Update on optics constraints for injection and dump protection elements

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Main constraints (04/08/2016):

- Q4 gradient fixed within maximum ±1%
- Horizontal phase advance MKDs➔TCDQ 90˚± 4˚
- TCDS: $\beta_{y,min}$ ≥ 200 m (no more than 10% smaller than present value)
- TCDQ: $\beta_{y,min}$ ≥ 145 m (no more than 10% smaller than present value)
- TCDS-MSD: $\beta_{x,max}$ ≤ 175 m at injection (aperture limitation)
- TCDQ: $\beta_{x,min}$ ≥ 630m and $|D_x|$ ≤0.2m
- TCDQ movement during squeeze unidirectional and towards the beam, accumulated mechanical play ➔ degraded alignment precision (required ±0.1 mm)! **Need BETS redesign**.
- Phase advance MKD➔TCTs 0˚ or 180 ˚(± 10˚)

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- Phase advance MKD➔TCTs 0˚ or 180 ˚(± 10˚) ✓
- Optics constraints at TDIS

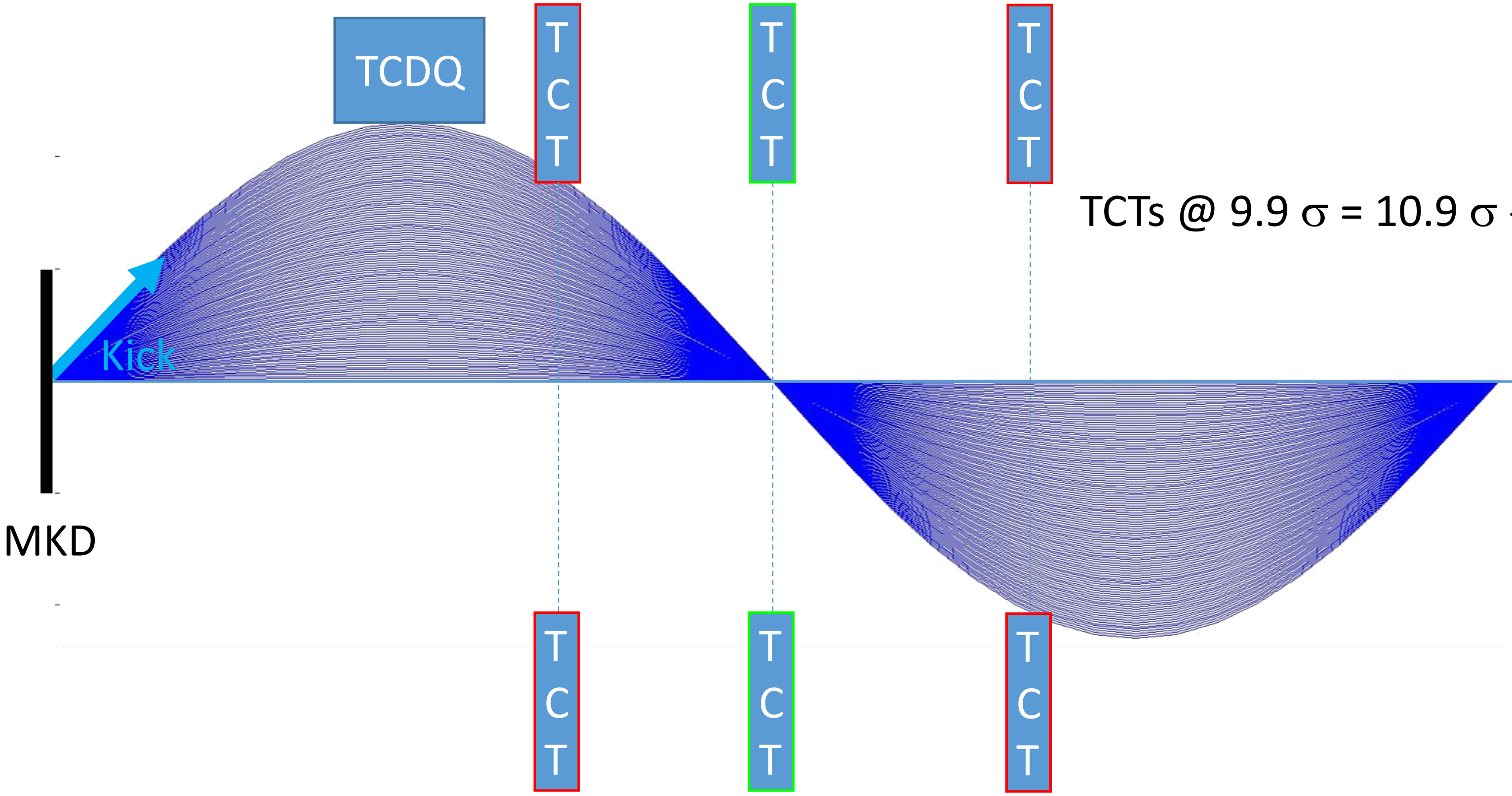
Assumptions for these studies

- Reference optics: HLLHCV1.2 round
- Normalised emittance for σ calculation = 3.5 mm mrad
- β^* in IP1 and IP5 squeezed down to 15 cm
- Settings at collision: TCDQ at 9 σ, TCT in IR1 and IR5 at 10.9 σ
- $\Delta p/p$ = 2E-4 (as used for aperture calculations)
- Maximum orbit drift at TCDQ = 1.2 mm (possible to reduce this number by improving interlock BPM reliability and implementing the possibility of adapting the thresholds wrt energy)
- Effect of dispersion at TCTs neglected (some general margins included in the calculations)
- Only analytical calculations ➔ the validation of the final optics will require particle tracking (collaboration with WP5)

D_x @ TCDQ and MKD/TCT phase advance (end of squeeze)

TCDQ @ 12 σ = 9 σ + 1 σ* + 2 σ **

NB: TCTs are assumed to be the smallest "sensitive" aperture in the machine!

