RPC 2018 - Puerto Vallarta - 2018.02.19

Performance of the ATLAS RPC Level-1 Muon trigger during the LHC Run-II data taking

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ATLAS RPCs and L1 Barrel Trigger

- RPCs are used in ATLAS as **trigger chambers** in the **barrel region** |η|<1.05

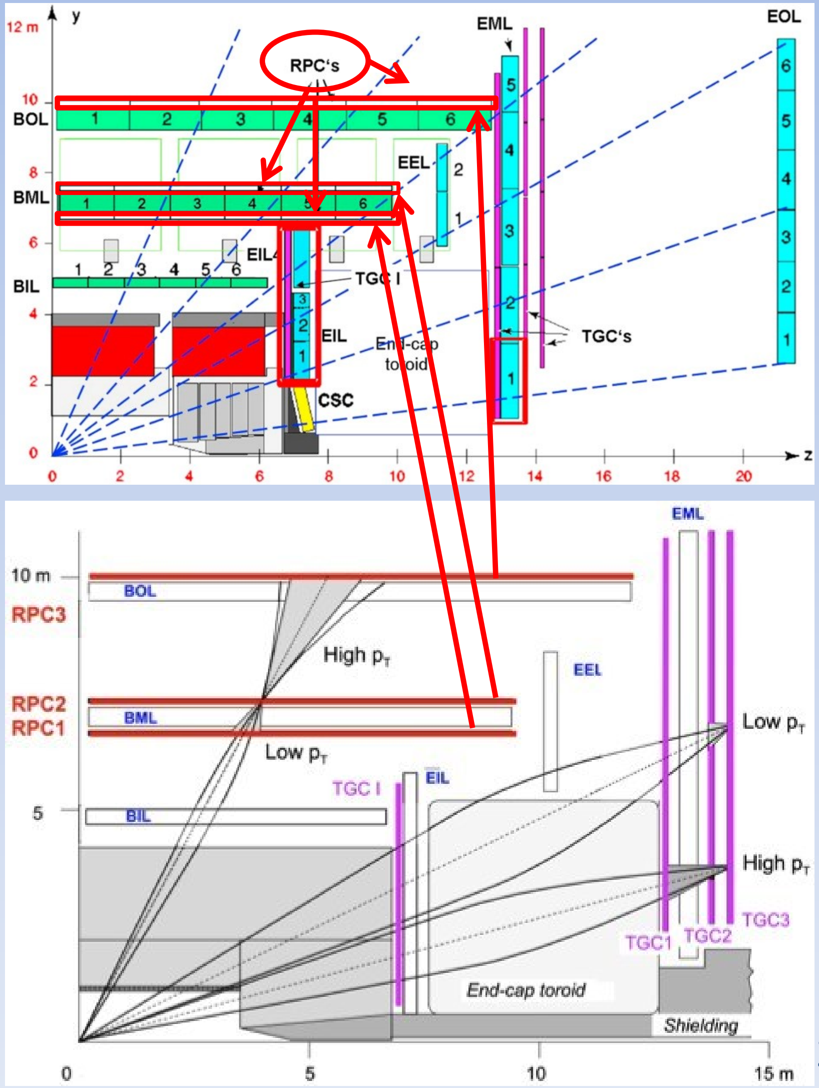
- **Trigger from coincidences of stations** formed by **double - layers** of RPCs.

- Each **gas gap** (standard 2mm) is read out with orthogonal **η and φ strips** pitch 2.3 - 3.5 cm.

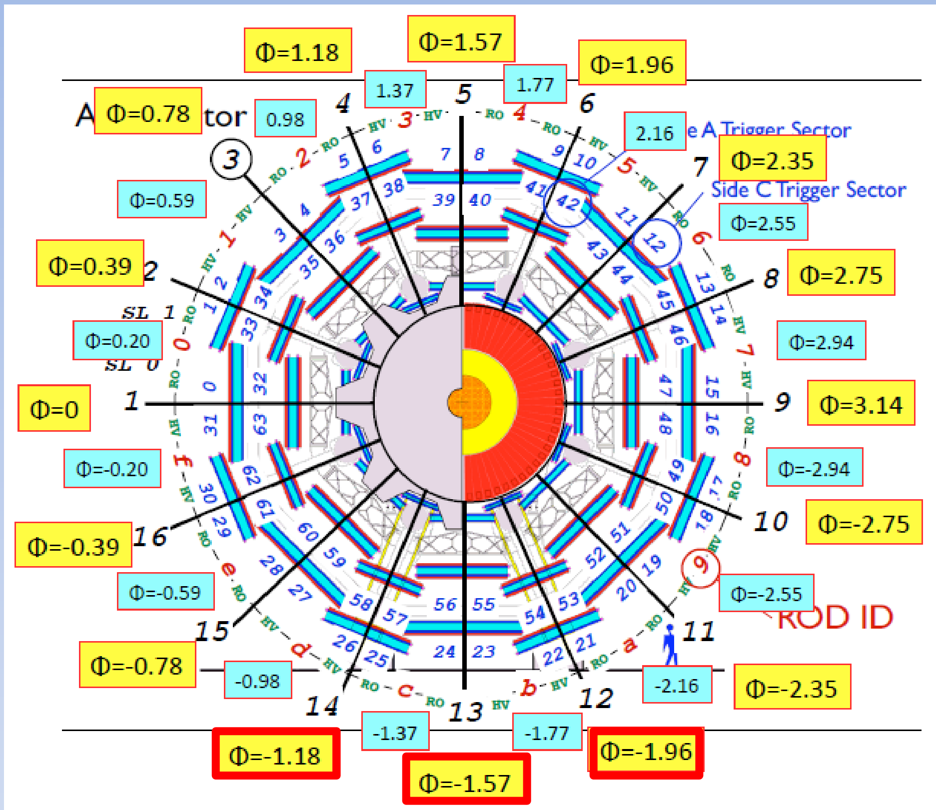
Two kind of triggers:

- **Low-p_T** projective **coincidence** of **2 stations**
  pivot (RPC2) and middle confirm (RPC1)
  p_T thresholds between 4 and 10 GeV
  multi-object signatures

- **High-p_T** projective **coincidence** of **3 stations**
  low-p_T trigger + outer confirm (RPC3)
  p_T thresholds between 11 and 20 GeV
  single muon signatures



