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Update on dipole field quality and DA at injection for FCC-hh

B. Dalena

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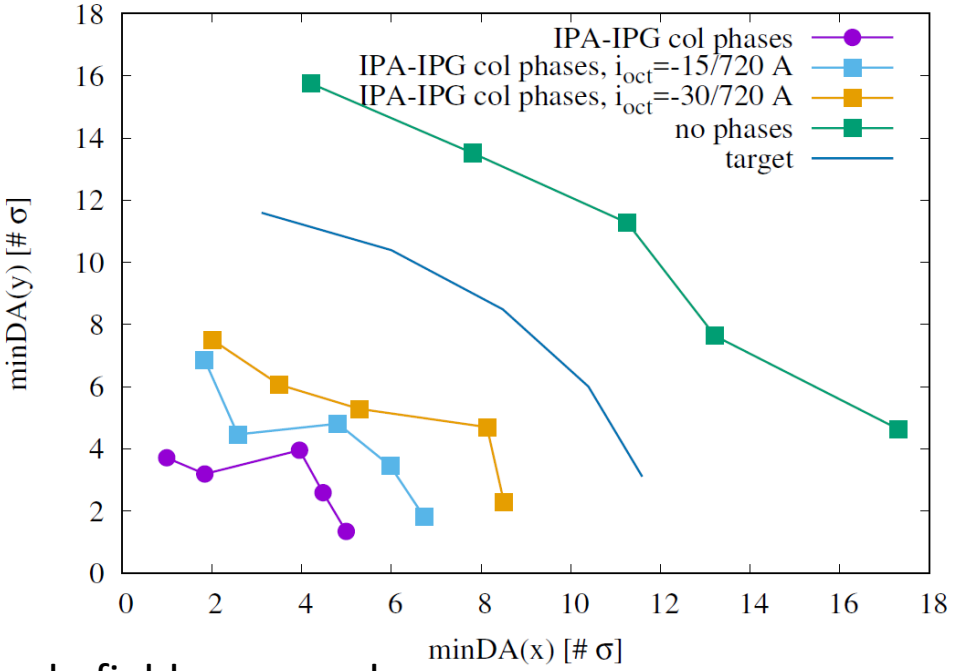
Outline

- Summary of Amsterdam DA results for table v3
- Understanding Amsterdam results:
  I. FCC RF acceptance and $\Delta p/p$
  II. SixTrack DA values
- First DA results for table v42
- Conclusion and perspectives

Puzzling Amsterdam DA results

main dipole field quality table v3, b_2=50 unit, Q'=2

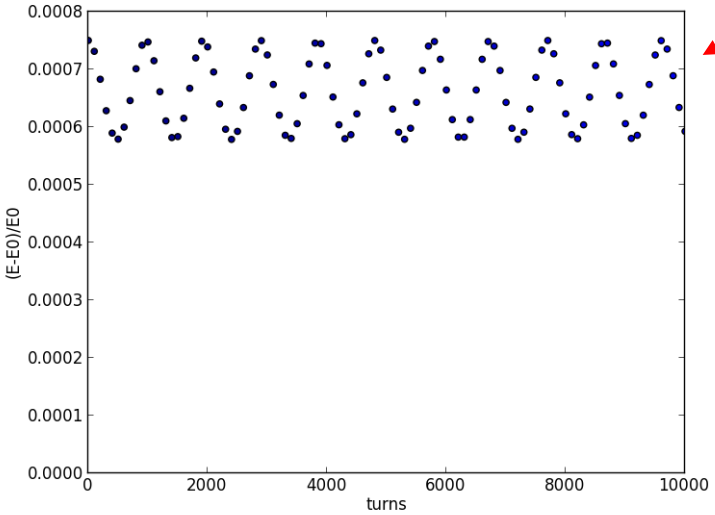
Min DA [σ]	Comments
16.8	no phases
34.1	IPA-IPG col phases
15.3	+tripD1D2 errors
3.7	+IPA-IPG col phases, tripD1D2 errors
5.1	+IPA-IPG col phases, tripD1D2 errors -15/720 A octupole strength
7.0	+IPA-IPG col phases, tripD1D2 errors -30/720 A octupole strength



- Very big DA and large uncertainty for main dipole field errors only
- Very small DA for main dipole + triplet errors at injection
- DA increase with negative octupoles polarity

