DIAMOND BEAM MONITOR AND LUMINOSITY MEASUREMENTS

October 2018

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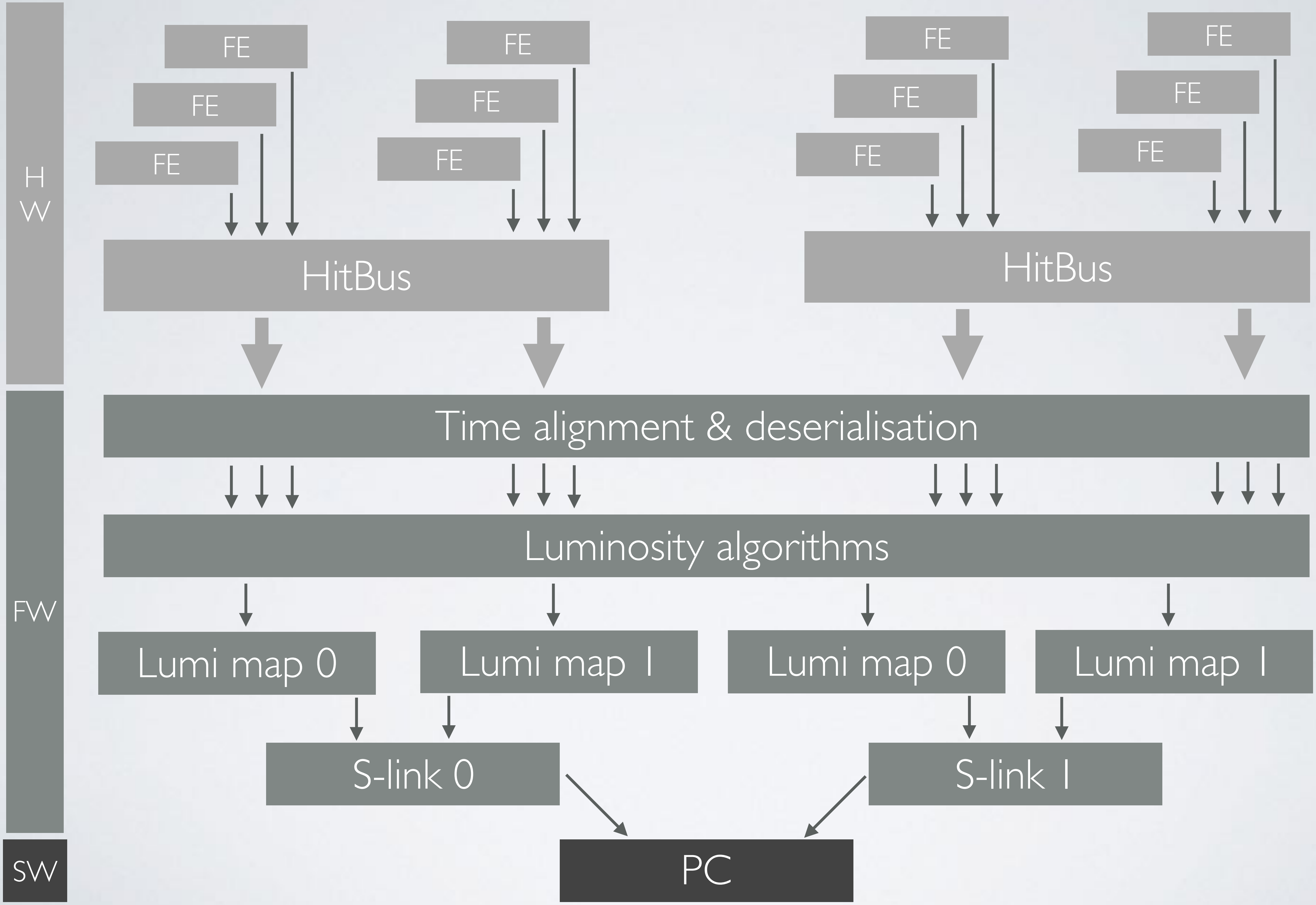
OVERVIEW

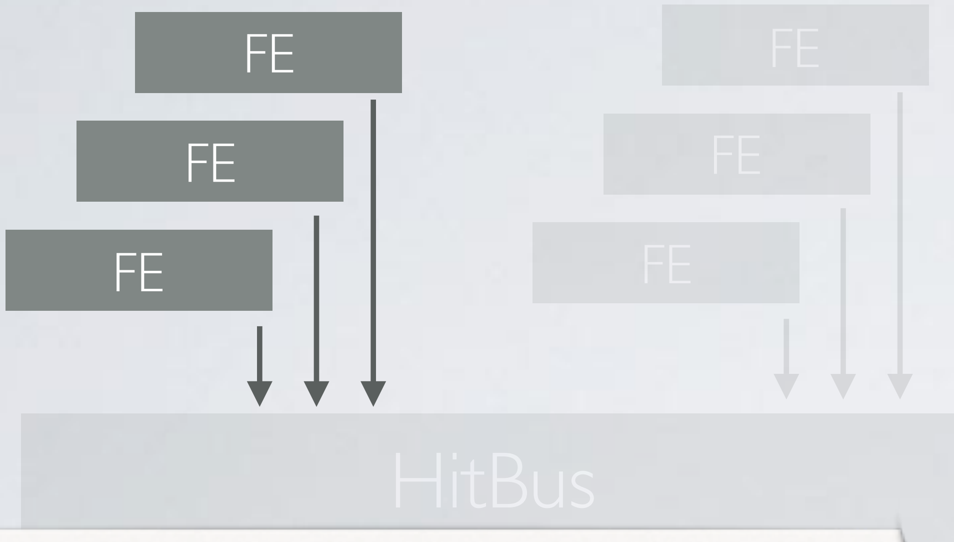
- luminosity readout system
- data format & available information
- system tests
- collected data & analysis
- conclusion

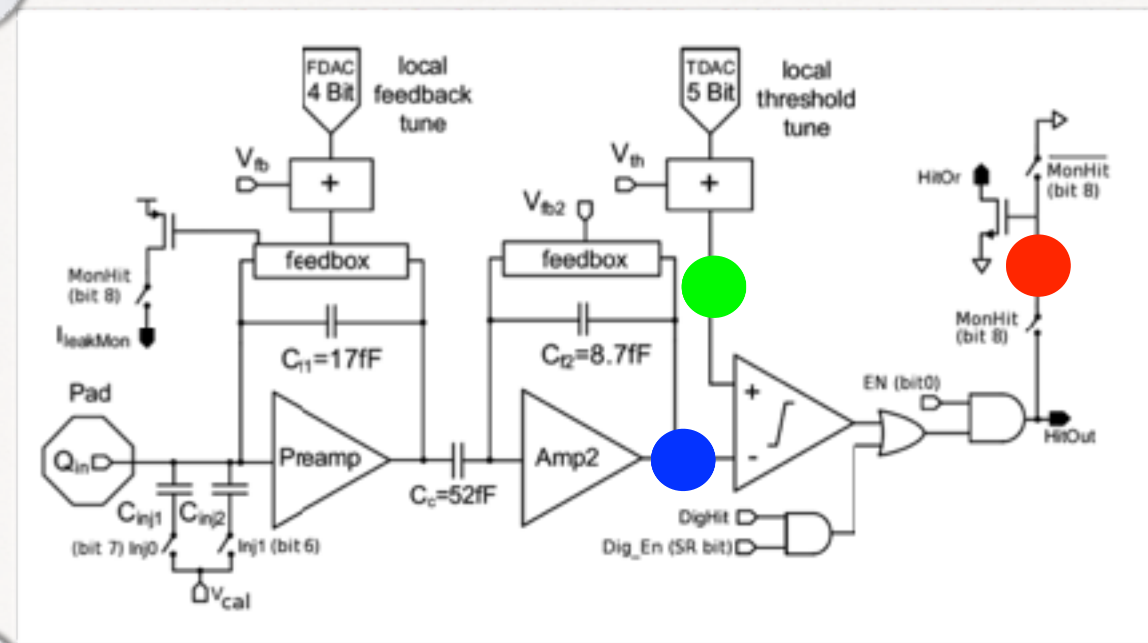
SYSTEM OVERVIEW

SYSTEM OVERVIEW

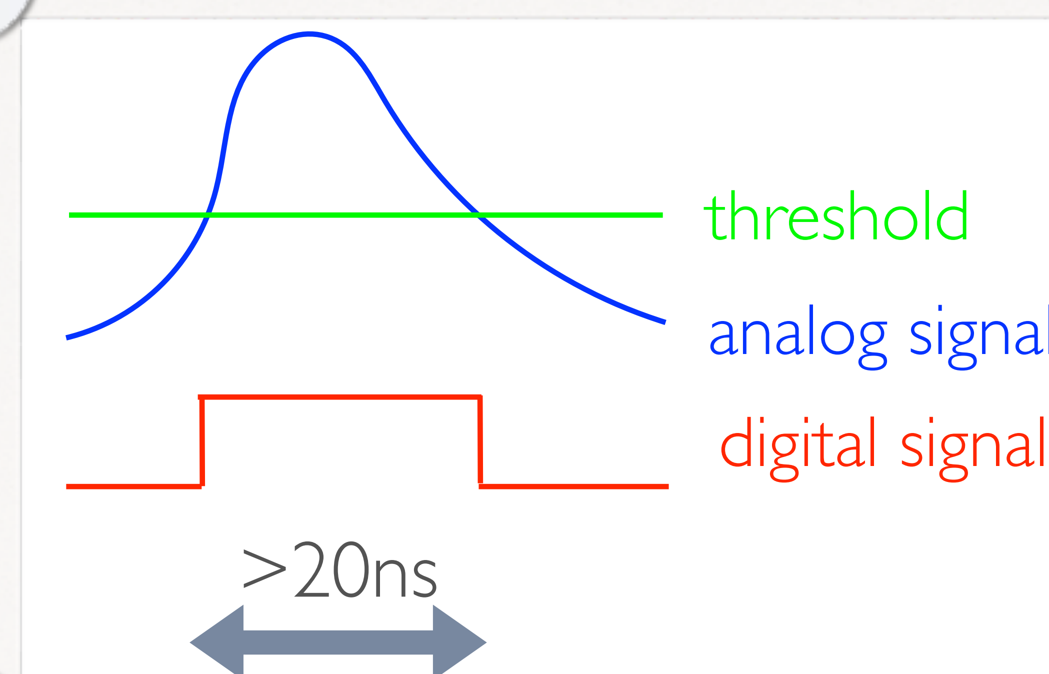


SIGNAL FORMATION

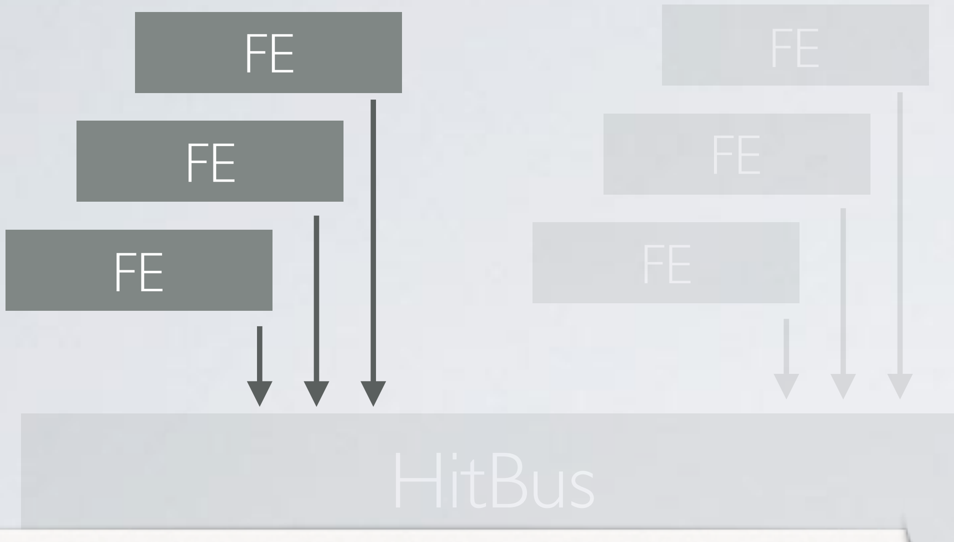




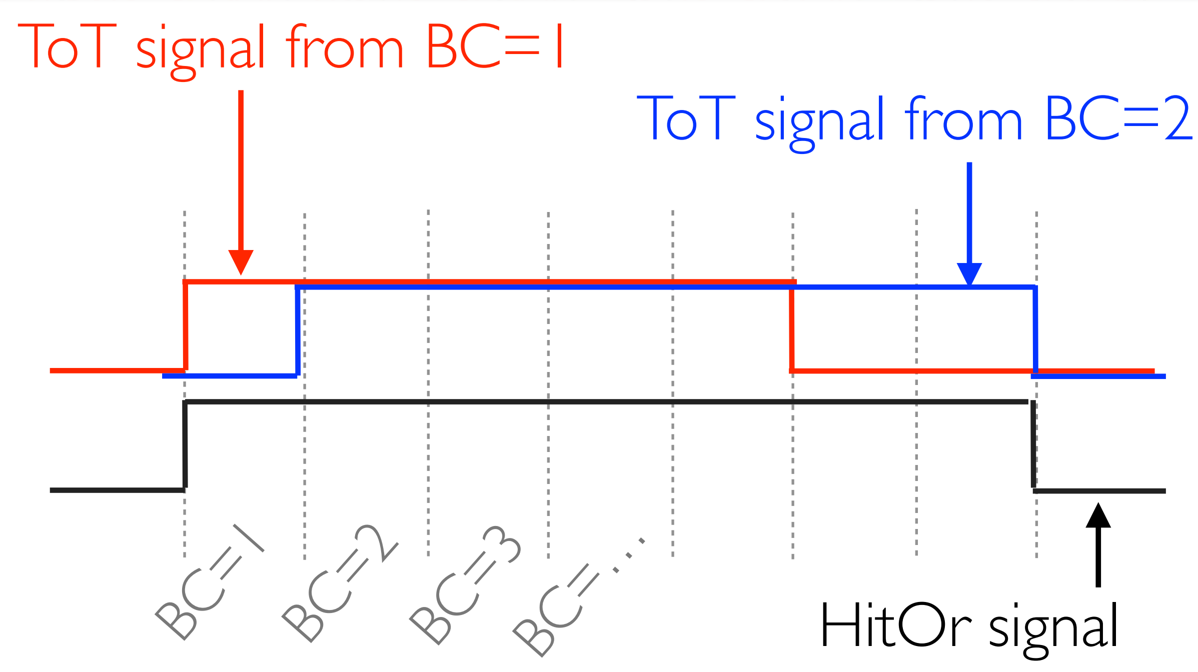
- **analog circuitry:** pixels are completely independent and each has its own time-over-threshold circuit
- two outputs:
  - **HitOr** is common for all pixels in the chip (one output signal per chip), but contribution from each pixel **can be masked**
  - **HitOut** is used for final digitisation

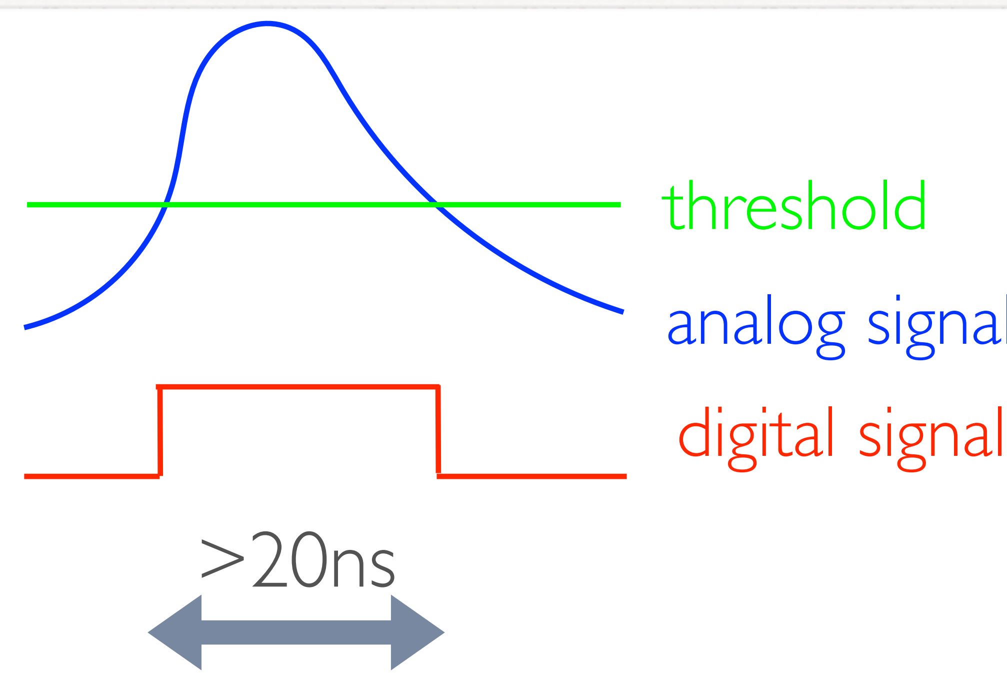


MAIN CHALLENGE

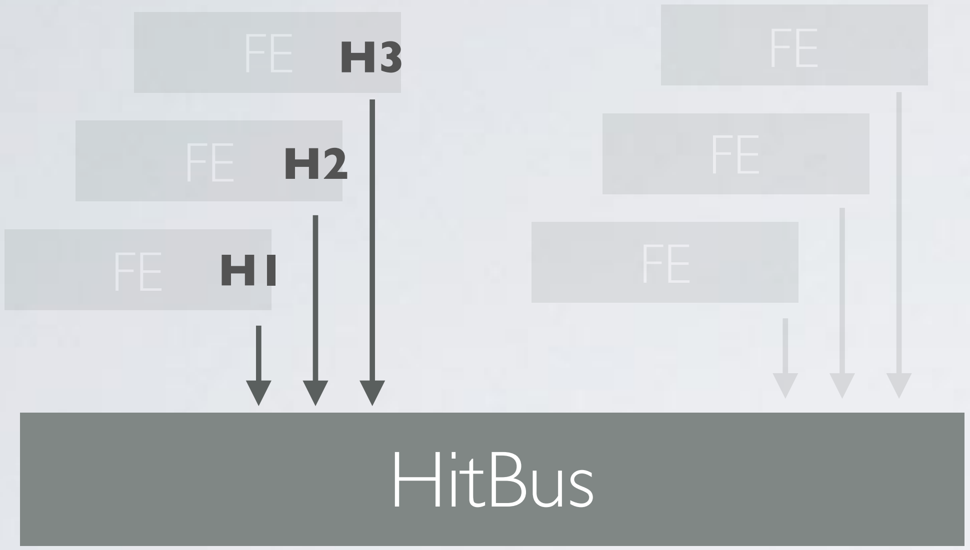


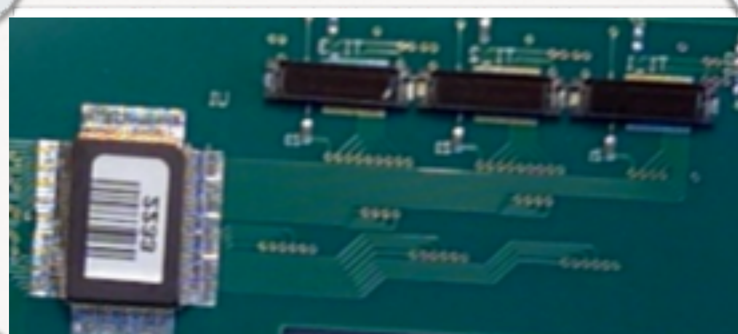
- long ToT signals (1-16 BCs) cause **digital pileup**
- no problem at low luminosity, but with increasing $<\mu>$ pile-up dominates over statistical error
- two direct handles possible:
  - different ToT calibration (same charge = shorter pulse)
  - reducing probability for HitOr signal by enabling smaller umber of pixels (coupled with noise)





HITBUS

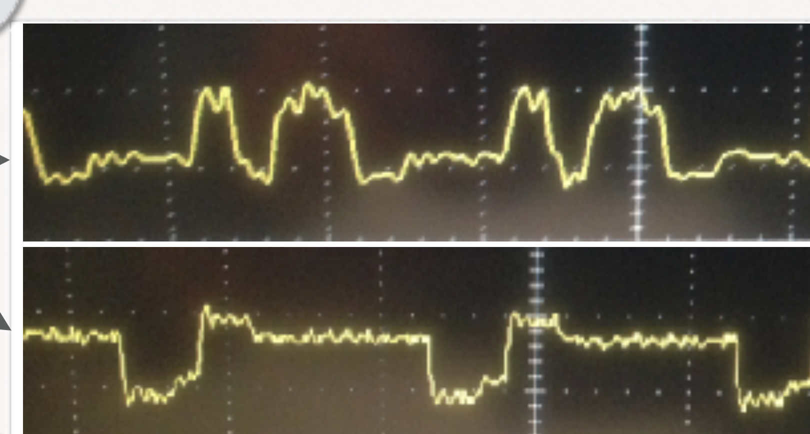




- transparent for luminosity measurement
- simply streams the the HitOr data on 320MHz link
- stream BPM encoded to provide robustness

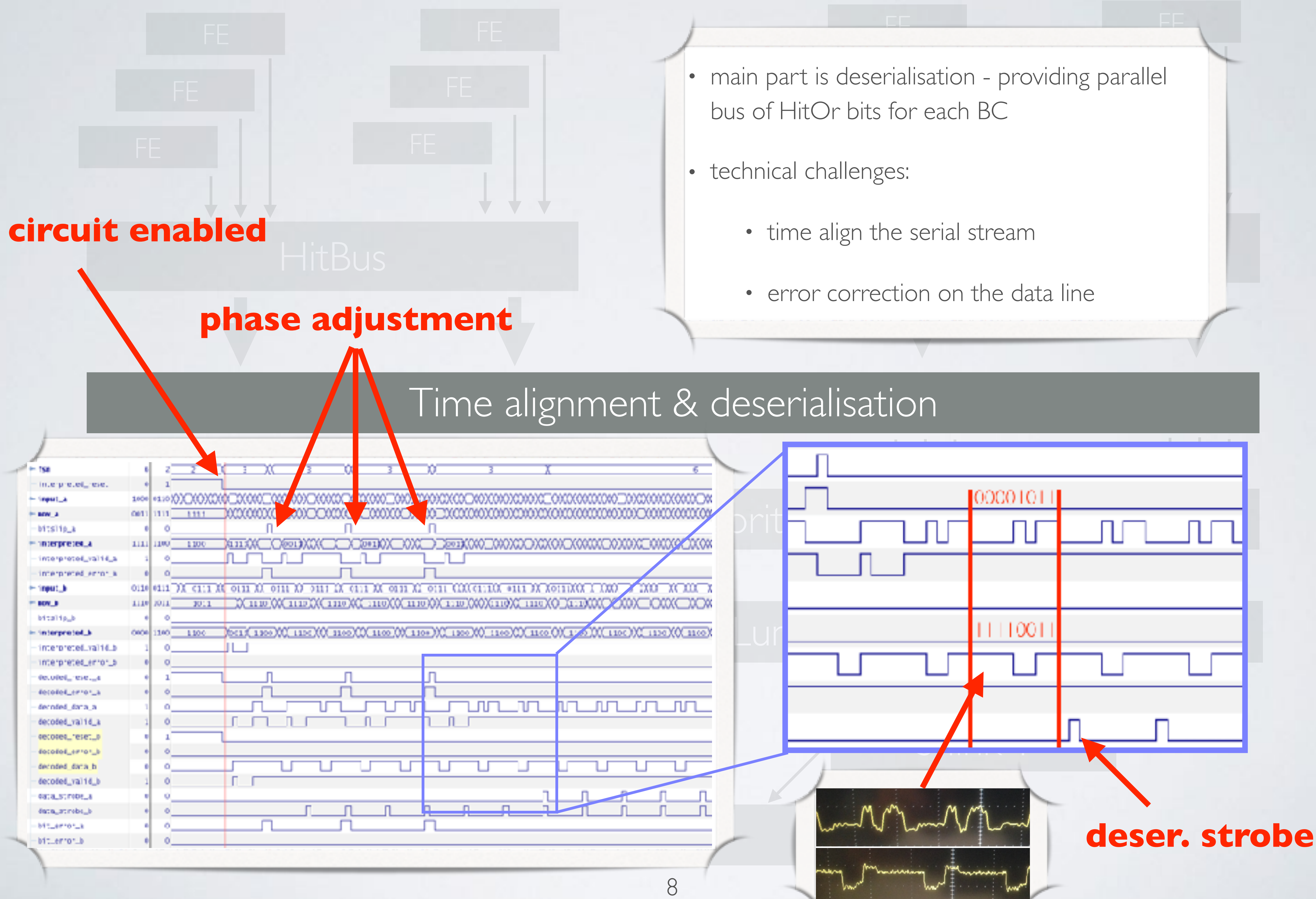
- has two such streams independent stream
- data streamed out of detector to the counting room
- has other modes of operation

- one mode is to output fixed data pattern in sync with input clock
- used for time alignment



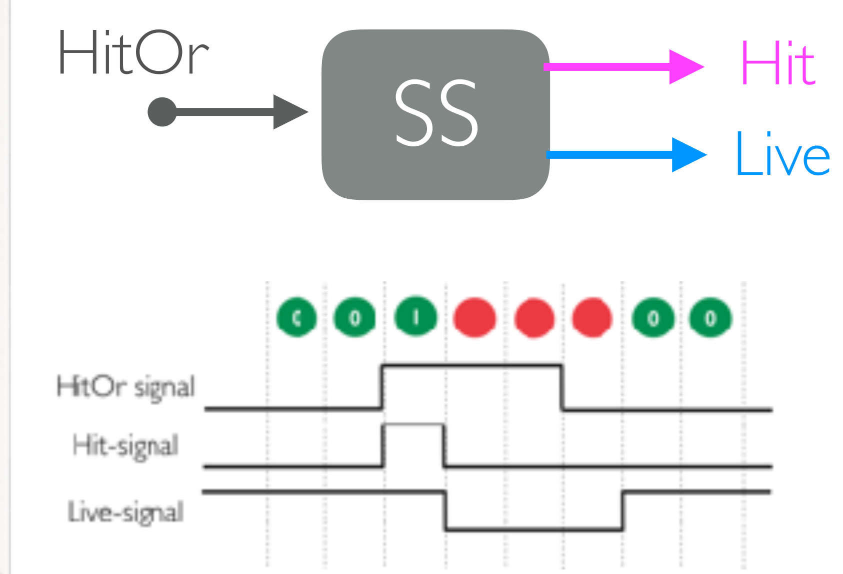
DATA RECEPTION

- main part is deserialisation - providing parallel bus of HitOr bits for each BC
- technical challenges:
  - time align the serial stream
  - error correction on the data line

