FCC-eh Proton Interaction Region Design

Emilia Cruz

Special thanks to: **R. Martin**, R. Tomas, B. Parker

FCC week 2019

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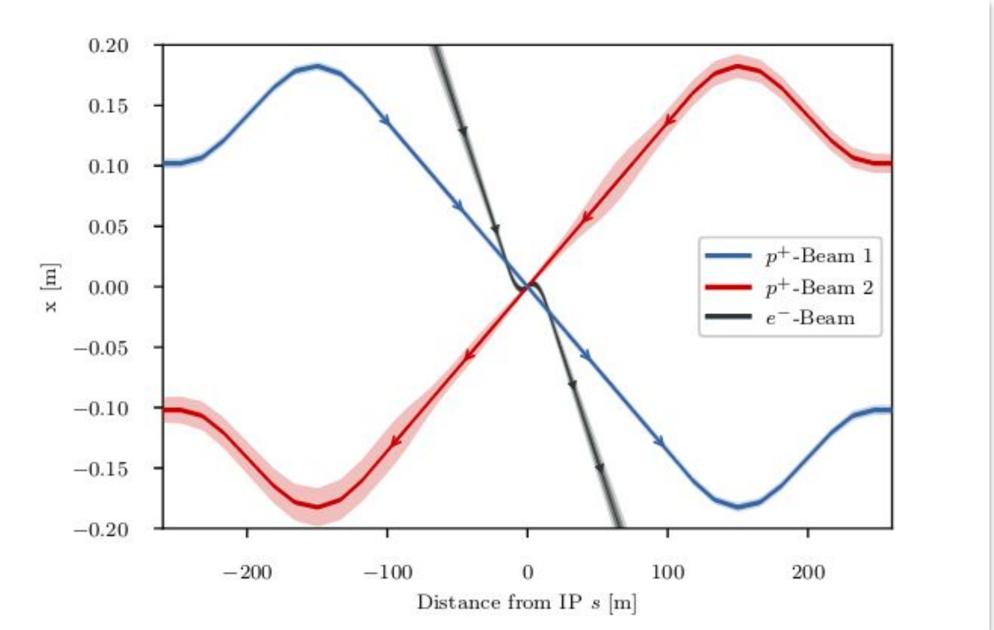
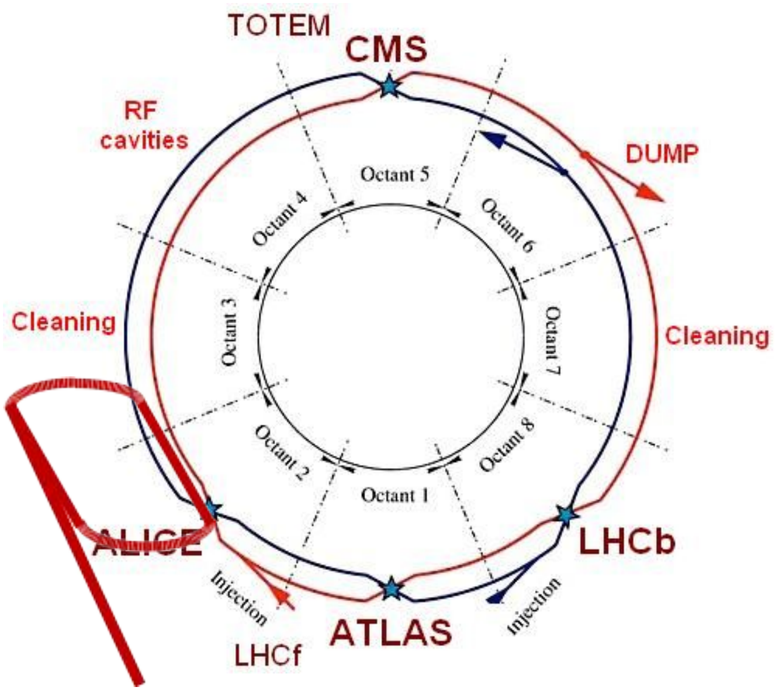
FCC-he IR

- **Aim of the design: Collide one of the proton beams of the FCC with and electron beam while the other beam bypasses the interaction**



