Dynamic Aperture and non-linear correctors studies

Emilia Cruz

On behalf of the JAI FCC Team

Special thanks to A. Chance, B. Dalena, M. Hofer, E. Maclean, R. Martin and R. Tomas.

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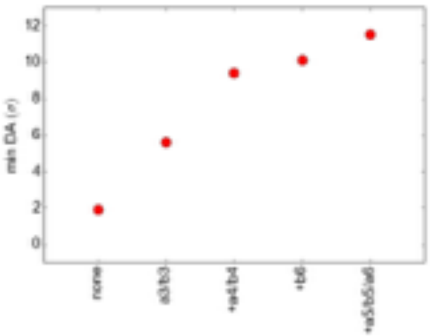
October 9th, 2017

Status on DA – FCC Week Berlin

- Studies were performed at collision energy with field errors on the triplet and crossing angles on.
- Field errors on the triplet with crossing angles have a big impact on DA. A positive DA was obtained without non-linear correctors but still low (~**2σ**).
- Implementation of **non-linear correctors** resulted in an increase of **DA up to 11.7σ** when using HL-LHC like spurious dispersion correction.



- **Main conclusion:** DA on the FCC relies heavily on non-linear correctors. This technique relies on knowing the magnetic model of the magnets. Magnetic measurements during construction do not always provide a good description of the real machine and must be complemented by beam-based studies -> Follow LHC studies to study its realiability

Dynamic Aperture Studies

➢ DA studies were performed in SixTrack :

- Collision energy
- Crossing angles on
- **Field Errors** on the triplet (Model HL-LHC adjusted new aperture)

$$B_y + iB_x = B_{ref} \sum_{n=1}^{N} (b_n + ia_n) \left(\frac{x + iy}{R_{ref}} \right)^{(n-1)}$$

$$b_n = b_{nS} + \frac{\xi_U}{1.5} b_{nU} + \xi_R b_{nR},$$

➢ And the following corrections:

- Chromatic and tune correction
- Spurious dispersion correction (HL-LHC like and SSC-like, A. Chance)
- Coupling correction (R. Martin)

Updates since Berlin

CHANGES

- Previous studies were done in the old lattice (99 km). The new lattice (97 km) was integrated and released so new studies can be performed using this lattice.
- L* shortened to 40 m.

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- BIG CHANGE with new lattice:
- New lattice resulted in a big increase in DA (~2 sigma – ~10 sigma) using SSC-like spurious dispersion correction.
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WORK TO DO

- check what is causing the difference on DA between the old and new lattice.
- Will give us an indication of problem with last lattice and what to avoid in the future.
- Will give us more flexibility to include more errors in the DA studies.

Changes from last lattice

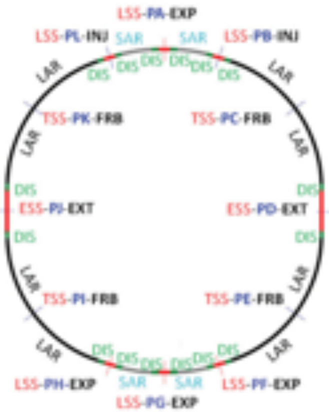

Figure 1: Layout of the FCC-hh ring.

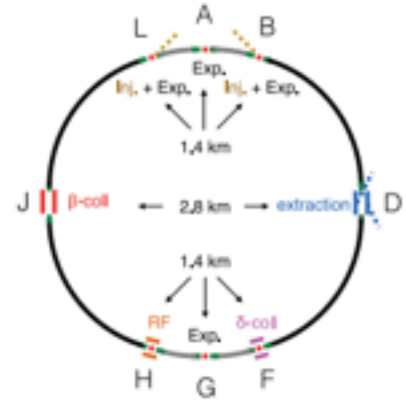

Table 1: Parameters of the FCC-hh Ring

Parameter	Value: Baseline	Value: Ultimate	Unit
Energy	50		TeV
Circumference	99.171		km
LSS and ESS length	1.4 and 4.2		km
SAR and LAR length	3.6 and 16		km
β^*	1.1	0.3	m
L^*	45		m
Normalized emittance	2.2		μm
γ_{tr}	99.580	99.469	
Q_x/Q_y	111.31/ 108.32		
Q'_x/Q'_y	2/2		
Beam separation	250		mm
Beam separation (RF)	420		mm

Table 2: Parameters of the Arc FODO Cell

Parameter	Value	Unit
Cell length	213.895	m
Cell phase advance H/V	90	deg
Number of dipoles per cell	12	
dipole magnetic length	14.3	m
dipole maximum field	15.9	T
quadrupole magnetic length	6.29	m
quadrupole maximum gradient	399	T/m
sextupole magnetic length	0.5	m
sextupole maximum gradient Baseline/Ultimate	8140/16030	T/m^2
dipole-dipole spacing	1.36	m
quadrupole-dipole spacing	> 3.67	m
quadrupole-sextupole spacing	1.0	m

Table 1: Parameters of the FCC-hh Ring

Parameter	Value: Baseline	Value: Ultimate	Unit
Energy	50		TeV
Circumference	97.75		km
LSS and ESS length	1.4 and 2.8		km
SAR and LAR length	3.4 and 16		km
β^*	1.1	0.3	m
L^*	45		m
Normalized emittance	2.2		μm
γ_{tr}	99.331	99.310	
Q_x/Q_y	111.31/ 109.32		
Q'_x/Q'_y	2/2		
Beam separation	204		mm
Beam separation (RF)	420		mm

