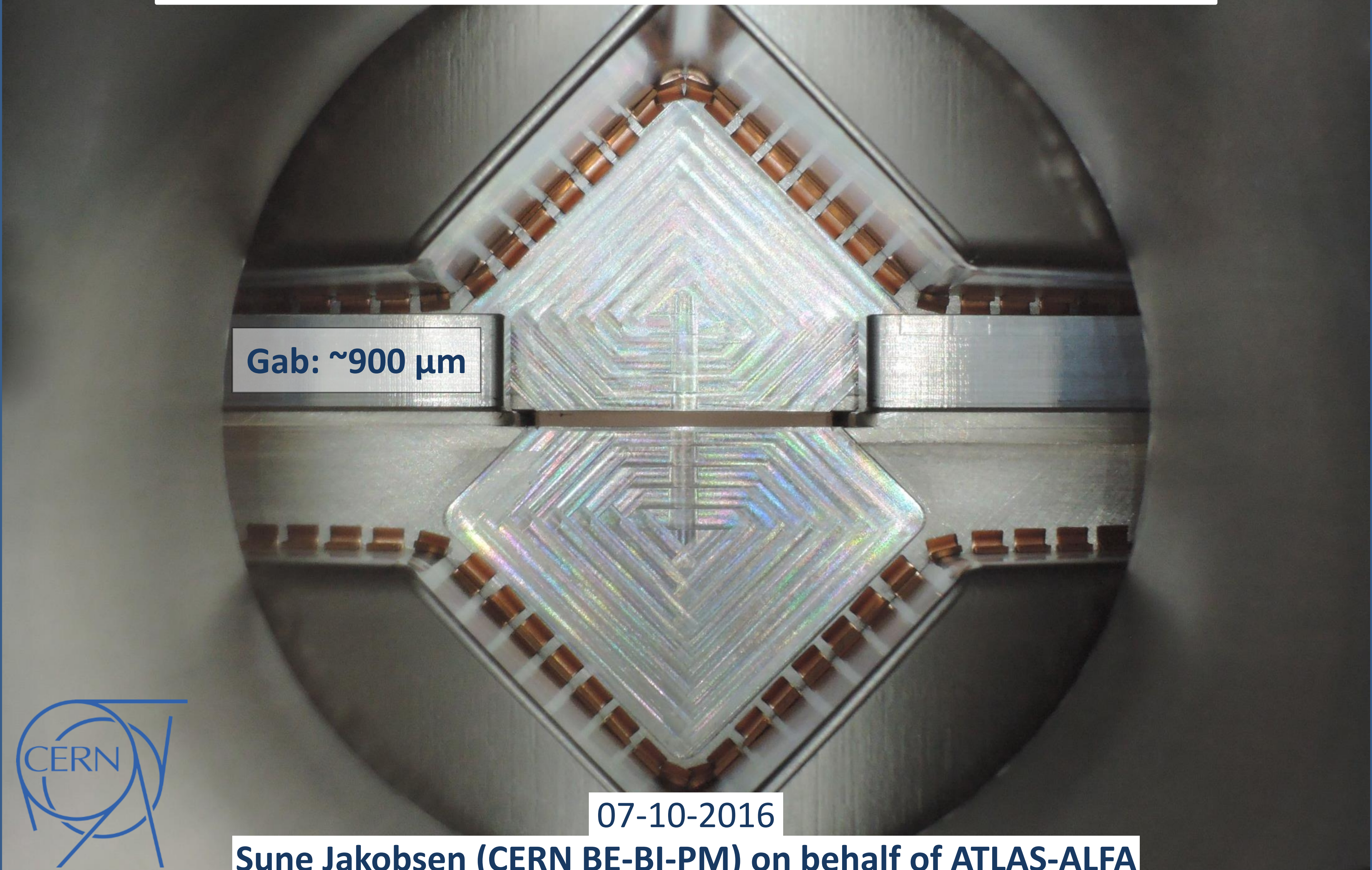
Overview of LHC high β* campaign



07-10-2016

Sune Jakobsen (CERN BE-BI-PM) on behalf of ATLAS-ALFA

Seminar at NBI about ALFA operation 2016

Physics goal

Physics goal and LHC setup

Measurement of luminosity and total cross section by elastic scattering at very low t

In dependence on t-range two options:

1. Only nuclear scattering and luminosity from ATLAS ▯ σ_{tot}

Done:
β* 90m
7,8 and 13 TeV

$$\frac{d\sigma}{dt} = \frac{1+\rho^2}{16\pi(\hbar c)^2}\sigma_{tot}^2 \exp(-Bt)$$

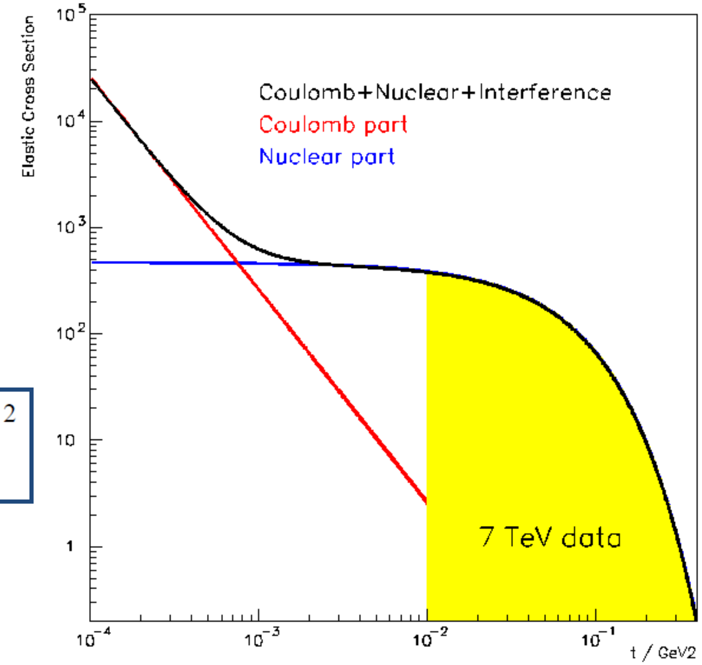
Coulomb + nuclear scattering: Luminosity, rho and σ_{tot}

Done:
β* 1000m, 8 TeV
This run:
β* 2500m, 13 TeV

$$\frac{dN}{dt} = L\pi|f_C+f_N|^2 \approx L\pi\left|-\frac{2\alpha}{|t|}+\frac{\sigma_{tot}}{4\pi}(i+\rho)e^{-b|t|/2}\right|^2$$

Key parameter: small t_{min} requires small emittance ε_N , close distance N_σ and large β*

$$t_{\min} = m_p \quad p\,\frac{\varepsilon_N N_\sigma^2}{\beta^*}$$



LHC setup:

Very high β* of 2.5 km.

Very low emittance (after several Machine Developments periods in the LHC injectors) of less than 1 µm.

Total intensity below 3E10 => Setup Beam Flag => allowing Roman Pots down to $N_{\sigma\ nominal}$ = 3.

Very special collimator setup to clean for Roman Pots at $N_{\sigma\ nominal}$ = 3.

ATLAS and LHC injector setup

ATLAS and LHC injector setup for high β* optics

ATLAS

Participating detectors:

All except muons (not needed and simplifies operation).

Latency:

ALFA latency (+8 BC).

Luminosity:

Most sensitive algorithm needed for finding collisions: MBTS_AND (MBTS_1_1).

Vertex based luminosity with and without IBL.

Trigger setup:

3 different setups (+ safe settings and standby) prepared (depending on filling and IBL in/OUT).

Fine tuning done during operation to maximise especially the trigger for vertex based luminosity.

DAQ and data preparation:

No problems handling the rates (all tested before).

The data from the first runs was processed in record time and allowed basic analysis for data quality and sanity check still DURING the run period.

LHC injectors

Very special settings for providing beams with emittance of ~0.7 um in both plans

This was the result of several dedicated MD during the spring and summer.

Optics

Optics comparison from fill 5284

The original β* = 2.5 km optics (Q6) have a phase advance vary close to 180 degree at the ALFA Roman Pots.

As a consequence the main analysis strategy does not work (no lever arm).

Many cross check and constrains to find the real optics are not possible.

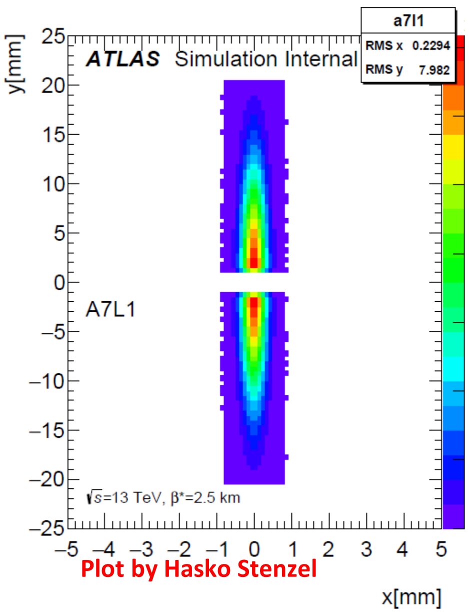
New optics (v4) was commissioned with changed the phase advance at the ALFA stations.

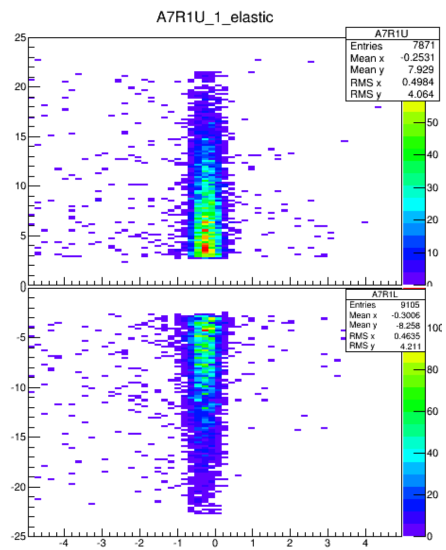
Unfortunately the normal methods to measure phase advance are not accurate enough to distinguish Q6 and v4 optics.

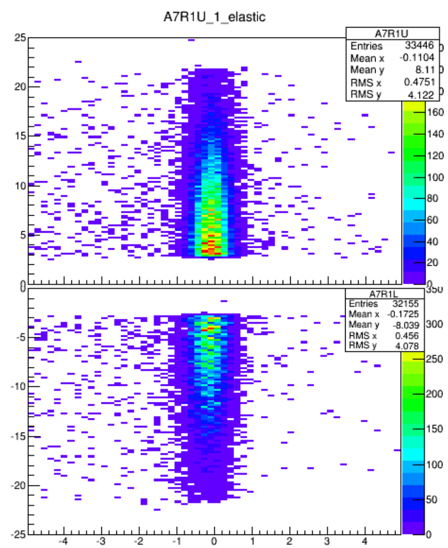
However the effect on the phase advance translate directly into the width of the elastic pattern in the ALFA detectors, so in fill 5284 a direct comparison was made.

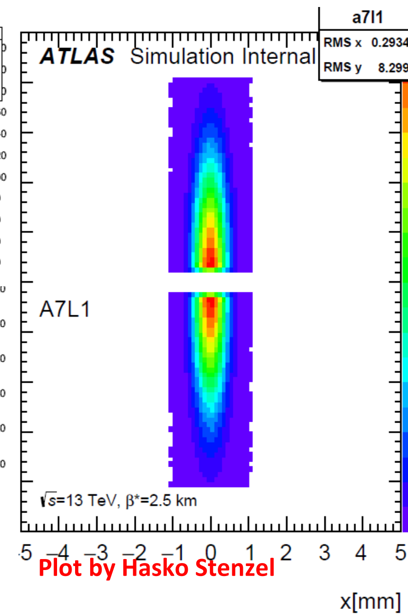
Comparison for inner stations:

Simulation of Q6 optics | **Online data with Q6 optics** | **Online data with v4 optics** | **Simulation of v4 optics**







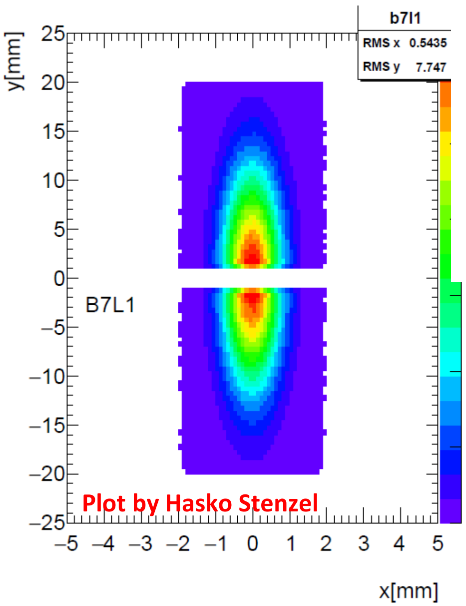


Tendency maybe visible already with the online plots, but offline analysis needed to quantify the difference.

