

HE-LHC IR Optics

Leon van Riesen-Haupt, Jose Abelleira, Emilia Cruz Alaniz, Andrei Seryi
(Oxford)

Jacqueline Keintzel, Michael Hofer, Thys Risselada (CERN)

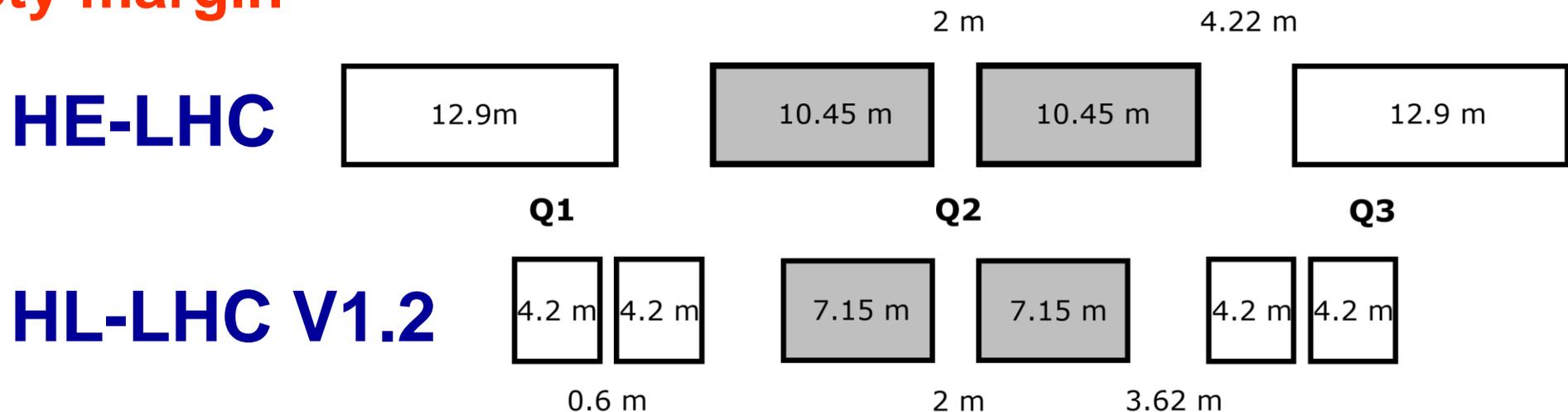


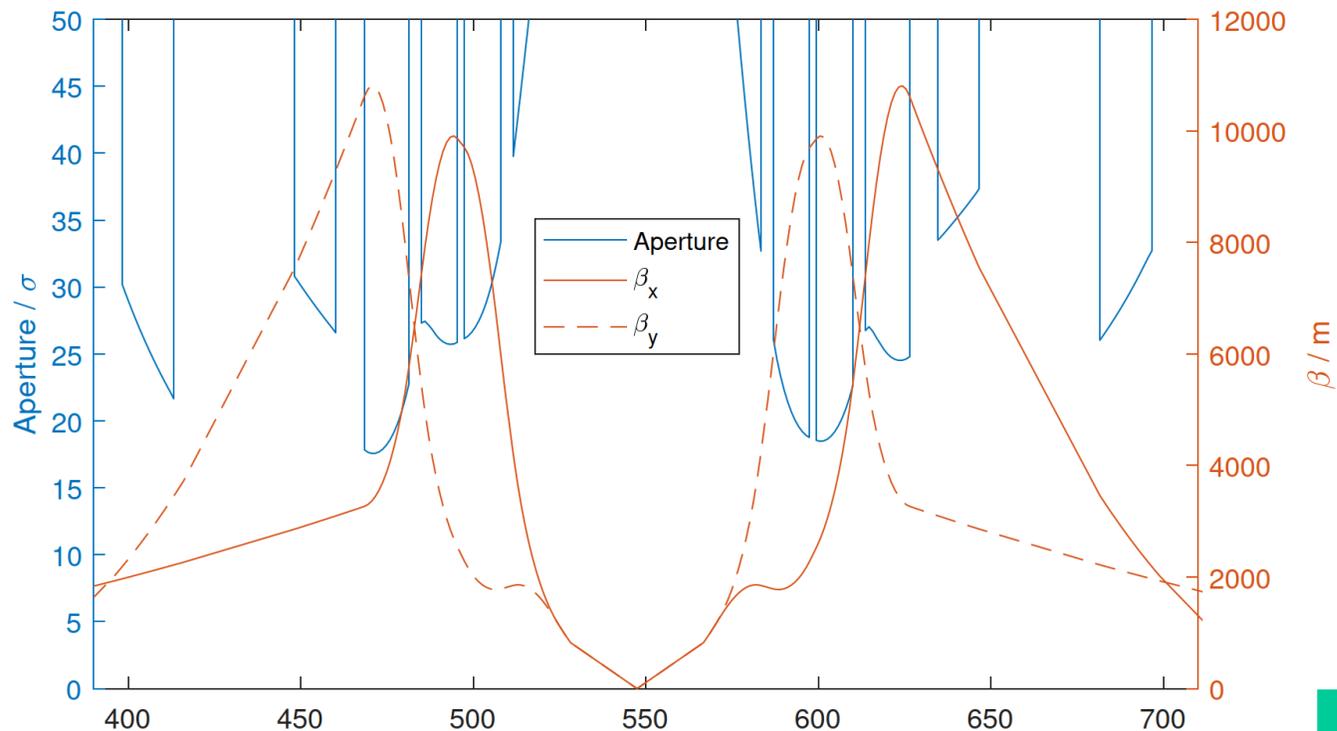
- **LHC Infrastructure**
 - LHC Tunnel Constraints
 - (Possibly) SPS injection at 450 GeV
- **FCC-hh Technology**
 - 13.5 TeV Beam Energy
 - Nb₃Sn Technology
 - Larger Beam separation
- **Updated Arc Cell**
 - 18 and 23 Cell Layout
 - New Dispersion Suppression Scheme
 - Update Correction Schemes

- **Triplet**
 - Achieve $0.45 \text{ m } \beta^*$
 - 16.8σ Crossing Angle
 - 12.5σ Aperture
 - Sufficient shielding for 10 ab^{-1} lifetime
 - Dose limit $\sim 30\text{-}100 \text{ MGy}$
 - As short as possible
- **Separation Dipoles**
 - Achieve 250 mm separation
- Compact as possible
- Sufficient shielding
- **Matching Section**
 - Match rigid beam
- **Correction Schemes**
 - Dispersion Suppressor
 - Spurious dispersion correction
 - Dynamic aperture with triplet errors

- **Triplet optimisation code**
 - Collaboration between optics and energy deposition (Jose Abelleira)
 - “Alternative Optics” talk on Tuesday
- **Based on experience of FCC-hh**
 - Allow for Additional β^* Margin
 - Uniform Beam Pipe
 - Magnet Length Limited to 15 m
- **HL-LHC V1.2 Triplet as starting point**
 - Use Magnet Separations
 - Initial estimate $\frac{13.5 \text{ TeV}}{7 \text{ TeV}} \approx 90 \%$ increase in length
 - Without considering increased shielding

