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Discussion on collimator settings and β^* reach

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LHC Collimation Project

CERN

Outline

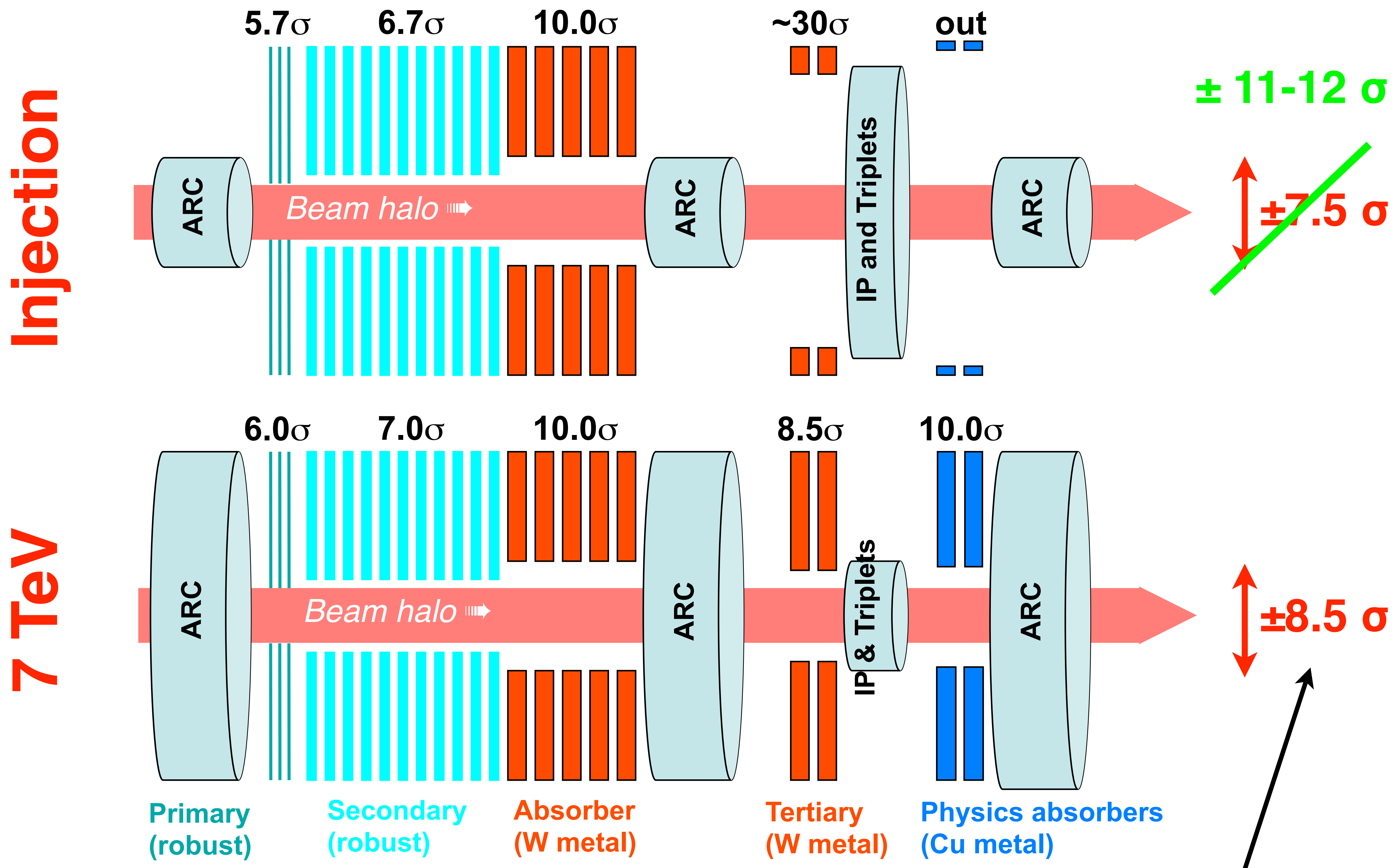
☑ Collimation hierarchy

☑ Collimator settings

☑ Baseline for minimum β*

☑ Conclusions

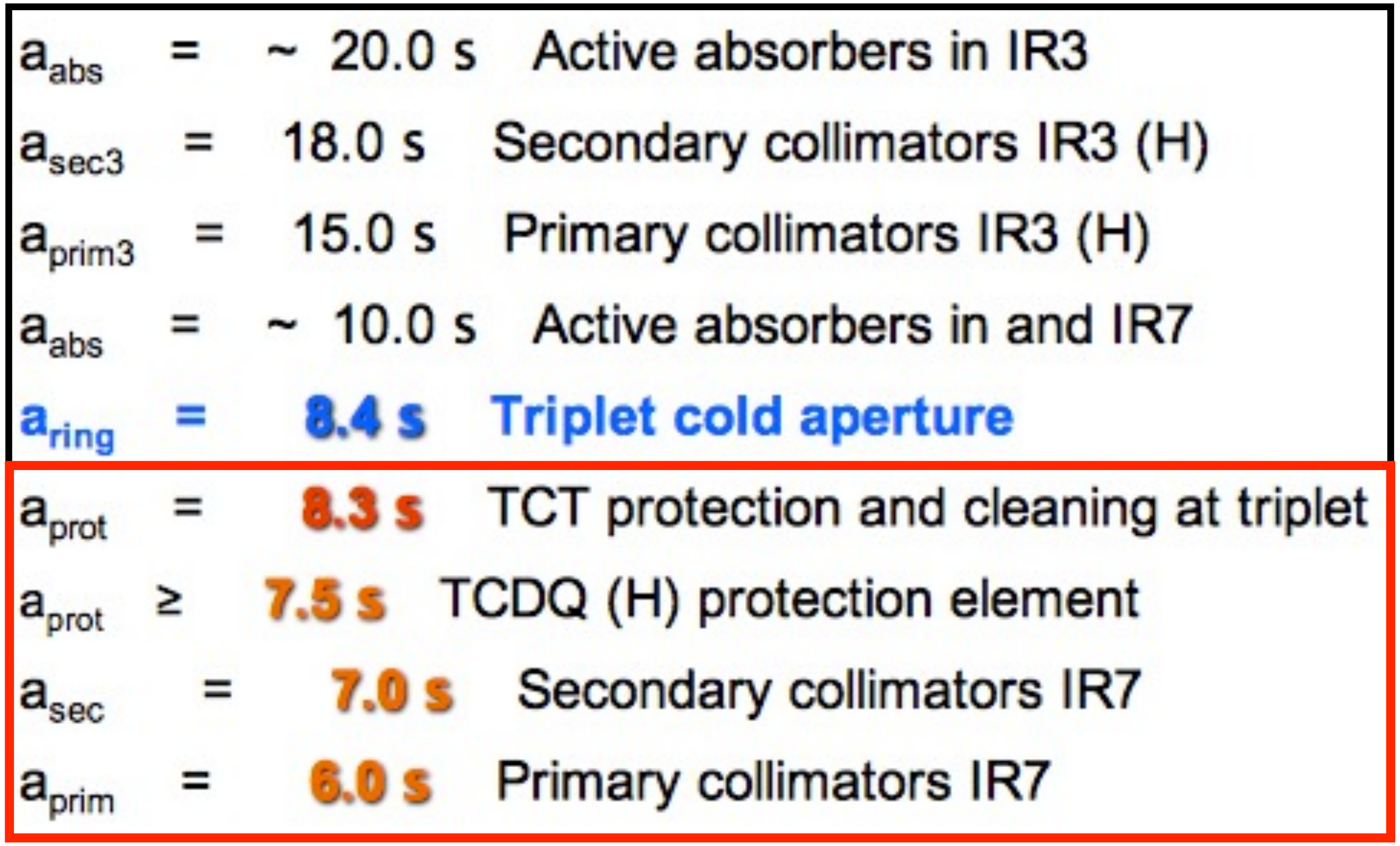
Collimator hierarchy



Much better! All margins are used to push the β reach!*

Nominal collimator settings

Nominal settings at 7 TeV



a_{abs} = ~ 20.0 s Active absorbers in IR3

a_{sec3} = 18.0 s Secondary collimators IR3 (H)

a_{prim3} = 15.0 s Primary collimators IR3 (H)

