LHC Collimation Project CERN

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Summary of aperture measurements and comparisons with n1

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Acknowledgement:
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Contents

- Collection of aperture measurements in previous run including references
- Comparison between n1 model and measurements
- For discussion: Can we conclude on an updated set of parameters to use in the n1 model?

Time-line of aperture measurements

- **2009-2010**
  - Global and local aperture for selected elements at injection, kicker method
- **2010**
  - Global aperture at injection, crossing 1/3 resonance (used for decrease in b*)
- **2011**
  - Global aperture at injection, crossing 1/3 resonance
  - Triplets IR1/5 using bump method
    - Injection
    - b*=1.5m
    - b*=1m

    } used for decrease in b*
  - IR2 triplet, b*=1m (used for Pb-Pb run)
- **2012**
  - Global aperture at injection, ADT method
  - Triplets IR1/5 using ADT method
    - b*=60 cm (used for decrease in b*)
  - IR8 triplet at injection, bump method (used to evaluate possible vertical crossing)
- **2013**
  - IR2 triplet with ADT method (used for p-Pb run)

First measurements

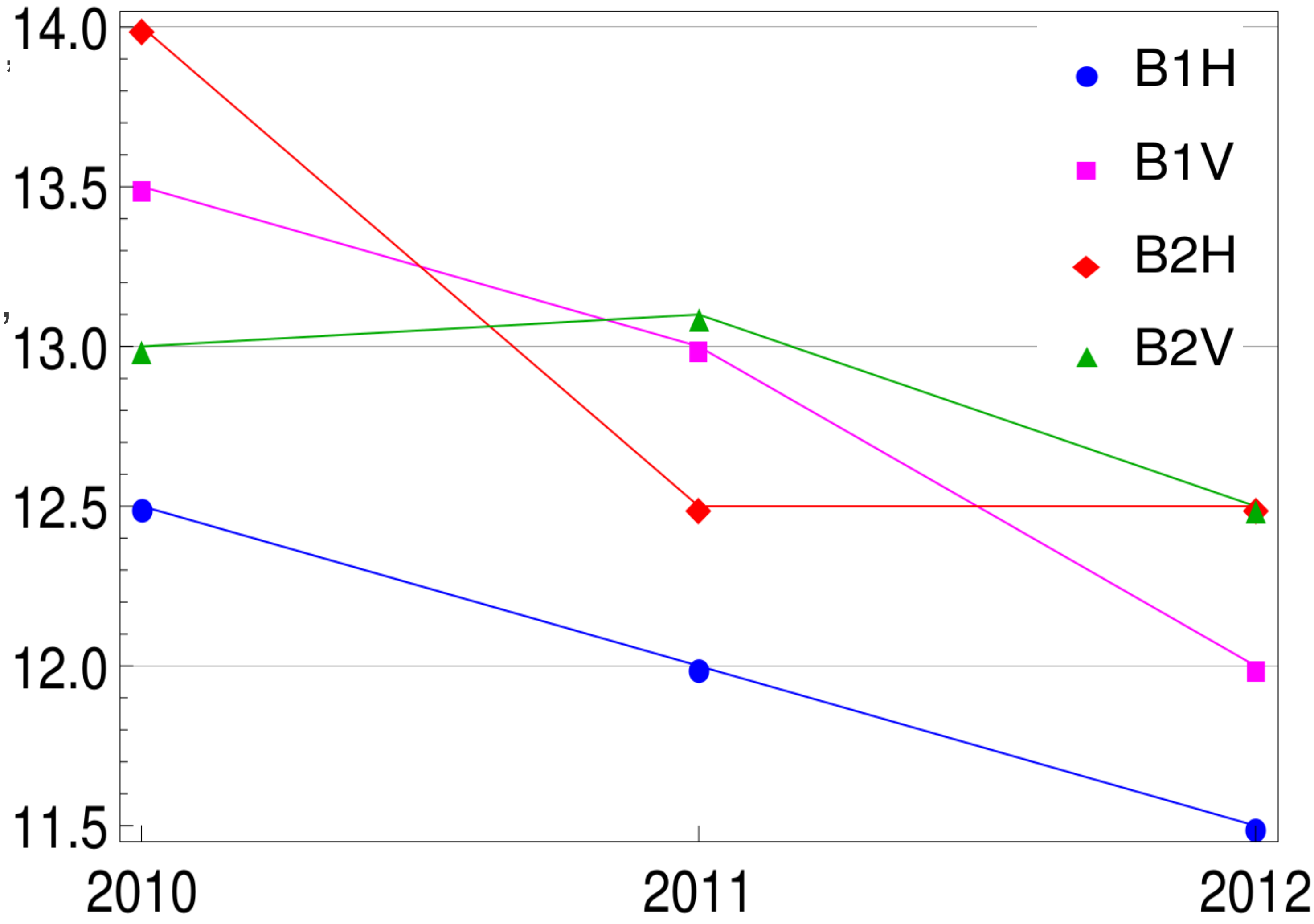
- Pons et al., IPAC10, MOPEC010
  - Global and local measurements using aperture kickers
  - $n_{1,meas} = n_{1,mod}(a_{meas})$