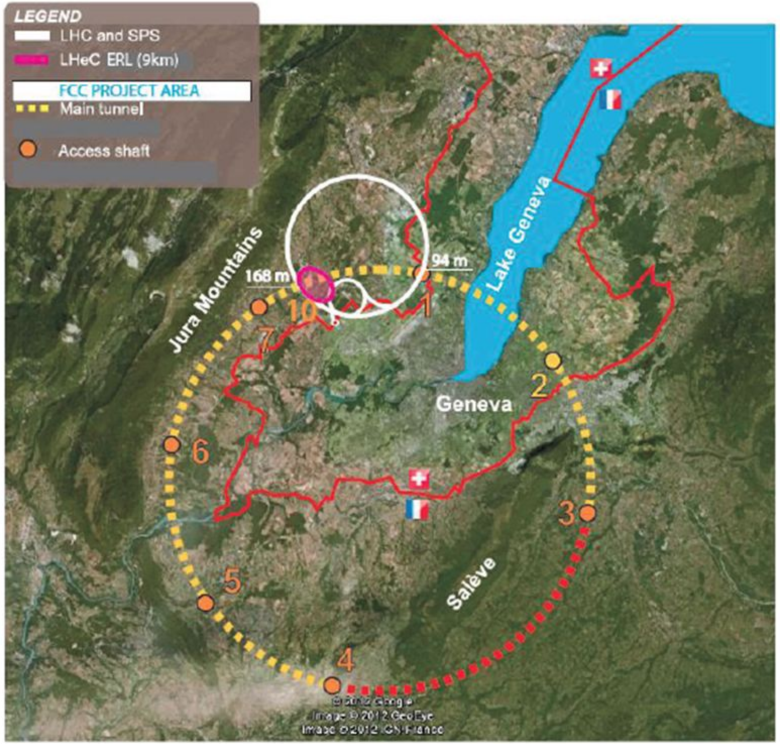
LHeC

- Collide electron beam coming from the ERL with one of the proton beams of the LHC
- IP -> IR2 (ALICE)
- IR designed for other purposes, minimal changes necessary to adapt to new conditions
- Working in parallel with the HL-LHC
- L*~15 m to minimize SR
- Achromatic Telescopic Squeezing scheme (ATS) to reduce beta* and increase chromatic correction efficiency



FCC-he lattice

- Work parallel with FCC-hh
- IPA and IPG main IRs
- Geology dictates point L best option
- Contrary to LHeC doesn't have to be implemented in a new IR with other purposes. Still some limitations:
  - IR to be shared with injection
  - Straight section 1400m
  - Next to IPA



LHeC and FCC-he

- **Follow design of the LHeC.**
- **Comparison of Parameters**

Tech Report CERN-ACC-2017-0019

Parameter	LHeC CDR	FCC-he
E_P [TeV]	7	50
γ_P	7460	53300
E_e [GeV]	60	60
$\sqrt{(s)}$ [TeV]	1.3	3.5
bunch spacing [ns]	25	25
protons per bunch [10^{11}]	1.7	1
$\gamma_p \epsilon_p$ [µm]	3.7	2.2
electrons per bunch [10^9]	1	3.0
electron current [µA]	6.4	20
IP beta function β^* [m]	0.1	0.15
hourglass factor H_{geom}	0.9	0.9
pinch factor $H_{b\text{-}b}$	1.3	1.3
proton filling H_{coll}	0.8	0.8
luminosity [$10^{33}cm^{-2}s^{-1}$]	1	15

Goal: $\gamma\epsilon_e = 10\,\mu m$

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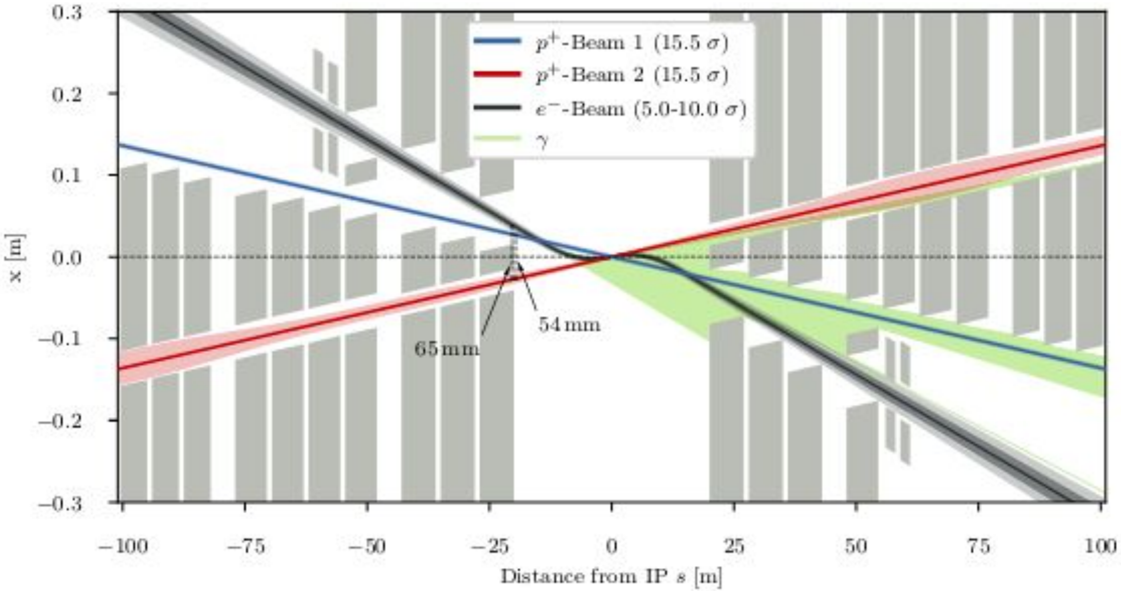
Try β*=0.3 m first

