TDI➔ TDIS Operational Aspects

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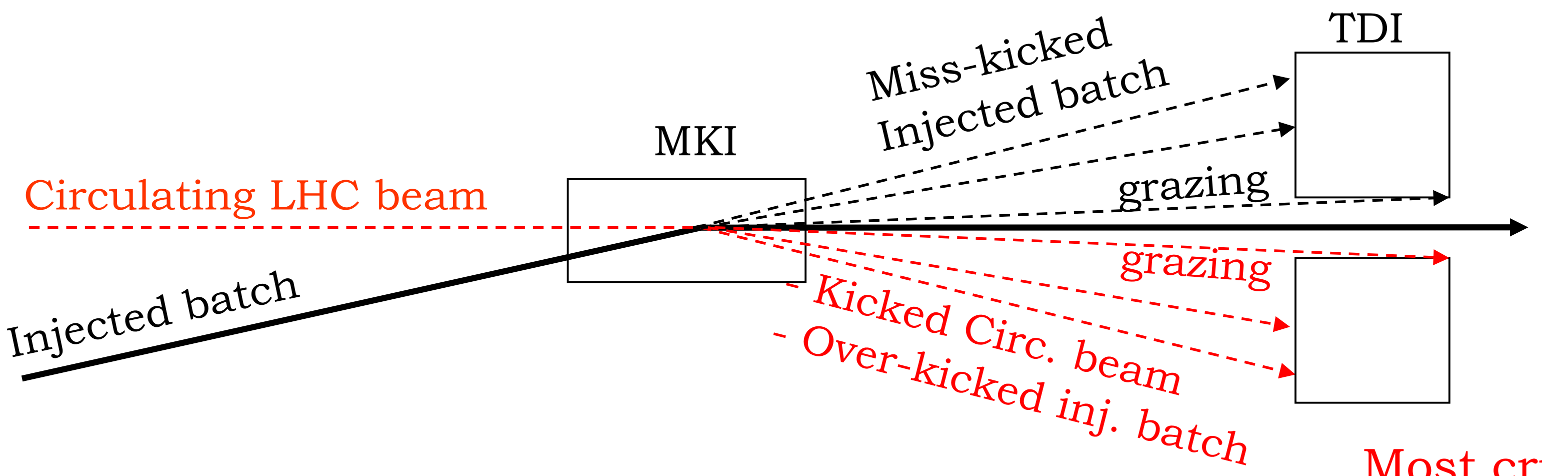
Outline

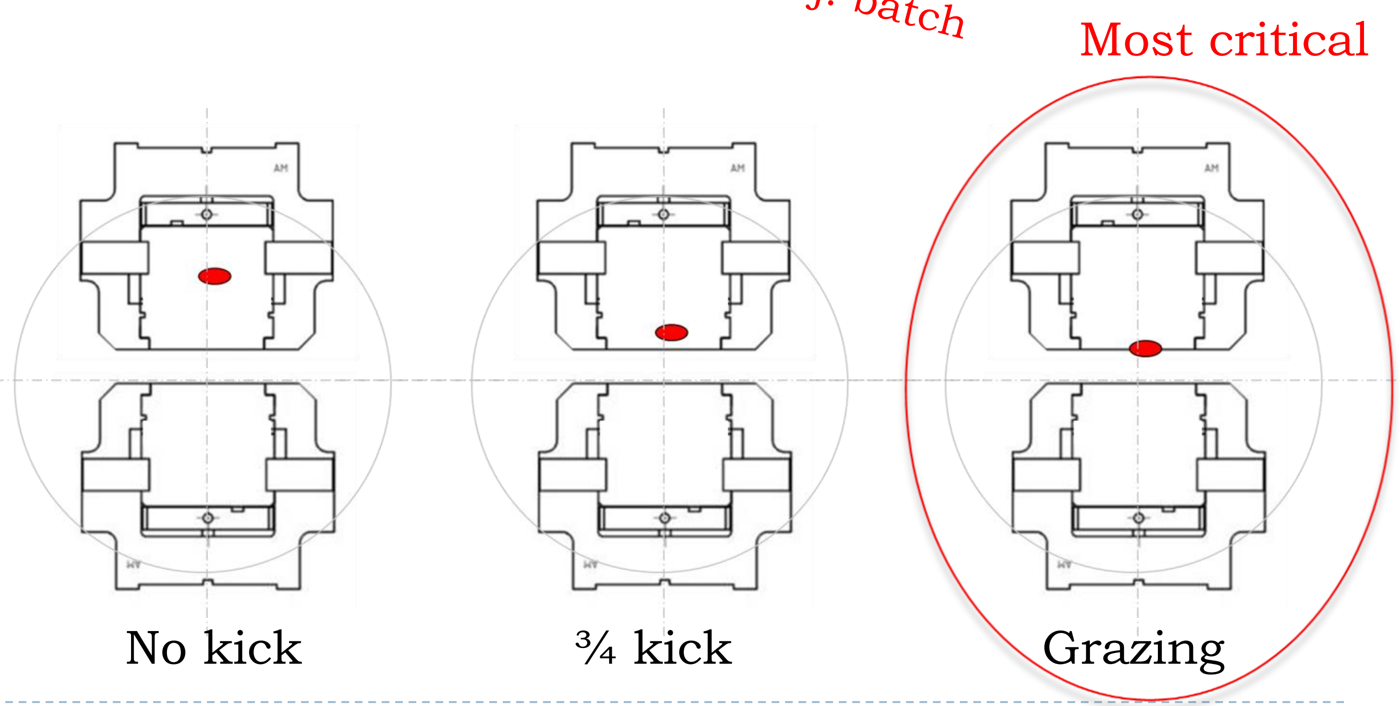
- TDI
  - Scope
  - Original beam based alignment → mechanical angle and offset
  - New angular alignment procedure → results
- TDIS
  - Advantages of new HW from operational point of view
  - Requirements
  - Expected accuracy
- Interlock logic
- Conclusions

Scope



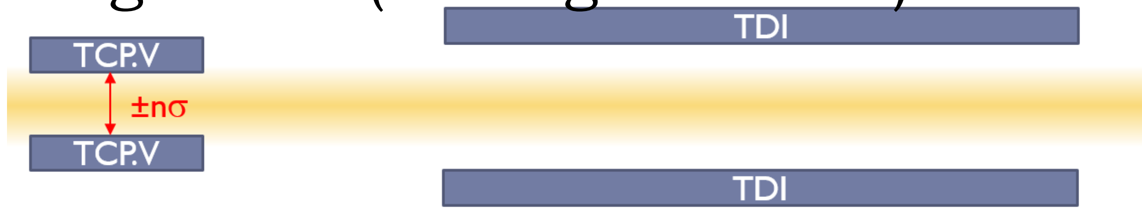
Injected beam:

Nominal kick



Beam Based Alignment

- Beam based alignment and size measurements at TDI after beam based alignment (no angular scan)

