Check-Sort-Push
and its application in CMS iRPC subsystem

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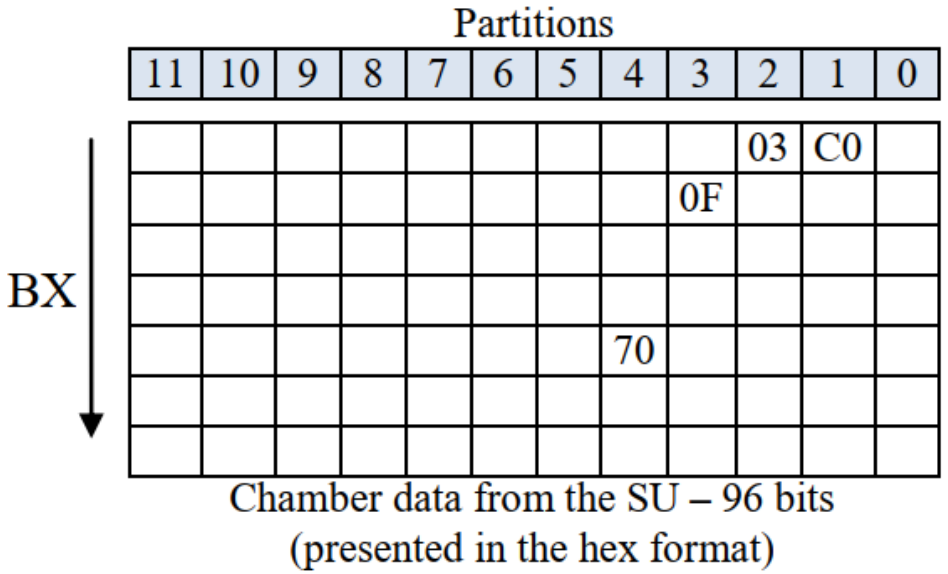
Outline

- Motivations
- Simulation and emulation study
- Check-Sort-Push and its implementation
- Emulation results
- GIF++ beam test results
- Summary

Motivation

- Modern Experiment like in CMS/RPC use serial link for data transmission
  - low occupancy and link sharing case, necessary data compression
- Detector side
  - 1 bit Digitization by BX (25ns)
  - Polling readout/Zero-suppression (Partitions with hits)
  - Serialization
  - Transmission
- Counting Room side
  - Reception
  - Deserialization with partition data
  - De-Compression back to hits
  - Hit/Cluster processing



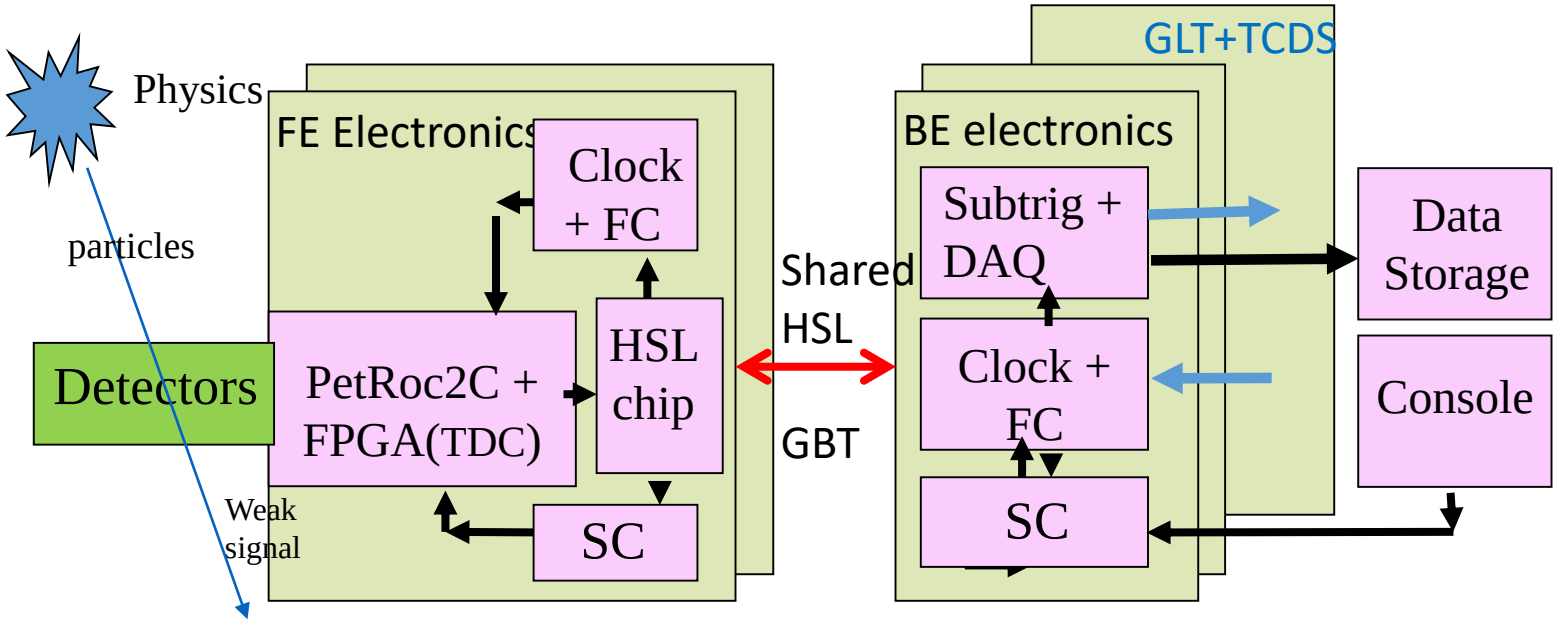
Chamber data from the SU – 96 bits (presented in the hex format)

EOD	Partition delay	Partition number	Partition data
0	0	2	03
0	1	1	C0
0	1	3	0F
0	0	4	70

Coder output data

Motivation

- New system like Belle II/CMS iRPC use an unified faster belle2link/GBT link for both data and control
  - FE Electronics(CMS iRPC)
    - Hits reading in Petroc2C ASIC
    - FPGA
      - Time measurement
      - Pulling readout and Serialize
    - Transmission in GBT frame
  - BE Electronics
    - DeMux based on a receive window
    - Trig/DAQ/Fast/Slow Control



