CT-PPS & AFP experiments in the (HL)-LHC optics landscape

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- **The conceptual "fragility"** (optics-wise) of the CT-PPS and AFP experiments

- Is there any **room or un-known yet dimensions for improvement**?
  - More or less "**symbolic" actions**: "Orbit bump" in 2016, "Optics bump" in 2017
  - **Telescopic optics** based on the ATS scheme, as **optics baseline for HL-LHC**
  - **Flat optics** with V crossing in CMS (.. but H crossing in ATLAS) under study for **Run III**

- **Summary and outlook**

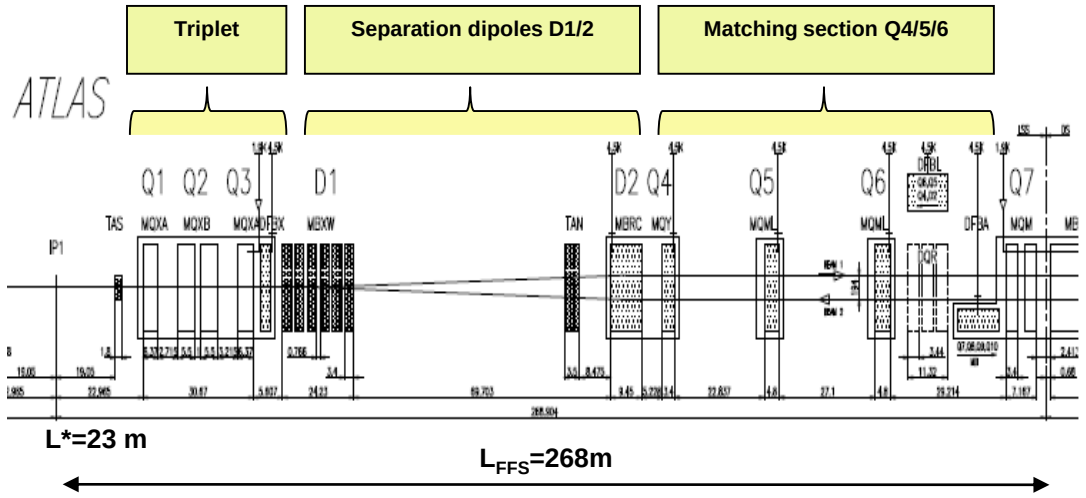
The conceptual “fragility” of the CT-PPS & AFP experiments

→ Both experiments rely on the **small and rigid** dispersion generated by the D1/D2 separation-recombination dipoles.

→ **At the D2 exit w/o crossing angle**

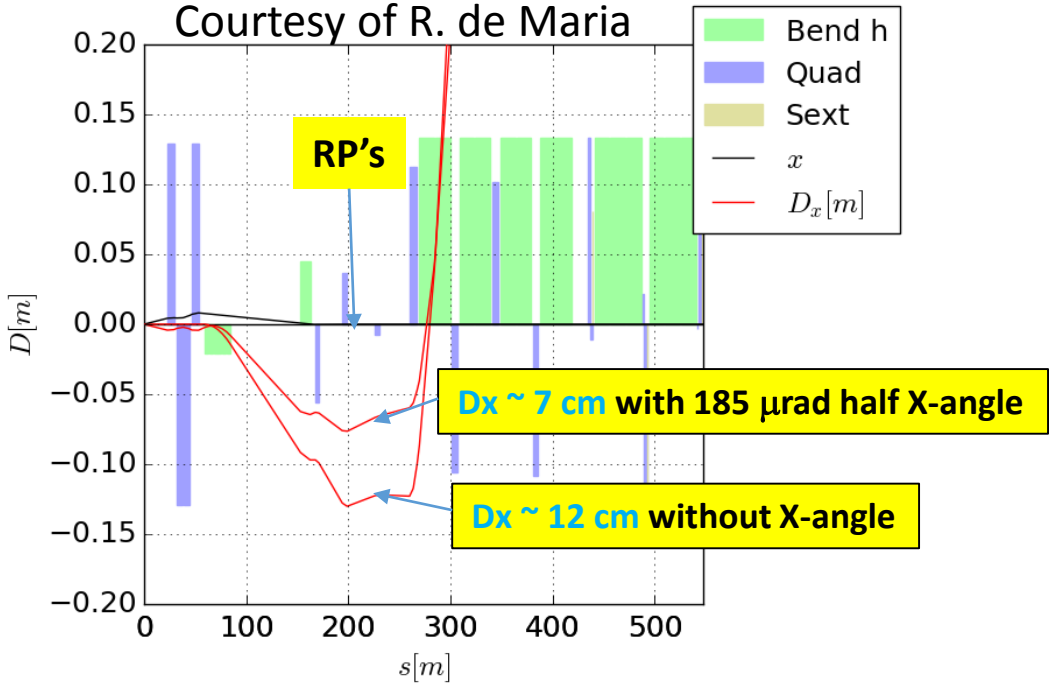
D_x ≈ 194 mm /2 ≈ 97 mm & D_{Px} ≈ 0 (angular dispersion).

This dispersion is fixed by the main dipole geometry !!



→ **At the RP’s between Q5 & Q6:**

It can hardly increase by more than 2 cm, because (i) the Q4/RP distance is short, and (ii) Q4 (H-defocusing) has a low gradient for (standard, i.e. non-ATS) squeezed optics.



→ **Additional impact of an horizontal crossing angle**

1. An H crossing angle can only be positive for beam1 (otherwise leading to a “second IP” in D1)
2. It induces a dispersion fighting against the D1/2 dispersion by about **2.5 cm per 100 µrad half X-angle**

How to improve?

- The min. mass reach is ~ inversely proportional to the normalized dispersion at the RP $1/M_{min.} \propto \frac{D_x}{\sqrt{\beta_x}}$

- **Dispersion (orbit):**

→ Options for increasing the dispersion are **quite limited.**

(i) At most 5 mm (7%) by decreasing the X-angle from 10 σ to 9 σ which is probably a conceptual limit.

(ii) <5% (below machine uncertainty, with some risk) by strongly modifying the Xing bump as in 2016.

(iii) The only way for drastic improvement (>50%) is to go to **vertical crossing with flat optics (see later).**

- **β-functions (optics):**

→ Options for decreasing β_x looks **more promising** (assuming in parallel a reduction of the min. RP gap).

