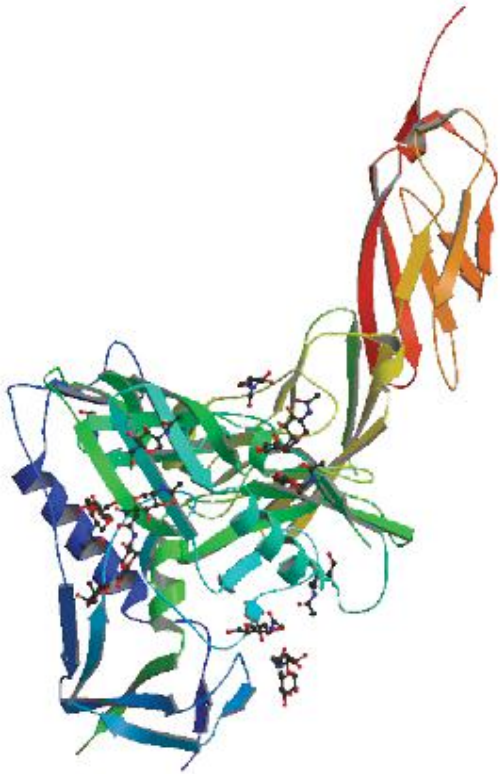


Constructive interference:
 $2 d \sin(\theta) = n \lambda$

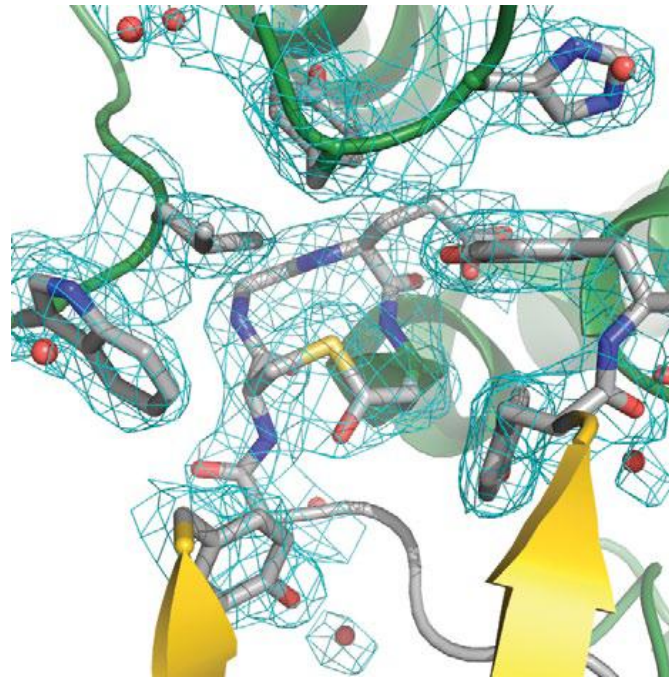
X-ray diffraction today



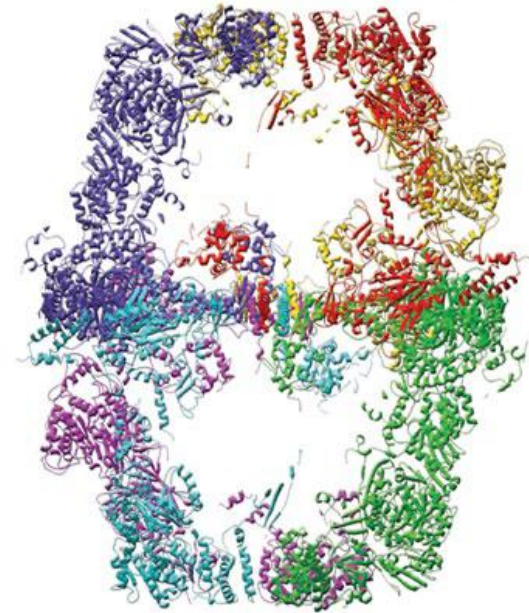
Protein structures



HIV glycoprotein



**mosquito
immune system**

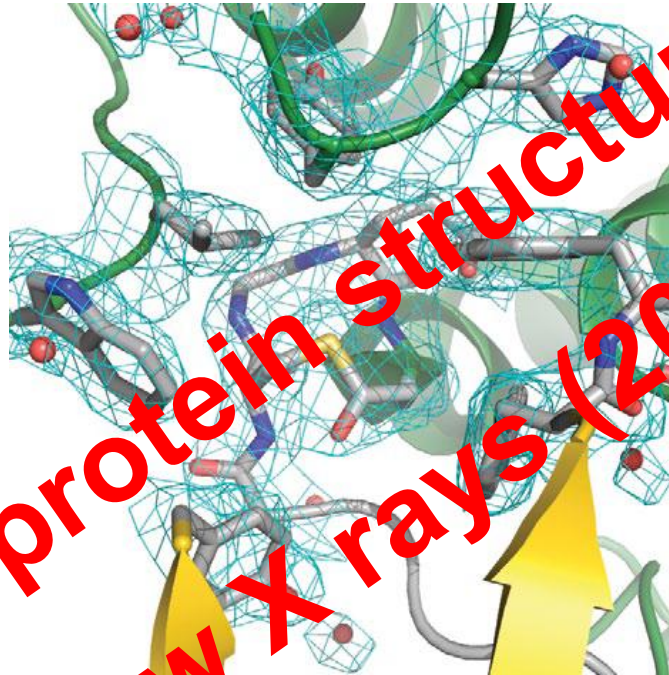


yeast enzyme

Protein structures

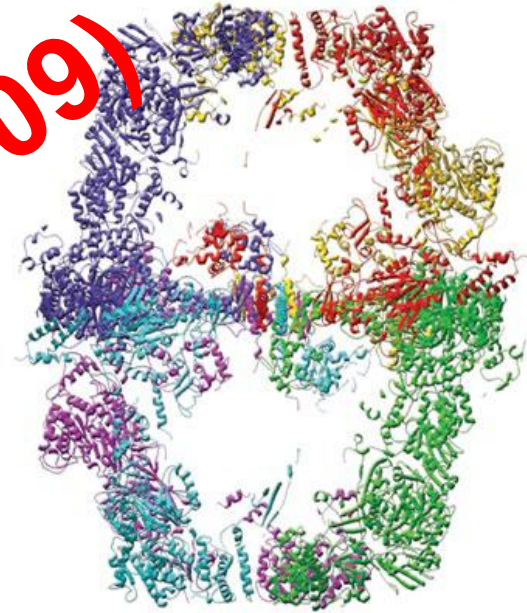


HIV glycoprotein



mosquito

immune system



yeast enzyme

> 50,000 protein structures solved w X rays (2009)

Diamond: synchrotron source of X-rays



Nobel Prizes based on X-ray work

19 Nobel Prizes Based on X-ray Work

CHEMISTRY:

- 1936 – Peter Debye
- 1962 – Max Perutz & Sir John Kendrew
- 1964 – Dorothy Hodgkin
- 1976 – William Lipscomb
- 1985 – Herbert Hauptman & Jerome Karle
- 1988 – Johann Deisenhofer, Robert Huber & Hartmut Michel*
- 1997 – Paul D. Boyer & John E. Walker*
- 2003 – Peter Agre & Roderick Mackinnon*
- 2006 – Roger Kornberg*

* Used SYNCHROTRON RADIATION

PHYSICS:

- 1901 – Wilhelm Röntgen
- 1914 – Max Von Laue
- 1915 – Sir William Henry Bragg & Sir William Lawrence Bragg
- 1917 – Charles Barkla
- 1924 – Karl Manne Siegbahn
- 1927 – Arthur Compton
- 1981 – Kai Siegbahn



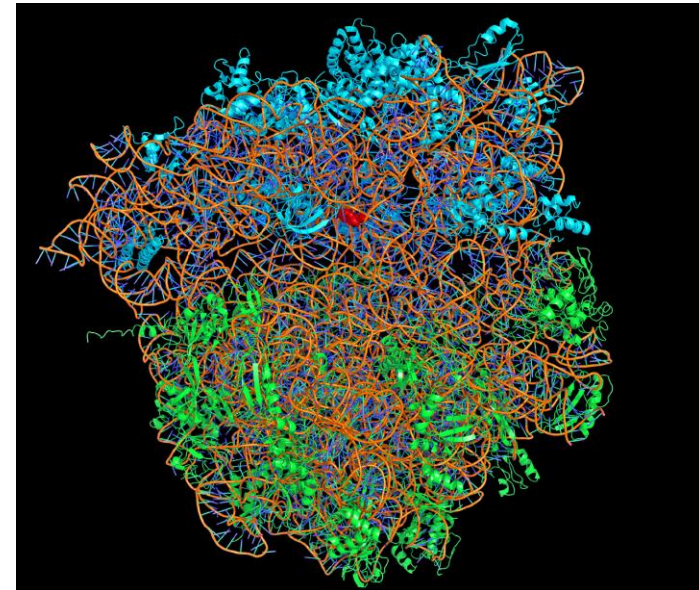
MEDICINE:

- 1946 – Hermann Joseph Muller
- 1962 – Francis Crick, James Watson & Maurice Wilkins
- 1979 – Alan M. Cormack & Sir Godfrey N. Hounsfield

2009 Chemistry Nobel Prize

Ramakrishnan, Steitz, Yonath

‘studies of the structure and function of the ribosome’



Synchrotron radiation: LHC?

Why isn't this a problem for LHC?

Synchrotron radiation: LHC?

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$$P \sim (E/m)^4$$

Synchrotron radiation: LHC?

Why isn't this a problem for LHC?

$$P \sim (E/m)^4$$

$$m_{\text{proton}} \sim 2000 * m_{\text{electron}}$$

$$P_{\text{proton}} \sim 2000^{(-4)} * P_{\text{electron}}$$

Synchrotron radiation: LHC?

Why isn't this a problem for LHC?