- **Converged on triplet with 2 cm shielding**
- **Only 35 % longer than HL-LHC V1.2 triplet**
 - **50% more magnetic length**
- **“Un-split” Q1 and Q3 magnet**
 - **Absorbed gap in inter magnet spacing**
 - **Safety margin**

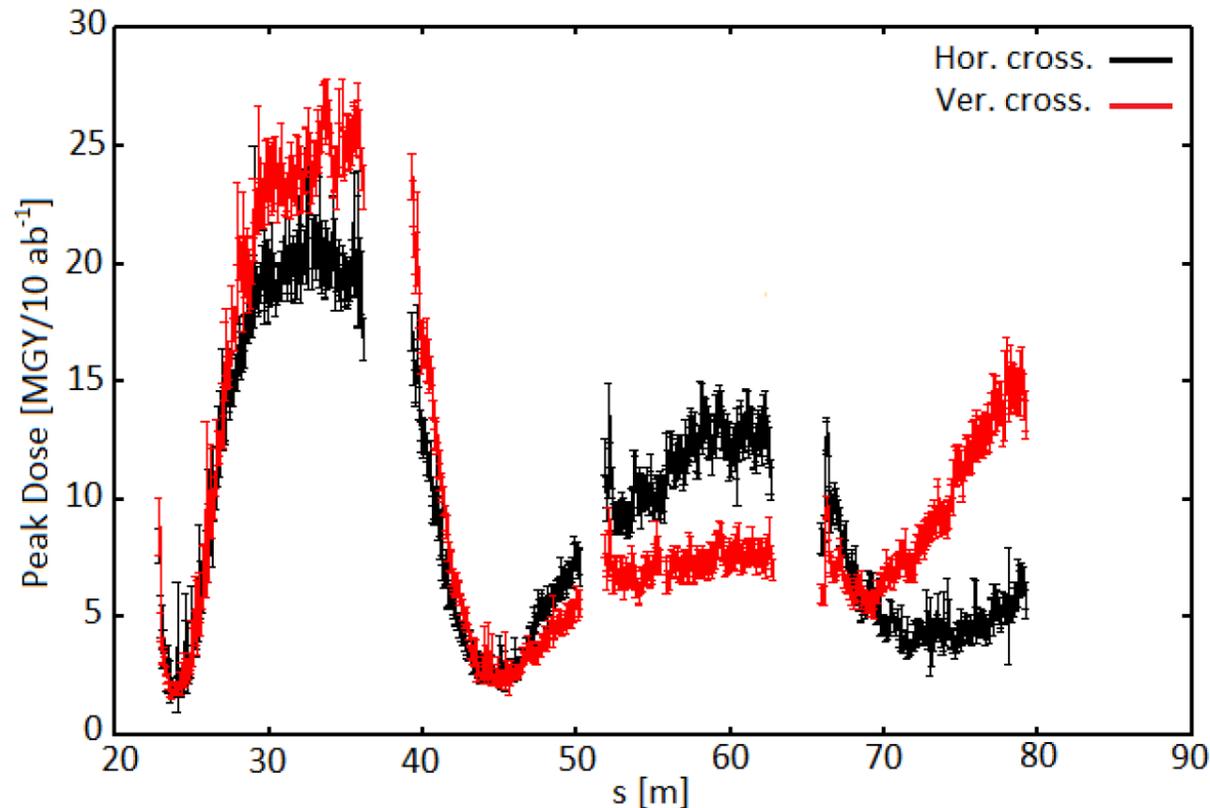




- **Aperture of 18σ**
 - **Larger than required 12σ**
 - **Allow to further reduce β^* by factor ~ 2 if needed**
- **Uniform magnetic aperture and shielding**

