Abrupt Crab-Cavity Failures, LHC

R. Calaga, T. Baer, J. Barranco, R. Tomas, J. Wenninger,
B. Yee, F. Zimmermann, PAC11, Mar 28, 2011

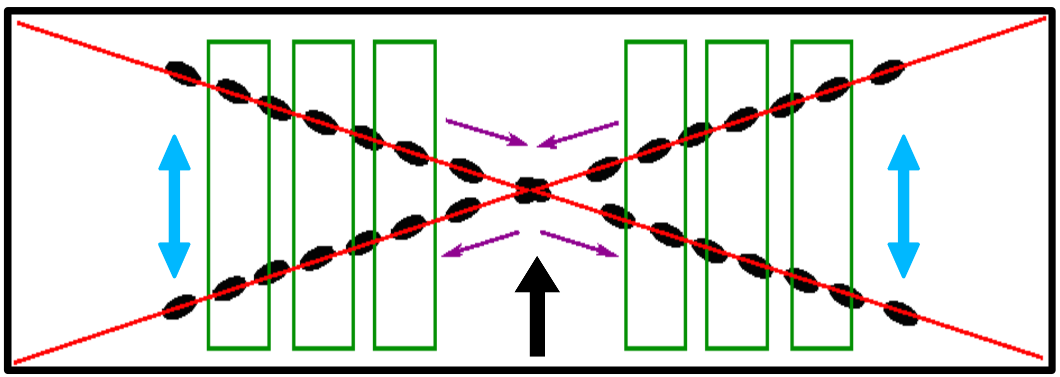
- Crab crossing for LHC upgrade
- Cavity failure(s) at KEKB
- Simulations for the nominal LHC
- Future studies

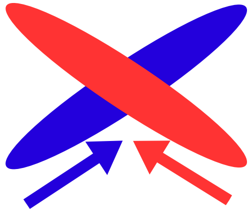
LHC Upgrade

- Peak luminosity of 5×10^{34} (leveled)
  - Interaction region upgrade (upto $\beta^*=15$cm) → High gradient triplets
  - Piwinski angle compensation → crab crossing

- Integrated luminosity of 250 fb^{-1}/yr → 3000 fb^{-1} in 12 yrs (circa 2030)
  - Lumi-Leveling (reduce Pile-up, radiation damage) → crab cavities, natural

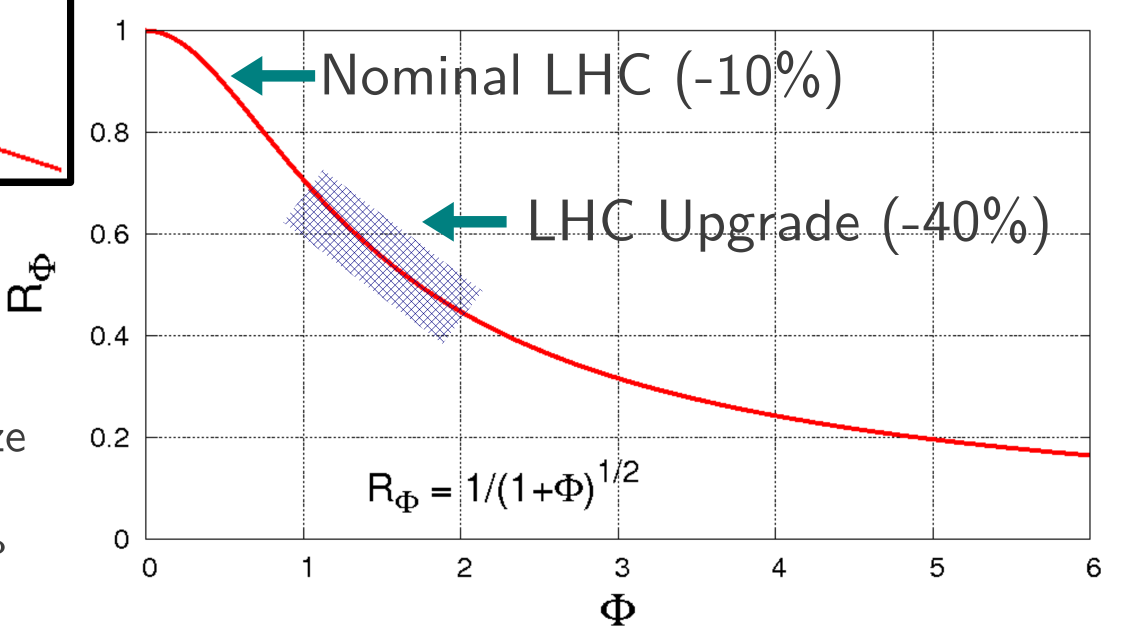
32 LR Beam-Beam per IP
(~10σ Nominal Sep)





Eff. beam size

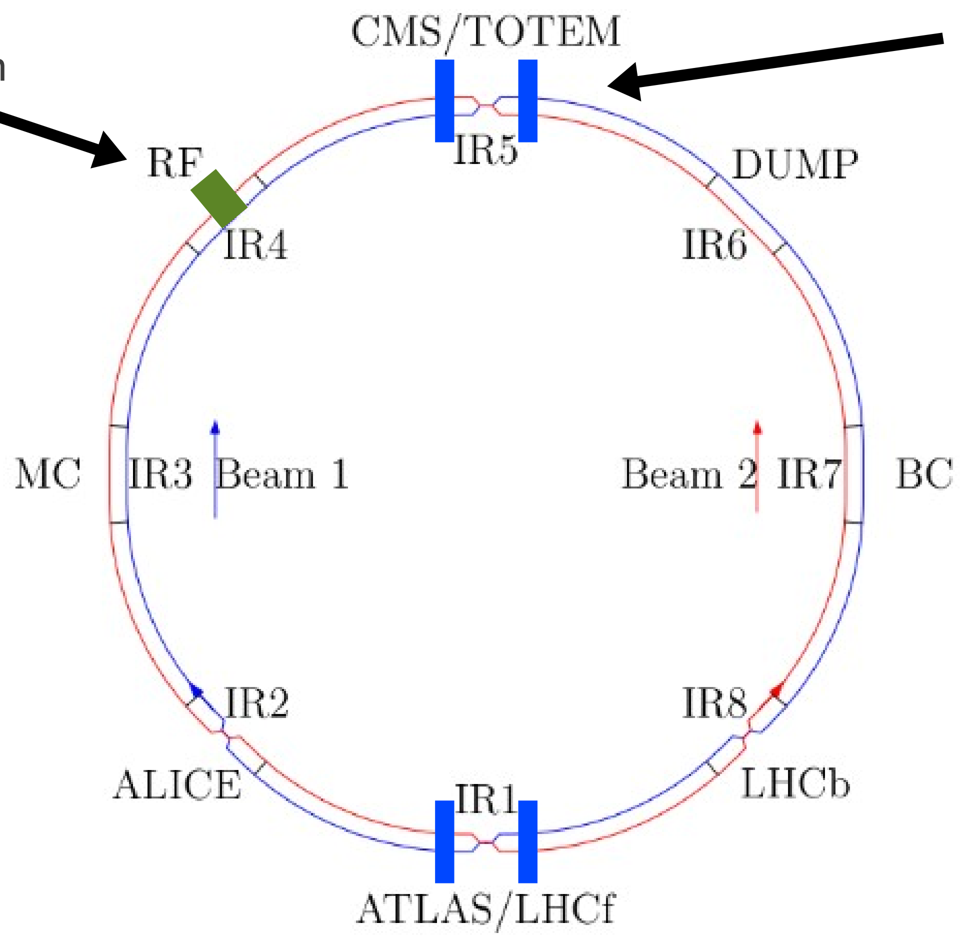
$\sigma \rightarrow \sigma/R_\Phi$



Possible Schemes

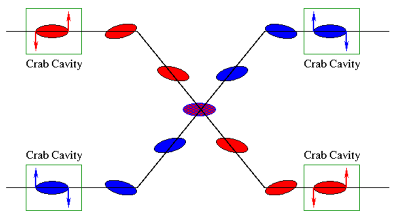
Single module per beam
@IR4, Global Scheme

