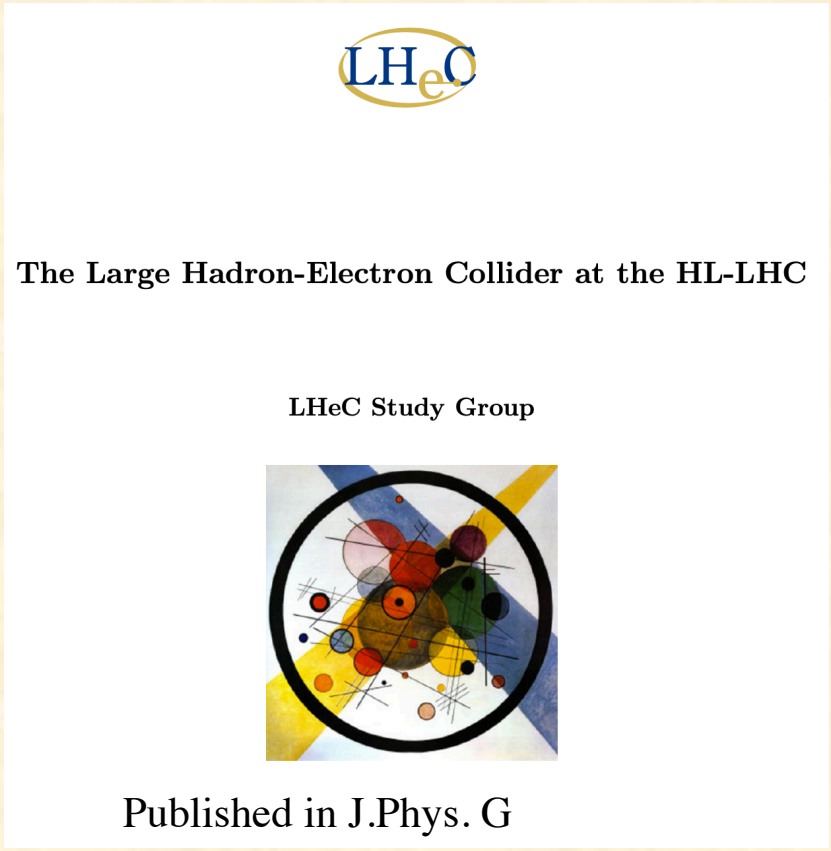
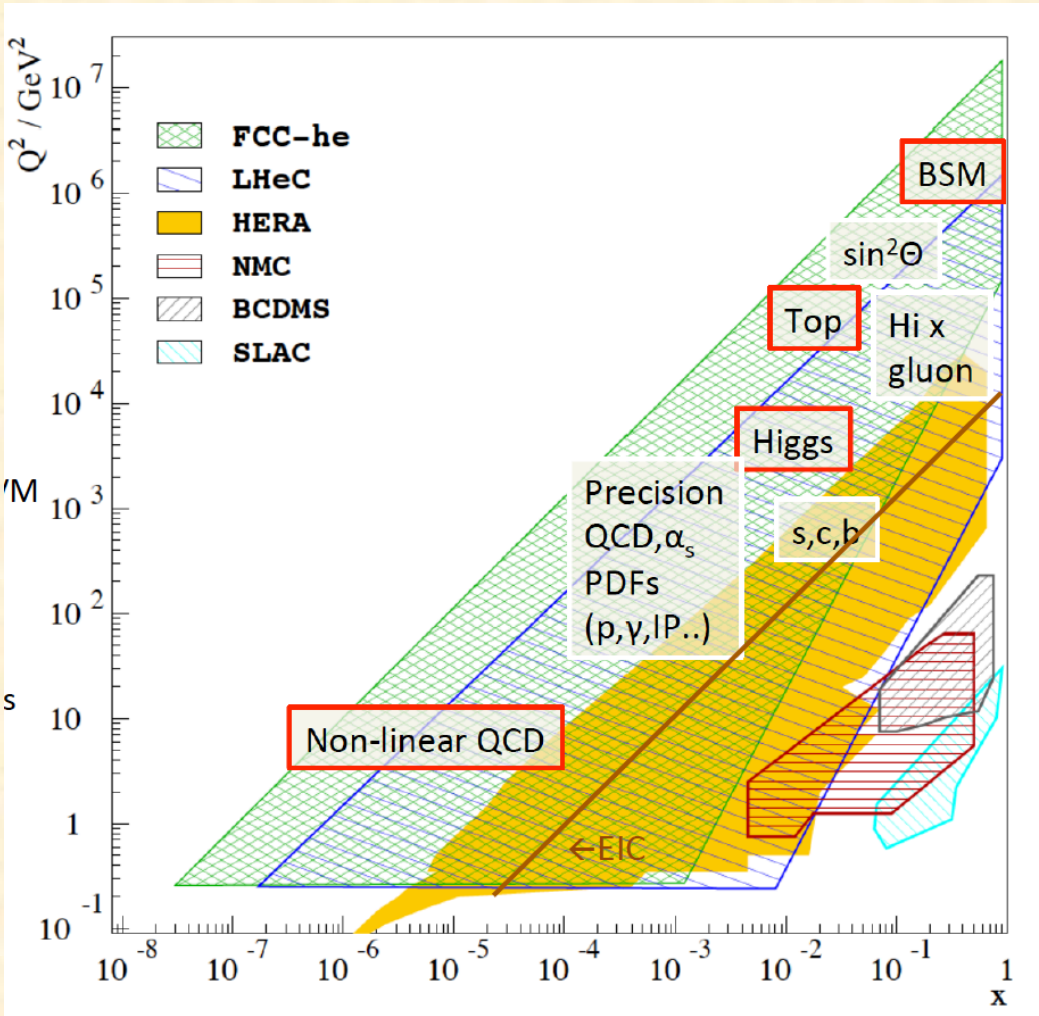
»The LHeC Overview of the LHeC and FCC-eh accelerator concepts «