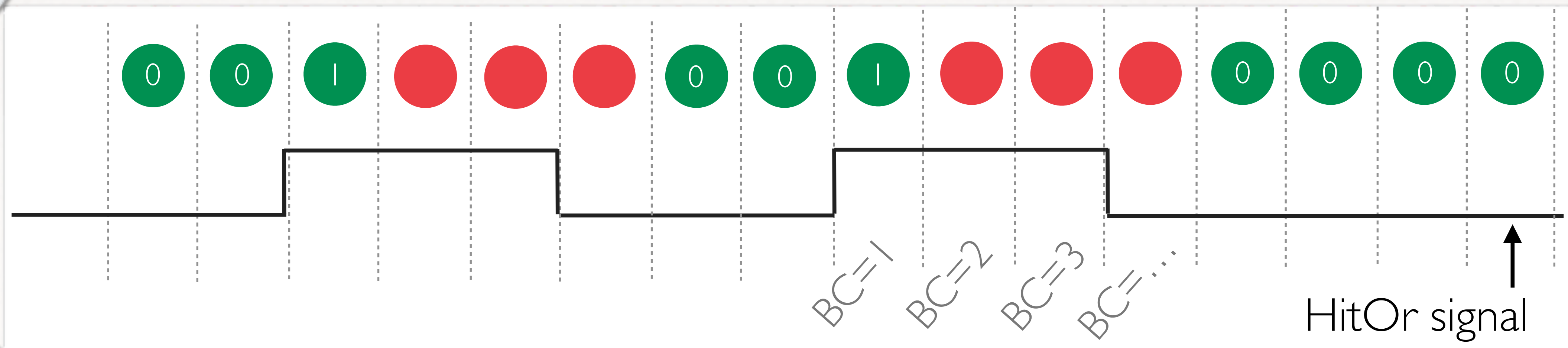


DEAD-TIME MONITORING

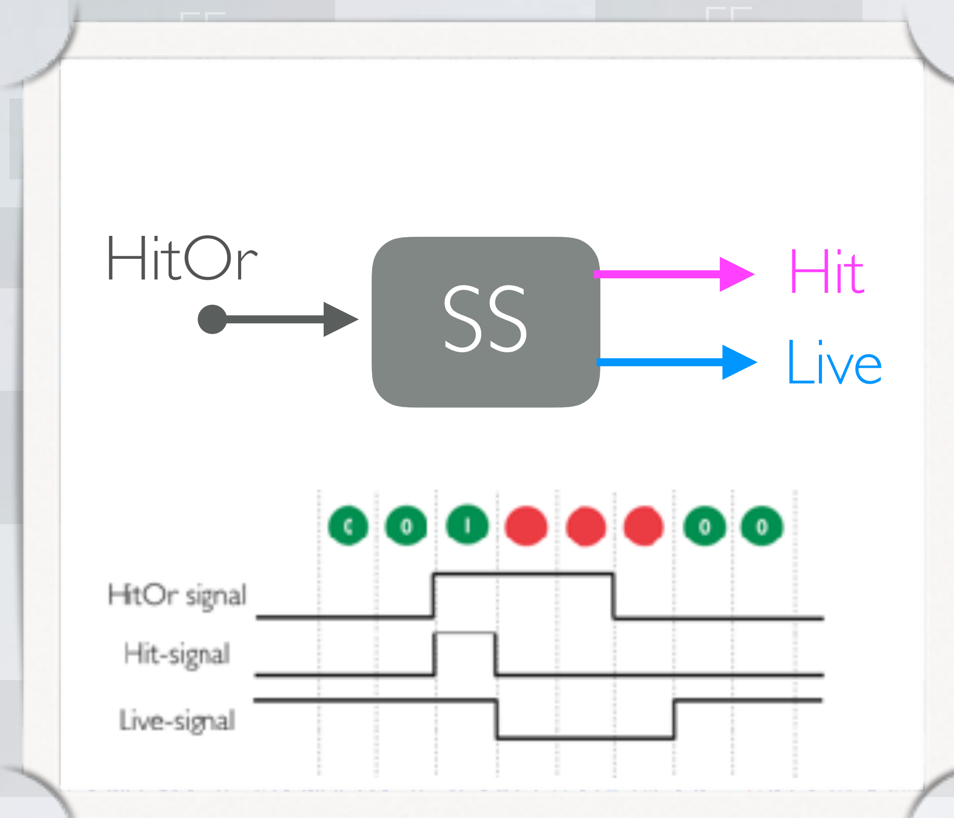
- we have 12 HitOr signals from the modules
- from FE a challenge was inherited - dead-time & pileup
- information is carried by the rising edges
- need to measure the dead-time



Luminosity algorithms



LUMINOSITY

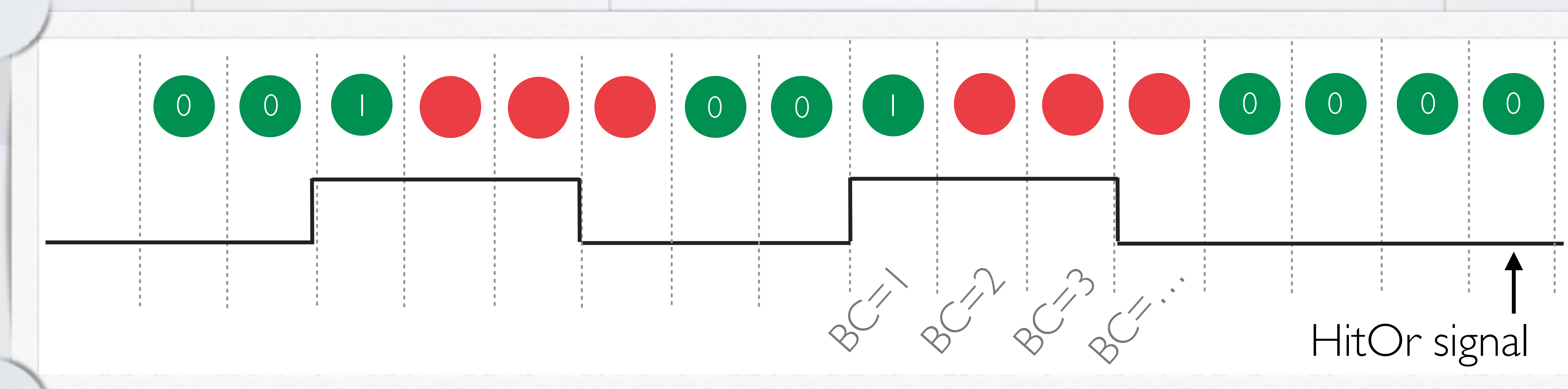


- given 'hit' and 'live' signals for a certain BC one can measure event rate as:

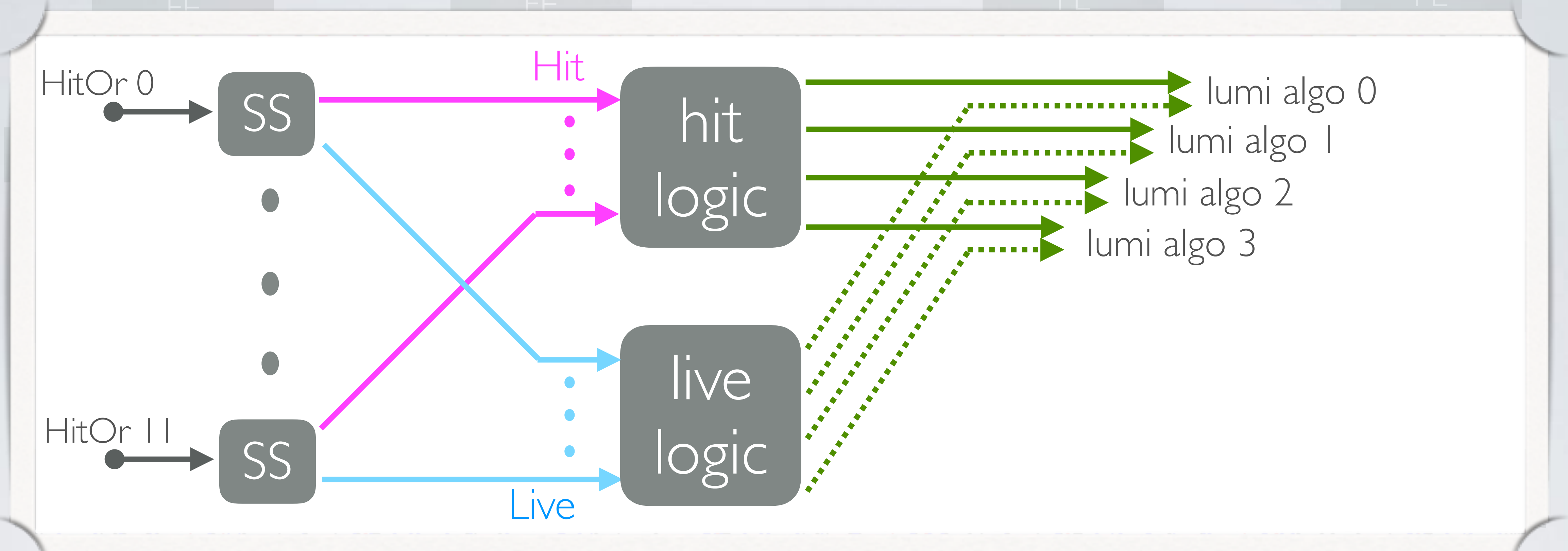
$$r = 1/(0+1)$$

- requires two counters instead of one - doubling the resources required

Luminosity algorithms



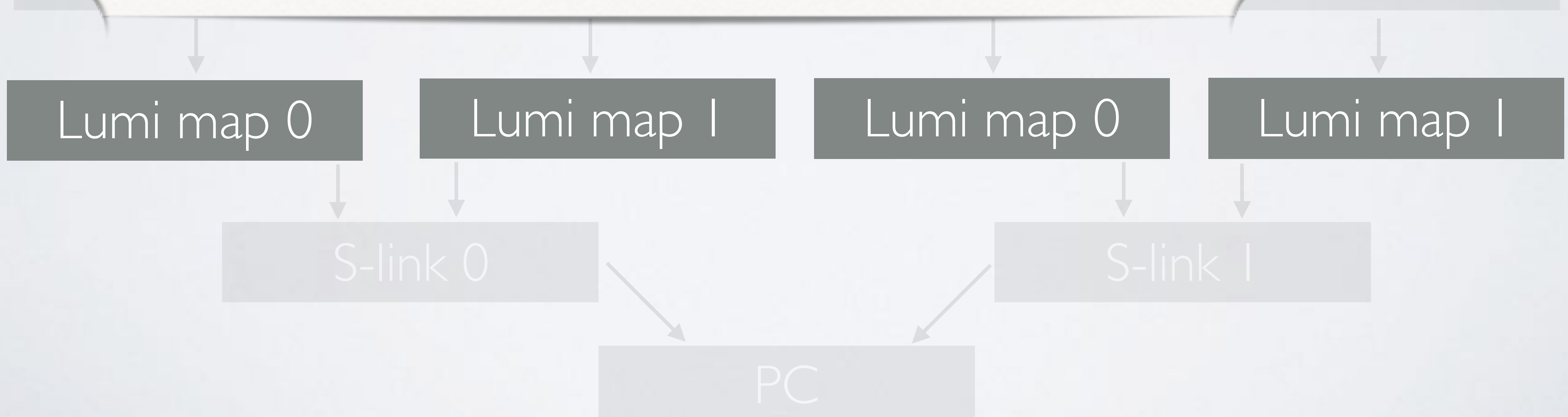
COMBINING SENSORS



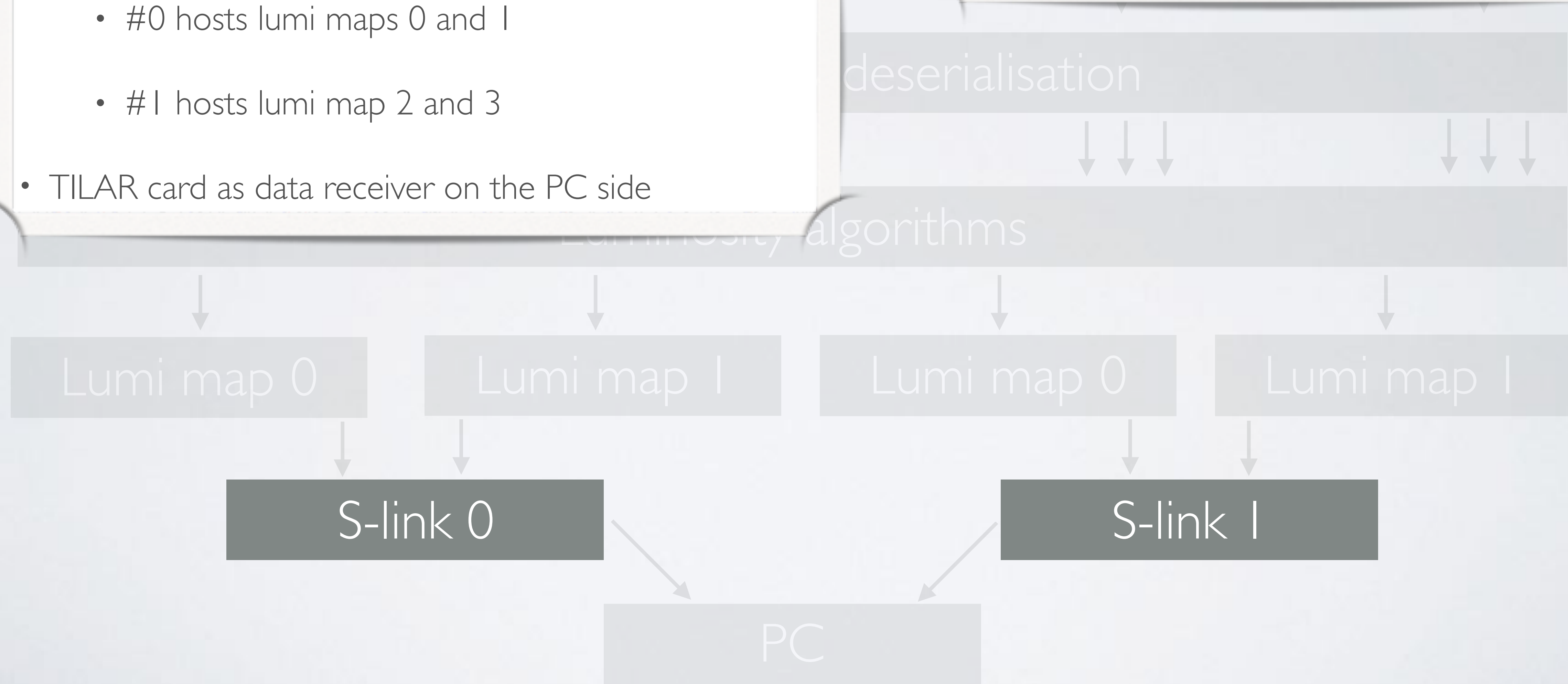
- logic can be uploaded without FW modification
- any combinatorial logic expression with up to 12 inputs possible
- 4 luminosity algorithms available on each FPGA

LUMINOSITY MAPS

- 4 luminosity maps - matches the number of algorithms
- histograms both 'live' and 'hit' signals for all BCIDs
- extra info:
    - Orbit counter
    - error checking circuit with the counter
    - unique ID
- no dead-time during the readout
- 16-bit accumulating counters - limits the readout to rates higher than 0.3 Hz



S-LINK



- 2 S-link channels per FPGA
  - #0 hosts lumi maps 0 and 1
  - #1 hosts lumi map 2 and 3
- TILAR card as data receiver on the PC side

SOFTWARE WORLD

- A dedicate software was developed for readout and processing of the data
- general purpose framework CatShell
  - https://gitlab.cern.ch/bmacek/CatShell
- DbmShell for DBM specific infrastructure parts
  - https://gitlab.cern.ch/bmacek/DbmShell
  - DBM hardware specifics
- common lumi infrastructure LumiShell
  - https://gitlab.cern.ch/bmacek/LumiShell
  - luminosity processing

DATA & TESTS

CLOSE LOOK AT THE DATA

```
[LumiMap32] Lumi map 32-bit for 3564 BCIDs.
Data source        : 1
FPGA source        : south
Stream ID          : 0
Map                : 1
Error count        : 0
Start orbit        : 999305637
End orbit          : 999329638
Start time (UTC)   : 2018-09-22 08:24:40.130799
End time (UTC)     : 2018-09-22 08:24:42.265081
Counters           :
   0: [    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],
   5: [    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],
  10: [    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],
  15: [    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],
  20: [    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],
  25: [    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],
  30: [    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],[    24001,       0],
....
```

ID of the luminosity algorithm

999329638-999305638 = 24001 orbits ~2s

kernel timestamps for book keeping

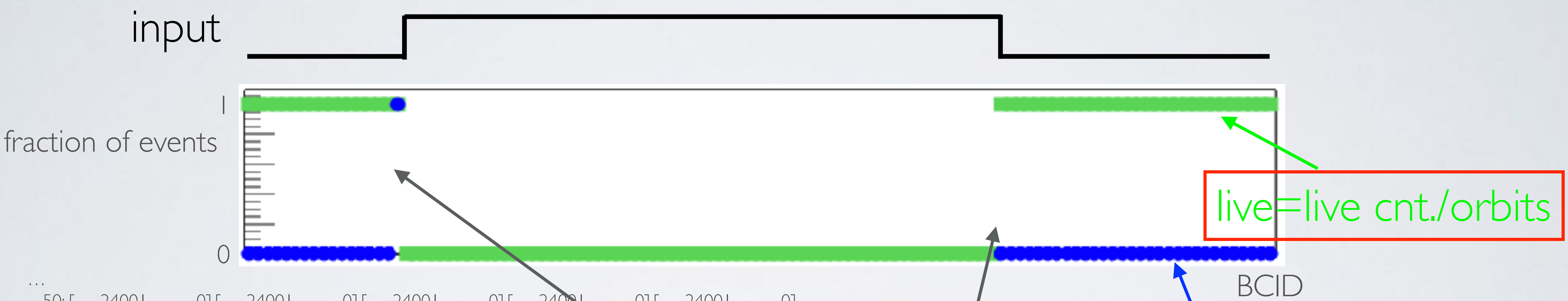
data for single BC

hit counter

live counter

TESTING THE SYSTEM

- first testing is always with internal number generator, instead of HitOr
- s pattern of repetitive digital pulses is re-played in a same manner on each ORBIT



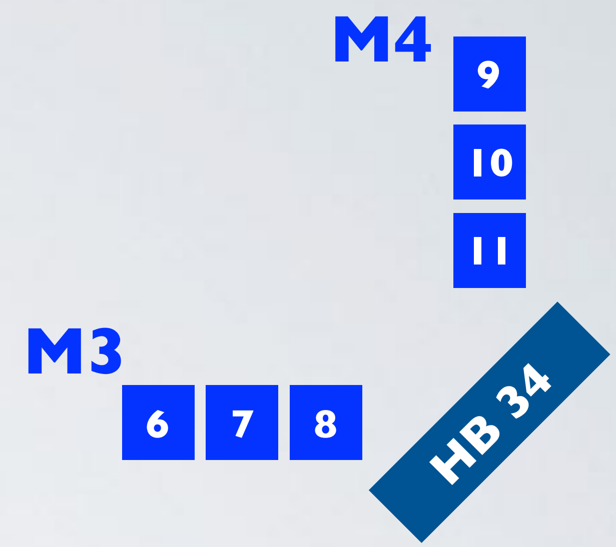

```
...
 50: [   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],
 55: [   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],
 60: [   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],
 65: [   24001,      0],[   24001,  24001],[       0,      0],[       0,      0],[       0,      0],
 70: [       0,      0],[       0,      0],[       0,      0],[       0,      0],[       0,      0],
 75: [       0,      0],[       0,      0],[       0,      0],[       0,      0],[       0,      0],
 80: [       0,      0],[       0,      0],[       0,      0],[       0,      0],[       0,      0],
 85: [       0,      0],[       0,      0],[       0,      0],[       0,      0],[       0,      0],
 90: [       0,      0],[       0,      0],[       0,      0],[       0,      0],[       0,      0],
 95: [       0,      0],[       0,      0],[       0,      0],[       0,      0],[       0,      0],
100: [       0,      0],[       0,      0],[       0,      0],[       0,      0],[       0,      0],
105: [       0,      0],[       0,      0],[       0,      0],[       0,      0],[       0,      0],
110: [       0,      0],[       0,      0],[       0,      0],[       0,      0],[       0,      0],
115: [       0,      0],[       0,      0],[       0,      0],[       0,      0],[       0,      0],
120: [       0,      0],[       0,      0],[       0,      0],[       0,      0],[       0,      0],
125: [       0,      0],[       0,      0],[       0,      0],[       0,      0],[       0,      0],
130: [       0,      0],[   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],
135: [   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],
140: [   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],
145: [   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],
150: [   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],
155: [   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],[   24001,      0],
...
```

rising edge

end of pulse

ANALYSIS

ALGORITHM SETUP-1



- running only side C
- only HB-34 used
- for first data an inclusive set of algorithms was configured

FPGA	Stream	Map	Algorithm	Logic
South	0	0	0	or*(FE6, FE7, FE8, FE9, FE10, FE11) **- everything**
		1	1	FE10 **- single module**
	1	0	6	or*(FE6, FE7, FE8) **- one telescope (M3)**
		1	7	or*(FE9, FE10, FE11) **- one telescope (M4)**

*special setup: live-algorithms modified
(pinpointing data, no measurement)

normally: live if all live (and) → *special: live if either live (or)*

RUN WITHOUT FE

- first collision run: DBM was un-configured (data tag: 2018_09_23_12_43_01)
- expected to see nothing - hits observed

Algorithms	
0	**everything**
1	**single module**
6	**M3**
7	**M4**

1730: [	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],
1735: [	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],
1740: [	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],
1745: [	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],
1750: [	24001,	1],[	24000,	0],[	24000,	0],[	24000,	0],[	24001,	0],
1755: [	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],
1760: [	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],
1765: [	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],
1770: [	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],[	24001,	0],

hit - 3 BC long

RUN WITHOUT FE

Algorithms	
0	**everything**
1	**single module**
6	**M3**
7	**M4**

- first collision run: DBM was un-configured (data tag: 2018_09_23_12_43_01)
- expected to see nothing - hits observed

Orbit number	Algorithms	BCID	Length
2089983080	0,1,7	861	1
2091495143	0,6	863	?
2094879284	0,6	398	?
2101023540	0,6	2188	?
2104119669	0,6	2188	?
2105583730	0,6	863	?
2107047791	0,6	339	?
2109831907	0,6	2188	?
2111991997	0,1,7	1750	3