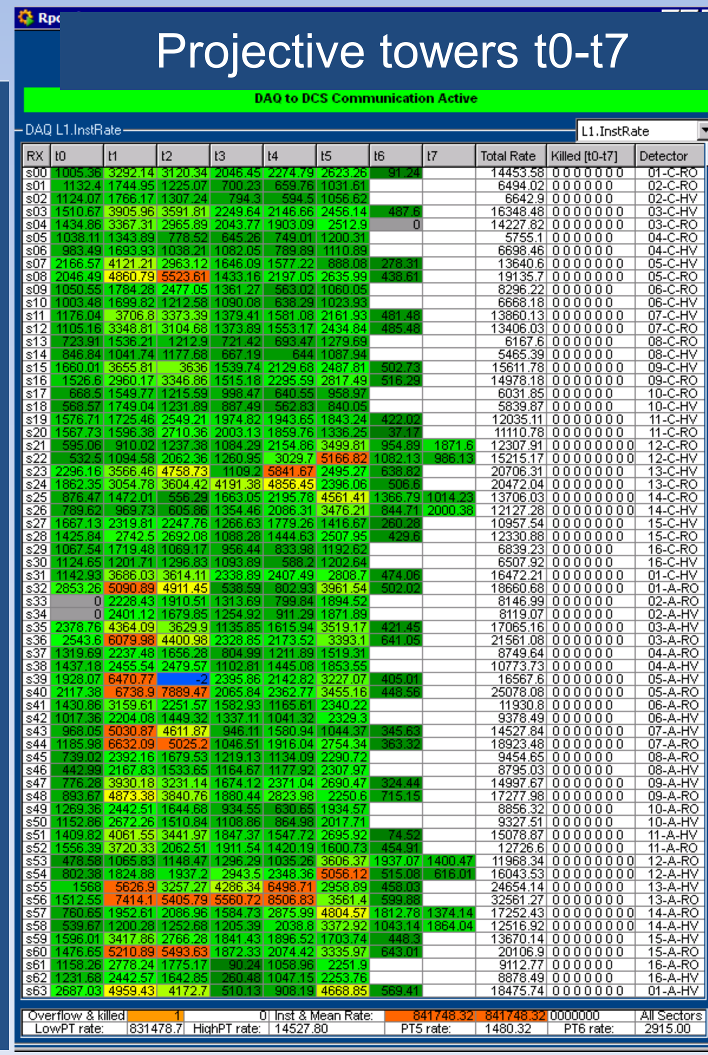
Level-1 Barrel Trigger



Trigger rates online monitor

Projective towers t0-t7

Trigger sector s00-s63



DAQ to DCS Communication Active

DAQ L1.InstRate — L1.InstRate

RX	t0	t1	t2	t3	t4	t5	t6	t7	Total Rate	Killed [t0-t7]	Detector
s00	1005.36	3292.14	3120.34	2046.45	2274.79	2623.26	91.24		14453.58	0 0 0 0 0 0 0	01-C-RO
s01	1132.4	1744.95	1225.07	700.23	659.76	1031.61			6494.02	0 0 0 0 0 0	02-C-RO
s02	1124.07	1766.17	1307.24	794.3	594.5	1056.62			6642.9	0 0 0 0 0 0	02-C-HV
s03	1510.67	3905.96	3591.81	2249.64	2146.66	2456.14	487.6		16348.48	0 0 0 0 0 0 0	03-C-HV
s04	1434.86	3367.31	2965.89	2043.77	1903.09	2512.9	0		14227.82	0 0 0 0 0 0 0	03-C-RO
s05	1038.11	1343.89	778.52	645.26	749.01	1200.31			5755.1	0 0 0 0 0 0	04-C-RO
s06	983.49	1693.93	1038.21	1082.05	789.89	1110.89			6698.46	0 0 0 0 0 0	04-C-HV
s07	2166.57	4121.21	2963.12	1646.09	1577.22	888.08	278.31		13640.6	0 0 0 0 0 0 0	05-C-HV
s08	2046.49	4860.79	5523.61	1433.16	2197.05	2635.99	438.61		19135.7	0 0 0 0 0 0 0	05-C-RO
s09	1050.55	1784.28	2477.05	1361.27	563.02	1060.05			8296.22	0 0 0 0 0 0	06-C-RO
s10	1003.48	1699.82	1212.58	1090.08	638.29	1023.93			6668.18	0 0 0 0 0 0	06-C-HV
s11	1176.04	3706.8	3373.39	1379.41	1581.08	2161.93	481.48		13860.13	0 0 0 0 0 0 0	07-C-HV
s12	1105.16	3348.81	3104.68	1373.89	1553.17	2434.84	485.48		13406.03	0 0 0 0 0 0 0	07-C-RO
s13	723.91	1536.21	1212.9	721.42	693.47	1279.69			6167.6	0 0 0 0 0 0	08-C-RO
s14	846.84	1041.74	1177.68	667.19	644	1087.94			5465.39	0 0 0 0 0 0	08-C-HV
s15	1660.01	3655.81	3636	1539.74	2129.68	2487.81	502.73		15611.78	0 0 0 0 0 0 0	09-C-HV
s16	1526.6	2960.17	3346.86	1515.18	2295.59	2817.49	516.29		14978.18	0 0 0 0 0 0 0	09-C-RO
s17	668.5	1549.77	1215.59	998.47	640.55	958.97			6031.85	0 0 0 0 0 0	10-C-RO
s18	568.57	1749.04	1231.89	887.49	562.83	840.05			5839.87	0 0 0 0 0 0	10-C-HV
s19	1576.71	1725.46	2549.21	1974.82	1943.65	1843.24	422.02		12035.11	0 0 0 0 0 0 0	11-C-HV
s20	1567.73	1596.38	2710.36	2003.13	1859.76	1336.25	37.17		11110.78	0 0 0 0 0 0 0	11-C-RO
s21	595.06	910.02	1237.38	1084.29	2154.86	3499.81	954.89	1871.6	12307.91	0 0 0 0 0 0 0 0	12-C-RO
s22	532.5	1094.58	2062.36	1260.95	3029.7	5166.82	1082.13	986.13	15215.17	0 0 0 0 0 0 0 0	12-C-HV
s23	2296.16	3566.46	4758.73	1109.2	5841.67	2495.27	638.82		20706.31	0 0 0 0 0 0 0	13-C-HV
s24	1862.35	3054.78	3604.42	4191.38	4856.45	2396.06	506.6		20472.04	0 0 0 0 0 0 0	13-C-RO
s25	876.47	1472.01	556.29	1663.05	2195.78	4561.41	1366.79	1014.23	13706.03	0 0 0 0 0 0 0 0	14-C-RO
s26	789.62	969.73	605.86	1354.46	2086.31	3476.21	844.71	2000.38	12127.28	0 0 0 0 0 0 0 0	14-C-HV
s27	1667.13	2319.81	2247.76	1266.63	1779.26	1416.67	260.28		10957.54	0 0 0 0 0 0 0	15-C-HV
s28	1425.84	2742.5	2692.08	1088.28	1444.63	2507.95	429.6		12330.88	0 0 0 0 0 0 0	15-C-RO
s29	1067.54	1719.48	1069.17	956.44	833.98	1192.62			6839.23	0 0 0 0 0 0	16-C-RO
s30	1124.65	1201.71	1296.83	1093.89	588.2	1202.64			6507.92	0 0 0 0 0 0	16-C-HV
s31	1142.93	3686.03	3614.11	2338.89	2407.49	2808.7	474.06		16472.21	0 0 0 0 0 0 0	01-C-HV
s32	2853.26	5090.89	4911.45	538.59	802.93	3961.54	502.02		18660.68	0 0 0 0 0 0 0	01-A-RO
s33	0	2228.43	1910.51	1313.69	799.84	1894.52			8146.99	0 0 0 0 0 0	02-A-RO
s34	0	2401.12	1679.85	1254.92	911.29	1871.89			8119.07	0 0 0 0 0 0	02-A-HV
s35	2378.76	4364.09	3629.9	1135.85	1615.94	3519.17	421.45		17065.16	0 0 0 0 0 0 0	03-A-HV
s36	2543.6	6079.98	4400.98	2328.85	2173.52	3393.1	641.05		21561.08	0 0 0 0 0 0 0	03-A-RO
s37	1319.69	2237.48	1656.28	804.99	1211.89	1519.31			8749.64	0 0 0 0 0 0	04-A-RO
s38	1437.18	2455.54	2479.57	1102.81	1445.08	1853.55			10773.73	0 0 0 0 0 0	04-A-HV
s39	1928.07	6470.77	-2	2395.86	2142.82	3227.07	405.01		16567.6	0 0 0 0 0 0 0	05-A-HV
s40	2117.38	6738.9	7889.47	2065.84	2362.77	3455.16	448.56		25078.08	0 0 0 0 0 0 0	05-A-RO
s41	1430.86	3159.61	2251.57	1582.93	1165.61	2340.22			11930.8	0 0 0 0 0 0	06-A-RO
s42	1017.36	2204.08	1449.32	1337.11	1041.32	2329.3			9378.49	0 0 0 0 0 0	06-A-HV
s43	968.05	5030.87	4611.87	946.11	1580.94	1044.37	345.63		14527.84	0 0 0 0 0 0 0	07-A-HV
s44	1185.98	6632.09	5025.2	1046.51	1916.04	2754.34	363.32		18923.48	0 0 0 0 0 0 0	07-A-RO
s45	739.02	2392.16	1679.53	1219.13	1134.09	2290.72			9454.65	0 0 0 0 0 0	08-A-RO
s46	442.99	2167.83	1533.65	1164.67	1177.92	2307.97			8795.03	0 0 0 0 0 0	08-A-HV
s47	776.28	3930.18	3231.14	1674.12	2371.04	2690.47	324.44		14997.67	0 0 0 0 0 0 0	09-A-HV
s48	893.67	4873.38	3840.76	1880.44	2823.98	2250.6	715.15		17277.98	0 0 0 0 0 0 0	09-A-RO
s49	1269.36	2442.51	1644.68	934.55	630.65	1934.57			8856.32	0 0 0 0 0 0	10-A-RO
s50	1152.86	2672.26	1510.84	1108.86	864.98	2017.71			9327.51	0 0 0 0 0 0	10-A-HV
s51	1409.82	4061.55	3441.97	1847.37	1547.72	2695.92	74.52		15078.87	0 0 0 0 0 0 0	11-A-HV
s52	1556.39	3720.33	2062.51	1911.54	1420.19	1600.73	454.91		12726.6	0 0 0 0 0 0 0	11-A-RO
s53	478.58	1065.83	1148.47	1296.29	1035.26	3606.37	1937.07	1400.47	11968.34	0 0 0 0 0 0 0 0	12-A-RO
s54	802.38	1824.88	1937.2	2943.5	2348.36	5056.12	515.08	616.01	16043.53	0 0 0 0 0 0 0 0	12-A-HV
s55	1568	5626.9	3257.27	4286.34	6498.71	2958.89	458.03		24654.14	0 0 0 0 0 0 0	13-A-HV
s56	1512.55	7414.1	5405.79	5560.72	8506.83	3561.4	599.88		32561.27	0 0 0 0 0 0 0	13-A-RO
s57	760.65	1952.61	2086.96	1584.73	2875.99	4804.57	1812.78	1374.14	17252.43	0 0 0 0 0 0 0 0	14-A-RO
s58	539.67	1200.28	1252.68	1205.39	2038.8	3372.92	1043.14	1864.04	12516.92	0 0 0 0 0 0 0 0	14-A-HV
s59	1596.01	3417.86	2766.28	1841.43	1896.52	1703.74	448.3		13670.14	0 0 0 0 0 0 0	15-A-HV
s60	1476.65	5210.89	5493.63	1872.33	2074.42	3335.97	643.01		20106.9	0 0 0 0 0 0 0	15-A-RO
s61	1158.26	2778.24	1775.17	90.24	1058.96	2251.9			9112.77	0 0 0 0 0 0	16-A-RO
s62	1231.68	2442.57	1642.85	260.48	1047.15	2253.76			8878.49	0 0 0 0 0 0	16-A-HV
s63	2687.03	4959.43	4172.7	510.13	908.19	4668.85	569.41		18475.74	0 0 0 0 0 0 0	01-A-HV

Overflow & killed	1	0	Inst & Mean Rate:	841748.32	841748.32	0000000	All Sectors
LowPT rate:	831478.7	HighPT rate:	14527.80	PT5 rate:	1480.32	PT6 rate:	2915.00

The trigger system consists of **two halves positive and negative η** each divided into **32 azimuthal sectors**

Each azimuthal sector is divided along **η** in **projective towers**.

Running Conditions and Data Taking

2017

Peak instantaneus luminosity **2.06 x10^{34} cm^{-2} s^{-1}**

Peak number of interactions

per bunch-crossing (pile-up) **~ 80**

Average number of interactions

per bunch-crossing **38.1**

99.0 - 99.5 % active trigger towers in data taking

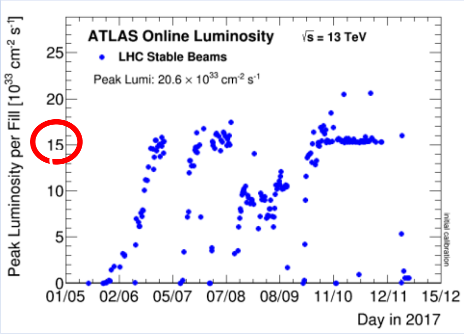
(0~3 off out of 404)

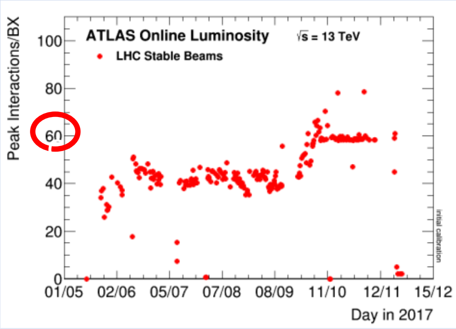
Run – 2 (2015-17)

LHC delivered **93 fb^{-1}**

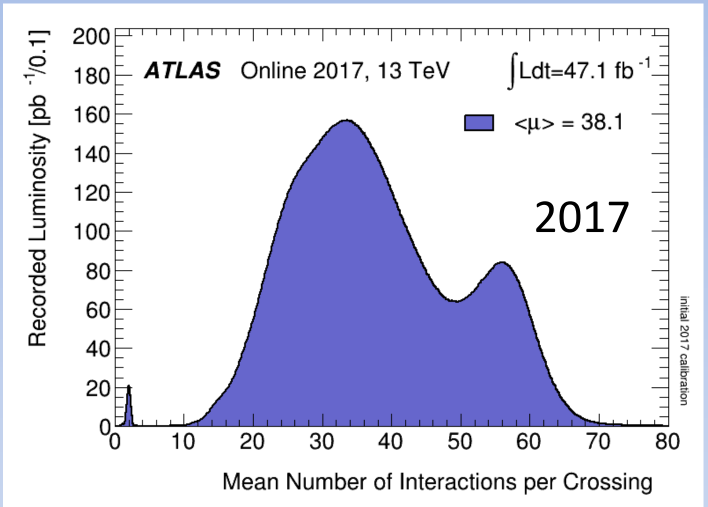
ATLAS recorded **87 fb^{-1}**

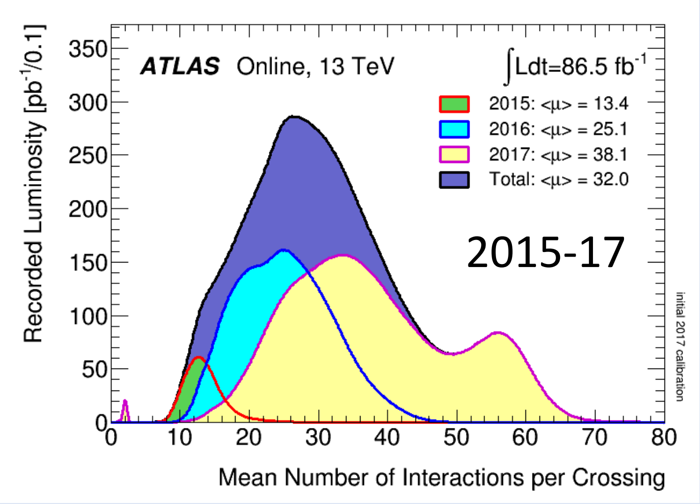
Good for physics **80 fb^{-1}**





Mean number of interactions





Monitoring of L1 Trigger Performances

Monitoring of RPC and L1/Barrel trigger is performed at **different levels**:

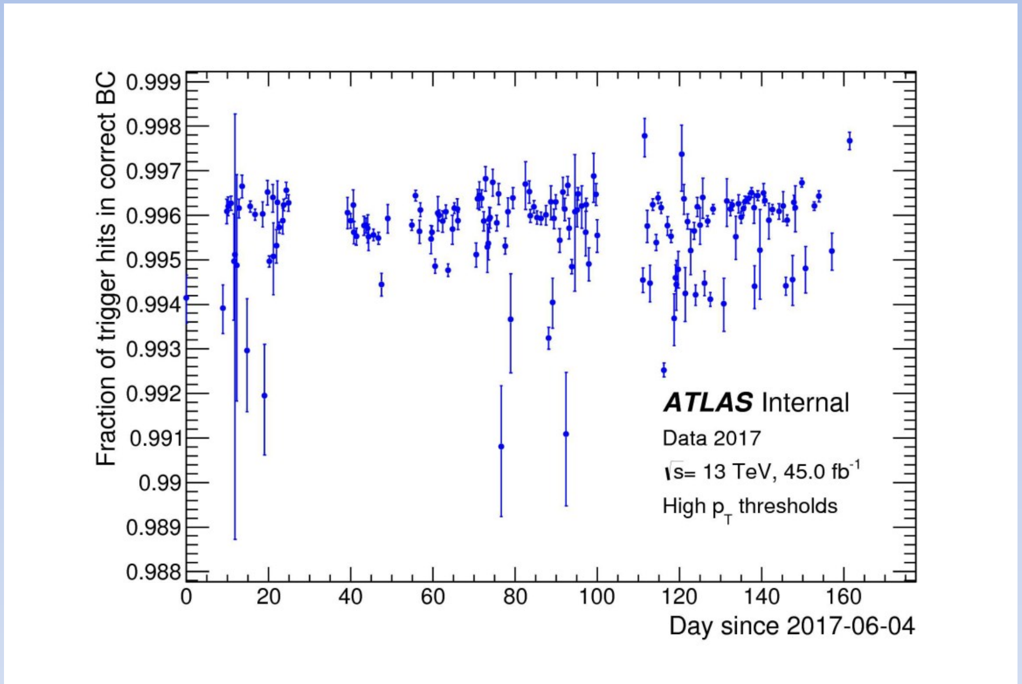
- **DCS**: Detector Control System, follows the slowly-varying parameters such as High Voltage, currents, temperature,….. and perform the automatic HV adjustment based on pressure and temperature measurements
- **Online Data-Quality monitor**:
  checks basic functionalities of readout, makes hit maps to spot holes, produces online histograms during data taking
- **Offline RPC Data-Quality monitor** : runs after data reconstruction, produces more detailed plots on detector quantities, such as efficiency, cluster size,…... for each detector unit.
- **L1-Barrel Calibration program**: runs offline for each run after reconstruction, used to monitor and calibrate timing and momentum selection and to measure trigger quantity such as efficiency. Uses muon-independent triggers and muon tracks reconstructed using inner detector and monitored drift tubes to select good muon probes
- **Tag and Probe analysis**: performed offline using a clean sample of muon tracks from $Z \rightarrow \mu\mu$ to measure detector and trigger efficiencies.

