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VIRTUAL CONFERENCE

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BCM'

System for Abort and Luminosity of the ATLAS Experiment at the HL-LHC based on pCVD diamond

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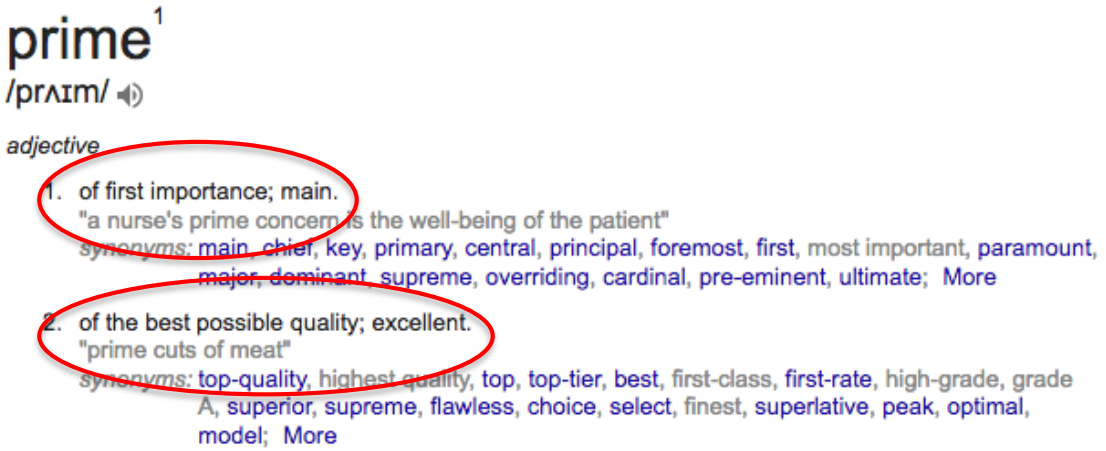
Aim

BCM’



prime[1]

/prʌɪm/

adjective

1. of first importance; main.
   "a nurse's prime concern is the well-being of the patient"
   synonyms: main, chief, key, primary, central, principal, foremost, first, most important, paramount, major, dominant, supreme, overriding, cardinal, pre-eminent, ultimate; More

2. of the best possible quality; excellent.
   "prime cuts of meat"
   synonyms: top-quality, highest quality, top, top-tier, best, first-class, first-rate, high-grade, grade A, superior, supreme, flawless, choice, select, finest, superlative, peak, optimal, model; More

The ultimate ATLAS Beam Conditions Monitor

Shall provide

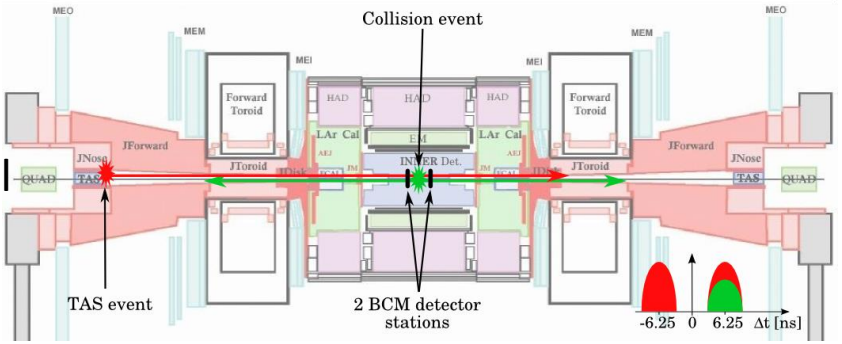
- Fast (bunch-by-bunch) safety system for ATLAS
- Luminosity measurement
- Background monitoring