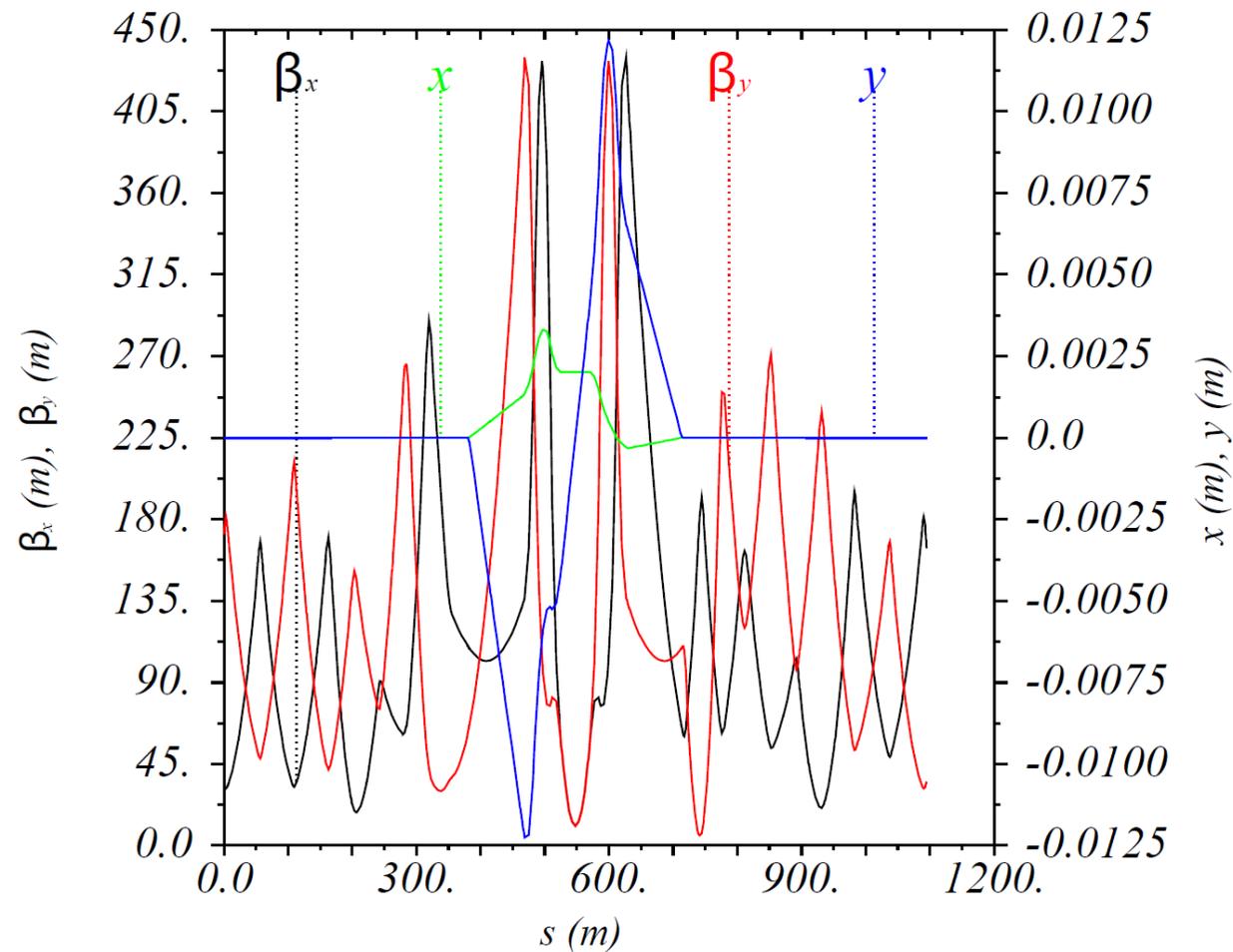
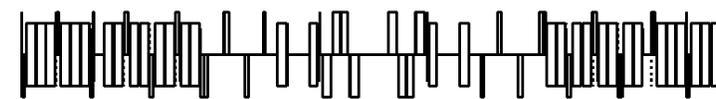
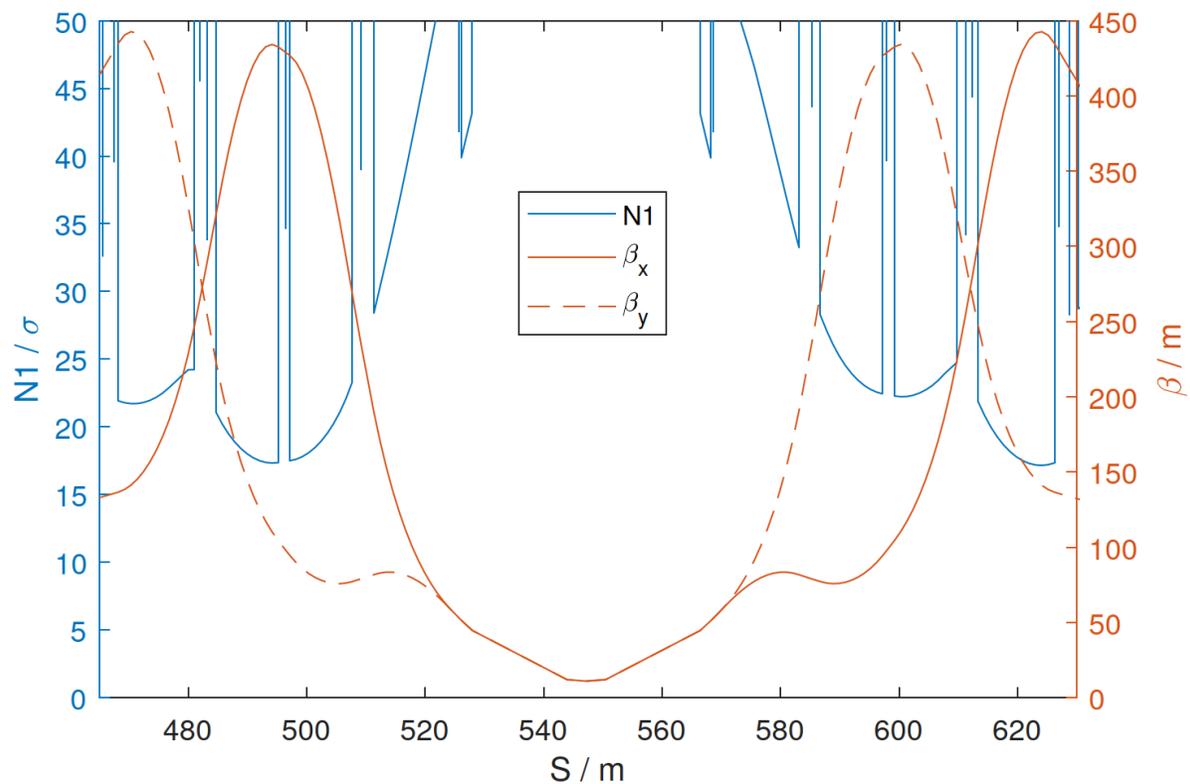
Parameter	Q1	Quadrupole Q2	Q3
Sub-magnets	1	2	1
Sub-magnet Length (m)	12.9	10.5	12.9
Coil Radius (mm)	70.4	70.4	70.4
Gradient (Tm^{-1})	145	145	145
Shielding (mm)	20	20	20

- **FLUKA Simulation**
 - **Based on FCC-hh magnet model**
- **Energy deposition safely below 30 ab⁻¹ margin**
- **Can reduce further by alternating crossing**
- **Extra room for shielding in Q1 and Q2 if needed**



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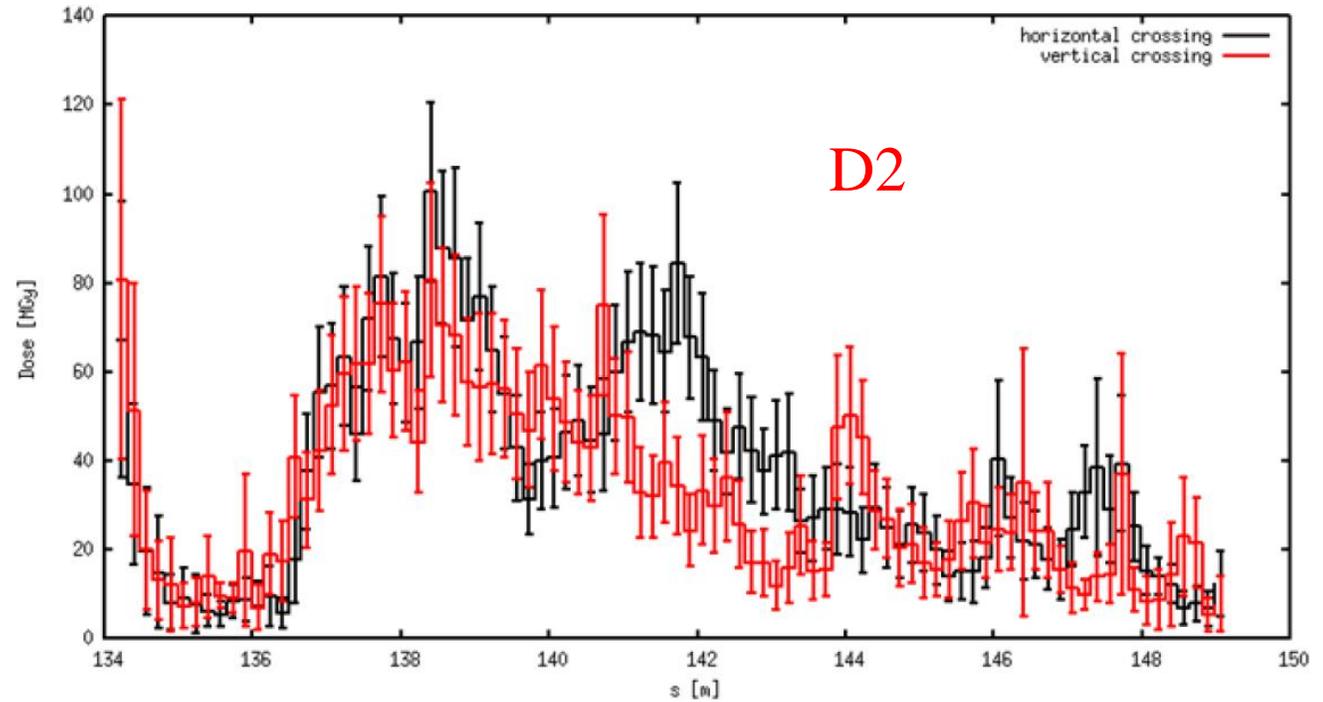
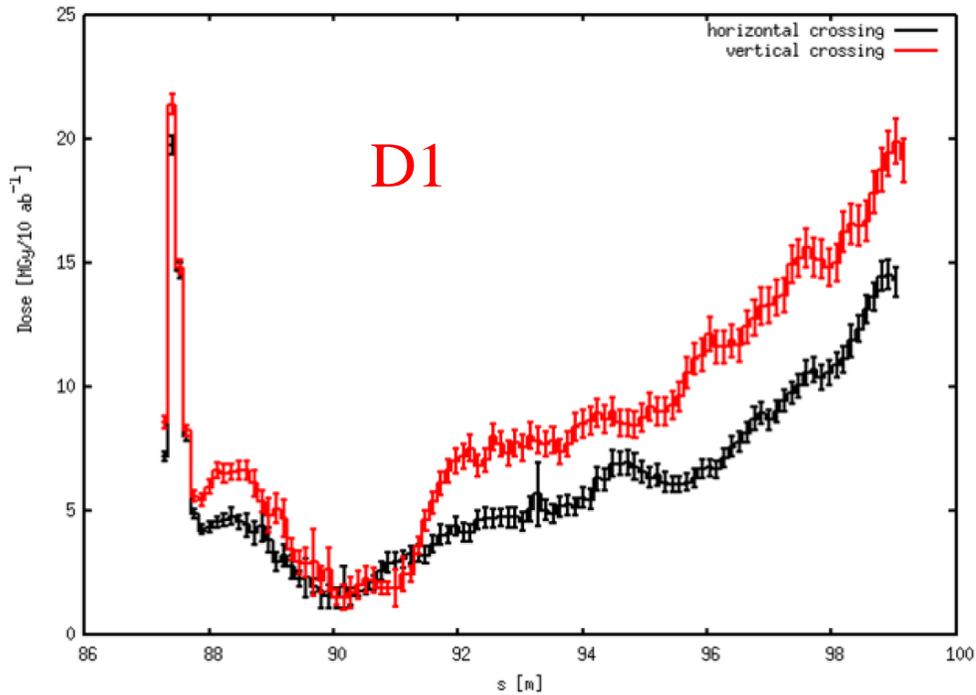
- **11 m β^***
- **16.8 σ separation and crossing**