Goal: $\gamma\epsilon_e = 10\,\mu m$

IR Design - Magnets

- **Possible design with β*=0.3 m and L*=20 m**

R.Martin/FCC week 2018

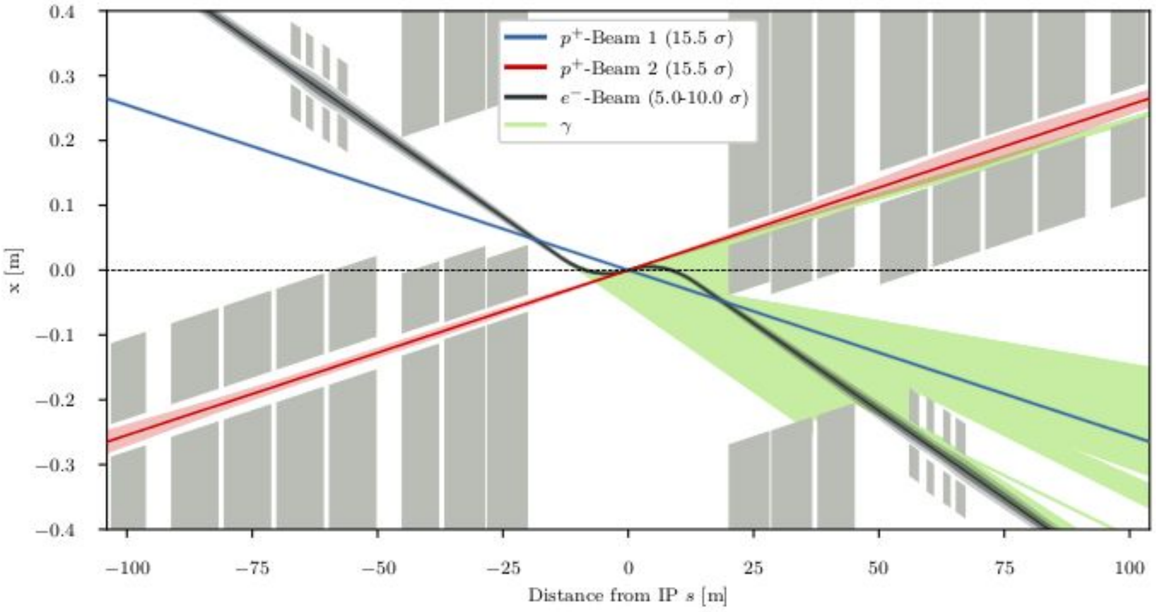


- **Use similar design fro LHeC- adapted to corresponding aperture/gradients**
- **Design with free- field aperture for electron and non-colliding proton beam**

IR Design - Magnets

- **Updated IR design: New magnets**

R.Martin



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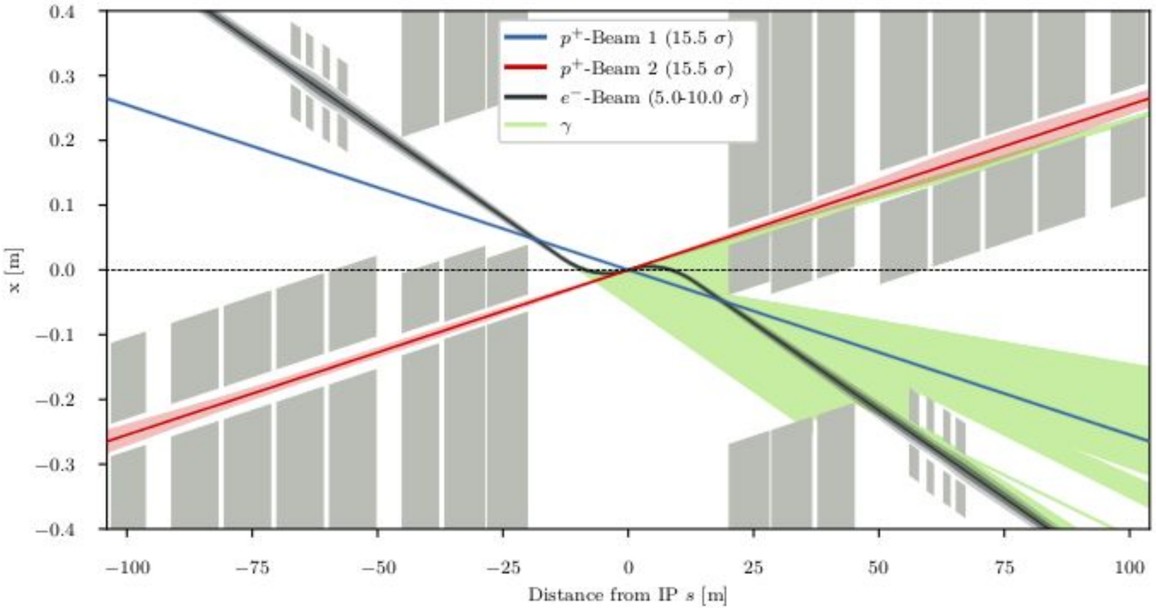

