

# Future hadron colliders

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**JAI FEST, RHUL**



- Future colliders.
- Conceptual Design report and plans
- FCC-hh and JAI contribution
- HE-LHC and JAI contribution
- JAI-Oxford publications
- Conclusions

# Future colliders

- (HL)-LHC will operate until, at least, 2035.
- Two different options are considered for its successor. Both of them with 16 T dipole magnets.
  - HE-LHC: LHC tunnel, 13.5 TeV beam energy,
  - FCC-hh: new tunnel, ~100 km, 50 TeV beam energy.

This will include a 'prequel': an  $e^+e^-$  collider in the new tunnel: **FCC-ee**, with 45.5 -182.5 GeV beam energy.

- Possibility to add electrons for an electron-proton collider.



The Large Hadron electron Collider

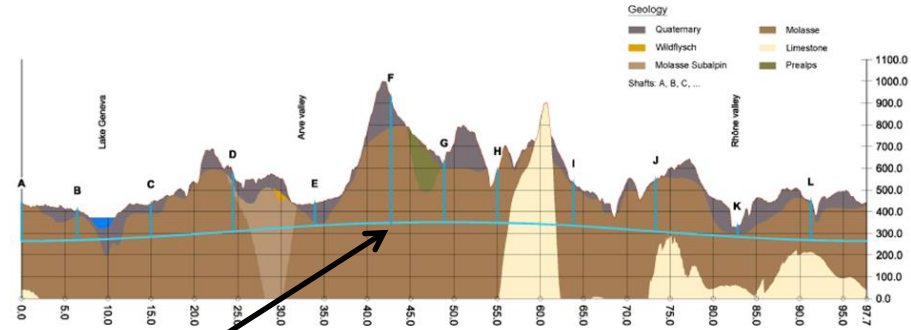
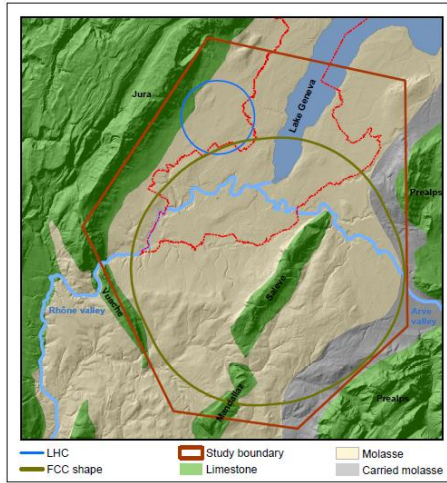
# Conceptual Design report and plans

- The CDR (short version) is being printed and will be released for Christmas. Volumes:
  - Physics: Vol 1
  - FCC-ee: Vol 2
  - FCC-hh: Vol 3
  - HE-LHC: Vol 4
- The long version will be available for 2019.
- European Particle Physics Strategy Update in 2020.