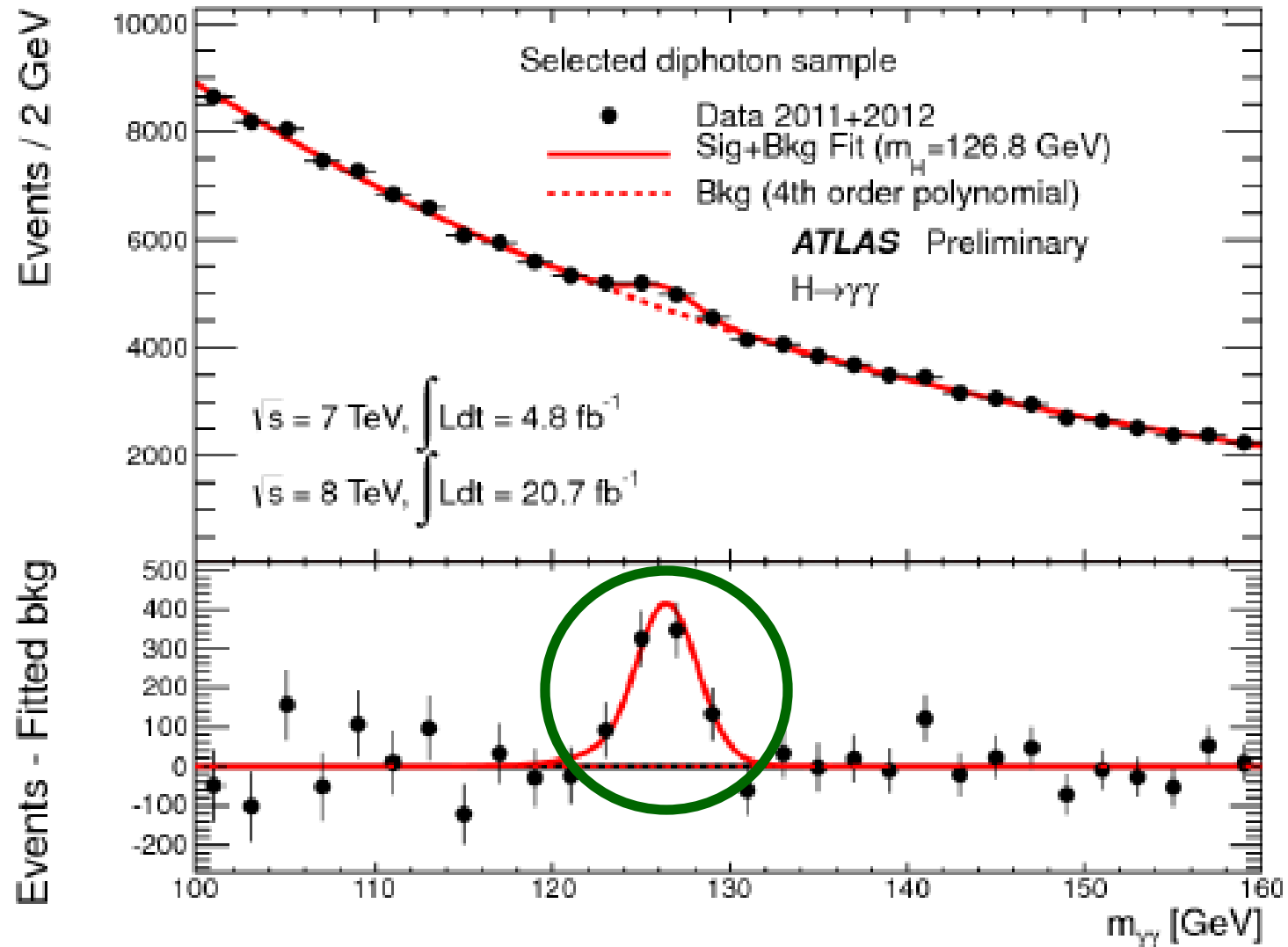
$$P \sim (E/m)^4$$

$$m_{\text{proton}} \sim 2000 * m_{\text{electron}}$$

$$P_{\text{proton}} \sim 2000^{(-4)} * P_{\text{electron}}$$

Even for LHC, $E = 70 * \text{LEP}$, each proton loses only
5 keV per turn **(0.000 000 1% negligible!)**

The new boson



Finger-printing the new boson

Is it:

The Standard Model Higgs boson?

Another type of Higgs boson?

Not a Higgs boson at all?

Finger-printing the new boson

Determine its 'profile':

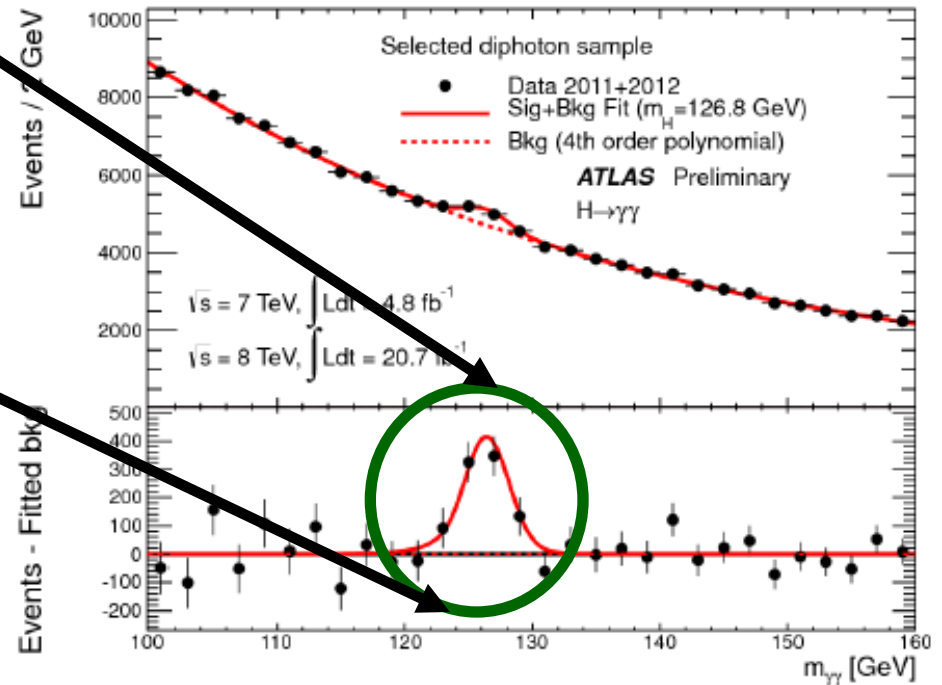
- **Mass**
- **Width**
- **Spin**
- **CP nature**
- **Coupling to fermions (quarks + leptons)**
- **Coupling to gauge bosons (W + Z)**
- **Yukawa coupling to top quark**
- **Self coupling \rightarrow Higgs potential**

Finger-printing the new boson

The LHC has started this endeavour!

and next

Microscope on the new boson



Higgs Factory

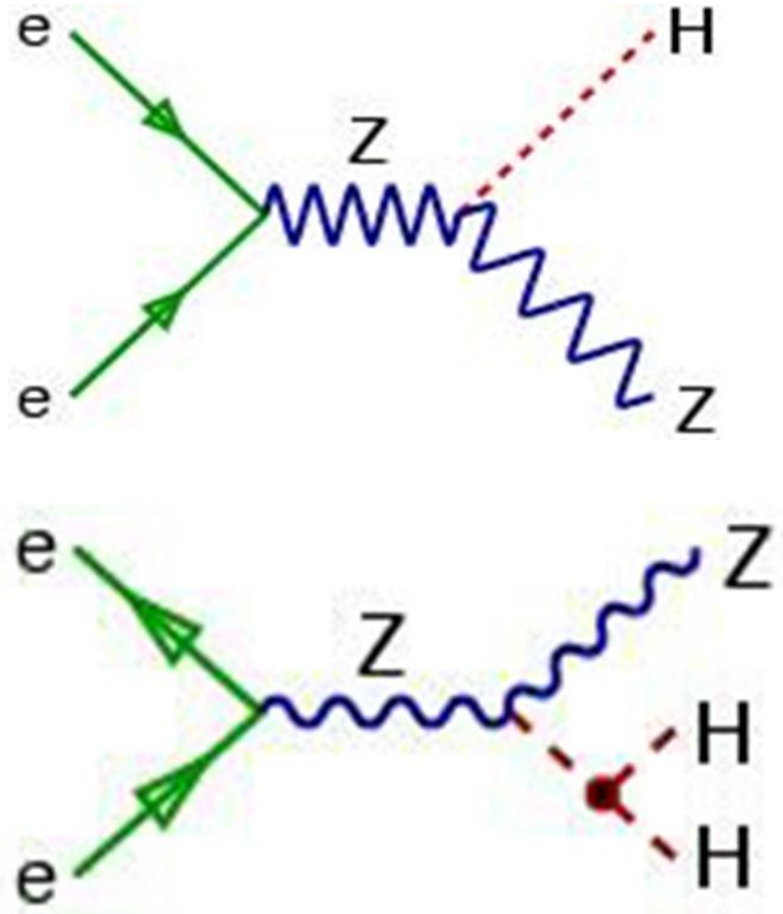
e+e- annihilations:

$E > 91 + 125 = 216$ GeV

$E \sim 250$ GeV

$E > 91 + 250 = 341$ GeV

$E \sim 350 - 500$ GeV



e+e- colliders

- **Produce annihilations of point-like particles under controlled conditions:**

e+e- colliders

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well defined centre of mass energy: $2E$

e+e- colliders

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complete control of event kinematics:

$$\mathbf{p} = 0, M = 2E$$

e+e- colliders

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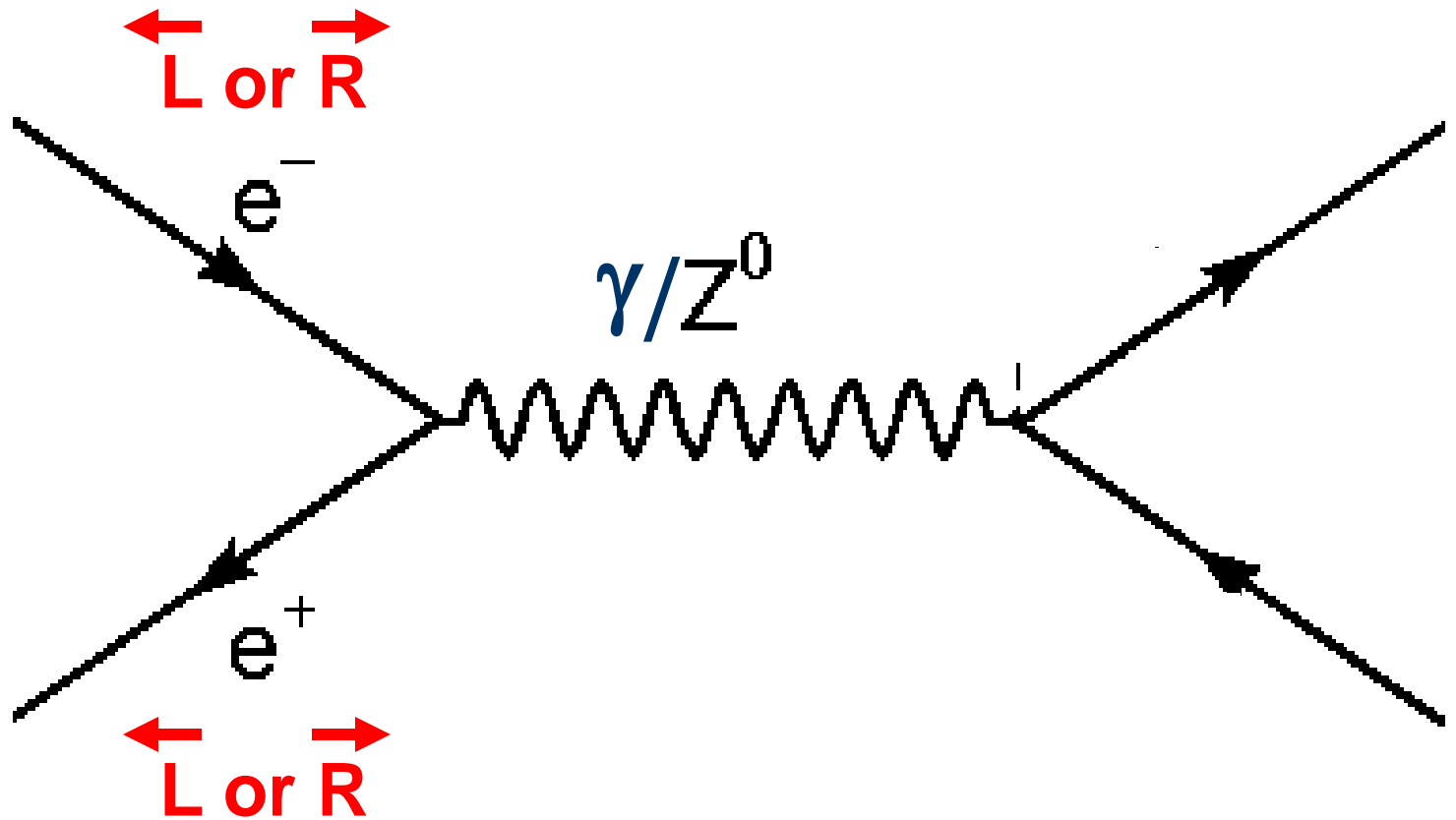
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polarised beam(s)