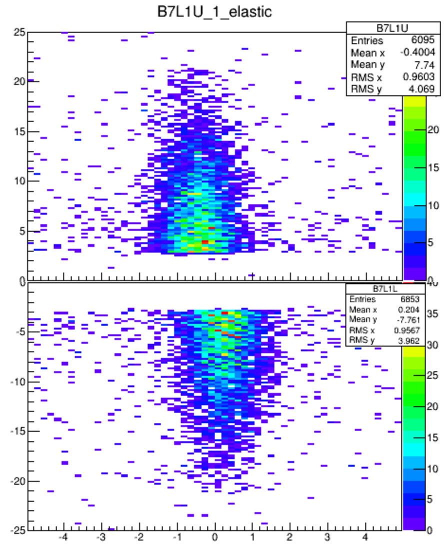
Optics comparison from fill 5284

Comparison for outer stations:

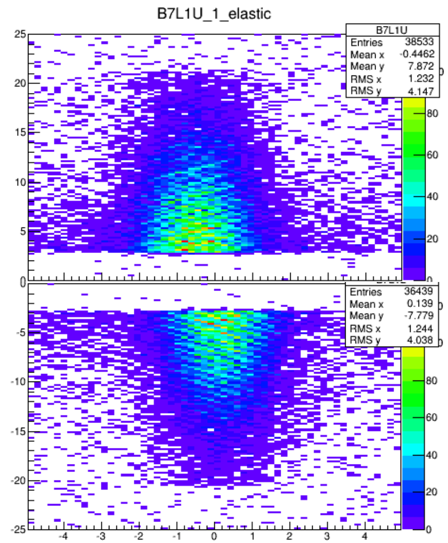
Simulation of Q6 optics



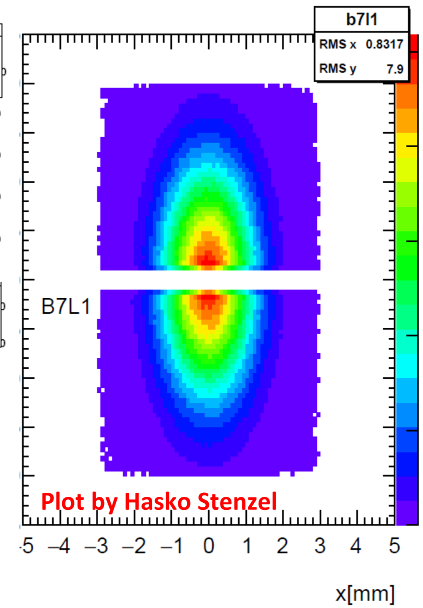
Online data with Q6 optics



Online data with v4 optics



Simulation of v4 optics



Tendency clearly visible already with the online plots, but offline analysis needed to quantify the difference.

Conclusion: The data taking should be with v4 optics.

Filling scheme and bunch intensity

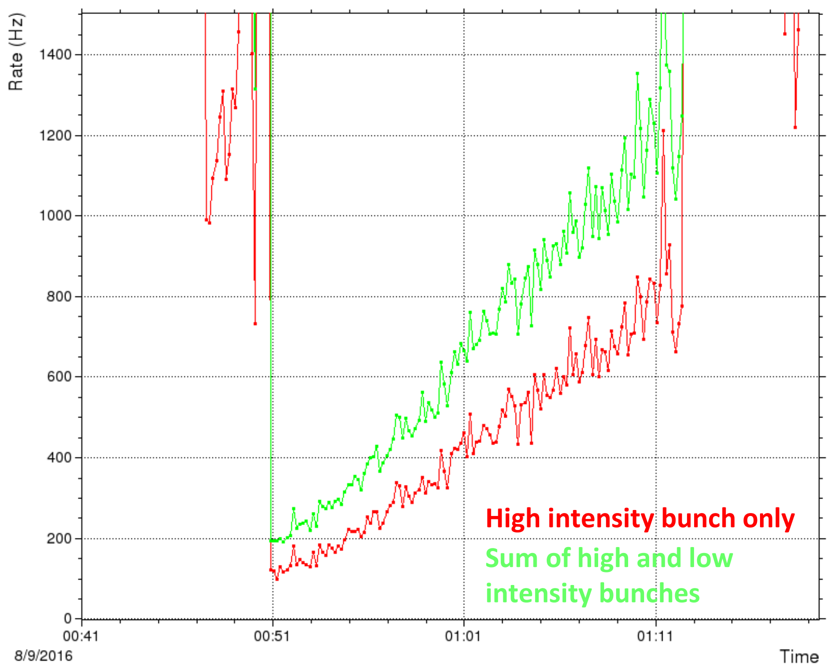
Comparison of bunch intensity in fill 5284

For a long time it was discussed if the data taking should be with 3x10E10 ppb or 4x7.5E10 ppb (total intensity below the setup beam flag of ~3E11)

In fill 5284 a set of colliding bunches of 7.5E10 ppb (~7.2 ppb actually filled) and 10E10 ppb (10.5E10 ppb actually filled) was injected.

This allows a direct comparison of the number of elastic events (luminosity) and background after scrapings etc. of the different bunch intensity.

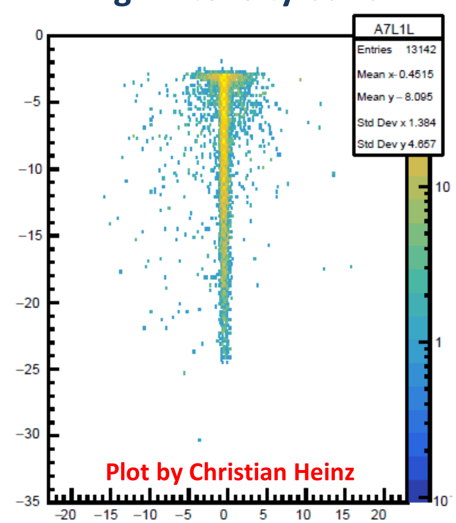
Rate comparison with the loosest trigger (ALFA_ANY) with the cleanest collimator setting:



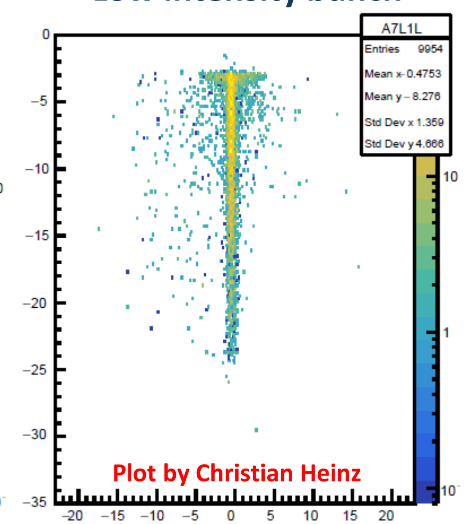
~62 % of the background rates originates from the high intensity bunch and the fraction is increasing with the time after scraping.

Comparison of hitmaps for background destitution:

High intensity bunch



Low intensity bunch



From the online reconstructed elastic tracks, there is no obvious difference in the background distribution.

Comparison of bunch intensity in fill 5284

Comparison of the number of online reconstructed events for each bunch:

	Low intensity bunch	High intensity bunch	Fraction in large bunch	Fraction in small bunch
B7L1U	8322	6156	0.57	0.43
B7L1L	7884	6167	0.56	0.44
A7L1U	12728	7860	0.62	0.38
A7L1L	13142	9954	0.57	0.43
A7R1U	8489	6662	0.56	0.44
A7R1L	8211	6131	0.57	0.43
B7R1U	11700	9109	0.56	0.44
B7R1L	10926	9452	0.54	0.46
Average			0.57	0.43

That the fraction of elastic events are lower (57 %) than the fraction of the background rate (62 %) indicates that the high intensity bunch has a higher fraction of background.

Based on this numbers the relative number of expected elastic events (luminosity) can be easily calculated.

All bunches colliding this (Elastic events (luminosity) in % of fill 5284):

3 bunch option 3*57 % = 171 %
4 bunch option 4*43 % = 172 %

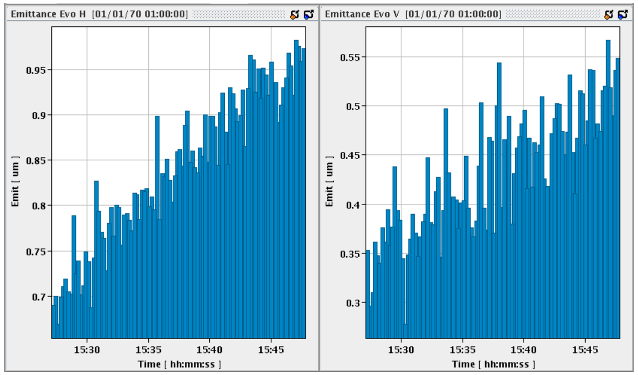
One non-colliding bunch this (Elastic events (luminosity) in % of fill 5284):

3 bunch option 2*57 % = 114 %
4 bunch option 3*43 % = 129 %

Likely the low intensity bunches are even more favoured:

Due to PS problems the low intensity bunch stayed at injection energy for about 1 hour and suffered from emittance blowup

The intensity of the low intensity bunch was lower than requested (~7.2E10 ppb) while the high intensity bunch was larger than requested (~10.5 ppb).



Changes during operation

Due to instabilities in the first fill, "LHC" recommended to reduced bunch intensity from 7.5E10 ppb to 6E10 ppb.

To partially compensate the loss of luminosity a bunch was therefore added to the filling scheme.

Trigger operation very fast adapted to this.

For the last fill with IBL, the filling scheme was even optimized for IBL to gain L1 rate (from ~10 kHz to ~18 kHz), which was highly beneficial for the efficiency measurement for vertex based luminosity

Used filling schemes:

Single_5b_3_0_0_1bpi_5inj: Did not make it fort quiet beam

Single_6b_4_0_0_1bpi_6inj: Invented during operation to add a bunch (with a non-colliding bunches)

Single_6b_5_0_0_1bpi_6inj: Invented during operation to add a bunch (without non-colliding bunches)

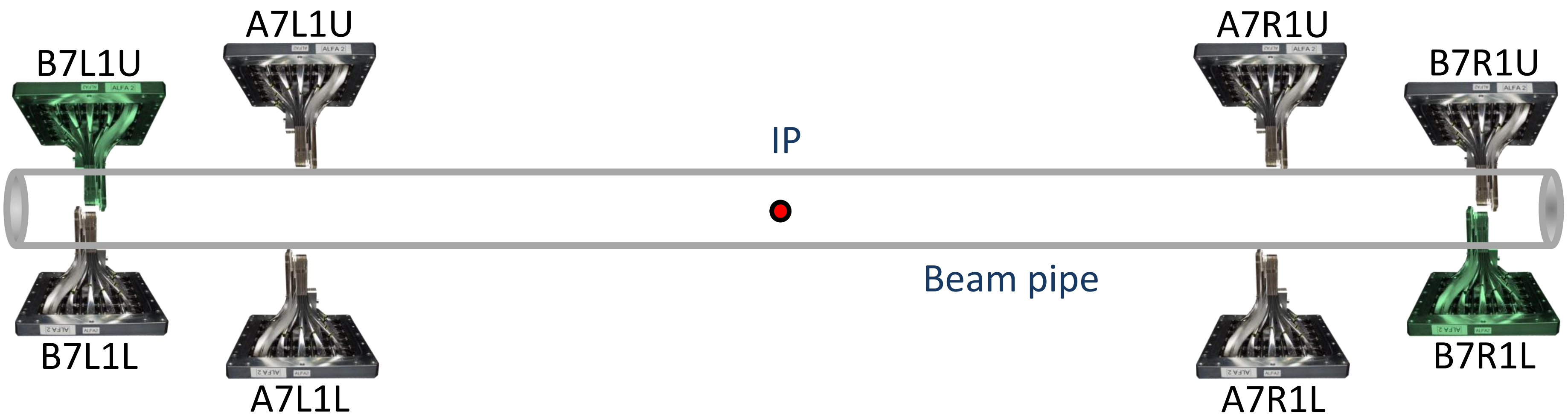
Single_5b_4_0_0_1bpi_5injalt: Invented during operation to optimize the L1 rate with IBL.

Due to very little useful data in the overlap detectors for the inner station, the high voltage was scanned and optimized during operation.

The combination of optimal HV and less background resulted in a good distance measurement for all detectors.

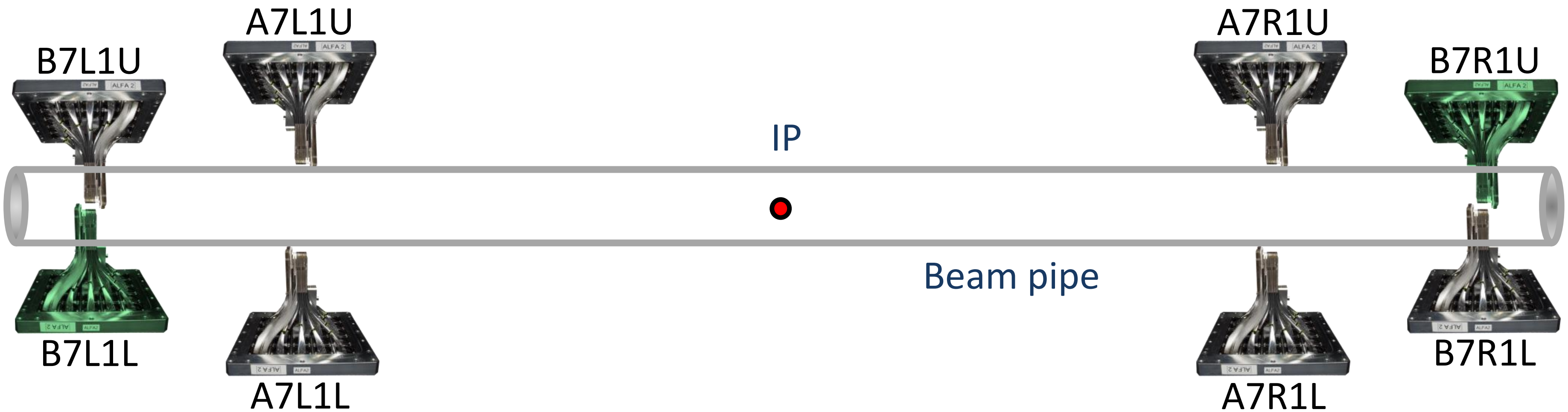
Background (Collimator setup)