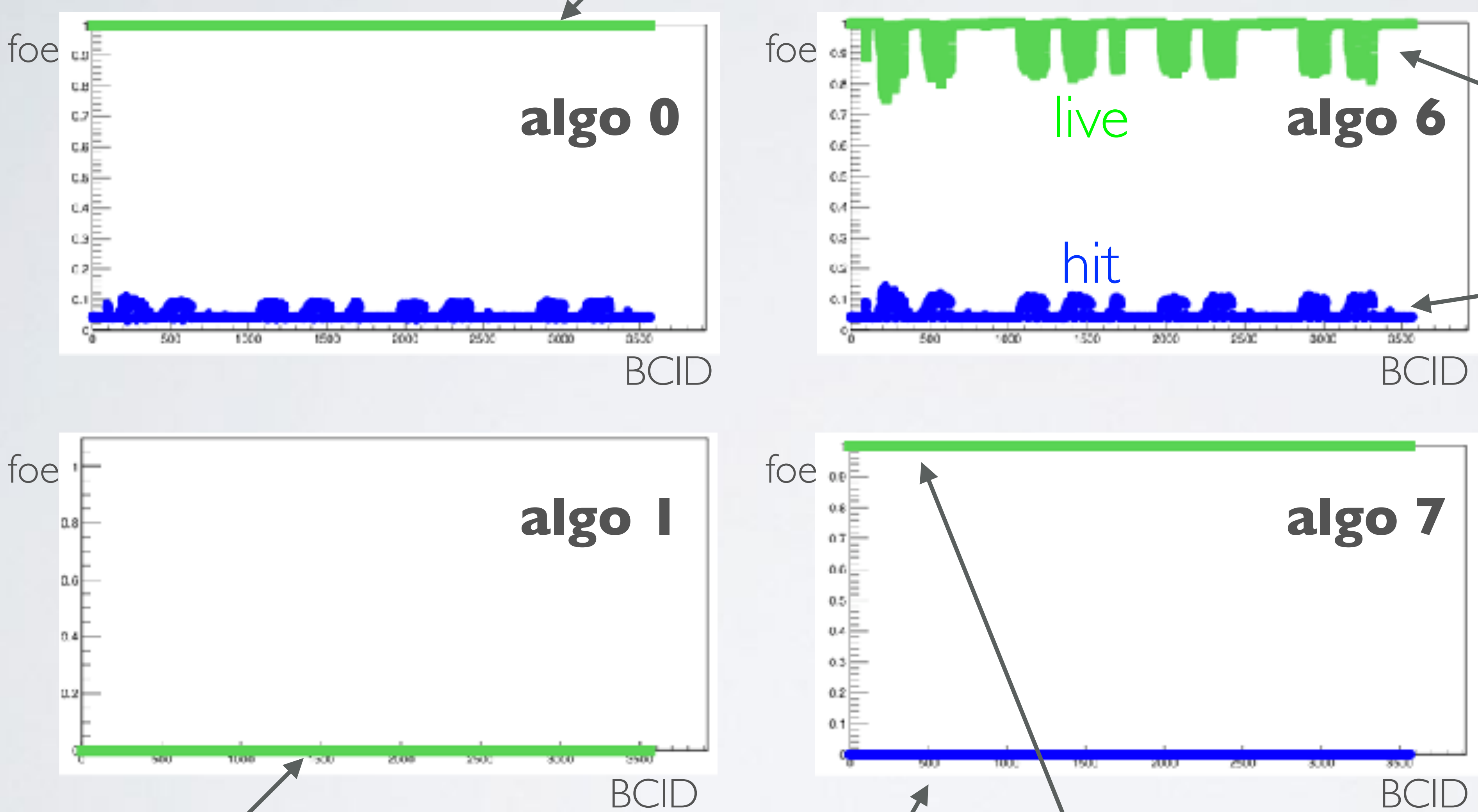
BCIDs repeat !!
-
some systematics

RUN WITH FE

Algorithms	
0	**everything**
1	**single module**
6	**M3**
7	**M4**

- first collision run with FEs configured (data tag: 2018_09_23_18_33_15)

inherits from map 7



some coincidences of 3 HitOr signals being 0

hits in M3

can only be explained, by the HitOr signal being constantly high

obviously HitOr signal for FE9 or FE10 const. =0

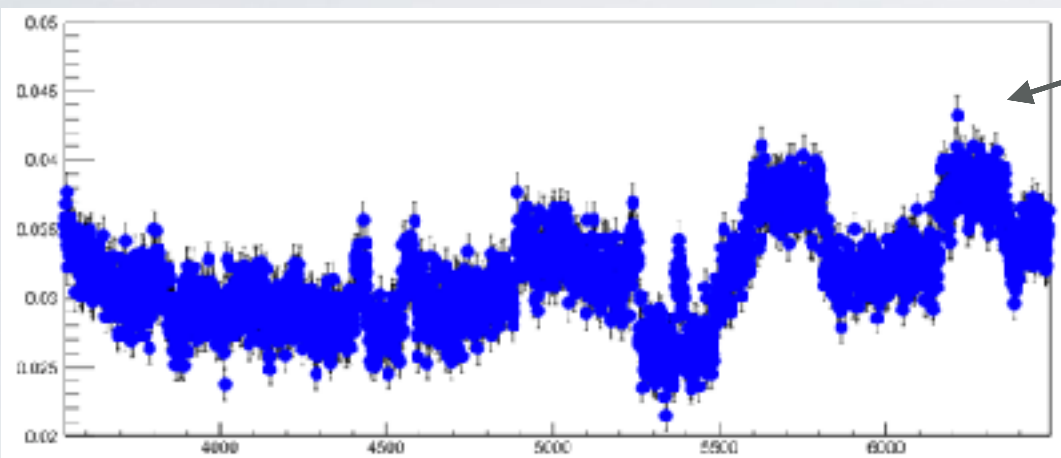
no hits in M4

RUN WITH FE

- a single BCID=2400 chosen, algorithm 6 = M3 telescope
- two runs in this lumi recordings

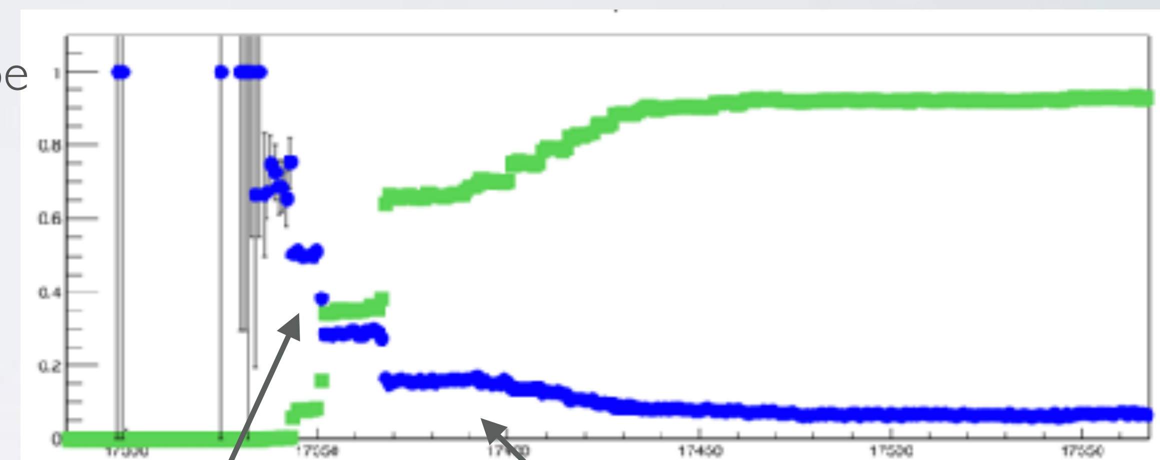
IBL included us in timing scan

foe



time

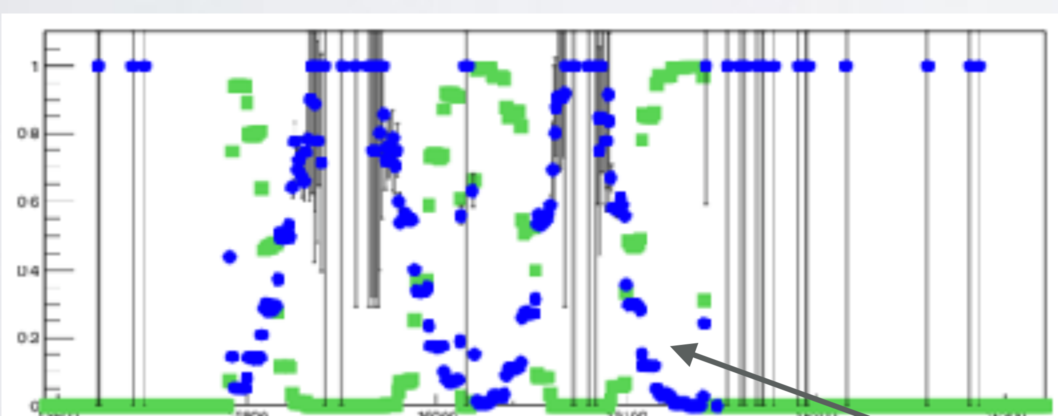
foe



time

second run/fill

foe



time

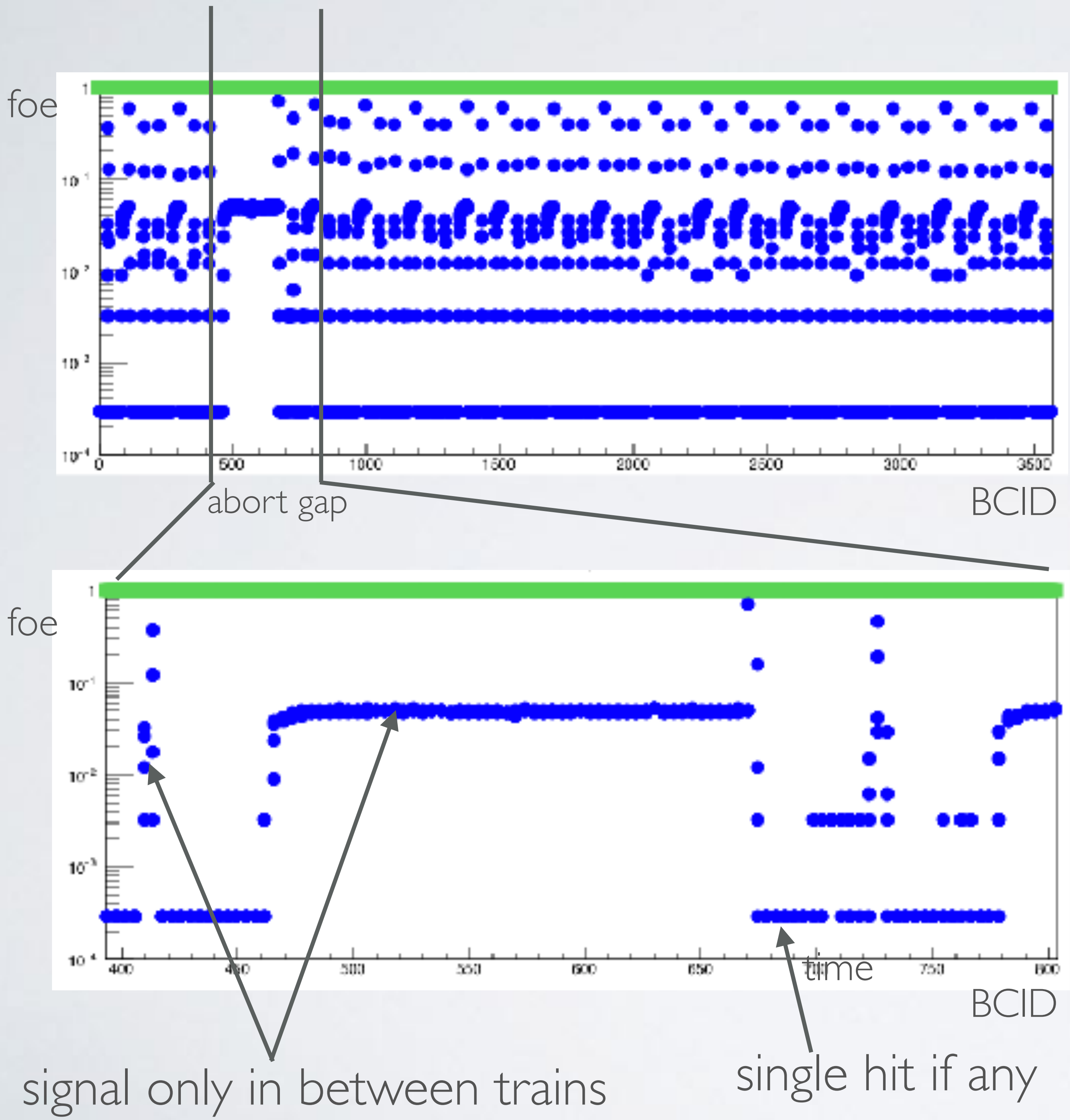
X,Y scans before the run

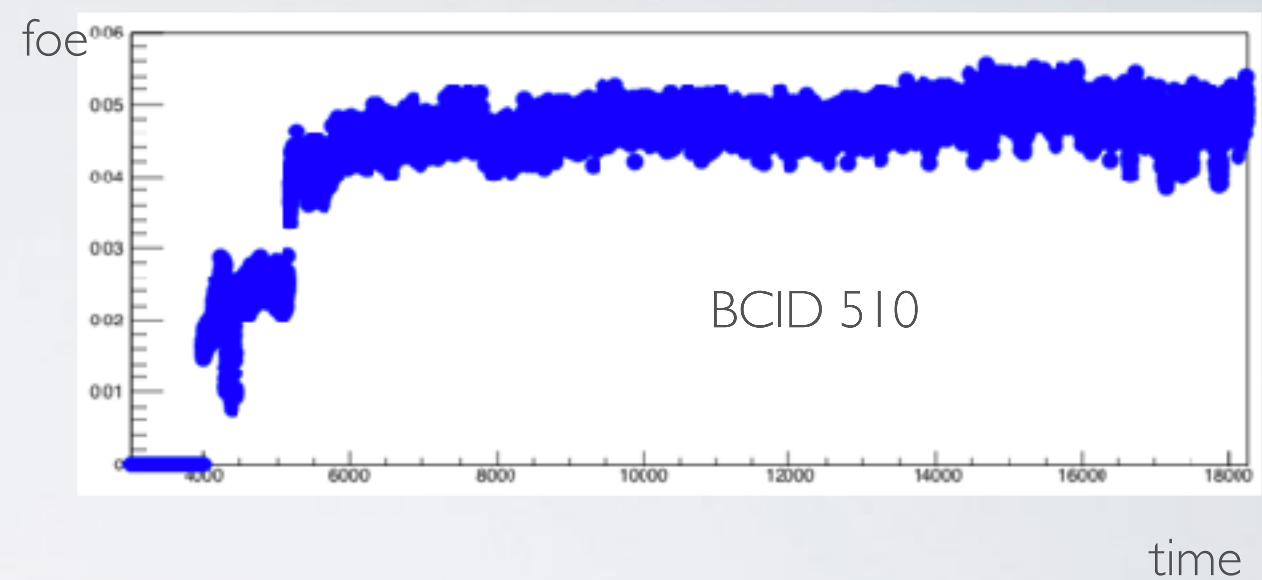
- counter quantisation seen
- error bars only for statistical error
- detector responding to pp collisions
- response sensible only when beams are not centred

saturation

RECORDING 2.

- recording containing two runs (data tag: 2018_09_24_13_24_51)





with pp collision

-

obvious saturation

ALGORITHM SETUP-2

- running only side C - only HB-34 used
- so far: M3 give some signal, M4 no signal
- trying to reduce acceptance - less inclusive algorithms

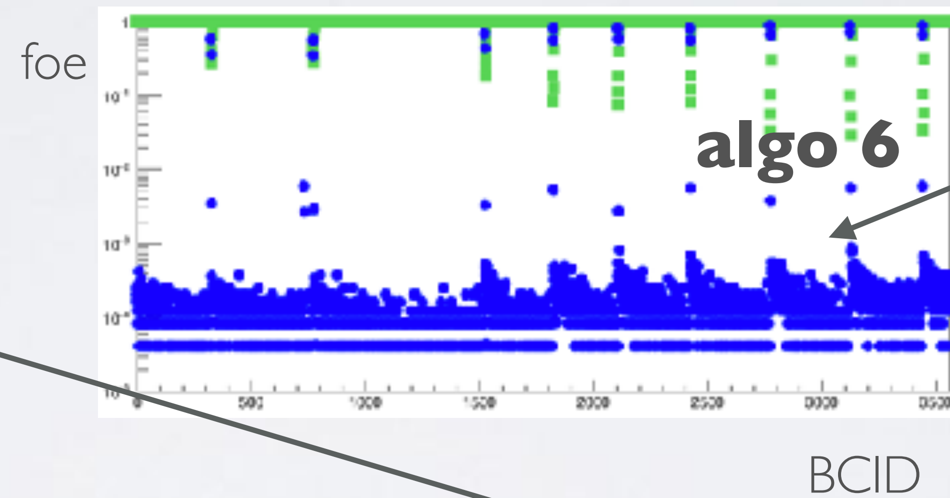
FPGA	Stream	Map	Algorithm	Logic
South	0	0	0	or*(FE6, FE7, FE8) **- one telescope (M3)**
		1	1	FE6 **- single module**
	1	0	6	FE7 **- single module**
		1	7	FE8 **- single module**

*no special setup: first measurements

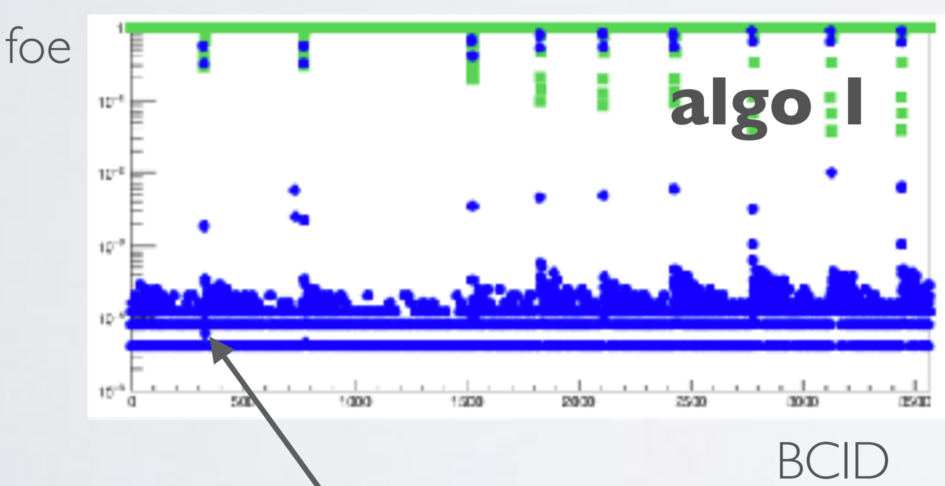
RECORDING 3.

Algorithms	
0	**M3**
1	**single module F6**
6	**single module F7**
7	**single module F8**

- recording containing two runs (data tag: 2018_09_25_17_00_17)
- interesting because has 9 isolated collision bunches



at this level F6 and F7 give consistent data



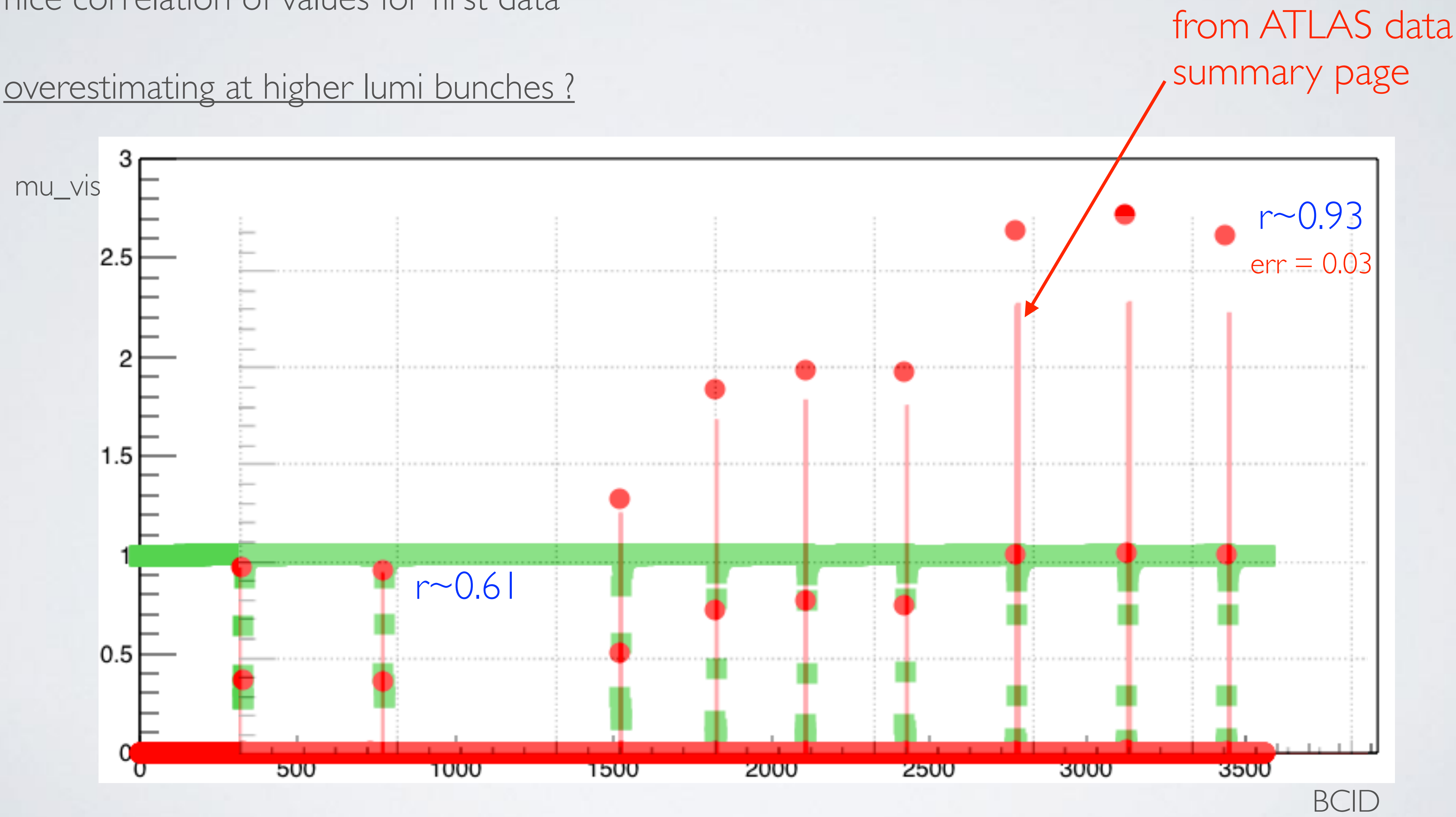
due to F8

noise rate hard to estimate due to tails and values at quantisation level

F8 non contributing any data since un-configured

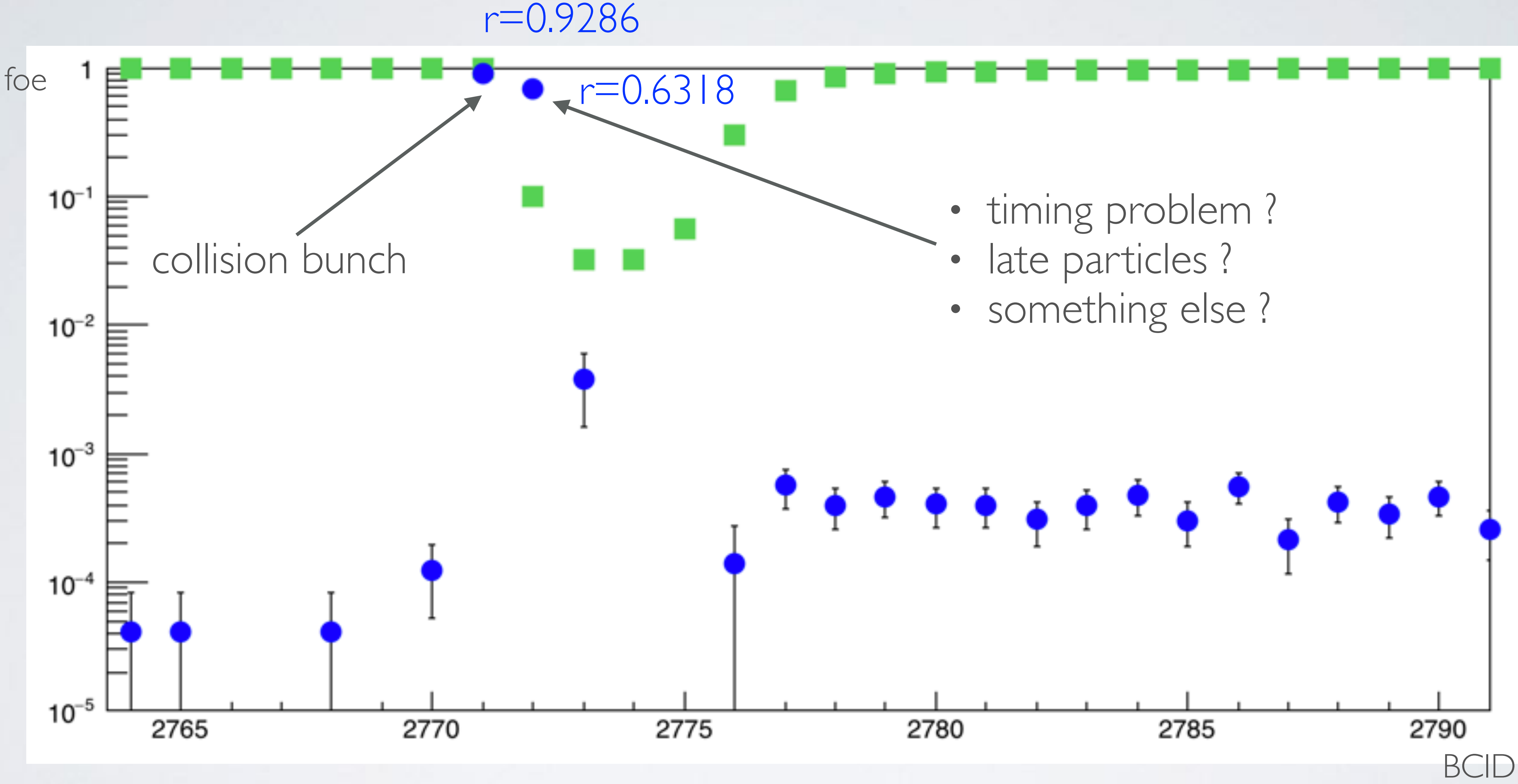
RECORDING 3.

- comparison with official ATLAS lumi statement
- nice correlation of values for first data
- overestimating at higher lumi bunches ?



RECORDING 3.

