Collimation

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CERN/BE

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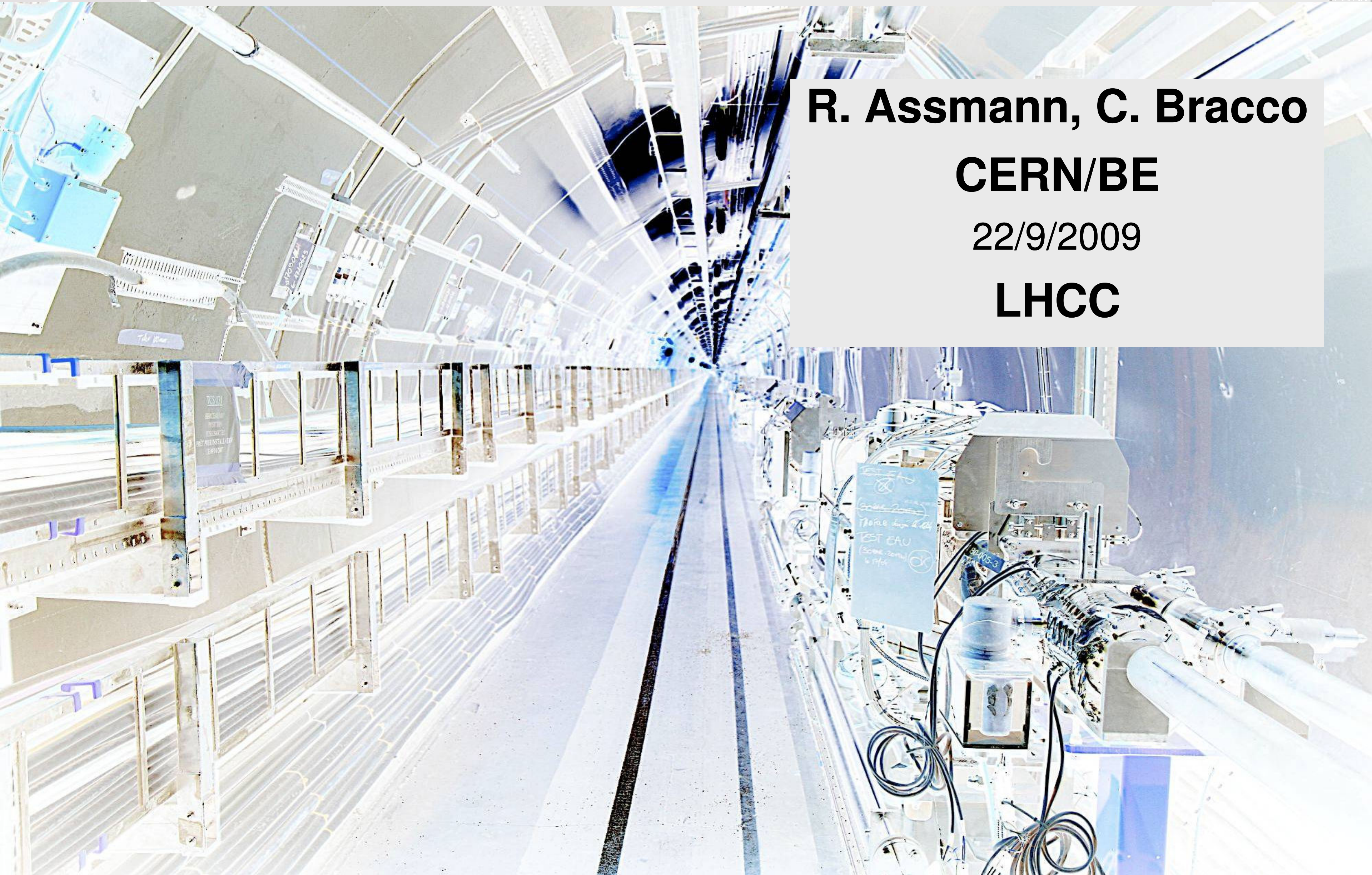
LHCC



Collimation Upgrade Plans

- Today only overview.
- Will speed through some slides. Apologies for this.
- Focus will be on issues from the phase I IR upgrade project. Acknowledgements to excellent work by C. Bracco on these issues.
- Full review of collimation plans at: http://indico.cern.ch/conferenceDisplay.py?confId=55195
- Report from review committee with mostly external experts: http://indico.cern.ch/getFile.py/access?resId=0&materialId=0&confId=55195

The Phased LHC Collimation Solution

Different for LHC triplets and IR's:
➔ Phase 0 installed, phase 1 is upgrade!

- Phase I (initial installation):
  - Relying on **112 robust collimators** with advanced but conservative design.
  - Perceived to be **used initially** (commissioning) and **always in more unstable parts of LHC operation** (injection, energy ramp and squeeze).
  - Provides **excellent robustness** and survival capabilities.
  - **OK for ultimate intensities in experimental insertions** (triplet protection, physics debris), except some signal acceptance.
  - L**imitations in efficiency (betatron & momentum) and impedance**.
  - Demanding R&D, testing, production and installation schedule over **6 years**.
- Phase II (upgrade for nominal/ultimate intensities):
  - **Upgrade for higher LHC intensities, complementing phase I.**
  - To be **used in stable parts of operation** like physics (robustness can be compromised).
  - **Fixes limitations in efficiency, impedance and other issues.**

Phase I Collimation Completed

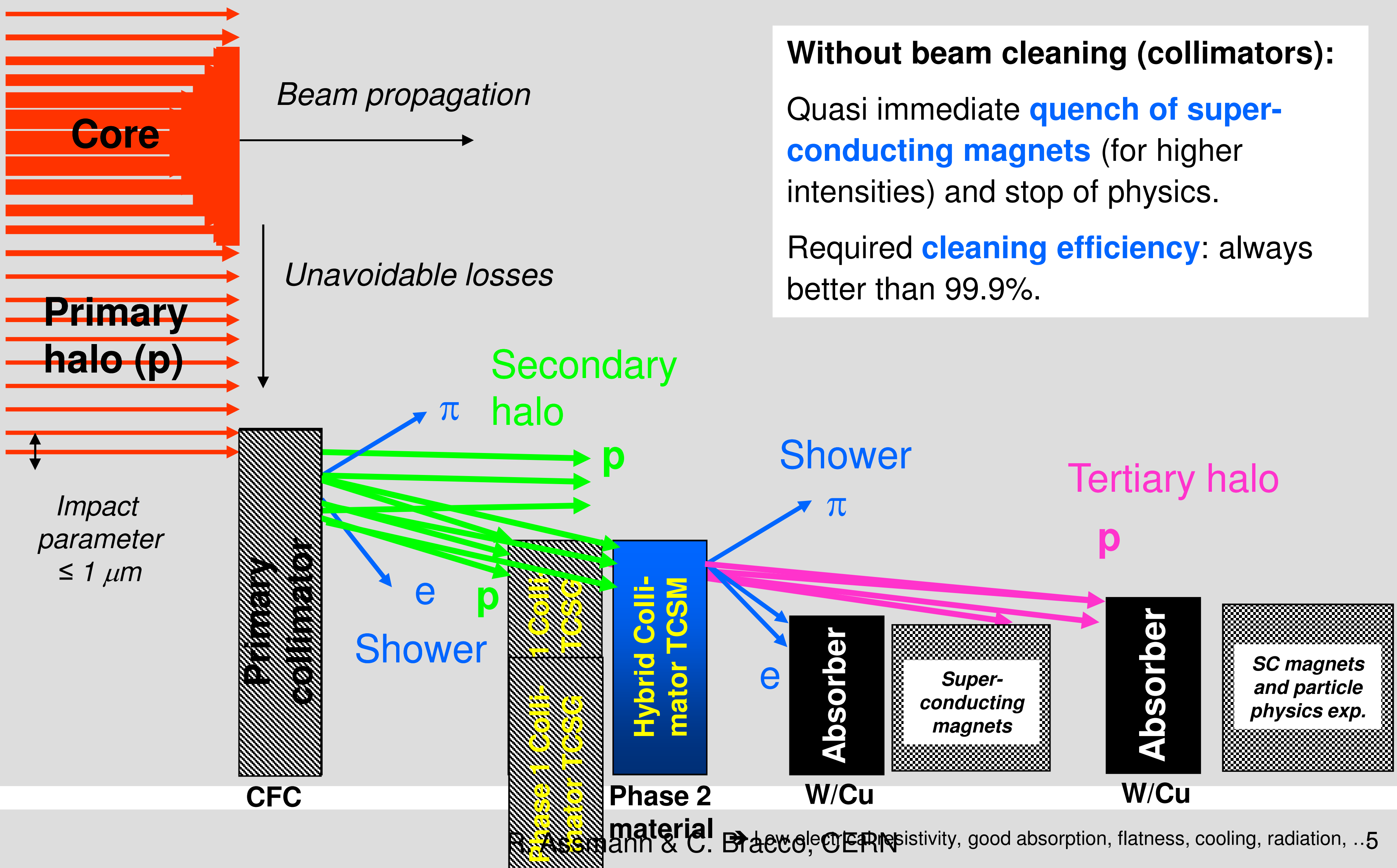
(June 2009)

LHC Phase II Cleaning & Protection

Without beam cleaning (collimators):

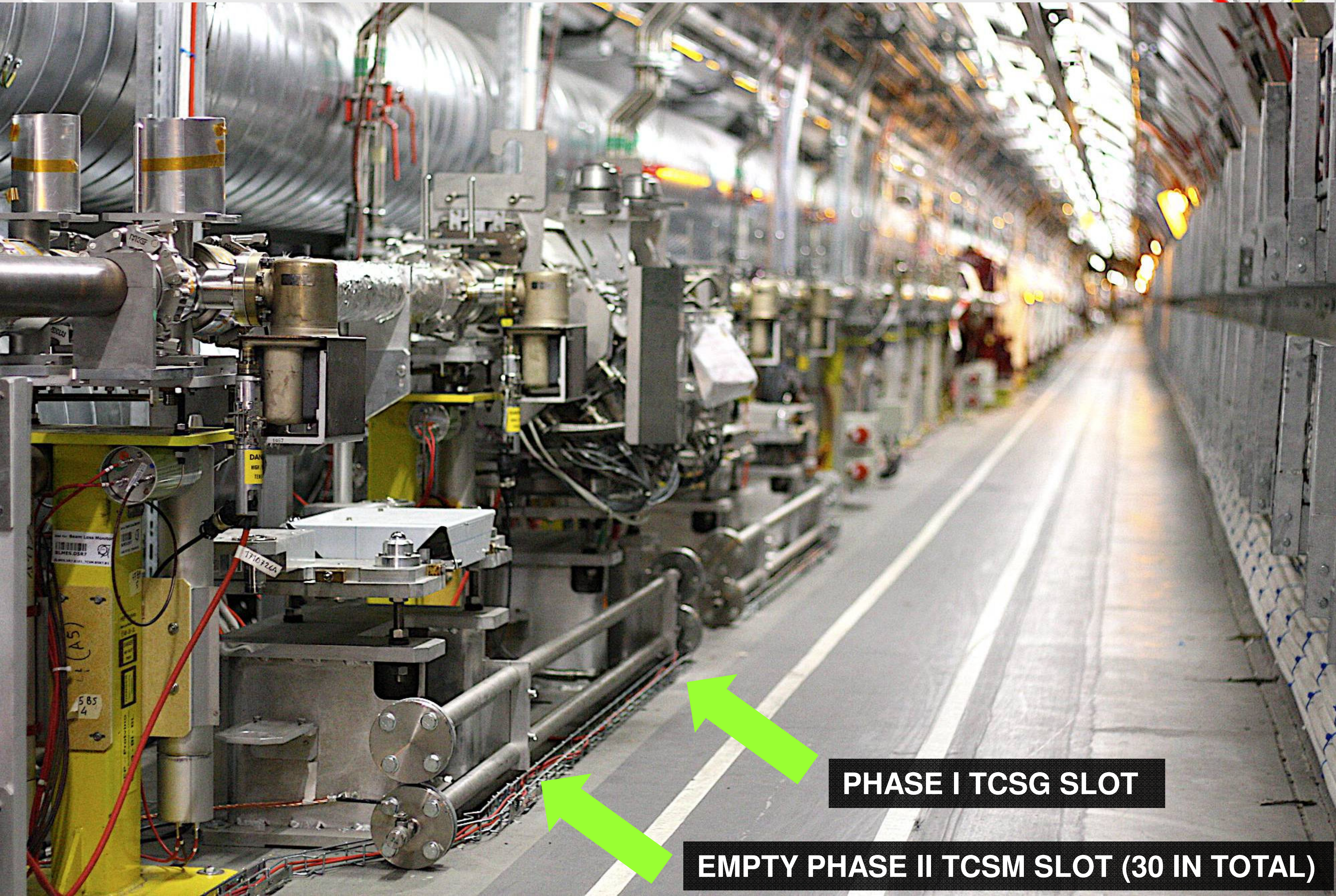
Quasi immediate **quench of super-conducting magnets** (for higher intensities) and stop of physics.

