Accelerator Status

Frank Zimmermann *for the FCC team*

Preparatory Meeting for the International Collaboration Board

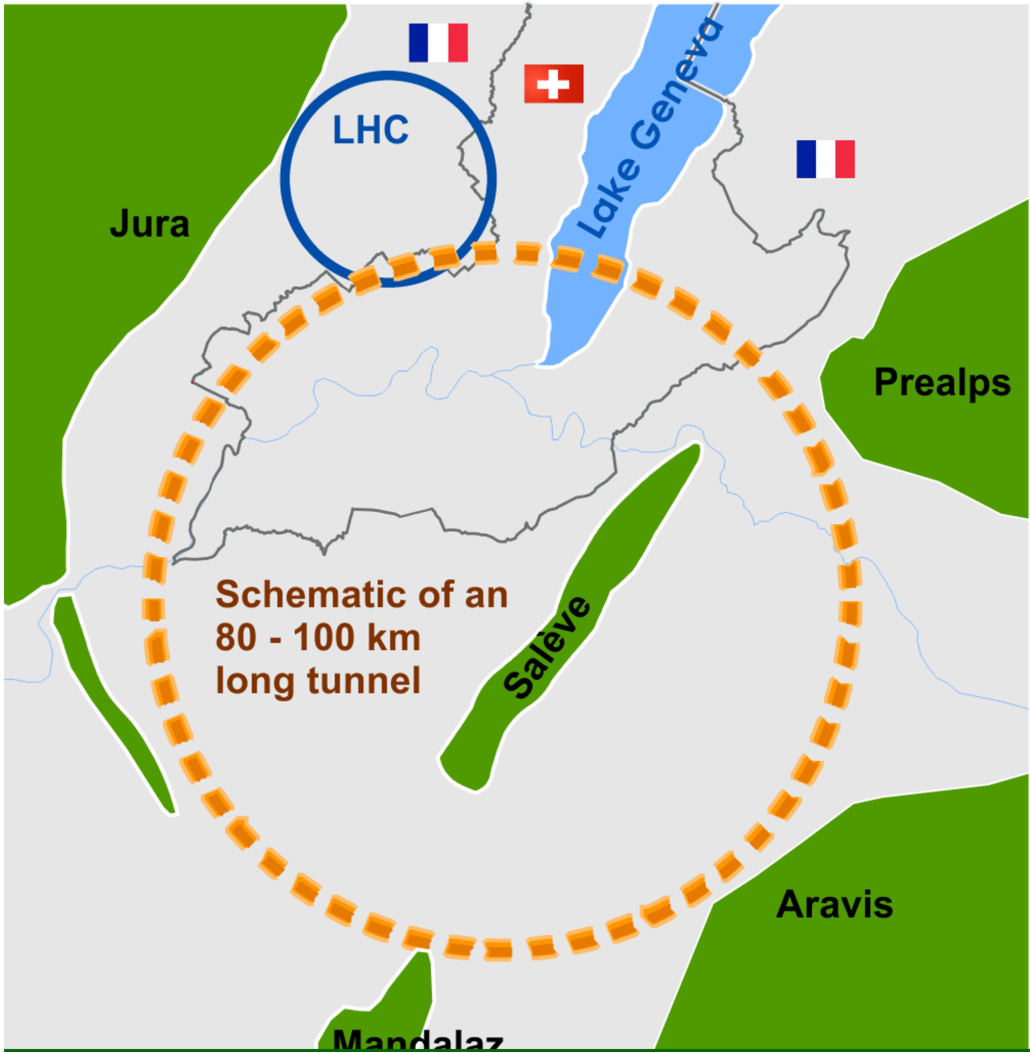
CERN, 8 September 2014

Particular thanks to Michael Benedikt, Bernhard Holzer, Giovanni Iadarola, Max Klein, Mike Koratzinos, Kazuhito Ohmi, Daniel Schulte, Rogelio Tomas, Jörg Wenninger…

FCC study scope

Conceptual Design Report (CDR) and cost review for the next European Strategy Update in 2018:

- *pp*-collider (*FCC-hh*): defining infrastructure requirements
  - **~16 T ➔ 100 TeV *pp* in 100 km**
  - ~20 T ➔ 100 TeV *pp* in 80 km
- e^+e^- collider (*FCC-ee*) as potential intermediate step
- *p-e* collider (*FCC-he*) option



requires a 80-100 km infrastructure in Geneva area

M. Benedikt

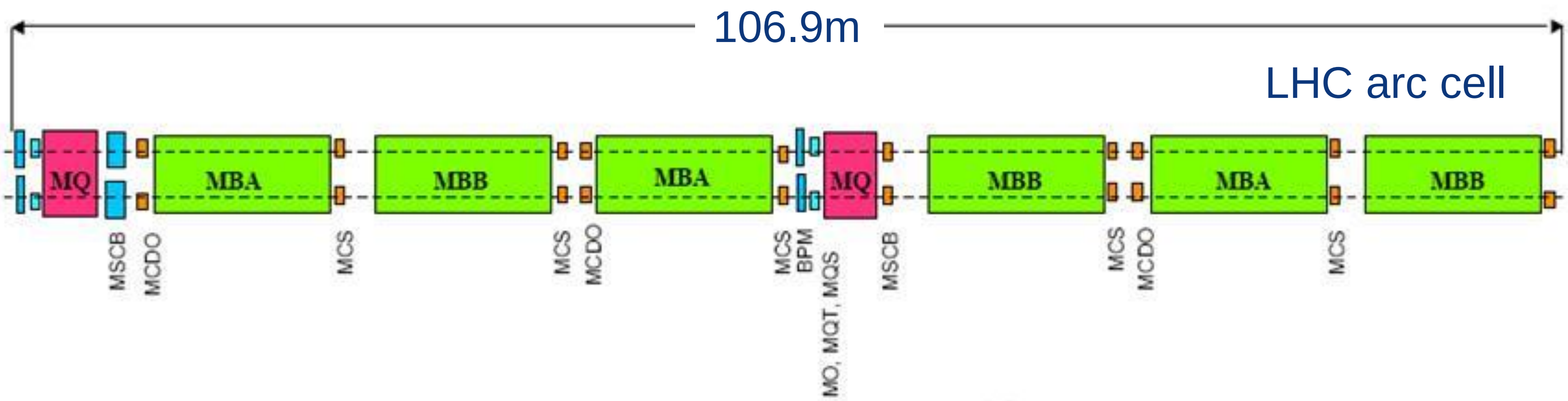
physics requirements for *FCC-hh*

- highest possible *pp* luminosity at 100 TeV
  - present baseline L=5x10^{34} cm^{-2}s^{-1} (as for HL-LHC)
  - higher luminosity appears possible
    - with implications for pile up, bunch spacing, shielding, cost, …
- also heavy-ion collisions & ion-proton collisions
- 2-4 experiments (like LHC, two special purpose detectors)
- proton polarization? (demonstrated at RHIC)

parameter	LHC	HL-LHC	FCC-hh
c.m. energy [TeV]	14		100
dipole magnet field [T]	8.33		16 (20)
circumference [km]	36.7		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)**

FCC-hh baseline parameters
defined in EDMS No. 1342402,
FCC-ACC-SPC-0001

arc cell design



longer cell → good dipole filling factor

shorter cells → more stable beam (smaller beta-function)

scaling from LHC

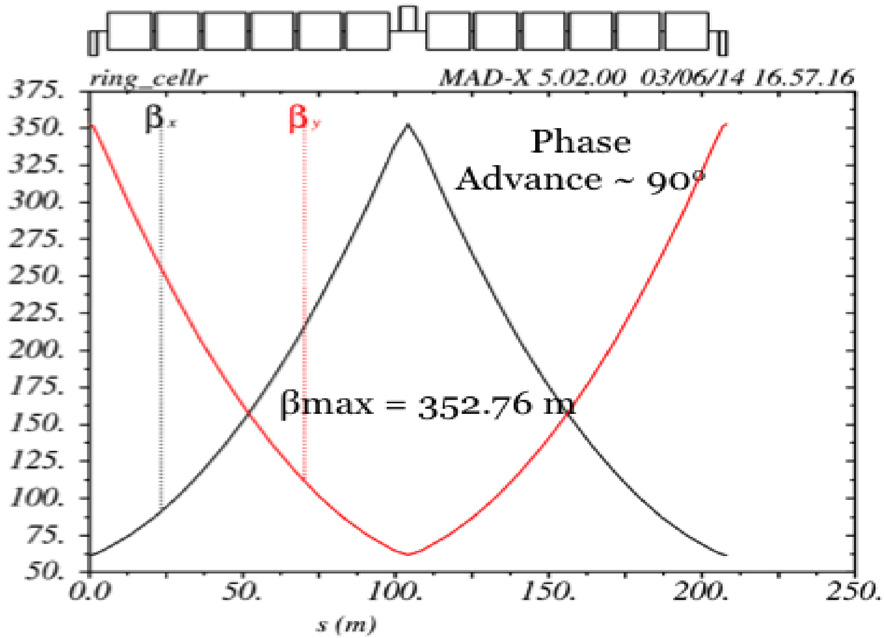
- "natural" scaling 107 m → ~300 m $\beta \propto L_{cell} \propto \sqrt{E}$
- for FCC magnet technology → 200 m $\beta \propto L_{cell} \propto \sqrt{C}$

dipole length should be similar to LHC (transport for installation)

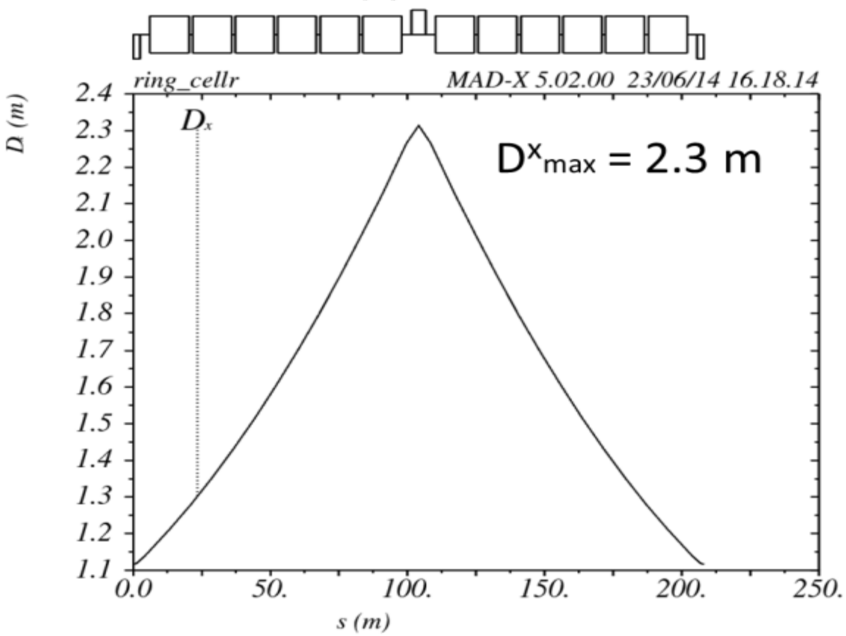
D. Schulte, B. Holzer, R. Alemany

example arc optics

$\beta_{x,y}$ [m]



D_x [m]



aperture in σ larger than for LHC

L_{cell} = 208.14 m

N_{dip}/cell = 12

N_{cell}/arc = 34

N_{dip} = 5016

L_{dip} = 14.2 m

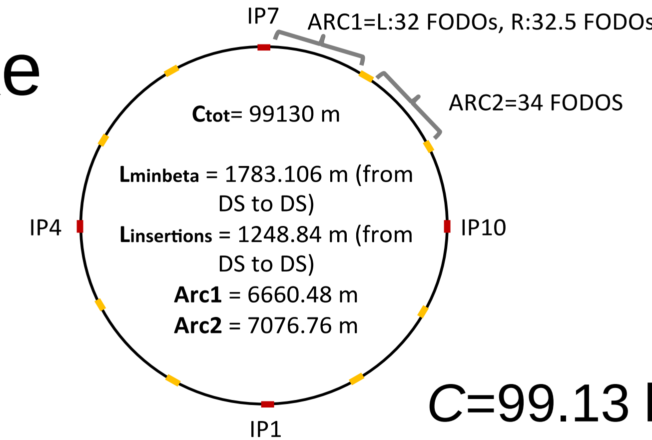
L_{quad} = 5.17 m

dipole filling factor in arc: η=82%

B. Holzer, R. Alemany; related work at CEA Saclay

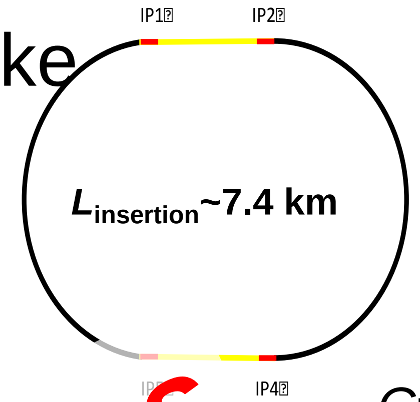
ring optics for alternative layouts

LHC-like circular



C=99.13 km

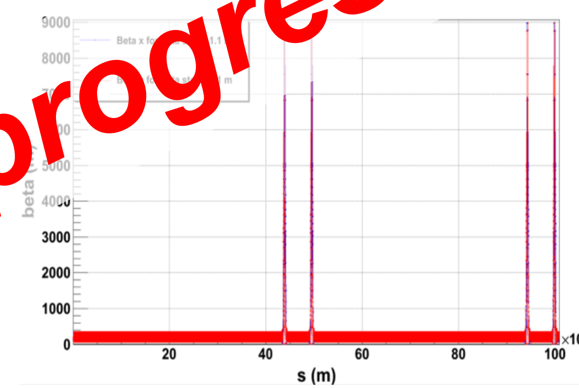
SSC-like race-track



C=100.8 km

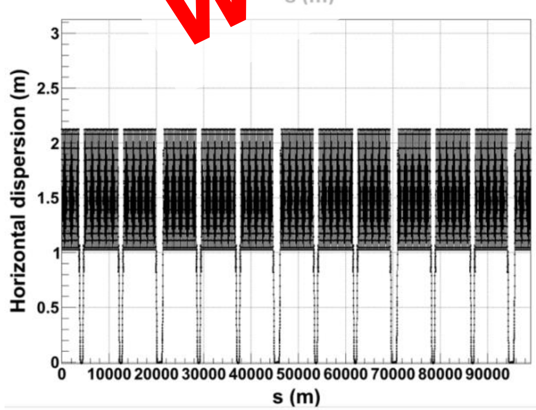
R. Alemany,
B. Holzer,
R. Tomas,
D. Schulte

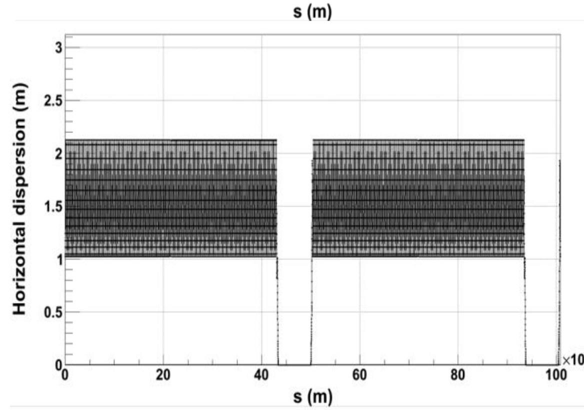
$\beta_{x,y}$ [m]



work in progress

D_x [m]



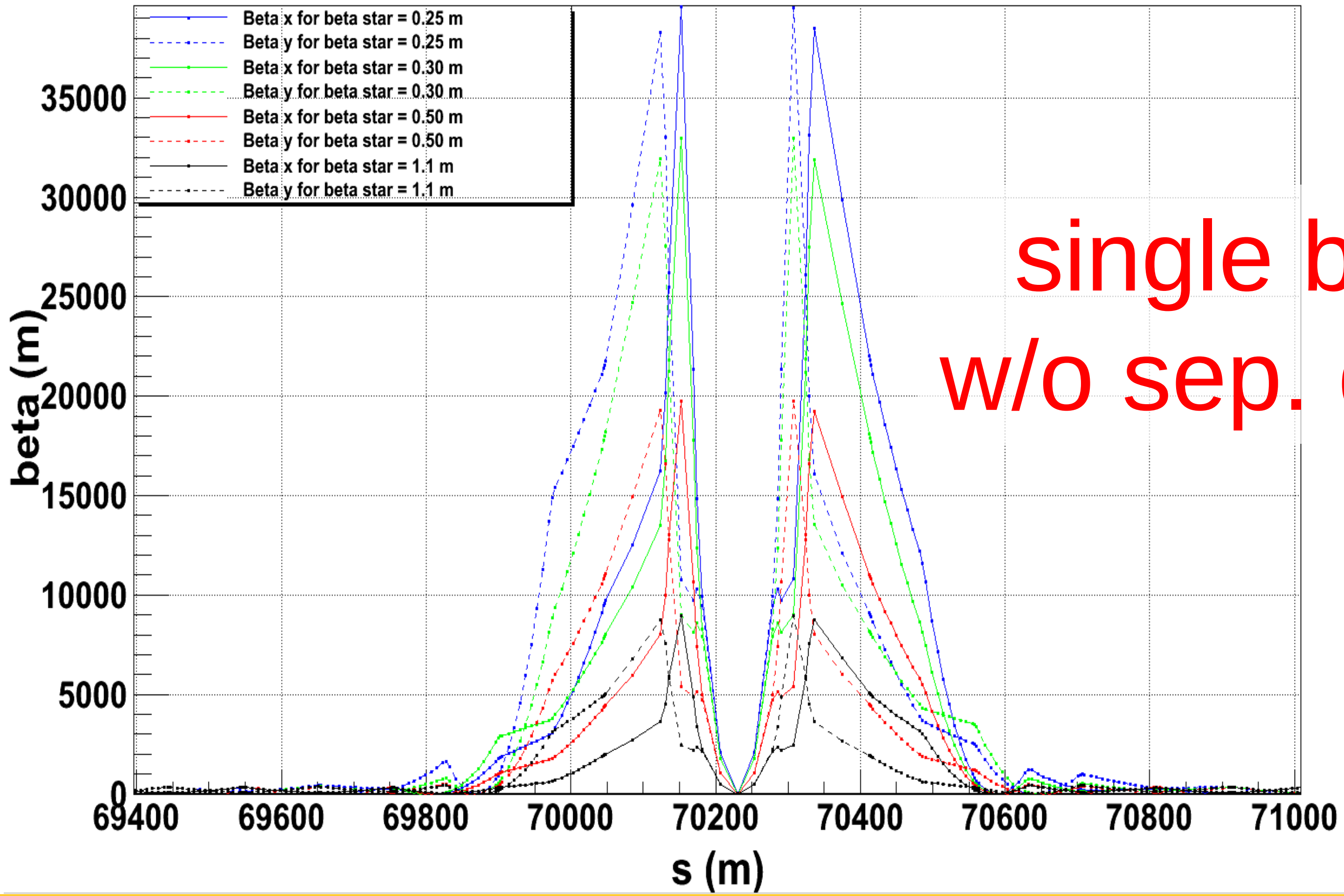


all optics files in FCC project database: /afs/cern/ch/eng/fcc/hh/LATTICE_V3/

IR optics for different β*

β* = 0.25 m, 0.30 m, 0.50 m and 1.1 m

R. Alemany
B. Holzer

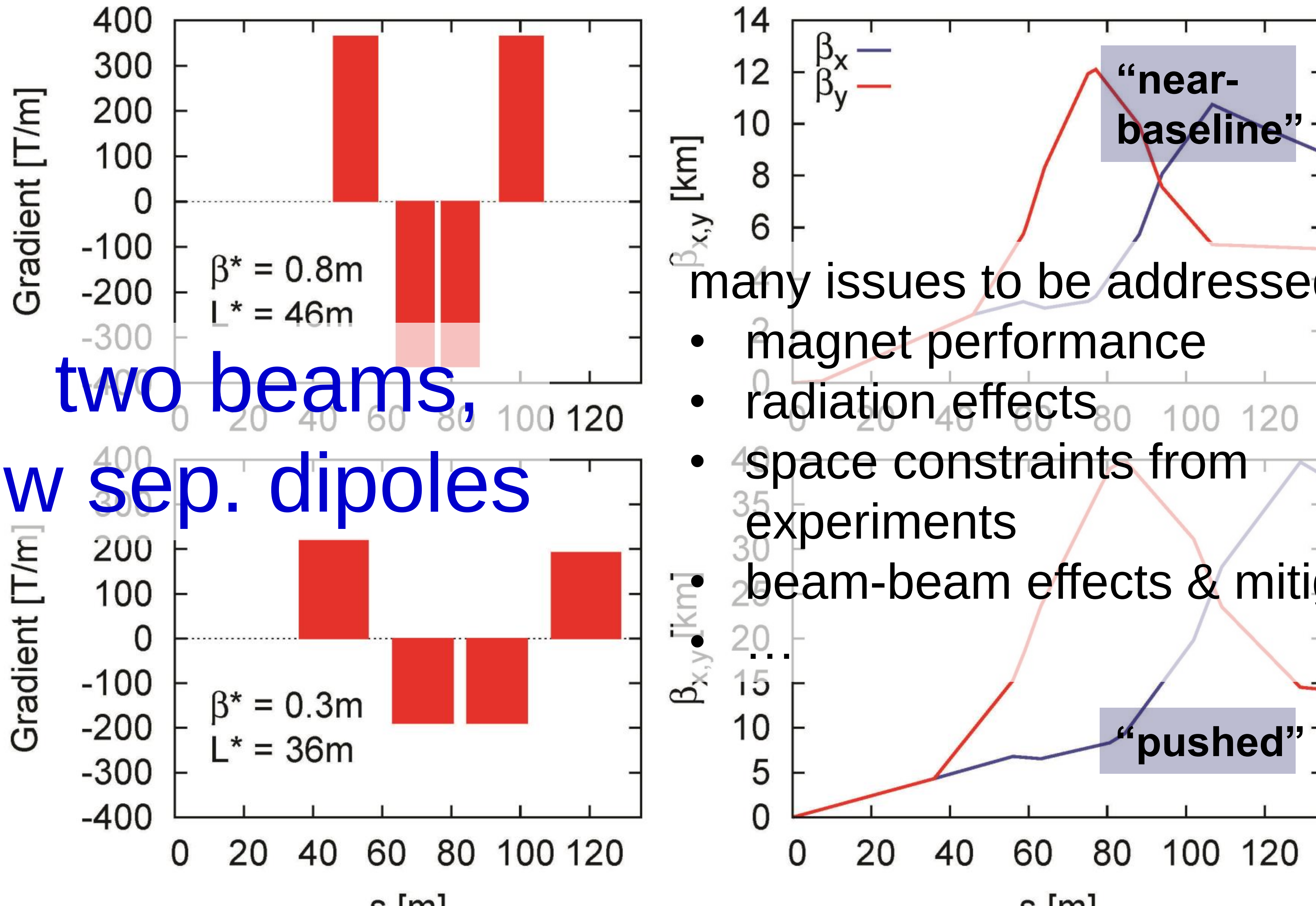


single beam, w/o sep. dipoles

β*=1.1→0.25 m: beam current & SR power lower by factor ~2 at constant average luminosity

