Data Quality: Online Luminosity Monitoring

Houry Keoshkerian, Witold Kozanecki, Michel Trottier-McDonald

Luminosity Taskforce

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Outline

- Luminosity Basics
- ATLAS Luminometers
- Online Luminosity Monitoring Infrastructure
- DQ Shifter Luminosity Monitoring Responsibilities During M9

What All Analysts Learn About Luminosity

From an arbitrary process $pp_{\text{inel}} \to Y$ at the LHC:

How many $pp_{\text{inel}} \to Y$ events were produced during a run of duration T?

$$N_{pp_{\text{inel}} \to Y} = \int_0^T \mathcal{L}(t)\,dt \times \sigma_{pp_{\text{inel}} \to Y}$$

where the instantaneous luminosity ($\mathcal{L}$) is time-dependent, accounting for the varying LHC conditions during the run (proton burn-off, etc.).

- Fundamental for cross-section measurements ($pp \to W/Z$, $pp \to t\bar{t}$, $pp \to H$, ...)
- Crucial for estimating sensitivity of model-dependent searches.
- Needed to normalize MC samples.

Other Uses for Luminosity Information

- LHC operators use $\mathcal{L}(t)$ measured by the experiments to optimize collisions at the interaction points.
- The luminosity signals (along with other indicators) when LHC conditions are adequate for physics data-taking.
- Forms the basis for the adjustment of the triggers during data-taking (prescales, etc.).
- The time-evolution of the luminosity together with the beam-spot parameters provide accelerator diagnostics that cannot be obtained by any other means:
  - Often needed during LHC development even if no ATLAS data is taken.

Luminosity Basics at the LHC

$$\mathcal{L} = \frac{R_{\text{inel}}}{\sigma_{\text{inel}}} = \frac{\mu n_b f_r}{\sigma_{\text{inel}}}$$

$\mathcal{L}$: Instantaneous luminosity

R_{inel} : Rate of inelastic p-p collisions

σ_{inel} : Cross-section of inelastic p-p collisions

μ : Average number of inelastic proton-proton interactions per bunch crossing

n_b : Number of bunch pairs colliding per revolution

f_r : Revolution frequency

Measuring Luminosity

- Luminometers and algorithms have efficiencies ϵ to pp_{inel} collisions:

$$\mu_{\text{vis}} = \epsilon\mu \qquad \sigma_{\text{vis}} = \epsilon\sigma_{\text{inel}}$$

$$\mathcal{L} = \frac{\mu_{\text{vis}} n_b f_r}{\sigma_{\text{vis}}}$$

- μ_{vis} is the **visible counting rate** per bunch-crossing. It varies depending on the luminometer and algorithm.
  - **The luminosity displays show:**
    - $\mathcal{L}$ summed over bunches: How many physics events we collect.
    - μ averaged over all bunches: How bad is the pileup.
- σ_{vis} is unique to each luminometer and algorithm: measured in van der Meer scans.
- n_b and f_r are provided by the LHC.

Online Luminosity Monitoring Responsibilities

- **Detector Desks**:
  - Monitor the performance of the detectors up to and including the raw luminosity data they publish on the Information Service (IS).
    - Calorimeters Desk: LUCID, FCal, Tile, EMEC.
    - Inner Detector Desk: BCM, DBM, (Pixel, SCT and IBL for offline).
    - Trigger Desk: MBTS.
- **Run Control Desk**:
  - Monitors the luminosity infrastructure:
    - Luminosity data flow from detectors to luminosity online tools (OLC).
    - Archiving in COOL database for offline use (OLC2COOL).
- **Data Quality Desk**:
  - Monitors the content of the luminosity publications from the luminosity infrastructure and their internal consistency.

Luminosity: Which One?

- **Instantaneous Luminosity**:
  - $\mathcal{L}$ as previously defined.
  - Calculated by the Online Luminosity Calculator (OLC) for the shortest time interval possible for a particular detector.
  - Updates typically every 1-2 seconds for BCM and LUCID.
- **Luminosity Block (LB)**:
  - A short time period (Δt_{LB}, order ~ 1 min) defined by TDAQ during which LHC and ATLAS conditions are assumed constant, for which the average luminosity is calculated.
  - Smallest time granularity with which luminosity data is stored in COOL.
- **LB-averaged Instantaneous Luminosity**:
  - Instantaneous luminosity averaged over the duration of a LB ($\mathcal{L}_{\mathrm{LB}}$).
  - ***_all:** summed over all Bunch-Crossing IDentifiers (BCIDs).
  - ***_phys:** restricted to colliding bunches used for physics.
- **Integrated Luminosity**:

$$\int \mathcal{L} dt = \sum_{i}^{N} \mathcal{L}_{\mathrm{LB}_i} \Delta t_{\mathrm{LB}_i}, \qquad i \in \{\mathrm{run/fill}\}$$

Luminosity Algorithms

$\mathcal{L}$ is calculated in different ways:

- **Event Counting:** some luminometers determine if the activity from a given bunch crossing satisfies one of the following criteria:
  - **Event OR**: activity is detected in the A-side, C-side or both.
  - **Event AND**: coincident activity is detected in A and C sides.
- **Hit Counting:** some luminometers register "hits", the number of which is correlated with the number of p-p inelastic collisions μ:
  - Number of tracks (ID), pixel clusters (IBL, TPX, DBM) or vertices (ID), number of PMTs (LUCID).
- **Particle Flux:** some luminometers provide an observable that is proportional to the average number of p-p inelastic collisions μ:
  - Current drawn by Photo-Multiplier Tubes (PMT) (TileCal).
  - Current drawn in HV lines of LAr systems (EMEC, FCal).

Online Luminosity Detectors

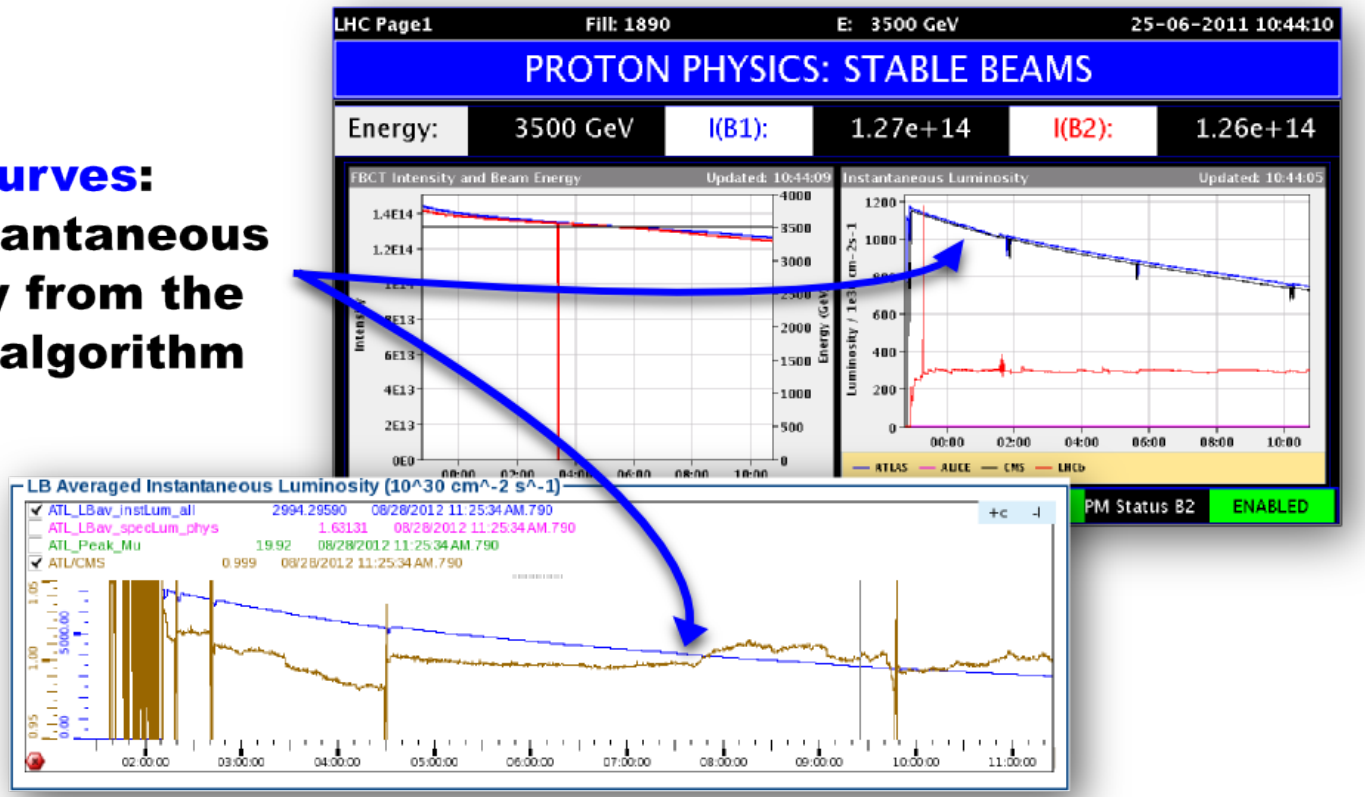
Black: At least partially commissioned **Grey:** no meaningful output yet

Device	Algorithms	Technology	BCID-aware	ACR Desk
BCM	Event counting	Diamond semi-conductors	•	ID
LUCID	Event (Hit) counting Particle flux	Cerenkov quartz windows + PMTs	•	Calo
FCAL	Particle flux	LAr under HV		Calo
MBTS	Event counting	Scintillators + PMTs	•	Trigger
TILE	Particle flux	Scintillator tiles + PMTs		Calo
EMEC	Particle flux	LAr under HV		Calo
TPX	Cluster counting	Hybrid pixel		(TBD)
DBM	Event counting Cluster counting Track counting	Diamond pixels	•	ID

- **Preferred Algorithm**: **The one luminosity value that is:**
  - distributed to ATLAS as a whole (public plots, trigger prescales, etc.),
  - sent to LHC page 1,
  - Typically used for a first pass of physics analysis,
  - The focus of the DQ shifter.