e^+e^- annihilations



e+e- colliders

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clean experimental environment

e+e- colliders

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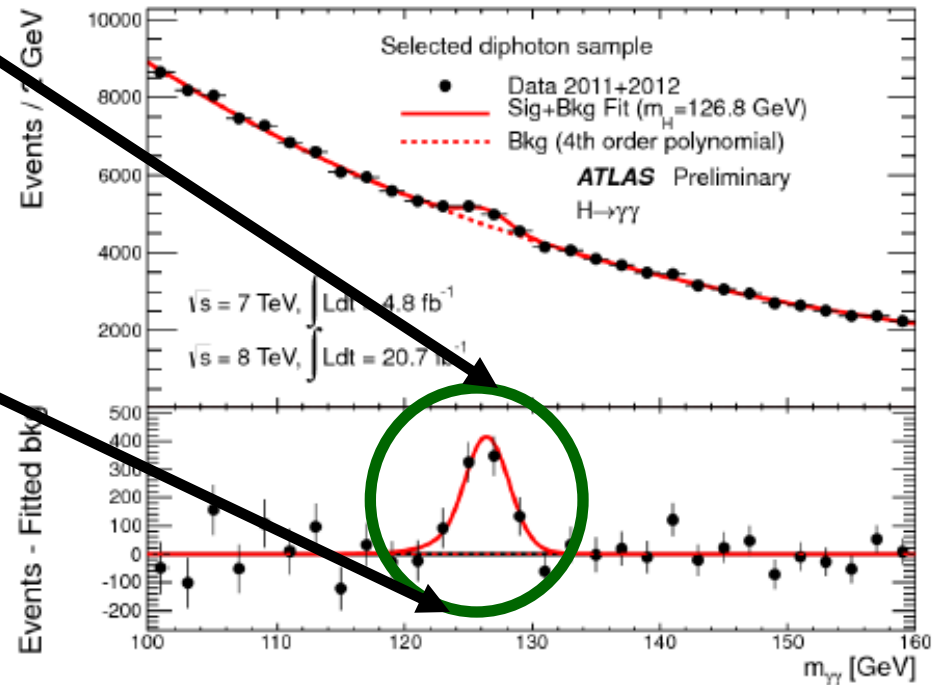
polarised beam(s)

clean experimental environment

- **Give us a precision microscope:**

**masses, decay-modes, couplings, spins,
CP properties ... of new particles**

Microscope on the new boson



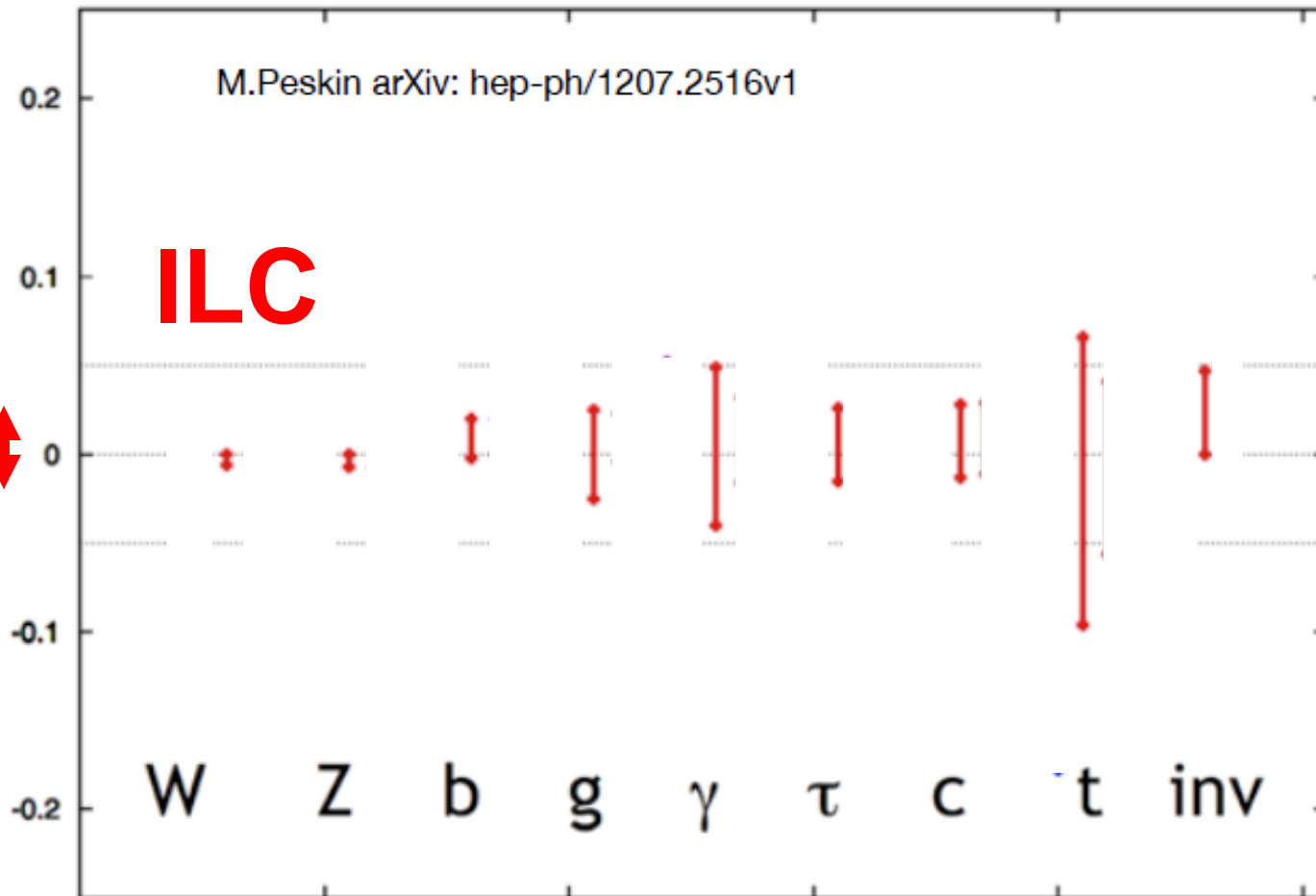
Higgs couplings determination

$g(hAA)/g(hAA)|_{SM} - 1$

M.Peskin arXiv: hep-ph/1207.2516v1

ILC

$\pm 2\%$ \updownarrow



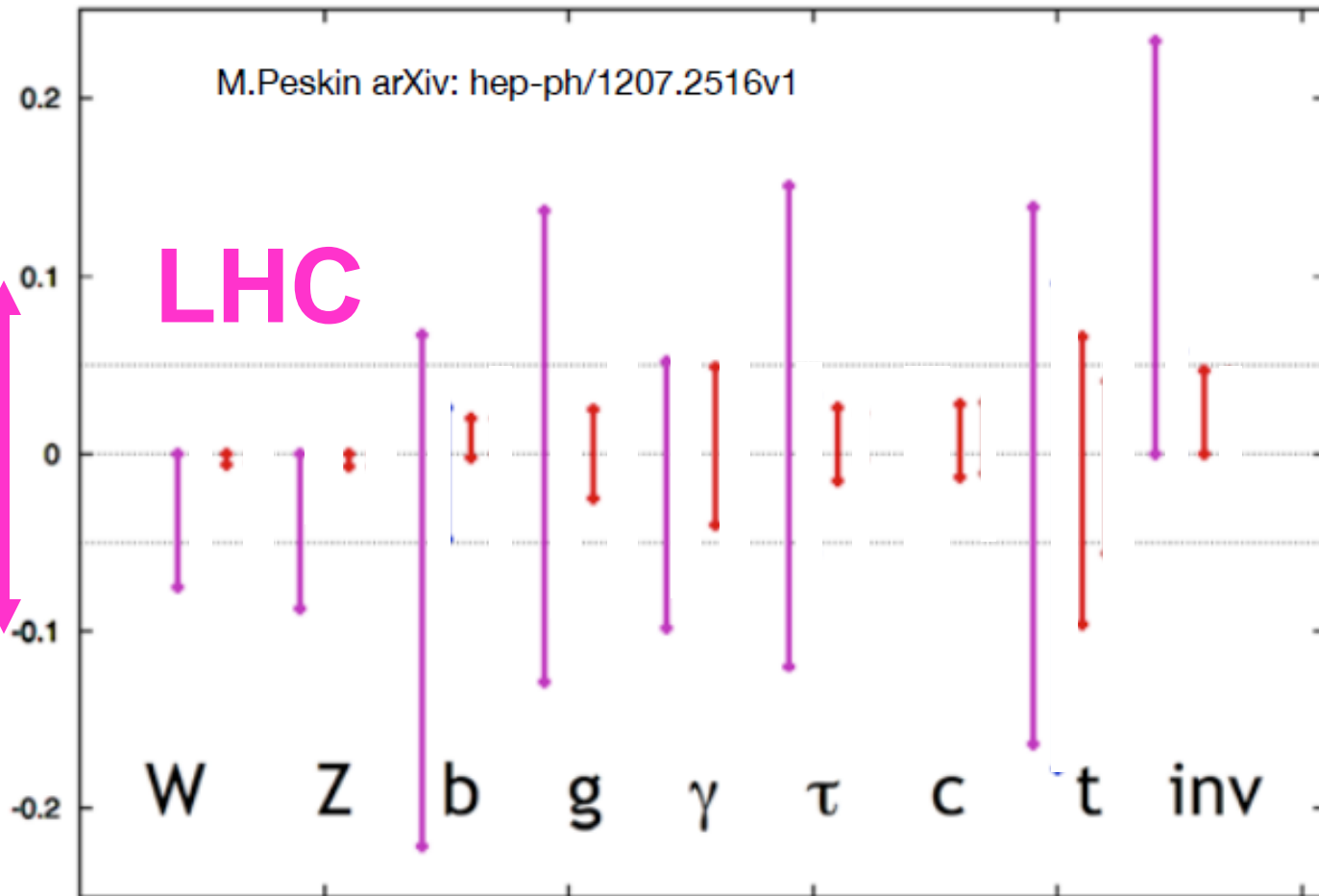
Higgs couplings determination

$g(hAA)/g(hAA)|_{SM} - 1$

M.Peskin arXiv: hep-ph/1207.2516v1

LHC

+/-10%



Super Large Electron Positron collider?



250 GeV

beams?

