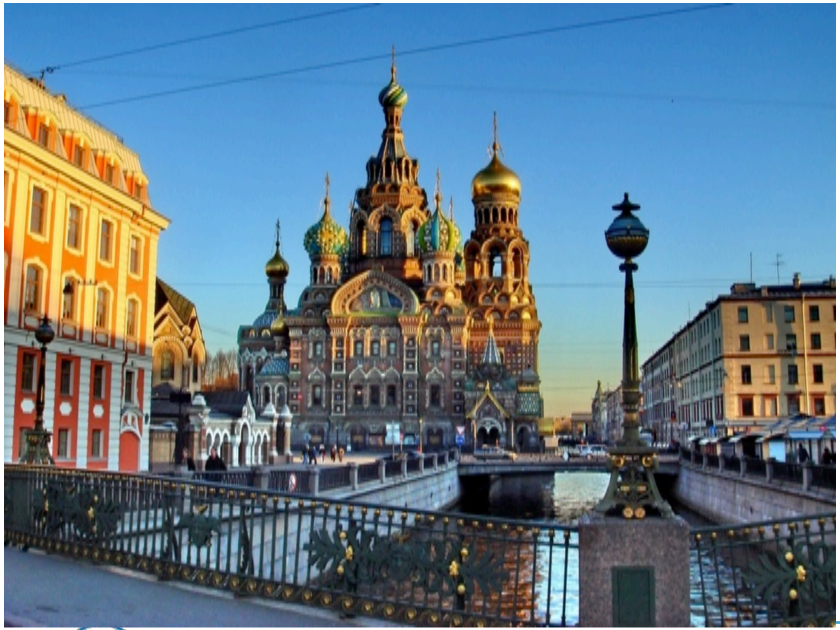
# LHC: Status and Outlook



LHCP2015

St. Petersburg, August 31, 2015

Sergio Bertolucci
CERN

# LHC in 2015

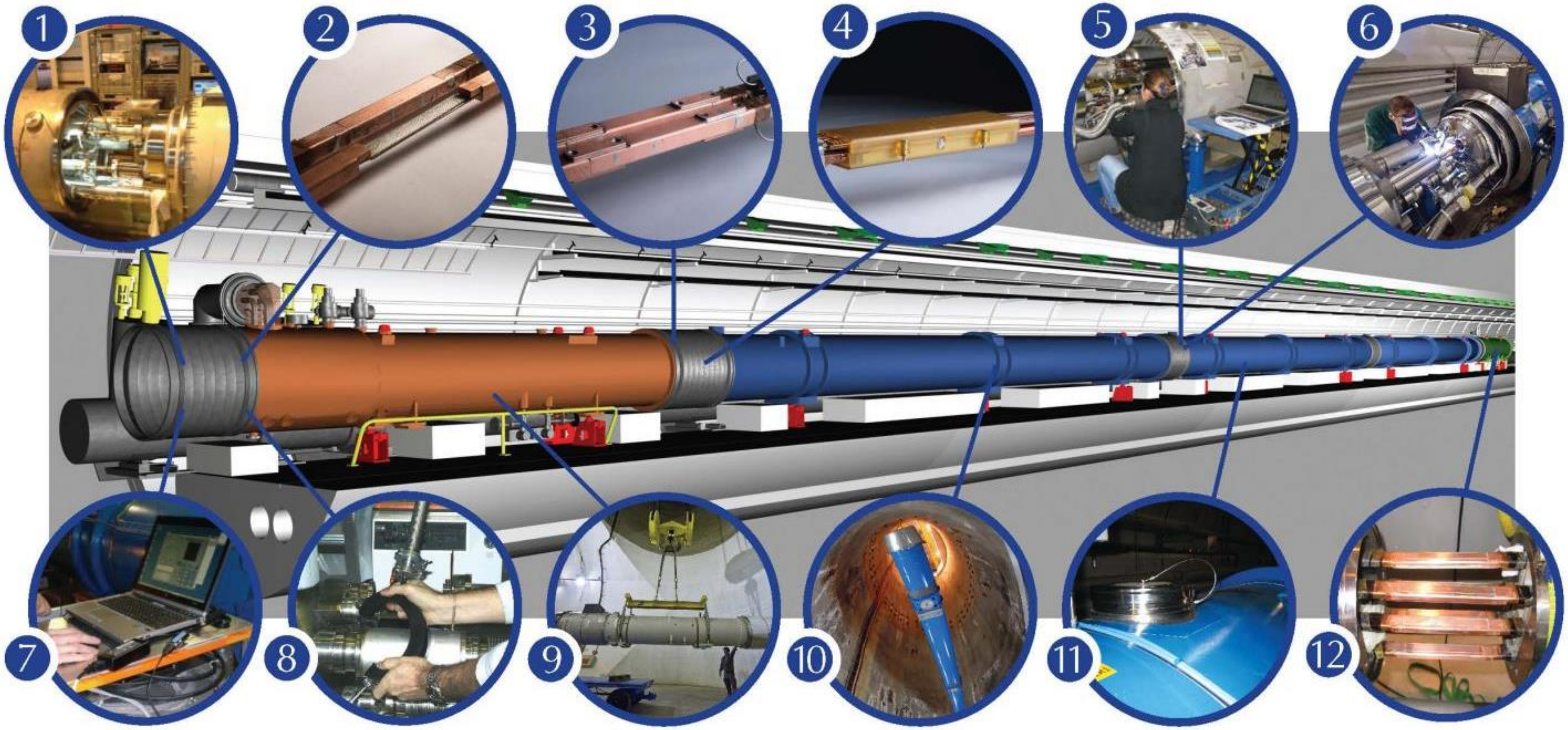
Priorities for the 2015 Run:

- Establish proton-proton collision at **13 TeV** with **25ns** and ***low*** $\beta^*$ to prepare production runs in 2016-2018.
- Optimise availability for physics
- Perform a Pb-Pb run at the end of 2015

The goal for Run 2 luminosity is **$1.3 \times 10^{34}$** $cm^{-2}\ s^{-1}$ and operation with **25 ns** bunch spacing (2800 bunches), giving an estimated pile-up of 40 events per bunch crossing.

# The main 2013-14 LHC consolidations

1. 1695 Openings and final reclosures of the interconnections
2. Complete reconstruction of 1500 of these splices
3. Consolidation of the 10170 13kA splices, installing 27 000 shunts
4. Installation of 5000 consolidated electrical insulation systems
5. 300 000 electrical resistance measurements
6. 10170 orbital welding of stainless steel lines



7. 18 000 electrical Quality Assurance tests
8. 10170 leak tightness tests
9. 3 quadrupole magnets to be replaced
10. 15 dipole magnets to be replaced
11. Installation of 612 pressure relief devices to bring the total to 1344
12. Consolidation of the 13 kA circuits in the 16 main electrical feedboxes

# LHC - 2015

- Target energy: 6.5 TeV
  - looking good after a major effort
- Bunch spacing: 25 ns
  - strongly favored by experiments – pile-up
- Beta* in ATLAS and CMS: 80 to 40 cm

**Energy**

- Lower quench margins
- Lower tolerance to beam loss
- Hardware closer to maximum (beam dumps, power converters etc.)

**25 ns**

- Electron-cloud
- UFOs
- More long range collisions
- Larger crossing angle, higher beta*
- Higher total beam current
- Higher intensity per injection

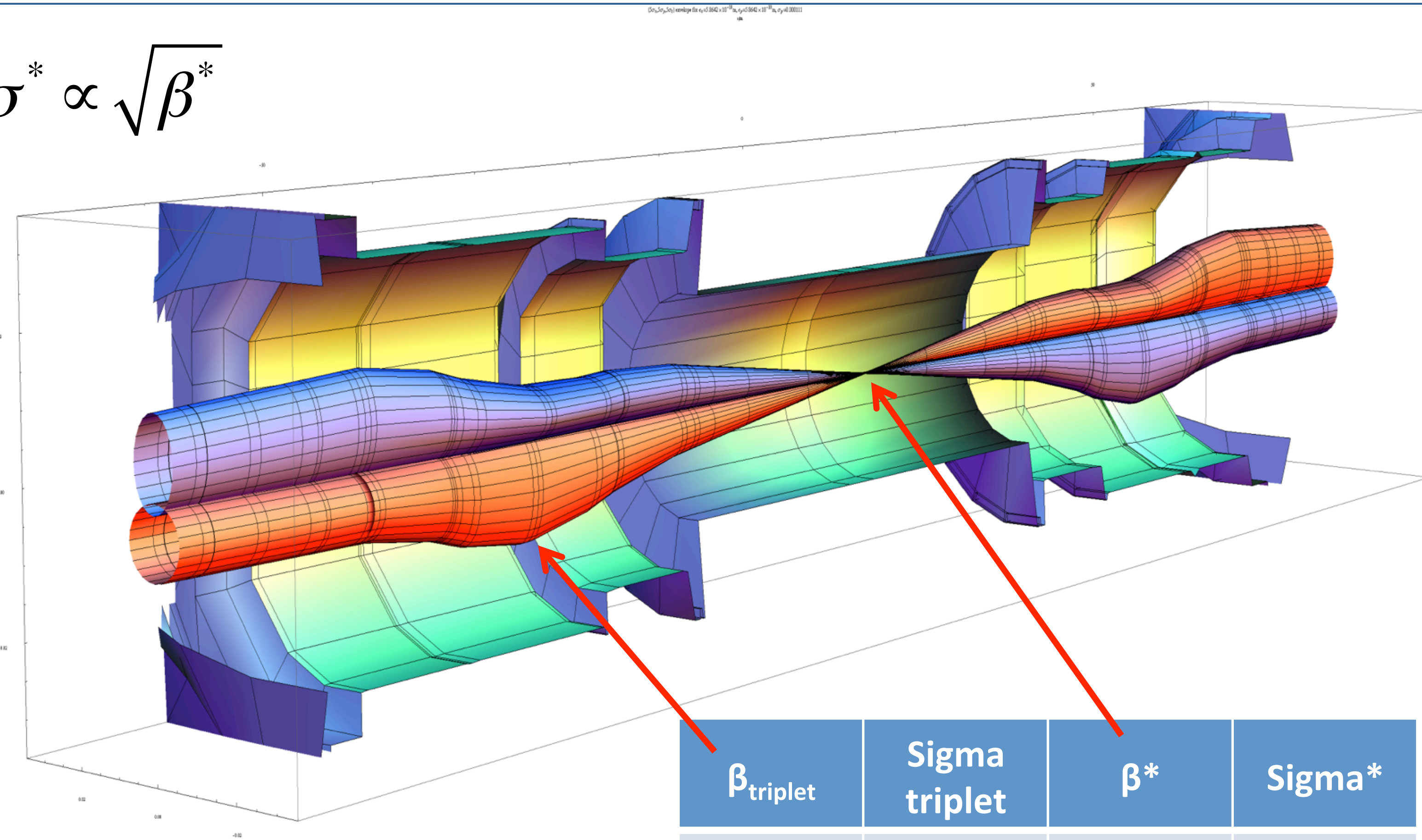
# Nominal LHC bunch structure

- 25 ns bunch spacing
- ~2800 bunches
- Nominal bunch intensity: 1.15 x $10^{11}$ protons per bunch

