Future Circular Colliders – Possibilities for Plasmas, Lasers, Dielectric Structures and Crystals

Frank Zimmermann, CERN

European Expert Panel, 30 Ma

<u>WARNING</u> - this talk does not necessarily reflect the view of CERN or FCC study management !

ks to Roy Aleksan, Ralph Assmann, Michael Benedikt, Iryna Chaikovska, dda Gschwendtner, Michael Hofer, Thibaut Lefèvre, Nikolai Muchnoi, Anke-Susanne Müller et al.

FUTURE CIRCULAR COLLIDER Innovation Study

EASITrain

ARIES

http://cern.ch/fcc

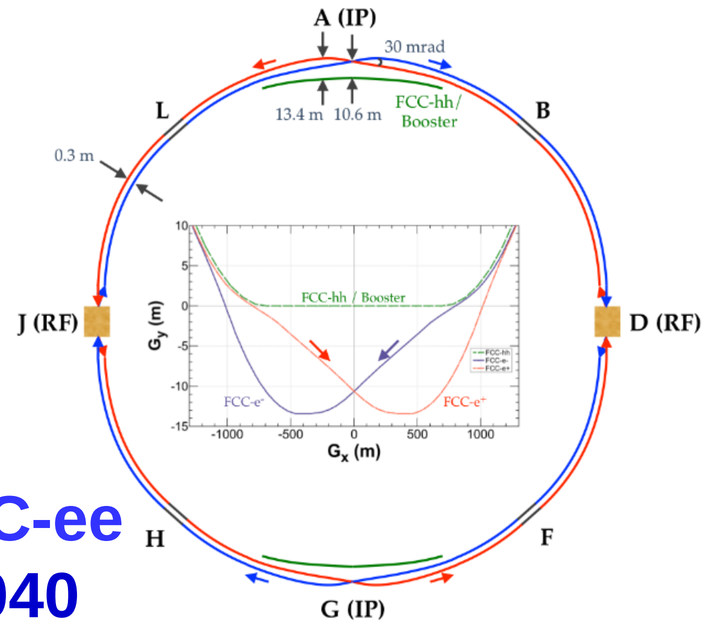
European Commission | Horizon 2020 European Union funding for Research & Innovation

Image: Polar Media/ FCC Study Office

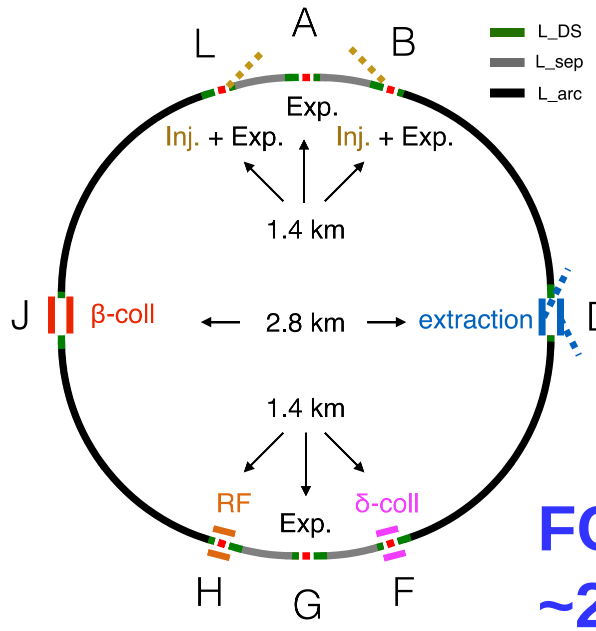
The FCC integrated program inspired by successful LEP – LHC programs at CERN

comprehensive long-term program maximizing physics opportunities

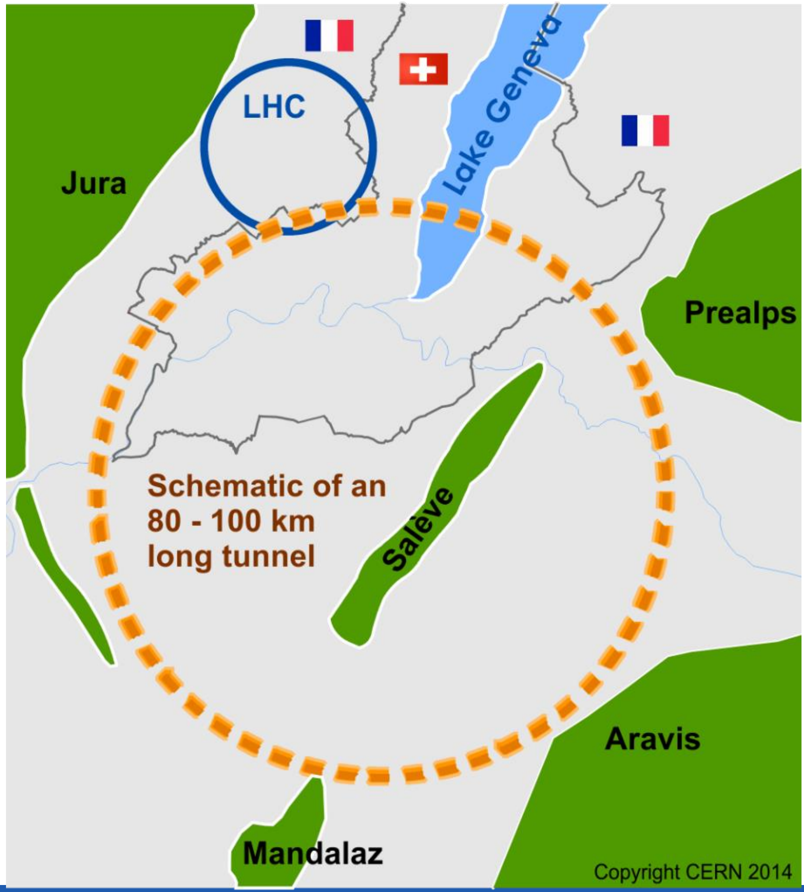
- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options**
- complementary physics
- common civil engineering and technical infrastructures
- building on and reusing CERN's existing infrastructure
- FCC integrated project allows seamless continuation of HEP after HL-LHC