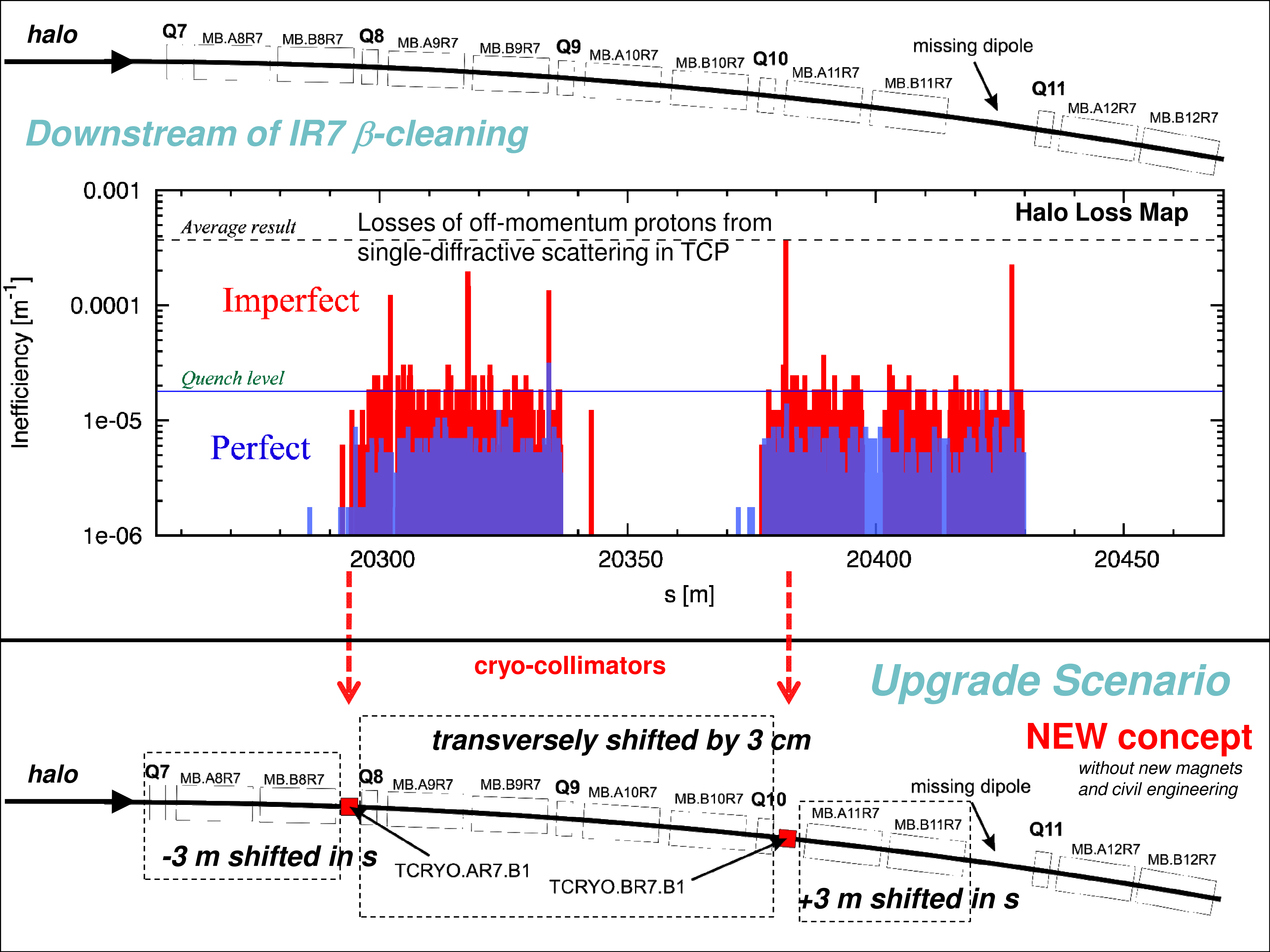
Required **cleaning efficiency**: always better than 99.9%.



Phase 2 material ➔ Low electrical resistivity, good absorption, flatness, cooling, radiation, ..

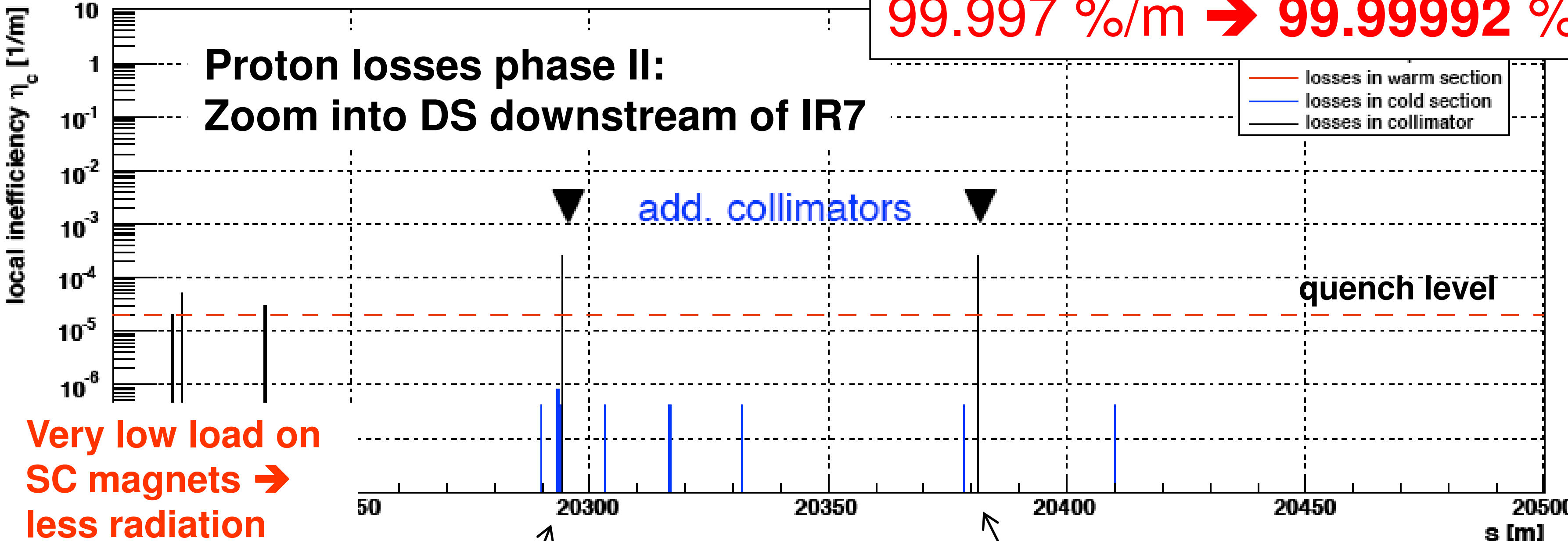
Phase II Secondary Collimator Slots




halo
Q7
MB.A8R7
MB.B8R7
Q8
MB.A9R7
MB.B9R7
Q9
MB.A10R7
MB.B10R7
Q10
MB.A11R7
MB.B11R7
missing dipole
Q11
MB.A12R7
MB.B12R7
Downstream of IR7 β-cleaning
0.001
0.0001
1e-05
1e-06
Inefficiency [m^-1]
Average result
Losses of off-momentum protons from single-diffractive scattering in TCP
Halo Loss Map
Imperfect
Quench level
Perfect
20300
20350
20400
20450
s [m]
cryo-collimators
Upgrade Scenario
NEW concept
without new magnets and civil engineering
transversely shifted by 3 cm
halo
Q7
MB.A8R7
MB.B8R7
Q8
MB.A9R7
MB.B9R7
Q9
MB.A10R7
MB.B10R7
Q10
MB.A11R7
MB.B11R7
missing dipole
Q11
MB.A12R7
MB.B12R7
-3 m shifted in s
TCRYO.AR7.B1
TCRYO.BR7.B1
+3 m shifted in s

99.997 %/m ➔ 99.99992 %/m

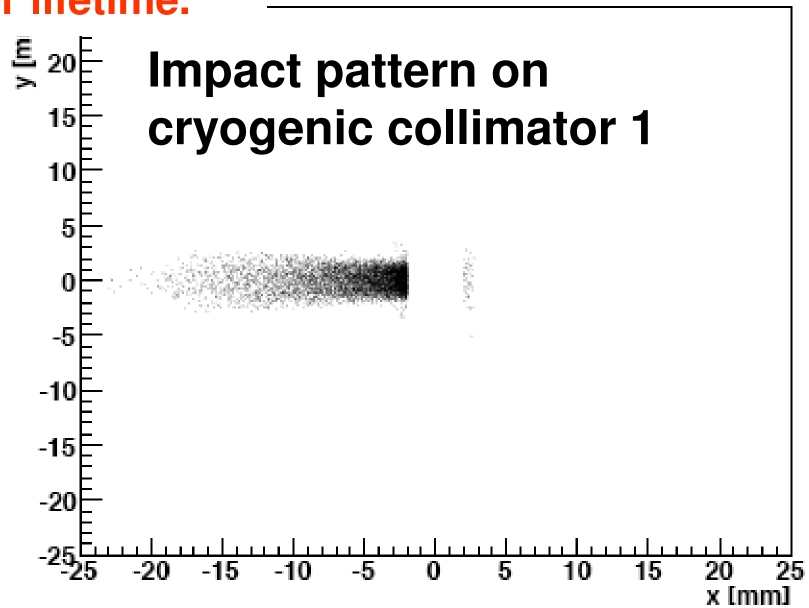
Proton losses phase II: Zoom into DS downstream of IR7



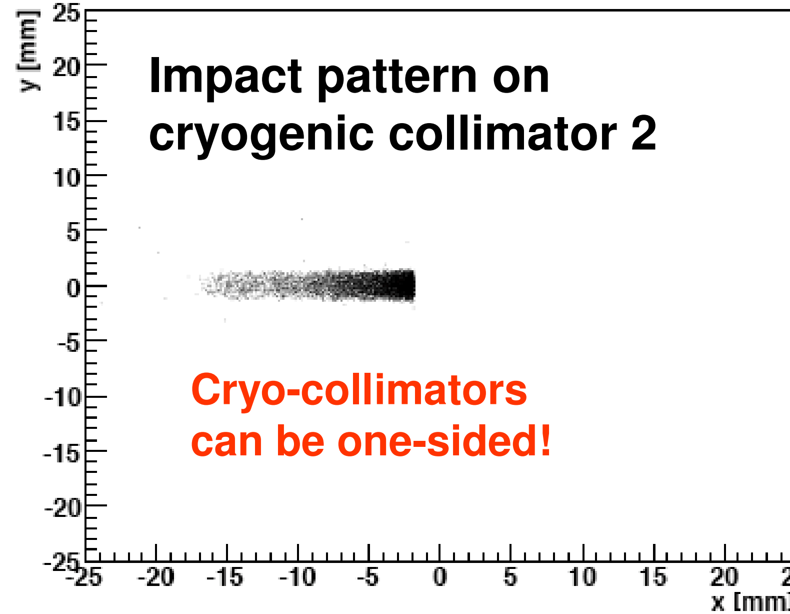
Very low load on SC magnets ➔ less radiation damage, much longer lifetime.

T. Weiler

Impact pattern on cryogenic collimator 1



Impact pattern on cryogenic collimator 2



Cryo-collimators can be one-sided!

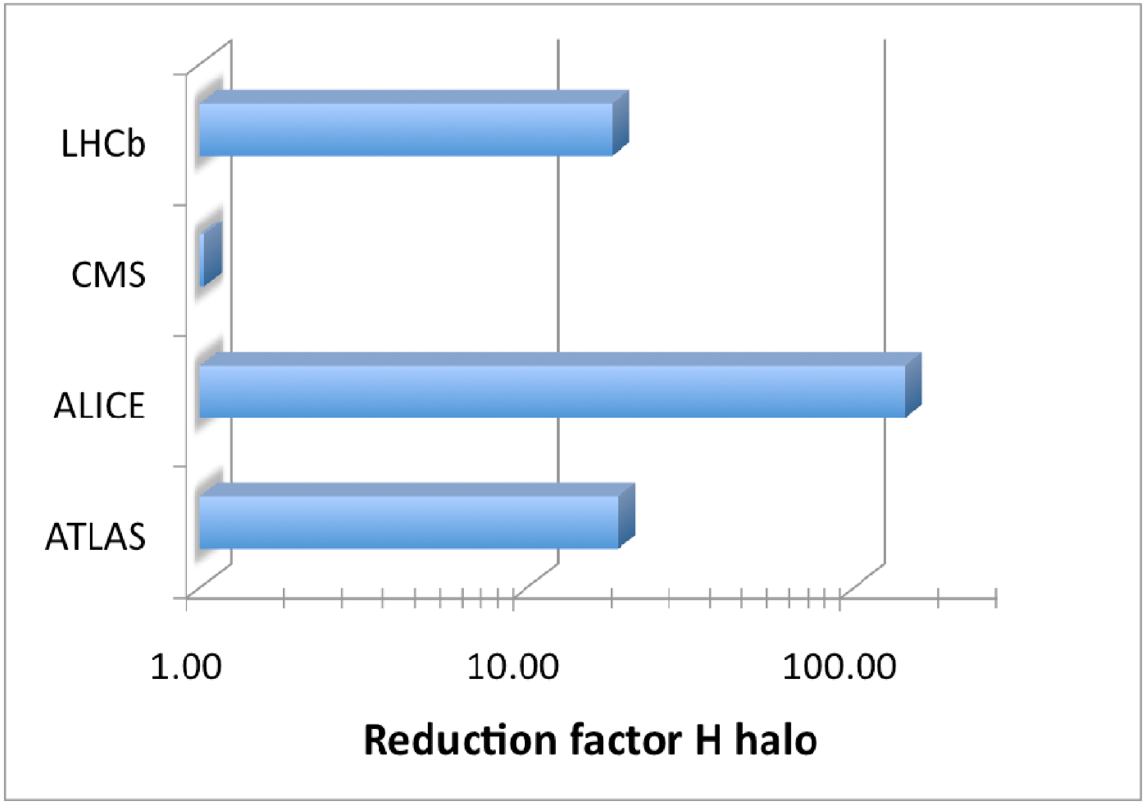
FLUKA Results

- Proton and ion tracking do not take into account showers.
- FLUKA provides more realistic estimates of energy deposition in SC magnets.
- Results for p:

