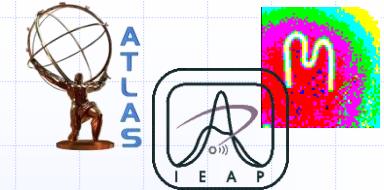


Status and Plans of ATLAS-TPX Data Analysis from Collisions at 13 TeV



Davide Caforio, André Sopczak

Institute of Experimental and Applied Physics, Czech Technical University in Prague

IEAP Seminar, 1 August 2017

dedicated to Stanislav Pospíšil 75th birthday

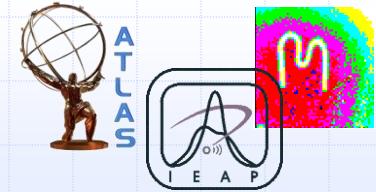
TPX Planning, Construction, Operation and Data Analysis Team

B. Ali, J. Begera, B. Bergmann, T. Billoud, B. Biskup,
P. Burian, D. Caforio, E. Heijne , J. Janeček,
C. Leroy, P. Mánek, Y. Mora, S. Pospíšil,
A. Sopczak, M. Suk, Z. Svoboda

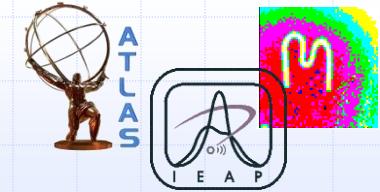
CTU in Prague, Univ. of Montreal

Outline

- Introduction
- 2015 Data Highlights
- 2016 Data Work in Progress
- Conclusions and Outlook

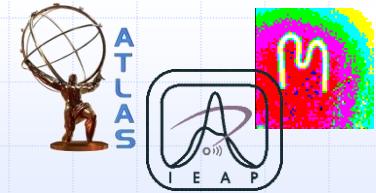


TPX luminosity, radiation field

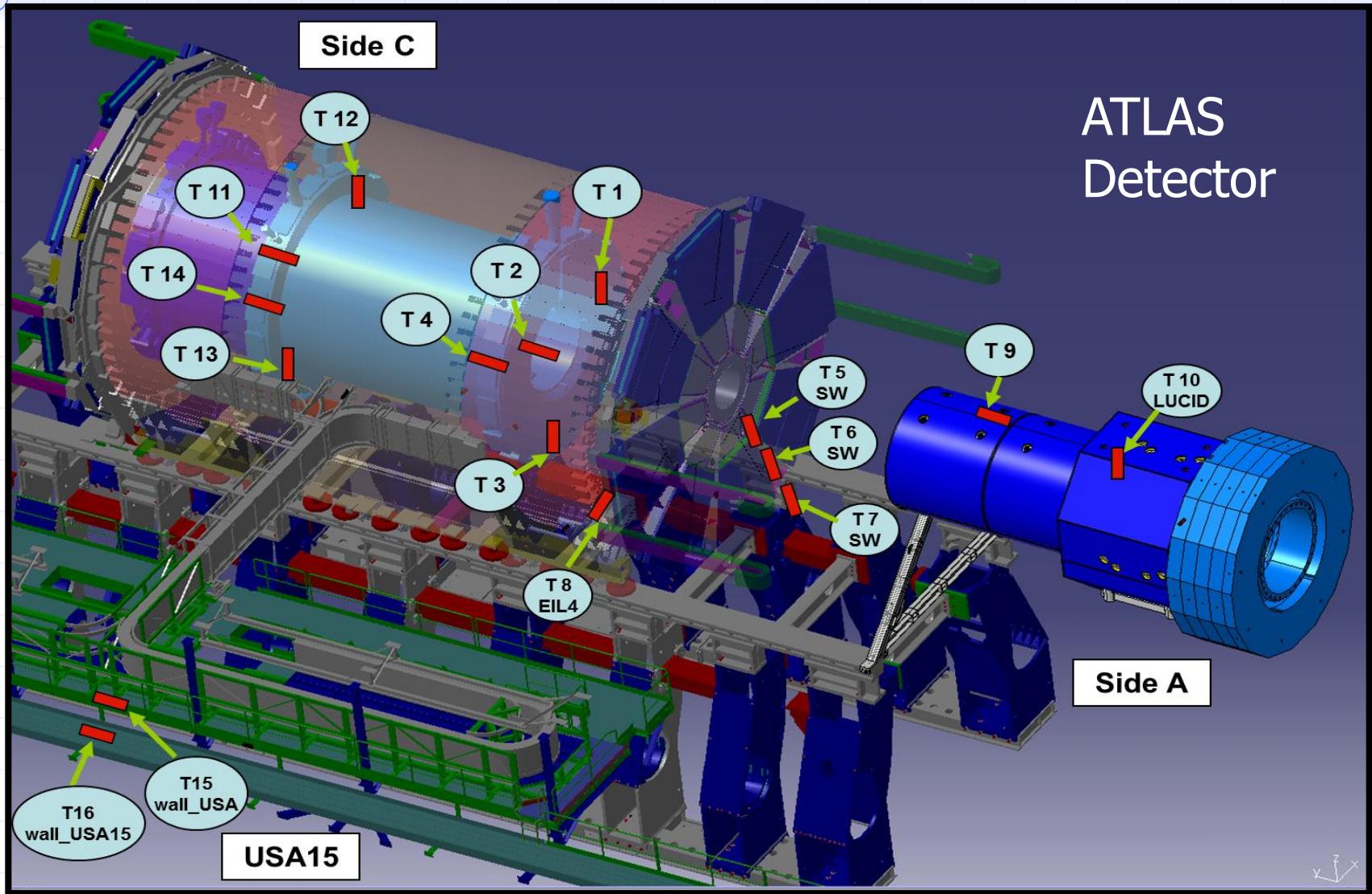


- (1) Internally:
 - (a) understanding/improving hit luminosity precision → PUB
 - (b) TPX cluster luminosity → PUB
 - (c) TPX activation, and application to luminosity determination → PUB
 - (d) TPX radiation field simulation/data and dosimetry → PUB
 - (e) TPX radiation hardness determination, self-healing → PUB
- (2) Comparison to other ATLAS luminometers
 - (a) calibration transfer → PUB (ATLAS)
 - (b) long-term stability → PUB (ATLAS)
 - (c) TPX online monitoring in control room
→ making TPX luminosity results more visible and useful
- (3) Using new features of TPX (hodoscope, energy deposit, time information)
- (4) TPX-3 data
- (5) ALFA, AFP for absolute luminosity determination

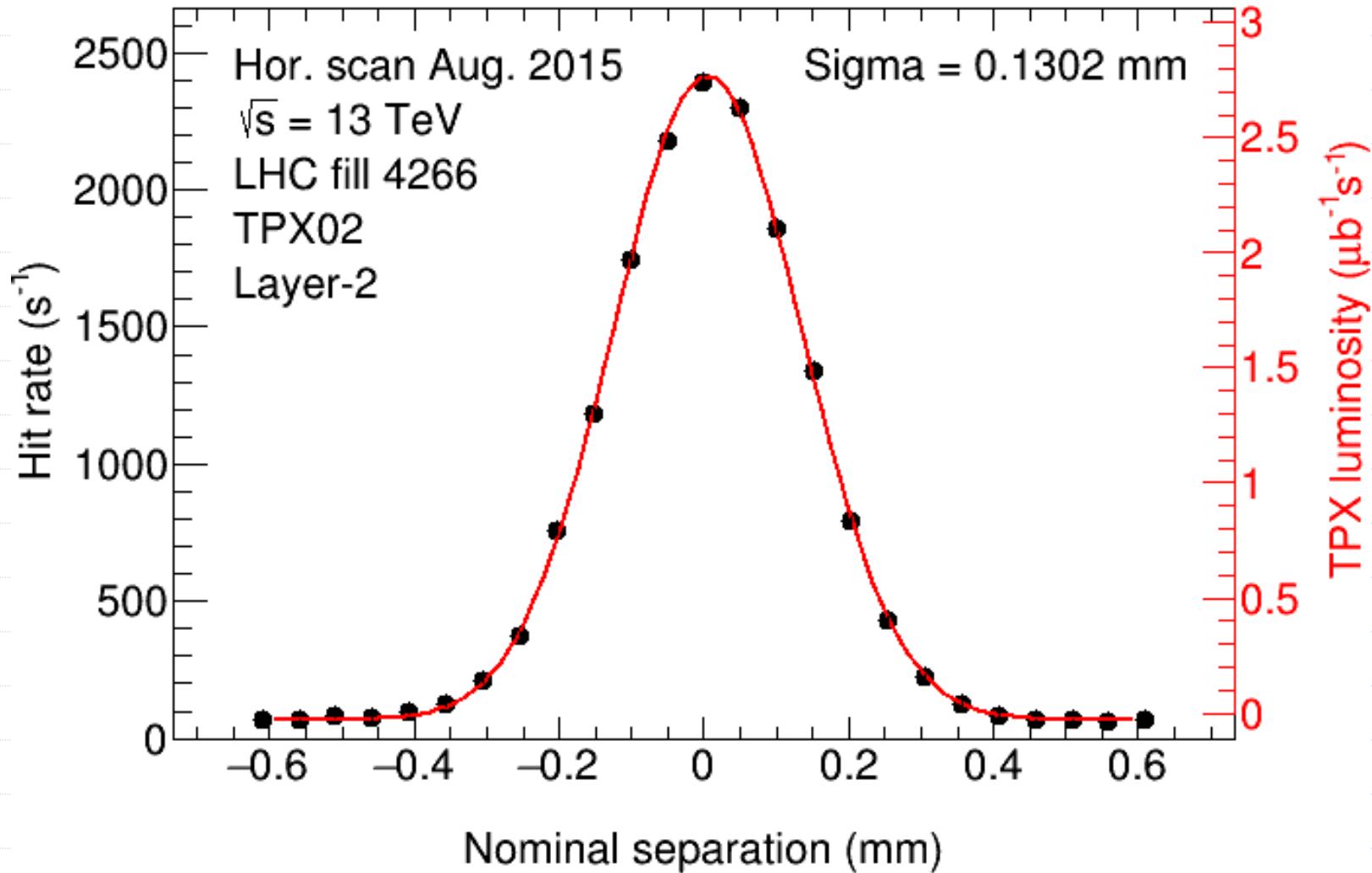
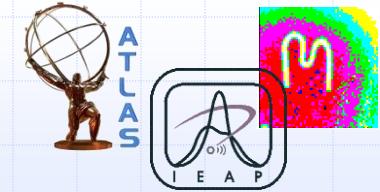
TPX device locations in the ATLAS cavern



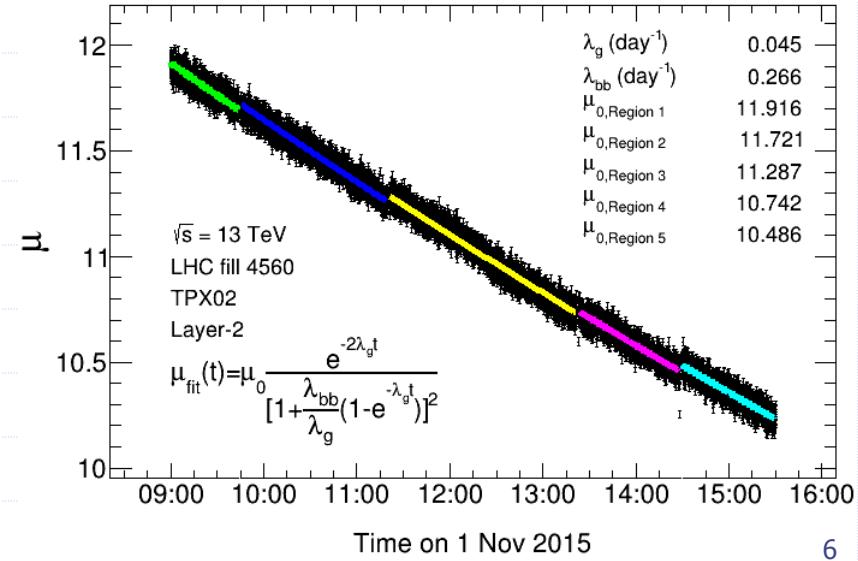
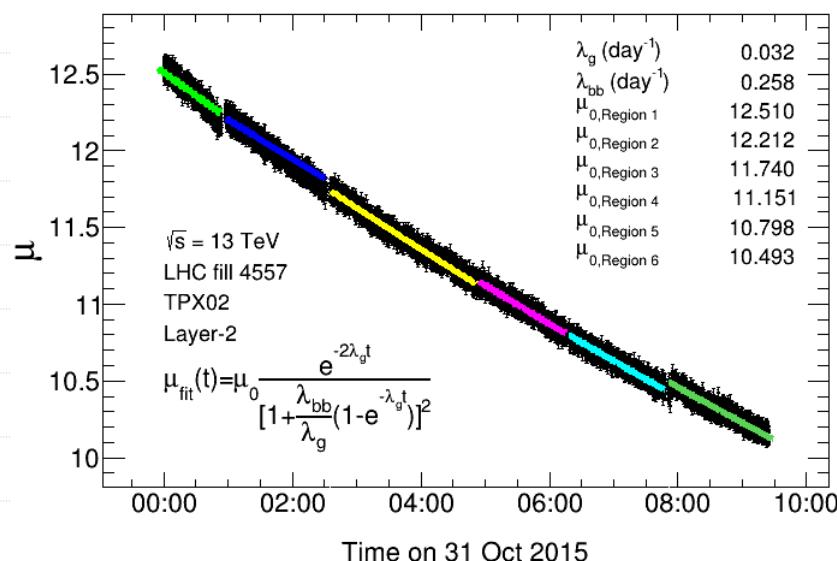
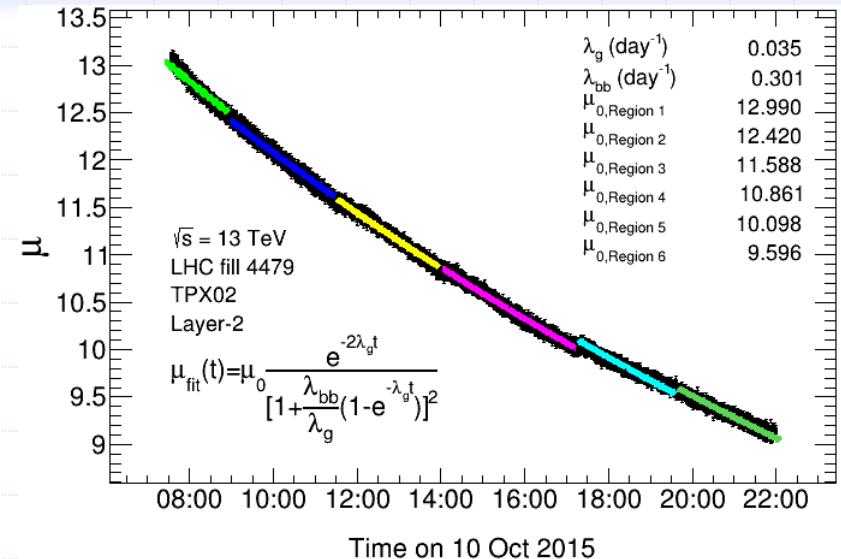
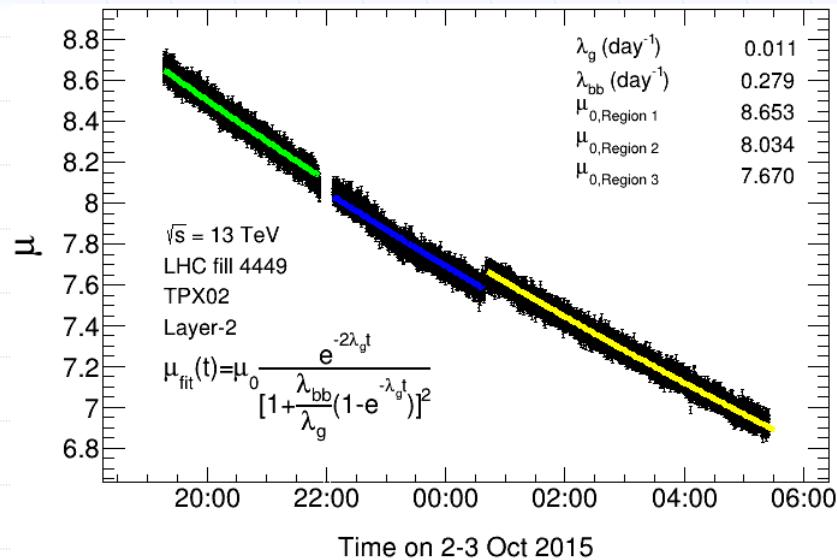
ATLAS
Detector



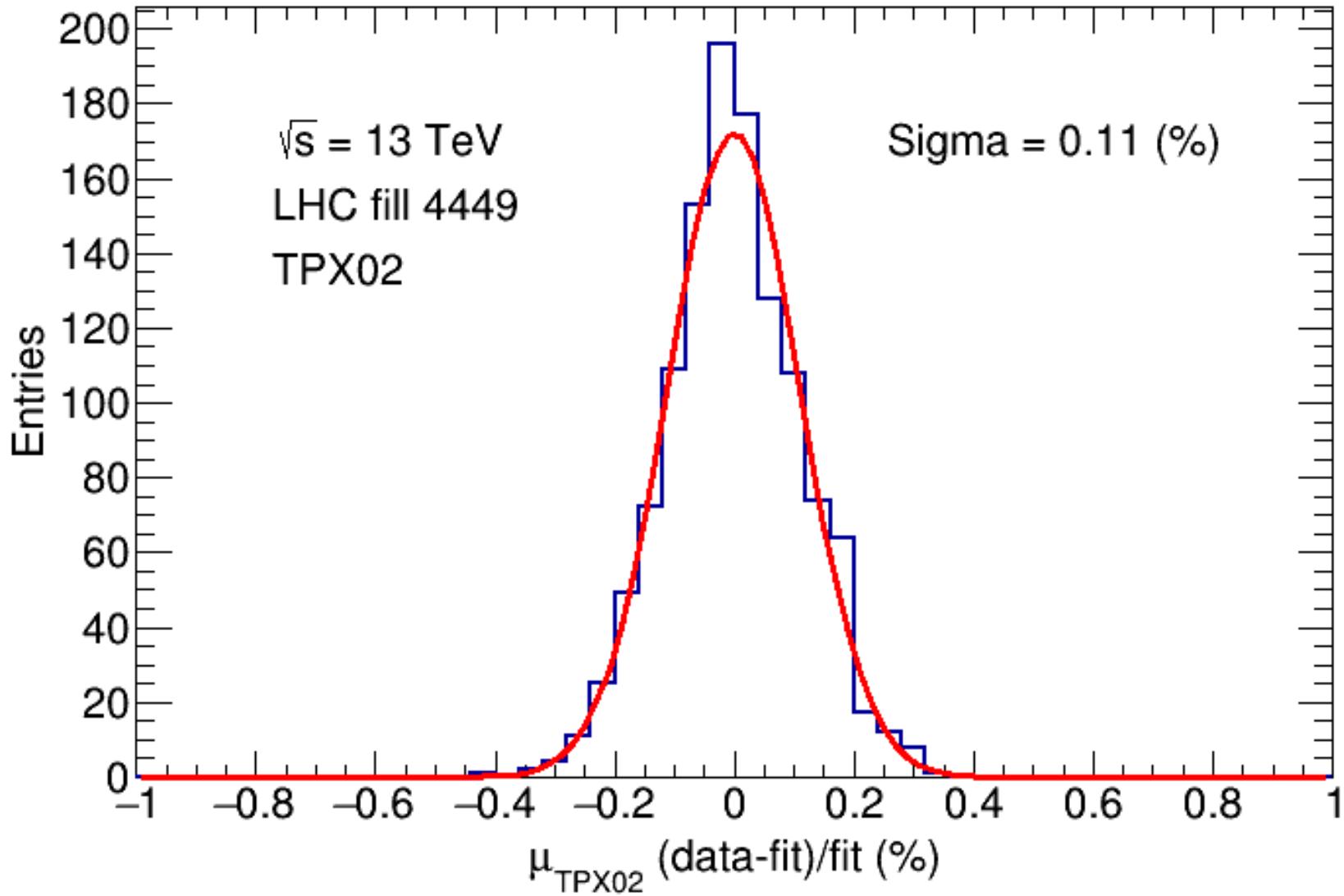
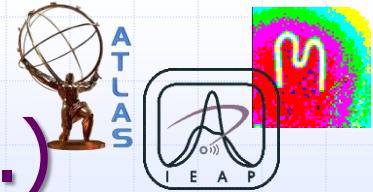
van der Meer scan peak (first horizontal scan in August 2015)



