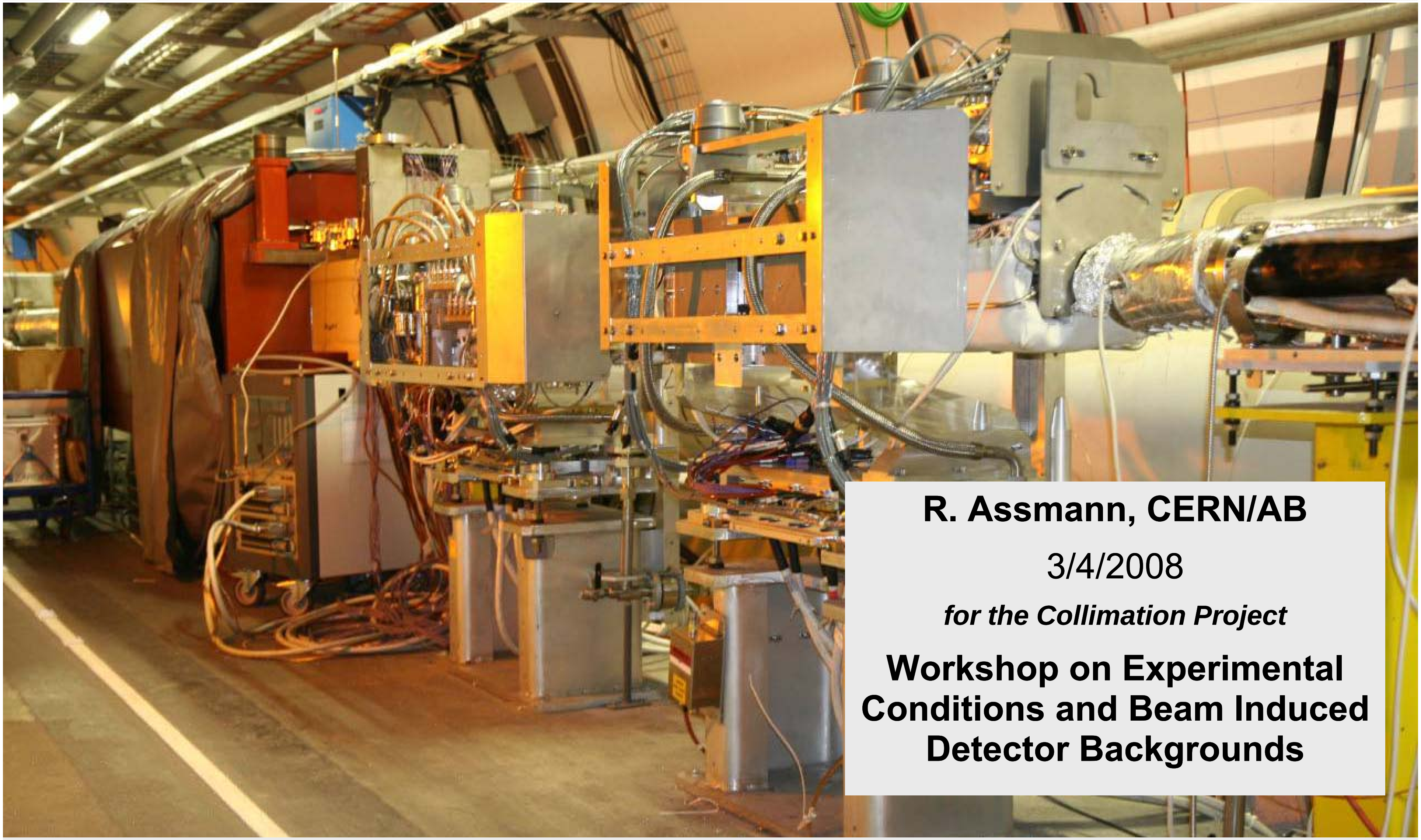
Collimation



R. Assmann, CERN/AB

3/4/2008

for the Collimation Project

Workshop on Experimental Conditions and Beam Induced Detector Backgrounds

Outline

1) The Team
2) LHC Collimation Scheme and Settings Hierarchy
3) Collimators in Experimental Regions
4) Settings of Tertiary Collimators Versus β^*
5) Losses on Tertiary Collimators
6) Available Freedom for “Background Tuning“ and Scraping
7) IR and Collimation Upgrade
8) Conclusion

1) The Team

- Accelerator physics studies at CERN on proton collimation performed by:
  - **R. Assmann**
  - **C. Bracco (PhD)**
  - **V. Previtali (PhD)**
  - **S. Redaelli**
  - **T. Weiler (Fellow)**
- Results from this team and former PhD student **G. Robert-Demolaize** (now BNL).
- Additional cleaning studies at IHEP by **I. Baychev et al.**
- Energy deposition studies in **CERN-FLUKA team**, **N. Mokhov et al** at FNAL and I. Baychev et al in IHEP.
- Main goal: **With collimators intercept losses such that losses in SC magnets are below quench limits for realistic loss rates.**

The Team II

- LHC **collimation design was driven by proton studies** (much higher stored energy and much higher risk for quenches).
- There is a strong ion collimation effort as well:
  - **J. Jowett, G. Bellodi, S. Gilardoni, H. Braun, R. Bruce (PhD)**
- The **same collimation system is used for ions as for protons**. Settings and protection requirements follow the same logic.
- All coordinated in **LHC collimation project and collimation WG**.
- There are some local ion loss problems due to ion interaction with collimator materials (fragmentation, dissociation, …).
- Here, concentrate on proton results.

2) LHC Collimation Scheme and Settings Hierarchy

- LHC collimation design since 1990. **Major review & redesign after 2002**:
  - Review of **peak loss rates** (design put 100 times higher).
  - Improved **robustness against beam loss** (collimator survival).
  - Improved **protection in experimental insertions** ➔ appearance of tertiary collimators.
  - Integration of **upgrade for LHC collimation** (“phase 2“ in 2011/12).
- Things have changed and good to review impact for background (ongoing activities with MIBWG).
- **Technical design criteria** for LHC collimation:
  - **Survival of collimators and downstream equipment.**
  - **Cleaning efficiency towards SC magnets (“quenches“).**
  - **Impedance.**
  - **Radiation impact.**
- **No request from experiments for collimators dedicated to background control**: quenches of SC magnets prevent running with high fractional loss rates.

Preventing Quenches

- Shock beam impact: **2 MJ/mm² in 200 ns (0.5 kg TNT)**

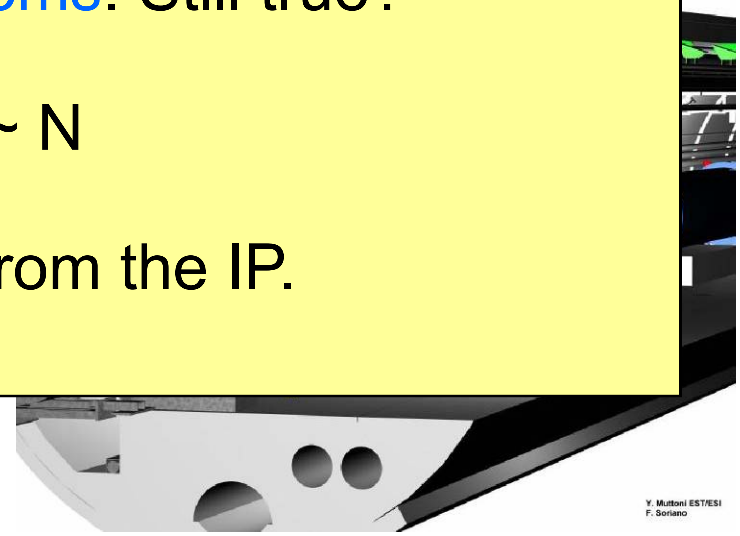
Collimation for the **LHC is 2-3 orders more critical for quenches than situation at HERA, Tevatron and RHIC**.

Past results (K. Potter et al): We would quench before we develop serious background problems. Still true?