Table 1: Results from the global and local measurements (the latter correspond to the cases notified by "*").

BEAM 1 - HORIZONTAL			
Magnet	$a_{mod/meas}$(mm)	$n_{1,mod/meas}$	c (mm)
MQM.6R2*	21 / 20	9.7 / 9.0	1.2
MQM.6R8	21 / 16	10.0 / 7.4	
MQY.4R6	28 / 26	9.4 / 9.1	
BEAM 1 - VERTICAL			
Magnet	$a_{mod/meas}$(mm)	$n_{1,mod/meas}$	c (mm)
MQ.13R8	17 / 13	10.6 / 8.5	
MQ.8R7	17 / 14	9.8 / 8.4	
MQ.14L8	16 / 14	10.3 / 8.9	
MQ.25R8	17 / 15	10.5 / 9.7	
MQY.4L6*	28 / 25	9.1 / 8.2	-0.3
MQM.6L2	22 / 18	9.6 / 8.1	
MQ.11L5	17 / 15	9.9 / 9.4	
MQY.6L4*	28 / 22	10.0 / 7.8	-2.4
MQY.5R6*	28 / 24	9.6 / 8.1	-1.5
BEAM 2 - HORIZONTAL			
Magnet	$a_{mod/meas}$(mm)	$n_{1,mod/meas}$	c (mm)
MQML.10R1*	21 / 19	9.7 / 9.4	1.0
MQY.4L6*	27 / 24	9.1 / 8.2	
MQY.5R6*	27 / 25	9.7 / 9.0	2.4
BEAM 2 - VERTICAL			
Magnet	$a_{mod/meas}$(mm)	$n_{1,mod/meas}$	c (mm)
MQY.4R6*	28 / 21	10.4 / 8.0	-0.7
MQ.9R7	16 / 16	11.2 / 11.2	
MQ.29L2	16 / 15	11.1 / 10.3	
MQ.21L2	16 / 15	11.4 / 10.2	
MQ.13L2	16 / 15	11.7 / 10.8	

Global aperture at injection - measurements

- 2010: Assmann et al., IPAC11, TUPZ006.
  Min: 12.5 sigma
- 2011: Assmann et al., IPAC11, TUPZ006.
  Min: 12.0 sigma
- 2012: elogbook
  Min: 11.5 sigma



- Same bottlenecks, but we lost 0.5 sigma every year
  (error bars on measurements still to be defined)

Global aperture at injection - compare with n1

Measured bottlenecks

	B1H	B1V	B2H	B2V
Element	Q2R6	Q4L6	Q5R6	Q4R6
Meas. ap. (sig)	11.5 – 12.5	12 – 13.5	12.5 – 14	12.5 – 13
n1 no errors	13.4	13.4	13.1	13.3
n1 1mm orbit	12.8	12.9	12.7	12.8
n1 3mm orbit	11.5	12.0	11.7	11.9

Bottlenecks found by n1 method

	B1	B2
n1 no tol.	12.6 (TCDQM.B4L6)	12.6 (TCDQM.B4R6)
n1 1mm orbit	12.1 (TCDQM.B4L6)	12.1 (TCDQM.B4R6)
n1 3mm orbit	10.8 (TCLIM.6L8)	10.9 (MQ.11R3.B2)

All n1 results without trueprofiles and layout apertures!

Conclusions:

- E.g. 3mm orbit gives good agreement at measured bottlenecks
- Predicted and measured bottlenecks are not the same
  - Not so surprising as random errors add differently.
- Comparing global predicted and measured aperture, 1mm orbit is sufficient except 2012 B1H

IR2 triplet aperture: measurements

- 2011: 3.5 TeV, b*=1m, +120 urad or -80 urad, bump method
  - Redaelli et al., CERN-ATS-Note-2012-017 MD
  - IPAC12, Redaelli et al., MOPPD062

Table 3: IR2 aperture measured with the bump and TCT scan method at 3.5 TeV with $\beta^* = 1.0$ min [7].