full IR optics: β* =0.8 & 0.3m

FCC hh ee he



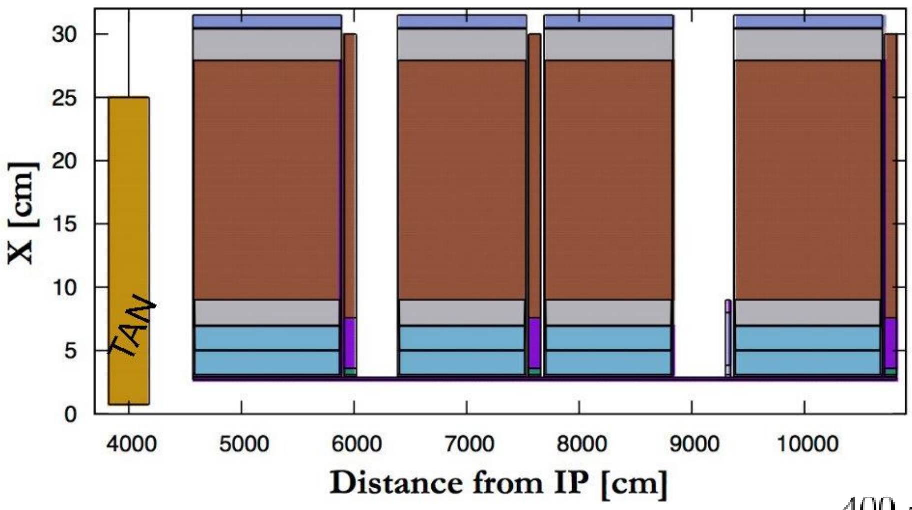
two beams,
w sep. dipoles

many issues to be addressed

- magnet performance
- radiation effects
- space constraints from experiments
- beam-beam effects & mitigation
- …

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

pp IR – radiation from debris



FLUKA model

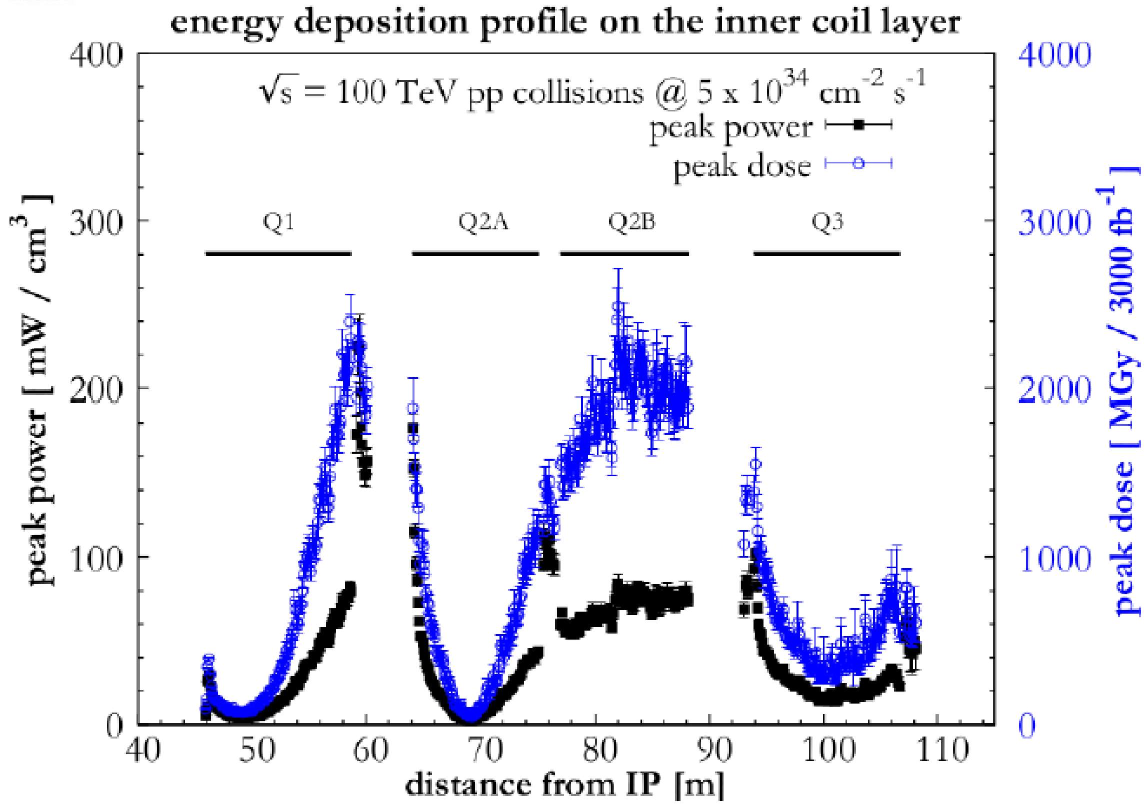
F. Cerutti and L. Esposito

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

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

R. Tomas

IR peak power and dose



machine protection

energy per proton beam

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

– kinetic energy of Airbus A380 at 720 km/h

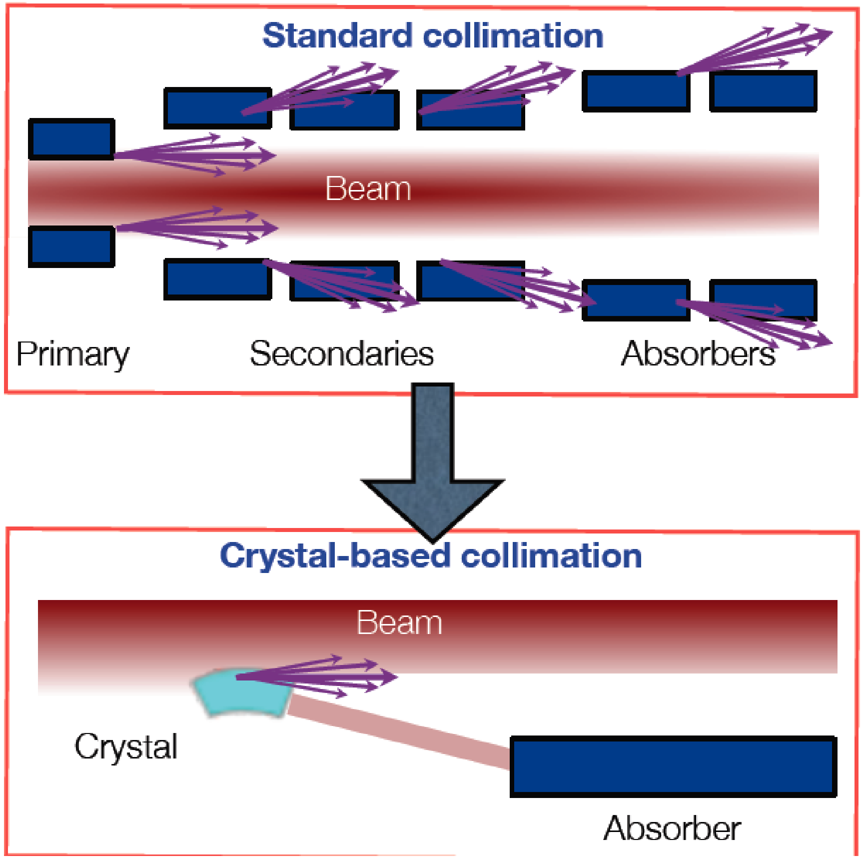
– can melt 12 tons of copper, or drill a 300-m long hole

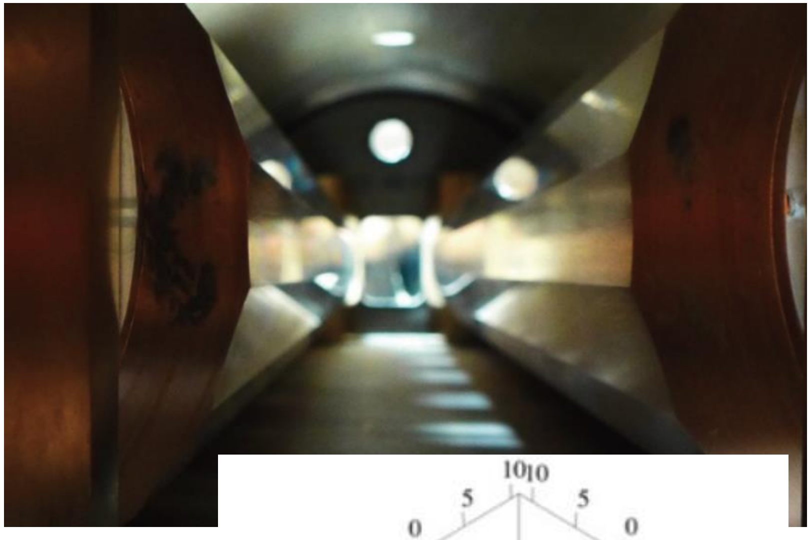
Collimation

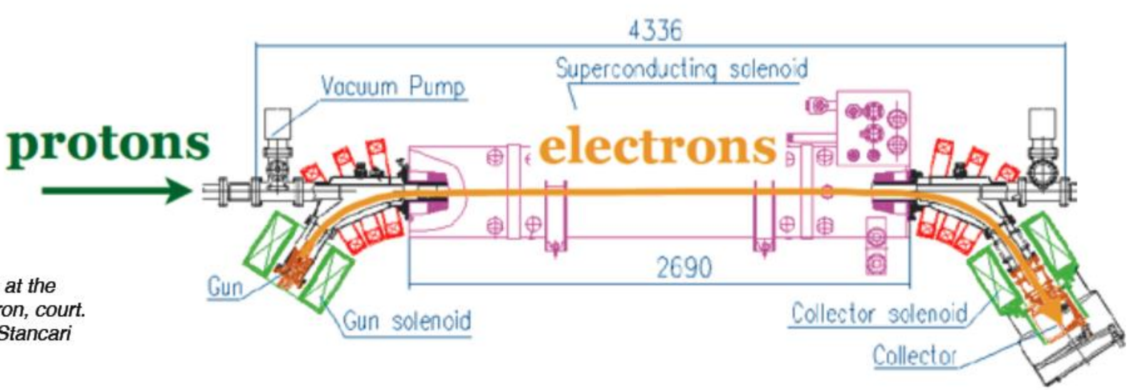
LHC-type solution is baseline, but other approaches should be investigated:

- hollow e^- beam as collimator
- crystals to extract particles
- renewable collimators

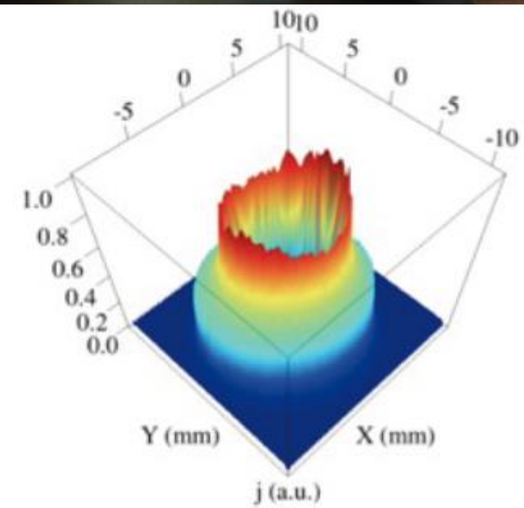
D. Schulte,
S. Redaelli



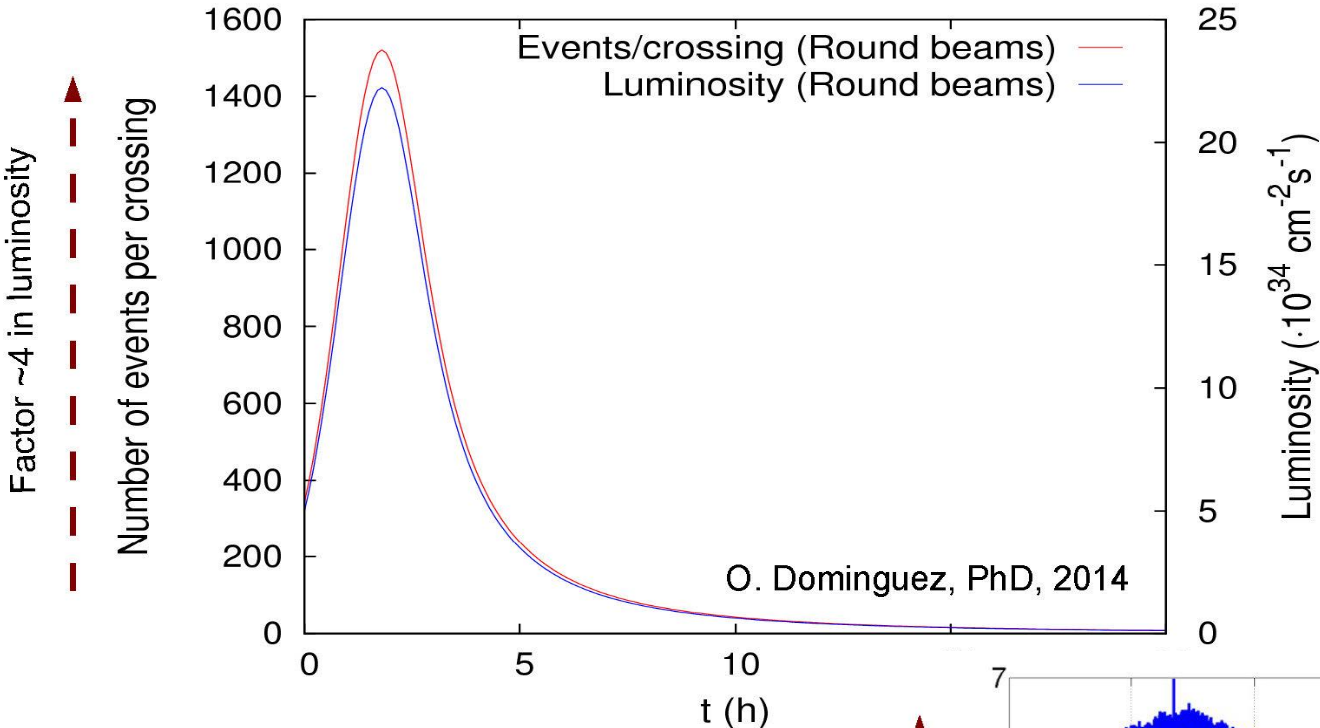




Setup at the Tevatron, court. of G. Stancari



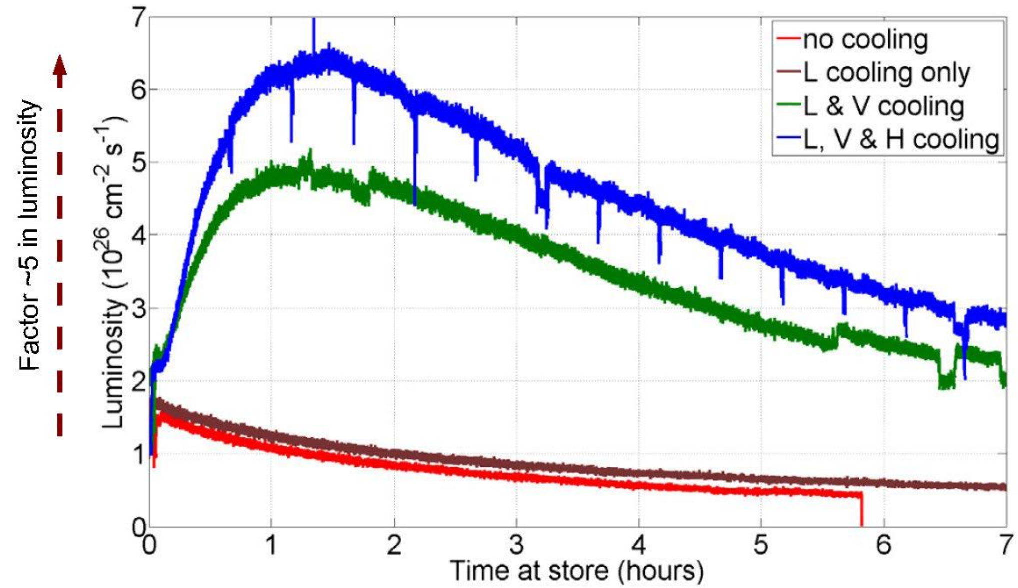
luminosity evolution w rad damping



emittance control by noise excitation

O. Domiguez

M. Blaskiewicz et al.



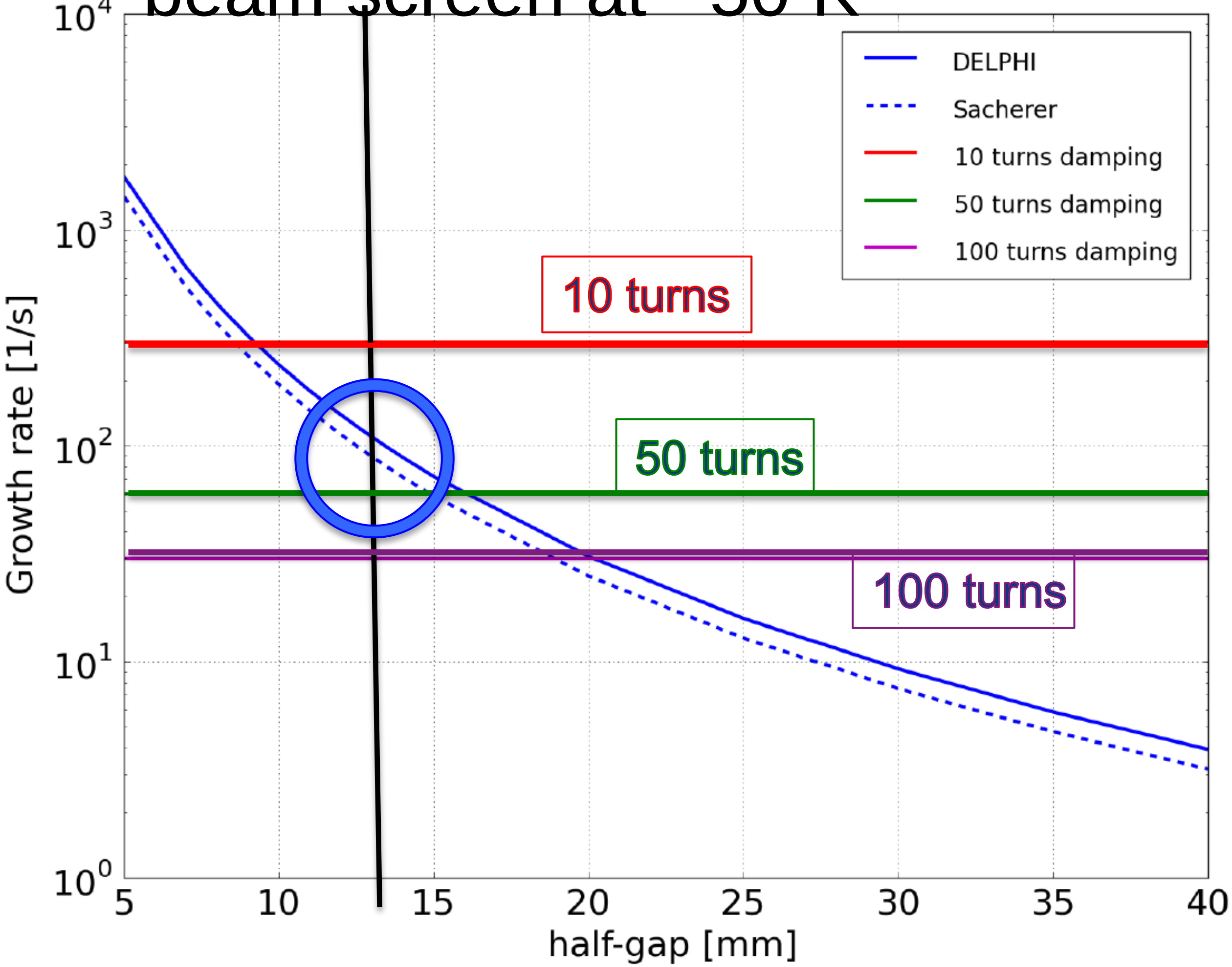
extremely similar to RHIC operation with stochastic cooling