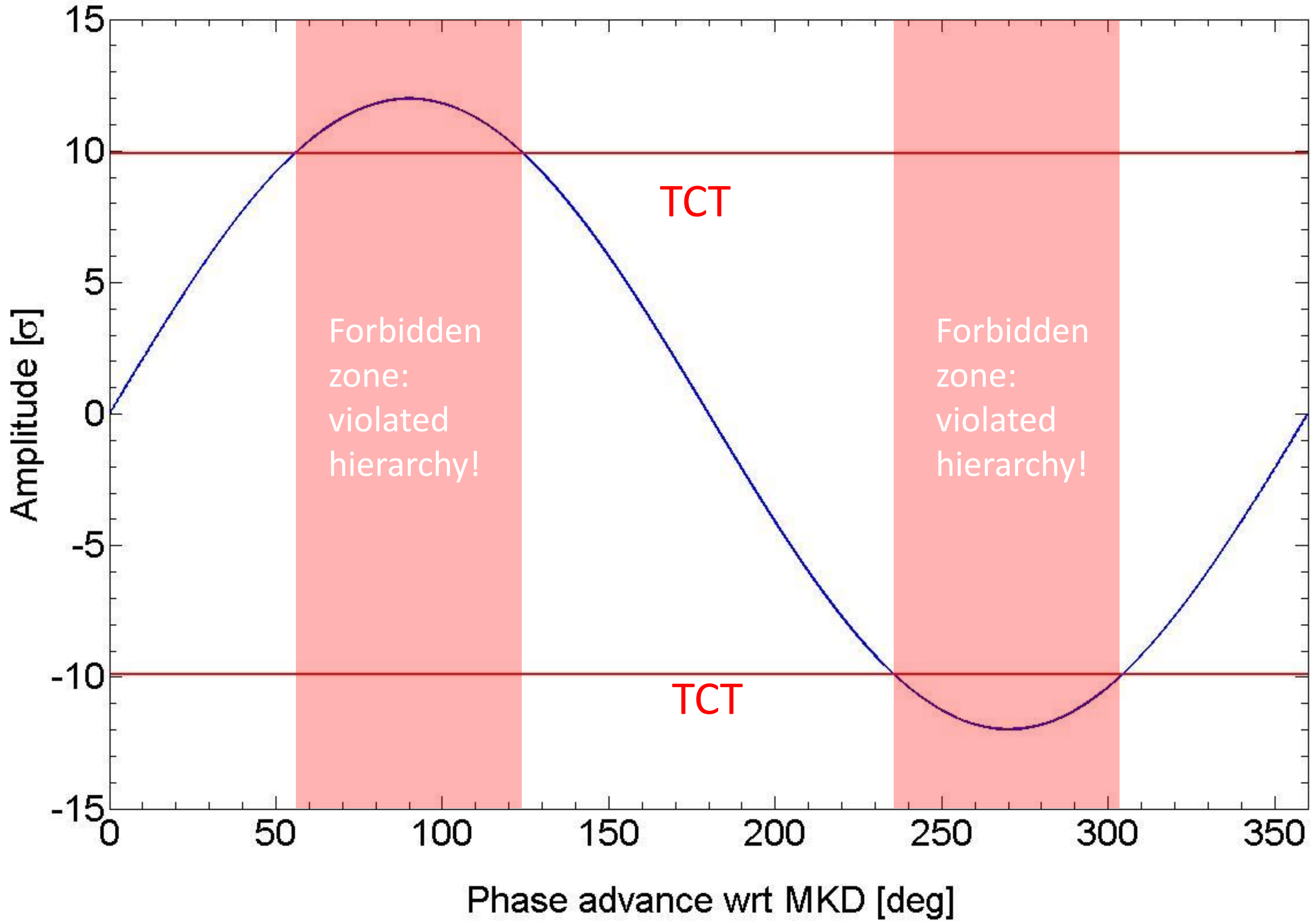


TCTs @ 9.9 σ = 10.9 σ - 1 σ*

Ideal phase advance MKD-TCTs
nπ with n=0,1,2…

* Margin for optics and setup errors
** 1.2 mm orbit drift at the TCDQ

D_x @ TCDQ and MKD/TCT phase advance (end of squeeze)



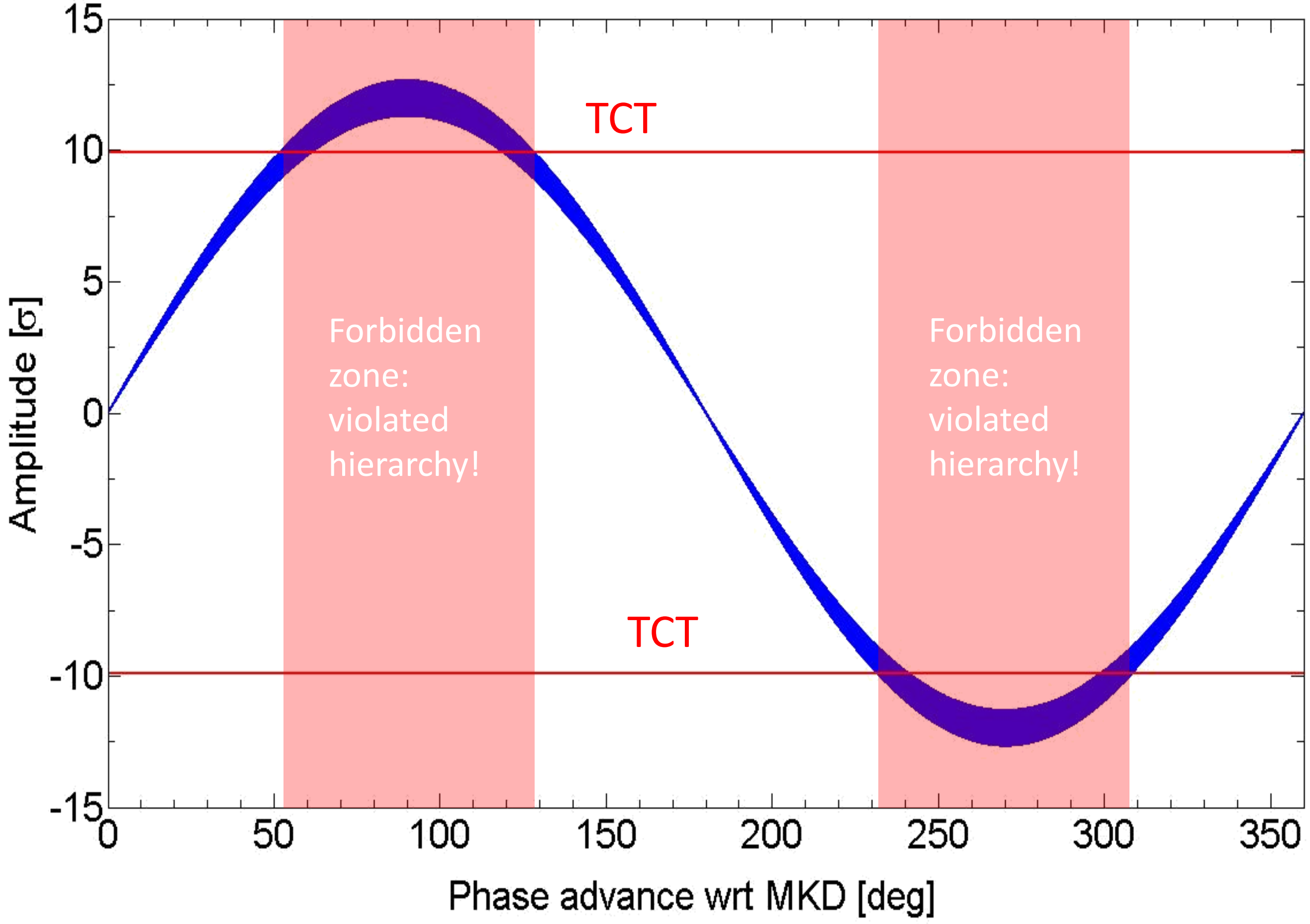
D_x = 0 at TCDQ
Phase advance between MKD and TCTs (μ_x):

forbidden zones:
$56° < \mu_x < 124°$ **and**
$236° < \mu_x < 304°$

Constraints:
$\mu_x \leq 56°$ **or**
$124° \leq \mu_x \leq 236°$ **or**
$\mu_x \geq 304°$

D_x @ TCDQ and MKD/TCT phase advance (end of squeeze)

$D_x \neq 0$ (-2 m $\leq D_x \leq$ 2 m) ➔ enlarged forbidden zone!



