Experimental Interaction Region Optics for the High Energy LHC

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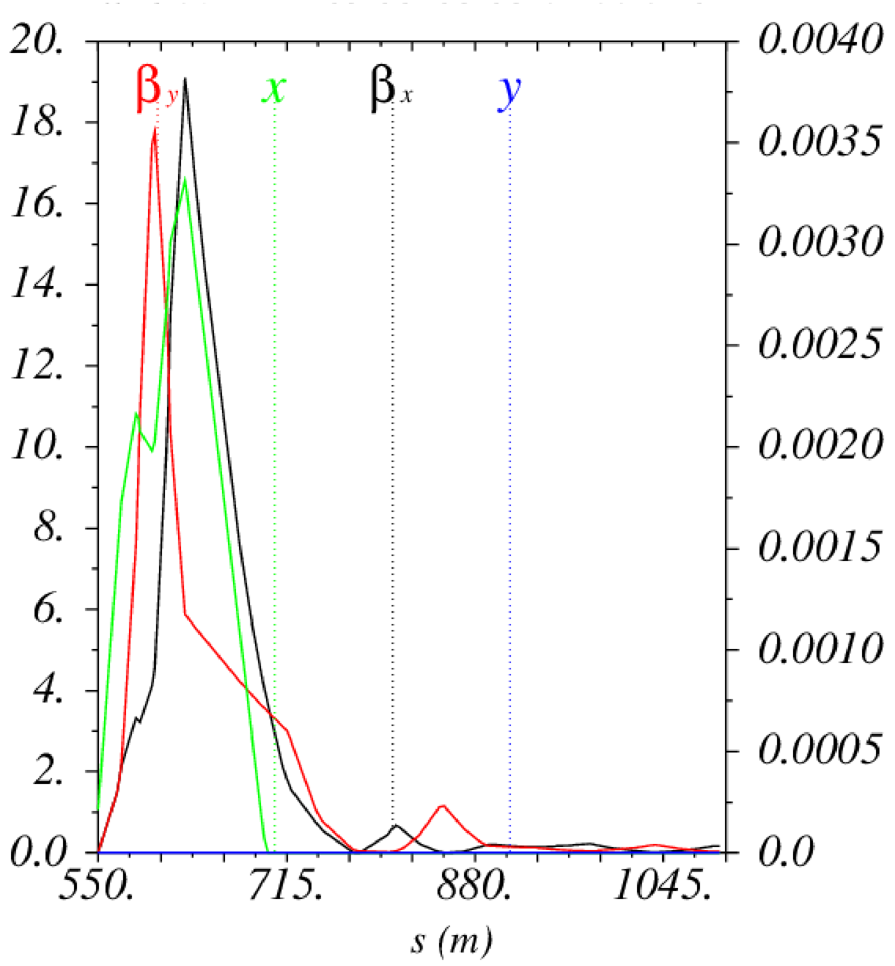
Experimental Interaction Region

- **Need a new triplet for the final focus**
  - ☹ More rigid beam
  - ☹ Increase in debris
  - ☺ FCC NbSn technology
- **Separation dipoles**
  - ☹ More rigid beam
  - ☹ Less space
  - ☺ FCC NbSn technology
- **Space for crab cavities**
- **Matching section**
  - ☹ More rigid beam
  - ☹ Has to fit in LHC tunnel



Algorithm

Set total length and fix required beam stay clear, β*, L*, gaps and shielding

- **Initially 10 mm shielding**

  FCC Week 2017

- $\bar{\epsilon} = 2.5\ \mu\mathrm{m},\ \beta^* = 25\ \mathrm{cm}$
- **12 σ Beam stay clear**
  - $12 \times 1.5 = 18\sigma$ **to consider crossing**

Algorithm

Set total length and fix required beam stay clear, β*, L*, gaps and shielding

Use fast FOM to scan large range in parameter space

Determine sensible range $g \pm 0.005$, $l_4 -2\% + 8\%$

Use PyMadX for small scan of accurate beam stay clear using current shielding (12×25 resolution)

Find setup with largest beam stay clear

If BSC smaller than required increase total length

If beam stay clear larger than required

Plot ideal setup and output lengths + strengths

Optics-FLUKA interaction

J. Abelleira

Set required β*, L* and use initial shielding

Use code to find shortest setup with good beam stay clear

Use this setup for radiation studies of triplet

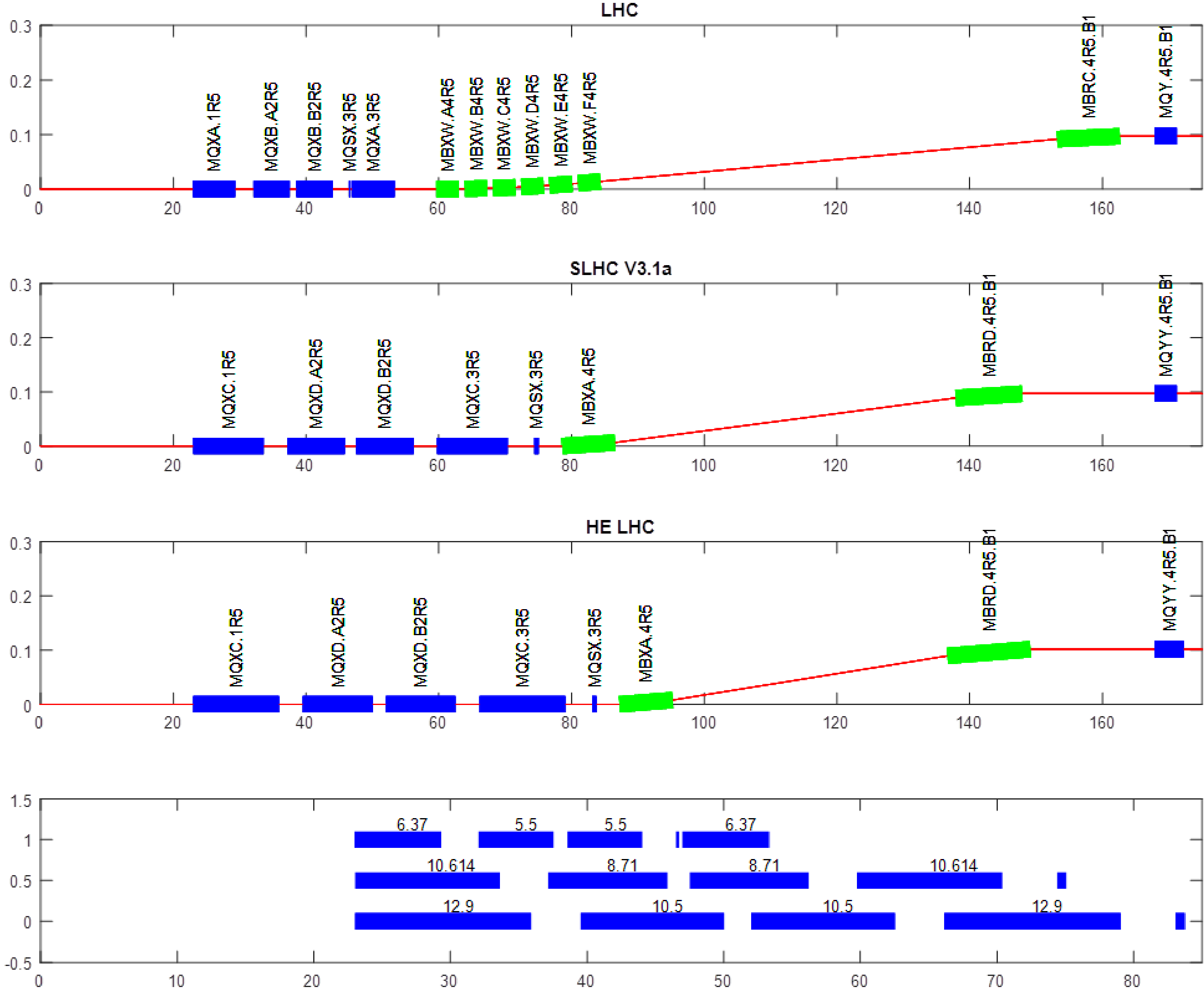
Work out shielding required for this setup

