FUTURE CIRCULAR COLLIDERS (FCC) AND ITS CHALLENGES TO NEW DETECTOR TECHNOLOGIES

Research Institute for Nuclear Problems

BSU

Alexander Lobko

Institute for Nuclear Problems

Belarusian State University

Minsk, Belarus

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European Strategy Update 2013

Design studies and R&D at the energy frontier

….“to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update”:

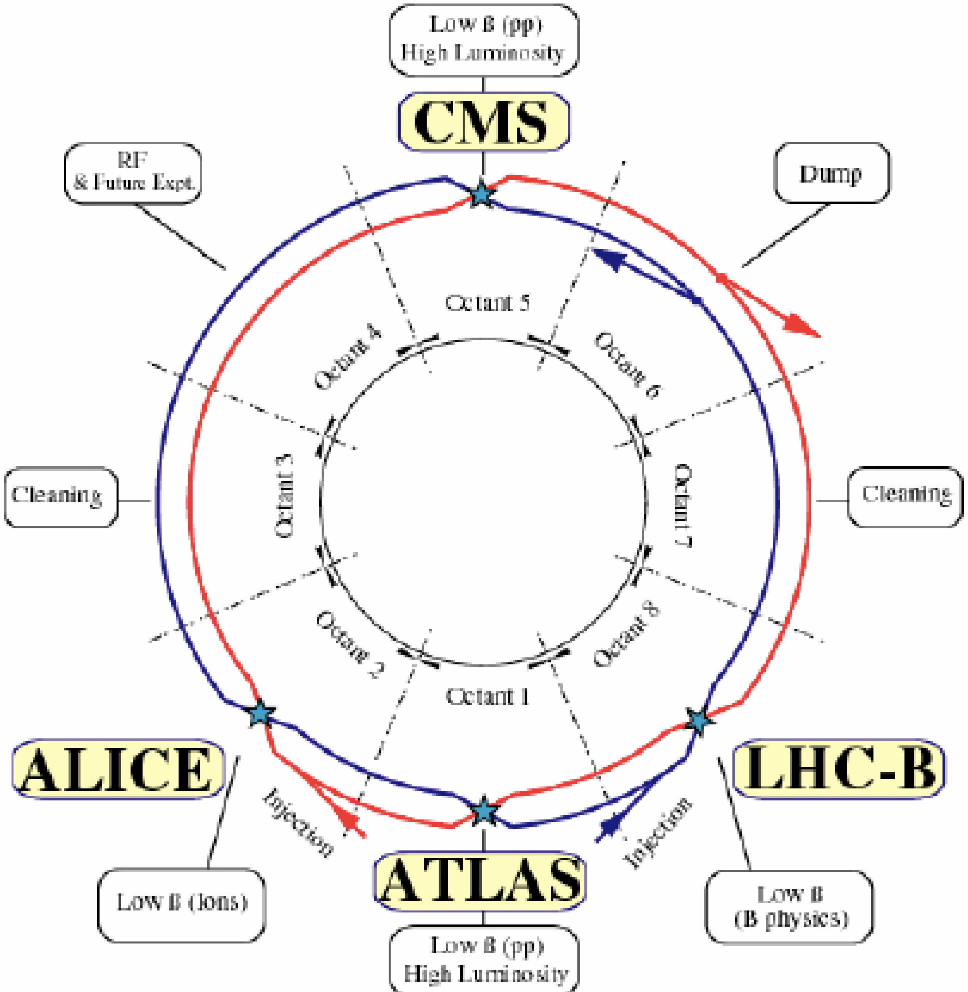
d) ***CERN should undertake design studies for accelerator projects in a global context,***

- *with emphasis on **proton-proton and electron-positron high-energy frontier machines**.*
- *These design studies should be coupled to a vigorous accelerator **R&D programme, including high-field magnets and high-gradient accelerating structures,***
- ***in collaboration with national institutes, laboratories and universities worldwide.***

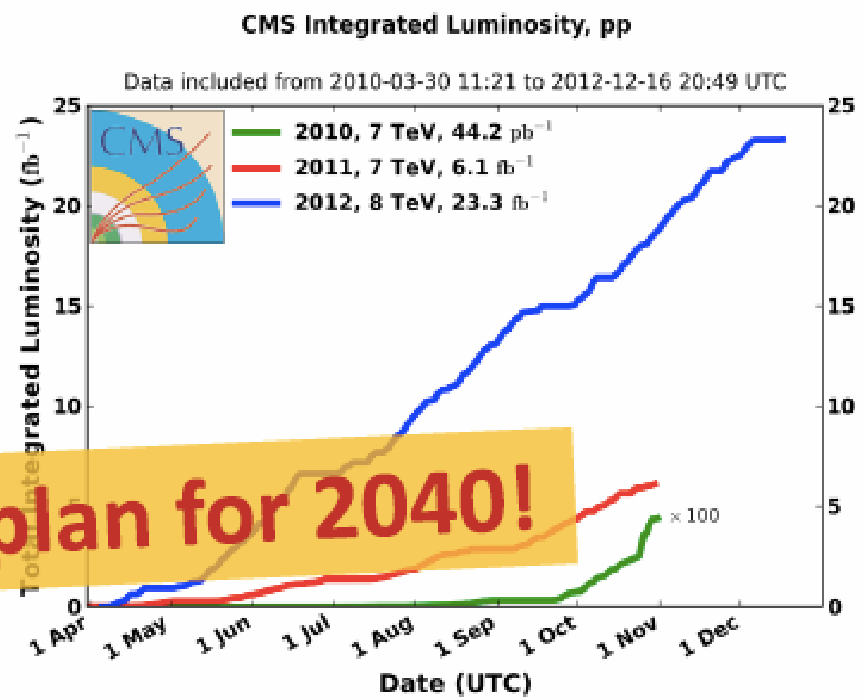
- http://cds.cern.ch/record/1567258/files/esc-e-106.pdf

strategy adopted at Brussels in May 2013, during exceptional session of the CERN Council in presence of the European Commission

Large Hadron Collider (LHC)



design:
c.m. energy 14 TeV (*pp*);
luminosity 10^{34} $cm^{-2}s^{-1}$;
1.15×10^{11} p/bunch;
2808 bunches/beam;
360 MJ / beam



