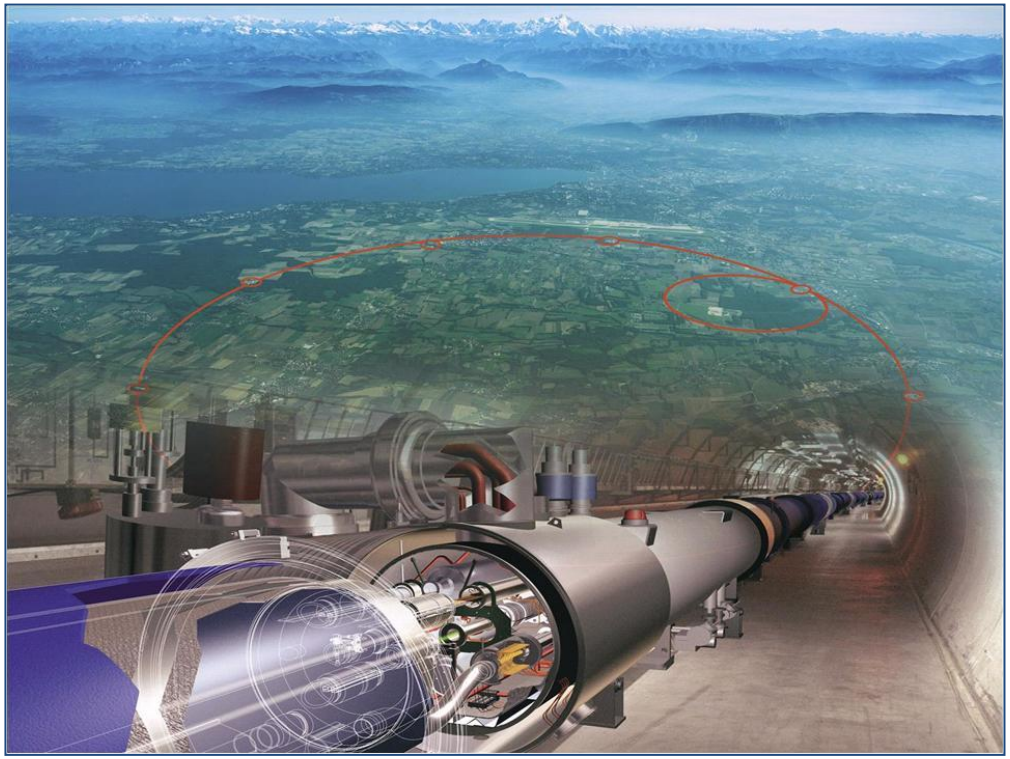


CERN Control Centre

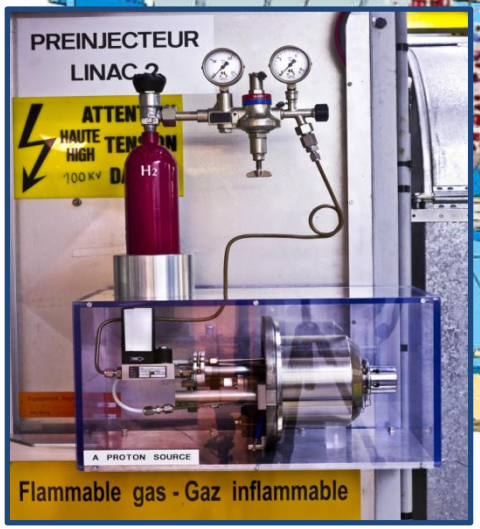
Netzwerk Teilchenwelt Lehrerworkshop

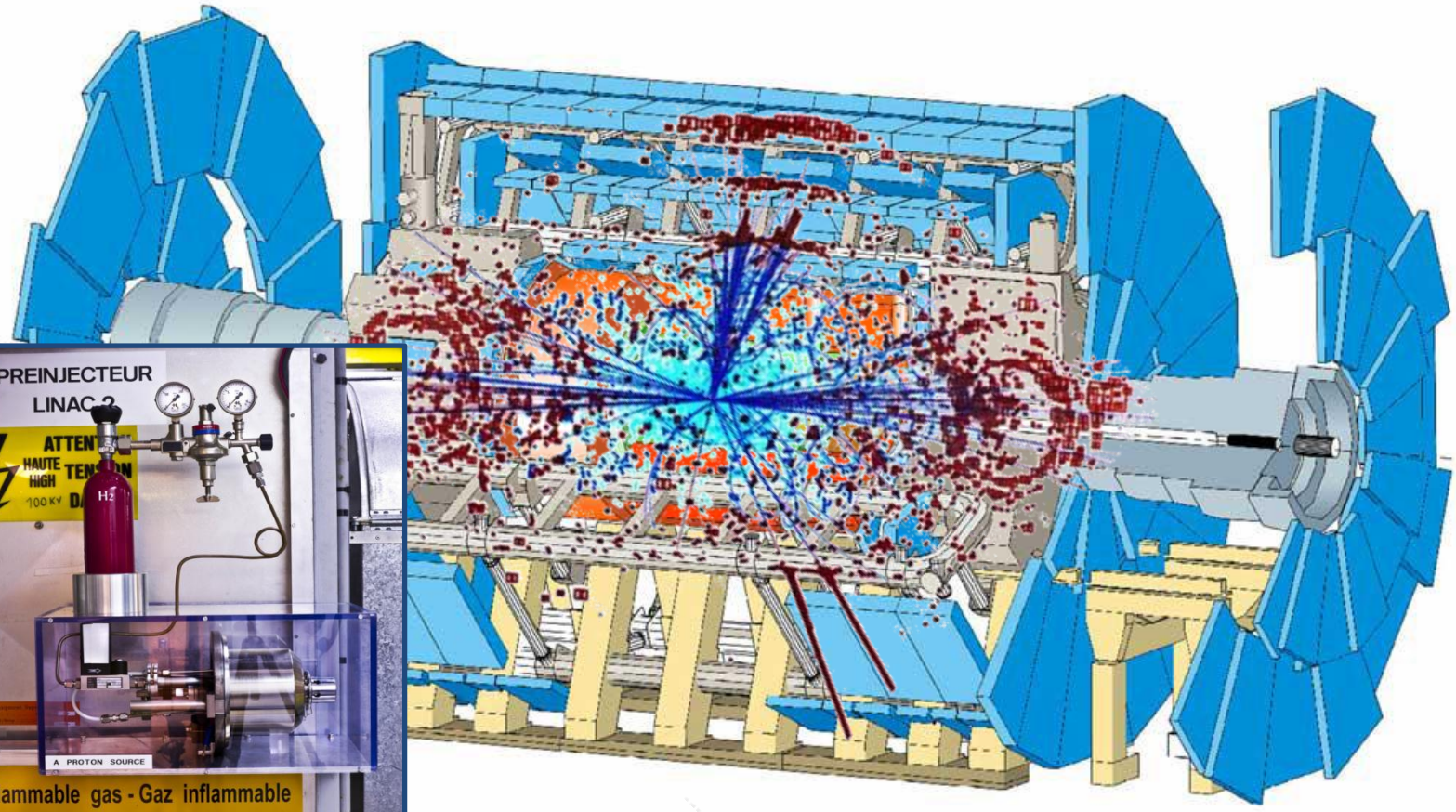
19. October 2011

Tobias Baer

LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SUISSE
FRANCE
CMS
ALICE
SPS 7 km
LHC 27 km

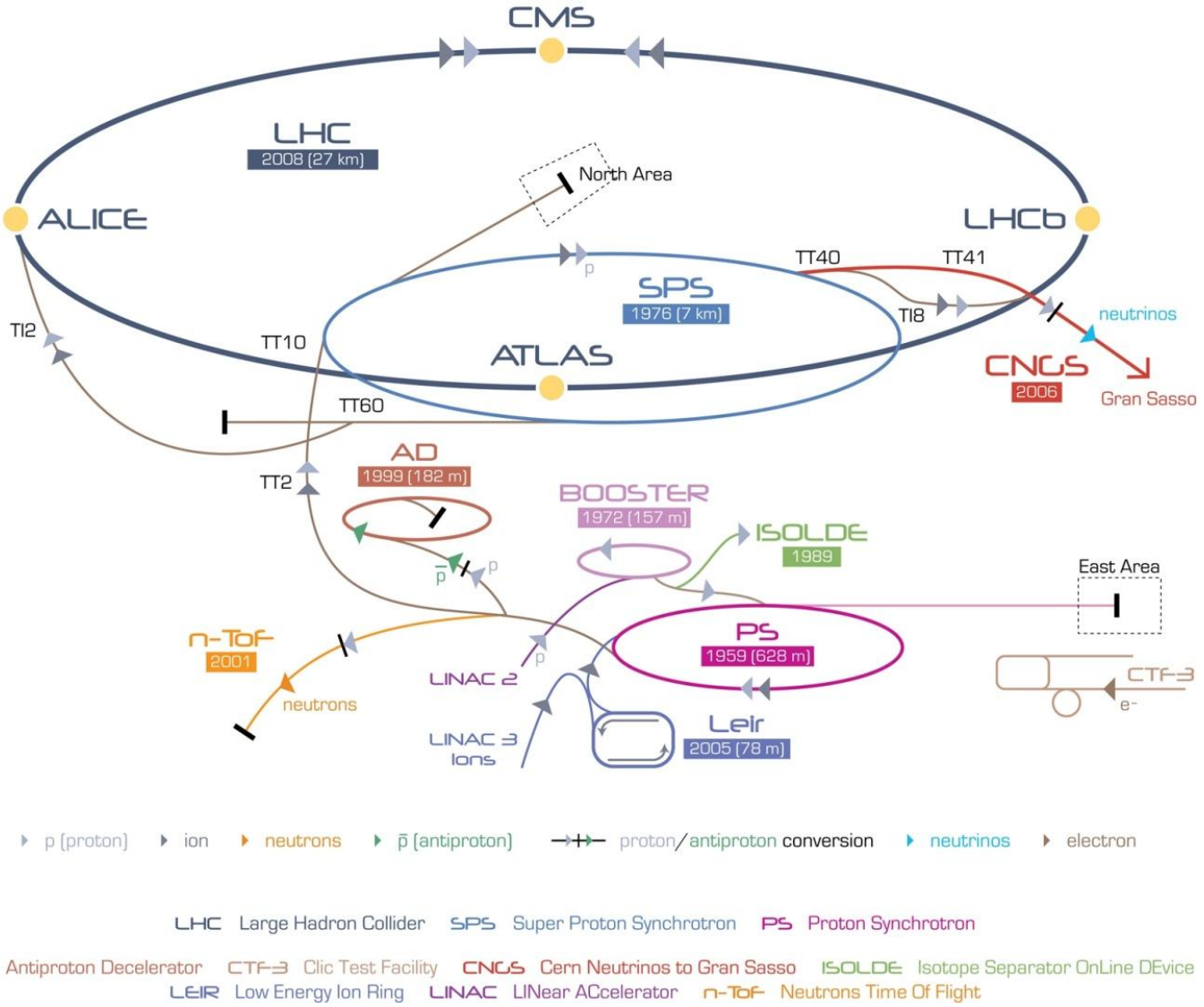
CERN Accelerator Complex





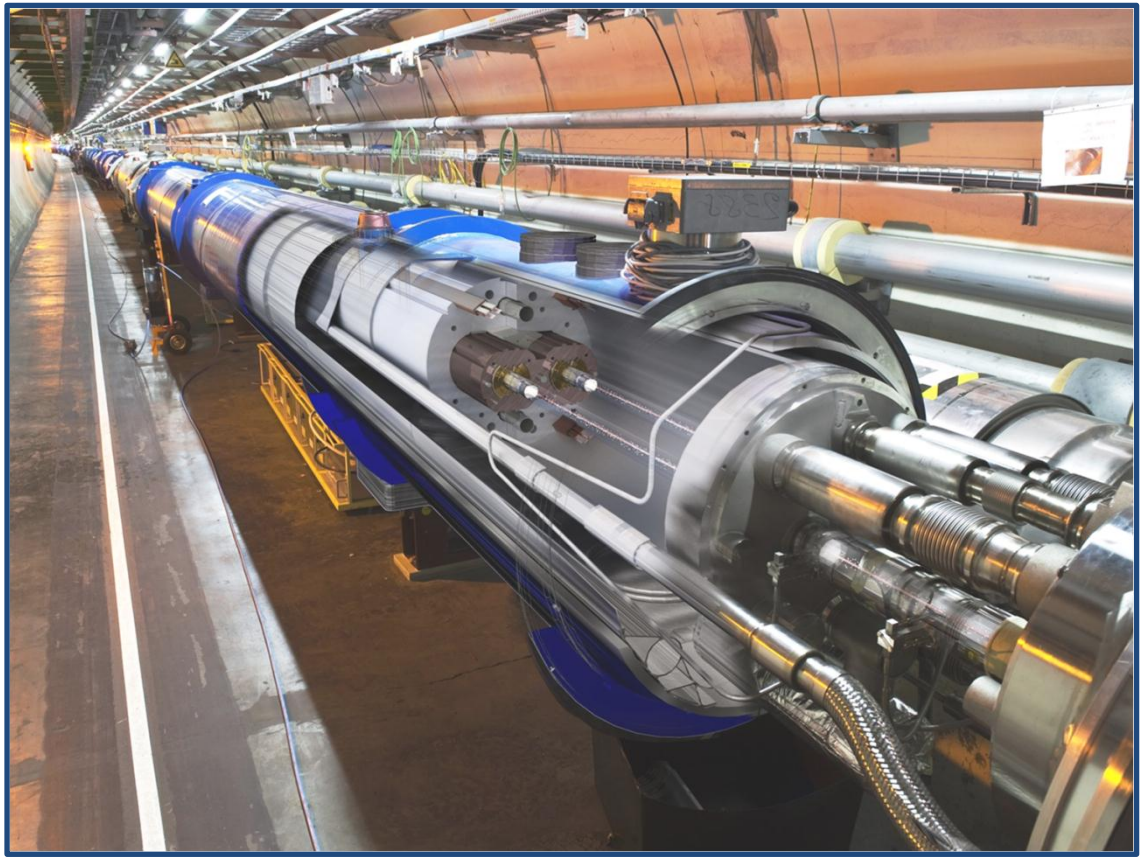
courtesy of M. Pojer

CERN Accelerator Complex



The LHC

- Circumference: 26,7 km.
- Depth: 70-140 m.
- Acceleration of protons and pb^{82+} to unprecedented energy of **2·7 TeV**. (v/c= 99.9999991%)
- Luminosity of up to $10^{34}cm^{-2}s^{-1}$.
  => About **1 Billion collisions per second** in every experiment.
- 2808 bunches with over 10^{11} protons/bunch.



Accelerator Physics Theory

Quadrupole-magnet

Quadrupole-magnet

Dipolemagnet

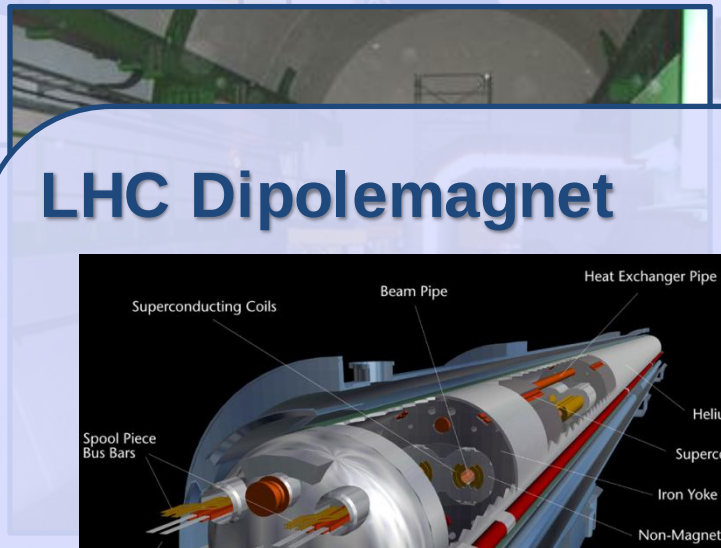
RF Cavity

Dipolemagnet

Experiment

Inject

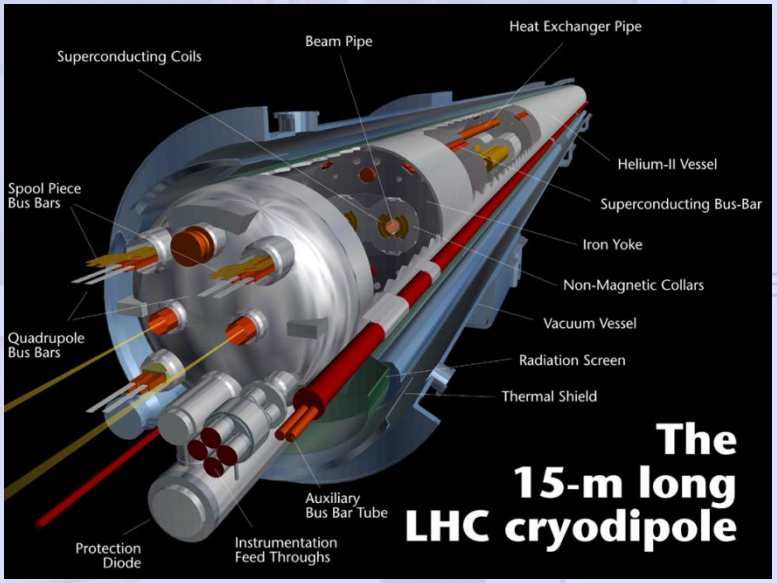
Beam dump



Beam

Open

LHC Dipolemagnet

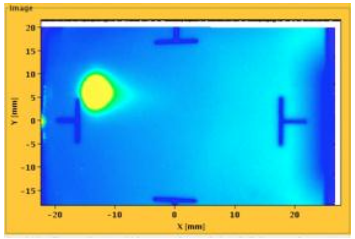


courtesy of M. Pojer

highest energy, in the

LHC Timeline

August 2008
First Injection tests



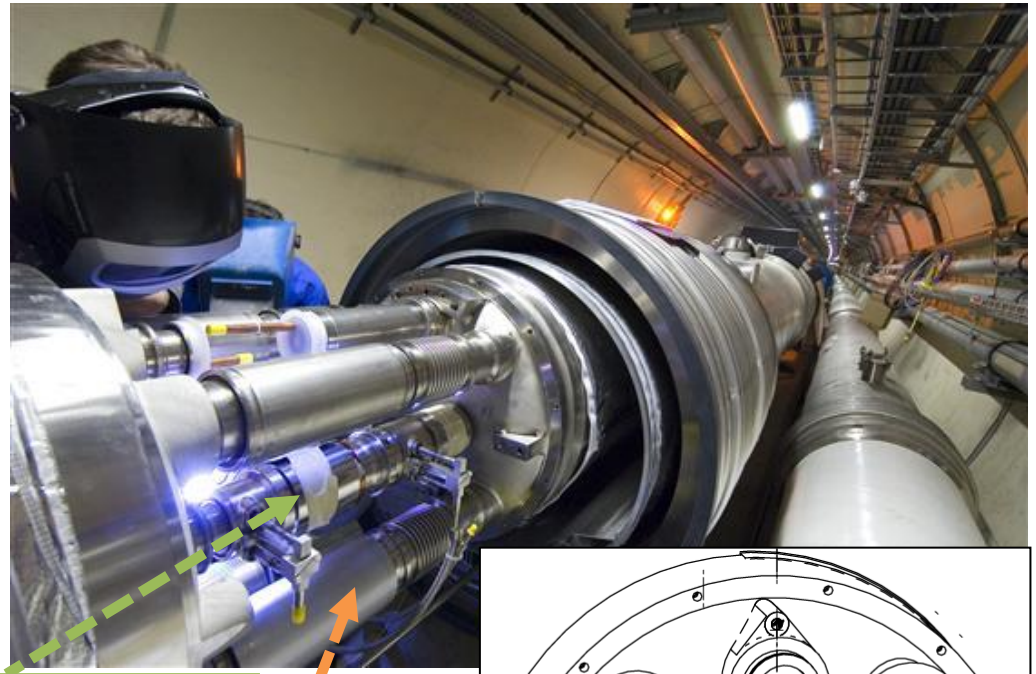
September, 10 2008
Both beams circulating