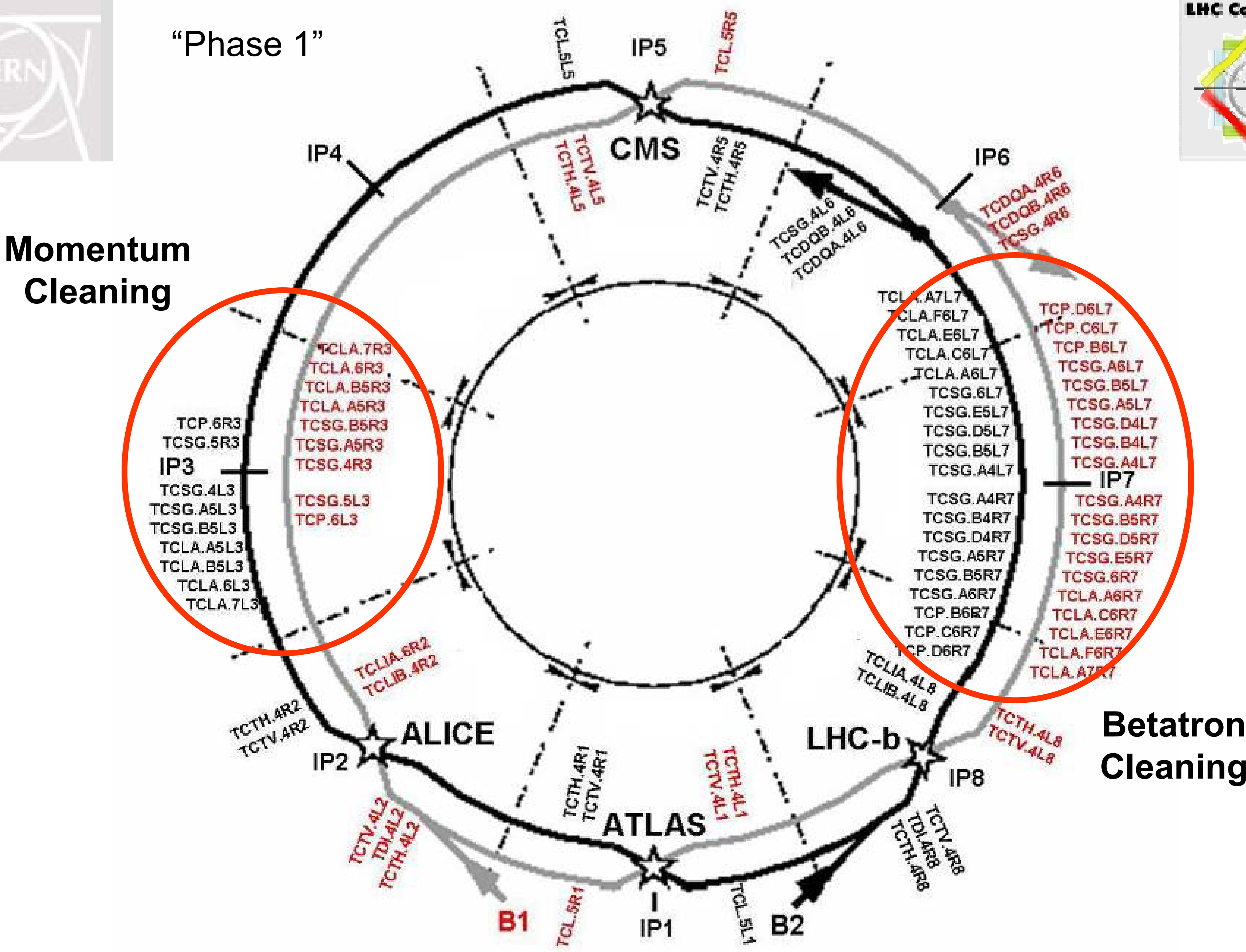
1) $L \sim N_p^2$ $dN_p/dt \sim N$

2) Strong background signal from the IP.

8.5 W/m

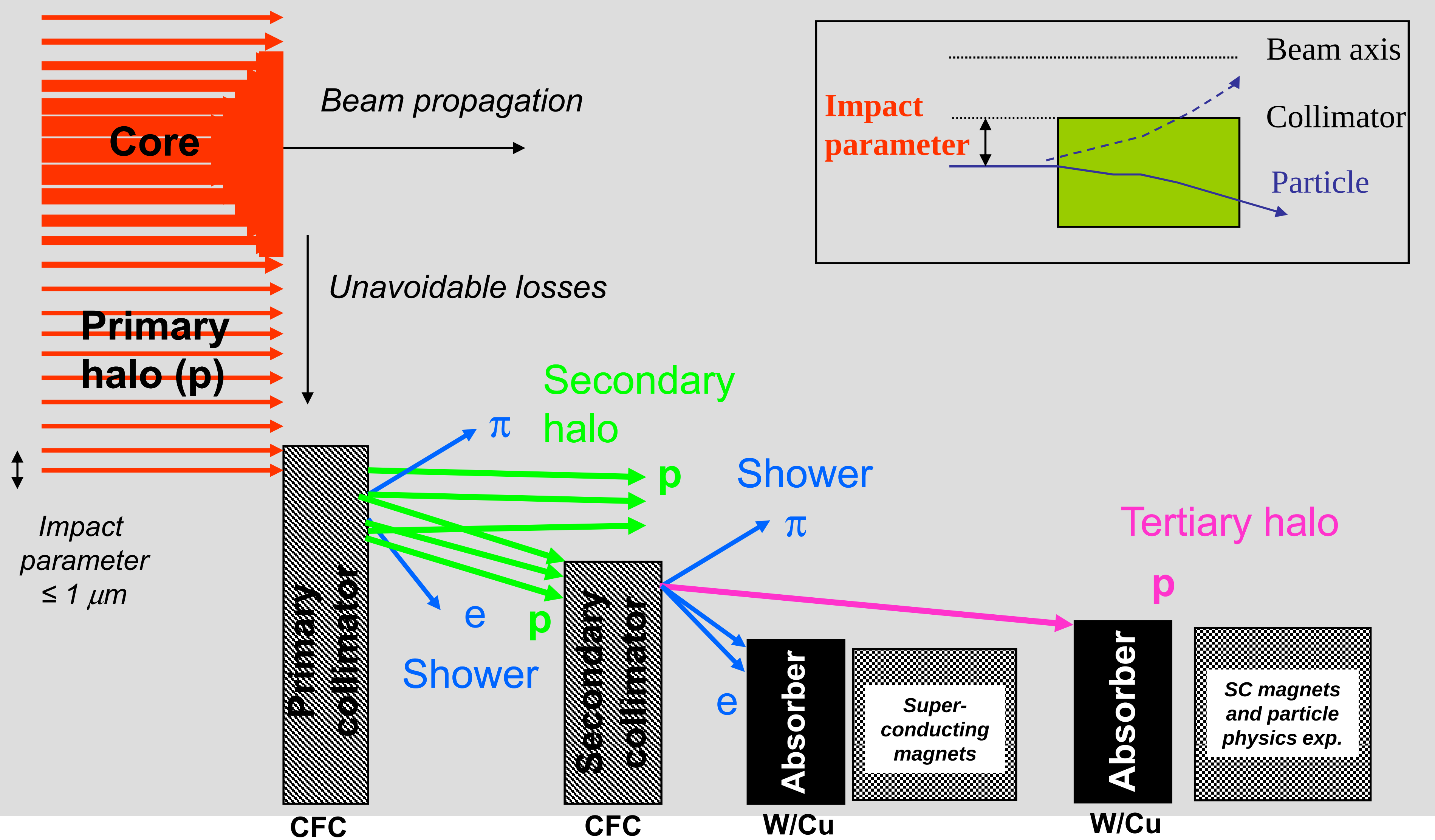


“Phase 1”



➔ Outcome of accelerator physics + energy deposition optimization

Multi-Stage Cleaning & Protection LHC



Hierarchy for Protection and Cleaning

- Clear requirements for settings (a is the half gap expressed in nominal beam sigma):

LHC ring aperture sets scale — a_{ring}

➔ *tight LHC aperture*

Protection devices must protect ring aperture — $a_{prot} < a_{ring}$

➔ *protect against injected beam; take into account accuracies*

Secondary collimators tighter than protection — $a_{sec} < a_{prot}$

➔ *avoid too much secondary halo hitting protection devices*

Primary collimators tighter than secondary — $a_{prim} < a_{sec}$

➔ *primary collimators define the aperture bottleneck in the LHC for cleaning of circulating beam!*

- These conditions should always be fulfilled:

Not allowed to use protection devices (or warm aperture limits) as a single-stage cleaning system!

Chamonix 2005

7 TeV Settings at (in σ_β ,$\delta=0$, nominal β^*)

Chamonix 2005

a_{abs}	=	~ 20.0 σ	Cleaning: Active absorbers in IR3
a_{sec3}	=	18.0 σ	δ cleaning: secondary collimators IR3 (H)
a_{prim3}	=	15.0 σ	δ cleaning: primary collimators IR3 (H)
a_{abs}	=	~ 10.0 σ	Cleaning: Active absorbers in and IR7
a_{ring}	**=**	**8.4 σ**	**Triplet cold aperture**
a_{prot}	=	8.3 σ	TCT protection and cleaning at triplet
a_{prot}	≥	7.5 σ	Dump (H) protection IR6 (TCDQ + TCS)
a_{sec}	=	7.0 σ	β cleaning: secondary collimators IR7
a_{prim}	=	6.0 σ	β cleaning: primary collimators IR7

➔ "Canonical" 6/7 σ collimation settings are achievable!

Color code:
Green – robust
Blue – cold aperture
Red – non-robust

3) Collimators in Experimental Regions

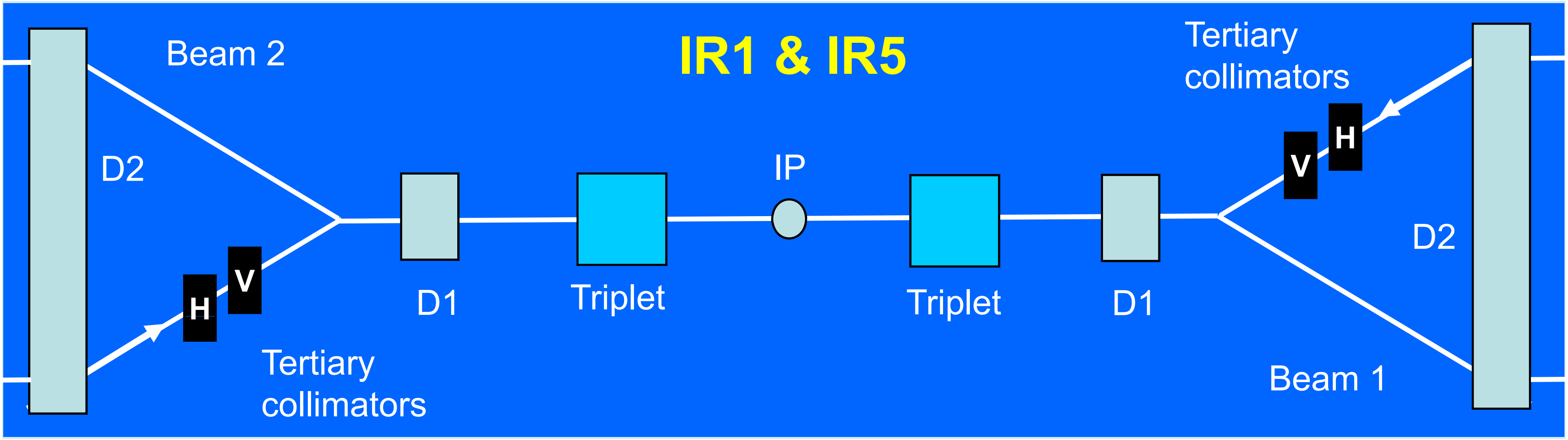
1. TCLI, TCDD ➔ Pro… rors in IR2 and IR8.
   2008…
   Lim… …jected.
   Complete: After 2008 shutdown.