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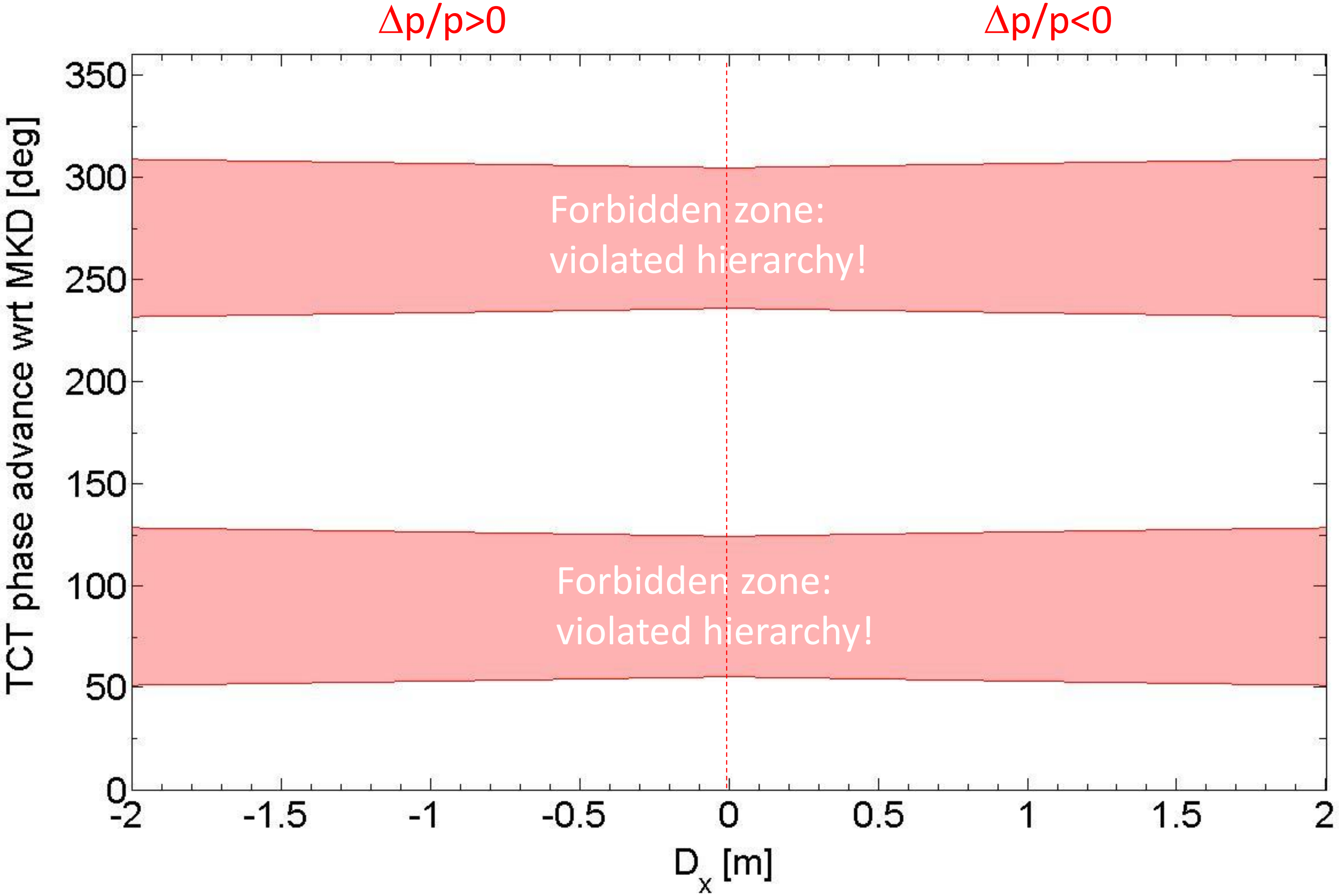


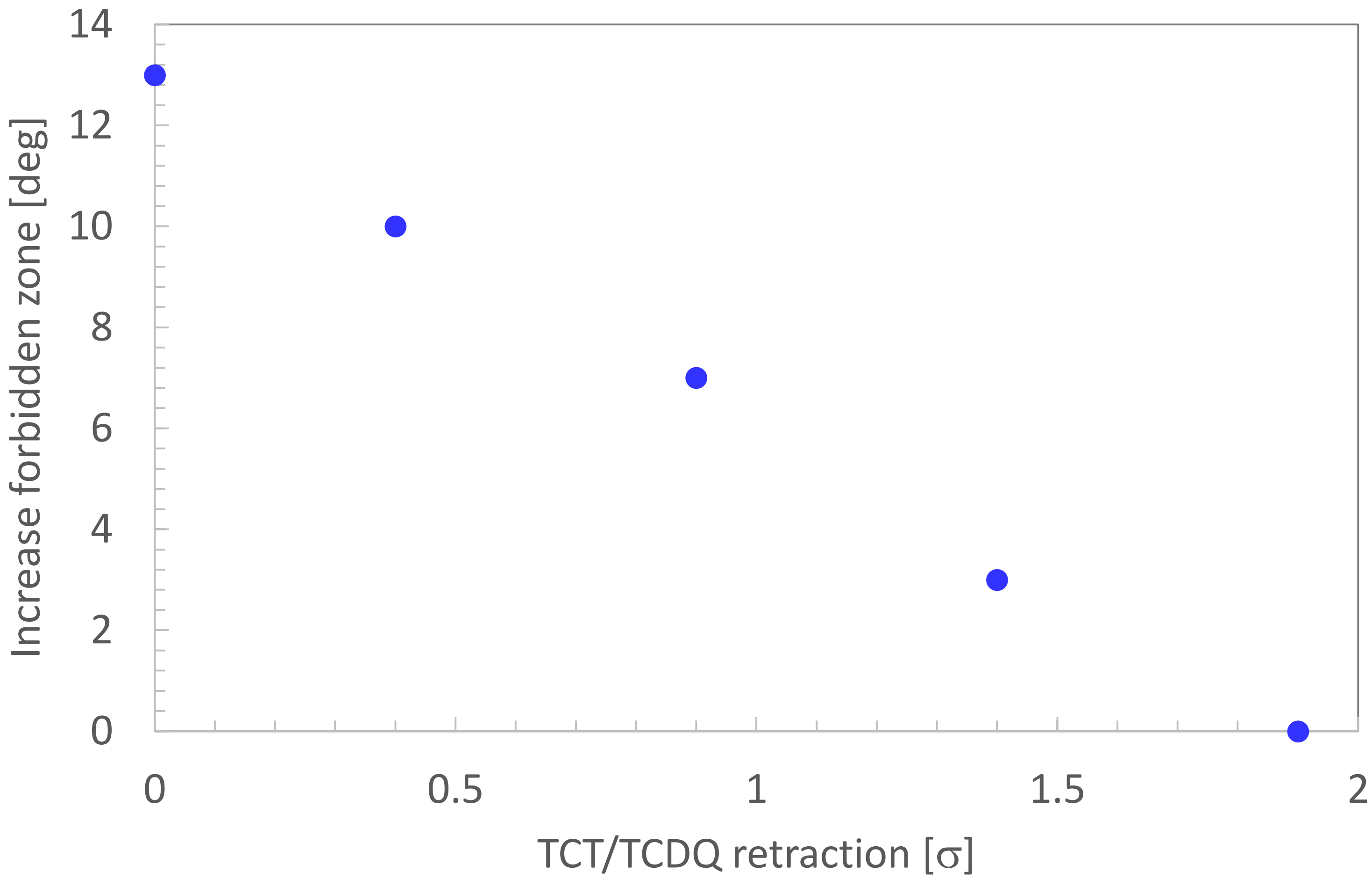
Dx $\neq$0 (-2 m $\leq$ Dx $\leq$ 2 m)

forbidden zones:
52° < μ_x < 129° **and**
232° < μ_x < 309°

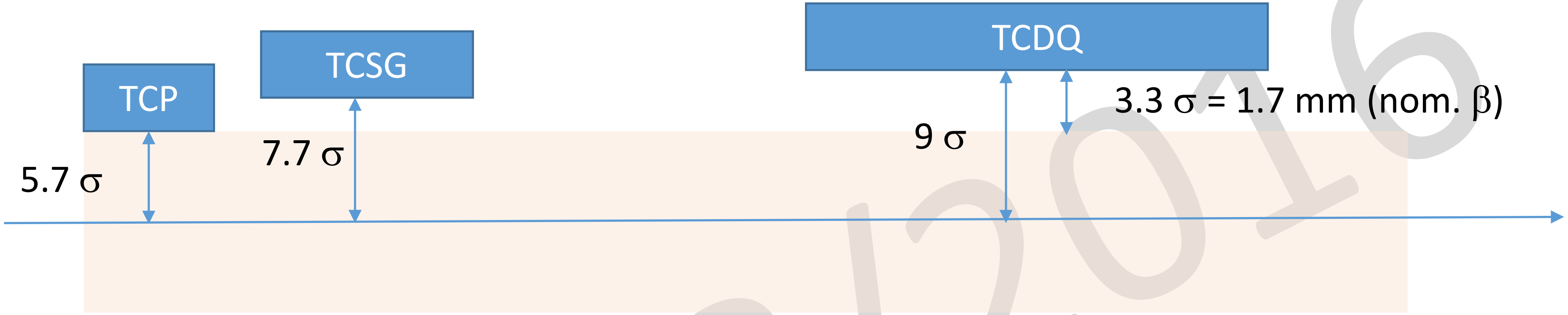
Constraints:
$\mu_x \leq 52°$ **or**
129° $\leq \mu_x \leq$ 232° **or**
$\mu_x \geq 309°$