Case	Peak Energy Deposition
Phase I	**5.0 mW/cm^3**
Phase II, 1 m Cu	**1.0 mW/cm^3**
Phase II, 1 m W	**0.3 mW/cm^3**

- **Factor 15** predicted from FLUKA simulations for p. Similar gains for ions.
- Additional gain expected with imperfections (aperture steps from misalignments shadowed with collimators).
- **Total efficiency gain will be between factor 15 to 90!**

Load Experimental Collimators (Beam 1)

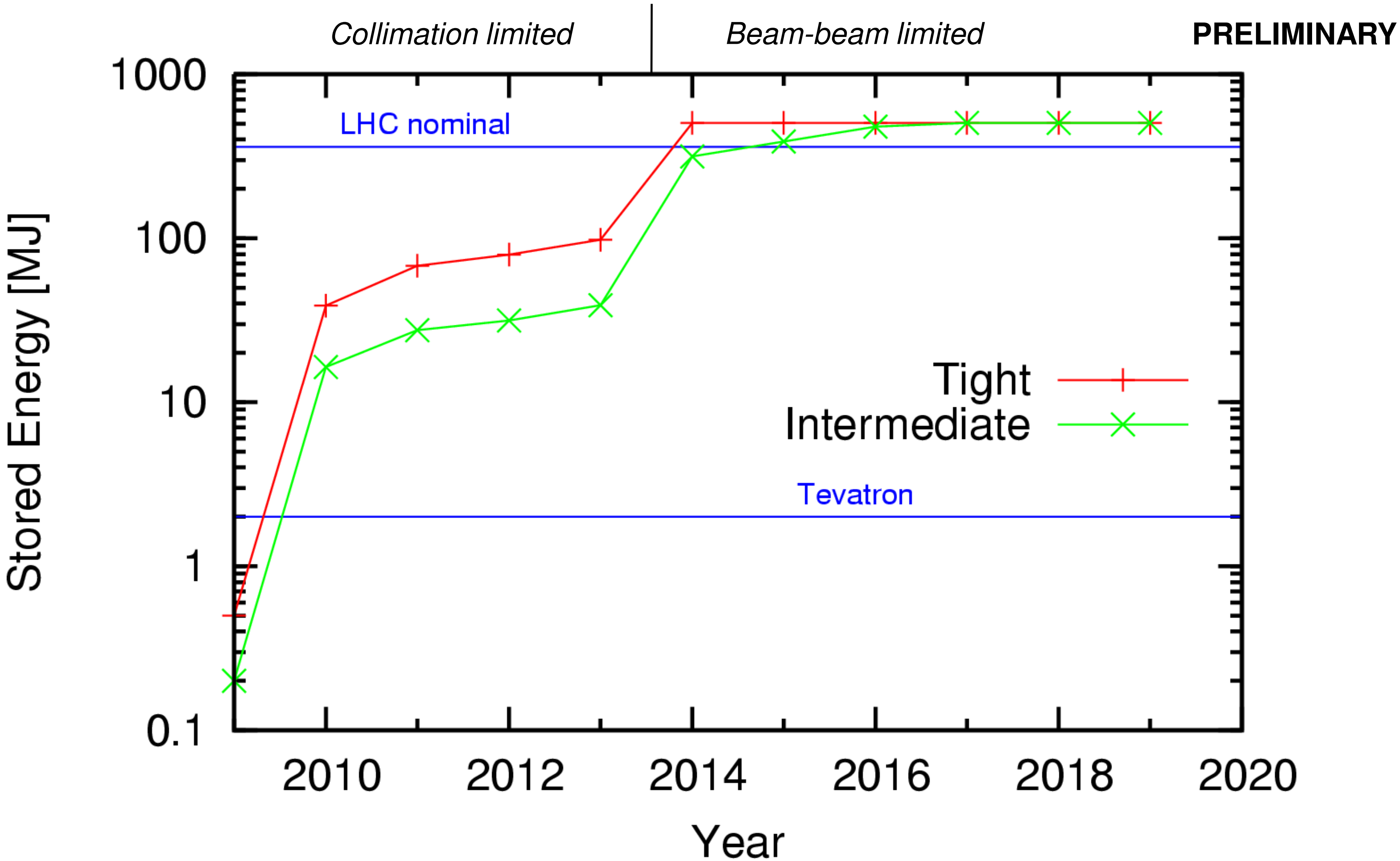


- Figure shows average reduction in loss at horizontal tertiary collimators in the various insertions (collimation halo load). CMS is not improved as cryo-collimators were not yet included in IR3.
- Phase II collimation upgrade reduces losses in IR's by a factor up to 100!

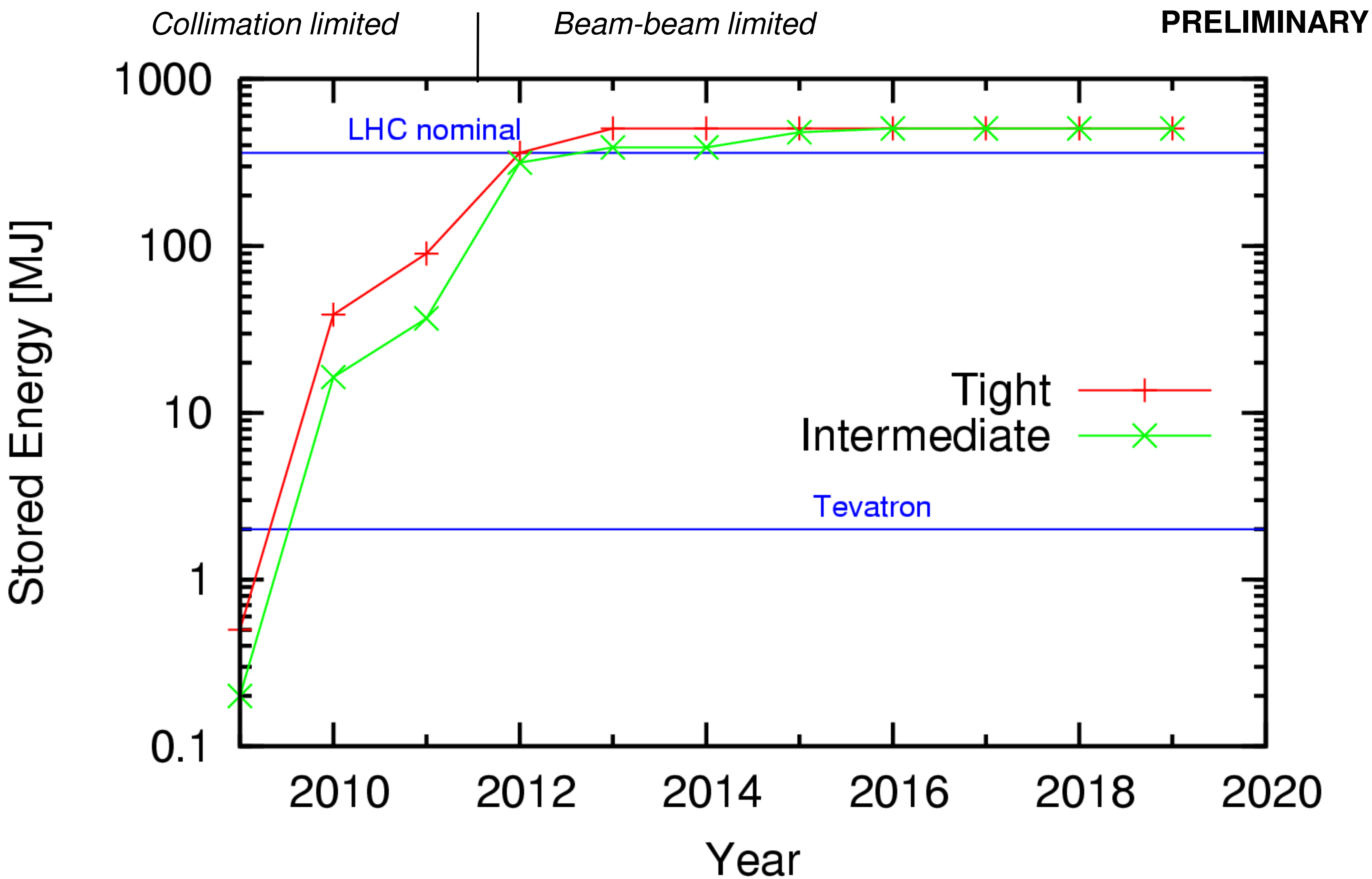
Two Scenarios

- Scenario 1:
  - **2013/14 shutdown:** Phase I IR upgrade and phase II of LHC collimation are installed at the same time.
- Scenario 2:
  - **Before 2013/14 shutdown:** Installation of collimators into cryogenic regions (requires no R&D). Gains big factor in cleaning efficiency.
  - **2013/14 shutdown:** Phase I IR upgrade and phase II secondary collimators are installed.
- Scenario 2 is very pushy and not given. Details to be worked out until March 2010…
- Adapted scenario will also depend on beam experience with the LHC (e.g. loss rates to be taken).
- Details on assumptions: http://lhc-collimation-project.web.cern.ch/lhc-collimation-project/PPT/2009_march_19_lmc_assmann_v6_windows.ppt

Result: Stored Energy versus Time (Scenario 1)



Result: Stored Energy versus Time (Scenario 2)



Issues from Phase I IR Upgrade

- This is a project led by R. Ostojic.
- Goal is to **increase LHC luminosity by a factor 2 with a β^* of 0.3 m and an increase of beam intensity by a factor 1.6**.
- This should be achieved with construction of a new triplet, new D1 and a new optics with stronger focusing.
- From collimation side we were always concerned, following the upgrade experience at HERA and TEVATRON.
- Their issues were different but losses, collimation and background were major issues after the upgrades of HERA and TEVATRON.
- So we agreed on a collimation WP inside the phase I IR upgrade project.

Collimation Evaluation

- It is very time-consuming to evaluate the upgrade optics for collimation:
  - Different cases exist, multiplying the time required by some factor 3-4.
  - There is no final upgrade optics yet, continuous optimization is in progress.
  - Same is true for the aperture model.
- At the same time collimation team not very much available for this:
  - Departure of a key person beginning of 2009.
  - New persons must work into this complicated domain.
  - First priority is completion of phase I and LHC commissioning for collimation which started in June 2009. Full collimation team busy on this.
  - No additional manpower from phase I triplet upgrade project for our work.
- Made an extraordinary effort up to end of June 2009.
- Report on results of first assessment.