- **New magnet design by B. Parker -validated for LHeC, work needed for FCC-he**
- **Increase separation to optimize free field region**
- **Tighter bend**

IR Design - Magnets

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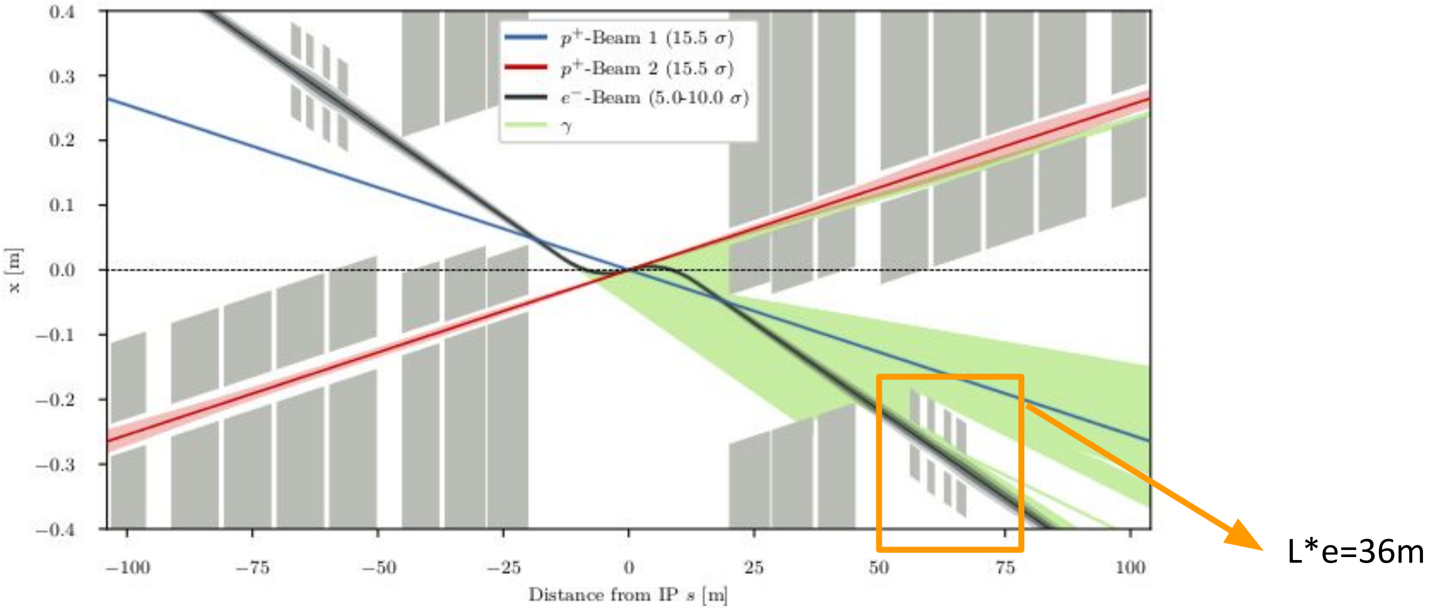
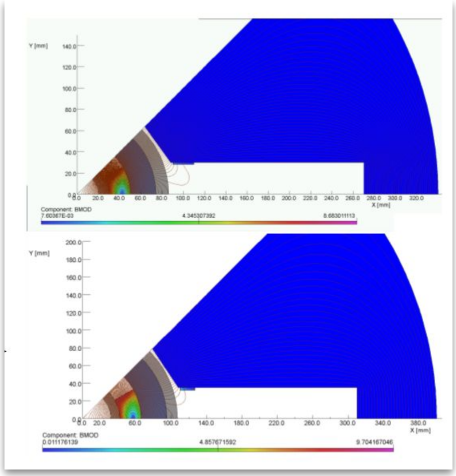


- **New magnet design by B. Parker -validated for LHeC, for FCC-he needs more work**
- **Increase separation to optimize free field region**
- **Tighter bend**