- **Compact as possible**
 - **Compensate for longer triplet**
- **Increased beam rigidity**
- **Requires superconducting dipoles**
- **Radiation studies required**

Property	D1	D2
Aperture Type	Single	Double
Coil Radius (mm)	80	38.5
Shielding (mm)	21.5	9
Length (m)	12	15
Field (T)	9.7	7.7

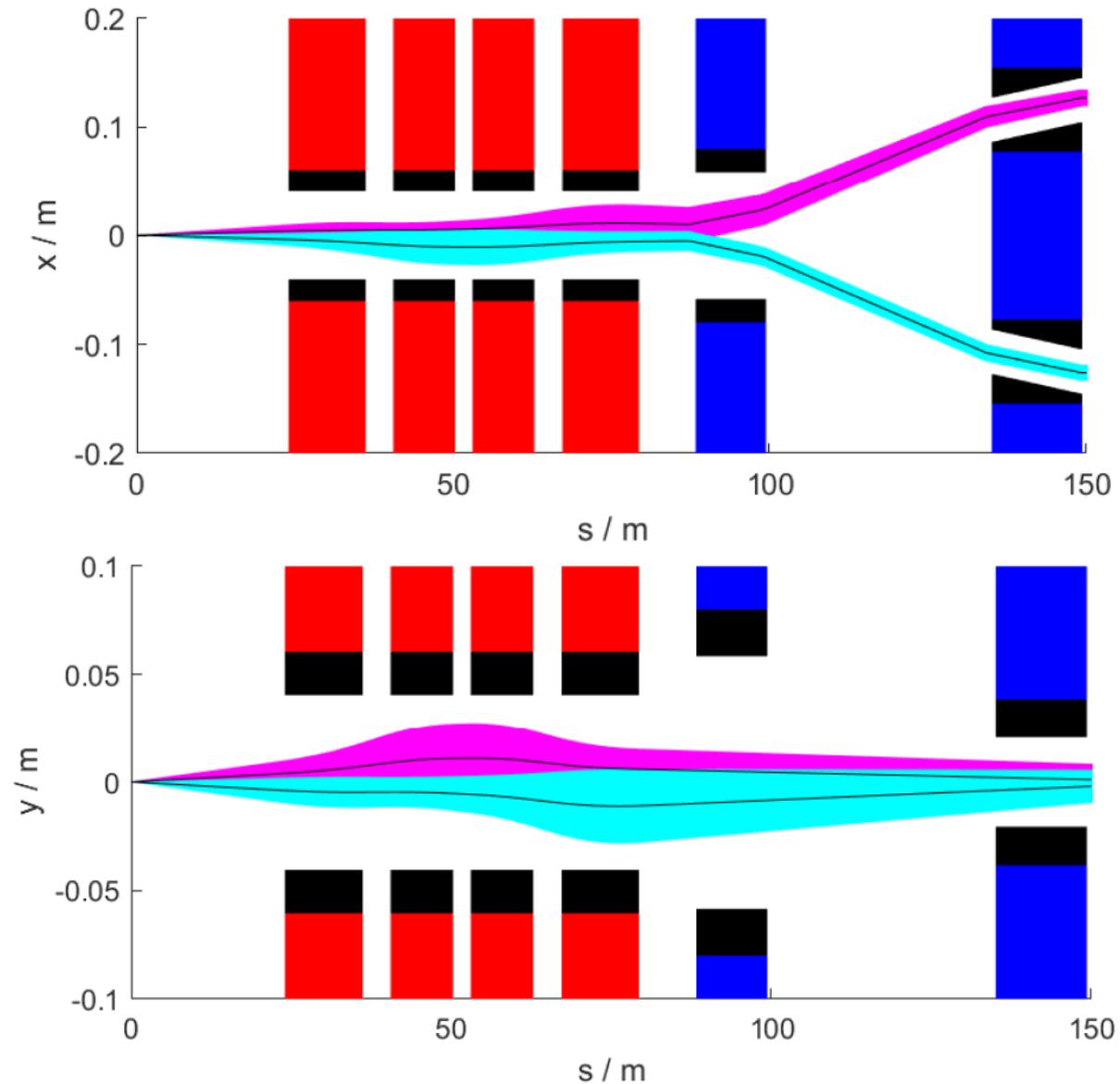
Energy Deposition



- Energy in D1 below 30 Mgy limit
- Large amount of deposition in D2
 - 9 mm not sufficient

