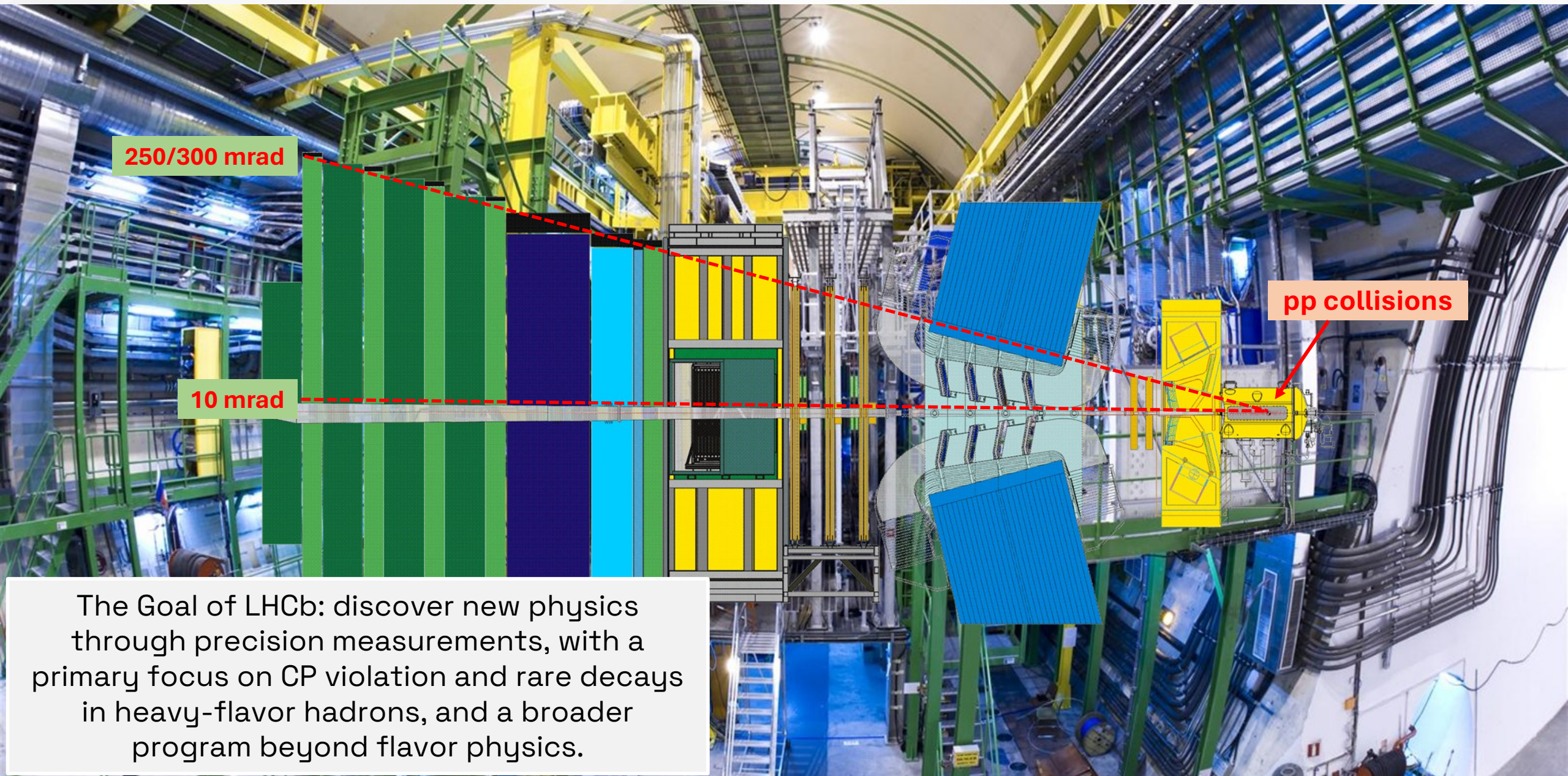


LHCb Upstream Tracker Operation and Radiation Effects during Run 3

¹Yuan Yuan on behalf of the LHCb UT team

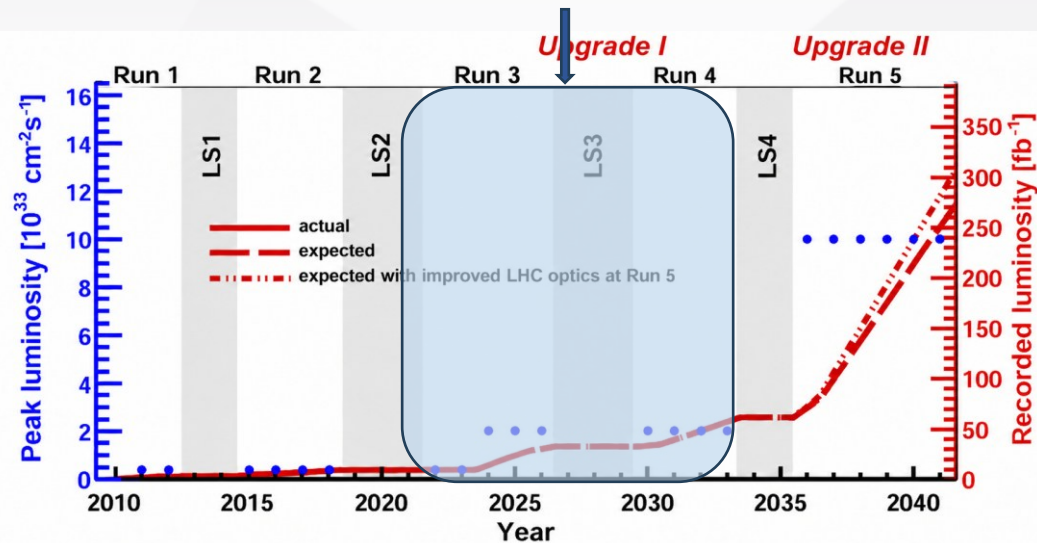
¹Institute of High Energy Physics, CAS

LHCb – A Forward Spectrometer @ LHC

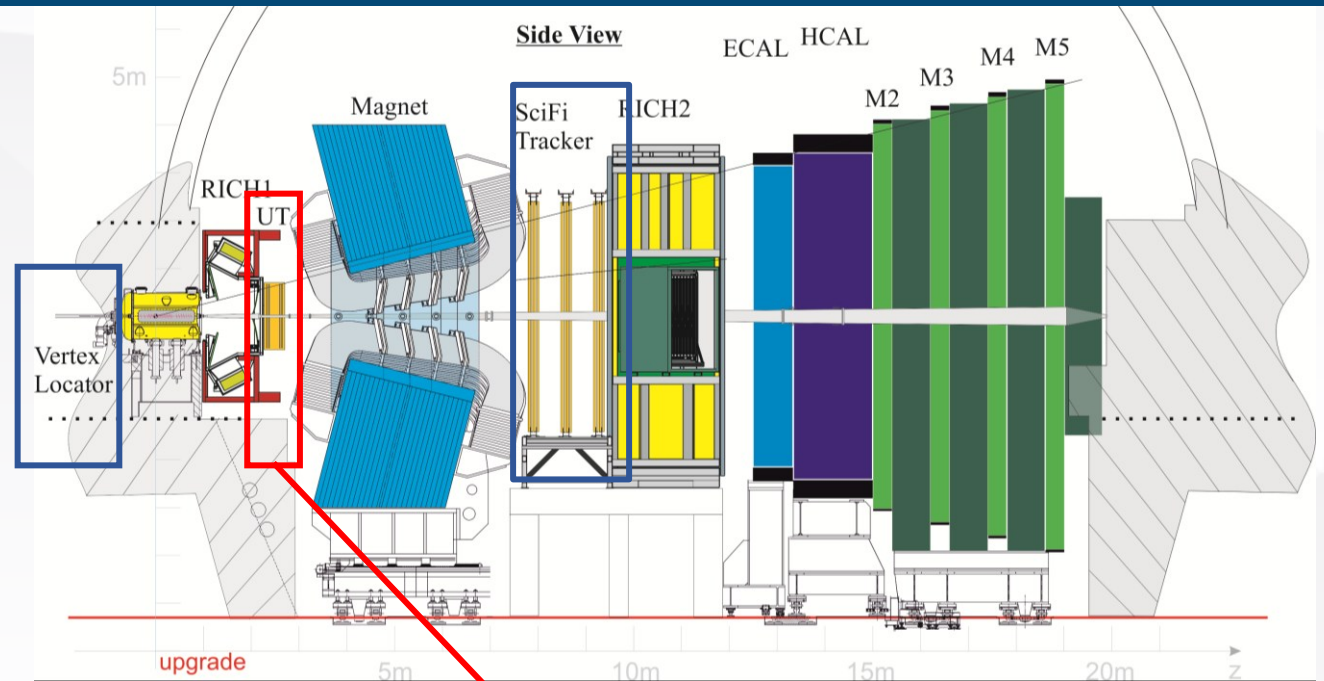


LHCb Upgrade

Where we are



[LHCb Upgrade II Scoping Document](#)

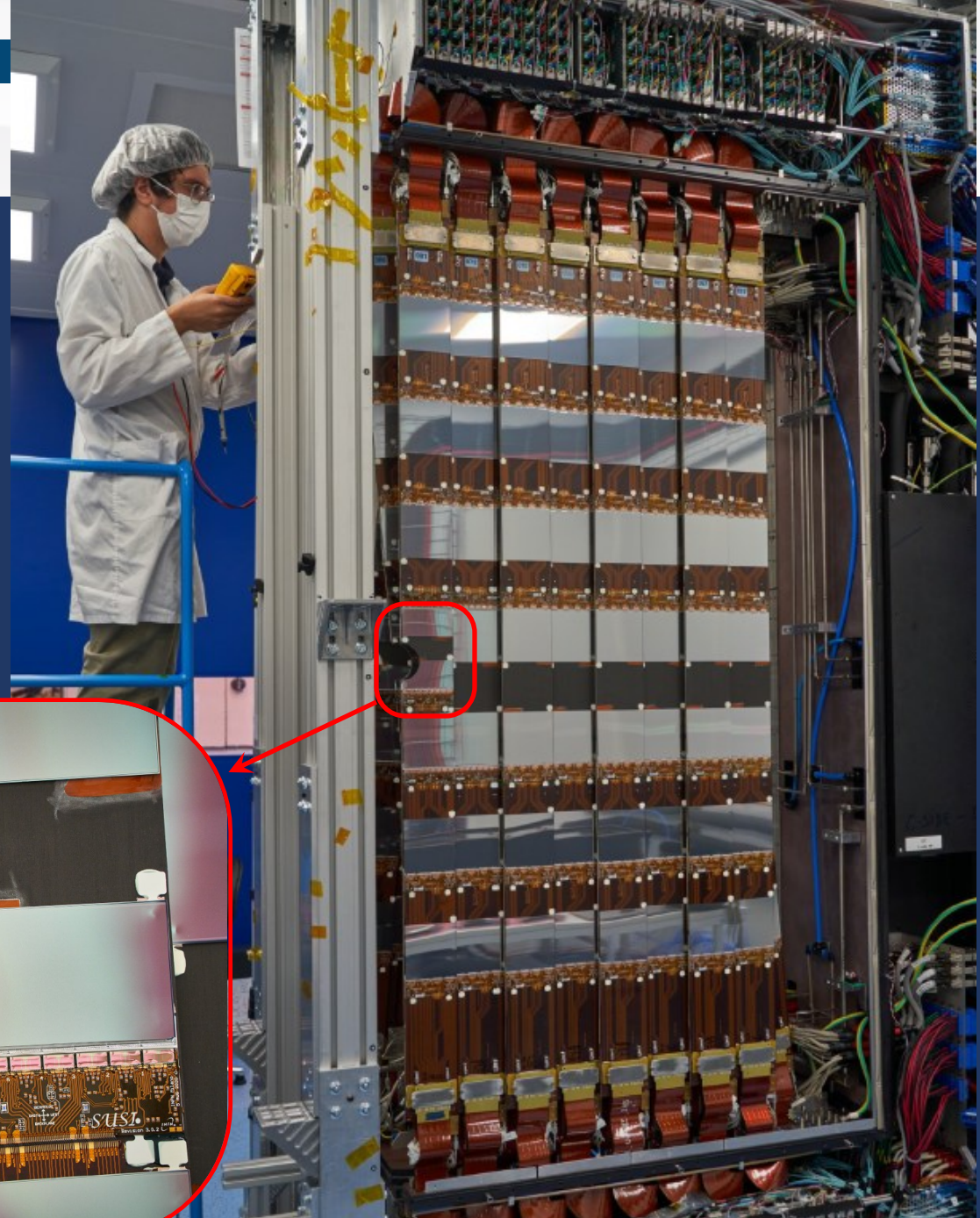
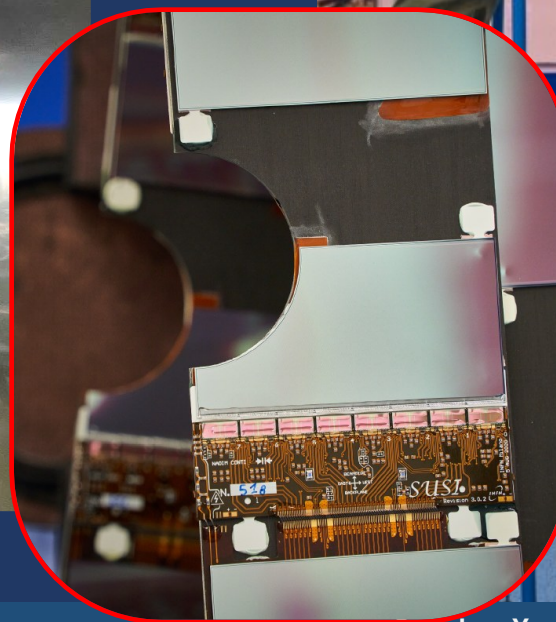
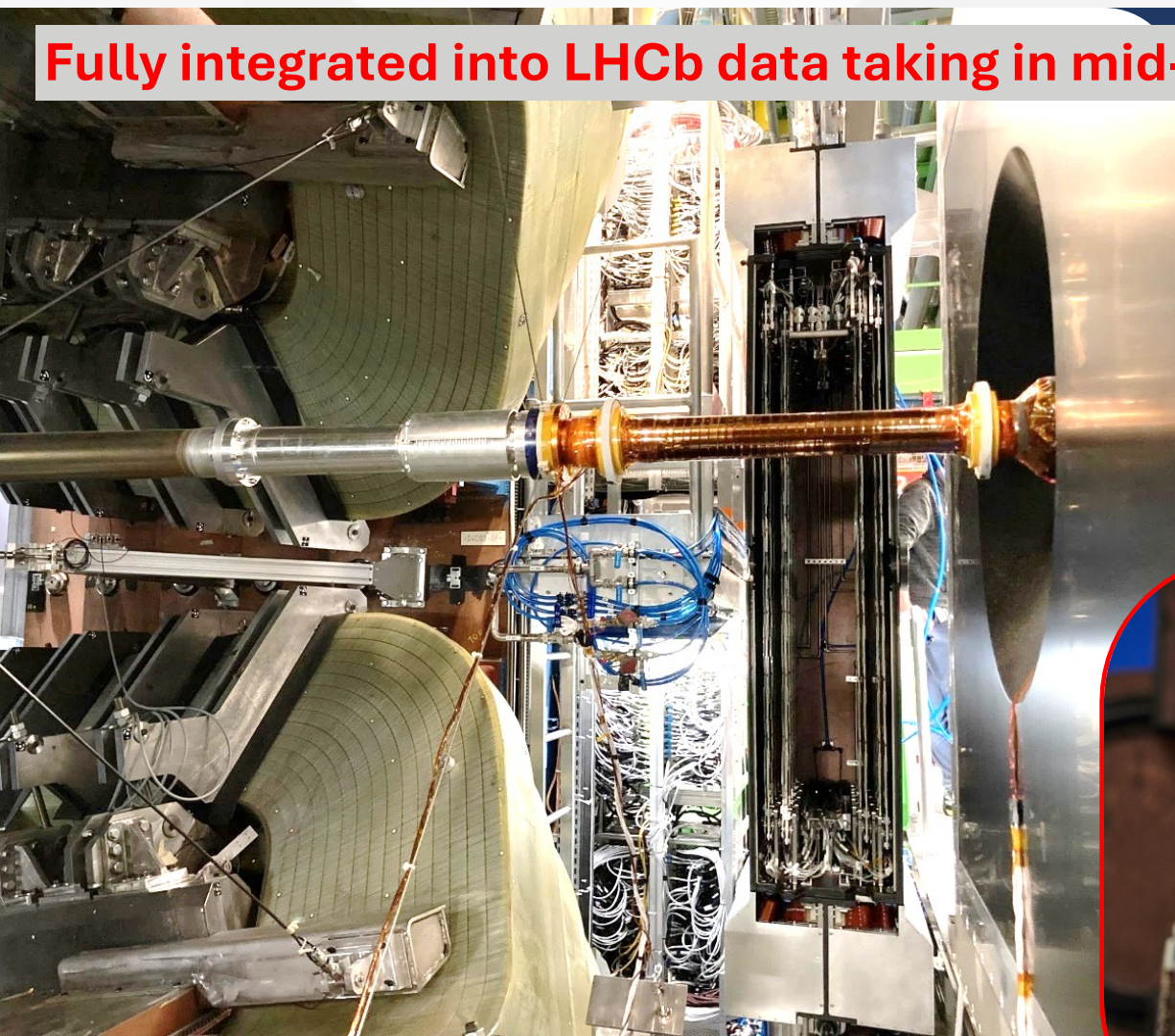


