Operation and performance of LHCb Upstream Tracker

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Part 1

Upstream tracker (UT) of LHCb

01 Upstream tracker (UT) of LHCb

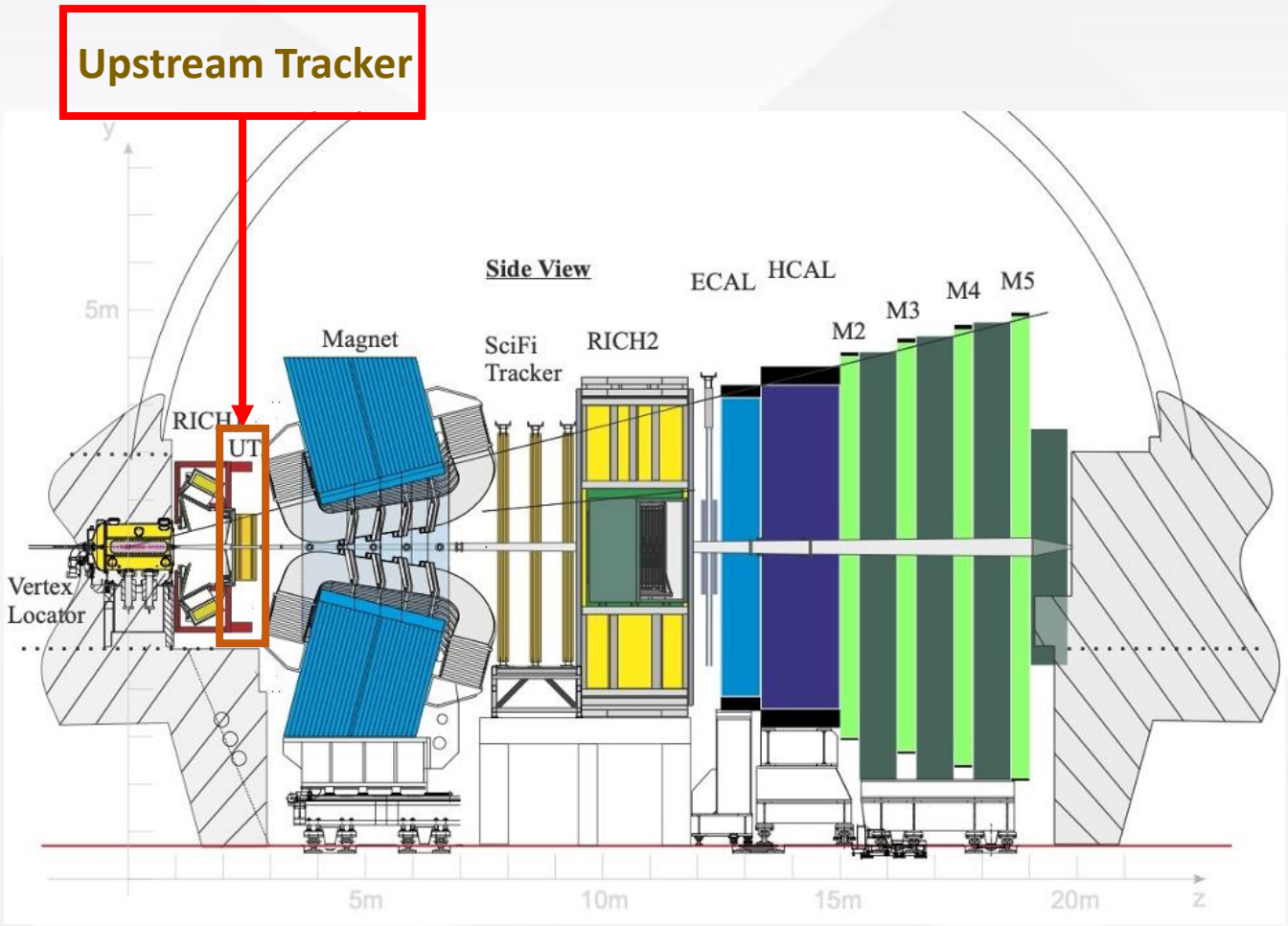


Fig 1. Layout of the upgraded LHCb detector

- The Upstream Tracker (UT) is designed for LHCb Upgrade Ⅰ data-taking .
  - $\mathrm{Lumi} = 2 \times 10^{33} cm^{-2} s^{-1}$
  - Crucial for track reconstruction of low-momentum particles and decay products of long-lived particles

01 Upstream tracker (UT) of LHCb

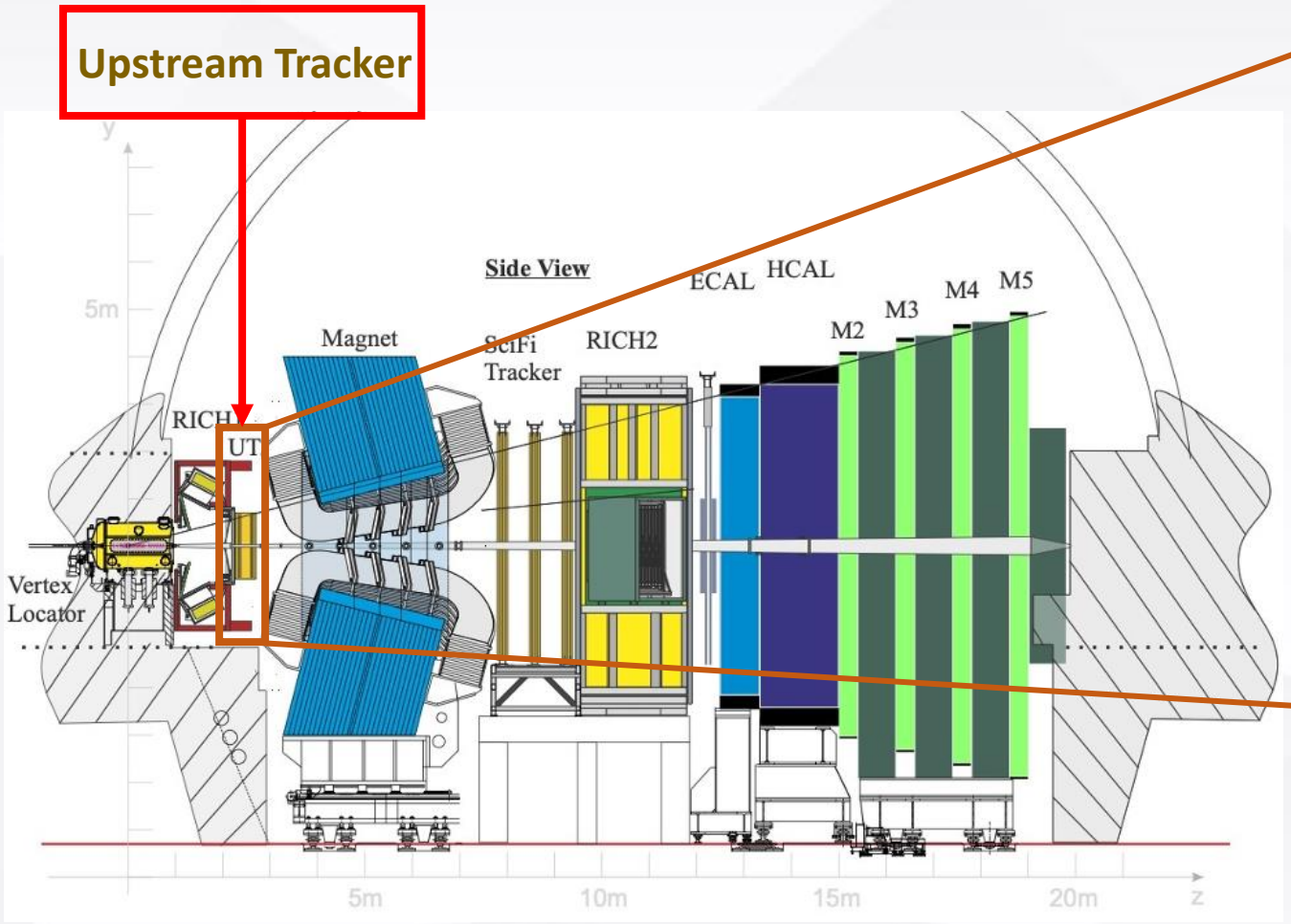


Fig 1. Layout of the upgraded LHCb detector

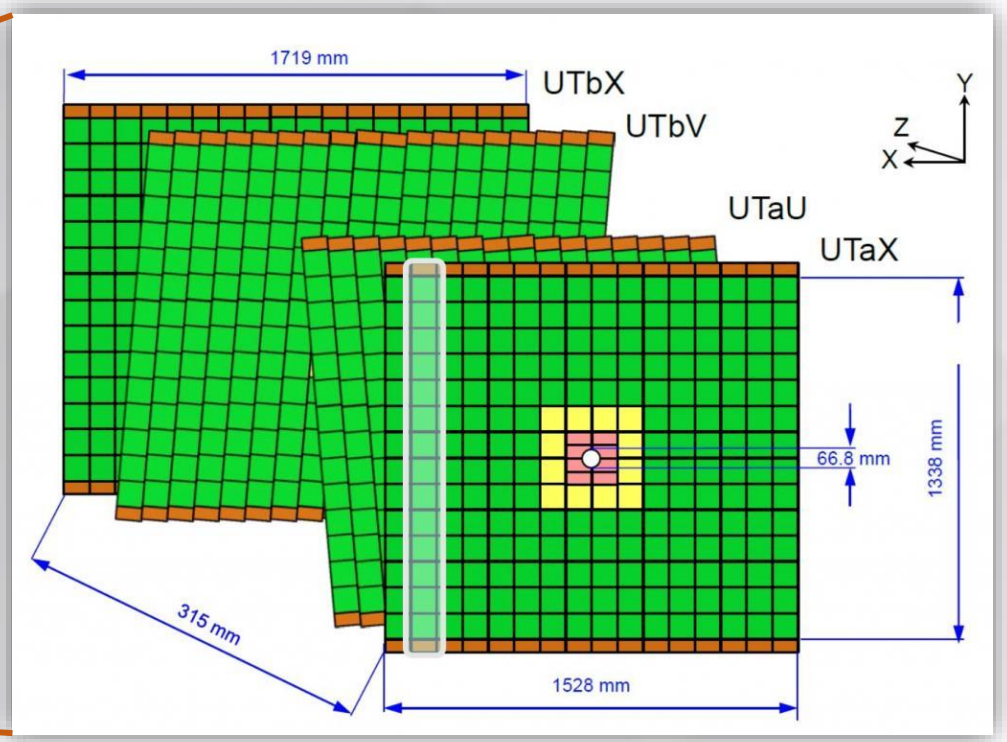


Fig 2. Schematic of the UT detector

- The UT is a silicon micro-strip detector
  - 4 layers (x , u, v, x).
  - 68 staves = 536,576 strips ≈ 2×(TT+IT) !
  - Read-out with 4192 SALT ASICs. (40MHz)

Part 2

The Operation of UT

02 The operation of UT

Calibration

- **Goal: To efficiently reject noise hits from output to get as pure as possible signals.**
- **We have 3 tools:**
  - **Trimming DAC (analogue)**
  - **Pedestal subtraction (digital)**
  - **Common Mode Noise Subtraction**

Monitoring

- Dedicated monitoring hub to make sure the detector is in a good shape.
- Real-time auto analyzed data can be access in Monet by everyone and everywhere (from LHCb)!