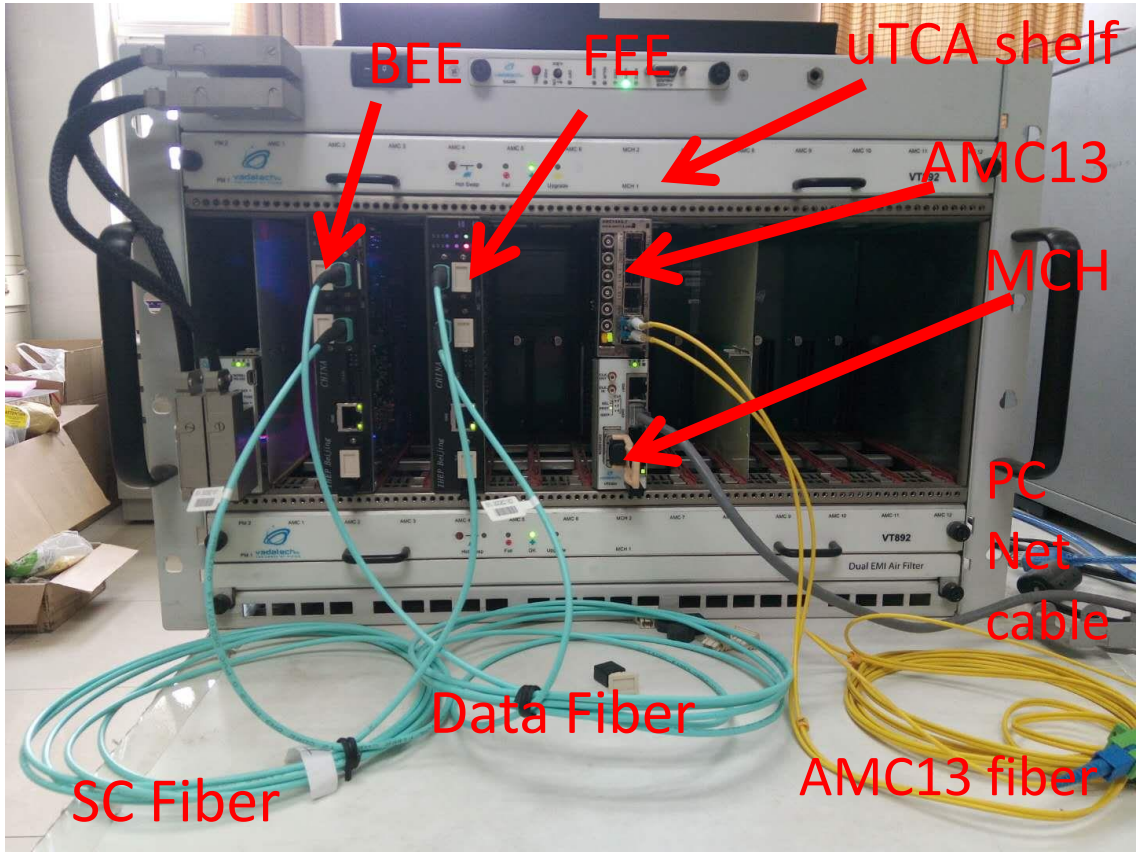
FC:FastControl, SC:SlowControl. By Z.A. LIU

- Question:
  - Polling readout is still ok in CMS/iRPC?
    - Enough transmission delay
    - Fixed latency of processing
  - How the DeMux window matters the system L1 latency and DAQ window for data completeness?

Simulation and emulation iRPC electronics system

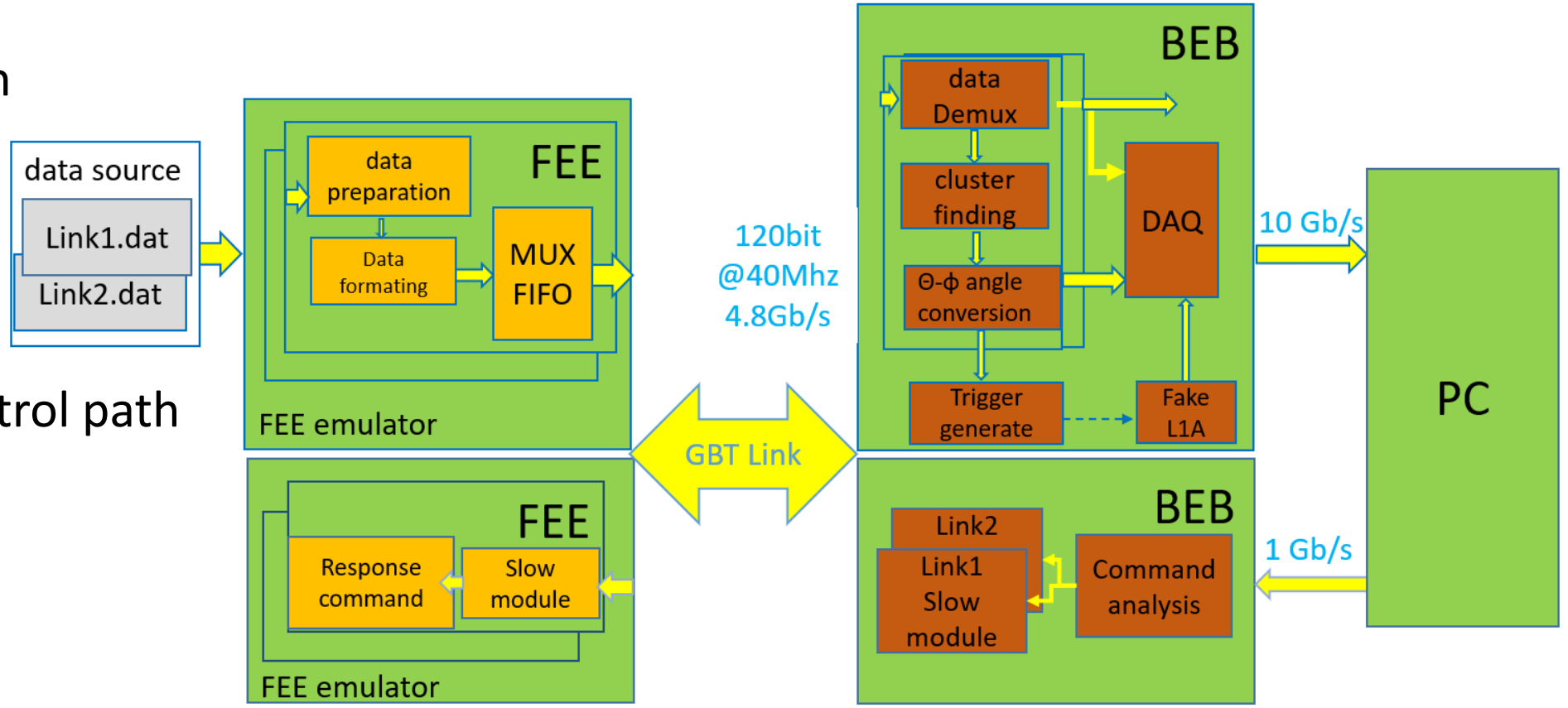
- uTCA based R&D System
  - 2 ixFP cards
    - 1 ixFP cards for slow control/processor
    - 1 ixFP cards for iRPC data source
  - 1 AMC13
    - TTC/TTS
    - Management
  - 1 MCH + 1 PC
    - Slow control
    - Management + data storage
- Functions
  - Emulation/Development System
  - Hardware, GBT/GBT based
  - Detector Simulator/data source
  - Fast/Slow control, cluster finding, data saving on to disk

IHEP Lab



Simulation and emulation iRPC electronics system

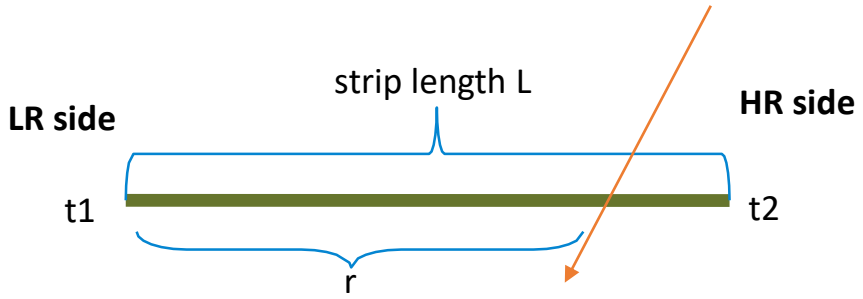
- Firmware development accordingly
  - Data path
  - Slow control path