“Forbidden zone” for different TCT/TCDQ retractions

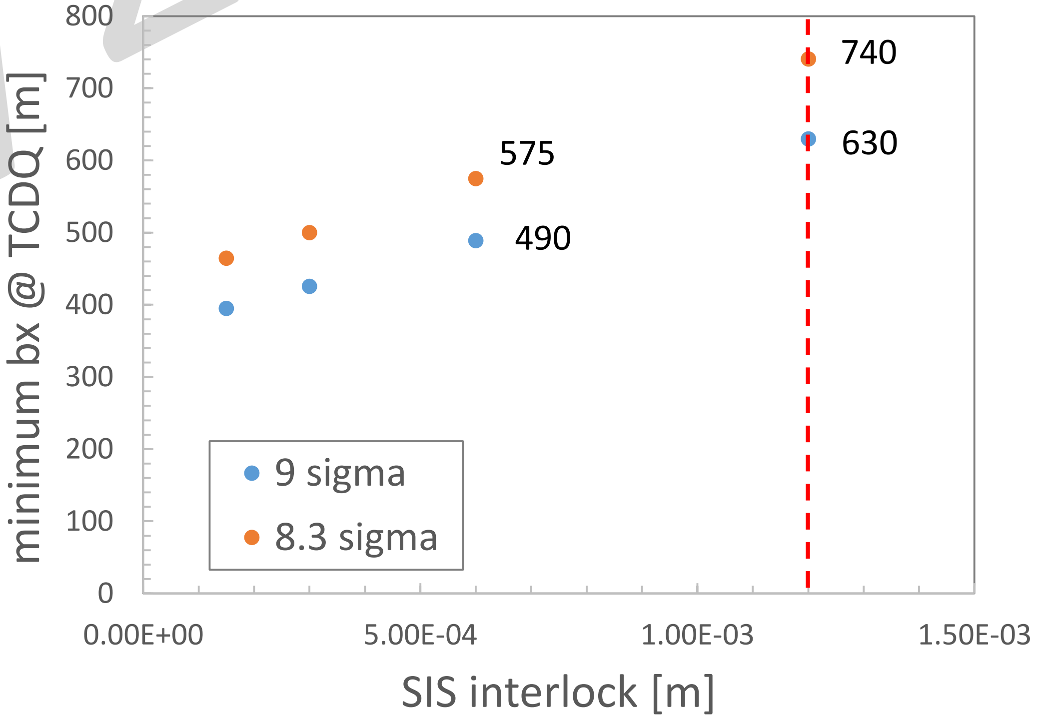
- TCDQ @ 9 σ (plus tolerances)
- TCT/TCDQ retraction reduced to 0 σ
- Assumed maximum $D_x*\Delta p/p$ contribution
- Forbidden zones enlarges by about 3° (on both sides) per 0.5σ



HL-LHC collimator settings @ 7TeV (20 cm β*)

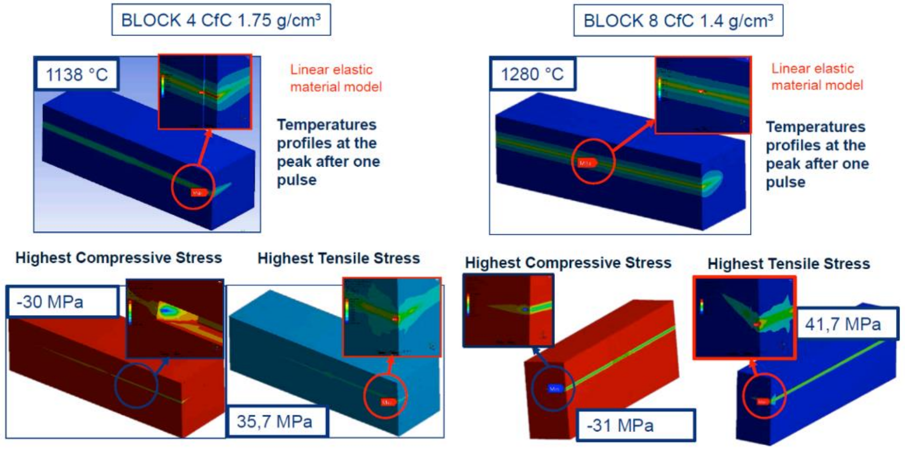


- Assuming a **maximum allowed temperature of 1400 ˚C** (“grey zone” for graphite, still ANSYS simulations needed!!) ➔ **minimum gap = 3.6 mm**
- **0.25 mm** setup error ➔ minimum gap = 3.85 mm
- **SIS interlock 1.2 mm** ➔ minimum gap = 5.05 mm ➔ **Minimum allowed β_x = 630 m**



Constraints due to energy deposition in TCDQ (asynchronous beam dump)

- β_x defines the position of the TCDQ
  - The smaller the gap, the higher the particle density at the TCDQ edge
- TCC #10/#19, HL Annual Meeting 2016:
  - First estimates of energy deposition and stresses in TCDQ absorber blocks for HL beams
    - HLLHCV1.2 (β_x at TCDQ = 497m)
    - TCDQ@3.9mm (= 8.6 σ - 0.5 σ margin)
    - Asynch beam dump Type 2 Erratic
  - No issues found, stresses well below material limits – studies still to be updated including dynamical strain data (M. Calviani et al.)



Material	C-C 1.75	C-C 1.4
Max. Temp. [°C]	1138	1280
Min. Princ. [MPa]	**-30**	**-31**
Compr. Strength	69.6	69.6
Max. Princ. [MPa]	**36**	**42**
Tensile Strength	61	61

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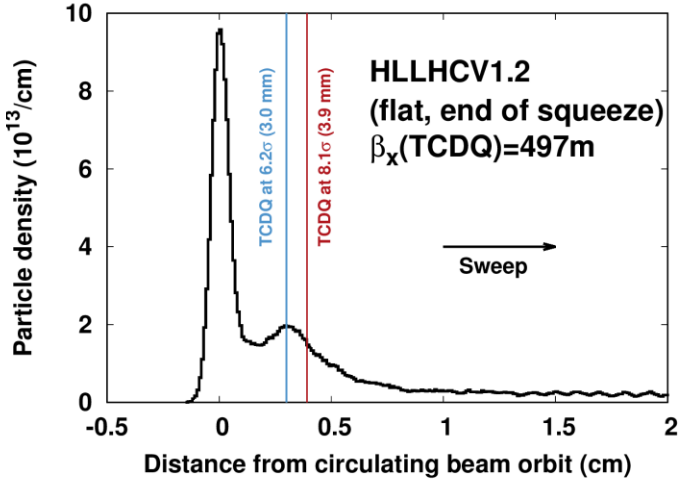
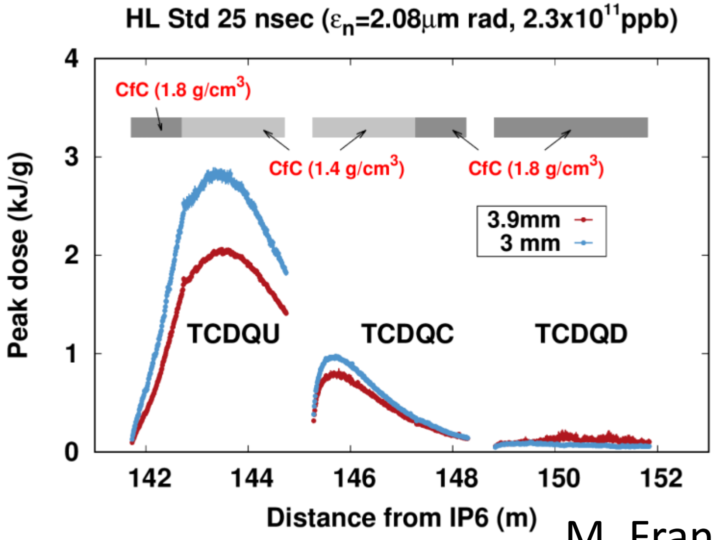
Constraints due to energy deposition in TCDQ (asynchronous beam dump)

- To evaluate effect of settings/optics on energy density in TCDQ, studied in addition a worst case scenario:
  - TCDQ@3mm = highest particle density at TCDQ in case of a Type 2 Erratic
- Conclusions:
  - Peak energy density increases by about 35%
  - Stresses to be evaluated, but might be close to limits
  - Recommend to aim for a gap larger than 3mm