This presentation

- **The LHCb Upgrade I: $\sim 5 \times$ luminosity (up to $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$) w.r.t Run 1 & 2**
 - New Tracker system: VELO (silicon-pixels), Sci-fi and **Upstream trackers (silicon strips)**
 - Enhanced PID detectors ([Invited talk from Antonios Papanestis](#))
 - **40 MHz readout with fully software trigger!**

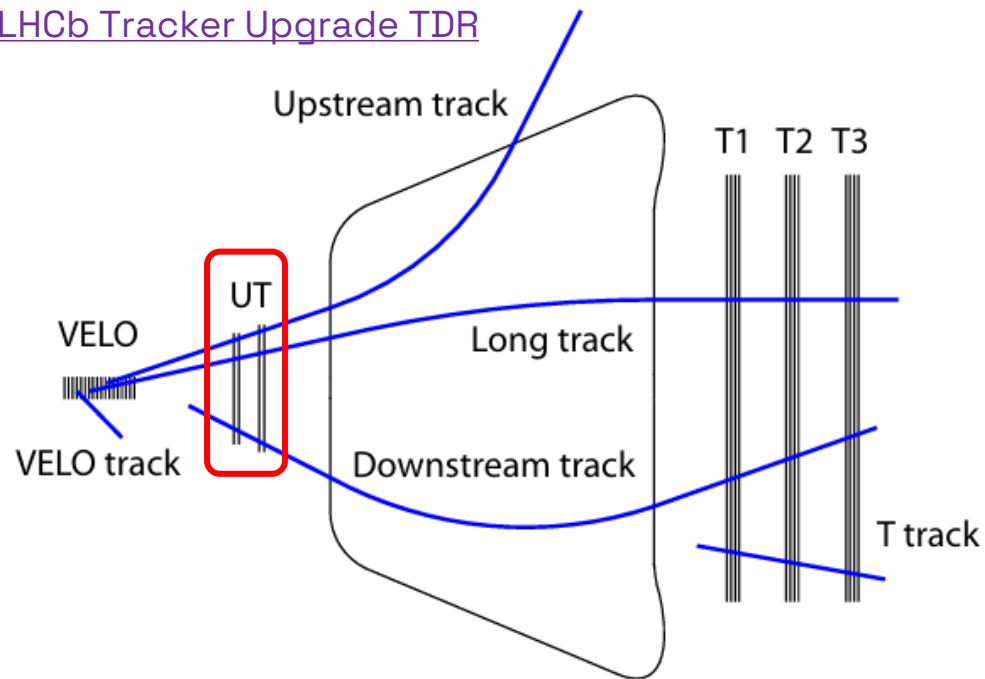
Micro-strip Upstream Tracker

Fully integrated into LHCb data taking in mid-2024



Why LHCb needs Upstream Tracker ?

[LHCb Tracker Upgrade TDR](#)



- **Role of the UT in the tracking system**

- ⇒ **Suppressing ghost tracks**
- ⇒ **Enabling faster software-trigger decision**
- ⇒ **Improving track momentum resolution**
- ⇒ **Reconstructing long-lived particle decays efficiently**

- **Upstream tracks:**

- Hits in the VELO and UT, without SciFi

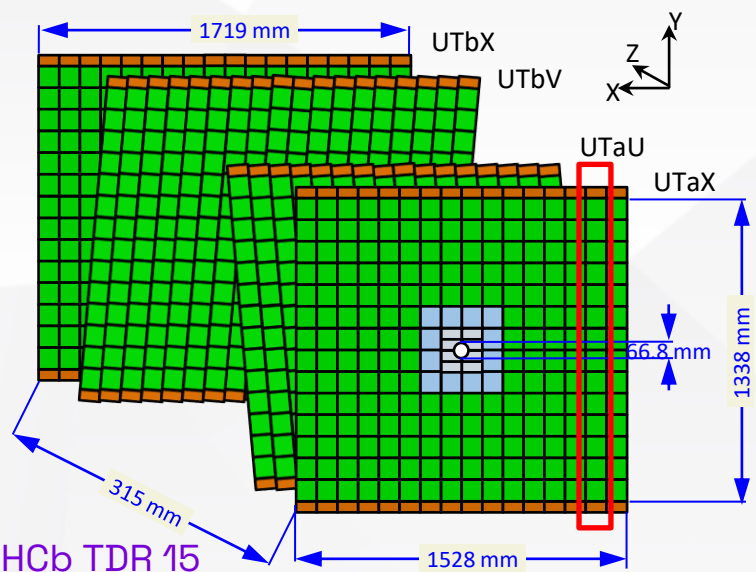
- **Downstream tracks:**

- Hits in the UT and SciFi, without VELO

- **Long tracks:**

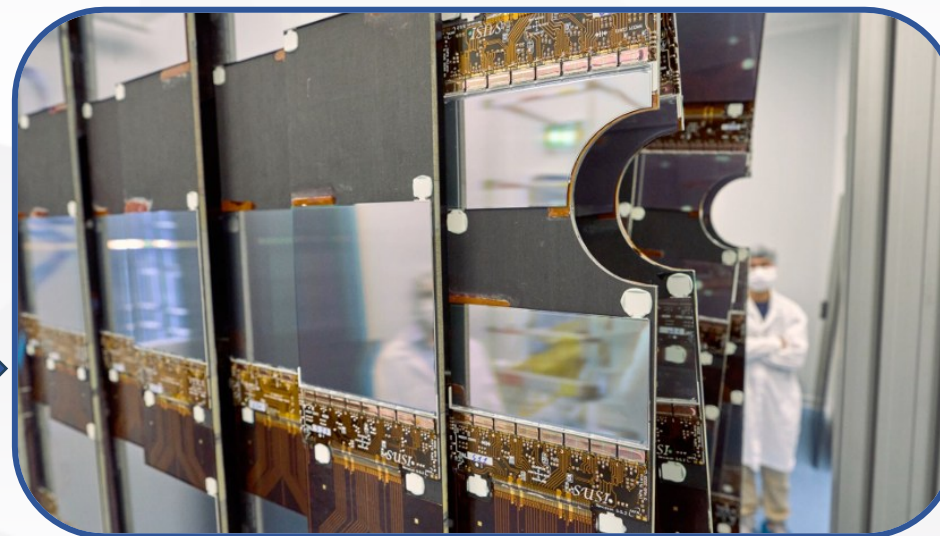
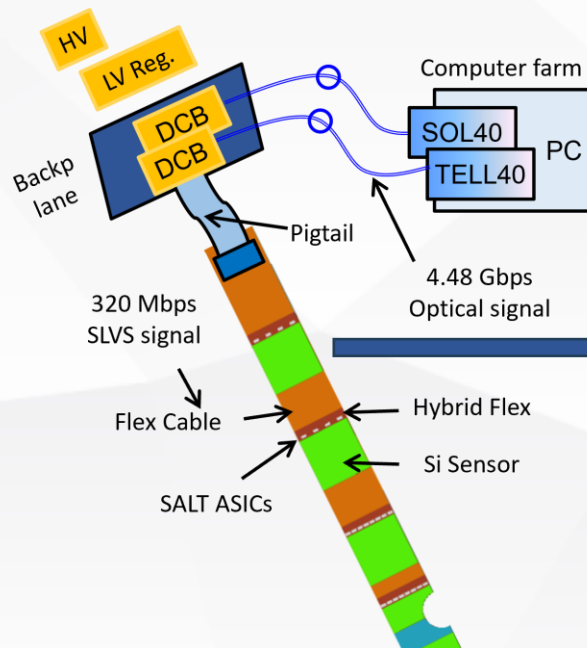
- Across the full tracking system

Components of the UT



- **4 layers of silicon micro-strip detectors**

- Arranged as **vertical/stereo layers ($\pm 5^\circ$)** to provide x-y position of particle
- 68 staves $\Rightarrow$ $\sim 500k$ strips
- Different types of sensor close to beam: **Pitch** $187.5 \mu m \rightarrow 93.5 \mu m$
Length $100 \text{ mm} \rightarrow 50 \text{ mm}$



SALT ASIC and Configuration Registers

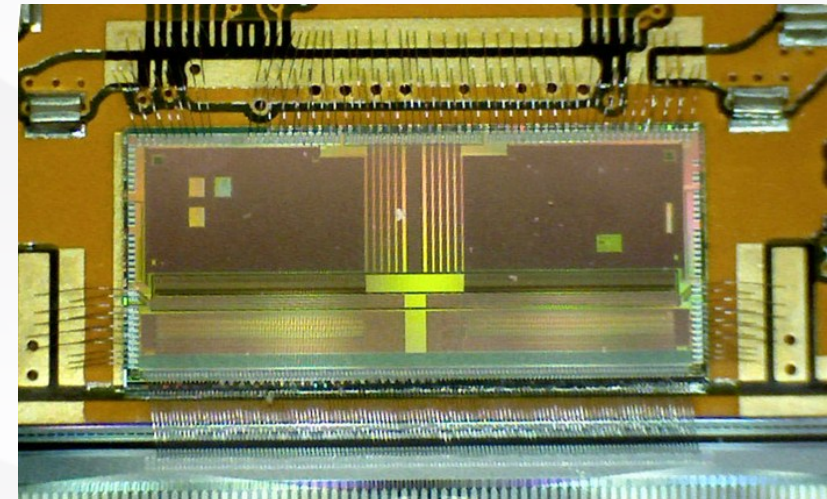
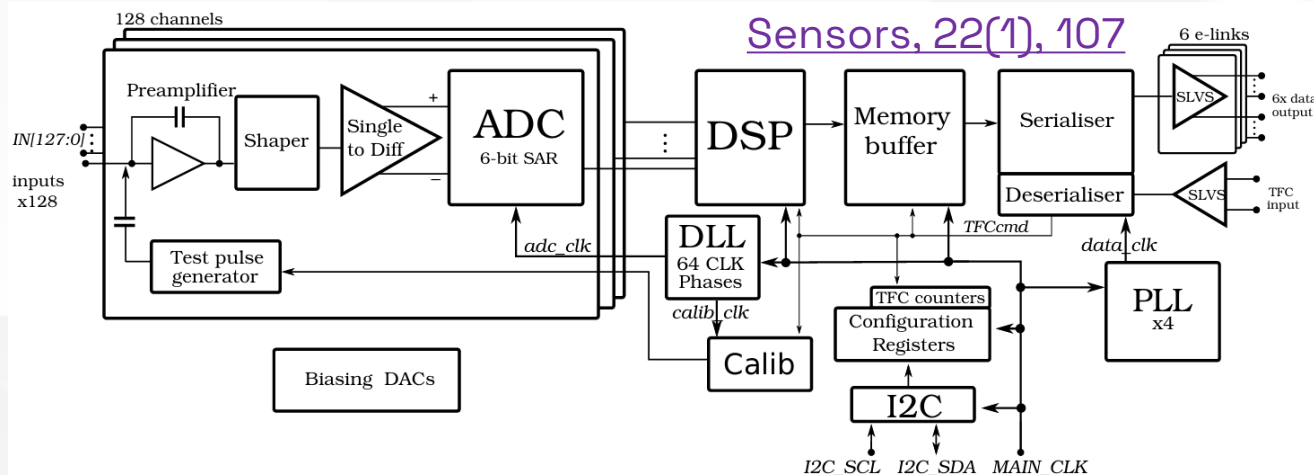
- **SALT: a custom front-end ASIC for UT**

- 128 readout channels implemented in 130 nm CMOS
- A 6-bit SAR ADC per channel, sampling at 40 MHz

- **Channel response controlled by configuration registers**

- Baseline DAC register: Analogue baseline adjustment
- Pedestal register: residual offset correction
- Other registers: shaper, pre_amp, kill_mask

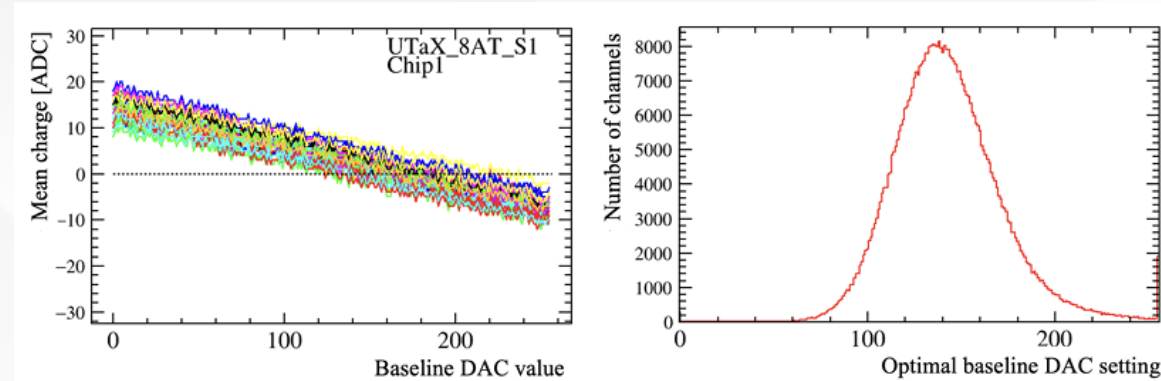
- **Single-Event Upset mitigation: Triple modular redundancy in registers**



Calibration for the UT

- **Analogue baseline equalization**

- Channel baseline currents are tuned using an 8-bit baseline DAC register
- Optimal DAC values are determined to equalize channel responses