R. Tomas

resistive-wall instability

D Schulte

beam screen at ~50 K



need <50-turn feedback

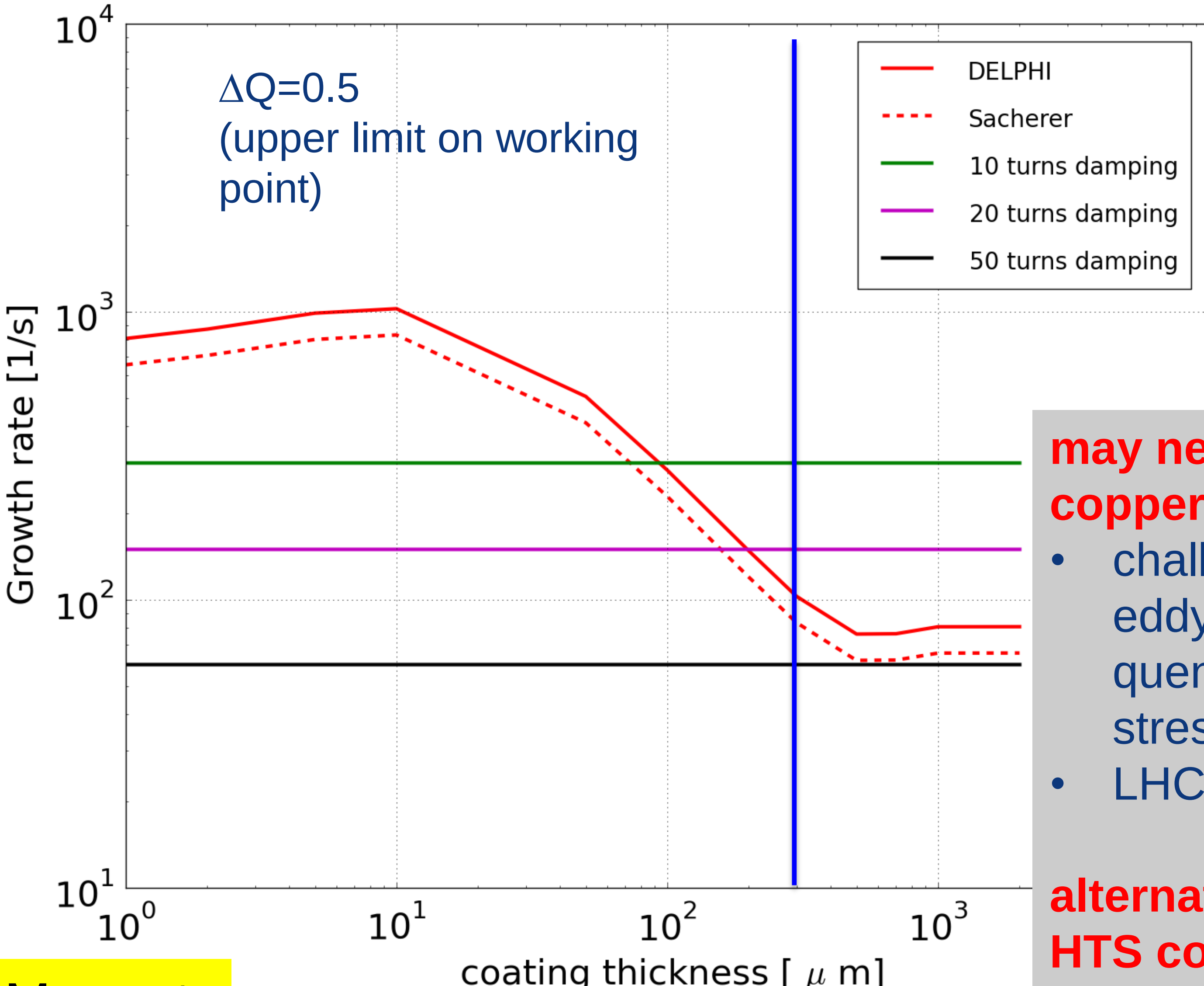
- or increase beam screen aperture
- or decrease beam current

TMCI is less important

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

N. Mounet, G. Rumolo

thickness of copper coating



may need ~300 μm of copper coating

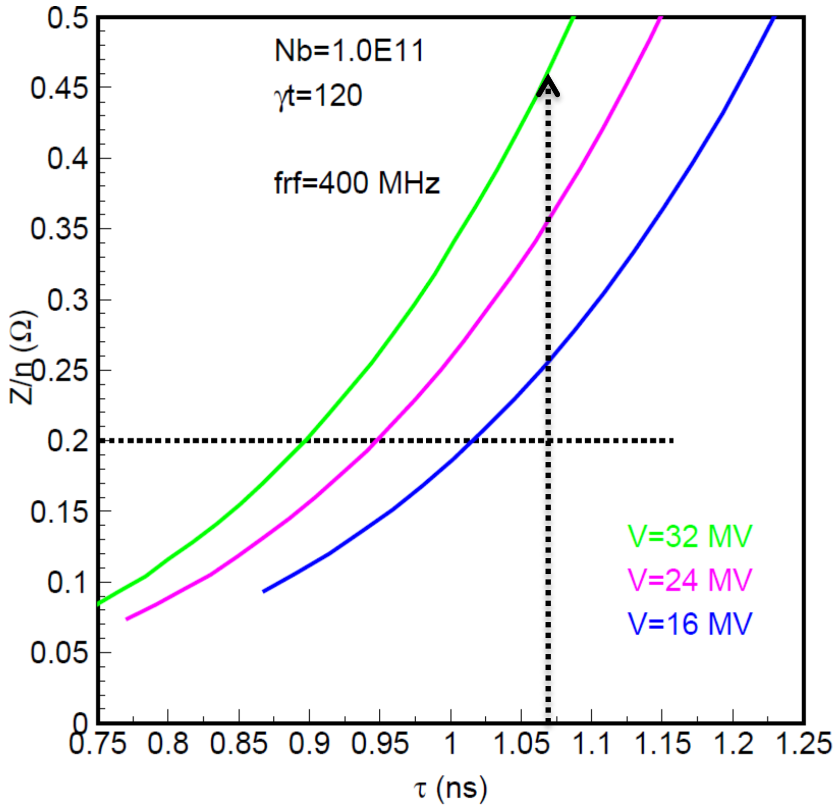
- challenge because of eddy currents in quench; induces stress on beam pipe
- LHC: 50-75 μm

alternative:
HTS coating? (L. Rossi)
impedance, coating technology, e-cloud, …?

N. Mounet,
D. Schulte

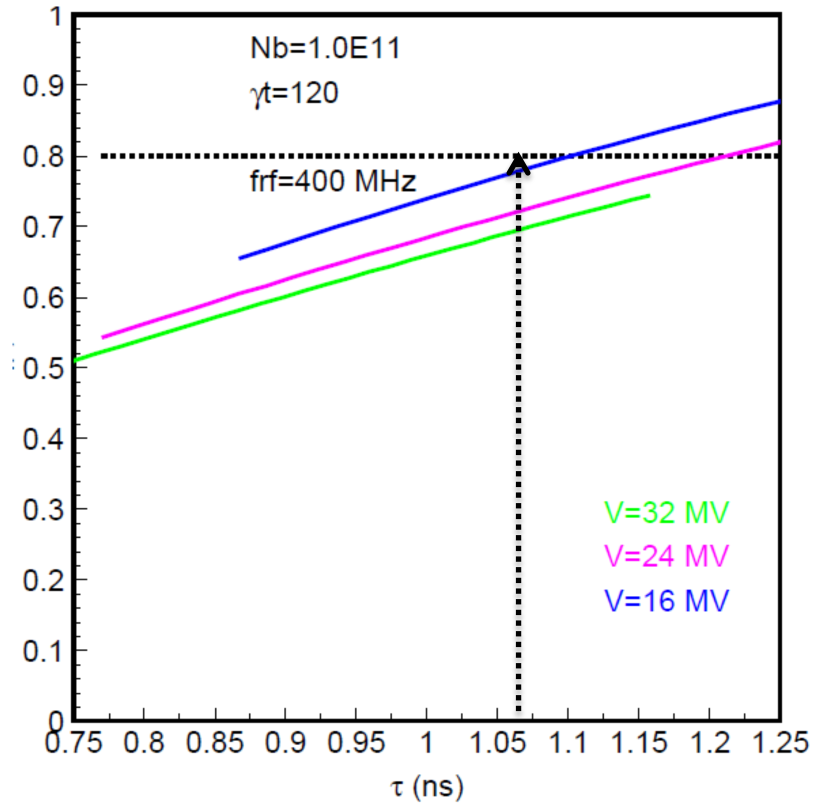
longitudinal stability

loss of Landau damping



need enough voltage to keep beam stable

filling factor in momentum



filling factor should not exceed 0.8

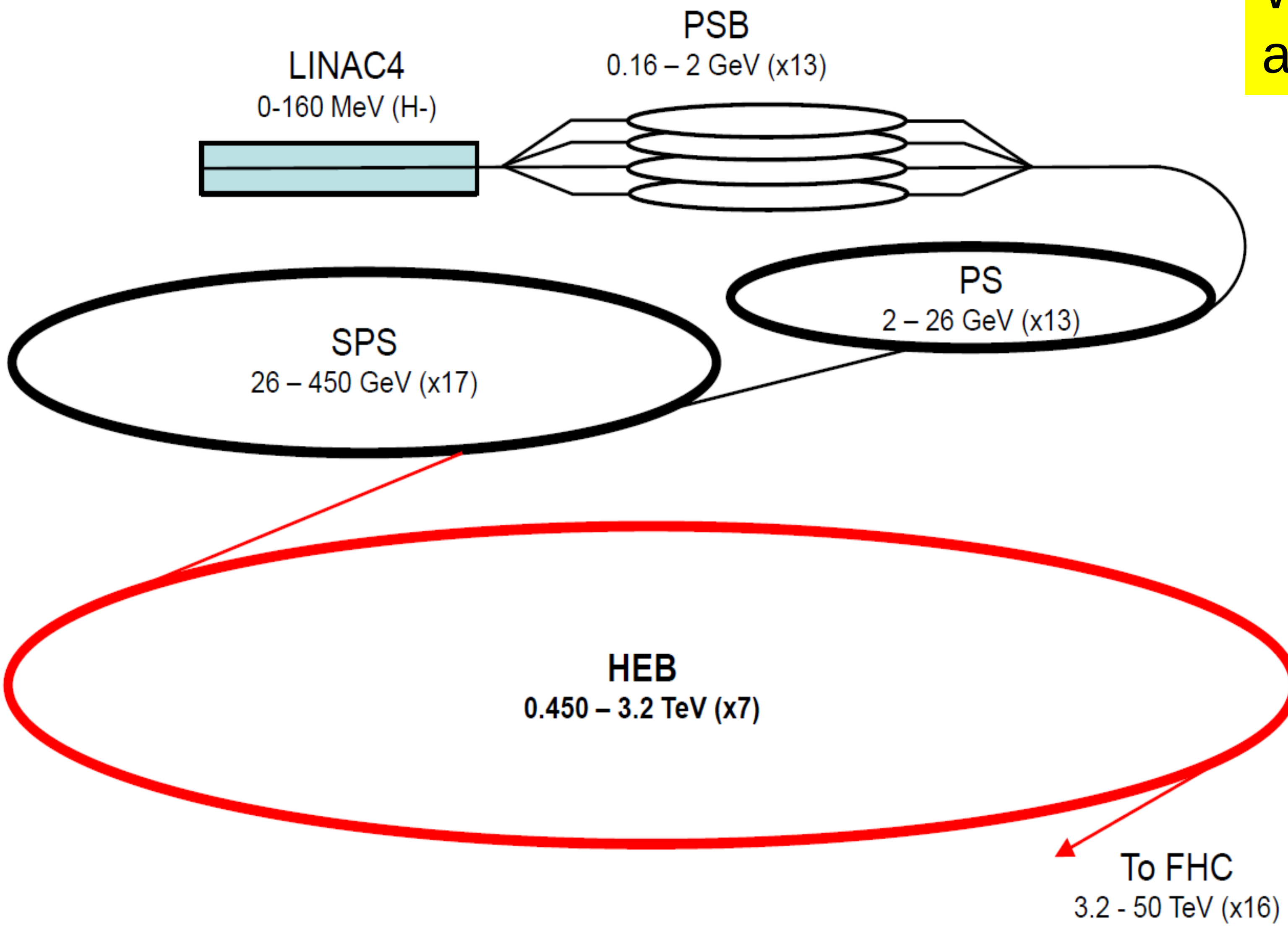
E. Shaposhnikova

FCC-hh injector complex

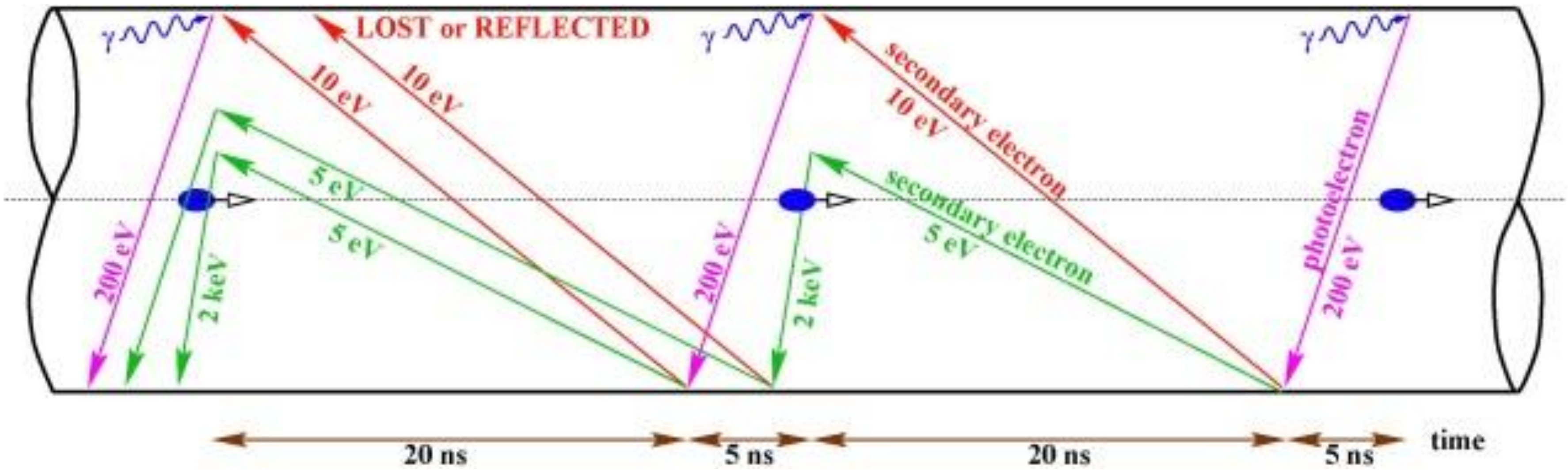
based on existing & planned (HL-LHC/LIU) injector chain;

HEB in LHC tunnel (e.g. modified LHC) or FCC tunnel

B. Goddard, W. Herr, et al.



electron cloud



schematic of e⁻ build up inside beam pipe with SR photons, emitted photoelectrons and secondary electrons. Horizontal axis is time. Electrons are accelerated in the field of passing bunches [Courtesy F. Ruggiero]

FCC-hh critical photon energy = 4.3 keV, similar to 2-3 GeV light sources, 100 x LHC

