DIAMOND BEAM MONITOR AND LUMINOSITY MEASUREMENTS

Seminar
Experimental Particle Physics Department
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OVERVIEW

- motivation
- luminosity reminder
- about DBM
- luminosity with DBM
- chalenges in upcoming DAQ develepment
- dedicated data acquisition
- conclusion

ANOTHER LUMI MONITOR

	η coverage	segmentation	per bunch	bkg. monitoring	speed
DBM	$3.2<\eta<3.5$	24x26880	✓	✓	★★
BCM	$\eta=4.2$	2x4	✓	✓	★★★
LAr	$2.5<\eta<4.9$	35632	✗	✗	★
LUCID	$5.6<\eta<6.0$	32	✓	✗	★★★
ZDC	$8.3<\eta$	12	✗	?	★
offline	vertex, phy. processes		✓	✓	

- previously uncovered η region with per bunch capability
- **higher segmentation** curtail for adaptability to different luminosity ranges
  - ability for large acceptance to gather enough statistics at low L
  - possible significant reduction of 'active area' to avoid saturation at high L
- long lasting (radiation hard)
- new approaches needed to push the precision even further (goal ~1% precision within luminosity block ~1min)

REMINDER ... PRINCIPLES OF MONITORING LUMINOSITY

- all previously mentioned ATLAS detectors offer luminosity *monitoring* - they need calibration
- monitoring can be done with two approaches:

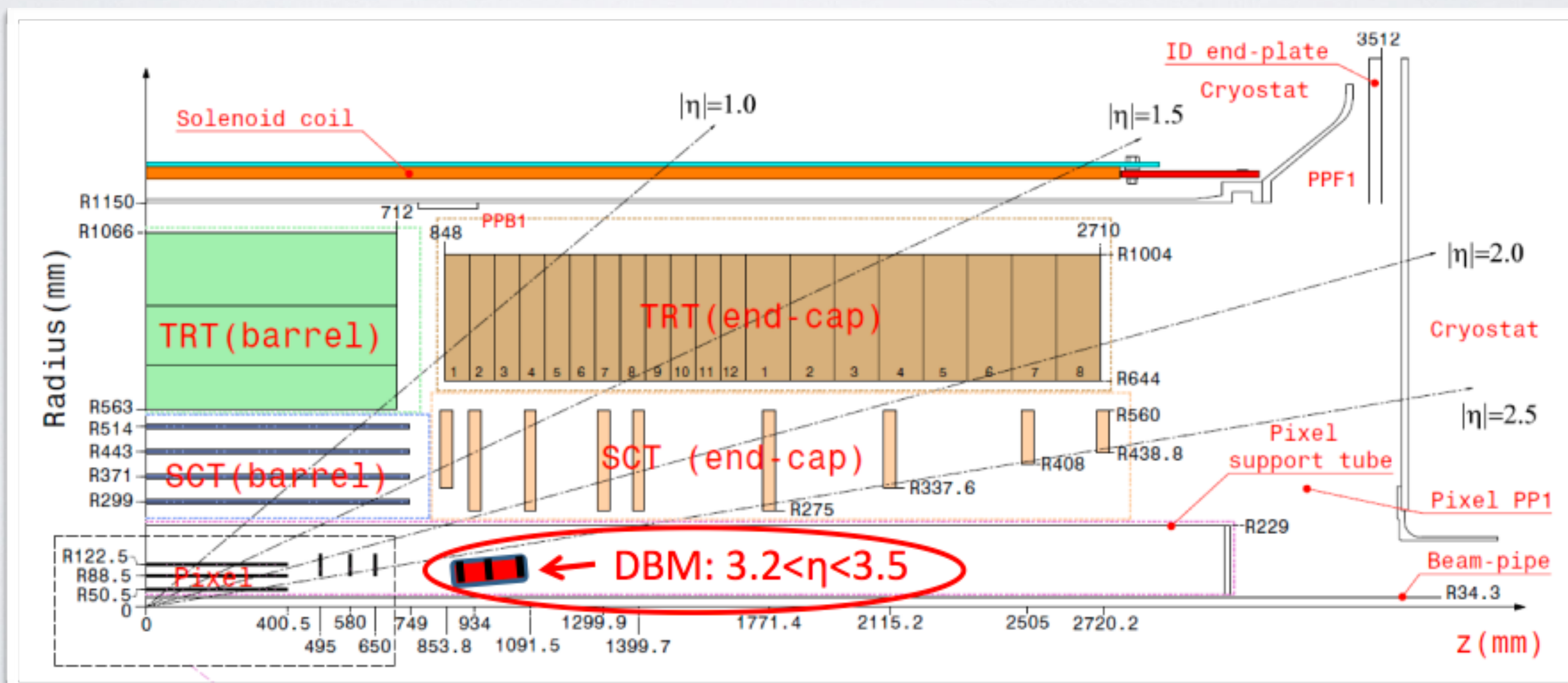
- **event counting**
  - event is defined as a single bunch-bunch collision
  - criteria is defined wether to accept (1) or reject (0) the event (simplest is 0-counting, where one counts number of collisions where nothing has been detected, many more algorithms could be defined)
  - one relies on Poisson statistics to relate average number of pp collisions $<\mu>$ (luminosity) to observed event rate
  - robust and easy for processing since data volume can be reduced early in the processing chain

- **particle counting**
  - one relies on linearity between luminosity and particle multiplicity
  - no distributions need to be assumed, but a much more detailed knowledge of the detector is needed since more details contribute to systematic uncertainty
  - data volume is significantly higher, which usually lowers the statistics
  - computationally much more challenging, especially if real-time measurement is desired

DBM should be both !

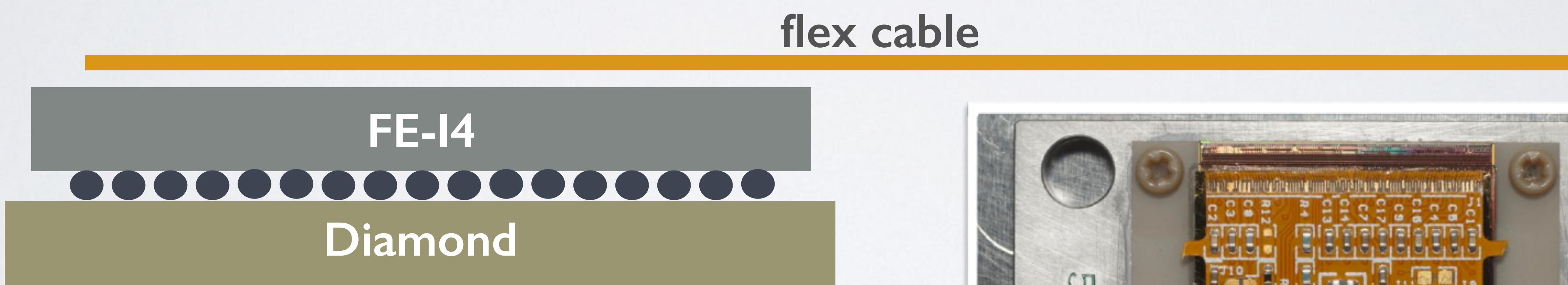
WHAT AND WHERE IS DBM

- first diamond based tracking device
- 8 telescopes 4 telescopes on each side of IP
    - 6 diamond and 2 silicon based telescopes
- each telescope contains three sensor planes (modules)
- placement out of IBL region to cover 3.2<η<3.5
- primary goal is luminosity measurement
- should provide also regular ATLAS stream data

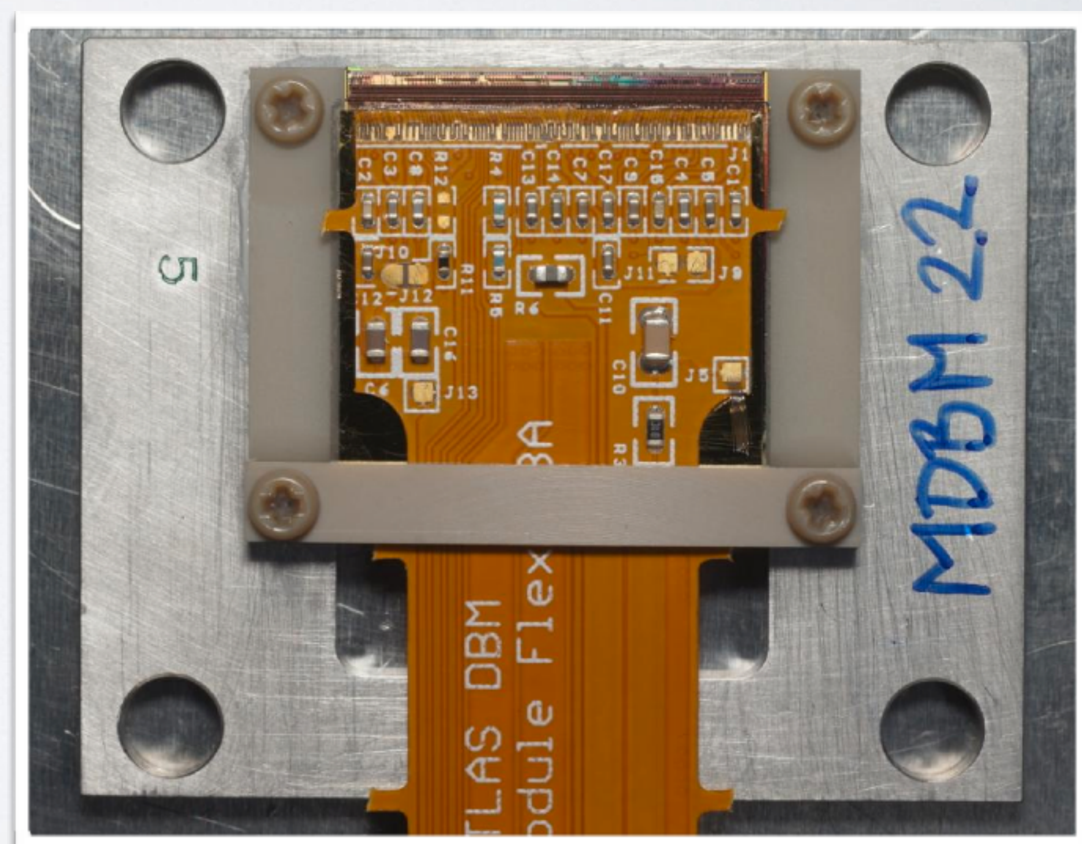


TRACKING PLANES

- polycrystalline diamond used as sensor material (500 μm thick)
    - metalized to 80x336 pixels in sizes 50x250 μm
    - this gives 20x16.8 mm2 of active area
    - layout compatible for digitisation with FE-I4, which is used for Insertable B-Layer of Pixels

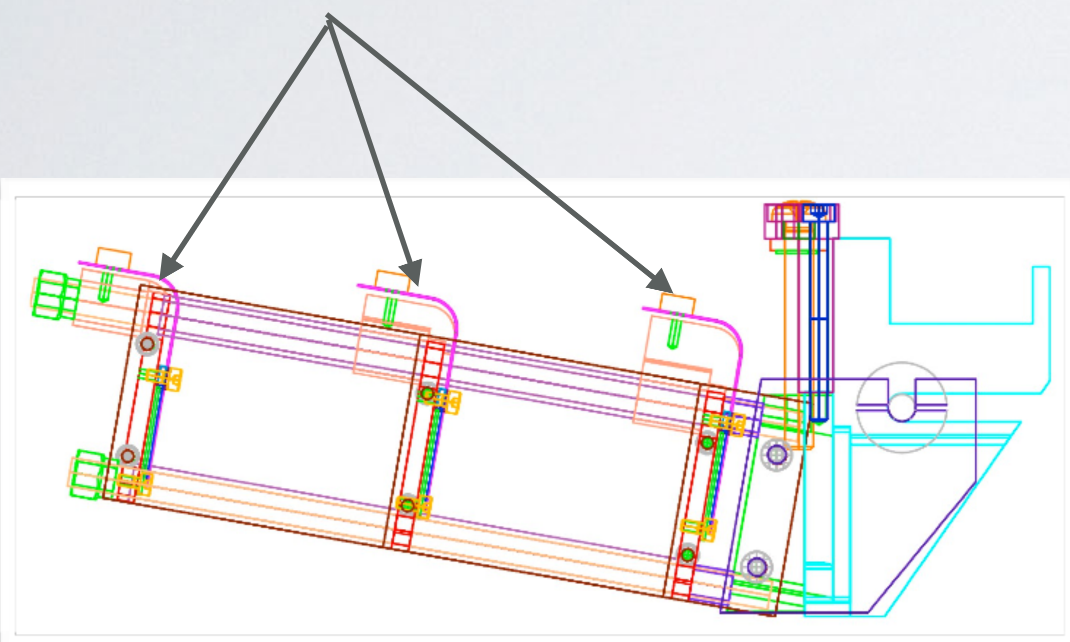


Property	Diamond	Silicon	Pro/Con
Band gap [eV]	5.5	1.12	Low leakage current
Electron mobility [cm²/Vs]	1900	1350	Fast signal
Dielectric constant - ε	5.7	11.9	Low capacitance
Displacement energy [eV/atom]	43	20	Radiation hardness
Aver. Signal Created / 100 μm [e_0]	3600	9000	Low signal