Change shielding accordingly

Integrate and match into machine for further studies

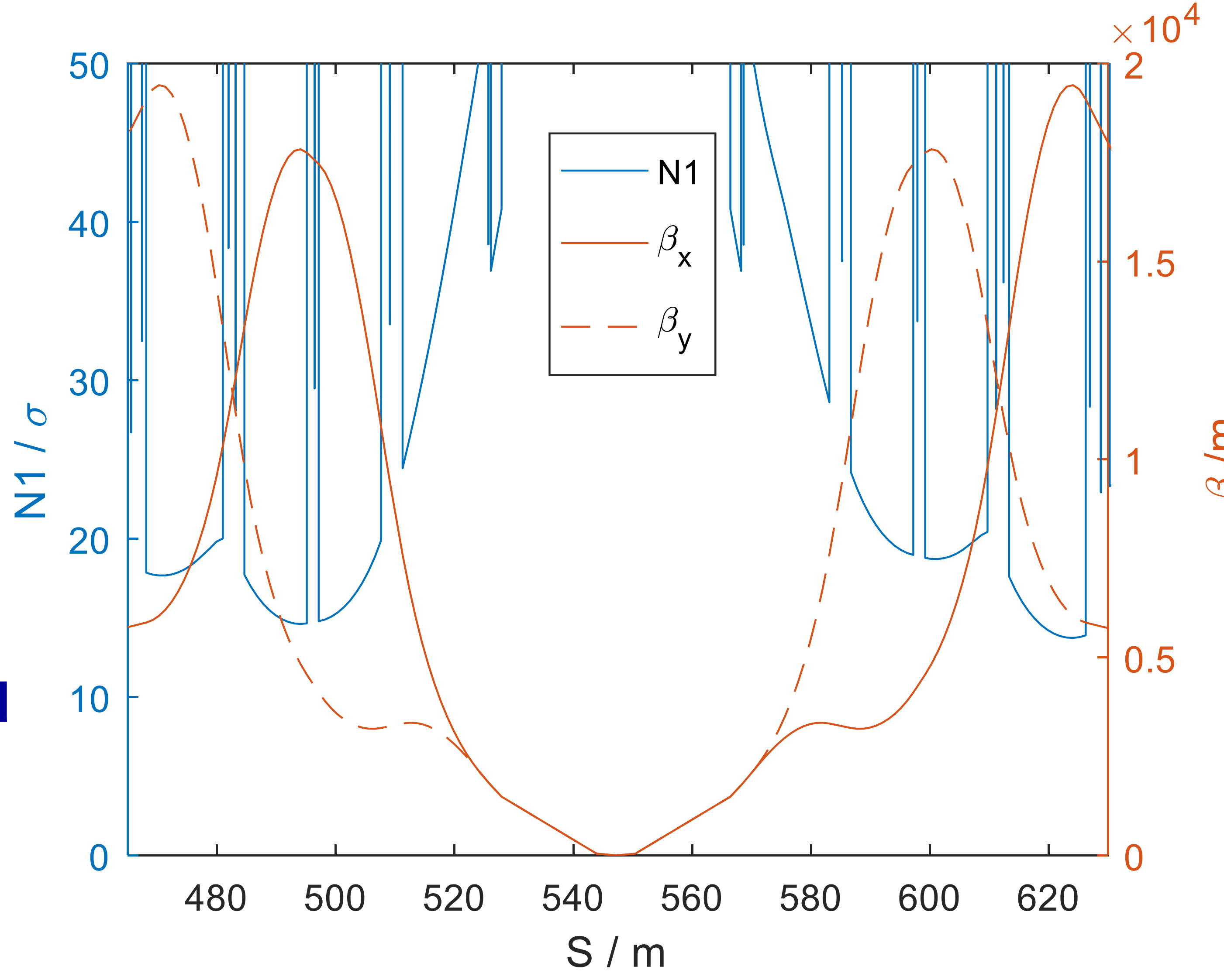
New Triplet

- **Overall 8.2 m longer than HL-LHC Triplet**
- **Study resulted in triplet with 2 cm shielding**
  - **Talk by J. Abelleira**