Achievements and Limitations

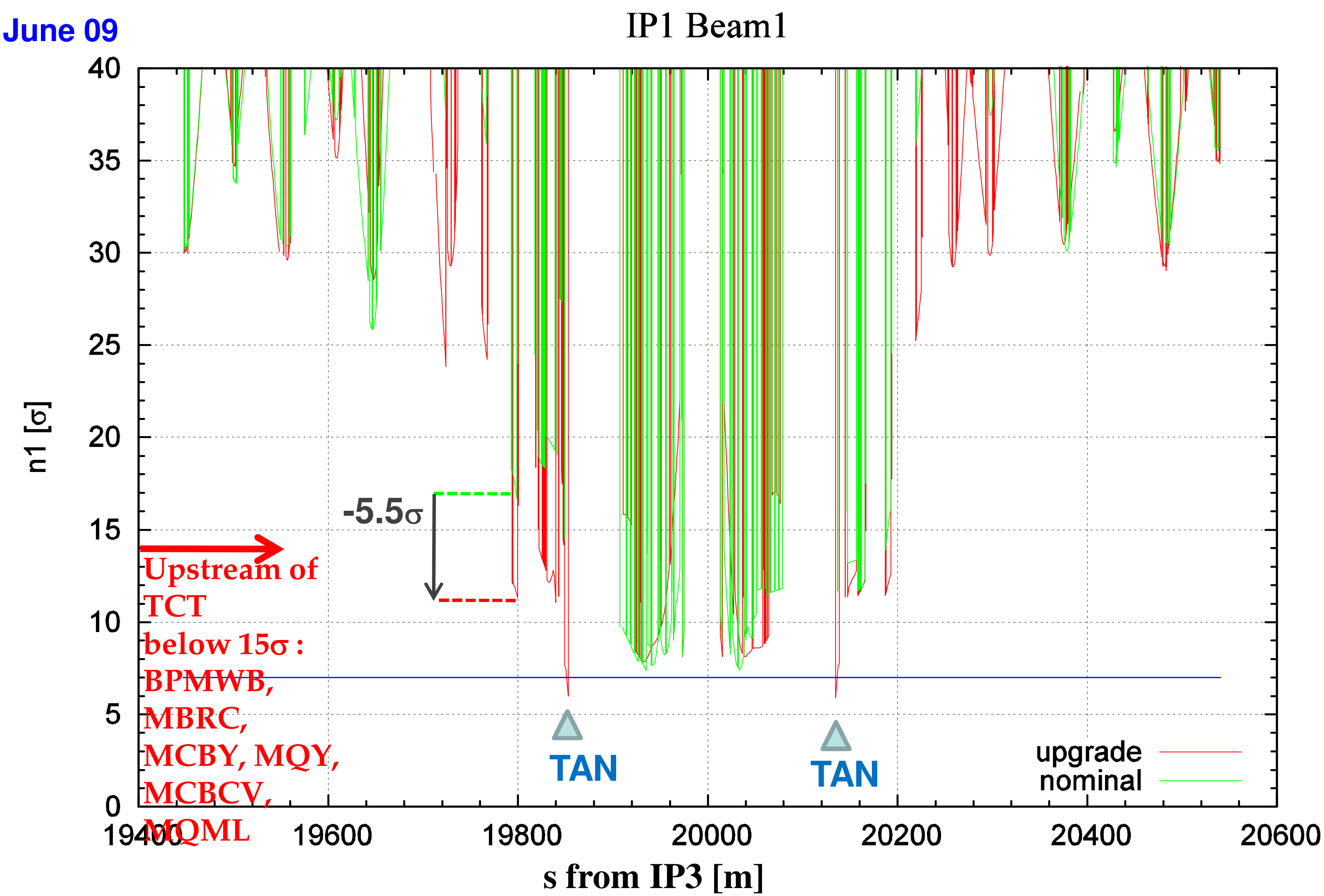
- Thanks to our collimation commissioning fellow C. Bracco for spending several months of her time on this.
- A first assessment was indeed completed, however, only without influence of imperfections, only for betatron halo and only for beam 1.
- Results are therefore only addressing IR1 issues which are driven by beam 1 halo losses.
- IR5 is driven by beam 2 halo losses which could not yet be assessed. We guess that the IR1 solution will also work in IR5.
- For IR7 we saw a factor ~10 increase in losses with realistic imperfections (design imperfections). Expect similar effects for experimental insertions.
- Results assume that phase II collimators have been installed before or with the phase I triplet upgrade. Due to time limits the proposed collimators in cryogenic regions could not be included yet (predicted to reduce losses in IR's).

Assumptions

- Here we only consider **loss maps for a perfect machine in terms of orbit, misalignments, linear optics errors, collimation set-up, …**
- Target losses relate to 7 TeV, expected quench limits and specified LHC beam loss rates.
- Present triplets relate to an optics with β^*=0.55 m, the phase I triplets to an optics with **β^*=0.3m** and increased triplet aperture.
- The model includes the full chromatic optics, including off-momentum beta beat and spurious dispersion.
- Chromatic dependencies are much stronger for the upgrade optics due to stronger focusing.
- Several optics scenarios exist (➔ S. Fartoukh) that correct these features for the triplet upgrade optics. They have been evaluated.
- Assume no collisions in IR2 and IR8: no squeeze and open TCT's!
- Only include halo losses from collimators, no direct losses from beam-gas: additional loss loads at similar locations expected!

IR1 Aperture after Triplet Upgrade

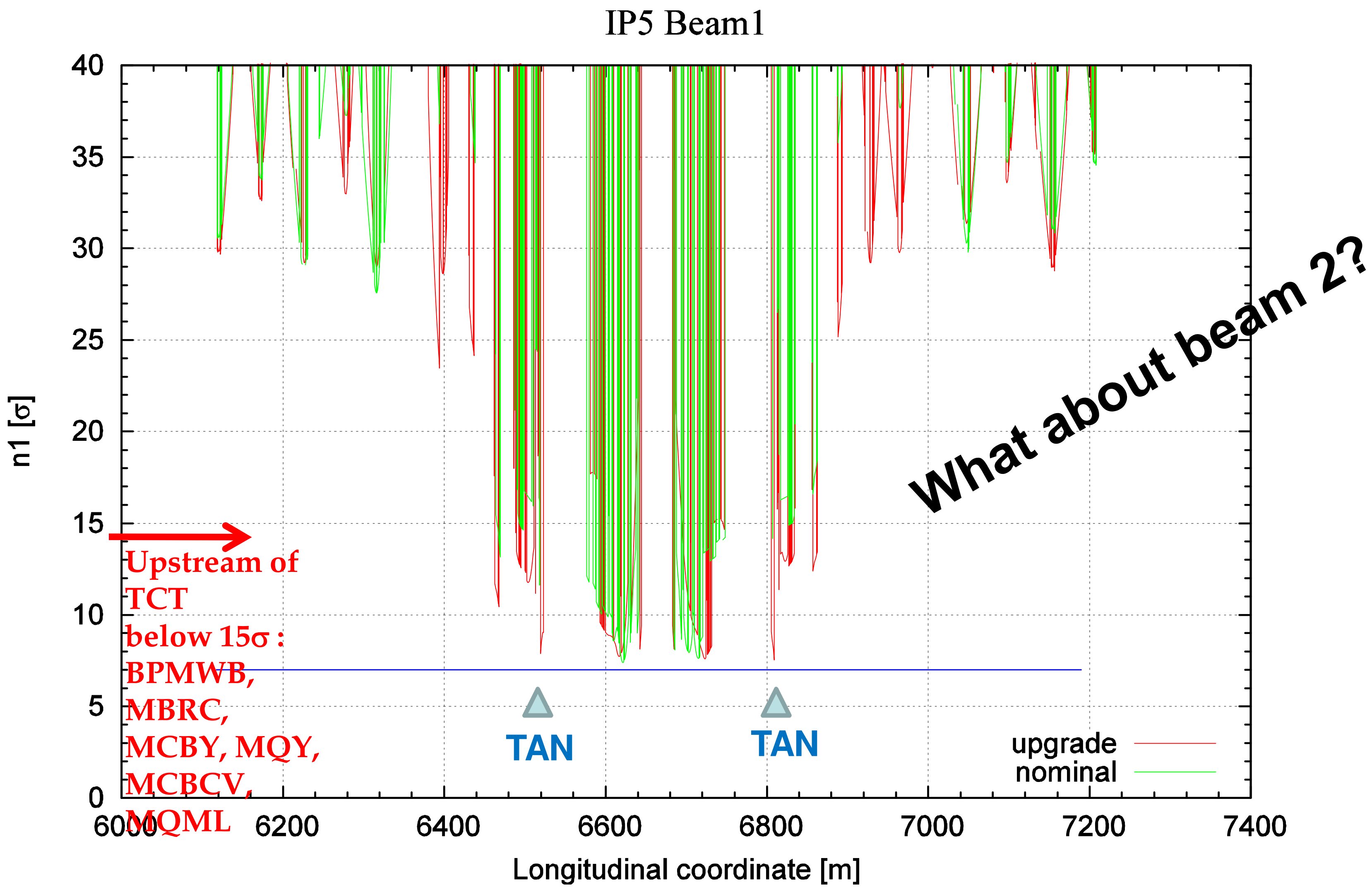
Status June 09



Observations

- It is evident that a squeeze to lower β^* in the phase I upgrade reduces aperture before the IP:
  - For the triplet and the D1 this is addressed by building new magnets with larger aperture, thus respecting the design constraint of n1=7.
  - It was originally planned that other equipment would remain unchanged (limited and fast phase I triplet upgrade).
- After the upgrade the warm **TAN** would have an aperture of down to n1=5. Even though it cannot quench it is outside of the machine protection and **must be changed to achieve n1>7**. Clear request sent.
- In addition, **aperture in magnets upstream of the TAN is reduced by up to 5.5 σ.** Outside of arc shadow. Much less comfortable than before!
- IR5 similar though somewhat better for TAN.
- Beam 2 aperture not checked by us due to limited resources!

