Laurence Wroe - CERN Report

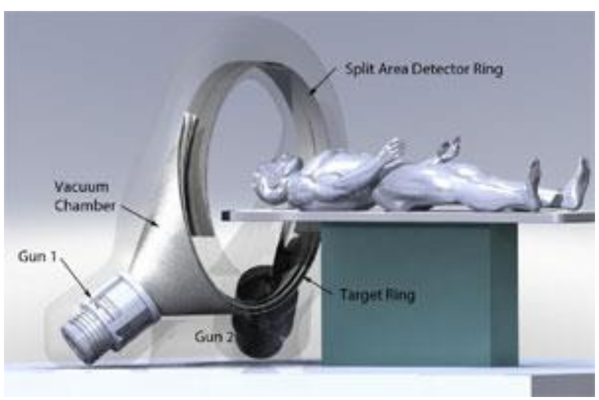
What I will be talking about…

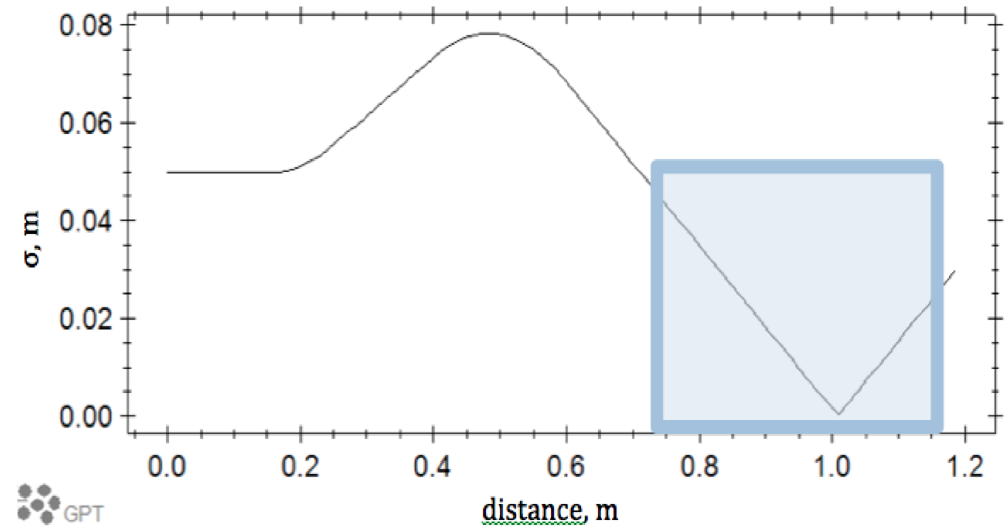
- Feasibility of using CLEAR to study effects of Very High Energy Electron (VHEE) beams

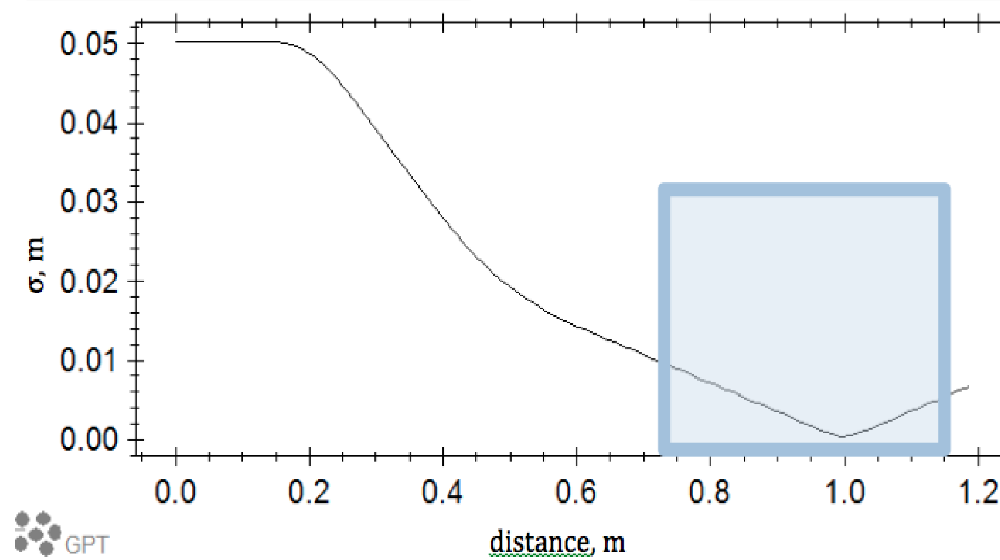
- Ground Vibration Effects on the beam dynamics of the LHC and HL-LHC

VHEE Study

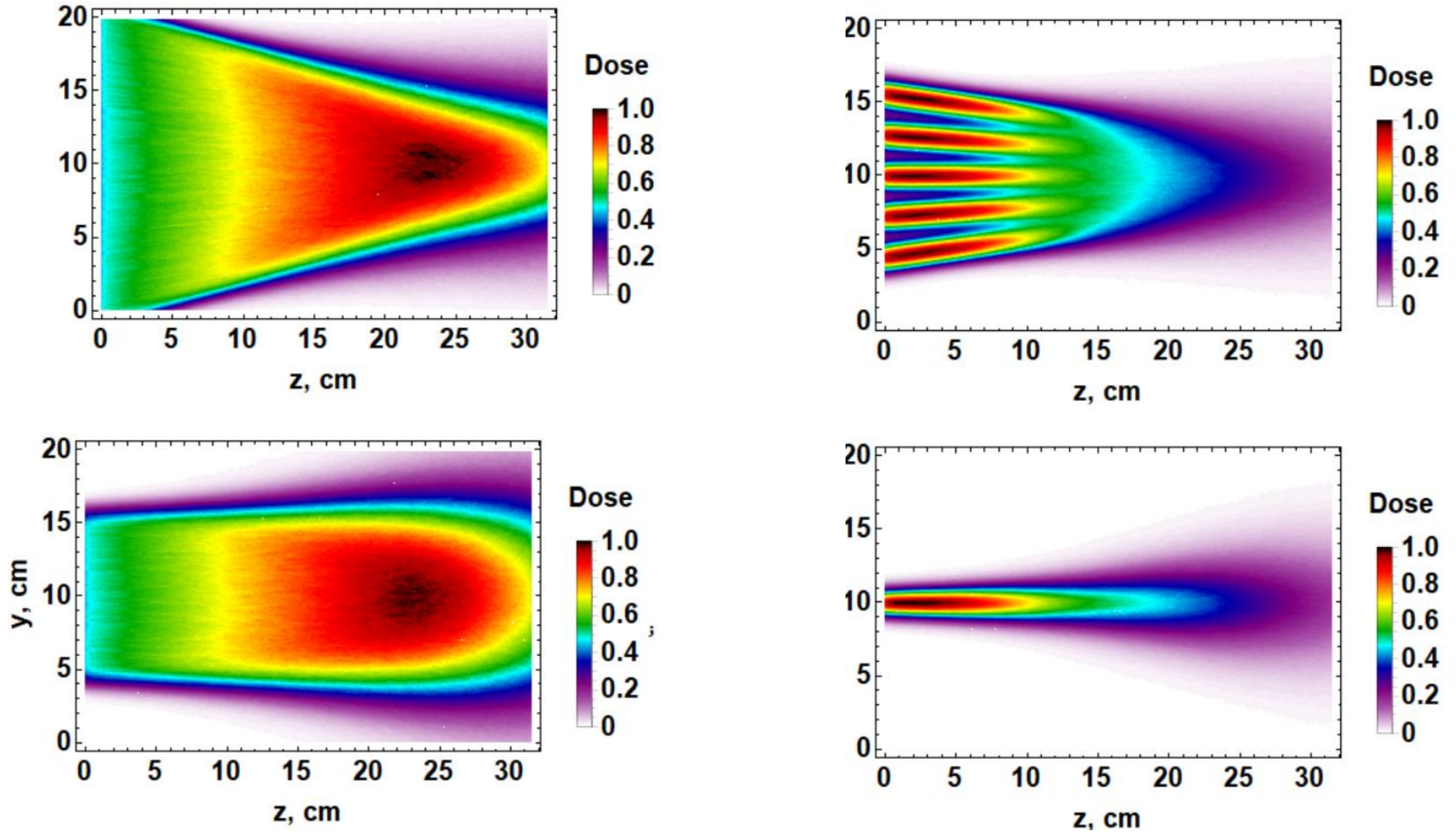
- Study of beam propagation through water tank (approximation to human tissue)



