Introduction to Particle Physics and Cosmology

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11 Lecture Course, module 03 17484

Course material (linked from the **WebCT page**)
https://www.ep.ph.bham.ac.uk/twiki/bin/view/General/Y1IntroToPpc
"Office hours" – 1300-1500 same day as lectures.

Cosmology, AV: linked from above page

Course Aims

- Provide a broad overview of current topics in Particle Physics and Cosmology
- Put emphasis on the questions or problems rather than on the solutions
- "Whet your appetite" so you can choose the most interesting area to you

- This course is not meant to
  - Confuse you
  - Answer any of the questions in any detail ☺

Learning / Assessment

Recommend

- Attending the Lectures (important!)
- Going through the unassessed problem sheets
  - See web pages – separate for PP and Cosmology
- Using references, mainly to help with problem sheets
- "Reading around" the subject for background information
  - It is really interesting (really)
  - If you find questions related to PP, bring them in!

Assessment will be through a single, 1 hour exam

References

- Particle Physics
  - *Particle Physics*, Martin and Shaw,
  - *High Energy Physics*, D.H. Perkins (2nd-4th editions OK)
  - *Feynman Lectures*, R.P. Feynman
  - (Friedman and Young also useful in places)

- Cosmology
  - An Introduction to Modern Cosmology, A. Liddle
  - Universe, W.J. Kaufmann and R.A. Freedman