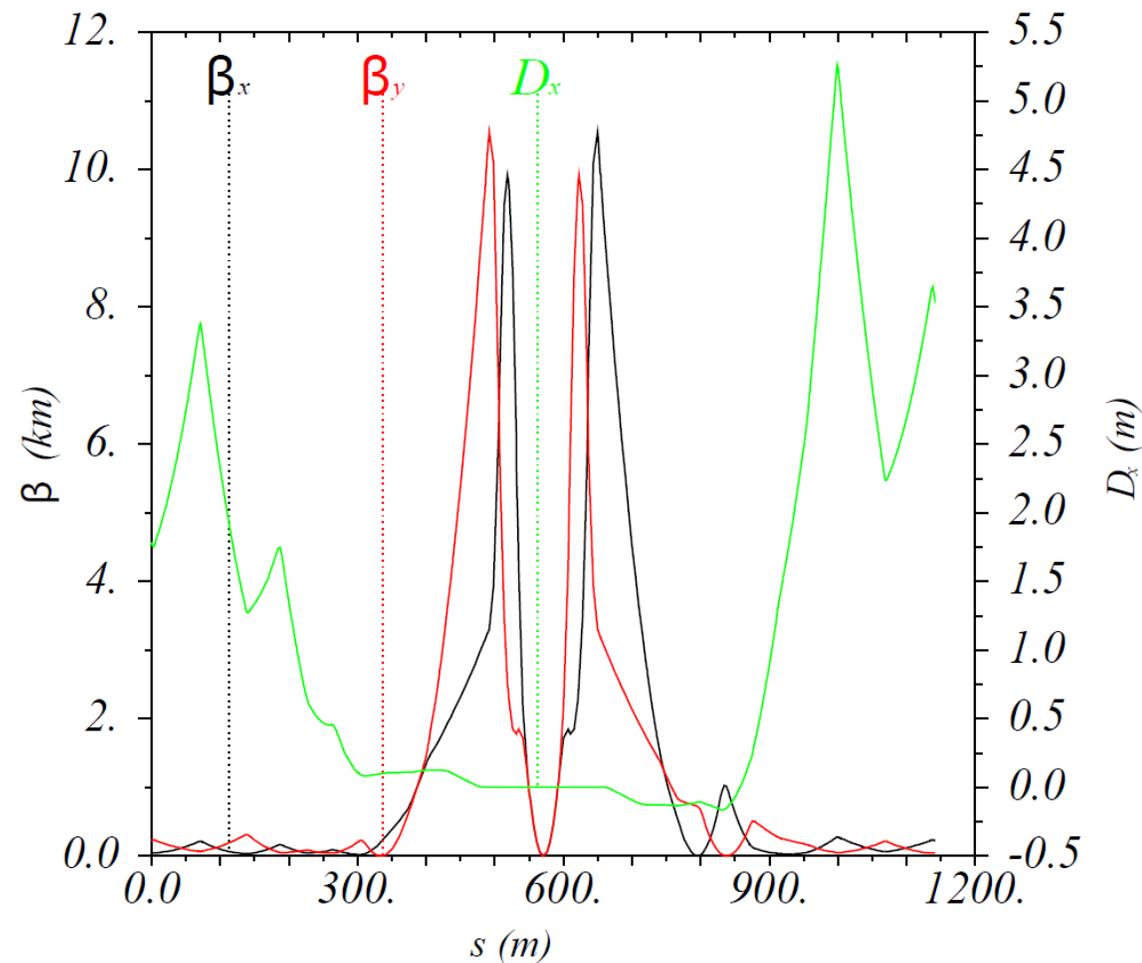
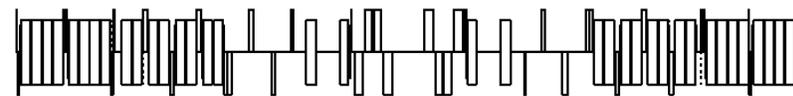
Jose Abelleira

- **Possibility of installing shielding at an angle**
 - **Extrude cylinder shielding block**
 - **Allows 9 mm – 27 mm shielding**
- **Reduces dose**
 - **40 MGy**
- **Further Reduction Possible**
 - **Split D2**



- **Based on HL-LHC Matching Section**
 - **Space reserved for crab cavities and instrumentation**
 - $V_{cc} \approx \frac{cE_{beam}\frac{\theta}{2}}{\pi f\sqrt{\beta^*\beta_{cc}}} \approx 10 \text{ MV}$
 - Slightly higher than ~6.6 MV in HL-LHC
 - **Layout of quadrupoles**
- **Adjusted Quadrupole Lengths**
 - **Match without strength constraints**
 - **Lengthen to achieve correct integrated strength**
- **Similar process for dispersion suppressor**
- **Matched for 23 and 18 cell lattice**

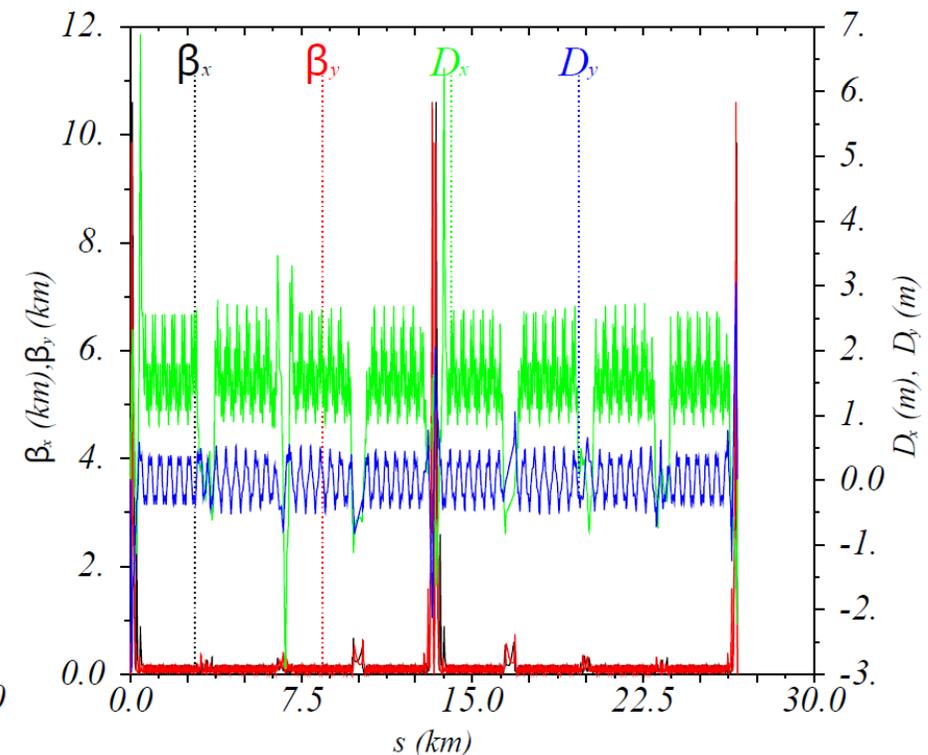
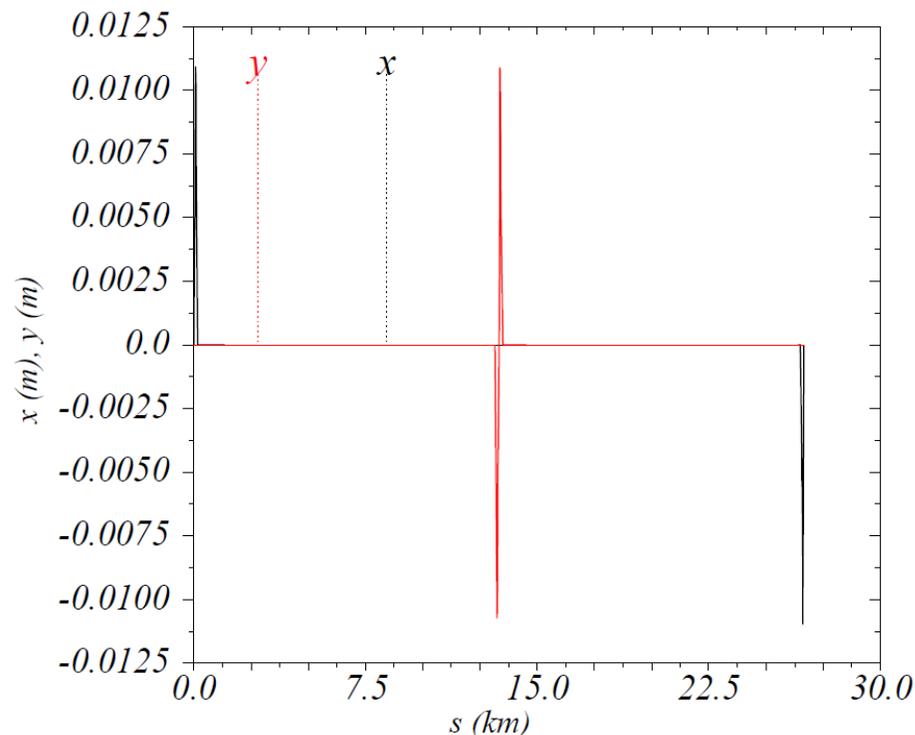
- Twiss matched to arc
- Phase advance matched to 3rd and 4th sextupole
 - Instead of 1st and 2nd
- Small quadrupole increase
 - Distances between quadrupoles ~ 20 m
 - Dispersion suppressor quadrupoles increase 25%