electron-cloud effects:
beam instabilities, emittance growth, heat load, …

e-cloud: δ_{max} threshold at injection

FCC injection

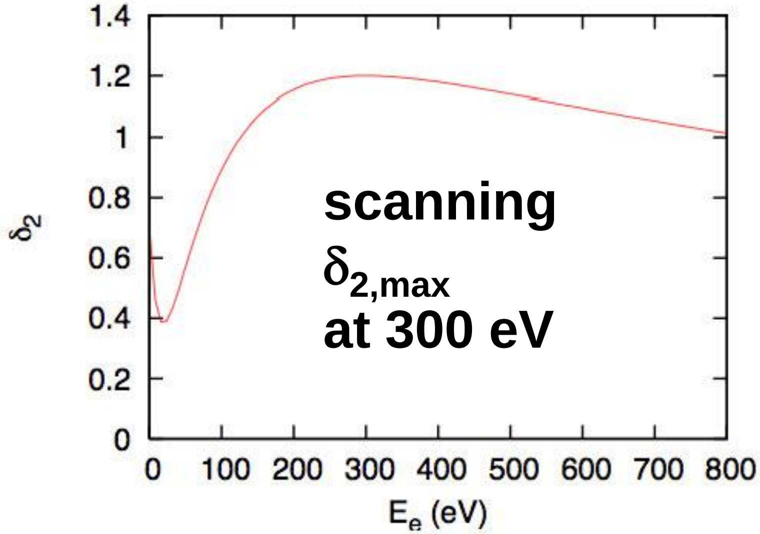
E_p=3.3 TeV, B=1 T

25 ns: $N_b=10^{11}$, ε=630 pm

5 ns: $N_b=2\times10^{10}$, ε=13 pm

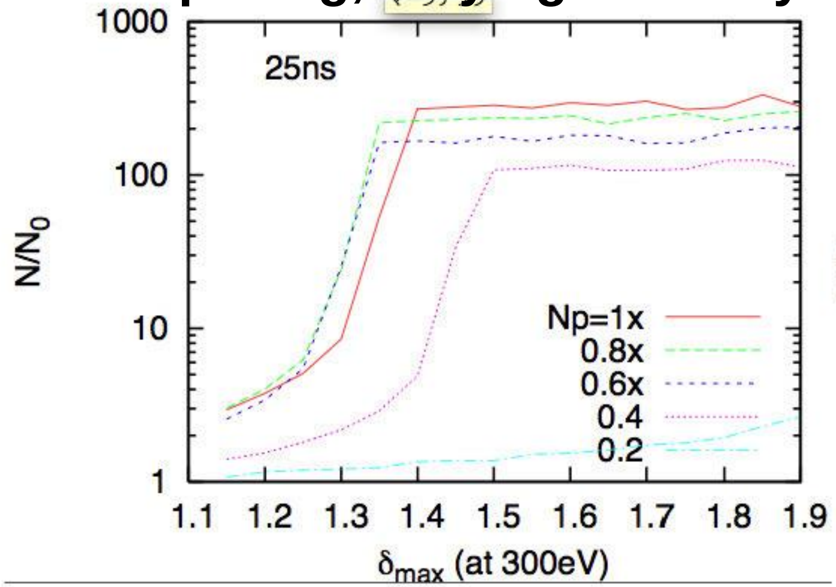
β=200 m,

σ_z=8 cm, R=1.3 cm

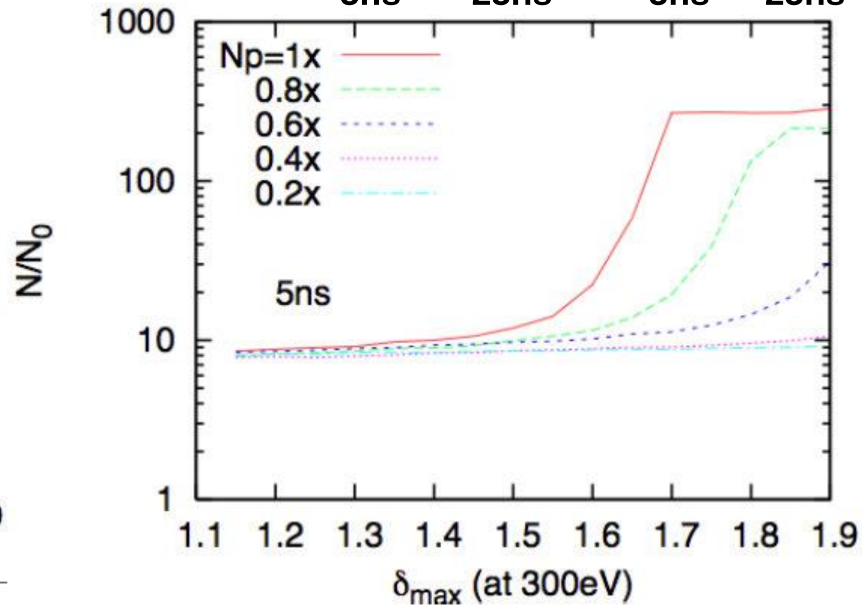


K. Ohmi,
O. Dominguez

25 ns spacing, varying intensity



5 ns, $N_{5ns}=N_{25ns}/5$, $\varepsilon_{5ns}=\varepsilon_{25ns}/5$

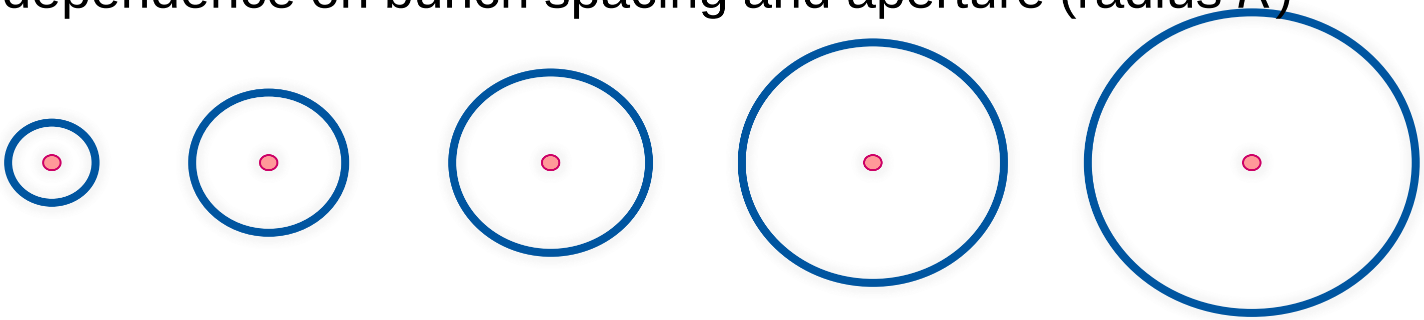


e-cloud in FCC-hh HEB: heat load

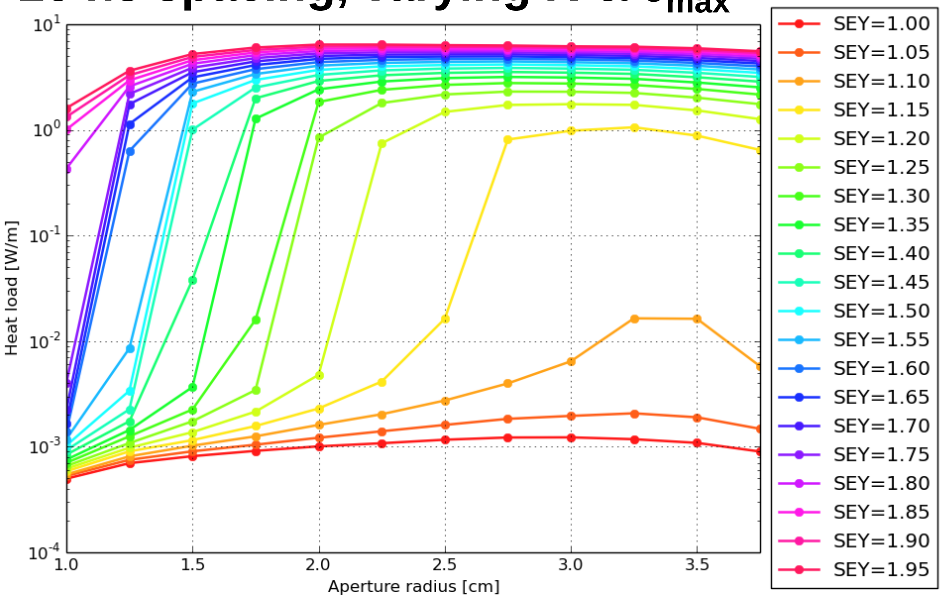
HEB injection 450 GeV

dependence on bunch spacing and aperture (radius *R*)

L. Mether,
G. Iadarola,
G. Rumolo

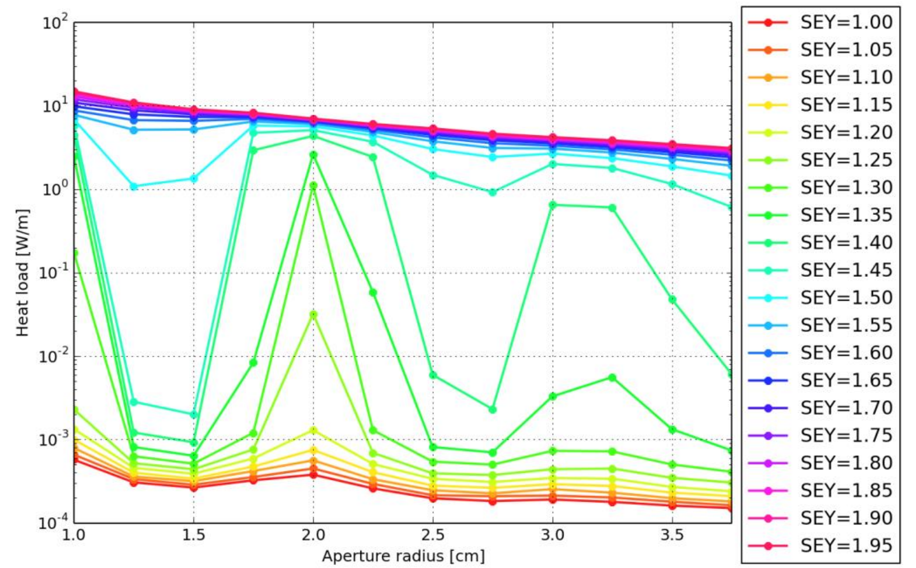


25 ns spacing, varying *R* & δ_{max}



heat load first increases with *R* and then decreases for large *R*

5 ns, $N_{5ns}=N_{25ns}/5$, varying *R* & δ_{max}



heat load decreases with growing *R*, but oscillates

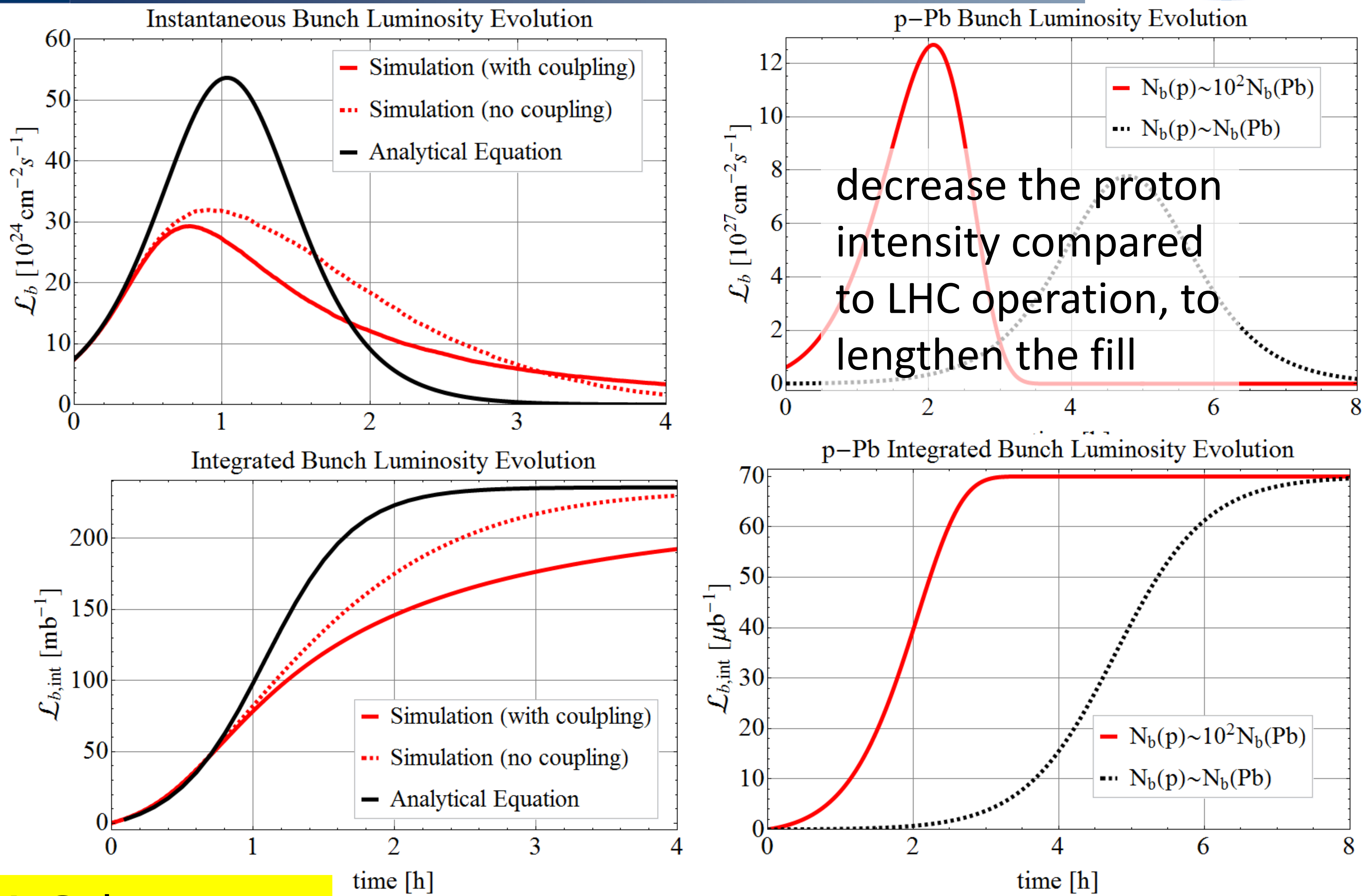
FCC-hh as heavy-ion collider

preliminary parameters

	Unit	LHC Design	FCC-hh	FCC-hh
operation mode	-	*Pb-Pb*	*Pb-Pb*	*p-Pb*
number of bunches		592	432	432
part. / bunch	[10^8]	0.7	1.4	115(1.4)/1.4
β-functionat IP	[m]	0.5	1.1	1.1
RMS beam size at IP	[um]	15.9	8.8	8.8
initial luminosity	[$10^{27}cm^{-2}s^{-1}$]	1	3.2	267(3.2)
peak luminosity	[$10^{27}cm^{-2}s^{-1}$]	1	12.7	5477(3356)
integr. lumi. per fill	[μb^{-1}]	<15	83	30240
total cross-section	[b]	515	597	2
initial luminosity lifetime	[h]	<5.6	3.7	3.2 (10.6)

M. Schaumann, J. Jowett

luminosity evolution for *Pb-Pb & p-Pb*



decrease the proton intensity compared to LHC operation, to lengthen the fill

M. Schaumann

physics requirements for *FCC-ee*

- highest possible luminosity for a wide physics program ranging from the *Z* pole to the $t\bar{t}$ production threshold
  - *beam energy range from 45 GeV to 175 GeV*
- main physics programs / energies:
  - *Z (45.5 GeV): Z pole, 'TeraZ' and high precision* M_Z & Γ_Z,
  - *W (80 GeV): W pair production threshold,*
  - *H (120 GeV): ZH production (maximum rate of H's),*
  - *t (175 GeV):* $t\bar{t}$ *threshold*
- some polarization up to ≥80 GeV for beam energy calibration
- optimized for operation at 120 GeV?!

parameter	LEP2	FCC-ee				
		Z	Z (c.w.)	W	H	t
E_{beam} [GeV]	104	**45**	**45**	**80**	**120**	**175**
circumference [km]	26.7	**100**	**100**	**100**	**100**	**100**
current [mA]	3.0	1450	1431	152	30	6.6
$P_{SR,tot}$ [MW]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
no. bunches	4	16700	29791	4490	1360	98
N_b [10^{11}]	4.2	1.8	1.0	0.7	0.46	1.4
ε_x [nm]	22	**29**	**0.14**	**3.3**	**0.94**	**2**
ε_y [pm]	250	**60**	**1**	**1**	**2**	**2**
β^*_x [m]	1.2	0.5	0.5	0.5	0.5	1.0
β^*_y [mm]	50	**1**	**1**	**1**	**1**	**1**
σ^*_y [nm]	3500	250	32	84	44	45
$\sigma_{z,SR}$ [mm]	**11.5**	**1.64**	**2.7**	**1.01**	**0.81**	**1.16**
$\sigma_{z,tot}$ [mm] (w beamstr.)	**11.5**	**2.56**	**5.9**	**1.49**	**1.17**	**1.49**
hourglass factor F_{hg}	0.99	0.64	0.94	0.79	0.80	0.73
L/IP [10^{34} $cm^{-2}s^{-1}$]	0.01	**28**	**212**	**12**	**6**	**1.7**
τ_{beam} [min]	434	**298**	**39**	**73**	**29**	**21**

the large number of bunches at *Z*, *W* & *H* requires 2 rings

FCC-ee baseline parameters defined in EDMS No. 1346081, FCC-ACC-SPC-0003 (Rev. 2.0)

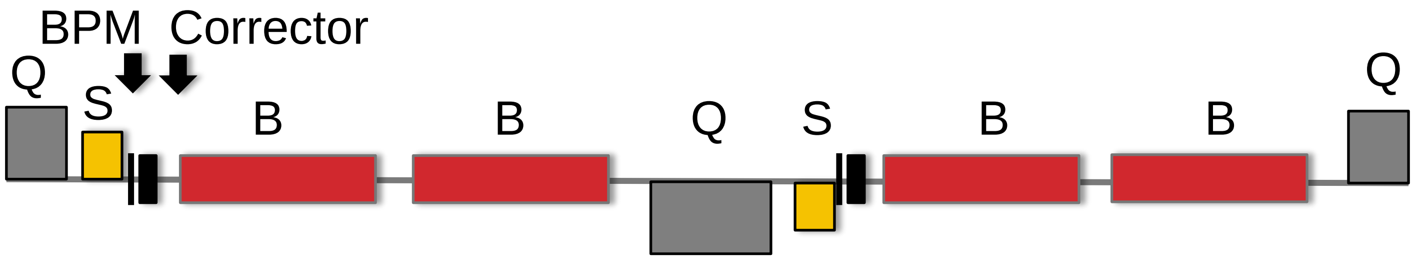
short lifetimes due to high luminosity
→ continuous injection (top-up)

layout & optics at 120 & 175 GeV

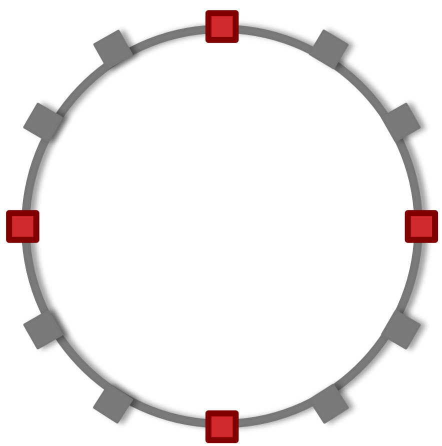
LATTICE V12B-S

arc cell

layout

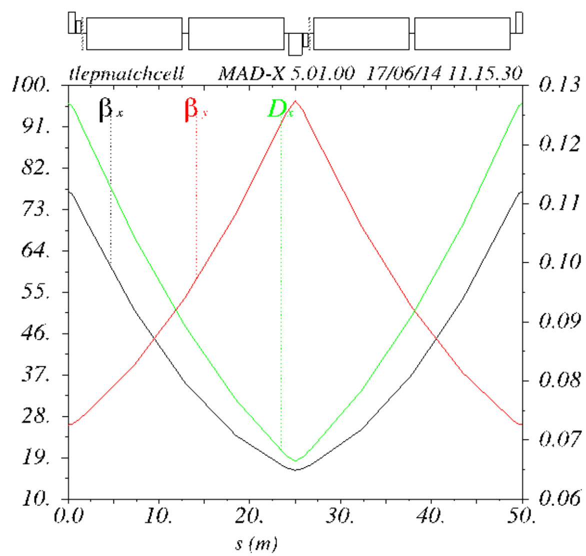


B = bending magnet, Q = quadrupole, S = sextupole

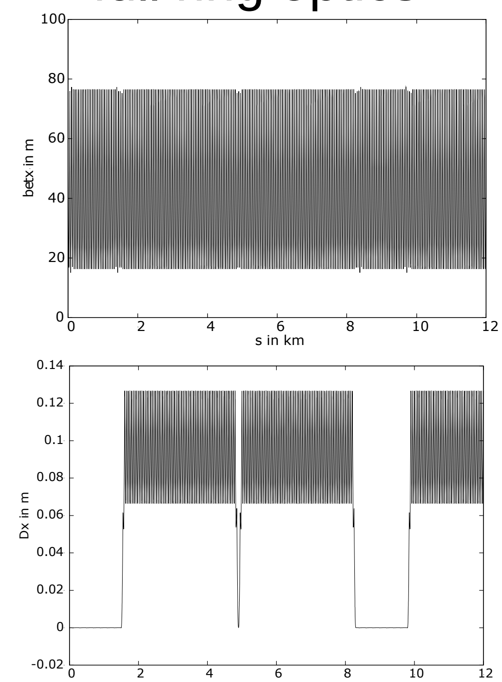


Circumference: 100 km
Arc length: 2 × 3.4 km
Straight section: 1.5 km

FODO cell optics
cell length 50 m



full ring optics



B. Harer, B. Holzer

optics 175 & 120 → 80 & 45.5 GeV

80 GeV

175 GeV and 120 GeV: L_{cell} = 50 m, Ψ = 90°/60°

Half-bend dispersion suppressor

80 GeV: L_{cell} = 50 m, Ψ = 45°/45°

Dispersion suppressor based on quadrupoles

80 GeV: L_{cell} = 100 m, Ψ = 90°/60°

- Arc cells
- Dispersion Suppressor
- Straight matching section (with RF)
- Straight cells (with RF)