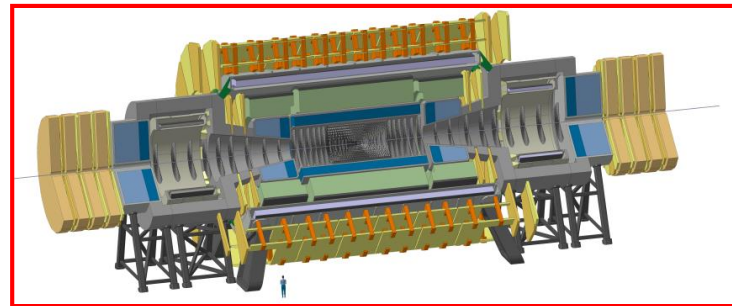


Future collider rivalry: linear vs circular

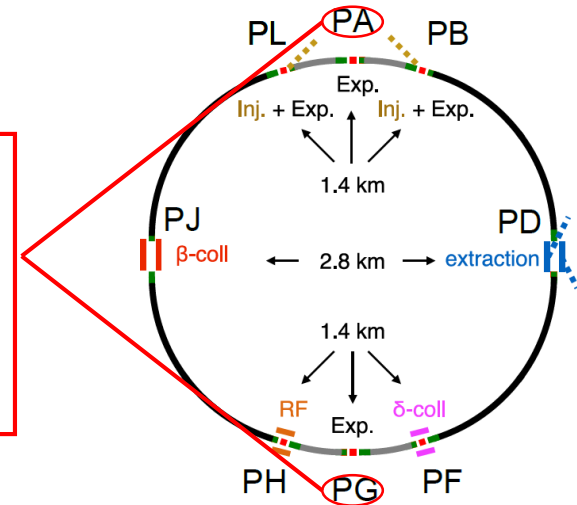
# FCC-hh



Sagitta: 80 m



Generic detector

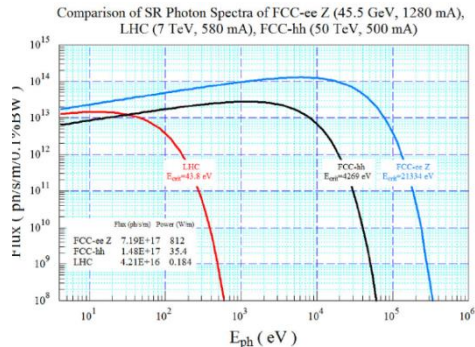
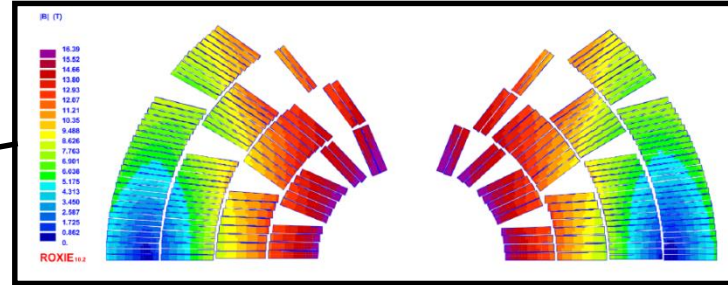
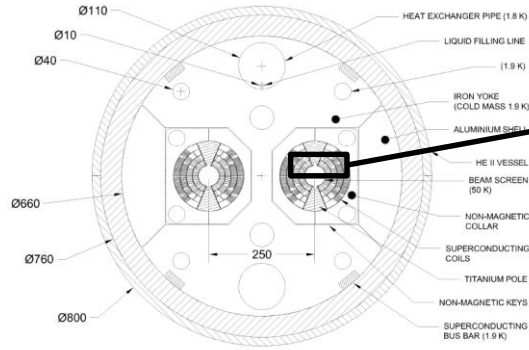


Luminosity =  $(20-30) \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

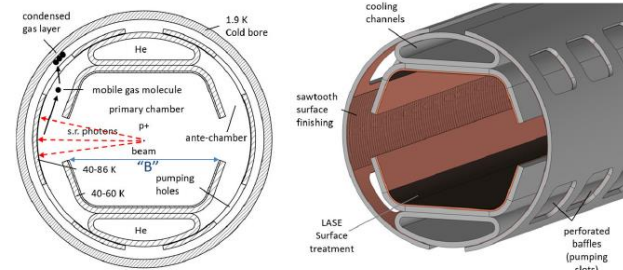
Daily Luminosity =  $2-8 \text{ fb}^{-1}$