a_{abs} = ~ 10.0 s Active absorbers in and IR7

a_{ring} = **8.4 s** **Triplet cold aperture**

a_{prot} = **8.3 s** TCT protection and cleaning at triplet

a_{prot} ≥ **7.5 s** TCDQ (H) protection element

a_{sec} = **7.0 s** Secondary collimators IR7

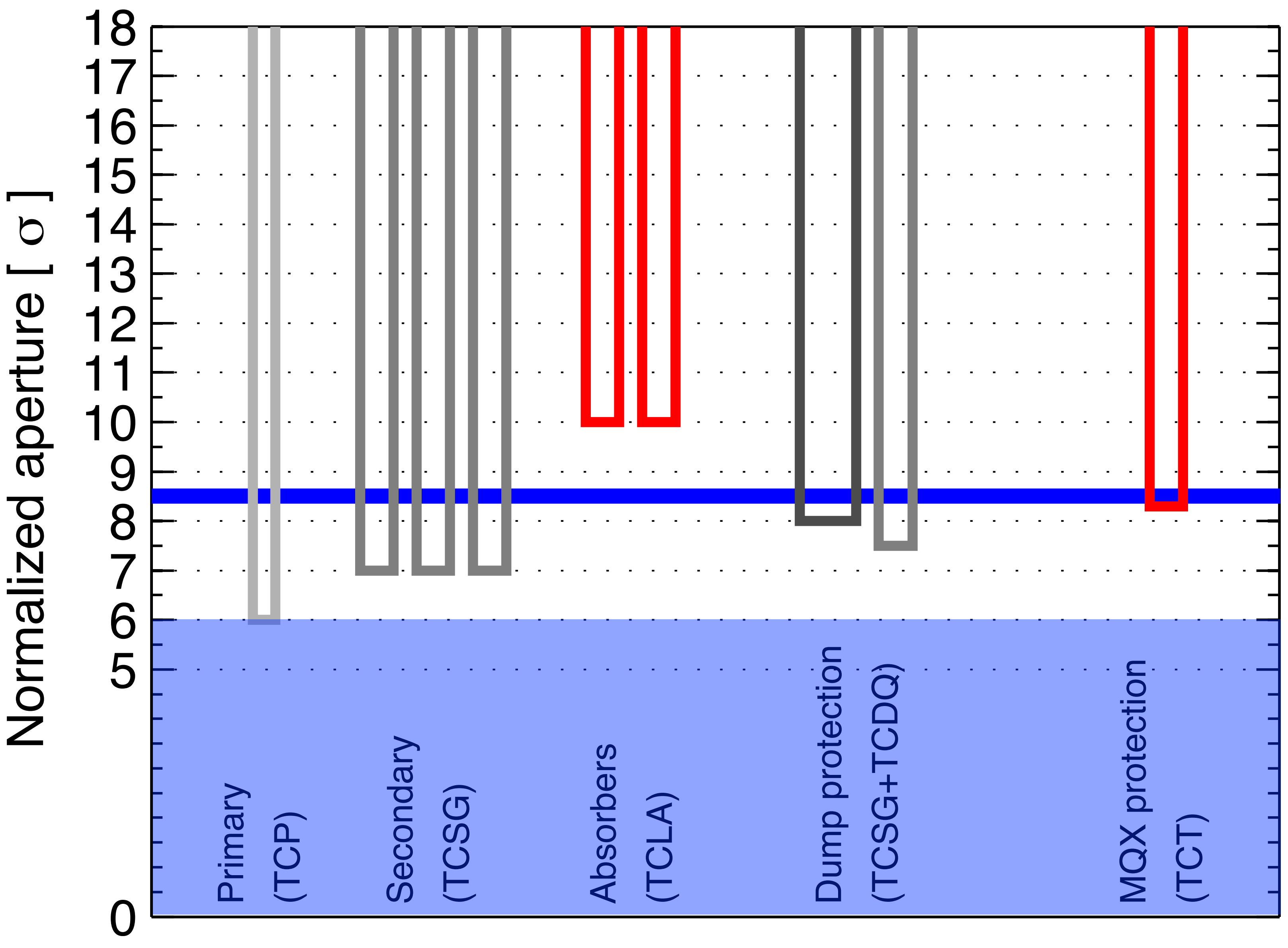
a_{prim} = **6.0 s** Primary collimators IR7

R. Assmann, Chamonix 2005

- ☑ Collimator hierarchy is determined by the aperture bottleneck that must be protected, e.g. the triplet aperture (top energy, squeeze)
- ☑ Primary collimator settings and minimum retraction between collimator families are determined by operational constrains (beam losses, tolerances on orbit and optics, fill-to-fill reproducibility, ...)

  - 2012: achieved minimum gaps of about 2 mm with 130 MJ beams!

Nominal settings in practice



Triplet aperture (function of β*)

Design: 2.5 sigma retraction between TCP and triplet aperture.

TCP/TCSG/TCDQ/TCT hierarchy must fit in this range!

Reminder: This is the reason why collimation settings limit the β reach of the LHC!*

“Relaxed” and “tight” settings

$$\boxed{\mathrm{NSIG}^{4\ \mathrm{TeV}}_{\mathrm{tight}} = \mathrm{NSIG}_{7\ \mathrm{TeV}} \times \sqrt{\frac{4\ \mathrm{TeV}}{7\ \mathrm{TeV}}}}$$

	Relaxed 2011	Nominal	Tight at 4 TeV
TCP-IR7	5.7	6.0	4.5
TCSG-IR7	8.5	7.0	5.3
TCLA-IR7	17.7	10.0	7.6
TCTs IP1/5/8	11.8	8.3	6.3
TCSG-IR6	9.3	7.5	5.7
TCDQ-IR6	10.6	8.0	6.0

☑ The “relaxed” settings concept was conceived to ease the early operation *(RA, Cham2006)*: larger retraction ⇒ relax orbit and beta-beating constrains

*- 2010/2011: TCSG/TCSG-6/TCT retraction from TCPs: **2.8/3.6/6.1** (nominal: **1.0/1.5/2.3**)*

☑ MD studies in 2011 on “tight” settings (7 TeV settings in [mm] scaled to 4 TeV)

- The settings that we can achieve with one single system alignment per year require a larger retraction than the “tight” settings equivalent to 7 TeV.

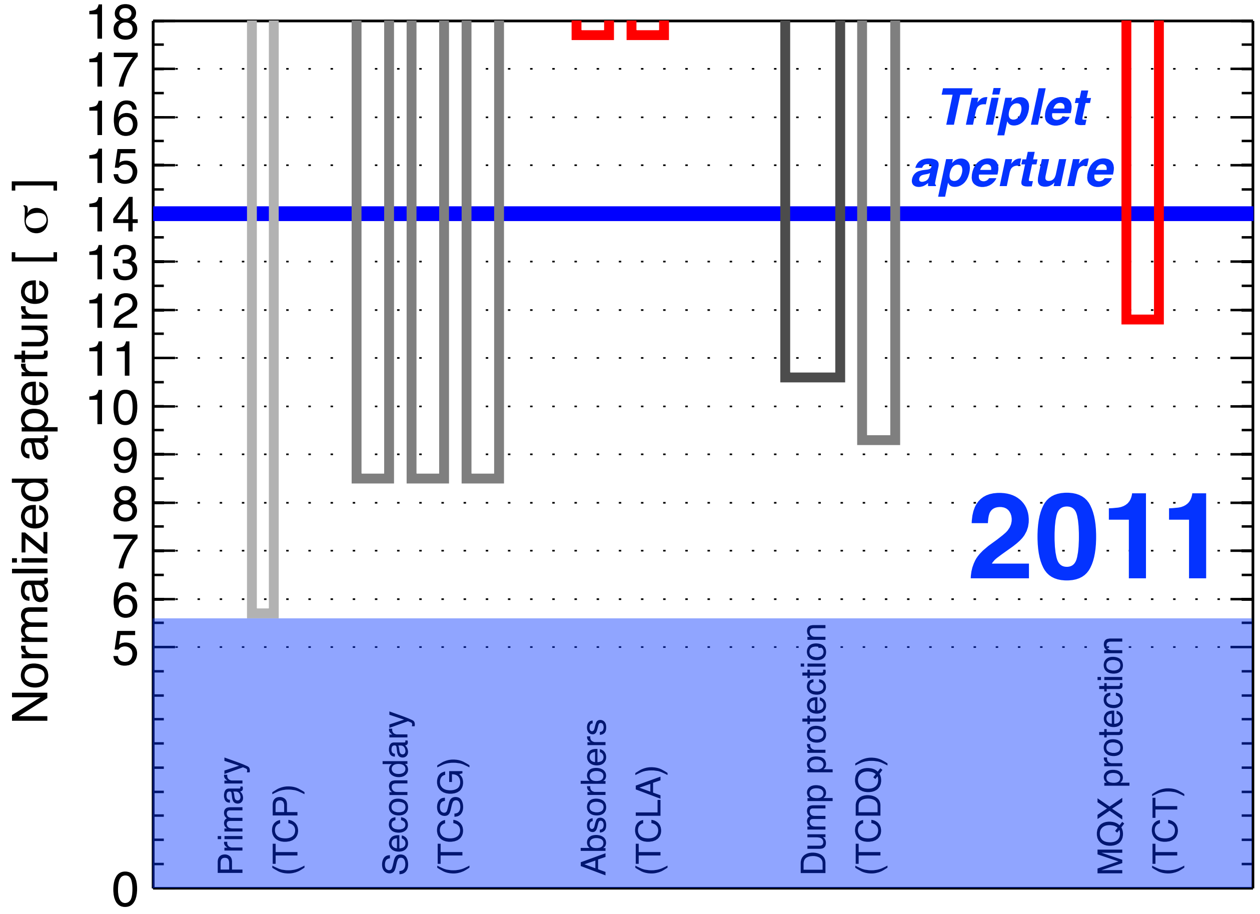
☑ 2012: some “relaxed-tight” settings compatible with the 2011 experience