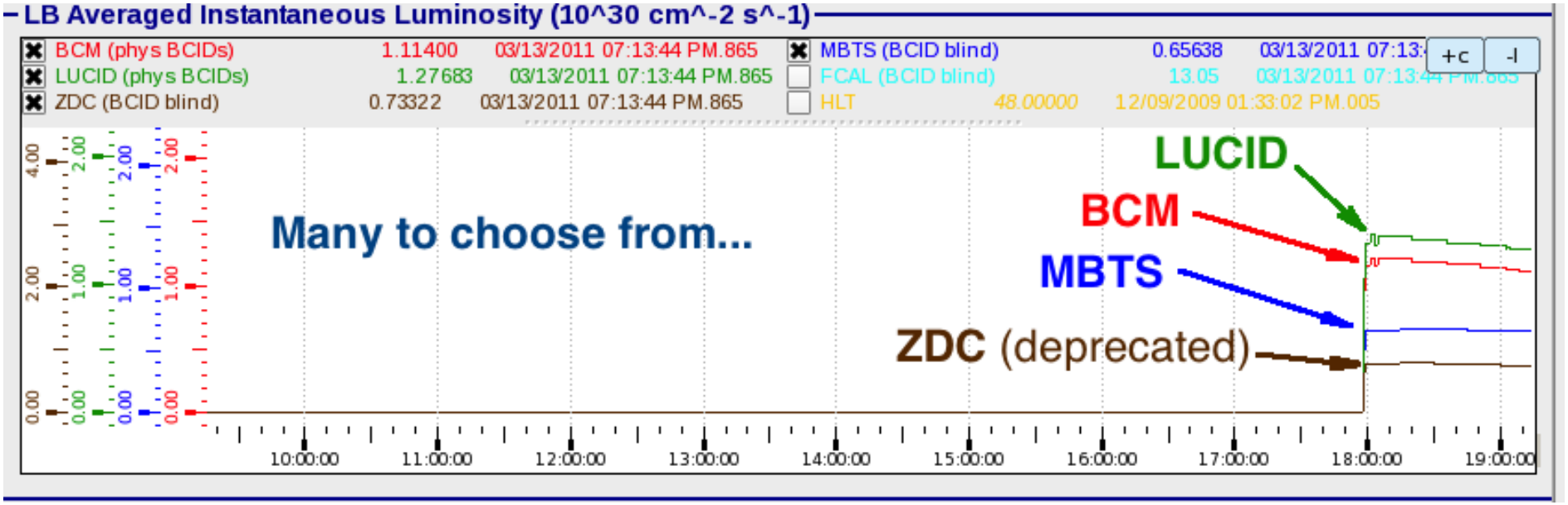
LHC Page 1

Blue curves:
ATLAS instantaneous luminosity from the preferred algorithm



ATLAS DCS Display

Preferred Algorithm for Run II start



- **The current preferred algorithm is BCMTOR.**
  - It's an OR of all 8 BCM sensors.
  - Maximizing acceptance for first collisions.

- **Right now:**
  - The BCM publishes what it currently measures.
  - The absolute scale may be off, but relative changes are meaningful.

Current Luminosity Monitoring Goals

- **Exercise the online $\mathcal{L}$: stability? problems?**
  - The software in the OLC partition is constantly evolving: testing stability is always a concern.
  - Some Luminosity DCS panels are also evolving: make sure the correct data make it to the displays.
- **Develop/exercise the DQ shifter tasks:**
  - Find out how to make you guys more effective shifters: expand documentation, render instructions unambiguous.
  - Currently in the process of updating ALL luminosity online monitoring documentation, all of which will become gradually accessible through the new Luminosity and Beam Conditions Whiteboard.

What We Want From the DQ Shifters

- Read the first section of the Luminosity Whiteboard at the start of shift.
- Keep an eye on the **luminosity values coming from the preferred algorithm**.
- Keep an eye on the **luminosity infrastructure monitoring plots**.
- Keep an eye on **luminosity FSM alarms**.
- **Be aware of interventions by experts:** elogs, phone calls, drop-in visits in the control room, etc.
- DQ shifters: attend tomorrow's dedicated DQ session at the filtration plant.

Locating the Luminosity Plots

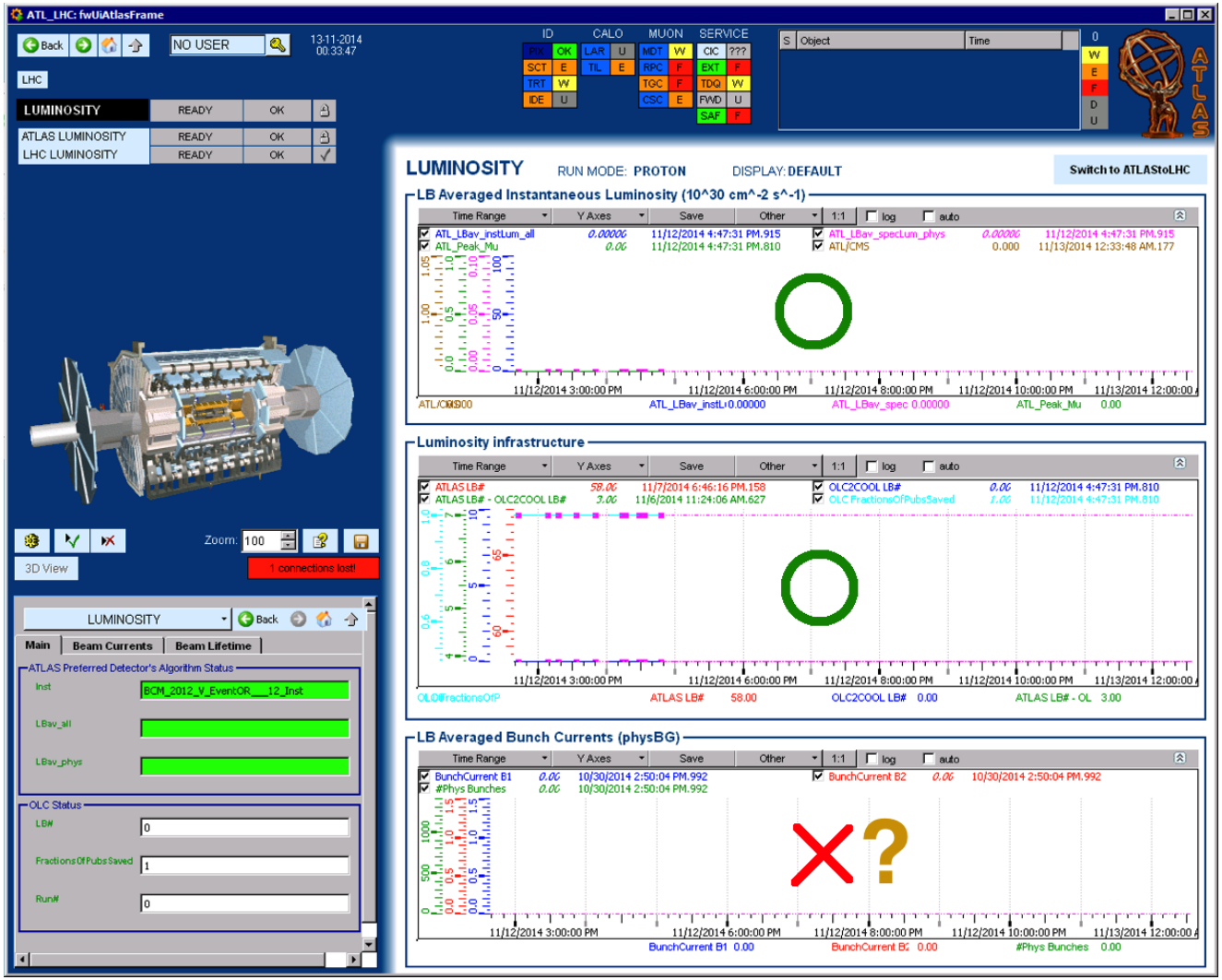
Finding the FSM display:

KDE Panel
↳LHC
↳LHC FSM Screen

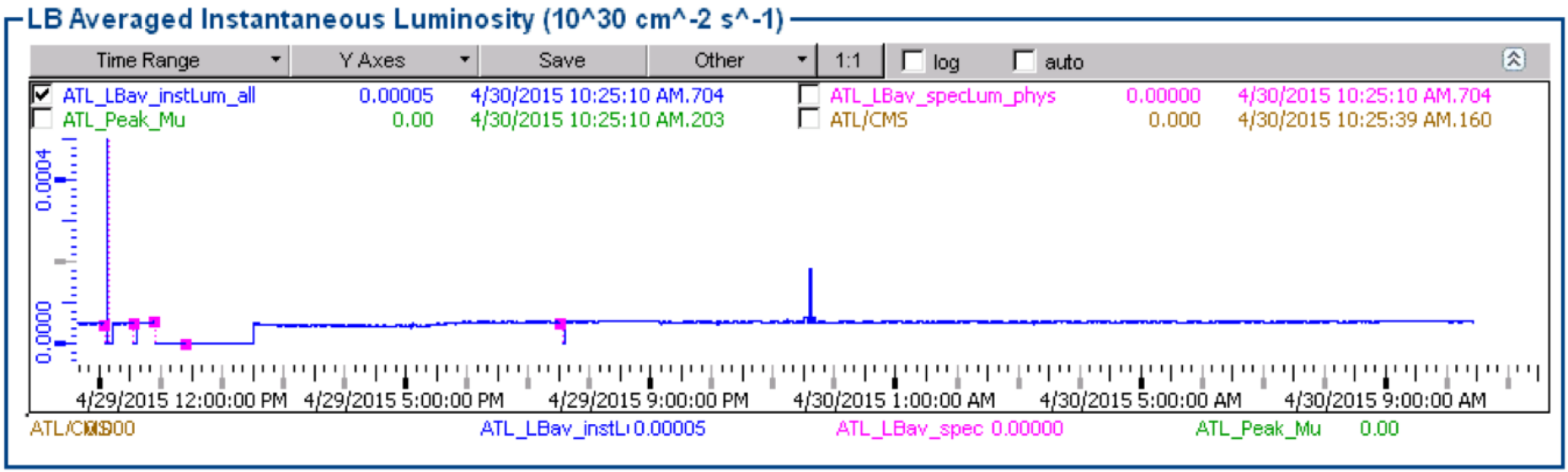
Finding the lumi plots:

Top left of FSM, go to:
↳LHC
↳LUMINOSITY

For M9:
Green: Look
Red: Don't look



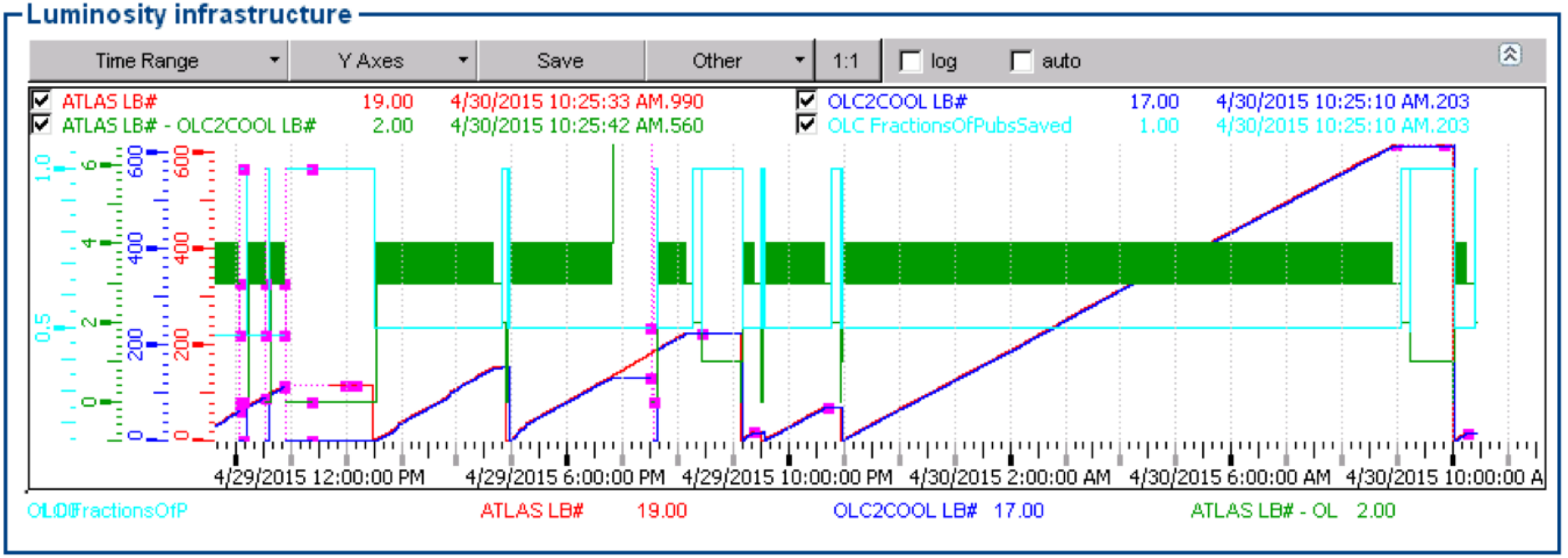
LB Average Instantaneous Luminosity



- **ATL_LBAv_instLum_all**: LB-averaged instantaneous luminosity from the preferred algorithm.
- This time series artificially flattens when ATLAS is not running (LBs are not issued).

Disclaimer These plots may look different due to changing conditions/testing from experts.

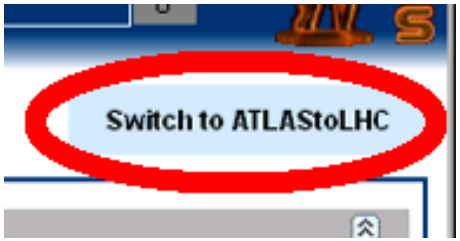
Luminosity Infrastructure



- **OLC2COOL LB#**: The LB last archived by OLC2COOL. Should increase linearly with time.
- **ATLAS LB# - OLC2COOL LB#**: The difference between the LB just issued by ATLAS and the one last archived by OLC2COOL. It should be no bigger than 5.
- **OLC FractionsOfPubsSaved**: Fraction of OLC publications saved. It is currently 0.45 when things are normal, but the normal will change. Instantaneous dips may occur.

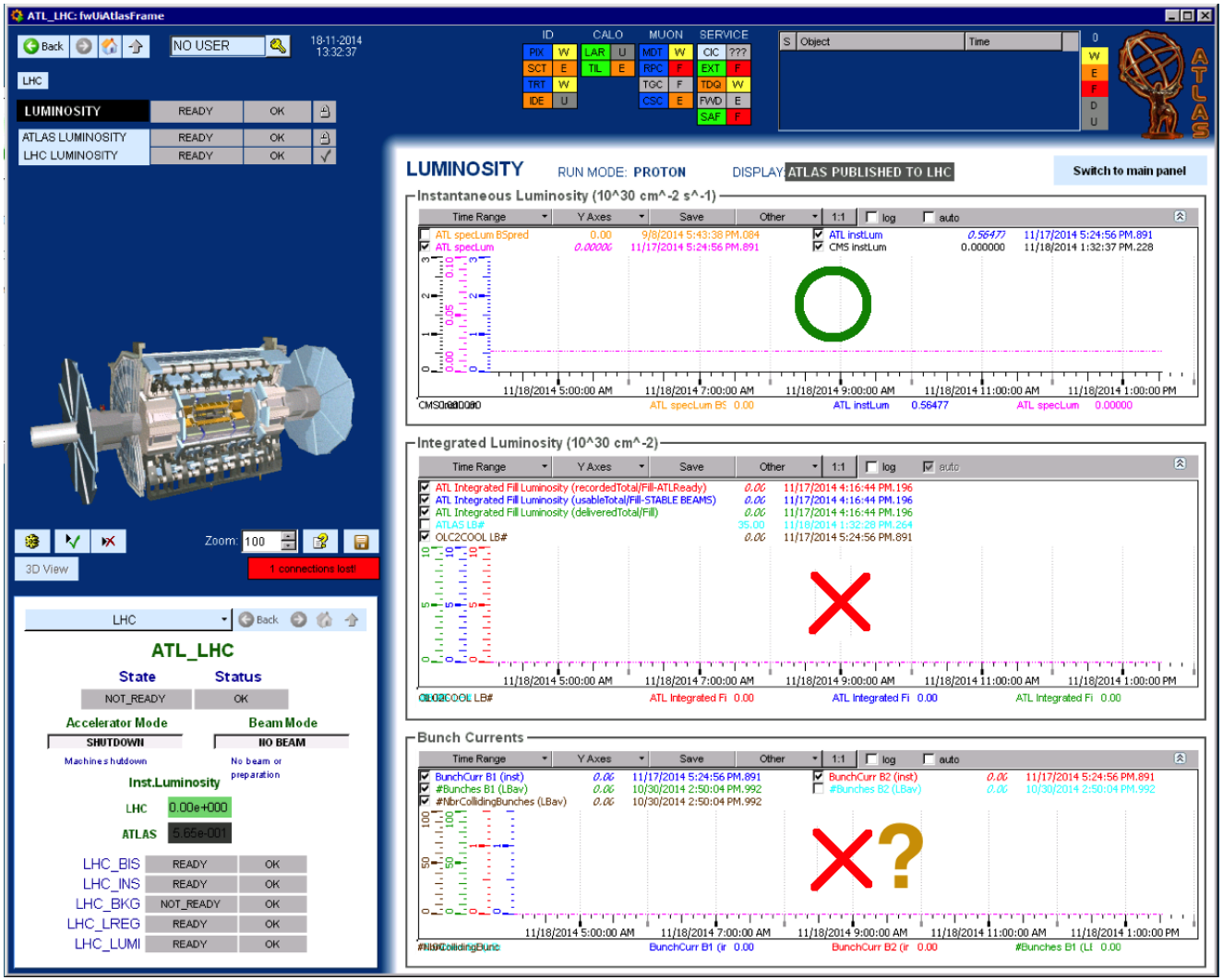
Disclaimer These plots may look different due to changing conditions/testing from experts.

Instantaneous Luminosity Plots

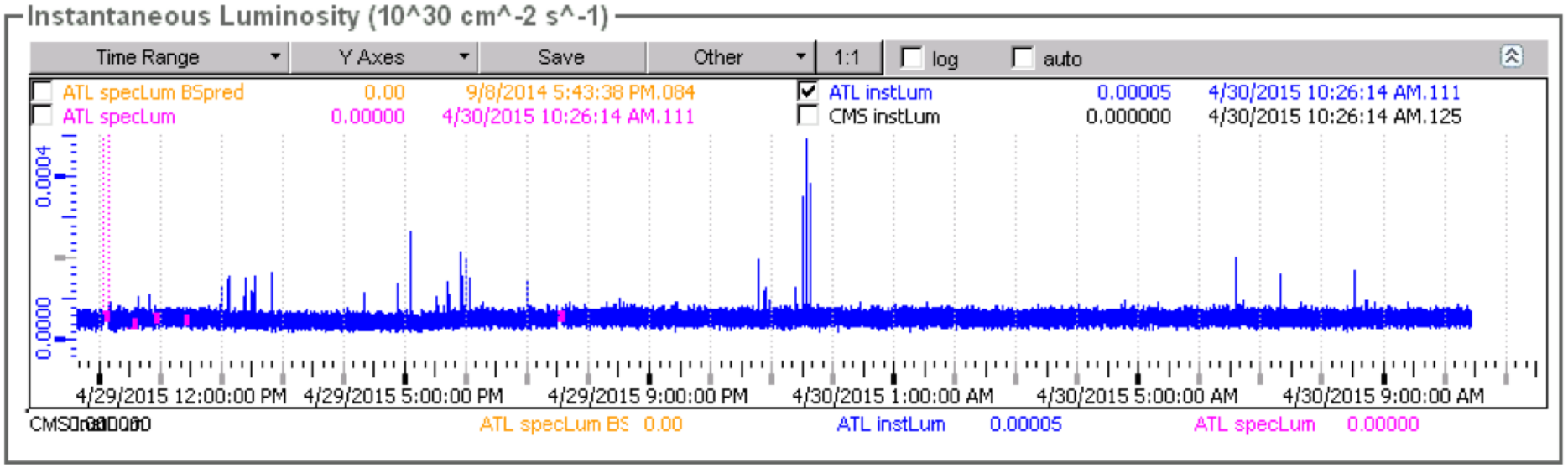


Click here to see plots of instantaneous and integrated luminosity

For M9:
Green: Look
Red: Don't look



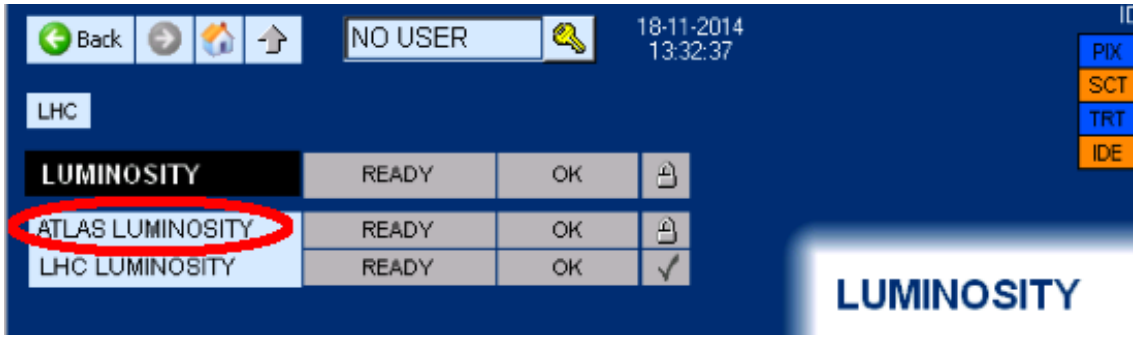
Instantaneous Luminosity



- **ATL instLum**: ATLAS preferred instantaneous luminosity.
- The time serires should be uninterrupted as long as OLC runs: independent of LBs.