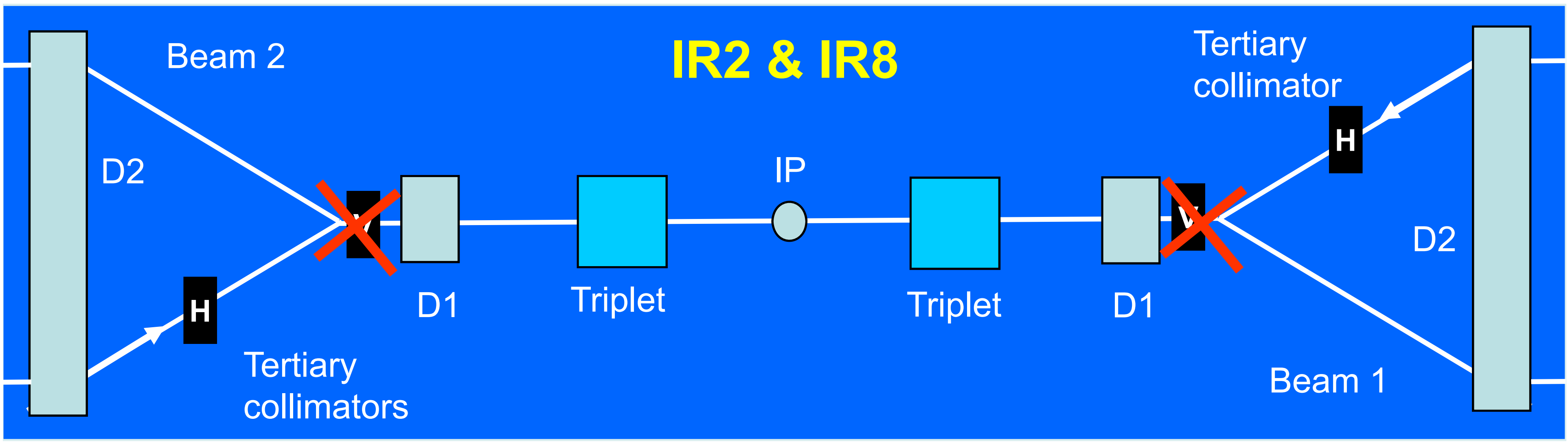
Act on outgoing beam: no effect on background!

2. TCLP ➔ Cleaning of luminosity debris in IR1 and IR5
   2008: None installed, interference with TOTEM.
   Limit: Luminosity < 1e33
   Complete: 4 in 2008 shutdown, 4 when needed (deinstall 2 TOTEM RP stations. Collimators exist.

3. TCT ➔ Cleaning of beam halo before triplet in IR1, IR2, IR5, IR8. Additional triplet protection.
   2008: All horizontal TCT's in place. IR1 and IR5 complete.
   Limit: b* in IR2 and IR8 limited (limit is below 6 m).
   Complete: 2 vertical TCT in IR2 and IR8 in 2008 shutdown.

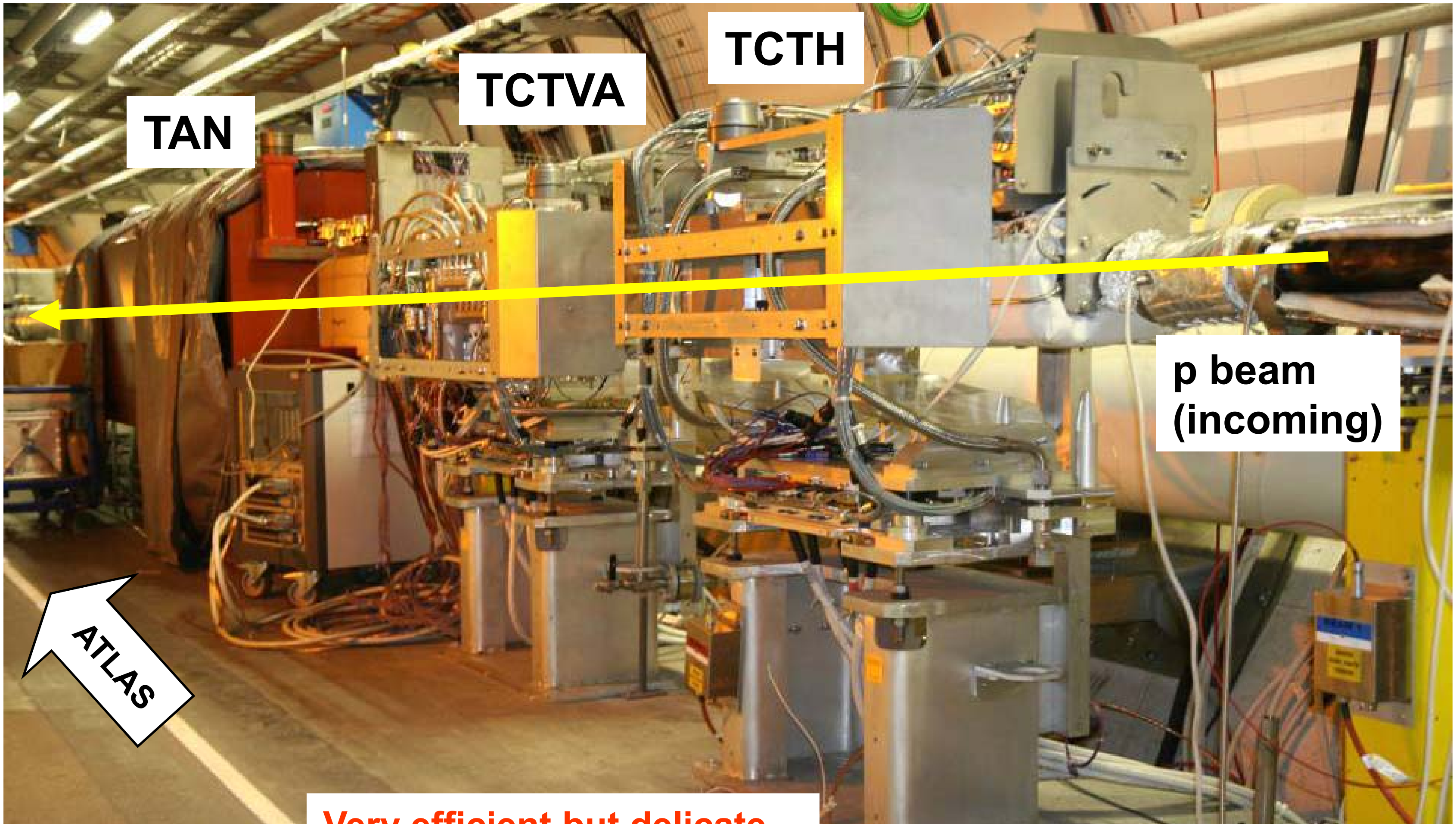
Tertiary Collimation in IR1/2/5/8





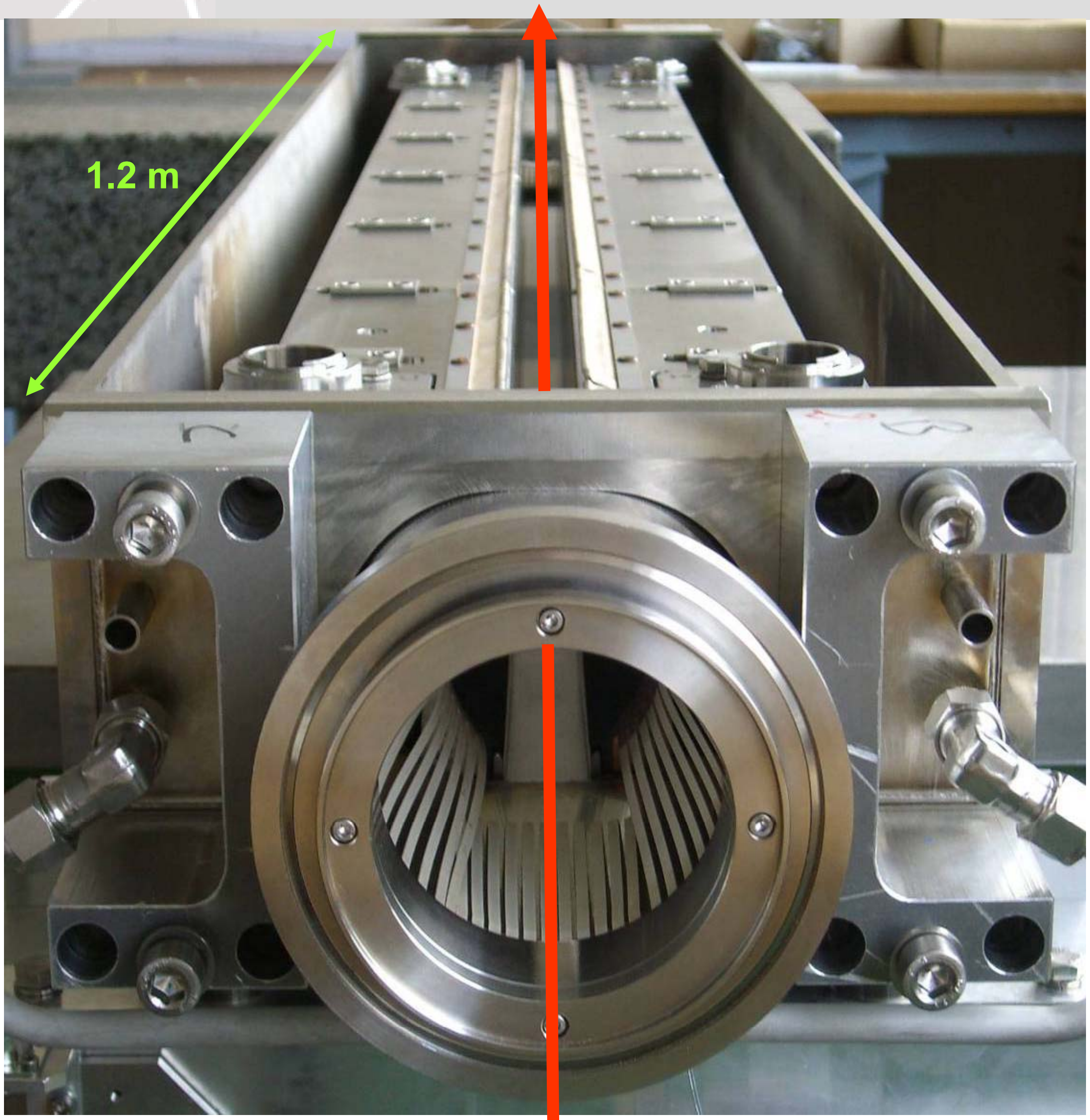
Delayed: Only after 1st shutdown!

