Challenges for Highest Energy Circular Colliders

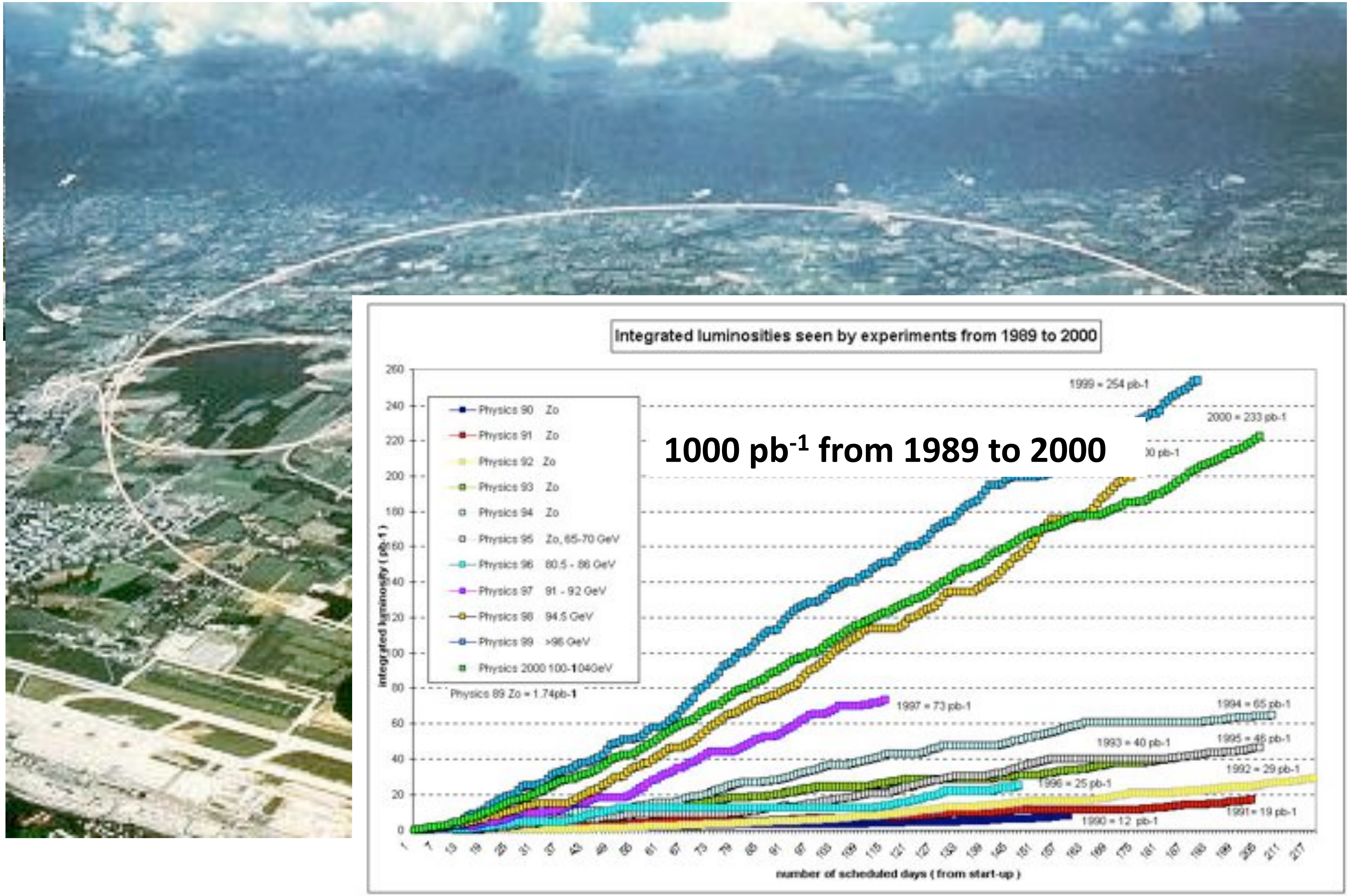
F. Zimmermann, CERN BE/ABP

KEK Accelerator Seminar, 31 July 2014

gratefully acknowledging input from FCC global design study & CepC/SppC team

Work supported by the ***European Commission*** *under Capacities 7th Framework Programme, Grant Agreement 312453*

LEP – largest circular e^+e^- collider so far

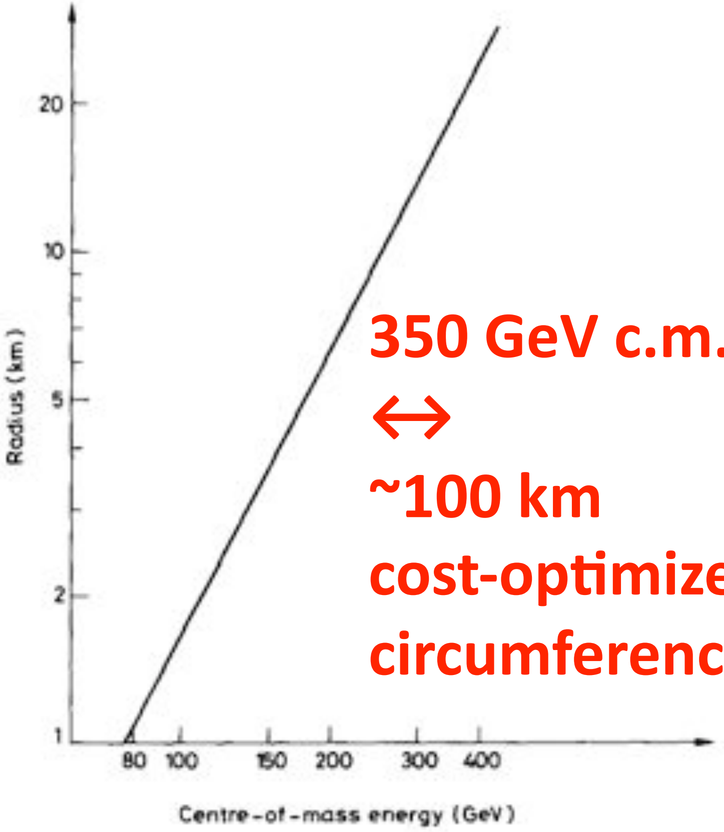


1000 pb^{-1} from 1989 to 2000

“An e^+-e^- storage ring in the range of a few hundred GeV in the centre of mass can be built with present technology. ...would seem to be … most useful project on the horizon.”

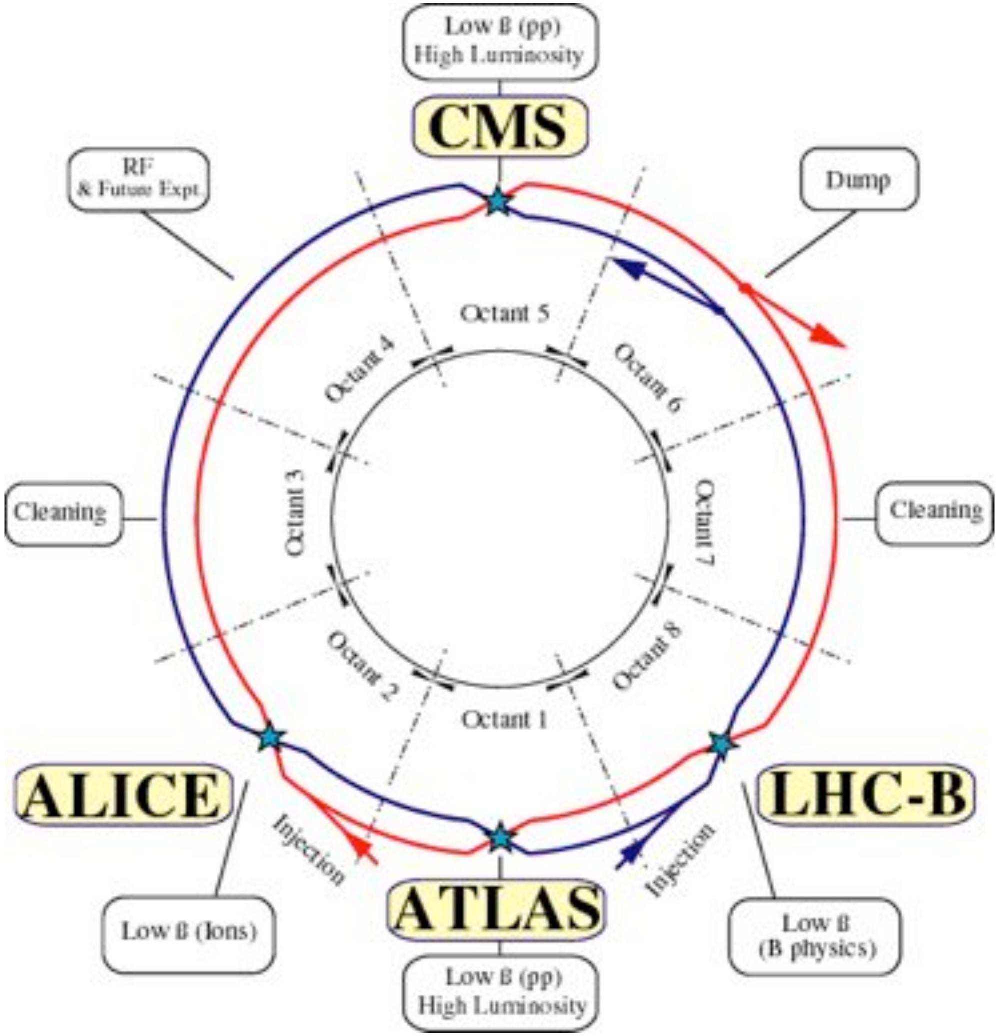
(original LEP proposal, 1976)

B. Richter, *Very High Energy Electron-Positron Colliding Beams for the Study of Weak Interactions*, NIM 136 (**1976**) 47-60

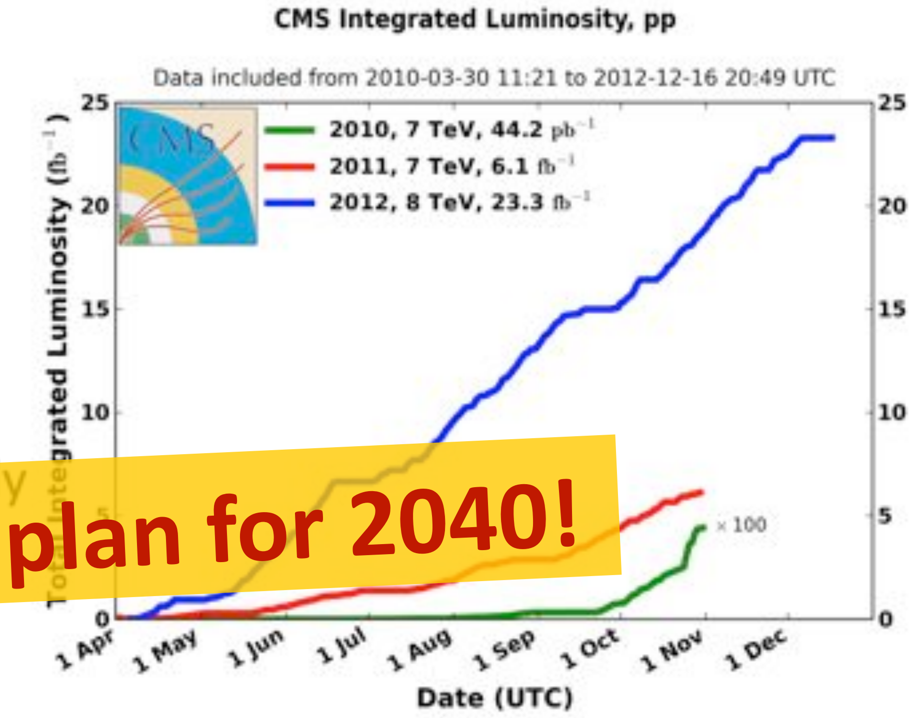


350 GeV c.m.
↔
~100 km
cost-optimized
circumference

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)

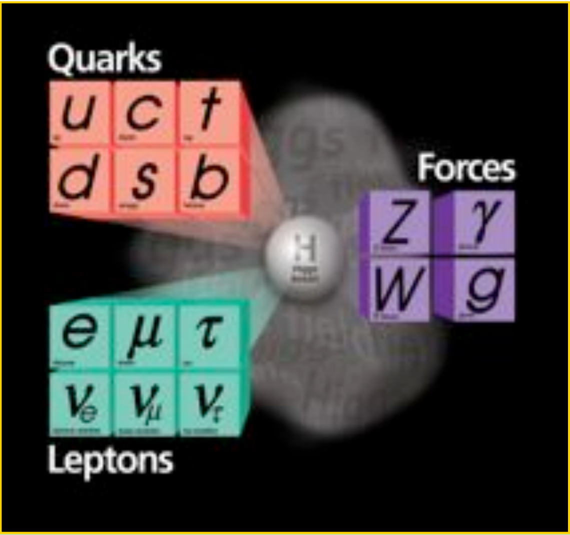
now is the time to plan for 2040!

Discovery 2012, Nobel Prize in Physics 2013

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider".*

2014 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 of particle physics**, as several outstanding questions remain (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

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

Future Circular Collider (FCC) study ; goals: CDR and cost review for the next European Strategy Update (2018)

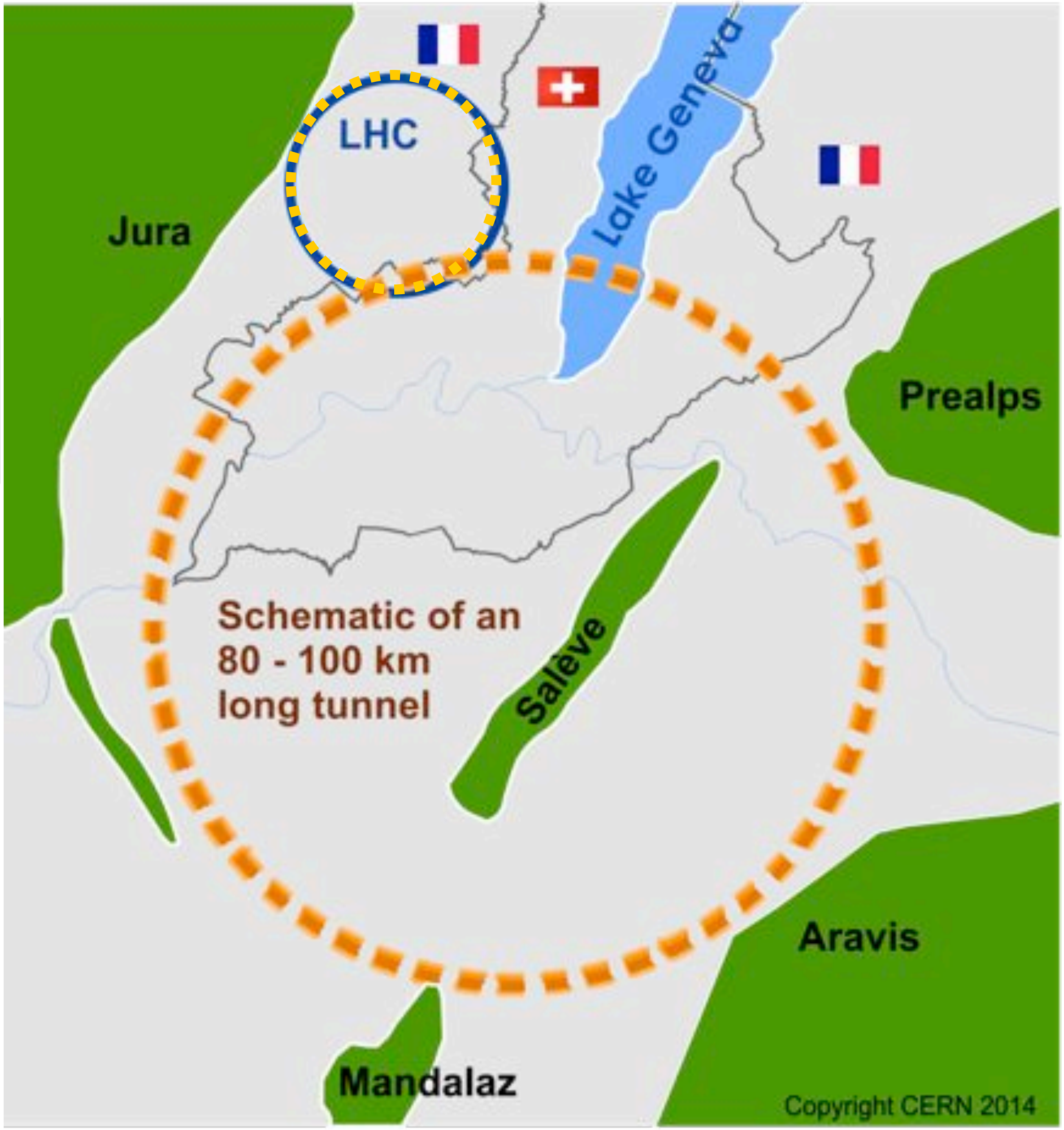
International collaboration :

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

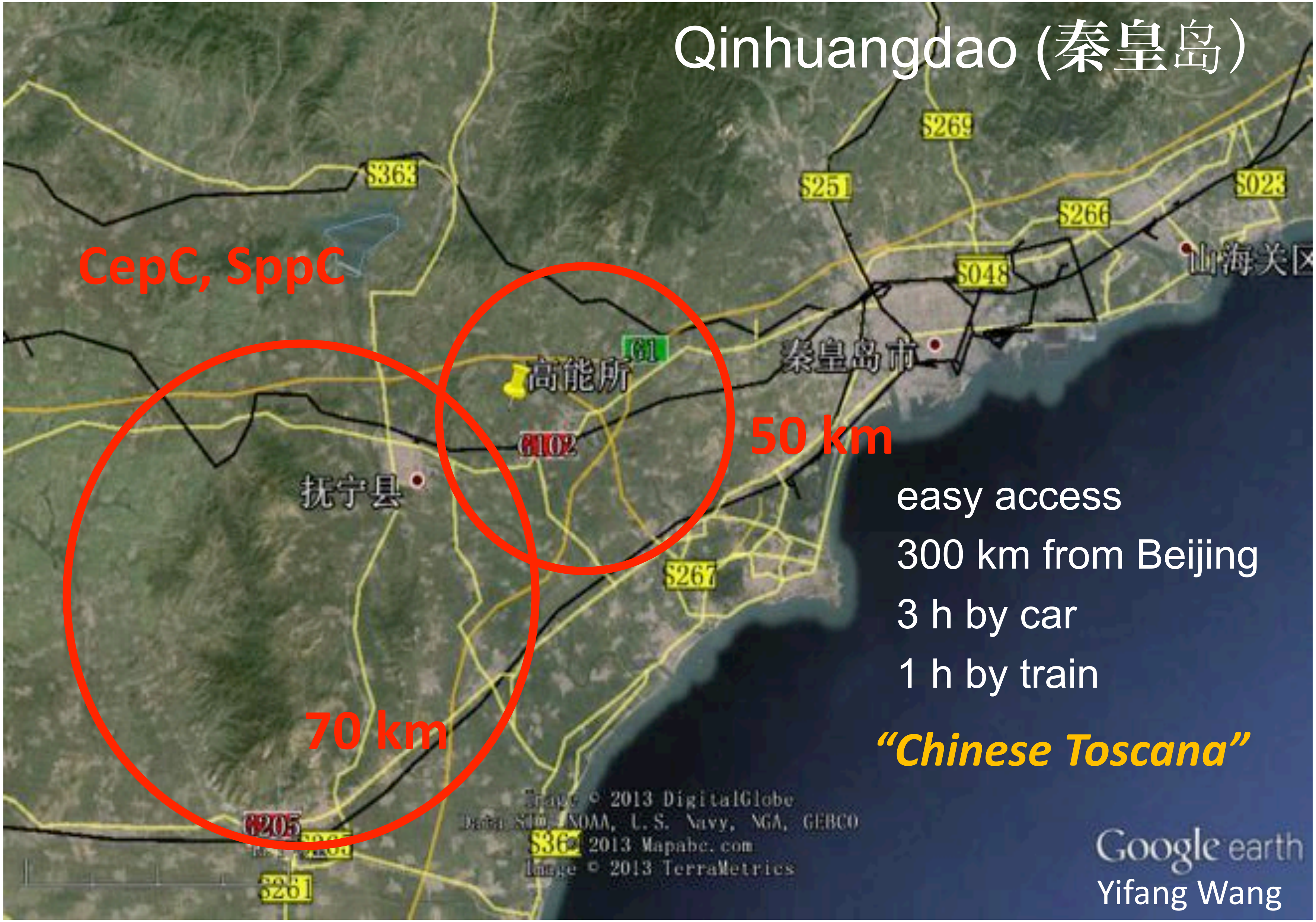
~16 T ⇒ 100 TeV in 100 km
~20 T ⇒ 100 TeV in 80 km

- including ***HE-LHC*** option: 16-20 T in LHC tunnel
- ***e^+e^-* collider (*FCC-ee/ TLEP*)** as potential intermediate step
- ***p-e* (*FCC-he*) option**
- **100 km infrastructure** in Geneva area

M. Benedikt



CepC/SppC study (CAS-IHEP), CepC CDR end of 2014, e^+e^- collisions ~2028; *pp* collisions ~2042



Qinhuangdao (秦皇岛)

easy access

300 km from Beijing

3 h by car

1 h by train

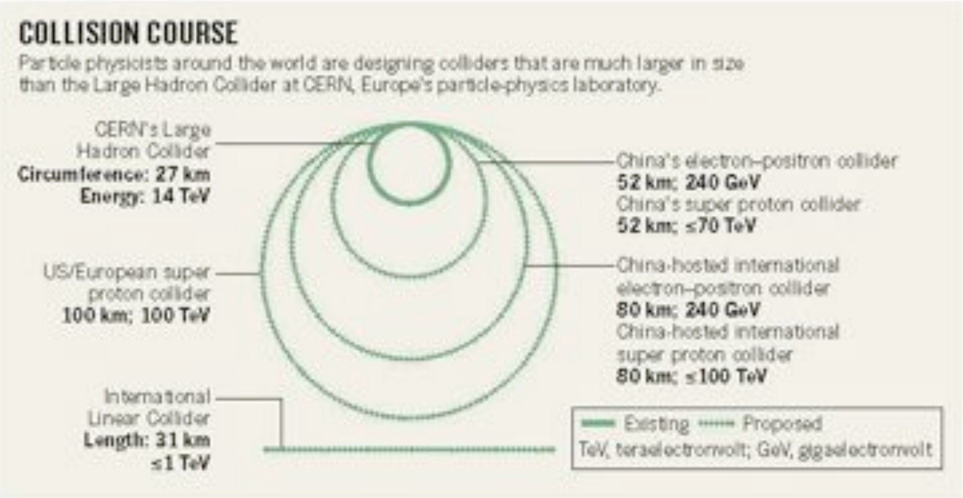
"Chinese Toscana"

Yifang Wang

CepC/SppC project – latest news in *Nature*

24 J U LY 2014 | VO L 511 | NAT U R E | 3

IN FOCUS NEWS



PARTICLE PHYSICS

China plans super collider

Proposals for two accelerators could see country become collider capital of the world.

BY ELIZABETH GIBNEY

For decades, Europe and the United States have led the way when it comes to high-energy particle colliders. But a proposal by China that is quietly gathering momentum has raised the possibility that the country could soon position itself at the forefront of particle physics.

