β Cleaning in IR3

R. Assmann

LCU 3.6.2008

See also talks by R. Losito (LTC) and T. Wijnands (ICC) on radiation to electronics.

Problem described there → **Can we do something to improve the situation?**

Here: **Describe possibility to reduce radiation to electronics for the same beam loss!**

This talk essentially repeats my presentations to LTC and R2E.

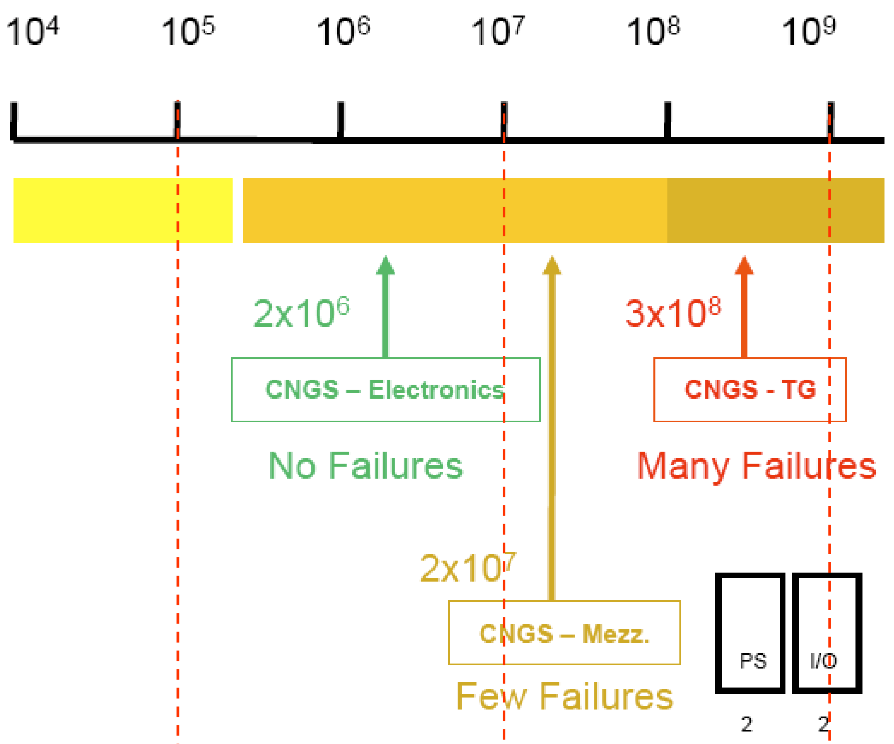
Results by accelerator physics team on collimation (several students/fellows):

R. Assmann, G. Bellodi, C. Bracco, V. Previtali, S. Redaelli, T. Weiler

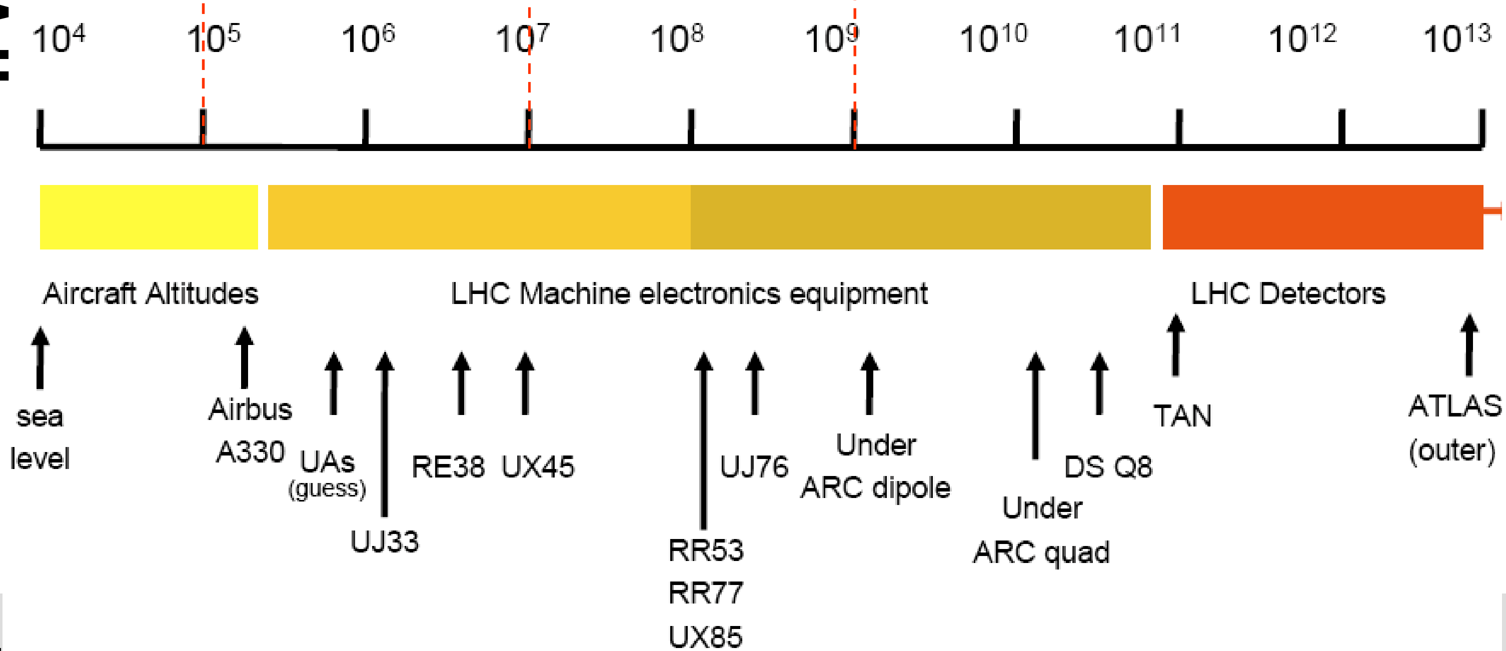
Discussion in the **LHC Collimation WG**.

What do we need to gain?

T. Wijnands, ICC



- Depends on electronics, location, topology of losses, … ➔ no detailed analysis exists
- Consider 1e5 h/cm^2/y as safe: **factor >1000**.
- Consider 1e6 h/cm^2/y as safe: **factor > 100**.
- Safety factor is important, also as accelerator physics and FLUKA calculations have uncertainty! Suggest **safety factor 10**.
- Severe limitation even for a few bunches at multi-TeV!



Reminder: LHC Loss Predictions

Losses for nominal parameters are listed in table (7 TeV equivalent number of protons).

	Injection + ramp	**Squeeze**	**Physics (8h)**	**Total in 233 fills (per beam)**
Momentum halo	1.2×10^{12}	0	1.2×10^{13}	3.1×10^{15}
Betatron halo	2.9×10^{12}	3.9×10^{13}	8.9×10^{12}	1.2×10^{16}

IR7 betatron cleaning

IR3 momentum cleaning

generic loss assignment here

Note:

- **ultimate parameters**: 60% higher for both betatron and momentum halo losses.
- **first year**: 20% lower for betatron and factor 3.8 lower for momentum halo losses.

➔ No factor 100 to be gained in beam losses without very low intensity!

LHC Project Note 375, M. Lamont

Evolution in beam loss

- My worry is that all energy deposition studies focus on nominal case:
  - Ideal case (ideal IR3 inelastic interactions were recently sent to FLUKA)
  - All collimators set to gaps required for $\beta^* = 0.55$ m
  - Best possible case after years of learning
- It was agreed that commissioning scenarios are studied (much worse?):
  - Reduced sets of collimators
  - Relaxed gaps
  - Relaxed setup and machine tolerances
- I expect that situation will look different and more realistic than now:
  - Lower cleaning efficiency (factor 10 shown in proton tracking)
  - Local loss spikes close to the quench limit
- There are **several orders of magnitude** here!