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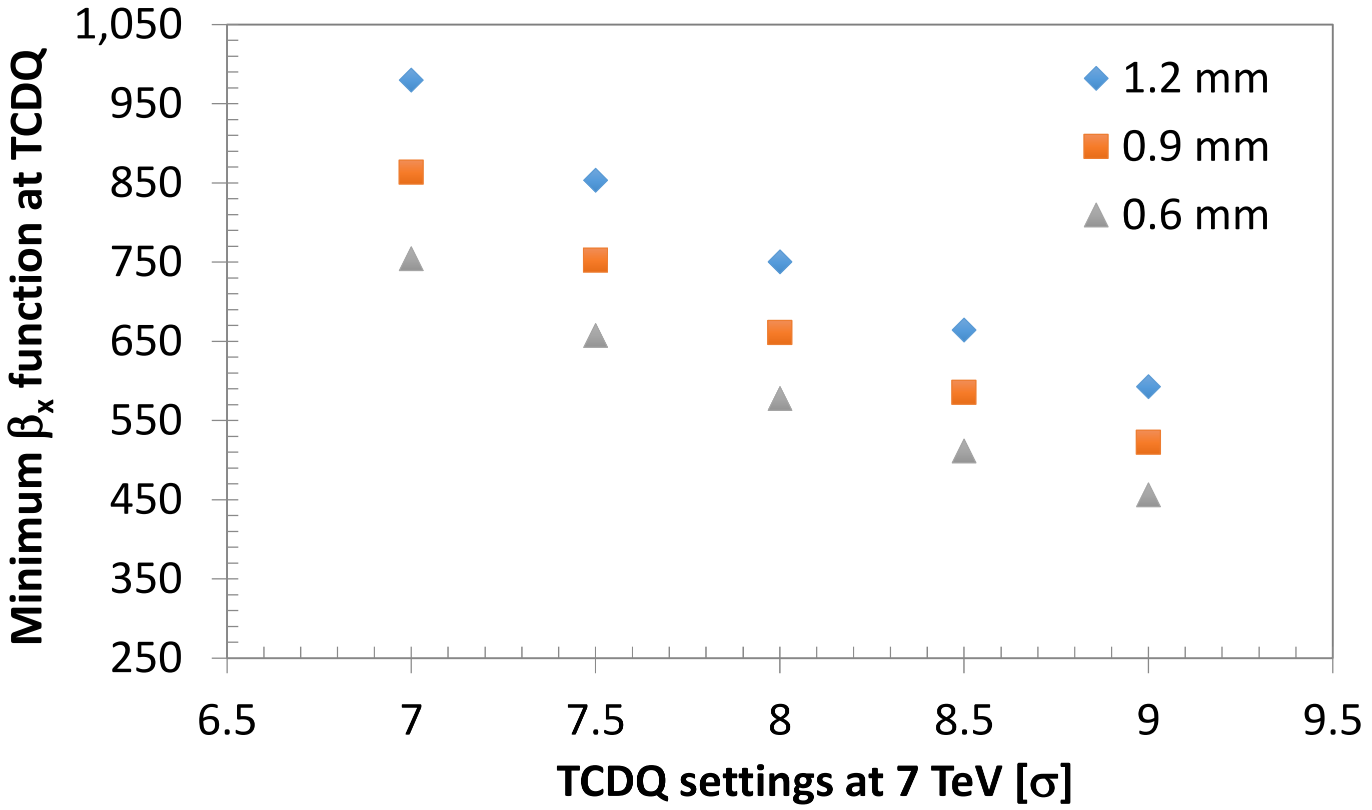
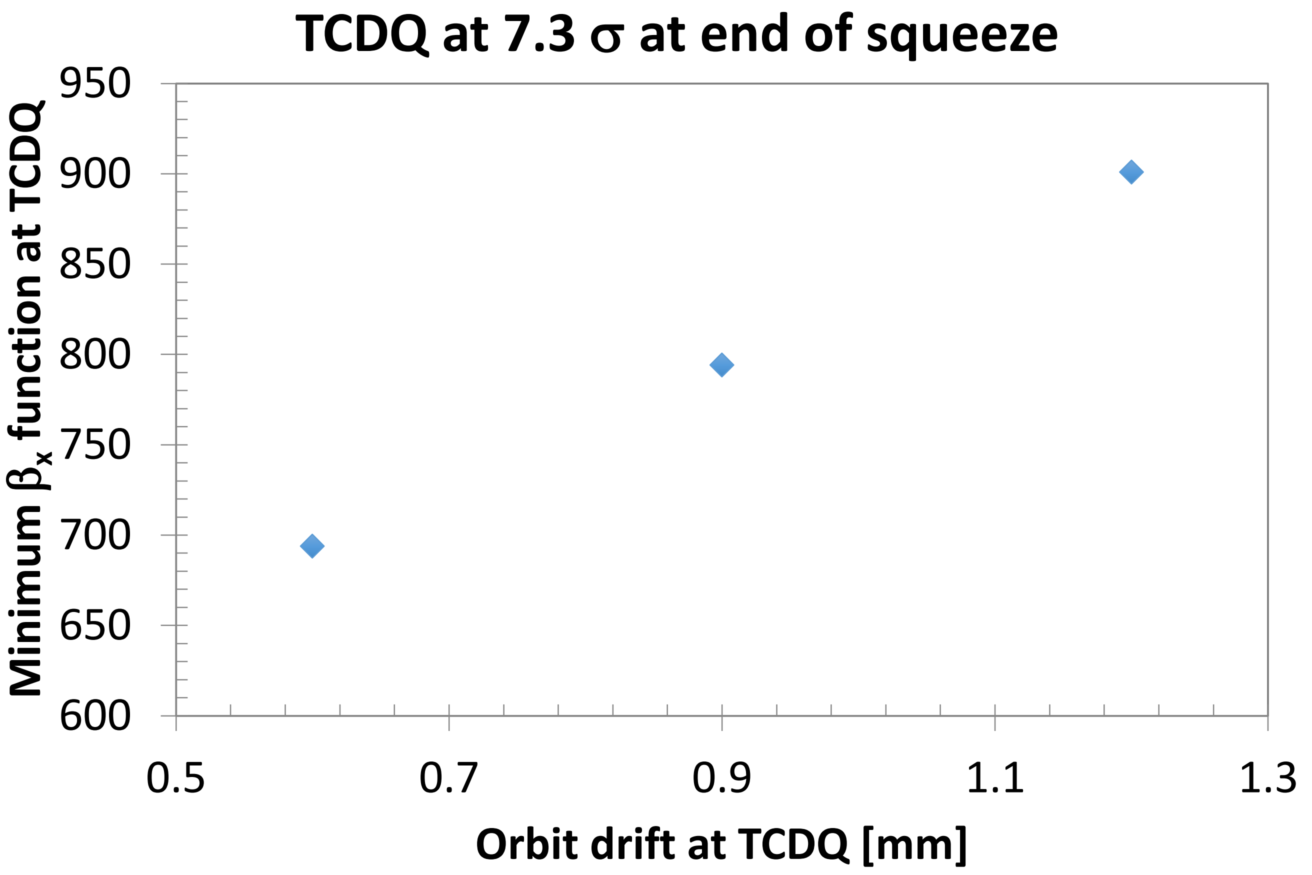
Constraints due to energy deposition in TCDQ (asynchronous beam dump)

- TCDQ minimum allowed gap > 3 mm
- Adding:
  - 1.2 mm orbit drift
  - 0.3 mm setup and optics errors
  - 0.4 mm for dispersion offset (D_x=2 m and $\Delta p/p$ =2e-4)
- TCDQ minimum allowed gap $\geq$ 4.9 mm
- Possible to relax it based on achievable reliability of interlock BPMs

