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SEE test for ABCStar V0 at CSNS for ITk Strip Upgrade

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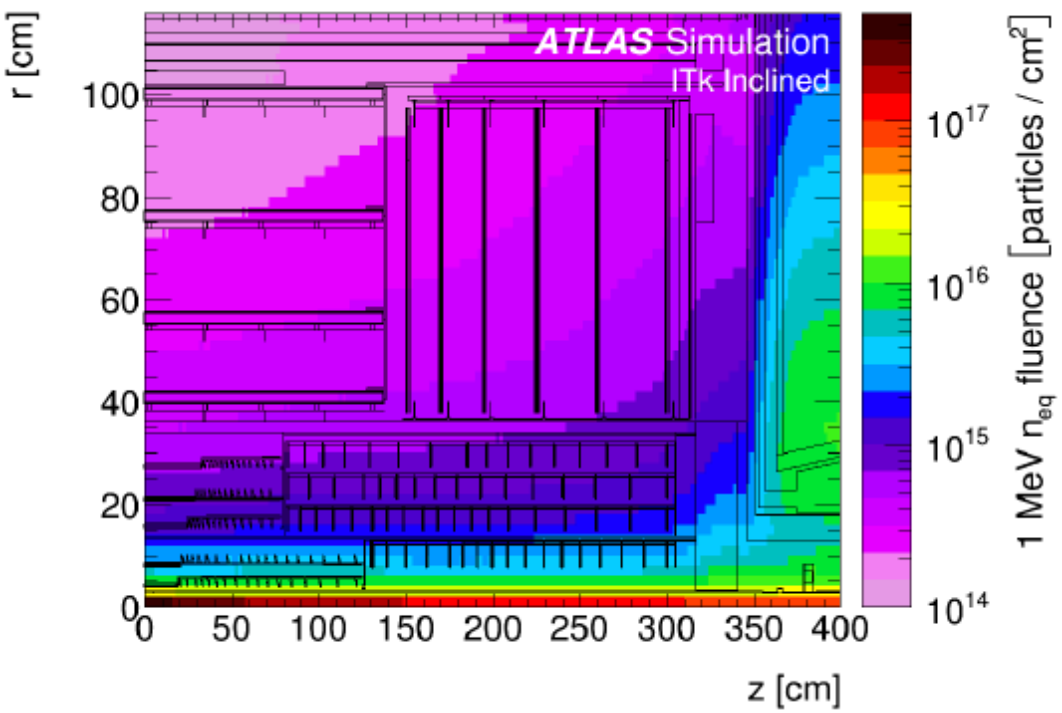
CLHCP 2022,Nanjing,11-26/2022