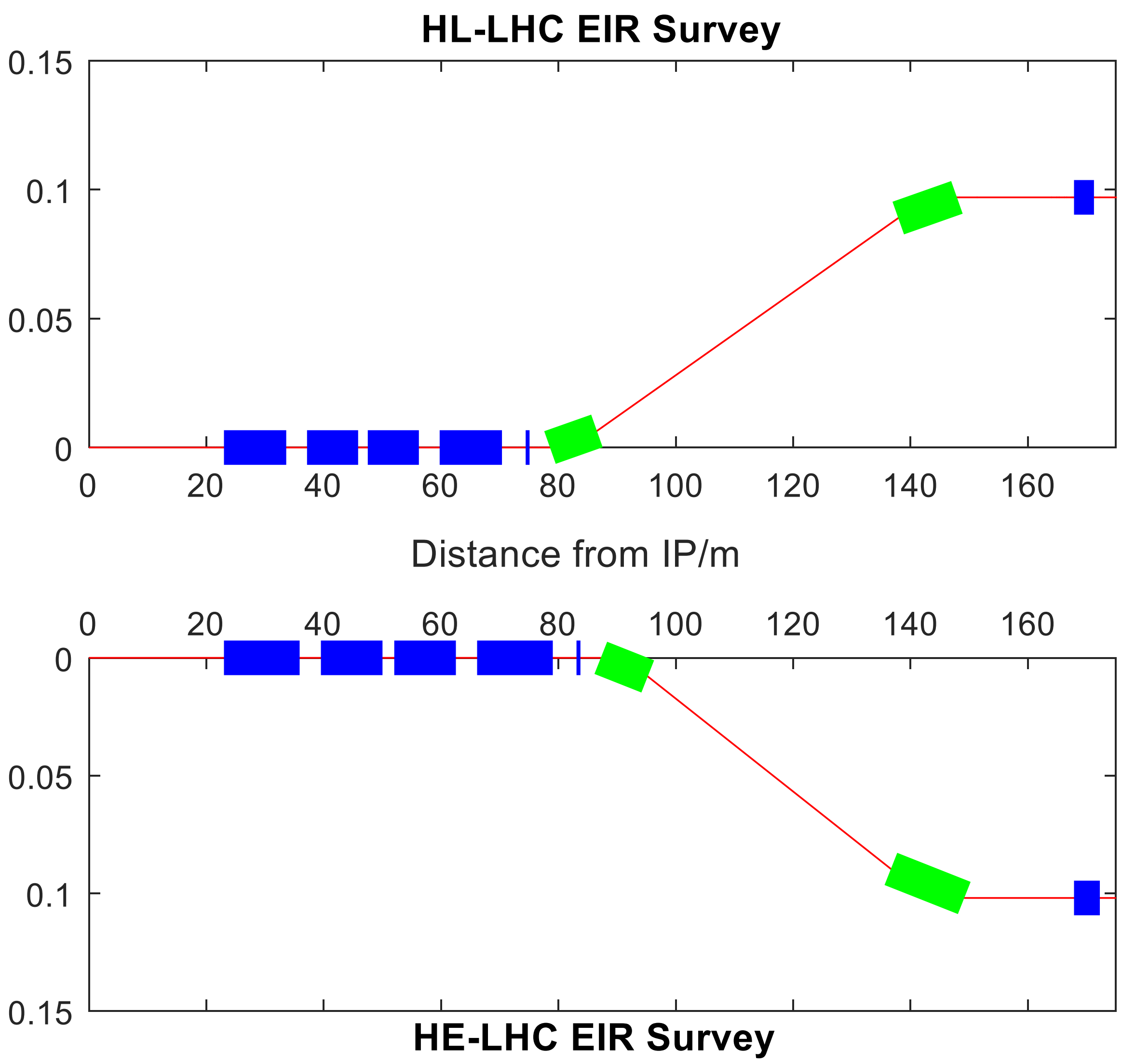
Aperture

- **Overall 8.2 m longer than HL-LHC Triplet**
- **Study resulted in triplet with 2 cm shielding**
- $\boldsymbol{\beta^* = 25}$ **cm**
- $\boldsymbol{\theta/2}$**=131 μrad**
- **14**$\boldsymbol{\sigma}$ **aperture**
- **Potentially much more shielding in Q1**
- **Larger crossing might be needed**
  - $\boldsymbol{\theta/2 = 180}$ **μrad possible**
  - $\boldsymbol{\theta/2 = 210}$**μrad with 1.8 mm shielding in Q3**
  - **See talk by T. Pieloni**



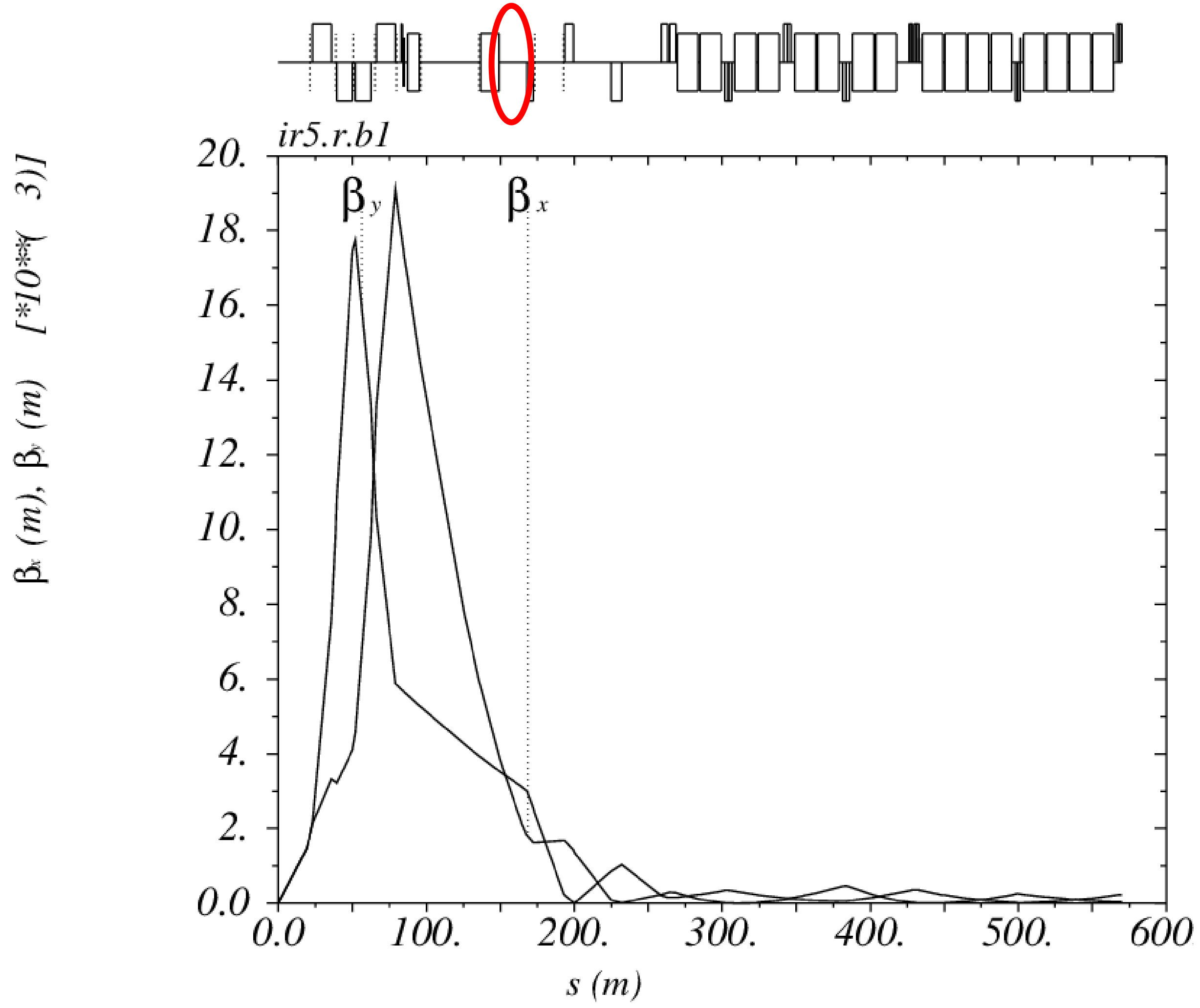
Dipoles

- **Less space for separation than LHC due to triplet**
- **Larger separation than LHC**
  - **205 mm vs. 194 mm**
- **D1 – Single aperture**
  - **Superconducting**
  - **140 mm aperture**
  - **11 T (challenging)**
- **D2 – Double aperture**
  - **Superconducting**
  - **70 mm aperture**
  - **7 T**



