CERN

Session 1:
Beam Losses and beam induced quenches at the LHC

Belen Salvachua *on behalf of LHC team*

Workshop on Beam-Induced Quenches

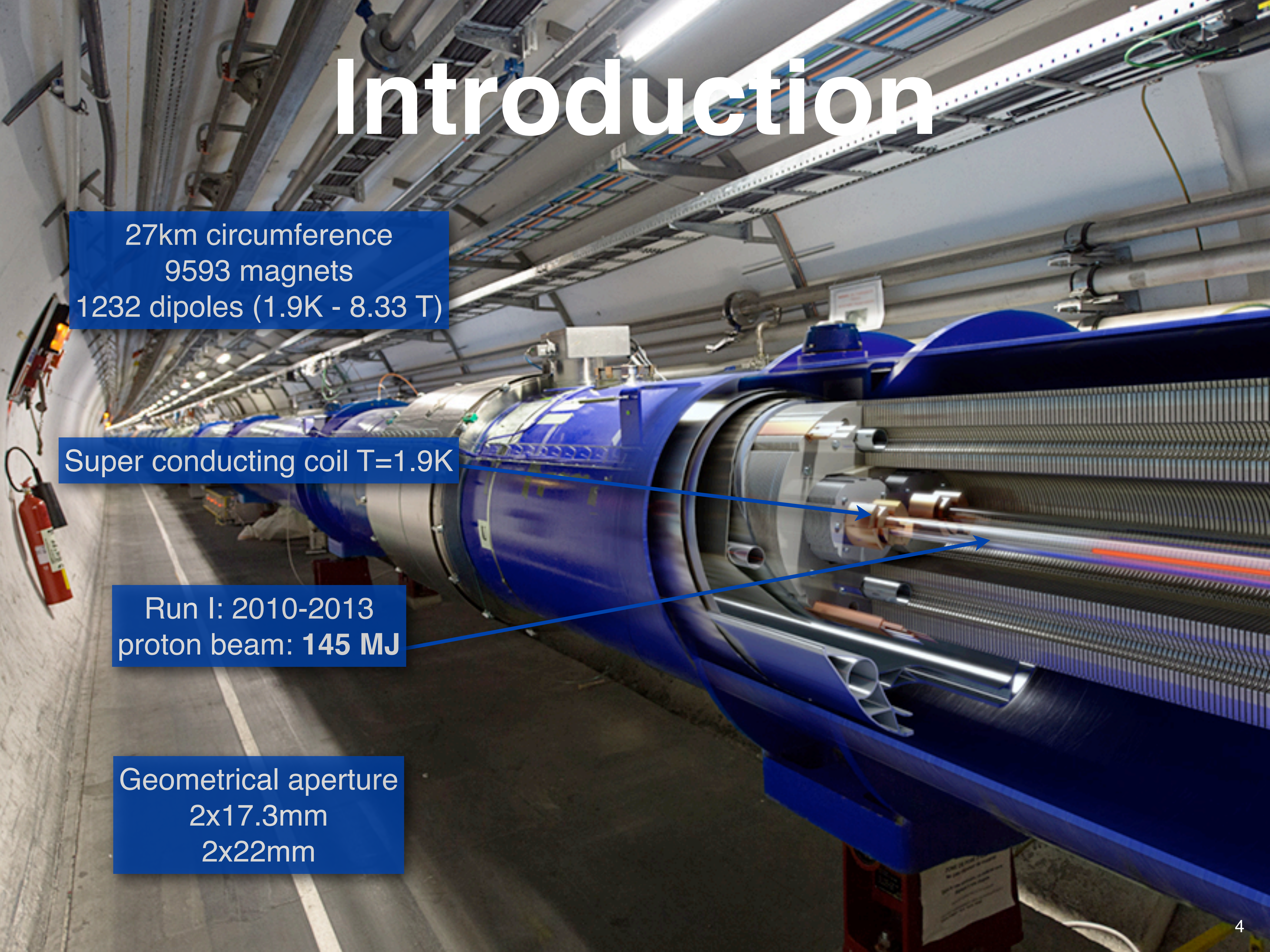
15-16 September 2014

Many thanks to J.Wenninger, T.Baer, C.Bracco, J.Uythoven, M.Barnes, A.Lecher, N.Vittal, S.Redaelli, B.Todd, D.Wollmann, G.Papotti, G.Arduini, M.Sapinski

Outline

- Introduction
- Beam losses during Run I
  - Beam Losses through the cycle
  - Unidentified Falling Objects (UFO)
  - Electron cloud
  - Beam Induced quenches
- Summary

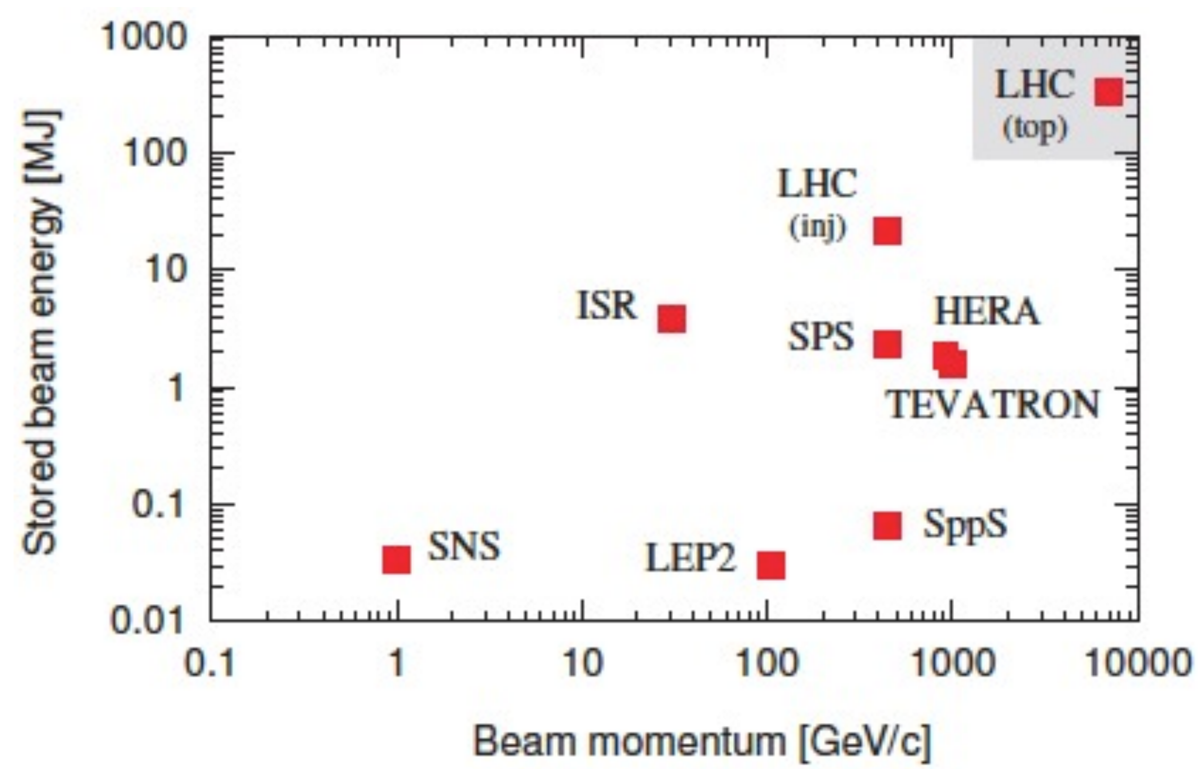
Introduction



LHC Machine Protection

- Main challenge for Run II:
  - Unprecedented beam stored energy, **362 MJ**
- 100 times larger than Tevatron and HERA

		Injection	Collision
Beam Data			
Proton energy	[GeV]	450	7000
Relativistic gamma		479.6	7461
Number of particles per bunch		1.15×10^{11}	
Number of bunches		2808	
Longitudinal emittance (4σ)	[eVs]	1.0	2.5^{a}
Transverse normalized emittance	[μm rad]	3.5^{b}	3.75
Circulating beam current	[A]	0.582	
Stored energy per beam	[MJ]	23.3	362



No beam induced magnet quenches @ **4TeV** during Run I

Beam Losses at LHC

- A tiny fraction of the full beam is enough to damage equipment
- A beam loss of $5x10^9$ protons (< 5% of nominal bunch) at 7TeV is enough to damage the tertiary tungsten collimator
- Therefore, a very control of beam losses is mandatory to ensure safe LHC operation

Normal Losses

They can be minimized but **cannot be avoided completely**
Due to beam dynamics: particle diffusion, scattering processes, instabilities.
Due to Operational variations: orbit, tune, chromaticity changes during ramp, squeeze, collision.