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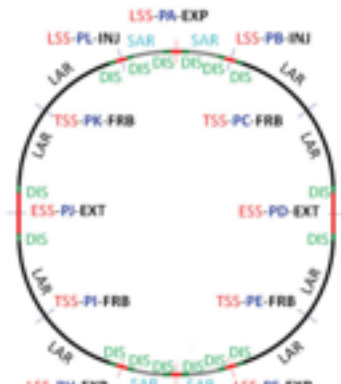
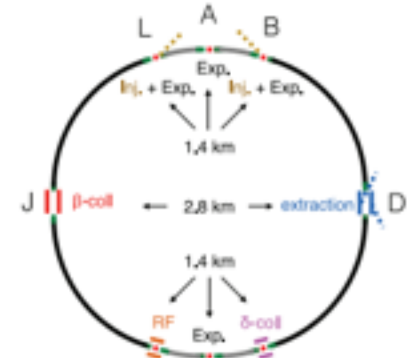
Parameter	Value	Unit
Cell length	211.986	m
Cell phase advance H/V	90	deg
Number of dipoles per cell	12	
dipole magnetic length	14.3	m
dipole maximum field	15.7	T
quadrupole magnetic length	6.0	m
quadrupole maximum gradient	380	T/m
sextupole magnetic length	1.2	m
sextupole maximum gradient Baseline/Ultimate	4545/8539	T/m^2

Changes from last lattice





	μ_x/μ_y Old	μ_x/μ_y New L*=45
SAR length	3.6 km	3.4 km
Tune	111.31/107.32	111.31/109.32
μ_x/μ_y IRA/IRG	2.62/2.65	2.65/2.62
μ_x/μ_y Short Arc	2.62/2.65	2.65/2.62
μ_x/μ_y Long Arc	90°+ε	90°+ε
μ_x/μ_y IRB	2.71/2.14	2.77/2.95
μ_x/μ_y IRL	2.42/2.01	3.21/2.62
μ_x/μ_y IPA -> IPG	54.85/52.83	55.08/54.66

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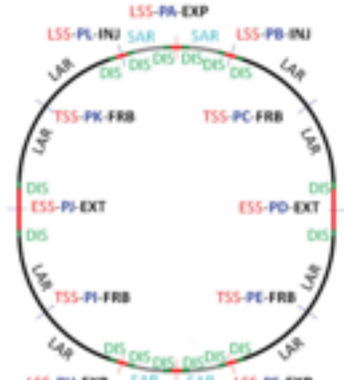

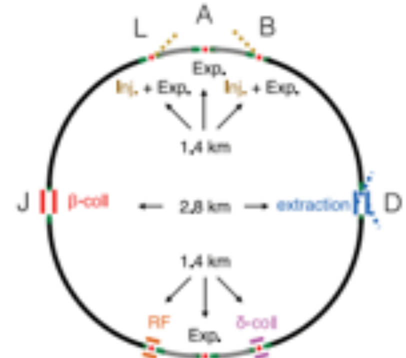

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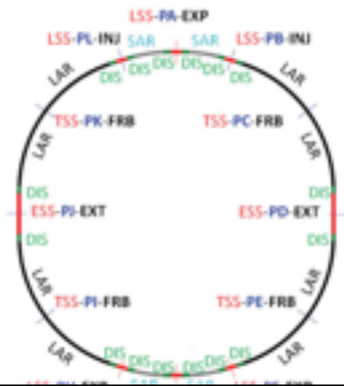

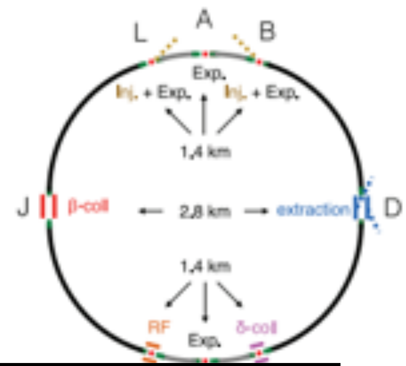

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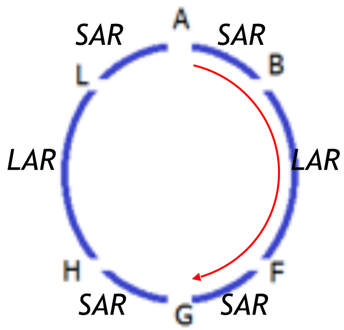
Phase Scan and min DA

- Study to analyse impact of phase between main IR and minimum DA.