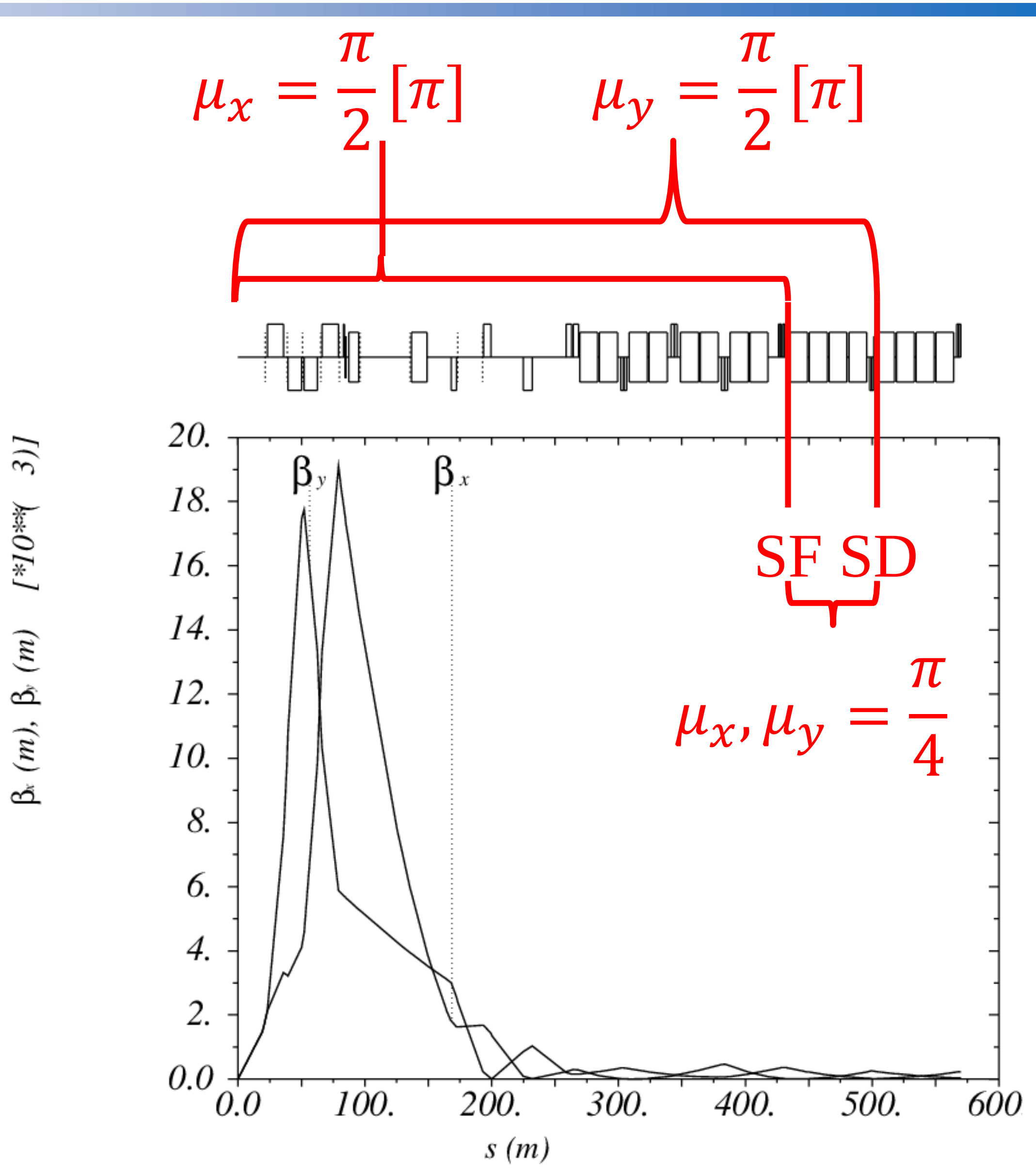
Crab Cavities

- **Currently space reserved between D2 and Q4**
  - **Adapted from HL LHC**
  - **Shares space with orbit corrector**
  - **11 m space in front of correctors**
- **β functions in this space**
  - $\beta_x = 7750 \rightarrow 14360\ \mathrm{m}$
  - $\beta_y = 4260 \rightarrow 5260\ \mathrm{m}$
- **Taking $\beta = 4500\ \mathrm{m}$, $\beta^* = 0.25\ \mathrm{m}$ and $130\mu\mathrm{rad}$ crossing**
  - **Voltage = 6.3 MV**
  - **Compared to 6 MV in HL LHC**
- **Larger angle needs more voltage**
  - **See talk by T. Pieloni**



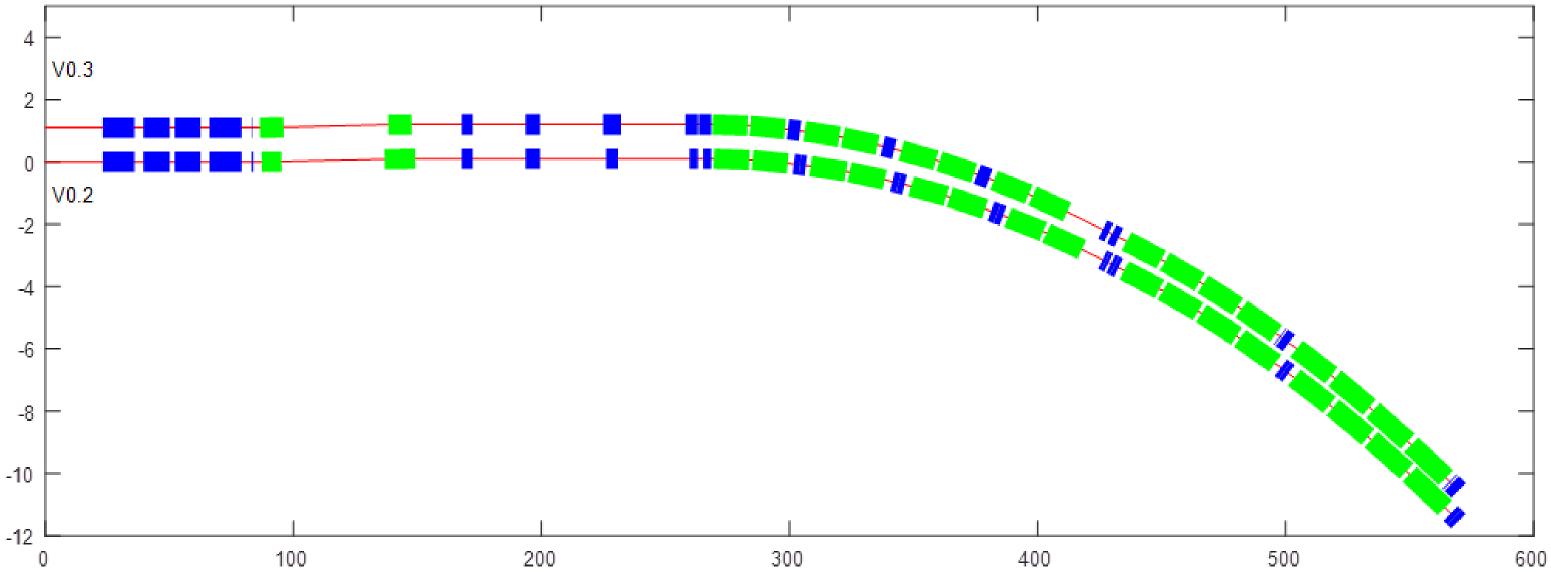
Matching to Arc

- **Optics Matching**
  - **Increase length of first four matching quadrupoles**
- **Chromaticity correction**
  - **Need to optimise this phase**
  - **π/2 [π] phase from IP to sextupoles**
  - **$\pi/4$ between sextupoles**
- **Challenging – compromise**
  - **Match to second sextupole only**