Disclaimer These plots may look different due to changing conditions/testing from experts.

One More Plot Under ATLAS LUMINOSITY



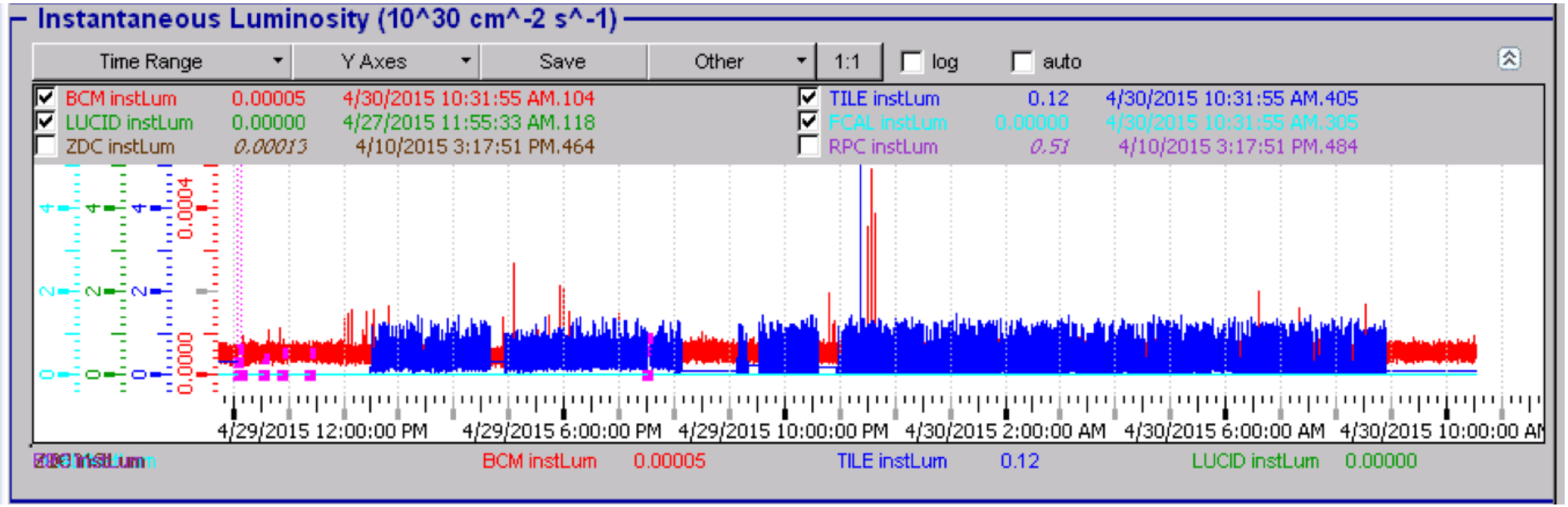
Look at Instantaneous Luminosity under:

FSM
- ↳**LHC**
  - ↳**LUMINOSITY**
    - ↳**ATLAS LUMINOSITY**

Currently:

- **BCM:** measuring noise.
- **LUCID:** hits from radioactive source or measuring noise (depends on progress by experts).
- **TILE & FCAL:** measuring noise.

Instantaneous Luminosity



- **BCM instLum**: Instantaneous luminosity as measured by BCM.
- **LUCID instLum**: Instantaneous luminosity as measured by LUCID (no reading on this plot).
- **TILE instLum** & **FCAL instLum**: same.

Disclaimer These example plots show what things looked like in M7. M9 plots may differ.

What to Expect in the Near Future

- Beams present, but no collisions (**yet:** next week)
- BCM is operational, measuring noise (unless tests are conducted).
- LUCID is operational, but a few displays are still absent: should be fixed soon.
- TILE & FCAL are operational.
- All plots using the physics bunches (LB_phys) will be empty, as the physics bunch group will not be defined **until we get collisions**.

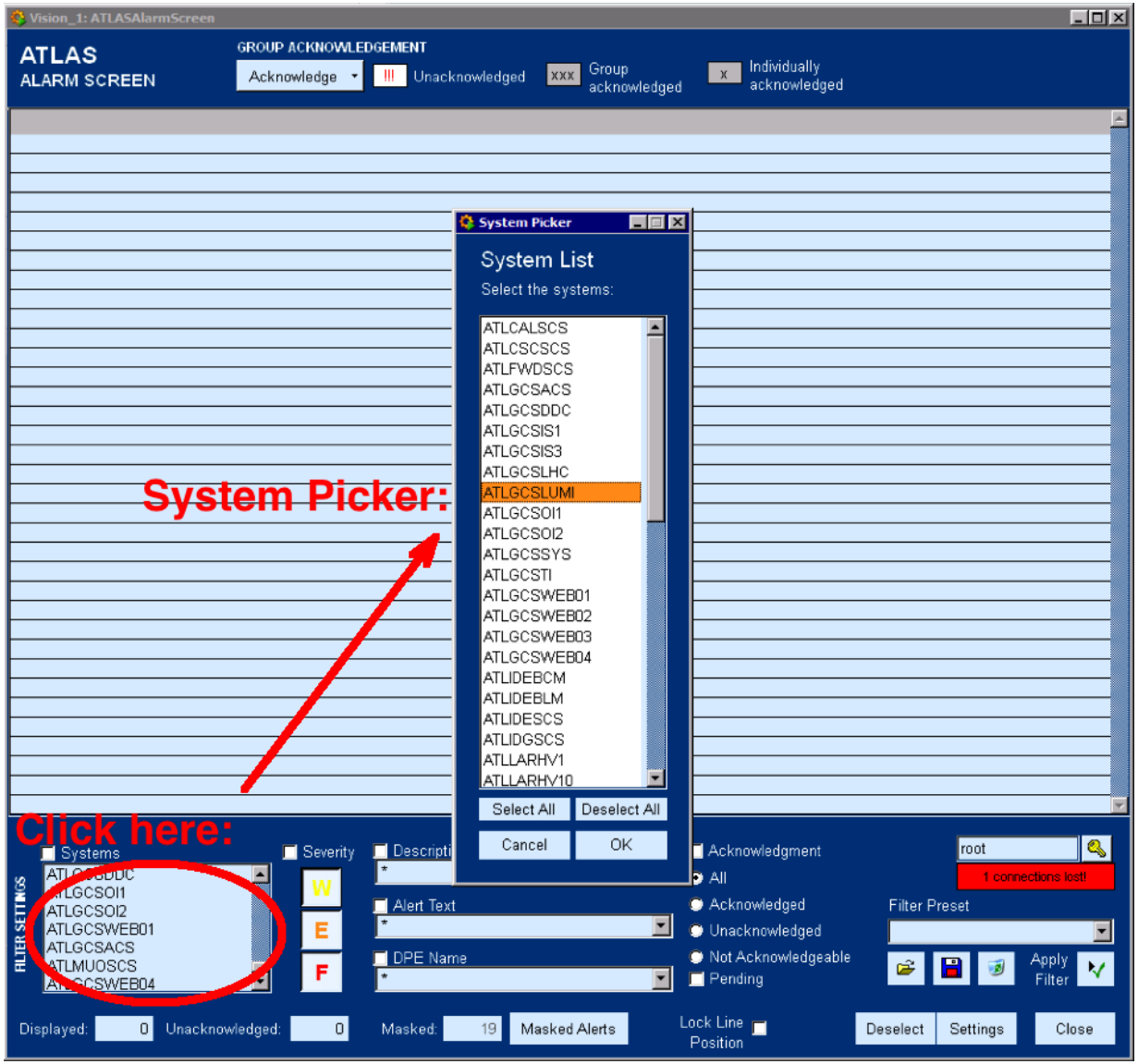
Loading the Alarm Screen

Finding the alarm screen:

KDE Panel
↳LHC
↳LHC Alarm Screen

Alarms to focus on:

- Click on the systems dialog box to open the system picker,
- Deselect All,
- click on ATLGCSLUMI,
- click OK,
- click Apply Filter.