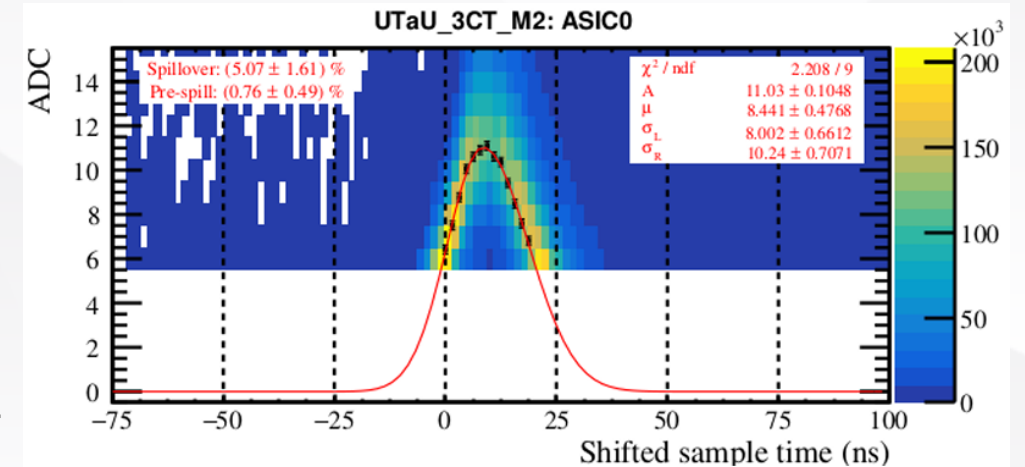


- **Digital pedestal correction**

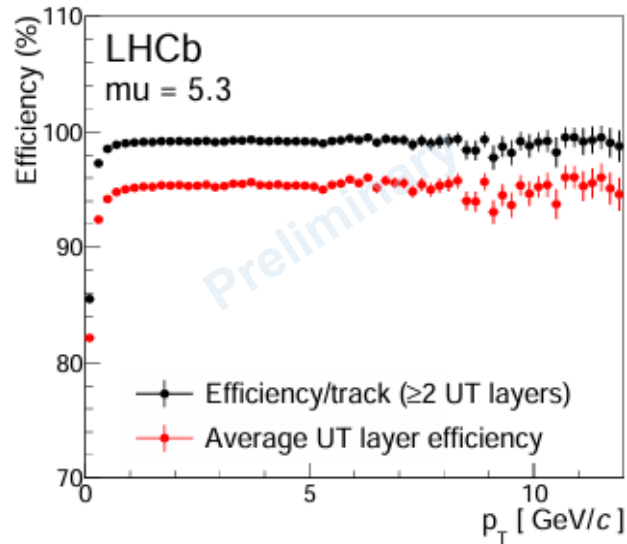
- Residual offsets are determined for outlier channels
- Pedestal values are stored in dedicated 6-bit SALT registers

- **Time alignment**

- Align hits with bunch filling scheme
- Choose ADC sampling time to digitize the peak of SALT analogue response



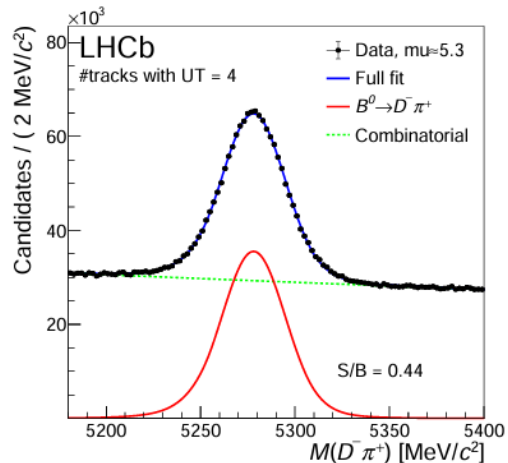
UT Performance in Track and Decay Reconstruction



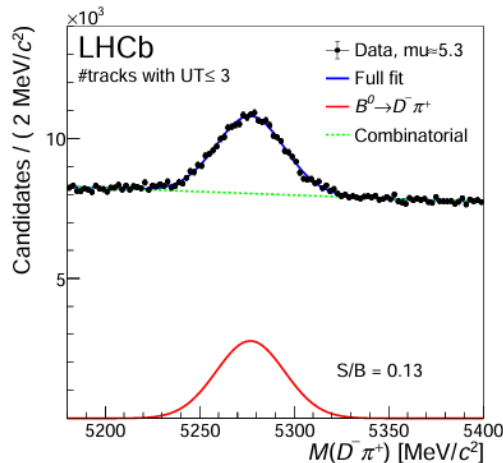
- Track reconstruction efficiency for finding hits in at least 2 UT layers:

- Achieved **~99% efficiency** beyond about 1 GeV/c
- **10% drop** for $p_T < 200$ MeV/c is seen
- Achieved an average layer efficiency of about **95%**

Tacks with UT = 4



Tacks with UT ≤ 3



- $B^0 \rightarrow D^- (K^+ \pi^- \pi^-) \pi^+$:

- Evaluated using Run 3 data for long tracks
- HLT selections applied
- All particles required to be within UT acceptance and constrain on D^- mass

⇒ **Requiring UT hits on all four decay tracks yields $\sim 3.5 \times$ higher S/B.**

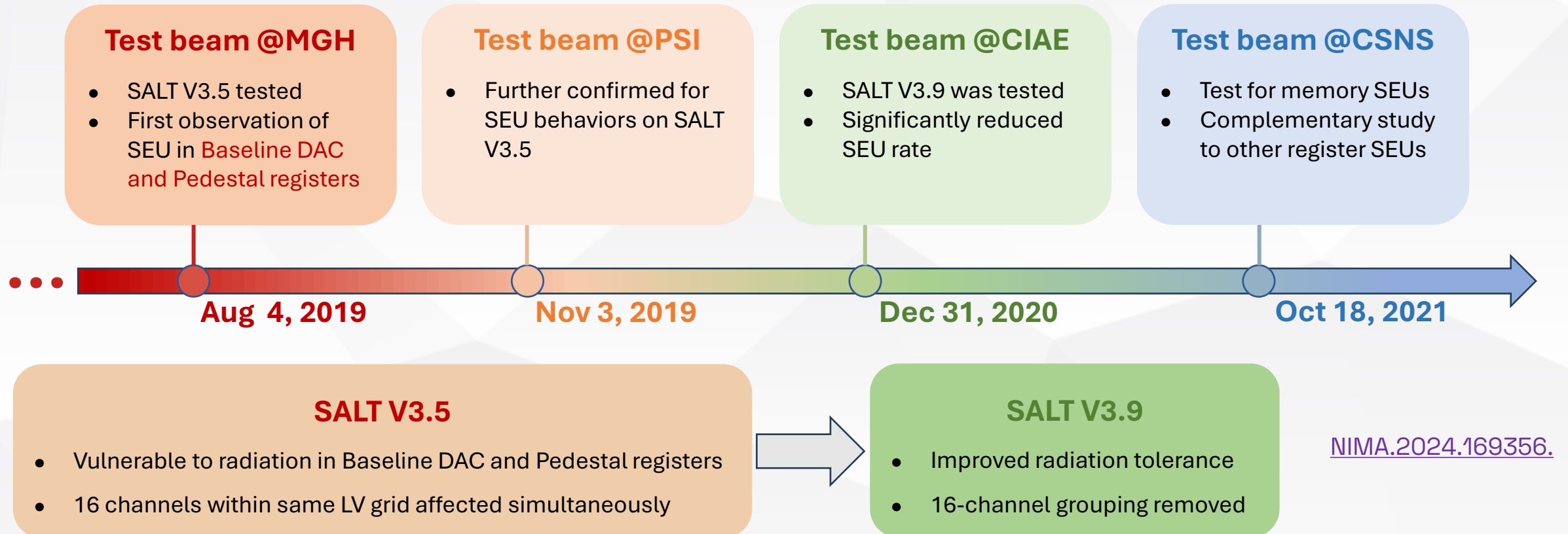
[UT Performance Paper \(In preparation\)](#)

Radiation Effects of the SALT ASIC

- Radiation-induced effects in SALT registers are investigated

- SEU may modify calibration parameters (baseline DAC and pedestal)
- Potential impacts: biased charge, increased fake hit rate

- Previous SEU studies in beam tests :

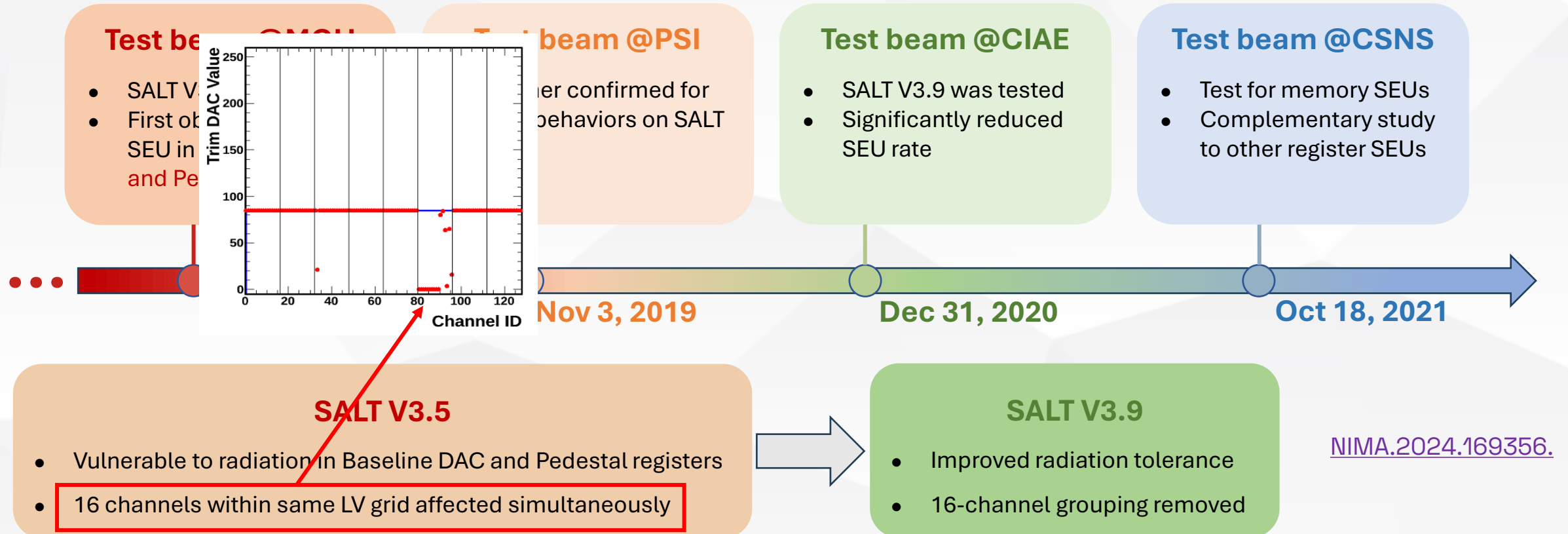


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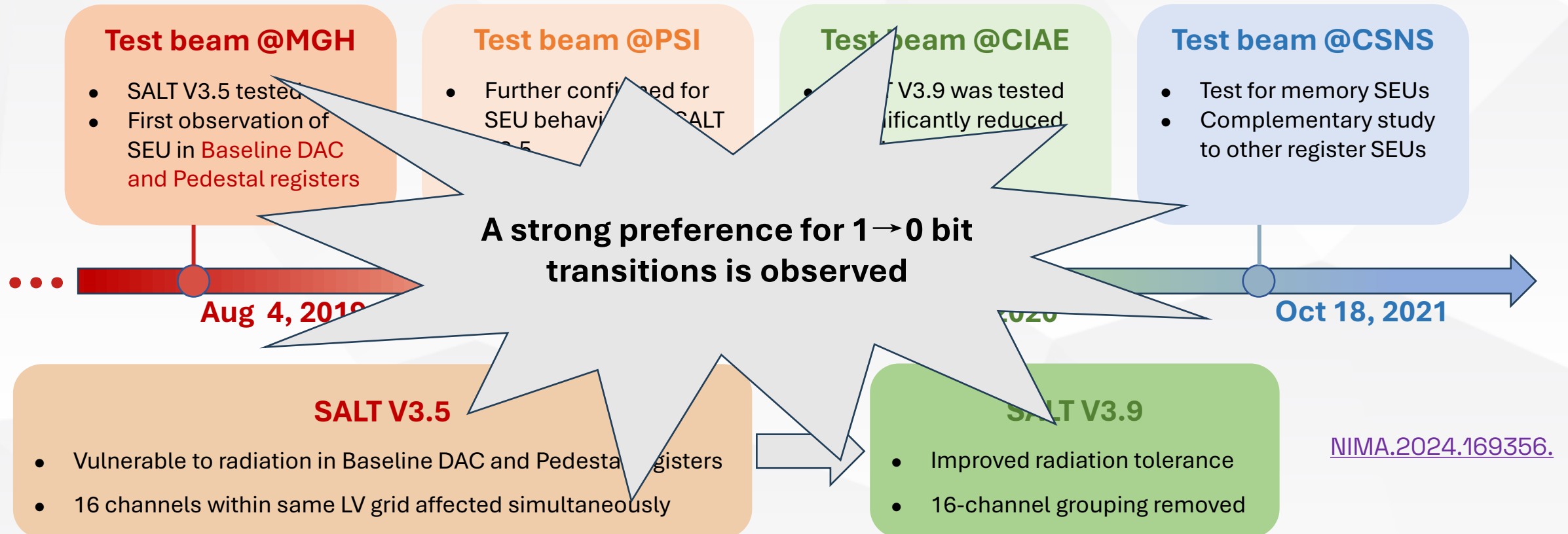


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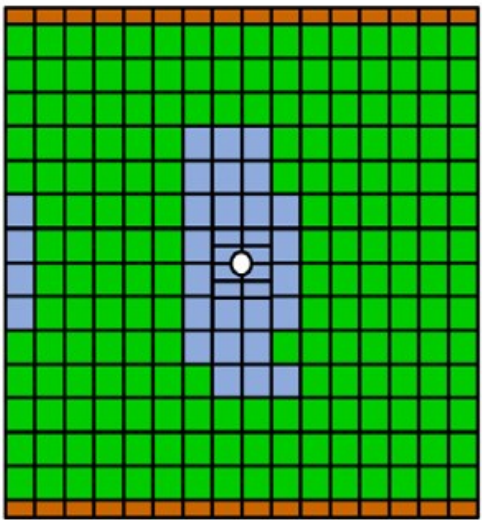
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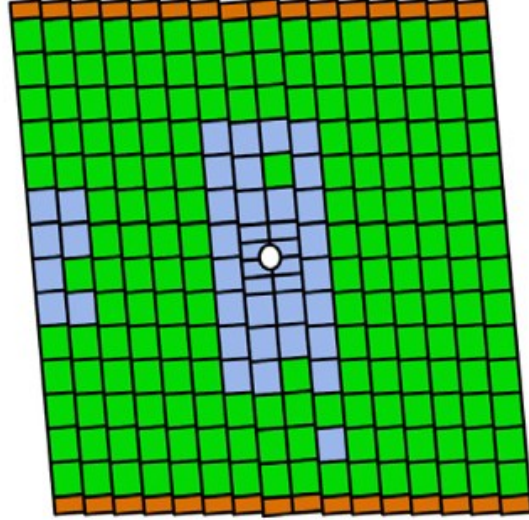
Radiation Effects of the SALT ASIC

- Radiation-induced effects in SALT registers are investigated
 - SEU may modify calibration parameters (baseline DAC and pedestal)
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- SALT versions installed in the real UT system:

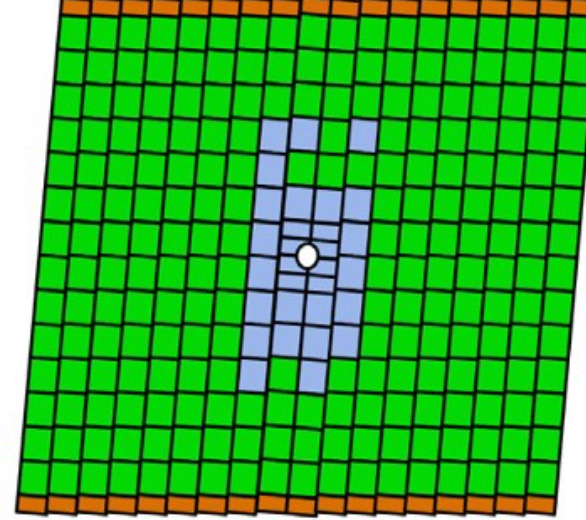
■ : SALT V3.9 ■ : SALT V3.5



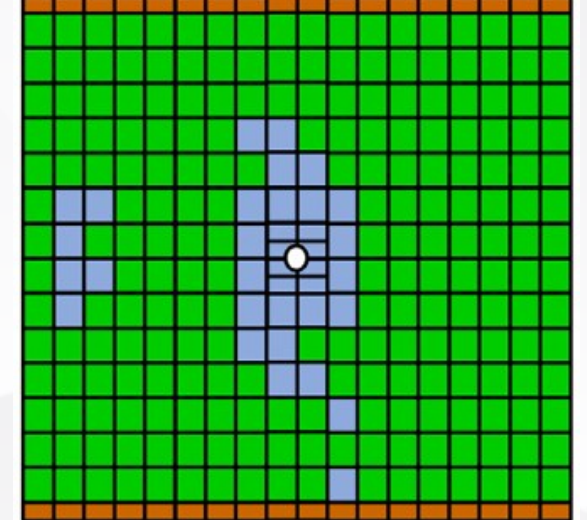
UTaX



UTaU



UTbV

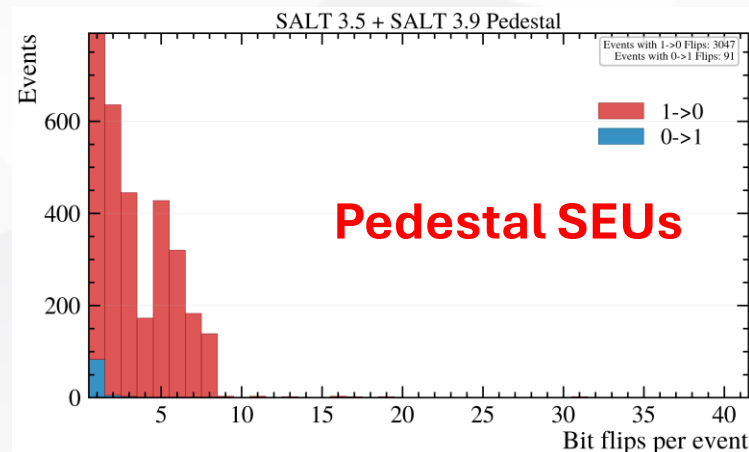
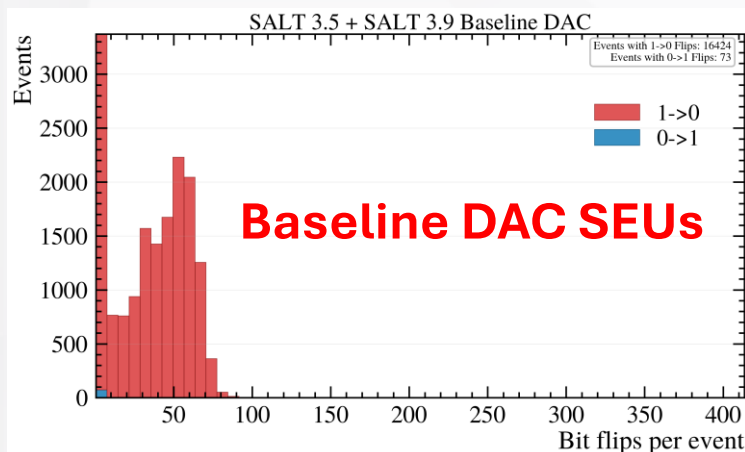
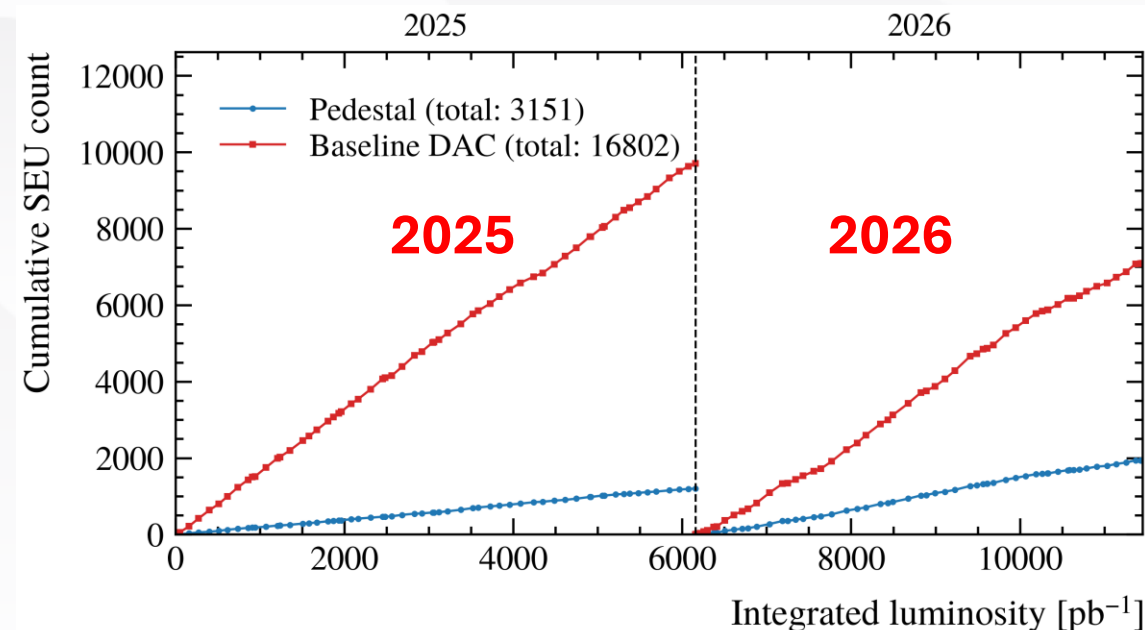


UTbX

- In-operation SEU studies provide a unique opportunity to validate the understanding gained from beam tests

Observed SEU Characteristics

- SEU occurrences increase with accumulated luminosity
 - SEU data period: Jul-Oct 2025 and Mar-Jun 2026
- Strong preference for $1 \rightarrow 0$ bit transitions
 - The initial configuration from calibration can influence the SEU sensitivity

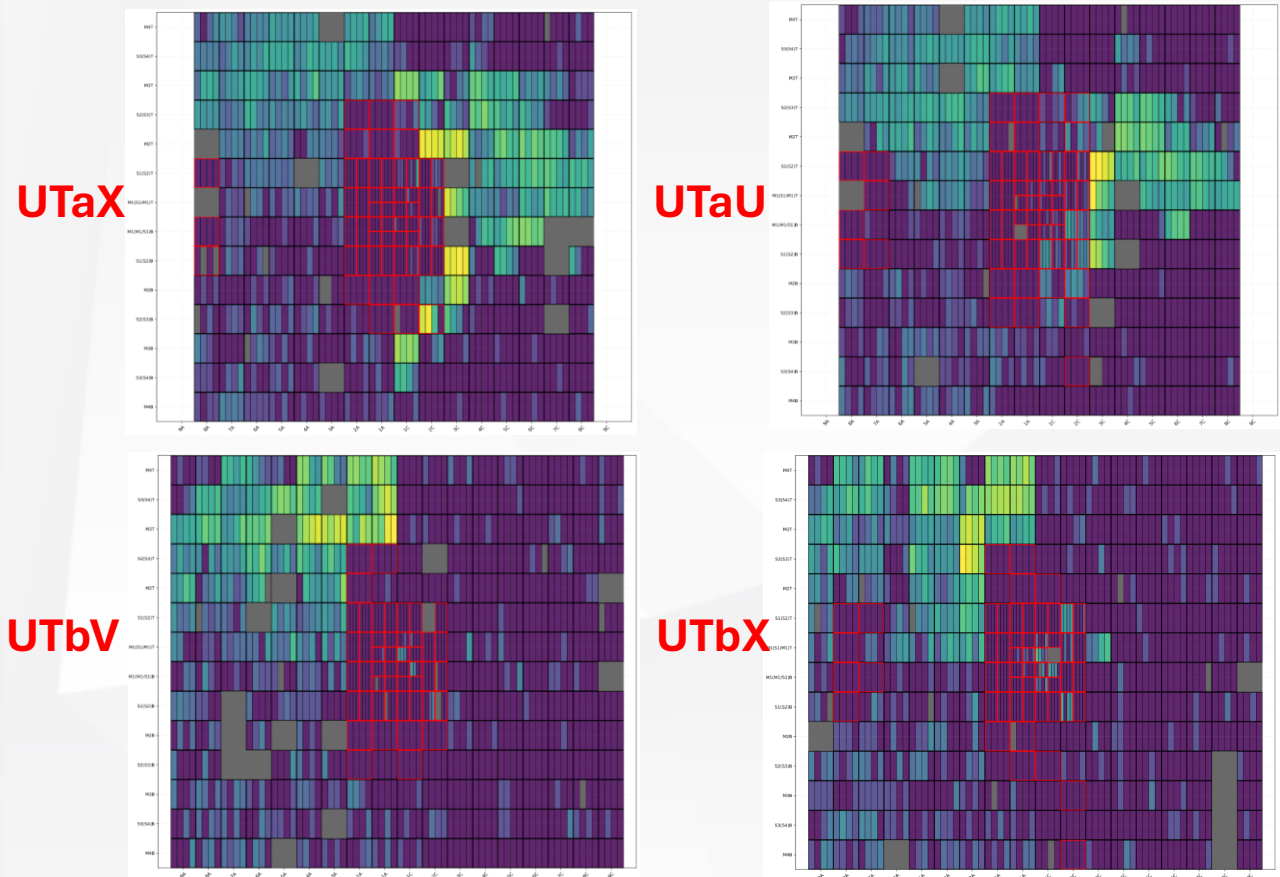
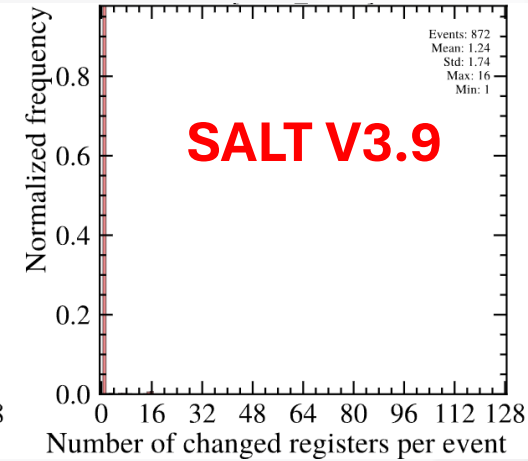
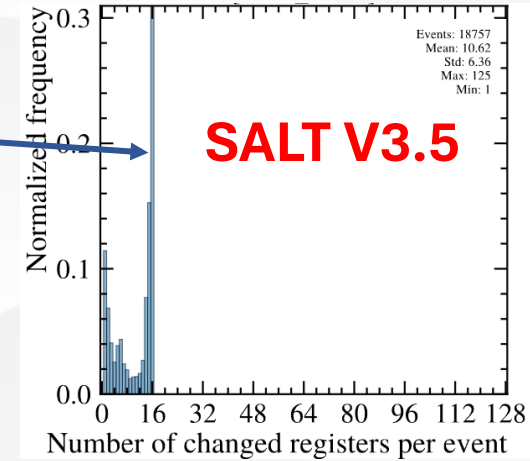


Initial configuration 1 bit proportion

year	Baseline DAC bit 1 fraction	Baseline DAC SEU Rate/mHz	Pedestal bit 1 fraction	Pedestal SEU Rate/mHz
2025	51.2%	2.36	4.4%	0.29
2026	51.4%	2.01	22.1%	0.60

Observed SEU Characteristics

- Group-of-16 channel effect observed for SALT V3.5
- The observed SEU distribution shows different patterns among UT layers/quarters



SEU vulnerable time window

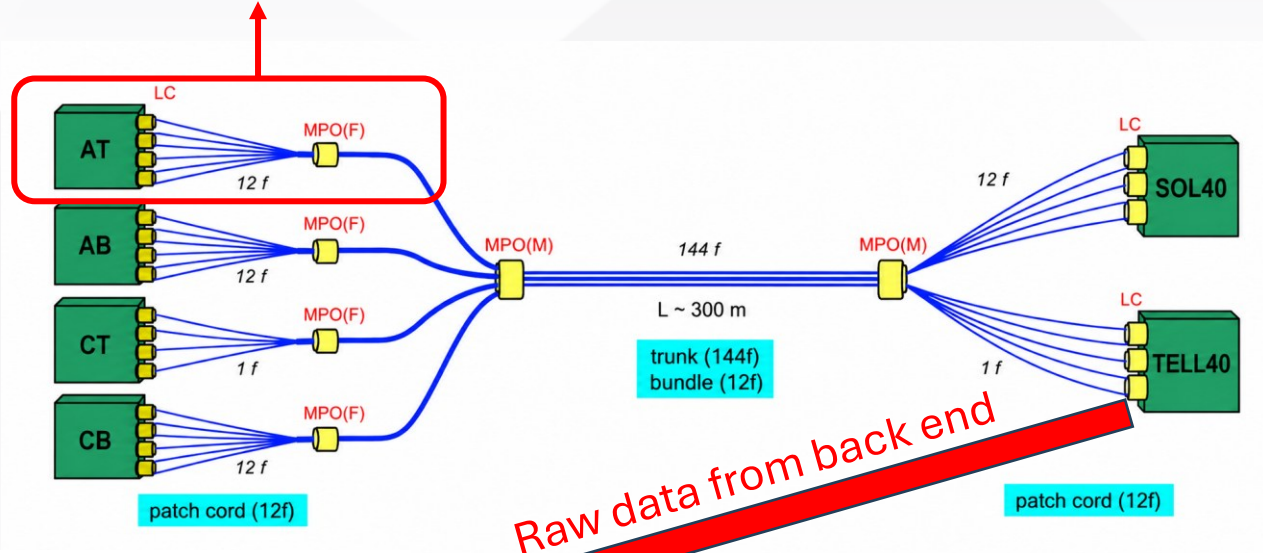
- When the SALT sampling time falls within this vulnerable window, SEU protection can be less effective, leading to observable SEUs.

