

# Interaction Region design

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**John Adams Institute**

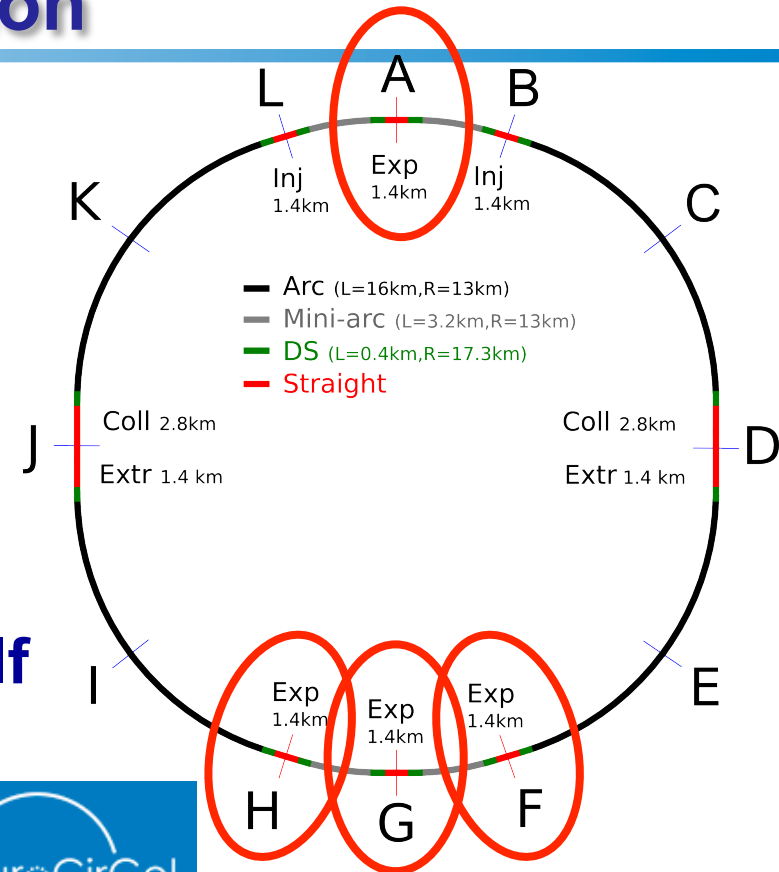
**On behalf of IR design team: JAI, CI, INFN, EPFL, CERN**

**FCC Week 2015**  
**Washington, 23-27 March 2015**

**24 March 2015**

# Disposition

- **Experimental Interaction Region**
  - One of critical areas defining FCC-hh performance
- The design team is arranging itself to undertake design studies
  - EU funded EuroCirCol project is enabling start of collaboration
  - EuroCirCol WP3 (IR) design work:
    - JAI, Cockcroft Inst., INFN, EPFL, CERN
    - IR design collaboration will include many more partner labs and institutions



# Motivation, design goals, tasks

- **FCC experimental insertion region design is critical for achieving the required luminosity and to control the beam background for the FCC experiments**
  - **The main goal is to optimise the luminosity per beam current to ensure that beam induced radiation does not compromise the experiments or affect collider operation**
- **Design tasks of EuroCirCol IR Work Package**
  - **Development of the interaction region lattice**
    - JAI/Oxford (lead), CERN, task 3.2
  - **Design of machine detector interface**
    - CI/Manchester (lead), INFN, CERN, task 3.3
  - **Study of beam-beam interaction**
    - EPFL (lead), CERN, task 3.4



# Goals of IR WP tasks

- **IR lattice development (3.2: JAI/Oxford (lead), CERN)**
  - Develop the collision optics for the IR aiming for min beam sizes
  - Aim at reaching higher luminosity at limited beam current
  - Care about limits of magnet performance and non-linear optics effects
  - Take into account radiation in IR estimated in MDI task
  - Develop of the IR optics at injection and ramping to collision energy
  - Provide input for the choice of beam current and for setting boundaries for the accelerator magnet design
- **Design MDI**
- **Study of beam-beam interaction**

# Goals of IR WP tasks

- IR lattice development
- Design MDI (3.3: CI/Manchester (lead), INFN, CERN)
  - Ensure that collider design is consistent with the detector performance
  - Determine the required apertures for the detector
  - Integrate detector components into the IR optics
  - Evaluate impact of debris from collimation system on IR
  - Optimise IR system together with other relevant tasks
  - Study the impact of synchrotron radiation on IR and develop mitigations
  - Study colliding beams debris in IR and develop shielding concepts
- Study of beam-beam interaction

# Goals of IR WP tasks

- IR lattice development
- Design MDI
- Study of beam-beam interaction (3.4: EPFL (lead), CERN)
  - Simulate the dynamic aperture and instabilities in the presence of beam-beam collisions for different design options
  - Study round and flat beam options and identify the acceptable limit to the beam-beam interaction
  - Explore methods to reduce the impact of beam-beam interactions (wire compensation schemes, electron lenses and crab cavities, etc.)
  - Identify and explore potential interactions of beam-beam effects with impedance related beam instabilities
  - Give input to a selection of preferred circulating beam currents and crossing angles at IR

# Disposition and next steps

- The EuroCirCol EU project gives start to build-up of design teams to the needed capacity
  - Hiring postdocs, getting graduate students
  - After this initial period, staffing of the teams will be even