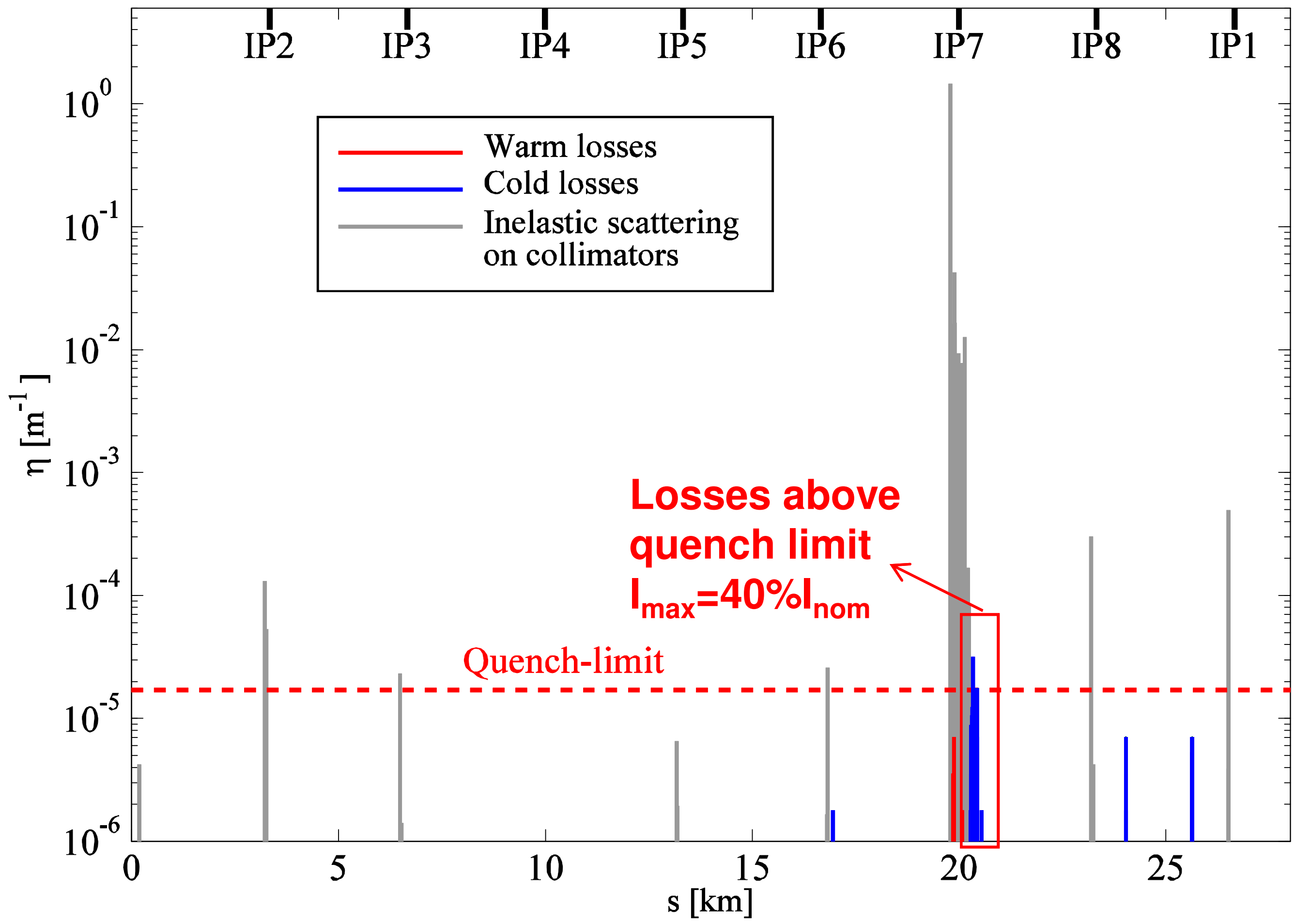
IR5 Aperture after Triplet Upgrade



Present Triplet, H Halo, 7 TeV

Losses versus longitudinal position

- **Phase 1 collimators**
- **All TCTs are set at 8.3σ**



Phase I Triplet, H Halo, 7 TeV

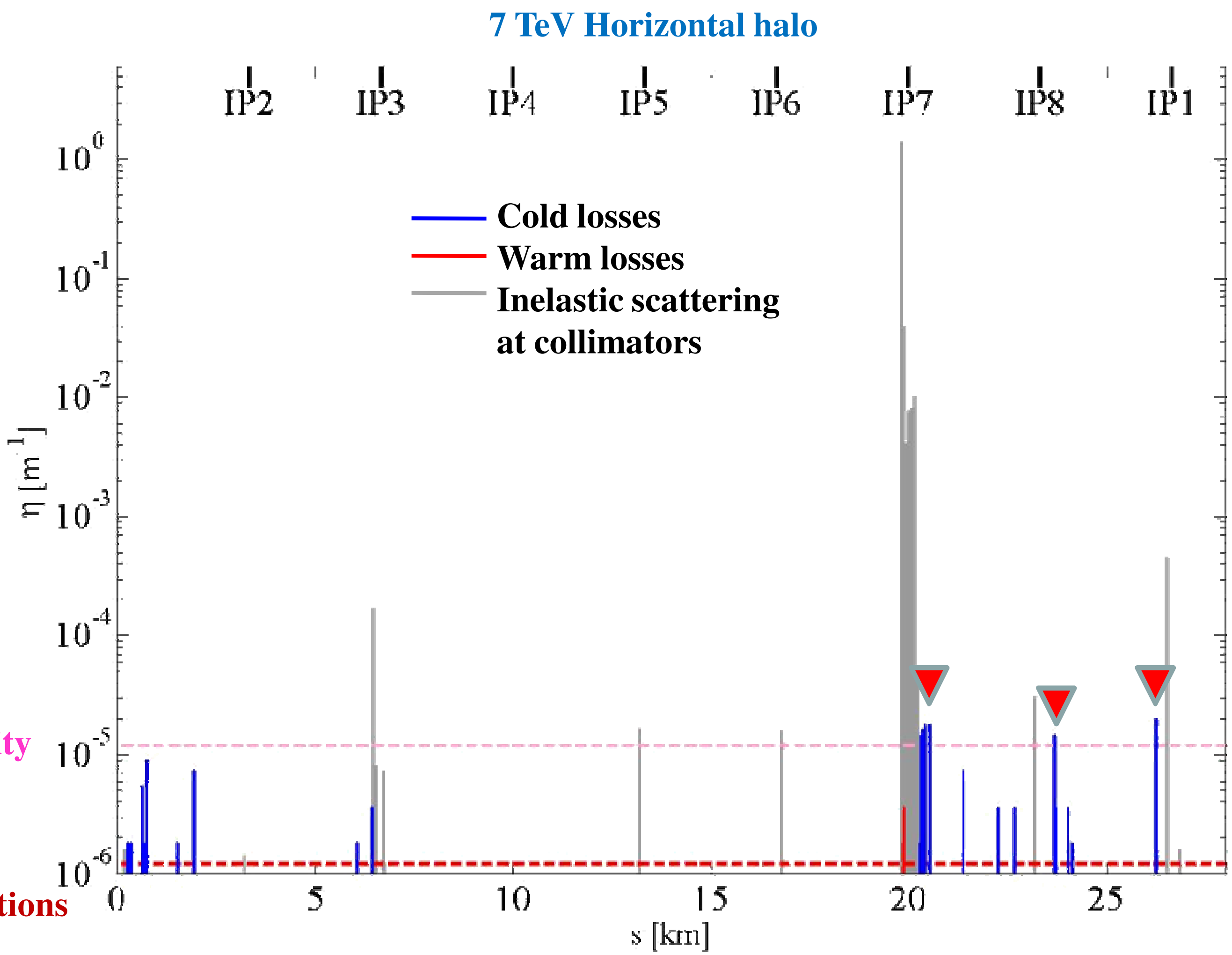
No Correction Off-Momentum β-beat & Dispersion

- Phase 2 collimators: TCSG(open)+ TCSM

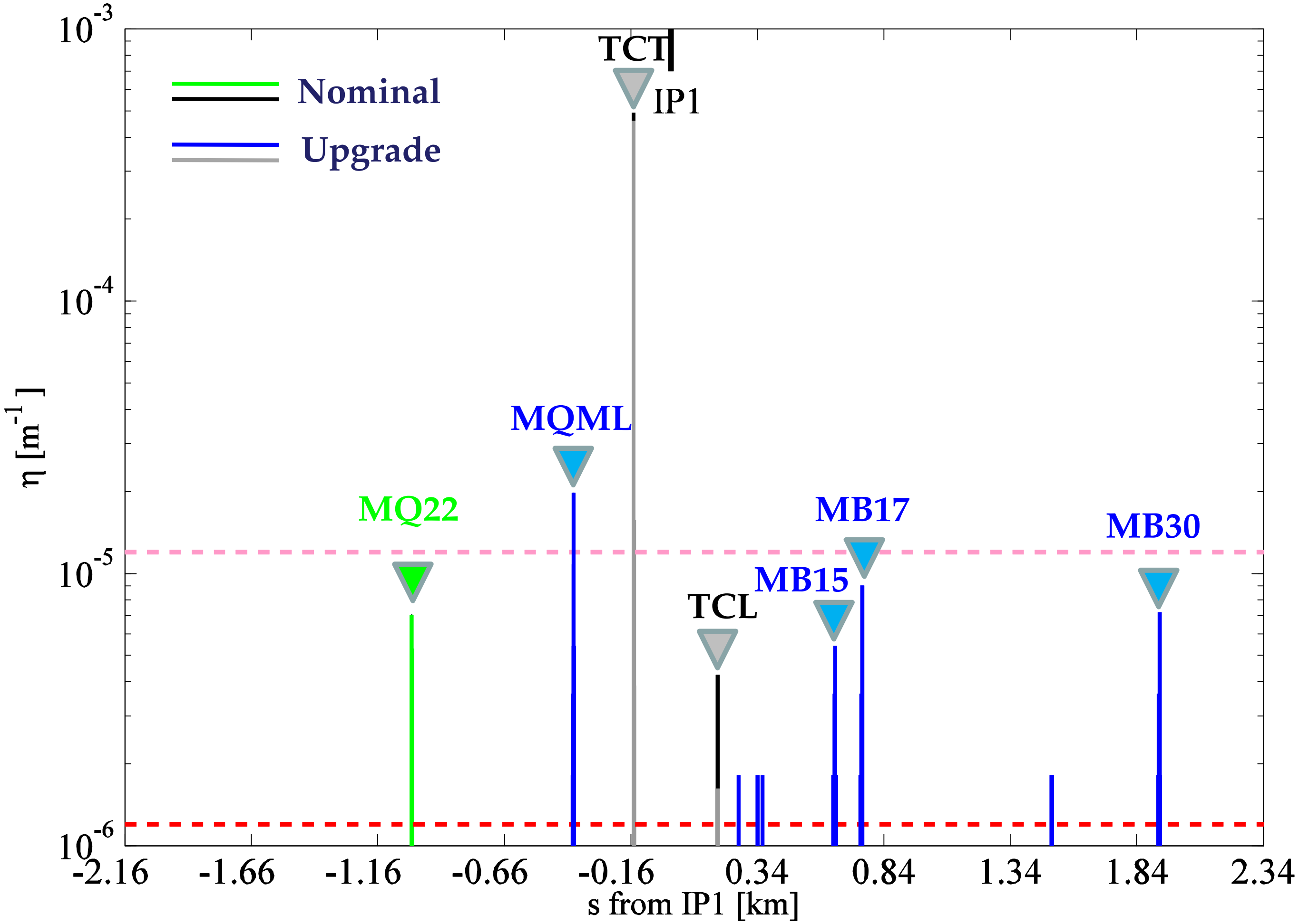
- TCTs are at:
7.2σ in IR1
33σ in IR2
9σ in IR5
34σ in IR8

Quench limit ultimate intensity

Equivalent quench limit with imperfections



Zoom into IR1 H Losses

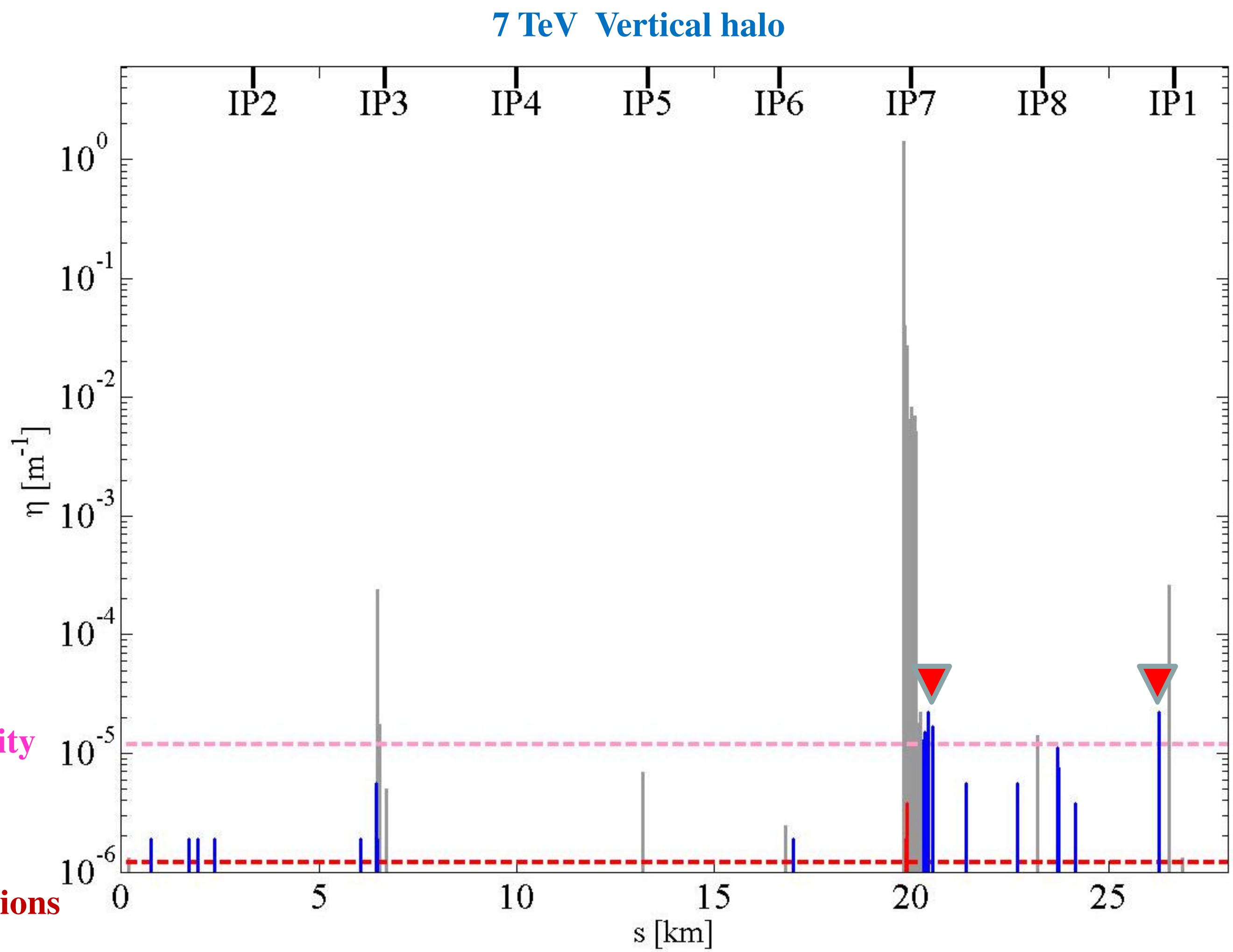


Phase I Triplet, V Halo, 7 TeV

No Correction Off-Momentum β-beat & Dispersion

- Phase 2 collimators: TCSG(open)+ TCSM

- TCTs are at:
7.2σ in IR1
33σ in IR2
9σ in IR5
34σ in IR8



Quench limit ultimate intensity

Equivalent quench limit with imperfections

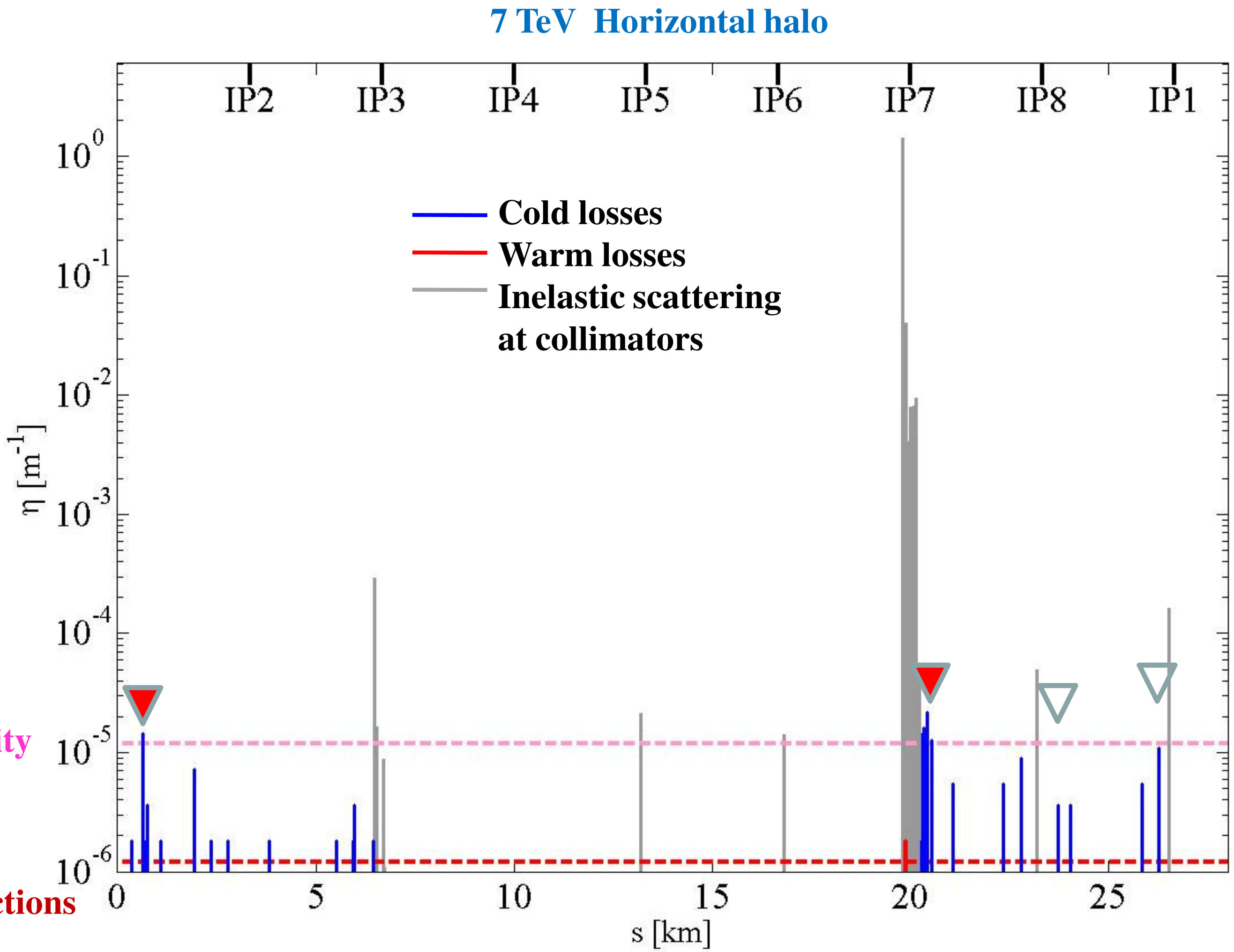
Observations

- **With the phase I triplet upgrade optics we find many additional spikes without special corrections of off-momentum beta beat and spurious dispersion.**
- This is confirmed both for H and V halo losses. No studies yet for beam 2.
- Higher losses appear in the region of reduced aperture upstream of the IP. We expected this…
- Even for the perfect case, losses are a factor ~2 above the specified limit. Including a margin for imperfections the losses are a **factor ~20** too high.