Determined by time alignment

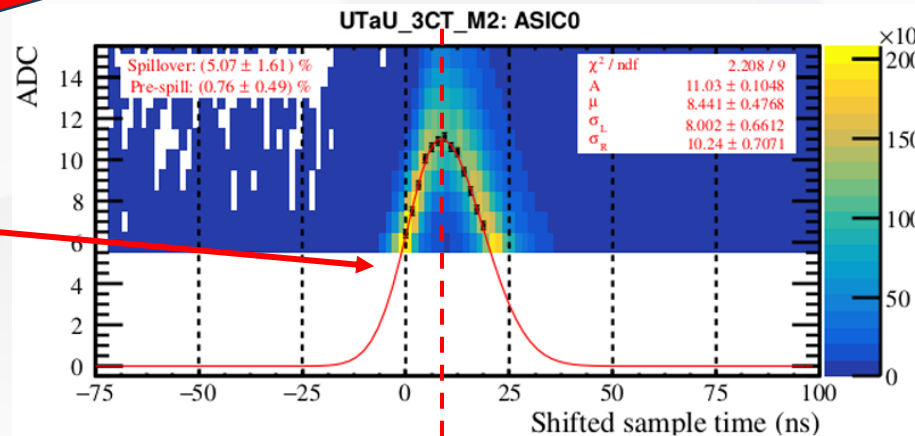
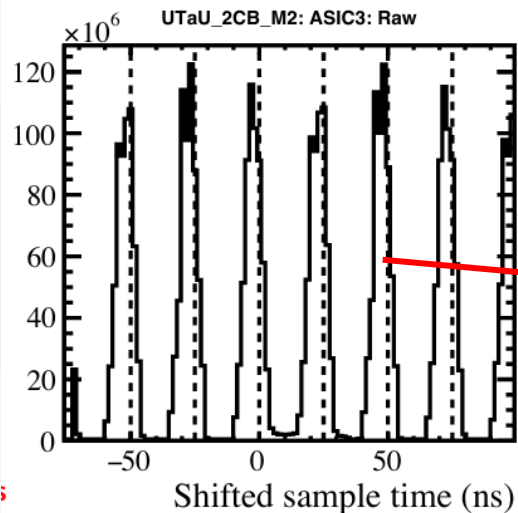
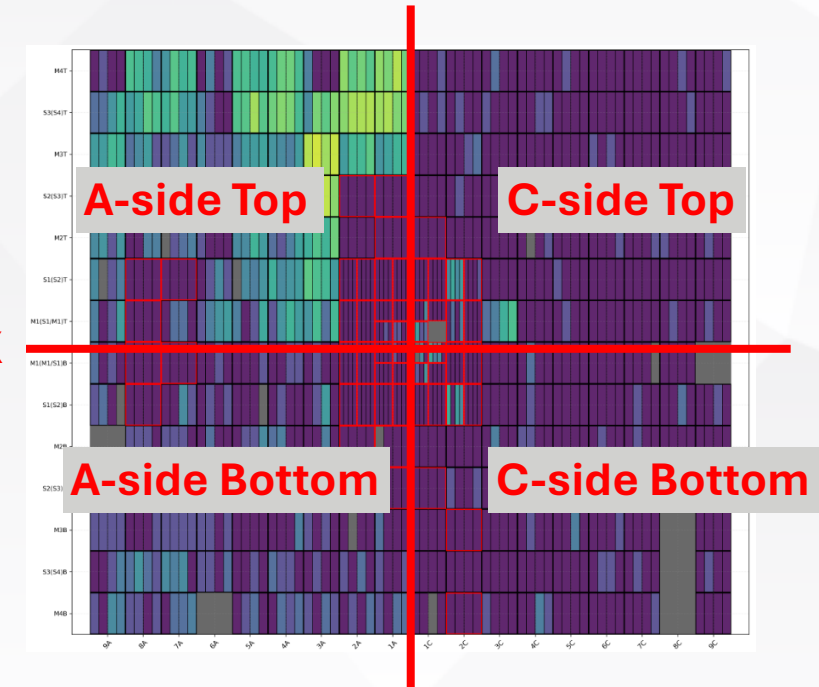
Observed SEU Characteristics

- Different optical fiber lengths for UT quarters

- Each quarter has different optical fiber lengths



UTbX

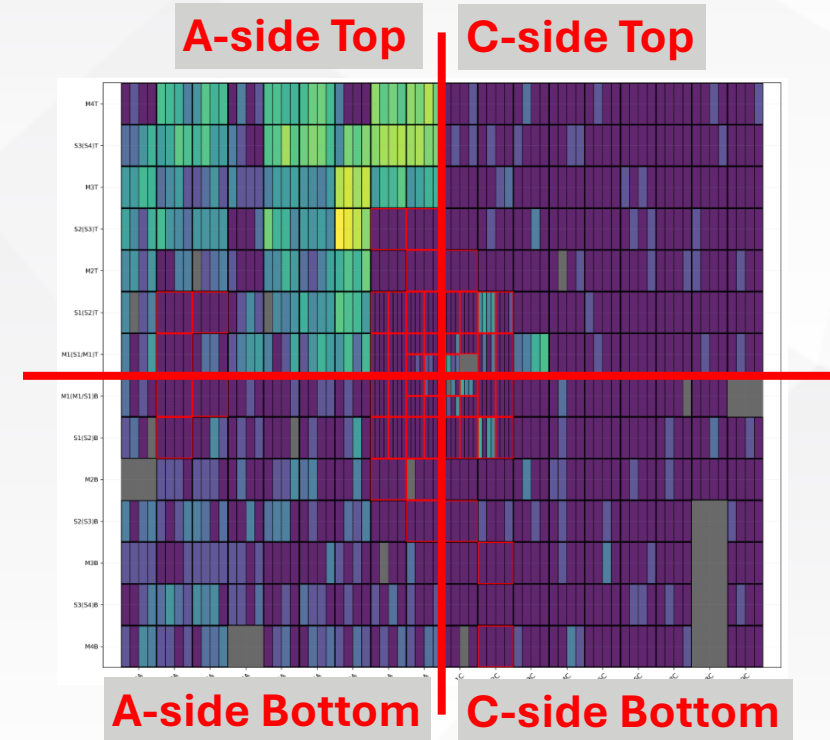
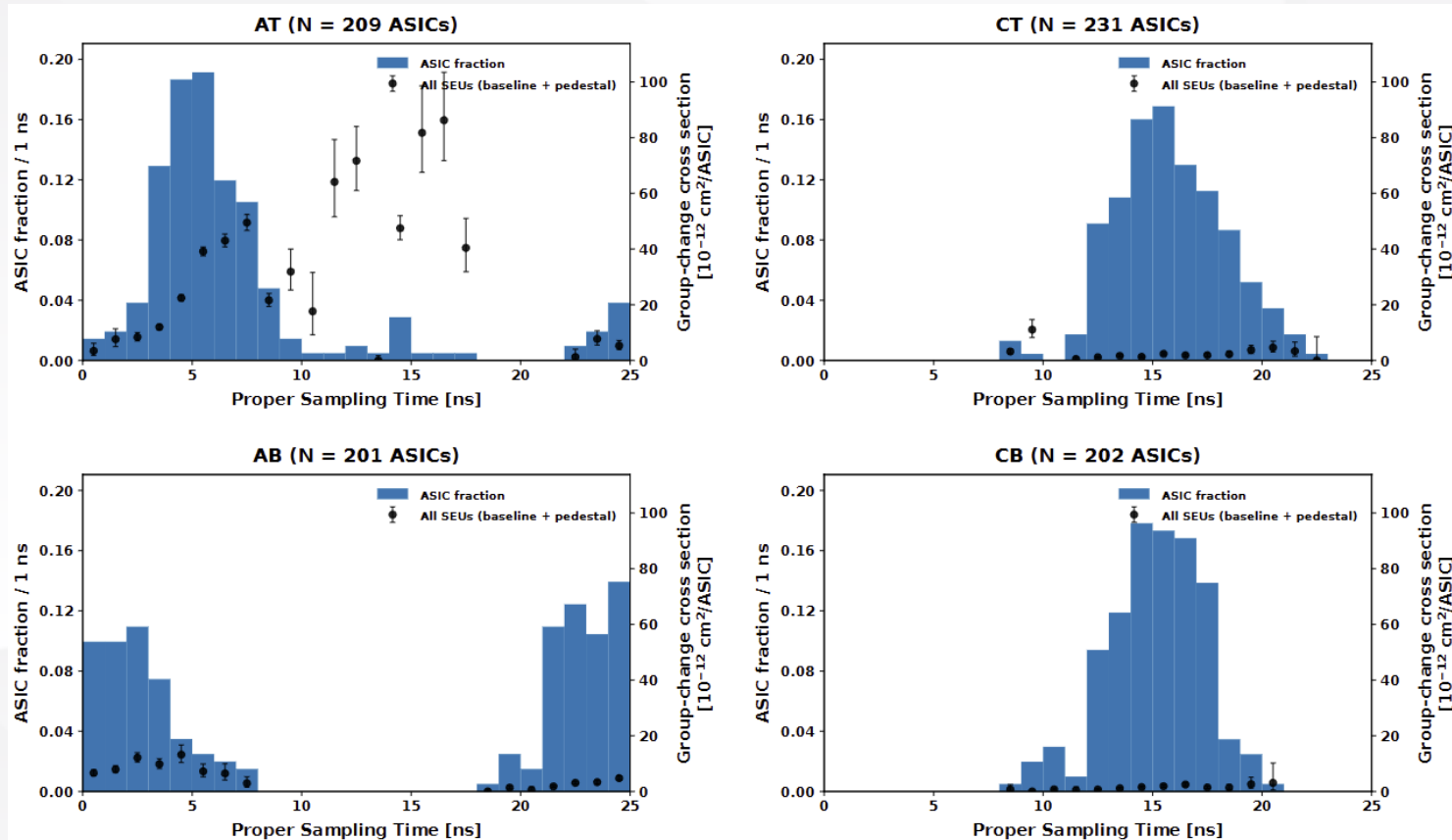


- These delays are included in the time alignment procedure, thus ASICs in different quarters require different sampling phases

Observed SEU Characteristics

- Different quarters within the same layer show different SEU distributions

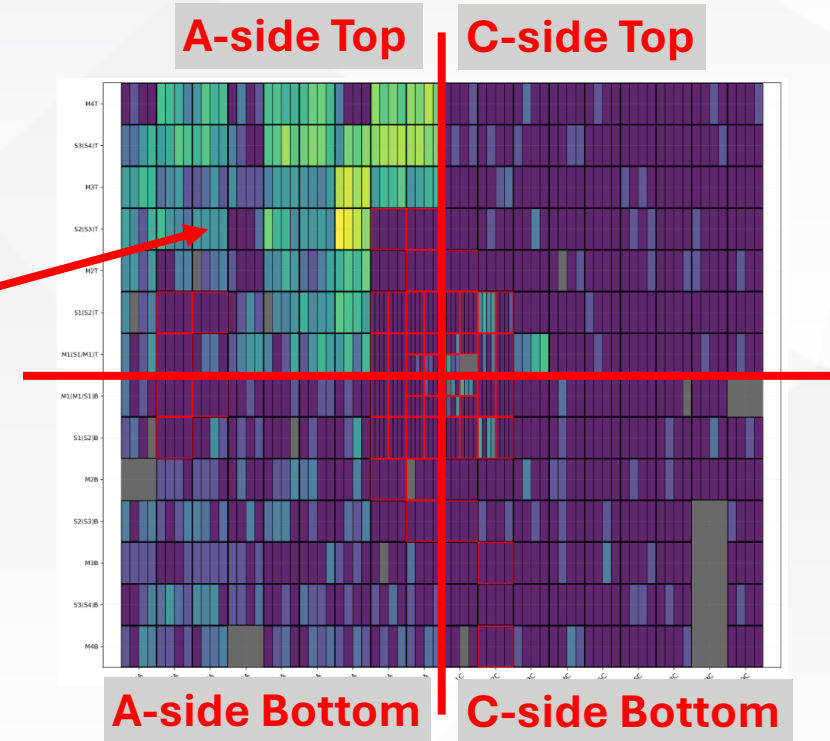
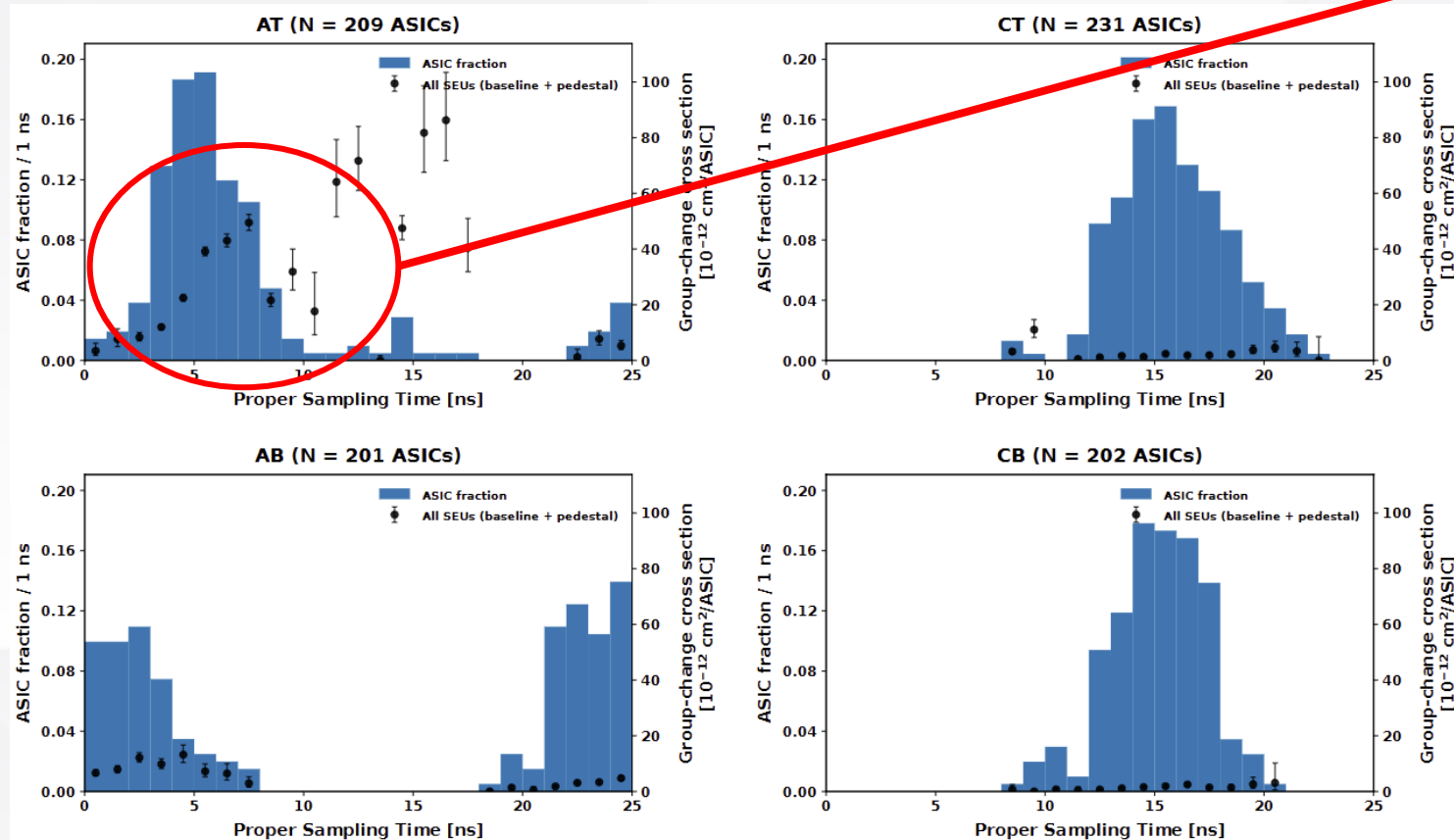
- Different proper sampling time distribution for each quarter
- Overlaid with observed SEU cross section at each sampling point