1. Take old lattice.
2. Adjust phase to between both main IR while leaving phase in other sections the same.
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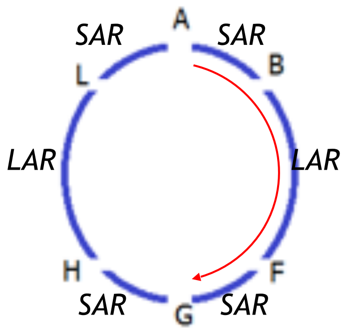

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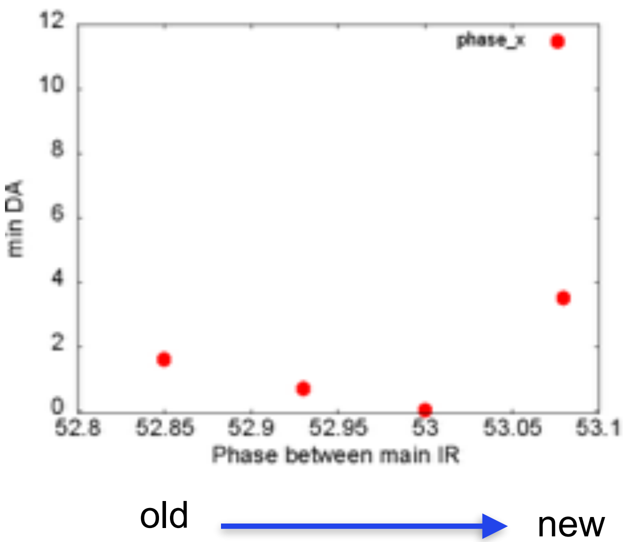

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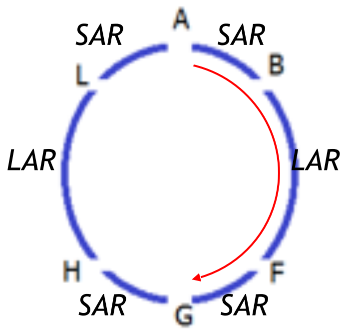

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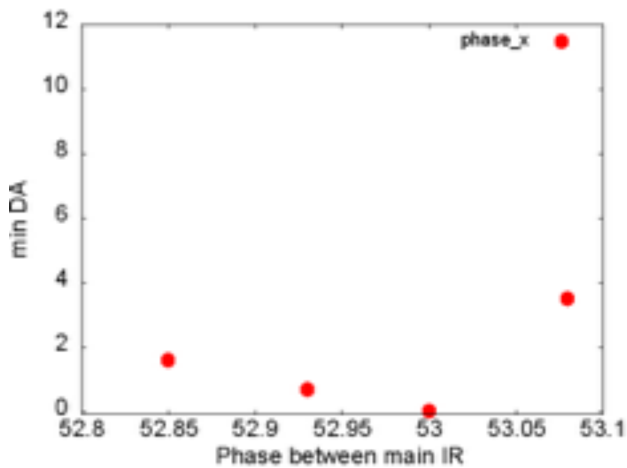

old → new

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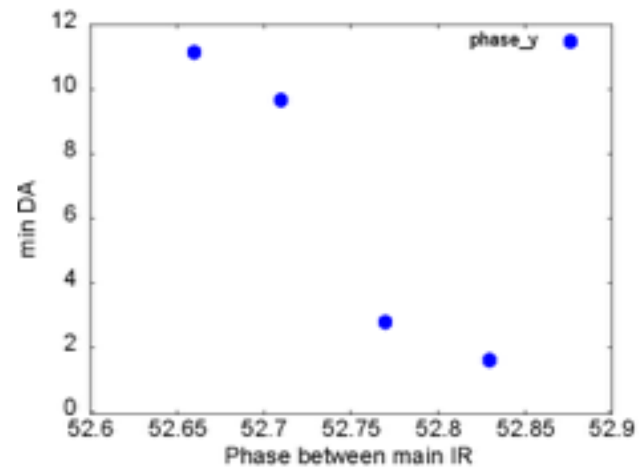

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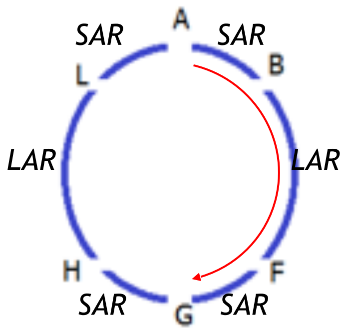

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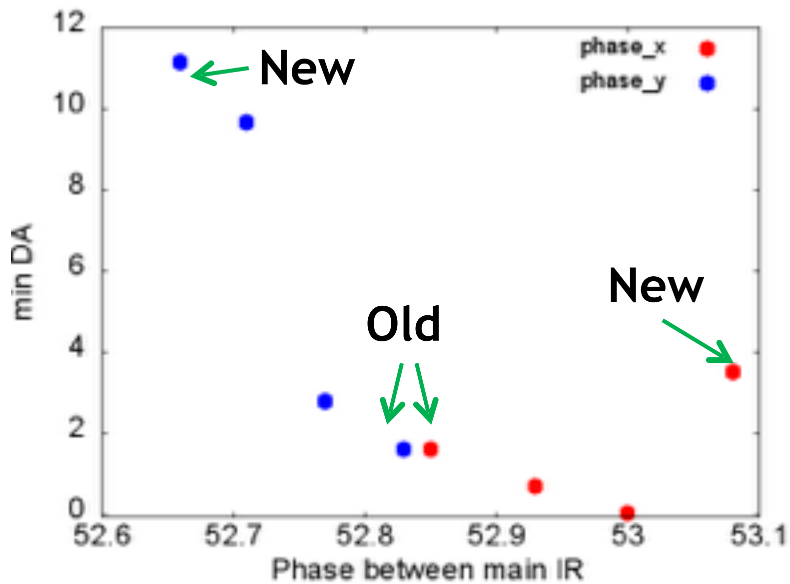

