
CERN

LHC Summary and Plans

Giovanni Iadarola for the LHC team

Our goals for 2016

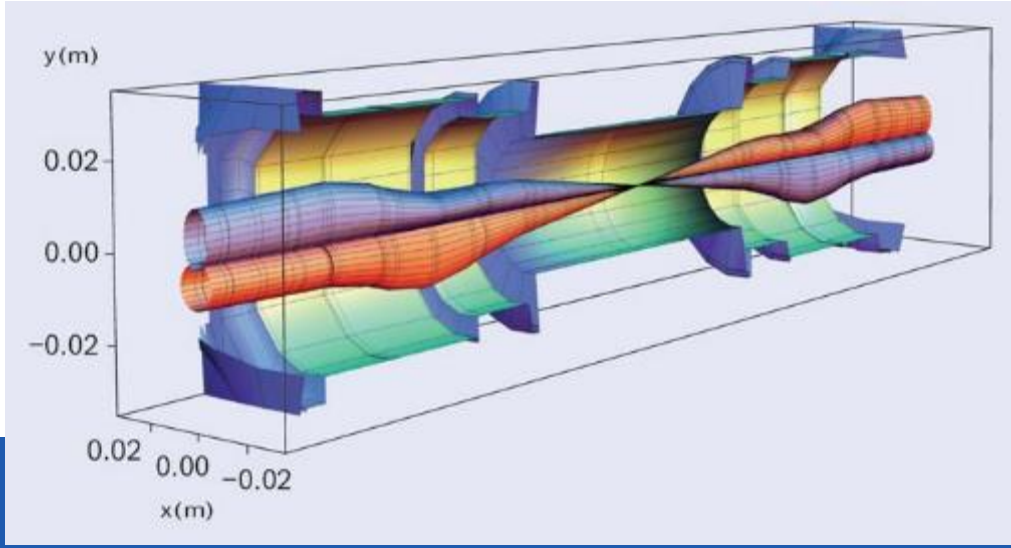
2015: Recommissioning and Exploration

- Recovered from a **2-year shutdown**
- Learnt how to cope with **new challenges** of operating at **6.5 TeV** with **25 ns** bunch spacing

2016: Production

- **Goal:** accumulating largest possible **integrated luminosity** (i.e. ”number of collisions”) **over the year**
- Used the **2015 machine configuration** with even **more focused beams** at the high luminosity experiments (β*: 80 cm → 40 cm)

  → result of **optimization** work on beam-beam effects, optics and aperture control



The startup: highs and lows

Beams back in the LHC on 25 March (Easter weekend, starts being a tradition…)

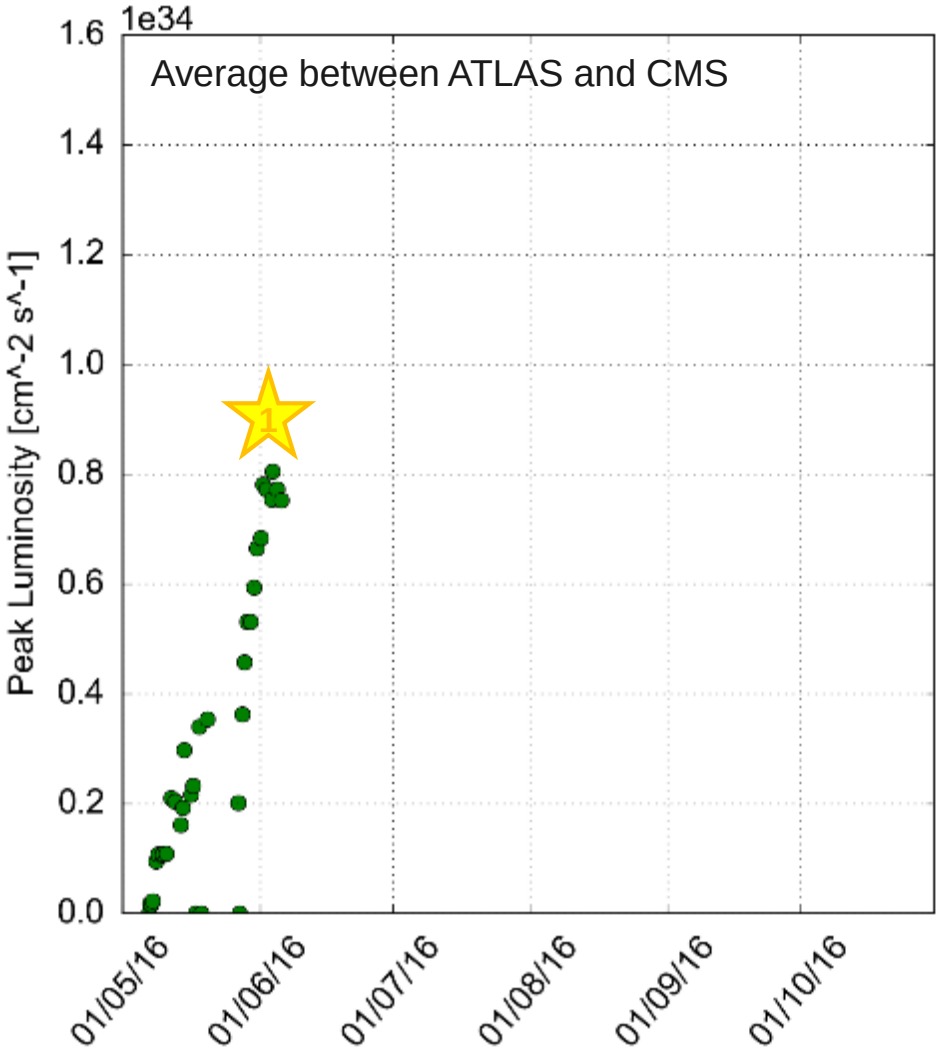
Very efficient **setup with low intensity beams**

→ **machine validated** for β* = 40 cm in ~1 month

But then **Week 17 came** - just about to start operation with higher intensity:

- 26 April: Vacuum leak in the **SPS beam dump** → limited beam intensity for the rest of the year ☹
- 27 April: Serious breakdown in the **PS main power supply** (POPS)
- 29 April **"Weasel incident"** at one of the 66 kV transformers feeding the LHC

p-p physics: quest for luminosity



Beginning of May: Operation resumed

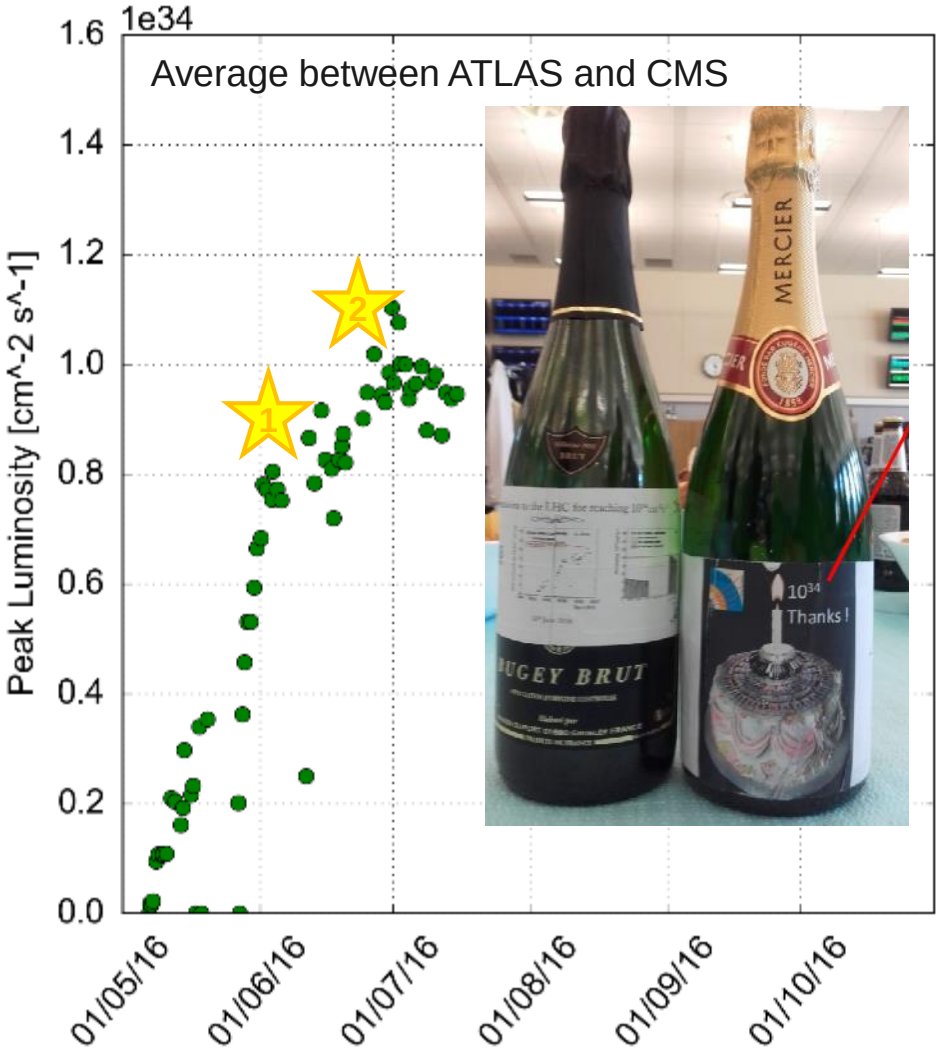
Number of proton bunches gradually increased