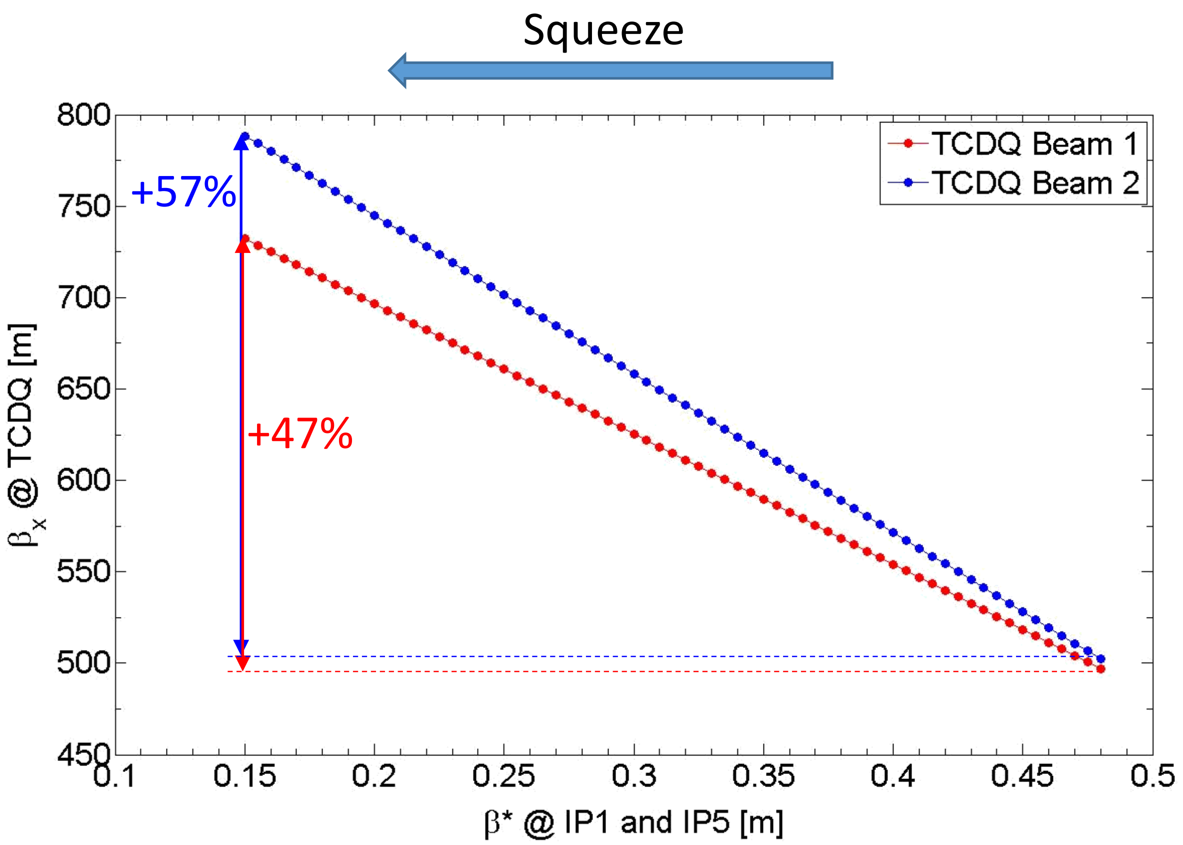


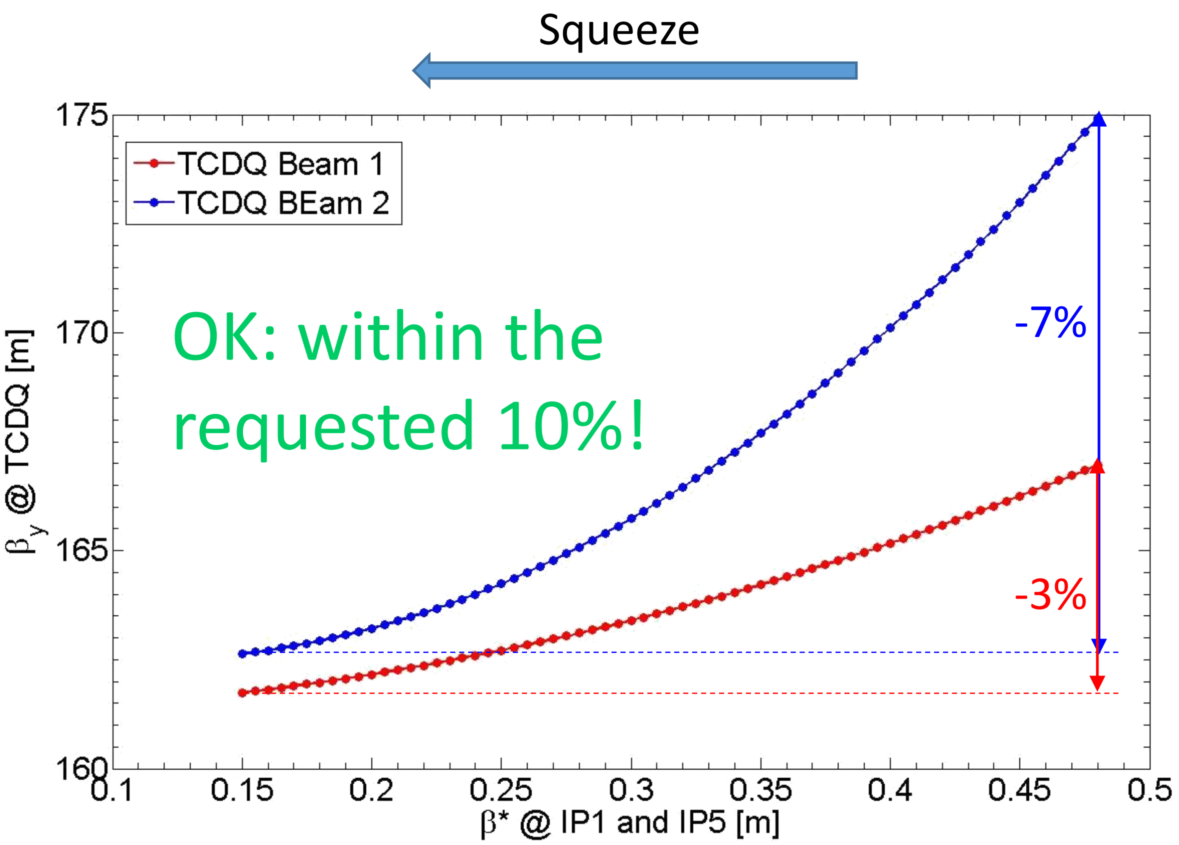
β_x @ TCDQ constraints to reach present settings (TCDQ @ 7.3 σ)

- TCDQ minimum allowed gap > 3 mm
- Adding:
  - 0.3 mm setup and optics errors
  - 0.4 mm for dispersion offset (D_x=2 m and $\Delta p/p$ =2e-4)
  - 1.2 or 0.9 or 0.6 mm orbit drift depending on achievable reliability of interlock BPMs