in the ATLAS ITK volume for the HL-LHC era

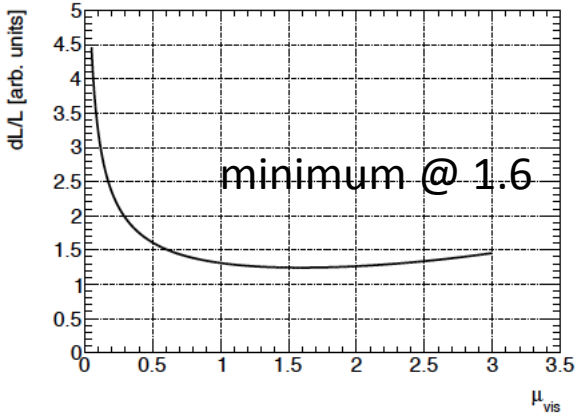
Functionality

BCM TOF concept

- **Collisions: in-time**
- **Background: out-of-time**



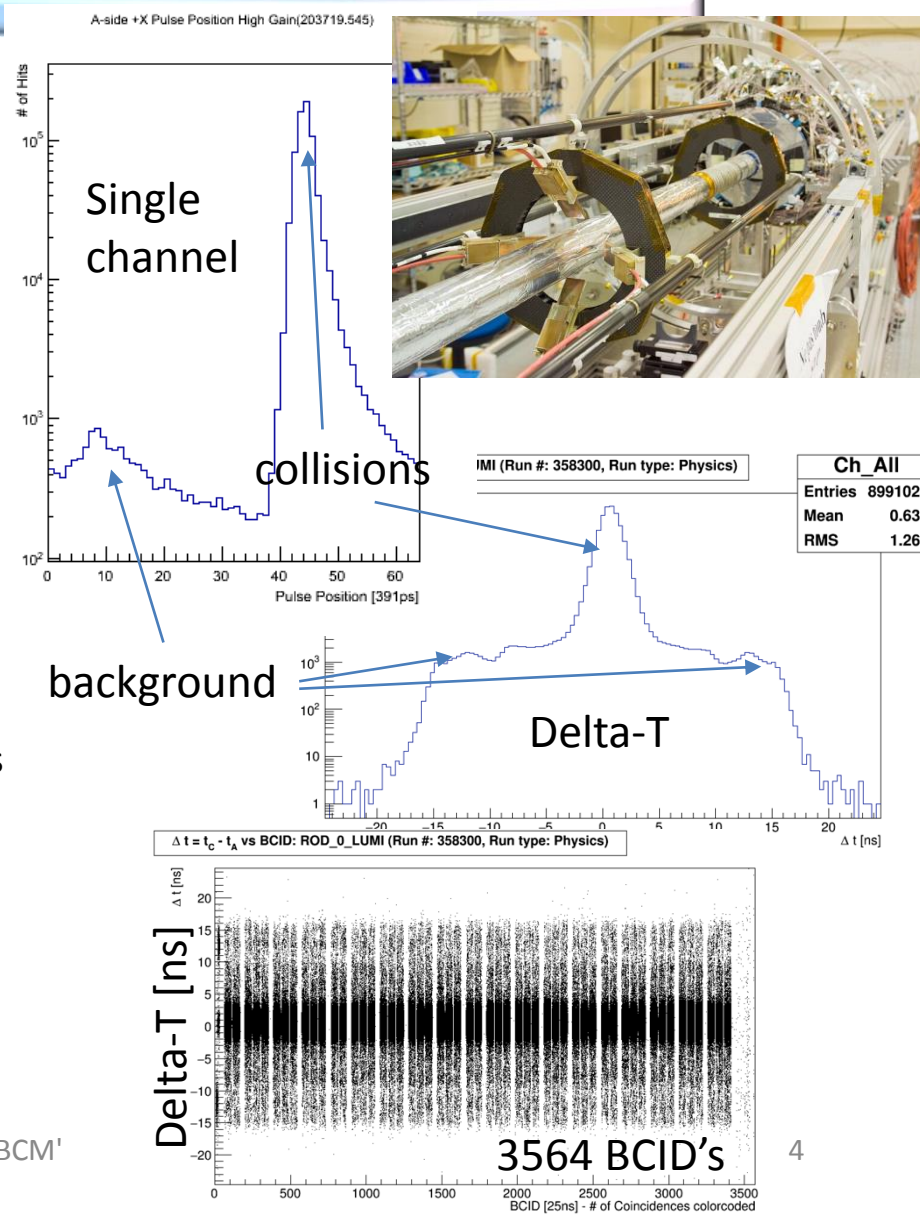
- Beam protection - *Abort*
  - ***out-of-time*** signals (~6 ns *before* collision) are a clear messenger of upstream non-collision background (NCB)
  - abort on *out-of-time* activity above threshold signifying beam background at ITk danger level
    - danger thresholds can be pretty high (now SCT 25k/cm^2/BC i.e. 4000x the lumi induced signal)
  - need to **keep flexibility** for threshold settings
  - include machine-style (slow, 40 μs integrating) Beam Loss Monitor (BLM)
- Luminosity measurement and NCB - *Lumi*
  - main algo: (absence of) ***in-time*** (~6ns *after* collision) signals (*r* - zero counting) -> single MIP sensitivity
  - max. statistical sensitivity – $r \approx 0.2$ -> ~1.6 hits/cell, shallow minimum
  - need robust device, signal stability paramount
  - have to cover μ-range from VdM (0.01 in tails) to μ=200 (ultimate HL-LHC lumi)



Current ATLAS BCM Highlights

- Fast pCVD based system with asynchronous 2.56 GB/s read-out
  - 4 sensors/side, 1.9 m from IP
  - 500 ps time resolution
  - Installed into ATLAS Pixel support tube in 2007
- Performance
  - PM diagnostics
    - Post-mortem buffer after each dump triggered by machine BLM's
  - A couple of aborts at danger level
    - Mostly UFO-induced
  - Beam background diagnostics
    - Timing with 500 ps resolution cleanly resolves collisions from background for each BCID
  - Luminosity measurement
    - Preferred ATLAS lumi-meter in Run1
    - Stability problems in Run2 conditions
    - Low (initial) S/N (<10), no diagnostics

See JINST 3 P02004 (2008) for design details



System Design

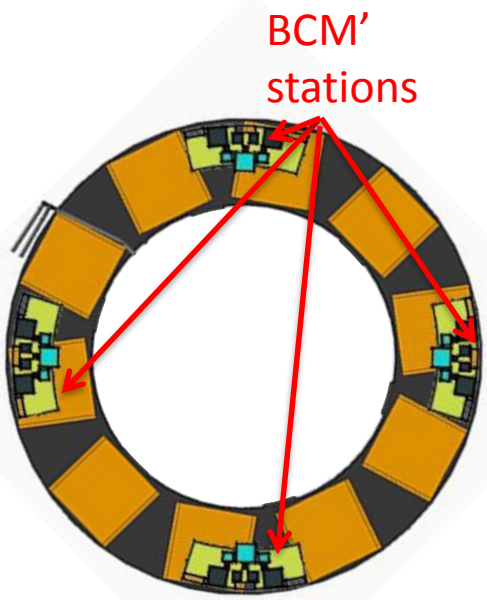
- BCM suffers from *abort* <-> *lumi* incompatibility
  - e.g. *abort* thresholds cannot be set higher without abandoning *lumi*
  - fast timing needed for *abort* lowers SNR thus limiting *lumi* stability
- Separate out functionalities for HL-LHC
- Two fast devices from sensor to off-detector
  - still keep commonality wherever possible
- For installation, group the *abort*, *lumi* BCM' and BLM into a *station*