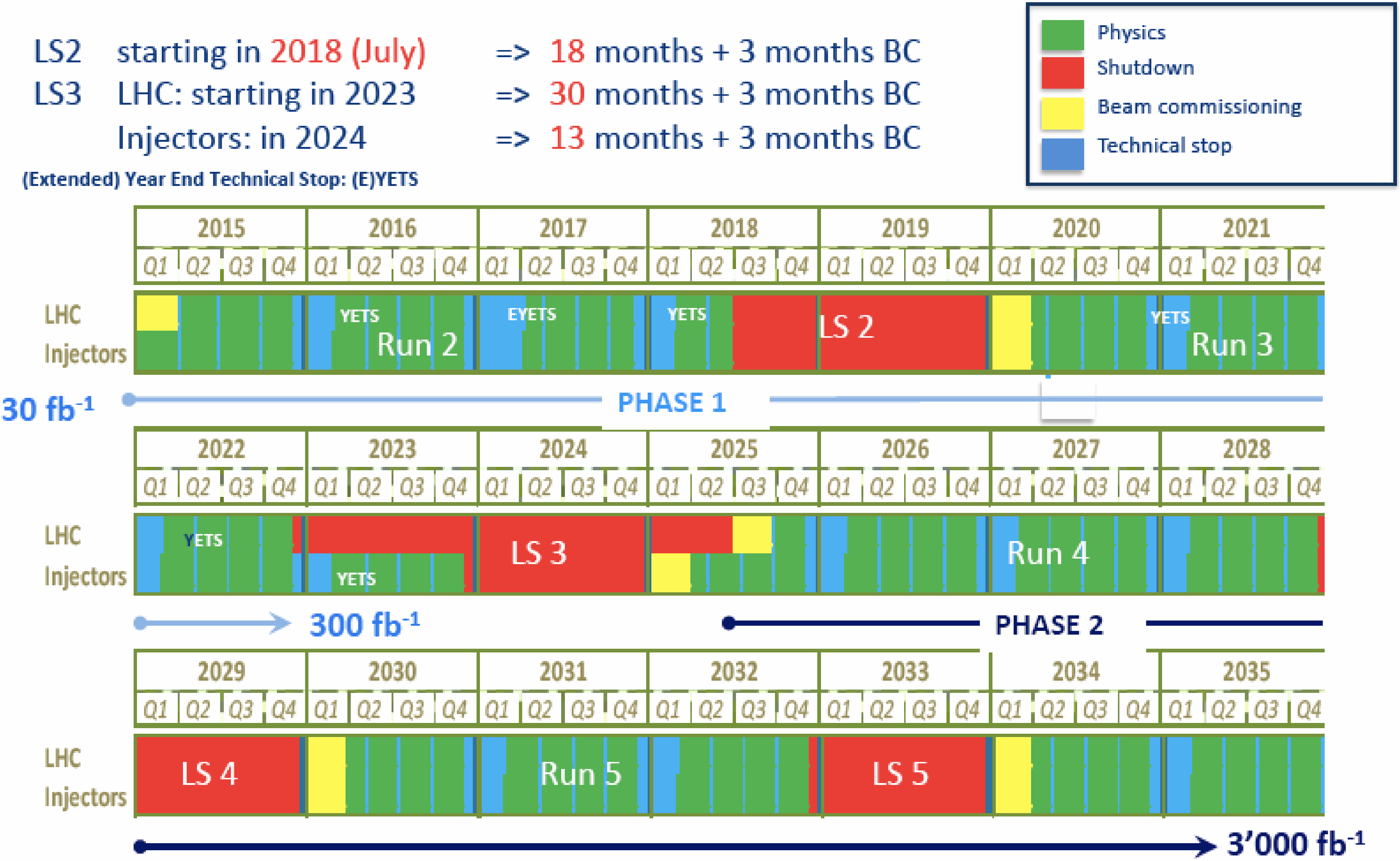
1983 first LHC proposal, launch of design study
1994 CERN Council: LHC approval
2010 first collisions at 3.5 TeV beam energy
2015 collisions at ~design energy (plan)

now is the time to plan for 2040!

LHC roadmap: schedule until 2035

LS2 starting in 2018 (July) => 18 months + 3 months BC
LS3 LHC: starting in 2023 => 30 months + 3 months BC
Injectors: in 2024 => 13 months + 3 months BC

(Extended) Year End Technical Stop: (E)YETS

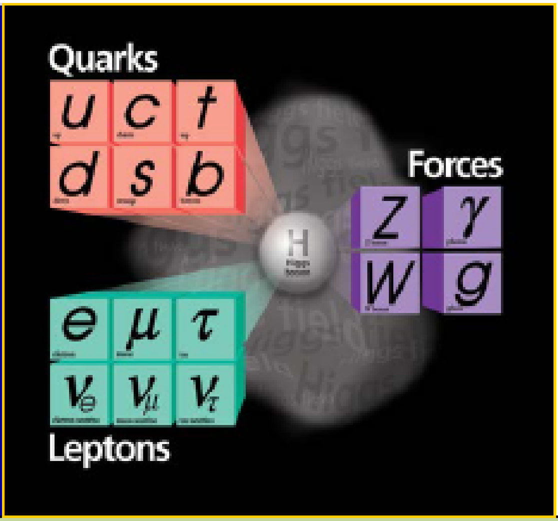


F. Bordry

Phase 2: HL-LHC

Prospects for Particle Physics

With the discovery of a Higgs boson in 2012, we have **completed the Standard Model** (almost 80 years of theoretical and experimental efforts !)



However: **SM is not a complete theory**

Several outstanding questions (e.g. composition of dark matter, cause of universe's accelerated expansion [dark energy / inflation], origin of matter-antimatter asymmetry, neutrino masses, why 3 families?, lightness of Higgs boson, weakness of gravity, ...) which cannot be explained within the SM. F. Gianotti et al.

These questions require NEW PHYSICS

Present knowledge is insufficient to determine energy scale of new physics ; **LHC will provide new information** from *pp* collisions at higher cm energy (13 TeV) **by 2017-18**

main questions in particle physics and main approaches to address them

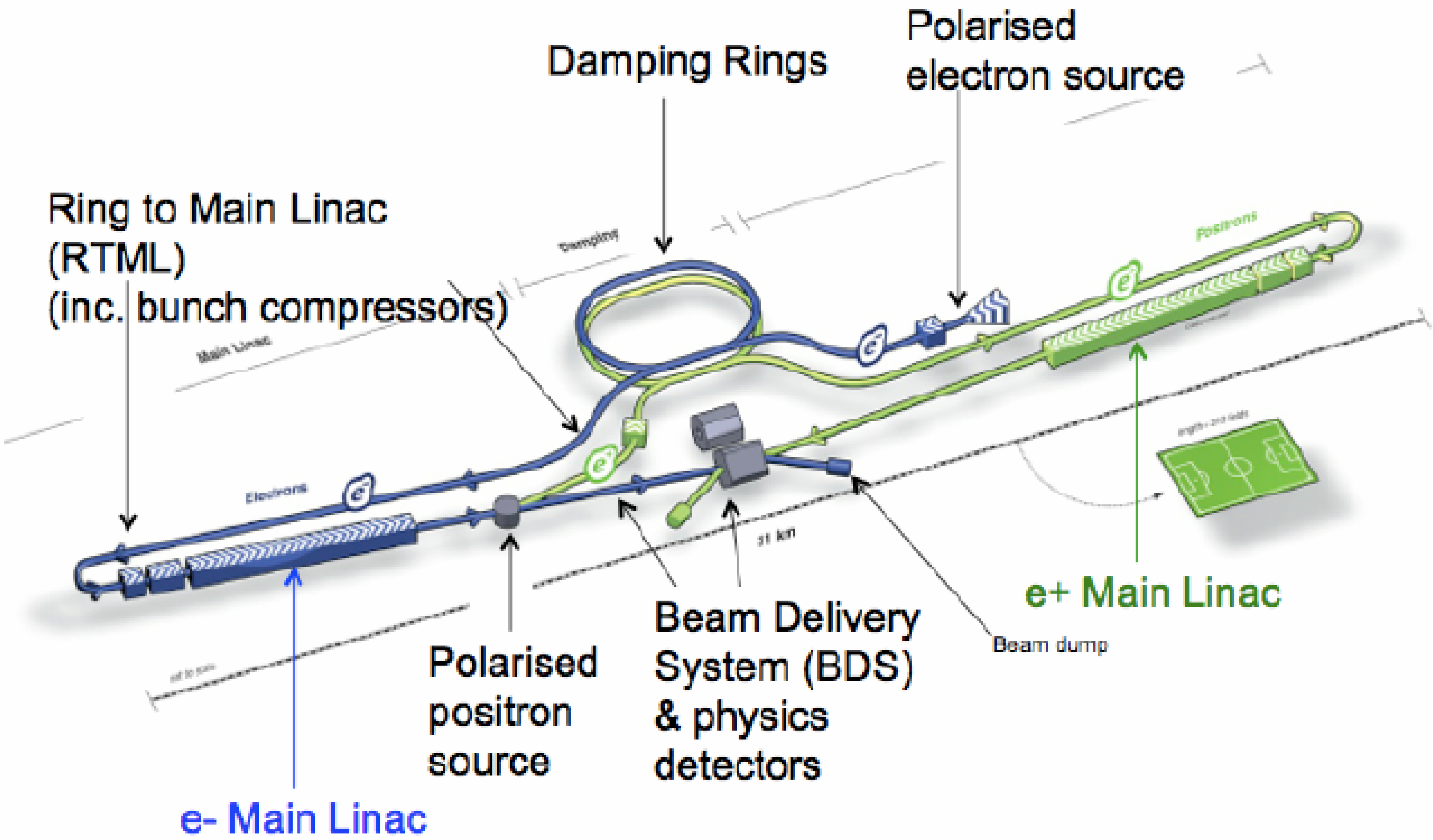
question	high-energy colliders	high-precision experiments	neutrino experiments	dedicated searches	cosmic surveys
Higgs, EWSB	X				
neutrinos	X		X	X	X
dark matter	X			X	
flavour, CP violation	X	X	X	X	
new particles and forces	X	X	X	X	
universe acceleration					X

