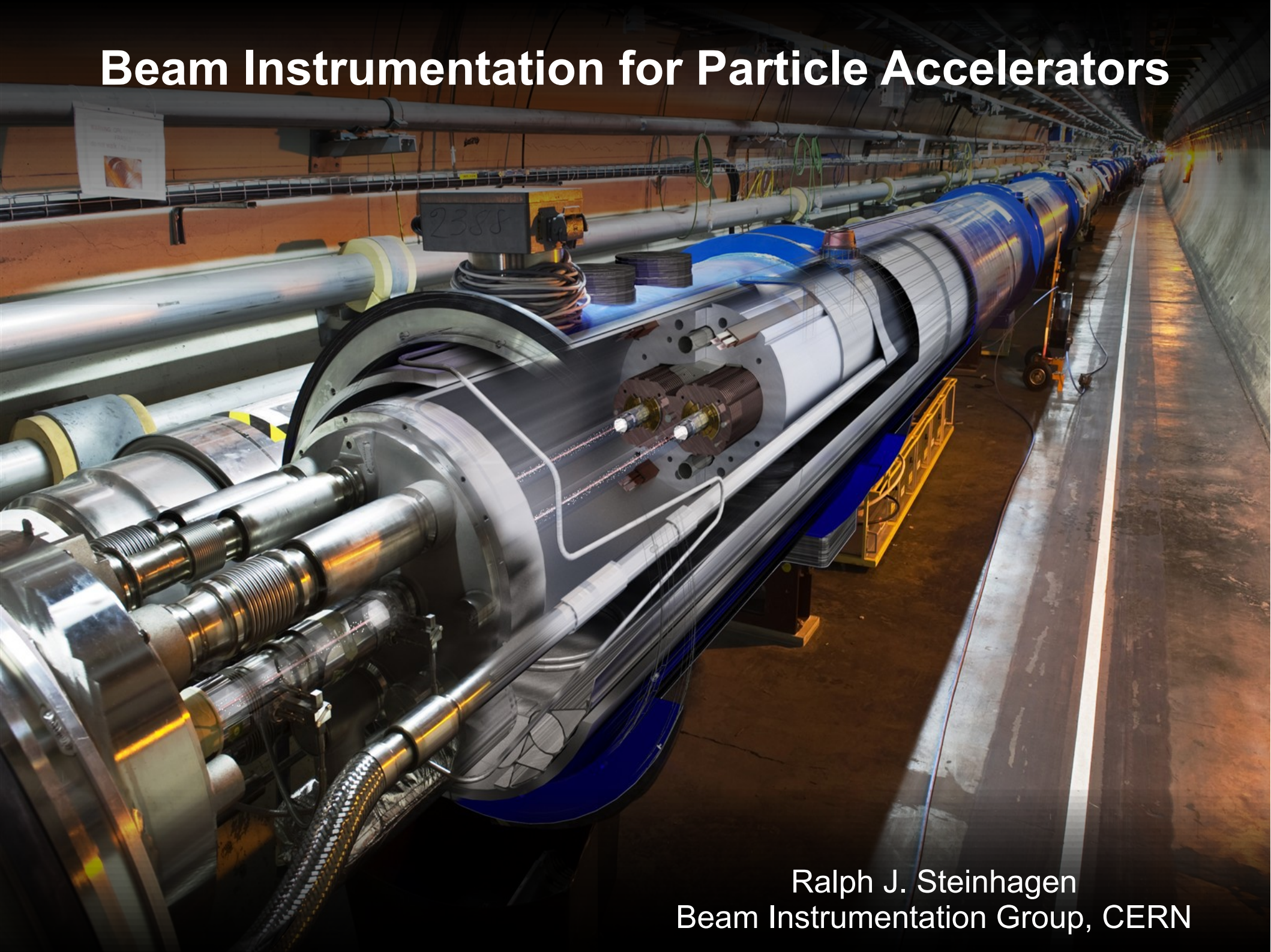
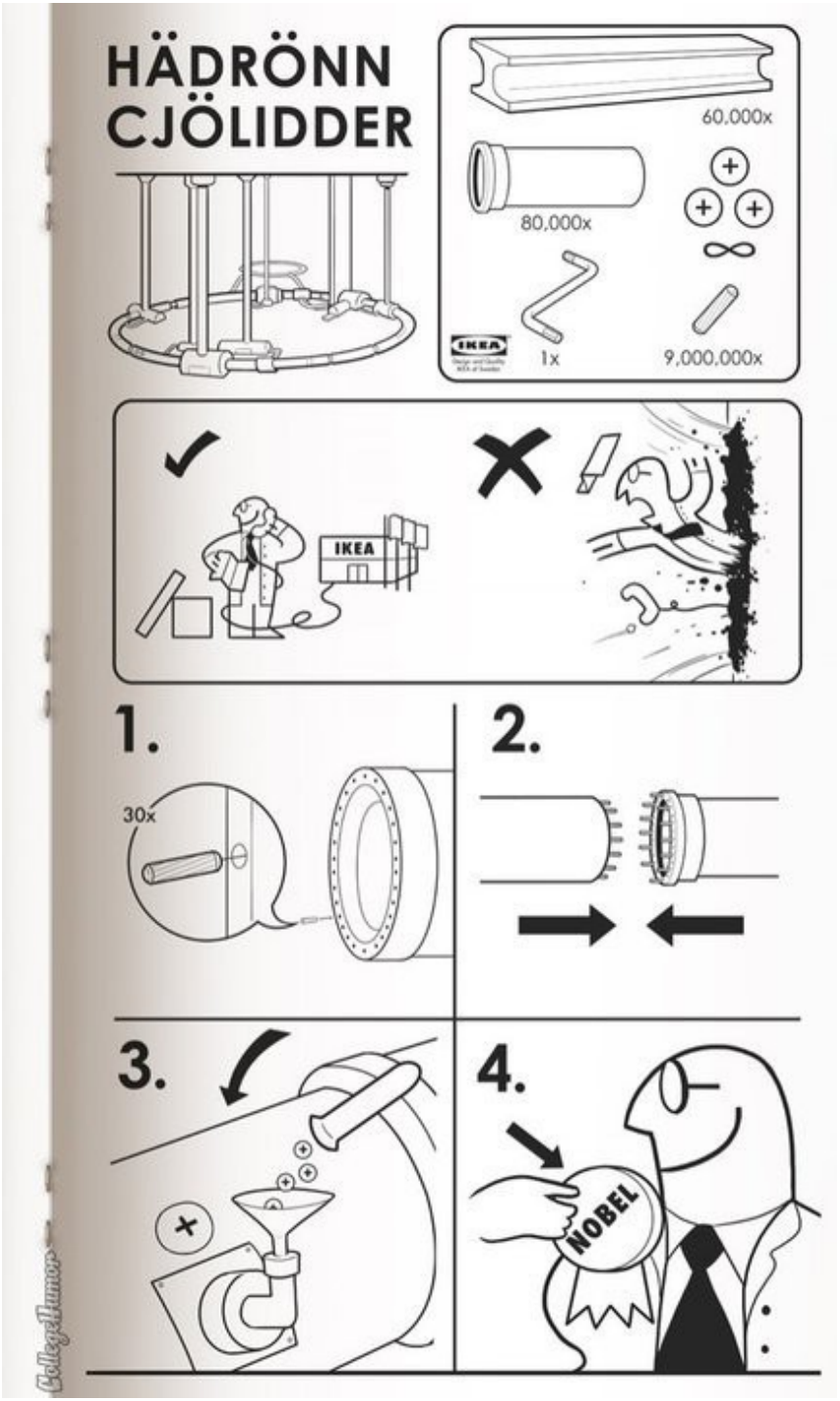
Beam Instrumentation for Particle Accelerators