# Beta*

- Lower beta* implies larger beams in the triplet magnets
- Aperture concerns dictate caution

$$\sigma^* \propto \sqrt{\beta^*}$$



| $\beta_{triplet}$ | Sigma triplet | $\beta^*$ | Sigma* |
|---|---|---|---|
| ~4.5 km | 1.5 mm | 55 cm | 17 um |

Image courtesy John Jowett

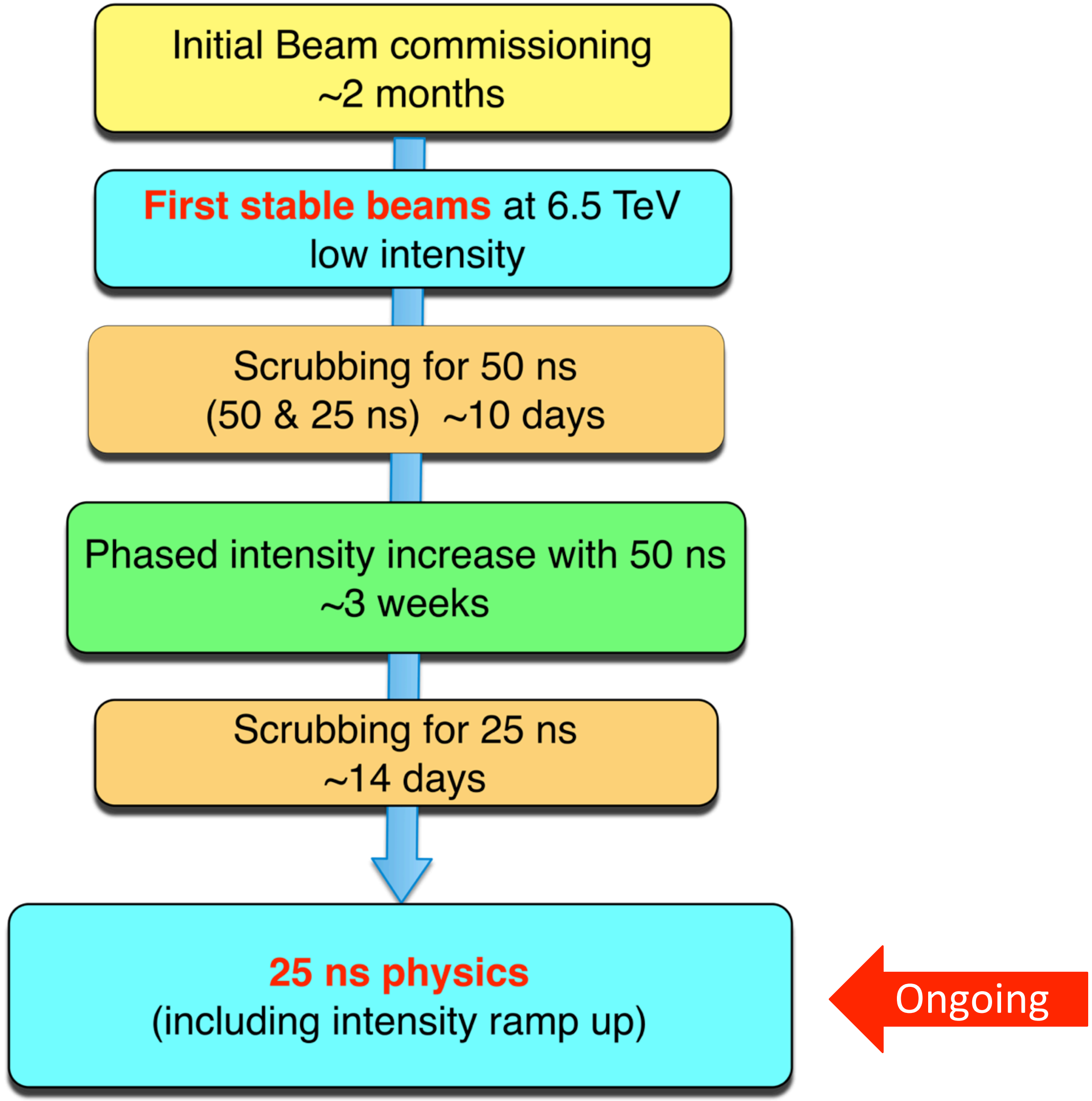
# 2015: beta* in IPs 1 and 5

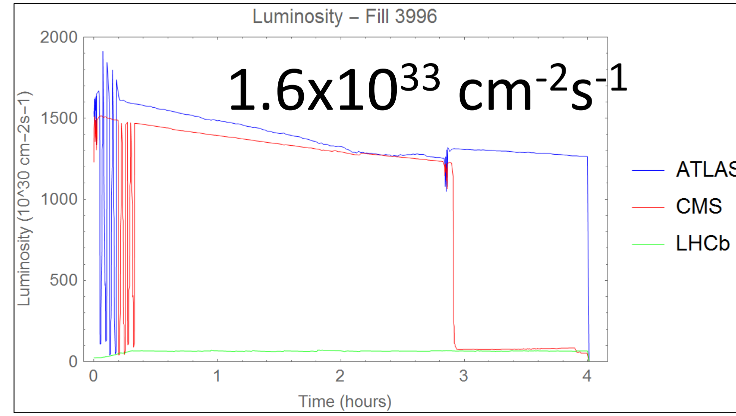
- Start-up: **$\beta^*$= 80 cm – (very) relaxed**
  - 2012 collimator settings
  - 11 sigma long range separation-> crossing angle
  - Check aperture, orbit stability… looking good

- Ultimate in 2015 and Run 2: **$\beta^*$= 40 cm**
  - Possible reduction later in the year

$$\mathcal{L} \propto \frac{1}{\beta^*}$$

# 2015 commissioning strategy



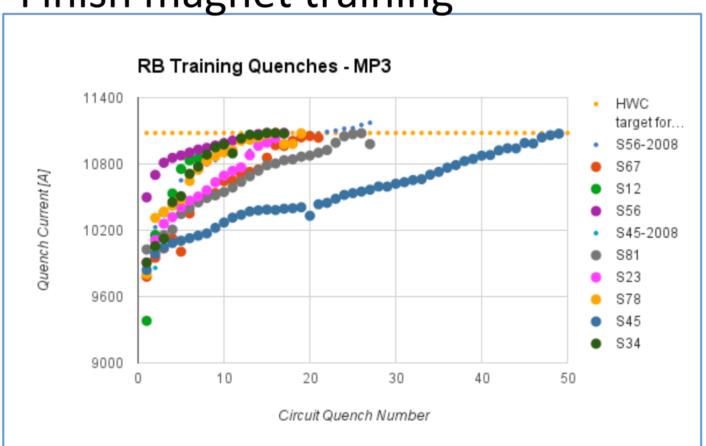



5th April first beam

10th April: 6.5 TeV for the first time

July 14th: 476b (50 ns)