Integrated Luminosity =  $18.5-30 \text{ ab}^{-1}$

- New, 16 T magnets based on Nb<sub>3</sub>Sn



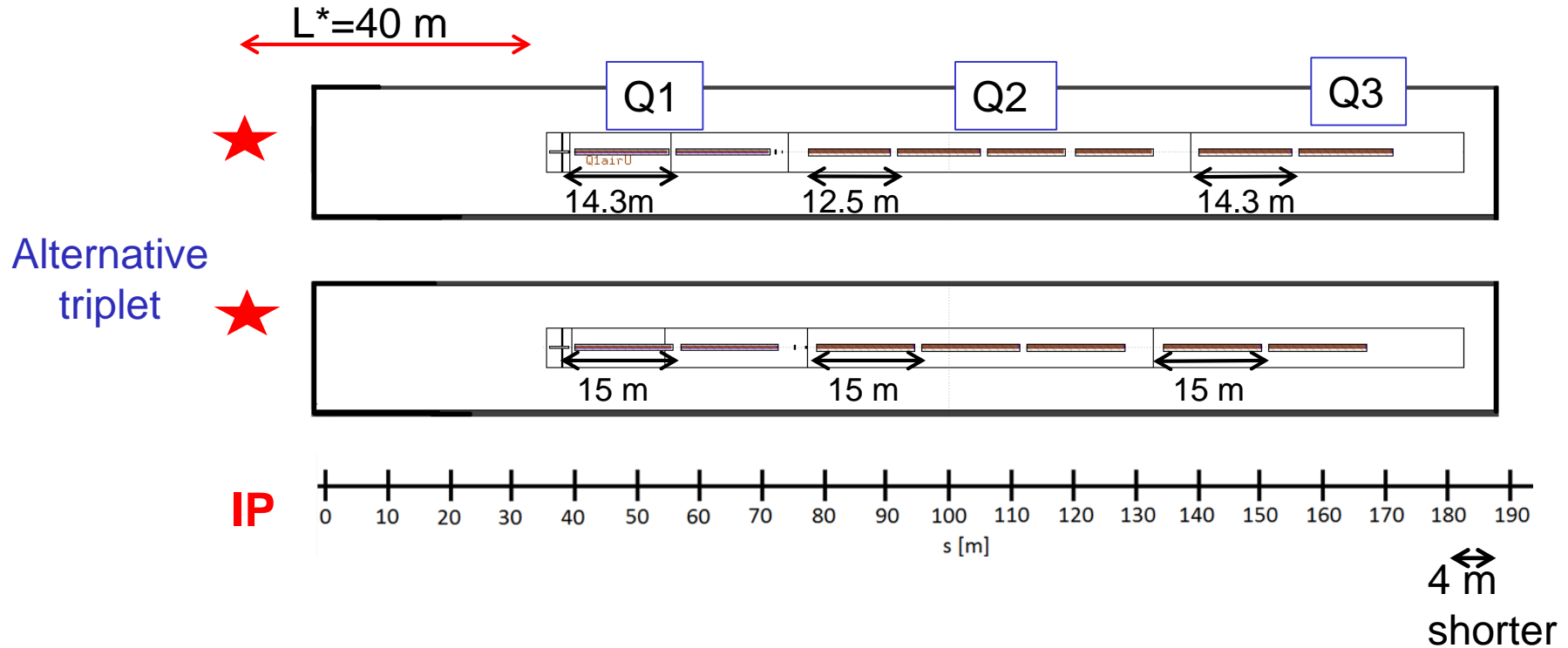
High SR radiation



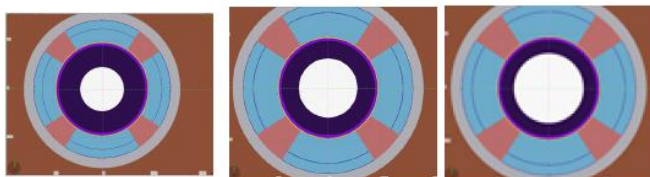
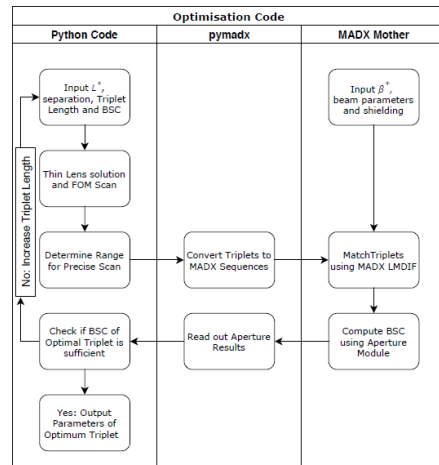
Vacuum pipe

# FCC-hh: JAI-Oxford contribution

- Design of an alternative option for the final triplet.