Ralph J. Steinhagen
Beam Instrumentation Group, CERN

It all looks so easy...

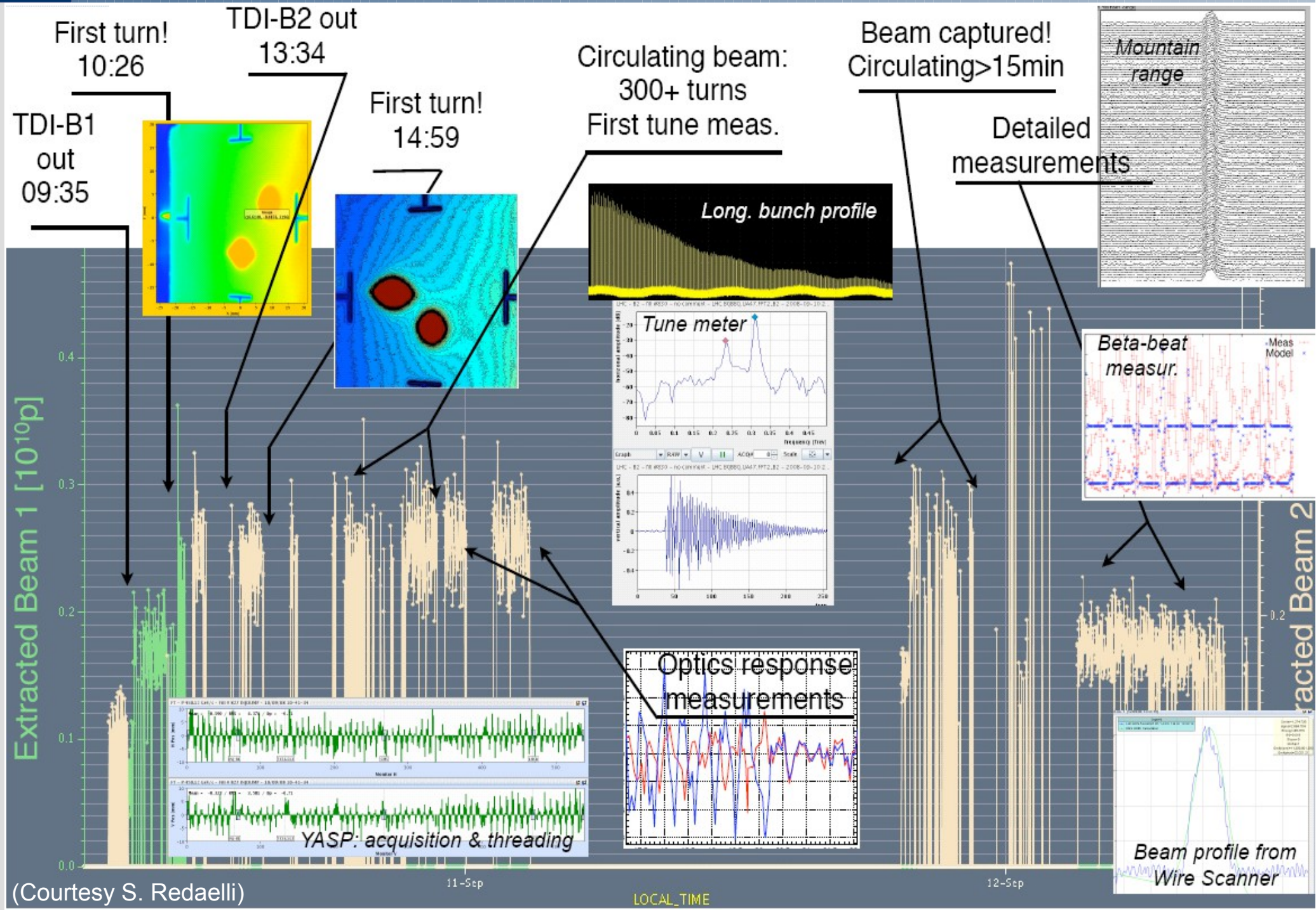


What is Beam Instrumentation about...

- Beam Instrumentation provides the “eyes and ears” of the operators:
  - accelerator only as good as the instrumentation measuring its performance
  - without operators become “blindfolded F1 driver travelling at 300 km/h!”

- Two goals
  - Machine Performance – “to keep the beam in the pipe”
    - assess and maintain tight beam tolerances required for the particle collisions that are detected and analysed by the HEP experiments
  - Machine Protection – detect dangerous situations that require a safe beam extraction
    - protect multi-billion LHC investment for fundamental research