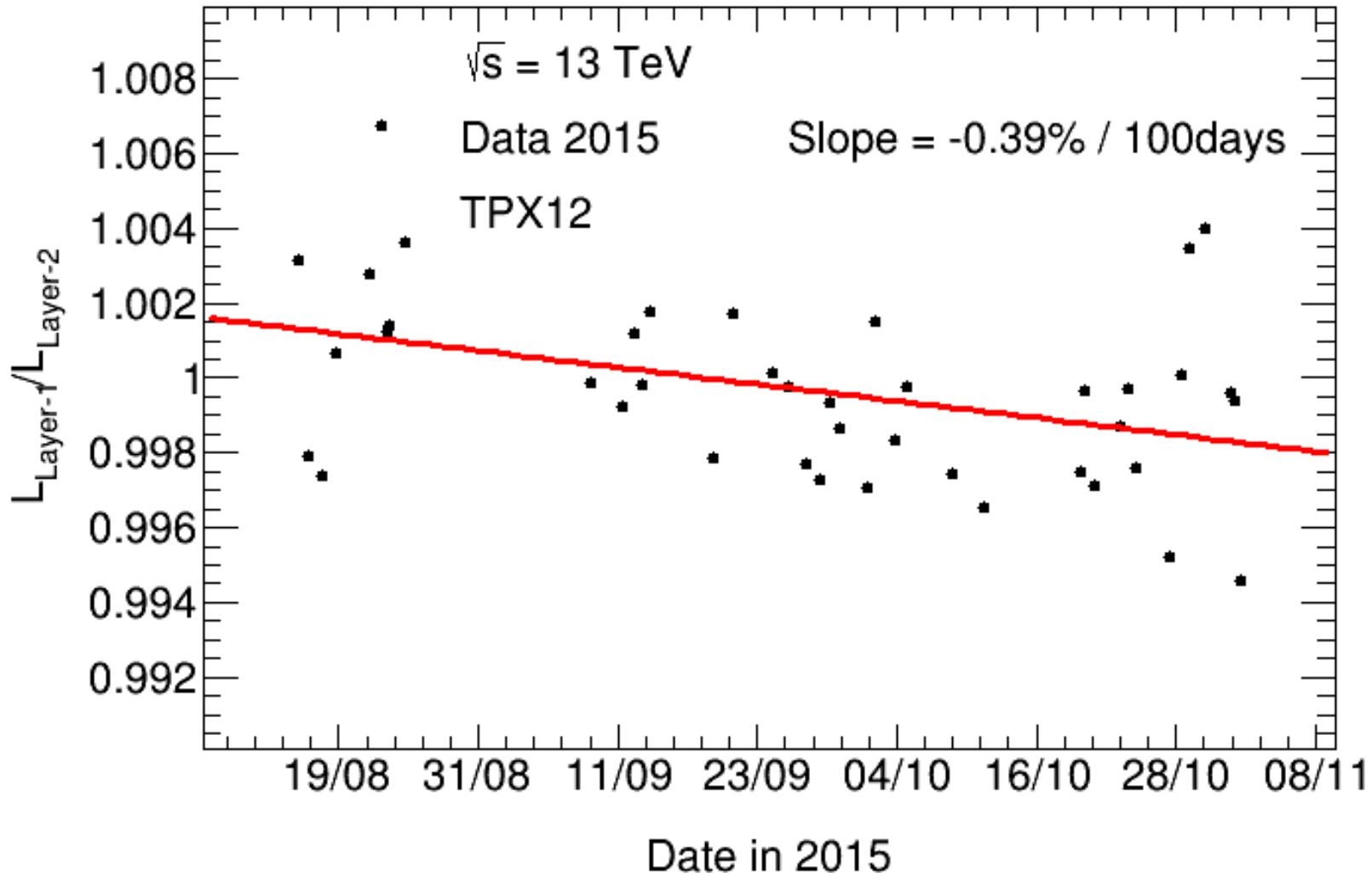
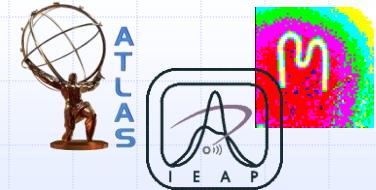
LHC luminosity curve: aver. number of interactions per bunch crossing μ



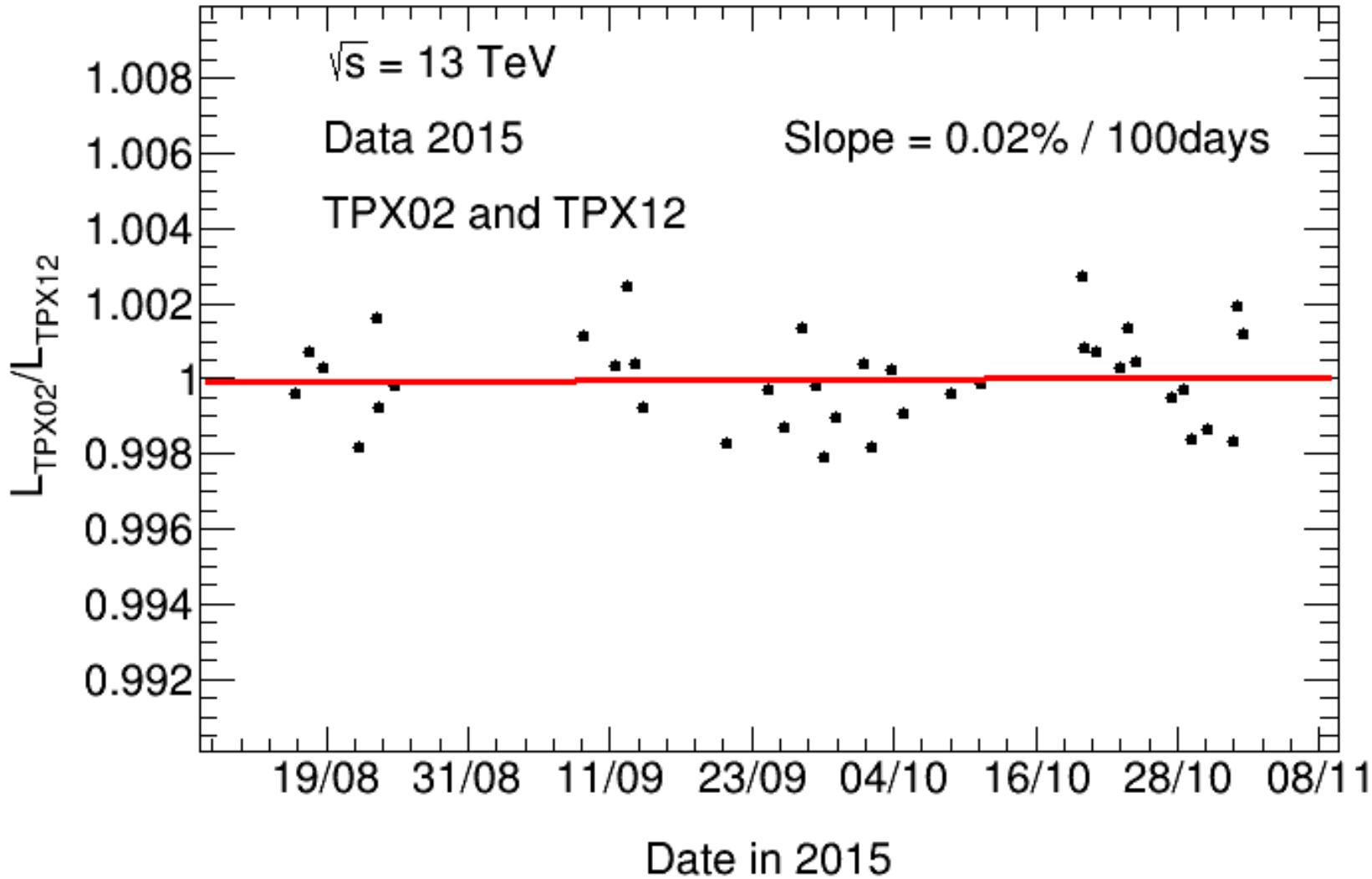
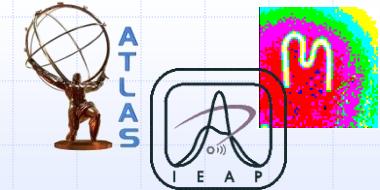
Internal precision wrt fit: 0.1% (aver. layers-1&2, 10 frames comb.)



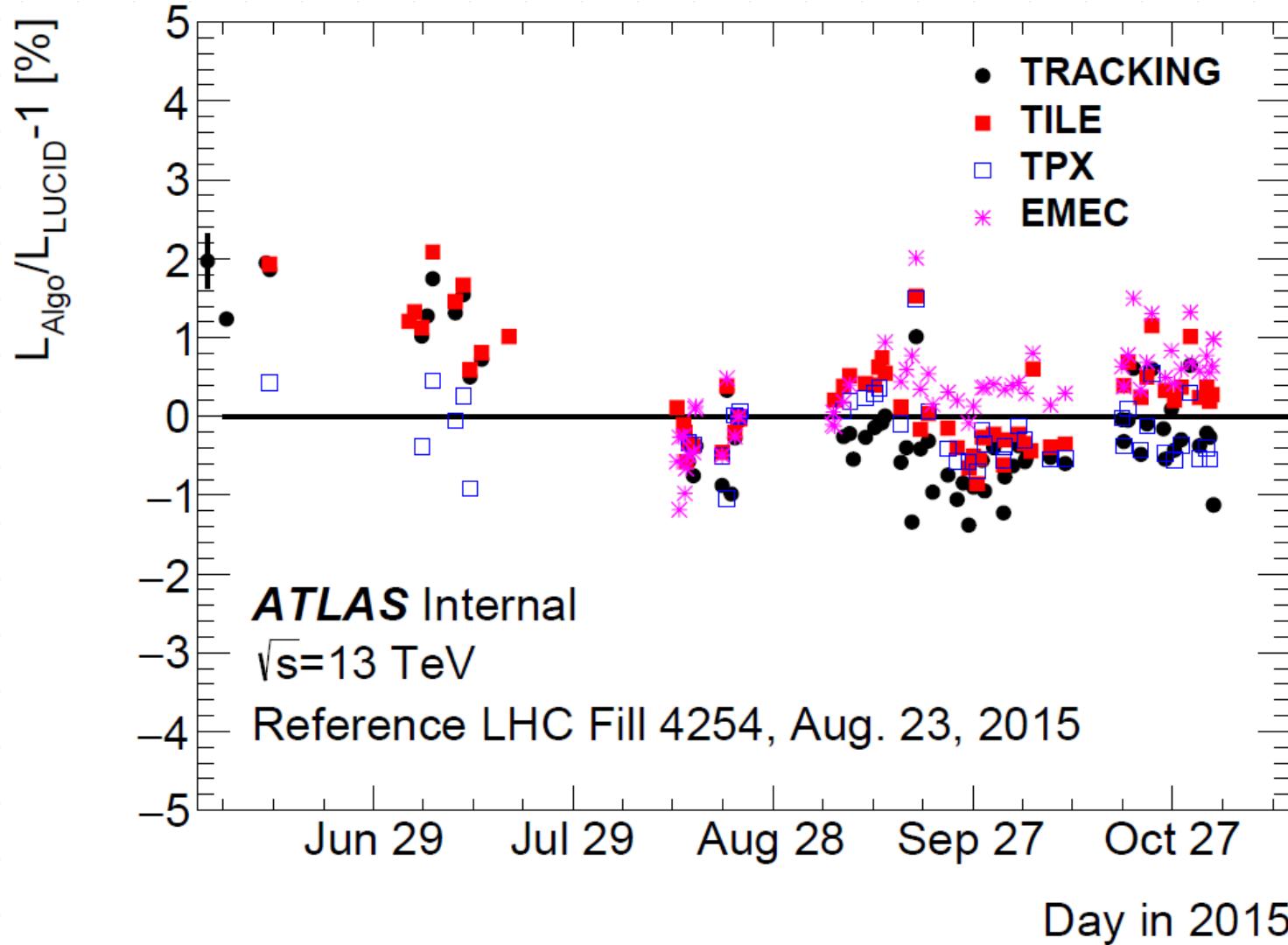
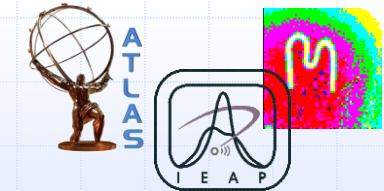
Long-term stability of individual TPX devices -0.4 to 0.6%/100days



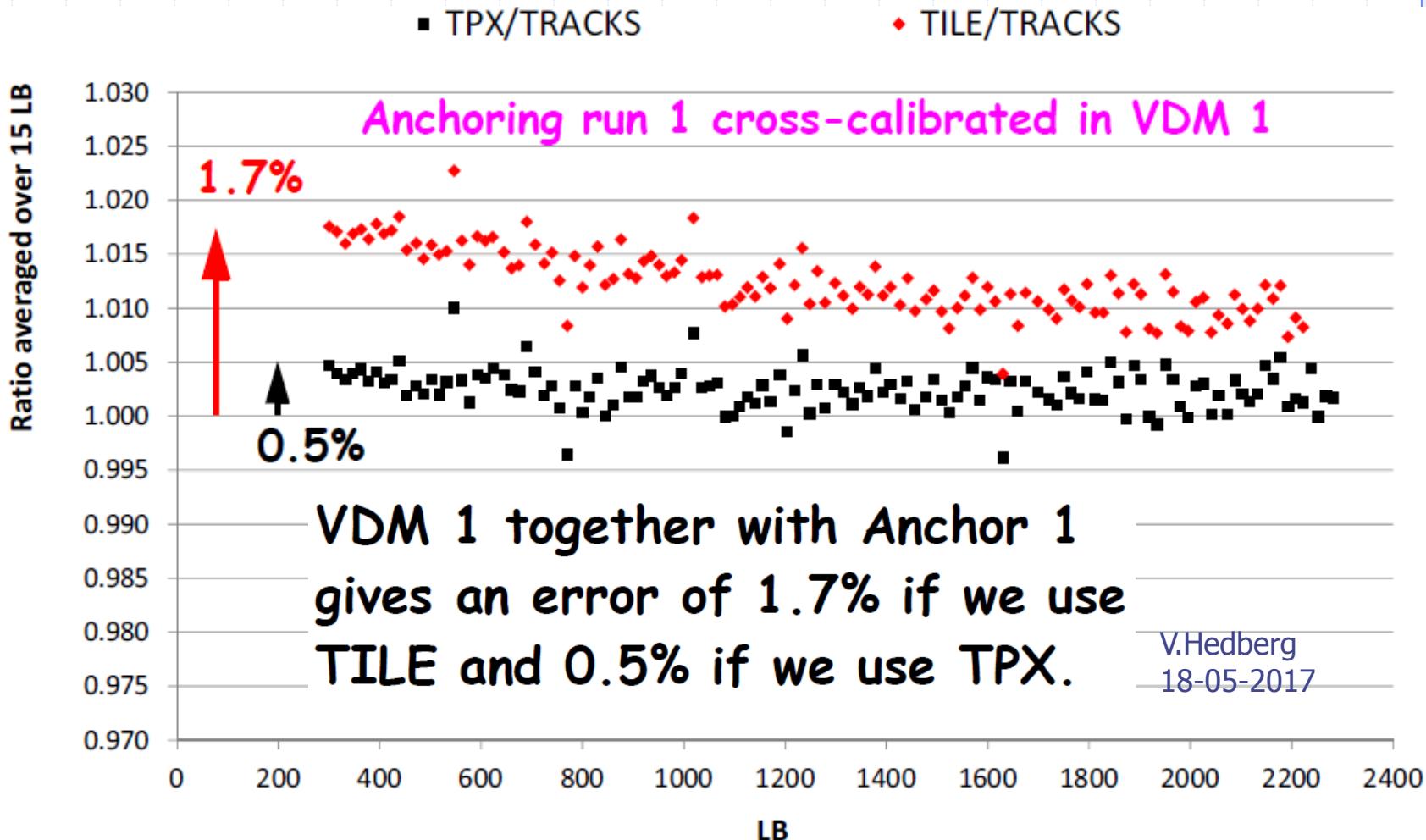
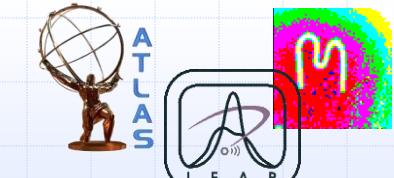
Long-term stability between different devices <0.5%/100days



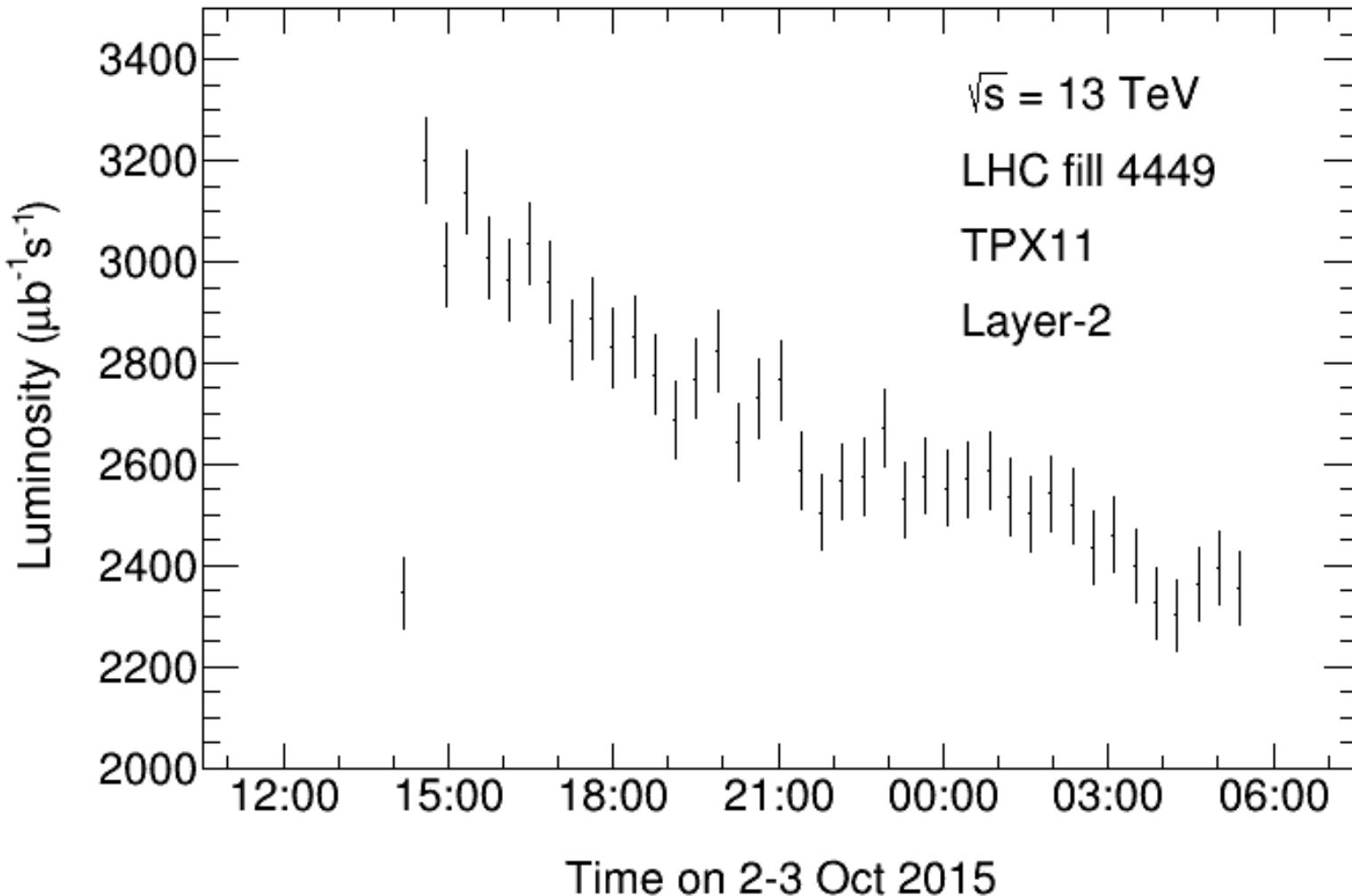
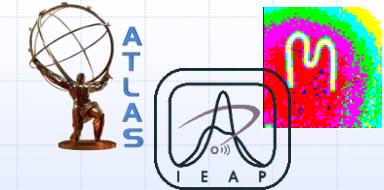
Long-term Stability of ATLAS Luminometers



