Summary of WP3 meetings Interaction Region design

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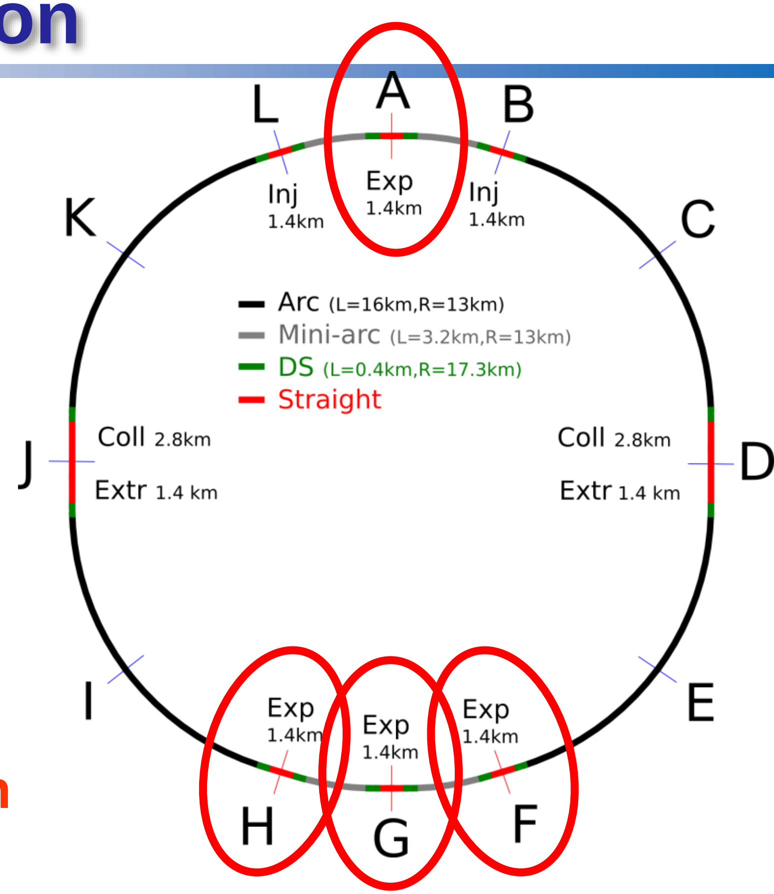
On behalf of IR design team: JAI, CI, INFN, EPFL, CERN

EuroCirCol Kick-off meeting, June 2015

Disposition

- **Experimental Interaction Region**
  - One of critical areas defining FCC-hh performance

- **Design tasks of EuroCirCol IR Work Package**
  - Coordination
    - JAI/Oxford (lead), CERN, task 3.1
  - 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



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Parameters

We have two preliminary parameter sets

- Beam current is the same
- But luminosity differs

$$\mathcal{L} \propto \frac{N}{\epsilon}\frac{1}{\beta_y} N n_b f_r$$

They have the same current but the ultimate set has more challenging collision parameters

The "baseline" in EuroCirCol should be capable to run with the **ultimate** parameters

	Baseline	Ultimate
Luminosity L [$10^{34}cm^{-2}s^{-1}$]	5	20
Background events/bx	170 (34)	680 (136)
Bunch distance Δt [ns]	25 (5)	
Bunch charge N [10^{11}]	1 (0.2)	
Fract. of ring filled η_{fill} [%]	80	
Norm. emitt. [μm]	2.2 (0.44)	
Max ξ for 2 IPs	0.01 (0.02)	0.03
IP beta-function β [m]	1.1	0.3
IP beam size σ [μm]	6.8 (3)	3.5 (1.6)
RMS bunch length σ_z [cm]	8	
Crossing angle [σ□]	12	Crab. Cav.
Turn-around time [h]	5	4

Slide from Daniel Schulte

Hiring plans in WP3

- **Hiring plans and status in IR Work Package**
  - **Development of the interaction region lattice**
    - **JAI/Oxford (lead), CERN, task 3.2**
    - **One PhD student accepted, will start Oct 2015**
    - **Two PostDocs to be hired, to be advertised in July, topics**
      - **{ OPTICS }**
      - **{ OPTICS / ENERGY DEPOSITION }**
  - **Design of machine detector interface**
    - **CI/Manchester (lead), INFN, CERN, task 3.3**
    - **One PostDoc to be hired in Manchester, topic:**
      - **{ MDI } (to be defined exactly)**
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  - **Details of PostDoc adverts to be discussed at special video mtg**

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A lot of PhD experts need to be hired to EuroCirCol project now

Two initial training networks run by Cockcroft colleagues will have large graduation this summer – about 40 PhD – this is an opportunity for FCC

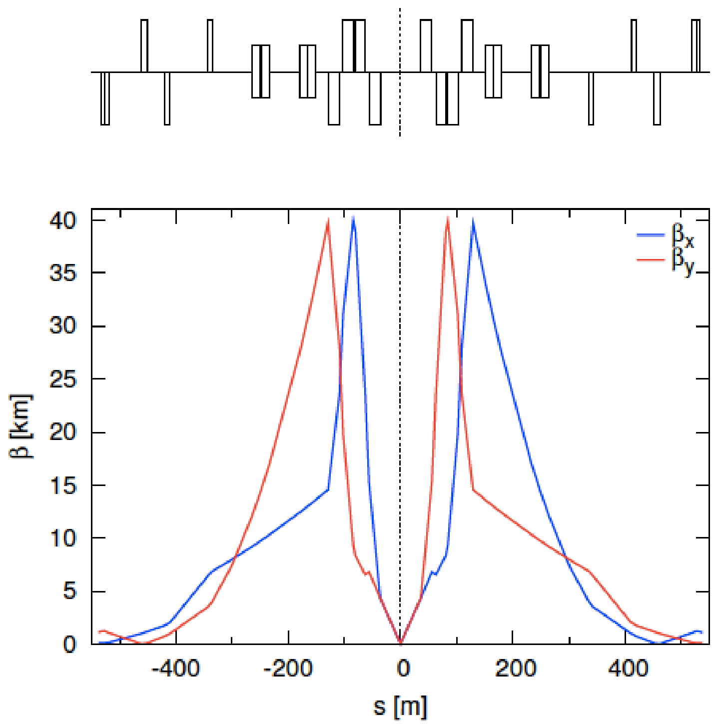
We may need FCC-wide coordination of the interview/hiring process