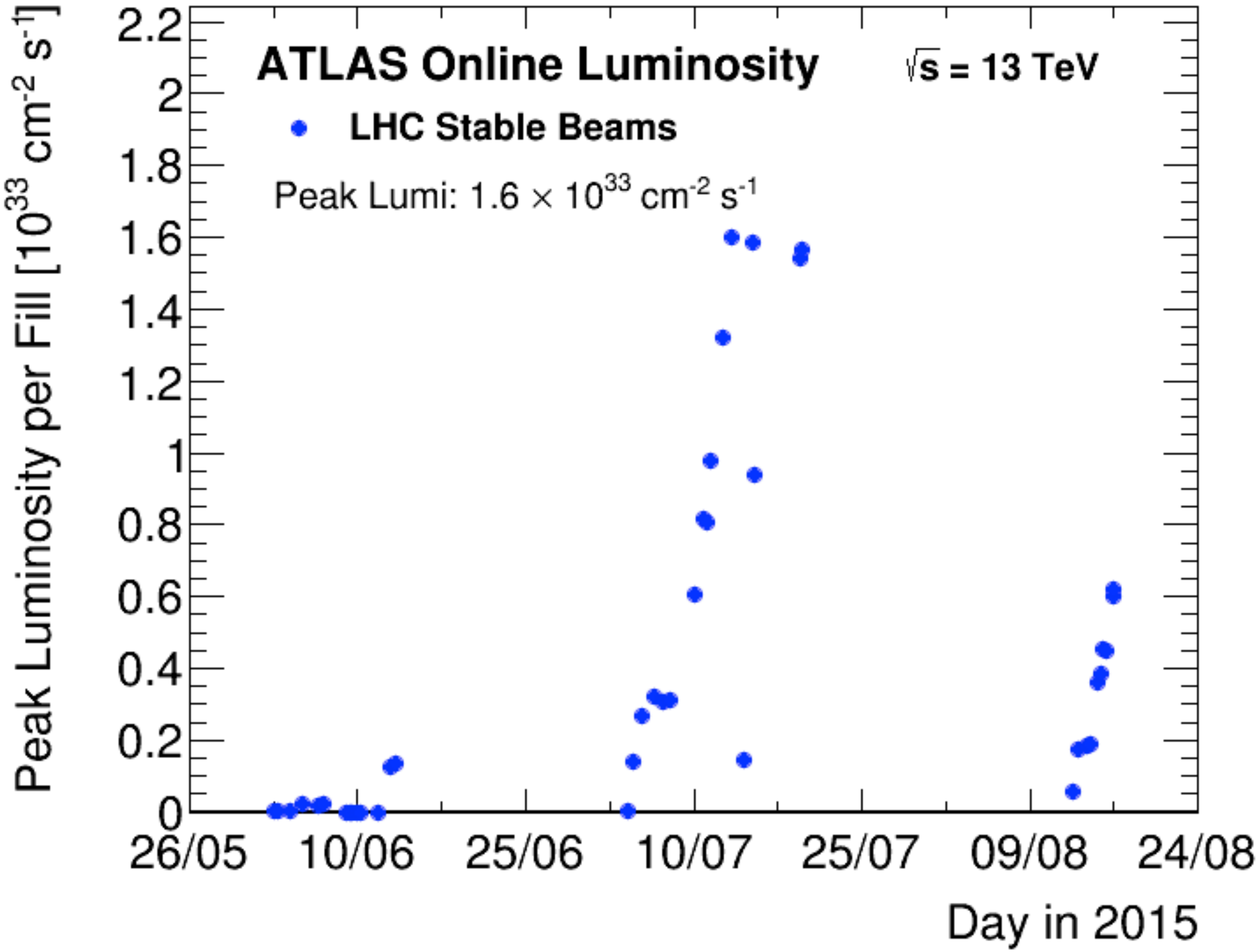

Finish magnet training




3rd June: First Stable Beams

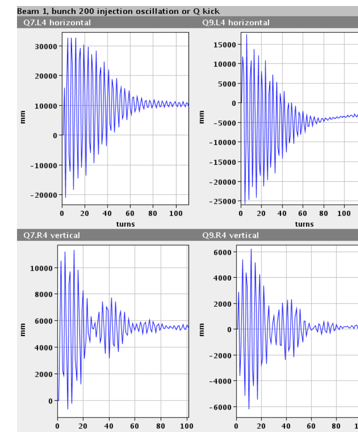
25 ns
219 bunches

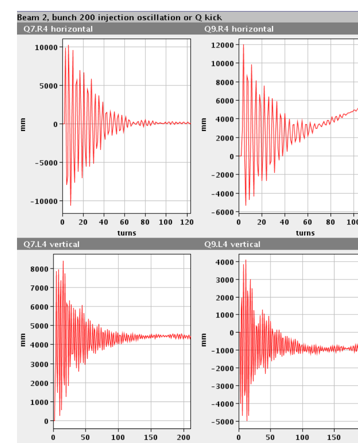
2015


ATLAS Online Luminosity
$\sqrt{s}$ = 13 TeV
LHC Stable Beams
Peak Lumi: 1.6 × 10^33 cm^-2 s^-1
Peak Luminosity per Fill [10^33 cm^-2 s^-1]
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
26/05
10/06
25/06
10/07
25/07
09/08
24/08
Day in 2015

# Initial commissioning 1/2

- **A lot of lessons learnt from Run 1**
- Excellent and improved system performance:
  - Beam Instrumentation
  - Transverse feedback
  - RF
  - Collimation
  - Injection and beam dump systems
  - Vacuum
  - Machine protection
- Improved software & analysis tools
- Experience!



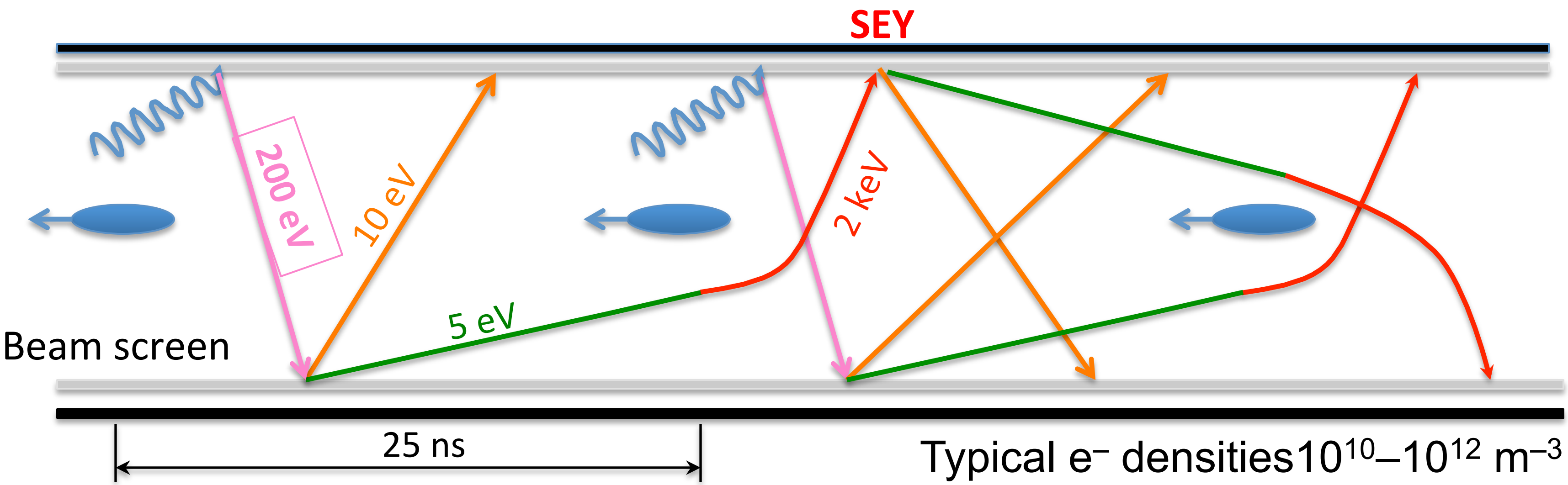
# Initial commissioning 2/2

- Magnetically reproducible as ever
- Optically good, corrected to excellent
- Aperture is fine and compatible with the collimation hierarchy.
- Magnets behaving well at 6.5 TeV
  - 11 additional training quenches
- Operationally things well under control
  - Injection, ramp, squeeze etc.

# Main issues

- Electron Cloud
- Quench Protection System (mQPS) non radiation hard components
- TDI protection device
- Unidentified Falling Objects (UFOs)
  - Distributed around the ring
- Earth faults (not intensity related)
  - RCS.A78B2 - 154 sextupole correctors on main dipoles
  - Main dipoles A78

# 25 ns & electron cloud




Possible consequences:

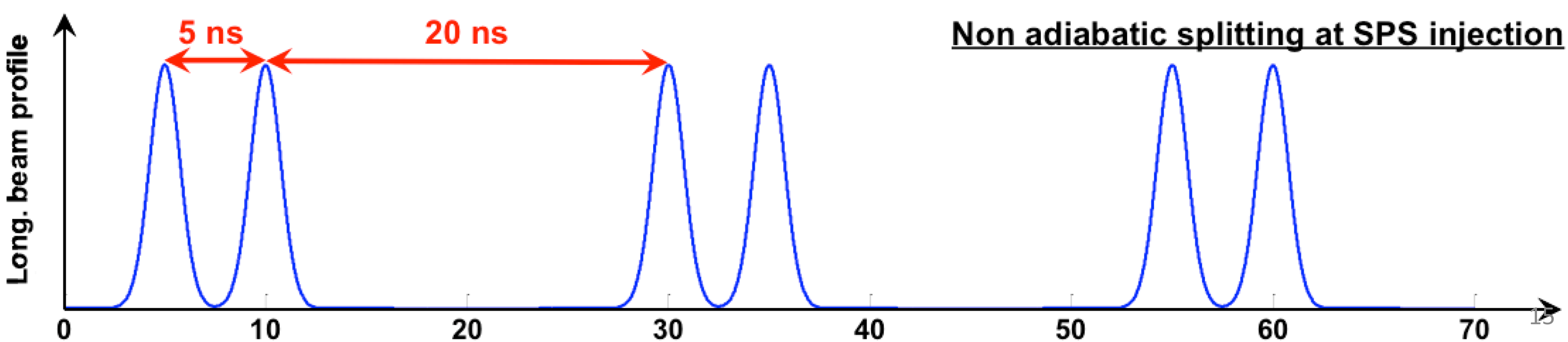
- instabilities, emittance growth, desorption – bad vacuum
- excessive energy deposition in the cold sectors

Electron bombardment of a surface has been proven to reduce drastically the **secondary electron yield (SEY)** of a material. This technique, known as **scrubbing**, provides a mean to suppress electron cloud build-up.

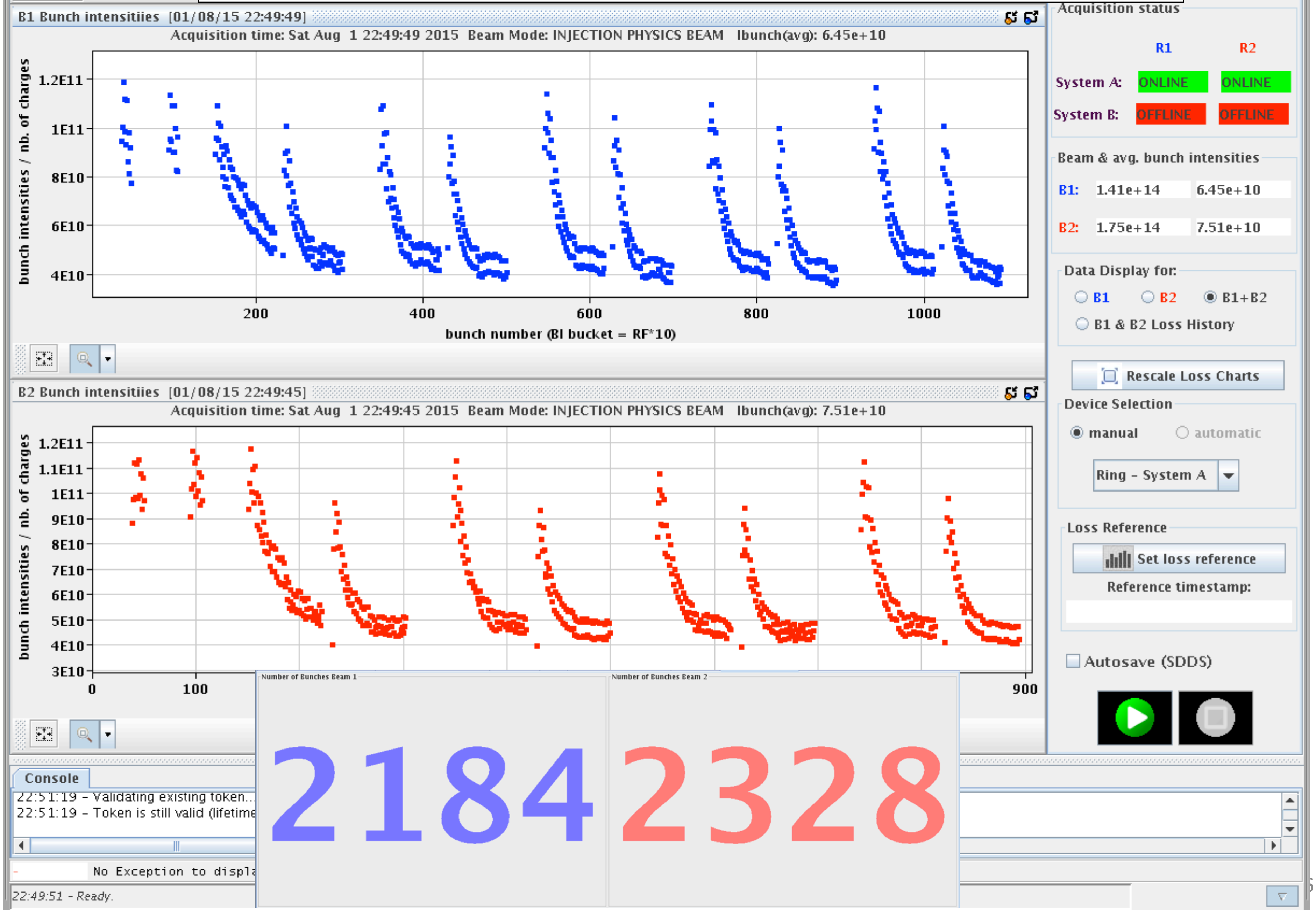
**Electron cloud significantly worse with 25 ns**