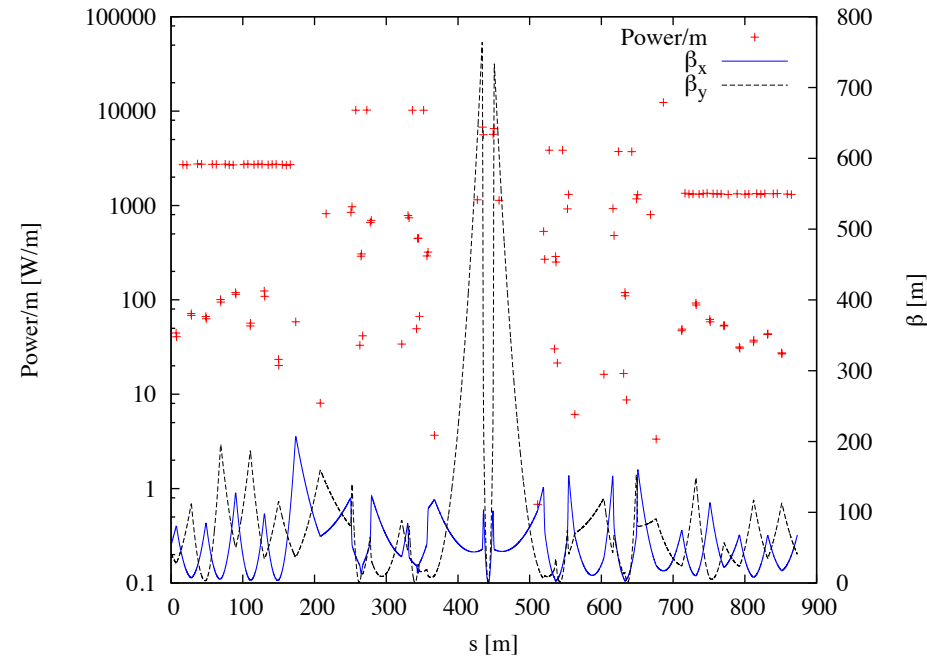


- Next – present the teams
  - Previous relevant experience, developed tools, etc
- Then – show some results already achieved
  - Primarily results from CERN colleagues

# Task 3.3 : CI

Relevant experience : MDI work and BDS for ILC, and interaction region/SR calculations using the specially developed code IRSYN to compute SR and integrate into optics design process.

Figure to right shows the LHeC interaction region and straight section, and the power of SR photons from the electron beam. R B Appleby *et al*, *J. Phys. G: Nucl. Part. Phys.* **40** 125004 (2013)



Staff : Rob Appleby plus 1 PDRA to be recruited later this year.

Goal: “to ensure that the collider design is consistent with the detector performance”

CI will focus on the determining the needed apertures, developing the layout of the detector region and computing the synchrotron radiation.



## Task 3.3: INFN -- SR in FCC-hh

- Application of SR tools to FCC-hh

### G4SynchrotronRadiation

now works for all

long lived charged particles

proton, ions ..

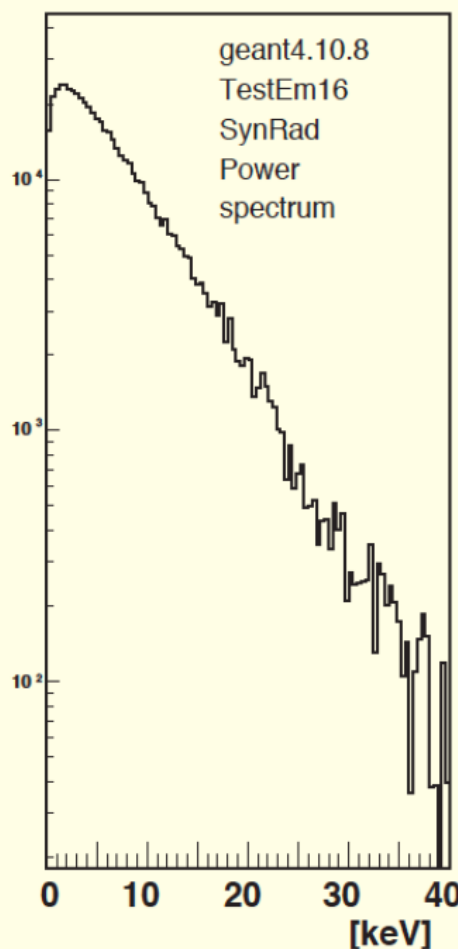


Presented at annual

Geant4 collaboration meeting

Sept. 2014 in Okinawa

Status and Validation of Standard EM Physics  
by Vladimir Ivanchenko  
for the G4 EM standard WG



### FCC example

100 TeV pp collisions

50 TeV/beam

20 Tesla magnetic field

3 MW in **proton synchrotron**  
radiation

**Ecrit = 5.4 keV**

**comparable to B-factories**

H. Burkhardt(CERN),  
M. Boscolo(INFN)

- **FCC-hh Beam-Beam and Collective Effects at the EPFL**
  - **L. Rivkin & T. Pieloni**
    - **Laboratory of Particle Accelerator Physics,  
EPFL & CERN/BE/ABP**