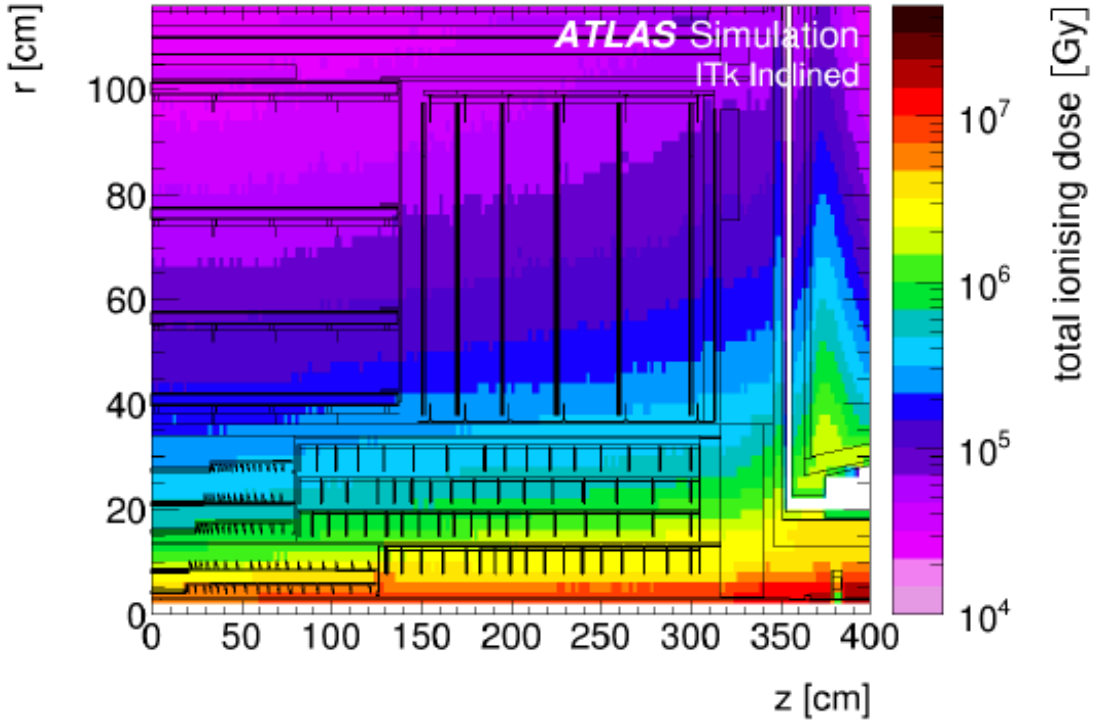
Outline

- ABCStar chips and radiation effect
- Data taking at CSNS
- Analysis results
- Summary

