Limits for Collimator positioning for weak beams at 6.5 TeV and details of wire collimators integration

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With thanks to: Y. Papaphilippou,
S. Fartoukh, D. Wollmann

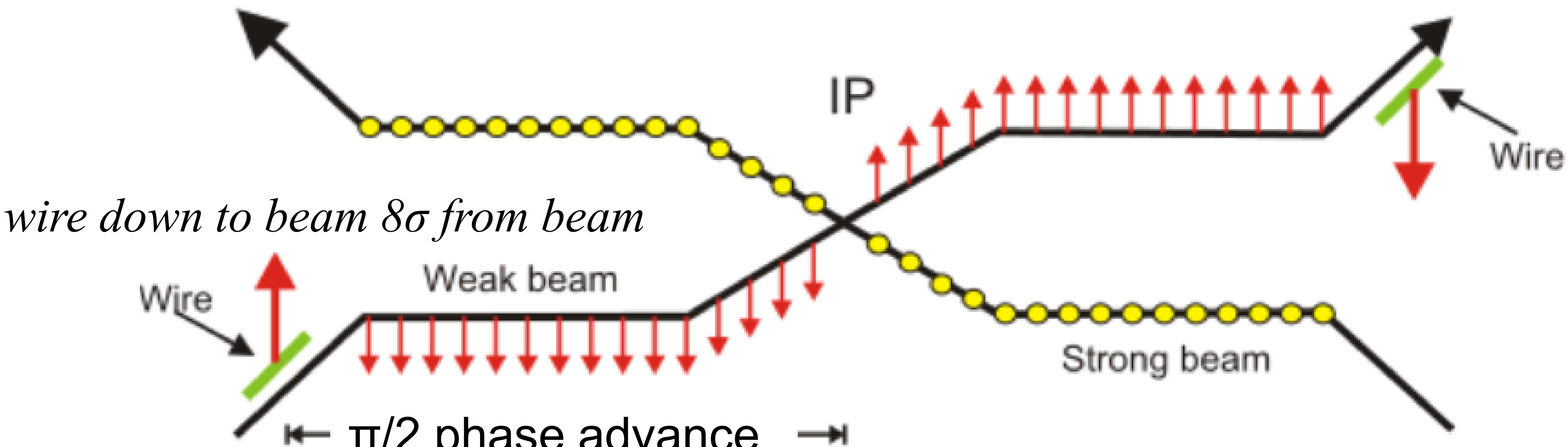
Outline

- Requirements and integration constraints
- Collimator settings and limits
  - Standard settings
  - Beam dump failure
  - Beam 1 vs Beam 2
  - Present Machine Protection envelope
- Proposal filling scheme and collimators settings
- Summary

Two wires per IP

- Integrated current can be reduced for the same correction reach
  - Ideally halved only if location with equal beta functions in both planes are used (round beam approximation)

- 1 collimator per IP side, on incoming and on outgoing beam
- In same plane as crossing = vertical in IP1 and horizontal in IP5
- Possibility to move wire in perpendicular plane
  - Additional knob, but also inducing some coupling (see below)



Wire collimators for BBRL compensation

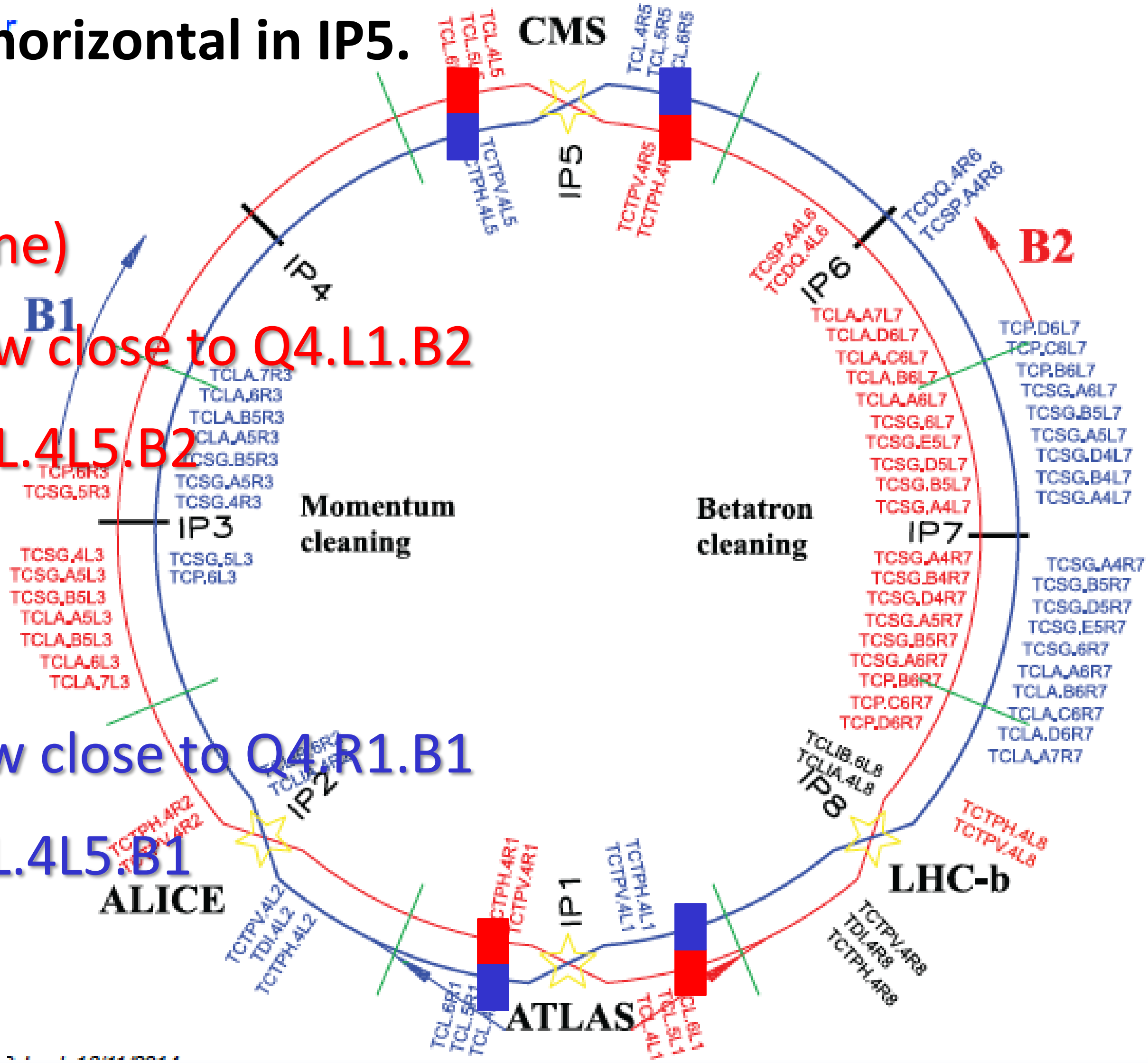
2 vertical in IP1 and 2 horizontal in IP5.

Beam 2 (current baseline)

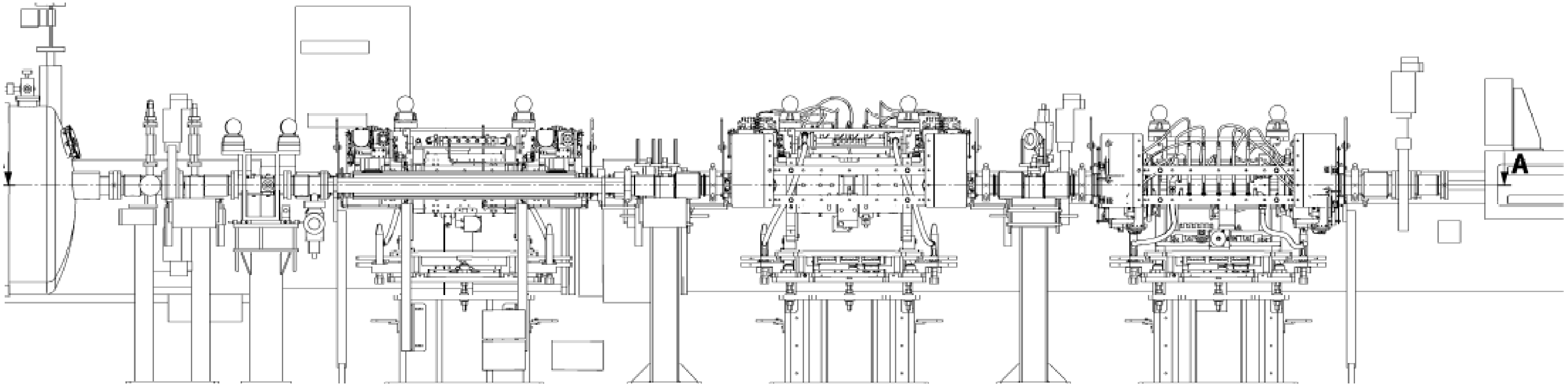
- TCTPV.4R1.B2 + new close to Q4.L1.B2
- TCTPH.4R5.B2 + TCL.4L5.B2