Some of recent highlights

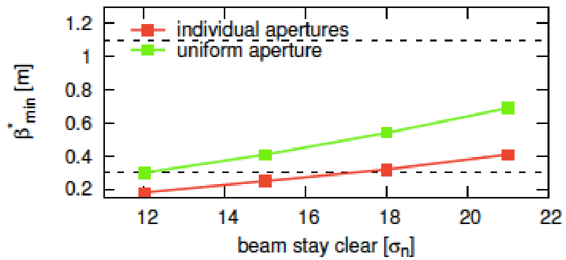
- **Discussed during WP3 meeting**
  - **IR optics and layout**
  - **Energy depositions / triplet shielding**
  - **Ideas to modify triplet shielding to achieve lower beta***
  - **Beam-beam effects**
  - **Cross-WP discussions with Arcs (WP2) and Magnets (WP5)**

IR optics, L*=36m

Option 1: $L^* = 36$ m



FCC-hh interaction region design $\beta^* = 0.3$ m

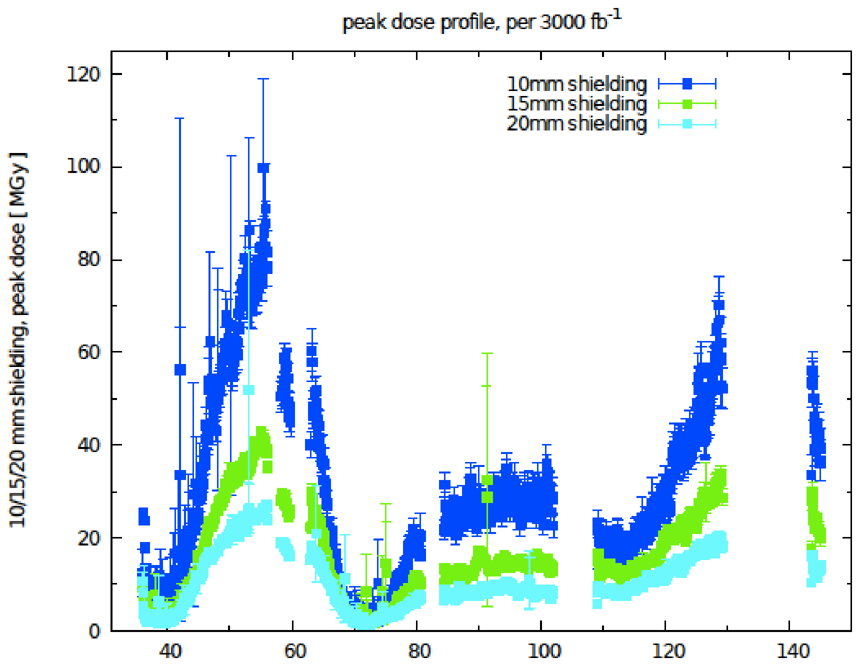


β^* reach with $B_{max} = 11$ T.

- β^* gain of 1.6 for individual apertures

IR optics, L*=36m

Option 1: $L^* = 36\,\text{m}$



Simulations by F. Cerutti and I. M. Besana

Chromaticity:

$$\xi = \frac{1}{4\pi} \int k_1 \beta(s) ds$$

For $\beta^* = 0.3\,\text{m}$:

$$\xi_x = 47.2$$

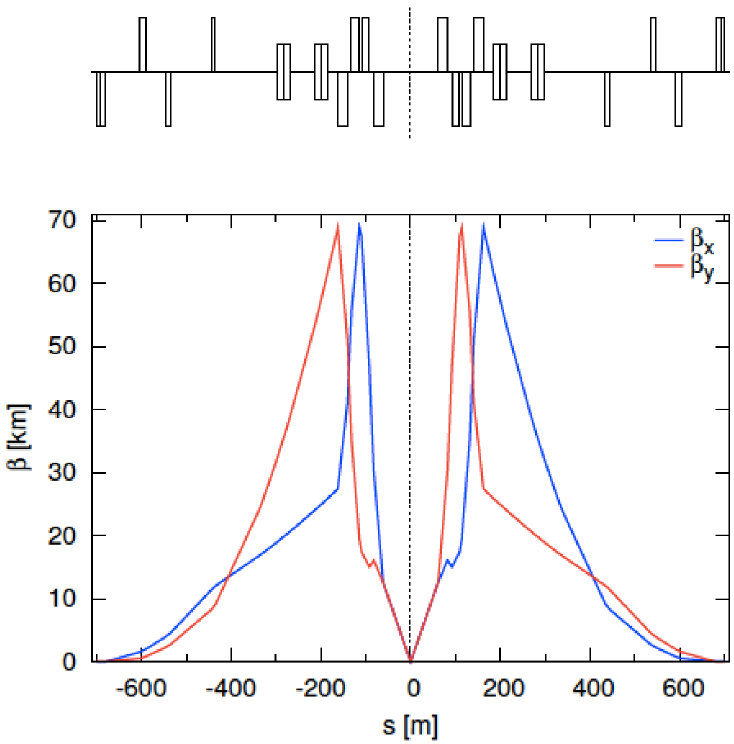
$$\xi_y = -61.5$$

(per side, triplet only)

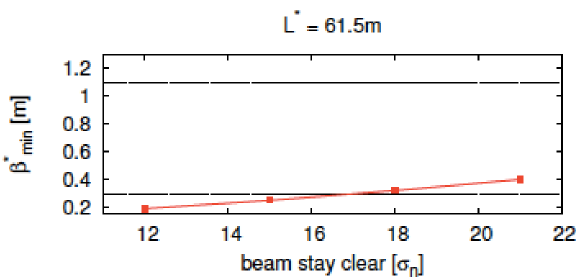
- dose seems acceptable for 15mm shielding at $3000\,\text{fb}^{-1}$, for higher luminosity, optimization is required

IR optics, L*=61.5m

Option 2 $L^* = 61.5\,\mathrm{m}$



- makes use of HL-LHC triplet magnets (SLHC V3.1b)
- aperture and beam size scale similary ⇒ impact of shielding decreases for larger aperture