For this course you are not expected to read them all

Course Overview

L1: Introduction to the course

Particle Physics

L2: Particles and Interactions

L3: Symmetries in PP

L4: Physics/Unification of Forces / Higgs

L5: Status of Standard Model and extensions

Cosmology

L6: Review of Big Bang Cosmology

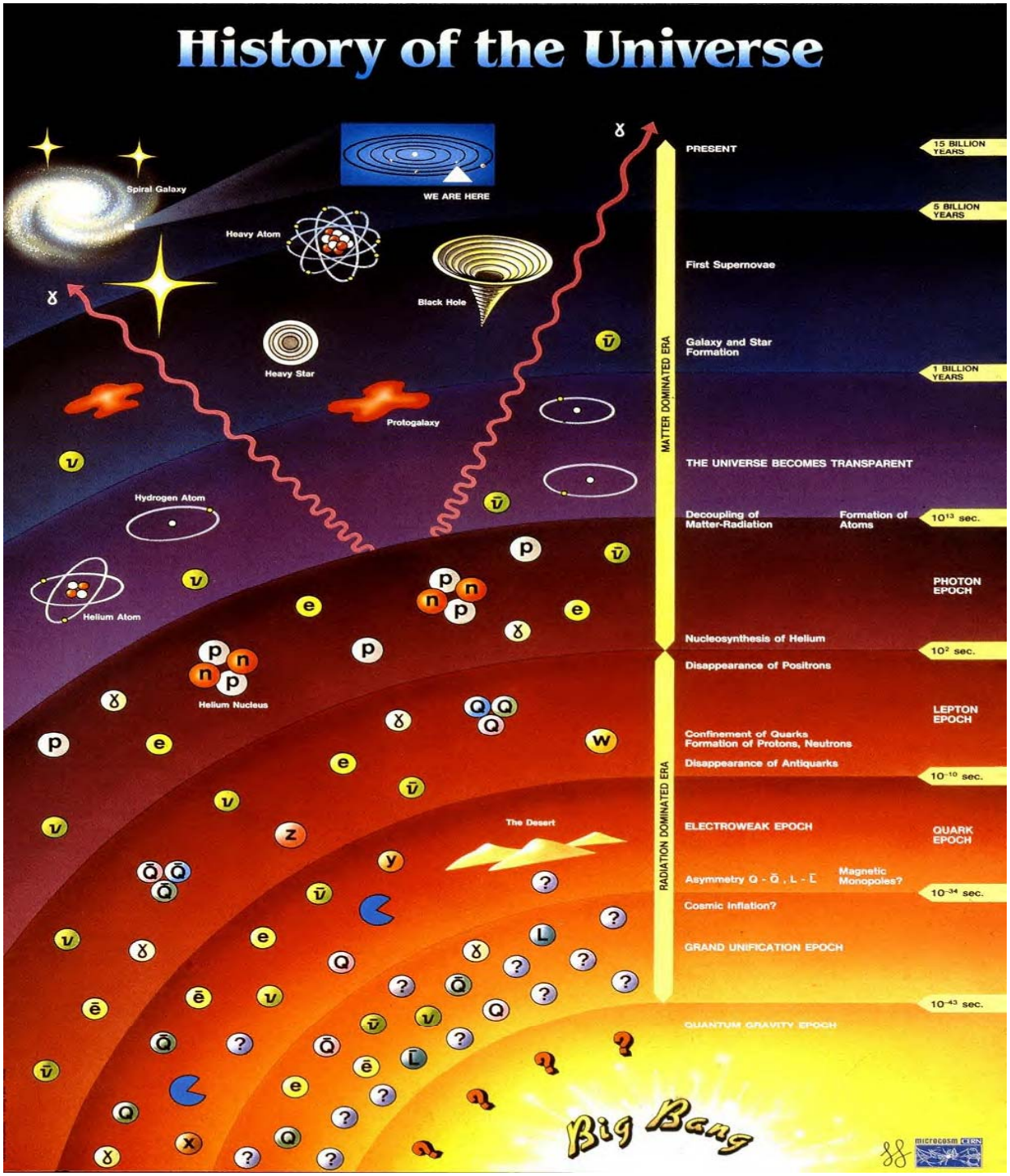
L7: The Friedmann Equation

L8: Cosmic Microwave Background

L9: Puzzles in Cosmology

L10: Cosmology or Particle Physics

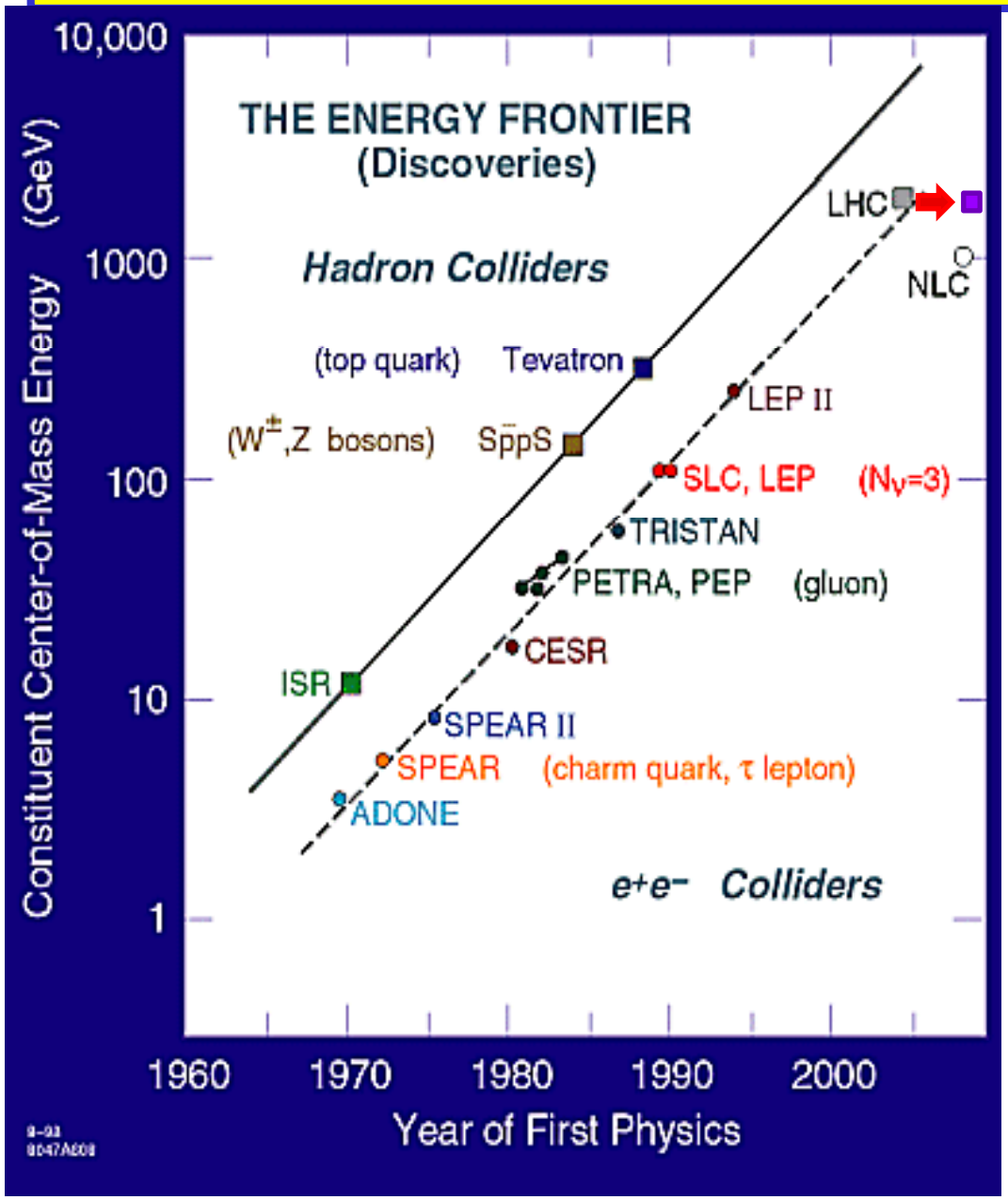
L11: Review/Revision Lecture – early in summer term