Calibration Transfer Uncertainty Reduction from 1.7% to 0.5% by TPX Luminosity Measurements

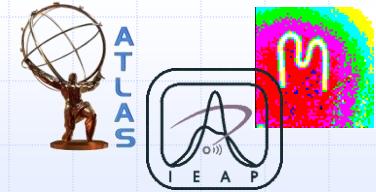


Thermal neutron luminosity, proof of principle



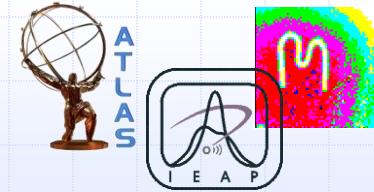
Simulation/Data (2015 examples)

Thermal Neutrons



Run Time Layer	Sim/Meas													
	TPX01	TPX02	TPX03	TPX04	TPX05	TPX06	TPX07	TPX08	TPX09	TPX11	TPX12	TPX14	TPX15	
2.-3.10.	1	3.57	-	4.92	13.47	9.39	9.90	12.08	11.56	13.34	4.12	-	13.77	56.43
	2	2.56	-	2.92	12.57	7.52	9.14	11.44	11.33	10.38	2.56	-	12.89	50.85
6.-7.10.	1	3.31	-	4.66	13.00	9.04	10.14	12.68	12.07	13.47	3.87	-	13.36	55.39
	2	2.41	-	2.76	12.22	7.31	9.43	11.97	11.72	10.60	2.39	-	12.47	52.79
9.-11.10.	1	5.38	-	3.40	10.94	9.62	8.39	10.70	10.39	12.03	6.44	-	11.34	56.11
	2	3.90	-	1.99	10.25	7.63	7.67	10.13	10.24	9.31	3.88	-	10.47	52.35
30.-														
31.10.	1	3.49	-	4.81	12.82	9.12	9.55	12.60	11.64	14.07	-	-	13.35	52.68
	2	2.48	-	2.78	12.10	7.29	8.74	11.71	11.29	11.09	-	-	12.51	47.91
31.10.- 1.11.	1	3.74	-	5.09	13.29	9.75	9.80	12.72	11.95	14.07	-	-	13.93	51.80
	2	2.65	-	2.98	12.59	7.82	9.05	12.07	11.70	11.23	-	-	12.89	48.48
20.7.	1	3.81	3.91	4.54	15.89	9.26	10.63	14.59	13.26	15.46	5.03	4.90	16.21	58.73
	2	2.79	2.75	3.25	15.04	9.76	11.02	12.91	13.09	12.31	3.45	3.24	15.94	41.38

Overview



□ 2015 Data

- TPX internal analysis 0.1% precision.
- TPX/ATLAS comparison, TPX has best stability among all ATLAS luminometers.
- Proof of principle that neutron luminosity can contribute.
- Simulation/data comparison well advanced. First: thermal neutron rates studies.
- Analysis of data for TPX01,03,04,06,07,08,09,11,12,14,15 for new analysers.

□ 2016 Data

- VdM analysis completed for TPX02/12.
- Noisy pixel removal crucial for precision. Large variations. Radiation damage study TPX02/12.
- Calibration transfer excellent with May data.
- After May, TPX02/12 slope wrt other ATLAS luminometers.
- Poor data quality compared to 2015, inclusion of TPX in ATLAS paper to be decided.
- Next milestone: IEEE Atlanta (3 accepted abstracts).
- Analysis of data for TPX01,03,04,06,07,08,09,11,12,14,15 for new analysers.

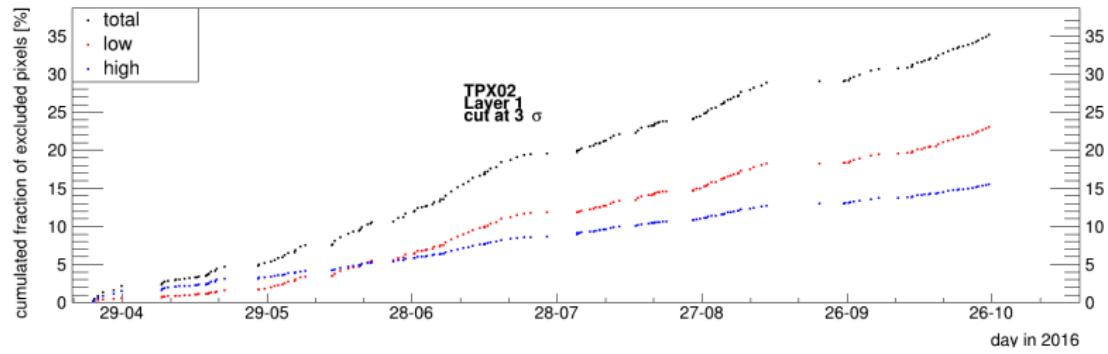
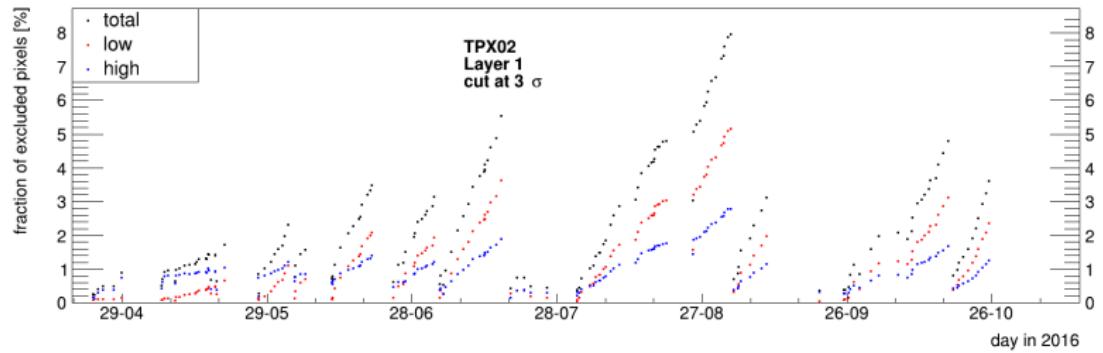
□ 2017 Data

- Since 3 July six devices recovered, including TPX02/12.
- Run coordination and data-quality control.
- Analysis of data from all devices for new analysers.

Part 2

- Introduction
 - Evolution of noisy pixels
 - Luminosity calibration
 - Normalization factors from vdM scan
- Internal consistency
 - Detailed investigation of individual runs Layer1/Layer2
 - Table of runs with observations
 - Luminosities of individual sensors (2 devices, 2 layers), before/after corrections
 - Layer1/Layer2 long-term stability before corrections
 - Layer1/Layer2 long-term stability after corrections
 - Layer1/Layer2 long-term stability best of 4 combinations TPX02/TPX12
- Study of pixel consistency
 - Hits versus individual pixels per run
 - Pull distributions per run
- Comparison with LUCID, TRACKING, TILE
 - Example runs
 - Correction for luminosity slope
 - Long-term stability

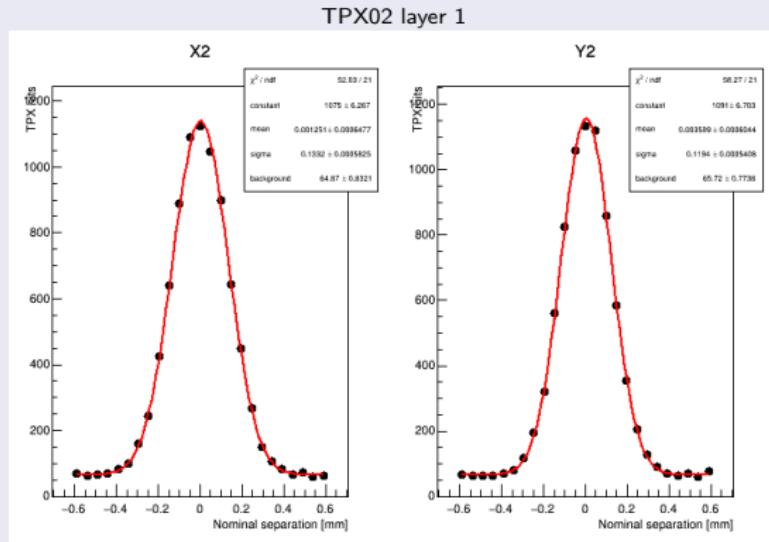
Noisy pixels - TPX02



Luminosity calibration

$$L = \frac{n_b N_{p1} N_{p2} f}{2\pi \Sigma_x \Sigma_y}$$

n_b : number of colliding bunches
 N_{p1}, N_{p2} : number of protons in each bunch
 f : revolution frequency
 Σ_x, Σ_y : transverse size of the bunch on the x and y direction



Normalization factors

vdM scan 27 May 2016 (run 300287)

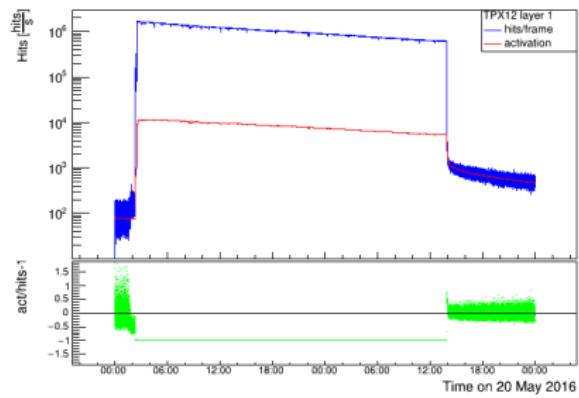
TPX	Layer	Σ_x (μm)	Σ_y (μm)	L_{specific} ($\mu\text{b}^{-1}\text{s}^{-1}/10^{22}$)	N_{peak} (hits/s)
02	1	133.2	119.4	0.1125	1083
02	2	134.1	120.9	0.1104	1649
12	1	133.5	121.1	0.1107	941
12	2	132.2	121.3	0.1116	1623
		average		0.1113	
		variance		6.992e-7	
		$\sqrt{\text{variance}}$		0.000836	

Uncertainty ($\sqrt{\text{variance}}/\text{average}$): 0.75%

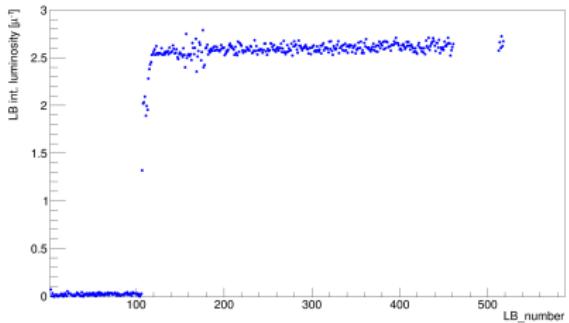
Normalization factors	Device	Layer	$1/n_f$ (hits/ μb^{-1})
	TPX02	1	400.6
	TPX02	2	621.7
	TPX12	1	353.7
	TPX12	2	605.4

Calibration transfer

activation: run 299584



"flat region" in vdM run 300287 - TPX02 layer 1



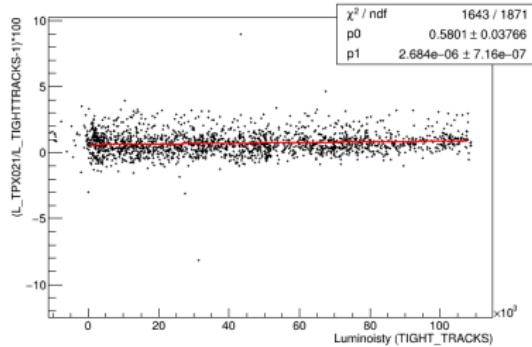
bad pixels removal at 3σ using data until end of July 2016

data corrected for activation

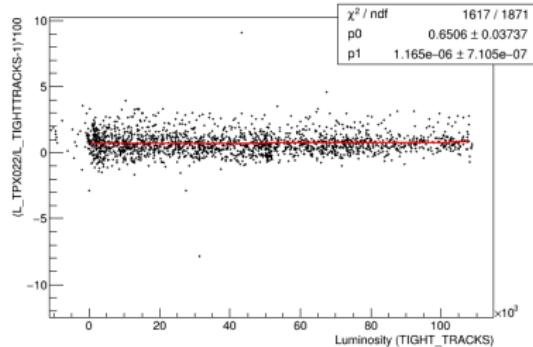
TPX/TRACKING vs Luminosity: no μ -dependence

Run 299584 - norm. TIGHT_TRACKS in run 299390

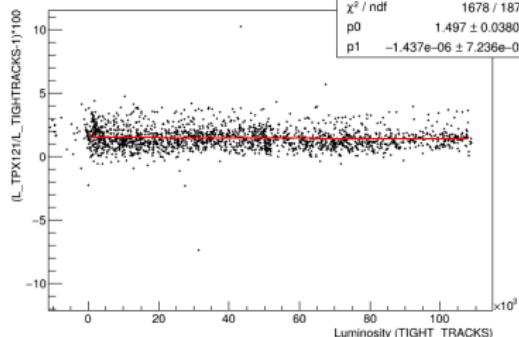
TPX02 layer 1



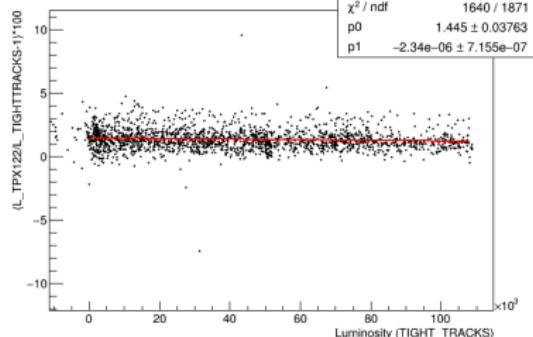
TPX02 layer 2



TPX12 layer 1

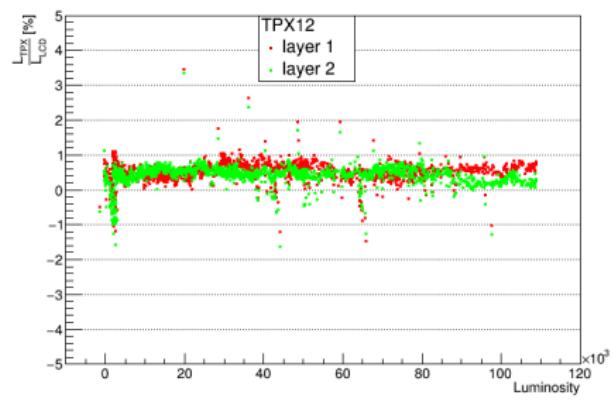
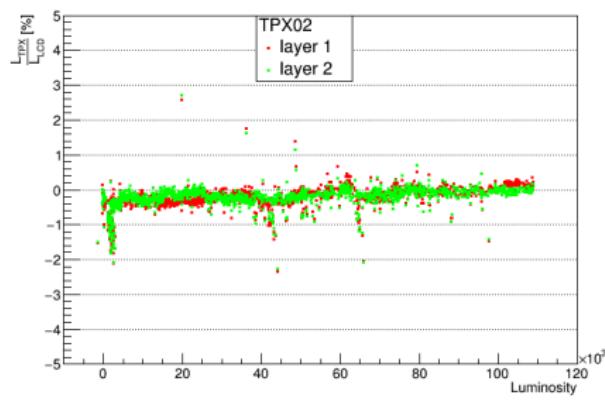


TPX12 layer 2

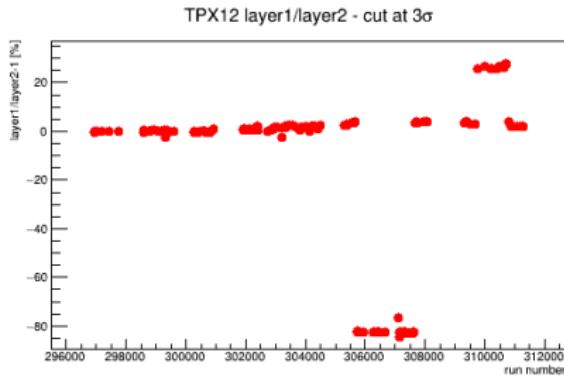
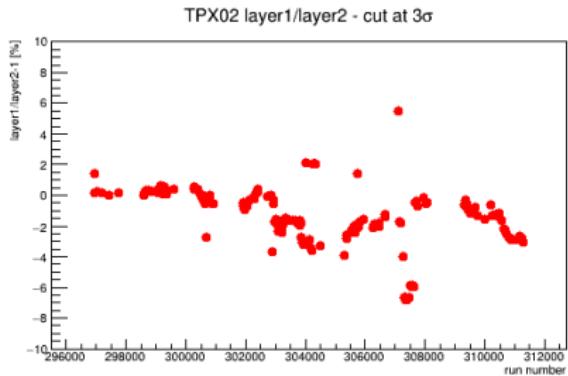


Calibration transfer - run 299584

Normalized to LUCID ORA_BI in the first vdM fill (299390)

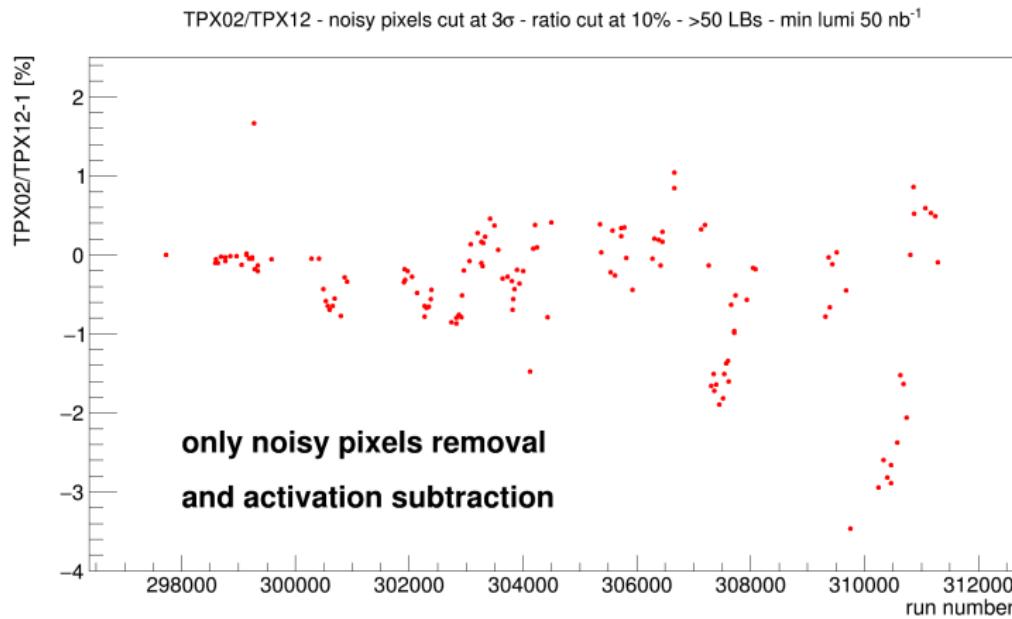


Layer1/Layer2 - Before internal corrections

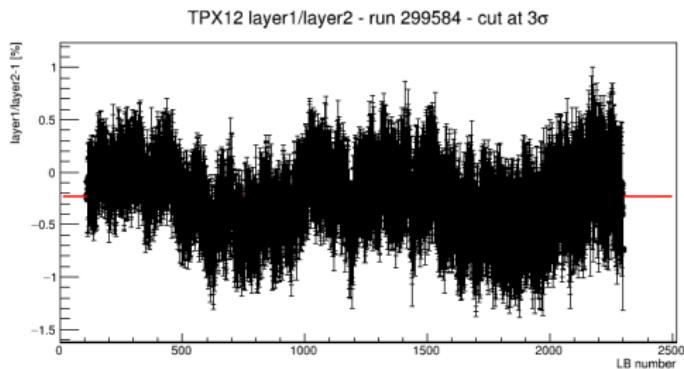
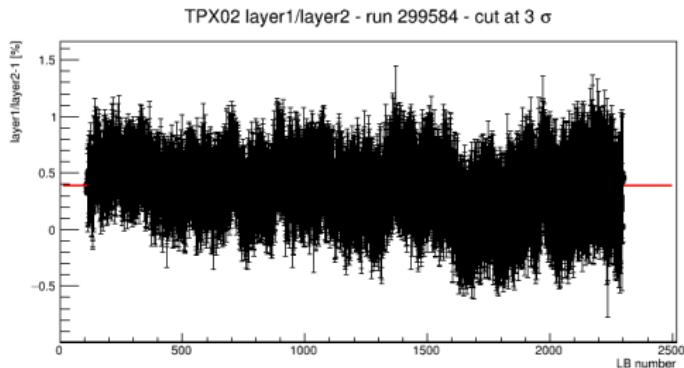