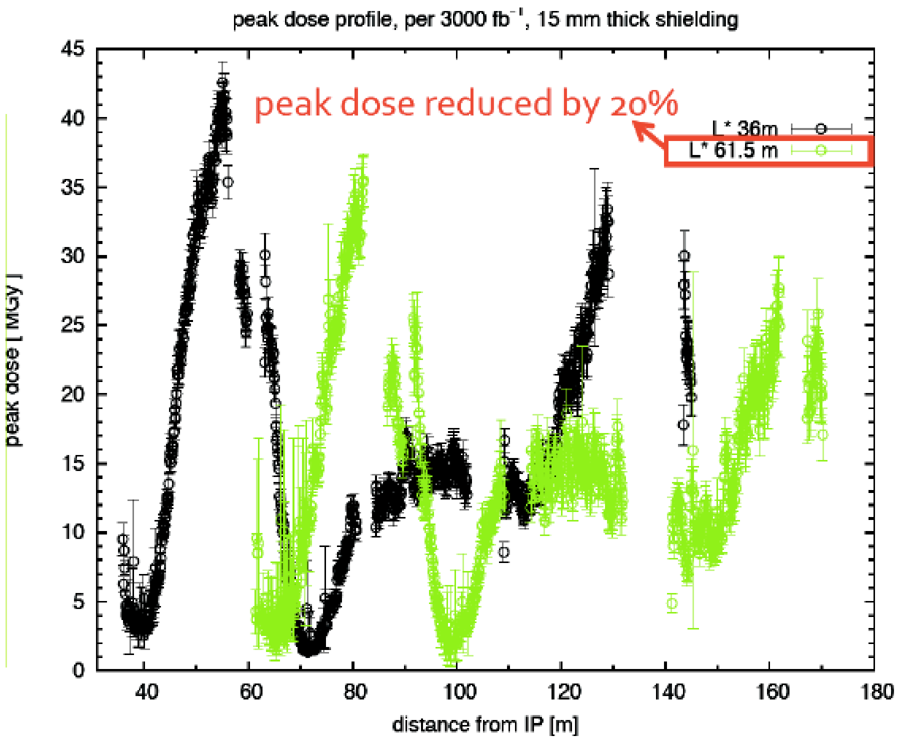


FCC-hh interaction region design $\beta^* = 0.3\,\mathrm{m}$

β^* reach with 140 mm aperture and 150 T/m gradient

IR optics, L*=61.5m

Option 2 $L^* = 61.5\,\text{m}$



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For $\beta^* = 0.3\,\text{m}$:

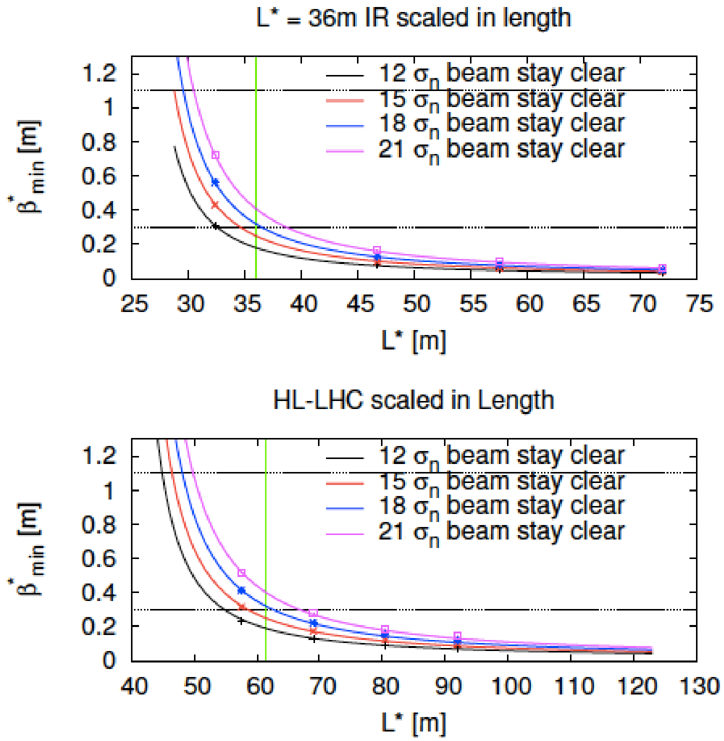
$$\xi_x = 81.0$$

$$\xi_y = -64.2$$

(per side, triplet only)

IR optics, L* dependence

Analytic length scaling



- scaling all lengths from a known and matched lattice
- larger crossing angle for longer triplet included
- Lines: analytically scaled, Dots: values found with MAD-X (no rematching of quadrupoles) ⇒ good agreement
- both scaled lattices differ in ratio of L^* and $L_{triplet}$
- conclusion: make L^* as long as possible, make $\frac{L_{triplet}}{L^*}$ as large as possible
- limits: chromaticity and overall length

IR optics, to be done

Work do be done

- split Q1 to reduce radiation dose
  $\Rightarrow$ pion tracking code
- start caring about limitations of L^* and $L_{triplet}$:
  - Chromaticity $\Rightarrow$ **dynamic aperture**
  - magnet errors $\Rightarrow$ higher order multipoles and misalignments
  - total IR length
  - magnet cost ($L_{triplet}$)
  - study dose / β^* vs. L^* and $L_{triplet}$
    $\Rightarrow$ try to get an analytical scaling for $\frac{L_{triplet}}{L^*}$ as well?