(2.5 x LEP)

Synch

rad →

700 MW

High energy electron-positron colliders

The path ahead is ...

linear

SLAC Linear Collider

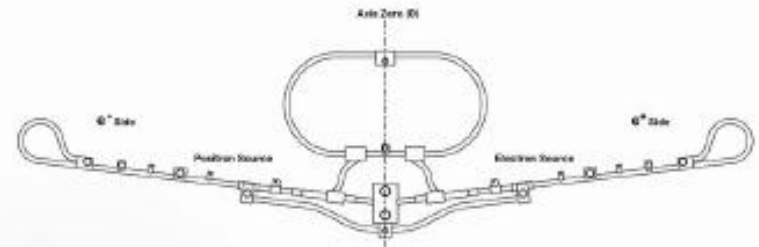
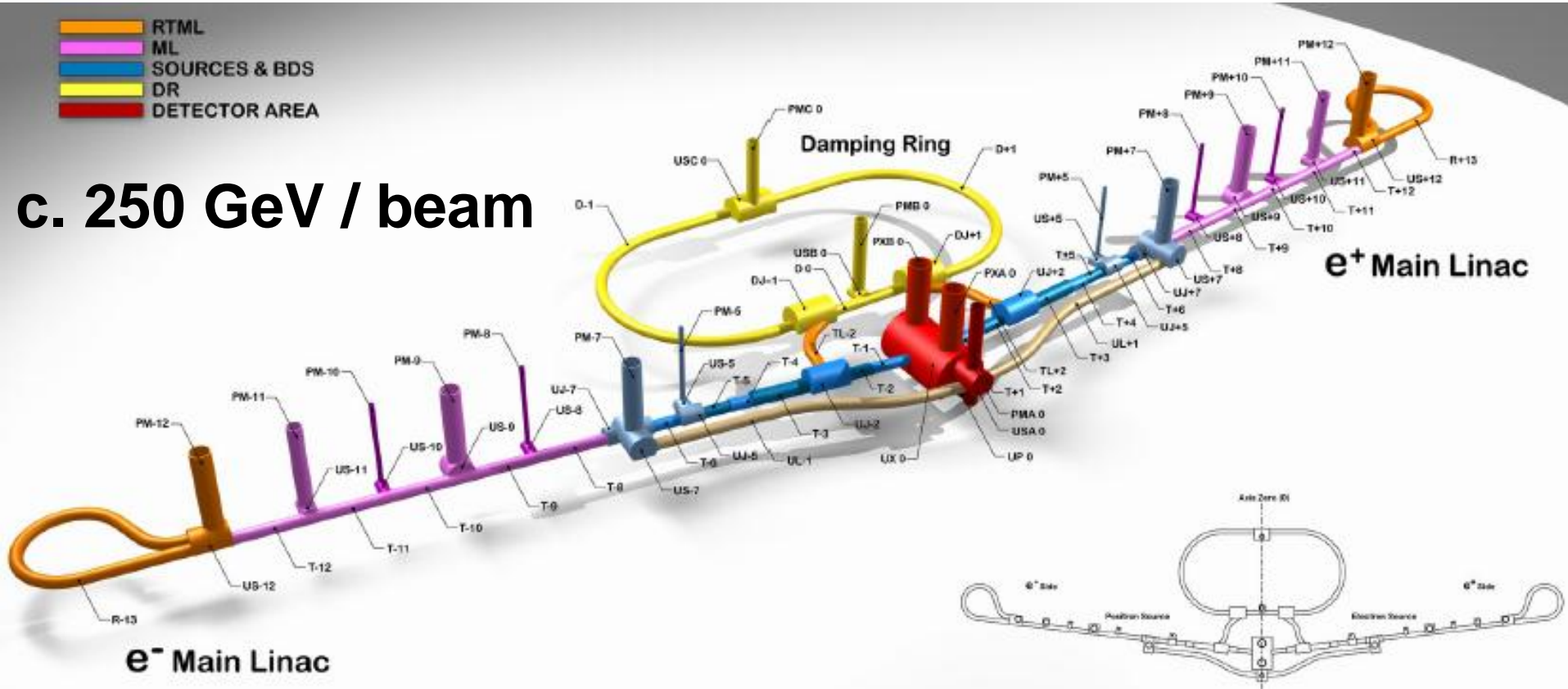
**c. 50 GeV
per beam**



International Linear Collider (ILC)

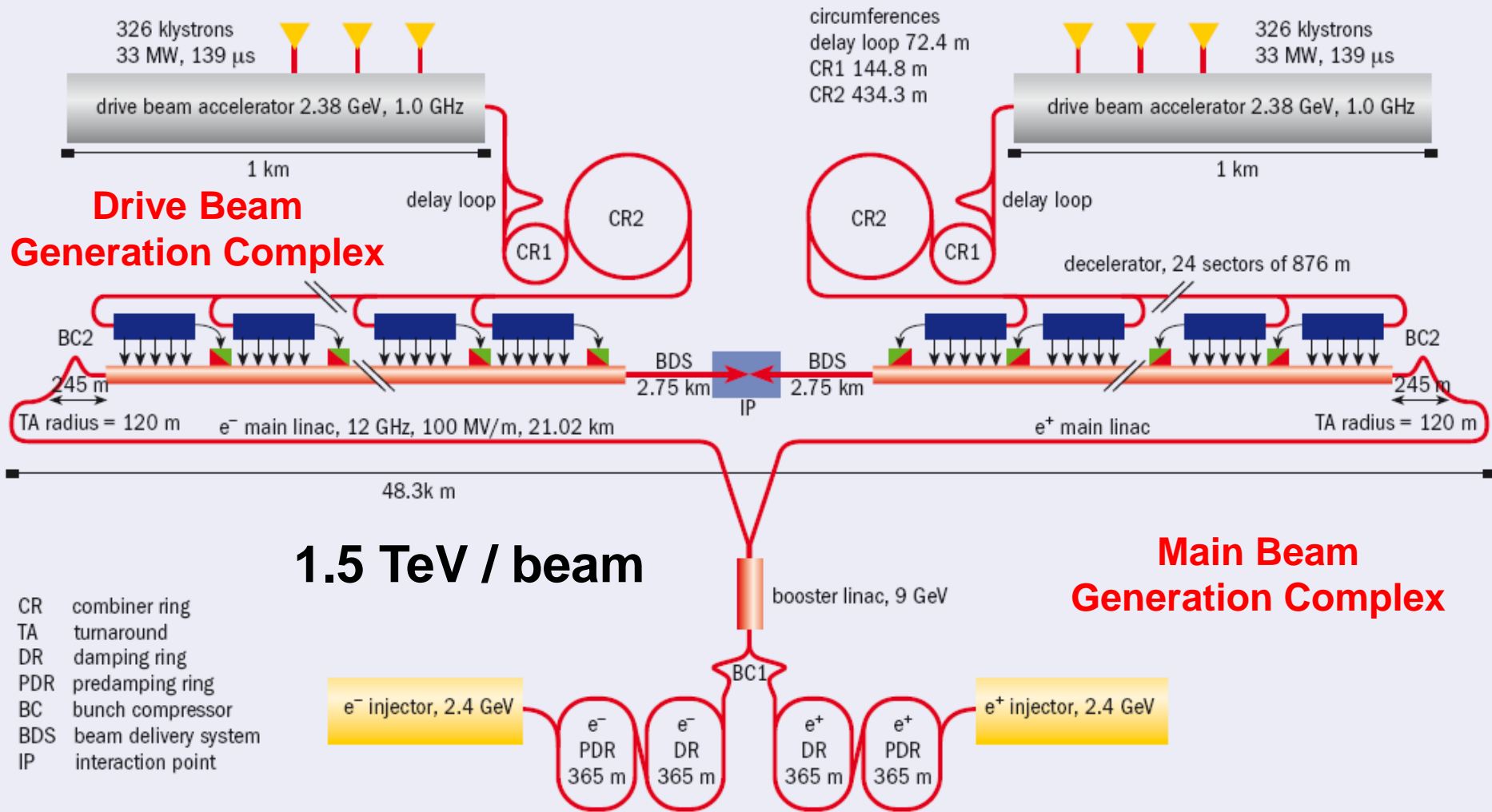
- RTML
- ML
- SOURCES & BDS
- DR
- DETECTOR AREA

c. 250 GeV / beam



31 km

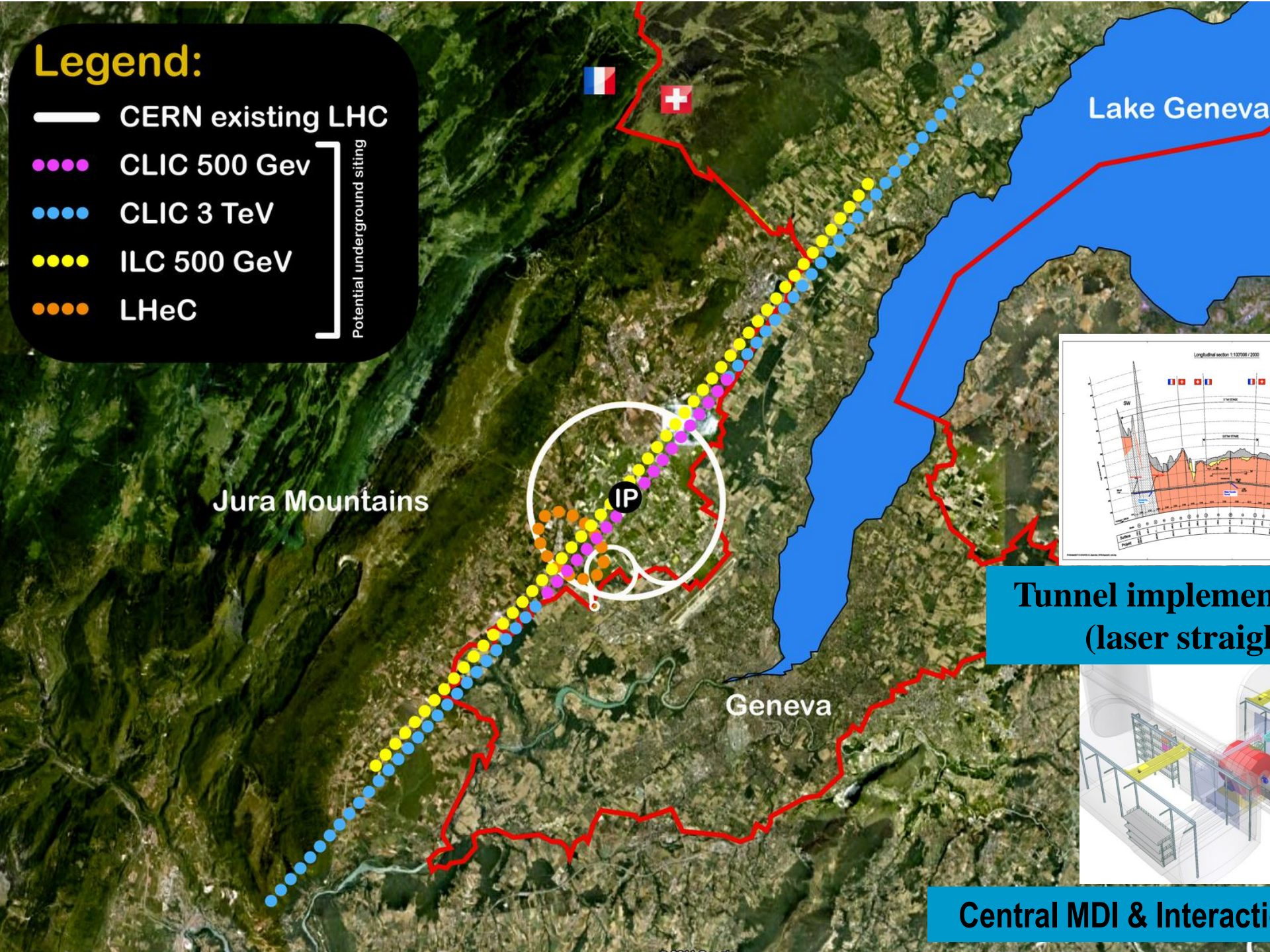
Compact Linear Collider (CLIC)