TPX02/TPX12 - Before internal corrections

Taking the best TPX02/TPX12 ratio: LB-by-LB, the difference among the 2 layers of TPX02 and TPX12 is evaluated (4 possibilities), and the layers corresponding to the minimum are chosen

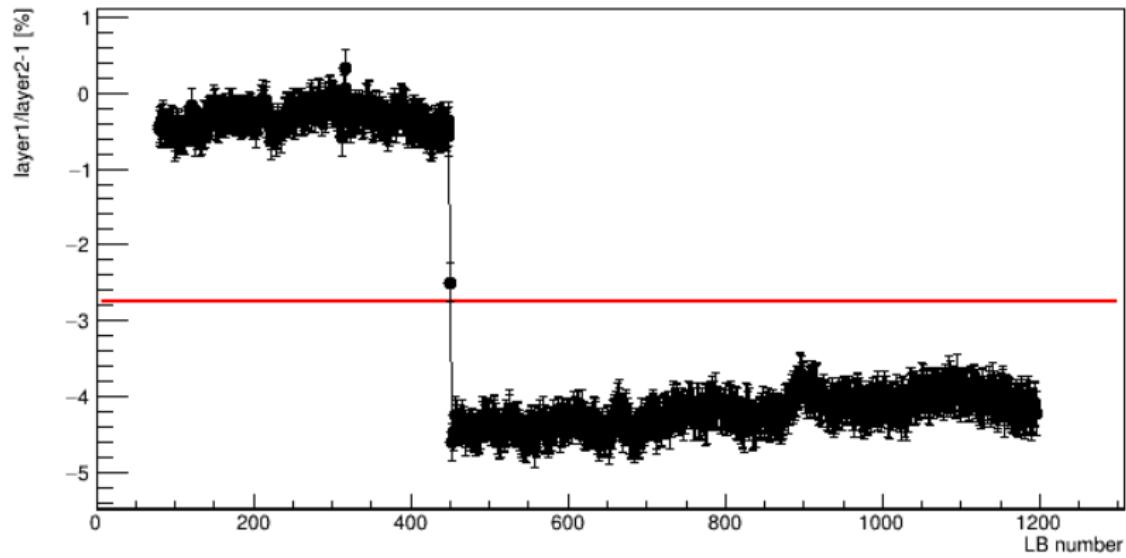


Layer1/Layer2 - Run 299584 (good)

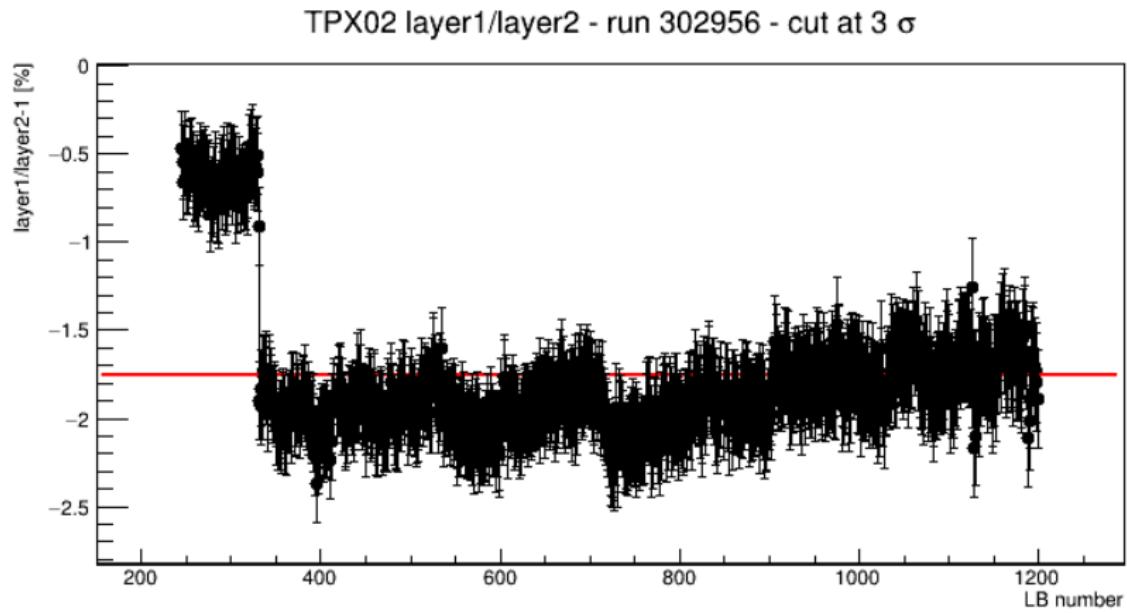


Layer1/Layer2 - Run 300687

TPX02 layer1/layer2 - run 300687 - cut at 3 σ

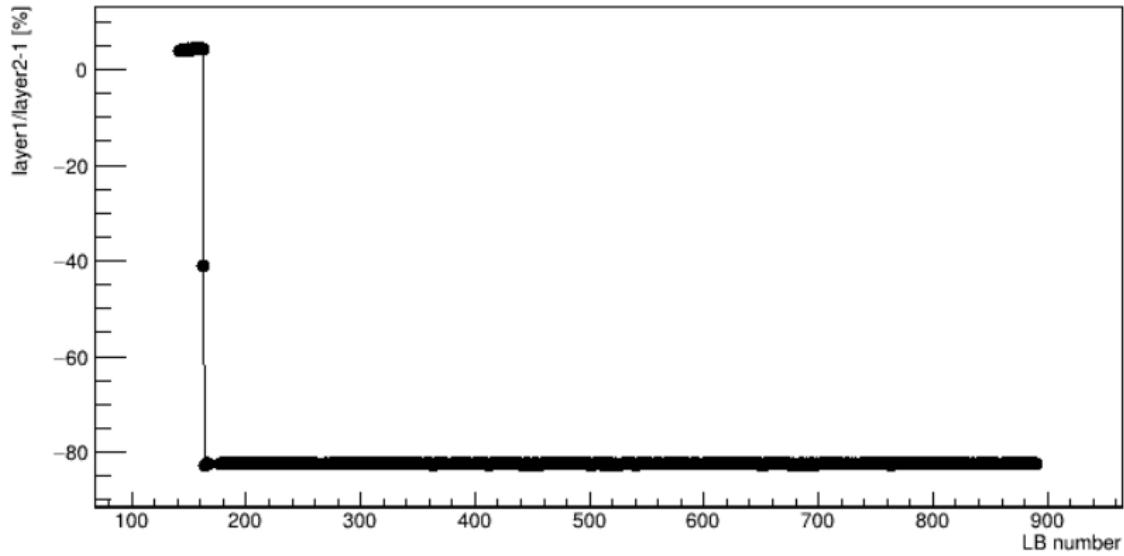


Layer1/Layer2 - Run 302956

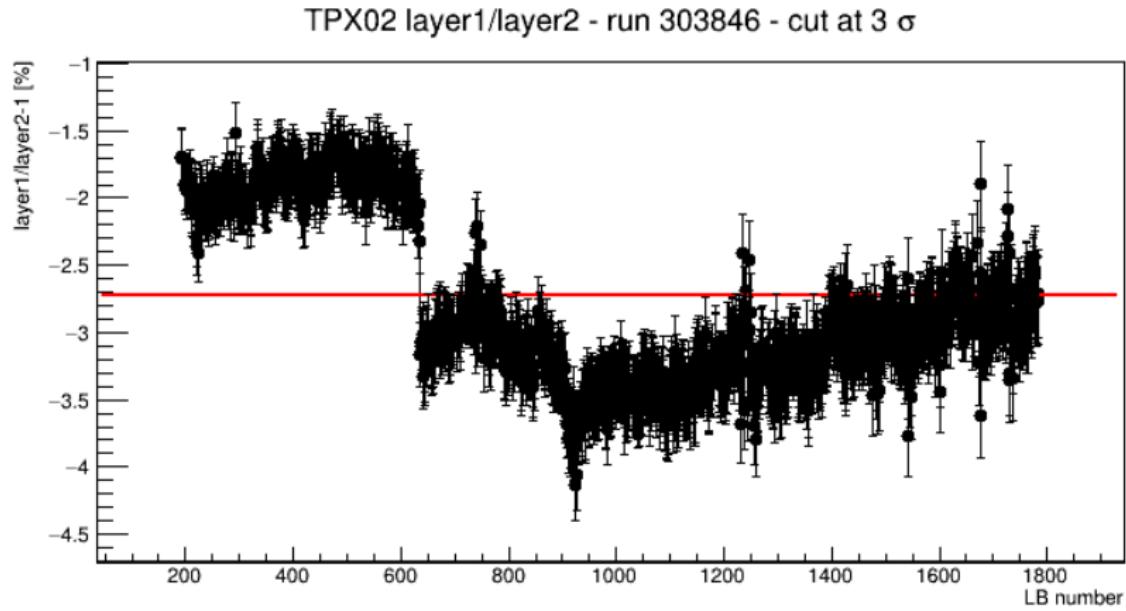


Layer1/Layer2 - Run 305723

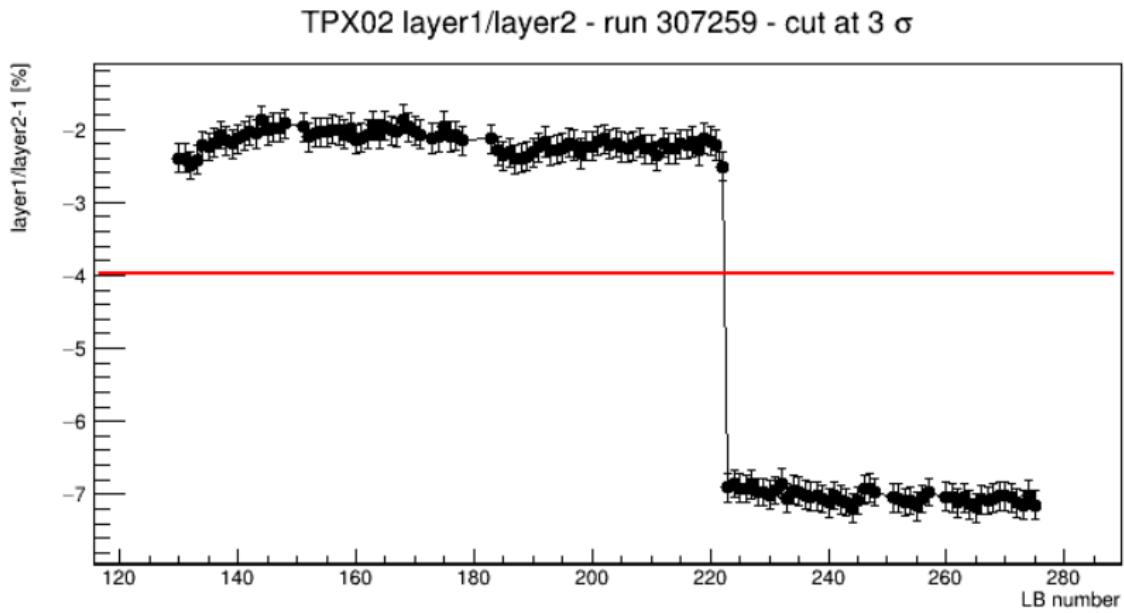
TPX12 layer1/layer2 - run 305723 - cut at 3σ



Layer1/Layer2 - Run 303846



Layer1/Layer2 - Run 307259



Observation of each of the ~ 200 runs

run	comment
296942	LB 274 off 70%
299315	many jumps
299391	many gaps (vdM scan)
299584	nice
300287	many gaps/jumps (vdM scan)
300687	LB 450: jump
302347	trend 1%
302393	trend 0.8%
302872	big jump at LB 1719, restart (?) 2000
302956	LB 331: -1.5% (then all at -2%)
303059	-1.4% \rightarrow -2.4%
303208	-2% \rightarrow -3.2%, gap
303291	gap
303421	-1% \rightarrow -2.5%
303817	only 3 LBs
303846	LB 635: jump -2% \rightarrow 3%
304178	gap

run	comment
304243	LB 707: 300% up
304409	very high .../noisy?
304431	very high .../noisy?
300415	nice
304258	only 3 LBs
305293	only 3 LBs
305359	LB 250: -10%
305777	from -2.7% to -1.8%
306384	-1.4% \rightarrow -2.2%
307259	LB 222: -2% \rightarrow -7%
307514	LB 445: -6% \rightarrow 5%
307619	\rightarrow -6%
307656	\rightarrow 0%
307732	LB 1111: -1.5% \rightarrow -0.5%
309314	LB 264: gaps
309346	LB 156: gaps
309375	strange
309440	LB 418

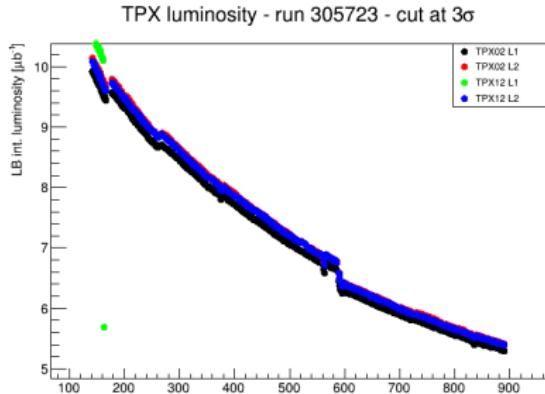
Corrections

Procedure: make the ratio L1/L2 the same before/after the jump

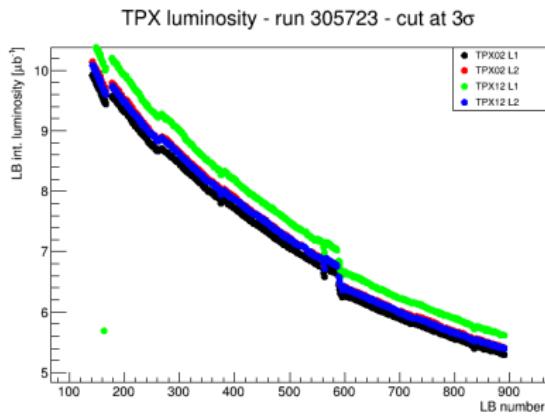
sensor	time range	correction
TPX02 L2	from run 307259 LB 223 to run 307619 LB 256	L2 multiplied by 0.950226
TPX12 L1	from run 305723 LB 163 to run 307619 LB 256	L1 divided by 0.167052
TPX12 L2	from run 309759 LB 172 to run 310738 LB 1039	L2 multiplied by 1.22254
TPX12 L2	from run 304128 LB 128 to LB 1146	L2 multiplied by 0.9768315
TPX02 L2	from run 310634 LB 403	L2 multiplied by 0.9923297

Luminosity

Before correction

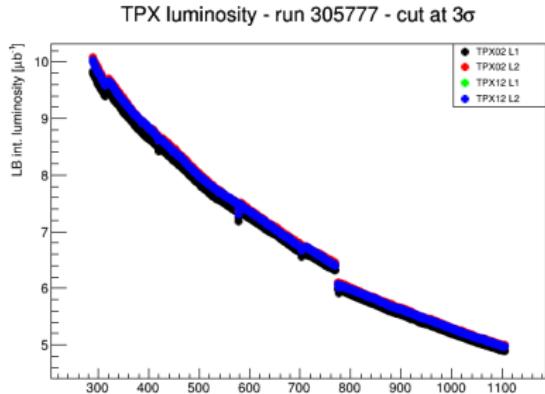


After correction

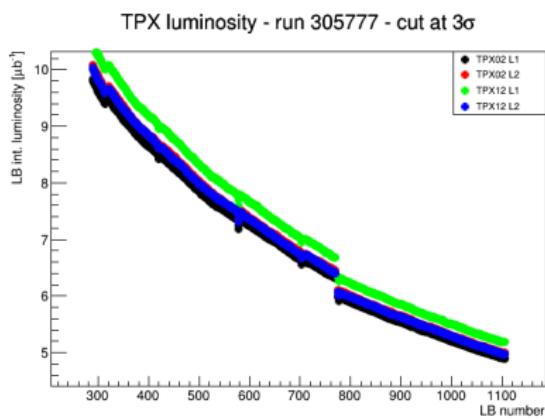


Luminosity

Before correction

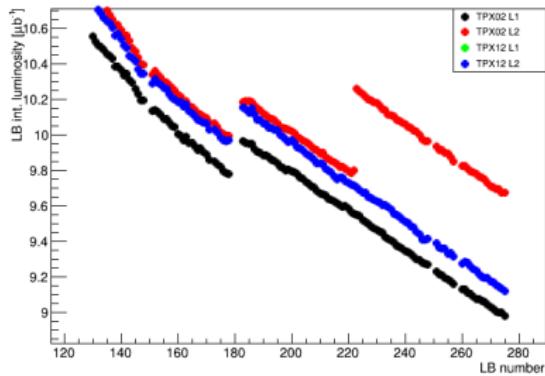


After correction



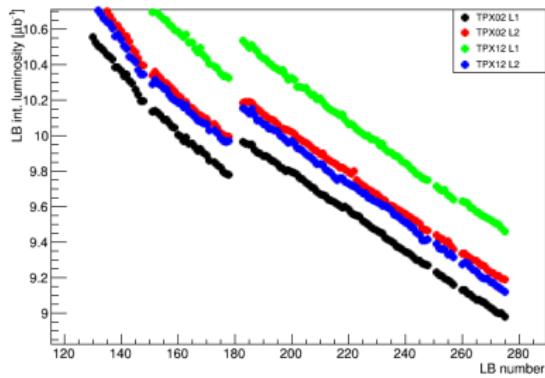
Luminosity

TPX luminosity - run 307259 - cut at 3σ



Before correction

TPX luminosity - run 307259 - cut at 3σ

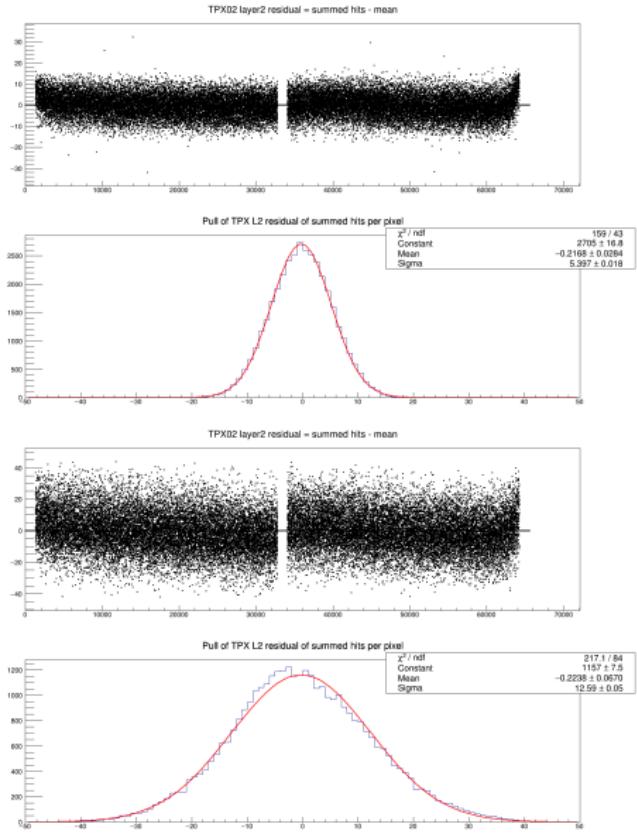
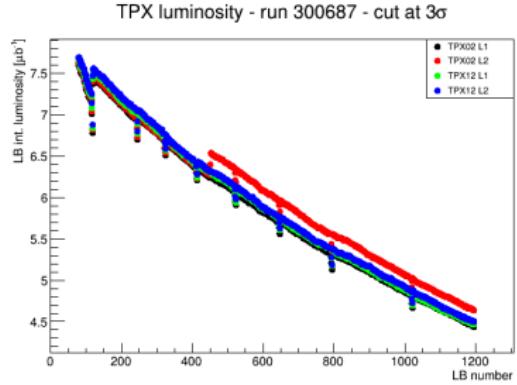