Single-Event Upset

- Record SEU events to ensure data quality, find anomalies and guide operation.
- Auto-recovery script to mitigate the SEU effects.

02 Calibration

- **TrimDAC adjustment to align the analog baseline**

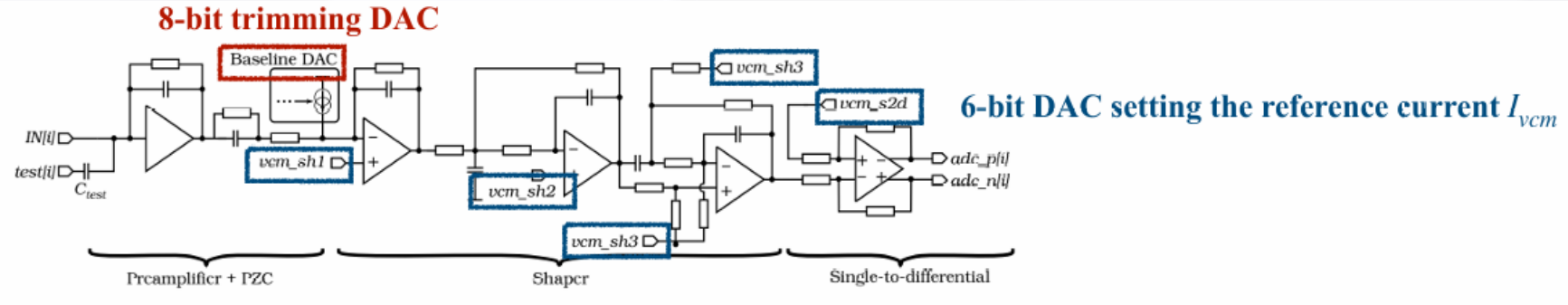


Fig 3. Schematic of Electronics for each channel

- Each channel contains an 8-bit trimming DAC for a precise baseline setting. And for each ASIC, we can set the reference current.
- We readout Non-Zero-Suppression data without beams, and scan each DAC from 0-255 (0.1 adjustment on ADC output).
- **We get the baseline DAC (where ADC output=0) for each channel by fitting those data points.**

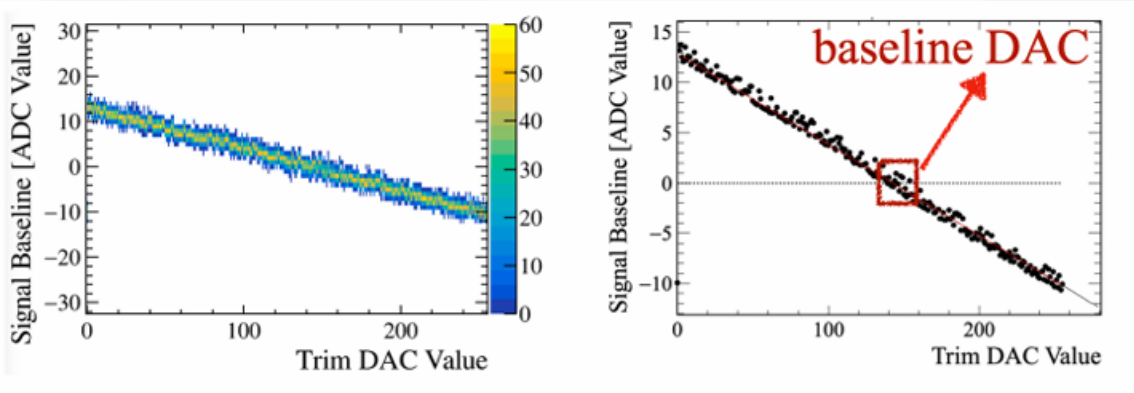


Fig 4. Typical results for each channel

02 Calibration

➢ TrimDAC adjustment

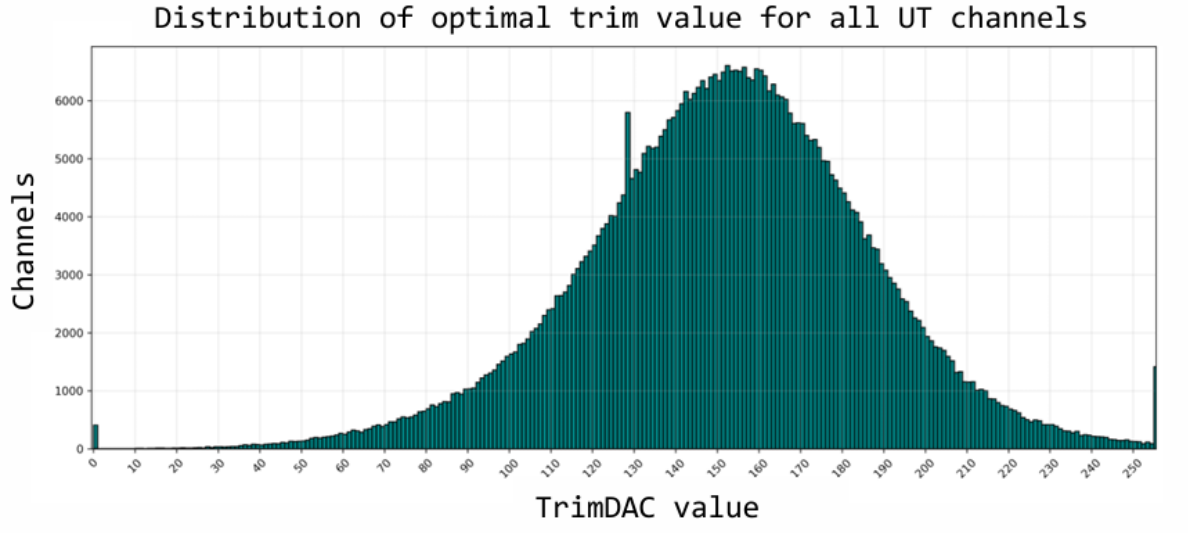
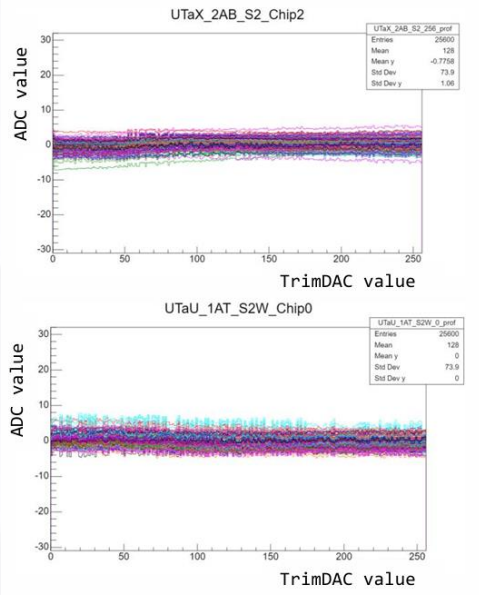


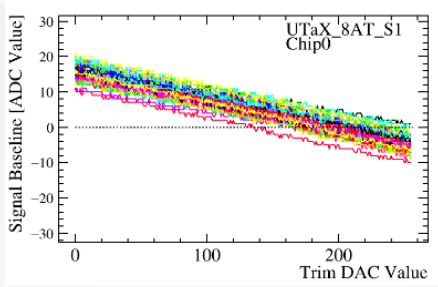
Fig 5. The most recent TrimDAC distribution deployed on UT

Status	No. of channels
Overflow	398
Underflow	2919
Bad fit	5812

Examples of hybrids where the fitting procedure failed



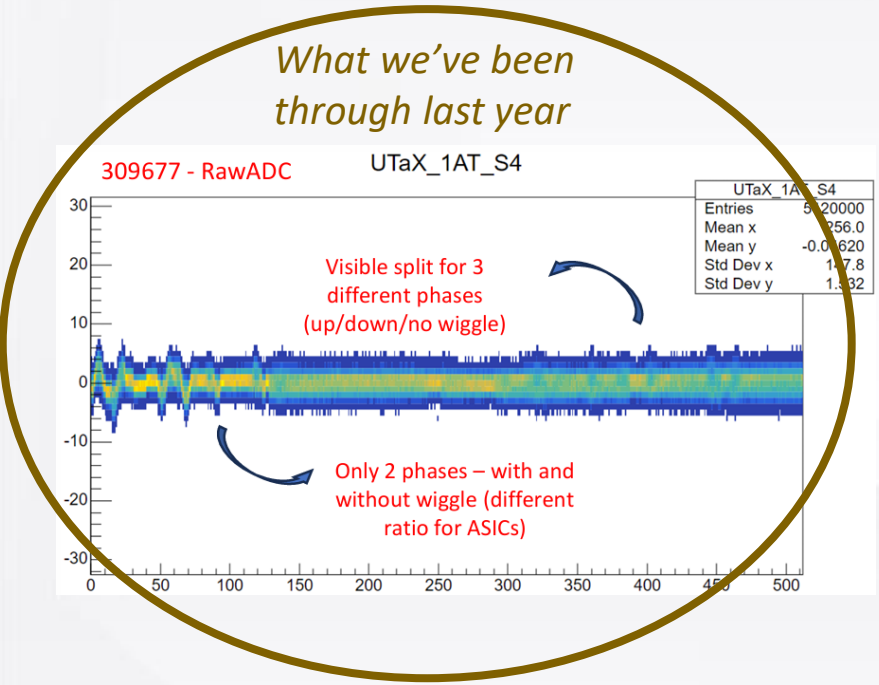
What a good one should look like



- ➢ Current TrimDAC was taken on May 15 and deployed on 23.
- ➢ The fitting procedure detected several "bad chips".
  - *UTaU_1AB_M2_0, UTaU_1AT_S2W_0, UTaU_2AT_M3_3*
  - *UTaX_1AT_S4_0, UTaX_2AB_M2_0, UTaX_2AB_S2_2*
  - *UTaX_3AB_M1_0, UTbV_2AB_M3_0, UTbX_2AB_M1W_0*
  - *UTbX_2AB_M3_1*

02 Calibration

- **Pedestal and Common Mode (CM) Noise subtraction**
  - The Pedestal + CM Noise represents the ADC output without beams (**baseline**).
  - $\boldsymbol{Final\ signal\ ADC\ Value = ADC_{raw} - (Pedestal + CM\ Noise)}$.
    - **<u>Pedestal stabilities</u>:** The pedestals were quite unstable last year (left). But pedestals calculated using 3 scans without beams during the last few months (right) shows no significant drift.