Beam 1

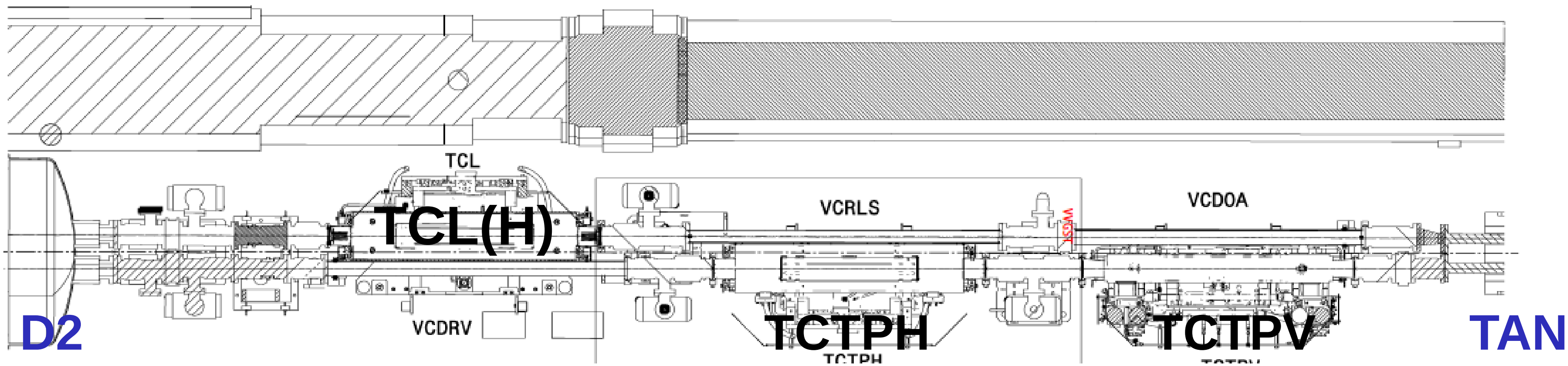
- TCTPV.4L1.B1 + new close to Q4.R1.B1
- TCTPH.4L5.B1 + TCL.4L5.B1



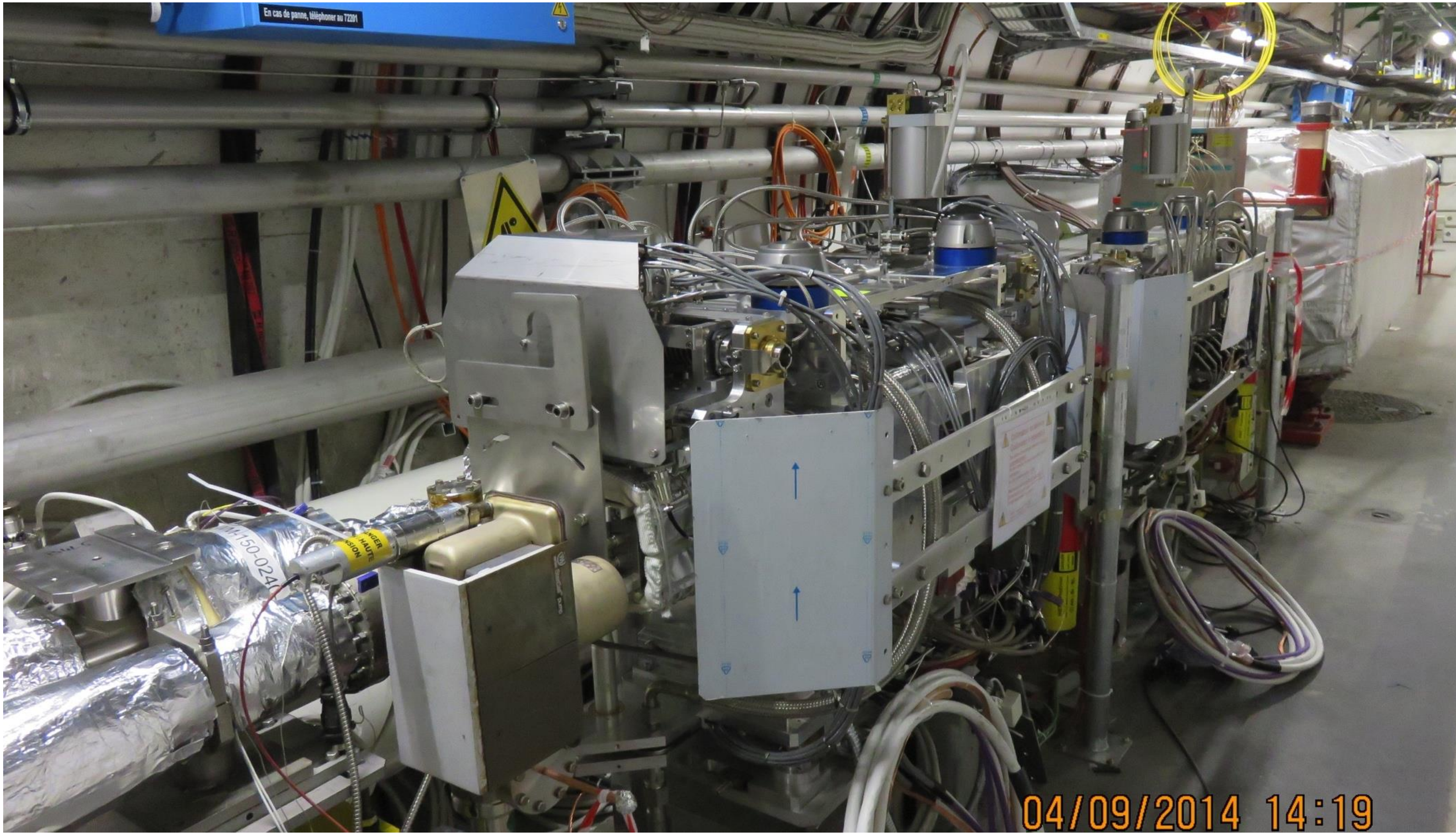
Zone between TAN and D2 (~π/2 phase from IP1/5) as from 2016



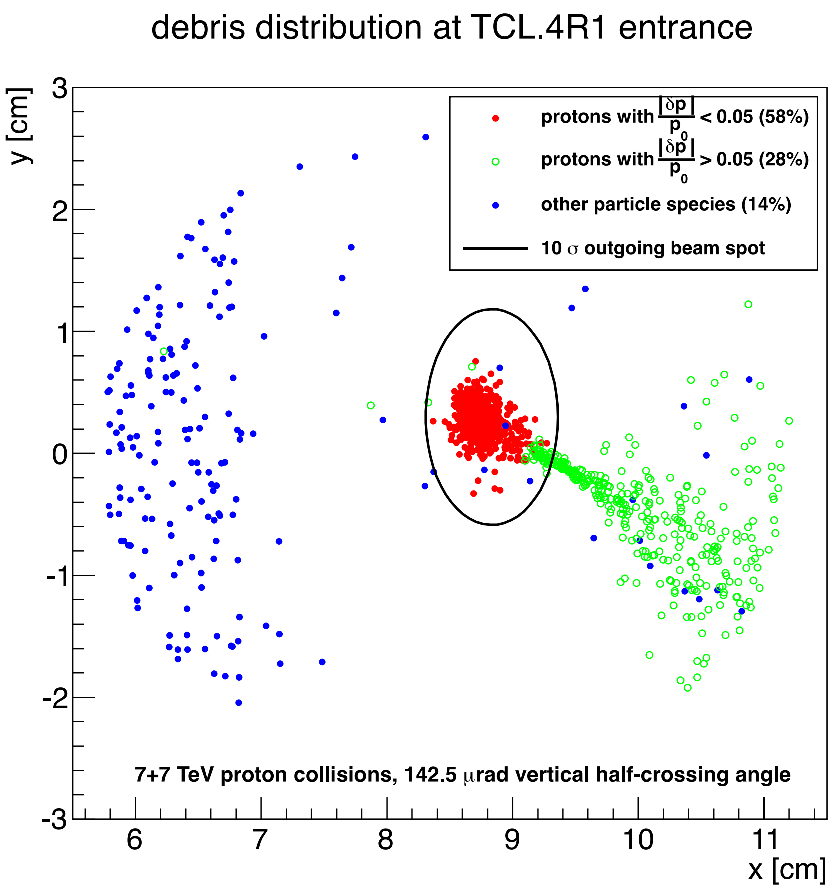
- TCL collimators are horizontal >>
  In IP1 need of a new collimator on outgoing beam



4L5



FLUKA results (2013)