Phase I Triplet, H Halo, 7 TeV
Correction Off-Momentum

• Phase 2 collimators: TCSG(open)+ TCSM

• TCTs are at:
7.2σ in IR1
33σ in IR2
9σ in IR5
34σ in IR8



Quench limit ultimate intensity

Equivalent quench limit with imperfections

Phase I Triplet, H Halo, 7 TeV

Correction Off-Momentum β-beat & Dispersion

- Phase 2 collimators: TCSG(open)+ TCSM

- TCTs are at:
7.2σ in IR1
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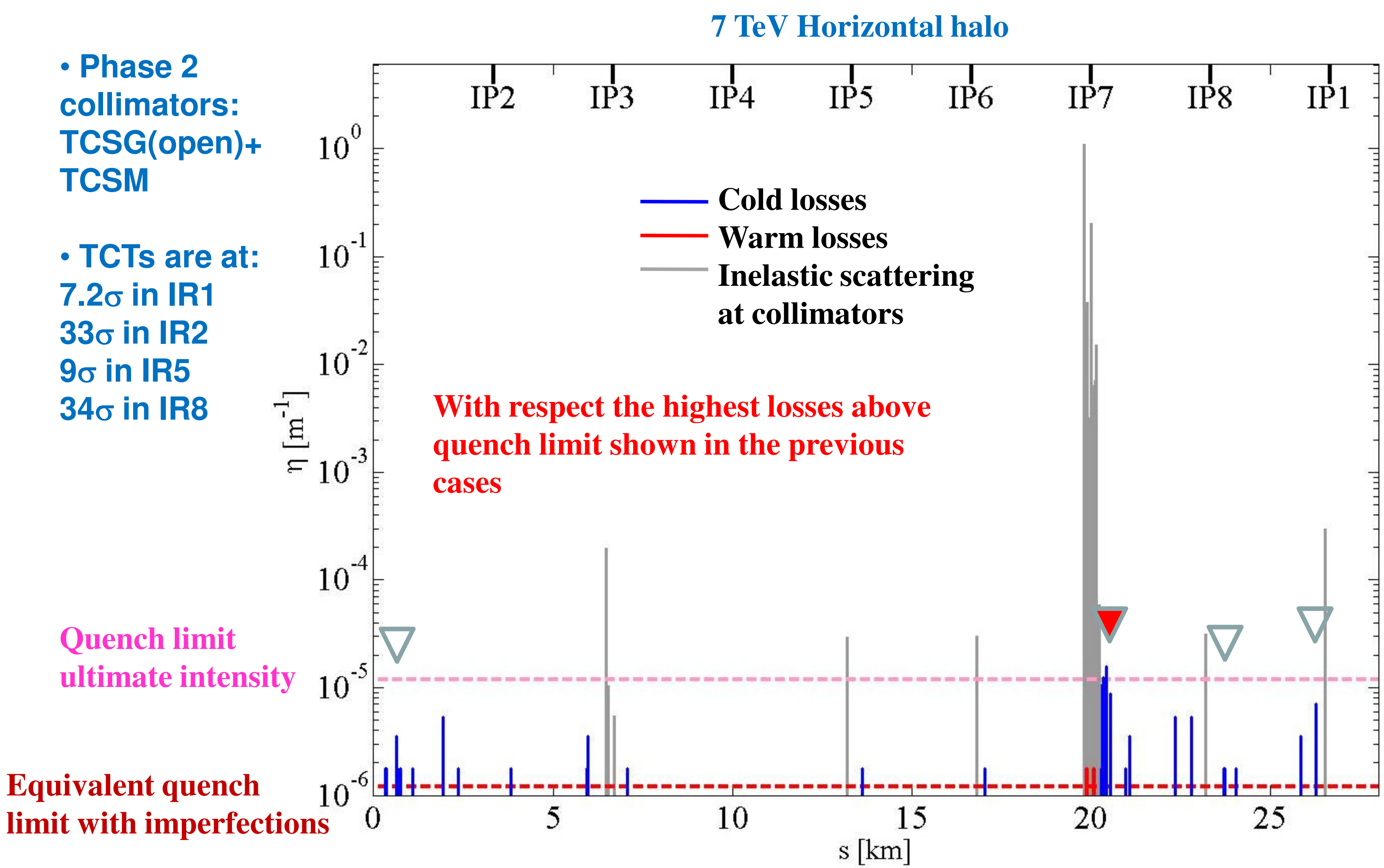
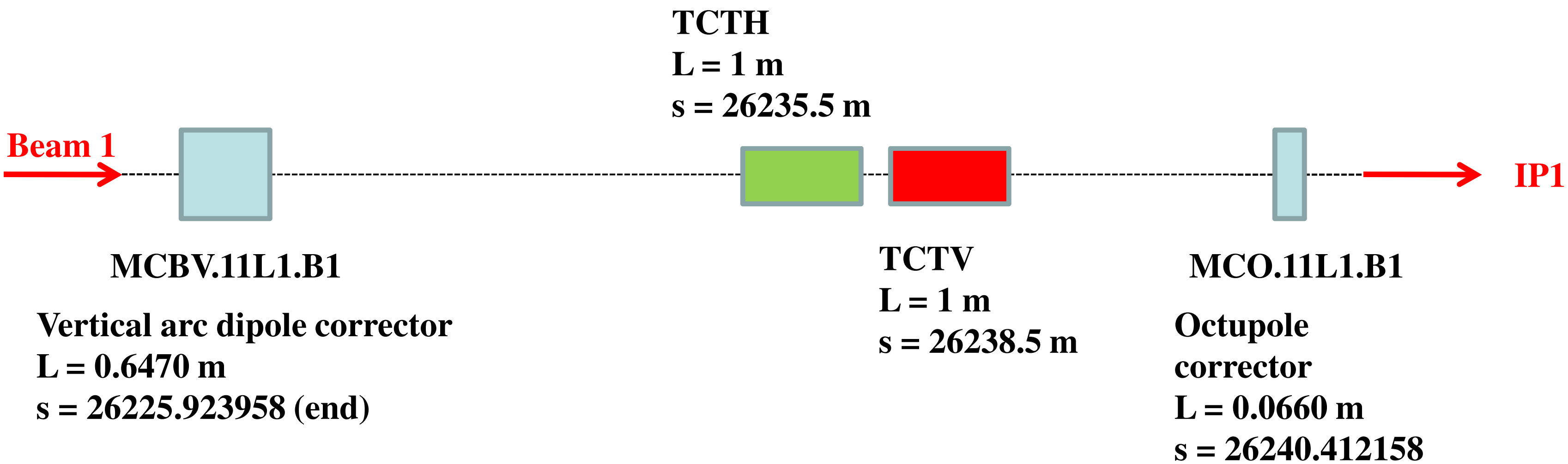


Observations

- Sophisticated corrections for off-momentum beta beat and spurious dispersion (➔ S. Fartoukh) cannot eliminate the extra loss locations but can reduce loss magnitudes by factor 2-3.
- These corrections are feasible and part of the phase 1 IR upgrade project.
- We still **request that additional losses are also addressed with additional collimators** (we should not take the risk that the triplet upgrade fails).
- Again, it is noted that direct losses from beam-gas scattering are not included and will lead to additional losses at lower aperture points!

Solution: Addition of More Collimators in IR1 and IR5

First guess:

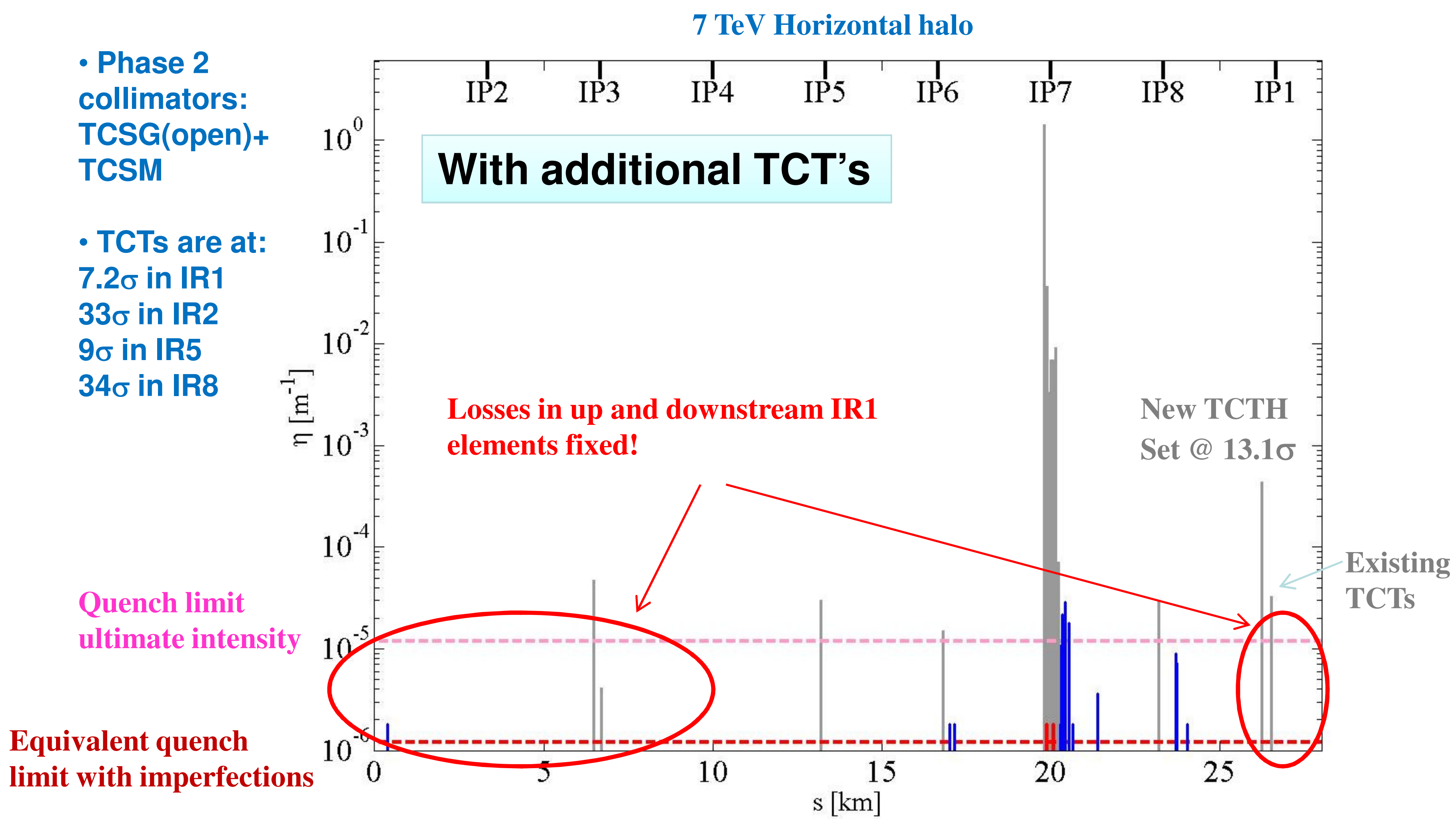


- ➔ Need to add 4 tertiary collimators in IR1 and 4 tertiary collimators in IR5.
- ➔ Must keep existing tertiary collimators with present understanding.
- ➔ Feasibility and detailed integration is part of the phase I IR upgrade project and not of the LHC collimation project.
- ➔ From past experience several iterations will be required between engineering and accelerator physics to specify details.