Emulation for iRPC detector

- iRPC provides better position by timing measurement from both strip ends
- Frontend Electronics board (FEB) emulator
  - Hit position
    - r is calculated by the time difference of signals from both ends
  - Digitization
    - For each fired strip, there are always 2 32-bit TDC data constructed.
      - Channel-HR Rising Edge + Channel-LR Rising Edge
  - Zero-suppression
    - Sends time info from only fired strips
  - TDC Data format(32 bits)
    - DevAddr： FPGA ID
    - ChanAddr : channel address
    - Coarse time: combine BCN(Preserved, 12 bits) and t1, t2
    - Fine time: responsible to the precision, 2.5ns/256≈10ps

iRPC: improved RPC

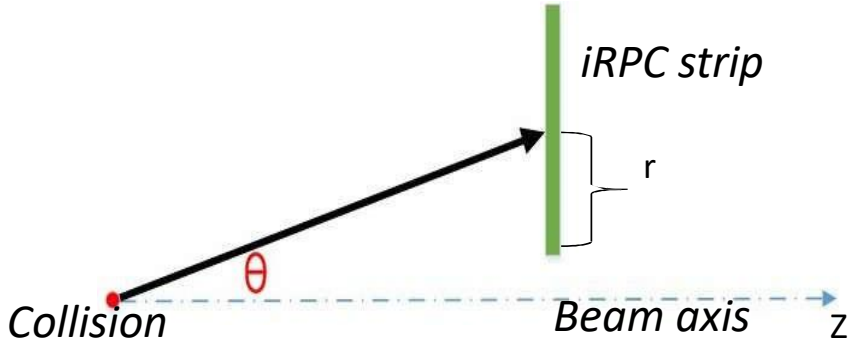


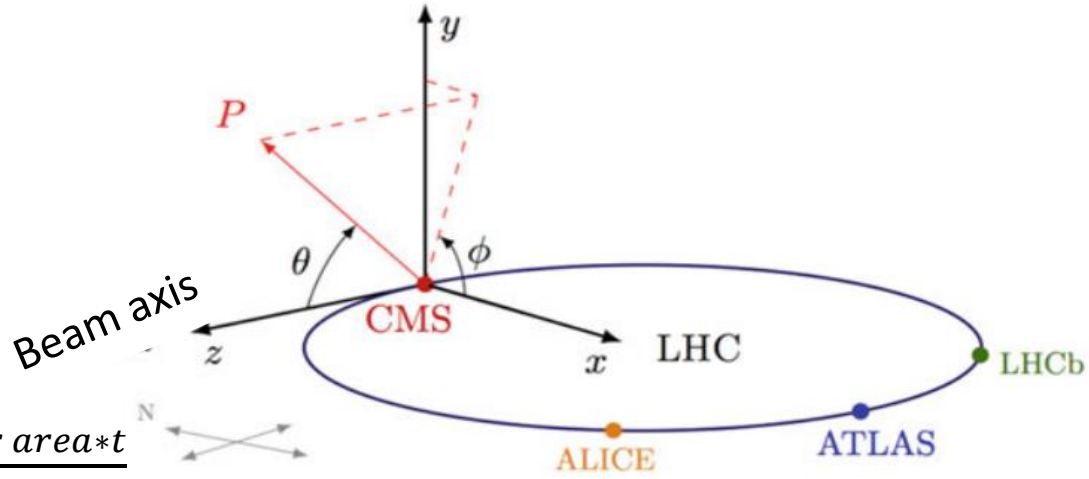
$$r = \frac{1}{2}\mathrm{L} - \frac{(\mathrm{t2} - \mathrm{t1})}{2} * v$$

DevAddr	ChanAddr	TDC data	
		Coarse time	Fine time
2	6	16	8

iRPC data source from simulation

- Data generation
  - Random hit point(r, ϕ) in half chamber
    - r: generates the hit point along strip.
    - ϕ: generates the strip number.
  - Smear of ϕ direction :
    - Generates a consecutive set of strips as a cluster.
  - Cluster size randomization :
    - Muon: 1-8,mean is 2.35
    - γ Background : 1(50%),2(50%), mean is 1.5
  - Number of cluster :
    - W/O γ source : 1 muon
    - With γ bkg: 1 muon + n gamma(random)
      - 0.7/1.2/1.8/2.7 KHz/cm2
      - γ particle $number(rate = x,\ time = t) = \frac{x * chamber\ area * t}{2}$