Definition of golden/anti-golden



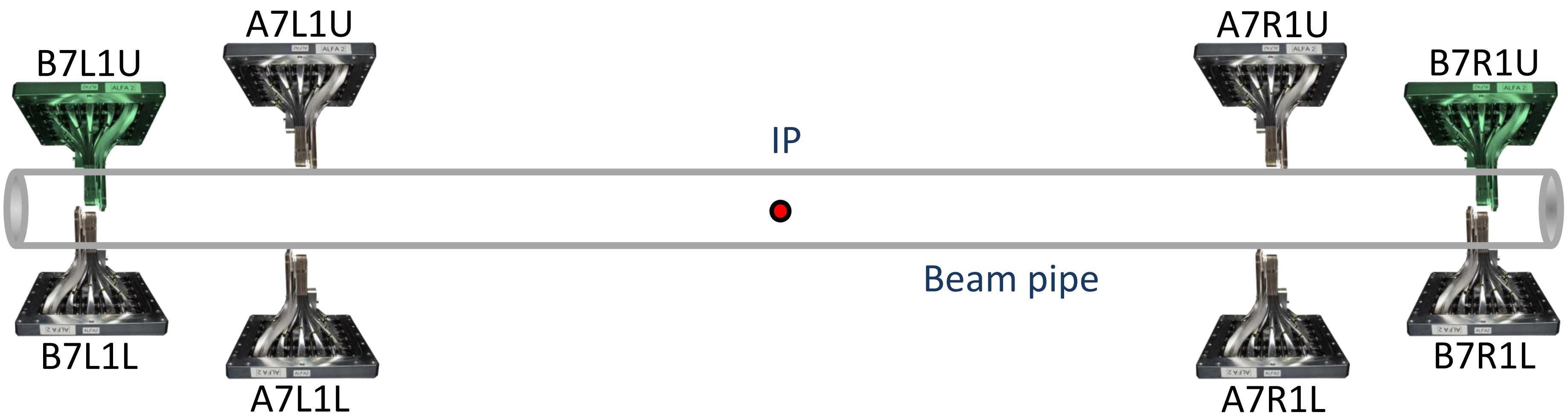
Golden1 (Elast15)	B7L1U and B7R1L
Golden2 (Elast18)	B7L1L and B7R1U
Anti-golden1	B7L1U and B7R1U
Anti-golden2	B7L1L and B7R1L

Definition of golden/anti-golden



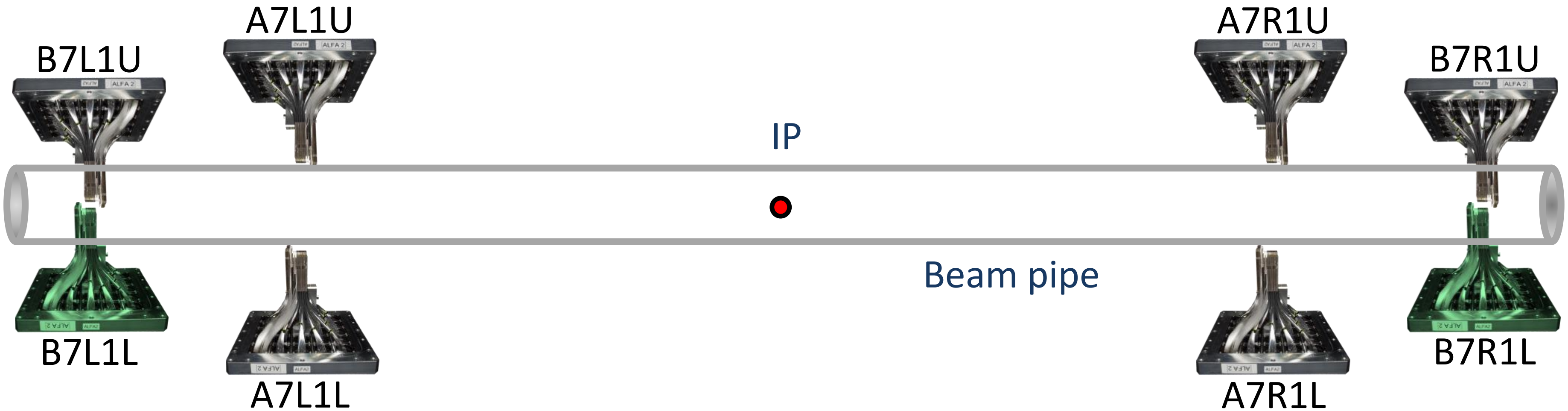
Golden1 (Elast15)	B7L1U and B7R1L
Golden2 (Elast18)	B7L1L and B7R1U
Anti-golden1	B7L1U and B7R1U
Anti-golden2	B7L1L and B7R1L

Definition of golden/anti-golden



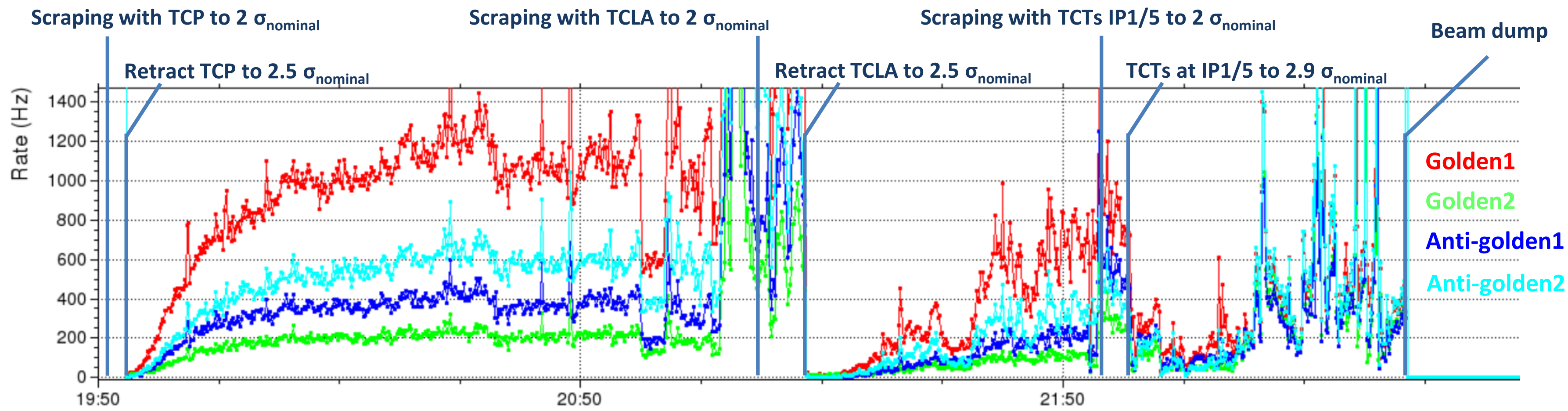
Golden1 (Elast15)	B7L1U and B7R1L
Golden2 (Elast18)	B7L1L and B7R1U
Anti-golden1	B7L1U and B7R1U
Anti-golden2	B7L1L and B7R1L

Definition of golden/anti-golden



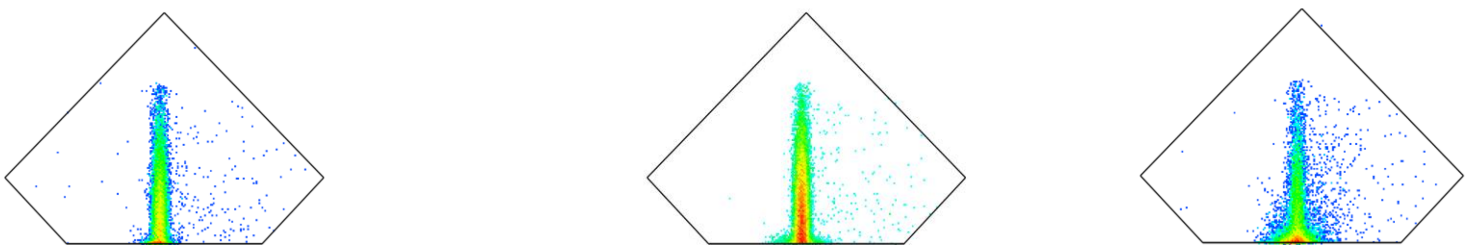
Golden1 (Elast15)	B7L1U and B7R1L
Golden2 (Elast18)	B7L1L and B7R1U
Anti-golden1	B7L1U and B7R1U
Anti-golden2	B7L1L and B7R1L

Summary of background reduction 31-07-2016

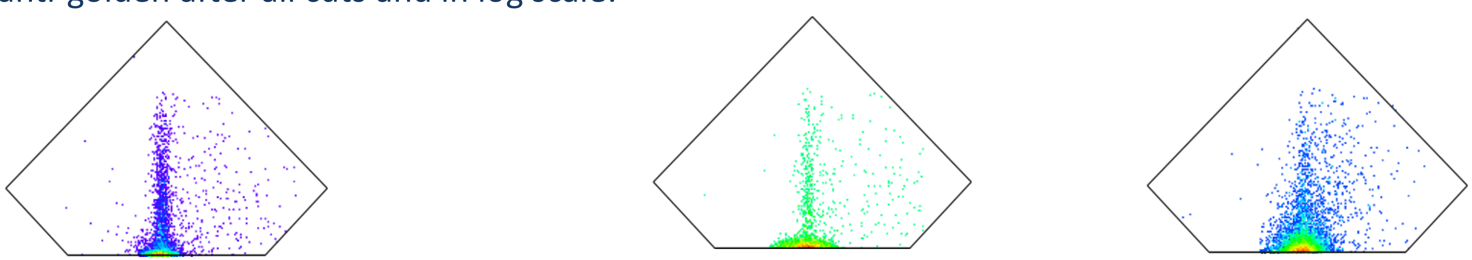


Physics rate expected: ~10 Hz

Hitmaps of elastic (golden) after all cuts and in log scale:

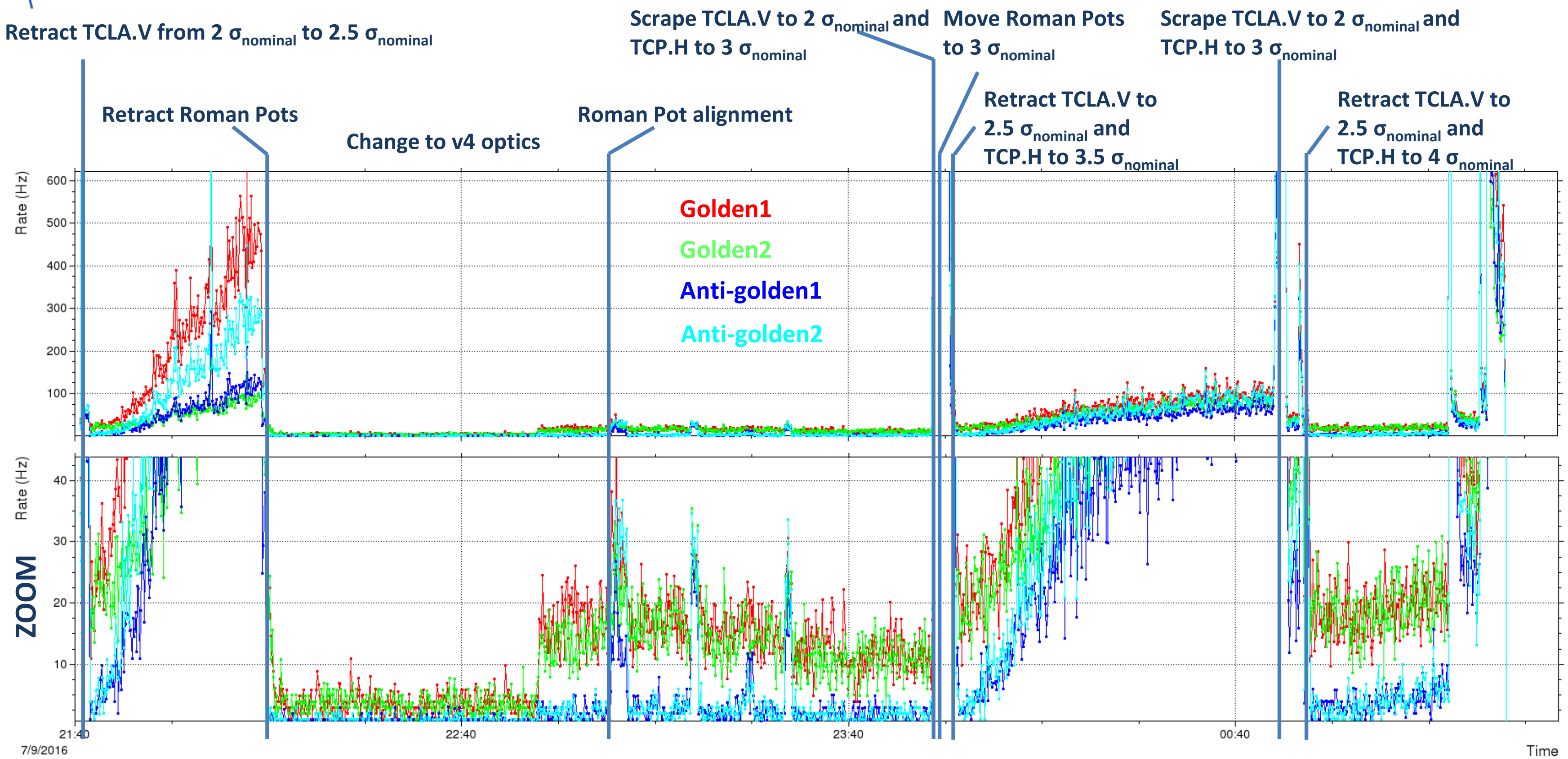


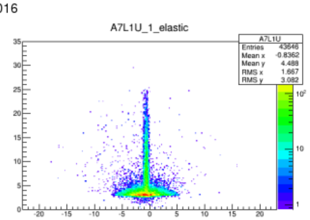
Hitmaps of anti-golden after all cuts and in log scale:



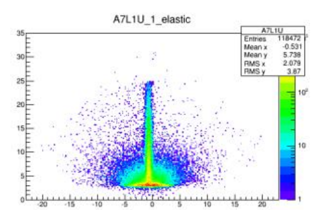
Conclusion: Of the tested options the use of only TCLAs are much preferred.

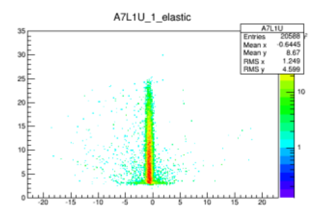
Summary of background reduction 07-09-2016 – Online results





Online Hitmaps of elastic events (in log scale).