(already has a dog-leg)



BASELINE

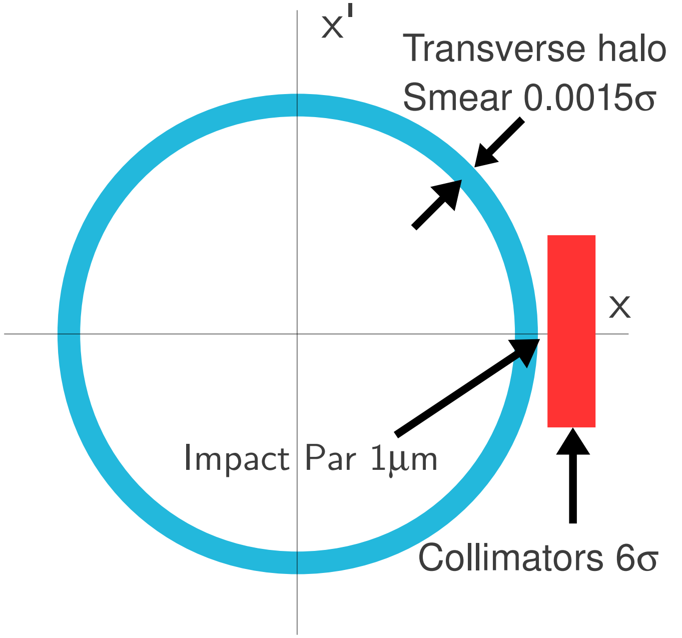
4 modules per beam
@IR5 & IR1, Local Scheme



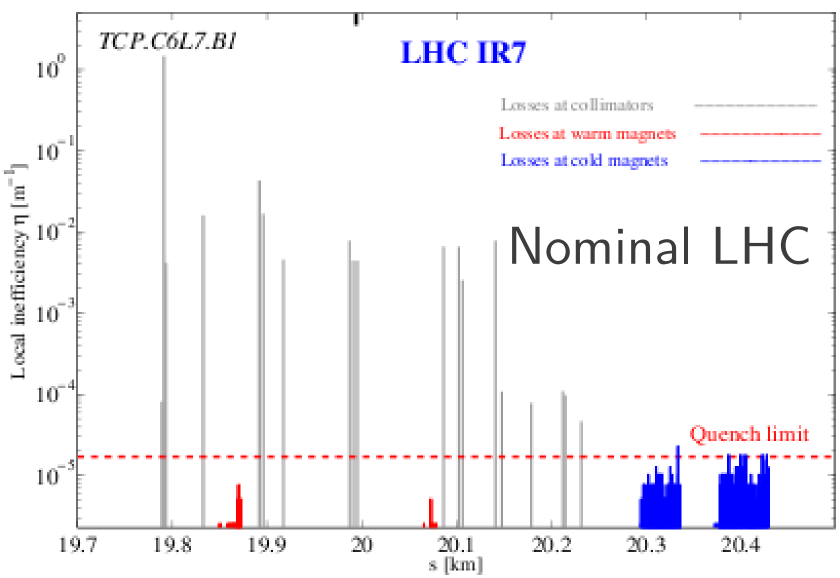
** For this study ONLY nominal LHC optics is considered

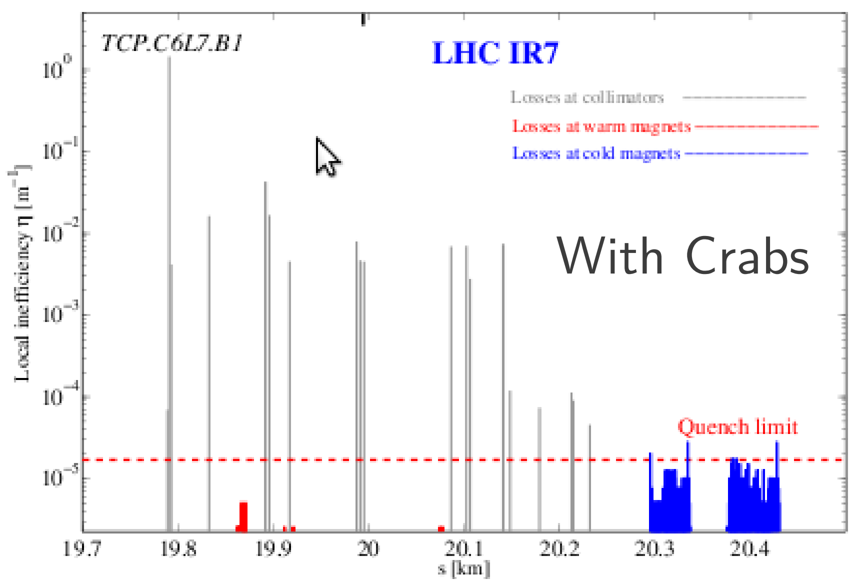
Global Scheme, Steady State

- Loss maps with crabs similar to w/o crabs
  - Additional 0.5σ aperture
  - Hierarchy preserved (primary, secondary, tertiary)
- Maximum DA decrease ~ 1σ (13σ nominal)
  - Suppression of synchro-betatron resonances



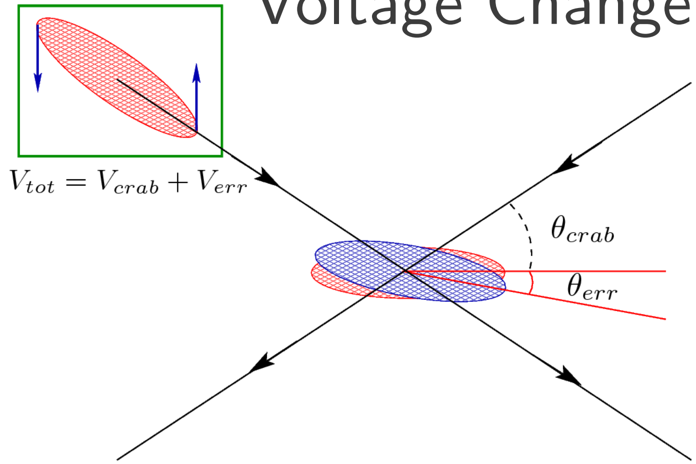
Y. Sun et al. PRST-AB 12, 101002 (2009)