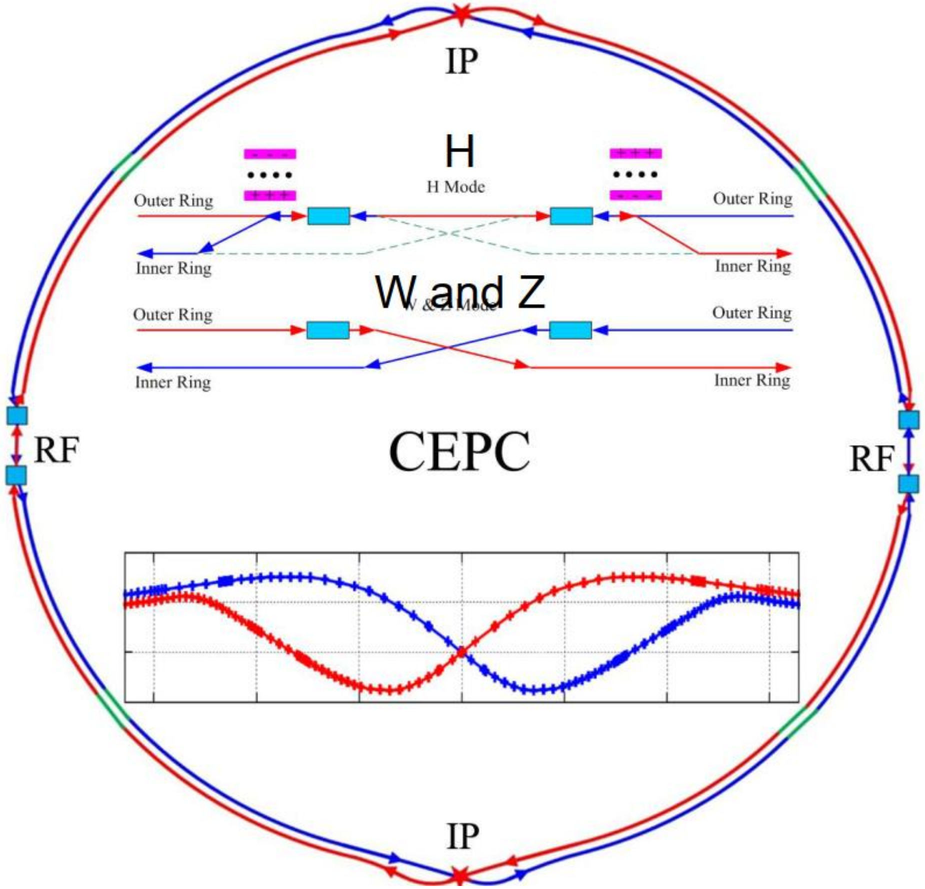
FCC-ee
~2040

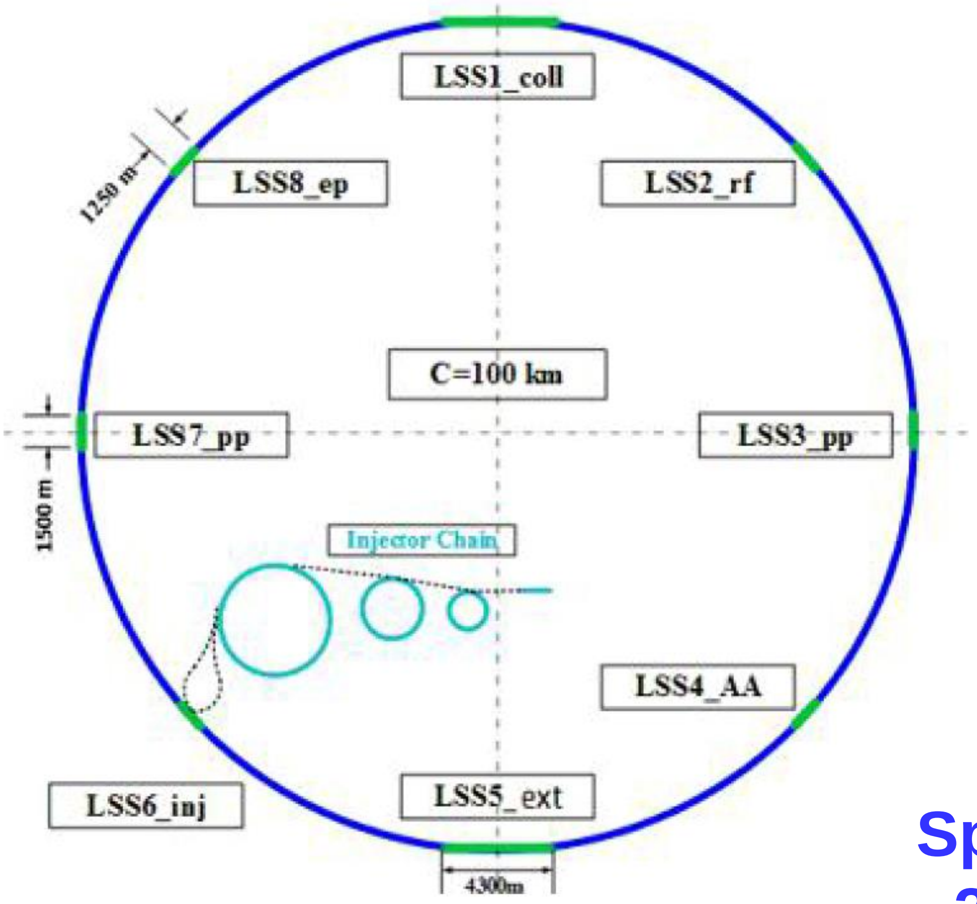


FCC-hh
~2065



similar proposal in China: CEPC / SppC





CEPC
~2034?

SppC
~2050?

The FCC integrated program projected baseline performance

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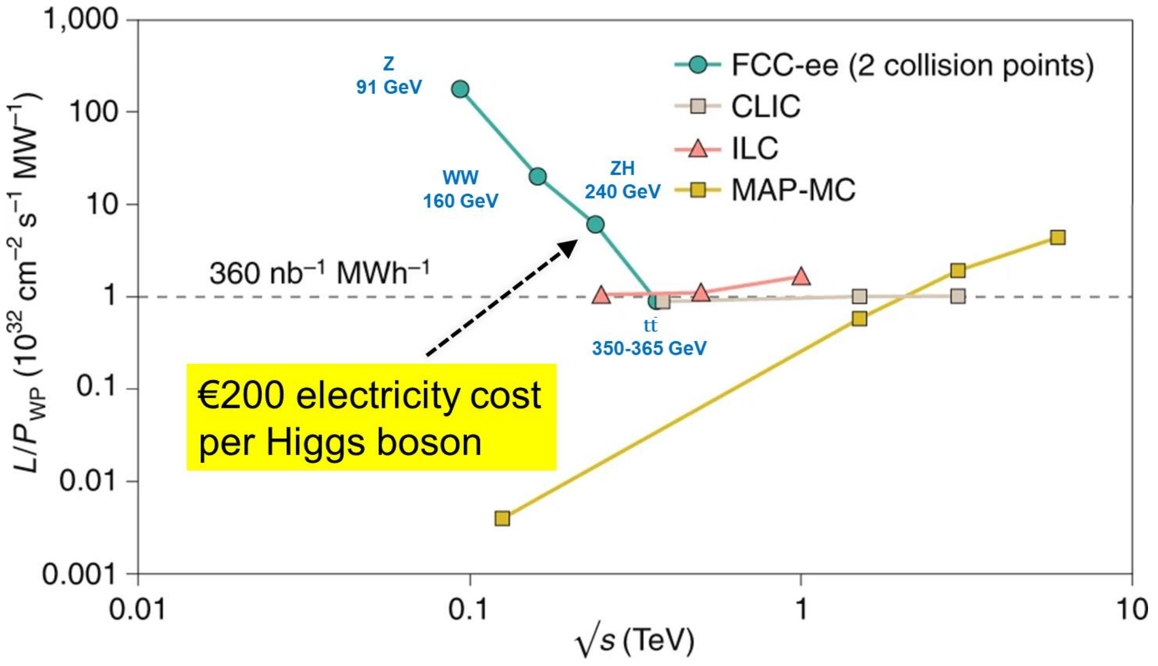
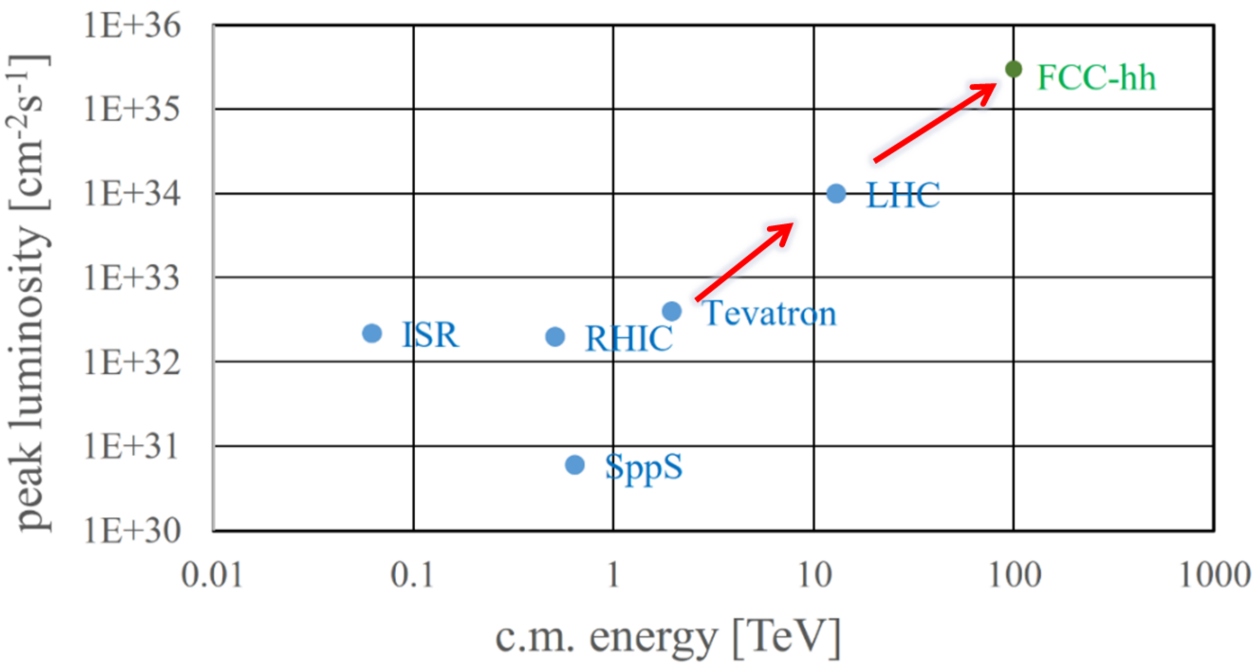
e+e- Higgs/electroweak Factory – energy efficiency