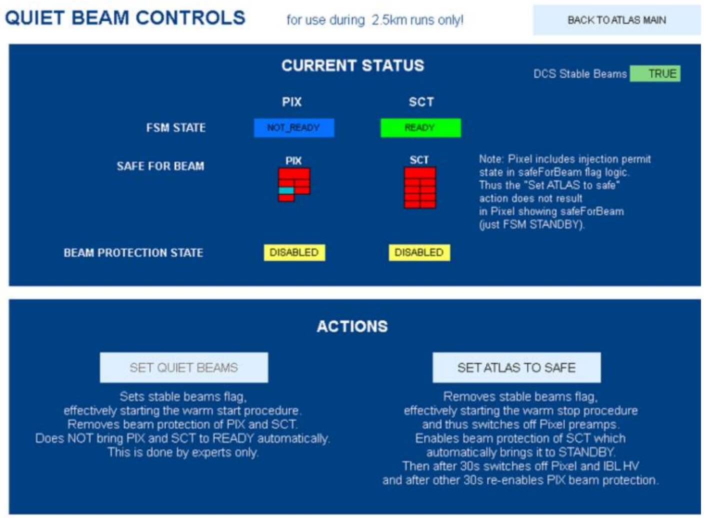
TCLA.V from 2 to 2.5 $\sigma_{nominal}$ + TCP.H 3 to 4 $\sigma_{nominal}$ is clearly very effective.

Background rate (physics triggers) reduction 10 min after scraping:

- TCP.V changed to TCLA: Factor ~10
- TCP.V changed to TCLA + TCP.$H_{3\text{ to }4}$: Factor ~100

Operational overview from week 38

Operation overview



Filling.

De-squeezing to β^* = 2.5 km (v4 optics).

Optimize collisions.

Align Roman Pots (only done in first fill).

Scrap down the beam with the TCPs: V to 2 $\sigma_{nominal}$, H to 3 $\sigma_{nominal}$.

Align TCLA.Vs and move them to 2 (1.9) $\sigma_{nominal}$.

Move Roman Pots to 3 $\sigma_{nominal}$.

Retract TCLA.Vs to 2.5 (2.7) $\sigma_{nominal}$ and TCP.H to 5.5 (4.0) $\sigma_{nominal}$.

Declare "Quiet beam" on LHC page 1 (no Roman Pot or collimator movement allowed).

Turn on ATLAS inner tracker.

Data taking until background is too high (35-90 min).

Turn off ATLAS inner tracker.

Remove "Quiet beam" from LHC page 1.

Re-scrape with the TCLA.Vs to 2 $\sigma_{nominal}$ and with the TCP.H to 3 $\sigma_{nominal}$.

Repeat until beam is lost (or scraped away)

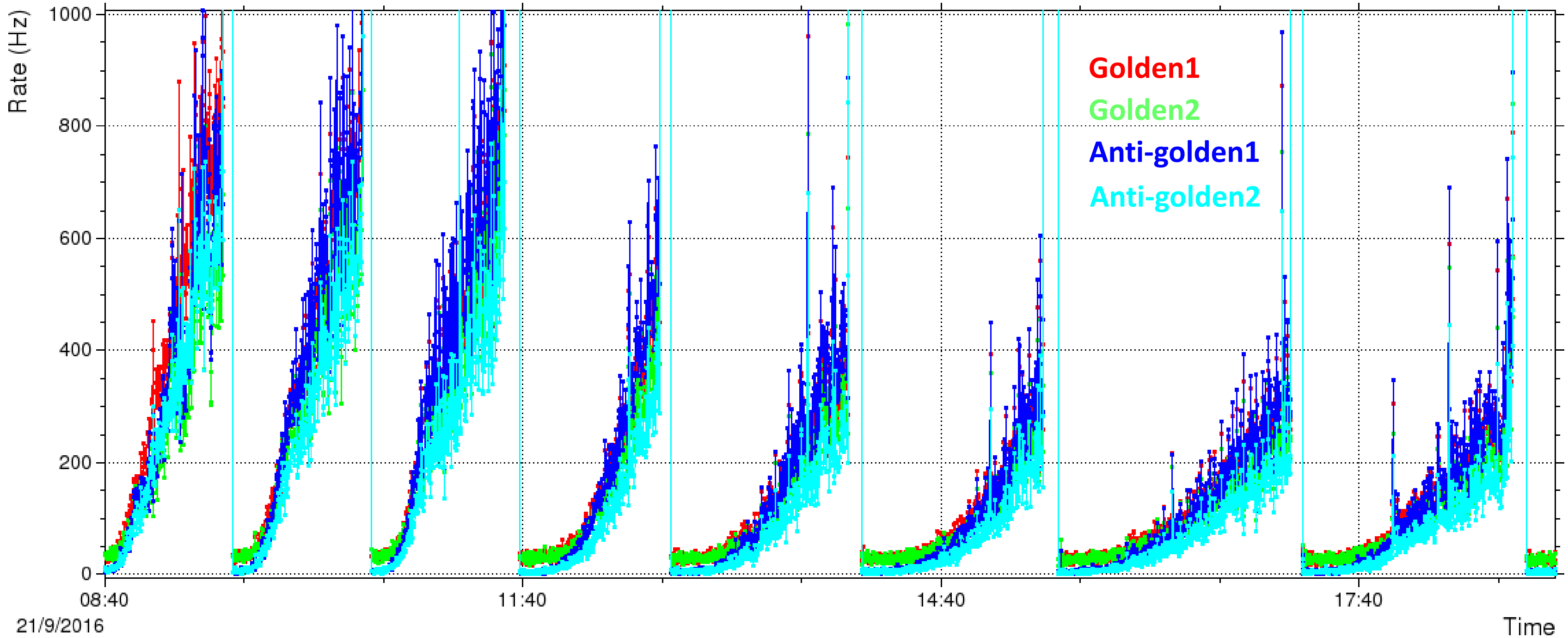
Values after optimization during operation. The optimization hugely minimized the background and prolonged the periods between scrapings.

The Stable Beam Flag was faked in DCS and was in the hands of ALFA in CCC.

Pixel and SCT experts called at all transitions to power on or check safe state.

To limit the number of cycle of the inner detector, eventually only 2nd (3rd at night) period was with inner detector on (in agreement with luminosity group).

Operation overview – scraping periods



The scraping at ~11:35 was to 0.1 $\sigma_{nominal}$ closer and extracted 0.1 $\sigma_{nominal}$ further with the vertical collimator. Huge improvement in time with minimum background and background growth (repopulation).

The scraping at ~was extracted 0.1 $\sigma_{nominal}$ further with the vertical collimator. Some minor improvement. This was the final setting.

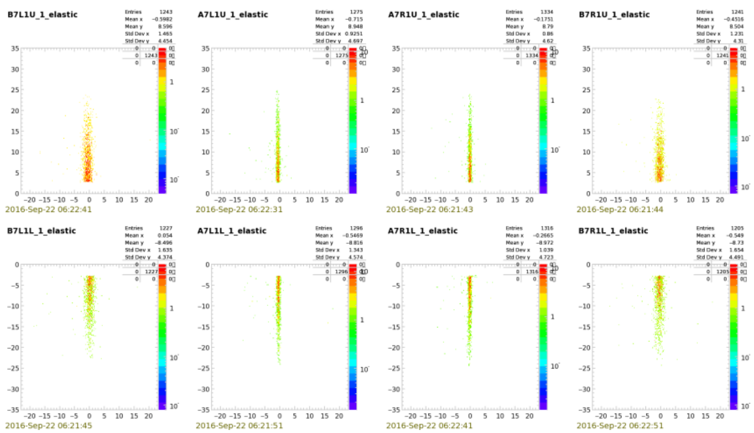
The change in background was also observed directly in central ATLAS.

Online/offline feedback

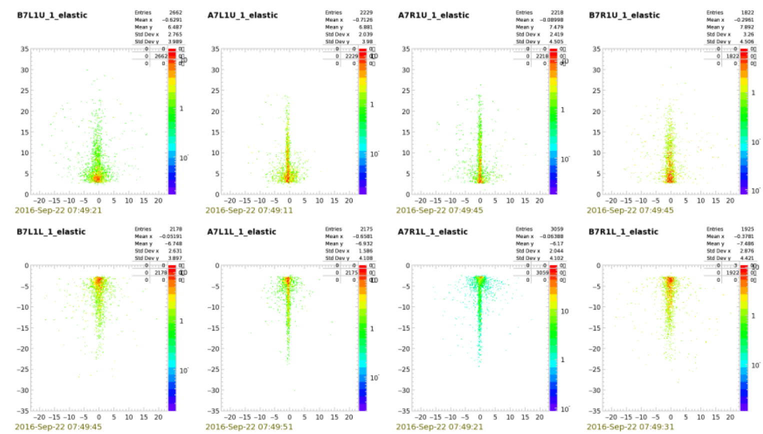
Online and offline feedback

The time between scraping periods was determined via the online rates and hitmaps (all tracks reconstructed on the HLT farm) and some ratios (~reconstruction efficiency).

Reconstructed online tracts at the start of a period (1 LB).

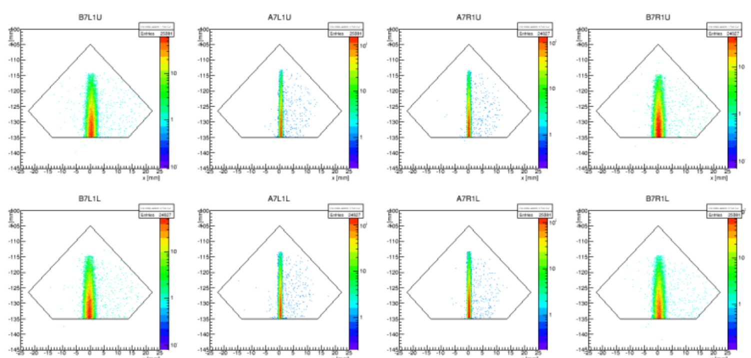


Reconstructed online tracts at the end of a period (1 LB).

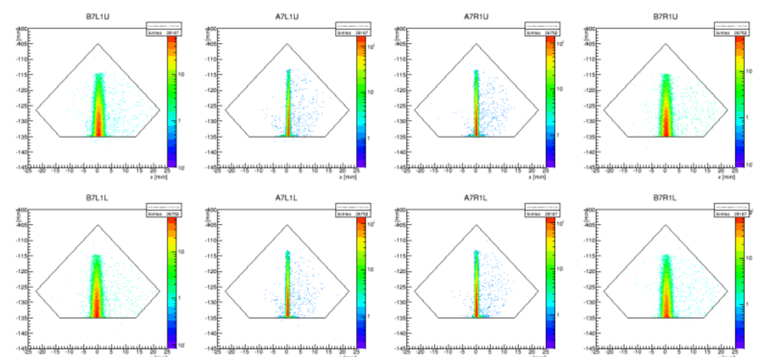


The VERY fast processing allow to also look at the offline data with all tracks (here the run with most background):

Reconstructed offline tracts at the start of a period (20 LB).



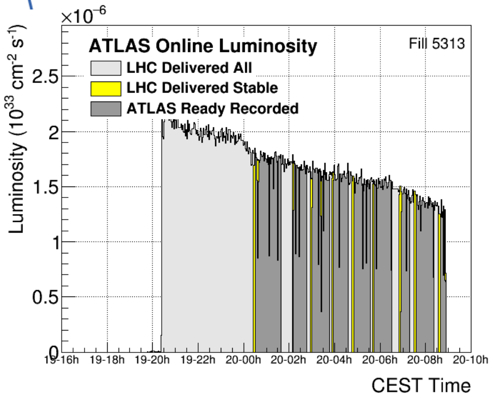
Reconstructed offline tracts at the end of a period (20 LB).

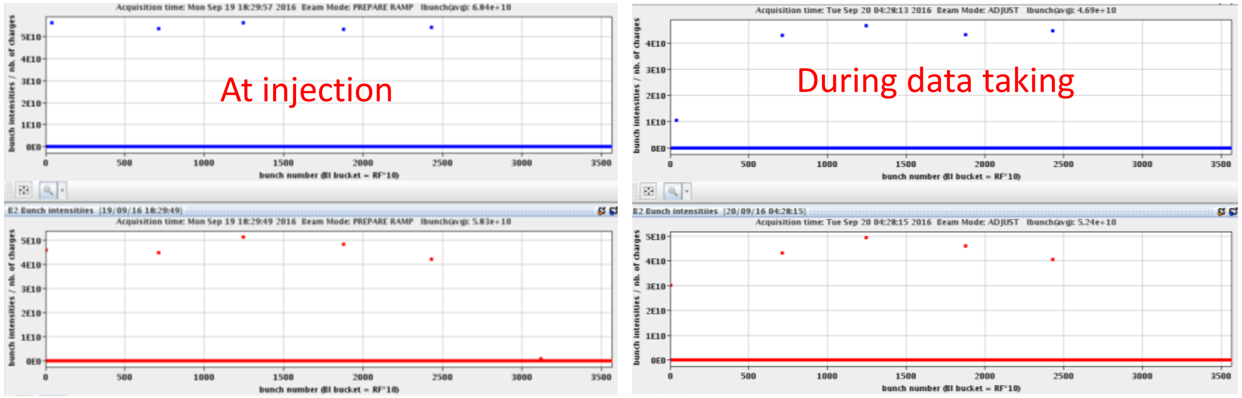


Only small difference ("beam sport") offline. Additional cuts after full alignment will clean the sample further.

Fill by fill summary

Fill 5313



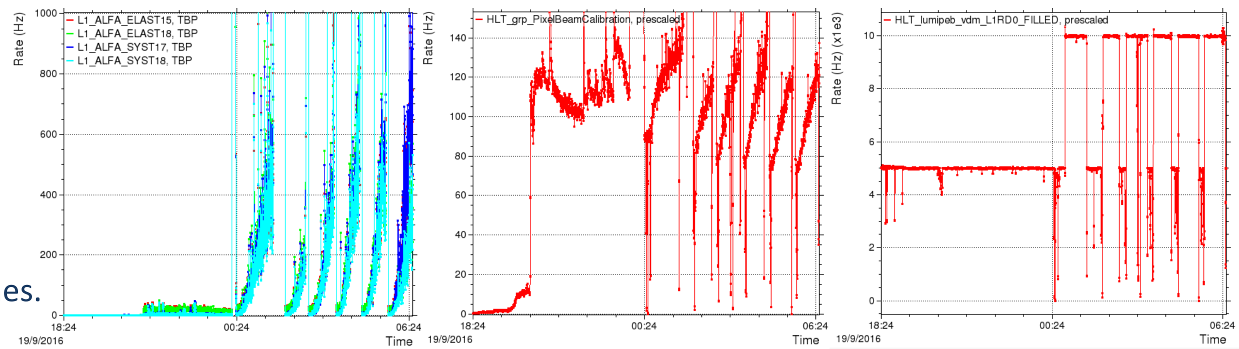


Filling scheme: Single_6b_4_0_0_1bpi_6inj (one bunch non-colliding).