Quadrupole	Length (m)		Increase (%)
	LHC	HE-LHC	
Q4	3.4	3.4	0
Q5	4.8	5.8	20
Q6	4.8	7.2	50
Q7	2 × 3.4	2 × 5.1	6.7

Spurious Dispersion

- Arises from crossing angle bumps
- LHC-like correction
 - Bump in arcs adjacent to EIR
- Correction through quadrupoles and sextupoles
- Results in no dispersion in adjacent IRs

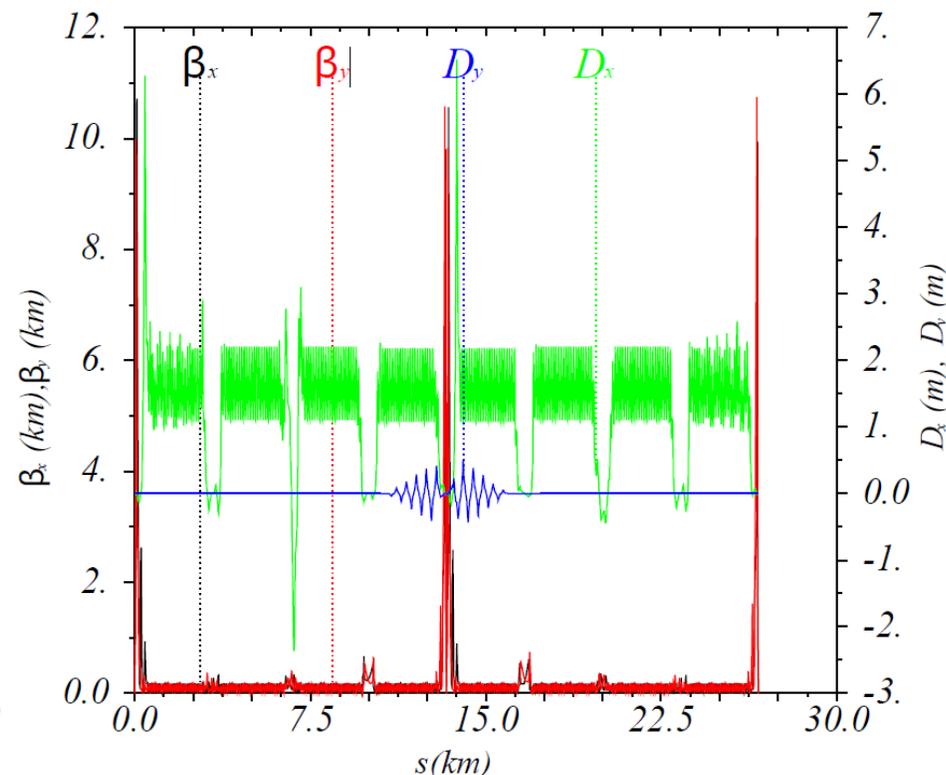
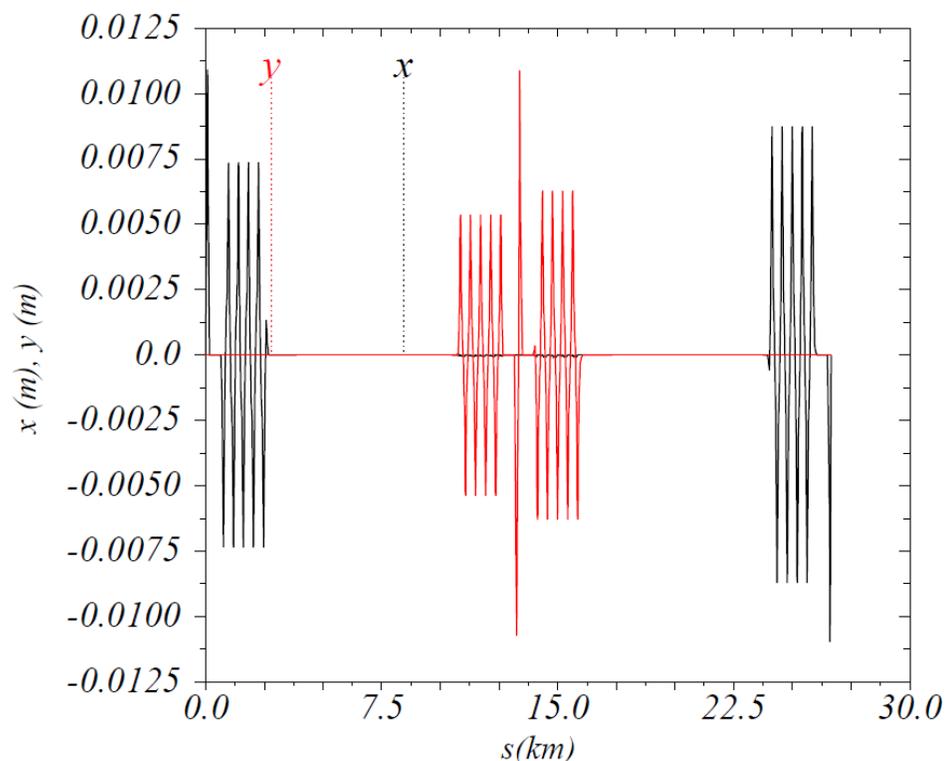