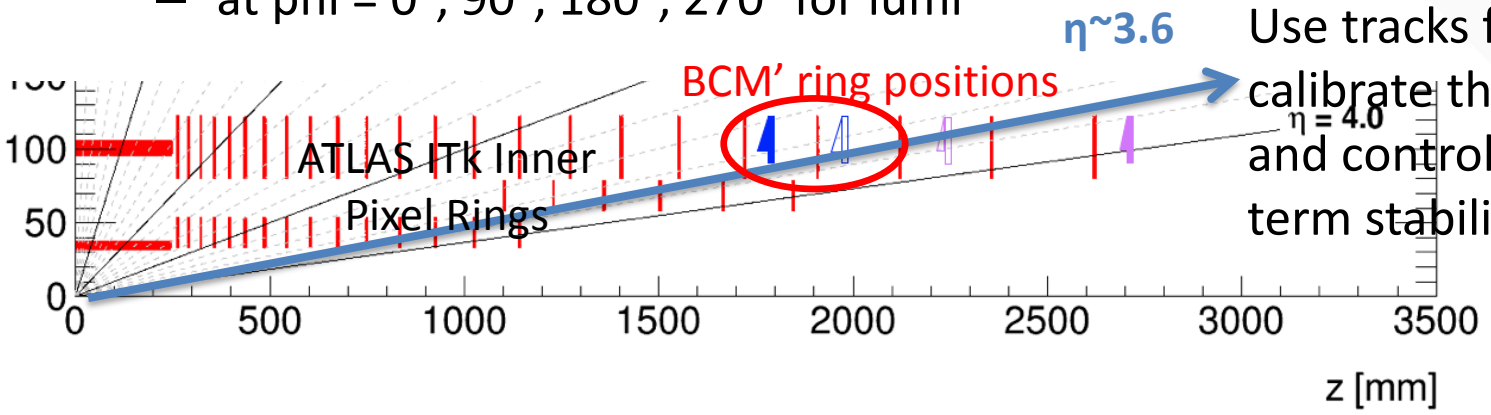
Location

- Stay within (removable) inner pixel part
- Keep close to sweet spot at *z*~1875 mm
- Turns out to be z~2000 (or 1800) mm in inner ITk layout
- Move out to *r*~100 mm *η*~3.6

➢ Occupy a separate R1 ring

- 4 *stations* per side
  - with abort, lumi BCM' and BLM
  - at phi = 0°, 90°, 180°, 270° for lumi





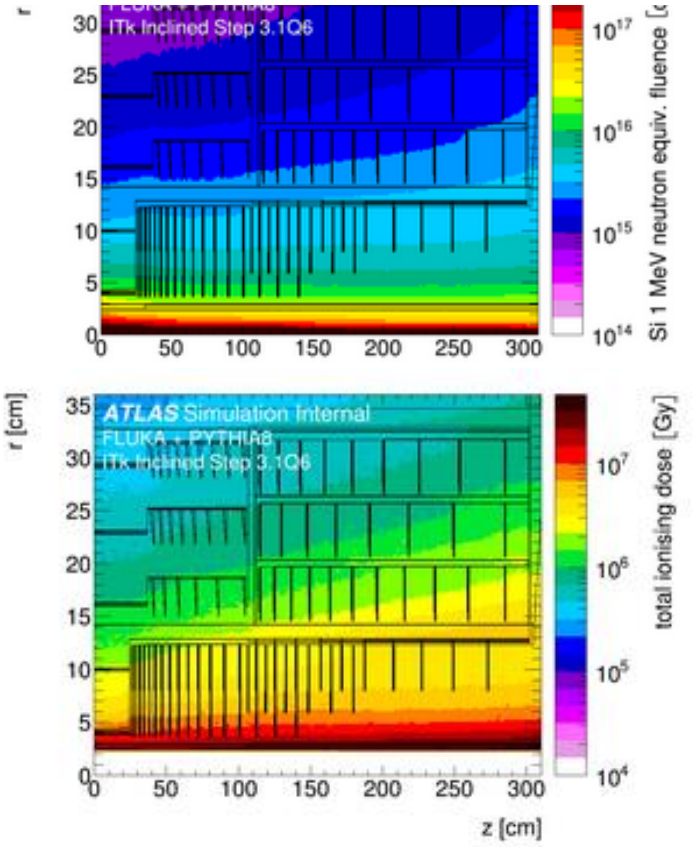
Use tracks from ITk to calibrate the detector and control its long-term stability

Environment

Fluence and dose values for BCM'. Values of 1 MeV fluences and dose are normalised to 2000 fb^{-1}. All other values are per event. **No safety factors have been applied to these values.**

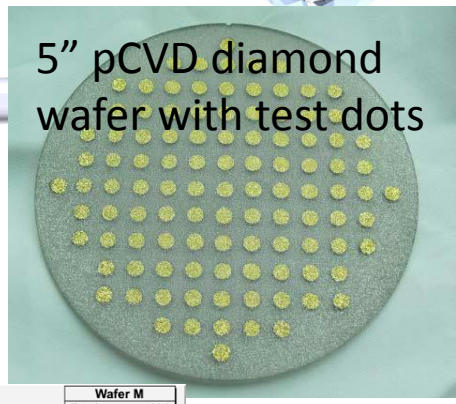
integrated luminosity (fb^{-1})	location	R (cm)	Z (cm)	1 MeV neq (10^{16} cm^{-2})	total ionising dose (MGy)	charged particle fluence (10^{-3} cm^{-2} pp^{-1})	hadrons > 20 MeV fluence (10^{-3} cm^{-2} pp^{-1})
2000	BCM'	9.0	179.5	22.5	1.99	36.3	19.2
	BCM'	10.0	179.5	19.9	1.78	31.8	16.1
	BCM'	11.0	179.5	18.5	1.60	29.1	14.2
	BCM'	12.0	179.5	17.8	1.58	28.6	12.8

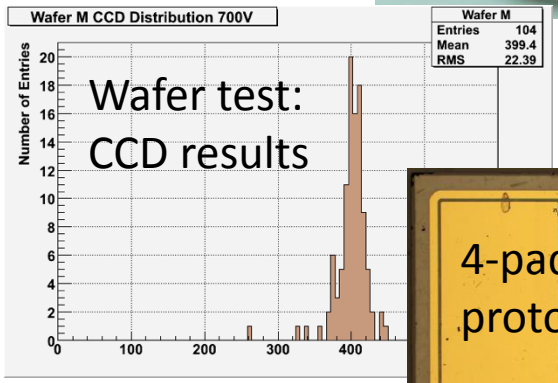
- ATLAS radiation simulation, *r*=9-12 cm, *z*=1.8 m
- NIEL&TID for 2/ab, no safety factors
  - NIEL ~2×10^{15} n_{eq}/cm^2
  - TID $\lesssim$ 200 Mrad
  - low neutron fraction
  - 3×10^{15} 800 MeV p/cm^2 for sensor benchmark (1.5 ITk safety factor – see W.Trischuk in Session II)
- Charged particle flux/BX @10 cm
  - ~0.032/cm^2 x μ (50% e^+e^-)
  - ~4.5(6.4)/cm^2 for μ = 140(200)
- Flux ~160(230) MHz/cm^2
  - Booked CERN HiRadMat facility to test high rate response for *lumi* and *abort*