Scientists at the Institute of High Energy Physics (IHEP) in Beijing, working with international collaborators, are planning to build a 'Higgs factory' by 2028 — a 52-kilometre underground ring that would smash together electrons and positrons. Collisions of these fundamental particles would allow the Higgs China hopes that it would also be a stepping stone to a next-generation collider — a super proton–proton collider — in the same tunnel.

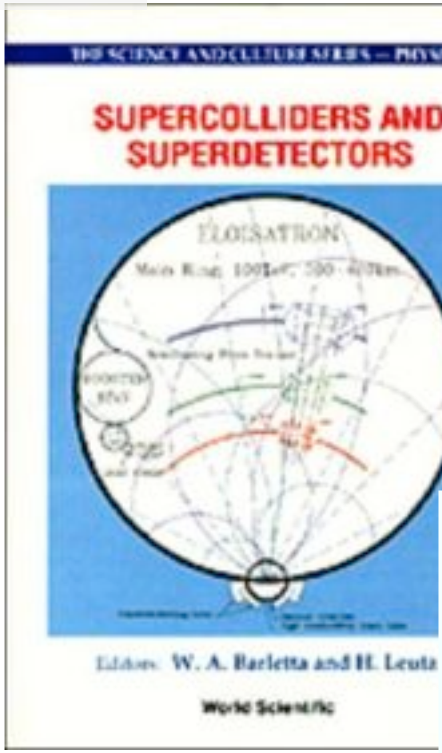
European and US teams have both shown interest in building their own super collider (see *Nature* **503**, 177; 2013), but the huge amount of research needed before such a machine could be built means that the earliest date either can aim for is 2035. China would like to build its electron–positron collider in the meantime, unaided by international funding if needs be, and follow it up as fast as technologically possible with the super proton collider. Because only one super collider is likely to be built, China's momentum puts it firmly in the driving seat.

Electron–positron colliders and hadron colliders such as the LHC complement each other. Hadron colliders are sledgehammers, smashing together protons (a kind of hadron that comprises three fundamental particles called quarks) at high energies to see what emerges. Lower-energy electron–positron machines produce cleaner collisions that are easier to analyse, because they are already smashing together fundamental particles. By examining in detail the interactions of the Higgs boson with other particles, the proposed Chinese collider should, for example, be able to detect whether the Higgs is a simple particle or something more exotic. This would help physicists to work out whether the particle fits with

previous studies in Italy (ELOISATRON 300 km), USA (SSC 87 km, VLHC & VLLC 233 km) …

ex. ELOISATRON

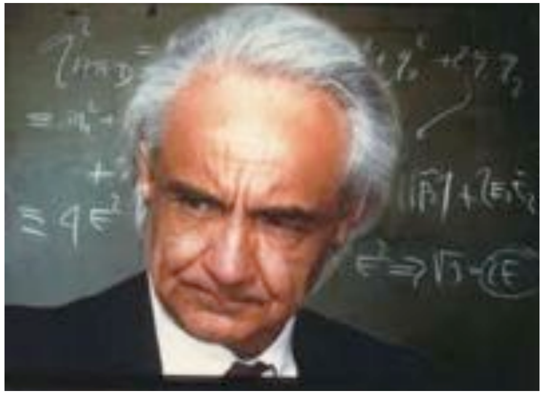
Supercolliders Superdetectors: Proceedings of the 19th and 25th Workshops of the INFN Eloisatron Project


THE SCIENCE AND CULTURE SERIES — PHYSICS

SUPERCOLLIDERS AND SUPERDETECTORS

Editors W. A. Barletta and H. Leutz

World Scientific



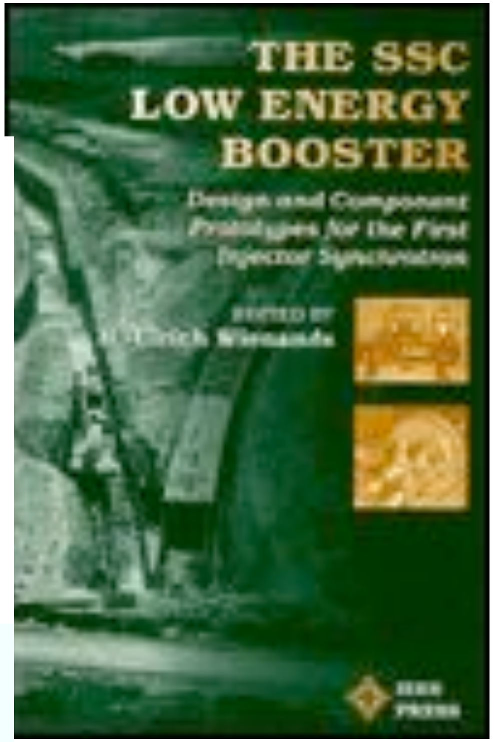
ex. SSC


C.T. Murphy

Conceptual Design of the Superconducting Super Collider

SSC Central Design Group*

SSC CDR 1986


THE SSC LOW ENERGY BOOSTER

Design and Component Prototypes for the First Injector Synchrotron

EDITED BY H. Ulrich Wienands

IEEE PRESS

H. Ulrich Wienands, The SSC Low Energy Booster: Design and Component Prototypes for the First Injector Synchrotron, IEEE Press, 1997

ex. VLHC

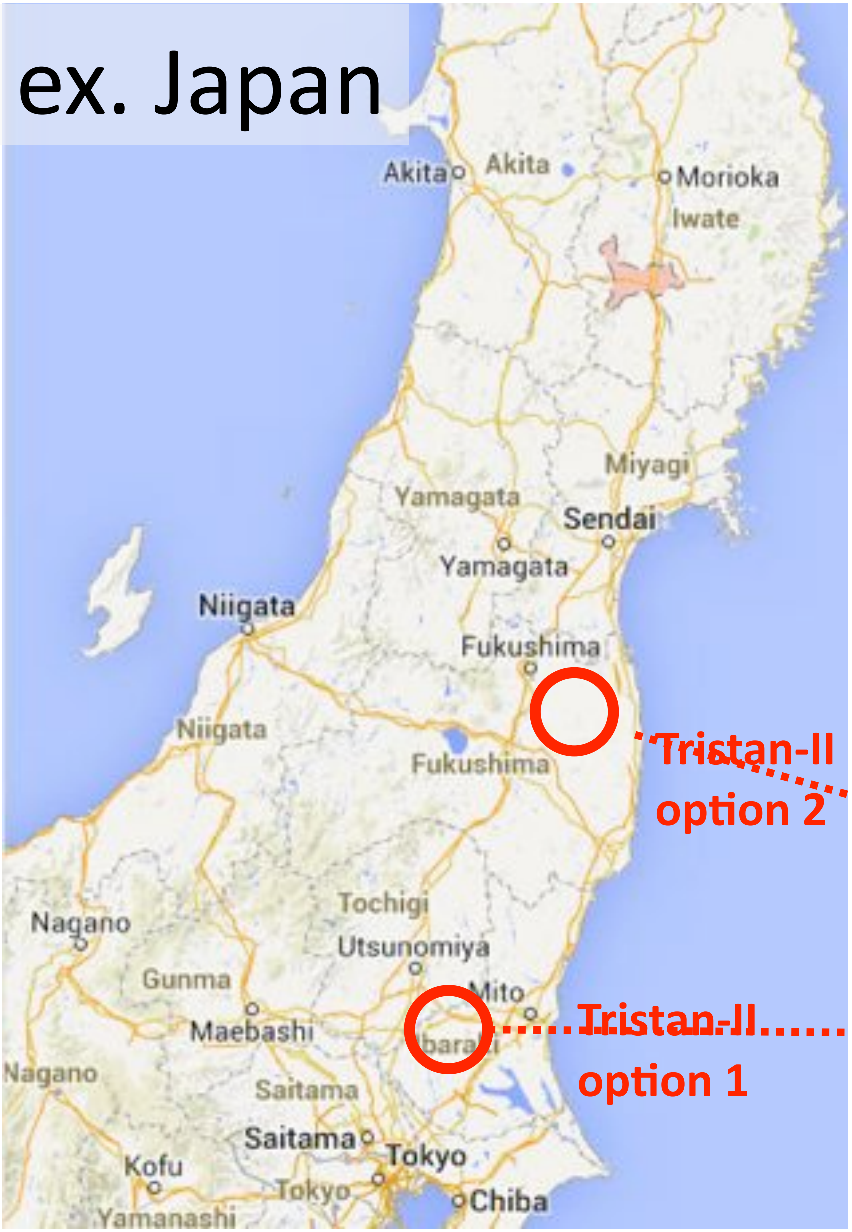

Very Large Hadron Collider

Design Study for a Staged Very Large Hadron Collider

VLHC Design Study Group Collaboration **June 2001**. 271 pp. SLAC-R-591, SLAC-R-0591, SLAC-591, SLAC-0591, FERMILAB-TM-2149

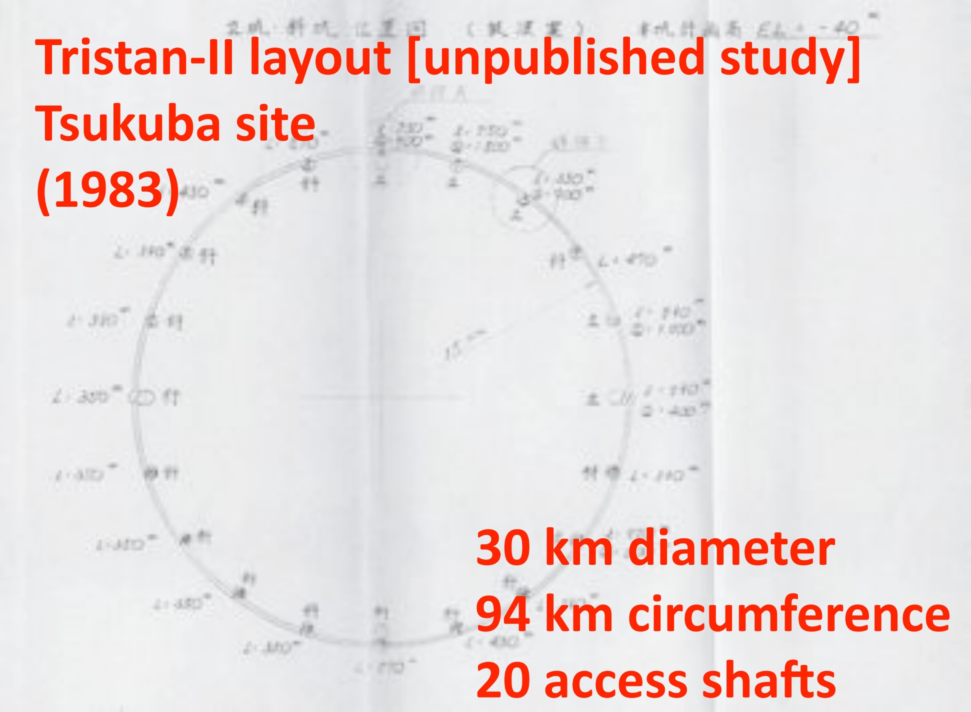
http://www.vlhc.org/

previous studies in Italy (ELOISATRON), USA (SSC, VLHC, VLLC), and Japan (“TRISTAN-II”)



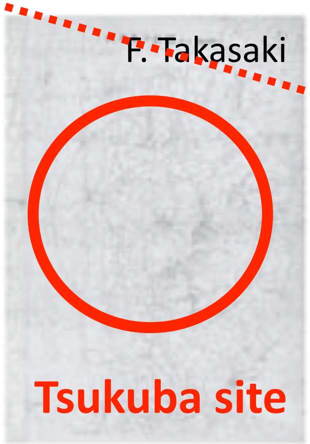
Tristan-II option 2

Tristan-II option 1



Tristan-II layout [unpublished study]
Tsukuba site
(1983)

30 km diameter
94 km circumference
20 access shafts



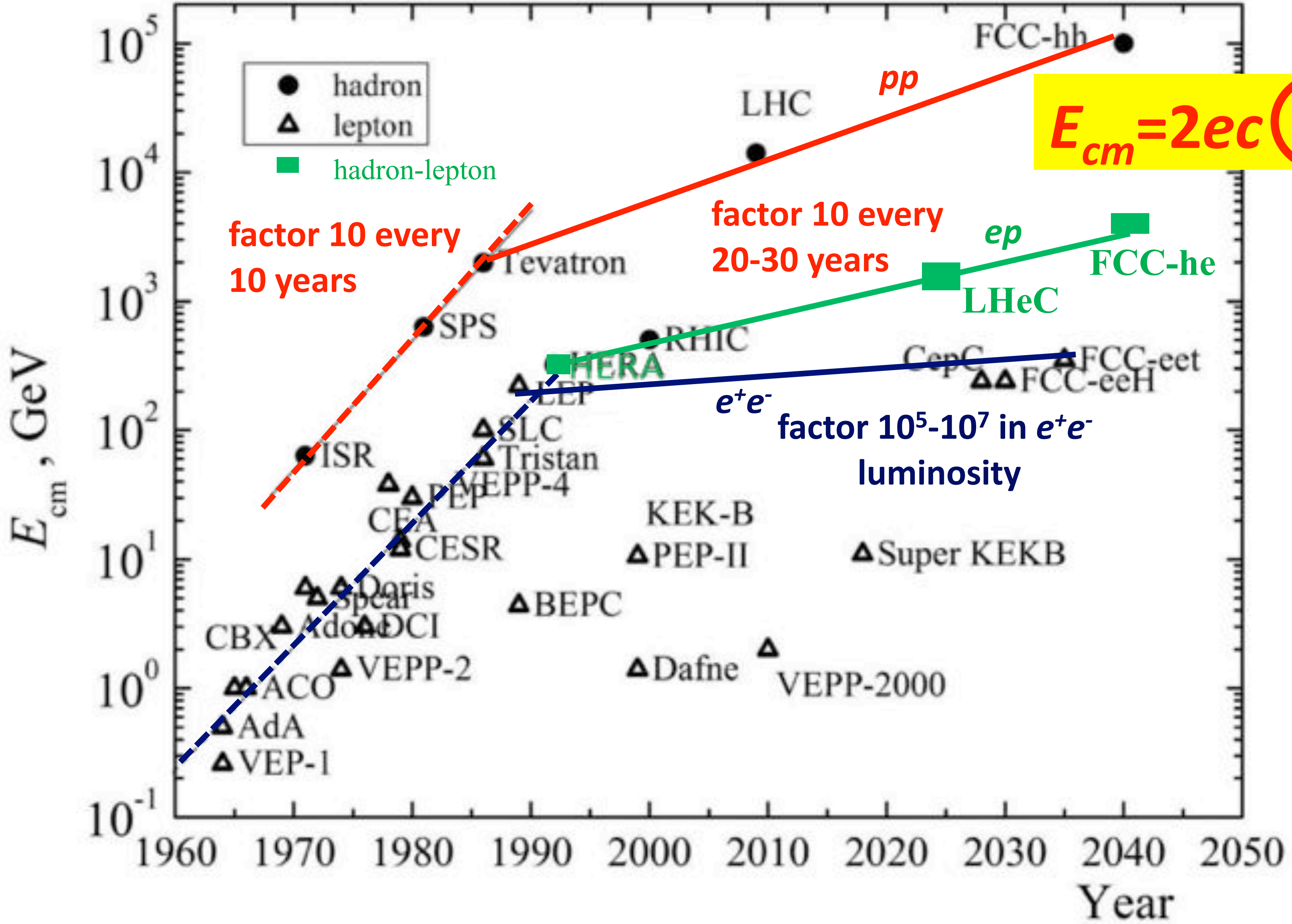
F. Takasaki

Tsukuba site

F. Takasaki

Fukushima site

collider c.m. energy vs. year



factor 10 every 10 years

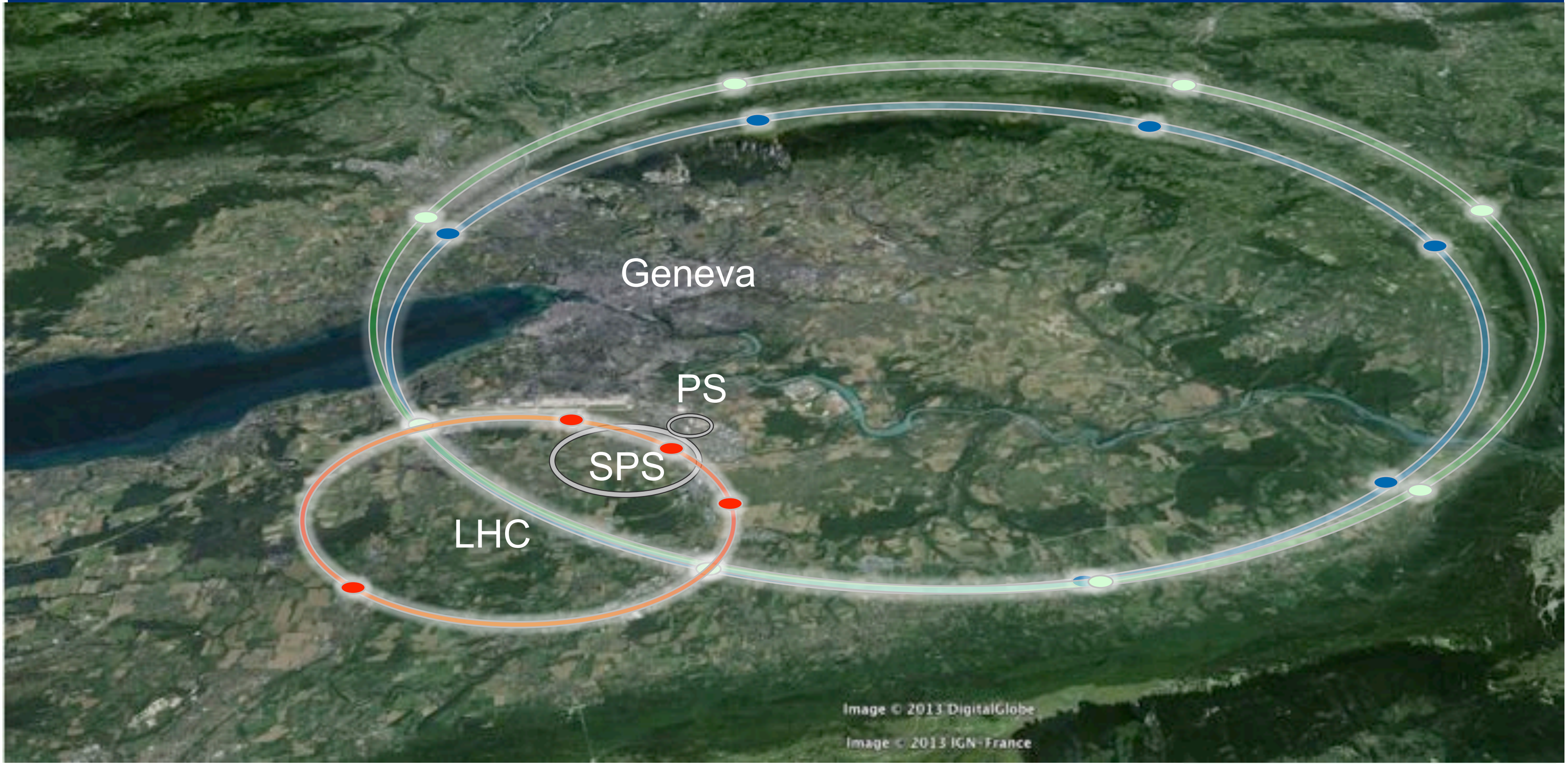
factor 10 every 20-30 years

factor 10^5-10^7 in e^+e^- luminosity

$$E_{cm}=2ec\boxed{B\rho}$$

Courtesy V. Shiltsev,

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.)

B. Strauss

FCC-hh opens three physics windows

➥ Access to new particles in the few TeV to 30 TeV mass range, beyond LHC reach

➥ Immense/much-increased rates for phenomena in the sub-TeV mass range → increased precision w.r.t. LHC and possibly ILC

➥ Access to very rare processes in the sub-TeV mass range → search for stealth phenomena, invisible at the LHC

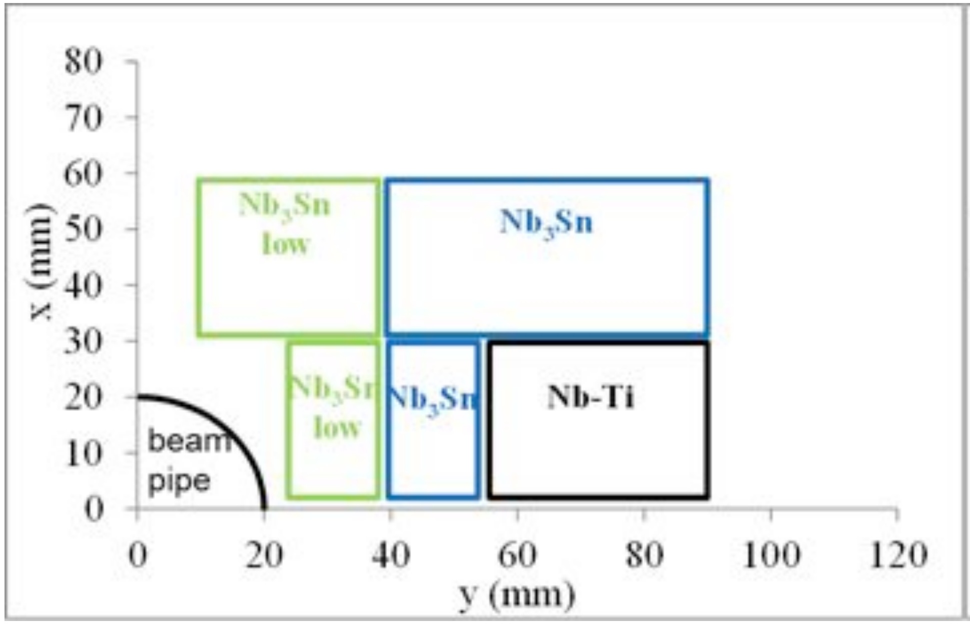
M. Mangano

parameter	LHC	HL-LHC	FCC-hh
c.m. energy [TeV]	14		100
dipole magnet field [T]	8.33		16 (20)
circumference [km]	26.7		100 (83)
luminosity [10^{34} cm^{-2}s^{-1}]	1	5	5 [→20?]
bunch spacing [ns]	25		25 (5)
events / bunch crossing	**27**	**135**	**170 (34)**
bunch population [10^{11}]	1.15	2.2	1 (0.2)
norm. transverse emitt. [μm]	3.75	2.5	2.2 (0.44)
IP beta-function [m]	0.55	0.15	1.1
IP beam size [μm]	16.7	7.1	6.8 (3)
synchrotron rad. [W/m/aperture]	0.17	0.33	28 (44)
critical energy [keV]	0.044		4.3 (5.5)
total syn.rad. power [MW]	**0.0072**	**0.0146**	**4.8 (5.8)**
longitudinal damping time [h]	**12.9**		**0.54 (0.32)**