F. Gianotti et al.

most of these questions require high-energy and/or high-intensity accelerators

International Linear Collider (ILC)

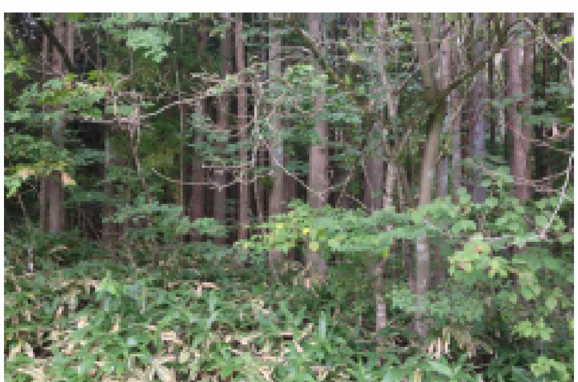
total length ~30 (500 GeV) - 50 km (1 TeV)



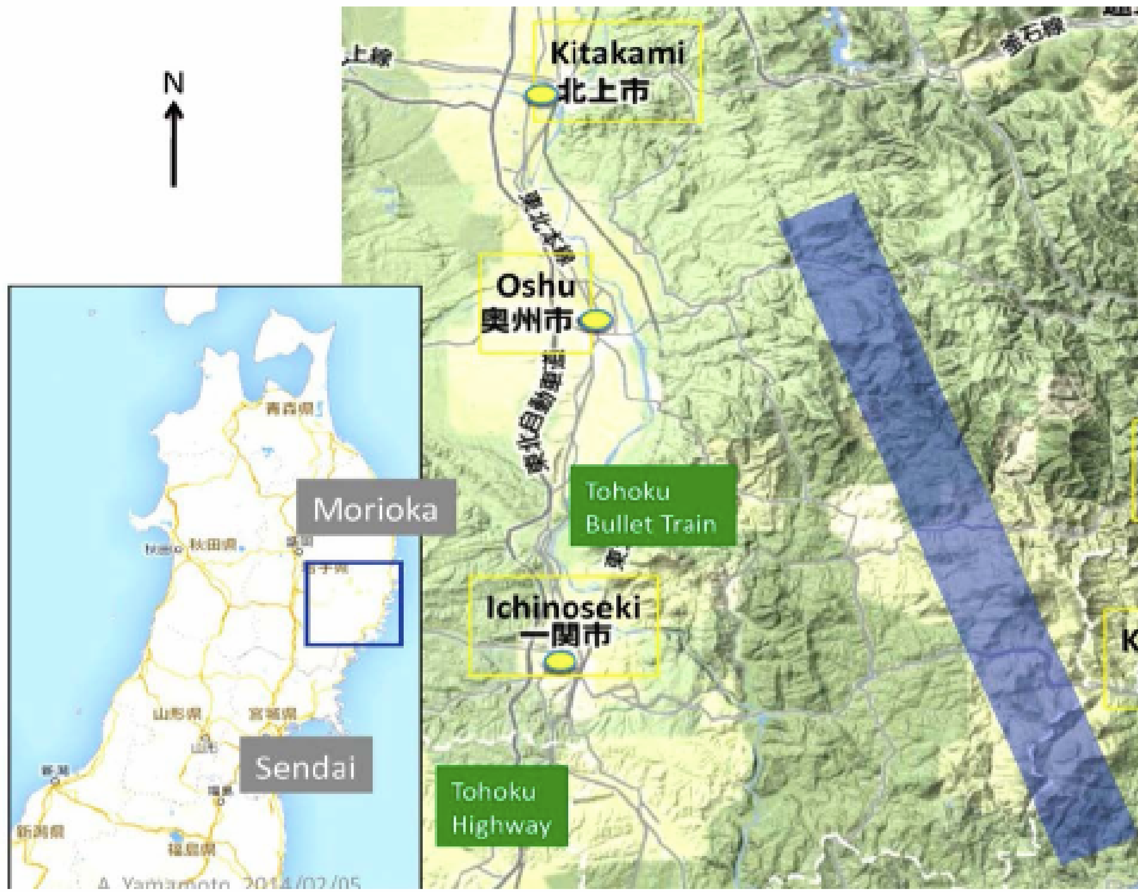
SC acceleration structures ~ 30 MV/m; **TDR completed in 2012**, ILC technology used for XFEL at DESY; present optimistic time line: construction start in 2018 & 1st physics in 2027?

International Linear Collider (ILC) - 2

Japanese HEP community expressed interest in hosting the ILC. Site chosen: 北上市 (Kitakami) in Northern Japan. Under review by Japanese ministry MEXT.