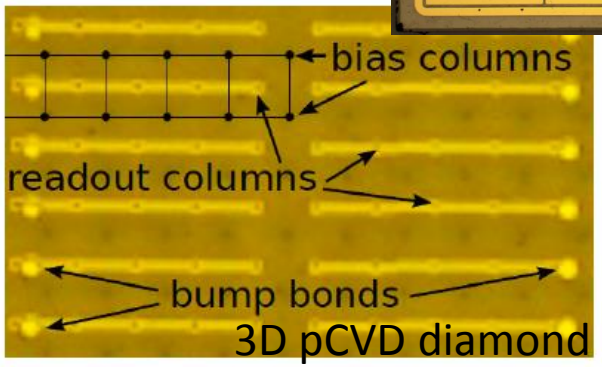


Sensors

- pCVD diamond chosen as sensor material
  - robustness (no cooling), low *C*, negligible *I*, fast signal, radiation hard
- 3 types of sensors
  - 1x1 cm^2 (*lumi*), 5x5 mm^2 (*abort*), ~1x1 mm^2 (3D lumi) (see H.Kagan in Session II)
  - 3&4 pads (*lumi)*, 4 pads (*abort)*, single pad (3D *lumi*), max size ~50 mm^2, min size ~1 mm^2
  - aim for C<5pF, not trivial for 3D (TCAD), see H.Kagan in Session II
- Working with RD42 to secure best possible pCVD diamond sensor quality
- Focus on US vendor having worked with RD42 for the last few years
  - 1-2 wafers to be grown for the project
  - sensors on loan for prototypes
- Evaluation of charge collection (~9ke @2 V/µm) and long-term current stability

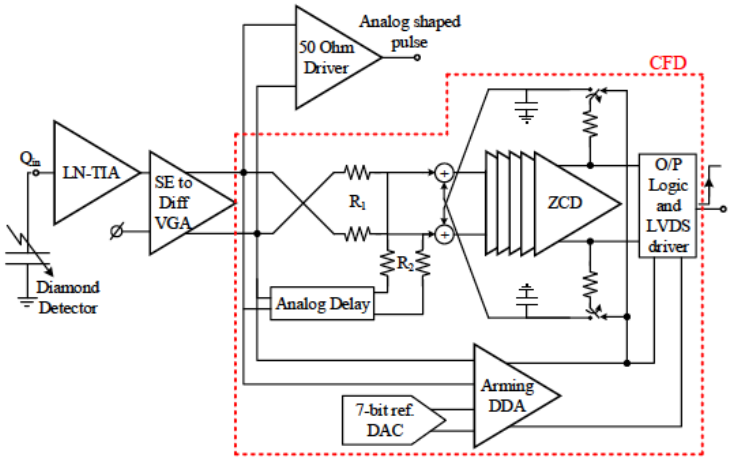


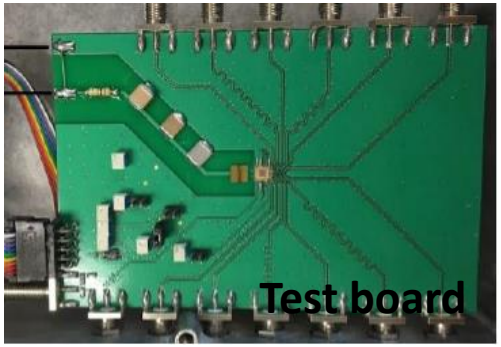


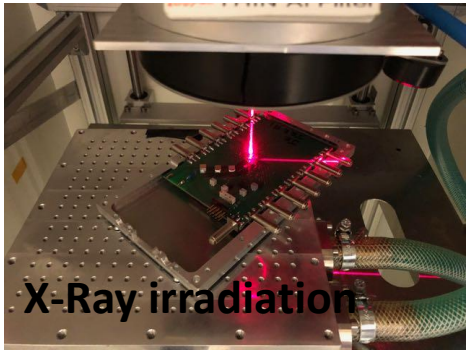


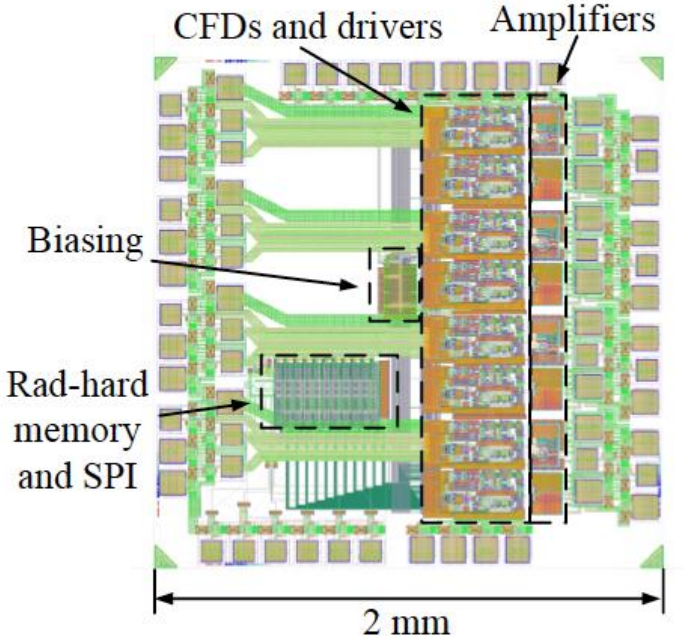
Front-End - Calypso

- 4-channel FE designed in TSMC 65 nm process
  - minimal reticle size 2x2 mm^2
  - affordable MPW through Europractice
- 2 inputs/channel: *lumi*/*abort*
  - optimized for 2-5 pF detector capacitance
  - <1.5 ns peak, <15 ns settling time @2pF
  - <100 ps time jitter @2pF for >3.6 ke signals
  - *lumi*: (110 + 55/pF)e noise , ±50ke dynamic range
  - *abort*: 830 ke noise @2pF, ± 750 Me dynamic range
- 2nd iteration Calypso_B meets all specifications
  - including preliminary TID radiation testing
- 3rd iteration Calypso_C to be submitted August 26th