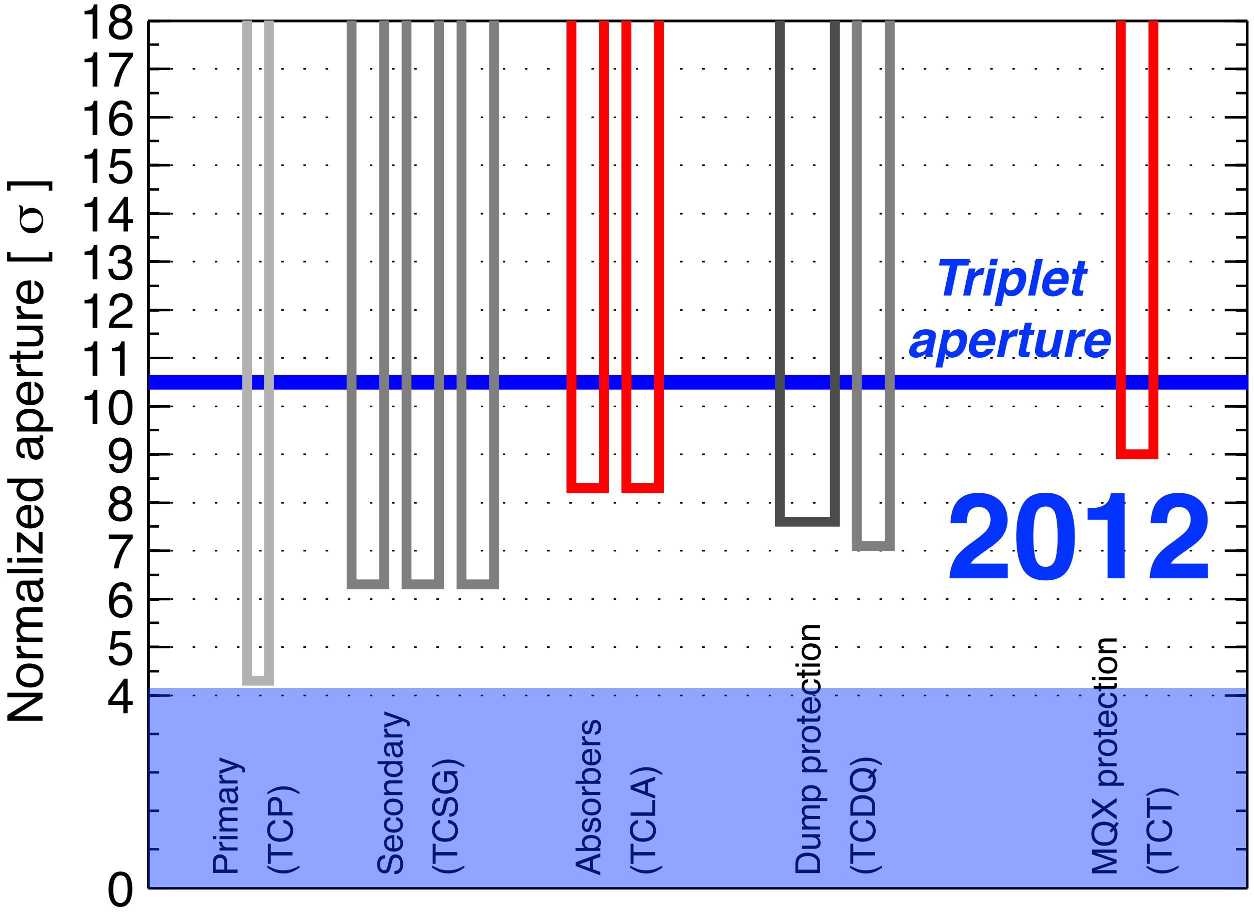
- TCSG/TCSG-6/TCT retraction from TCPs: 2.0/2.8/4.7

Reminders

- The TCTs are made of Tungsten to maximize triplet protection (“sacrificial” design as they are not robust)
  - The choice to go for high-Z was taken in absence of detailed studies
  - Experts contacted and take a conservative choice in terms of absorption
  - Later background studies confirmed that W is okay for background!
- The IR protection has constrained the β^* reach:
  the retraction between TCDQ and TCTs has to be chosen such as to minimize the risk to hit TCT (for a given measured orbit stability).
- The concurrency of a few combined failures is required to hit TCT.
  Very unlikely to hit the TCT’s with more than 1 bunch.
- The simulations indicate that the TCTs are likely to survive the hit of 1 bunch (will be tested at HiRadMat this year).
- All TCTs will be replaced in LS1 to get the BPM-embedded design but we decided to keep the same material.
  Changes of this baseline are excluded (actions possible in LS2 at the earliest)!
- What can we gain with more robust TCTs?

Settings in 2011 and 2012





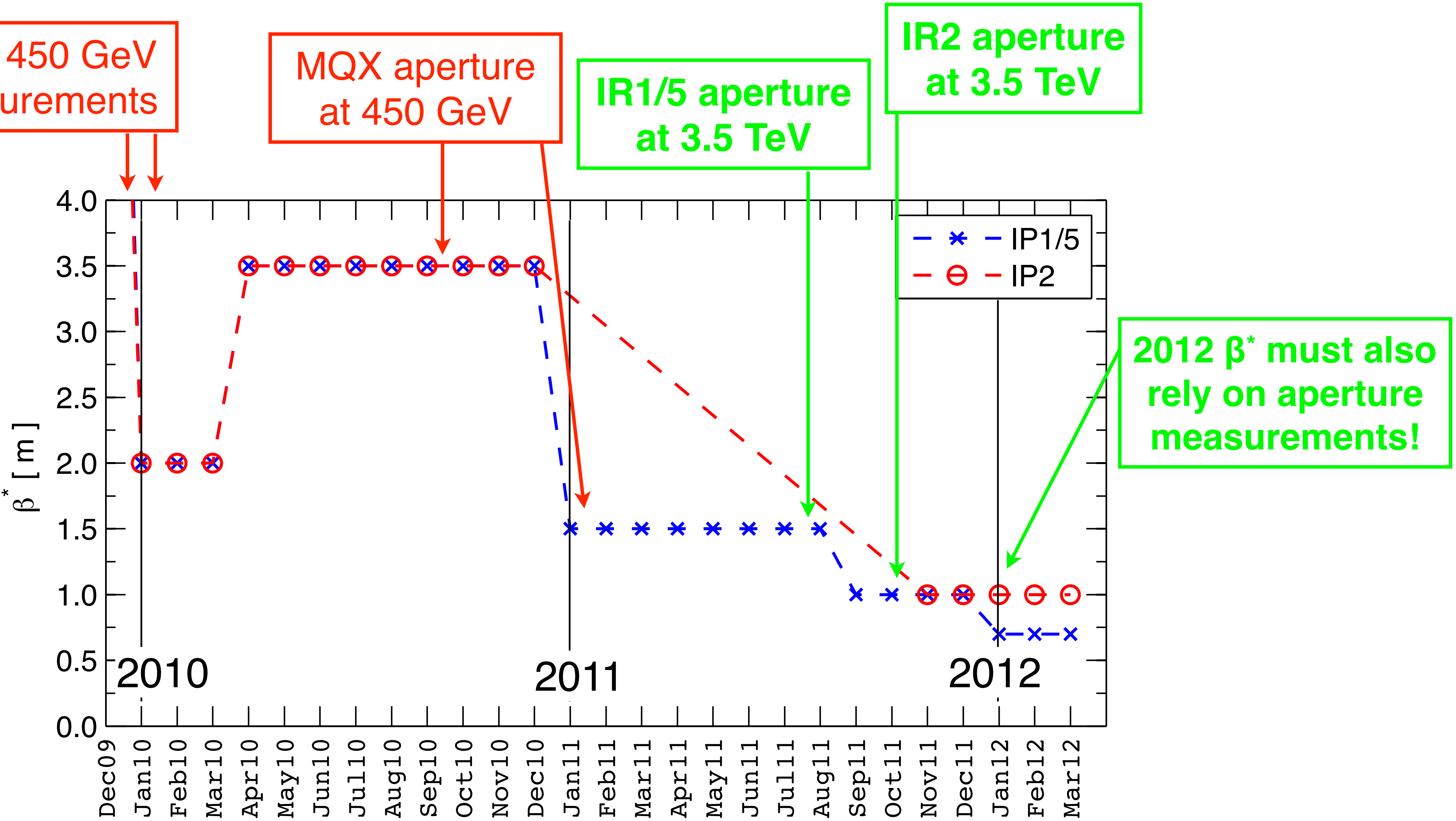
☑ 2011 → 2012: (See RB's talk at the Chamonix2012)
Maintained similar retractions (same orbit and optics tolerances) and reduced margins with respect to MQX aperture