Uncertainty in losses

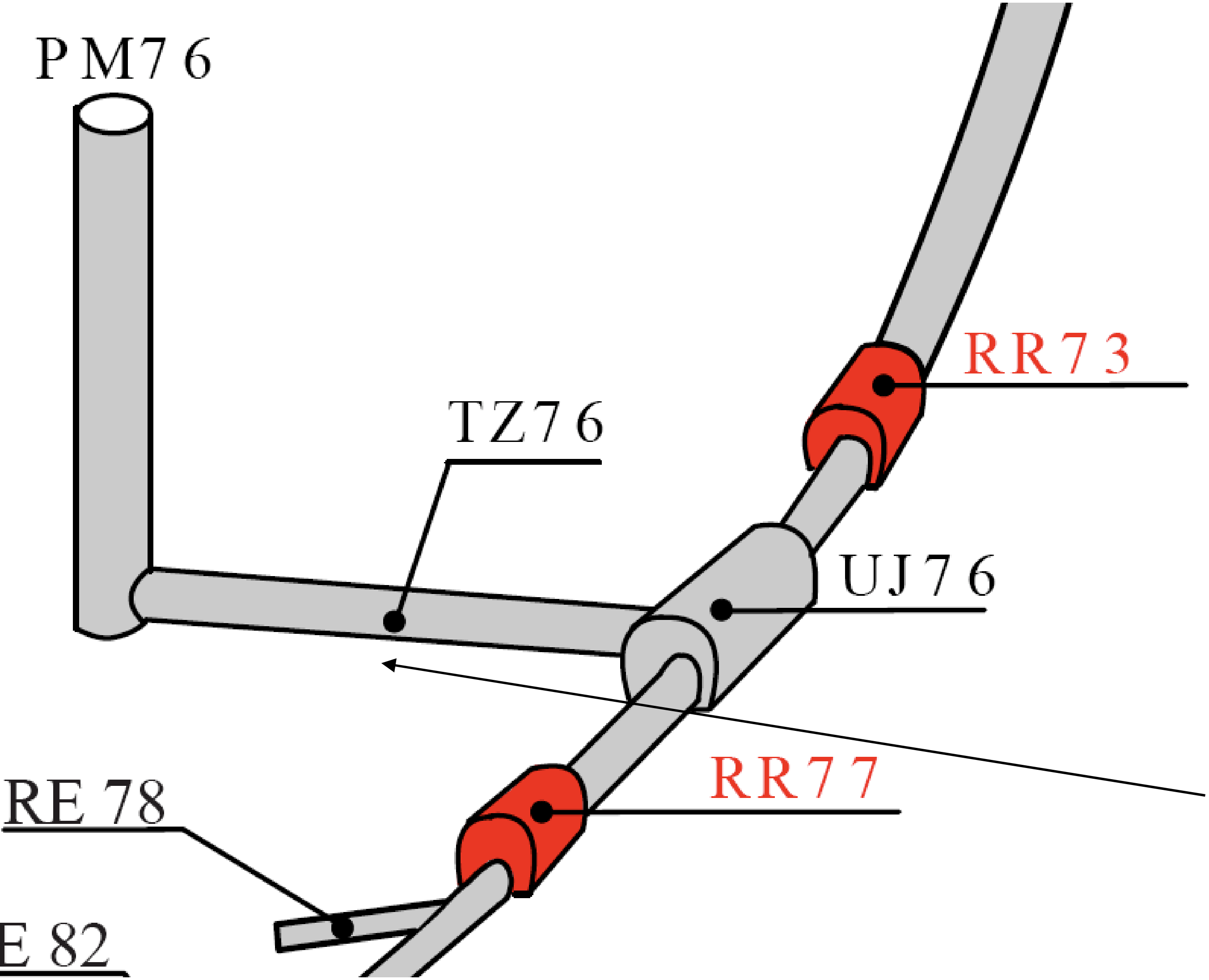
- **Overall losses per IR:**
  - Relatively well constrained.
  - Low errors (factor 2?).
  - Used e.g. for environmental impact.
- **Local losses N_p (s) around the machine:**

0.1 ⟷ 10^{-6}

$$\frac{dN_p(s)}{dt} = \frac{dN_{p,tot}}{dt} \times \tilde{\eta}_{ineff}(s)$$

- **Inefficiency will be brought up by several orders of magnitude over the first years.**
- Even **with quite low intensity we can reach nominal loss rates** at some locations (see SNS experience, also see Tevatron loss evolution).
- Prepare for the real situation in energy deposition (AP studies exist).

Electronic Locations in IR7: UJ76, RR73, RR77



Most electronics in UJ76, RR73 and RR77:

➔ Exposed to radiation from tangential beam losses. Impossible to shield.

Electronics for collimation and machine protection was relocated to **TZ76** in 2004/5.

Look at Published IR7 Results

- Accelerator physics data for the **perfect system** (optimistic assumptions). Imperfections: more losses downstream of primary collimators ➔ more losses in front of UJ76.
- Shielding imperfections not included.
- Assumed losses: **4e16 p per year in IR7** (from both beams). These are ultimate parameters.