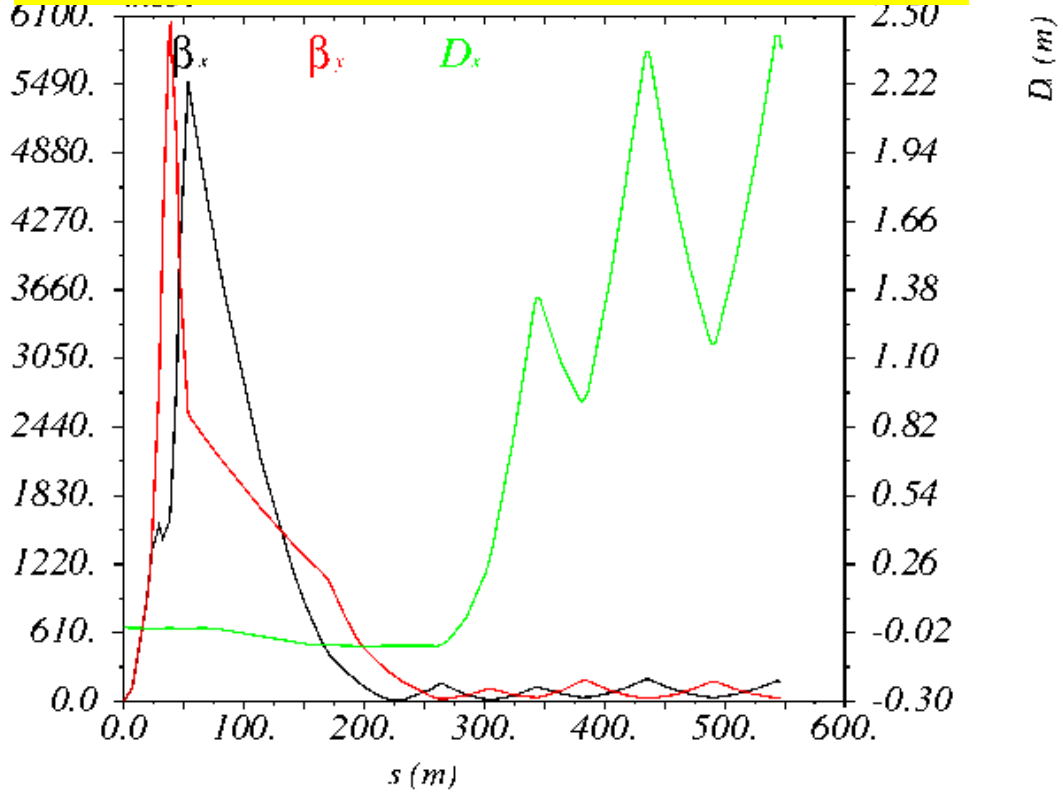
(i) "CT-PPS squeeze" (option 3bis) chosen for 2017 (LMC#297) by pushing the matching quads, as e.g. Q6 down to 200A: ~10% min. mass re-improvement …at the limit of significance, but better than 0 !

(ii) Much more can in principle be gained **with telescopic optics (see later)** by

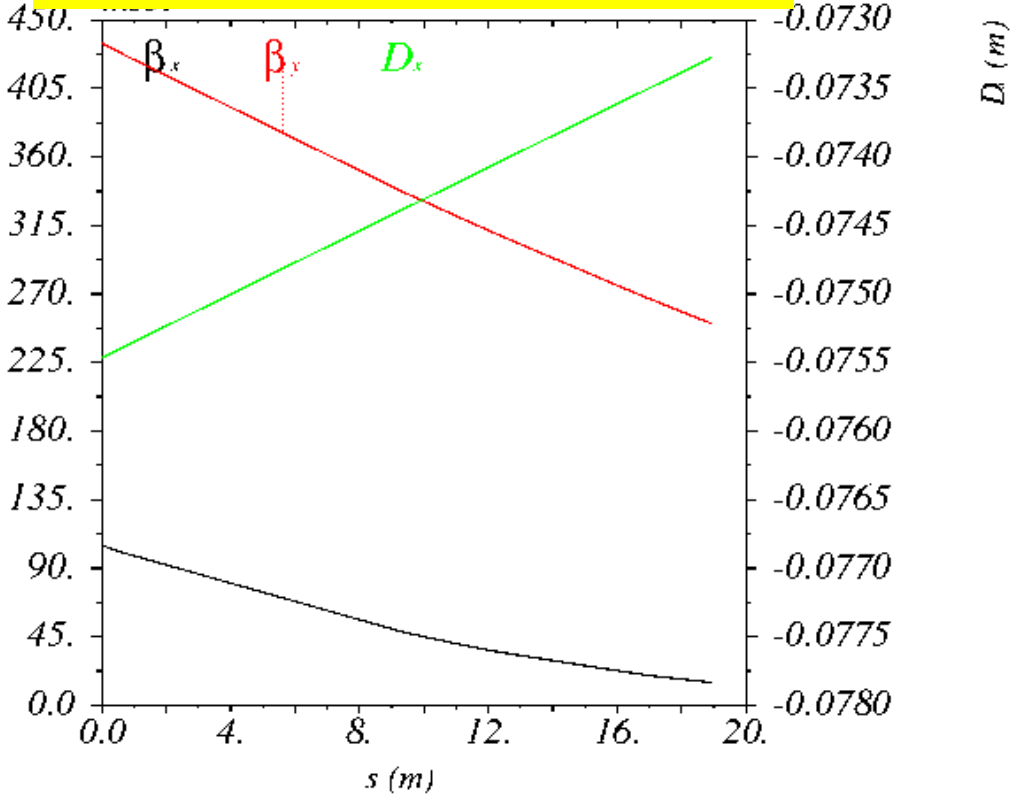
1. Downgrading β* in a first step (so-called pre-squeezed optics) for more **internal optics flexibility with stronger Q6 and more potential for CT-PPS-like-squeeze to create a kind of second IP @ Q6**
2. Then "re-squeezing from outside" (telescopic squeeze) to preserve β^* for CMS (see later).

Beginnings of a CT-PPS squeeze in 2017 (animation) …

Beta's and Single-pass dispersion for beam1 on the right side (β* is cst at the IP)



Zoom in the zone of the CT-PPS RP's (200-220 m w.r.t. the IP)