Trigger Timing and Sincronization

Bunch Crossing Identification is one of the main tasks of the Level-1 Barrel Trigger

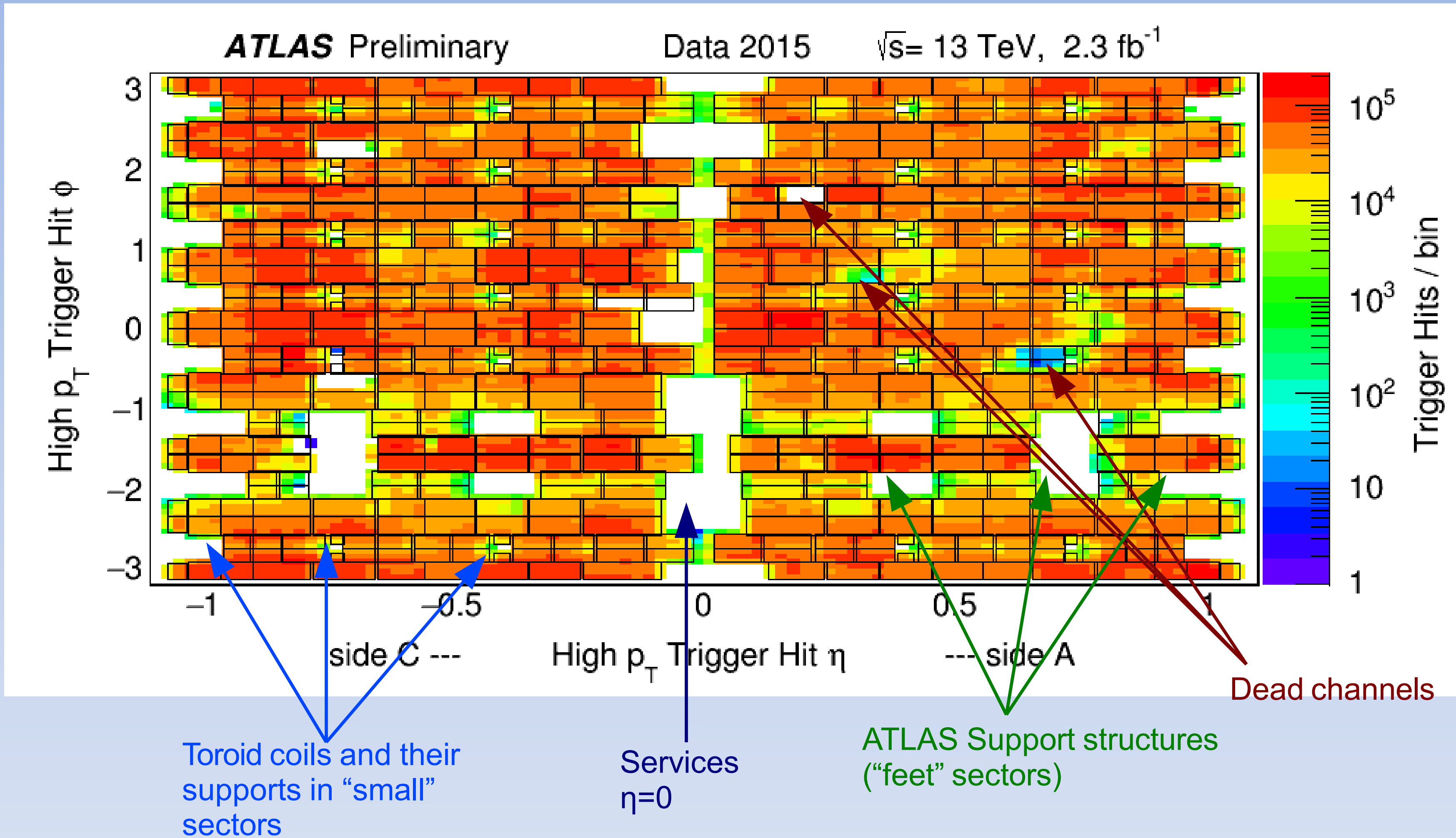
- Hits from various RPC planes are **synchronized** in order to provide the correct hit timing
  The calibration is performed using programmable delays in steps of 1/8 BC time = 3.125 ns

- **99,6 % of L1 Muon Barrel triggers are associated with the correct BC**



Very good stability in time

RPC Trigger Coverage



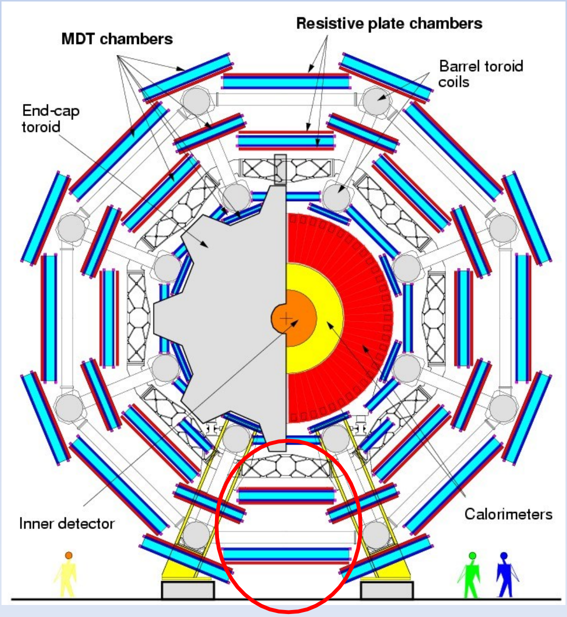
- **Hit map** from Offline Data-Quality monitor
- All η-φ coincidences on RPC - 2 stations for high-p_T (3-stations) trigger
- **Acceptance holes** well visible

Trigger Acceptance ~78% for $|\eta|<1.05$ high-p_T

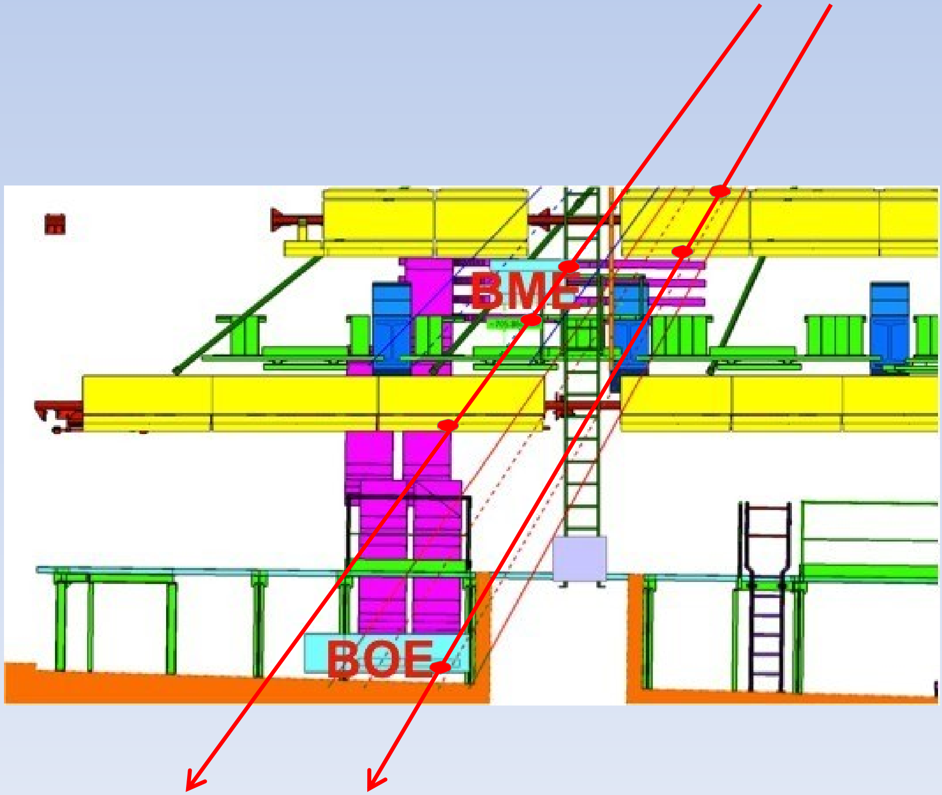
"Elevator" Upgrade

- **4 new muon stations** have been installed
  2 BME (Barrel Middle) with new RPCs with 1 mm gas gap
  2 BOE (Barrel Outer) of standard type with 2mm gas gap
- cover two holes in bottom sectors (~**0.8%** coverage) due to the "elevator" shafts

from late 2017 are fully integrated in the trigger framework
data are being analyzed



Φ ~ -1.6

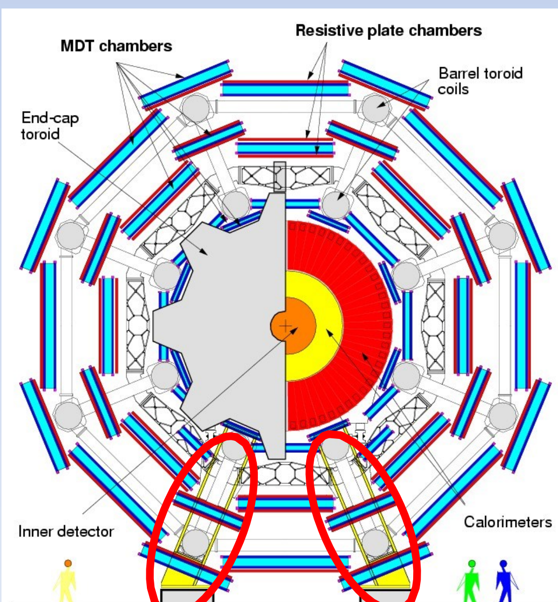


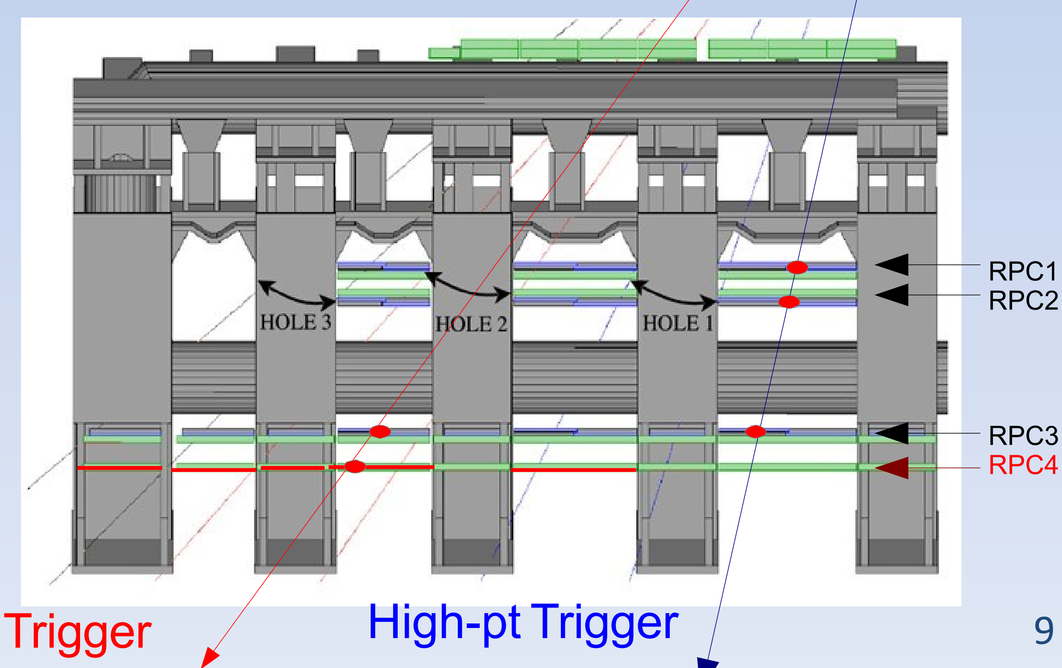
"Feet" Upgrade (1)