energy efficiency frontier hadron collider



both colliders breaking new grounds in luminosity and energy

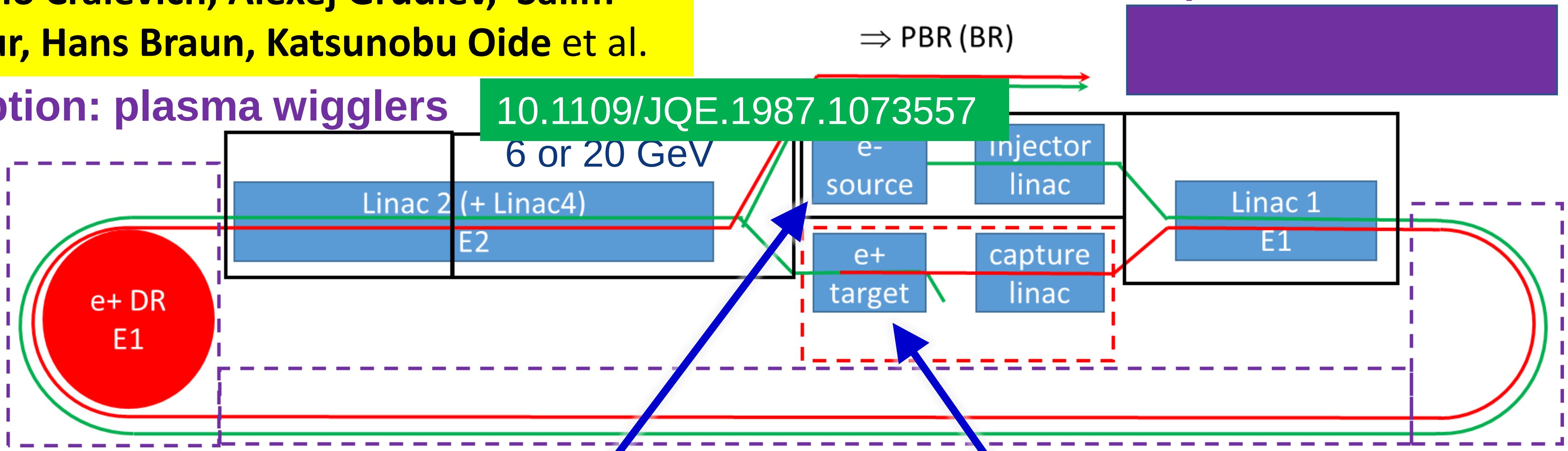
feasibility study 2020-2025 as requested by ESPPU 2020

FCC-ee injector

Paolo Craievich, Alexej Grudiev, Salim Ogur, Hans Braun, Katsunobu Oide et al.

option: plasma wigglers

10.1109/JQE.1987.1073557



baseline: 6 or 20 GeV S- or C-band linac + full energy booster

options: plasma acceleration (e^- and e^+!),

e.g. Z. Y. Xu et al., PRAB 23, 091301

dielectric or laser acceleration

crystal hybrid target (baseline)

baseline: laser for e^- photo RF gun, 6.5 nC, 0.6 μm

option: low-emittance plasma gun

e.g. PhysRevSTAB.11.070703

option: plasma based e^+ target

e.g. D.K. Johnson, UCLA 2006

SLAC-PUB-7378

PRAB 12, 111302

options: plasma energy spread compensation, plasma collimation, plasma bunch compression

collider needs > 10^{12} $e^{\pm}$ per second

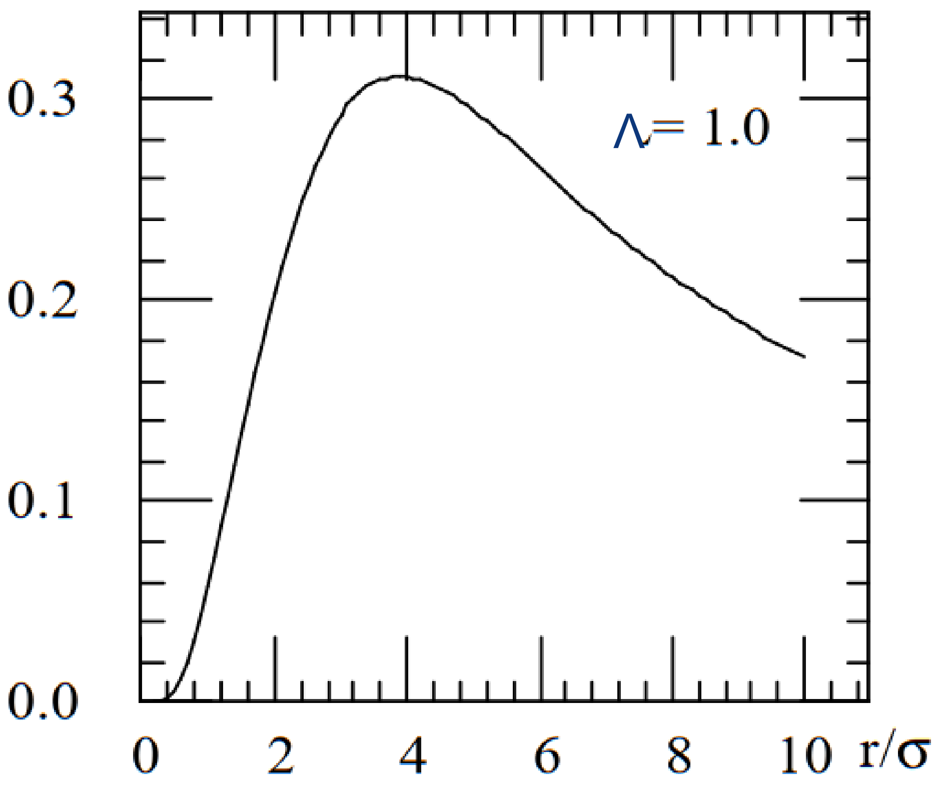
J. Seeman, FCC Week 2017

plasma collimation

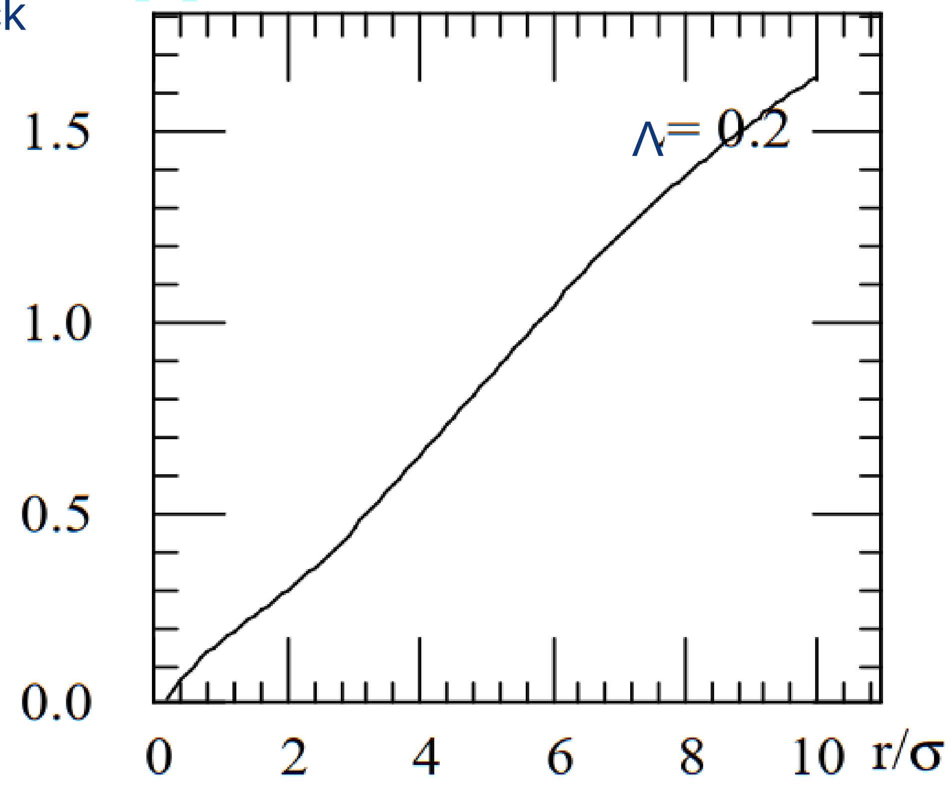
SLAC-PUB-7378

$$\Lambda = 0.123 \times 10^9 \frac{U}{m\omega_b^2 \sigma_r} \frac{1}{\text{cm}}$$