# Scrubbing 2015

- More scrubbing than in 2012 was mandatory
- Doublet scrubbing beam looked attractive…
- A two stage scrubbing strategy was pursued:
  - Scrubbing 1 (50 ns and 25 ns) to allow for operation with 50 ns beams at 6.5 TeV
  - Scrubbing 2 (25 ns and Doublet) to allow for operation with 25 ns beams at 6.5 TeV

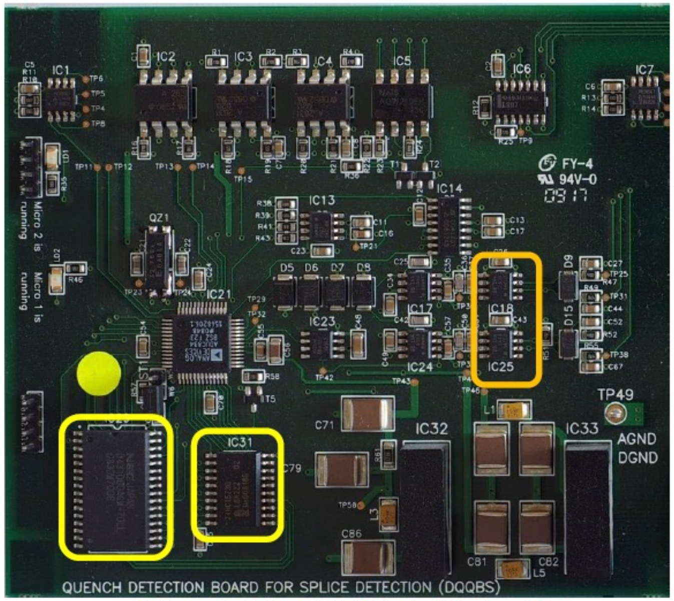


# Scrubbing phase 2…



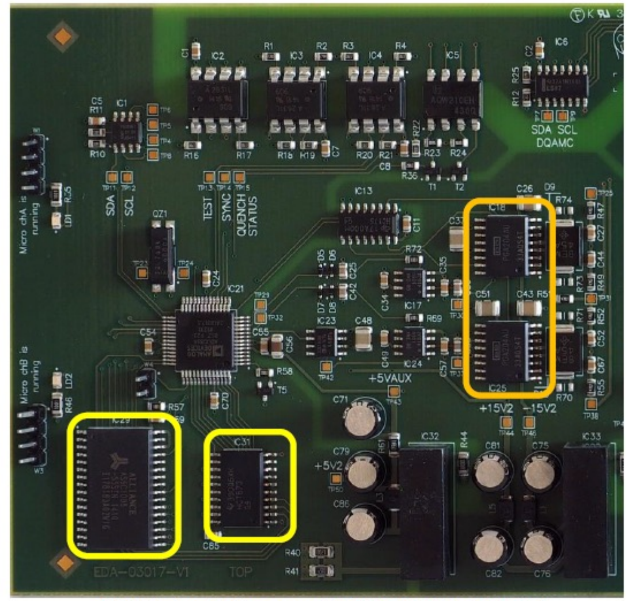
## Origin of the SEU problem – recall
## Relevant differences between mDQQBS and DQQBS

**DQQBS**




SRAM: NEC D431000AGW-70LL
D-Latch: NXP 74HCT573
Amplifier: INA141

**mDQQBSv2/v3**



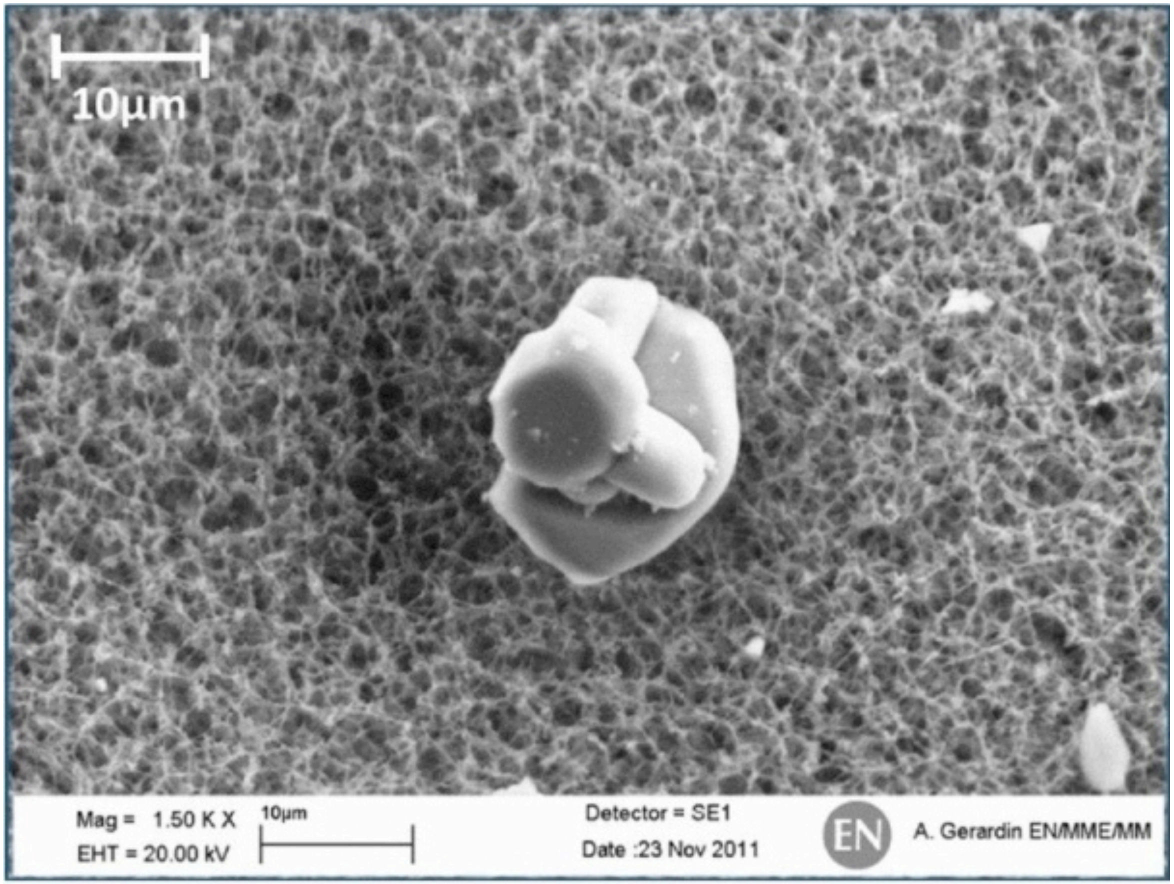
SRAM: Alliance AS6C1008-55SIN
D-Latch: TI 74HCT573
Amplifier: PGA204
Different batch of ADuC834

CERN

- 1268 modified boards used for special tests (CSCM) during circuit re-commissioning.
- **Should have come out**
- To be replaced during upcoming technical stop