__Collimation__ system (smallest aperture) is designed to __catch__ increased __beam losses up to 500kW over 10sec.__

Beams are dumped when losses exceed the specified max. rates.

Abnormal losses

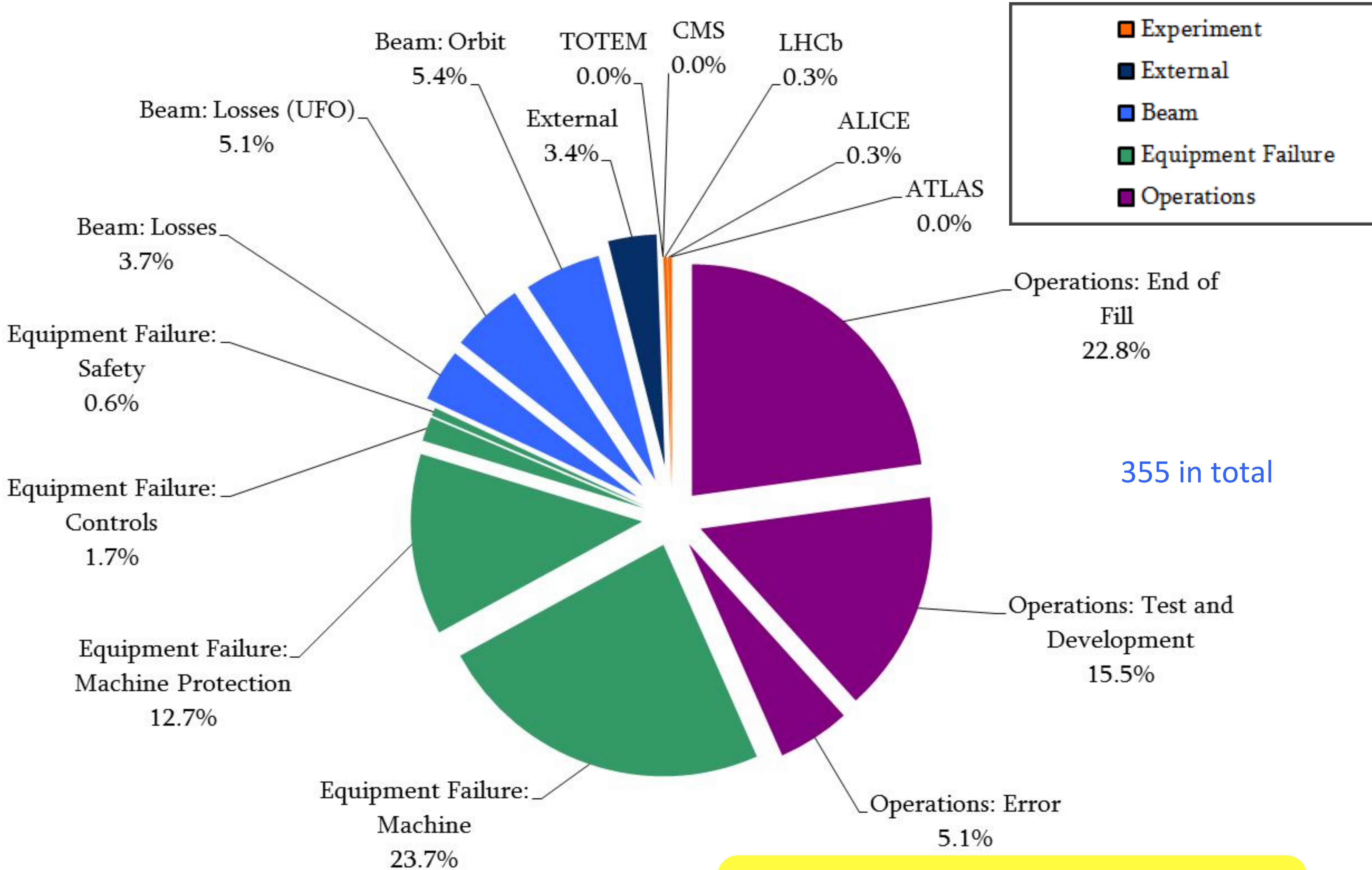
Due to failure or irregular behavior of accelerator components.

Time scale abnormal failures

Slow losses > 1s manual intervention possible	Cryogenic problem, transverse beam instability, failure of orbit/tune feedback, etc... Can be characterized by beam lifetime. The LHC is well protected.
Fast > 15ms (170 turns) protection by multiple systems	Many equipment failures: trip of RF, quench of super-conducting magnet, powering failure of SC circuit. The LHC is well protected.
Very fast > 270μs (3 turns) protection of fastest systems	Few equipment failures: non-SC magnets and transverse damper. And abnormal losses due to UFOs (macro particles interacting with beam) The LHC is protected by the fastest MP systems like Beam Loss Monitors and fast magnet current change monitors.
Ultra fast < 3 turns too fast for protection dump	Too fast to ensure an active protection by a beam dump. Injection/Dump failures. The LHC aperture is protected by collimators.