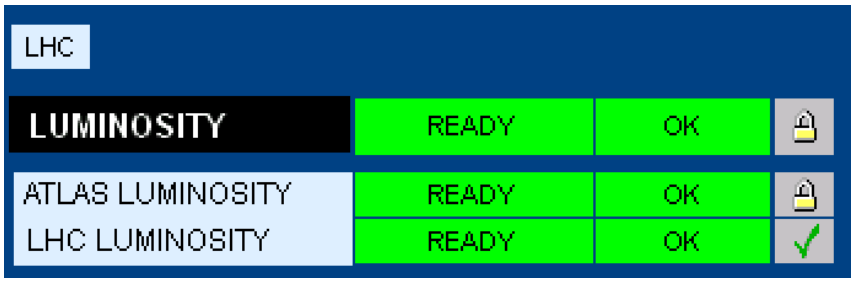


Reporting problems

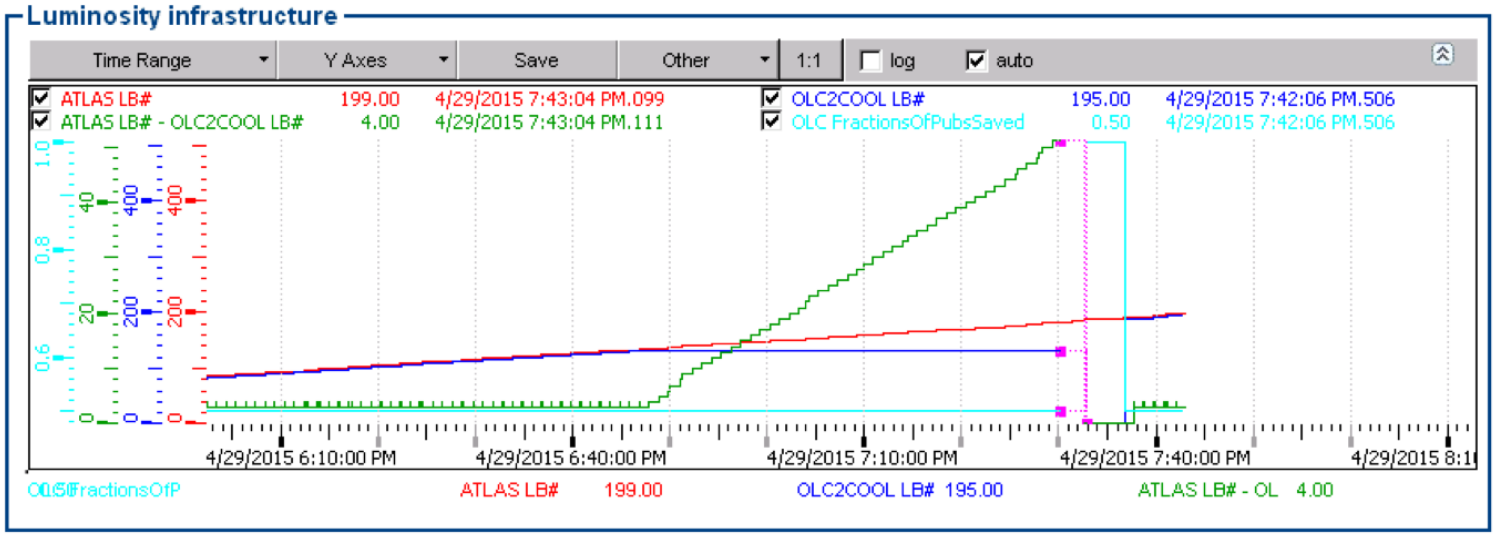
72299

- Check the FSM Alarm Screen regularly.
- Report persistent alarms (WARNING, ERROR, FATAL) to the shift leader.
- Document in elog in a timely manner: one elog per alarm, or group of alarms. **Tick"BeamConditions" in "System Affected"!** This way, luminosity experts get an instant email notification.
- If it looks like there is anything wrong with the luminosity infrastructure: call the luminosity on-call expert.
- **If something seems abnormal in a plot, and no alarm is issued: also document in elog and call the expert**).

Make sure everything says "**READY**" & "**OK**" when the ATLAS partition is **RUNNING** (or at least CONFIGURED).



Problem Case Study (fresh from yesterday)



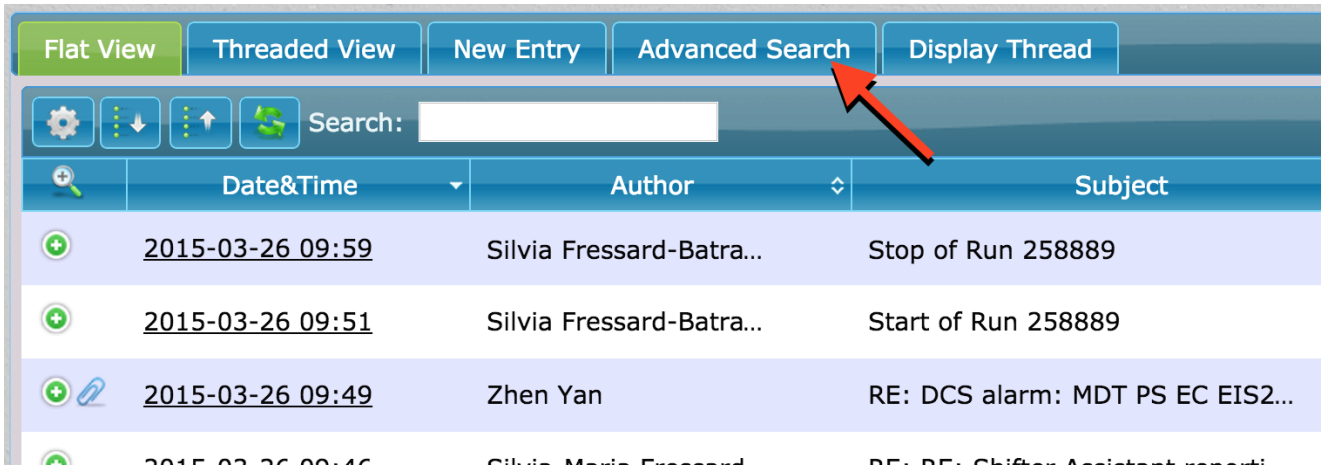
- **FATAL Alarm** was noticed by the DQ Shifter: ATLGCSLUMI:LumiBlockDifference.value : LHC LuminosityAtlasOlc2CollLBDifference : Lumi Infra crashed.
- This is seen in the plot as the OLC2COOL LB# flat-lining.
- The source of the problem was the occurence of a NaN value instead of an expected float: fundamental problem with the code that needs to be fixed.
- The shifter told the shift leader (good!).
- The shift leader called me (good, could also have been the shifter directly).
- I posted an elog (should have been an elog from the shifter as well).
- The DQ shifter mentioned the occurence in the DQ shift report (good!).

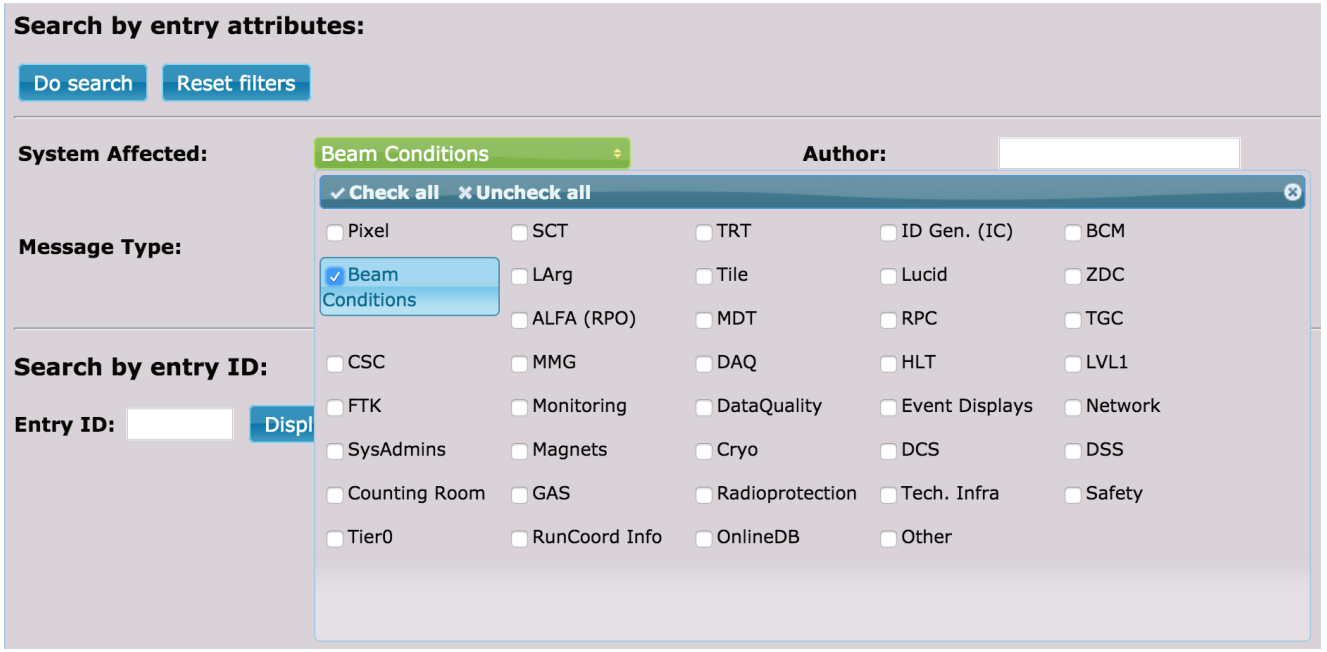
Problem Case Study 2

- **No Alarm issued:** The BCM publications stopped arriving the displays (dashed line) around 5AM.
- The shifter reported it in the DQ shift summary (OK but largely insufficient).
- The shifter didn't want to call during uncivilized hours, as requested by us at the time (OK).
- The shifter didn't produce a dedicated elog entry with "Beam Conditions" ticked under System Affected (not good).
- The shifter only told us the next day that the publications were still missing (I should look at the displays twice a day).
- We we have been taking collision data, we would have missed over 24h of BCM data, which renders luminosity analysis extremely difficult.
- **This is the kind of situation we need to avoid**.
- **In case of doubt, it's better to call the on-call expert, tell the shift leader and post an elog than not do it**.

Finding Elogs About Expert Interventions

- Go to Elisa
- Go to **Advanced Search**
- Select **Beam Conditions** under System Affected
- Click **Do Search**
- Pay special attention to Date&Time to focus on relevant entries
- You'll come to identify the relevant experts with time





Phone Numbers and Links

Role	Name	Phone
On-call Expert (call first)	(currently me)	**72299**
Luminosity Run Coordinator	Michel Trottier-McDonald	167296
Online Luminosity Software Expert	Houry Keoshkerian	167404
Luminosity Convenor (last resort)	Witold Kozanecki	162382

Page	Link
Lumi Whiteboard	.../twiki/bin/view/Main/BeamConditionsWhiteboardRunII
DQ shifter main page	https://atlasop.cern.ch/twiki/bin/view/Main/DQManualShifter
M7/M8/M9 Lumi twiki	https://atlasop.cern.ch/twiki/bin/view/Main/LumiDQRunII...
Lumi DCS Plots (old)	https://atlasop.cern.ch/twiki/bin/view/Main/LumiOnlineDQ
Lumi DCS Alarms (old)	https://atlasop.cern.ch/twiki/bin/view/DcsHelp/DcsLhcAlarms
Elog (ElisA)	https://atlasop.cern.ch/elisa/

Backup Material

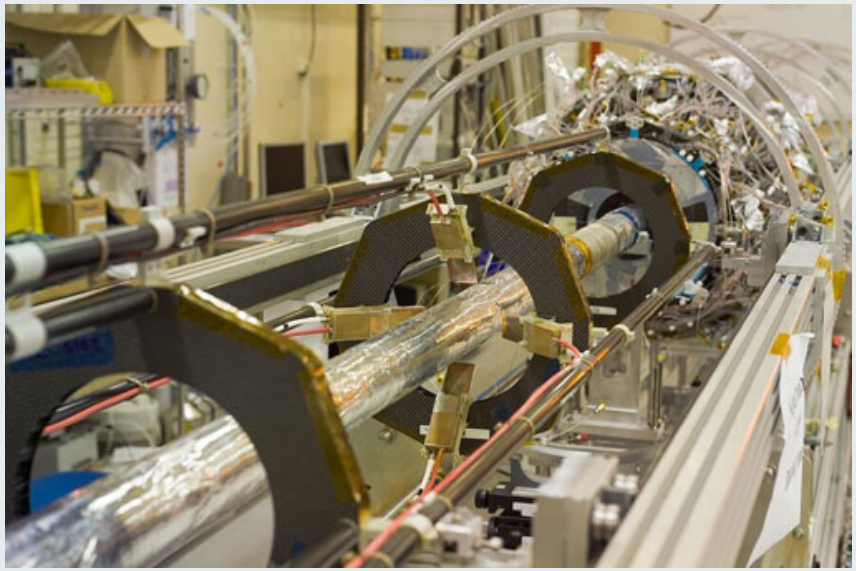
More Luminosities...