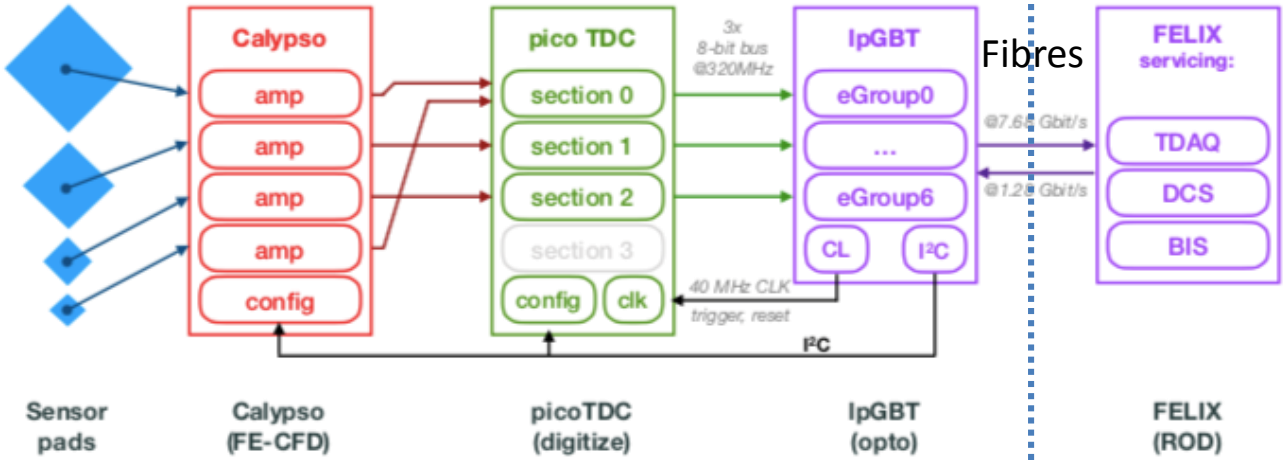




Read-Out Chain

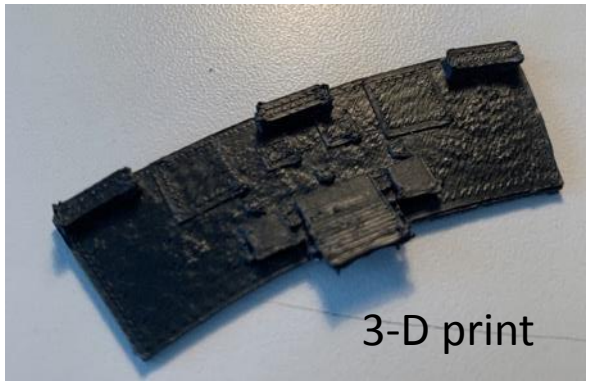
- Baseline: complete chain on the ring
- FE->picoTDC->lpGBT->VTRx+
  - Barely matches the radiation spec
  - Adds power on ring, on-module bPOL2V5's for chips
  - \+ Complete readout with optical fibre in/out

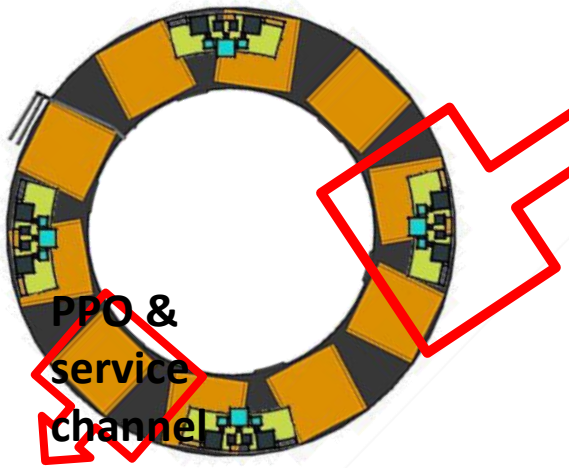
- Proceeding with sequentially adding R/O chain components
  - PicoTDC done
  - lpGBT to follow
  - Radiation tests of all ASICS at CERN X-ray
    - Progressive TID
    - Calypso_B 30, 70, 240 Mrad done, preliminary check ok

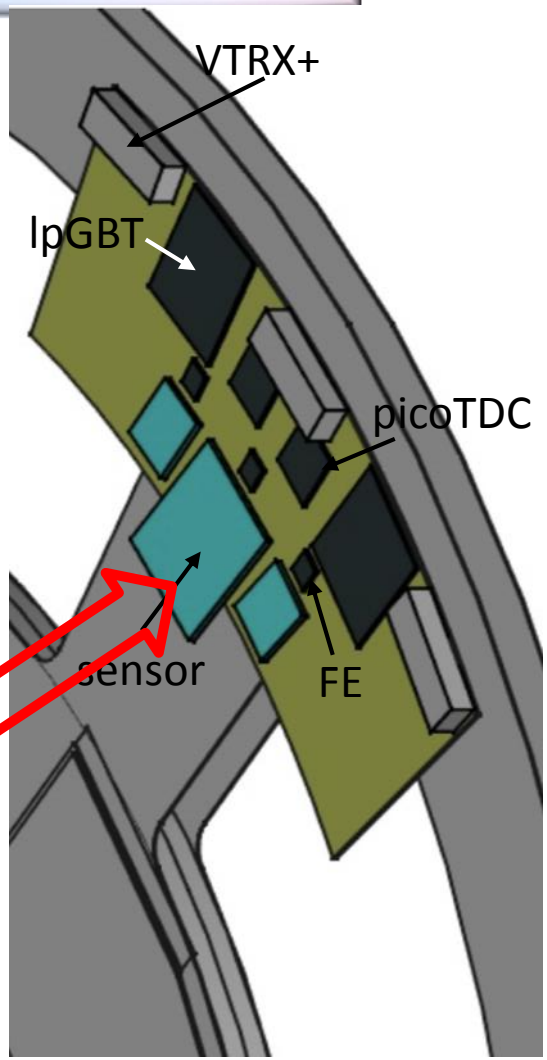


Station

- Many chips now on the station
  - 3 sensors, 3 FE, 2 picoTDC, lpGBT, VTRx+
    - bPOL's… and the BLM sensor
  - Occupies ~1/3 of available space on ring
  - MOPS on PP0 on ring at service channel phi
  - Thermal load ~30 W / ring
    - Need thermal sink => cooling pipe in carbon foam of the ring