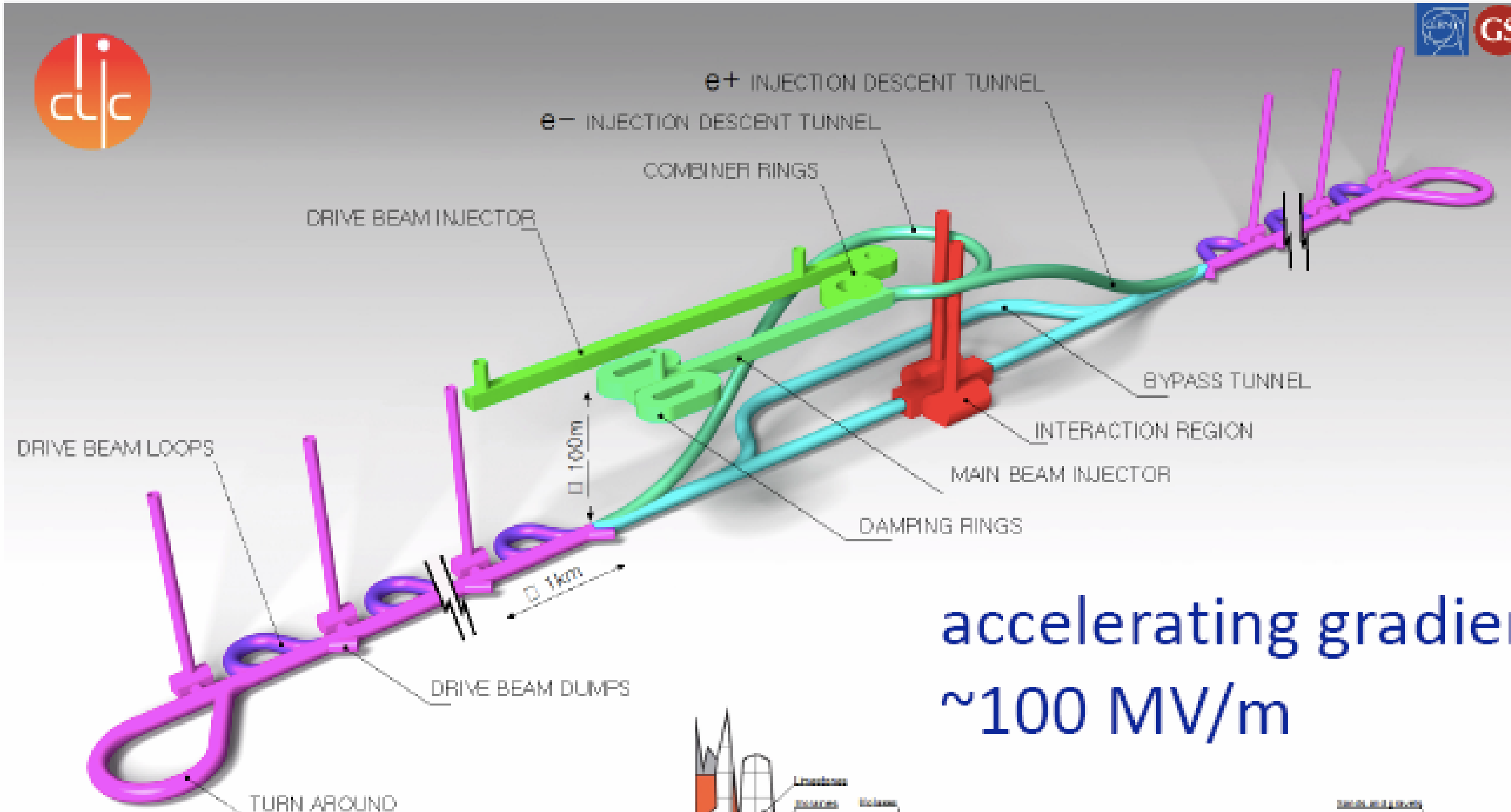


Courtesy F. Simon



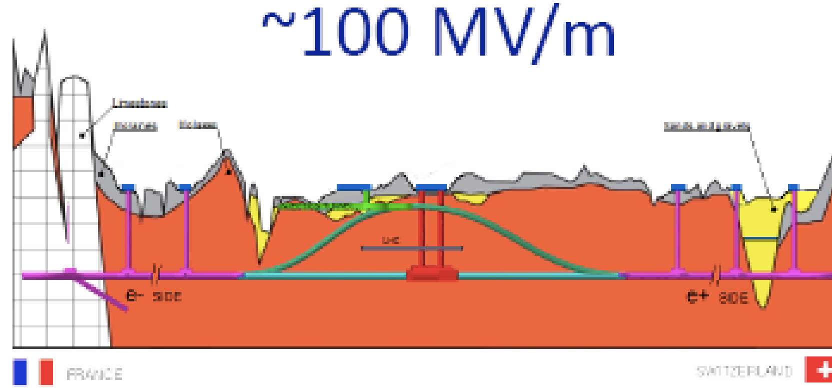
Compact Linear Collider (CLIC)

total length (main linac) ~11 (500 GeV) - 48 km (3 TeV)



accelerating gradient

~100 MV/m

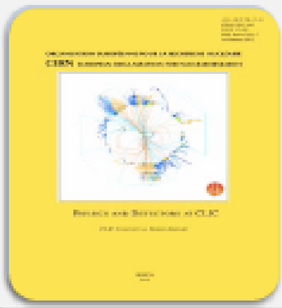


key technologies: 2-beam accel., drive-beam , X-band RF

CLIC Conceptual Design Report 2012

Vol 1: The CLIC accelerator and site facilities (H.Schmickler)

- CLIC concept with exploration over multi-TeV energy range up to 3 TeV
- Feasibility study of CLIC parameters optimized at 3 TeV (most demanding)
- Consider also 500 GeV, and intermediate energy range
- Complete, presented in SPC in March 2011, in print: https://edms.cern.ch/document/1234244/



Vol 2: Physics and detectors at CLIC (L.Linssen)

- Physics at a multi-TeV CLIC machine can be measured with high precision, despite challenging background conditions
- External review procedure in October 2011
- Completed and printed, presented in SPC in December 2011 http://arxiv.org/pdf/1202.5940v1

Vol 3: “CLIC study summary” (S.Stapnes)

- Summary and available for the European Strategy process, including possible implementation stages for a CLIC machine as well as costing and cost-drives
- Proposing objectives and work plan of post CDR phase (2012-16)
- Completed and printed, submitted for the European Strategy Open Meeting in September http://arxiv.org/pdf/1209.2543v1

In addition a shorter overview document was submitted as input to the European Strategy update, available at: http://arxiv.org/pdf/1208.1402v1