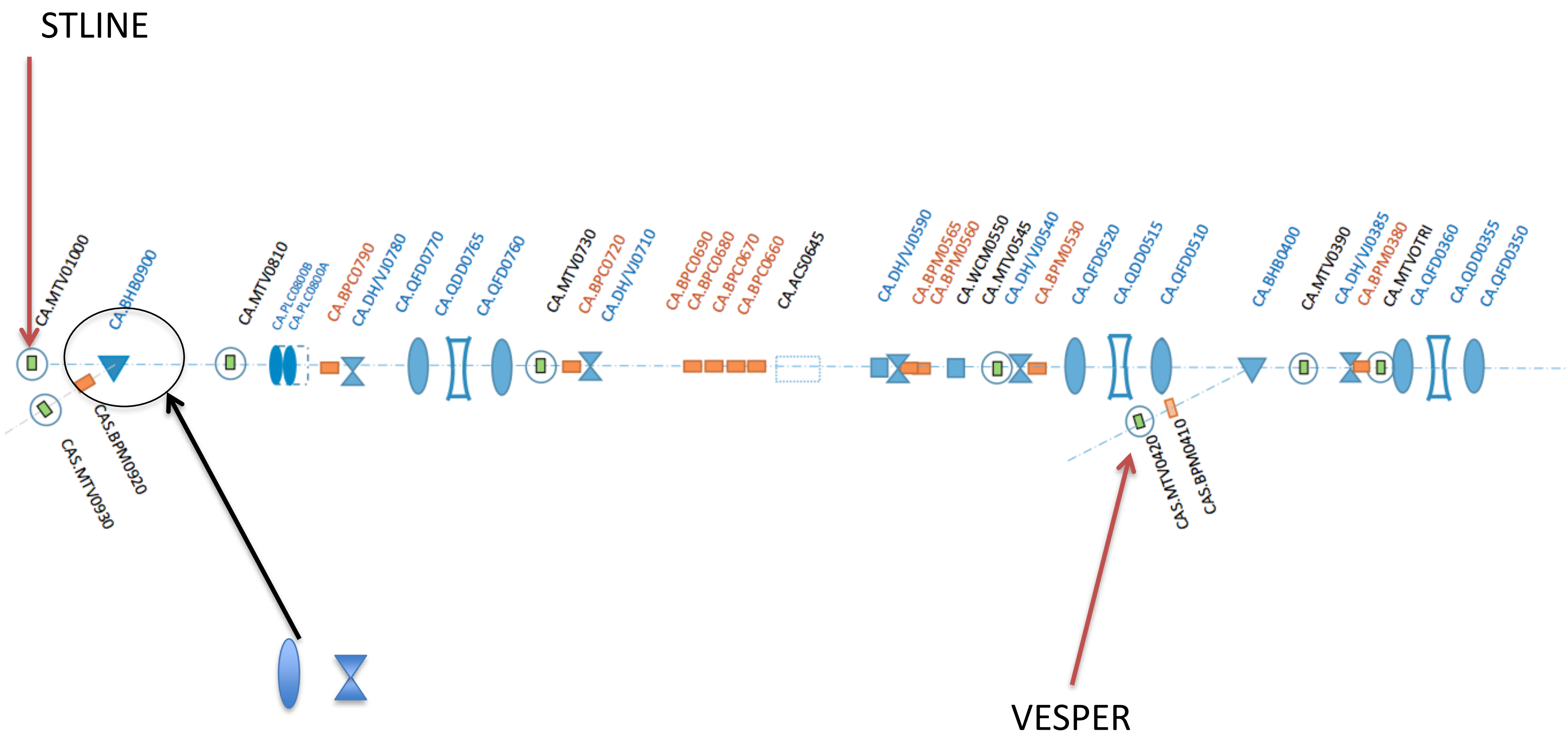




How to achieve this convergence?

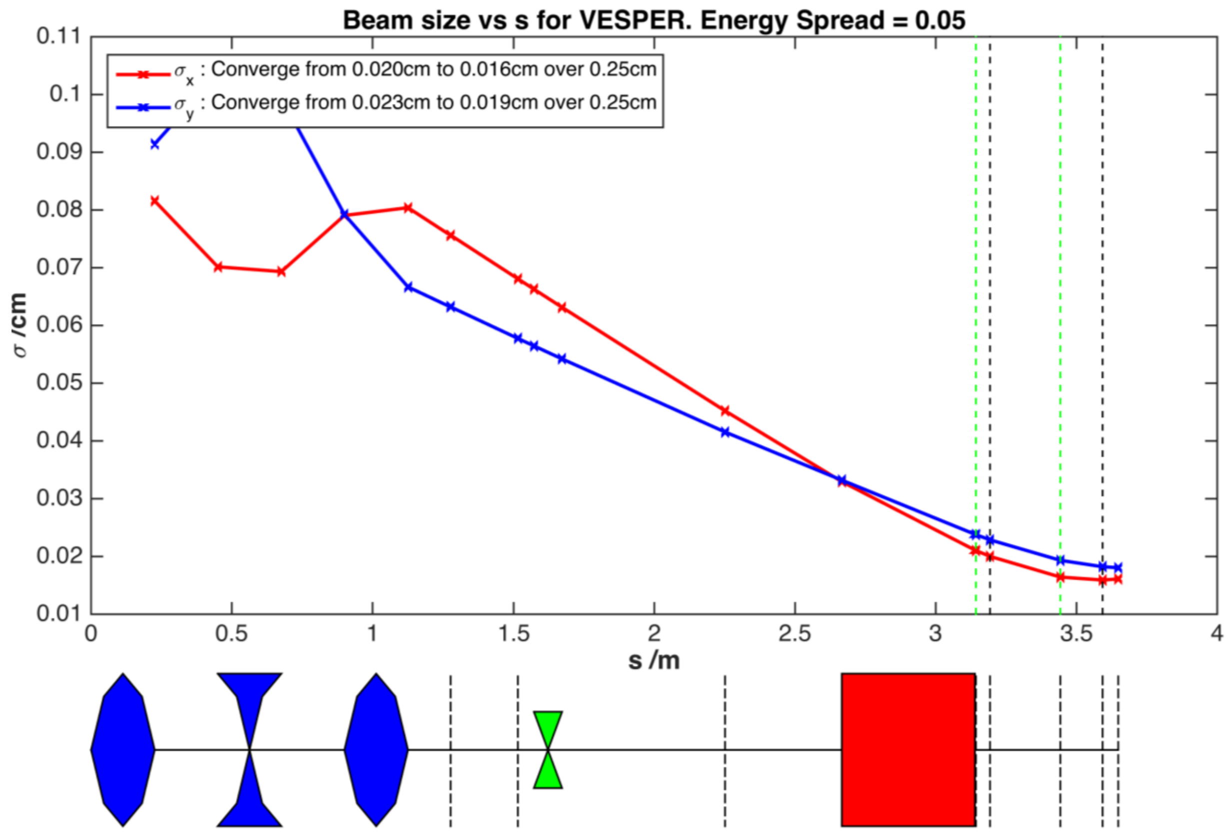


CLEAR Layout



Simulation

- Simulation performed using MAD
- Used the MATCH function with constraints at certain points



Results for converging large beam

- Desired convergence:
  50000μm to <1000μm in x
  10000μm to <1000μm in y

		$\sigma_x/\mu m$		$\sigma_y/\mu m$	
		At Box Edge	At Target	At Box Edge	At Target Point
STLINE	No Extra Quadrupole	320	100	350	110
	Extra Quadrupole Before Dipole	1210	140	210	90
	Extra Quadrupole After Dipole	3060	100	190	100
VESPER	0% Energy Spread	160	150	180	170
	1% Energy Spread	170	150	190	170
	5% Energy Spread	200	160	230	190

Results for converging multiple pencil beams

- Desired convergence:
  50000μm to <1000μm in x
  10000μm to <1000μm in y

		Displacement From Centre Point/μm	
		At Box Edge	At Target
STLINE	No Extra Kicker	-670	-4
	Extra Kicker, All Operating	-1680	-20
	Extra Kicker, Final Two Operating	-1390	-30
VESPER	0% Energy Spread	740	250
	1% Energy Spread	740	250
	5% Energy Spread	740	250

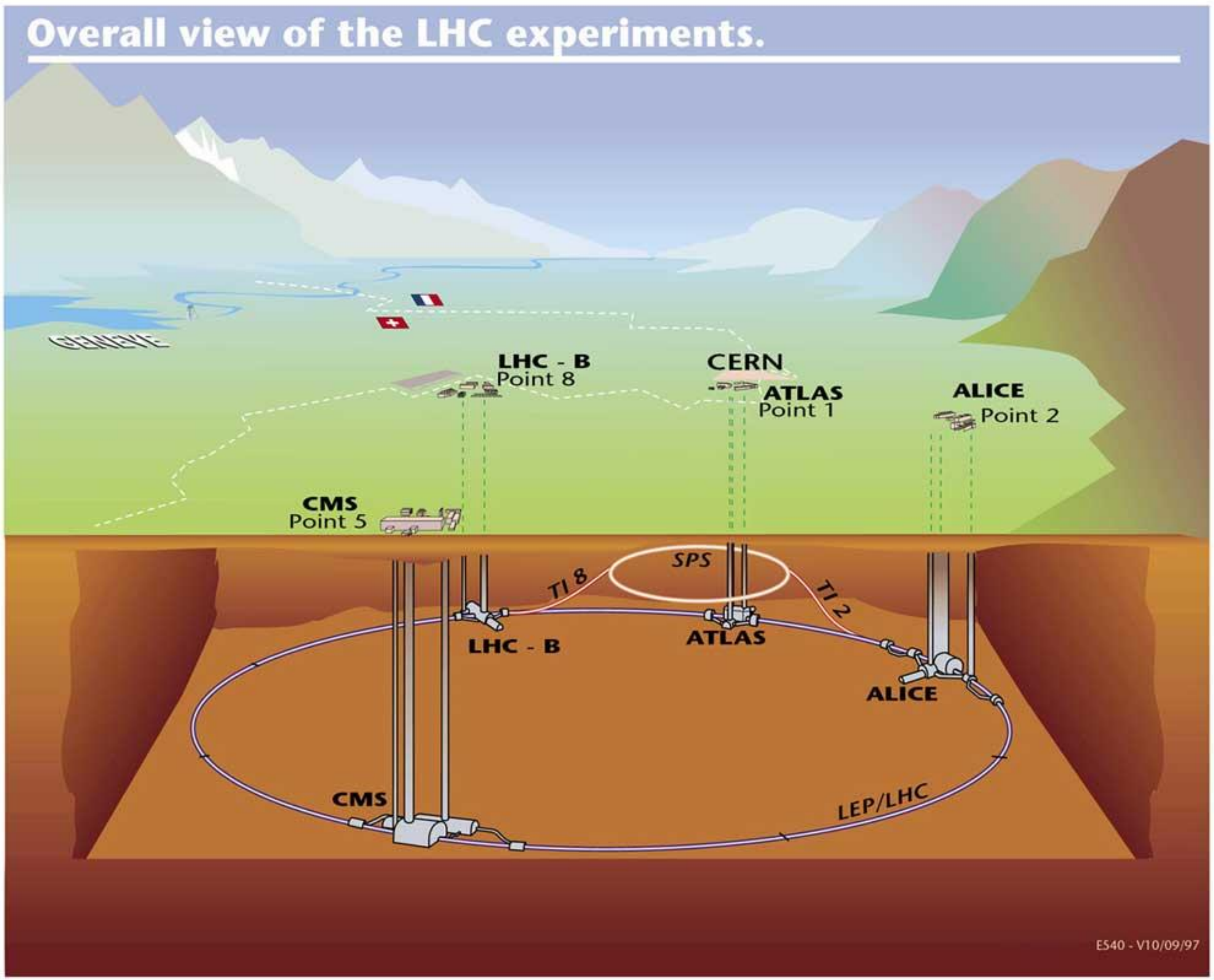
Conclusion

- Greatest convergence is:
  3060μm to 100μm in x
  190μm to 100μm in y
  (Placing an extra quadrupole after the CA.BHB0900 dipole at the end of STLINE section)