Cavity Failures

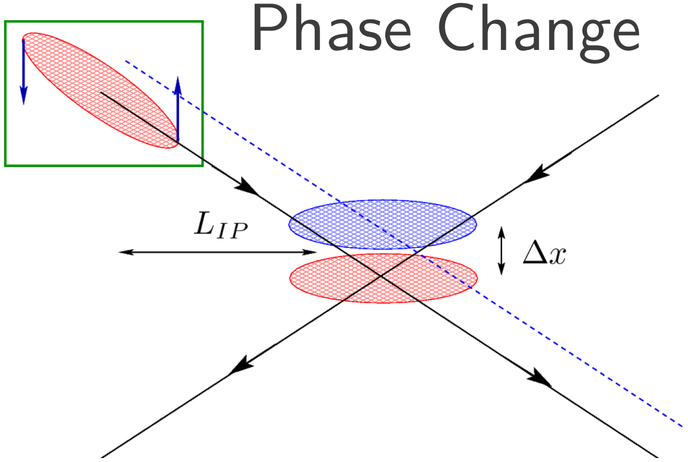
Voltage Change



Change in crossing angle

Over -or- under compensation

Phase Change

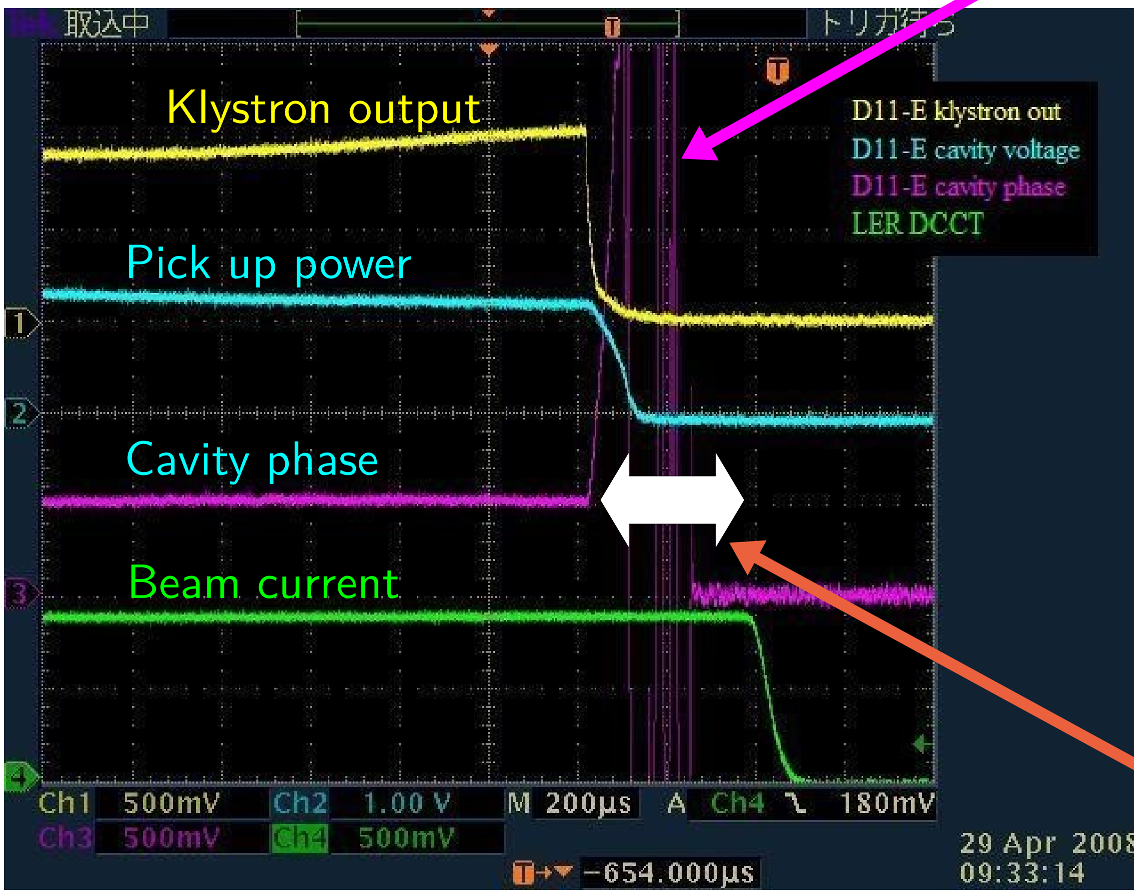


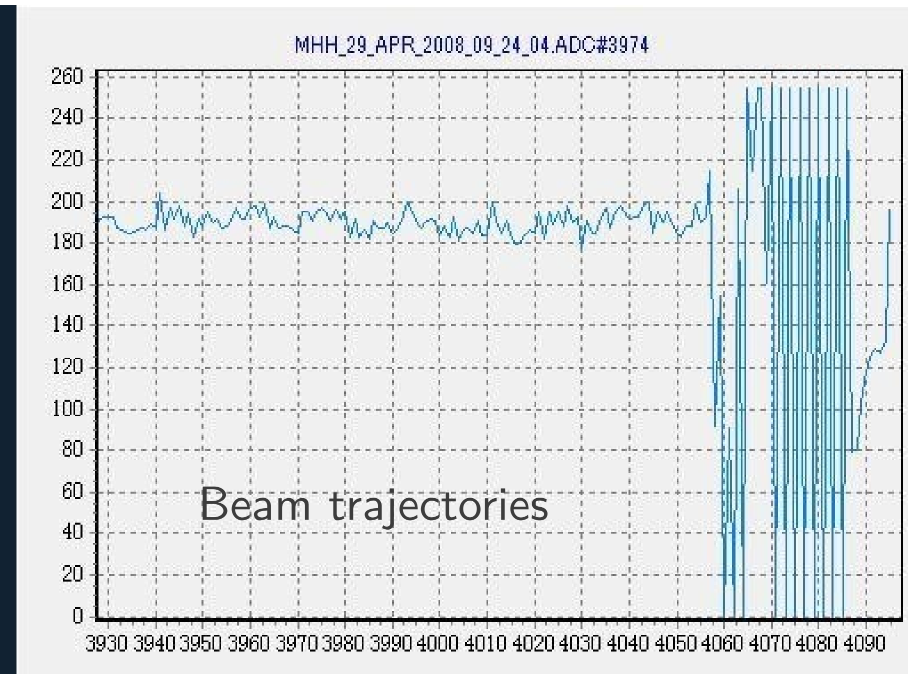
Offset at the collision point

Change in closed orbit

When Cavity Behaves Badly (KEKB)

Potentially from a cavity quench
(N. Kota, IPAC10)





~50 deg in 50 µs (1/2 LHC turn)

Abrupt phase changes → corresponding orbit changes and beam losses

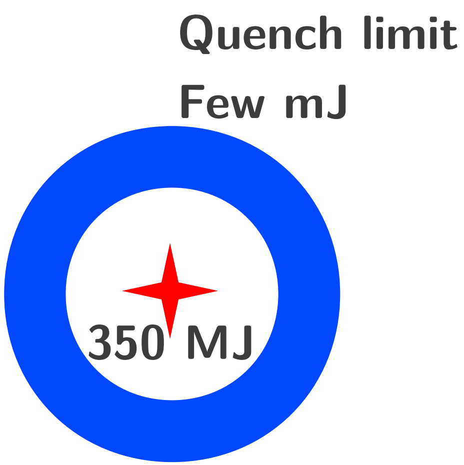
Beam abort is triggered & beam dumped

Machine Protection, 350 MJ !!

