FCC-hh IR – JAI updates

JAI FCC team

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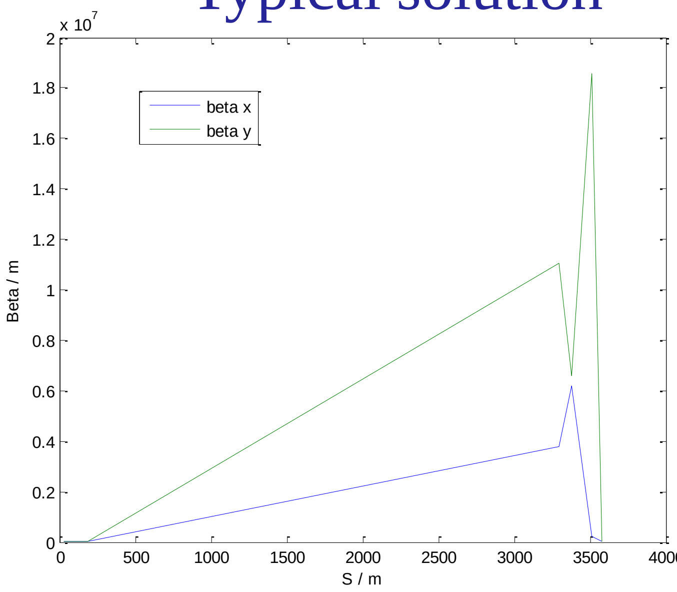
Triplet optimization

- Model quadrupoles as **thin lenses** with specific **focal lengths**
- **Analytically** find configuration to obtain required transfer matrix
- Use this to obtain estimates on properties like **beam stay clear**
- Vary elements to **scan through parameters quickly**
- Find ideal setup and **convert to thick lens**

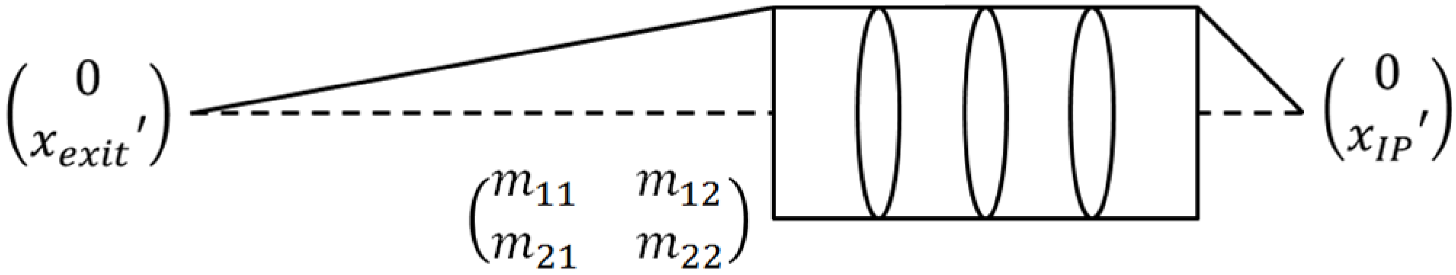
- Telescope made of **two triplets**
- **Vary** strengths of **outer triplet** lenses
- **Calculate inner triplet** using method by A.W. **Chao**
- Work out **figure of merit**:

$$N = \frac{r}{\sqrt{\varepsilon\beta}} = \frac{B l_Q}{g_i\sqrt{\varepsilon\beta}} \propto \frac{l_Q}{g_i\sqrt{\beta}}$$