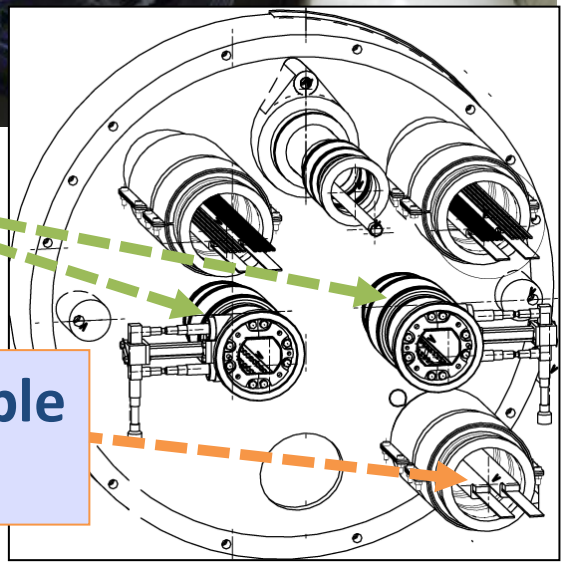
2008 | 2009 | 2010 | 2011

M. Lamont

September, 19 2008
Incident
Accidental release of 600 MJ stored in one sector of LHC dipole magnets

Incident September 19th



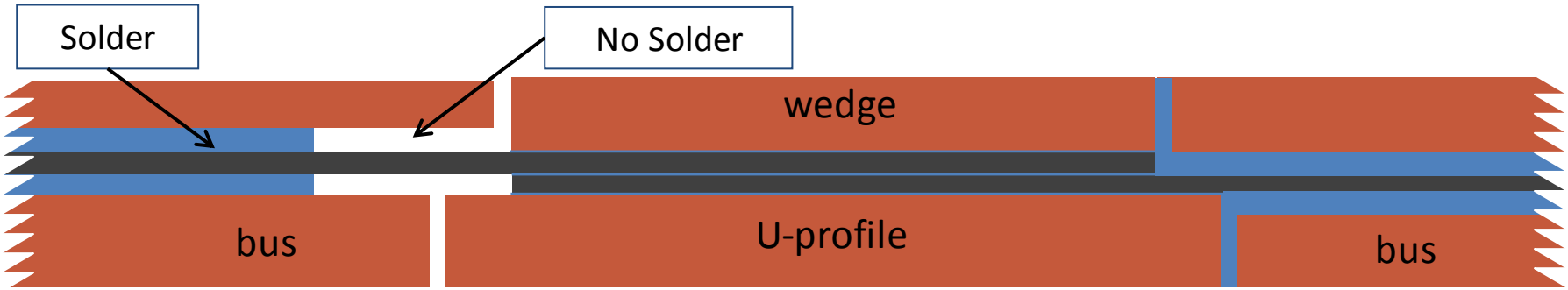


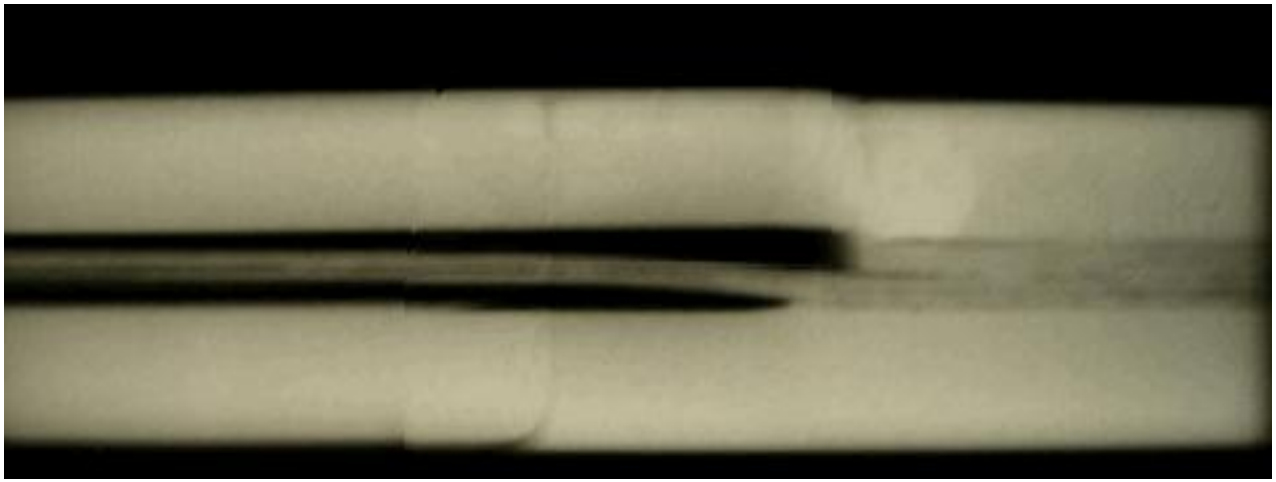
Vacuum chamber

Superconducting cable interconnection

Interconnections

Bad joint



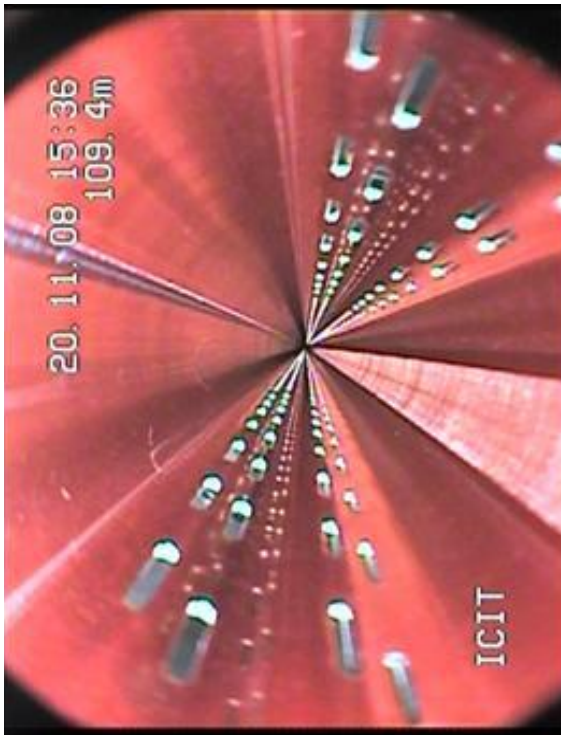


Incident September 19th

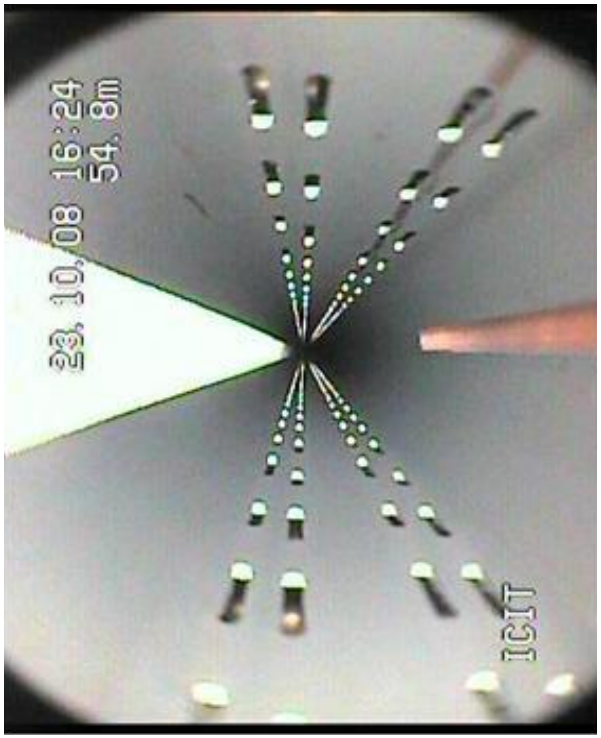
- Last commissioning step of sector 34 main dipole circuit:
  ramp to 9.3 kA (5.5 TeV).
- At 8.7 kA electrical fault in **interconnection** between dipole and quadrupole
  - Local resistance: **~220 nΩ** (nominal 0.35 nΩ)
- **400MJ** out of 600MJ stored in the circuit were dissipated in cold-mass and electrical arcs
- **6 tons of helium** were released

Beam Screen Contamination

Beam screen with clean copper surface	contaminated by super-isolation	contaminated by soot

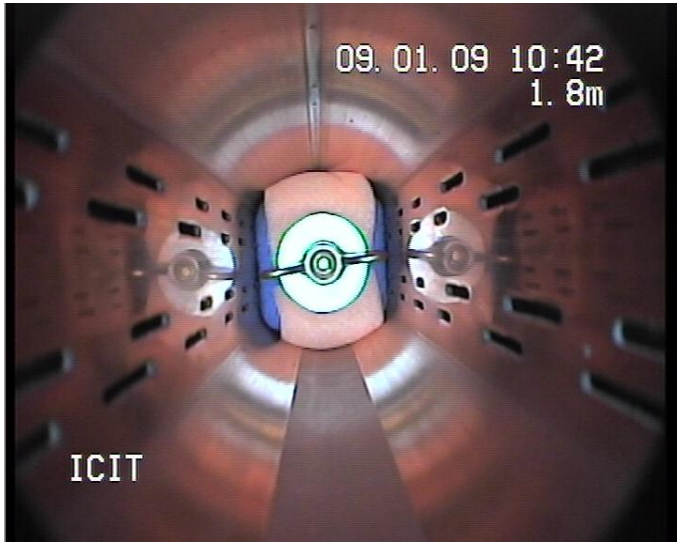


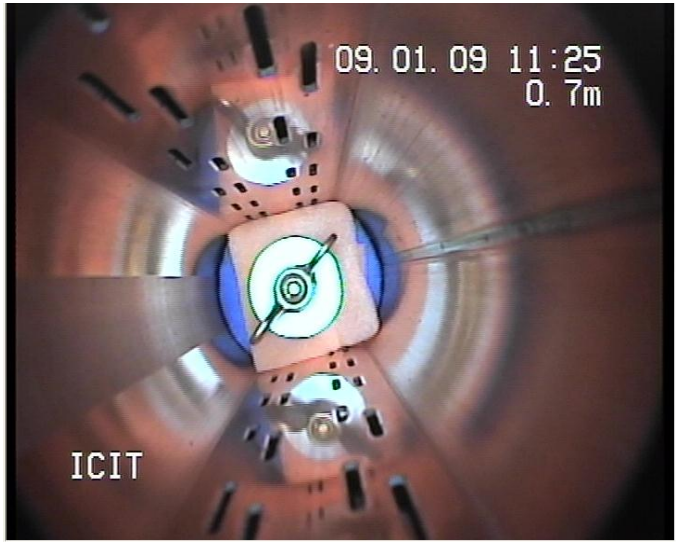
≈ 60% of the chambers



≈ 20% of the chambers

Beam Screen Cleaning





- Up to 50 passages in each direction with wet foam (alcohol)
- Up to 15 passages with dry foam

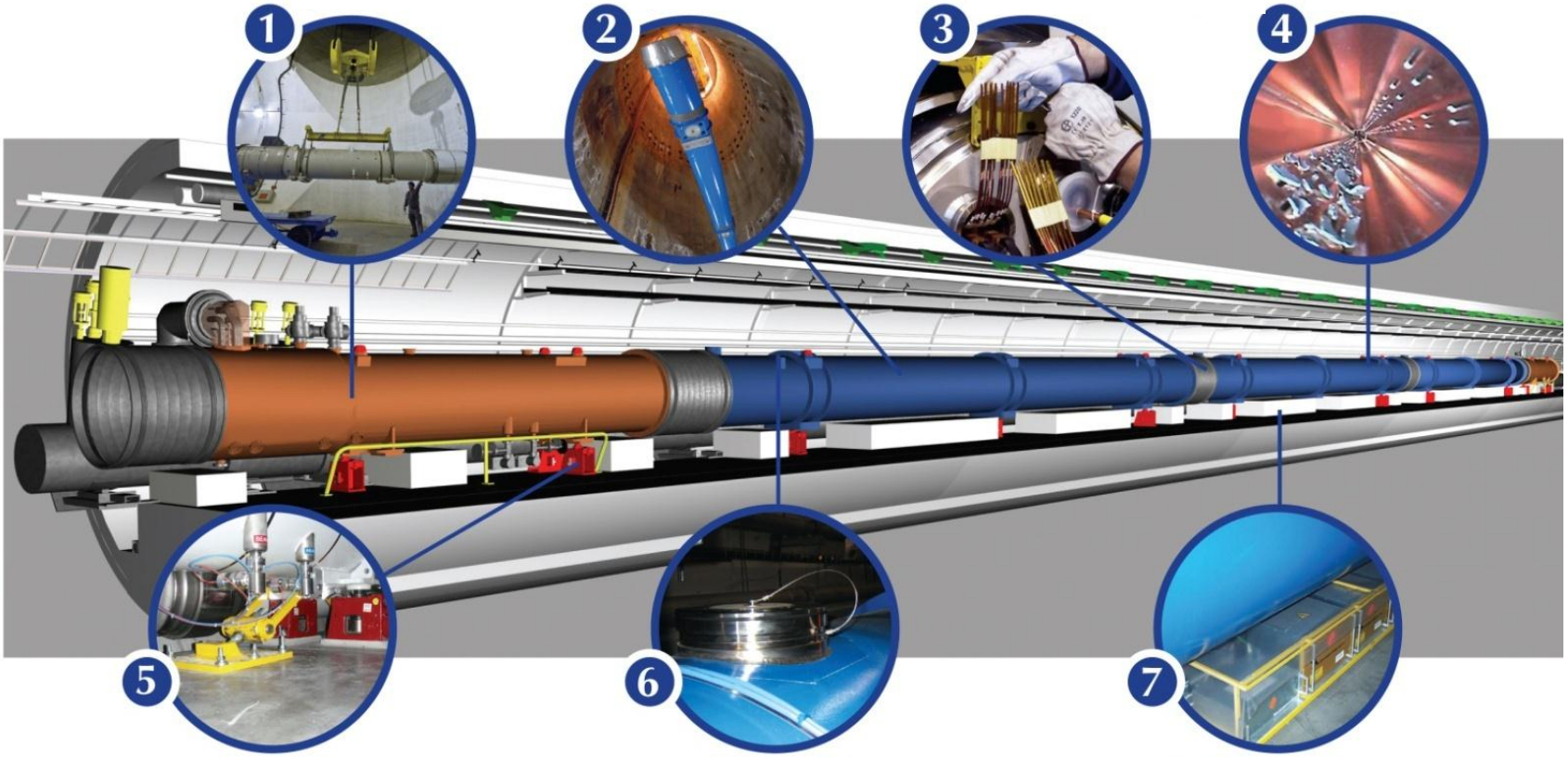
LHC Repairs in Detail

14 quadrupole magnets replaced

39 dipole magnets replaced

204 electrical inter-connections repaired

Over 4km of vacuum beam tube cleaned



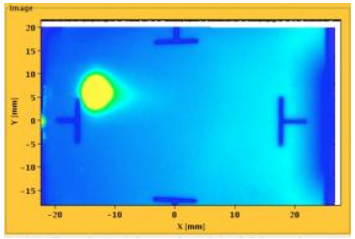
New longitudinal restraining system for 50 quadrupoles

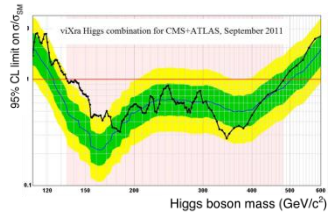
Almost 900 new helium pressure release ports

6500 new detectors and 250km cables for new Quench Protection System

LHC Timeline

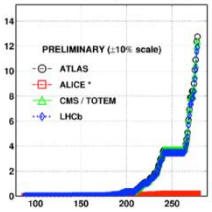
August 2008
First Injection tests





October, 2011
3.4e33, 5.4 fb^{-1}

November 29, 2009
Beams back



October 14, 2010
1e32
248 bunches

June, 28 2011
1380 bunches
1.2 fb^{-1}

1380

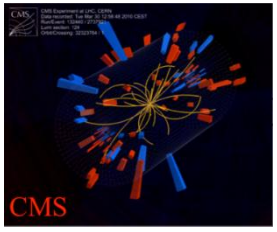
September, 10 2008
Both beams circulating

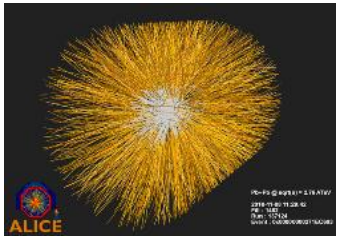
2008 | 2009 | 2010 | 2011

M. Lamont

September, 19 2008
Incident
Accidental release of 600 MJ stored in one sector of LHC dipole magnets