- **More than 10 years of productive and exiting collaboration on several subjects in accelerator physics, with special emphasis on beam-beam and collective effects for LHC, LHeC and HL-LHC**
  - 24 PhD thesis, 6 Master thesis and several stage periods at CERN and outside (PSI, BNL, SLAC...)
- **Consolidated experience in beam-beam and collective effects:**
  - LHC studies and commissioning, LHeC Conceptual Design Study and HL-LHC Project partner for Task. 2.5 Beam-beam studies (3 post-doc fellows & 4 PhD)
- **Infrastructures : High Power Computing center (1 member in steering committee) and support to CERN LHC@HOME BOINC system (1 LPAP scientific collaborator)**
  - Beam-beam simulations already possible thanks to EPFL infrastructures
- **Hands-on LHC machine development studies (BE/ABP and OP) and follow up of accelerator R&D with external collaborators (BNL e-lenses, LBNL, KEK& Fermilab beam-beam simulations)**

**Present collaboration on LHC and HL-LHC.**

**Hands-on LHC machine is fundamental!**

## Beam-beam studies for FCC-hh:

- IR set-up (crossing angle operation, bunch spacing...)
- Dynamic aperture studies (WP2 and WP3 arc and IR optics)
- Beam-beam and radiation damping
- Coherent beam-beam
- Landau Damping properties
- Noise on colliding beams
- Orbit, chromatic, tune effects for train operation
- Leveling scenarios and beam-beam (Experiments)
- Mitigating techniques (e-lenses, wire compensators, crab cavities)
- Define possible operational scenarios (parameter space exploration)

## Collective effects:

- Interplay of beam-beam and machine impedance (WP2 impedance model)
- Stability of colliding beams with transverse feedback

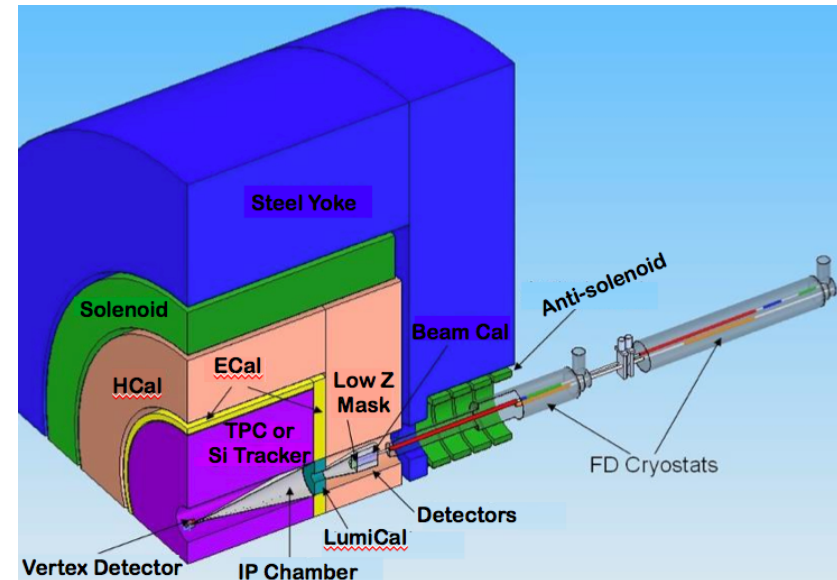
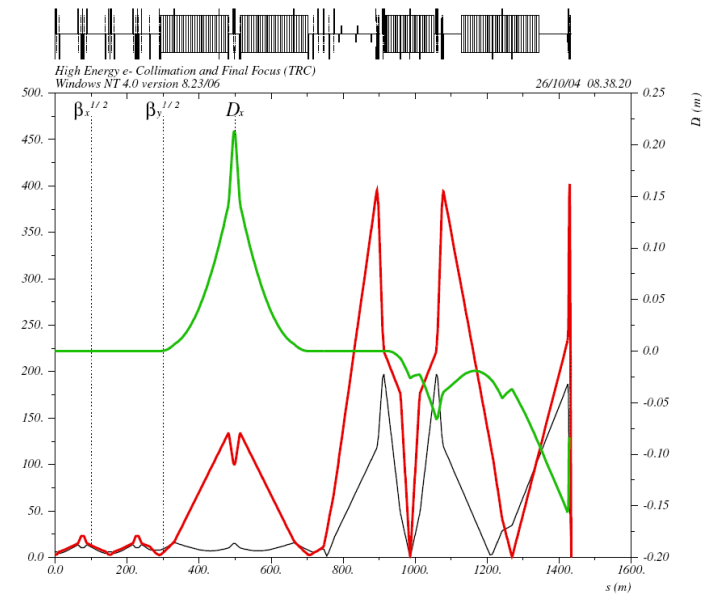
**Keep beam-beam effects under control, define IR operation, set parameters to avoid luminosity deterioration and instabilities**

- **Sixtrack** single particle tracking for Dynamic aperture studies
- **Frequency Map Analysis** (from Sixtrack developed for HL-LHC)
- **COMBI** (Coherent Multi Bunch multi Interaction code)
  - Coherent Beam-beam
  - Impedance and beam-beam interplay
  - Landau Damping
- **TRAIN** code → self consistent orbit, tune and chromaticity computations

**Standard tools for Beam-Beam studies at CERN  
(LHC benchmark and code2code benchmark)**

# JAI / Oxford team, task 3.2 and 3.1

- Vast experience in optics design of final focus and IR
  - Nonlinear effect and corrections
- Large experience in working with detector colleagues on optimization of MDI requirements and on MDI design
- The team includes (fraction of times of) A.S., Daniela Bortoletto, Androula Alekou
  - New graduate student starting in Oct 2015 already accepted our offer
  - Plan to hire postdoc(s) in the coming months