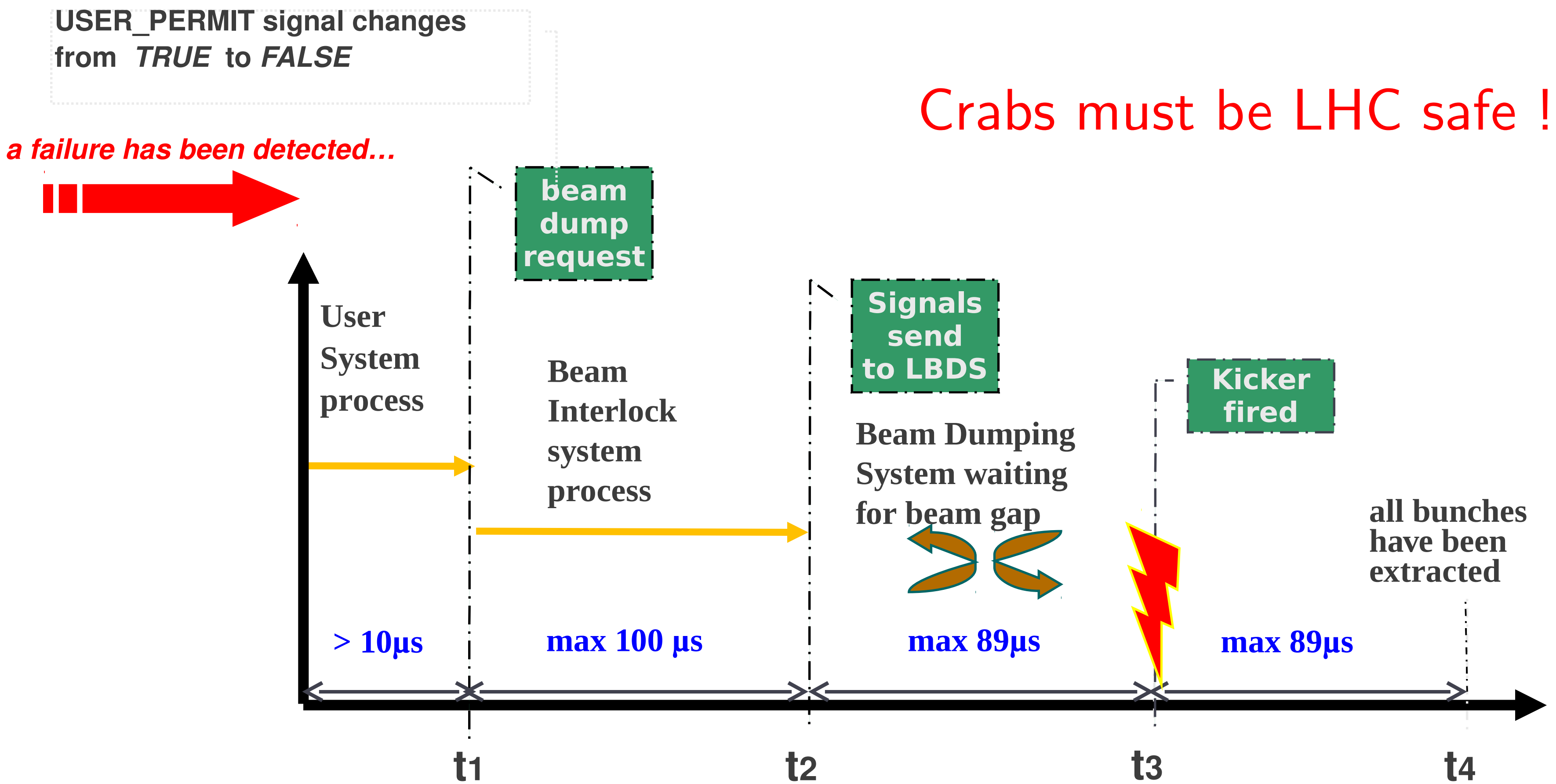
100's of interlock systems → complex

Best/worst case scenario:

Detection - 40µs (½ turn), response - 3 turns



Crabs must be LHC safe !!



Courtesy J. Wenniger

Potential Failure Scenarios

Fast failures

- Cavity quench or RF breakdown
- Sudden discharge in the cavity or couplers
- Fast orbit change due to external sources

Slow Failures

- Power supply trips (50-300 Hz $>$ 7 ms) $\rightarrow$ greater than 300 turns
- Mechanical changes (100's of ms) $\rightarrow$ high Q SC cavity
- RF arcing (few µs) $\rightarrow$ Response of cavity voltage/phase slower

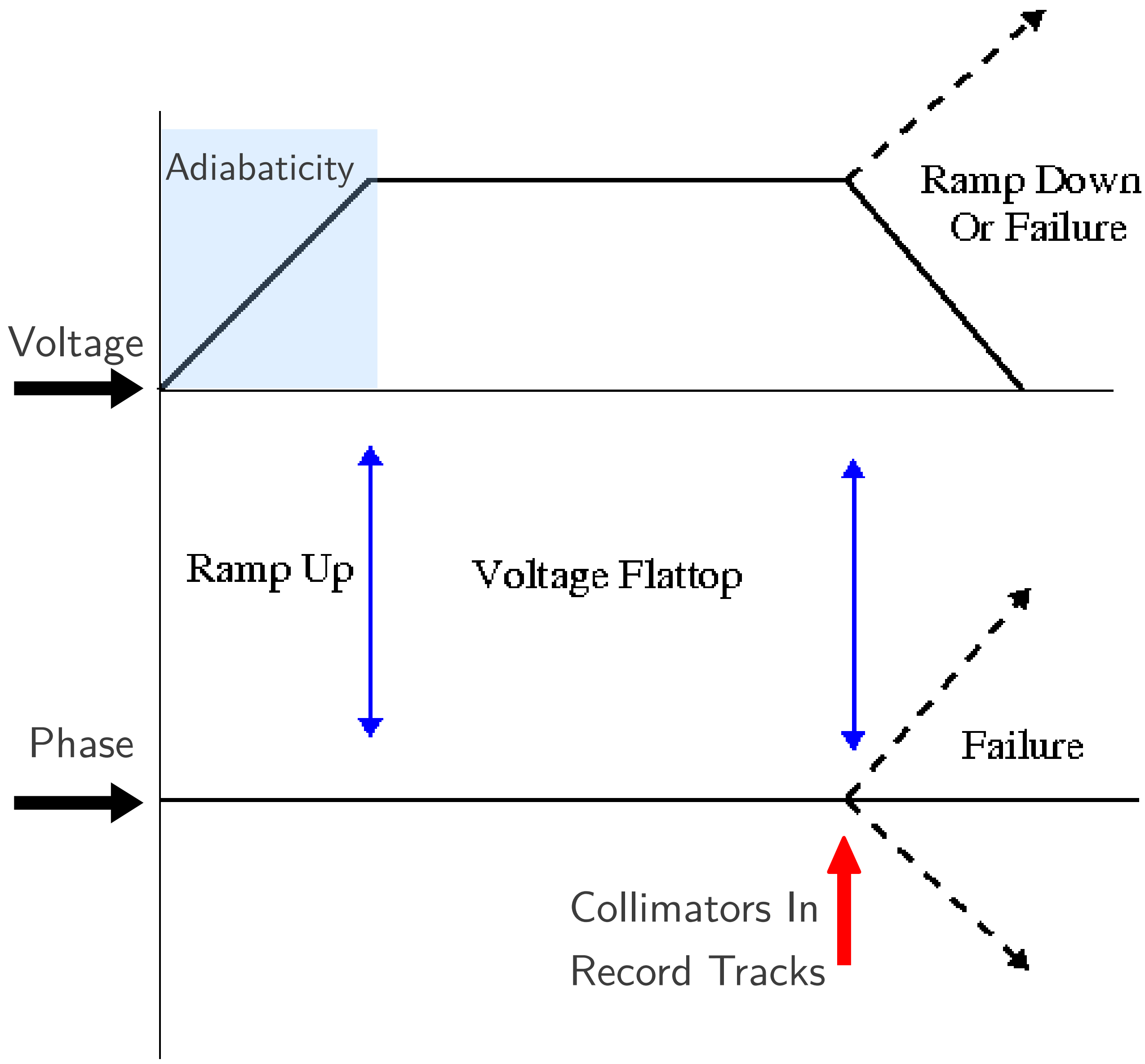
LHC Collimation, maximum allowed losses (R. Assmann, HB2010):

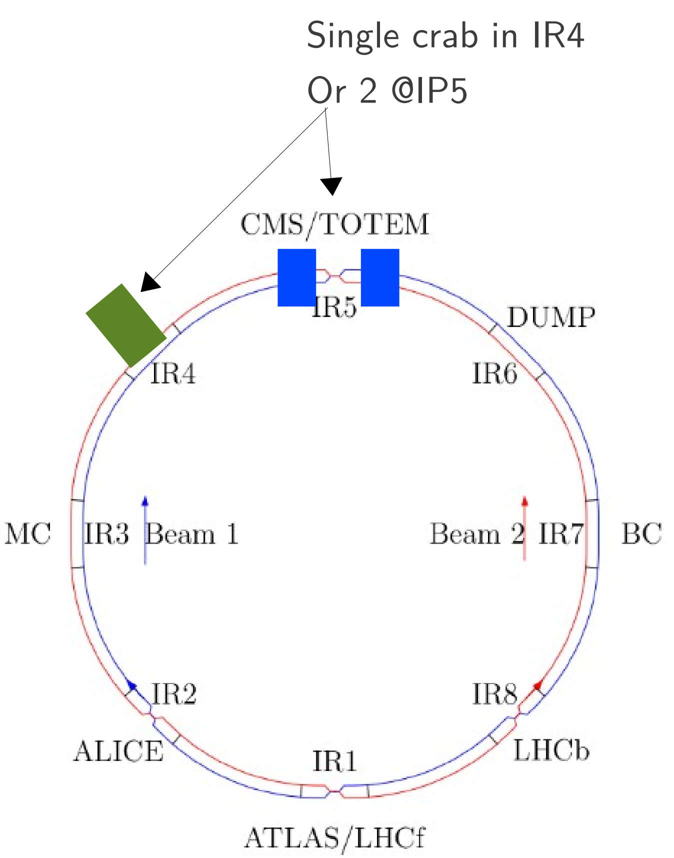
- Slow: 0.1% of beam per second for 10s
- Transient: 5 x 10^{-5} in $\sim$ 1ms
- Fast: Upto 1 MJ in 200ns into $0.2mm^2$