Run 308979.

IBL included.

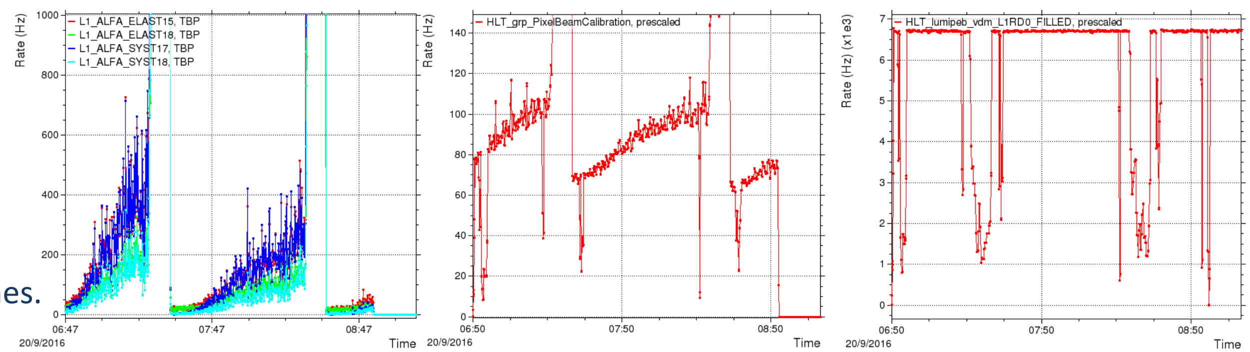
Comment: Non-colliding bunch hugely reduced in intensity (likely due to blow up) and is not comparable to the colliding bunches.



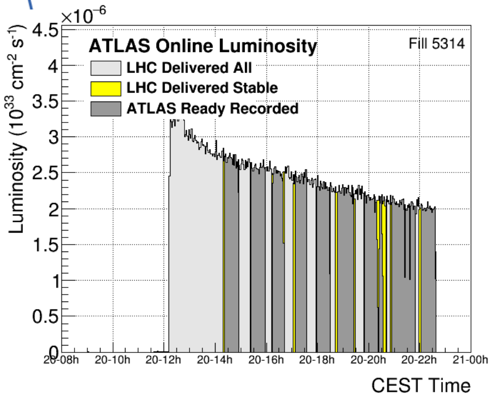
Run 308982.

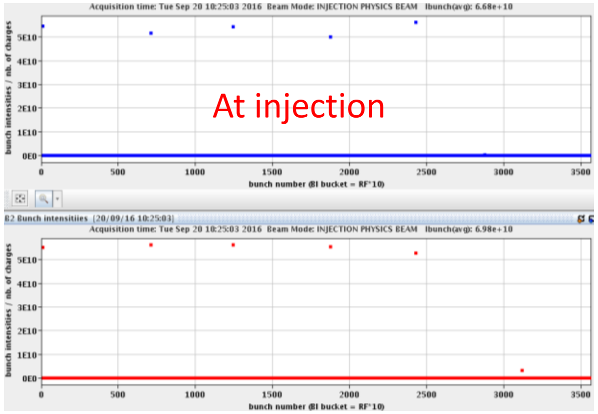
IBL NOT included.

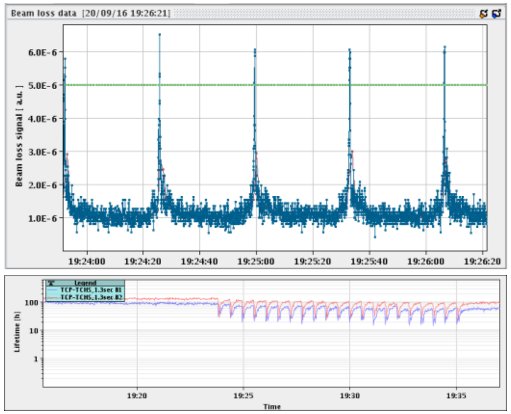
Comment: Non-colliding bunch hugely reduced in intensity (likely due to blow up) and is not comparable to the colliding bunches.



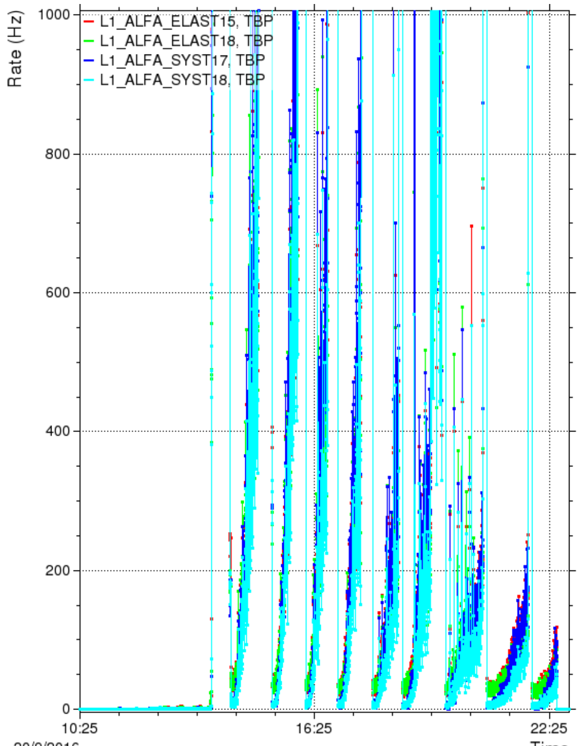
Fill 5314

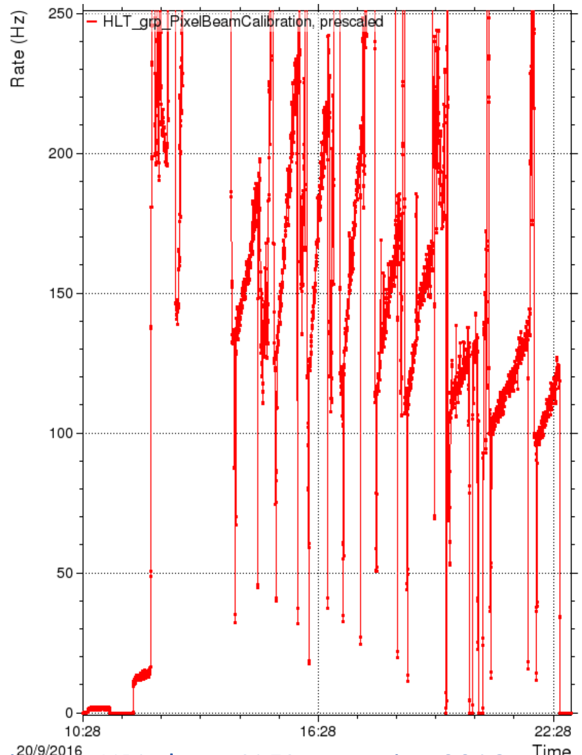


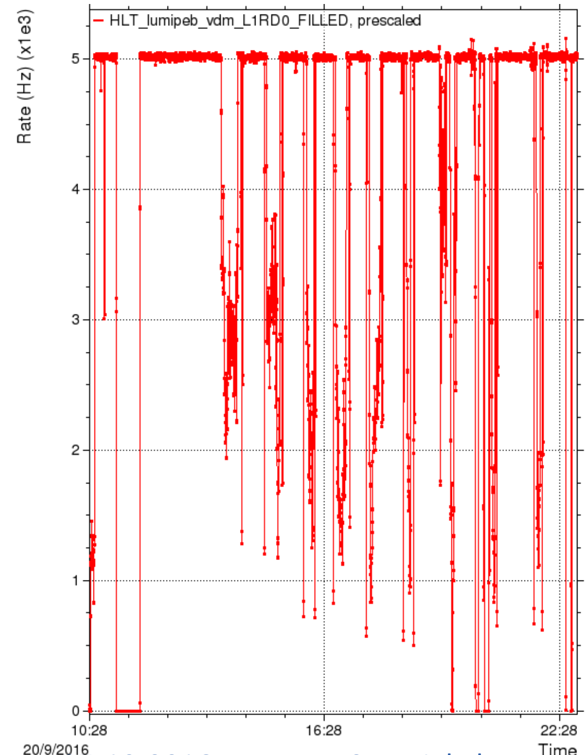




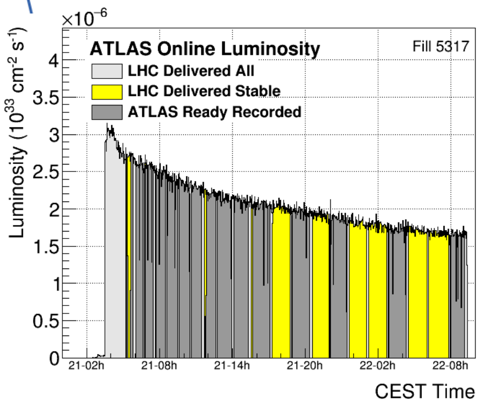
Filling scheme: Single_6b_5_0_0_1bpi_6inj **Run 309010.** IBL NOT included. Comment: Period with beam instabilitys.

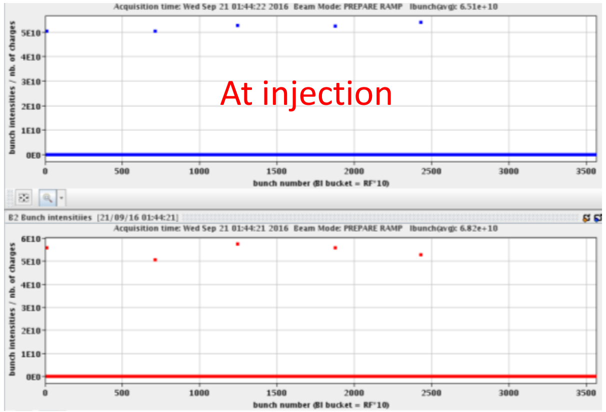


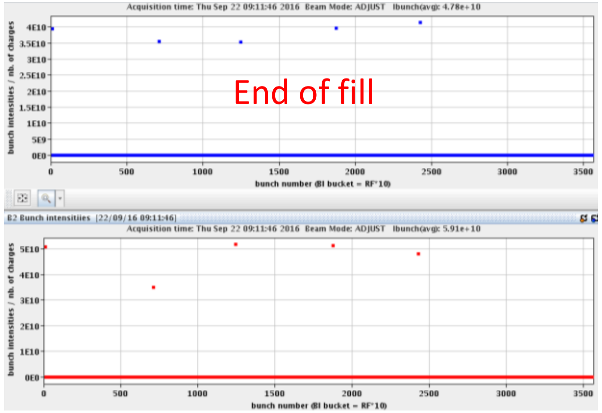




Fill 5317





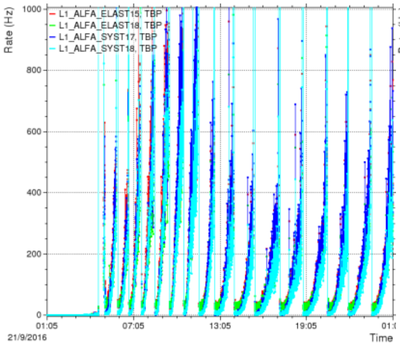


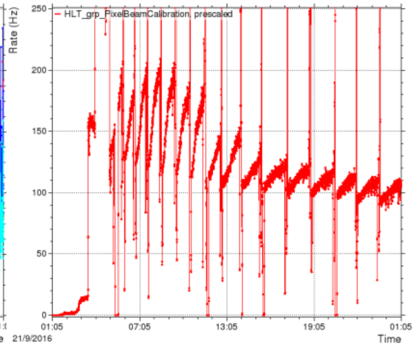
Filling scheme: Single_6b_5_0_0_1bpi_6inj

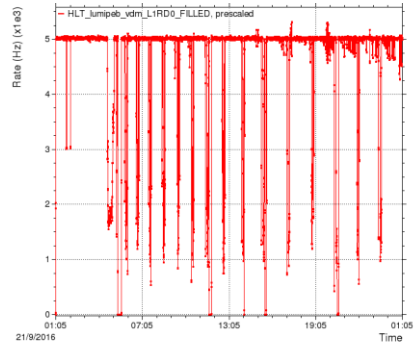
Run 309039.

IBL NOT included.

Comments:
Periods with inner detector off, but good ALFA data.
TCLA scheme changed at ~11:35, so background reduced.



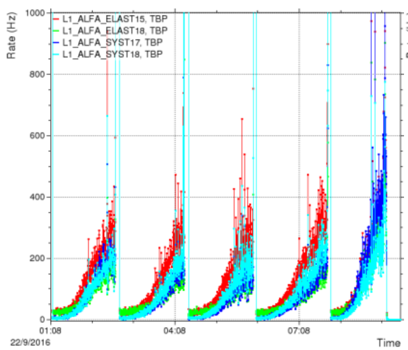


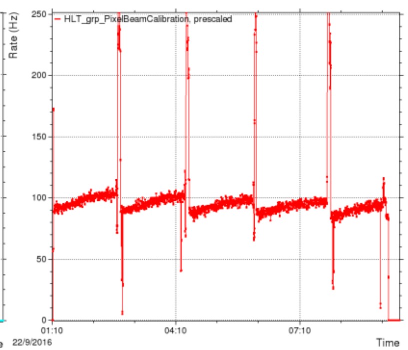


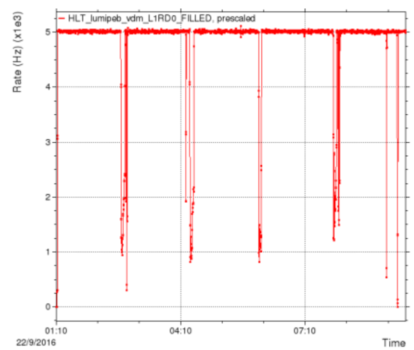
Run 309074.

IBL NOT included.