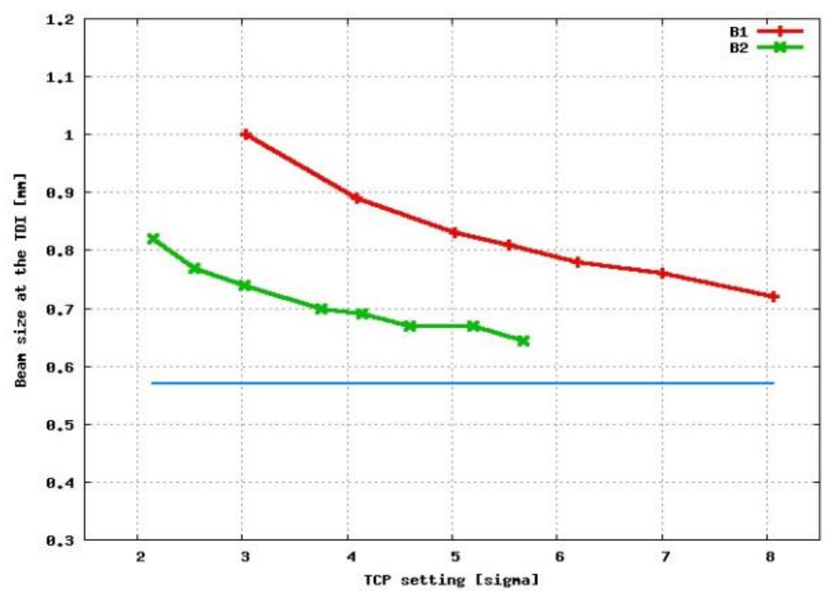


  - Beam edge defined with TCP.V (±n nominal σ)

Beam Based Alignment

- Beam based alignment and size measurements at TDI after beam based alignment (no angular scan)

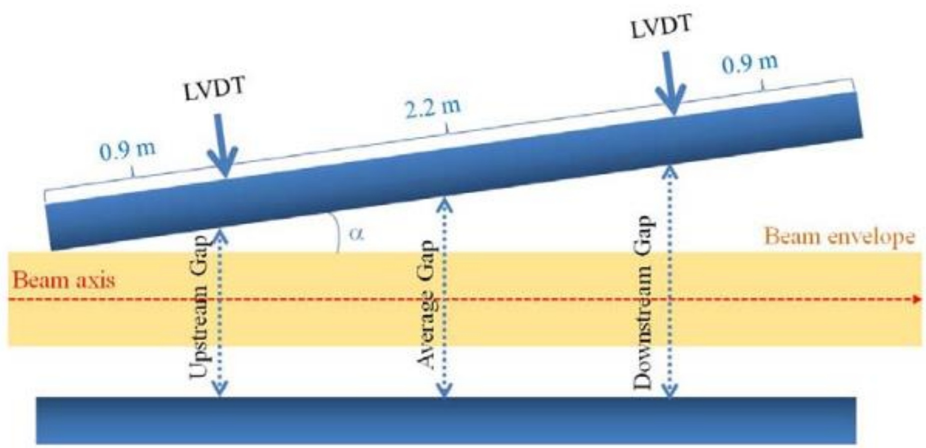
  - Beam edge defined with TCP.V (±n nominal σ)
  - Move TDI jaws into the beam until seeing losses ➔ define beam centre and calculate beam size as 1σ = half gap[mm]/n
  - Measured a beam size varying as a function of TCP setting and up to x2 larger than nominal value !



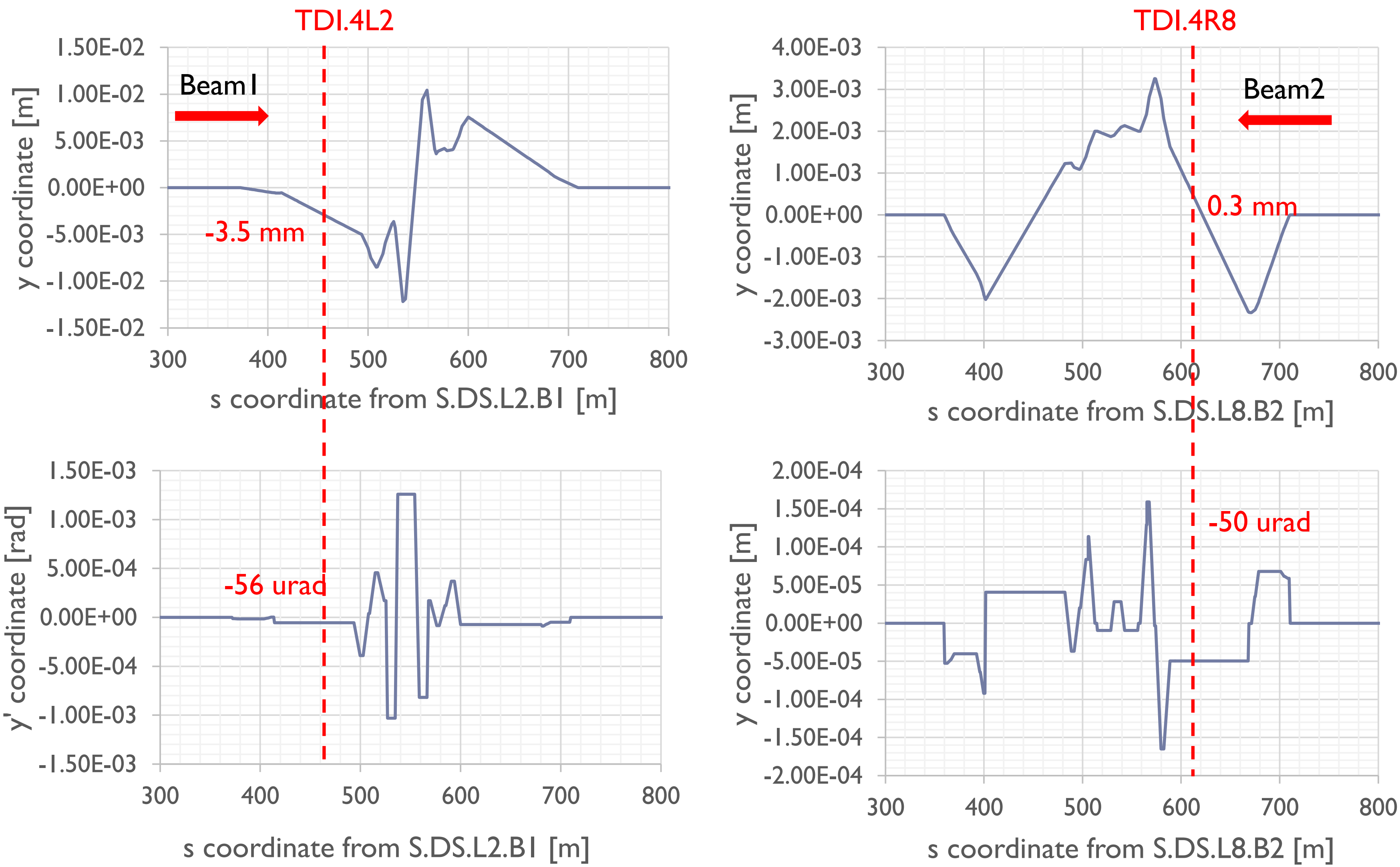
Non-Zero Angle

- Possible explanation: effective non-zero angle of the jaws with respect to the beam (half-gap defined as average of up and downstream LVDTs)