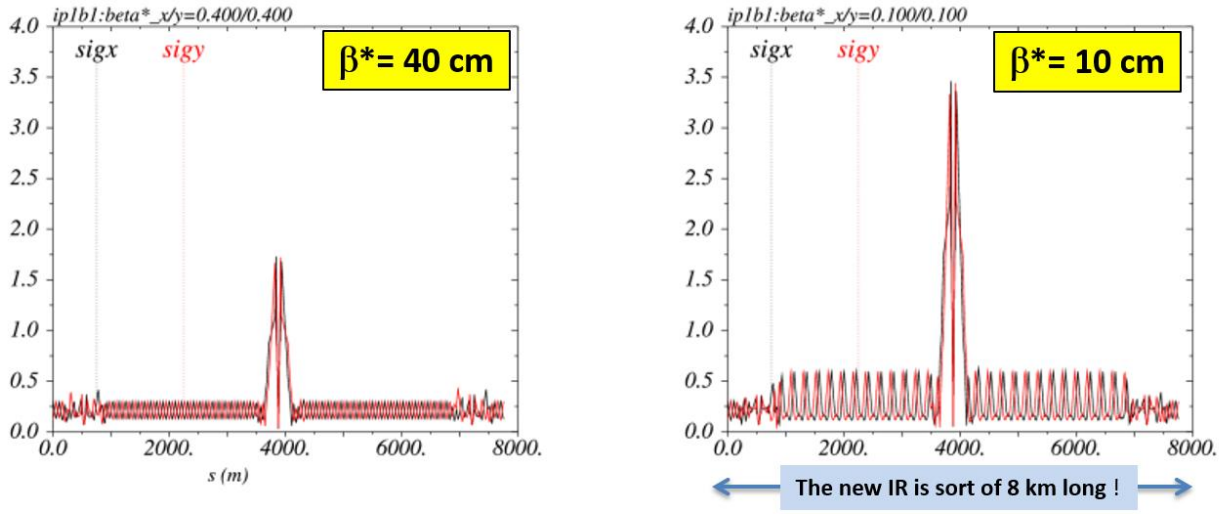
.. **Not very impressive for a squeeze** (only 15-20% β_x-reduction at the RPs, 200 μm dispersion increase). **We should be able to do better.**

Telescopic optics (1/3)

- **Recap on ATS optics (in principle) for very small β* (HL-LHC Baseline optics)**

*The **Achromatic Telescopic Squeezing** (ATS) scheme (1/2)*

- **Small β* is limited by aperture but not only**: optics matching & flexibility (round and flat optics), chromatic effects (not only Q'), spurious dispersion from X-angle,..
- **A novel optics scheme was developed** to reach un-precedent β^* w/o chromatic limit based on a kind of generalized squeeze involving 50% of the ring



Beam sizes [mm] @ 7 TeV from IR8 to IR2 for typical ATS "pre-squeezed" optics (left) and "telescopic" collision optics (right)

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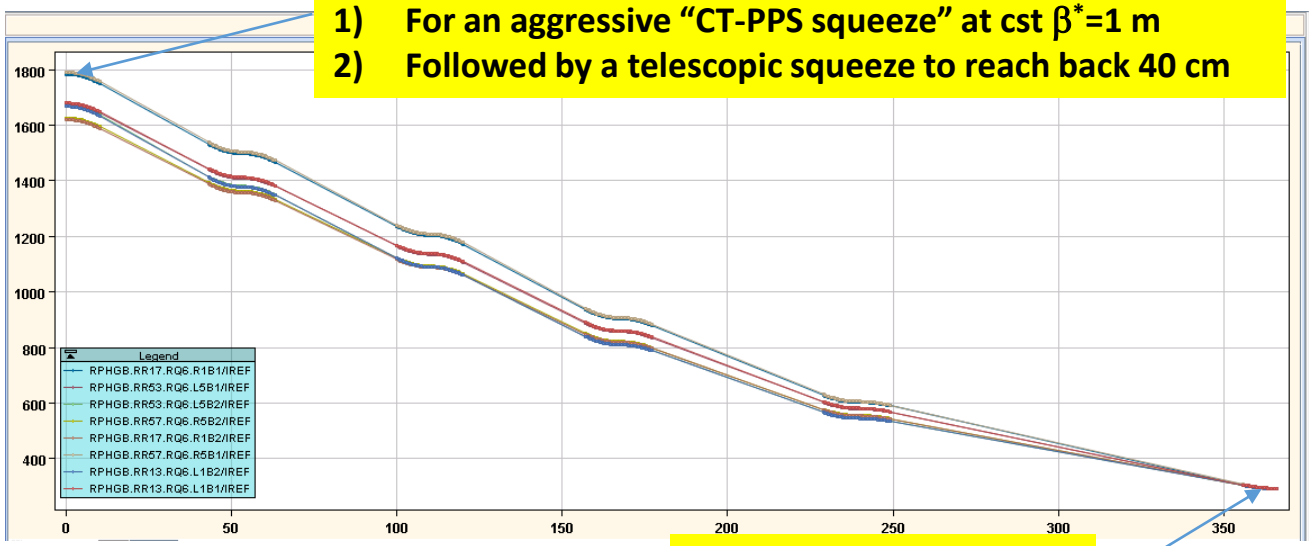
Telescopic optics (2/3)

- Viewed differently, the ATS can be used to preserve "standard" LHC β^* (e.g. β^* =40-30 cm) in a telescopic manner:

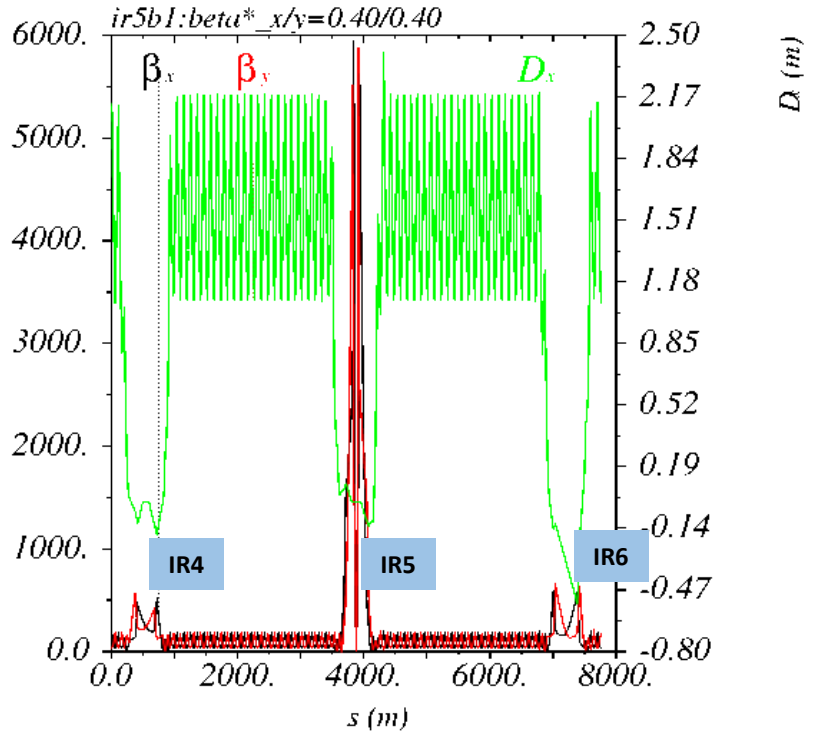
→ To **relax the demand on the IR1/5 matching quadrupoles** themselves,

→ Then to better **optimize internal IR1/5 constraints other than β^*,** e.g. much smaller β_x at the pots !