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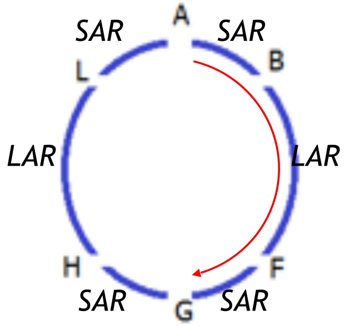

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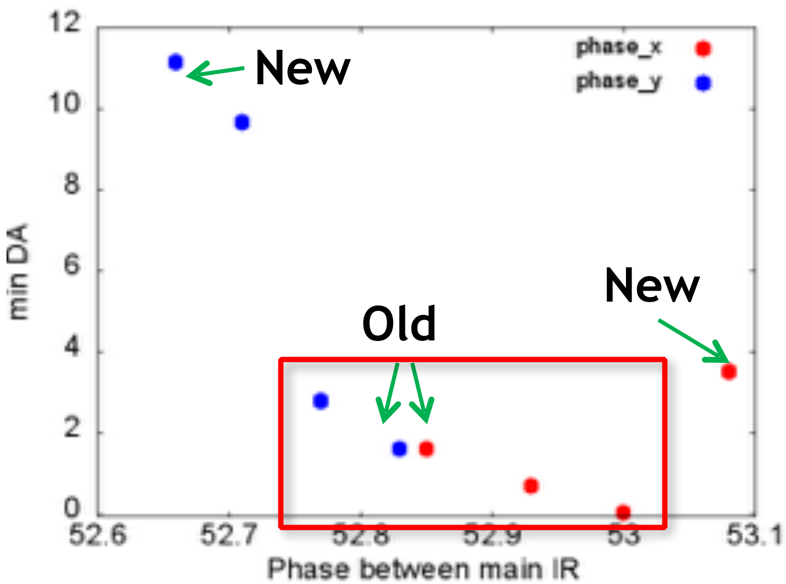

Extra Slides

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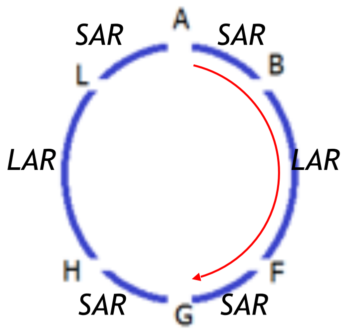

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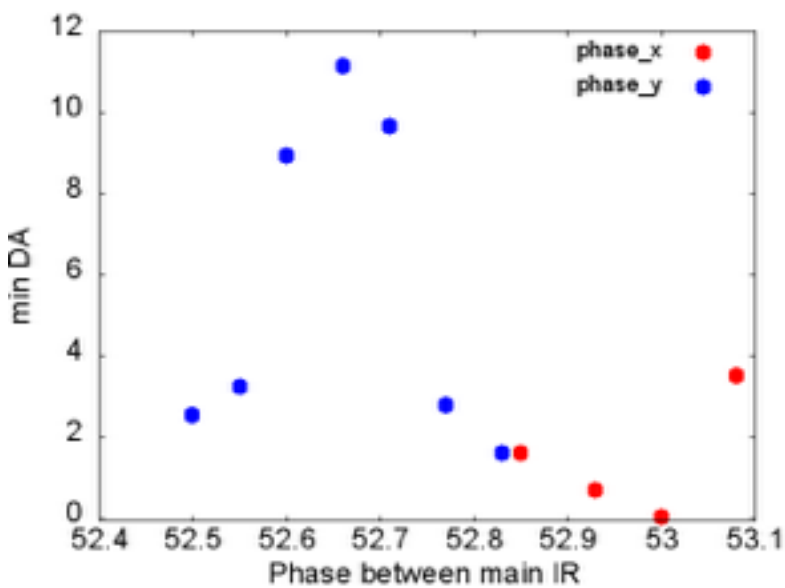
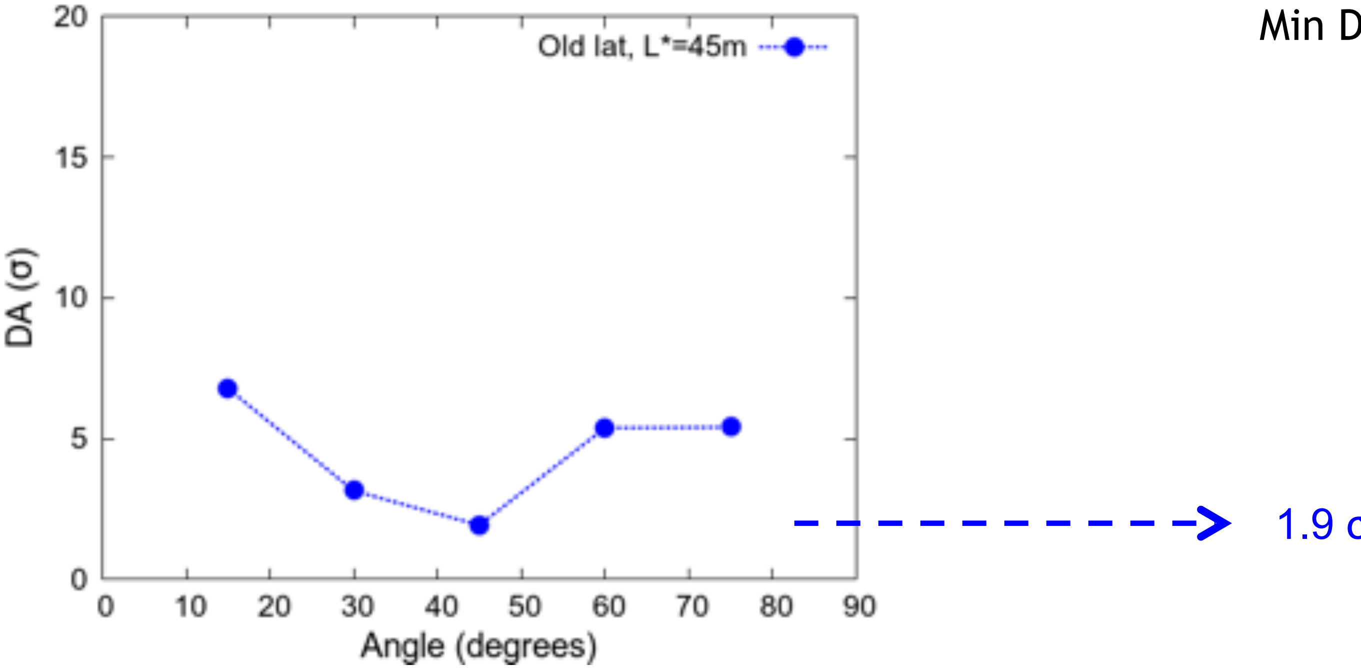