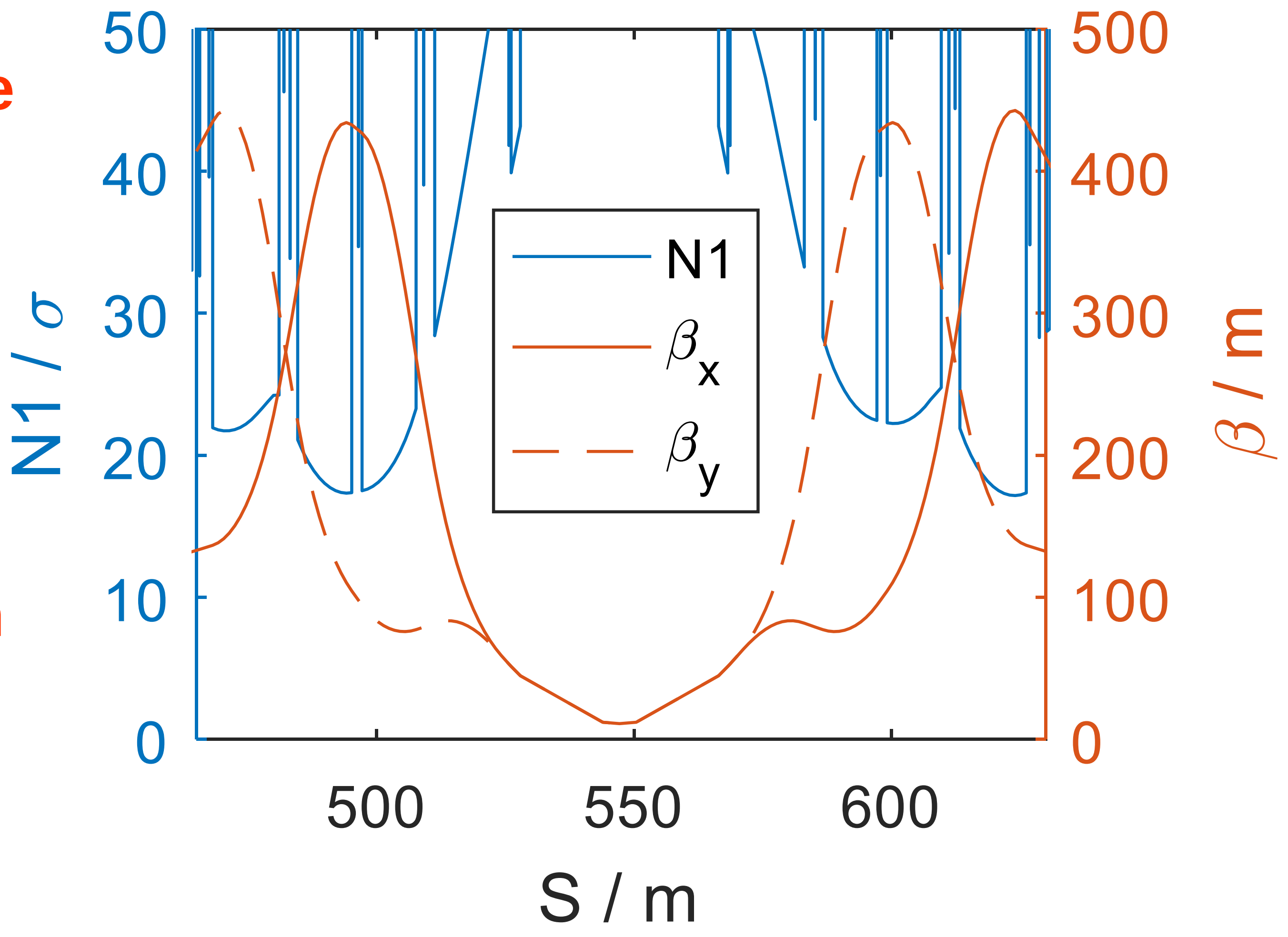
Matching to Arc

- **Lack of flexibility in Dispersion suppressor**
  - **Geometry fixed from LEP**
  - **TWIS constrained by arc**
- **Very dependant on rest of lattice including DS**
  - **Worked in V0.2**
  - **Currently no solution in V0.3**
  - **See talk by R. Tomas on lattice versions**



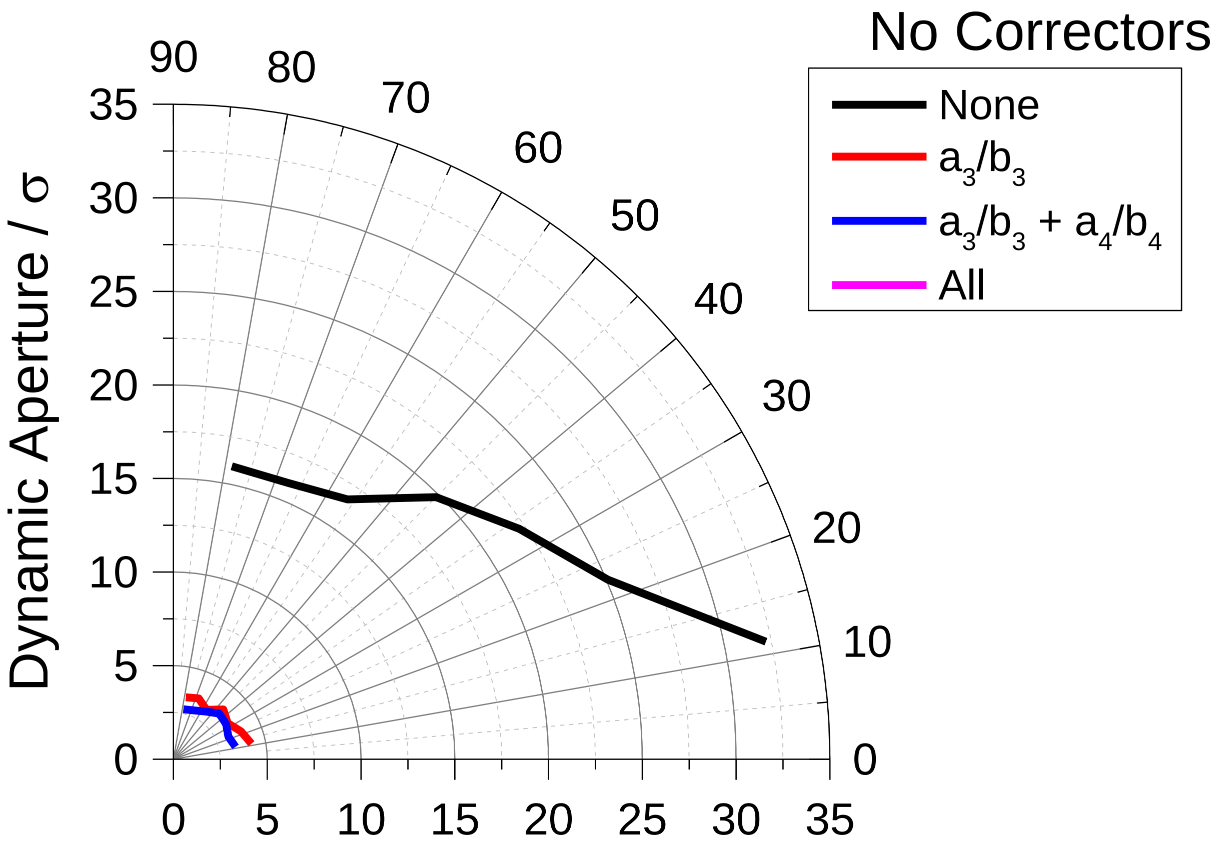
Injection Optics

- **HL LHC injection optics has $\boldsymbol{\beta^* = 11\ \mathrm{m}}$**
  - Use this as provisional baseline
  - Using 12σ separation
  - This gives $>12\ \sigma$ N1 in triplet
- **Limit $\boldsymbol{\beta}$ to 275 m – like arcs**
  - Could face similar aperture problems
  - Potentially same 450 GeV beam as LHC
  - Smaller beam screen aperture



Dynamic Aperture with Triplet Errors

- **Using V0.2**
- **Errors scaled from FCC**
- **Added errors one by one**
  - No errors for reference
  - Added a3/b3 errors
  - Added a4/b4 errors
  - Included all errors