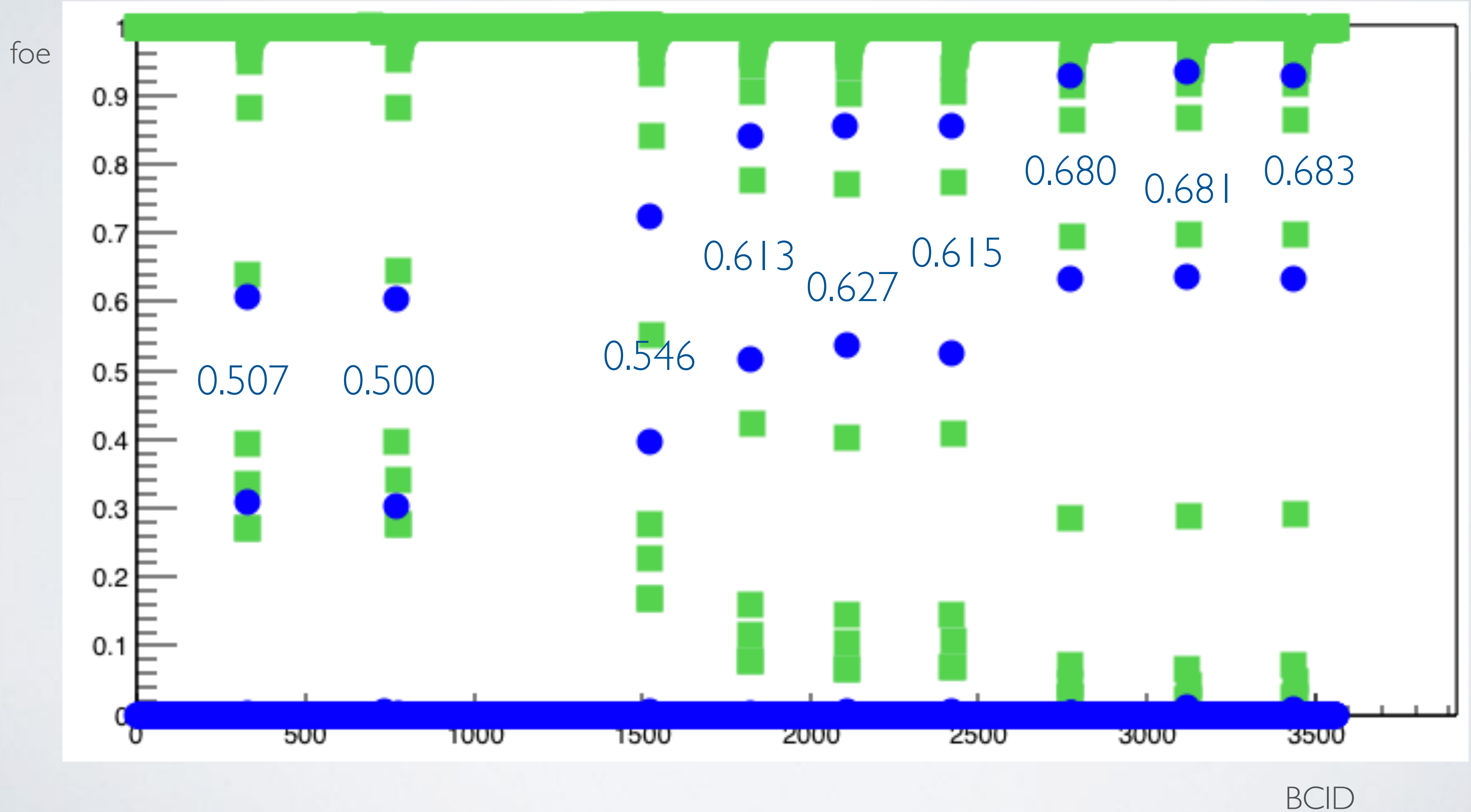
- closer look at individual BCs



RECORDING 3.

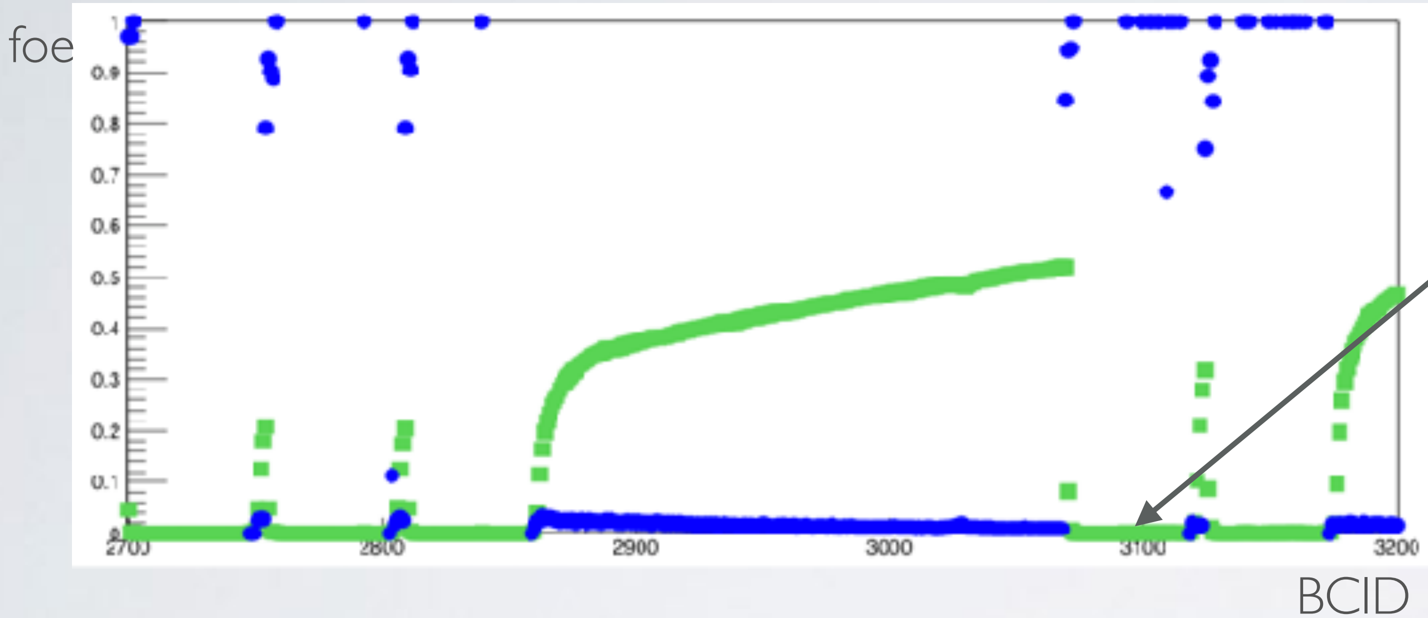
- correlation between the two following BCID

r(BCID)/r(BCID-1)



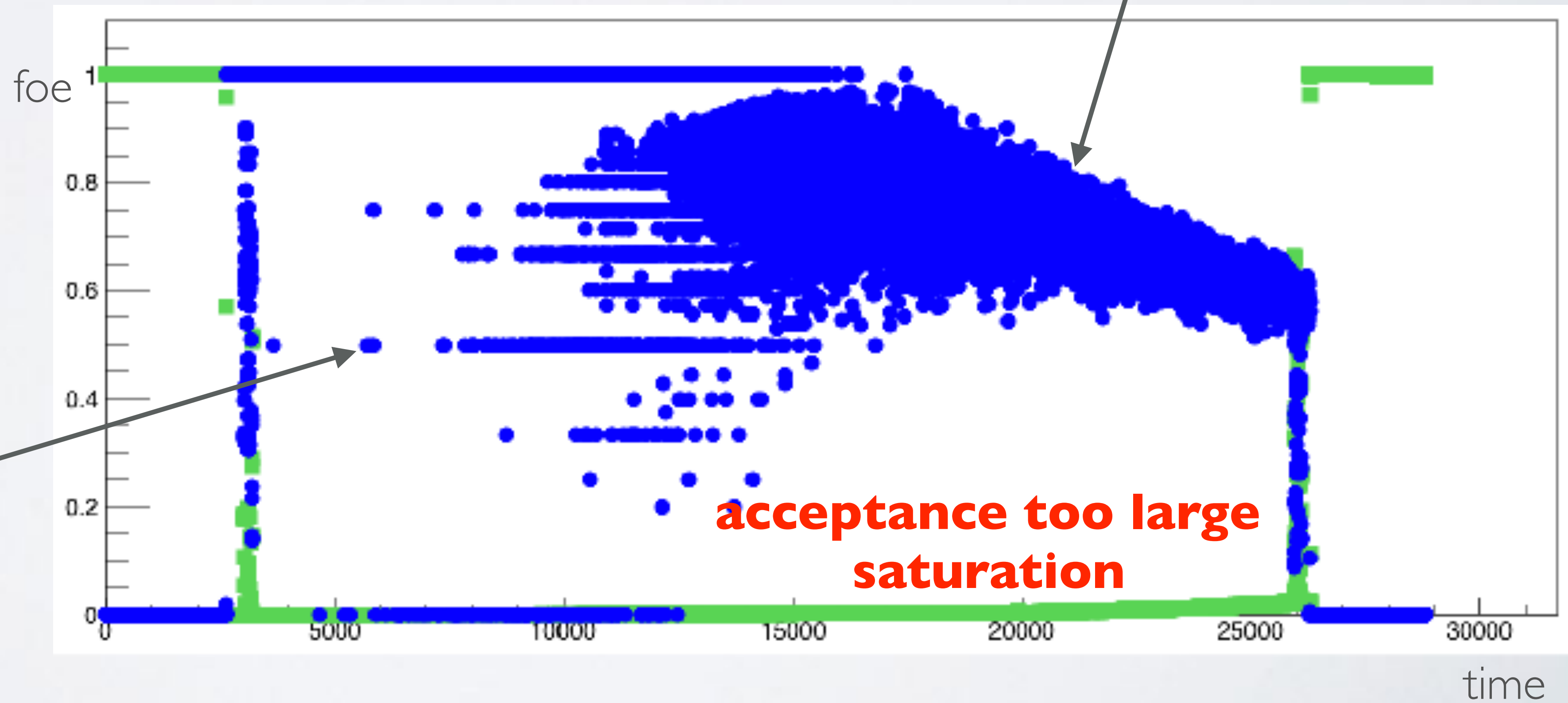
RECORDING 4.

- single run with 2544 colliding bunches (data tag: 2018_09_25_22_48_03)



saturation in the train

as lumi drops, we move away from pile-up and start getting hit information



extreme pileup where only in 2 out of 24k instances a BC has been marked 'live'

only 0, 1, or 2 hits possible

ALGORITHM SETUP-3

- running only side C - only HB-34 used
- so far: M3 give some signal, M4 no signal, FE8 does not contribute

FPGA	Stream	Map	Algorithm	Logic
South	0	0	0	FE6 **- single module**
		1	1	FE7 **- single module**
	1	0	6	or(FE6, FE7) **- or**
		1	7	and(FE6, FE7) **- and**

RECORDING 5.

Algorithms	
0	**single module F6**
1	**single module F7**
6	**or**
7	**and**

- DBM was un-configured (data tag: 2018_09_27_16_38_52)
- no atlas recording, DBM un-configured, but beam present

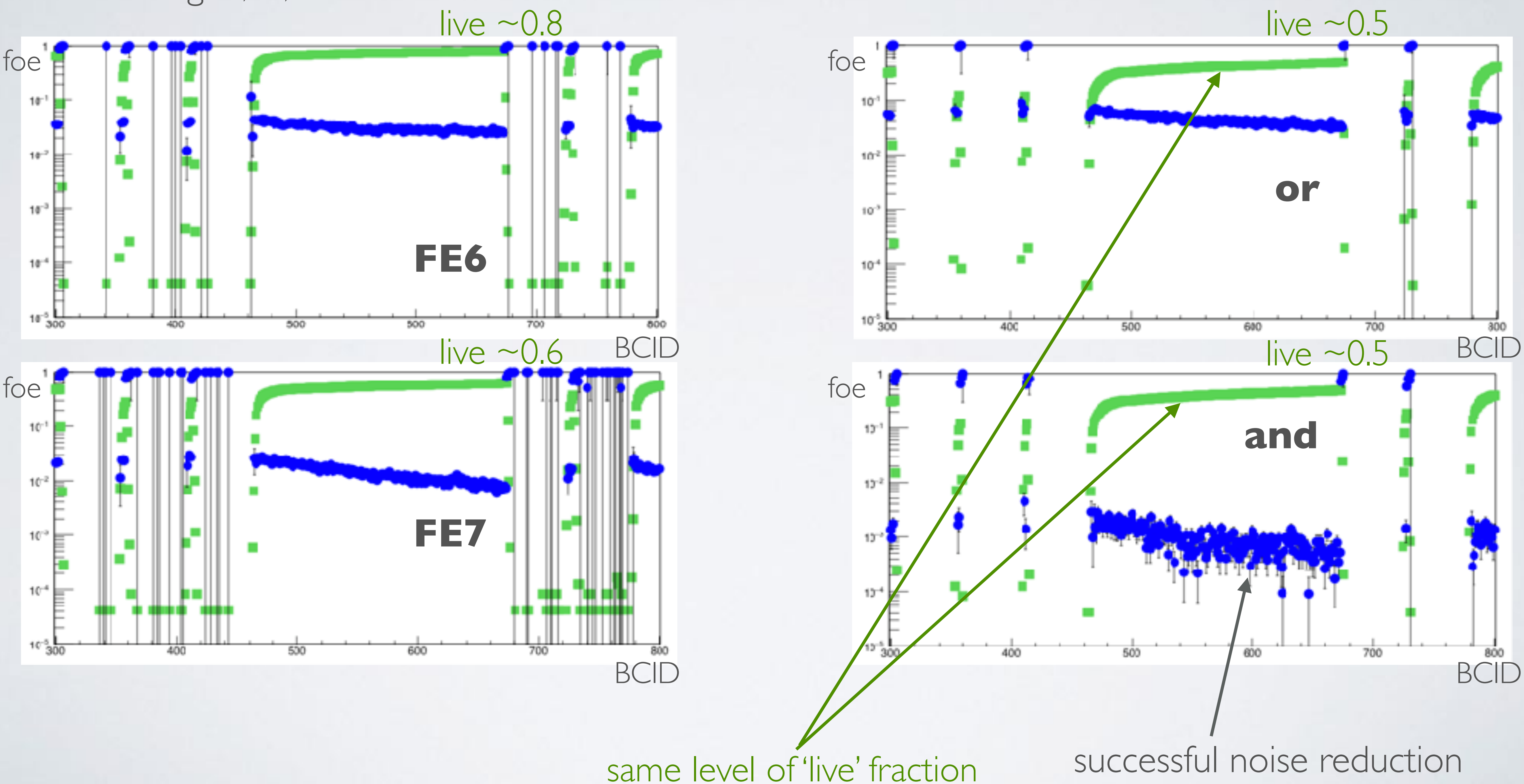
Orbit number	Algorithm	BCID	Length
1815471296	6,7	3526	1
1816311331	6,1	3354	1
1816839353	6,1	3282	1
1818831436	6,1	3116	1
1819071446	6,1	1654	1
1819215452	6,1	942	1
1819695472	6,1	230	1
1820487505	6,1	422	1
1821591551	6,1	574	1
1821975567	6,1	1414	1
1822143574	6,1	1786	1
1822215577	6,1	2426	1
1822671596	6,1	2758	1
1823391626	6,1	1802	1
1823847645	6,1	1590	1
1824375667	6,1	1750	1
1826127740	6,1	822	1
1826991776	6,1	1818	1
1827039778	6,1	346	1
1828935857	6,1	2442	1
1829775892	6,1	50	1
1832127990	6,1	2170	1
1833280038	6,1	1790	1

Orbit number	Algorithm	BCID	Length
1833832061	6,1	3434	1
1834264079	6,1	1990	1
1834528090	6,1	810	1
1834912106	6,1	2370	1
1835512131	6,1	1138	1
1836520173	6,1	1078	1
1836760183	6,1	1762	1
1836904189	6,1	3298	1
1862369250	6,1	2802	1
1865393376	6,1	2268	1
1866449420	6,1	1994	1

RECORDING 6.

Algorithms	
0	**single module F6**
I	**single module F7**
6	**or**
7	**and**

- two ATLAS runs (data tag: 2018_09_28_22_57_05)
- recording 7., 8., and 10. similar



RECORDING 9.

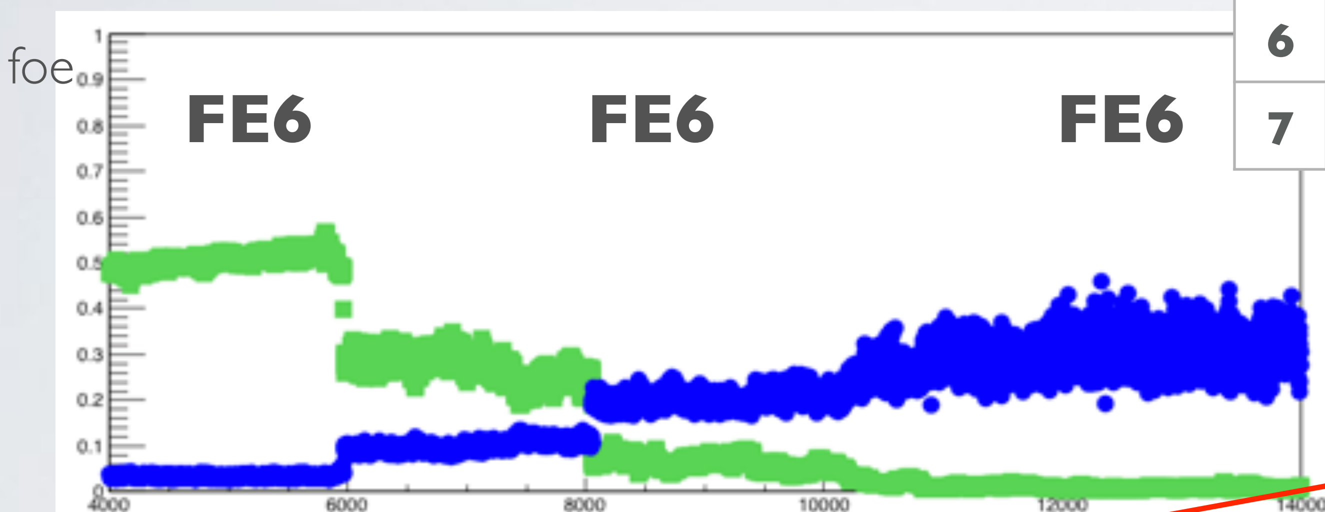
- testing the real-time lumi algorithm reconfiguration
- system works as expected
- ~55 s of data lost

Algorithms	
0	**single module FE6**
1	**single module FE7**
6	**or**
7	**and**

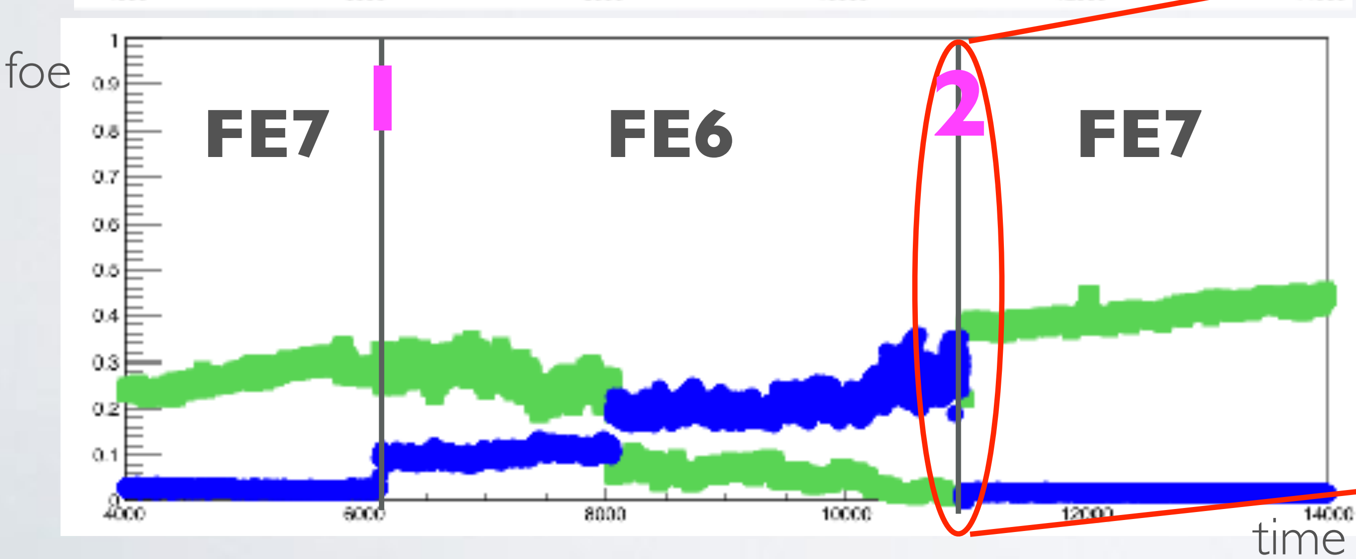
1 →

← 2

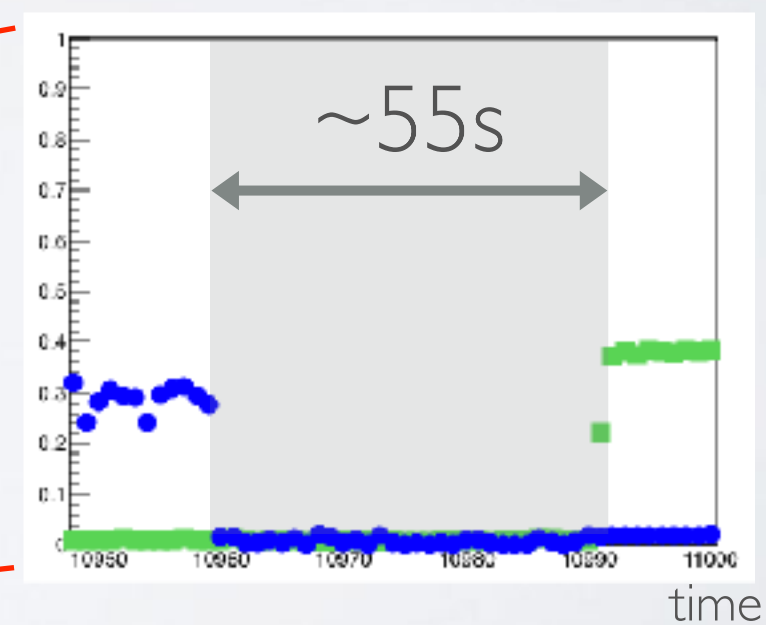
Algorithms	
0	**single module FE6**
1	**single module FE6**
6	**or**
7	**and**



algo 0



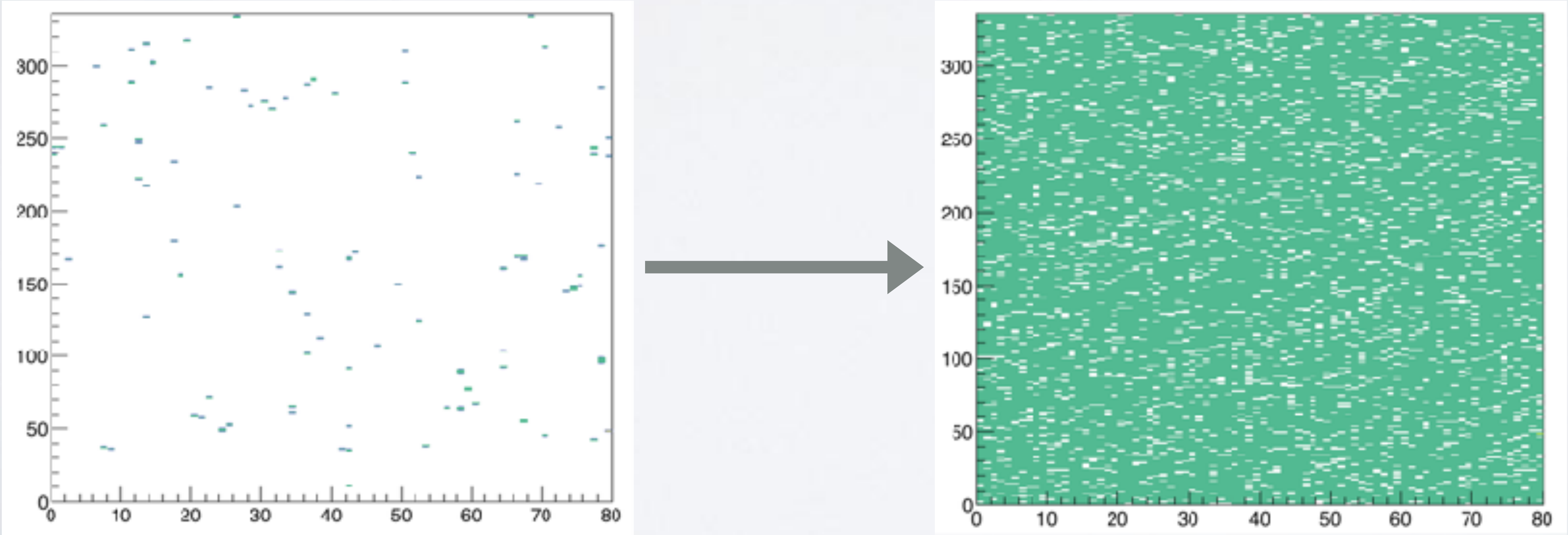
algo 1



CHANGE OF MASK 1.