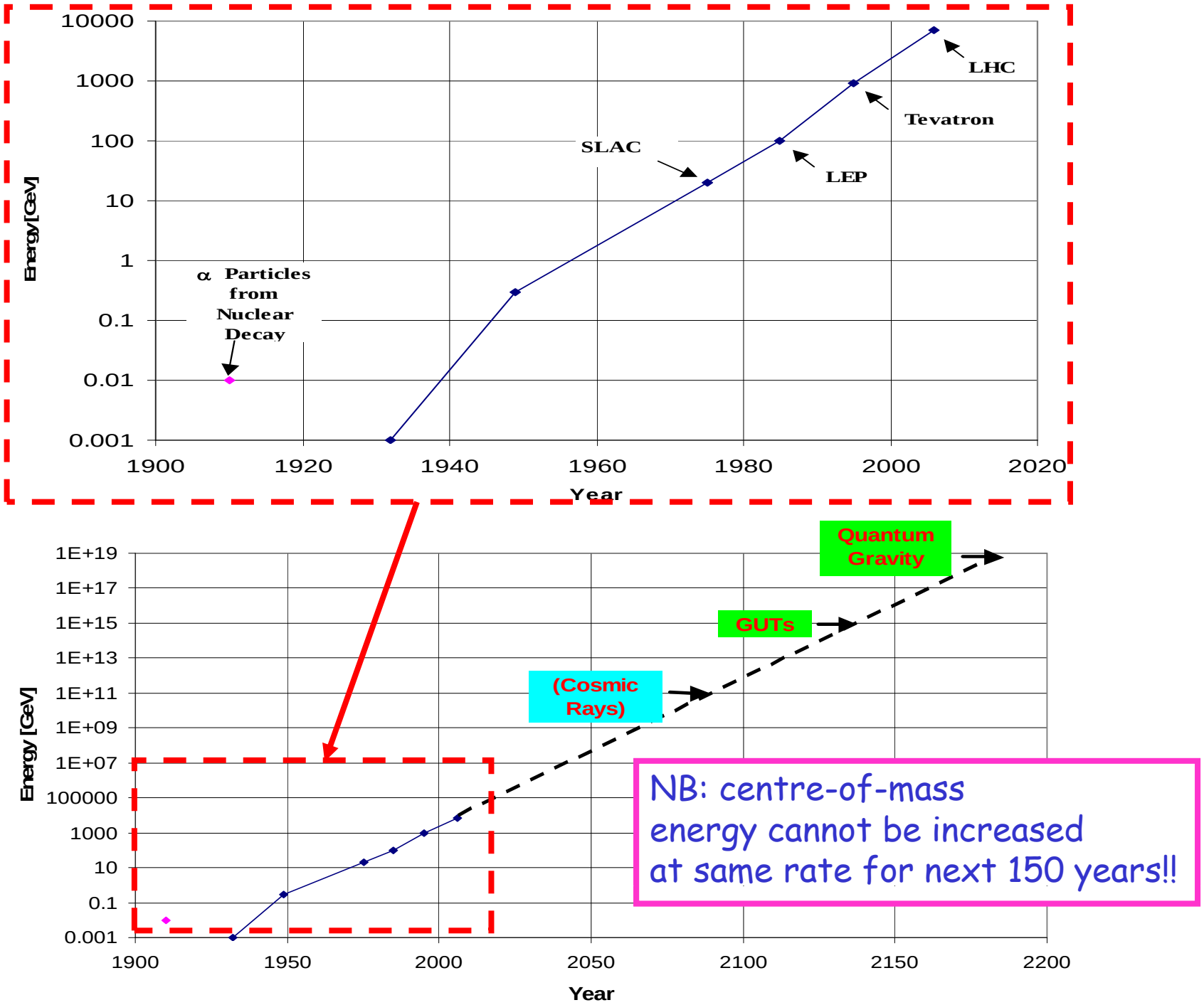
cosmology

Particle physics

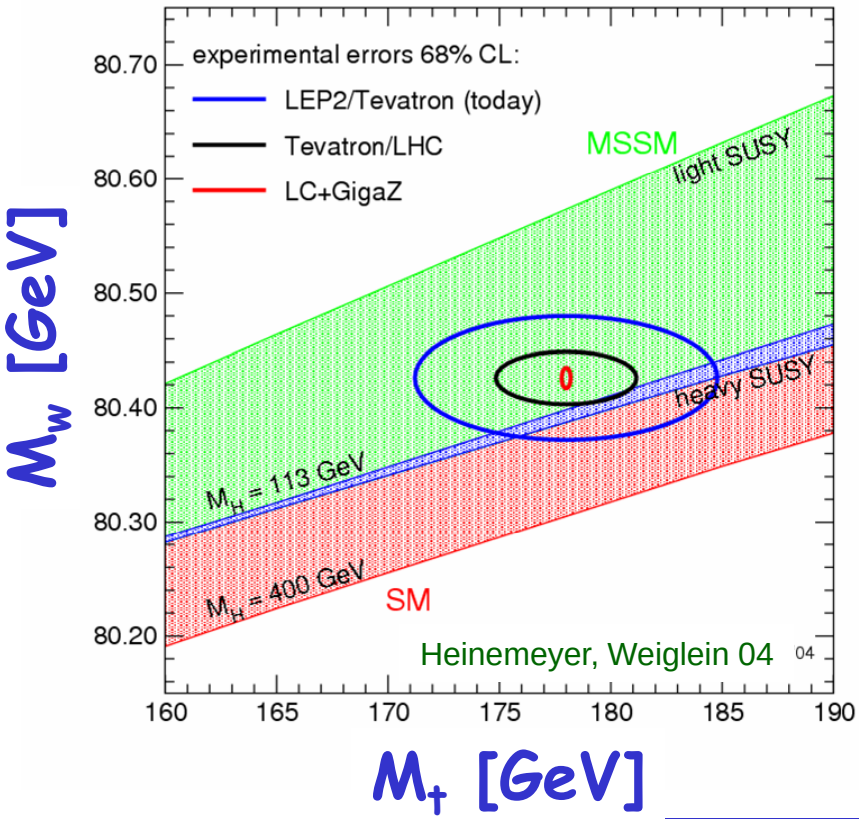
Energy Frontier e^+e^- Colliders



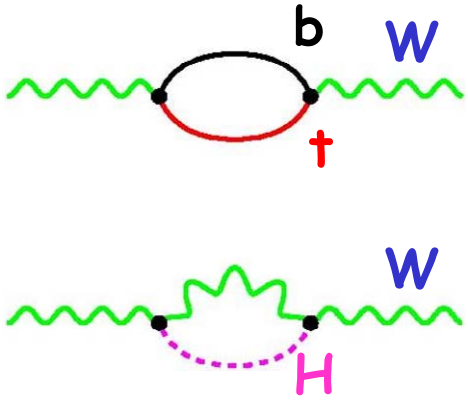
[c/o/ N.Walker]


10000
1000
100
10
1
0.1
0.01
0.001
Energy [GeV]
1900
1920
1940
1960
1980
2000
2020
Year
α Particles from Nuclear Decay
SLAC
LEP
Tevatron
LHC
1E+19
1E+17
1E+15
1E+13
1E+11
1E+09
1E+07
100000
1000
10
0.1
0.001
Energy [GeV]
1900
1950
2000
2050
2100
2150
2200
Year
(Cosmic Rays)
GUTs
Quantum Gravity
NB: centre-of-mass energy cannot be increased at same rate for next 150 years!!

Precise measurements



Mw sensitive to top, Higgs via loops

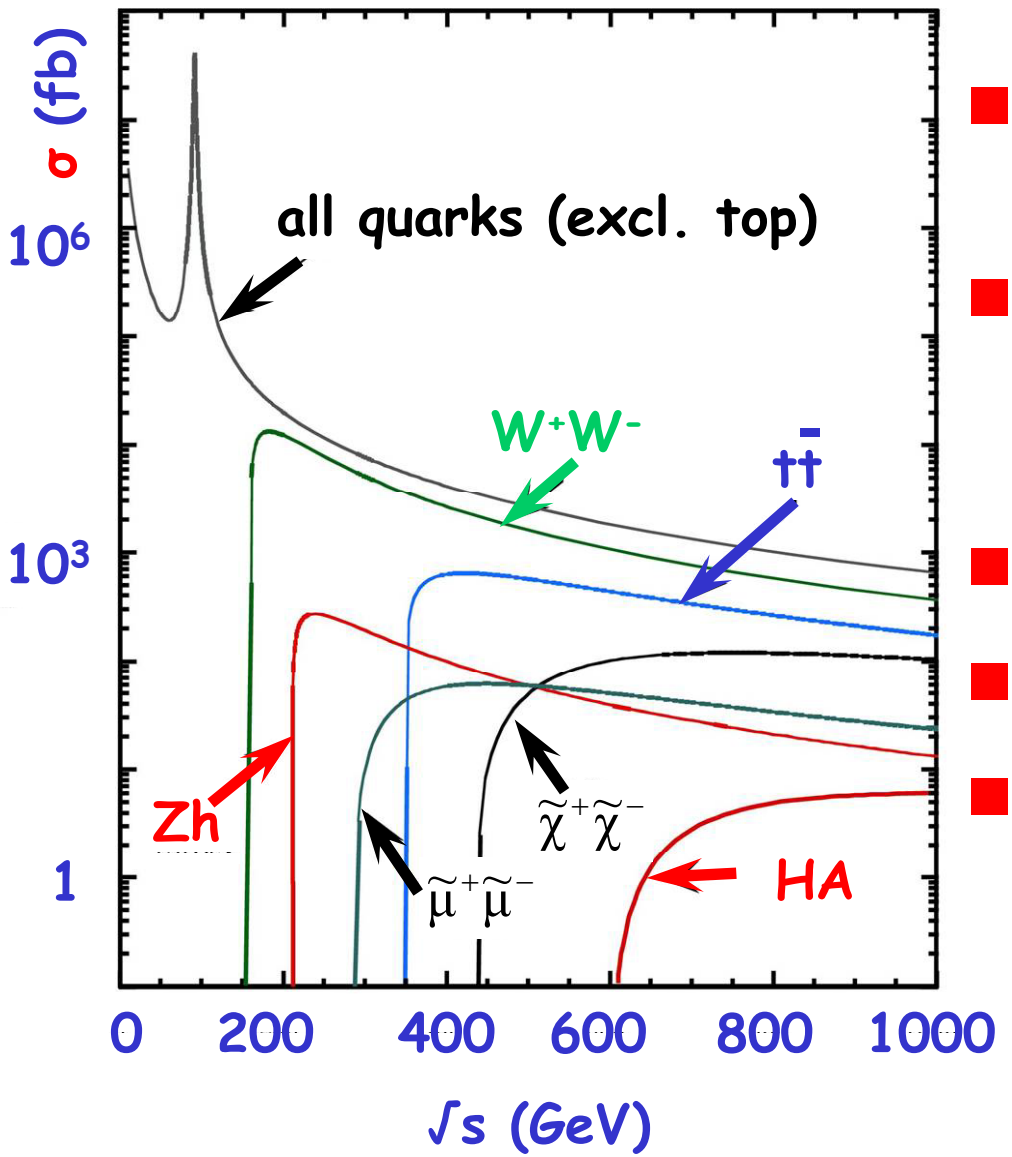


[Heinemeyer et al (LHCLC report)]