T.Baer, PhD 2013

Post Mortem : Dump Cause – 2010

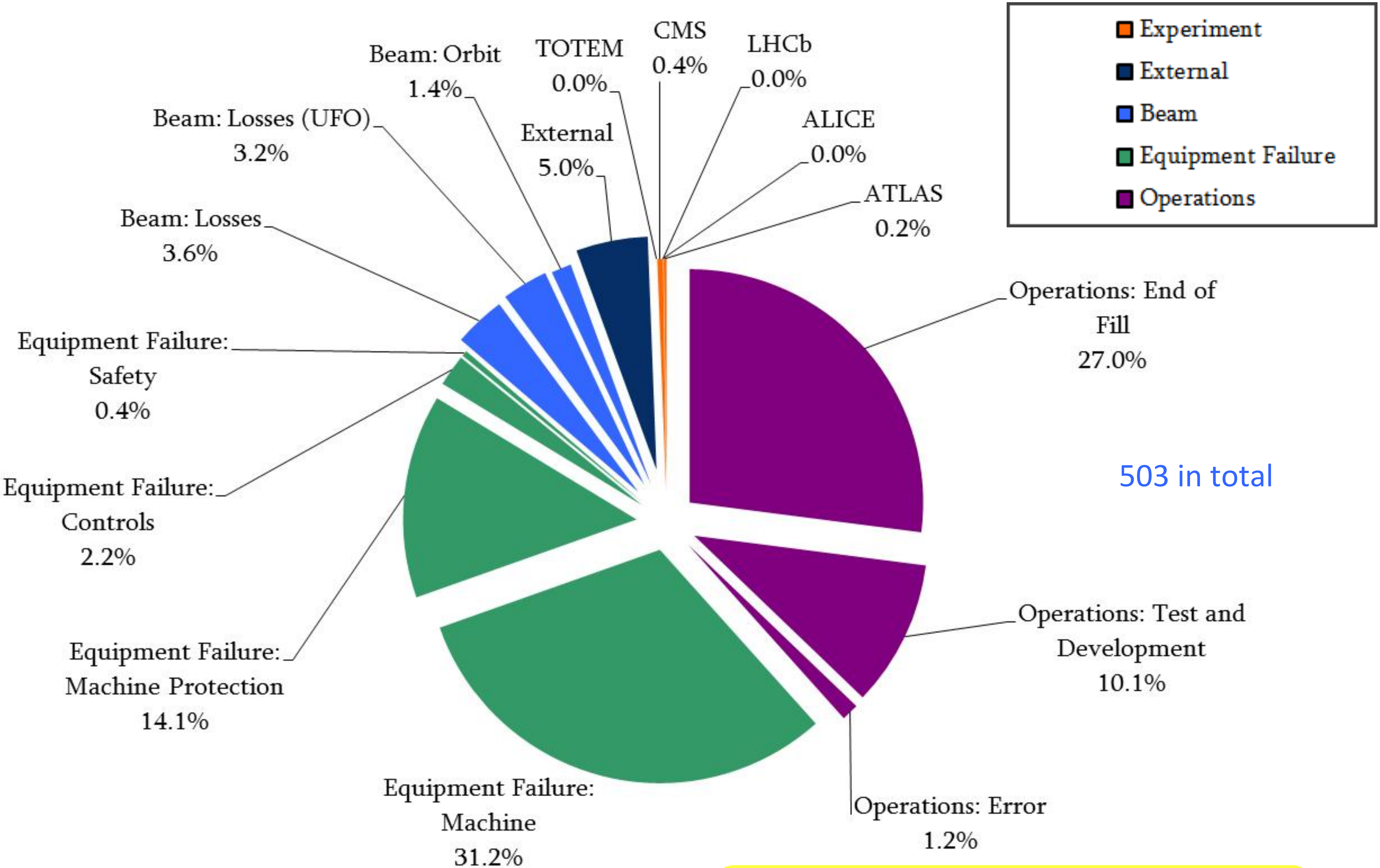


355 in total

B.Todd, Evian OP workshop 2012

[1]

Post Mortem : Dump Cause – 2011



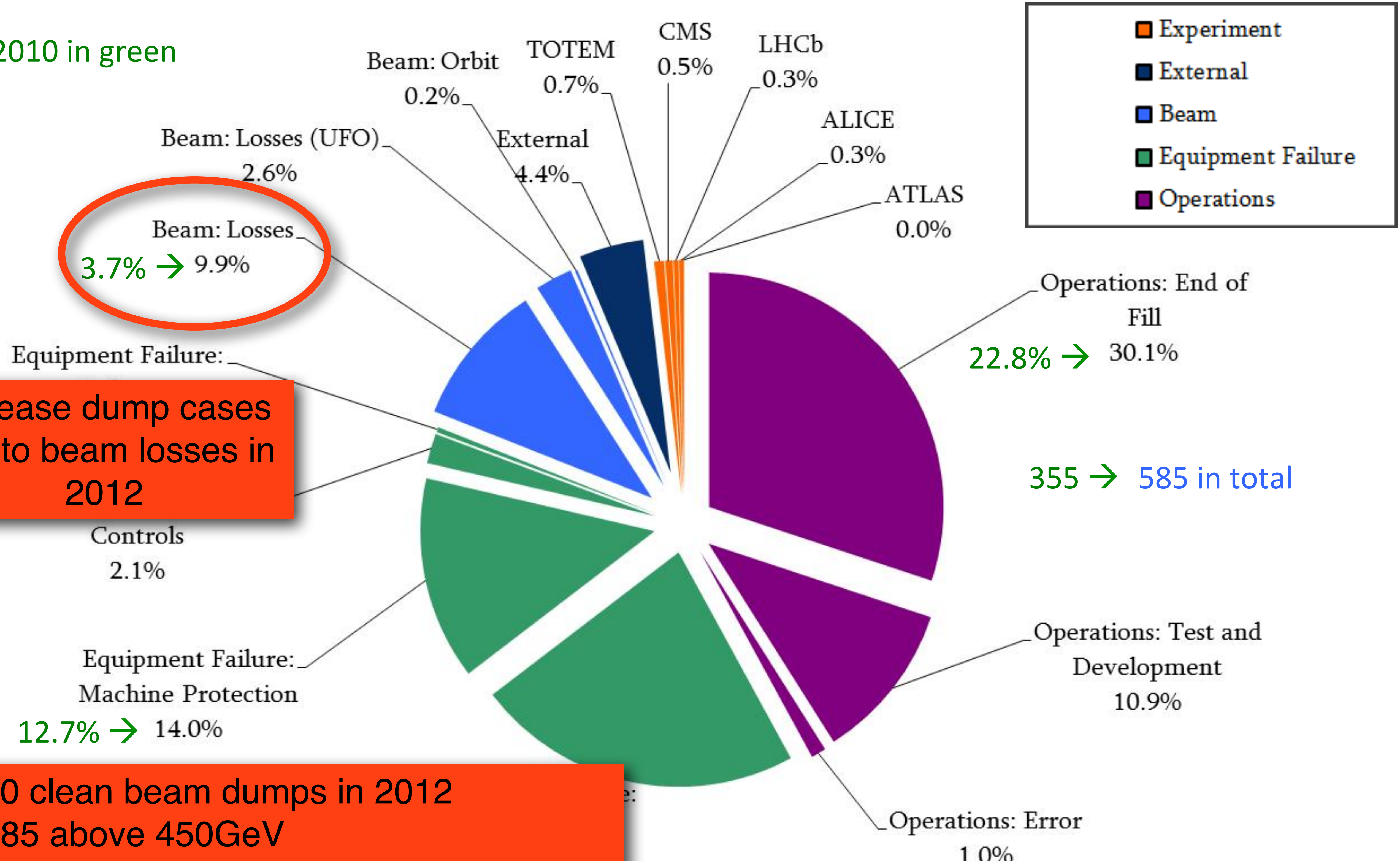
503 in total

B.Todd, Evian OP workshop 2012

[2]

Post Mortem : Dump Cause – 2012

2010 in green



Increase dump cases due to beam losses in 2012

~1000 clean beam dumps in 2012
- 585 above 450GeV
- majority of dumps with beam energy > 100MJ (reaching max 146MJ)

B.Todd, Evian OP workshop 2012

[3]

Losses during operation

- During 2010-2011 losses were nearly negligible before collisions, with beam transmission close to 100%
- For 2012 with “tight” collimators settings to decrease beta-star down to 60 cm