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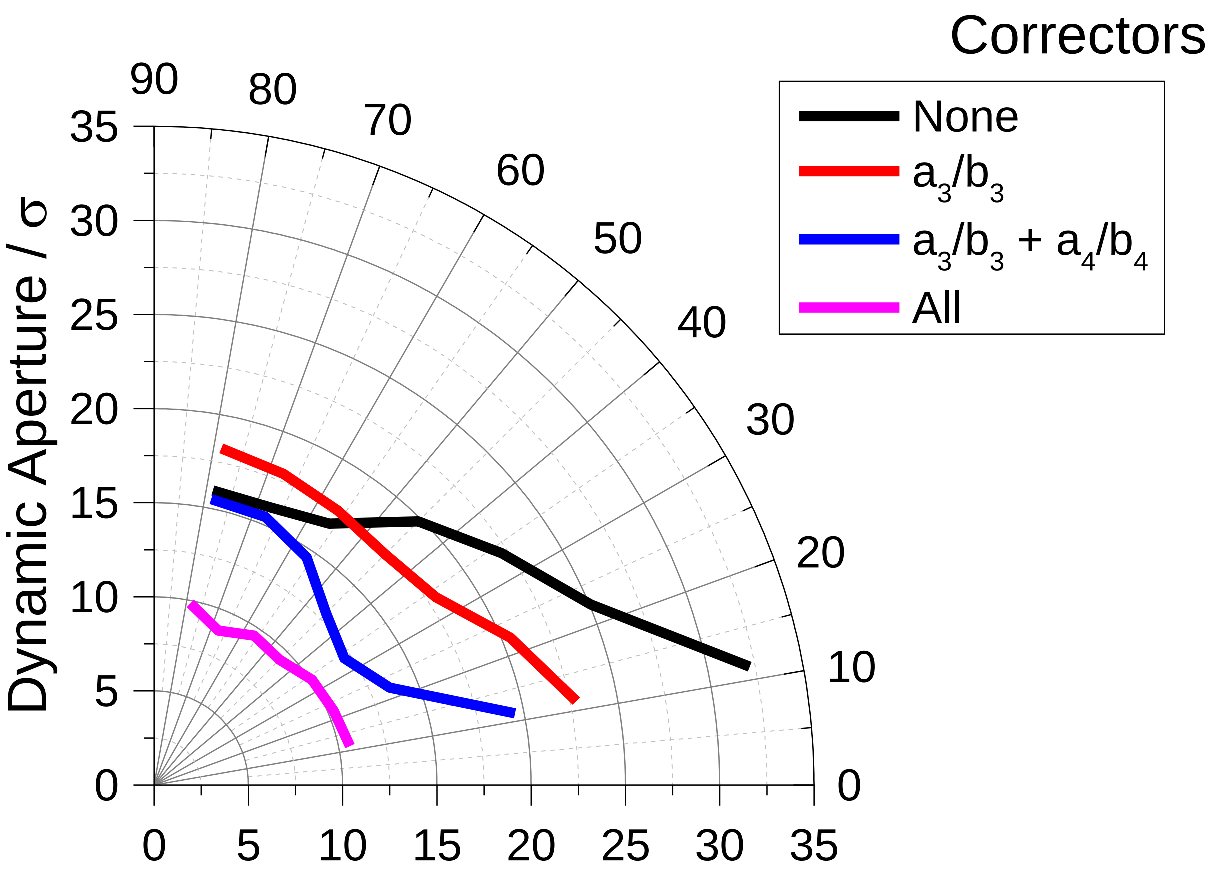
  - **Included all errors**
- **Non-linear correctors**
  - **Package behind triplets**
  - b_3 **using** $c(b_3; 1, 2\ )$ & $c(b_3; 2, 1\ )$
  - a_3 **using** $c(a_3; 3, 0)$ & $c(a_3; 0, 3\ )$



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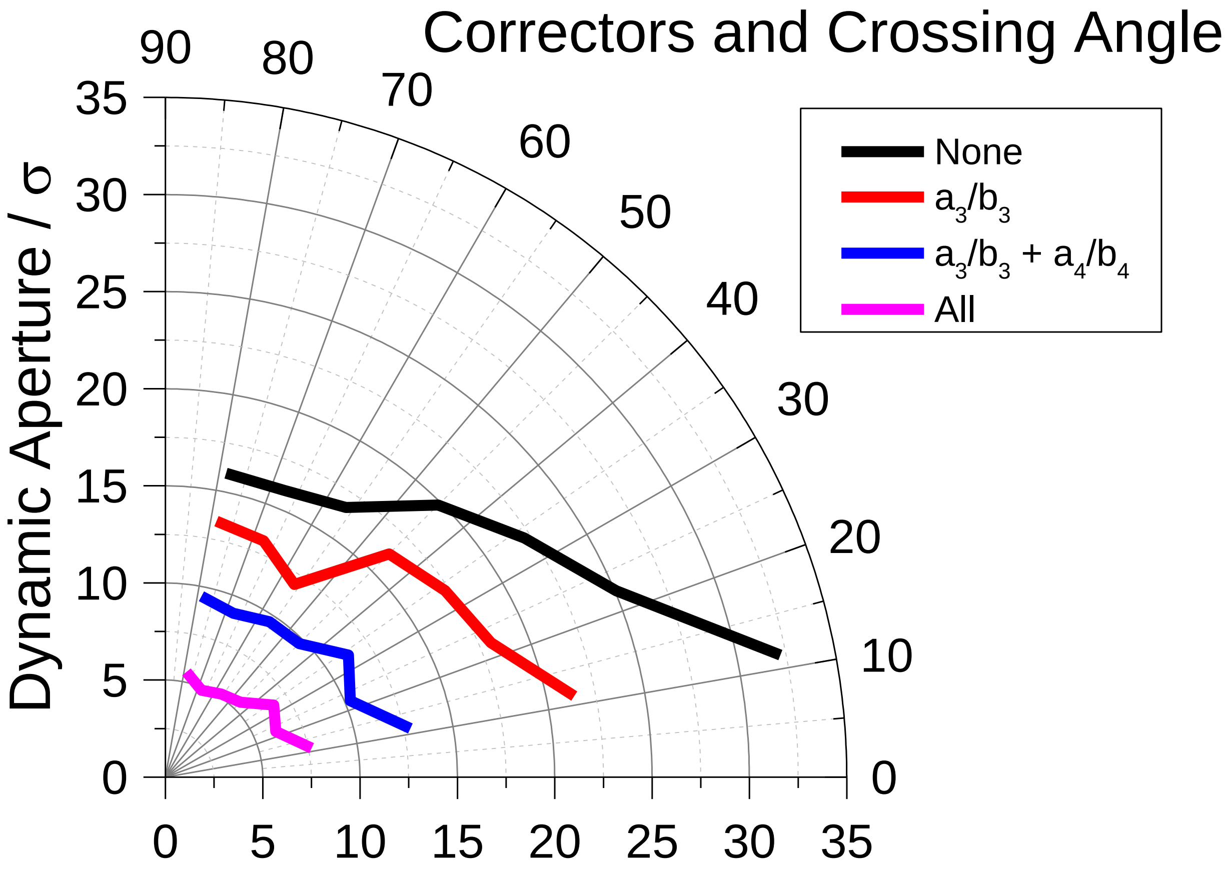
- **Added crossing angle**