Results

- Comparison of minimum dynamic aperture for **different lattices**

- All studies are done with:
  - 60 seeds and 5 angles
  - SSC-like spurious dispersion correction
  - Without non-linear correctors.
  - **Errors only on triplet** in main IRs (IRA, IRG)

Min DA



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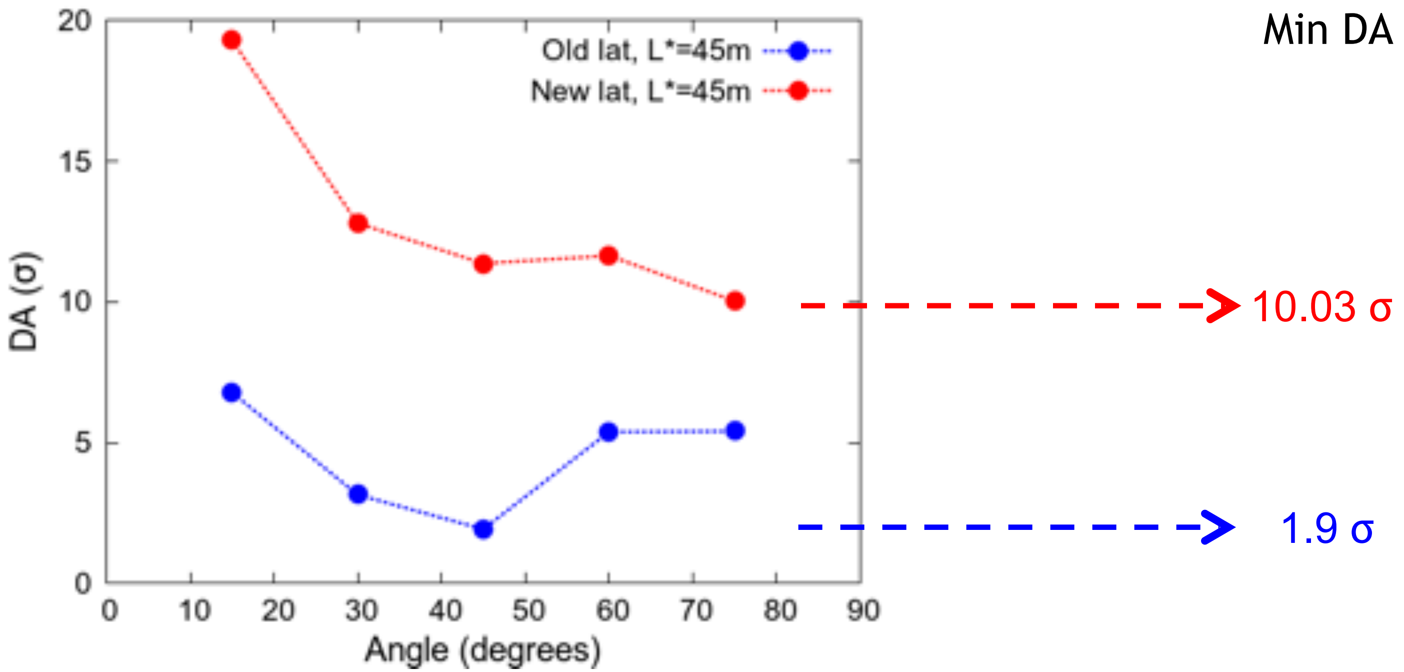