B.J. Holzer for the LHeC and FCC-eh Study Group

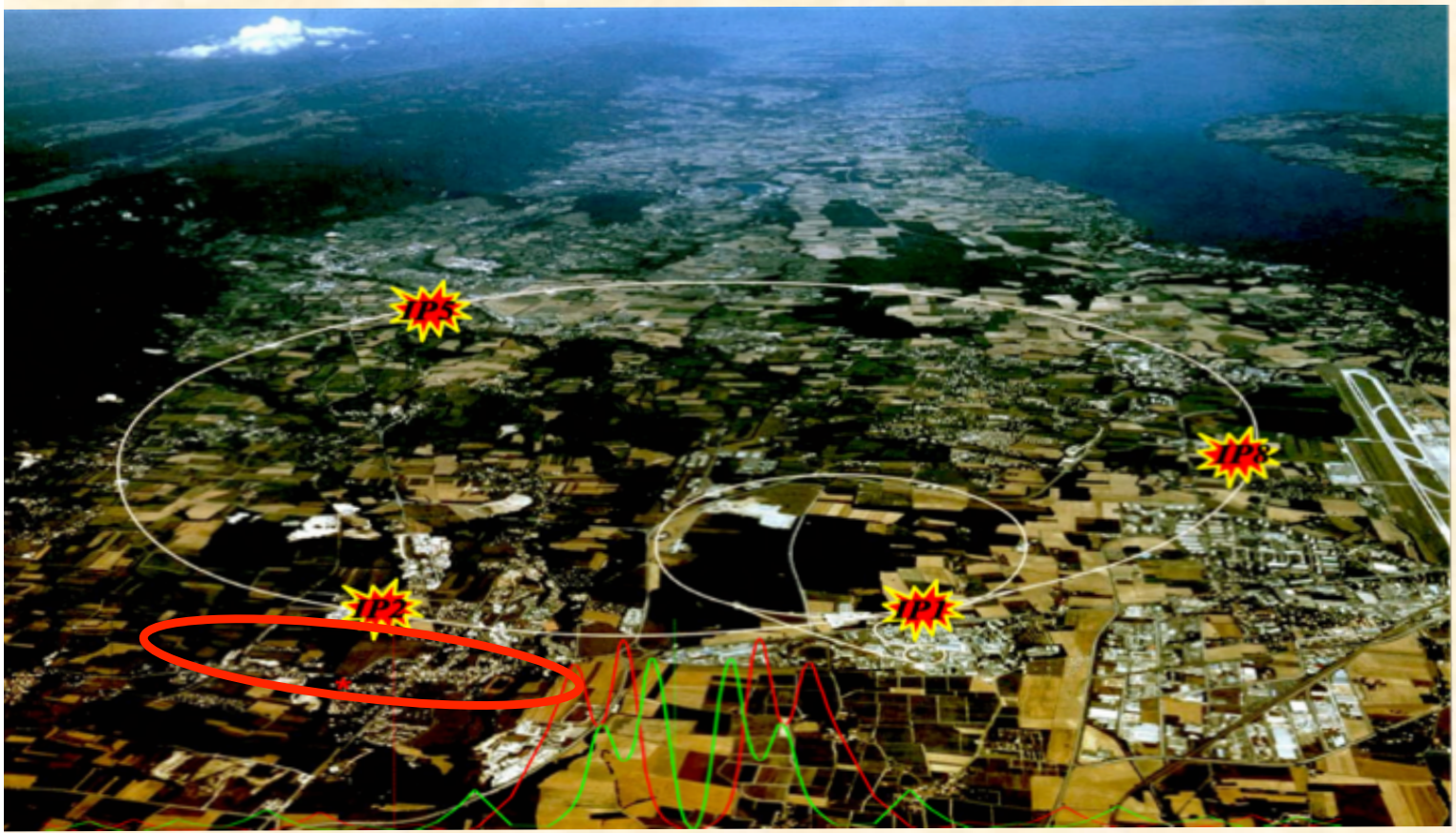




LHeC Layout and Main Parameters:

Design of an ERL based Linac to accelerate electrons and collide with one LHC proton beam

- ***limited size** of the electron "ring"*
- ***beam-beam limit pushed far up***
- ***synchrotron radiation limited** to "one turn"*
- ***beam energy recovered** in the deceleration branch*



Main challenges, … what is needed

Electron Acceleration:
compact, efficient, "green" — > ERL

IR-region: ***Electron mini-beta***
Beam separation
Proton mini beta

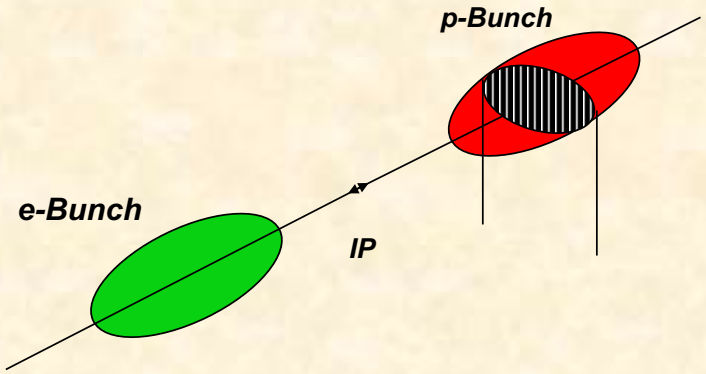
Individual optics ***for p-p collisions***
and e-p collisions

—> ***colliding p-beam***
—> ***non-colliding proton beam***

Concurrent e-p and p-p operation

Beam-Beam Effect: ***limit impact for p & e beam***

LHeC Layout and Main Parameters:



	Electrons	Protons
Energy (GeV)	50	7000
N /bunch	3.1 10^9	2.2 10^{11}
bunch distance (ns)	25	
I (mA)	20	1100
Emittance (nm)	0.31	0.33
Beam size @ IP (μm)	6 / 6	
Luminosity (cm^{-2} s^{-1})	9*10 ^{33}	

wall plug power: 100 MW

$$L = \frac{N_e \cdot N_p \cdot n_b \cdot f_{rev} \cdot \gamma_p}{4\pi \cdot \epsilon_p \cdot \beta_p^*} \quad * \Sigma_i H_i$$

hourglass factor, $H_1 \simeq 0.9$
pinch or beam-beam factor, $H_2 \simeq 1.3$
filling factor $H_3 = H_{coll} \simeq 0.8$

$$\Sigma_i H_i \approx 1$$

$$L \approx 10^{34} cm^{-2} s^{-1}$$

Attention:

We need "matched beam sizes" at the IP

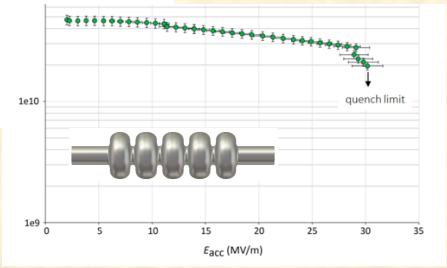
$$\sigma_x^*(e) = \sigma_x^*(p)$$

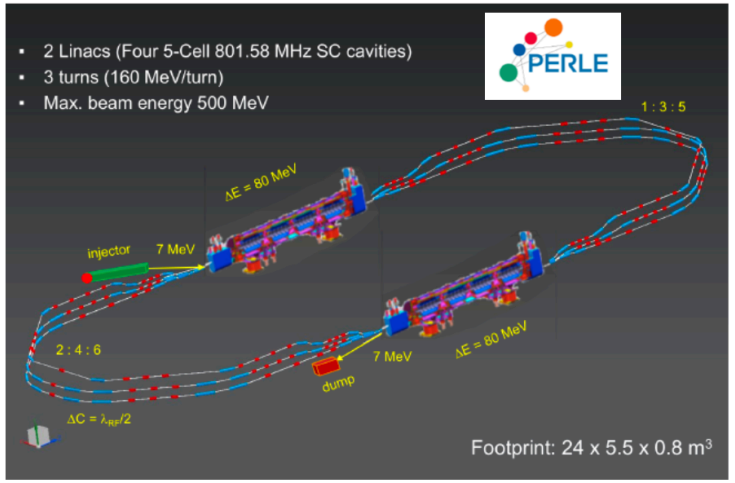
$$\sigma_y^*(e) = \sigma_y^*(p)$$

Main Systems: ERL

* s.c. RF System: 20 MV/m

J-lab: Prototype design of a 5 cell cavity

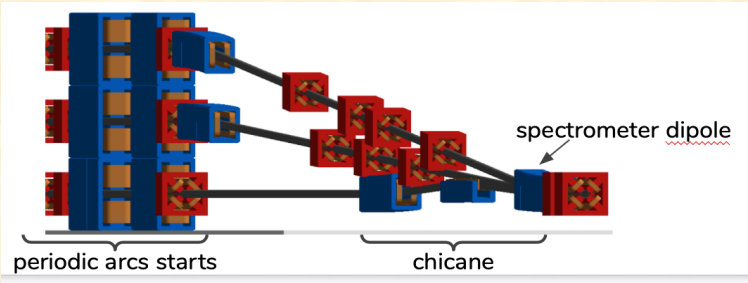




prototype ERL "PERLE"

