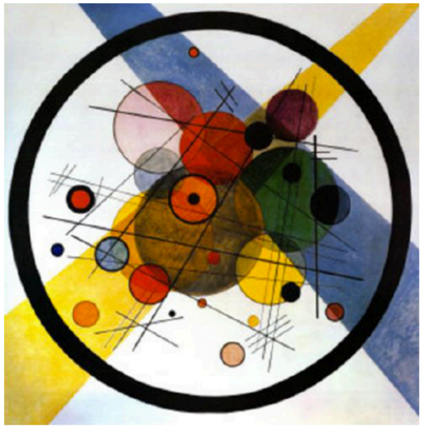
»The LHeC Overview and Status«

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

The Large Hadron-Electron Collider at the HL-LHC

LHeC Study Group



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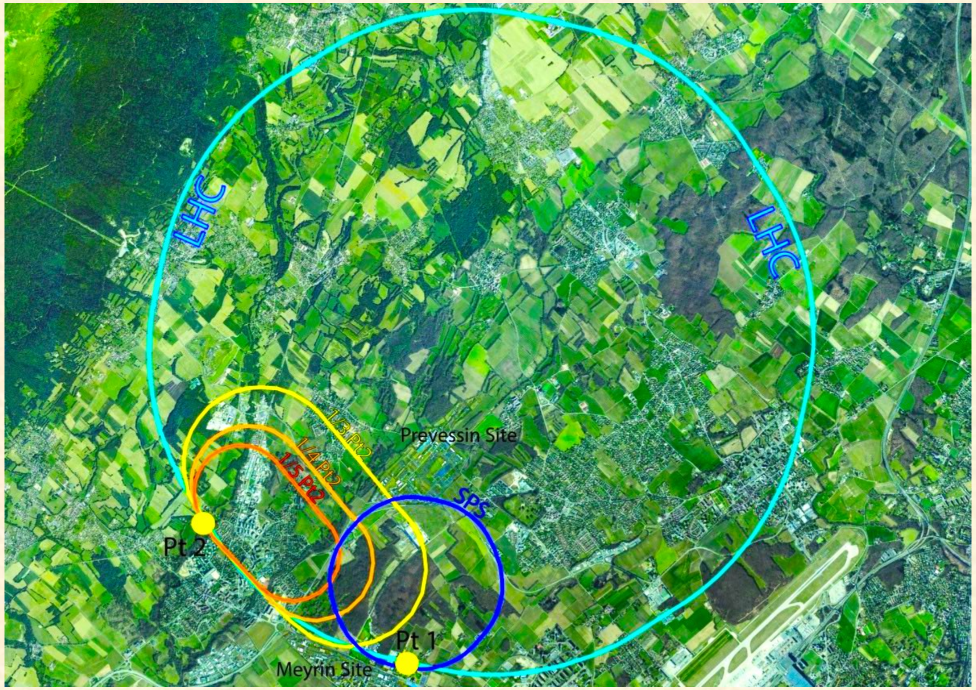
LHeC Layout and Main Parameters:



	Electrons
Energy (GeV)	50
N_p /bunch (10^{11})	2.2
N_e /bunch (10^9)	3.1
bunch distance (ns)	25
I_e (mA)	20
Emittance (nm)	0.31
Beam size @ IP (μm)	6 / 6
Luminosity ($cm^{-2}\ s^{-1}$)	$9*10^{33}$

wall plug power: 100 MW

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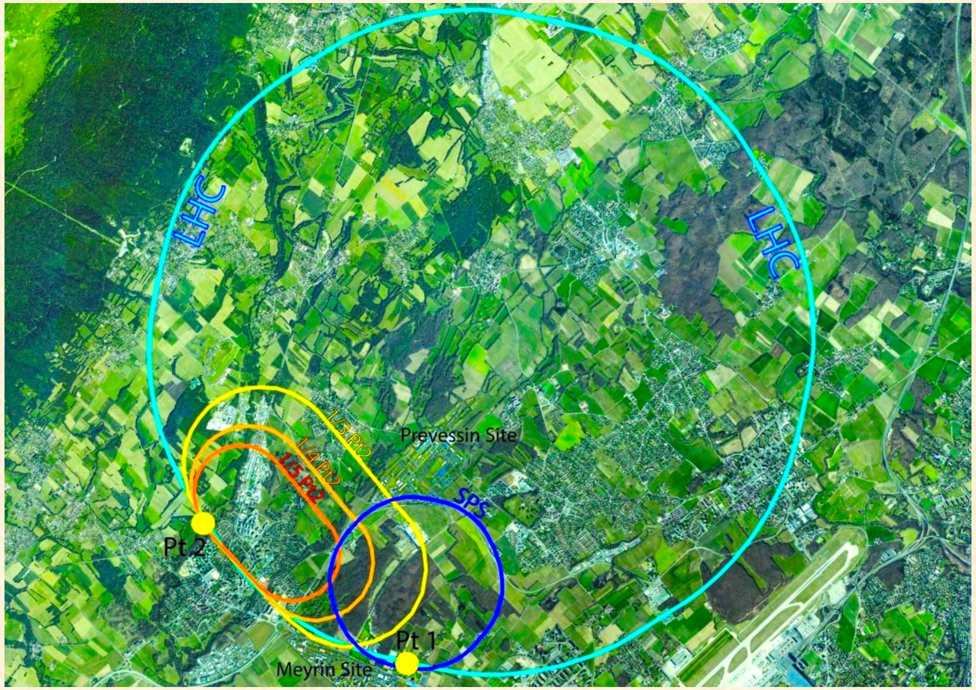

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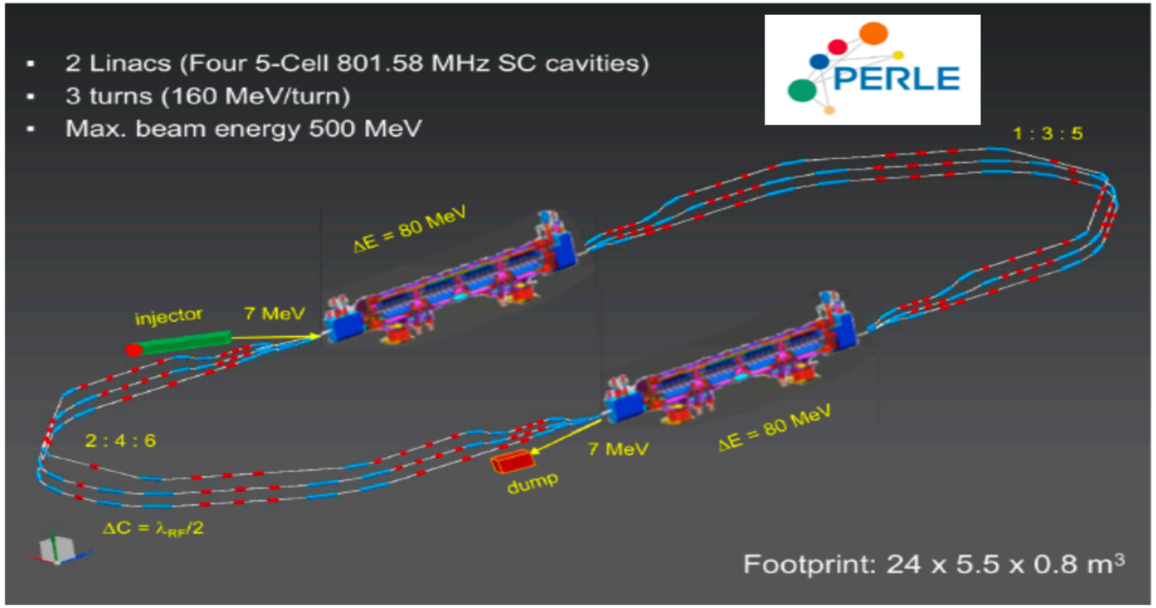
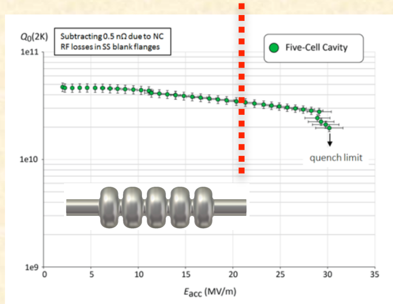
~~three~~ sizes proposed
1/3 … 1/4 … ~~/ 1/5~~ LHC

$ <—> beam energy



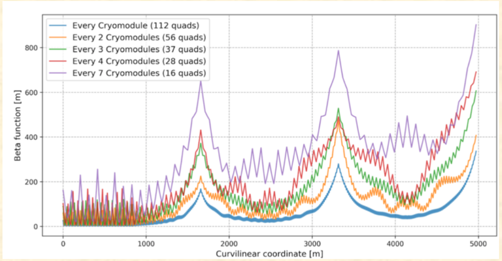
LHeC: What has been done:



high Q sc. RF system

Jefferson Lab

Prototype design of a 5 cell sc. cavitiy
crucial test: PERLE



Linac Focusing Structure: 130^0 *FODO*

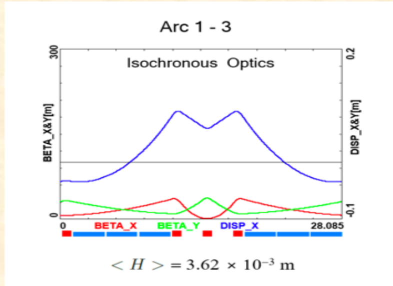
Alex Bogacz

Return Arcs

Alex Bogacz

isochronous optics for arc 1,2,3
keep the bunch length short
low emittance optics arc 4,5,6