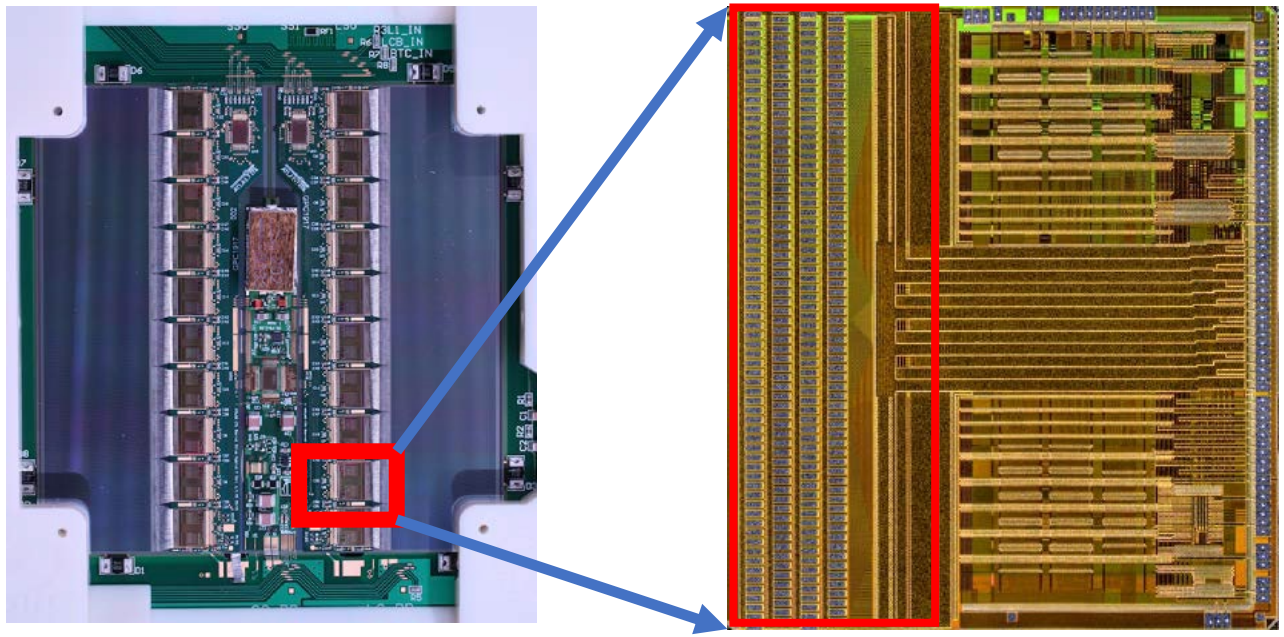
Radiation environment in ITk

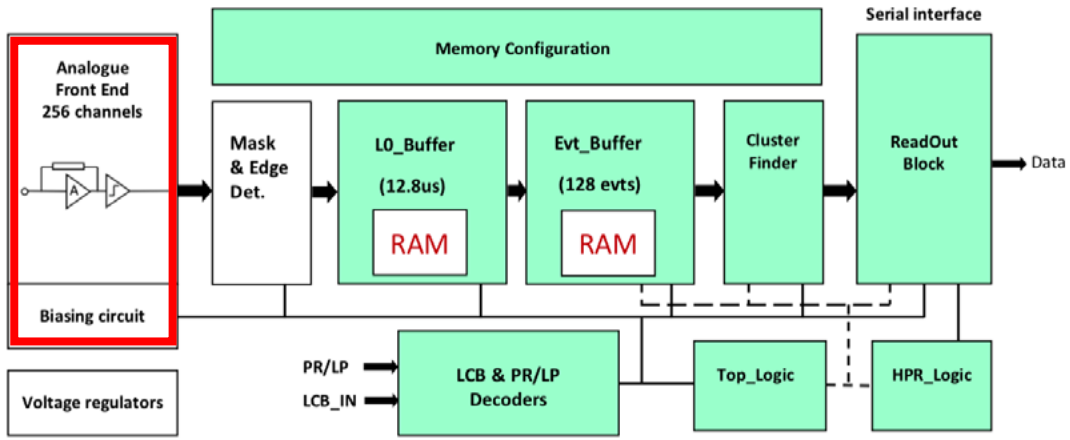
- The fluence and dose distributions for the ITk layout
  - NIEL: $1.2\times10^{15} n_{eq}/cm^2$ TID:50 MRad



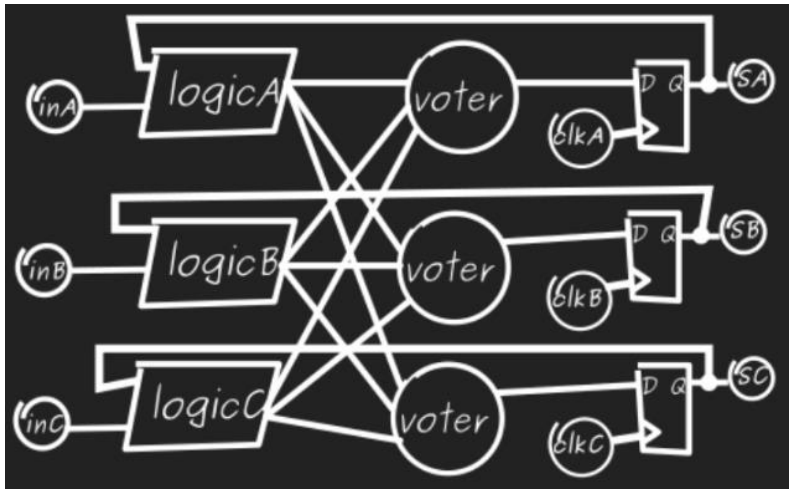


ABCStar chips





- front end readout ASIC for ATLAS ITk detector
- Key component of the ITk strip module, ~230,000 needed for production
- Process of signals from 256 silicon strips channel
- Two versions of design
  - V0
  - V1 (TMR protection)