1 June: reached 2000 bunches

$L_{peak} = 0.8 \times 10^{34}\ cm^{-2}s^{-2}$

beating previous record from 2012

p-p physics: quest for luminosity



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beating previous record from 2012

Increased bunch population
Decreased bunch length

2

26 June:

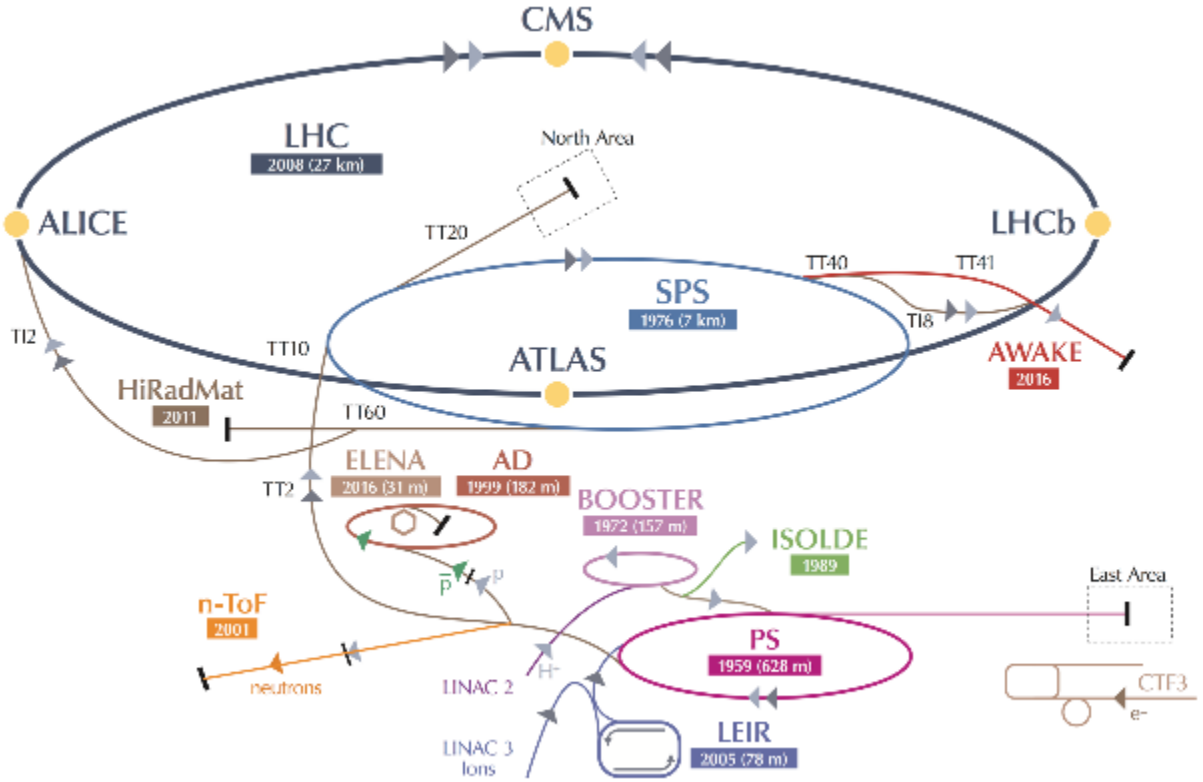
$L_{peak} = 1.0 \times 10^{34}\ cm^{-2}s^{-2}$

LHC design luminosity!!!

An extra boost from the injectors

The LHC performance fully relies on the **performance of its injector complex**

- By itself **one of the largest accelerator facilities in the world** with its own diverse and, for many aspects, unique physics program



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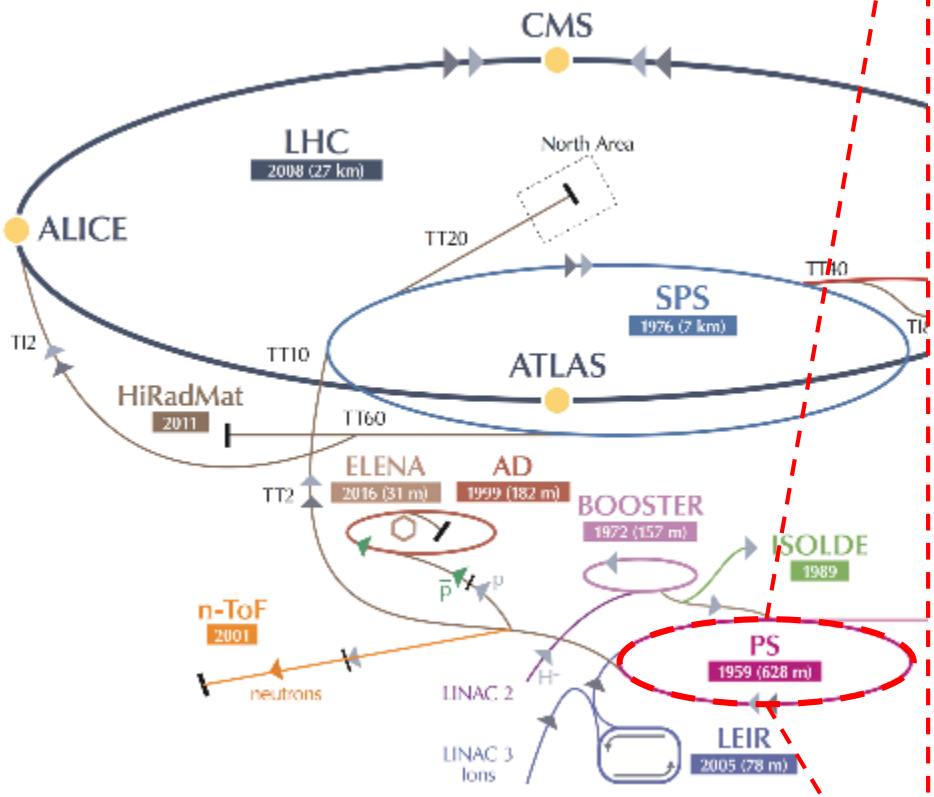
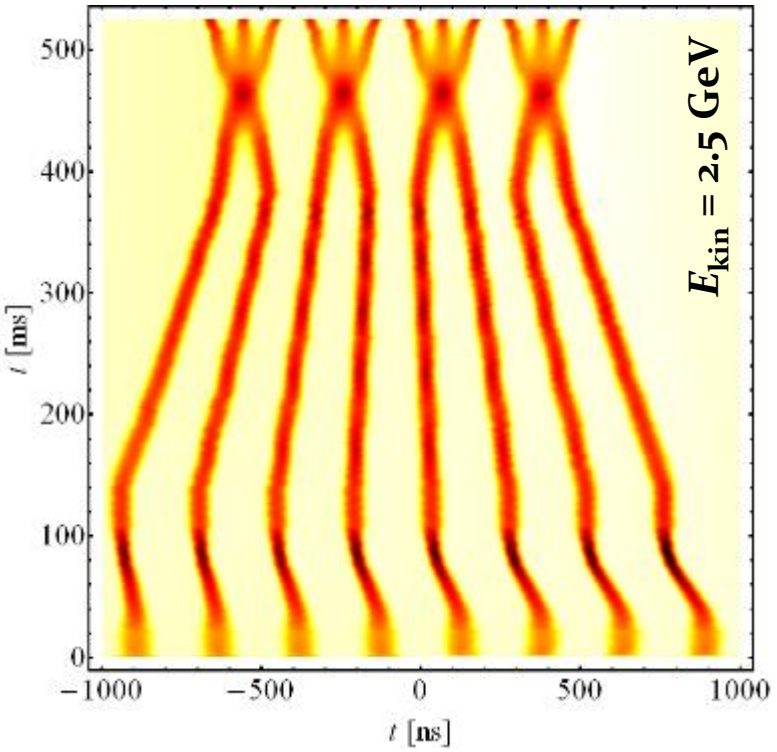
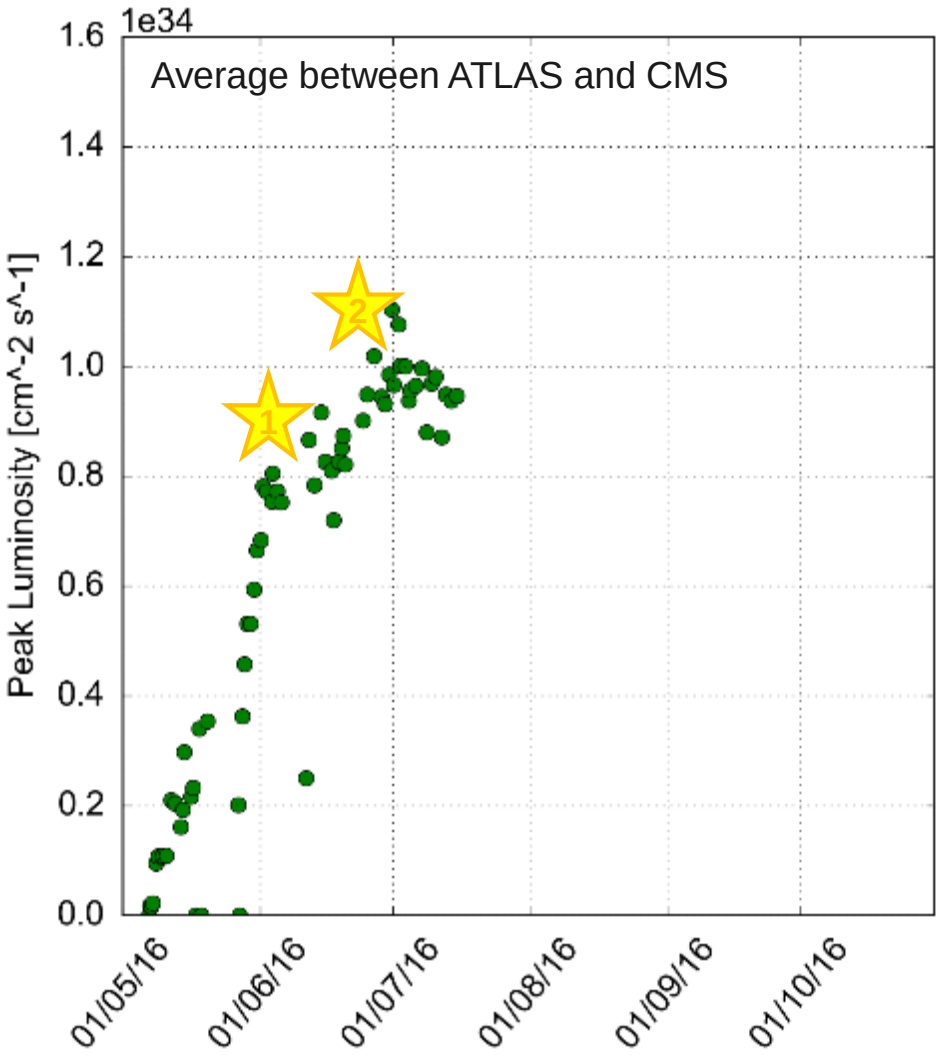