Some info courtesy J. Tuckmantel

Crab-Cavity Failure Setup

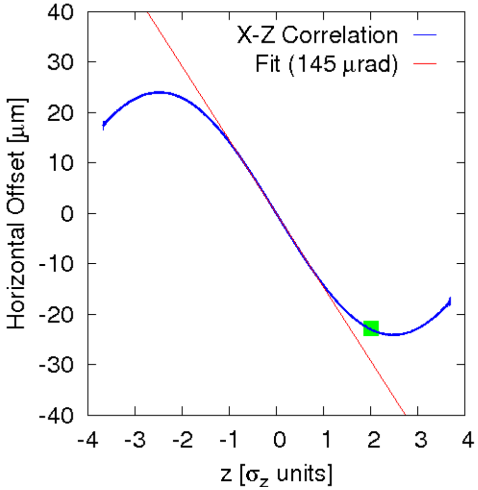
Voltage is kept constant during phase failure and vice-versa

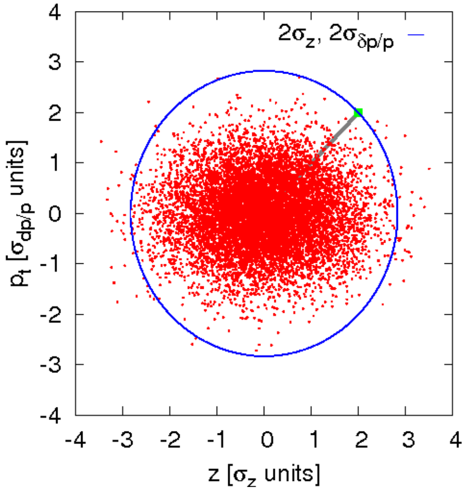




Sixtrack & MADX are now setup for failure scenarios (J. Barranco, R. Calaga, R. Tomas)