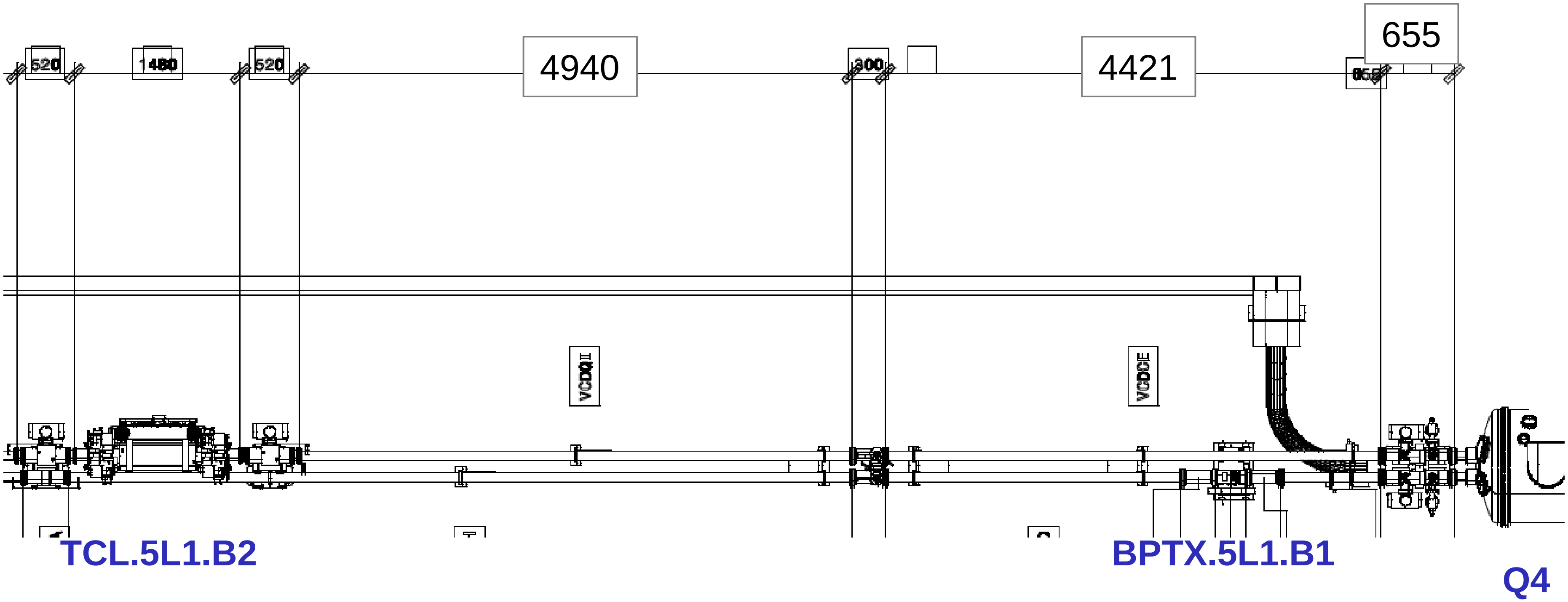


F. Cerutti & L. Esposito

Results referring to the TCL.4 position for vertical crossing - maximizing the debris amplitude in the vertical plane. Scattered protons with magnetic rigidity within 5% of the beam one [red points] represent more than half of the debris inside the outgoing beam tube but cannot be intercepted by 10sigma jaws. On the other hand, the other two population components are clearly displaced in the horizontal plane (and so Intercepted only by horizontal TCLs): more dispersed protons [green points] are pushed by the D1 on the external side whereas most of the other particles [blue points], being mainly photons of several hundred GeV, are found on the internal side.

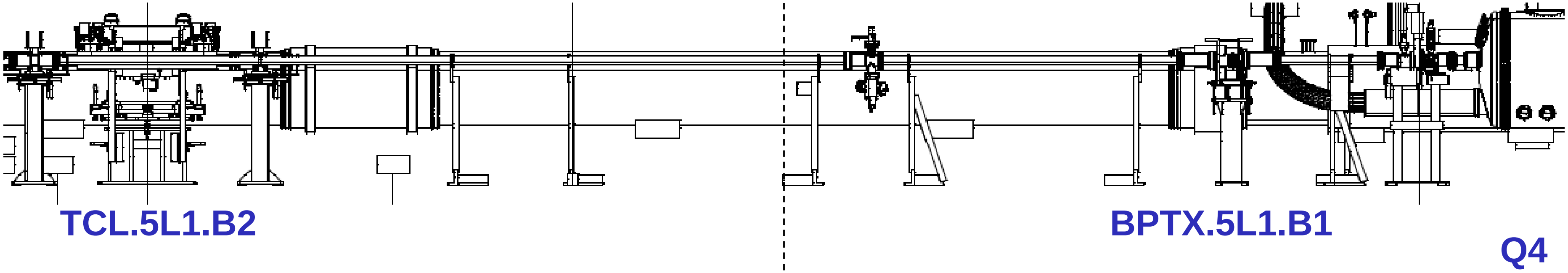
Consistent features are obtained at further locations.

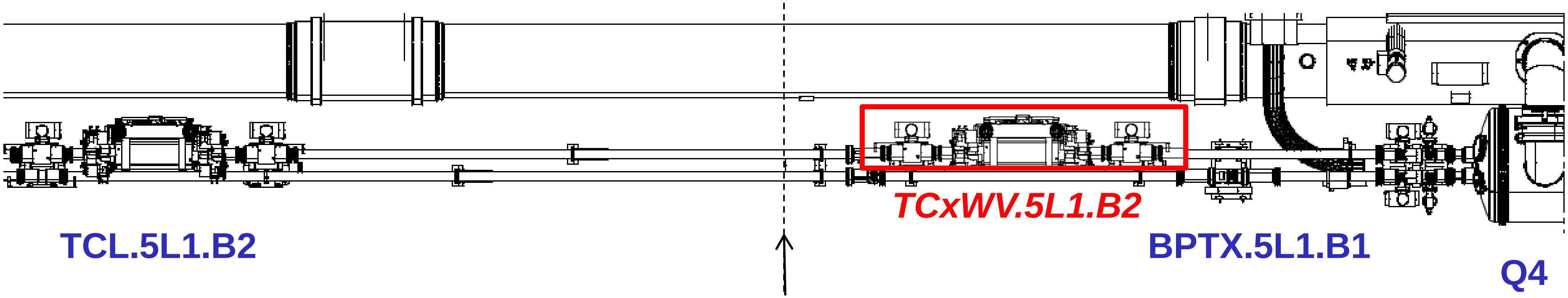
TCLV should be as close as possible to Q4