I. RF acceptance

Evolution of energy in SixTrack for initial $\Delta p/p$ of **7.5 10^{-4}**



$$\left(\frac{\Delta p}{p_0}\right)_{max} = \sqrt{\frac{2V_{RF}}{\pi h|\eta|cp_0}}$$

	V_{RF} [MV]	P_0 [TeV]	$\Delta p/p$ max 10^{-4}
FCC	16	3.3	4.8
	32	50	1.7
LHC	8	0.45	9.6
	16	7	3.4

$\Rightarrow$ FCC @ injection **3.2 10^{-4}** (2/3 of max RF acc)

$\Rightarrow$ FCC @ collision **1.15 10^{-4}** (2/3 of max RF acc)

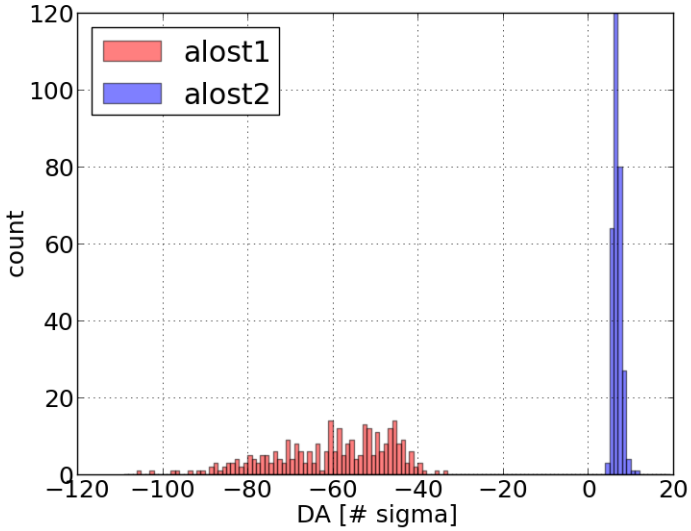
II. DA with dipole errors only (table v3)

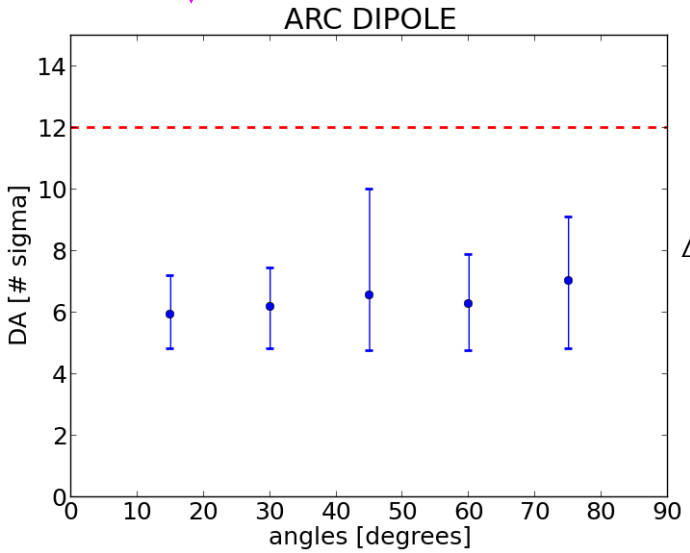
SixTrack output

Angle/seed	achaos	achaos1	alost1	alost2	Firstamp	lastamp

DA values I used up to now came from alost1

- Unless particular values of distance of two very close particles and max slope of this distance alost1=alost2
- For FCC alost1 is always negative and with large spread (|alost1| > 30 σ)
- For FCC alost2 is positive for all the seeds





Δp/p of **7.5 10^{-4}**

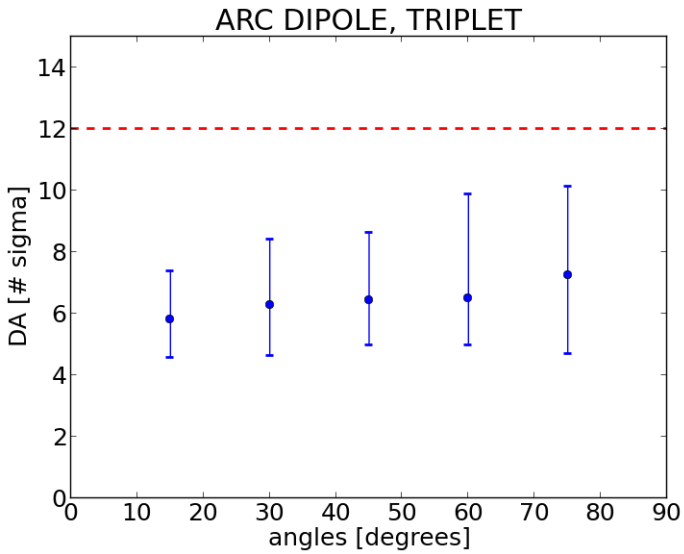
⇒ **DA below the target at injection**

DA with dipole, triplet errors and MO (table v3)