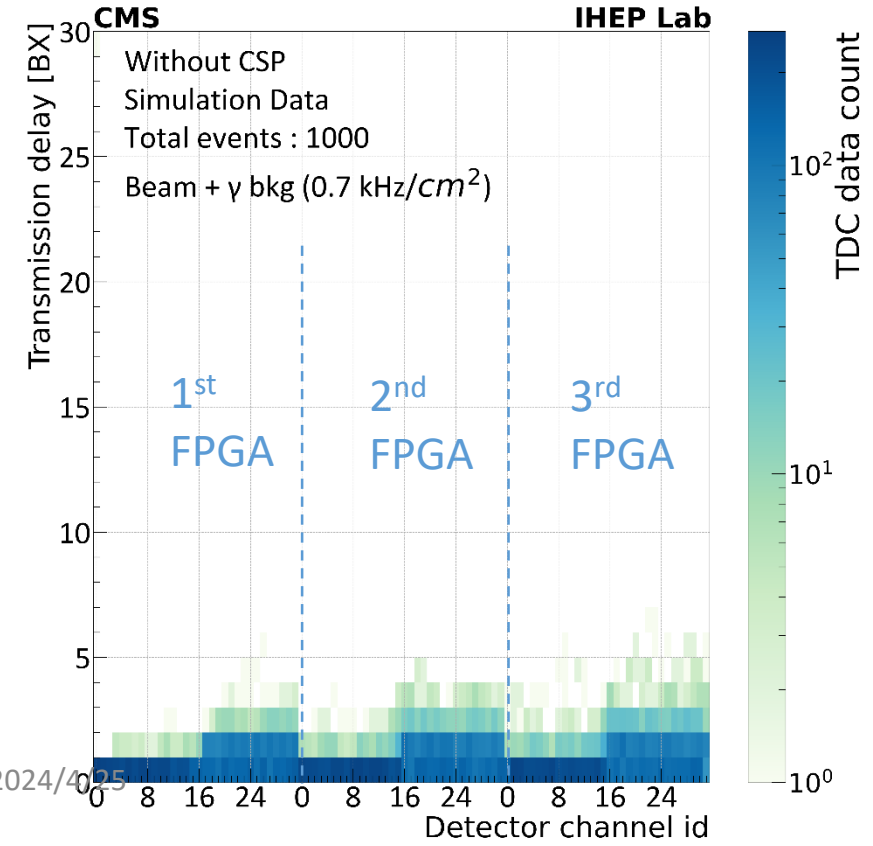


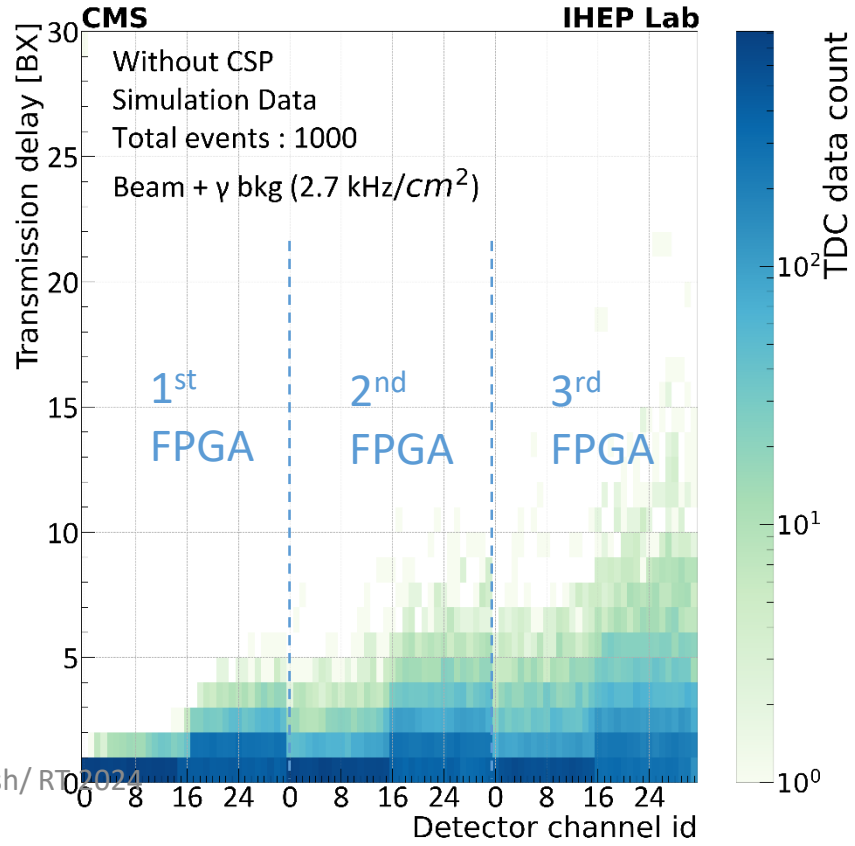
Issues/Problems

- Problems come out as hit rate increases
  - Partial DAQ data readout increase
    - ◆Polling readout/Frame readout
      - All data are read out which requires additional processing and compression
    - ◆Polling/Sparse readout/Zero suppression
      - External event sets a flag which is then checked by the readout circuitry
  - Sending Delay increases in FEE
  - Demux window in BEE should increase avoid losing information for trigger efficiency

Issues/Problems

- Transmission delay(BX = Bunch crossing = 25 ns): Time difference between data generation time and data sending time
- The problem has reproduced by simulation data
  - In different γ bkg rate, transmission delay is increasing with detector channel id
  - With increasing γ bkg rate, maximum transmission delay becomes bigger

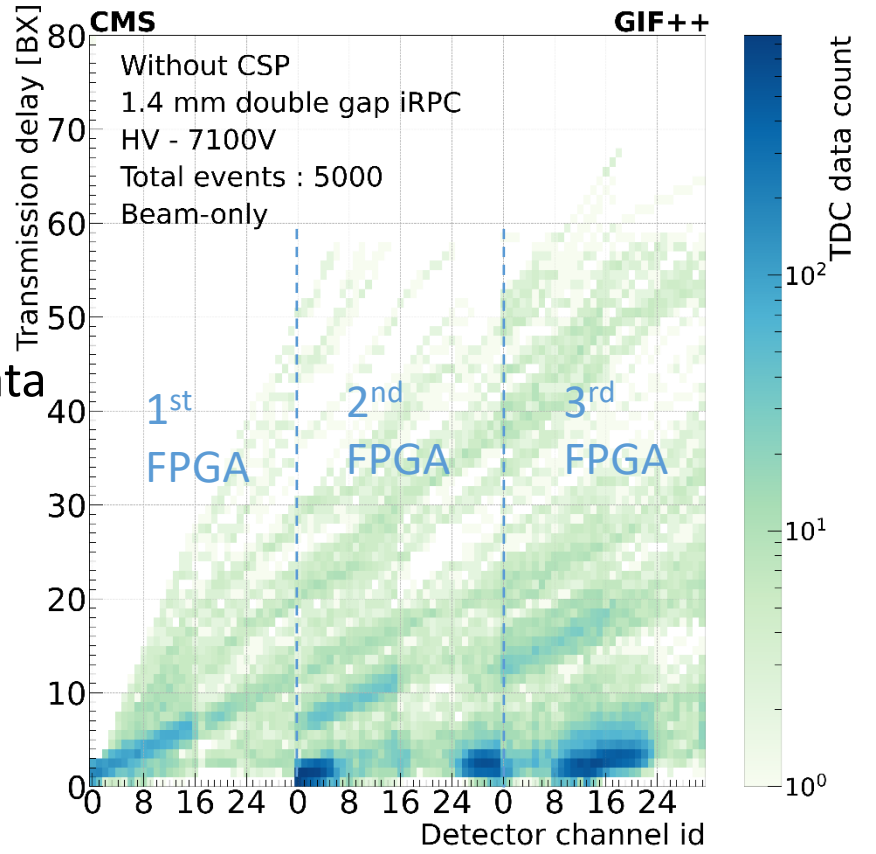




Issues/Problems

- Problem existence also is in the GIF++ beam test data
  - Transmission delay has a strong dependence on detector channel id
  - Transmission delay is becoming bigger with the detector channel id increasing. The maximum delay is around 60 BX
  - Need larger DAQ window and receiver Demux window for full TDC data
- Conclusion
  - Polling Readout(sequential sending) is problematic!