Schedule Focus for This Year

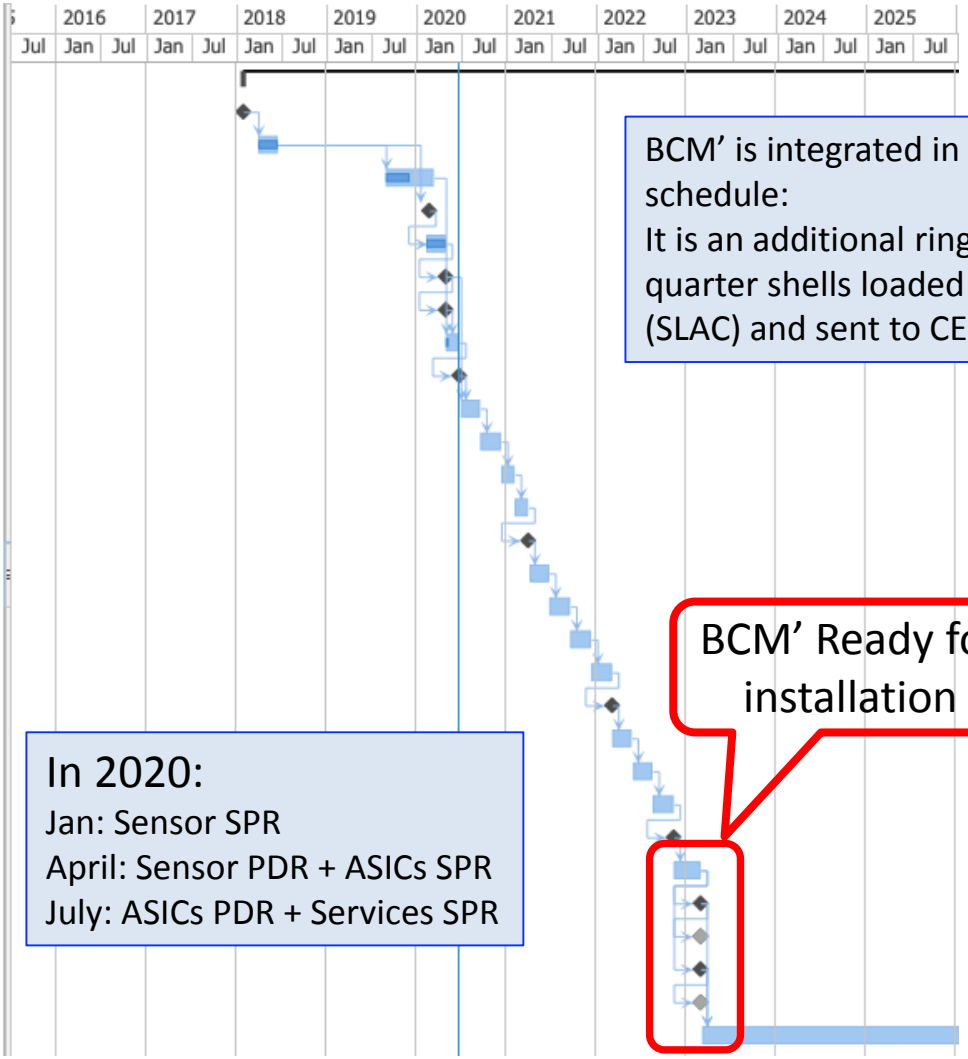
- PDR to FDR schedule (~covers 2020 + COVID delay ?)
  - Build prototype modules (~4 of each)
    - BCM' *abort*
    - BCM' *lumi*
    - BLM
    - Includes sensor/IC's (proto ?)/flex
  - Design and prototype integration of 3 module types (BCM' *abort*, BCM' *lumi*, BLM) into a station as the object to install
  - Prototype services and data-links as realistic as feasible
  - Test beam of system, including irradiated modules (1-2 of each)
- Schedule contingent on Covid-19 development
  - Many developments scheduled at CERN and other labs (SLAC, PSI, DESY)

Work Division

- Up to module production workload divided between Ohio State and Ljubljana
  - Manchester help on sensor design
  - Wiener Neustadt starting on powering scheme
- Integration on LS, services, links etc. rely heavily on help of respective ATLAS Pixel/ITk
  - CERN help on integration & commissioning
- (Sub-)critical, new collaborators welcome !

Schedule Overview

Task Name
2.4.4 Luminosity and Beam Protection
Internal Specifications review
FE & Proto-digital design review, submit
TB: sensor/FE & proto-digital
SPR: Sensors
Preparation for PDR: Sensors
PDR: Sensors
SPR: Modules (ASIC)
Preparation for PDR: Modules
PDR: Modules, submit proto-IC + services specs
Design and build proto-module board: Calypso + picoTDC
Test of proto-module
Irradiate proto-module (*)
Testbeam of proto-module (*)
FDR, submit pre-production IC
Fabricate pre-series sensors, IC's
Assemble module boards (2 sets for pre-production, 2 for radiation QC)
Irradiations of system
Test-beam / lab tests of system
PRR
Submit production IC
QA of production
Production system built
All systems built
Final station QA/QC, mechanics, back-end
BCM' Ready for Installation - I Pixel IS EC A Quadrant 4
BCM' Ready for Installation - I Pixel IS EC A Quadrant 4
BCM' Ready for Installation - II Pixel IS EC C Quadrant 4 PUSH IN FRON
BCM' Ready for Installation - II Pixel IS EC C Quadrant 4 PUSH IN FRON
BCM' Commissioning & Integration - follows pixel cabling