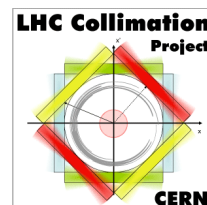
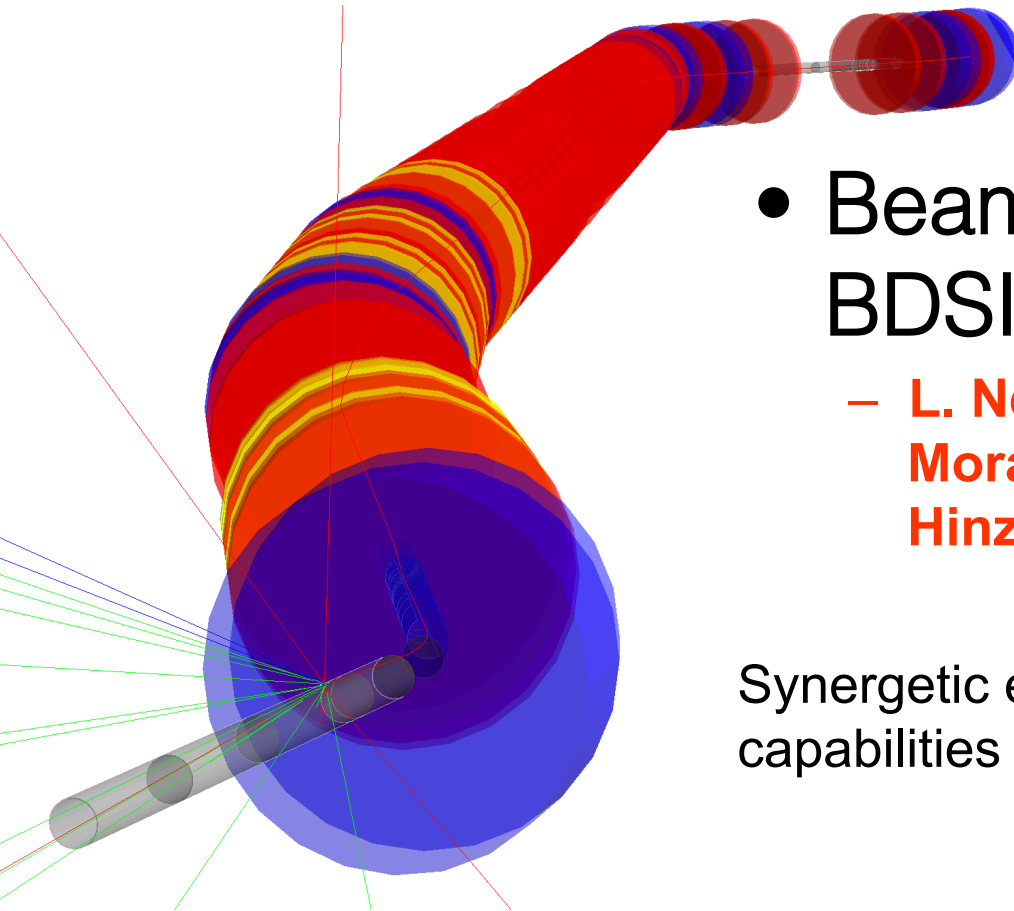




- Beam Delivery Simulation  
BDSIM

- L. Nevay, S. Boogert, H. Garcia-Morales, S. Gibson, R. Kwee-Hinzmann, J. Snuverink

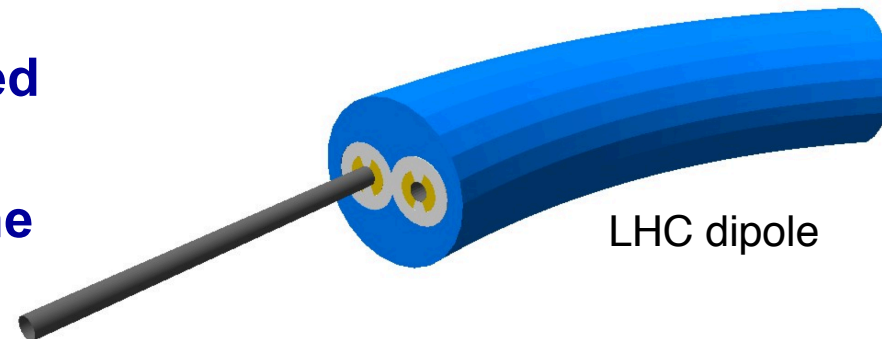
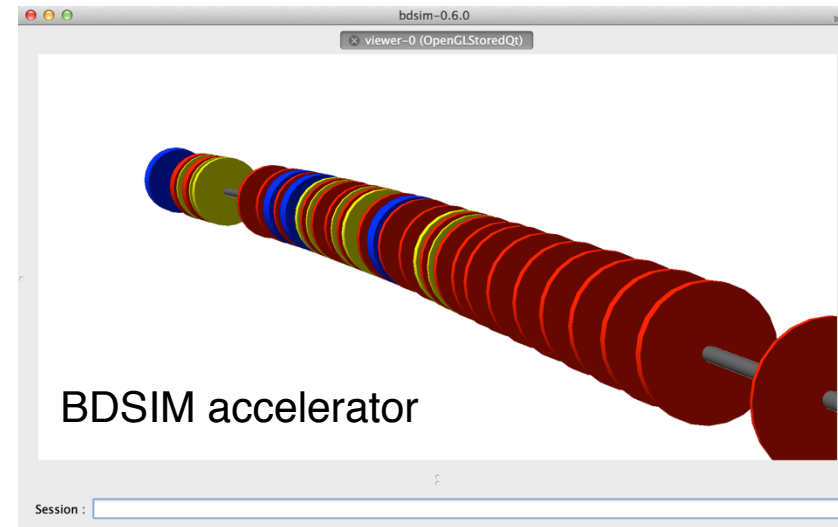
Synergetic experience and tools – will augment capabilities of FCC design team