March 30, 2010
First collisions at 2·3.5 TeV





November 2010
Ion run

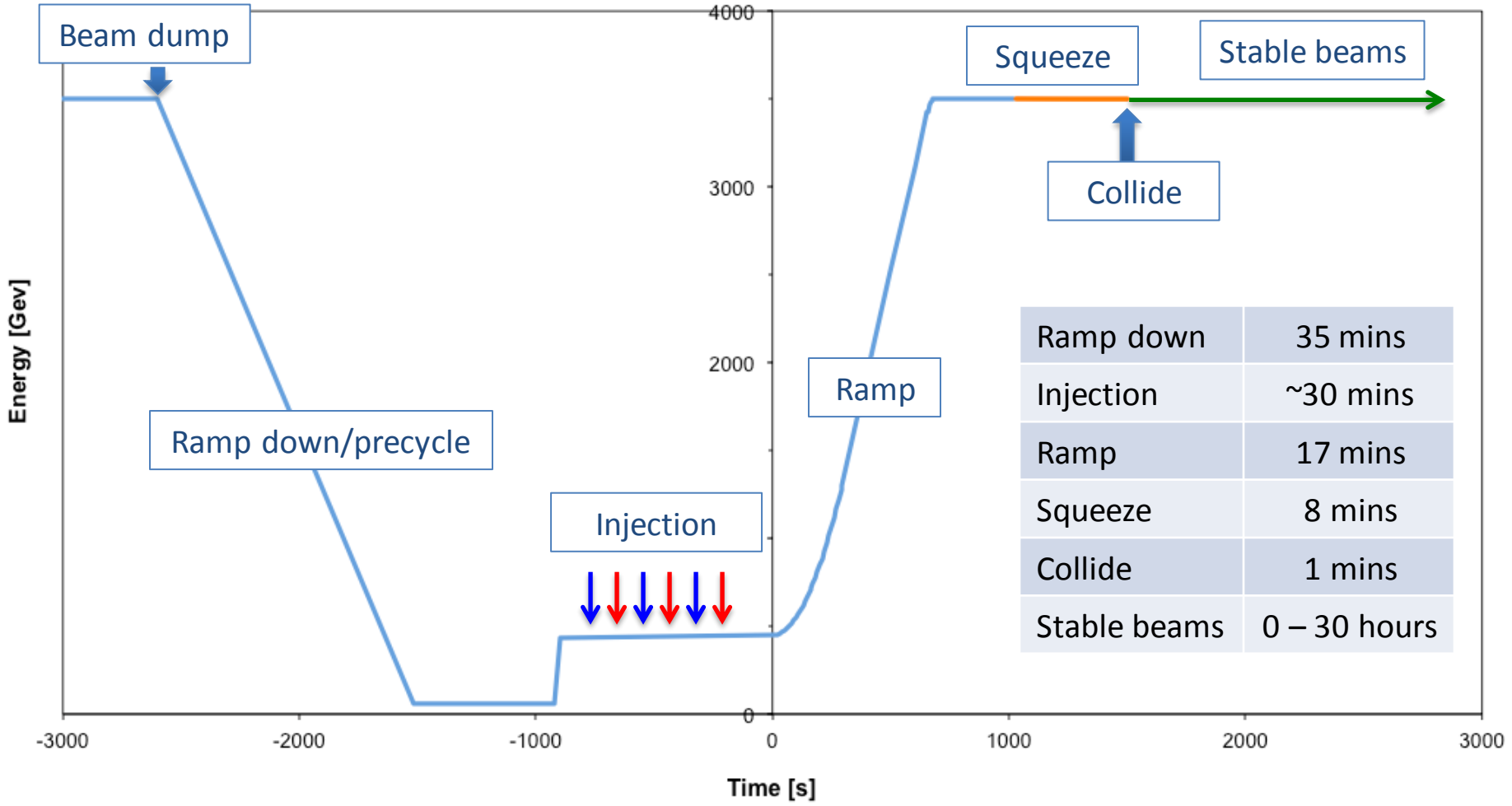
Operational Parameter

$$\frac{dN_{event}}{dt} = L \cdot \sigma, \qquad L = \frac{kN^2 f \gamma}{4\pi\beta^* \varepsilon} F$$

Parameter	2010	2011	Nominal
Beam energy [TeV]	3.5	3.5	7.0
N: protons/bunch [10^{11}]	**1.2**	**1.4**	1.15
ε: normalized emittance [μm·rad]	**2.4-4**	**2-2.2**	3.75
Bunch spacing [ns]	150	50	25
k: Number of bunches	368	1380	2808
Stored beam energy [MJ/beam]	**28**	**110**	362
β^*: beta function at IP [m]	3.5	1.5 → 1	0.55
L_{peak}: Peak luminosity [$cm^{-2}s^{-1}$]	**2×10^{32}**	**3.4×10^{33}**	10^{34}

f = revolution frequency (11.25 kHz), F = geometric loss factor (≈0.95), σ = cross section

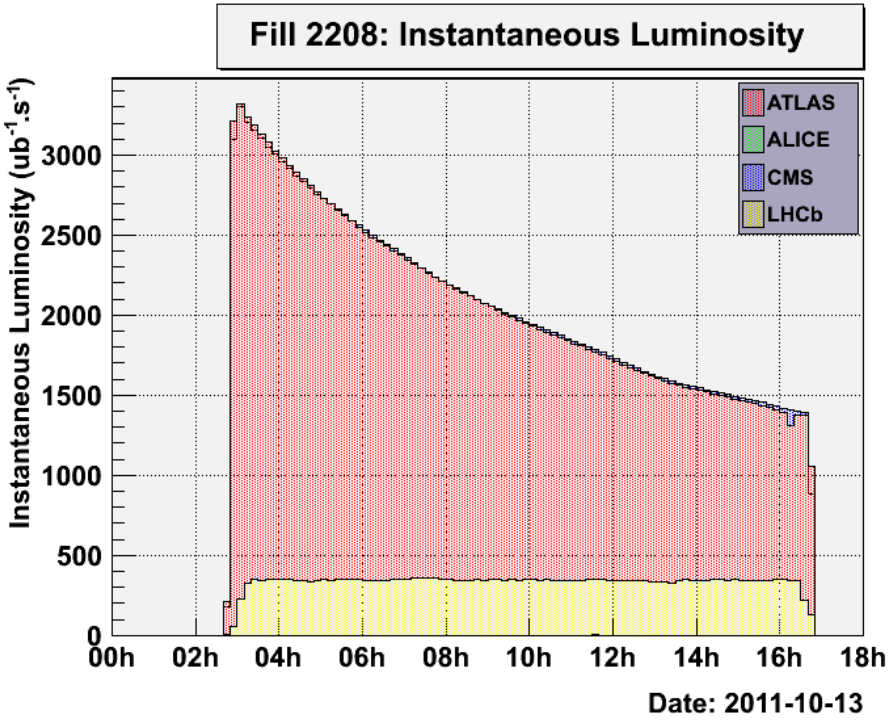
Nominal cycle

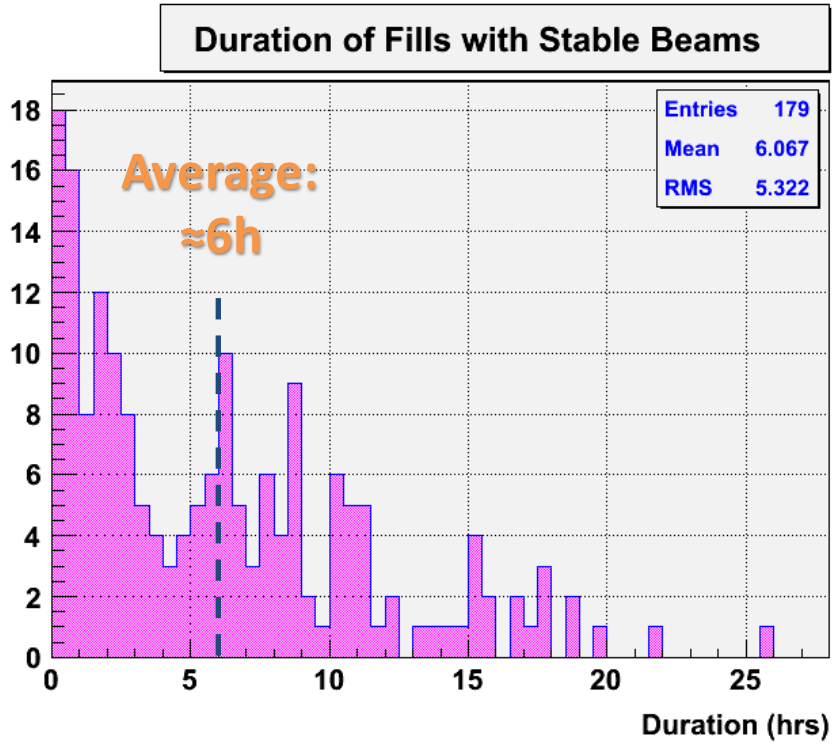


Ramp down	35 mins
Injection	~30 mins
Ramp	17 mins
Squeeze	8 mins
Collide	1 mins
Stable beams	0 – 30 hours

Fastest turn around: 2h7m in 2011 (3h40m in 2010).

Real cycle



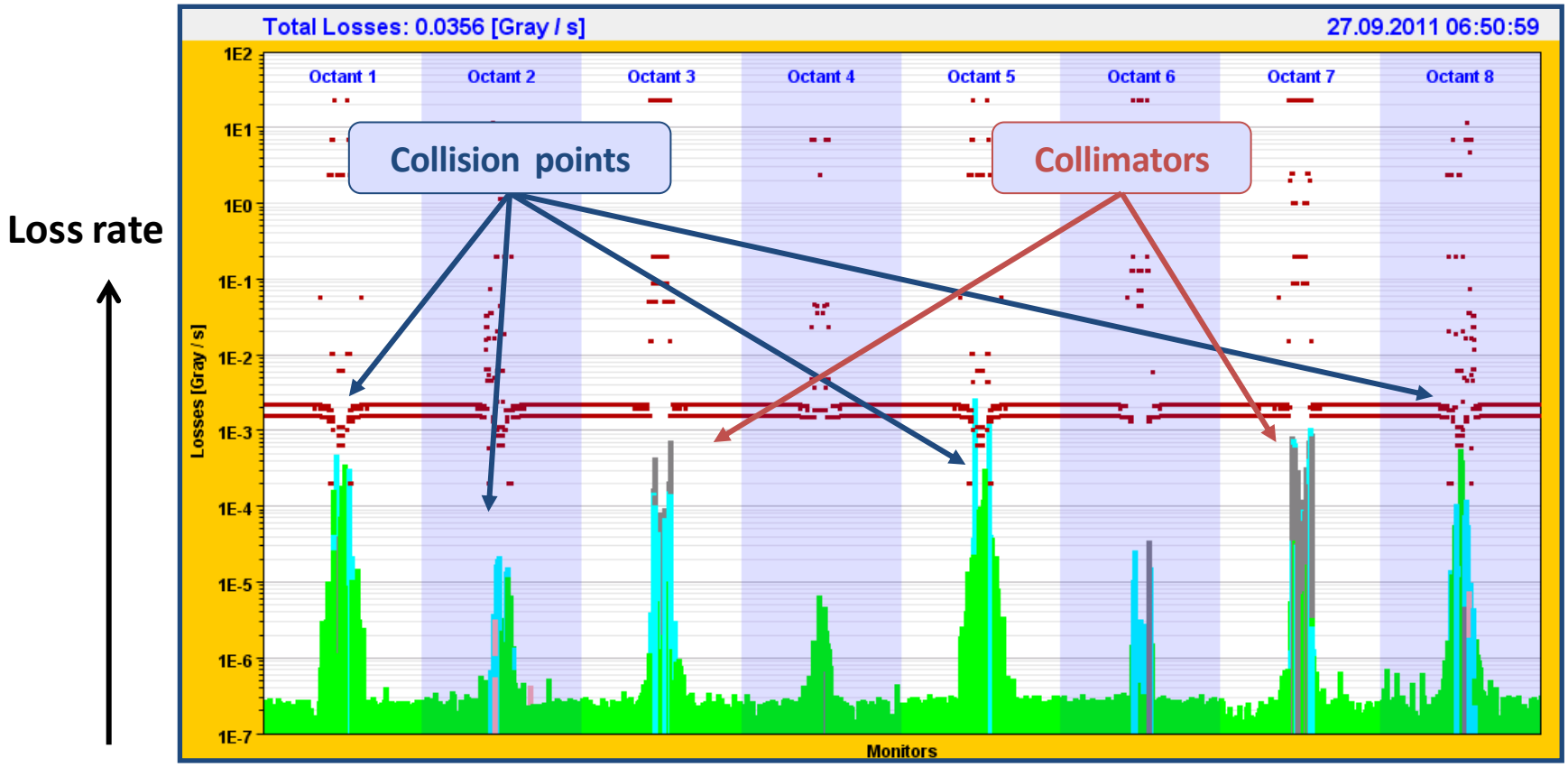


- LHCb luminosity limited to ~$3.5 \cdot 10^{32}$ cm^{-2}s^{-1} (leveling by transverse beam offset)
- Optimum fill length: **12-15h**.

But: In general fills are interrupted by the machine protection system.

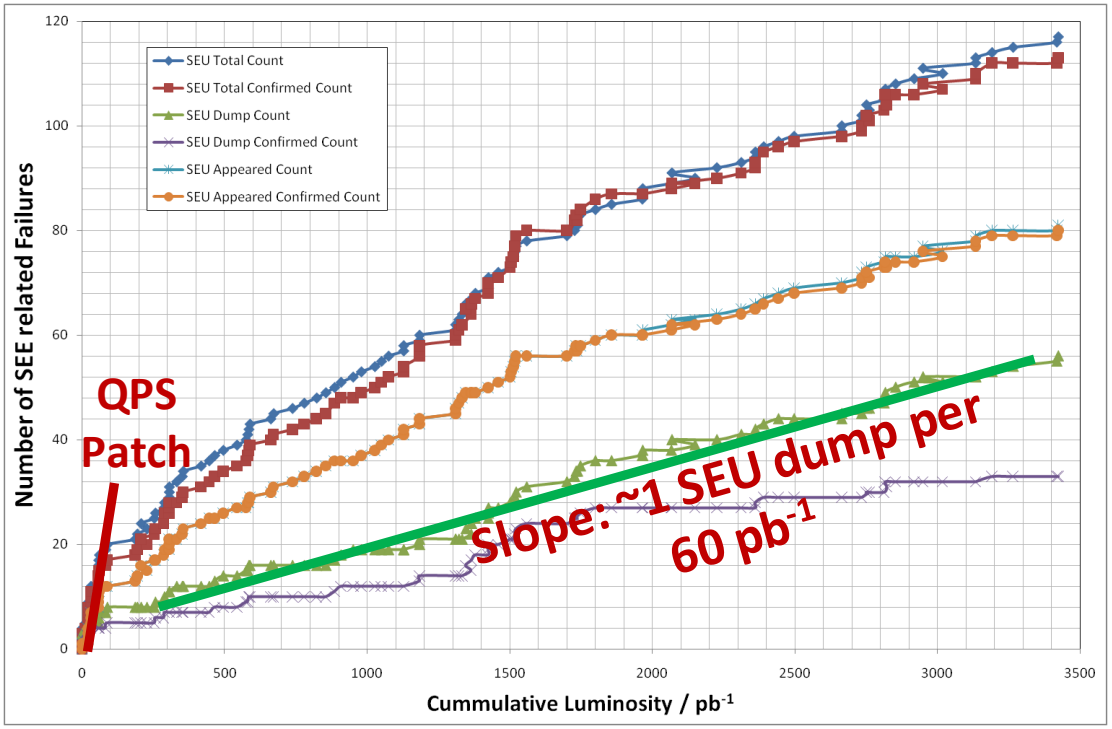
Single Event Upsets

- Tunnel electronics suffers from beam loss induced single event errors (especially QPS and cryogenics).



Single Event Upsets

- With over **50 beam dumps**, SEUs are the main dump cause.
- Number of SEUs increases with integrated luminosity.
- **1 SEU dump per 60pb^{-1}**

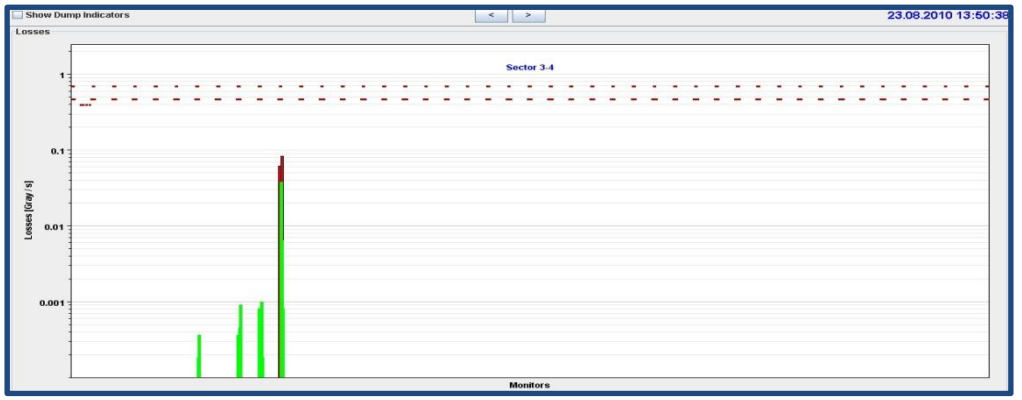


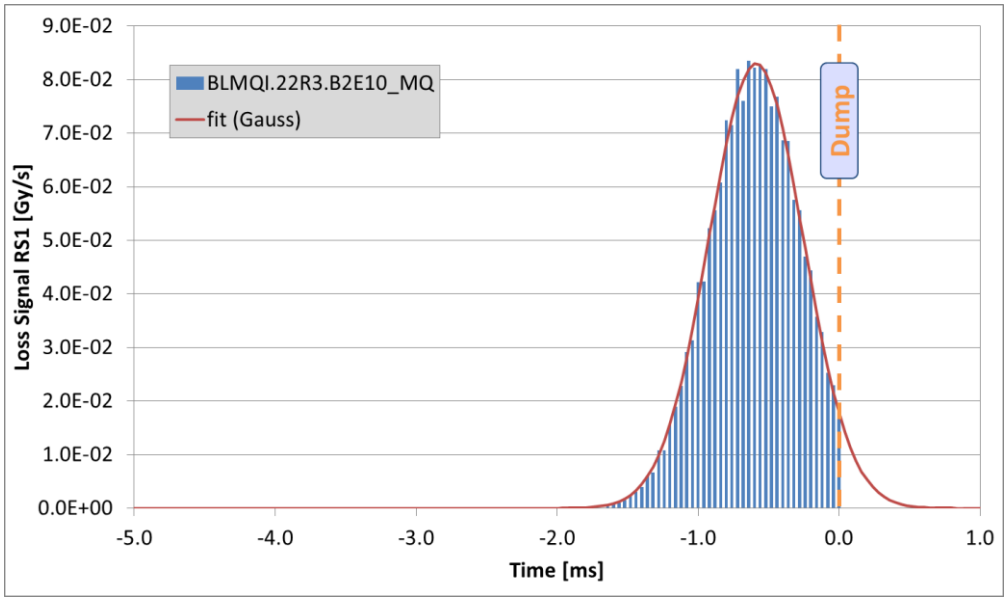
M. Brugger

- **Mitigation:**
  - Equipment relocation, sometimes to surface.
  - Additional shielding in critical areas.
  - Improvement of embedded (FPGA) codes to cope with errors.

UFOs in the LHC

- Since July 2010, **35 fast loss events led to a beam dump.**
- Typical characteristics:
  - Loss duration: about 10 turns
  - Often unconventional loss locations (e.g. in the arc)
- The events are believed to be due to (***U***nidentified) ***F***alling ***O***bjects (UFOs).
- Over **10,000** candidate UFO events below threshold observed in 2011.