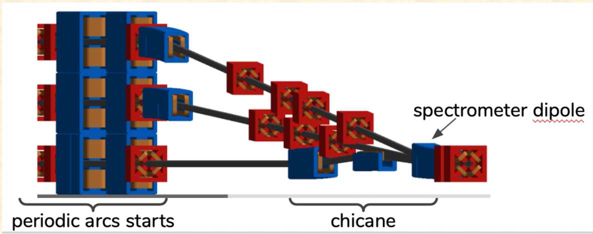
$$\mathscr{H}_x = \gamma_x(\eta_x)^2 + 2\alpha_x\eta_x\eta'_x + \beta_x(\eta'_x)^2$$



Spreaders / Recombiners

Alex Bogacz / K. Andre

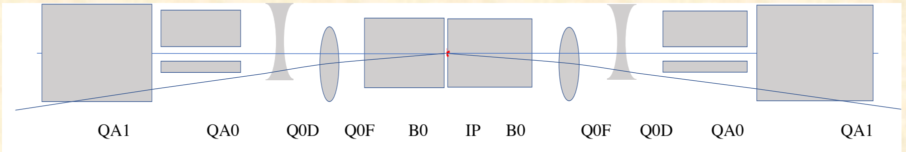
Non-dispersive (i.e. "achromatic")
vertical deflection system

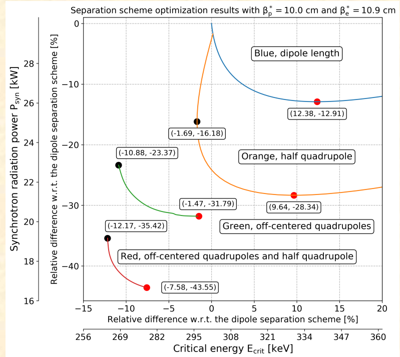


LHeC: What has been done:

The Interaction Region / Beam Separation

K. Andre



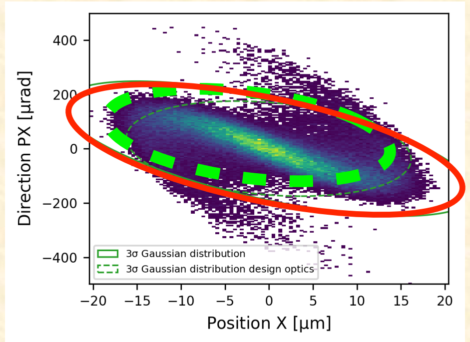


Minimum of power & crit. energy of synchrotron light emission

Emittance & Beam Beam Effect

Kevin Andre'

IR Optics for minimum Optics mismatch

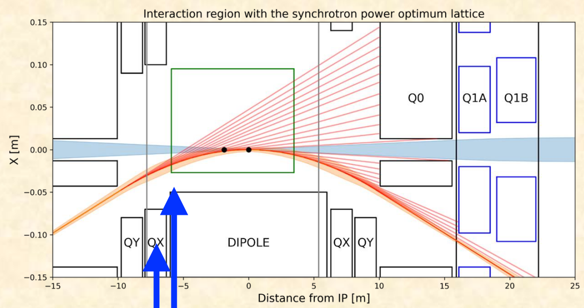


Energy Recovery Performance: ≈ 98 %… why not 100 % ??

Synchrotron Radiation & MDI

Kevin Andre', Peter Kostka
D. Hanstock, A. Kumar, D. Clayton,
C. Monaghan, ***Laurent Forthomme***

$$P_b(L,\theta) = \frac{e}{6\pi\varepsilon_0}\gamma^4 I_e \frac{\theta^2}{L}$$



emitted light & absorbers

detector beam pipe

ALICE 3 / LHeC Interaction Region

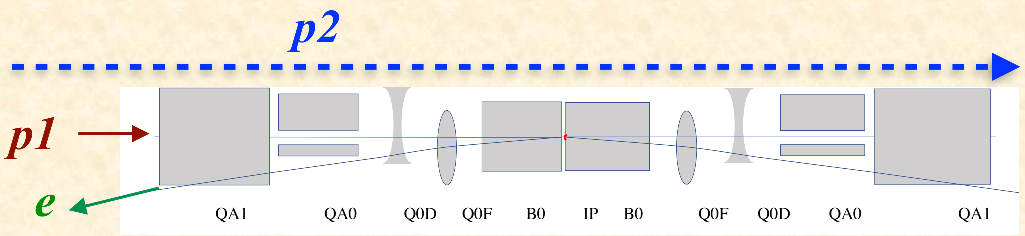
… it is a Three Beam Problem

Concurrent LHeC operation with IP1,5,8

Alternating operation ALICE 3 / LHEC

Interaction Region
a Three Beam Problem

T.v. Witzleben



keep the non-colliding proton beam in the same magnet structure

—> Separate the non-colliding beam during LHeC operation

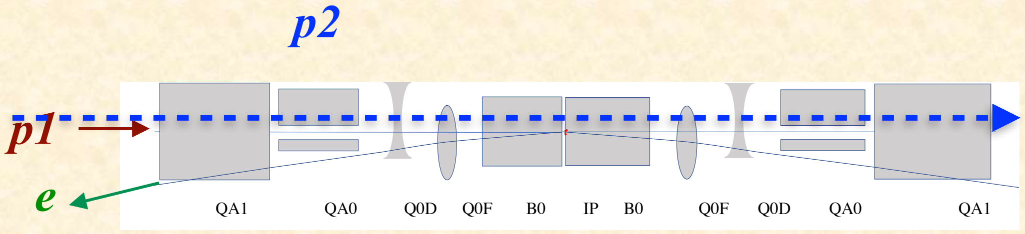
—> Aperture need

—> develop a colliding p1-optics

—> develop a relaxed p2-optics

Interaction Region
a Three Beam Problem

T.v. Witzleben



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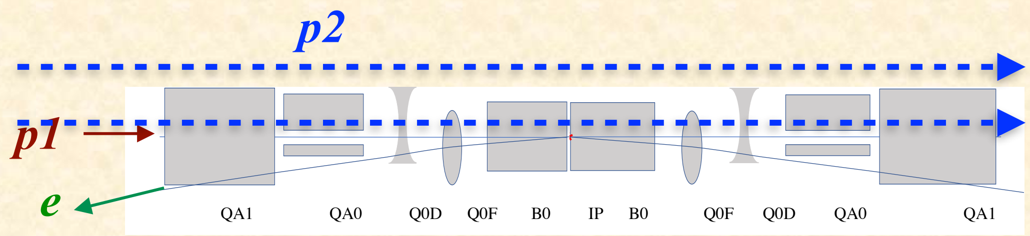

Colliding Proton Beam

Matched Beam Optics p & e

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

Interaction Region
a Three Beam Problem

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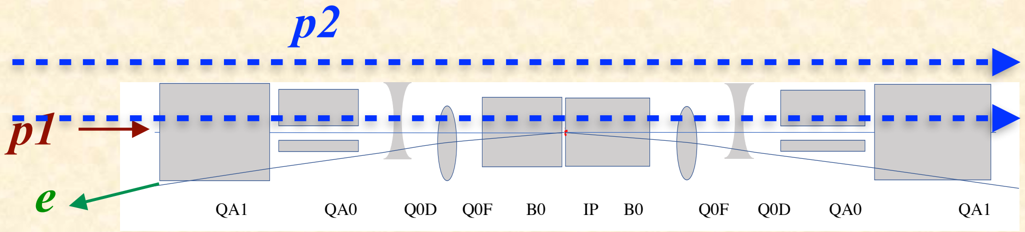