# Beam Delivery Simulation - BDSIM

- Tracking code that uses Geant4
- Used to simulate energy deposition and detector backgrounds
- Particles tracked through vacuum using normal tracking routines
- Geant4 provides physics processes for interaction with machine
- Full showers of secondaries created by Geant4 processes
- Secondaries tracked throughout the accelerator
- Ability to simulate synchrotron radiation
- Library of generic geometry used

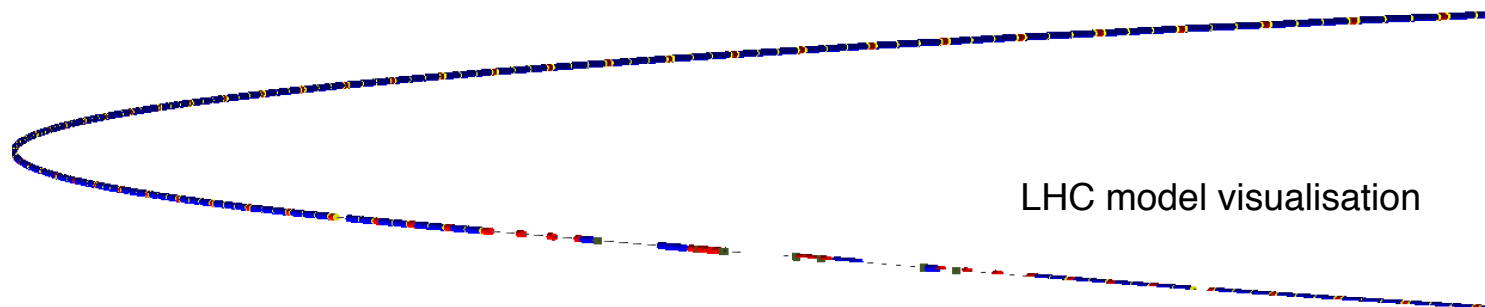
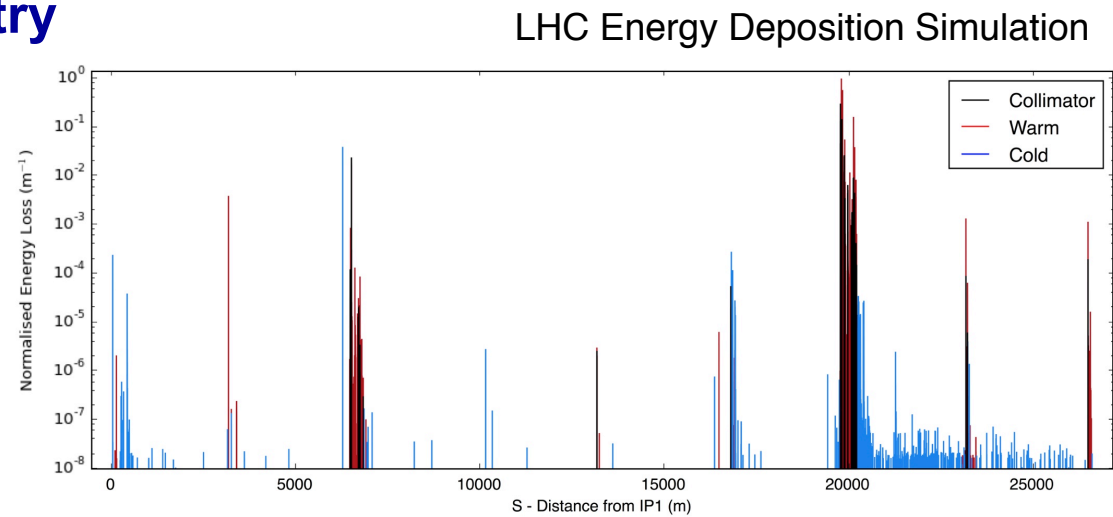
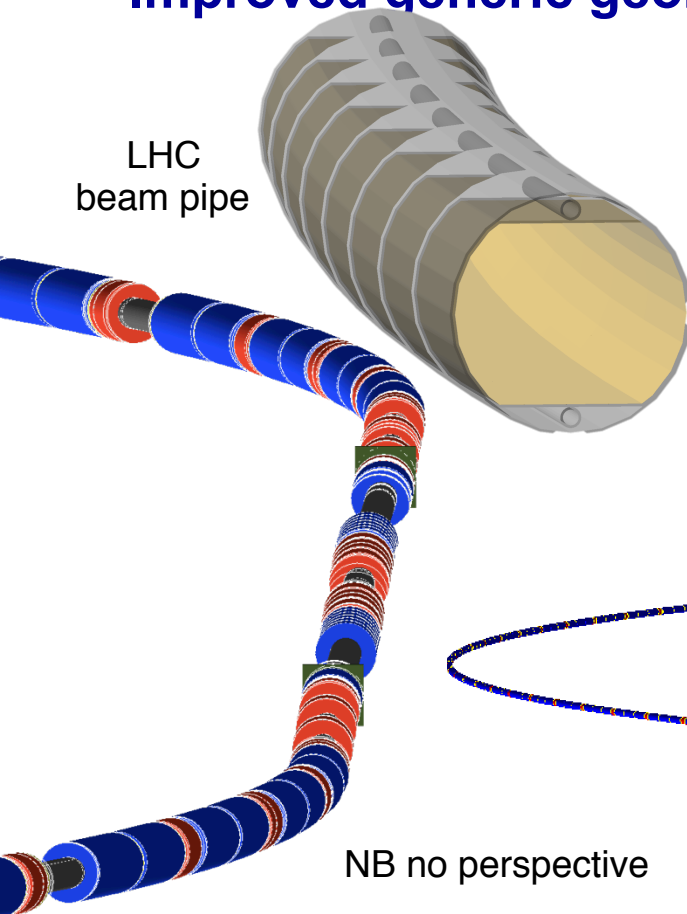