- *TCT/MQX retraction: started conservatively with 2σ, now 1.5σ (limited by BPM)*

☑ Crucial role of local triplet aperture measurements: set the scale for β^*

- *Extrapolations from injection measurements proved to be too conservative*
- *Allowed change of β* from 1.5m to 1.0m in 2011 and **60 cm** in 2012 (tight settings)*

β* in IR1/5 versus time



Initial 450 GeV measurements

MQX aperture at 450 GeV

IR1/5 aperture at 3.5 TeV

IR2 aperture at 3.5 TeV

2012 β^* must also rely on aperture measurements!

β* reach goes together with a detailed knowledge aperture in squeezed conditions!

Can we go even tighter?

In principle yes, but there are some risks:

☑ Higher losses on the TCPs if they are closer to beam core

- Unless we can scrape or we have an hollow lens!

☑ Higher loads on other IPs

- Remember that we dumped several times due to losses in IP6!

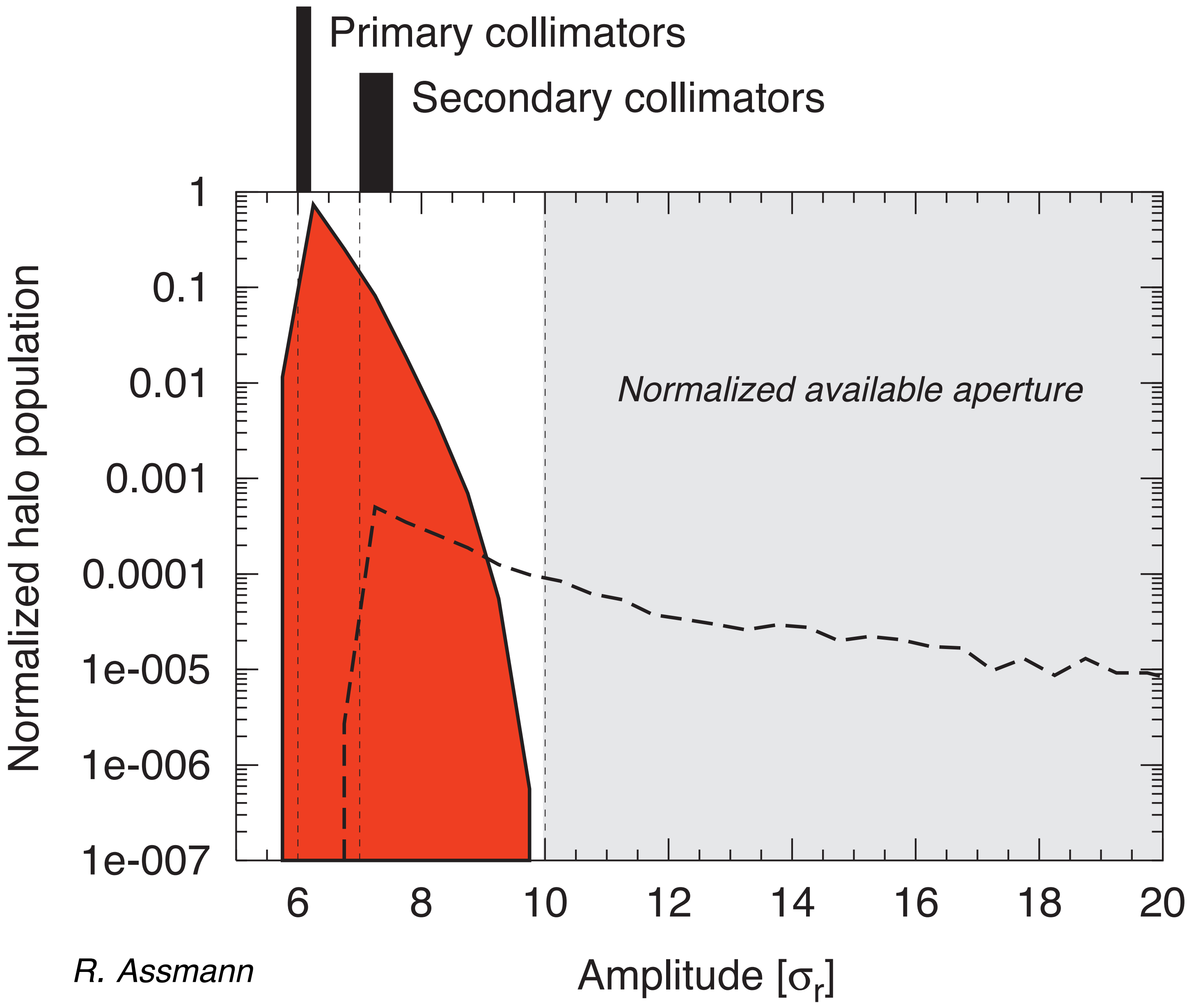
☑ **Increased impedance**

☑ Larger background in the experiments if TCTs get closer to the TCSG aperture

☑ Even tighter tolerances on orbit and beta-beating

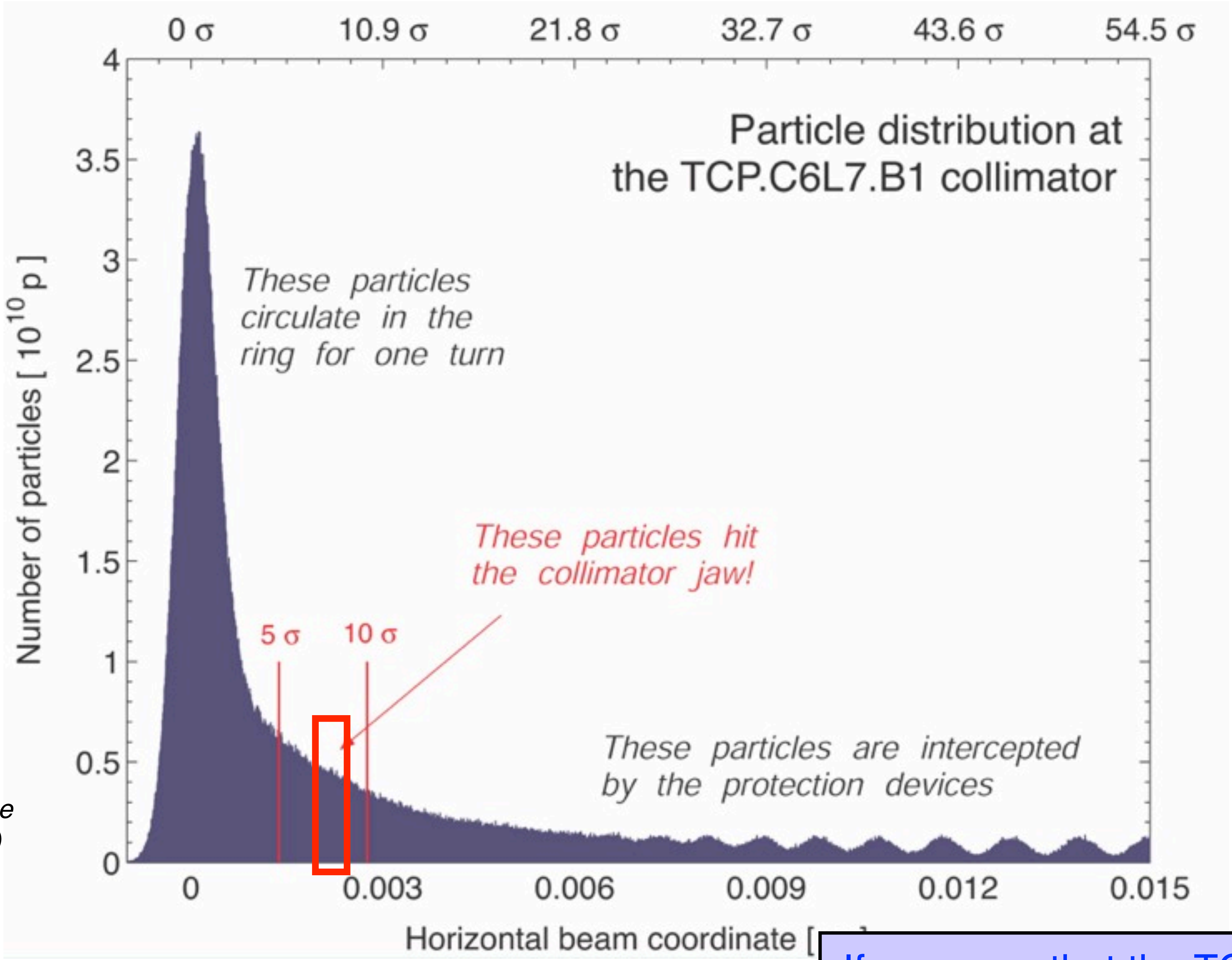
☑ More losses in case of an asynchronous dump

By going too tight with TCSG/ TCT settings, we risk to have troubles without real gain!



R. Assmann

Asynchronous dump distribution



Particle distribution at the TCP.C6L7.B1 collimator

These particles circulate in the ring for one turn

These particles hit the collimator jaw!

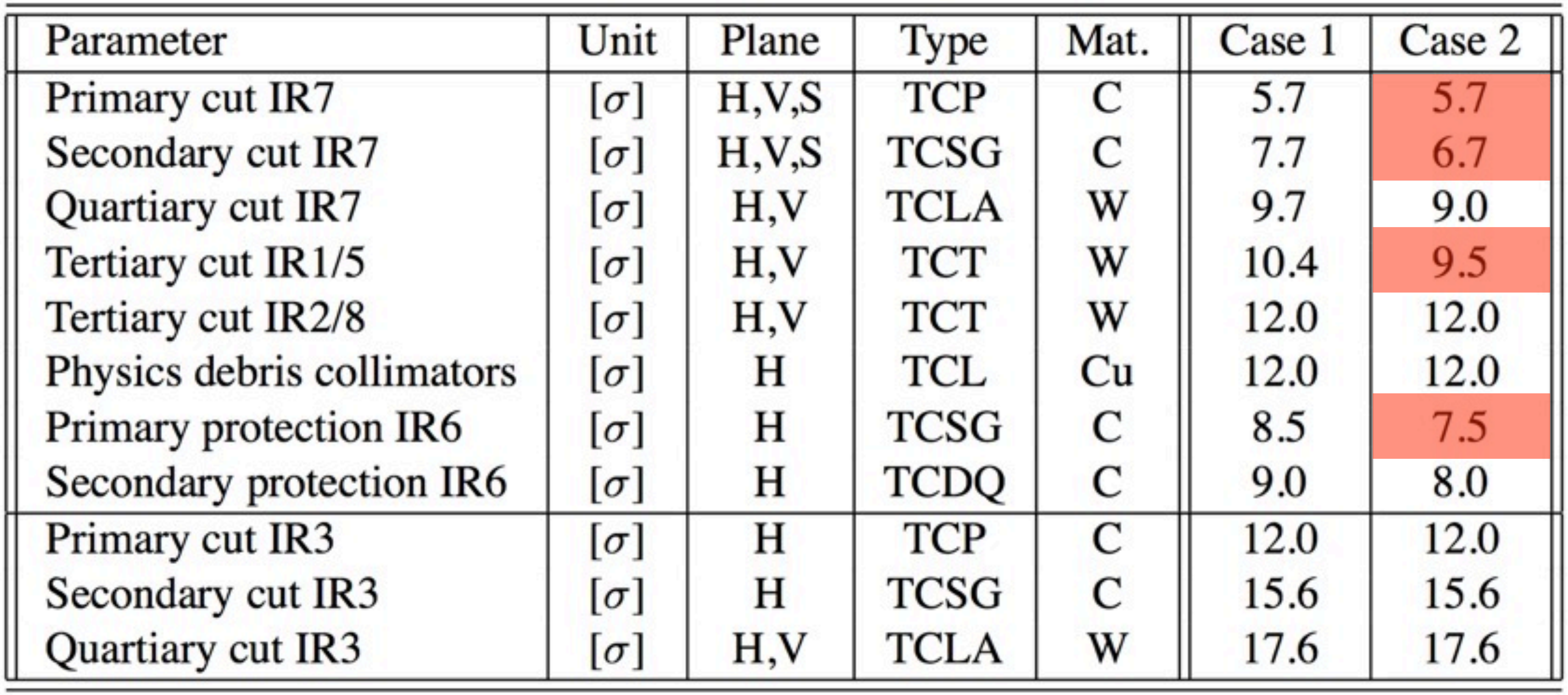
These particles are intercepted by the protection devices

Inputs on kicker shape by BG's team (2004)

There is about 1 bunch per sigma in the regi
the TCT: realistically, about 1 bunch car

If we prove that the TCTs are safe for 1 bunch, we can consider them "robust"