# UFOs

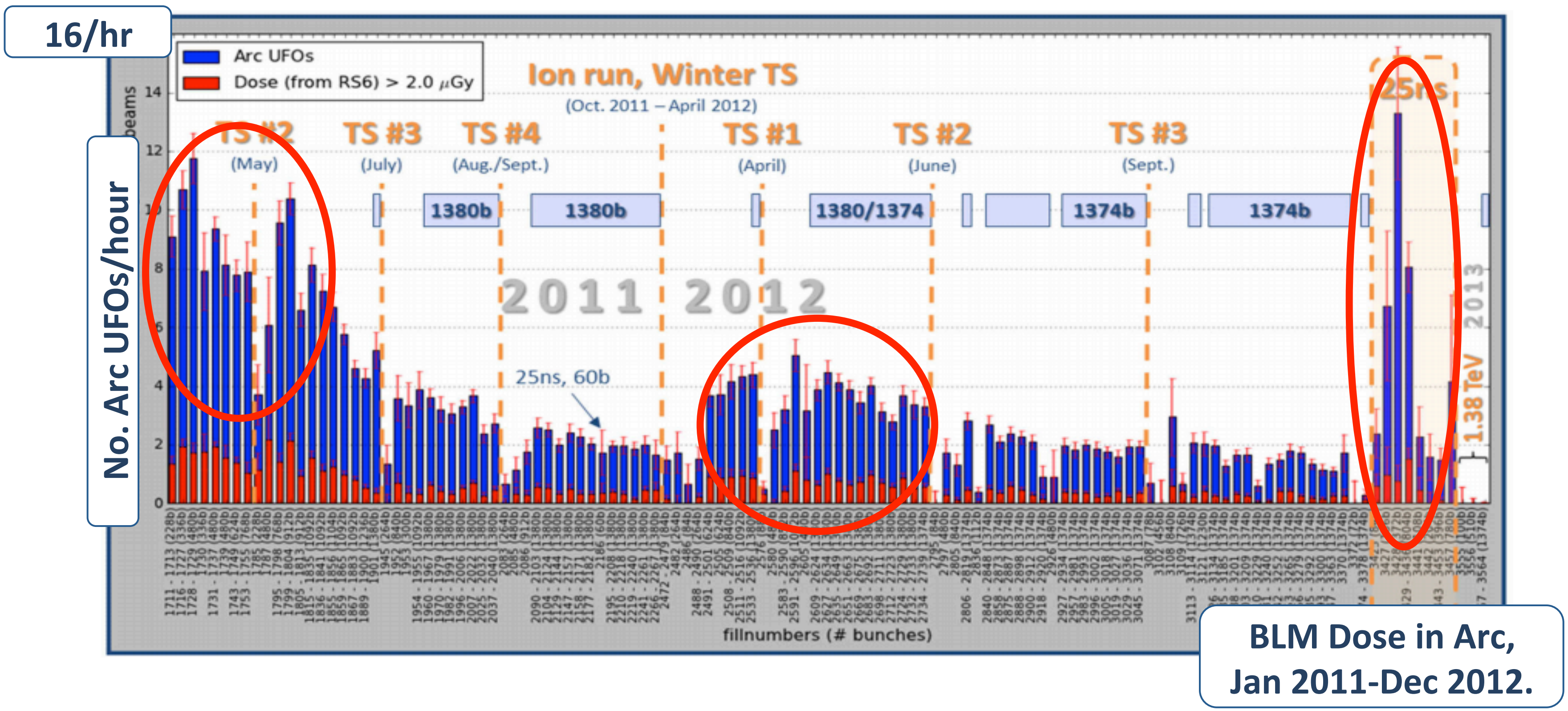
**A nice picture of some dust**




**T. Baer CERN-THESIS-2013-233**

# UFOs - strategy

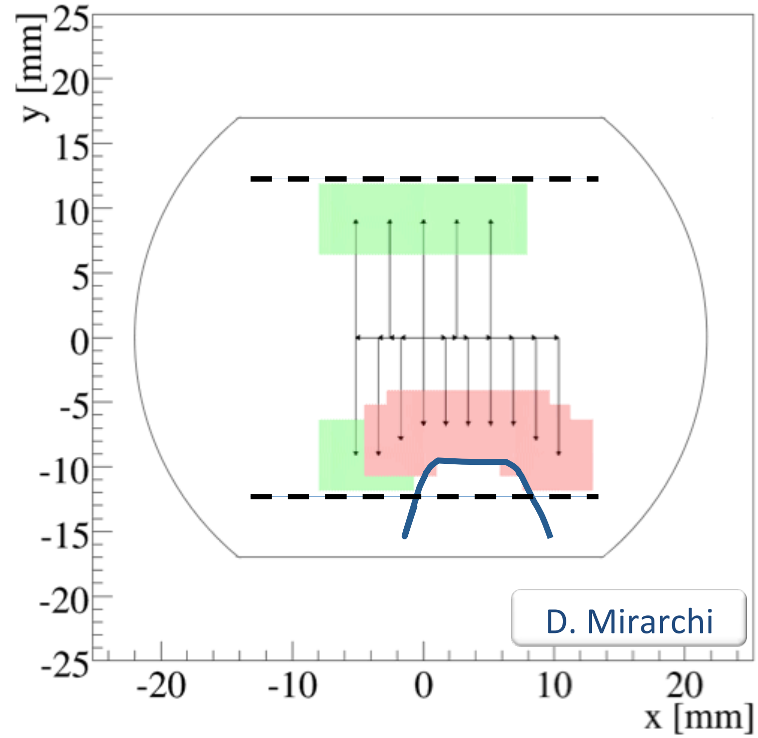
- **No. of UFO events** have been seen to **exceed 10+/hour** with notable increases after long shutdowns and or with a decrease in bunch spacing




- Beam loss monitor thresholds have been set judiciously
- Essentially relying on conditioning
- Other variables: total beam intensity, beam size

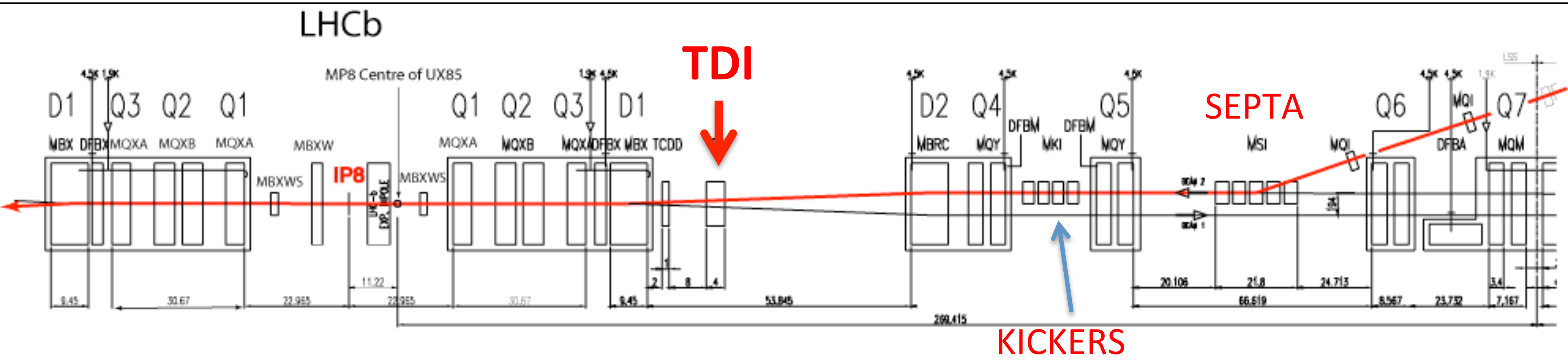
# Aperture restriction in 15R8
## ULO (Unidentified Lying Object)

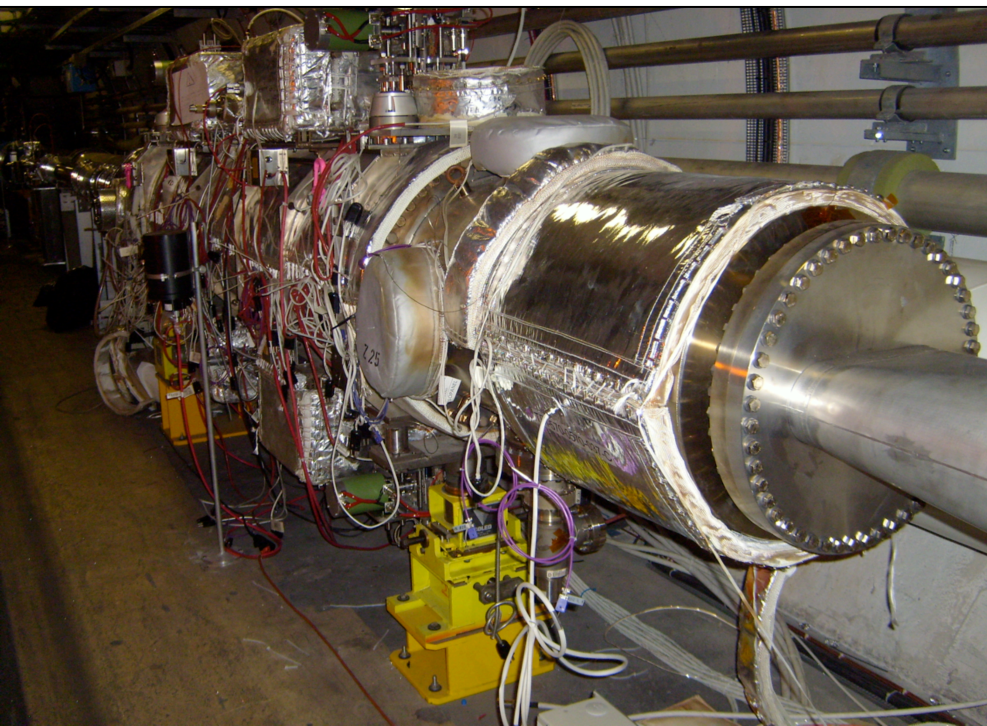
- Aperture restriction measured at injection and 6.5 TeV
- Presently running with orbit bumps
  - -3 mm in H, +1 mm in V, to optimize available aperture
- Behaviour with higher intensities looks OK



# TDI (Injection protection devices)

**TDI: movable vertical absorbers – 4.2 m in length – down stream of injection kickers**



- Main blocks: hex-boron-nitride
- However during bake-out tests…

# TDI.R8

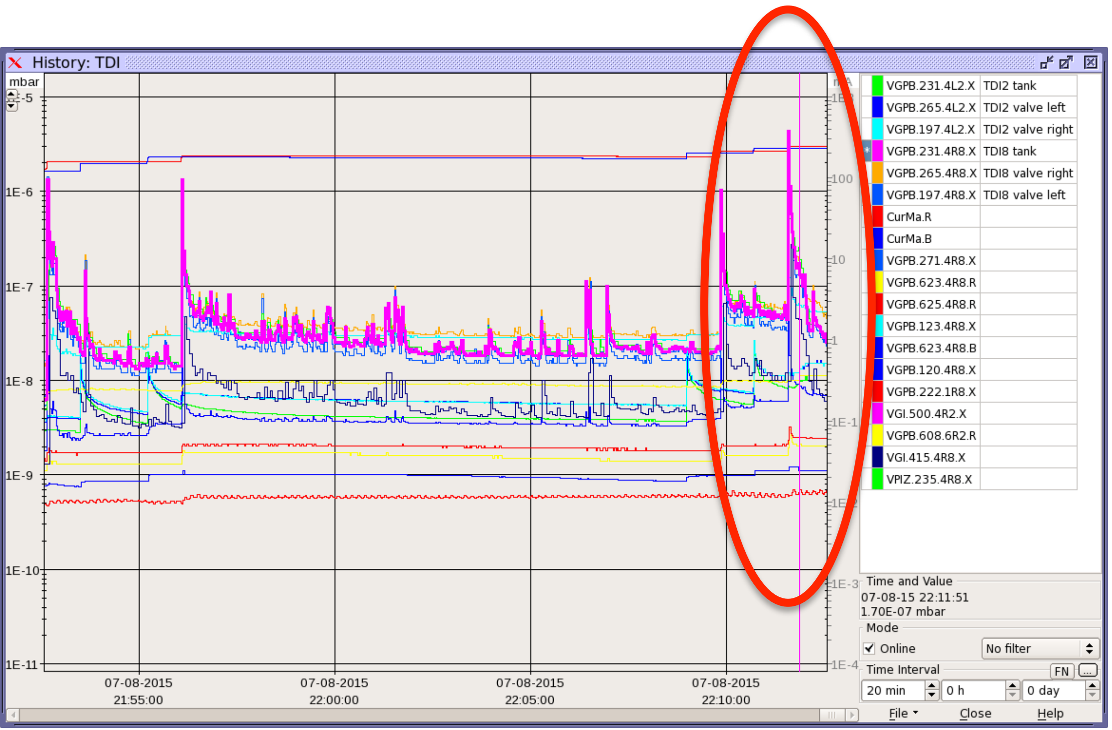
- TDI hBN block cannot withstand temperatures higher than 450 °C ($B_2O_3$ reactant melting temperature)
- Limitation on number of injection to avoid potential damage (maximum allowed temperature = 400 °C )

**Limits of ~2 PS batches per injection (144b) from the injection protection absorbers will reduce the maximum number of bunches to around 2400**