radial kick



radial kick



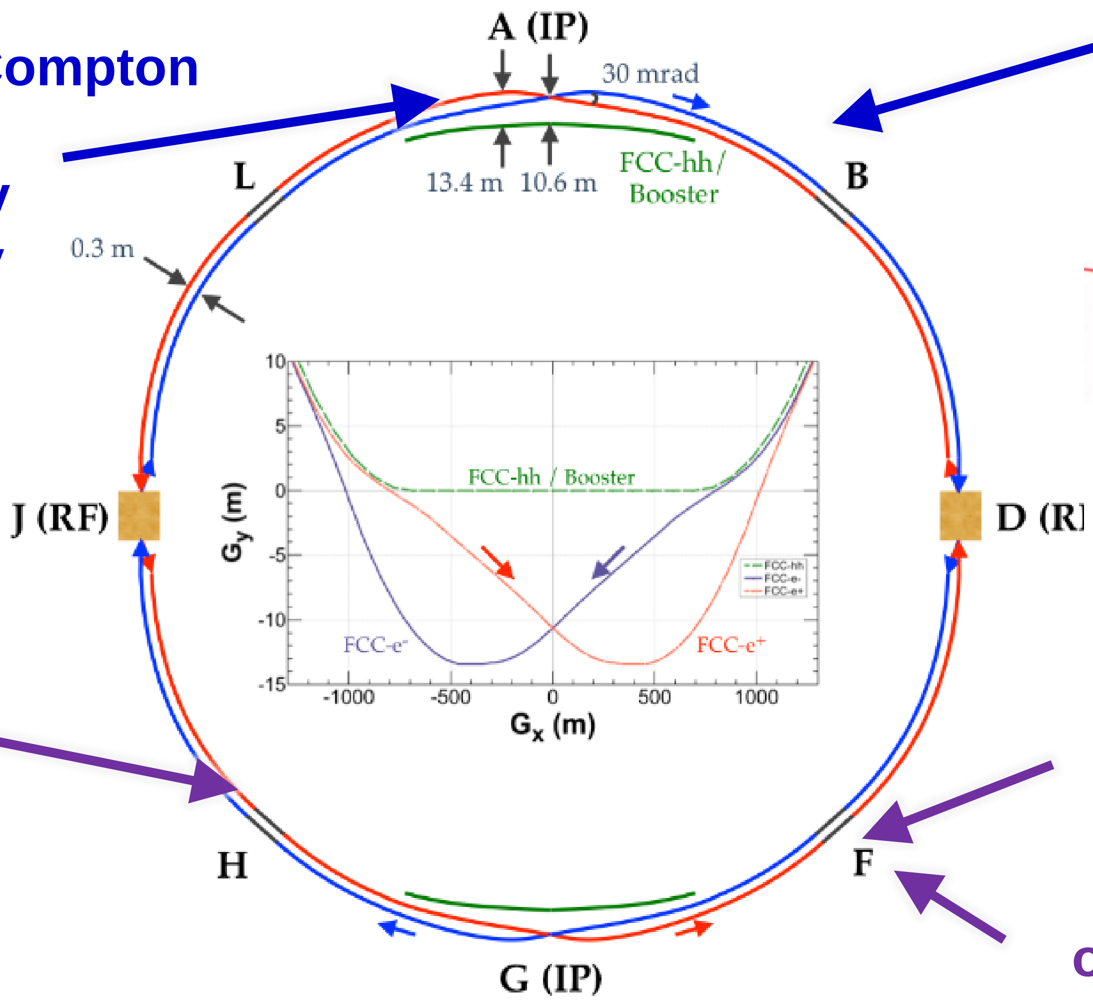
S. Heifets, T. Raubenheimer, 1996

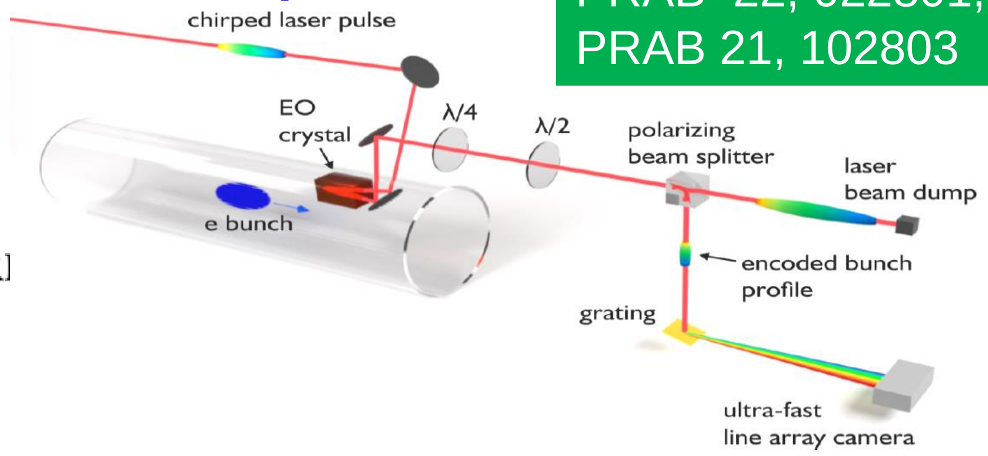
FCC-ee collider rings

baseline: Compton lasers for polarimetry and energy calibration

baseline: bunch-by-bunch profile measurement based on electrooptical sampling (crystal & laser)

PRAB 22, 022801,
PRAB 21, 102803



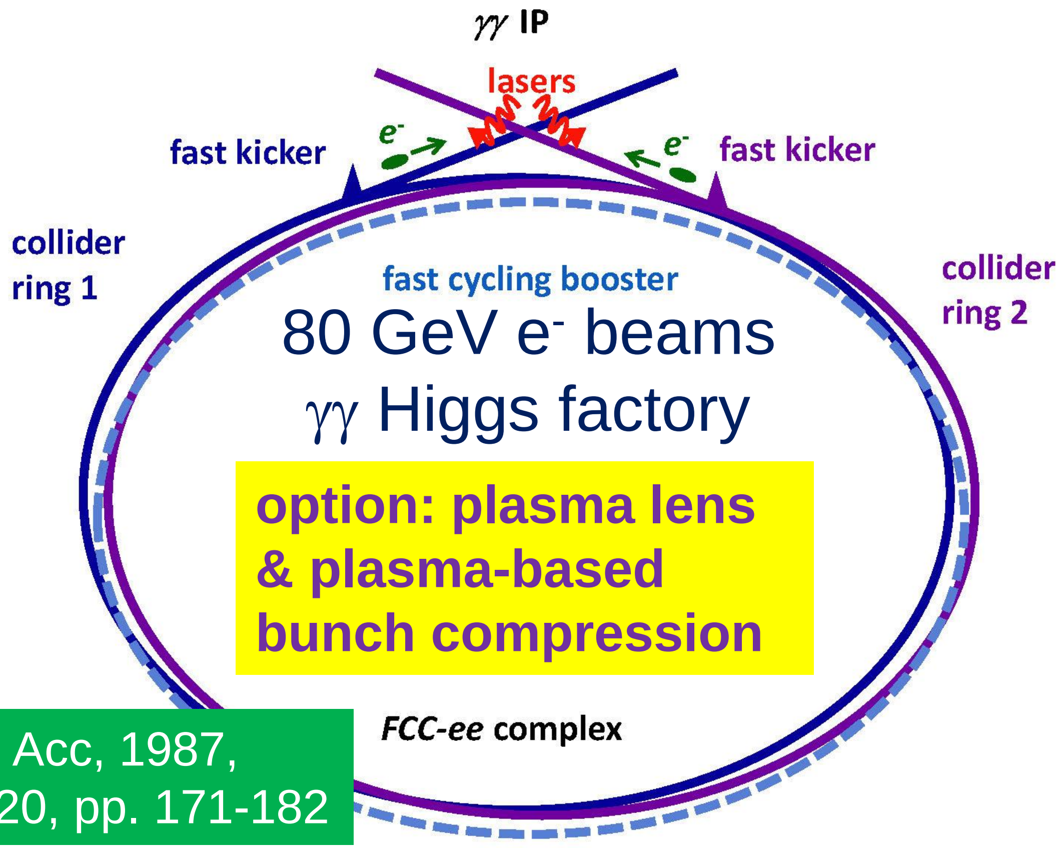


option: laser wires for transverse beam size measurement

option: crystal collimators
alternative option: plasma collimators

option: plasma-based beam dump

FCC-ee γγ option

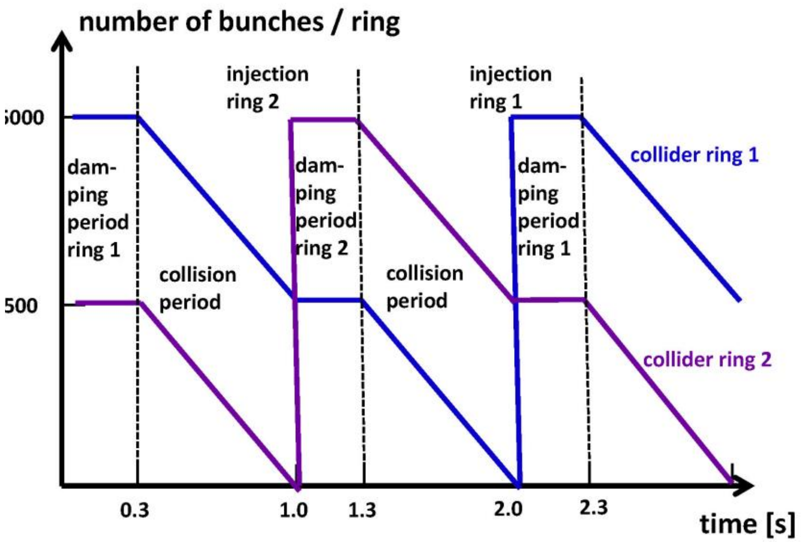


80 GeV e^- beams

γγ Higgs factory

option: plasma lens & plasma-based bunch compression

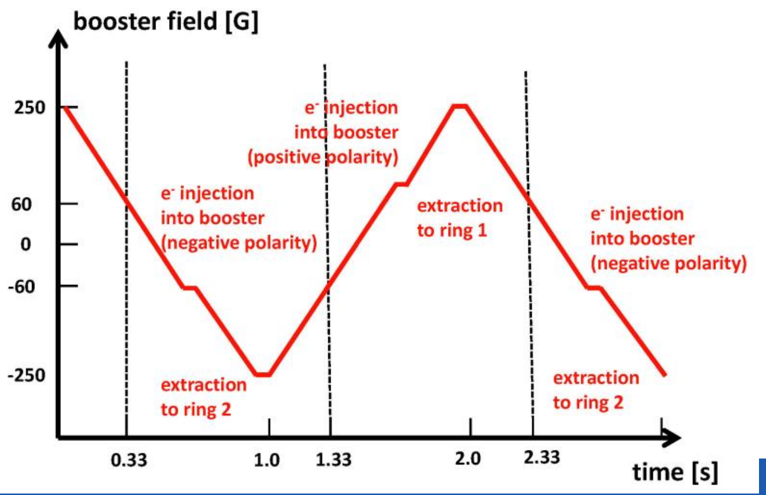
Part. Acc, 1987, Vol. 20, pp. 171-182



cycle pattern for the two collider rings

IPAC2015, TUPTY057

cycle pattern for the booster (inj. at 20 GeV)