2011

Crossing angle [μrad]	Beam–Plane	Bump Type	Aperture [σ]
−80	B1–H	Sep	16.0 – 16.5
−80	B2–H	Sep	15.5 – 16.0
−80	B1–V	Xing	15.5 – 16.0
−80	B2–V	Xing	16.0 – 16.5
+120	B1–V	Xing	12.5 – 13.0
+120	B2–V	Xing	15.0 – 15.5

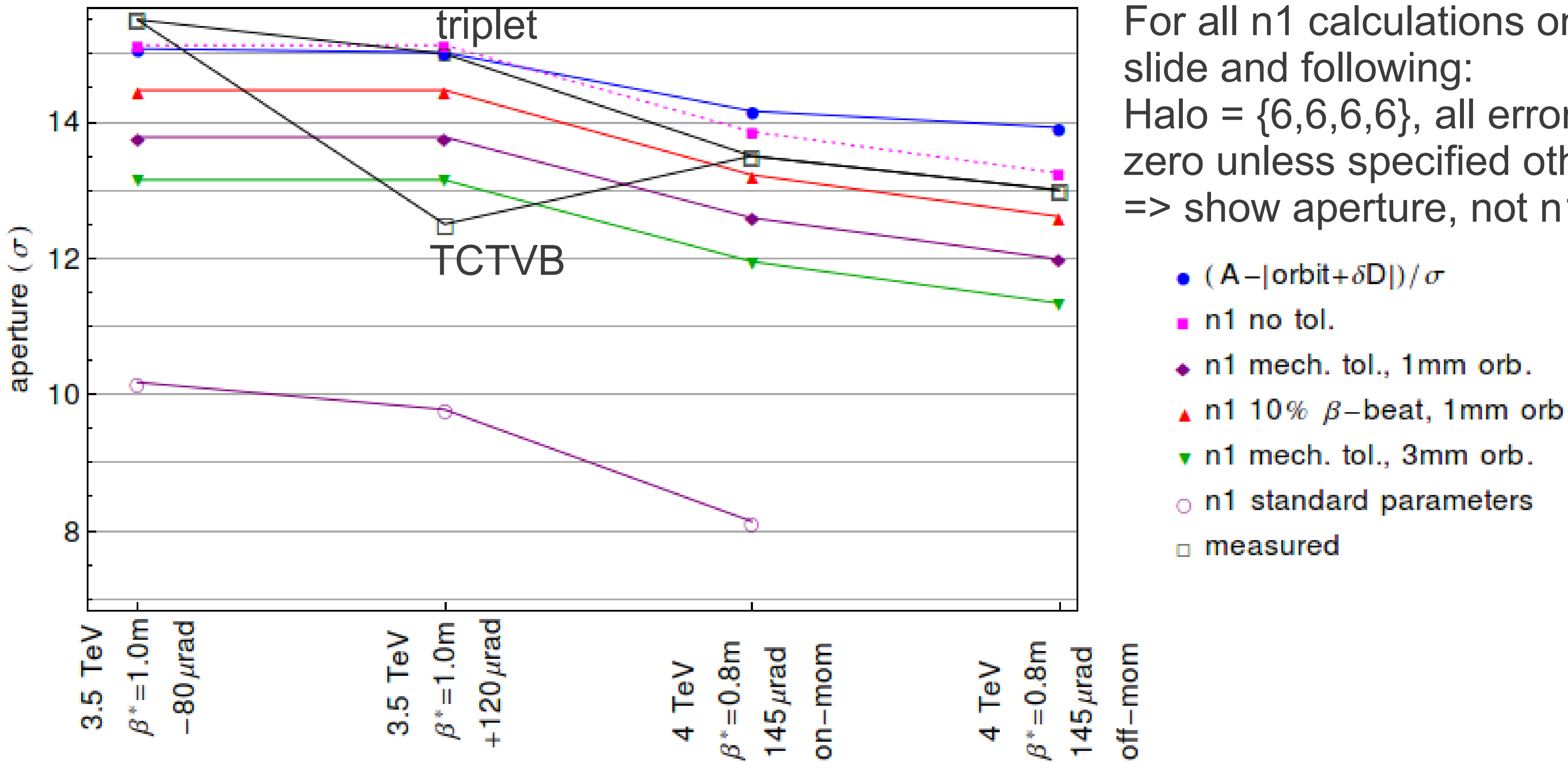
- 2013: 4 TeV, b*=80cm, 145 urad, bump method, on-momentum or off-momentum
  - Hermes et al., CERN-ACC-NOTE-2013-001

Table 2: Summary of the results of the aperture measurements.