E-deposition, triplet protection

RADIATION FIELD AND ENERGY DEPOSITION

Collision debris impact on the triplet

peak power density and dose in the Nb_3Sn coils

as a function of the (tungsten, i.e. INERMET) inner shielding thickness

explored L*=36 and 61.5m technical report in preparation

Effect of operation condition optimization

regular swap of the vertical crossing angle sign [and of the crossing plane], as suggested by S. Fartoukh

Radiation levels in the detector

maps of dose, 1MeV neutron equivalent fluence, high energy hadron fluence, charged particle fluence

Beam interaction in the collimators and particle shower development

Beam-gas interaction impact on the arc cell

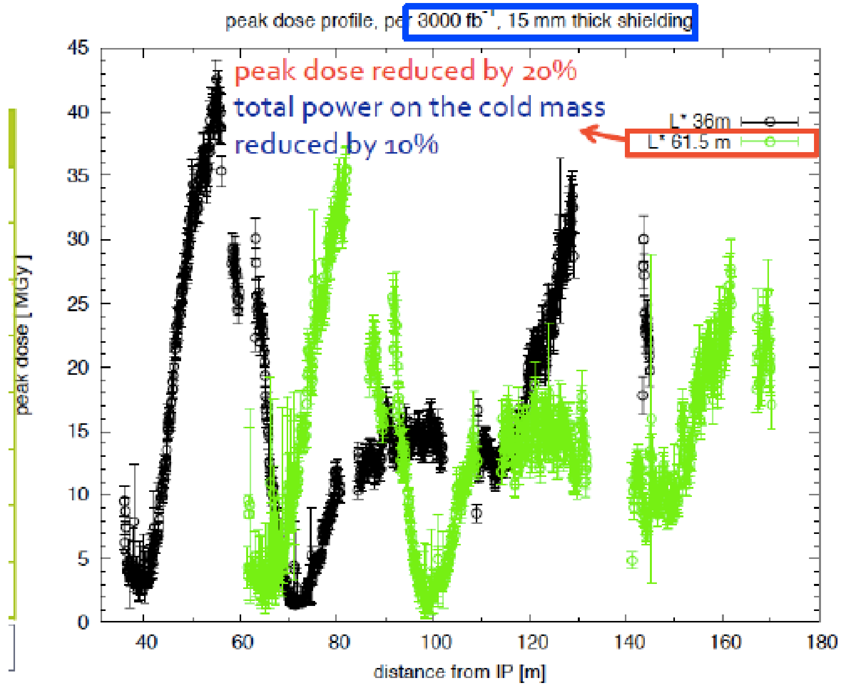
see Besana's talk in Washington

E-deposition, triplet protection

COLLISION DEBRIS IMPACT ON THE FCC TRIPLET

L* [m]	36	61.5	Effect
crossing plane	vertical	vertical	
half crossing angle [μrad]	70	85	↑
coil aperture [mm]	100	140	↓
maximum gradient [Tm^{-1}]	220	**150**	↓
TAS aperture [mm]	20	35	
Q1/Q3 length [m]	20.0	20.54	
Q2 length [m]	17.5	17.58	
corrector length [m]	1.5	3	

R. Tomas and R. Martin

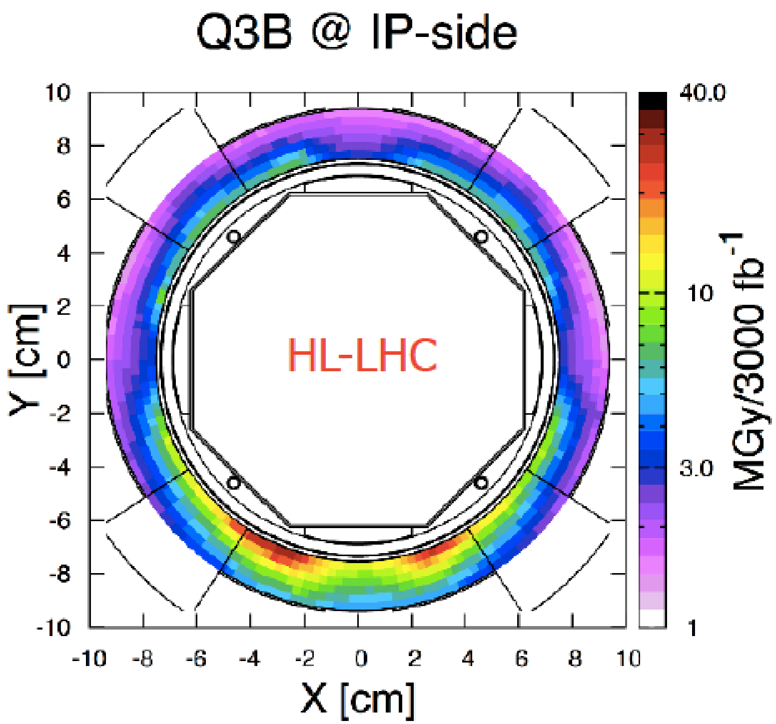


~40 MGy after $3ab^{-1}$, present insulation limit taken at ~30 MGy, goal of $30ab^{-1}$ ...

preliminary (not conservative) assumption: continuous shielding along the InterConnects!, no beam screen

E-deposition, triplet protection

OPTIMIZING OPERATION MODE



+295 urad half vertical crossing angle (upwards)

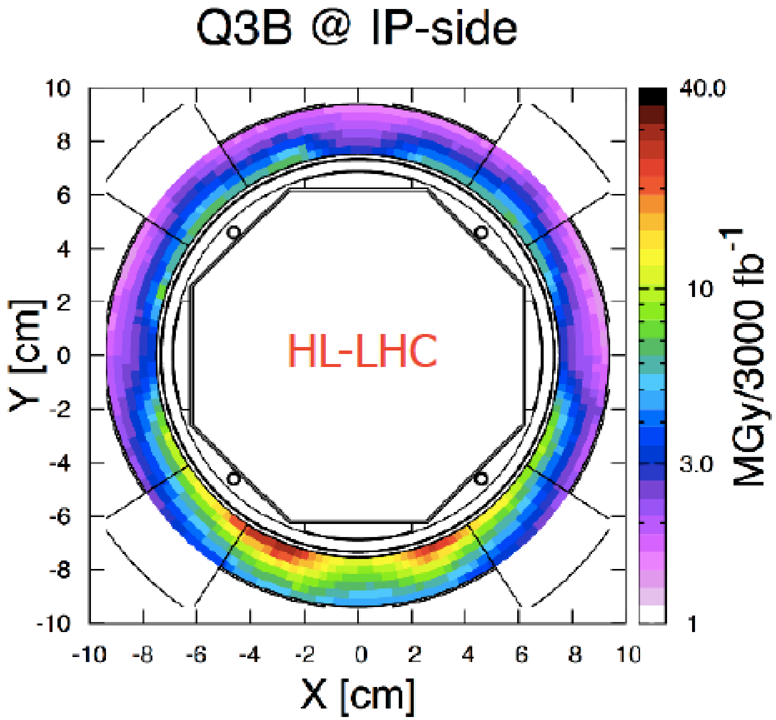
what about running half of the time at inverted angle? [S. Fartoukh]

for a –y reduction of a factor x (=5),

peak dose gain of (x-1)/2x (=40%) and integrated lumi increase of (x-1)/(x+1) (=67%)

E-deposition, triplet protection

OPTIMIZING OPERATION MODE



+295 urad half vertical cros (upwards)

We observe that vertical crossing angle is more difficult

Why is that? Is it because there are more positive pions than negative? Need to check.