~1400 authors, ~1200 pages

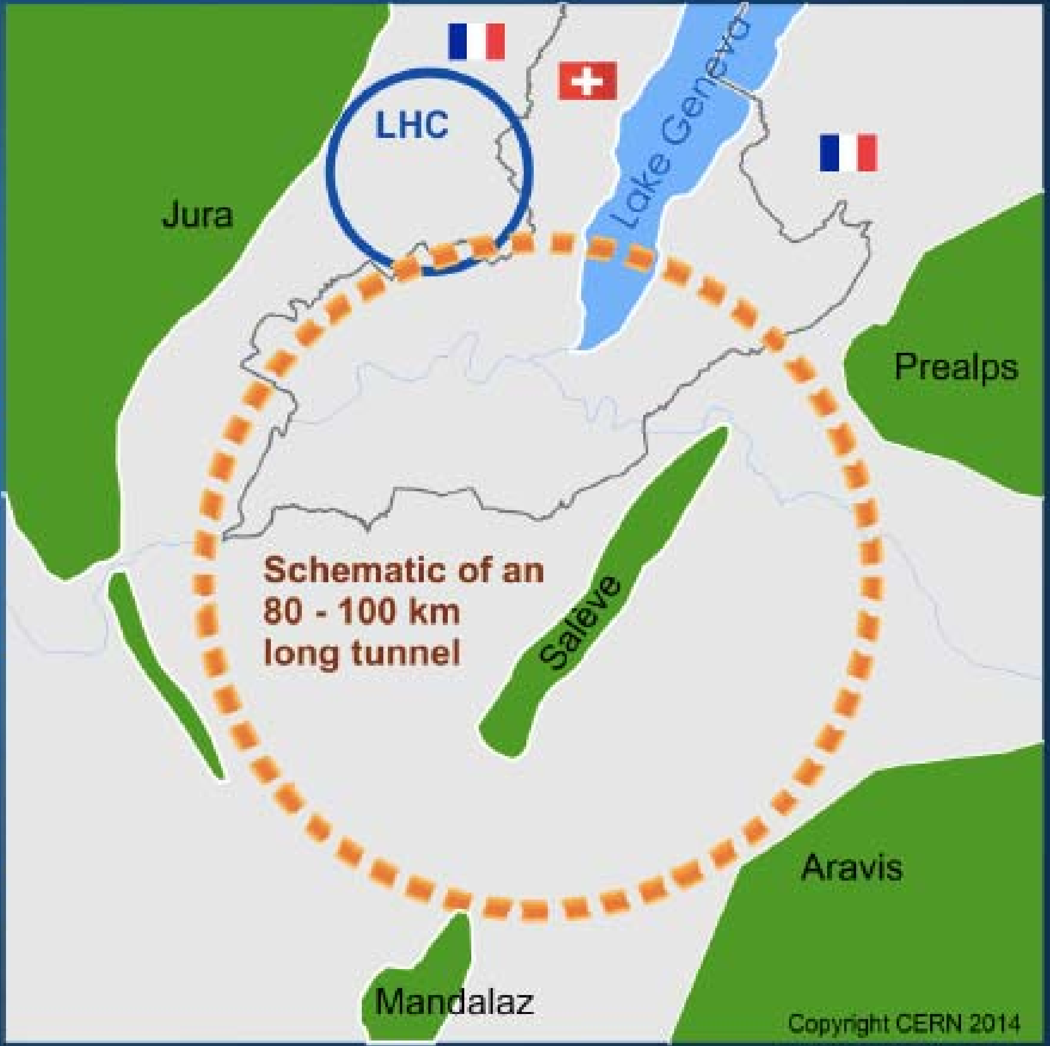
Future Circular Collider Study - SCOPE
CDR and cost review for the next ESU (2018)

Forming an international collaboration to study:

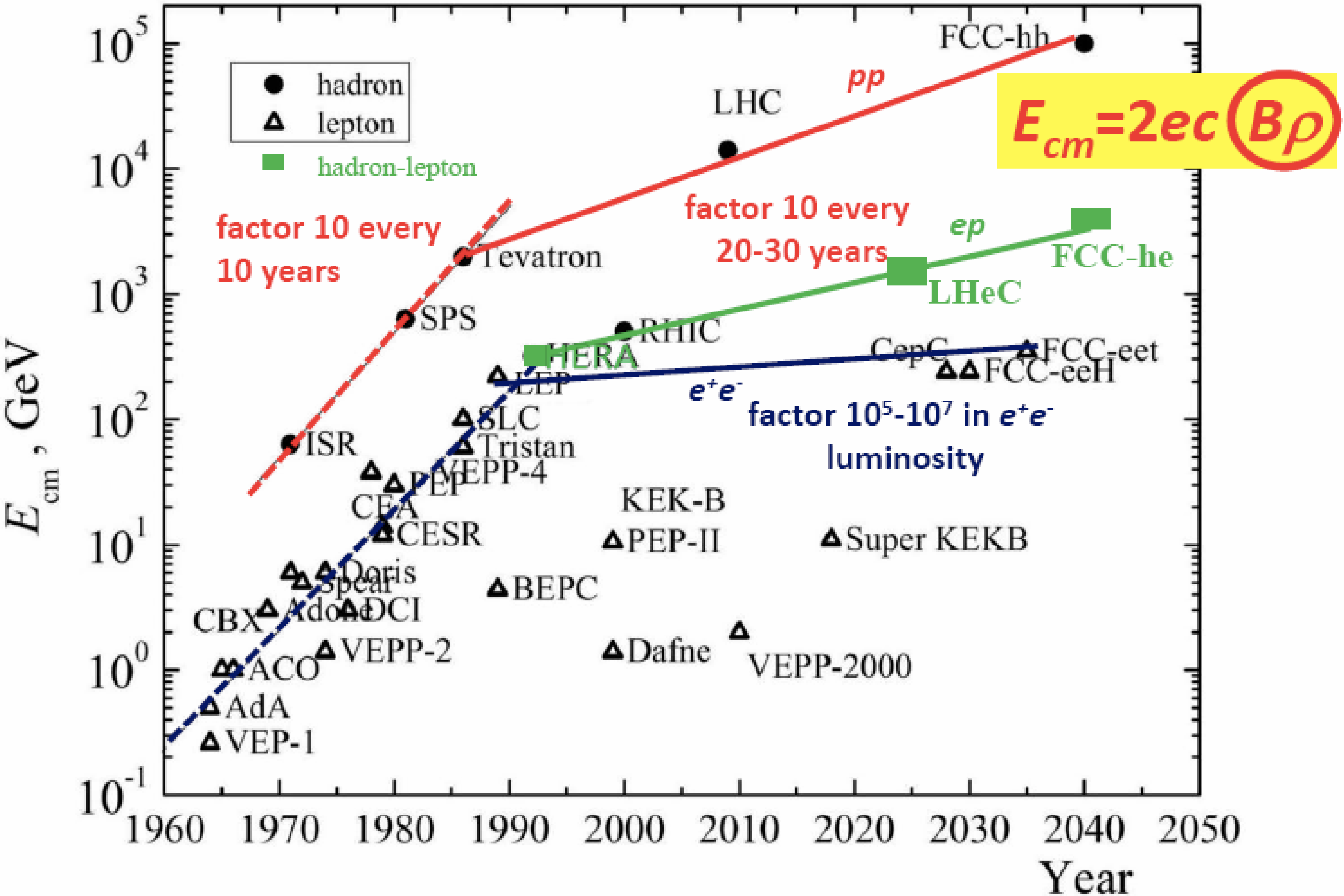
- ***pp*-collider (*FCC-hh*)**
  → defining infrastructure requirements

~16 T ⇒ 100 TeV *pp* in 100 km
~20 T ⇒ 100 TeV *pp* in 80 km

- **80-100 km infrastructure** in Geneva area
- **e^+e^- collider (*FCC-ee*)** as potential intermediate step
- ***p-e* (*FCC-he*) option**