IR Design - Magnets

- **Updated IR design: New magnets**

B. Parker

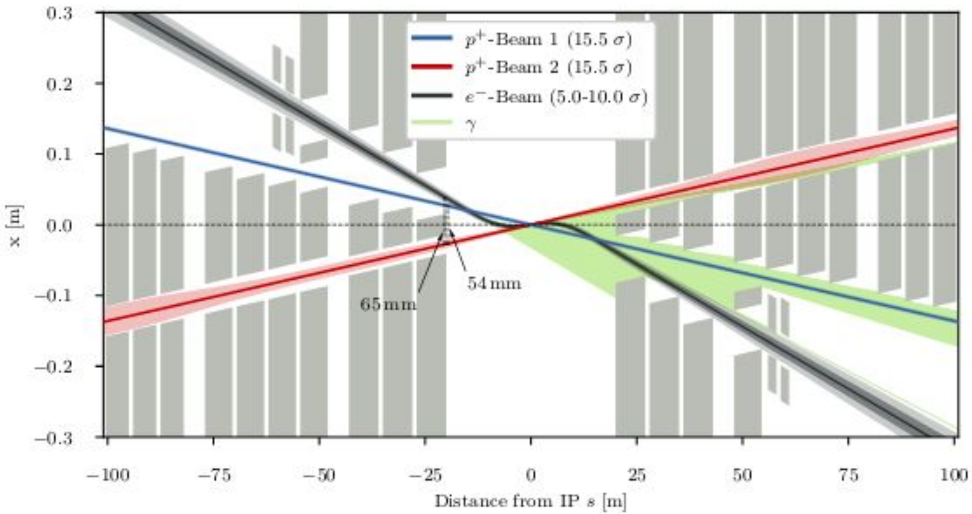


	Q1a	Q1b	Q2	Q3
Length (m)	8.2	7.5	9.5	7
k1 (m-2)	0.001439	0.001476	0.0011297	0.0011
Aperture (m)	0.013	0.017	0.025	0.025

- **New magnet design by B. Parker -validated for LHeC, still needed for FCC-he magnets**
- **Increase separation to optimize free field region**
- **Tighter bend**

Synchrotron Radiation

- **Previous design - using old LHeC magnets**
- **IR design with β*-0.3 m and L*=23 m**



FCC-he
Psynch=13kW
Ecrit=176 KeV

LHeC
Psynch=49kW
Ecrit=718 KeV

Synchrotron Radiation

- **Using updated magnets - stronger bending**
- **IR design with β^*-0.3 m and L^*=23 m**

Synchrotron Radiation

- **Using updated magnets - stronger bending**
- **IR design with β*-0.3 m and L*=23 m**

LHeC

	50 GeV, 6.4 mA	50 GeV, 20 mA	60 GeV, 6.4 mA	60 GeV, 20 mA
P_{synch}	13 kW	40 kW	27 kW	83 kW
E_{crit}	296 keV		513 keV	

FCC-eh

Psync	16.7 kW	34.7 kW
Ecrit	165 keV	286 keV

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FCC-eh

Psync	16.7 kW	34.7 kW
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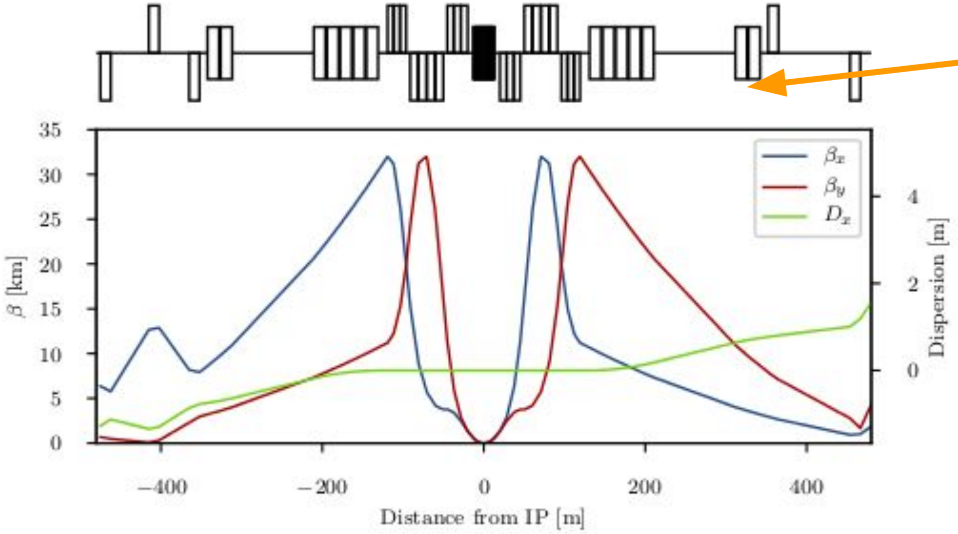
- SR Power and Ecrit is more than halved in comparison with similar case with LHeC
- Even lower if 50 GeV is considered