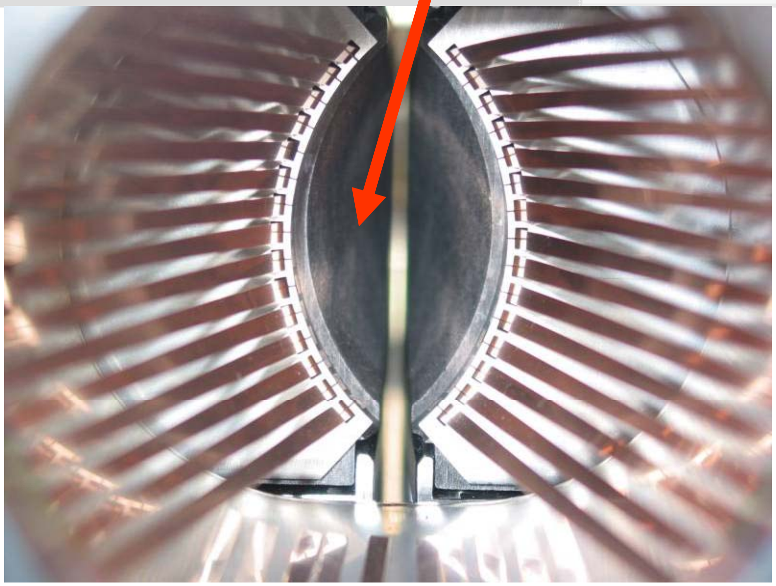
IR1 Tertiary Collimation



Very efficient but delicate protection: W jaws!

The LHC Standard Collimator





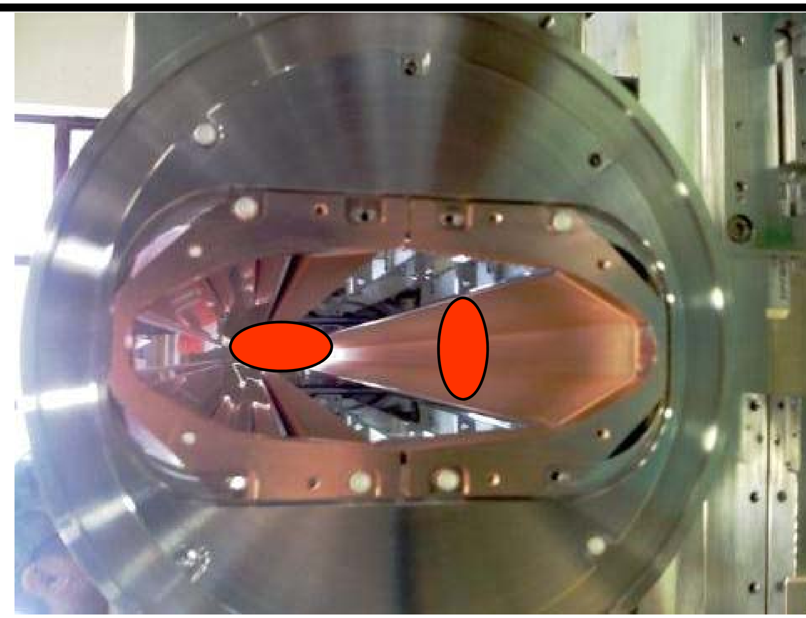
3 mm beam passage with RF contacts for guiding image currents

Designed for maximum robustness:

Advanced CC jaws with water cooling!

Other types: Mostly with different jaw materials. Some very different with 2 beams!

TCTVB (two beam tertiary vertical collimators in IR2 and IR8)



Two-beam collimator

➔ Special design required in IR2 and IR8 (interference with LHCf and ZDC).

➔ Delayed due to last minute production problem…

➔ Will be there after first shutdown (end of 2008).

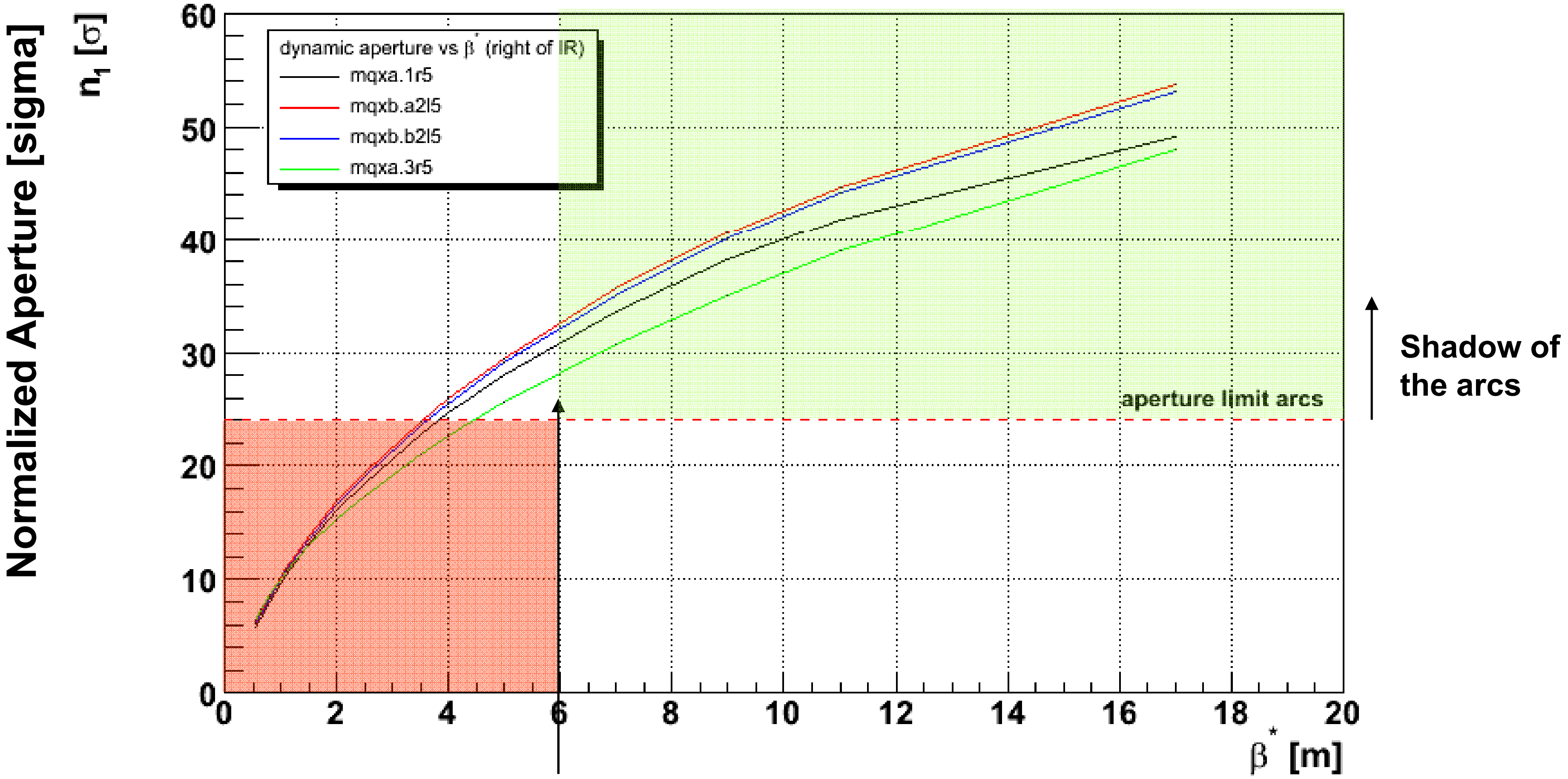
4) Settings of Tertiary Collimators Versus β*

- The TCT's have the only purpose to protect the triplet. Two reasons:
  - Against damage in case of a rare damaging event (irregular dump with compromised TCDQ protection).
  - Against quench for possibly frequent drops in beam lifetime (spikes in beam loss).
- If they would sit directly in front of triplet they could be fixed masks.
- As they sit further away, some **limited movement is required**.
- However, required **gap depends on β* and also crossing angle**. Higher β* means larger gap! Smaller crossing angle means larger gap!