- Desired convergence:
  50000μm to <1000μm in x
  10000μm to <1000μm in y

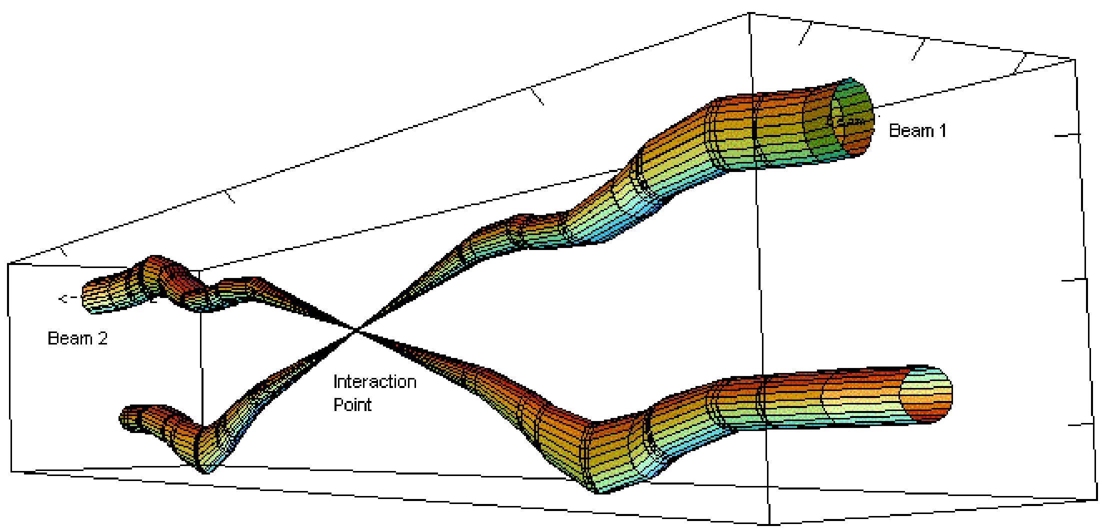
  Perhaps the CLEAR facility is still useful for the experiment…

Ground Vibration Effects on the beam dynamics of the LHC and HL-LHC



Closed Orbit Separation

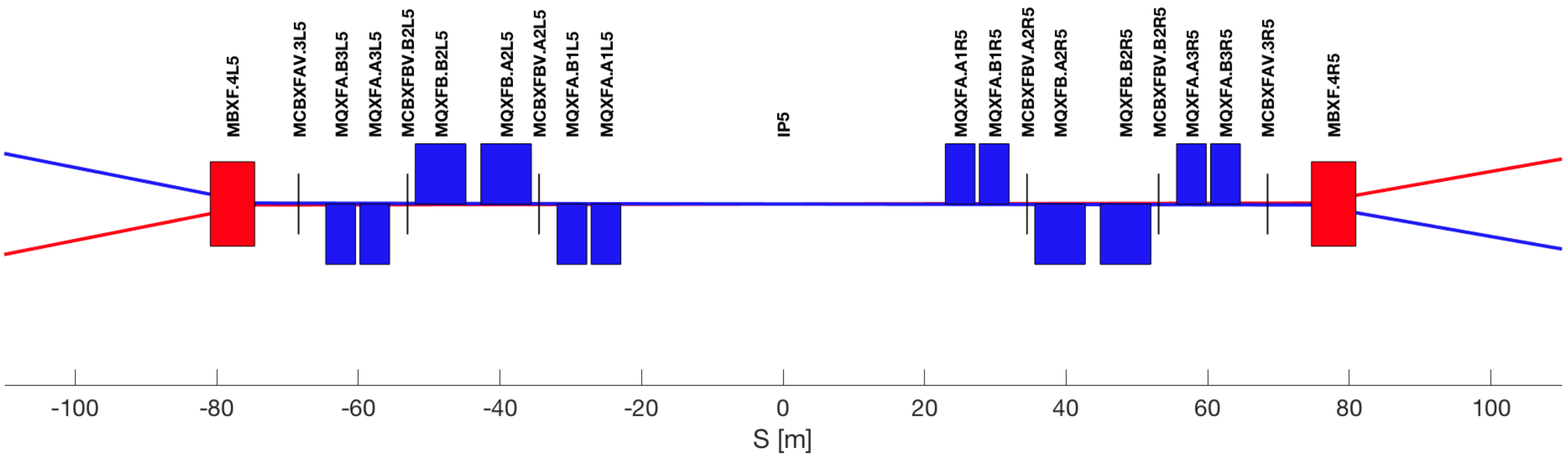
- The closed-orbit separation is the distance of the beams from the ideal interaction point. This can affect luminosity of the accelerator
- Particularly important for High Luminosity LHC



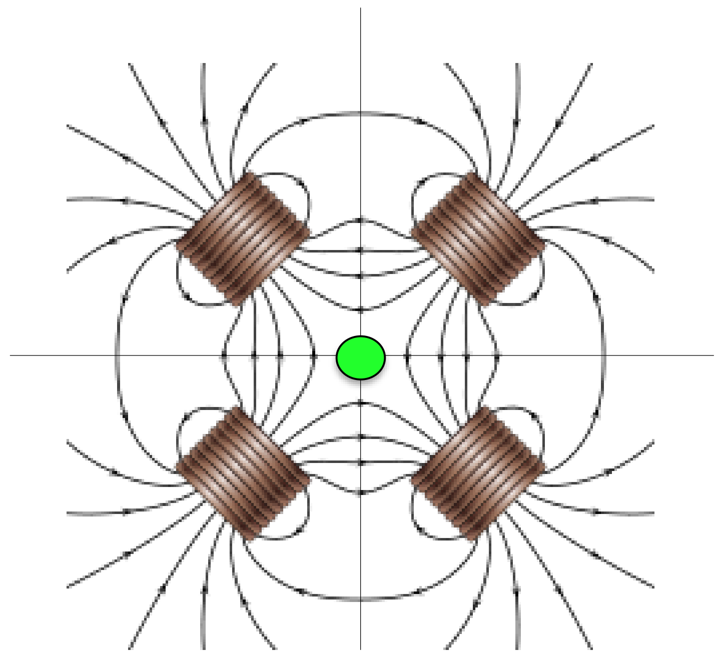
Relative beam sizes around IP1 (Atlas) in collision

Initial work

- MAD used to calculate closed orbit perturbation but it is slow
  For a reasonable computation time, only offset the quadrupoles that comprise the triplets in LHC. This is only 32 of the 844 quadrupoles that comprise LHC.
  Need to validate this assumption that triplets are dominant
- Example of triplets at IP5:



Effect of a quadrupole vibrating

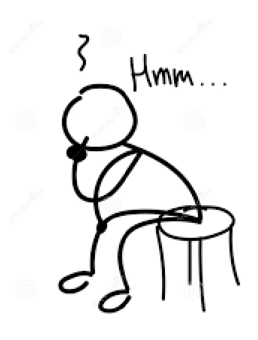


$$\Delta x_s = k_0 \sqrt{\beta_s \beta_0} \frac{cos(\mu_{0s} - \pi Q_x)}{2sin(\pi Q_x)}, \tag{1}$$

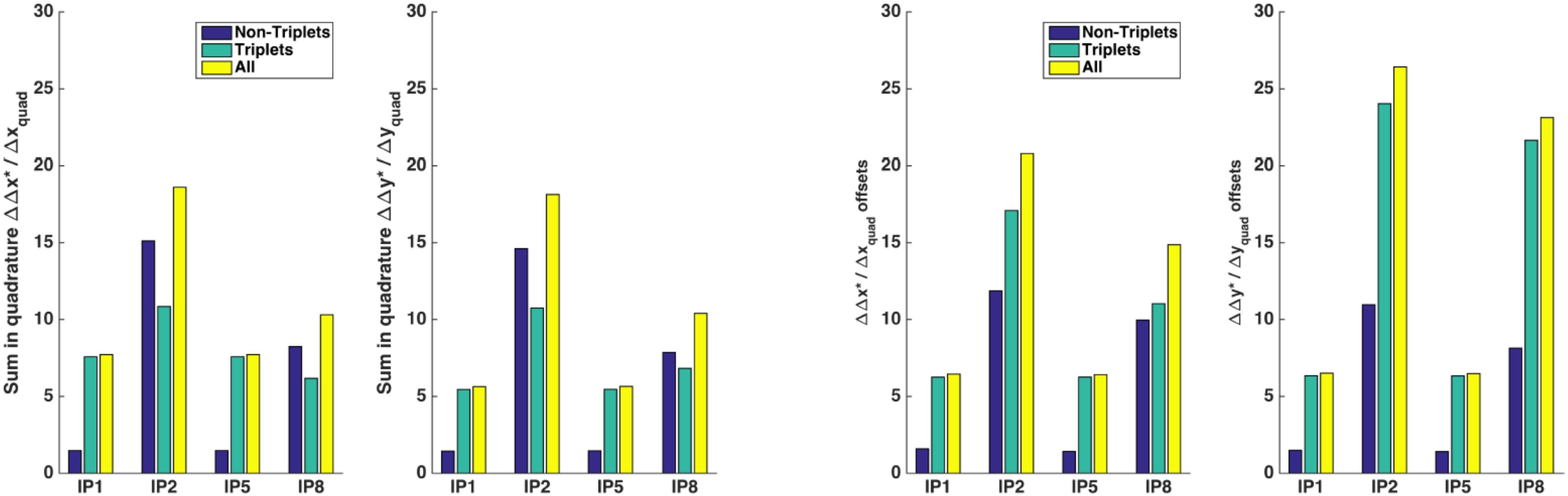
where Δx_s is the orbit variation, k is the kick amplitude of the quadrupole, Q is the tune of the accelerator, β is the beta-function and μ_{0s} is the difference in phase advance between s, the position of interest, and 0, the position of the offset quadrupole.