- Interaction region optimization for an alternative triplet

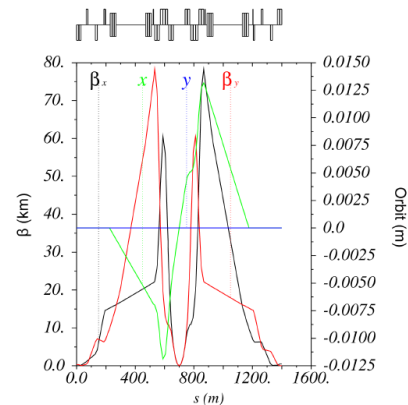


Q1

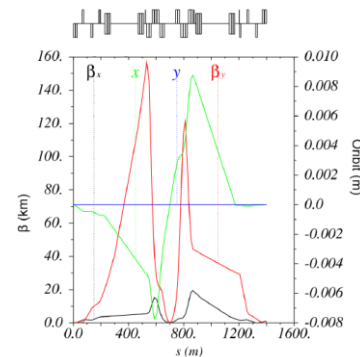
Q2

Q3

Magnets cross sections



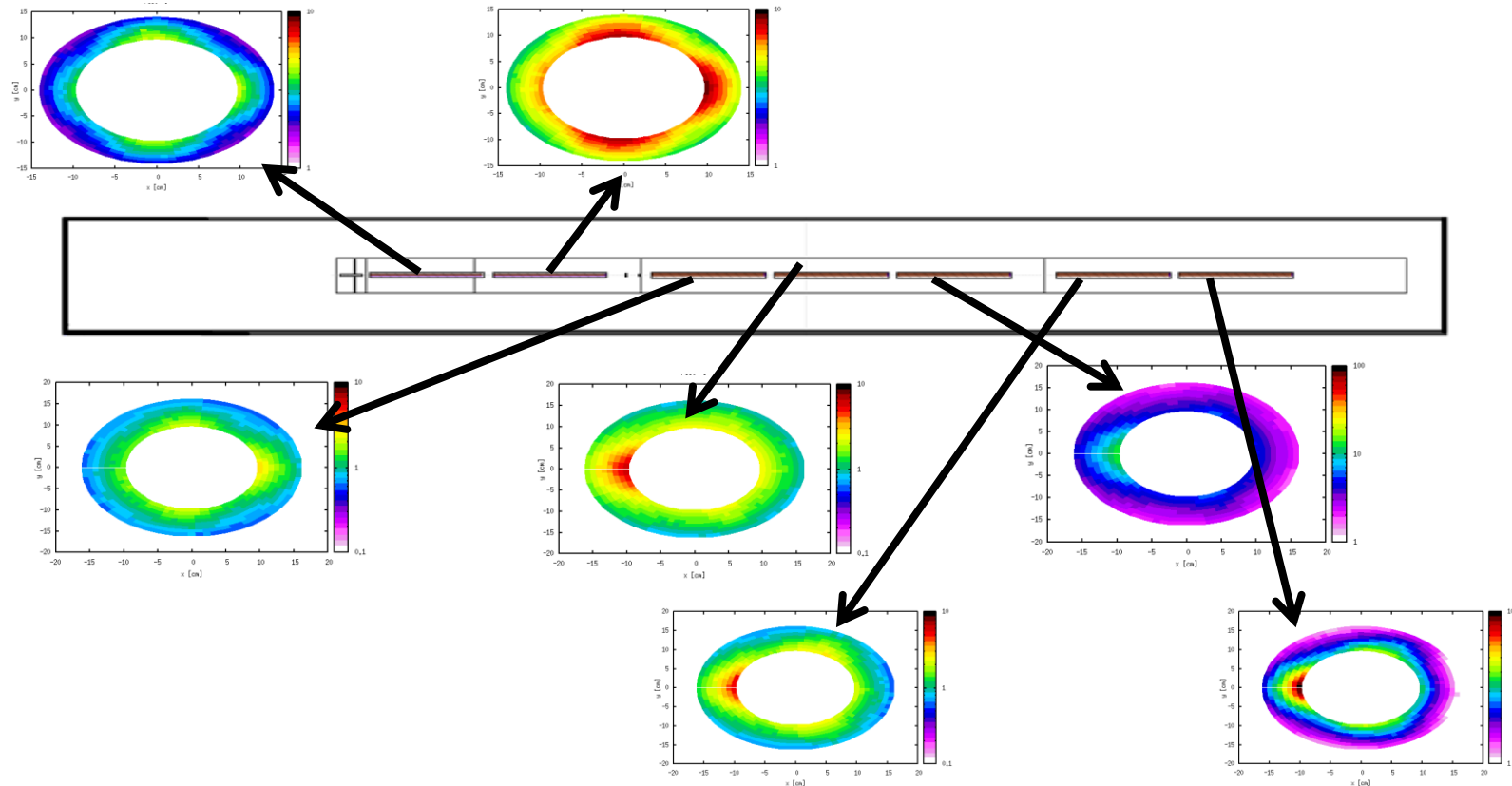
$$\beta_x^* = 0.3\text{m}$$



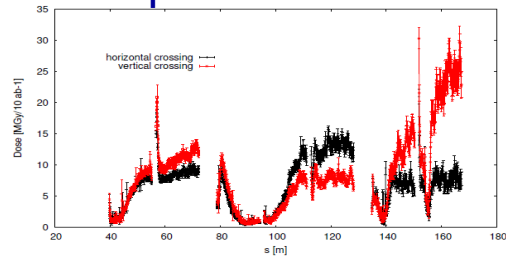
$$\beta_x^* = 1.2\text{m}, \beta_y^* = 0.15\text{m}$$

# FCC-hh: JAI-Oxford contribution

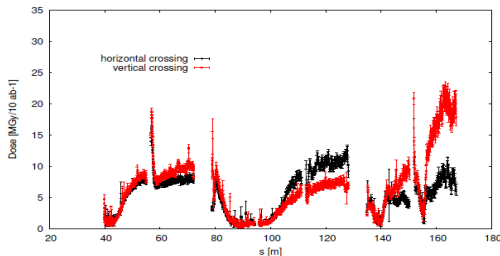
- Energy deposition for the alternative triplet