After correction

Evolution in hit counting stability

Stability in hit counting is investigated. Correlation between instabilities (e.g. TPX02 layer 2 in run 300687 at 450 LB shown here) and pull defined as

$$Pull = \frac{\text{hits} - \text{mean}}{\sigma_{\text{stat}}} \text{ is seen.}$$



Studying the pull

Evaluating the systematic uncertainty

$$Pull = \frac{hits - mean}{\sigma_{stat}}$$

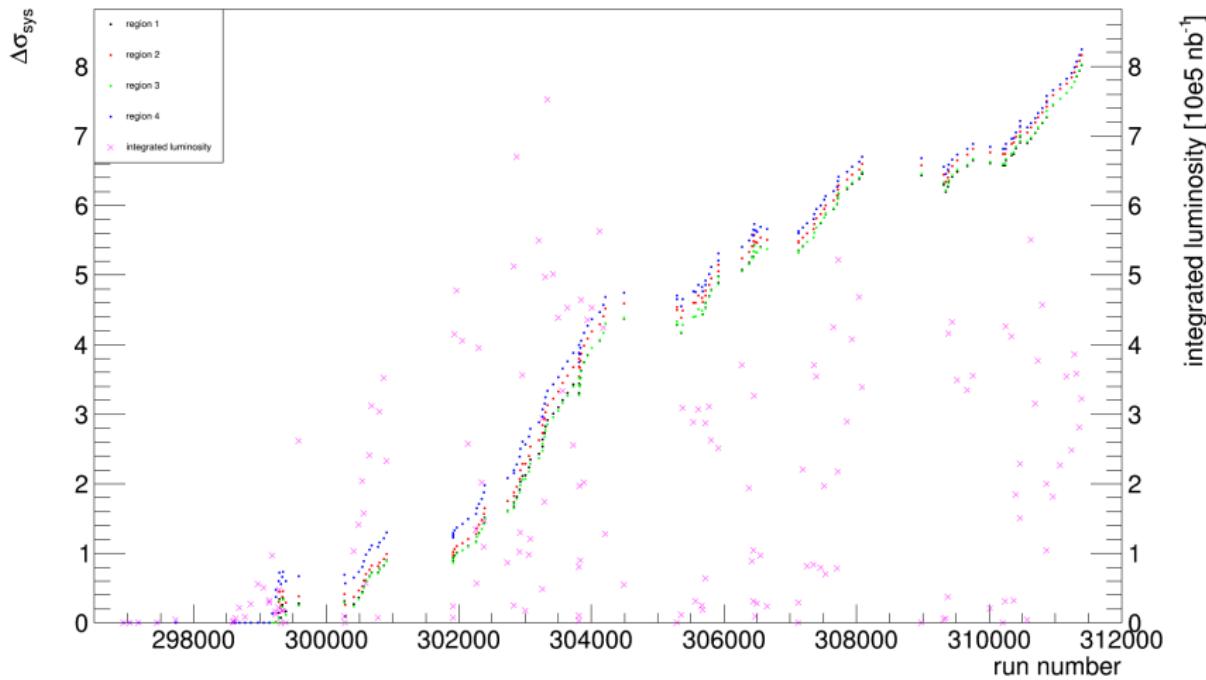
$$\sigma_{Pull} = \sqrt{\sigma_{stat}^2 + \sigma_{sys}^2}$$

For each run:

$$\sigma_{sys} = \sqrt{\sigma_{Pull}^2 - 1}$$

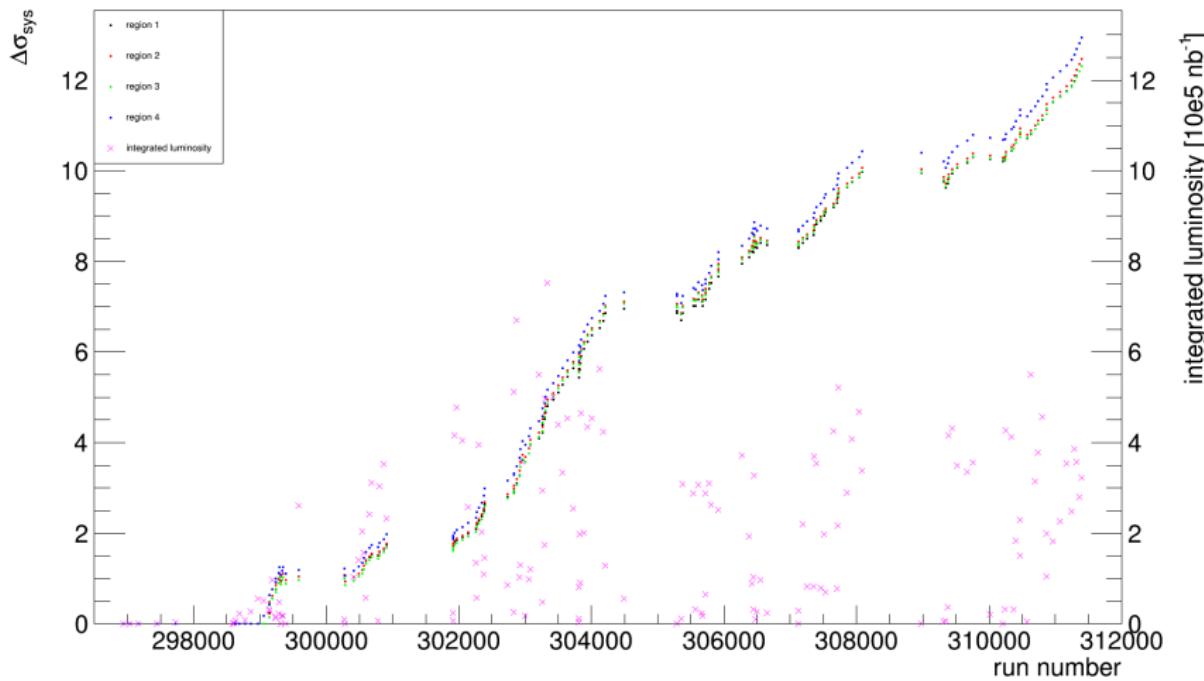
Pull - TPX02 Layer 1

Relative systematic uncertainty - TPX02 L1



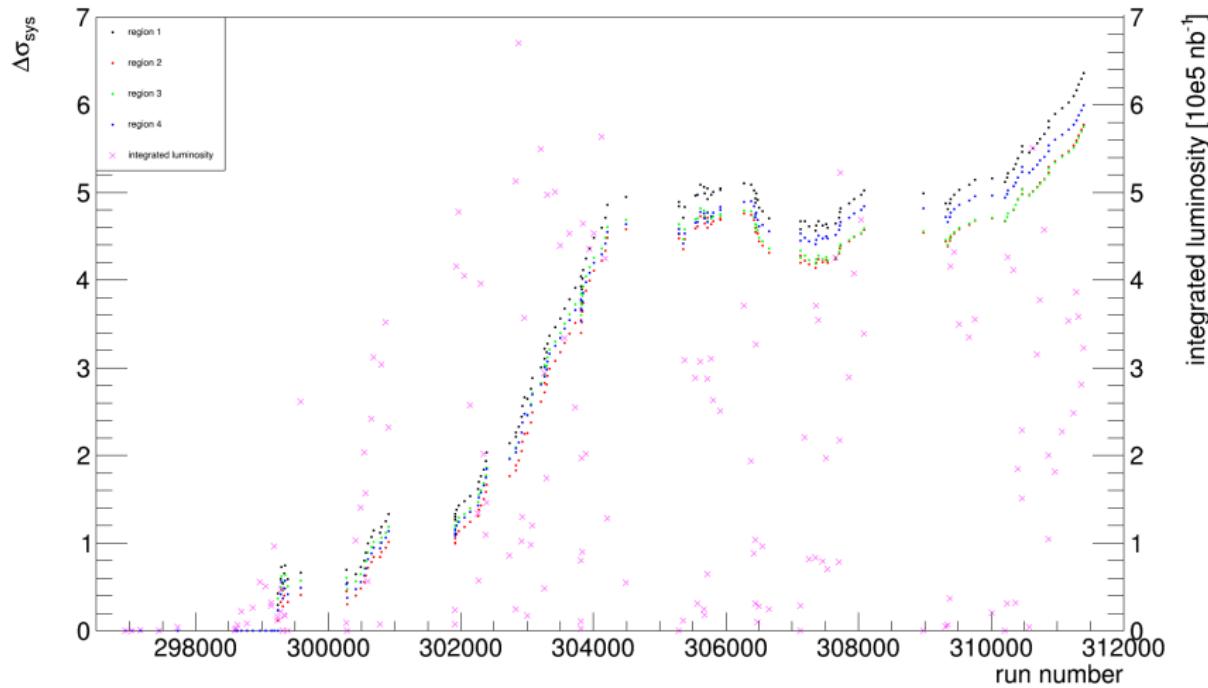
Pull - TPX02 Layer 2

Relative systematic uncertainty - TPX02 L2



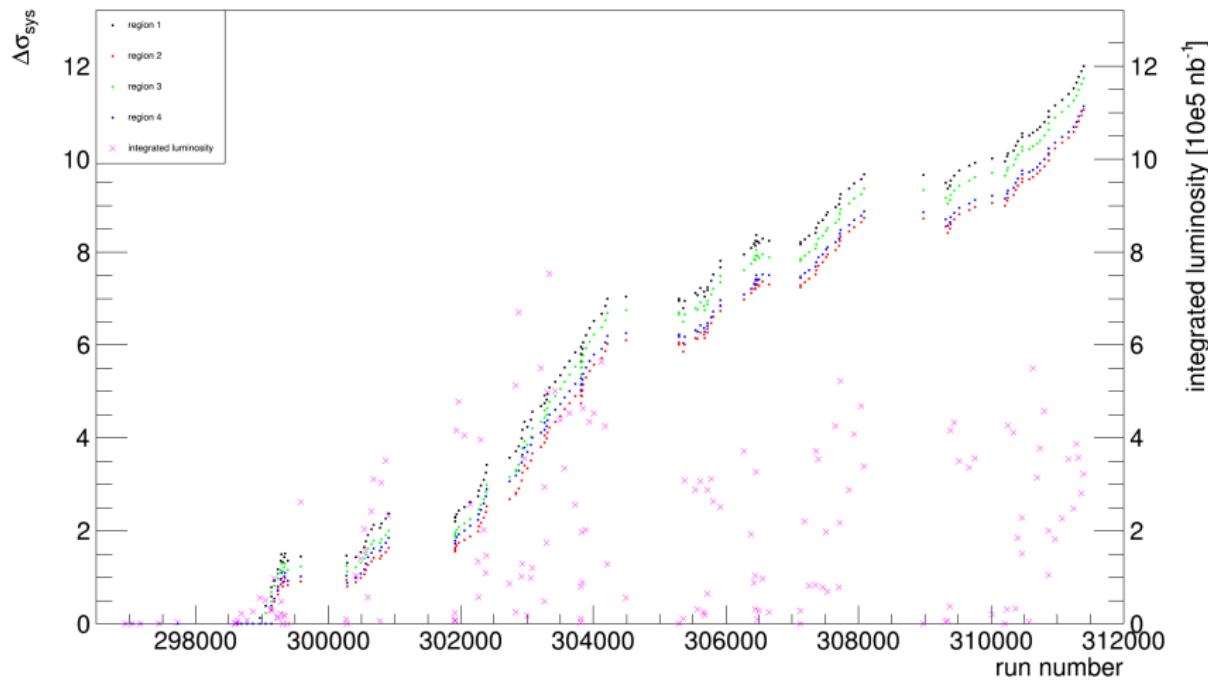
Pull - TPX12 Layer 1

Relative systematic uncertainty - TPX12 L1



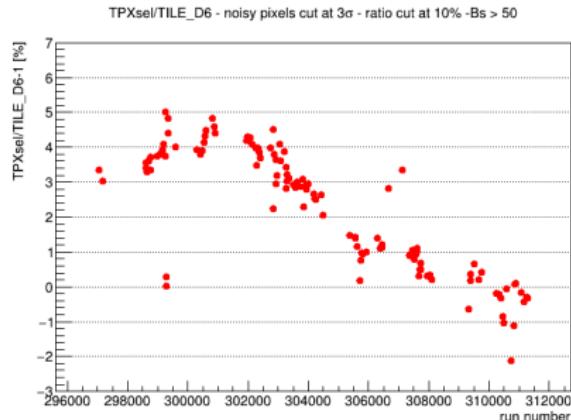
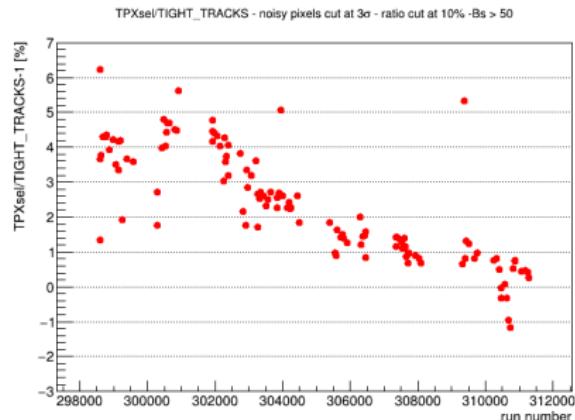
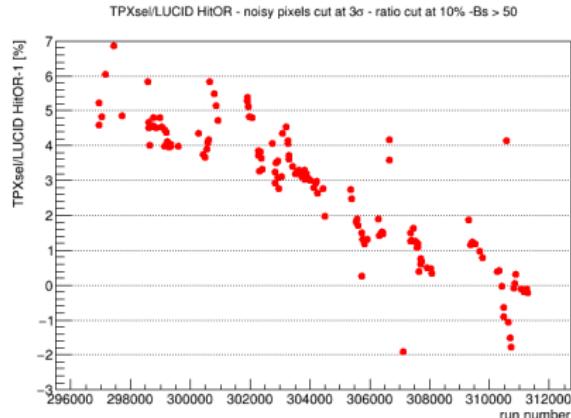
Pull - TPX12 Layer 2

Relative systematic uncertainty - TPX12 L2



TPX luminosity slope wrt ATLAS luminometers

TPX luminosity (best combination of 4 sensors)
shows a slope when compared to the other
luminometers



TPX luminosity slope correction

Luminosity slope is corrected using the fit parameters of a 1-order polynomial:

$$L' = \frac{L}{1 + \frac{p_0 + p_1 \cdot (t - t_0)}{100}}$$

where $t_0 = 1461365420$ is the start time (epoch, i.e. seconds from 1970-01-01) of the first run (296939), t the start time of each run, and the factor 100 accounts for the percent in the graphs.

The fit parameters are evaluated using as reference the algorithms LUCID_HitOR, TIGHT_TRACKS and TILE_D6
("PerLB_IntegratedLumi_XXXXXX_MuCorrTracks_CalibCorr.dat", 7th June 2017).

The fit parameters are evaluated individually for each sensor and for the best of the 4 combinations as summarized in the table in the following slide.

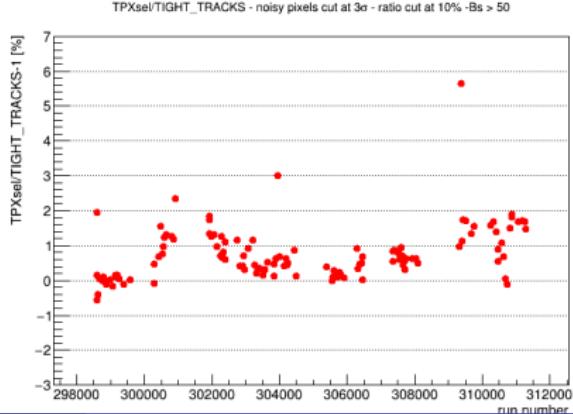
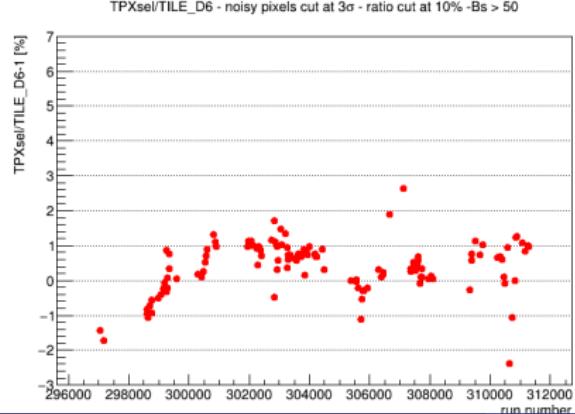
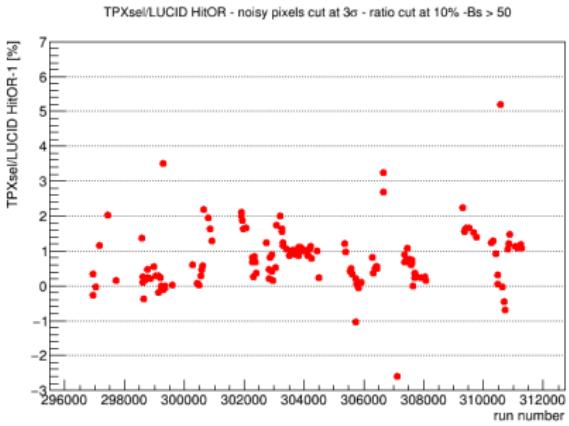
The correction is performed using the average over the 3 reference algorithms.