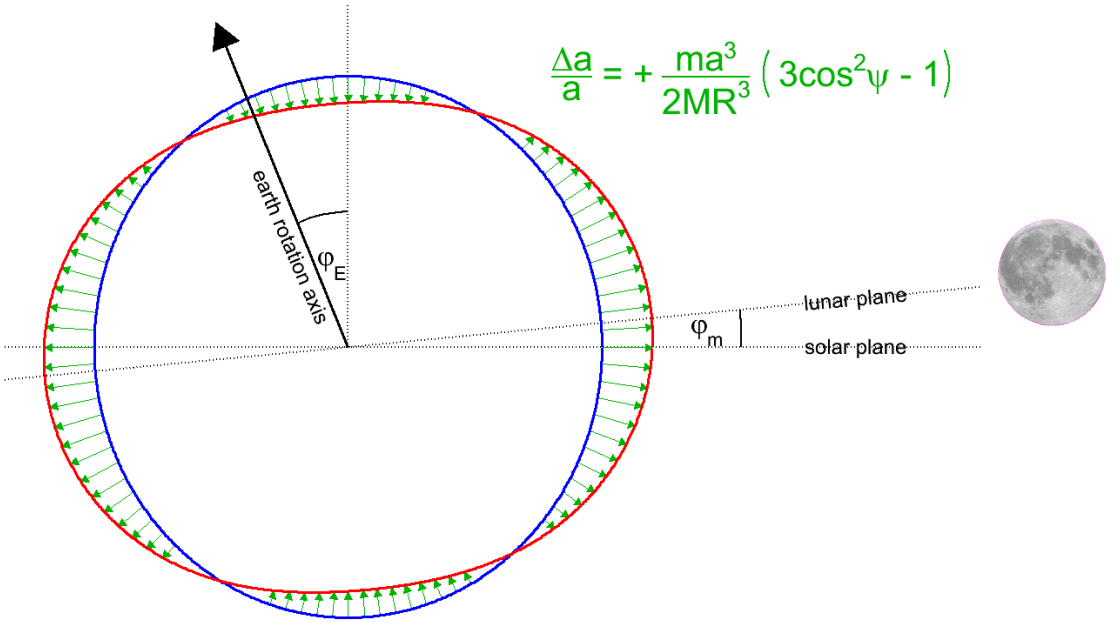
Example: 10th September 2008
Milestones of 50 Hours of LHC Beam Commissioning

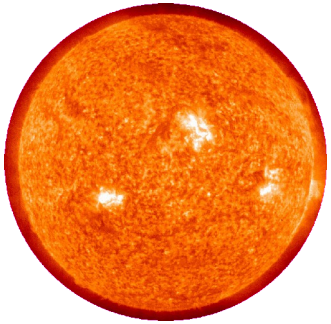


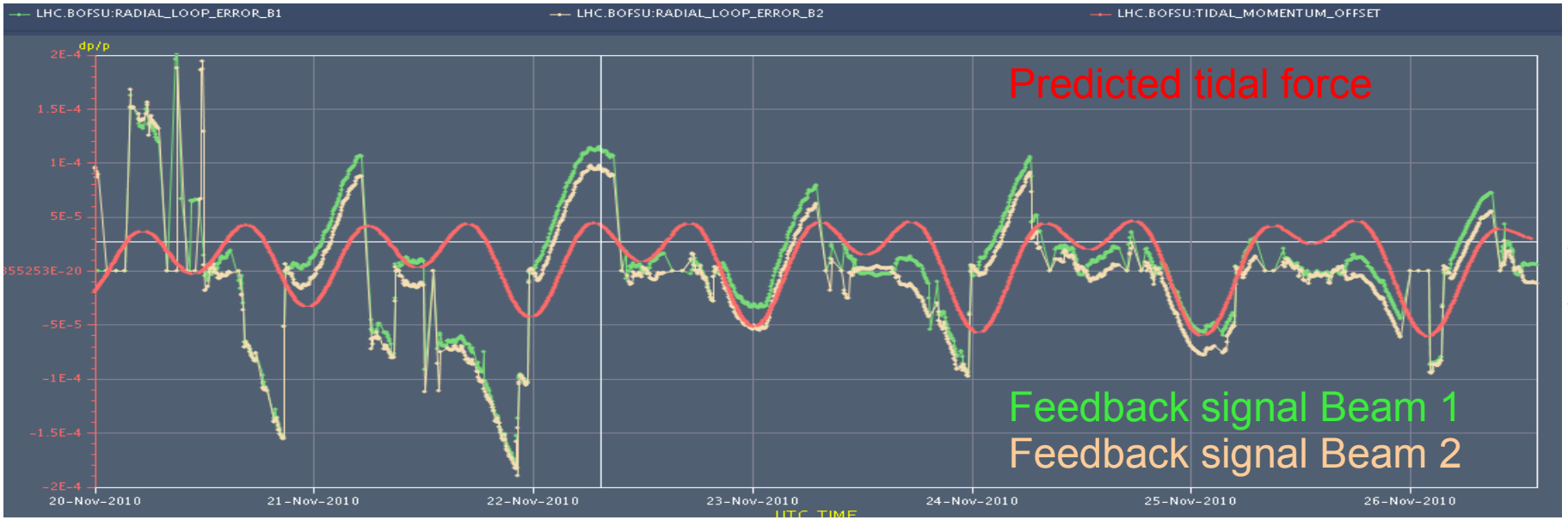
(Courtesy S. Redaelli)

Beam Orbit Stability and Tides ...

$$\frac{\Delta a}{a} = + \frac{ma^3}{2MR^3}\left(3\cos^2\psi - 1\right)$$







$\Delta x \approx 200\ \mu m$

~ one week

- LHC's magnets may “quench” (loose superconducting state)

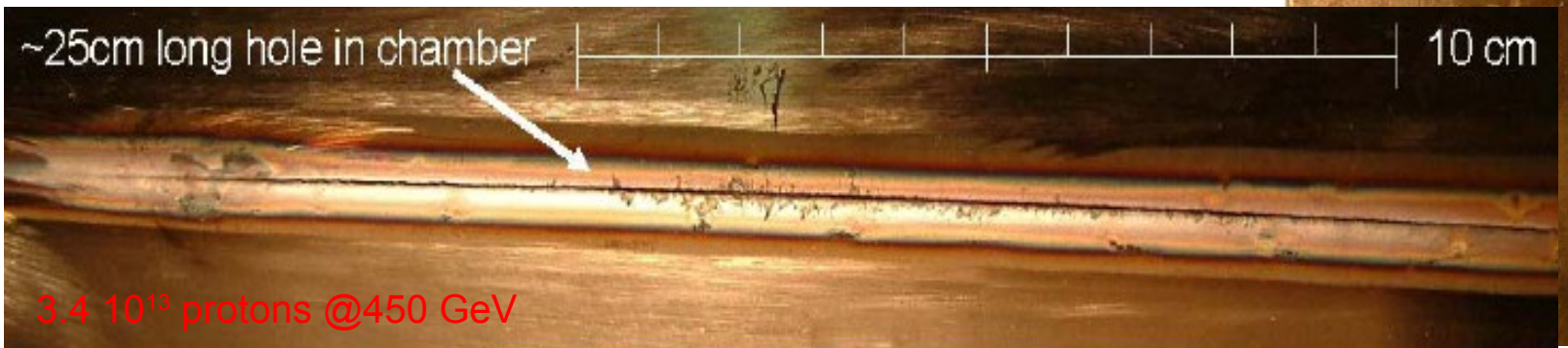
$$E_{MQE} < 10\ mJ/cm^{-3} \quad vs. \quad E_{stored} = 350\ MJ/beam$$