## Peak dose profile



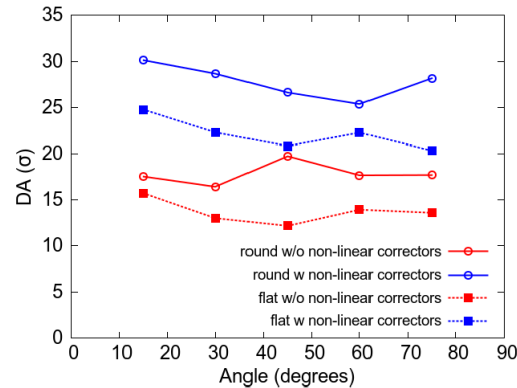
Round optics



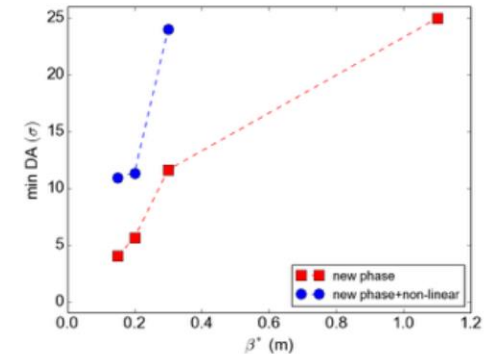
Flat optics

Flat optics advantage: lower crossing angle

Parameter	Round	Flat
$\beta_x^*$ [m]	0.3	1.2
$\beta_y^*$ [m]	0.3	0.15
Full crossing angle [ $\mu$ rad]	200	130
Beam-beam separation [ $\sigma$ ]	17	22



Dynamic aperture for  
the alternative

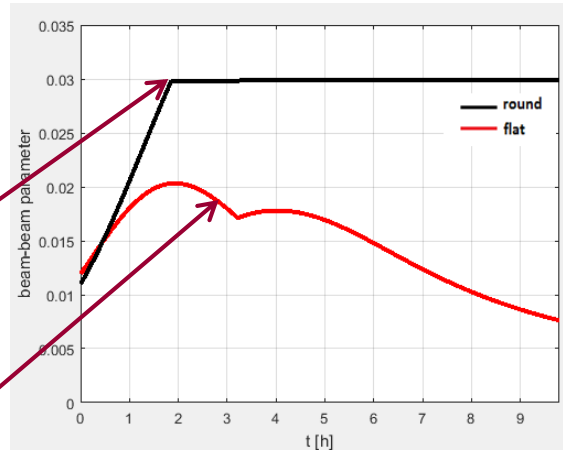


Dynamic aperture for  
nominal

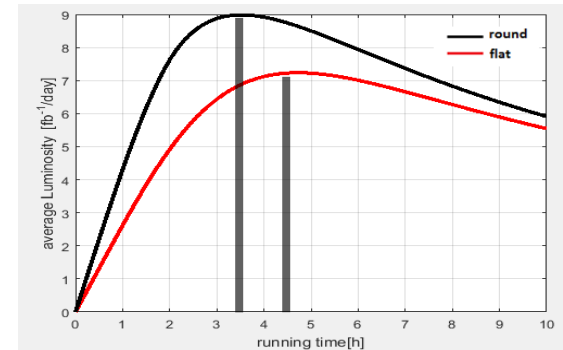
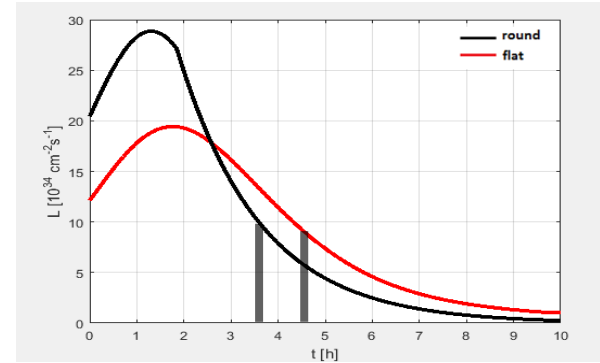
# FCC-hh: JAI-Oxford contribution

- Time evolution comparison for luminosity, beam-beam parameter and integrated luminosity.