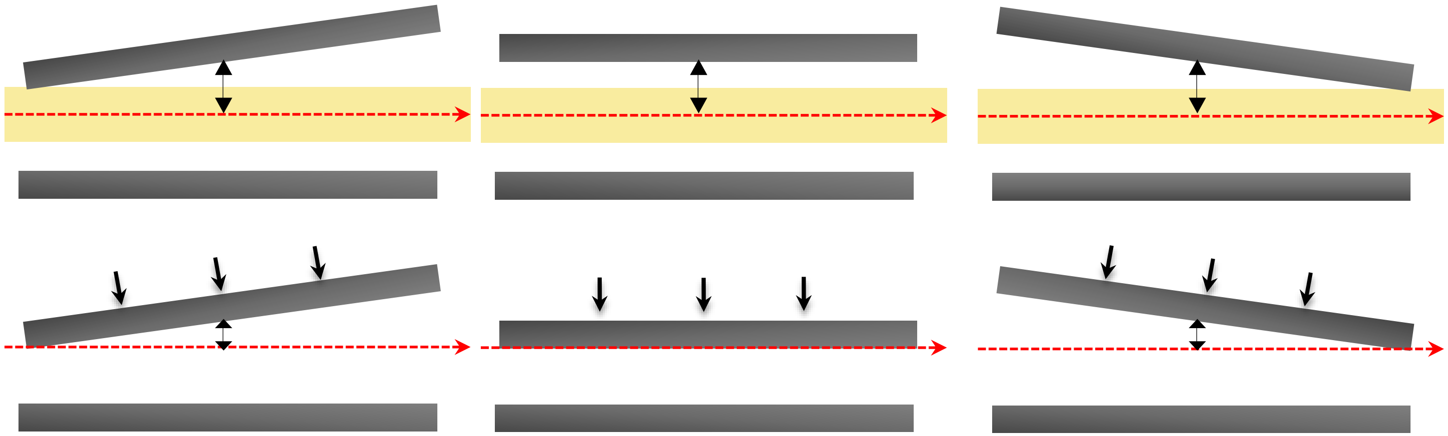
$$\sigma_{TDI} = \frac{HalfGap_{meas}}{n_{TCP}} = \frac{HalfGap_{paral}}{n_{TCP}} \pm \frac{0.5 \cdot length_{TDI} \cdot \sin\alpha}{n_{TCP}}$$



Crossing Scheme for Run 1 Optics

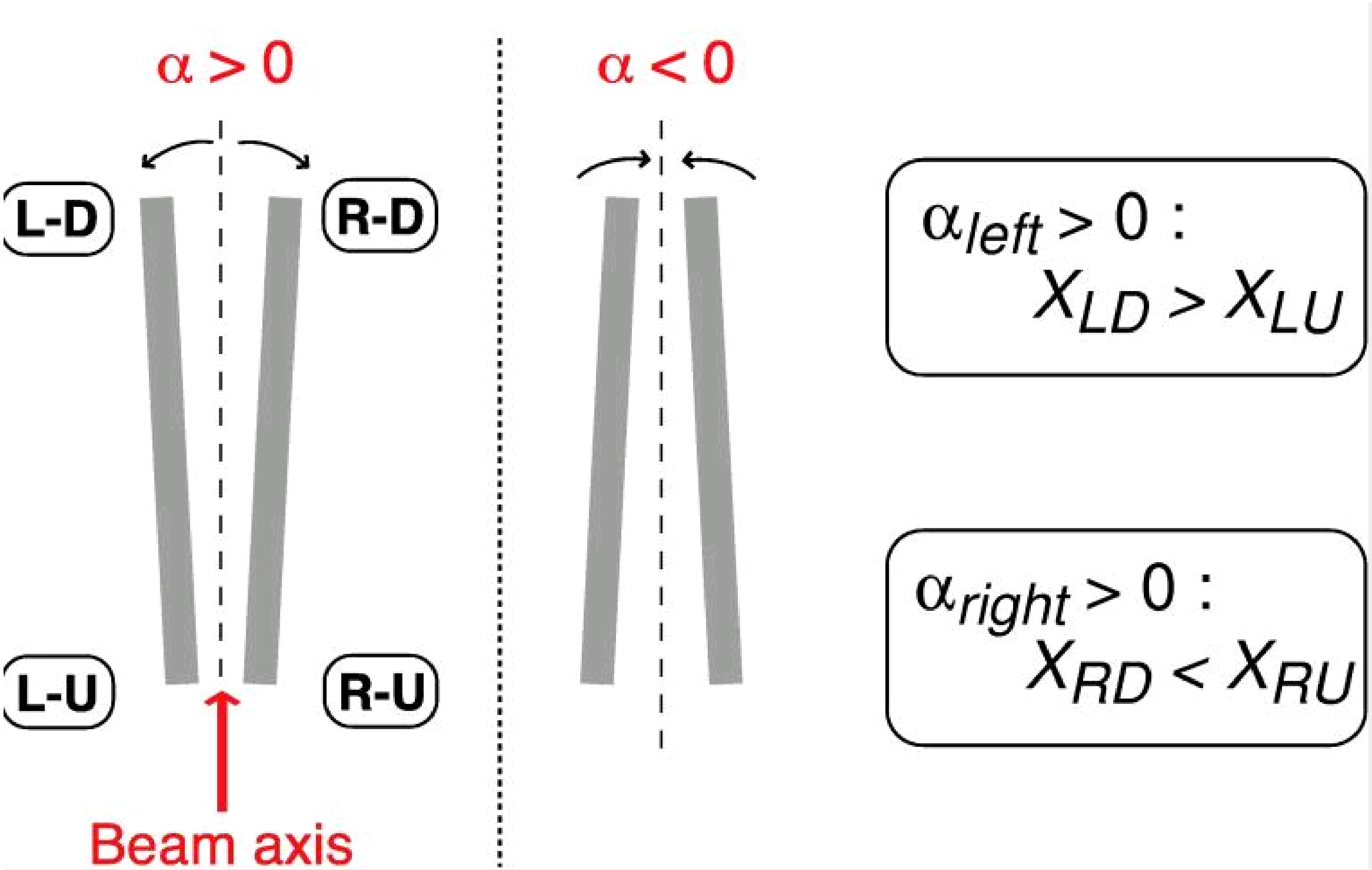


Angular Alignment Procedure

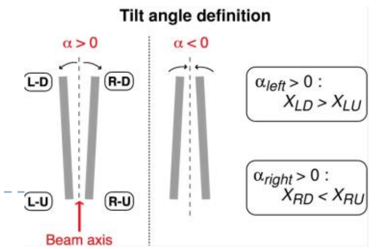


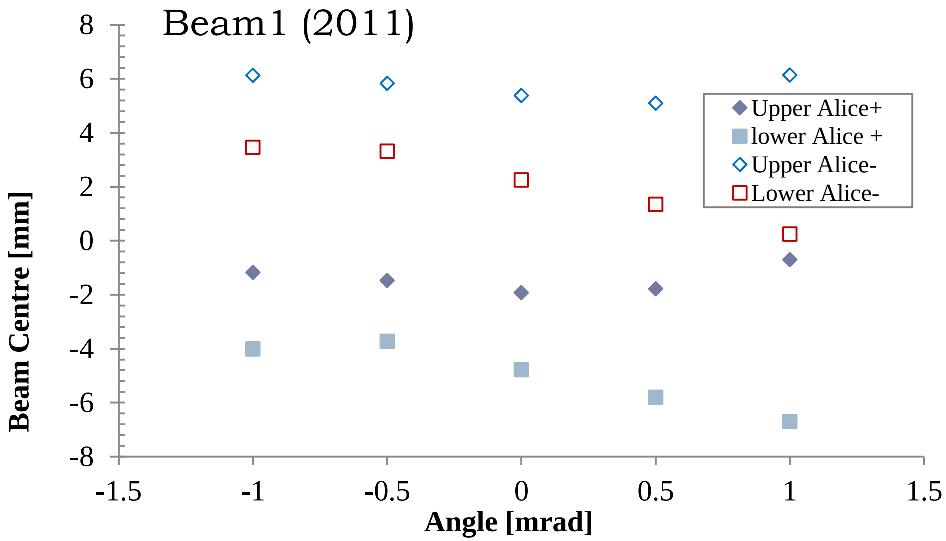
- Each jaw is closed in steps with different applied angles until the beam is fully scraped
- The beam centre is defined as the average between the up and downstream corner position corresponding to the beam losses going to zero.
- The angle for which the jaw can be closed farthest into the beam (minimum beam centre for left jaw and maximum beam centre for right jaw) defines the position parallel to the beam axis.
- Different beam centres can be found for the two jaws if the LVDTs are not correctly calibrated
- The parallelized jaws can then be set to the nominal aperture retracting them by their respective number of nominal σ with respect to the beam edge defined by the TCP