→ sufficient to quench all magnets and/or may cause serious damage

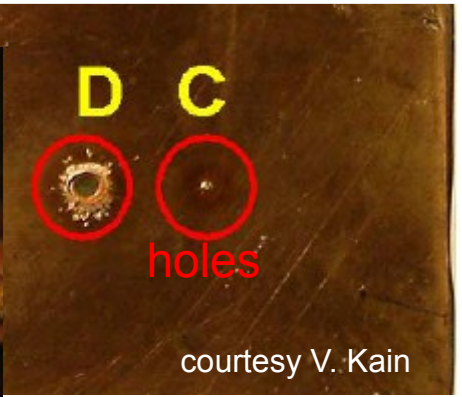
– Multitude of mechanism that may cause an accidental release of this energy
  - Require detailed analysis and
  - design of robust control measures

– Example of uncontrolled vs. controlled release in an accelerator

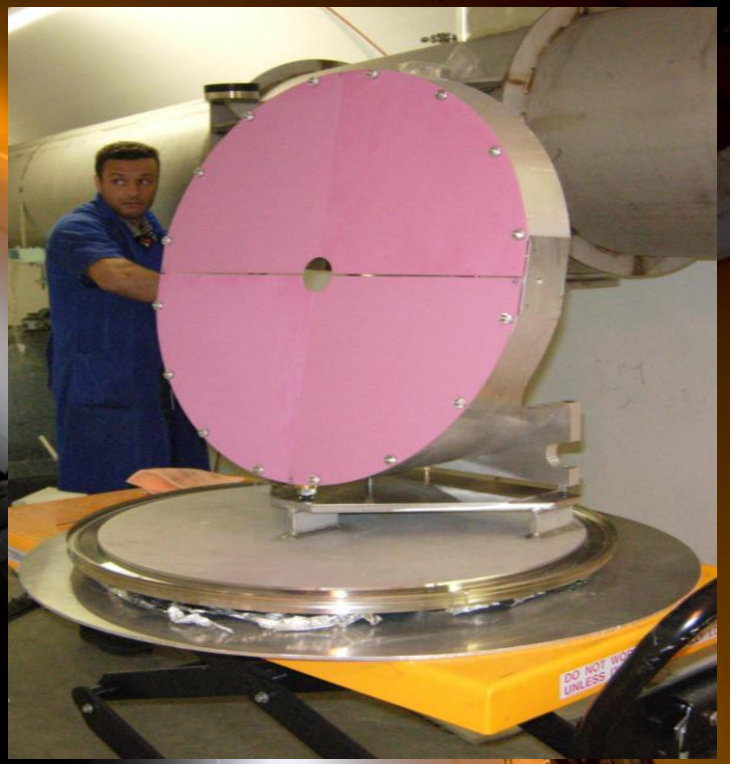
Vacuum pipe of QTRF in TT40

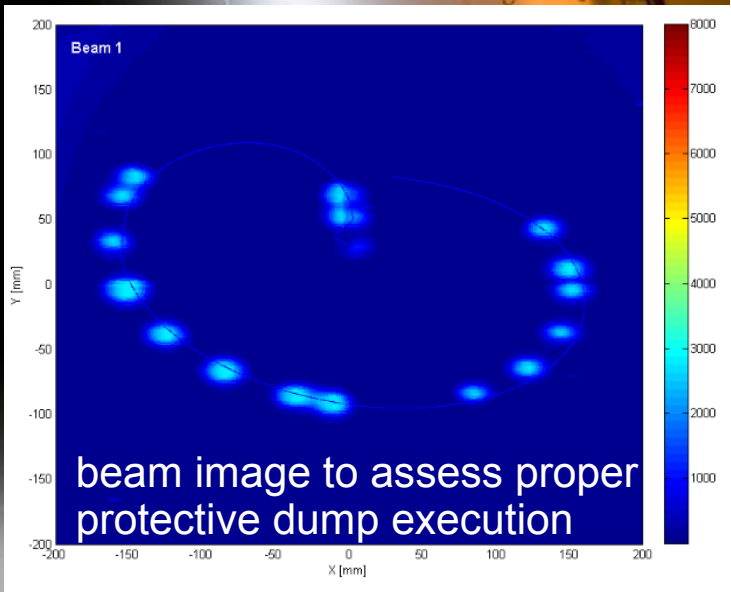


C = 5.4 10^{12} protons @ 450 GeV
D = 7.9 10^{12} protons @ 450 GeV



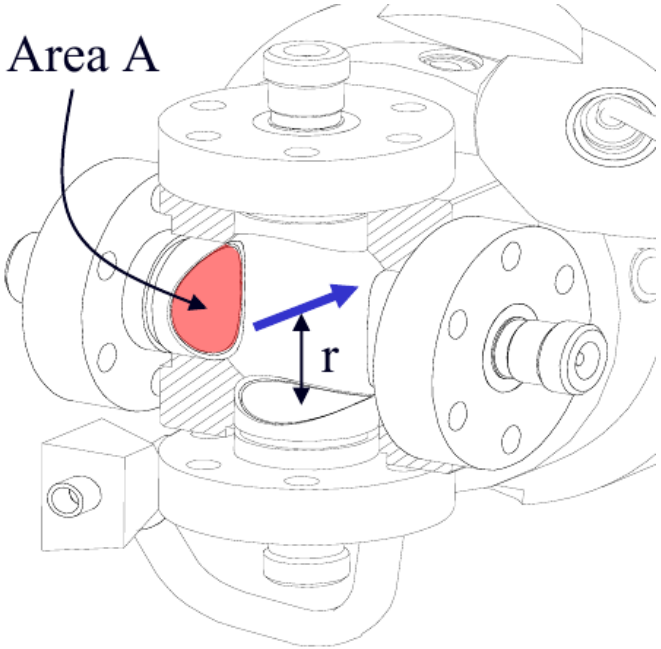
The only device withstanding an impact of a nominal LHC Beam: … in a deep, quiet and dark corner... the LHC Beam Dumps and Screens