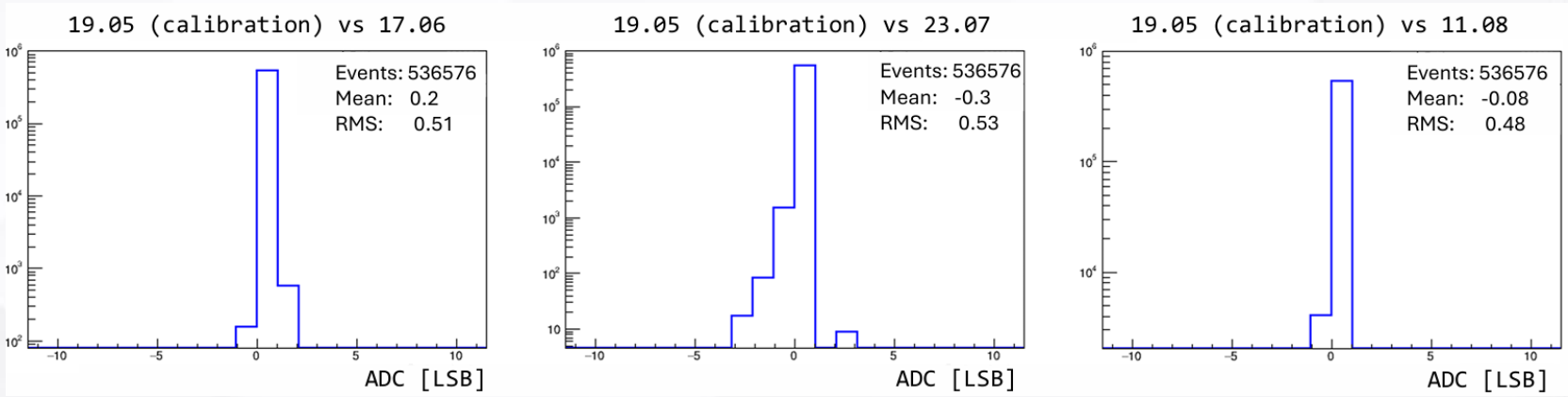
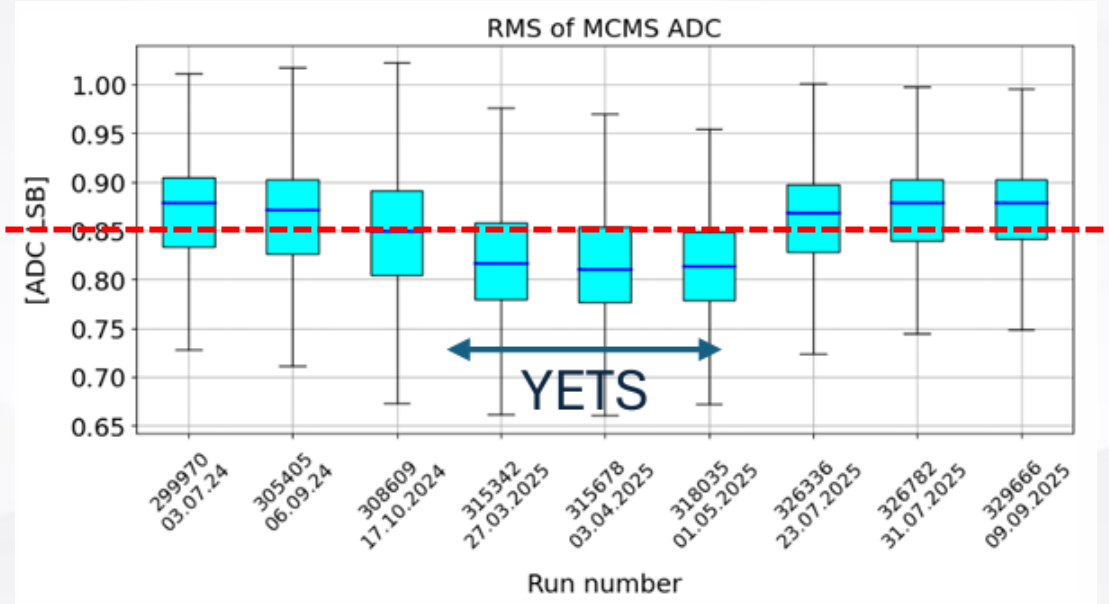


Fig 6. Pedestals over 3 scans for UT

02 Calibration

- **Pedestal and Common Mode (CM) Noise subtraction**
  - The Pedestal and CM Noise are calculated from the ADC output value without beams (**baseline**).
  - $\boldsymbol{Final\ signal\ ADC\ Value = ADC_{raw} - (Pedestal + CM\ Noise)}$.
    - **Long-term RMS of CM Subtracted ADC** without beams for UT (after pedestals subtraction already)



An acceptable level

Fig 7. Long-term (The duration is slightly more than 1 year)

RMS of MCMS ADC

02 The operation of UT

Calibration

- Goal: To efficiently subtract noise from the ADC output to get as pure as possible signals.
- Can be done in 2 ways:
- Trimming DAC.(Analogue)
- Pedestal subtraction.(Digital)
- Mean Common Mode Subtraction(MCMS)

Monitoring

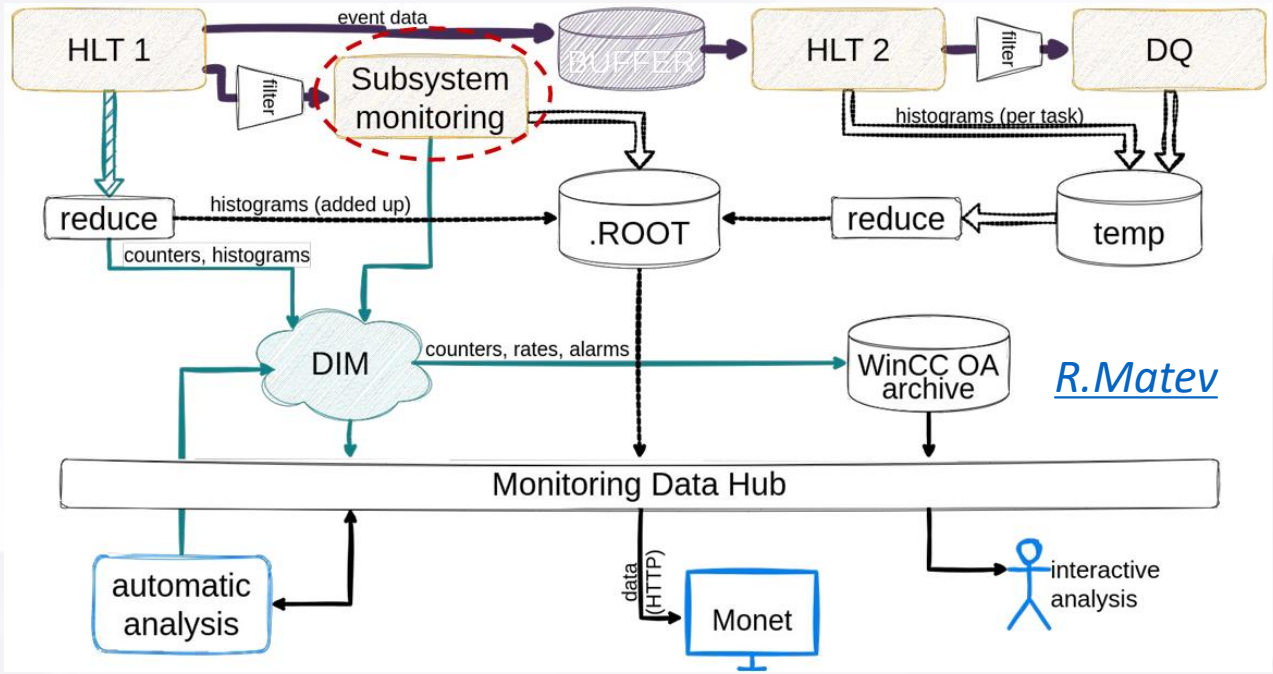
- **Dedicated monitoring hub to make sure the detector is in a good shape.**
- **Real-time auto analyzed data are accessible in Monet by everyone and everywhere (from LHCb)!**

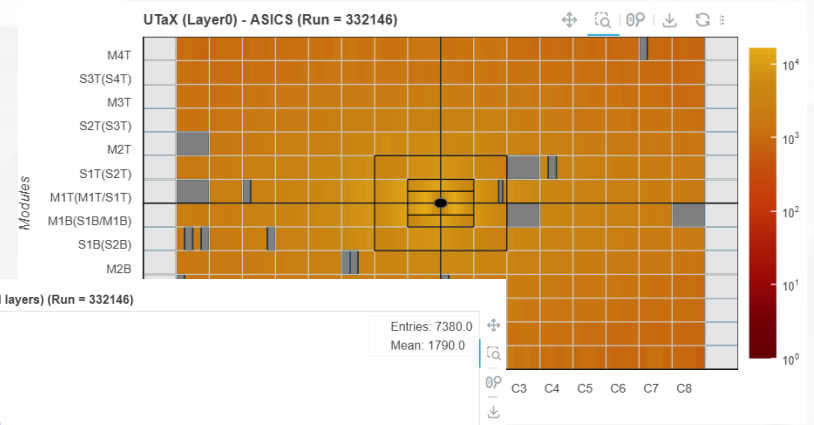
Single-Event Upset

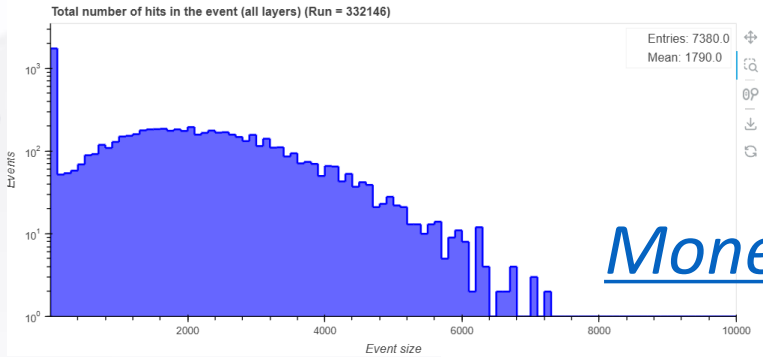
- Record SEU events to ensure data quality, find anomalies and guide operation.
- Auto-recovery script to mitigate the SEU effects.