Artificial  
emittance blow-  
up  $\xi_T = \xi_x + \xi_y$



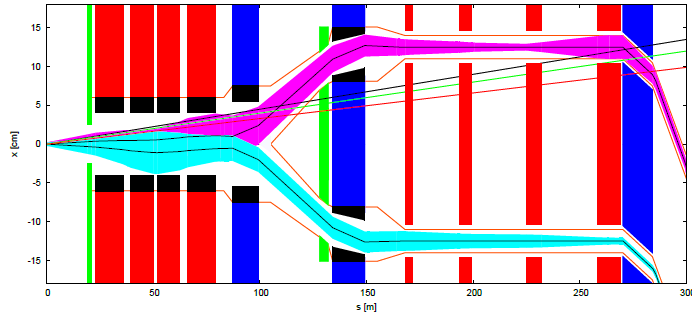
$\xi_T = 2 \cdot \max(\xi_x, \xi_y)$  (HH crossing, worst case)  
 $\xi_x$  first dominant, then  $\xi_y$



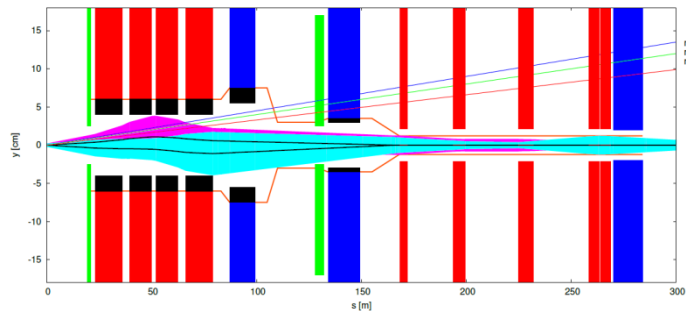
- [illegible]