TMR

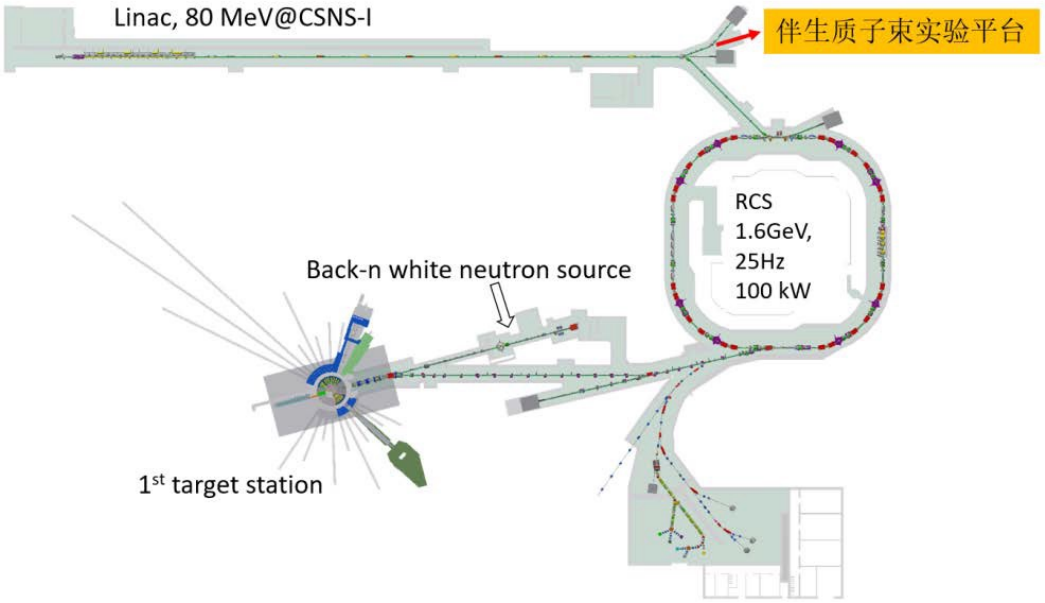
Radiation effect in electronics

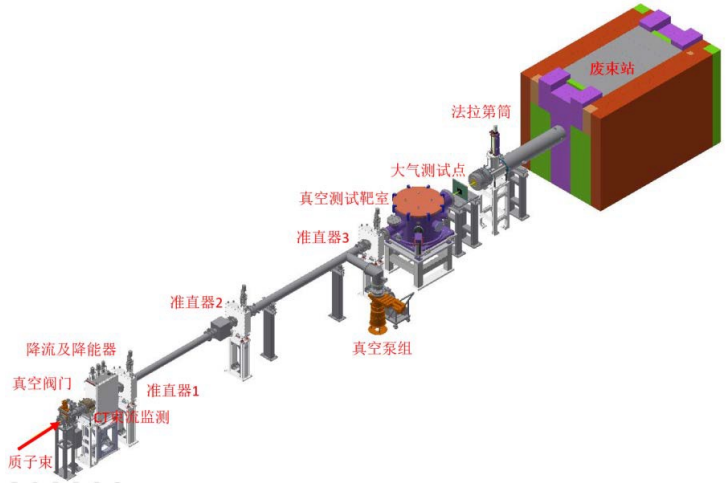
- Cumulative radiation effects
  - TID effects
  - Displacement damage
- Single-Event effects
  - Single event upsets
    - change of state in memory due to an electrical disturbance from radiation
  - result in wrong data and misconfiguration

Category	Type	comment
Non-destructive （soft errors）	SEU(Single -Event Upsets)	• Static upsets in storage cell such as SRAM， latches and flip-flops • High Error rate can cause system degradation • Correctable by reprogramming
	SET(Single- Event Transients)	Transient voltage perturbation for combinational logic
	SEFI(Single-Event Functional Interrupts)	
Destructive （hard errors）	SEL(Single-Event Latchup)	Recover from power cycle if current limiting functions embedded in design
	SEB(Single-Event Burnout)	Catastrophic failure in high voltage device
	SEGR(Single-Event Gate Rupture)	Permanent damage