* spreader /recombiner

non-dispersive deflection system



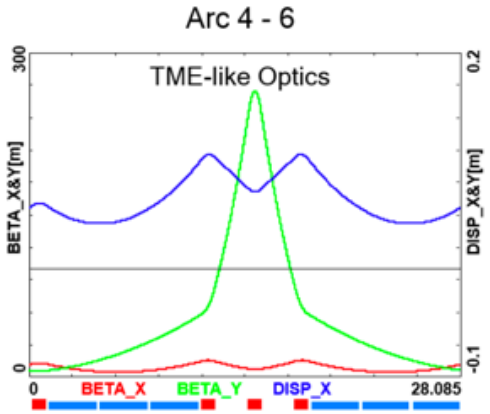
* arc optics

typical light source optics

$$\varepsilon_0 = C_q \frac{\gamma^2}{j_x} \frac{I_5}{I_2} \qquad I_2 = \oint \frac{1}{\rho^2} ds \approx \frac{2\pi}{\rho}$$

$$I_5 = \oint \frac{\mathcal{H}_x}{\rho^3} ds$$

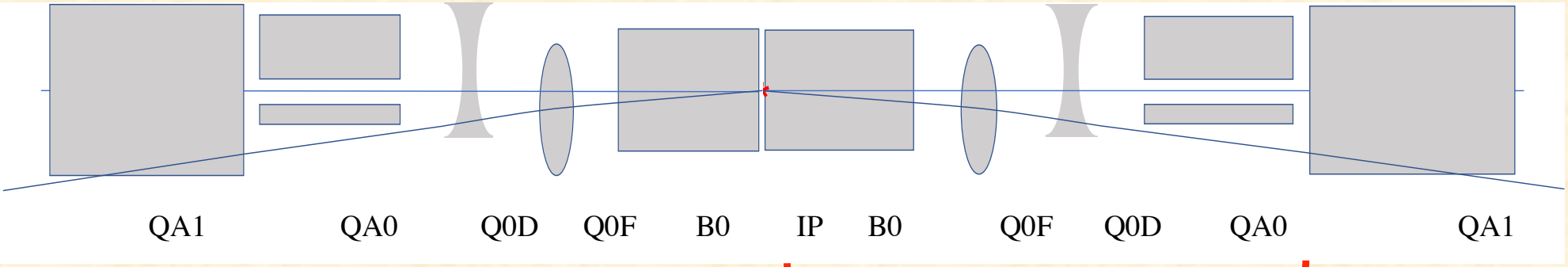
optimised arc cell for smallest beam emittance

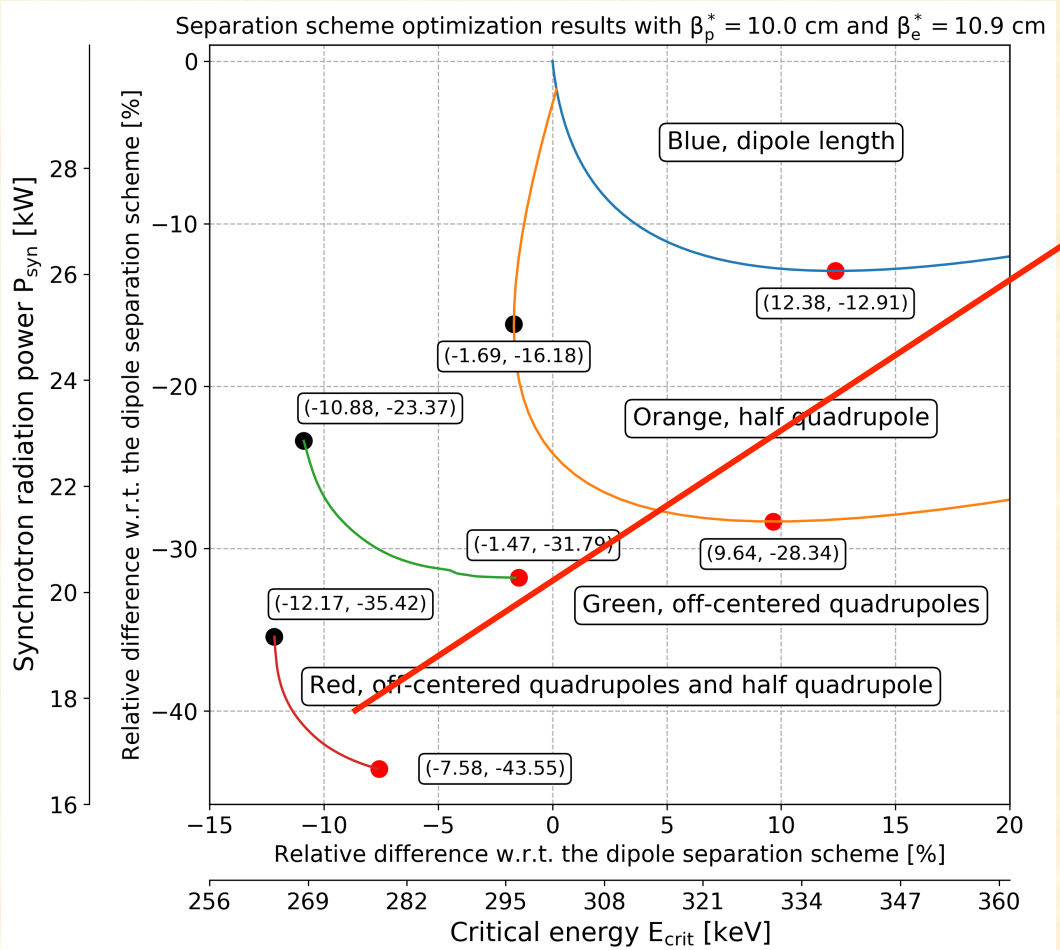


$< H > = 0.59 \times 10^{-3}$ m

court. A. Bogacz

Main Systems: *Interaction Region,* *optimise for smallest synchr. radiation*





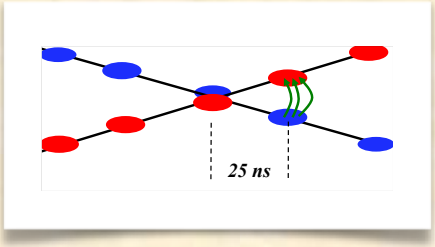
combine a detector integrated dipole field with an early focusing scheme, off-centre quadrupoles (1/ρ = const) and very compact proton quadrupole design