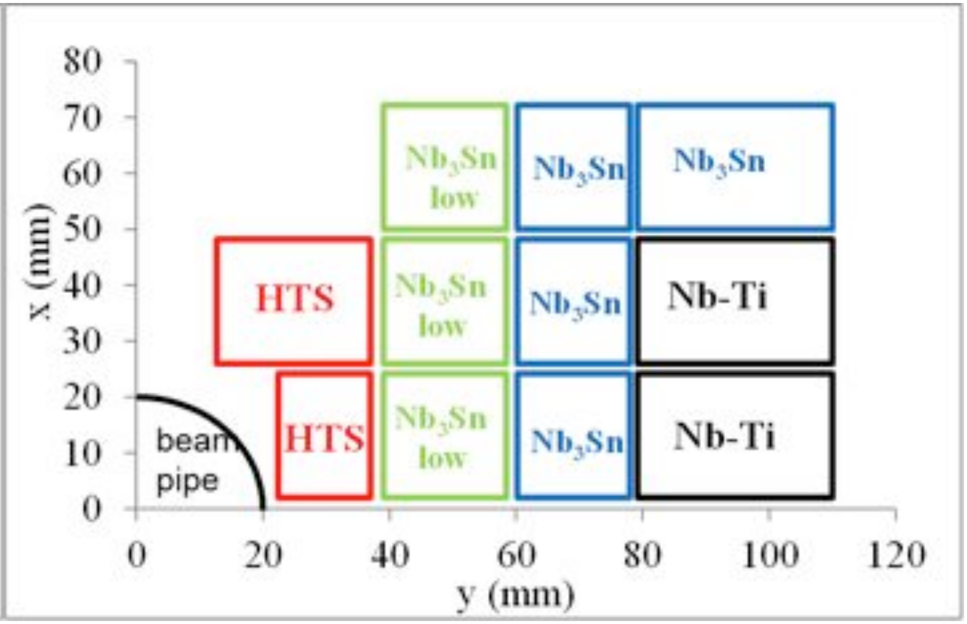
parameter	LHC	HL-LHC	FCC-hh	SppC (May14)
c.m. energy [TeV]	14		100	63
dipole magnet field [T]	8.33		16 (20)	20
circumference [km]	26.7		100 (83)	50
luminosity [10^{34} $cm^{-2}s^{-1}$]	1	5	5 [→20?]	12
bunch spacing [ns]	25		25 (5)	25
events / bunch crossing	**27**	**135**	**170 (34)**	**373**
bunch population [10^{11}]	1.15	2.2	1 (0.2)	2
norm. transverse emitt. [μm]	3.75	2.5	2.2 (0.44)	3.3
IP beta-function [m]	0.55	0.15	1.1	0.75
IP beam size [μm]	16.7	7.1	6.8 (3)	8.5
synchrotron rad. [W/m/ aperture]	0.17	0.33	28 (44)	46
critical energy [keV]	0.044		4.3 (5.5)	2.2
total syn.rad. power [MW]	**0.0072**	**0.0146**	**4.8 (5.8)**	**3**
longitudinal damping time [h]	**12.9**		**0.54 (0.32)**	**1.0**

cost-optimized high-field dipole magnets

15-16 T: *Nb-Ti* & *Nb_3Sn*



20 T: *Nb-Ti* & *Nb_3Sn* & *HTS*



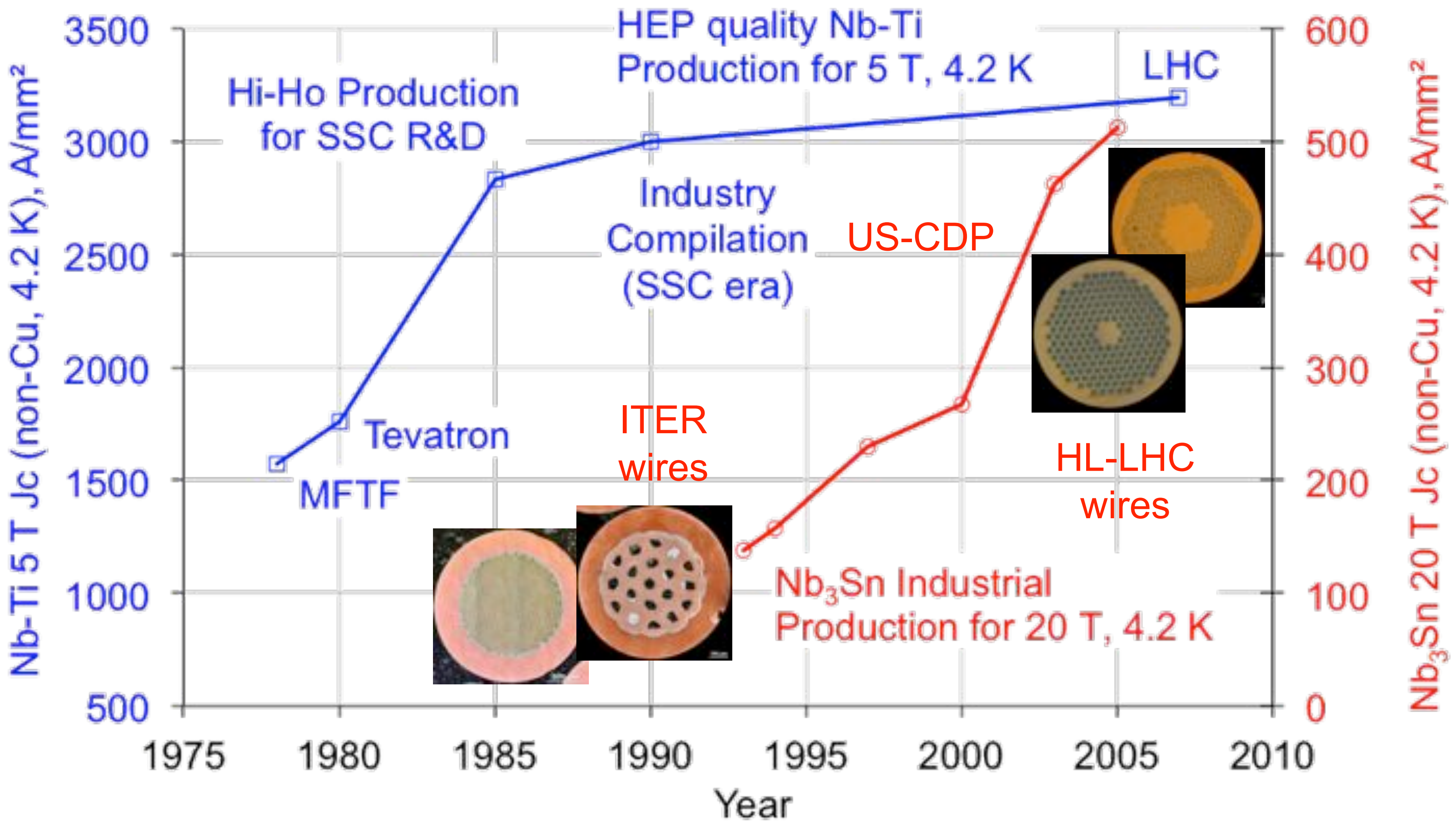
only a quarter is shown

"hybrid magnets"

example block-coil layout

L. Rossi, E. Todesco, P. McIntyre

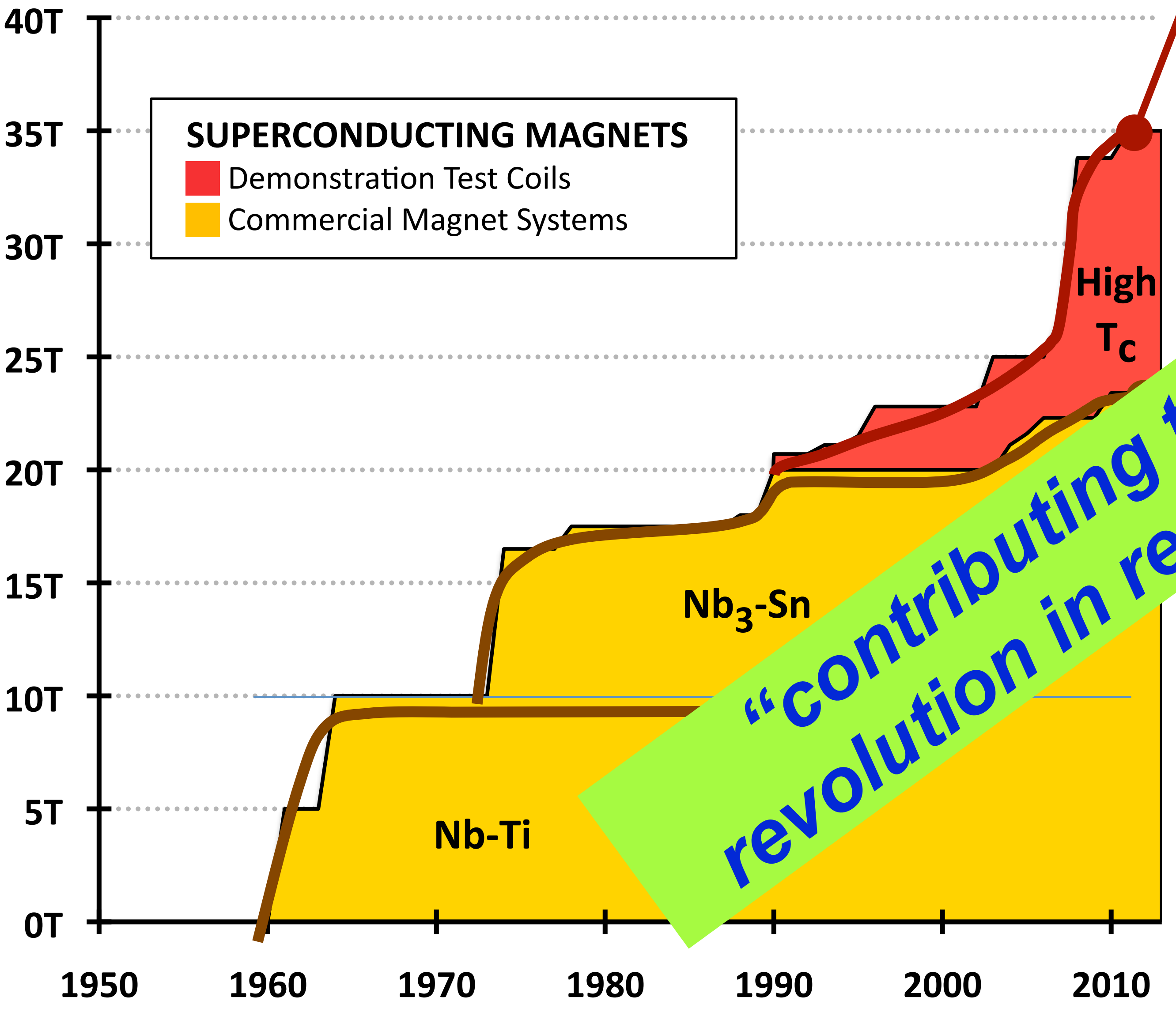
Nb_3Sn vs *Nb-Ti* SC wire production



B. Strauss, data by courtesy of J. Parrell (US DOE OST)

superconducting magnet technology

SC solenoid magnets (dipoles to follow)



“contributing to a revolution in real time”

35 T Proof-of-Principle Demo

(4T HTS Test Coil in a 31T Background Magnetic Field)

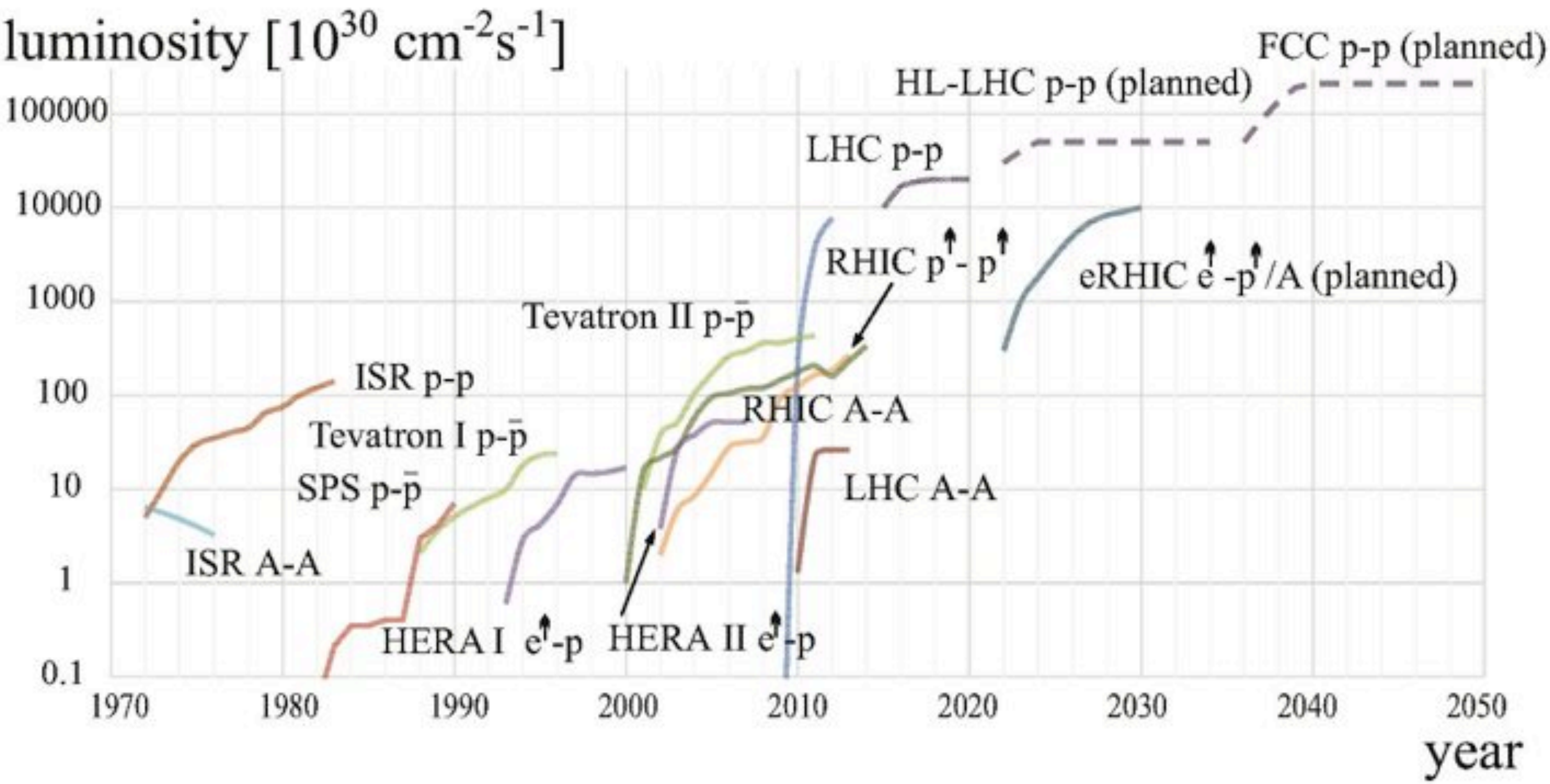
ϕ 39 mm

23.5 T (1GHz NMR) Nb_3-Sn Superconducting Magnets

(Manufactured Commercially)

G. Boebinger, NHMFL

hadron-collider peak luminosity vs. year



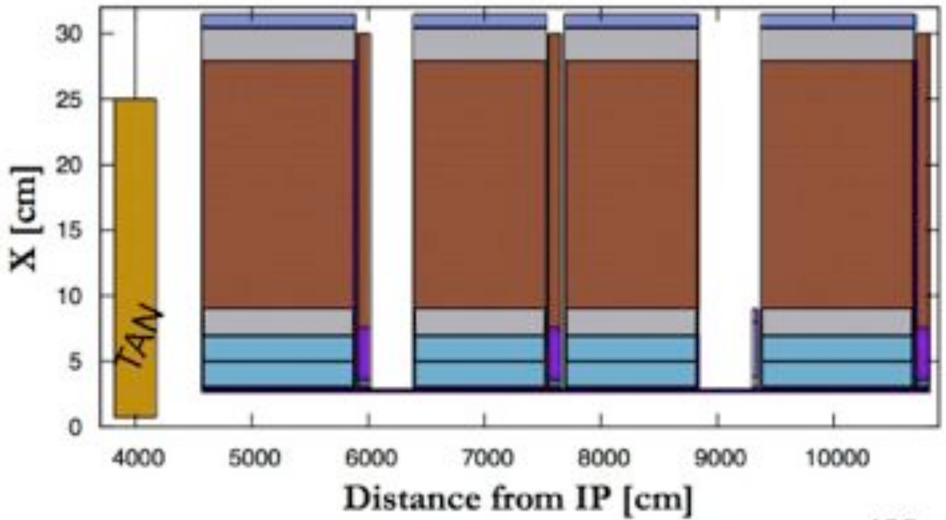
Courtesy W. Fischer

LHC run 1 (2012-13) accumulated more integrated luminosity than all previous hadron colliders together!

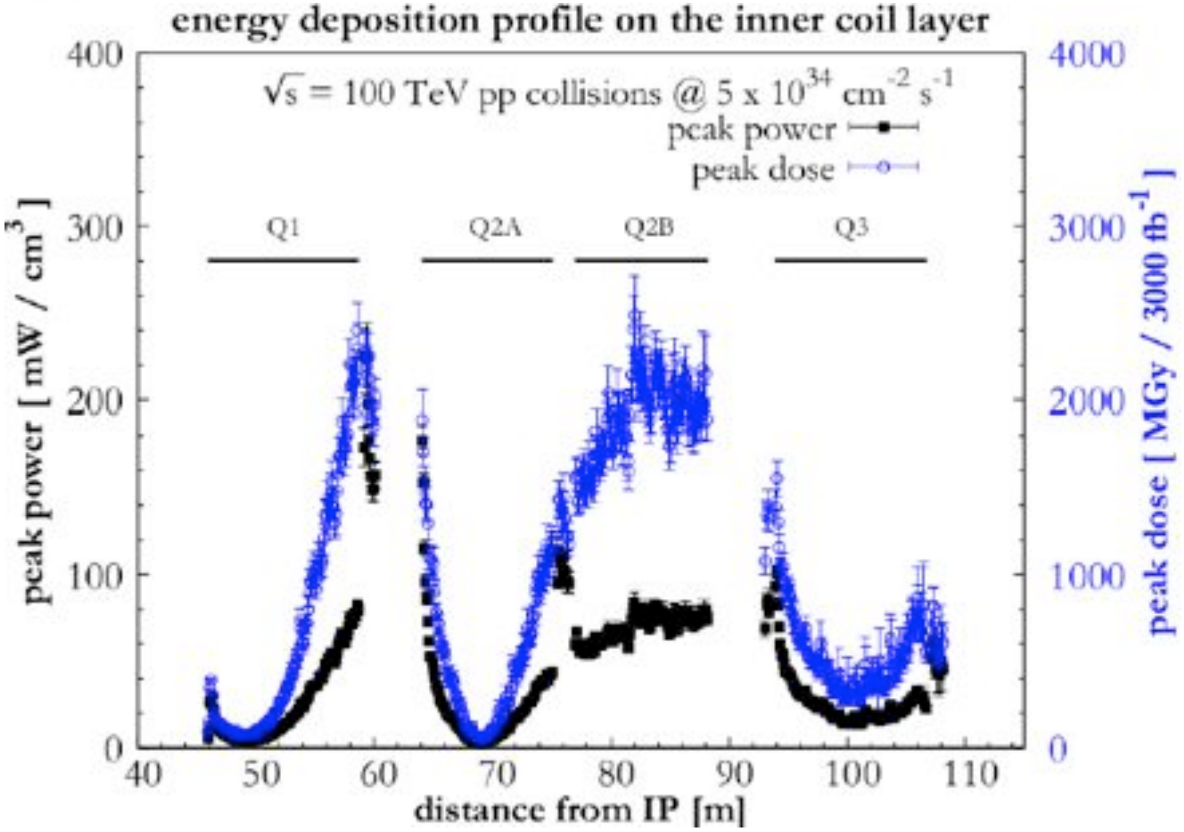
pp IR – radiation from collision debris

F. Cerutti and L. Esposito

FLUKA model



IR peak power and dose



HL-LHC* IR can handle 10x more radiation than *LHC

***FCC-hh* IR radiation another 10-100x higher**

R. Tomas

pp – machine protection / collimation

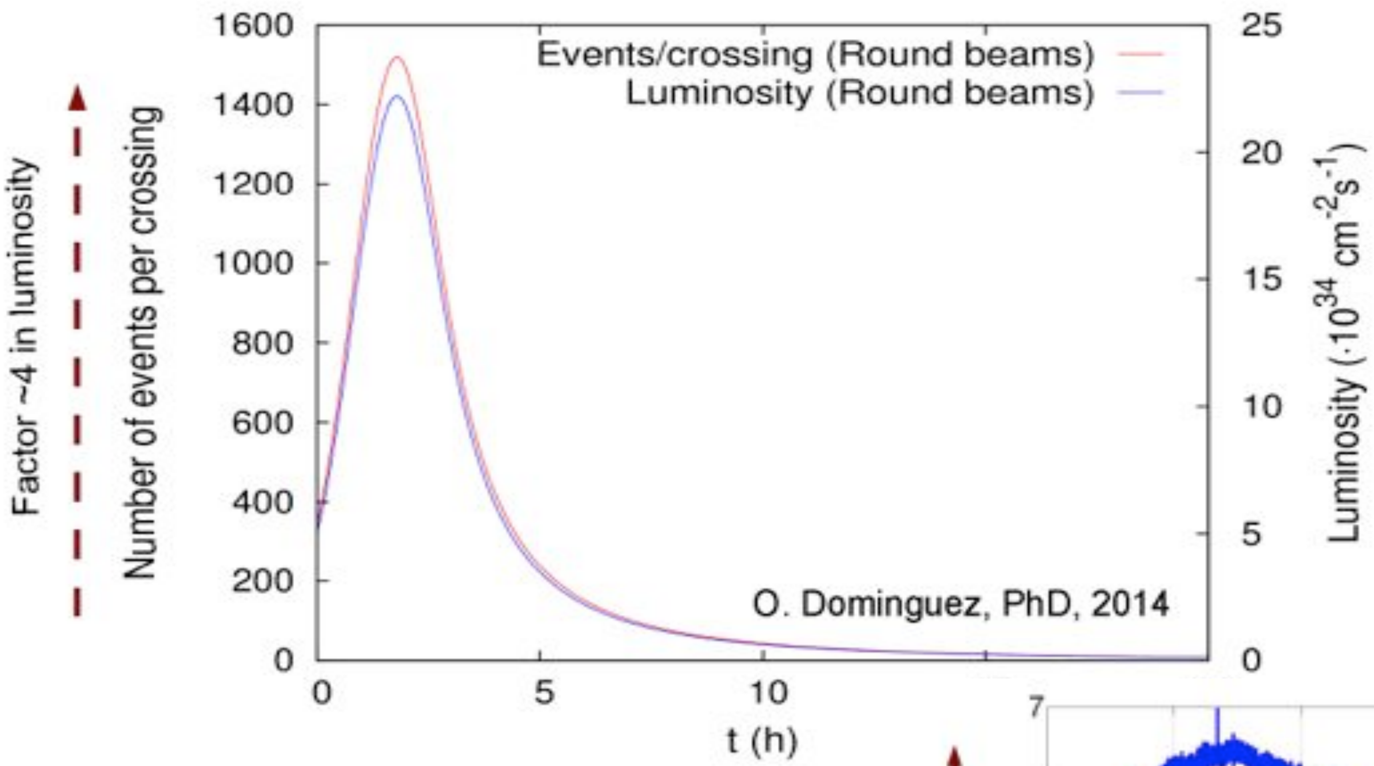
energy per proton beam
LHC: 0.4 GJ → *FCC-hh*: 8 GJ (20x more !)