APEP at CSNS

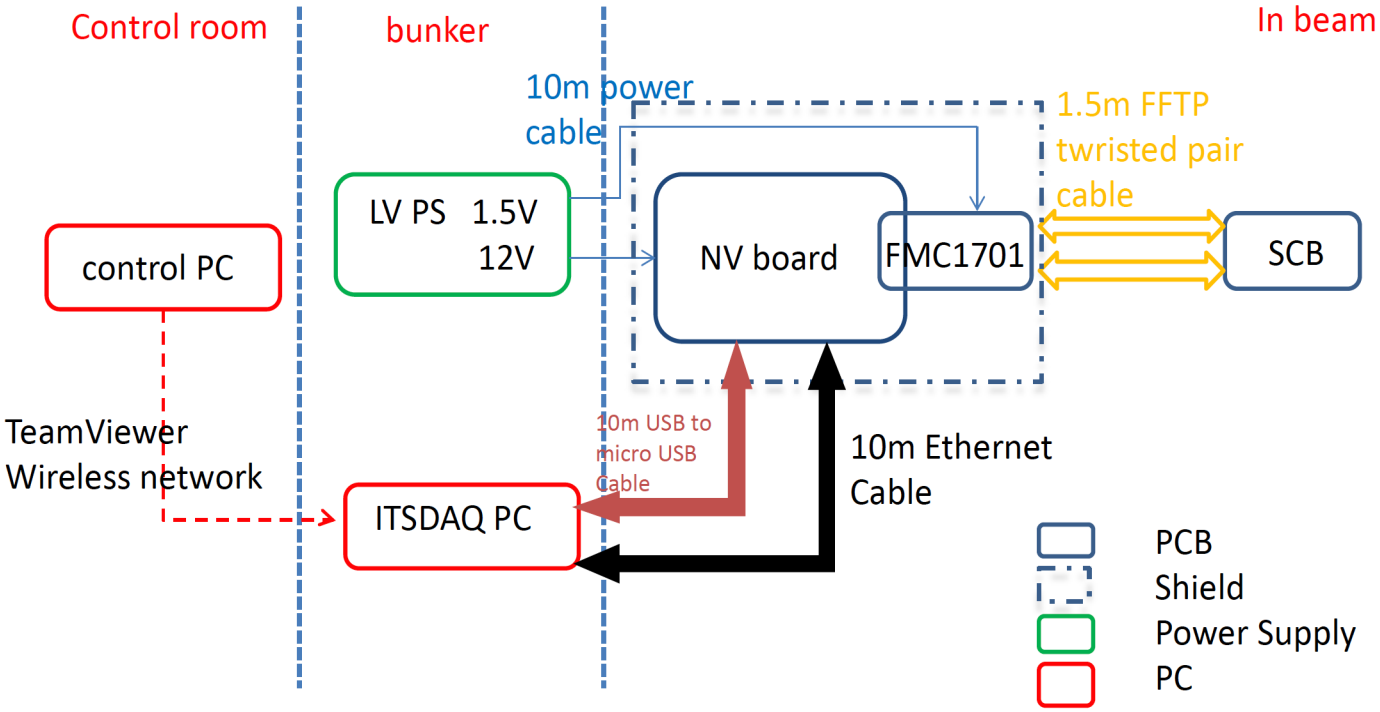
- CSNS: China Spallation Neutron Source
- APEP: Associated Proton Experiment Platform
- Beam parameter
  - Energy: 10-80MeV, FWHM < 8.65%@>30MeV
  - Size: 10mm*10mm-50mm*50mm, continuous tuned square window
  - Flux:10^5-10^{10} p/cm^2/s
  - Height: 1.2m
  - Beam time: ~5000hrs/year
- TRIUMF team have performed the SEE exp already.