What do we do with this equation?

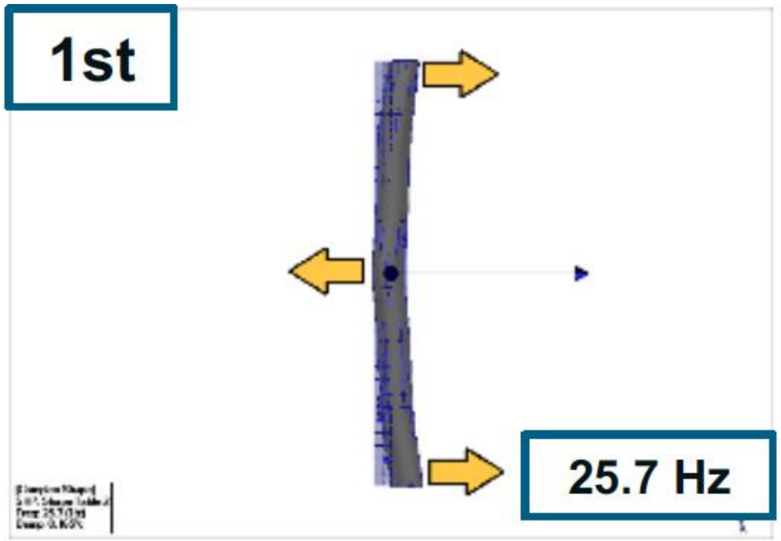
- For loop in MATLAB running over all quadrupoles
- With each run of for loop, offset a quadrupole and calculate the orbit perturbation this causes at the 4 IPs (for both beams). Store numbers in a matrix
- Take the difference between the two beams and normalise by dividing by quadrupole offset – dimensionless amplification factor obtained
- Sum in quadrature the results for the different quadrupoles

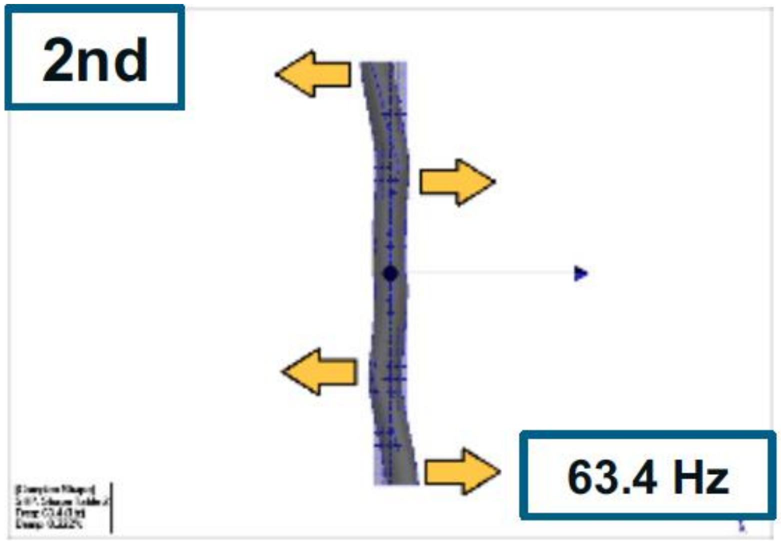


Results – are the triplets dominant?

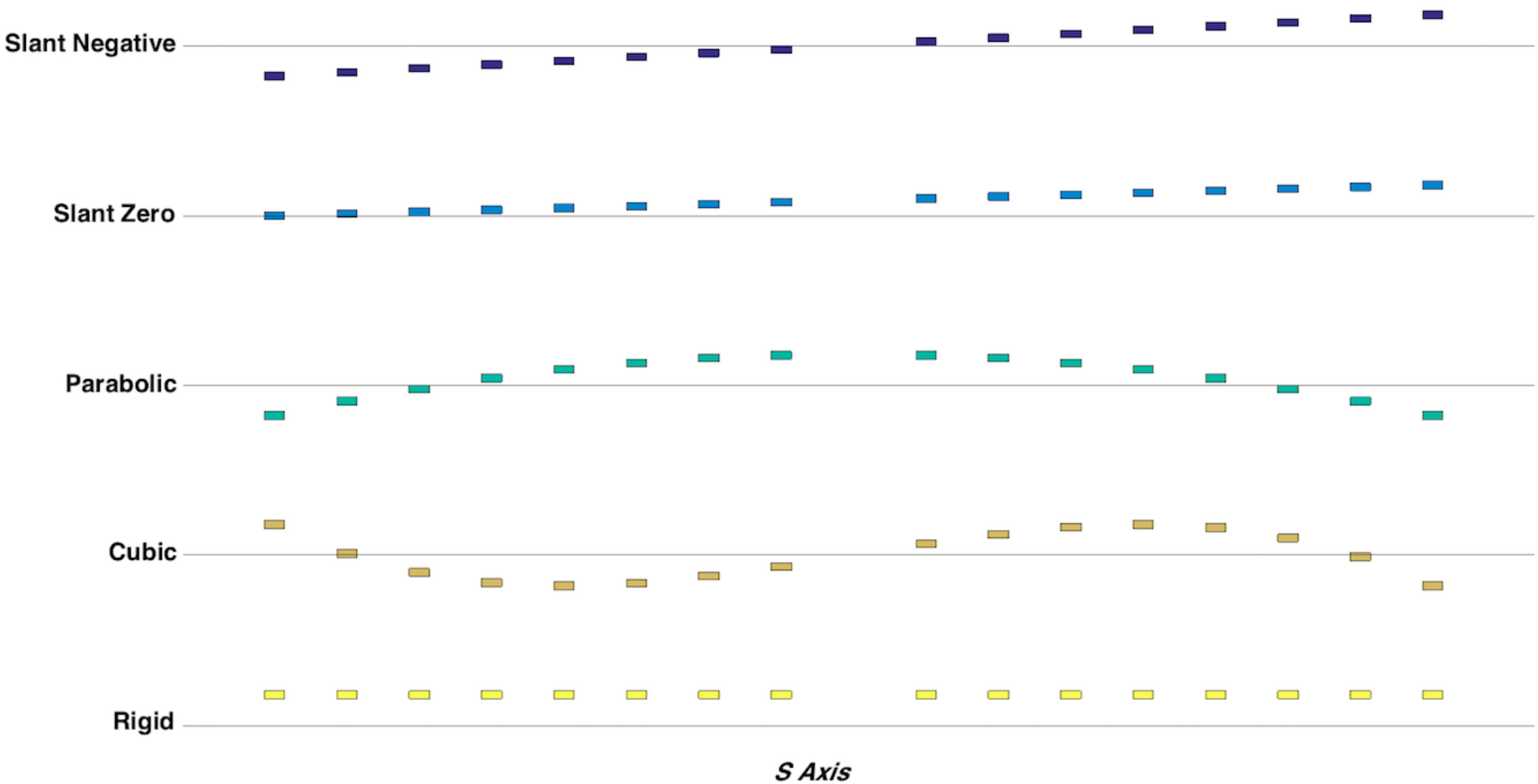


Triplets Vibrate in Modes



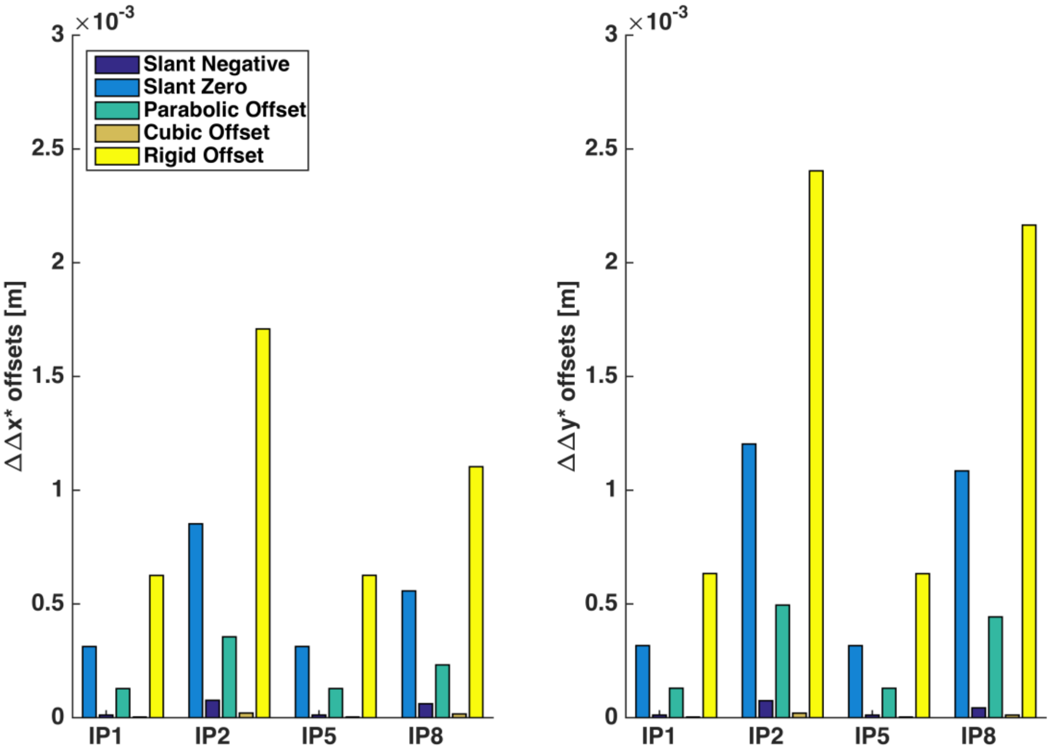


Simulated triplet modes



Results of vibration in different modes

- 0.1mm maximum offset of the quadrupole
- Lower order oscillations that with large antisymmetry over the central axis have dominant effect