4.3σ assuming nominal transverse emittance
Important scraping of beam tails

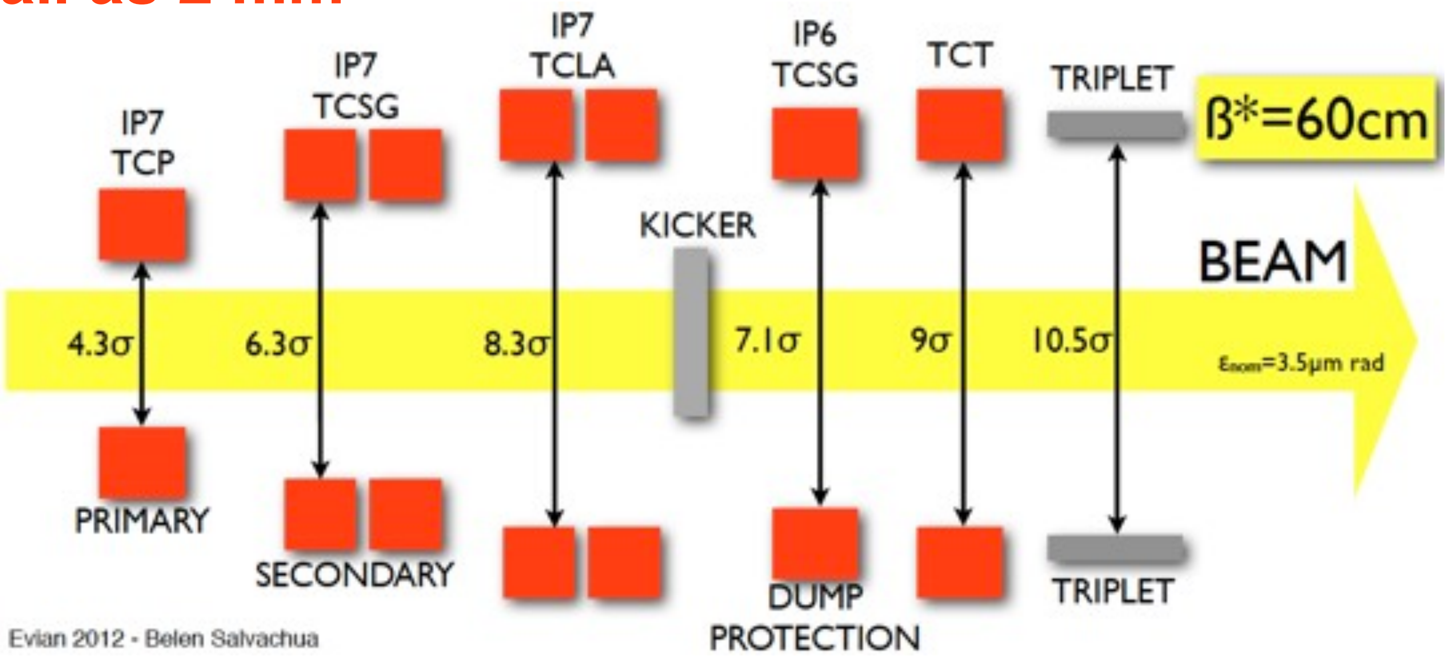
+

Increased Impedance

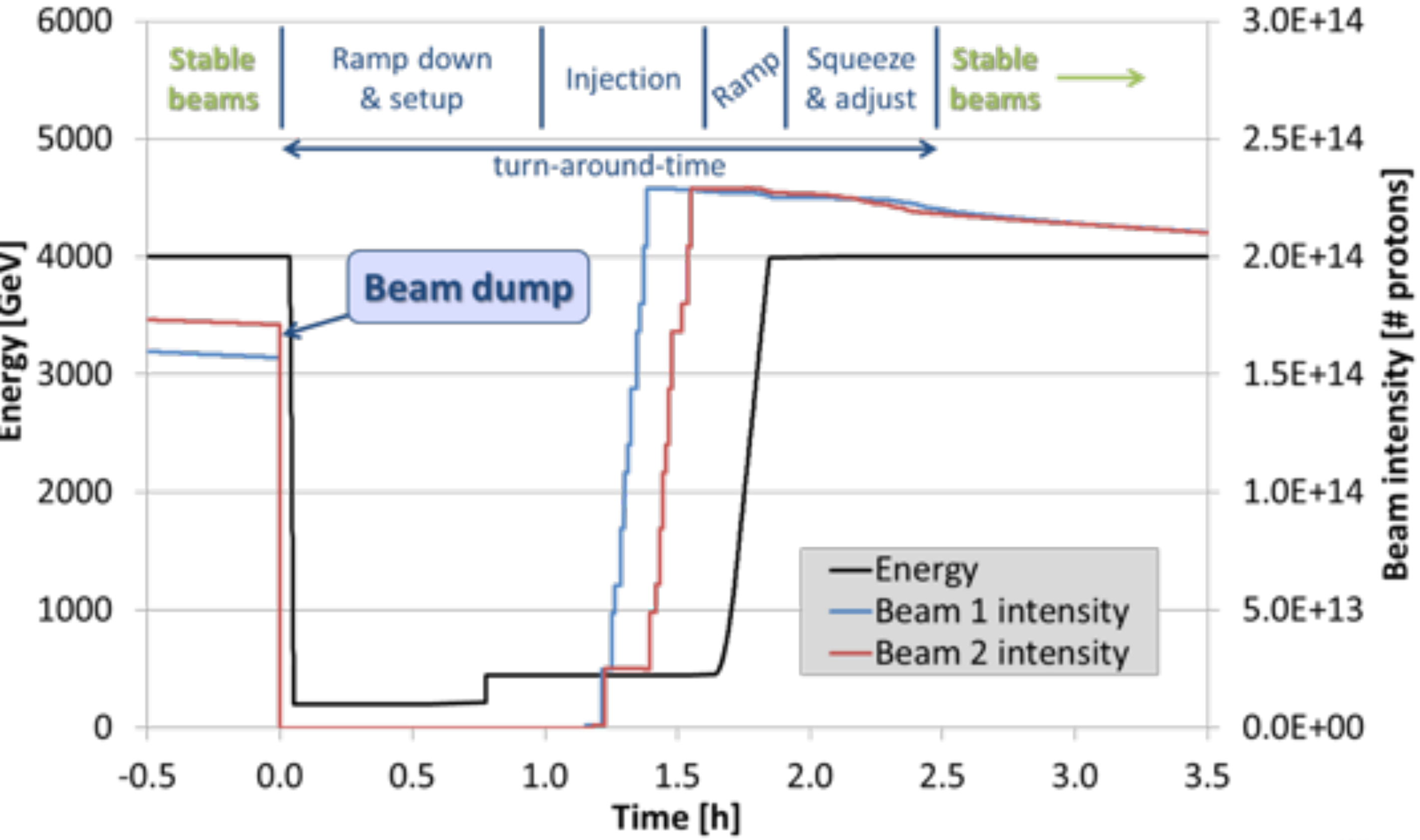
=

2012 increased beam losses by a factor of 10

Collimator gaps as small as 2 mm



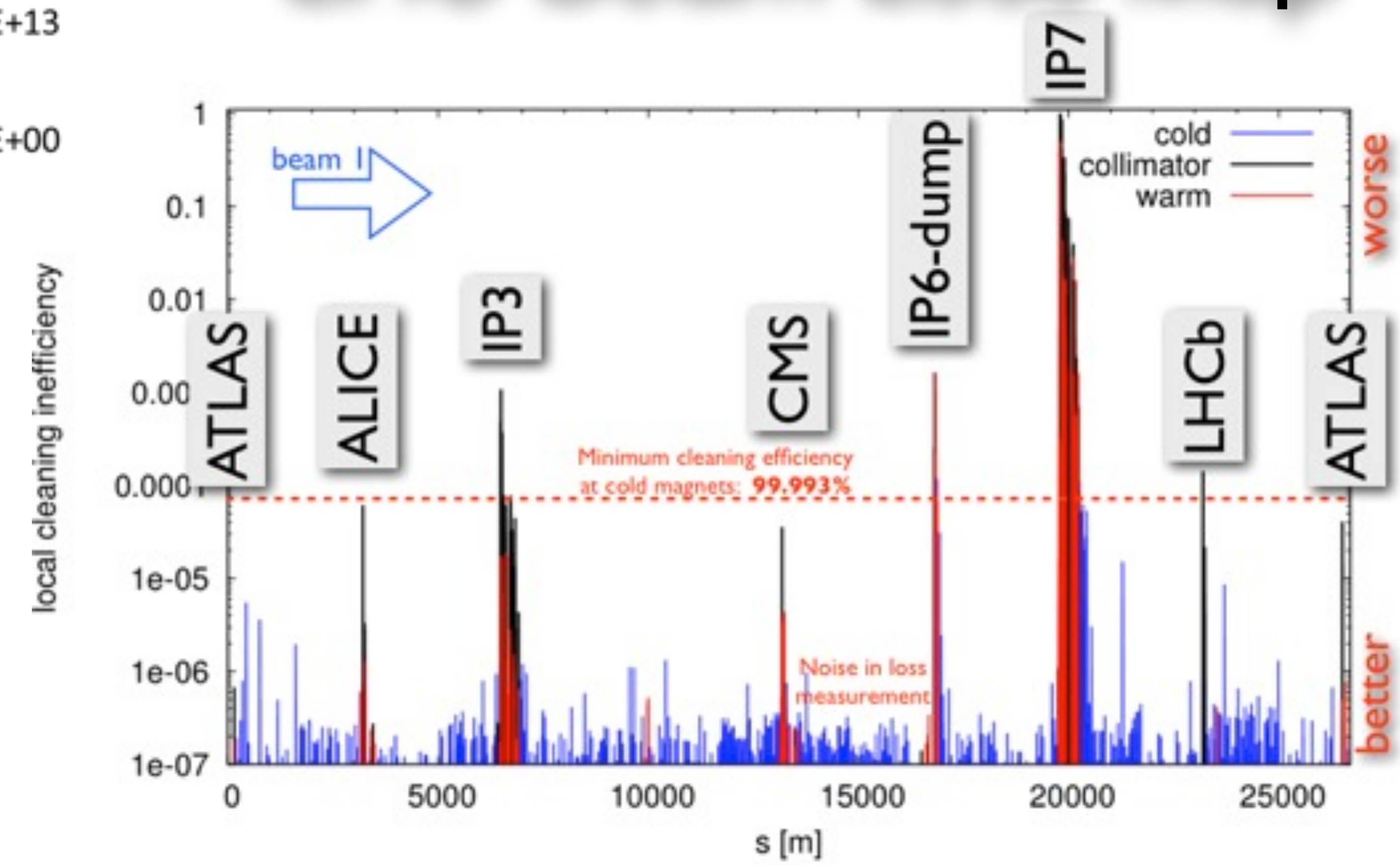
LHC beam cycle



Beam losses concentrated in Collimation locations:

- IP7: betatron cleaning
- IP3: off-momentum cleaning

LHC Beam Loss Map

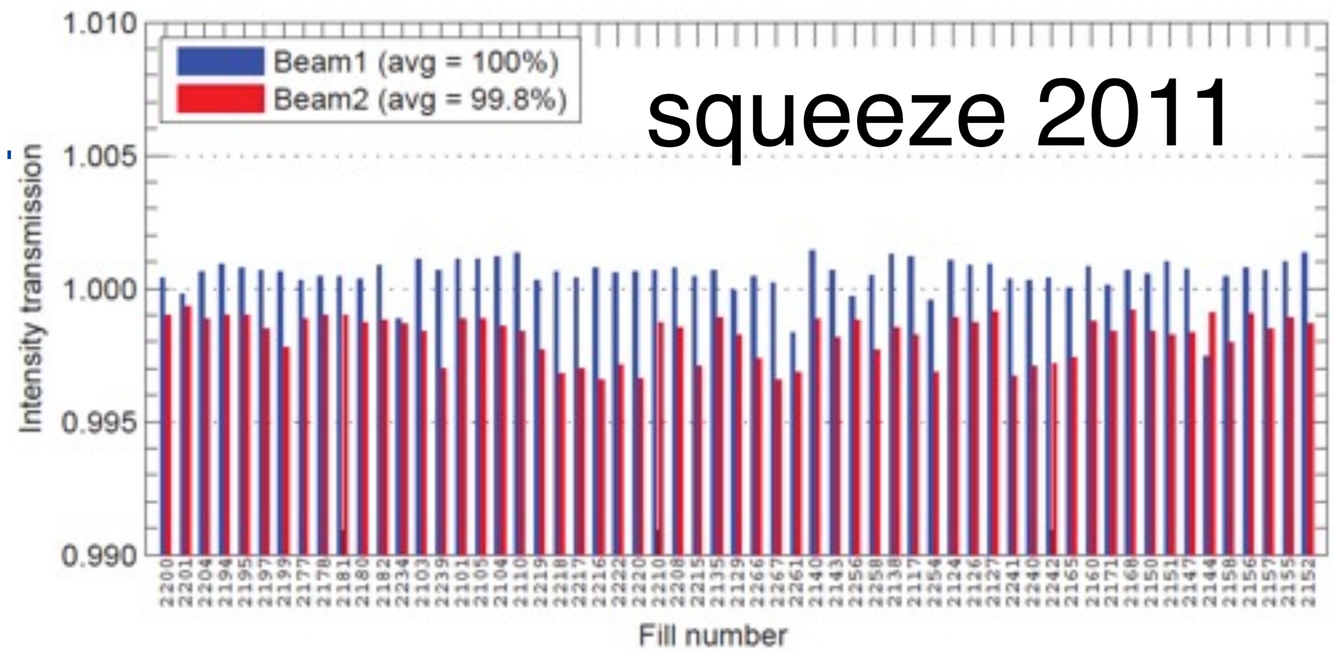


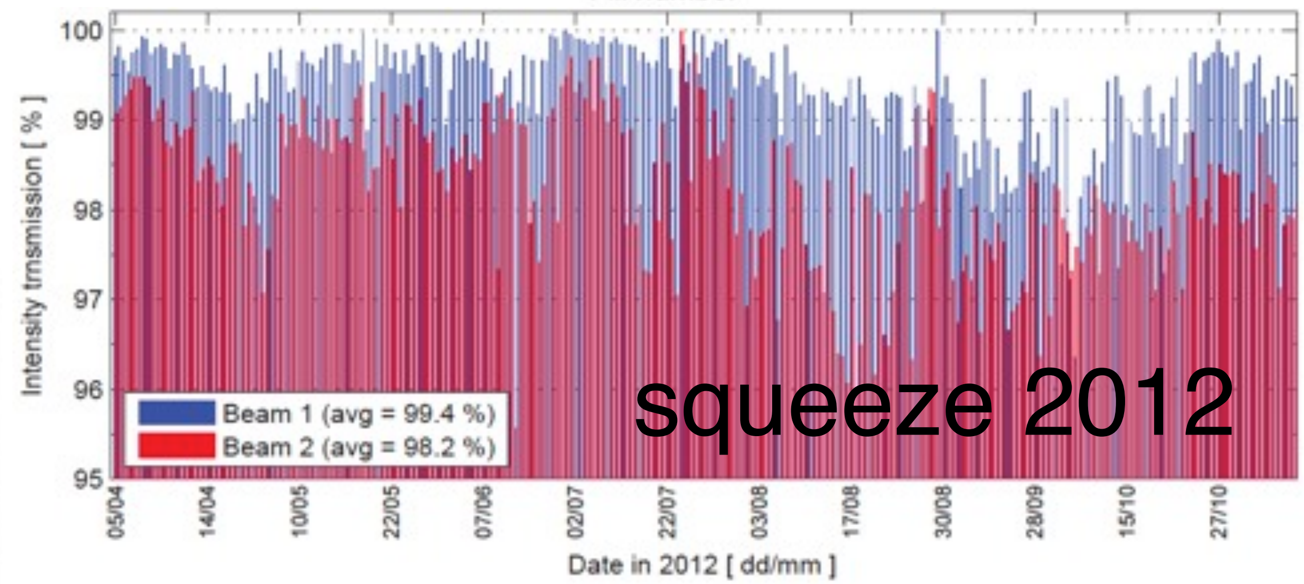
LHC stores the beam for few hours:

- ***Ramp down & setup***
- ***Injection***
- ***Ramp:***
  - Capture losses between 450-500GeV
  - Beam scraping all over the ramp (smaller gaps at collimators)
- ***Squeeze:*** reducing beam size at interaction points
- ***Adjust:*** beams are brought into collisions

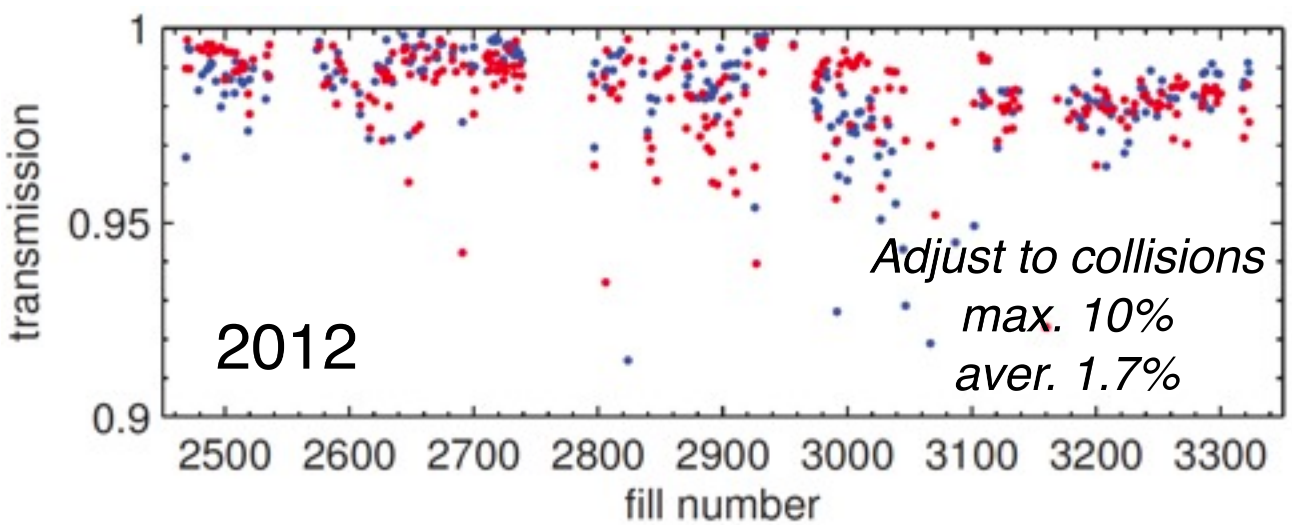
Losses through cycle

- 2011: almost “loss free” scenario.
- 2012:
  - Ramp: 1.2%
  - Squeeze: 1-2%
  - Adjust: 1.7%
- ~ 1-2 MJ of beam loss per beam mode