TELESCOPES

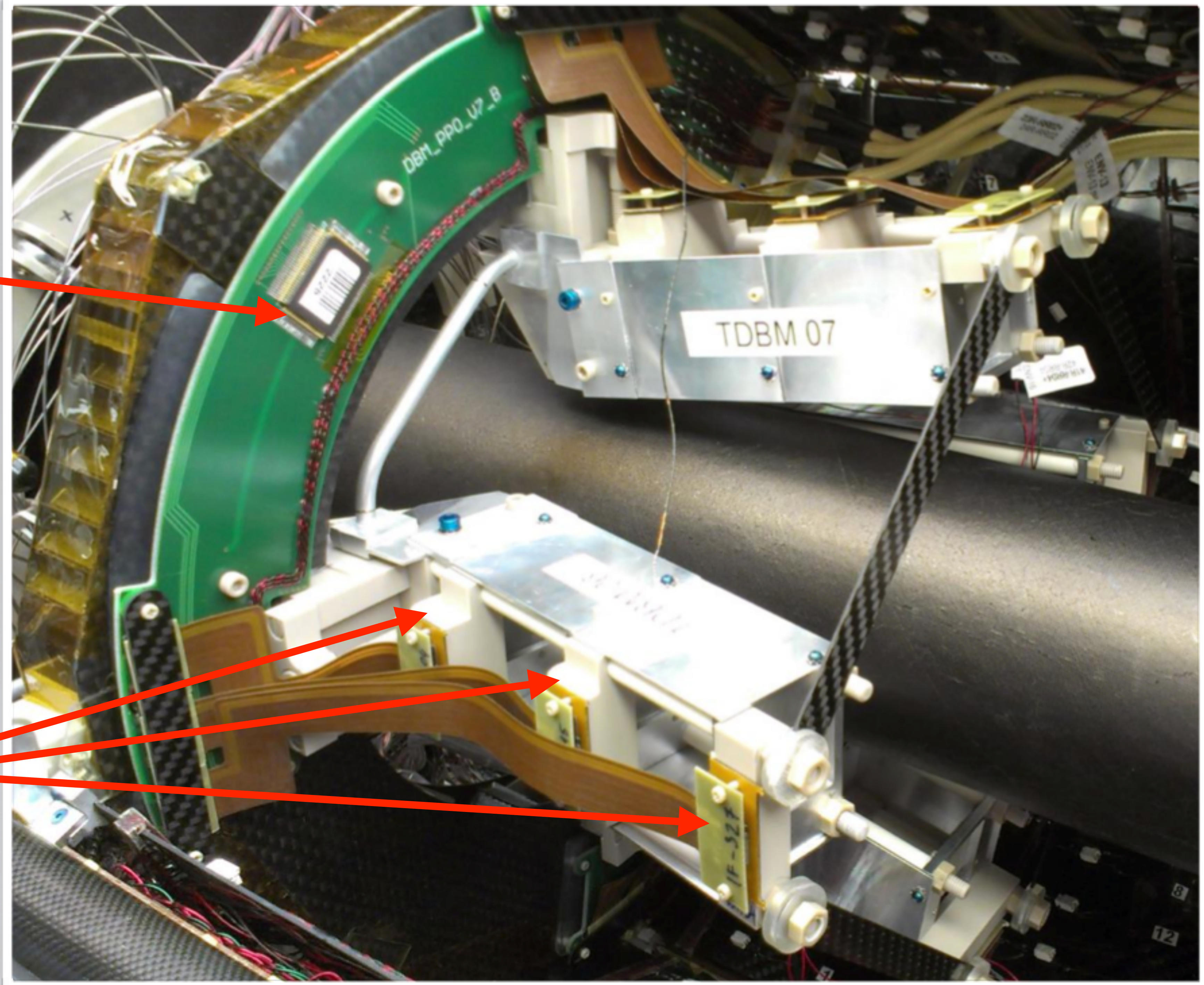
- 3 planes (modules) per telescope 5 cm apart



- 6 diamond based telescopes
- 2 silicon based telescopes

DETECTOR SIDE

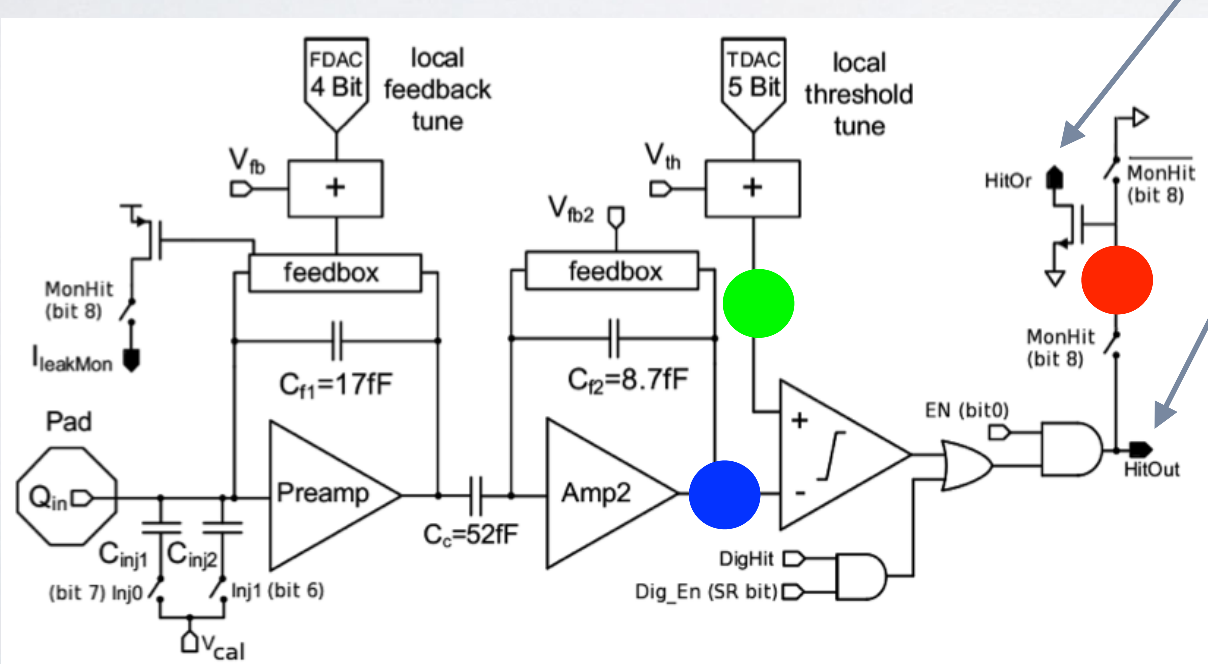
- 4 telescopes per station
- 2 telescopes grouped as a connection unit one Hitbus chip
- one such stations placed symmetrically on both sides of Interaction Point at ~z=90cm



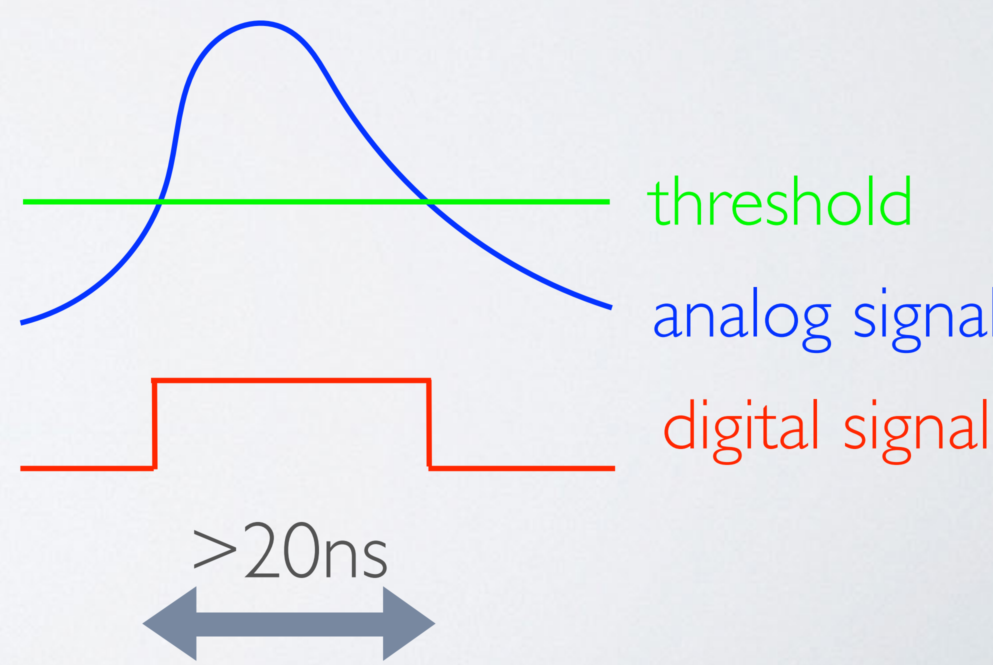
planes

FRONT-END ELECTRONICS

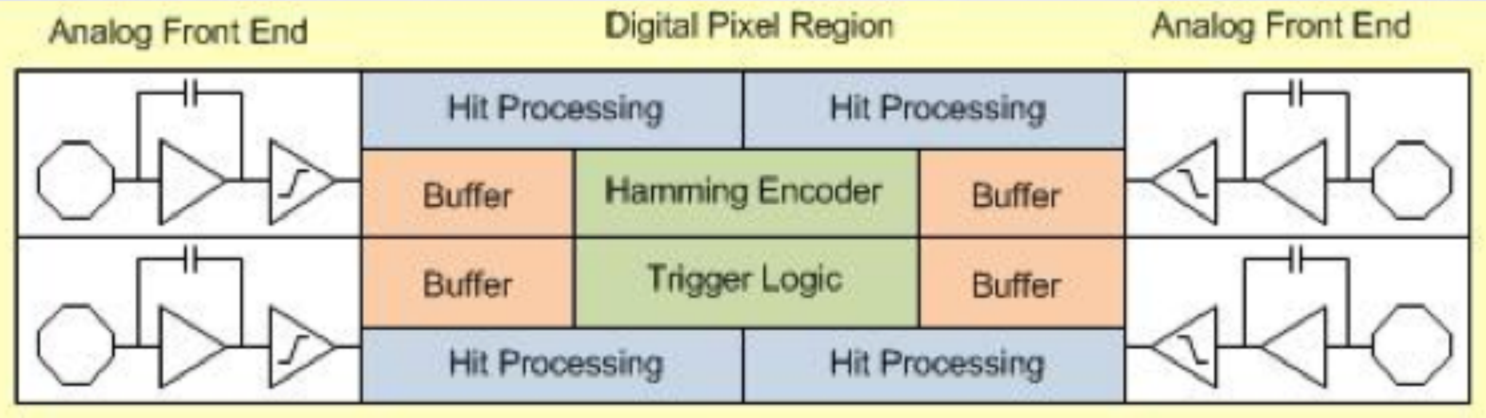
- same digitisation electronics as for IBL: FE-I4
- a lot of configurable parameters: some global some per-pixel
- extensive calibration needed, but can vary both threshold and charge scale
- contains both analog and digital circuity



- **analog circuitry:** pixels are completely independent and each has its own time-over-threshold circuit
- moral of the story is two outputs:
  - **HitOr** is common for all pixels in the chip (one output signal per chip), but contribution from each pixel can be masked
  - **HitOut** is used for final digitisation

