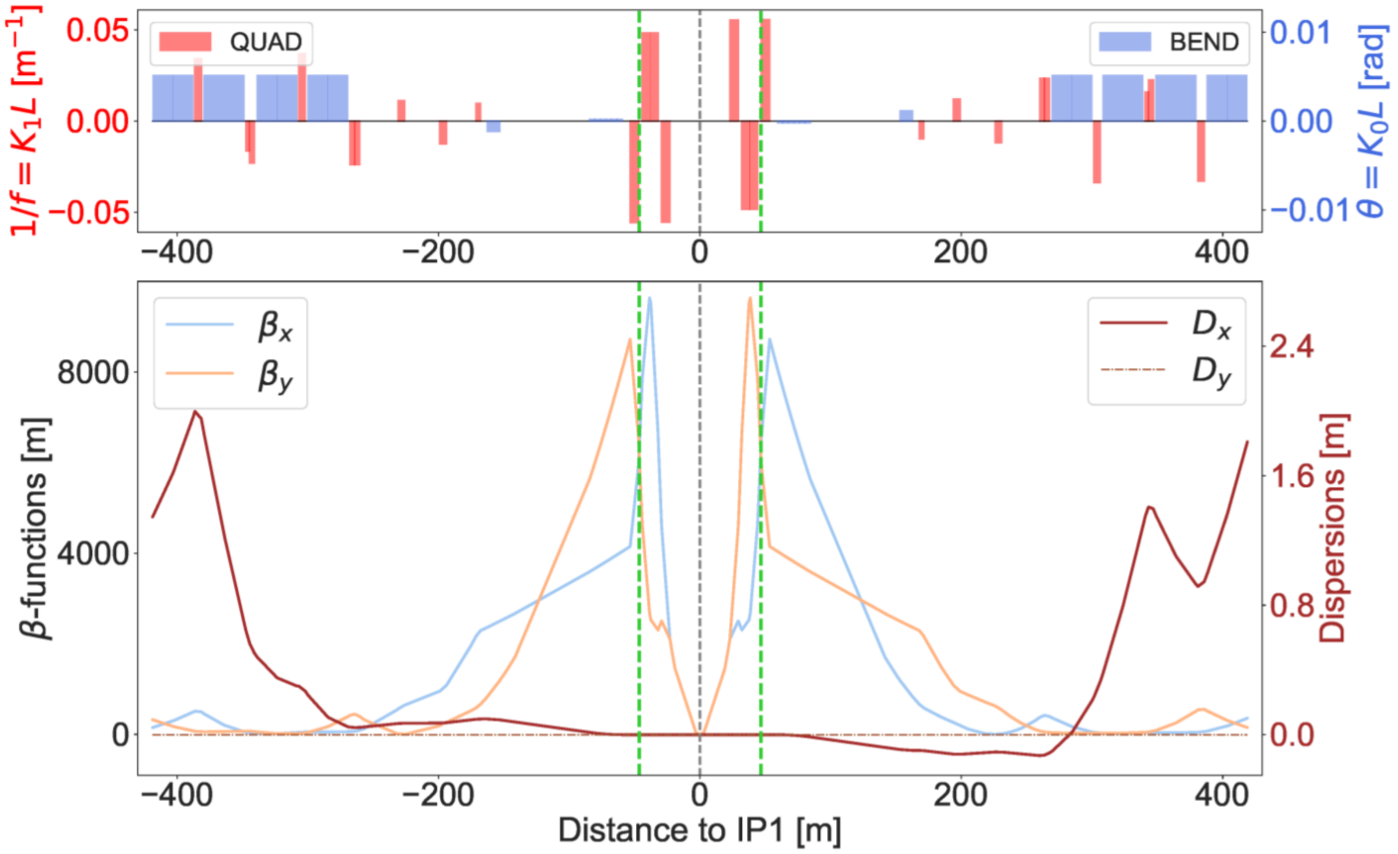
Failing MQSX

T. Persson

Many thanks to:

F. Soubelet, R. Tomas, R. de Maria, E.H Maclean

Layout



The two green lines here show where the MQSXs are located

F. Soubelet

It is predicted that the MQSX for IP1 and/or IP5 could fail in Run 3 due to radiation

IN SUMMARY: MCBX & MQSX

	with variable angle (with fixed angle)	+ 2025 (as 2023/2024)
CORRECTOR MAGNET	PEAK DOSE [MGy]	
	after 395 fb^{-1}	after 480 fb^{-1}
MCBX1 IR1	8.5 (8.5)	11 (11) / * 10.5 (10.5)
MCBX1 IR5	6	7.5
MCBX2 IR1	3.5 (3.5)	4 (4) / * 4 (4)
MCBX2 IR5	2	2.5
MQSX IR1	7.5 (7.5)	9 (9) / * 9 (9)
MQSX IR5	8 (8)	9.5 (9.5)
MCBX3 IR1	5 (5)	6 (6.5) / * 6 (6)
MCBX3 IR5	3	3.5