Q6> 1.5 KA @ 1m, offering quite some flexibility
1) For an aggressive "CT-PPS squeeze" at cst β^*=1 m
2) Followed by a telescopic squeeze to reach back 40 cm



Q6@300A (quite low)
at 40 cm (w/o telescope)



"<u>Natural</u>" Q6 current for a standard ATS pre-squeeze (w/o telescope) from 1 m to 40 cm

Un-squeezing IR5, and re-squeezing from outside to relax the demand on matching quad.'s at cst β^*=40 cm

Final considerations on Telescopic optics (3/3)

- Even if not for β^* proper, telescopic optics will need to be implemented soon in the LHC for HL-LHC optics validation, and with a large telescopic index (3→4).

- At that moment CT-PPS (& AFP) will be able to profit from a much more performing "2017-like CT-PPS squeeze"

→ *..provided that roman pots equipped with new HW (as e.g. 220F), and the machine protection are ready to go beyond the 1.5 mm minimum gap.*

- Flat optics are also in the pipeline (for Run III) and are planned anyway to be done in a telescopic manner because of the aggressive (15-20 cm) β^* in one of the two planes

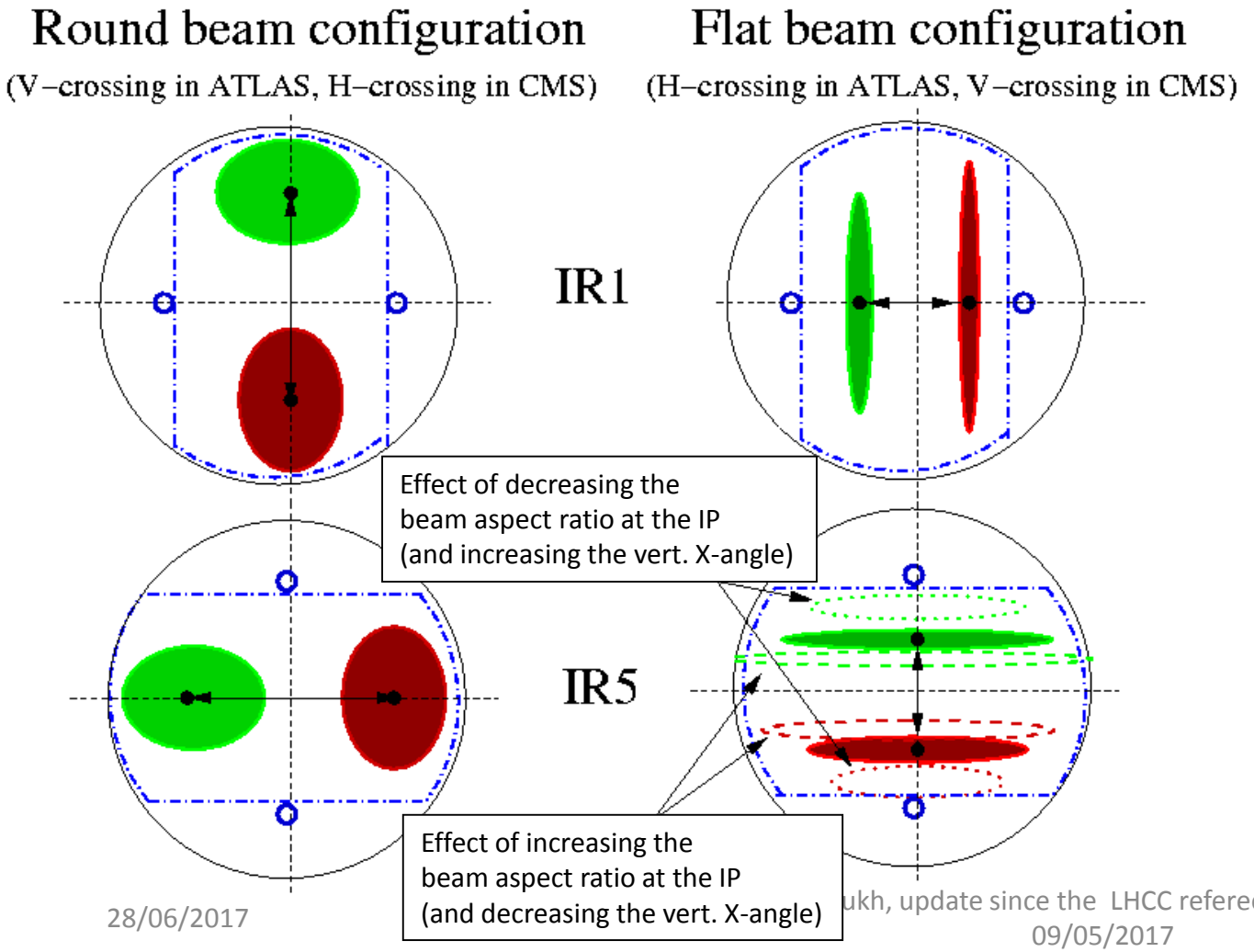
→ *CT-PPS will certainly "double gain" with* ***Telescopic flat optics*** *(& V crossing)*

→ *AFP will gain less (due to H crossing for flat optics in ATLAS).*

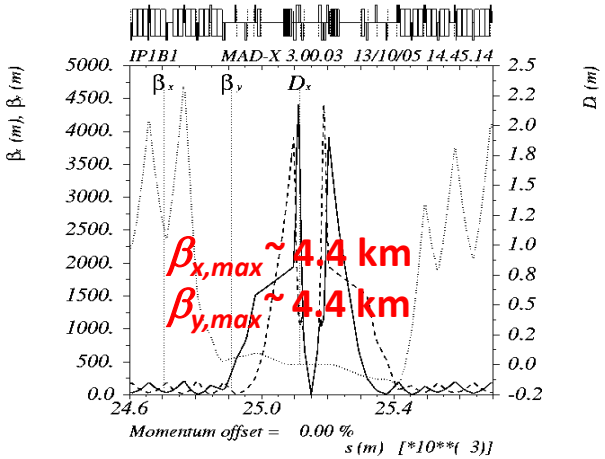
Some non-negligible R&D + MD time is still ahead to develop & validate all these idea, then precisely quantify the benefits for CT-PPS, but certainly in the 50%-100% range

