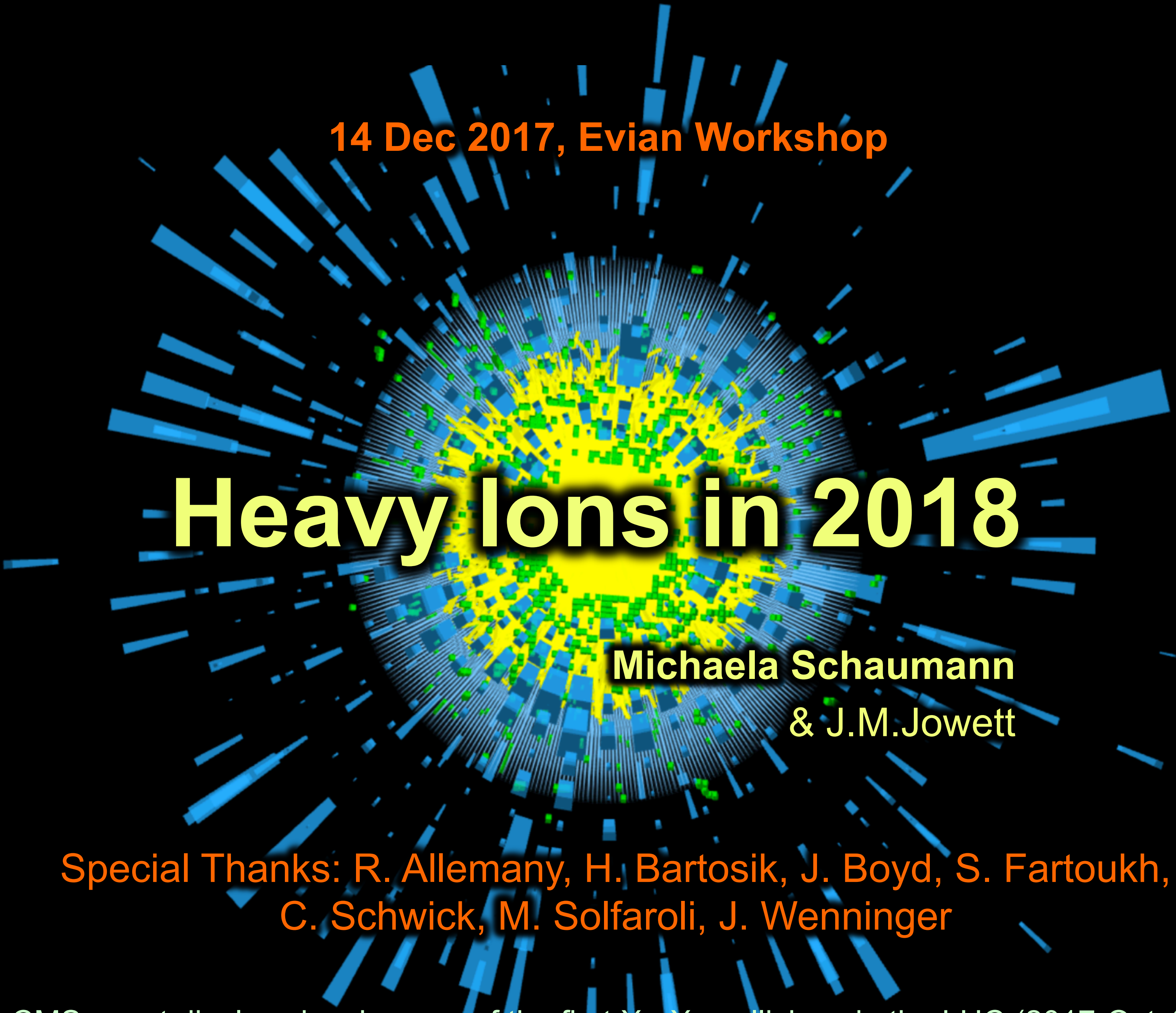


14 Dec 2017, Evian Workshop

Heavy Ions in 2018

Michaela Schaumann

& J.M.Jowett

Special Thanks: R. Allemany, H. Bartosik, J. Boyd, S. Fartoukh, C. Schwick, M. Solfaroli, J. Wenninger

CMS event display showing one of the first Xe-Xe collisions in the LHC (2017-Oct-12)

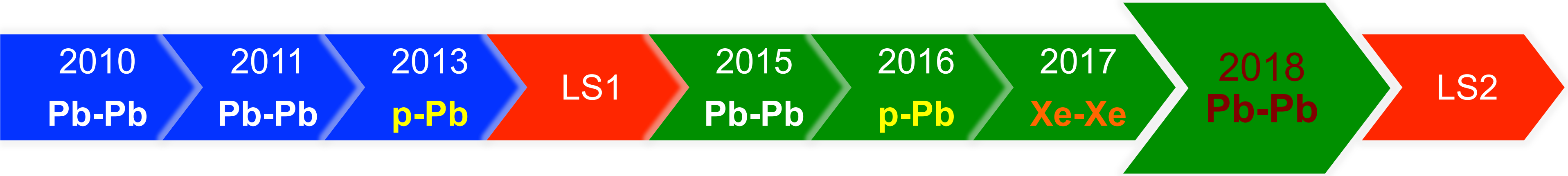
Outline

- Run Schedule
- Machine configuration
    - Optics (Ramp & Squeeze, β* reach)
    - Energy
- Expected Beams
    - Beam production in the injectors
    - Bunch parameters
- Performance Predictions
    - Integrated luminosity projections
    - Luminosity levelling options
- BFPP bumps (quench mitigation)
- Conclusions

Setting the Scene

- 2018 will be only the 4th Pb-Pb run (2nd in Run 2)
  - Since 2013 all 4 main experiments have participated in data taking
- Full one-month run will be the last physics before LS2
- Board goal is to fulfil the *"initial 10 years"* LHC design **goal of 1 nb^{-1} Pb-Pb luminosity for ALICE, ATLAS and CMS**

- Studies and discussions are on-going
  - Not all run configurations can be decided yet
  - Presenting **current status and possible options**



2010 **Pb-Pb**

2011 **Pb-Pb**

2013 **p-Pb**

LS1

2015 **Pb-Pb**

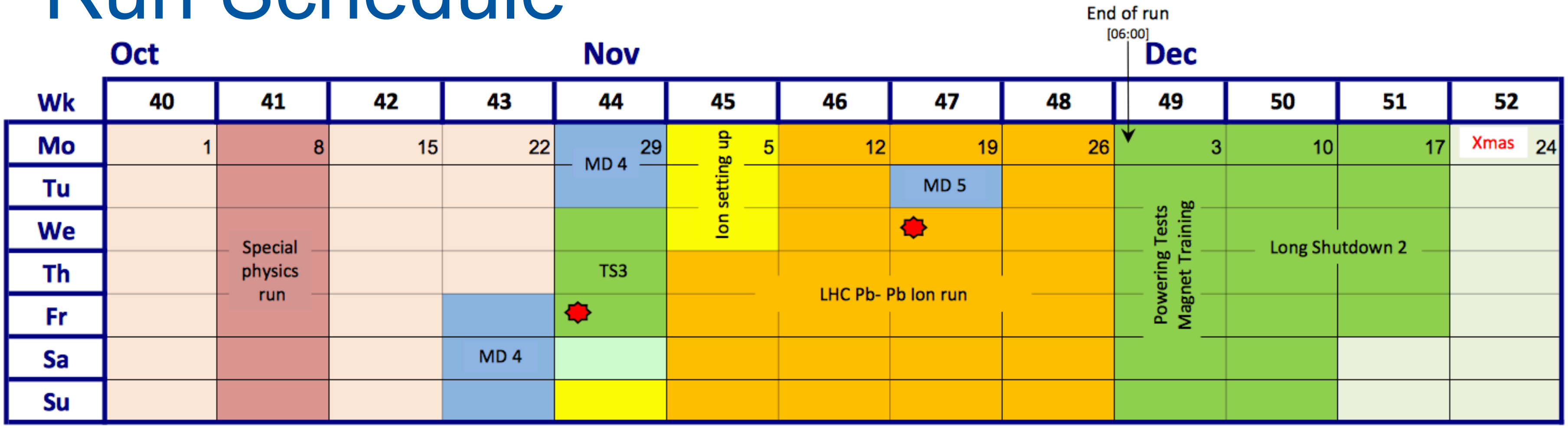
2016 **p-Pb**

2017 **Xe-Xe**

2018 **Pb-Pb**

LS2

Run Schedule



End of run
[06:00]