Tapered collimator



# Recent Developments – (HL) LHC

- Currently being developed to simulate the LHC & HL-LHC
- Tracking being factorised – inject losses from other codes into BDSIM
- Improved generic geometry



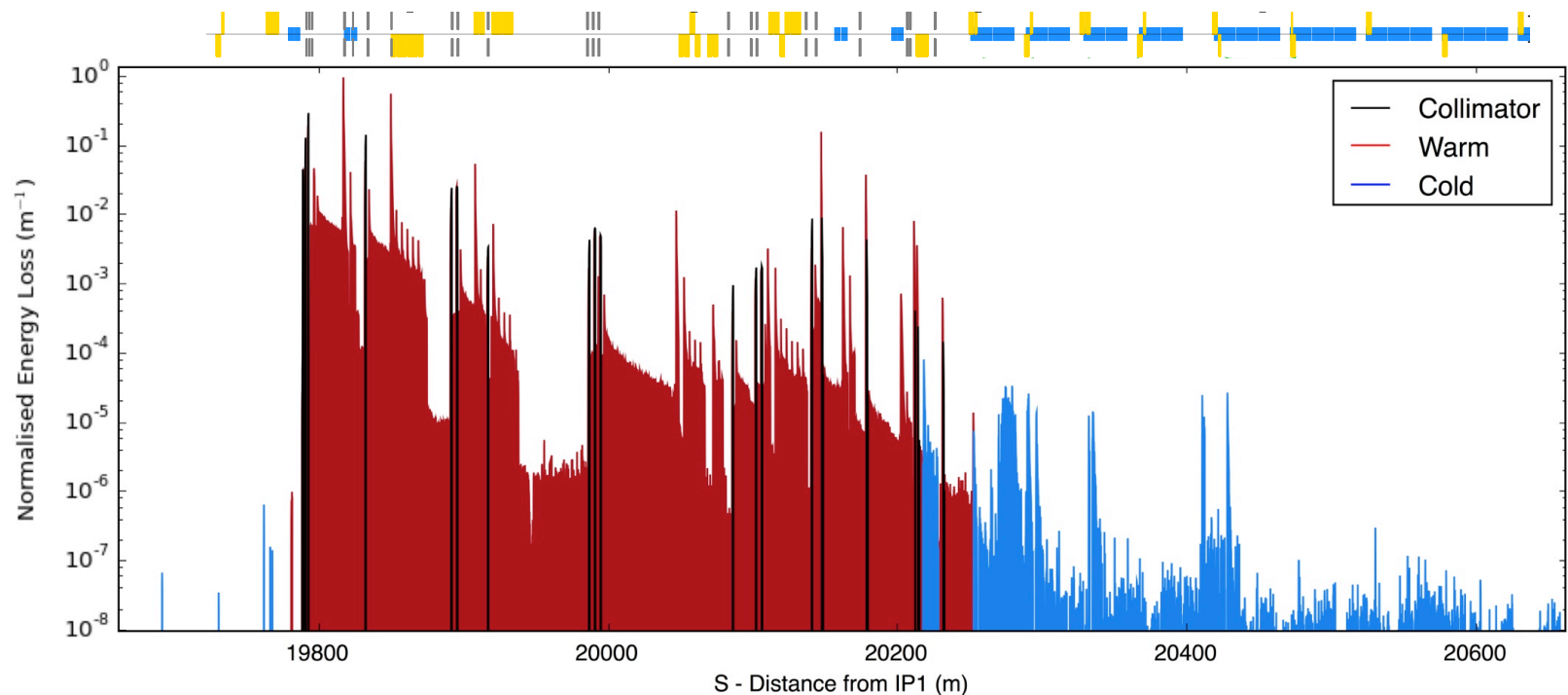
NB no perspective

Presented at 4<sup>th</sup> Joint HiLumi LARP Annual Meeting Nov. 2014

<https://indico.cern.ch/event/326148/session/30/contribution/91>

# Energy Deposition

- BDSIM records energy deposition (GeV/m)
- Continuous distribution of losses
- LHC Model under process of validation with CERN collimation team