	δm_W (MeV)	δm_{top} (GeV)	$\delta \sin^2\theta_{5eff} \times 10$
now	34	3.9	17
TeV Run 2	16	1.4	29
LHC	15	1.0	14-20
ILC-GigaZ	7	0.1	1.3

[after Stirling, ECFA w/s, Durham Sep.04]

High Energy e^+e^- Collider Physics



- Interesting physics requires high energies
- Event Rate,
  $R = L(cm^{-2}s^{-1})\ \sigma(cm^2)$
  Units of σ: b("barn")=$10^{-24}cm^{-2}$
- Cross-sections (σ) v. small
- Need high luminosity (L)
- New challenge: "beamstrahlung"

e.g. LHC-LC Study Group,
Georg Weiglein et al.,
hep-ph/0410364 (485 pages)

Why a Linear Collider after LEP?

		LEP-II	Super-LEP	Hyper-LEP
E_{cm}	GeV	180	500	2000
L	km	27	200	3200
ΔE	GeV	1.5	12	240
$\$_{tot}$	10^9 CHF	2	15	240

Cost/size optimisation

- RF power to balance synchrotron radiation losses: $\Delta E \propto E^4/\rho m^4$
- Magnets & tunnel: linear, proportional to ρ

Optimal when these are comparable

$\Rightarrow$ Cost scales as E^2

ρ is radius of synchrotron
m is particle mass

[c/o/ N.Walker]

Luminosity: storage ring vs. LC

Event rate=luminosity x reaction cross-section

"Cross-section" from PP theory: [area] (1 "barn"=10^{-24}cm^2)

"Luminosity" (L) from accelerator design: 1/[area][time]

LEP f_{rep} = 44 kHz

LC f_{rep} = few-100 Hz
(power limited)

$$L = \frac{f_{rep}}{4\pi} \frac{n_b N^2}{\sigma_x \sigma_y} H_D$$

⇒ factor ~400 in L already lost

Solution: very small beam cross-section at "IP" (interaction point)

LEP: $\sigma_x \sigma_y \approx 130 \times 6\ \mu m^2$

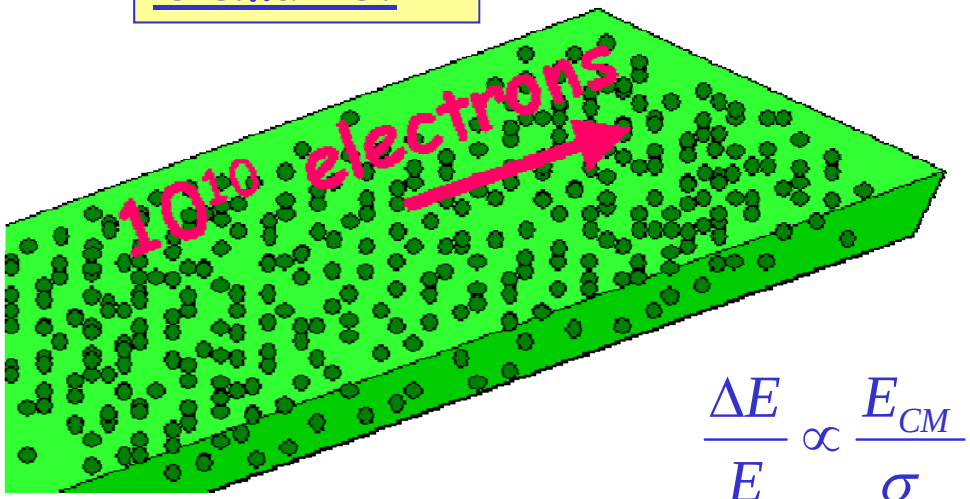
LC: $\sigma_x \sigma_y \approx (200\text{-}500) \times (3\text{-}5)\ nm^2$

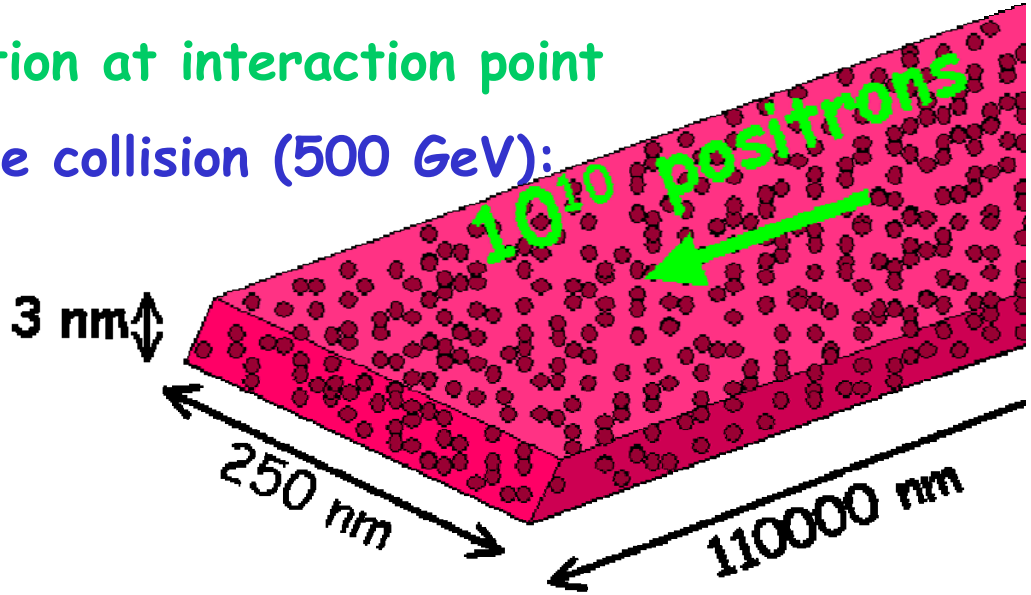
Factor of 10^6 gain!
Needed to obtain high luminosity of a few 10^{34} cm^{-2}s^{-1}