Phase I Triplet, H halo, 7 TeV

No Correction Off-Momentum β-beat & Dispersion

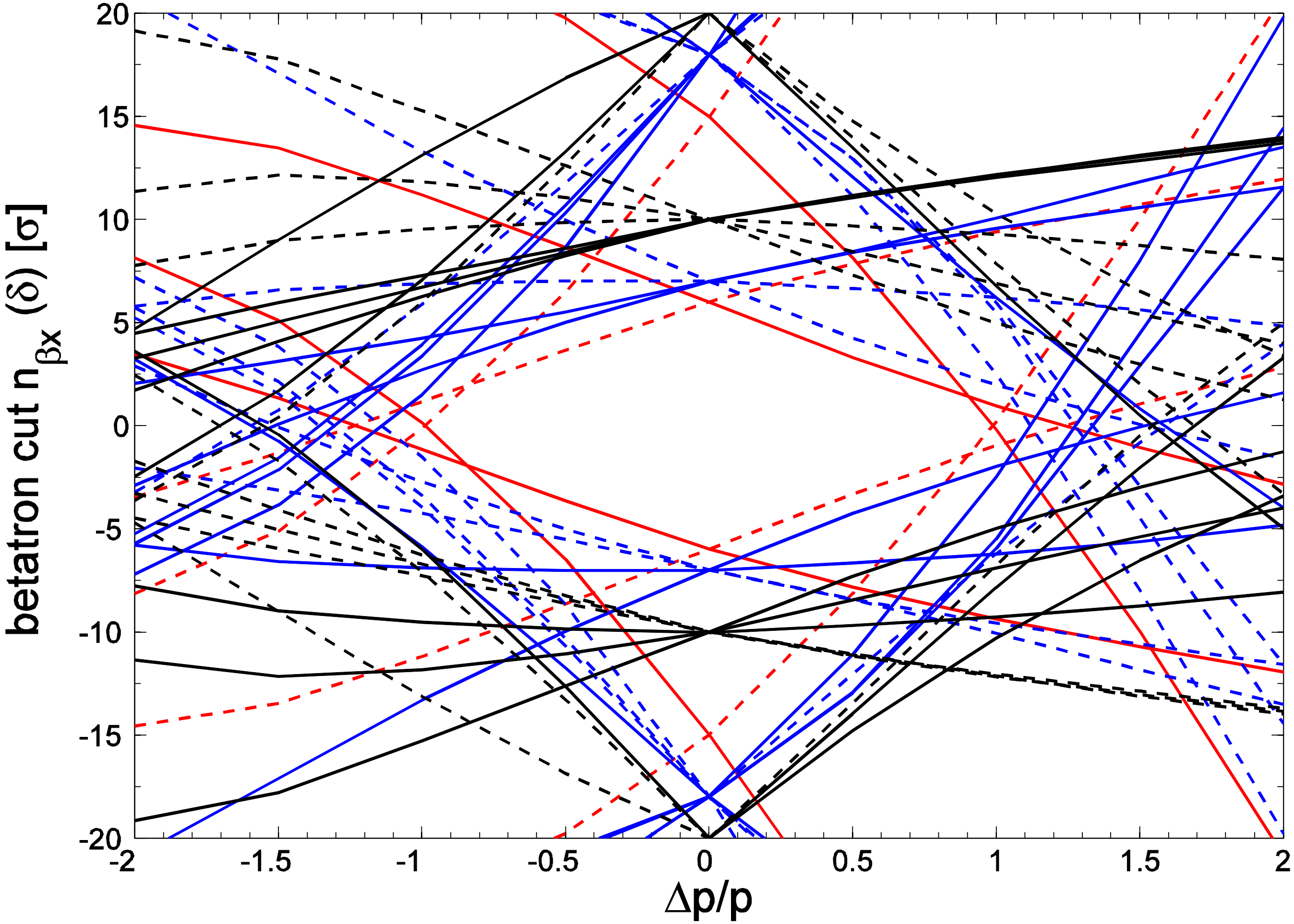
- Phase 2 collimators: TCSG(open)+ TCSM
- TCTs are at:
  7.2σ in IR1
  33σ in IR2
  9σ in IR5
  34σ in IR8



Collimator Hierarchy

- Collimators must **respect a very strict setting hierarchy**. Not useful to explain here. Just sketching it:
  - Primary collimators (TCP) must always be closest to the beam.
  - Secondary collimators (TCSM) must always be second-closest to the beam.
  - Protection collimators (TCLA) must always be closer to the beam than local magnet or vacuum pipe aperture. They shall, however, never act as primary or secondary collimators.
- Optics perturbations can lead to violations of this hierarchy. In particular beta beat is dangerous (changes of machine beta functions).
- The upgrade optics faces a special problem: **off-momentum beta-beat** ➔ head and tail of beam can be collimated at different places from the core!
- This is due to stronger focusing with phase I triplets, compared to present optics.

Phase Space Cut, 7 TeV, No Corrections, Separation ON



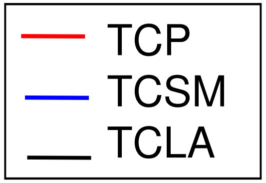
Seems OK, even without correction!

Still, we fully support to correct this!

Curved lines indicate effect of off-momentum changes.

However, hierarchy respected.

Must check beam2!



Conclusion I

- The phase I of LHC collimation has been completed and is being put into full operation. Should allow to reach 10-20 times Tevatron performance (measured in stored energy).
- The upgrade program for LHC collimation ("phase II") has been defined and reviewed. A path to gain another factor 15-90 in efficiency has been identified. Work proceeding well supported but at limits of manpower.
- An extraordinary effort was spent to achieve first assessment of the phase I triplet upgrade for collimation. Limited due to lack of manpower: only beam 1, only betatron halo, no realistic imperfections, only partial inclusion of the collimation upgrade, no beam-gas, …
- We find: **Triplet upgrade optics has reduced aperture upstream of IP. TAN aperture must be fixed with new hardware.** MANDATORY!
- **Additional and higher losses seen as expected in regions of reduced aperture upstream of the TAN.** Unacceptable (factor ~20 too high)…

Conclusion II

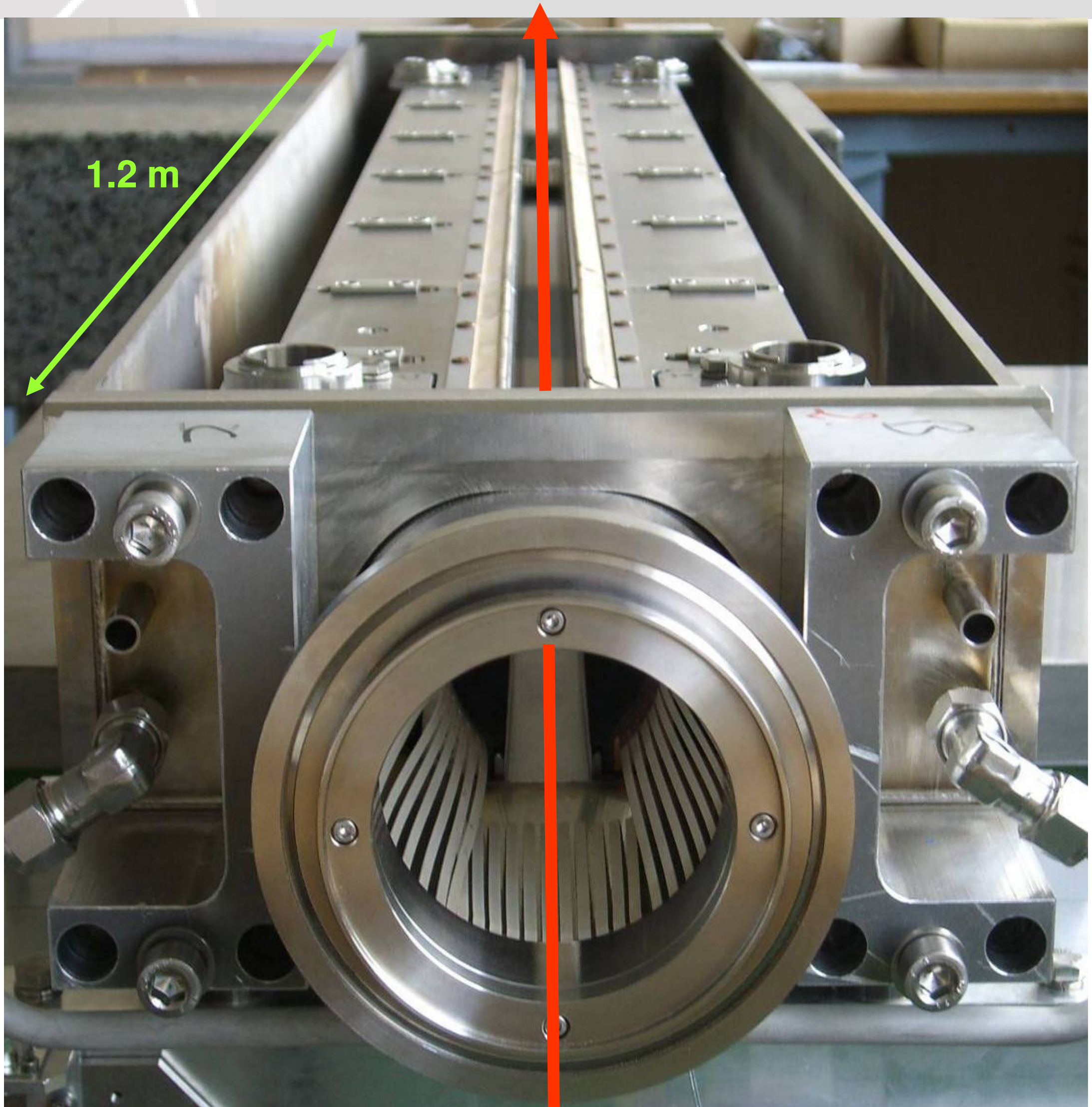
- Very sophisticated chromatic and dispersion corrections (➔ S. Fartoukh) cannot eliminate additional loss locations but can reduce loss magnitude by factor 2-3. Feasibility of these corrections shown (➔ R. Ostojic).
- It is **required to add 4 tertiary collimators to both IR1 and IR5 to eliminate the add. loss locations.** MANDATORY! Existing TCT's must stay!
- Further iterations required to arrive at real solution ➔ done as part of the phase I triplet upgrade project (R. Ostojic).
- Uncertainties due to limited scope of studies. E.g. the intensity goal for phase I IR upgrade requires installation of phase II collimation, including collimators in cryogenic regions. Maybe this solves IR1 and IR5 losses. Must stay conservative for the moment.
- **Presently cannot conclude that the phase I triplet upgrade is safe for collimation aspects.** Depends on outcome of detailed integration studies. Once a technical layout is worked out, losses can be estimated in more details and input maps to background studies can be provided.

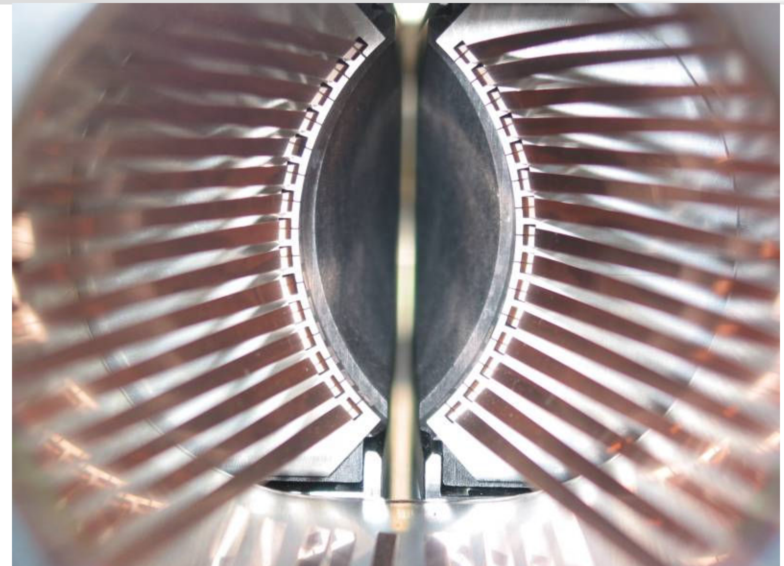
Final Remarks

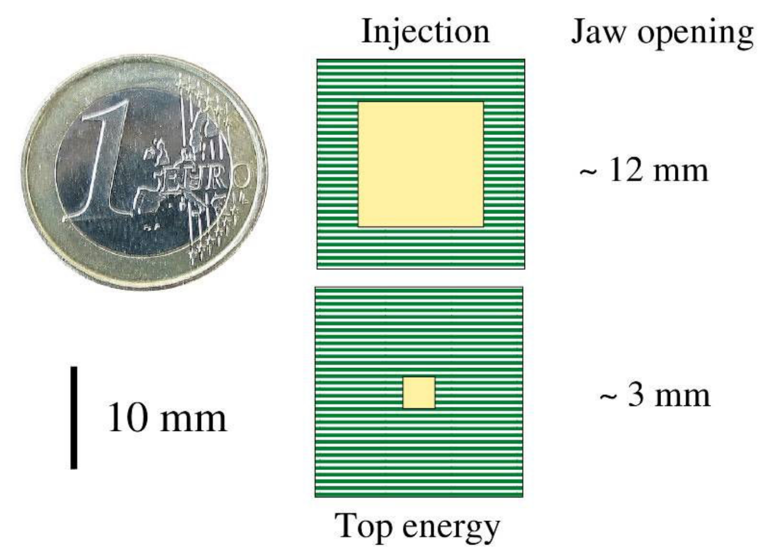
- All recent upgrades for proton colliders (HERA and TEVATRON) were hit by loss and background problems, partly severe. We know this!
- We must realize: **The LHC phase I triplet upgrade is also challenging!** Some of the challenges relevant for collimation (there are others):
  - The upgrade reduces the aperture in parts of the experimental IR's by up to 5.5 σ, outside of the shadow from the arcs!
  - Chromatic beta beat and spurious dispersion are stronger and more disturbing with the stronger focusing in the IR's.
  - The "phase I triplet" performance assumes that the beam intensity after the upgrade is 60% higher than before (ultimate beam intensity).
  - Beam position and optics drifts can be stronger with stronger IR quads.
- Limited first collimation studies have shown some consequences of this: additional and higher losses even for the perfect machine!
- **We must work out adequate solutions!**