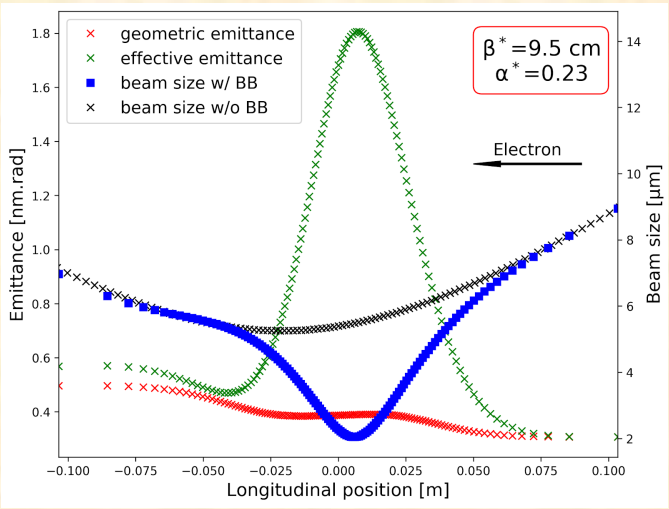
$$P_{syn} = \frac{e^2 c}{6\pi\varepsilon_0} \frac{\gamma^4}{\rho^2}$$

court. K. André

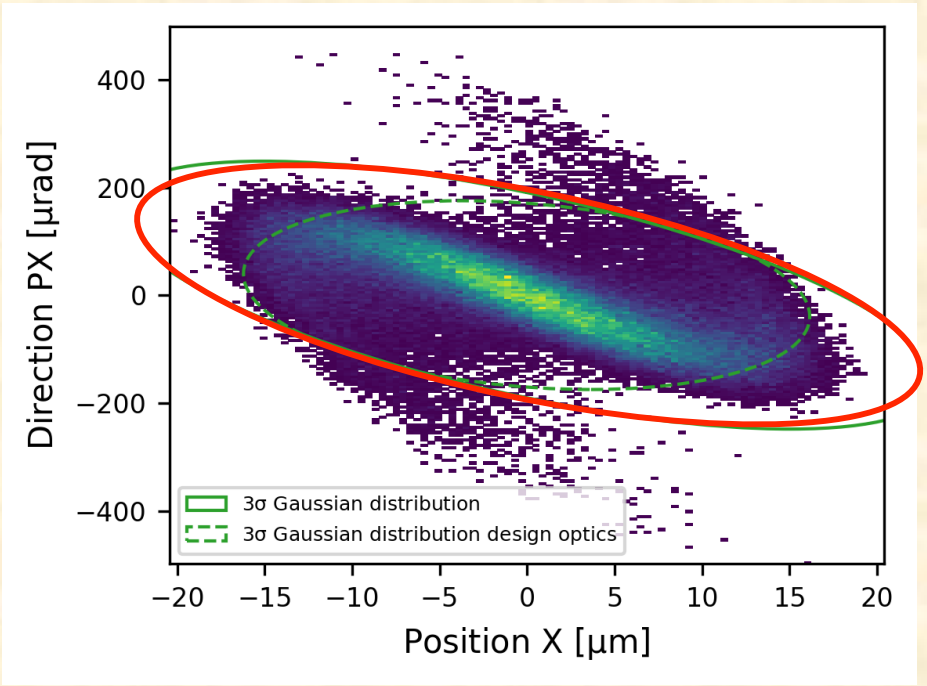
Main Systems: *Interaction Region, emittance & beam-beam effect*

Rematch e-Optics, including the beam-beam focusing





IR Optics for minimum Optics mismatch



development of tails due to non-linear beam beam force

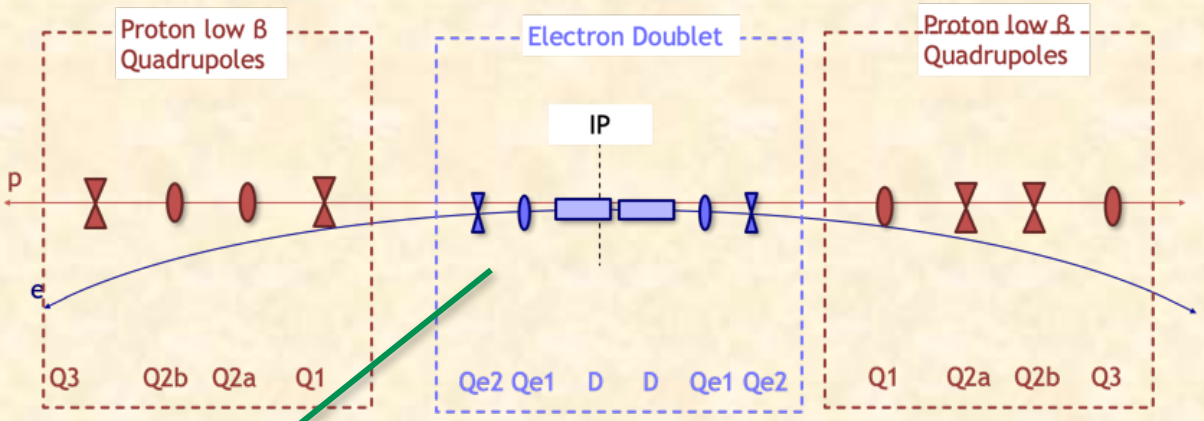
$$\Delta Q_{x,y} = \frac{N\, r_0\, \beta^*_{x,y}}{2\pi\gamma\, \sigma_{x,y}\, (\sigma_x + \sigma_y)}$$