Jaw Angle Definition

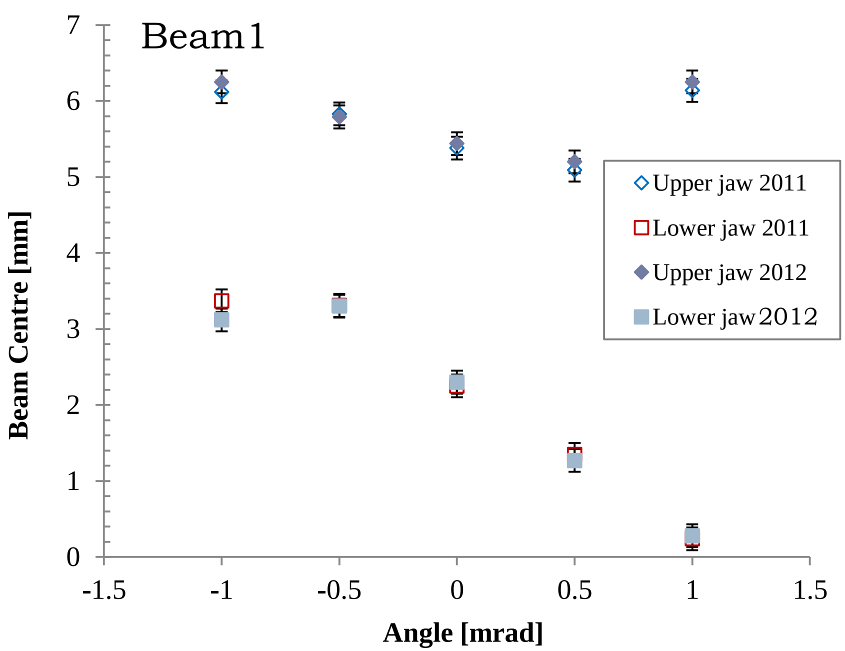


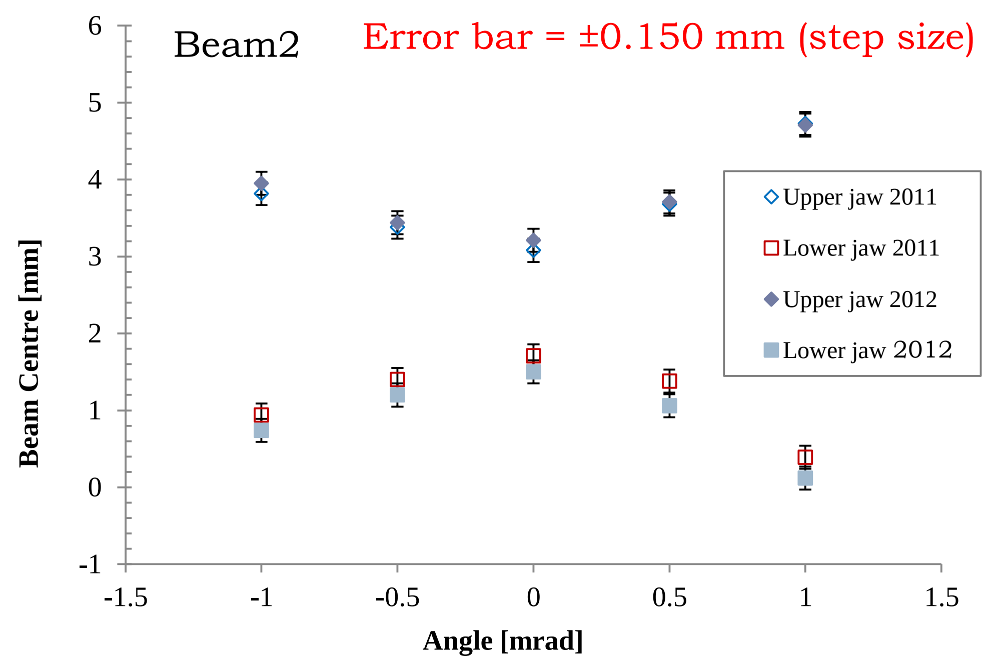
Angular Alignment Results Run I





	Angle Upper [urad]	Offset Upper [mm]	Angle Low [urad]	Offset Low [mm]
2011 B1(+)	325	-2.2	-550	-3.8
2011 B1 (-)	480	5.1	-510	3.3
2011 B2	150	2.9	230	1.9
2012 B1	435	5.1	-500	3.3
2012 B2	165	3.0	179	1.7





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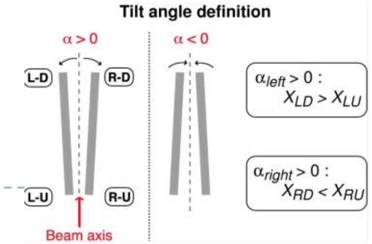

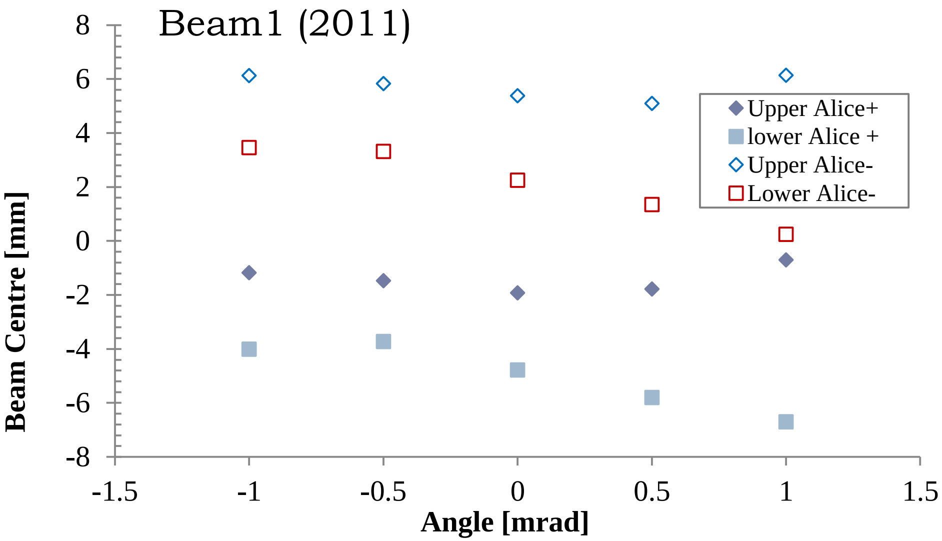

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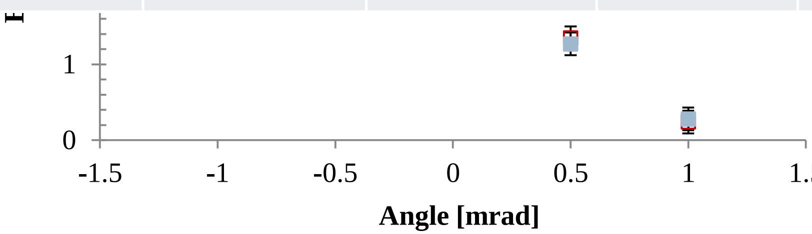
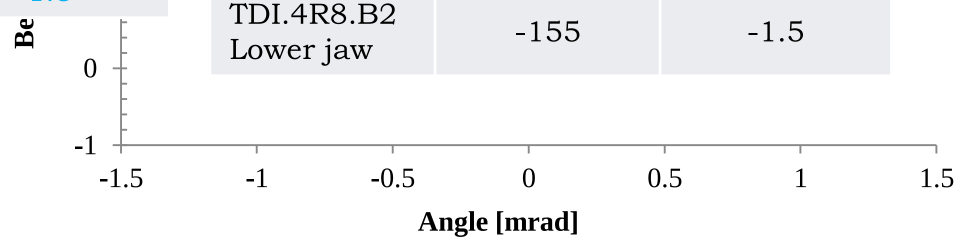
	Angle Upper [urad]	Offset Upper [mm]	Angle Low [urad]	Offset Low [mm]
Optics I +	-56	-3.5	-56	-3.5
Beam1 +	325	-2.2	-550	-3.8
Optics 1 -	56	3.5	56	3.5
Beam I -	460	5.1	-505	3.3
Optics 2	-50	0.3	-50	0.3
Beam 2	160	3	205	1.8