* assuming IR1 polarity inversion in the middle of 2025

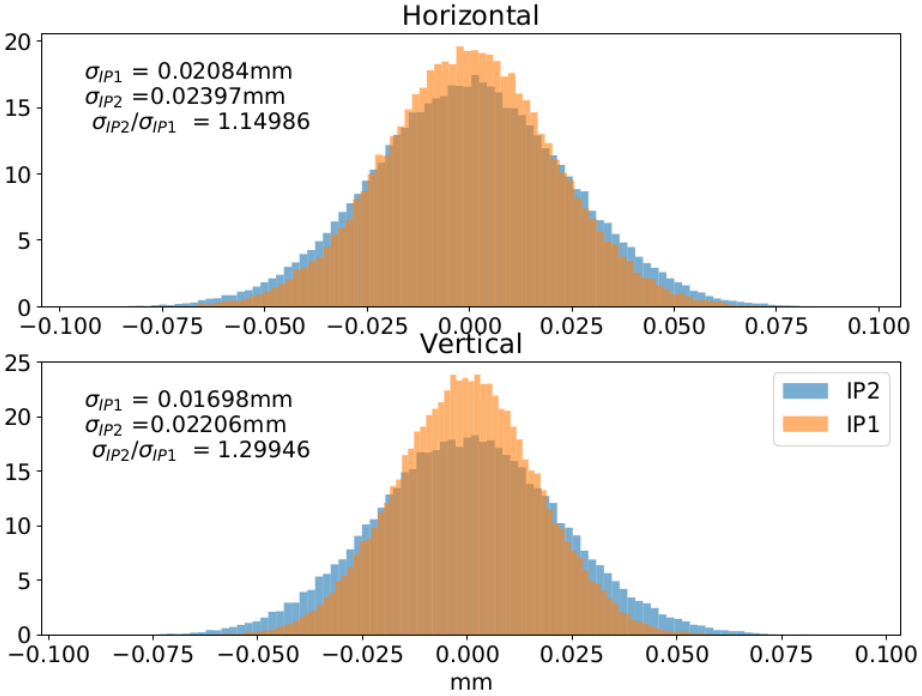
Francesco Cerutti

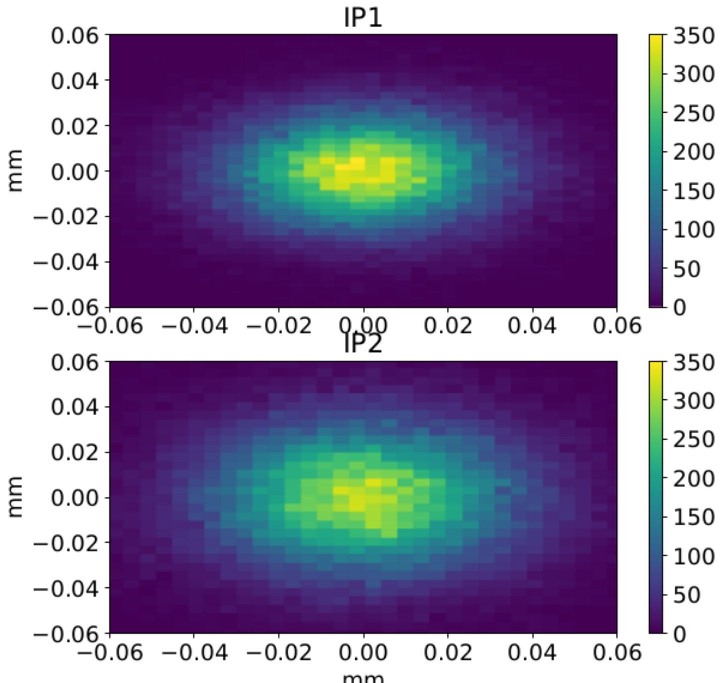
Introduction

- MQSXs at IR2 and IR8 are not expected to fail so they will be left out of this presentation
  - IR2 has the largest correction but on the other hand are they operating with larger β^* (50cm is the smallest so far)
- In this presentation focus is on single failure per IP
  - Unlikely that 2 will fail at the same time
  - In case one fail we study in more detail if another fail

What are the correction for?

- Two purposes:
  - Help control the global coupling which for small β* would be too large to correct with the global C- knobs
  - The beam size at the IP will increase





How strong are the corrections?

MQSX3.L1	$8.0*10^{-4}$
MQSX3.L5	$6.0*10^{-4}$
MQSX3.R1	$6.0*10^{-4}$
MQSX3.R5	$6.0*10^{-4}$

← RQSX3.L1 was at $1.1*10^{-3}$ in run 2

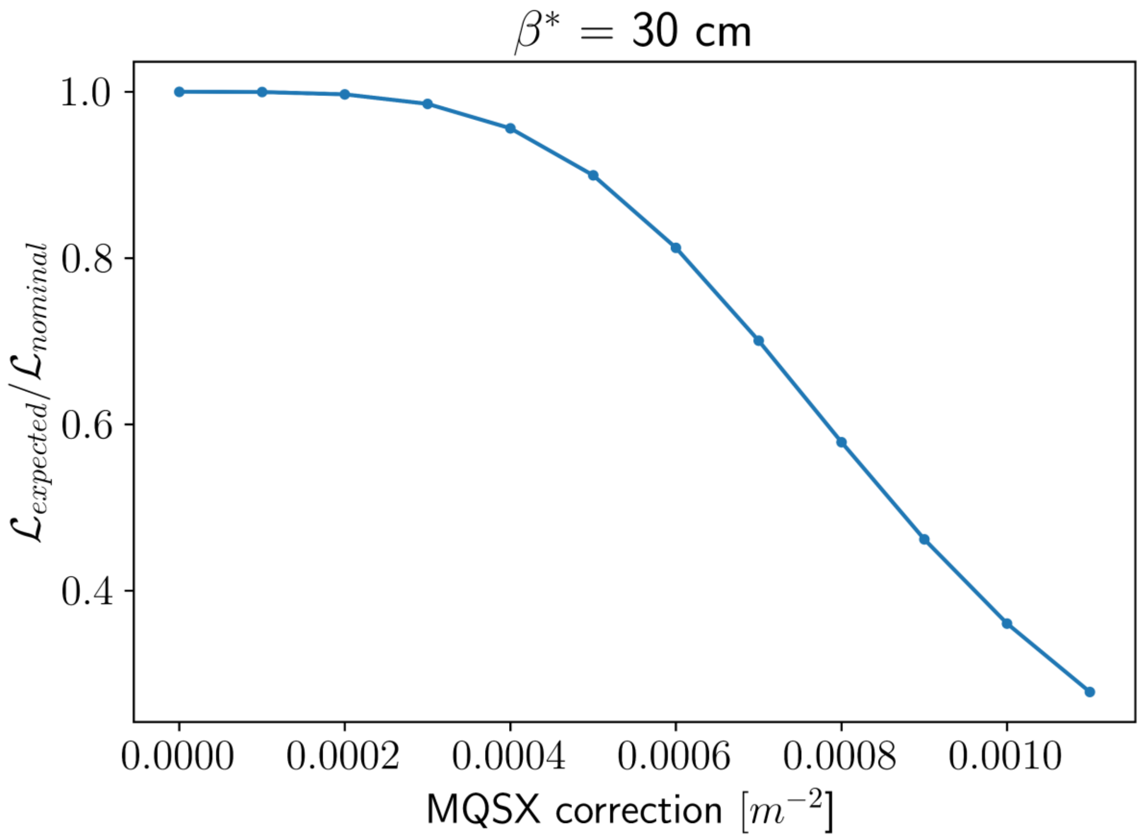
This is what we measured during the beam-test. This is slightly lower than Run 2 but might be less precise since it was evaluated at injection. The final values will be measured in 2022 commissioning.