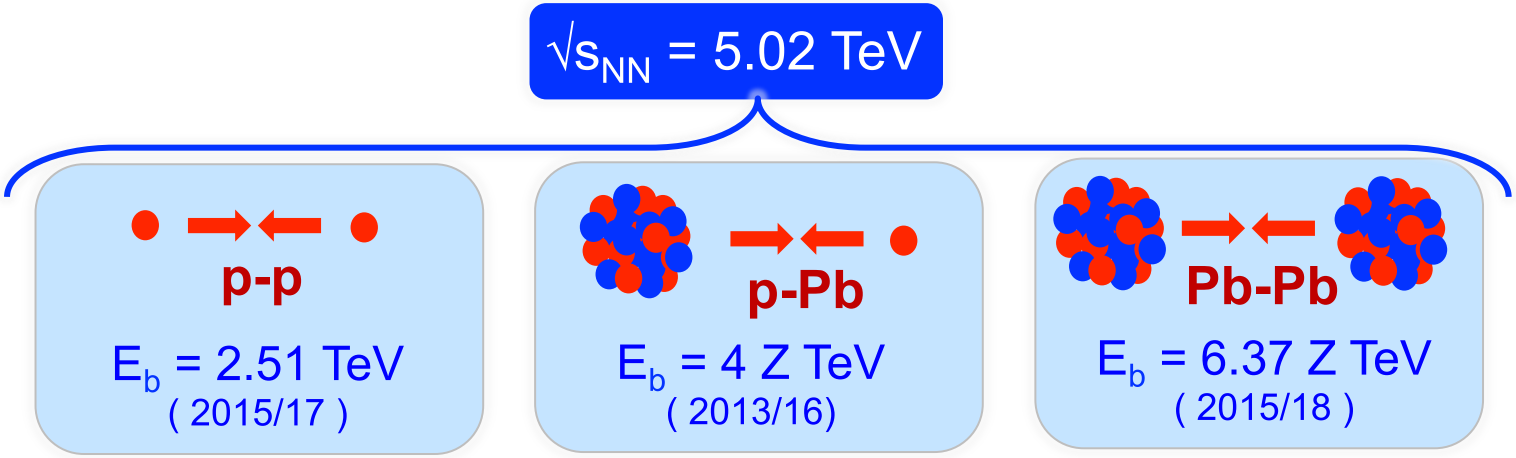
Oct · Nov · Dec

Wk	40	41	42	43	44	45	46	47	48	49	50	51	52
Mo	1	8	15	22	29 MD 4	Ion setting up 5	12	19	26	3	10	17	Xmas 24
Tu								MD 5					
We		Special physics run						✹		Powering Tests Magnet Training	Long Shutdown 2		
Th					TS3		LHC Pb- Pb Ion run						
Fr					✹								
Sa				MD 4									
Su													

- TS3 for re-installation of ZDC in ATLAS/CMS
- 4 days commissioning (starting form Sunday)
- 25 days of physics operation
  - Intensity ramp-up similar to previous years
  - Maximum number of bunches 500-600
- 1-2 days of MD
  - Crystal Collimation
  - Secondary beam (BFPP) induced quench test
  - Potentially other things to be tested before LS2
- ALICE polarity reversal, ion source refill, van der Meer Scans, …

6.37 Z TeV Beam Energy

Reduction of the beam energy from **6.5Z TeV** to **6.37Z TeV** provided the possibility to compare all collision modes at the **same centre-of-mass energy per colliding nucleon pair**:



$\sqrt{s_{NN}}$ = 5.02 TeV

p-p

E_b = 2.51 TeV
(2015/17)

p-Pb

E_b = 4 Z TeV
(2013/16)

Pb-Pb

E_b = 6.37 Z TeV
(2015/18)

Optics Configuration

- As usual we want to make the most rapid and efficient transition from p-p to Pb-Pb configuration
- Main differences to p-p:
  - Different beam energy: 6.37 Z TeV instead of 6.5 Z TeV
  - Must squeeze ALICE and LHCb further than in p-p
  - No telescopic squeeze (judgement: simplicity, risk, time)

Options for Ramp & Squeeze (R&S)

1) **Prepare one combined R&S for p-p and Pb-Pb to reach β* of (IP1, IP2, IP5, IP8) = (1, 2, 1, 2) m**
   - \+ avoid commissioning of new combined R&S for Pb run
   - \+ small squeeze segment from 2m to 0.5m at top energy
   - \- can ALICE accept 2m for proton run?
   - \- more initial commissioning to be done in p-p
   - \- coupling of p-p to Pb-Pb configuration

2) **Keep ALICE at 10m in R&S (IP1, IP2, IP5, IP8) = (1, 10, 1, 3)** m
   - \- long IR2 squeeze from 10m to 0.5m to be done at top energy for each fill

3) **As 1) but commissioning during Pb-Pb run (IP1, IP2, IP5, IP8) = (1, 2, 1, 2) m**
   - \+ small squeeze segment from 2m to 0.5m at top energy
   - \+ decouple p-p and Pb-Pb run configurations
   - \+ more time to prepare missing optics files
   - \- more Pb-Pb commissioning time

Preferred Option

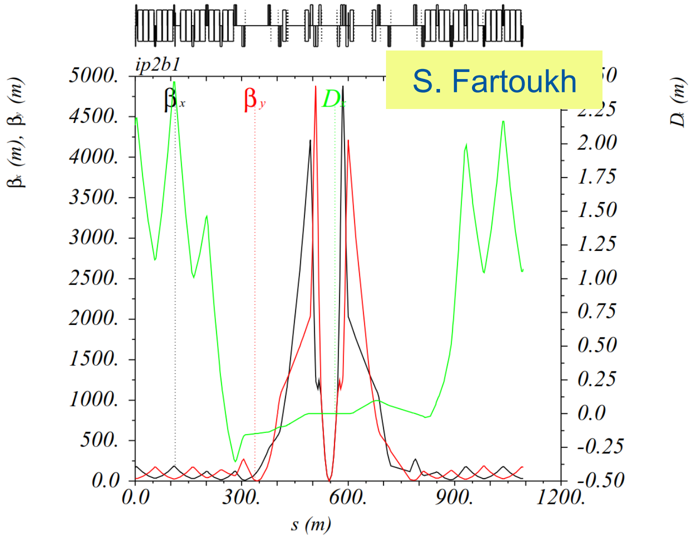
Collision Optics

Baseline:

- Crossing angles as in p-p except for ALICE
  - ALICE at 60μrad for efficiency of ZDC [=135μrad external]
- **ALICE / ATLAS / CMS** at same β*
  - Final choice depends on available aperture
  - Considered options: **β*= 0.8m, 0.6m or 0.5m**
- **LHCb: β* = 2 – 1.5m** (aperture depends on polarity)

Optics for ALICE squeeze sequence still to be prepared:

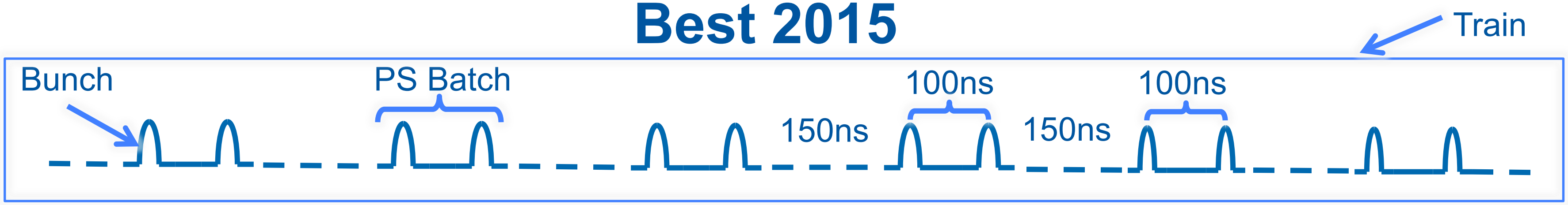
- Preliminary optics for β* = 0.5m in ALICE are available
- With IP2 ~vertical shift and crossing angles aperture is OK on paper
- Possibly confirm available aperture with measurements early in 2018



S. Fartoukh

Beam Production in the Injectors

Best 2015



LEIR: 2 bunches
PS: **100ns** batch compression
SPS: **12 PS-batches** with
150ns batch spacing

Trains to LHC:
12x2b = 24b spaced by 100/150ns

LEIR: 2 bunches
PS: **bunch splitting** with 100ns
SPS: **≥6 PS-batches** (to be decided)
150ns batch spacing

Trains to LHC:
≥6x4b ≥ 24b spaced by 100/150ns

Shorter trains with same number of bunches and intensity per bunch.