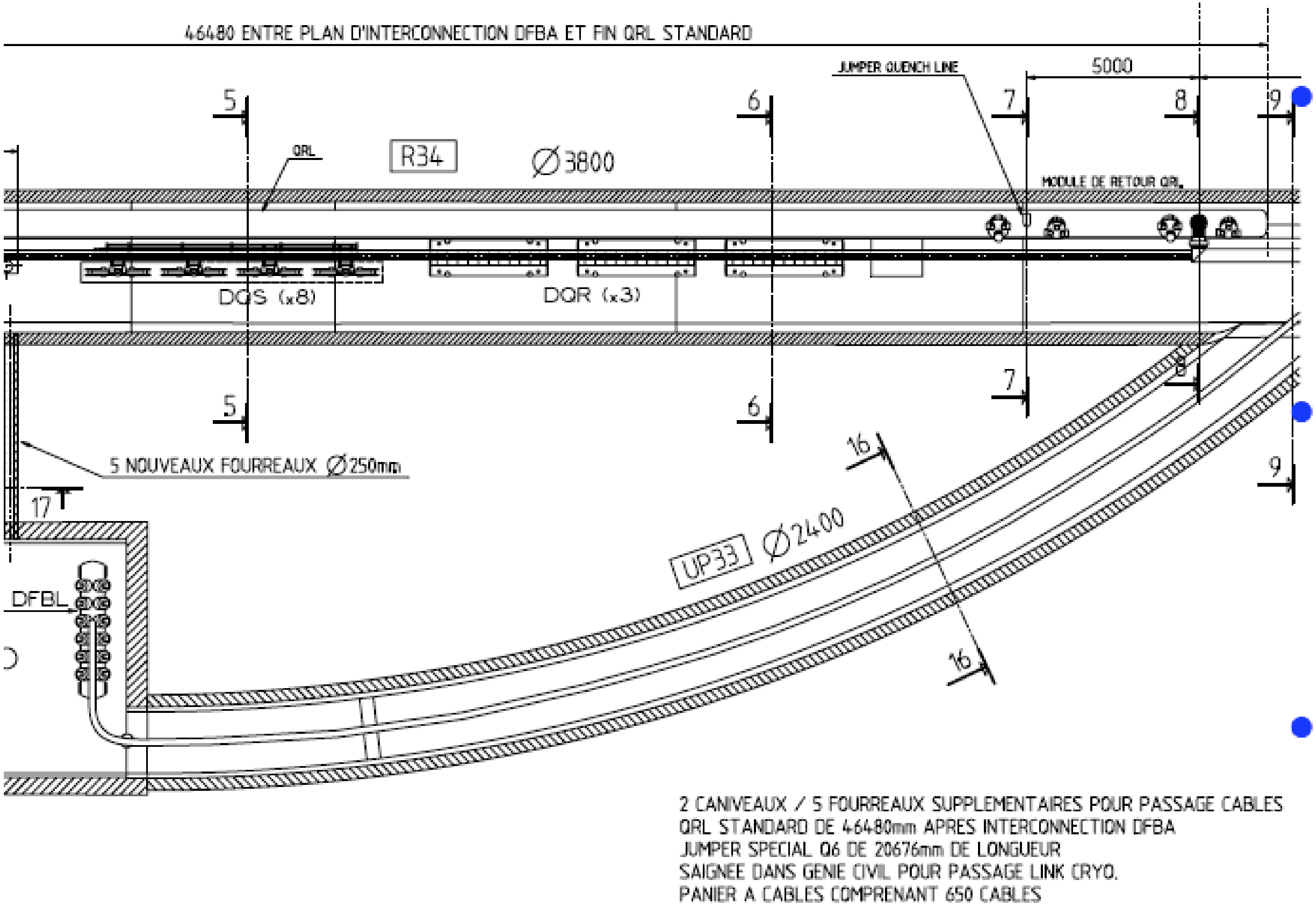
Table 2

Radiation levels at the electronic rack positions at IR7 (average values for the racks situated on the ground floor). The statistical error is ≤20%.

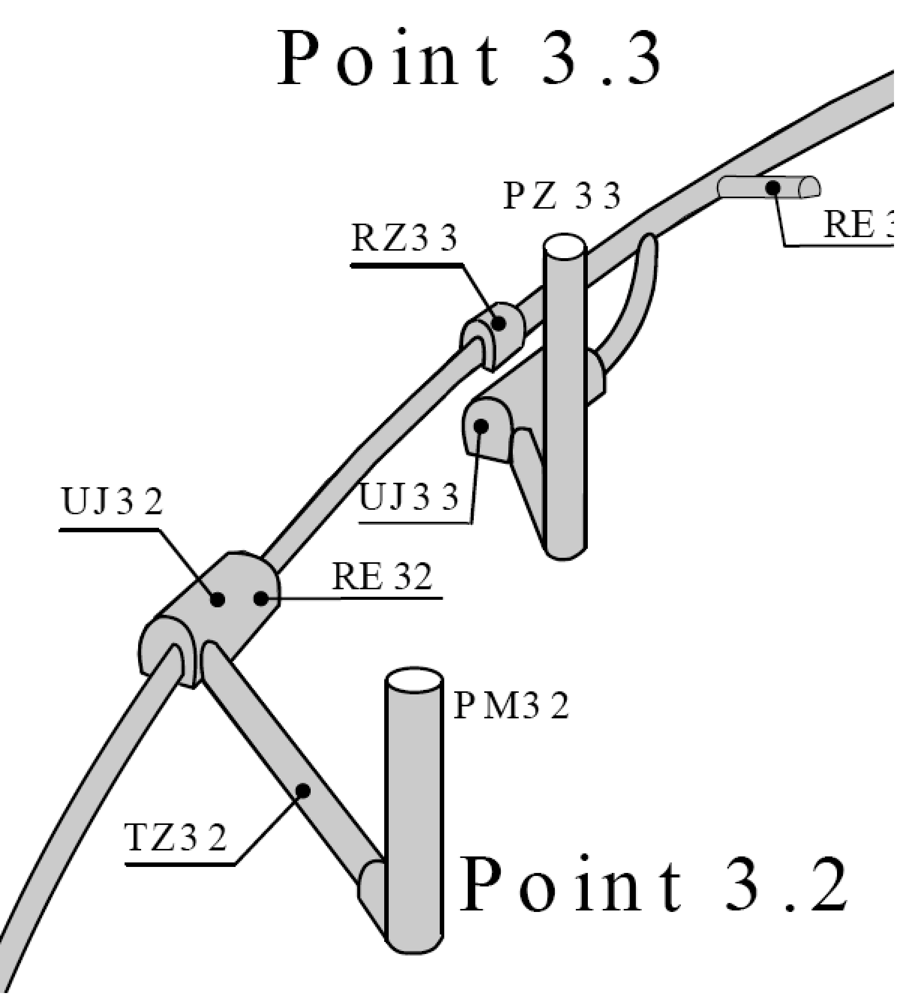
	Dose (Gy/y)	Hadrons > 20 MeV (cm^{-2}/y)	1 MeVeq. flux (cm^{-2}/y)
UJ76	0.5	8 _ 10^{8}	2 _ 10^{9}
RR73/77	0.3	1 _ 10^{8}	6 _ 10^{8}

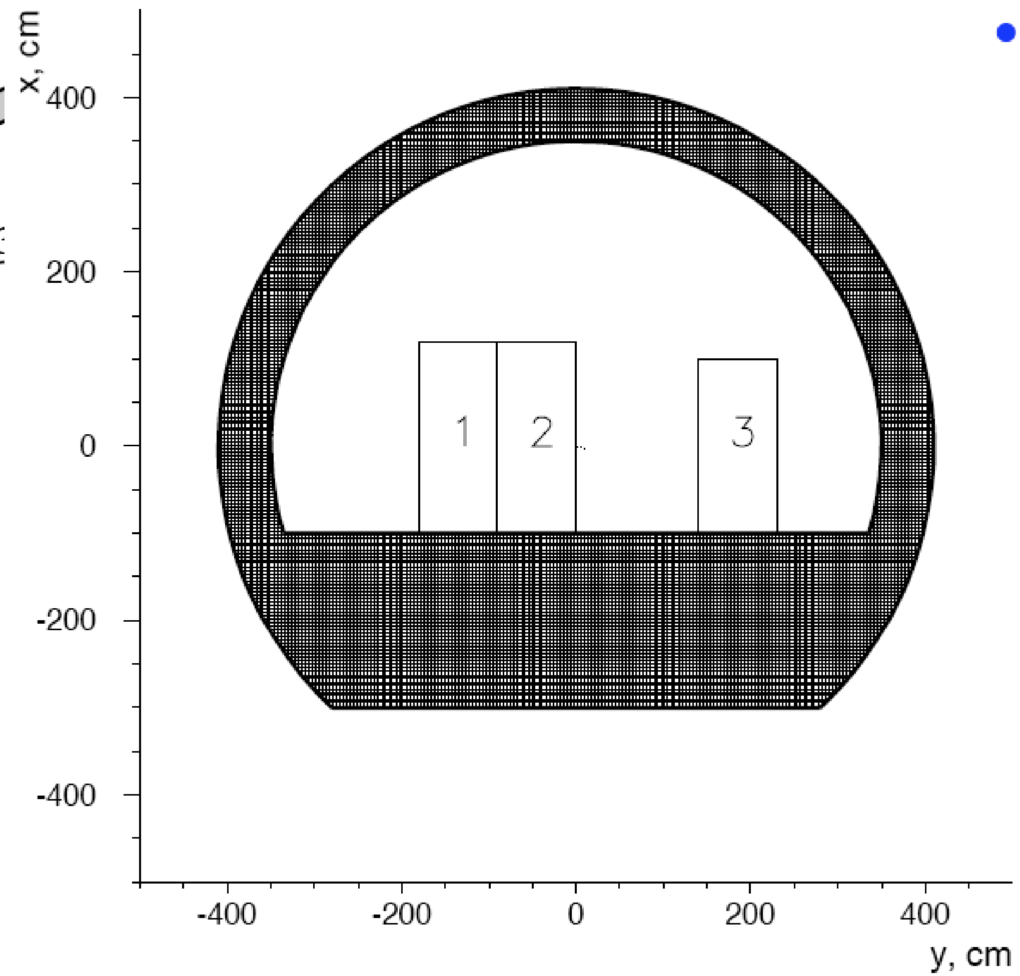
LHC Project Note 372 (2005)