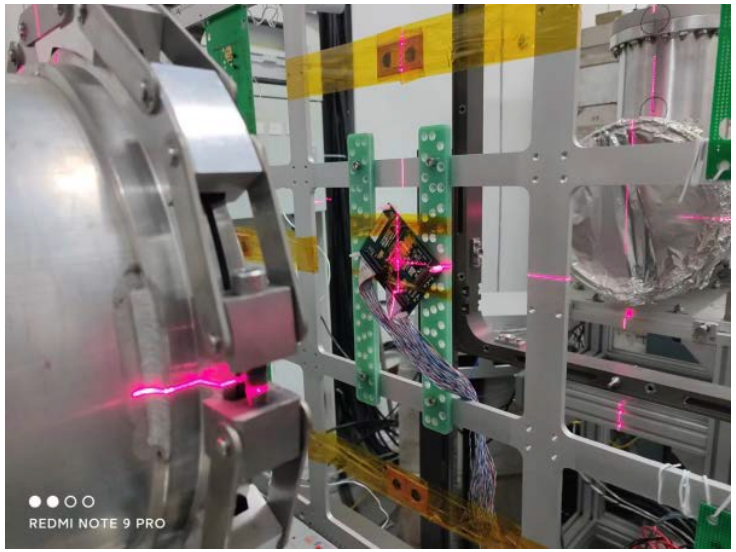




Data taking

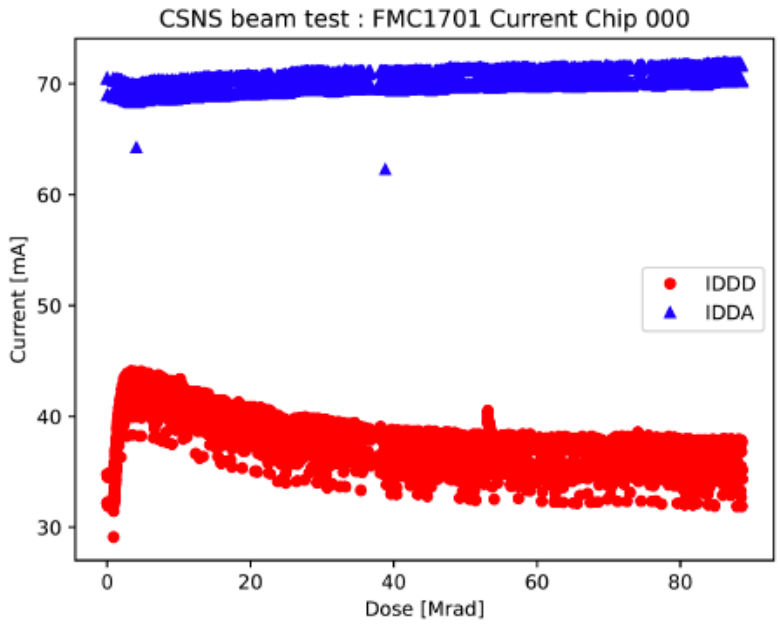
- Data taking
  - Taking procedure using scripts
    - Fixed pattern mode
    - ~1hr time block, 20 cycles
  - 3 time slots
    - ~37.5 hours
      - May-10, May-11
    - ~12 hours
      - May-13
    - ~14 hours
      - May-14