Typical solution



Triplet optimization



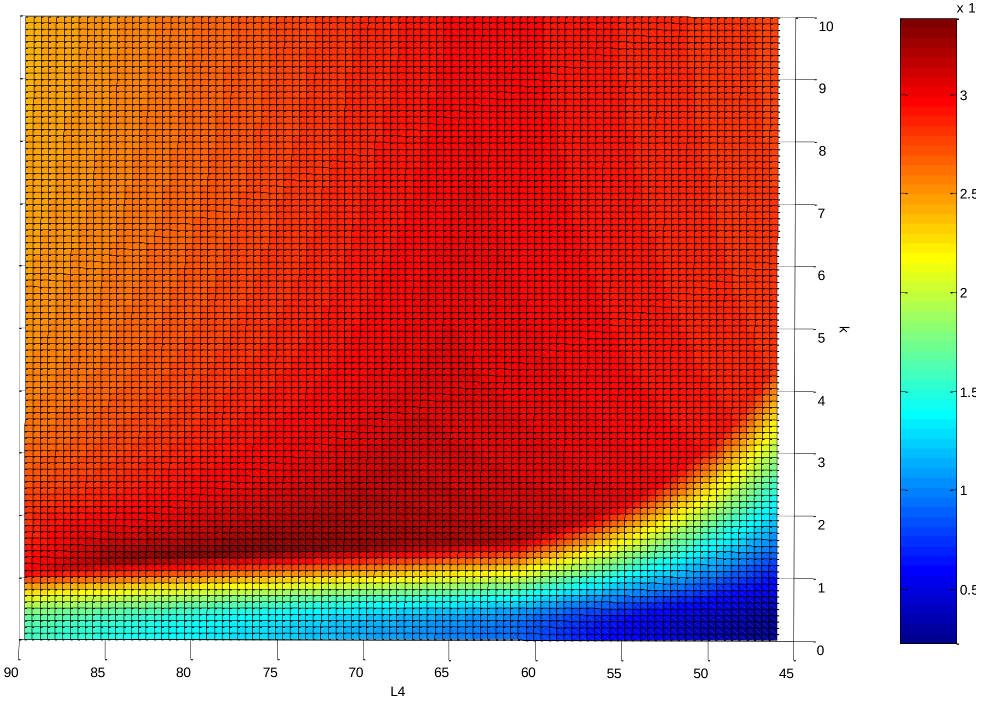
- **Further simplification – only look at inner triplet**
- $\boldsymbol{m_{x12} = m_{y12} = 0}$
- Arbitrary constraint $k = \frac{strength\ Q1}{strength\ Q3}$
- **Work out strengths** for given drifts
- Impose **further constraints** e.g. total length, equal internal drifts

Triplet optimization

- Start at **IP** (based on current values)**:**

$$\begin{pmatrix} x \\ x' \end{pmatrix} = \begin{pmatrix} -1.36 \times 10^{-11} \\ -1.00 \times 10^{-14} \end{pmatrix}; \begin{pmatrix} y \\ y' \end{pmatrix} = \begin{pmatrix} -3.51 \times 10^{-14} \\ -7.10 \times 10^{-13} \end{pmatrix}$$

- Work out **FOM** $= \frac{x_i}{g_i} L_{Qi}$ at each lens
- Scan through parameters and attempt to **maximise FOM**

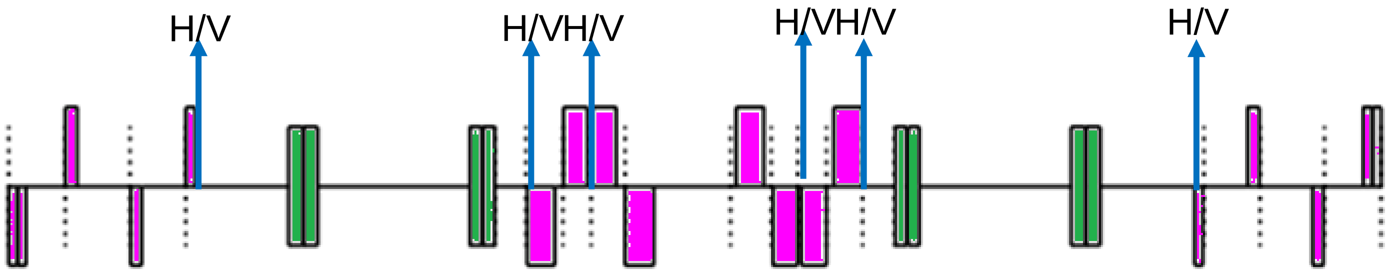


Orbit correction studies

Objectives of the correction Scheme:

Control possible misalignments of the quadruples of the interaction region (in particular the IT) while maintaining the crossing angle.