Legend:

- CERN existing LHC
- CLIC 500 GeV
- CLIC 3 TeV
- ILC 500 GeV
- LHeC

Potential underground siting



Lake Geneva

Jura Mountains

IP

Geneva

Tunnel implementation
(laser straight)

Central MDI & Interacti

Beam parameters

ILC (500)

Electrons/bunch	0.75	10**10
Bunches/train	2820	
Bunch separation	308	ns
Train repetition rate	5	Hz
Horizontal IP beam size	655	nm
Vertical IP beam size	6	nm
Luminosity	2	10**34

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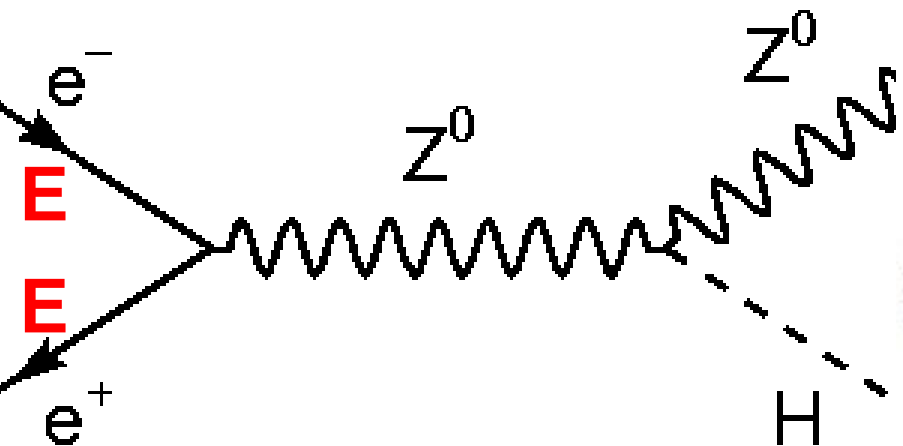
Like firing bullets to hit in middle ...



Like firing bullets to hit in middle ...