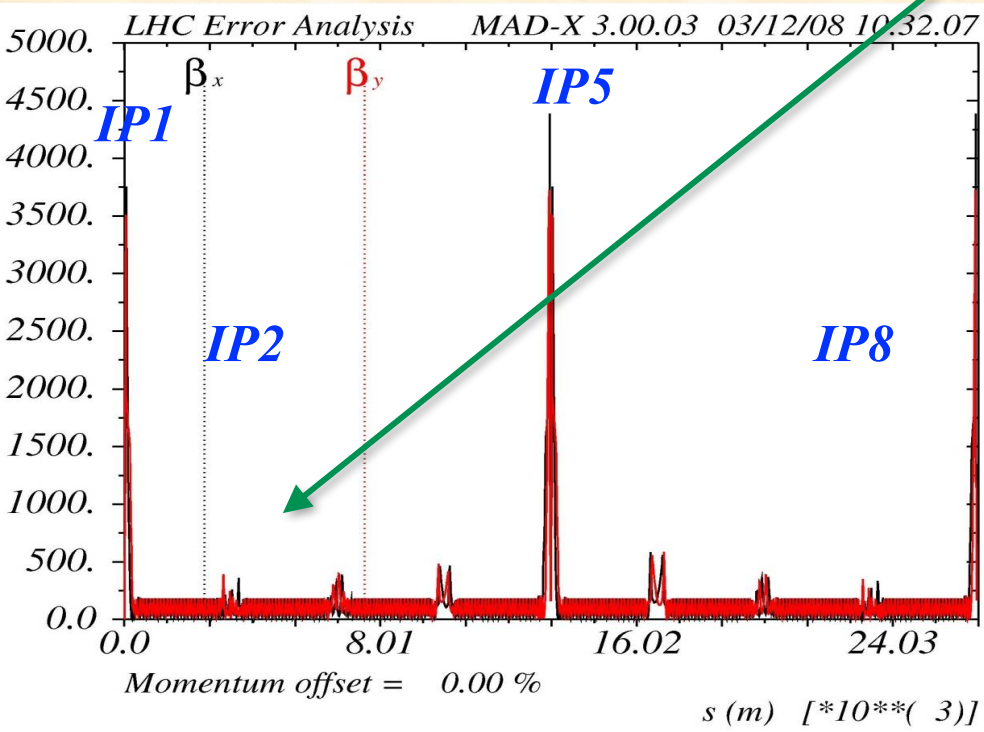
ERL performance: ≈ 98 %

court. K. André

Main Systems Protons: Interaction Region

Double Mini-Beta Insertion
imbedded e-p collisions in LHC standard structure





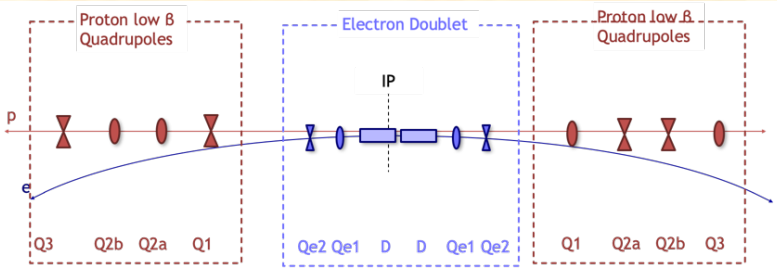
proton optics ***"modular" within the LHC periodic arc structure***

electron optics ***insertion within the p-final focusing***

early beam separation scheme

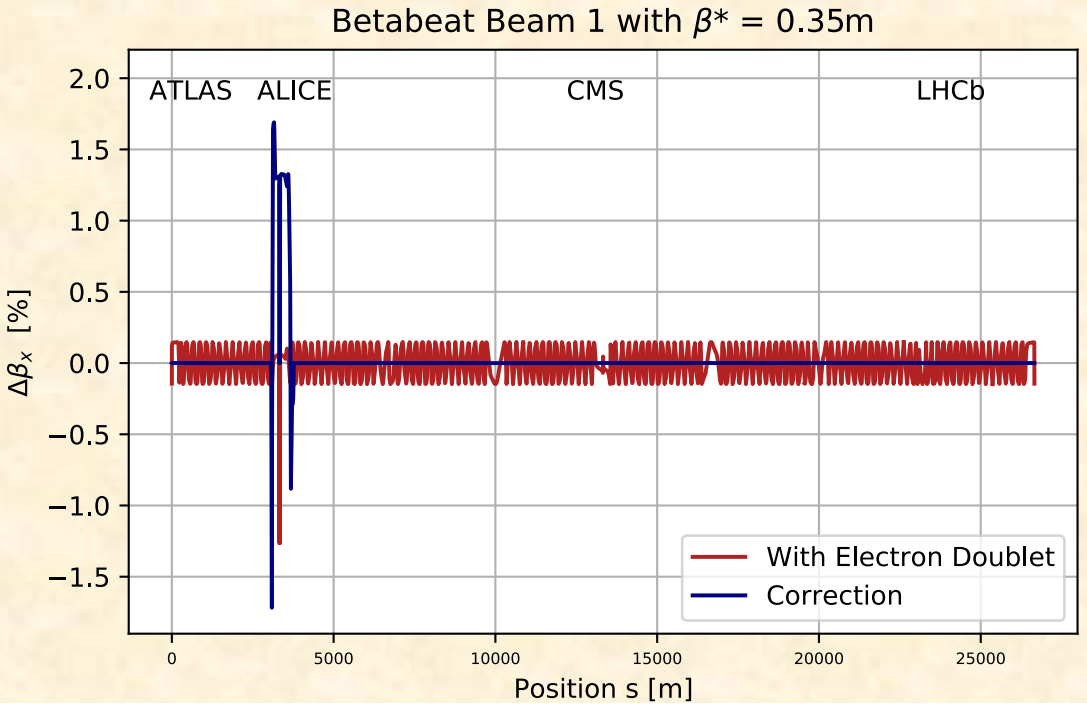
Proton Beam Performance

p-Optics & e-Quadrupoles



local orbit bump
local optics distortion
—> on colliding proton beam
—> non-colliding proton beam

corrected locally via LHC matching quadrupoles



beam-beam effect: —> negligible

in linear approximation —> tune shift

$$\Delta Q_{x,y} = \frac{N\, r_0\, \beta^*_{x,y}}{2\pi\gamma\ \sigma_{x,y}\ (\sigma_x + \sigma_y)}$$

$\Delta Q_{p,p} \approx -3.1 \cdot 10^{-3}$ *per IP* *for* $N_p = 1.5 \cdot 10^{11}$

for $N_e = 3.1*10^{9}$ *—> negligible*

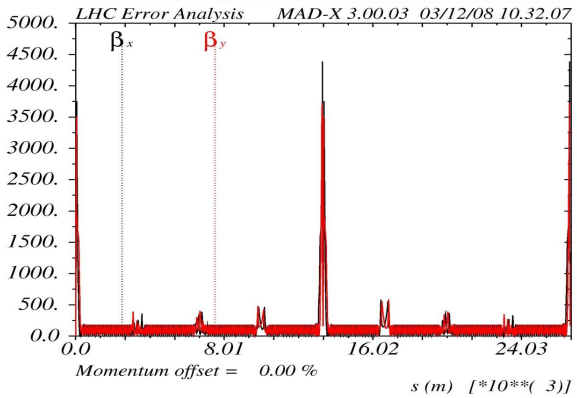
$\Delta Q_{e,p} \approx +6.4 \cdot 10^{-5}$ *for* $N_e = 3.1 \cdot 10^{9}$

Proton Beam Performance: two fold operation mode

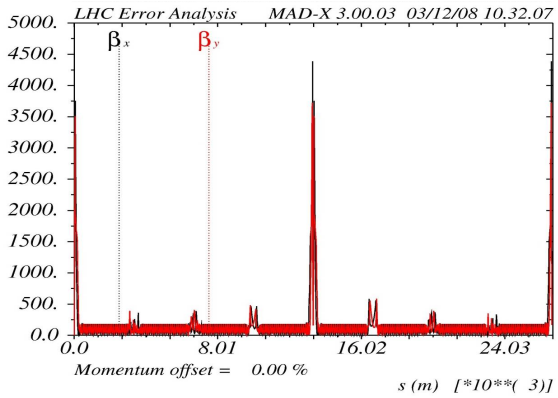
h-h operation:

standard LHC collision optics

p-beam 1

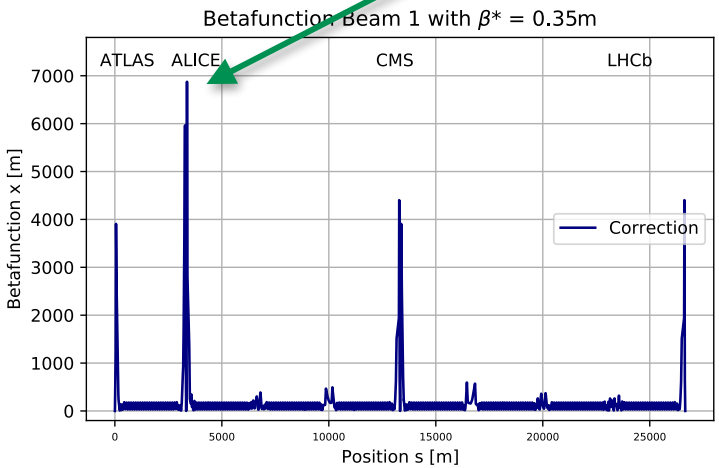


p-beam 2

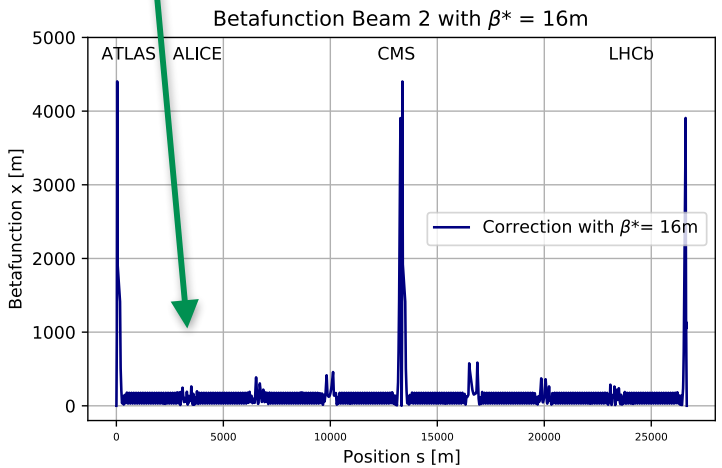


e-p operation:

p-beam 1
—> high luminosity optics



p-beam 2
—> relaxed optics
max aperture margin

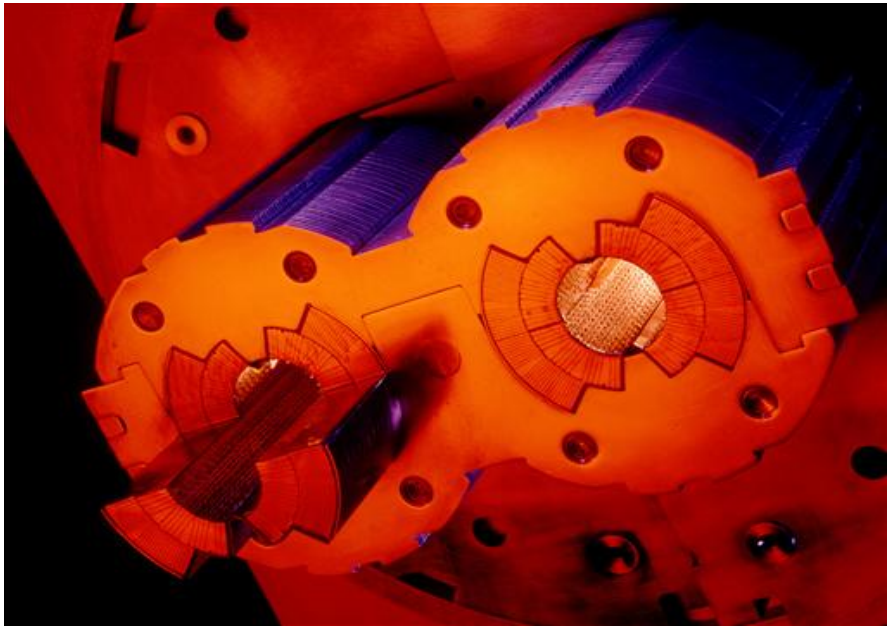


court. T. vonWitzleben

Technical Challenges: LHC Proton Lattice

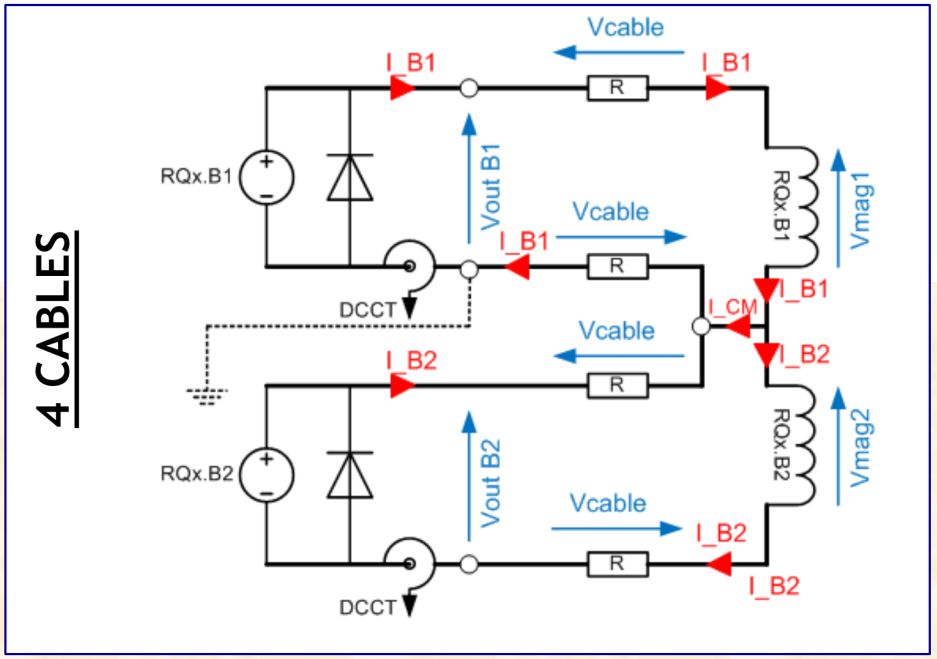
LHC double aperture

—> ***flexibility for independent quadrupole fields ?***



—> ***YES***

recabling needed for 1 Magnet

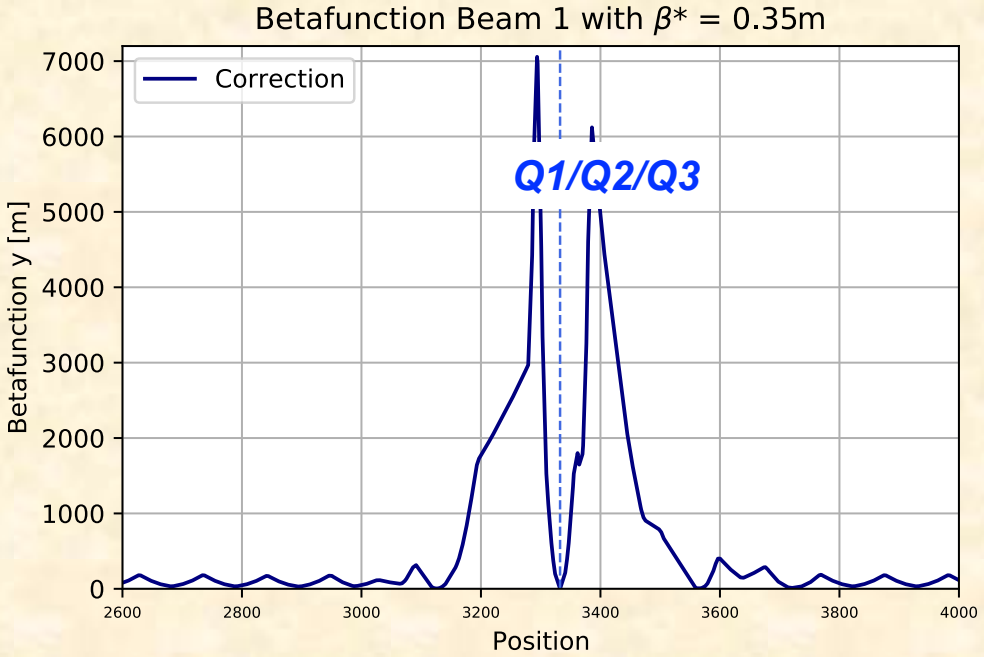


Proton Beam Performance

Independent Beam, Optics p1, p2

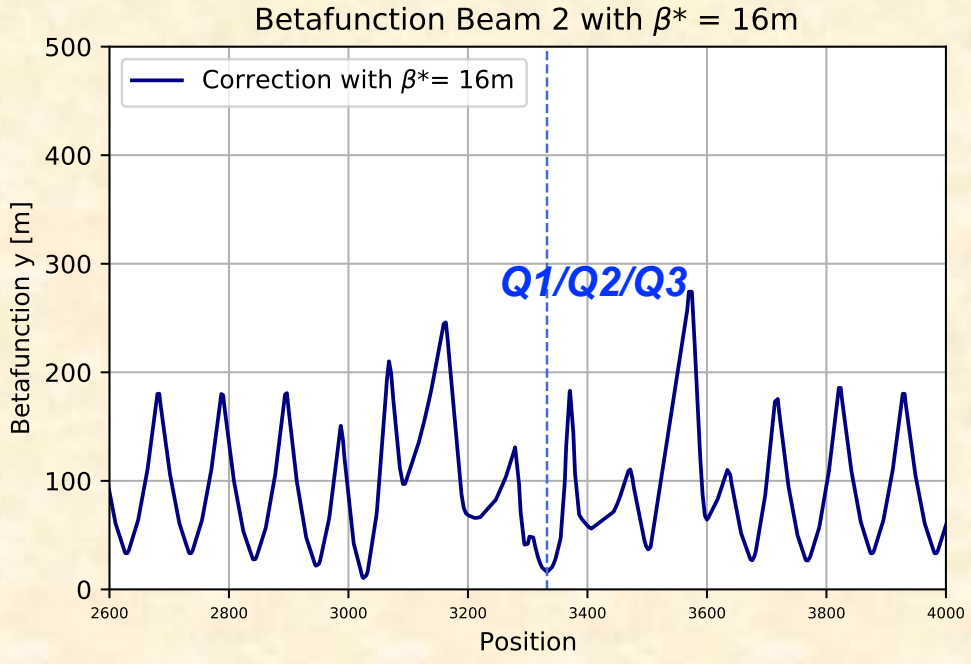
Colliding Proton Beam:

luminosity optics,
matched to e-beam
defines the aperture need



NON-Colliding Proton Beam:

relaxed optics,
reduced aperture need,
separated in position & angle

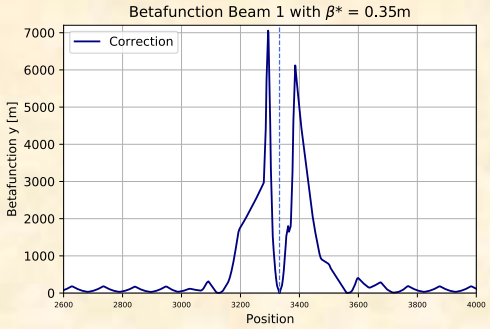


court. T. vonWitzleben

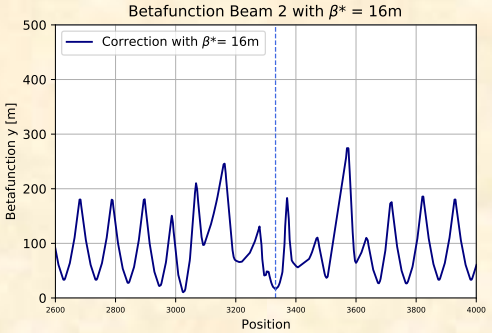
Proton Beam Performance

Design Orbits & Aperture Need

p-beam 1

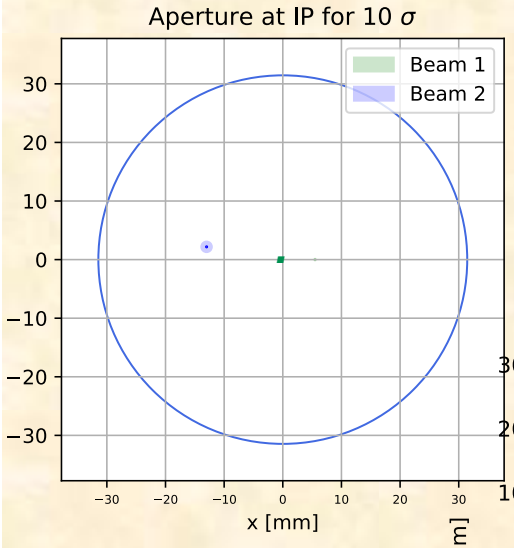


p-beam 2

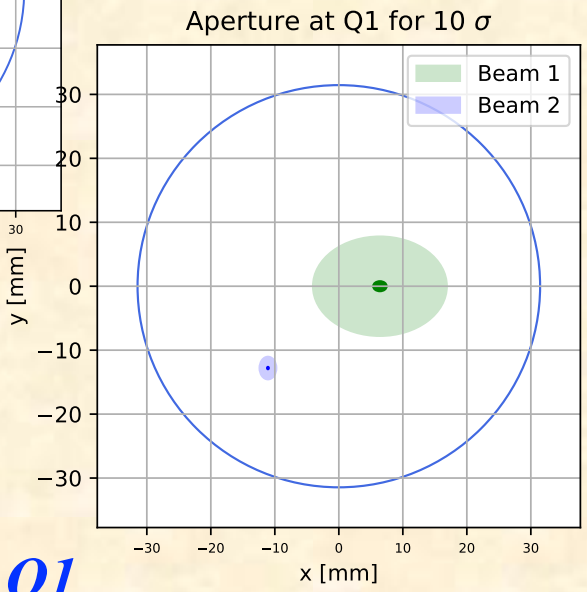


$$\sigma_1 = \sqrt{\varepsilon\beta} = 10\mu m$$

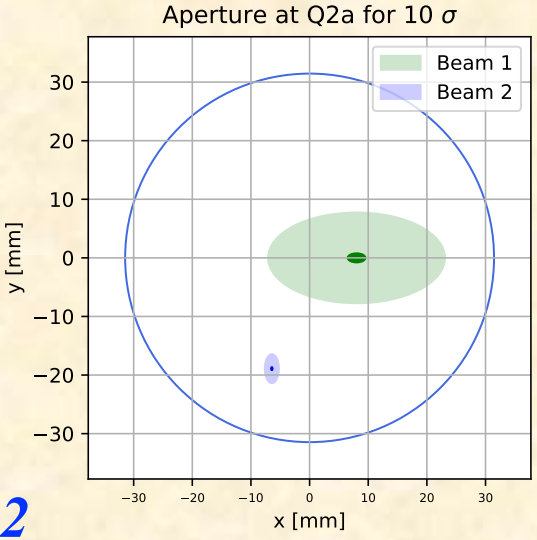
$$\sigma_2 = \sqrt{\varepsilon\beta} = 73\mu m$$