Upgrade project to cover acceptance holes in the "feet" sectors (12-14) 4th RPC layer
2.8% increase of barrel acceptance

20 RPC chambers installed before 2008,
equipped with services and electronics
during long shutdown 2013-2014

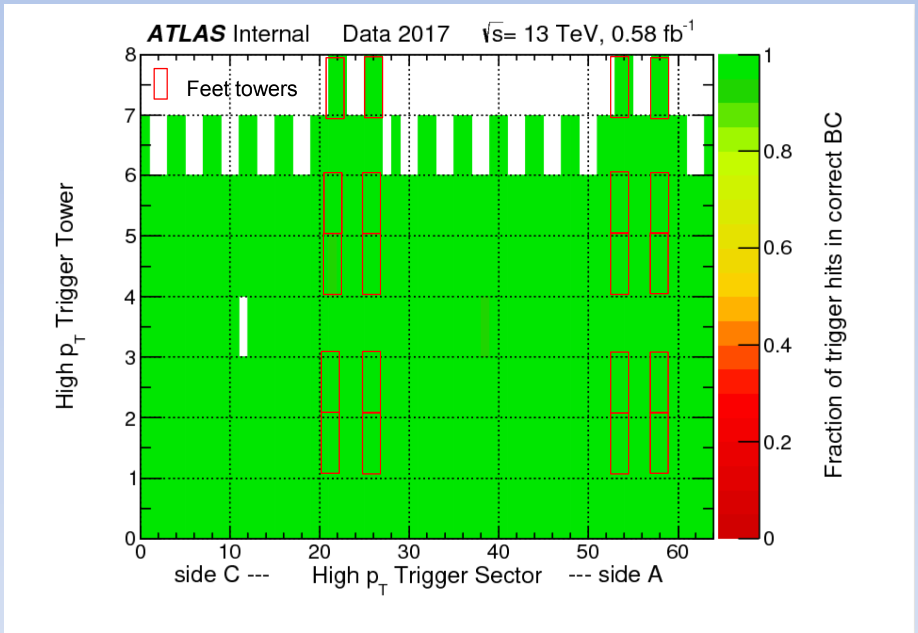
Special trigger "towers" implementing simple two-station coincidences (4 layers)





Trigger Feet Upgrades (2)

- All “feet” trigger towers inserted in the ATLAS trigger at the end of 2015.
- Timing synchronization and tuning of the trigger coincidences that define the p_T thresholds completed in 2016

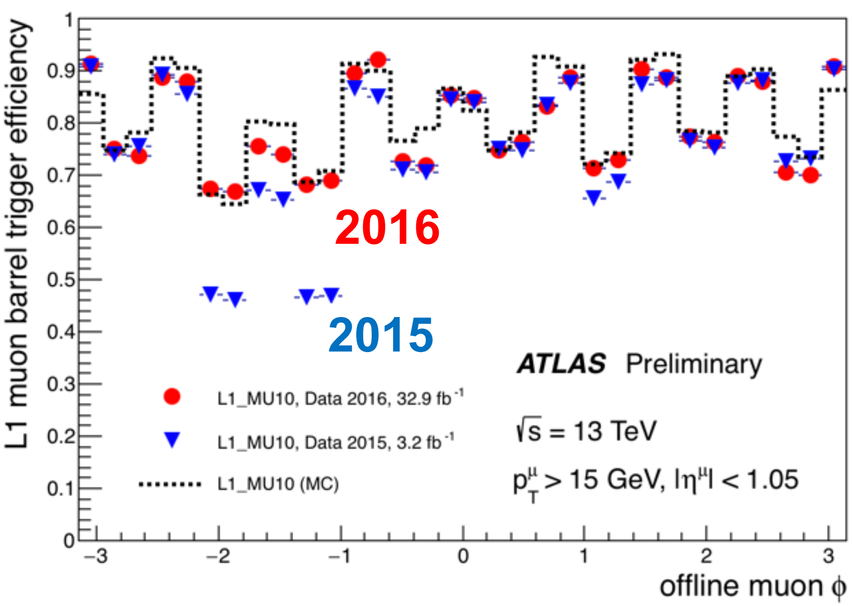


Fraction of the RPC high pT trigger hits associated correctly to the collision Bunch Crossing for each RPC trigger tower

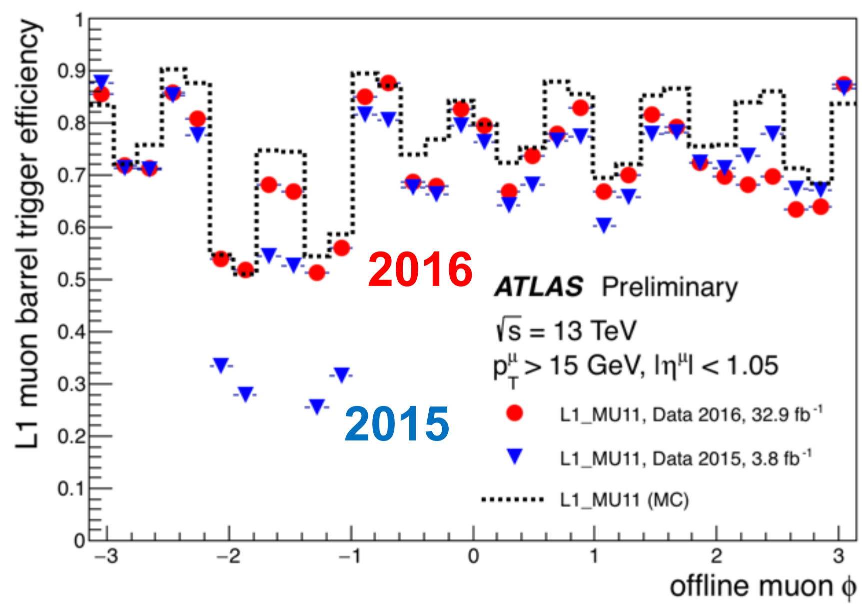
Trigger Upgrade results

Effective efficiency of Level 1 - MU10 - **low-pt** and MU11 **high-pt** trigger in **2015** (blue triangles) and in **2016** (red dots) plotted as a **function of ϕ**