**BN block to be replace with graphite in YETS – temporary limitation**

# TDI beam 2 - vacuum

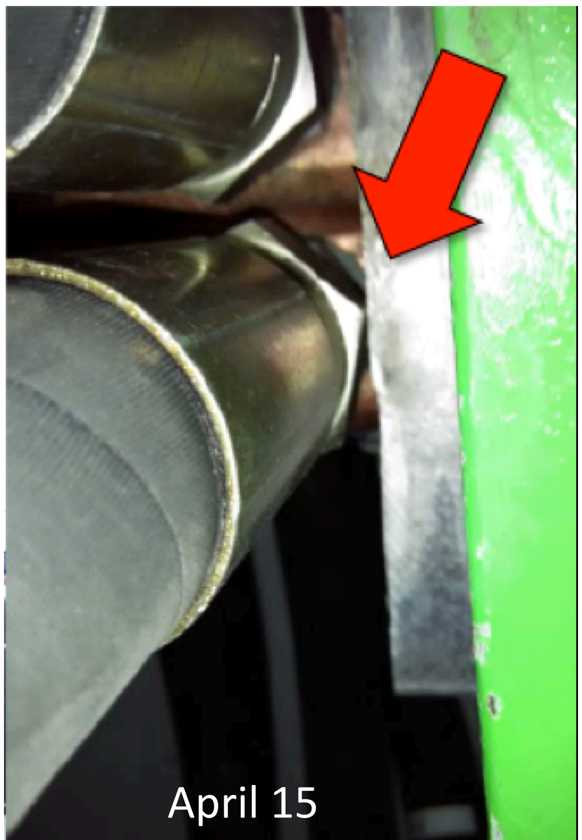
- In addition during scrubbing, heating and outgassing of TDI right of point 8 has been observed
  - Vacuum spikes up to and above interlock limits

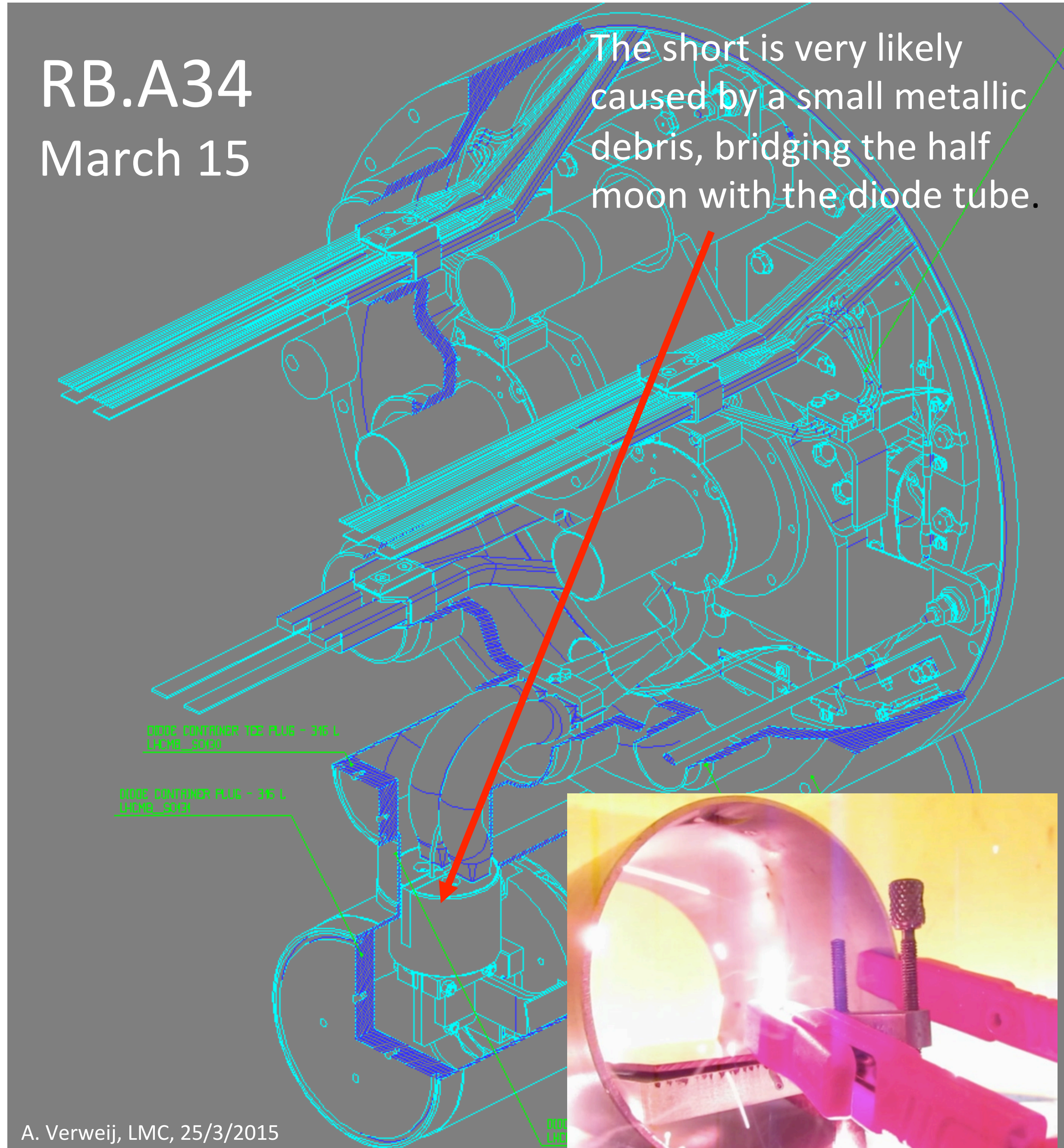



- Investigations of mitigation measures in progress
- For the moment we are assuming a (soft) limit of around 1200 bunches

# Earth faults earlier in the year

RB.A78 – contact between water cooled cables and protection covers



# Q3/Q4 2015 - latest

# Experiments Status

- Following the LHC intensity ramp-up, using beams for calibrations, alignment, debugging…and physics!
- Detectors generally in excellent shape
  - The main outstanding issue, the CMS solenoid cryogenics, is being solved

# 2015 performance - comments

- Time is limited
- Scrubbing for 25 ns is not complete
  - Wrestle with electron cloud above ~1500 bunches
- TDI.R8 will provide a soft limit of around 1200 bunches
  - Will be pushed
- Luminosity potential could be increased by a judicious choice of beam and beta*
  - Low emittance (BCMS scheme) and an intermediate beta* (60 cm) are being considered.

# 2015: ATLAS and CMS performance

- Beta* = 80 cm, or ~60 cm
- Nominal bunch population
- Nominal emittance into collisions, or lower
- **>> Assume Injection limit for 25 ns: max colliding bunches 1200**
- **Moderate availability plus need for intensity ramp-up**

| | Nc | Beta * | ppb | EmitN | Lumi [$cm^{-2}s^{-1}$] | Days (approx) | Int lumi | Pileup |
|---|---|---|---|---|---|---|---|---|
| 50 ns | 476 | 80 | 1.1e11 | 1.8 | 1.6e33 | 14 | 0.1 $fb^{-1}$ | 27 |
| 2015.1 | 1200 | 80 | 1.2e11 | 3.5 | 3.6e33 | 50 | ~2.3 $fb^{-1}$ | 21 |
| 2015.2 | 1200 | 60 | 1.2e11 | 2.3 | 5.6e33 | 47 | ~3.4 $fb^{-1}$ | 33 |

**Detailed limitations lead to a modest total for the year**
**Still getting to grips with the issues…**

# LHCb & ALICE

- LHCb (pile-up limited) will also suffer if the number of bunches is limited.
- ALICE – 5e29 to 2e30 $cm^{-2}s^{-1}$ - min. impact

| LHCb | Levelled lumi [$cm^{-2}s^{-1}$] | Days (approx) | Int lumi $fb^{-1}$ | Pileup |
|---|---|---|---|---|
| 25 ns | 4e32 | 50 | 0.5 | 1.1 |
| 25 ns (1200b) | 2e32 | 50 | 0.3 | 1.2 |

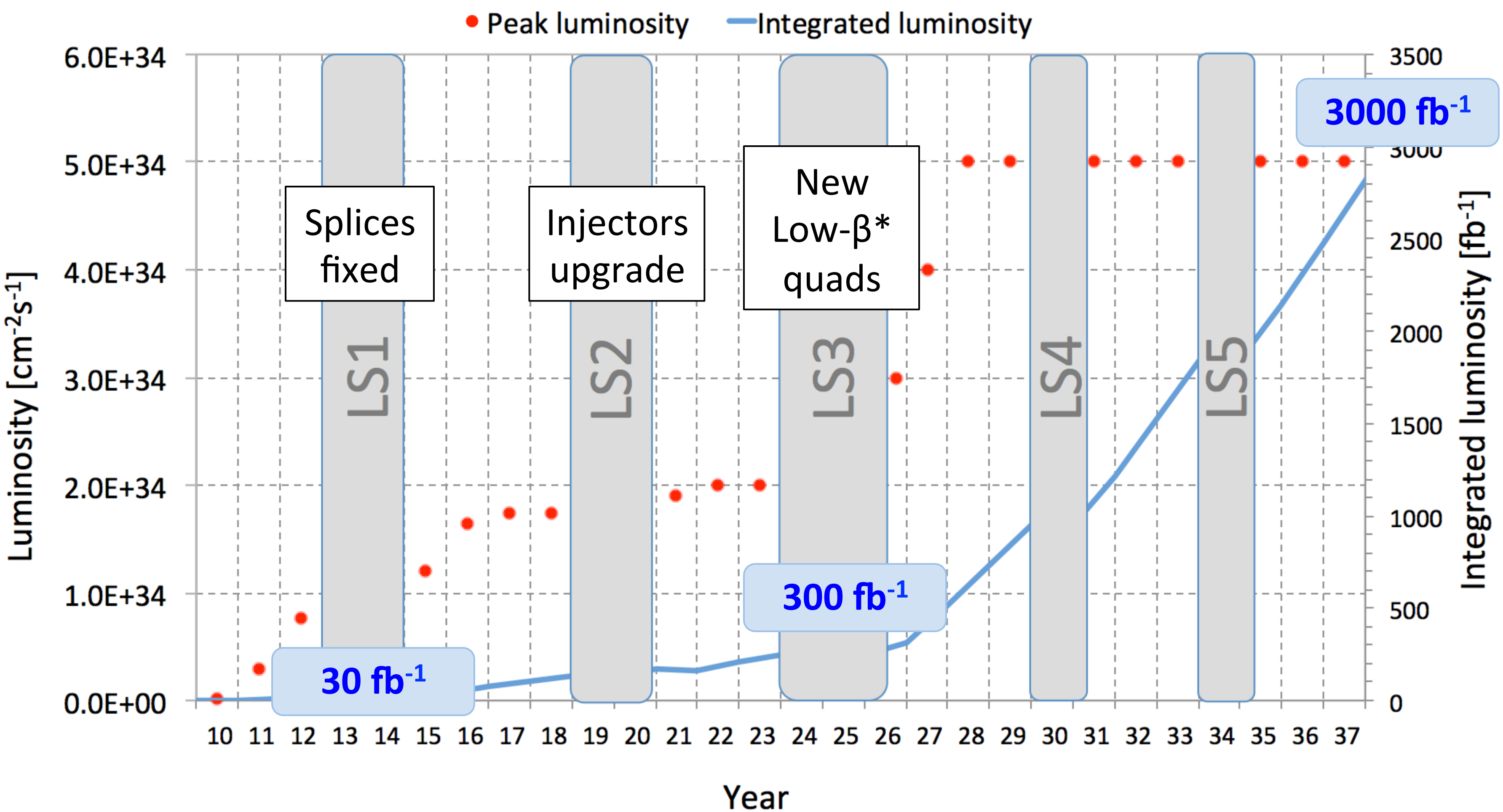
- 30% physics efficiency (~36% in 2012)