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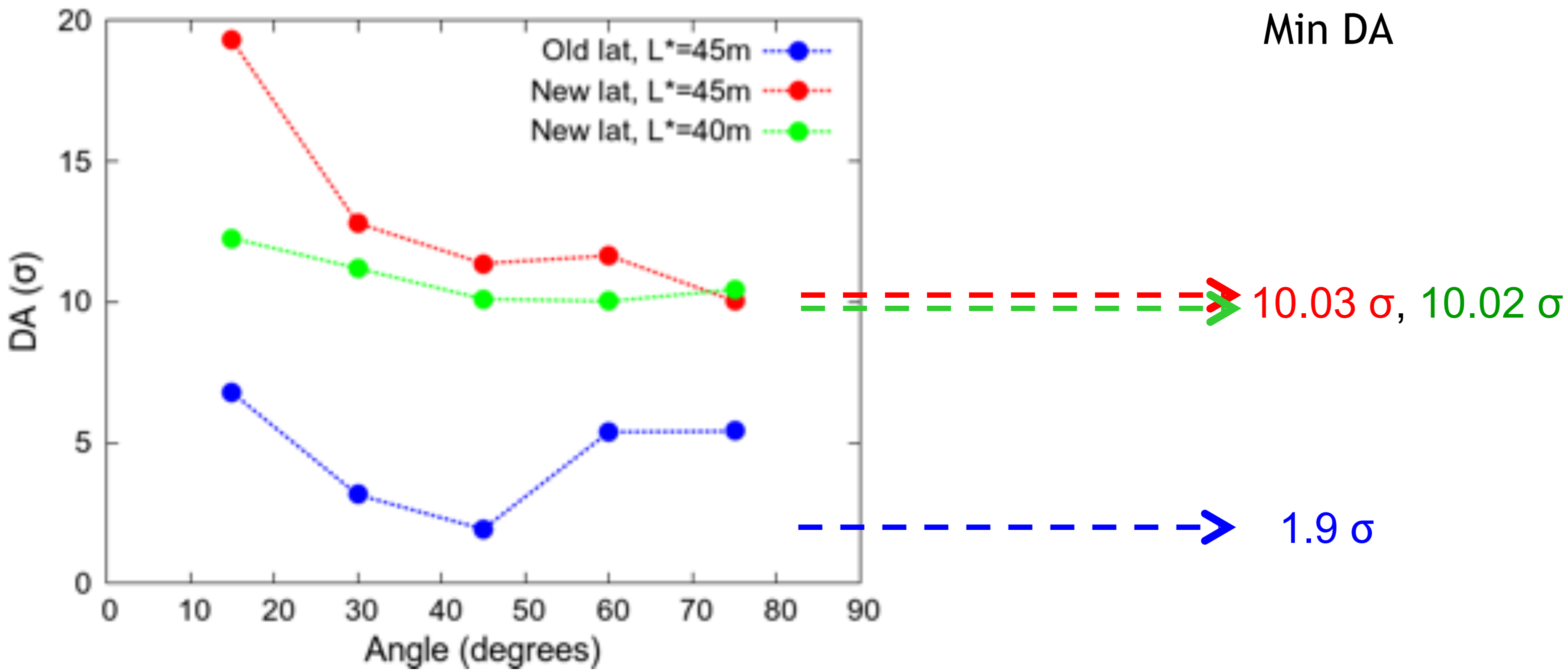

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- Higher DA allows to **consider more errors.**
- All studies are done with:
  - New lattice, L*=40 m
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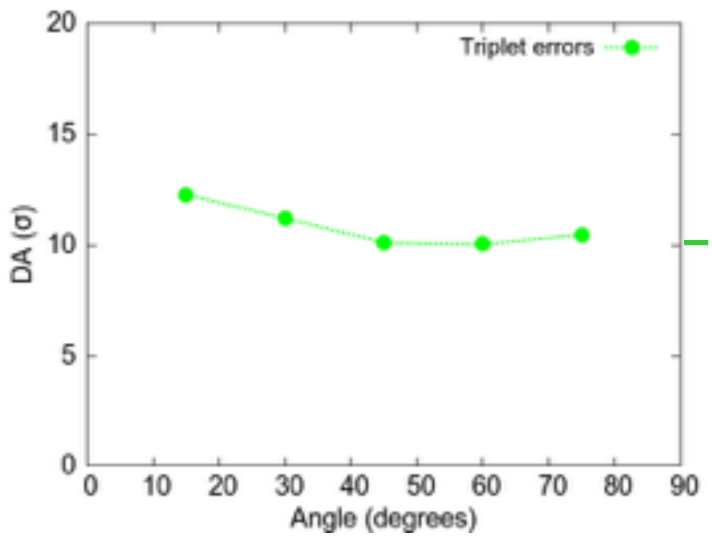