	Mech. Angle [urad]	Mech. Offset [mm]
TDI.4L2.B1 Upper jaw	**-390±10**	-1.5±0.2
TDI.4L2.B1 Lower jaw	**530±80**	0.2±0.05
TDI.4R8.B2 Upper jaw	-210	-2.7
TDI.4R8.B2 Lower jaw	-155	-1.5





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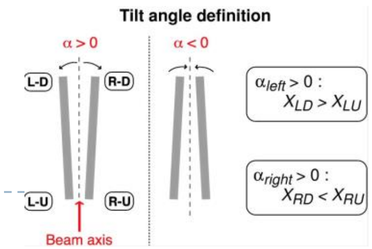

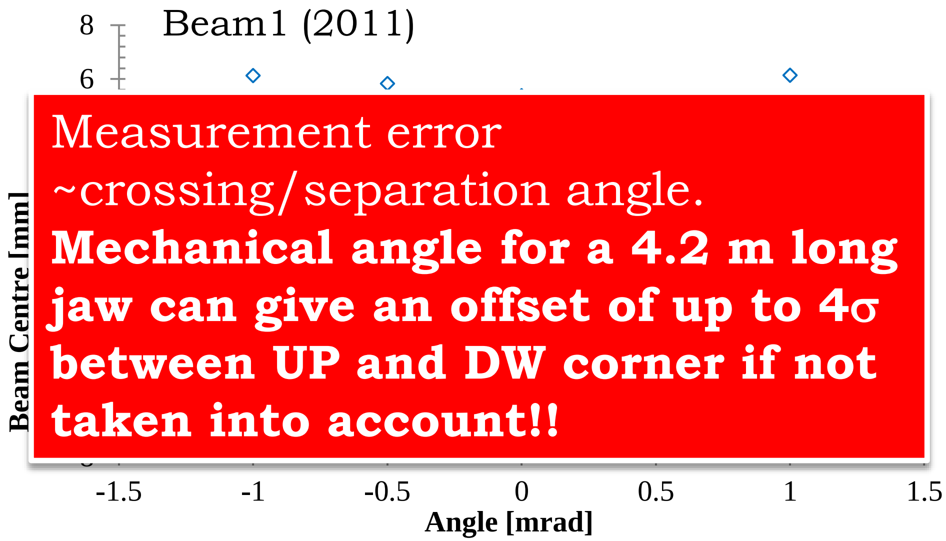

Measurement error ~crossing/separation angle.

Mechanical angle for a 4.2 m long jaw can give an offset of up to 4σ between UP and DW corner if not taken into account!!

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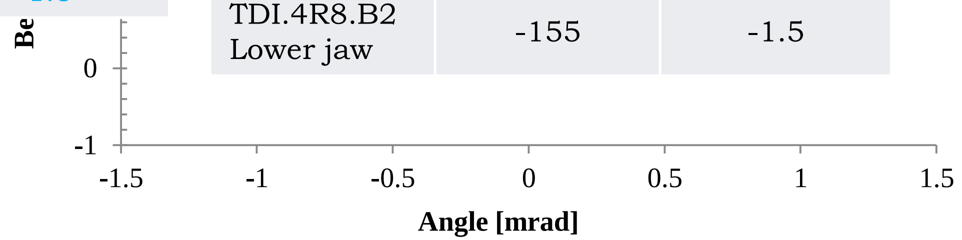
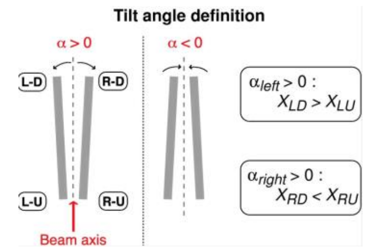
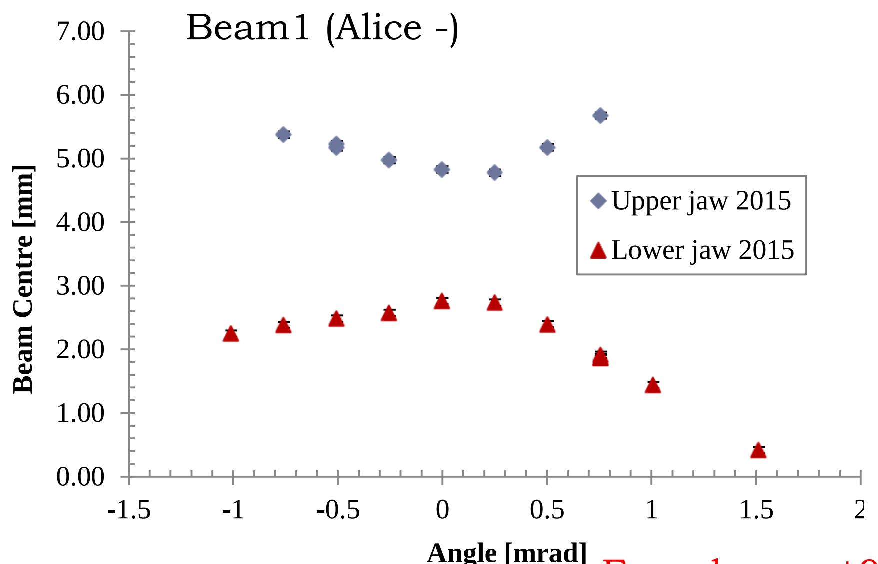
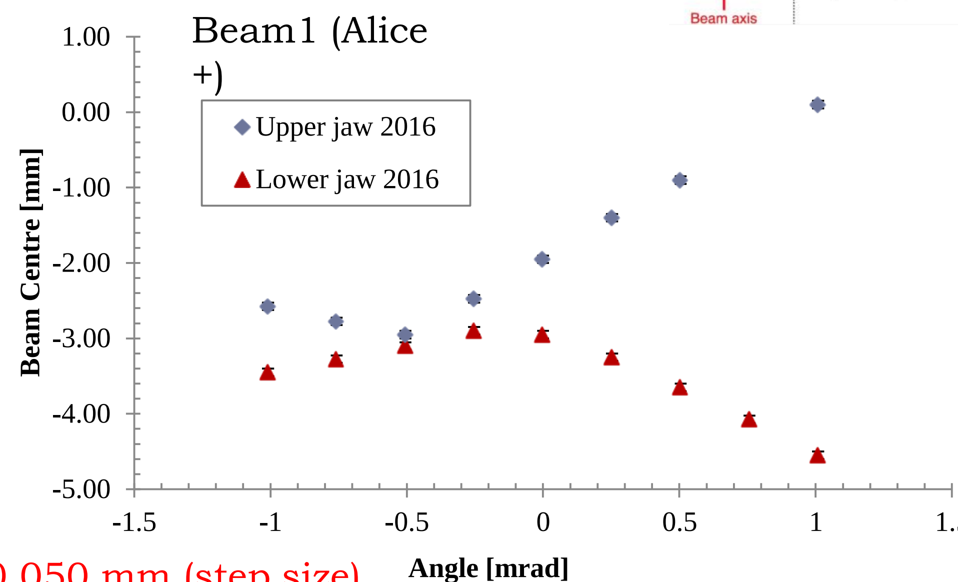