Beam transmission I_{END}/I_{START}



2011 ~ 0.5% beam losses

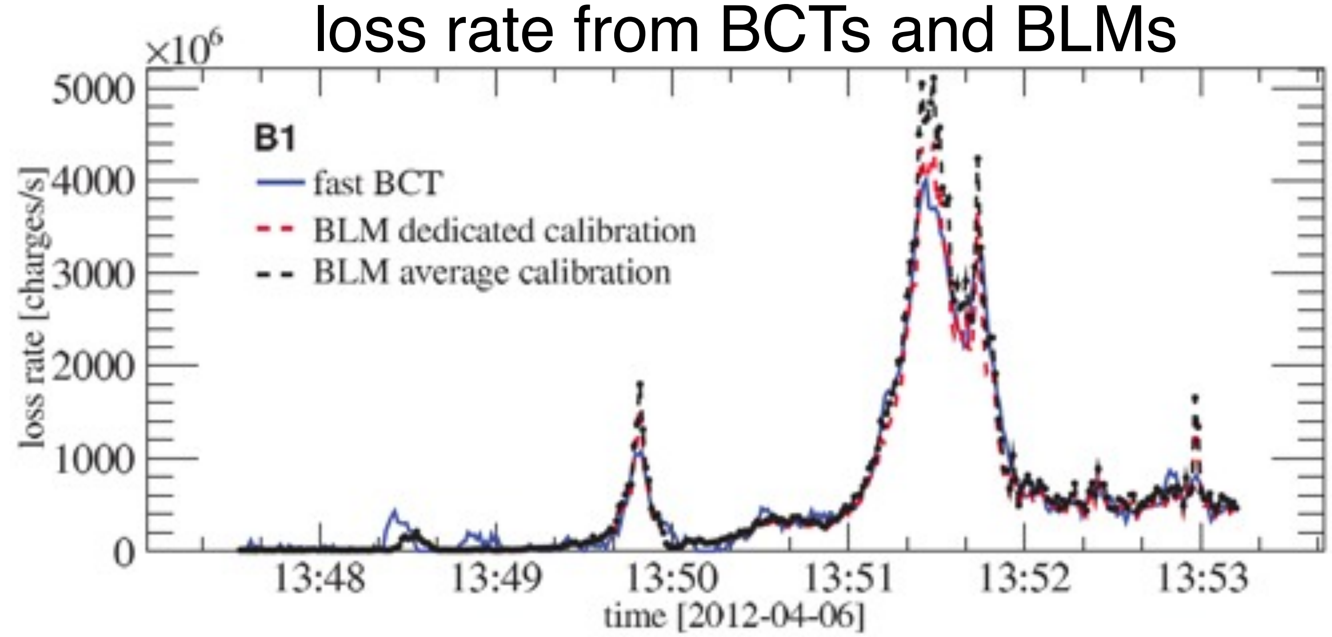
2012 ~ 2-3% beam losses

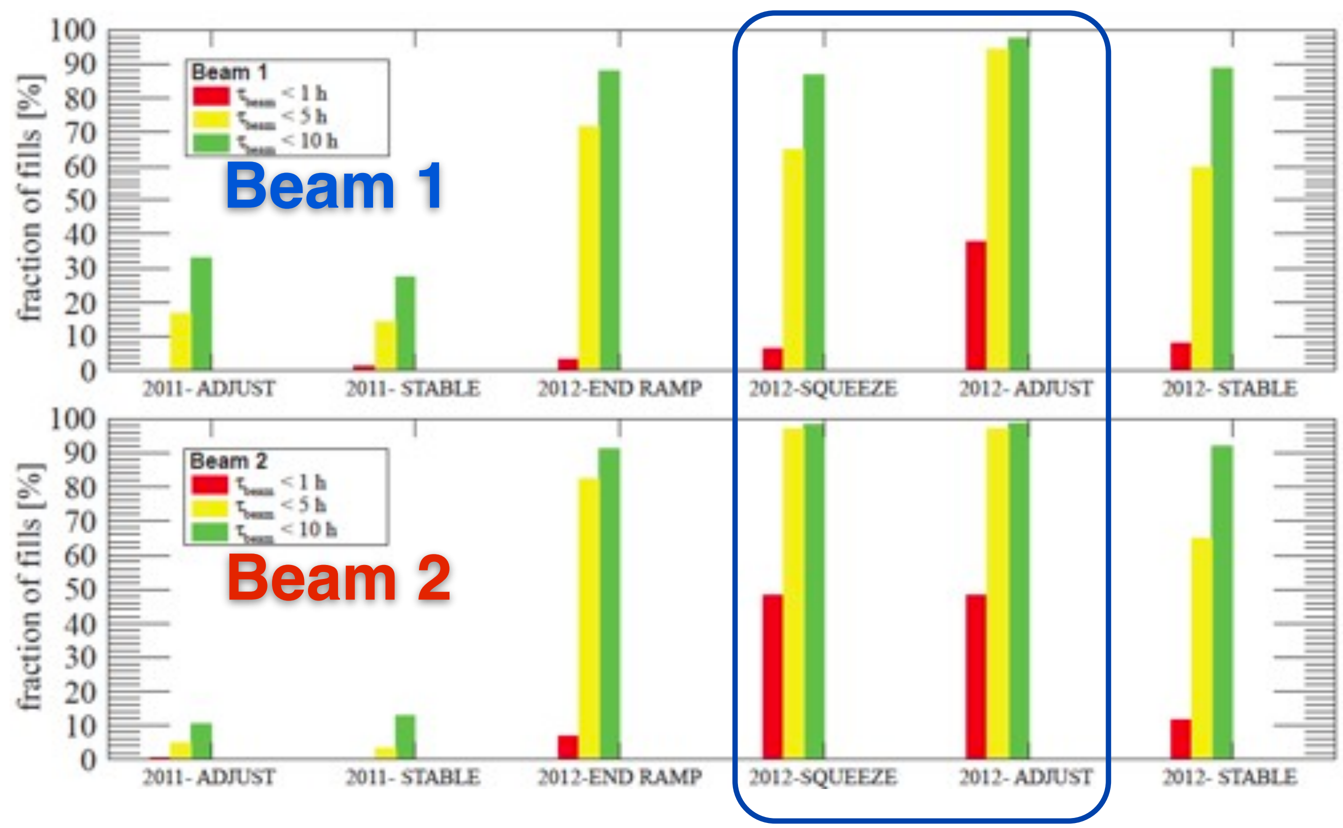
G.Papotti, IPAC’13 TUPFI028
S.Redaelli et al. IPAC’13 TUPFI038