Impact on global coupling

- At β*= 30 cm -> $\sqrt{\beta_x\beta_y}$ at the MQSX around 5000m -> length around 0.2m -> so if powered at 10^{-3} |C-|=1
  - Follow up here to check that they actually are interlocked..
- The phase advance between the right and left enables the possibility to move the correction to the other MQSX
  - Almost transparent to the global coupling
  - We have enough margin to do this for all the mqsx (we are using less than 50% of the maximum)

Impact on beam size

This is what we expect in luminosity loss if we correct with the “wrong” MQSX

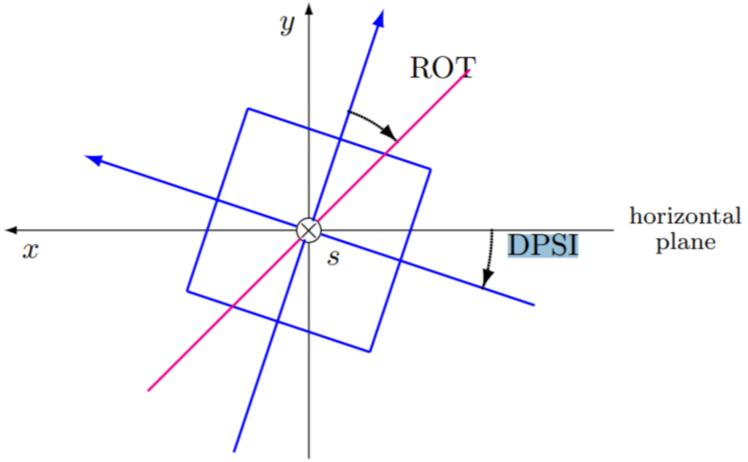


What can we consider as mitigation?

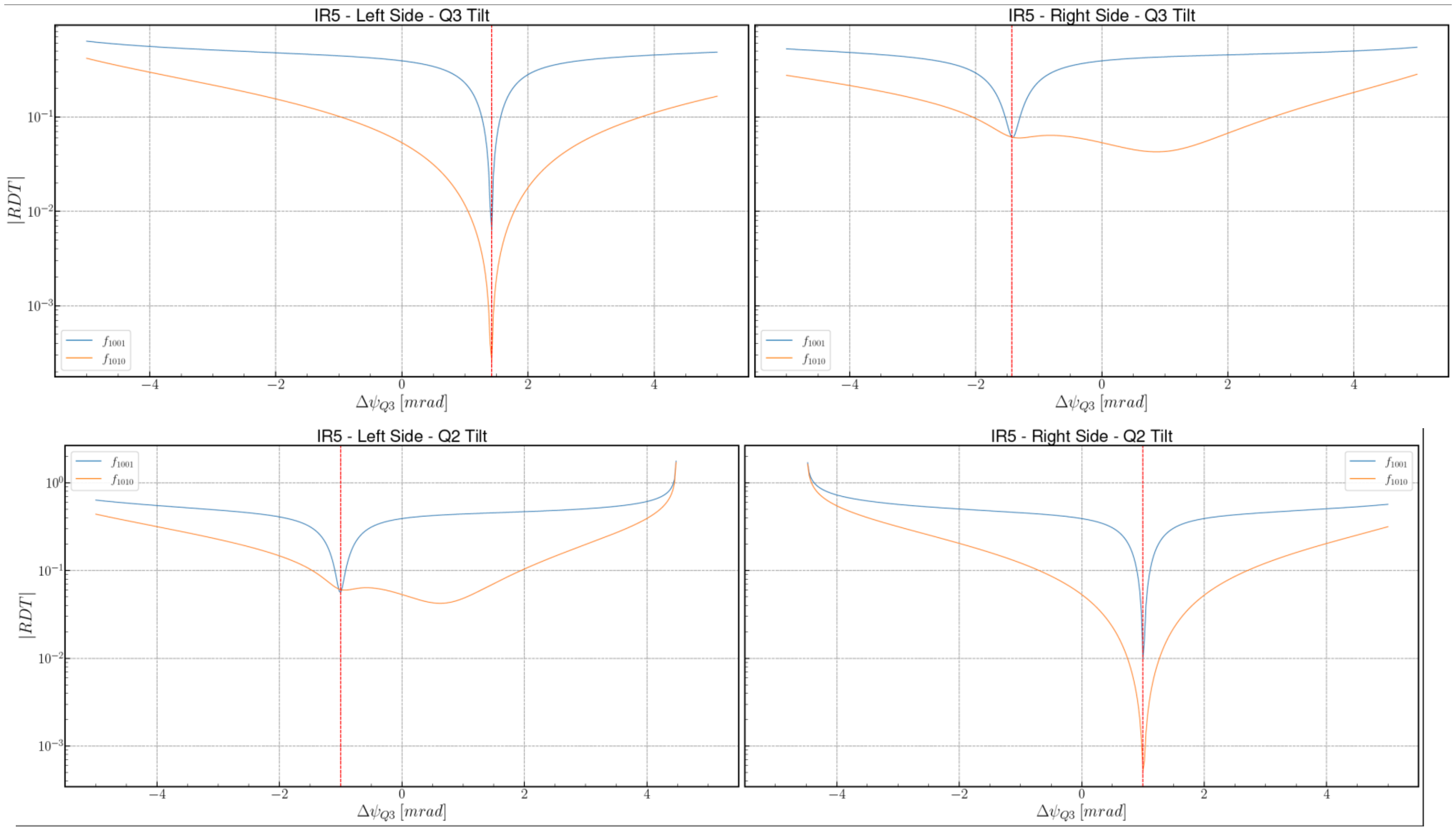
1. Tilting the Q2 and/or Q3s
2. Install a warm skew quadrupole
3. Using the MCSSX and MCSX?
4. If we can’t fight it maybe we can learn to live with the local coupling?