Additional Slides

The Phase I Collimator

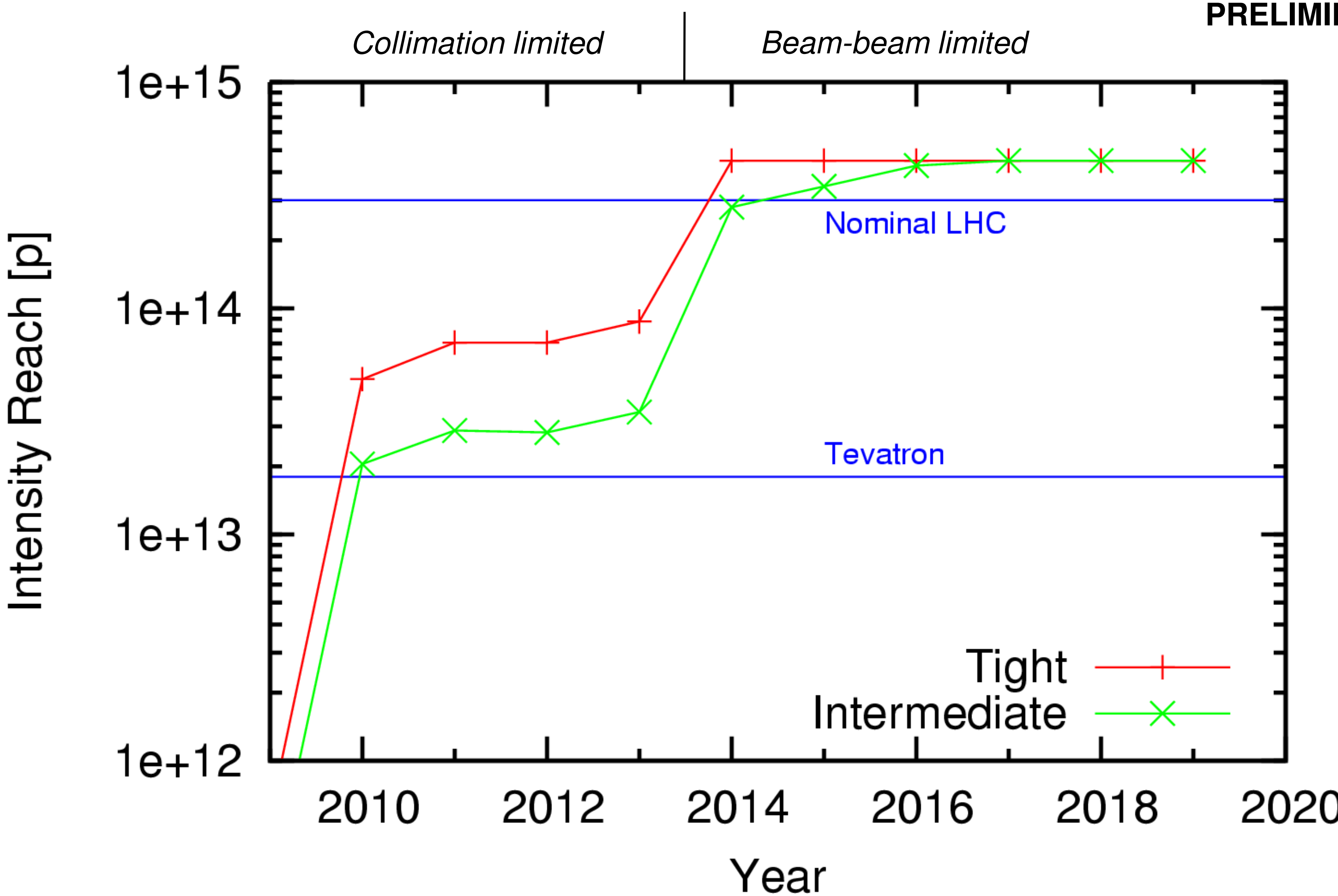






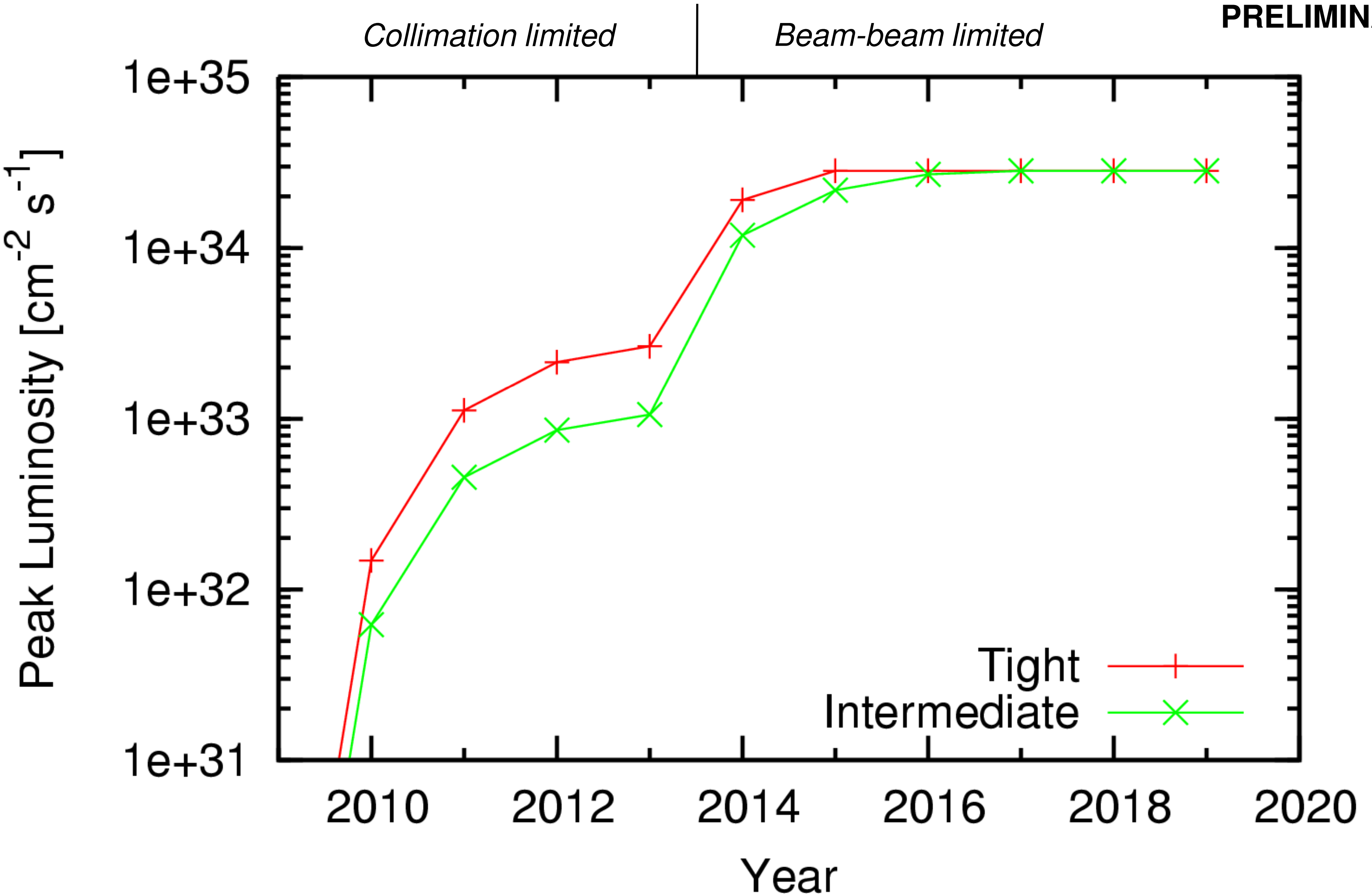
Result: Intensity versus Time (Scenario 1)

PRELIMINARY

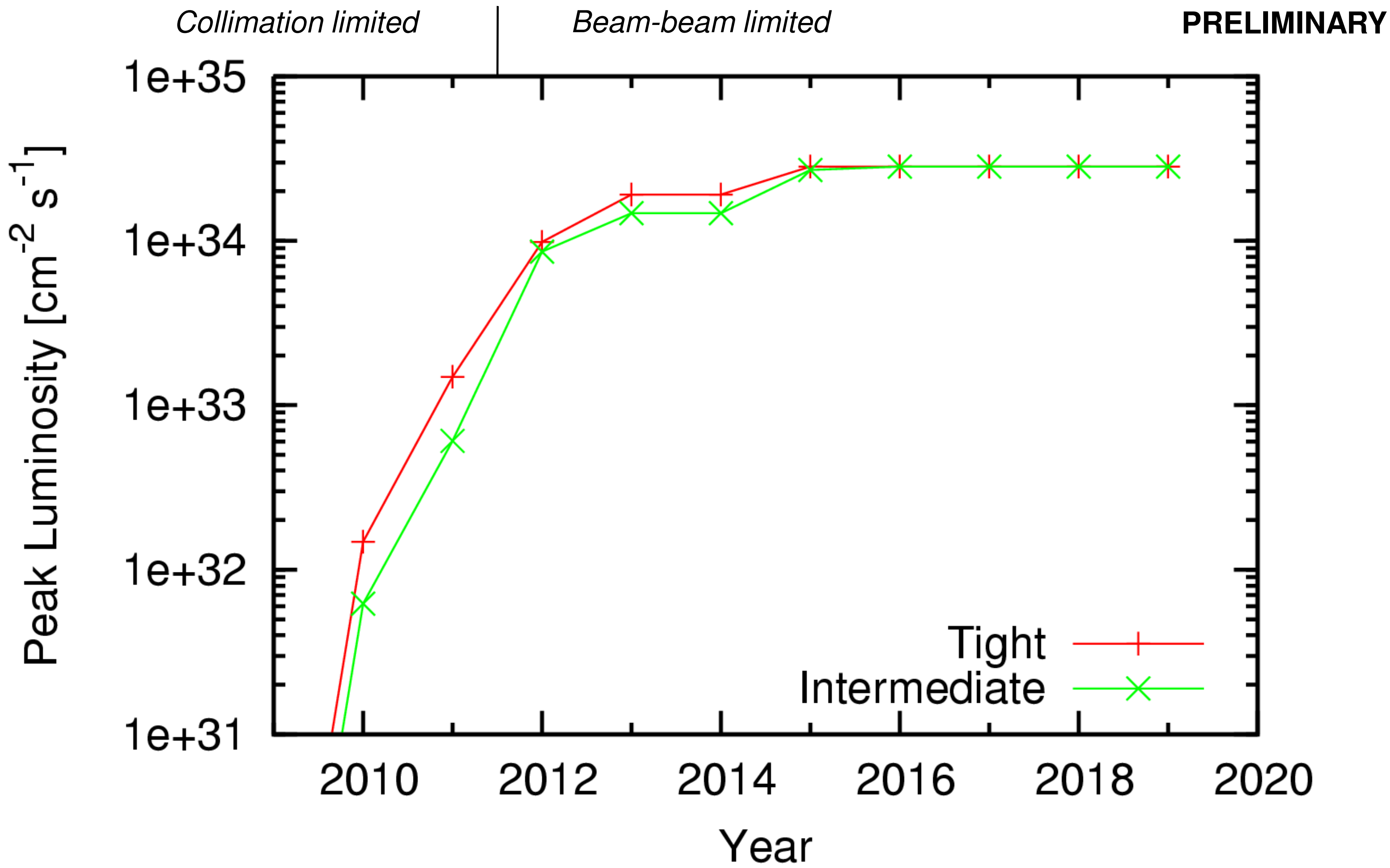


Result: Peak Luminosity versus Time (Scenario 1)

PRELIMINARY



Result: Peak Luminosity versus Time (Scenario 2)



Collimation Wish Schedule (Scenario 2)

(ambitious and result-oriented "wish" schedule)

Year	Milestone
2009	Conceptual solution presented. Start/continuation of serious technical design work on all work packages (delays will shift all future milestones).
2010	Review of lessons with LHC beam. Technical design review.
2011	HiRadMat test facility completed and operational.
2012	Cryogenic collimation installed and operational ➔ nominal intensity in reach. Production decision for phase II secondary collimators.
2013	Hollow e-beam lens operational for LHC scraping.
2014	Phase II completed with installation of advanced secondary collimators ➔ Ready for nominal & ultimate intensities.