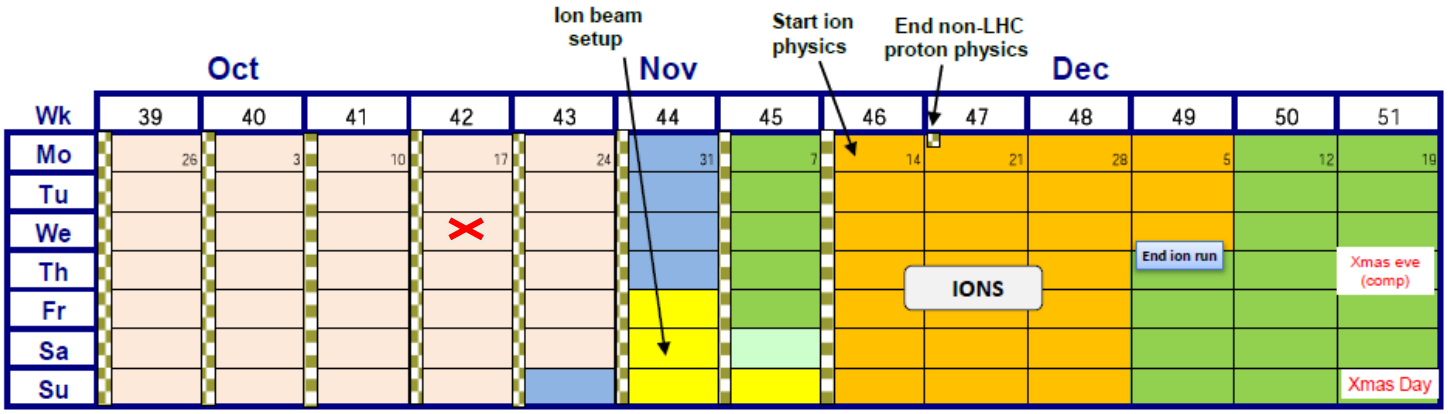




Spatial and temporal loss profile of UFO on 23.08.2010

(T. Baer, IPAC11, TUPC137)

Outlook

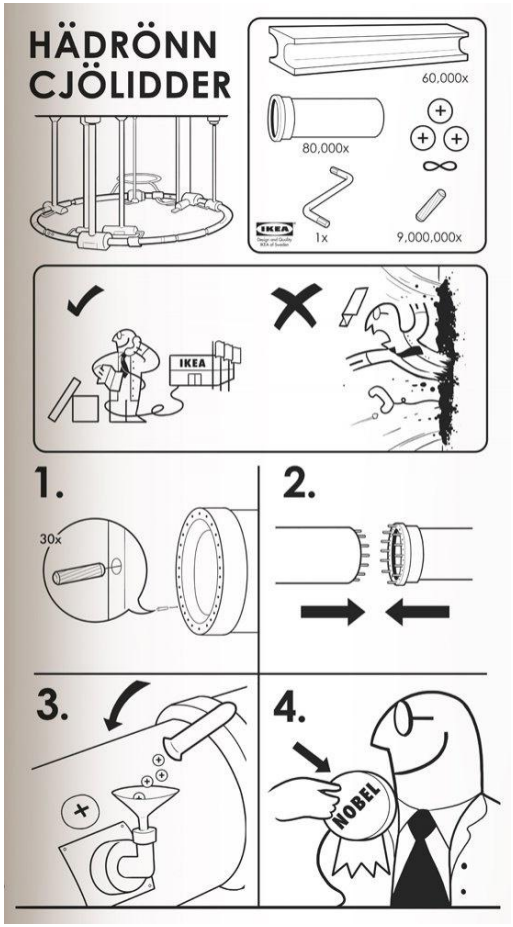


2012: Larger Energy? 25ns vs. 50ns?

	J	F	M	A	M	J	J	A	S	O	N	D
2011		1	2	3	4	5	6	7	8	9	IONS	
2012			1	2	3	4	5	6	7	8	IONS	
2013	LS1 - SPLICE CONSOLIDATION											
2014									RECOM	RECOM	1	2
2015	1	2	3	4	5	6	7	8	9	10	IONS	
2016		1	2	3	4	5	6	7	8	9	IONS	
2017		1	2	3	4	5	6	7	8	9	IONS	
2018	LS2											
2019		1	2	3	4	5	6	7	8	9	IONS	
2020		1	2	3	4	5	6	7	8	9	IONS	
2021		1	2	3	4	5	6	7	8	9	IONS	
2022	HL-LHC upgrade											

Technical stop or shutdown
Proton physics
Ion Physics
Recommissioning

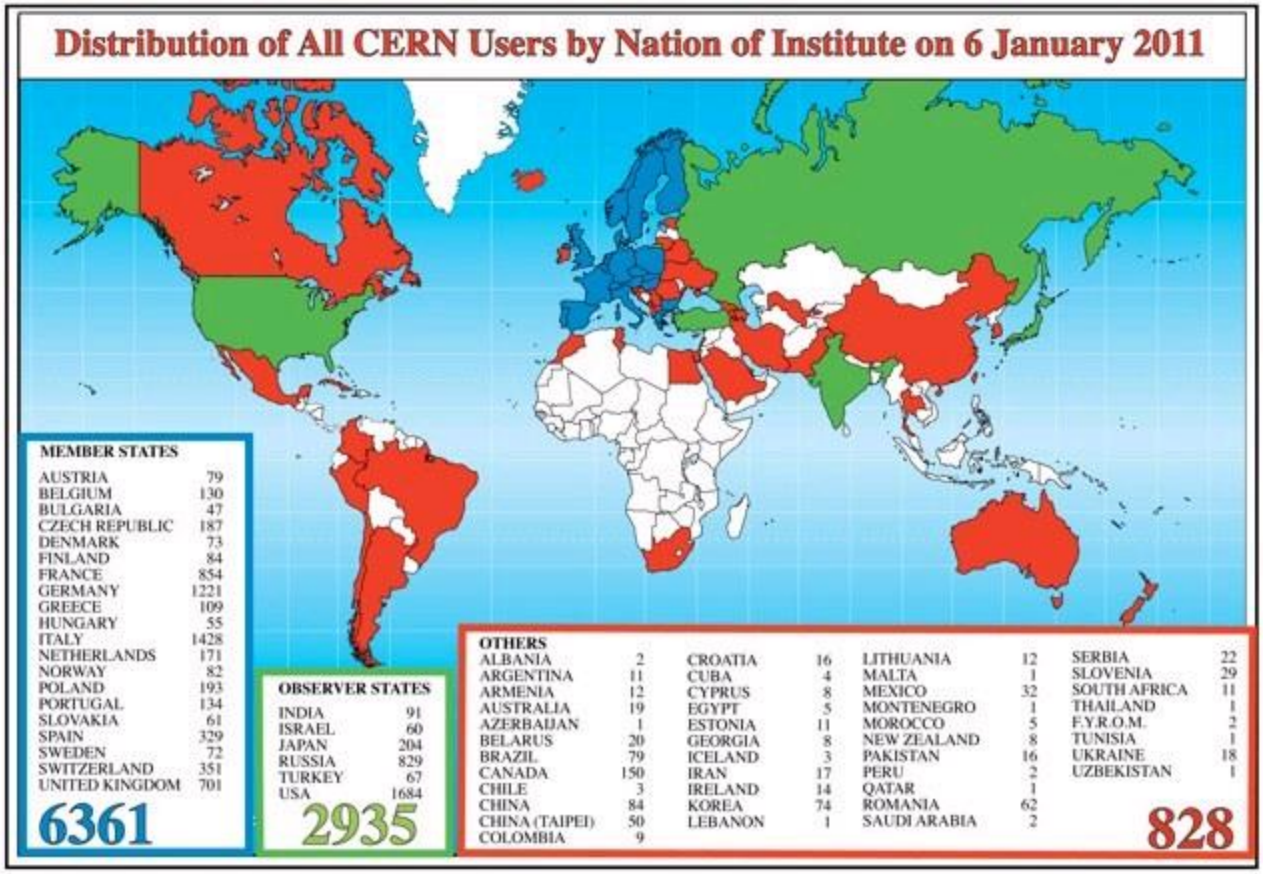
Thank you for your attention!



Tobias Baer
CERN BE/OP
Tobias.Baer@cern.ch
Office: +41 22 76 75379

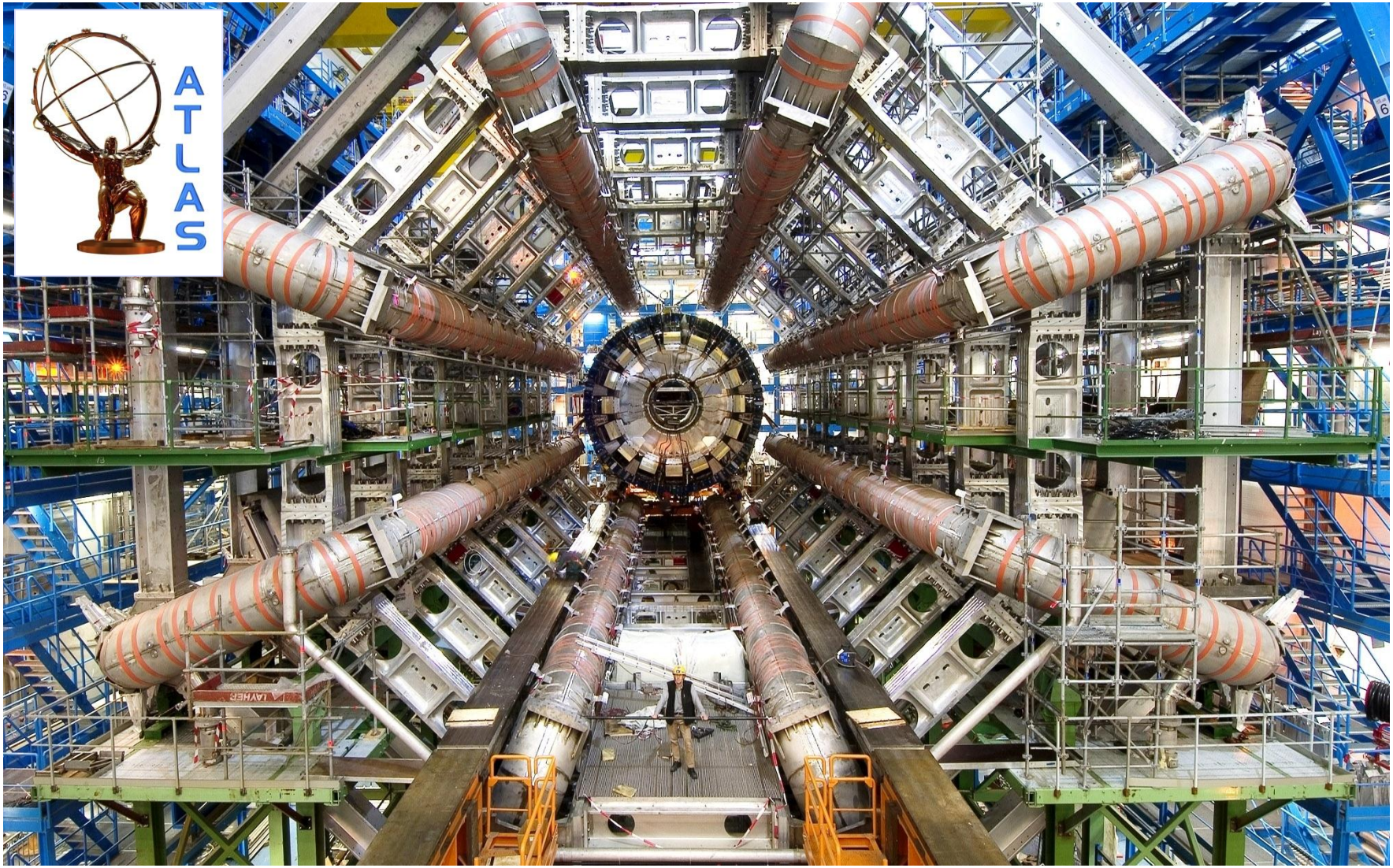
Backup slides

CERN

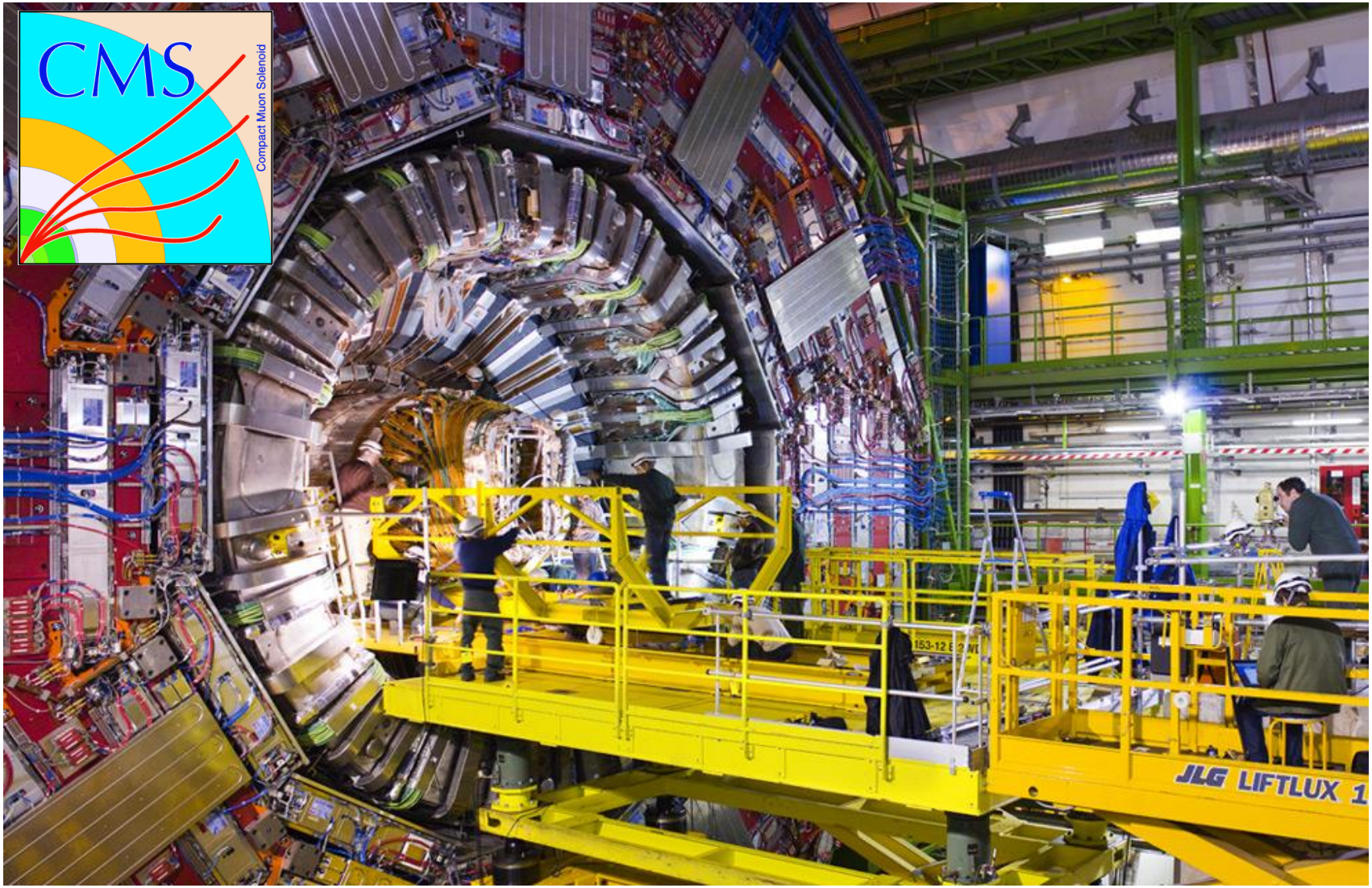


- Über **10.000 user** + ca. **3300 Angestellte** (inkl. Studenten, etc.)