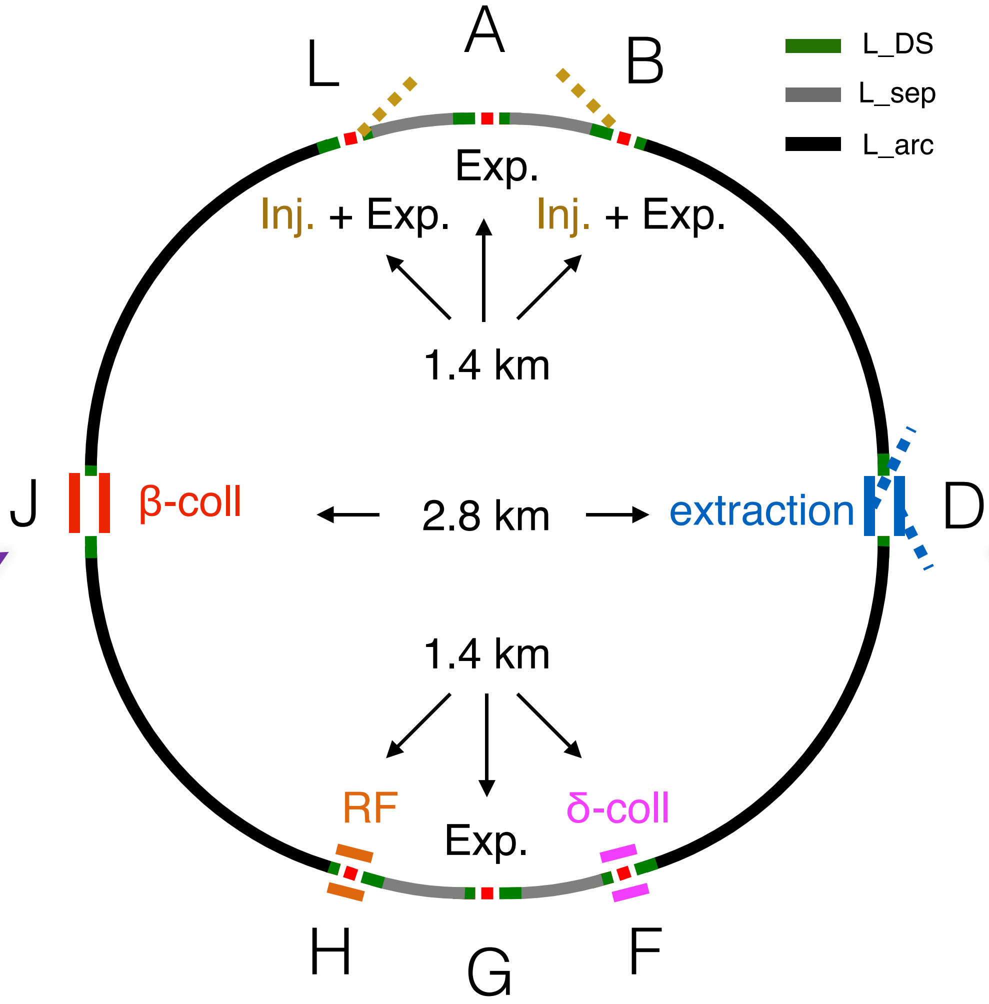


Schematic γγ collider based on filling the two FCC-ee collider rings with e^- bunches and extracting one bunch per beam and per turn into a dedicated γγ line.

R. Aleksan, F. Zimmermann et al., 2015

FCC-hh – the hadron collider

baseline: beam from plasma ion sources, for H^- (RF-ICP) and heavy ions (ECRIS)



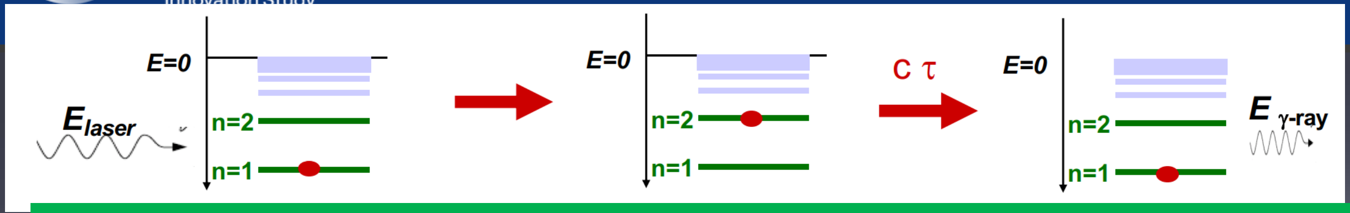
question: crystals or plasma to replace the high-field bending magnets??

PhysRevSTAB.4.091301

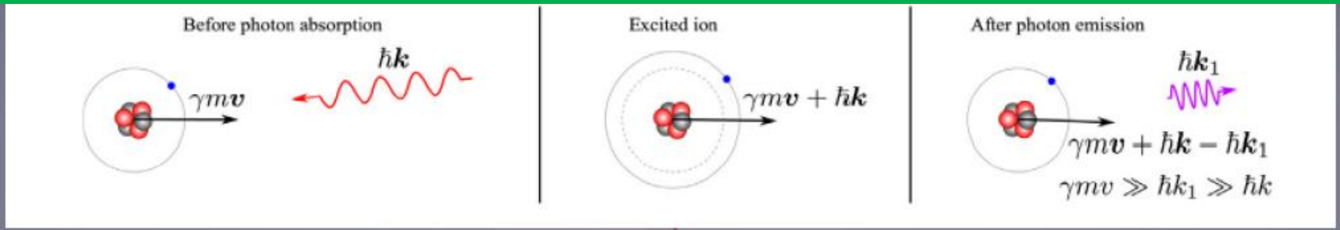
option: crystal collimators
alternative option: plasma collimators

option: plasma-based beam dump with integrated "AWAKE/SHIP" facility

FCC-hh – Gamma Factory option



partially stripped heavy-ion (PSI) beam in FCC-hh: high-stability laser-light-frequency converter



$$\nu^{max} \longrightarrow (4\,\gamma_L^{\,2})\ \nu_{Laser}$$

arXiv:1511.07794

proposed applications:

intense source of e^+ (10^{16}-10^{17}/s) , π, μ etc

doppler laser cooling of high-energy beams

FCC w. laser-cooled isocalar ion beams

Novel technology: Resonant scattering of laser photons on ultra-relativistic atomic beam

options: plasma target, plasma acceleration of secondary beams?

FCC-eh – lepton-hadron & γγ collider

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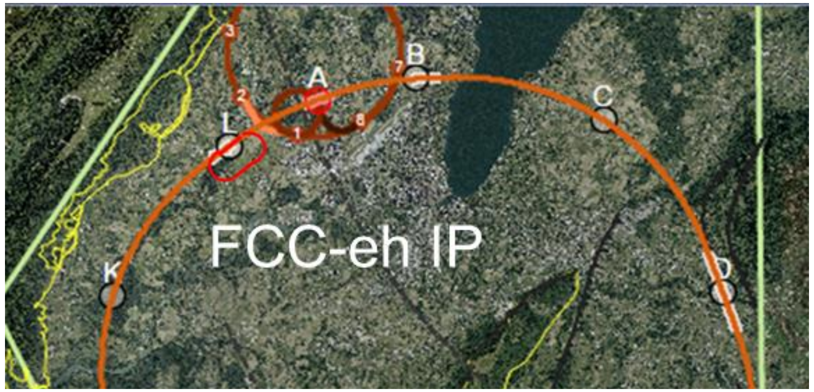
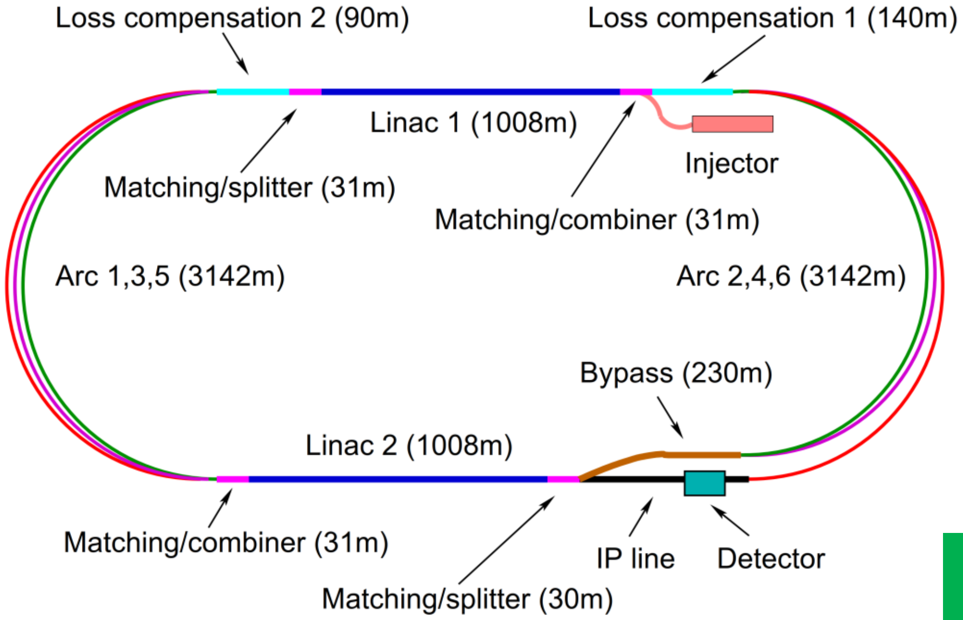