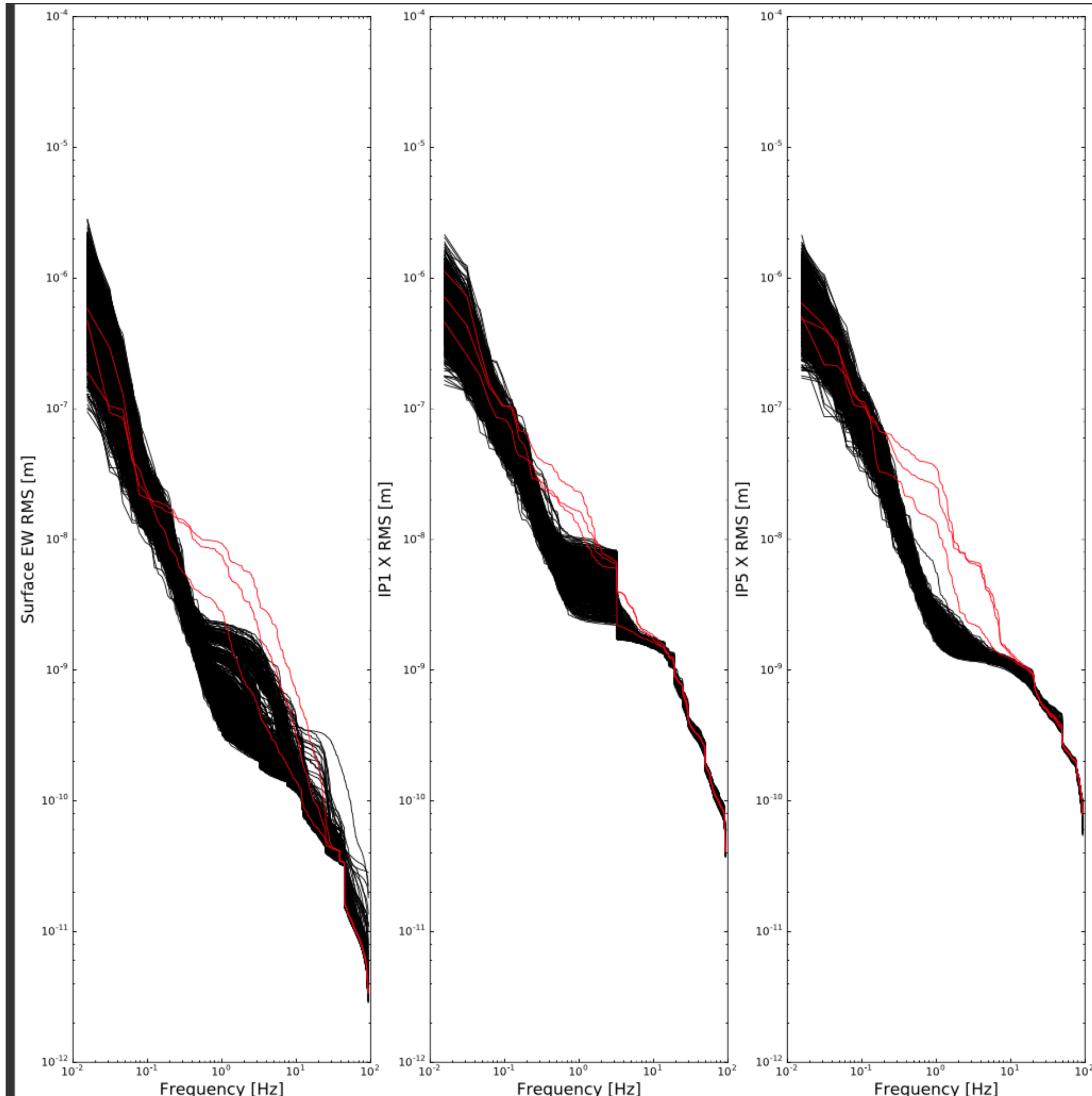


Vibration effects on measured beam parameters

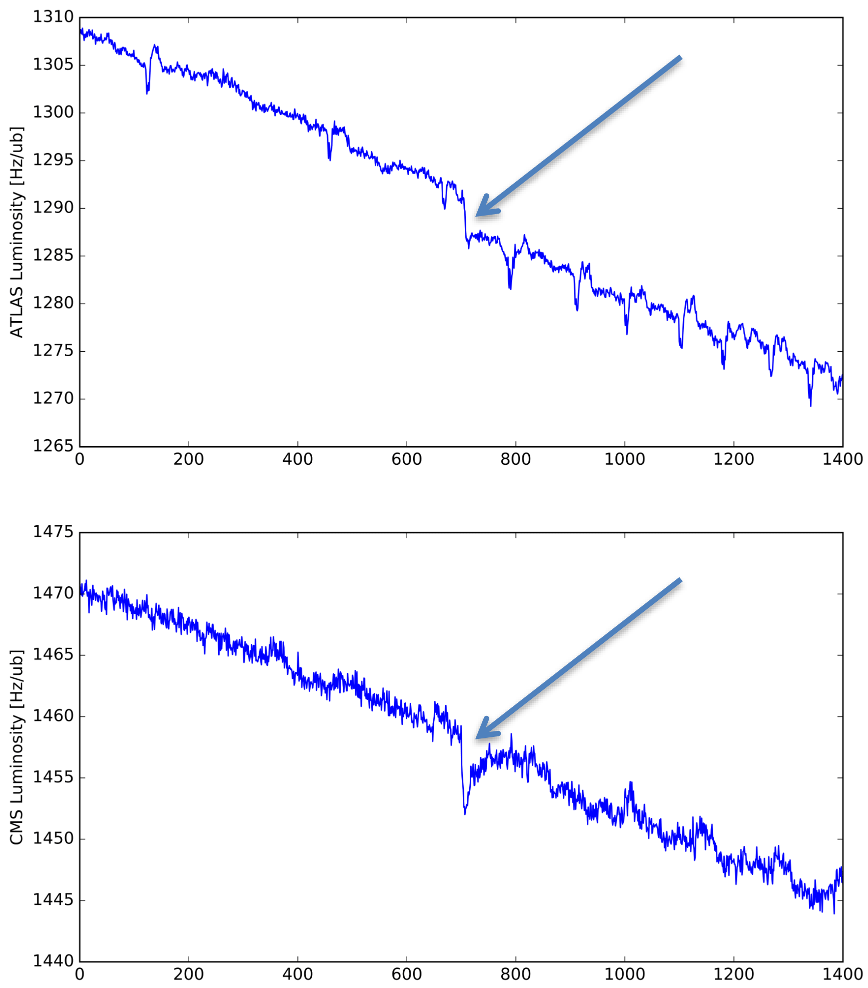
- Three vibration sensors recently installed:

- on the surface
- underground near IP1
- underground near IP5

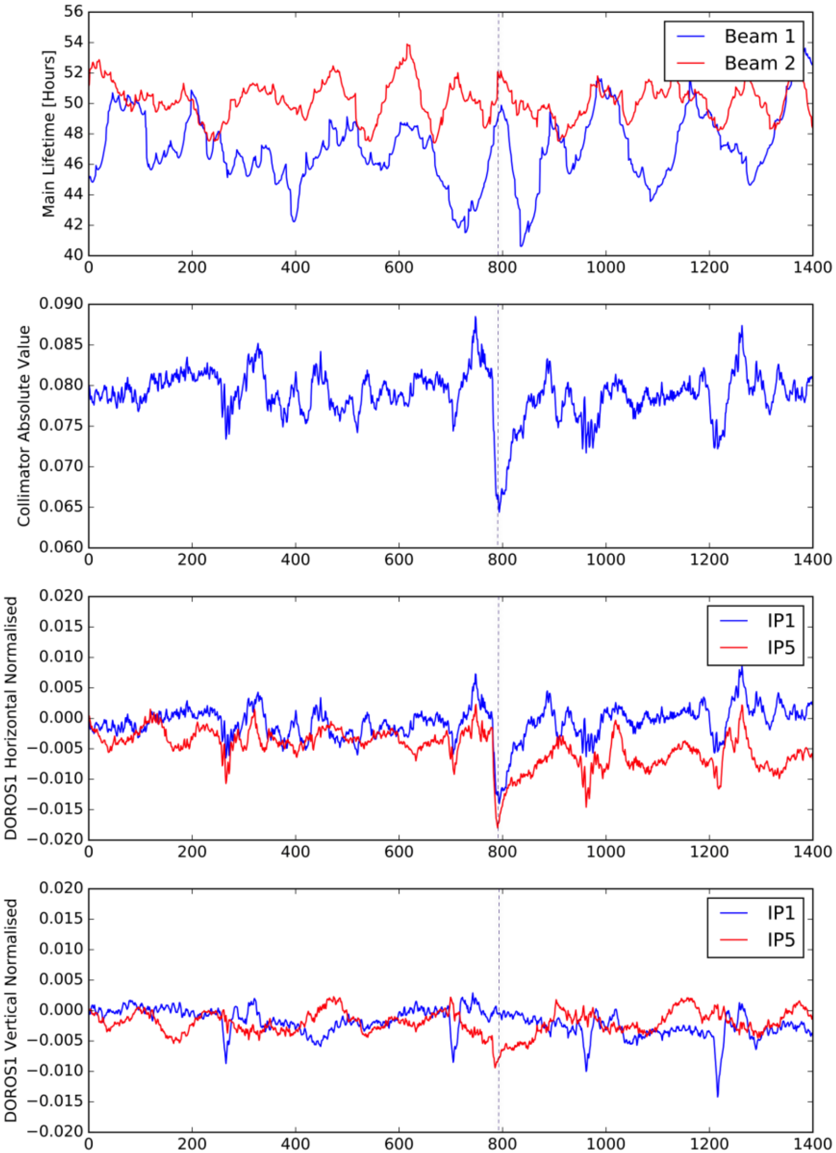
- Can pick up large vibration effects, e.g. earthquakes