45.5 GeV

175 GeV and 120 GeV: L_{cell} = 50 m, Ψ = 90°/60°

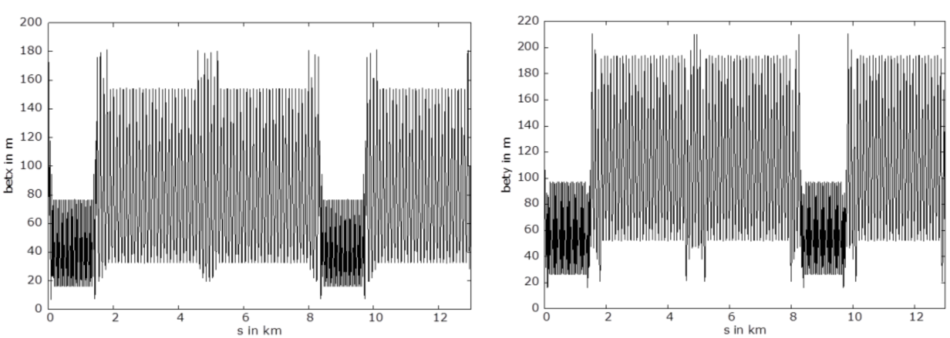
45.5 GeV: L_{cell} = 200 m, Ψ = 60°/60°

Dispersion suppressor based on quadrupoles

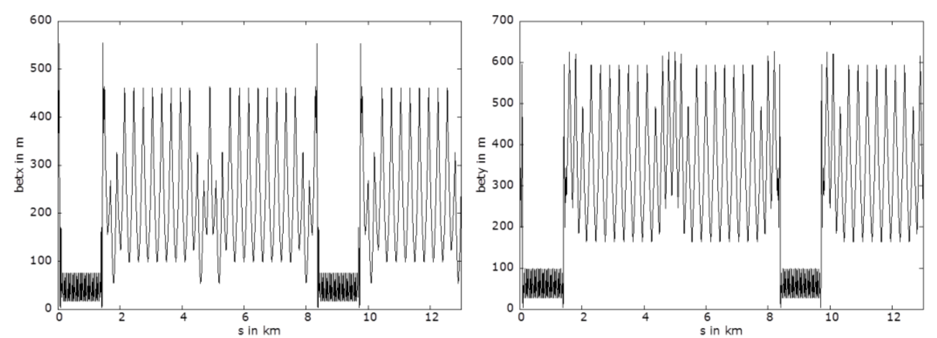
45.5 GeV: L_{cell} = 250 m, Ψ = 72°/72°

45.5 GeV: L_{cell} = 300 m, Ψ = 90°/60°

example: 100 m cell length



example: 300 m cell length



B. Harer, B. Holzer

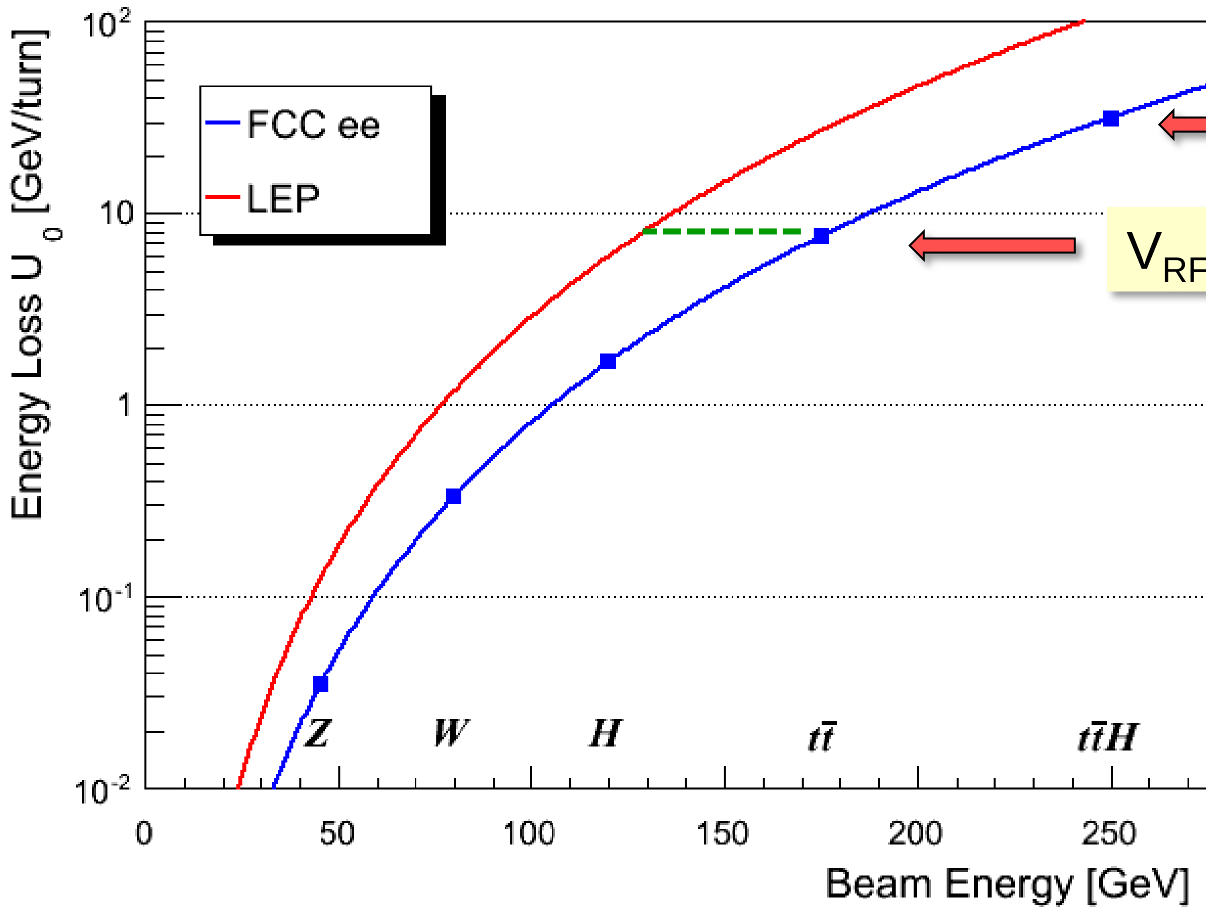
all emittances $\varepsilon_x \leq 0.5$ baseline

Synchrotron radiation power

The maximum synchrotron radiation (SR) power P_{SR} is set to **<u>50 MW per beam</u>** – design choice ⇔ power dissipation.

⇒ *defines the maximum beam current at each energy.*

Note that a margin of a few % is required for losses in straight sections.

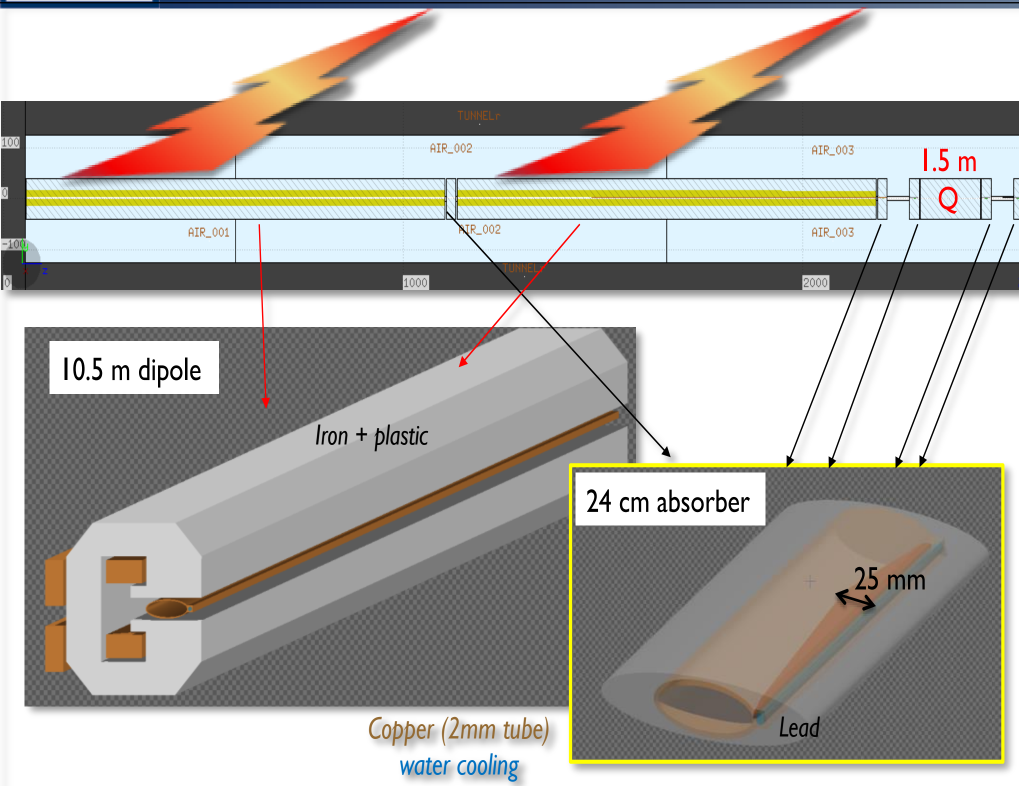


V_{RF} ~35 GV

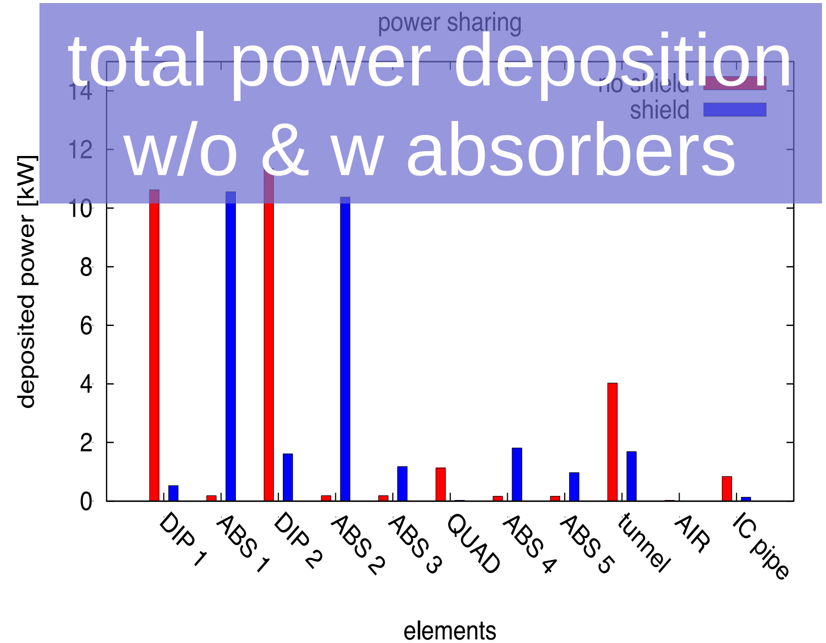
V_{RF} ~10-**<u>11</u>** GV

J.Wenninger

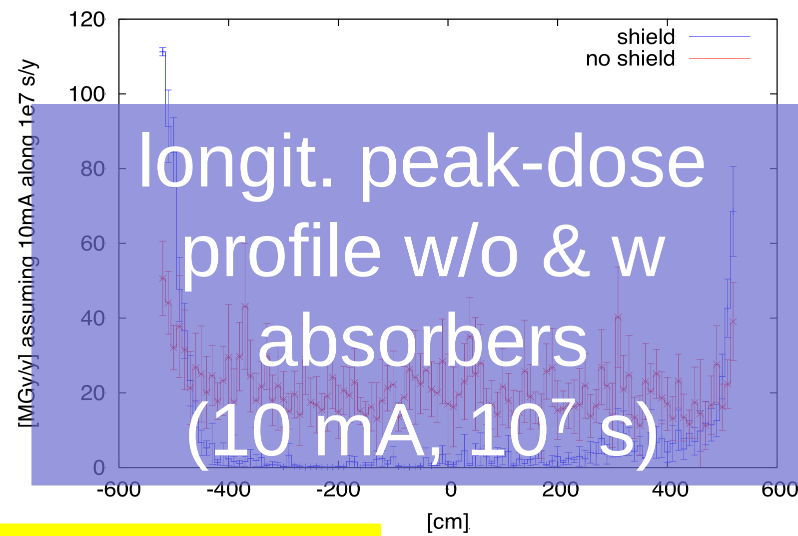
shielding 100 MW SR at 175 GeV



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



total power deposition w/o & w absorbers

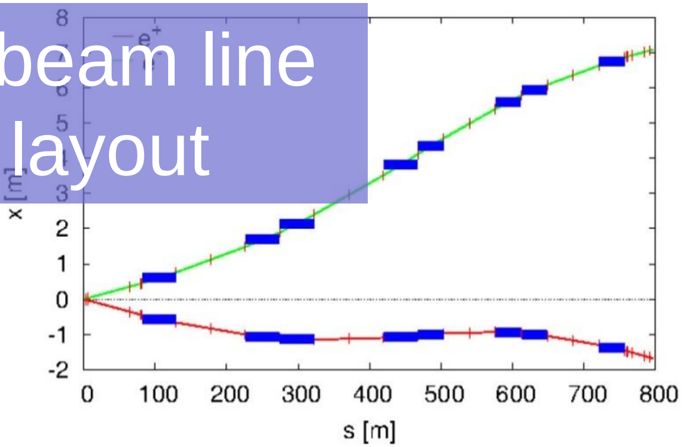


longit. peak-dose profile w/o & w absorbers (10 mA, 10^7 s)

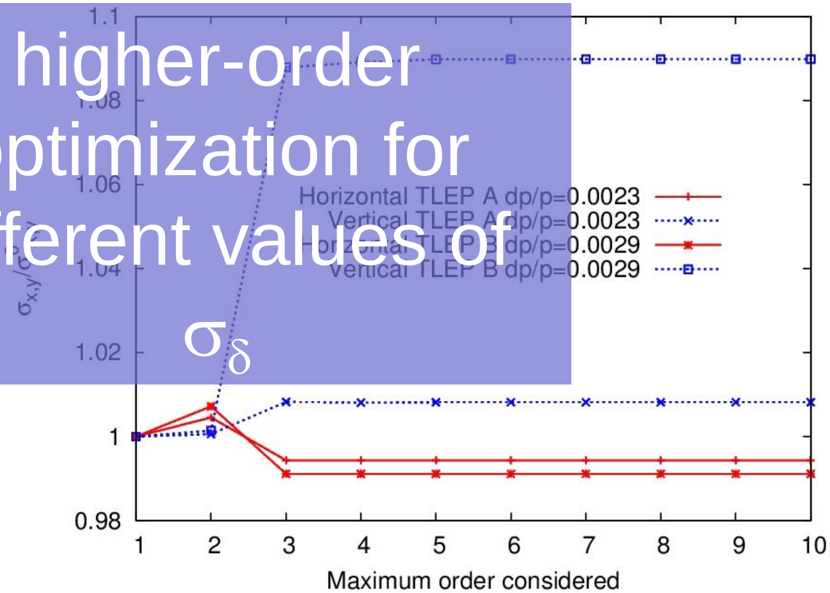
L. Lari, F. Cerutti, A. Ferrari, A. Mereghetti

FCC-ee IR design #1

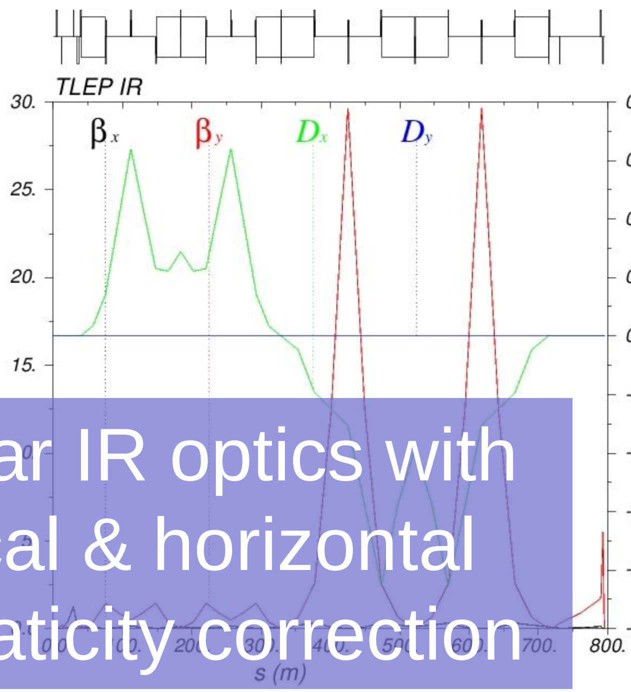
e± beam line layout



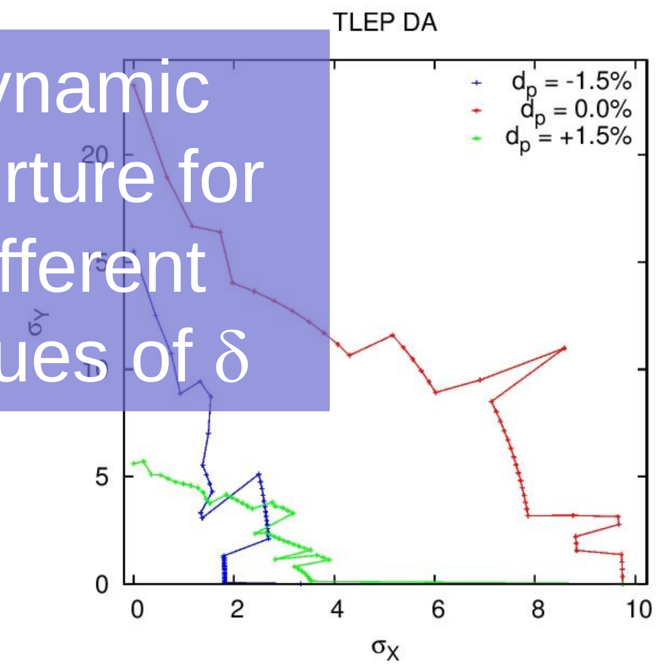
higher-order optimization for different values of σ_δ