Tilting (rotation around the Z-axis)

- If we want to completely replace the MQSX of **$6*10^{-4}$** :
  - Tilting Q3s with 1.2 mrad would work (note opposite sign for right/left)
  - Tilting Q2s with 0.9 mrad (opposite sign to Q3)
  - Any linear combination of the two



From the simulations



Note that this simulation was for $7*10^{-4}$

F. Soubelet

Consistent with analytical estimates

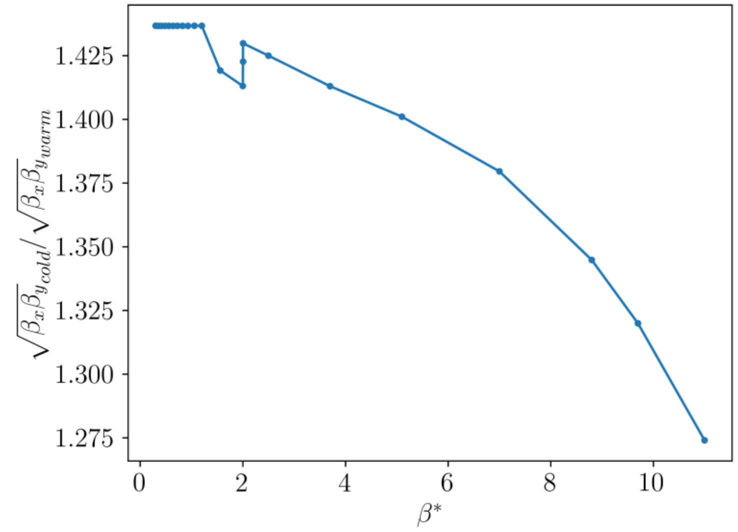
Tilting is considered risky and difficult

- We had a meeting with the responsible for the equipment and two main issues were identified **:
  - Induces mechanical stress since the bellows are not designed for torsion
  - Difficult to achieve the desired tilt
- Only safe way would be to detach the bellows, rotate and then re-attach

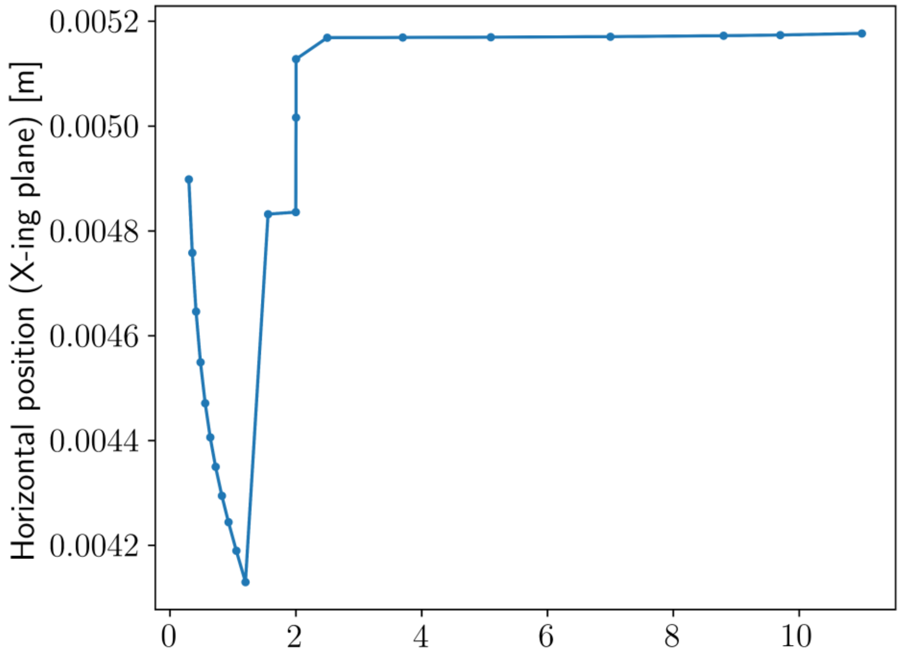
**Meeting to discuss the possibility to tilt the Q3 and/or Q2 on the 13th of December 2021. Invited to the meeting: Helene Mainaud Duran, Jorg Wenninger, Rogelio Tomas, Sandrine Le Naour, Delio Duarte Ramos, Cedric Garion, Felix Soubelet, Matteo Solfaroli Camillocci, Tobias Persson, Vincent Baglin

Installing a warm magnet

- There is some space between the TAN and D1
  - The closer to D1 the larger the $\sqrt{\beta_x \beta_y}$ gets
  - Place in the vicinity of D1 in the simulation
- The ratio between warm-cold skew quadrupole is rather constant and the effect could be cancelled by adjusting strength or the arc skew quadrupoles



Horisontal position as a function of β* in the magnet



- This is with the crossing angles that were in the optics files on the afs repository
- It does **not** include any crossing angle levelling

What strength do we need?