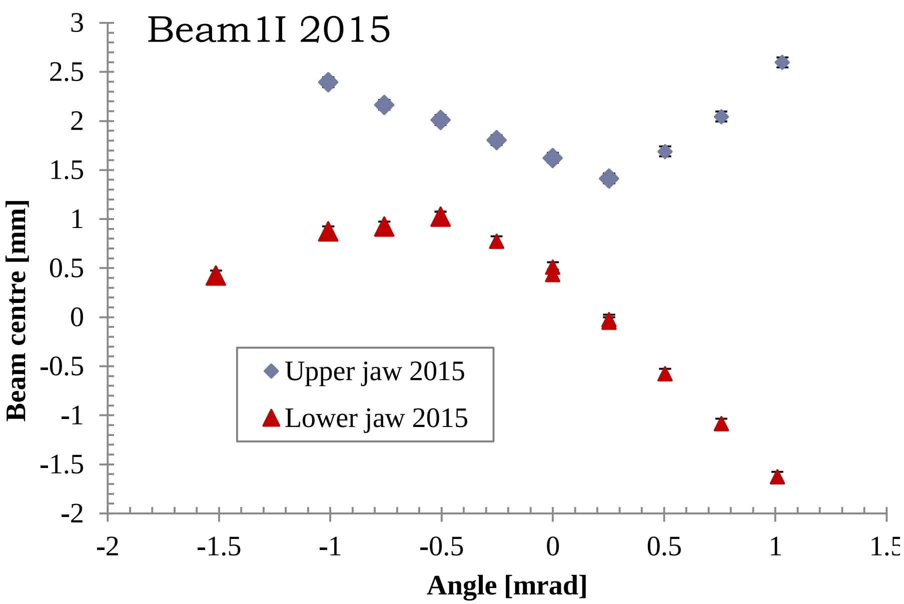
Angular Alignment Results Run II

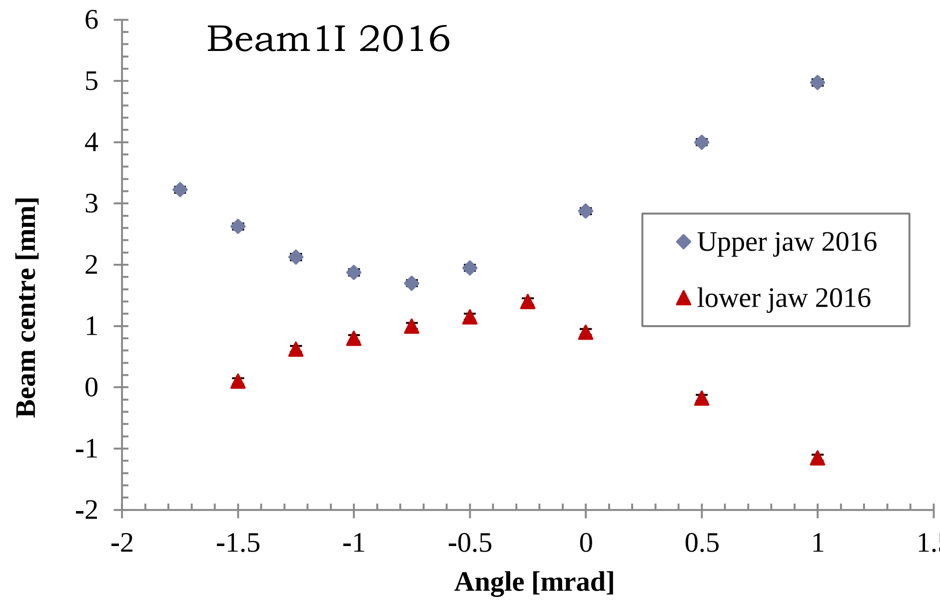






Error bars = ±0.050 mm (step size)





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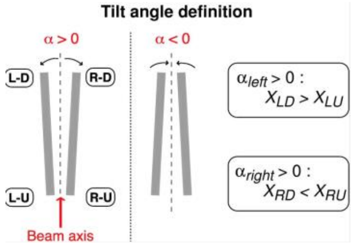
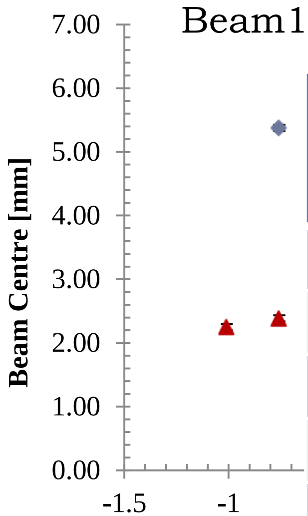
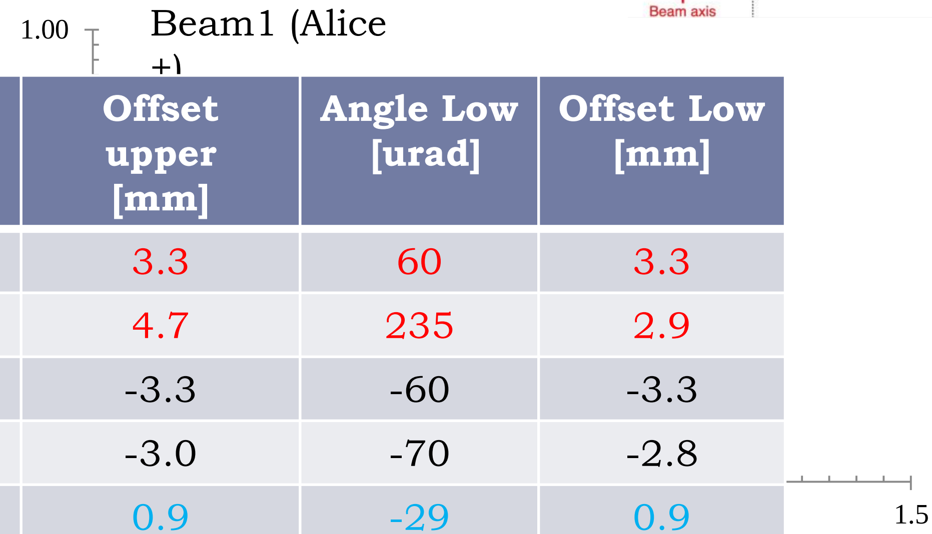
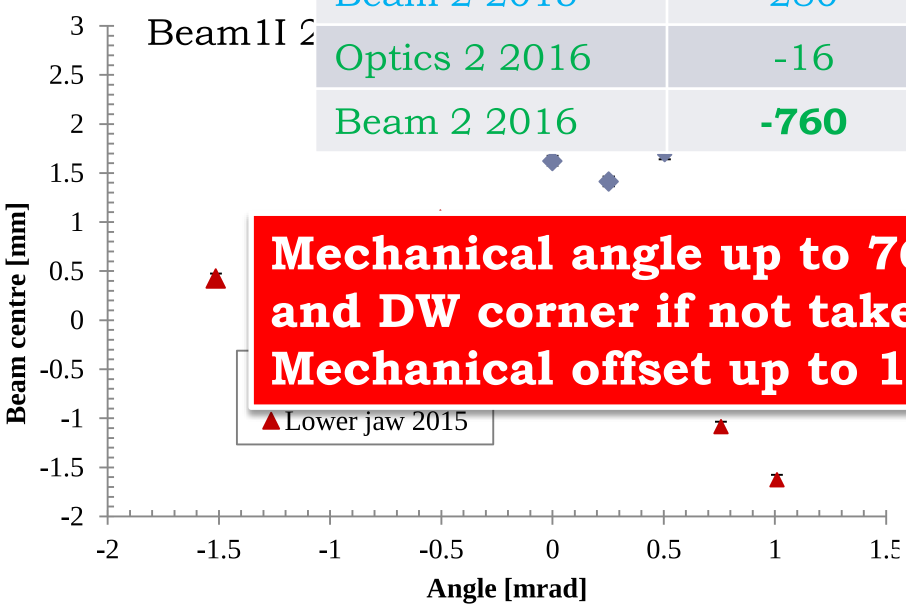
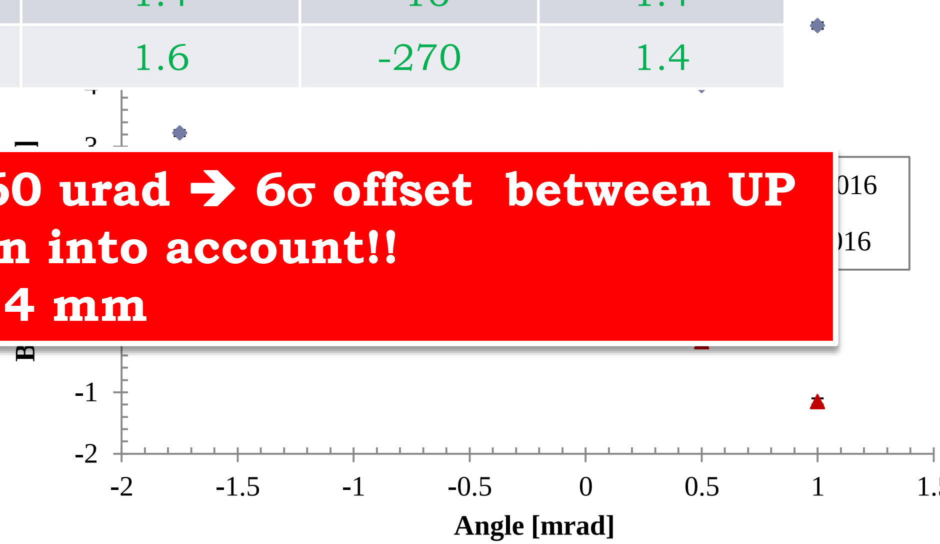