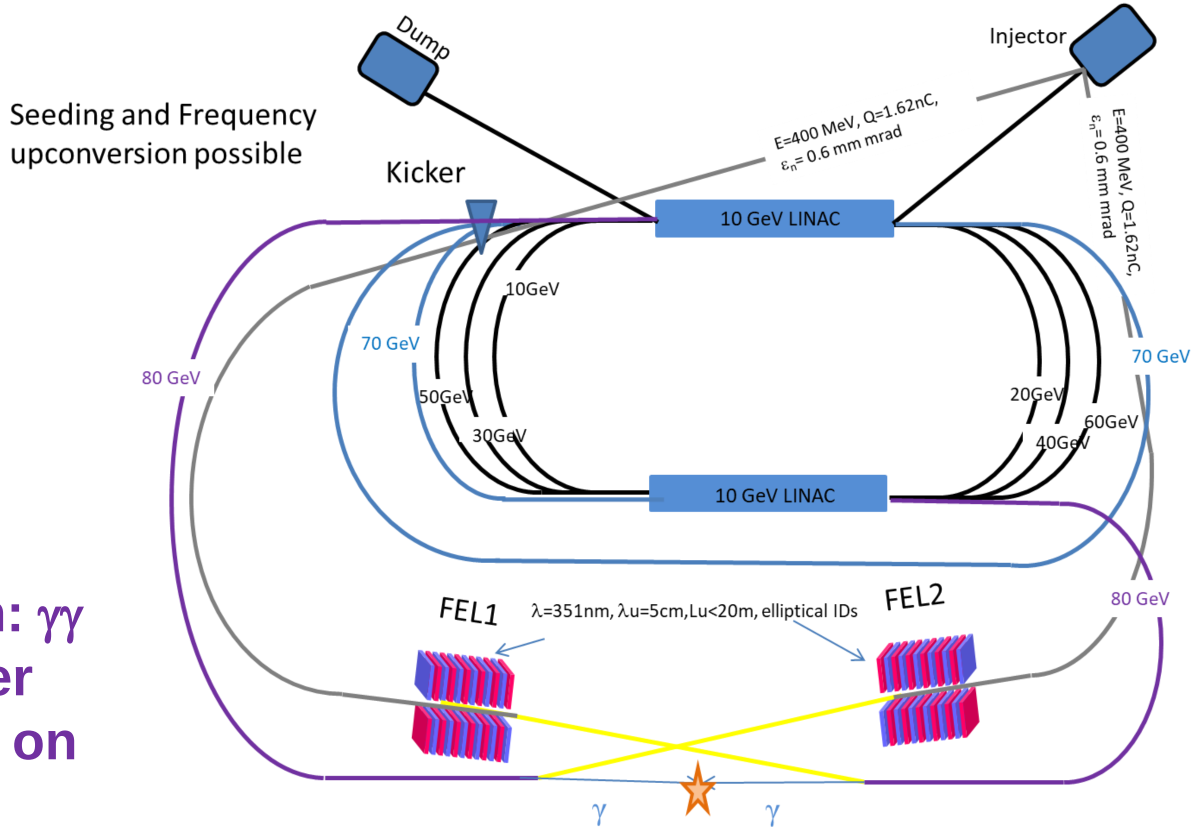
option: replace 9 km ERL by plasma acc. of AWAKE type!

10.1140/epjc/s10052-016-4316-1



option: γγ collider based on lasers

arXiv:1208.2827



option: γγ collider based on FELs

A. Meseck,
ARIES Photon Beams

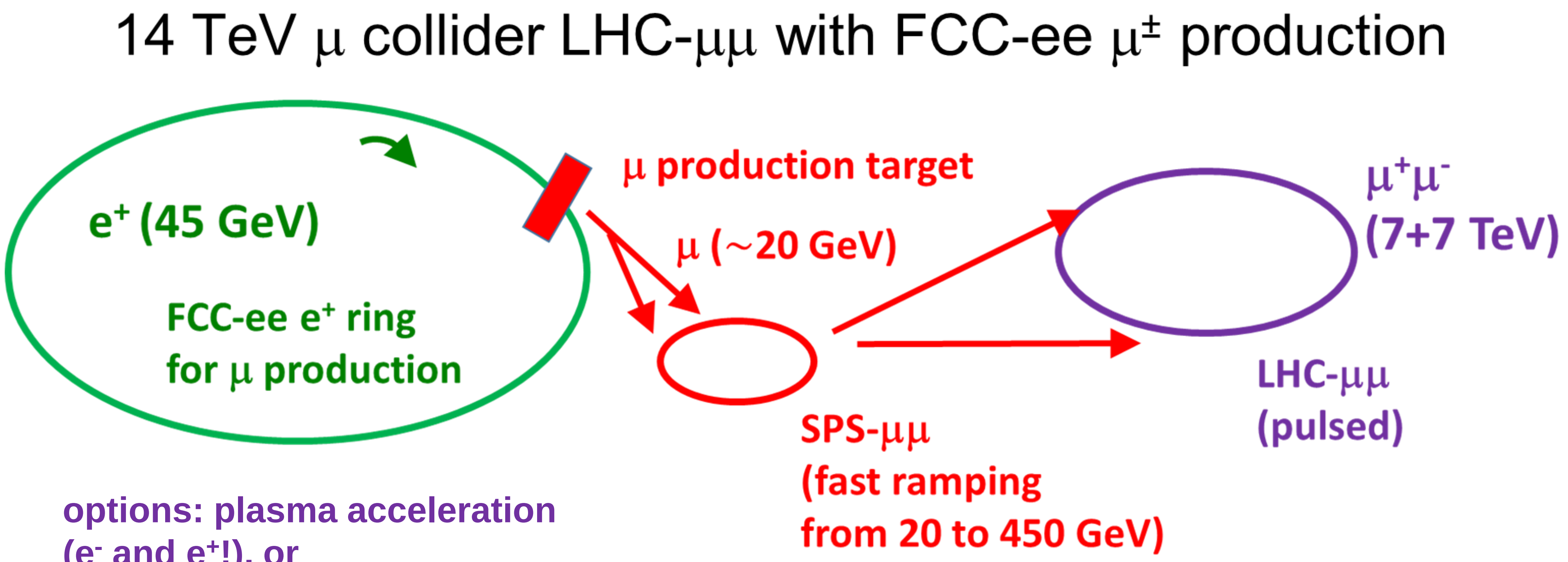
option: plasma lens & plasma-based bunch compression

laser/FEL for FCC-eh Sapphire & FCC-ee $\gamma\gamma$ option

	symbol	SAPPHIRE	FCC-ee
average el. power	P	100 MW	100 MW
beam energy	E	80 GeV	85 GeV
b. polarization	P_e	0.80	0.80
bunch popul.	N_b	10^{10}	7.7×10^{10}
laser rep rate	f_{rep}	200 kHz	3 kHz
av. collision rate	f_{coll}	200 kHz	2 kHz
laser pulse energy		5 J	5 J
laser power		1000 kW	15 kW
laser wave length	λ	350 nm	350 nm
Rayleigh length	z_R	0.3 mm	0.3 mm
rms laser spot CP	$\sigma_{\gamma;x,y}$	4 μm	4 μm
laser pulse length	σ_λ	0.25 mm	0.15 mm
# bunches / beam	n_b	-	4000
collider period		-	2 s
bunch length	σ_z	30 μm	350 μm