Colliding Proton Beam

Matched Beam Optics p & e

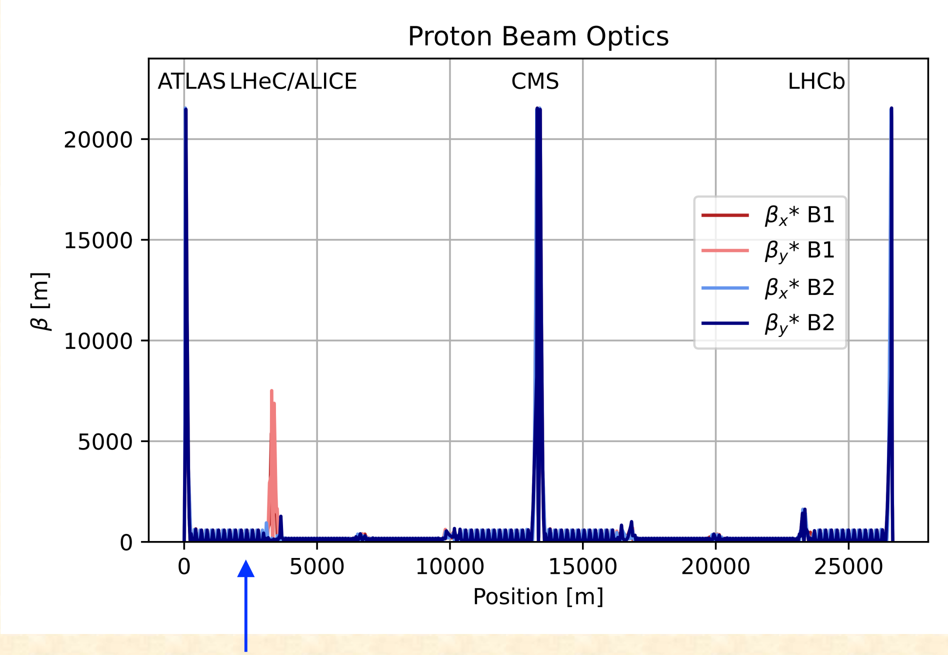
$$\sigma_x^*(e) = \sigma_x^*(p) \qquad \sigma_y^*(e) = \sigma_y^*(p)$$

Colliding p-beam:

ATS compatible,
concurrent to IP1, 5, 8
alternating LHeC & ALICE

$\beta * = 35\ cm$

—> LHC Standard: NbTi



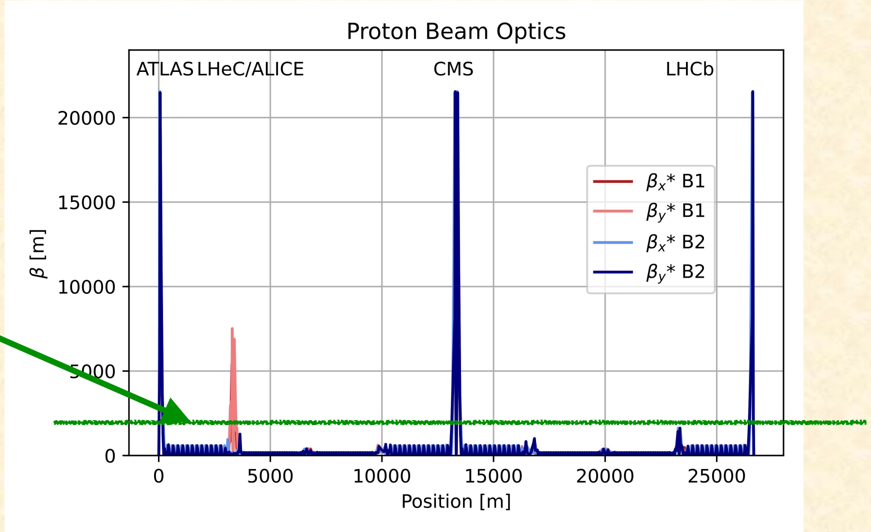
ATS: quadrupoles in IR2 —> Lumi IP1
... and the other way round ???
... and IR2 —> IR 3 ???

Interaction Region: The non-colliding Proton Beam

Tiziana v. Witzleben

Save Aperture for the colliding beam

"Relaxed" optics for non-colliding proton beam
*—> **reduced aperture** need in Triplet Quadrupoles!!*



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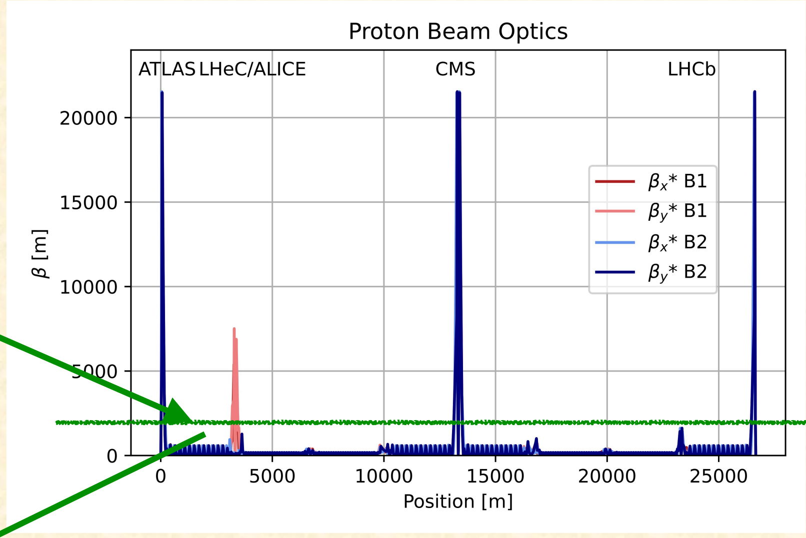

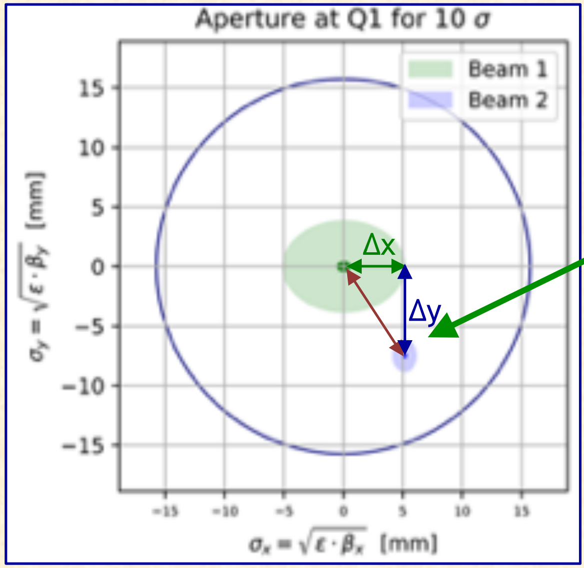

$$\beta(s) = \beta^* + \frac{s^2}{\beta^*}$$

separate 2nd proton beam to avoid (parasitic) encounters

Tiziana v. Witzleben

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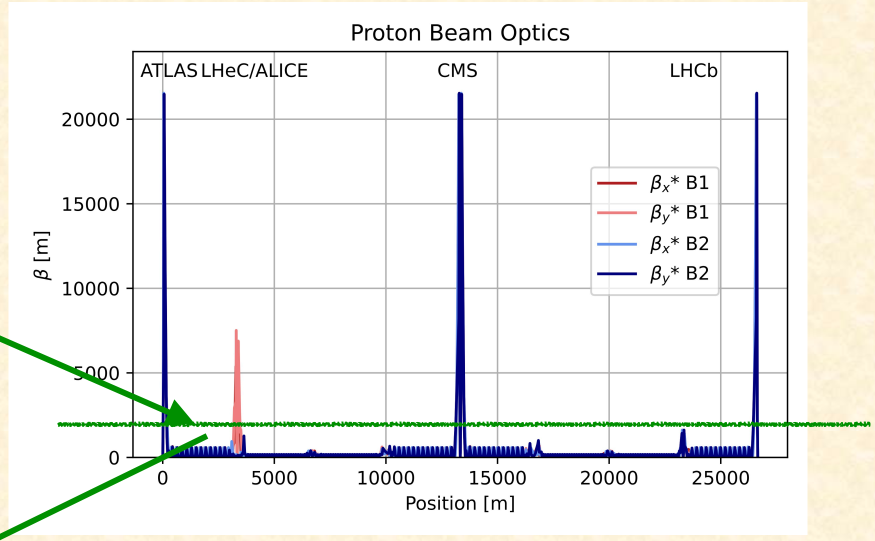