An **advanced production scheme** – the **"BCMS"** - was put in place in the PS

- RF cavities tuned at different frequencies play together to **compress, merge and split proton bunches**
- Beams **~30% brighter** than standard scheme



p-p physics: quest for luminosity



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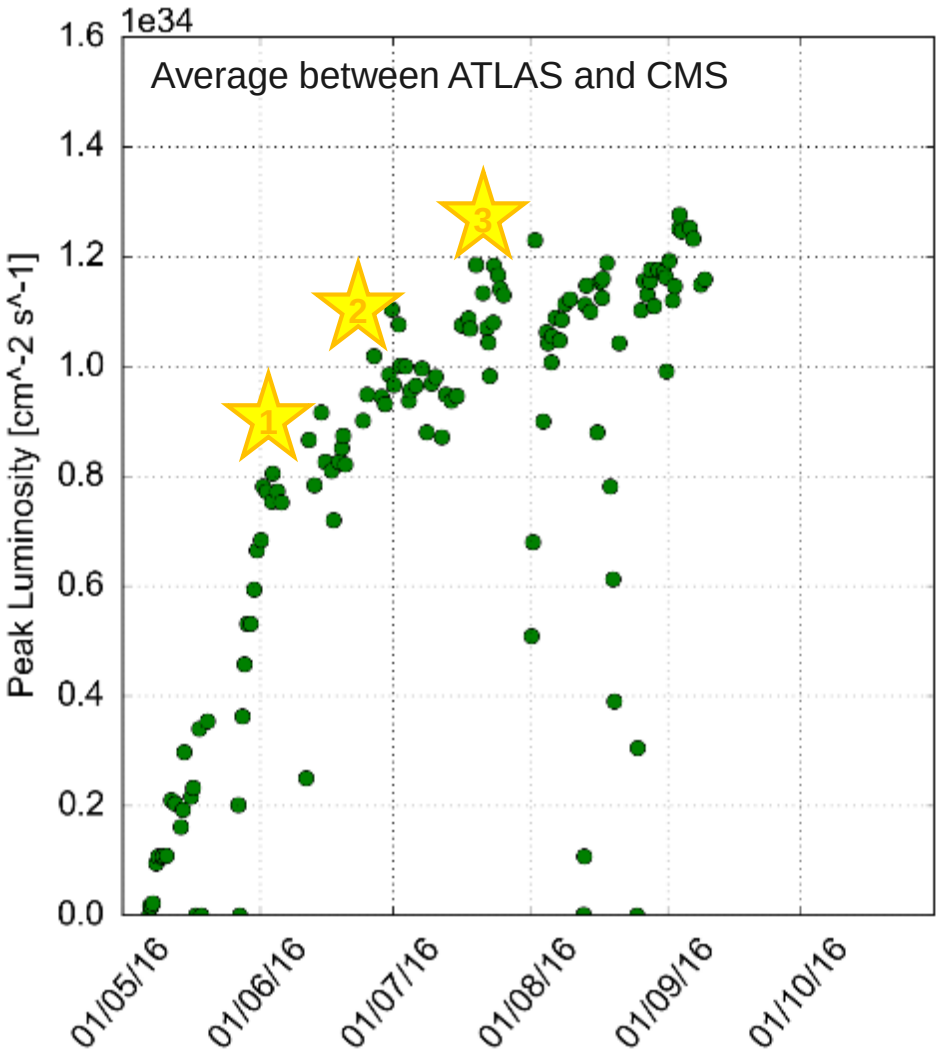
LHC design luminosity

BCMS scheme in the PS

→ Beams gradually brighter

p-p physics: quest for luminosity



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LHC design luminosity

BCMS scheme in the PS

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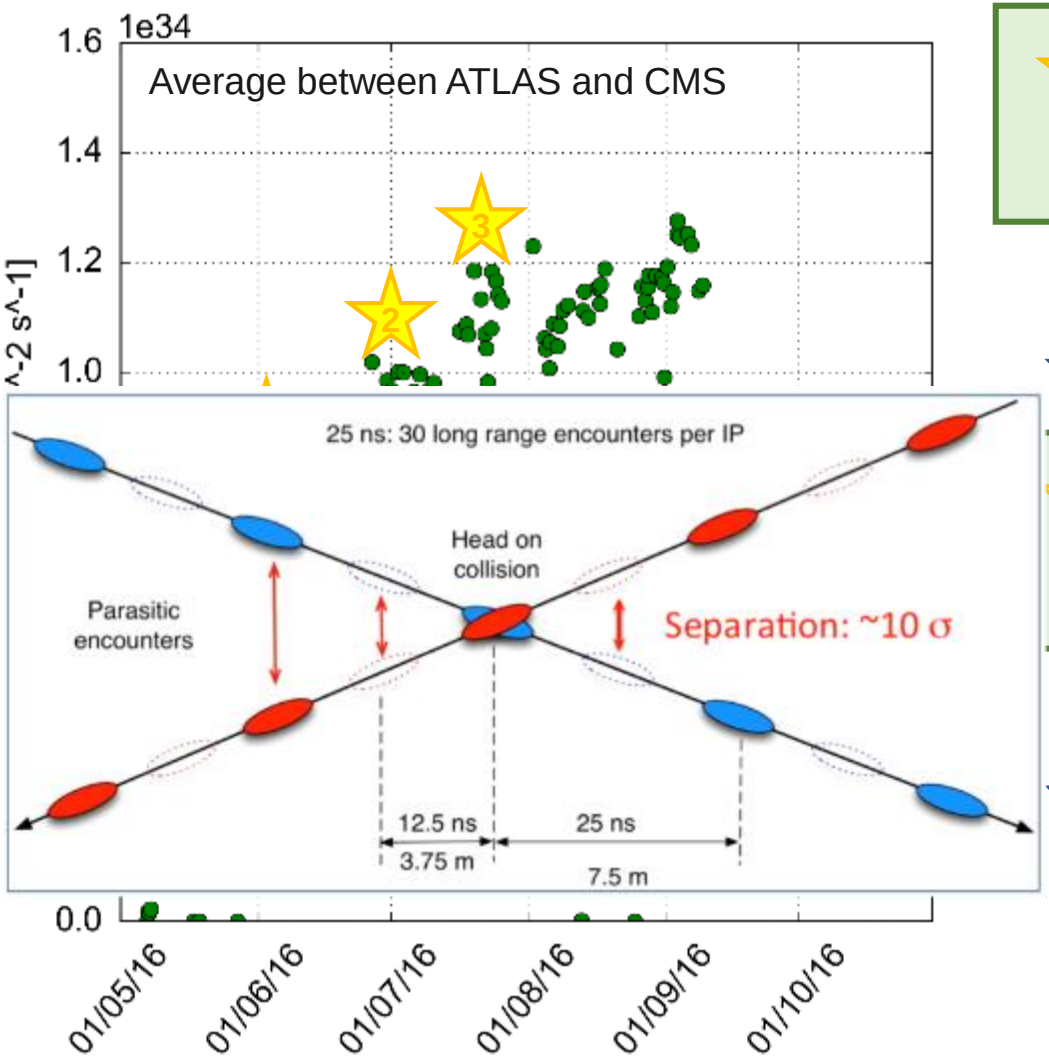
19 July:

$L_{peak} = 1.2 \times 10^{34}\ cm^{-2}s^{-2}$

20% above LHC design

p-p physics: quest for luminosity



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LHC design luminosity

BCMS scheme in the PS

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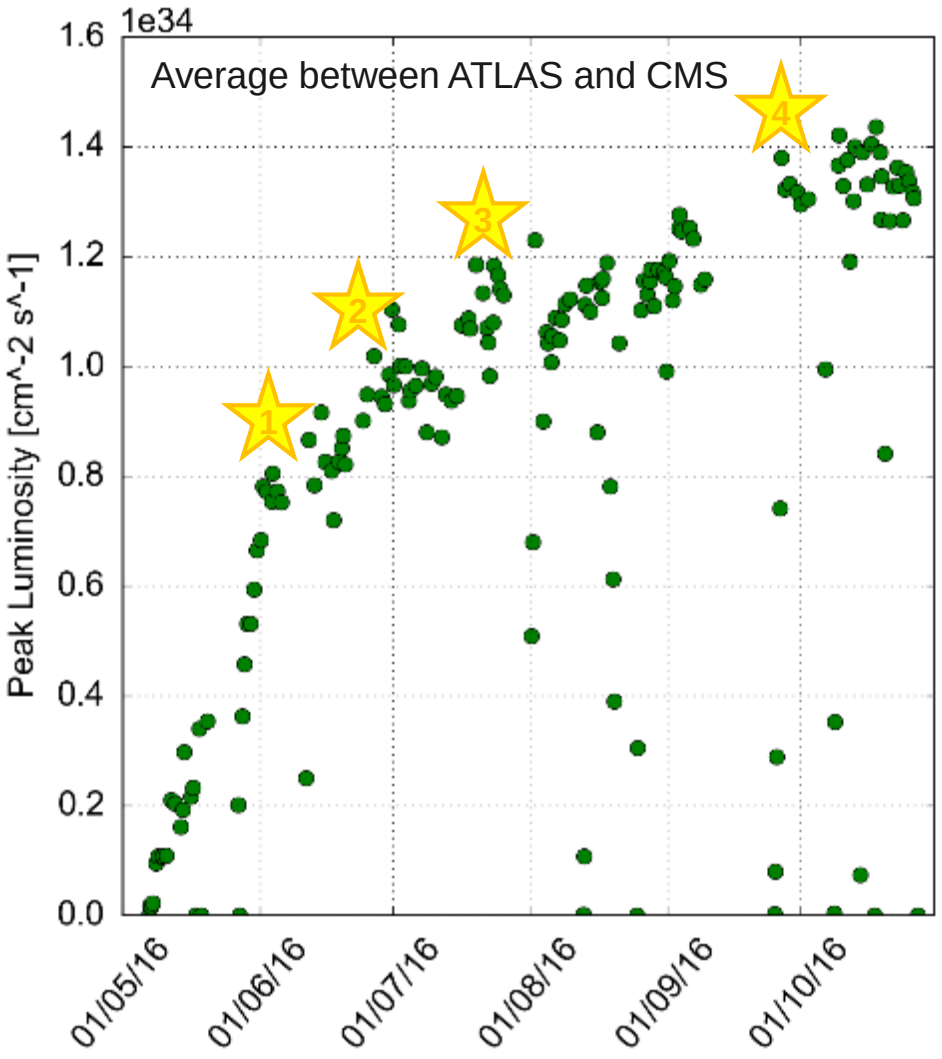
Reduction of the crossing angle (profiting from the smaller beam sizes)

p-p physics: quest for luminosity



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LHC design luminosity

BCMS scheme in the PS

→ Beams gradually brighter

19 July:

$L_{peak} = 1.2 \times 10^{34}\ cm^{-2}s^{-2}$

20% above LHC design

Reduction of the crossing angle (profiting from the smaller beam sizes)

26 September:

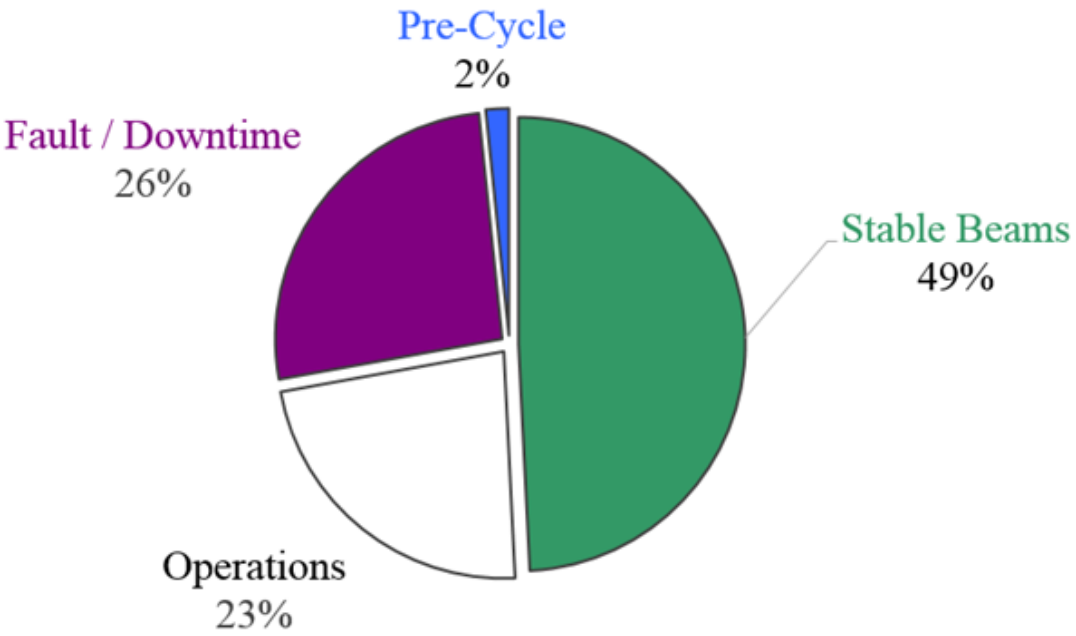
$L_{peak} = 1.4 \times 10^{34}\ cm^{-2}s^{-2}$

40% above LHC design!

p-p physics – machine availability

2016 was characterized by **unprecedented machine availability**:

- The machine was **available for operation 72% of the time** scheduled for physics
- Overall **Stable Beam efficiency of 49%** (to be compared to 36% in 2012, and 30% for the short production period in 2015)