- Say we want to correct equivalent of 10^{-3} in mqsx cold
- Assume that we make it 2.3 m so 10 times longer
  - $\sqrt{\beta_x \beta_y}$ is a factor 1.42 smaller at the warm
  - K1 = 1.4 * 10^{-4} -> 3.3 T/m
- Vincent said that an aperture for the magnet of around 300mm would be needed
  - -> ~1T peak
- Riccardo informed me that D1 aperture is ~ 60mm
- Clearly more to be done to optimize the aperture etc
  - But before that I think there are another avenues to explore

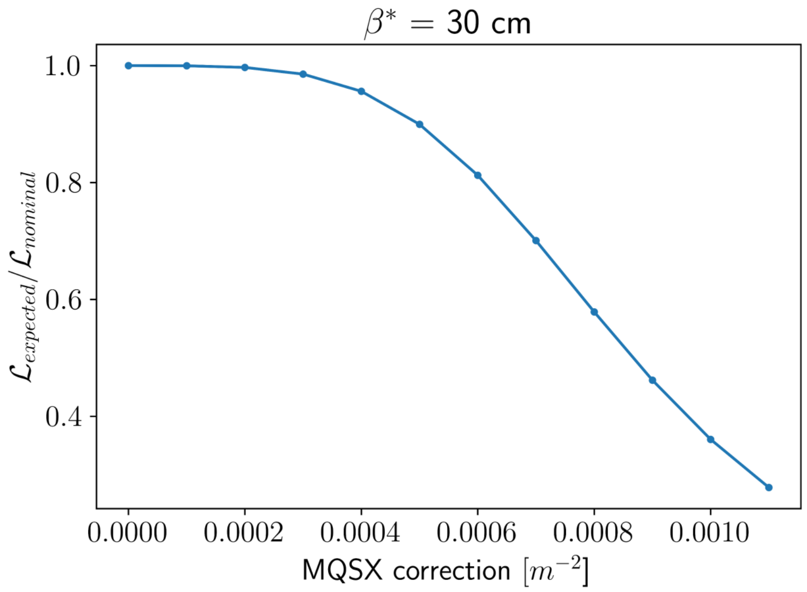
What about feed-down from the sextupoles in the IR?

- There is an orbit in the MCSSX and MCSX but just powering them up to the maximum and calculating the feed-down to skew quadruples gives a maximum of ~ 10^{-4} in equivalent MQSX strength

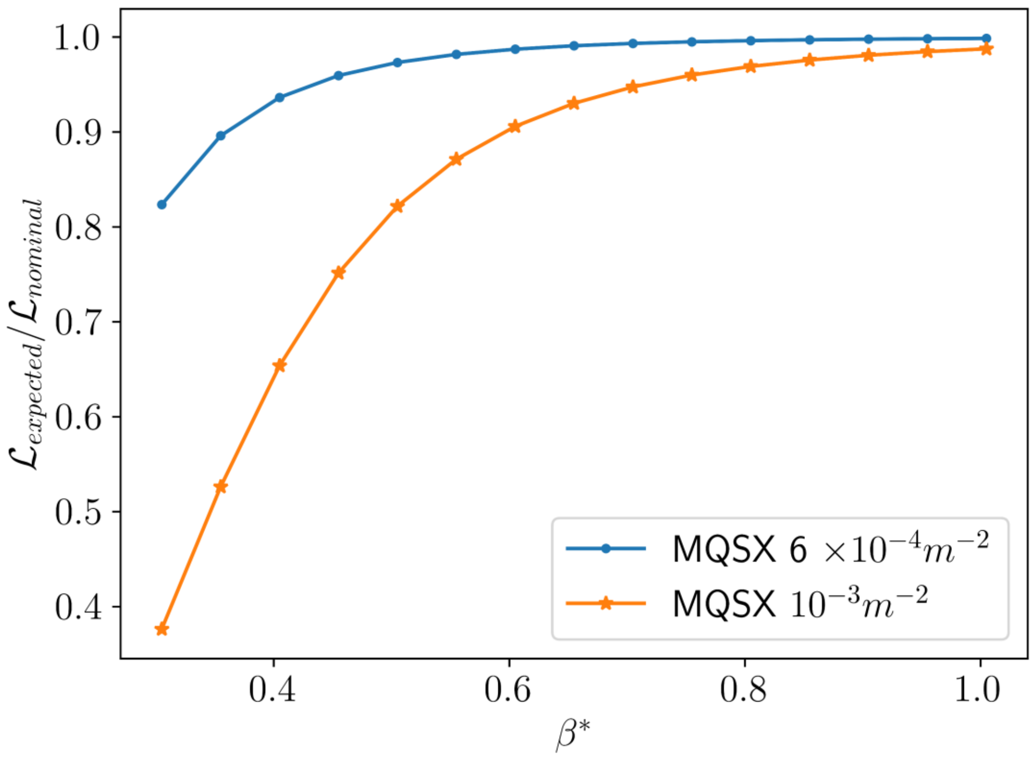
  -> We can exclude using them to compensate for the missing MQSX

Maybe we can consider a different approach?

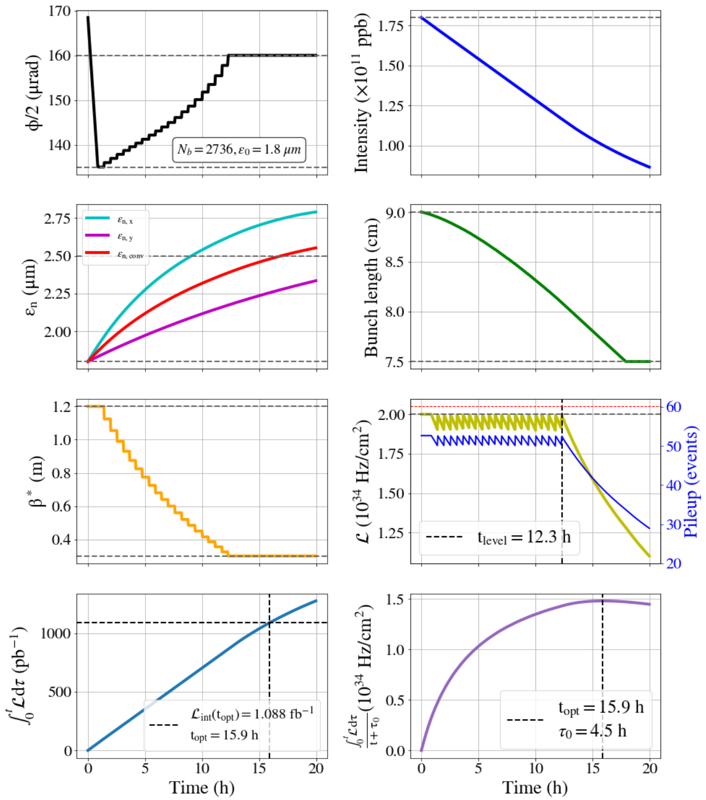
- 3 out of 4 of the MQSX risk of failure only need to be powered to $6*10^{-4}$. What is the impact on luminosity?
- The 4th one might only need $8*10^{-4}$ but can also be 10^{-3}