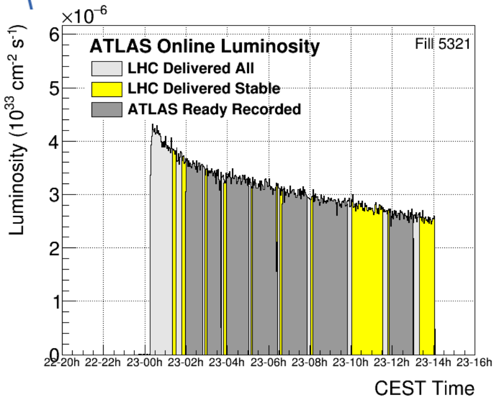
Comment: Periods with inner detector off, but good ALFA data.

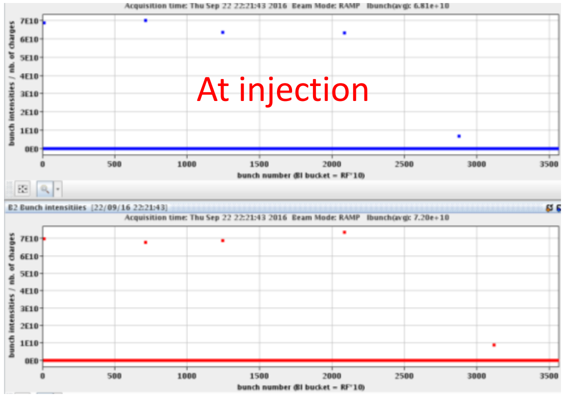






Fill 5321



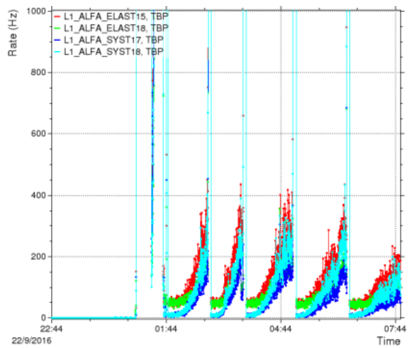


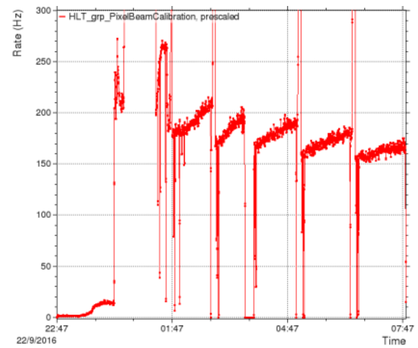
Filling scheme: Single_5b_4_0_0_1bpi_5injalt

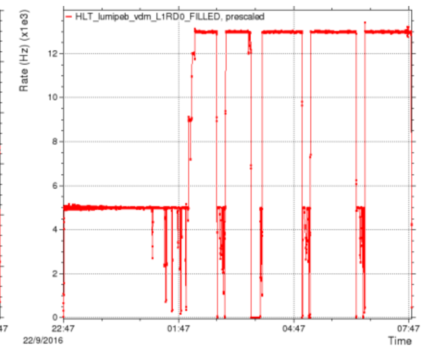
Run 309165.

IBL included.

Comment: None



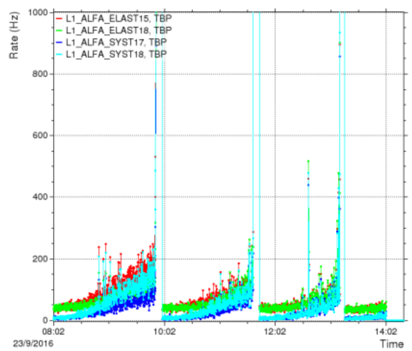


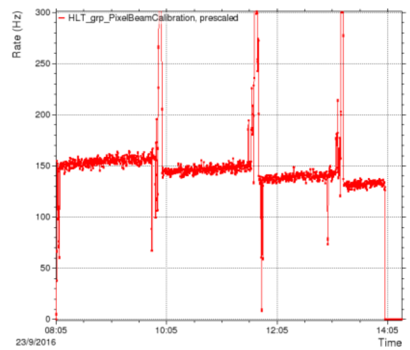


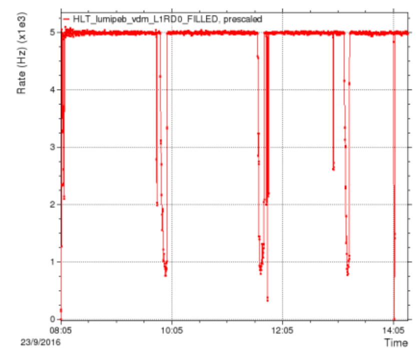
Run 309166.

IBL NOT included.

Comment: Periods with inner detector off, but good ALFA data.





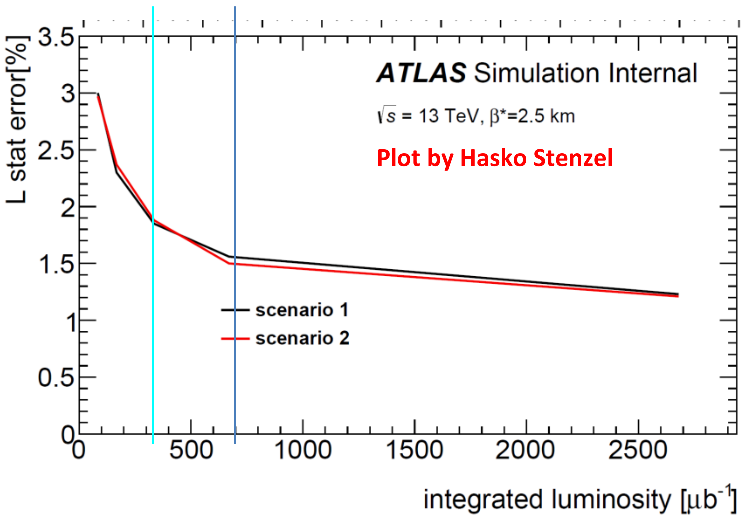


Integrated luminosity

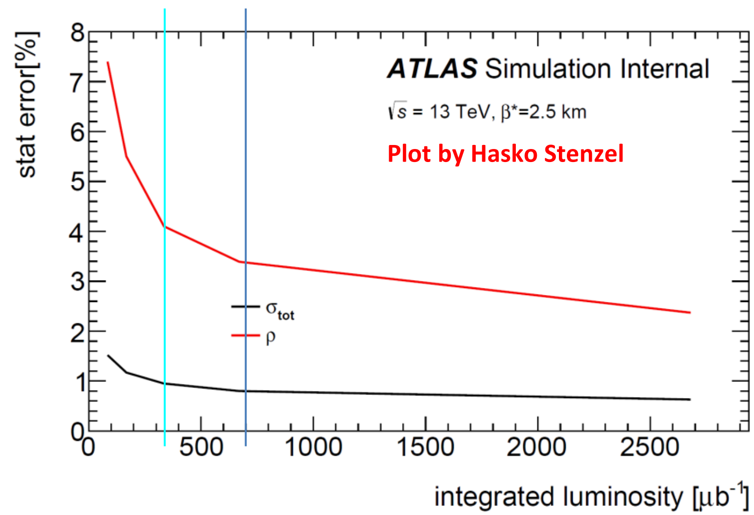
Integrated luminosity

For the first time ever the elastic program is likely to be limited by integrated luminosity.

Statistical error on luminosity determination vs integrated luminosity:



Statistical error on total cross section and rho vs integrated luminosity:

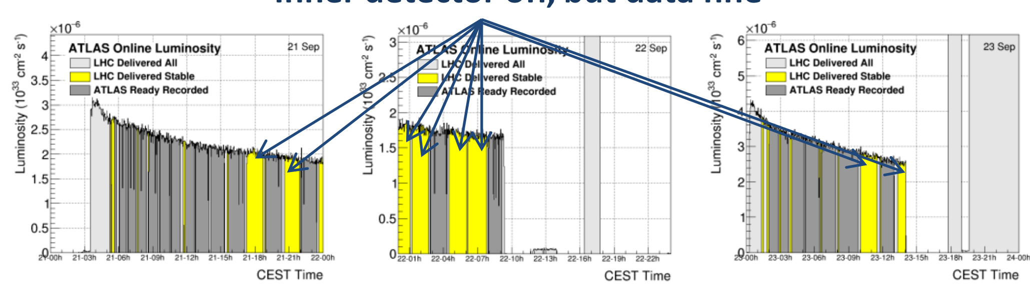


Original luminosity aim: Minimum 700 µb^{-1}, and more is highly desirable.

Due to an beam instability in the first fill, LHC recommended reducing the bunch intensity from 7.5E10 to 6E10 (~35 % reduction in instantaneous bunch luminosity).

Inner detector off, but data fine

Integrated luminosity:
~330 1/µb (+/- 10 %)



Problems during operation

Problems during operation

For one run RF noise close to the ALFA stations was observed (correlated noise for different detectors and even in different LHC sectors).

Symptom: High rate (~10^6 Hz) overlap detector rate (coincidence of upper and lower station)

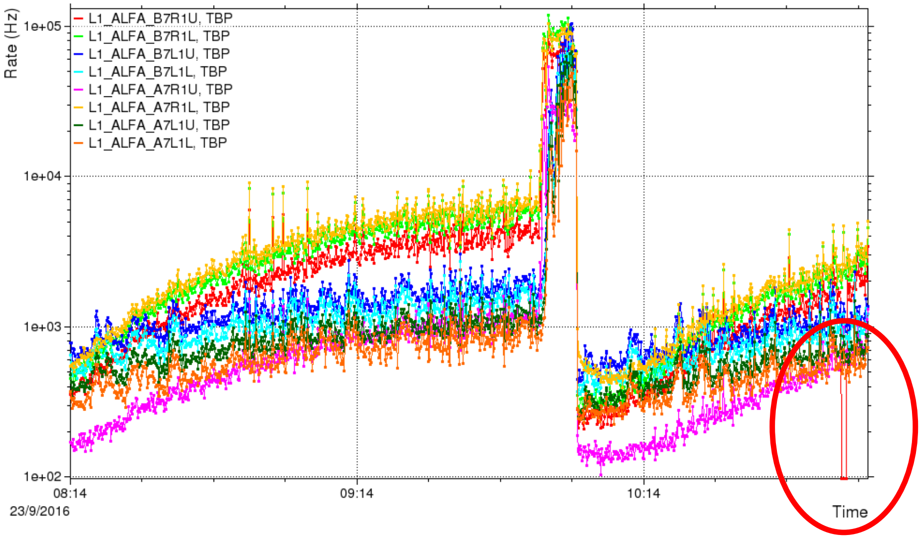
Mitigation: Lower the OD trigger gain in the front ned to still have some efficiency but avid the high rate.

At the end of fill the RF disappeared and did not return and the OD trigger gain was restored (no explanation on LHC side).

During scraping (and a few times also during data taking) SEU occurred

PMFs: Hold trigger, power cycle, reconfigure detectors, TTC restart.

Trigger: Just reconfigure.
If it does not solve the problem: Hold trigger, power cycle, reconfigure detectors, TTC restart.



During scraping the high voltage current spiked

Often no problem, but DCS warnings/errors.

Few times HV trip: Clear error to start a new HV ramp.

Thanks

Thanks

Thanks to all sub-system for the huge extra effort for the high β* program.

Special thanks to:

Pixel and SCT for the MANY cycles and smooth collaboration throughout the period.

Trigger menu and operation for very smooth and effective collaboration.

Data preparation for making an extra effort to processing the ALFA data fast enough to make check still. during running and for smooth collaboration.

Central DCS for the very useful "quiet beam" panel.

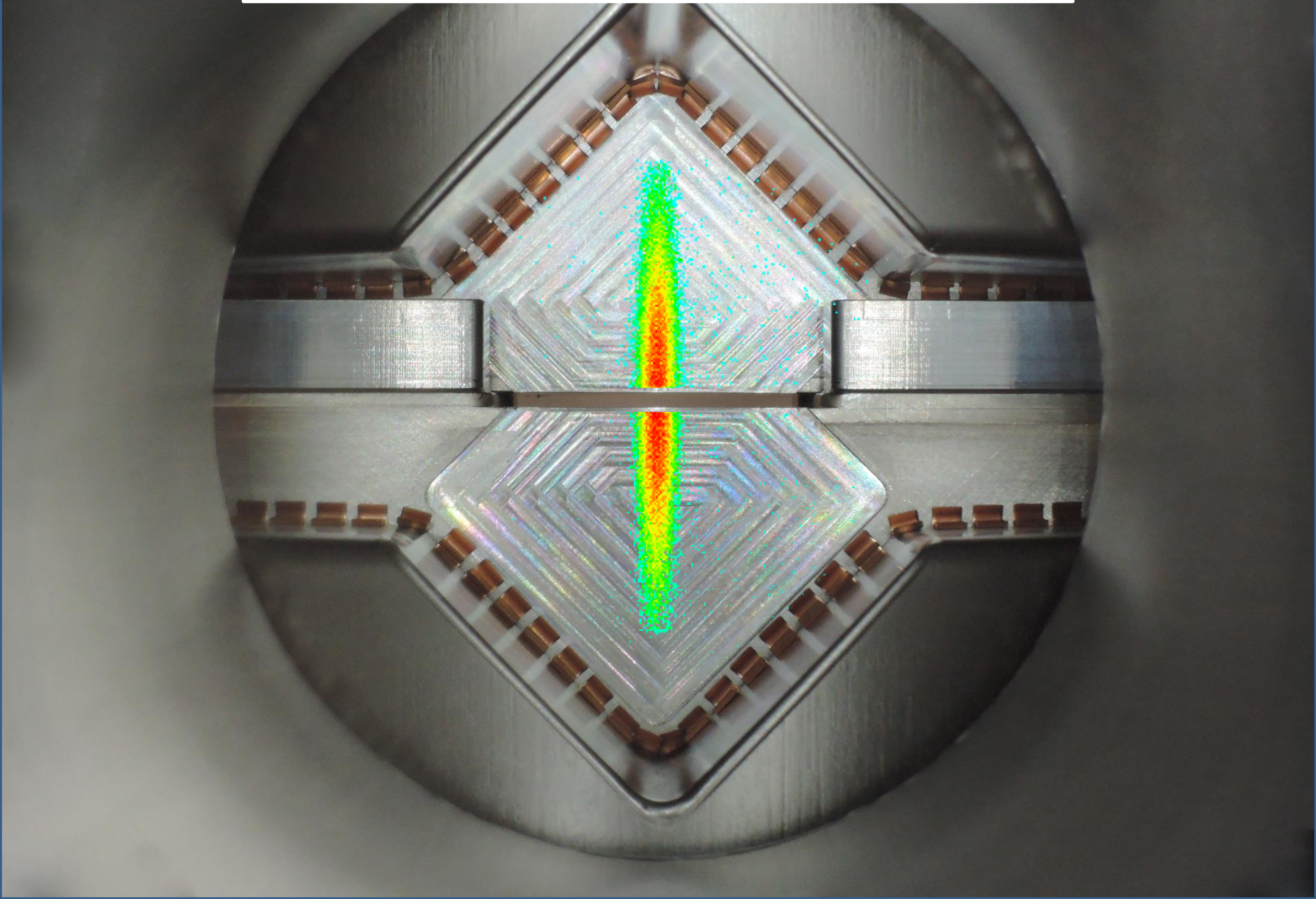
Run coordination for the extensive support.