ATLAS

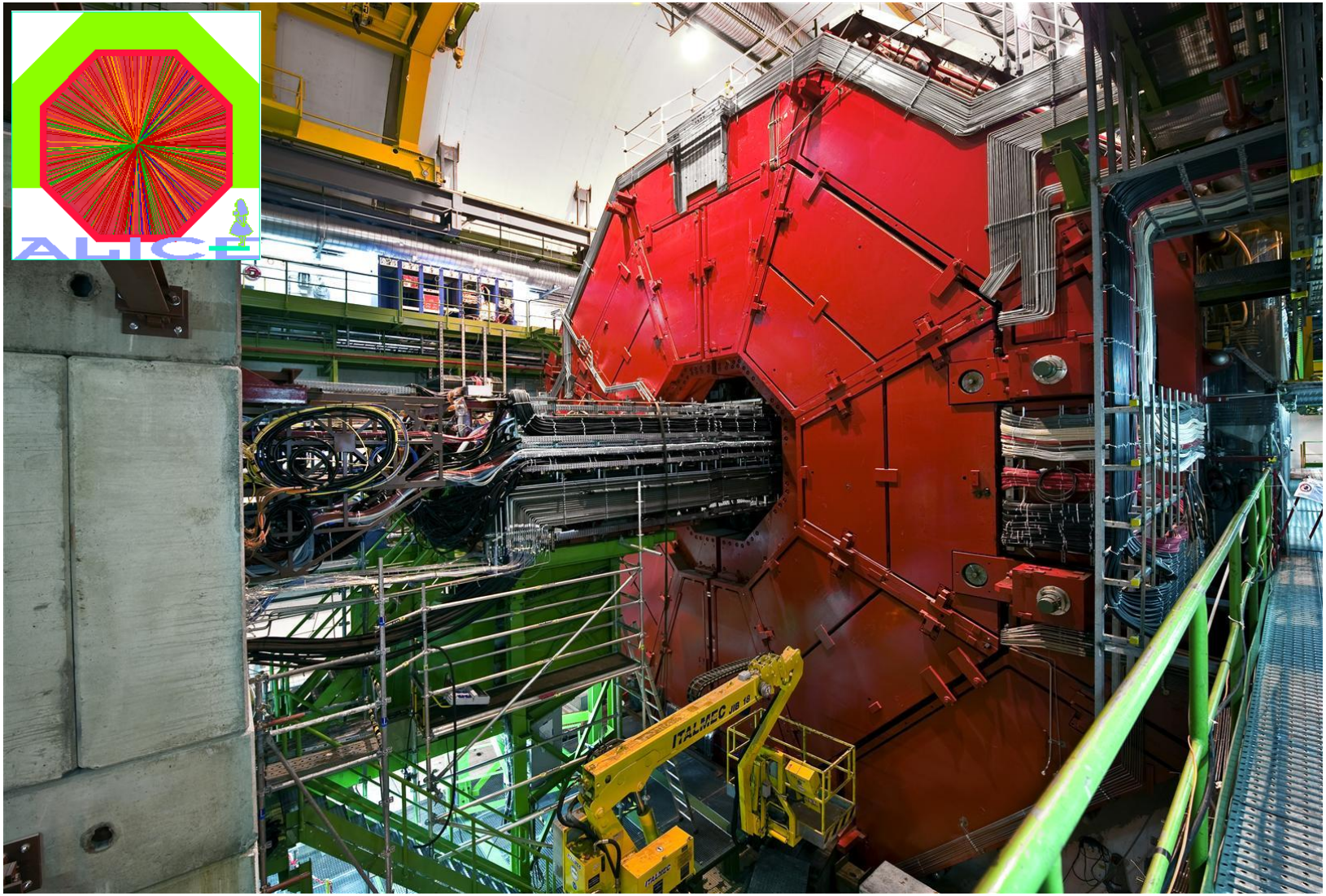


CMS

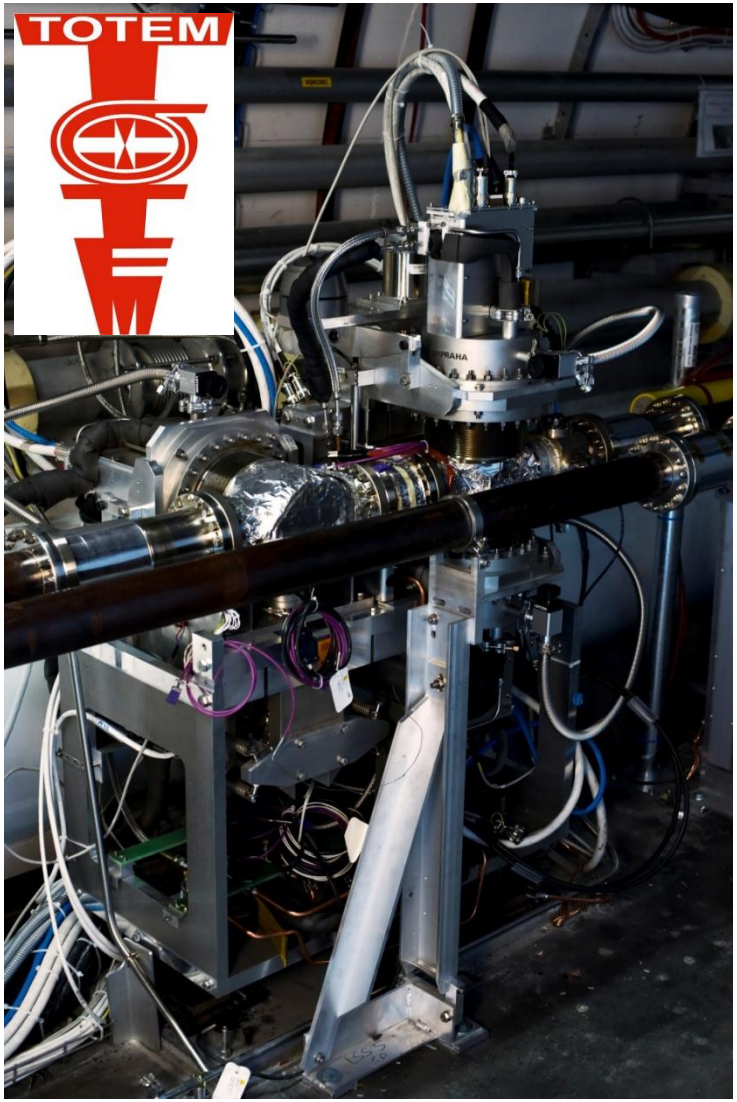


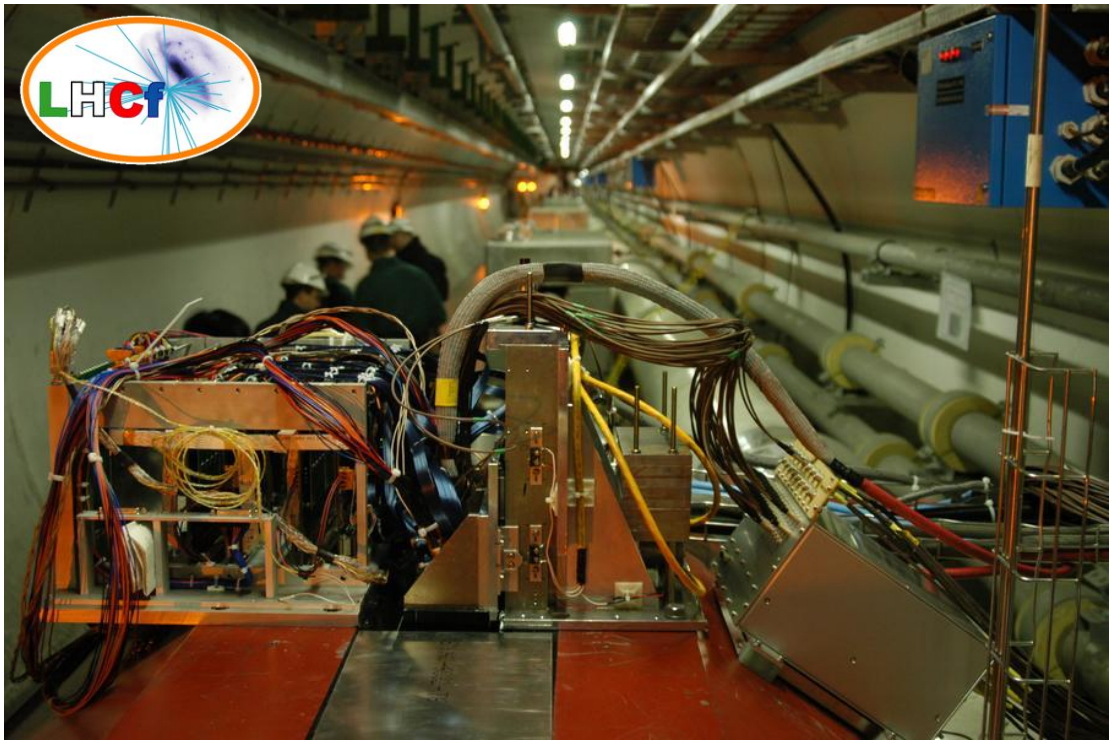
LHCb

ALICE



TOTEM and LHCf

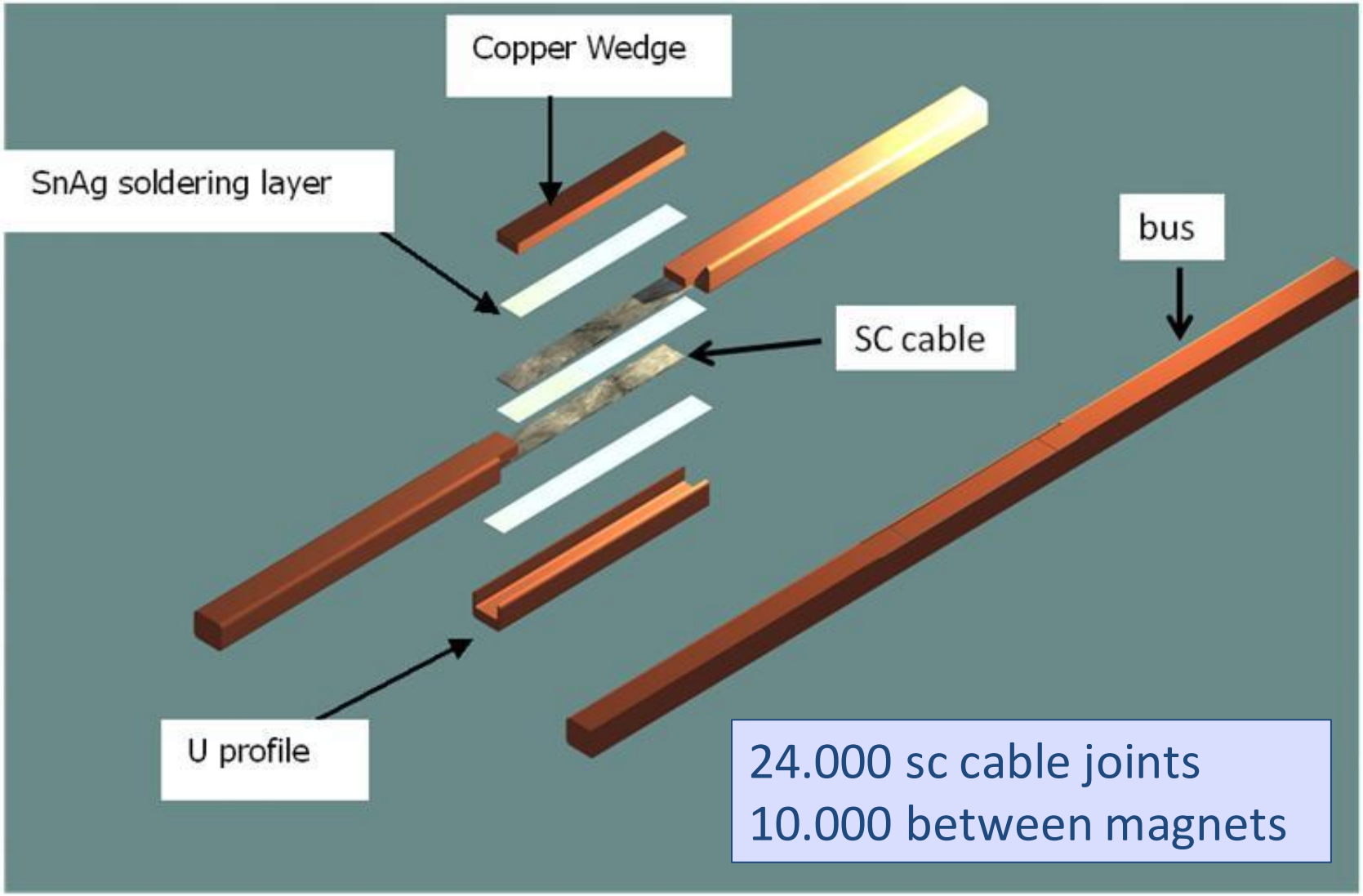




SPS Incident June 27th 2008

- Beam impact of high intensity beam
- (about $3 \cdot 10^{13}$ protons @ 400 GeV)

Interconnections

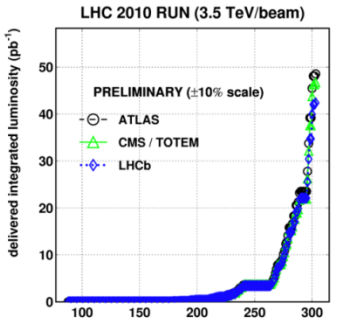


A Closer Look at 2010

March 30, 2010
First collisions
3.5 TeV

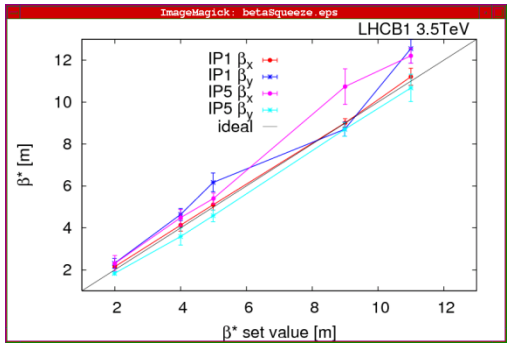
February 27, 2010
Beam back

QUALIFICATION



October
Luminosity
production

February | March | April | May | June | July | August | September | October | November

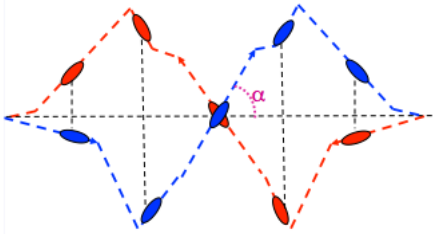


April
Commission
squeeze

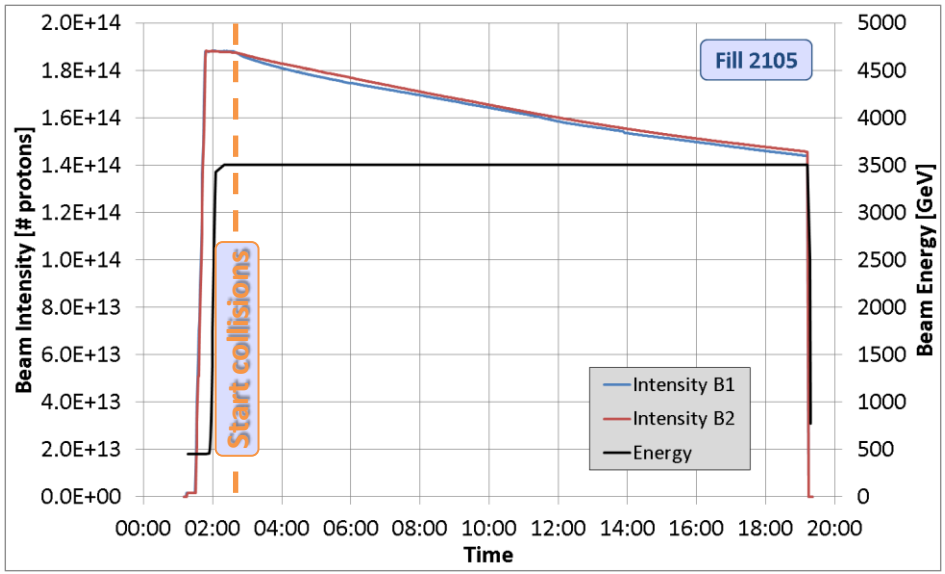
June
Commission
nominal bunch
intensity

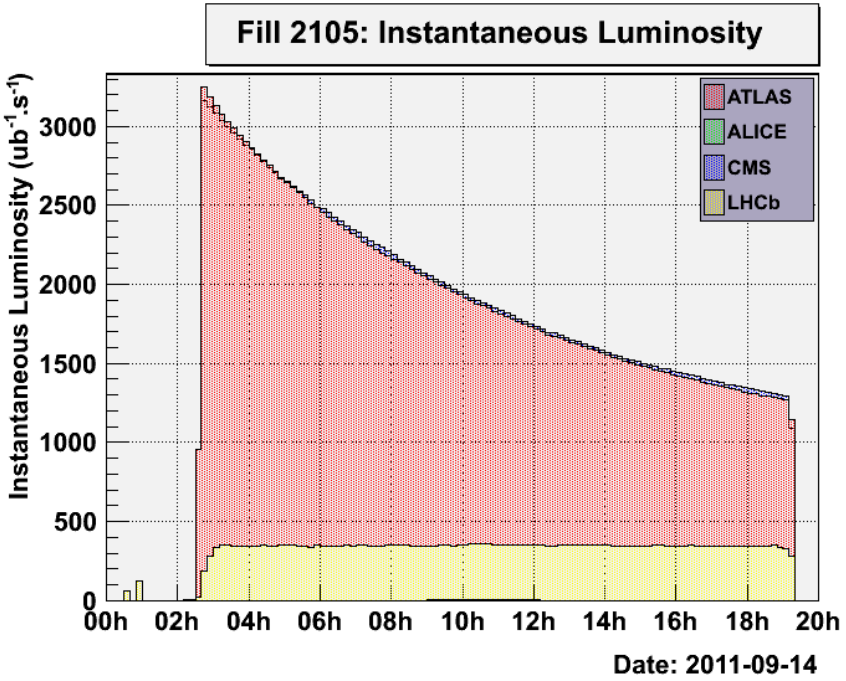
September
Crossing angles on

M. Lamont



In (ideal) Reality



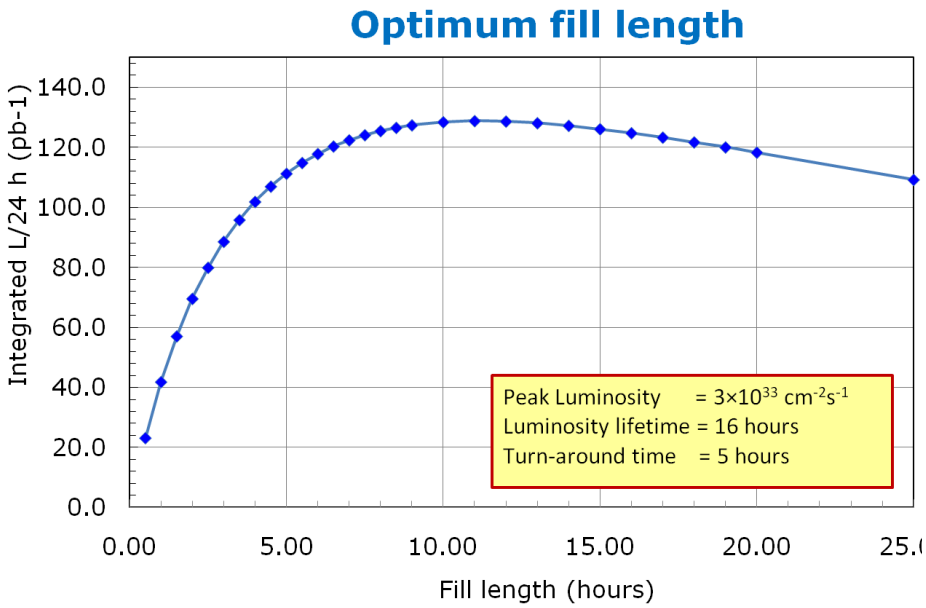


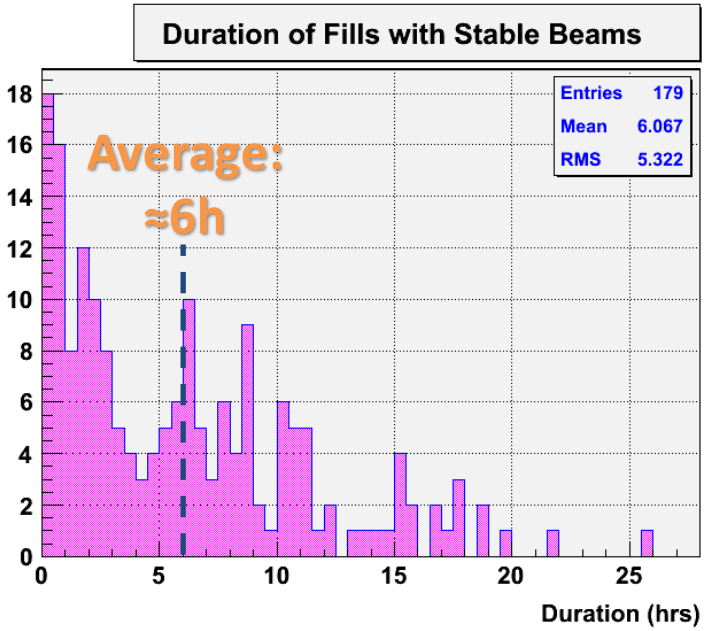
- Low losses during ramp/squeeze (Lifetime often remains > **25h**).
- Peak luminosity: **$3.3 \cdot 10^{33}$ cm^{-2}s^{-1}.**
- LHCb luminosity limited to ~$3.5 \cdot 10^{32}$ cm^{-2}s^{-1} (leveling by transverse beam offset)

Fill length

- Luminosity lifetime is typically **16-25h**.
- Optimum fill length: **12-15h**.