Thanks to JP Corso for the drawings

TCLV should be as close as possible to Q4

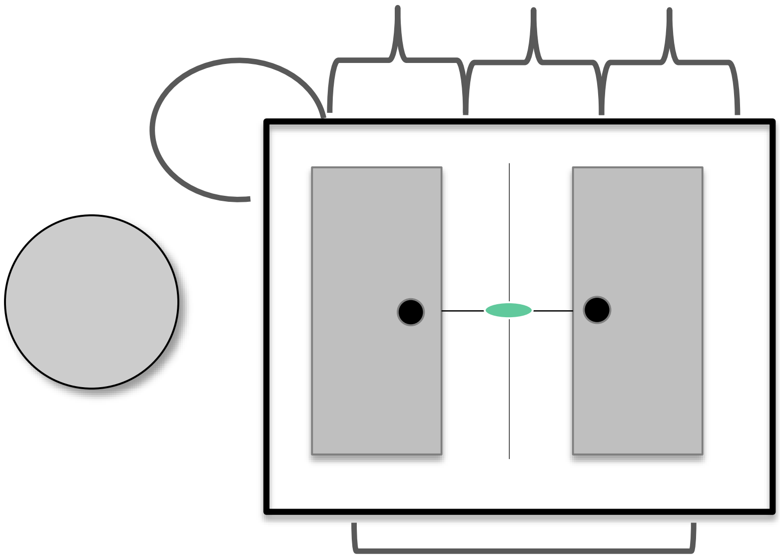


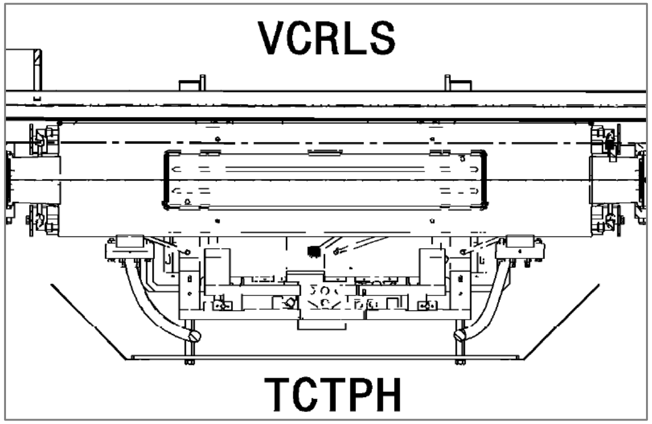


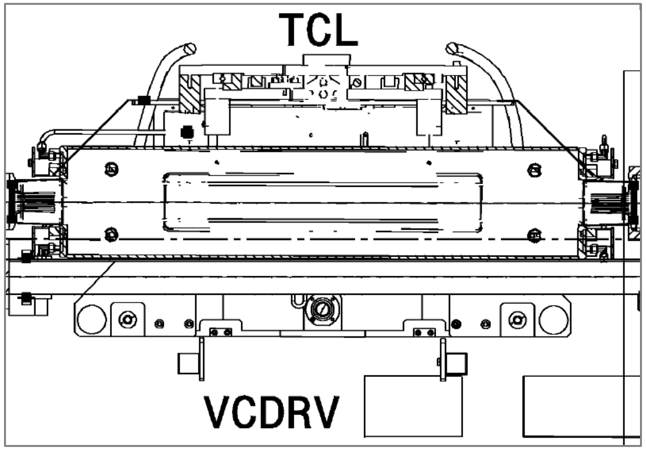
For Beam 1 is symmetrical on R1.B1

Thanks to JP Corso for the drawings

Horizontal collimator 5th axis

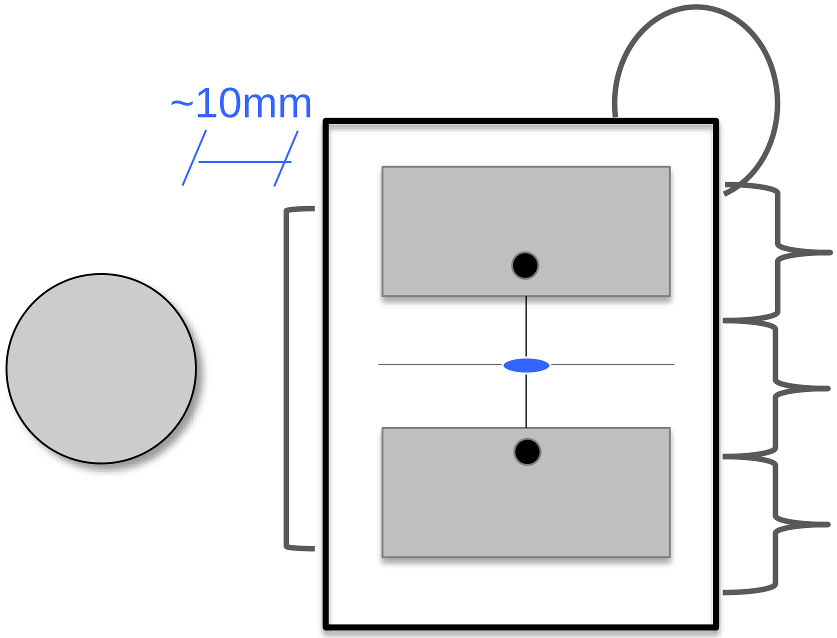


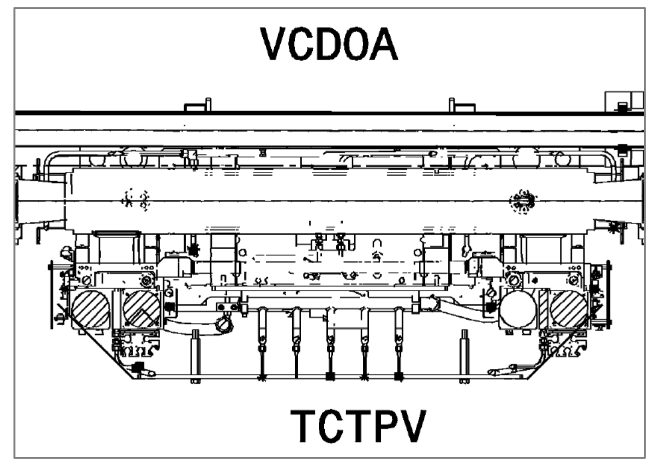




- Enough room (without heating jackets) to move the collimator up and down ($\leq \pm 10$mm)

Vertical collimator 5th axis

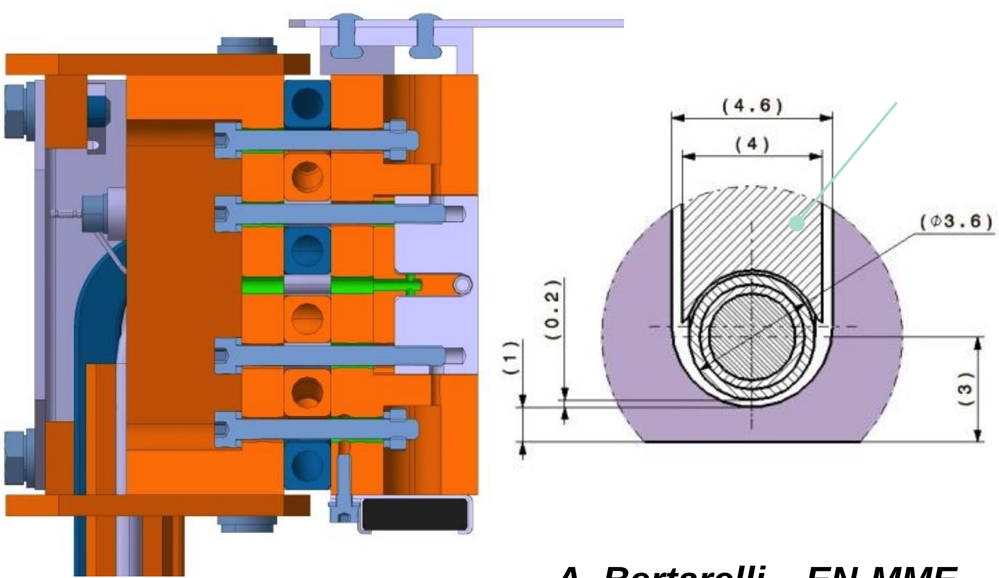




- ~2mm margin on 5th axis movement to avoid hitting the parallel vacuum chamber >> 8mm left in one direction
- After installation dedicated time to commission 5th axis before beam line pump-down

Limits for Collimator positioning for weak beams

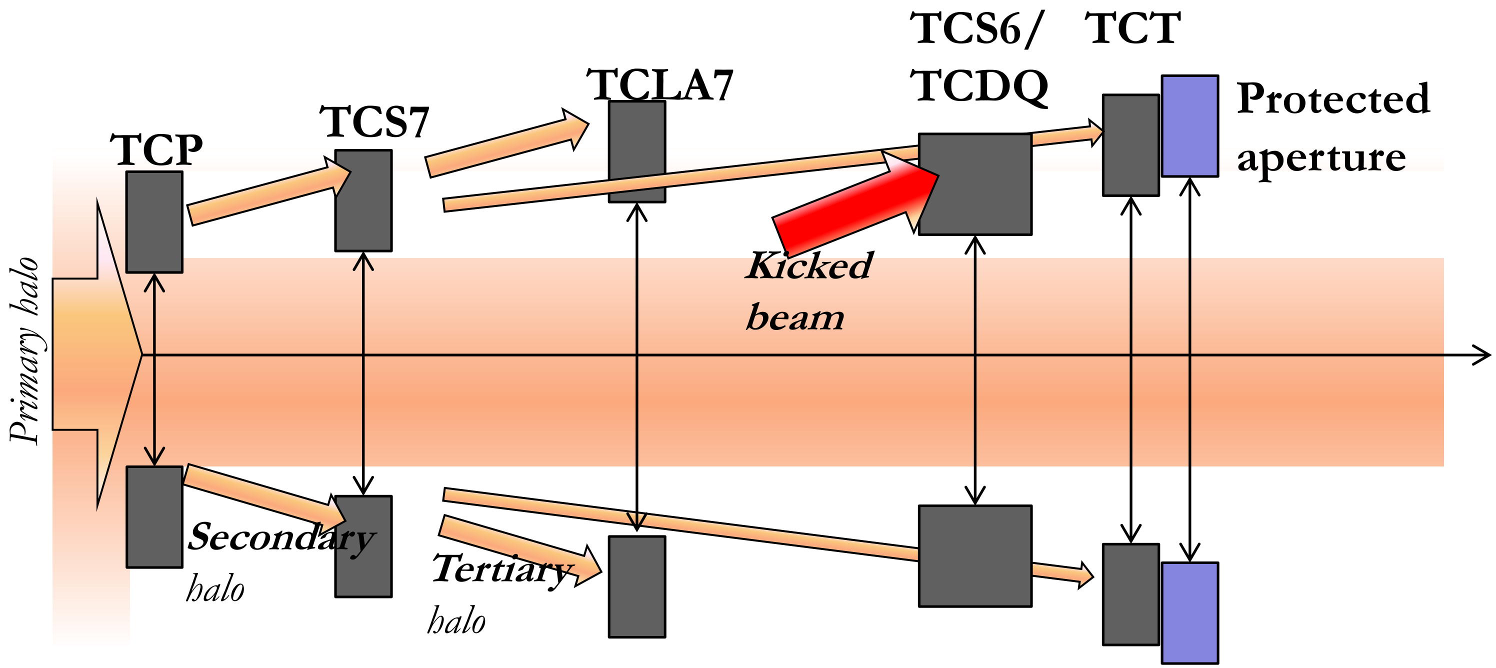
- Damage limits for W (Inermet) collimators established with simulations and HiRadMat tests:
  - Deposited energy for onset of damage: plastic deformation just above 0.2%.
  - Damage threshold for wire collimators estimated to be the same as standard tertiary collimators.