## IR optics

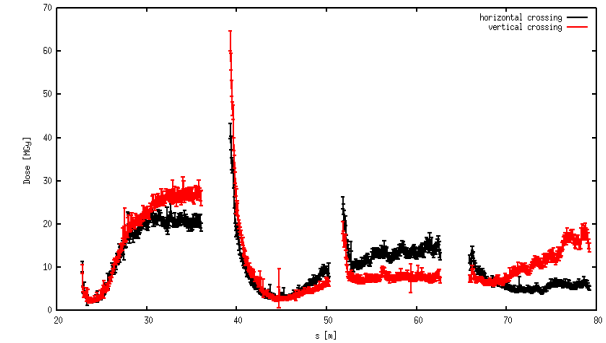
- Fully designed by JAI-Oxford



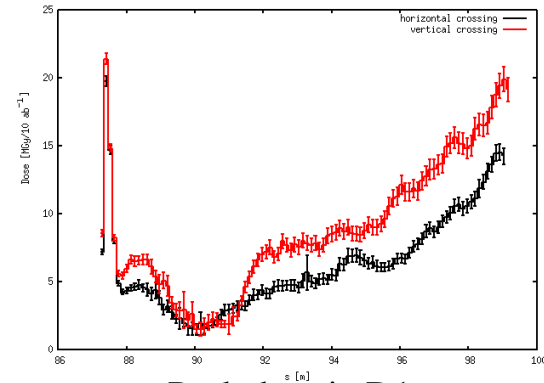
Horizontal plane



Vertical plane

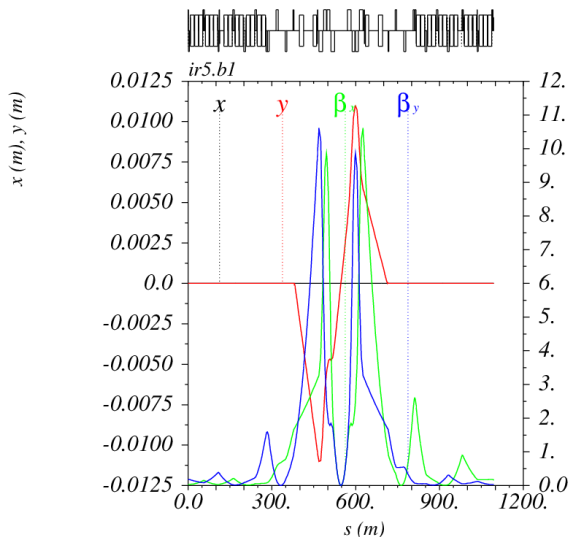


Peak dose in triplets

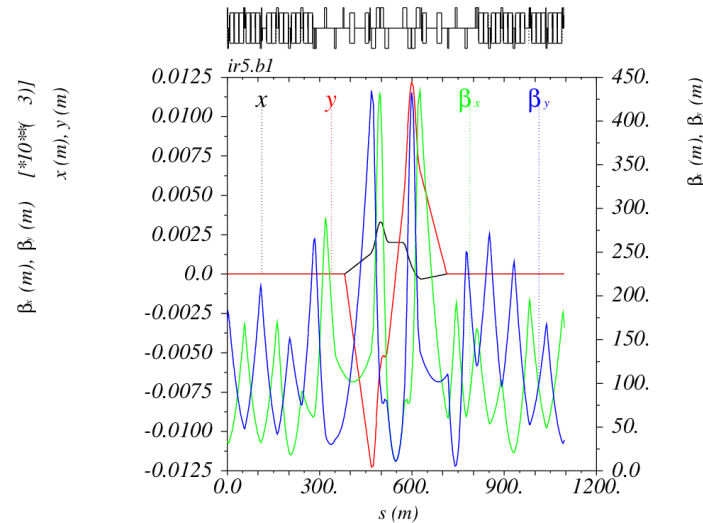


Peak dose in D1

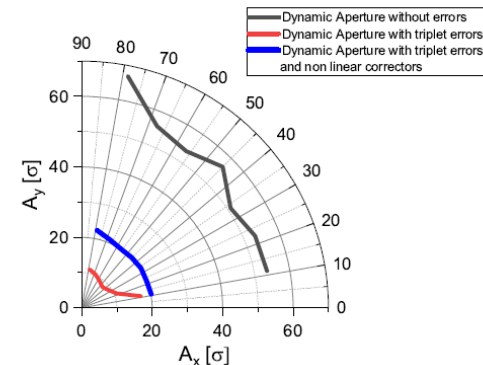
- Matched and integrated in the lattice: very challenging due to space constraints!



Collision



Injection



Dynamic aperture

## PhD thesis (2019)

- L. van Riesen-Haupt, “Advanced Accelerator Optics for Experimental Interaction Regions of FCC-hh and HE-LHC Future Colliders and for LHC Operation”.

## To be submitted to journal

- L. van Riesen-Haupt et al., “HE-LHC Interaction Region Design: Triplet, dipoles and energy deposition” (draft).
- J. L. Abelleira et al., “An alternative final-focus system for the FCC-hh: Triplet optimization with energy deposition studies” (in progress).

## Journal collaboration

- R. Martin, et al, ‘Interaction region design driven by energy deposition’ PRAB 20, 081005. 19 p (2017).

## CDR

‘Future Circular Collider Study’ (2018).

## FCC Week 2018

- JAI students: A. Picksley, E. Senes, J. Li, C. Colgan, T. Christodoulou, A. Oleinik, H Pikhartova: Accelerator Design Studies for the High-Energy LHC (poster).
- L. van Riesen-Haupt: “An Optimised Alternative Triplet for the Final Focus of the FCC-hh with a 40m Final Drift ”. (poster).

## FCC Week 2017

- L. van Riesen-Haupt: “A Code for Optimising Triplet Layout ”. (poster).
- J.L. Abelleira: Energy Deposition Studies for the New Compact FCC-hh Final-Focus System (poster).
- J.L. Abelleira: A Fully Symmetric Final Focus System For FCC-hh (poster).

## Conference papers led by JAI:

- J.L. Abelleira et al., “Energy Deposition Studies and Luminosity Evolution for the Alternative FCC-hh Triplet”, IPAC’18, p. 352.
- E. Cruz-Alaniz et al., “Methods to Increase the Dynamic Aperture of the FCC-hh Lattice”, IPAC’18, p. 3593.
- J.L. Abelleira et al., “HE-LHC Final Focus: Flat Beam Parameters and Energy Deposition Studies”, IPAC’18, p. 356.
- L. van Riesen-Haupt et al., “Optics for RF Acceleration Section in IR4 for the HE-LHC”, IPAC’18, p. 345.
- L. van Riesen-Haupt et al., “Experimental Interaction Region Optics for the High Energy LHC”, IPAC’18, p. 360.
- L. van Riesen-Haupt et al., “An Optimised Triplet for the Final Focus of the FCC-hh with a 40m Final Drift”, IPAC’18, p. 364.
- J.L. Abelleira et al., “Cross-Talk Studies Between FCC-hh Experimental Interaction Regions”, IPAC’17, p. 2136.
- J.L. Abelleira et al., “FCC-hh Final-Focus for Flat Beams: Parameters and Energy Deposition Studies”, IPAC’17, p. 2139.
- E. Cruz Alaniz et al., “Effect of Alignment Errors and orbit correctors on the Interaction Region Of the FCC-hh”, IPAC’17, p. 2147.
- L. van Riesen-Haupt et al., “Exploring the Triplet Parameter Space to Optimise the Final Focus of the FCC-hh”, IPAC’17, p. 2155.
- L. van Riesen-Haupt et al., “A Code for Optimising Triplet Layout”, IPAC’17, p. 2163.
- L. van Riesen-Haupt et al. “K-Modulation Developments via Simultaneous Beam Based Alignment in the LHC” IPAC’17, p. 2159.
- E. Cruz Alaniz et al., “Non linear field correction effects on the dynamic aperture of the FCC-hh”, IPAC’17 p. 2143.