- **Use correctors in IR lattice (L*=45 m)**
  - MCBXDH/V.A2 before to quad 2 (MQXD.A2)
  - MCBXCH after quad 3 (MQXC.3)
  - MCBXDH/V.A2 before quad 4(MQYY.4)

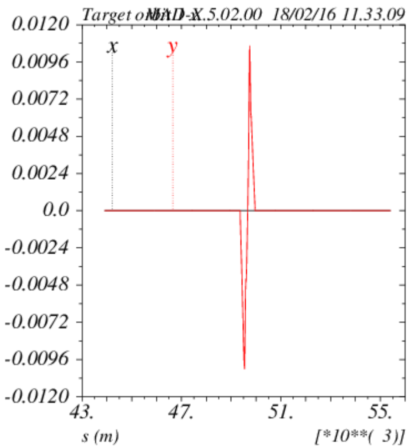


- Installed BPMs along IR as a reference for orbit correction. Maintain position close to the quadrupoles.
- Installed correctors next to other correctors of the IR (Next to MQ4-6 in the image).

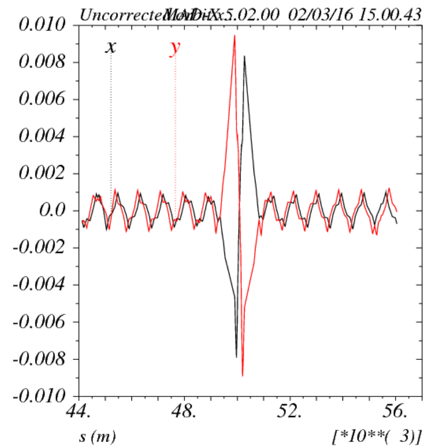
Orbit correction studies

The ideal corrected orbit would restore the original orbit in the presence of alignment errors by adjusting the strength of the correctors.

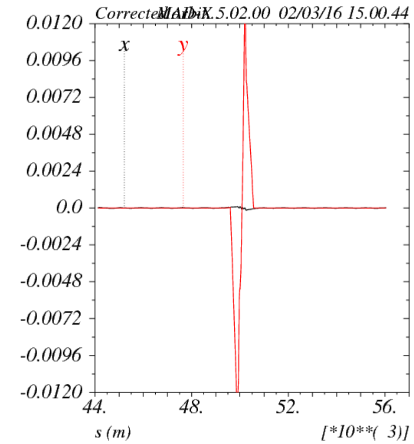
No errors



Added IT errors



Correction



Correction Procedure:

1. Add alignment errors in inner triplet
2. Use CORRECT procedure in MADX
3. Repeat procedure for 500 seeds of transverse alignment errors.

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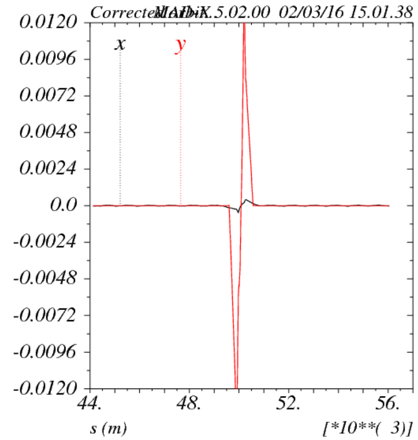
Orbit correction studies