# Run 2 performances

- Start 2016 in production mode
  - 6.5 TeV, machine scrubbed for 25 ns operation
  - Beta* = 40 cm in ATLAS and CMS
  - New injection protection absorbers
  - Peak lumi limited to 1.7e34 by inner triplets
  - Reasonable availability assumed – usual caveats apply – really need to gain experience with 25 ns operation

| | Peak lumi E34 $cm^{-2}s^{-1}$ | Days proton physics | Approx. int lumi [$fb^{-1}$] |
|---|---|---|---|
| 2015 | ~0.5 | 65 | 3 |
| 2016 | 1.2 | 160 | 30 |
| 2017 | 1.5 | 160 | 36 |
| 2018 | 1.5 | 160 | 36 |

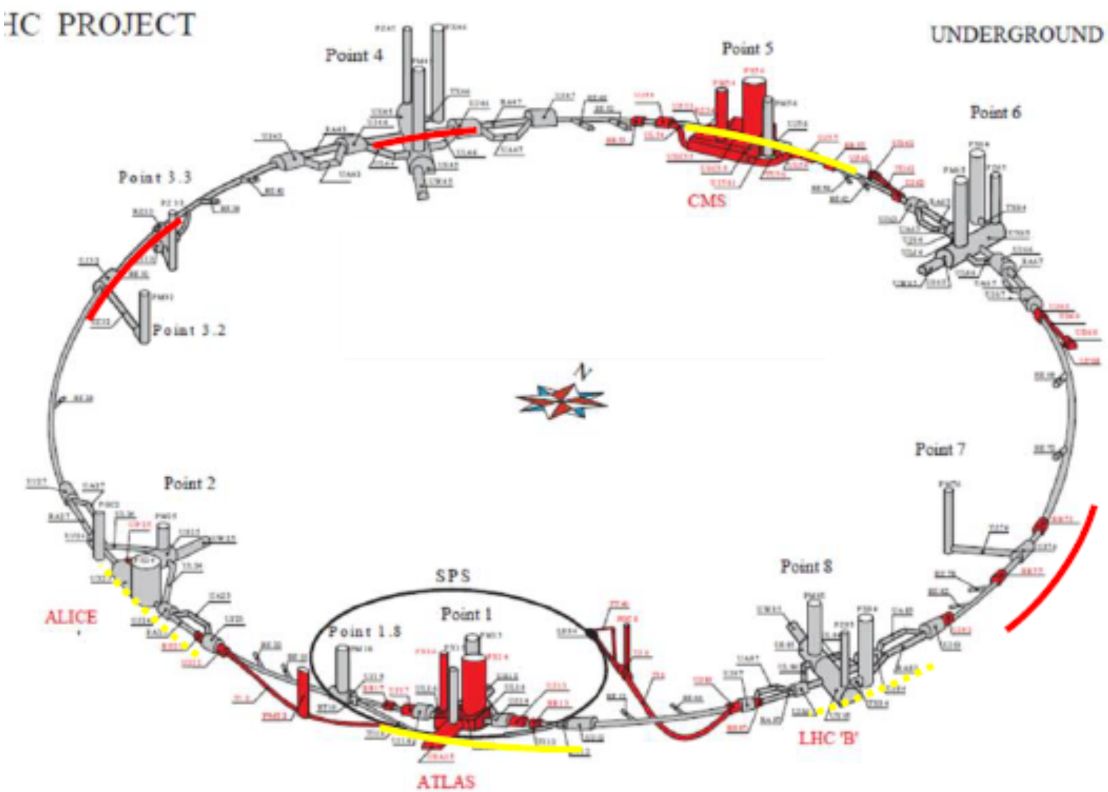
# And beyond




LHC is highest-E, highest-L operational collider → full exploitation ($\sqrt{s}$ ~ 14 TeV, 3000 fb$^{-1}$) is mandatory:

FG EPS 15

# The HL-LHC Project

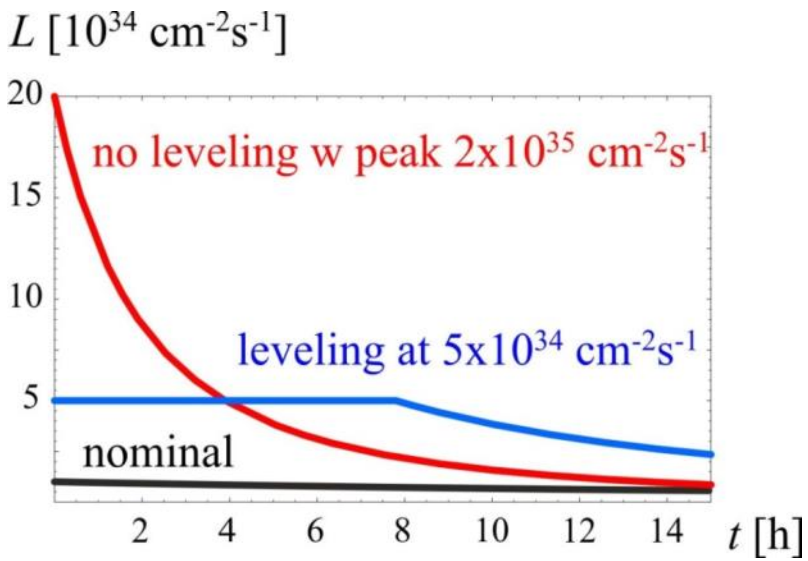



- New IR-quads $Nb_3Sn$ (inner triplets)
- New 11 T $Nb_3Sn$ (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- …

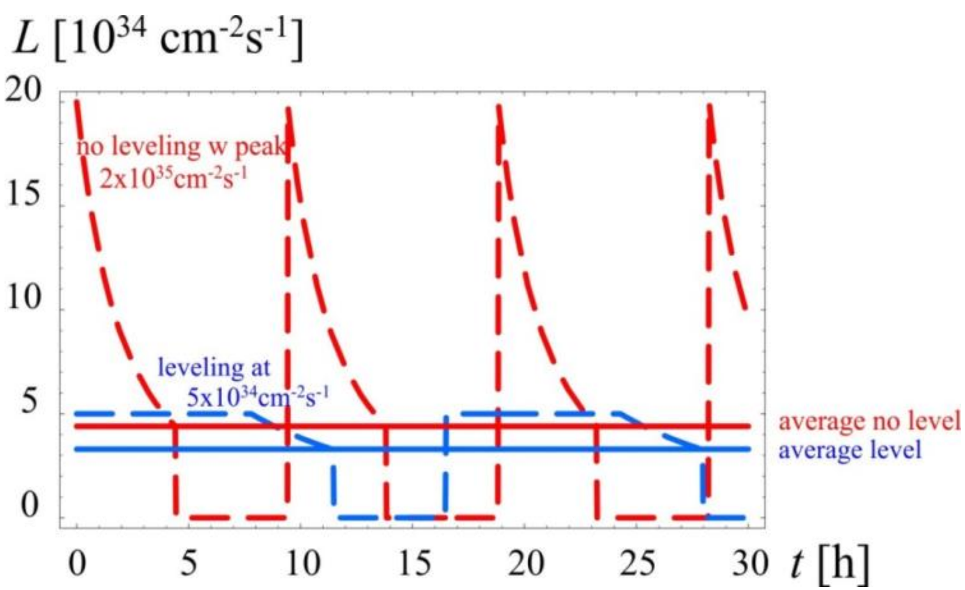
**Major intervention on more than 1.2 km of the LHC**

**Project leadership: L. Rossi and O. Brüning**

# Luminosity Levelling, a key to success




- High peak luminosity
- Minimize pile-up in experiments and provide "constant" luminosity




- Obtain about 3 - 4 $fb^{-1}$/day (40% stable beams)
- About 250 to 300 $fb^{-1}$/year

# Baseline parameters of HL for reaching 250 -300 $fb^{-1}$/year

**25 ns is the option**

**However:**

**50 ns should be kept as alive and possible because we DO NOT have enough experience on the actual limit *(e-clouds, $I_{beam}$)***

| | 25 ns | 50 ns |
|---|---|---|
| # Bunches | 2808 | 1404 |
| p/bunch [$10^{11}$] | **2.0 (1.01 A)** | **3.3 (0.83 A)** |
| $\varepsilon_L$ [eV.s] | 2.5 | 2.5 |
| $\sigma_z$ [cm] | 7.5 | 7.5 |
| $\sigma_{\delta p/p}$ [$10^{-3}$] | 0.1 | 0.1 |
| $\gamma\varepsilon_{x,y}$ [$\mu$m] | **2.5** | **3.0** |
| $\beta^*$ [cm] (baseline) | 15 | 15 |
| X-angle [$\mu$rad] | **590 (12.5 $\sigma$)** | **590 (11.4 $\sigma$)** |
| Loss factor | 0.30 | 0.33 |
| Peak lumi [$10^{34}$] | 6.0 | 7.4 |
| Virtual lumi [$10^{34}$] | 20.0 | 22.7 |
| $T_{leveling}$ [h] @ 5E34 | **7.8** | **6.8** |
| #Pile up @5E34 | 123 | 247 |

Continuous global optimisation with LIU

# The detectors challenge

In order to exploit the LHC potential, experiments have to maintain full sensitivity for discovery, while keeping their capabilities to perform precision measurements at low $p_T$, in the presence of:

- Pileup
  - <PU> ≈ 50 events per crossing by LS2
  - <PU> ≈ 60 events per crossing by LS3
  - <PU> ≈ 140 events per crossing by HL-LHC
- Radiation damage
  - Requires work to maintain calibration
  - Limits performance-lifetime of the detectors
    - Light loss (calorimeters)
    - Increased leakage current (silicon detectors)

# The Experiments Upgrades

A two phase process:

- Phase I, to happen during LS2 (2019-2020) is fully in swing for all the experiments.
  - Phase 1 is the main upgrade for ALICE and LHCb.
- Phase II for ATLAS and CMS being finalized with the Funding Agencies.