    Data sending must based on time of hit generation

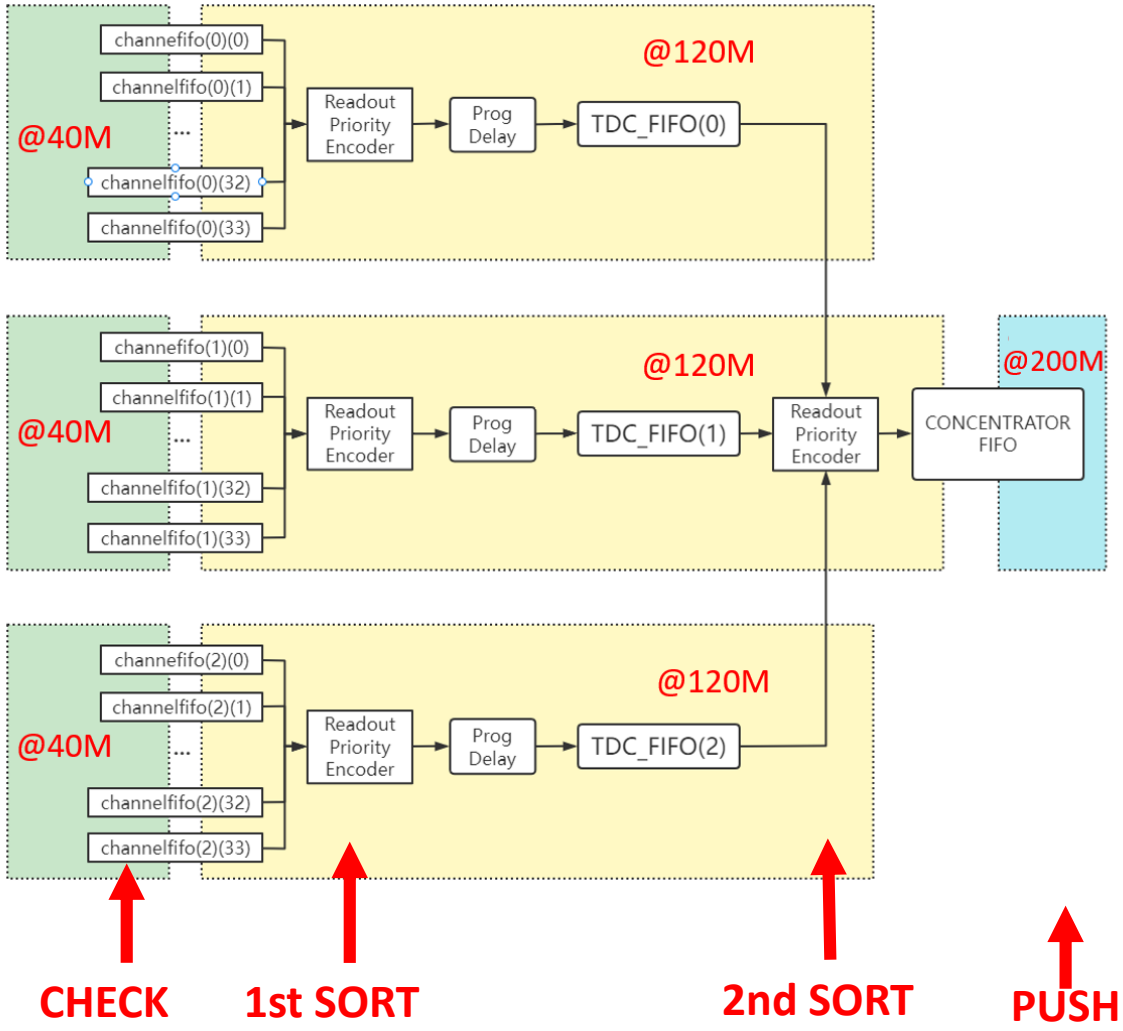


What is CSP

- A new protocol ("Check-Sort-Push" protocol based on timing) is proposed to get shorter sending delay to ease backend electronics Demux design such a way that
  - Check(read) for new hits every BX(25ns)
  - Sort the new hits data against existing ones in the data buffer in sequence of generation
  - Push(send) long GBT frame with earliest data with 40 MHz system clock

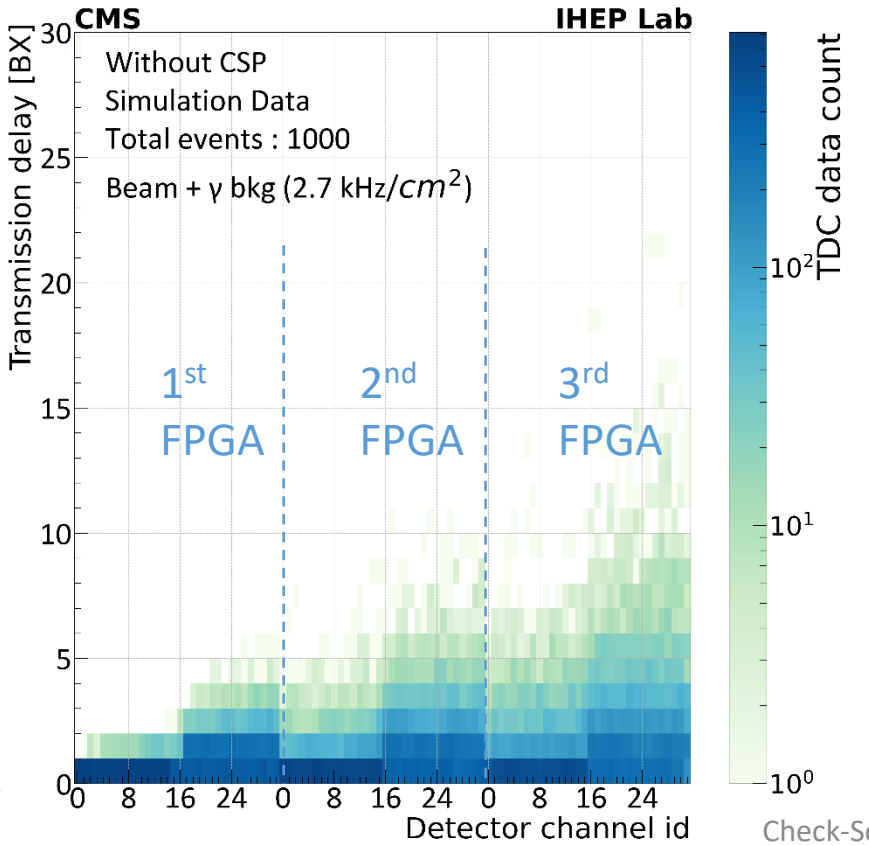
CSP implementation in FEE

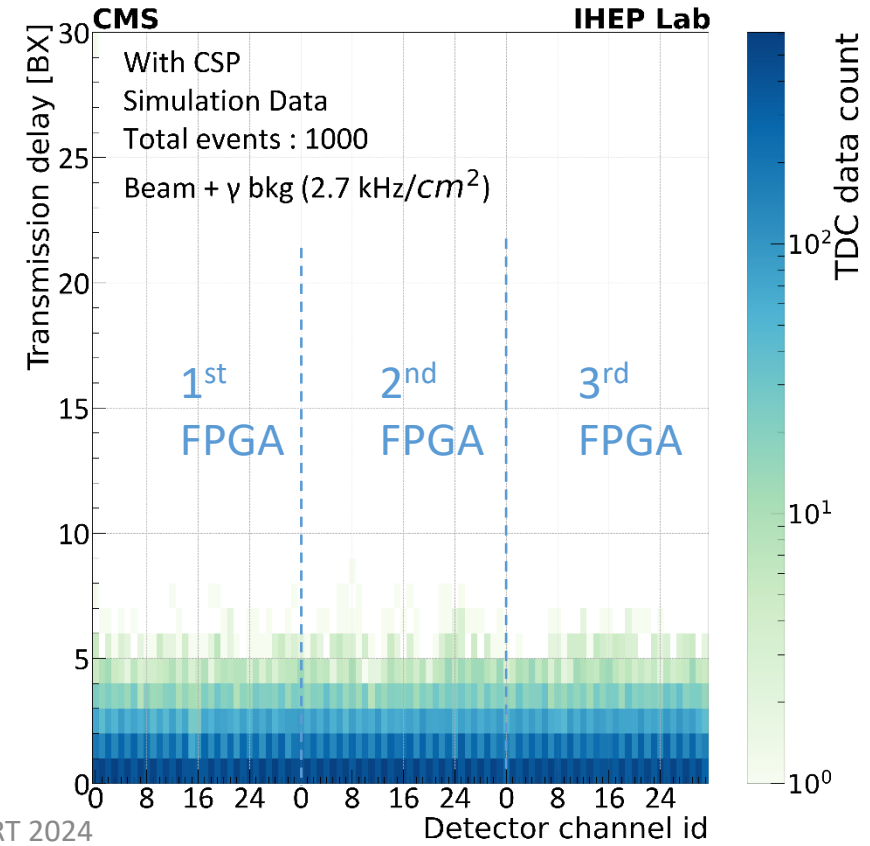
- Check
  - Sequential readout for Id with hit flag with digitizing clock
  - Data with generation time(in BX) and channel id
- Sort(priority encoding) with merging clock(in shared link)
  - First sorting by generation time before moved to FIFO
  - Second sorting by generation time in the merger module before moved to concentrator FIFO
- Push
  - Sending long frame with concentration clock