2018

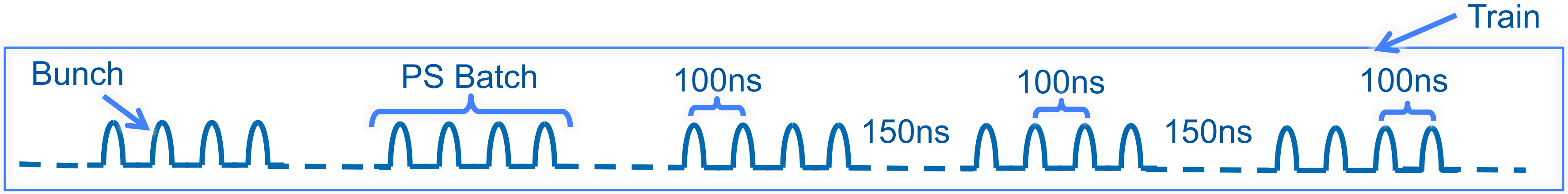
LHC Filling Pattern

Several improvements since 2015:

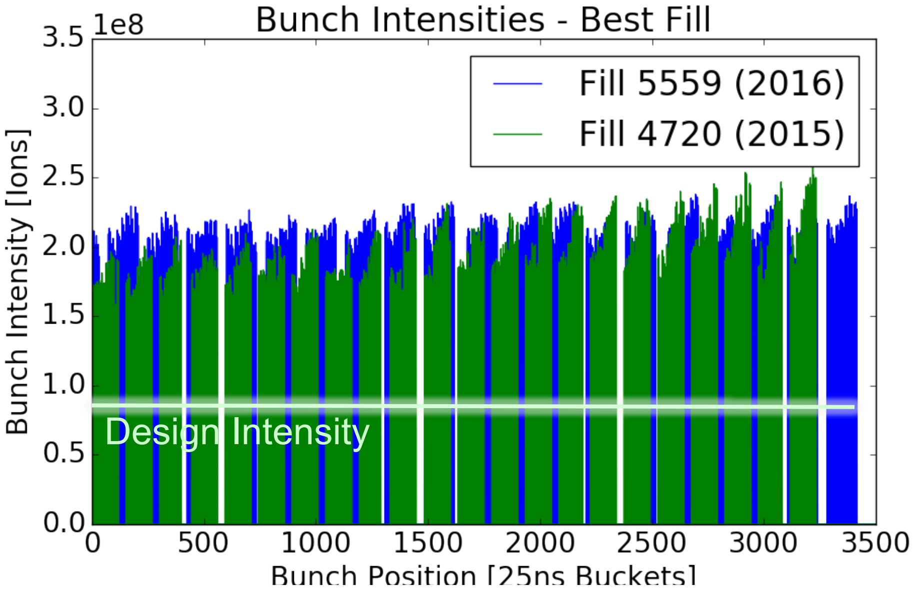
- Best 2015 filling scheme had **518 bunches**
  - Colliding 492b in ATLAS/CMS, 444 in ALICE, 24 in LHCb
- **Shorter trains from injectors** with same number of bunches and intensity per bunch
  - Optimization of SPS train length to reduce LHC injection gaps
- **Train spacing reduction** in LHC: 900ns → **800ns**
- Optimization of **Abort Gap Keeper**

✧ **Less gaps → more bunches to LHC** compared to 2015

✧ Different filling schemes can be used through the run, to help optimize luminosity sharing between experiments.



Bunch Parameters



Average bunch intensity again improved by ~10% in 2016:

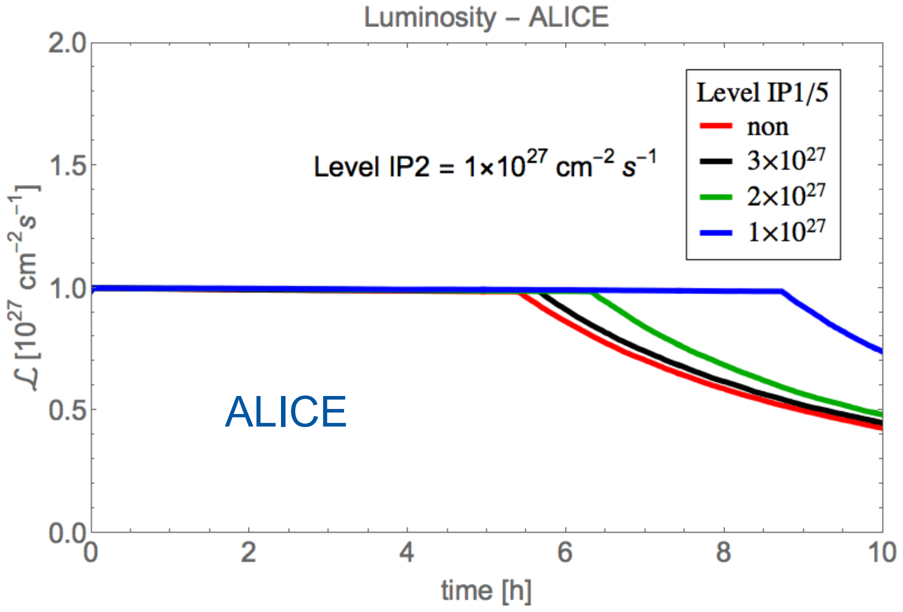
- N_b (2015) = 1.96×10^8
- **N_b (2016) = 2.14×10^8**

Emittances are around nominal value:

- **ε_n = 1.5µm**

Assumption: **Get best injector performance from 2016 from the beginning in 2018.**