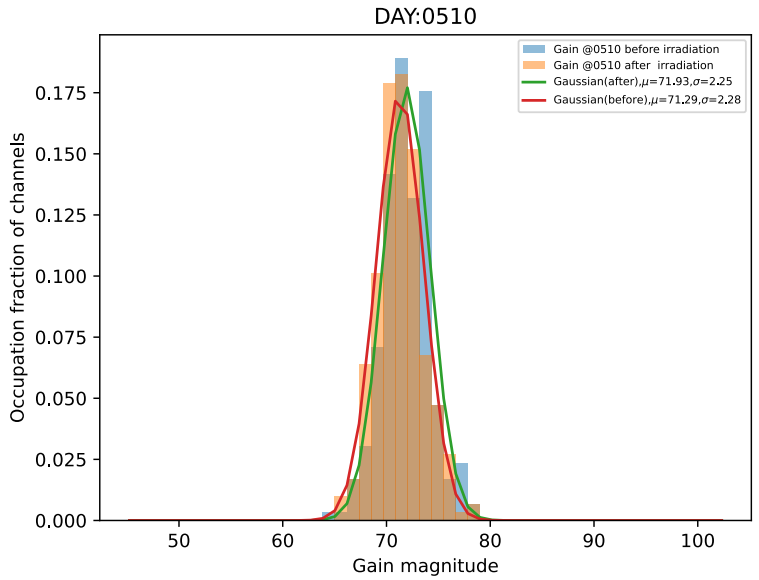


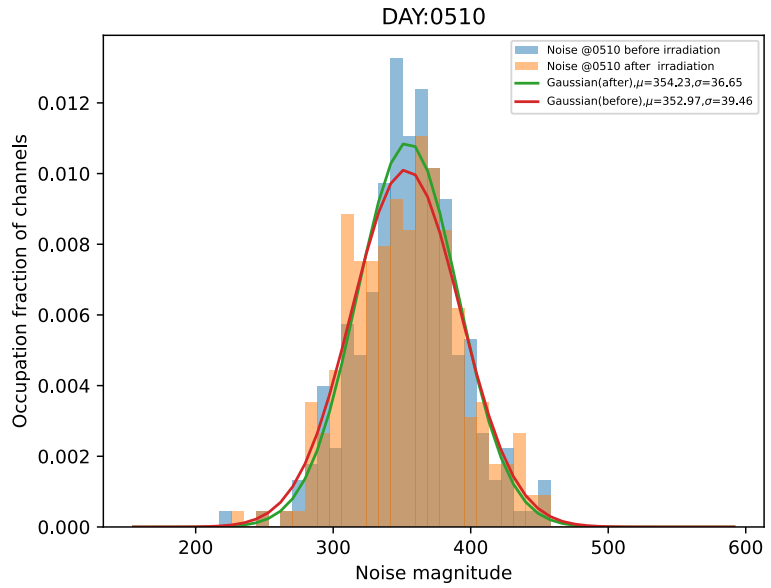


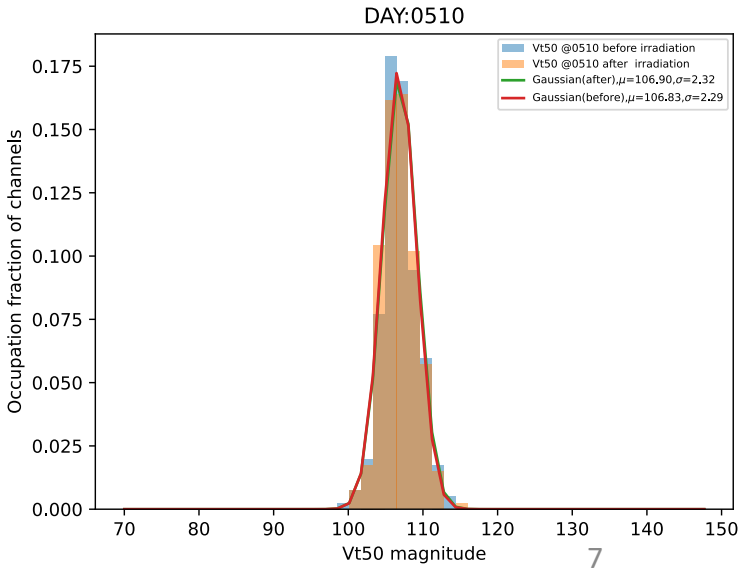
Results– current and performance

- Current measurements
  - IDDA and IDDD vs total dose
  - Total dose up to 88 Mrad
  - Peak of TID bump at ~2Mrad
- Analog performance
  - No obvious difference observed before and after irradiation









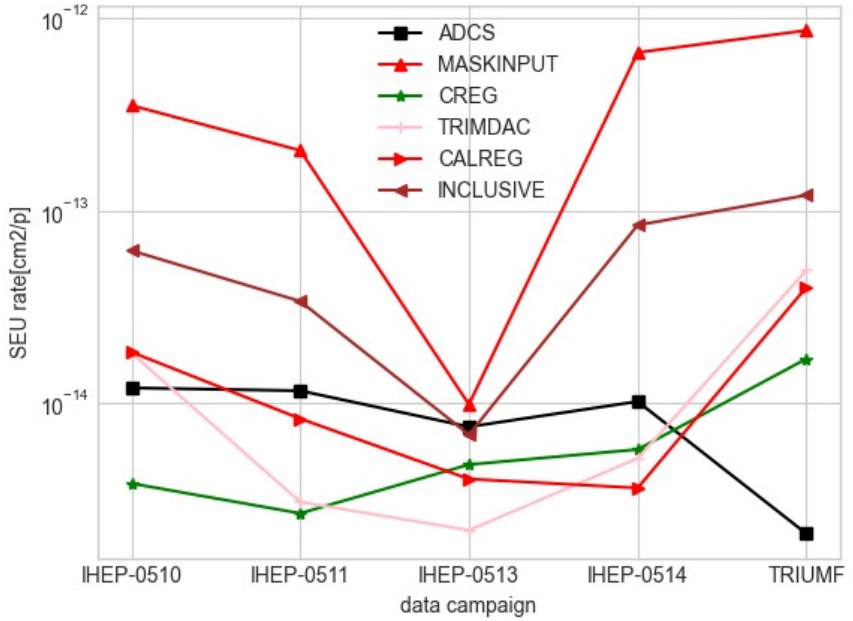
Results– Physics packets

- $\sigma_{SEU} = \frac{n_{0\to1}+n_{1\to0}}{\int d\phi}$
  - $\int d\phi$: total fluence
  - $n_{0\to1}/\ n_{1\to0}$: bit flips
- the difference of two causes:
  - the number of SEM counts
  - the distance of the SCBs from the beampipe

Chip Type	Institute	Fill-type	$n_{0\to1}$	$n_{1\to0}$	N-bits	$\int d\phi[p/cm^2]$	$\sigma_{SEU}[cm^2/p]$
V0	IHEP	Fixed	1832293	119324	52153344	3.1×10^{17}	$(6.3\pm0.08)\times10^{-12}$
V0	TRIUMF	Fixed	33699	34546	15250176	1.86×10^{16}	$(3.7\pm0.03)\times10^{-12}$
V1	TRIUMF	Fixed	16343	16506	7462368	4.47×10^{15}	$(7.4\pm0.08)\times10^{-12}$