Minimum Beam Lifetime

- Beam lifetime: decay time of the beam intensities
- Beam dumped with lifetimes of 0.2h
- Bottleneck for beam losses in 2012 was:
  - Squeeze
  - Adjust
- In **2012, 90%** of the fills had lifetime **below 10h**, while in 2011 only 30%.
- In **2012, 50%** of the fills with **lifetime < 1h** during **ADJUST**
- In **2012, 50%** of the fills with **lifetime < 1h** during **SQUEEZE** for **Beam 2** and 10% for Beam 1

loss rate from BCTs and BLMs



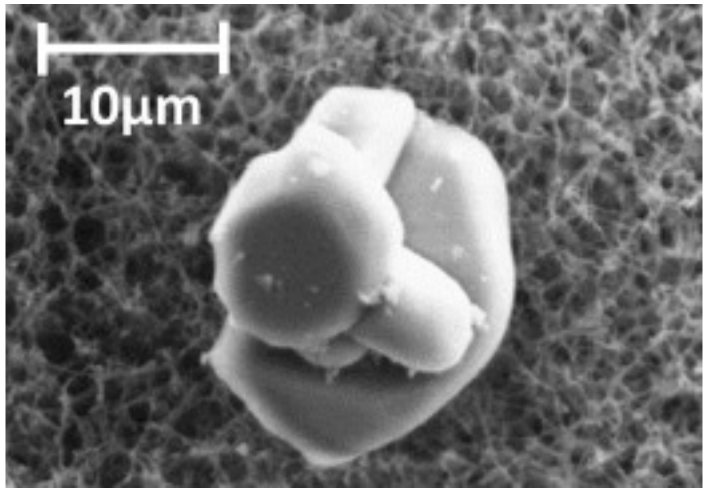


B.Salvachua et al. IPAC'13 MOPWP049

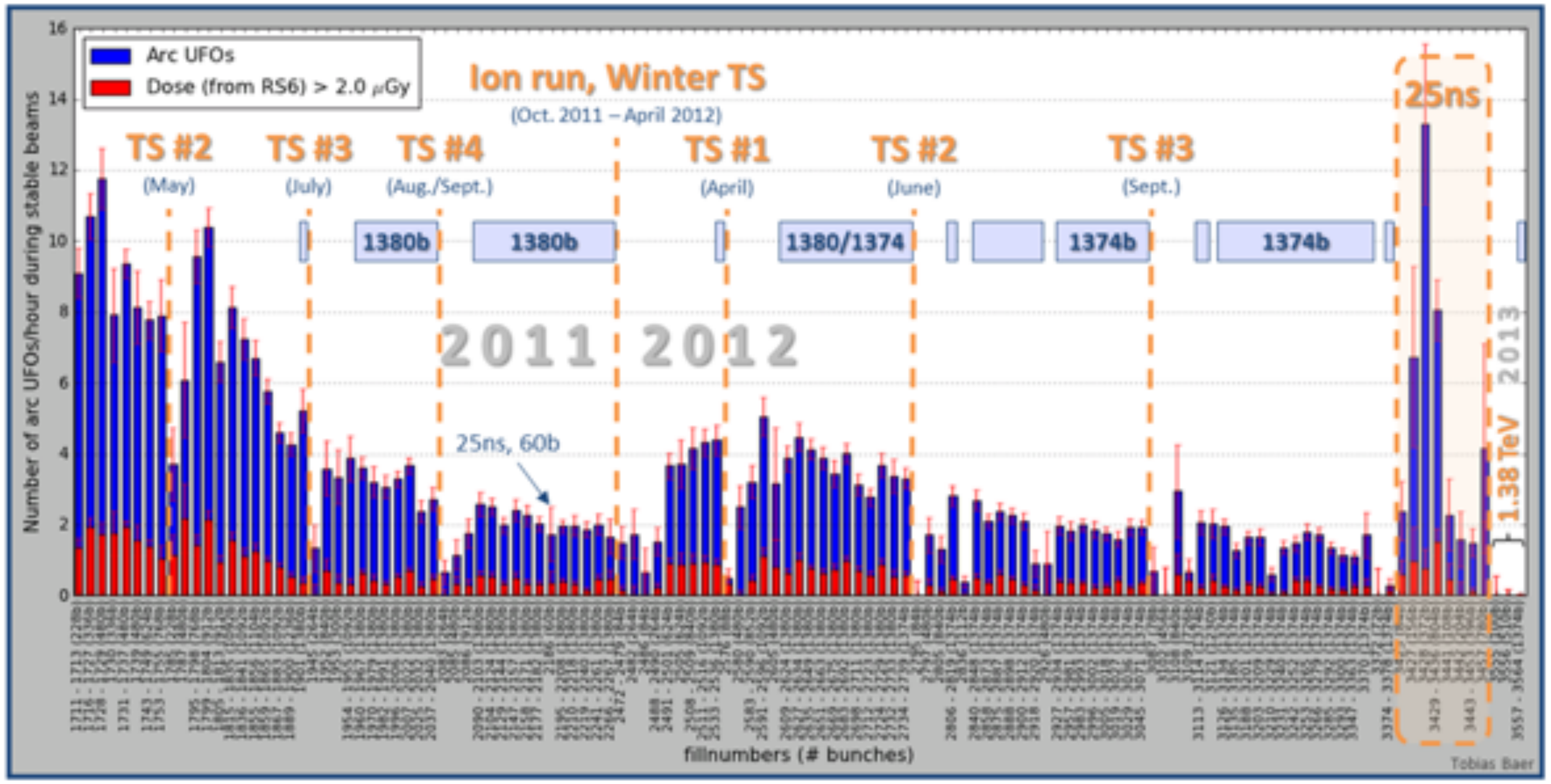
UFO losses

- UFO: Unidentified falling objects
- 58 beam dumps with similar characteristics:
  - Loss duration: few LHC turns
  - Unconventional loss locations (e.g. in the arc)
  - Events occur randomly throughout the LHC cycle

Reason: macro particles falling from Al_2O_3 ceramic tube



Courtesy of A.Gerardin, N.Garrel



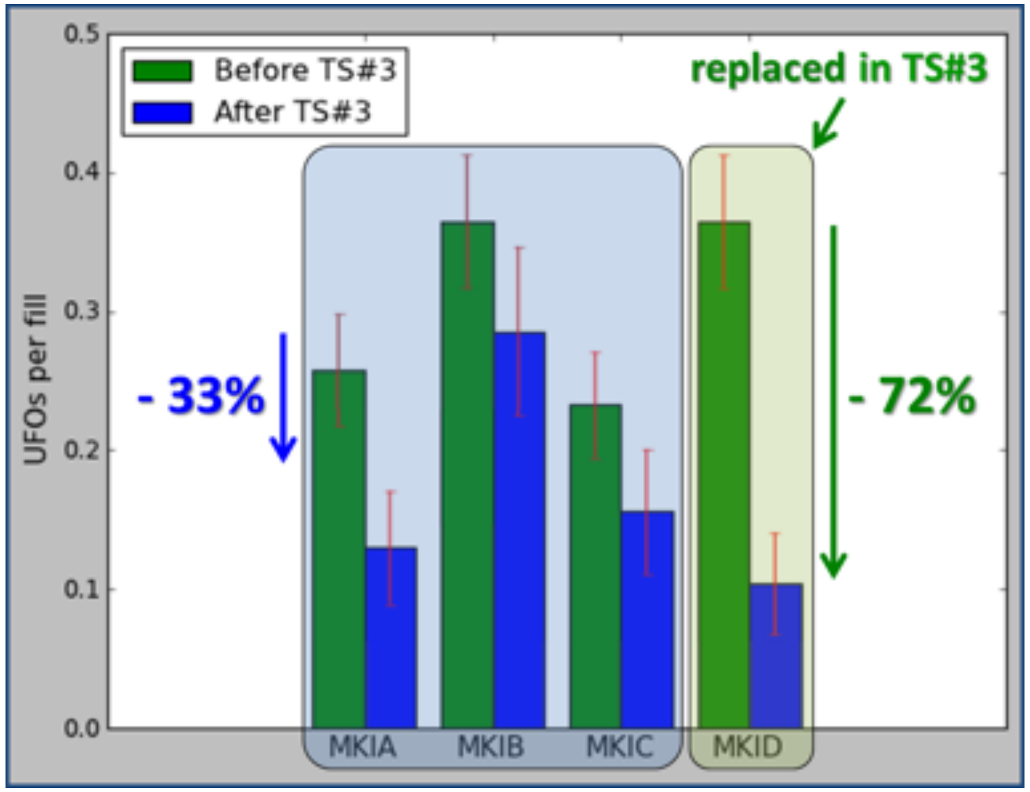
2011: *Decrease from ≈ **10 UFOs/hour** to ≈ **2 UFOs/hour.***

2012: *Initially, ≈ **2.5 times higher** UFO rate than in Oct. 2011. Decrease to ≈ **1 UFO/hour** since then. Initially over **10 times** higher UFO rate with **25ns.***

T.Baer PhD 2013

Refurbishing of the MKI

- UFO occurred all around the LHC but specially close to the injection kicker magnets.
- Mitigation procedure during LS1:
  - Improved cleaning procedure of the ceramic tube during installation of the screen conductors
  - Installing 24 (instead of 15, pre-LS1) screen conductors in the ceramic tube which is the aperture of the MKIs which will reduce the electric-field further and thus decreasing the UFO rate.