Observed SEU Characteristics

- Different quarters within the same layer show different SEU distributions

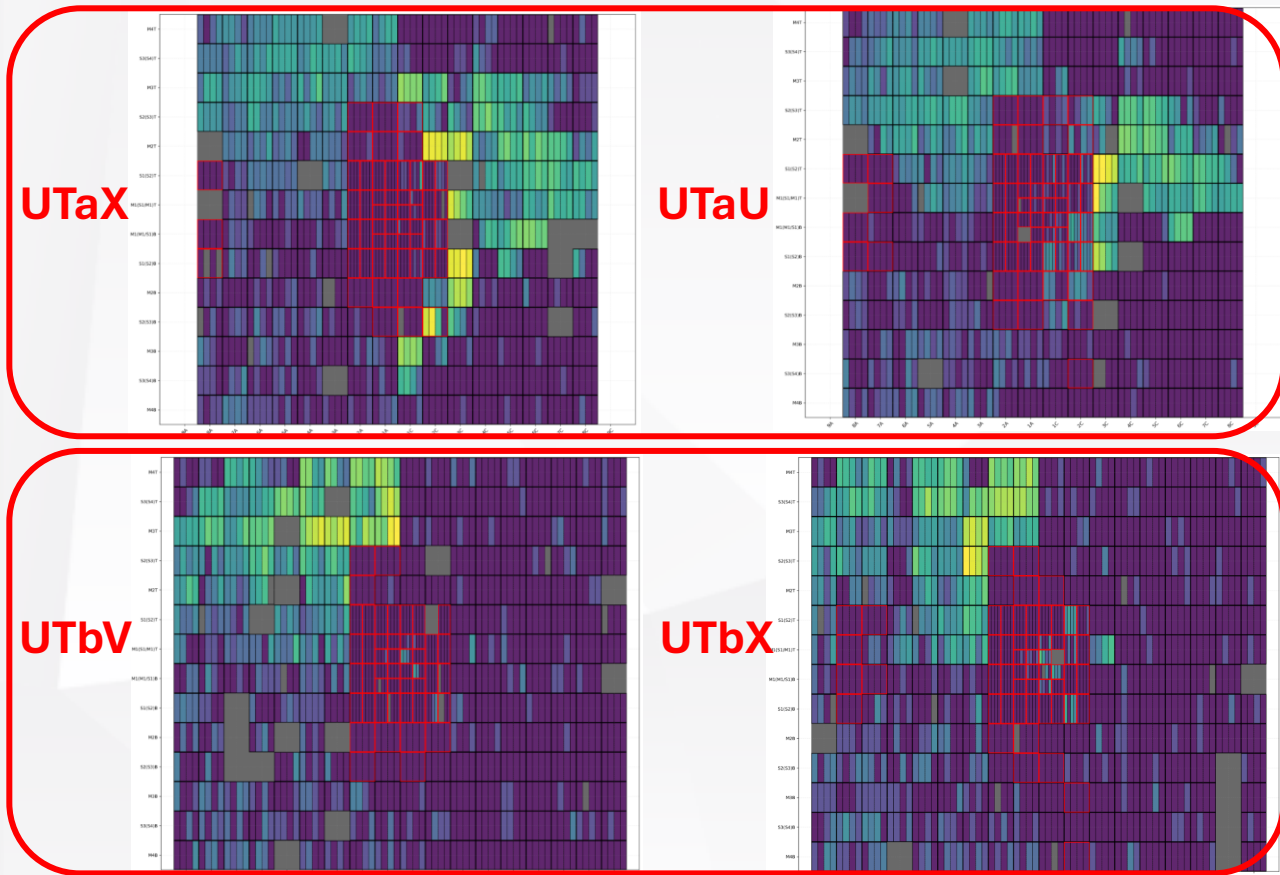
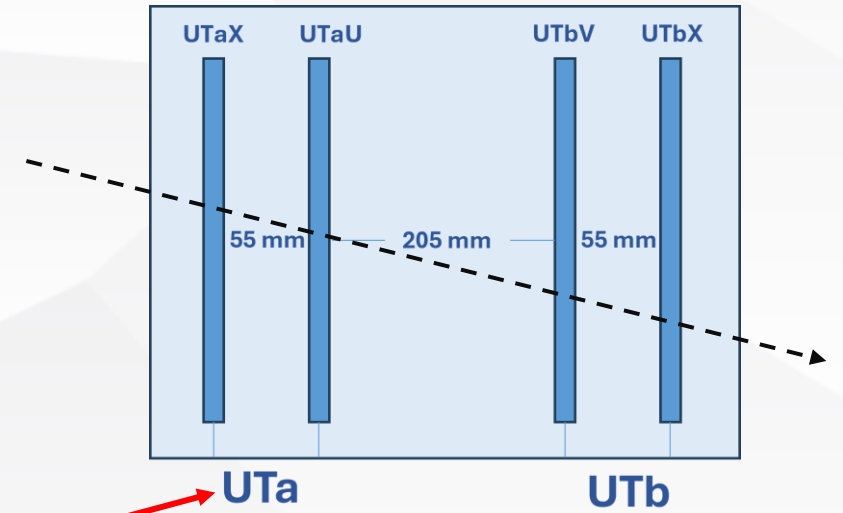
- Different proper sampling time distribution for each quarter
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- The sampling region for AT overlaps with the SEU-vulnerable window, which result in the enhancement of SEU rate in AT

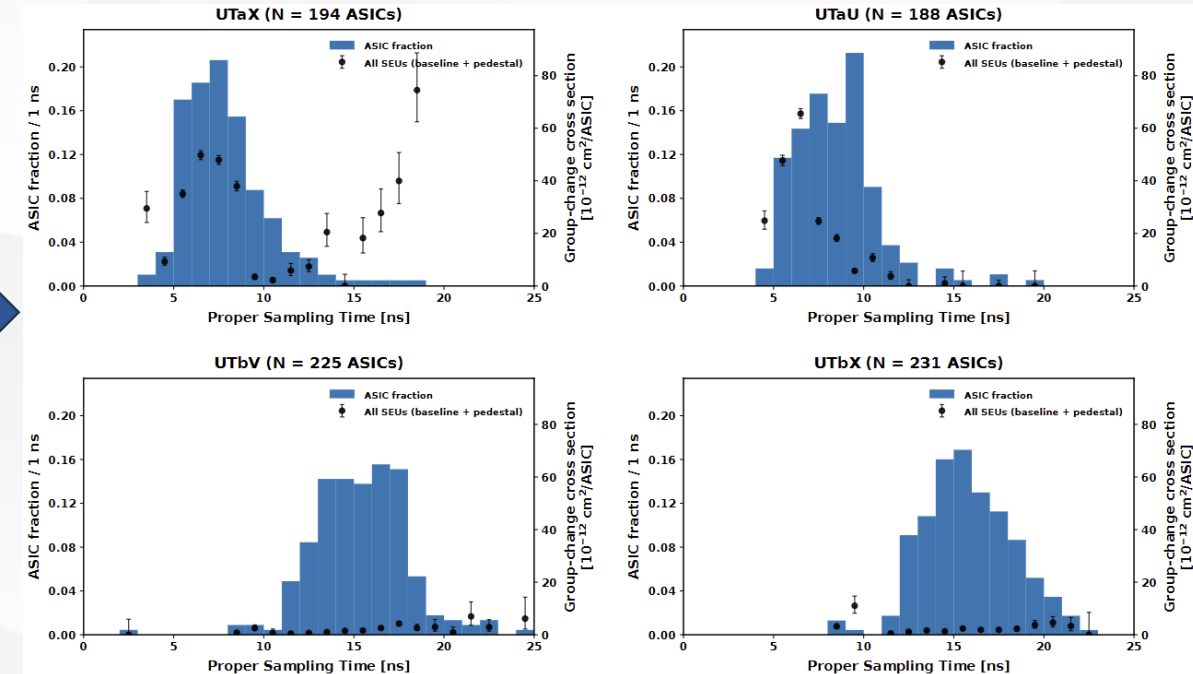
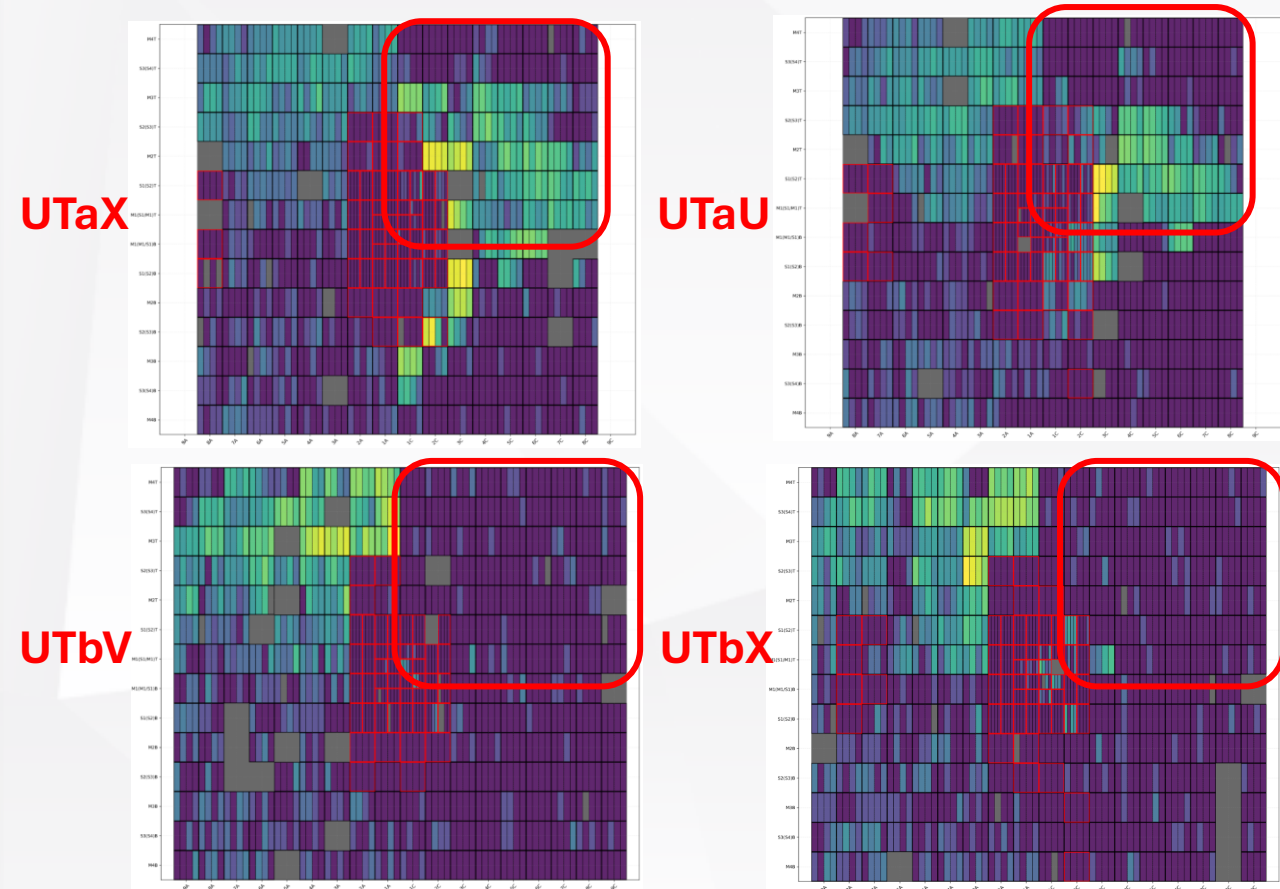
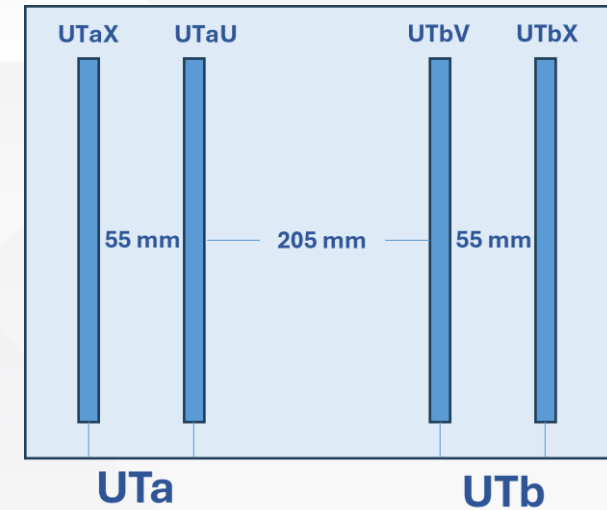
Observed SEU Characteristics

- Different layers show different SEU distributions
 - Different z-positions of the UT layers
 - Particles reach different layers at slightly different times