IR3 Layout


46480 ENTRE PLAN D'INTERCONNECTION DFBA ET FIN QRL STANDARD
JUMPER QUENCH LINE
5000
QRL
R34
Ø3800
MODULE DE RETOUR QRL
DQS (x8)
DQR (x3)
5 NOUVEAUX FOURREAUX Ø250mm
17
DFBL
UP33
Ø2400
16
2 CANIVEAUX / 5 FOURREAUX SUPPLEMENTAIRES POUR PASSAGE CABLES
QRL STANDARD DE 46480mm APRES INTERCONNECTION DFBA
JUMPER SPECIAL Q6 DE 20676mm DE LONGUEUR
SAIGNEE DANS GENIE CIVIL POUR PASSAGE LINK CRYO.
PANIER A CABLES COMPRENANT 650 CABLES

Location of Electronics in UJ33





IR3 Layout Comments

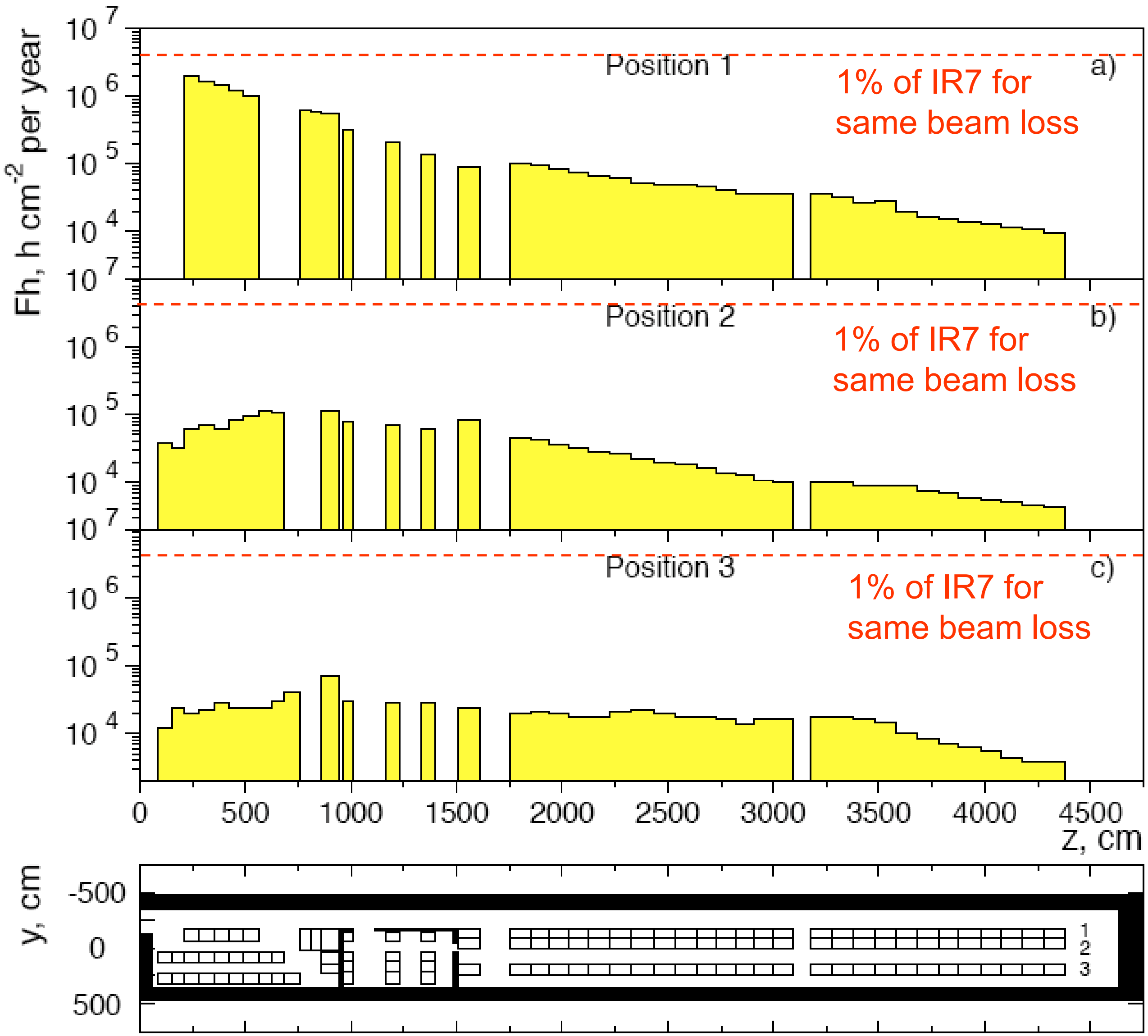
- Foreseen electronics locations much better than in IR7:
  - **No alcovens** (UJ76, RR73, RR77) parallel to beam like in IR7.
  - **UJ33 samples only radiation from 1 beam**. UJ76 gets radiation from both beams as it is located in the middle of the IR.
  - **Larger distance and shielding from the earth**.
- Additional complications:
  - SC link cable can quench…
  - Less protection for warm magnets.
- Past studies all done by IHEP collaboration.

Hadron fluence

- Normalization factor is to 10^{16} inelastic proton interactions per year in each Ring

More than 200 times below IR7 value for the same loss!

IHEP studies 2005



Flow of Thinking

- Radiation to some electronics installed in the IR7 betatron cleaning insertion is too high: >100 times above acceptable value
- Can't accept limitation of LHC intensity to < 1% and resulting reduction in luminosity.
- Best solution: Guarantee that proper electronics is installed in various regions of the LHC.
- If this cannot be guaranteed for the first luminosity run with > 1% intensity:
  - Cannot do anything locally in IR7: Open collimators in front of UJ76 will cause more losses downstream: RR73 and RR77.
  - Radiation to electronics in IR3 for the same loss is at least a factor 100 lower than in IR7.
  - **Studied interim solution: Temporary combined momentum and betatron cleaning in IR3!**
  - Not sufficient to just move horizontal betatron cleaning into IR3 (no HW change)!

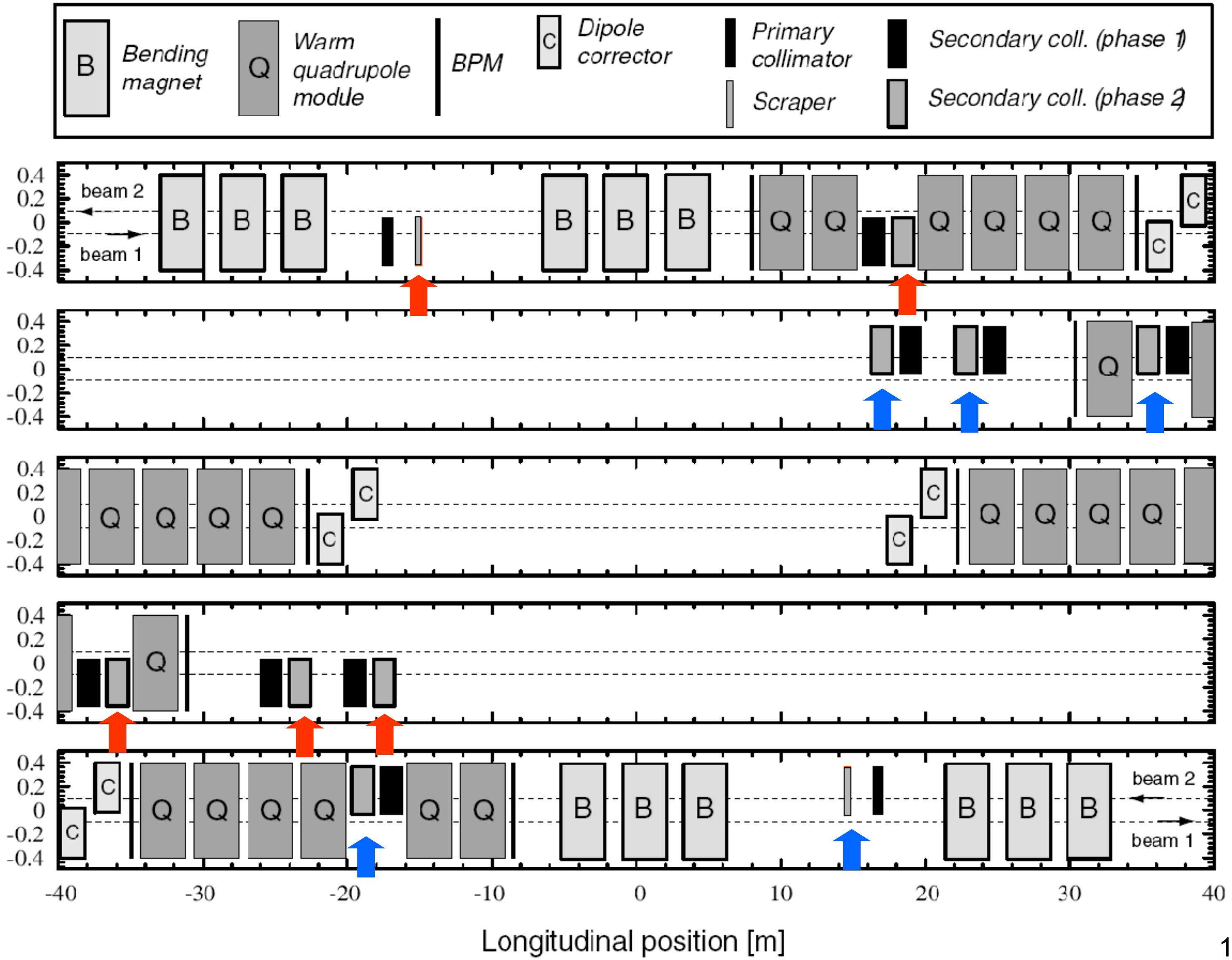
How?