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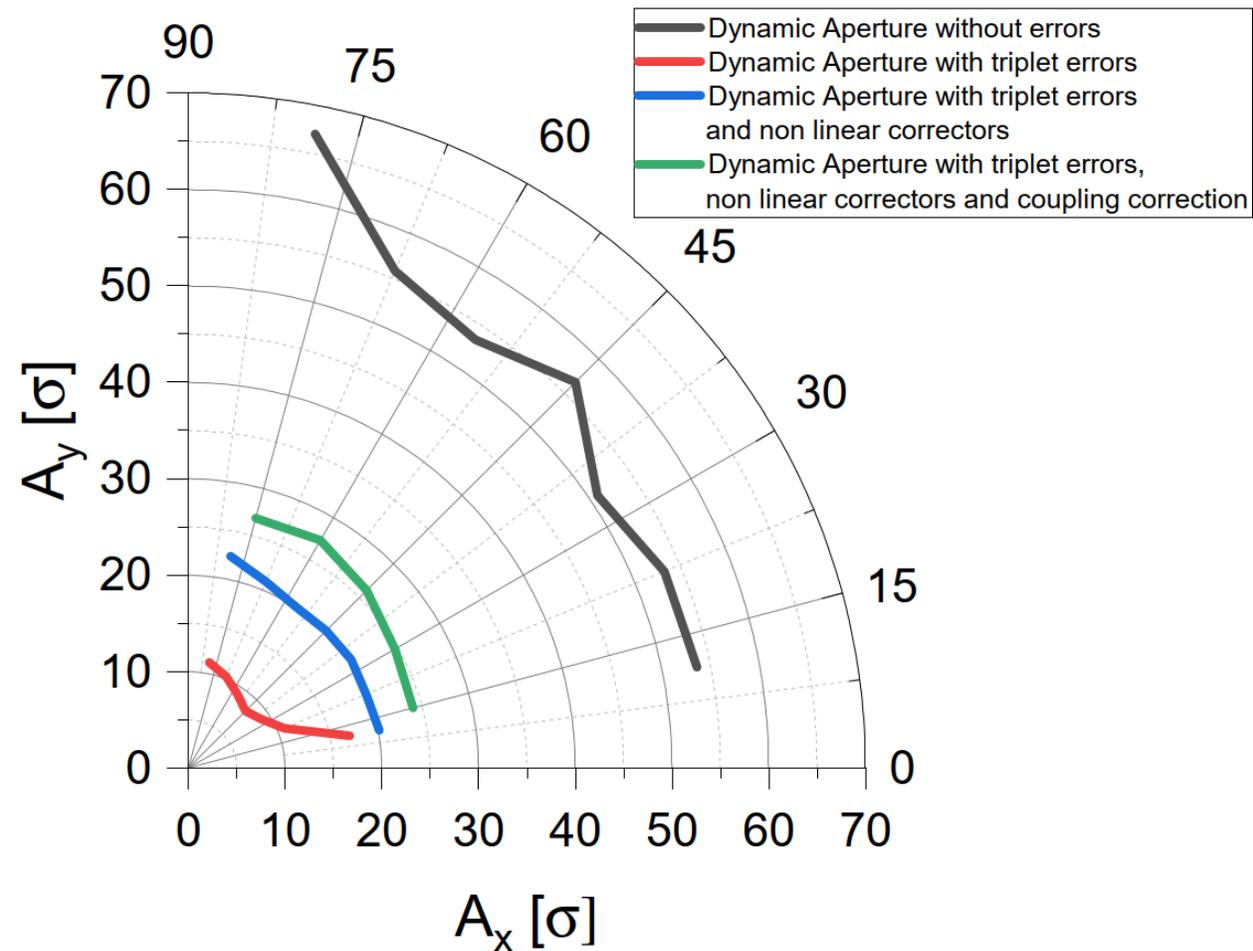
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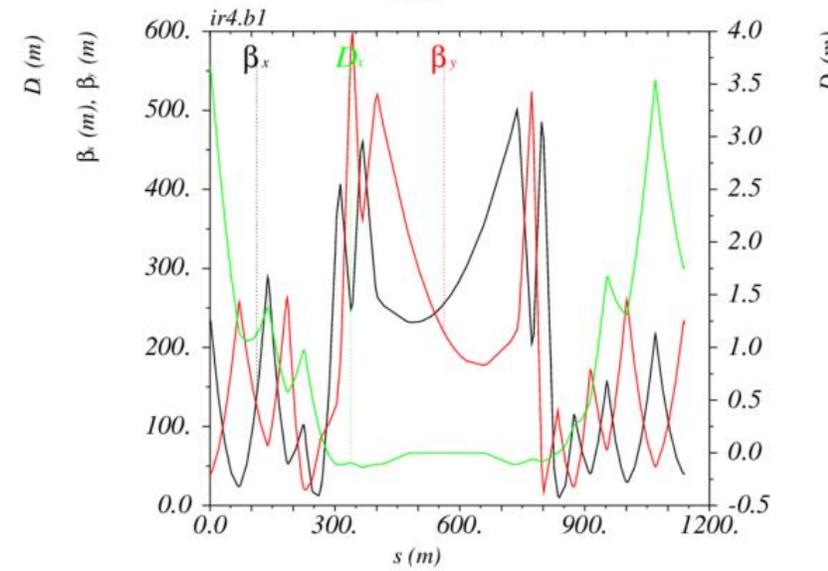
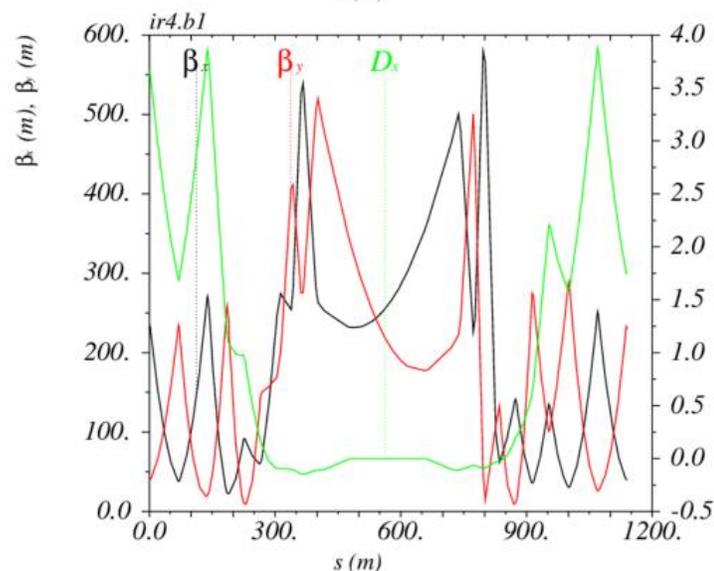
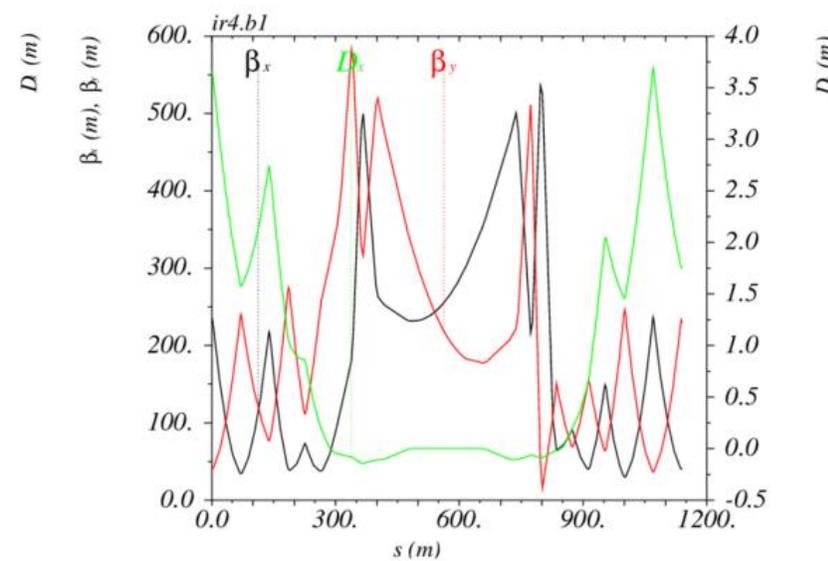
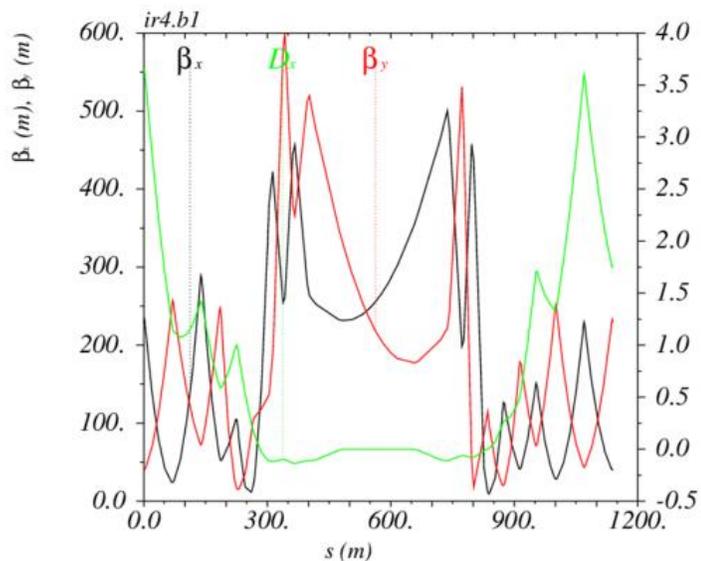