Impact of $\beta*$



Significant time in collision is planned to be from 1.2m-0.40m

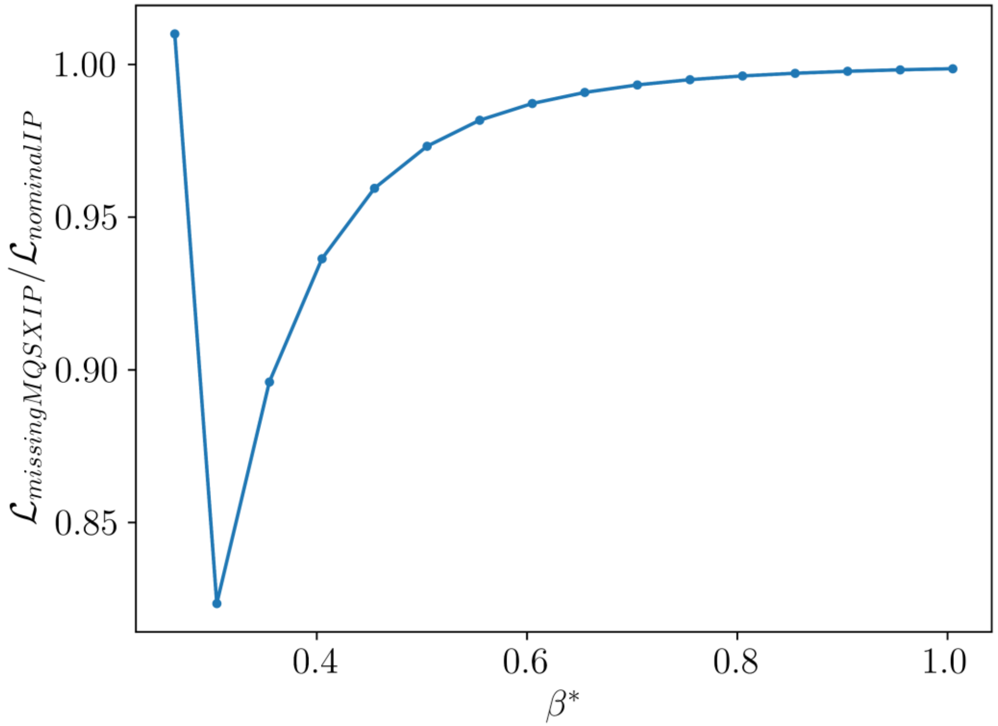


S. Kostoglou and S. Fartoukh

How can we use this?

- One could of course try to set up a complete new squeeze where the IP of interest is squeezed slightly more meaning that the beam-size is the same between the two
  - Would need to redo the commissioning so very time consuming
- Alternatively, one accepts that it is slightly less in a range but in the end one continues the squeeze slightly further and then recover the “missing luminosity”
  - This could also mean stopping the squeeze slightly earlier for the other IP
  - This should faster and more suited in case the problem appears in the end of the run

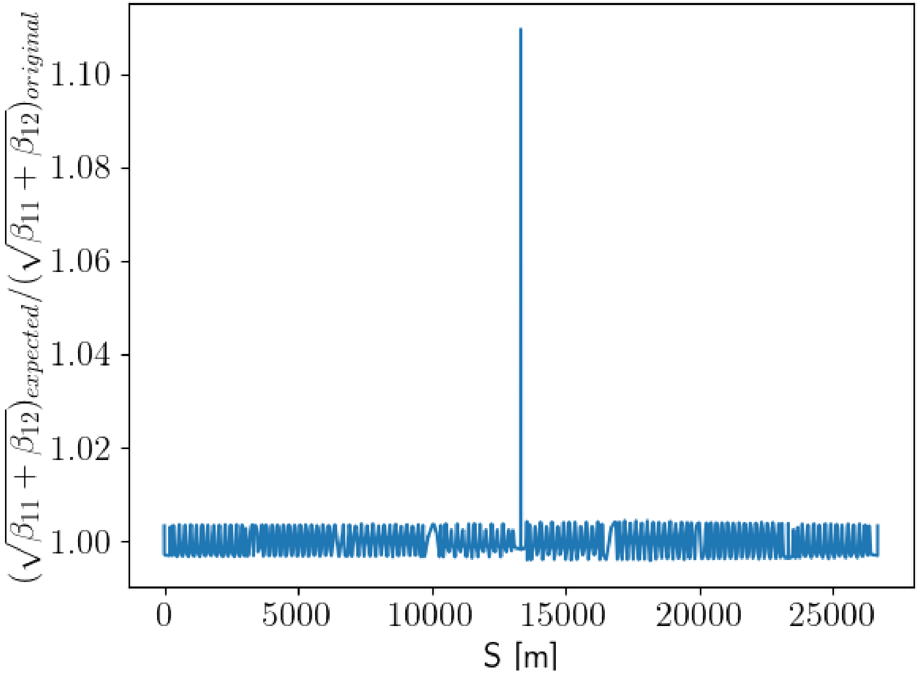
How could that look like?