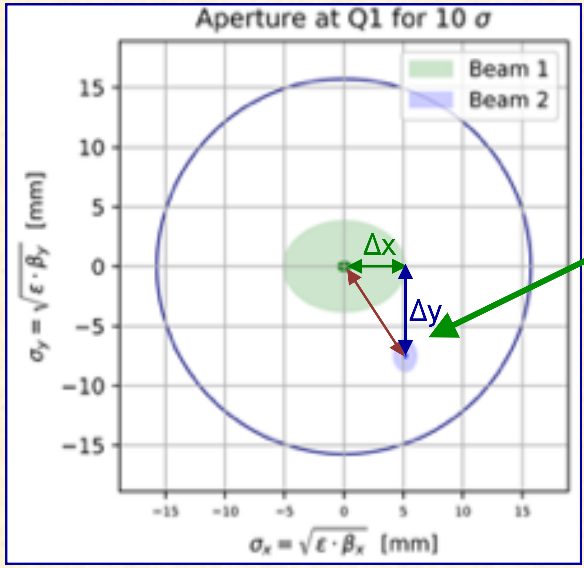

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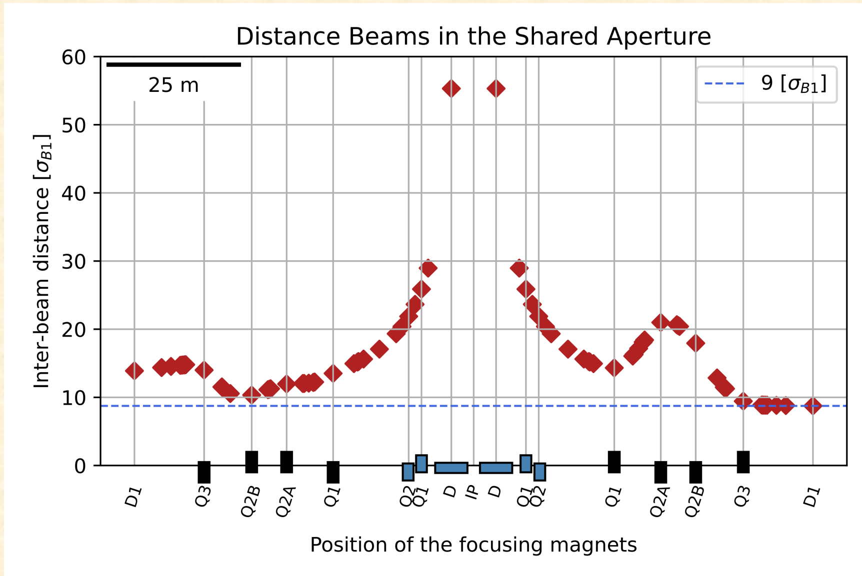


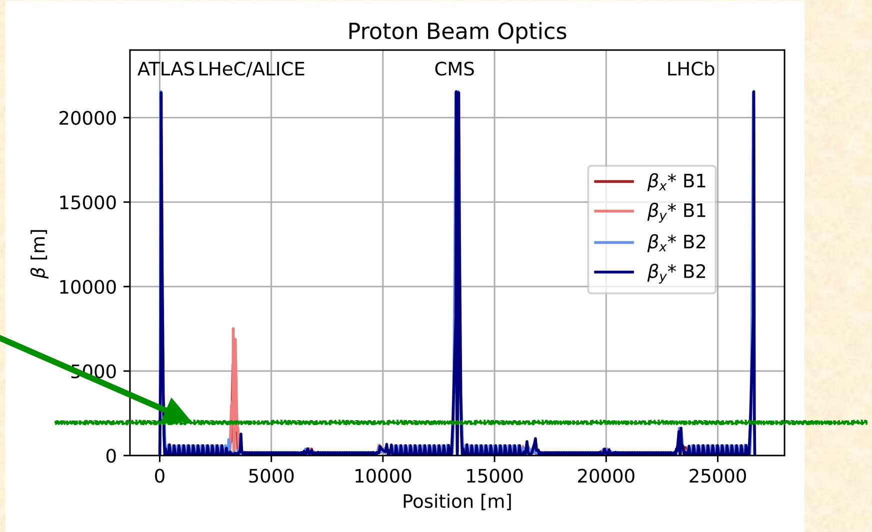
Distance between the two proton beams in their shared aperture in σ of the colliding beam.

Interaction Region: The non-colliding Proton Beam

Tiziana v. Witzleben

Save Aperture for the colliding beam

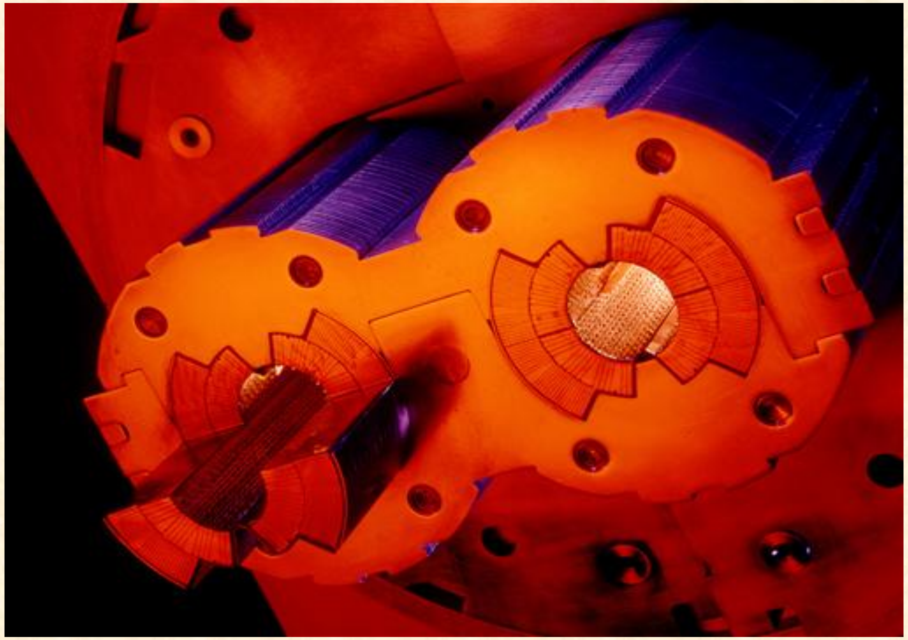
"Relaxed" optics for non-colliding proton beam
*—> **reduced aperture** need in Triplet Quadrupoles!!*



Can we do that ?
—> techn. feasibility …

Yes & No

==> YES



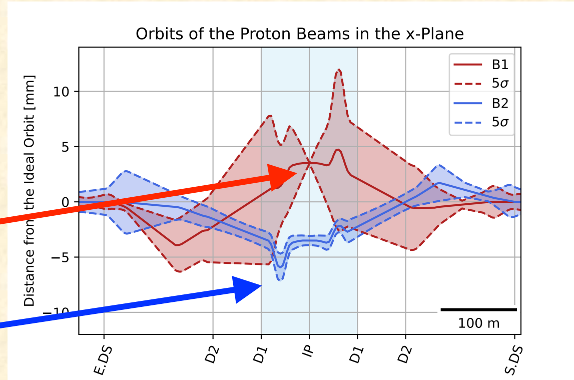
Interaction Region: Protons
… it's a three beam problem

Matthew Smith

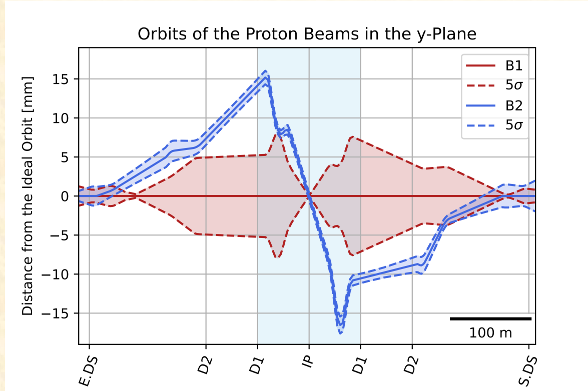
separate 2nd proton beam to avoid (parasitic) encounters

$\beta^*_{p1} = 35\ cm$

$\beta^*_{p2} = 21\ m$



hor Orbit: Separation at IP



vert. Orbit: crossing angle at IP

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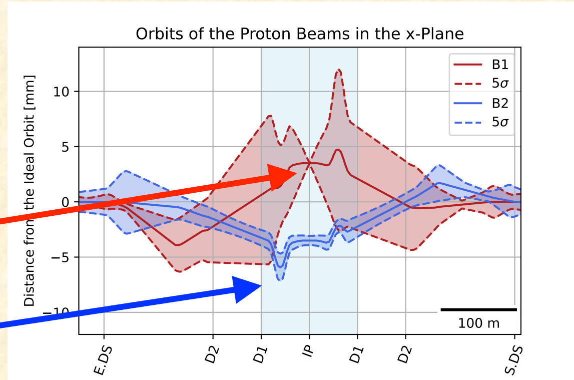

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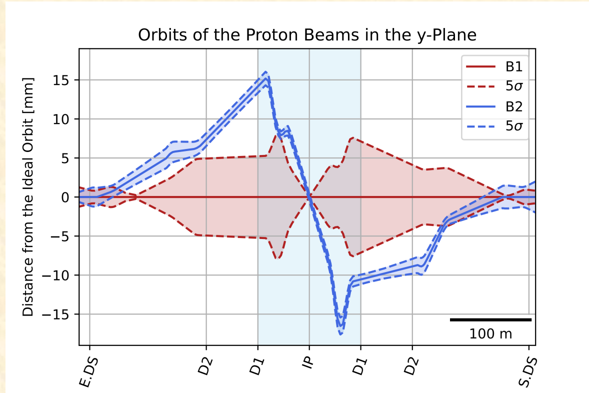
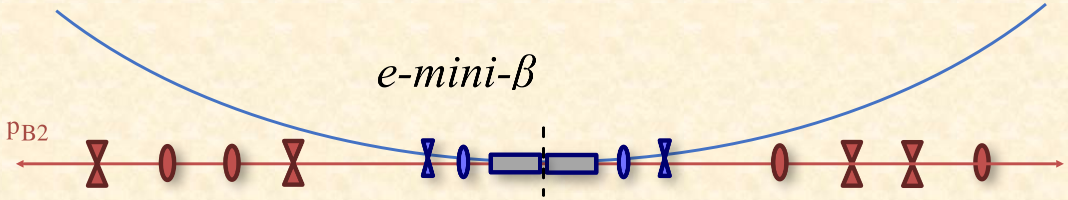


vert. Orbit: crossing angle at IP

compensate influence of e-quads on p-optics & orbit



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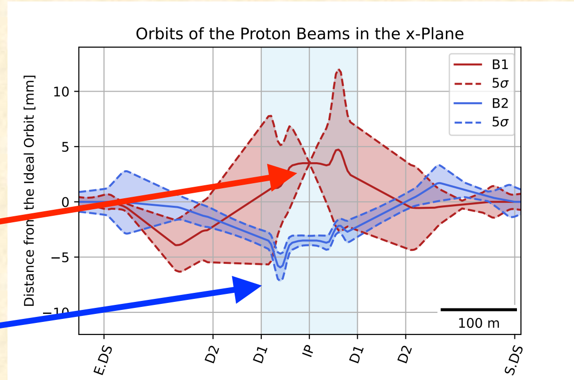