- **Sixtrack studies**
 - **23-Cell Lattice**
 - **10^6 turns**
- **Double tuning applied**
 - **FCC experience (E. Cruz-Alaniz)**
- **Triplet errors applied**
 - **Based on HL-LHC error table**
 - **9σ DA**
- **Corrections**
 - **Non-linear local correction**
 - **Coupling correction**
 - **24σ DA**

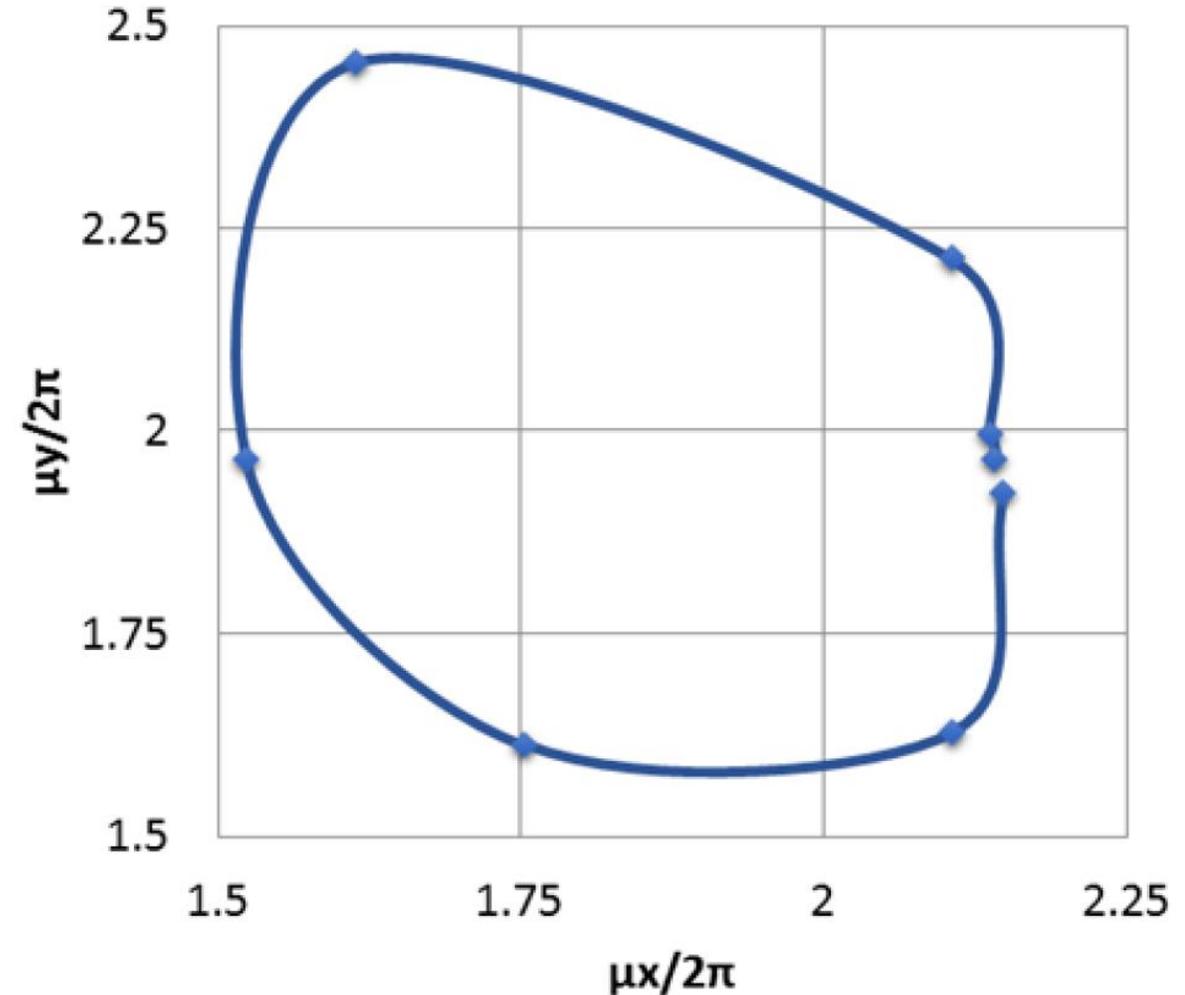


Double Tuning – IR4

- RF insertion
- Based on LHC
- Additional quadrupole
 - Extra freedom for tune
 - Change tune by changing optics
 - No beating in cavities
- Range of π in both planes
 - Double tuning
 - Should be repeated with IR6



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- **Full HE-LHC EIR Design**
- **Triplet Optimised using FCC-hh Methods**
 - Length and shielding optimised
 - Significantly shorter than expected
- **Separation Dipole Design**
 - Including radiation studies and shielding options
- **Matching Section**
 - For both lattices
 - Injection optics
- **Dynamic Aperture**
 - Meets requirements
 - Full set of correction tools