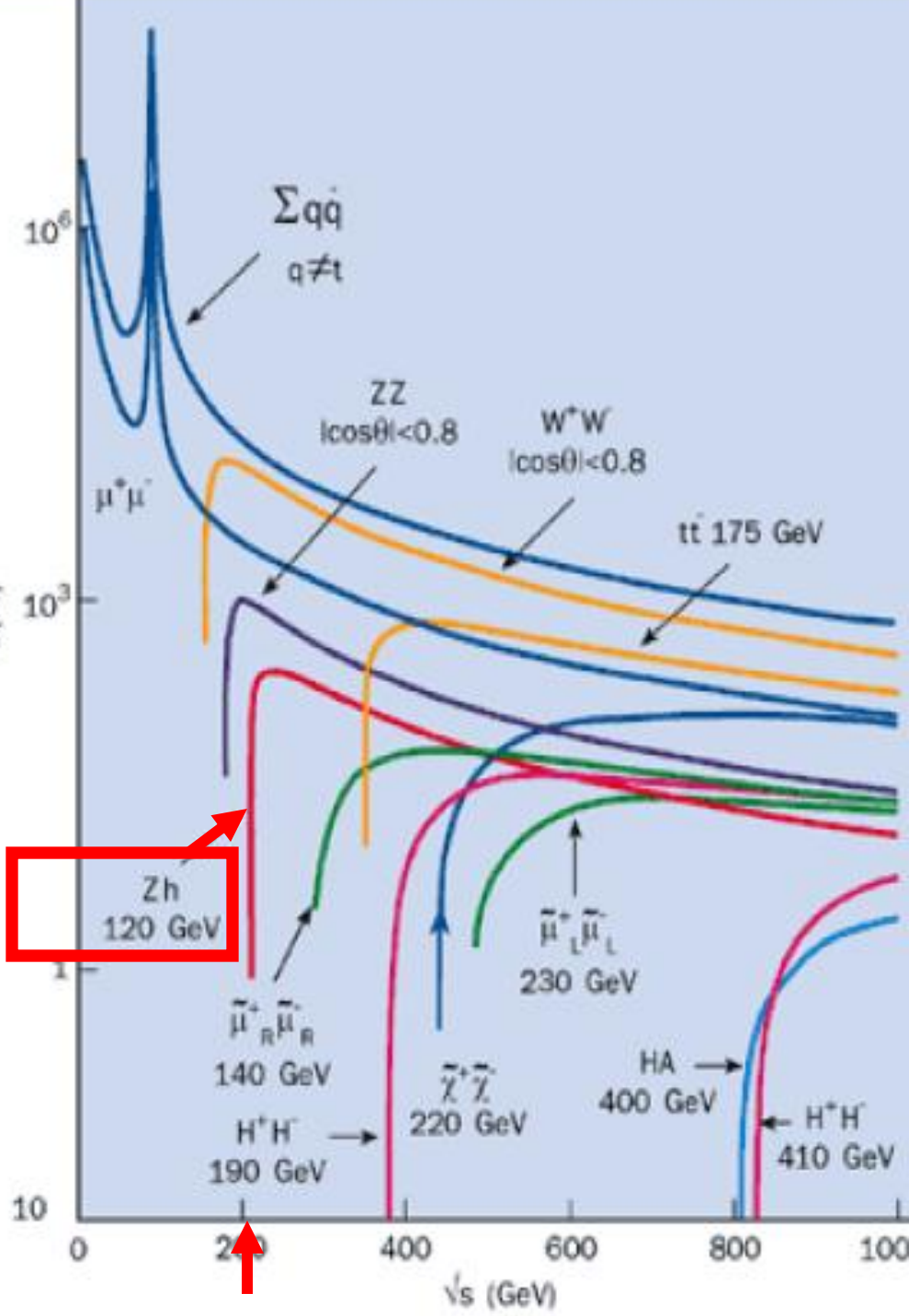


e+e- annihilations

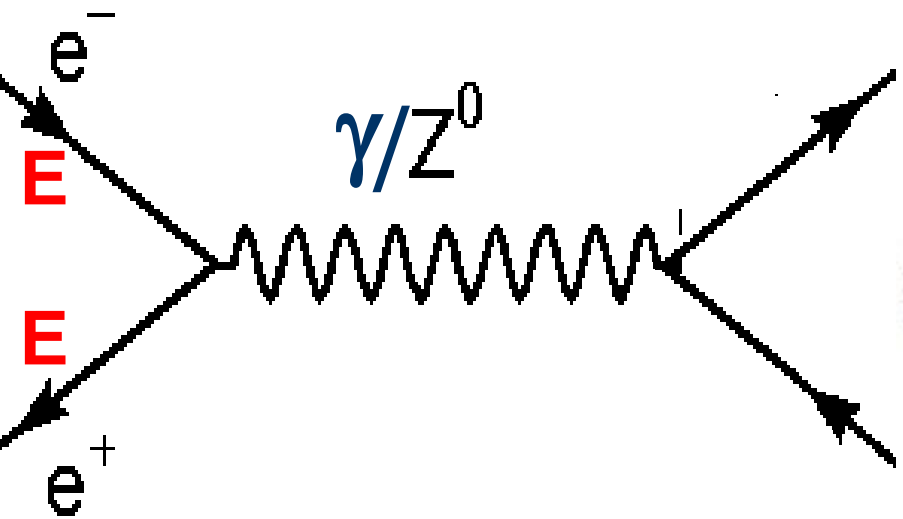


$2E > 220 \text{ GeV}$

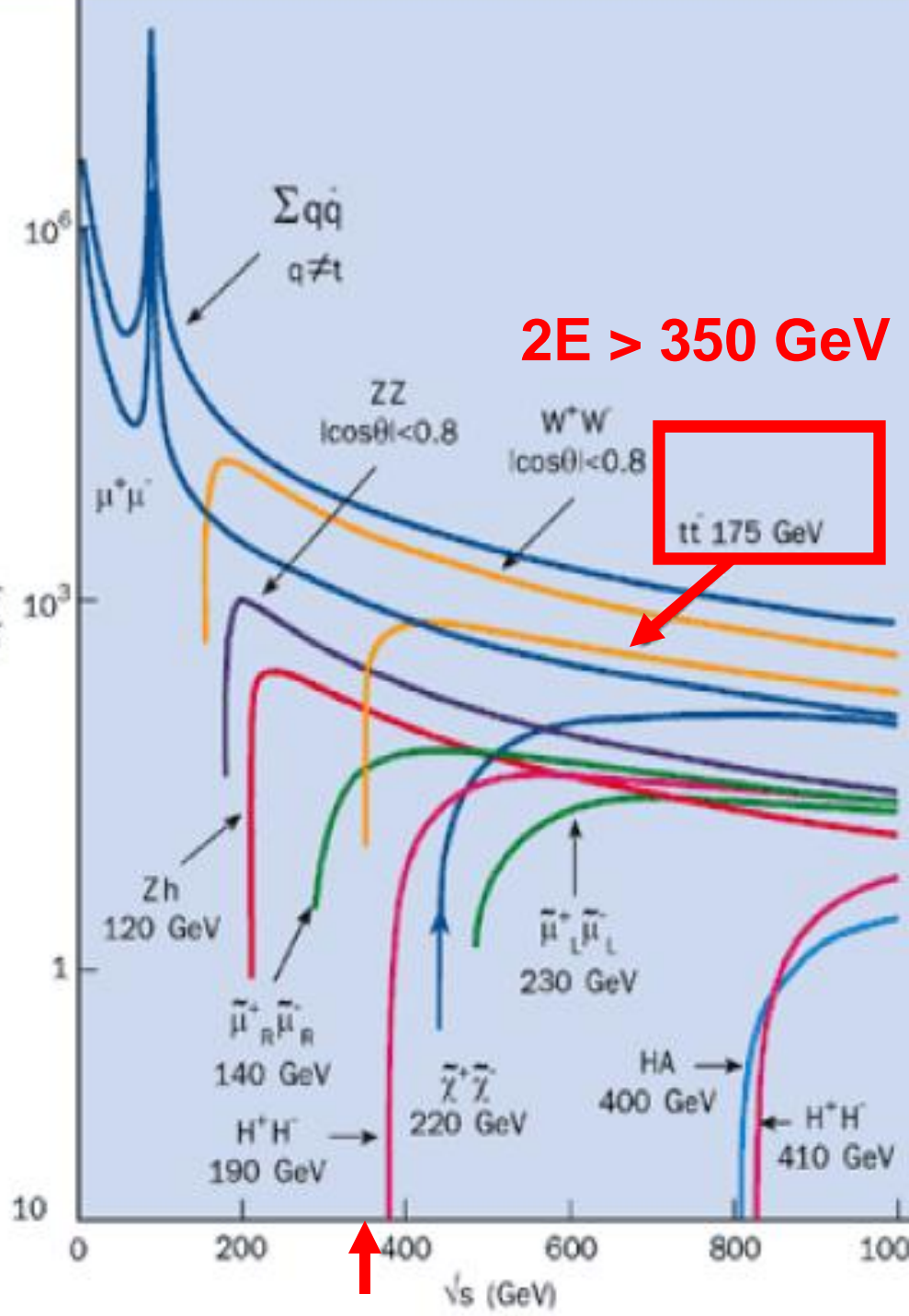
$\rightarrow 20,000 \text{ H / year}$



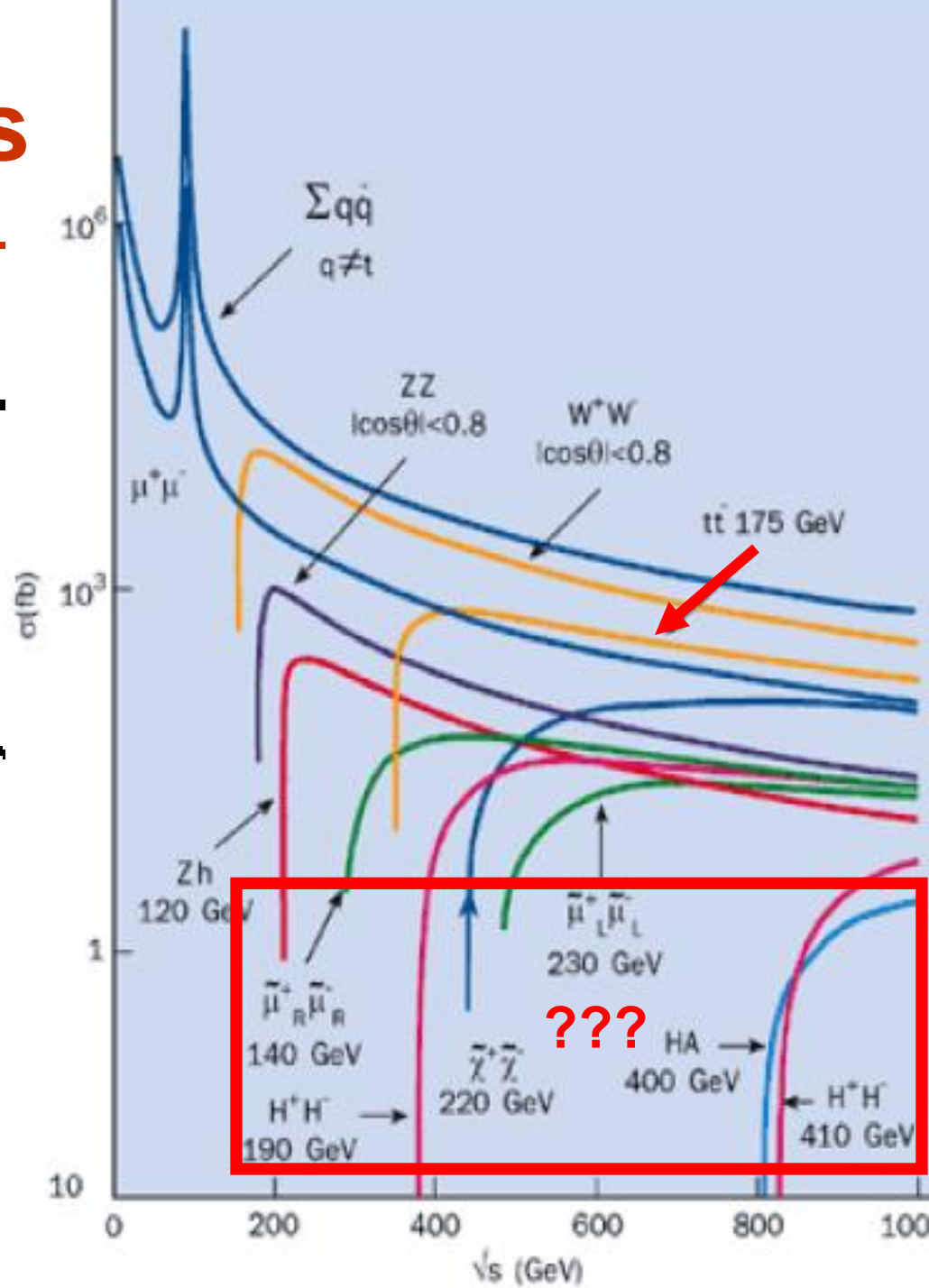
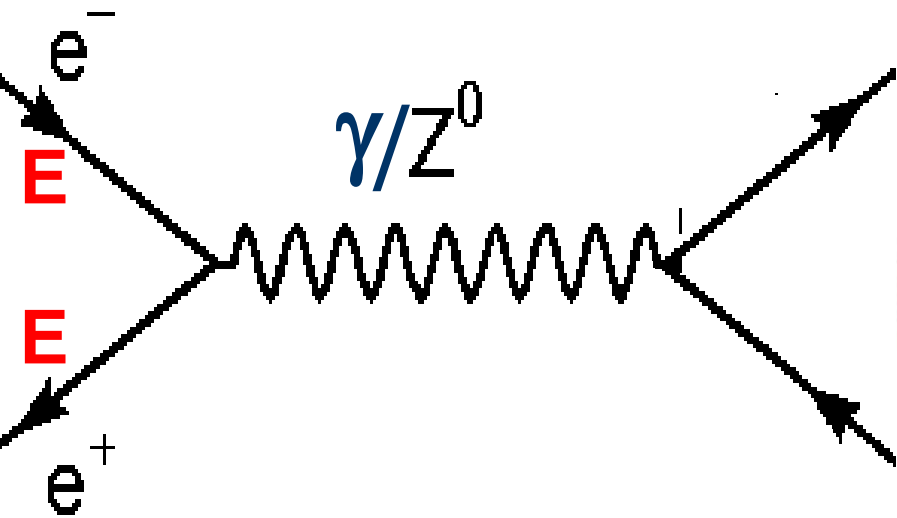
e+e- annihilations



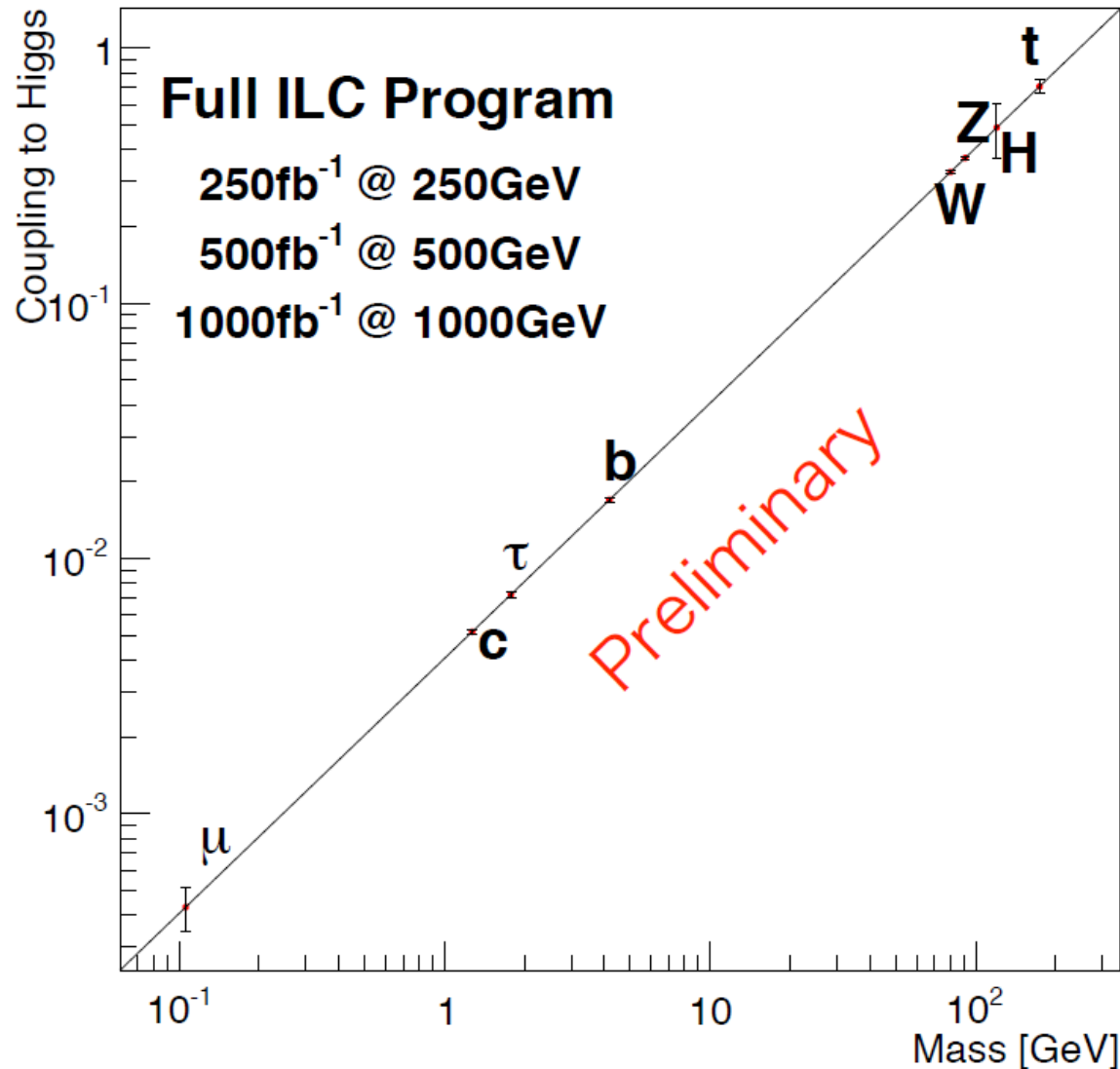
→ 100,000 t / year



e+e- annihilations

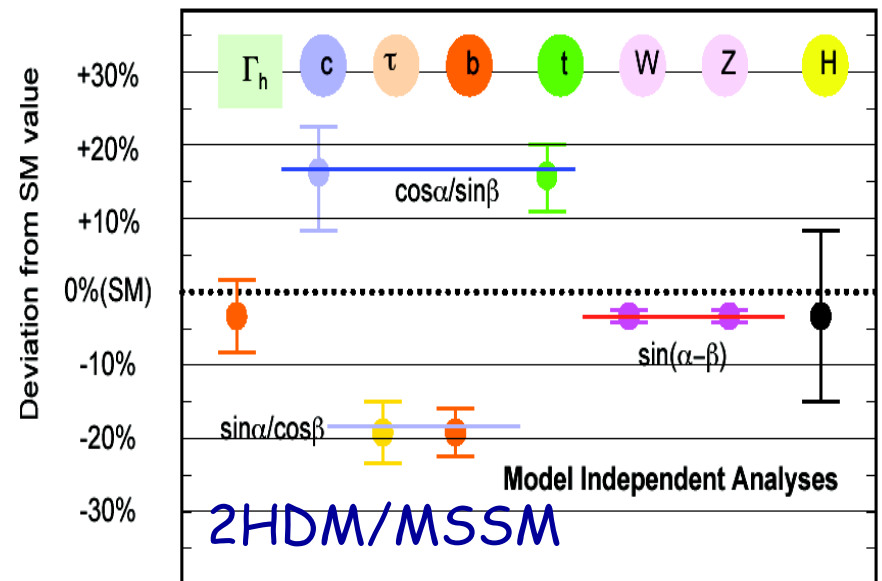
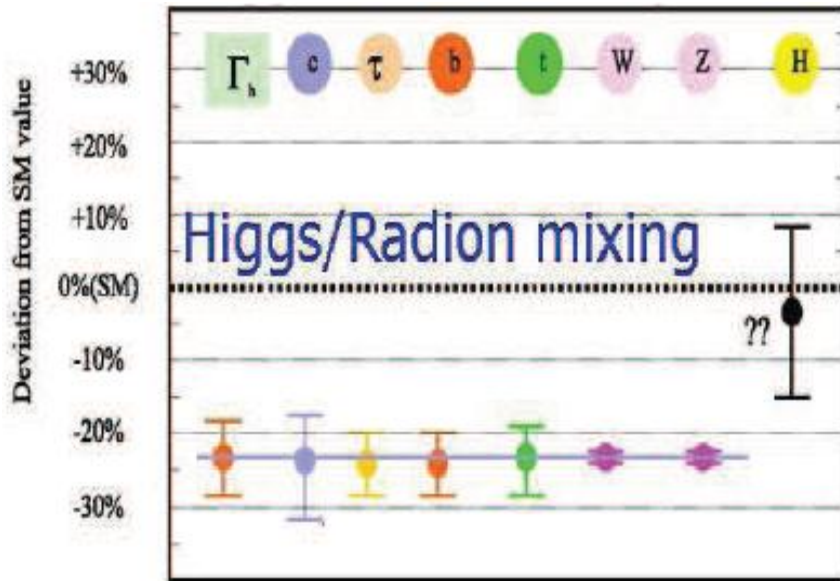