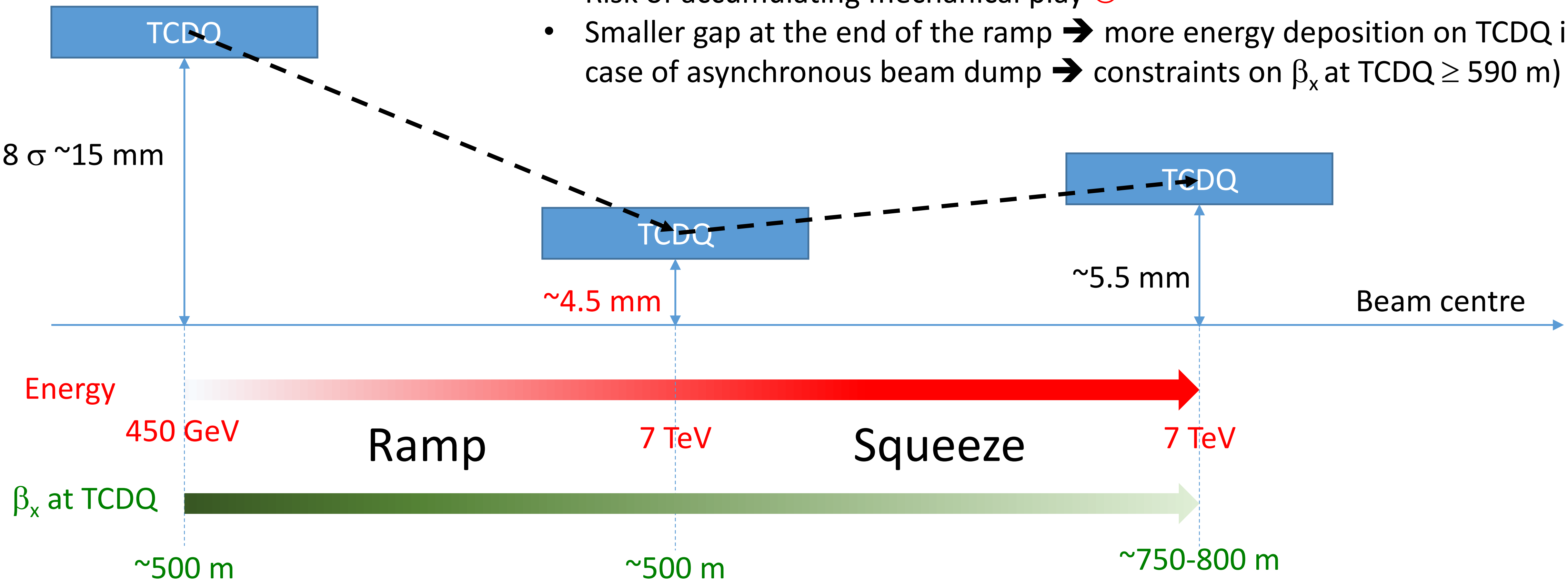
Beta Function @ TCDQ During Squeeze





Option 1: TCDQ @ 9 σ during squeeze

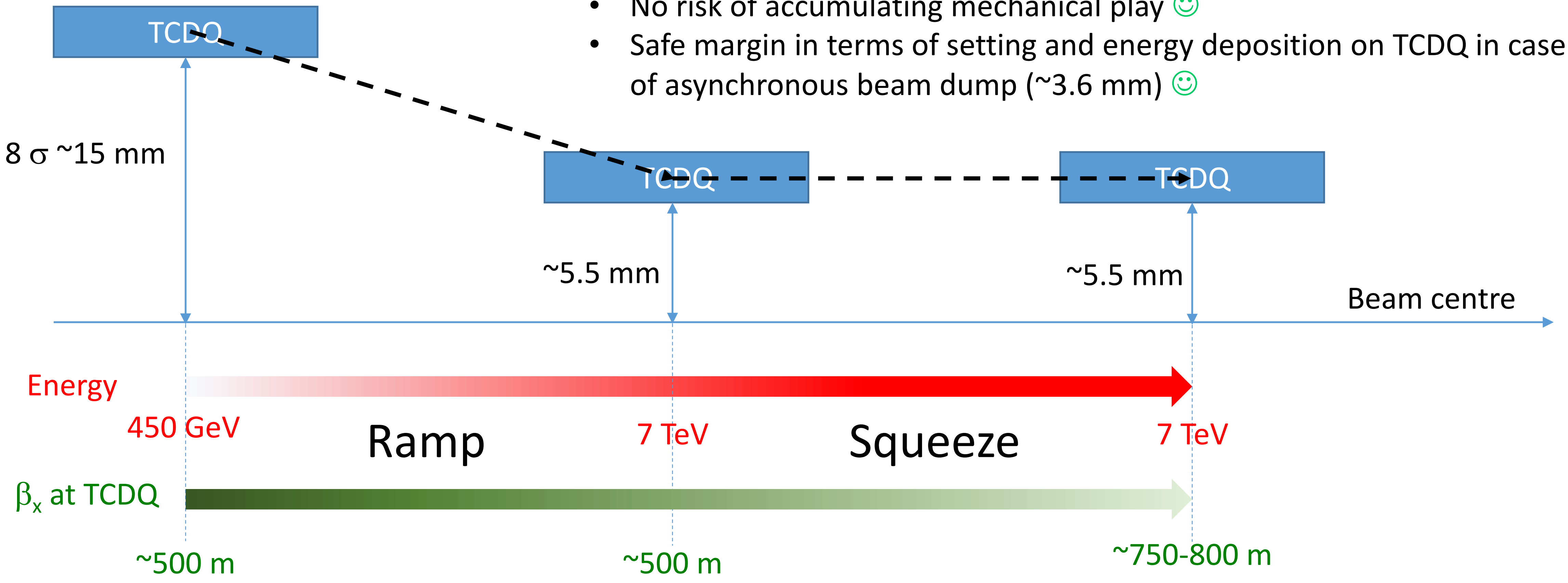
- Optimum hierarchy wrt other collimators during full cycle ☺
- Need BETS redesign 😐
- Risk of accumulating mechanical play ☹
- Smaller gap at the end of the ramp ➔ more energy deposition on TCDQ in case of asynchronous beam dump ➔ constraints on β_x at TCDQ ≥ 590 m) ☹



* Assuming 1.2 mm orbit drift

Option 1: TCDQ @ 5.5 mm during squeeze

- Slightly degraded protection of IR7 collimators (more escaping bunches in case of asynchronous beam dump) 😐 to be checked by WP5!
- No need of BETS redesign ☺
- No risk of accumulating mechanical play ☺
- Safe margin in terms of setting and energy deposition on TCDQ in case of asynchronous beam dump (~3.6 mm) ☺



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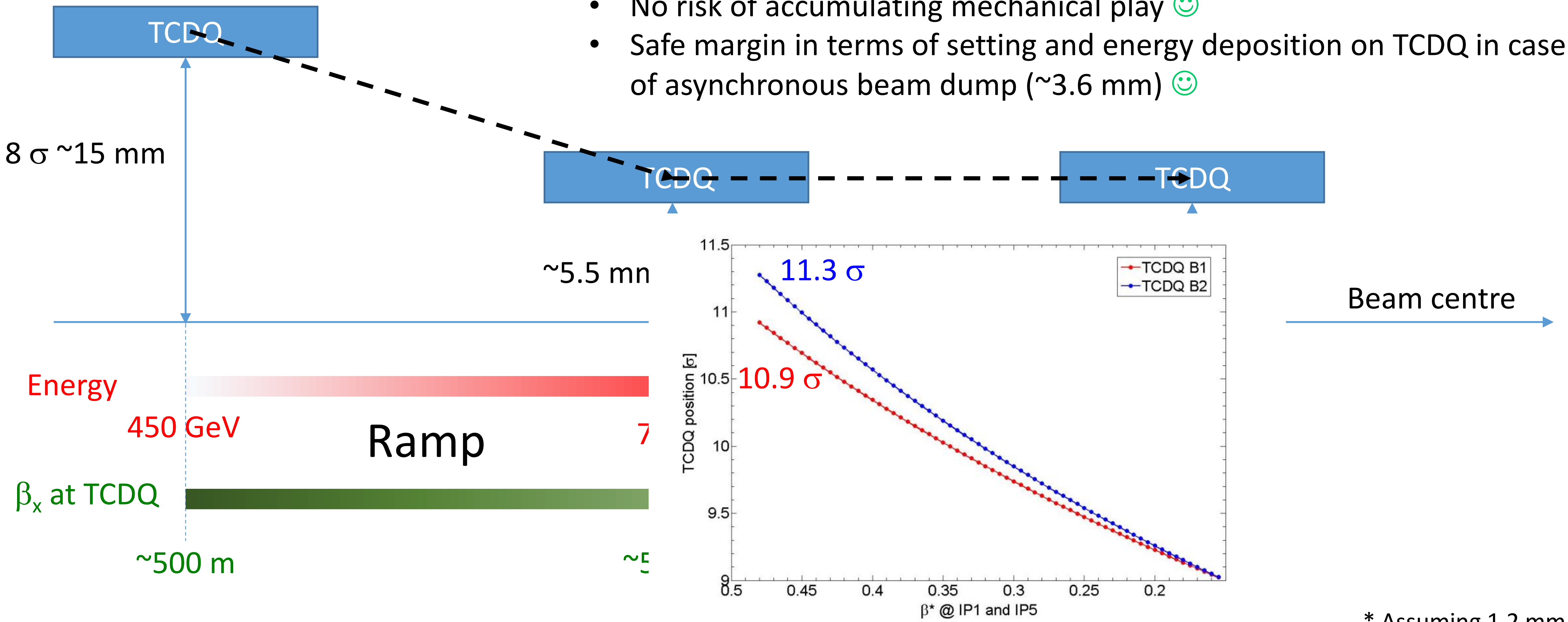