Also, visualizing trajectories of pions will help to understand the possible mitigation strategy

We also need to know the longitudinal distribution of energy deposition in the coil from a single pion

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E-deposition, triplet protection

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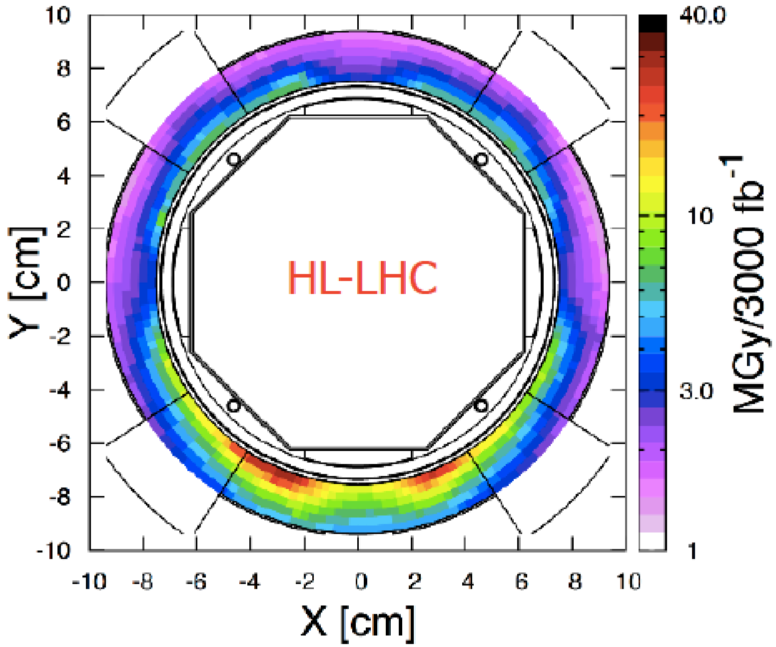
OPTIMIZING OPERATION MODE

Q3B @ IP-side



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2015 June 3rd F. Cerutti EuroCirCol WP3 meeting 5

A lot of discussion about switching crossing angle from plus to minus in one plane or between planes

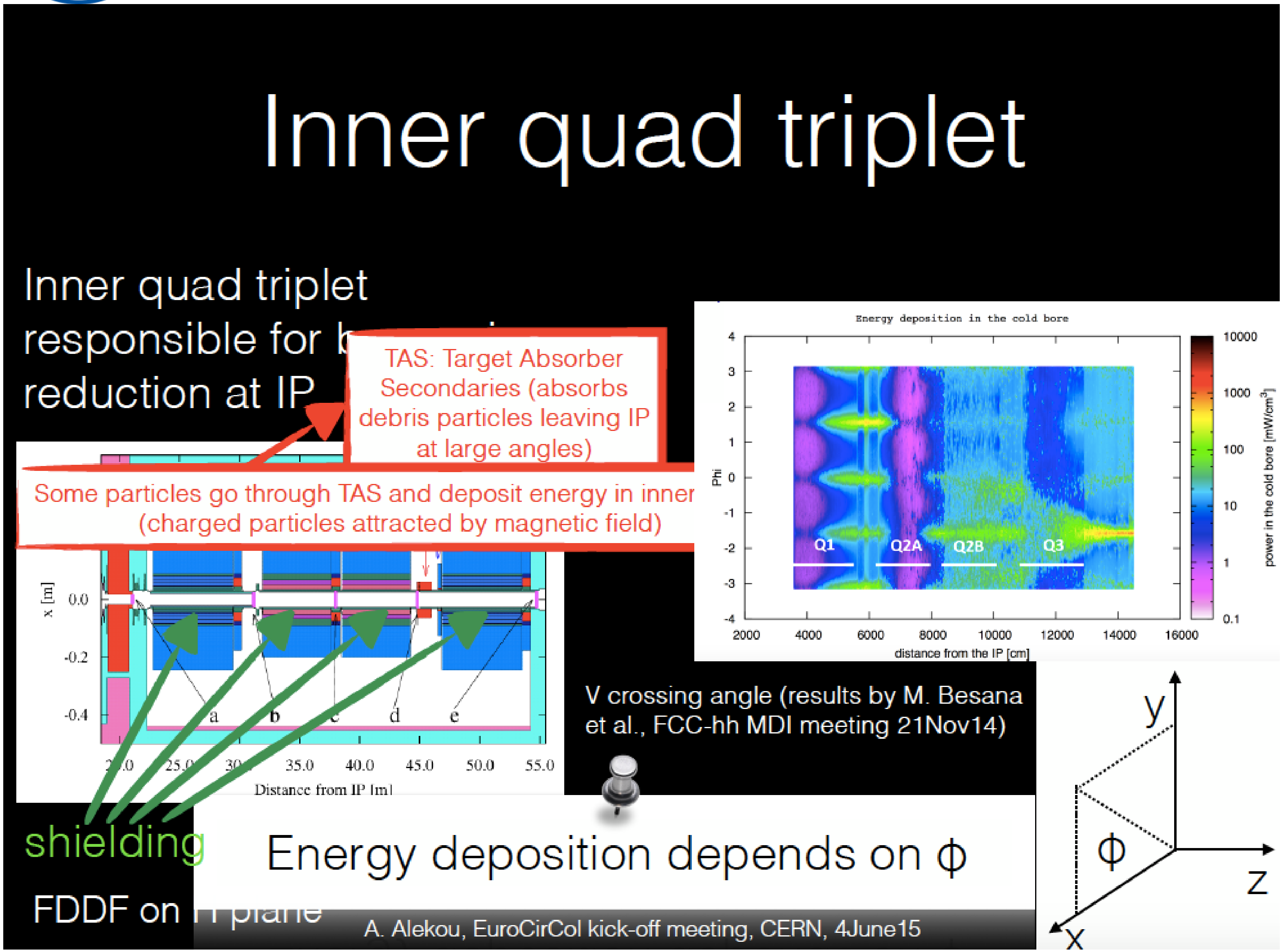
What is possible and what is easier – need to be further studied