02 Monitoring

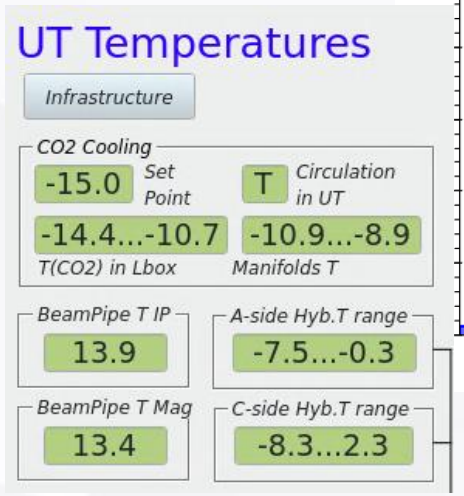
- **Monitoring in the LHCb includes:**
  - Environmental quantities (HV, temperature…)
  - Detector raw data
  - Output of HLT (High level trigger) reconstruction/selections
  - Automatic analyses (e.g. combined histograms, fits to shapes)

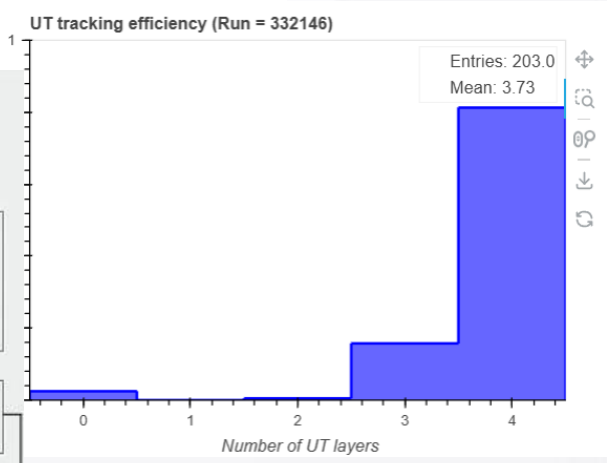






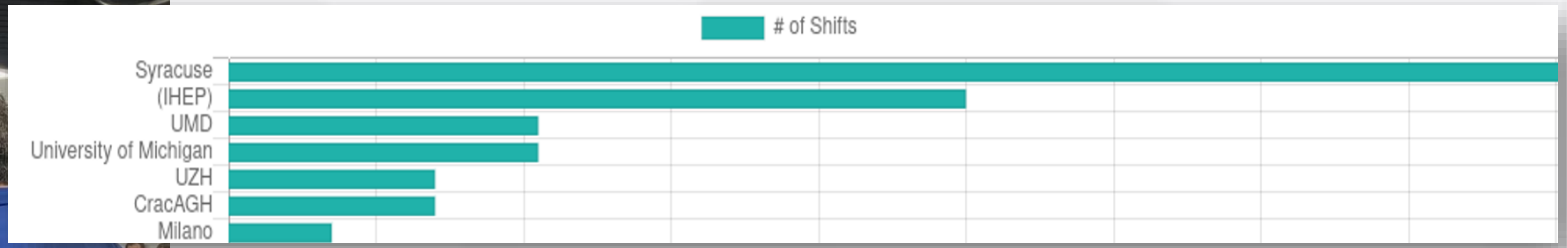
Monet!

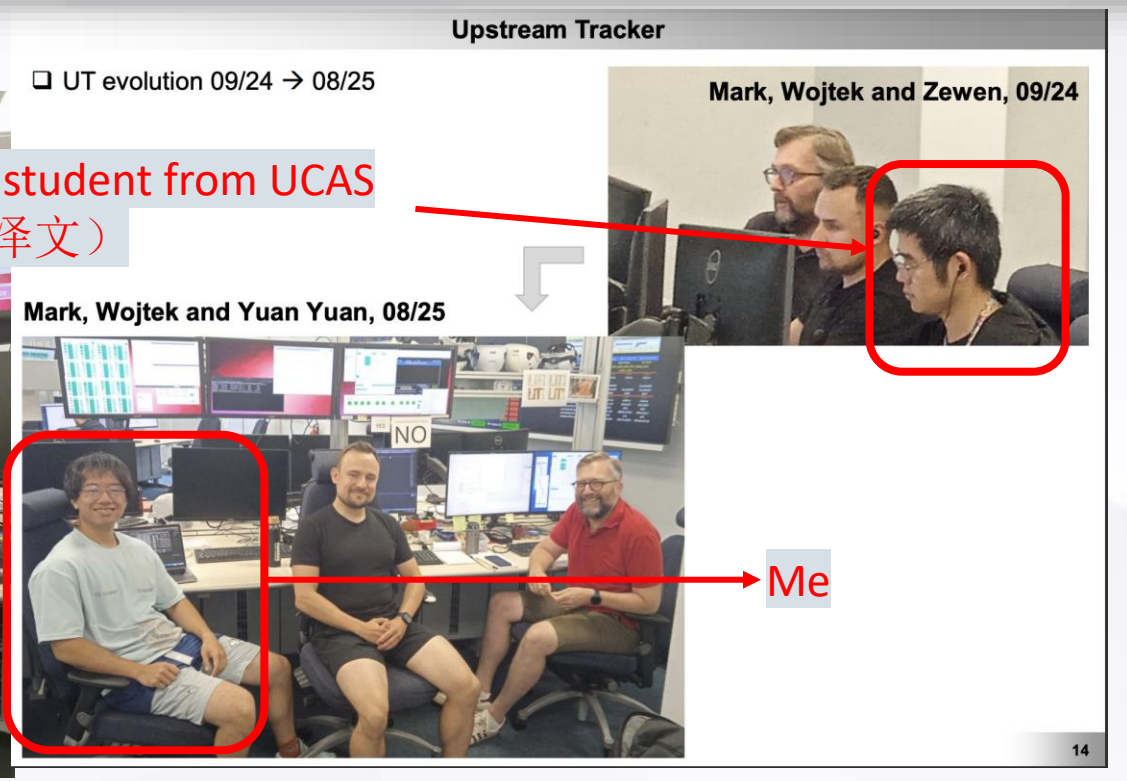




02 Monitoring

- **Monitoring in the LHCb includes:**
  - And of course, a dedicated shift crew taking care of issues happened in the detector





02 The operation of UT

Calibration

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- Can be done in 2 ways:
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- Mean Common Mode Subtraction(MCMS)

Monitoring

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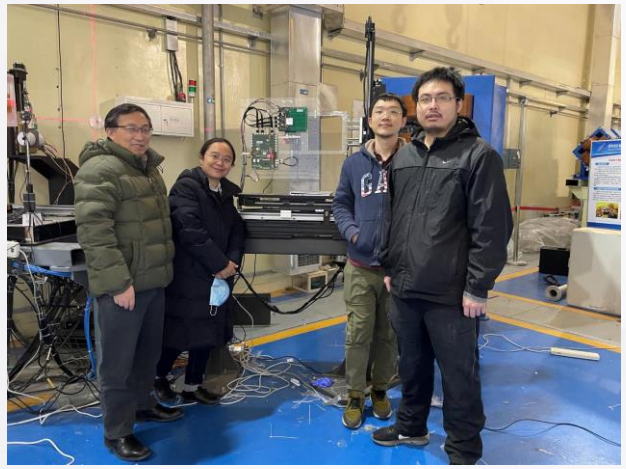
- Real-time auto analyzed data can be access in Monet by everyone and everywhere (from LHCb)!

Single-Event Upset

- **Record SEU events to ensure data quality, find anomalies and guide operation.**
- **Auto-recovery script to mitigate the SEU effects.**

Single-Event Upset

- IHEP UT group had a long history on tackling the SEU issues in the readout ASIC.
  - ✓ During the **early production stage**, we have conducted 3 radiation tests at PSI (Paul Scherrer Institute, 2019), CIAE (China Institute of Atomic Energy, 2020) and CSNS (China Spallation Neutron Source, 2021) for different versions of the readout chip (v3.5 and 3.9).
  - ✓ We have estimated the impact on the final UT system (e.g. Rate and cross section of SEU).
  - ✓ Mark, Petre, Baasansuren and me (from IHEP) are working on analyzing and tackling the current UT SEUs.



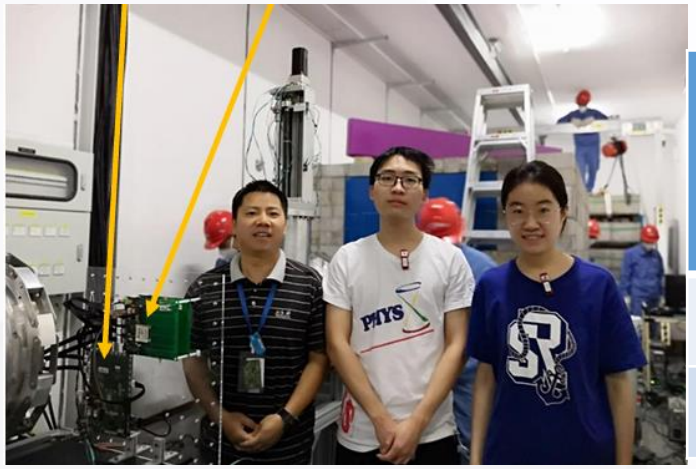


Fig 8. Test beam @CIAE (left), and test beam @CSNS (right).

Chip version	Register SEU cross section		Mem SEU cross section/cm^2
	TrimDAC/cm^2	Pedestal/cm^2	
v3.5	6.4×10^{-12}	1.8×10^{-12}	-
v3.9	4.7×10^{-13}	6.1×10^{-13}	2.6×10^{-15}

SEU during data transmission

Single-Event Upset

- In the current UT, we detect trimdac/pedestal registers SEUs (baseline SEUs) every 30s.
  - ✓ If detected, an auto-recovery script will be activated to re-write the register (by Mark).
- We also handle analogue register SEUs (e.g. pre_amp, shaper_cfg, which would cause hot/cold channels) by detecting anomalies in the hit map.

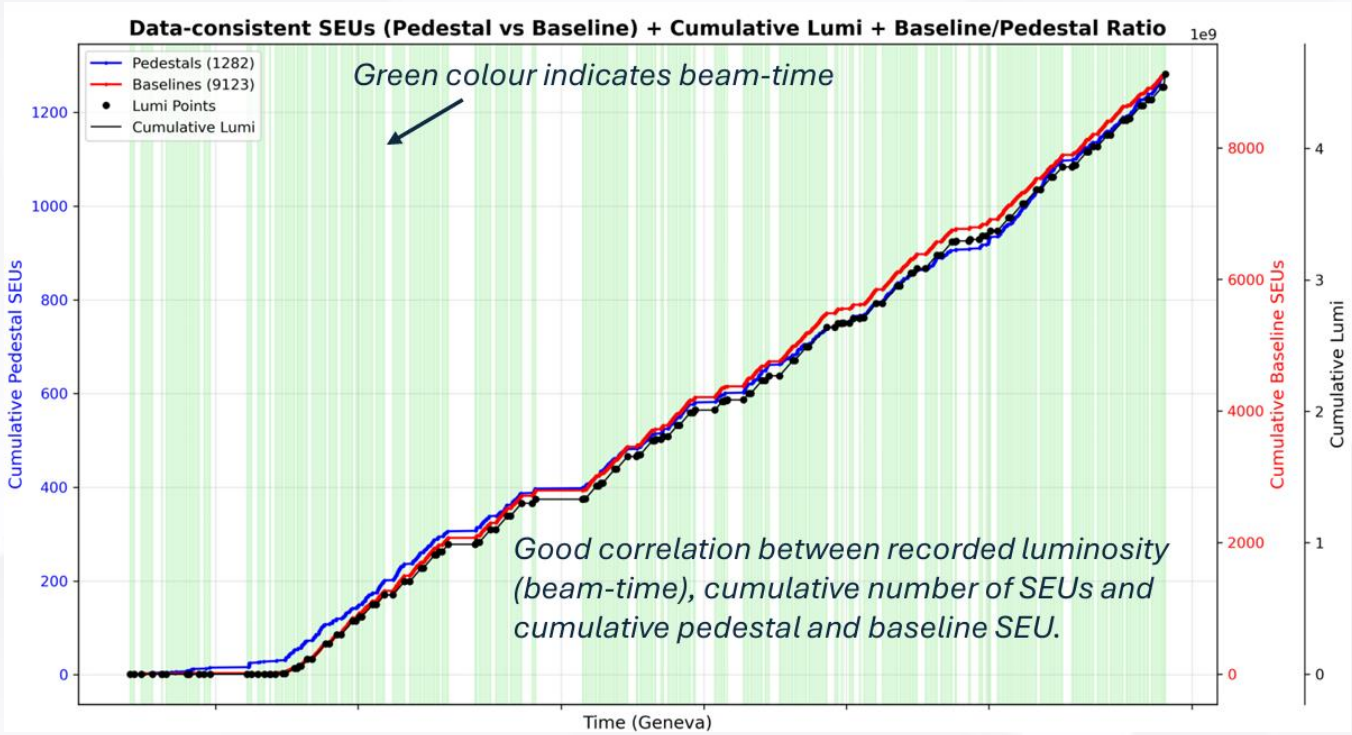


Fig 8. Cumulative number of trimdac SEUs (red), pedestal SEUs (blue), and recorded luminosity vs time for 2025 proton physics & special runs.