Min DA

10.02 σ

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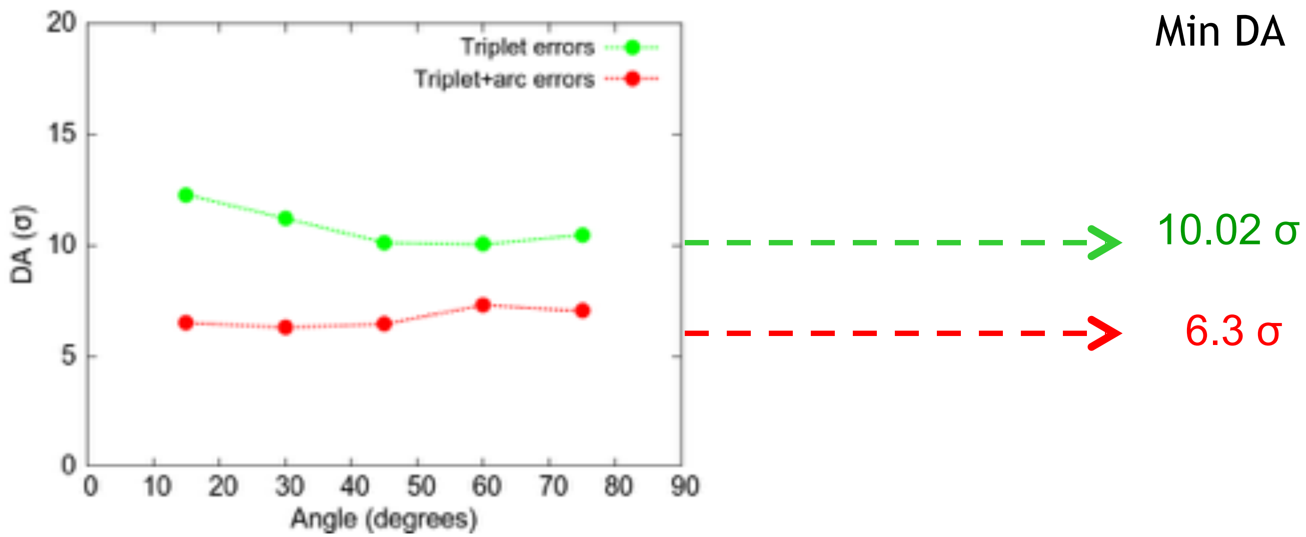

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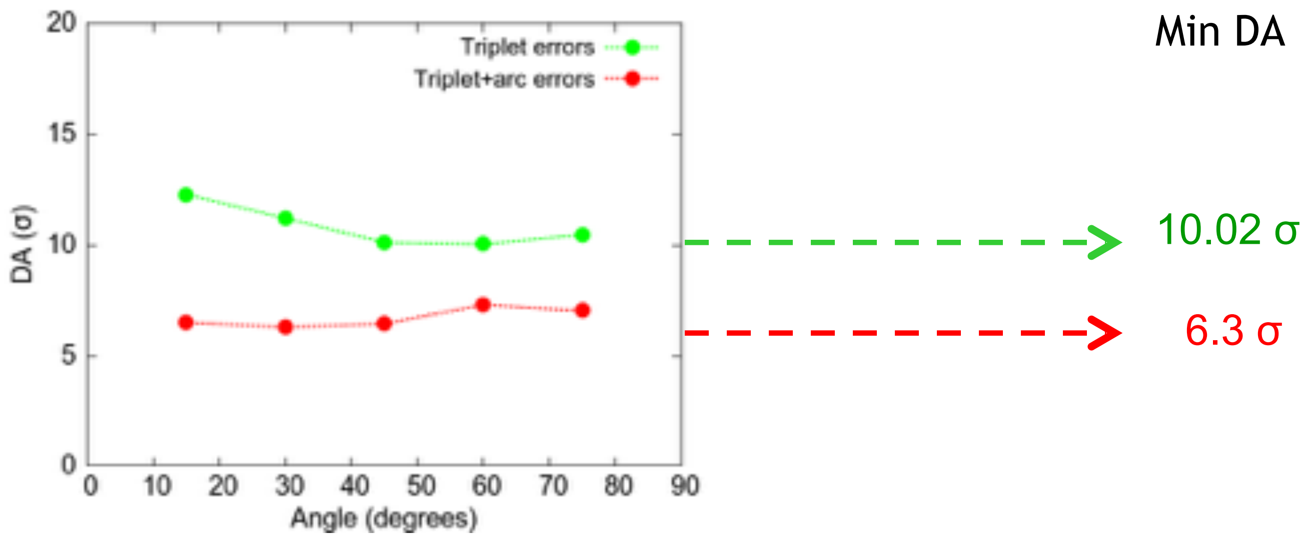

- Arc errors have an impact of about 4σ on the DA.

Non-linear correctors

- So far studies have been done without non-linear correctors.
- Although not as critical in this case non-linear correctors were included to observe its impact

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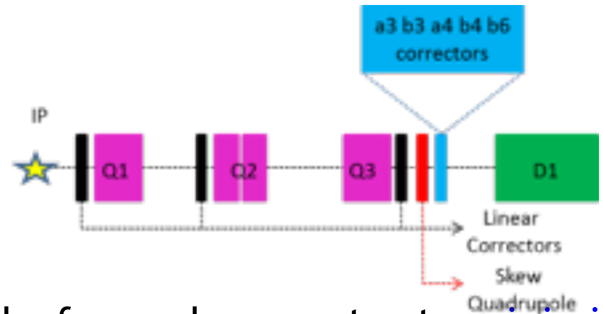
METHOD

- Add non linear correctors:
  - Normal and skew
  - Left and right of the IR.