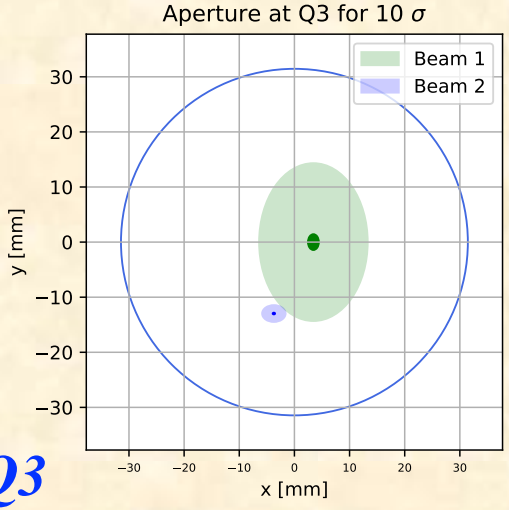
IP



Q1



Q2



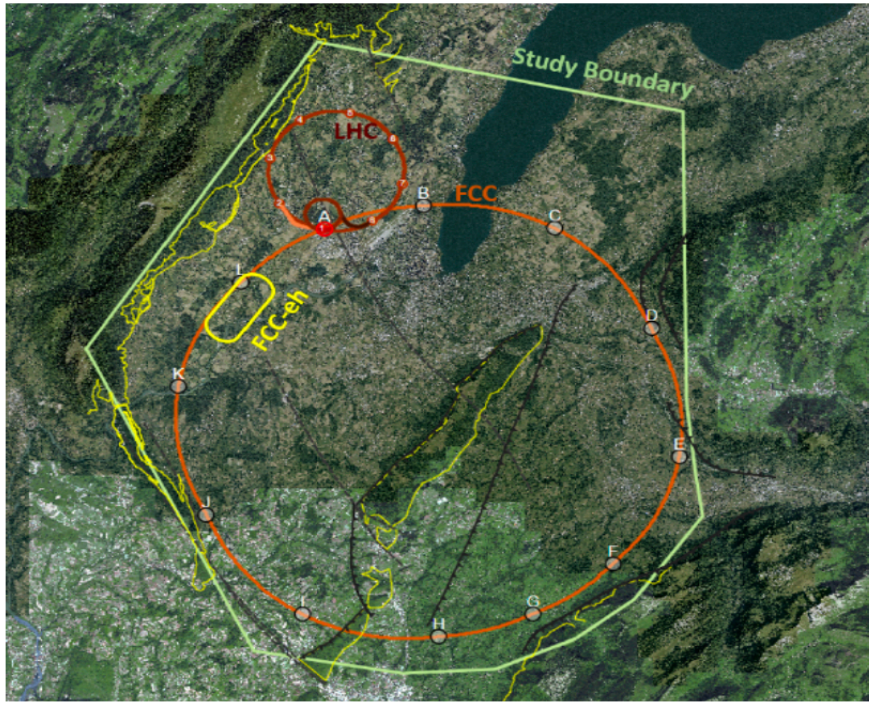
Q3

court. M. Smith

FCC-eh

e-p IR-Design modular

—> *ERL & IR can be imbedded at any straight section e.g. point "L"*



	Electrons	Protons
Energy	60 GeV	50 TeV
N /bunch	3.1 10^{9}	2.2 10^{11}
bunch distance (ns)	25	
I (mA)	20	1100
Emittance (nm)	0.31	0.05
Beam size @ IP (μm)	2.5 / 2.5	
Luminosity (cm^{-2} s^{-1})	1.5*10 ^{34}	

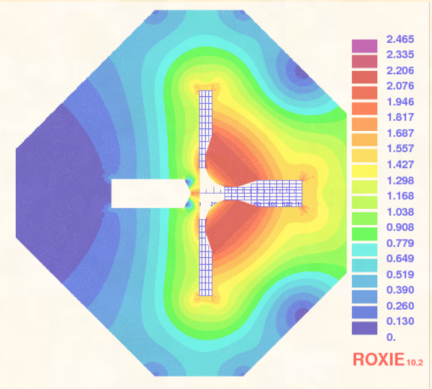
FCC-CDR: Eur.Phys.J.ST 228 (2019, 4.755) ***FCC-hh/eh***

60 GeV × 50 TeV

—> 1.5 TeV collider

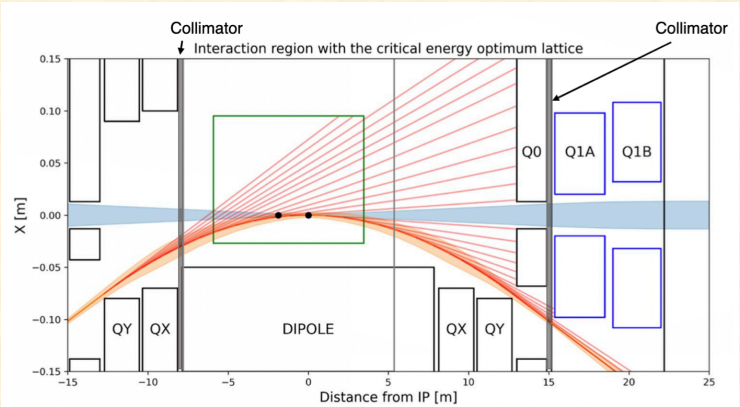
Operation: 2050 +

Challenges & Next Steps:



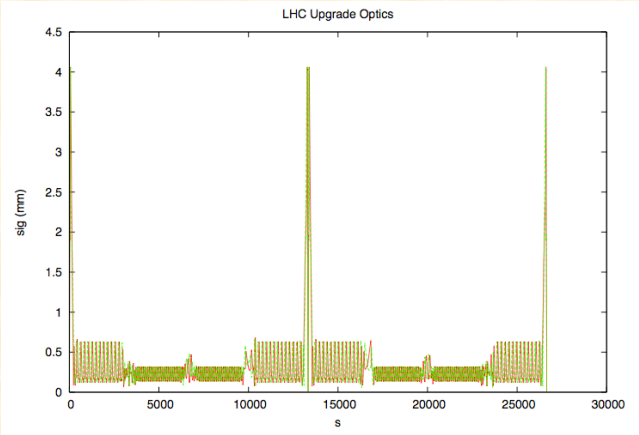
Design for prototypes of special magnets Q0/Q1:

- *half-quadrupole in IR*
- *sc. "field free" quadrupole*



Synchrotron Radiation & Shielding

- *MDI - inner detector*
- *sc. Quadrupoles down-stream IP*



Optimise e-p Performance

- *HL-LHC optics*
  —> ATS for extreme p-optics

Conclusion:

Design of a ERL based 50 GeV electron beam
in collision with the 7 TeV LHC protons

Fully Modular Concept

—> ***imbedded in a LHC Interaction Region***

influence ***on optics & orbit*** ***compensated***

flexibility of the LHC rings ***checked***

asymmetric beam optics ***for ultimate e-p luminosity***

non-colliding p-beam ***well separated***

negligible beam beam force ***on both proton beams***

Design optimised for

* ***alternate e-h / h-h operation in IP2***

* ***concurrent eh with hh at other IPs***