Luminosity Evolution: Levelling Scenarios



ALICE needs to be levelled at

$L = 1.0x10^{27}cm^{-2}s^{-1}$

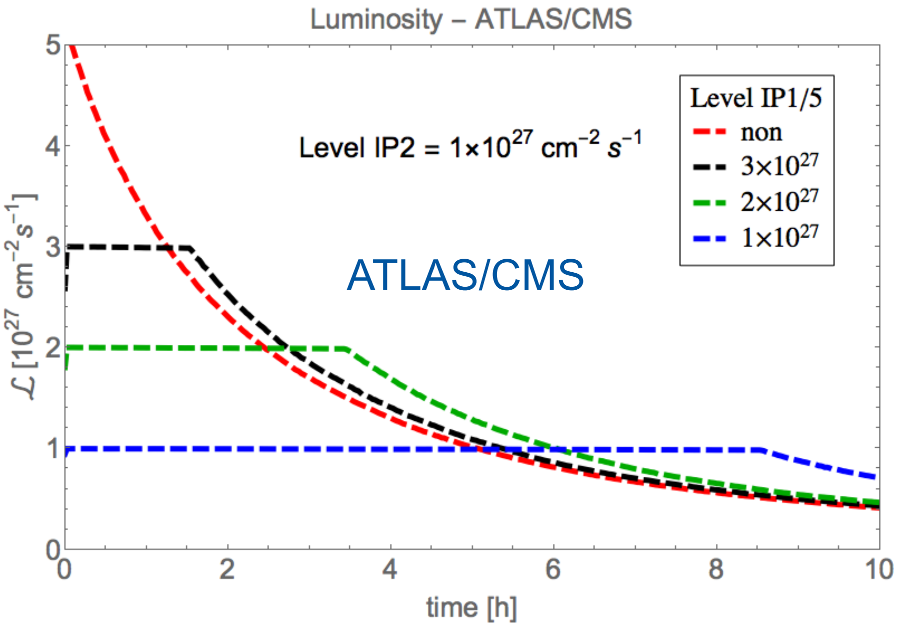
Estimates for β* = 50cm

- Highest luminosity potential
- Longest ALICE levelling times

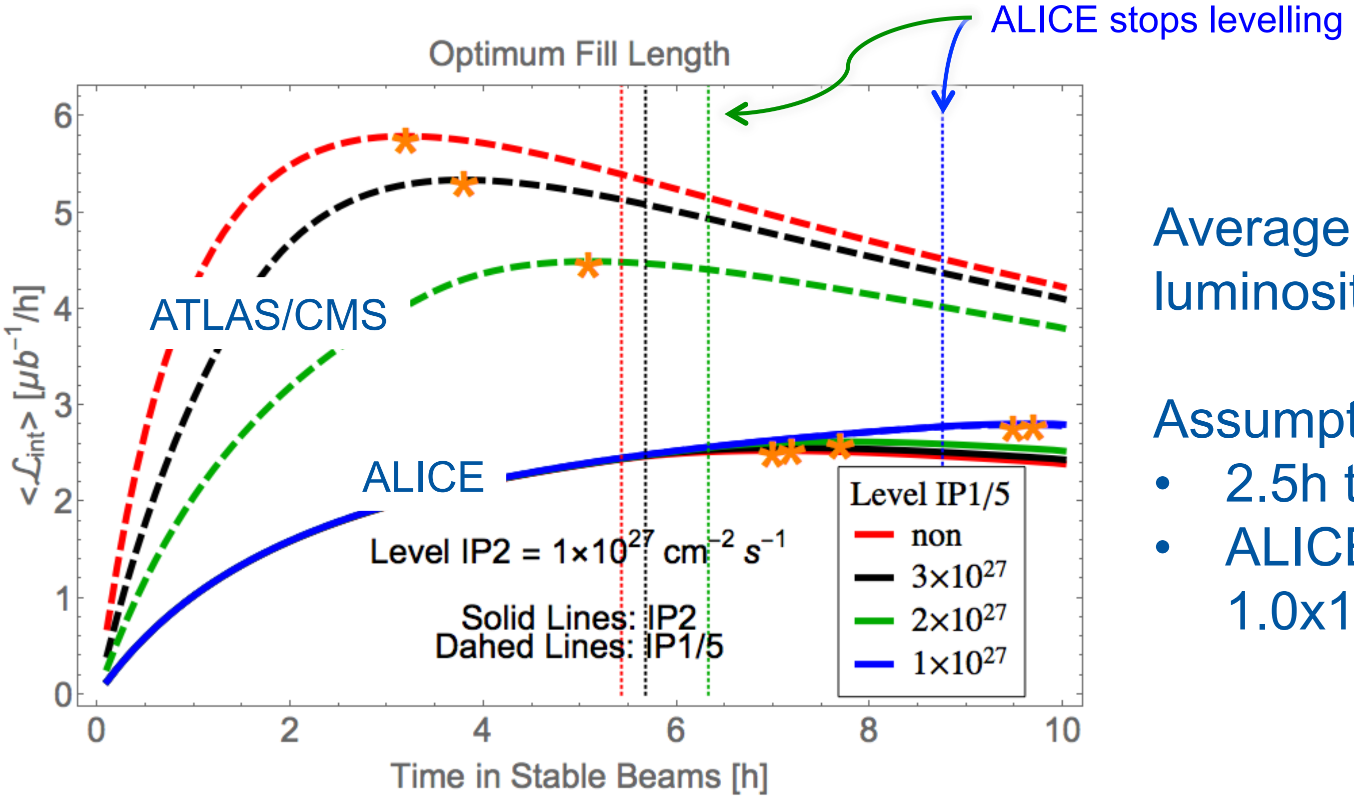
4 levelling scenarios in ATLAS/CMS are evaluated:

The lower IP1/5 are levelled

- the longer ALICE can level
- the lower their luminosity



Optimum Fill Length


ALICE stops levelling

ATLAS/CMS

ALICE

Average integrated luminosity per hour

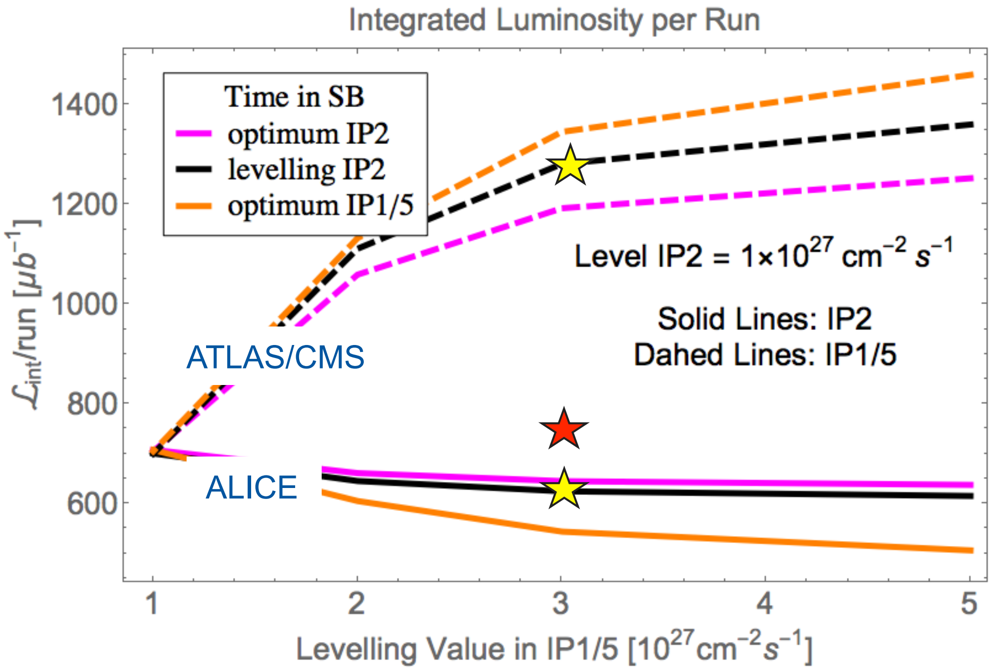
Assumptions:

- 2.5h turn-around time
- ALICE levelled at $1.0\text{x}10^{27}\text{cm}^{-2}\text{s}^{-1}$

Optimal time in collisions

- ALICE: > max. ALICE levelling time
- ATLAS/CMS: < max. ALICE levelling time

Integrated Luminosity



IP2 level	L_{int} IP2	L_{int} IP1/5
1x10^{27}cm^{-2}s^{-1}	620 μb^{-1}	1280 μb^{-1}
1.3x10^{27}cm^{-2}s^{-1}	740 μb^{-1}	1300 μb^{-1}
Gain	+20%	+1%

Values for IP1/5 levelled at 3x10^{27}cm^{-2}s^{-1}

Assumptions:

- 2.5h turn-around time
- 50% efficiency
- 21 days of full physics operation

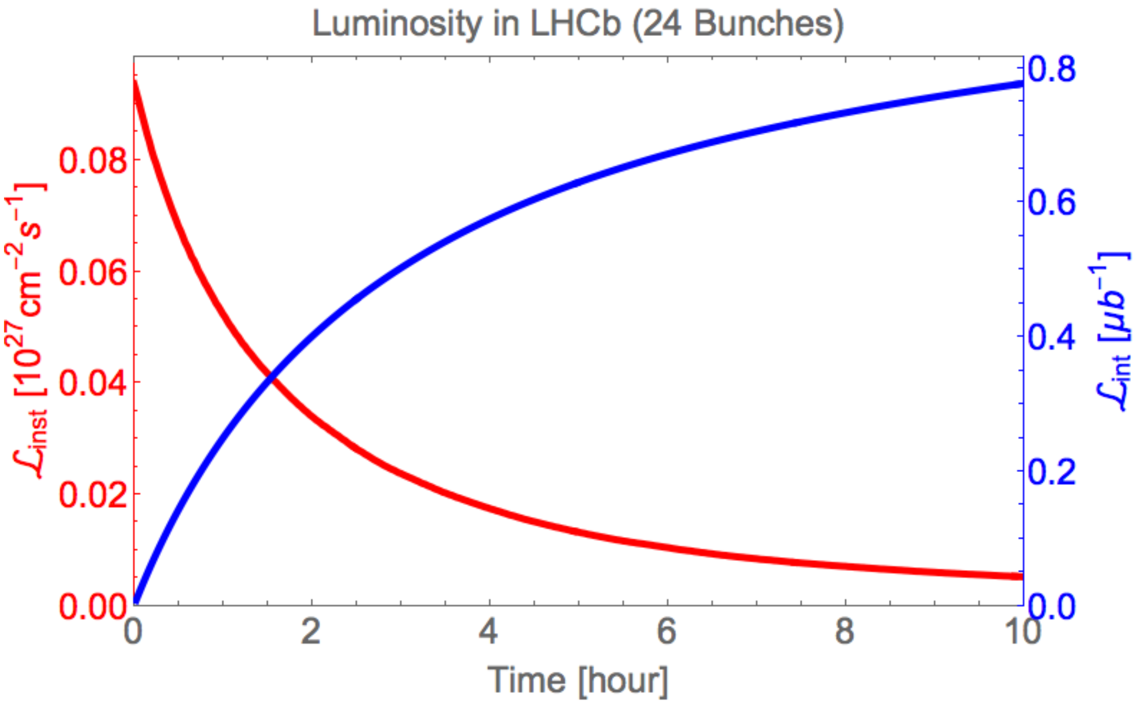
Highest integrated luminosity for ALICE, if ATLAS/CMS are levelled to the same value.