Triplet Aperture as a Function of β*

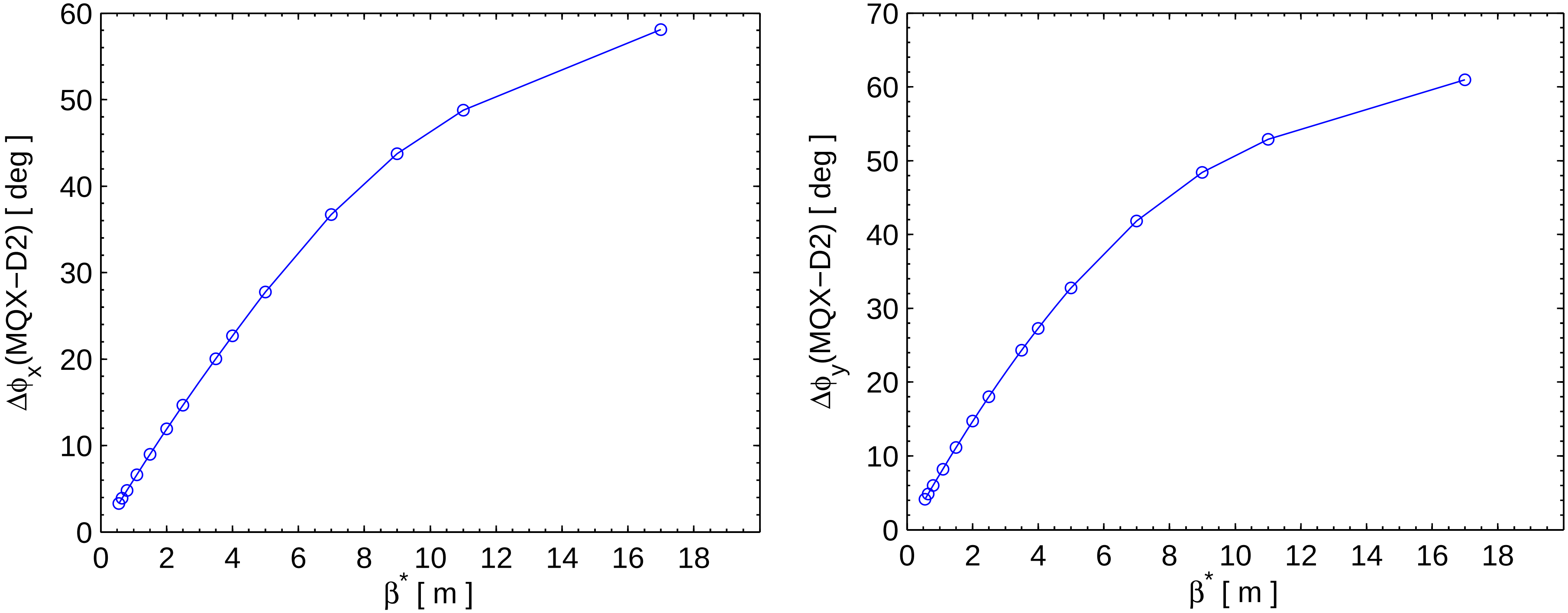
T. Weiler & R. Assmann

Example: IR1, Beam 1, right, nominal



Protect triplet locally for squeeze below ~ 6 m!

Phase advance from D2 to the triplet



S. Redaelli, V. Kain

Gap needs to tightened at TCT for larger β* to maintain protection due to phase advance!

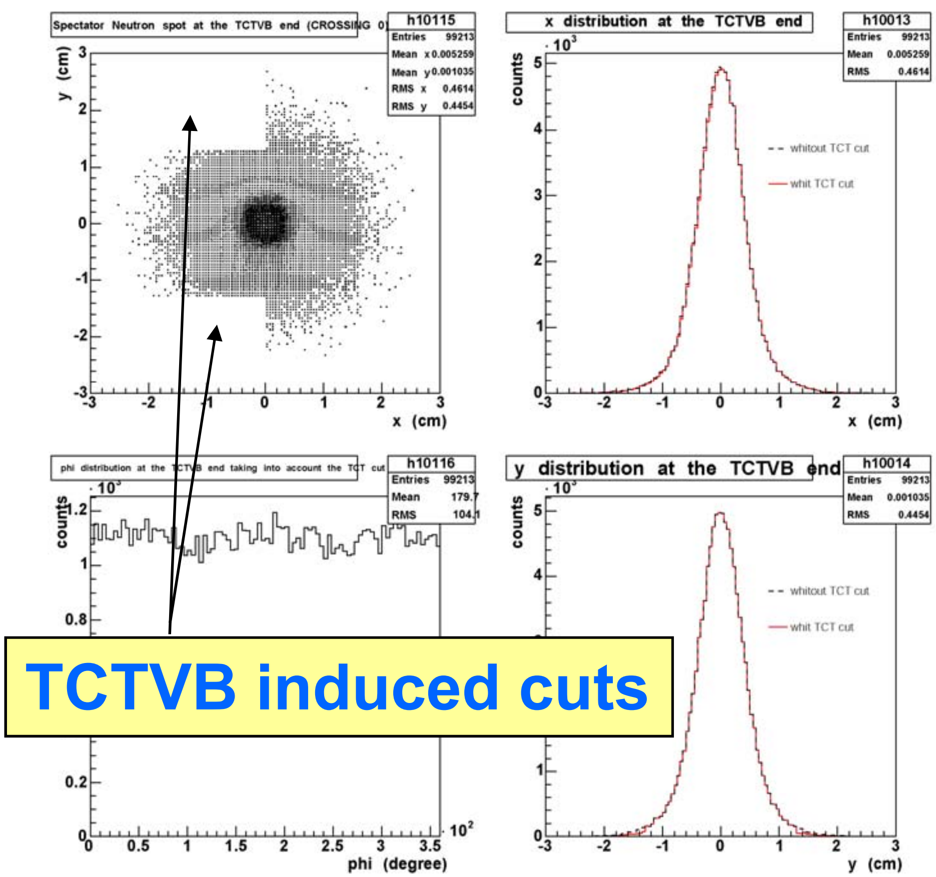
However, already at 2 m almost negligible!

TCT Setting Studies

- **IR1 and IR5 considered in detail**. Two cases (nominal crossing angle):
  - **β^* = 0.55 m ➔ 8.3 σ**
  - **β^* = 2 m ➔ 17 σ**
- TCT's can and will be left open initially!
- **IR2 has been analyzed** due to interference with background signal:
  - Can gain due to local nature of protection (**orbit at triplet and collimator is strongly correlated, same for beta**).
  - For IR2 nominal physics parameters: **13 σ is OK.**
- Note: Cross talk between different insertions:
  - **Opening of IR2 and IR8 will increase load to downstream insertions!**
  - MIBWG June 07: Factor 2 from this side is possible in halo loss rates.
- Note: TCT's might be useful at tighter settings in IR2/8 to protect against local sources of background (beam-gas) ➔ See Tevatron and HERA.

Special Kind of “Background”

- TCL and TCLP can affect signals at Roman Pots away from the IP.
- **TCTVB’s can cut physics signal** (had to be put in front of ZDC in IR2):



Plot from ZDC collaboration: zero crossing angle

Worse for larger crossing angle.

Review of TCTVB gap in IR2: Can be relaxed to 13 mm.

Still some residual cuts.

Needs and possibilities for further improvements are being discussed.

5) Losses on Tertiary Collimators

- Losses from incoming beam can come from various sources:
  - **Leakage from betatron cleaning (IR7)** ➔ betatron halo
  - **Leakage from momentum cleaning (IR3)** ➔ off-momentum halo
  - **Direct losses due to luminosity events** (e.g. IR5 induced losses in IR1)
  - **Direct losses from beam-gas scattering, e-cloud, ...** (local, from arc = long-range)
- What is the difference between leakage and direct losses:
  - **Leakage (inefficiency) includes all protons that first touch a collimator** around the ring = mainly diffusive multi-turn losses! Normally we calculate this as collimation is involved!
  - **Direct losses include protons that are lost i.e. after a beam-gas event before making it to the first collimator**. Collimation is not involved in loss process and **these losses we normally do not calculate** in the collimation team (other teams follow up).

Incoming Losses on Collimators

- **At CERN we mostly focus on betatron losses:**
  - Tune changes, chromaticity, instabilities, orbit changes and other operational actions will mainly affect betatron space (10^{-3} loss after unfavorable action).
  - **Momentum stability should be much better** and is given by the RF system performance which is not operationally tuned.
  - **Peak losses should occur at betatron collimators.**
- Losses at collimators in IR3 and IR7 in physics (including all sources):

	IR3	**IR7**
Fill average (M. Lamont)	**4×10^8 p/s**	**3×10^8 p/s**
Assumed “normal“	**8×10^8 p/s**	**4×10^9 p/s**
Peak for > 10 s	***$\leq (8 \times 10^{10}$ p/s)***	**$\leq 8 \times 10^{10}$ p/s**
Peak up to 10 s	***$\leq (4 \times 10^{11}$ p/s)***	**$\leq 4 \times 10^{11}$ p/s**