CSP improvement verification with simulation

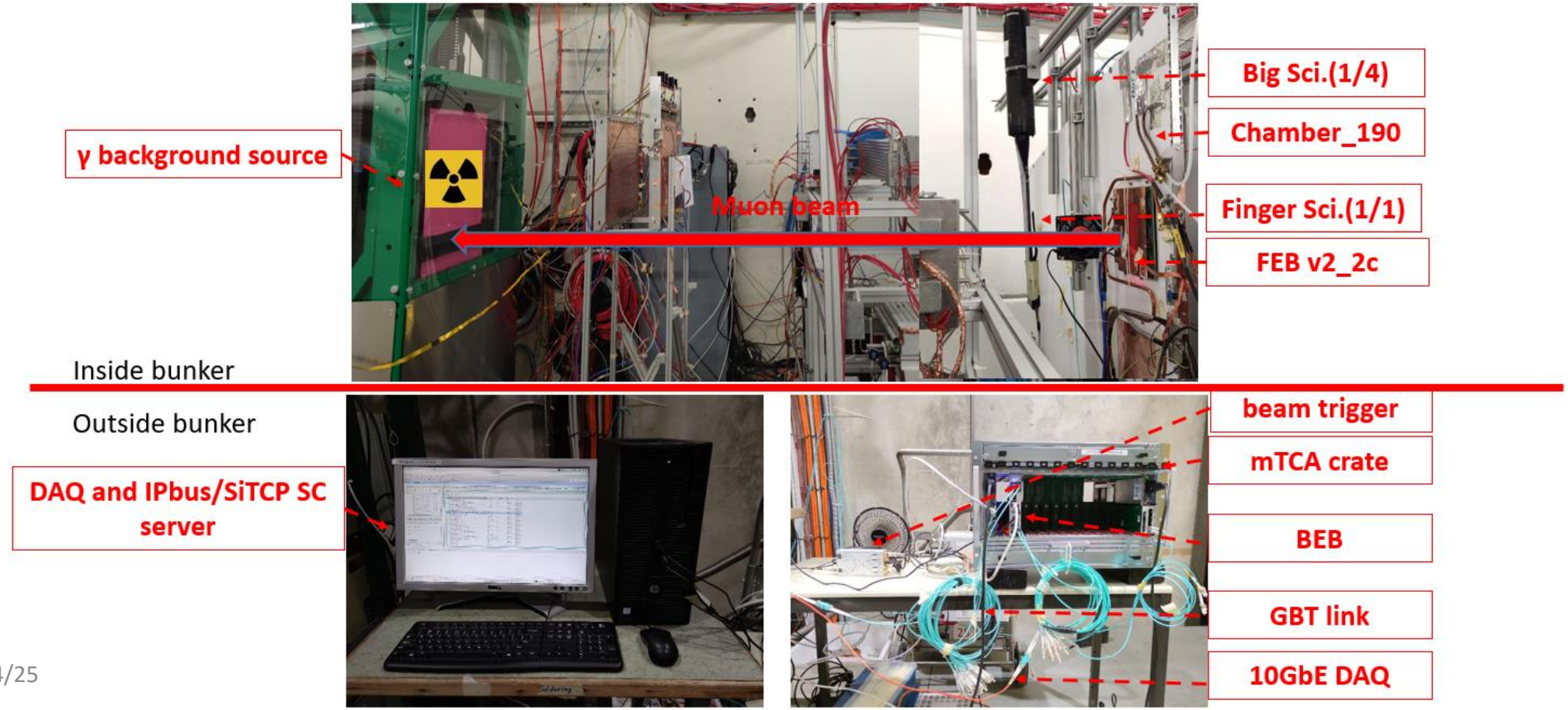
- Simulation data shows CSP has shows great improvement on decreasing transmission delay
  - In the same γ bkg rate, maximum transmission delay decreases by ~50%, from ~15BX to ~7BX





Verification with beam test

- Data taking with beam trigger
  - W/O CSP : beam-only; beam + γ bkg(2.0~2.7 kHz/cm2)
  - With CSP : beam-only; beam + γ bkg(2.0~2.7 kHz/cm2)



Beam data analysis

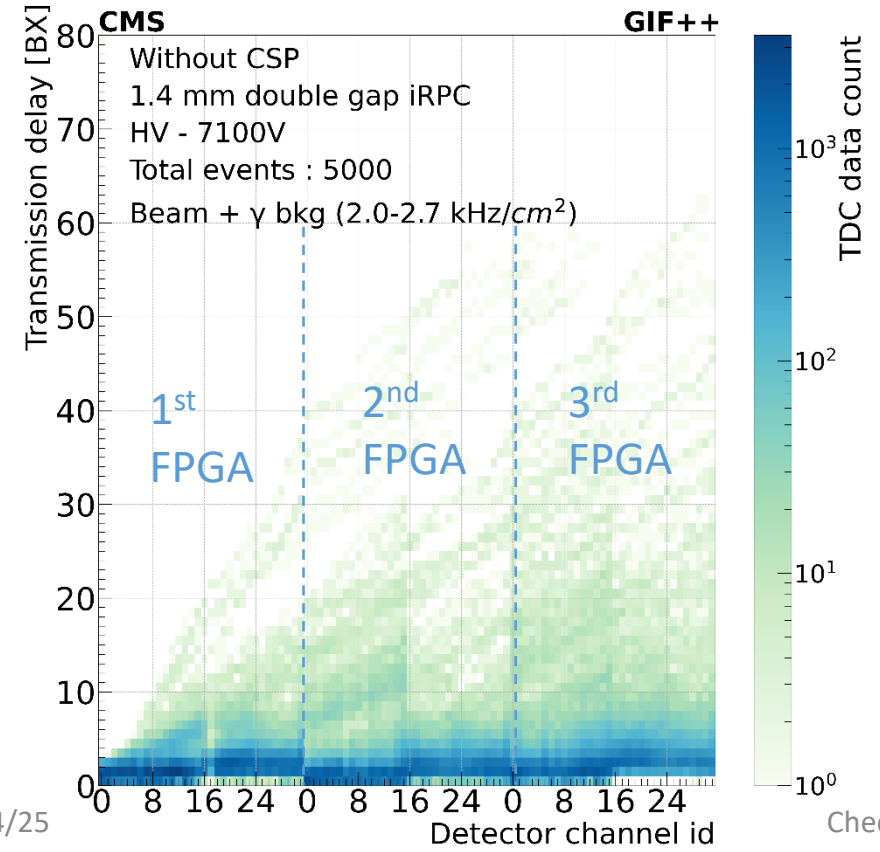
- Study the good hits behavior
  - Selecting the good hit
    - A hit with paired tdc data whose position is within scintillator aera and time is fixed with L1A
  - Study the rate of good hit in different DAQ window
    - Find good hit → check its position in the DAQ window → statistic good hit count in different DAQ window
    - $Rate\ of\ good\ hit\ (x) = \frac{Good\ hit\ count\ in\ window\ x}{Total\ good\ hit}$
  - Different DAQ window
    - If 2 muon particle hit in the chamber and muon maximum cluster size is 8
      - DAQ window: 8 strips*2*2(both ends)/3(tdc data in one frame) = ~11BX
    - 12 BX: 11 BX + 1 BX(target)
    - 18 BX: 12 BX*1.5
    - 24 BX: 12 BX*2
    - 36 BX: 12BX*3