Discussed also rotating the quads 90 degrees – difficult because they will be rad hot and because of the connectors

Switching crossing angle may be easier

Was also proposed to look at DFD – FDF in one IP and FDF-DFD in the other IP

Ideas of shielding for lower beta*



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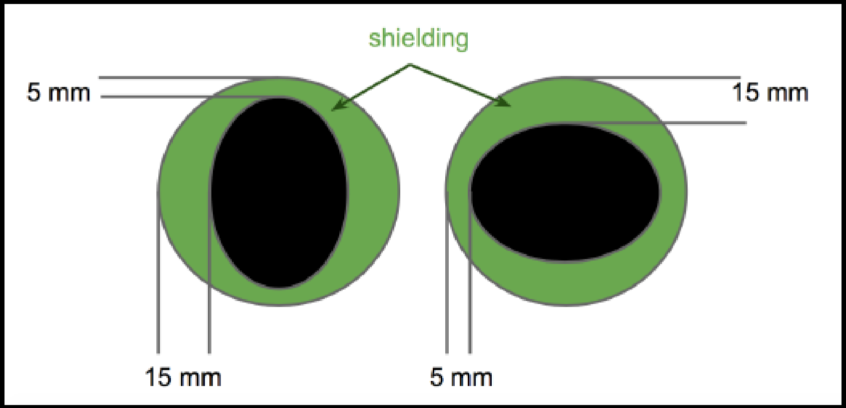
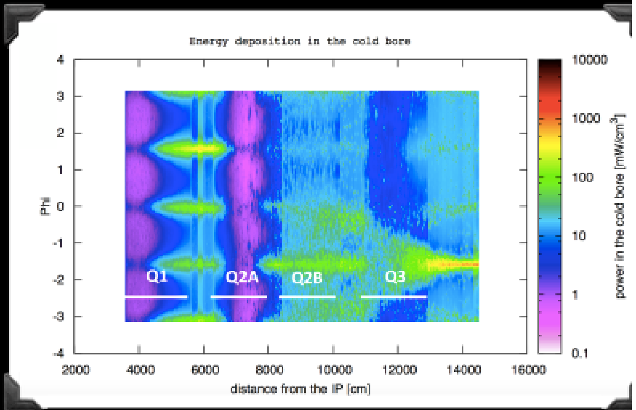
Ideas of shielding for lower beta*

Changing aperture shape

Thickness of shielding inside triplet-quads does not need to be uniform and can vary, resulting in elliptical aperture





May be able to find a configuration of inner triplet optics and elliptical apertures that losses will have a favourable pattern, allowing us to significantly decrease β*

A. Alekou, EuroCirCol kick-off meeting, CERN, 4June15 4

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Ideas of shielding for lower beta*

Plan

- Study triplet optics together with energy deposition:
  - Create simple analytical model of losses
  - Make triplet optimisation to see if we can find a favourable optics and loss pattern
- Collaborate with R. Tomas and R. Martin; R. Martin wrote python code to track pions* from IP and detect losses to possibly optimise optics

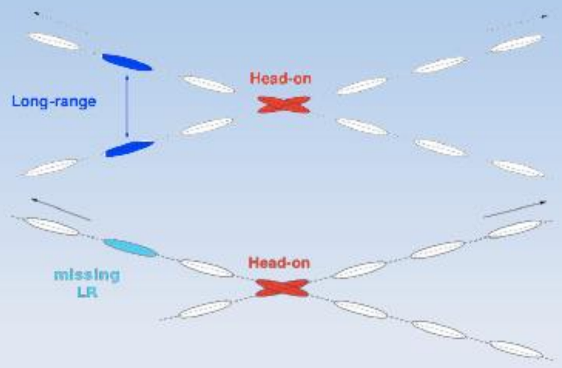
Feasibility of this plan need to be further discussed based on additional information about pions – their trajectories and distribution function of energy deposition from a single pion

*From debris collisions, energy deposition on triplet is mainly due to pions

A. Alekou, EuroCirCol kick-off meeting, CERN, 4June15 5

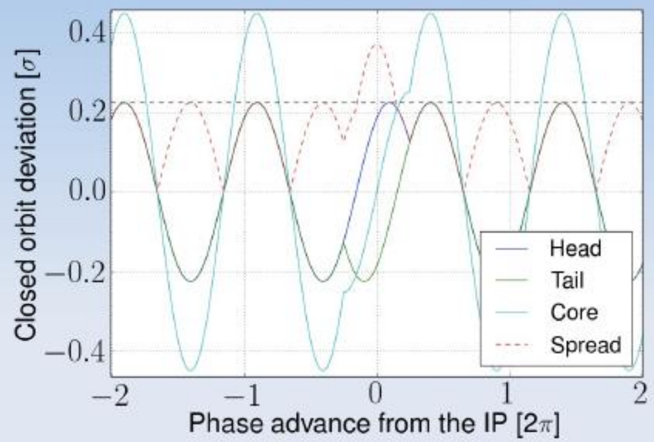
Beam-beam

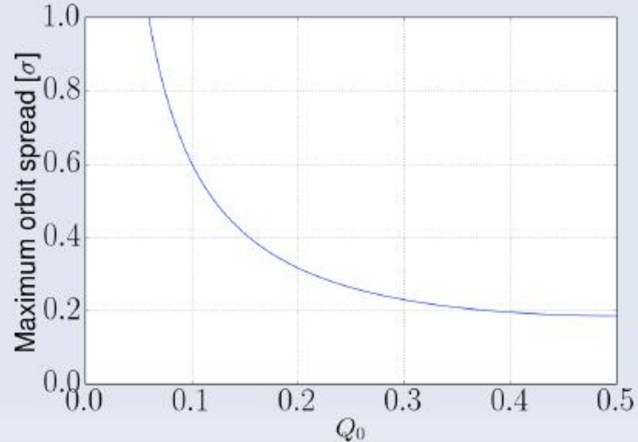
Orbit effect



$$\text{orbit spread} \propto \frac{N_{LR} N r_0}{\epsilon d} \frac{1}{sin(\pi Q_0)}$$