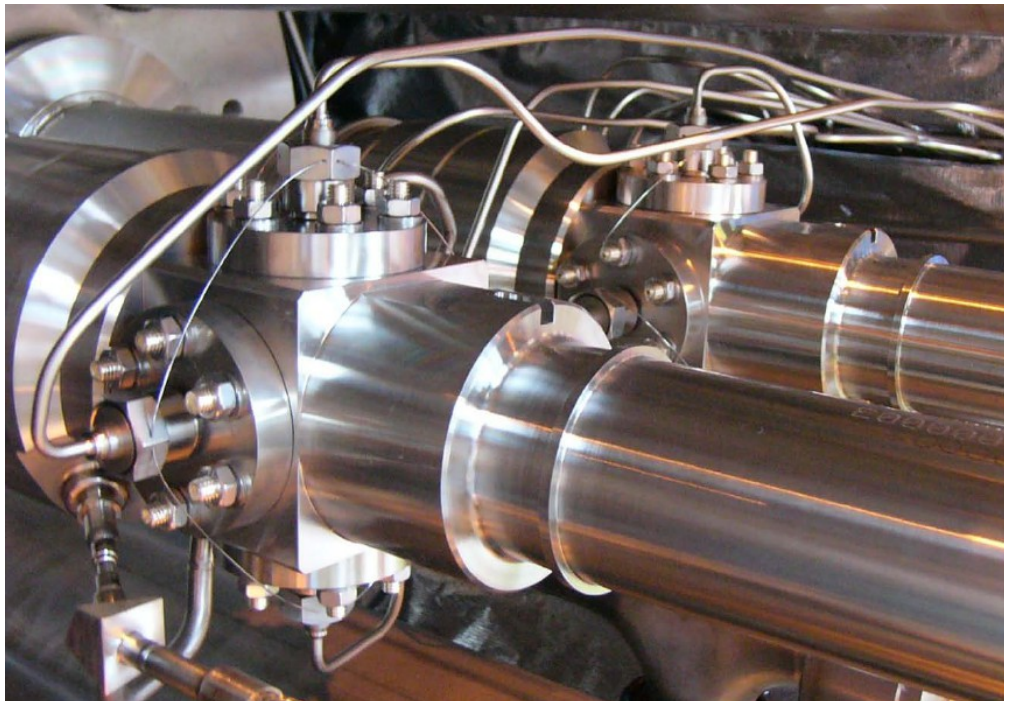




LHC Beam Position Monitors … "Bread-and-Butter for Accelerators"

- Electro-magnetic pick-ups (antennas) operating at ~100 MHz up to 12 GHz
  - Massively distributed system (27 km circumference)
  - Non-interceptive, um-level resolution

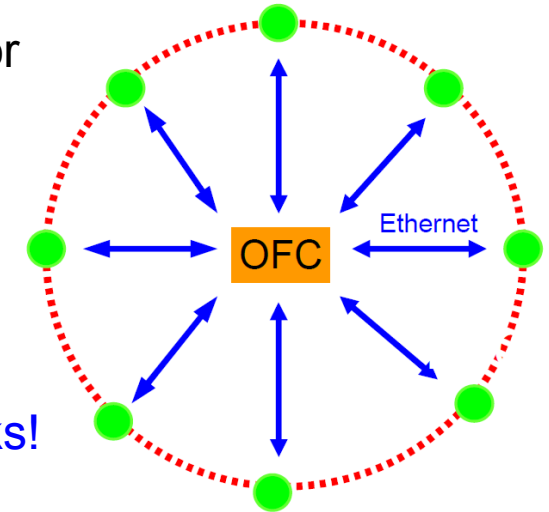




- Many BI exploited by feedbacks cont. re-adjusting the accelerator
- Orbit-Feedback is the largest and most complex of these:
  - 1088 BPMs → 2176+ readings@25 Hz (68 front-ends)
  - 1060++ correction magnets (~50 front-ends)