- **Evaluate the efficiency of the correction by:**

    1. Calculate necessary field of the correctors. Is it achievable?
    2. Calculate maximum x deviation after correction.



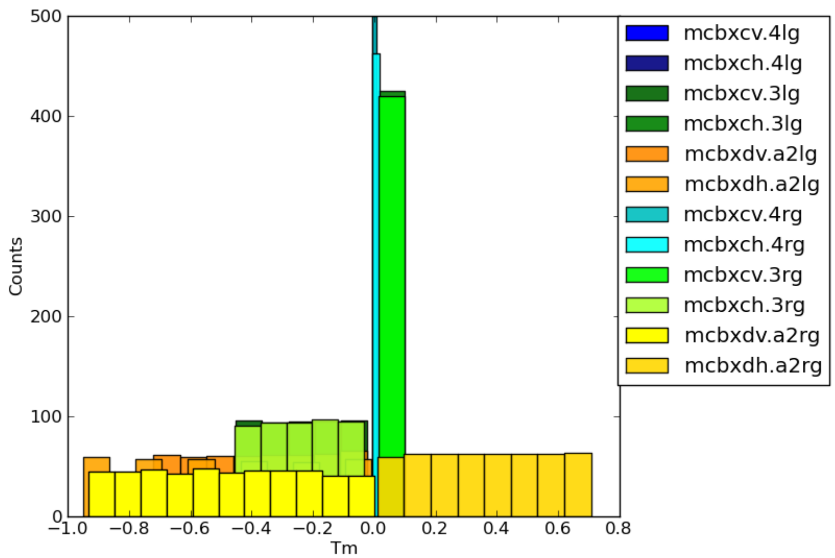
LHC studies required 0.5 mm maximum deviation after the correction. At the moment we are aiming for the same.

- Correction depends of position on the BPM and number/position of the correctors. Several scenarios were tested to find the correction scheme fulfilling the previous points.
- Explored option with new correctors between MQX2A and MQX2B and/or before MQX1 but there may be problems with space. Previous results didn't show consistent good results for a large number of seeds.

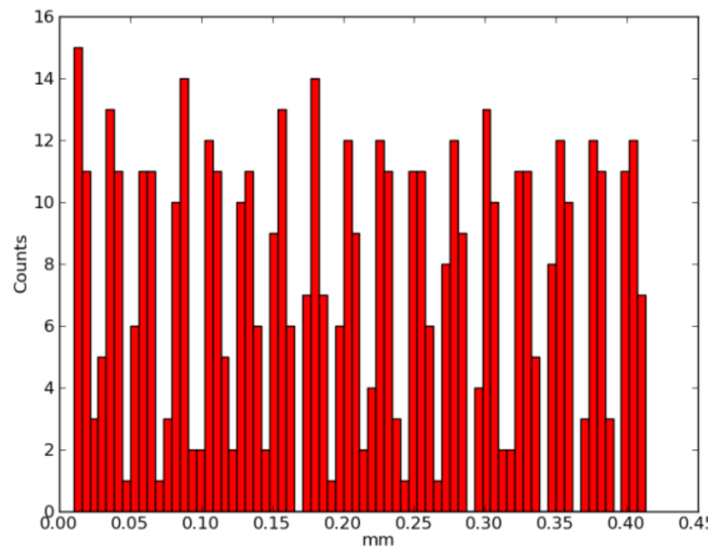
Orbit correction studies

Results of the best correction:

- Errors on the inner triplet with a transverse maximum misalignment of 0.5 mm.
- Length added to the existing correctors (MQX2-4) but no NEW correctors added.