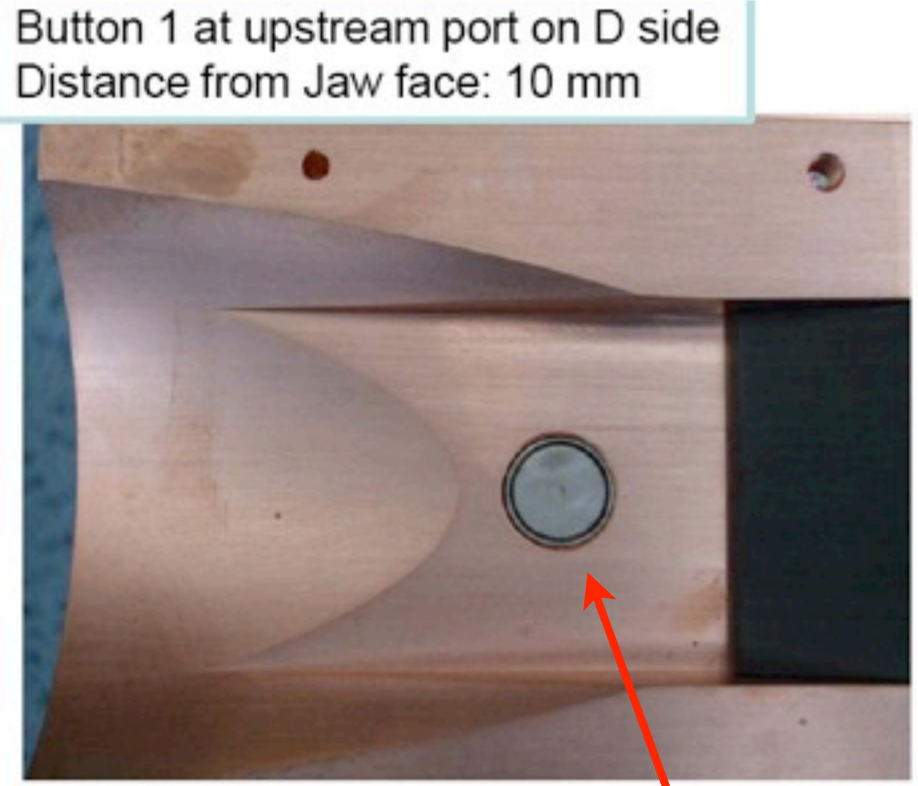
Scenarios after LS1 at 6.5-7.0 TeV

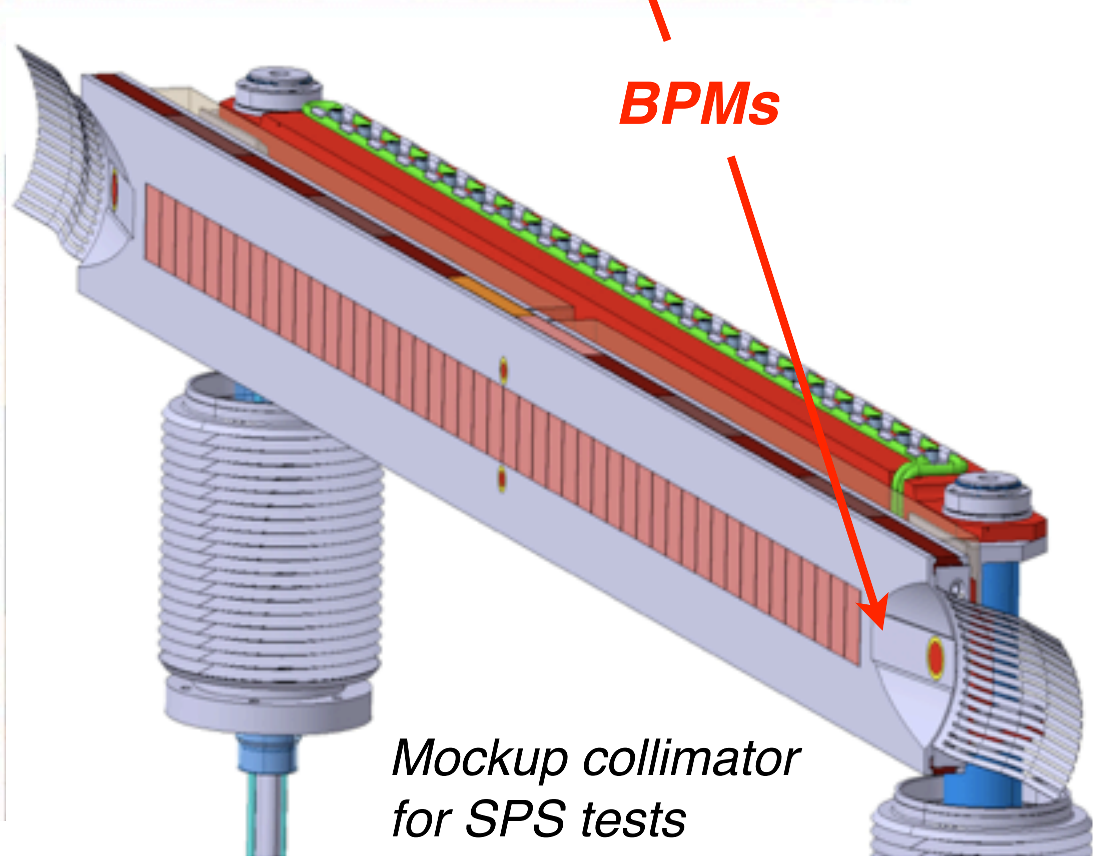


Parameter	Unit	Plane	Type	Mat.	Case 1	Case 2
Primary cut IR7	$[\sigma]$	H,V,S	TCP	C	5.7	5.7
Secondary cut IR7	$[\sigma]$	H,V,S	TCSG	C	7.7	6.7
Quartiary cut IR7	$[\sigma]$	H,V	TCLA	W	9.7	9.0
Tertiary cut IR1/5	$[\sigma]$	H,V	TCT	W	10.4	9.5
Tertiary cut IR2/8	$[\sigma]$	H,V	TCT	W	12.0	12.0
Physics debris collimators	$[\sigma]$	H	TCL	Cu	12.0	12.0
Primary protection IR6	$[\sigma]$	H	TCSG	C	8.5	7.5
Secondary protection IR6	$[\sigma]$	H	TCDQ	C	9.0	8.0
Primary cut IR3	$[\sigma]$	H	TCP	C	12.0	12.0
Secondary cut IR3	$[\sigma]$	H	TCSG	C	15.6	15.6
Quartiary cut IR3	$[\sigma]$	H,V	TCLA	W	17.6	17.6

- ☑ Case 1: essentially the same settings in mm than in 2012
  - *Based on R. Bruce's work presented at Evian2011*
  - *Case 1 is slightly tighter than 2012 settings: kept a 2 sigma retraction*
- ☑ Case 2: improvement from present situation, even without BPMs
  - *Nominal 1 sigma retraction between TCP/TSCG*
  - *Same retraction to TCDQ/TCTs that we have now in units sigma*
- ☑ We will have a further gain from the BPM-design!
  - *Detailed analysis ongoing (RB); PRELIMINARY: **β* between 30 and 40 cm!***

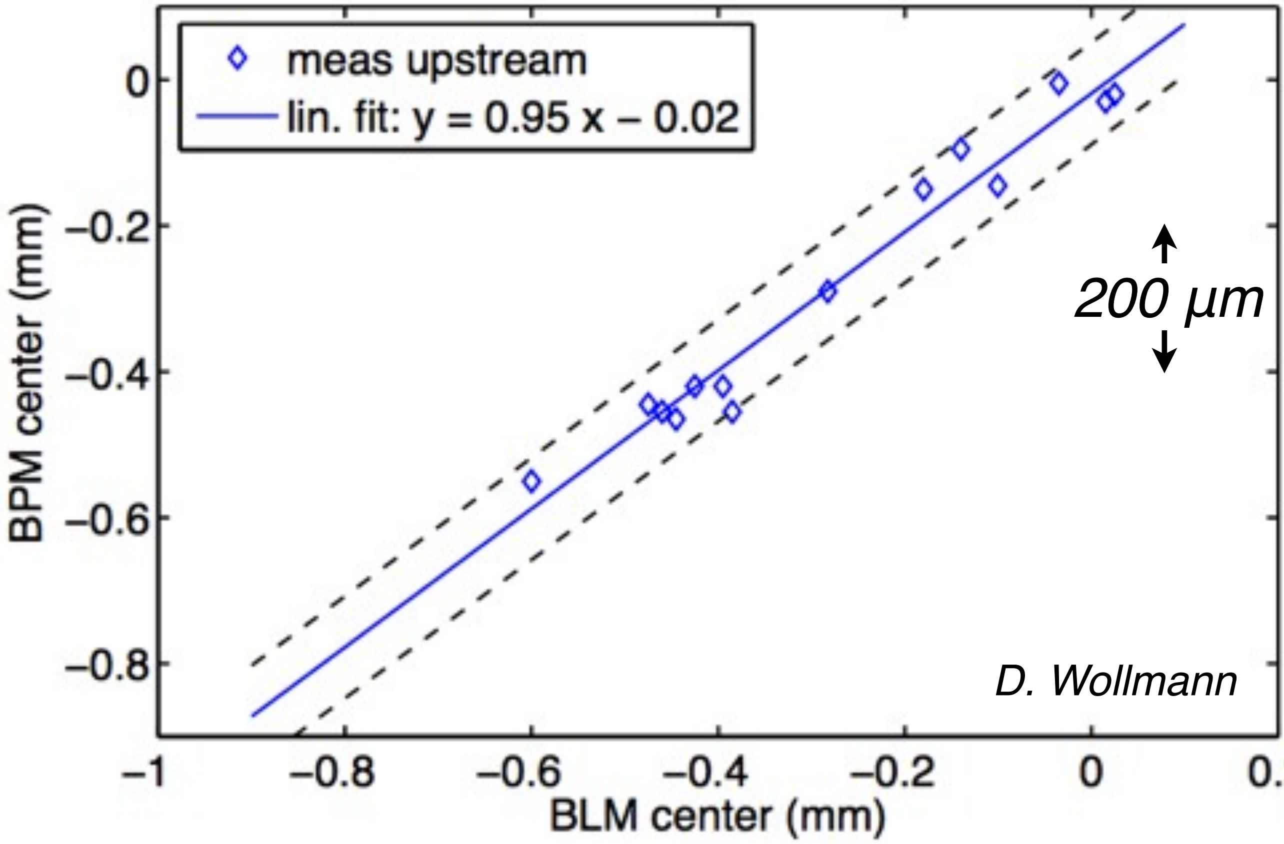
BPM-integrated for TCTs and TCSG-6





Mockup collimator for SPS tests (A. Dallocchio)