- Use flexibility of phased LHC collimation approach.
- IR3 existing per beam:
  - 1 primary collimator TCP (H)
  - 4 secondary collimators TCS (H)
  - 4 TCLA collimators (3 H, 1V)
- Additional installation:
  - **1 primary collimator (V)** ➔ prepared slot for scraper after TCP (H)
  - **4 secondary collimators (V)** ➔ 4 prepared phase 2 locations
- Make use of flexibility in the phased LHC collimation system and of the existing preparations for phase 2 collimator installation.

IR3 Scheme (without TCLA and TCAPA)

Beam 1

Beam 2



Known Collimation Limits
IR3 and IR7 Issues

Issue for protons	Prediction	Consequences
Radiation dose IR7 MBW (FLUKA, CWG 7.12.2007)	3.3 MGy per 1.15e16 p (1.15e16 p per nominal year)	Lifetime ~10 nominal years (specified 50 MGy, 30 MGy promised)
Radiation dose IR7 MQY (FLUKA, CWG 7.12.2007)	0.9 MGy per 1.15e16 p (1.15e16 p per nominal year)	Lifetime ~10 nominal years (specified 50 MGy, 10 MGy promised)
Radiation dose IR3 MBW (MARS, CWG 29.10.2004)	2.7 MGy per 1e16 p (0.3e16 p per nominal year)	Lifetime ~30 nominal years (specified 50 MGy, 30 MGy promised)
Radiation dose IR3 MQY (MARS, CWG 29.10.2004)	1.6 MGy per 1e16 p (0.3e16 p per nominal year)	Lifetime ~20 nominal years (specified 50 MGy, 10 MGy promised)
SC link in IR3 (MARS, CWG 9.5.2005)	Reach steady QL (1.5 mW/cm^3) Reach transient QL (30 mJ/cm^3)	Loss rate ≤ 1.4e11 p/s ≤ 3.5% uncaptured beam

Nominal conditions only simulated. No understanding on dependence of dose on collimation settings (will commissioning scenarios with open collimators be more serious?).

Remedies include phase 2 with high Z, a warm SC link design (FP7), additional absorbers, new warm magnets, …

Scenarios Considered

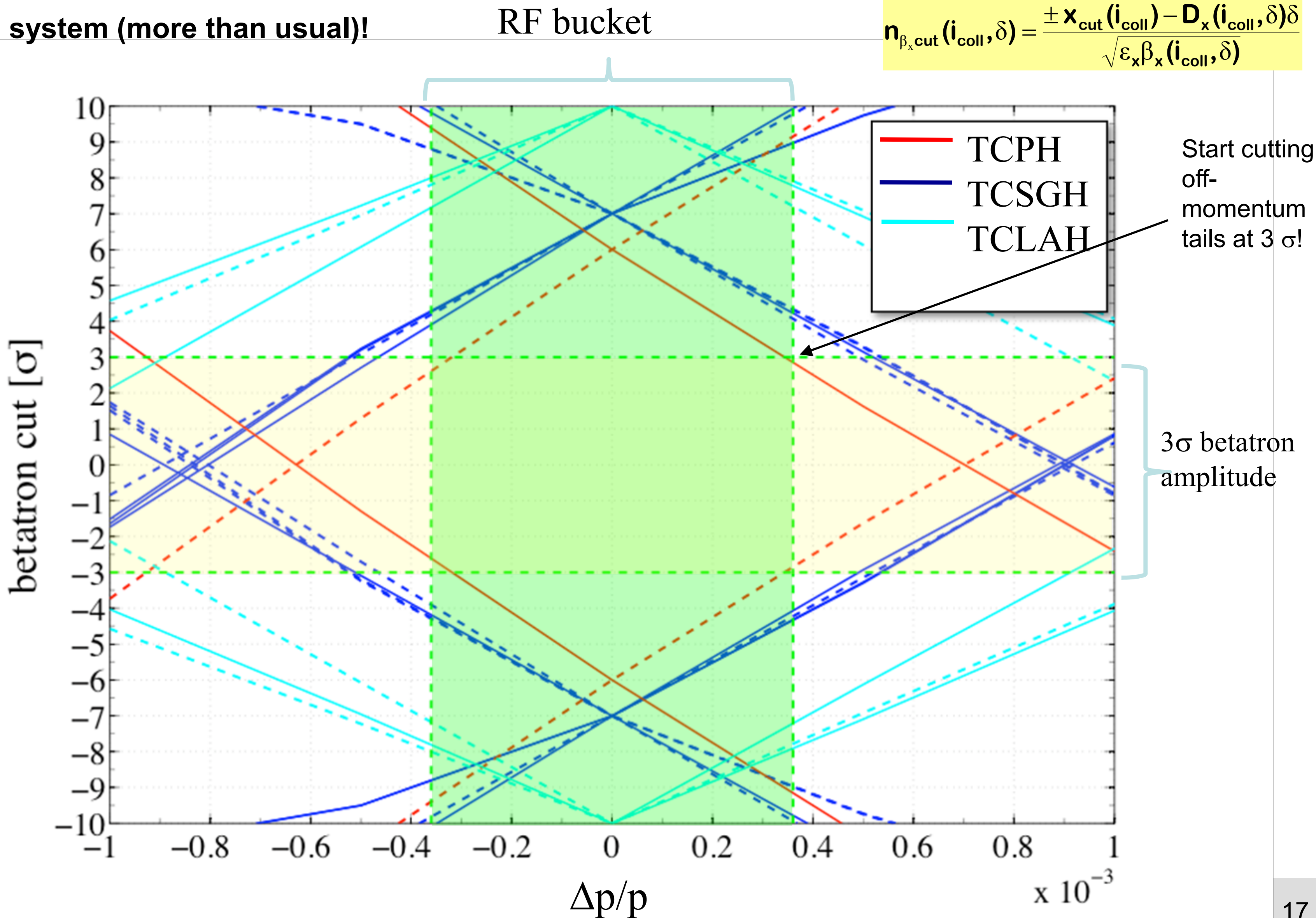
	TCPH [σ_β]	TCPV [σ_β]	TCPS [σ_β]	TCSH [σ_β]	TCSV [σ_β]	TCLAH [σ_β]	TCLAV [σ_β]	Halo
scenario0	15	6	-	18	-	20	10	vert
scenario1	15	6	-	18	7	20	10	vert
scenario2	6	6	-	7	7	10	10	vert/hor
scenario3	8	6	-	7	7	13	10	vert/hor
scenario4	8	6	6	7	7	13	10	vert/hor

Here focus on scenario 2 (installation and usage of 2+8 vertical collimators into IR3)!