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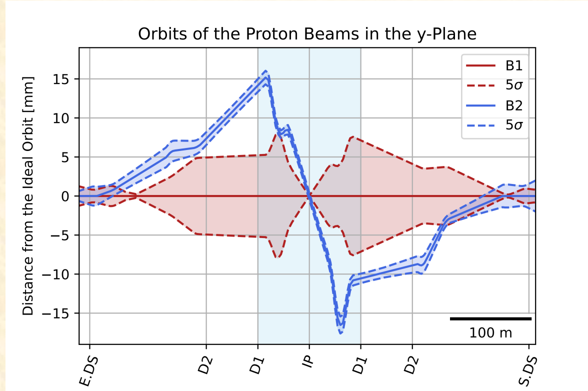

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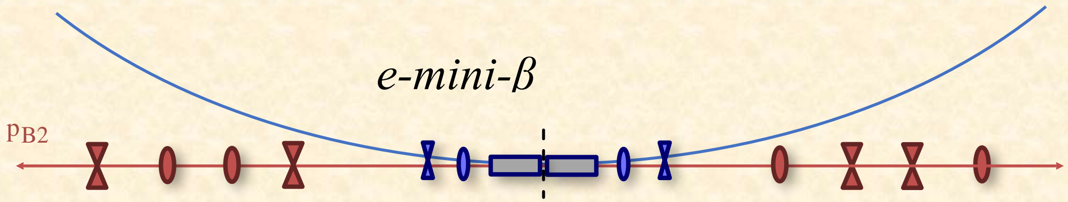
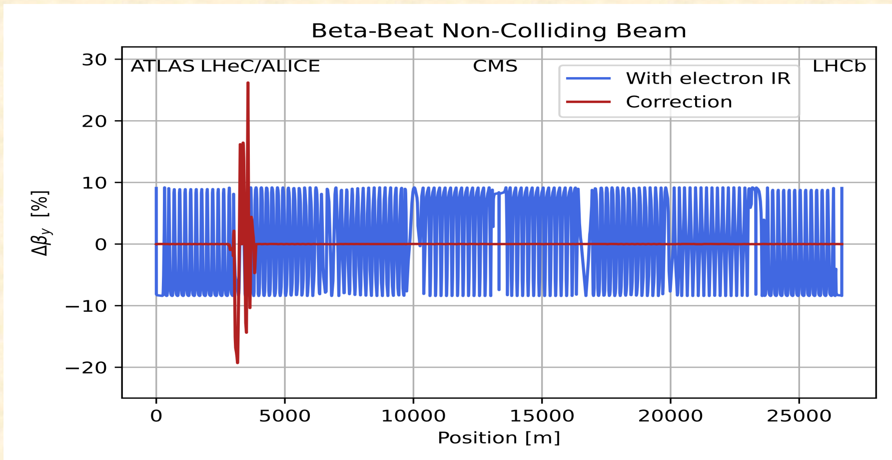
compensate influence of e-quads on p-optics & orbit



re-match of p-optics (2 beams) and correction of p-orbit

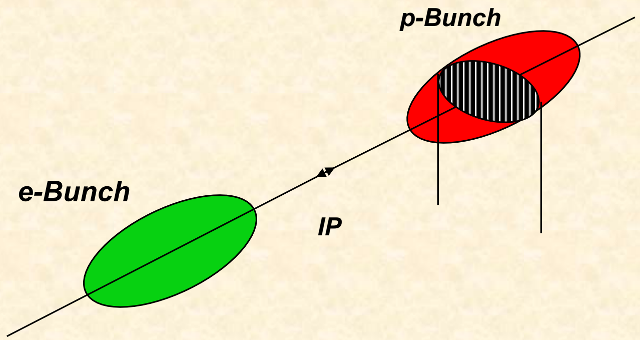


Interaction Region: Luminosity

Tiziana v. Witzleben

$$N_e = 3.1 \cdot 10^9$$
$$\varepsilon_{pn} = 2.5\ \mu m$$
$$\varepsilon_0 = 3 \cdot 10^{-10} rad\ m$$
$$\beta_{x,y} = 35\ cm$$

$\sigma_{xp}^* = \sigma_{yp}^*$ 10 μm

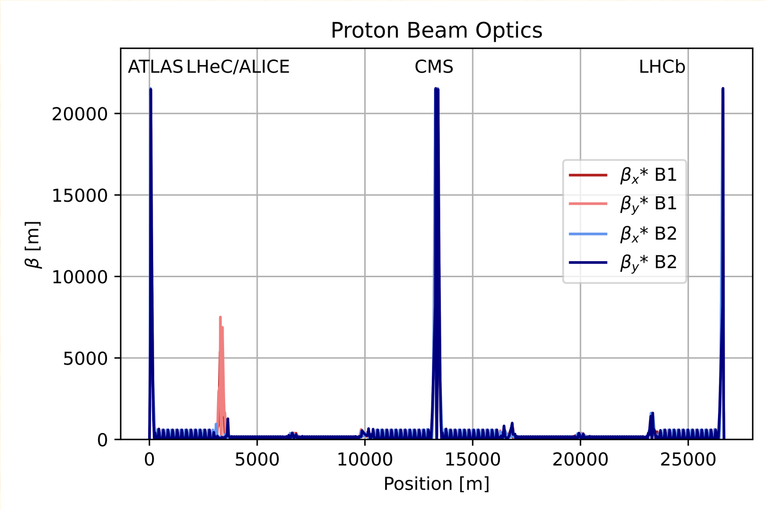


$$L = \frac{N_e \cdot N_p \cdot n_b \cdot f_{rev} \cdot \gamma_p}{4\pi \cdot \epsilon_p \cdot \beta_p^*} * \Sigma_i H_i$$

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

$\Sigma_i H_i \approx 1$

$$L \approx 2 \cdot 10^{33} cm^{-2} s^{-1}$$



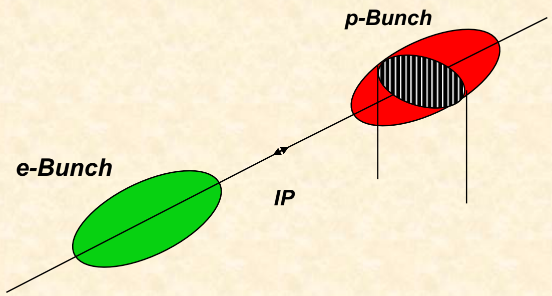
Luminosity:
pushing for the maximum

Tiziana v. Witzleben

$$\beta_{x,y} = 35\ cm \quad \longrightarrow \quad \beta_{x,y} = 15\ cm$$

$$\beta_(s) = \beta^* + \frac{s^2}{\beta^*}$$

ATS design



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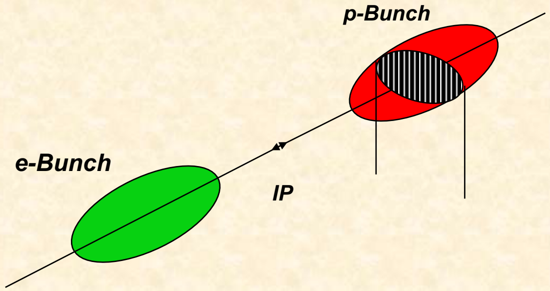
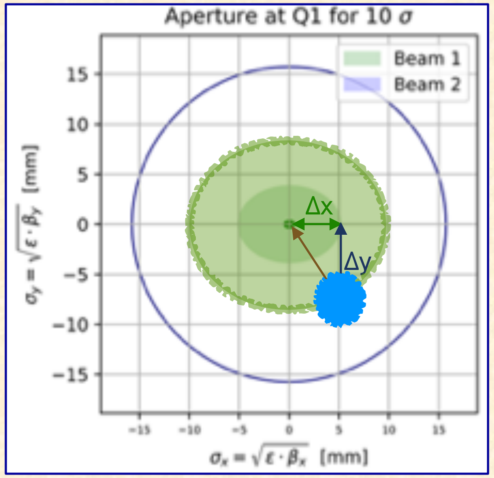




—> ***larger beam size*** *in triplet*

—> ***larger crossing angle*** *p1 / p2*

—> *more* ***aperture need***

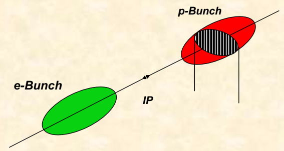
—> ***stronger matching quadrupoles*** *(Q7 … Q12)*

—> *new magnet technology for the triplet:* ***Nb_3Sn***

$$L \approx 2\ \ldots\ 5 \cdot 10^{33} cm^{-2} s^{-1}$$

Luminosity: pushing for the maximum ?