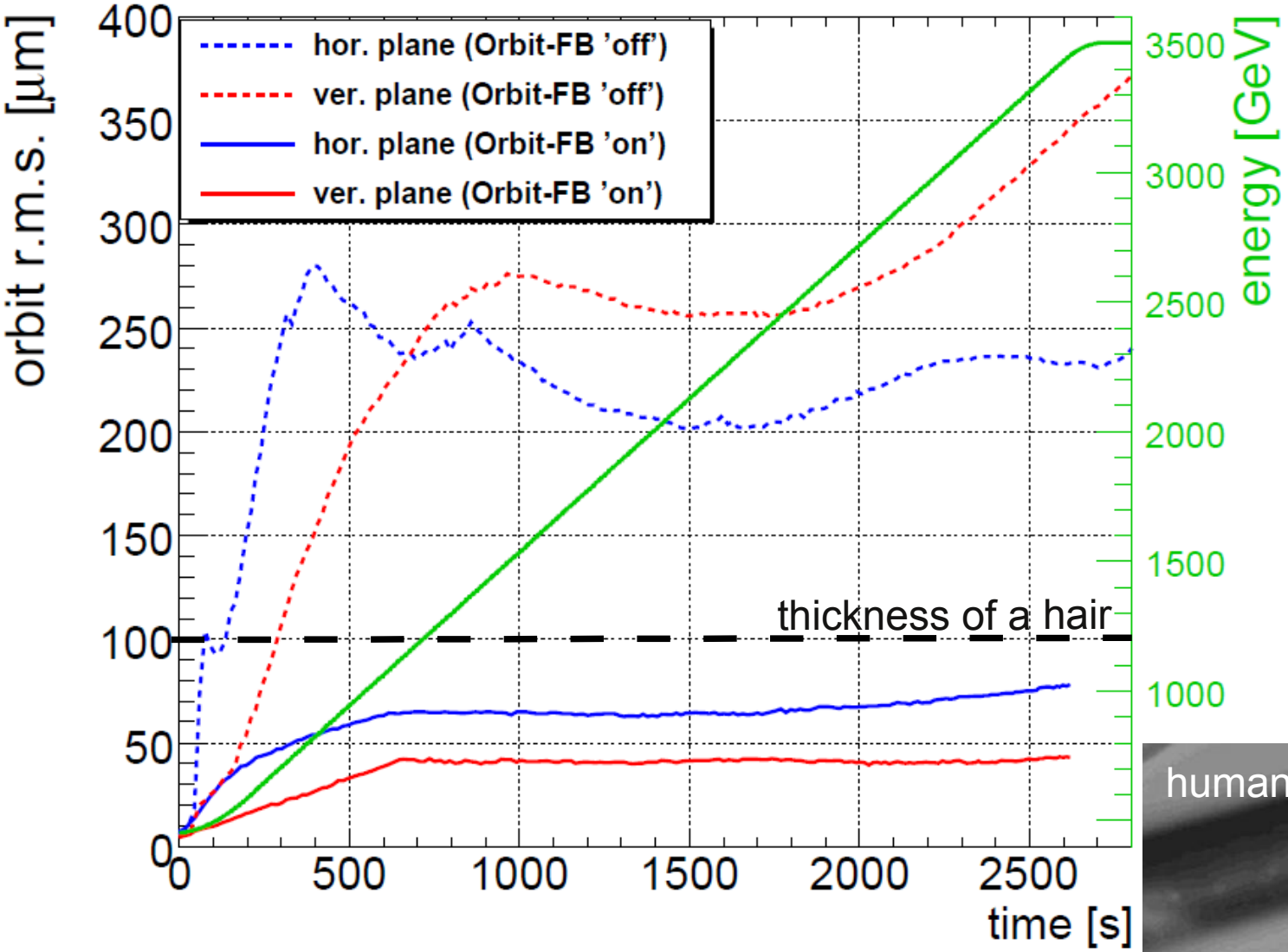
→ Total >3500 devices involved

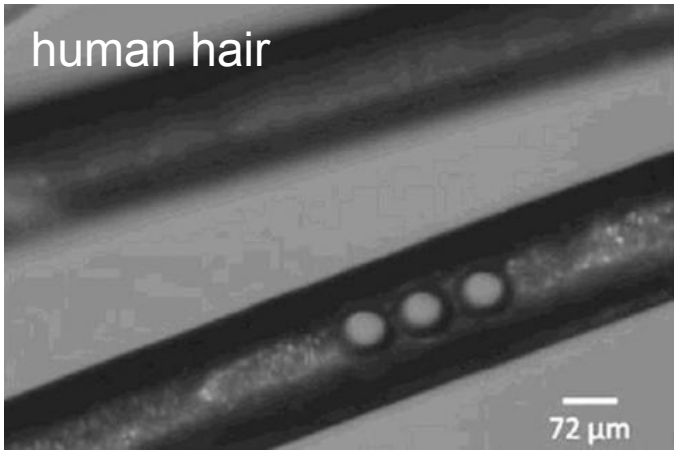
→ more than half the LHC is controlled by beam based feedbacks!



Orbit Feedback Performance

- Orbit feedback used routinely and mandatory for nominal beam





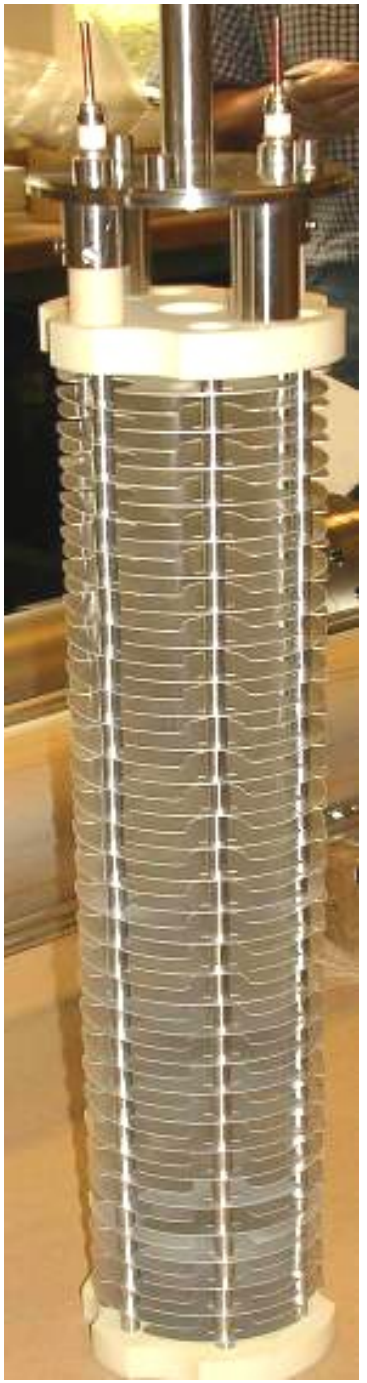
"colliding two pin needles on the middle of the Atlantic"

LHC Beam Loss Monitors

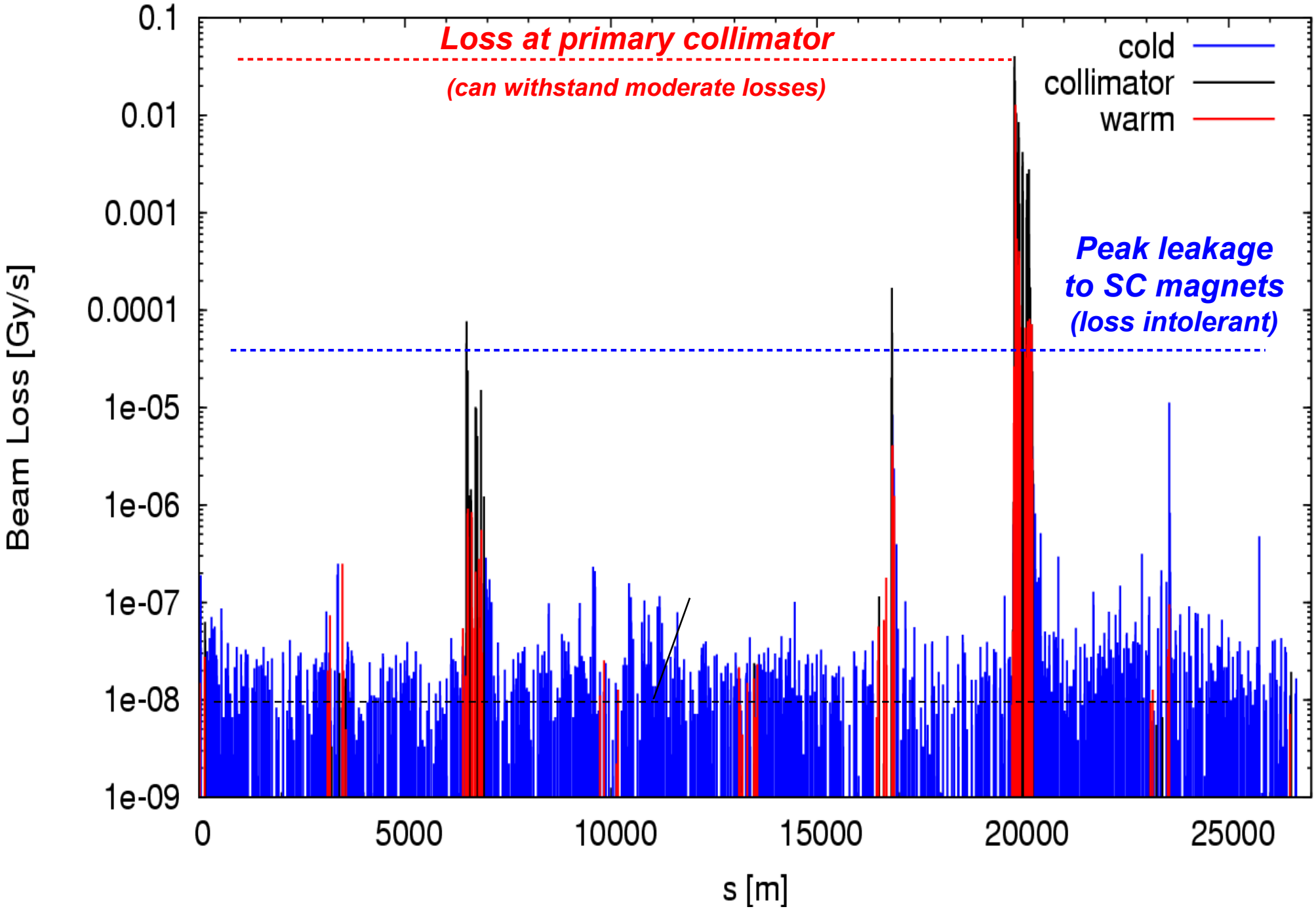
- Function:
  - Detect and protect the LHC from damage
  - Dump the beam to avoid magnet quenches