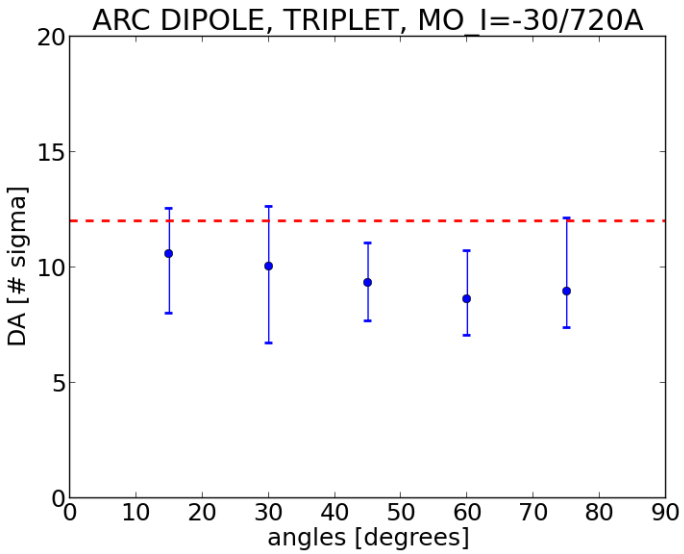
SixTrack output

Angle/seed	achaos	achaos1	alost1	alost2	Firstamp	lastamp

- alost1 and alost2 values in this case are more similar
- alost1 has still some negative values < 4 σ



Triplet has no significant impact on DA at injection



Δp/p of **7.5 10^{-4}**

Octupoles slightly increase DA at injection

More correct Amsterdam results (table v3)

DA below the target at injection

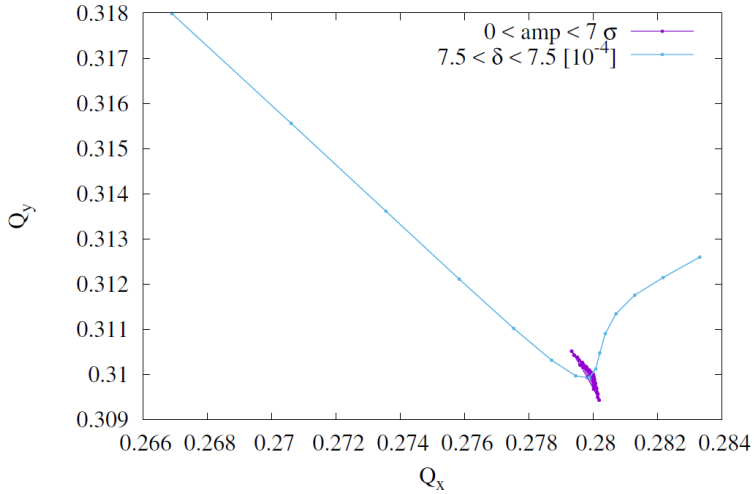
Triplet has no significant impact on DA at injection