→ Significant reduction in luminosity potential for ATLAS/ CMS.

Levelling ALICE at 1.3x10^{27}cm^{-2}s^{-1}

- ALICE could gain +20%
- ATLAS/CMS small impact

LHCb Luminosity Evolution



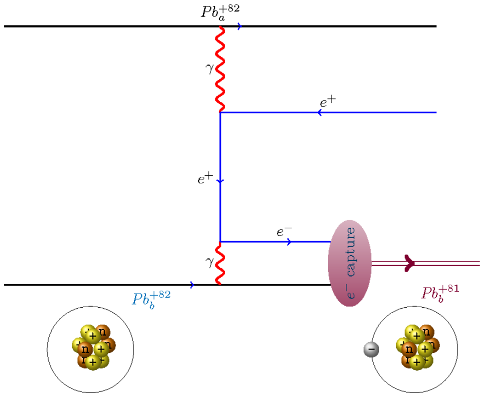
Prediction for **β*=1.5m** and 2015 filling scheme with **24 colliding bunches**

- Request for 60-70 bunches
- Possible filling schemes have not yet been studied.
- Luminosity sharing with other experiments to be taken into account.

Secondary Beams created in the Collision

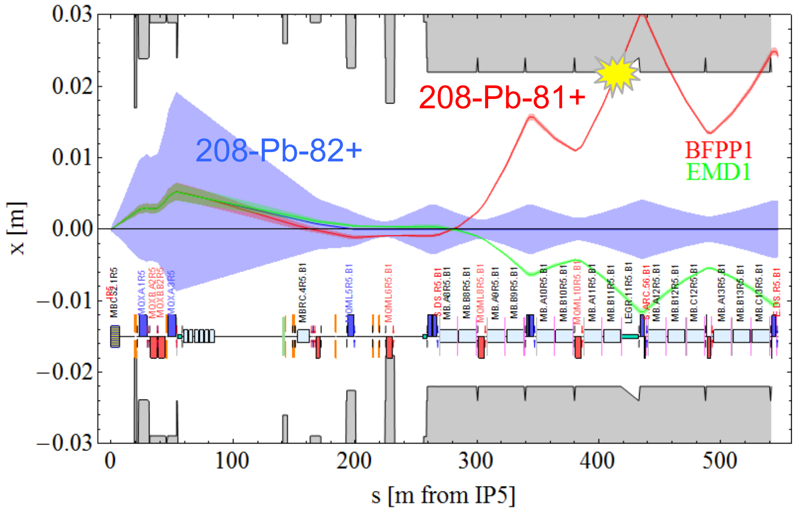
Bound-free pair production (BFPP)

$$^{208}\mathrm{Pb}^{82+} + ^{208}\mathrm{Pb}^{82+} \longrightarrow ^{208}\mathrm{Pb}^{82+} + ^{208}\mathrm{Pb}^{81+} + \mathrm{e}^{+}$$



Has large interaction cross-section (>200b) in Pb-Pb collisions and is the main contribution to fast luminosity burn-off.

Secondary beams impact in superconducting magnets downstream the interaction points.

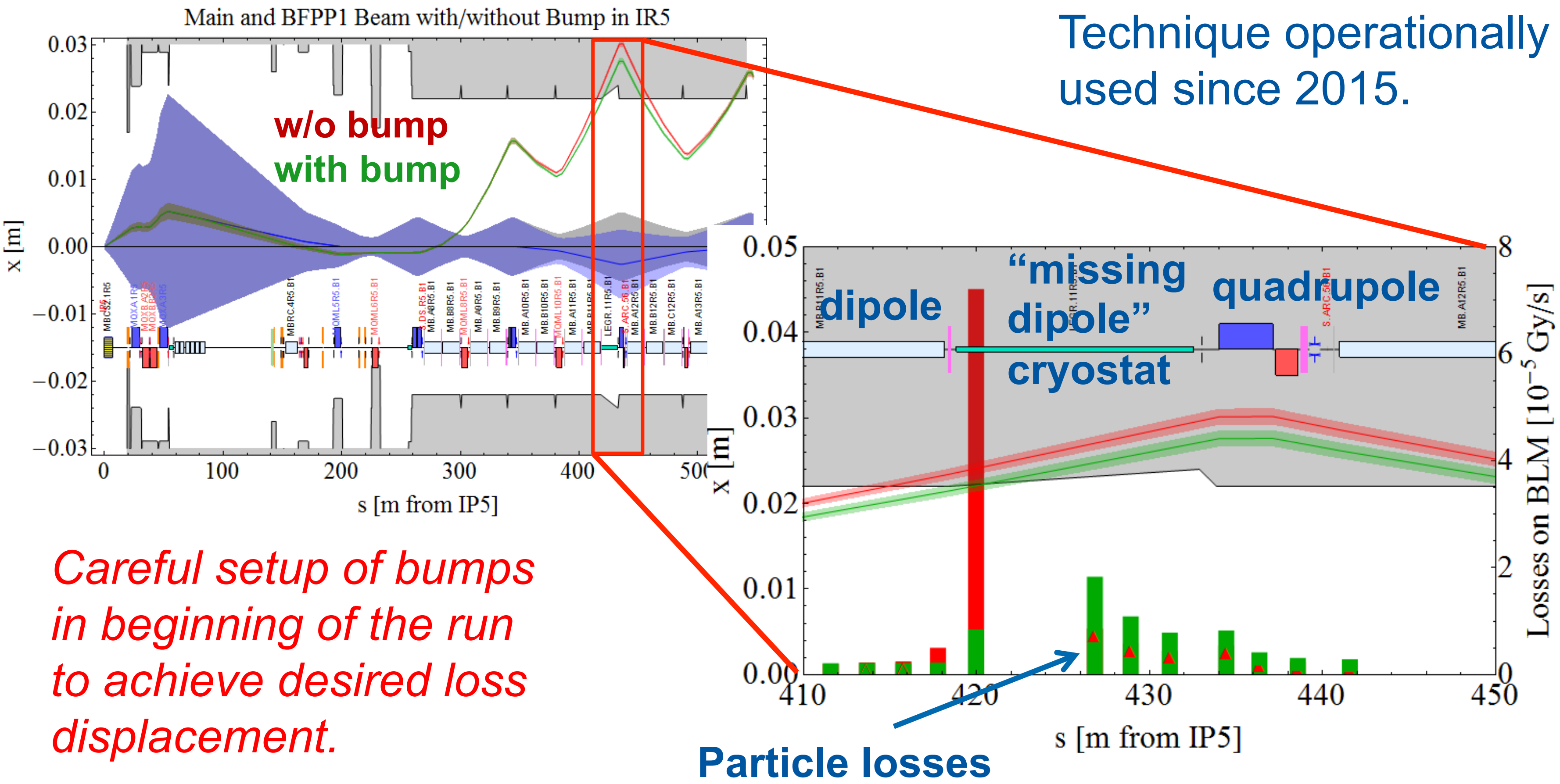


Deposited power exceeds quench limit.

Luminosity limit found at
L≈2.5e27cm^{-2} s^{-1} (≅50W into magnet)

Quench Risk Mitigation with Orbit Bumps

Orbit bumps are used to move the secondary beam losses to a less vulnerable location in order to reduce risk of quench.