- Orbit effect from long-range beam-beam interaction might require mitigation in the 5 ns scenario
  - Needs to be taken into account in the aperture margin in any case





X. Buffat

5 ns leads to several sigma effect at IP – quite severe – will need bunch by bunch orbit correction to mitigate this

Beam-beam

CERN

Dynamic β

FCC hh ee he

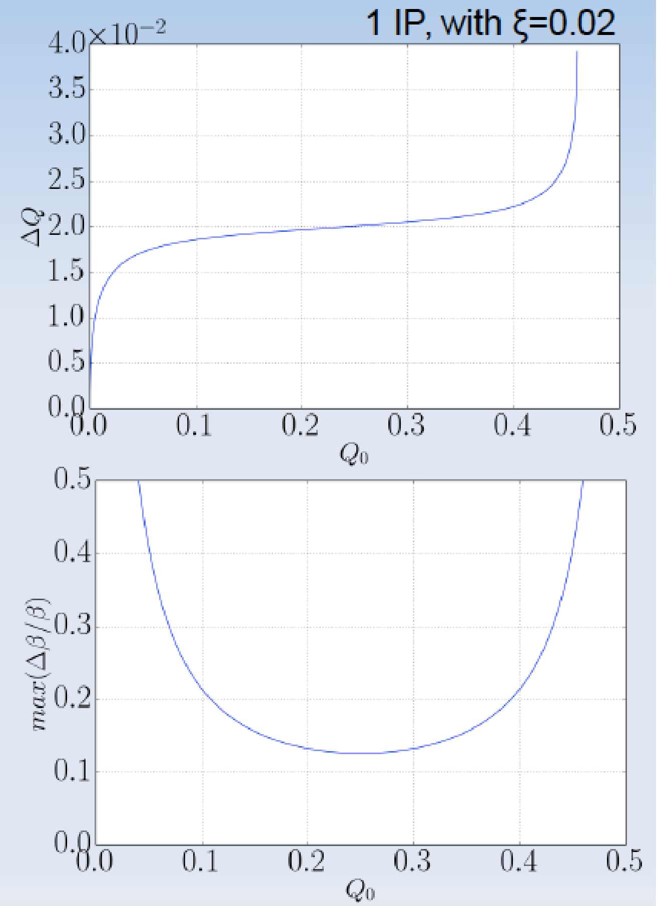
$$cos(2\pi Q) = cos(2\pi Q_0) - 2\pi\xi sin(2\pi Q_0)$$

$$\max\left(\frac{\Delta\beta}{\beta}\right) = \frac{2\pi\xi}{sin(2\pi Q_0)}$$

- The extra focusing due to head-on beam-beam interactions introduce a large β beating

→ Effect of the phase advance between IPs

→ Local compensation ?

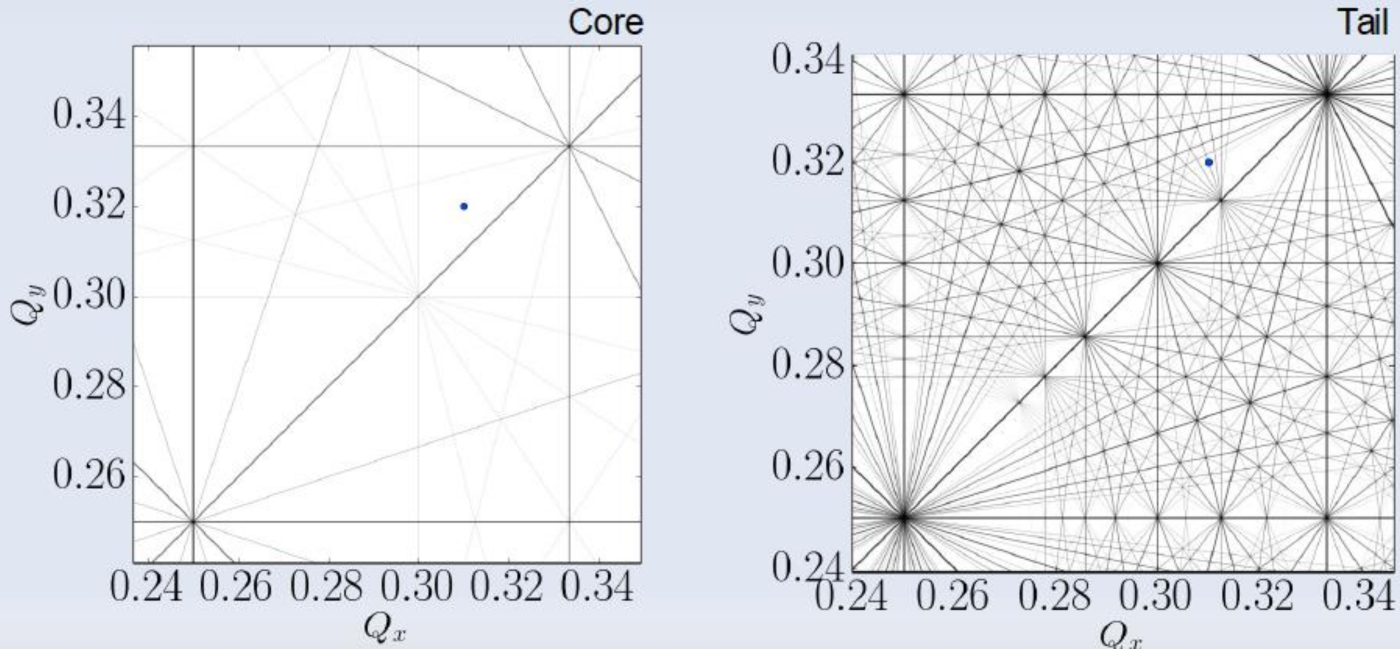


Can we study correction of beta-beating experimentally, at Super-B factory?