# Phase II Upgrades Approval Process

Document detailing the process prepared in consultation with the LHCC, UCG, RRB and the experiments:

- Step1: Approval of preliminary design for the complete set of Phase II upgrades - September 2015
- Step2: Approval of final design, cost and schedule - TDRs starting in 2016
- Step3: Approval for construction
- Step4: Approval for operation

Sent to the RRB in April for comments. Comments received and included. Final version being sent to the RRB.

# Phase II documents

**Technical Description**

- ATLAS LOI: CERN-LHCC-2012-022, (Dec 29, 2012)
- CMS TP: CERN-LHCC-2015-010, (Jun 1, 2015)

**Scoping document**

- Examine options and physics trade-offs for total cost in the 200, 235, 275 MCHF range

**Money matrix**

- Preliminary, confidential assessment of contributions to the upgrades.

# Timeline

LHCC/UCG need some time to digest these complex documents.

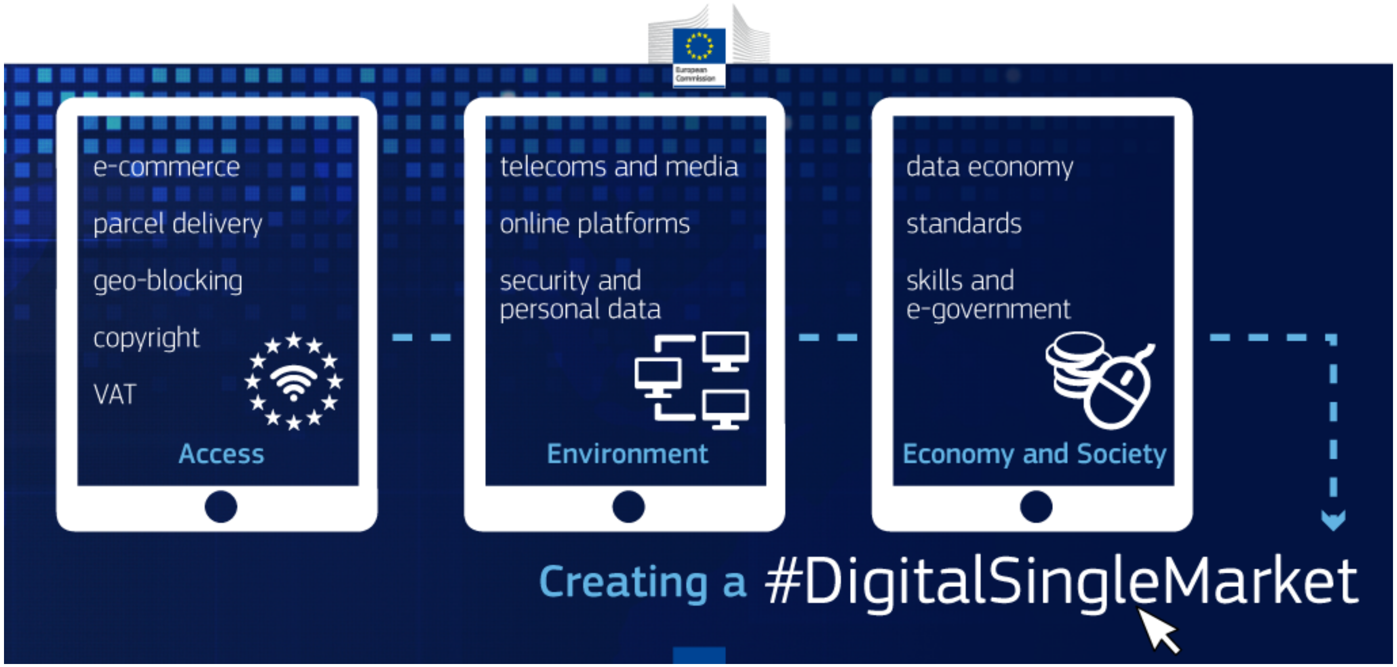
- **June – July**: review by LHCC referees of LOI/TP (Q&A via email; video meetings)
- **July**: draft of scoping document. Initial interaction with the UCG and LHCC
- **August (Sep 1)**: final version of scoping document. Basis for the review. UCG will formulate questions
- **Mid Sep**: money matrix
- **Sep**, prior to LHCC meeting: dedicated UCG meeting
- **Sep 23-24**: LHCC recommendations to the Research Board
- **Sep 30**: RB deliberations
- **Oct 10**: RB deliberations  presented to the RRB

# Computing

# LHC and Open Science Cloud

- Important to understand **long-term sustain**ability of WLCG services and infrastructures
- Under assumption that long term computing **funding remains flat**, essential that we understand how best to make use of funding
- Essential to understand how to procure commercial services
  - Highly likely to be an important component of LHC(HEP) computing in future
  - Costs are becoming very interesting
- Today still more cost effective to operate our own facilities, but this situation is expected to change
- Hybrid model gives us flexibility
  - Does not save staff effort as we still need to operate services there, as well as maintaining in-house services

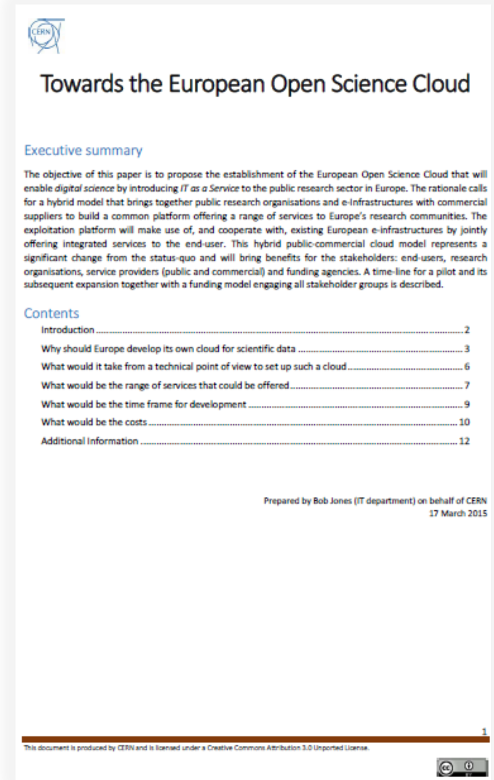
# European Open Science Cloud and the Digital Single Market




*"The Commission will launch a European Cloud initiative including cloud services certification, contracts, switching of cloud services providers and a* ***research open science cloud****."*

# What is the European Open Science Cloud?

- **Hybrid** – link public research organisations, e-Infrastructures & commercial cloud services
  - Use GEANT network to link Research Infrastructures, repositories (EUDAT, OpenAIRE), EGI, PRACE etc. to commodity commercial cloud services (multiple providers)
  - A cornerstone of the Open Science Commons*
- **Trust** - Researchers keep control of the cloud and their data
  - Guarantee a copy of all the data is kept on public resources
  - Ensure long-term preservation of the data
  - Insulate users from changes of service supplier and technology
- **Economy** - Must be cheaper than the '*build our own*' approach
  - Avoid separate 'silos' for each Research Infrastructure/Community
  - Profit from the economies of scale in commercial data centres



Towards the European Open Science Cloud

Executive summary

The objective of this paper is to propose the establishment of the European Open Science Cloud that will enable *digital science* by introducing *IT as a Service* to the public research sector in Europe. The rationale calls for a hybrid model that brings together public research organisations and e-Infrastructures with commercial suppliers to build a common platform offering a range of services to Europe's research communities. The exploitation platform will make use of, and cooperate with, existing European e-infrastructures by jointly offering integrated services to the end-user. This hybrid public-commercial cloud model represents a significant change from the status-quo and will bring benefits for the stakeholders: end-users, research organisations, service providers (public and commercial) and funding agencies. A time-line for a pilot and its subsequent expansion together with a funding model engaging all stakeholder groups is described.

Contents



Prepared by Bob Jones (IT department) on behalf of CERN
17 March 2015

1



* http://go.egi.eu/osc

http://dx.doi.org/10.5281/zenodo.16140

# Proposed Joint Pre-Commercial Procurement

The group of buyers have committed

- >1.6M€ of funds
- Manpower
- Applications & Data
- In-house IT resources

To procure innovative cloud services

Integrated into a hybrid cloud model:

- Commercial cloud services
- e-Infrastructures
    - GEANT network
    - eduGAIN Fed. Id mgmt.
    - EGI Fed Cloud
- Potentially host data services from EUDAT, INDIGO-Datacloud, etc.
- In-house IT resources

Made available to end-users including BBMI, DARIAH, ELIXIR, EISCAT_3D, EPOS, INSTRUCT, LifeWatch, LHC, etc.

# Key objectives of the PCP

**Proposal approved by the EC**

- Design a technical architecture for t[illegible]d cloud that can build on the existing pu[illegible]commercial developments
- Agree on a security mod[illegible]tible with EC legislation including d[illegible]ection
- Assemble, deplo[illegible]t a 5% scale prototype
- Verify the bu[illegible]odel to ensure the hybrid cloud is economi[illegible]tainable beyond the PCP phase
- Set-u[illegible]lusive governance structure where all stak[illegible]ers are represented
- Develop a roadmap for full-scale implementation

# How to reach full-scale

- Grow from 5% to 100%
  - Engage more research infrastructures/communities & cloud service providers
  - Increase commodity service capacity at the IaaS level
  - Offer higher-level features (Platform as a Service, Software as a Service, etc.)
  - Expand coverage to broader public sector (eGovernment) and private sector (industries that use research data – energy, pharmaceutical, insurance etc.)
  - Interact with other regions (Africa, Asia, Latin America, North America)

- Leverage the 2016-2017 work-programme
  - Work with DG CNECT to engage e-infrastructures and cloud providers
  - Work with DG RTD to engage Research Infrastructures
  - Develop s/w technologies that can scale to the Exabyte range at the infrastructure, data and application layers
  - Continue investment in the public e-infrastructures during the same period

# In summary

Run II has started!

- LHC@13 is progressing remarkably well
- Experiments are in good shape and eagerly follow the LHC intensity ramp

The exploration of the new energy frontier has begun!

# Thank You