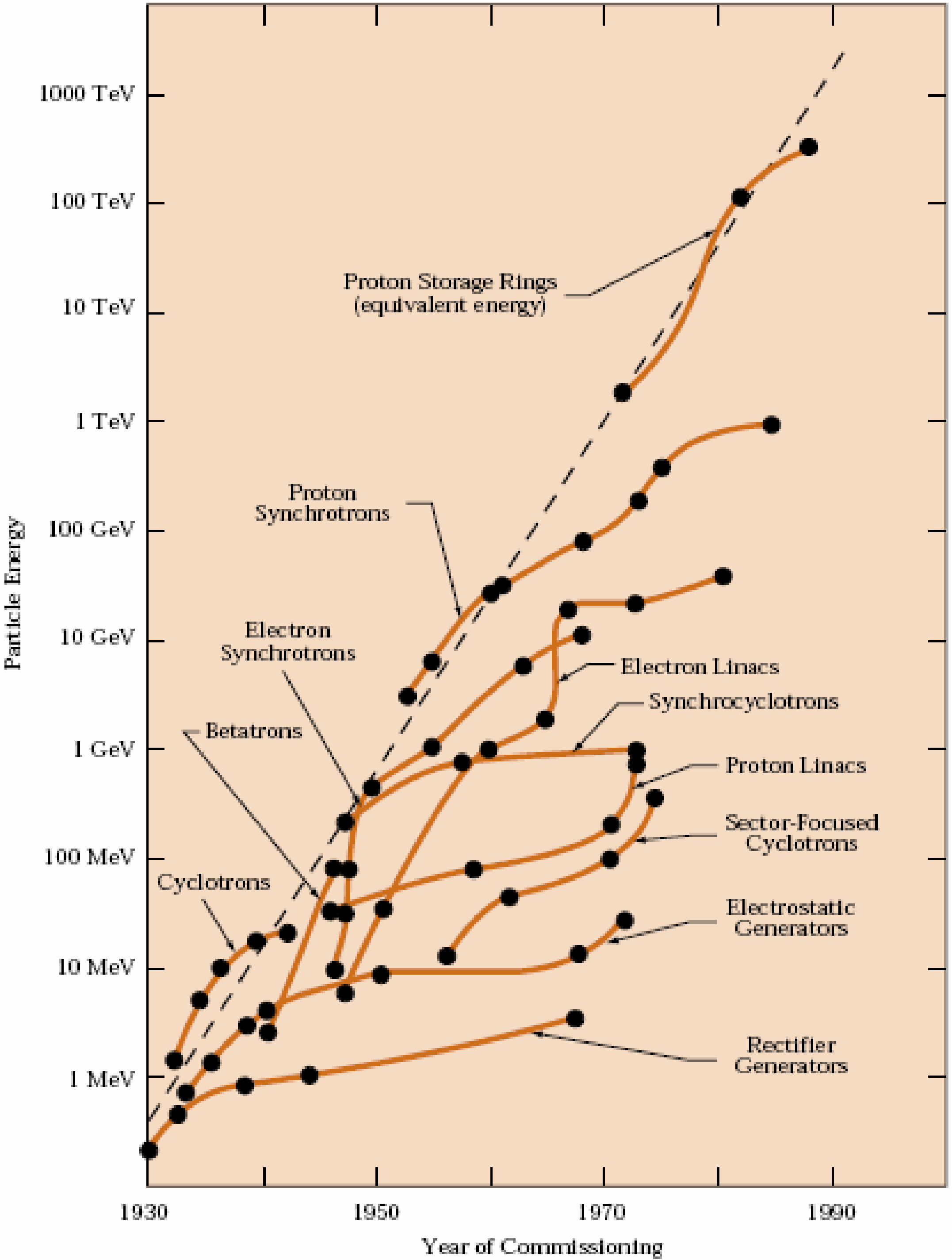


collider c.m. energy vs. year



Courtesy V. Shiltsev

Livingston plot



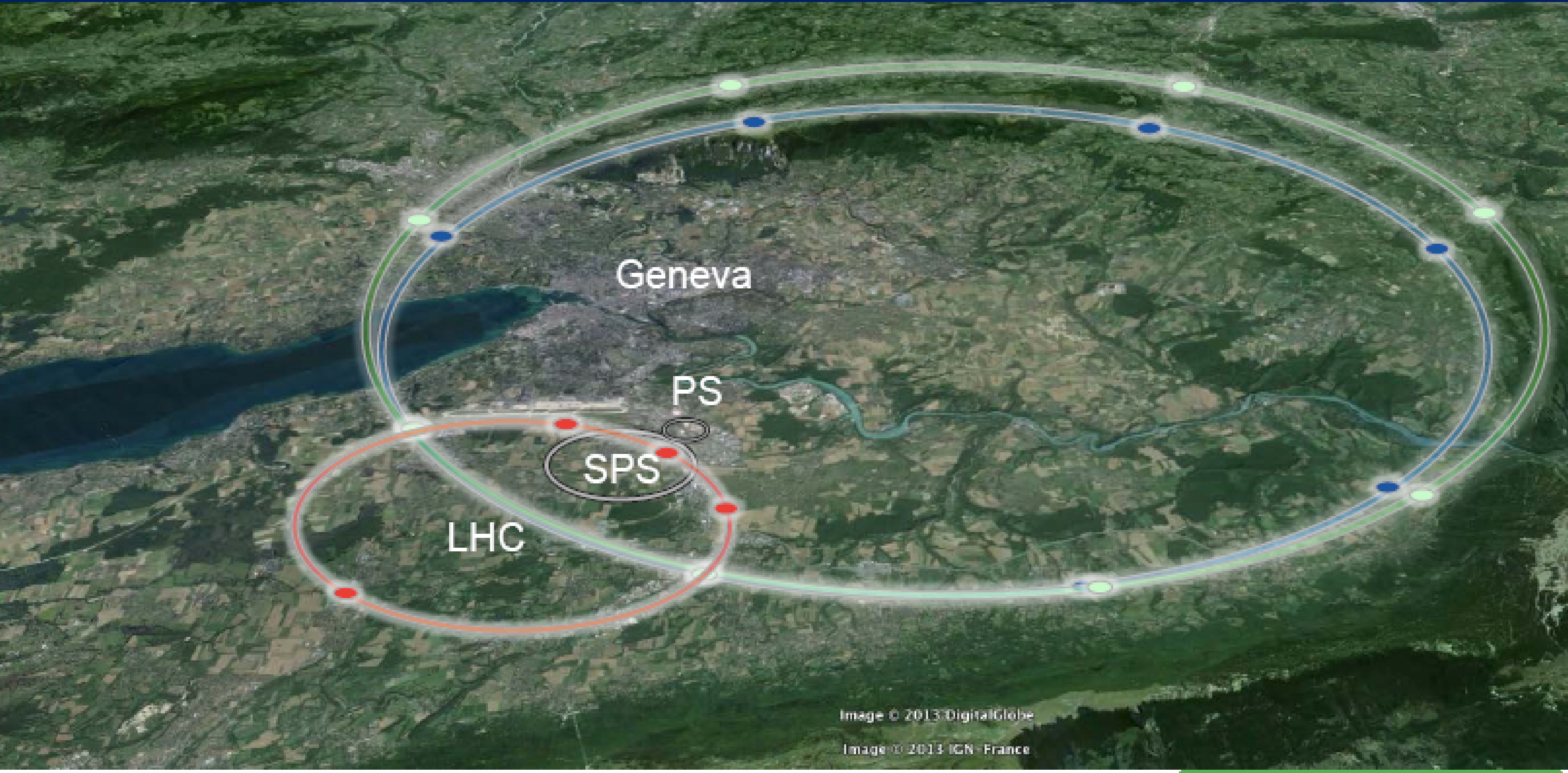
The conclusion is that this spectacular achievement has resulted from a succession of technologies rather than from construction of bigger and better machines of a given type. When any one technology ran out of steam, a successor technology usually took over.