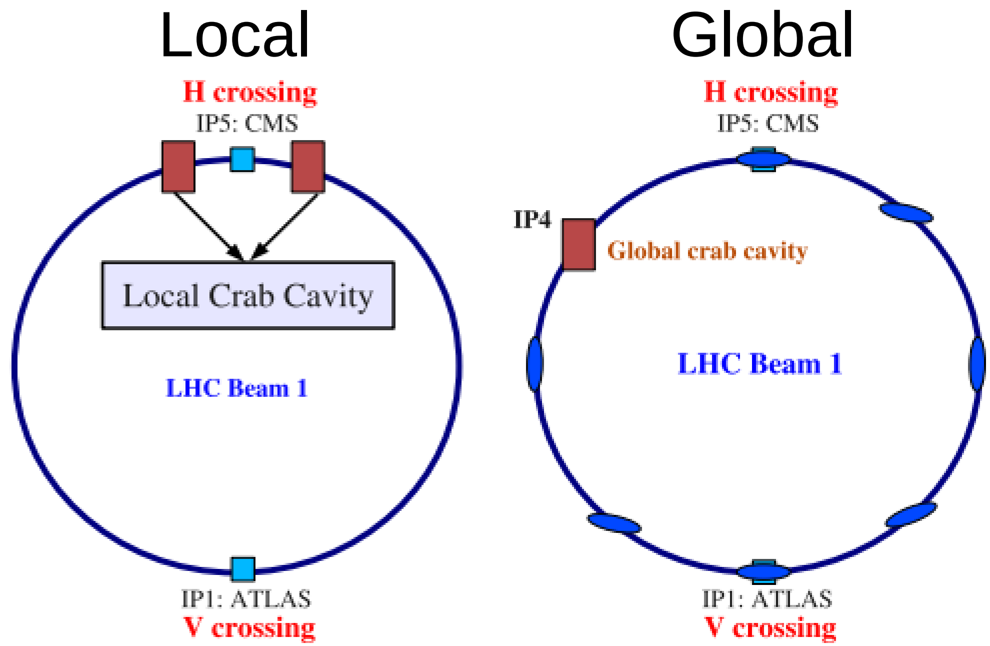
All correctors in the achievable range of -1, 1 TM



All seeds with a maximum deviation below 0.5 mm

Crab Cavities in the FCC

- The crab cavities schemes for the HL-LHC proposed two designs: the local Scheme, with two crab cavities at each side of the IP and a global scheme with a single crab cavity.



- Consider Local Scheme for the FCC.

Crab Cavities in the FCC

- **Calculate voltage necessary in the crab cavities (local) for the FCC:**

$$V_1 = \frac{c^2 \cdot p_s \cdot \tan(\frac{\theta}{2})}{q \cdot \omega \cdot \sqrt{\beta^* \cdot \beta_{\text{crab}}} \cdot \sin(\Delta\varphi_0)},$$

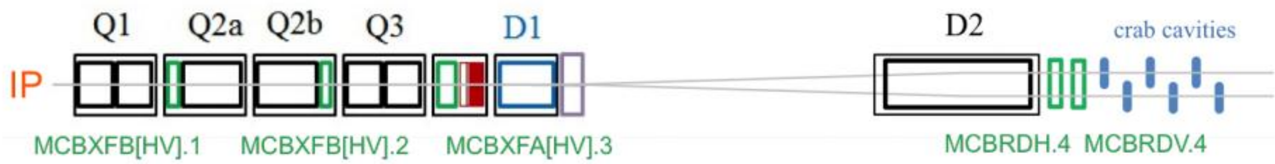
$$V_2 = -R_{22} \cdot V_1,$$

- **Choose the location of the crab cavities:**

Requirements:

1. Need physical space.
2. High beta function
3. Phase advance with respect to IP close to π/2

Following the experience of the HL-LHC: Locate them After D2, before MQ4



Crab Cavities in the FCC

- **Calculate voltages for the different luminosity scenarios:**

	IPA	IPG
Nominal Luminosity **β*= 1.1 m**	V_1 = 4.99 MV V_2 = -3.05 MV	V_1 = 4.76 MV V_2 = 1.97 MV
Upgraded Luminosity **β*= 0.3 m**	V_1 = 9.59 MV V_2 = -8.25 MV	V_1 = 9.17 MV V_2 = 3.74 MV