→ new challenges for machine protection
(e.g. at injection) and collimation

some approaches considered:

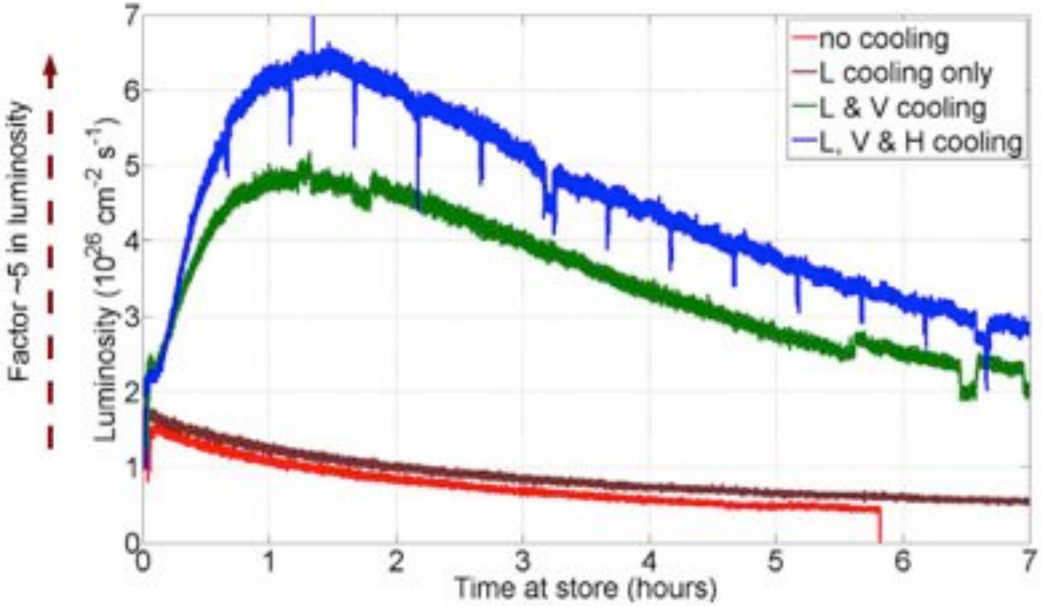
- advanced, more robust collimator materials
- shorter bunch trains at injection?
- crystal collimators or hollow electron lenses

luminosity evolution with syn. rad. damping



emittance
control
by noise
excitation!?

M. Blaskiewicz et al.

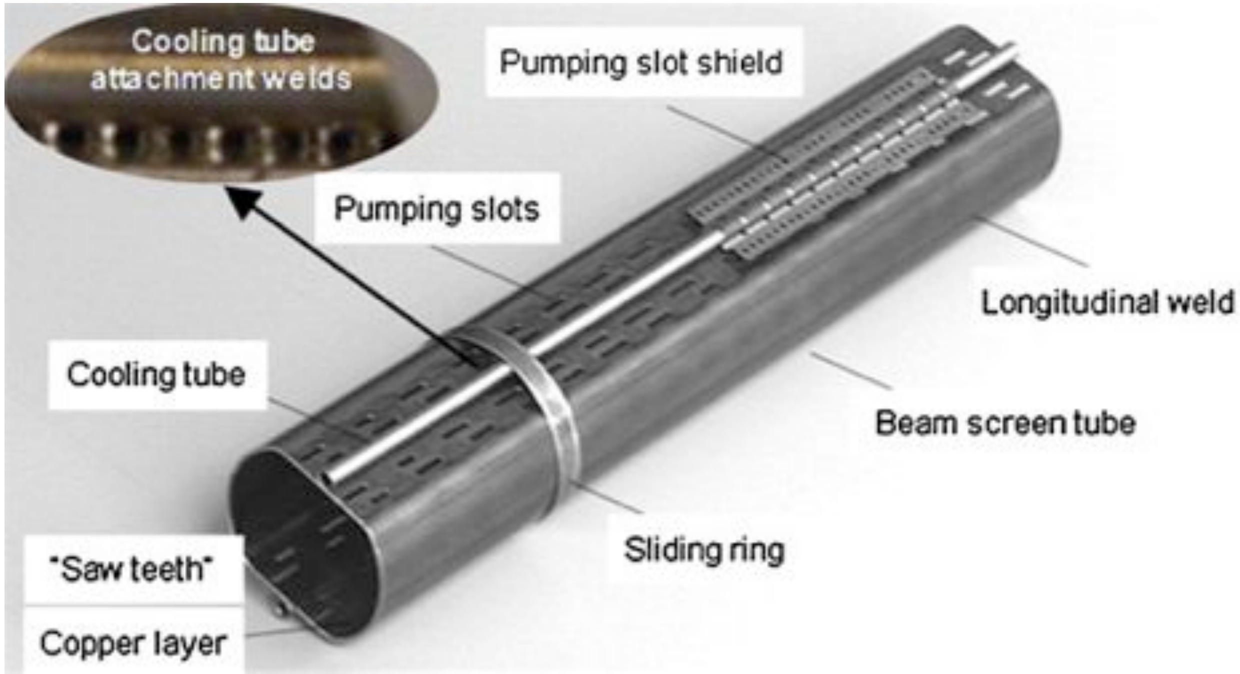


extremely similar to RHIC operation with stochastic cooling

R. Tomas

LHC-type beam pipe?

synchrotron radiation (SR): 28 W/m/beam at 16 T



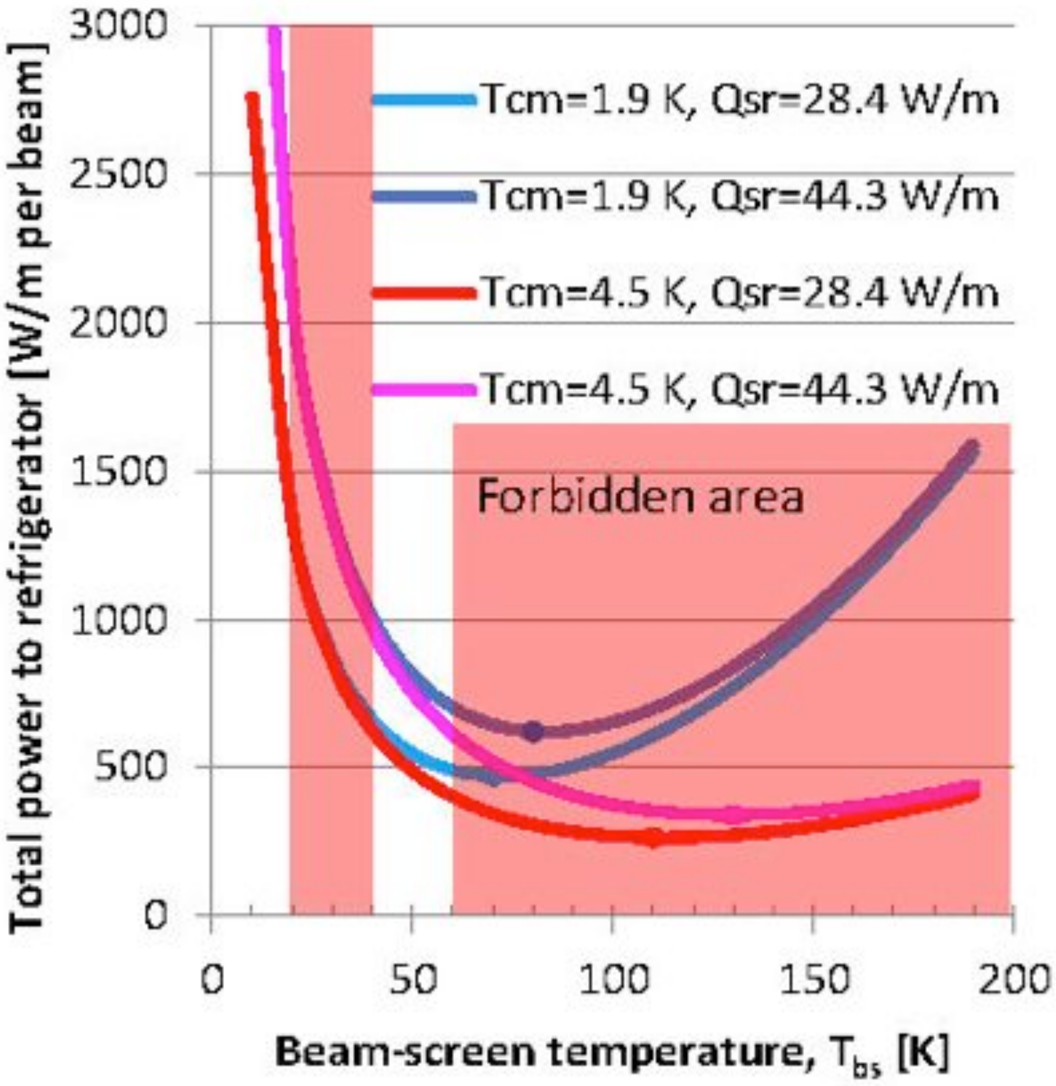
SR power mostly cooled at beam screen temperature; part going to magnets at 2-4 K

options:

- LHC-type copper coated beam screen (baseline)
- LHC-type beam screen coated with HTS + advanced cryogens (*He-Ne* mixtures)
- photon stops at room temperature

D. Schulte

total cryo power for cooling of SR heat



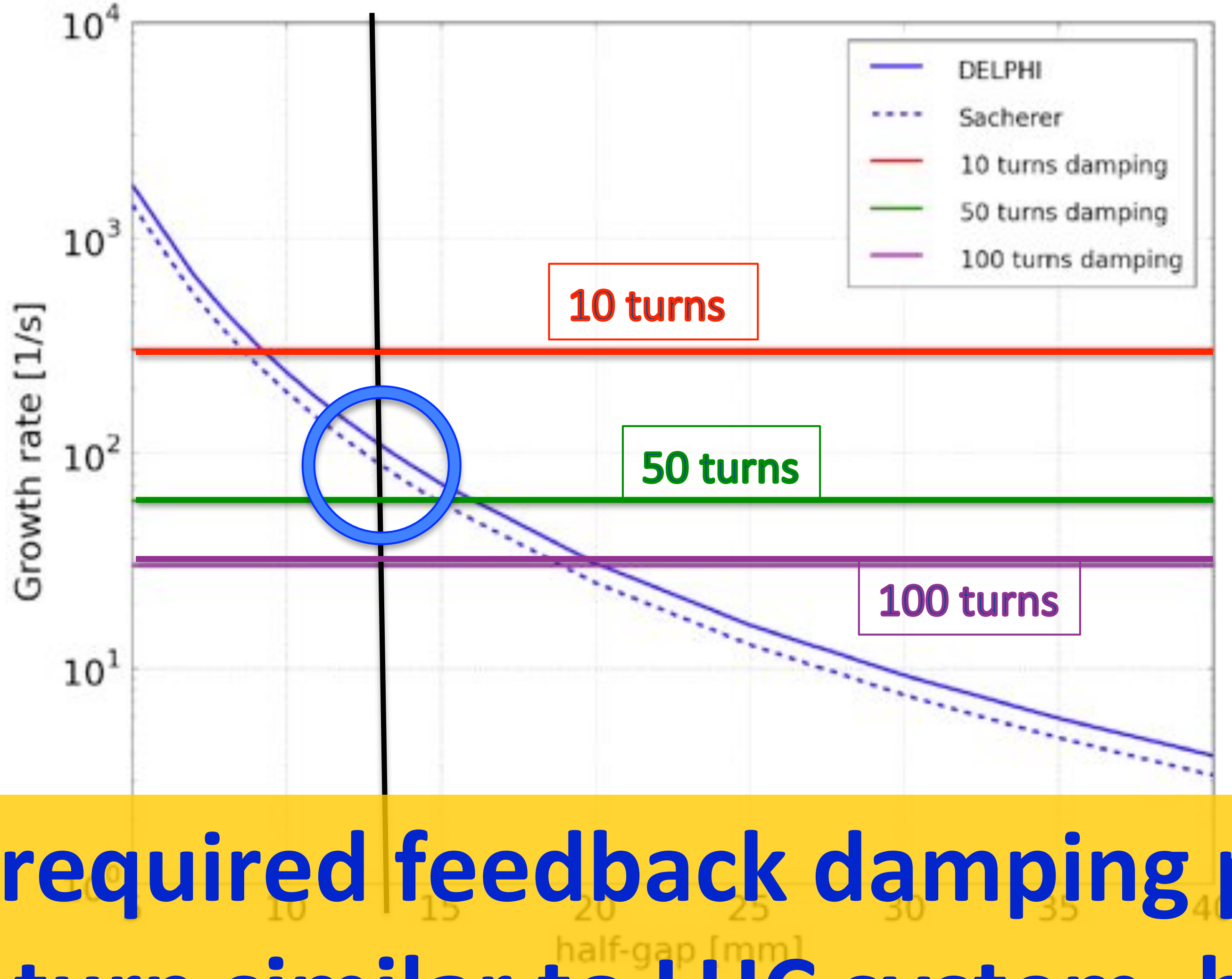
contributions: beam screen (BS) & cold bore (BS heat radiation)

P. Lebrun, L. Tavian, *Beyond the Large Hadron Collider: a first look at cryogenics for CERN future circular colliders*, ICEC 25/ICMC 2014 Twente, 7-11 July 2014

at 1.9 K cm optimum BS temperature range: 50-100 K; 40-60 K favoured by impedance & vacuum considerations

at higher magnet/cm temperature (4.5 K instead of 1.9 K) optimum BS temperature increases & power decreases

resistive-wall instability



N. Mounet, G. Rumolo

need <50-turn feedback

- or increase beam screen aperture
- or decrease beam current

multi-bunch effect at 50 K & injection;
only resistive wall (infinite copper layer)

required feedback damping per turn similar to LHC system, but time per turn 4x longer

TMCI is less important

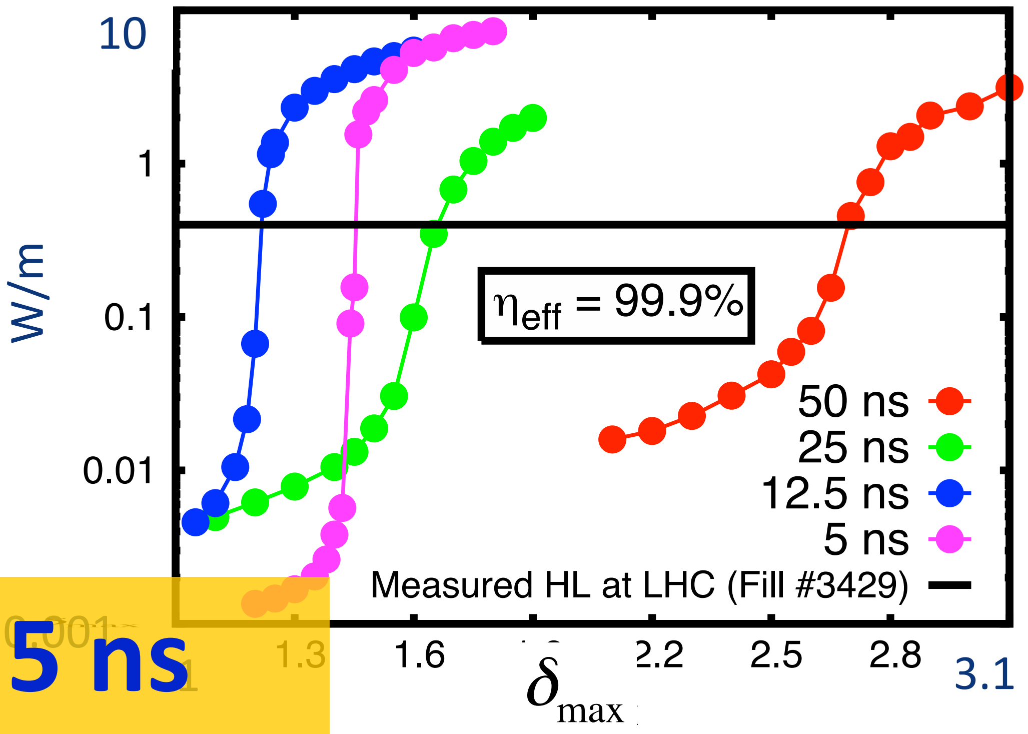
D Schulte

electron cloud

critical photon energy 4.3 keV
similar to 2-3 GeV light
sources i.e. 100 x LHC

additional heat load
beam stability?

O. Dominguez Sanchez De La Blanca



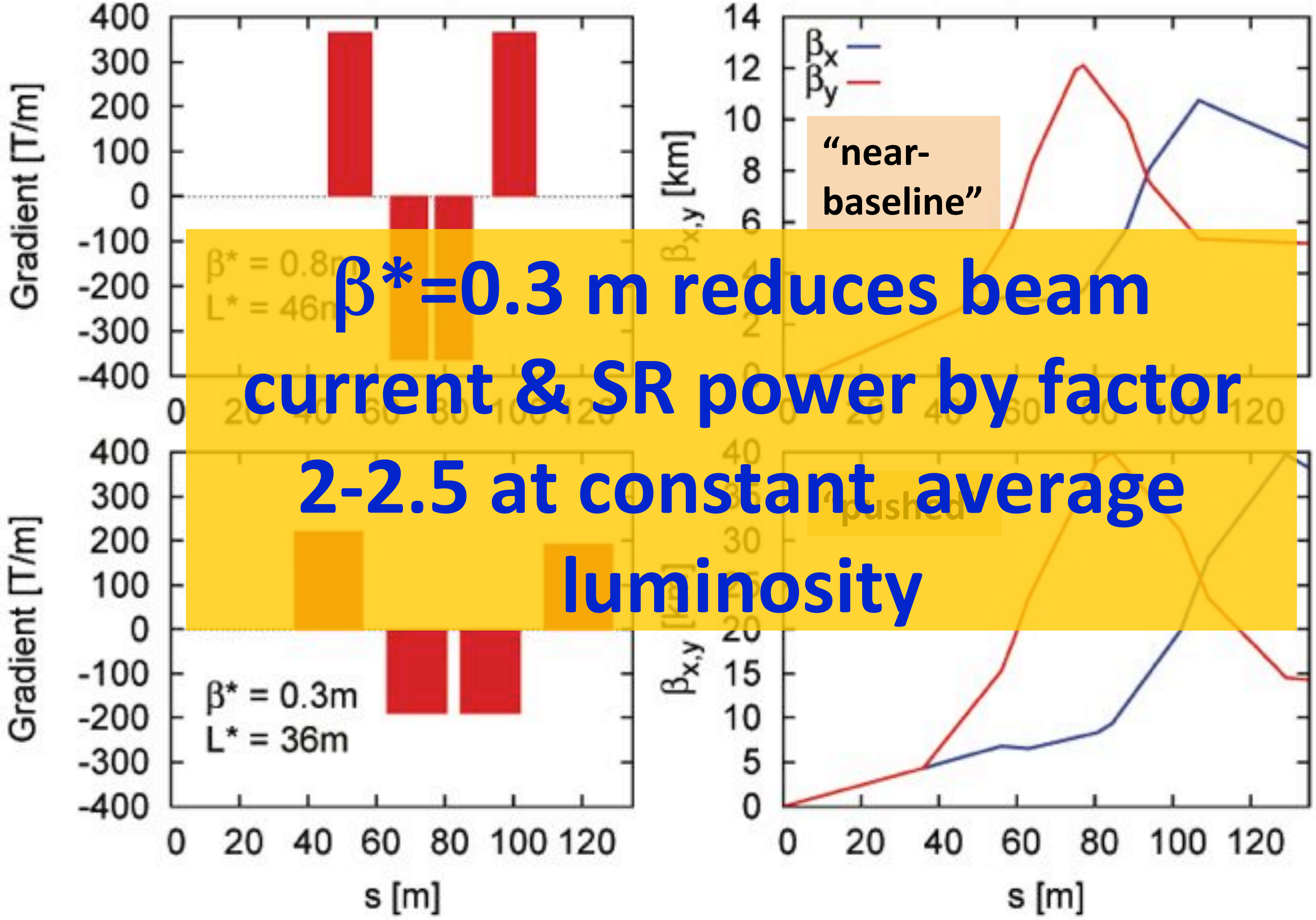
R&D items:
- photon capture efficiency?
- dependence on beam pipe aperture
- surface properties at 40-60 K
- surface properties of HTS coating

aside from 25 ns, 5 ns could be possible bunch spacing→ better use of SR damping & 4-5 times higher luminosity

O. Dominguez, PhD Thesis EPFL Lausanne, 2014; also G. Iadarola, H. Bartosik et al., IPAC2014

D. Schulte

pp IR optics – low β* at 100 TeV?