A. Bertarelli – EN-MME

Onset of damage	
Energy [TeV]	7
Impact depth [mm]	0.5
Beam size [σ_x x σ_y mm^2]	0.5 x 0.5
Number of bunches	1
Jaws gap [mm]	20
Pulse intensity [p]	**5×10^9**

Collimation hierarchy



Hor kick

- Limit on β* (and settings)
  – IR6 dump protection must protect TCTs
  – TCTs must protect triplet aperture

R. Bruce, 2014.06.13

- Must ensure sufficient margins so that we are protected also in case of orbit or optics drifts

Scenarios for β*=40 cm

Scenario A: β*= 40 cm

- Re-matched MKD-TCT phase to ~20deg
- 205 μrad half Xing (11 σ BB)

Scenario B: β*= 40 cm

- Present 40cm optics
- 185 μrad half Xing (10 σ BB)

Assuming we stay with the old policy for collimator margins, not accounting for the phase advance, and including 2015 orbit analysis: **backup scenario**

Scenario backup: β*=50cm

- 165 μrad half Xing (10 σ BB)

Collimator	Scenario A	Scenario B	Scenario backup
TCP IR7	5.5	5.5	5.5
TCSG IR7	7.5	7.5	7.5
TCSG IR6	8.3	8.3	8.3
TCDQ IR6	8.3	8.3	8.3
TCT IR1/5	8.9	8.9	10.0
Aperture	9.5	9.9	11.4

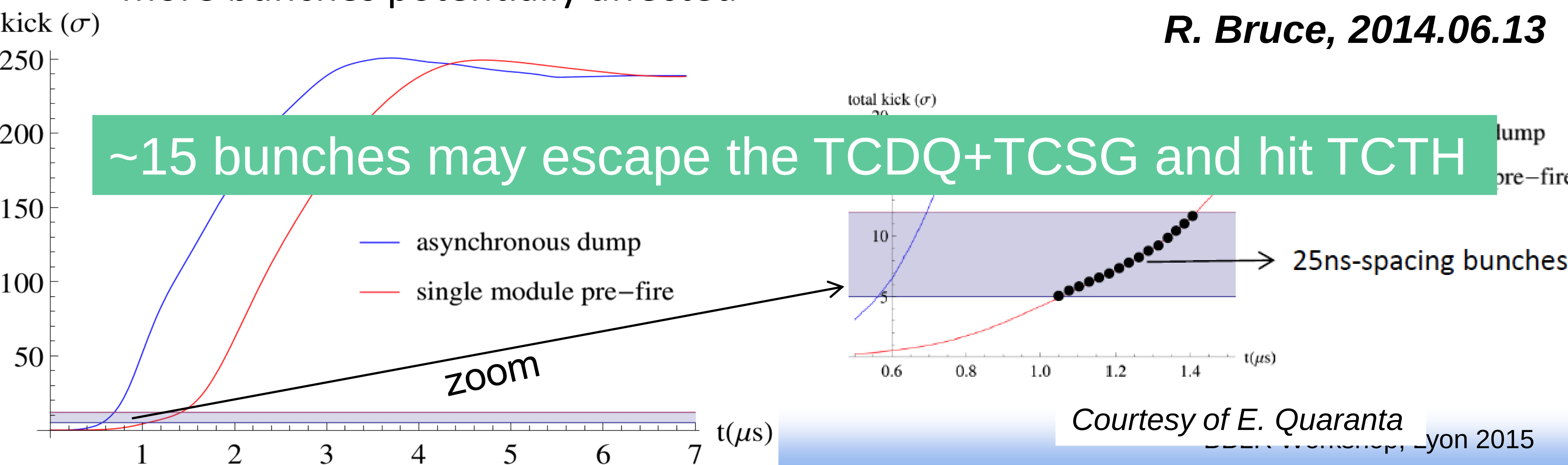
R. Bruce, Nov. 2015

Beam dump failure

- Waveform of kick in µrad from one MKD provided by B. Goddard
- Asynchronous dump: total kick is sum of 15 kickers
- Single module pre-fire: Re-triggering time (650 +50 N) ns, N integer distance from pre-firing kicker (worst case)
- Below certain kick amplitude, nothing is hit
- Above certain kick amplitude, everything intercepted by TCDQ
- Single module pre-fire more dangerous: stay longer time at small kicks => more bunches potentially affected

Dangerous "window"

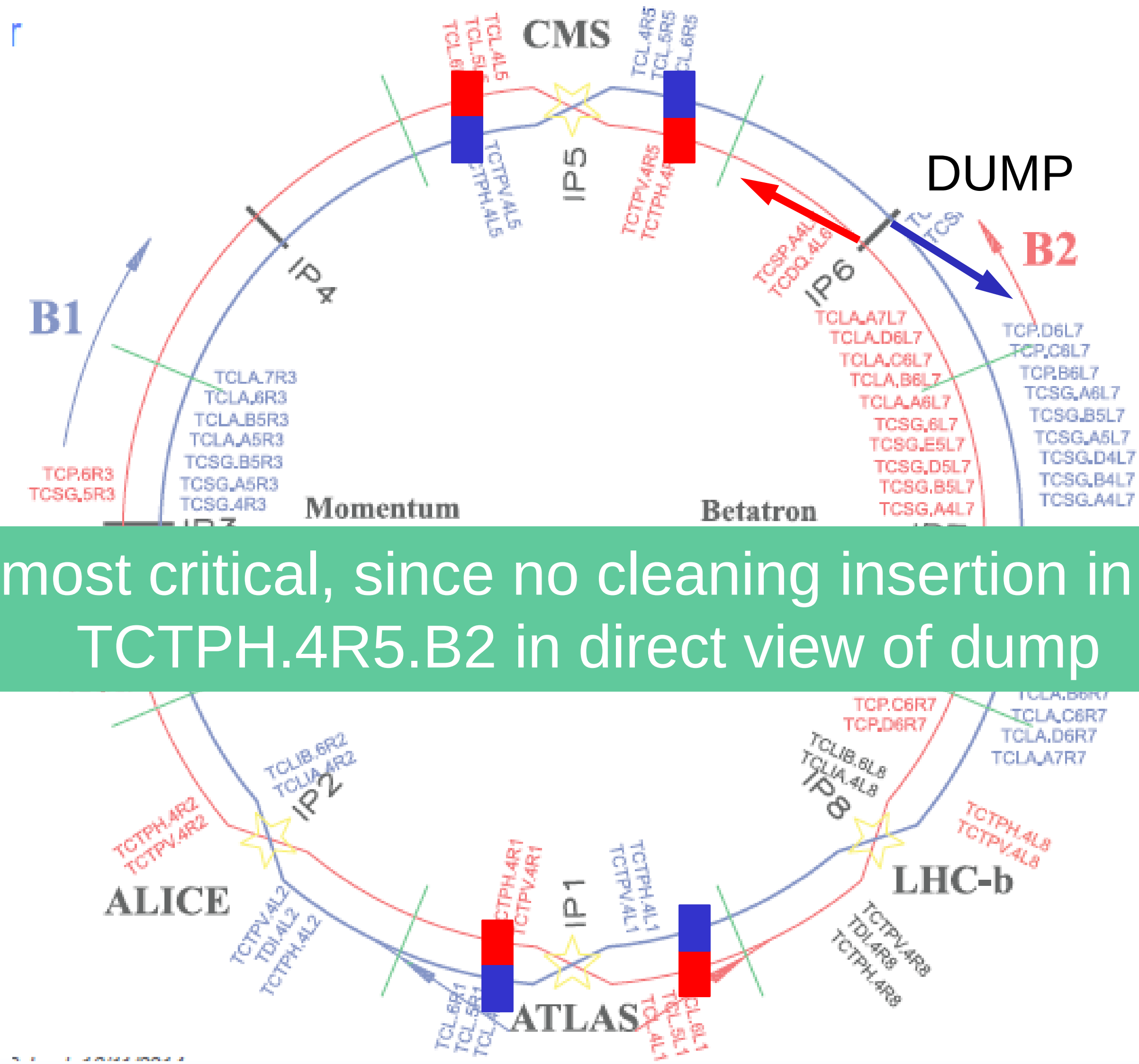
R. Bruce, 2014.06.13



~15 bunches may escape the TCDQ+TCSG and hit TCTH

Courtesy of E. Quaranta

Beam 1 vs Beam 2



B2 IR5 most critical, since no cleaning insertion in between
TCTPH.4R5.B2 in direct view of dump