In another respect, however, the Livingston plot is misleading. It suggests that energy is the primary, if not the only, parameter that defines the discovery potential of an accelerator or collider. Energy is indeed required if physicists wish to cross a new threshold of discovery, provided that this threshold is defined by the energy needed to induce a new phenomenon.

But there are several other parameters that are important for an accelerator to achieve—for example, the intensity of the beam, or the number of particles accelerated per second.

From: W. Panofsky

FCC-hh: 100 TeV *pp* collider



LHC	"HE-LHC"	FCC-hh (alternative)	FCC-hh (baseline)
27 km, 8.33 T	27 km, **20 T**	80 km, **20 T**	100 km, **16 T**
14 TeV (c.m.)	33 TeV (c.m.)	100 TeV (c.m.)	100 TeV (c.m.)

L. Bottura
B. Strauss

Key technology - magnets

The maximum beam energy of a hadron collider is directly proportional to the bending dipole magnetic field and to the ring circumference.

The LHC magnets are based on Nb-Ti superconductor and achieve a maximum operational field of 8.33 T.

The high luminosity upgrade project (HL-LHC) develops the technology of higher field Nb_3Sn magnets as well as cables made from high-temperature superconductor (HTS). Nb_3Sn dipoles could ultimately reach an operational field around 16 T and HTS inserts could boost field strength further. A cost-effective hybrid magnet design incorporating Nb-Ti, two types of Nb_3Sn, and an inner layer of HTS could provide a field of 20 T.

If installed in the LHC tunnel, such dipole field would increase the beam energy by a factor 2.5 compared with the LHC.

FCC-hh Key Parameters

Parameter	FCC-hh	LHC
Energy	**100 TeV c.m.**	14 TeV c.m.
Dipole field	**16 T**	8.33 T
# IP	2 main, +2	4
Luminosity/IP_{main}	**5 x 10^{34}** $cm^{-2}s^{-1}$	1 x 10^{34} $cm^{-2}s^{-1}$
Energy/beam	**8.4 GJ**	0.39 GJ
Synchr. rad.	28.4 W/m/apert.	0.17 W/m/apert.
Bunch spacing	25 ns (5 ns)	25 ns

Preliminary, subject to evolution

Beam energy stored

energy per proton beam

LHC: 0.4 GJ → *FCC-hh*: 8 GJ (20x more !)

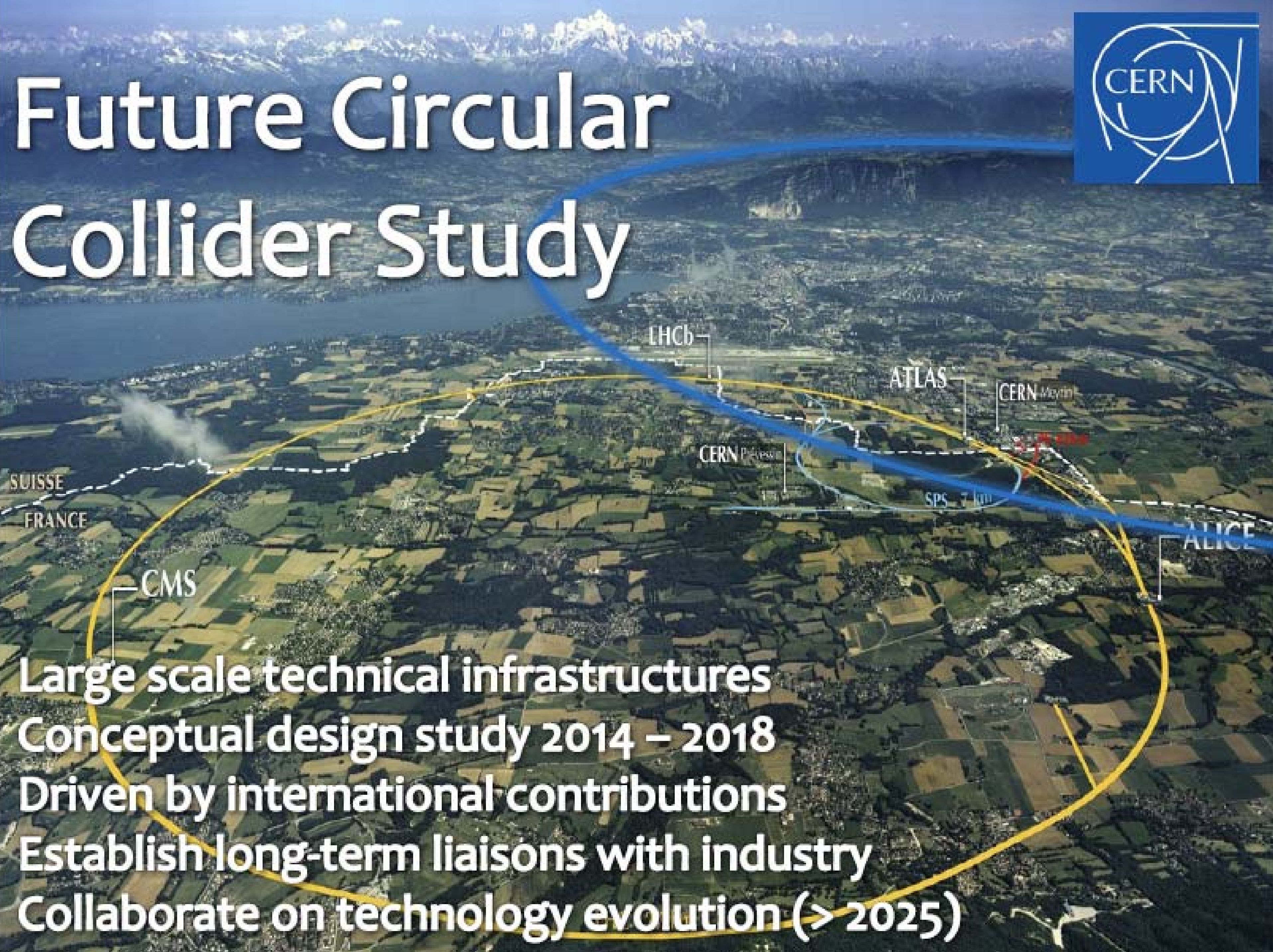
– kinetic energy of Airbus A380 at 720 km/h

– can melt 12 tons of copper, or drill a 300-m long hole

FCC-ee Key Parameters

Parameter	FCC-ee	LEP2
Energy/beam	45 – 175 GeV	105 GeV
Bunches/beam	**98 – 16700**	4
Beam current	**6.6 – 1450 mA**	3 mA
Luminosity/IP	**1.8-28** x 10^{34} $cm^{-2}s^{-1}$	0.0012 x 10^{34} $cm^{-2}s^{-1}$
Energy loss/turn	0.03-7.55 GeV	3.34 GeV
Synchr. power	**100 MW**	22 MW
RF Voltage	2.5 – **11 GV**	3.5 GV