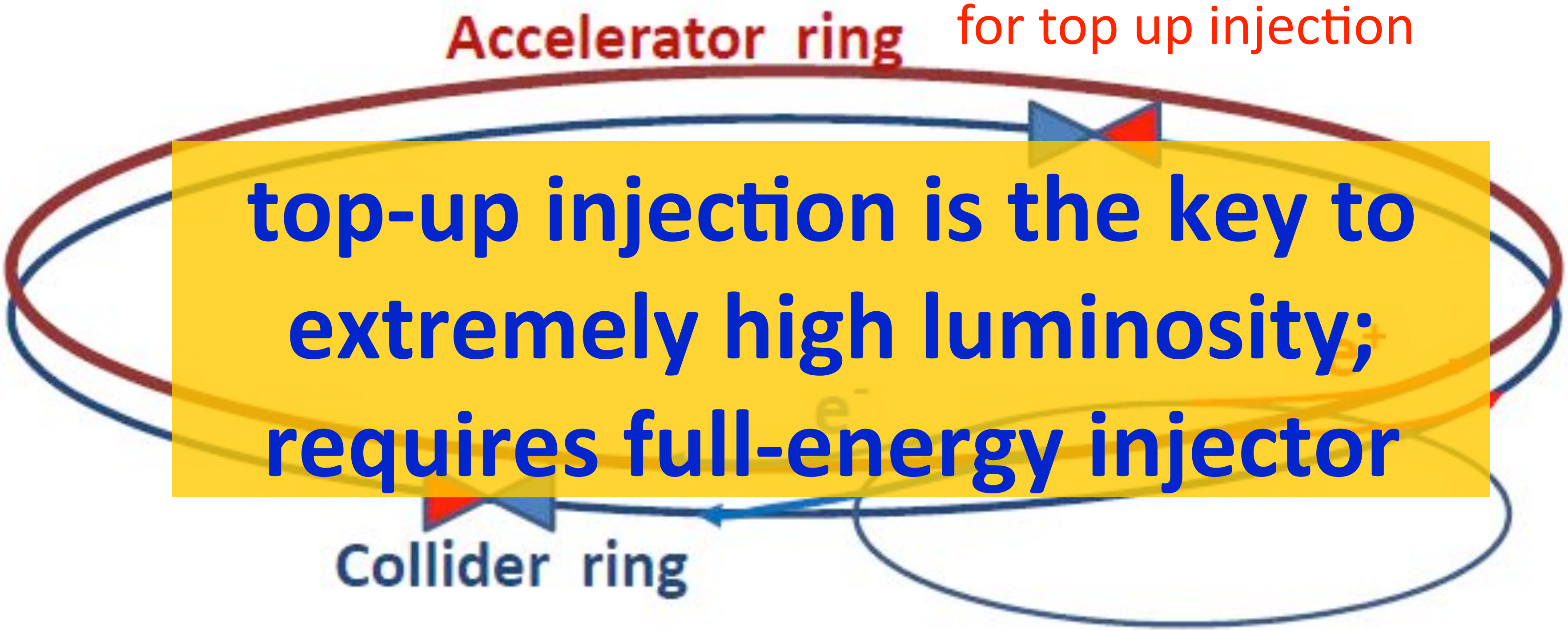
β*=0.3 m reduces beam current & SR power by factor 2-2.5 at constant average luminosity

R. Tomas, R. Martin, E. Todesco et al.

FCC-ee: e^+e^- collider up to 350 (500) GeV

circumference ≈100 km

A. Blondel



for top up injection

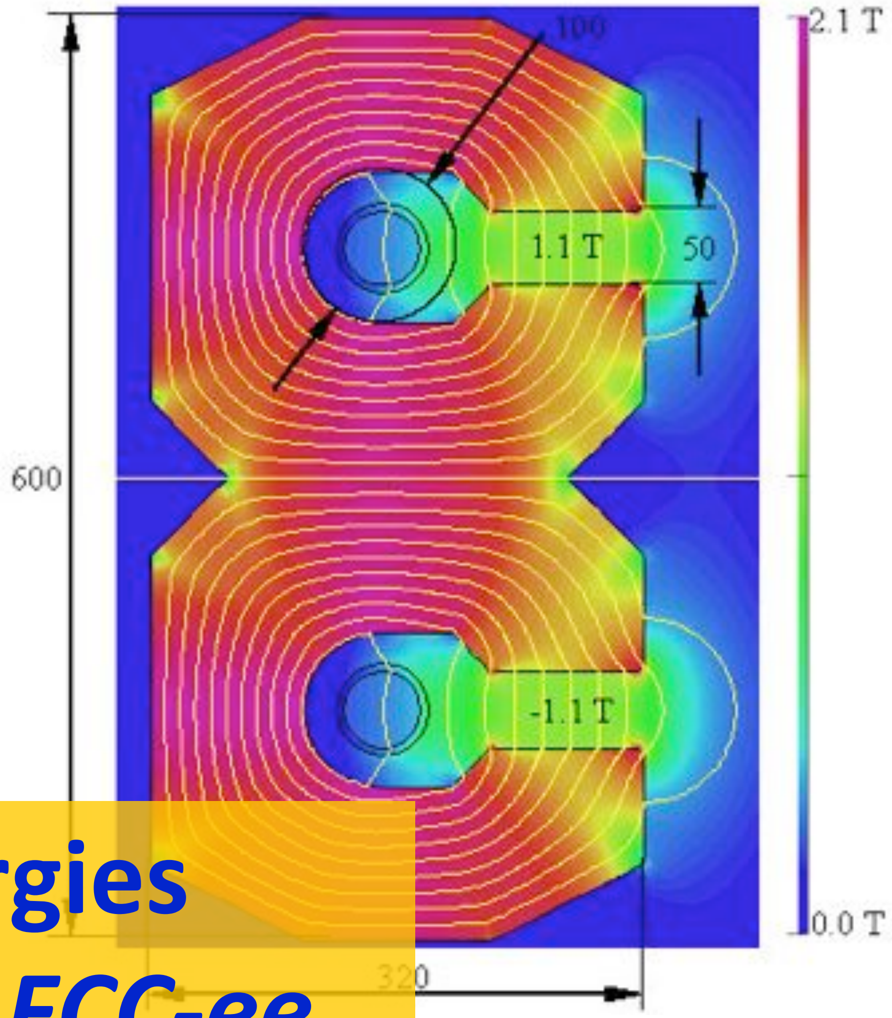
top-up injection is the key to extremely high luminosity; requires full-energy injector

short beam lifetime (~τ_{LEP2}/40) due to high luminosity **supported by top-up injection** (used at KEKB, PEP-II, SLS,…); top-up **also avoids ramping & thermal transients, + eases tuning**

FCC-ee/hh: hybrid NC & SC arc magnets

twin-aperture iron-dominated, compact hybrid “transmission line” dipoles - for injector synchrotrons in FCC tunnel

- resistive cable
  for lepton machine
- superconducting
  for hadron operation



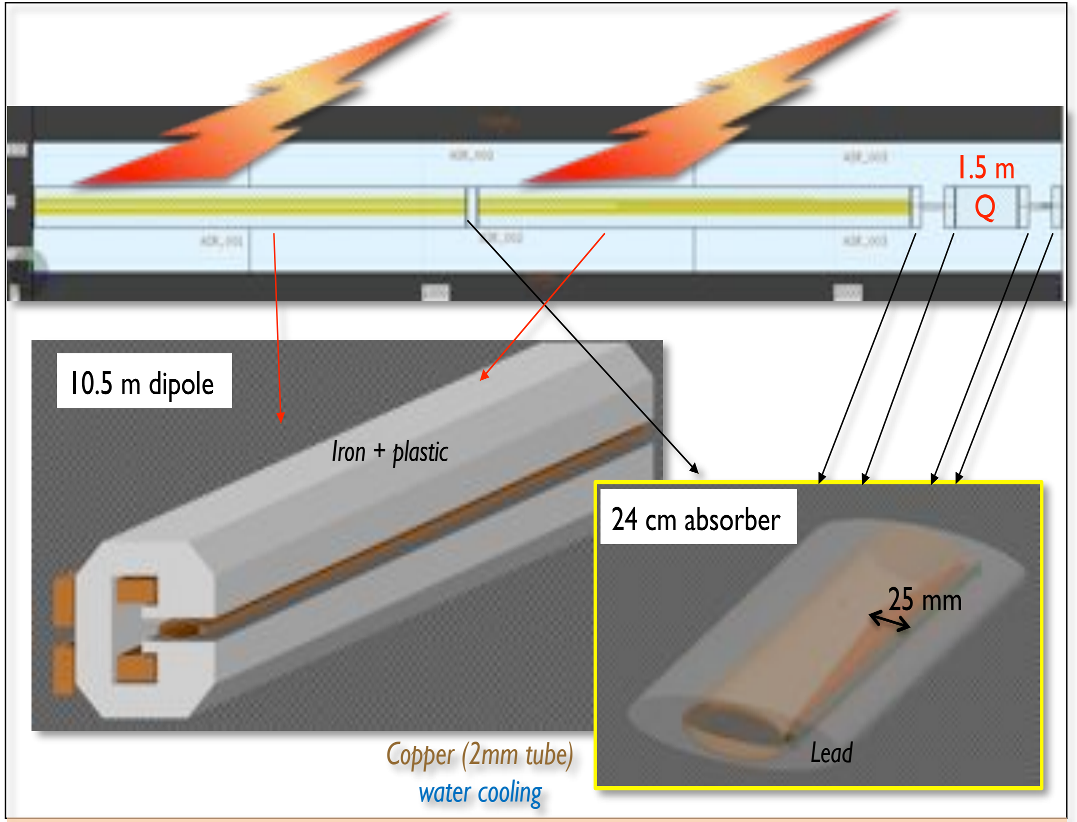
required dynamic range ~100
hadron extraction 1.1 T
lepton injection: 10 mT

one of many synergies between *FCC-hh* and *FCC-ee*

A. Milanese, H. Piekarz, L. Rossi, IPAC2014

parameter	**LEP2**	**FCC-ee**					**CepC**
		Z	**Z (c.w.)**	**W**	**H**	**t**	**H**
E_{beam} [GeV]	104	**45**	**45**	**80**	**120**	**175**	**120**
circumference [km]	26.7	**100**	**100**	**100**	**100**	**100**	**54**
current [mA]	3.0	1450	1431	152	30	6.6	16.6
$P_{SR,tot}$ [MW]	22	**100**	**100**	**100**	**100**	**100**	**100**
no. bunches	4	16700	29791	4490	1360	98	50
N_b [10^{11}]	4.2	1.8	1.0	0.7	0.46	1.4	3.7
ε_x [nm]	22	**29**	**0.14**	**3.3**	**0.94**	**2**	**6.8**
ε_y [pm]	250	**60**	**1**	**1**	**2**	**2**	**20**
β^*_x [m]	1.2	0.5	0.5	0.5	0.5	1.0	0.8
β^*_y [mm]	50	**1**	**1**	**1**	**1**	**1**	**1.2**
σ^*_y [nm]	3500	250	32	130	44	45	160
$\sigma_{z,SR}$ [mm]	**11.5**	**1.64**	**2.7**	**1.01**	**0.81**	**1.16**	**2.3**
$\sigma_{z,tot}$ [mm] (w beamstr.)	**11.5**	**2.56**	**5.9**	**1.49**	**1.17**	**1.49**	**2.7**
hourglass factor F_{hg}	0.99	0.64	0.94	0.79	0.80	0.73	0.61
L/IP [10^{34} cm^{-2}s^{-1}]	0.01	**28**	**212**	**12**	**6**	**1.7**	**1.8**
τ_{beam} [min]	300	**287**	**39**	**72**	**30**	**23**	**40**

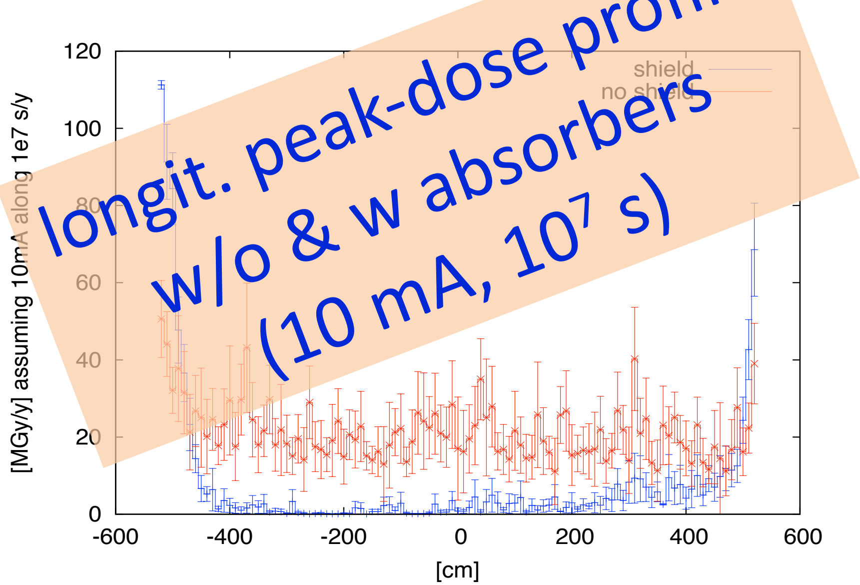
FCC-ee: Shielding 100 MW SR at 350 GeV



FLUKA geometry layout for half FODO cell, dipoles details, preliminary absorber design incl. 5 cm external *Pb* shield

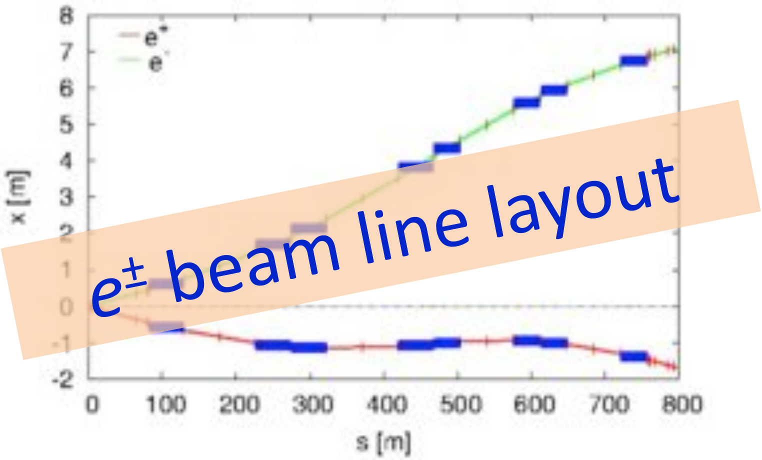
L. Lari et al., IPAC2014

total power deposition w/o & w absorbers

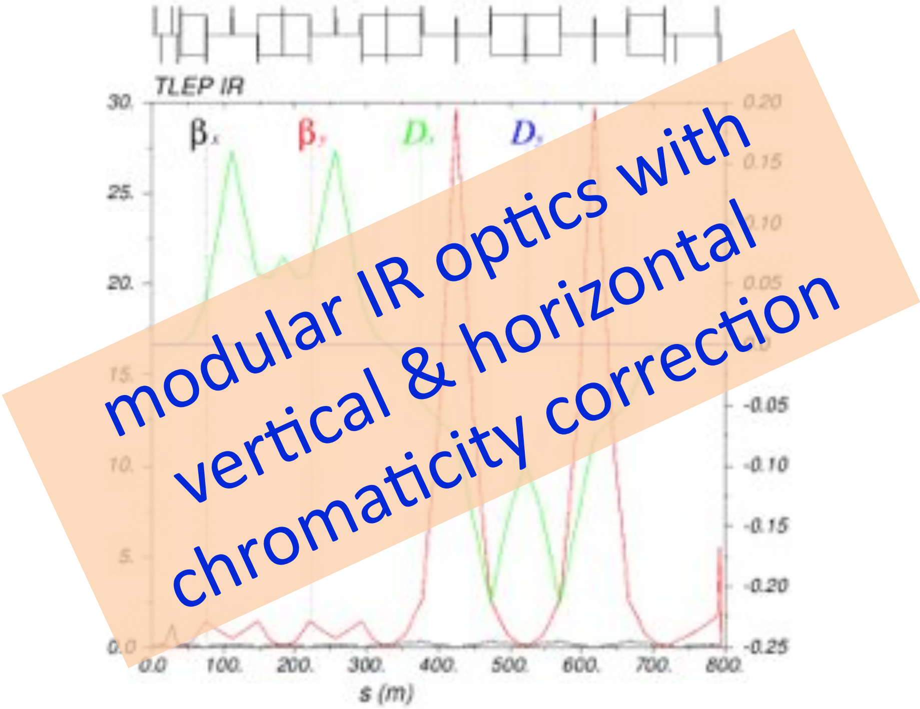


longit. peak-dose profile w/o & w absorbers (10 mA, 10^7 s)

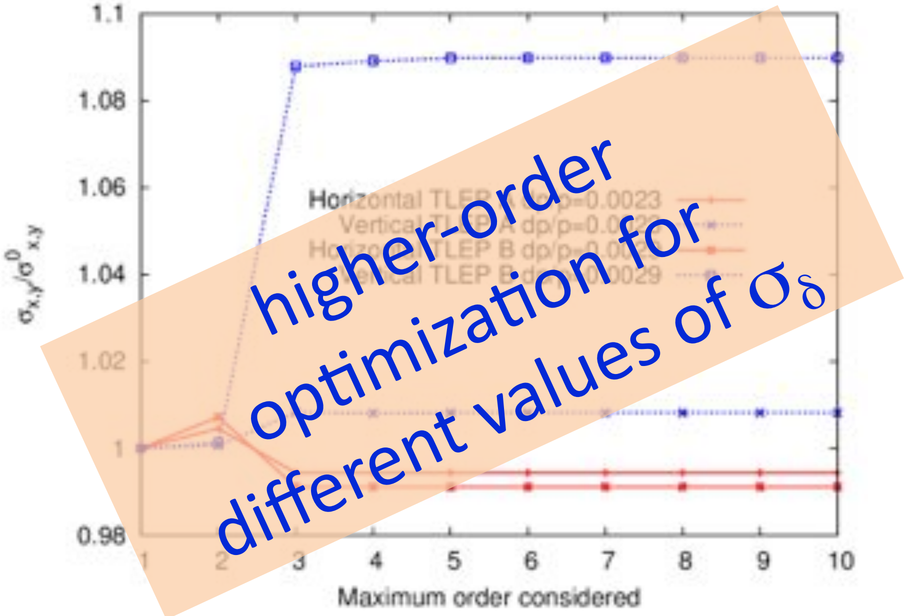
FCC-ee IR design #1



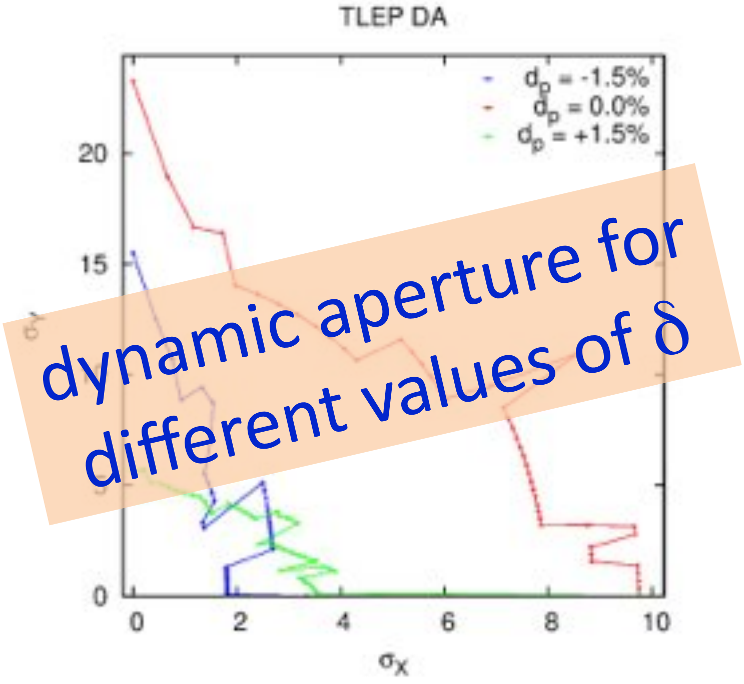
e± beam line layout



modular IR optics with vertical & horizontal chromaticity correction



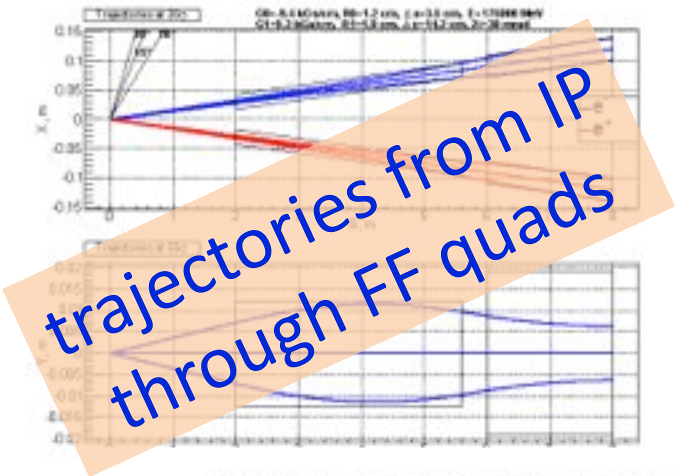
higher-order optimization for different values of σ_δ

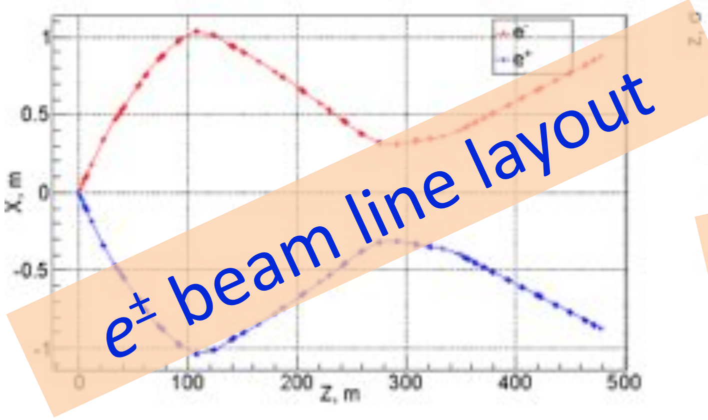


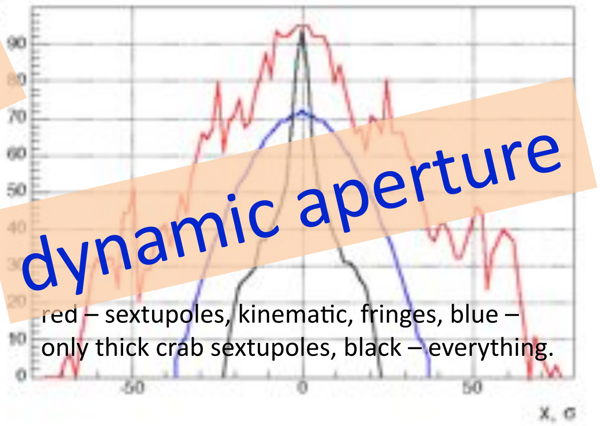
dynamic aperture for different values of δ

H. Garcia, L. Medina, R. Tomas, IPAC2014

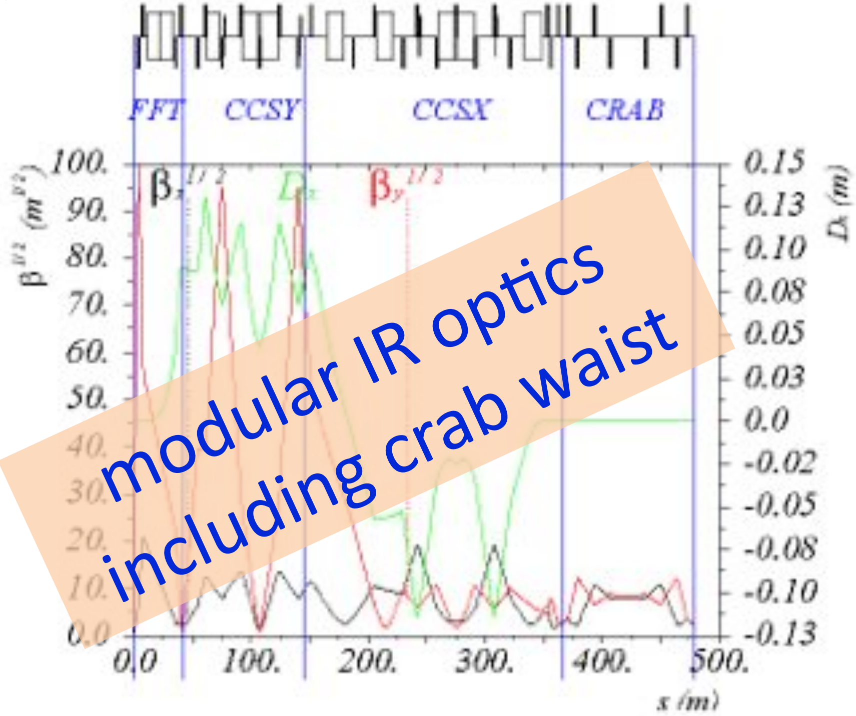
FCC-ee IR design #2

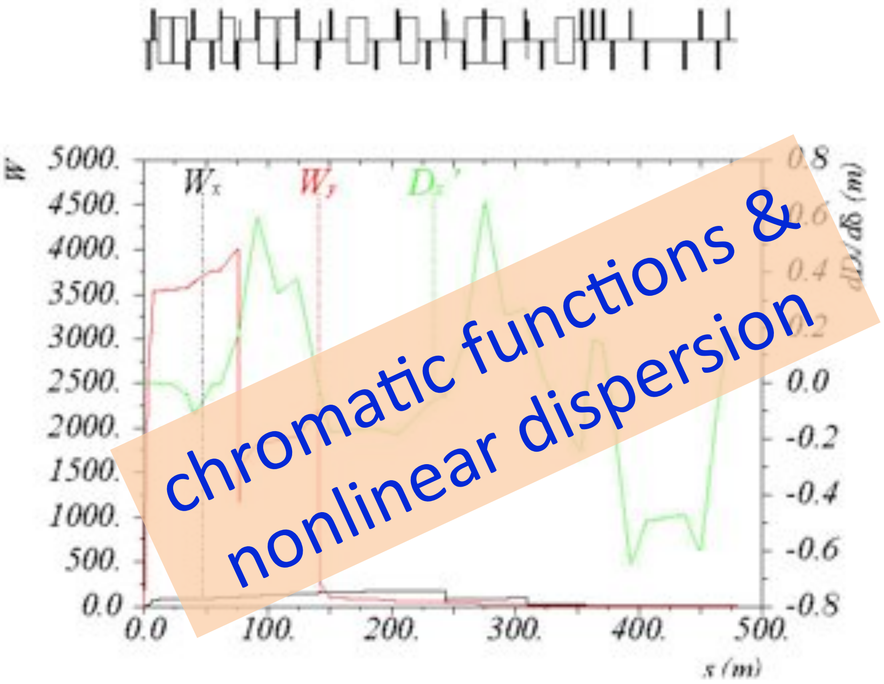

trajectories from IP through FF quads


$e^{\pm}$ beam line layout


dynamic aperture

red – sextupoles, kinematic, fringes, blue – only thick crab sextupoles, black – everything.