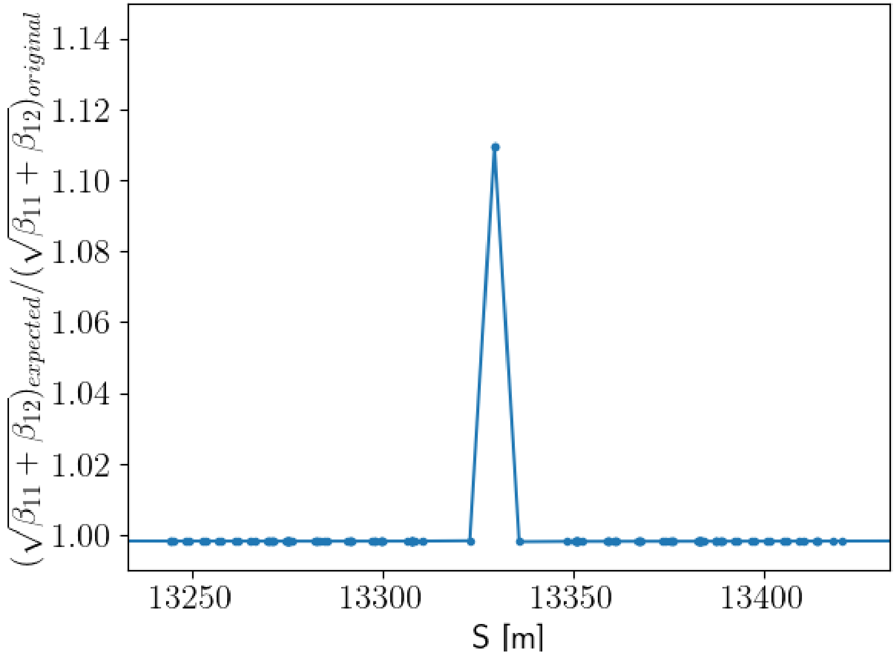


In the last point we have then only continued the squeeze to 25 cm
β^* is no longer directly related to the beam-size

What are the potential issues with this?

Beam size at other locations





$$\hat{\Sigma}_{11} \equiv \langle x^2 \rangle = \varepsilon_1 \beta_{1x} + \varepsilon_2 \beta_{2x} \,,$$

$$\hat{\Sigma}_{13} \equiv \langle xy \rangle = \hat{\Sigma}_{31} = \varepsilon_1 \sqrt{\beta_{1x}\beta_{1y}} \cos \nu_1 + \varepsilon_2 \sqrt{\beta_{2x}\beta_{2y}} \cos \nu_2 \,,$$

$$\tan(2\psi) = \frac{2\langle xy \rangle}{\langle x^2 \rangle - \langle y^2 \rangle}$$

Not the full story since there is also a potential tilt of the beam that should be studied

M. Hofer and R. Tomas, "Effect of local linear coupling on linear and nonlinear observables in circular accelerators"

V A Lebedev and S A Bogacz 2010 JINST 5 P10010

Beam-beam

- Had a discussion with Xavier and it needs to be evaluated in detail but no obvious show stoper since we are starting to collide already at large β*
- The main issue directly identified are with the witness bunches that could get unstable from long-range
  - Might need to give up on them in the sense that we would need them tohave them collide as well

Things that needs to be studied

- A more detailed study of the available aperture
  - Not possible to simulate directly in the MAD-X aperture module since coupling is not included
    - Could be extended to include the "design" coupling in MAD-X or by making some external adjustments
- Xavier kindly agreed to have a look at the beam-beam effect linked to instabilities
- Any issues for the non-linear corrections?
  - Naively I would assume that the ones that are optimized IR by IR, i.e. local should be fine but maybe the a4 which is compensating globally will struggle.

Idea for MD

1. Squeeze one IP to ~β^* = 27 cm while the other is at 30 cm **
2. Unblance the correction to a single MQSX
3. Measure optics and potentially correct global coupling
4. Dump and reinject 3 nominals
5. Go back to 27cm with the mqsx at nominal
6. Go to collision and measure the impact of unbalancing the MQSX correction
7. Measure the available aperture

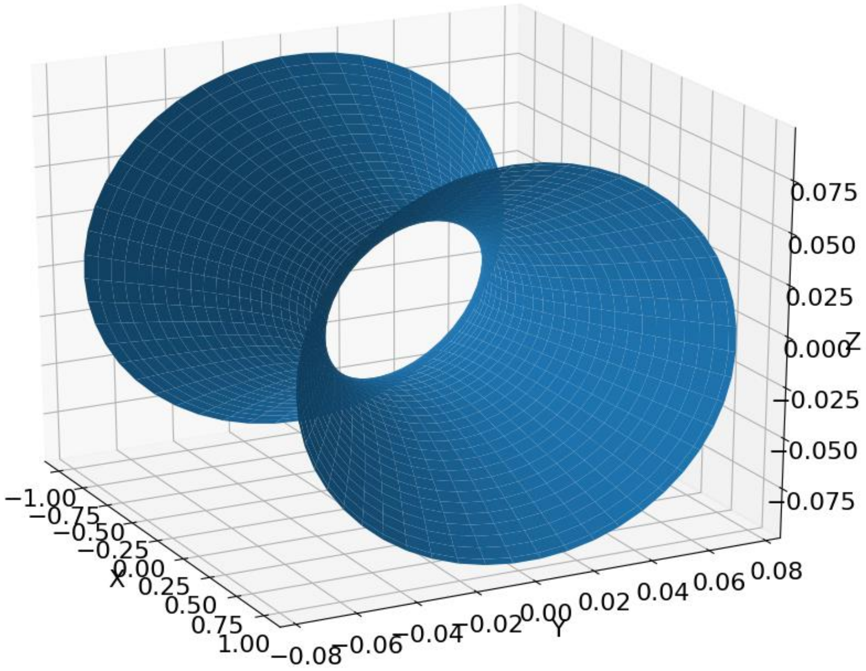
**Note that one could equally stop IP one at 35cm and continue to 30cm for the other IP