Failure, Simulation Setup

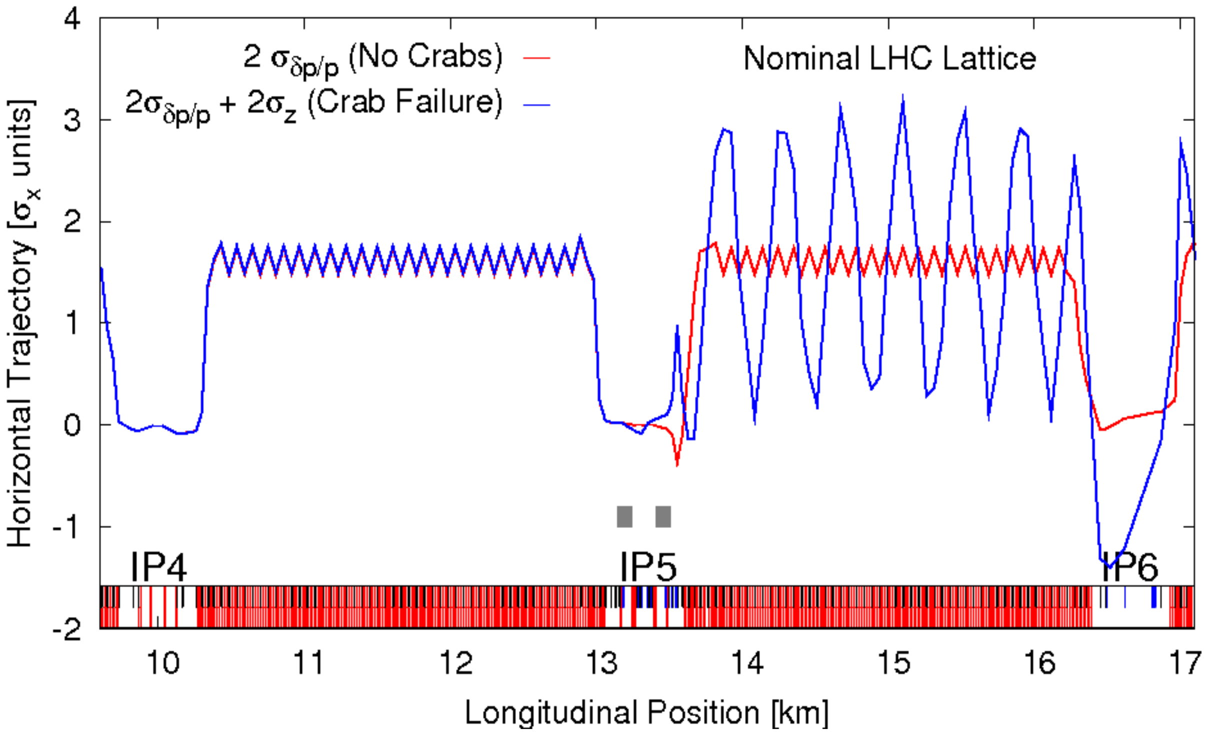




X-Z correlation with crab cavity

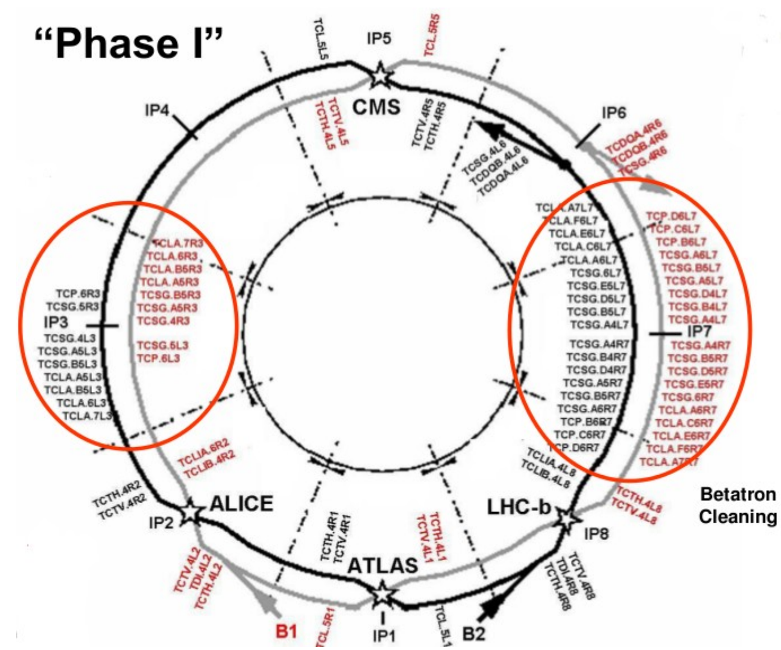
Sample distribution

Particle trajectory of sample particle at $2\sigma_z + 2\sigma_{dp/p}$

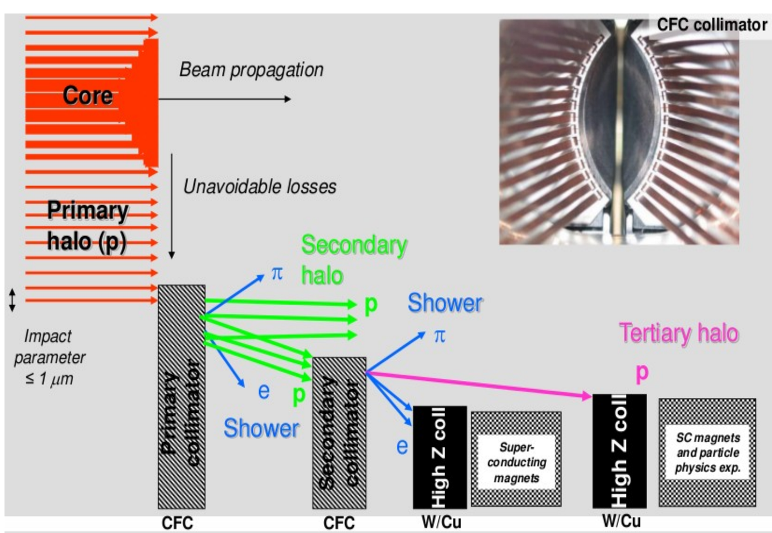


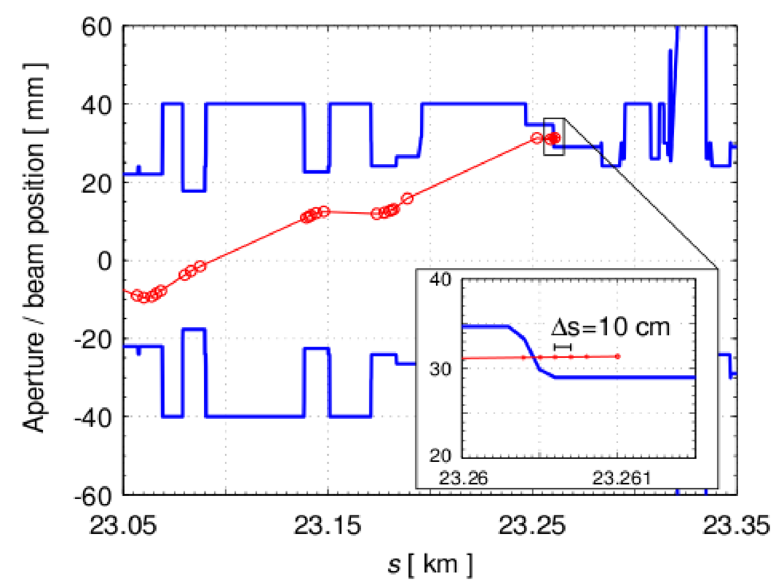
LHC Collimation & Simulations

R. Assmann et al, HB2010



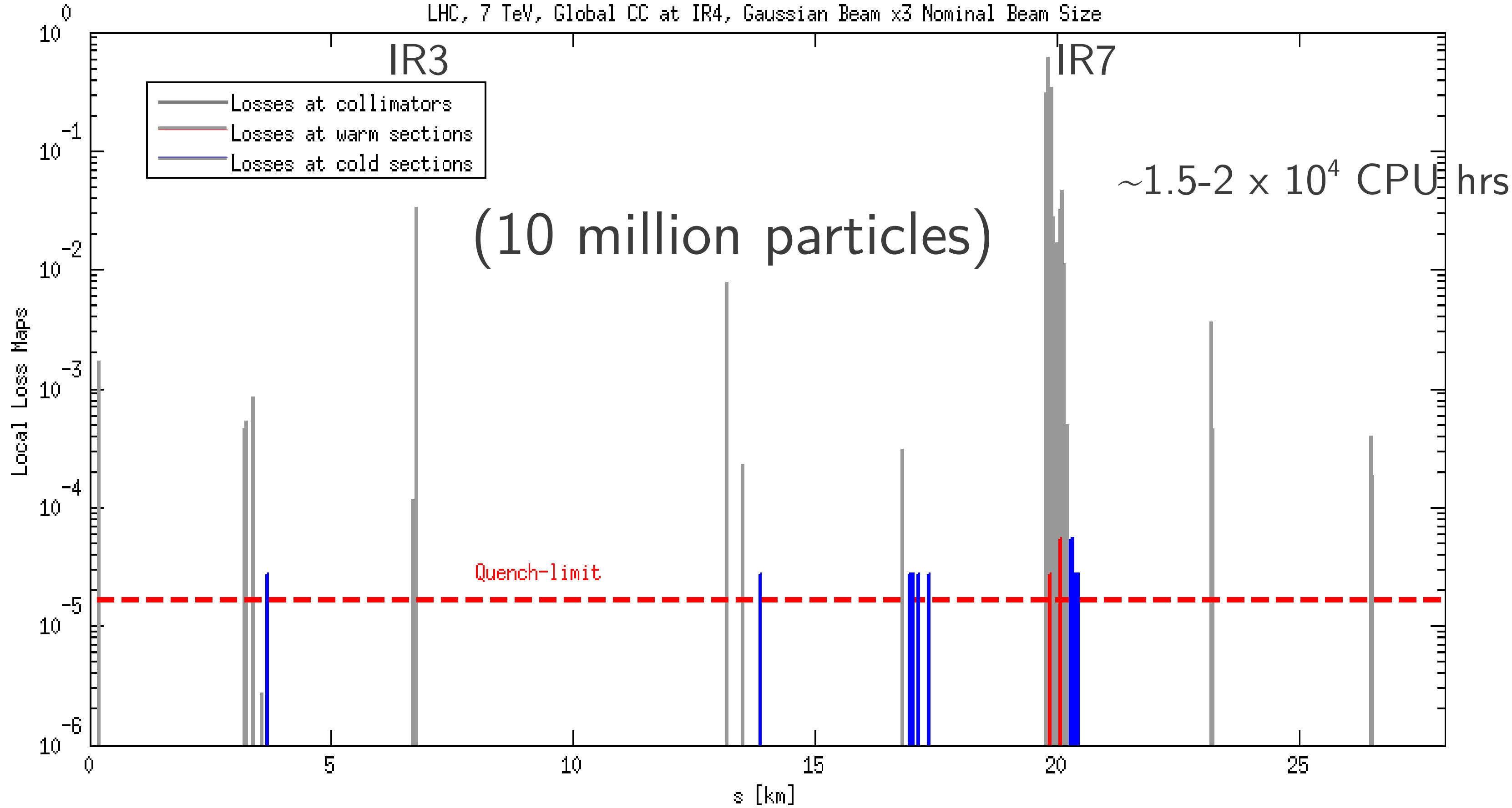
- 108 movable collimators and absorbers in the LHC
  - Nominal gap at 7 TeV, 1mm
  - 99.9% or higher efficiency (hierarchy crucial)
- Simulations
  - All trajectories are recorded after failure
  - Aperture model applied to within 10cm resolution





G. Robert-Demolaize et al..

Example Loss Map (Pessimistic Case)