Phase Space Cuts

Coupled system (more than usual)!

$$n_{\beta_x cut}(i_{coll},\delta) = \frac{\pm x_{cut}(i_{coll}) - D_x(i_{coll},\delta)\delta}{\sqrt{\varepsilon_x \beta_x(i_{coll},\delta)}}$$

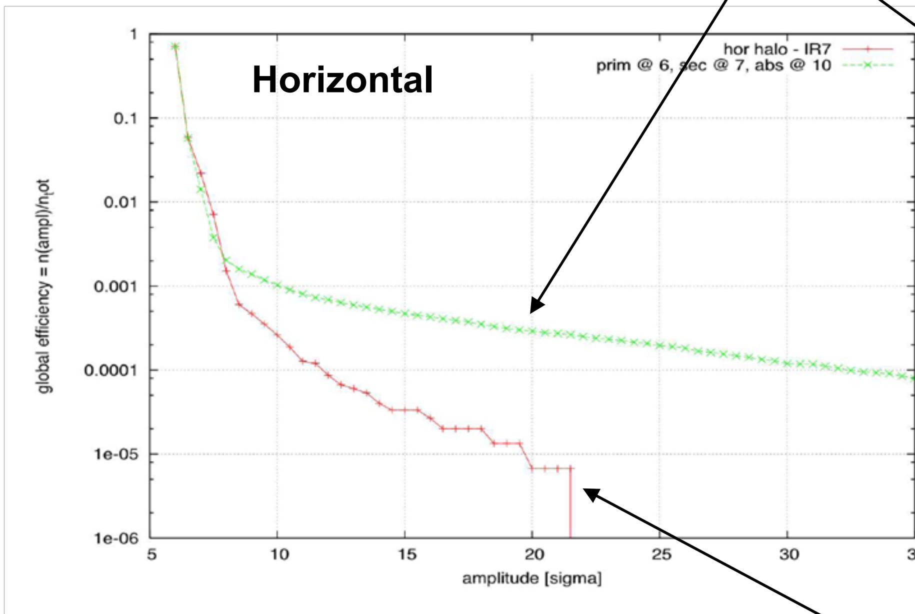


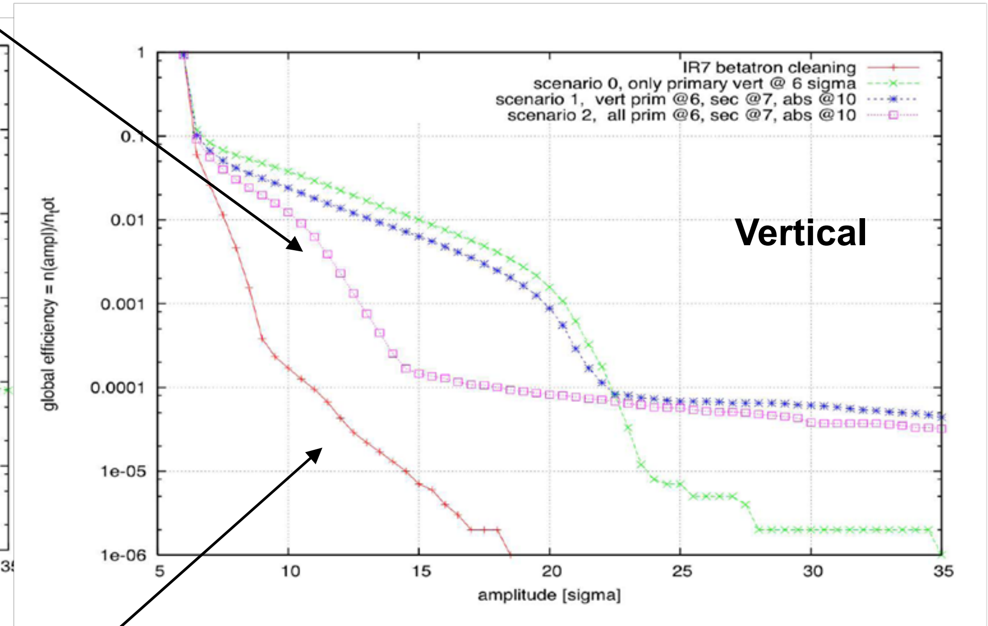
Adjusting β and δ cut

- A **combined system looses orthogonal setting of β and δ cuts**!
- This is the reason why functionalities are separated in all accelerators.
- With a combined system the β and δ cuts can be adjusted by several means:
  - rematching of the optics (D versus β).
  - Orbit and dispersion bumps.
  - One sided cleaning system.
- **Not convenient but manageable** until the electronics issue is handled correctly.
- Further look at this also in context with **phase 2 improvement** in cleaning efficiency (factor 10-30). If transverse feedback cannot stabilize the beam, combined system uses less collimators and induces lower overall impedance.

Global Inefficiency 7 TeV

Proposed scenario 2 (2+8 vertical collimators installed)





IR7

better

Observe: **Can establish working betatron cleaning into IR3!**

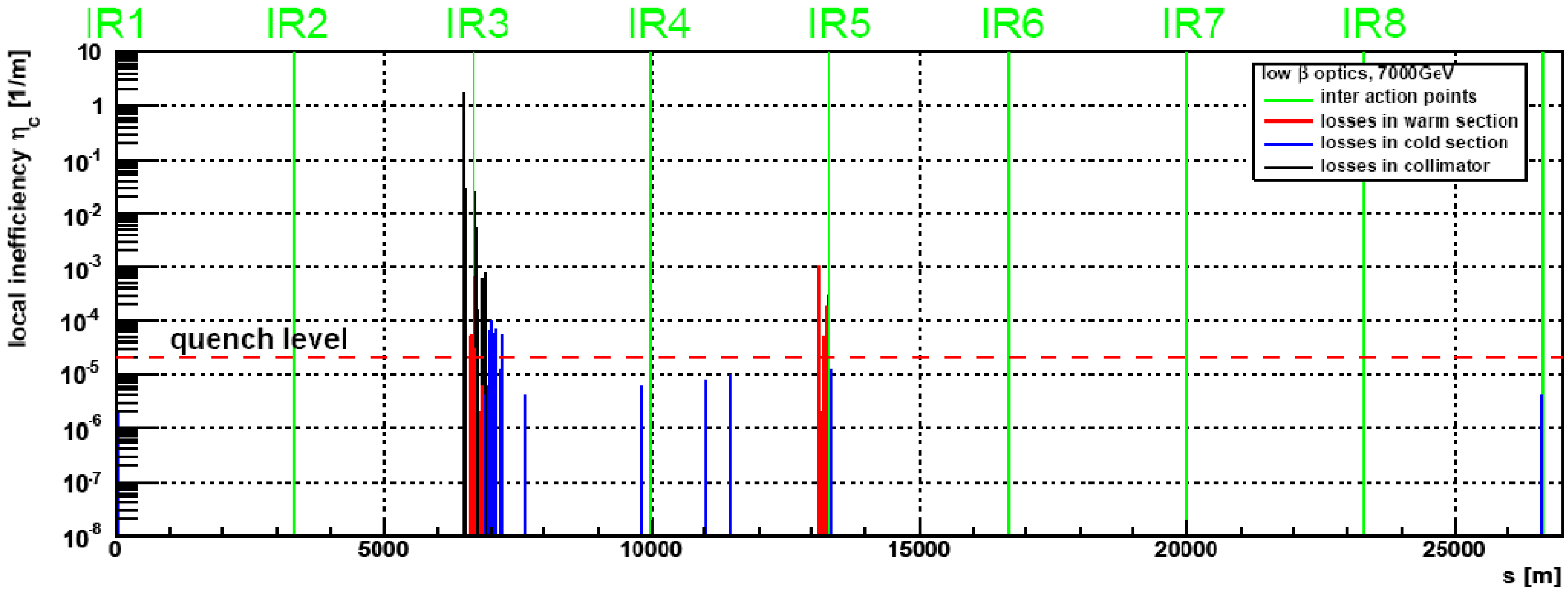
Performance worse than IR7 which was optimized!