  → triggers fast safe beam extraction within less than a turn

- Design criteria: signal speed and reliability, >10^9 dynamic range
  (via current to frequency conversion)
- Massively distributed system:
  - ~3600 Ionisation Chambers (1.5l N_2 gas filled at 1.1 bar, 1 kV)
  - ~300 Secondary Emission Monitors

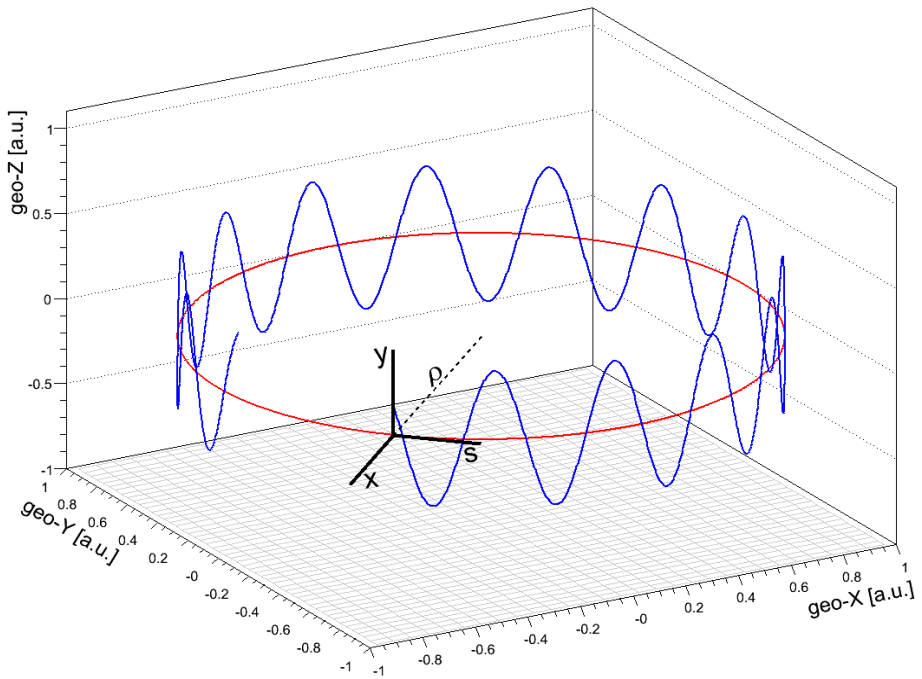


Controlled Beam Loss Monitoring Example – Collimator Hierarchy



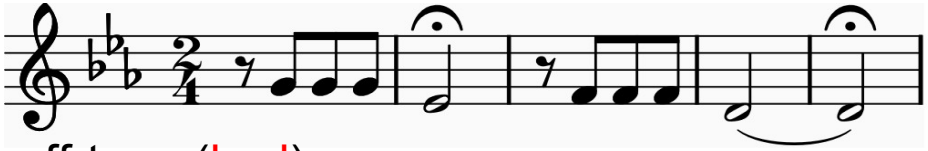
World famous Example of structural Resonances
Tacoma Narrows Bridge 1940

Tuning the LHC – a Diagnostics

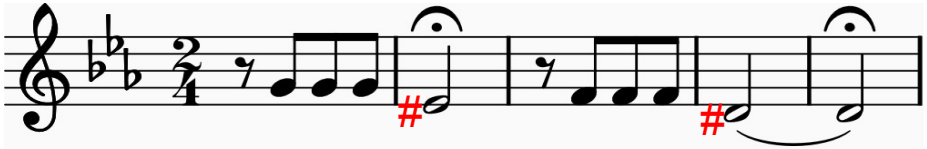


- Laymen/Musician's view (Beethoven's 5th):

in tune (good):