- saturation due to HitOr mask that is too inclusive
- more selective mask should increase the live-time fraction of the detector
- in absence of more data/information a random subset of already included pixels chosen
- number of contributing pixels reduced by factor ~10

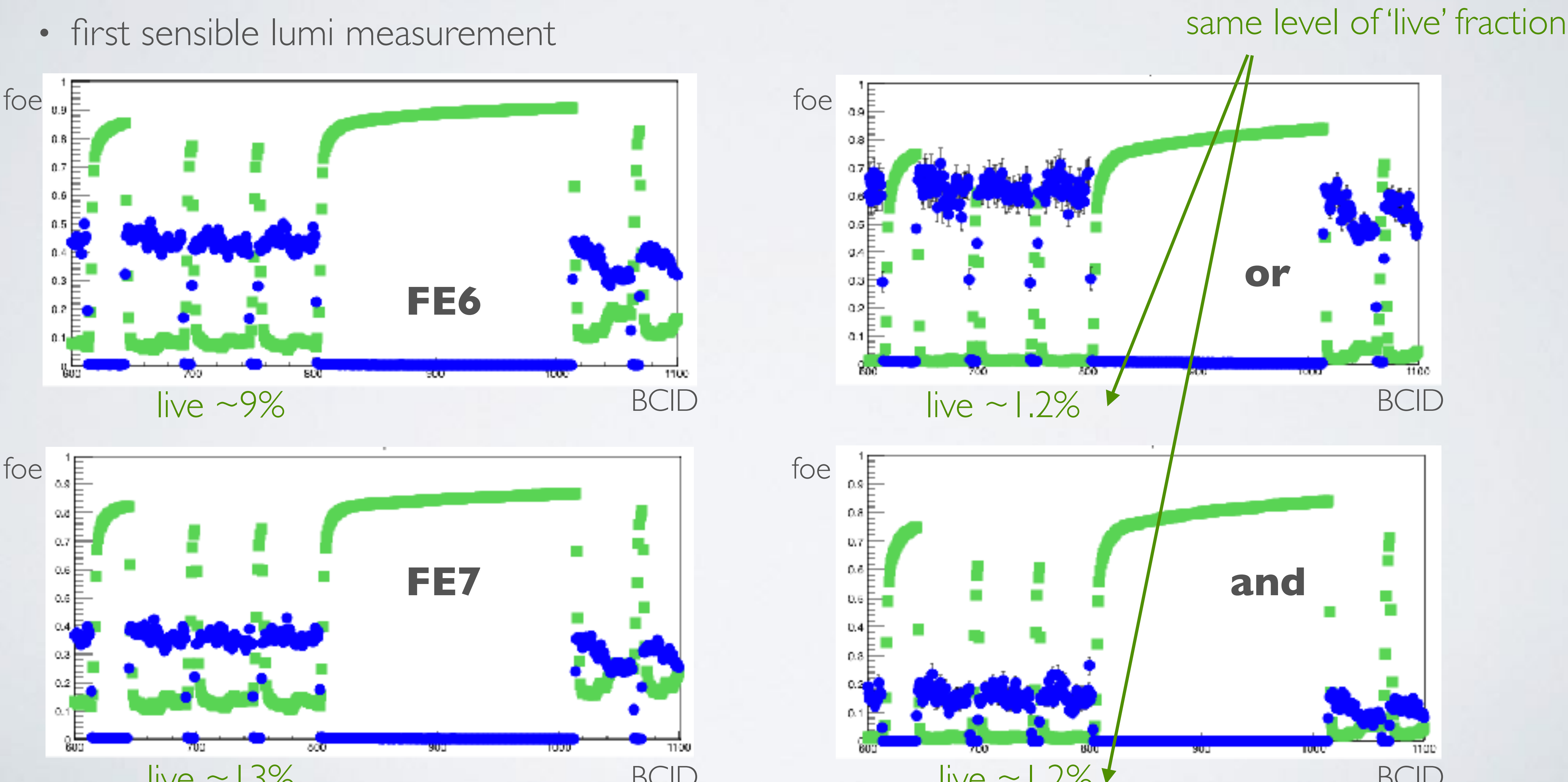
99% → 8,5%



RECORDING 11.

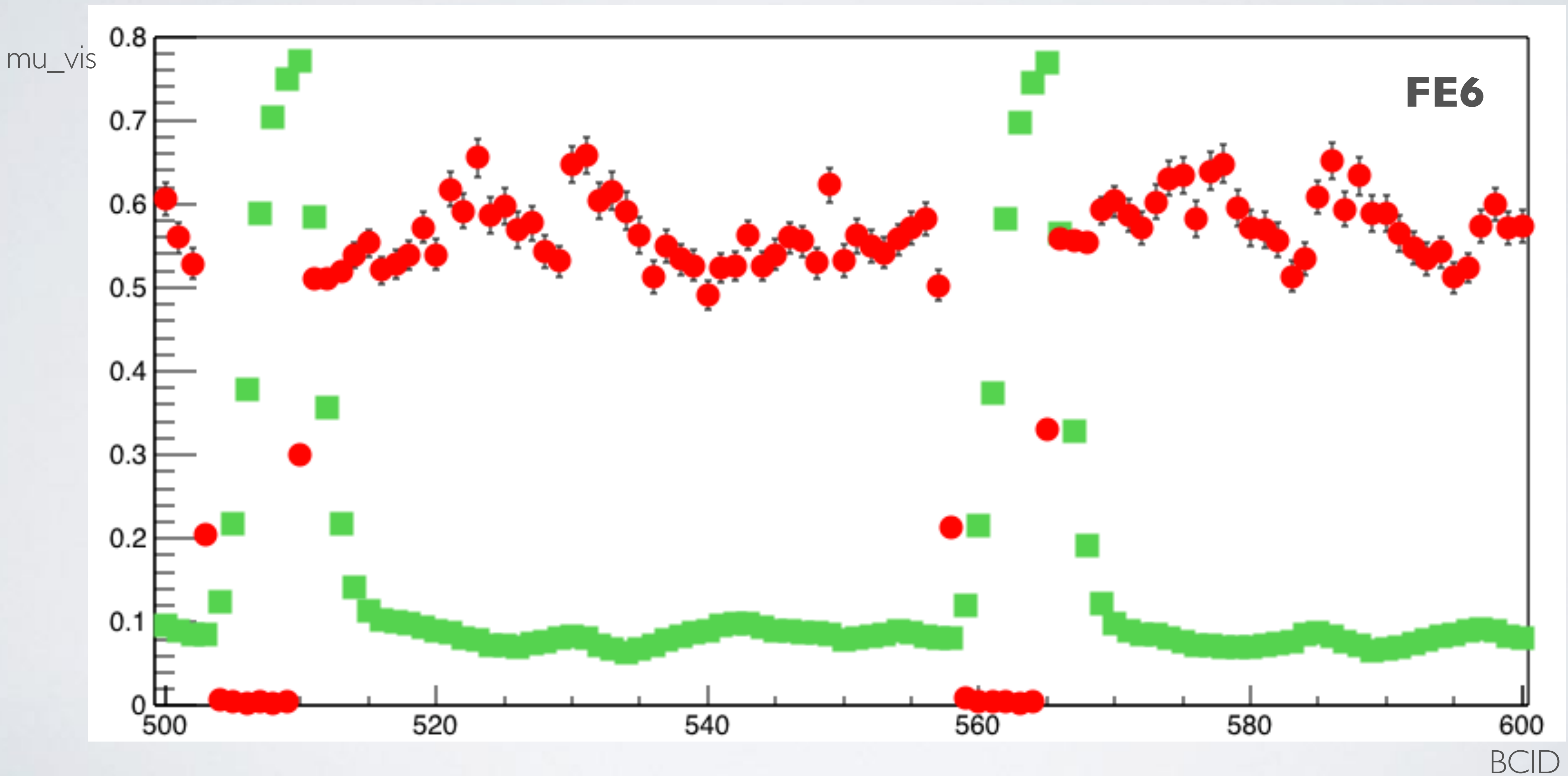
- single run with 2544 colliding bunches (data tag: 2018_10_02_07_48_48)
- mask change well pronounced in the results
- first sensible lumi measurement

Algorithms	
0	**single module FE6**
1	**single module FE7**
6	**or**
7	**and**



RECORDING 11.

- actual lumi data (mu-corrected)

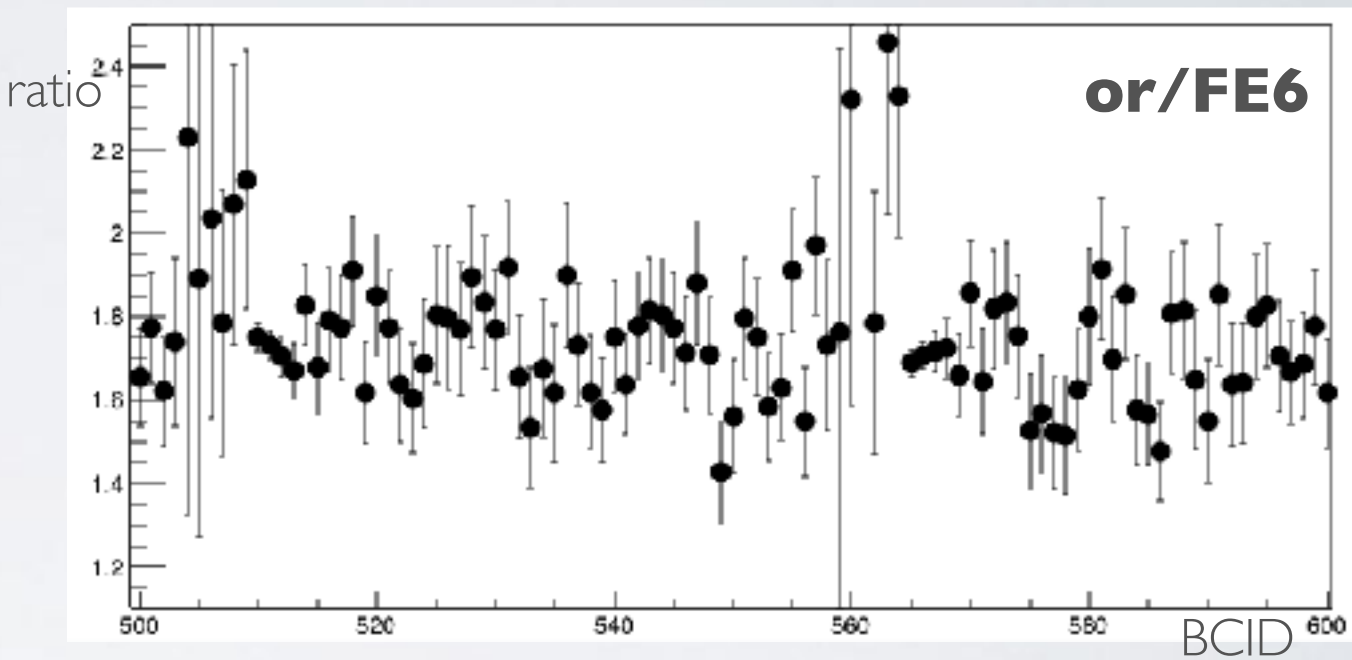


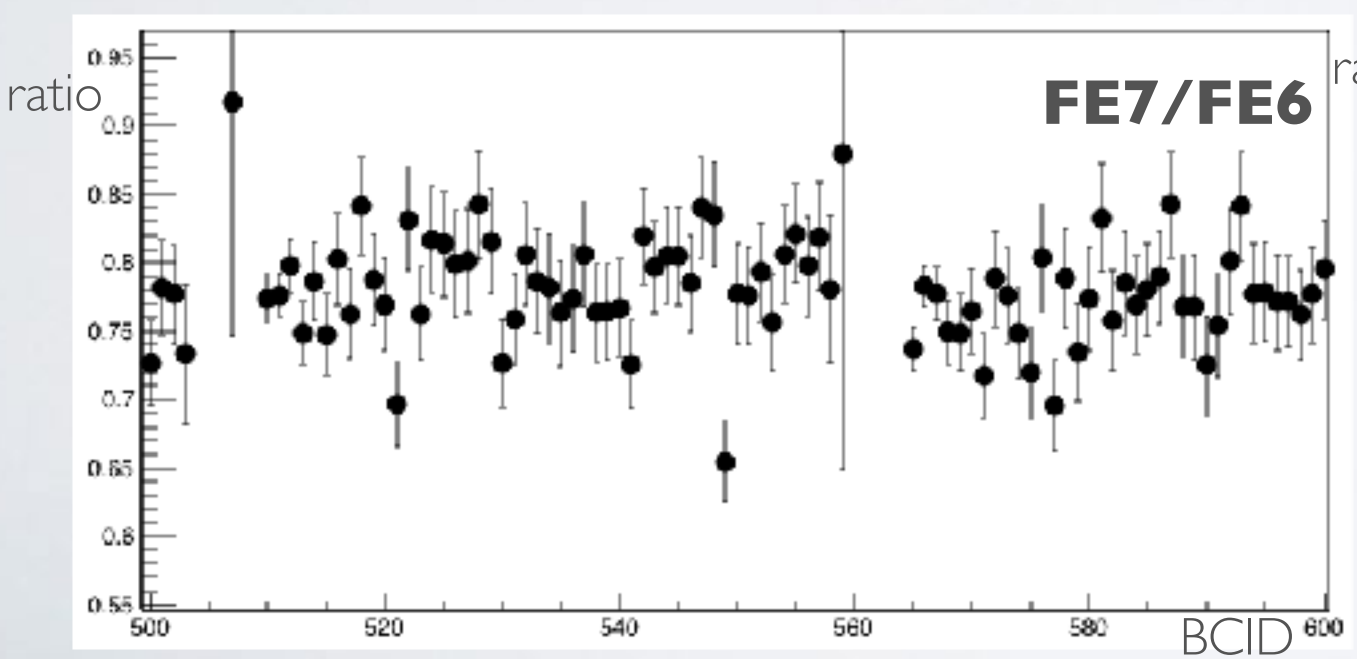
RECORDING 11.

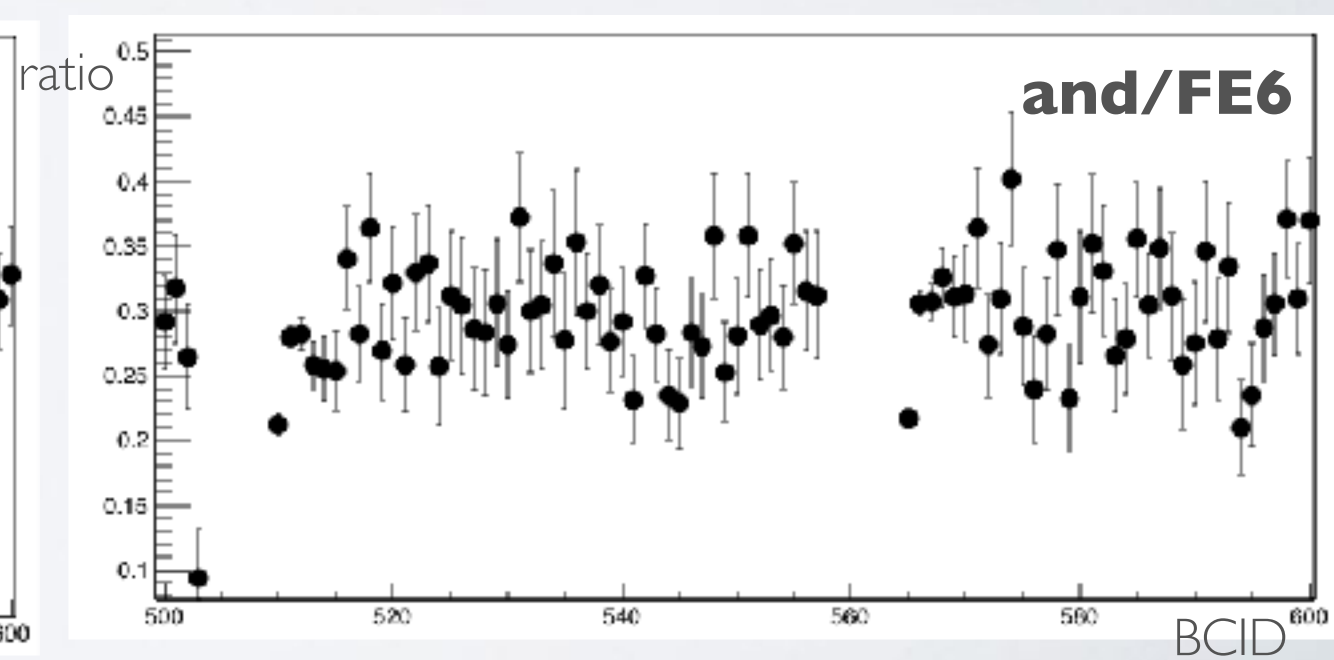
- consistency comparison between the algorithms
- algo0 = FE6 taken as a reference

$$\text{ratio} = \frac{\textbf{lumi(algo X)}}{\textbf{lumi(algo 0)}}$$

- ratio should be independent of BCID and time



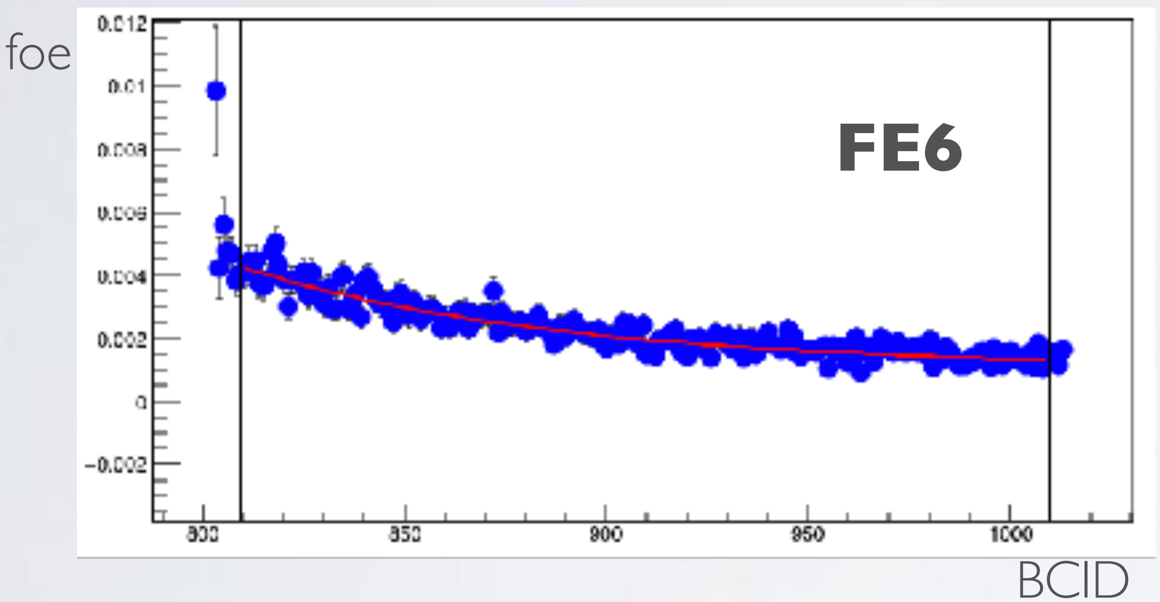


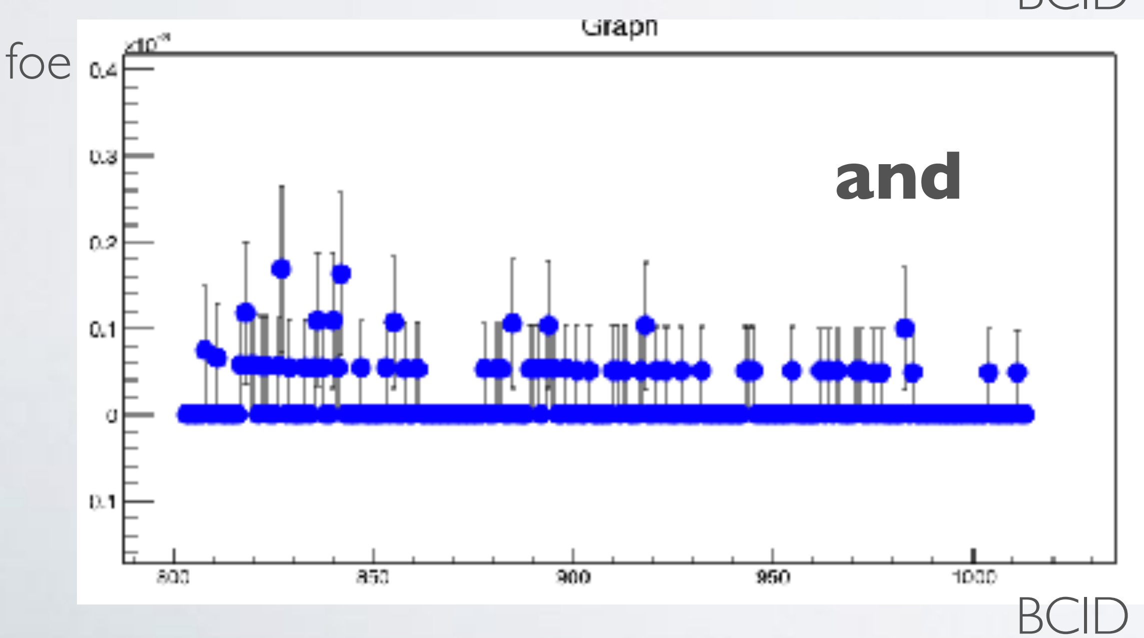


RECORDING 11.

- estimating noise

- looking at the abort gap and fitting: exp+C





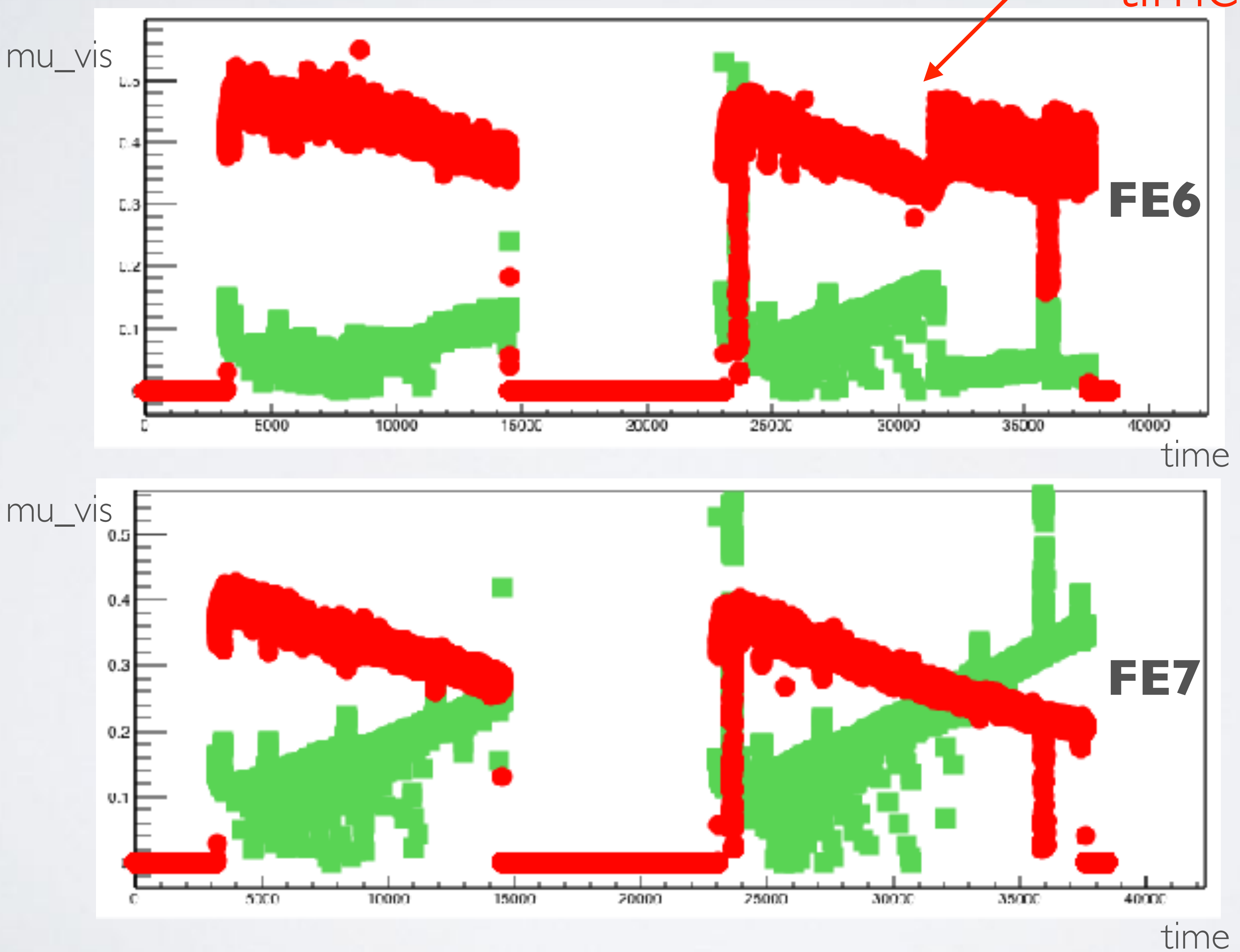
algo	λ	const.
FE6	$(1.26\pm0.13)*10^{-2}$	$(1.06\pm0.03)*10^{-3}$
FE7	$(1.06\pm0.10)*10^{-2}$	$(0.92\pm0.16)*10^{-3}$
or	$(1.16\pm0.08)*10^{-2}$	$(2.04\pm0.18)*10^{-3}$
and	/	/

- decay constants consistent
- individual modules noise level consistent
- or gives ~2 times higher noise

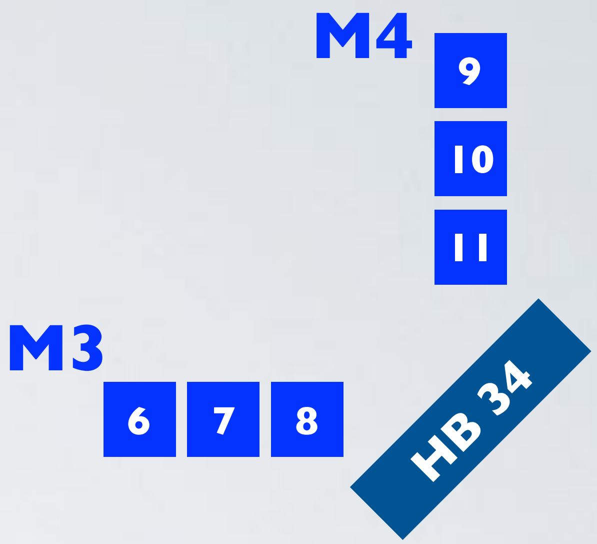
RECORDING 12.