- **Specific Luminosity**:
  - The luminosity per bunch per unit bunch population,
  - inversely proportional to $\Sigma_x \Sigma_y$, the beam width along the x and y axes respectively:

$$\mathcal{L}_{\text{spec}} = \frac{\mathcal{L}_b}{n_1 n_2} = \frac{f_r}{2\pi \Sigma_x \Sigma_y},$$

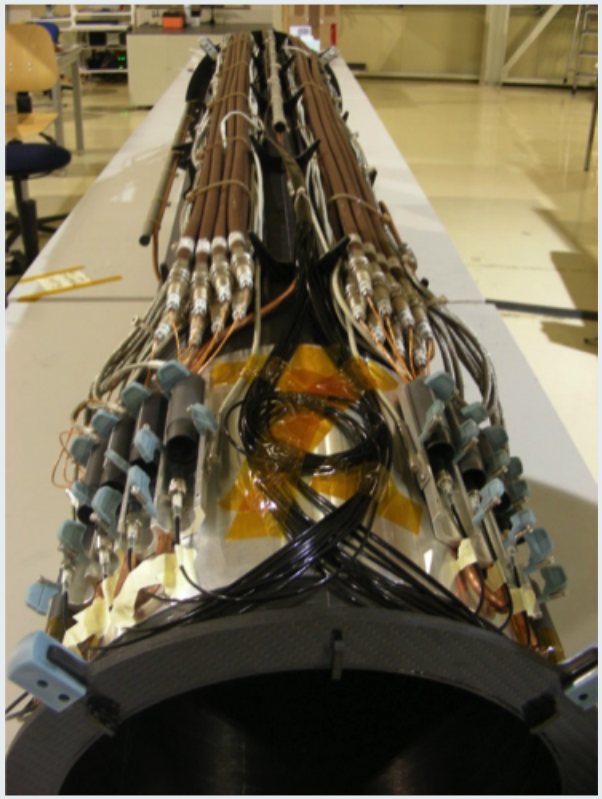
  $\mathcal{L}_b$ being the bunch luminosity.

Beam Conditions Monitor (BCM)



- **Main role:** Provide baseline luminosity for most of Run I (and start of Run II), protect the inner detector from dangerous beam conditions.
- **Technology:** Diamond semi-conductors.
- **Configuration:** 4 sensors on each side of ATLAS, close to the beamline.
- **Highlights:** Fast response time, designed to quickly abort the beams. Redundant measurements (vertical/horizontal A/C sides).
- **Sampling/Time resolution:** Every BCID, 0.7 ns resolution.

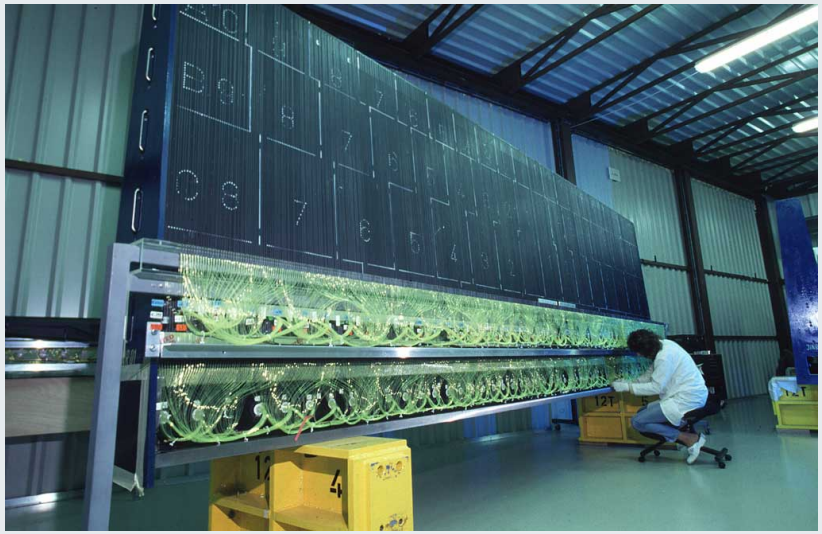
LUCID



- **Main role:** Luminosity Measurement.
- **Technology:** Cherenkov emitting quartz windows connect to PMTs.
- **Configuration:** 16 PMTs on each side of ATLAS, 17m from the IP.
- **Highlights:** Fast and high redundancy (each PMT read out individually). Capable of event and hit counting as well as and particle flux measurements.

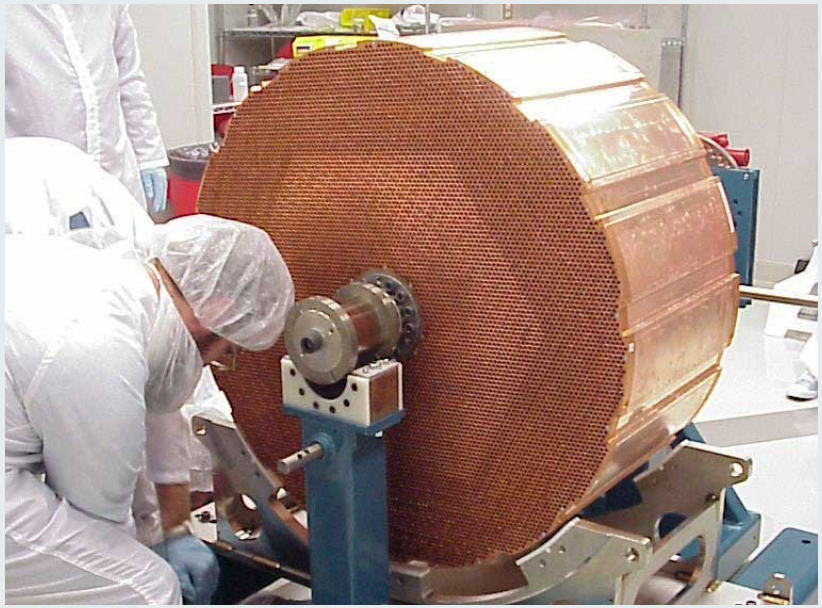
- **Sampling/Time resolution:** Every BCID.
- Major upgrades for Run II: new calibration, more redundant measurements, reduced acceptance.

Tile Calorimeter



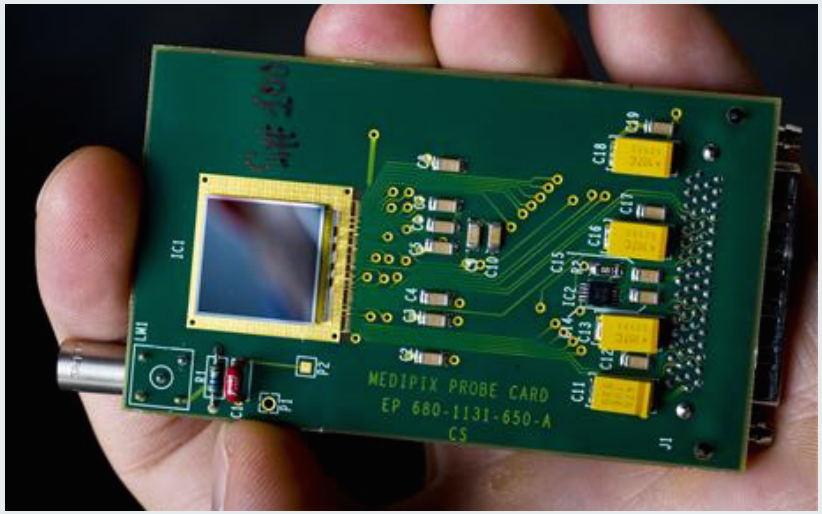
- **Technology:** Scintillator tiles connected to PMTs.
- **Highlights:** Particle flux measurement, far from beamline.
- **Sampling/Time resolution:** bunch-integrated response every few seconds.

EMEC and FCal



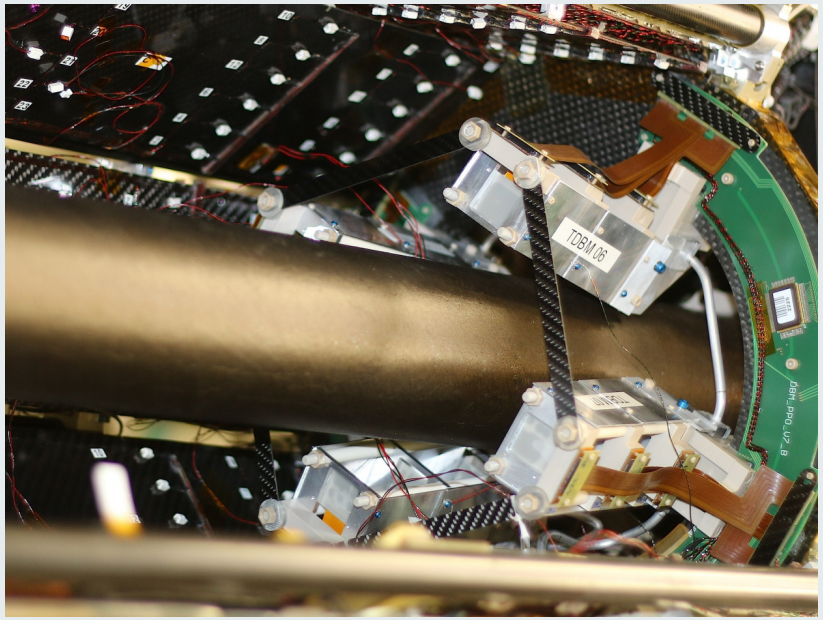
- **Technology:** Liquid argon gaps between electrodes under HV.
- **Highlights:** Particle flux measurement, closer to beamline.
- **Sampling/Time resolution:** bunch-integrated response every few seconds.