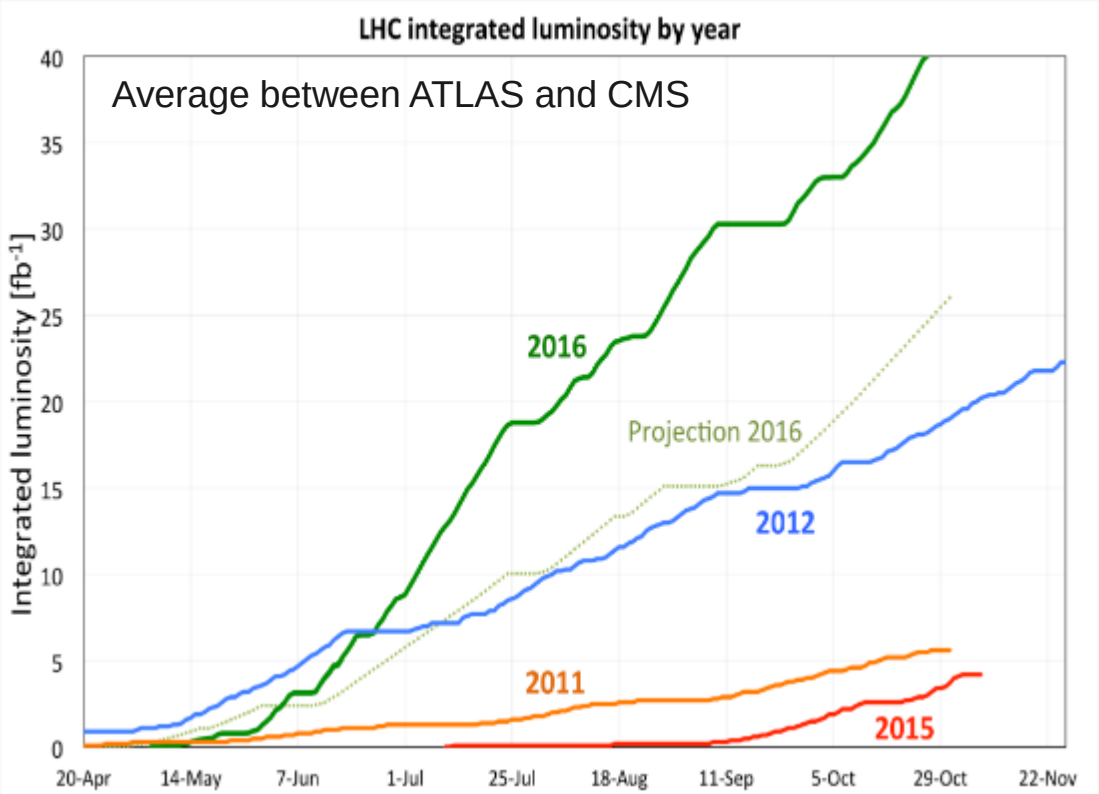
Possible thanks to:

- **Professionalism**, **commitment** and **attention to the details** from all the different **equipment groups**
- **Solid understanding** of the machine and beam behaviors
- Continuous effort in **fault and availability tracking**

p-p physics – summing all up

Combination of high **peak performance** and excellent **machine availability**

→ quite impressive progression of the **integrated luminosity**



~40 fb^{-1}

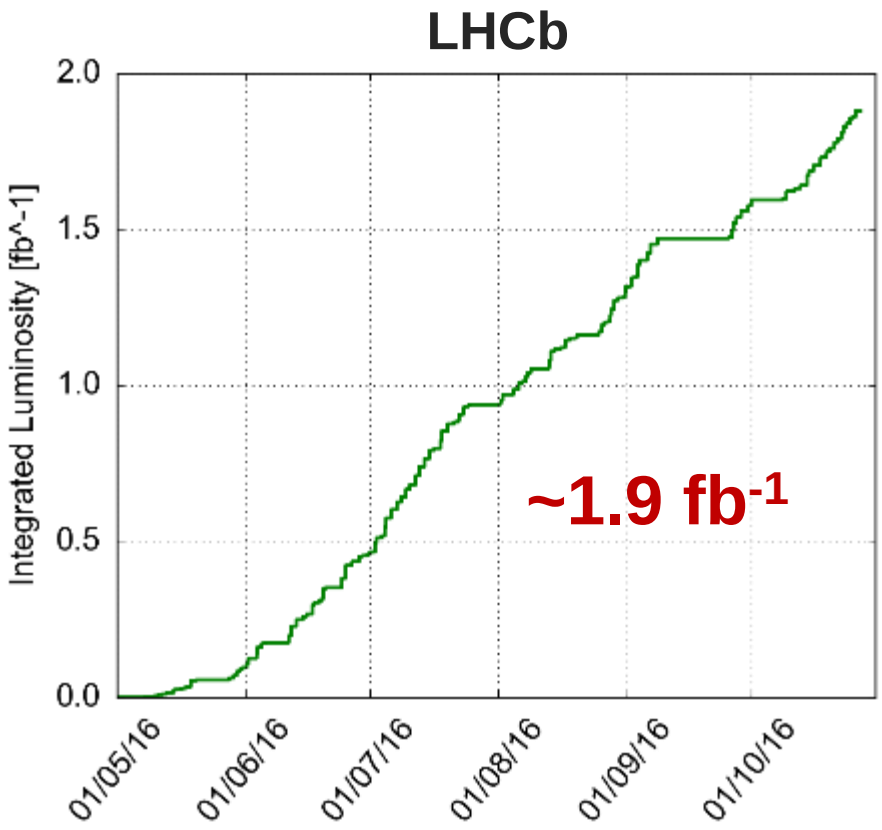
for ATLAS and CMS

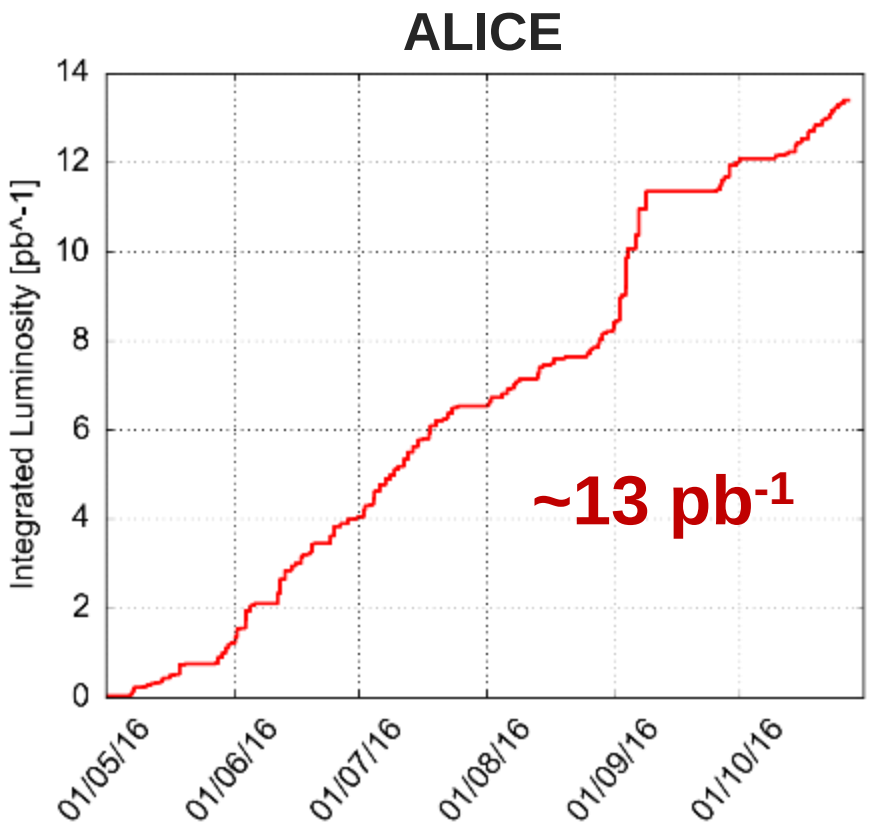
(2016 target was 25 fb^{-1}!)

More data in 2016 than in all previous years together!

p-p physics – ALICE and LHCb

… acquiring data with **luminosity leveled at their desired values** all along the p-p fills

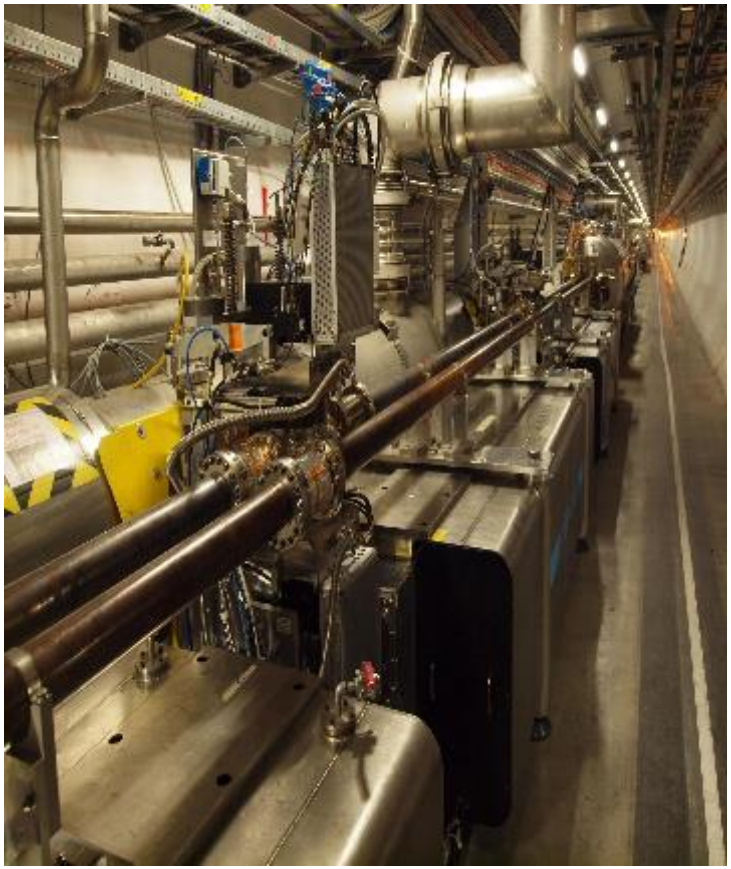




Special run at β* = 2.5 km

- Special period for data collection by **TOTEM** and **ATLAS/ALFA** experiments
  - Looking for small angle deviations (elastic p-p interactions)