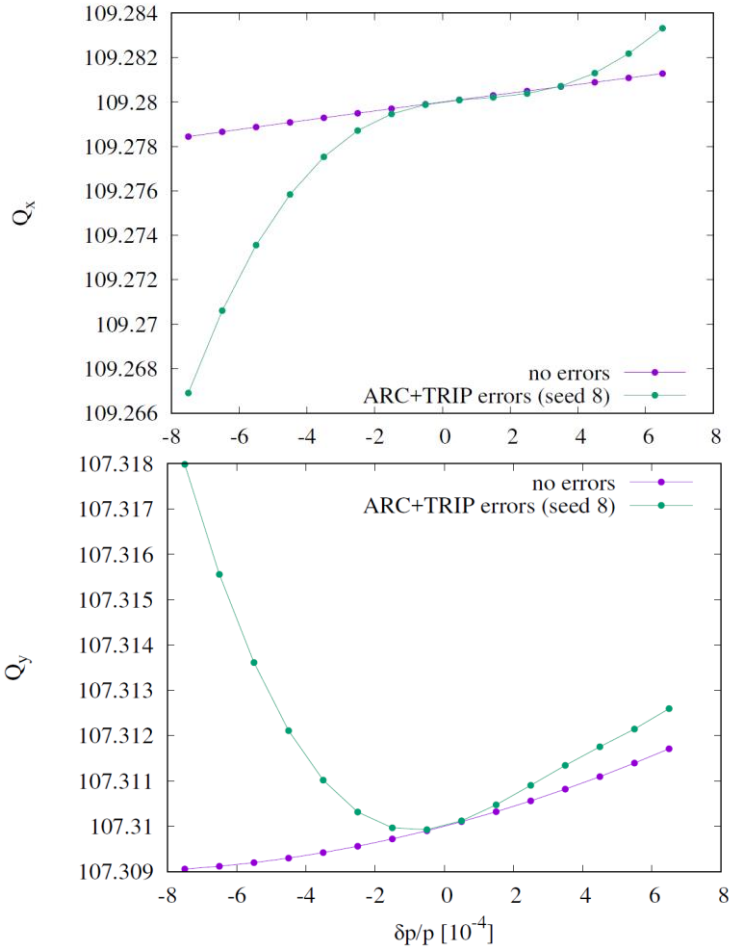
Main Octupoles increase DA at injection

All theses values are for particles out of RF acceptance

	Min DA [σ] $\Delta p/p = 7.5e^{-4}$
arc dipoles	4.2
arc + triplet	4.5
arc + triplet + oct -30A	6.0

Detuning with amplitude and momentum (table v3)





$$Q_z(\epsilon_x, \epsilon_y) = Q_{z0} + \left(\frac{\partial Q_z}{\partial \epsilon_x}\epsilon_x + \frac{\partial Q_z}{\partial \epsilon_y}\epsilon_y\right) + \frac{1}{2!}\left(\frac{\partial^2 Q_z}{\partial \epsilon_x^2}\epsilon_x^2 + 2\frac{\partial^2 Q_z}{\partial \epsilon_x \partial \epsilon_y}\epsilon_x\epsilon_y + \frac{\partial^2 Q_z}{\partial \epsilon_y^2}\epsilon_y^2\right) + \ldots$$

$$Q_z\left(\frac{\delta p}{p_0}\right) = Q_{z0} + Q_z'\left(\frac{\delta p}{p_0}\right) + \frac{1}{2!}Q_z''\left(\frac{\delta p}{p_0}\right)^2 + \frac{1}{3!}Q_z'''\left(\frac{\delta p}{p_0}\right)^3 + \ldots$$