TimePix (TPX)



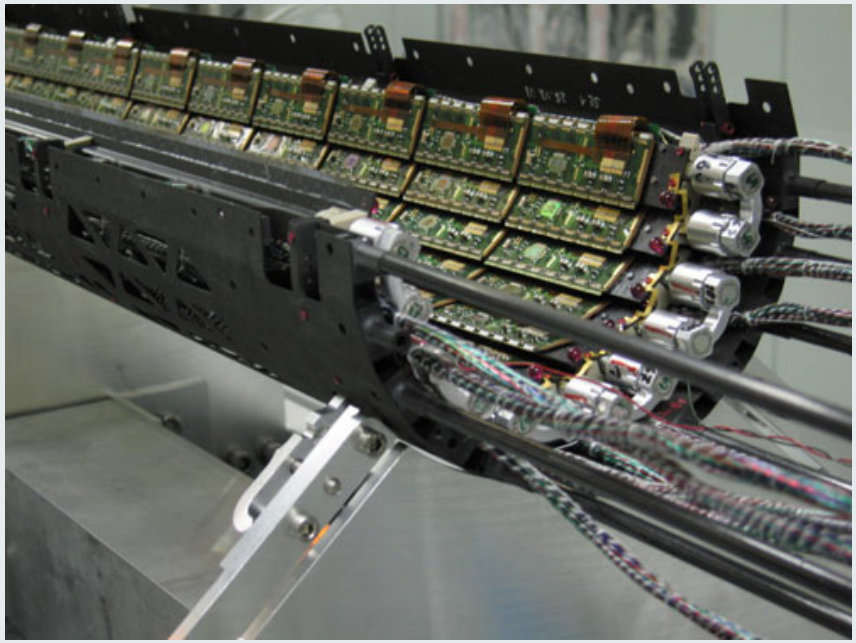
- **Technology:** Hybrid pixel detector.
- **Highlights:** pixel cluster counting, standalone DAQ.
- **Sampling/Time resolution:** bunch-integrated response every few seconds.

Diamond Beam Monitor (DBM)



- **Technology:** 8 Diamond pixel telescopes near IP.
- **Highlights:** Good redundancy, many types of measurements.
- **Sampling/Time resolution:** Individual BCIDs (dead-time).

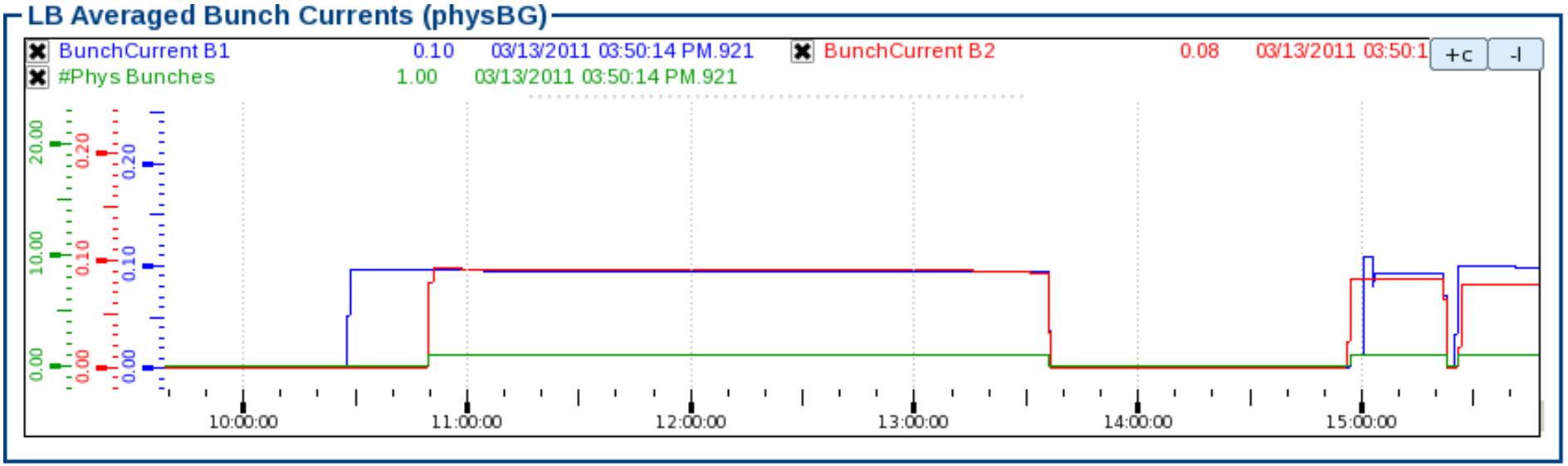
Inner Detector



- **Main role:** Reconstruct charged particle tracks.
- **Technology:** Silicon pixels and strips.
- **Configuration:** barrel and endcap geometry, surrounds IP.

- **Highlights:** Can reconstruct pixel clusters, tracks and vertices.
- **Sampling/Time resolution:** Trigger-bound BCIDs.
- Addition of IBL for run II, closest layer to IP with unique readout capabilities.

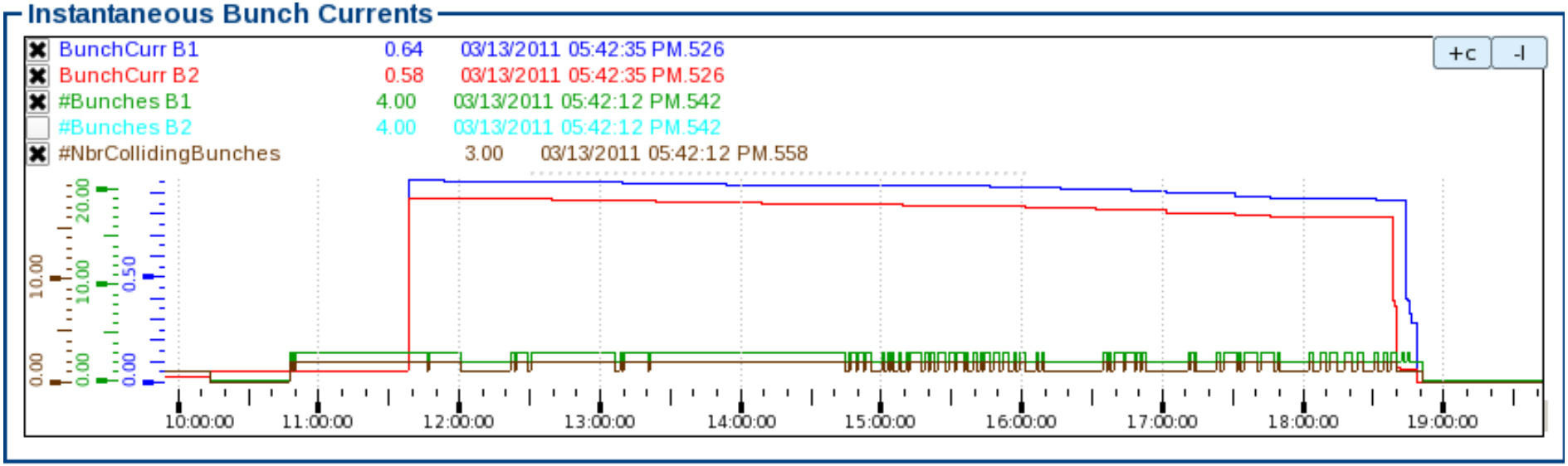
LB Average Bunch Currents (physBG)



- **BunchCurrent B1**: Beam 1 bunch current.
- **BunchCurrent B2**: Beam 2 bunch current.
- **#Phys Bunches**: Number of bunches in the physics bunch group.

Disclaimer These example plots show physics conditions. They won't look like this during M8.

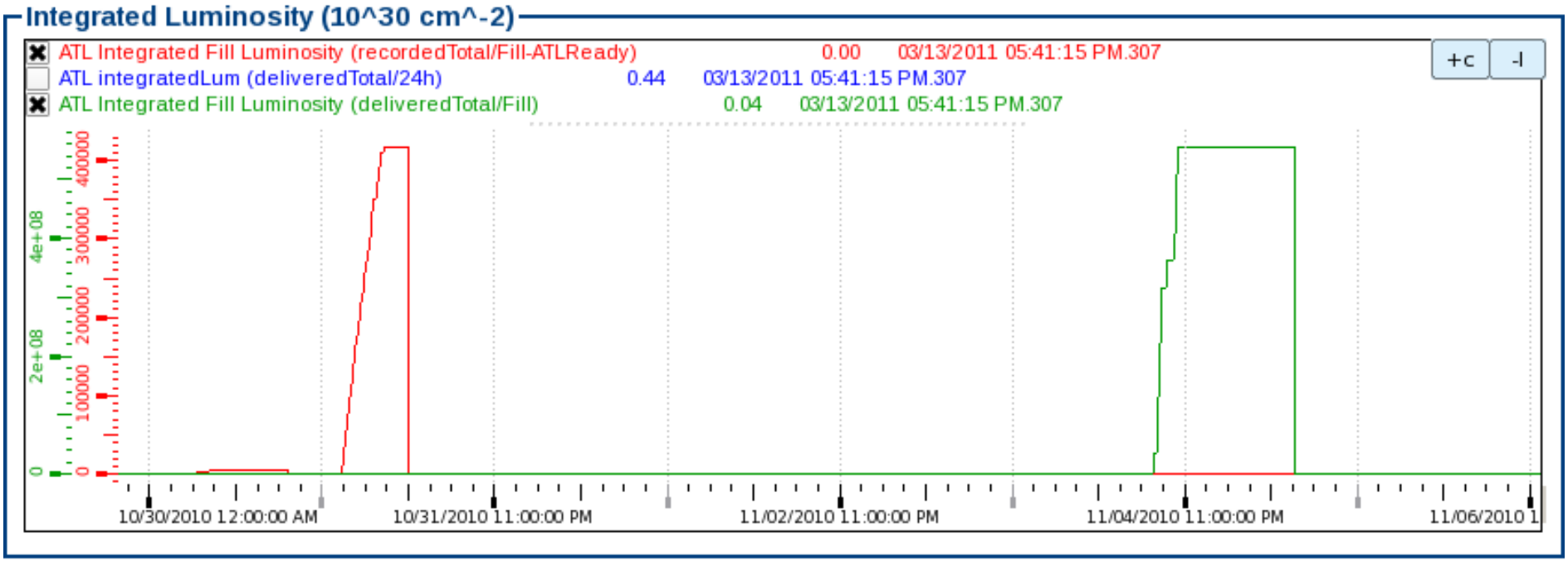
Instantaneous Bunch Currents



- **BunchCurr B1**: Bunch current for beam 1.
- **BunchCurr B2**: Bunch current for beam 2.
- **# Bunches 1**: Number of bunches in beam 1.
- **# Bunches 2**: Number of bunches in beam 2.
- **# NbrCollidingBunches**: Number of colliding bunches.