ATLAS/ALFA Roman Pots



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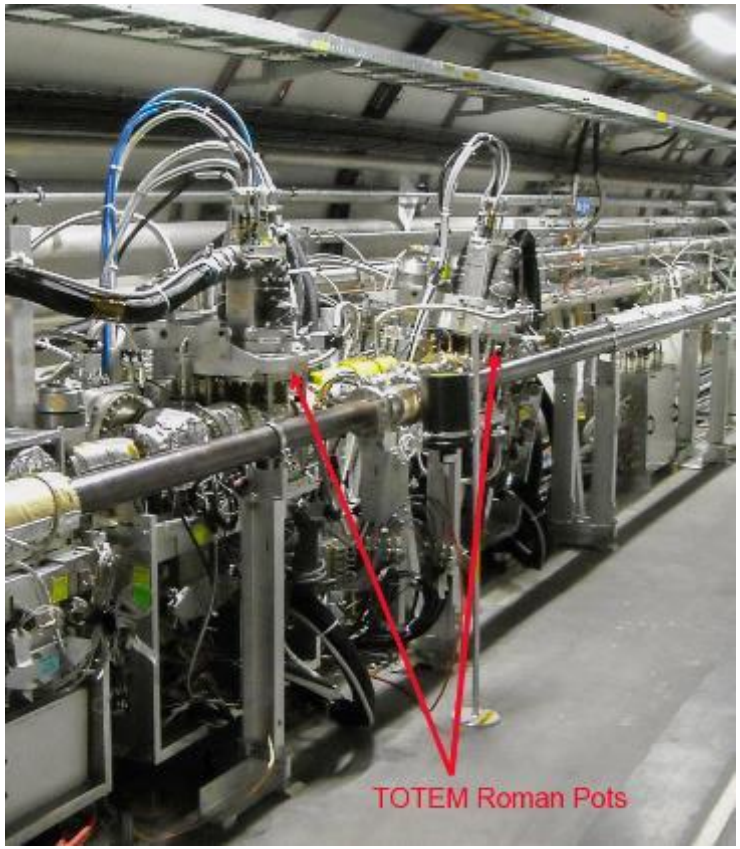

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- Special period for data collection by **TOTEM** and **ATLAS/ALFA** experiments
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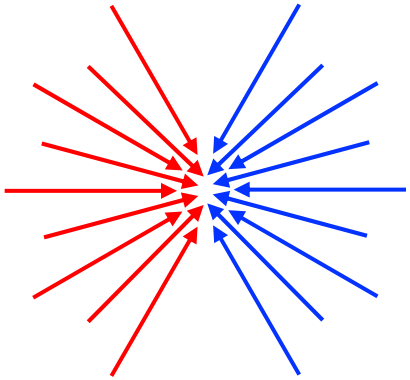
  - LHC reconfigured to operate with **"de-squeezed" beams**
  - Quite **difficult regime** for a machine conceived to do exactly the opposite
- Implementation of the special optics required a few days of commissioning

Standard configuration

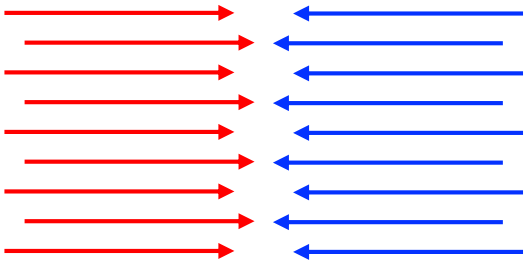
β* = 0.4 m



Small collision spot → high luminosity
Large beam divergence

Special configuration

β* = 2500 m



Large beam spot → low luminosity
Very small angular deviations

Special run at β* = 2.5 km

- Special period for data collection by **TOTEM** and **ATLAS/ALFA** experiments
  - Looking for small angle deviations (elastic p-p interactions)
  - LHC reconfigured to operate with **"de-squeezed" beams**
  - Quite **difficult regime** for a machine conceived to do exactly the opposite
- Implementation of the special optics required a few days of commissioning
- Followed by **4 days** of very **successful data taking**

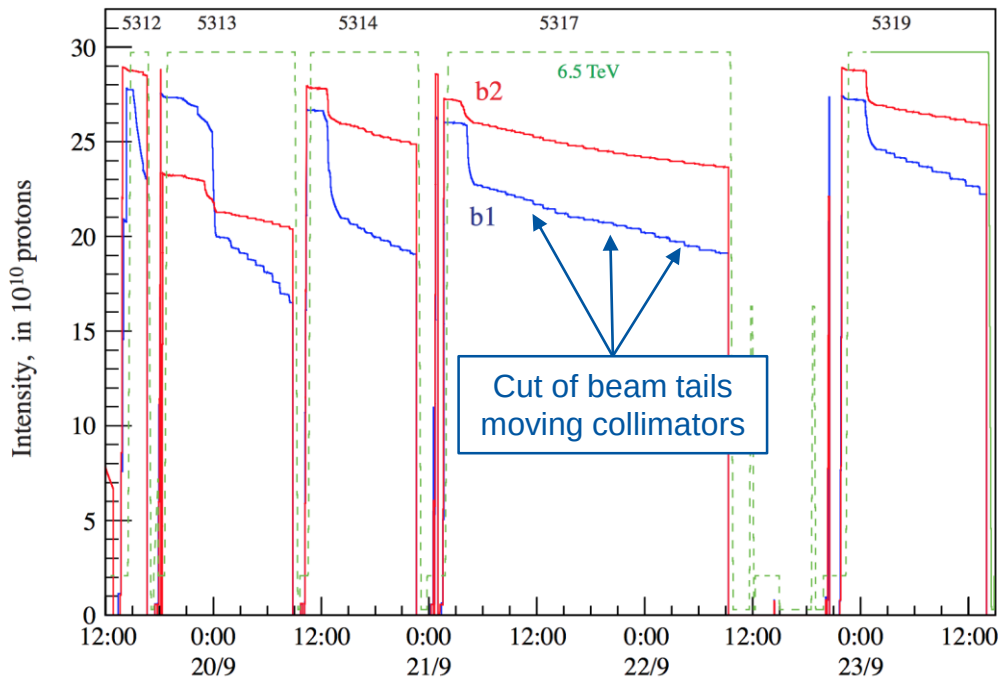
Standa **guration**

) m

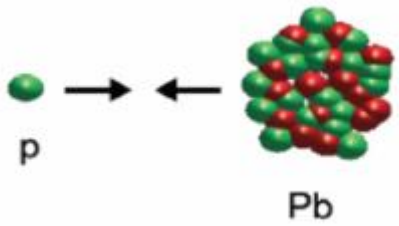
Small collisior low luminosity

Large l r deviations

Data taking at β*=2.5km



The final rush: proton-ion run



The last month of operation was devoted to **proton-ion collisions**

- Very interesting regime for accelerator specialists: the two beams would naturally have different revolution periods!

Ambitious program with **three different machine configurations** to be carried out in exactly **four weeks** (including commissioning!)

- Performance of LHC and ion injectors well beyond expectation

Configuration	Goal	
5 TeV p-Pb	ALICE	700×10^6 m.b. events
8 TeV p-Pb	ATLAS - CMS	50 nb^{-1}
	LHCb - ALICE	10 nb^{-1}
	LHCf	9-12 h at 10^{28} $cm^{-2}s^{-1}$
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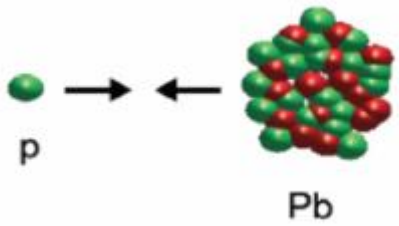

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- Very interesting regime for accelerator specialists: the two beams would naturally have different revolution periods!