Options Beam 1 vs Beam 2

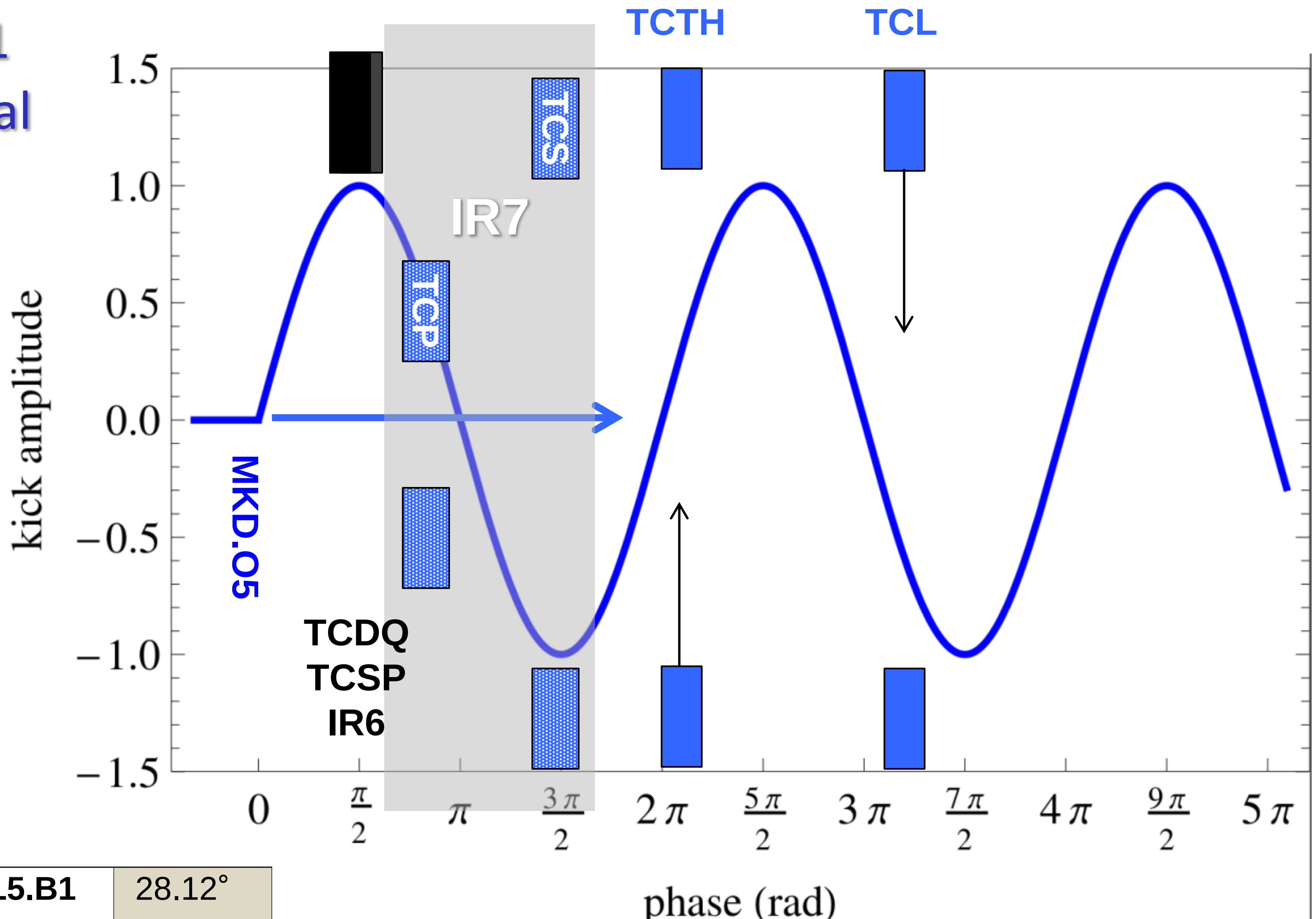
LHC Run II optics round collision 40cm

Beam 1	H Phase Advance [degree] (from MKD.O5)	Phase Advance [degree] (H or V plane) from IP
TCTPV.4L1.B1		92.29 V
DRIFT_88 (TCLV)		267.61 V
TCTPH.4L5.B1	28.11	91.77 H
TCL.4R5.B1	212.51	267.37 H
Beam 2		
DRIFT_555 (TCLV)		92.46 V
TCTPV.4R1.B2		92.36 V
TCL.4L5.B2	341.66	92.56 H
TCTPH.4R5.B2	157.31	91.80 H

- Preferable: phase advance is >40 deg away from 90 or 270 deg
- Here it is assumed that other TCTs on weak beam can be kept at large aperture

Where are the wire collimators with respect to the kicker?

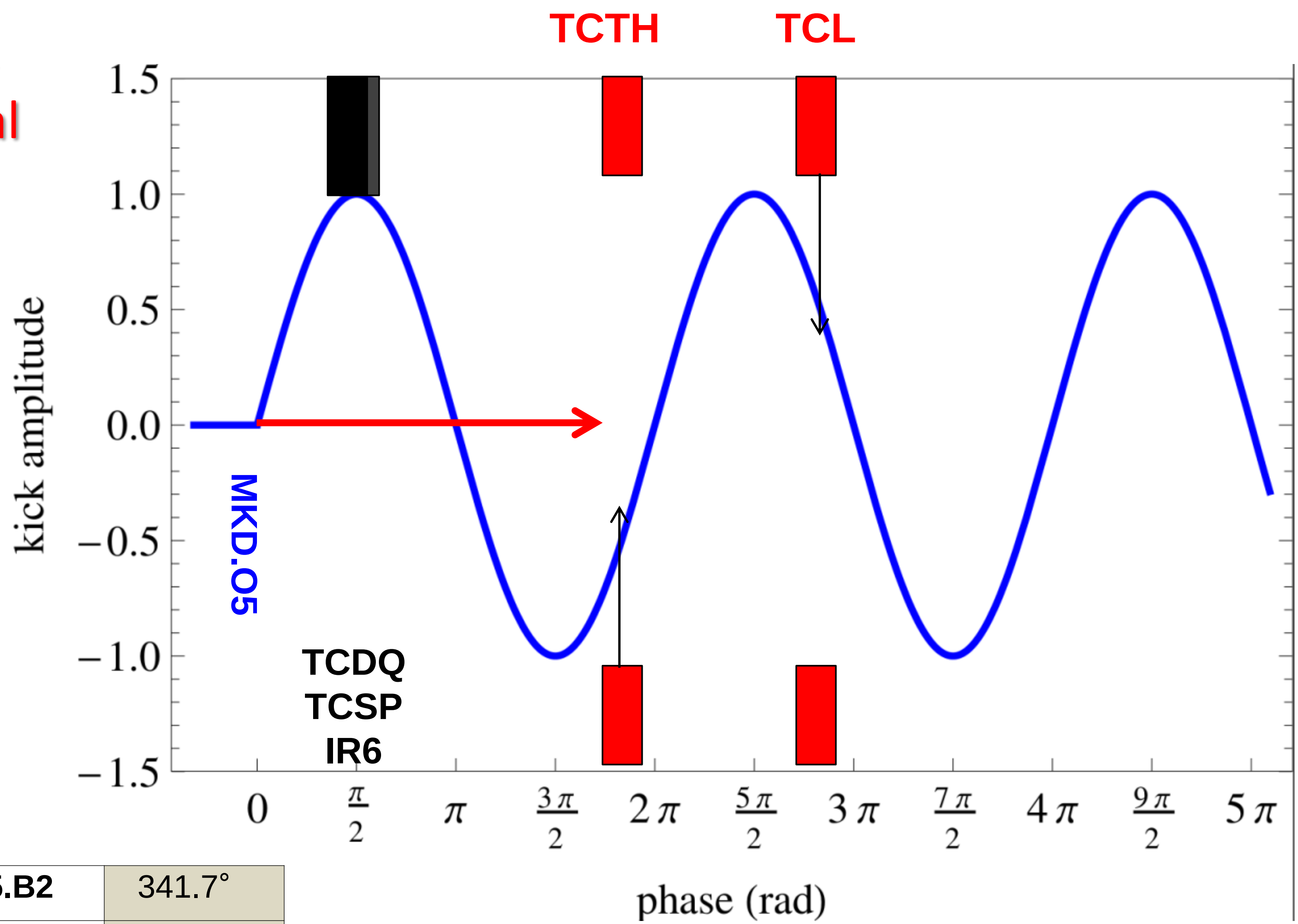
- Beam 1 Nominal



TCTPH.4L5.B1	28.12°
TCL.4R5.B1	212.5°

Where are the wire collimators?