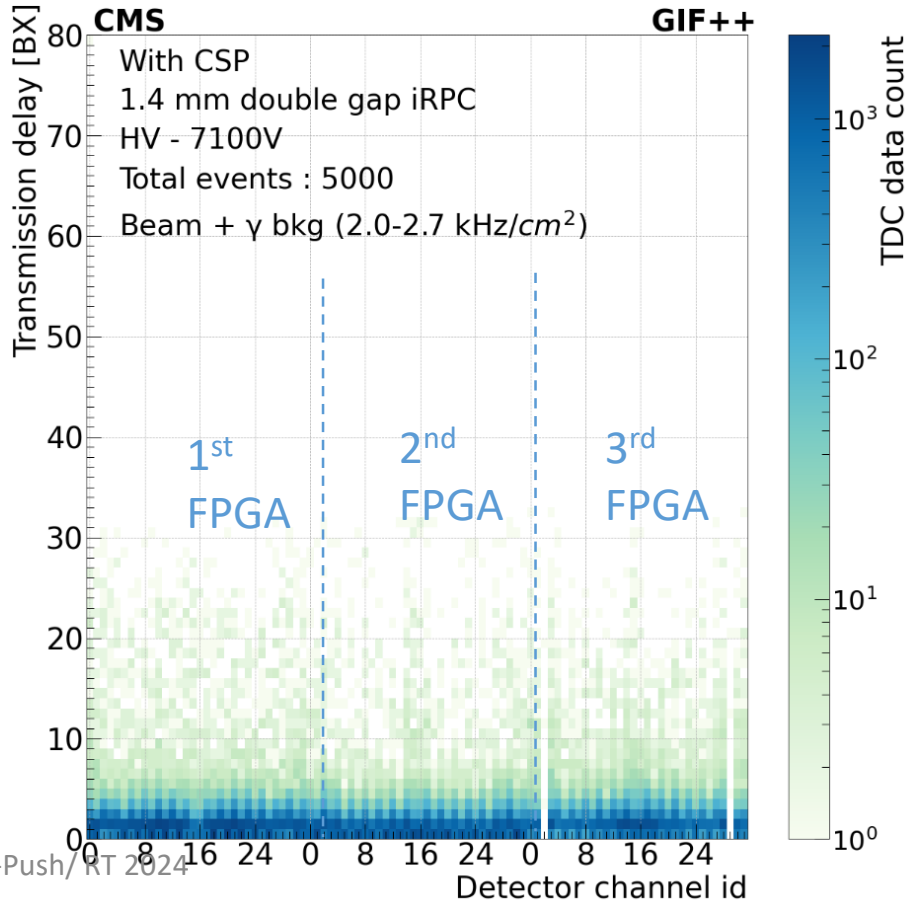
Beam data analysis

- Evaluate the transmission efficiency of good hit in different receiver Demux window
  - Find good hit → calculate its transmission delay → get good hit count in different receiver Demux window
  - $Transmission\ efficiency(x) = \frac{Good\ hit\ count\ in\ receiver\ Demux\ window\ x}{Total\ good\ hit}$
  - Different receiver Demux window
    - If 2 muon particle hit in the chamber and muon maximum cluster size is 8
      - DAQ window: 8 strips*2*2(both ends)/3(tdc data in one frame) = ~11BX
    - 8 BX: RPC CPPF link system maximum delay
    - 12 BX: 11 BX + 1 BX
    - 16 BX: 8 BX*2
    - 23 BX: iRPC BEE Demux depth

Good improvements in transmission

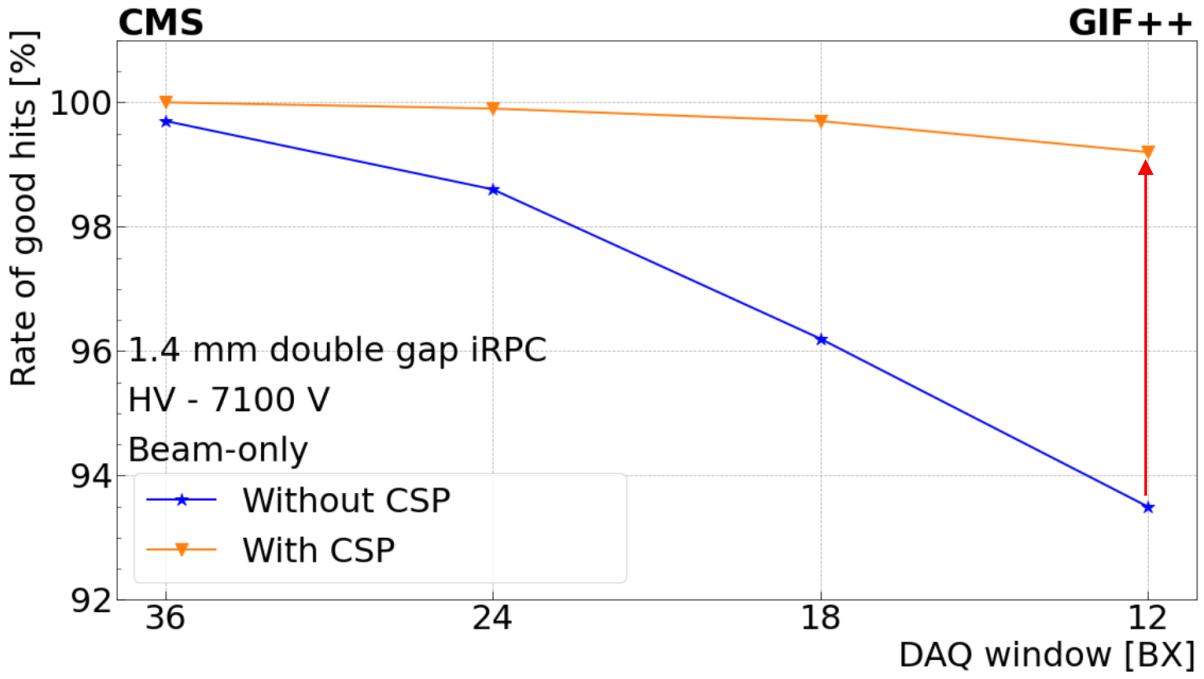
- CSP improves
  - No dependence on detector channel id
  - Maximum delay from 60 BX (left plot) to less 30 BX(right plot).