Beam-beam

Non-linear effects
LHC working point

- Use the space between 1/3 and ¼
- Nominal beam-beam parameter is 0.0033 per IP
  - Operated with ~0.007 per IP in 2012

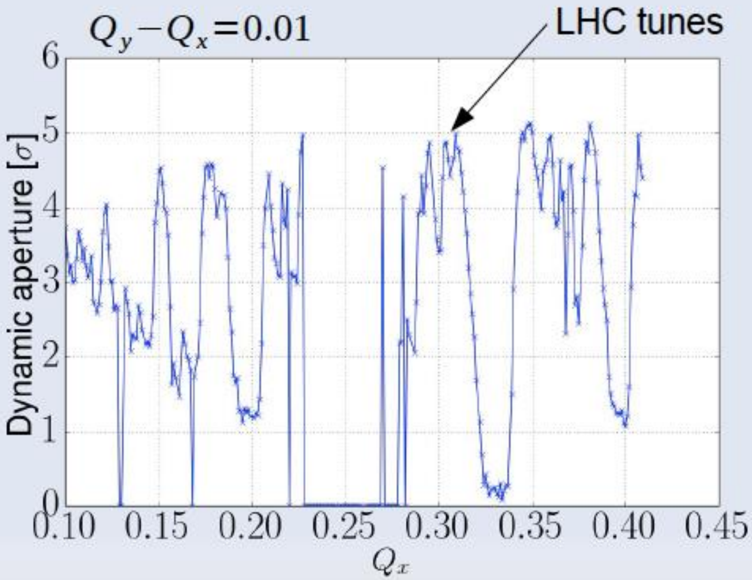


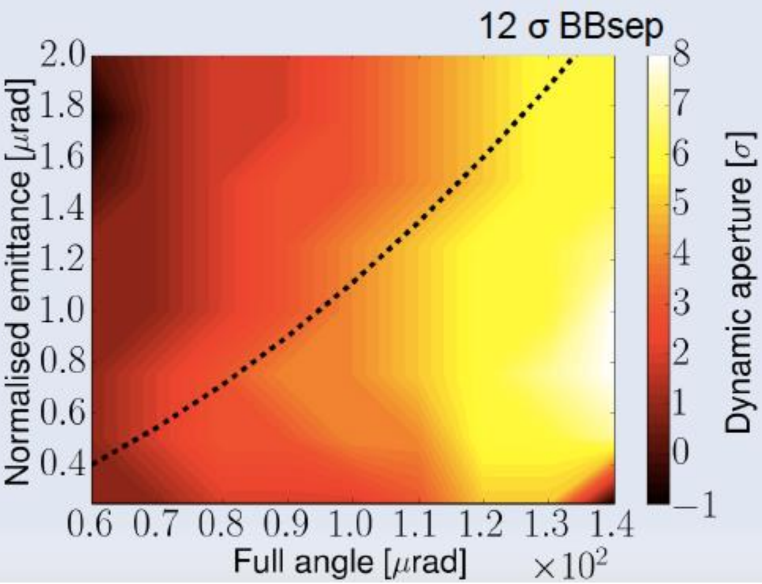
Beam-beam

Dynamic aperture

- Small effort to re-use software developed for the LHC and HL-LHC
- Dynamic aperture studies are on going using Sixtrack on LHC@home using the TOY_V1 lattice
  - Recovered LHC results

  → Need to characterize different IR design (L*, triplet length, Xing scheme, ...)

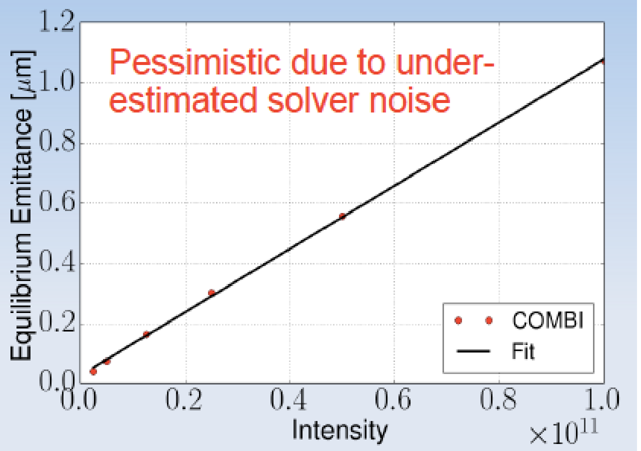


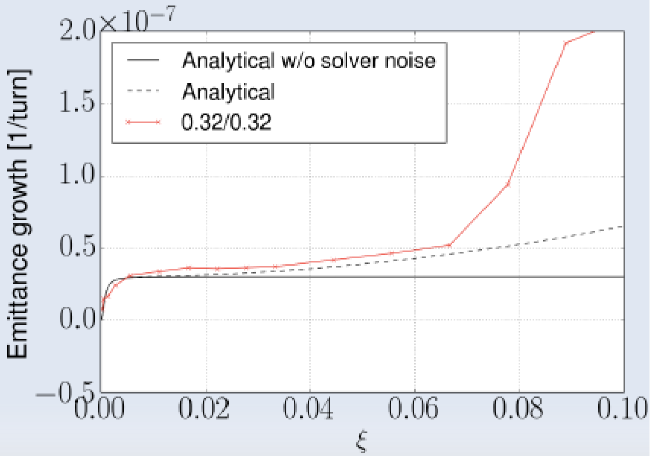


Beam-beam

Emittance growth

- Synchrotron damping and quantum excitations were implemented in COMBI to estimate beam-beam limitations
  - Challenging in term of field solver noise
  - High computing resources are necessary (EPFL-HPC)
- Benchmark of the code against Analytical models for the emittance growth due to external sources of noise
  - Synergy with HL-LHC : J. Barranco (EPFL) and T. Pieloni (CERN)





Beam-beam

Tentative plan

- Understand brightness limitations
  - External sources of noise / decoherence of beam-beam modes with large beam-beam parameter
  - Interplay between beam-beam interactions and quantum excitation and IBS (i.e. “beam-beam limit”)
  - Describe the dynamic aperture with small emittance beams and different IR design
  - All of the above with non-round beams
- Describe linear effects of beam-beam (orbit, dynamic β)
- For all of the above, study compensation scheme

Summary

- **Very good discussions this week**
- **The design work started and will escalate to full speed in the coming months**