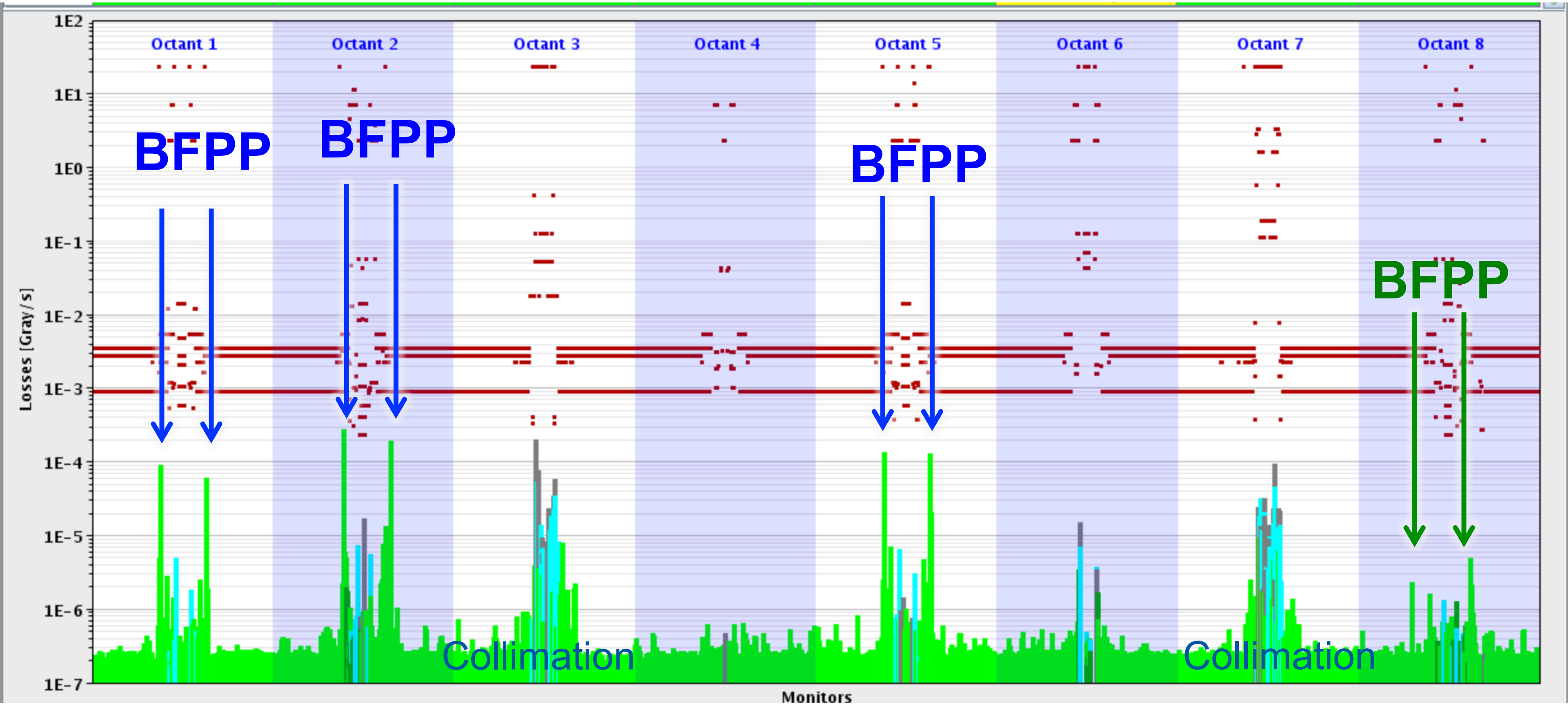


Technique operationally used since 2015.

Careful setup of bumps in beginning of the run to achieve desired loss displacement.

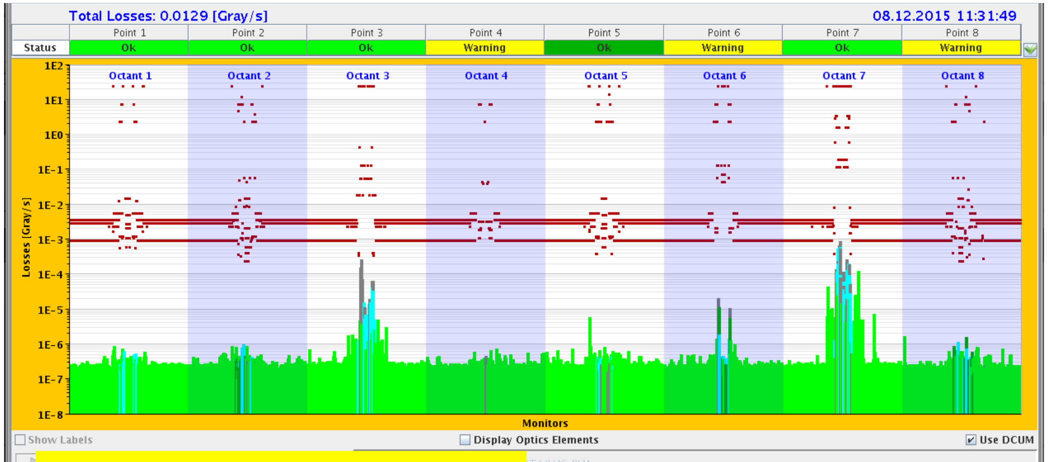
Loss Pattern around the Ring

Loss spikes around all IPs where ions collide …



ATLAS ALICE CMS LHCb

Potential Intensity and Luminosity Limitation

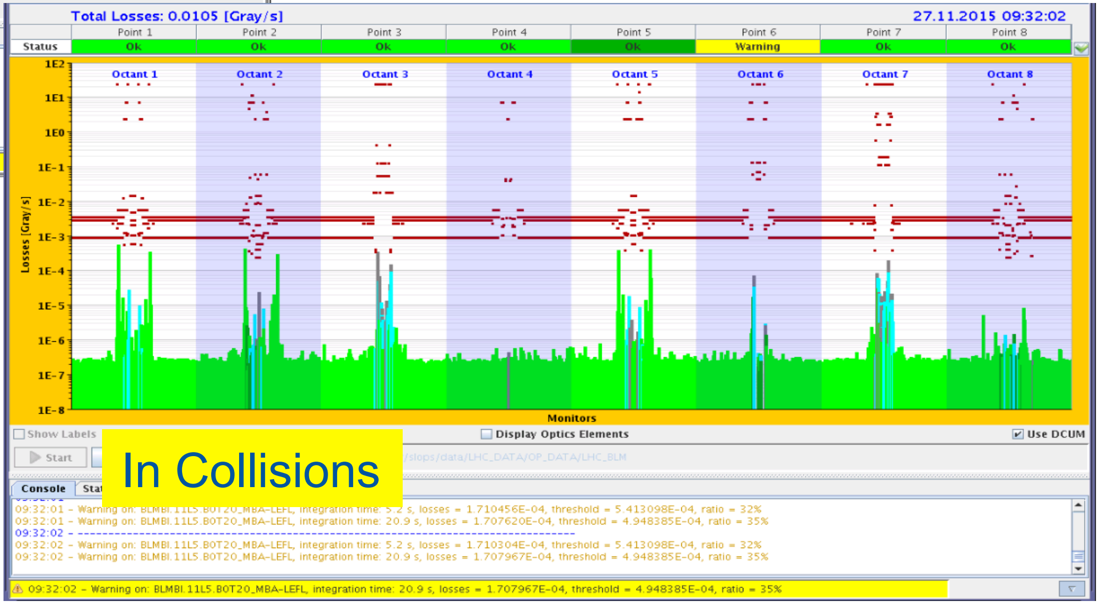


Arrival at Top Energy

```
11:3                                                        threshold = 4.933000E-04, ratio = 30%
11:3                                                        ---
11:31:47 - Warning on: BLMBI.11R7.B0T20_MBB-LEDR, integration time: 83.8 s, losses = 1.498952E-04, threshold = 4.933000E-04, ratio = 30%
11:31:48 - ------------------------------------------------------------------------------------
11:31:48 - Warning on: BLMBI.11R7.B0T20_MBB-LEDR, integration time: 83.8 s, losses = 1.490017E-04, threshold = 4.933000E-04, ratio = 30%
11:31:49 - ------------------------------------------------------------------------------------
11:31:49 - Warning on: BLMBI.11R7.B0T20_MBB-LEDR, integration time: 83.8 s, losses = 1.485001E-04, threshold = 4.933000E-04, ratio = 30%

11:31:49 - Warning on: BLMBI.11R7.B0T20_MBB-LEDR, integration time: 83.8 s, losses = 1.485001E-04, threshold = 4.933000E-04, ratio = 30%
```

High loss rates observed in 2015: often reached warning level when arriving at **top energy (DS in IR7)** and **in collisions (BFPP)**



In Collisions

```
09:32:01 - Warning on: BLMBI.11L5.B0T20_MBA-LEFL, integration time: 5.2 s, losses = 1.710456E-04, threshold = 5.413098E-04, ratio = 32%
09:32:01 - Warning on: BLMBI.11L5.B0T20_MBA-LEFL, integration time: 20.9 s, losses = 1.707620E-04, threshold = 4.948385E-04, ratio = 35%
09:32:02 - ------------------------------------------------------------------------------------
09:32:02 - Warning on: BLMBI.11L5.B0T20_MBA-LEFL, integration time: 5.2 s, losses = 1.710304E-04, threshold = 5.413098E-04, ratio = 32%
09:32:02 - Warning on: BLMBI.11L5.B0T20_MBA-LEFL, integration time: 20.9 s, losses = 1.707967E-04, threshold = 4.948385E-04, ratio = 35%

09:32:02 - Warning on: BLMBI.11L5.B0T20_MBA-LEFL, integration time: 20.9 s, losses = 1.707967E-04, threshold = 4.948385E-04, ratio = 35%
```

Carefully evaluation of BLM thresholds necessary before the run to avoid quenches without compromising availability.