Flat optics (1/3) .. **CT-PPS will gain, AFP might loose !**

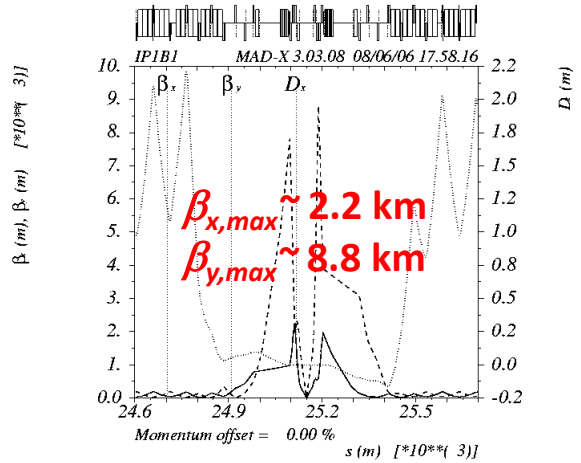
- **<u>Competitive flat optics in LHC</u>** (typically $\beta^*_{x/y}$= 100/25 cm instead of 50/50, down to 60/15 instead of 30/30) requires to **change the crossing plane orientation** (for triplet aperture)



Round 50/50



Flat 100/25



Very old idea (CERN MAC, 2006) recently revived

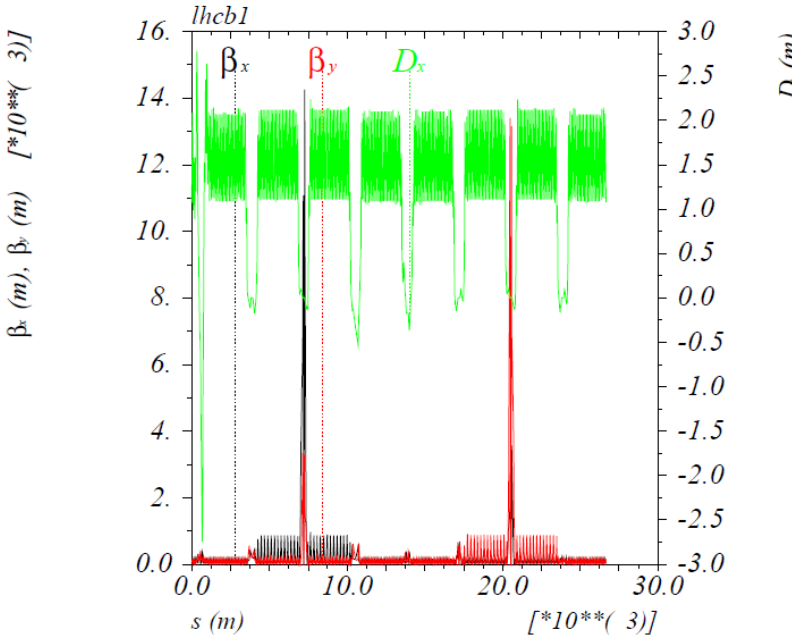
ukh, update since the LHCC referee ses
09/05/2017

Flat optics (2/3)

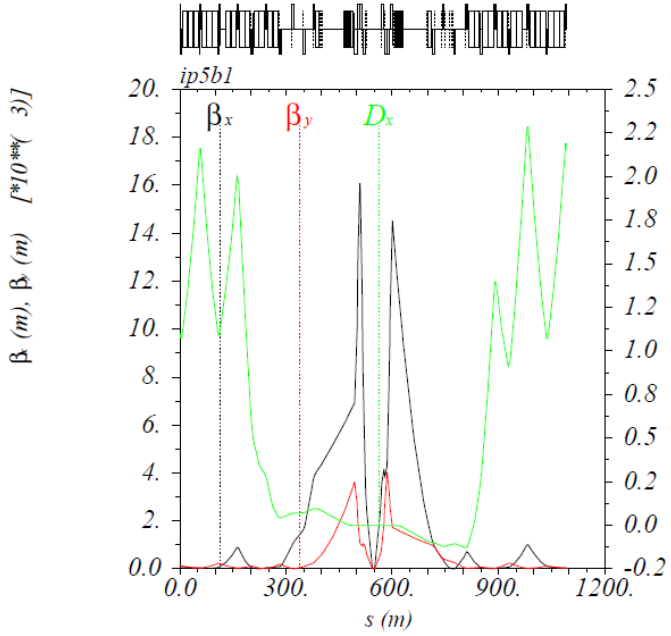
- **Most promising and competitive flat optics for LHC**

→ **60/15 cm with 150 μrad Half X-angle H/V in ATLAS/CMS**

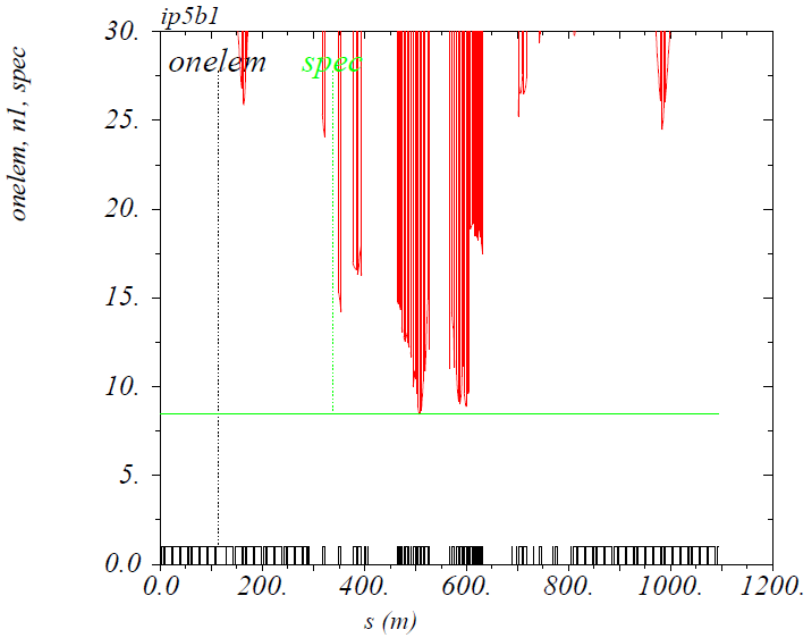
→ **2.4E34 peak lumi @ 6.5 TeV with BCMS beam** (2592 collisions, 1.2E11, $\gamma\varepsilon$=2.5 μm, σ_z=7.5 cm) **and up to 3.5E34 with 8b4e !...**



Can be realized with a tele index of ~ (1,4) for ATLAS and (4,1) for CMS (still to be optimized for beam-beam)