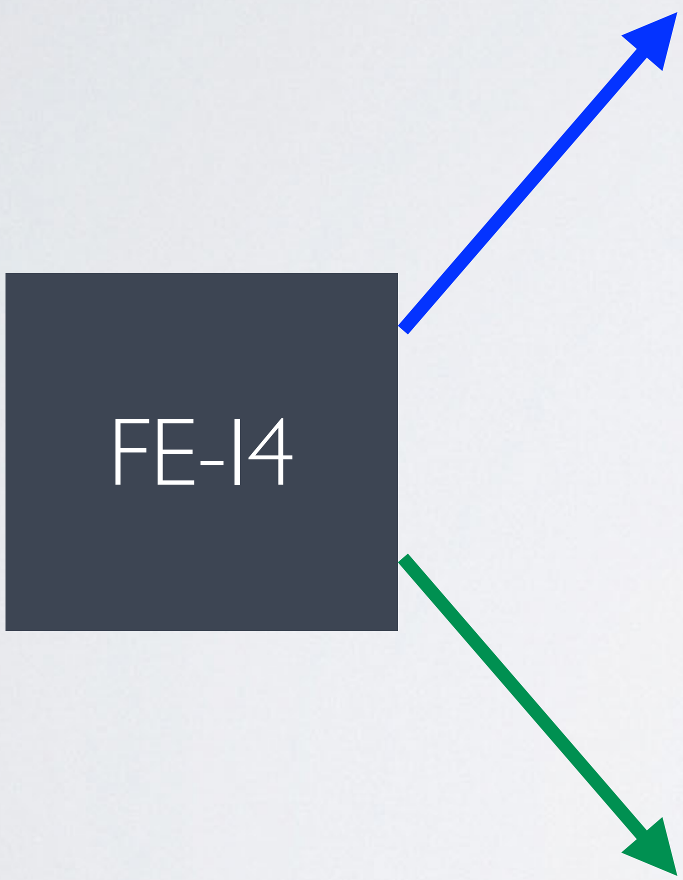


FRONT-END ELECTRONICS



- digital part is common to 4 neighbouring pixels
- configurable digital filter is used which rejects signals that are over the threshold for less than 1 or 2 x 25ns
    - this implies that HitOr signal will be a bit more noisy than trigger-based recorded data
- once one of the pixel signal is accepted (exceeds threshold for long enough) all four are digitised and stored
    - final result is ToT value for each pixel in 25ns units
- each such Digital Pixel Region has 5 memory cells, which hold data up to 256 clock cycles
- once the readout of the chip is triggered only non-empty 4-pixel-units are transferred into the data stream

FRONT-END LUMI-VIEW



T-stream (trigger-based stream)

- all available information bust be read out for each trigger which reduces the rate (un-useful for event counting methods)
- rate depends on occupancy (thus on luminosity)
- has detailed information: coordinate + ToT
- can do particle counting, even tracking
- will be used for *particle counting approach* to luminosity measurement

H-stream (HitOr-based stream)

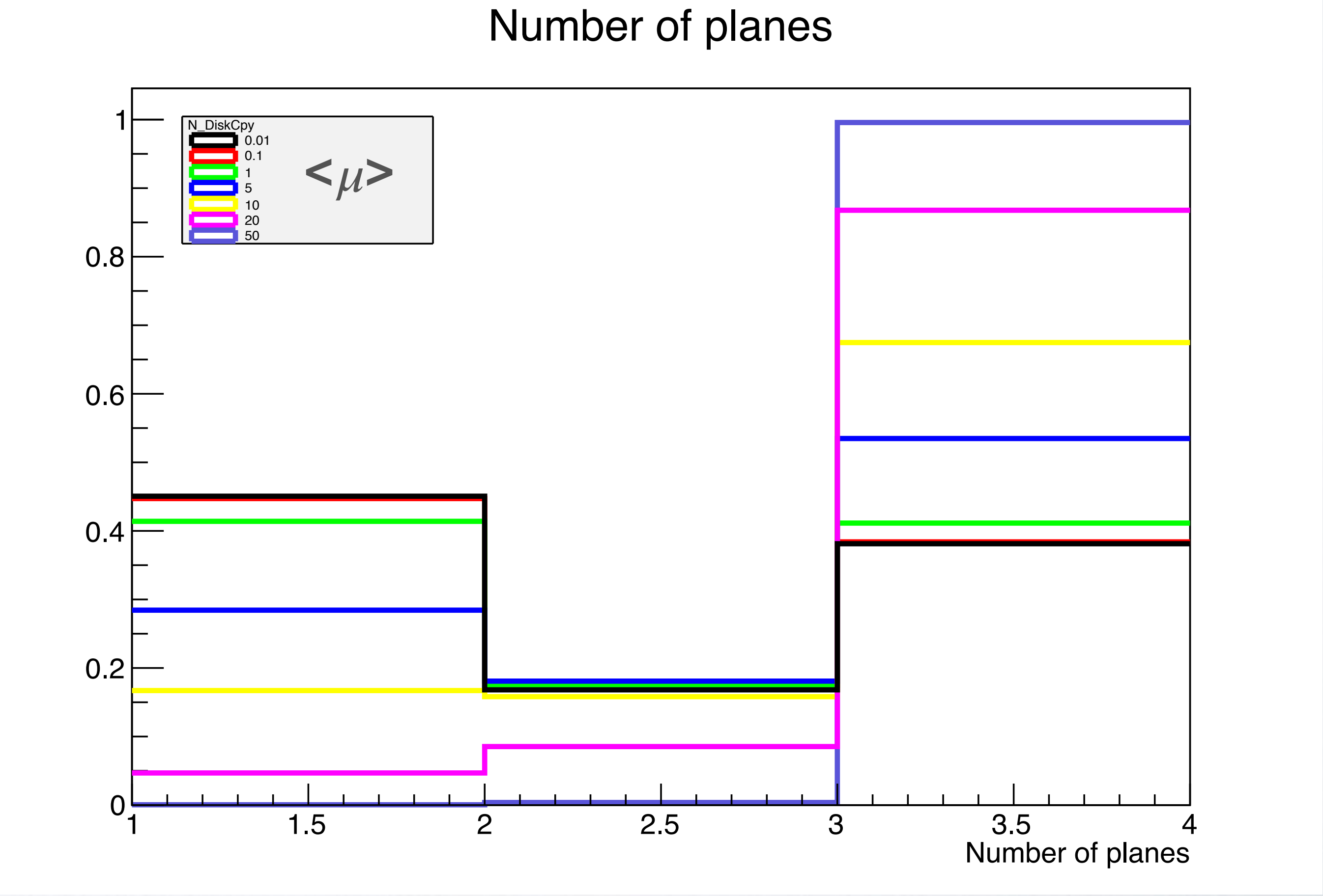
- single bit information per event '0' or '1'
- no intrinsic dead-time thus one can obtain larger statistics
- only useful as an *event counting approach* to luminosity monitoring
- contribution of individual pixels to HitOr can be included or excluded

ORIENTEERING WITH SIMULATION

- full ATLAS simulation up to hit-level used
- low pT minimum bias sample of 10^7 events :
    - mc14_13TeV.119995.Pythia8_A2MSTW2008LO_minbias_inelastic_low.merge.HITS.e3038_s2045_s2008

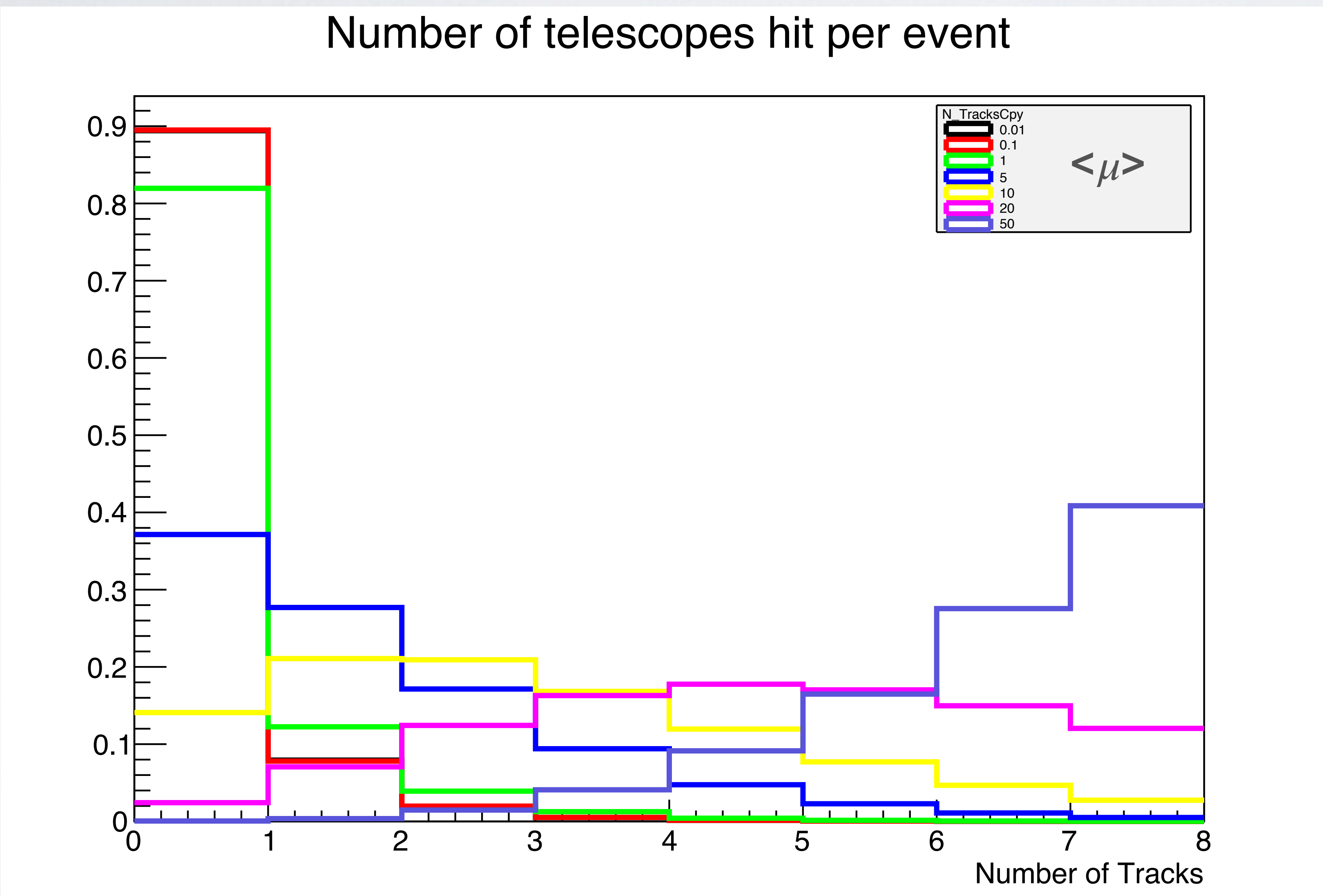
Probabilities

< μ >	Cpx (plane 0)	Cpx
0.01	0.001339	0.001979
0.1	0.013319	0.019621
1	0.125448	0.179737
5	0.488828	0.628801
10	0.738286	0.86176
20	0.931765	0.980778
50	0.998778	0.999925



T-STREAM POINT OF VIEW

- interested in number of tracks
- probability for event with given number of tracks in one telescope:

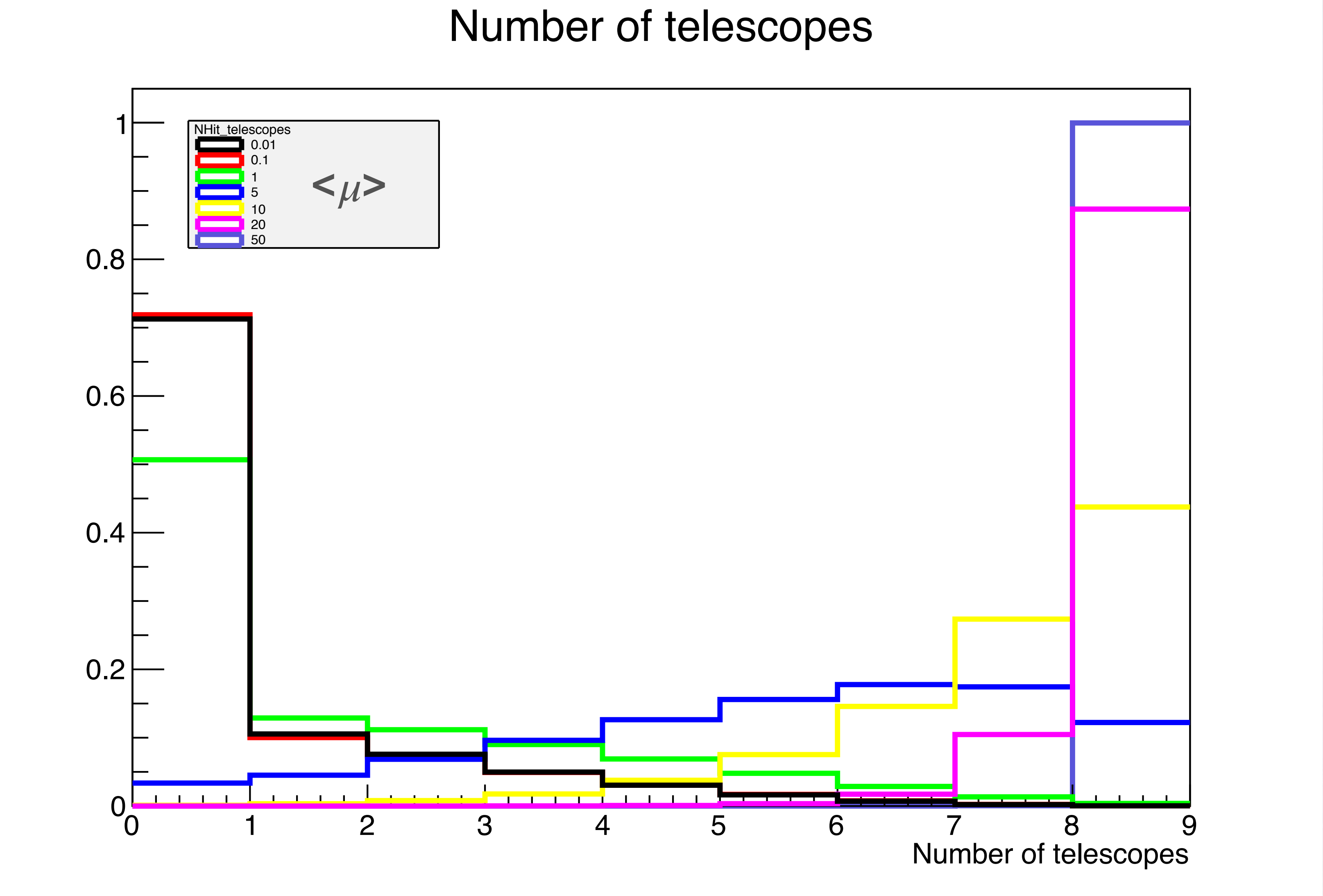


no apparent problems with this measurement approach

one could fit the distribution to get the number of pp collisions

H-STREAM POINT OF VIEW

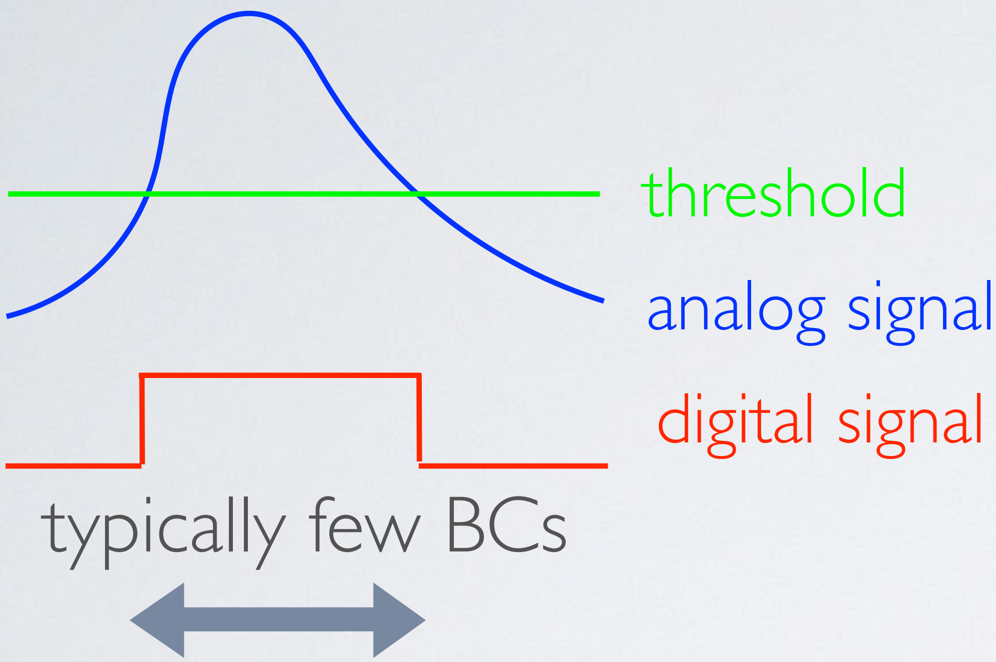
- interested in number of planes or telescopes hit (single HitOr signal provided)
- probability for event with given number of telescopes hit:

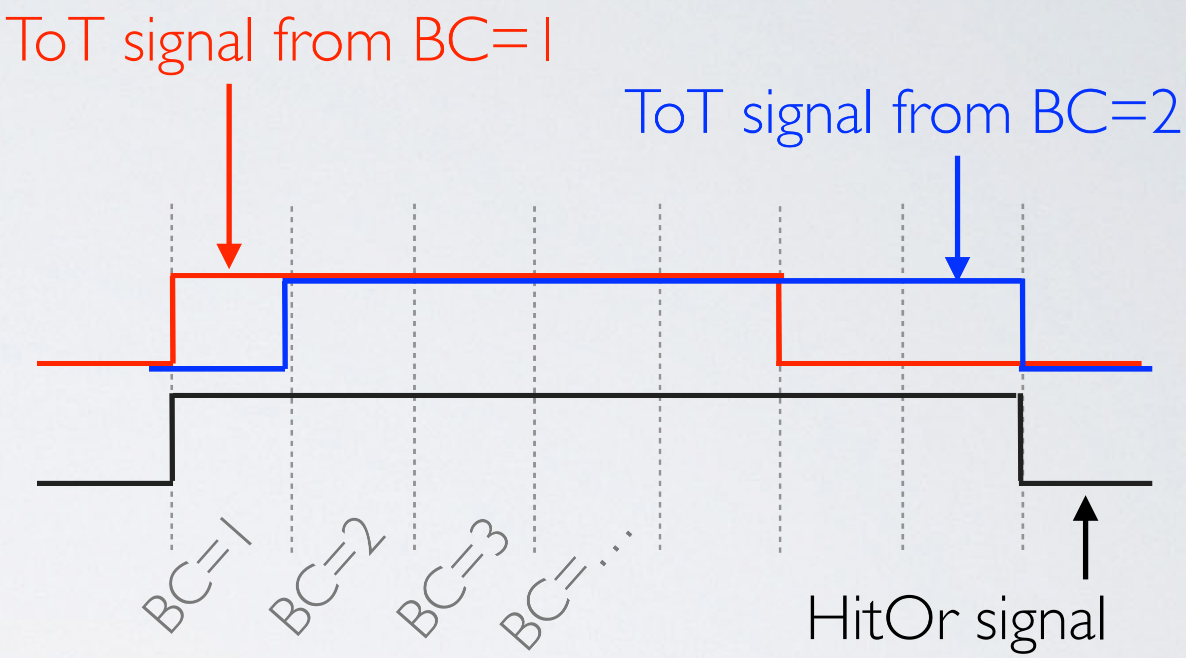


shows saturation at high luminosity

all telescopes hit, meaning that consecutive bunch collisions will result in HitOr='1'

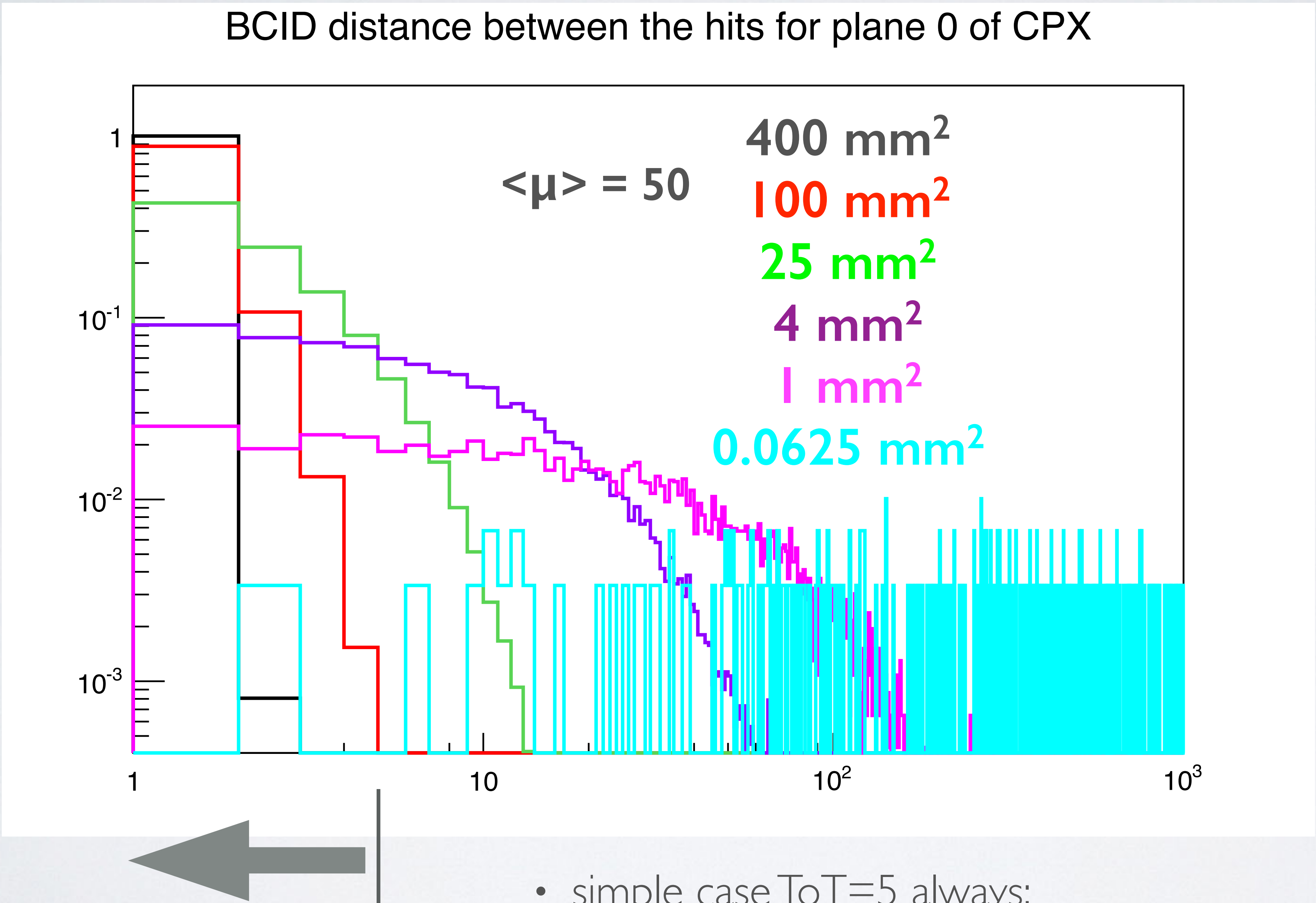
CHALLENGE/PROBLEM?