Not to forget…

- Before the run
  - Collimation simulations of expected losses in IR7 for quench protection and spike identification
  - Evaluation of BLM thresholds

- During the run
  - BSRT calibration

Conclusion

- Planning and studies are still on-going.
  → All projections presented are still preliminary and subject to changes!

- Aim for **β* (IP1, 2, 5, 8) = (0.5, 0.5, 0.5, 1.5) m**
  - ramp & squeeze to β* ≈ (1,1,1,1.5-2) m
  - small squeeze element at top energy

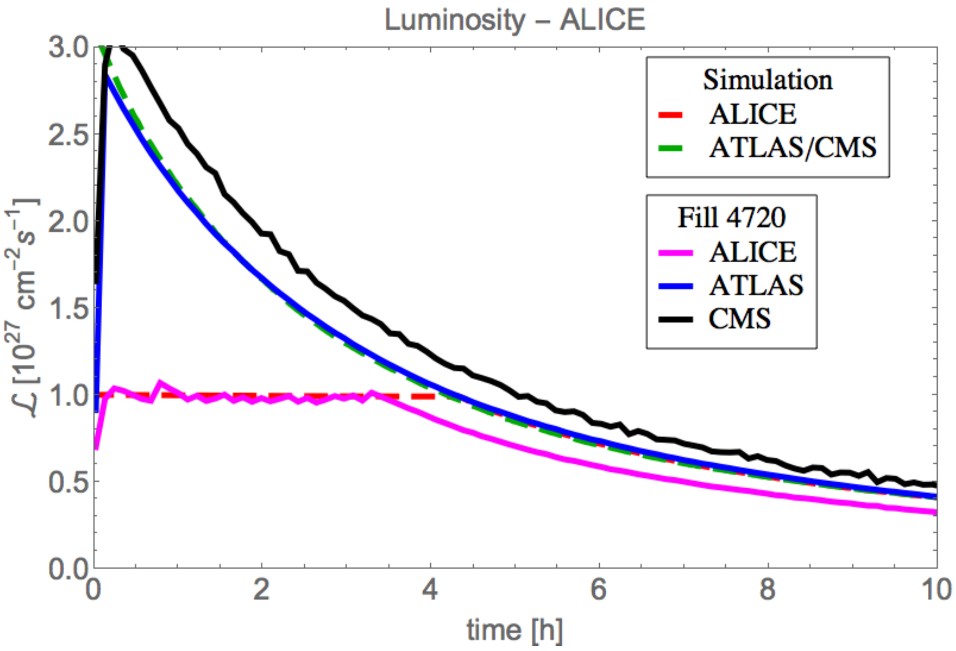
- **Peak luminosity** could approach **5x design** value, mainly because of *outstanding injector performance.*
  - Potential limitation by too high losses in BFPP locations and IR7.

- All 4 main experiments are taking data.
  - Strong intensity burn-off from high luminosity experiments
  - More bunches for LHCb

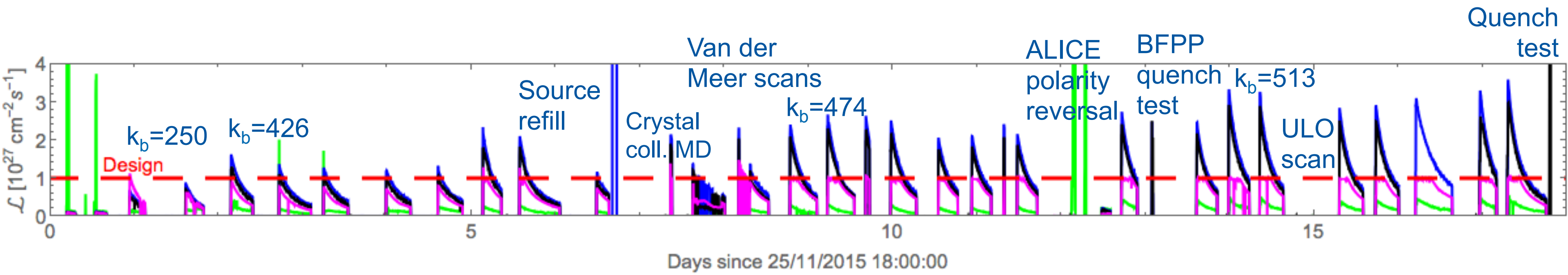
  → **Luminosity sharing strategies have to be discussed.**

Back - up

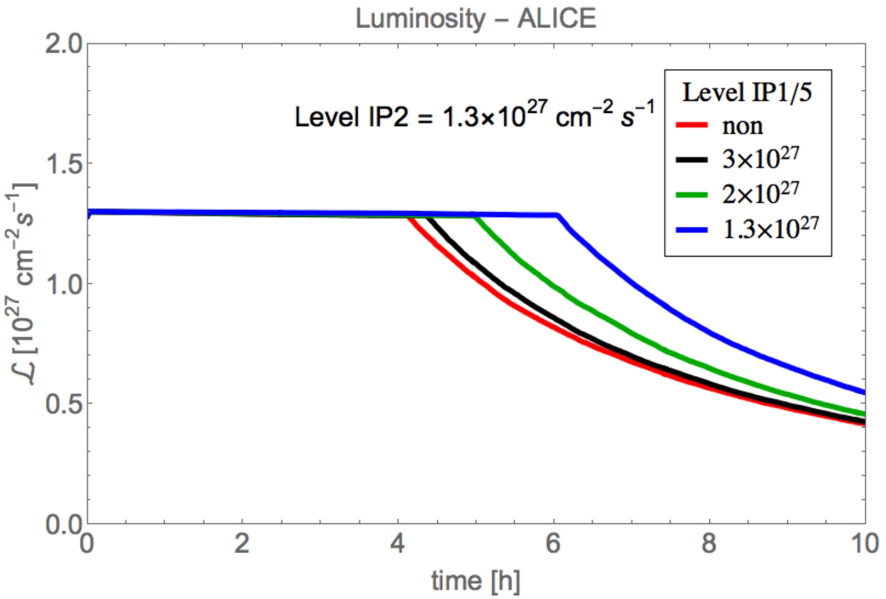
Luminosity Evolution 2015



- Simulated peak agrees with ATLAS measurement
- CMS measured higher peak
- ALICE was levelled <1h shorter than predicted.
- Possible Error Sources:
  - Initial emittances smaller than the assumed 1.5µm.
  - Unaccounted emittance blow-up.
  - Additional losses during storage.