Ambitious program with **three different machine configurations** to be carried out in exactly **four weeks** (including commissioning!)

- Performance of LHC and ion injectors well beyond expectation
- All **physics goals were met** and in some cases largely exceeded!

Configuration	Goal		Achieved
5 TeV p-Pb	ALICE	700x10^6 m.b. events	**780x10^6**
8 TeV p-Pb	ATLAS - CMS	50 nb^{-1}	**69.5 - 65.5 nb^{-1}**
	LHCb - ALICE	10 nb^{-1}	**14 - 13 nb^{-1}**
	LHCf	9-12 h at 10^{28} $cm^{-2}s^{-1}$	**9.5 h**
8 TeV Pb-p	ATLAS - CMS	50 nb^{-1}	**124 - 118 nb^{-1}**
	ALICE - LHCb	10 nb^{-1}	**25 - 19 nb^{-1}**

run

proton-ion collisions

ecialists: the two
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to be carried out in

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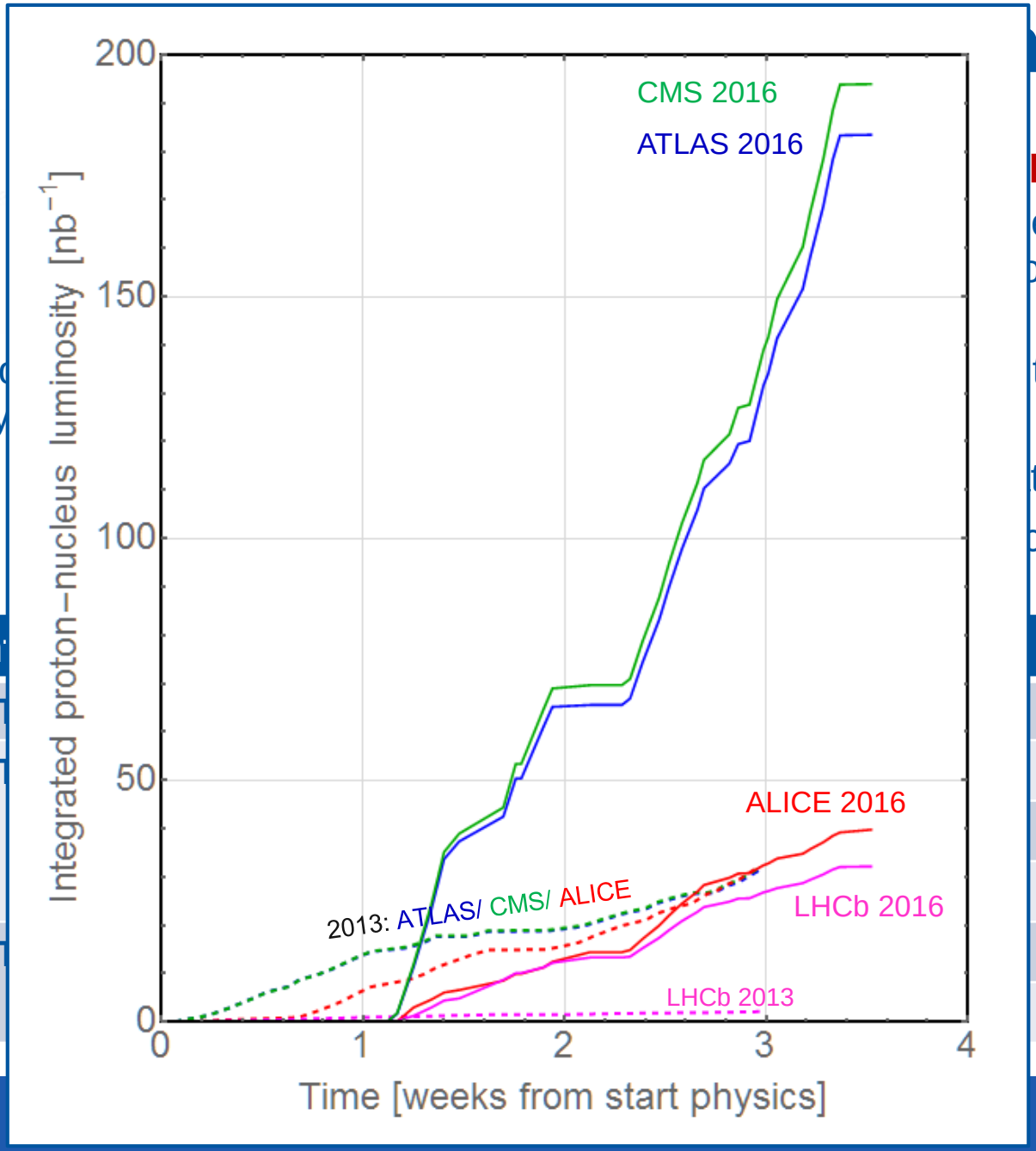
ceeded!



Con	Achieved
5 T	780x10^6
8 T	69.5 - 65.5 nb^{-1}
	14 - 13 nb^{-1}
	9.5 h
8 T	124 - 118 nb^{-1}
	25 - 19 nb^{-1}

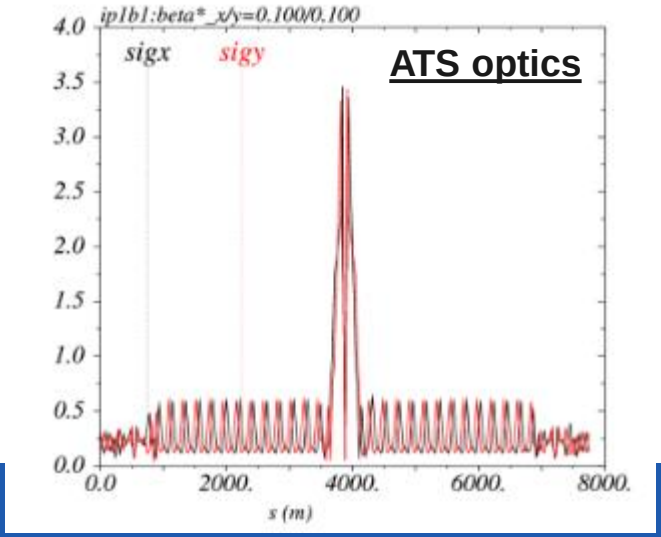
LHC for LHC: machine development

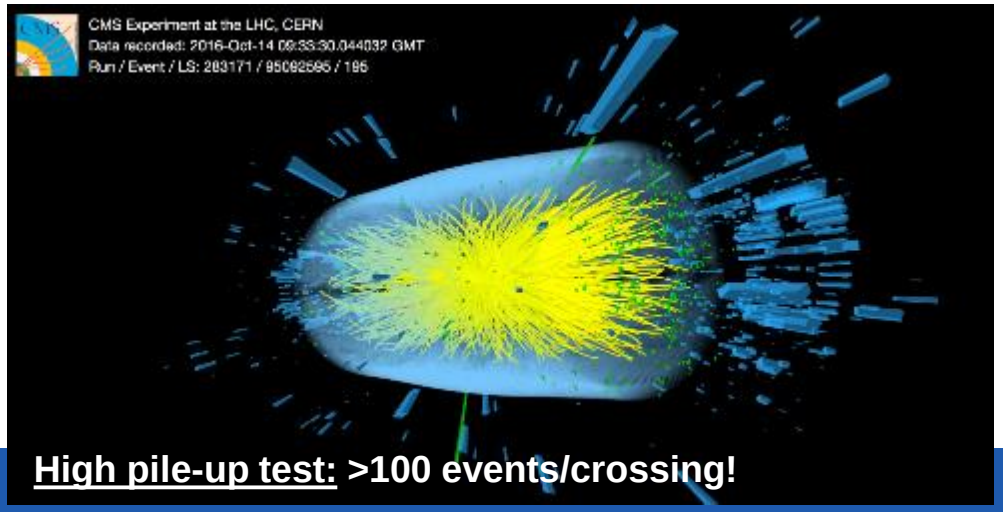
For an accelerator physicist the **LHC is by itself a wonderful experiment!**

- **21 days** dedicated to Machine Development in 2016
- Additionally, many **tests performed in parallel with physics** (thanks to the LHC experiments for their very collaborative spirit!)