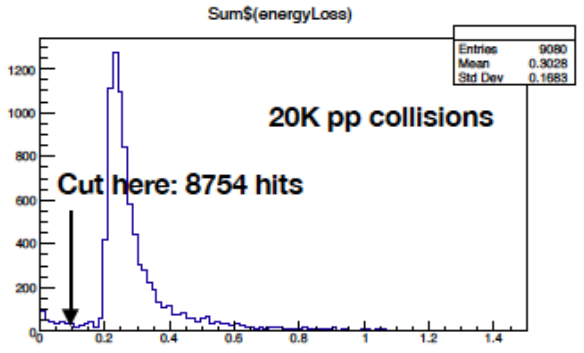
Summary

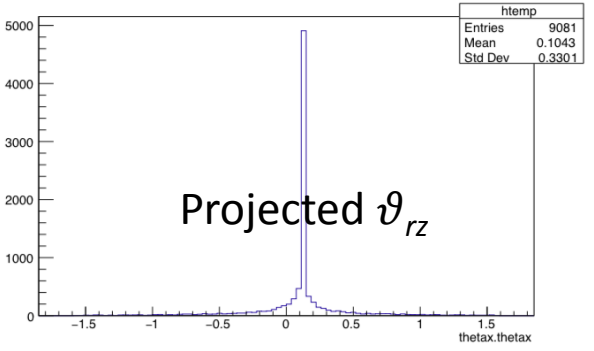
- BCM’ - fast protection and lumi measurement device inside ATLAS ITk inner pixel end-cap
  - Includes machine-style (slow, integrating) BLM
- Many milestones, including formal reviews, passed, many more to come
- Schedule requires BCM‘ ready for installation in 2023 – tight, but achievable

Backup

ATHENA Simulation

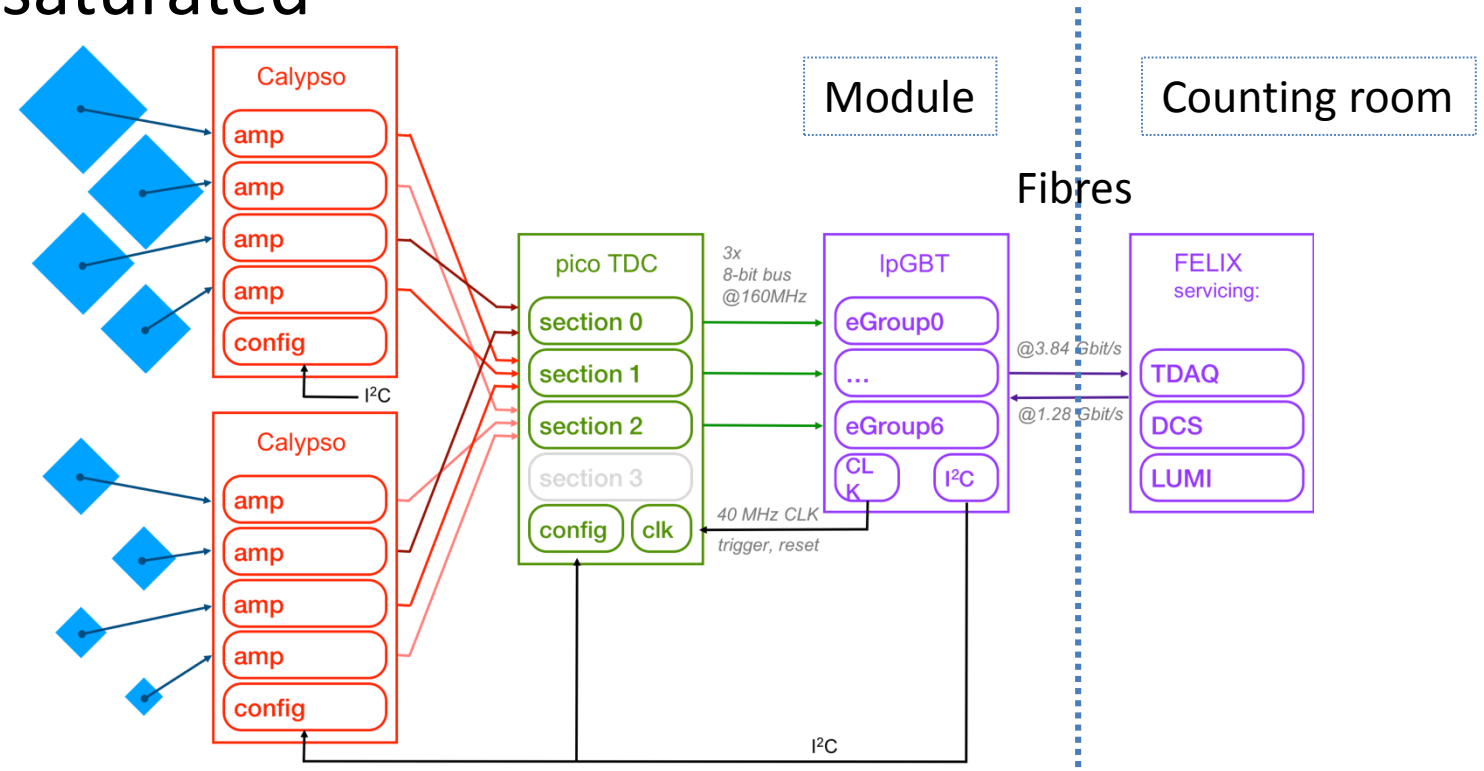
- Diamond positions (centre):
  - z = 179 cm, r = 9.0 cm, 1x1 cm^2
  - Inclined at 10° for erratic current suppression
  - ~ perpendicular impact of primaries
    - Minimal charge sharing
    - Tails due to secondaries
- 20k min bias 14 TeV *pp* collisions
  - 8754 hits in 16 sensors
  - 27.3x10^{-3} cm^{-2}/pp
  - 1/cos(ϑ) weighting yields 35.5x10^{-3} cm^{-2}/pp, in full accordance with FLUKA flux estimate