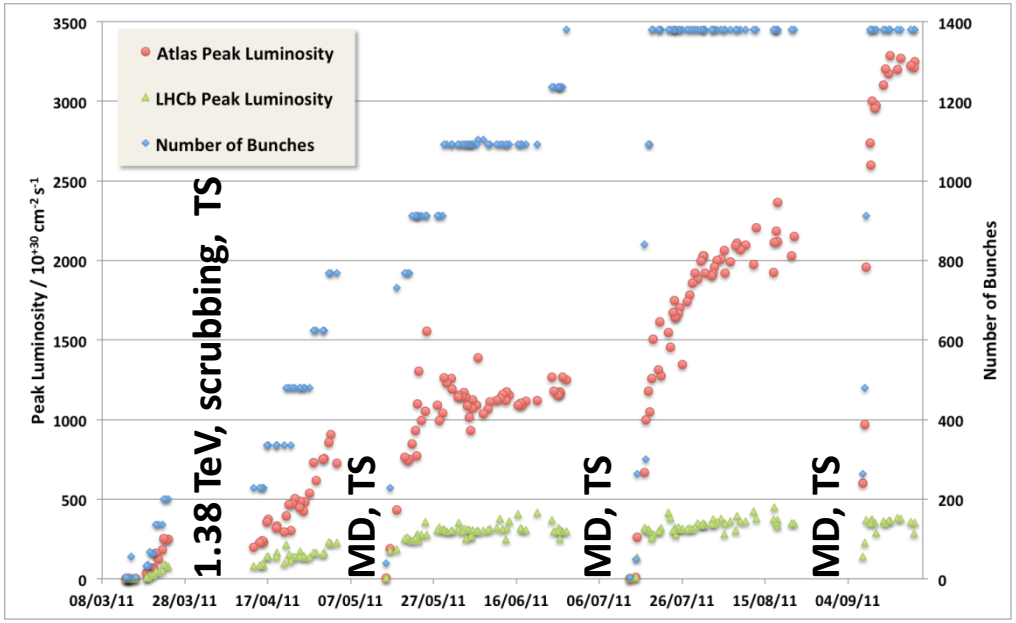
But: In general fills are interrupted by the machine protection system.

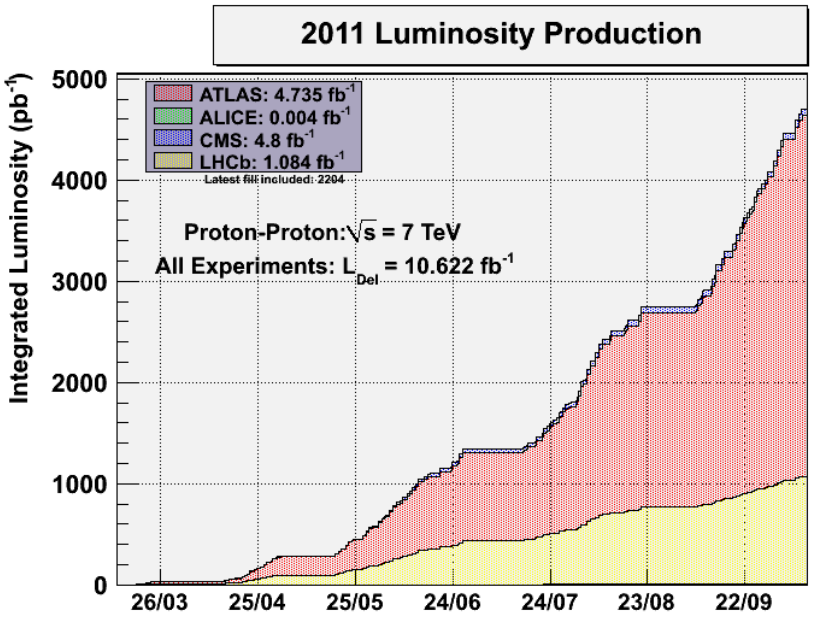




courtesy of J. Wenninger

Luminosity 2011





75 ns | 50 ns

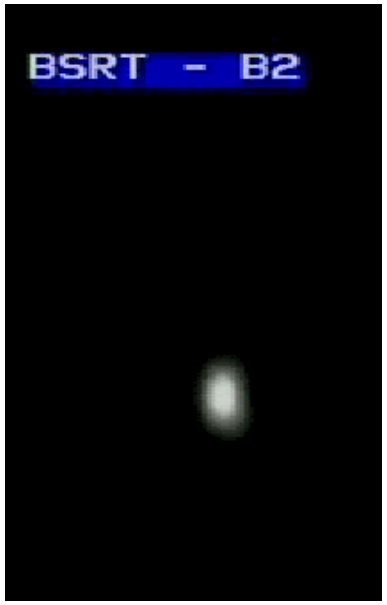
Intensity ramp up | ε decrease | 1m β*

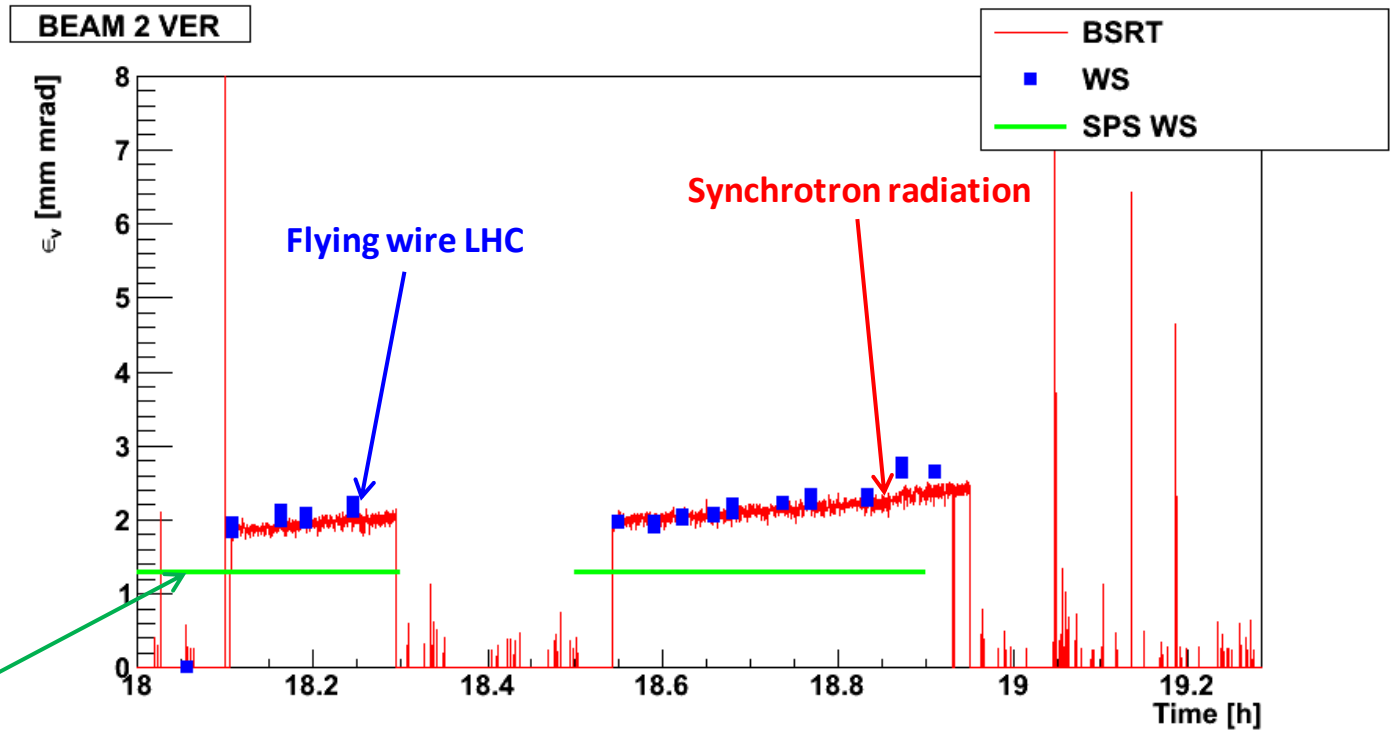
- Integrated luminosity **4.8fb^{-1}**.

  initial goal for 2011: 1fb^{-1}, design luminosity till 2030: 3000fb^{-1}.

Synchrotron Light Monitor

- LHC Protonen und Ionen emittieren sichtbare Synchrotonstrahlung, die zur Bestimmung des Strahlprofils verwendet wird





High intensity issues

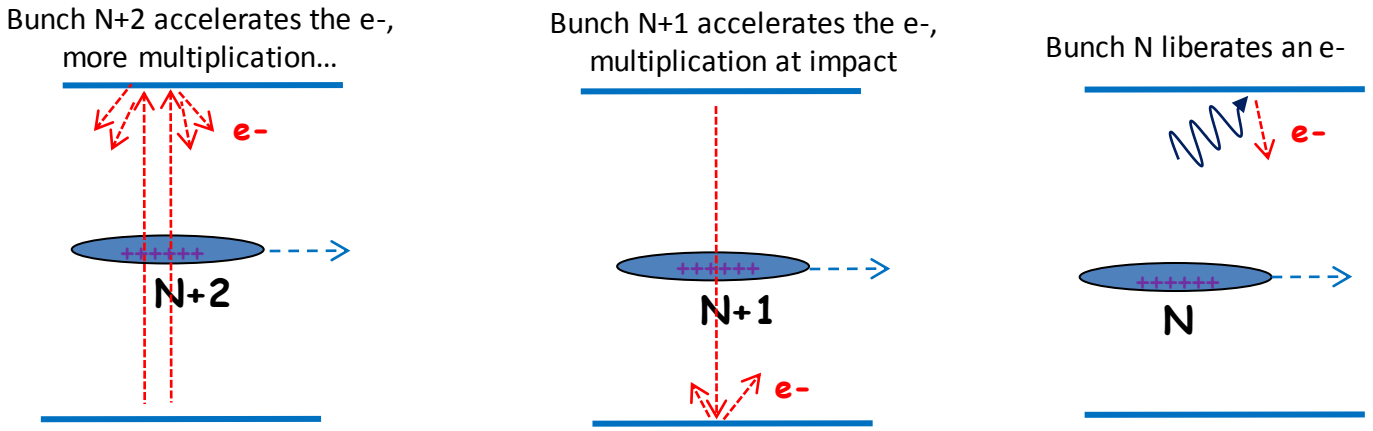
With 50 ns operation and with stored intensity of ~1.8×10^{14} protons (1380 bunches) a number of issues related to high intensity have started to surface:

- *Vacuum pressure increases,*
- *Radiation induced failures of critical tunnel electronics,*
- *Heating of the beam screen temperature,*
- *Heating of injection kickers, collimators,*
- *Losses due to (supposed) dust particles,*
- *RF beam loading,*
- *Beam instabilities leading to emittance blow-up.*

*Those effects have slowed down the pace of the intensity increase, and affect the **machine availability**.*

Vacuum - electron clouds

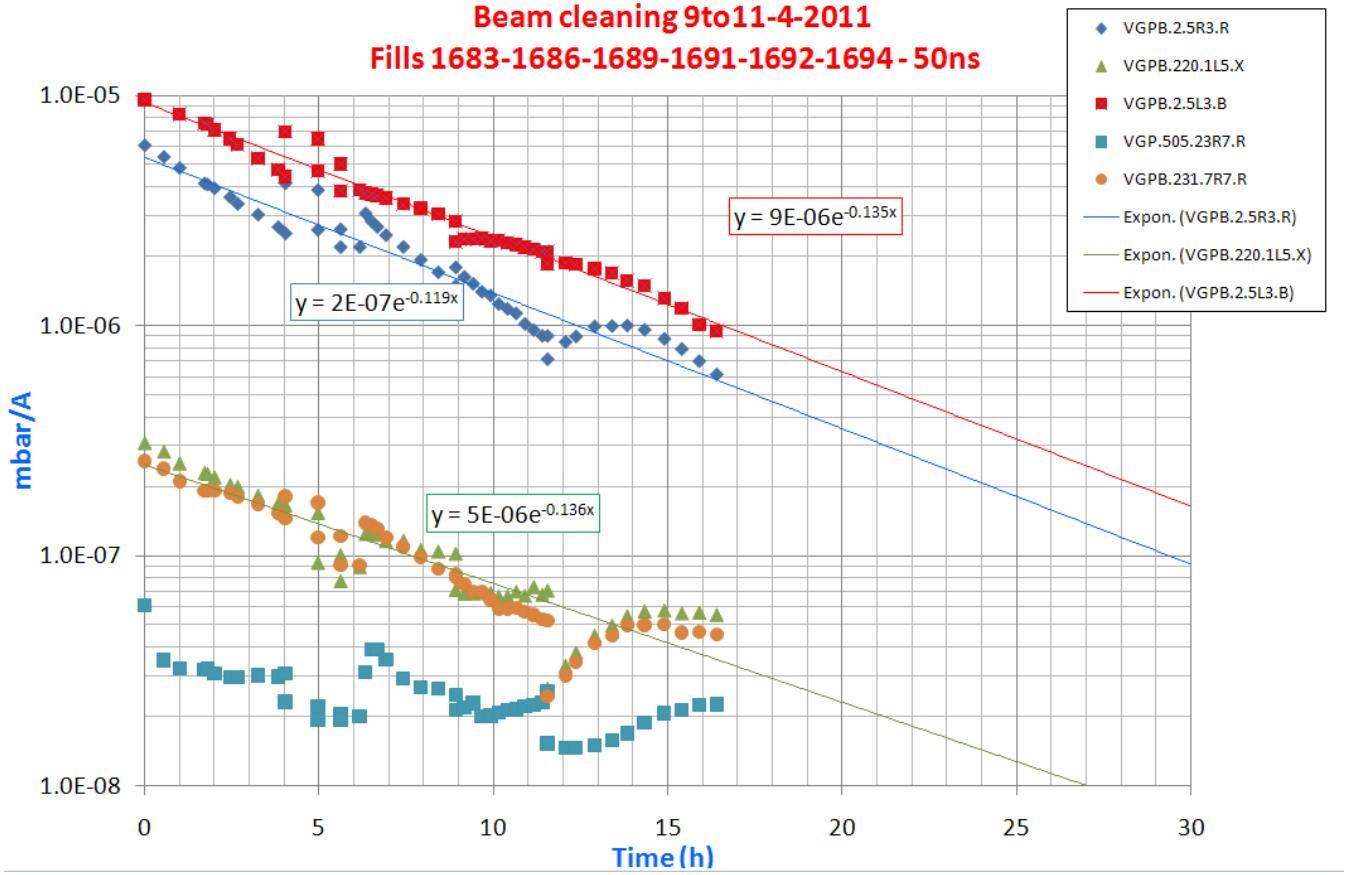
- Since LHC switched to trains, electron cloud are with us.
  - *E-clouds induced pressure rise and beam instabilities (→ large emittance).*
  - *Can be conditioned away… by e-clouds !*



- In April high intensity beams of 50 ns (up to 1080b) were used at injection to condition the vacuum chamber over a ~10 day period.
  - *Provided adequate conditions for stable beam operation (vacuum, beam stability) for operation at 3.5 TeV, with gradual increase of intensity / number of bunches.*

Vacuum cleaning with beam

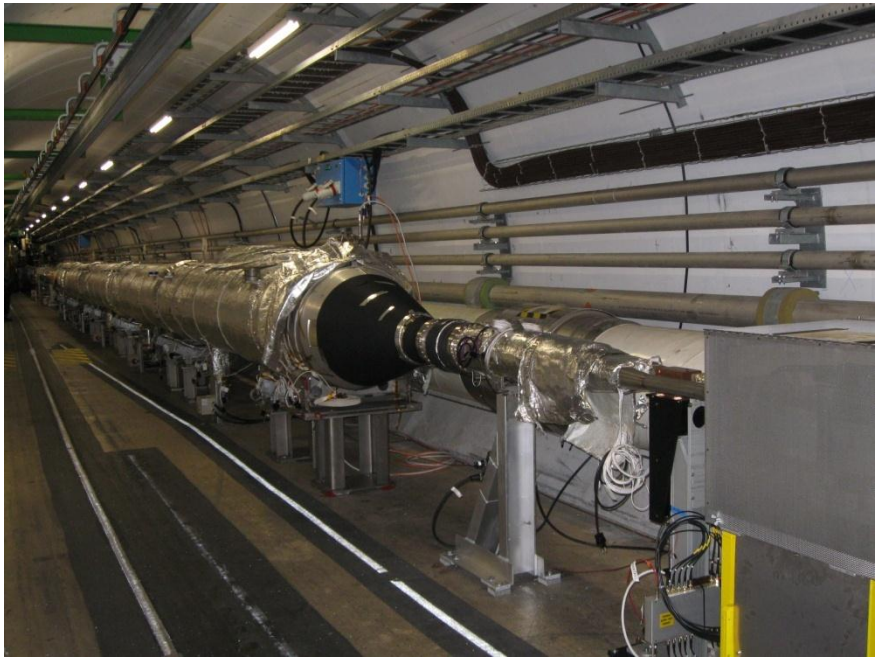
- Pressure decrease (normalized to intensity) as a function of effective beam time in April.
  - *Gain one order of magnitude / 15 hours.*



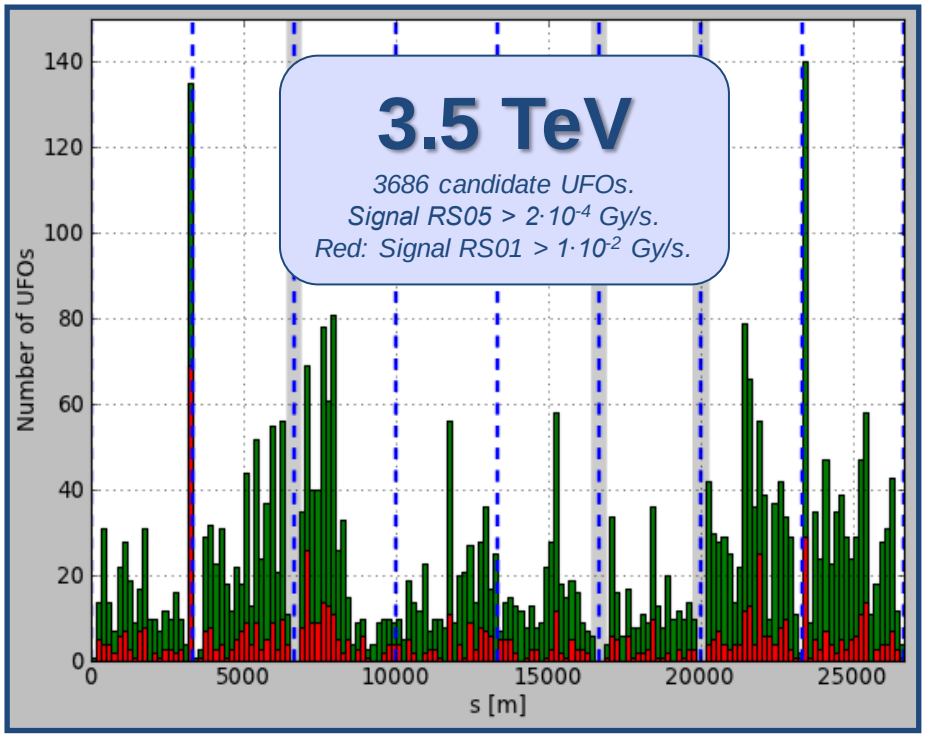
Courtesy J.M. Jimenez

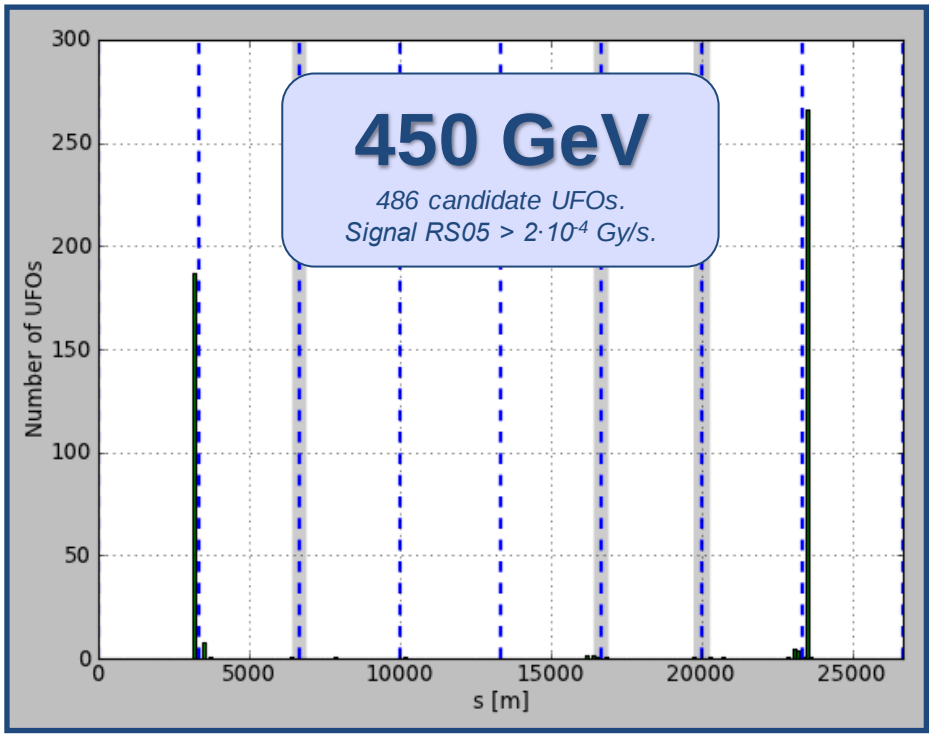
Vacuum - electron clouds

- No major issues over the run, except for ALICE when the solenoid and spectrometer polarities were flipped.
  - *Strong local pressure – prevented ALICE from switching ON for some time.*
  - *ALICE had to be patient until vacuum was conditioned, plus install new solenoids to reduce multi-pacting from the electrons (see below)*