Luminosity

- High luminosity achieved by
  - Many incident particles
  - Small transverse cross-section at interaction point
- e.g., LC beam sizes just before collision (500 GeV):
  250 * 3 * 110000 nm
  (x y z)

vertical size is smallest



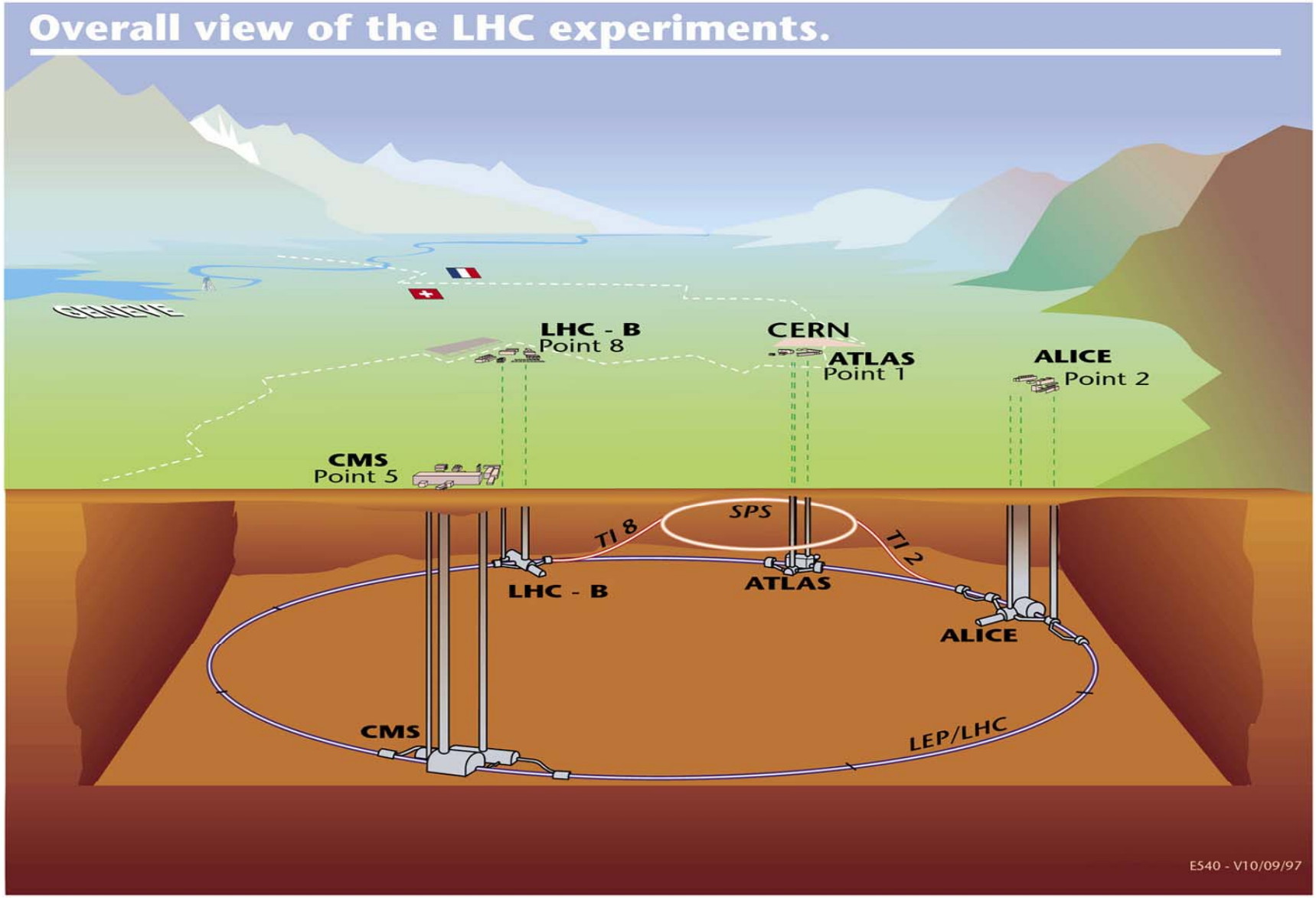


$$\frac{\Delta E}{E} \propto \frac{E_{CM}}{\sigma_z} \frac{N^2}{(\sigma_x + \sigma_y)^2}$$

$$L = \frac{f_{rep}}{4\pi} \frac{n_b N^2}{\sigma_x \sigma_y} H_D$$

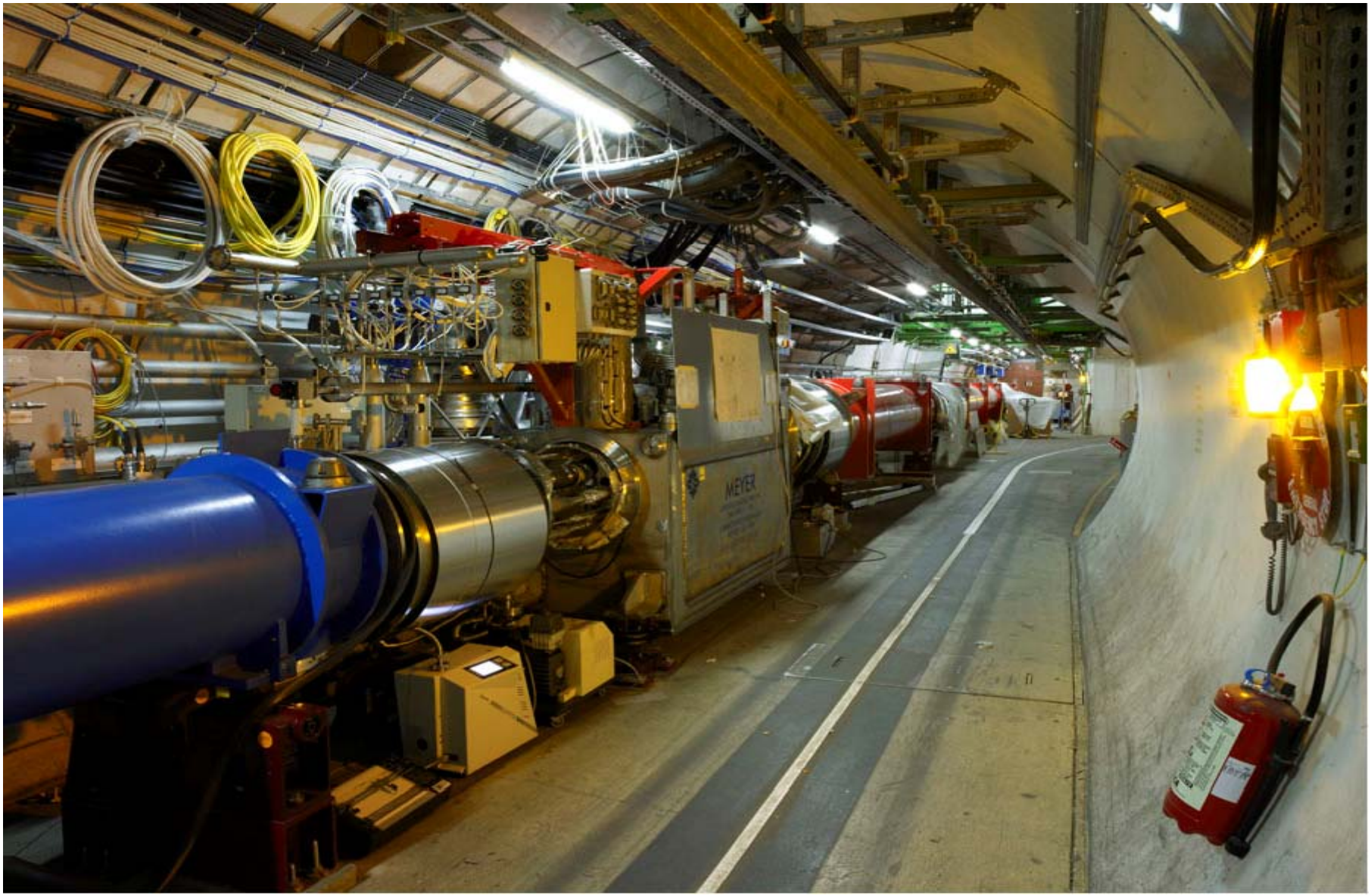
[c/o A.Seryi]