	Angle Upper [urad]	Offset upper [mm]	Angle Low [urad]	Offset Low [mm]
Optics I 2015 (-)	60	3.3	60	3.3
Beam1 2015	200	4.7	235	2.9
Optics 1 2016 (+)	-60	-3.3	-60	-3.3
Beam I 2016	**-500**	-3.0	-70	-2.8
Optics 2 2015	-29	0.9	-29	0.9
Beam 2 2015	280	1.4	**-430**	1.1
Optics 2 2016	-16	1.4	-16	1.4
Beam 2 2016	**-760**	1.6	-270	1.4





Mechanical angle up to 760 urad → 6σ offset between UP and DW corner if not taken into account!!
Mechanical offset up to 1.4 mm

Summarising

- TDI is the main protection element in case of MKI failures
- It has to be correctly aligned wrt the beam in terms of position and angle to insure the adequate protection ➔ full active length!
- Long jaws of the present HW imply:
  - Difficult mechanical alignment of the jaws in the tank (>760 urad and ~ 3 mm)
  - Unacceptably large errors in case of non correct alignment wrt the beam ➔ loss of protection
  - Larger deformation in case of beam induced heating
- A beam based alignment procedure was developed which:
  - Allows to measure and compensate for mechanical offsets and angle
  - An accuracy of ±0.05 mm (step size) and better than ±100 urad could be achieved with this method
- Lengthy procedure!

New TDIS

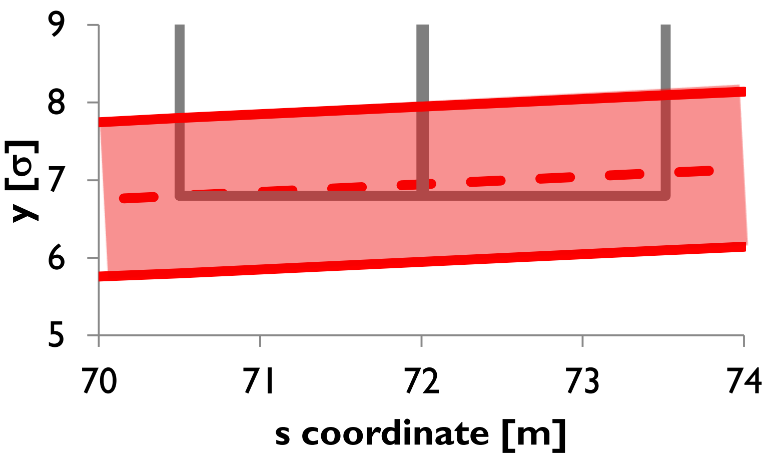
- Three jaws each 1.5 m long
  - Better alignment of the jaws in the tank
  - Beam based alignment for each module independently as for a standard 1m long collimators ➔ no angular alignment (check with full beam scraping with 0 angle can still be performed)
  - Expected accuracy per module: ±0.02 mm and better than ±100 urad

- Requirements:
  - **20 mm relative retraction between modules**
  - **Possibility to cross machine axis by 5 mm**
  - **Allow an angle of ±2 mrad for each module** (in case angular alignment needed)

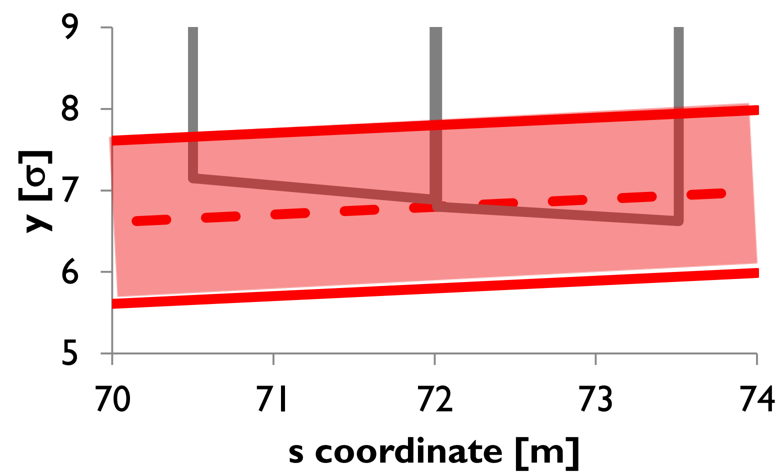
- Advantages:
  - Faster beam based alignment
  - Less sensitive to mechanical angles
  - Less deformation in case of beam induced heating

Relative Setup Accuracy

Need to ensure relative retraction between first two modules as close to avoid reducing the effective active length!