Effect on Luminosity



Effect on some other measurements

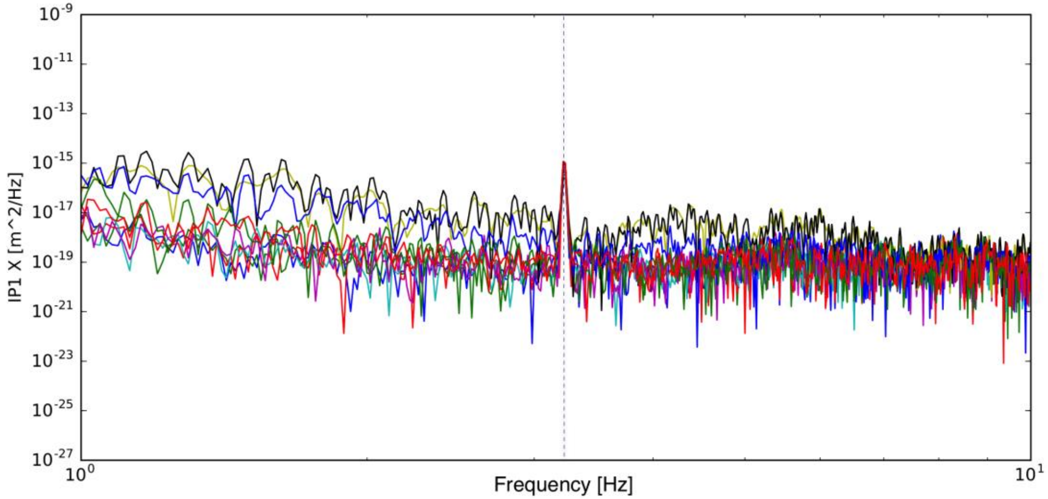


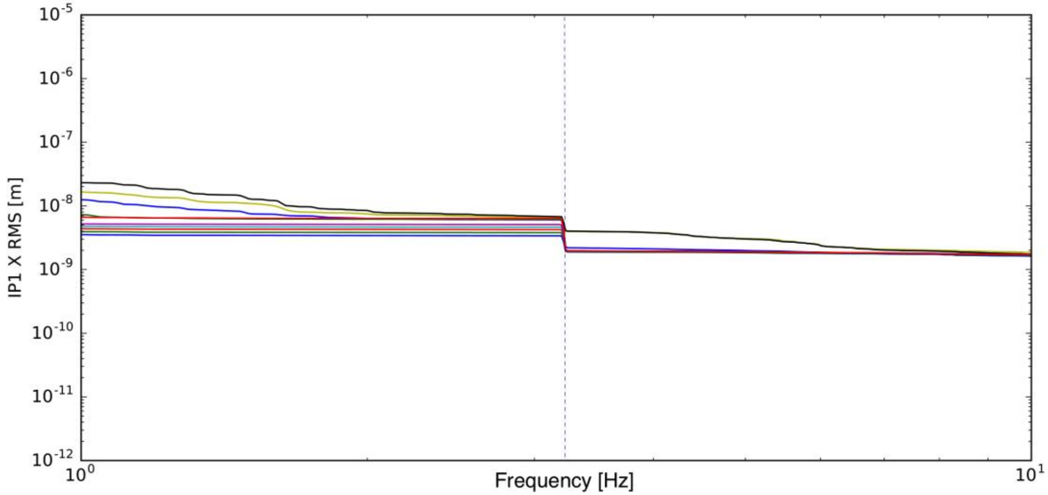
Conclusion and Future Work

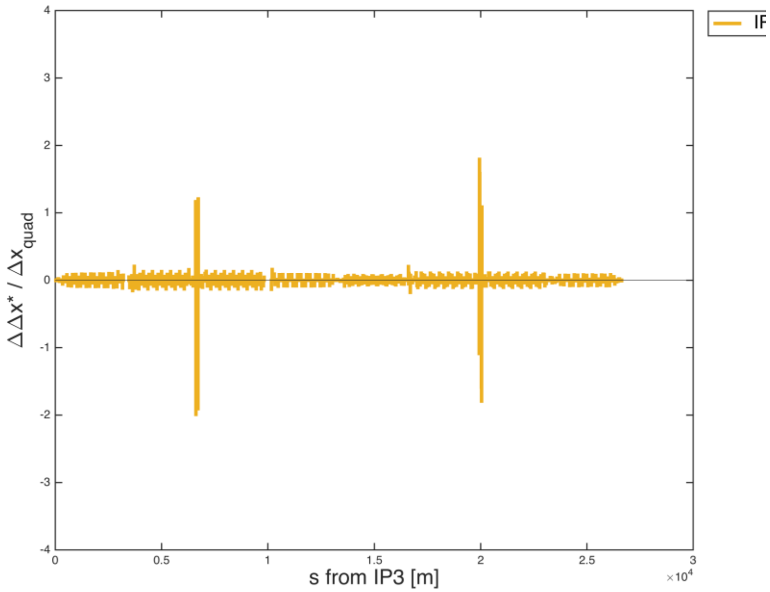
- Triplets have dominant effect on closed orbit separation at IPs 1 & 5
- Possible to see earthquakes. Try to see and determine effect of larger earthquakes
- Transfer function between source of ground motion and triplet cold mass is known – convolve with vibration sensor data to determine vibration offset caused