- **Similar to the voltages needed for the HL-LHC. Same technology is therefore feasible also for this experiment (?).**

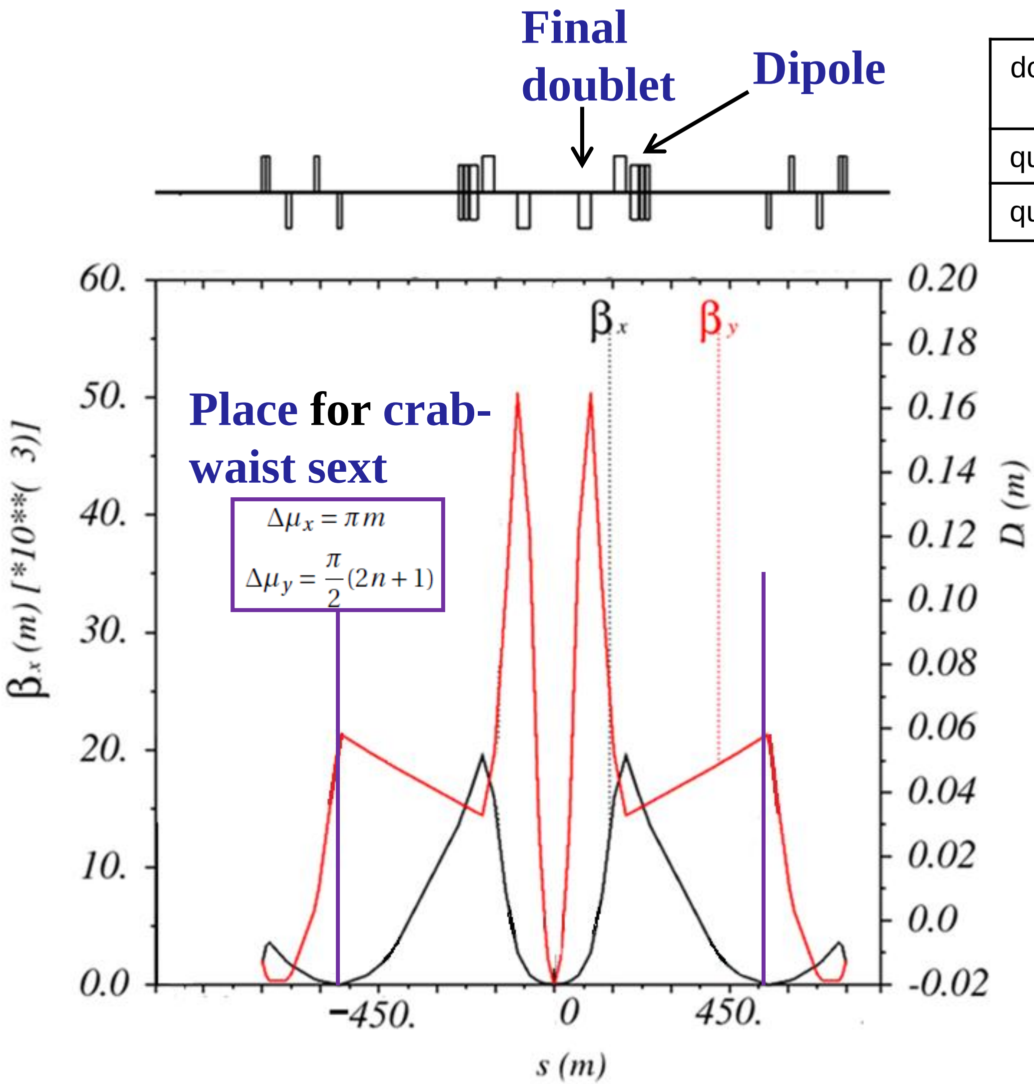
An alternative final-focus design

- One of the main limitations for hadron colliders is beam-beam tune shift.
- The standard scheme for a final focus (common aperture triplet quads., dipole separators, dedicated aperture quads.) does not present the optimal solution in terms of acceptance (beam diverges in the triplet and wide aperture for two beams).
- Can we define a completely new scenario for the FCC EIR?
  - Twin aperture final-focus quads.
  - Large crossing angle.
  - Symmetric optics (opposite polarity in the twin quadrupoles).
  - Horizontal crossing in the 2 EIR (only).
  - Elliptical beams ($\sigma_x^*/\sigma_y^* \sim 7$).
  - Crab-cavities?
  - Crab-waist sextupoles?