IR Design β*=0.3 m - Optics

R.Martin



Matched **colliding beam**:
Collision optics

IR Design β*=0.3 m - Optics

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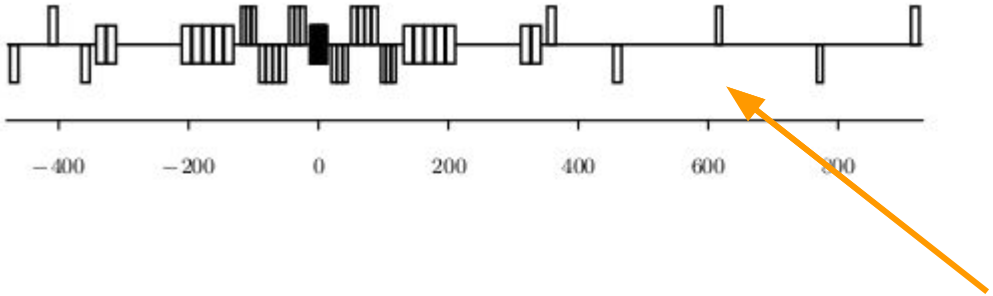
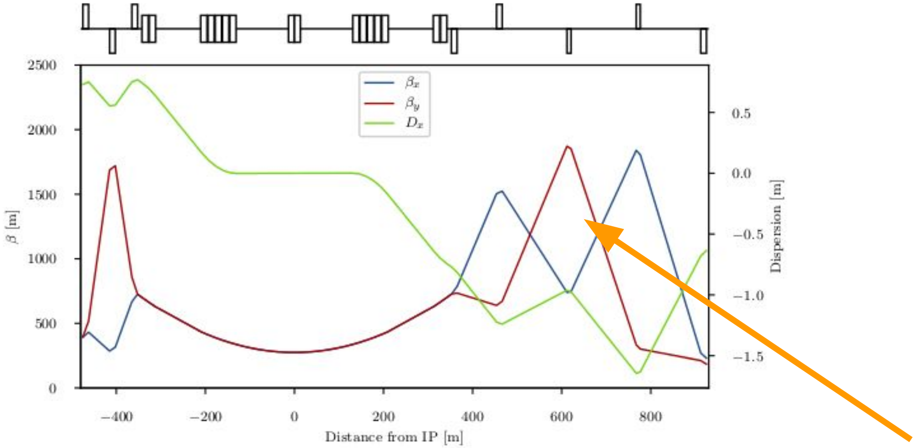


Injection section provides additional matching - quadrupoles on one side

IR Design β*=0.3 m - Optics

R.Martin



Non-colliding beam at collision
High β function in quadrupoles

Injection Optics more challenging

FCC-he lattice Integration

- Based on FCC-hh lattice (β^*=30 cm in IPA and IPG)
- New low-β^* IR (IRL)
- No ATS-scheme (unlike LHeC)
- Chromaticity correction
  - Achievable for this case? How does it compare to nominal FCC-hh
- Extensive DA studies have been done for the FCC-hh
  - Is the DA affected when including the new IR?
  - Estimate errors on the triplet, what’s the effect?
  - Do we need non-linear correctors on this IR as well?

Chromaticity Correction

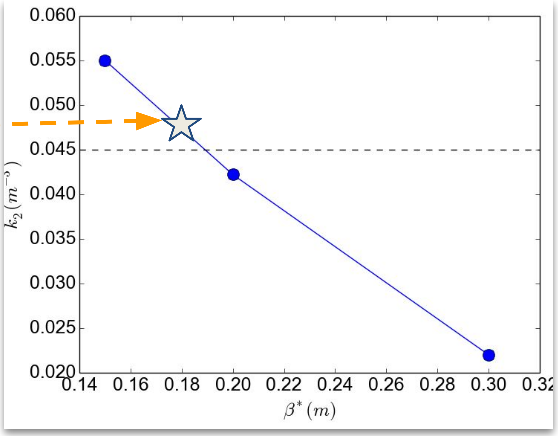
- LHeC uses ATS to correct chromaticity not implemented in FCC-eh
- ATS allows to increase the efficiency of the chromatic correction
- FCC-eh, as well as the cases for lower β* of FCC-hh, is beyond the chromaticity correction limit

Some of the sextupole families are above the limit:
k2:=-0.0480

Perhaps can be fixed by optimizing the chromaticity correction

Otherwise a different scheme must be implemented

ATS?



E. Cruz
DA Studies

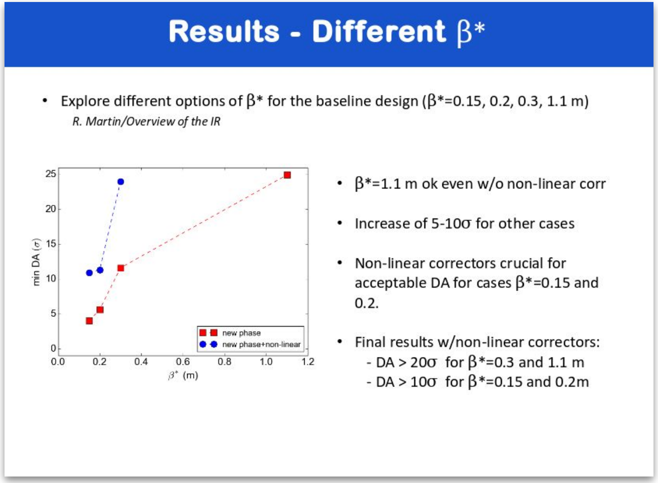
DA studies at Collision

- 60 seeds/10^5 turns/5 angles no beam-beam

- Field errors in triplet, separation/recombination dipole/arcs

- Baseline Corrections →
  - Chromaticity +tune correction
  - Crossing IPA and IPG
  - Spurious dispersion (SSC and HL-LHC like)
  - Coupling correction
  - Arc dipoles correction (*B. Dalena/ DA at injection*)
  - Non-linear correctors
  - Phase optimization