*Present (10-15min/coll) to BPM (**~ten sec**)*



- BPM bottoms integrated in the collimator jaws to measure the **local beam position**.
- **We will replace all 16 tertiary collimators and the 2 TCSGs in IP6 in LS1**
- We can zero the fill-to-fill uncertainty on the orbit errors between TCDQ and TCTs (H).
- **Can reach a β^* < 40 cm after LS1!**
- Nominal collimator settings within reach!
- Still limited by BPM accuracy that forces ~1σ retraction between TCT and IT

Conclusions

☑ We believe that a β* of **30-40 cm** is within reach after LS1

- *Details being worked out (RB) - soon reviewed at a CWG on 2015 performance reach*
- *Collimation upgrade work for LS1: will add 18 collimators with BPM integrated*

☑ Pushing the "HL" era after LS1 might be possible thanks to

- *Good aperture (much better "n1" predictions), good collimation and machine stability*
- *Addition of BPMs at TCTs and TCSG-IP6 that improve orbit uncertainties*
- *The nominal collimation settings (TCP/TCSG/TCT=6.0/7.0/8.4) are within reach!*

☑ Initially, there were margins to gain in the collimation hierarchy

- *Relaxed setting approach in early commissioning: conservative but safe*
- *IR protection did limit the β* reach, but every year we have gained some margin!*
- *We considered options to improve this situation (robust TCTs)*

☑ There is not much that we can gain in addition to our baseline

- *It seems unlikely to tighten hierarchy more, but we are open to suggestions.*

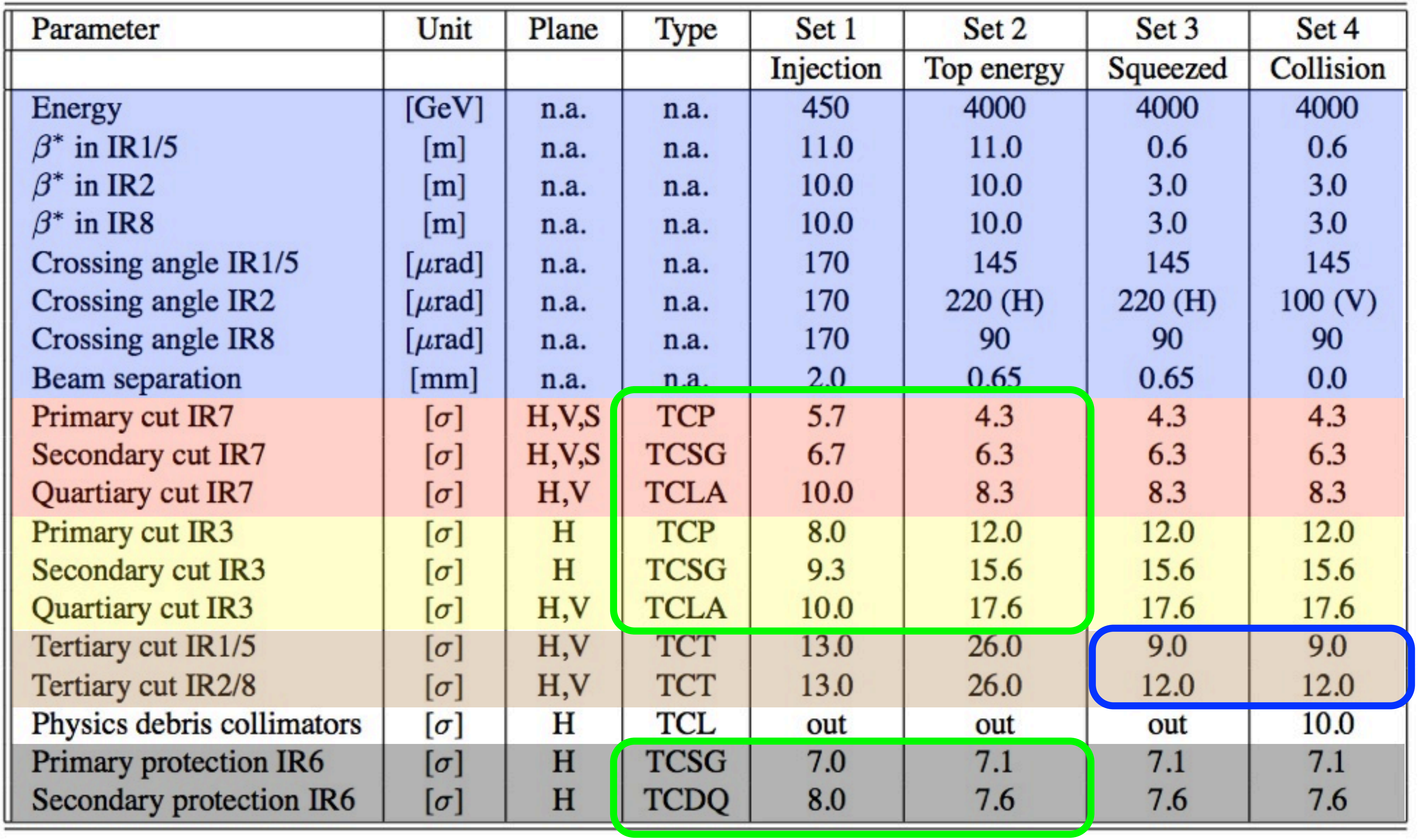
☑ We have been pursuing R&D on new materials to find improvements

- *HiRadMat SOON to address the damage limit of TCTs - hoping in good news!*
- *Studying TCT loads for realistic failure scenarios (followup Chamonix 2011)*
- *FLUKA studies to address effects on IRs from showers from TCTs*

☑ We will be ready for possible further improvements in LS2, if needed.

- *More H collimators with BPMs in IR7. New TCT materials if W damaged for ≪ 1 bunch*

2012 settings



Parameter	Unit	Plane	Type	Set 1	Set 2	Set 3	Set 4
				Injection	Top energy	Squeezed	Collision
Energy	[GeV]	n.a.	n.a.	450	4000	4000	4000
β^* in IR1/5	[m]	n.a.	n.a.	11.0	11.0	0.6	0.6
β^* in IR2	[m]	n.a.	n.a.	10.0	10.0	3.0	3.0
β^* in IR8	[m]	n.a.	n.a.	10.0	10.0	3.0	3.0
Crossing angle IR1/5	[μrad]	n.a.	n.a.	170	145	145	145
Crossing angle IR2	[μrad]	n.a.	n.a.	170	220 (H)	220 (H)	100 (V)
Crossing angle IR8	[μrad]	n.a.	n.a.	170	90	90	90
Beam separation	[mm]	n.a.	n.a.	2.0	0.65	0.65	0.0
Primary cut IR7	[σ]	H,V,S	TCP	5.7	4.3	4.3	4.3
Secondary cut IR7	[σ]	H,V,S	TCSG	6.7	6.3	6.3	6.3
Quartiary cut IR7	[σ]	H,V	TCLA	10.0	8.3	8.3	8.3
Primary cut IR3	[σ]	H	TCP	8.0	12.0	12.0	12.0
Secondary cut IR3	[σ]	H	TCSG	9.3	15.6	15.6	15.6
Quartiary cut IR3	[σ]	H,V	TCLA	10.0	17.6	17.6	17.6
Tertiary cut IR1/5	[σ]	H,V	TCT	13.0	26.0	9.0	9.0
Tertiary cut IR2/8	[σ]	H,V	TCT	13.0	26.0	12.0	12.0
Physics debris collimators	[σ]	H	TCL	out	out	out	10.0
Primary protection IR6	[σ]	H	TCSG	7.0	7.1	7.1	7.1
Secondary protection IR6	[σ]	H	TCDQ	8.0	7.6	7.6	7.6

4 sets of beam-based settings, smooth transition between different sets.

Each setting set must be validated by loss maps.