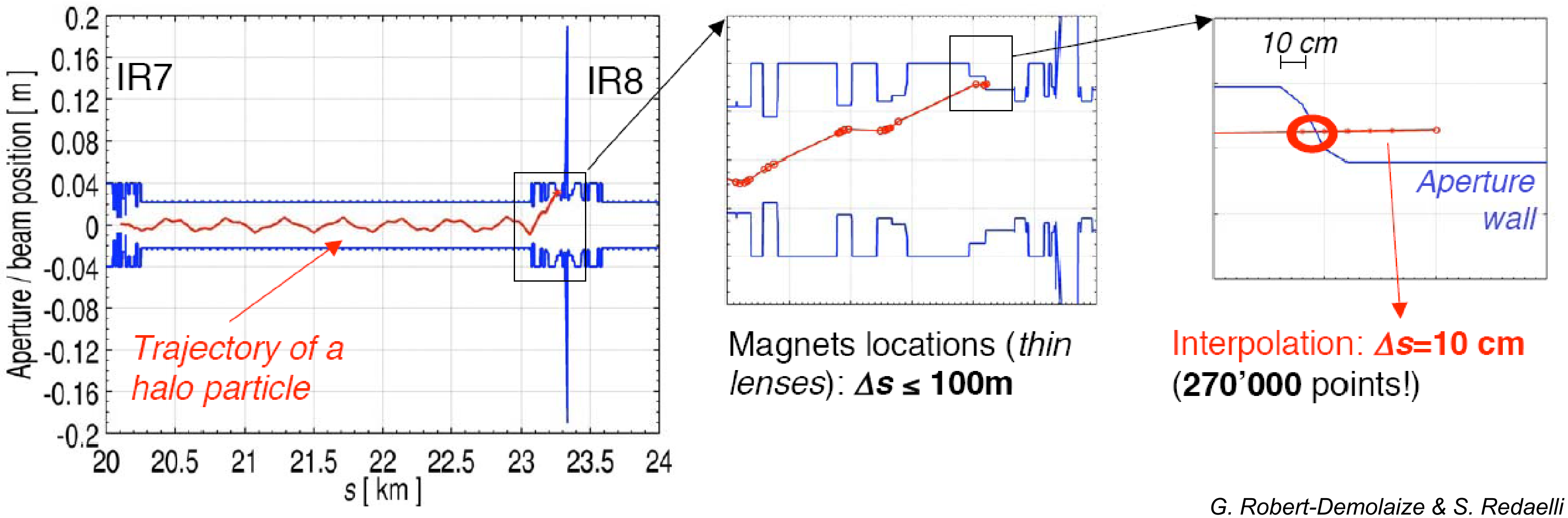
Cleaning Efficiency

Simulations: 5 million halo protons

200 turns

realistic interactions in all collimator-like objects

LHC aperture model (p losses) and FLUKA



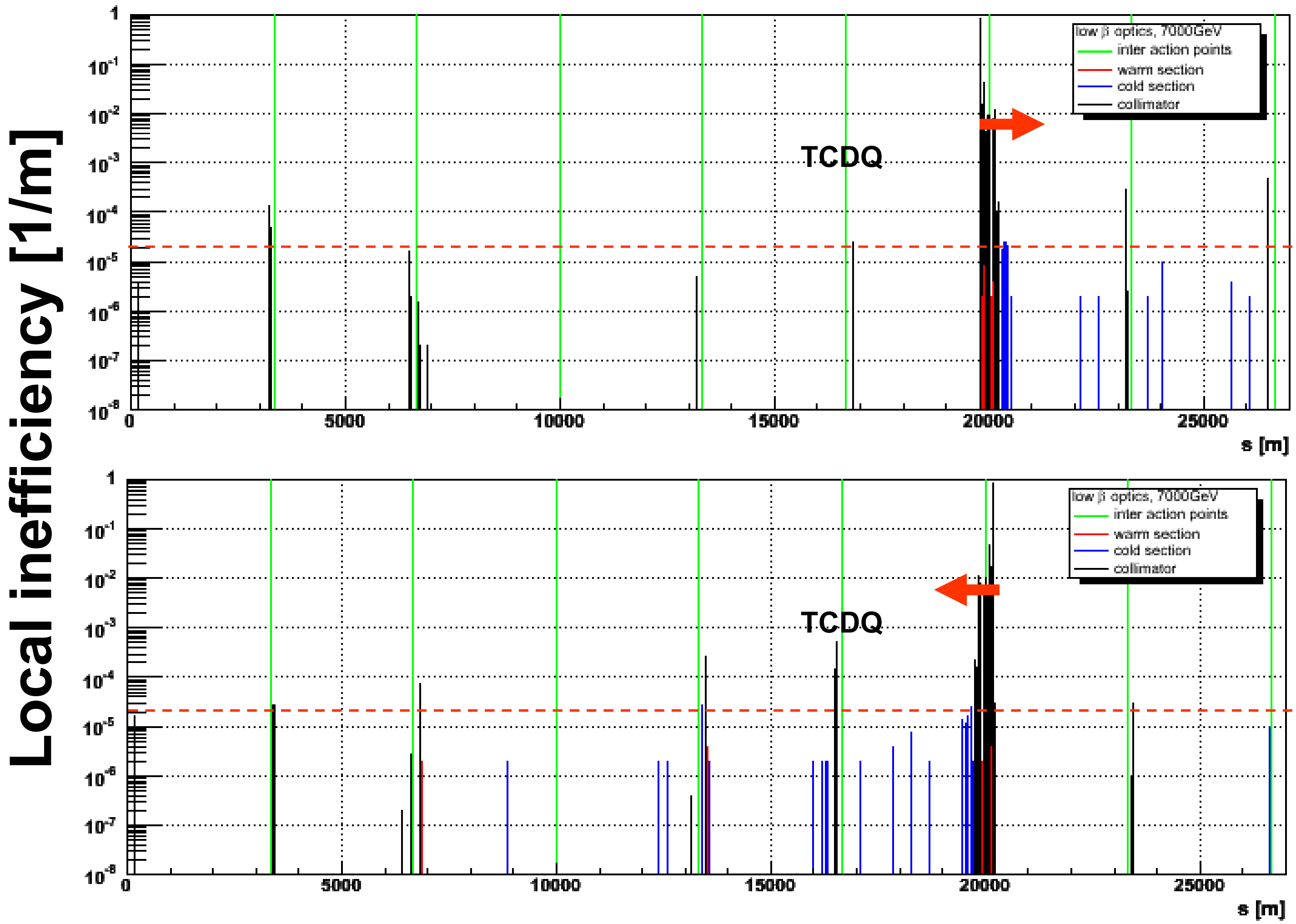
G. Robert-Demolaize & S. Redaelli

➔ Multi-turn loss predictions

Efficiency

- Assumption always: Lost protons/ions are hitting the primary collimator (multi-turn diffusion process with 5 nm per turn).
- Ideally: Protons/ions just disappear ("black hole" collimator):
  - ➔ 100 % efficiency (1 - #protons escaping / total)
  - ➔ 0 inefficiency (# protons escaping / total)
  - ➔ zero heat load from halo protons on SC magnets
- In reality: A few protons/ions can escape:
  - ➔ efficiency < 100% (we talk about **> 99.95%**)
  - ➔ inefficiency > 0 (we talk about **$< 5 \times 10^{-4}$**)
- Quenches: Heat load per m. Critical parameter are losses per m of SC magnet, or efficiency per m! No problem if losses are distributed over 27 km…
  - ➔ efficiency (we talk about **> 99.994% per m**)
  - ➔ inefficiency (we talk about **$< 2 \times 10^{-5}$ per m**)

Beam1 and Beam 2 Asymmetry



Beam1, 7 TeV
Betatron cleaning
Ideal performance

Quench limit
(nominal I, τ=0.2h)

Beam2, 7 TeV
Betatron cleaning
Ideal performance

Quench limit
(nominal I, τ=0.2h)

Local inefficiency: #p lost in bin over total #p lost over length of aperture bin!

Losses at TCT's from IR7 Leakage

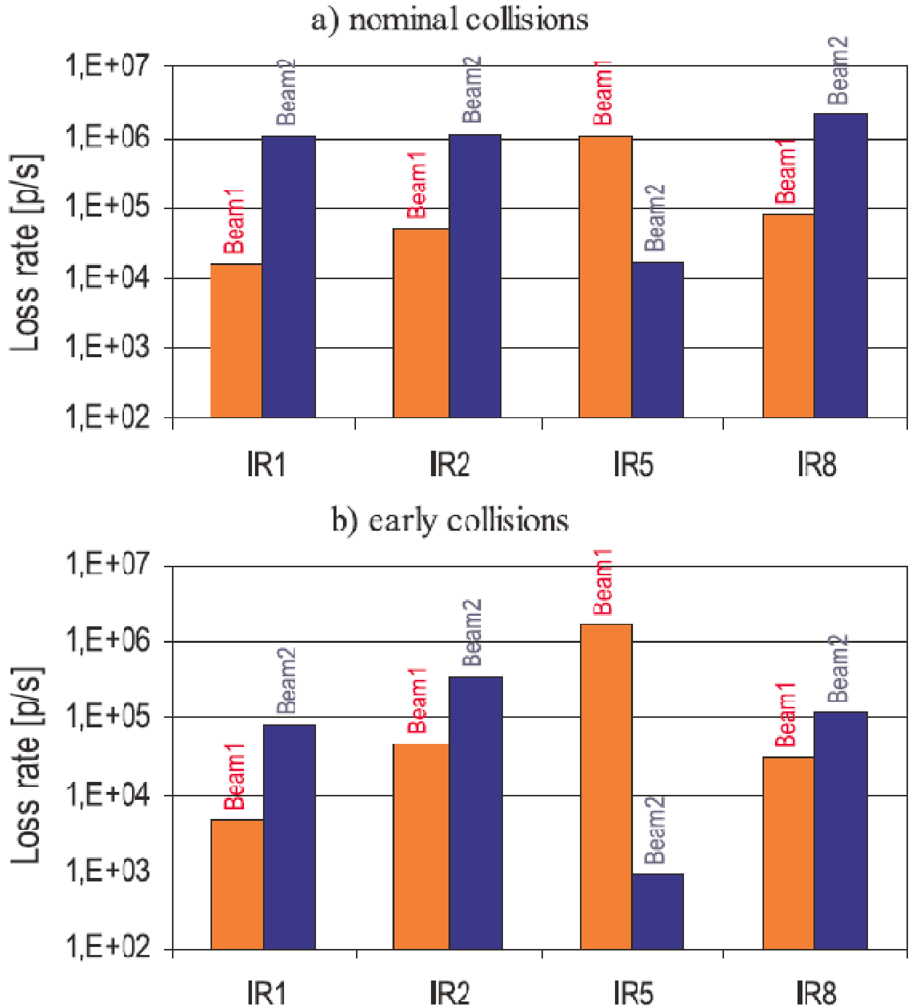
- **Beam 1 betatron halo** losses on TCT left sides of IP:
  - IR8: **4e-4** of total halo loss
  - IR1: **5e-4** of total halo loss
  - IR2: **1e-4** of total halo loss
  - IR5: **5e-6** of total halo loss
- **Beam 2 betatron halo** losses on TCT right sides of IP:
  - IR5: **3e-4** of total halo loss
  - IR2: **3e-5** of total halo loss
  - IR1: **2e-5** of total halo loss
  - IR8: **3e-5** of total halo loss

Up to 2e-6 p/s on TCT's from betatron halo cleaning for "normal" situation

Can increase by factor 2 if we open IR2 and IR8 (TCT's as loose as possible from protection)

- **Halo losses in experimental insertions are asymmetric.** Detailed losses depend on collimator settings, phase advance and halo phase space properties.
- Above settings assume IR2 and IR8 collimators present and at same setting as IR1/IR5 teriary collimators. We might open them and losses in IR1/IR5 will increase
  ➔ In worst case increase losses by a factor ~2.