modular IR optics with vertical & horizontal chromaticity correction

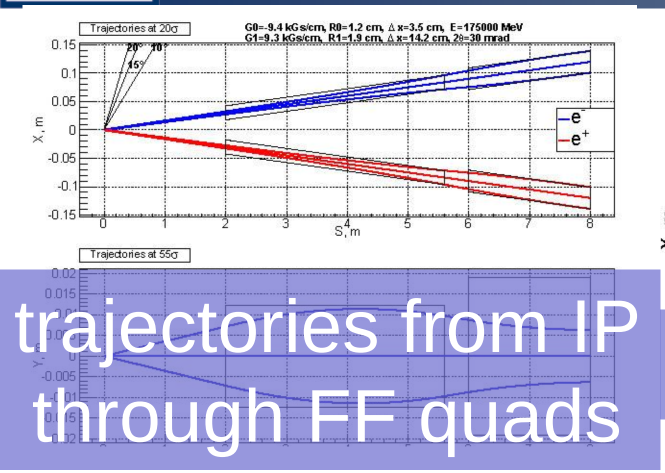


dynamic aperture for different values of δ

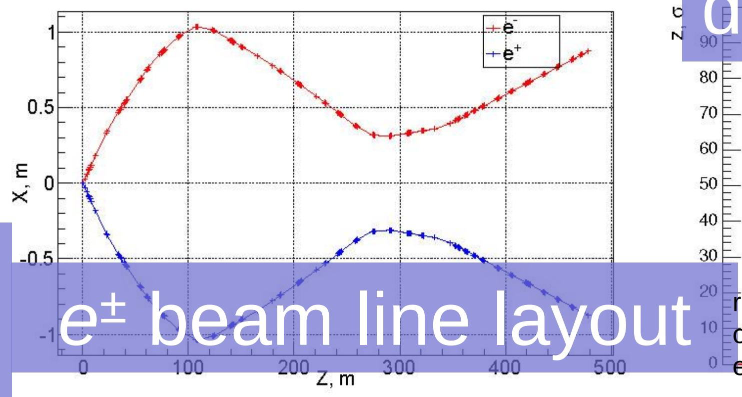


H. Garcia, L. Medina, R. Tomas

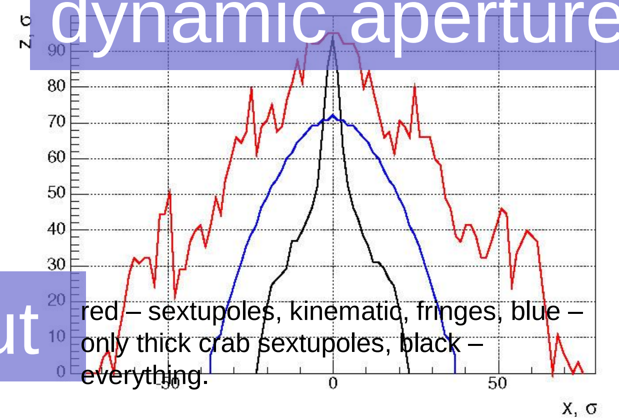
FCC-ee IR design #2



trajectories from IP through FF quads

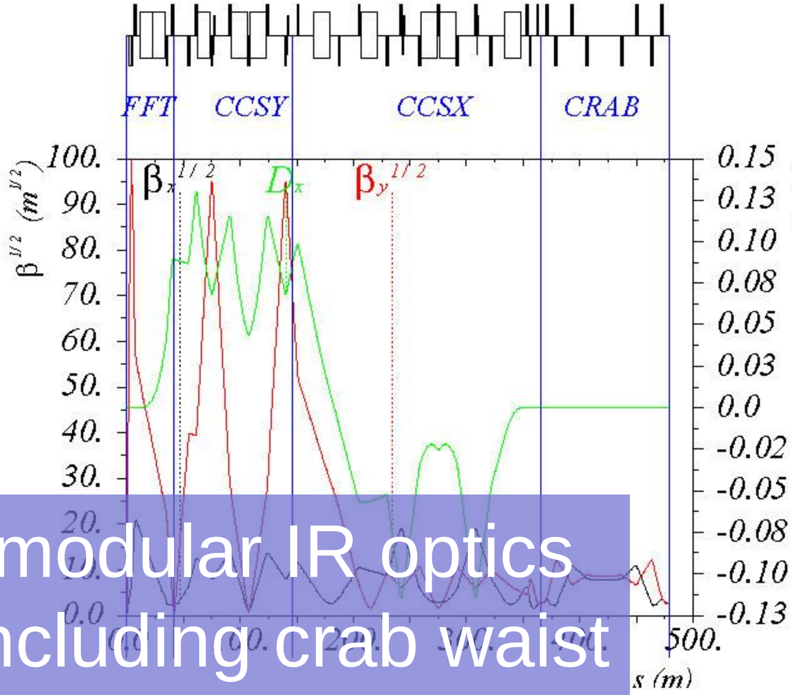


e± beam line layout

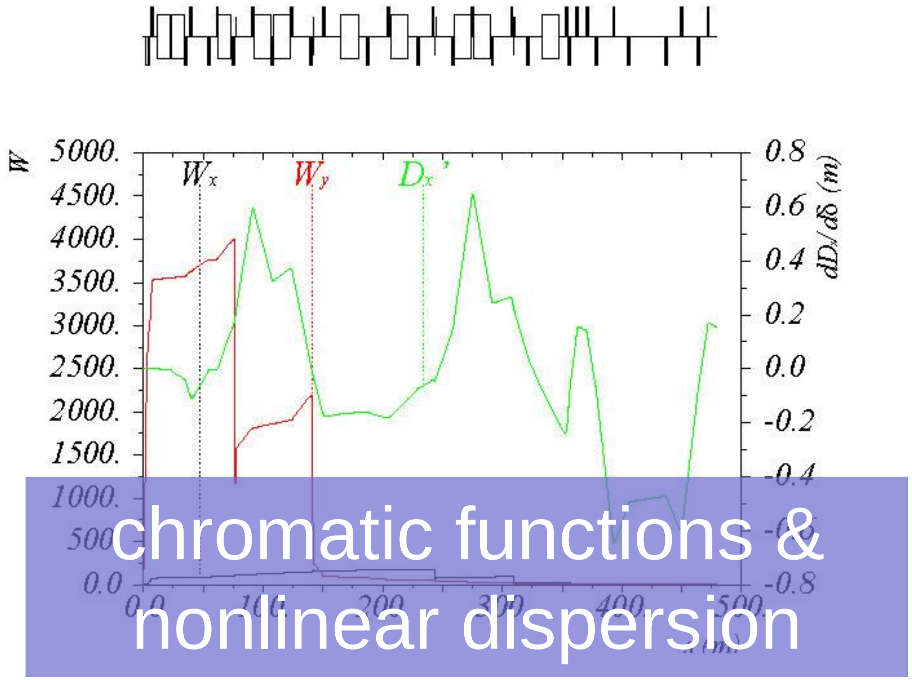


dynamic aperture

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

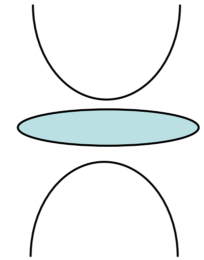
luminosity

$$e\, f\, k\, N = \text{beam current} \propto \frac{1}{E^4}$$

$$L = \frac{f\, k\, N^2}{4\pi\sigma_x\sigma_y} F\, H$$

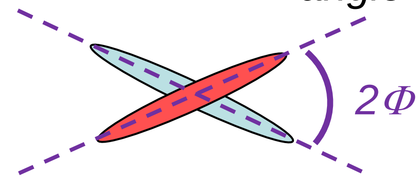
H ≤ 1

Hour-glass



F ≤ 1

Crossing angle



$$\xi_y \propto \frac{\beta_y^* N}{E\sigma_x\sigma_y} \le \xi_y^{\max}(E)$$

Beam-beam parameter

$$L \propto \frac{P_{SR}}{E^3}\frac{\xi_y}{\beta_y^*}$$

σ = beam size

k = no. bunches

f = rev. frequency

N = bunch population

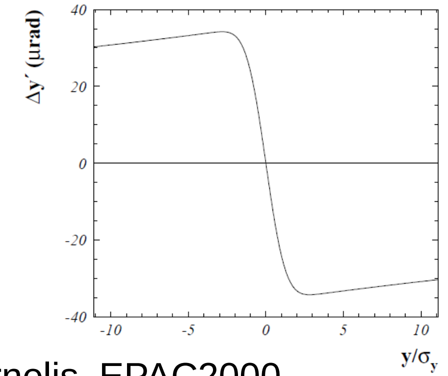
P_{SR} = synch. rad. power

β^* = betatron fct at IP (beam envelope)

J. Wenninger

beam-beam parameter

- beam-beam parameter ξ measures strength of field sensed by the particles in a collision
- beam-beam parameter limits are empirically scaled from LEP data (also 4 IPs)

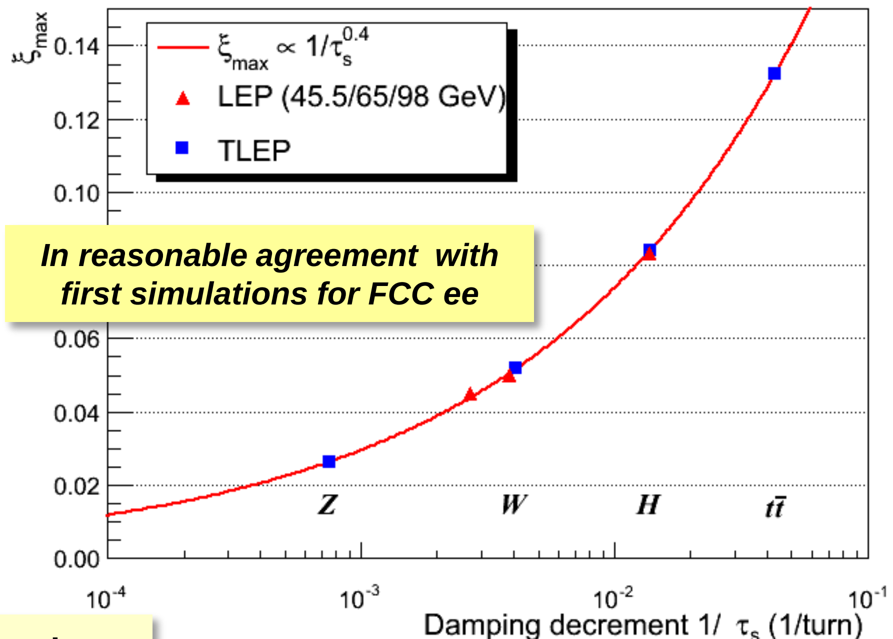


$$\xi_y \propto \frac{\beta_y^* N}{E\sigma_x\sigma_y} \leq \xi_y^{\max}(E)$$

$$\xi_y^{\max}(E) \propto \frac{1}{\tau_s^{0.4}} \propto E^{1.2}$$

$$L \propto \frac{P_{SR}}{E^{1.8}} \frac{1}{\beta_y^*}$$

R. Assmann & K. Cornelis, EPAC2000



In reasonable agreement with first simulations for FCC ee

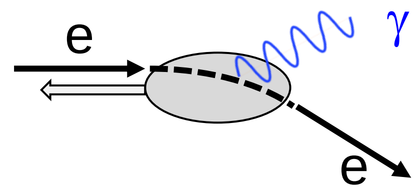
The beam-beam limit may be raised significantly with Crab-Waist schemes !

J. Wenninger, R. Assmann, S. White, K. Ohmi, D. Shatilov, et al.

beamstrahlung

- hard photon emission at the IPs, '*Beamstrahlung*', can become lifetime / performance limit for large bunch populations (N), small hor. beam size (σ_x) & short bunches (σ_s)

$$\tau_{bs} \propto \frac{\rho^{3/2}\sqrt{\eta}}{\sigma_s} \exp(A\eta\rho) \qquad \frac{1}{\rho} \approx \frac{N r_e}{\gamma \sigma_x \sigma_s}$$



ρ *: mean bending radius at the IP (in the field of the opposing bunch)*

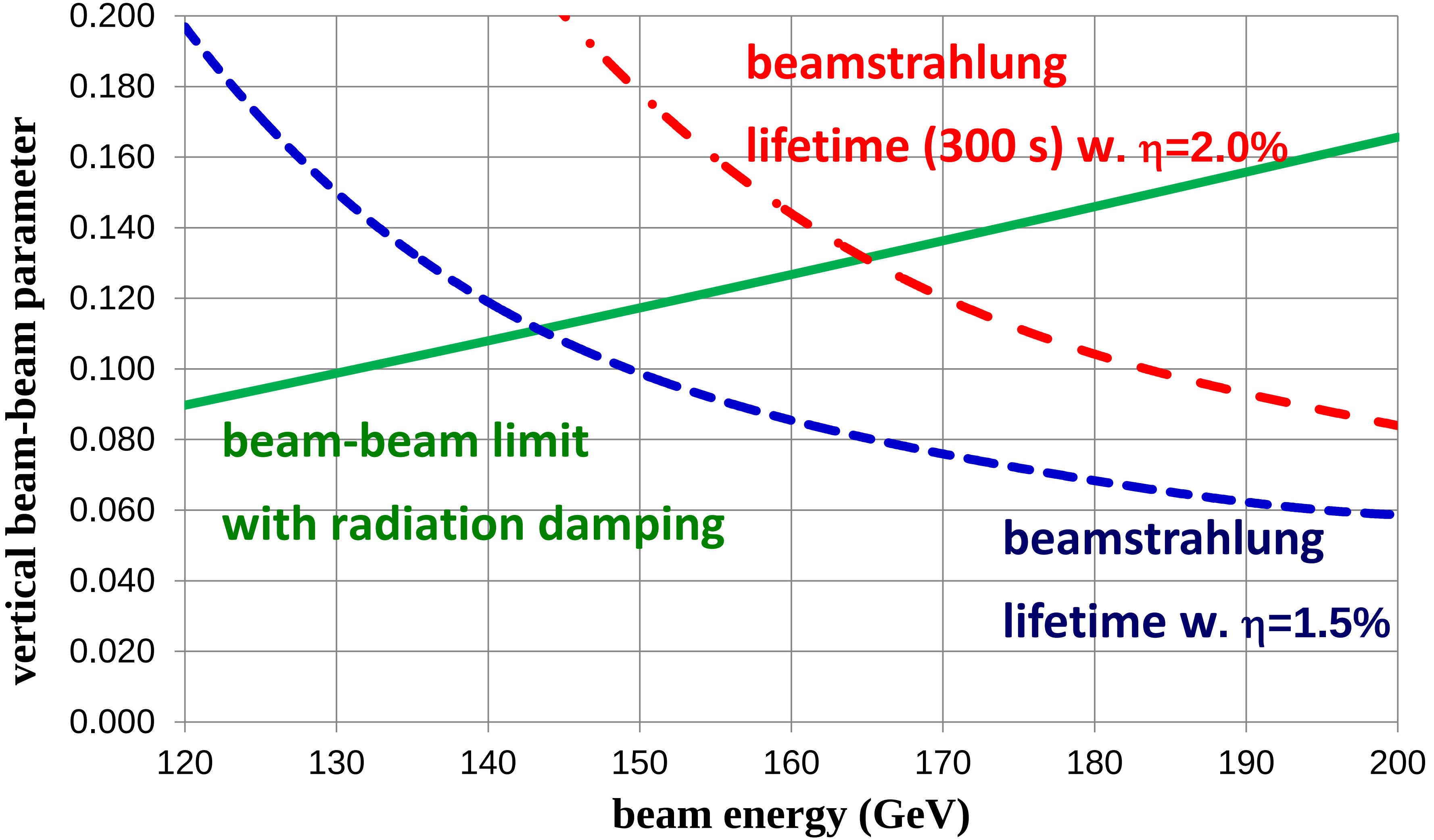
η : ring energy acceptance

lifetime expression by V. Telnov, modified version by A. Bogomyagkov et al

- to ensure an acceptable lifetime, ρ×η must be sufficiently large
  - *flat beams (large σ_x) !*
  - *bunch length !*
  - *large momentum acceptance of the lattice: **1.5 – 2% required**.*
    - LEP: < 1% acceptance, SuperKEKB ~ 1-1.5%.

J. Wenninger, et al

beam-beam limits: 2 regimes

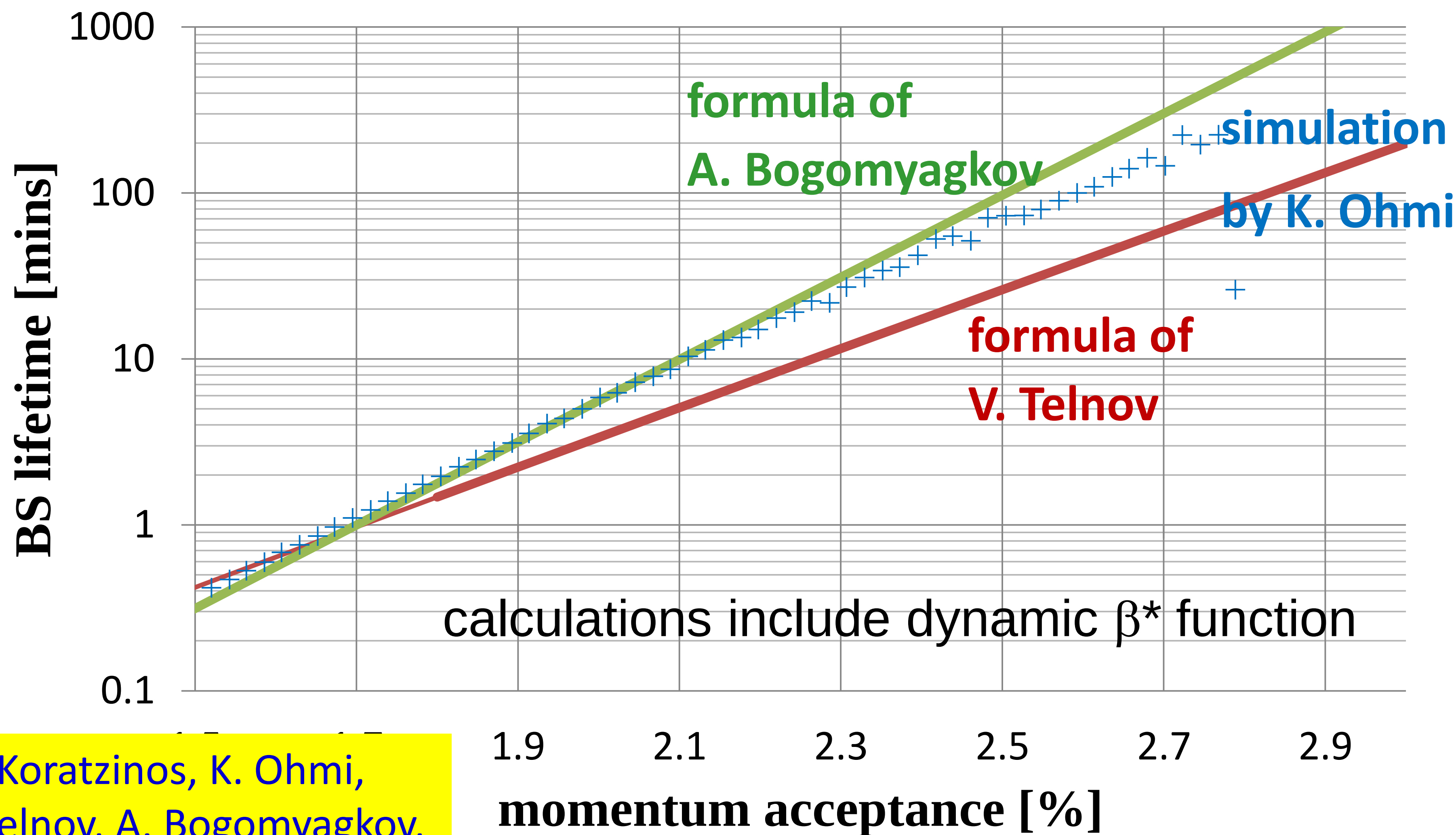


ε_y = 2 pm,
β_y^* = 1 mm

M. Koratzinos, A. Bogomyagkov, E. Levichev, D. Shatilov, K. Yokoya, V. Telnov, K. Oide, …

beamstrahlung lifetime

FCC-ee, E_{beam} =175 GeV (most critical case)



M. Koratzinos, K. Ohmi,
V. Telnov, A. Bogomyagkov,
E. Levichev, D. Shatilov

IR parameters

smallest possible β* desired; target β^*_y = **<u>1 mm</u>**; so small a value of β* requires local chromaticity correction

- *design inspired by linear collider IR;*
- *additional complexity that beam does not pass the IR only once → effects of optical aberrations critical*
- *bending magnets close to the IP → SR fan !*

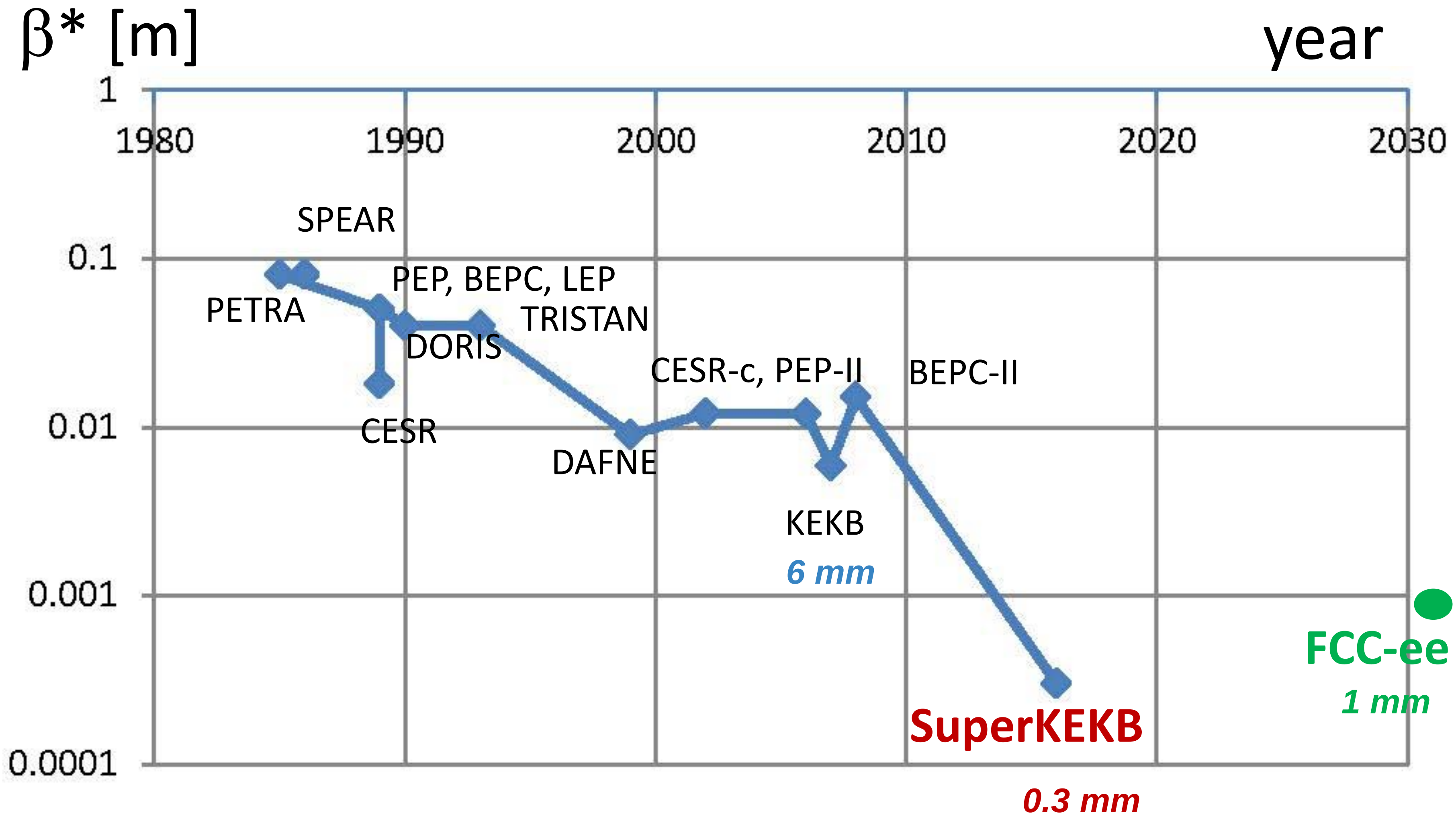
distance between IP and front-face of first quadrupole currently set to **L* ≥ 2 m** (SuperKEKB ~1 m)

- *detector acceptance, luminosity measurement,… .*

combination of very small β_y* and required large energy acceptance is challenge for optics design !