E damping time	τ_E	-	67 ms
energy spread	σ_δ	?	7×10^{-4}
RF frequency	f_{rf}	800 MHz	800 MHz
RF voltage	V_{rf}	2×10 GV	6 GV
$\gamma\gamma$ crossing angle	θ_c	≥20 mrad	≥20 mrad
nor.hor./vert. emit	$\gamma\varepsilon_{x,y}$	5, 0.5 μm	69, 0.06 μm
geom. h./v. emit.	$\varepsilon_{x,y}$	32, 3 pm	440, 0.4 pm
hor. IP beta funct.	β_x^*	5 mm	1 mm
vert. IP beta funct.	β_y^*	0.1 mm	0.1 mm
hor. rms spot size	σ_x^*	400 nm	700 nm
vert. rms spot size	σ_y^*	18 nm	6 nm
hor. rms CP spot	σ_x^{CP}	410 nm	1000 nm
vert. rms CP spot	σ_y^{CP}	180 nm	60 nm
distance IP – CP		~1 mm	1 mm
e^-e^- geometric luminosity	L_{ee}	2.2×10^{34} $cm^{-2}s^{-1}$	1.3×10^{34} $cm^{-2}s^{-1}$
$\gamma\gamma$ luminosity >125 GeV	$L_{\gamma\gamma}$	6×10^{32} $cm^{-2}s^{-1}$	8×10^{32} $cm^{-2}s^{-1}$

14 TeV μ collider based on FCC-ee & LHC

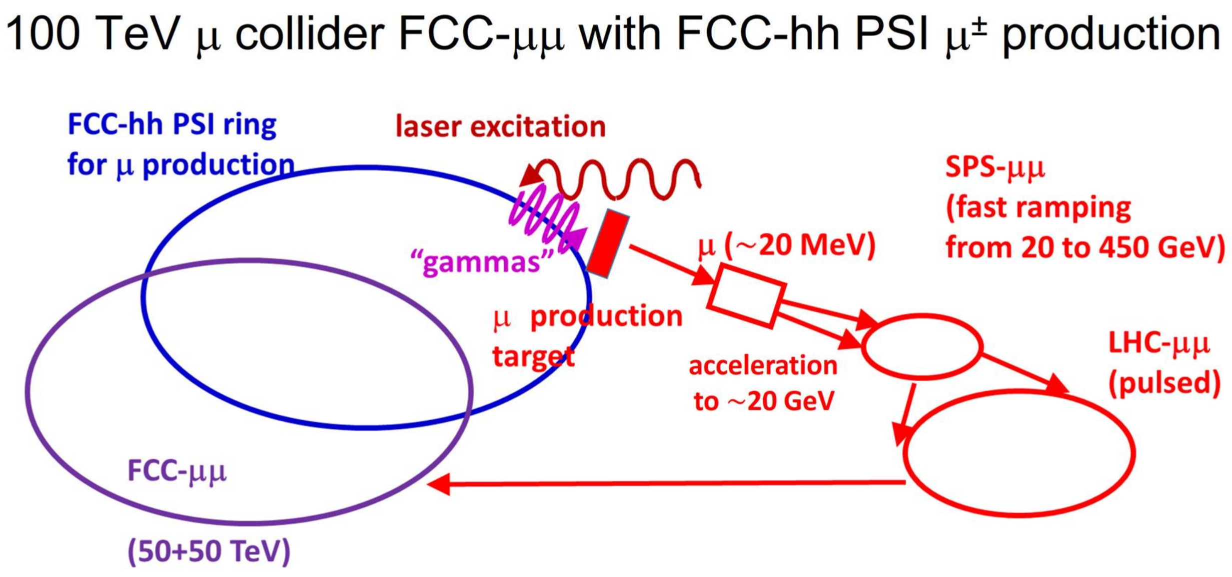


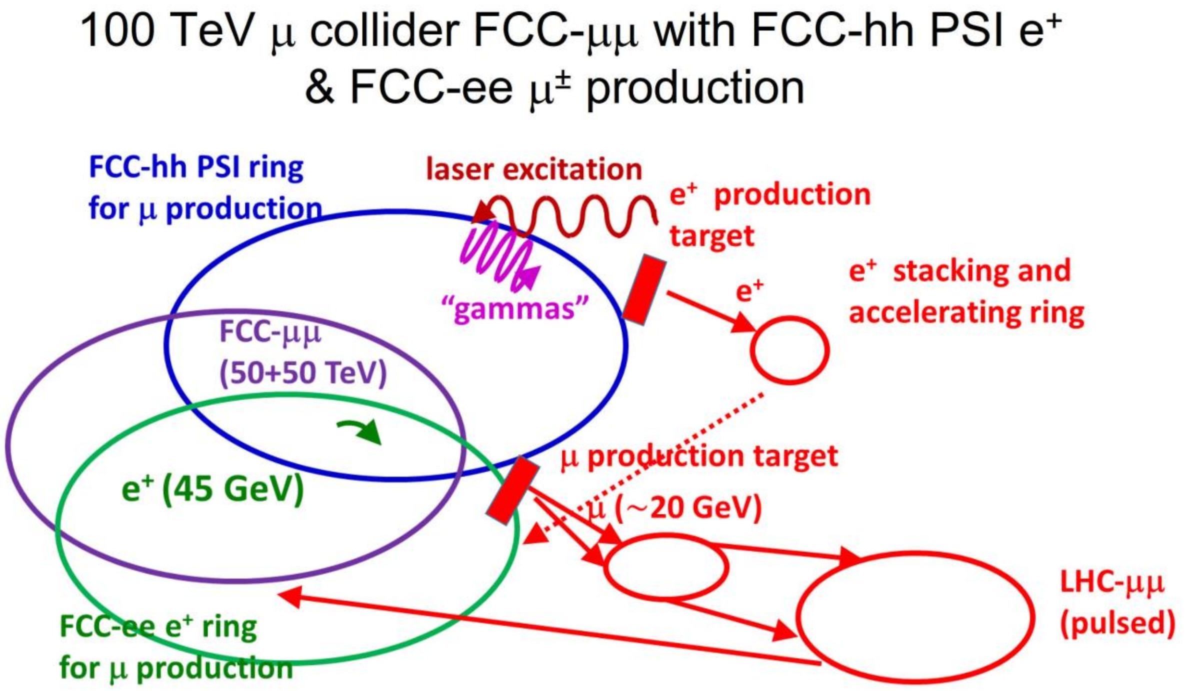
options: plasma acceleration
(e^- and e^+!), or
dielectric or laser acceleration,
plasma lenses

IOP J. Phys.: Conf. Ser. 1067 022017

100 TeV μ collider based on FCC-ee & hh

IOP J. Phys.: Conf. Ser. 1067 022017





options: plasma acceleration (e^- and e^+!), or dielectric or laser acceleration; plasma lenses

the ultimate challenge

synchrotron radiation (SR)

- FCC-ee: 100 MW SR power
- FCC-hh: 5 MW SR power at cold → 100 MW cryo power

can we use crystals or plasma to shield and to suppress the photon emission ?

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FCC – take home messages

- FCC baseline is conservative and can be built based on existing technologies
- however, the FCC collider complex offers **enormous wealth of opportunities for applying advanced acceleration concepts** to achieve better performance and/or greatly reduce cost
- dedicated studies are needed - CEPC is pursing these…

"*Make a small effort soon to investigate possibilities*" (John Seeman, 2017)

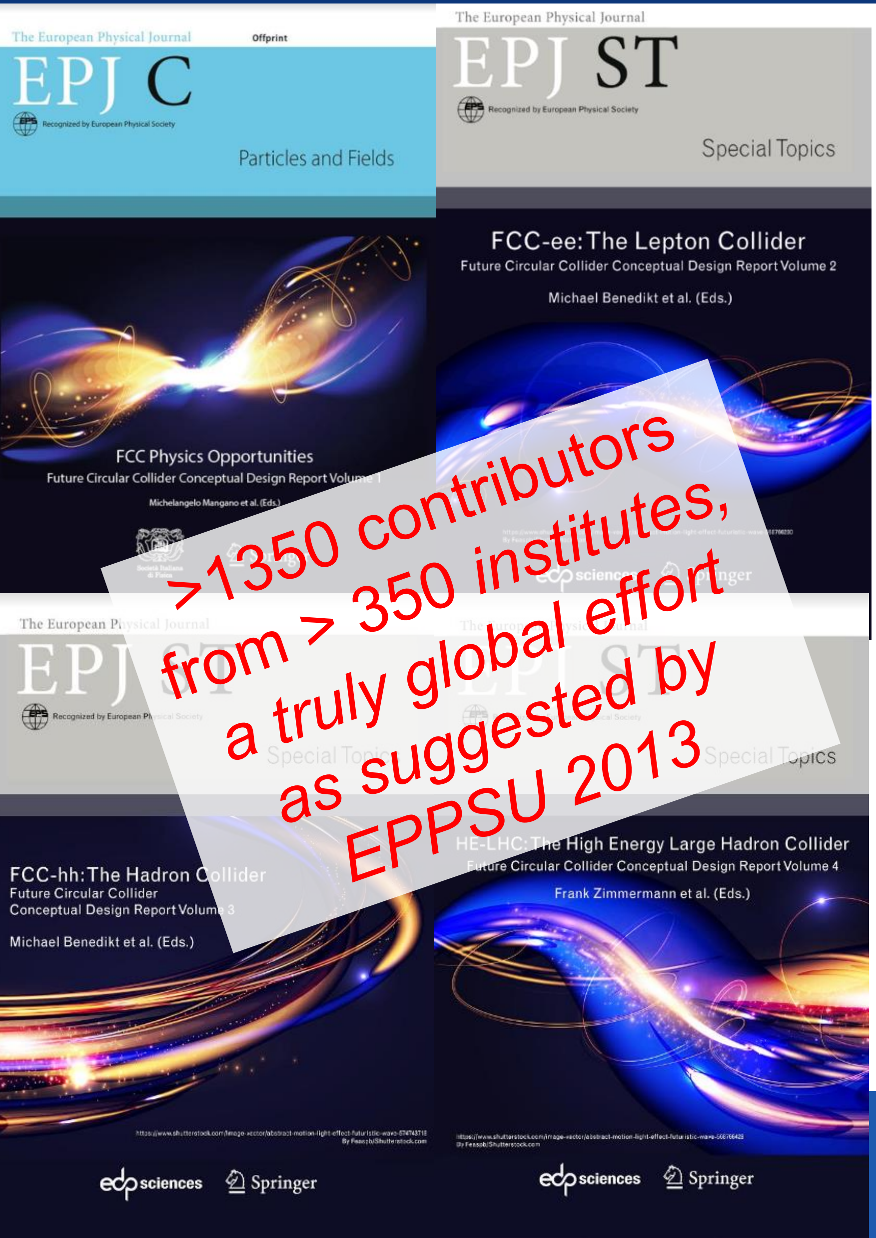
we are counting on your help !