modular IR optics including crab waist


chromatic functions & nonlinear dispersion

A. Bogomyagkov, E. Levichev, P. Piminov, IPAC2014

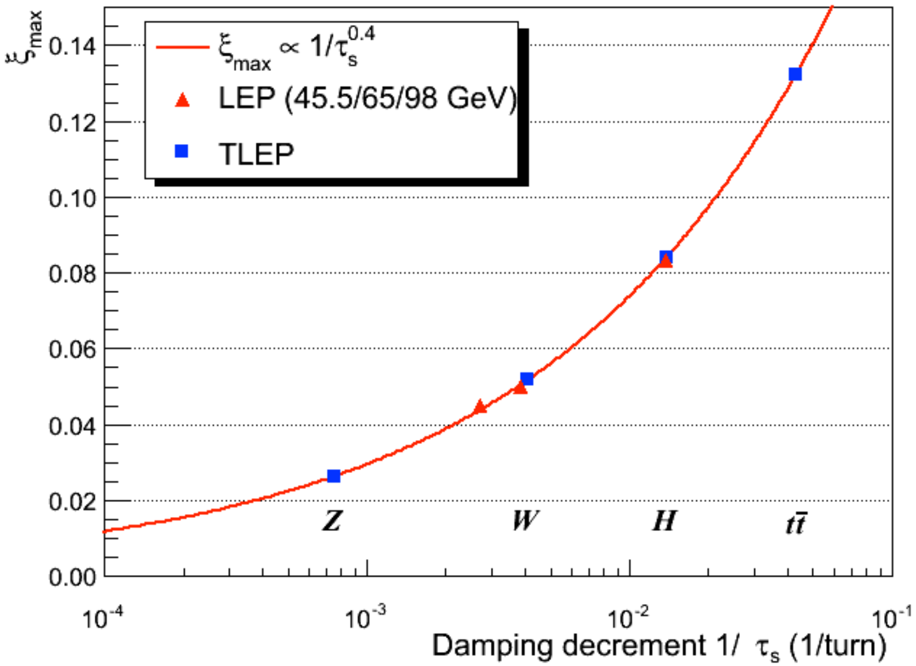
beam-beam tune shift & energy scaling

tune shift limits scaled from LEP data, confirmed by FCC simulations (S. White, K. Ohmi, A. Bogomyagkov, D Shatilov,…):

$$\xi_y \simeq \frac{\beta_y r_e N}{2\pi\gamma\sigma_x\sigma_y} \le \xi_{y,\max}(E)$$

$$\xi_{y,\max}(E) \propto \frac{1}{\tau_s^{0.4}} \propto E^{1.2}$$

R. Assmann & K. Cornelis, EPAC2000

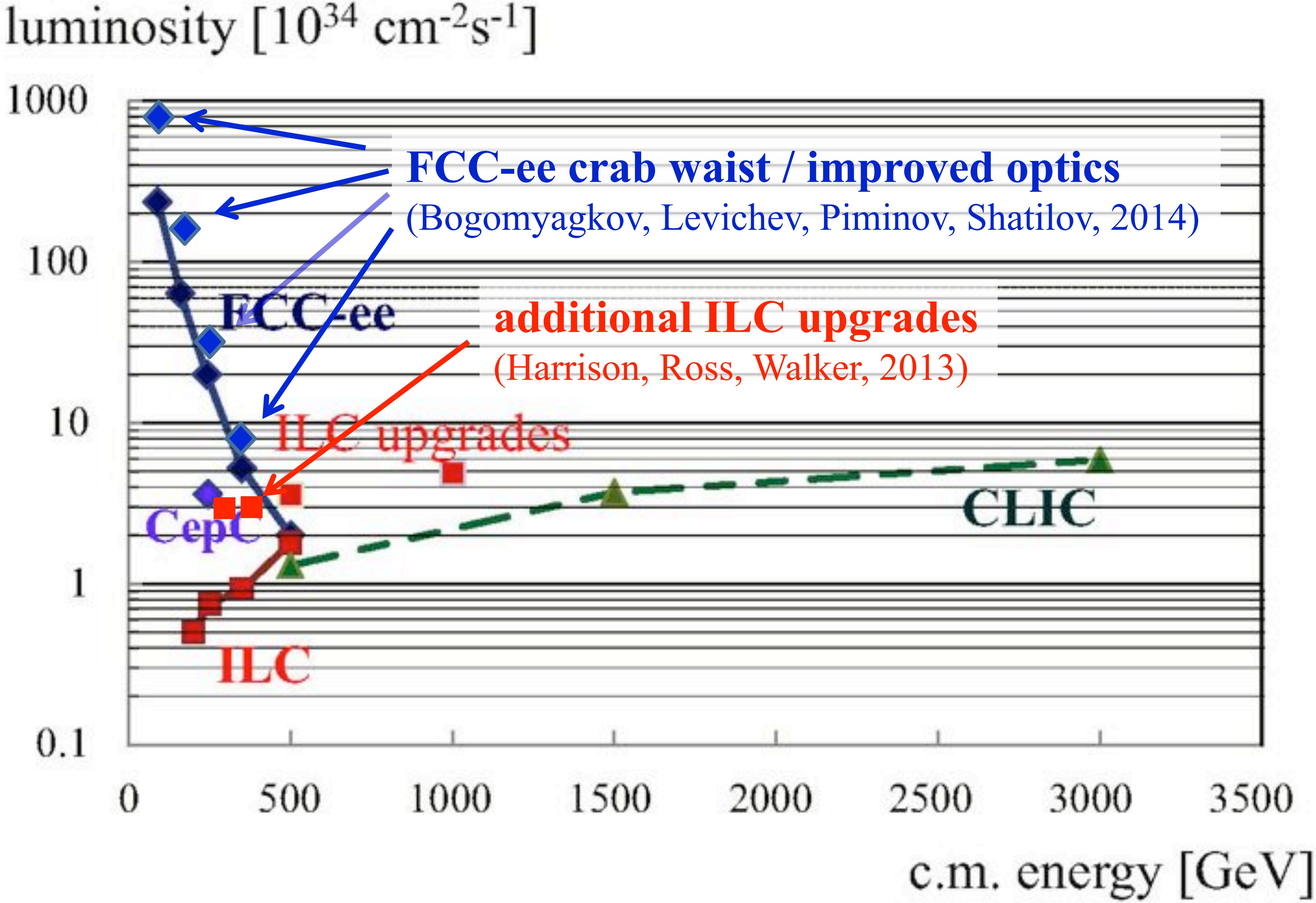


→ luminosity scaling with energy:

$$L = n_{IP}\frac{f_{coll}N^2}{4\pi\sigma_x\sigma_y}F_{hg} \propto \frac{\eta P_{SR}}{E^3}\frac{\xi_y}{\beta_y^*} \propto \frac{\eta_{w\to b}P_{wall}}{E^{1.8}}\frac{1}{\beta_y^*}$$

J. Wenninger

e^+e^- luminosity vs energy



FCC-ee crab waist / improved optics

(Bogomyagkov, Levichev, Piminov, Shatilov, 2014)

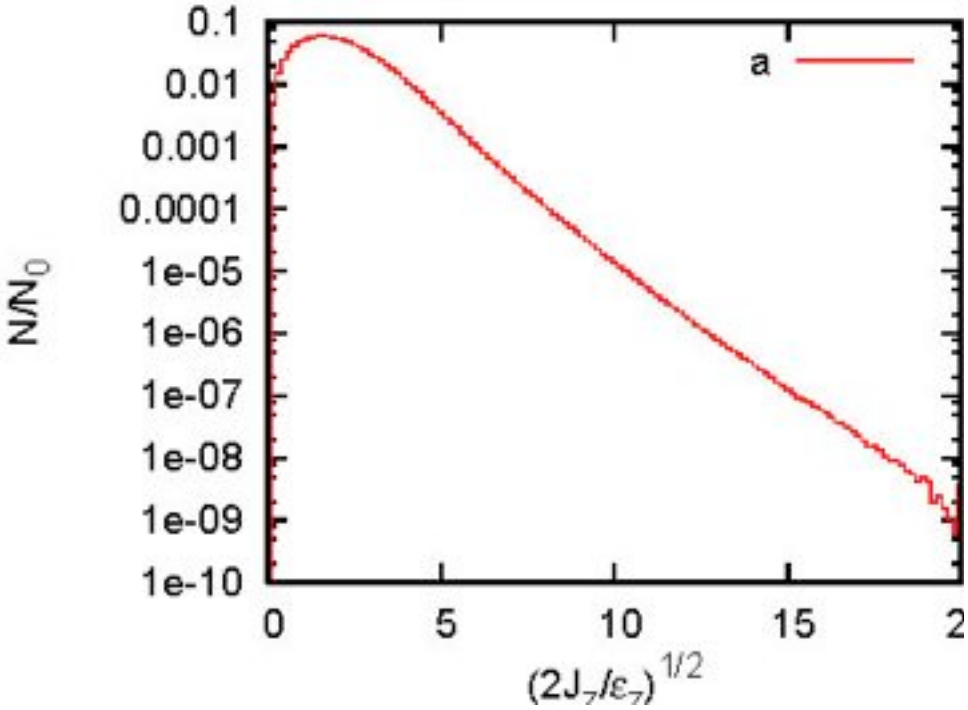
additional ILC upgrades

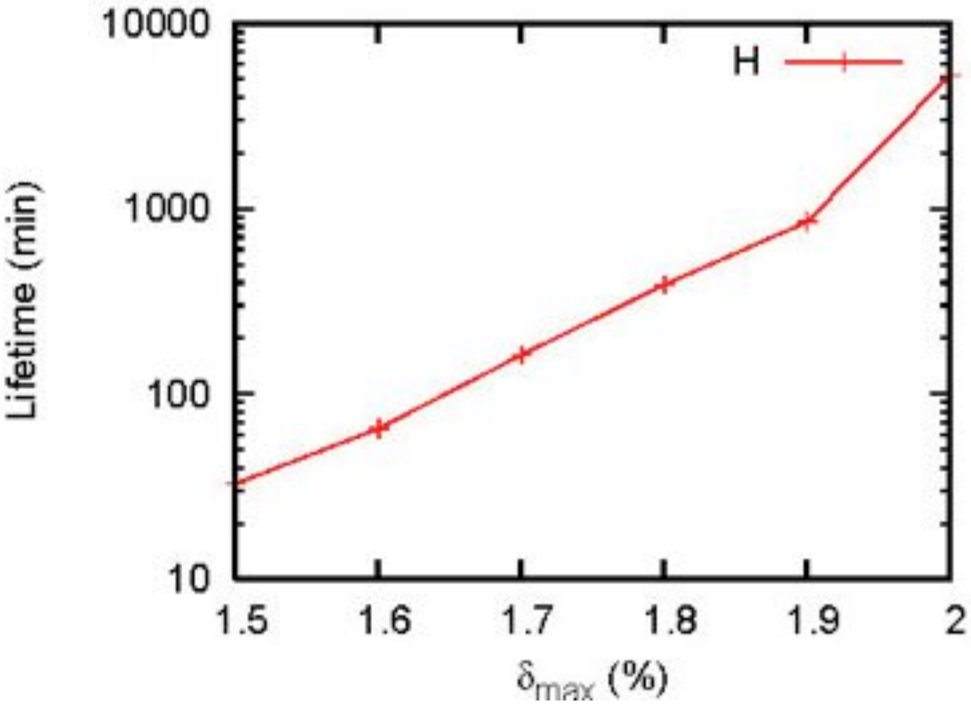
(Harrison, Ross, Walker, 2013)

beamstrahlung lifetime

example: *FCC-ee H* (240 GeV c.m.)

equilibrium distribution w/o aperture limit from simulation → lifetime vs. momentum acceptance





K. Ohmi et al., IPAC2014

The Twin Frontiers of *FCC-ee* Physics

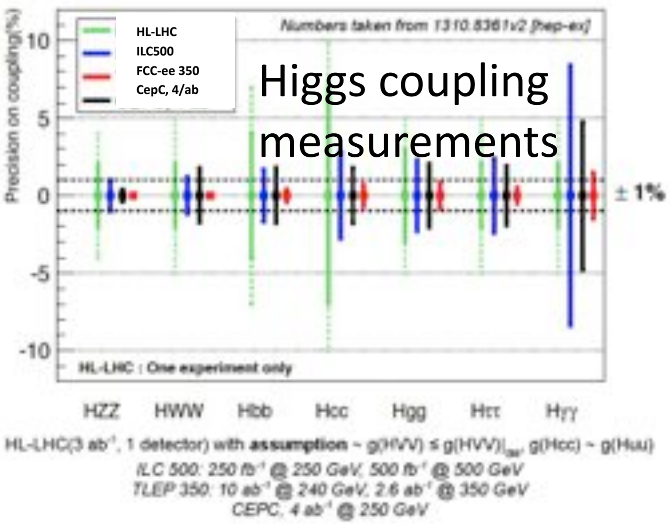
Precision Measurements

- Springboard for sensitivity to new physics
- Theoretical issues:
  - Higher-order QCD
  - Higher-order EW
  - Mixed QCD + EW

Rare Decays

- Direct searches for new physics
- Many opportunities
- Z: 10^{12}
- b, c, τ: 10
- W: 10^{8}
- H: 10^{6}
- t: 10^{6}

***FCC-ee* promises much higher precision & and many more rare decays than any competitors**

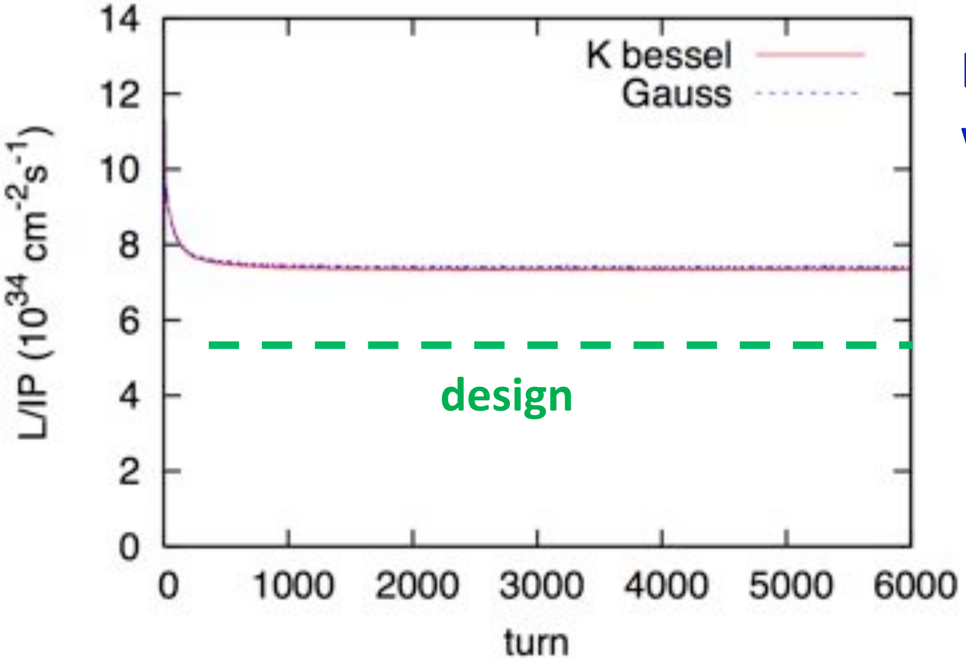


Higgs coupling measurements

M. Bicer et al., "First Look at the Physics Case of TLEP," JHEP 01, 164 (2014)
S. Dawson et al., arXiv:1310.8361v2

J. Ellis
P. Janot
M. Ruan

simulations confirm tantalizing performance

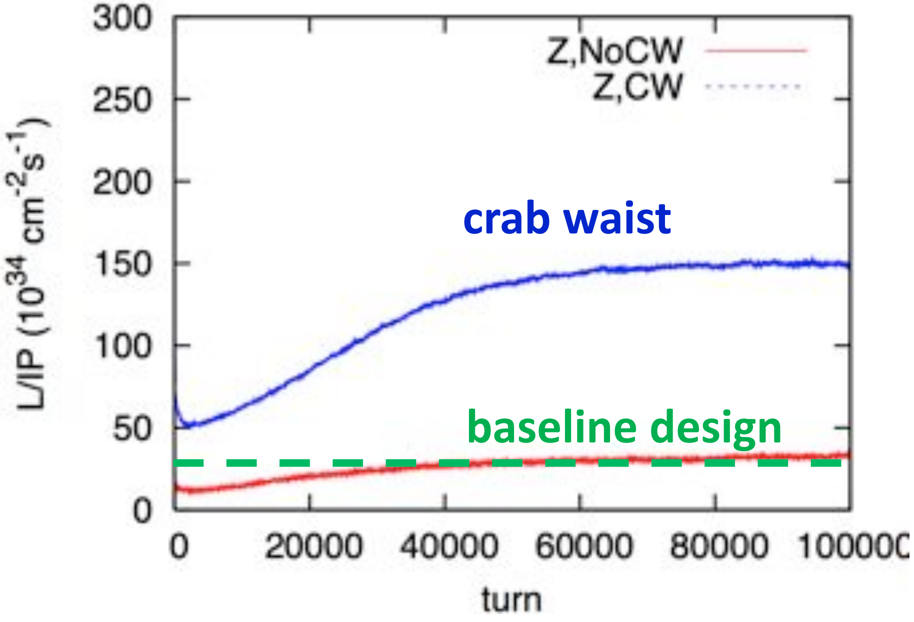


BBSS strong-strong simulation
w beamstrahlung

FCC-ee in Higgs production mode (240 GeV c.m.):
L$\approx 7.5\times 10^{34}$ cm^{-2}s^{-1} per IP

BBWS crab-strong simulation
w beamstrahlung

FCC-ee in crab-waist mode at the Z pole (91 GeV c.m.):
L$\approx 1.5\times 10^{36}$ cm^{-2}s^{-1} per IP



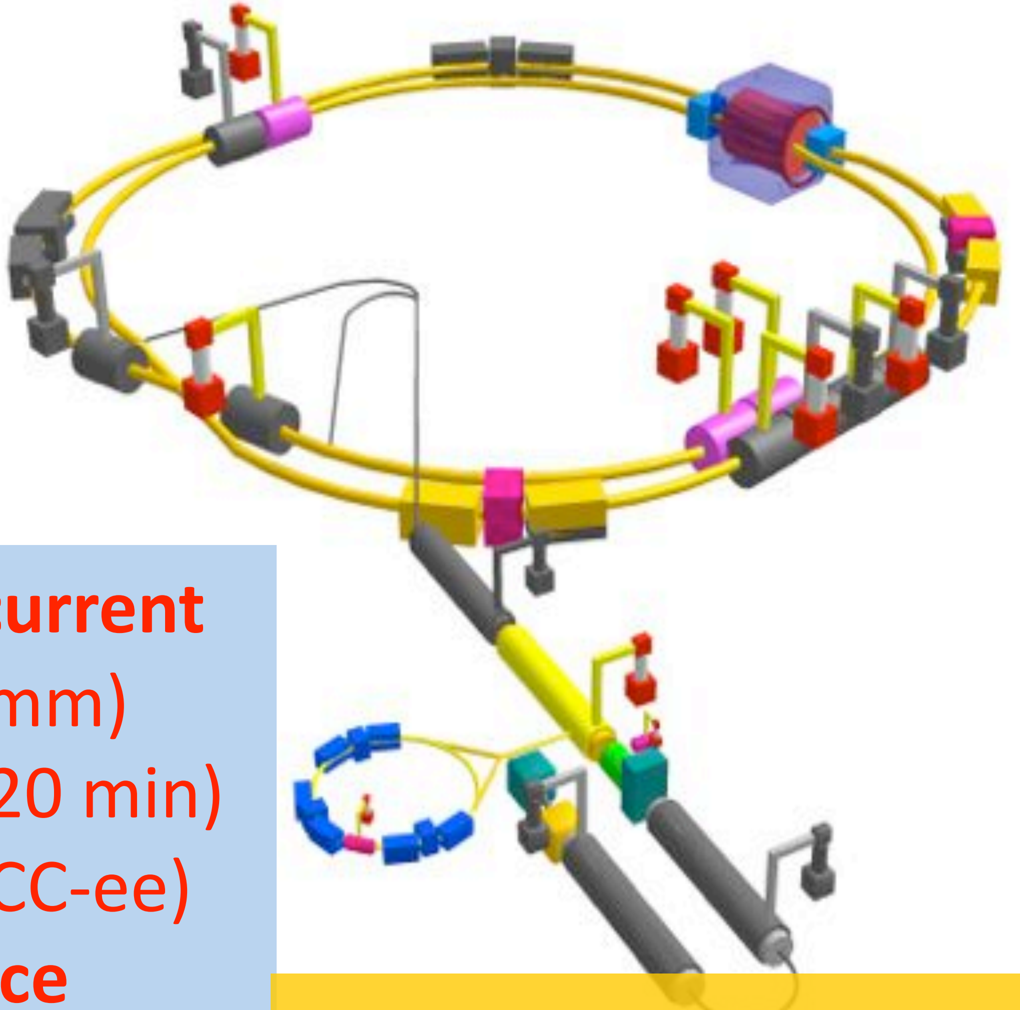
K. Ohmi et al., IPAC2014

A. Bogomyagkov, E. Levichev, P. Piminov, IPAC2014

SuperKEKB = *FCC-ee* demonstrator

beam commissioning
will start in 2015

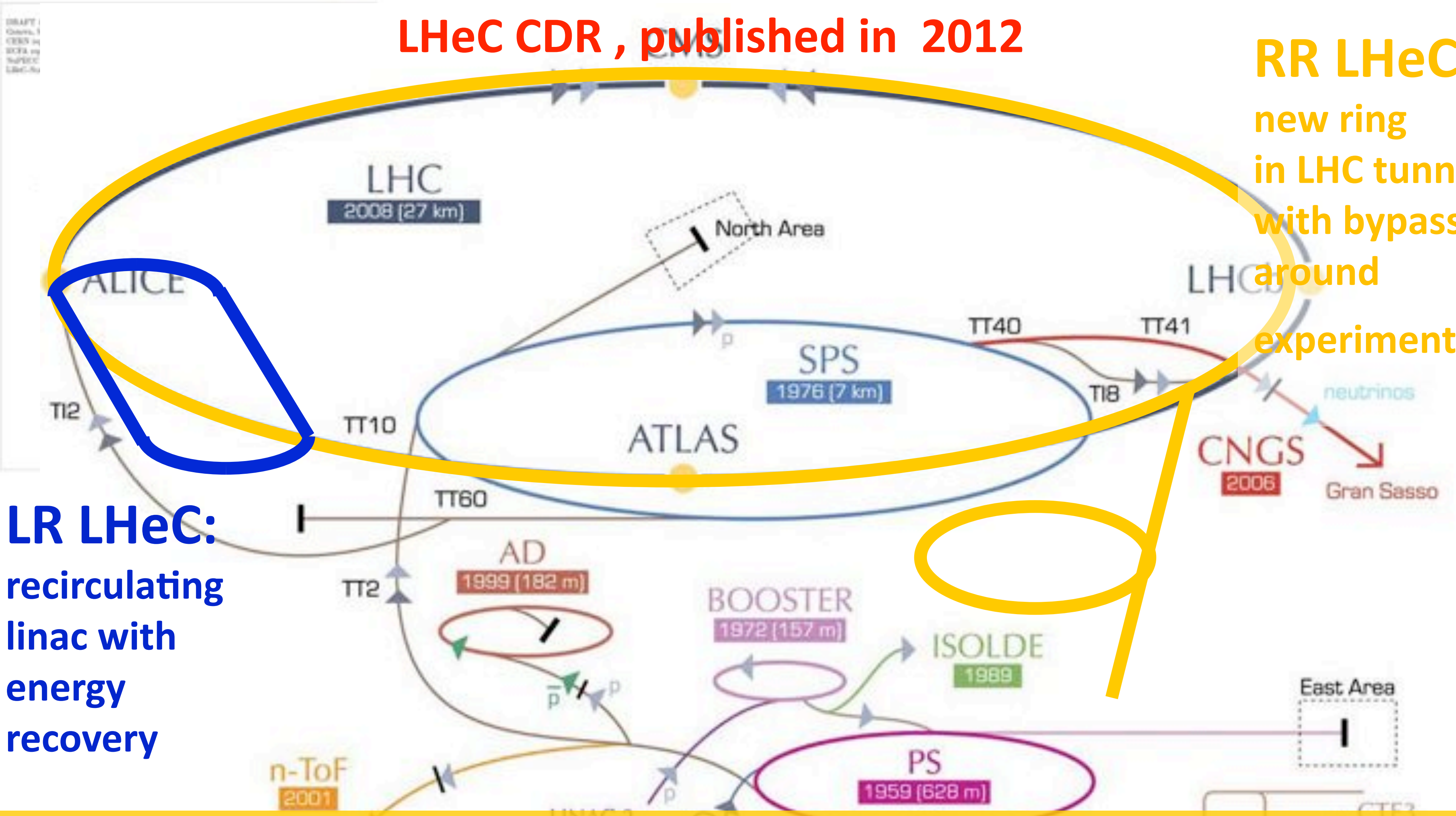
N. Ohuchi et al.,
IPAC2014



top up injection at high current
β_y^* =300 μm (FCC-ee: 1 mm)
lifetime 5 min (FCC-ee: ≥20 min)
$\varepsilon_y/\varepsilon_x$ =0.25% (similar to FCC-ee)
off momentum acceptance
(±1.5%, similar to FCC-ee)
e^+ production rate (2.5x10^{12}/s,
FCC-ee: <1.5x10^{12}/s (Z cr.waist)