The Higgs coupling map



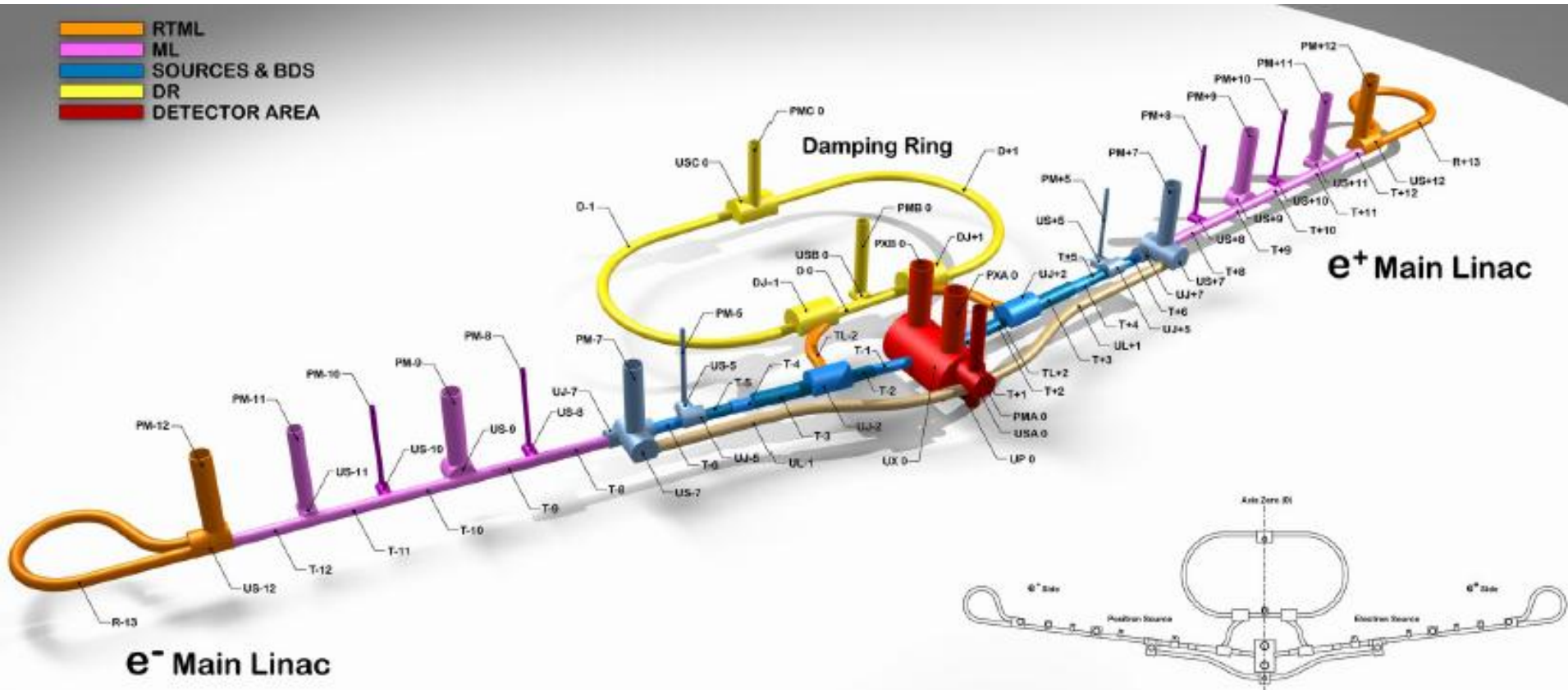
(Fujii)

Finger-printing the Higgs



Zivkovic et al

Higgs Factory: International Linear Collider



We are ready!

dimensions
of
particle
physics

symmetry

A joint Fermilab/SLAC publication

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most popular

June 14, 2013

The march of the penguin diagrams

More than 30 years ago, a physicist honored a bet by naming a particle decay diagram after an aquatic bird.

June 26, 2013

50-foot physics experiment on the move

Symmetry writer Andre Salles tells you everything you always wanted to know about moving a gigantic electromagnet but were afraid to ask.

July 8, 2013

Physics and the birth of the emoticon

Carnegie Mellon University alumni trace the origin of the smiley to a group of computer scientists discussing a physics puzzle in 1982.

symmetry tweets

July 09, 2013

Gunnar Maehlum, a particle physicist who took his ideas into the business world: <http://t.co/iqfscrAL0w> (by @GqrmGLO7AH)

July 08, 2013

Physics and the origin of the smiley: <http://t.co/iqfscrAL0w> (by @juliannewyrick)



At CERN, Global Design Effort European Regional Director Brian Foster (right) presents the report to International Committee for Future Accelerators member Gert Hoff-Dieter Heuer.

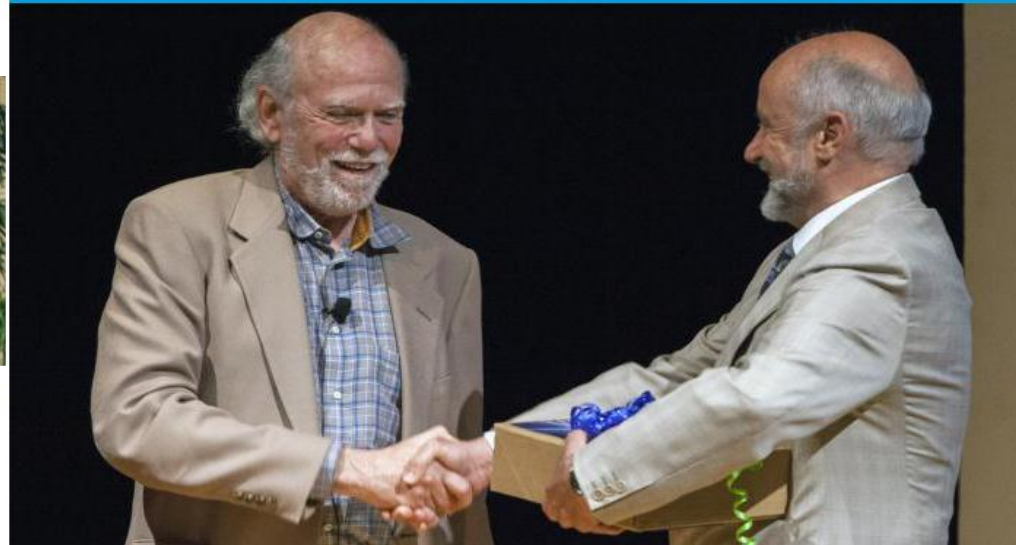


Photo: Cindy Arnold, Fermilab

breaking

June 13, 2013

International Linear Collider design is 'good to go'

After nearly a decade of R&D, the International Linear Collider global design effort crosses the finish line.

By Leah Hesla



PDF Download

Related *symmetry* content

[Explain it in 60 seconds: International Linear Collider](#)

[Deconstruction: The cherry pie collider](#)



Wrapping things off in Tokyo, Linear Collider Board Director Sachio Komamiya hands over the ILC Technical Design Report to Lyn Evans, Linear Collider collaboration director.

Photo: Nobuko Kobayashi, KEK

It's been noticed!

EXTREME TECH

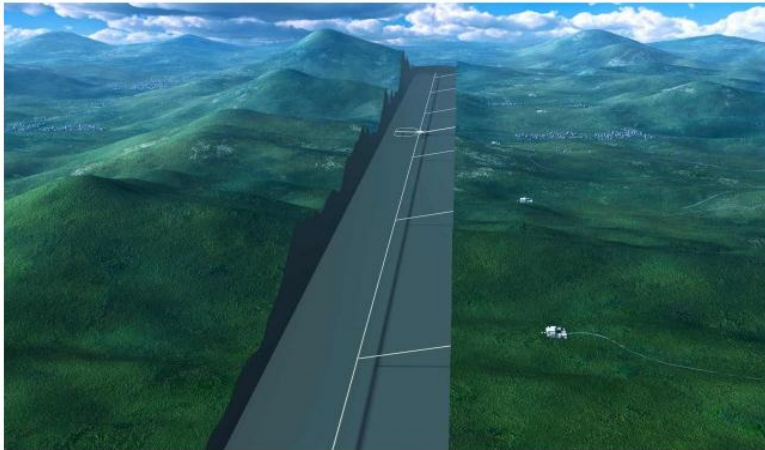
Top Searches: Windows 8 • Autos • Quantum • Intel Trending: Linux • Windows 8 • NASA • Batteries

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EXTREME > **NEW 19-MILE-LONG INTERNATIONAL LINEAR COLLIDER WILL INVESTIGATE THE HIGGS BOSON, DARK ENERGY, A**

New 19-mile-long International Linear Collider will investigate the Higgs boson, dark energy, multiple dimensions

By Sebastian Anthony on June 13, 2013 at 6:37 am | [36 Comments](#)



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The new 31-kilometer-long (19.2 mi) International Linear Collider (ILC) is finally ready for construction, according to CERN and the Linear Collider Collaboration. The ILC will initially augment the LHC's attempt to identify and characterize the Higgs

boson, but in the future it could investigate new areas such as supersymmetry, dark matter and energy, and the superstring theory of multiple dimensions, significantly advancing our knowledge of the universe.