⇒ **Detuning is larger with momentum than with amplitude!**

⇒ **Q''' and Q'' are present**

Detuning with momentum table v3

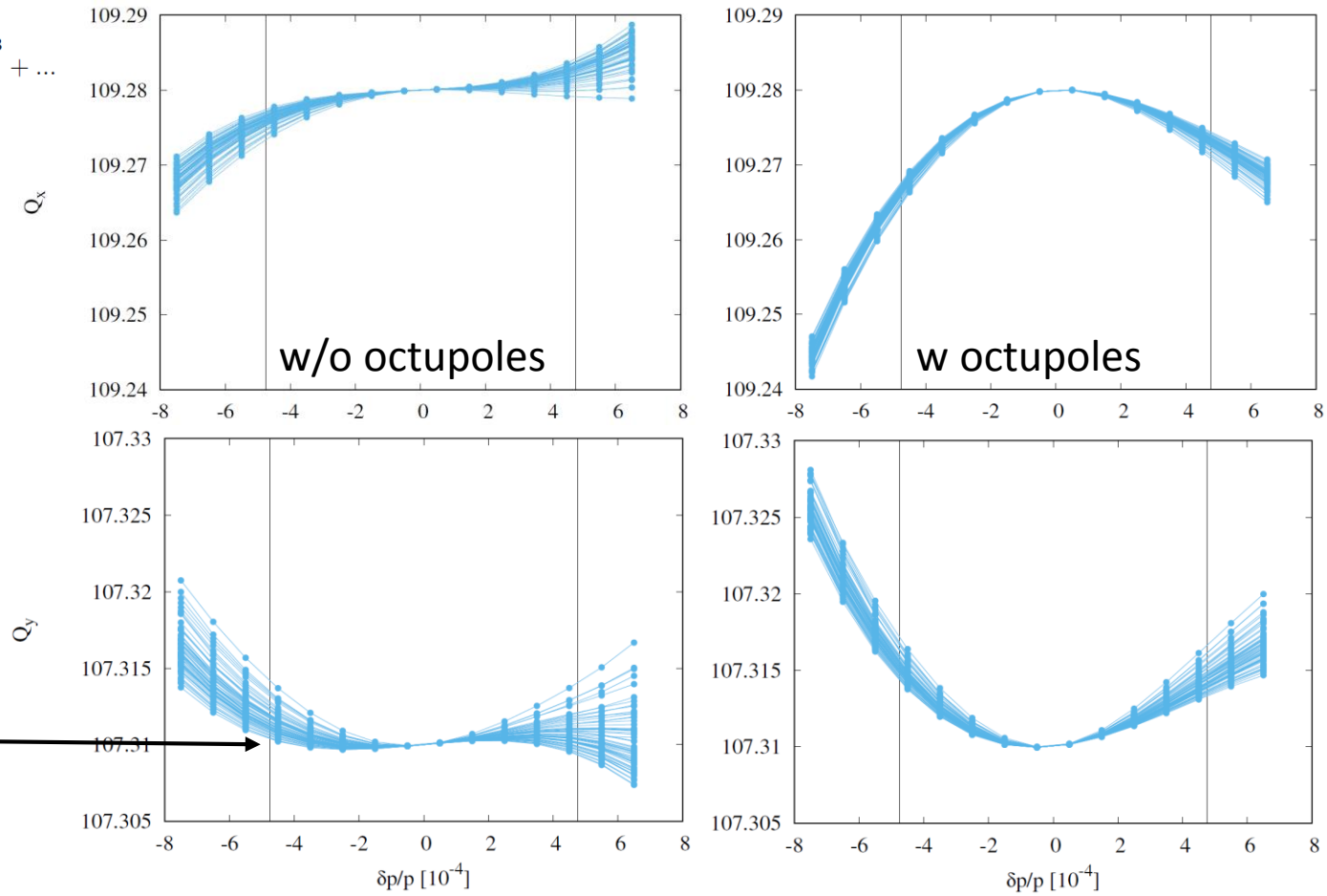
$$Q_z\left(\frac{\delta p}{p_0}\right) = Q_{z0} + Q_z'\left(\frac{\delta p}{p_0}\right) + \frac{1}{2!}Q_z''\left(\frac{\delta p}{p_0}\right)^2 + \frac{1}{3!}Q_z'''\left(\frac{\delta p}{p_0}\right)^3 + \ldots$$

$Q_z'' \propto 3\beta b_4$+...

$Q_z''' \propto 12\beta b_5$+...

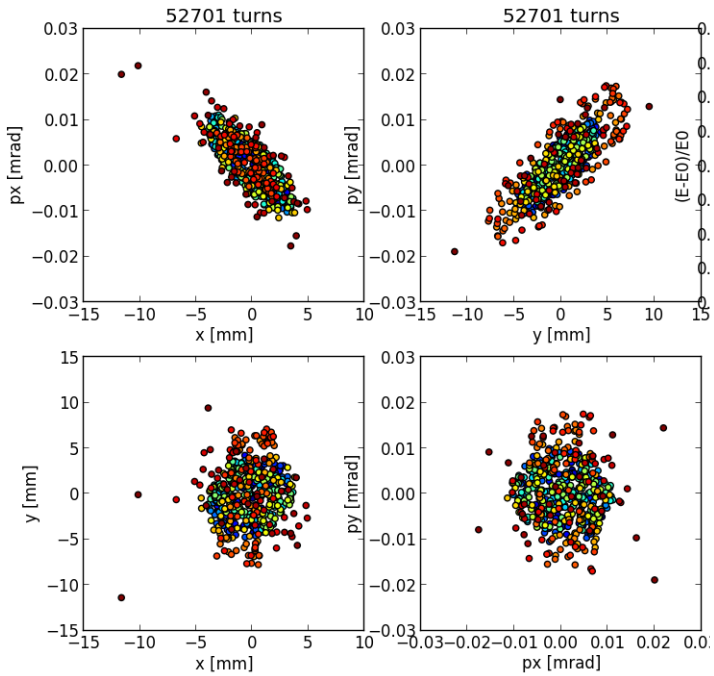
Fitting with a 3rd order polynomial for seed giving minimum DA
⇒ Q''' is stronger than Q''