- due to long ToT signals (1-16-…) a digital pileup occurs
- would be a problem for 50ns bunch spacing (every second BC filled), and will be even more so with every bunch filled
- no problem at low luminosity, but eventually with increasing $<\mu>$ probability for pileup becomes larger than statistical error
- two direct handles possible:
    - different ToT calibration (same charge = shorter pulse)
    - reducing probability for HitOr signal by enabling smaller umber of pixels

H-STREAM MASK AREA



unseen because of pileup

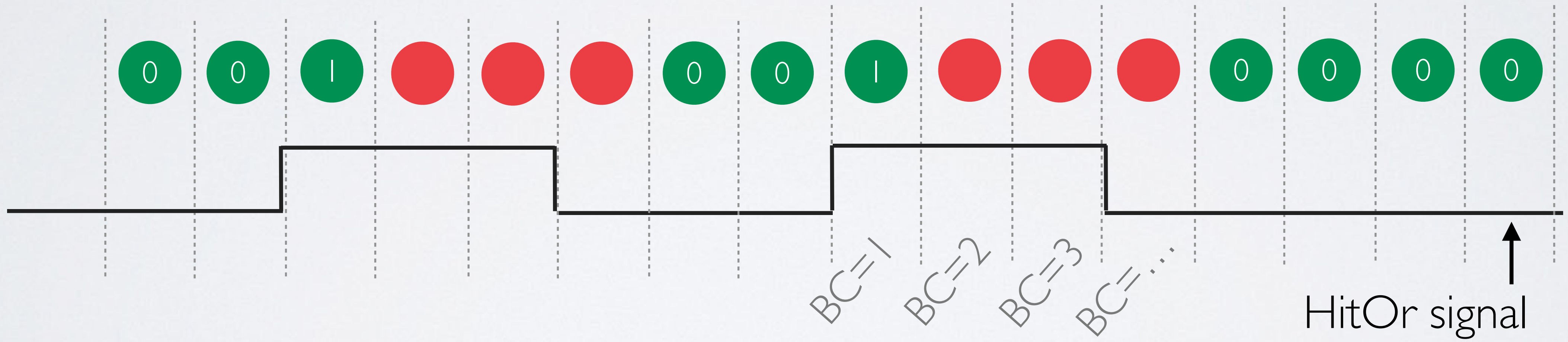
- simple case ToT=5 always:
    - if only 1=0,3% of area is active ~10% events are missed

PROPOSED SOLUTION

- active area not only reduces also the statistics - sub-optimal
- what needs to be measured is event rate:

(number of events that HitOr=1)/(number of times we looked at BC)

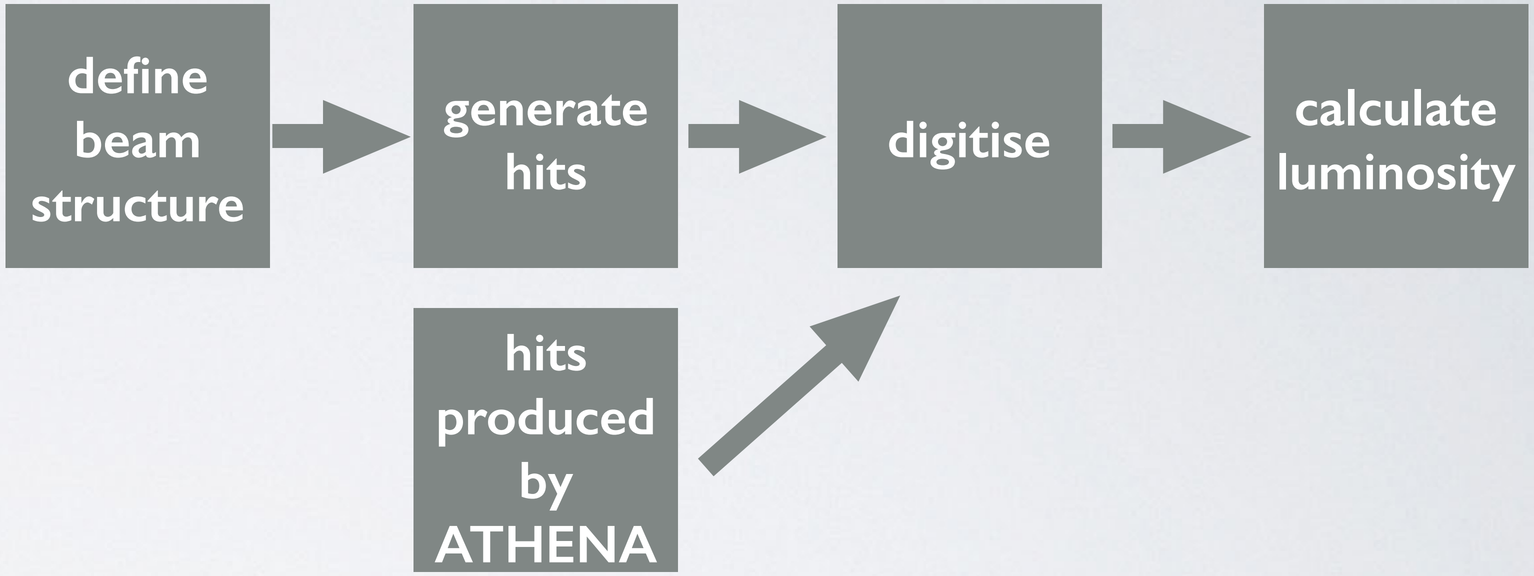
- since only rising edges carry information, once can take 'high' and 'falling edge' out of the sample



- with the same active area a larger statistics can be obtained
- brings the need for an extra counter for each BCID, thus doubling the data

TESTING THE THEORY

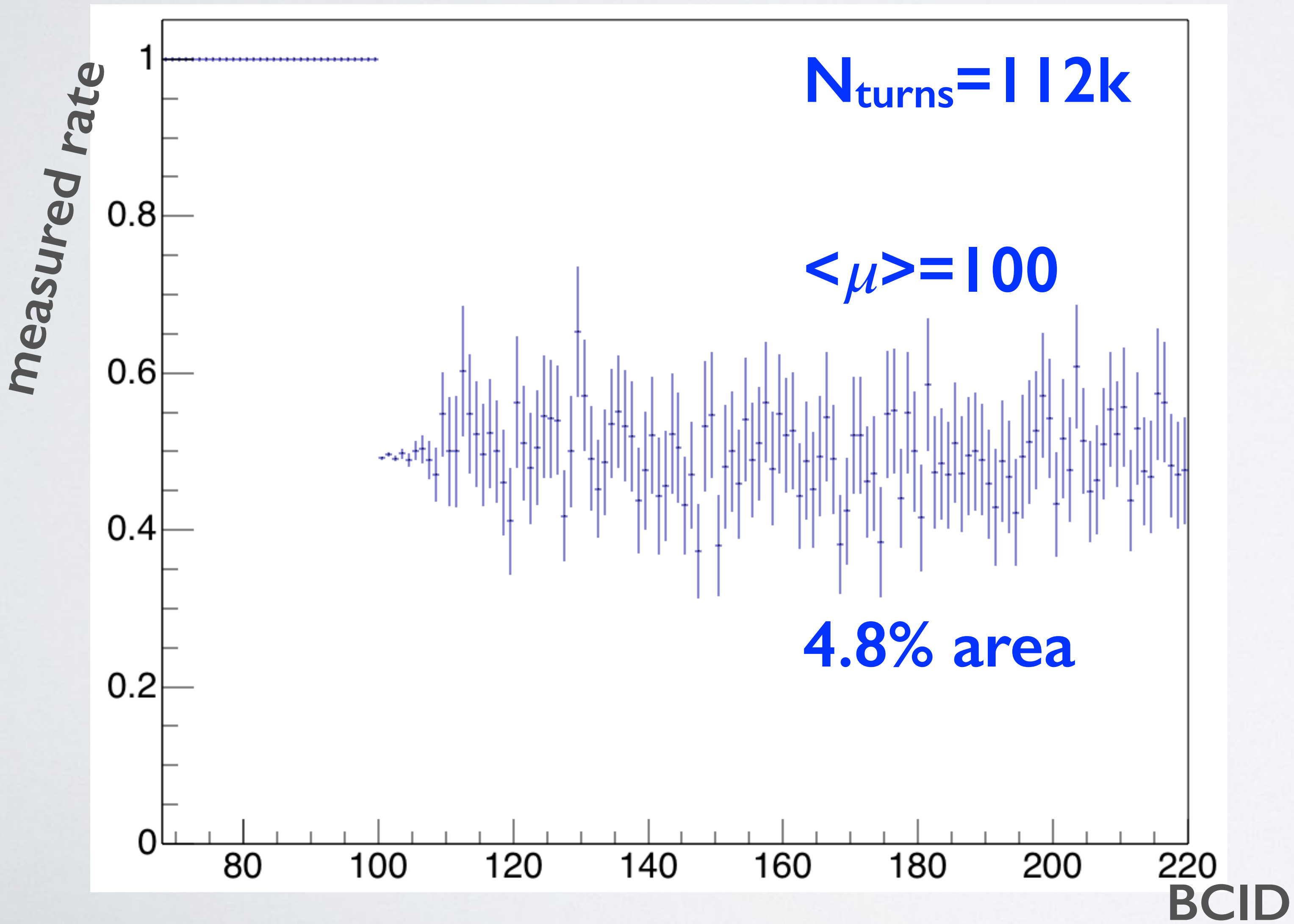
- in order to test the proposal a simple simulation framework has been written
  - no digitisation of HitOr within ATHENA!
  - faster simulation



- due to limited number of available samples hits were generated with a local Monte-Carlo engine, giving the same distribution as resulted from ATHENA simulation
- deliberately simplifying a system:
  - each hit generates a signal of 9000e (no Landau)
  - all tracks are perpendicular (no charge sharing)
- all these simplifications can be removed

SIMULATED RATE

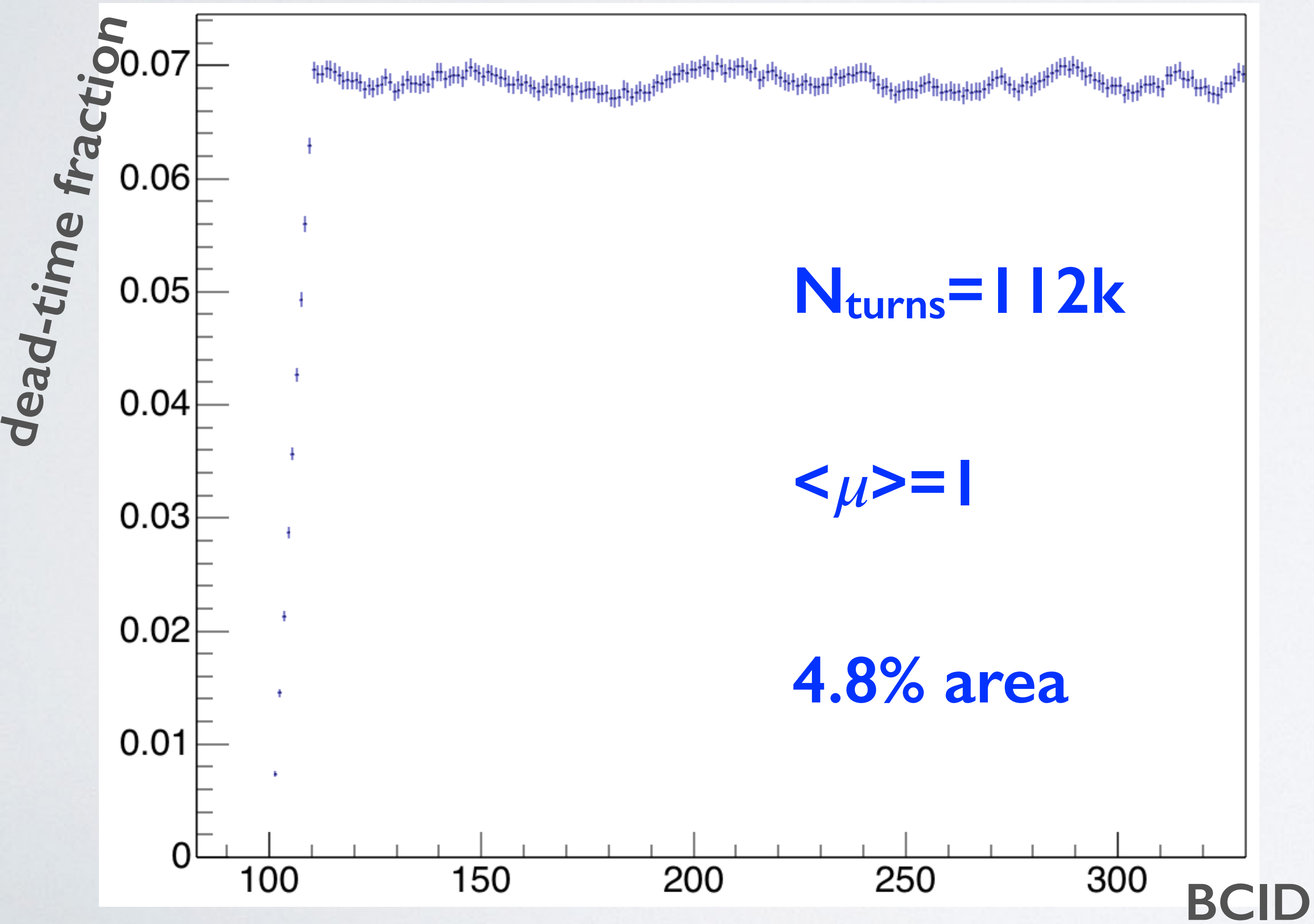
- rate of observed events for 0-counting (empty events fraction)
- statistical error significantly better for start of the bunch train