CNET > News > Crave > Scientists unveil plans for 19-mile-long particle smasher

Scientists unveil plans for 19-mile-long particle smasher

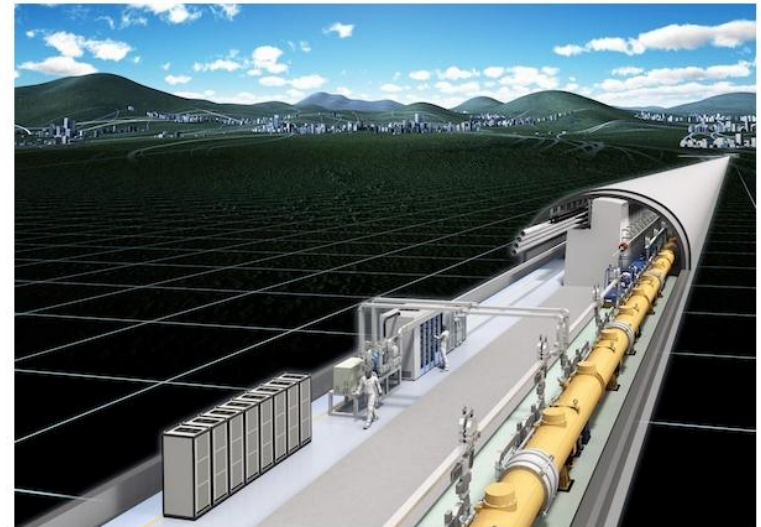
The blueprints are ready. If it gets funded, the multibillion-dollar International Linear Collider could help solve the mystery of cosmic dark matter.



by Tim Hornyak | June 12, 2013 1:38 PM PDT

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A rendering of the International Linear Collider, which could be built in the Japanese mountains. (Credit: Rey Hori/KEK)

The Large Hadron Collider is a monumentally awesome machine, and has given us tentative confirmation of the existence of the **Higgs boson**, the so-called "God particle." Now scientists hope to follow that with a new accelerator that could explain what makes up 95 percent of the universe.

What will happen?

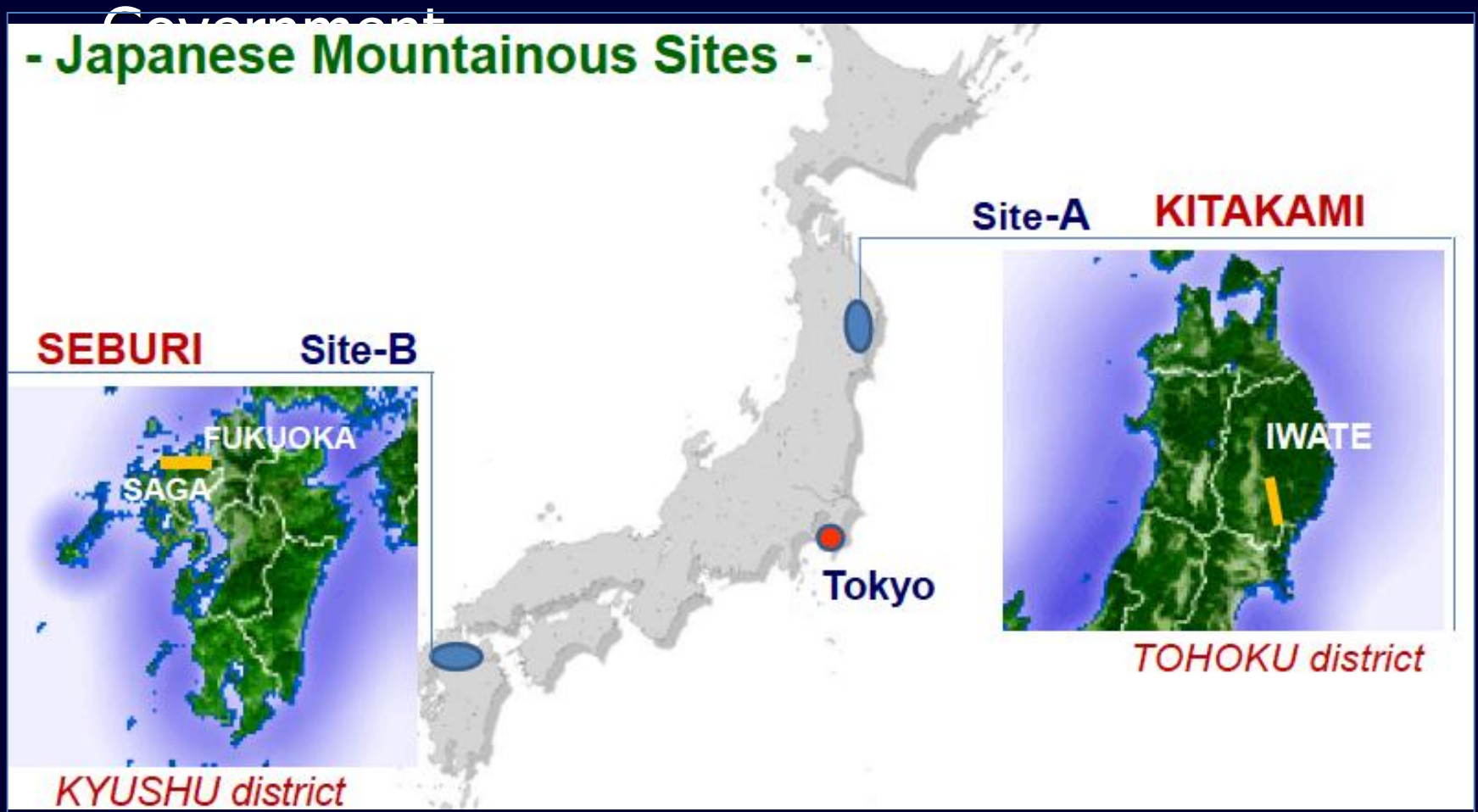


ILC Plan in Japan

- ▶ Japanese HEP community proposes to host ILC based on the “staging scenario” to the Japanese Government.
 - ILC starts as a 250GeV Higgs factory, and will evolve to a 500GeV machine.
 - Technical extendability to 1TeV is to be preserved.

ILC Plan in Japan

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ILC Plan in Japan

Our new prime minister
Shinzo Abe



LDP policy document
for the election

The ILC appears twice explicitly in
the policy document:

- Science and technology policies
- Creation of top-class research centers

It's been noticed!

Japan a candidate to house planned super-collider

June 13, 2013

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By AKIRA HATANO/ Staff Writer

An international physicist group plans to build an \$8.75 billion (830 billion yen) particle accelerator with Japan as a leading candidate to be home to the 31-kilometer, next-generation super-collider.

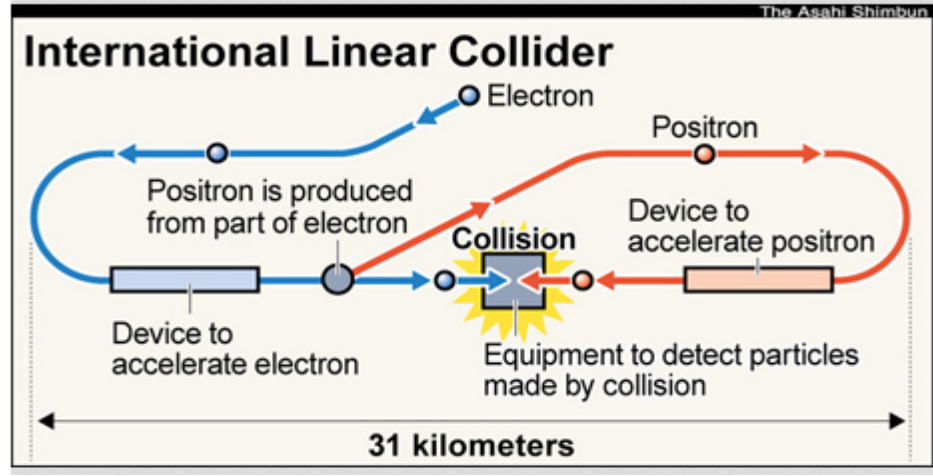
The Linear Collider Collaboration project team released a technical design report on June 12 for the International Linear Collider project in the hope of unraveling more mysteries of the universe using a huge particle accelerator.

According to its report, the length of the planned collider is 31 kilometers, which would make it the longest in the world.

Japan and the United States, along with nations in Europe and elsewhere, will discuss the feasibility of the collider construction based on the report.

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European particle physics strategy 2013

There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded.

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The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate.

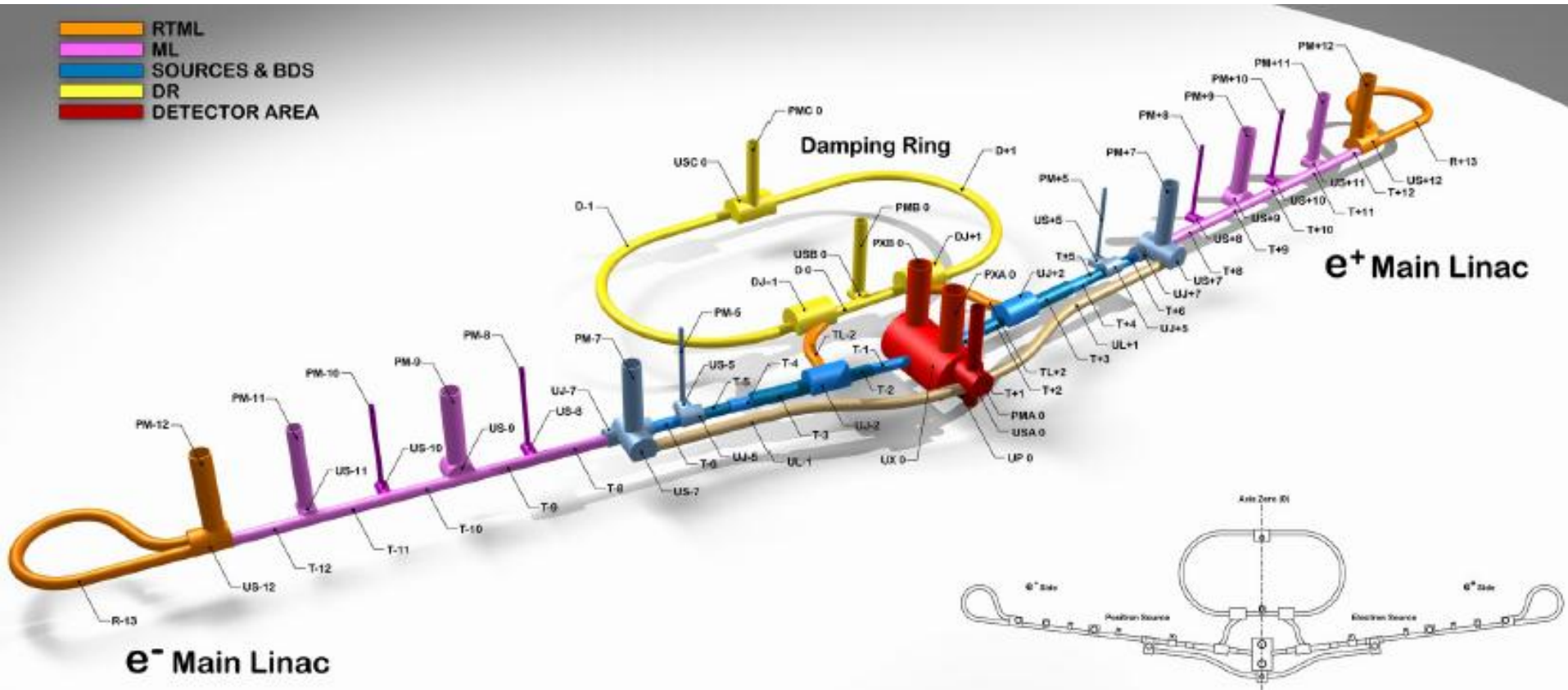
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Europe looks forward to a proposal from Japan to discuss a possible participation.

Higgs Factory: International Linear Collider



Microscope on the new boson