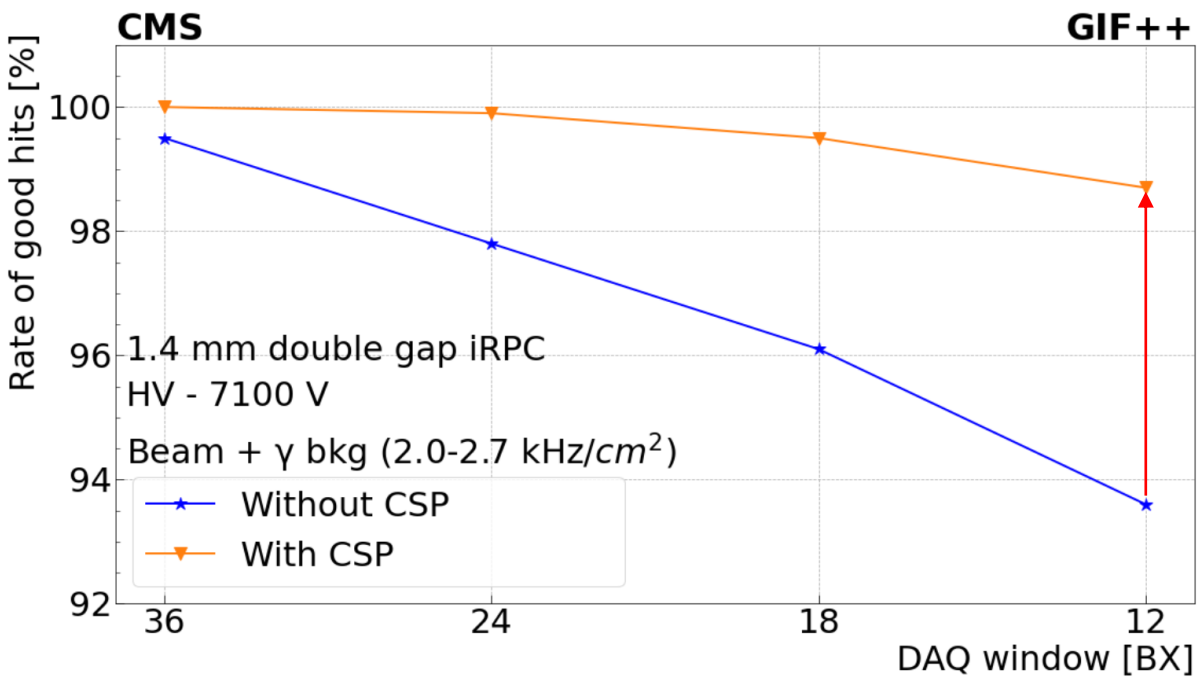




Good improvements in DAQ Window

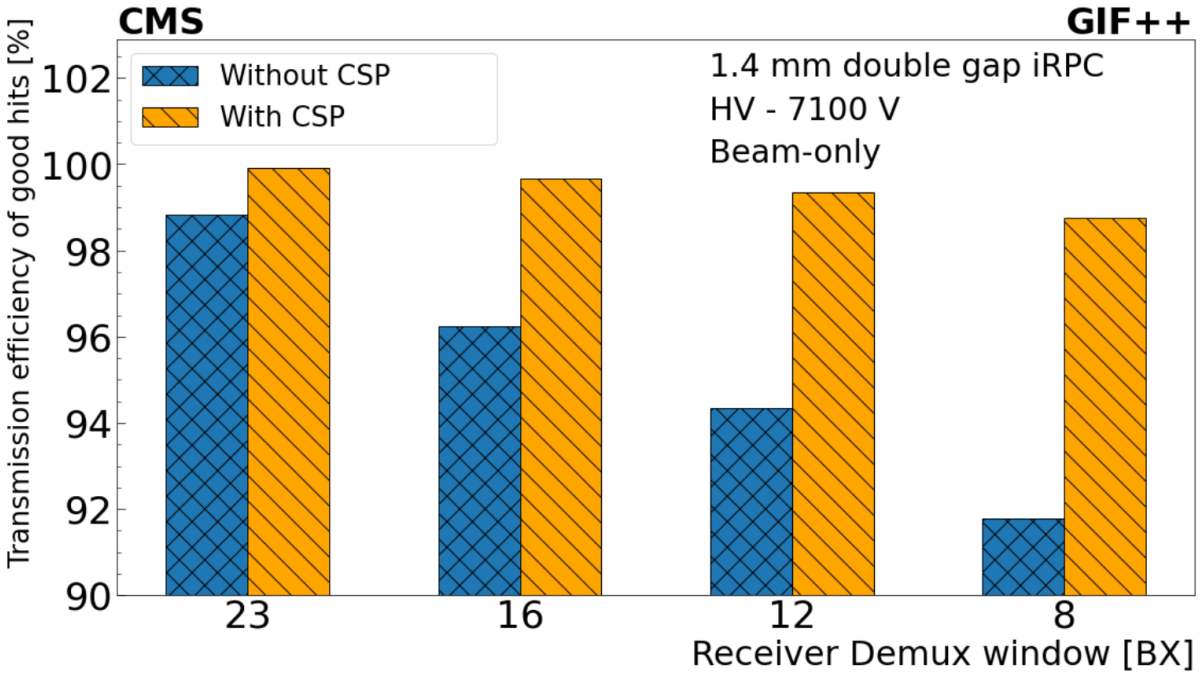
- Rate of good hits in 24 BX window is good enough with help of CSP
- The CSP function allows us to reach a narrow DAQ window
  - Aiming small DAQ window at 12 BX in both beam-only and beam + γ bkg (2.0-2.7 kHz/cm2) , rate of good hits increases from 93% to 99%

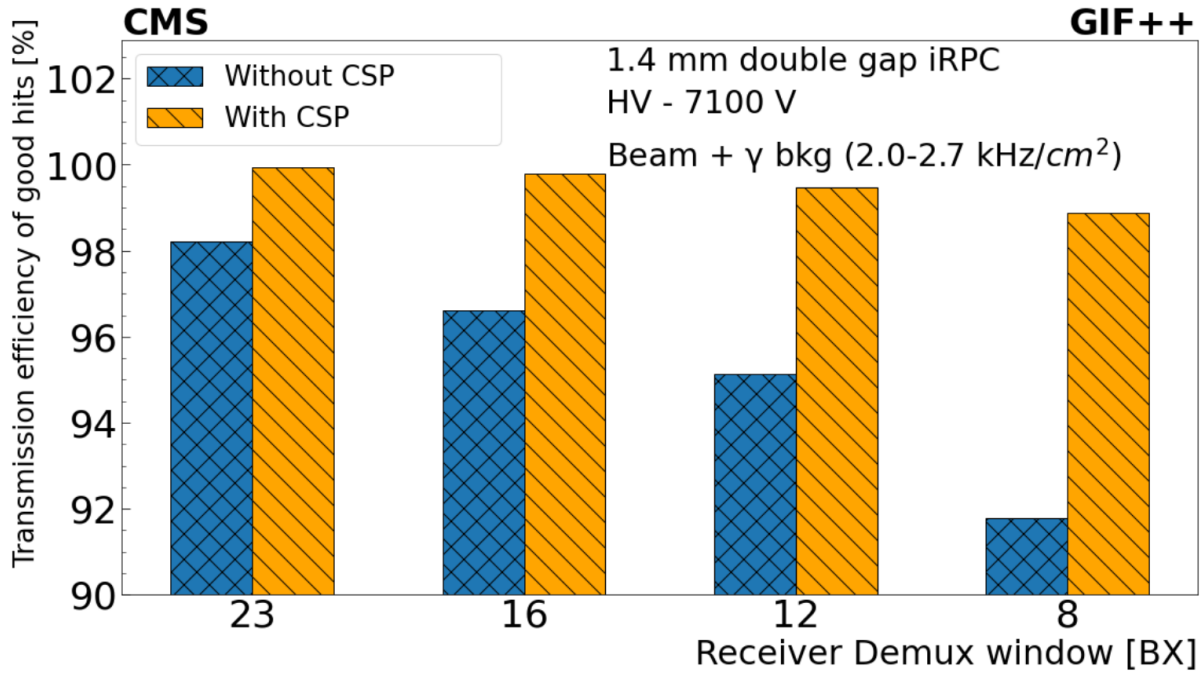




Good improvements in receiver window

- Above 99.9% good hits is received within 23 BX Demux window with the help of CSP
- Transmission delay decreases greatly to reach a narrow receiver Demux window
  - Smaller receiver Demux window of 8 BX in both beam-only and beam + γ bkg (2.0-2.7 kHz/cm2) , transmission efficiency of good hits increases from 92% to 99%





Summary

- Polling readout and transmission introduce a large range of delay which leads to a partial data loss. A new protocol is necessary!
- Check-Sort-Push is proved effective in solving the issue with simulation data and emulation setup
- GIF++ beam test results show a successful CSP application and be used in CMS iRPC system

Thank you very much for your attention!

Backup

Reference

- *K. Bunkowski , Optimization, Synchronization, Calibration and Diagnostic of the RPC PAC Muon Trigger System for the CMS detector*
- *Shchablo Konstantin[1] on behalf of the CMS Muon group, Front-End electronics for CMS iRPC detectors（RPC2020, Roma）*
- *Zhenan Liu on behalf of the CMS Muon group,* New Check-Sort-Push protocol in iRPC data compression, transmission and decompression in Backend electronics system（*RPC2022, Geneva）*
- *D. Sun, Zhenan Liu Belle2Link: A Global Data Readout and Transmission for Belle II Experiment at KEK, https://doi.org/10.1016/j.phpro.2012.01.036*