- Current location is set next to MQX3



- Make python routine that calculate strengths for each corrector to minimize corresponding RDTs.

$$c(b_n;p,q) = \int_{IR_{left}} ds K_{n-1}(s) \beta_x^{p/2} \beta_y^{q/2} + (-1)^n \int_{IR_{right}} dx K_{n-1}(s) \beta_x^{p/2} \beta_y^{q/2}.$$

$$c(a_n;p,q) = \int_{IR_{left}} ds K^s_{n-1}(s) \beta_x^{p/2} \beta_y^{q/2} + (-1)^n \int_{IR_{right}} dx K^s_{n-1}(s) \beta_x^{p/2} \beta_y^{q/2}.$$

- Include this routine to the tracking mask file calculating the correctors strengths for each of the 60 seeds followed by other corrections (coupling correction, crossing, chrom and tune,…)

Results

- Comparison between studies **with and without non-linear correctors.**
- All studies are done with:
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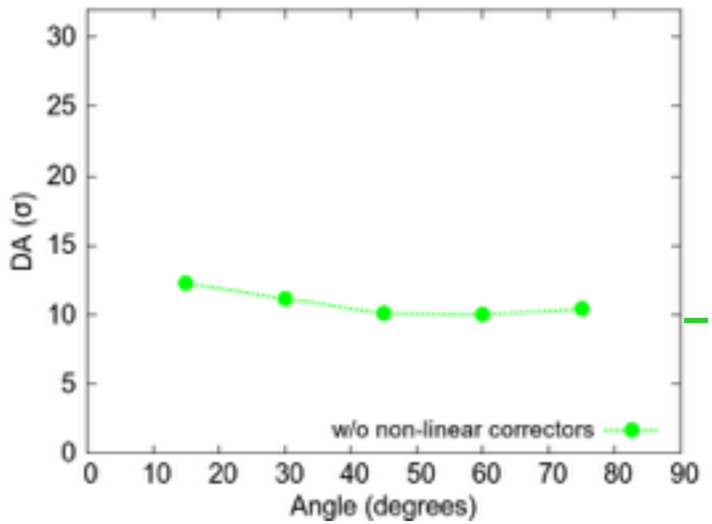

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10.02 σ

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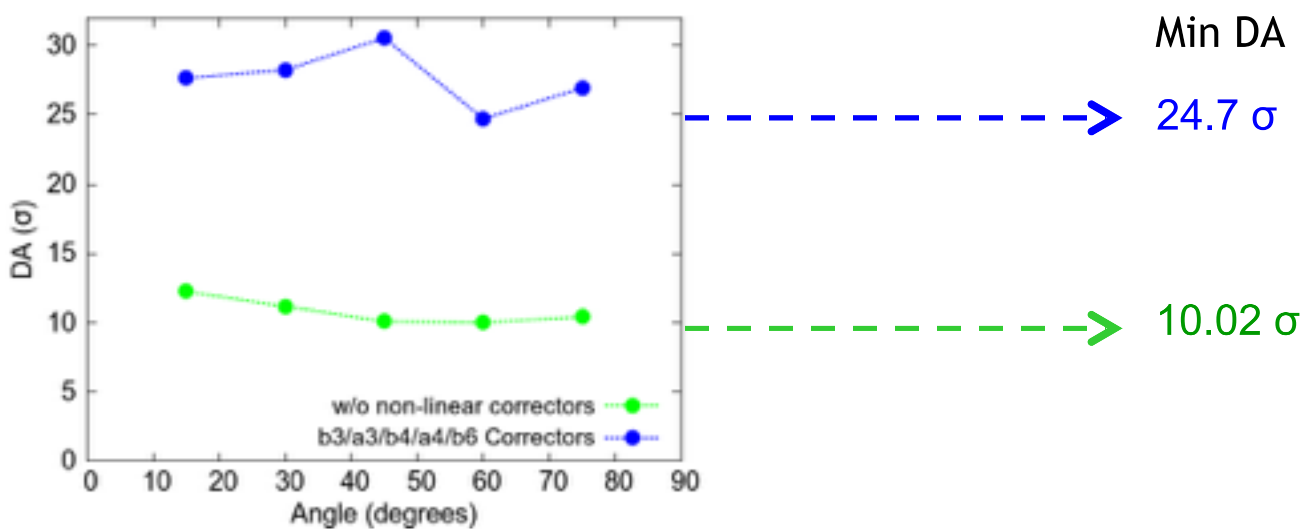

- Although not as critical as with the last lattice non-linear correctors again provide an increase in the DA.

Conclusions

- New shorter lattice shows much better results for the DA (at collision energy and including triplet errors) in comparison with old lattice (10 sigma vs 2 sigma).
- Studies show that this increase in DA seems to come from a much optimal phase advance between the main IR for the new lattice.
- This larger DA allows us to consider further errors. Studies with arc and triplet errors were performed at collision energy resulting in a DA of 6 sigma.
- Studies considering error table for the separation-recombination dipoles D1 and D2 and errors on the triplet of the low luminosity insertions are being performed (R. Martin, M. Hofer).
- Studies including non-linear correctors were also performed. Although not as critical as for last lattice the inclusion of this non-linear correctors increased the DA up to 25 sigma with triplet errors only.
- The inclusion of the non-linear correctors can be used in case the DA gets lower by the inclusion of other errors.

Thanks!