TPX luminosity slope correction

	reference	p_0	p_1 units of 10^{-7}
TPX02 layer 1	LUCID	5.17	-4.62
	TRACKING	4.22	-3.68
	TILE	4.15	-4.05
	average	4.51	-4.12
TPX02 layer 2	LUCID	5.21	-3.20
	TRACKING	4.35	-2.61
	TILE	4.30	-2.89
	average	4.62	-2.90
TPX12 layer 1	LUCID	5.40	-1.01
	TRACKING	4.62	-0.62
	TILE	4.51	-0.62
	average	4.84	-0.75
TPX12 layer 2	LUCID	5.71	-3.70
	TRACKING	4.88	-3.04
	TILE	4.80	-3.27
	average	5.13	-3.34
best combination	LUCID	5.53	-3.89
	TRACKING	4.60	-3.82
	TILE	4.57	-4.02
	average	4.90	-3.91

TPX/Ref - Selected sensors

After luminosity slope correction (using the best combination of 4 sensors)

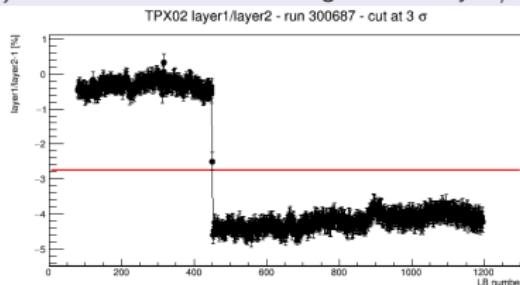


Summary of corrections

In the next slides, 4 plots per slide are shown:

1) each sensor corrected for noisy pixels and activation only

2) each sensor corrected for changes in ratio layer1/layer2:



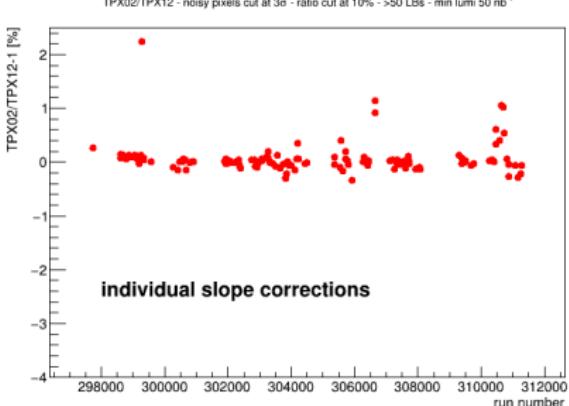
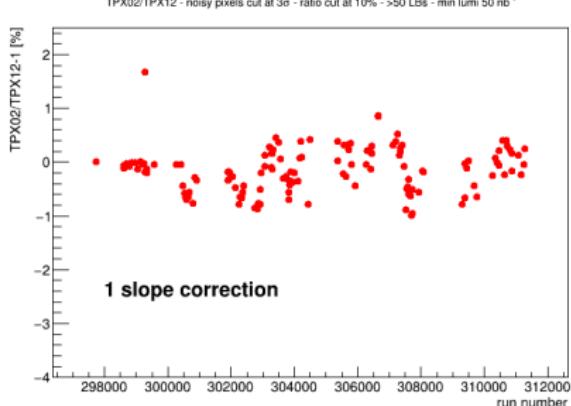
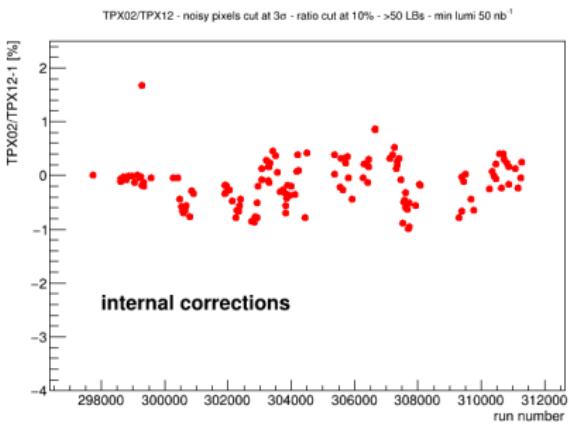
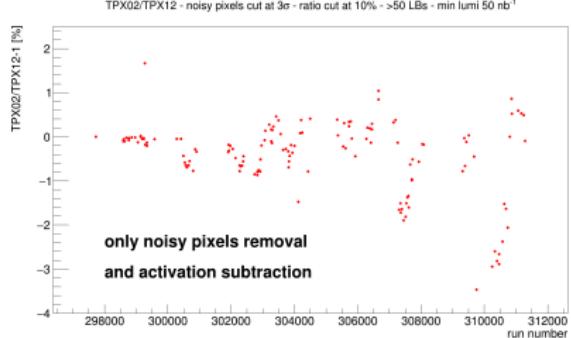
3) each sensor corrected for luminosity slope, using the best combination of the 4 sensors

4) each sensor corrected for luminosity slope, using individual sensors separately

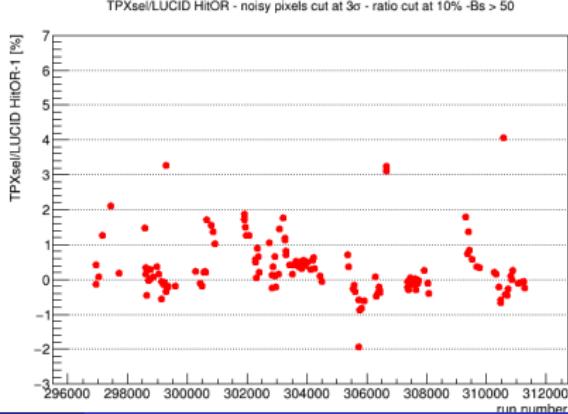
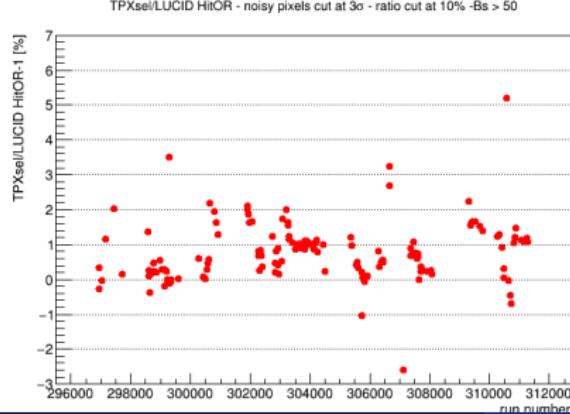
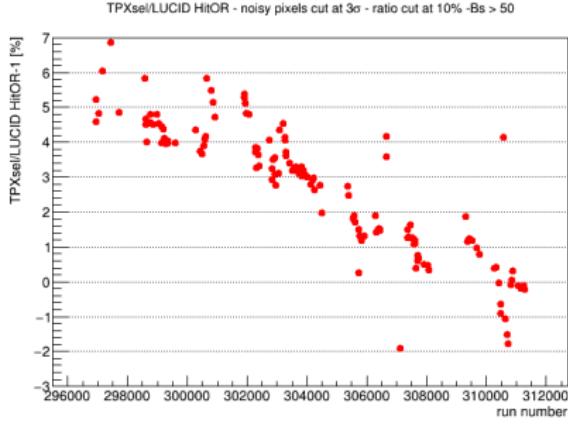
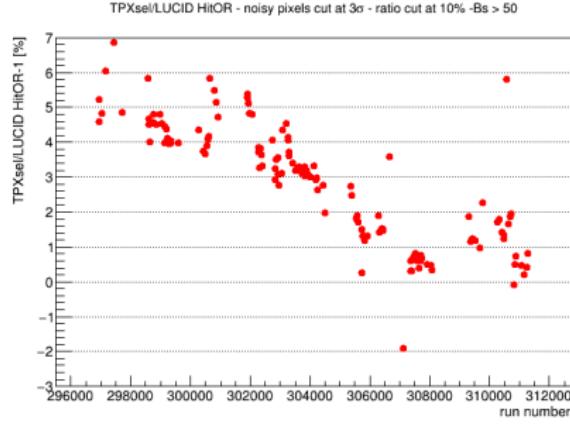
Step (2) includes the corrections of step (1), steps (3) and (4) include the corrections of both steps (1) and (2)



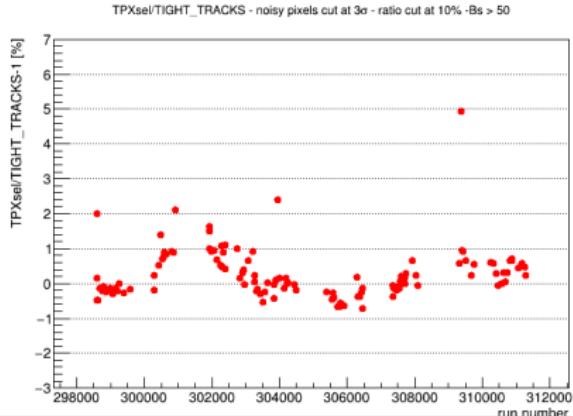
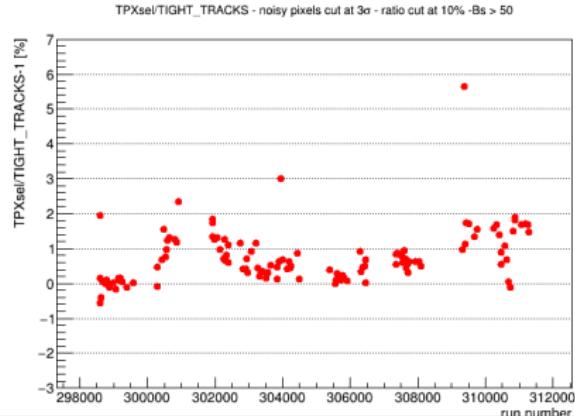
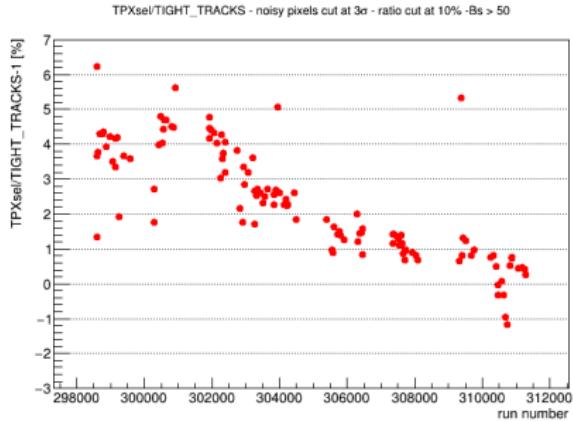
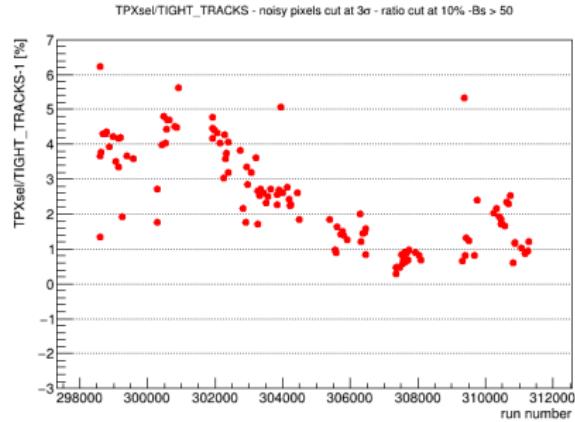
TPX internal



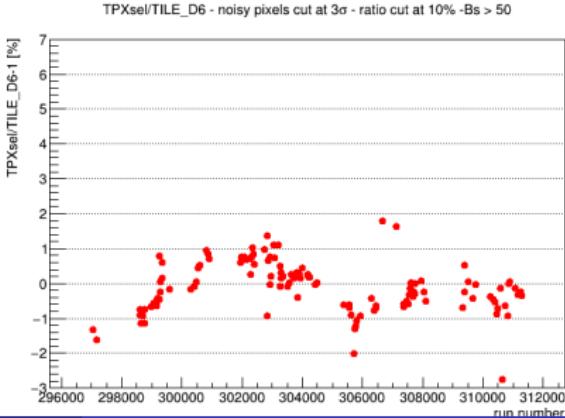
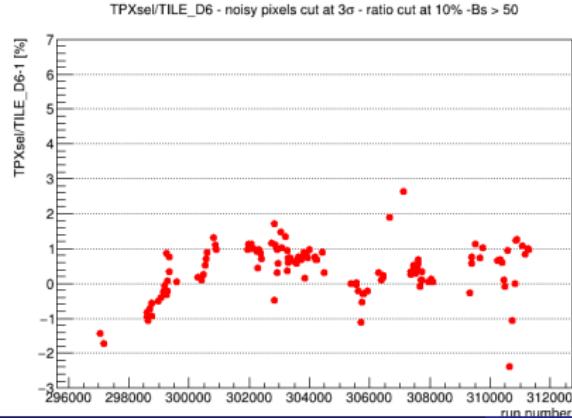
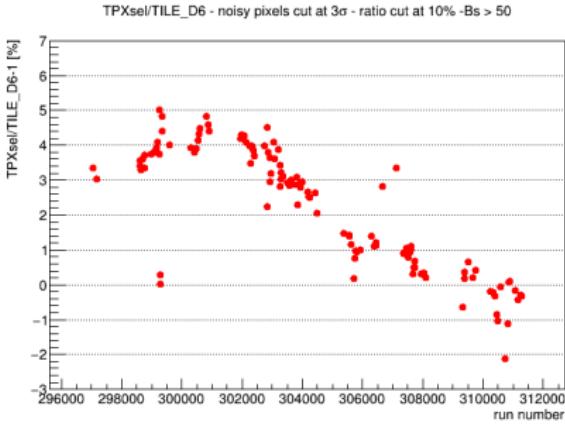
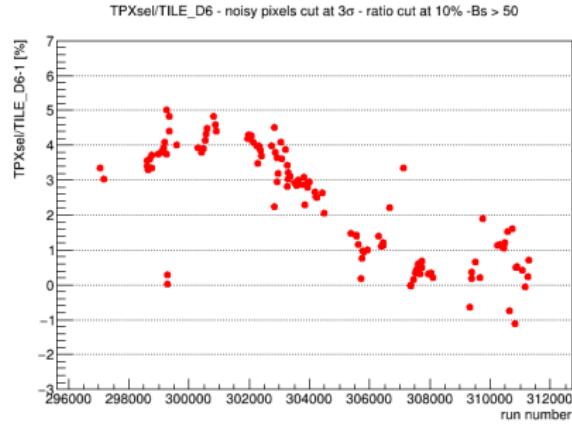
TPX best combination/LUCID



TPX best combination/TRACKING

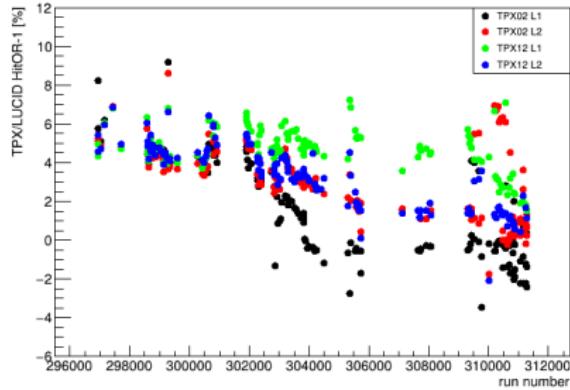


TPX best combination/TILE

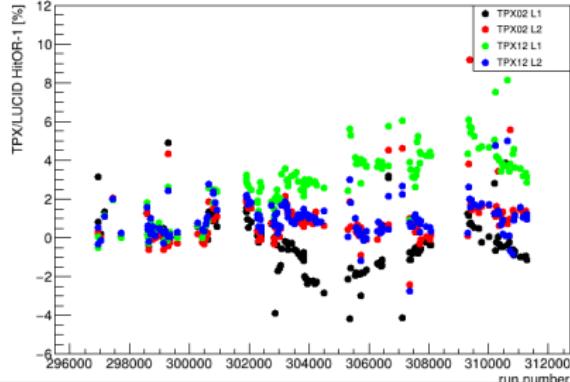


TPX/LUCID

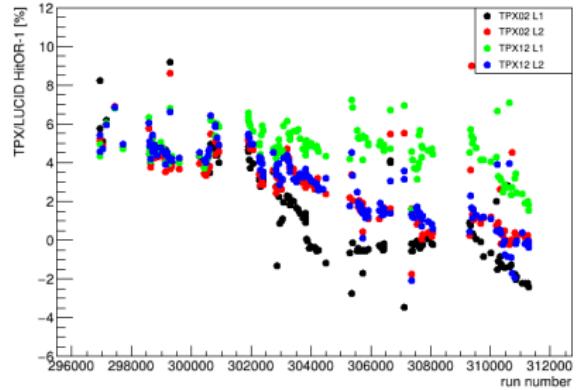
TPX/LUCID HitOR - noisy pixels cut at 3σ - ratio cut at 10% -Bs > 50



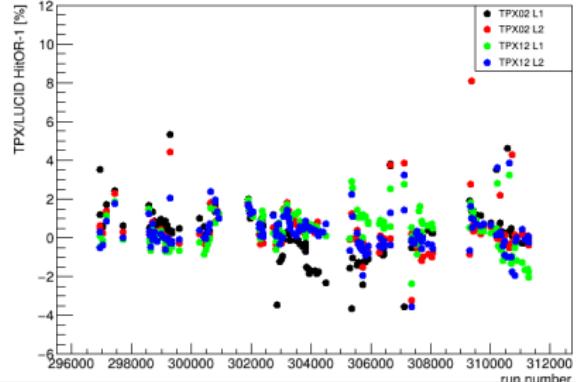
TPX/LUCID HitOR - noisy pixels cut at 3σ - ratio cut at 10% -Bs > 50



TPX/LUCID HitOR - noisy pixels cut at 3σ - ratio cut at 10% -Bs > 50

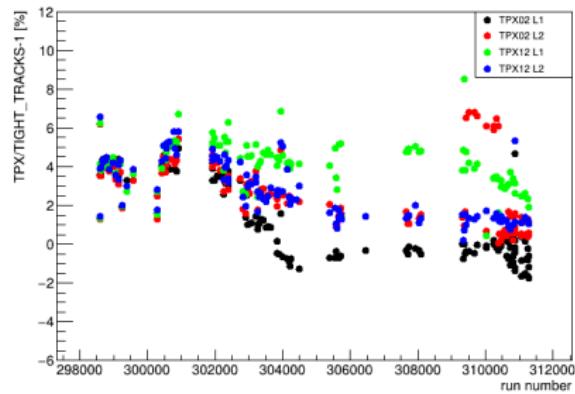


TPX/LUCID HitOR - noisy pixels cut at 3σ - ratio cut at 10% -Bs > 50

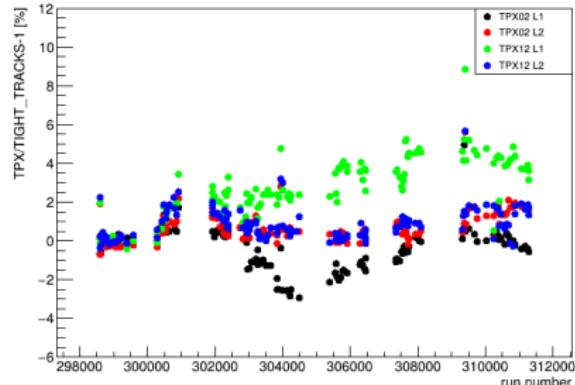


TPX/TRACKING

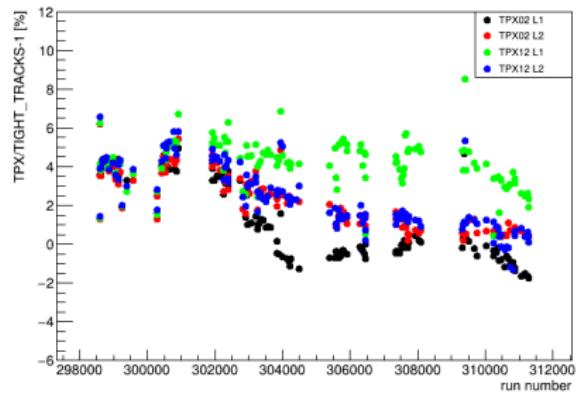
TPX/TIGHT_TRACKS - noisy pixels cut at 3σ - ratio cut at 10% -Bs > 50



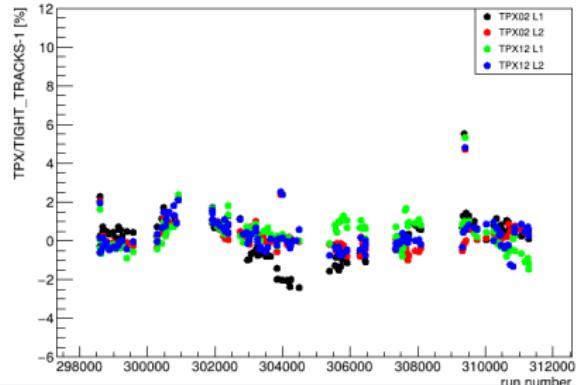
TPX/TIGHT_TRACKS - noisy pixels cut at 3σ - ratio cut at 10% -Bs > 50