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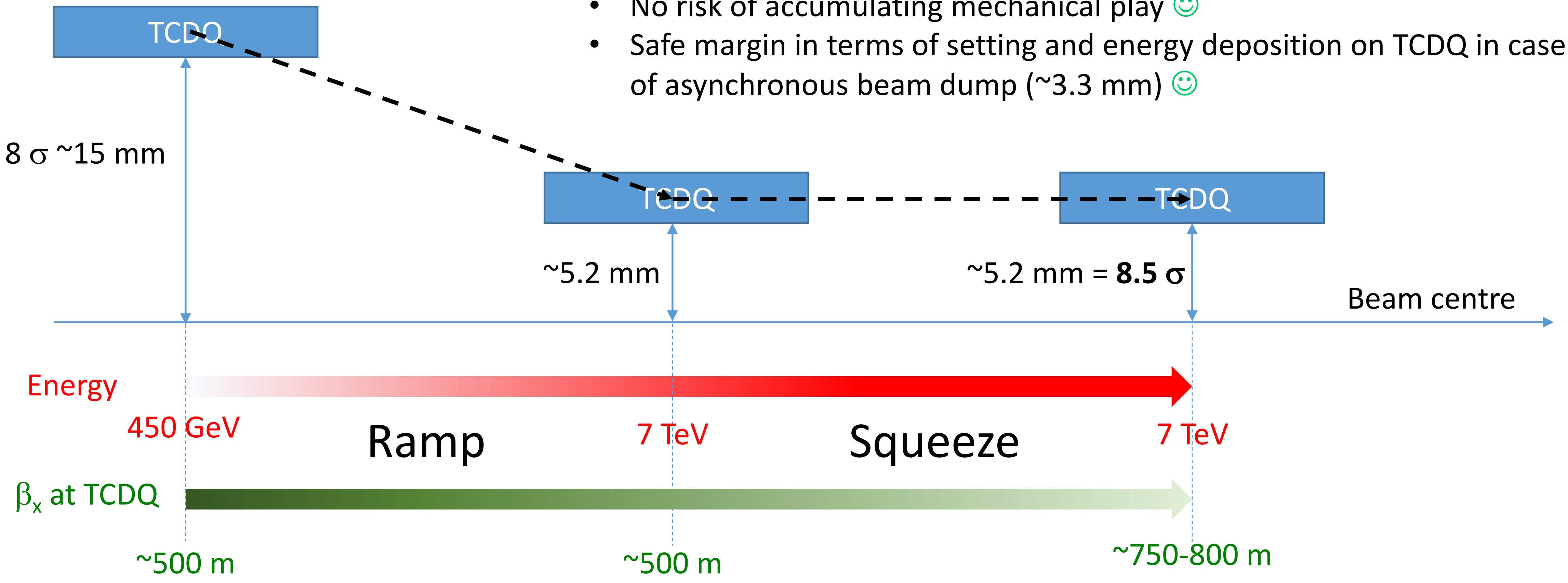

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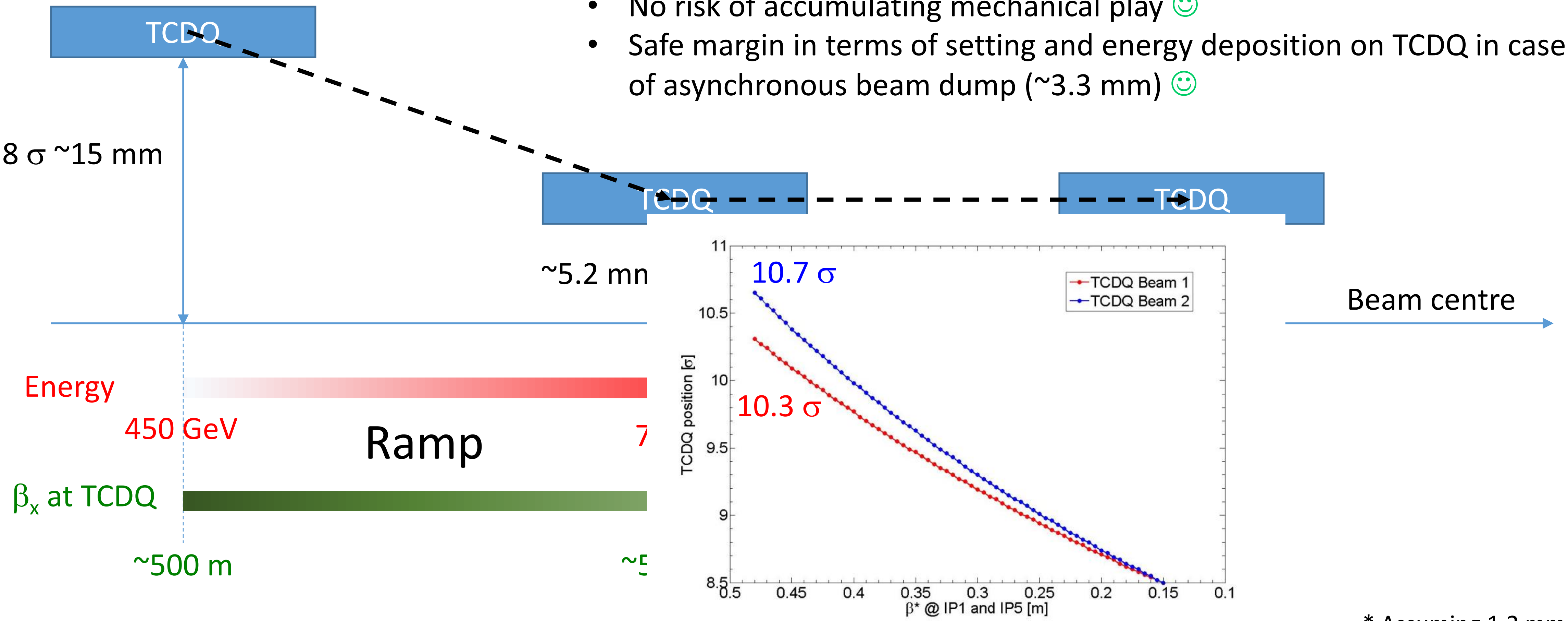

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- TCDS-MSD: $\beta_{x,max} \leq 175$ m at injection (aperture limitation) ✓
- TCDQ: $\beta_{x,min}$ such that minimum gap at 7 TeV > 3 mm taking into account all margins (0.3 mm setup and optics errors + D_x*Dp/p + orbit offset depending on achievable interlock BPM reliability/accuracy) ✓
- Ideally no TCDQ movement during squeeze (favourable also from point of view of minimum allowed gap and thus $\beta_{x,min}$ constraints) ✓
- D_x and Phase advance (strongest constraint!): for $-2\text{ m} \leq D_x \leq 2\text{ m}$ MKD➔TCTs $\mu_x \leq 52°$ **or** $129° \leq \mu_x \leq 232°$ **or** $\mu_x \geq 309°$ ✓

All these constraints are aimed to define an envelope for ABP optics studies, the final optics will have to be carefully checked and validated by means of particle tracking

Constraints due to energy deposition in TDIS (injection failure)

- β_x x β_y defines the peak energy density in the TDIS during injection failures
  - Thermo-mechanical studies showed that, with the present optics (β_x x β_y = 104 m x 43 m), the stresses in Graphite could be at the material limit for HL beams
  - To be verified in HiRadMat if the material can sustain HL energy densities (HRMT-28: joint test with LIU-TCDIs which have similar requirements – test to be completed soon)
- In any case, larger βs at the TDIS would be highly desirable to increase the margin