Spatial UFO Distribution



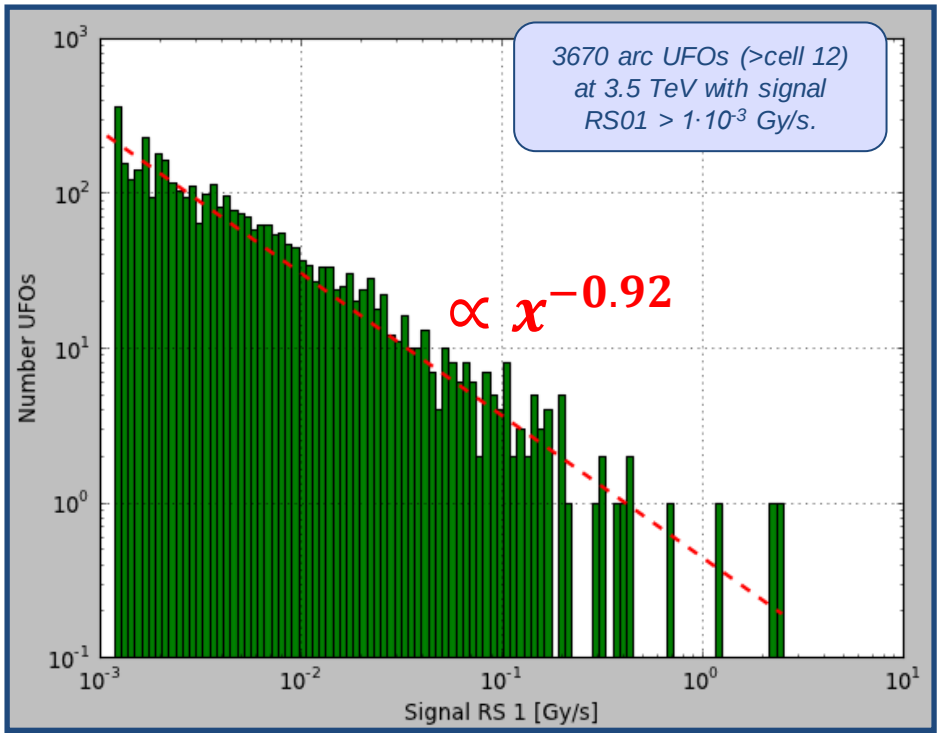


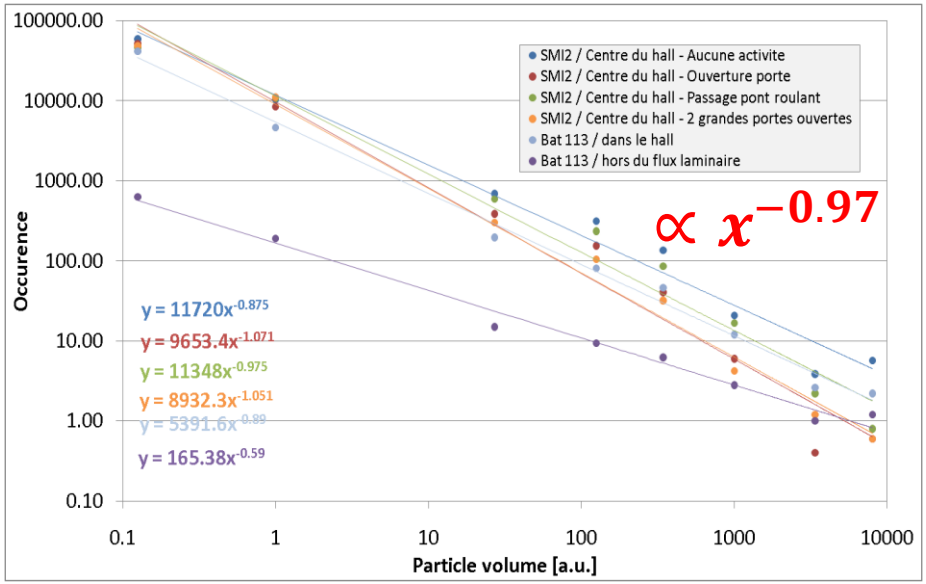
UFOs occur all around the machine.
Many UFOs around **injection kicker magnets (*MKIs*).**

Mainly UFOs around MKIs

gray areas around IRs are excluded from UFO detection.

UFO Amplitude Distribution

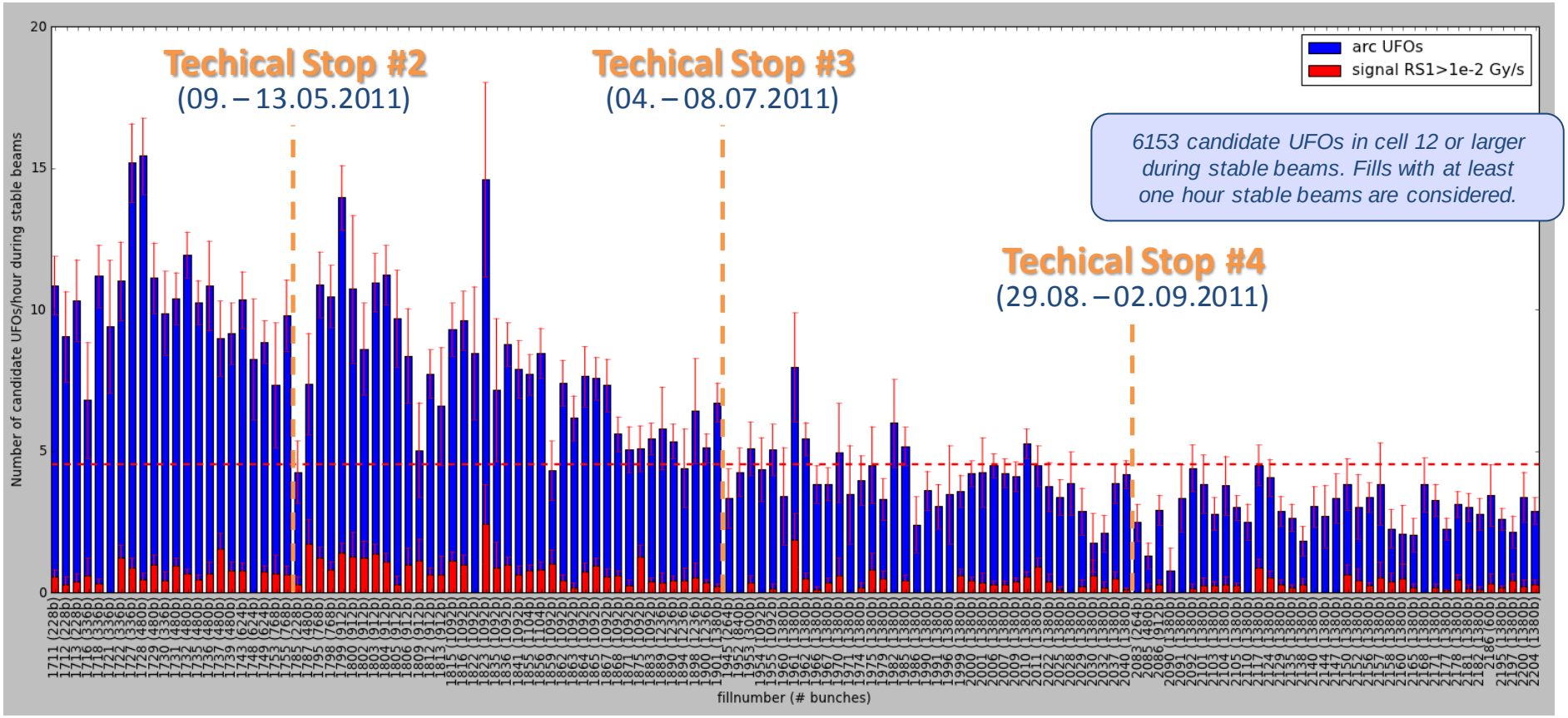




courtesy of J. M. Jimenez

The size distribution of dust particles can explain the UFO distribution.

UFO rate



UFO rate decreased from 10 UFOs/hour to about 4 UFOs/hour.

Energy Dependency

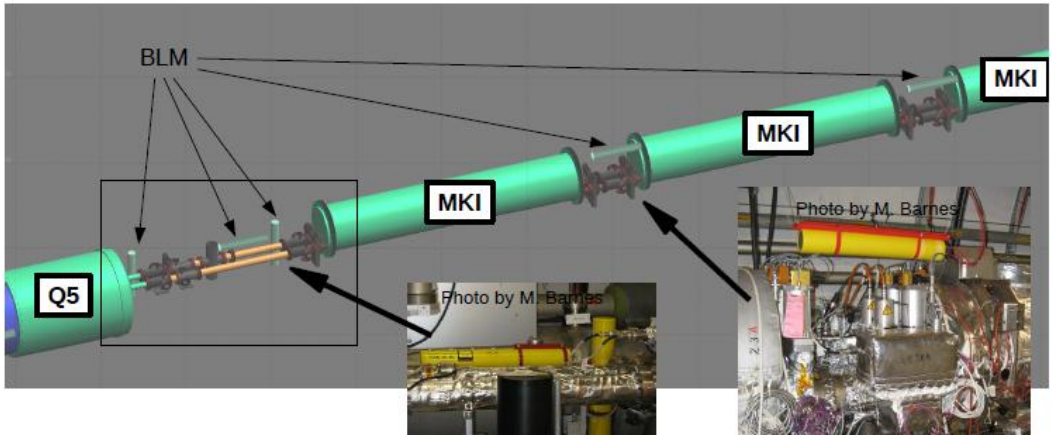
- Ufo amplitude: At 7 TeV about **3 times higher** than at 3.5TeV. (from wire scans).
- BLM thresholds: Arc thresholds at 7 TeV are about a **factor 5 smaller** than at 3.5 TeV. (E. Nebot, IPAC11, TUPC136)
- From 2011 data: About **100 UFO dumps** by arc UFOs for **7 TeV.** (compared to 2 actual dumps at 3.5 TeV).

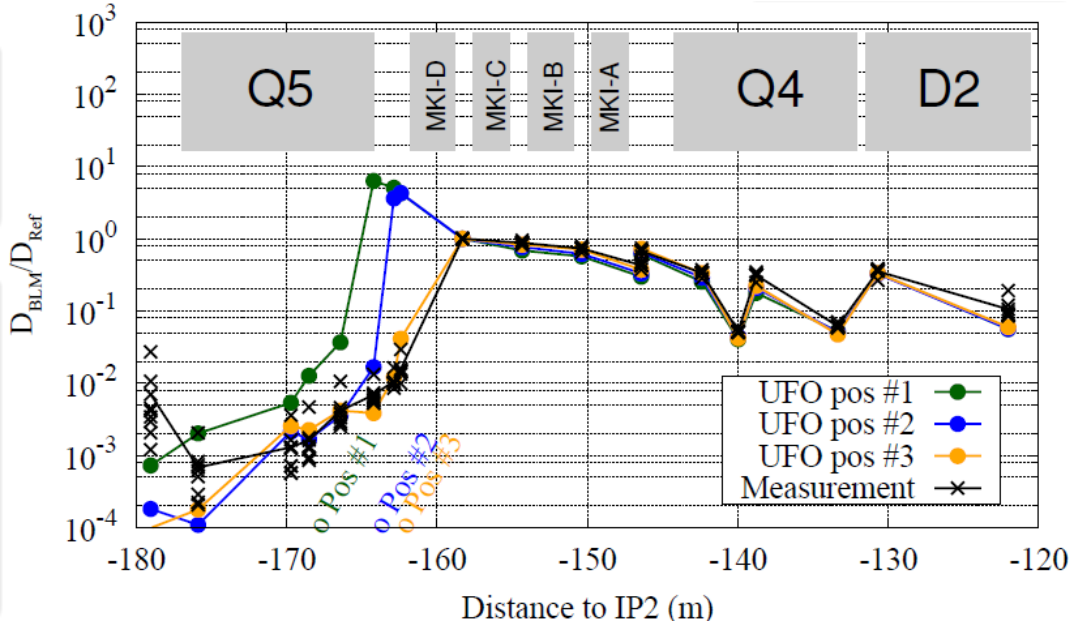
- ***Mitigation***: Mainly further increase of BLM thresholds...

But: Do we have enough margin at higher energies?

Injection Kicker UFOs

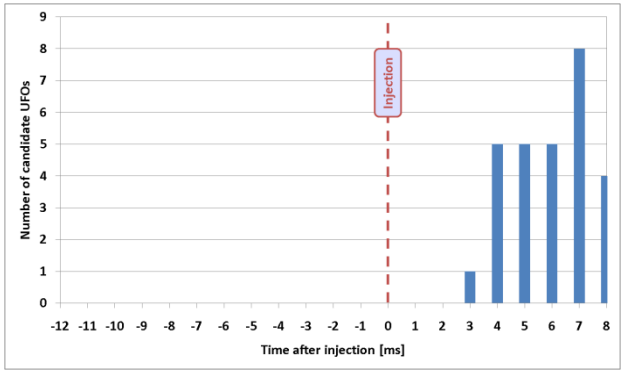
- 13 beam dumps due to UF
- Dedicated FLUKA studies a location.

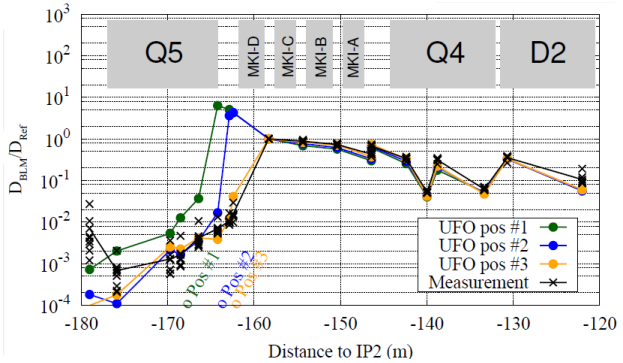




UFO Studies

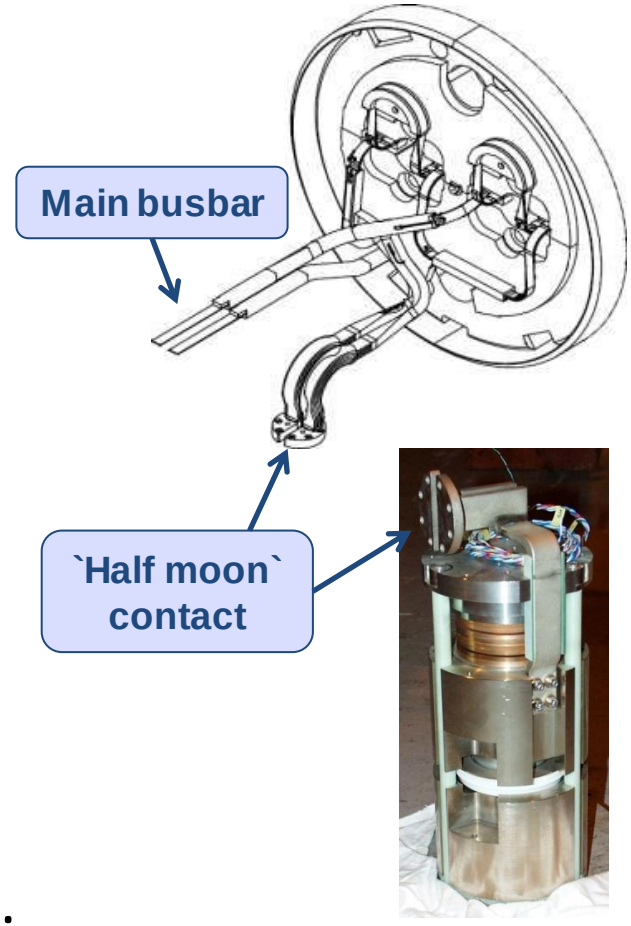
- MKI UFO MDs
  - *Study UFO production mechanism.*
  - *Study dust particle dynamics.*
- Improve diagnostics.
- FLUKA simulations on MKI UFOs.
- Open MKI and search for dust particles.
- Dust particle dynamics model.
- Better understanding of Quench Limit.





The Energy Story

- Bad soldering of busbar joints (splices) led to 2008 incident and limits the save energy to **3.5 TeV**.
- Quench propagation tests showed that magnet quenches do not reach the joint at 3.5 TeV.
- **BUT:** Resistances of the **diode leads** are much larger than expected. The heat could propagate to the splice and cause a quench.