With Octupoles ON Q'' dominates and out of the **RF acceptance** the octupoles reduce the tune spread due to different seeds of main dipole errors



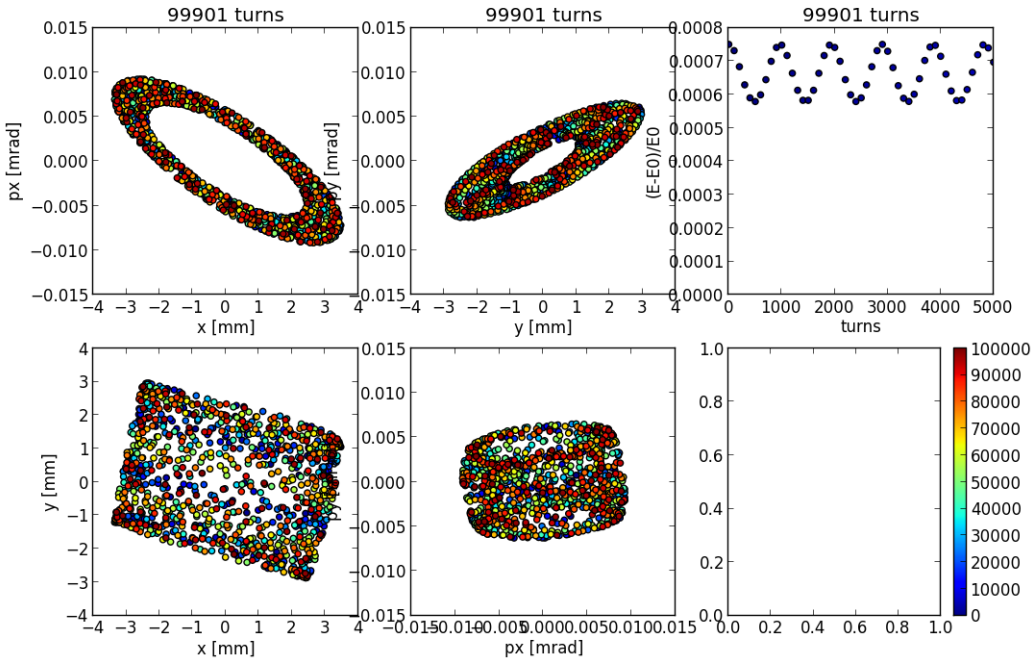
Effect of the main octupoles @ $\delta p/p = 7.5e^{-4}$

Arc errors only



Lost

Arc, IRs errors and octupoles I=-30 A



Stable

DA at injection for August 2018 optics and table v3

- New optics: new insertions, b_{2S} =0 at collision and b_{2S} =20 units at injection, no phase advance fixed between the two high luminosity IRs at injection
- Improvements in the matching macros for thin lattice
- Improvements in the mask file to generate SixTrack inputs

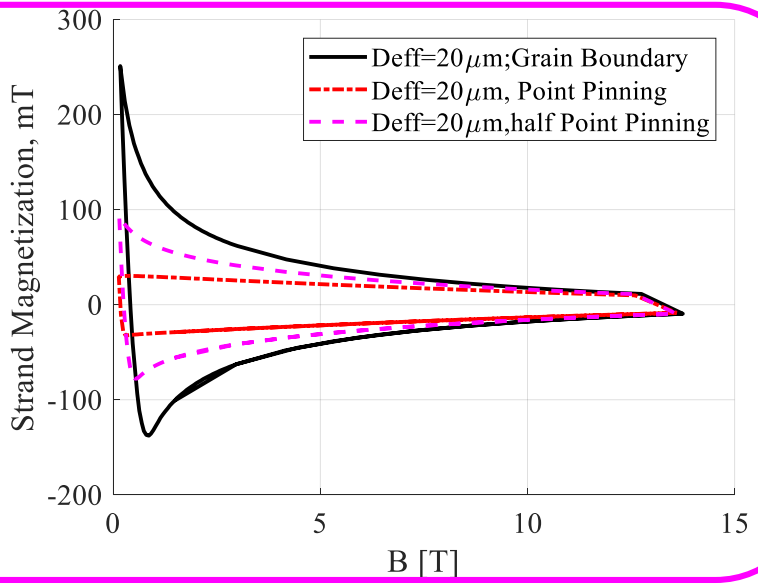
- Initial amplitude of particles lost used to evaluate DA (alost2)
- Energy corresponding to the max RF acceptance considered