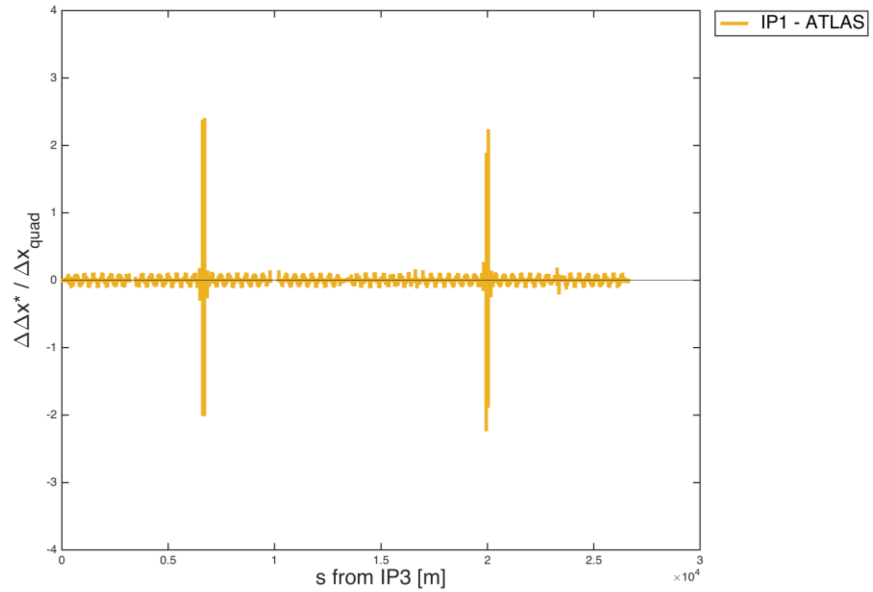
Any questions… Thanks

Back up slides



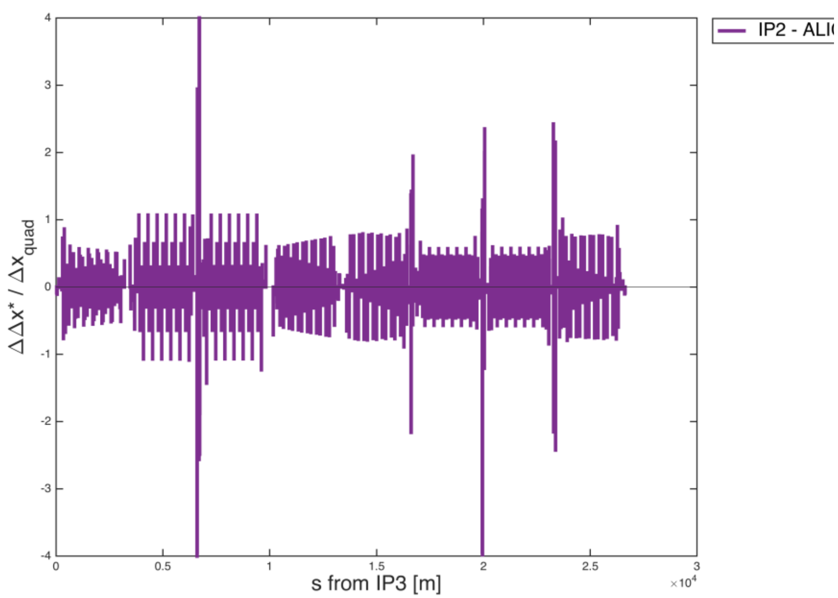


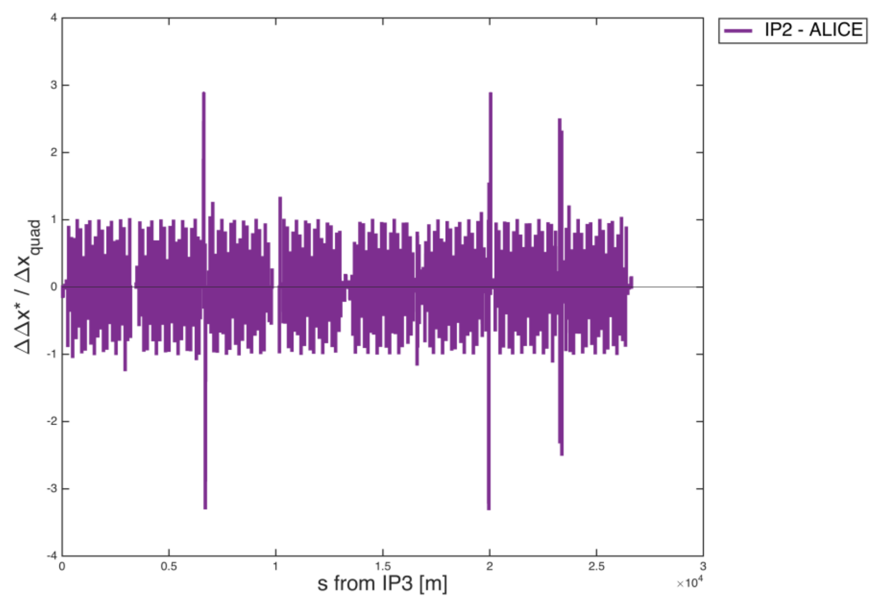

IF
ΔΔx* / Δxquad
s from IP3 [m]
×10^4

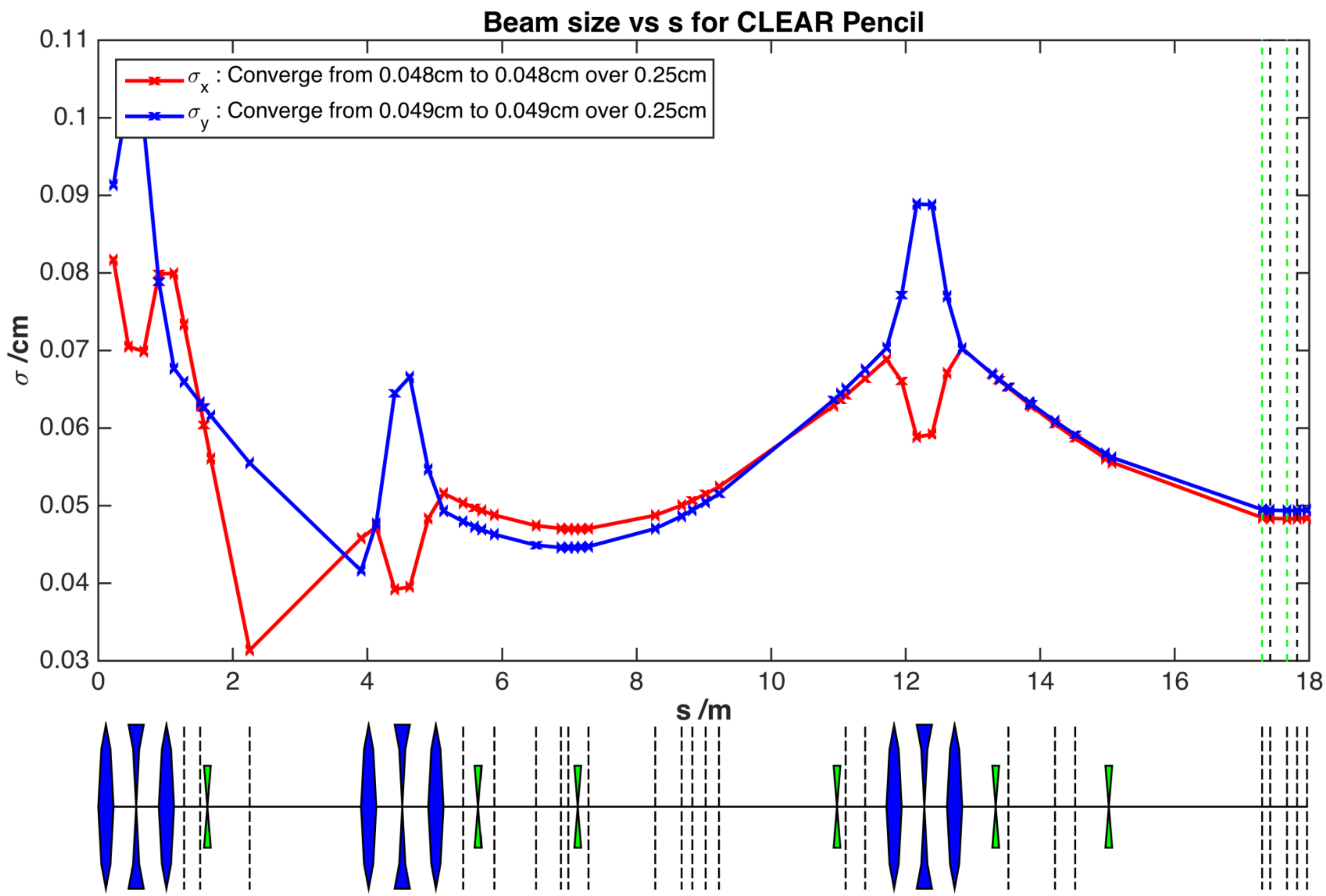

IP1 - ATLAS
ΔΔx* / Δxquad
s from IP3 [m]
×10^4

HL-LHC

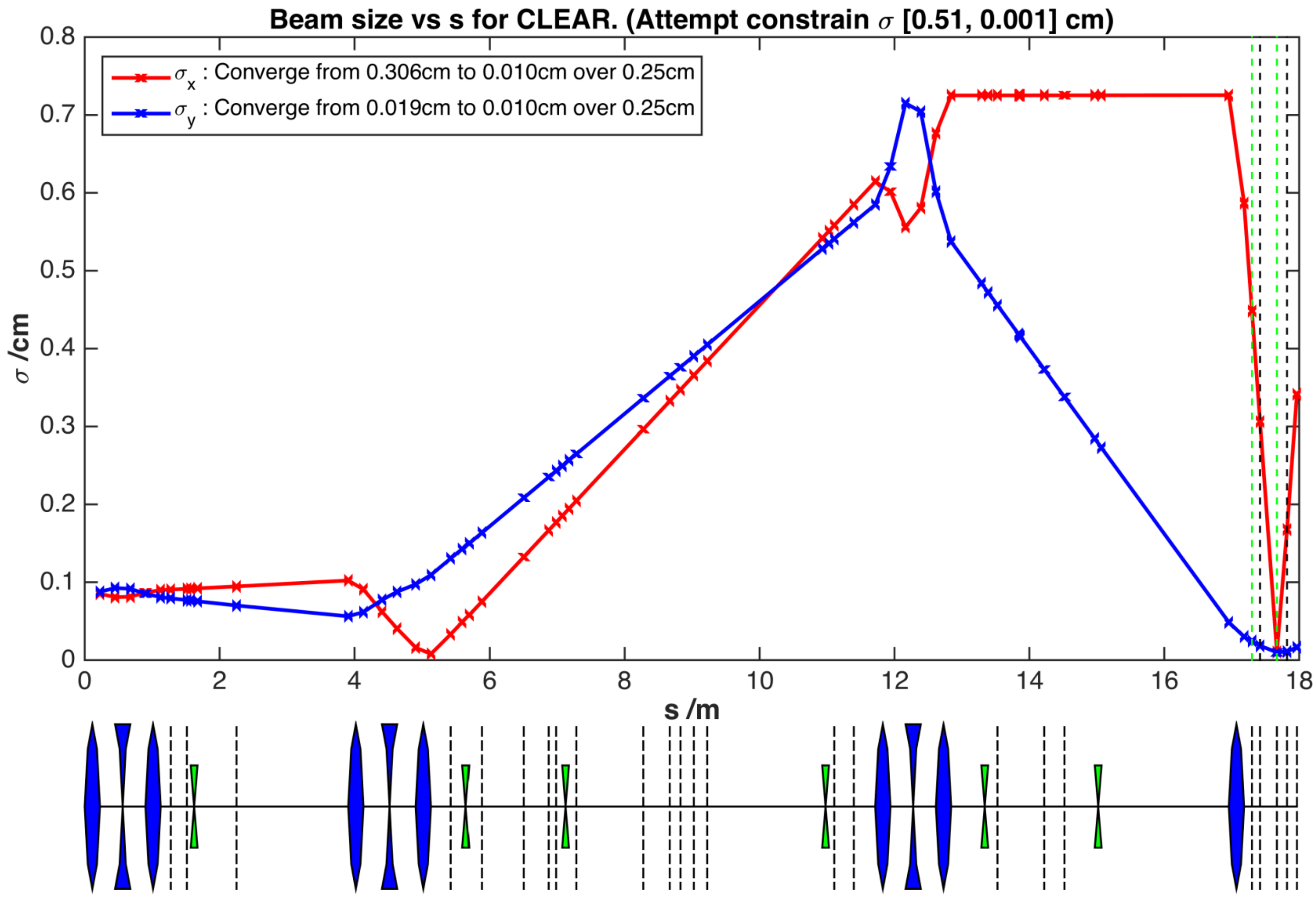
LHC


IP2 - ALI
ΔΔx* / Δxquad
s from IP3 [m]
×10^4

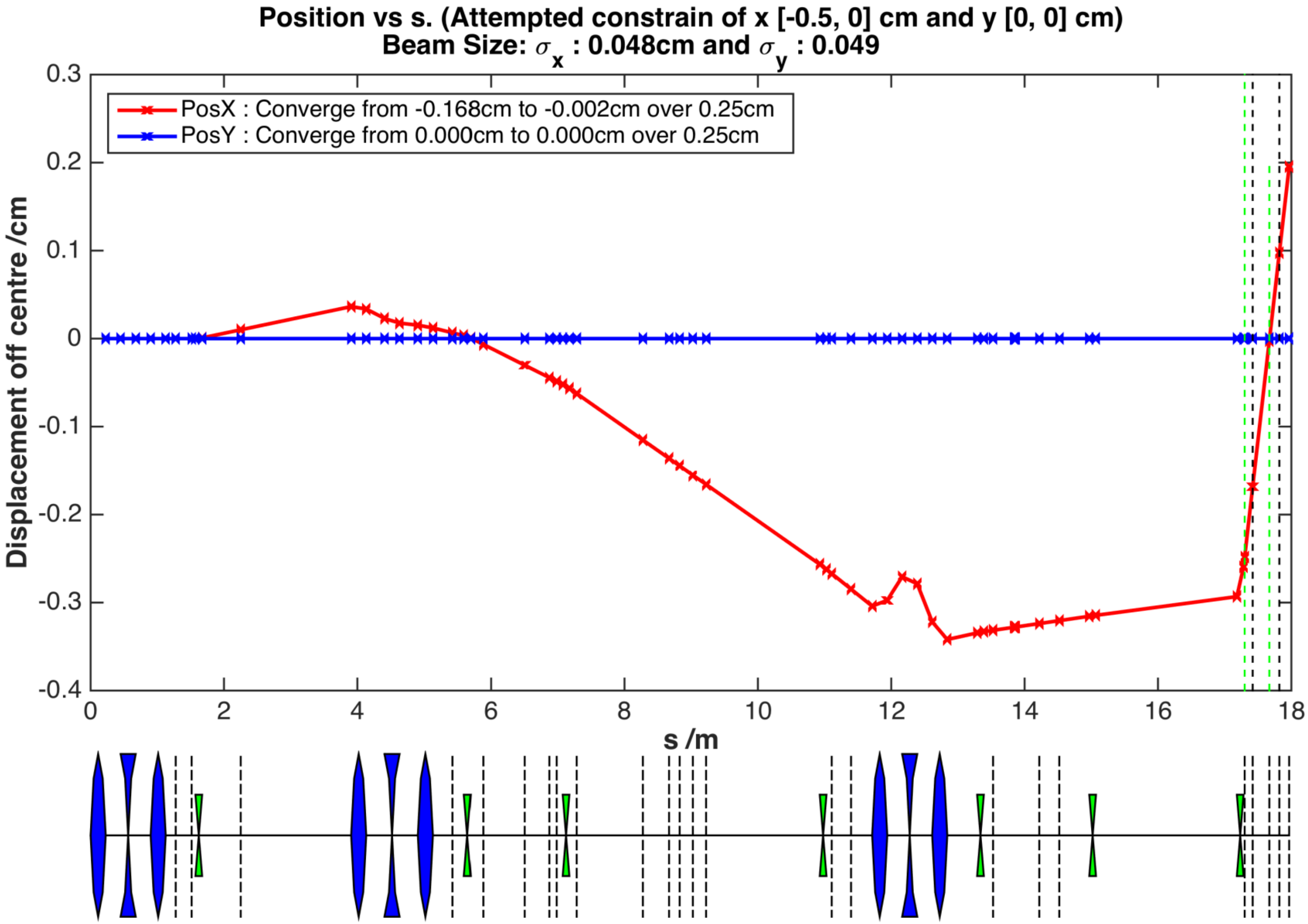

IP2 - ALICE
ΔΔx* / Δxquad
s from IP3 [m]
×10^4



Beam size vs s for CLEAR Pencil
σx : Converge from 0.048cm to 0.048cm over 0.25cm
σy : Converge from 0.049cm to 0.049cm over 0.25cm
σ /cm
s /m
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0
2
4
6
8
10
12
14
16
18



Beam size vs s for CLEAR. (Attempt constrain σ [0.51, 0.001] cm)
σx : Converge from 0.306cm to 0.010cm over 0.25cm
σy : Converge from 0.019cm to 0.010cm over 0.25cm
σ /cm
s /m
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
4
6
8
10
12
14
16
18

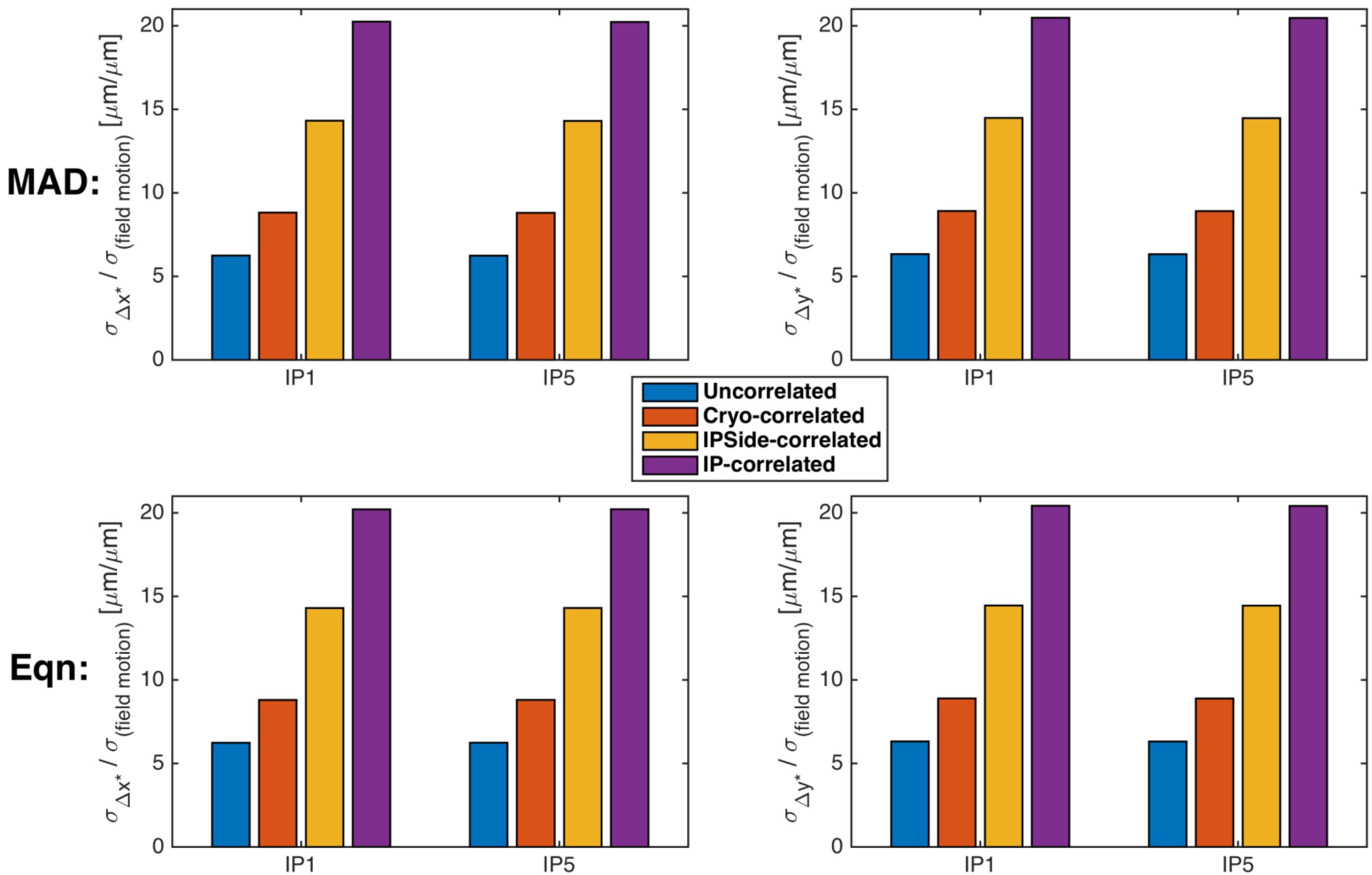


Position vs s. (Attempted constrain of x [-0.5, 0] cm and y [0, 0] cm)
Beam Size: σ_x : 0.048cm and σ_y : 0.049
PosX : Converge from -0.168cm to -0.002cm over 0.25cm
PosY : Converge from 0.000cm to 0.000cm over 0.25cm
Displacement off centre /cm
s /m
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
2
4
6
8
10
12
14
16
18

Back Up Slides

test this, a single quadrupole (MQXFA.A3L5) in the HL-LHC sequence is displaced by 0.1mm in the x-direction. The resulting perturbation in the orbits of both beams can then be calculated at all 13356 positions in the HL-LHC MAD sequence. The