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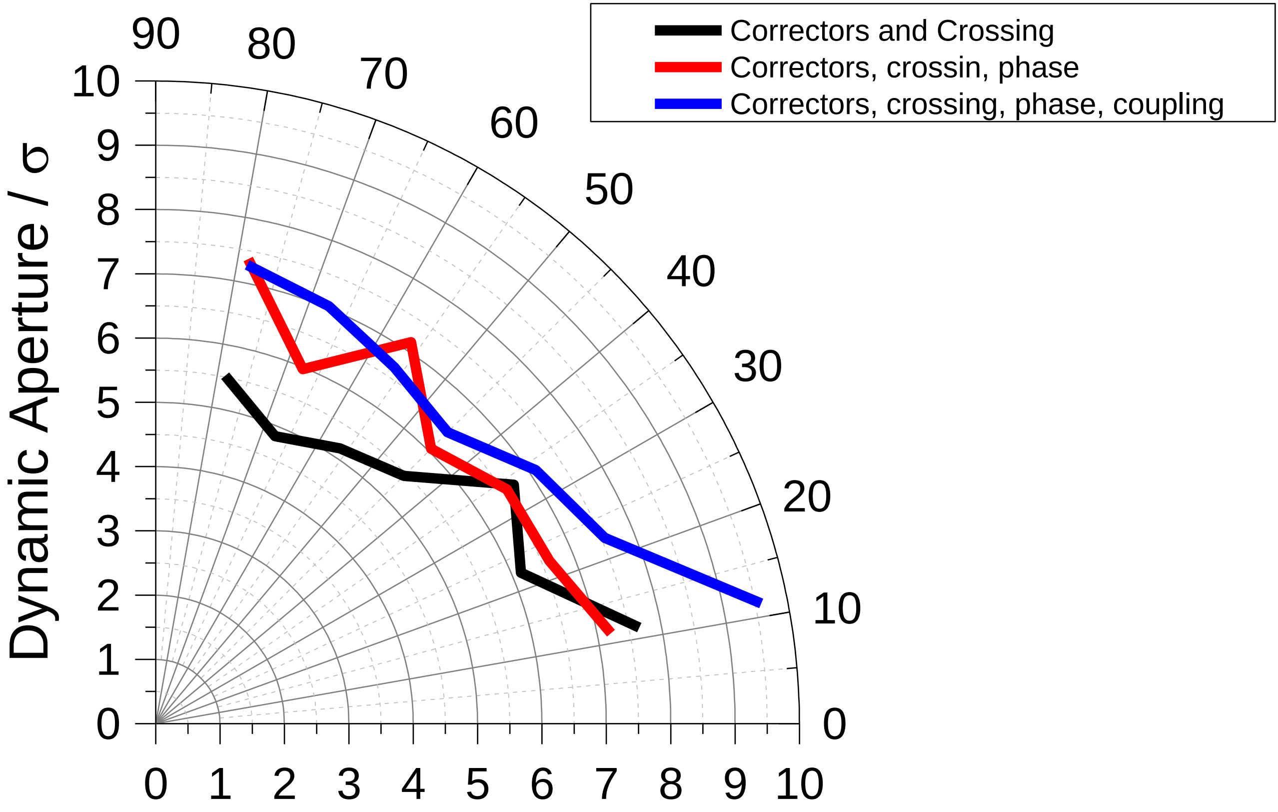
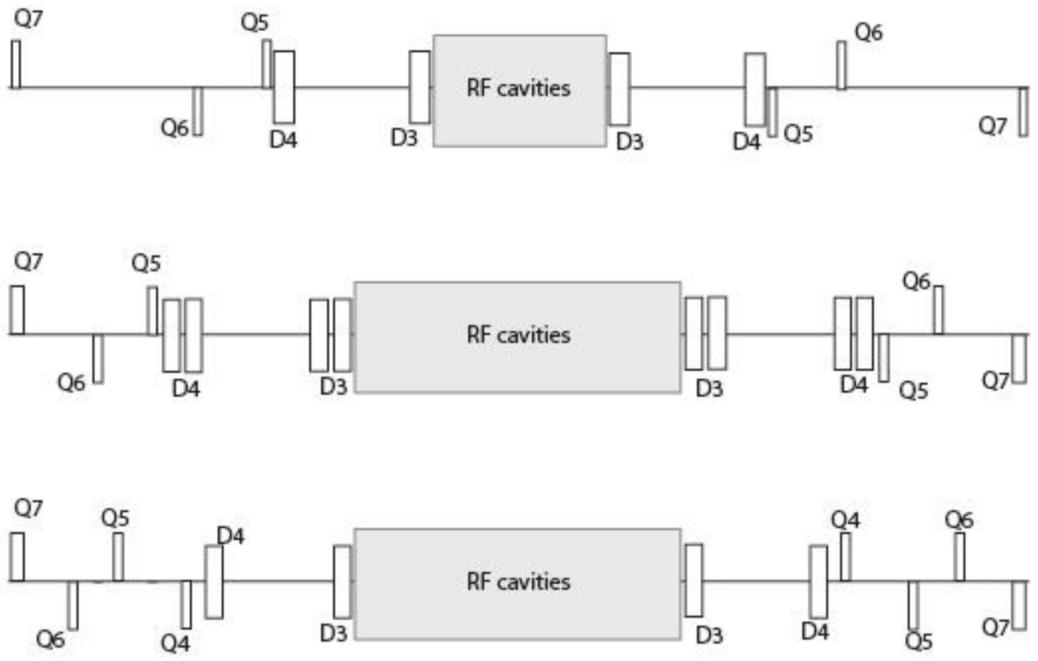
Dynamic Aperture with Triplet Errors

- **Double tuning approach**
  - **Vary phase between EIRs**
  - **Big impact in FCC**
    - **E. Cruz, Dynamic aperture at collision**
  - **Done using arcs**
- **Coupling correction**
  - **Using skew quadrupoles**
  - **Match $R_{11} = R_{12} = R_{21} = R_{22} = 0$ at both ends of EIR**
- **Increases DA to 6.4σ**
  - **No other errors added yet**
  - **Need to further increase**



IR4 and Tuning

- **Doubled space for RF cavities**
- **Added another pair of quadrupoles for tuning**