- extreme case
- masking of pixels provides means to make DBM saturation free also for highest luminosity
- biggest challenge will be to make detector fast + precise due to statistical error

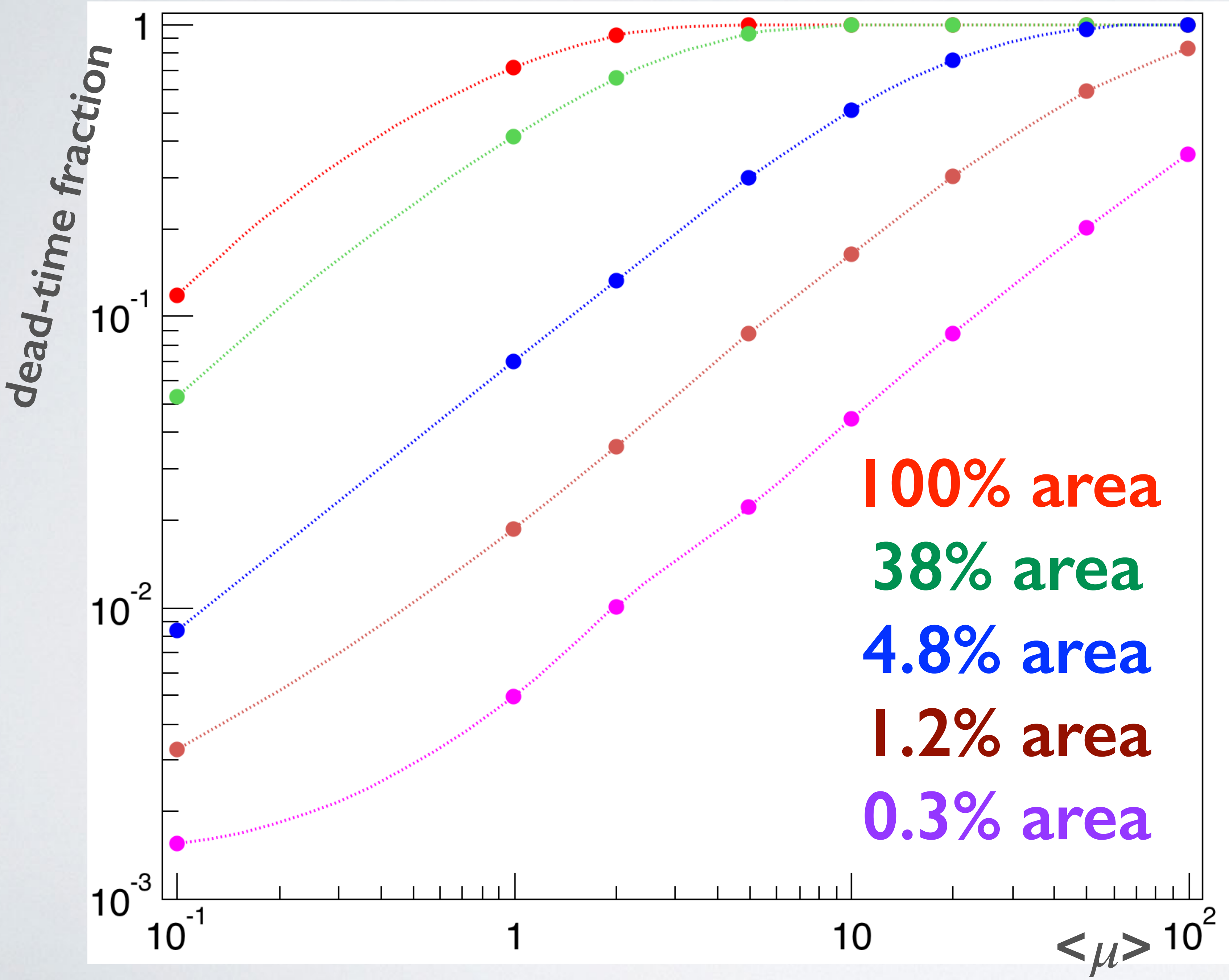
SIMULATED DEAD-TIME

- dead time defined as fraction of time where HitOr is constant and equals '1'
- rise time on beginning of bunch train depends on ToT calibration



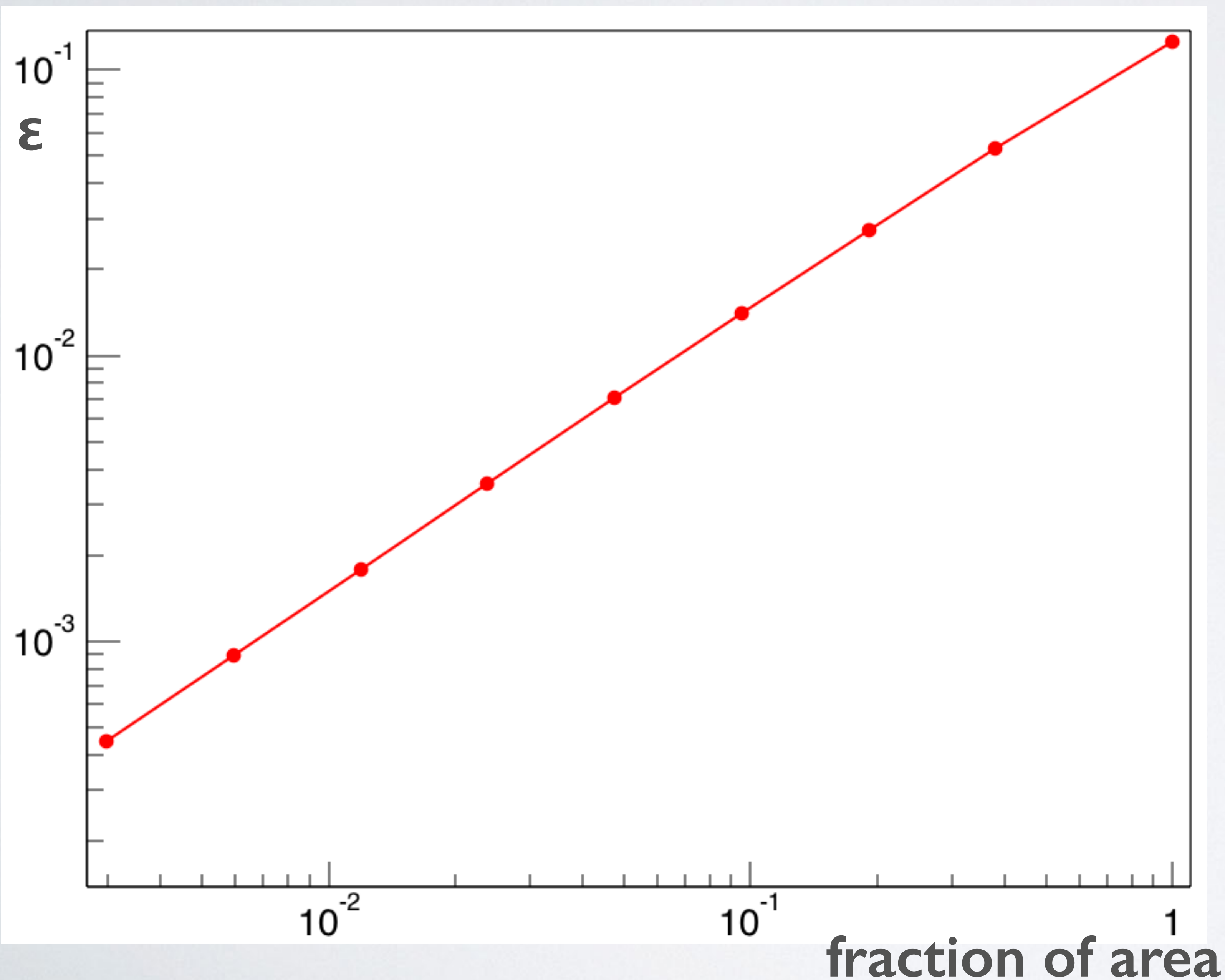
- statistical significant fluctuation of dead-time
- pattern more pronounced when we near saturation region
- will reduce in real life, because Landau charge distribution has not been taken into account

DEAD-TIME FRACTION



- statistics reduction can be a problem for DBM
- we might need to adapt mask according to expected luminosity
    - not a robust system
    - unfortunately a quick set of a mask within a feedback loop might not be doable + it costs time

EFFICIENCY



- efficiency for HitOr is a function of active area
- determined for 0-counting algorithm:

$$r = e^{-\langle\mu\rangle\,\varepsilon}$$

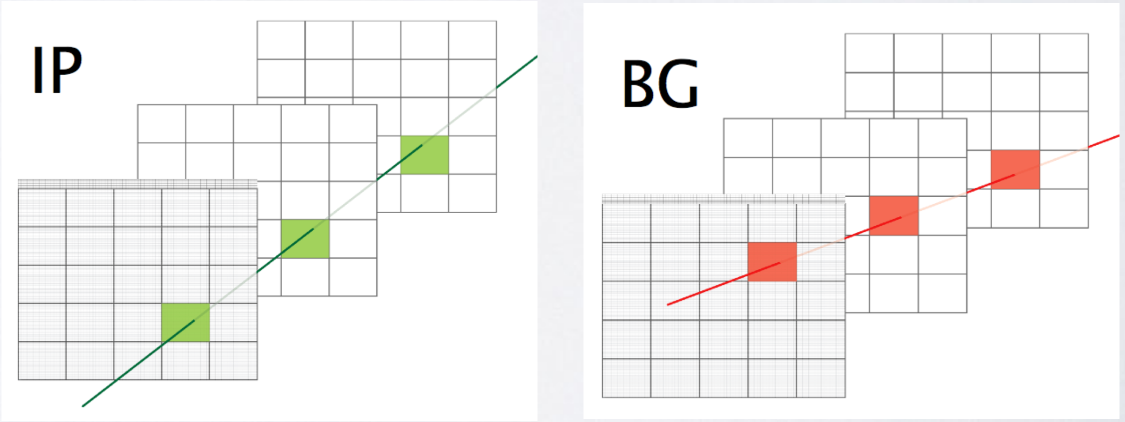
- with simulated rate and knowledge about true $\langle\mu\rangle$ one can determine **ε**
- this can be used as first estimation of calibration

FINAL THOUGHTS ON H-STREAM

- a robust approach that offers a low systematical uncertainty
- relatively flexible and adaptable to different <μ> regimes
- area can be optimised to certain <μ> to optimise the statistical uncertainty

$$\frac{1}{\sqrt{N}} = \frac{1}{\sqrt{N\_stat\ r}} = \frac{1}{\sqrt{N\_orbits\ (1 - d[area, \mu])\ e^{-\mu\, \epsilon}}}$$

- one can in principle offer 24 such measurements in parallel (number of FE-I4s)
- could do even more complicated things (combinatorics)
- initial proposal is to go with simple single FE4I output
- data volume: 3564 * (2bytes) * (2counters for BCID)



- for 5 Hz publications: for one measurement: 70kB/s (1.6 MB/s for all 24) really low volume needed