Broad spectrum of studies aiming at :

- **Performance** improvement for 2017 and beyond
- Preparation of **High Luminosity Upgrade**
- Testing new ideas for **beam dynamics** and **accelerator technology**
- Laying the groundwork for the **next generation of high energy colliders**





Conclusions

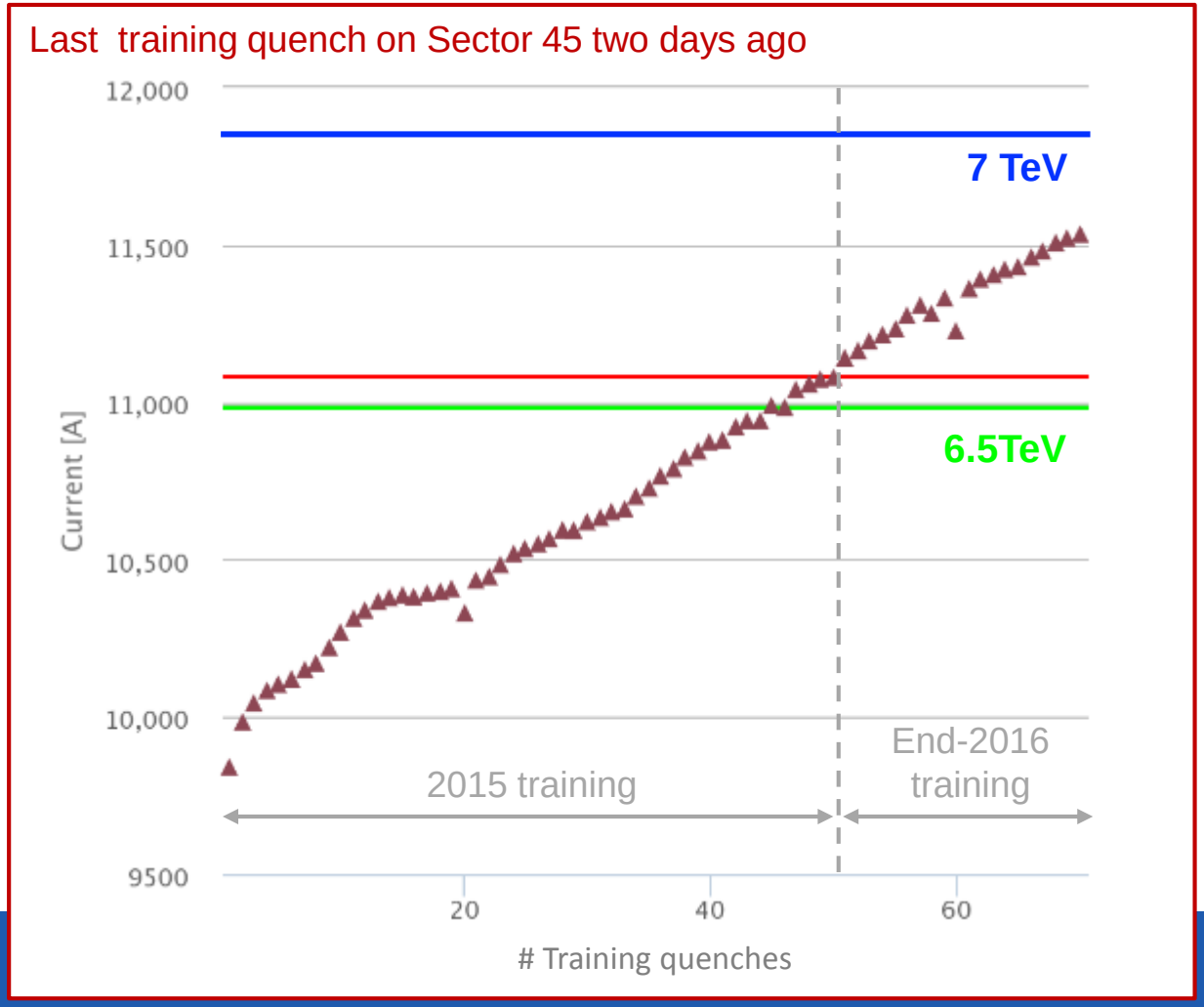
A **memorable year** for CERN and the LHC

- **Reached design luminosity** and exceeded it by 40%!
- While maintaining **Stable Beams efficiency of ~50%!**
- …plus β^*=2.5 km, proton-ion, machine developments…

Next steps

Beam operation ended one week in advance to allow a **magnet training campaign**

→ probe the possibility of increasing the energy to **7 TeV** in the coming years



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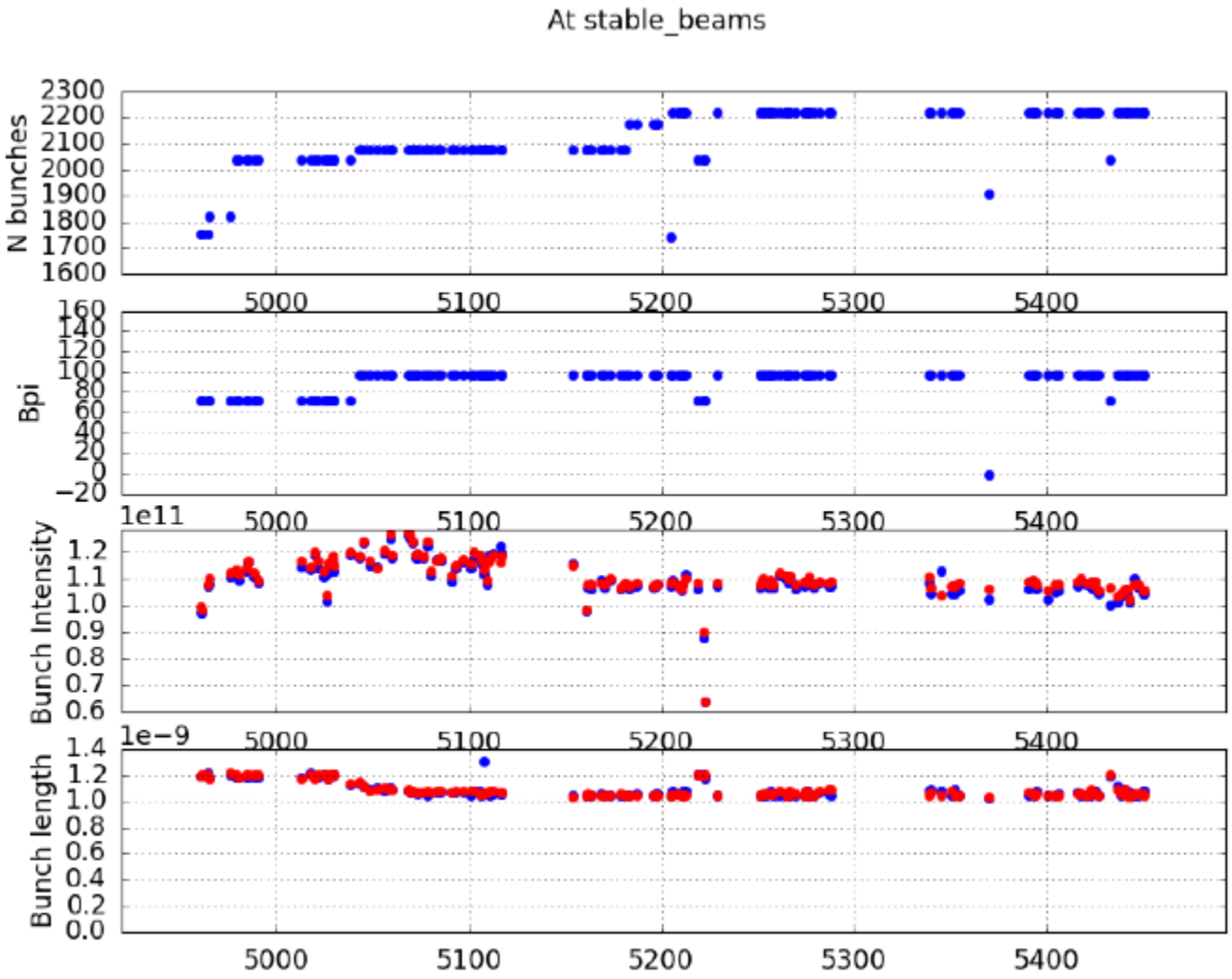
This winter the LHC will have a longer than usual **end-of-year stop**

- **Upgrade activities in the experiments**
- Enough time to implement a **few fixes** on the accelerator side:
  - → Exchange a “sick” **dipole magnet** (need to warm up ~2 km of LHC)
  - → Replace **SPS beam dump** → will allow to inject more bunches in LHC
  - → Improve vacuum in **injection kicker** region → will allow for slightly larger bunch intensity

Restarting p-p physics in June 2017

Aiming at doing even better than in 2016!

Thanks for your attention!


At stable_beams
N bunches
2300
2200
2100
2000
1900
1800
1700
1600
5000
5100
5200
5300
5400
Bpi
160
140
120
100
80
60
40
20
0
−20
1e11
Bunch Intensity
1.2
1.1
1.0
0.9
0.8
0.7
0.6
1e−9
Bunch length
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0