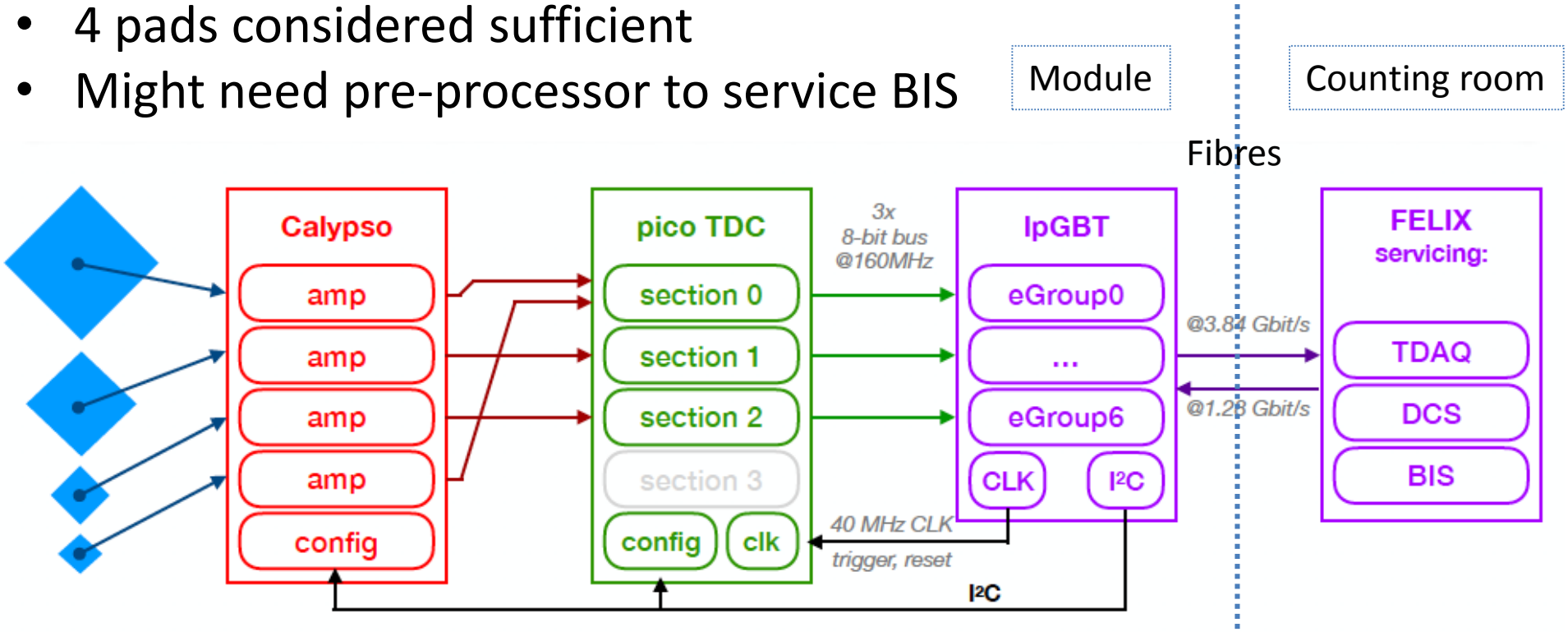
R/O Schematic - Lumi

- 8 sensor channels to 1 picoTDC->lpGBT
- Successively switch larger pads off if R/O saturated



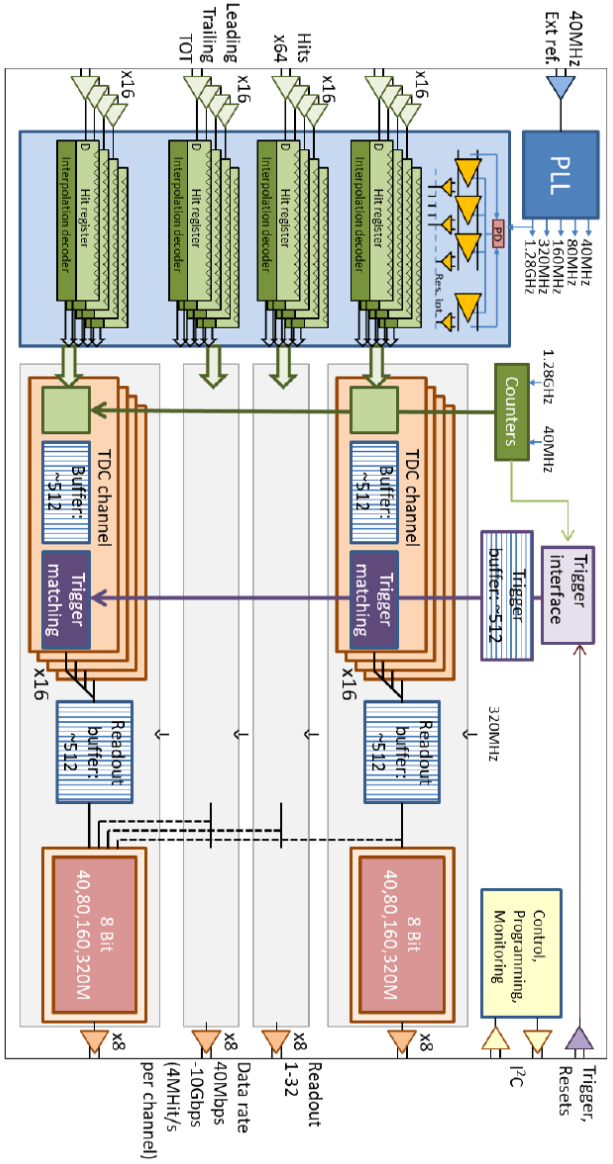
R/O Schematic - Abort

- picoTDC buffer deep enough to sustain data flow from 4 pads up to abort condition
- 4 pads considered sufficient
- Might need pre-processor to service BIS



picoTDC

- Timing chip in 65 nm by CERN-ESE
- Use 1 picoTDC per 4/8 FE channels
  - Generates 32 bits info per FE hit
- 3 out of 4 ports can be interfaced to lpGBT
  - User BW for 5G output: 24x160 = 3.84 G
  - 120 Mhits/s, pre-select pads to be read out in case of buffer overflow



lpGBT/VTRx

- Use 24 inputs at 160 M
  - 3.84 G user data in 5.12 G up-link
- Down-link at 2.56 G should provide clean clock to preserve timing
- Fall-forward: 10 G up-link