T-STREAM

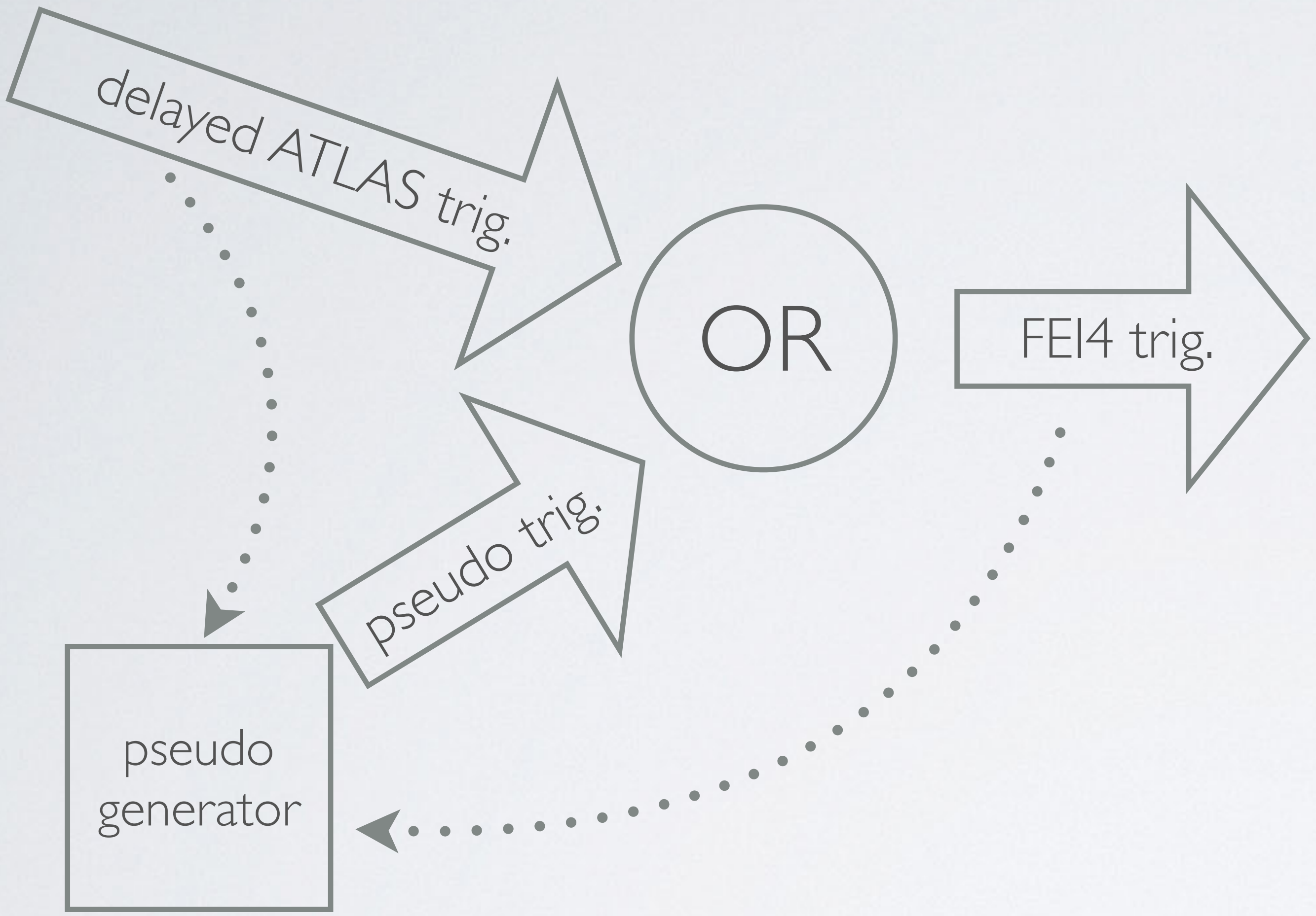
- DBM should normally record all ATLAS triggered events and be fully integrated in the TDAQ
- expected max 100kHz triggers from ATLAS
- FE-I4 permits more: specs = 200kHz
    - no hard limit on triggers, only limit is bandwidth (160 Mb/s)
    - thus actual readout rate depends on occupancy (luminosity)
- this extra bandwidth could be used to readout events using extra triggers

pseudo-triggers

- challenge is to make this pseudo-triggers non-biased
- truly random sampling over all BCIDs, while still accounting for regular ATLAS triggers
    - simple dead time: two triggers can not be closer than 6 BCIDs (6x25ns)
    - no more than 16 triggers can be in queue at any given time

Item	Value	Units
Pixel size	50×250	μm^2
Bump pad opening diameter	12	μm
Input	DC-coupled -ve polarity	
Maximum charge	100,000	e^-
DC leakage current tolerance	100	nA
Pixel array size	80×336	Col × Row
Last bump to physical chip edge on 3 sides	≤ 100	μm
Last bump to physical edge on bottom	≤ 2.0	mm
Normal pixel input capacitance range	100-500	fF
Edge pixels input capacitance range	150-700	fF
In-time threshold with 20 ns gate (400 pF)[1]	≤ 4000	e^-
Hit-trigger association resolution	25	ns
Same pixel two-hit discrimination (time)	400	ns
Single channel ENC sigma (400 fF)	< 300	e^-
Tuned threshold dispersion	< 100	e^-
Charge resolution	4	bits
ADC method	ToT	
Radiation tolerance (specs met at this dose)	300	Mrad
Operating temperature range	-40 to $+60$	°C
Average hit rate with < 1% data loss	400	MHz/cm²
Readout initiation	Trigger command	
Max. number of consecutive triggers	16	
Trigger latency (max)	6.4	μs
Maximum sustained trigger rate	200	kHz
External clock input (nominal)[2]	40	MHz
Single serial command input (nominal)[2]	40	Mb/s
Single serial data output (nominal)[2]	160	Mb/s

IMPLEMENTATION IDEA



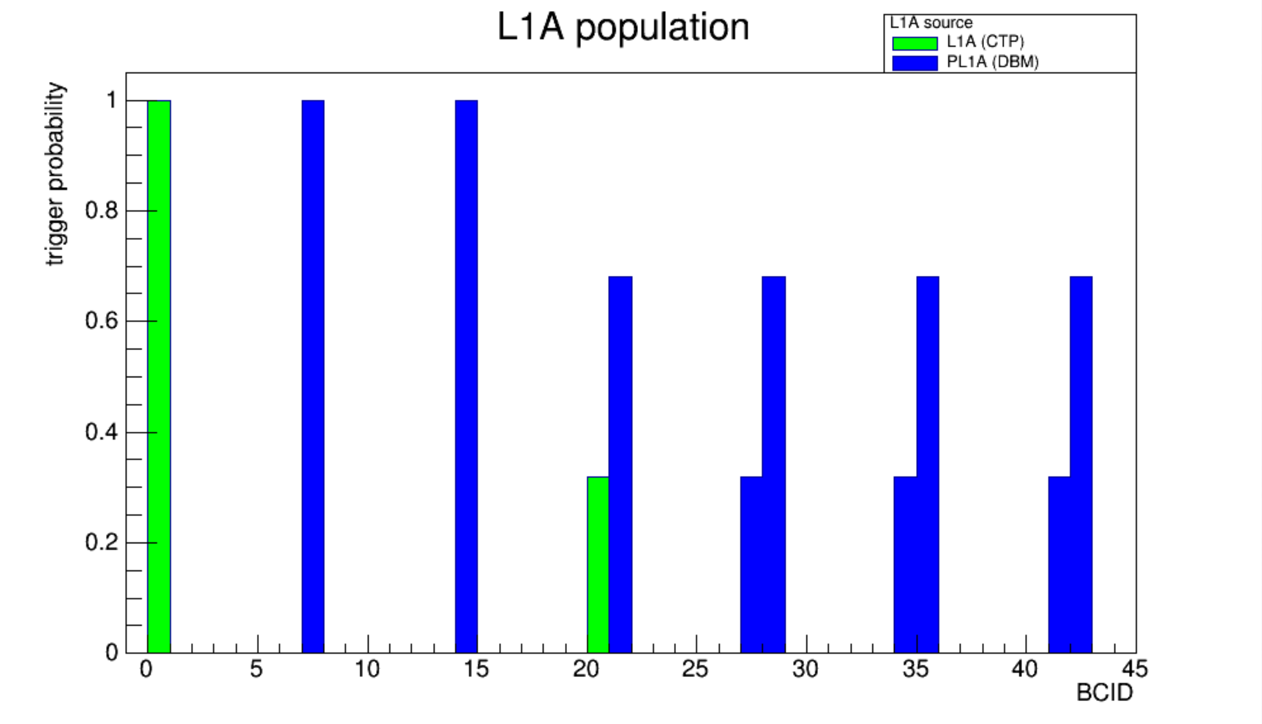
- biggest challenge is to avoid collision between ATLAS trigger and pseudo triggers
- simple & complex dead-time require that you look ahead in time if ATLAS trigger will arrive
- this dictates that extra latency will have to be introduced into the system
  - limit is the FEI4 timing which limits trigger latency of 256 clock cycles

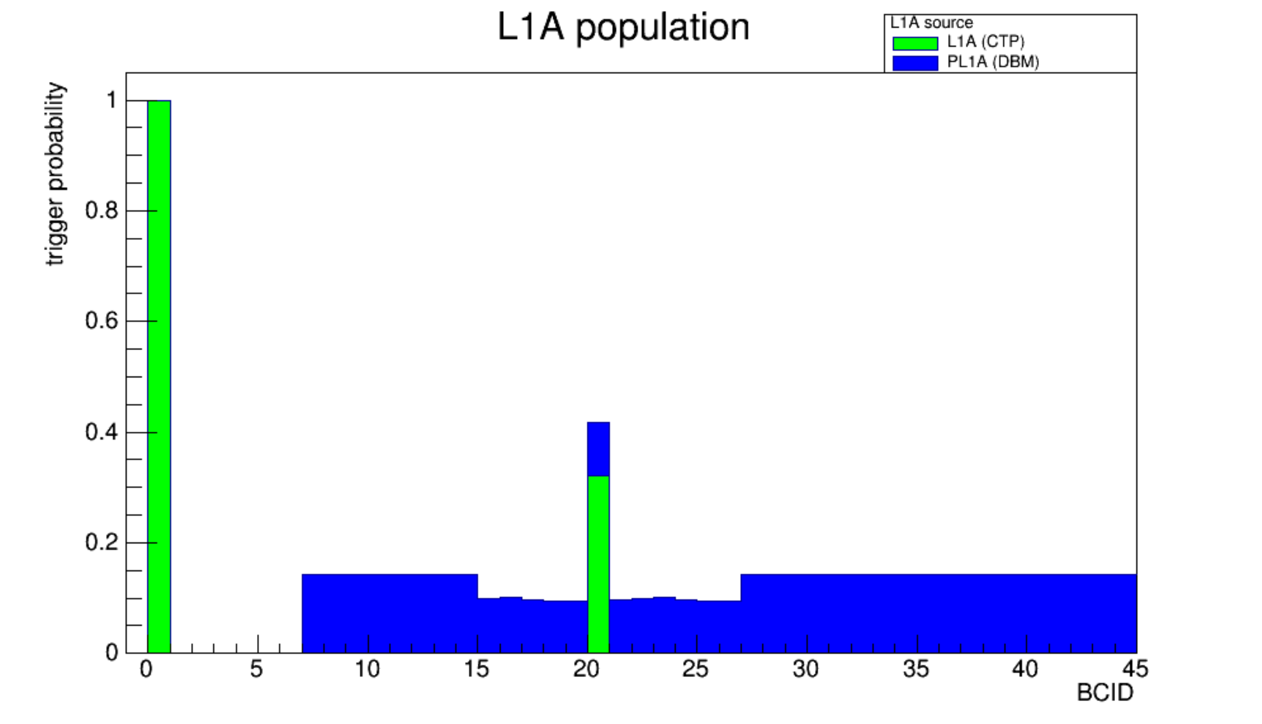
- no deterministic way to implement this since ATLAS triggers must be considered random
- different bunches will be read out different number of times - extra statistics will be needed to record these triggers for each bunch

EXAMPLE GENERATORS

- issuing pseudo-trigger as soon as simple dead-time allows
- blind spots could occur

- generating pseudo-triggers independently of ATLAS triggers:
  - 1. orbit: BCIDs 0, 20, 40, 60, …
  - 2. orbit: BCIDs 1,21,41,61,….
- not optimal in terms of statistics