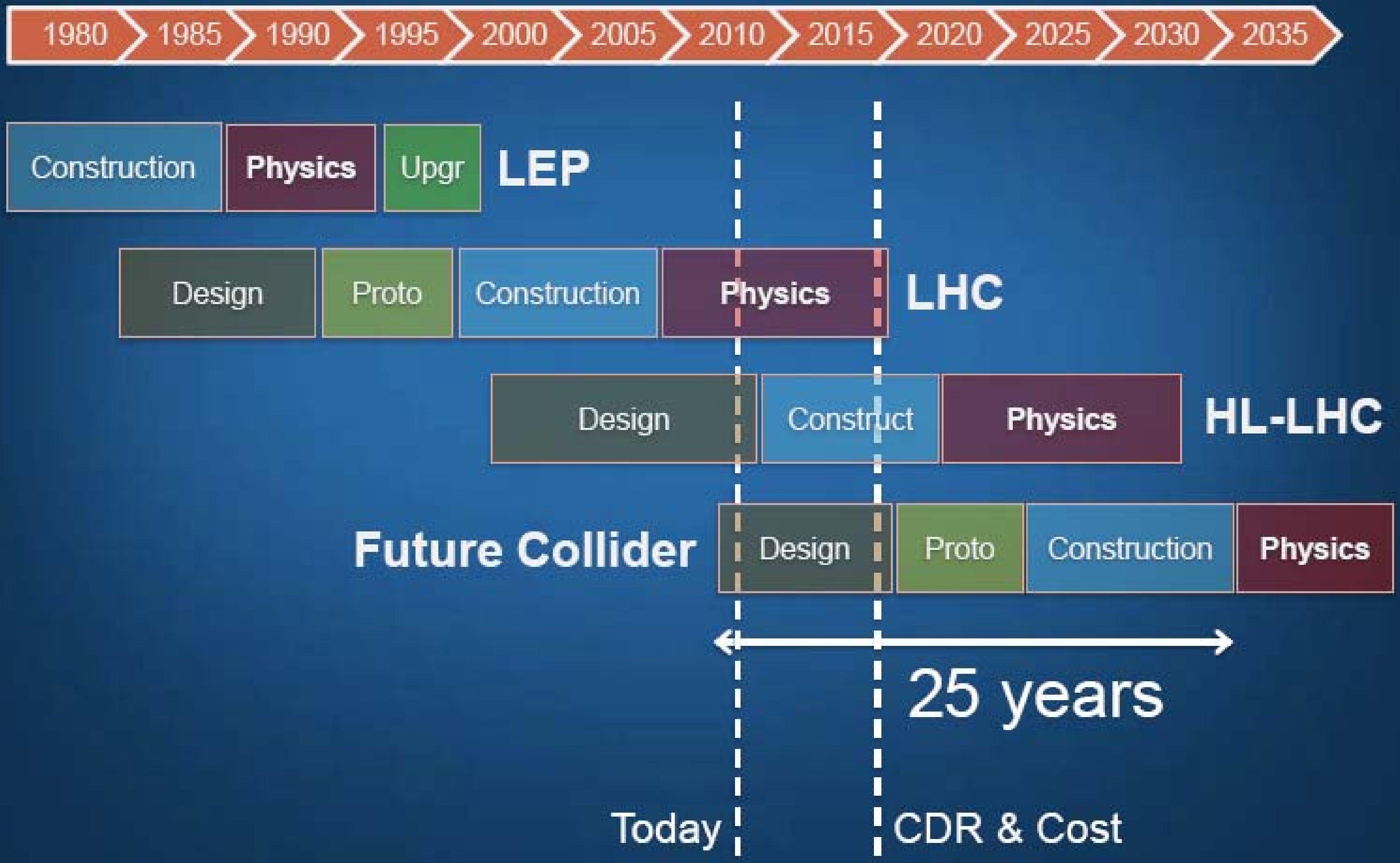
Preliminary, subject to evolution


Future Circular
Collider Study
CERN
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SUISSE
FRANCE
SPS 7 km
ALICE
CMS
Large scale technical infrastructures
Conceptual design study 2014 – 2018
Driven by international contributions
Establish long-term liaisons with industry
Collaborate on technology evolution (> 2025)

FCC MoU's 3 Oct. 2014

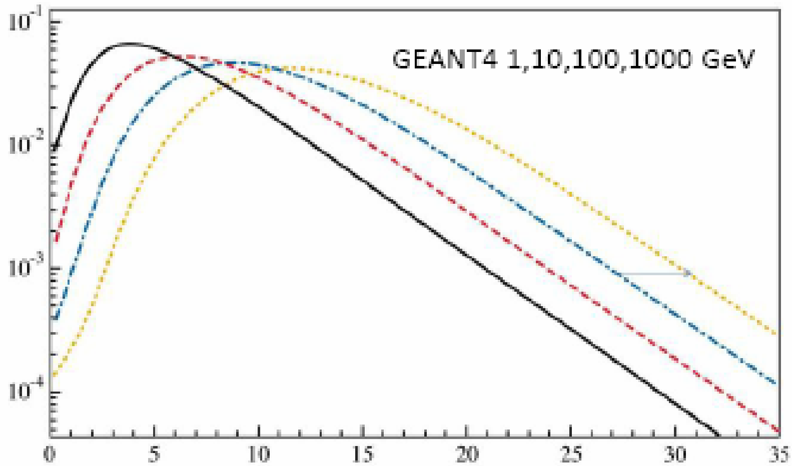
- ALBA/CELLS, Spain
- BINP, Russia
- CASE (SUNY/BNL), USA
- CBPF, Brazil
- CERN, Switzerland (Int'l)
- CIEMAT, Spain
- CNRS, France
- Cockcroft Institute, UK
- CSIC/IFIC, Spain
- DESY, Germany
- EPFL, Switzerland
- Gangneung-Wonju Nat. U., Korea
- Goethe U. Frankfurt, Germany
- GSI, Germany
- Hellenic Open U, Greece
- IFJ PAN Krakow, Poland
- INFN, Italy
- INP Minsk, Belorussia
- IPM, Iran
- JAI/Oxford, UK
- KEK, Japan
- King's College London, UK
- MEPhI, Russia
- Northern Illinois U., USA
- NC PHEP Minsk, Belorussia
- Sapienza/Roma, Italy
- UC Santa Barbara, USA
- TU Darmstadt, Germany
- TU Tampere, Finland
- U. Geneva, Switzerland
- U. Iowa, USA
- U Silesia, Poland

HEP Timescale



ECAL

- Depth: + ~$3X_0$ for x 10 in energy
  -CMS crystals: 25 X_0
  -ATLAS LAr (segmented in depth) 23-29 X_0



- Dynamical range
  -16 bits at LHC→19 bits
  (can be mitigated by high segmentation)
  (max electron energy 3 TeV→~20 TeV)

- Resolution
  -measuring H→γγ will remain an essential requirement
  -in the ~60 GeV ET range need to be as good as ATLAS/CMS

- Speed of response
  -25ns bc → Crystals, LAr OK
  -5 ns ??

- Particle flow? High segmentation desirable
  In general not so good for constant term…

From presentation of D. Fournier at FCC kick-off

CONCLUSION

Expecting parameters of the future colliders and corresponding physics impose many requirements to the key detector technologies.

Detector dimensions, dynamical range, resolution, speed of response, radiation hardness, and many other impressive challenges resulted from energy frontier particle beams together with a future collider record luminosity and high beam currents will be hot research topics in the near future.

Many thanks to Frank Zimmermann (CERN), who kindly permit me to use some slides from his presentation at 6th Intl Conference "Channeling-2014" (Capri, Italy)

Thank you for attention