- Beam 2 Nominal



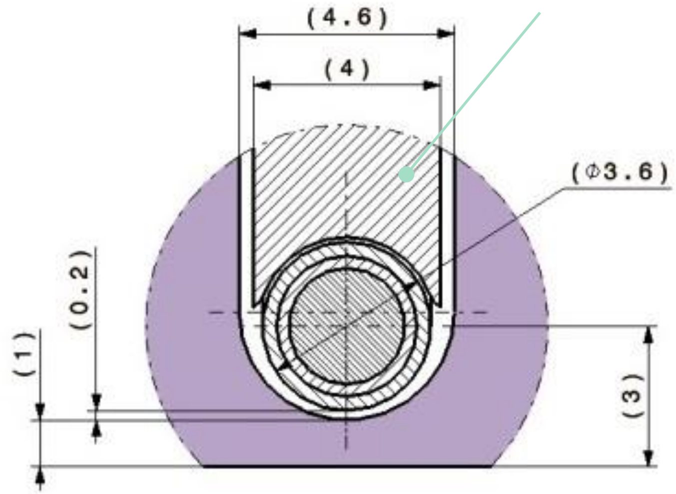
TCTPH.4R5.B2	341.7°
TCL.4L5.B2	157.3°

Options Beam 1 vs Beam 2

LHC Run II optics round collision 0.4m

Beam 1	BETX [m]	BETY [m]	σ_x [mm]	σ_y [mm]
TCTPV.4L1.B1	2164.74	885.62	1.05	0.67
DRIFT_88 (TCLV)	225.89	1307	0.34	0.81
TCTPH.4L5.B1	2156.11	839.02	**1.04**	0.65
TCL.4R5.B1	753.51	2139.61	0.62	1.04
Beam 2				
DRIFT_555 (TCLV)	311.34	1907.74	0.40	**0.98**
TCTPV.4R1.B2	2159.61	857.73	1.04	0.66
TCL.4L5.B2	779.66	2144.74	0.63	1.04
TCTPH.4R5.B2	2150.97	811.88	**1.04**	0.64

ε_n=3.5µm.rad



3mm between wire center and jaw surface translate to up to ~ 3σ

- Wire @ 8σ from beam = jaw @ 5σ (TCP presently at 5.5σ) with fat beam
- Nominal 2808x1.15e11p and 1h lifetime >> 0.89e11p/s losses

Present machine protection envelope

- The setup beam flag (SBF) is a parameter used in operation defined to allow the mask of several interlocks:
  - BLMs, IR6 BPMs, Collimator movements, RF, AC dipole mode, PIC and some SIS interlocks.
- It is considered 'normal' when the beam intensity is below the Cu transient damage limit

Limiting intensities for different level SBF at 450 GeV and 6.5TeV

	450 GeV	6.5 TeV
Normal	5.5e11	1.1e10
Relaxed	5.5e11	3e11
Restricted	5.5e11	>3e11

Relaxed flag used for beam setup and collimation alignment

2015 MPS re-validation

- The machine **always needs to be qualified** after changes in:
  - optics, energy, aperture, collimator settings, etc.

non-negotiable re-validation

Minimum qualification	Betatron loss map				Off-momentum loss map (B1 + B2)		Asynchronous beam dump (B1+B2)
	B1H	B1V	B2H	B2V	Negative	Positive	
Injection	X	X	X	X	X	X	X
During Ramp	-	-	-	-	-	-	-
Flat top	X	X	X	X	X	X	X
During (De-)Squeeze	-	-	-	-	-	-	-
(De-)Squeezed	X	X	X	X	X	X	X
Stable Beams	X	X	X	X	X	X	X

We do not propose loss maps during (de-)squeeze or ramp, but this can change if the ramp-squeeze or squeeze during collisions are implemented.

- **Provided that the orbit is stable and that there are no changes** and collimation system has been qualified for the corresponding settings, **no additional tests are required**, **however**, a **minimum validation** of the cleaning **must be guaranteed through loss maps at regular intervals.**

Periodic checks	Betatron loss map				Off-momentum loss map (B1 + B2)		Asynchronous beam dump (B1+B2)
	B1H	B1V	B2H	B2V	Negative	Positive	
Injection	X	X	X	X	X	X	X
Flat top	-	-	-	-	-	-	X
(De-)Squeezed	X	X	X	X	-	-	X
Stable Beams	X	X	X	X	X	X	X

Periodicity needs to be defined, after a TS or every 3 months was defined in 2012

Analysis of these tests responsibility of individual systems

Proposed safe filling schemes and collimator settings

Assuming that injection energy is not of relevance because of wrong phase advance of wire collimator (which if corrected could create aperture problems)

IF

- Pilot bunches only (5e9 p/bunch) @ top energy
  - \+ Bunch spacing ≥ 15x25ns (beam dump dangerous window)
  - = max. 1 bunch projected onto TCTW/ TCLW after asynchronous beam dump
- Total beam intensity ≤ 1.1e10p

THAN

- 'Normal' beam setup flag
- TCTW/TCLW can be set down to 5σ with fat pilot

Other possibilities

- With nominal – 40cm – beam optics, and total beam intensity >3e11p, normal collimator settings shall be applied.

  = TCTW/TCLW between 8.9 and 10 collimation σ

- Between 1.1e10 and 3e11 p total intensity the ‘relaxed’ beam flag can be negotiated prior simulations and loss maps (overhead on machine time to be taken into account) to validate settings.

- Machine protection can rely on phase advance only if it is sure that this does not change: analysis and validation on-going on interlocks with quadrupole current by MP team.

Summary

- Wire collimators for BBRL compensation will be installed in place of a **TCTPH +TCL in IP5**, and a **TCTPV + TCLV(new) in IP1**.
  - Integration of the new collimator is ongoing, guaranties ~π/2 phase advance to IP1
  - 5th axis movement will allow alignment of the wire onto the beam
  - Distance between wire center and jaw surface (3mm) ~ 3σ (collimation)
- Beam 1 gives more flexibility – IR7 collimator between TCTPH in IP5 and Dump.
- Intensity limits @ 6.5TeV:
  - With fat pilot beam (5e9p/b) + ≥15x25ns bunch spacing and tot intensity < 1.1e10p ⟶ Normal SBF (playground) 😋
  - Between 1.1e10 and 3e11 p tot beam intensity preparation work (simulations+loss maps) to validate settings and set 'relaxed' SBF
  - Above 3e11 p tot beam intensity collimators settings = operational >> between 8.9 and 10 σ (collimation)

Thank you

Back up slides

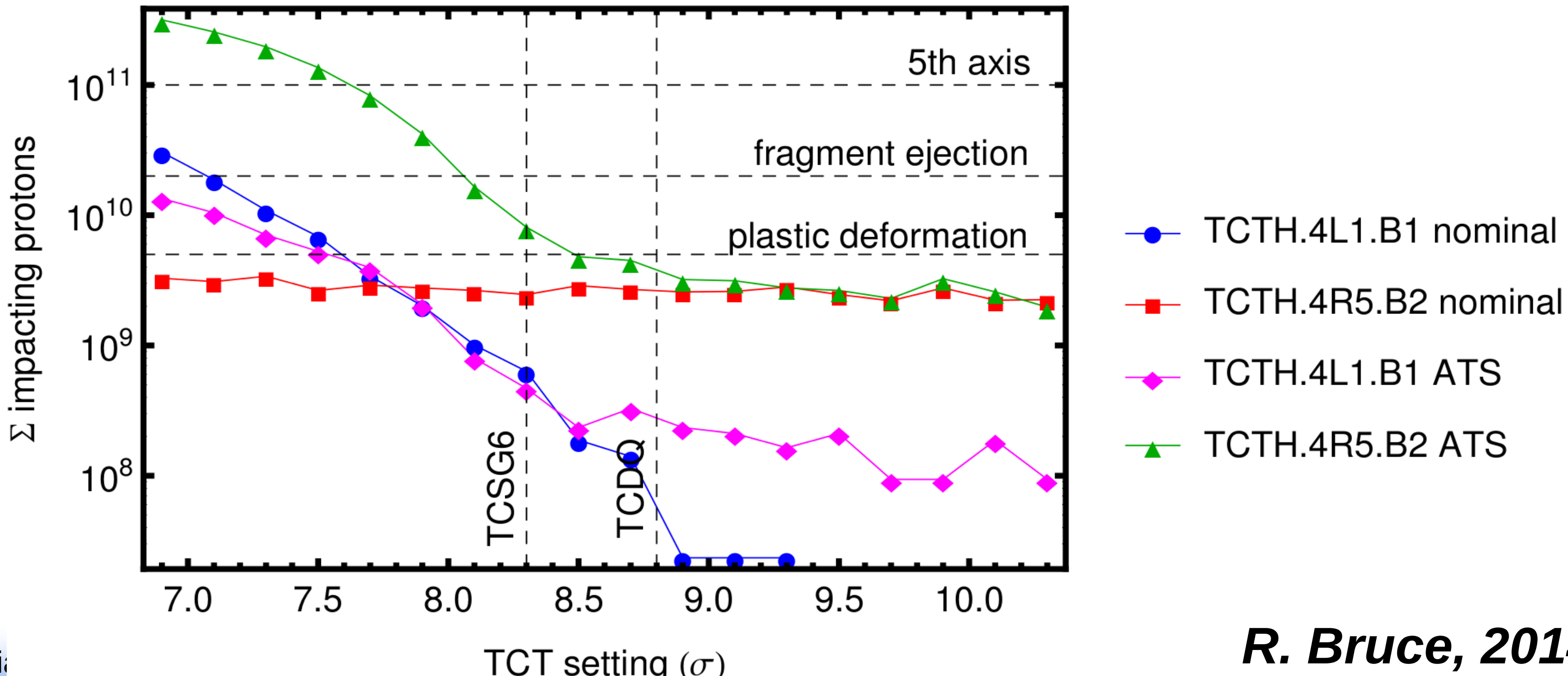
What are we afraid of?