***SuperKEKB* goes beyond *FCC-ee*, testing all concepts**

FCC-he: high-energy lepton-hadron collider



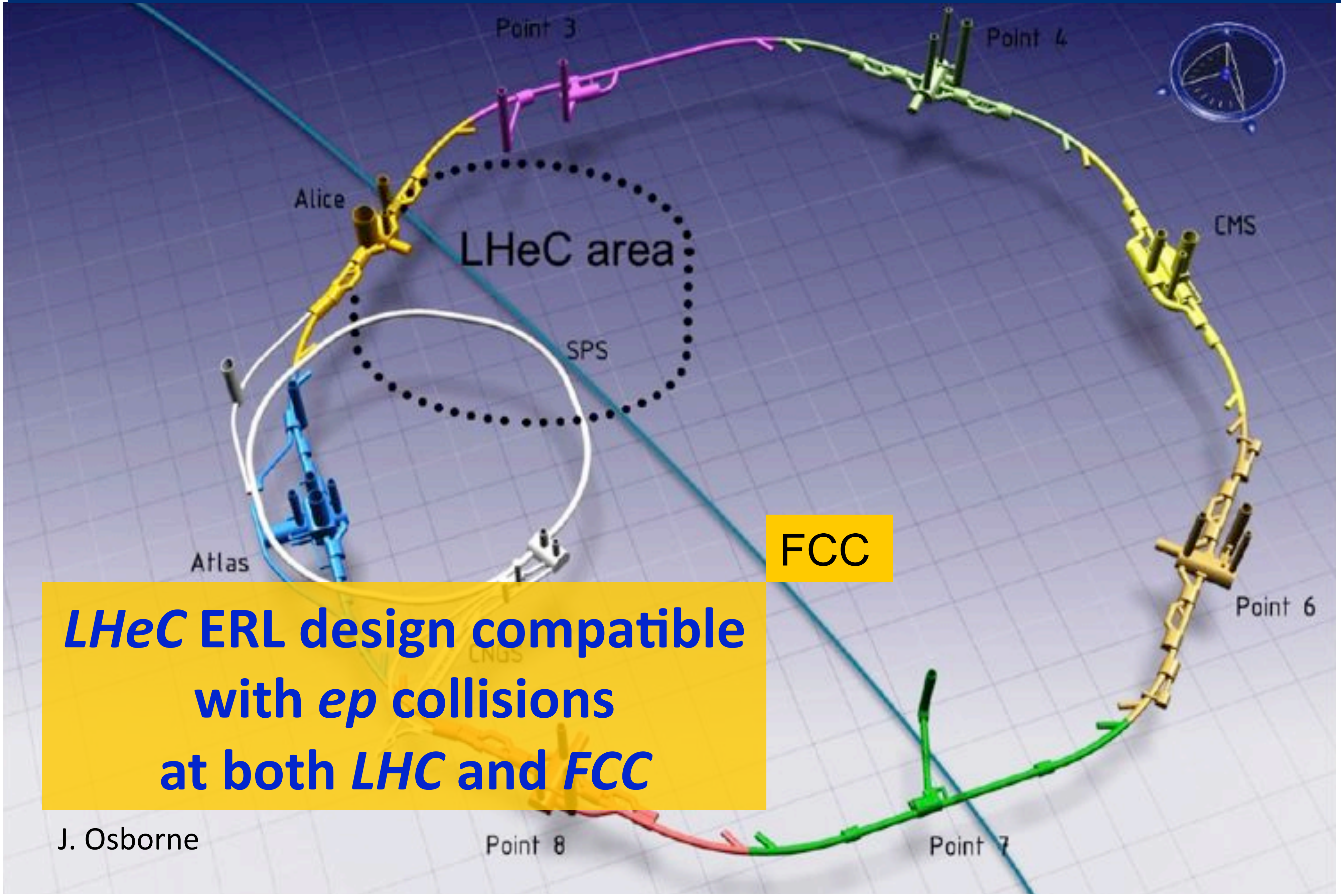
LHeC CDR , published in 2012

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

LR LHeC:
recirculating
linac with
energy
recovery

similar two options for *FCC*:
(1) *FCC-ee* ring, (2) ERL – from *LHeC* or new

FCC-he – 2nd option: based on *LHeC*



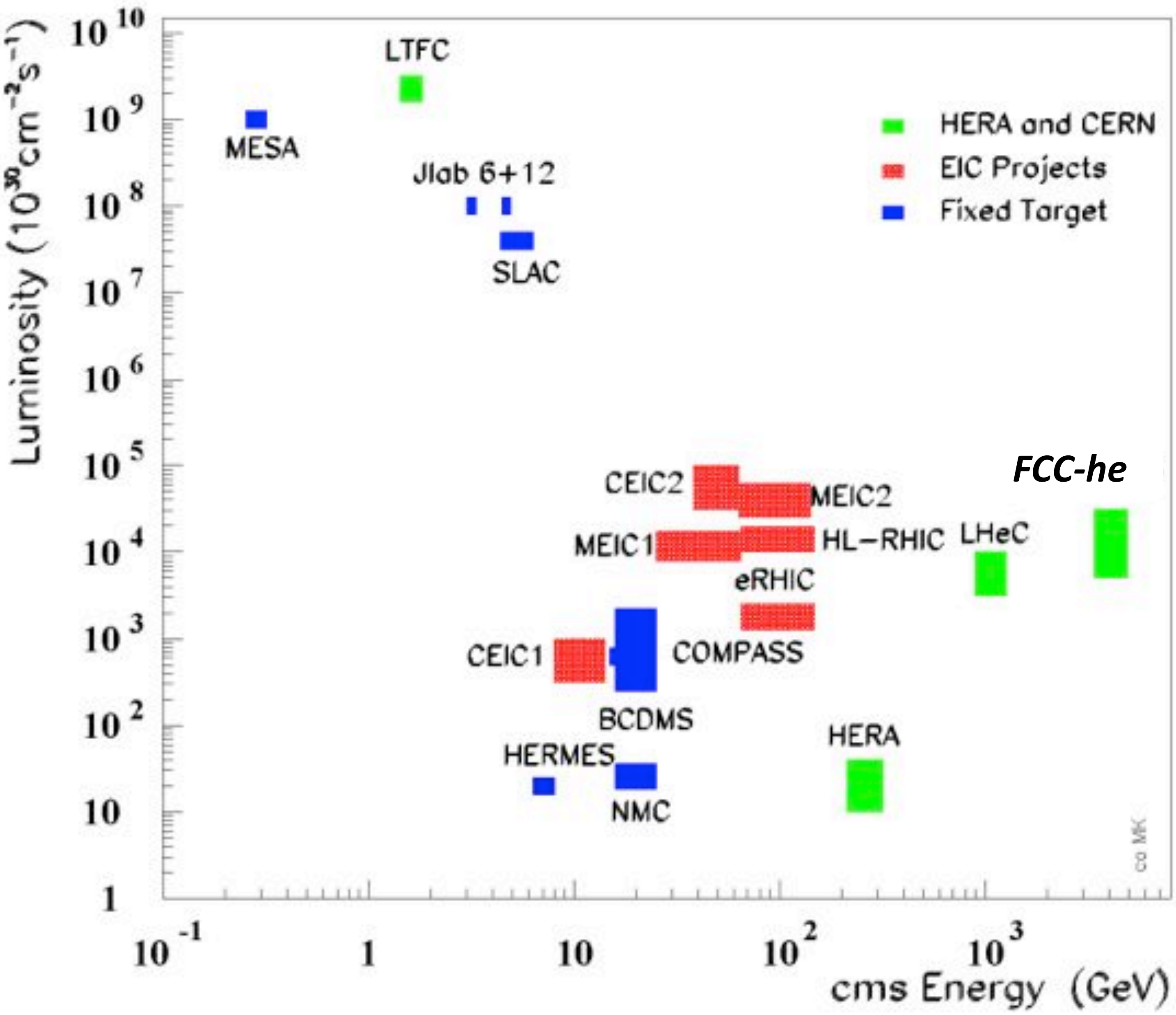
LHeC **ERL design compatible with *ep* collisions at both *LHC* and *FCC***

J. Osborne

collider parameters	FCC ERL	FCC-ee ring		protons
species	**e^- (e^+?)**	**$e^\pm$**	**$e^\pm$**	p
beam energy [GeV]	60	80	120	50000
bunches / beam	-	4490	1360	10600
bunch intensity [10^{11}]	0.04	0.7	0.46	1.0
beam current [mA]	25.6	152	30	500
rms bunch length [cm]	0.02	0.15	0.12	8
rms emittance [nm]	0.17	3.3 (x)	0.94 (x)	0.04 [0.02 y]
$\beta_{x,y}$*[mm]	1000	6.0, 3.0	22, 11	500 [250 y]
$\sigma_{x,y}$* [μm]	4.0	4.5, 2.3		equal
beam-b. parameter ξ	(D=32)	0.05	**0.13**	0.017 (0.0002)
hourglass reduction	0.94 (H_D=1.35)	**~0.24**	~0.60	
CM energy [TeV]	3.5	4.0	4.9	
luminosity[10^{34}cm^{-2}s^{-1}]	**1.0**	**2.3**	**1.2**	

preliminary

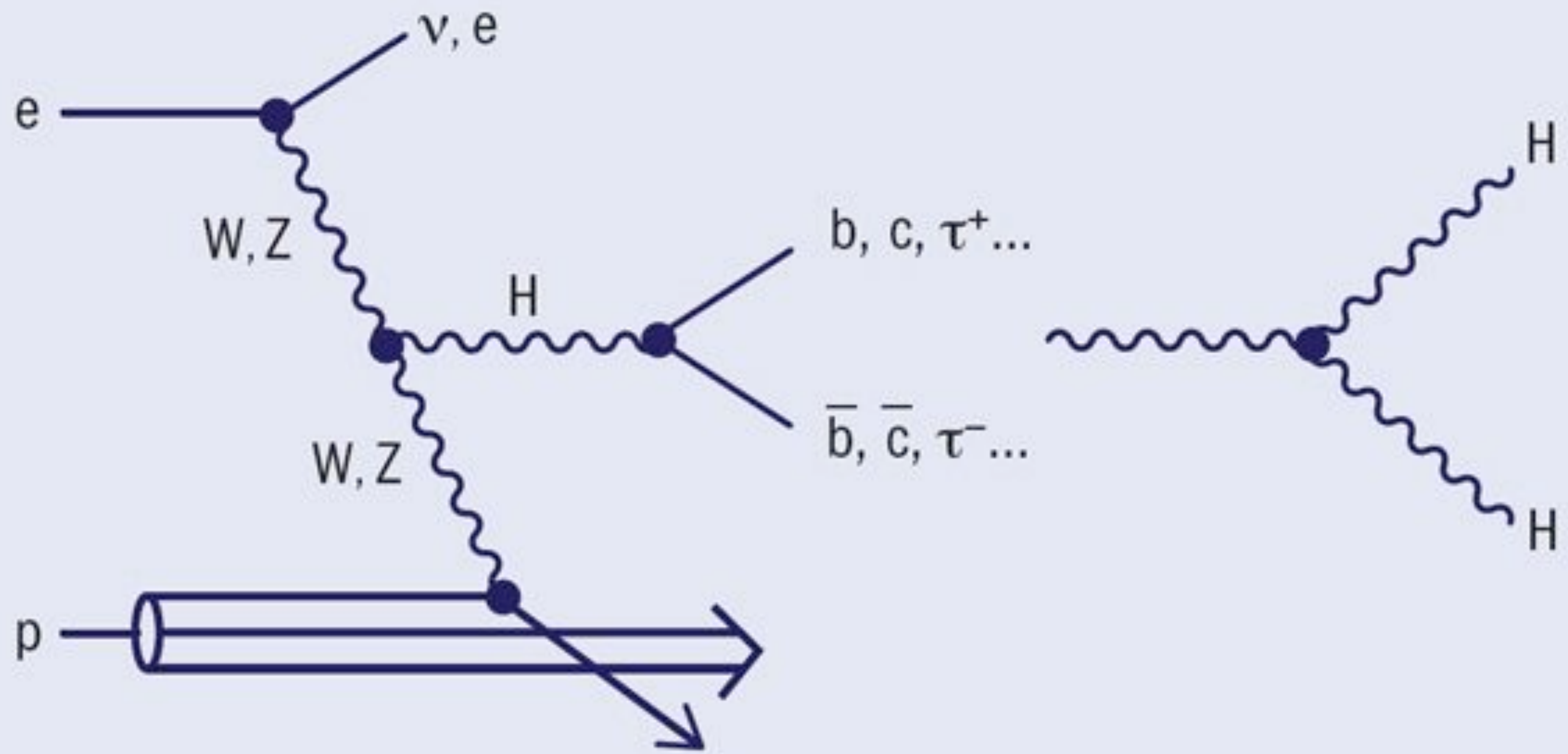
lepton-hadron scattering facilities till *FCC-he*



M. Klein and H. Schopper

CERN Courier June 2014

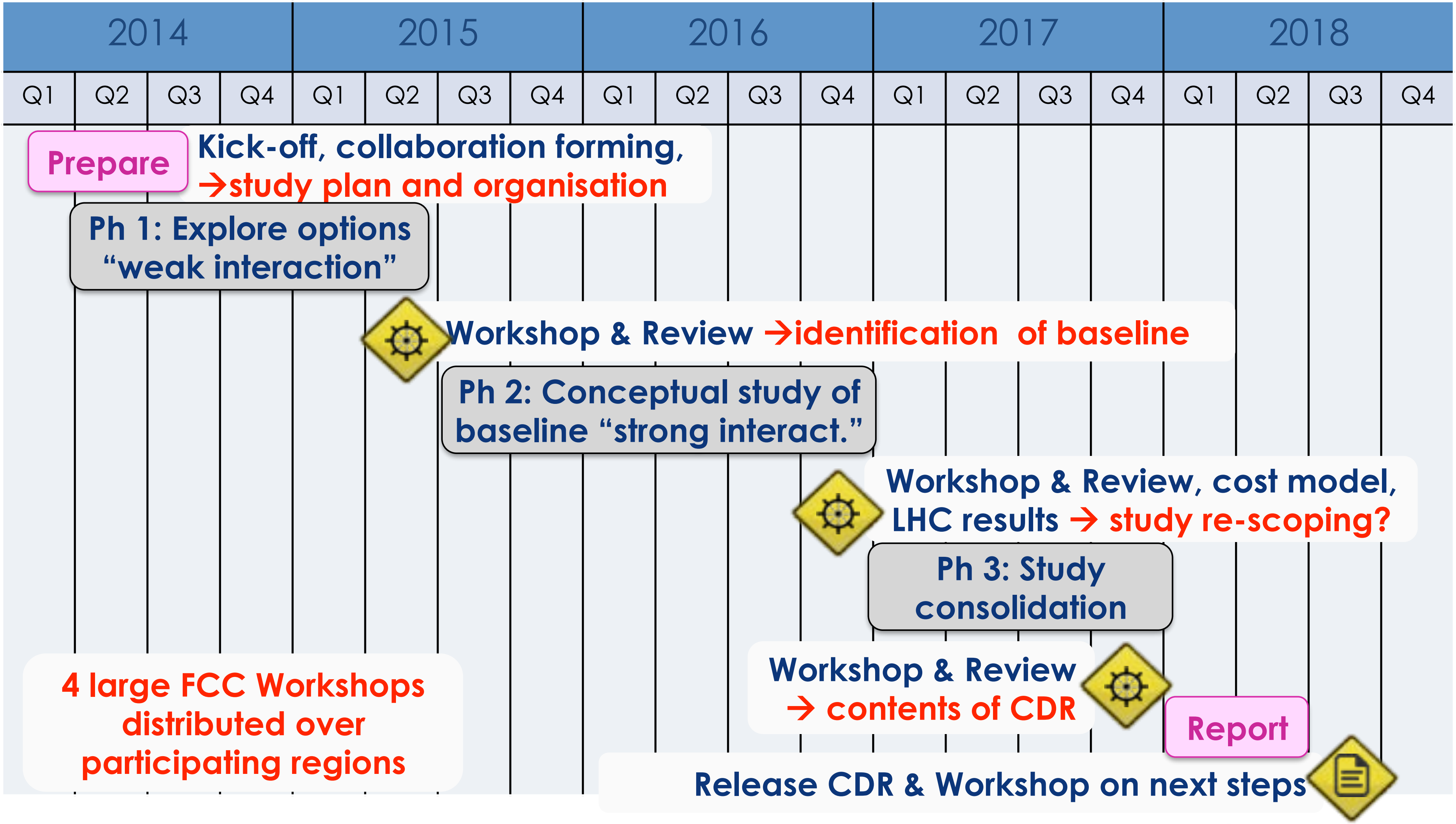
Higgs physics at *LHeC* & *FCC-he*



h-e* Higgs-boson production and decay**; and precision measurements of the ***H–bb* coupling** in ***WW–H* production**; *FCC-he* also gives access to **Higgs self-coupling *H–HH (<10% precision!? - under study), to **lepto-quarks up to ≈4 TeV** & to **Bjorken *x* as low as 10^{-7} - 10^{-8}** [of interest for ultra high energy ν scattering]

M. Klein and H. Schopper, CERN Courier June2014

FCC global design study – time line



2014 2015 2016 2017 2018

Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4

Prepare

Kick-off, collaboration forming,
→study plan and organisation

Ph 1: Explore options
"weak interaction"

Workshop & Review →identification of baseline

Ph 2: Conceptual study of
baseline "strong interact."

Workshop & Review, cost model,
LHC results → study re-scoping?

Ph 3: Study
consolidation

Workshop & Review
→ contents of CDR

Report

Release CDR & Workshop on next steps

4 large FCC Workshops
distributed over
participating regions

- → presently discussions with potential partners (MoUs)
- → first international collaboration board meeting at CERN on 9 & 10 September 2014

M. Benedikt

Future Circular Collider Study Kick-off Meeting

12-15 February 2014,
University of Geneva,
Switzerland

LOCAL ORGANIZING COMMITTEE

University of Geneva
C. Blanchard, A. Blondel,
C. Doglioni, G. Iacobucci,
M. Koratzinos

CERN
M. Benedikt, E. Delucinge,
J. Gutleber, D. Hudson,
C. Potter, F. Zimmermann

SCIENTIFIC ORGANIZING COMMITTEE

FCC Coordination Group
A. Ball, M. Benedikt, A. Blondel,
F. Bordry, L. Bottura, O. Brüning,
P. Collier, J. Ellis, F. Gianotti,
B. Goddard, P. Janot, E. Jensen,
J. M. Jimenez, M. Klein, P. Lebrun,
M. Mangano, D. Schulte,
F. Sonnemann, L. Tavian,
J. Wenninger, F. Zimmermann

UNIVERSITÉ DE GENÈVE

http://indico.cern.ch/e/fcc-kickoff

http://indico.cern.ch/e/fcc-kickoff
http://cern.ch/fcc

FCC
hh ee he

FCC Kick-off Meeting
University of Geneva
12-15 February 2014

>340 participants


UNIVERSITÉ DE GENÈVE
FCC Kick-Off 2014
Future Circular Collider (FCC) Study
FCC
R.D. Heuer, CERN


maticity correction similar to SuperKEKB,
tum acceptance will be similar, about ±1.4%.