Part 3

Recent performance results of UT

03 Efficiency across Run3

- **Overall, very good performance!**
  - Thanks to Yisheng Fu 傅逸昇 (IHEP) and Zhijie Wang 王智颉(LZU) who wrote the UT tracking efficiency calculation script !

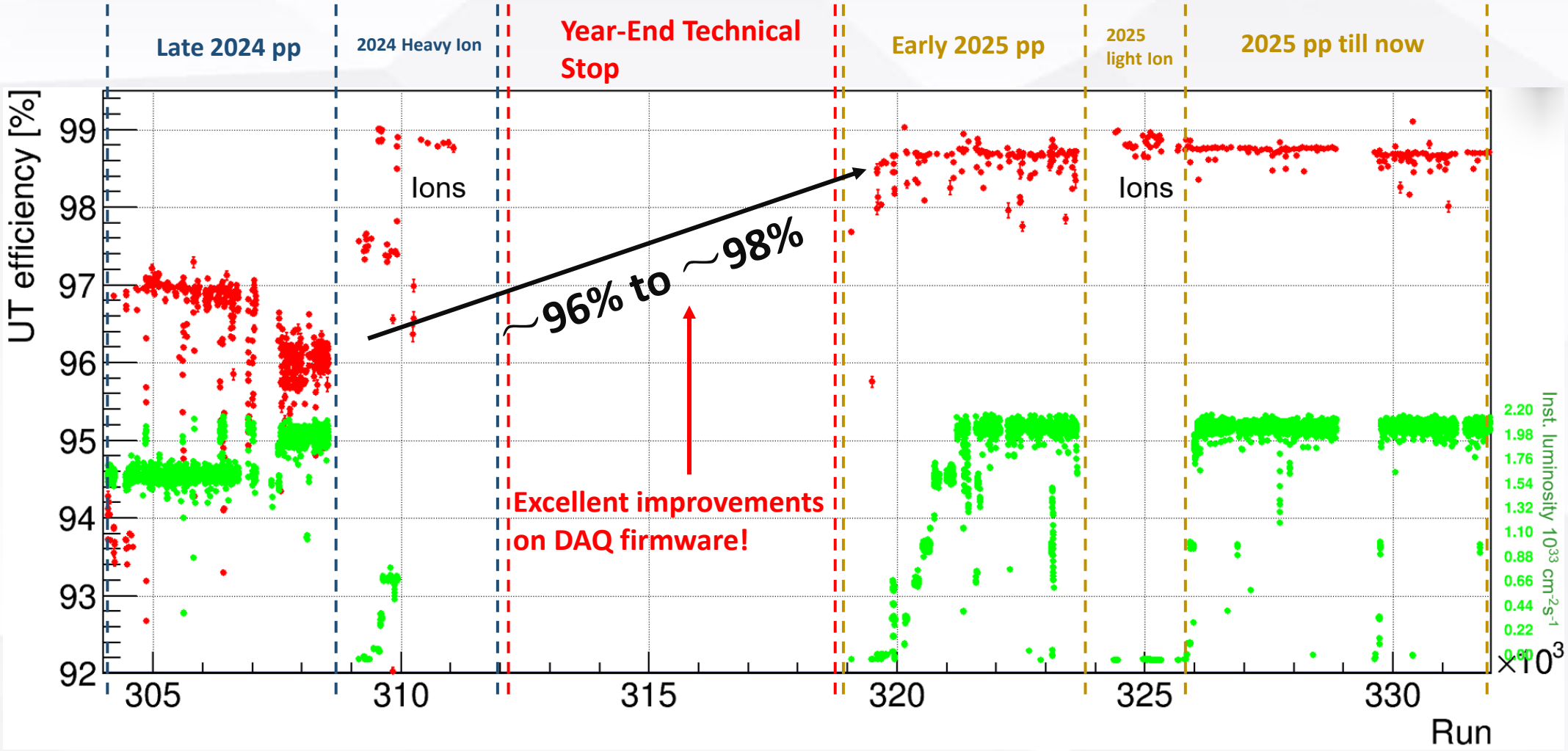


Fig 9. UT tracking efficiency(>= 3 UT hits) 2025 vs 2024

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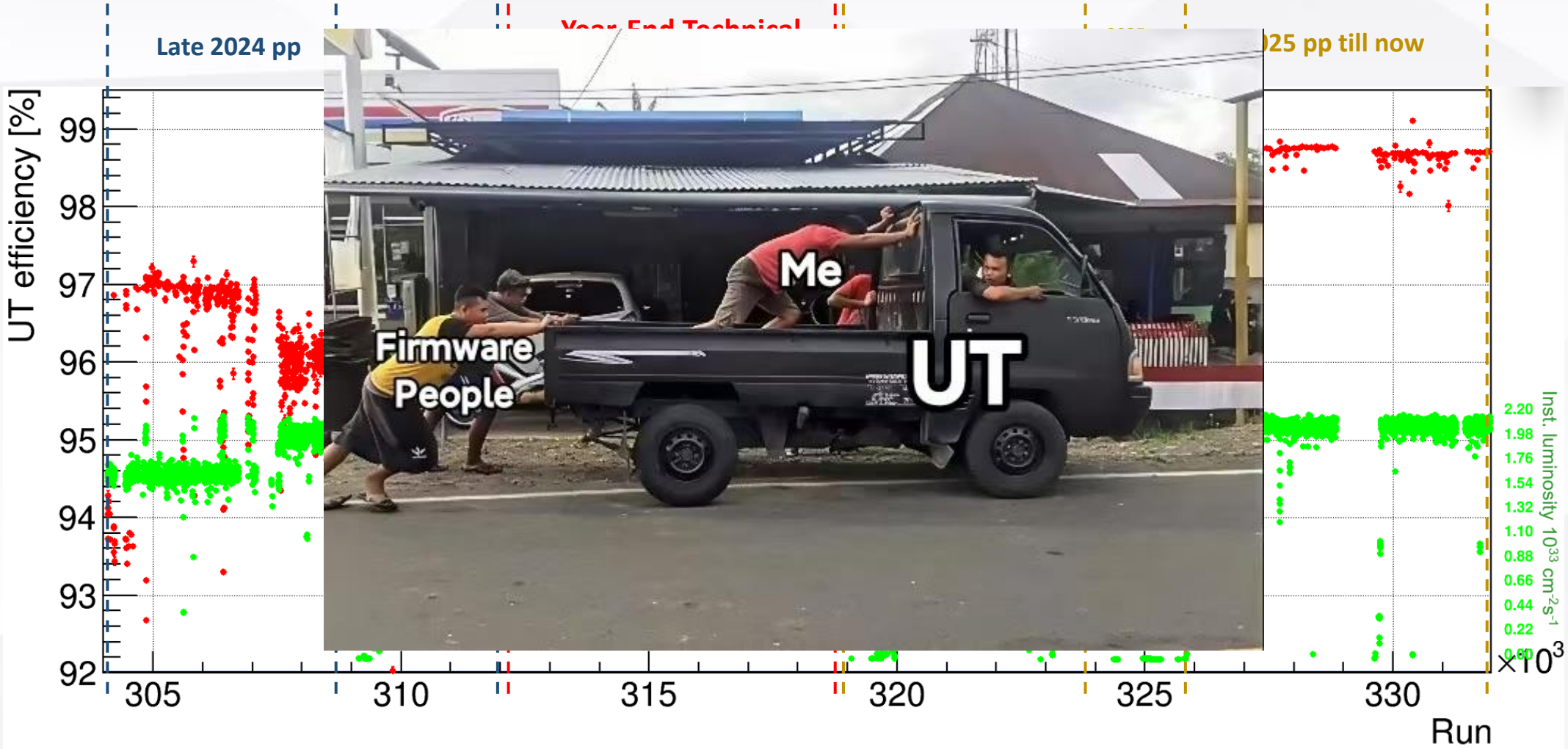

Fig 9. UT tracking efficiency(>= 3 UT hits) 2025 vs 2024

03 Efficiency across Run3

- **Performance study by comparing data from run2 and run3 via $\Xi_c^0 \to \Xi^-\pi^+, \Xi^- \to \Lambda\pi^-, \Lambda \to p\pi^-$**
  - π^+/π^-: long track (across the whole tracking system: VELO, UT and SciFi).
  - $p\pi^-$: long/downstream track (only across downstream tracking system: UT and SciFi).
- **Mass resolution of Λ:**