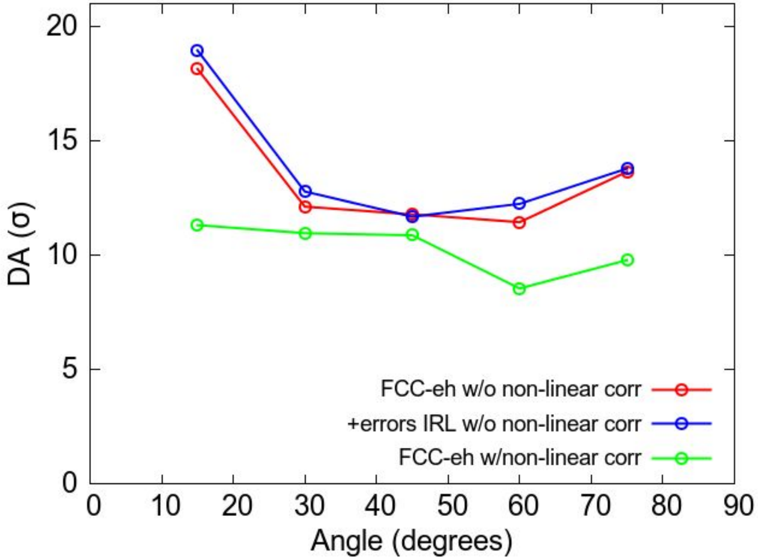
E. Cruz
DA Studies



- Main result for FCC-hh is:
  - **DA > 10σ** w/o non-linear corr
  - **DA > 20σ** w/ non-linear corr
- Same for FCC-he?

FCC-he

Repeat studies for case including FCC-eh (β*=0.3m in IPA, IPG and IPL)



- Min DA is similar to case for FC-hh
  - DA= 11.4σ
- Similar errors were added to the new triplet (IRL) to check impact and DA stay the same
  - DA= 11.6σ
- Surprisingly when non-linear errors were added DA went down (only case when this happens)
  - DA= 8.55σ

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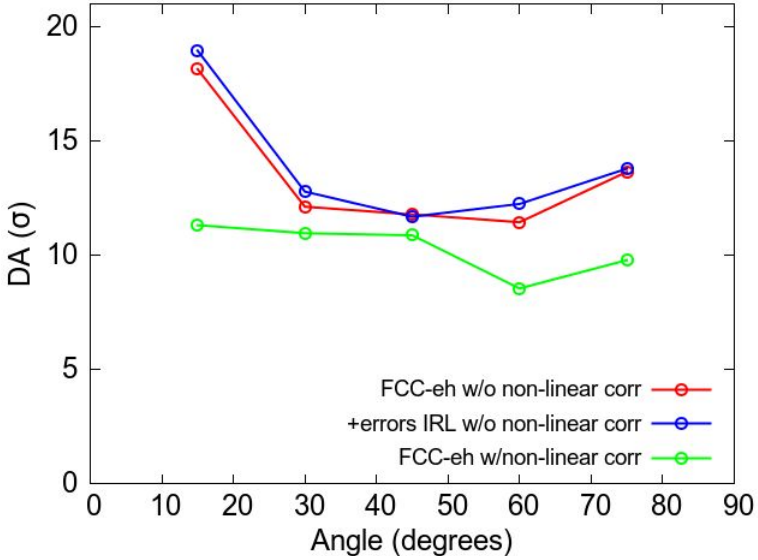

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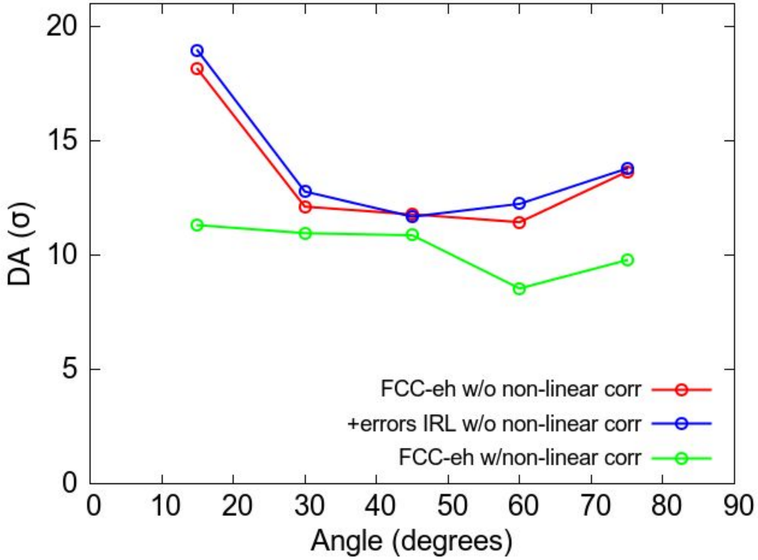