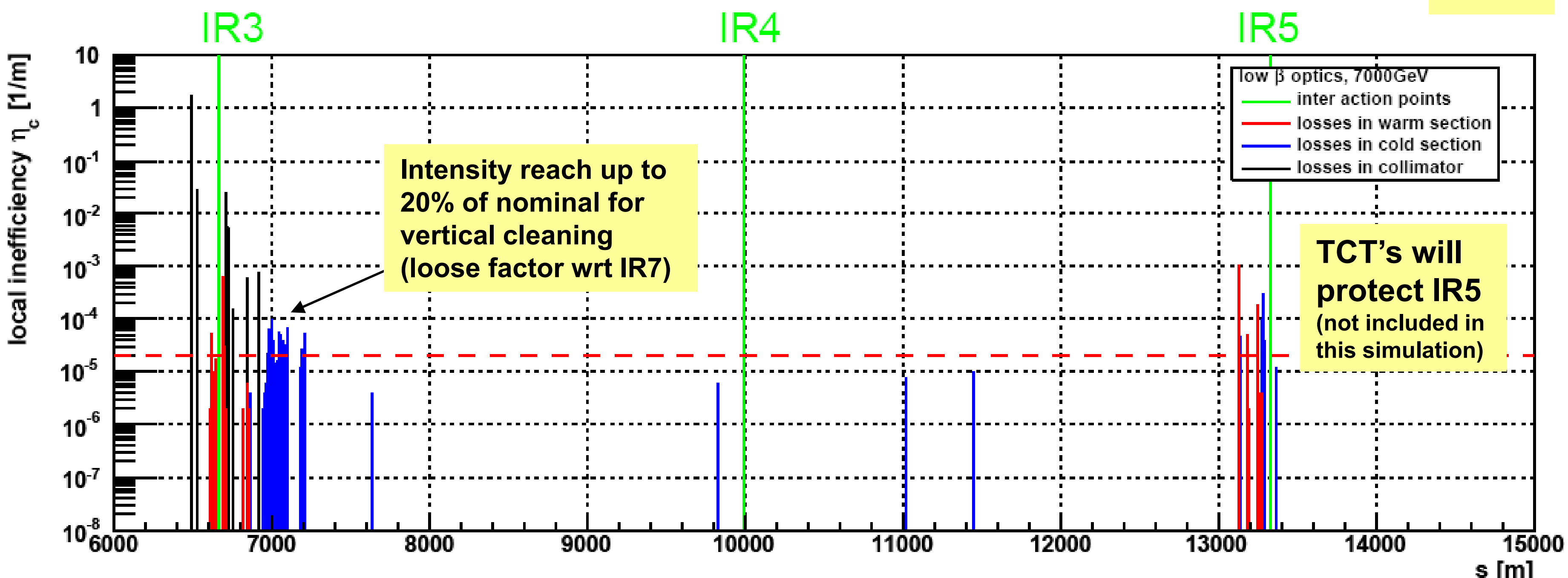
Factor 5-10 more leakage than IR7 system!

How are losses distributed? Will give intensity reach!

V. Previtali et al

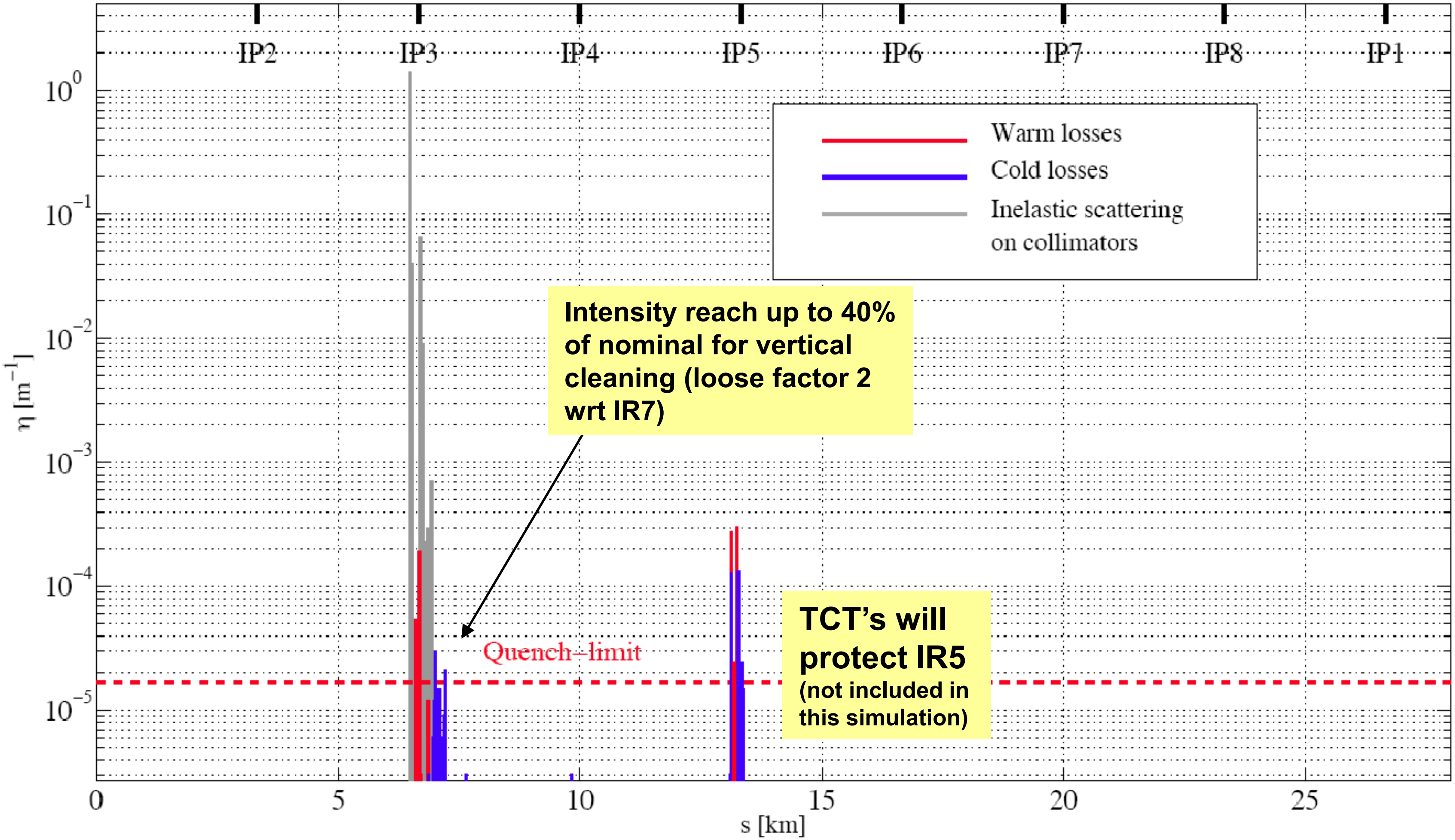
VERTICAL β-cleaning in IR3





T. Weiler et al

HORIZONTAL β-cleaning in IR3



C. Bracco et al

Horizontal works very well in IR3, as in IR7 (designed for H).