Low-pt

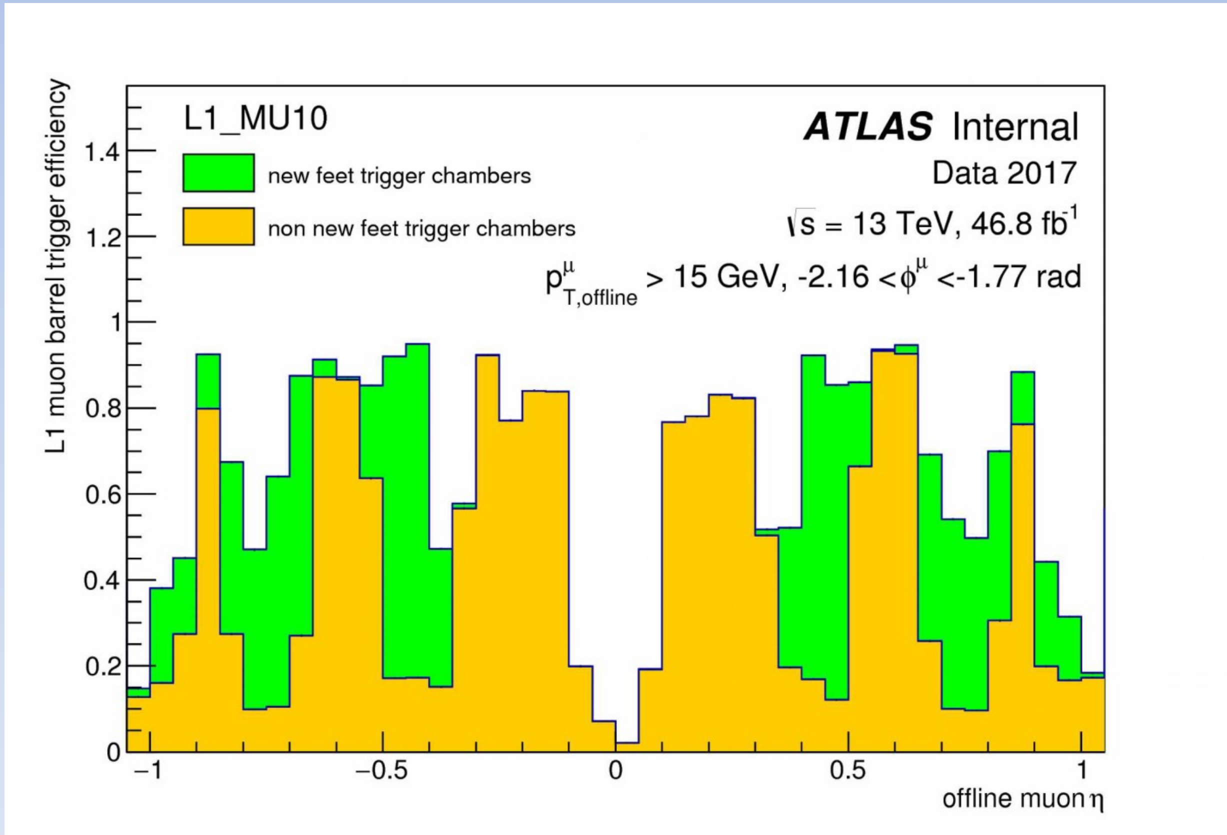


High-pt



Trigger Upgrade Results

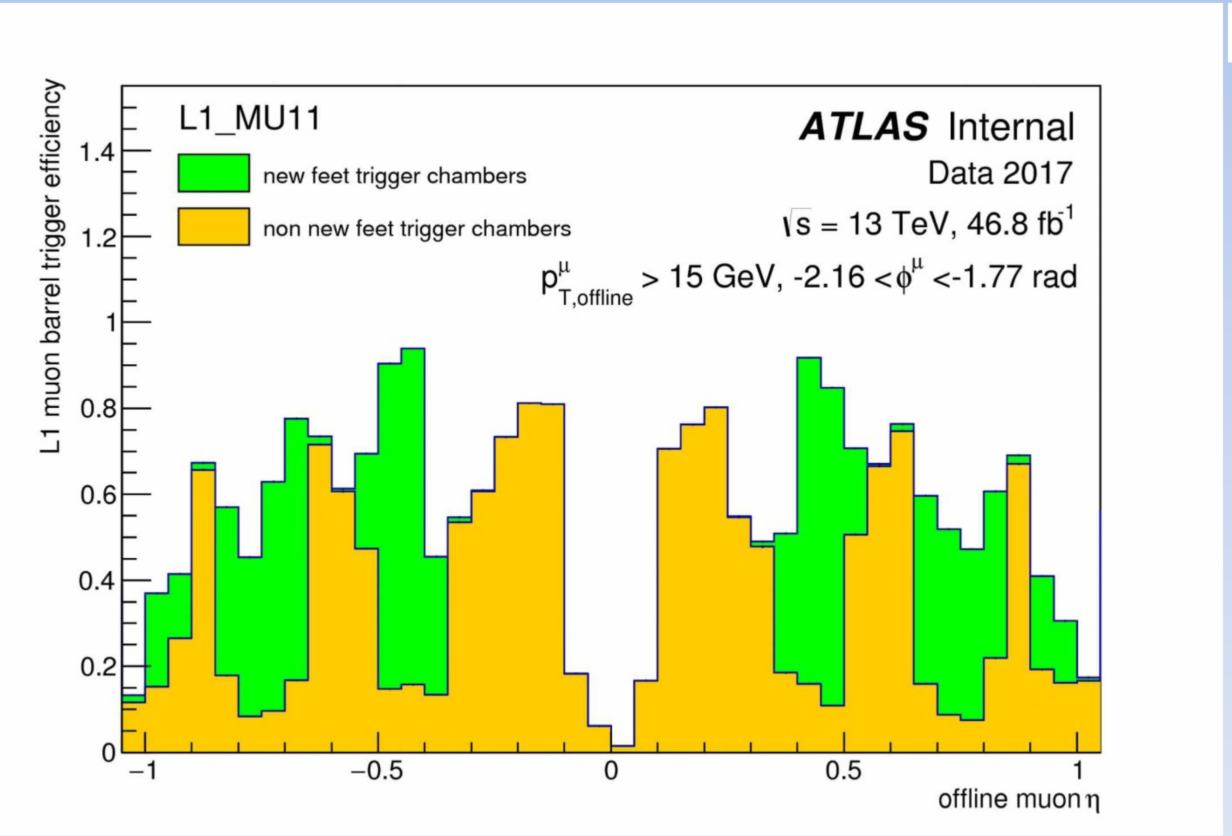
L1 MU10 **Low-pt** barrel muon trigger **effective efficiency** as a function of **muon η in 2017** for a "feet sector" (Sector 12), with and without the "feet trigger chambers"



Low-pt

Trigger Upgrade Results

L1 MU11 **High-pt** barrel muon trigger **effective efficiency** as a function of **muon η** in **2017** for Sector 12, with and without the “feet trigger chambers”



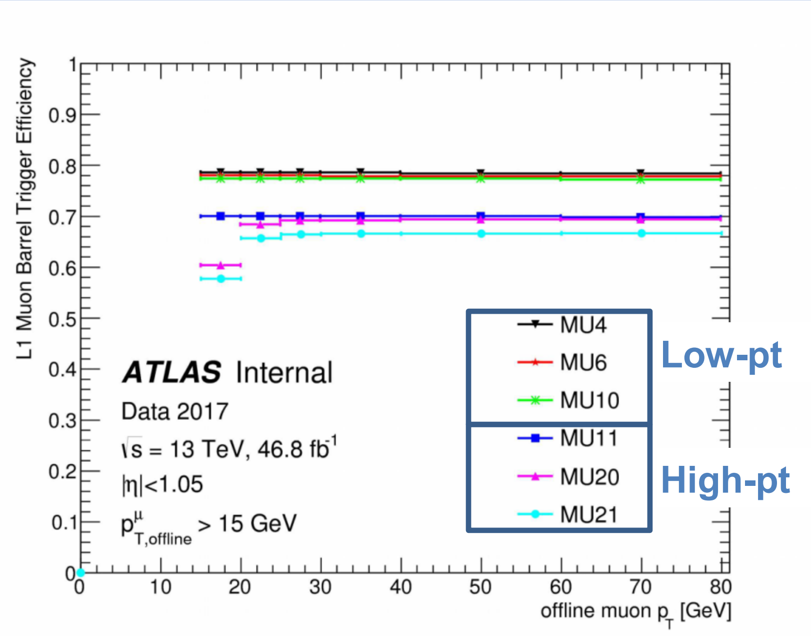
High-pt

Trigger Efficiency in 2017

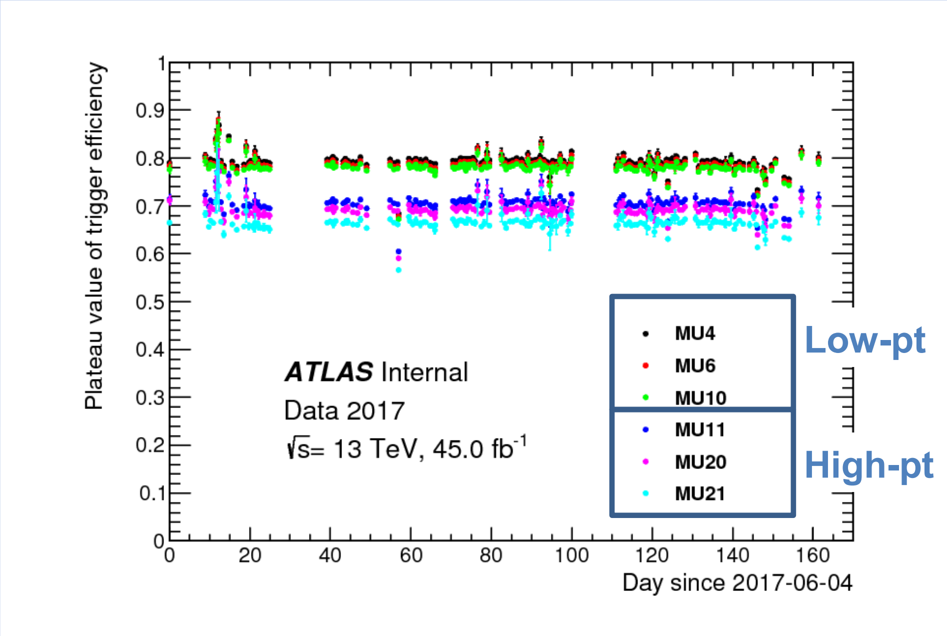
Trigger efficiency x geometrical acceptance as a function of p_T (for p_T > 15GeV)

Low- p_T trigger MU10 : effective efficiency ~ **78%**
High- p_T trigger **MU20** : effective efficiency - **with feet 69.3 %**
High- p_T trigger **MU 21** : effective efficiency - **without feet 66.6 %**
Feet Trigger Contribution 2.7%

L1 Barrel muon trigger efficiency with 2017 data



Plateau value of the L1 Barrel muon trigger efficiency for many runs in 2017 dataset: **good stability**



Trigger Efficiency

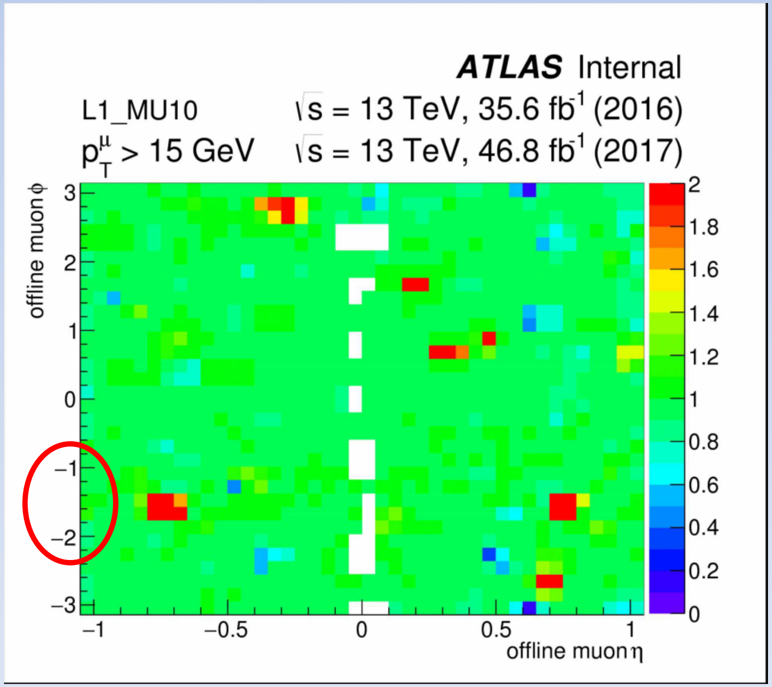
η and φ map of the ratio between the L1 Barrel muon trigger efficiency in **2017 and 2016**

Low-pt shows some localized improvements

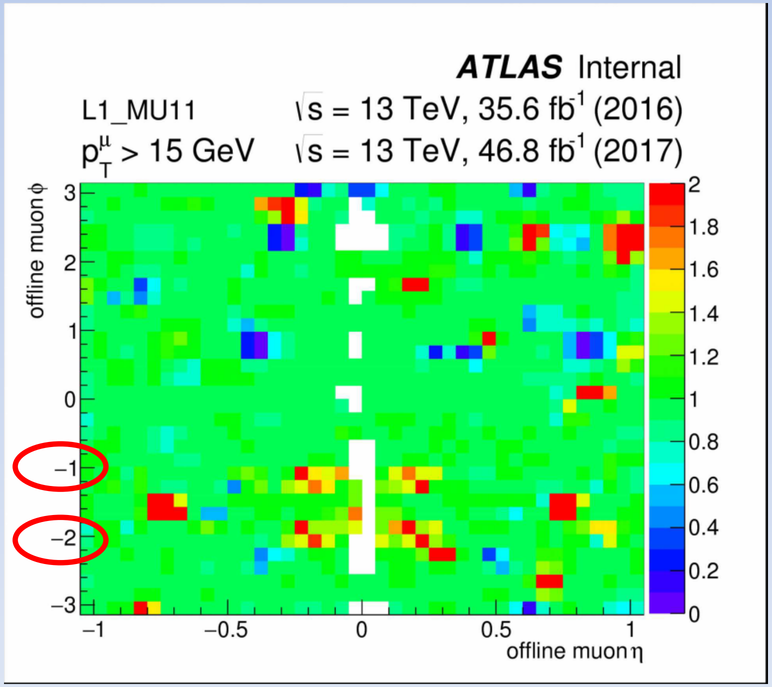
High-pt shows some localized improvements

local problems mainly due to gas losses in BO stations

Low-pt



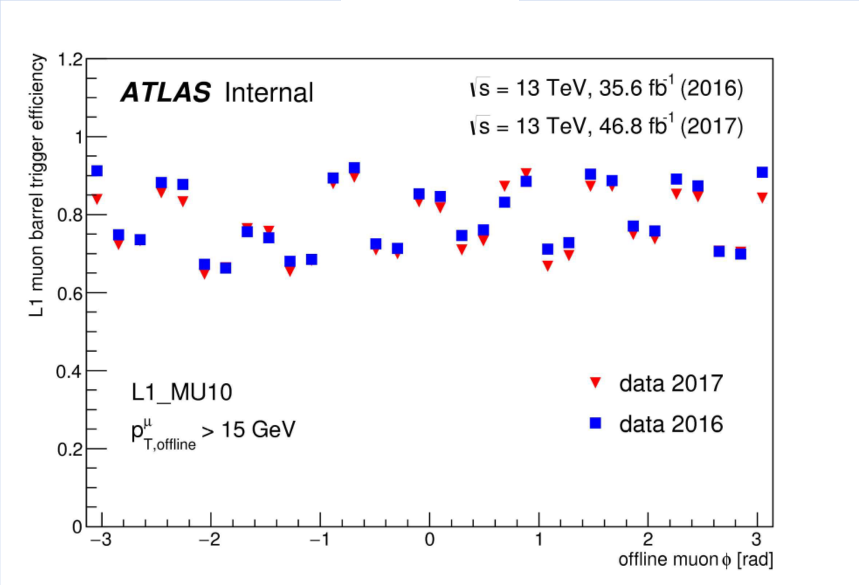
High-pt



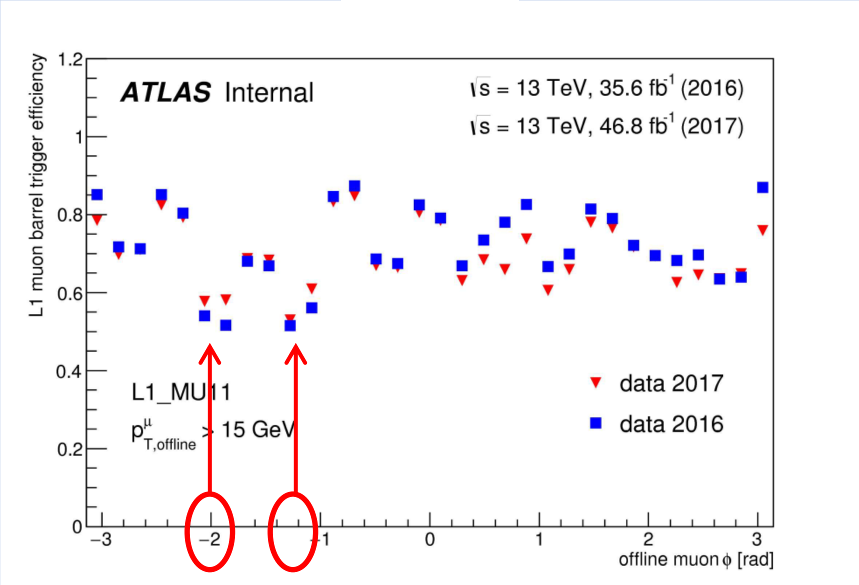
Trigger Efficiency in 2017

L1 Barrel muon trigger **effective efficiency** as a function of the **azimuthal coordinate ϕ** with **2016** and **2017** data
for the trigger threshold MU10 and MU11