Disclaimer These example plots show physics conditions. They won't look like this during M8.

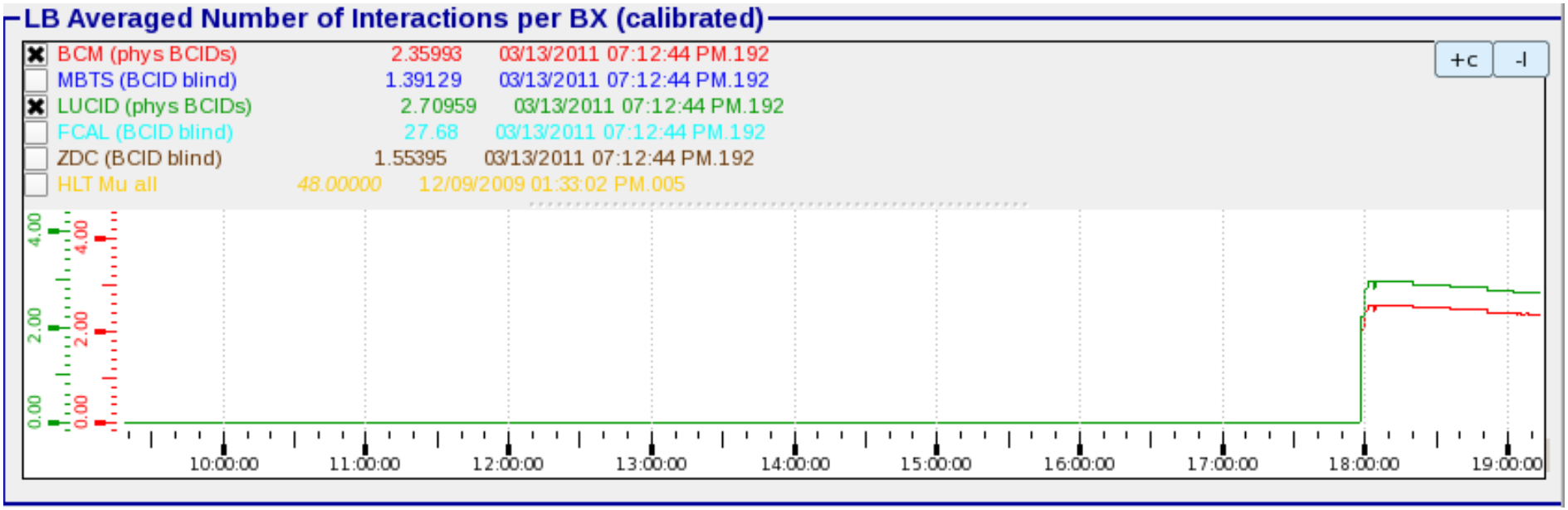
Integrated Luminosity



- **ATL Integrated Fill Luminosity (recordedTotal/Fill-ATLReady)**: ATLAS preferred integrated luminosity for an LHC fill during the time ATLAS was ready for physics.
- **ATL Integrated Fill Luminosity (deliveredTotal/Fill)**: ATLAS preferred integrated luminosity for a complete LHC fill.

Disclaimer These example plots show physics conditions. They won't look like this during M8.

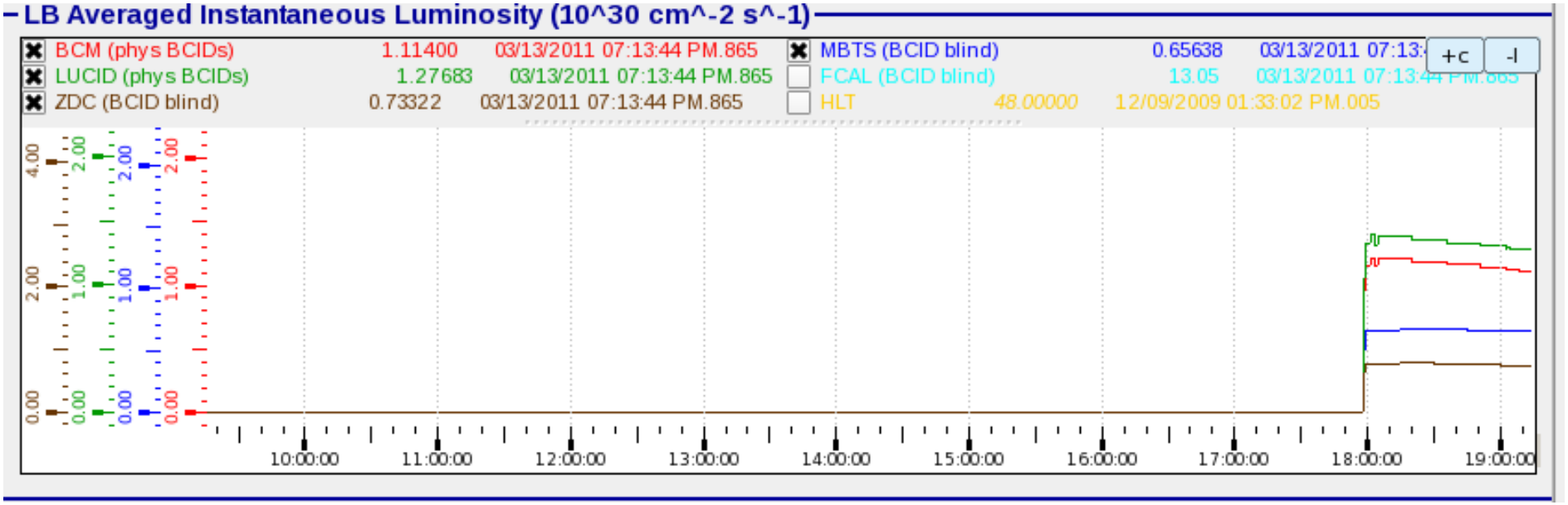
LB Averaged Number of Interactions per BX



- **BCM (phys BCIDs)**: LB-averaged number of interactions (μ) measured by BCM over colliding BCIDs (phys).
- **LUCID (phys BCIDs)**: LB-averaged number of interactions (μ) measured by LUCID over colliding BCIDs (phys).

Disclaimer These example plots show physics conditions. They won't look like this during M7.

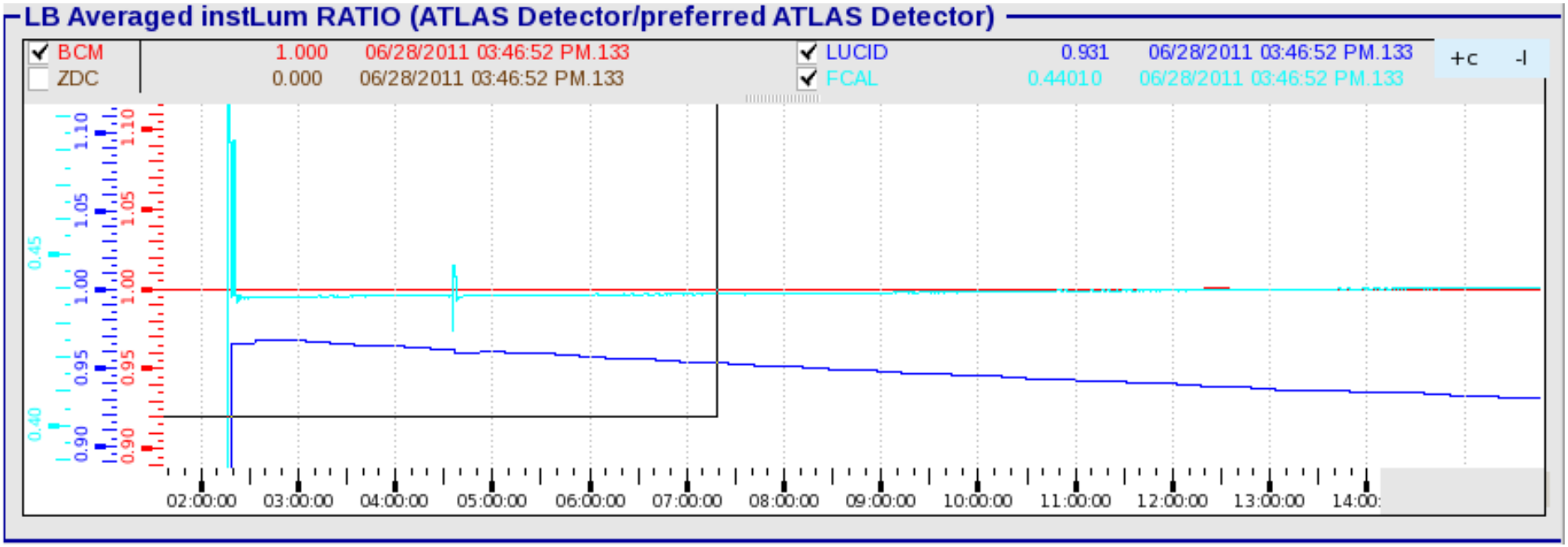
LB Averaged Instantaneous Luminosity



- **BCM instLum**: LB-averaged instantaneous luminosity as measured by BCM over colliding BCIDs (phys).
- **LUCID instLum**: LB-averaged instantaneous luminosity as measured by LUCID over colliding BCIDs (phys).

Disclaimer These example plots show physics conditions. They won't look like this during M8.

LB Averaged InstLum RATIO



- **BCM instLum**: BCM over ATLAS preferred (should be 1, since BCM is ATLAS preferred).
- **LUCID instLum**: LUCID over ATLAS preferred.

Disclaimer These example plots show physics conditions. They won't look like this during M8.