- time evolution for two runs
- FE6 experiences problems from time to time

some configuration on FE changes (observed multiple times on FE6, FE10)



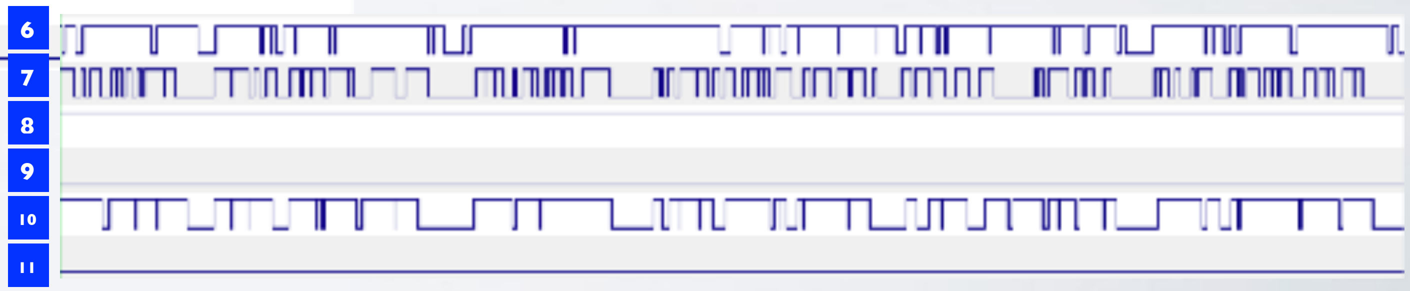
ALGORITHM SETUP-4



- running only side C - only HB-34 used
- so far: M3 give some signal, FE8 does not contribute, FE10 recovered

FPGA	Stream	Map	Algorithm	Logic
South	0	0	0	FE6 - **single module**
		1	1	FE7 - **single module**
	1	0	6	FE10 - **single module**
		1	7	or(FE7, FE10) - **or**

before mask change

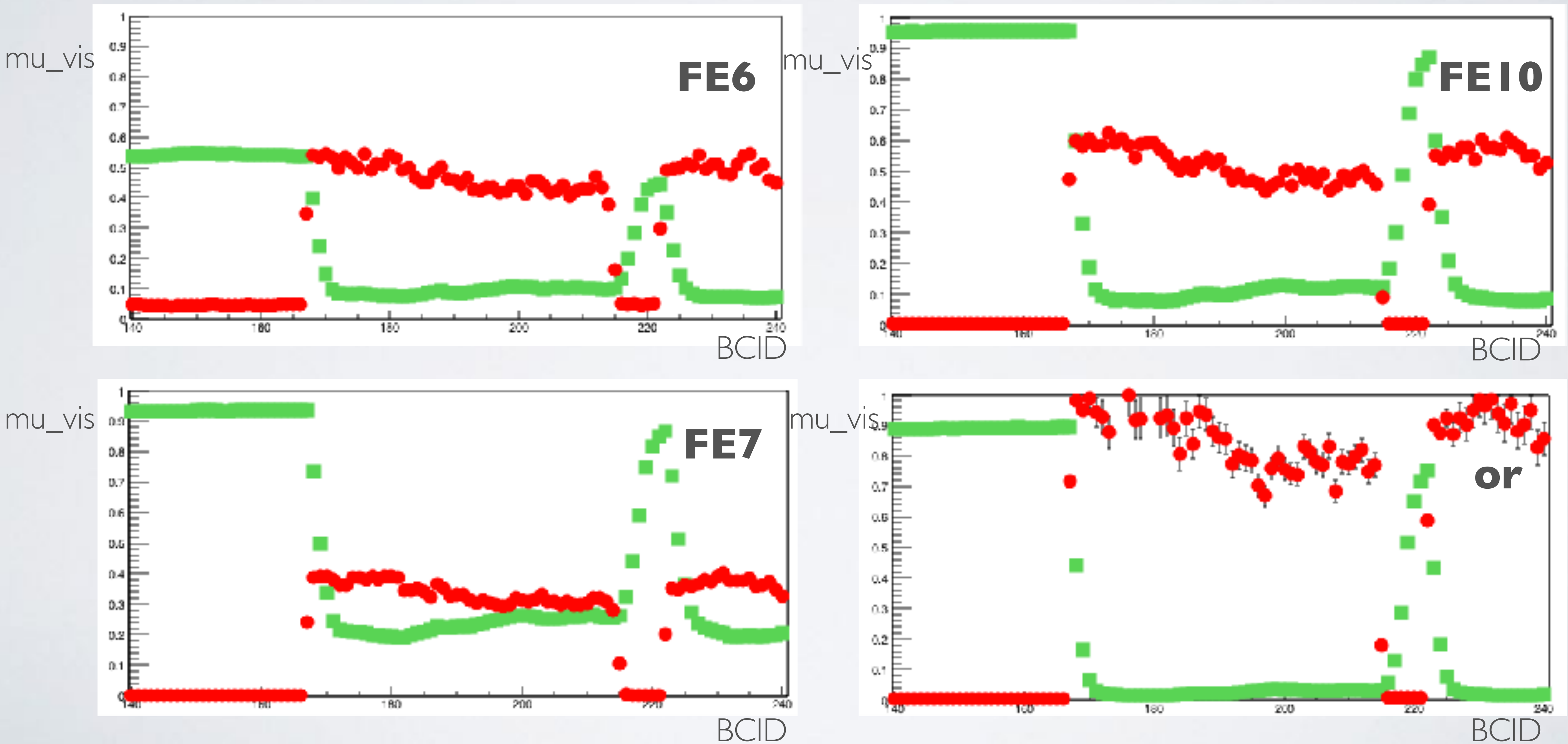


after mask change

RECORDING 13.

Algorithms	
0	**single module FE6**
1	**single module FE7**
6	**single module FE10**
7	**or of two**

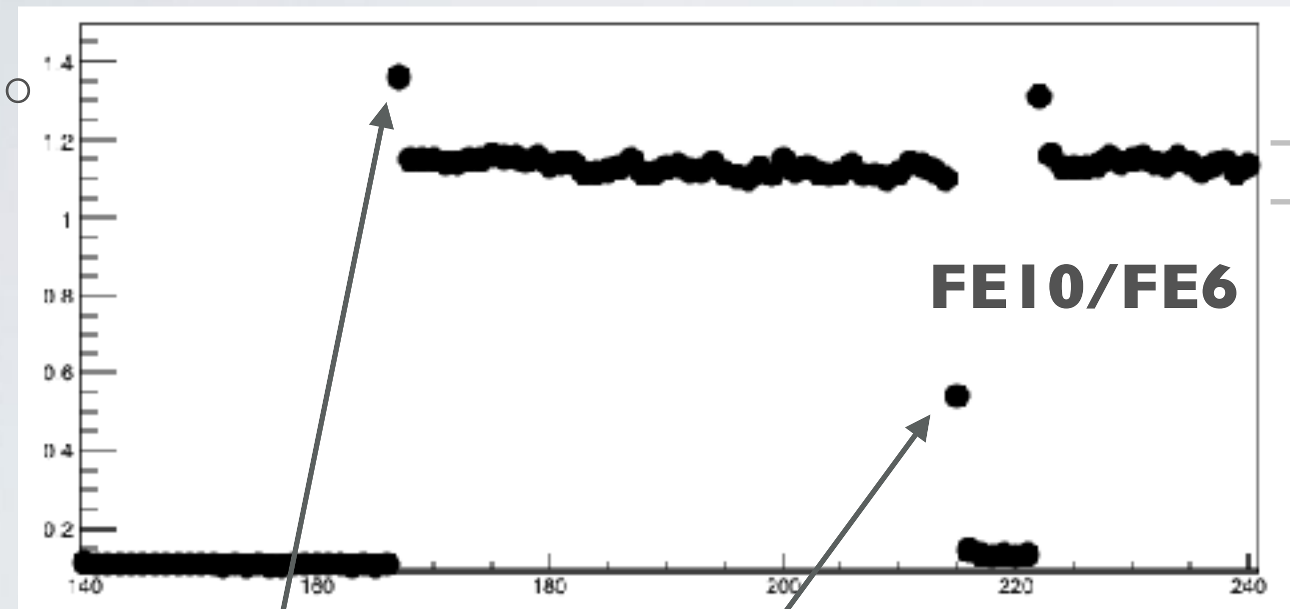
- F10 as a new input to the algorithms
- functional as others



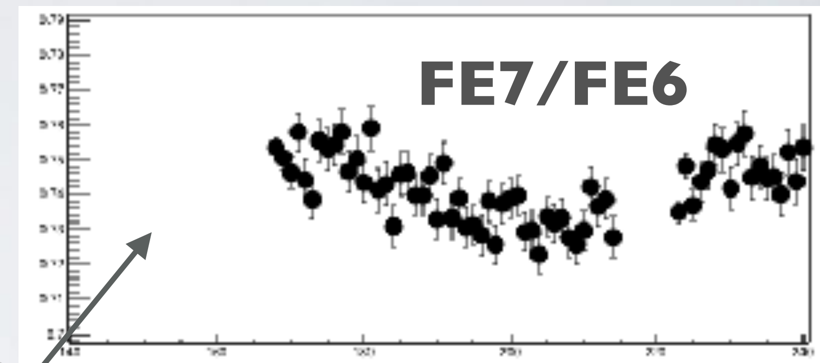
RECORDING 13.

- check of FE10 data
- first and last bunch of the train different

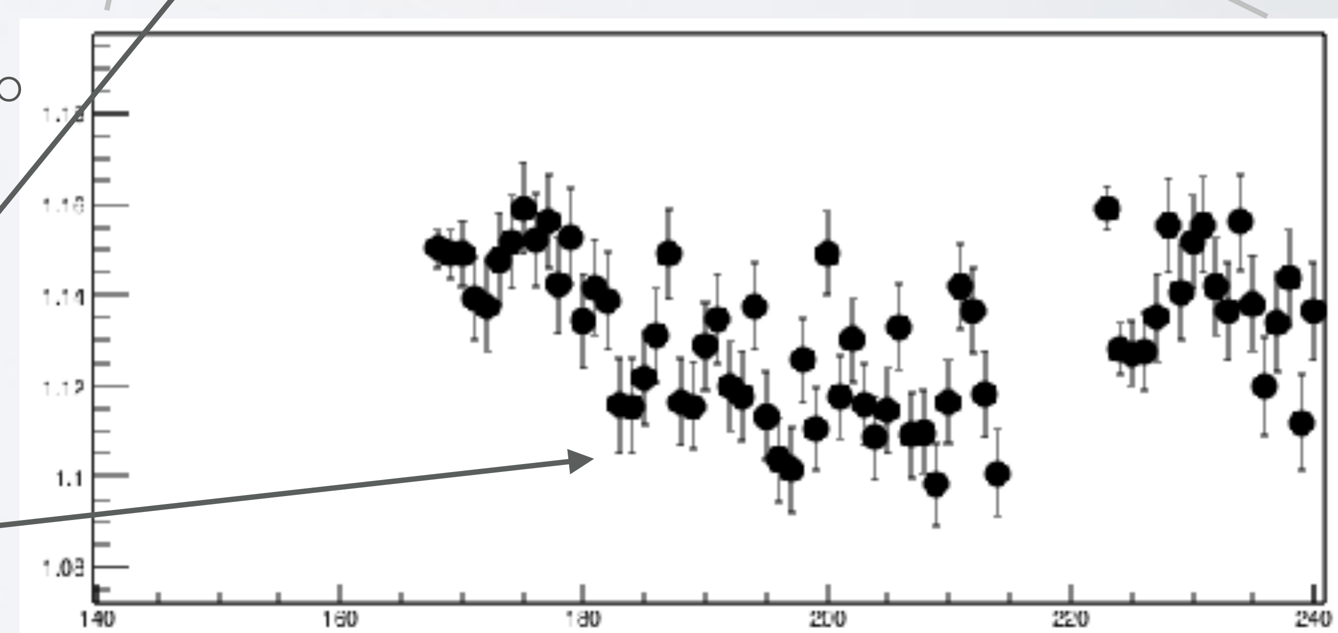
ratio



BCID



ratio



BCID

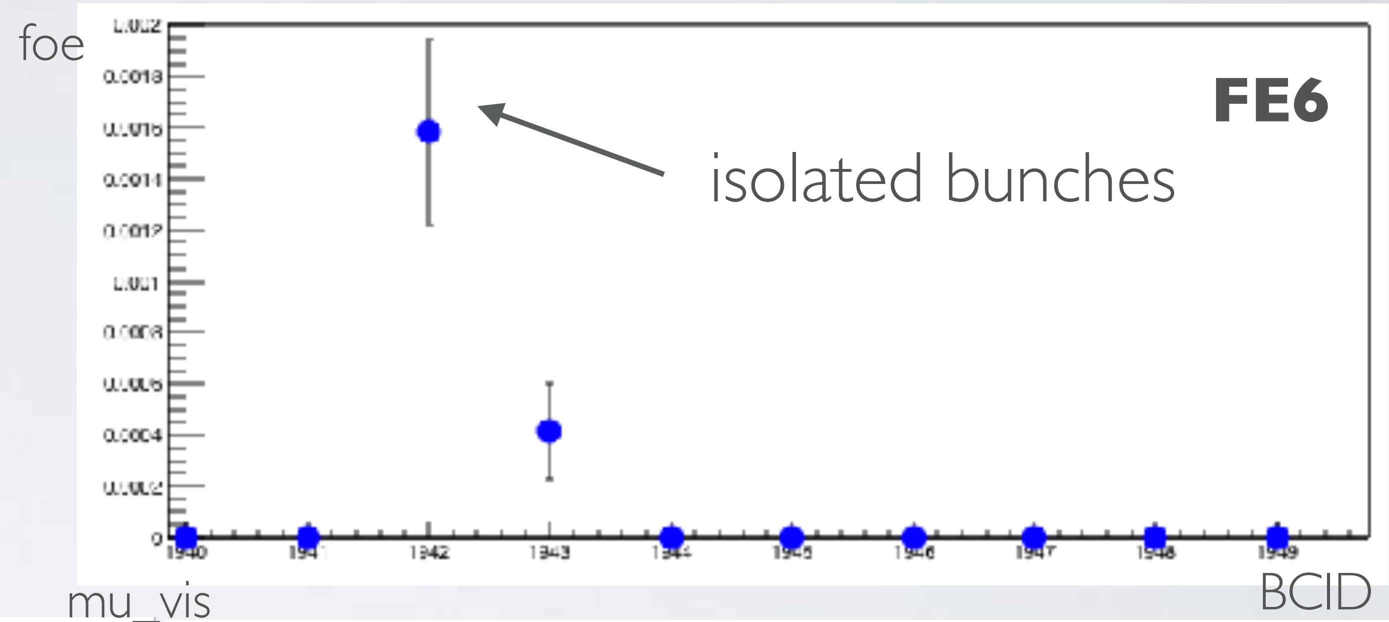
significant disagreement between the modules

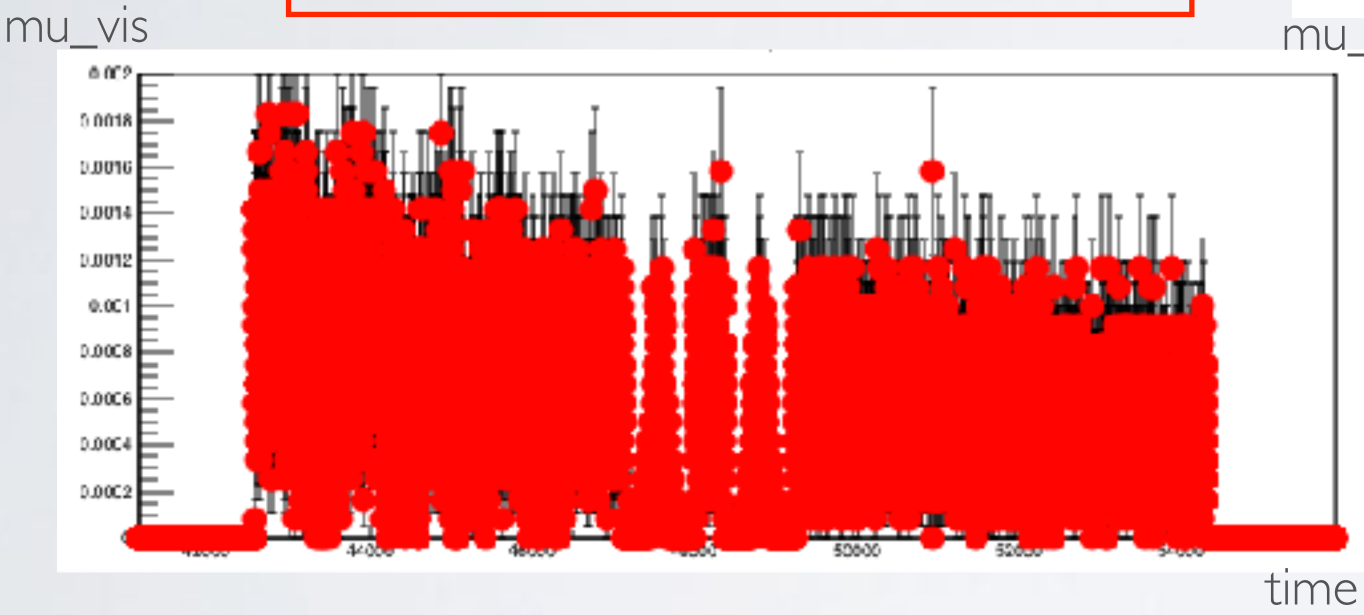
some stat. sig. deviation within the train

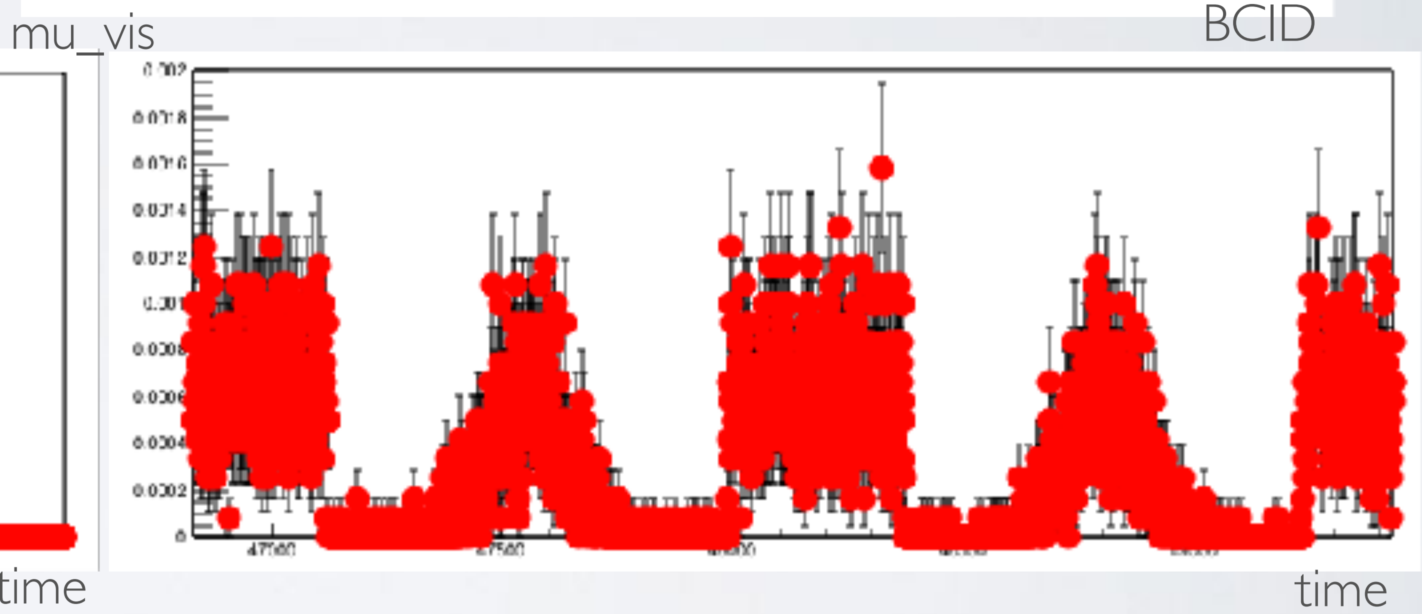
RECORDING 21.

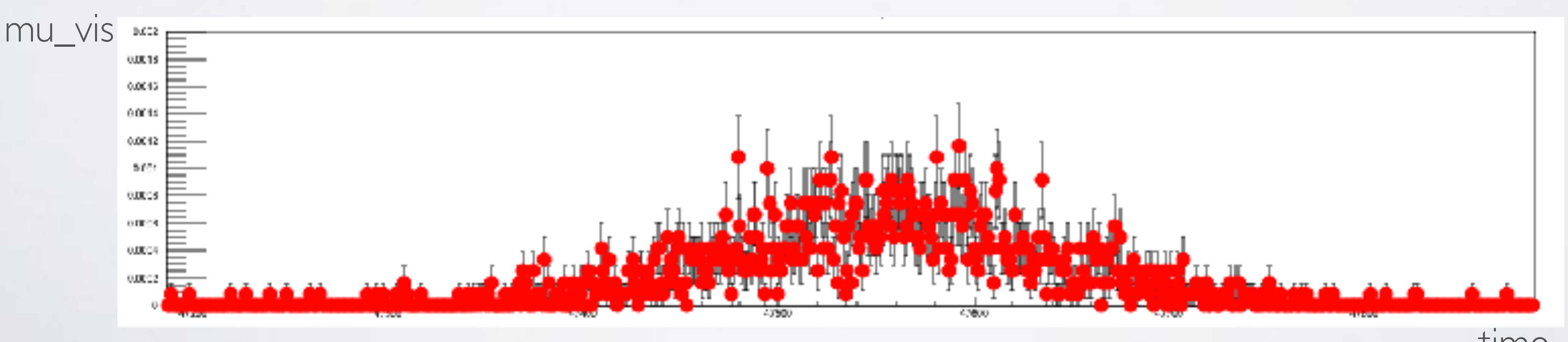
- low lumi runs, includes VdM scan
- readout period changed from ~2s to ~1s

statistic too low for any proper analysis





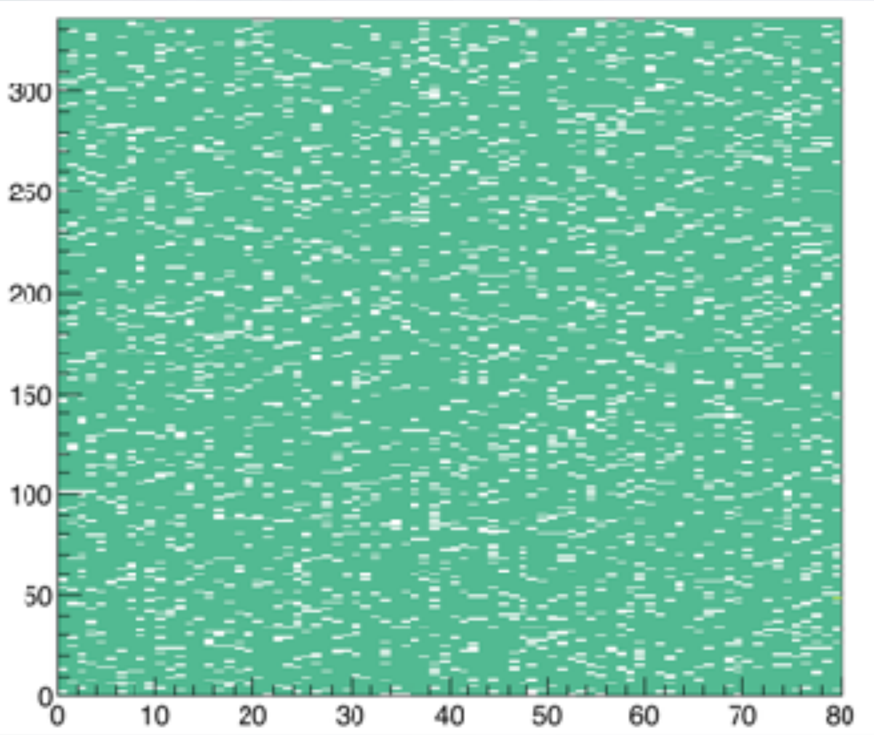




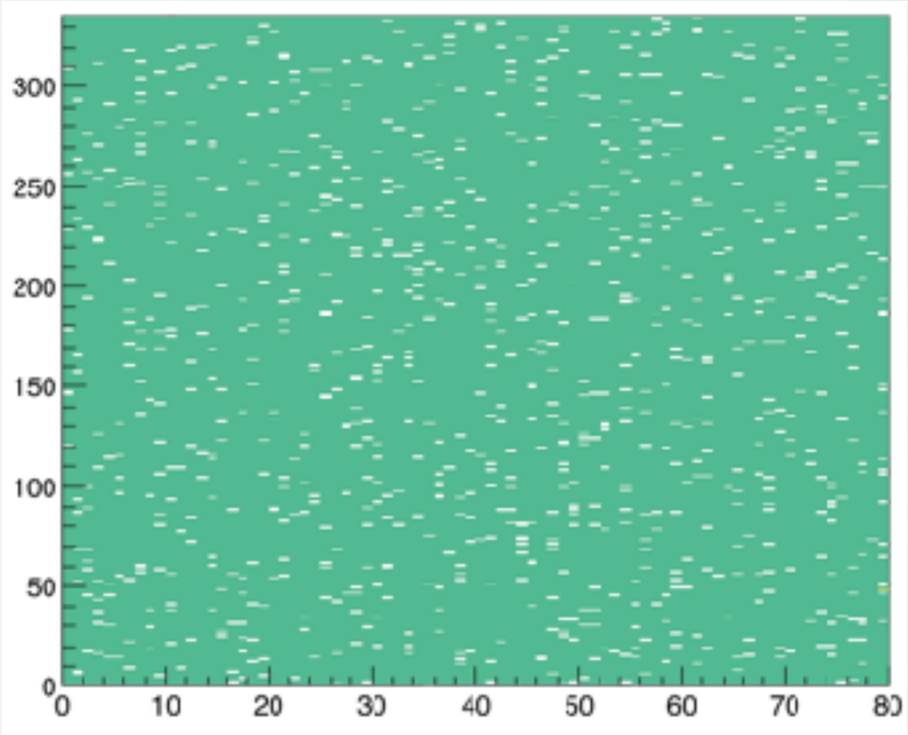
CHANGE OF MASK 2.