Low-pt



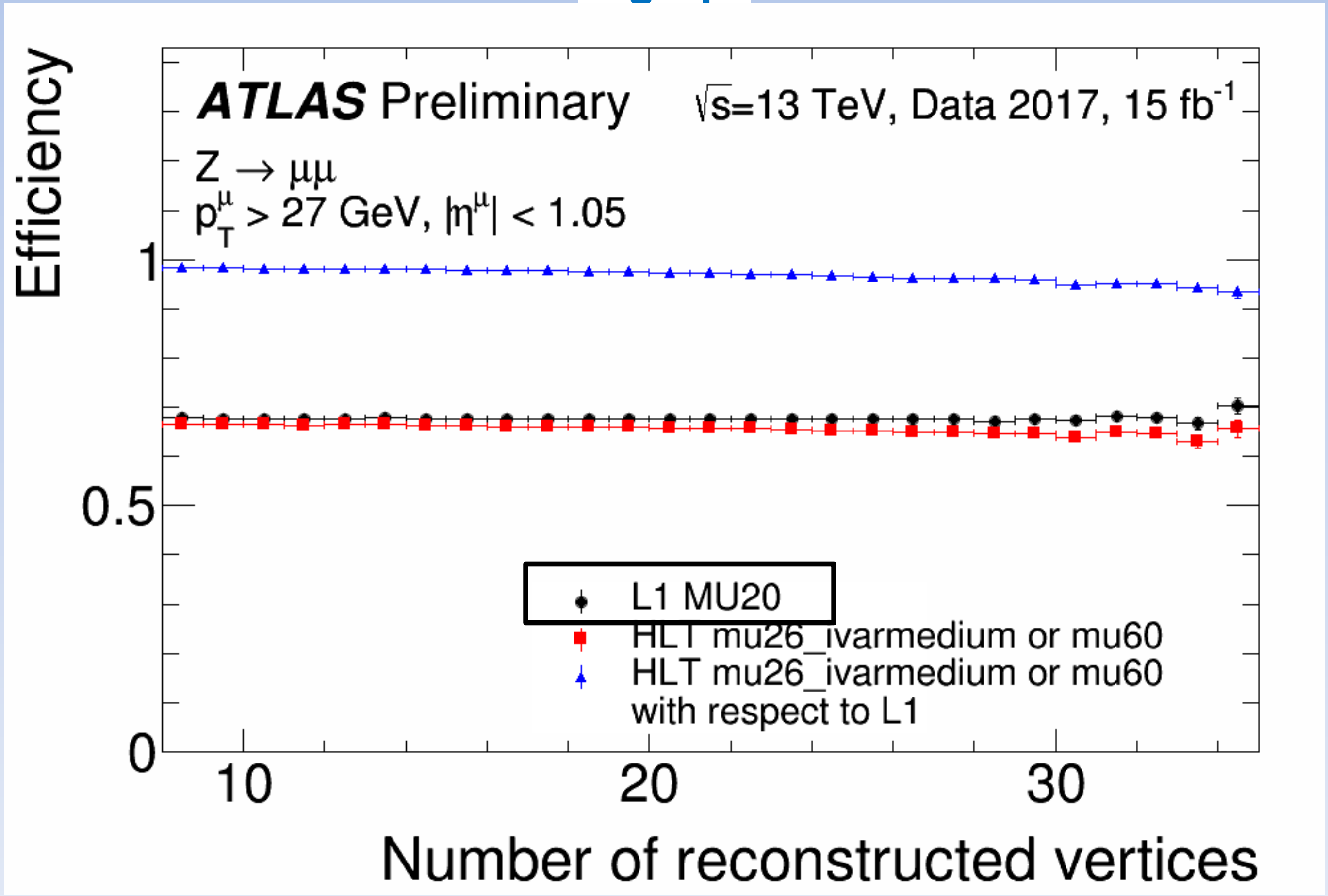
High-pt



Trigger Efficiency in 2017

Effective efficiency of Level 1 MU20 – **high–pt** trigger plotted as a function of the number of reconstructed vertices in the event (black points)

High-pt



Summary

- ATLAS RPC system were operated in high luminosity conditions with **high reliability and stability** in Run-2 (2015-2017)
  exclusively providing the level-1 “barrel” muon trigger for ATLAS

- Detector performances measured with different methods are
  stable and close to nominal results

- **Trigger performances**:
  very good rate, efficiency slightly lower than in run-1
  mainly due to chambers disconnected due to gas leaks
  ongoing repair campaign to (partly) fix the remaining leaks

- Minor upgrades (feet/elevators):
  produced enhancement of the overall trigger performance

Thank you again

Backup

Detector Efficiency

- Efficiency measured for each strip panel:
  *"**Detector**" (or panel) efficiency :*
  probability to see >=1 hit in a given strip panel

  *"**Gap**" efficiency :*
  probability to see >=1 hit in at least 1 of the 2 strip panels (η or φ) attached to a gas volume

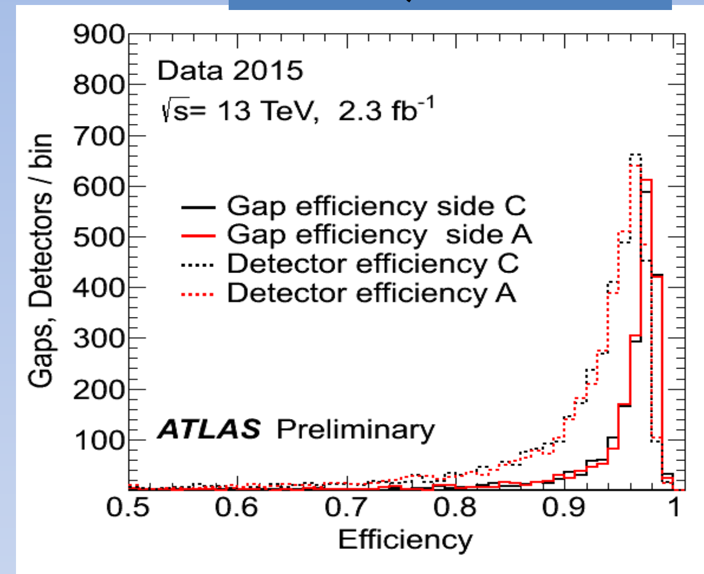
- Gap efficiency peaks at ~98%
  (~1% inefficiency from spacers)

- Detector efficiency has lower tails due to **dead strips** and channels with **"harder" thresholds** to prevent noise

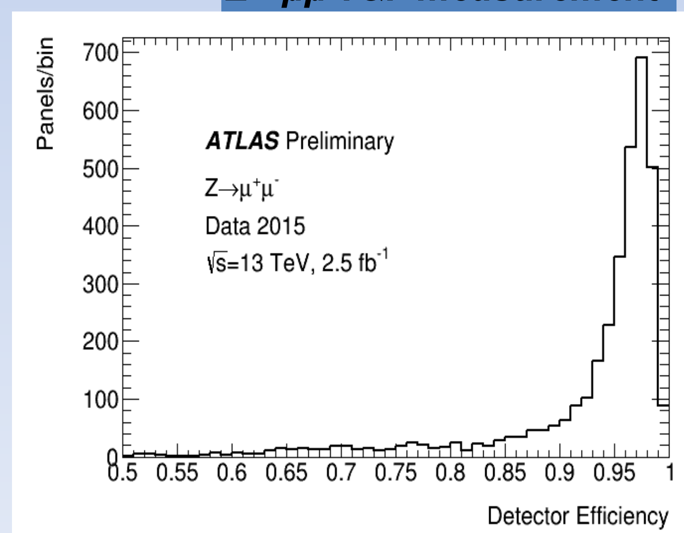
- No visible deterioration w.r.t. Run-1

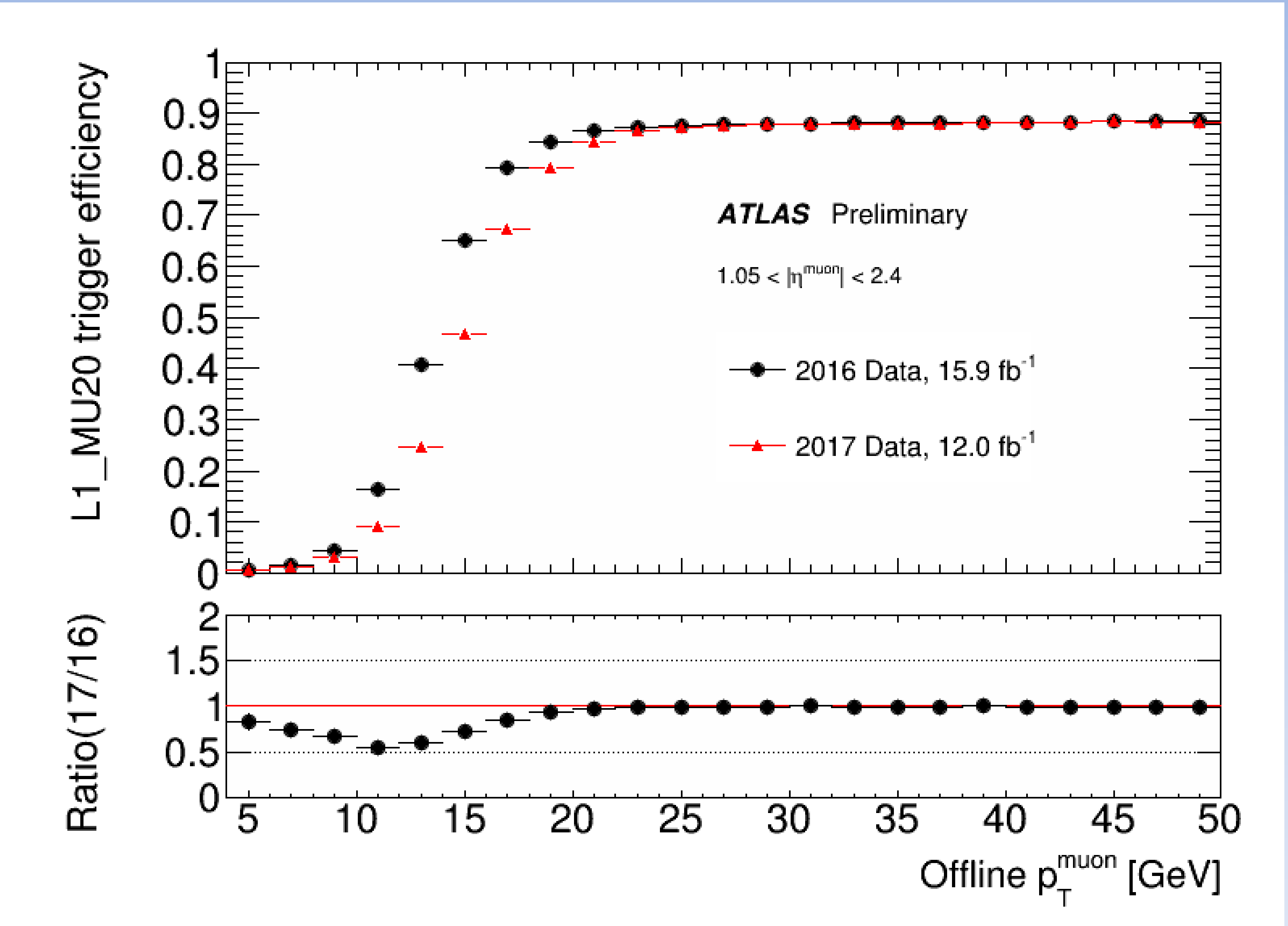
- **Offline Data Quality**
  RPC standalone tracks and Z->μμ agree at ~1% level.