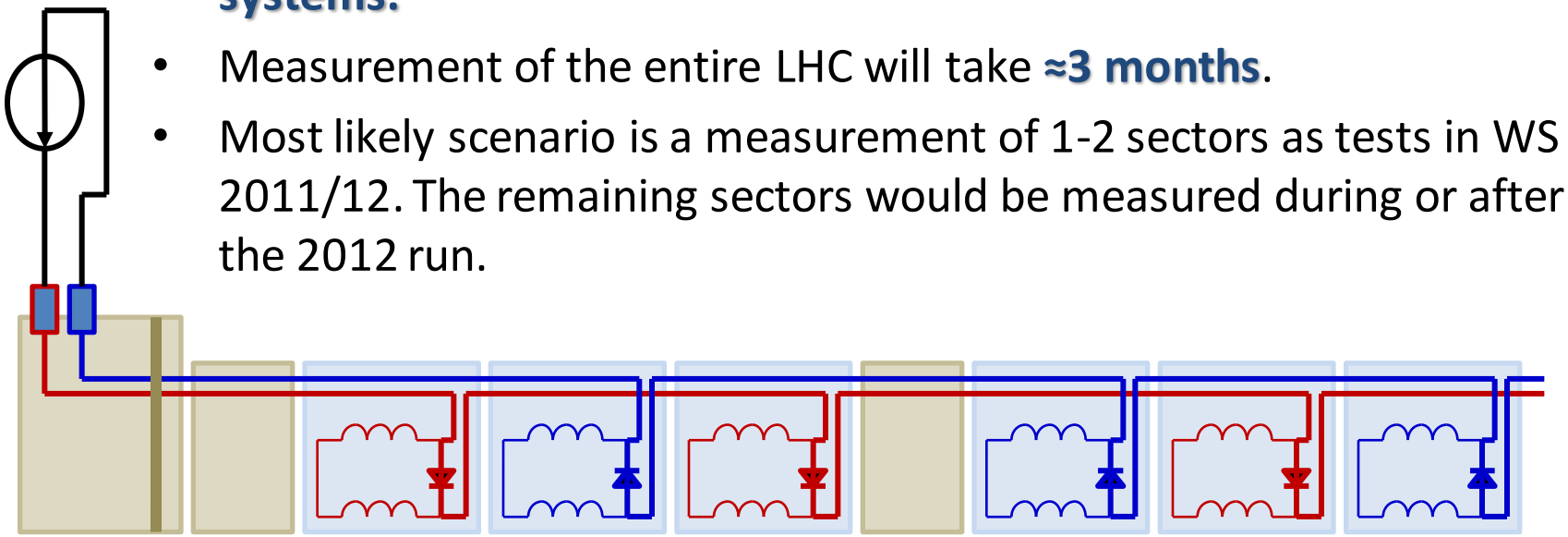


Diode is used as current bypass in case of a quench

Energy Reach and CSCM

The CSCM project aims at measuring the nc resistance of the main circuits with limited risk and at determining the maximum safe energy for each sector.

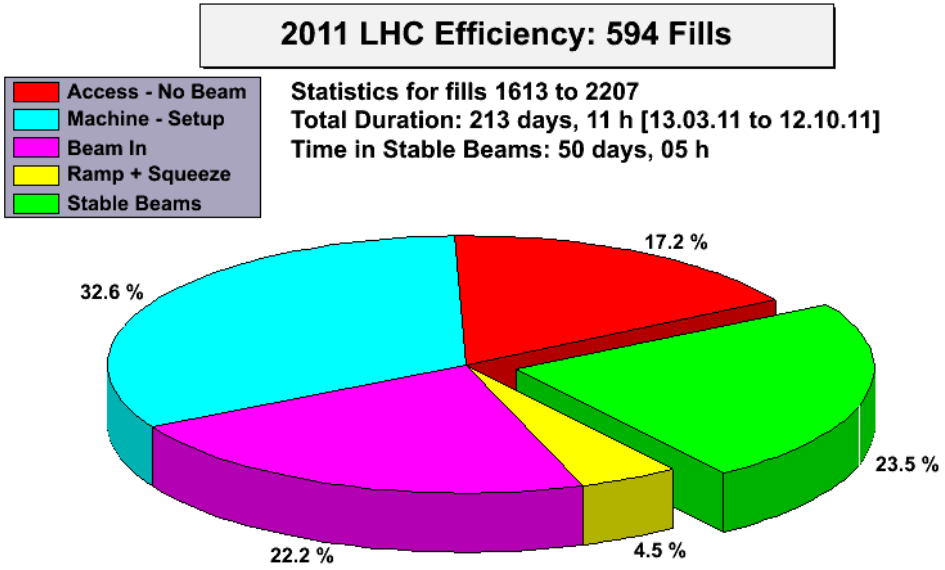
- Conditions similar to a quench, but no stored energy in the magnets.
- Measurements are performed at **20 K**, current bypasses magnets.
- **Requires modifications to power converters and protection systems.**
- Measurement of the entire LHC will take **≈3 months**.
- Most likely scenario is a measurement of 1-2 sectors as tests in WS 2011/12. The remaining sectors would be measured during or after the 2012 run.



Efficiency

Total duration includes :

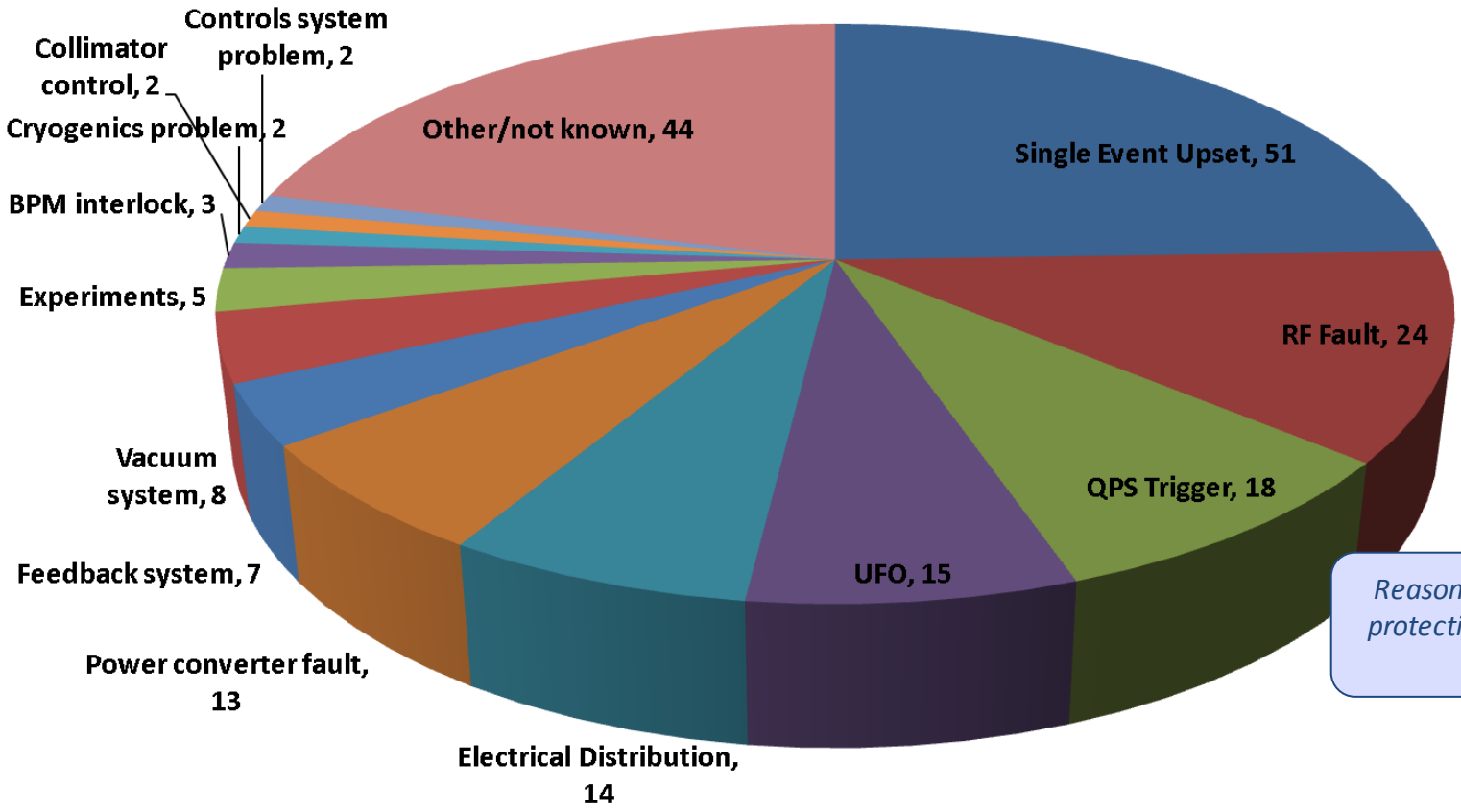
- Scheduled loss of days:
  - *18 days of Technical Stops*
  - *10 days of scrubbing run*
  - *≈16 days of MDs*
- 11 days lost due to cryogenics problems.



Scheduled winter technical stop excluded.

About 50% of time beam in machine.

Protection Beam Dumps

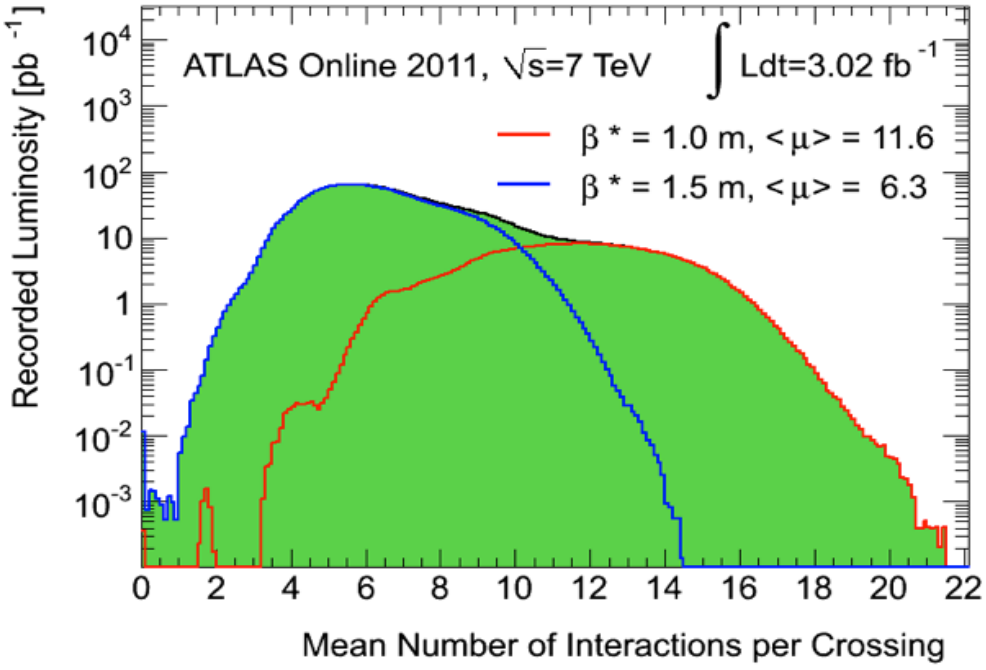


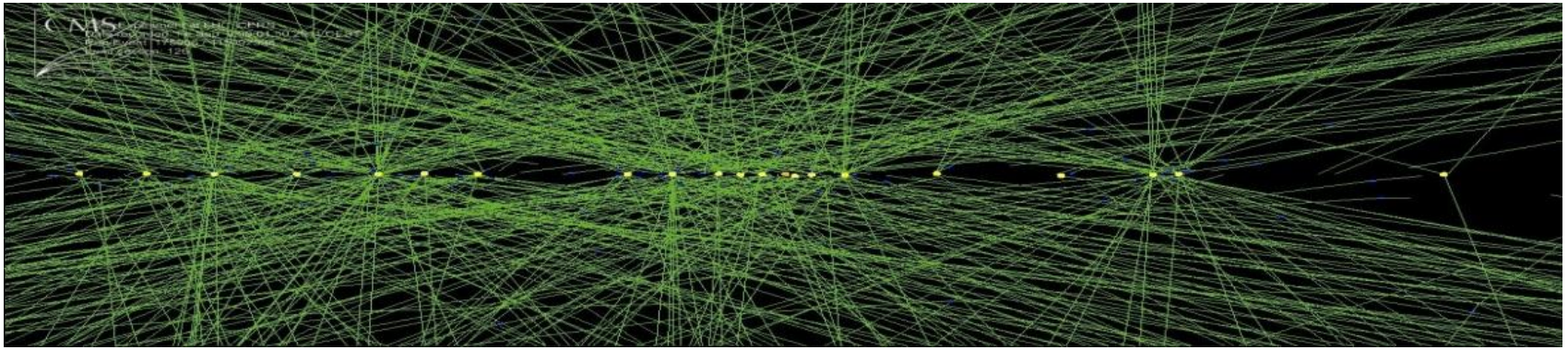
Reasons for high intensity protection beam dumps at 3.5 TeV.

Much room for improvement!

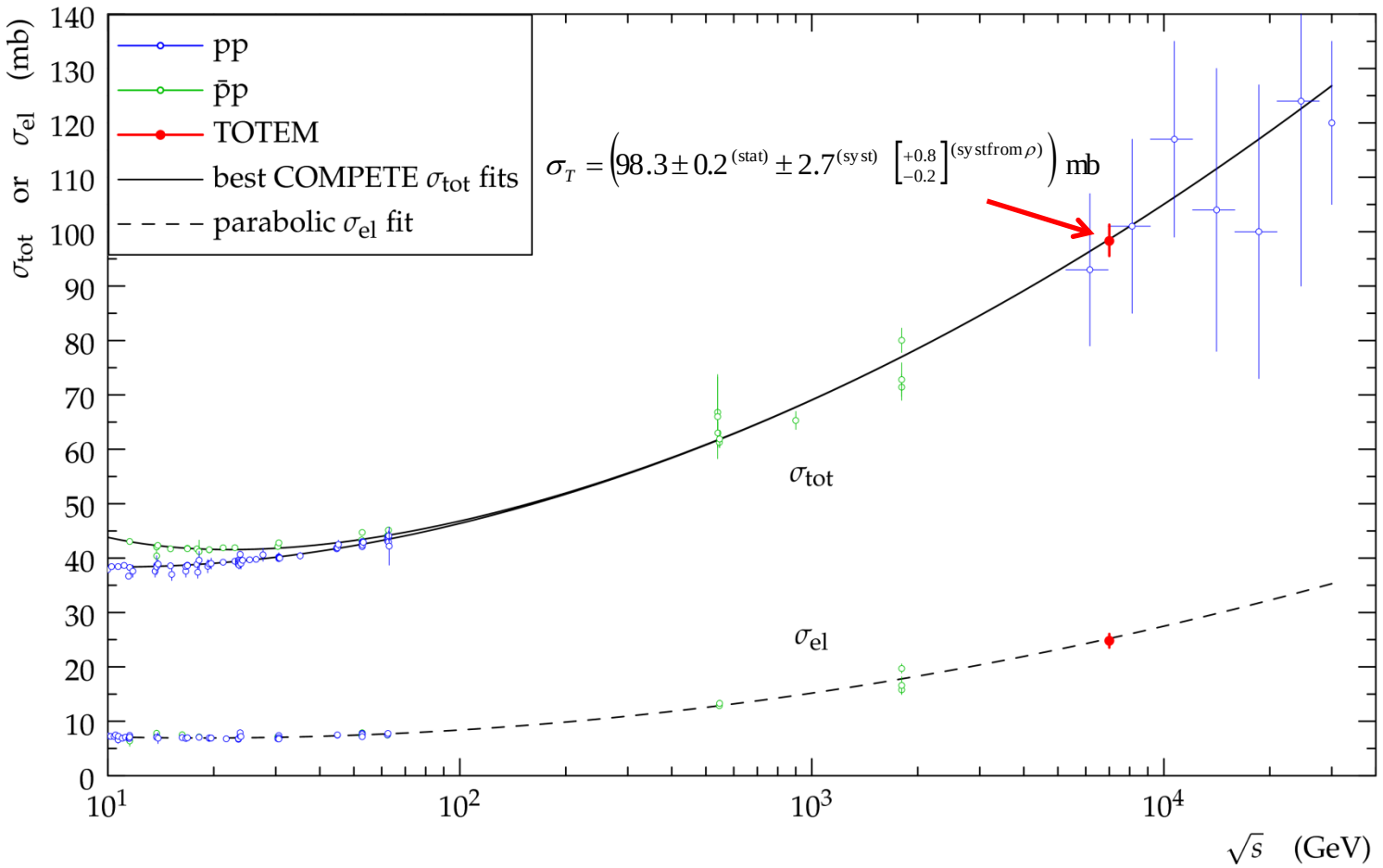
Pileup

- Up to 22 events per bunch crossing.
- ATLAS and CMS do not expect significant problems for data analysis.





p–p cross section

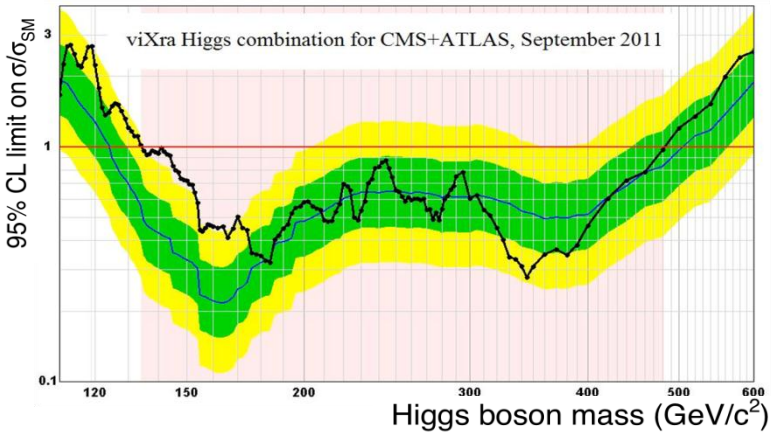
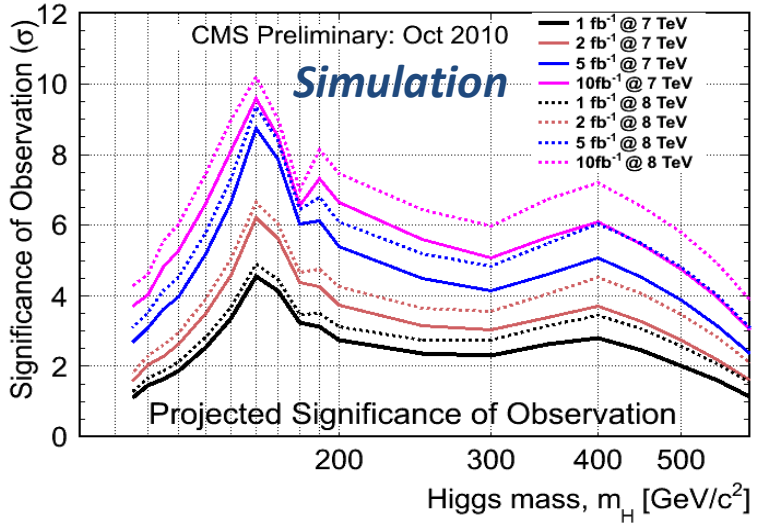


(CERN-PH-EP-2011-158)

Precision measurement of pp cross section by TOTEM.

Higgs search

*95% CL exclusion of standard model Higgs between **135 and 480 GeV**.*



*Until 2012, 15fb^{-1} are realistically achievable => **Higgs discovery potential** in large mass range.*