Large Hadron Collider (LHC)



ATLAS: 100m underground

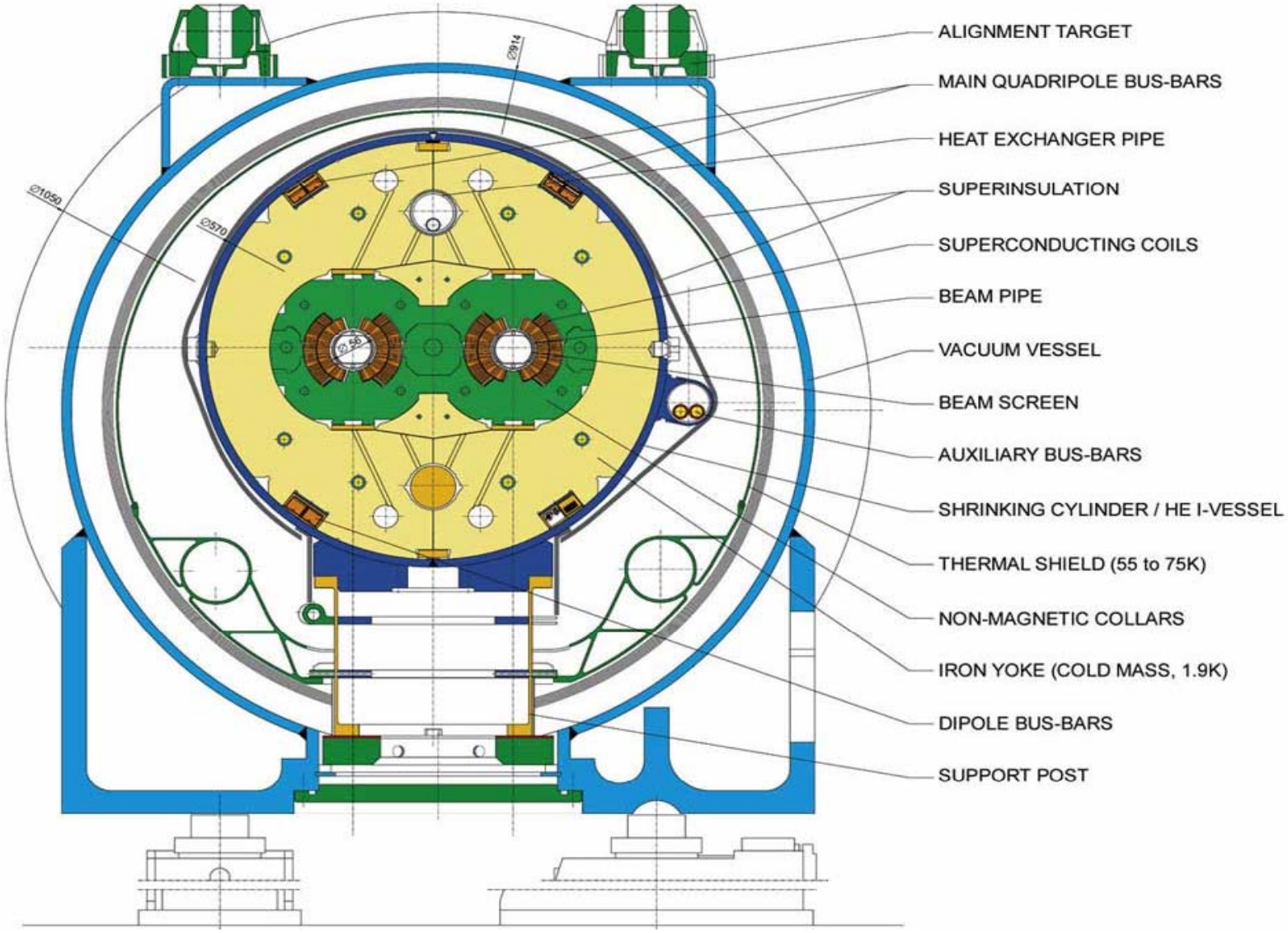
LHC beamline



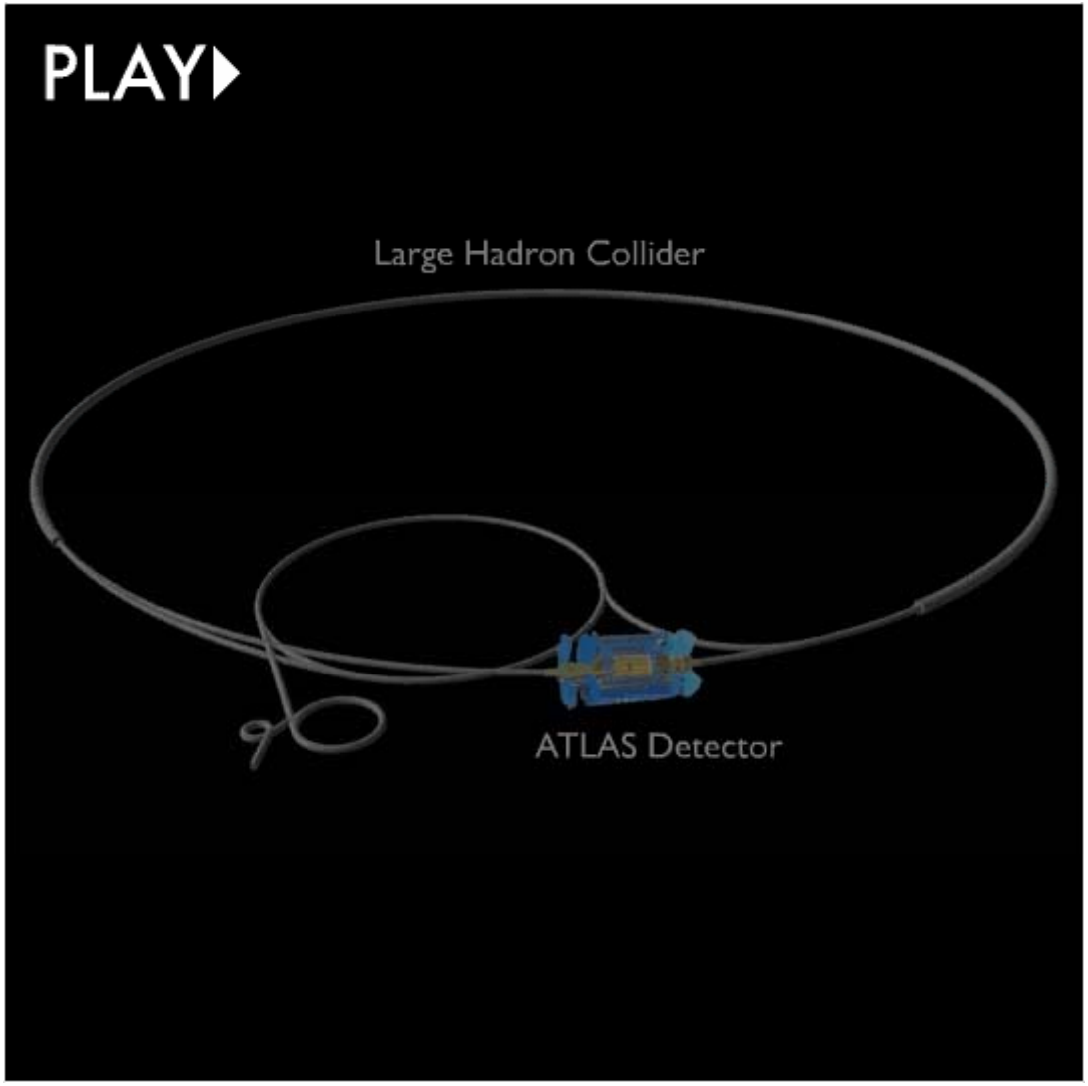
Superconducting magnets (1K)