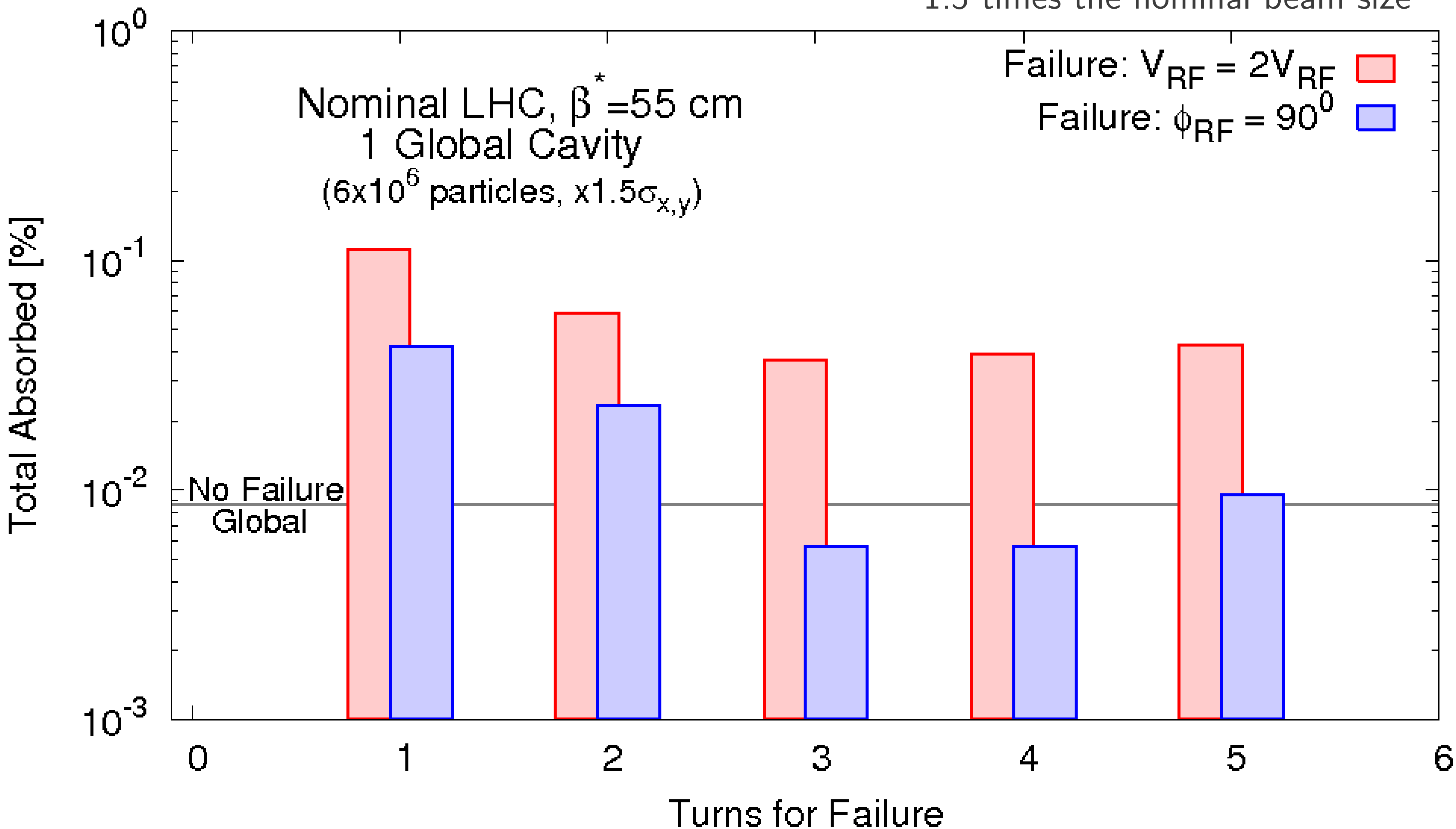


- Beam size is 3-times nominal beam (overpopulated tails)
- A failure of 3-turns induced where phase shift 90 degree occurs
- 4% of total particles absorbed in the collimators