- lumi data available, but no estimate how optimal
- estimates show a further reduction would be beneficial
- factor ~4 chosen

8,5%



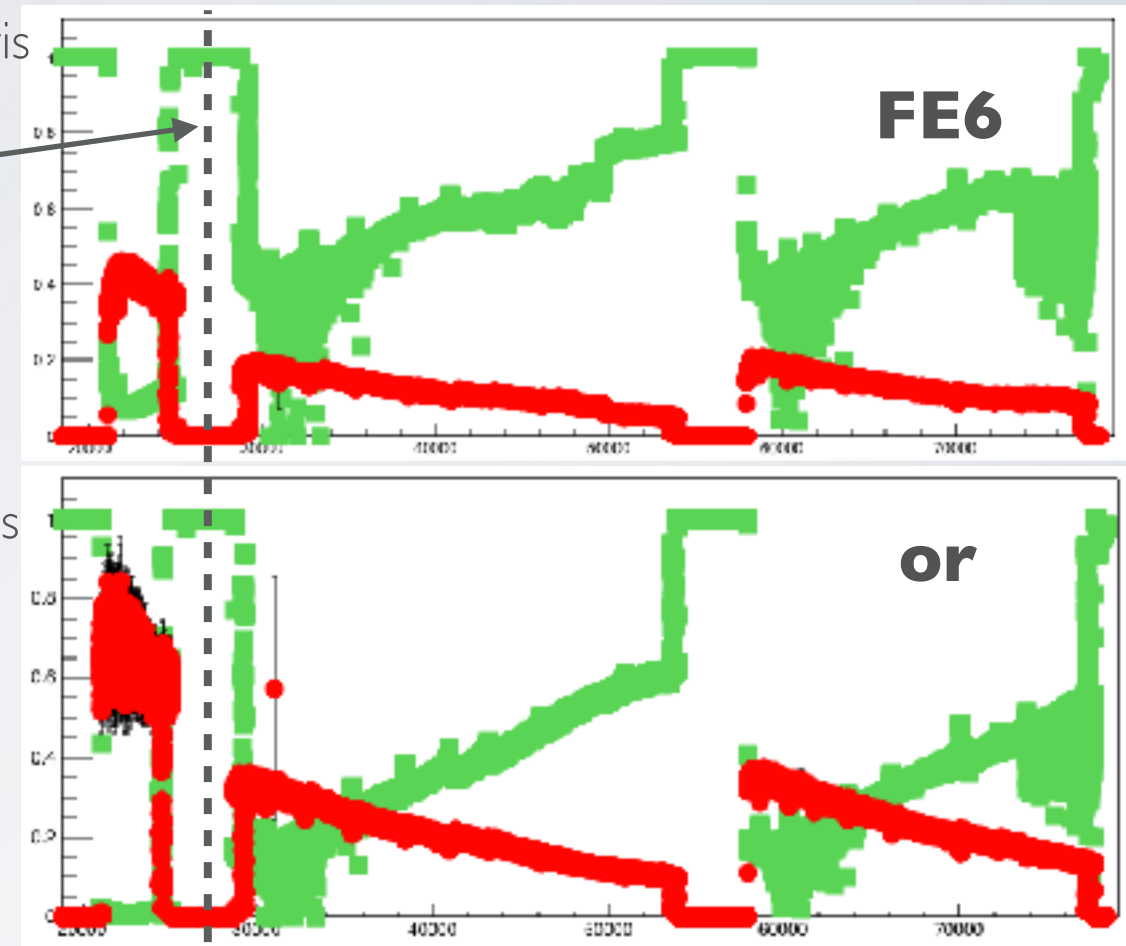
1,2%



RECORDING 22.

- 3 ATLAS runs within this recording
- mask changed between the 1st and 2nd run
- live fraction increased for factor ~5
- hit rate decreased for factor ~3

mu_vis

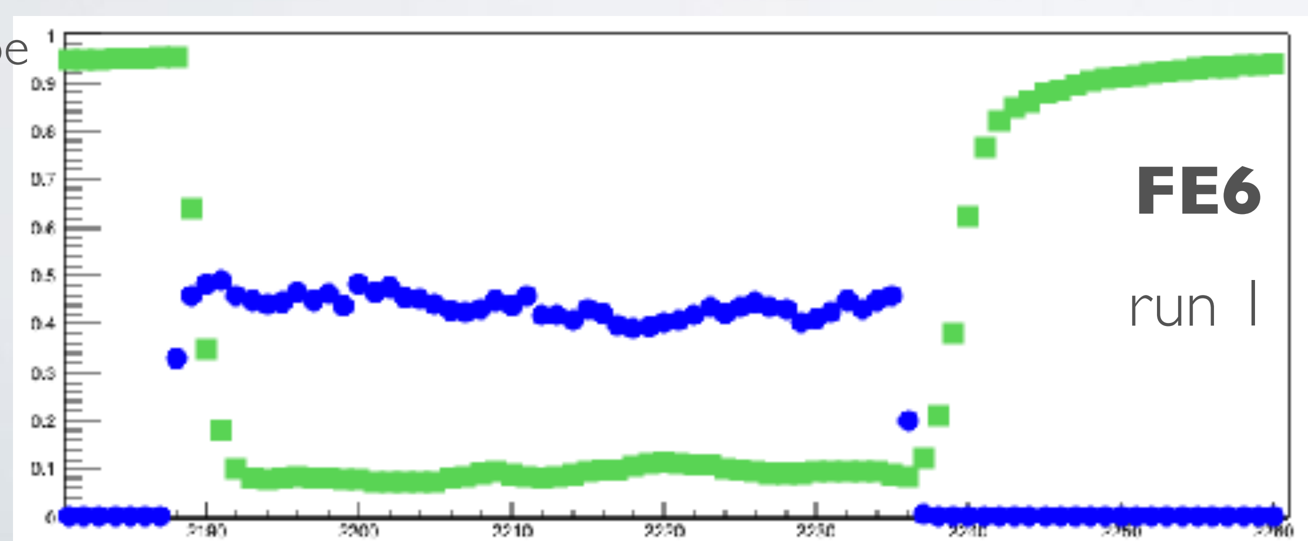


mu_vis

time

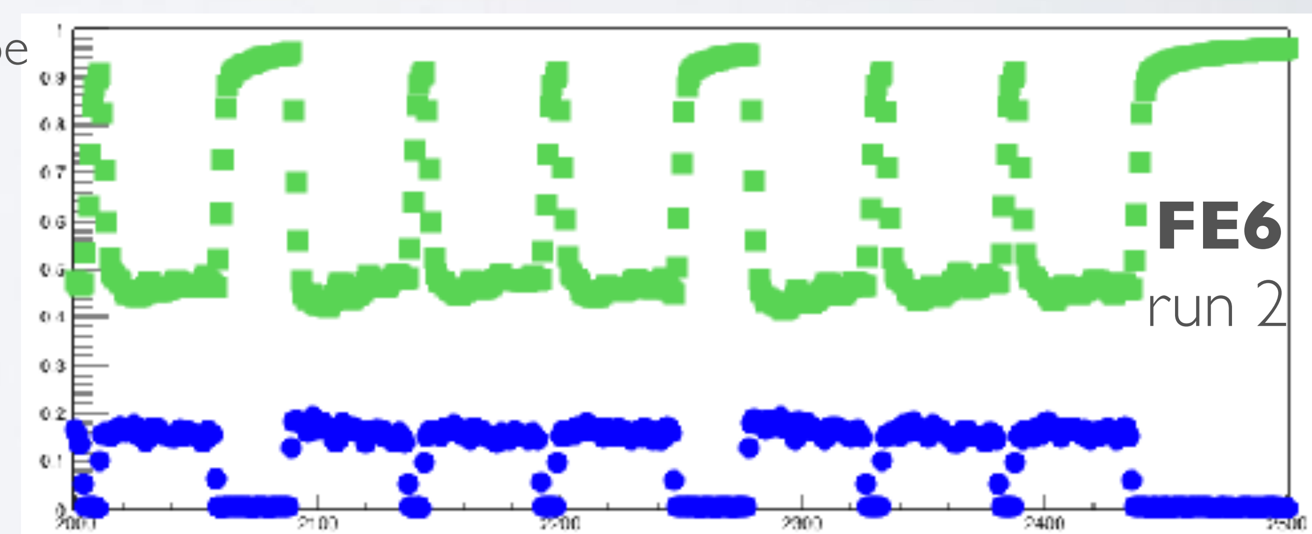
Algorithms	
0	single module FE6
1	single module FE7
6	single module FE10
7	or of two

foe



BCID

foe

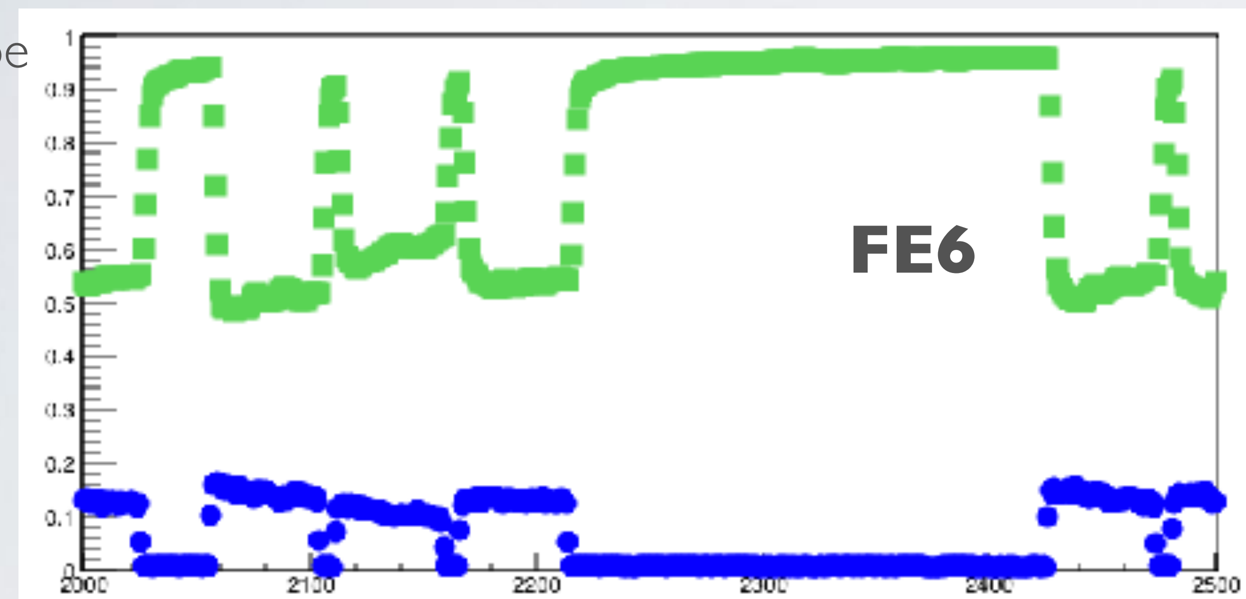


BCID

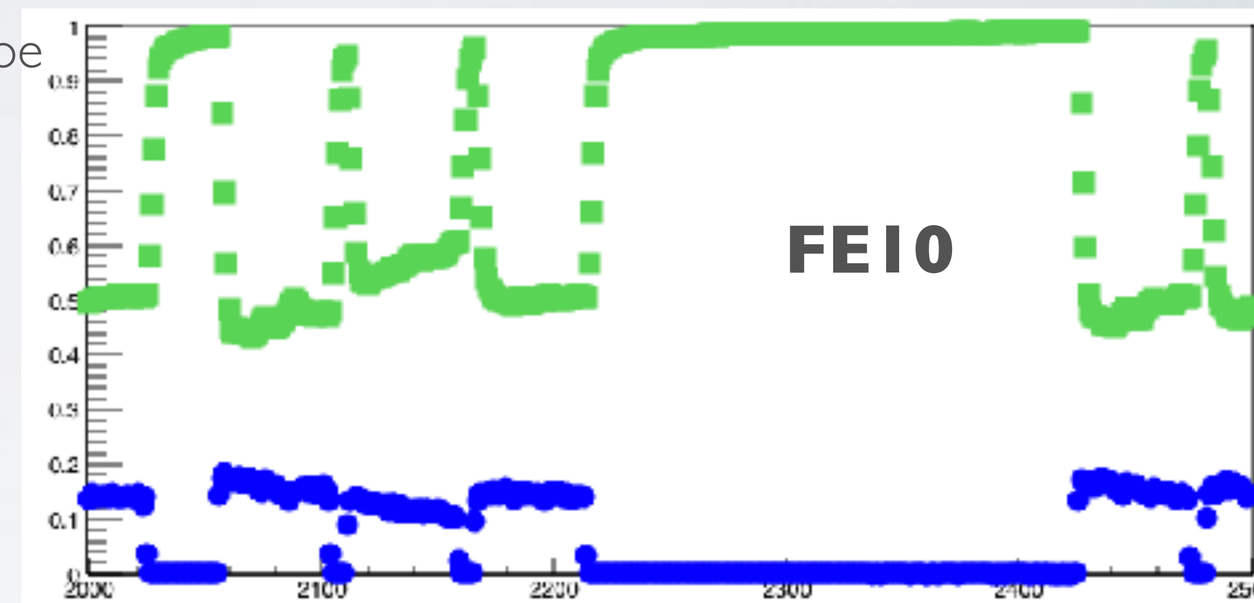
RECORDING 22.

- comparison of algorithms within run 2

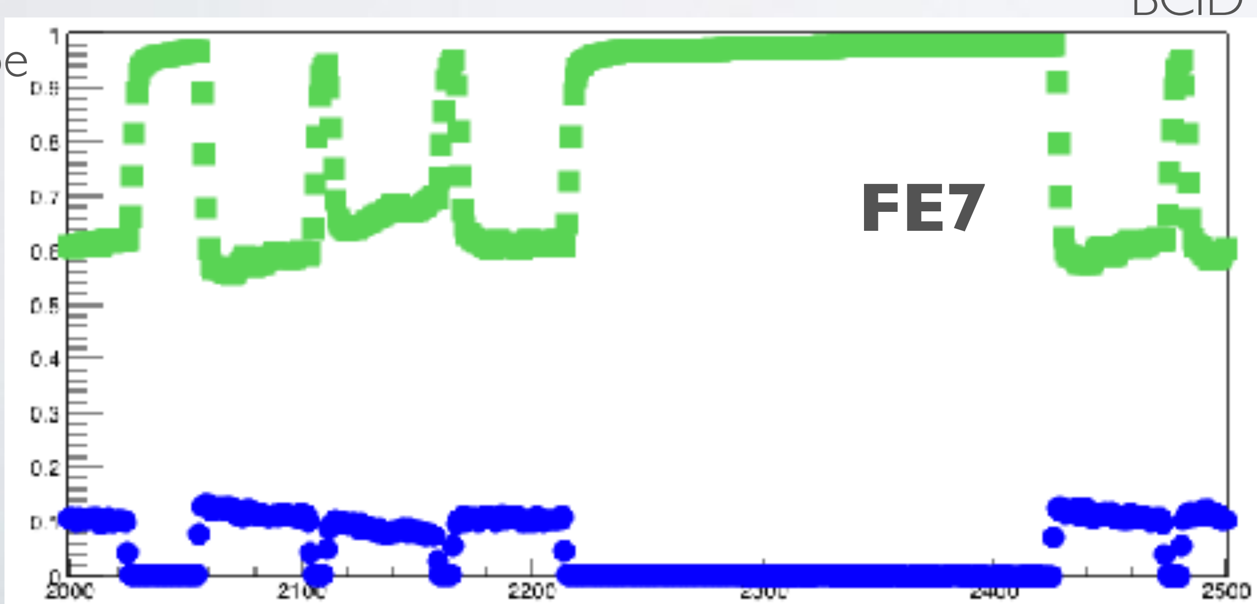
Algorithms	
0	**single module FE6**
1	**single module FE7**
6	**single module FE10**
7	**or of two**

foe


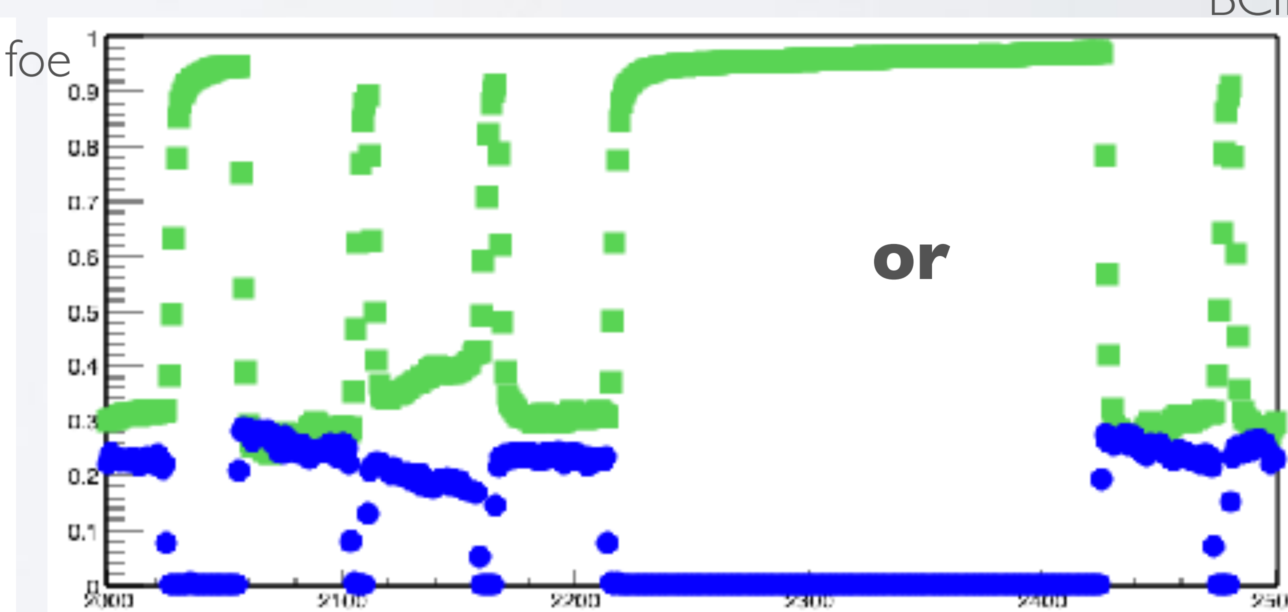
BCID

foe


BCID

foe


BCID

foe


BCID

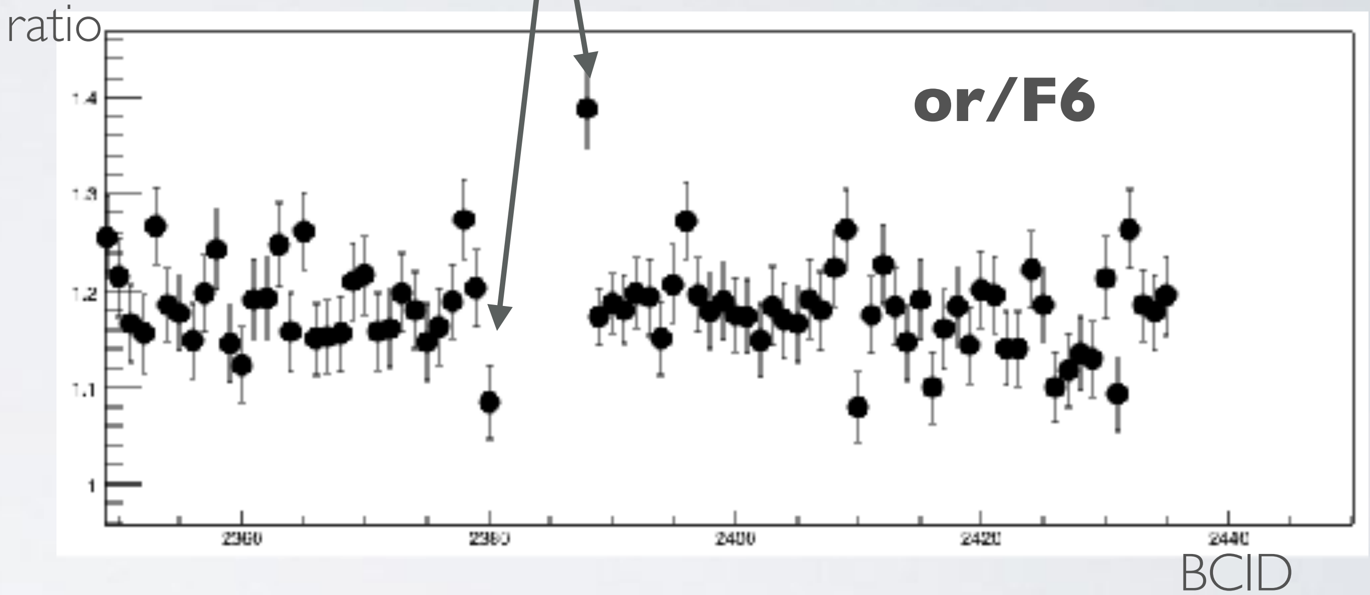
RECORDING 22.

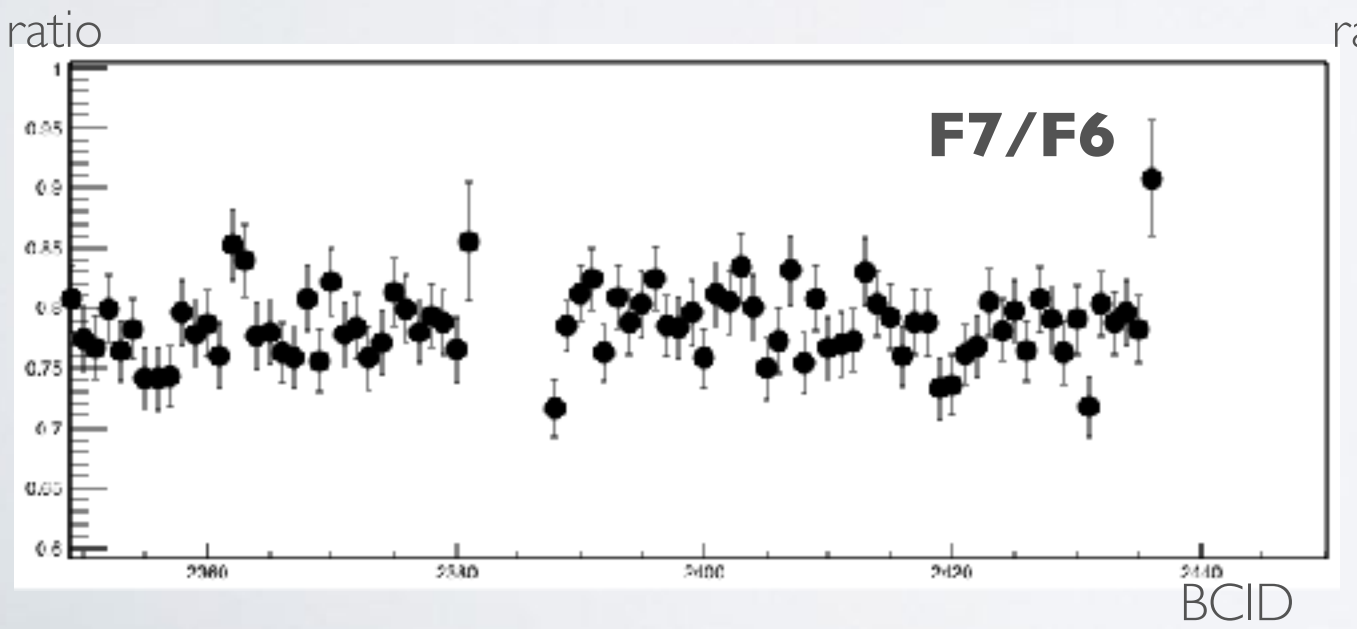
- run 2 used for comparing algorithm consistency
- algo0 = F6 taken as a reference

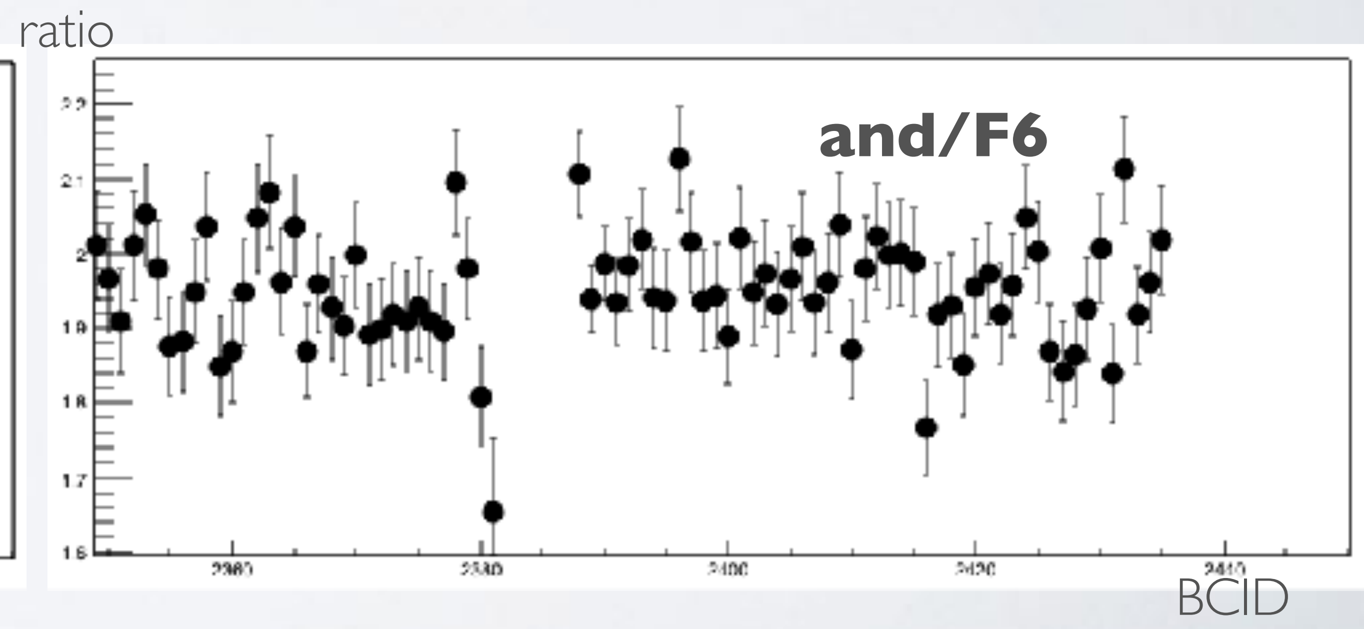
$$\text{ratio} = \frac{\textbf{lumi(algo X)}}{\textbf{lumi(algo 0)}}$$