An alternative final-focus design

- **Advantages:**
  - **More beam separation.**
  - **Quadrupoles with much lower aperture.**
  - **Allows more bunch intensity due to tune shift reduction.**
  - **No need for emittance blow up and more integrated luminosity.**
  - **TAS and TAN before quads?**
  - **Only one set of dipole separators needed.**
- **Disadvantages**
  - **Final element: not easy to have a separated quadrupole with opposite polarity.**
  - **Luminosity penalty in terms of crossing angle (but can be compensated by crab-cavities).**
  - **It may need crab-waist sextupoles to compensate for the betatron resonances induced by the crossing angle (but design allows them).**

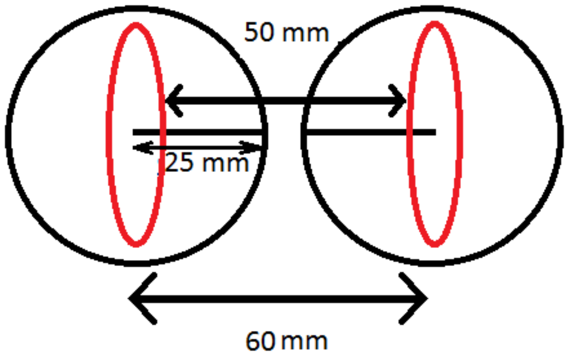
An alternative final-focus design



Beam 1 & Beam 2 optics

doublet	g [T/m]	L [m]	a [mm] (>15σ)	Beam sep [mm]
quad1	-111.4	30.81	21.5	62- 93
quad2	63.5	30.81	13.5	152.7-183.5

beam size as 15σ



Quad1: opposite sign quadrupoles.

- Challenging hardware solution?
- Increase crossing angle?

An alternative final-focus design

$$L = \frac{N_1 N_2 f n_b}{4\pi\sigma_x^* \sigma_y^*} S, \qquad S = \frac{1}{\sqrt{1+\phi^2}}, \qquad \phi = \frac{\sigma_s}{\sigma_{cro}^*} \cdot \tan\frac{\theta}{2}. \qquad \Delta_{in} = \frac{\theta}{\sigma_{cro}'^*} = \Delta_{beam}[\sigma_{cro}]$$

	round					sym
N [10^{11}]	**1.0**	**1.0**	**2.0**	**1.0**		**2.0**
βx^*, βy^* [m]	1.1	0.3		1.34		5, 0.1
Θ [mrad]	0.091	0.175		0.0827		1
σ_s[cm]	8					8
Φ	0.54	2.0		0.45		2.78
S	0.87	0.45		0.9		0.34
L [$x10^{34}$ $cm^{-2}s^{-1}$]	4.9	9.2	37	**4.2**		12
ξx [x100]	0.46	0.16	0.31	0.48		0.2
ξy[x100]	0.52	0.35	0.69	0.53		0.1
	$\xi_T=\xi_x+\xi_y$					ξ_T=2xMAX(ξx+ξy)
ξ_T[x100]	**1.0**	0.50	**1.0**	**1.0**		0.4
Δ_{in}[σ]	15					348

No crab-cavities considered

Energy deposition & MI studies

- Close collaboration with colleagues from CERN and Cockcroft Institute
- Energy deposition simulation tools (FLUKA course, BDSIM collaboration)
- Study of energy deposition for alternative optics.
- Impact of muons through the tunnel to adjacent EIR.