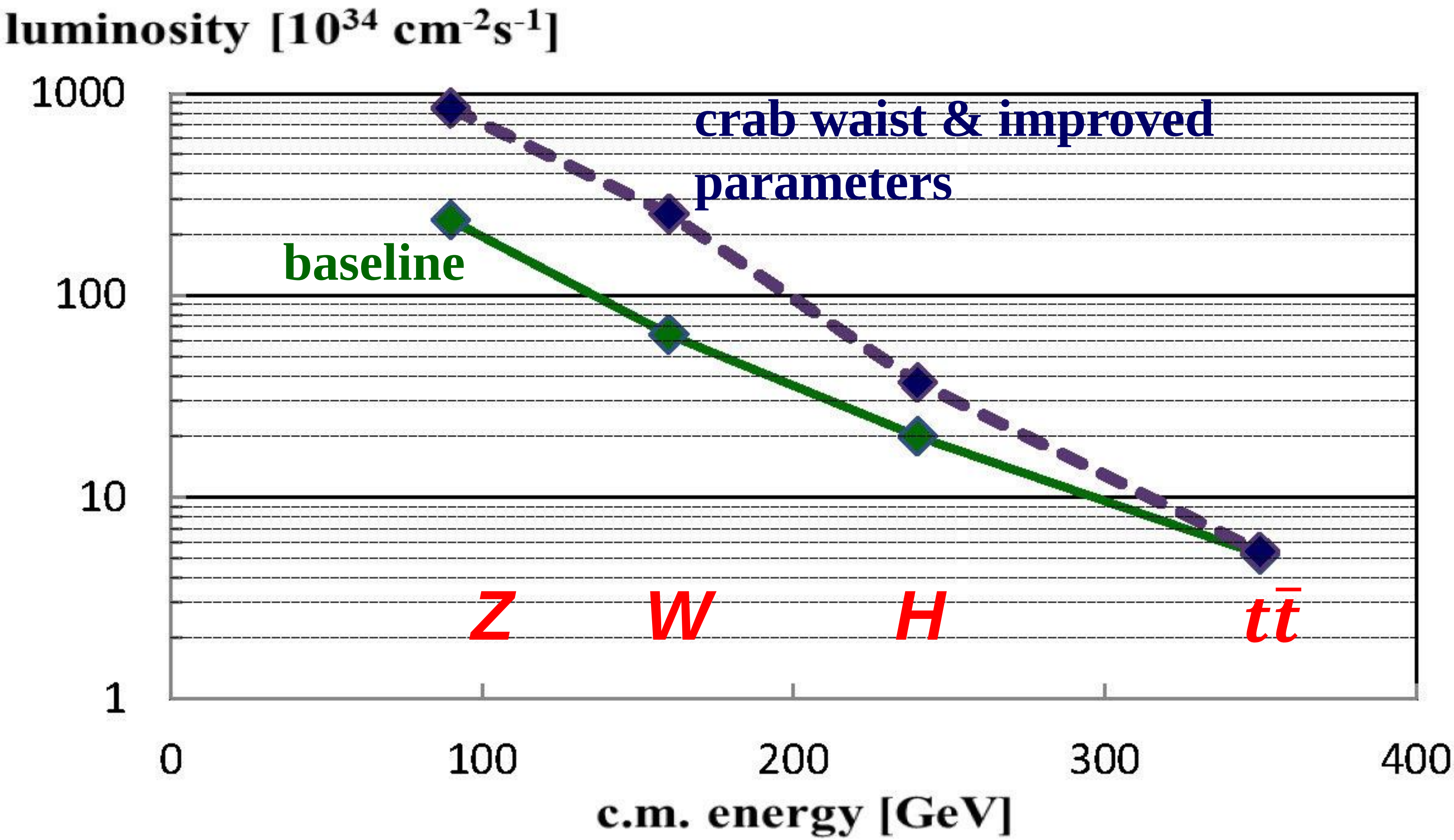
J. Wenninger, R. Tomas,…

β* evolution



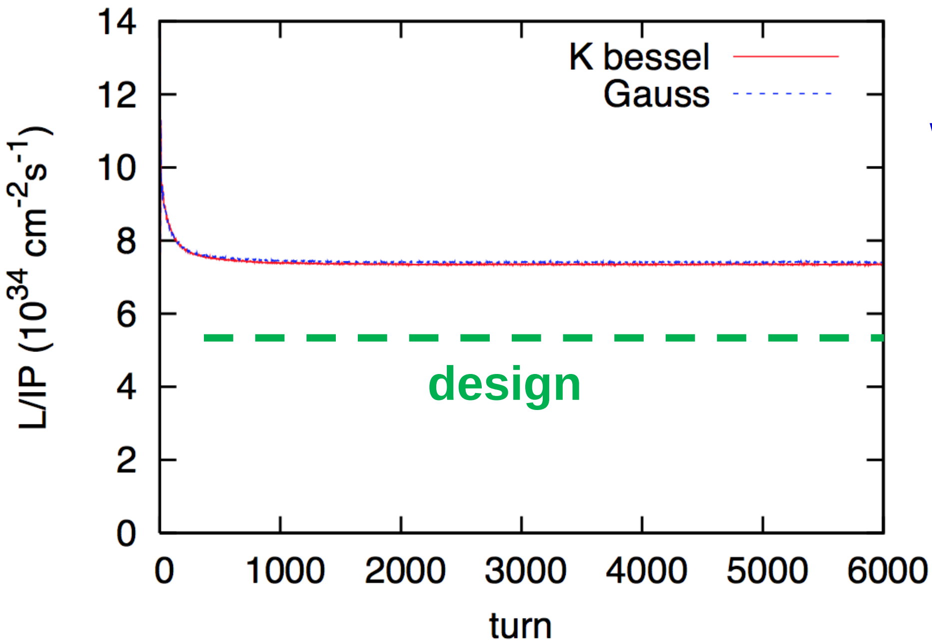
SuperKEKB will be an *FCC-ee* demonstrator for certain optics aspects !

FCC-ee luminosity vs energy



A. Bogomyagkov, E. Levichev, D. Shatilov

beam-beam performance checks

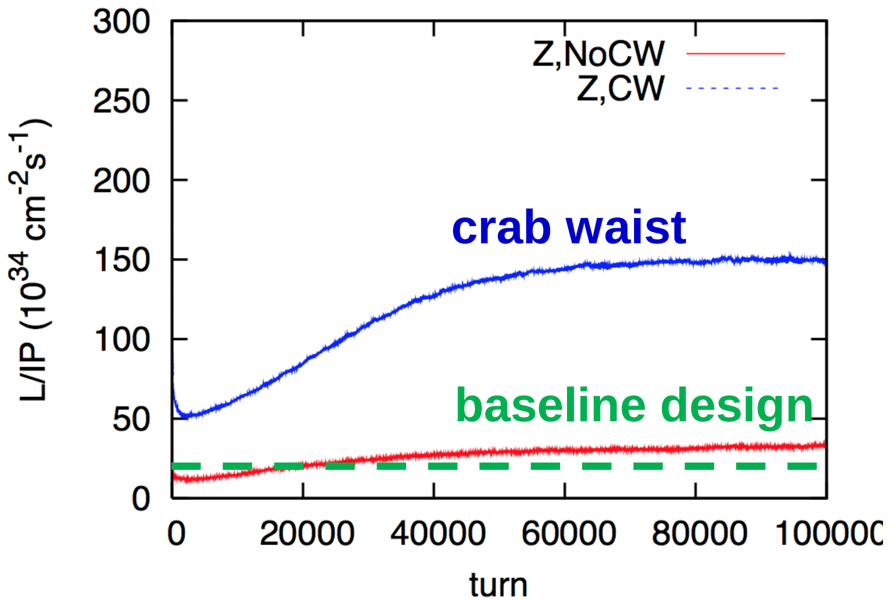


BBSS strong-strong simulation
w beamstrahlung

FCC-ee in Higgs production mode (240 GeV c.m.):
$L \approx 7.5\times10^{34}$ cm^{-2}s^{-1} per IP

BBWS weak-strong simulation
w beamstrahlung

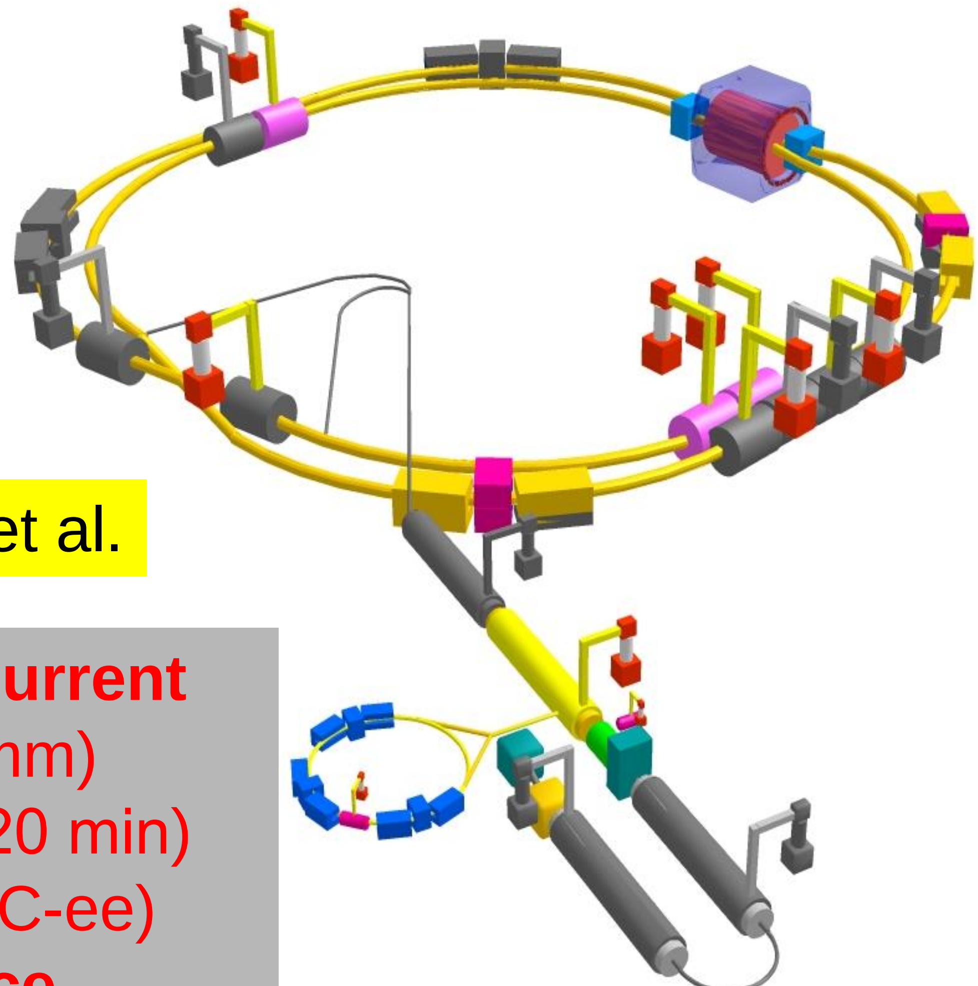
FCC-ee in crab-waist mode at the Z pole (91 GeV c.m.):
$L \approx 1.5\times10^{36}$ cm^{-2}s^{-1} per IP



K. Ohmi, A. Bogomyagkov, E. Levichev, P. Piminov

SuperKEKB = *FCC-ee* demonstrator

beam commissioning will start in 2015



K. Oide et al.

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

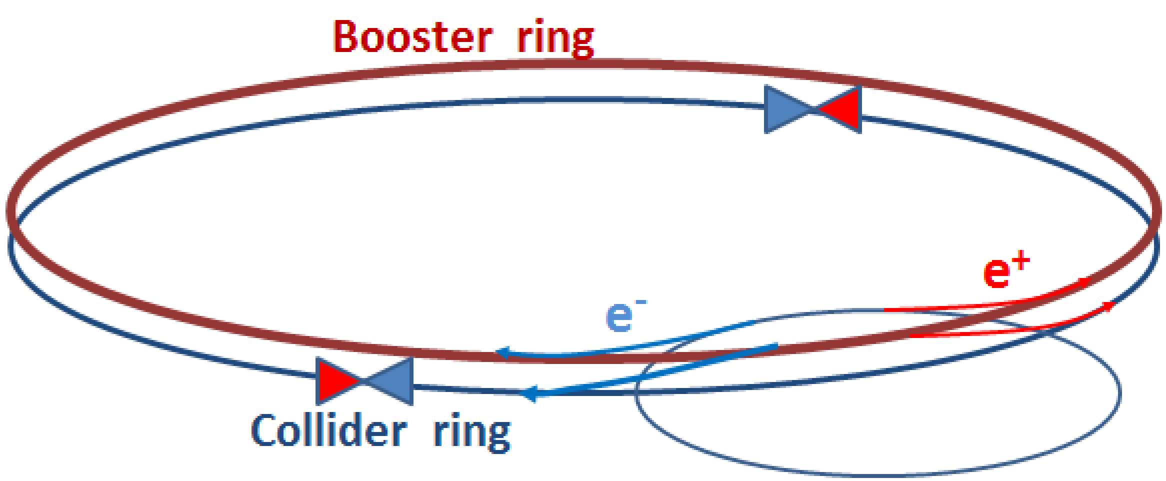
FCC-ee injection

beside the collider ring(s), a booster of the same size (same tunnel) must provide beams for top-up injection

- same size of RF system, but low power (~ MW)
- top up frequency ~0.1 Hz
- booster injection energy ~20 GeV
- bypass around the experiments

injector complex for e^+ and e^- beams of 10-20 GeV

- Super-KEKB injector ~ almost suitable



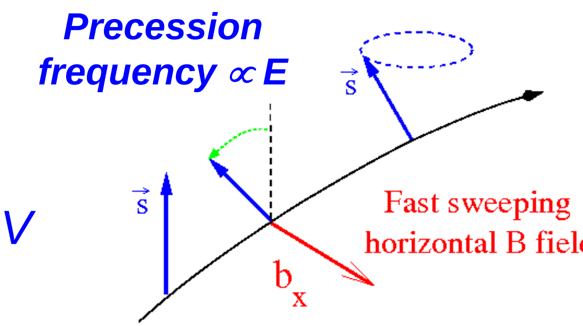
A. Blondel

polarization

two primary interests:

accurate energy calibration using resonant depolarization ⇒ measurement of M_Z, Γ_Z, M_W

- *nice feature of circular machines, δM_Z, $\delta\Gamma_Z$ ~ 0.1 MeV*



physics with longitudinally polarized beams

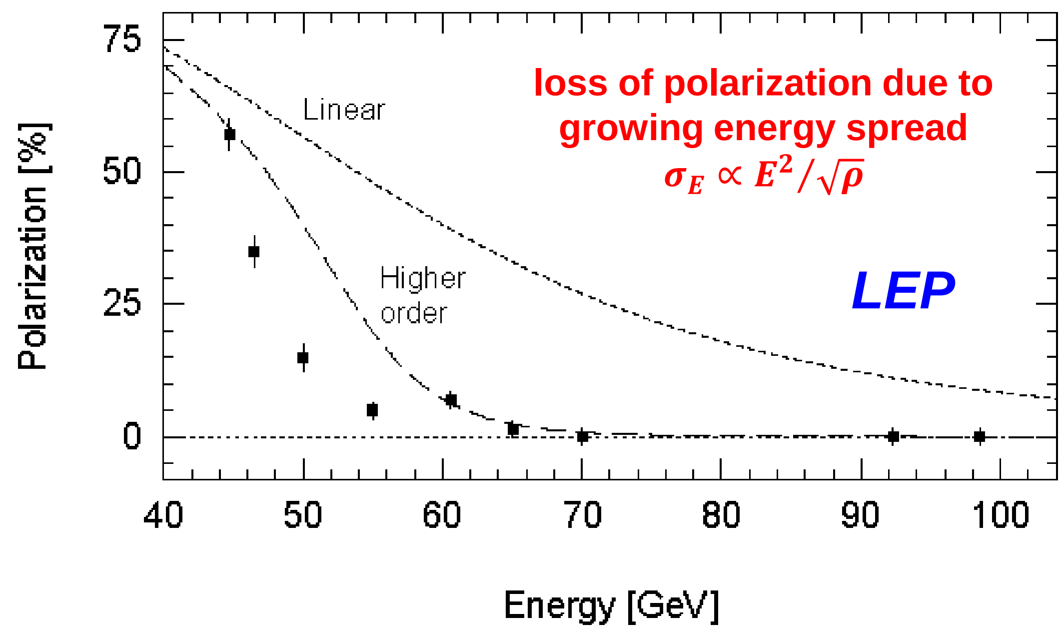
- *transverse polarization must be rotated in the longitudinal plane using spin rotators (see e.g. HERA)*

scaling from LEP observations :

polarization expected up to the WW threshold !

integer spin resonances are spaced by 440 MeV:

energy spread should remain below ~ 60 MeV



A. Blondel, S. Mane, U. Wienands, J. Wenninger, et al.

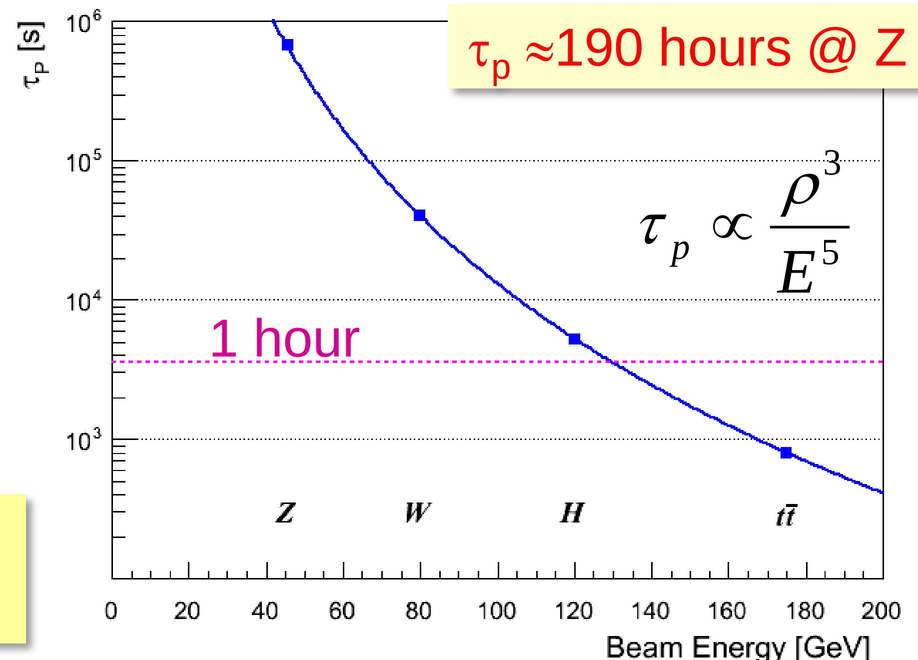
polarization build up

transverse polarization build-up (Sokolov-Ternov) is slow at *FCC-ee* (large bending radius ρ)

build-up is ~40 times slower than at LEP

wigglers may lower τ_p to ~12 h, limited by $\sigma_E \leq$ 60 MeV and power

due to power loss the wigglers can only be used to pre-polarize some bunches (before main injection)



≈ OK for energy calibration (few % P sufficient)

<u>longitudinal polarization</u>: levels of ≥ 40% required on both beams; excellent resonant compensation needed

expected to be difficult, requires spin rotators or snakes, most likely only possible at lower intensity and luminosity

SLIM, PETROS, SITF simulations being prepared

E. Gianfelice

A. Blondel, U. Wienands, J. Jowett, R. Rossmanith, J.Wenninger

physics requirements for *FCC-he*

- $e^{\pm}$-proton & $e^{\pm}$ - ion collisions at high energy + high luminosity
  - *$e^{\pm}$-beam energy range from 50 GeV to ≥120 GeV*

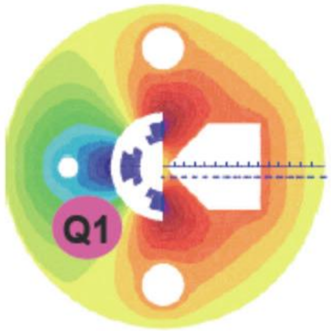
- main physics energies (tentative):
  - *60 GeV $e^{\pm}$ high luminosity, polarization*
  - *120 GeV $e^{\pm}$ high energy, still decent luminosity*