- Accident scenario: beam dump failure
  - LHC filling scheme has "hole" – abort gap – to allow rise of the 15 dump kickers (MKD) from zero to full field - standard dump. Errors possible:
    - Asynchronous dump: all dump kickers firing simultaneously at the wrong moment
    - Single-module pre-fire: one module fires, followed by re-trigger of others
  - These failures could give intermediate kicks to some bunches and send beam directly onto sensitive equipment (TCTs / aperture)

R. Bruce, 2014.06.13

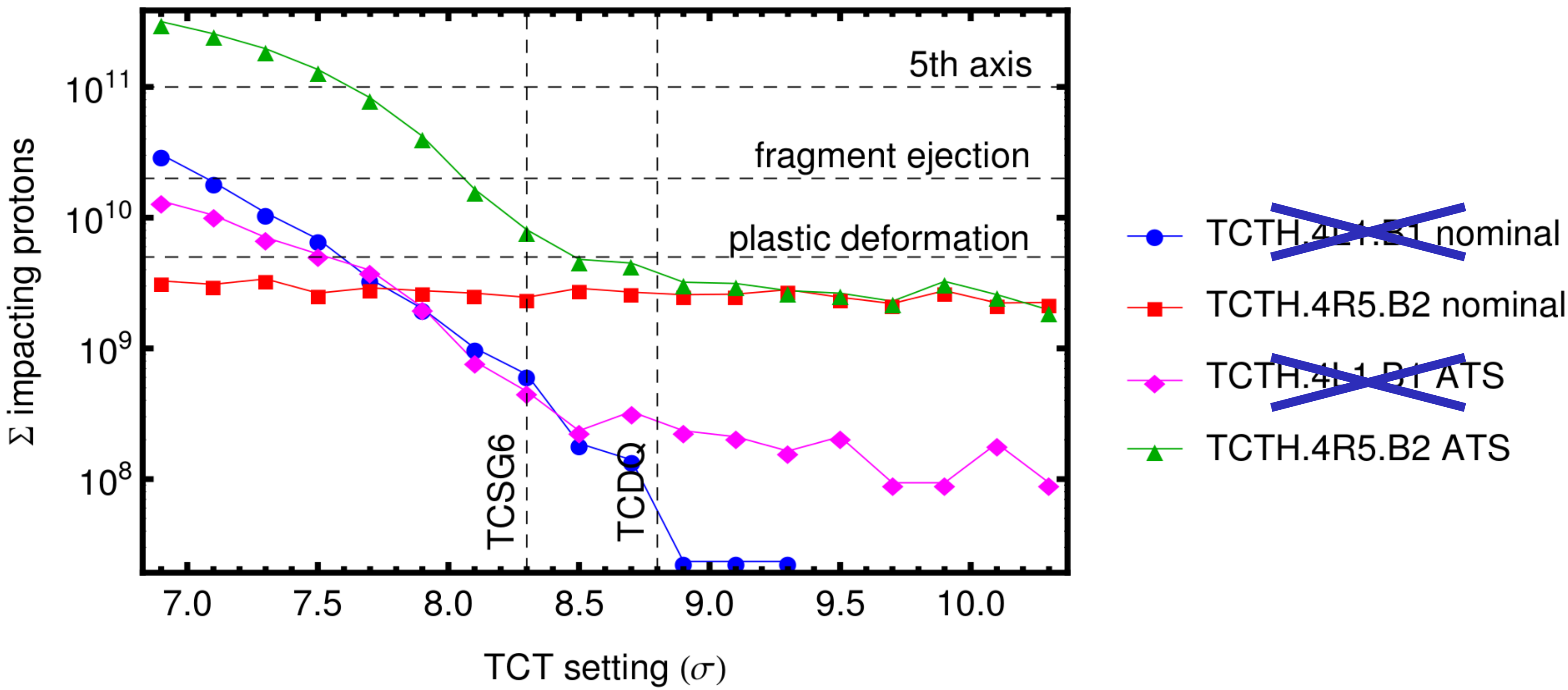
Simulations of losses at TCTHs vs retraction

- Single module pre-fire, MKD.A5R6 fires (most downstream kicker)
- Summing all bunches (1.5e11 p/bunch @25ns spacing), ATS + nominal (55cm) optics @6.5TeV, assuming 2σ retraction for collimator settings.
- Compare with damage limits (A. Bertarelli et al.)
  - Plastic deformation: 5e9, Fragment ejection 2e10, 5th axis unusable 1e11.



R. Bruce, 2014.06.13

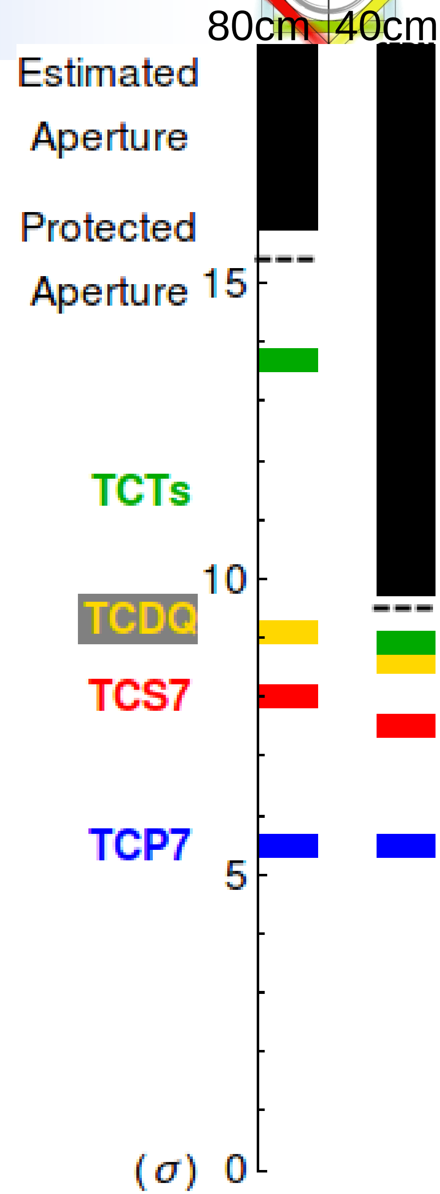
Scaling for BBLR compensation MD



- In P1 only vertical collimators
- Max total bunch intensity for ATS ~1/100 of nominal (reducing number of bunches still expose to damage risks).

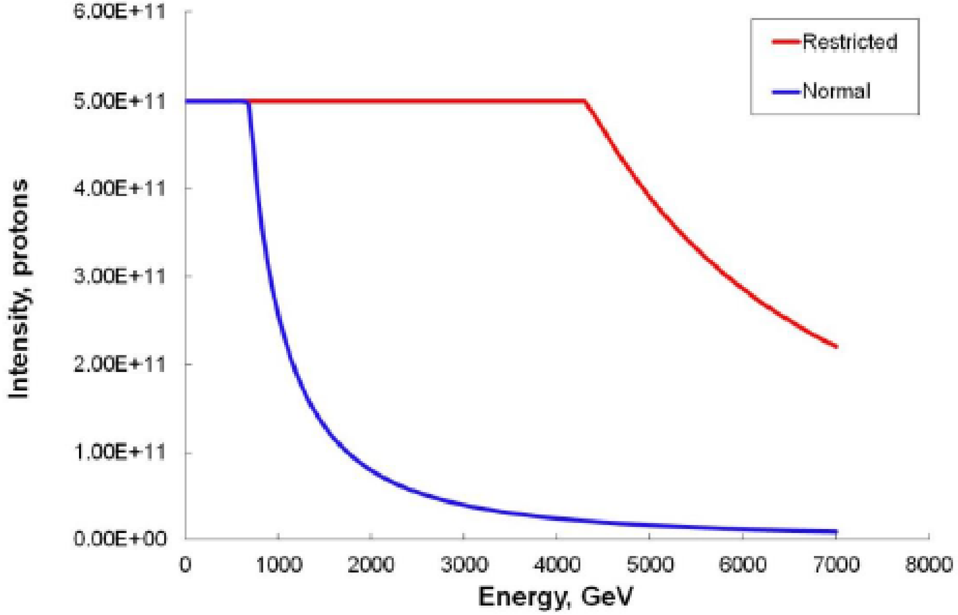
Considerations for β*=40 cm

- Aperture at β*=40 cm, measured in MD2:
  - V 9.5 σ, H 10 σ (205 μrad half Xing, 11 σ BB for 3.75μm)
- Must reduce collimation margins, relying on phase advance from MKDs to TCTs / triplets
  - Need 2σ retraction in IR7.
  - Reduce TCT setting to 8.9 σ. With present MKD-TCT phase advance (37 deg), we can protect 9.9σ aperture for as. dump
    - post-MD2 analysis – worse losses in IR1 B2
  - To make aperture fit with collimators:
    - Improve TCT phase advance (easy with nominal optics)
    - Go down from 11 σ to 10 σ beam-beam sep => gain ~0.5σ aperture. Good also for lumi reduction factor
    - Rely on BPM interlocks to allow smaller margin but possibly more beam dumps



Updated values for SBF

1) Normal SBF: 1.1e10 [ALL]
2) Restricted SBF: 1.25e11 x 2 bunch [Special users – Coll, collision setup]
3) Restricted SBF: 1.5e10 x 16 bunches [MDs with MP doc.]



Limiting intensities for different-level SBFs at 6.5 TeV and 7 TeV

	6.5 TeV	7 TeV
Normal	1.1e10	9.4e9
Restricted	2.5e11	2.2e11

D. Wollmann, 92th MPP meeting