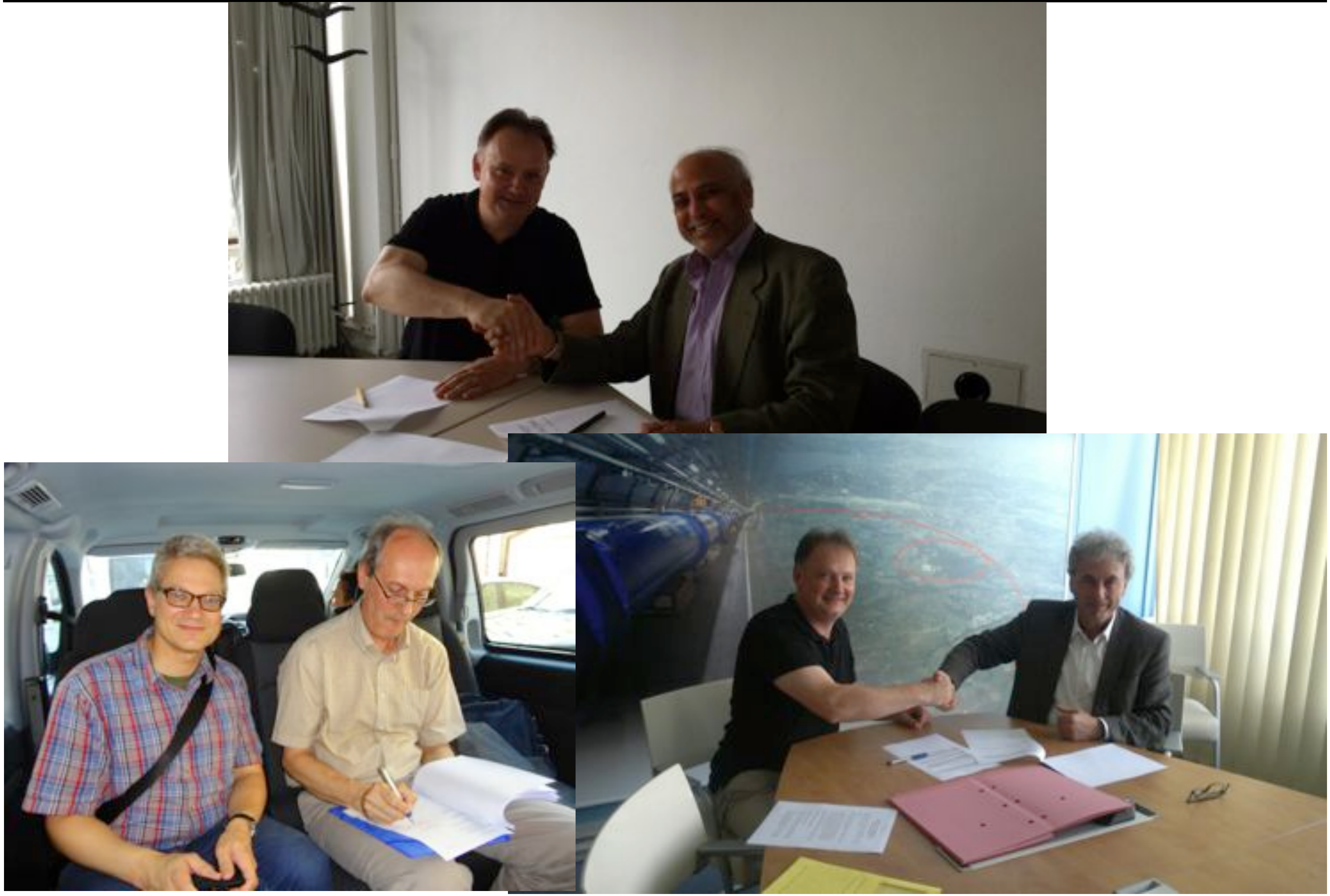

FCC
HL-LHC (3000 fb⁻¹)
LHC 13-14 TeV (300 fb⁻¹)
LHC 7-8 TeV (30 fb⁻¹)


Beautiful Place for a Science Center

FCC Kick-Off Parallel Sessions

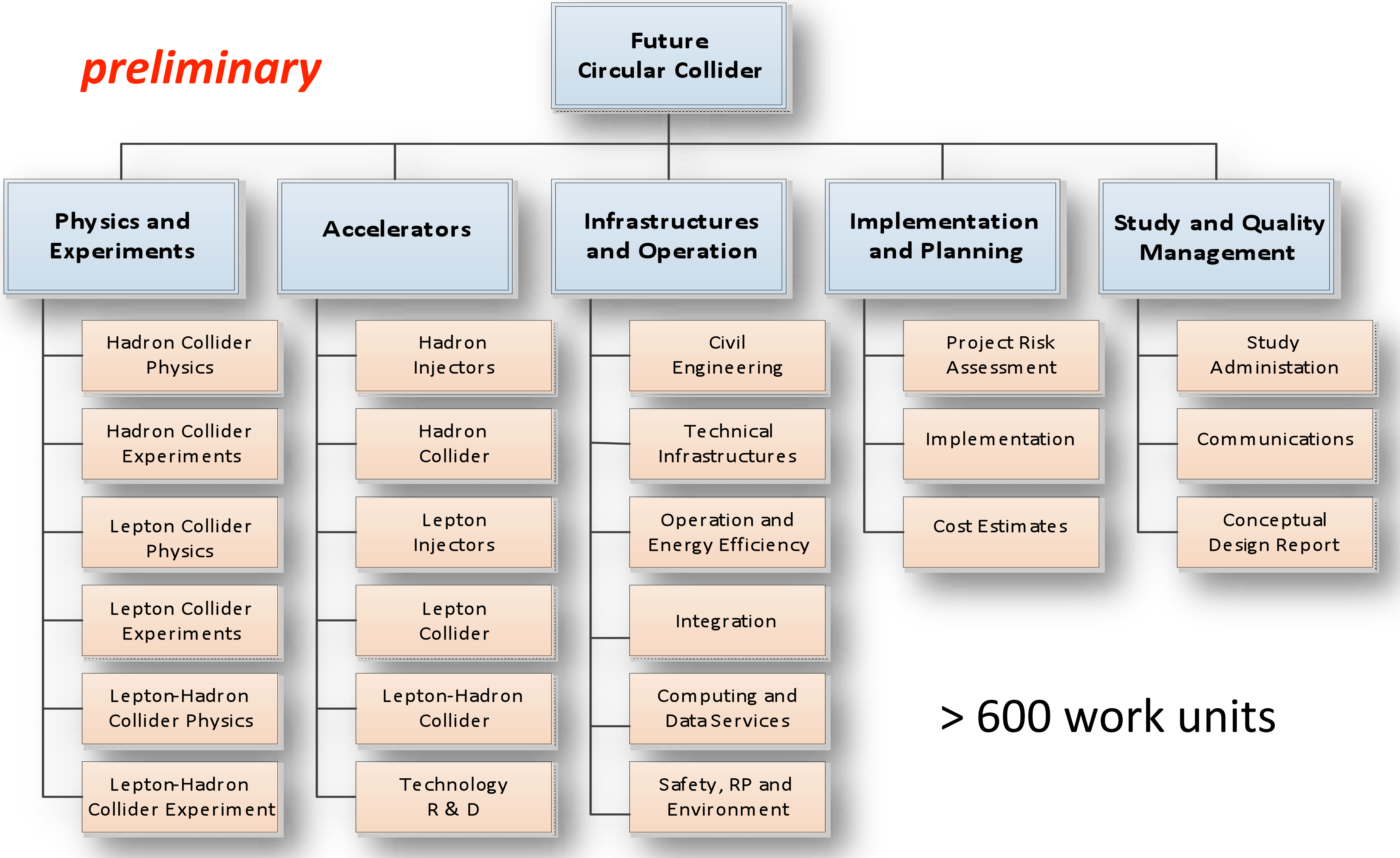
Session	# Participants
Technical infrastructure and civil engineering	47
Hadron collider design (+ SC magnets + injectors)	75
Lepton collider design (+ SC RF + injectors)	62
Hadron Physics, Experiments, Detectors	93
Lepton Physics, Experiments, Detectors	54
e-p Option	18
Overall physics and phenomenology	63

signing FCC MoUs with partners



FCC WBS top level

preliminary



- **Future Circular Collider**
  - **Physics and Experiments**
    - Hadron Collider Physics
    - Hadron Collider Experiments
    - Lepton Collider Physics
    - Lepton Collider Experiments
    - Lepton-Hadron Collider Physics
    - Lepton-Hadron Collider Experiment
  - **Accelerators**
    - Hadron Injectors
    - Hadron Collider
    - Lepton Injectors
    - Lepton Collider
    - Lepton-Hadron Collider
    - Technology R & D
  - **Infrastructures and Operation**
    - Civil Engineering
    - Technical Infrastructures
    - Operation and Energy Efficiency
    - Integration
    - Computing and Data Services
    - Safety, RP and Environment
  - **Implementation and Planning**
    - Project Risk Assessment
    - Implementation
    - Cost Estimates
  - **Study and Quality Management**
    - Study Administation
    - Communications
    - Conceptual Design Report

> 600 work units

M. Benedikt

Subset in EU H2020 FCC Design-Study Proposal “EuroCirCol” – 5 Work Packages

Management, Coordination and Implementation

Coordination, CDR, Strategy, Cost

HH Arc design

HH Interaction region design

Collider functional machine design and optimization

HH Cryo-magnet-vacuum-beam pipe

HH High-field magnet design

Key technological aspects

M. Benedikt

main questions in particle physics and main approaches to address them

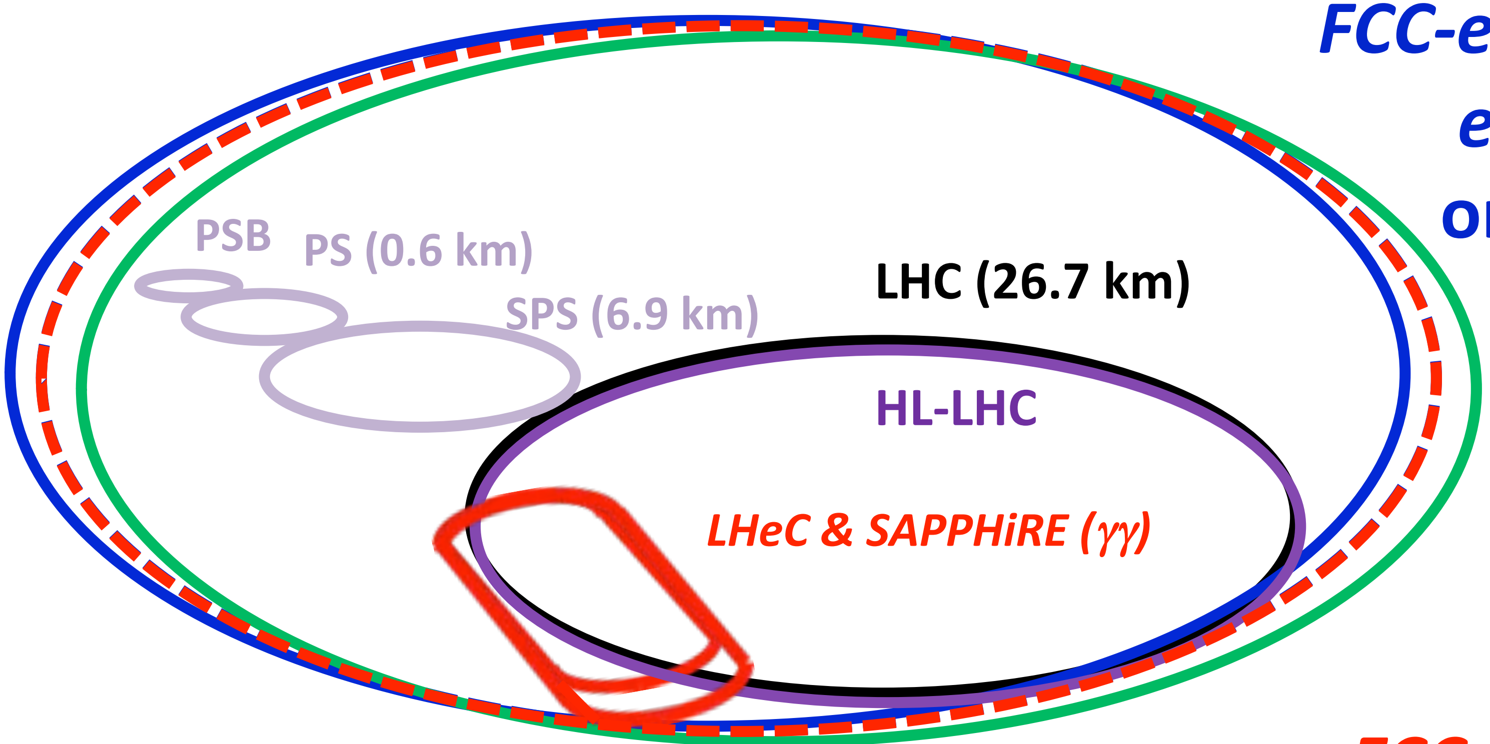
question	high-energy colliders	high-precision experiments	neutrino experiments	dedicated searches	cosmic surveys
Higgs, EWSB	X				
neutrinos	X		X	X	X
dark matter	X			X	
flavour, CP violation	X	X	X	X	
new particles and forces	X	X	X	X	
universe acceleration					X

within the scope of FCC

F. Gianotti et al.

many questions require high-energy and/or high-intensity accelerators

possible evolution of FCC complex



PSB

PS (0.6 km)

SPS (6.9 km)

LHC (26.7 km)

HL-LHC

LHeC & SAPPHiRE (γγ)

FCC-ee **(80-100 km,**
e^+e^-, up to 350
or 500 GeV c.m.)

FCC-hh
(*pp* up to
100 TeV c.m.
& *AA*)

LHeC as FCC-ee injector?

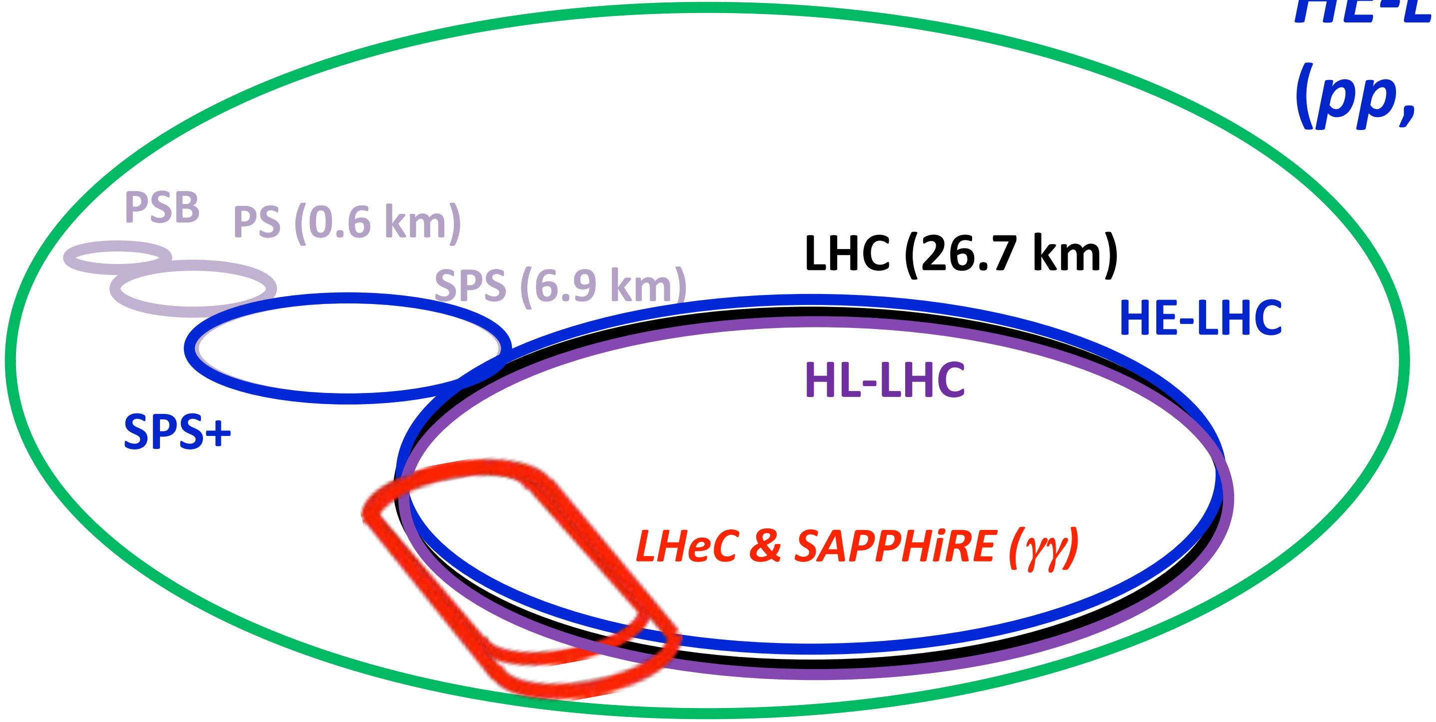
LHeC-based FCC-he collider?!

FCC-he **as ring-ring**
collider ?!

FCC-he: $e^\pm$ (60-250 GeV) – *p*(50 TeV)/A collisions

≥50 years e^+e^-, *pp*, $e^\pm p/A$ physics at highest energies

another possible evolution of FCC complex



HE-LHC & SPS+
(*pp*, 27 TeV c.m.)

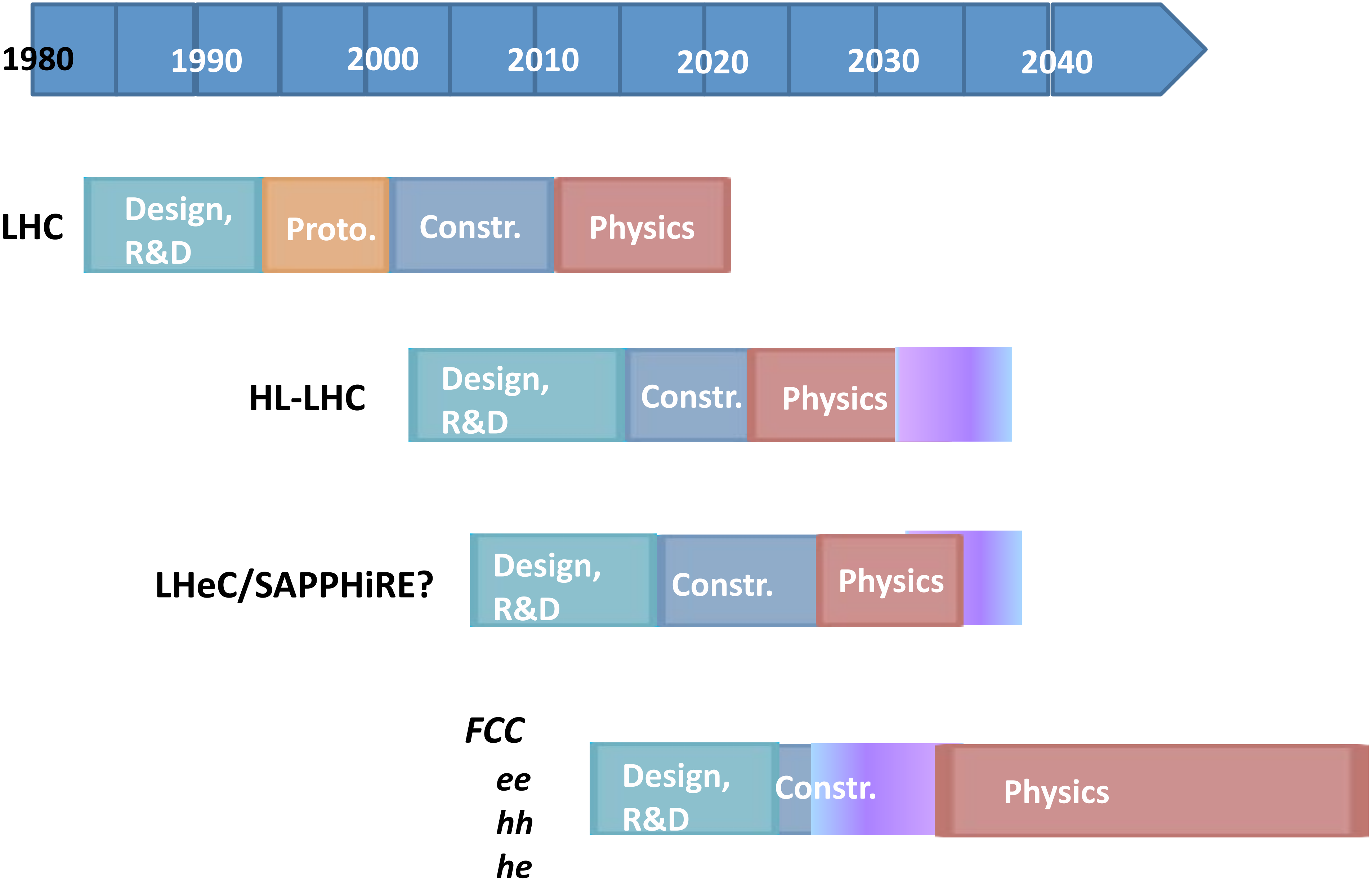
FCC-hh
(*pp* up to
100 TeV c.m.
& *AA*)

LHeC-based FCC-he collider

***FCC-he*: $e^{\pm}$ (60 GeV) – *p*(50 TeV)/A collisions**

≥50 years *pp*, *AA*, $e^{\pm}p/A$ physics at highest energies

tentative time line



1980 1990 2000 2010 2020 2030 2040

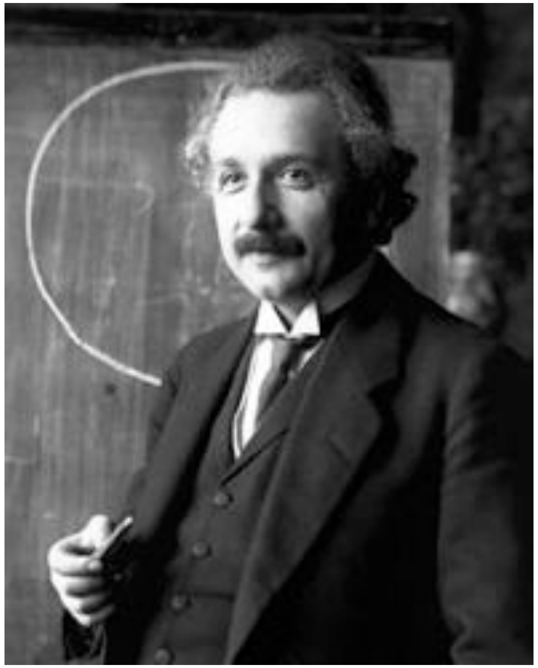
LHC Design, R&D | Proto. | Constr. | Physics

HL-LHC Design, R&D | Constr. | Physics

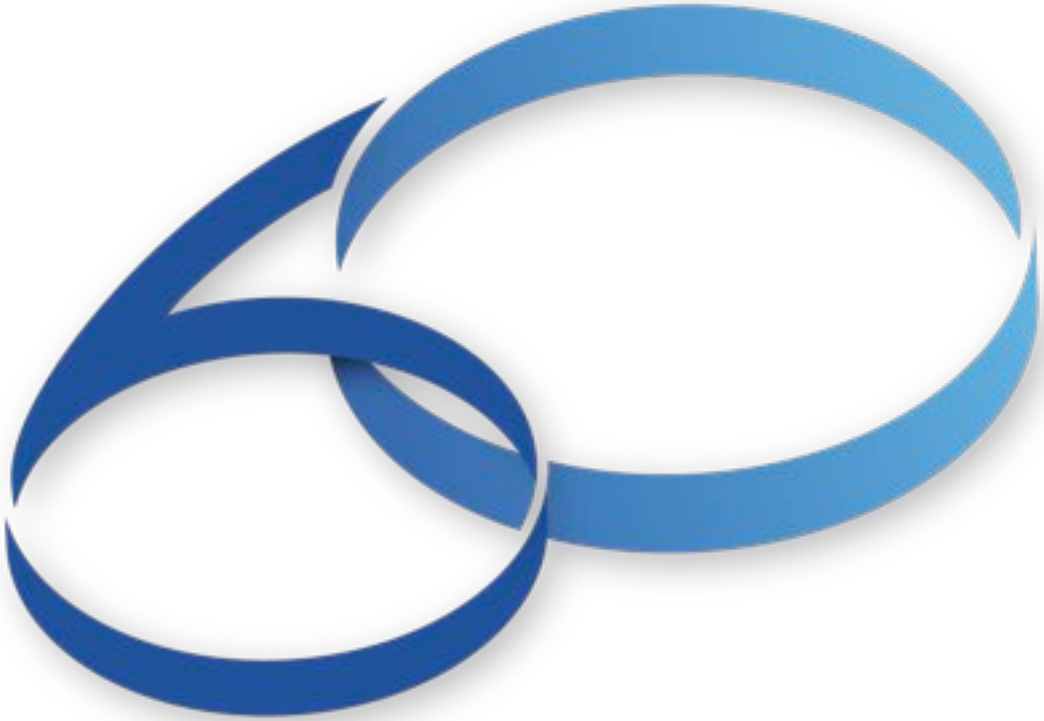
LHeC/SAPPHiRE? Design, R&D | Constr. | Physics

FCC
ee
hh
he
Design, R&D | Constr. | Physics

„A really good idea is easily recognizable. It's one whose implementation seems doomed at the outset.”



Albert Einstein



YEARS / ANS **CERN**