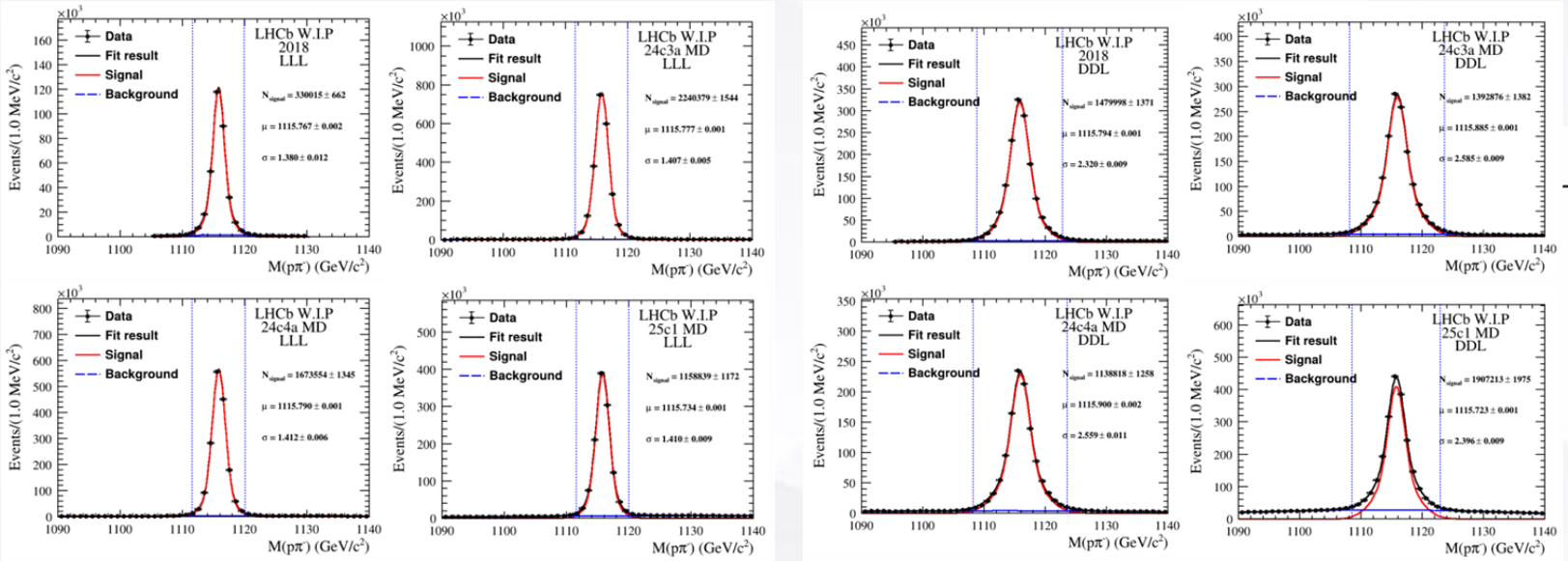

Fig 10. Mass resolution of Λ, using long tracks (left) and downstream tracks (right)

σ (MeV)	LLL	DDL
2018	1.380 ± 0.012	2.320 ± 0.009
24c3a	1.407 ± 0.005	2.585 ± 0.009
24c4a	1.412 ± 0.006	2.559 ± 0.011
25c1	1.410 ± 0.009	2.396 ± 0.009

- The Λ mass resolution is comparable between Run2 and 2024/2025.

03 Efficiency across Run3

- **Performance study by comparing data from run2 and run3 via $\Xi_c^0 \to \Xi^- \pi^+, \Xi^- \to \Lambda \pi^-, \Lambda \to p\pi^-$**
  - π^+/π^-: long track (across the whole tracking system: VELO, UT and SciFi).
  - $p\pi^-$: long/downstream track (only across downstream tracking system: UT and SciFi).
- **Signal yield/luminosity:**
  - **Trigger:**
    - ✓ **L0 (only applied in 2018): L0Hadron_TOS||TIS**
    - ✓ **Hlt1: Inclusive HLT1 trigger (= no specific requirements)**
  - **Selections**
    - ✓ **Apply the same cuts on 2018, 2024c3/c4, 2025c1 samples**

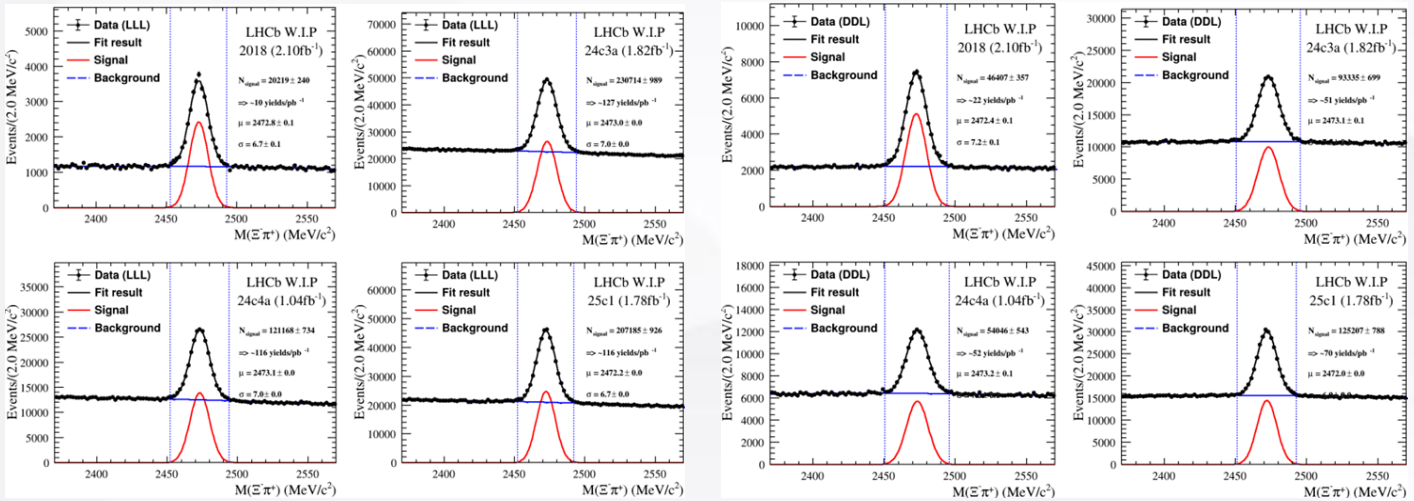

Fig 11. Signal yield using long tracks(left) and downstream tracks(right)

Yields/pb^{-1}	LLL	DDL	DDL/LLL
2018	10	22	2.20
24c3a	127	51	0.40
24c4a	116	52	0.45
25c1	116	70	0.60

- Compare to 2018
  - Significant increase in Ξ_c^0 reconstruction
  - LLL **~10x**
  - DDL **~3x**
  - Gain: No L0 trigger & improvement in HLT1

Part 4

Summary

04 Summary

- The operation of UT includes calibration, monitoring and strategies of tackling single-event upset issue.
- Recent TrimDAC and pedestals results show the stability and reasonable low noise in UT.
- The performance of UT, in terms of tracking level efficiency, has achieved ～98% this year !
- Also, a comprehensive performance study via a Ξ_c^0 decay channel is conducted; we see very promising enhancement on the luminosity averaged signal yield.
- For the future: The Phase II upgrade (Upstream Pixel detector) will be installed in 2033-2034.

  Many Chinese teams play leading role. (高能物理研究所，华南师范大学，湖南大学，河南师范大学，西北工业大学， 兰州大学，中国科学院大学，中南大学)

中國科學院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

LHCb

UT Upstream Tracker

Thanks for your attention!

SYRACUSE UNIVERSITY
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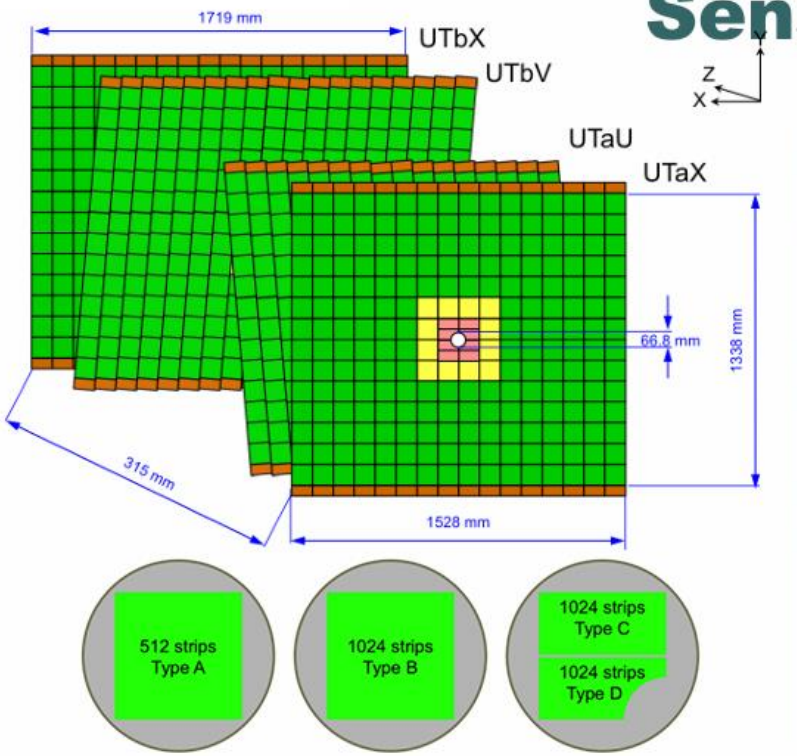
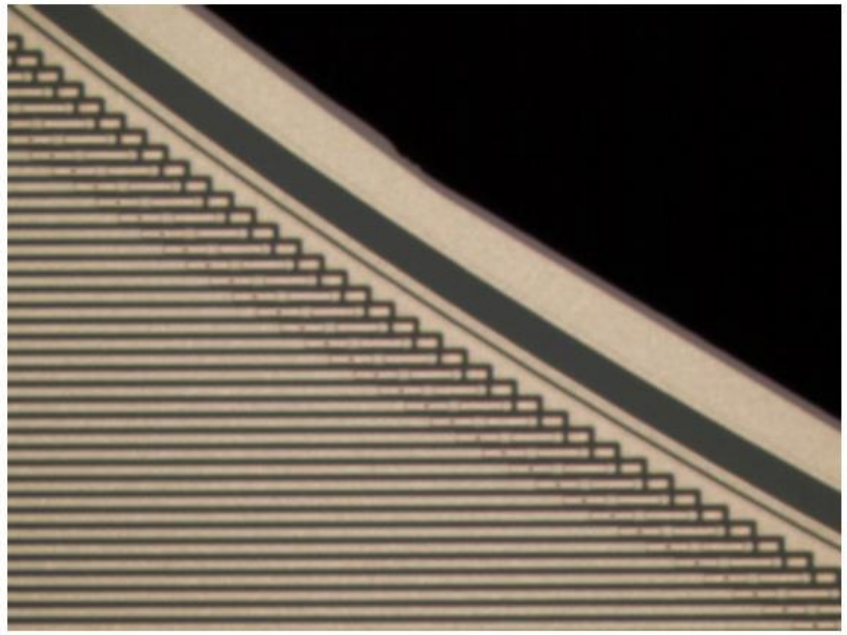
FOUNDED A·D· 1870