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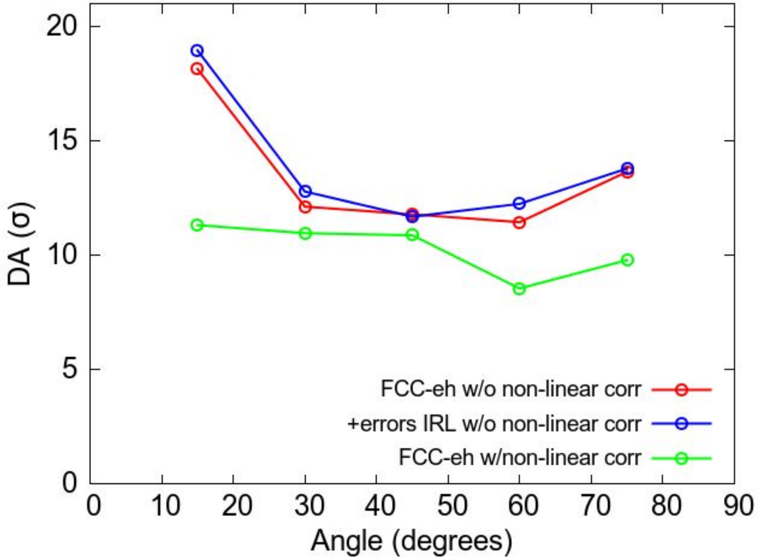

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FCC-eh is the case where phase impacts the most, so more tests will be made with non-linear correctors

Cases for lower β*

Goal β*=15 cm ---> Can we get there?

Possible limitations:

- Available space
- Synchrotron Radiation Power
- Magnet aperture and gradients

R.Martin

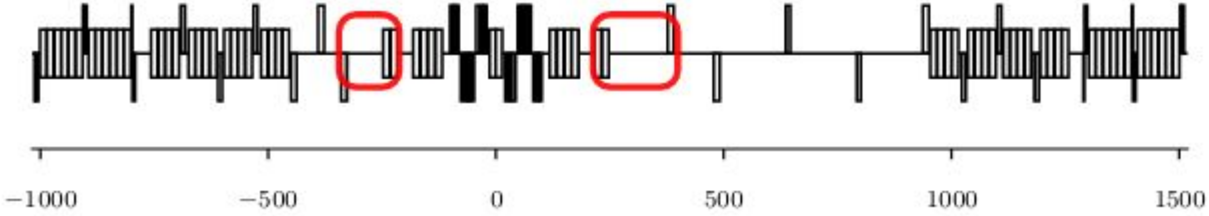
Cases for lower β*

Goal β*=15 cm ---> Can we get there?

Possible limitations:

- **Available space**

  Some margins are left



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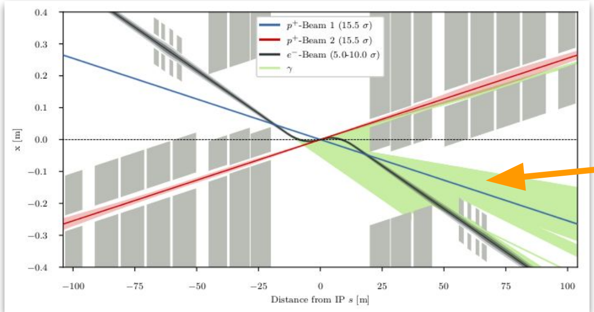

- Currently **Psynch=34 kW Ecrit=286 KeV**
- How much more can we take?

- Magnet aperture and gradients

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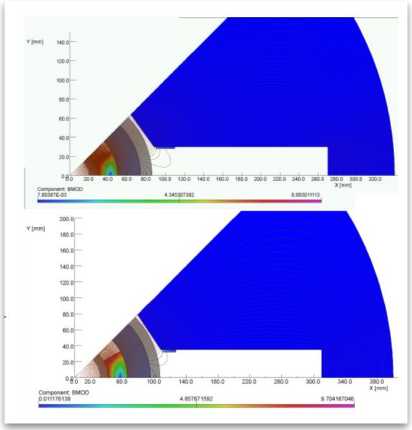
Goal β*=15 cm ---> Can we get there?

Possible limitations:

- Available space
- Synchrotron Radiation Power
- **Magnet aperture and gradients**



- We have LHeC magnet model
- Free field for non-colliding beam provides challenging design
- Needs to be validated for FCC-eh
- Likely to be the **real limitation**

Summary

- The **new magnet design** for the LHeC has been adapted to the FCC-eh IR
- The new magnets provide a better field quality, particularly on the free field region, but results in **higher SR** than the previous design. Still better than for the LHeC case
- The case for β^*=0.3 m has been matched and integrated into the lattice but cases for **lower β^*** has extra challenges
    - **Chromaticity correction** needs to be addressed (maybe even for the case with β^*=30 cm)
    - IRL has to be shared with injection -> **limitation on space**
    - **Magnet design** has to be validated for this case
- The **gradient/aperture of the magnets**, just like the LHeC, might give the biggest limitation.


YouTube BE
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Figure 2.14: Layout of the FCC-eh interaction region. Quadrupole parameters are estimates based on magnets designed for LHeC.
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Thanks!