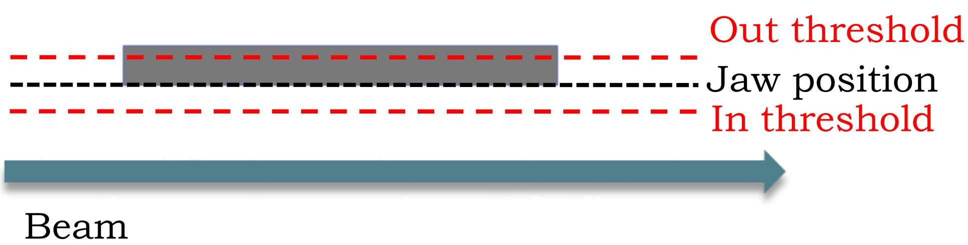


1 sigma envelope
Grazing event 10% nominal kick (0.85 mrad)

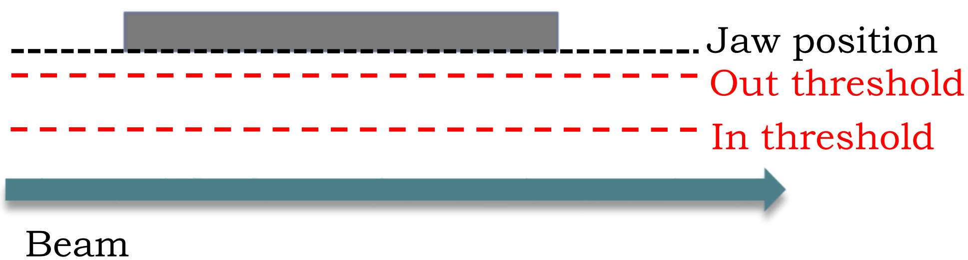


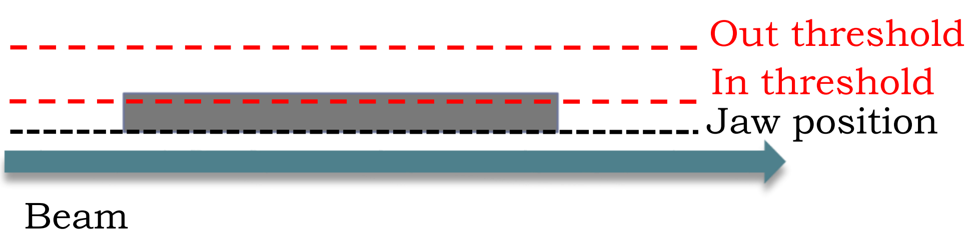
1 sigma envelope
Grazing event 10% nominal kick (0.85 mrad)
50 um offset between first two modules and 100 urad angle

Logic for TDI Position Interlock



- If:



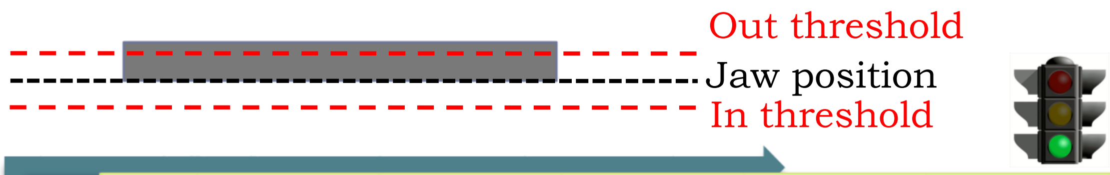


TDI:

Jaw movement is not blocked
+ Injection inhibit

Jaw movement is blocked
+ Injection inhibit + beam dump

Logic for TDI Position Interlock



✓Check performed on **UP** and **DW corners** (direct LVDT measurements) and the **Gap UP** and **Gap DW** (calculated from LVDT UP and DW measurements)

✓**Thresholds** do not have to be changed during operation to open injection collimators ➔ **always kept at injection setting**

✓ **Energy interlock** for **TDI:** injection inhibit if gap bigger than defined thresholds ➔ **redundant collimator** and **BETS** checks but **same signal**

✓**Proposal for new TDIS: independent gap measurement (interferometry* or additional LVDTs) for BETS check ➔ fully redundant!**

* Need direct measurement of gap to quantify deformation induced by heating for shorter jaws?

Conclusions

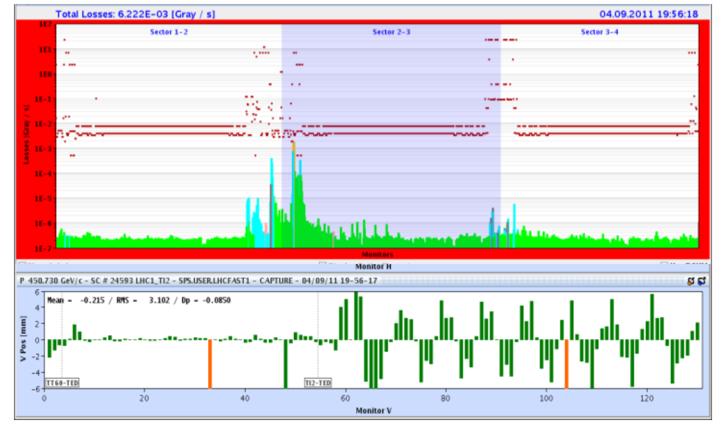
- Several operational issues encountered with present HW:
  - Mechanical angle and offsets ➔ compromised protection if not corrected
  - Angular beam based alignment ➔accuracy of ±0.05 mm and <±100 urad
  - Lengthy procedure

- New TDIS:
  - Shorter jaws ➔ better alignment in the tanks
  - No need for angular beam based alignment ➔ faster setup
  - Expected accuracy per module: ±0.02 mm and better than ±100 urad ➔ ok also from point of view of relative alignment of first two modules

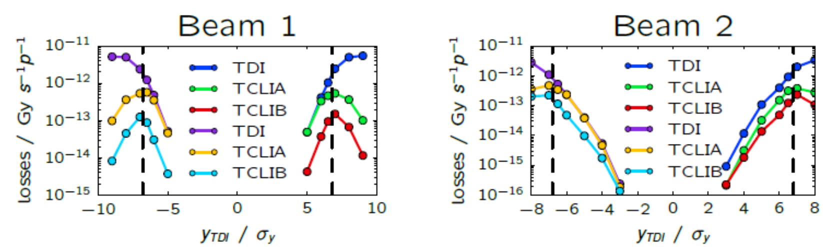
- Option of adding a fully redundant gap measurement (interferometer or LVDTs) and interlock via BETS explored

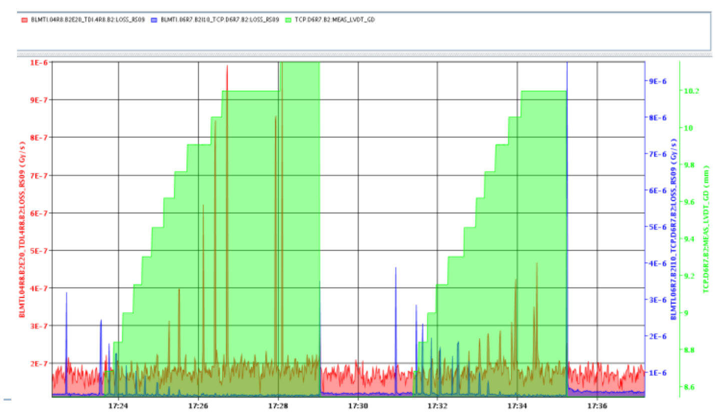
Validation Procedure

- Validation of TDI settings
  - Create open oscillation at the TDI
  - Check losses unset



- X-Measurements
  - TDI at nominal setting (1 jaw at the time)
  - TCP at nominal setting
  - Blowing beam until losses at TCP
  - Open TCP jaws (0.1σ step) and blow the beam
  - Check when dominant losses move from TCP to TDI





- Loss maps with injection protection IN (hierarchy)