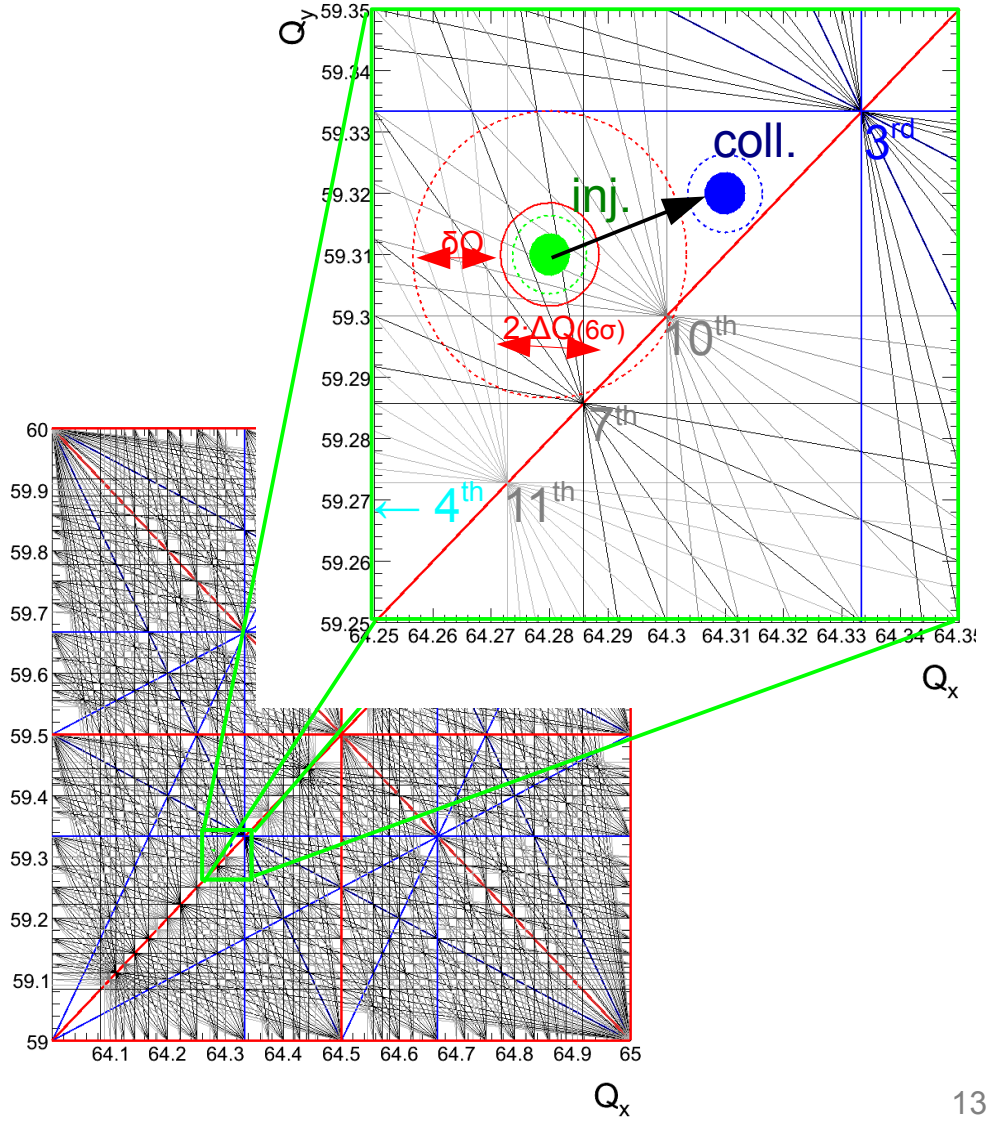
off-tune (bad):



- Audience will leave the concert

↔ Beam will leave the vacuum pipe

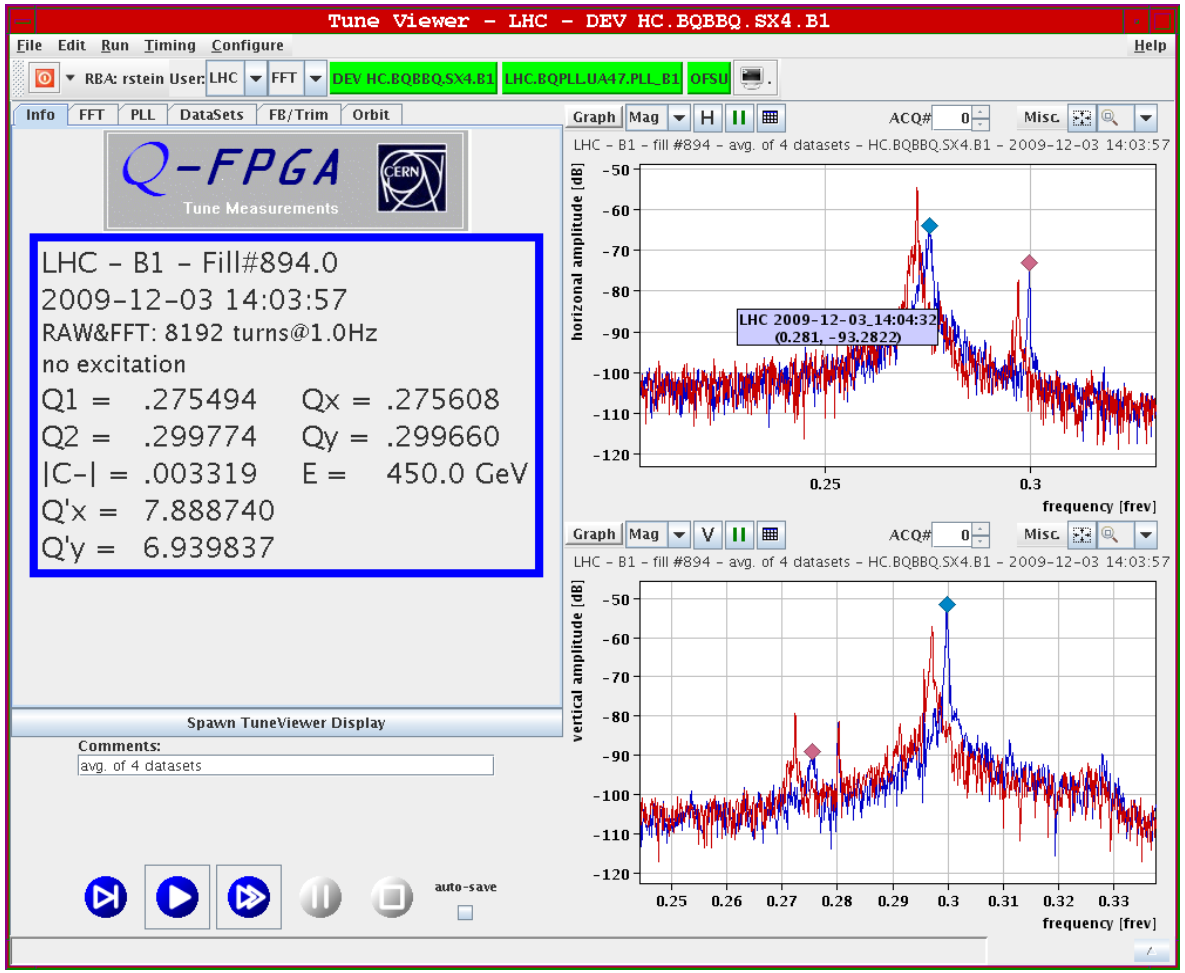
- Particle beam life-time defined by structural accelerator resonances:



Tune and Chromaticity Diagnostics

"Hadron beams are like elephants –
treat them bad and they'll never forgive you!"

- Absence of natural damping provides quite some challenge:
  how to measure resonance without driving/loosing the beam due to an instability !?!?



- … exploited by feedbacks that continuously "re-tune" the accelerators

Summary

"Accelerators are only as good as the beam instrumentation and diagnostics methods that measure it!"

- What does work in beam instrumentation entail?
  - Design, construction & operation of instruments
  - R&D to find novel or improve existing techniques to fulfil new requirements
  - Encompasses a wide range of disciplines:
    … engineering, … physics, data analysis and a lot of curiosity
  - A fascinating field of work!