LHC IR7 loss map -

Beam line schematic from R. Bruce et al,  
Phys. Rev. ST Accel. Beams 17, 081004 (2014)

## JAI team and graduate training

- **JAI (Oxford, Imperial College, RHUL) is perhaps one of the biggest producers of accelerator PhD experts**
  - **In average 5-6 PhD in acc.sci./year – perhaps larger than any national scale laboratory**
  - **All our graduates are well employed & stay in the acc. Field**
  - **Same applies to Cockcroft Institute**
  - **This year “design project” by 1<sup>st</sup> year JAI grad students aimed at FCC:**

### **Accelerator Design Studies for the Future Circular Collider JAI Student Design Project**

**Christopher Arran, Mehpare Atay, Talitha Bromwich, Hannah Harrison, Robert Shalloo,  
Rob Williamson, Huibo Zhang, Alberto Arteche**

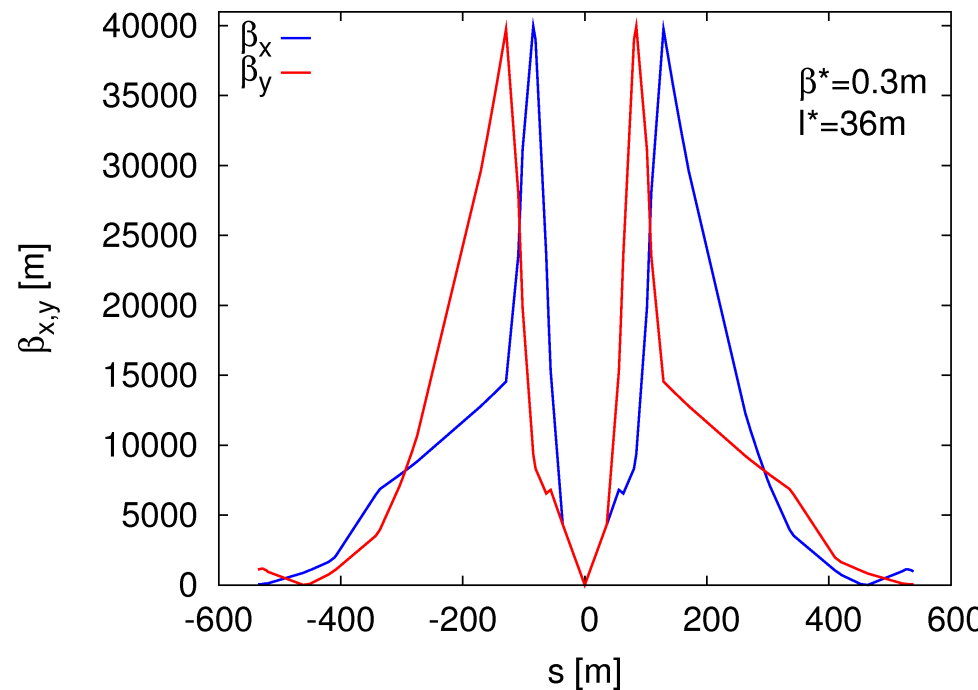
**Presented in Oxford – 12 March 2015**

**To be presented to JAI Advisory Board – 9 April 2015**

**To be presented at CERN – 5 June 2015**

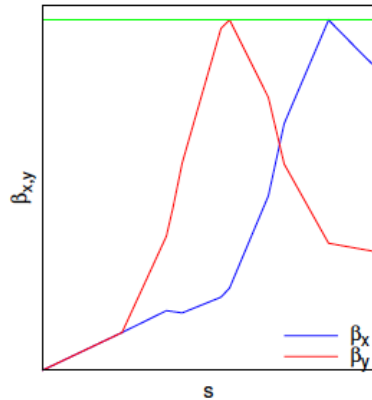
# Examples of recent studies – beta\* reach

- Starting from upscale HL-LHC IR optics
- For given beta\*, rematch triplet so that max betas in x and y are equal
- Then recalculate max aperture from quadrupole gradients and Bmax, and check beam stay clear



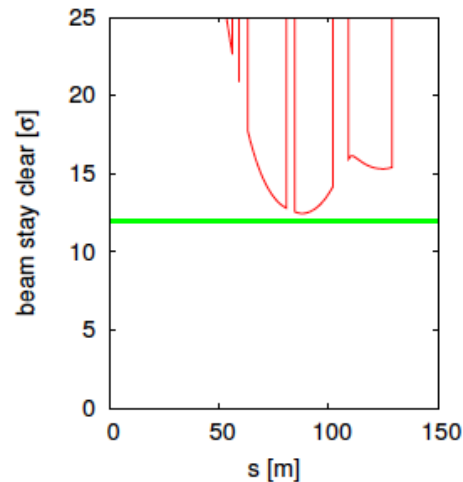
Upscale HL-LHC design,  
R. Martin, R. Tomas, E. Todesco, L. Bottura