2012

Beam	Direction	$\Delta p/p$	Full TCT gap [σ]
B1	Vert.	0	14.0 – 14.5
B2	Vert.	0	13.5 – 14.0
B1	Hor.	0	> 14.0
B2	Hor.	0	> 14.5
B2	Vert.	$-2.33 \cdot 10^{-4}$	13.0 – 13.5
B2	Vert.	$+2.17 \cdot 10^{-4}$	13.0 – 13.5

IR2 triplet aperture: compare with n1



For all n1 calculations on this slide and following:
Halo = {6,6,6,6}, all errors set to zero unless specified otherwise
=> show aperture, not n1

- n1 using small realistic errors (e.g. bbeat=1.05, cor=0.001, dp=0), and setting the mechanical and alignment to zero, gives more conservative results than measurements
- Exception: one “bad” measurement point at TCTVB – now removed

IR8 triplet aperture at injection, measurements in vertical

- 2012: bump method
  Hermes et al, CERN-ATS-Note-2013-026 MD
- Compare with design aperture:
  - 24 mm

Table 1: Summary of the obtained apertures by means of different methods.

	Crossing Bump	Aperture Beam 1 [mm]	Aperture Beam 2 [mm]
Theoretical bump	on/off	23.8	23.8
Interpolated BPM (uncorrected)	on	21.7	20.6
	off	21.7	20.6
Interpolated BPM (corrected)	on	25.4	25.1
	off	24.4	23.2

IR1/5 triplet aperture: measurements

- 2011: Injection 450 GeV, bump method
  - Assmann et al., IPAC11, TUPZ006.

Table 3: Results from 2011 on the LHC aperture in the triplets with injection optics at 450 GeV and for beams 1 and 2. All data uses the normalization to the stored beam intensity and to the BLM response.

IR	$a_x(s_i)$ (b1/b2)	$a_y(s_i)$ (b1/b2)
1	-/-	16.0/16.2
5	15.1/17.3	-/-
2	-/-	14.6/16.4
8	15.6/15.6	-/-

- 2011: 3.5 TeV, b*=1.5m, 120 urad, bump method
  - IPAC12, Redaelli et al., MOPPD062
  - Redaelli et al., CERN-ATS-Note-2011-110 MD

Table 2: IR1/5 aperture measured with the bump and TCT scan method at 3.5 TeV with $\beta^* = 1.5$ m [6].

IR	Plane	Bump type	Measured aperture [σ]
1	H	Sep	19.8 – 20.3
1	V	Xing	18.3 – 18.8
5	H	Xing	19.8 – 20.3
5	V	Sep	> 20.3

IR1/5 triplet aperture: measurements

- 2011: 3.5 TeV, b*=1.0m, 120 urad, bump method
  - IPAC12, Redaelli et al., MOPPD062

Table 4: Triplet aperture measured with the TCT scan method at 3.5 TeV with $\beta^* = 1.0\,\text{m}$.