Offline DQ measurement



Z->μμ T&P measurement

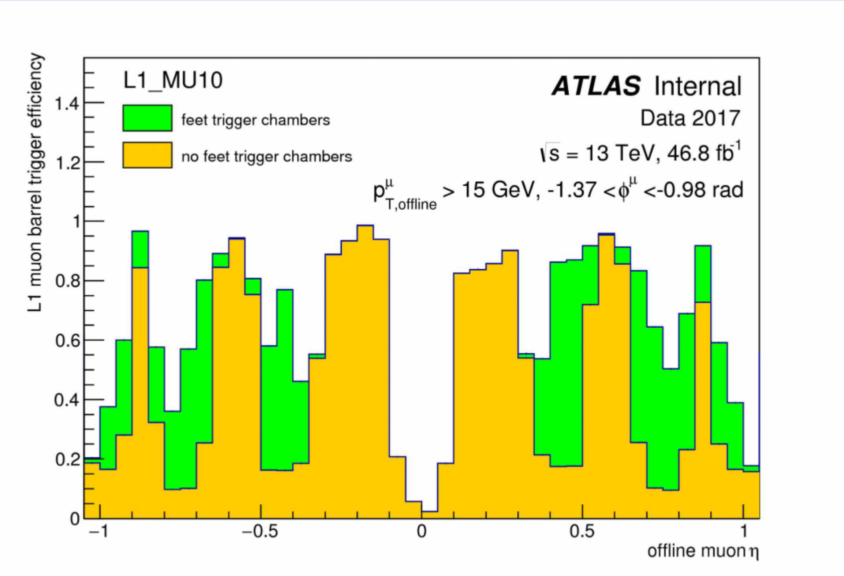



L1_MU20 trigger efficiency
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
ATLAS Preliminary
1.05 < |η^muon| < 2.4
2016 Data, 15.9 fb^-1
2017 Data, 12.0 fb^-1
Ratio(17/16)
0
0.5
1
1.5
2
5
10
15
20
25
30
35
40
45
50
Offline p_T^muon [GeV]

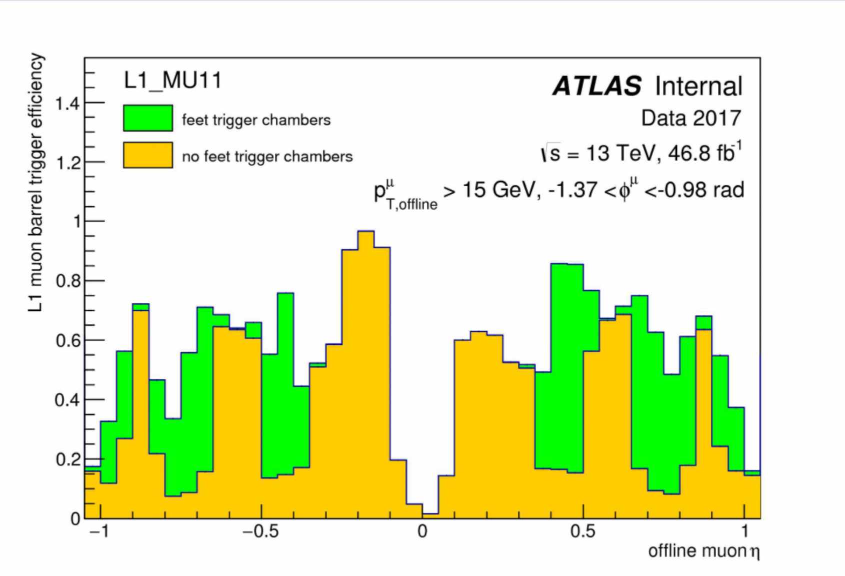
Trigger Upgrade Results

L1 MU10 and 11 barrel muon trigger effective efficiency as a function of muon η in 2017 for a different feet sector (Sector 14), with and without the feet trigger chambers

Low-pt



High-pt

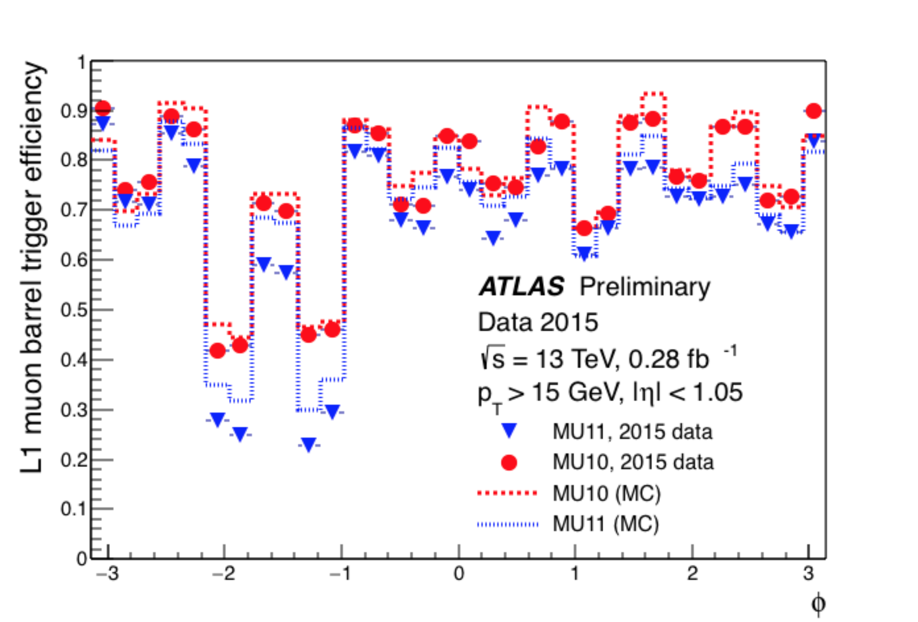


Trigger Efficiency

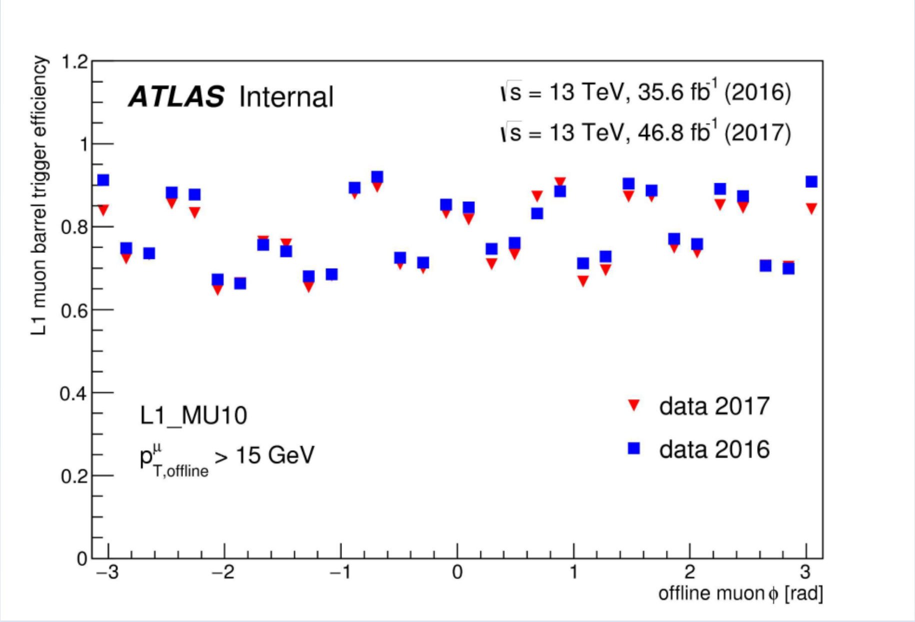
L1 Barrel muon trigger efficiency as a function of the azimuthal coordinate ϕ for the trigger threshold MU10 and MU11

RPC trigger system shows considerable stability in high luminosity conditions after several years of running

2015

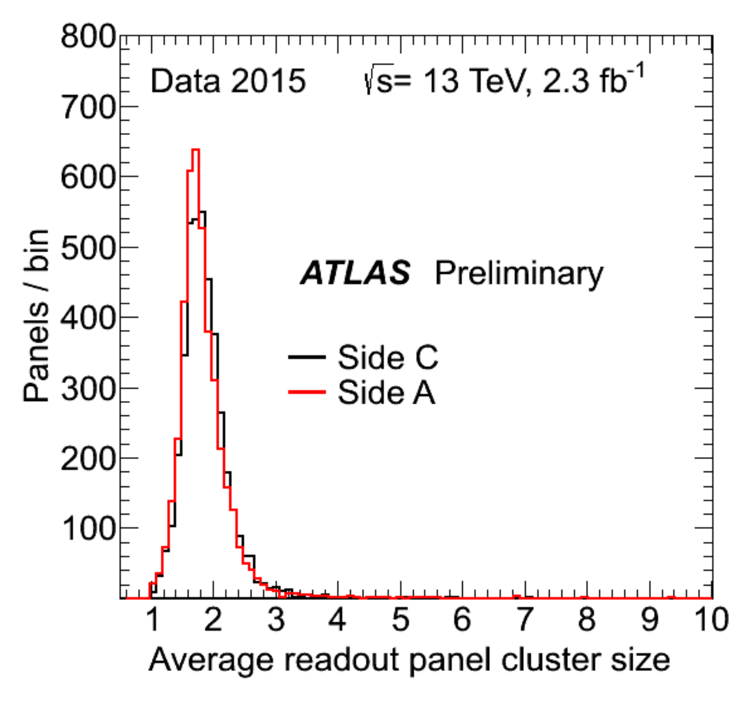


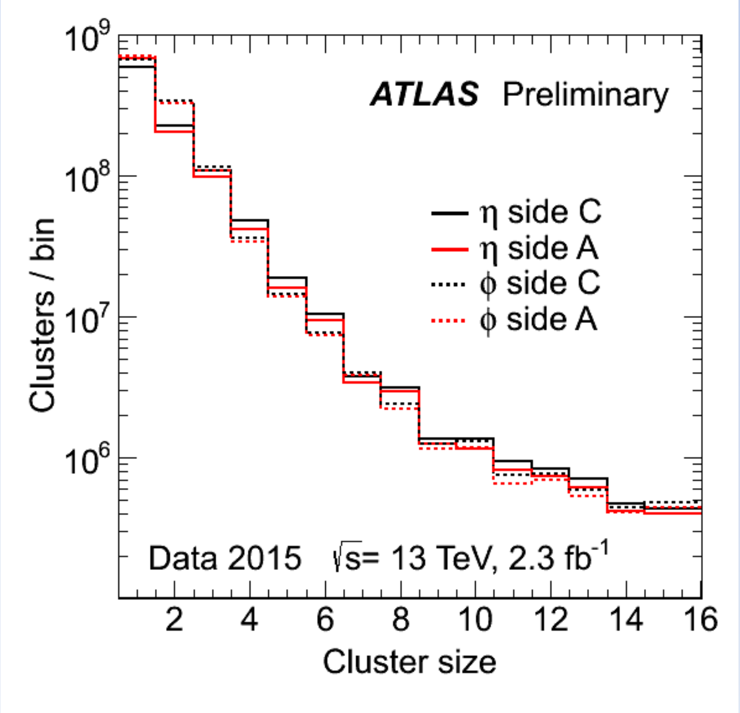
2016-17



Cluster Size

- Several quantities are monitored by Offline Data-Quality
- Example : cluster size
- Average cluster size 1.64 (for cluster with ≤ 8 strips)
- Consistent with RUN-1