LPC coordinators. Especially for the commissioning time for the program.

Pre-injector specialist for finding a way to inject record low emittance beam.

LHC collimation team for collaboration in finding the good collimator settings to reduced background

Thank you for your attention



Backup

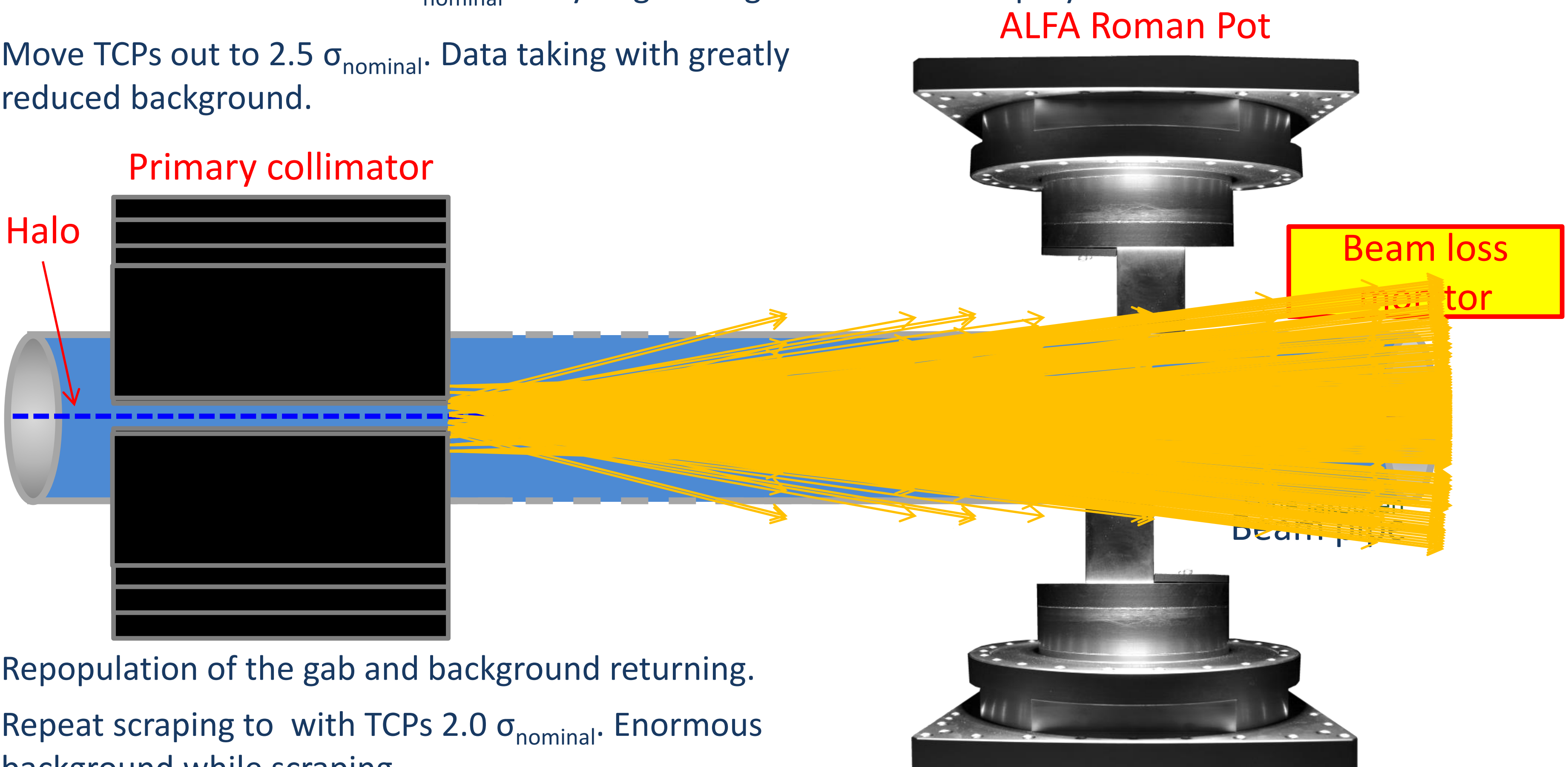
Method of background cleaning for data taking

Goal: Data taking with Roman Pots at 3.0 $\sigma_{nominal}$ without being dominated by background.

Scrap down the beam with the TCPs (Primary collimator) in IR7 to 2.0 $\sigma_{nominal}$.

Position Roman Pots at 3.0 $\sigma_{nominal}$. Very large background from TCP spray observed.

Move TCPs out to 2.5 $\sigma_{nominal}$. Data taking with greatly reduced background.



Repopulation of the gab and background returning.

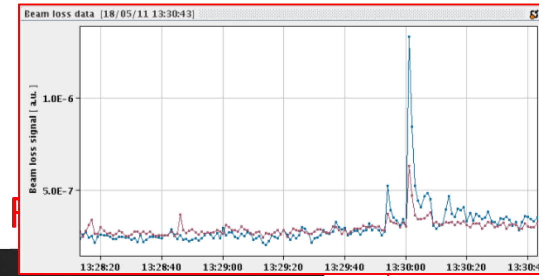
Repeat scraping to with TCPs 2.0 $\sigma_{nominal}$. Enormous background while scraping.

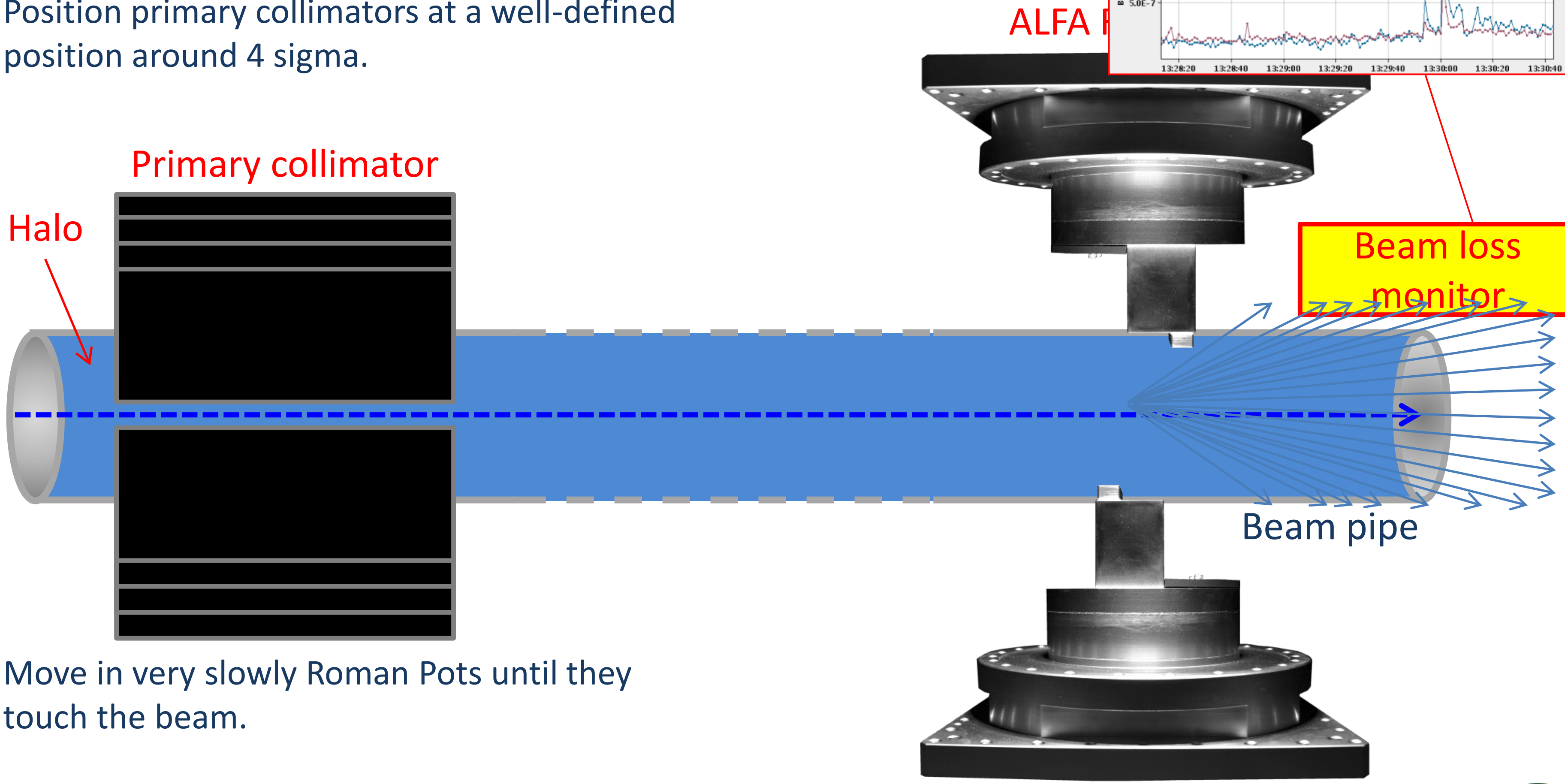
Retract TCPs to 2.5 $\sigma_{nominal}$ and continue data taking with reduced background.

Beam based alignment (scraping)

Goal: Find accurately the beam center relative to the Roman Pots. This allows positioning of the Roman Pots very close to and symmetric around the beam center.

Position primary collimators at a well-defined position around 4 sigma.

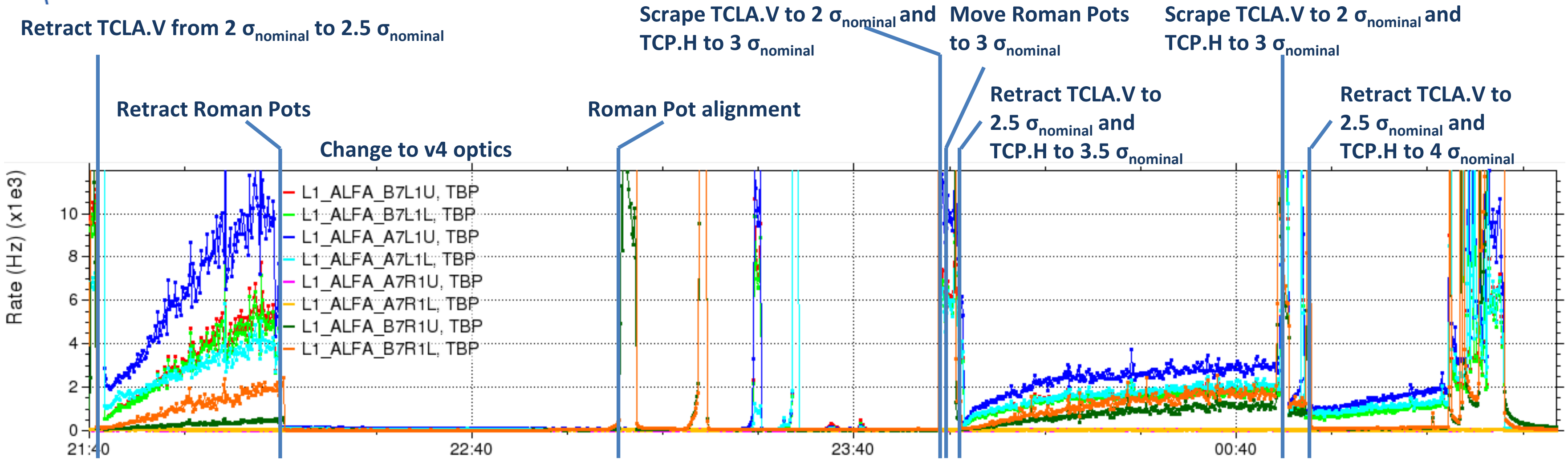


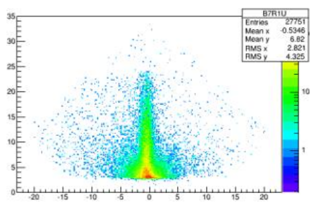


Move in very slowly Roman Pots until they touch the beam.

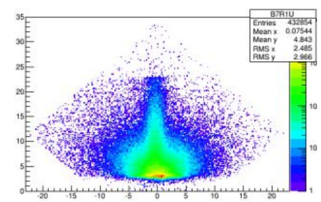
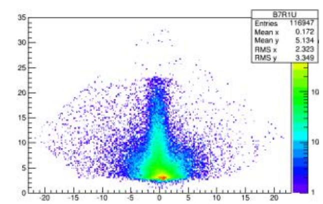
Stop by BLM signal (or very high trigger rate).

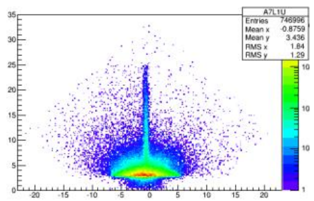
Colliding bunches in fill 5284



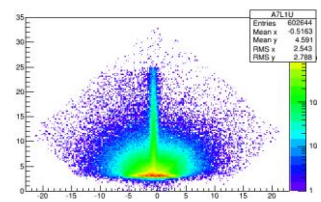
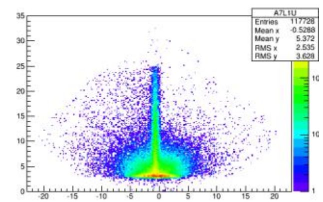


Online Hitmaps beam 1 for colliding bunches (in log scale).