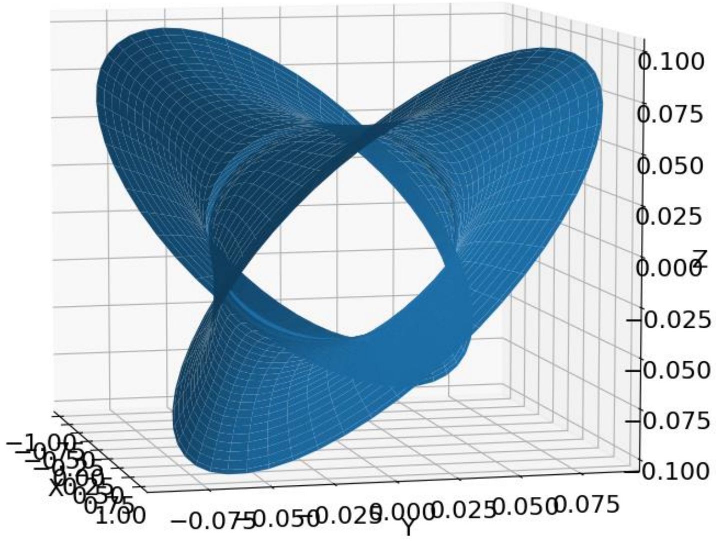
Conclusion

- For the MQSX at $6*10^{-4}$ a mitigation strategy based on compensating with the other MQSX could work
  - After the commissioning we will know the optimal MQSX corrections for Run 3
  - Additional studies needed
  - Could be tested in MD
- We could again try to reiterate and see if ~0.5 mrad could be acceptable as a tilt to partially compensate in case the strong MQSX fails
  - If not then one could anyway use the same approach as for the weak but limit operation to beta* =50-60 cm.
    - An assessment of the impact on integrated luminosity should be made
    - Also negative for LHCB which prefers long fills
- A warm skew quadrupole magnet seems feasible but needs more study and is of course less attractive than solving the issue with existing infrastructure
- In case both sides MQSXs fail should also be studied but without tilting the Q2 or Q3 it will be very challenging

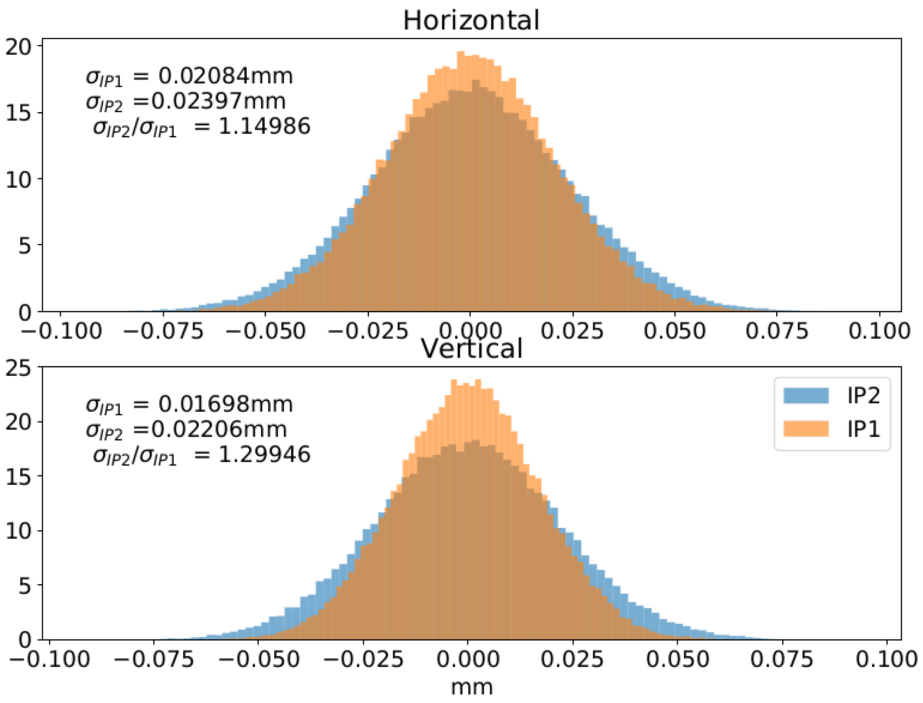
Backup slides

Does the coupling change the beam size?

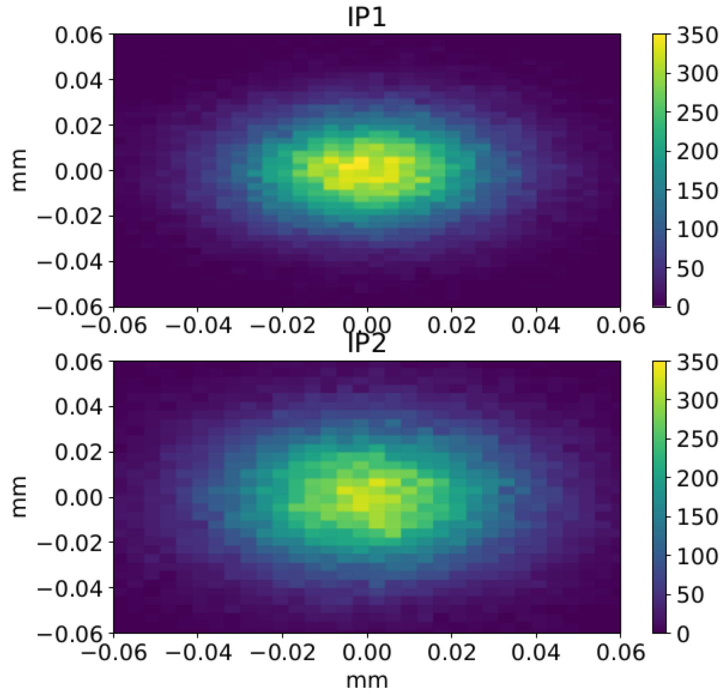




Simulation of the local coupling error



2d histogram x-y



Tracking simulation: Ideal machine (beam 1) + trim of the **colinearity knob = 10** (MQSX.3L2 = 10^{-3} m^{-2} and MQSX.3R2 = -10^{-3} m^{-2})

Start with 50% larger emittance in horizontal compared to vertical

→ **Beam size is 15% larger in horizontal and 30%** in vertical in IP2 compared to IP1

→ **33% lower luminosity** (neglecting effect from crossing angles) compared to the 50% that was observed in the machine

→ Almost identical beam size increase for beam 2 (less than 1% difference)