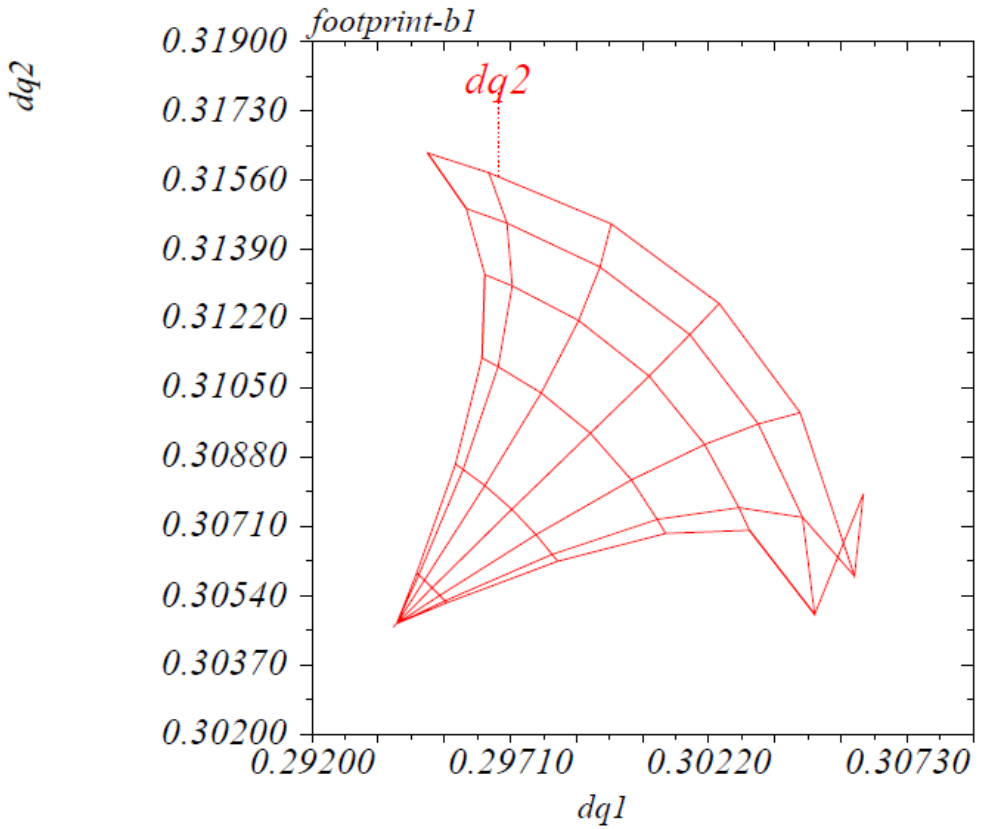
β_{max} ~ 16 km in the separation plane !
→ IT multipole correction is vital !

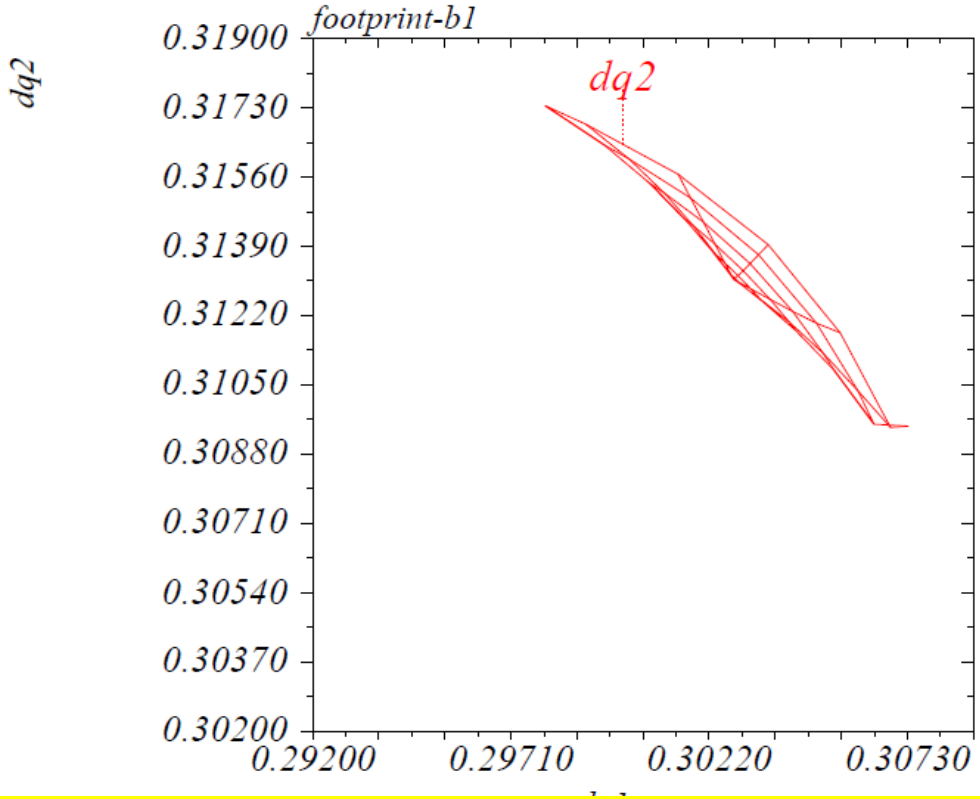


Aperture is at the limit @6.5TeV 8.5 σ in the IT and 15 σ in the MS (@Q5 for the worst case of CMS)

Flat optics (3/3)

- Footprint with 2 IP's, 154 μrad half X-angle (12.5 σ @ 6.5TeV and γε=2.5 μm)