Online Hitmaps beam 2 for colliding bunches (in log scale).

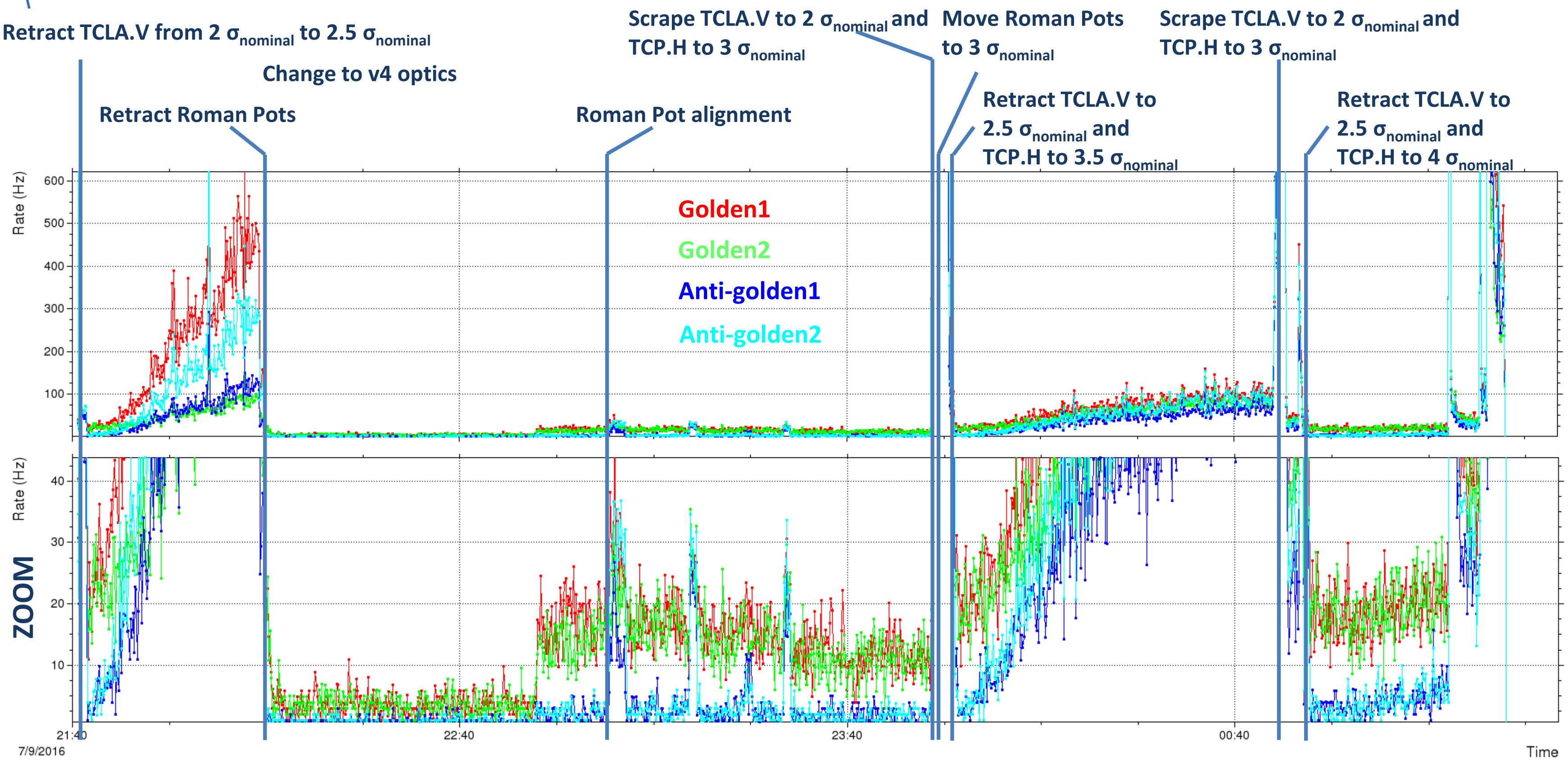
Significate change in shape on both beams when introducing the TCP.H.

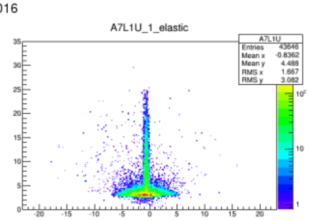
Some change in shape when retracting TCP.H further for both beams.

Significate reduction in rate when retracting the TCP.H.

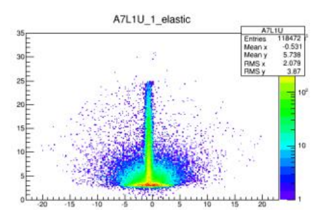
Significate reduction in rate when retracting the TCP.H further.

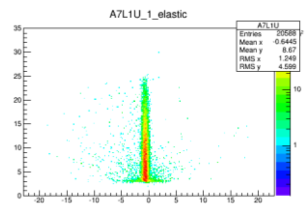
Elastic events in fill 5284





Online Hitmaps of elastic events (in log scale).





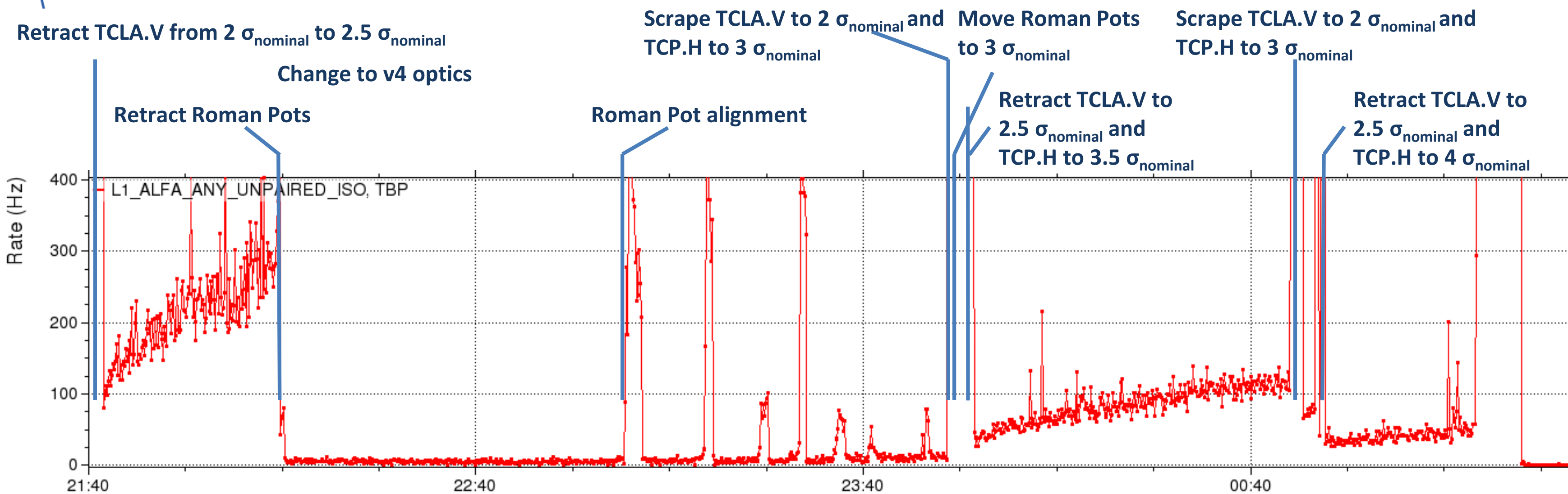
TCLA.V from 2 to 2.5 $\sigma_{nominal}$ + TCP.H 3 to 4 $\sigma_{nominal}$ is clearly very effective.

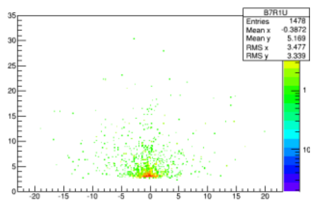
Background rate (physics triggers) reduction 10 min after scraping:

TCP.V changed to TCLA: Factor ~10

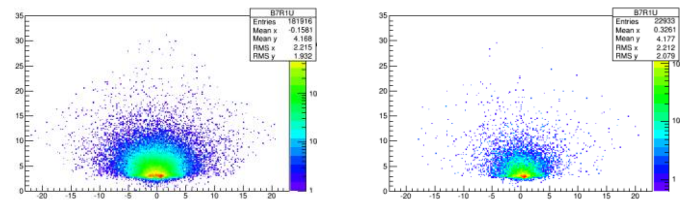
TCP.V changed to TCLA + TCP.$H_{3 \text{ to } 4}$: Factor ~100

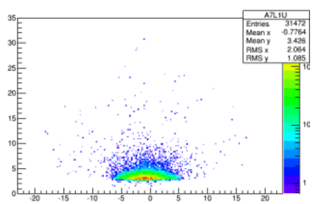
Non-colliding bunches in fill 5284



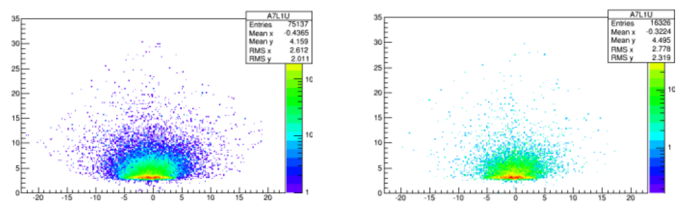


Online Hitmaps beam 1 for non-colliding events (in log scale).





Online Hitmaps beam 2 for non-colliding events (in log scale).



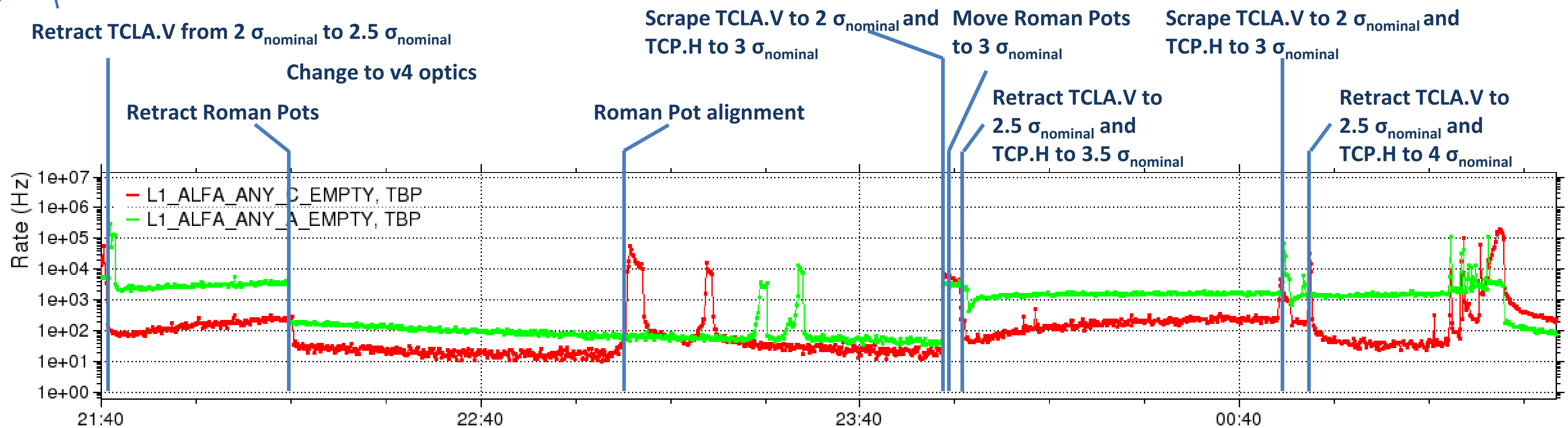
Significate change in shape on beam 2 when introducing the TCP.H.

Significate change in shape when retracting TCP.H further for beam 1, but not for beam 2 (natural as the TCP.H is at IR7.

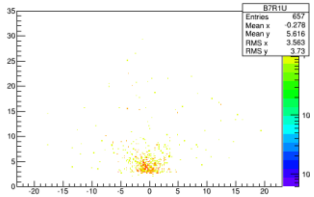
Significate reduction in rate when retracting the TCP.H.

Significate reduction in rate when retracting the TCP.H further.

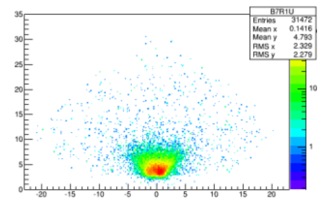
Empty bunches in fill 5284

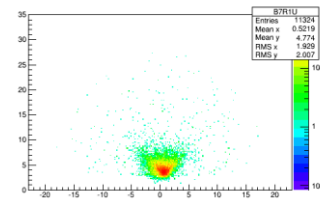


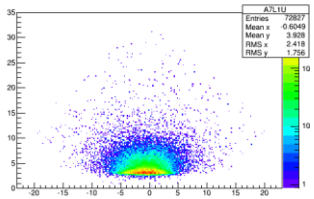
Significantly higher rates from beam 2.



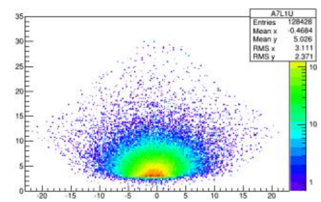
Online Hitmaps beam 1 for empty bunches (in log scale).

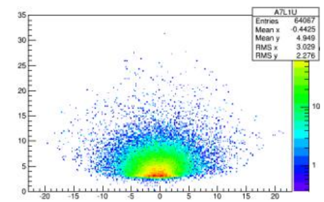






Online Hitmaps beam 2 for empty bunches (in log scale).





Significate change in background shape on beam 2 when introducing the TCP.H.

No significate change in background shape when retracting TCP.H further.

Some change in background rate on beam 1 when retracting TCP.H further.

No significate change in background rate on beam 2 when retracting TCP.H further.