root mean square (RMS) value is then calculated for the orbit variation at all these positions. The difference between the beams is also taken and an RMS value calculated. Comparing the MAD calculation to the analytic equation modelled in MATLAB, it is found that there is a 7.90% discrepancy for the unsliced, thick sequence and a 0.425% discrepancy for the thin sequence, with each triplet sliced into 16 pieces and all other quadrupoles into 4.

Back up slides



Back up slides

		Horizontal			Vertical		
		Non-Triplets	Triplets	Total	Non-Triplets	Triplets	Total
IP1	LHC	1.48	7.58	7.72	1.44	5.50	5.64
	HL-LHC	1.59	6.25	6.45	1.50	6.34	6.51
IP5	LHC	1.48	7.58	7.72	1.46	5.46	5.65
	HL-LHC	1.42	6.26	6.42	1.41	6.33	6.49

		Horizontal				
		Slant Negative	Slant Zero	Parabolic	Cubic	Rigid
IP1	Individual	0.16	3.13	1.28	0.03	6.25
	Pairs Combined	0.19	3.65	1.90	0.08	7.29
IP5	Individual	0.12	3.13	1.28	0.03	6.26
	Pairs Combined	0.19	3.65	1.90	0.08	7.29

		Vertical				
		Slant Negative	Slant Zero	Parabolic	Cubic	Rigid
IP1	Individual	0.16	3.17	1.30	0.03	6.34
	Pairs Combined	0.19	3.69	1.92	0.08	7.37
IP5	Individual	0.15	3.17	1.30	0.03	6.33
	Pairs Combined	0.19	3.68	1.92	0.08	7.36

$$\sigma_x = \sqrt{\int_{-\infty}^{+\infty} \Phi_{xx}(\omega) d\omega.} \qquad (2)$$

$$\sigma_x(\omega) = \sqrt{\int_{\omega}^{\infty} \Phi_{xx}(\omega) d\omega.} \qquad (3)$$

HL-LHC to describe

- Outline the issue. Vibration of quadrupoles affects the HL-LHC and LHC
- What are the most important quadrupoles? Is it the triplets?
- What about the different modes of oscillation?
- Study of real data
- Future work