	Min DA [σ] $\Delta p/p = 0$	Min DA [σ] $\Delta p/p = 4.7e^{-4}$	Min DA [σ] $\Delta p/p = 7.5e^{-4}$
arc dipoles		5.8	4.9
arc + triplet	14.4	4.9	4.7
arc + triplet + oct -30A	7.9	3.2	6.7

Tables v42 (half artificial pinning)

- New asymmetric coil design (INFN-LASA & INFN GENOVA)
- New strand magnetization for persistent current effects

Susana Izquierdo Bermudez, Davide Tommasini
01-10-2018



- Initial amplitude of particles lost used to evaluate DA (alost2)
- Energy corresponding to 2/3 of the max RF acceptance considered
- Main Octupoles current of -15A @ injection (Sergey ARSENYEV communication)

	Min DA [σ] Δp/p=0	Min DA [σ] Δp/p=3.2e^{-4}
arc	16.21	9.2
arc+triplet		
arc+triplet+oct =-15 A	10.55	6.3

DA w/o systematic b_5 of table v42

DA evaluated for b_{5S} = 0 units

- Minimum DA with arc errors only above the target of 12 σ
- Minimum DA with arc, main IRs errors and octupoles current of -15A above primary collimators settings

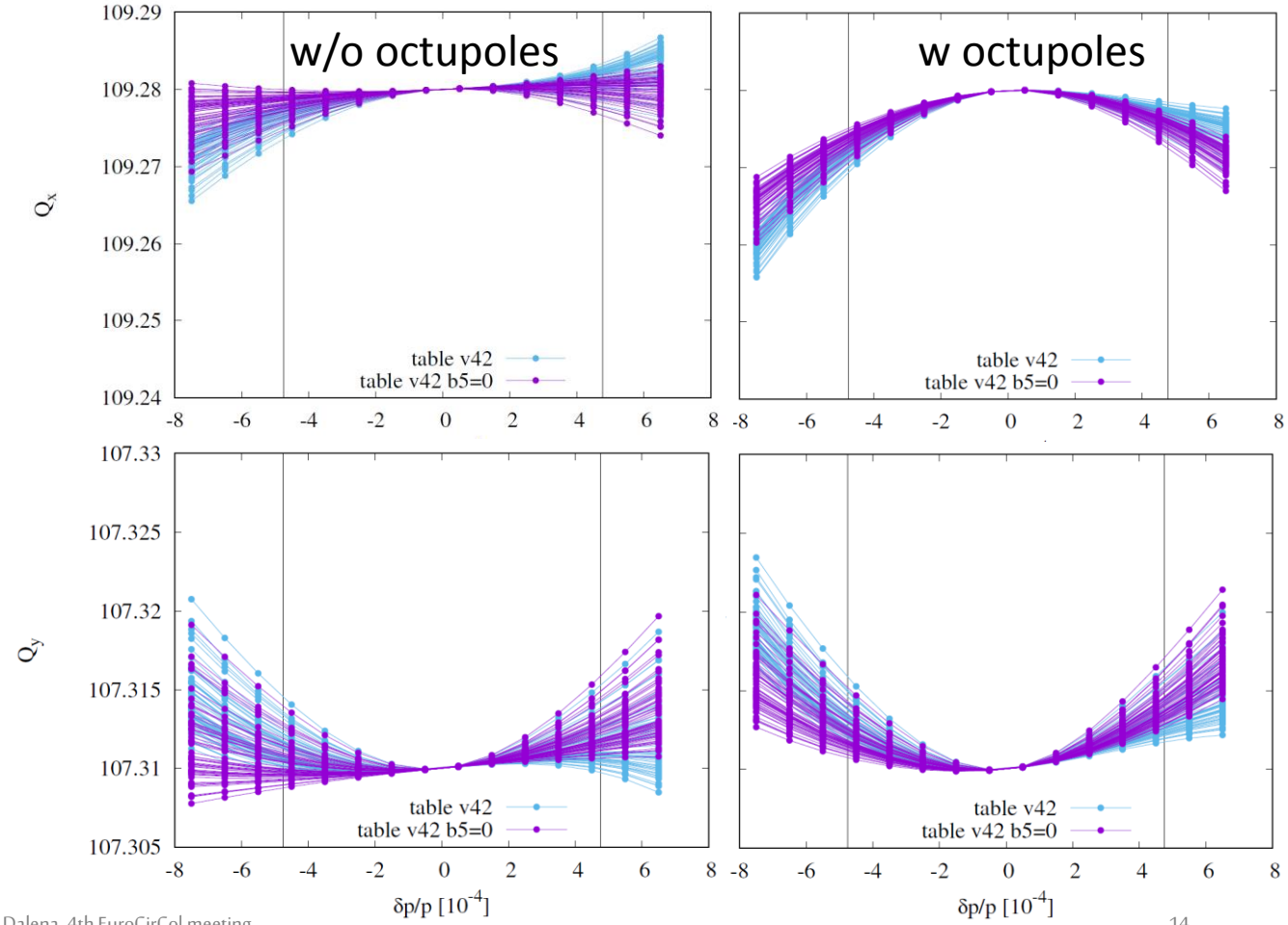
	Min DA [σ] $\Delta p/p=0$	Min DA [σ] $\Delta p/p=3.2e^{-4}$
arc	16.21	14.1
arc+triplet		
arc+triplet+oct =-15 A	10.55	8.1