a pity that
today’s expert
panelists
cannot share
a meal
in the “expert
restaurant”

thank you!

spare slides

FCC CDR & Study Documentation



- **FCC-Conceptual Design Reports:**
  - **Vol 1 Physics, Vol 2 FCC-ee, Vol 3 FCC-hh, Vol 4 HE-LHC**
  - CDRs published in **European Physical Journal C (Vol 1) and ST (Vol 2 – 4) [Springer]**

    EPJ C 79, 6 (2019) 474 , EPJ ST 228, 2 (2019) 261-623 ,

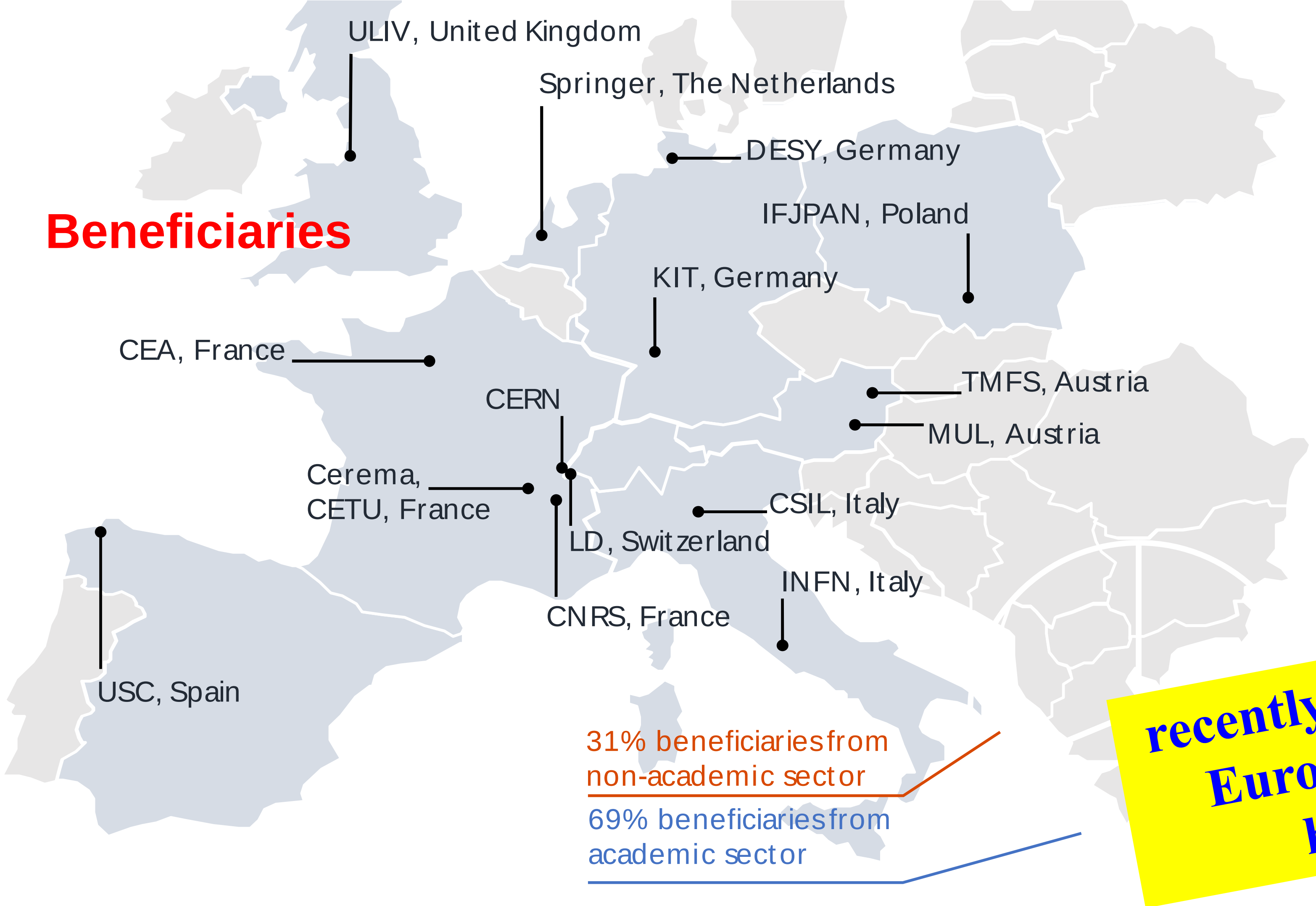
    EPJ ST 228, 4 (2019) 755-1107 , EPJ ST 228, 5 (2019) 1109-1382

- EPJ is a merger and continuation of *Acta Physica Hungarica, Anales de Fisica, Czechoslovak Journal of Physics, Fizika A, Il Nuovo Cimento, Journal de Physique, Portugaliae Physica* and ***Zeitschrift für Physik***. 25 European Physical Societies are represented in EPJ, including the DPG.

- **Summary documents provided to EPPSU SG**
  - **FCC-integral, FCC-ee, FCC-hh, HE-LHC**
  - Accessible on http://fcc-cdr.web.cern.ch/

H2020 DS FCC Innovation Study 2020-24

Beneficiaries



Partners

- D.R.R.T. (F)
- Etat de Geneve (CH)
- DOE (US)
- BINP (Ru)
- U Oxford (UK)

recently accepted for funding by the European Commission with the highest achievable score

Design optimisation, construction planning, environmental impact assessment, management of excavation materials, user community building and public engagement, socio-economic impact,…

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FCC-ee CDR baseline parameters

parameter	Z	WW	ZH	$t\bar{t}$	LEP2
energy/beam [GeV]	**45.6**	**80**	**120**	**182.5**	105
bunches/beam	16640	2000	328	48	4
beam current [mA]	1390	147	29	5.4	3
luminosity/IP x 10^{34} $cm^{-2}s^{-1}$	**230**	**28**	**8.5**	**1.6**	0.0012
energy loss/turn [GeV]	0.036	0.34	1.72	9.2	3.34
synchrotron power [MW]		**100**			22
RF voltage [GV]	0.1	0.75	2.0	4.0 + 6.9	3.5
rms bunch length (SR,+BS) [mm]	3.5, 12	3.0, 6.0	3.2, 5.3	2.0, 2.5	12, 12
rms emittance $\varepsilon_{x,y}$ [nm, pm]	0.27, 1	0.84, 1.7	0.63, 1.3	1.5, 2.9	22, 250
longit. damping time [turns]	1273	236	70	20	31
crossing angle [mrad]		30			0
beam lifetime [min]	68	59	12	12	434

FCC-hh (pp) collider parameters

parameter	FCC-hh		HL-LHC	LHC
collision energy cms [TeV]	**100**		14	14
dipole field [T]	**16**		8.33	8.33
circumference [km]	**97.75**		26.7	26.7
beam current [A]	0.5		1.1	0.58
bunch intensity [10^{11}]	1	1	2.2	1.15
bunch spacing [ns]	25	25	25	25
synchr. rad. power / ring [kW]	**2400**		7.3	3.6
SR power / length [W/m/ap.]	28.4		0.33	0.17
long. emit. damping time [h]	0.54		12.9	12.9
beta* [m]	1.1	0.3	0.15 (min.)	0.55
normalized emittance [mm]	2.2		2.5	3.75
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	**5**	**30**	5 (lev.)	1
events/bunch crossing	**170**	**1000**	132	27
stored energy/beam [GJ]	8.4		0.7	0.36