With HO and LR

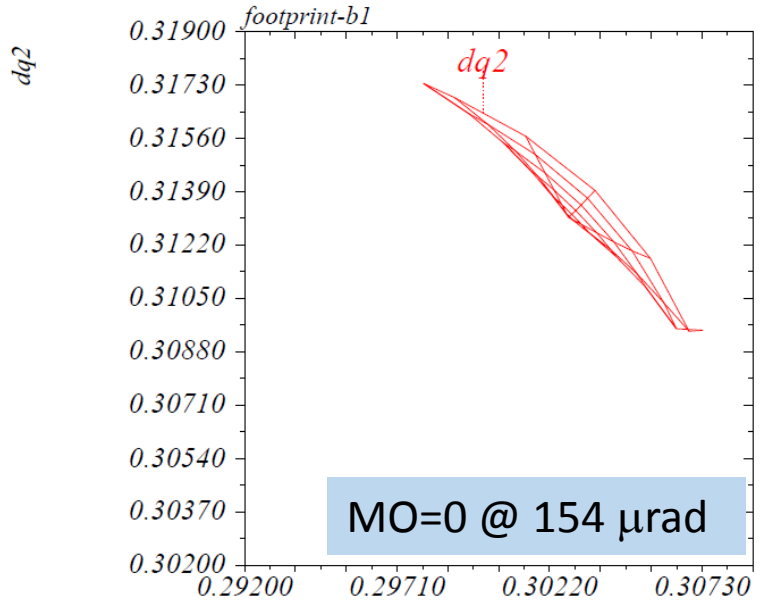
New features showing up with LR only

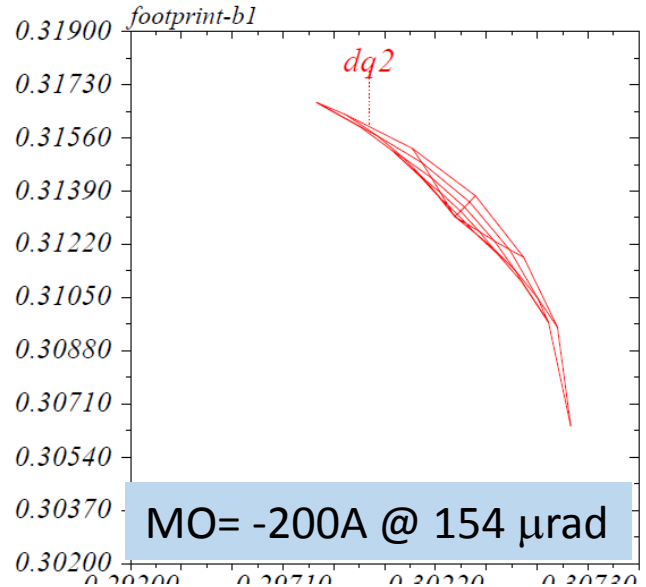
→ **LR tune shift of - 0.0035/IR**

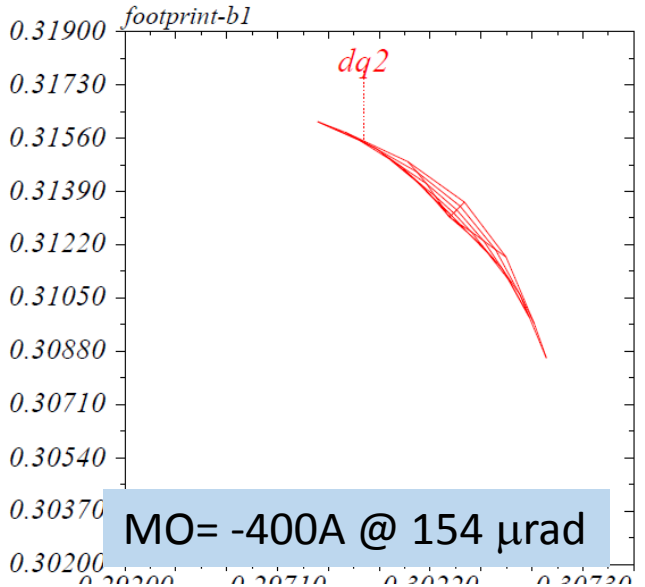
→ **Reduced cross-anharmonicity (LR spread> 0 along the diagonal)**

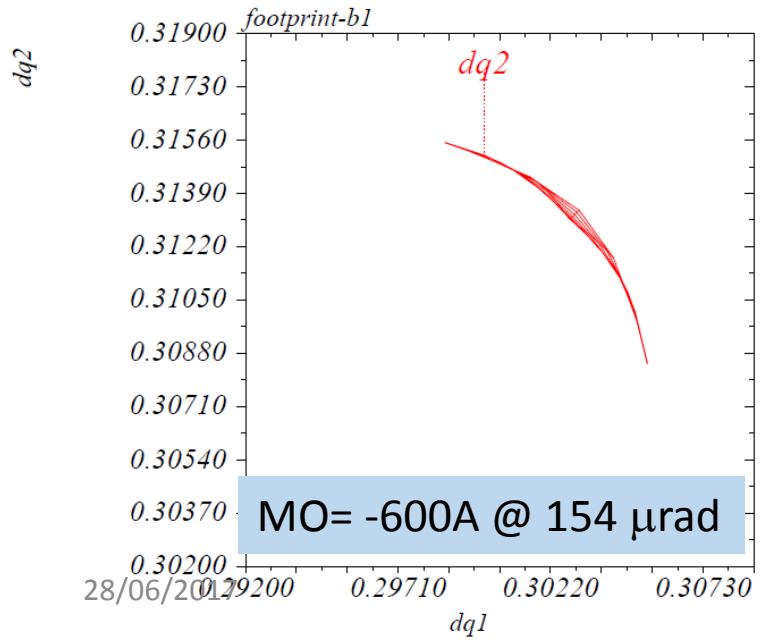
→ **B6-like spread showing up ($\Delta Q \propto J^2$)**

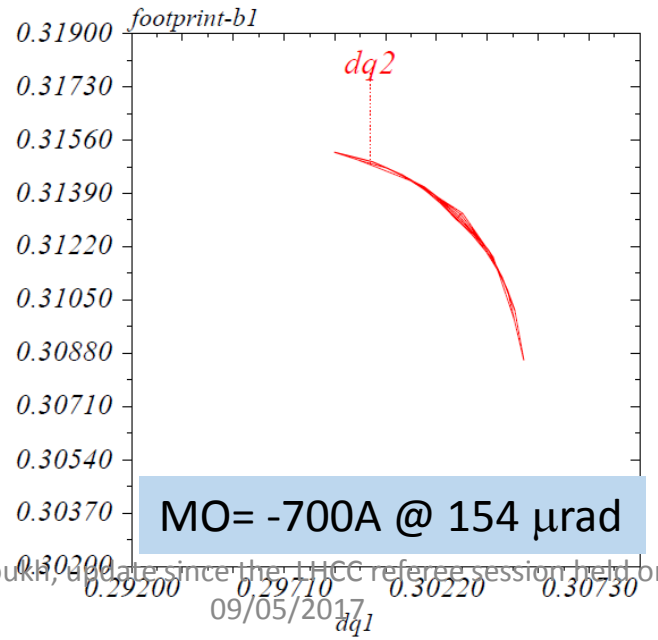
With very good LR Correctability with MO (even with badly optimized telescope)