Detuning with momentum w and w/o b_5 (table v42)

$$Q_z\left(\frac{\delta p}{p_0}\right) = Q_{z0} + Q_z'\left(\frac{\delta p}{p_0}\right) + \frac{1}{2!}Q_z''\left(\frac{\delta p}{p_0}\right)^2 + \frac{1}{3!}Q_z'''\left(\frac{\delta p}{p_0}\right)^3 + \ldots$$

With b_{5S} = 0 we have only Q'' left and both w and w/o octupole max detuning is < 0.01 @ $3.2e^{-4}$ dp/p

⇒ Correction of b_4 from Table v42 not required



Conclusion and perspectives

- Amsterdam results have been understood and corrected
  - DA at injection due to dipole field quality (table v3) below the target
  - Strong decapole component induces large detuning with momentum

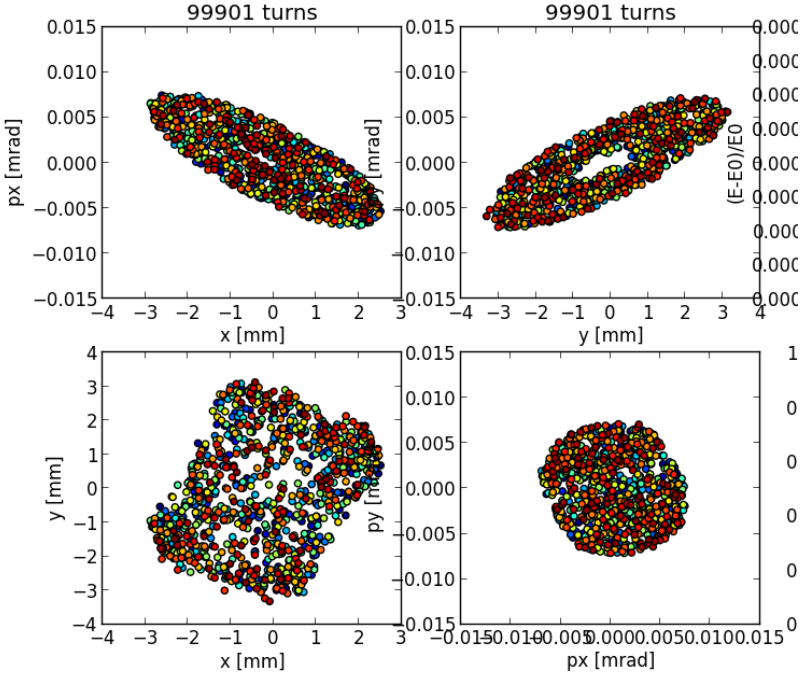
- New asymmetric design and new strand magnetization (table v42) improve DA but decapole component correction is also required in order to be above the target of 12 σ at injection

- ➢ b_5 correction scheme
- ➢ Impact of main quadrupoles on DA
- ➢ Impact of linear imperfection on DA
- ➢ working point at injection

Spares

Effect of the main octupoles @ δp/p = 7.5e-4

Arc errors only



Arc, IRs errors and ocutpoles I=-30 A