Tiziana v. Witzleben
Sophie Gresty



$\beta_{x,y} = 35\ cm \longrightarrow \beta_{x,y} = 15\ cm$

… not the easiest task

—> ***larger beam size*** *in triplet*

—> ***larger crossing angle*** *p1 / p2*

—> *more* ***aperture need***

—> ***stronger matching quadrupoles*** *(Q7 … Q12)*

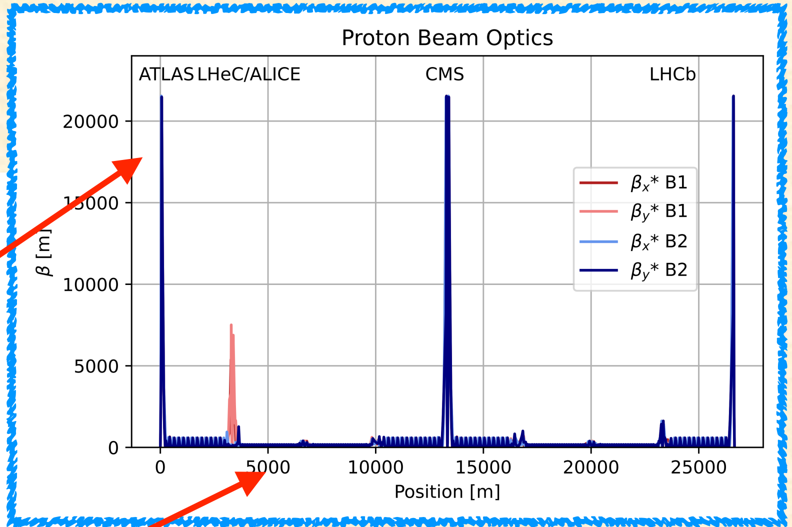
—> *new magnet technology for the triplet … and beyond:* ***Nb₃Sn***

—> *additional* ***chromatic*** *contribution*

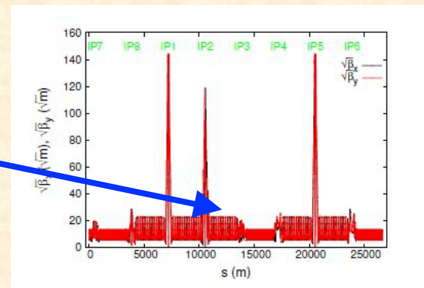
—> *sextupole strength limited*

—> ***ATS towards IR3*** *… which is the momentum cleaning section, where the* ***ratio β/D and μ are fixed***

—> ***dynamic aperture problems***



LHeC 2019,
E. Cruz / R. Martin
L=15m, 1 beam,*
DA limited

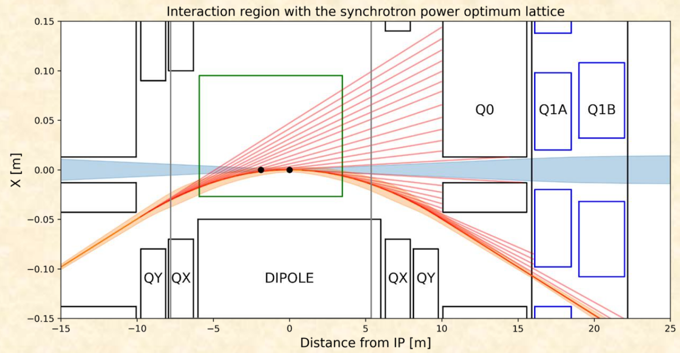


The Challenges & Next steps

Synchrotron light power in arcs ✓

- *absorber design*
- *cooling*

The Challenges & Next steps



Synchrotron light power in arcs ✓

- *absorber design*
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Machine Detector Interface ✓

- *geometry of synchrotron light fan*
- *absorber design*
- *protection of acc. magnets*

The Challenges & Next steps

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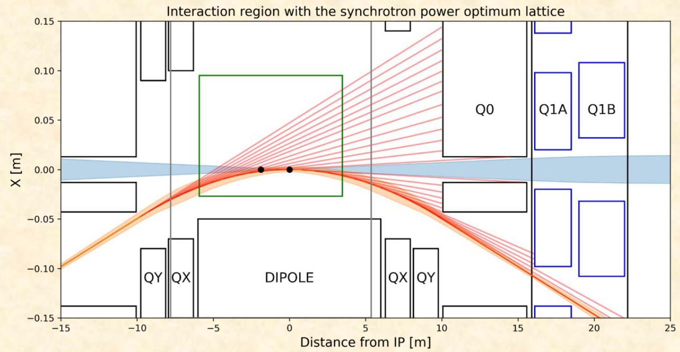

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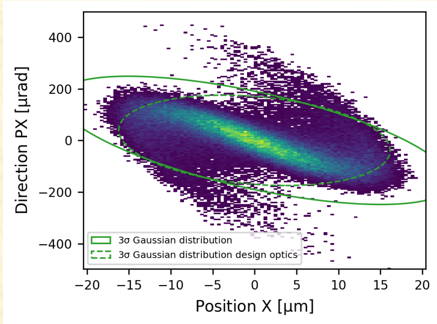
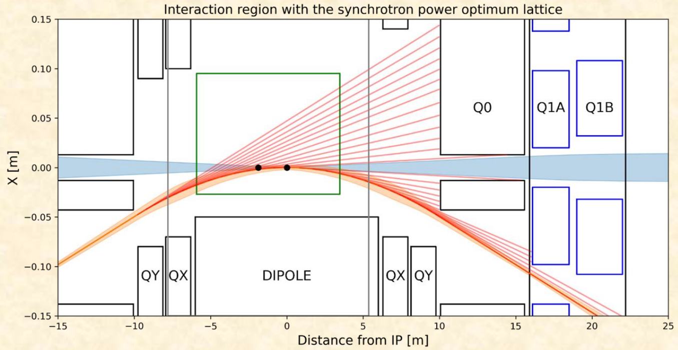


Front-to-End tracking ✓

- *ERL performance / emittance preservation (including beam-beam effect & decelaration mode)*

The Challenges & Next steps



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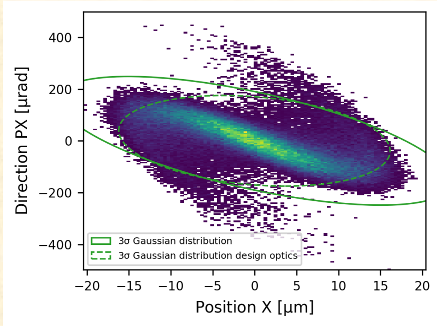

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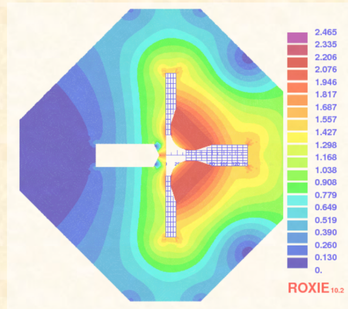
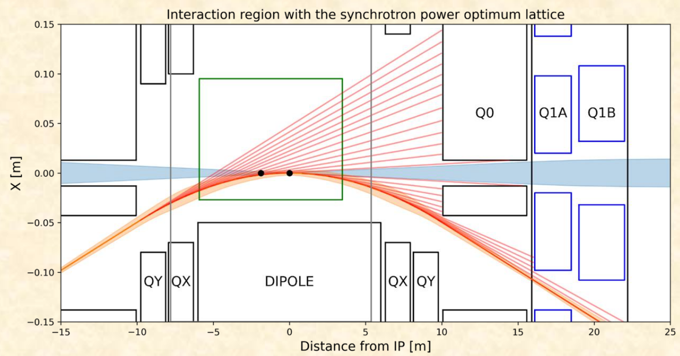


Design for prototypes of special machine elements <—

- *half-quadrupole in IR*
- *spectrometer dipole in spreader*

The Challenges & Next steps



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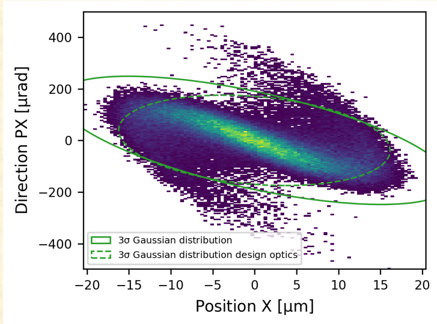
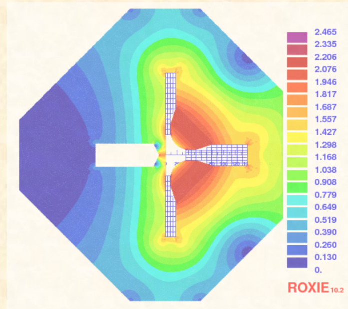
- *absorber design*
- *cooling*