Reminder of present collimation

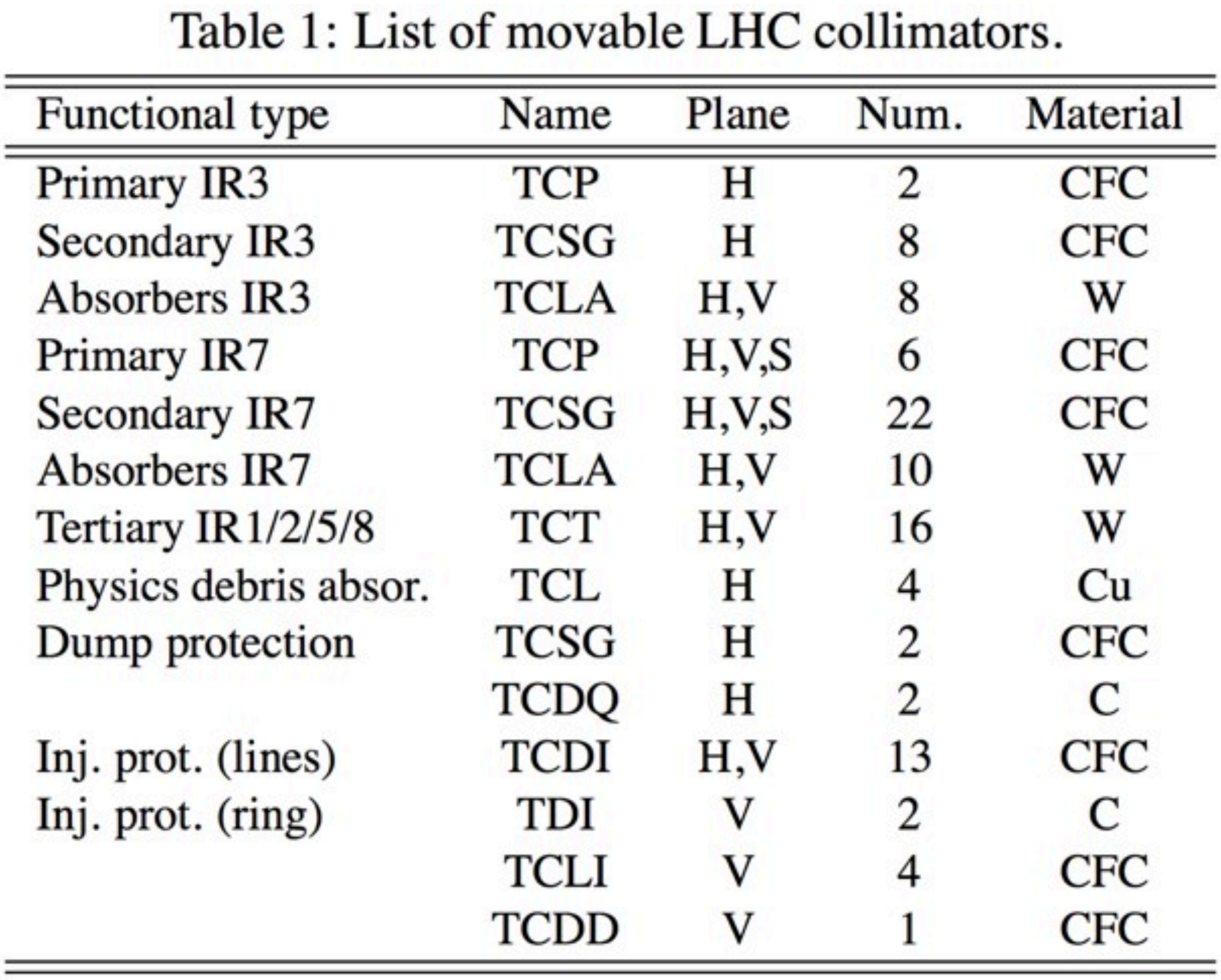


Table 1: List of movable LHC collimators.

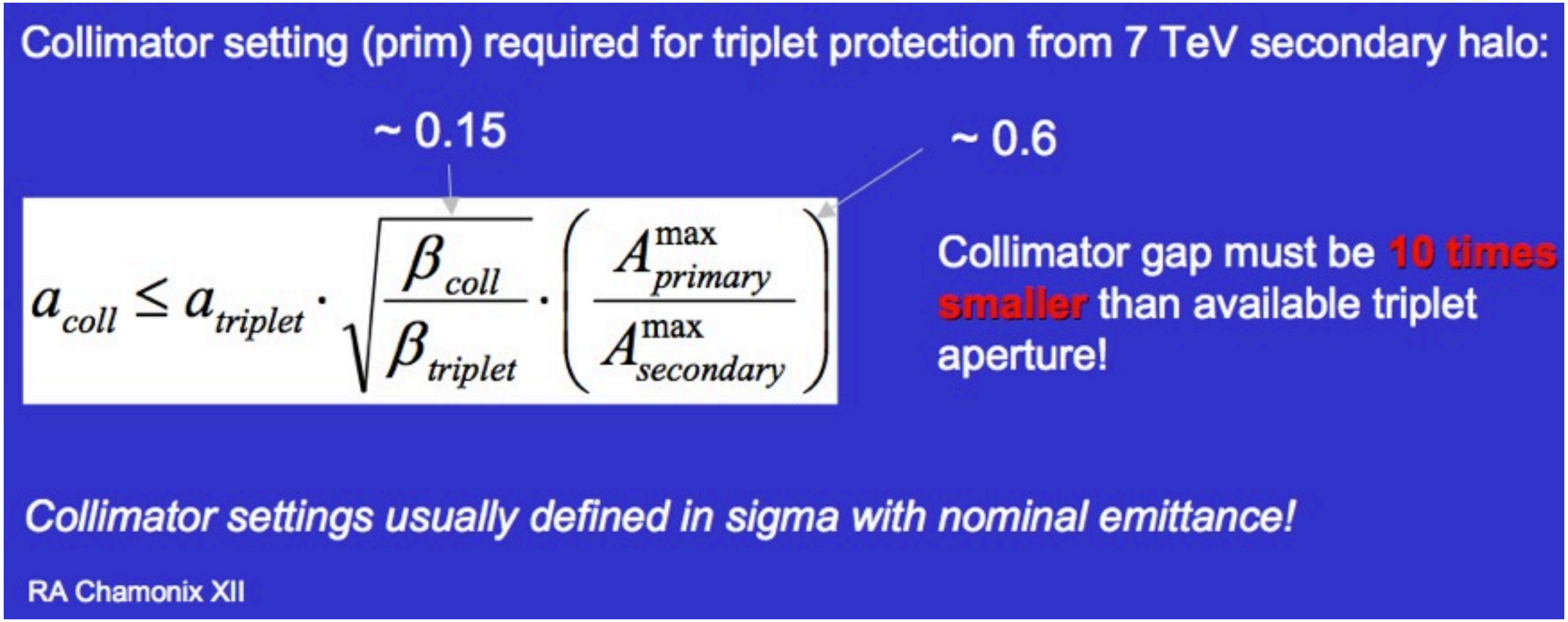
Functional type	Name	Plane	Num.	Material
Primary IR3	TCP	H	2	CFC
Secondary IR3	TCSG	H	8	CFC
Absorbers IR3	TCLA	H,V	8	W
Primary IR7	TCP	H,V,S	6	CFC
Secondary IR7	TCSG	H,V,S	22	CFC
Absorbers IR7	TCLA	H,V	10	W
Tertiary IR1/2/5/8	TCT	H,V	16	W
Physics debris absor.	TCL	H	4	Cu
Dump protection	TCSG	H	2	CFC
	TCDQ	H	2	C
Inj. prot. (lines)	TCDI	H,V	13	CFC
Inj. prot. (ring)	TDI	V	2	C
	TCLI	V	4	CFC
	TCDD	V	1	CFC

Reminder: all settings will be given in units of the betatron beam size along the collimator axis:

$$\sigma_{\mathrm{coll}} = \sqrt{\beta_{\mathrm{coll}}\epsilon_{\mathrm{nom.}}}$$

$$\beta_{\mathrm{coll}} = \sqrt{\beta_x^2 \cos^2(\theta_{\mathrm{coll}}) + \beta_y^2 \sin^2(\theta_{\mathrm{coll}})}$$

Collimation limits for beta* reach



Collimator setting (prim) required for triplet protection from 7 TeV secondary halo:

~ 0.15

~ 0.6

$$a_{coll} \leq a_{triplet} \cdot \sqrt{\frac{\beta_{coll}}{\beta_{triplet}}} \cdot \left(\frac{A_{primary}^{\max}}{A_{secondary}^{\max}} \right)$$

Collimator gap must be **10 times smaller** than available triplet aperture!

Collimator settings usually defined in sigma with nominal emittance!

RA Chamonix XII