TPX/TIGHT_TRACKS - noisy pixels cut at 3σ - ratio cut at 10% -Bs > 50

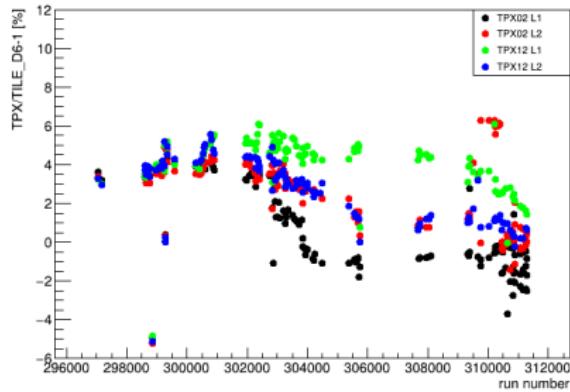


TPX/TIGHT_TRACKS - noisy pixels cut at 3σ - ratio cut at 10% -Bs > 50

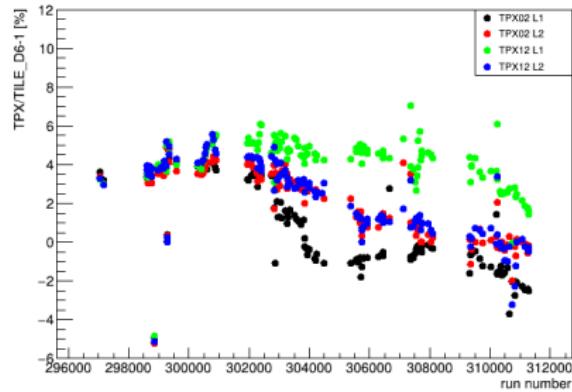


TPX/TILE

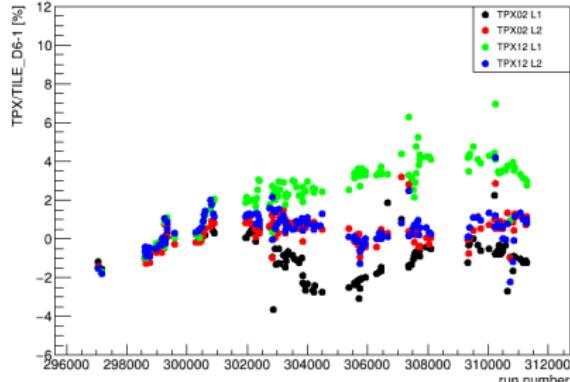
TPX/TILE_D6 - noisy pixels cut at 3σ - ratio cut at 10% -Bs > 50



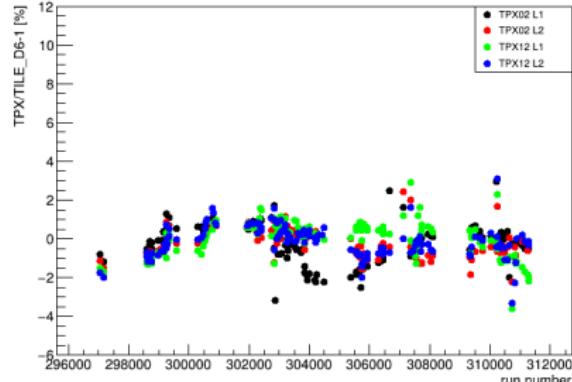
TPX/TILE_D6 - noisy pixels cut at 3σ - ratio cut at 10% -Bs > 50



TPX/TILE_D6 - noisy pixels cut at 3σ - ratio cut at 10% -Bs > 50



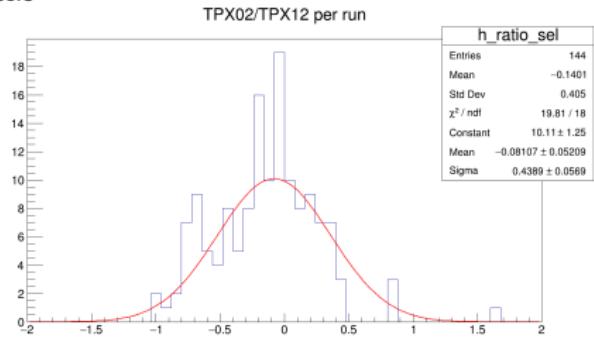
TPX/TILE_D6 - noisy pixels cut at 3σ - ratio cut at 10% -Bs > 50



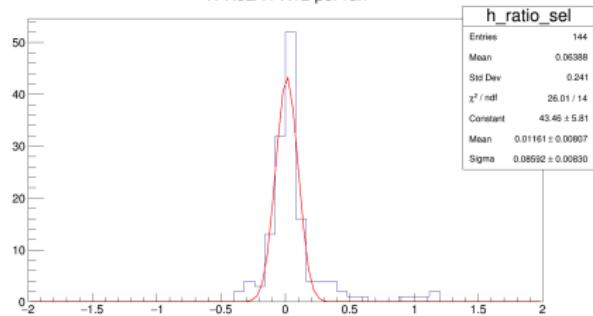
TPX long-term stability precision

Distributions and fits of TPX02/TPX12 using the best combination of 4 sensors

corrected for luminosity slope using the best combination of 4 sensors



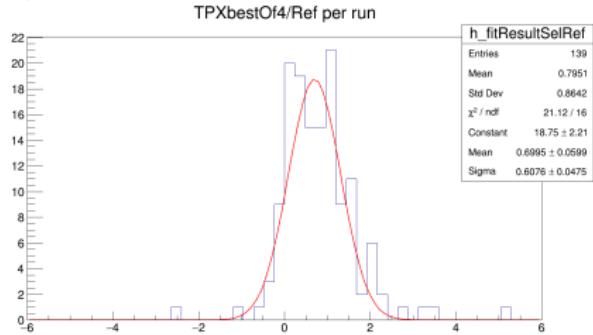
corrected for luminosity slope separately for each sensor
TPX02/TPX12 per run



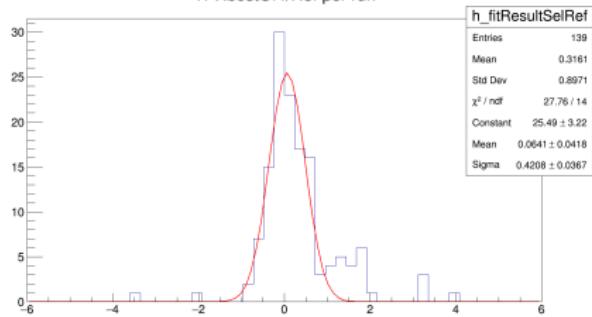
TPX long-term stability precision

Distributions and fits of TPX/LUCID using the best combination of 4 sensors

corrected for luminosity slope using the best combination of 4 sensors



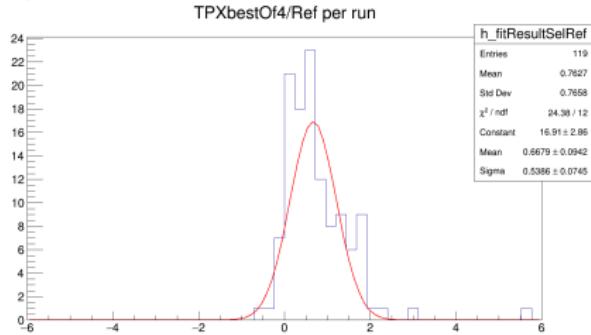
corrected for luminosity slope separately for each sensor
TPXbestOf4/Ref per run



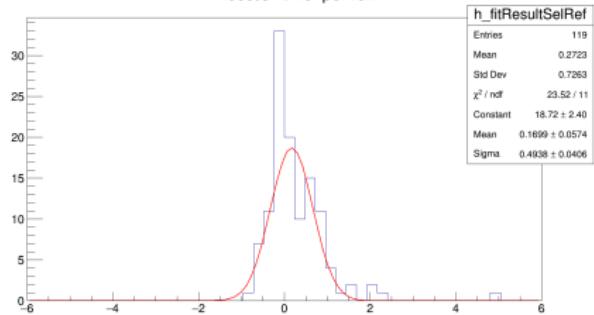
TPX long-term stability precision

Distributions and fits of TPX/TRACKING using the best combination of 4 sensors

corrected for luminosity slope using the best combination of 4 sensors



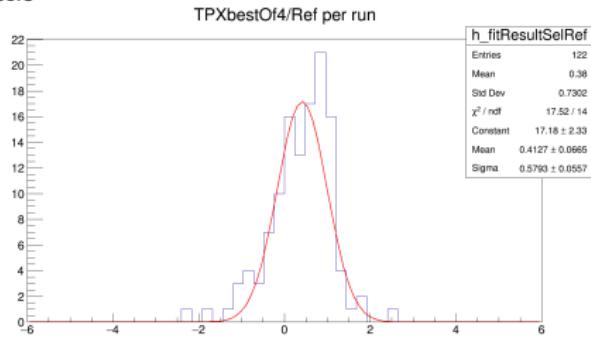
corrected for luminosity slope separately for each sensor
TPXbestOf4/Ref per run



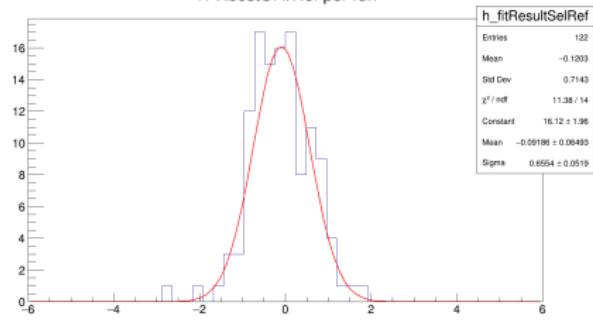
TPX long-term stability precision

Distributions and fits of TPX/TILE using the best combination of 4 sensors

corrected for luminosity slope using the best combination of 4 sensors

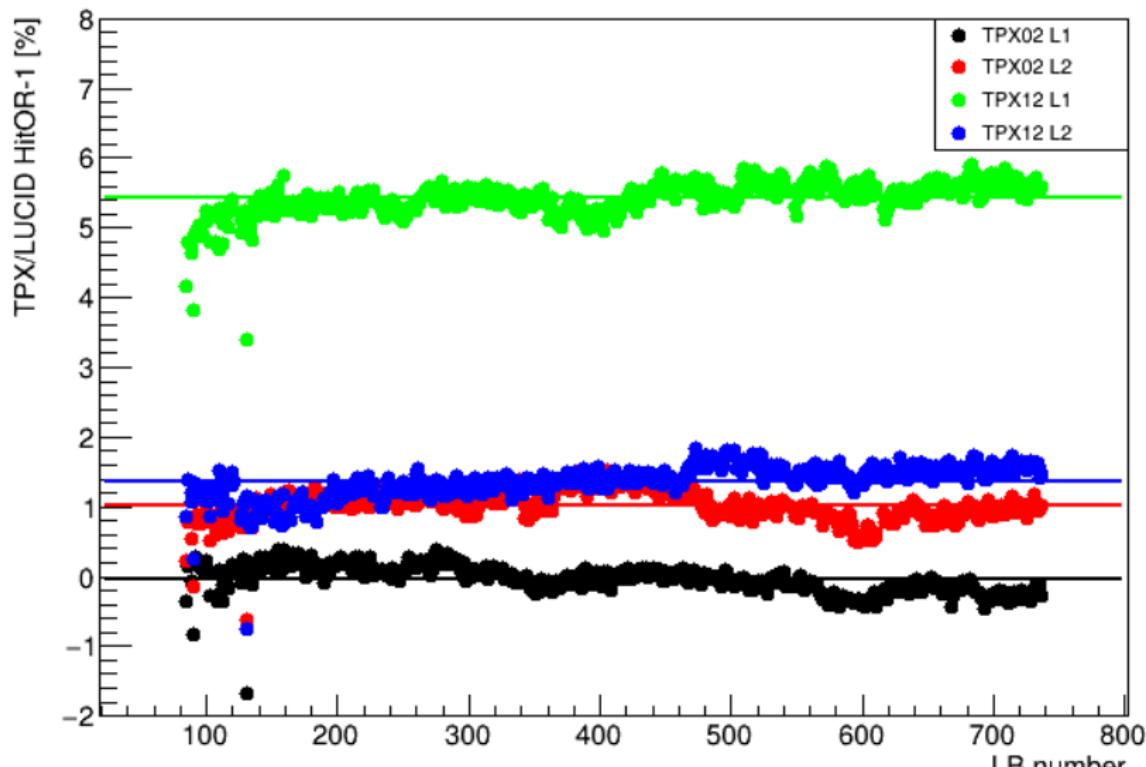


corrected for luminosity slope separately for each sensor
TPXbestOf4/Ref per run



TPX/LUCID HitOR Bi

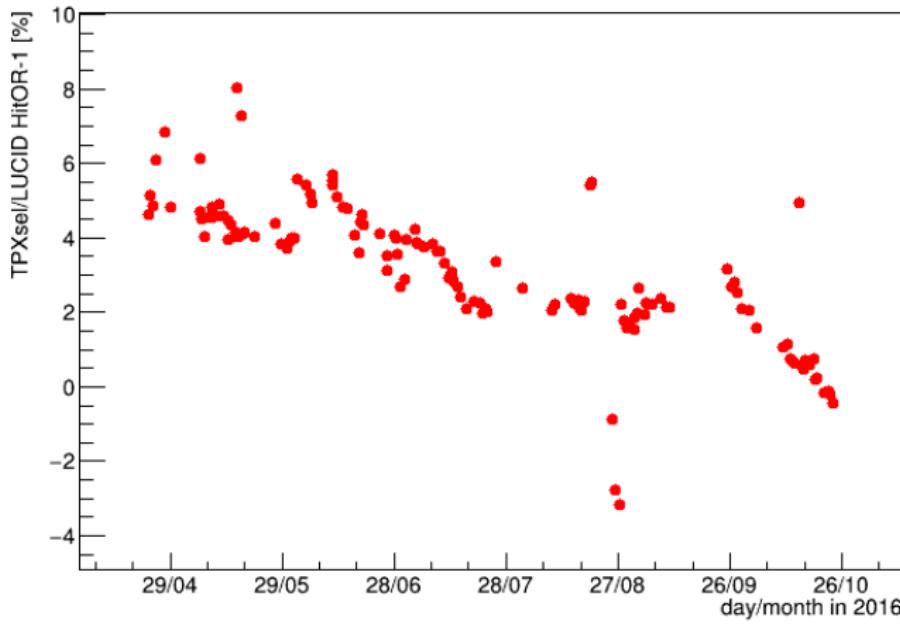
TPX/LUCID HitOR luminosity - run 307601 - cut at 3σ



TPX/LUCID HitOR - Before corrections

Taking the best TPX02/TPX12 ratio: LB-by-LB, the difference among the 2 layers of TPX02 and TPX12 is evaluated (4 possibilities), and the layers corresponding to the minimum are chosen

TPXsel/LUCID HitOR - noisy pixels cut at 3σ - ratio cut at 5% -Bs > 50

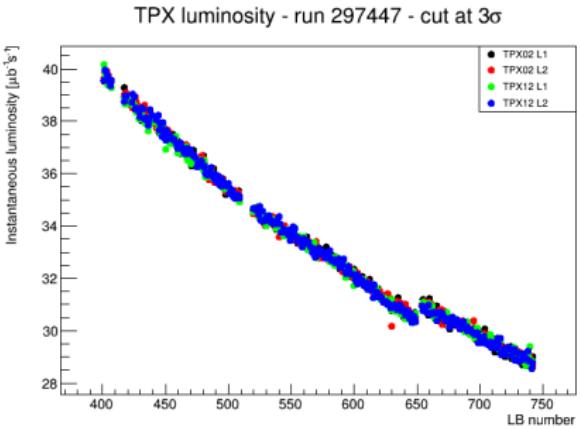


Study on outliers: run 297447, low luminosity

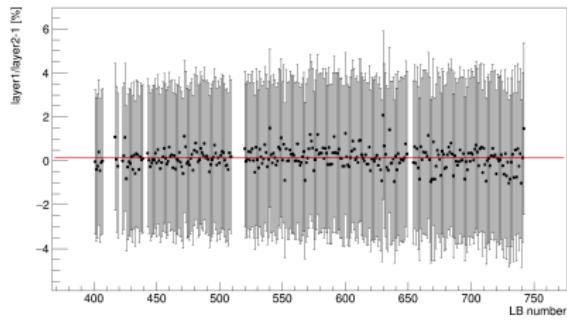


No. of coll. bunches: 8
No. of bunch trains: 1
The first "bunch train" is trivial and consists of only the colliding pilot bunch

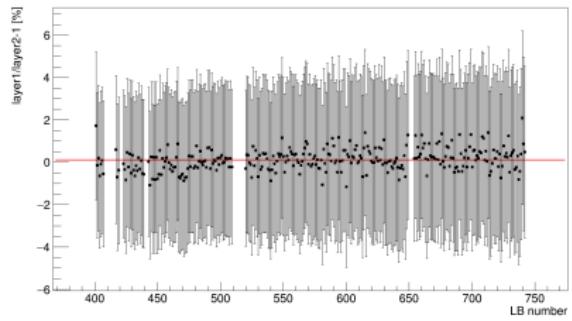
[Mouse over for train configuration. Click for full list of BCIDs]



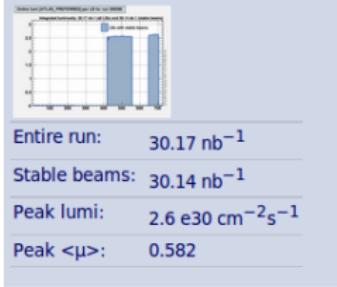
TPX02 layer1/layer2 - run 297447 - cut at 3σ



TPX12 layer1/layer2 - run 297447 - cut at 3σ



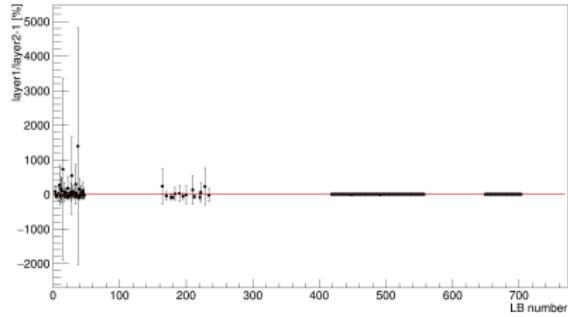
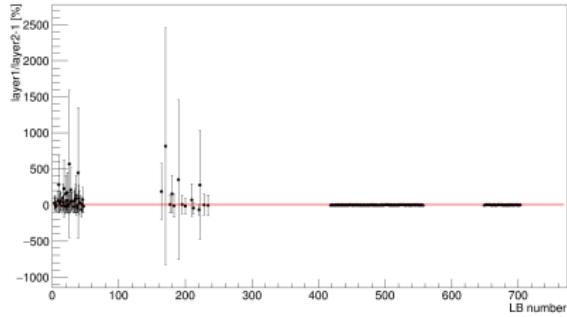
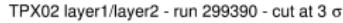
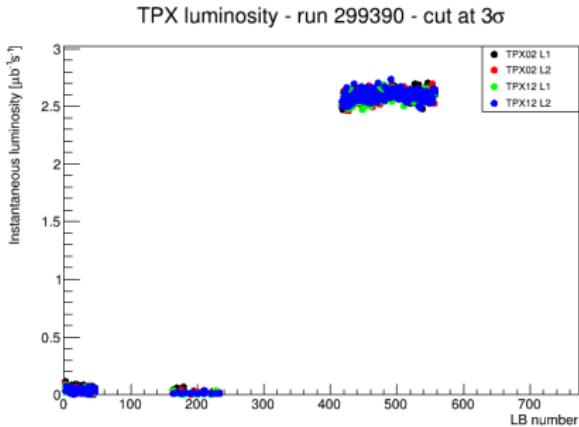
Study on outliers: run 299390, vdM fill



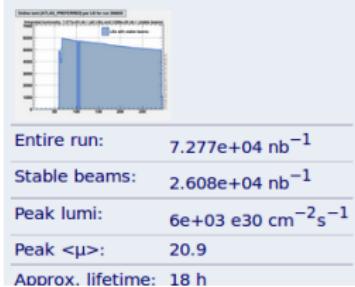
No. of coll. bunches: **32**
No. of bunch trains: **1**