# Beta\* reach studies



## Re-matched triplet

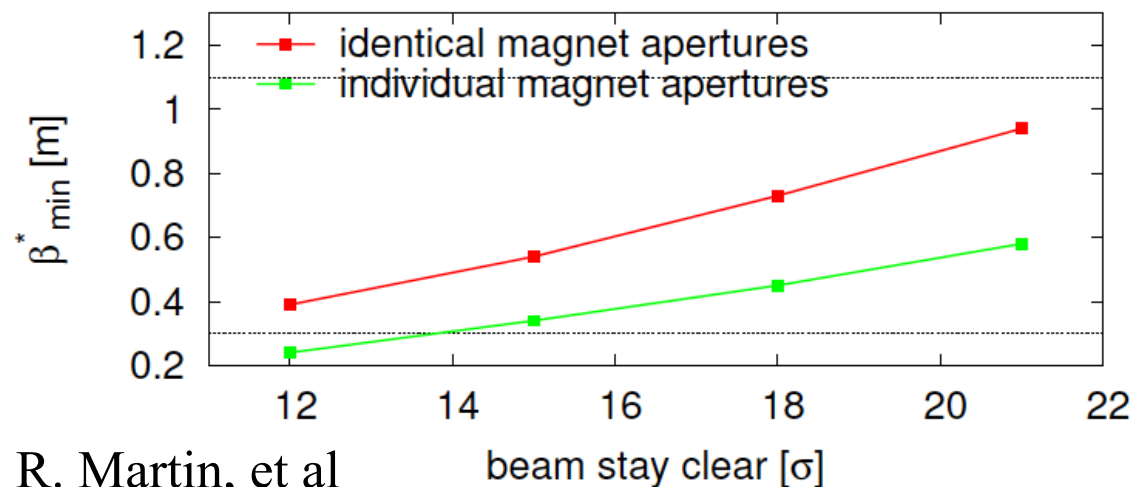
- $B_{\max} = 11$  T
- $L^* = 36$  m
- $L_{Q1} = 20$  m
- Beam stay clear =  $12\sigma$
- Beam separation =  $12\sigma$
- Shielding = 15 mm
- Further layers:
  - Cold bore: 2.0 mm
  - Kapton insulator: 0.5 mm
  - LHe: 1.5 mm
  - Beam screen: 2.05 mm
  - Beam screen insulator: 2.0 mm



Checking beam  
stay clear

## Initial results for stay clear vs beta\*

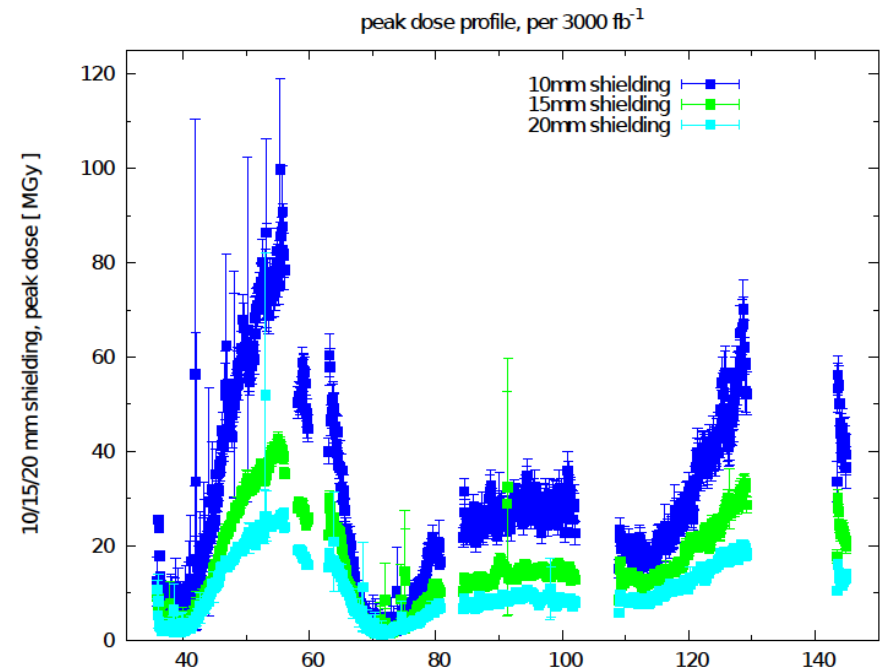
closed orbit uncertainty = 0.001 m



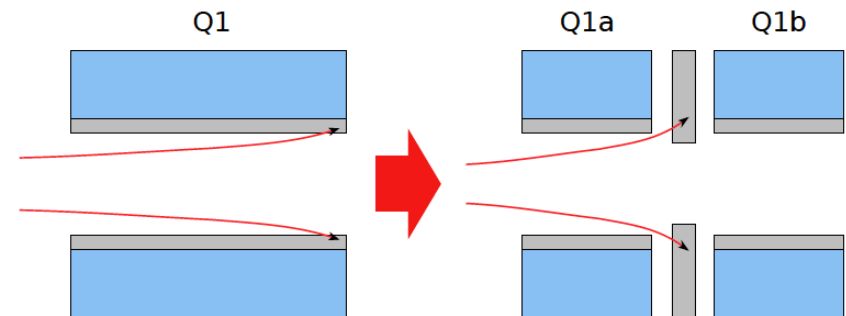
R. Martin, et al

# Beta\* reach and triplet shielding

- Such results need to be iterated with energy deposition studies as shielding thickness affects the clear aperture of triplets
- Various modification of optics (split quads) will be studied to optimize the design and maximize beta\*reach



M. I. Besana and F. Cerutti



# Summary

- IR is the key area of FCC-hh
- Enabled by EuroCirCol, the team is ready to undertake the IR design
  - Ready to work with many partners, within the larger and worldwide FCC design collaboration
- The preliminary studies help to jump-start the design work