## Contributions

- M. Hofer et al. "Integrated Full HE-LHC Optics and Its Performance" IPAC'18 p. 348.
- F. Zimmermann et al., "High Energy LHC design", IPAC'18, p. 269.
- Y.M. Nosochkov et al. "Optimized Arc Optics for the HE-LHC" IPAC'18 p. 277.
- A. Seryi et al., "Overview of Design Development Of FCC-hh Experimental Interaction Regions", IPAC'17, p. 2151.
- E.H. Maclean, et al, Report from LHC MD 2158: IR-nonlinear studies. CERN-ACCNote-2018-0021. March, 2018.
- S.A.Bogacz, et al, "Novel Solutions for the LHeC". ICFA Newsletter #71, August 2017.
- H. Rafique et al., "Proton Cross-Talk and Losses in the Dispersion Suppressor Regions at the FCC-hh", IPAC'17, p. 1763.
- R. Alemany-Fernandez et al. "Cross-Calibration of the LHC Transverse Beam-Profile Monitors" IPAC'17 p. 437.
- F. Zimmermann et al., "Beam Dynamics Issues in the FCC", HB'16, p. 373.

## Presenter, title

### **EuroCirCol meeting October 2018 Karlsruhe, Germany**

- J.L. Abelleira: “HE-LHC IR energy deposition simulations”.
- E. Cruz-Alaniz: “Dynamic aperture studies of FCC-hh”.
- L. van Riesen-Haupt: “Alternative IR for FCC-hh and HE-LHC IR”.

### **LHeC/FCCeh and PERLE Workshop. Orsay, France June 2018**

- E. Cruz-Alaniz: Dynamic “Aperture studies for the LHeC and FCC-eh”.

### **FCC week 2018, Amsterdam, Netherlands.**

- J.L. Abelleira: “Flat beam alternative”.
- J.L. Abelleira: “HE-LHC with at beams”.
- J.L. Abelleira: “IR1/5 radiation shielding”.
- E. Cruz-Alaniz, “Dynamic aperture at collision”.
- L. van Riesen-Haupt: “Experimental Interaction Region Optics for the High Energy LHC”.
- L. van Riesen-Haupt: “Summary HE-LHC machine design”.

### **HE-LHC review December 11, 2017; CERN, Geneva, Switzerland.**

- J.L. Abelleira: “IR1/IR5 Radiation Shielding”.
- L. van Riesen-Haupt: “Experimental IR1/5 optics”.
- L. van Riesen-Haupt: “IR4 Optics”.

## Presenter, title

### **EuroCirCol meeting 2017. October 9, 2017; CERN, Geneva, Switzerland.**

- J.L. Abelleira: “Energy deposition studies for new triplet”.
- L. van Riesen-Haupt: “New triplet and EIR optics”.
- E. Cruz-Alaniz: “Dynamic aperture and nonlinear corrections studies”.

### **FCC Week 2017**

- E. Cruz-Alaniz: “Correction schemes for the interaction region of FCC-hh”.
- L. van Riesen-Haupt: “HE-LHC Triplet”
- L. van Riesen-Haupt “Exploring the triplet parameter space to optimise the final focus of the FCC”.

### **EuroCirCol meeting 2016. November 7, 2016; Barcelona, Spain.**

- J.L. Abelleira: “FLUKA studies on alternative designs”.
- L. van Riesen-Haupt: “Global chromatic aspects,  $L^*$ , triplet length, etc”.
- E. Cruz-Alaniz: “Error corrections schemes”.

### **FCC Week 2016**

- A. Seryi: “Experimental Insertion Design”.
- E. Cruz-Alaniz: “Interaction region of the FCC-he”.

# summary

- JAI-Oxford has been funded by EuroCirCol and STFC. Thanks!
- We have worked for three major projects: FCC-hh, HE-LHC, and LHeC.
- We have contributed with beam optics, energy deposition and dynamic aperture studies.
- Very productive team, we found many synergies. Good team work.
- Very proud of the contribution to the CDR and other publications.

***Thank you for  
your attention***