% Absorbed Due To Failure

Main losses are in the collimators in IR7, IR3 and the TCTs

1.5 times the nominal beam size

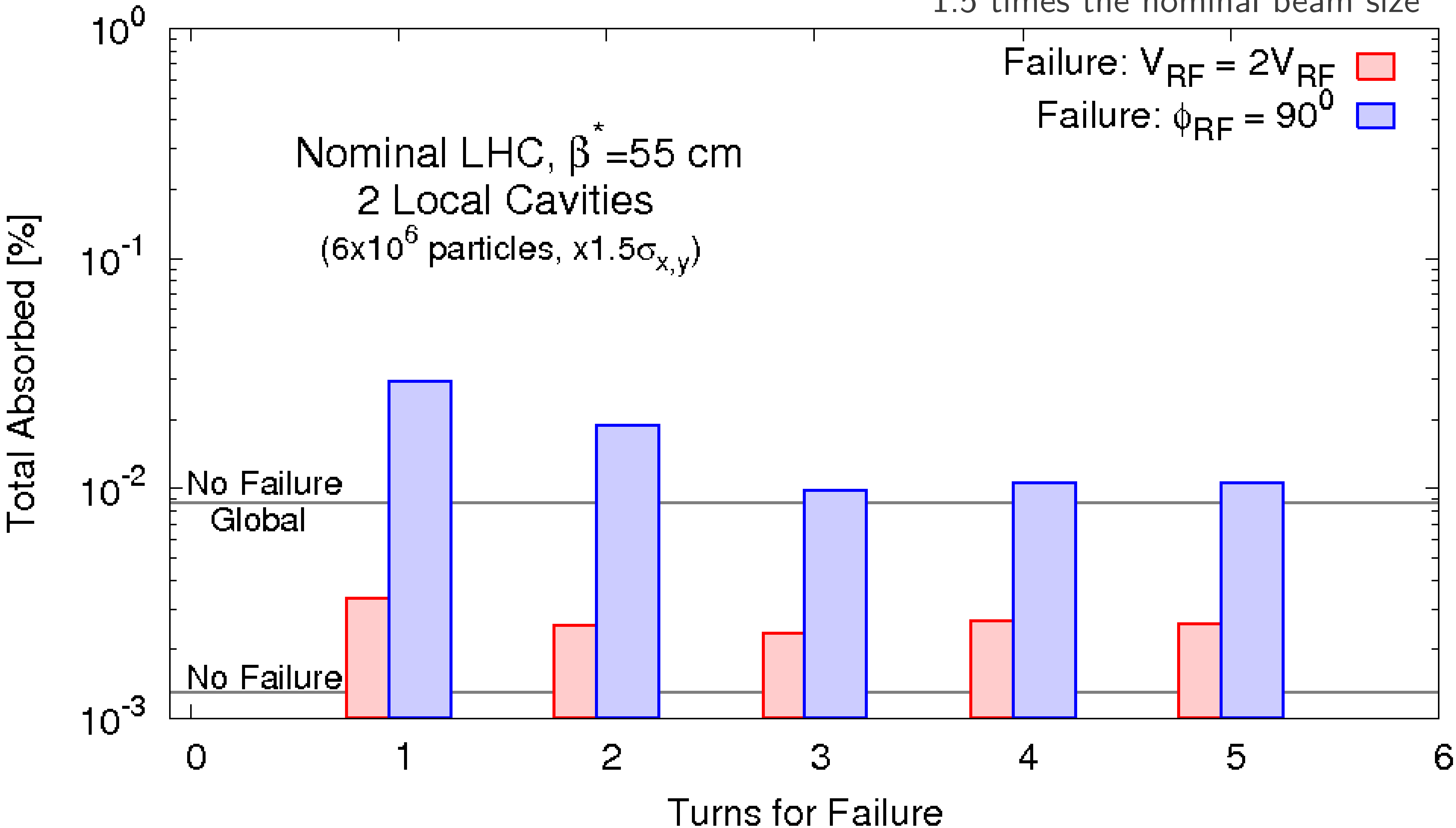


% Absorbed Due To Failure

Local Scheme

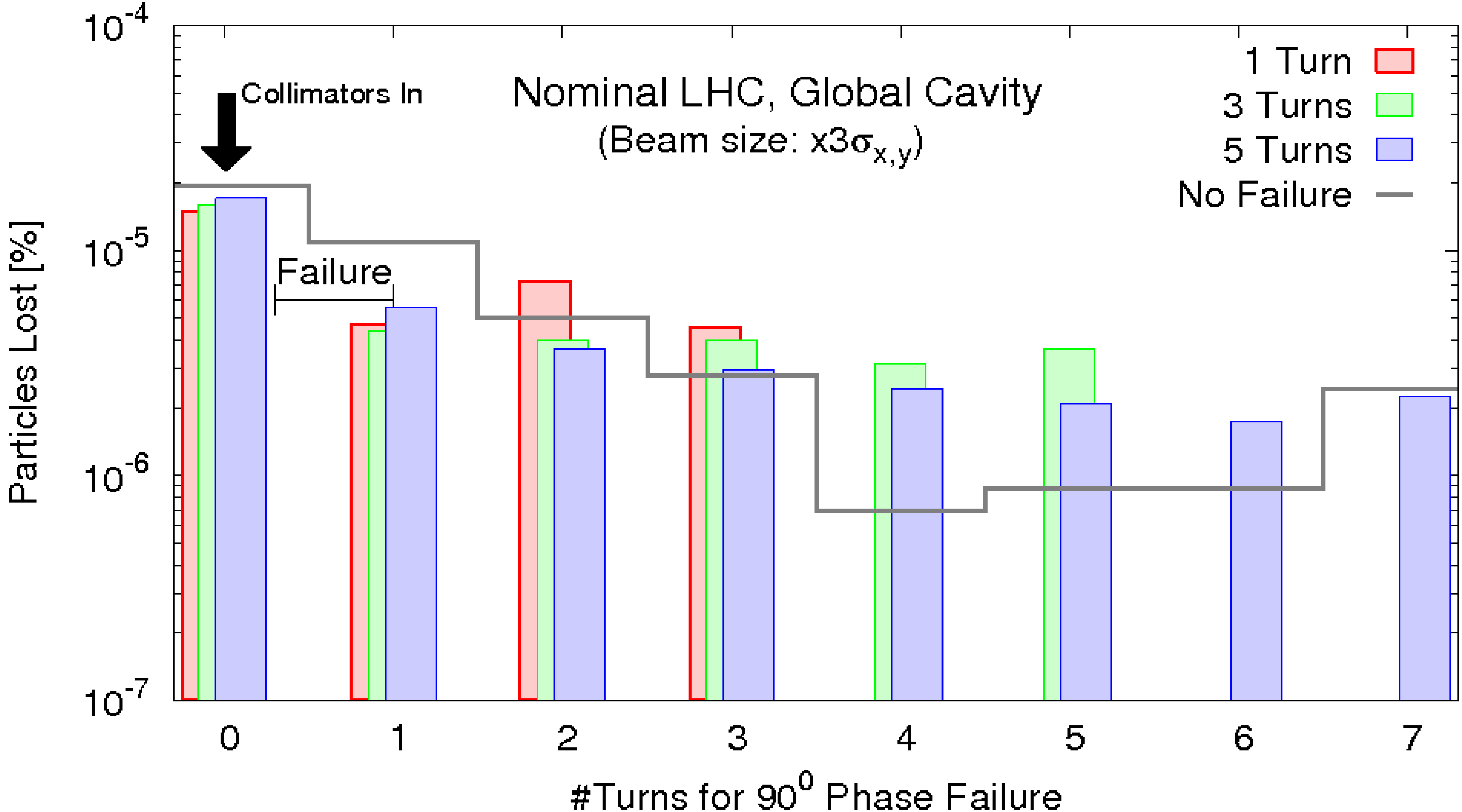
Main losses are in the collimators, losses different & smaller than global

1.5 times the nominal beam size



% Lost Due To 90^0 ϕ–Failure

Global Scheme

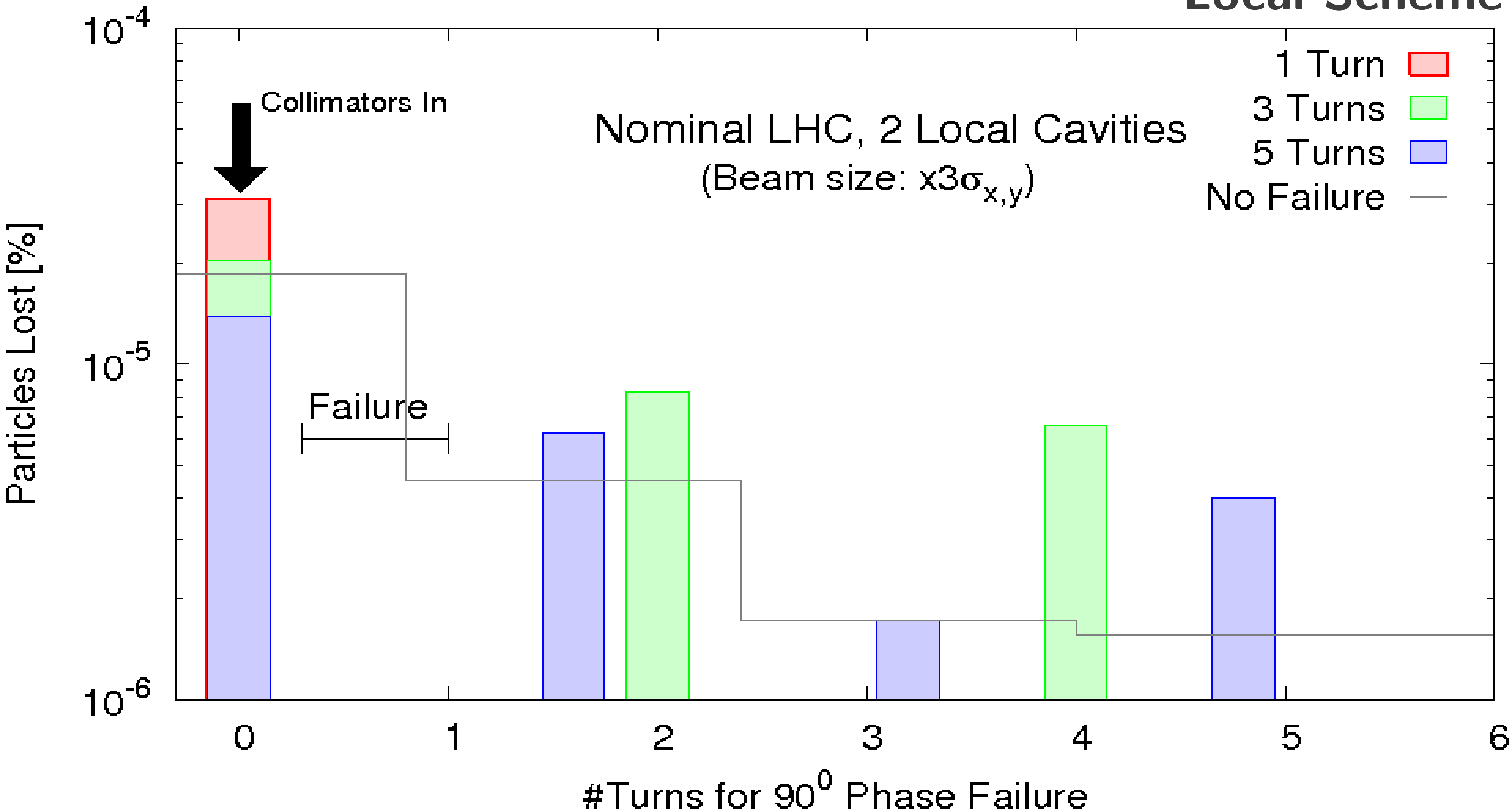


Artificially large beam $\rightarrow$ to study the losses as a function of turn

No particles lost for x1.5 the beam size (voltage or phase failure)

% Lost Due To 90^0 ϕ–Failure

Local Scheme



Artificially large beam $\rightarrow$ to enhance losses

No particles lost for x1.5 the beam size (voltage or phase failure)

Conclusions

Crab crossing established as a key ingredient for HL-HLC

However, crab cavity failures should be in the shadow Machine Protection

- Prevent fast failures from the design stage (perhaps difficult)
- Fast RF/beam interlocks for safe extraction

<u>Presented</u>: Nominal LHC (β^*=55cm, ϕ=0.3mrad)

- Voltage & phase failures have different loss signatures
- Nominal beam parameters lack statistics for conclusive tolerances
- Losses for grossly large beams are within quench limits

<u>Future</u>: HL-LHC Upgrade ($\beta^*\sim$15cm, $\phi\geq$0.6mrad)

- Losses may become important, first optics only recently available
- Upgraded collimation system needs be defined for simulations
- Multi-cavity module to help reduce the risk