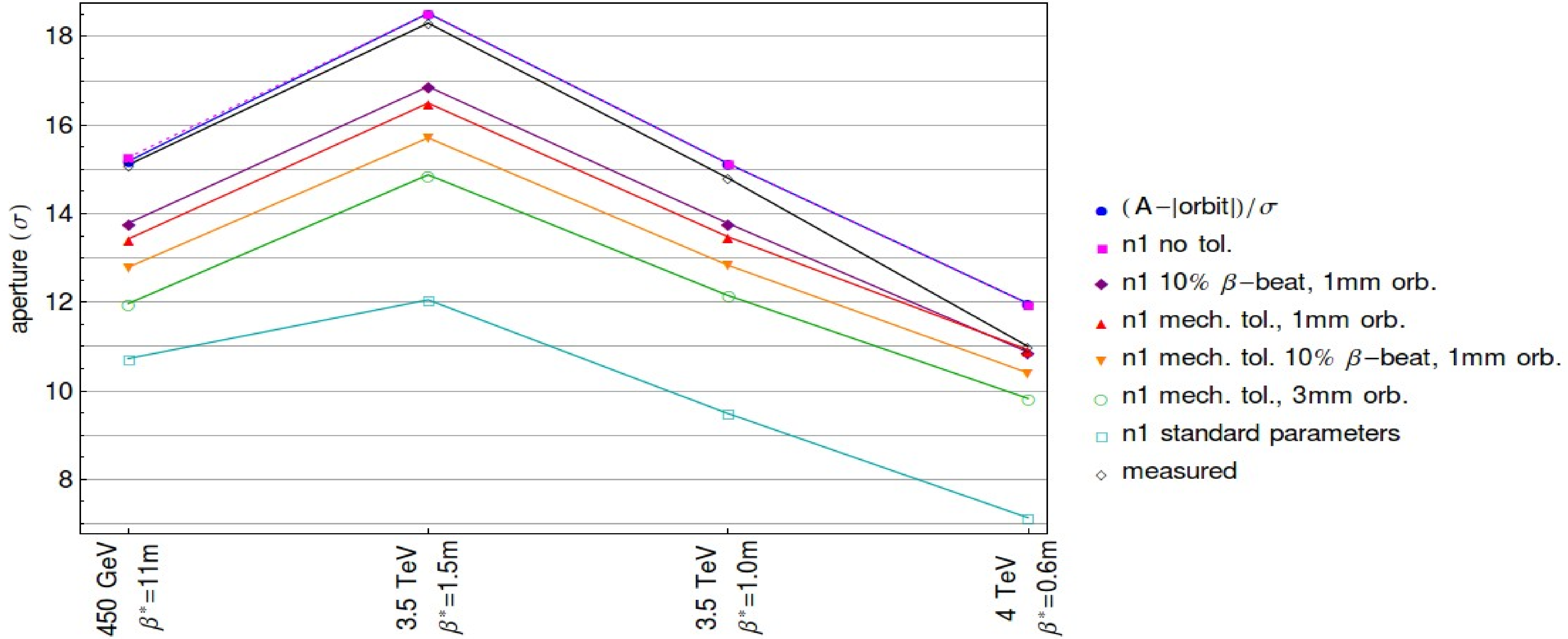
IR	Plane	Bump type	Measured aperture [σ]
1	H	Sep	> 16.0
1	V	Xing	$14.8 - 15.3$
5	H	Xing	$15.3 - 15.8$
5	V	Sep	> 16.0

- 2012: 4 TeV, b*=60cm, 145 urad, ADT global method
  - IPAC12, Redaelli et al., MOPPD062

Table 5: Global bottlenecks at 4 TeV and $\beta^* = 60$ cm.

Beam	Plane	Elem.	Measured aperture [σ]	Calculated aperture [σ]
B1	H	Q2-L5	$11.5 - 12.0$	12.0
B1	V	Q3-L1	$11.0 - 11.5$	11.6
B2	H	Q3-R1	$11.5 - 12.0$	12.0
B2	V	Q3-R1	$11.0 - 11.5$	11.6

IR1/5 triplet aperture: compare with n1



- 2012 measurement breaks trend. ADT method vs bump? Or real physical effect?
- n1 using e.g. {bbeat=1.05, cor=0.001, dp=0}, and setting the mechanical and alignment to zero, gives results equal to or more conservative than measurements

New n1 parameters?

- The LHC aperture seems very well aligned, close to the design parameters
- For the present IR1/5 triplets as installed it seems reasonable to use as baseline n1 parameters that are slightly more conservative than the measurements
  - Many different combinations of parameters in n1 model give equivalent results
    - E.g. {bbeat=1.05, cor=0.001, dp=0} gives reasonable results.
    - Compare with machine: 10% of beta-beat is probably pessimistic for triplet, orbit in triplet hard to estimate accurately from BPMs
  - Clearly aperture measurements have to be re-done after startup
  - safe to set dp=0? Chroma measurements only performed with small intensity. Can we think of dangerous RF failures where we actually need to protect the off-momentum aperture (would dump anyway if RF trips)?
- For global injection aperture, more conservative parameters needed
  - Statistically likely that errors add linearly somewhere in the machine

New n1 parameters? (2)

- For the LHC upgrade, need to estimate aperture of new magnets not yet built
- Can we now commit on that the upgraded machine will behave as well as the present one?
  - Use more conservative n1 parameters?
- But if we assume more conservative apertures, the upgrade might look less attractive compared to the present machine
  - Possible solution: use two numbers (pessimistic and “as present LHC”) to give a range in performance? Use different methods in triplet and matching section, where we so far have no aperture measurements? To be discussed!