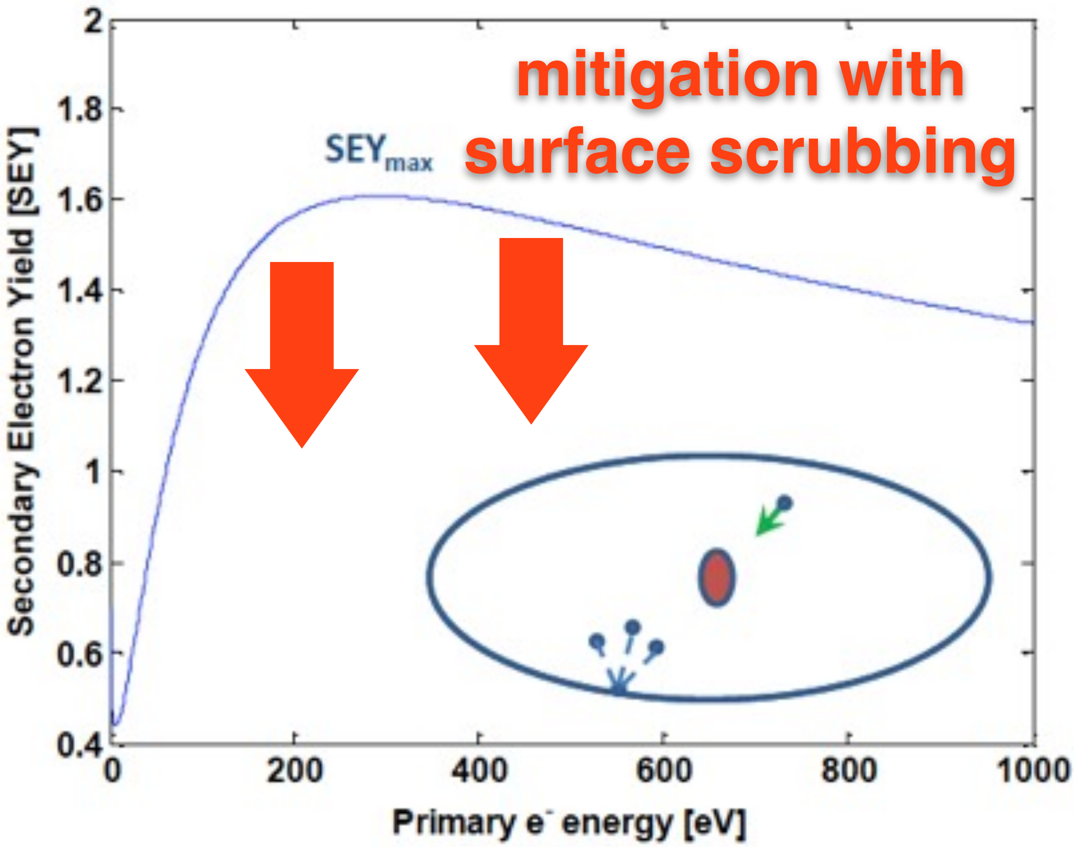
Cleaning was tested on an MKI in IP8 during 2012

Currently: The worst-case during LS1 is almost a factor 20 better than that measured for the MKI8D installed during TS3, 2012 – which itself was better than the pre-TS3 MKI8D.

T.Baer PhD
M.Barnes, LS1 activities

Electron cloud (EC)

- When an accelerator is operated with **close bunch spacing** an **Electron Cloud** can develop in the beam chamber due to Secondary Emission from the chamber's wall.
  - inducing instabilities, particle losses and emittance growth



In 2011, 4 days of scrubbing at 50ns beams + 2 days of tests with 25ns beam

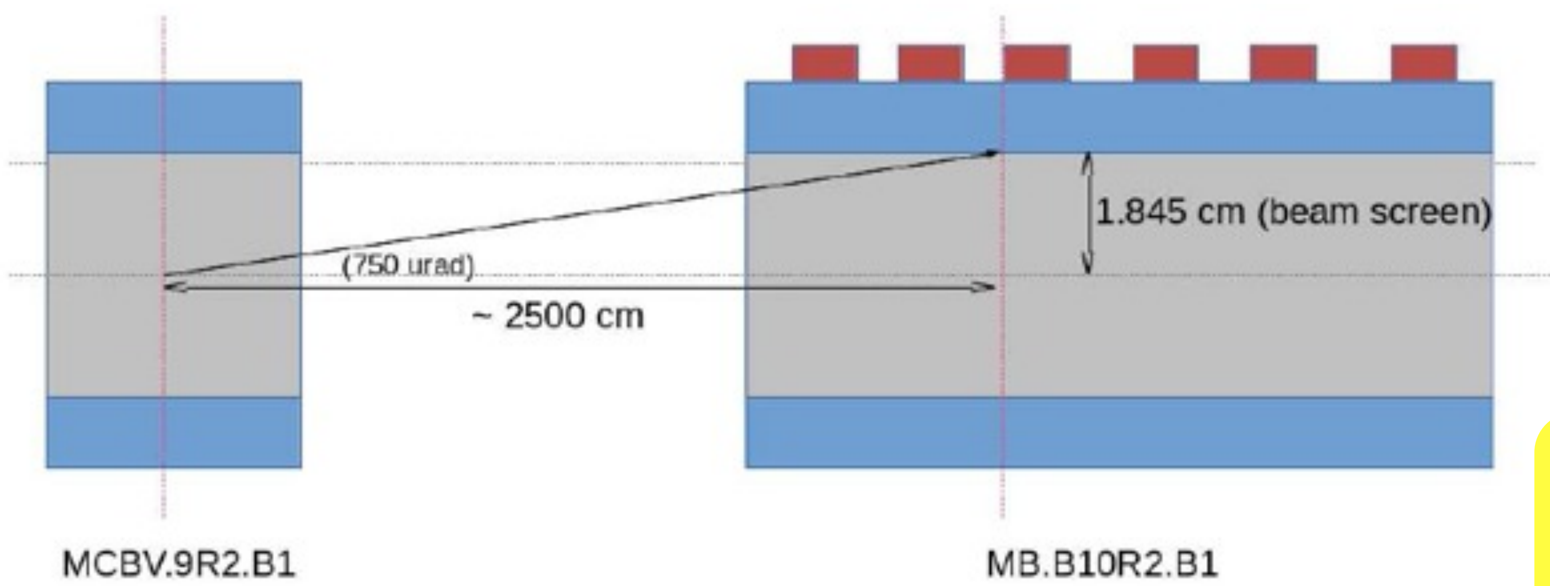
2012 : "EC free" operation

For operation at 25ns scrubbing runs at 450GeV only once is not enough

G.Arduini, Evian 2012

Quench @ 450GeV

- **2008/09/07** during aperture scan in IR2
- A bunch of **$2x10^9$ protons quenched an Main Dipole** in a large vertical kick (MB.B10R2.B2)
- Beam kicked with MCBCV.9R2.B1 with mistyped amplitude 750 µrad instead of 75 µrad



Used in 2008 for the analysis on quench level at injection energy. Documented in [LHC Project Note 422]
(B.Dehning, A.Priebe and M.Sapinski)

C.Bracco, A.Lecher, N.Vittal, 6th Quench tests Analysis WG
https://indico.cern.ch/event/309325/

Summary

- Main challenge for Run II will be to deal with 362MJ beams
- During 2012 on average:
  - 1-2% lost during squeeze
  - 1-2% lost during adjust
- Expect similar losses in Run II, keeping same collimator hierarchy
- About 5-10 times increased UFO activity with 25 ns (without mitigation measures). Extrapolation to 7TeV predicts about a factor of 4 more energy deposited, review of quench margins needed.
- At 25 ns it is expected important beam losses contribution from electron cloud, scrubbing runs are scheduled to mitigate it.

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