Machine Detector Interface ✓

- *geometry of synchrotron light fan*
- *absorber design*
- *protection of acc. magnets*

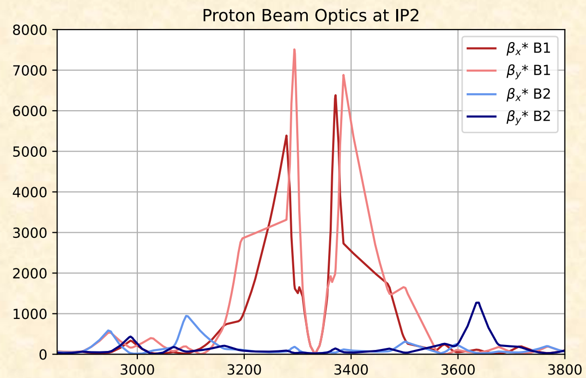


Front-to-End tracking ✓

- *ERL performance / emittance preservation (including beam-beam effect & decelaration mode)*

Design for prototypes of special machine elements <—

- *half-quadrupole in IR*
- *spectrometer dipole in spreader*



Proton Optics —> pushing Luminosity ✓

Conclusion

Optics & Lattice of LHeC nearly done,
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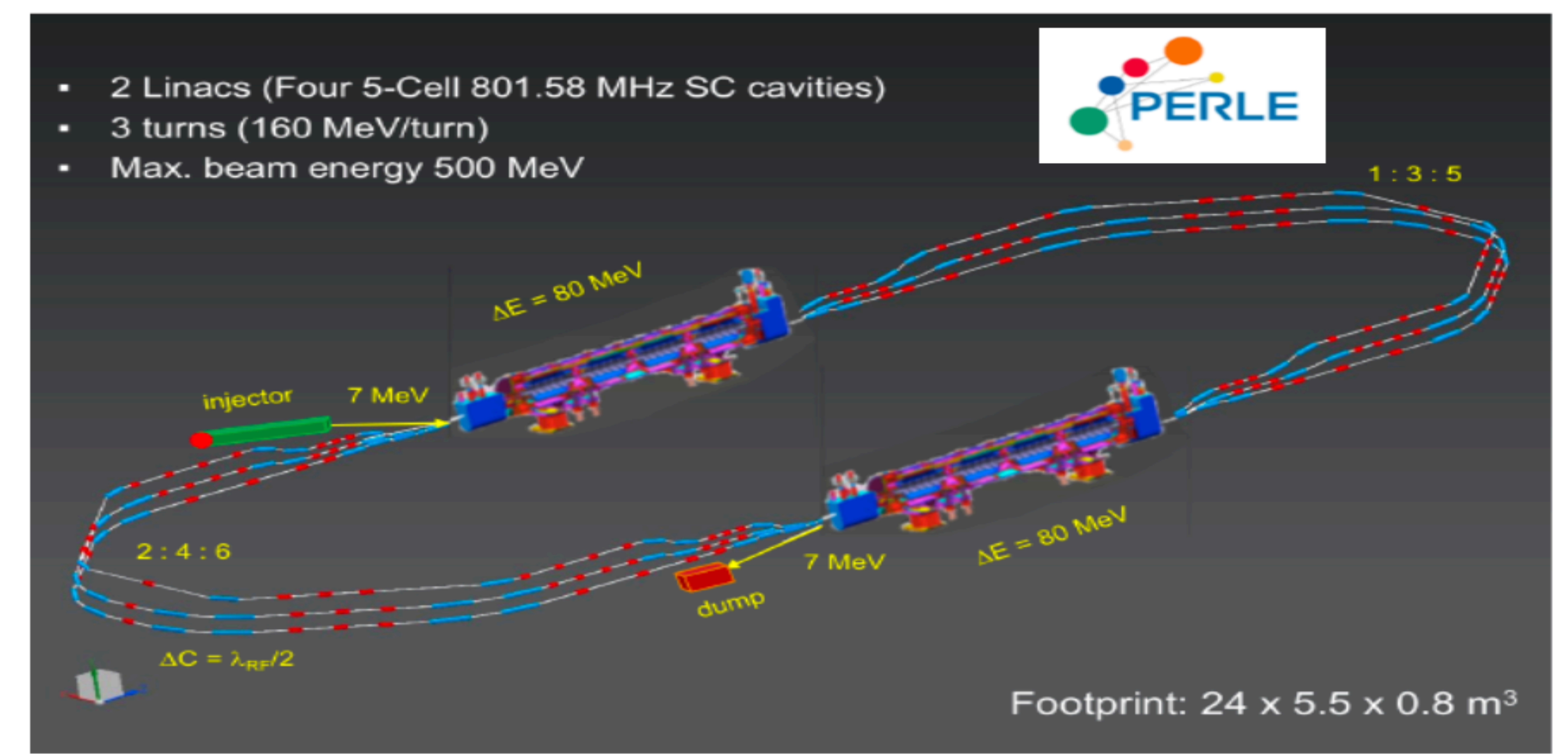
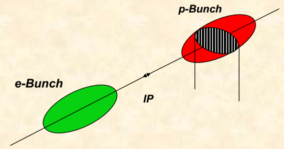
we need PERLE



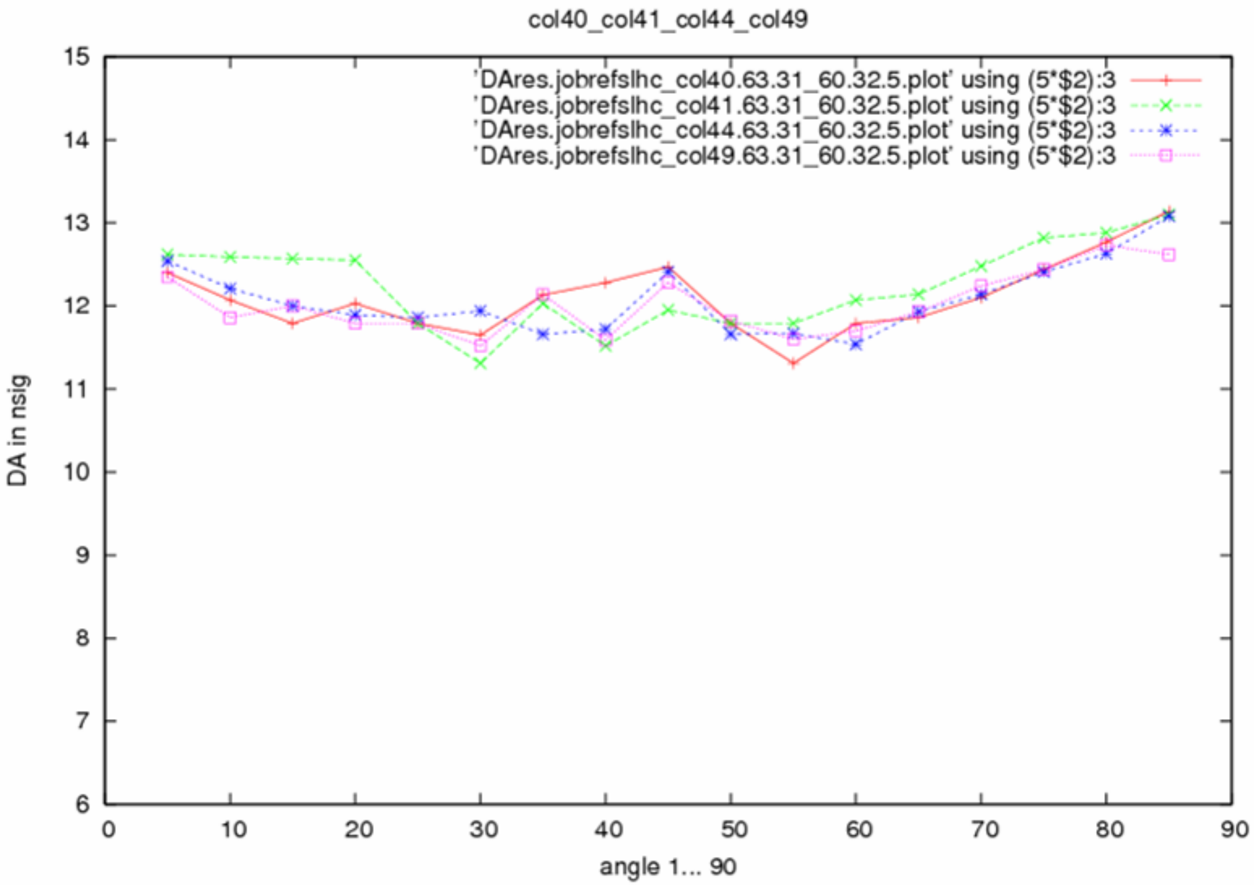
Merci

Dynamic Aperture

$$\beta_{x,y} = 35\ cm \quad \longrightarrow \quad \beta_{x,y} = 15\ cm \quad \ldots \quad 10cm \quad \ldots$$