Losses from Off-Momentum Halo



Loss rate: ≤ 2e6 p/s

Predicted loss rates from IR3 halo very much comparable to IR7 predictions.

Behaves like expected ➔ no inconsistency to my knowledge!

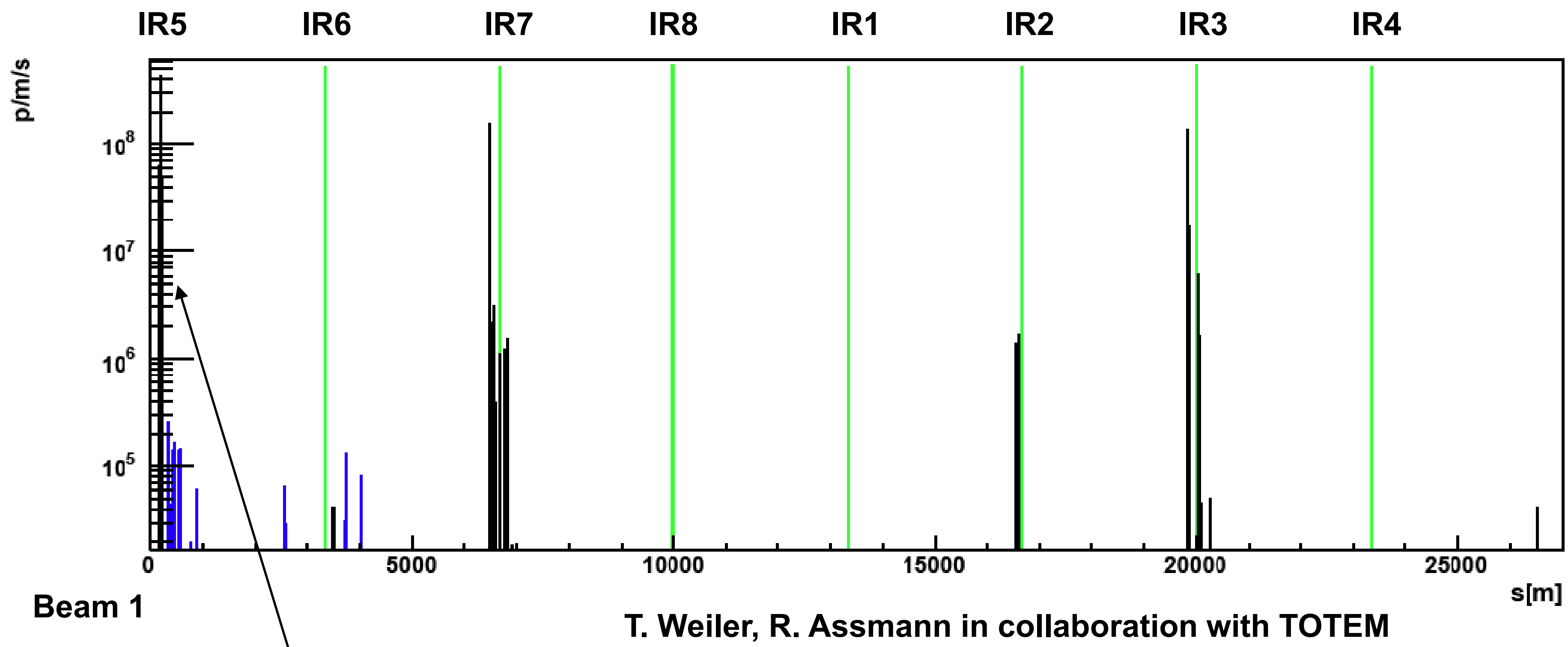
I. Bayshev et al, Project Note 407, July 2007

Other Sources of Losses

- To this we must add:
  - Direct losses due to p-p interactions
  - Direct losses due to beam gas events
  - Direct losses due to e-cloud
- Unfortunately we do not have the resources to provide a full analysis from CERN accelerator physics side.
- Therefore, we collaborate with various teams outside CERN looking at the various aspects ➔ more difficult to put it all together!
- Shown (IHEP): **In normal conditions, beam-gas scattering losses should be dominant over beam halo induced!**
- Still: **Remember loss and background spikes from halo in physics!**

Loss Map Due to p-p Collisions in IR5

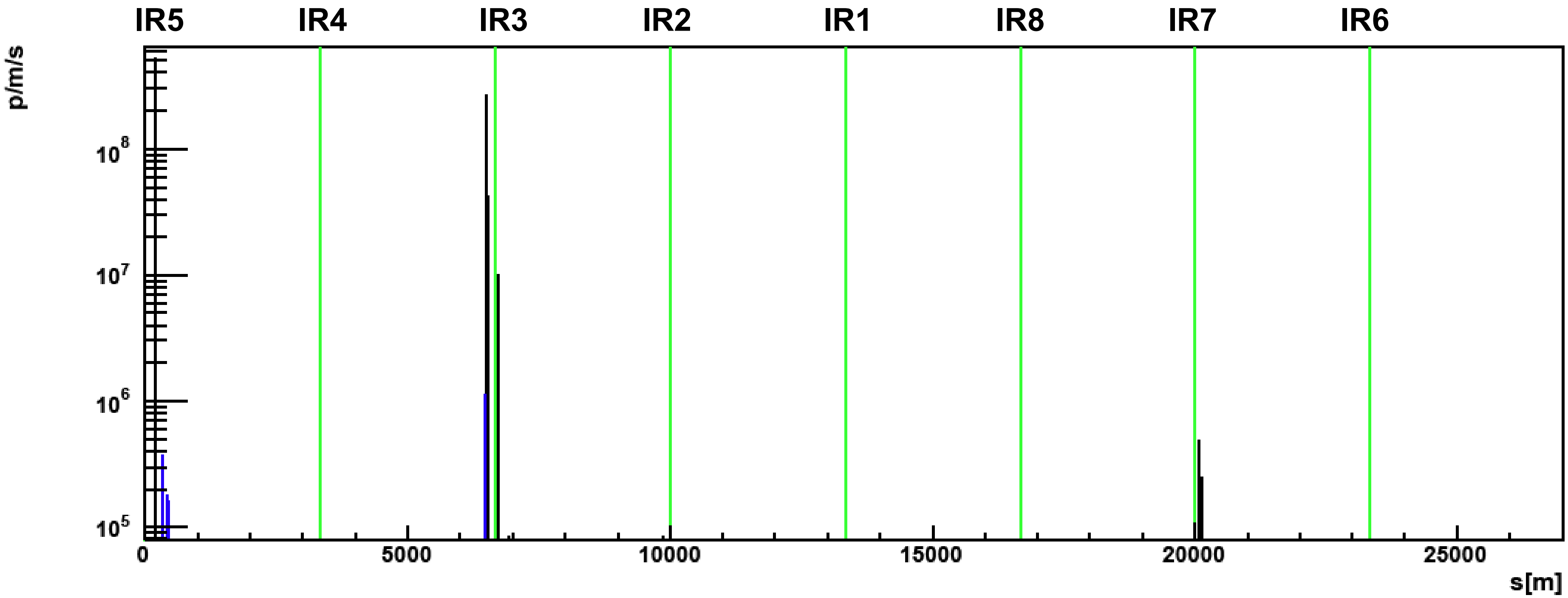
(nominal parameters and luminosity)



- Additional load of **10^6 p/s** at IR2 TCT's from IR5 collisions. Optimize TCT settings (less when we open in IR2).
- **Assumes TCL/TCLP in IR5 in place**. If not there increase initial load.
- **Cross talk between experiments** ➔ need to add it all up.

Loss Map Due to p-p Collisions in IR5

(nominal parameters and luminosity)



Beam 2

T. Weiler, R. Assmann in collaboration with TOTEM

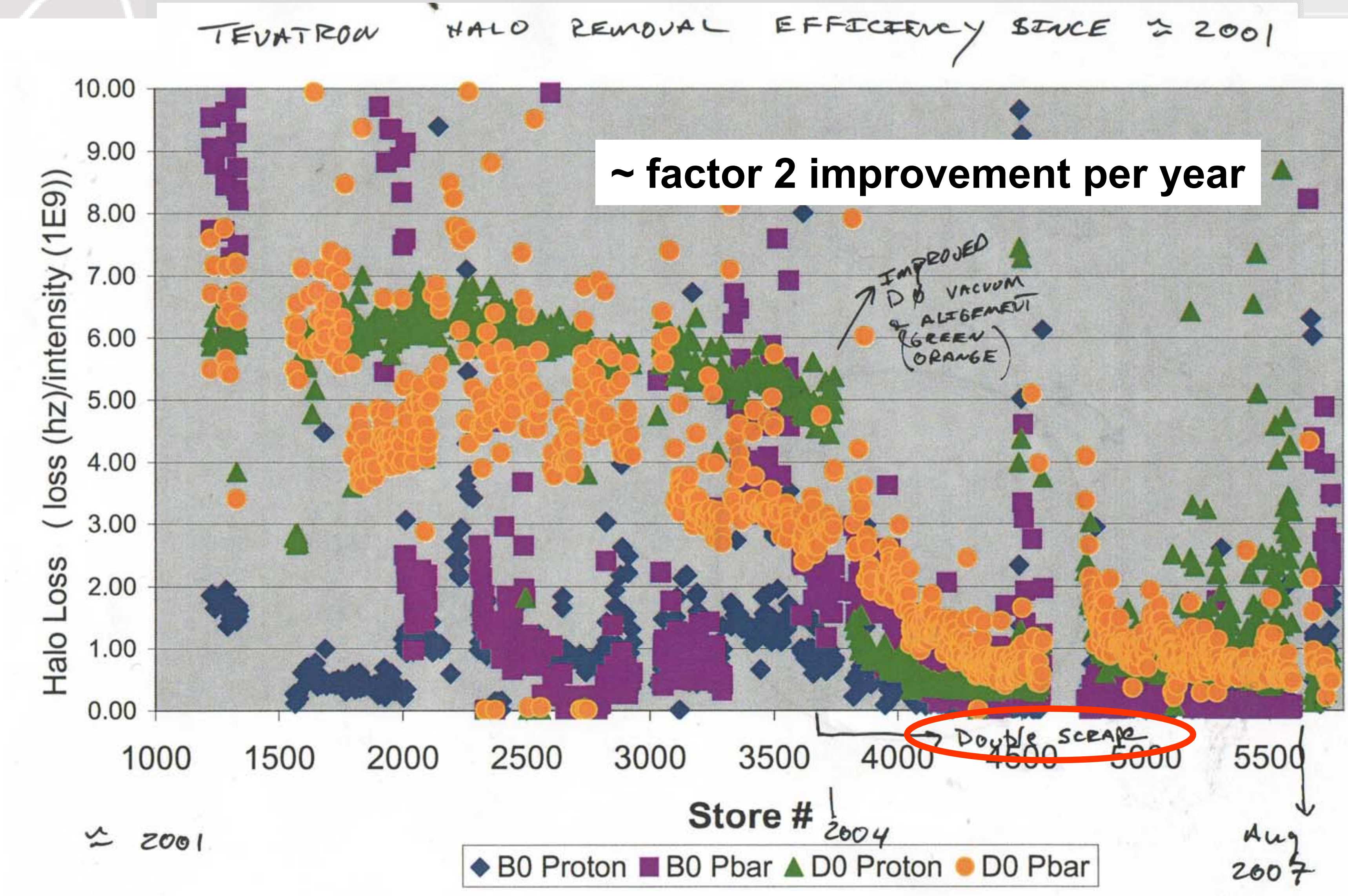
- No additional load on TCT's due to IR5 collisions for beam 2!
- IR3 catches almost everything!