The first "bunch train" is trivial and consists of only the colliding pilot bunch

[Mouse over for train configuration. Click for full list of BCIDs]

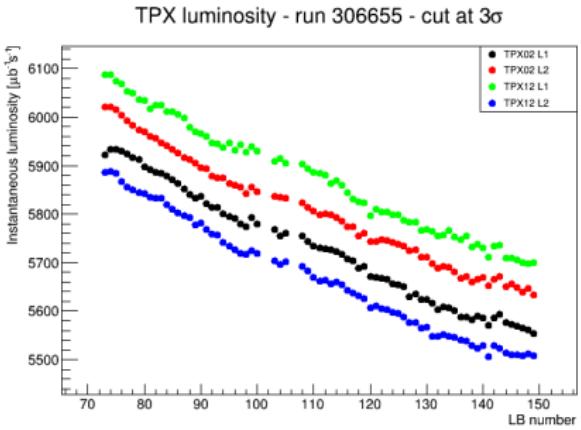


Study on outliers: run 306655, TPX inconsistency

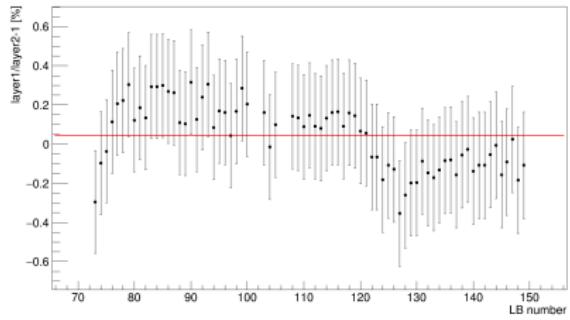


No. of coll. bunches: **2028**
No. of bunch trains: **29**
Bunch dist. in trains: **1 (25 ns)**

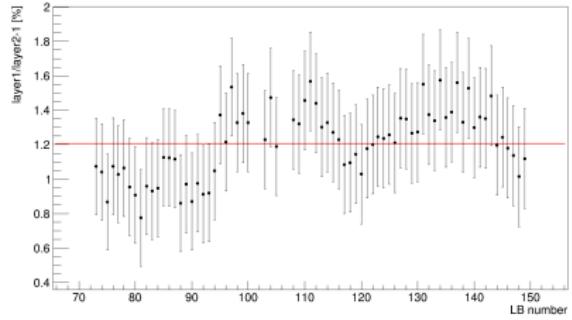
[Mouse over for train configuration. Click for full list of BCIDs]



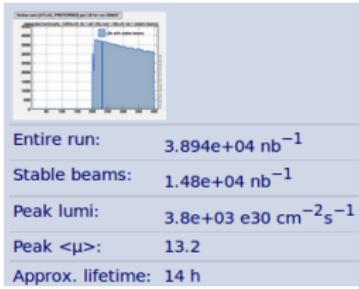
TPX02 layer1/layer2 - run 306655 - cut at 3σ



TPX12 layer1/layer2 - run 306655 - cut at 3σ

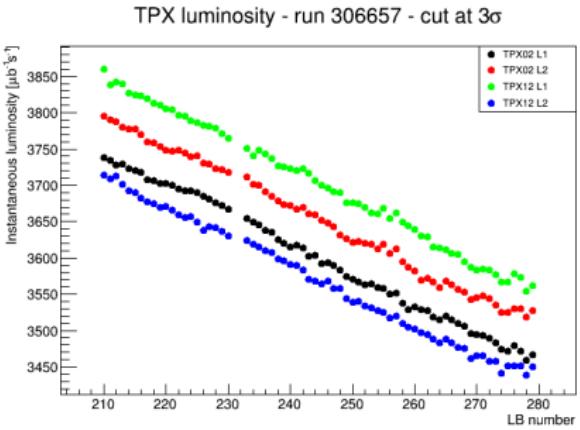


Study on outliers: run 306657, TPX inconsistency

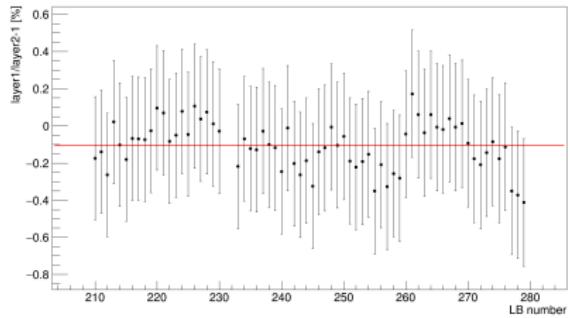


No. of coll. bunches: **208**
No. of bunch trains: **29**
Bunch dist. in trains: **1** (25 ns)

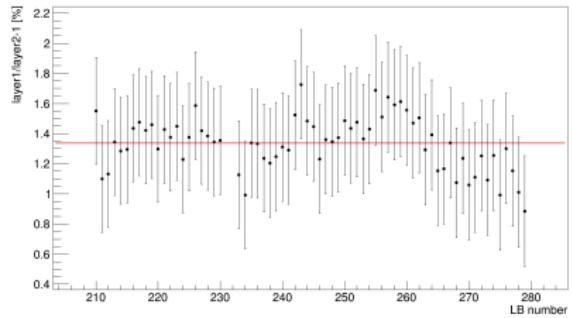
[Mouse over for train configuration. Click for full list of BCIDs]



TPX02 layer1/layer2 - run 306657 - cut at 3σ

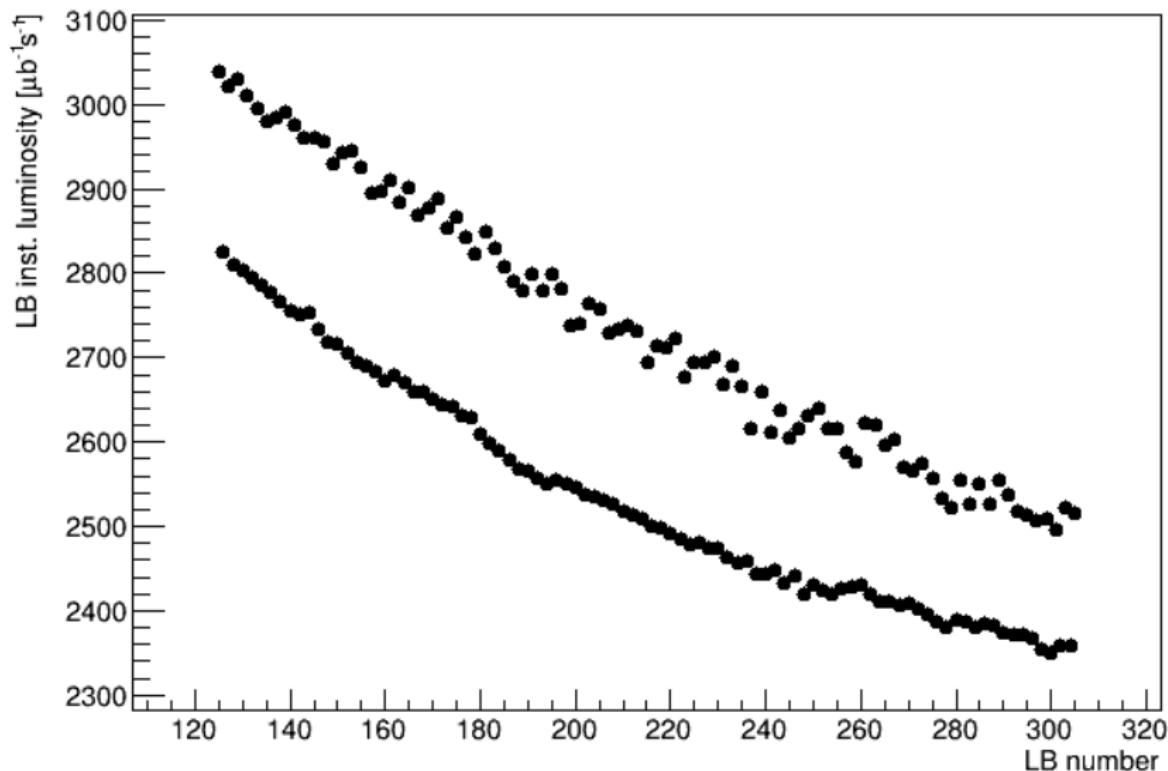


TPX12 layer1/layer2 - run 306657 - cut at 3σ

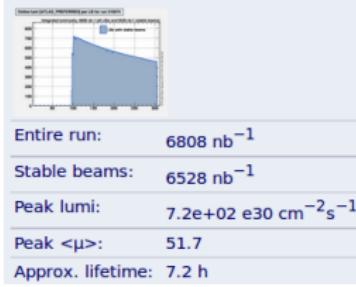


Study on outliers: run 307126, LUCID inconsistency

LUCID HitOR luminosity - run 307126

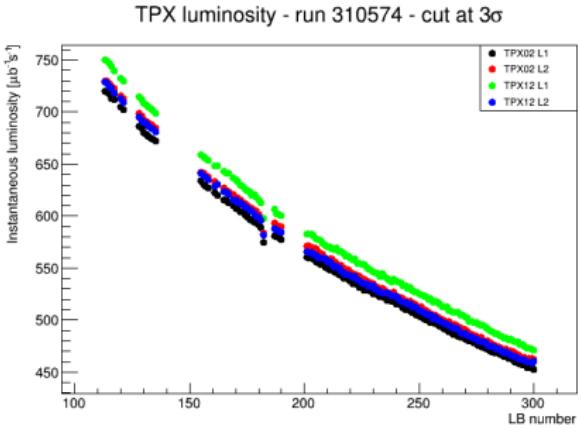


Study on outliers: run 310574, LUCID inconsistency

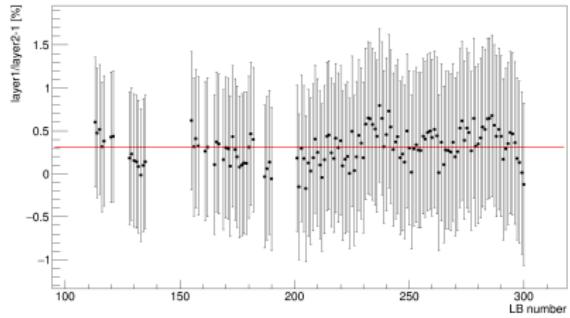


No. of coll. bunches: **99**
No. of bunch trains: **3**
Bunch dist. in trains: **1** (25 ns)
The first "bunch train" is trivial and consists of only the colliding pilot bunch

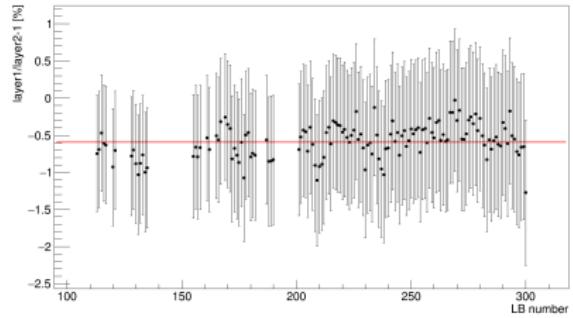
[Mouse over for train configuration. Click for full list of BCIDs]



TPX02 layer1/layer2 - run 310574 - cut at 3σ

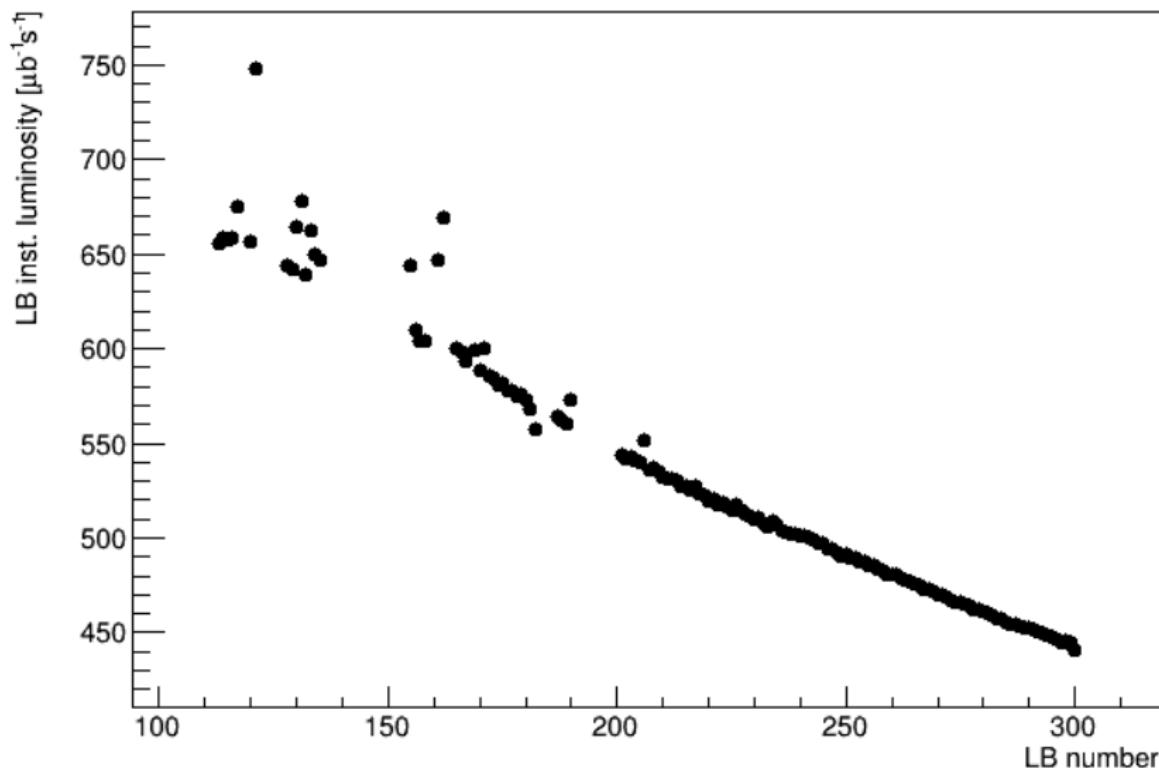


TPX12 layer1/layer2 - run 310574 - cut at 3σ



Study on outliers: run 310574, LUCID inconsistency

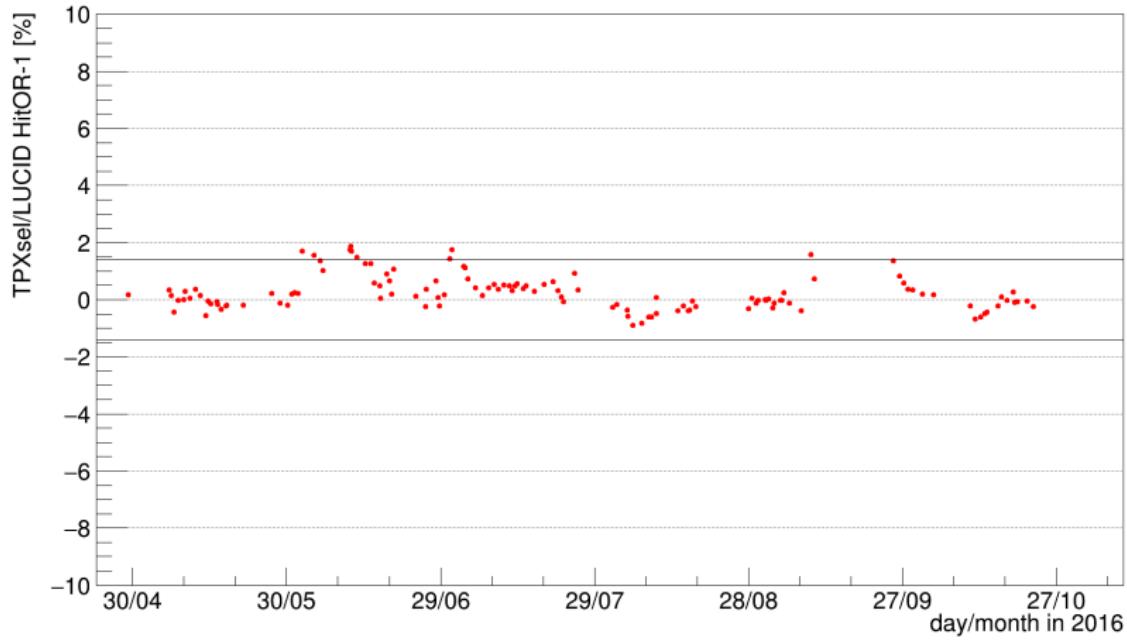
LUCID HitOR luminosity - run 310574



TPX/LUCID (after cuts)

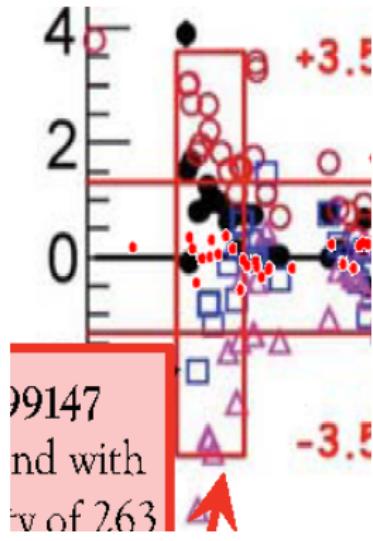
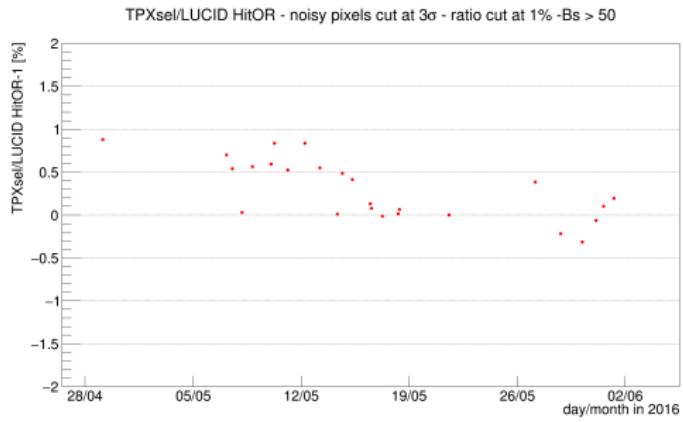
TPX vdM normalization, only runs with peak lumi $>100 \mu b^{-1}s^{-1}$ (vdM fills etc.)

TPXsel/LUCID HitOR - noisy pixels cut at 3σ - ratio cut at 1% -Bs > 50



TPX/LUCID (no luminosity slope correction)

Normalized to run 299584



Conclusions and Outlook

- Internal consistency: in 2016 data layer1/layer2 shows larger fluctuations wrt 2015 data
- Detailed study of variations (Table), no obvious reason of fluctuations
- Long-term comparison with LUCID HitOR Bi shows 5% drift (likely TPX decrease)
- Luminosity corrections applied for internal consistency, overall and for individual sensors
- Layer1/Layer2 long-term stability best of 4 combinations, then average TPX02/TPX12 as best TPX luminosity
- Study of pixel consistency shows correlation between variations (large pull) of individual pixels per run, and overall measurement variations
- Quantification of fluctuations with $\text{Pull } \sigma_{\text{sys}}$, larger increase after June 2016
- Correction for individual TPX luminosity slope leads to internal consistency $\sigma < 0.1\%$, and long-term stability wrt LUCID $\sigma = 0.4\%$
- Outliers (above $\pm 1.5\%$) investigated and 6 runs removed by general cuts on minimum luminosity (e.g. vdM fills), internal TPX consistency, and LUCID features
- Comparison with LUCID HitOR Bi: within $\pm 1.5\%$ for the whole year, and within $\pm 0.7\%$ for May without luminosity slope correction
- Initial analysis of 2016 TPX02/12 data brought many questions for new analysers (analysis of other devices could contribute essential information to understand better TPX02/12 data and could lead to an independent long term stability determination)
- Radiation damage, neutron luminosity, activation and new features of TPX need to be addressed by additional analysers