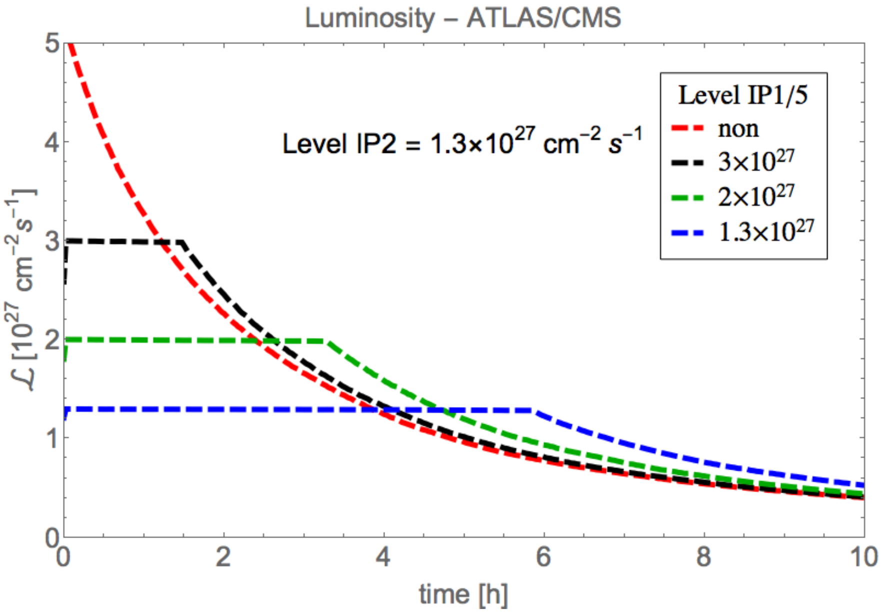


Levelling Scenarios: Level ALICE @ 1.3e27



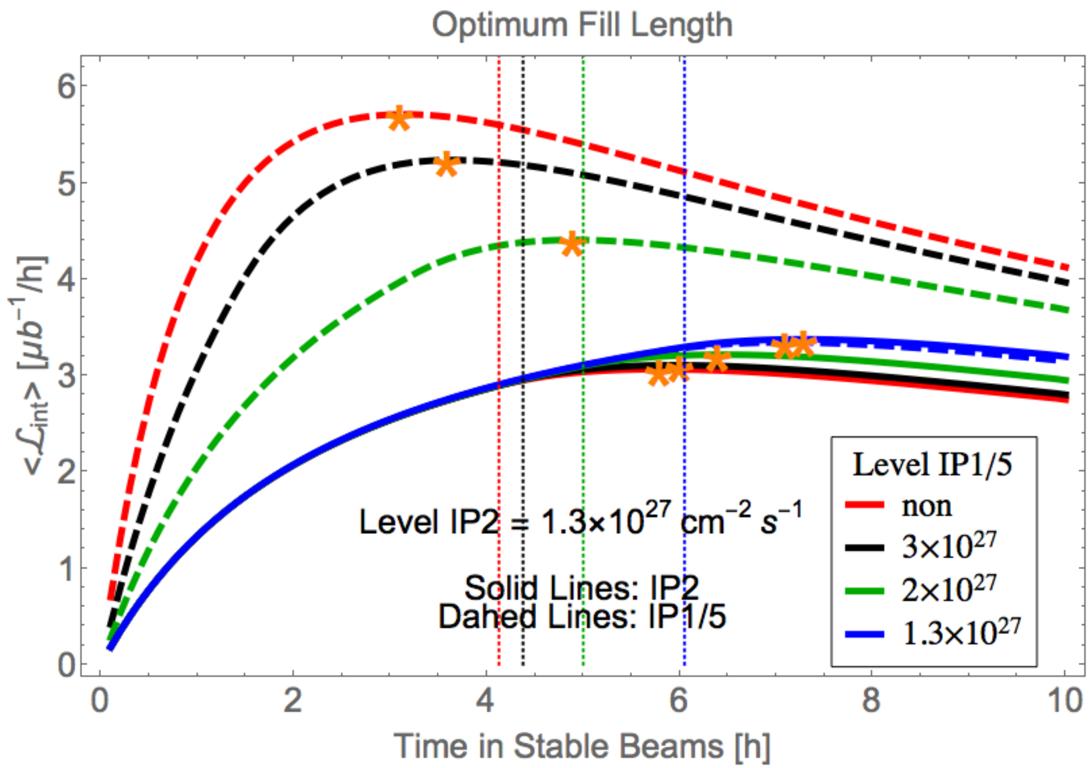
Estimates for on β* = 50cm

- Highest luminosity potential
- Longest ALICE levelling times



- ALICE always levelled at **$L = 1.3 \times 10^{27} cm^{-2} s^{-1}$**
- ATLAS/CMS levelled at 4 different values

Levelling Scenarios: Level ALICE @ 1.3e27



Average integrated luminosity per hour

Assumptions:

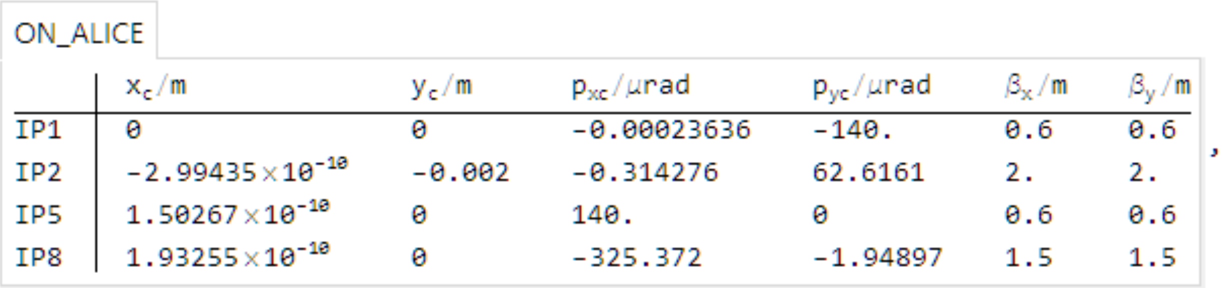
- 2.5h turn-around time
- ALICE levelled at **1.3×10^{27}cm^{-2}s^{-1}**

Higher levelling value in ALICE has relatively small effect on ATLAS/CMS

Optimal time in collisions

- ALICE: > max. ALICE levelling time
- ATLAS/CMS: < max. ALICE levelling time

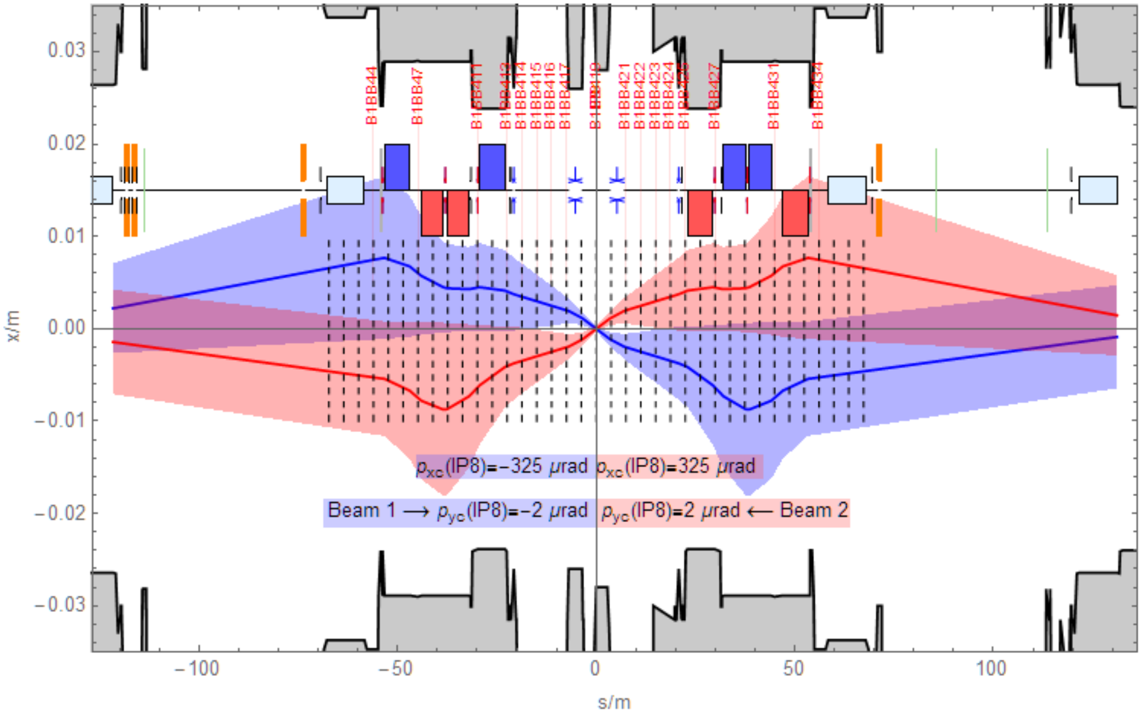
IR8 optics for LHCb in 2016 (p-Pb at 8 TeV)



ON_ALICE

	x_c/m	y_c/m	$p_{xc}/\mu\mathrm{rad}$	$p_{yc}/\mu\mathrm{rad}$	β_x/m	β_y/m
IP1	0	0	-0.00023636	-140.	0.6	0.6
IP2	-2.99435×10^{-10}	-0.002	-0.314276	62.6161	2.	2.
IP5	1.50267×10^{-10}	0	140.	0	0.6	0.6
IP8	1.93255×10^{-10}	0	-325.372	-1.94897	1.5	1.5

$(10\sigma_x, 10\sigma_y, 5\sigma_t)$ envelope for $\epsilon_x=5.41311\times10^{-10}$ m, $\epsilon_y=5.41311\times10^{-10}$ m, $\sigma_p=0.0001137$



IR8 horizontal, We used only the “good” spectrometer polarity in 2016.

Confirming if still OK in 2018.