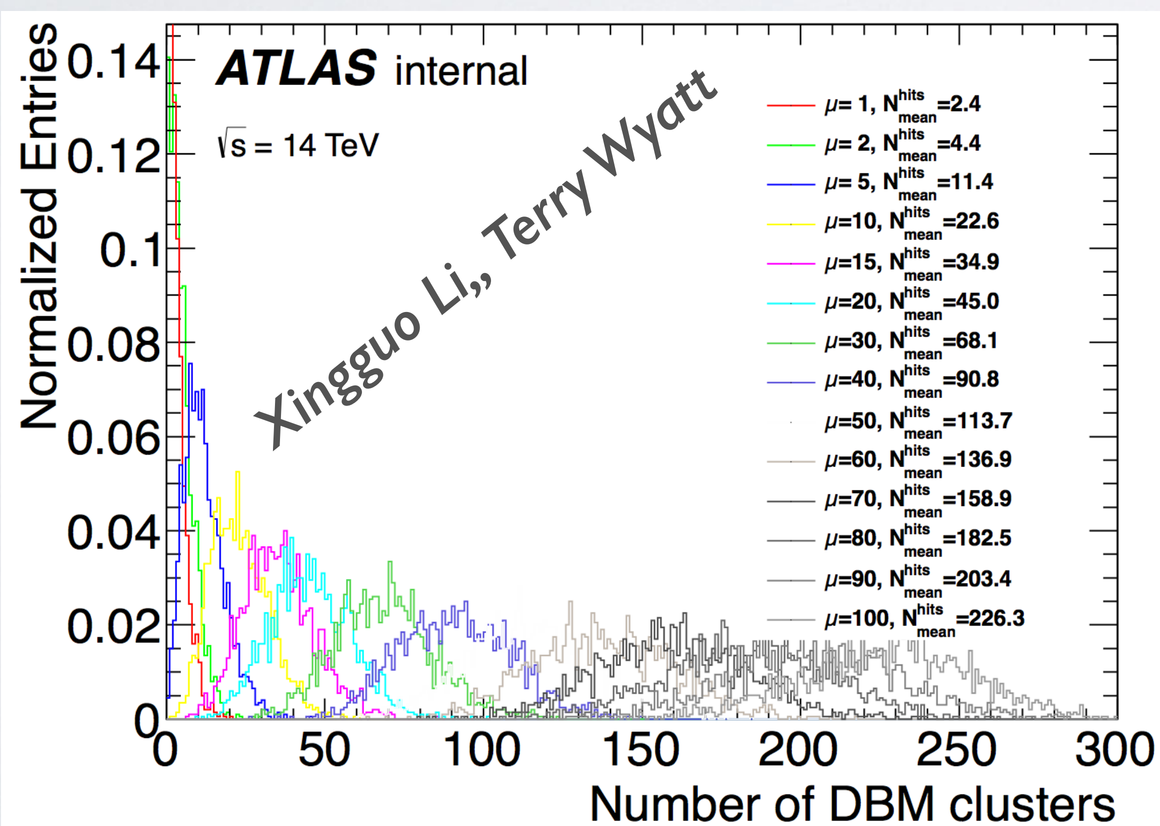


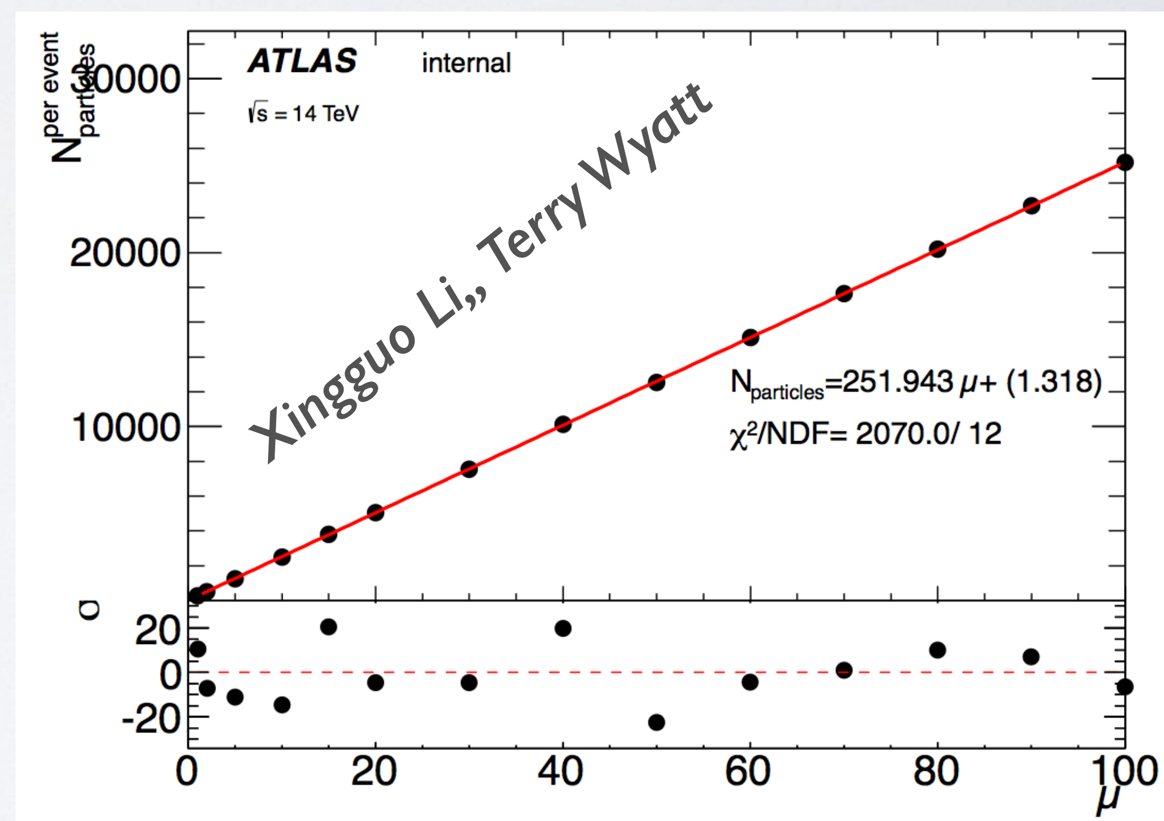


- more sophisticated could be envisaged, where least triggered BCID from a sliding window is selected

WHAT TO DO WITH T-STREAM DATA

- data contains pixel hit coordinates and ToT values
- one can do pixel cluster counting (Xingguo Li, Terry Wyatt)
    - simulation was done on 2000 events of full ATLAS simulation with FEI4 digitisation



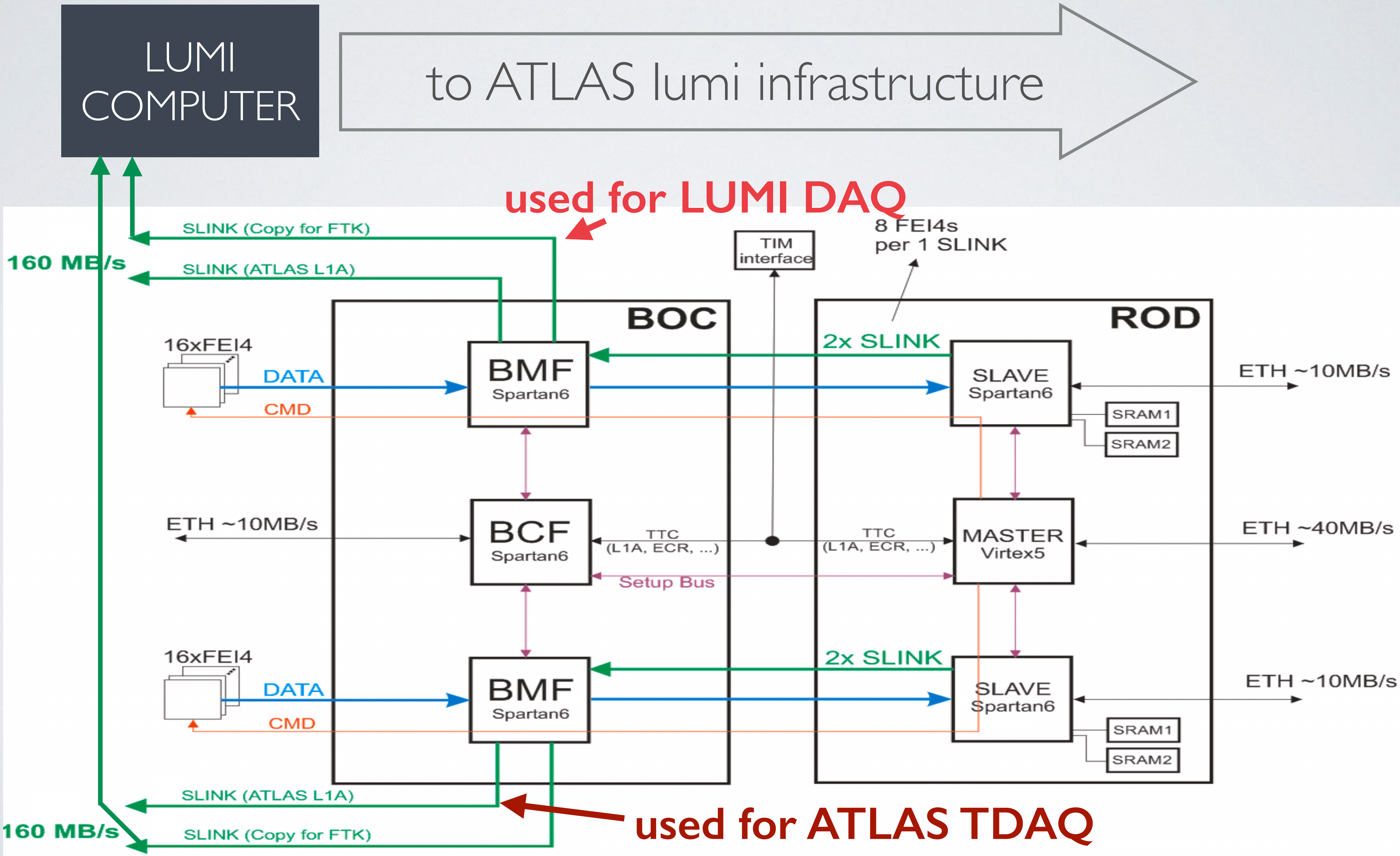


- another possibility is track counting (Miriam Deborah Joy Diamond)

FINAL THOUGHTS ON T-STREAM

- this data will need more sophisticated algorithms
  - much more CPU will be needed to digest is
  - larger systematics
- estimation:
  - max. data from FE: 160Mb/s*24=480MB/s
  - data channel to PC: 320MB/s
- the limiting factor will be the computational power on PC side (CPU and MEM)
  - could play a game of online pixel filtering to reduce the effective area
  - similar challenges/tradeoffs can be expected
  - indicating the need for data back-pressure switch in DAQ

LUMI DATA TRANSFER



BOC <> LUMI-PC CONNECTION

- 2 S-link connections available on BOC, one accessible from each FPGA
- Tilar PCIe card to be tested as receiver within lumi-computer:
    - 2 ports, fully compatible with CERN S-LINK interface standard
    - both ports operate independently at 160MBytes/s
    - essential: PCIe bandwidth more than factor 2 greater than combine input bandwidth
    - thus places no restrictions on data acquisition, thus the limiting factor will be the CPU power
    - nice features like:
        - direct write to host memory, without intermediate memory
        - Interrupt generation selectable on reception of one or several data blocks
        - drivers for SLC and base libraries maintained by ATLAS
- material for development in hand

LUMI-COMPUTER

- expected to process all received the data
- with any complex processing like tracking the CPU and memory might become the limiting factor of the system
- the number of the cores should reflect the number of independent lumi measurements
- desired output of the system:
  - IS publications
  - local debugging stream?
  - should leave some manoeuvre space for potential future outputs

SUMMARY

- DBM as a additional luminosity monitor
- it will be able to monitor wide range of luminosities and is not expected to saturate during LHC lifetime
- good understanding of limitations imposed by hardware
- simulation available to study the systematics
- special luminosity data acquisition is yet to be done
  - requirement and limitations are now well defined
- all the required material is at hand … should not be long before we see data