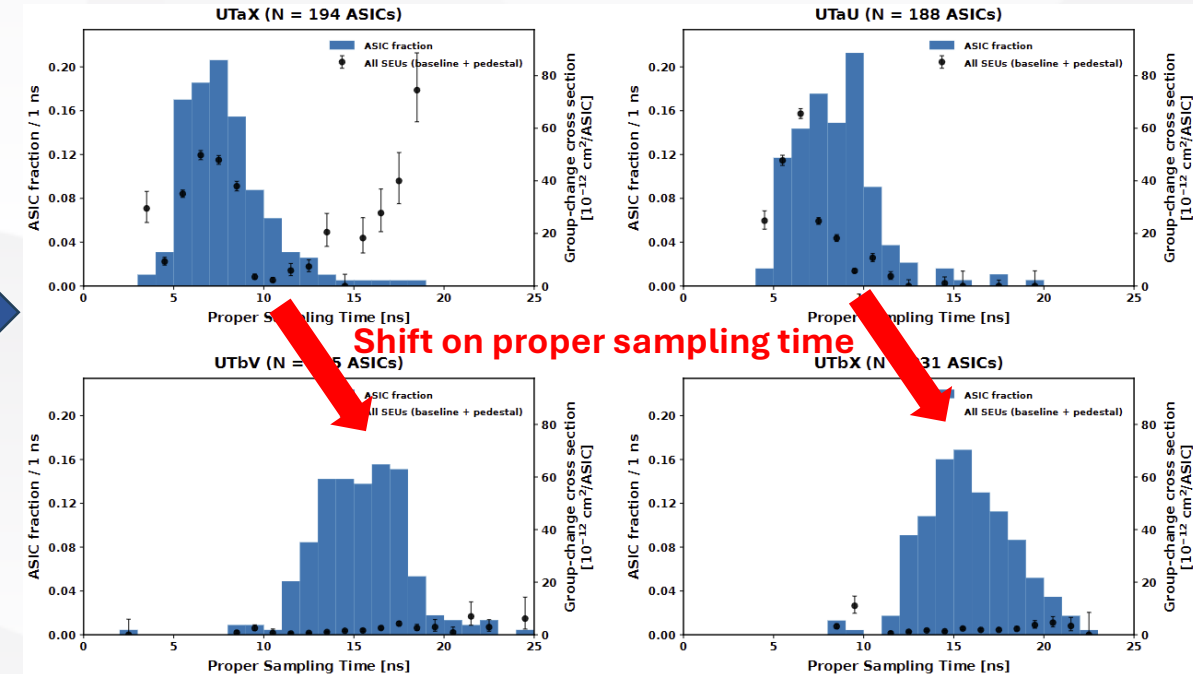
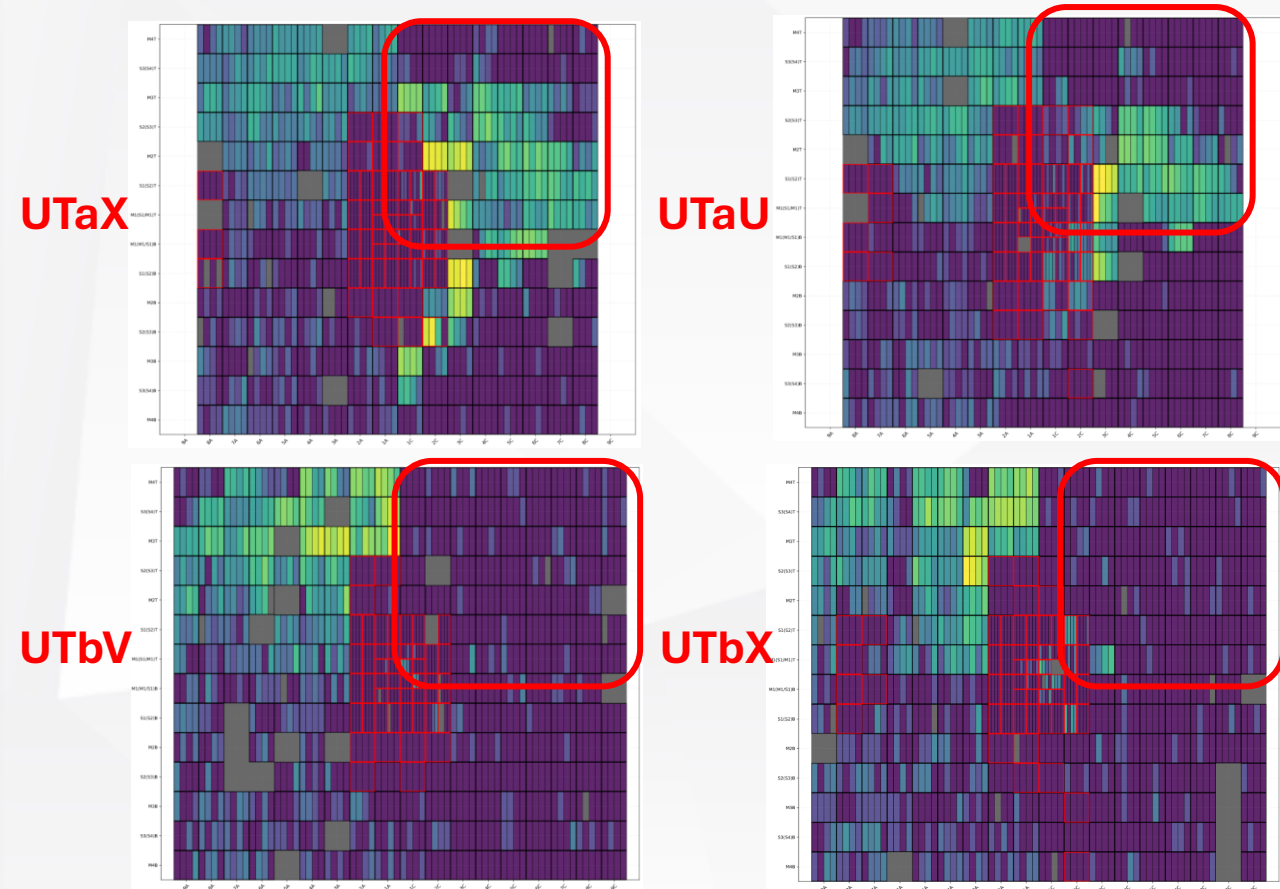
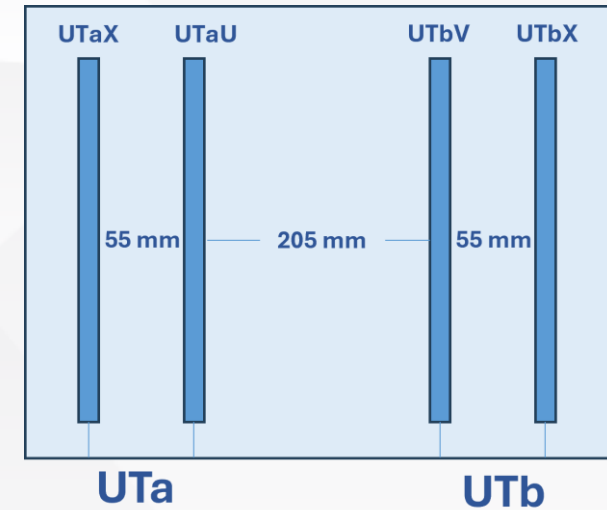
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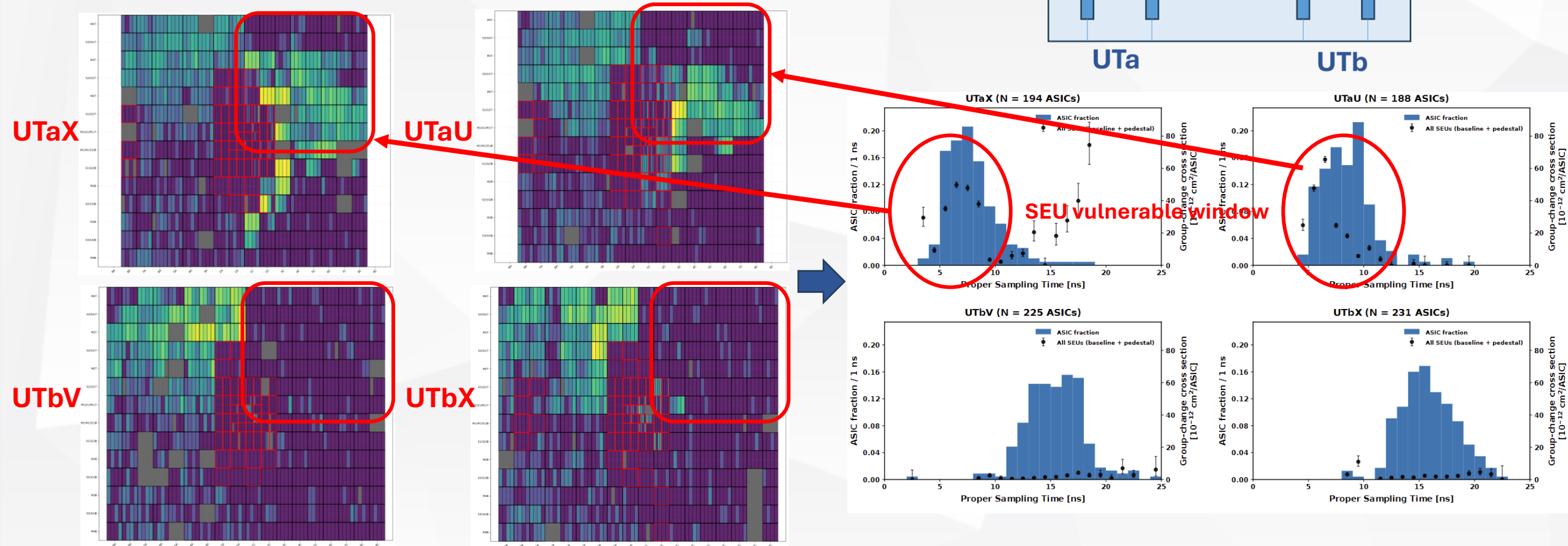
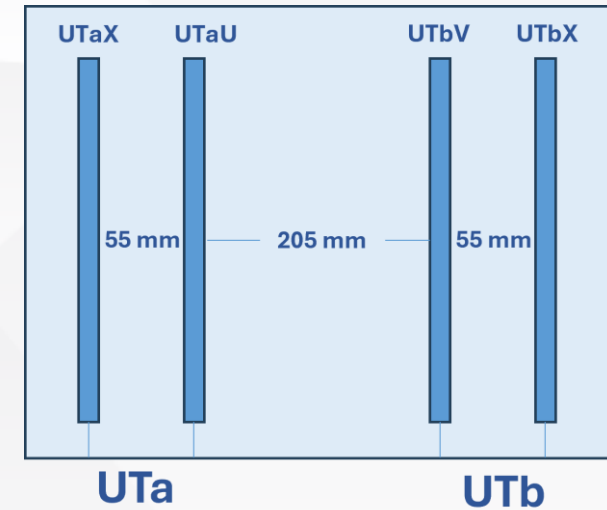
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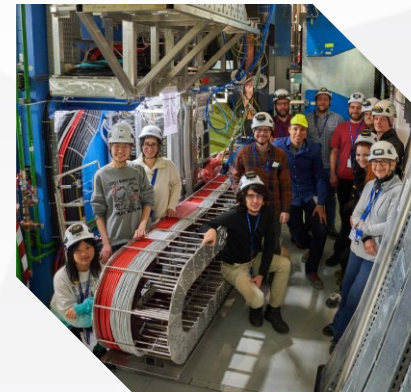
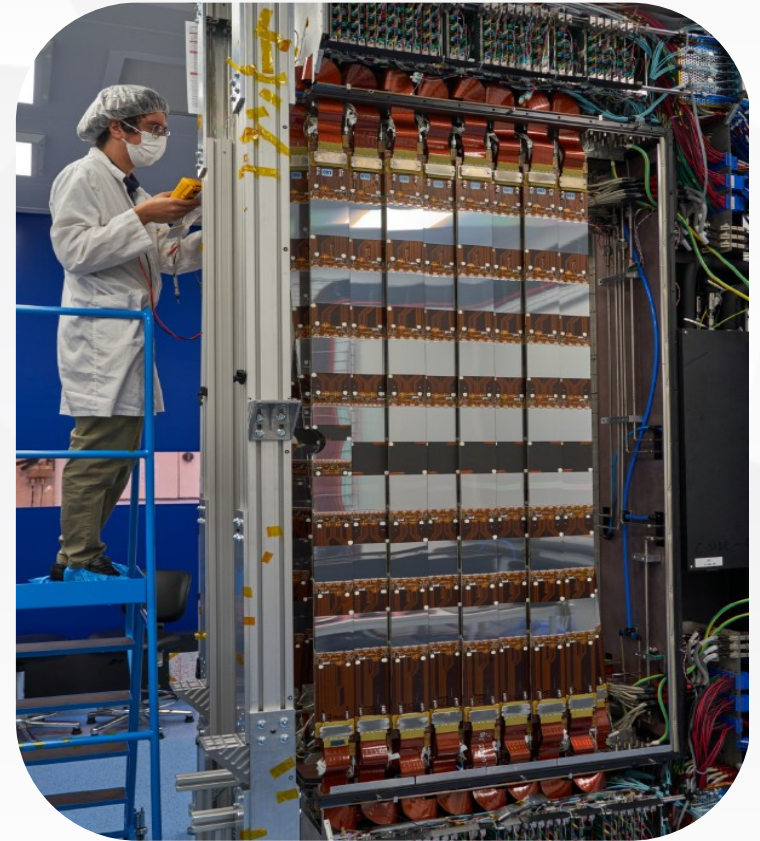
- Different layers show different SEU distributions

- Different z-positions of the UT layers
- Particles reach different layers at slightly different times



Conclusions

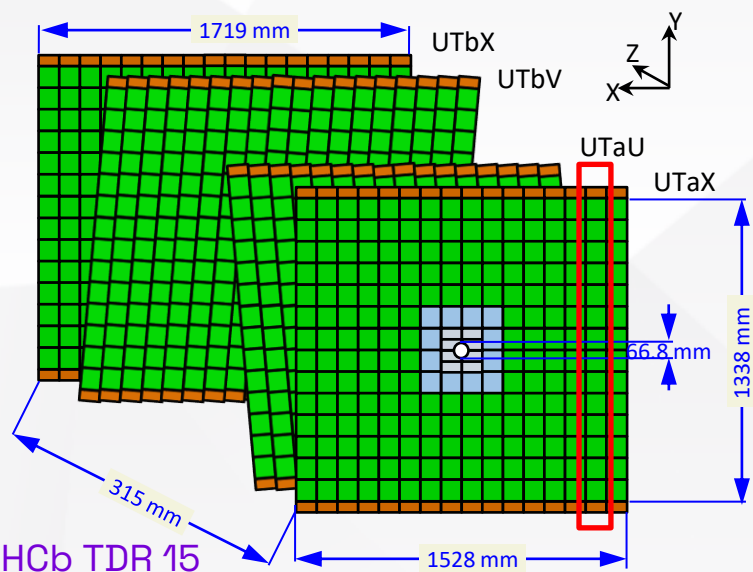
- **The Upstream Tracker has demonstrated excellent performance during Run 3 operation**
 - Providing high-efficiency hit reconstruction
 - Stable and reasonable low noise performance
- **The Single-event upsets of the SALT front-end has been studied using collision data**
 - The observed SEU signatures are consistent with previous beam test results: 1→0 bit-flip preference, group-of-16 channel effect for SALT V3.5, etc.
 - We can optimize initial register and timing configurations to reduce SEU rate
- Experiences from the current Upstream Tracker guide the design for the future upgrade: Upstream Pixel



Thanks for your attention!

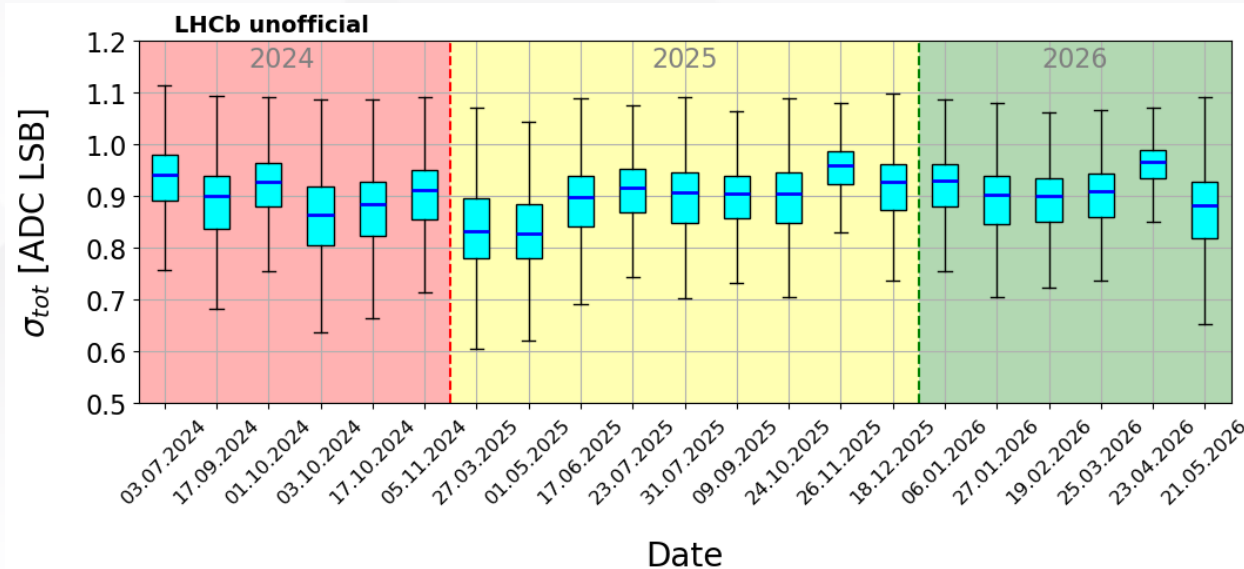
Back up

Components of the UT



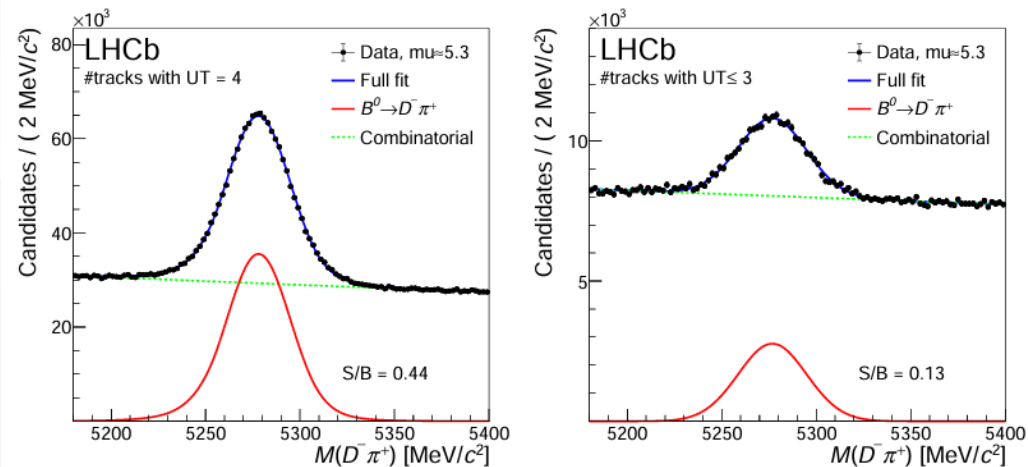
Sensor	A	B	C	D
Pitch (μm)	187.5	93.5	93.5	93.5
Length (mm)	~100	~100	~50	~50
Strips/sensor	512	1024	1024	1024
SALTs/sensor	4	8	8	8

- 4 types of silicon micro-strip sensors
- UT has maintained a total noise of ~0.9 ADC counts over Run 3 operation !