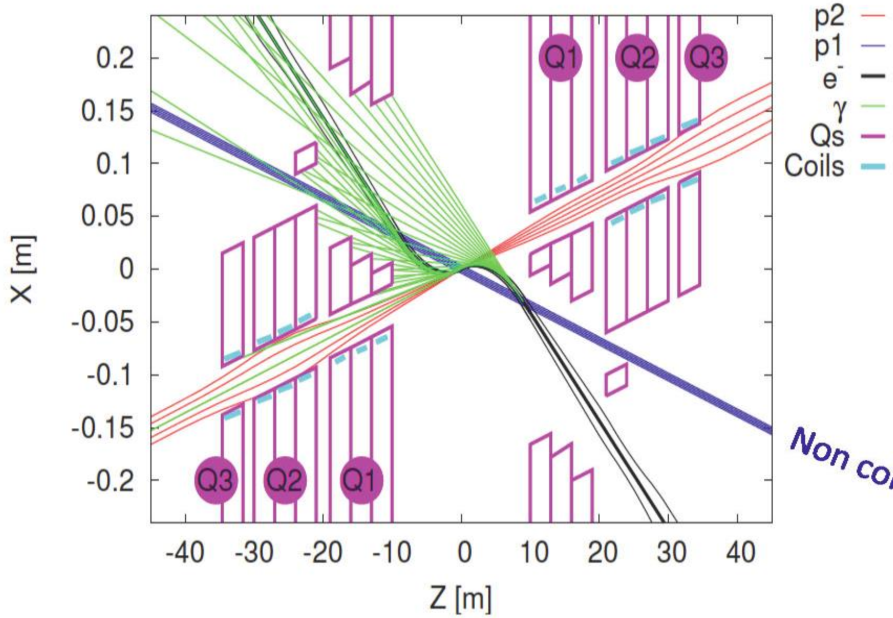
- ring-ring (based on *FCC-ee*) and ERL-ring options
  - ERL limited to about 60 GeV

collider parameters	FCC ERL	FCC-ee ring		protons
species	e^- (e^+?)	$e^{\pm}$	$e^{\pm}$	p
beam energy [GeV]	60	60	120	50000
bunches / beam	-	10600	1360	10600
bunch intensity [10^{11}]	0.05	0.94	0.46	1.0
beam current [mA]	25.6	480	30	500
rms bunch length [cm]	0.02	0.15	0.12	8
rms emittance [nm]	0.17	1.9 (x)	0.94 (x)	0.04 [0.02 y]
$\beta_{x,y}$*[mm]	94	8, 4	17, 8.5	400 [200 y]
$\sigma_{x,y}$* [μm]	4.0	4.0, 2.0		equal
beam-b. parameter ξ	(D=2)	**0.13**	**0.13**	0.022 (0.0002)
hourglass reduction	0.92 (H_D=1.35)	**~0.21**	~0.39	
CM energy [TeV]	3.5	3.5	4.9	
luminosity[$10^{34}cm^{-2}s^{-1}$]	**1.0**	**6.2**	**0.7**	

preliminary FCC-he parameters shown at ICHEP'14

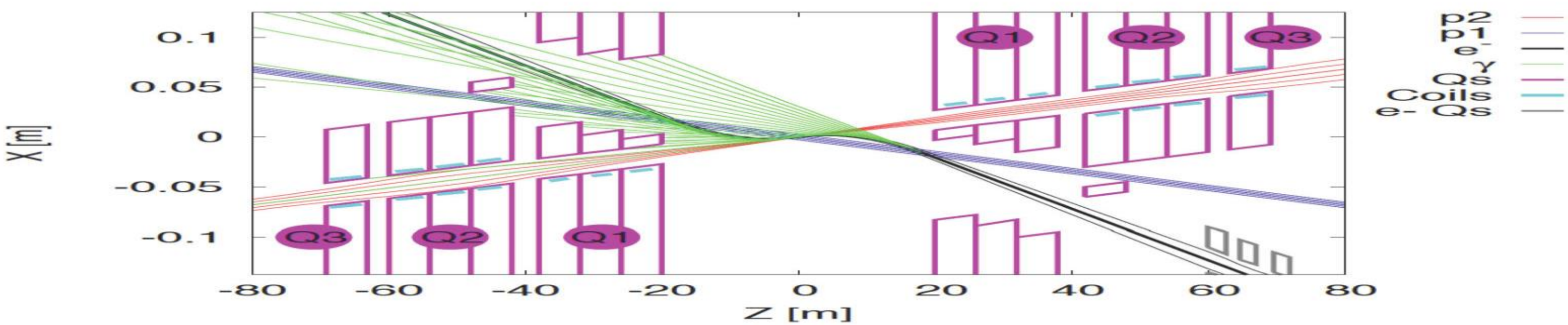
eh IR with parallel *pp* operation





LHeC (CDR)
60 GeV * 7 TeV

Still work in progress: may not need half quad if L*(e) < L*(p)



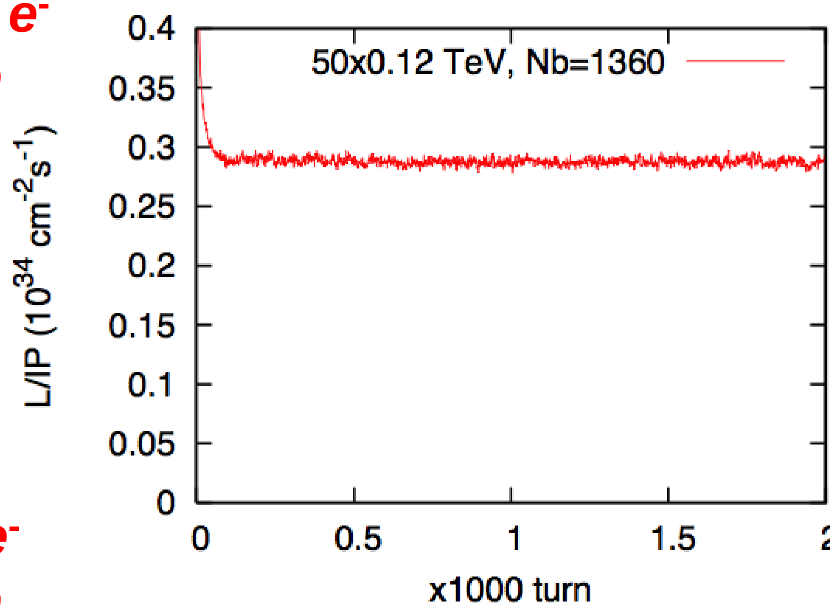
Tentative: ε_p=2µm, β*=20cm → σ_p=3µm ≈σ_e matched! ε_e=5µm ..

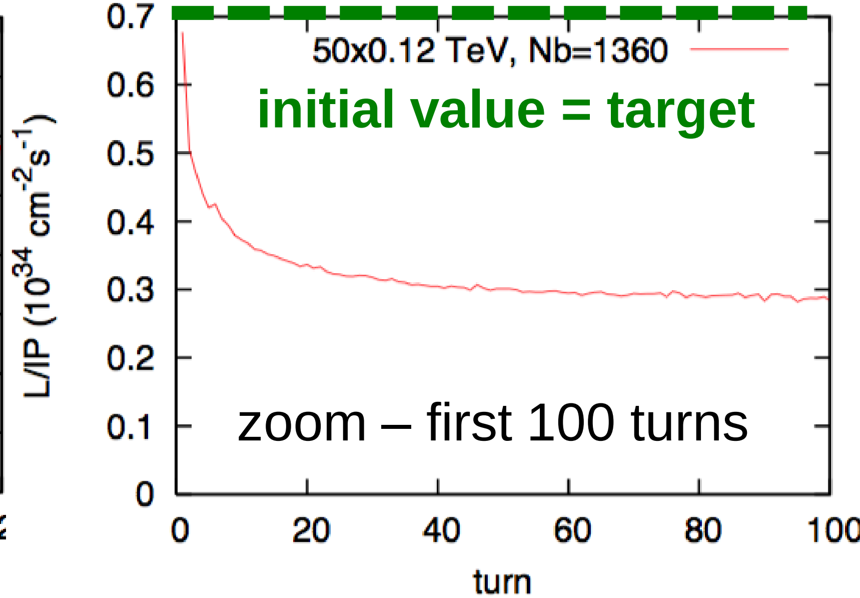
FCC-he (ERL)
60 GeV * 50 TeV

R. Tomas, M. Klein

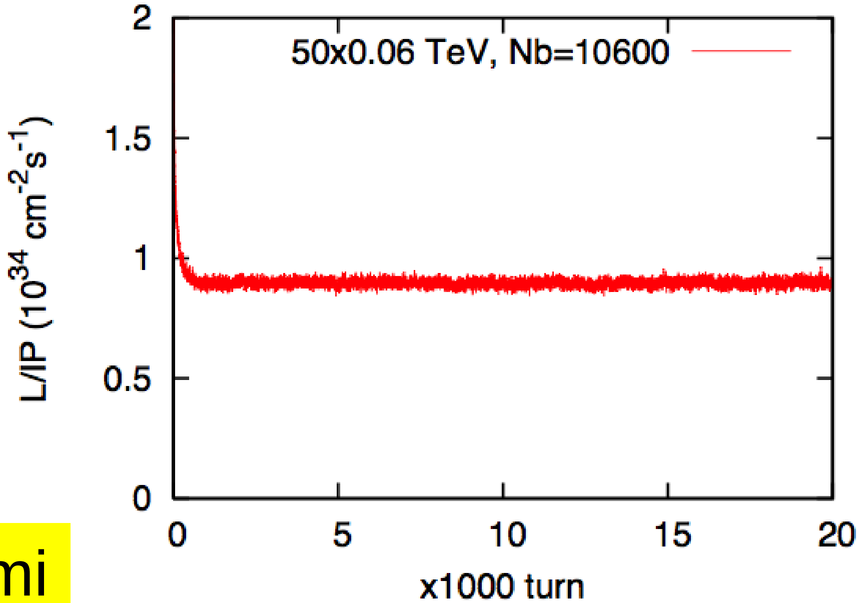
he beam-beam performance

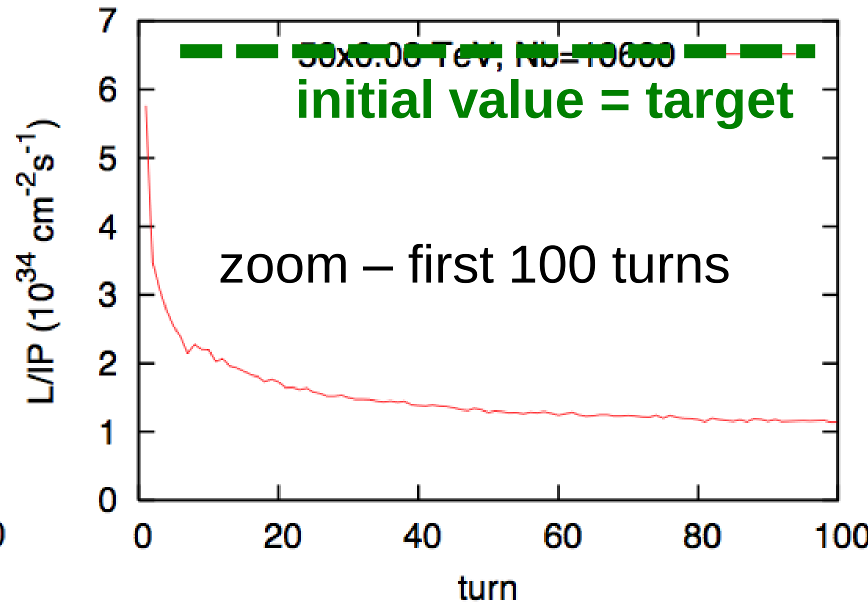
120 GeV e^-
50 TeV *p*





60 GeV e^-
50 TeV *p*





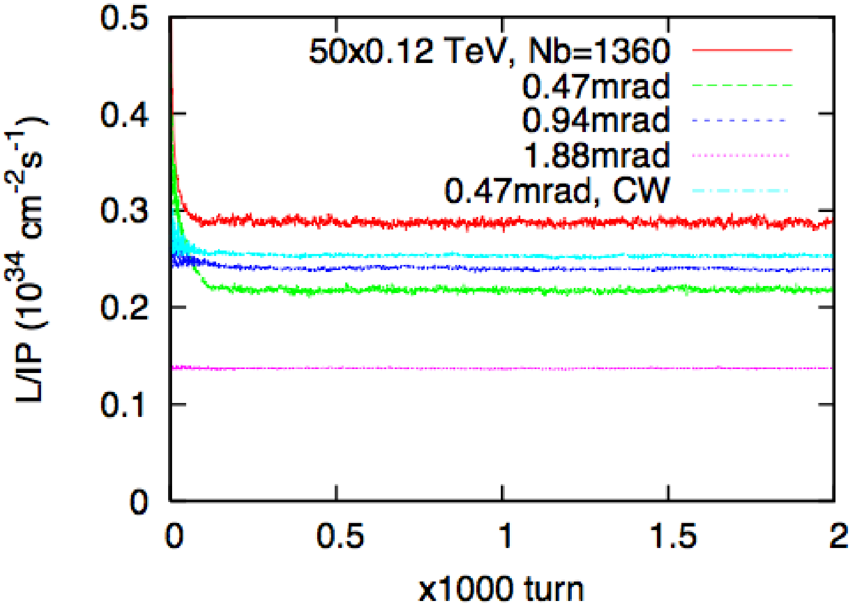
K. Ohmi

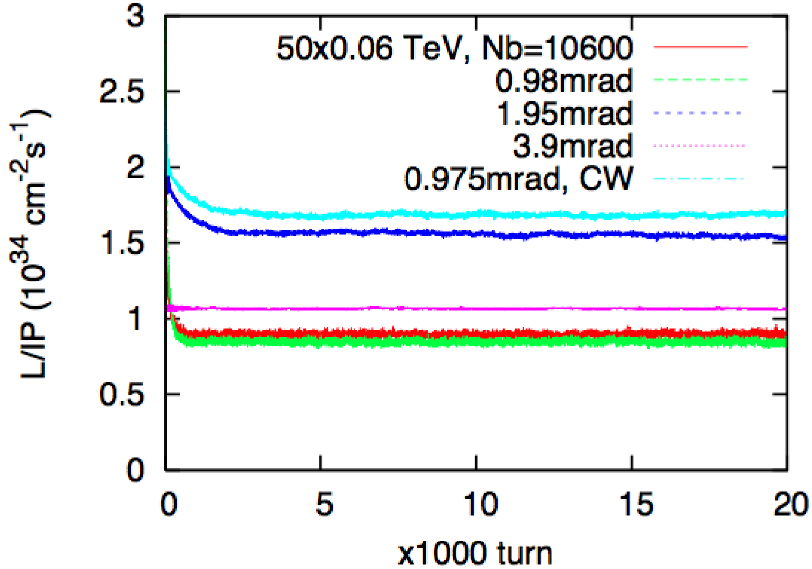
he luminosity optimization

120 GeV e^- , 50 TeV *p*

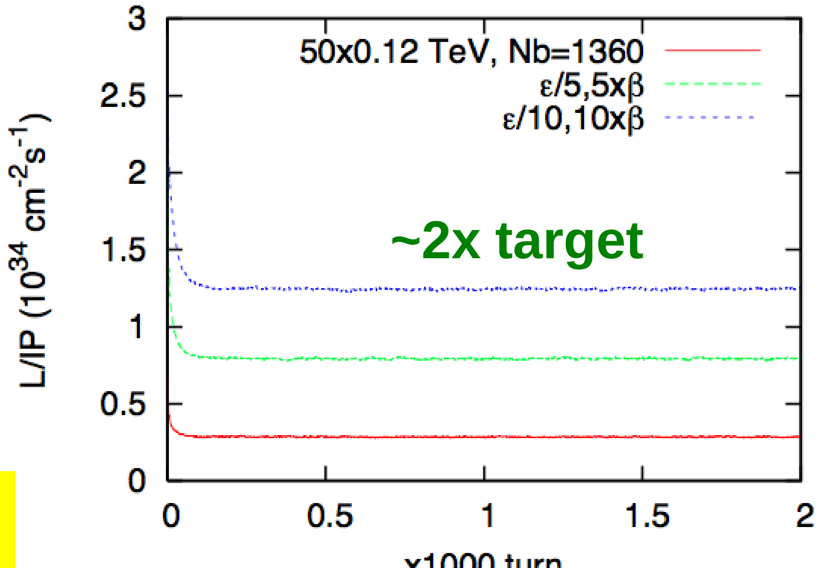
60 GeV e^-, 50 TeV *p*

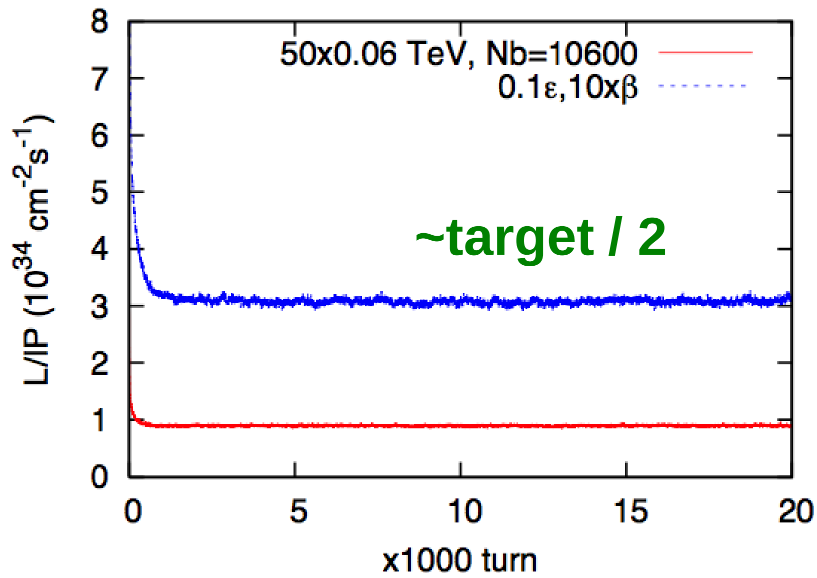
varying crossing angle & crab waist





ε /10, β* x10





K. Ohmi

FCC-hh Work Units

1.2.1	**Overall design parameters**
1.2.1.1	Baseline layout
1.2.1.2	Baseline parameters
1.2.1.3	Baseline parameters for HE-LHC
1.2.1.4	Injector complex requirements and constraints
1.2.1.5	Physics requirements
1.2.1.6	Staging scenarios
1.2.2	**Functional machine design**
1.2.2.1	Single beam collective effects
1.2.2.2	Collimation and absorber concepts
1.2.2.3	Injection and extraction concepts and designs
1.2.2.4	Ion beam operation design considerations
1.2.2.5	Interaction region and final focus design
1.2.2.6	Lattice design and integration and single particle dynamics
1.2.2.7	Machine detector interface
1.2.2.8	Machine protection, magnet protection, QPS, BLM concepts
1.2.2.9	Radiation maps and effects
1.2.2.10	HE-LHC performance needs and conceptual design
1.2.2.11	Beam-beam collective effects and dynamic aperture
1.2.2.12	RF and feedback conceptual design
1.2.3	**Technical systems**
…	

M. Benedikt, J. Gutleber, D. Schulte

FCC-ee Work Units

1.4.1	**Overall design parameters**
1.4.1.1	Baseline layout
1.4.1.2	Baseline parameters
1.4.1.3	Injector complex requirements and constraints
1.4.1.4	Physics requirements
1.4.1.5	Staging scenarios
1.4.2	**Functional machine design**
1.4.2.1	Beam-beam effects
1.4.2.2	Collimation and absorber concepts
1.4.2.3	Injection and extraction concepts and designs
1.4.2.4	Interaction region and final focus design
1.4.2.5	Booster ring conceptual design and integration
1.4.2.6	Lattice design and single particle dynamics
1.4.2.7	Polarization and energy calibration
1.4.2.8	Machine detector interface
1.4.2.9	Machine protection concepts
1.4.2.10	Radiation effects
1.4.2.11	Impedance and single-beam collective effects
1.3.3	**Technical systems**
…	

M. Benedikt,
J. Gutleber,
J. Wenninger

conclusions

- real design work has started in (almost) all work units
- great progress since FCC kick-off in February
- wide study scope, many interesting questions
- emphasis shifting to optimization and choice between alternatives (→ FCC annual WS in March '15)
- many technologies also need work (magnets, SRF, collimators, vacuum system,…)
- witnessing a lot of enthusiasm and excitement
- colleagues contributing from around the world (EU, Switzerland, BINP, KEK, ESS, SLAC, MSU, …)
- more partners & contributions welcome!

… surely great times ahead!