中国科学院大学
University of Chinese Academy of Sciences

Back up

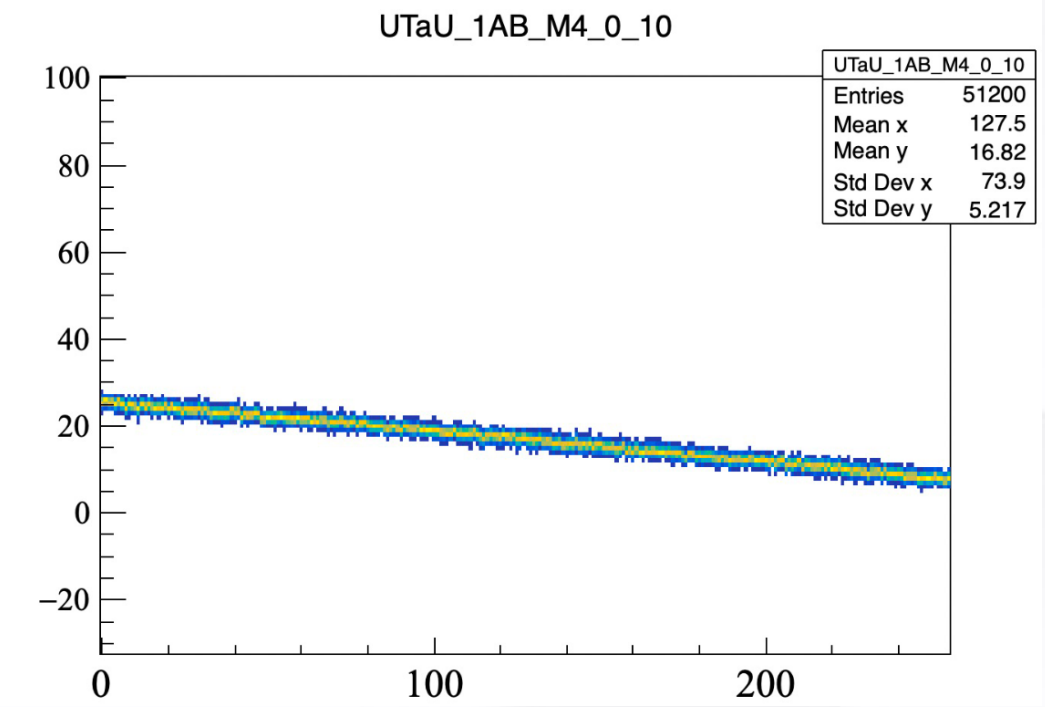
Sensors



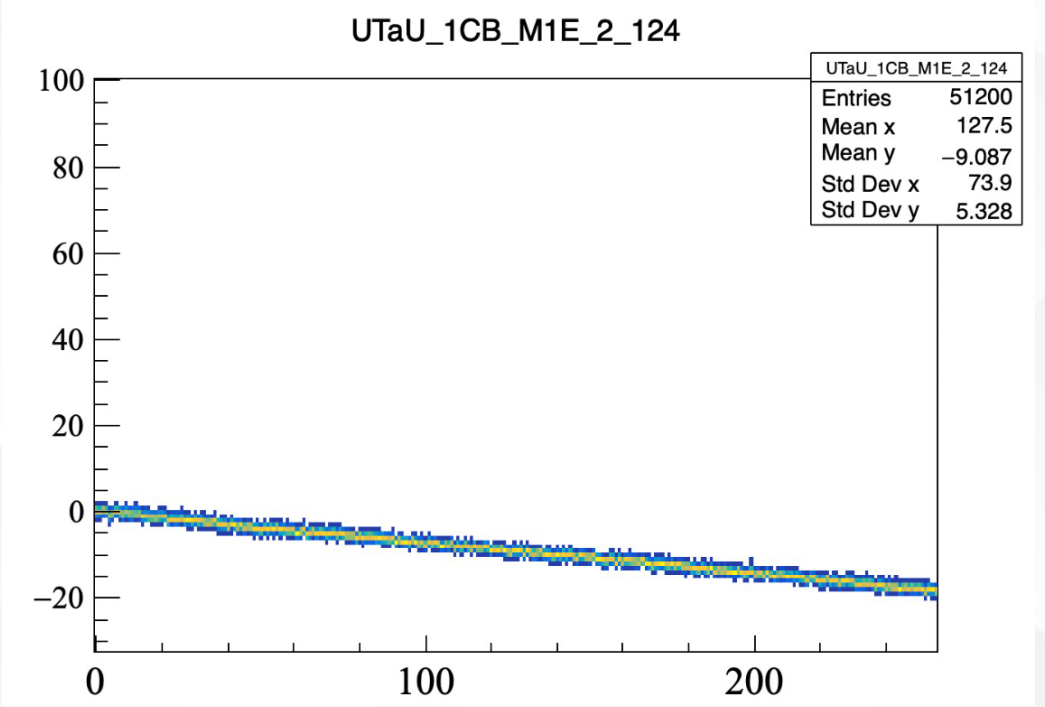


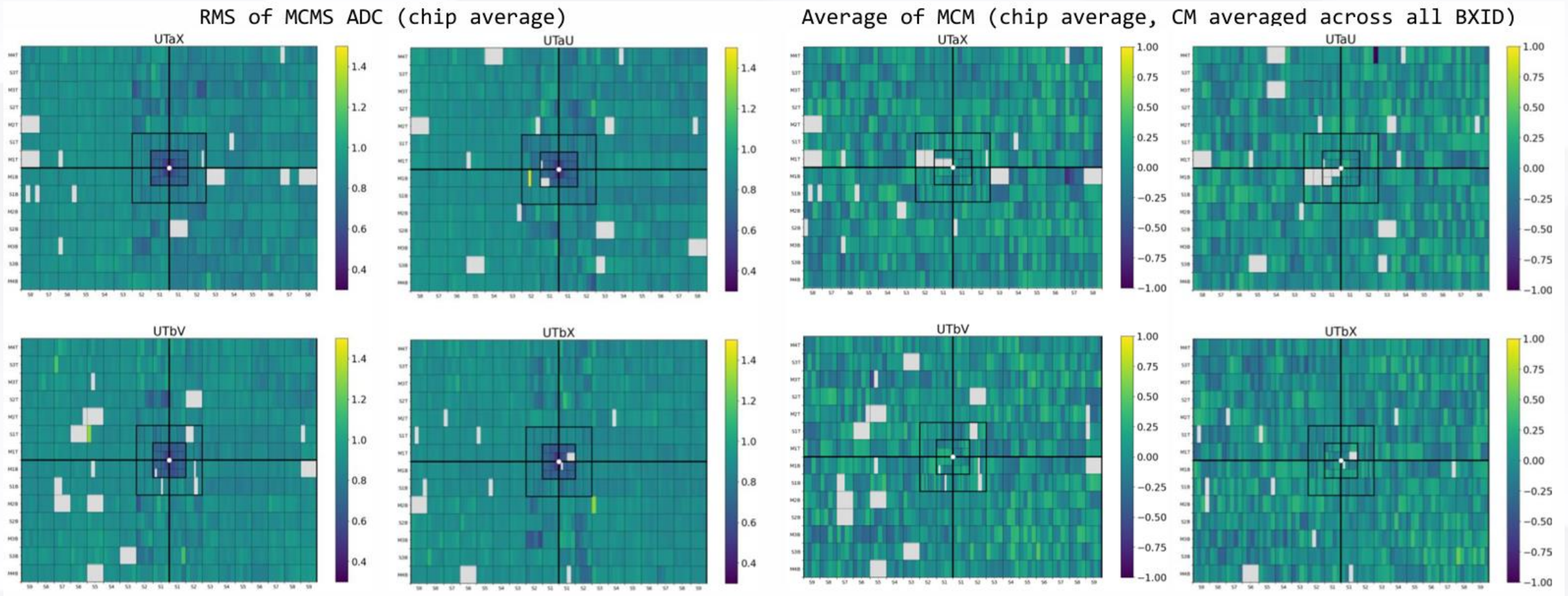
- Four types of sensors.
  - n- and p-type with 512 or 1024 strips.
  - 320/250 µm thick; 187.5/93.5 µm pitch.
- 888, 48, 16 & 16 type A, B, C, D, respectively!

example of overflow channel:



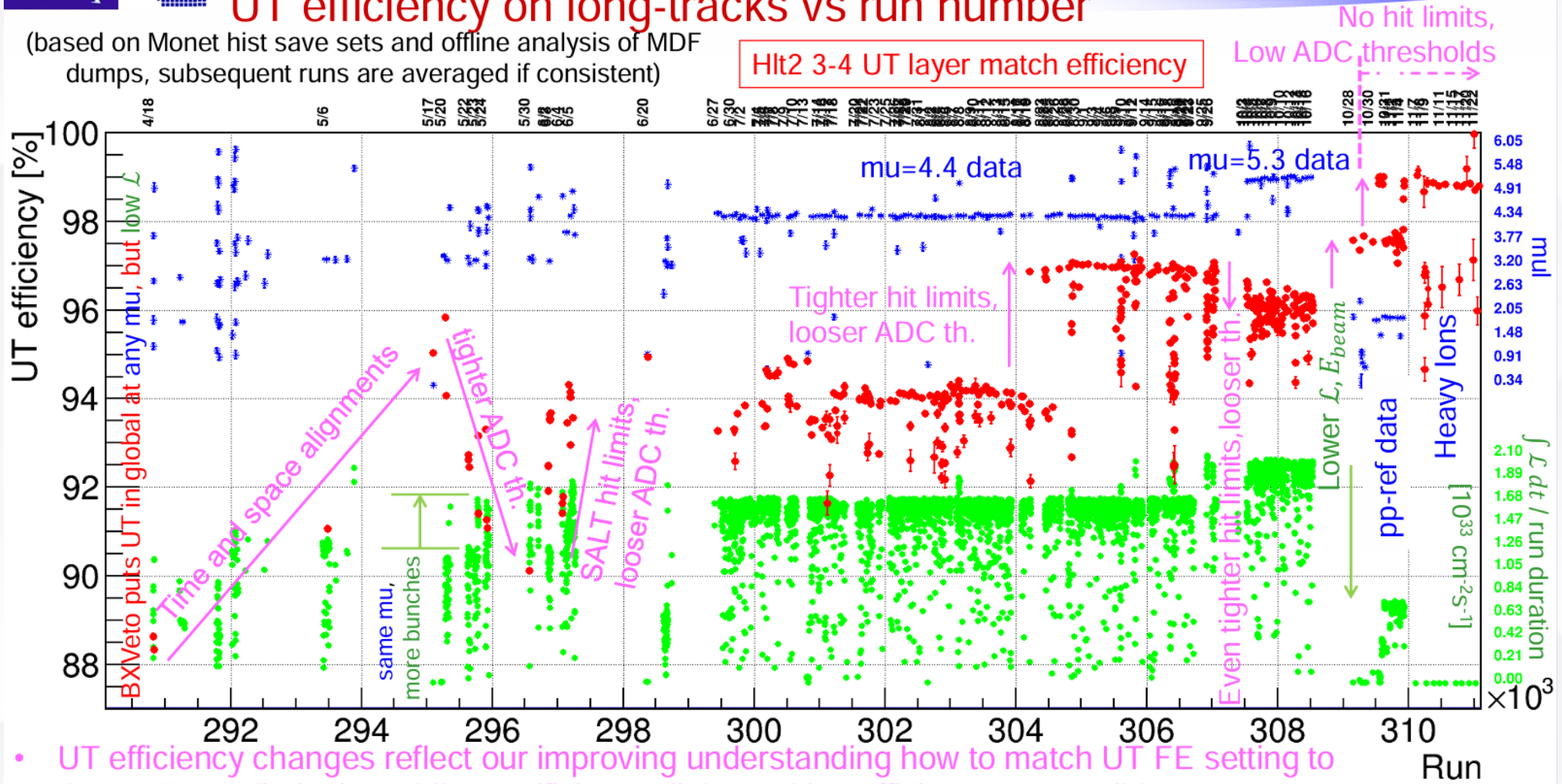
example of underflow channel:




RMS of MCMS ADC (chip average)
UTaX
UTaU
UTbV
UTbX
Average of MCM (chip average, CM averaged across all BXID)
UTaX
UTaU
UTbV
UTbX

UT efficiency on long-tracks vs run number

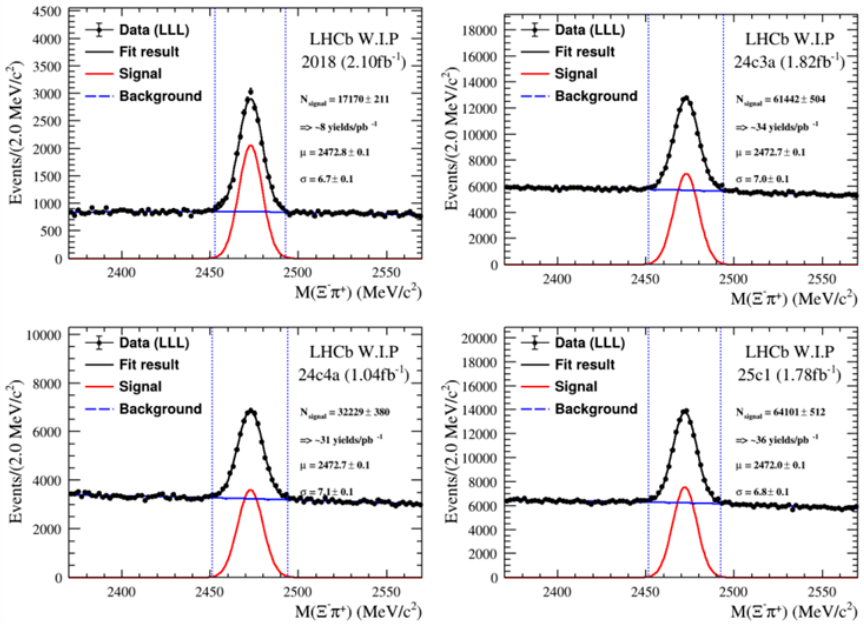
(based on Monet hist save sets and offline analysis of MDF dumps, subsequent runs are averaged if consistent)

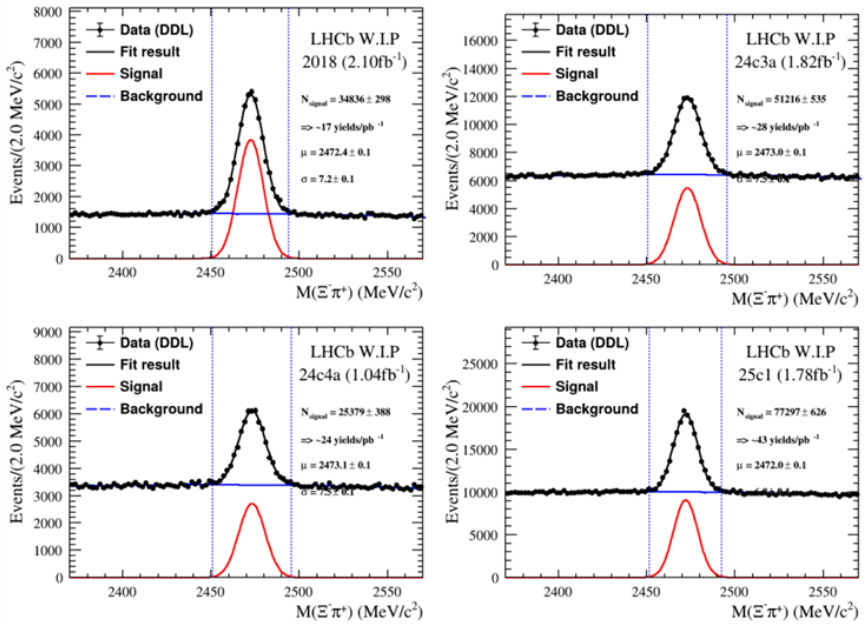


- UT efficiency changes reflect our improving understanding how to match UT FE setting to the DAQ rate limitation while sacrificing as little tracking efficiency as possible

- **Triggers**
  - ✓ L0 (only applied in 2018): L0Hadron_TOS||TIS
  - ✓ Hlt1: Exclusive HLT1 trigger (Xic_{Track, TwoTrack}MVA_TIS||TOS)

- **Selection**
  - ✓ Apply the same cuts on 2018, 2024c3/c4, 2025c1 samples





$\text{Yields}/\text{pb}^{-1}$	LLL	DDL	DDL/LLL
2018	10 → 8	22 → 17	2.13
24c3a	127 → 34	51 → 28	0.82
24c4a	116 → 31	52 → 24	0.77
25c1	116 → 36	70 → 43	1.19

Compare to 2018
- **LLL ~4.5x**
- **DDL ~2.5x**

Compare to 2024
- **$\text{Yields}/\text{pb}^{-1}$ of DDL case increase**
- **Improvement from UT & rec. Algorithm**

- **Triggers**
  - ✓ L0 (only applied in 2018): L0Hadron_TOS||TIS
  - ✓ Hlt1: Exclusive HLT1 trigger (Xic_{Track, TwoTrack}MVA_TIS||TOS)
- **Simulation Options:**
  - ✓ 2024: Official production (AP!3703) (sim10f)
  - ✓ 2025: private production (Moore/v57r6p3, config_pp_2025)

- **Selection**
  - ✓ Apply the same cuts on 2018, 2024c3/c4, 2025c1 samples

Simulation	2024			2025		
	LLL	DDL	DDL/LLL	LLL	DDL	DDL/LLL
After DaVinci	272	564	2.07	274	647	2.36
TrueID Match	211 (77%)	388 (69%)	1.84	217 (79%)	457 (71%)	2.11
Mass Window (Λ/Ξ^-)	205 (97%)	379 (98%)	1.85	211 (97%)	444 (97%)	2.10
Apply same cut	185 (90%)	311 (82%)	1.68	161 (76%)	340 (77%)	2.11
Hlt1 Trigger	28 (15%)	38 (12%)	**1.36**	29 (18%)	40 (12%)	**1.38**

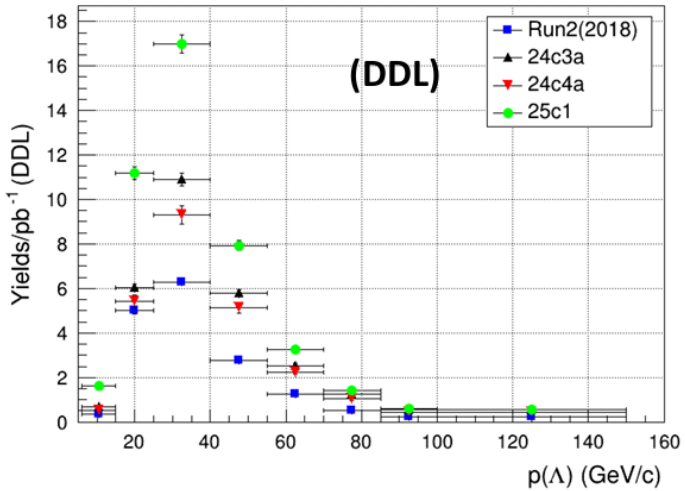
The last Step I for DATA procedure **($DDL/LLL \approx 0.5$)**

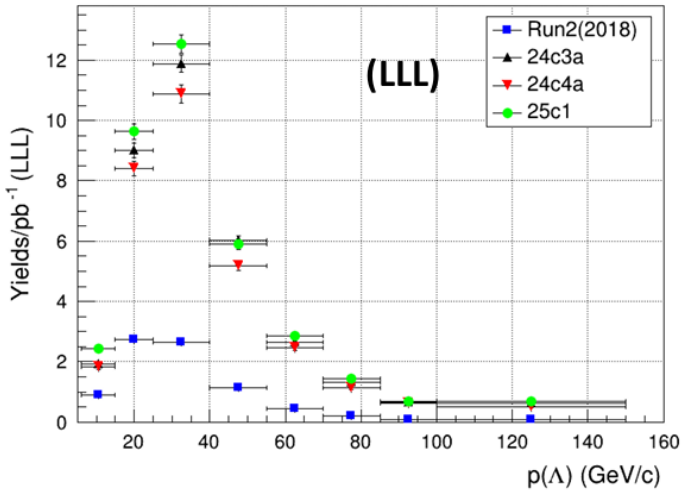
- **The DDL/LLL ratio is comparable to 2025 data (~ 1.19)**

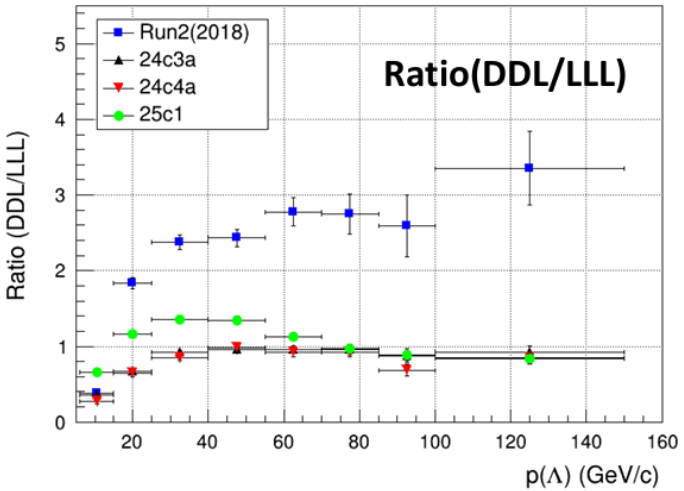
- **Triggers**
  - ✓ L0 (only applied in 2018): L0Hadron_TOS||TIS
  - ✓ Hlt1: Exclusive HLT1 trigger (Xic_{Track, TwoTrack}MVA_TIS||TOS)
- **Binning method**
  - ✓ Separate bins on $p(\Xi_c^0)$, $p_T(\Xi_c^0)$, $\boldsymbol{p(\Lambda)}$, $\eta(\Lambda)$ (see other plots in backup)
  - ✓ Plots show as the order: $\mathrm{Yields/fb^{-1}}$(DDL), $\mathrm{Yields/fb^{-1}}$(LLL), Ratio (DDL/LLL)

- **Selection**
  - ✓ Apply the same cuts on 2018, 2024c3/c4, 2025c1 samples

$\boldsymbol{p(\Lambda)}$







- **The lower ratio in Run 3 (w.r.t. Run 2) is mainly due to the significant increase in LLL production rate (no L0 trigger & dedicated HLT1 trigger …)**
- **In Run3, increase in DDL yields w.r.t. Run2 of about a factor 2.5**