P. Mirave

IR4 and Tuning

- **Doubled space for RF cavities**
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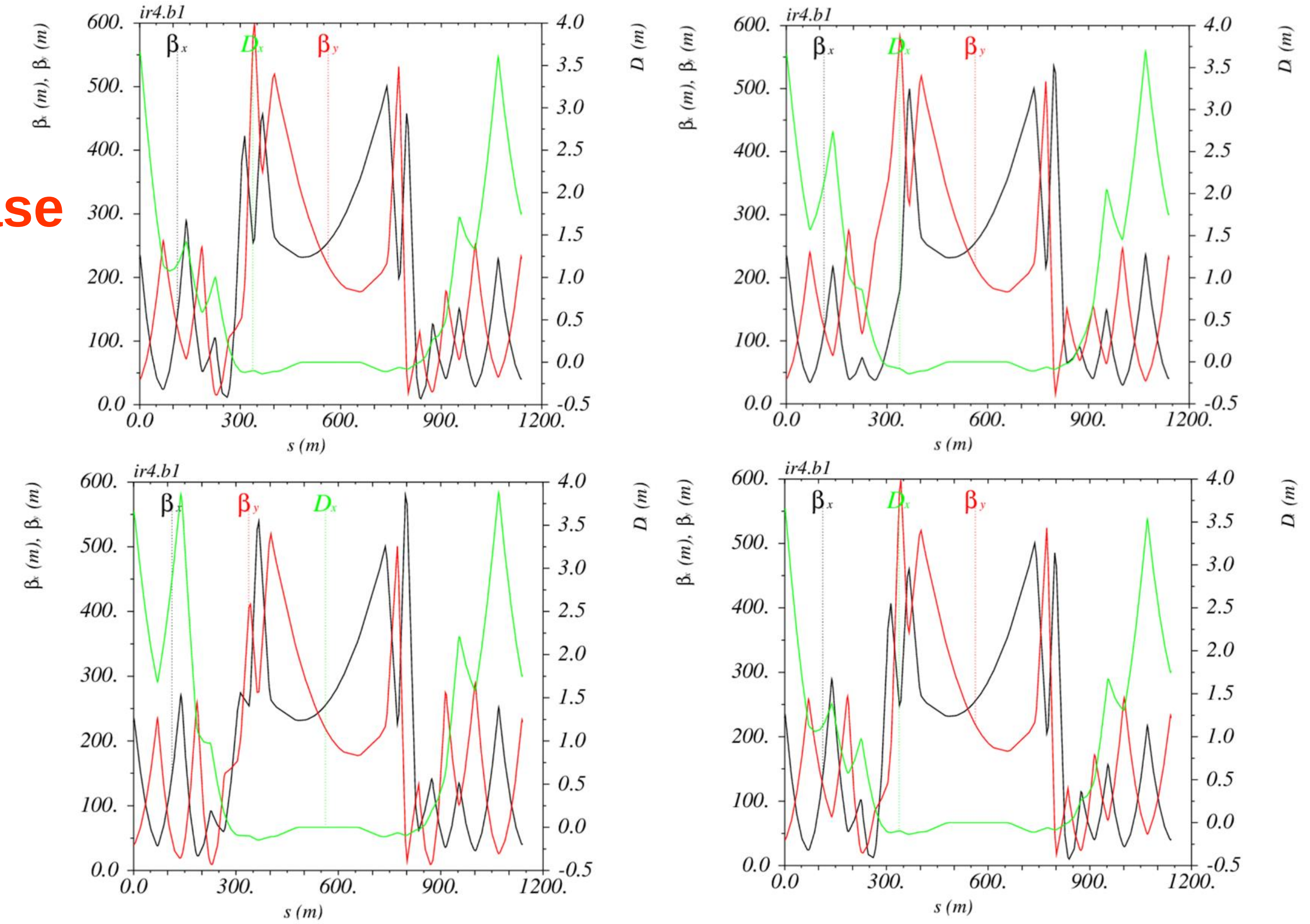
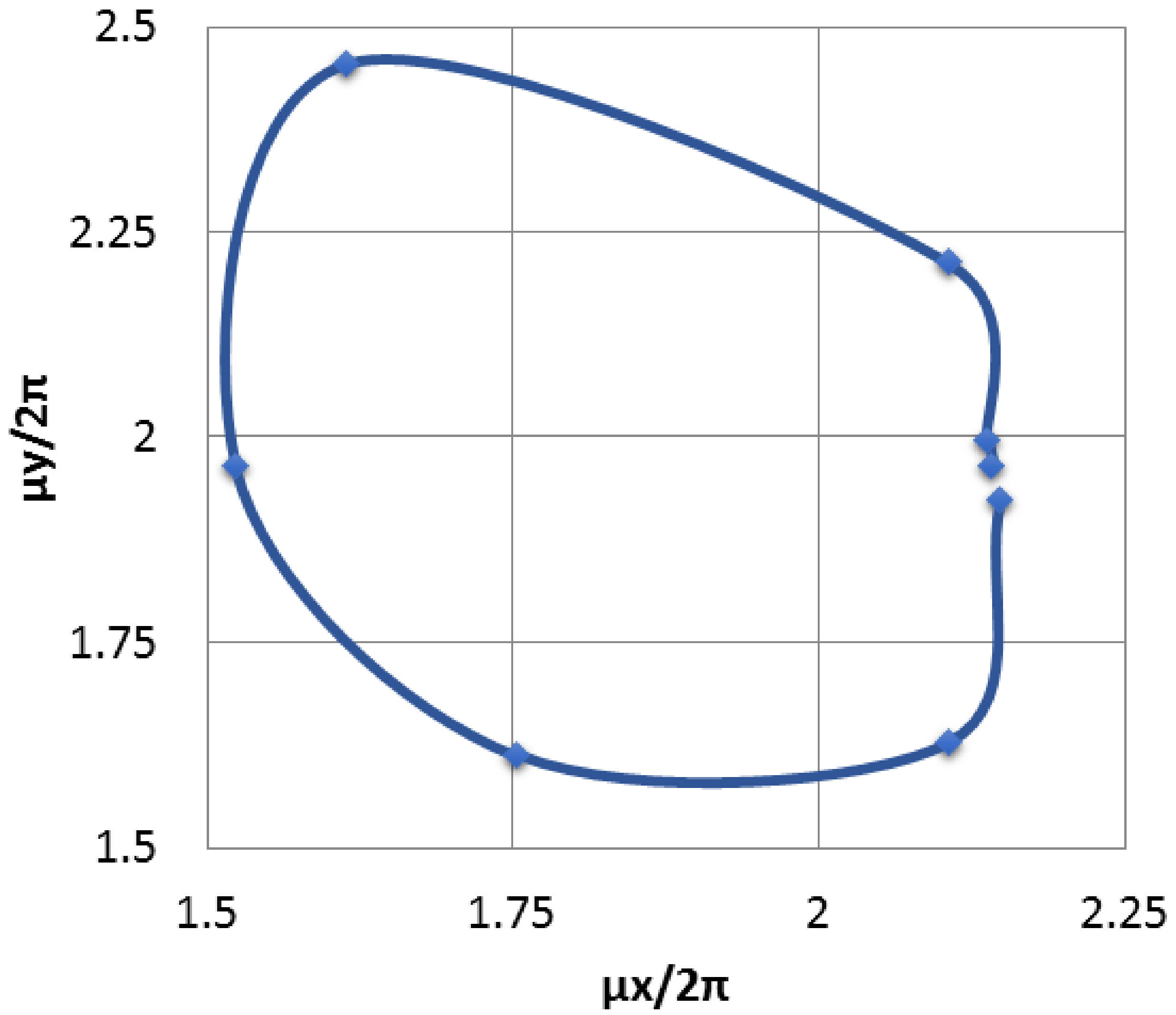
  - **Allows one to change phase advance**
  - **No beating in cavities**



IR4 and Tuning

- **Doubled space for RF cavities**
- **Added another pair of quadrupoles for tuning**
  - **Allows one to change phase advance**
  - **No beating in cavities**
- **Large range of phase advance**
  - **Can be used as handle to increase DA**
  - **Aim to implement something similar in IR6**



Conclusion

- **Experimental IR first design iteration complete**
  - **Triplet optimisation**
  - **Separation and crab schemes**
  - **Further work needed on matching and dispersion suppressor**
- **Dynamic aperture studies with triplet errors**
  - **Non-linear correctors**
  - **Double tuning and coupling correction**
  - 6.4σ **achieved**
- **IR4 optimised for HE-LHC and tune change**

Thank you!

Backup

Triplet Optimisation

- **Parameters affecting triplet beam stay clear**
  - **↑Gradient =↓Aperture**
  - **Individual magnet lengths**
  - **β functions in magnets**
- **Scan parameter space**
  - **Fixed length triplet**
  - **Find triplet with largest beam stay clear**
  - **Thin lens scan first**
  - **Then precise MADX scan**