Trigger Performance

- Efficiency of Barrel Trigger
  for reconstructd muons with $|\eta|<1.05$

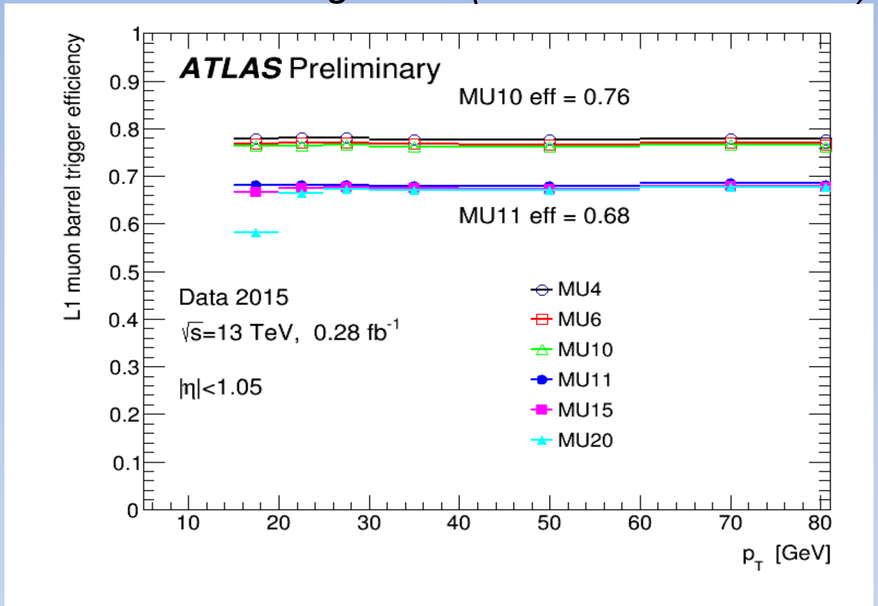
Acceptance x efficiency	2015	2012
Low-p_T (2 stations)	76%	78%
High-p_T (3 stations)	68%	72%

- Inefficiency mostly related to dead channels or inefficient RPC detectors (next page)

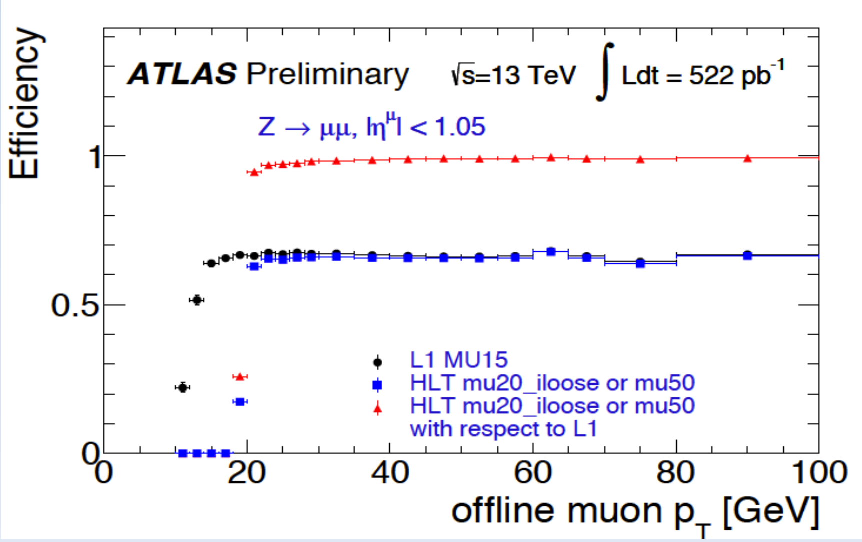
- Agreement between run-by-run measurements based on "orthogonal triggers" and Z->μμ "tag and probe" analysis

- Lowest p_T threshold for single muon triggers: MU15 (full efficiency for p_T>15 GeV)
  Rate (barrel) : 600 Hz @ L=3x10^{33} cm^{-2}s^{-1}
  small fraction of ATLAS L1 rate (100 kHz)

Single run (L1 Barrel calibration)



Z->μμ tag and probe

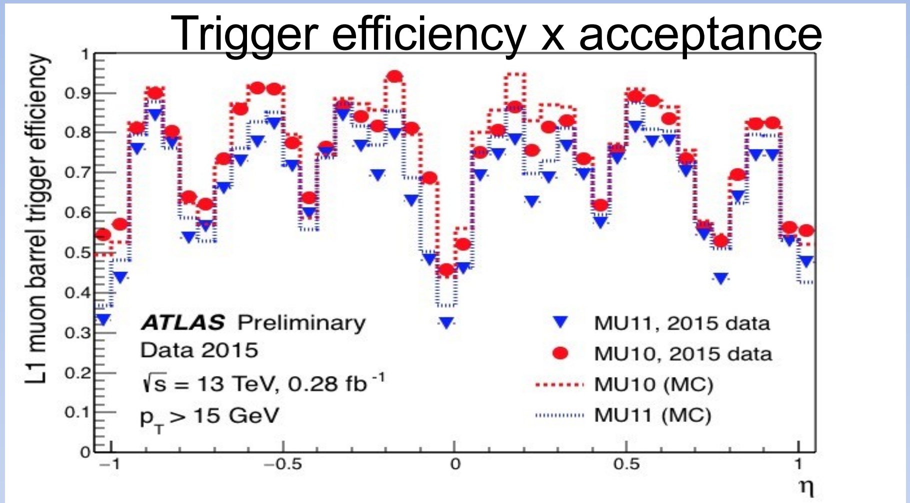


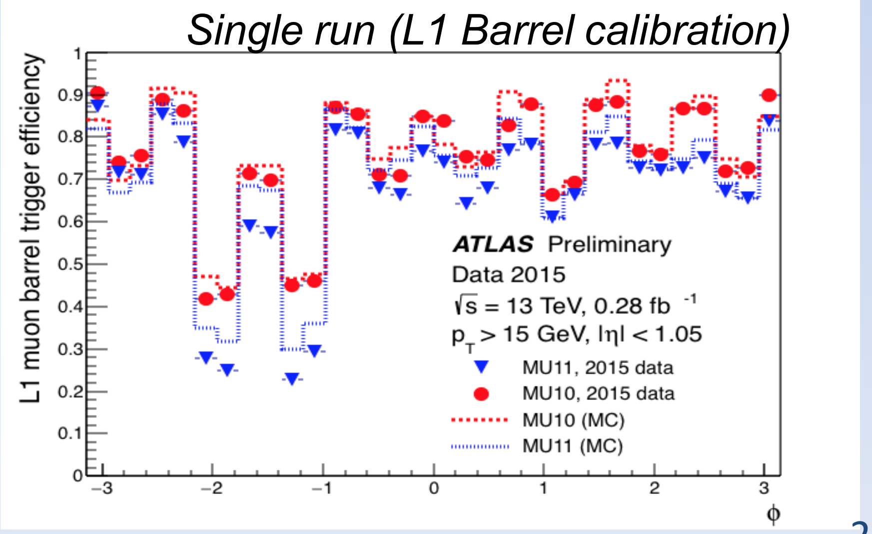
Trigger Efficiency and Simulation

- Trigger efficiency x acceptance in η, φ (larger structures are acceptance holes)

- Special MC simulation with measured RPC detector efficiencies.

- Reasonable data-MC agreement
  Residual differences ascribed to trigger electronics (1%) and to RPC efficiency in MC set to nominal value in regions were efficiency measurements were not available.



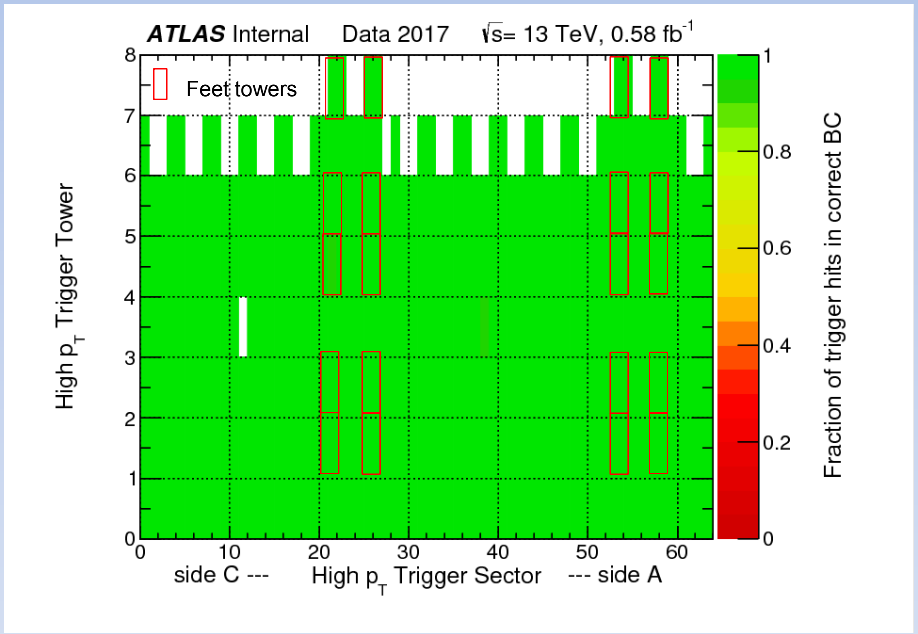


Trigger Feet Upgrades

- Commissioning during 13 TeV pp run
- All "feet" trigger towers finally inserted in the ATLAS trigger at the end of 2015.
- Timing synchronization and tuning of the trigger coincidences that define the p_T thresholds completed in 2016

Elevator chambers:

- 2 BME chambers were repaired in 2016-17 winter shutdown. BOE are working



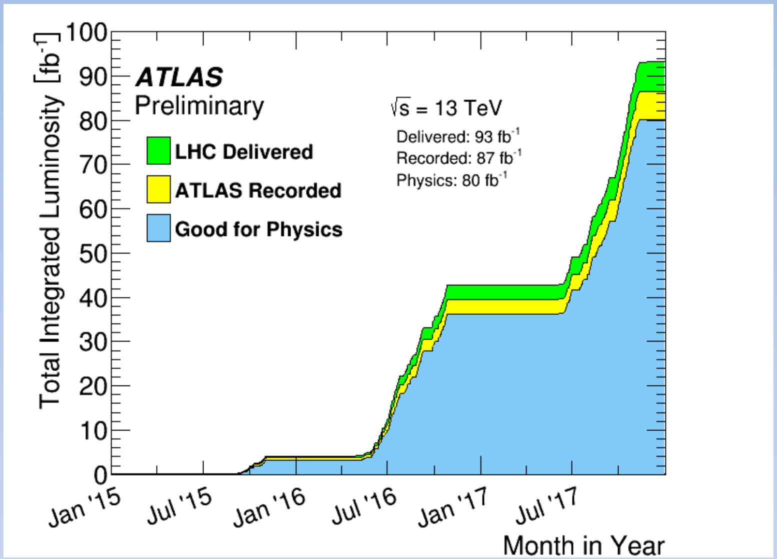
Fraction of the RPC high pT trigger hits associated correctly to the collision Bunch Crossing for each RPC trigger tower

ATLAS Data Taking

pp collisions at **√s=13 TeV**,
runs with **25ns** bunch spacing

Run - 2 Full Dataset:

delivered integrated luminosity of **93 fb^{-1}**
recorded integrated luminosity of **87 fb^{-1}**
good for physics **80 fb^{-1}**



Active trigger towers: 99.0 - 99.5%
(0~3 off out of 404)

Run - 2 luminosity
LHC delivered **93 fb^{-1}**
ATLAS recorded **87 f**

	Number hours Stable Beam	Efficiency % (Ready for Physics)
2017	**1453**	**94.2%**
2016	1832	92.9%
2015	938	91.4%