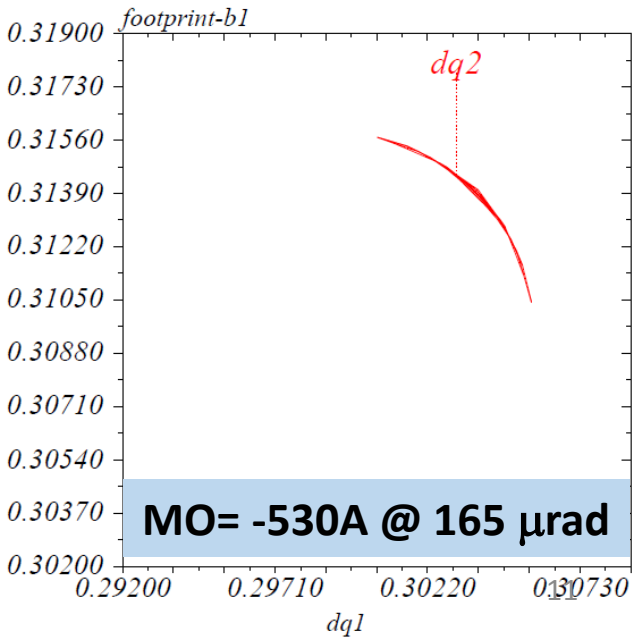






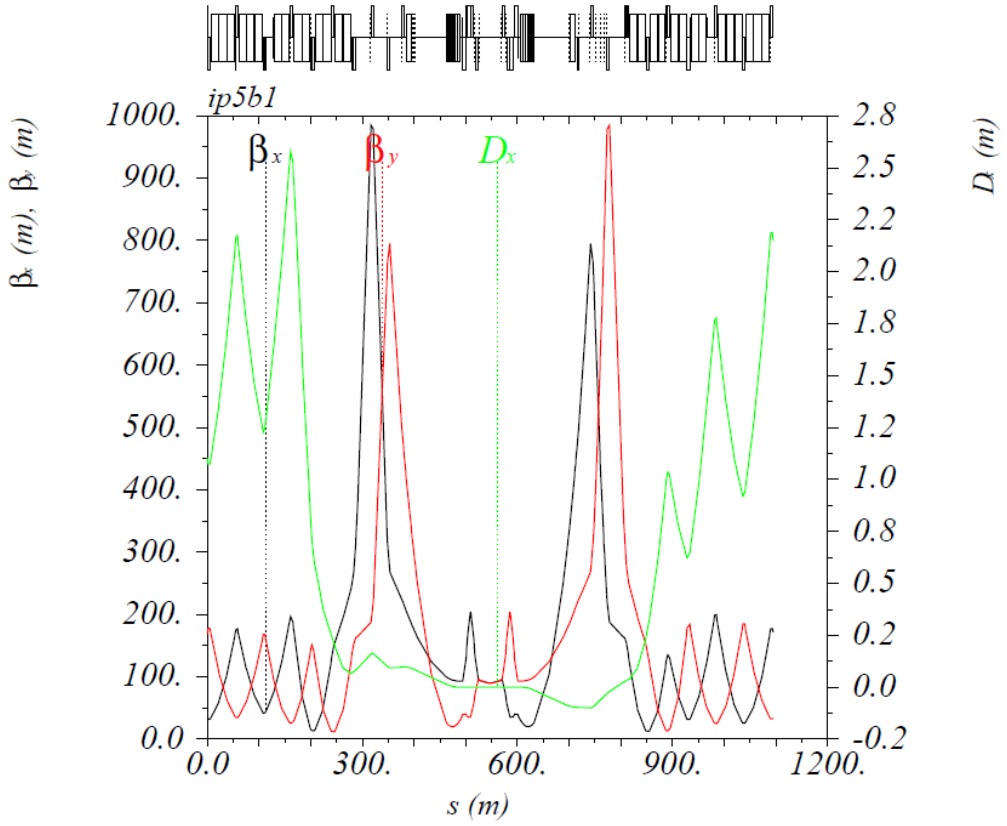




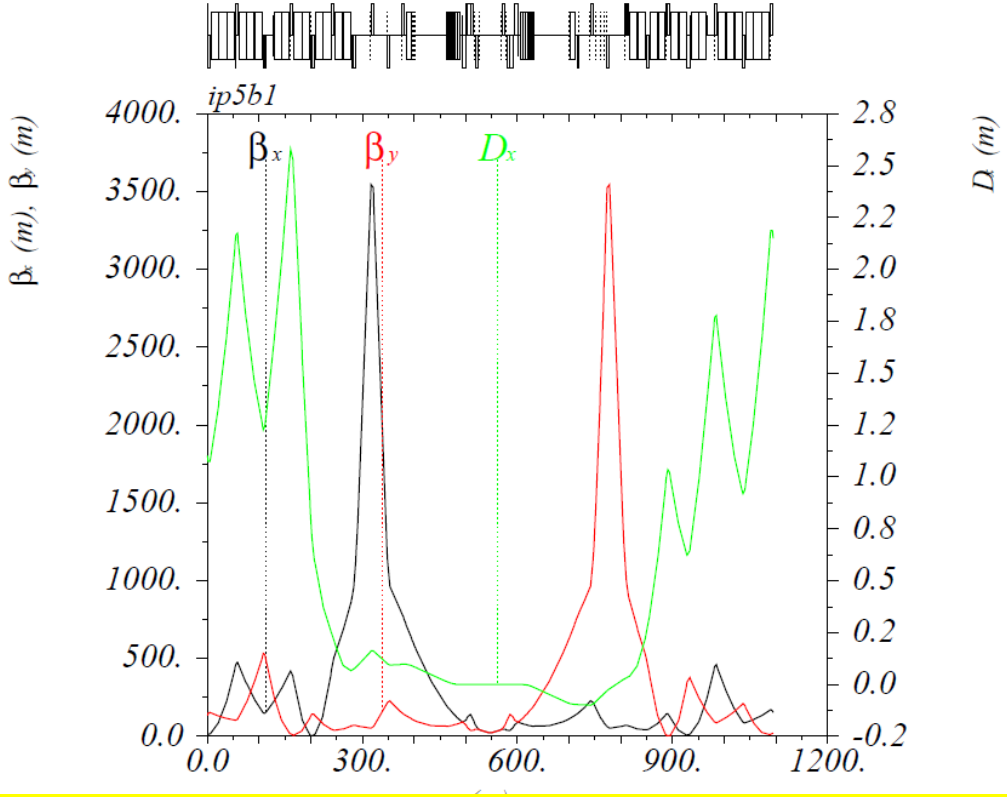


Other “telescopic by-products” (one example amongst others)

From huge β* optics and/or faster de-squeeze using the telescopic techniques, to more luminous 90 m-like optics !



“Standard” 90 m-optics
with **prescribed R12 and R34 from the IP to the RP**



..4 times more luminous by telescopically re-squeezing to 25 m
.. therefore **at constant R12 and R34** !!
.. and reopening **25 ns possibilities** (at least for beam-beam effects)

→ Still preliminary (many details to be looked at), but it might be a good idea to re-start to brainstorm on a possible 25 ns upgrade of the electronics .. If so up to a **factor ~10 in lumi !!**

Summary & Outlook

- The first step has been achieved this year by implementing the ATS in the LHC, with some immediate inconvenience for CT-PPS but also much more potential for future improvements.

- The ATS is a wonderful tool for small β^* but not only. A lot of imaginative work is indeed ahead to extract the best of it, in particular to serve the entire FP community.

- The CT-PPS and AFP needs and limitations are now well-understood, together with clear directions for net improvement. Entering in the "telescopic era of the LHC", both experiments can only profit from this move in the near future: not talking at the 5-10% level, but more at the 50-100% level !