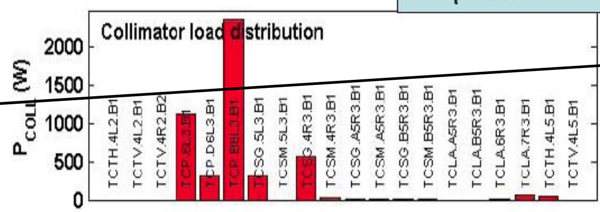
Ions

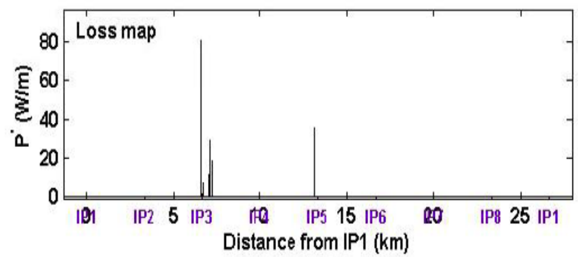
- No ion run in first year but impact on ions was looked at.
- Unexpected losses in IR3 DS.
- Limited to 10% of nominal intensity?
- Can reach 20% of nominal intensity when closing collimators!

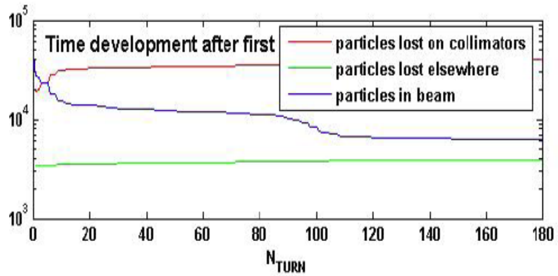
TCPs/TCSs/TCTs/ TCLAs at

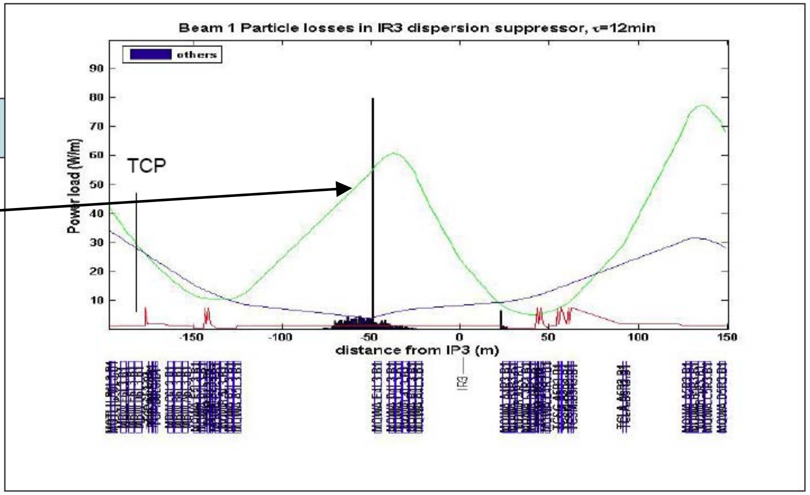
N= 6,7,8.3,10 σ

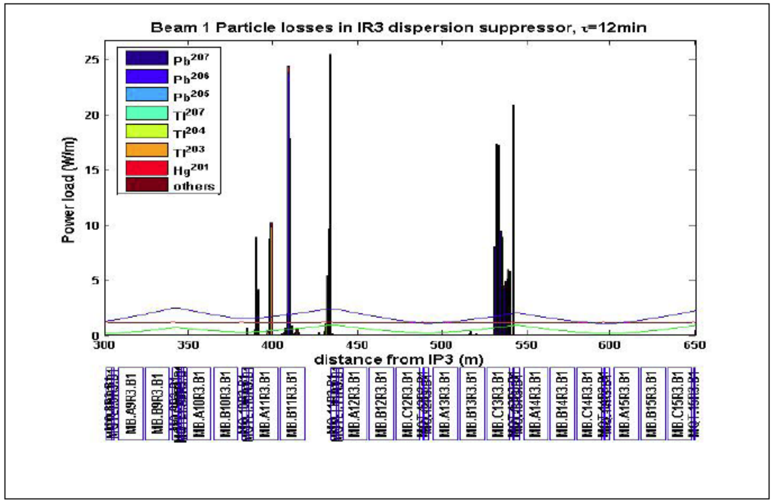
η=0.098











G. Bellodi et al

Summary I

- Using the flexibility of the collimation system design we have an option:
  - **Keep IR7 as installed (can be used anytime for betatron cleaning).**
  - **Install 2+8 collimators (existing 2nd installation and spares) into prepared slots in IR3 (phase 2).**
  - **Use IR3 for momentum and betatron cleaning until electronics is sorted out.**
- Propose to implement this, if it cannot be guaranteed that all electronics problems in IR7 are sorted out, at latest during the 2008/9 shutdown.
  - Crash effort might allow to put some collimators already during next months into IR3 (should be investigate).
  - Can certainly be installed in shutdown.
- It does not come for free:
  - Cost of preparation, installation, production of additional collimators,
  - Additional work…

Summary II

- Further AP work:
  - Need to consider also injection case, even if less critical (should work very similar).
  - Better halo models for coupled case (6D).
  - Consider 1-sided cleaning (one side betatron, other side momentum).
  - Optics rematch in IR3 for better performance?
- Further studies being prepared (AP data transferred):
  - FLUKA energy deposition and radiation
  - Environmental impact
  - Dose to warm magnets in IR3 (anyway high)
  - Power to SC link cable in IR3 (anyway known quench limitation)
- No show-stopper during CWG discussion pointed out, proposed options looks realistic…

Plus and Minus

- Minus:
  - **Additional work, cost**, …
  - Loss in cleaning performance
  - **Complication** of coupled betatron/momentum cleaning, of interaction in collimator at non-zero dispersion location, …
  - Additional loss locations (more load on experimental collimators, …).
  - Loss of skew collimation in betatron cleaning.
- Plus:
  - **Operational flexibility** to react to radiation problems during commissioning (choice of betatron cleaning for IR7 or IR3).
  - **Factor 200 less radiation to electronics for the same beam loss!**
  - **Only way to go above 1% of design intensity until electronics is fixed?**
  - Interim solution might bring us up to 10-20% of design intensity (gain time for fixing IR7 electronics problem).

Summary combined β and δ cleaning in IR3

- **Ideal intensity reach is up to 20% of nominal intensity** from cleaning efficiency. Less in reality.
- **Factor ~200 less radiation** to electronics for same loss (IR3 vs IR7).
- For **10% of nominal intensity** (just scaling existing results for nominal case – see later comments):
  - No problem from SC link cable expected (factor 3 margin for steady state, factor 6 for transient case).
  - No issue from lifetime of warm magnets expected (15% of a nominal year, less than 2% of expected lifetime which is predicted to be higher in IR3 than in IR7).
- Good to compare FLUKA and MARS, as planned. Factor 3 inconsistent?
- Environmental impact OK: see report by Stefan.
- Overall flexibility is increased (freedom to distribute radiation loads between IR3 and IR7, react to loss problems experimental insertions, …).

Actions and Decisions

- Need between **10 (H, V) and 12 (H, V, S) collimators in addition**.
- **Additional construction** should be started. Not advisable to install all spares into the tunnel and to limit IR7 system.
- **Preparations should be done now** as much as possible:
  - plug-in supports in all phase 2 locations
  - prepare scraper locations for TCP's as much as possible
  - procure electronics
- **Prepare shutdown** installation.
- <u>**Decision at recent R2E meeting (chaired by Steve Myers):**</u>
  - Go ahead.
  - Work and studies for this modification of the collimation system fully coordinated in collimation project and collimation WG (different groups involved). Concerns especially required FLUKA work.