Evolution of Efficiency with Time

- **Absolut loss rates should always be lower or equal than the one given for nominal conditions** (intensity can only be increased if cleaning efficiency is brought up).
- Initial installation will have by a **factor 1.3 reduced efficiency**. Full phase 1 installed after first shutdown.
- **Initially TCT's can be opened and fewer protons will be intercepted** (more towards collimators).
- We will do our best to get predicted cleaning efficiency as soon as possible. What is possible? **On paper we are fast...**
- No way to predict this with certainty today. **Will we be much faster than Tevatron?** We will have surprises!
- At **Tevatron**: System set up to **excellent performance after ~5 years with a factor ~2 improvement per year**!

A Look at Tevatron

D. Still



6) Available Freedom for “Background Tuning“ and Scraping

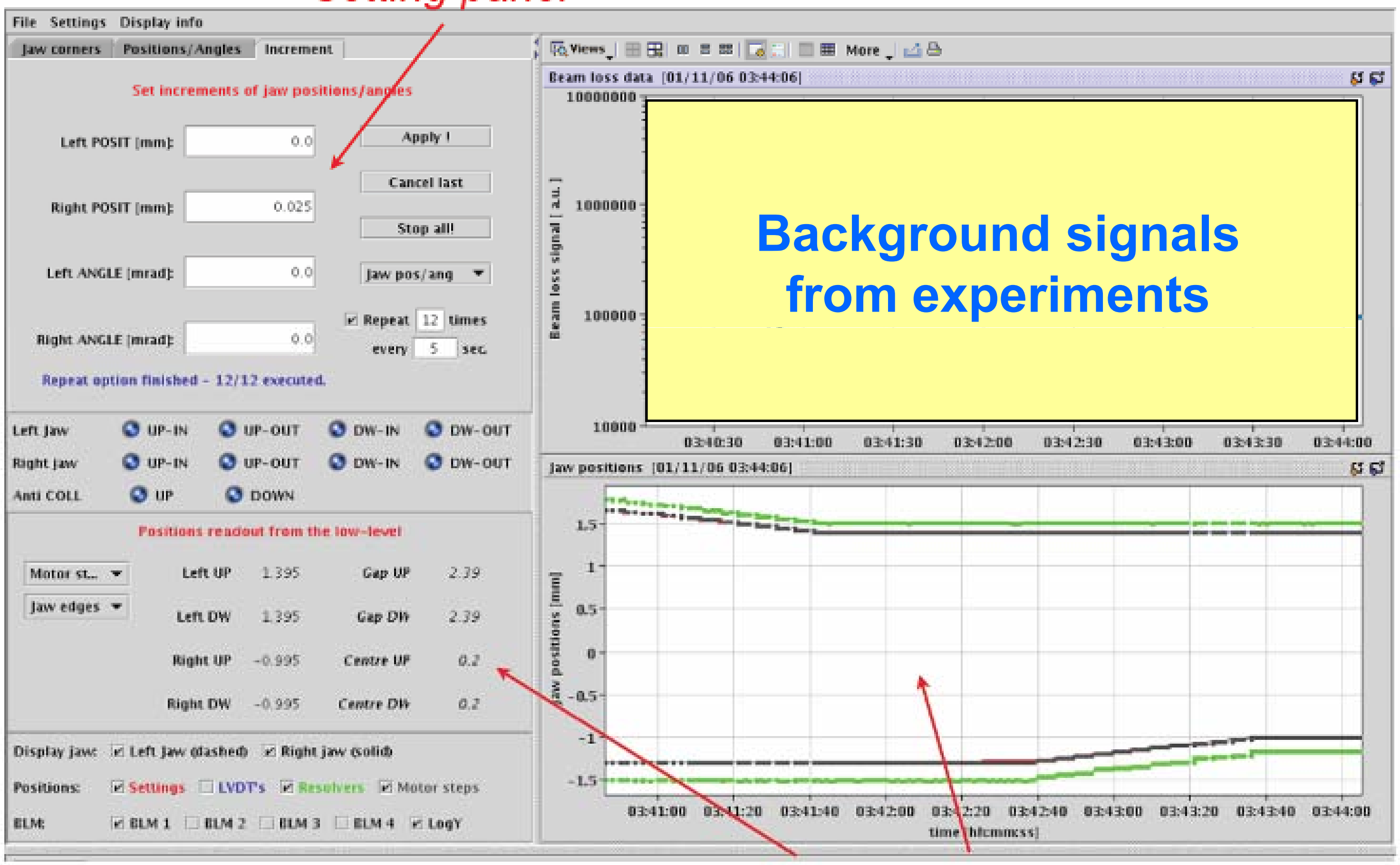
- LHC collimation is a system with a required **hierarchy of settings**!
- **TCT setting**: between TCDQ setting (dump) and triplet aperture.
- There is very limited (no) room for tuning at nominal conditions:
  - **H range without margin:** **-0.8 σ to +0.1 σ**
  - **V range without margin:** **-1.3 σ to +0.1 σ**
  - Tuning is risky: Damage to a TCT can result in a water leak into vacuum (better than triplet destruction but still serious)!
- For IR2/8, and for IR1/5 initially with larger β^*:

  ➔ **Larger range for tuning. Can reach several σ.**
- Sensitivity to loss spikes is a worry: **Scraping**!?
- **Scraping is possible with primary collimators but risky!** Techniques like in Tevatron are being developed: **scraping with automatic stop on intensity loss and/or BLM reading**.

Input to Our Application is Needed

Setting panel

S. Redaelli et al



On-line monitoring of jaw positions

S. Redaelli, LCWG 04/12/2006 *10*

➔ **Add background signals from experiments!!!**

7) IR and Collimation Upgrade

- A collimation upgrade is being prepared for 2011 shutdown, in coordination with the phase 1 triplet upgrade:

  ➔ White paper Project for Phase 2 Collimation

- This will allow to solve the open issues and improve collimation (efficiency, impedance, instrumentation, …).

- It makes sense to consider background related improvements for collimation!

- **Any input from the experiments for this upgrade?**

Questions from Mika

Q Is the TCT increasing the background wrt no-TCT (esp. for large β*)

A I do not think so. If set to protect the triplet then it will intercept losses that otherwise hit the triplet. Larger distance from the IR helps ➔ Nikolai Mokhov.

Q When and how will the TCT (and others) be aligned during commissioning

A They will be aligned as soon as we start squeezing below 6 m or so (depending on crossing angle). They are aligned in special collimator calibration runs (low intensity) by touching the primary beam halo (method a la Tevatron).

Q Are there local monitors to measure losses on the TCT (would be usefulto disentangle TCT and beam-gas background)

A Yes, every ring collimator has two BLM's attached to it.

Q What is the roadmap to reach full collimation efficiency (in IR7 & IR3)

A See earlier remarks.

8) Conclusion

- Cleaning efficiency is good in experimental IR‘s (no losses in triplets).
- TCT‘s play a crucial role in delivering stable physics fills without quenches and without risk for triplets. Tevatron has similar devices!
- The CERN AP collimation team supports studies on energy deposition and background to our best abilities. Only collimation-related studies! About 130 cases on disk with15 “customers“!
- Collimation-related losses are highly asymmetric. Cross talk shown!
- We collaborate with external partners (IHEP, FNAL). Results indicate that collimation-related losses should be in shadow of beam-gas for normal conditions.
- Collimation losses in physics will increase if lifetime drops (loss spikes). Working on automatic algorithms that allow scraping.
- TCT‘s can be opened in a number of cases. Little room for “tuning“ in IR1/5 at nominal conditions. TCT‘s have a high associated risk (water).

Requests from Collimation Side

- Lot of progress but things can always be improved.
- Our requests:
  - Provide background signals for inclusion and tests in collimation top level control (when?)!
  - Agree on a limited number of running scenarios for studies of background: early, intermediate, nominal.
  - Specify intensity, number of bunches, β^*, crossing angle, ... (decide on conservative, realistic, ultimate, worst case, … approach).
  - Formalize scenarios in one document which is updated once needed. With > 130 cases on disk we start getting confusion.
  - Provide input to collimation upgrade, if required.
- We will be happy to work out collimator settings and to provide official loss scenarios for each of the agreed cases.