LHC DIPOLE : STANDARD CROSS-SECTION

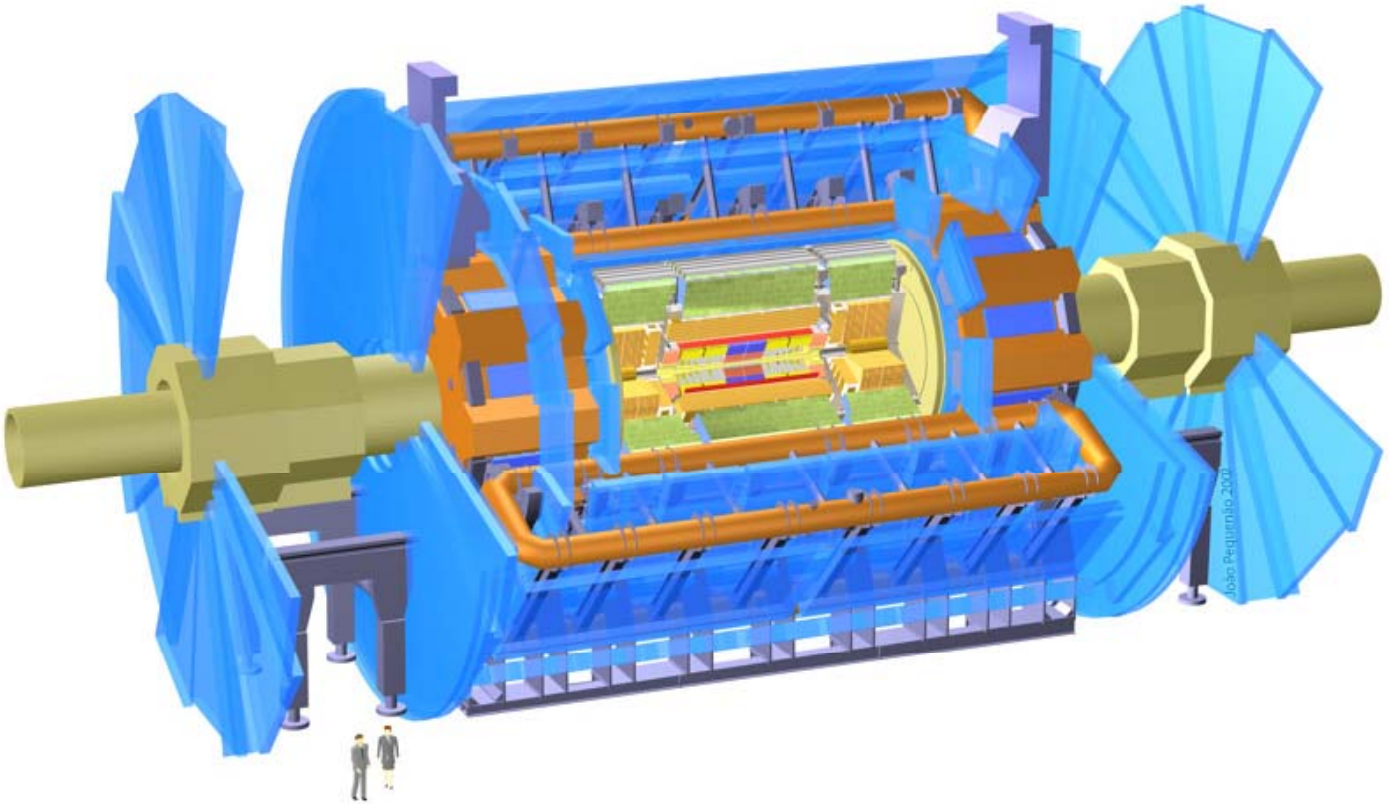
CERN AC/DI/MM - HE107 - 30 04 1999



Head-on proton collisions

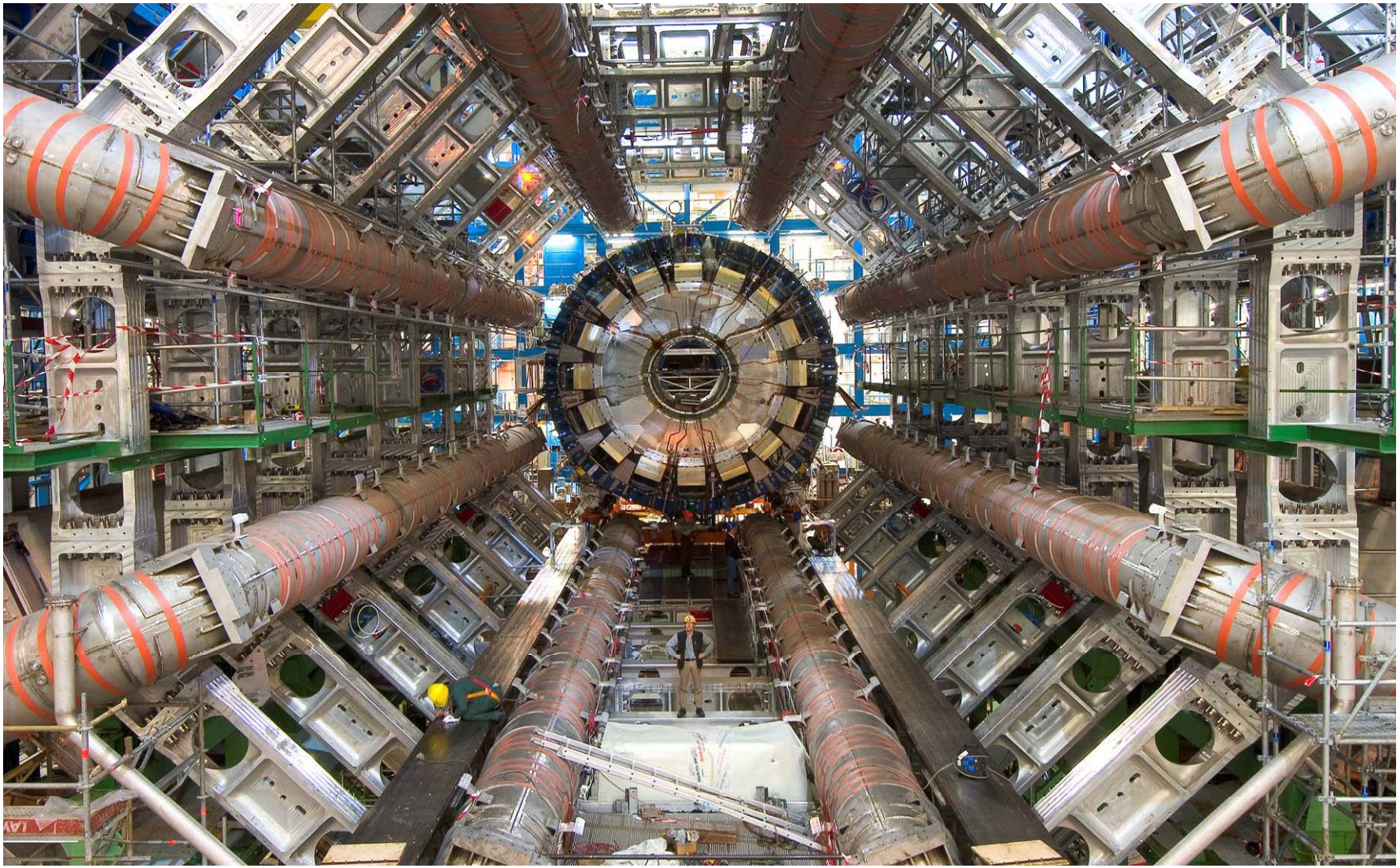


ATLAS experiment at the LHC

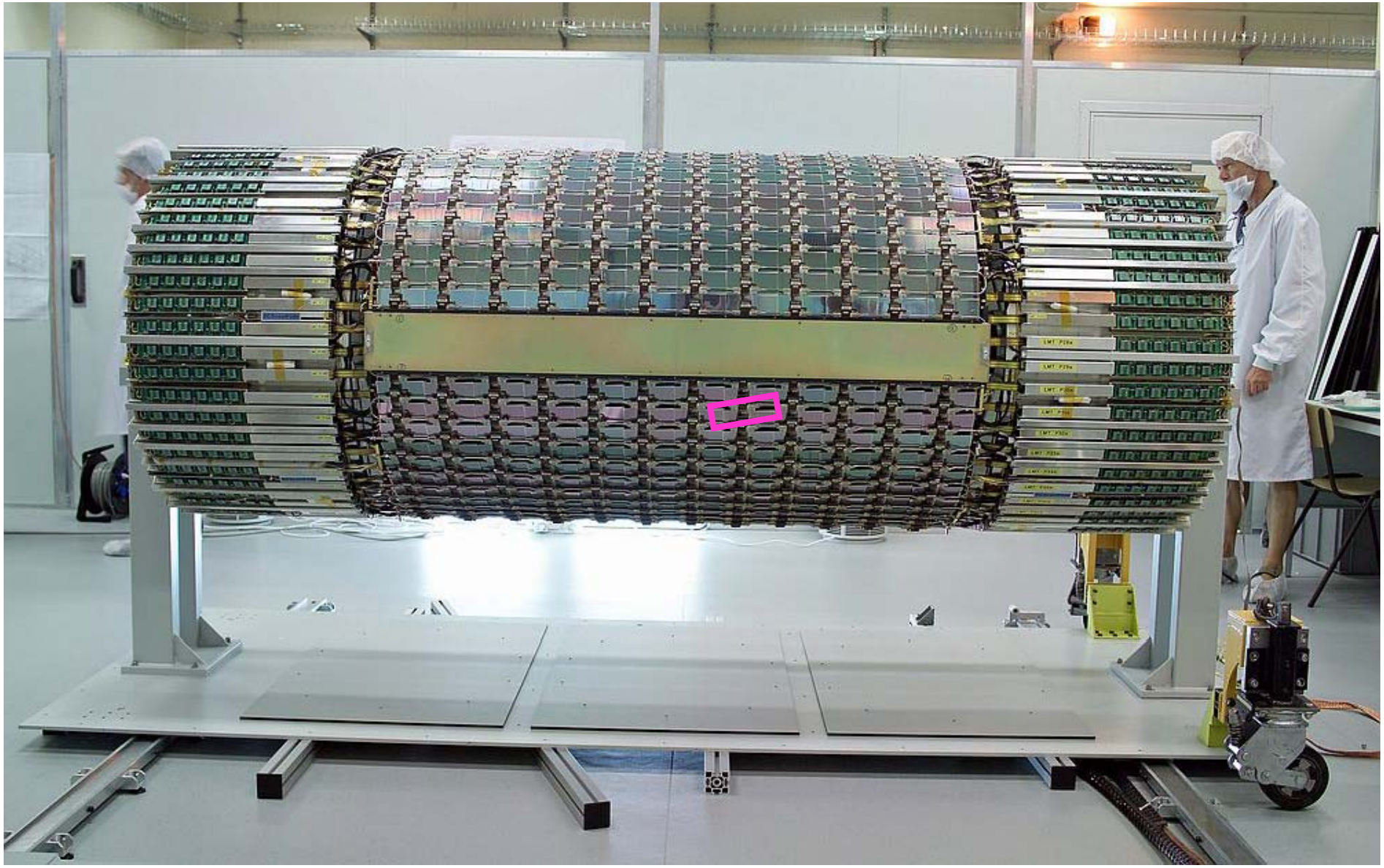


- Proton + proton collisions
- 14 x 10^{12} eV – world's highest energy facility
- (cf. 10^{20} eV max. cosmic rays. ~10^{18} eV equivalent to LHC energy in centre-of-mass frame)

ATLAS: inside the toroids



ATLAS: general purpose expt



ATLAS

ATLAS (barrel calorimetry)

ATLAS

ATLAS

CMS