Results– Register packets

- Mismatch of cross-section
- The potential causes:
  - Beam energy
    - 80MeV at CSNS
    - 480 MeV at TRIUMF
  - Fluence uncertainty
    - angle of incidence of beam through chips
  - Synergistic Effects
    - Total ionizing dose on SEU



Register Type	Fill-type	Chip Type	Institute	$n_{1\to0}$	$n_{0\to1}$	N-bits	$\int d\phi[p/cm^2]$	$\sigma_{SEU}[cm^2/p]$
ADCS	Fixed	V0	TRIUMF/ IHEP	1/19	0/10	301792/ 1684608	$2.5\times10^{14}/2.7\times10^{15}$	$2.1\times10^{-15}/1.1\times10^{-14}$
MASKINPUT				281/336	1/768	402400/ 2246048	$3.3\times10^{14}/3.7\times10^{15}$	$8.6\times10^{-13}/3.0\times10^{-13}$
CERG				1/2	4/8	352096/ 1964736	$2.9\times10^{14}/3.2\times10^{15}$	$1.7\times10^{-14}/3.1\times10^{-15}$
TRIMDAC				82/131	1/1	2010592/ 11226080	$1.7\times10^{15}/1.8\times10^{16}$	$4.9\times10^{-14}/7.0\times10^{-15}$
CALREG				13/31	1/0	401856/ 2245056	$3.5\times10^{14}/3.8\times10^{15}$	$4.0\times10^{-14}/8.1\times10^{-15}$
INCLUSIVE				378/688	16/804	3518912/ 19647296	$3.2\times10^{15}/3.2\times10^{16}$	$1.2\times10^{-13}/4.6\times10^{-14}$

Results– HPR reset and unlock rates

- High Priority Register packets
  - contain link status information
  - be sent at regular intervals
    - integer multiples of 40,000 BCs(1 ms)
    - Out-of-time packets used to detect the **resets** in ASIC
  - LCB_Locked bit(bit 29) in HPR packet to
    - identify the **unlocked** HPR packets

Chip Type	Institute	Fill-type	Unlocked rate(upper limit)	Out of time packets rate
V0	IHEP	Fixed	9×10^{-5}	5×10^{-3}
	TRIUMF		1.65×10^{-5}	9×10^{-5}

Results– Register status bits

- The status bit for register read packets are checked
  - IHEP: 0.0005% for LP/PR FIFO
  - TRIUMF: 0.0007% for LP/PR FIFO
- Non zero Register and cluster FIFO indicate ASIC resets in IHEP experiments, which is consistent with the large out-of-time HPR packet rate.

Chip Type	Institute	Fill-type	PR_FIFO_almost_full	LP_FIFO_almost_full	RegFIFO	CLusterFIFO	Npackets
V0	IHEP	Fixed	148	147	277	288	28880406
	TRIUMF		159	228	0	0	22916647

Results– Estimated impact on operation

- Typical HL-LHC parameters
  - pileup 200
  - BC rates 40MHz
  - $Rate_{SEU} = O(10^{-10})$ errors/event/ABCStar

- Error rate due to thermal noise occupancy: 10^{-2} errors/event/ABCStar
- During the normal operation, the hit errors in physics packet clusters is $20\ s^{-1}$, so there is **no practical concern**.

Summary

- SEE test is critical for ABCStar under ITk strip environment
  - Successful data collection at CSNS APEP provides a new platform for SEE test with medium energy proton
  - More than 60 effective hrs data taking based on ABCStar V0 SEE test setup
- Data analysis has been done
  - The result is mostly consistent with that obtained from TRIUMF experiments.
  - Still need further test to check the specific causes.
- Perform SEE test for ITk Strip ASICs ABCStar V1 and other chips
  - check the TMR protection.

Backup

- $\Phi_{hadrons} = O(10^7)\ hadrons/cm^2/s$
- expected fluences $O(10^{-3})\ hadrons/cm^2/pp$
- $Rate_{SEU} = \left(\Phi_{hadrons} \times \frac{time\ in\ pipeline}{packet}\right) \times \frac{packets}{event} \times \sigma_{SEU}$

$= O(10^7) \times O(10^{-5}) \times O(10^{-12})$

$= O(10^{-10})$ errors/event/ABCStar

Effect of Total Ionizing Dose on SEUs for 0.25 μm SRAM - change in SEU cross-section