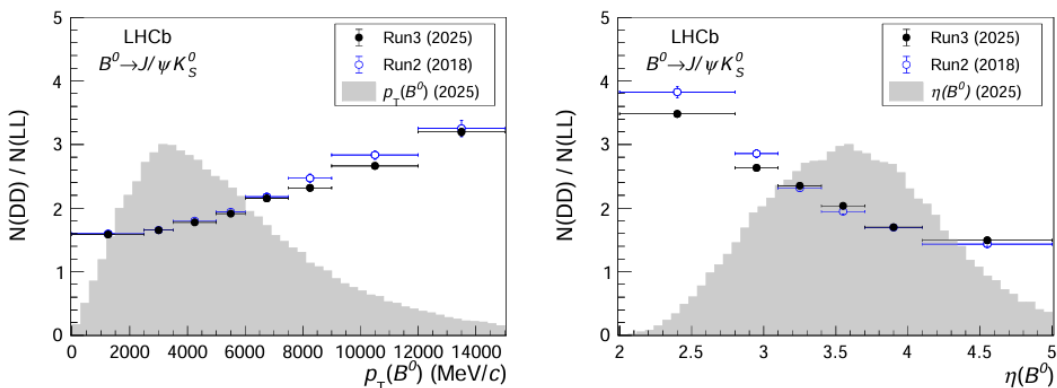


Performance with Signal Decays

$$B^0 \rightarrow D^- \pi^+$$



$$B^0 \rightarrow J/\psi K_S^0$$



- $B^0 \rightarrow D^- (K^+ \pi^- \pi^-) \pi^+$:

- Evaluated using Run 3 data for long tracks
- HLT selections applied
- All particles required to be within UT acceptance and constrain on D^- mass

⇒ **Requiring UT hits on all four decay tracks yields $\sim 3.5\times$ higher S/B.**

- $B^0 \rightarrow J/\psi (\mu^+ \mu^-) K_S^0 (\pi^+ \pi^-)$:

- Reconstructed using downstream (DD) or long (LL) track pairs
- Similar $N(DD)/N(LL)$ across p_T and η in Run 2 & 3

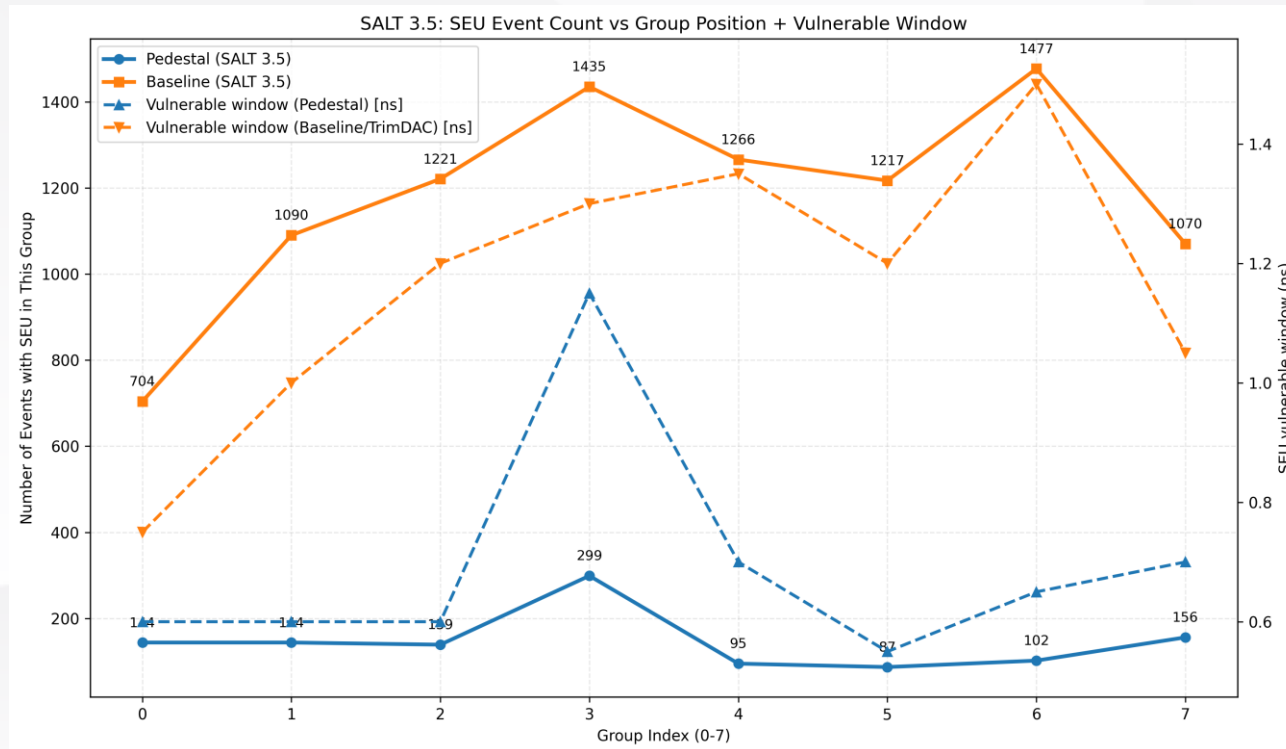
⇒ **Relative downstream tracking efficiency maintained at $\sim 5\times$ higher luminosity**

Observed SEU Characteristics

- SEU vulnerable window for each position of SALT 3.5 registers

Group	0	1	2	3	4	5	6	7	Mean
TrimDAC	0.75	1.00	1.20	1.30	1.35	1.20	1.50	1.05	1.17
Pedestal	0.60	0.60	0.60	1.15	0.70	0.55	0.65	0.70	0.69

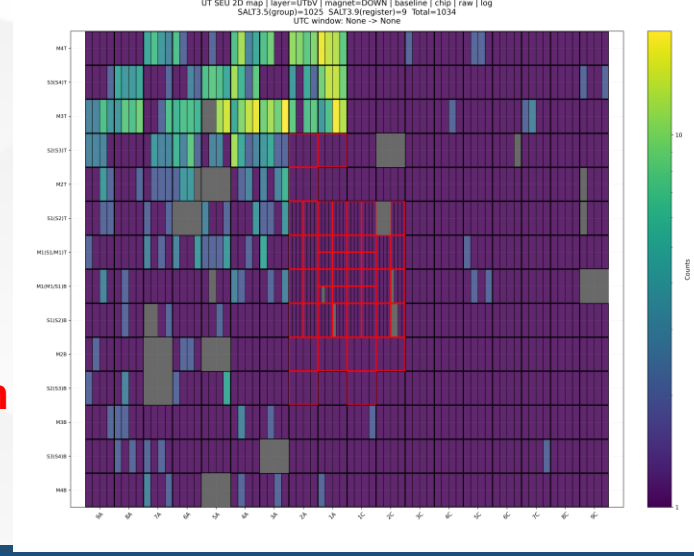
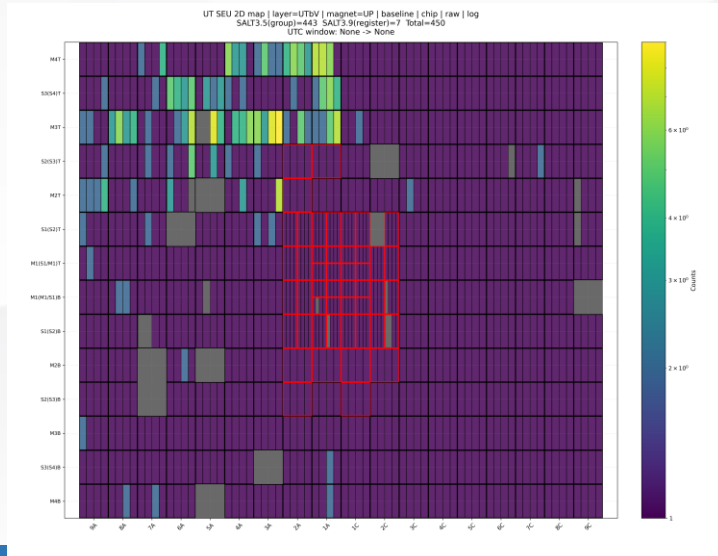
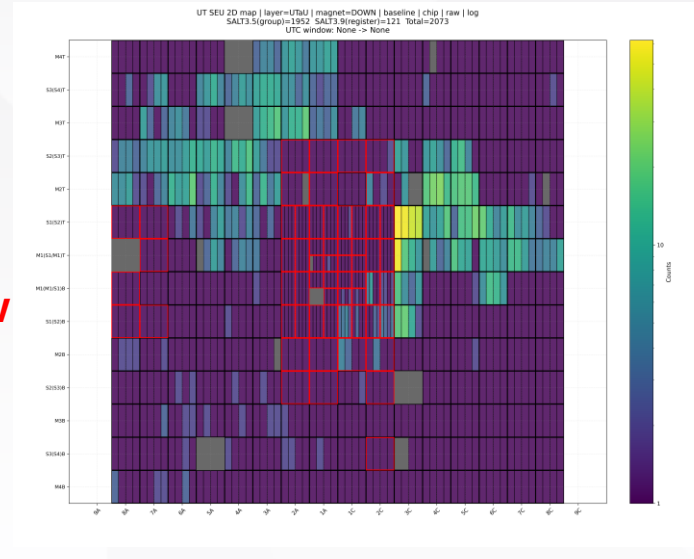
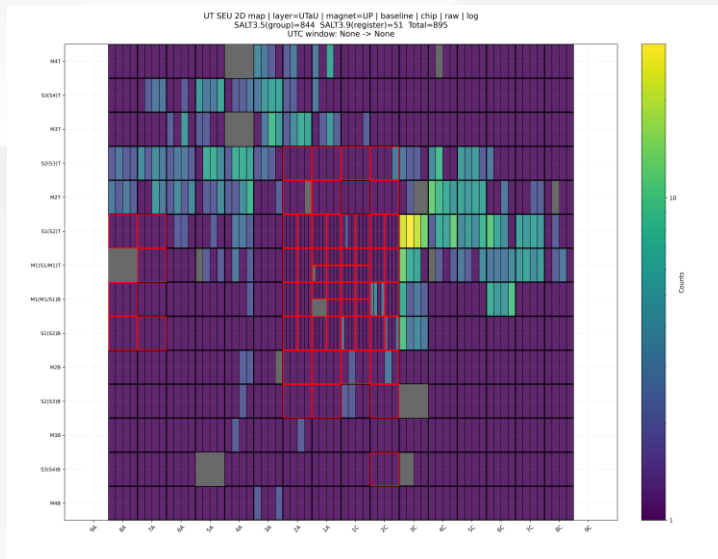
- The observed distribution of SEU events across different group positions.



The overall trend is consistent with the simulation.

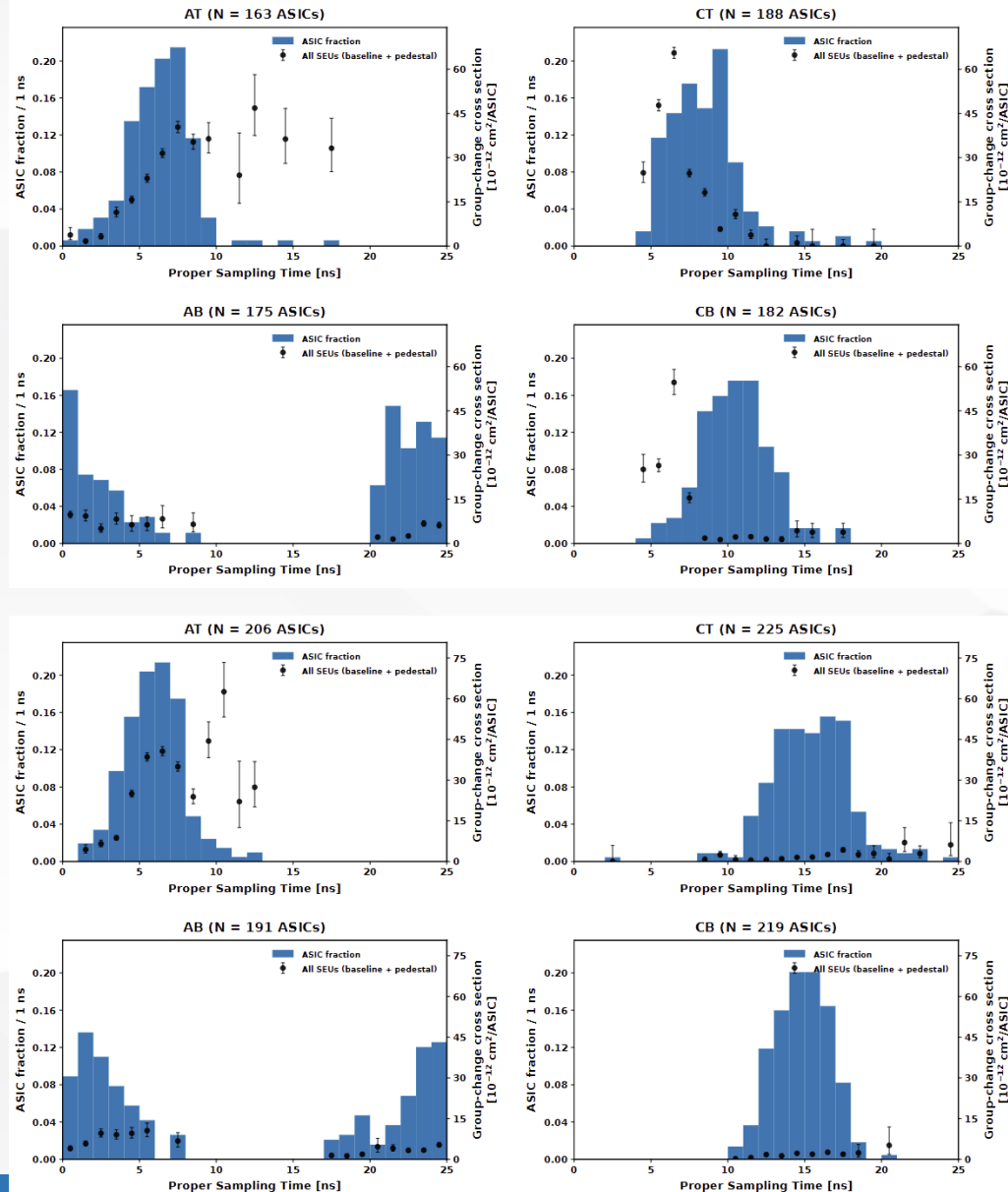
Observed SEU characteristics

- **Split by magnet – no significant difference observed**

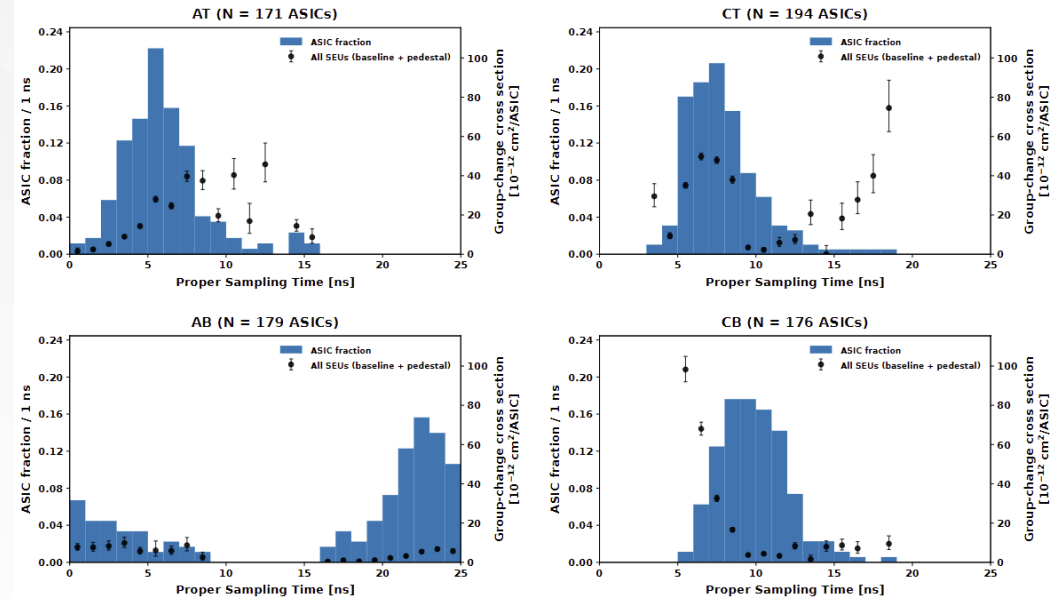


Observed SEU characteristics

UTaU



UTaX



- Proper sampling time distribution overlaid with SEU cross section for each quarter of each layer

UTbV