One beam situation: L* = 15 m



LHeC workshop
Chavannes 2019

Dynamic Aperture

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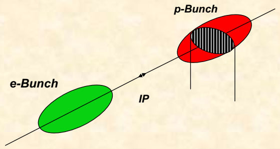

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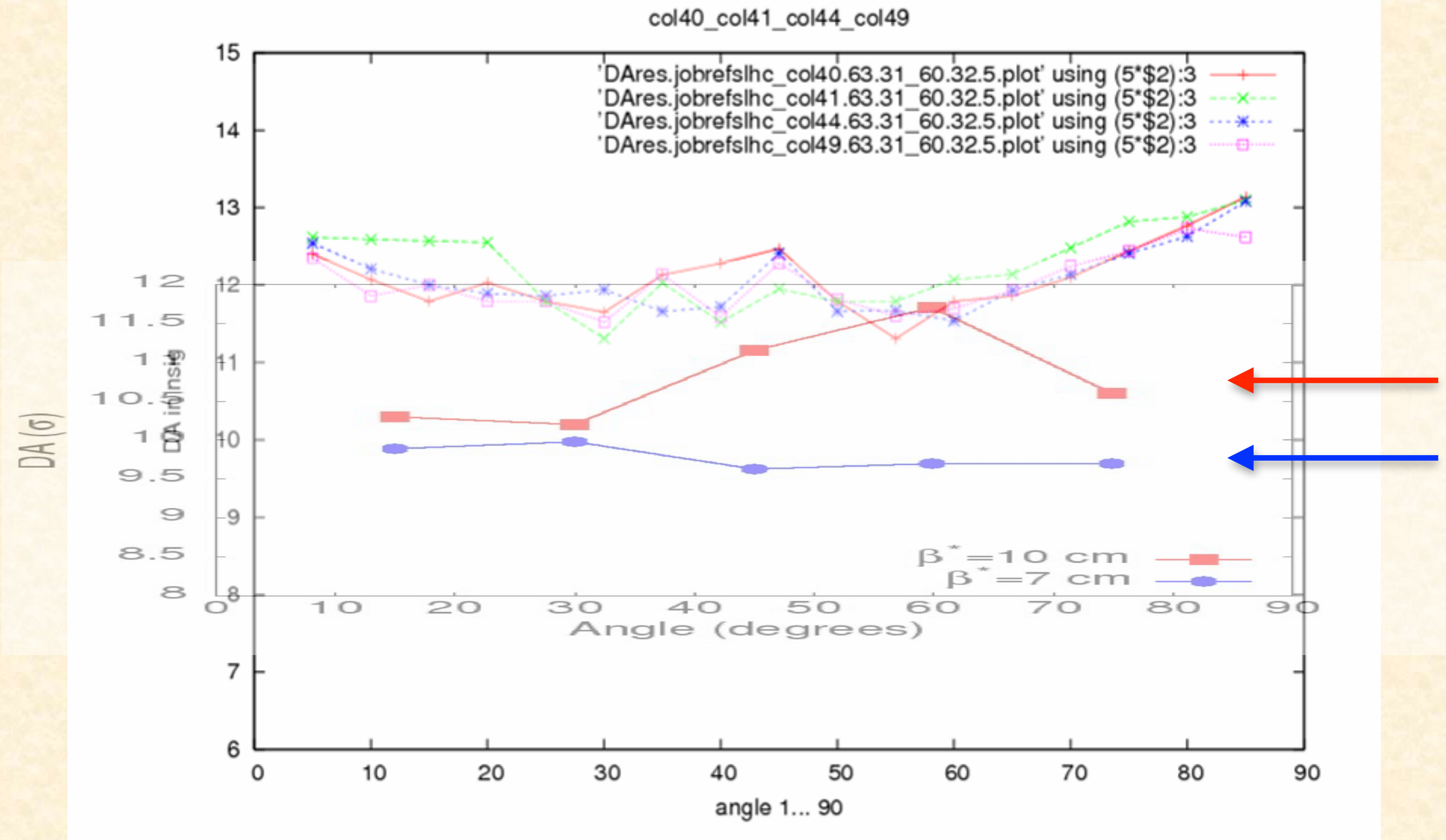


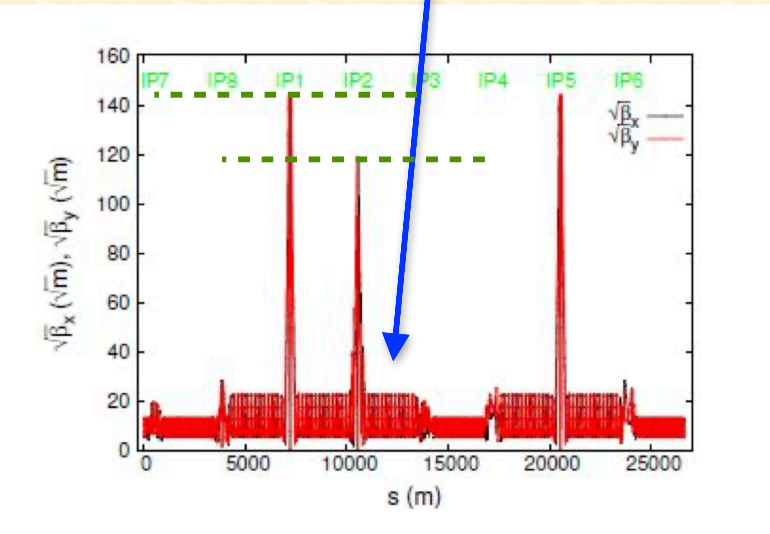
β* = 10cm

β* = 7cm

LHeC workshop
Chavannes 2019

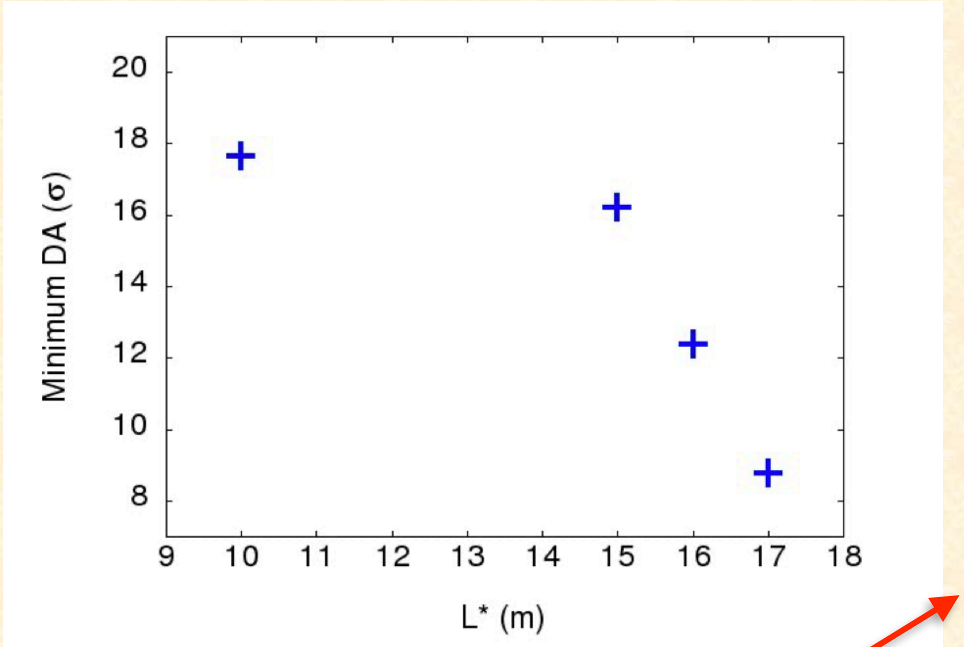
LHeC Workshop Chavannes, 2019

ATS extended to Arc 23

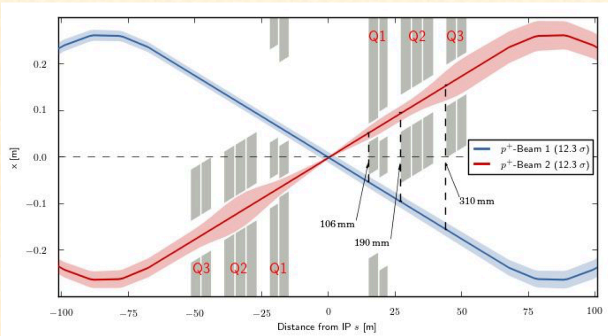


DA Studies for β = 10cm*

$$Q' \propto \frac{(L^*)^2}{\beta^*}$$



Standard: L = 21m*



second proton beam ??
DA ?
Δp/p cleaning ?