- ratio should be independent of BCID and time

first and last still stand out



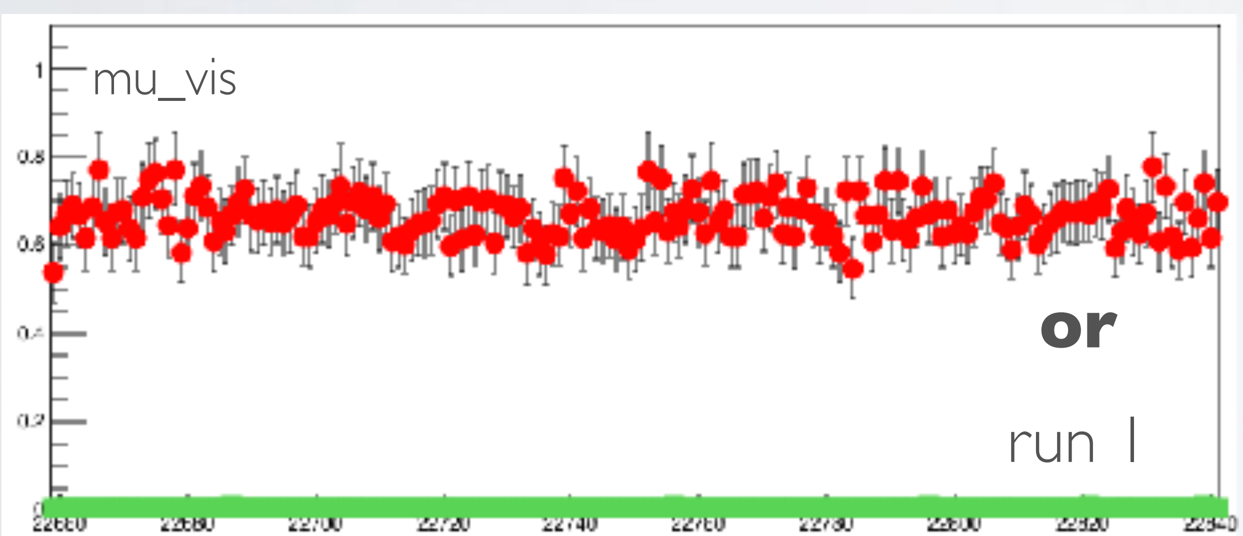




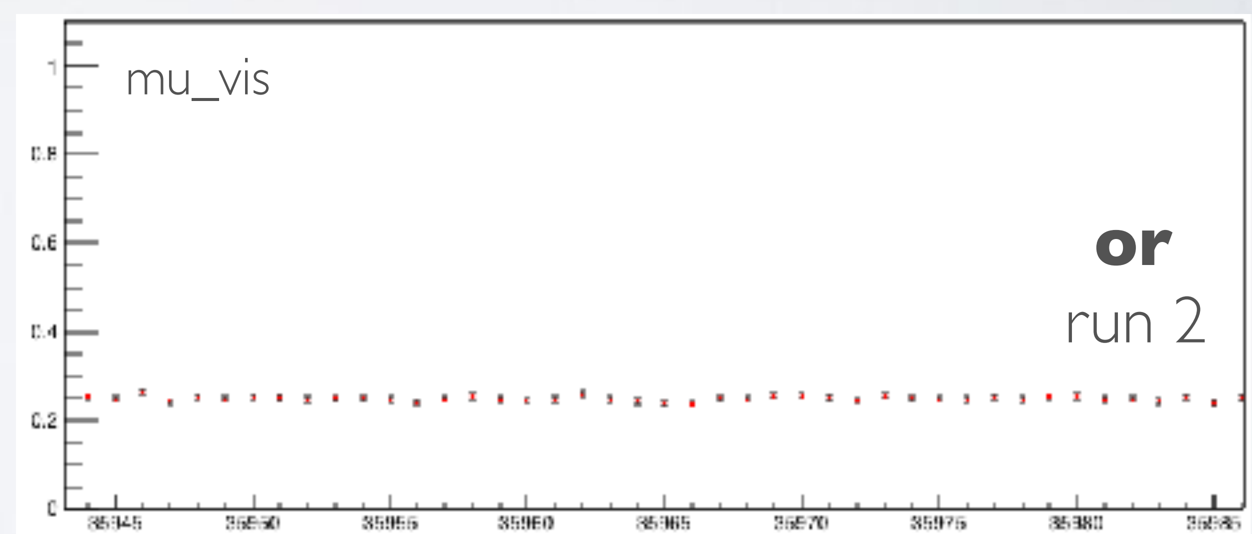
RECORDING 22.

- comparison of statistical errors for a single reading
- main drive of change is the effective area
- statistical error estimated on mu_vis

mu_vis	run 1	run 2
F7	0.35±0.01 (2,8%)	0.1±0.003 (3,0%)
or(F7,F10)	0.7±0.07 (10%)	0.3±0.007 (2.4%)



time



time

RECORDING 22.

- knowledge of the stat. errors so far
- for single module algorithms we are in the right region
- for combinations of 2 modules we should not increase the size much
- reducing the active area?
  - estimating that would not help
  - measured rate is decreasing already so we would start losing statistics

area	error
1	3,0%
2	2,4%
4	2,8%
8	10%

correct area for this level of understanding

ALGORITHM SETUP-5

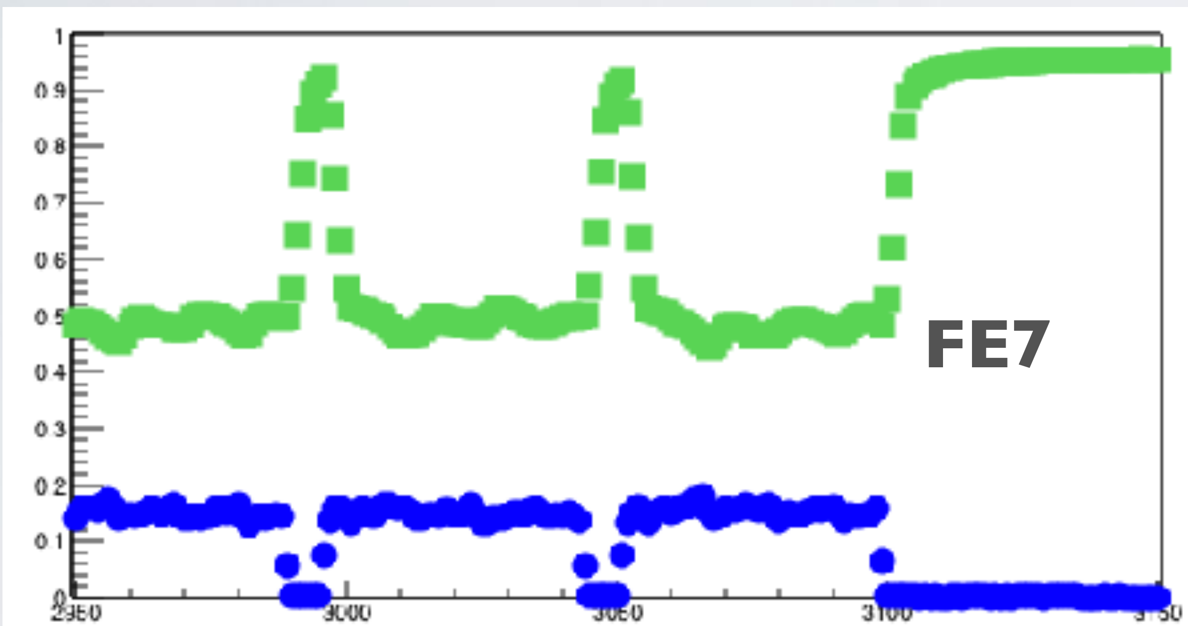
- running only side C - only HB-34 used
- so far: M3 give some signal, FE10 recovered, high level of live fraction

FPGA	Stream	Map	Algorithm	Logic
South	0	0	0	FE7 **- single module**
		1	1	FE10 **- single module**
	1	0	6	or(FE7, FE10) **- or**
		1	7	and(FE7, FE10) **- and**

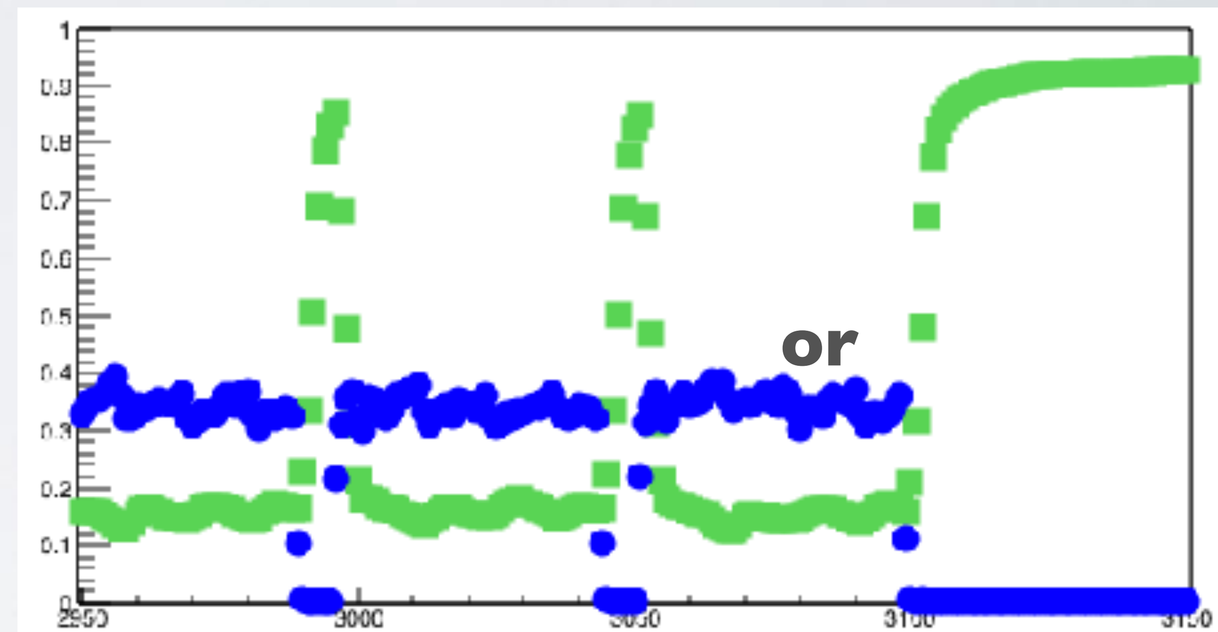
RECORDING 25.

- comparison of AND and OR algorithm
- algorithm consistency can not be checked because of different mu-correction for 'AND'

foe



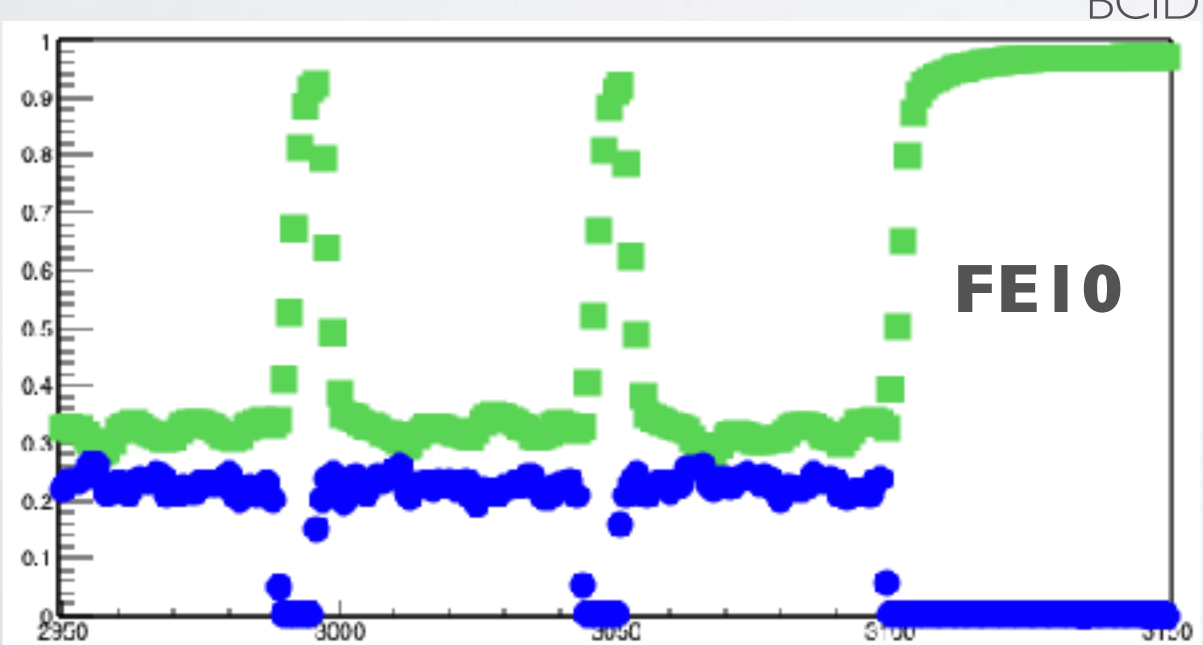
foe



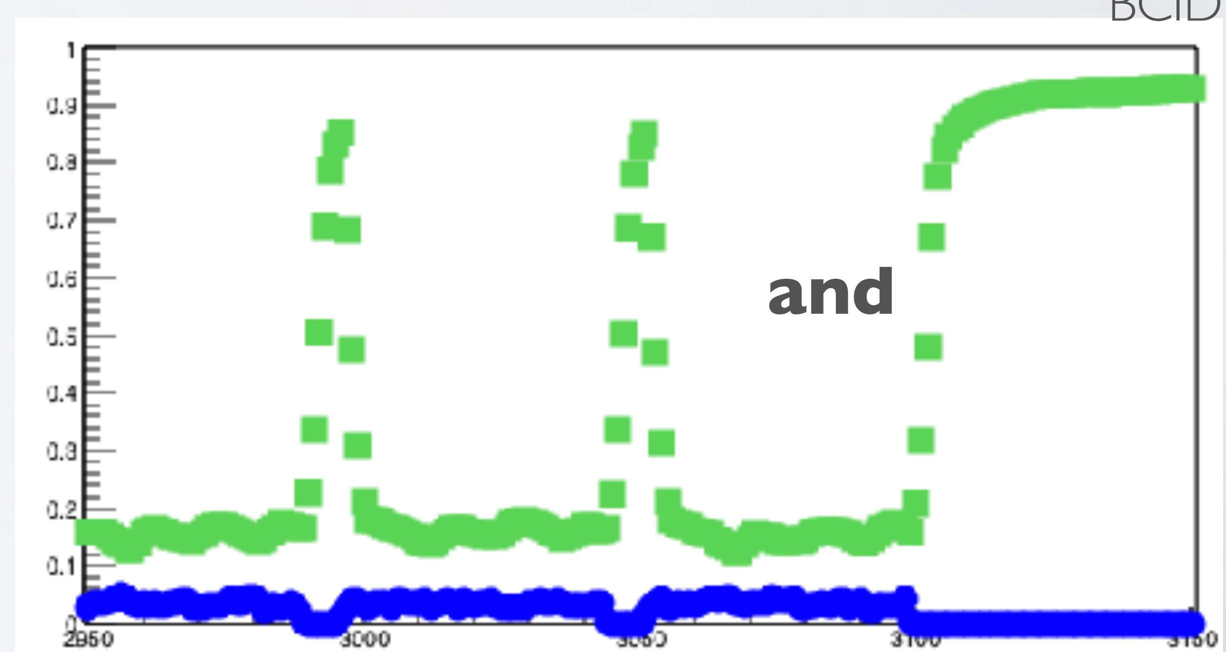
BCID

BCID

foe



foe

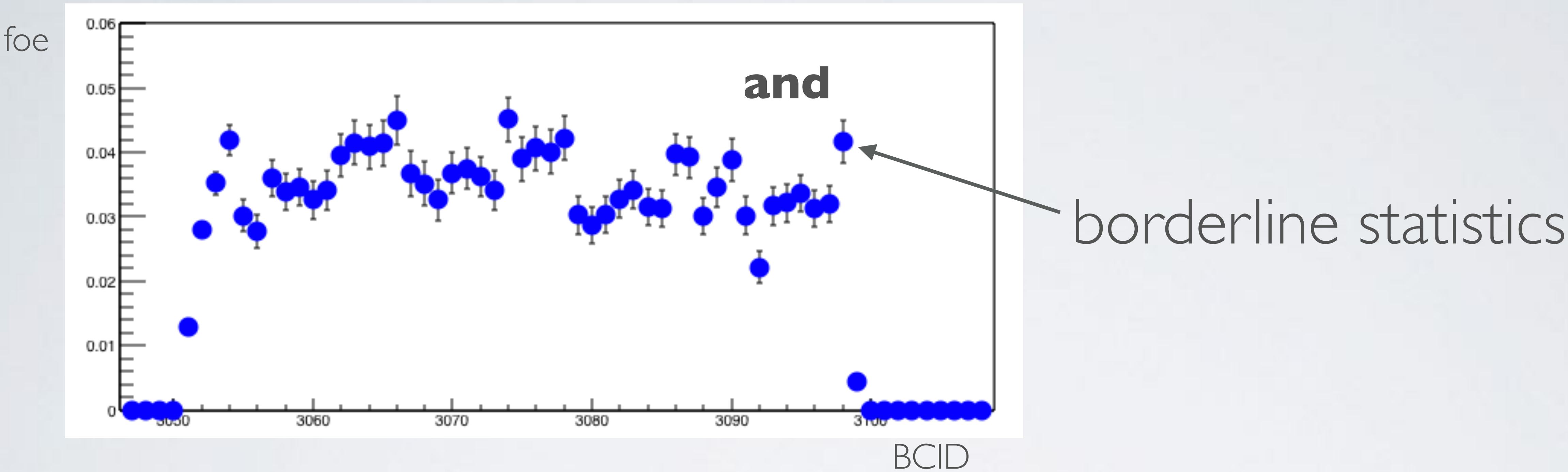


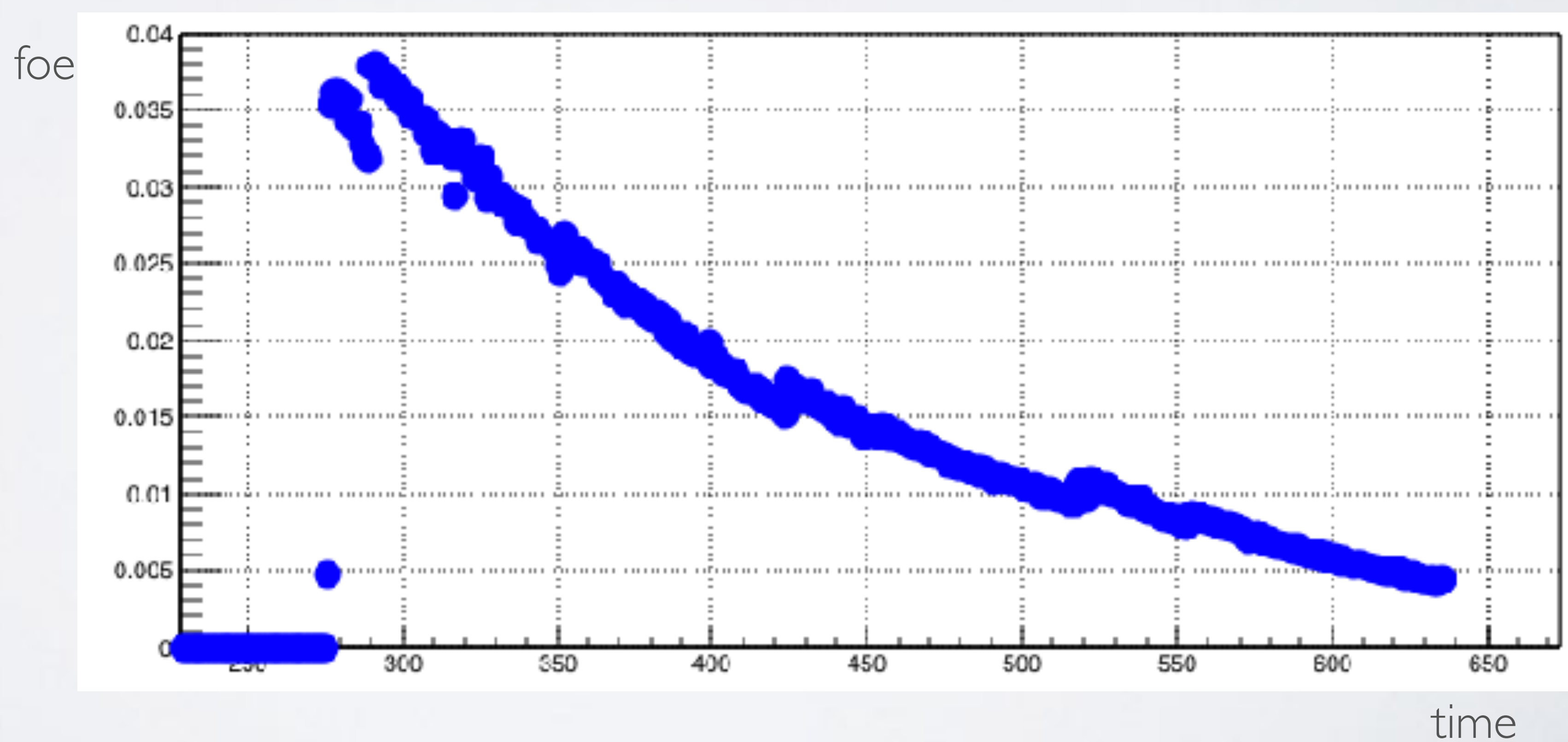
BCID

BCID

RECORDING 25.

- 'AND' algorithm data





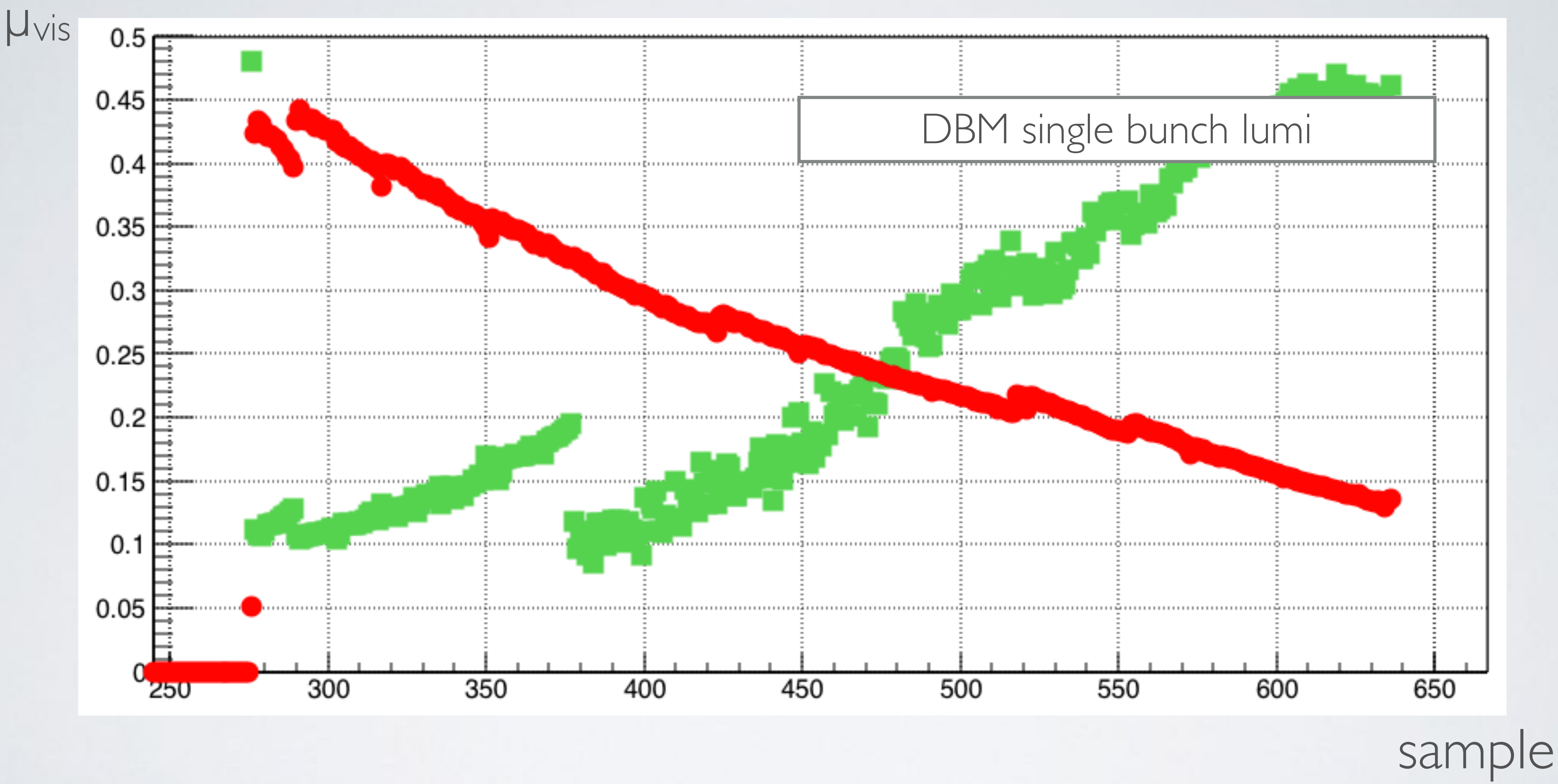
OTHER

- a time constant in the detector response observed
  - order of ~5min

CONCLUSION

- luminosity readout system operational and reliable - no issues in 3 weeks of usage
- configuration iterated to a sensible working point
- no absolute calibration obtained
- some systematic issues remaining - more data and configurations would be needed

SAMPLE DATA


μvis
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
250
300
350
400
450
500
550
600
650
DBM single bunch lumi
sample

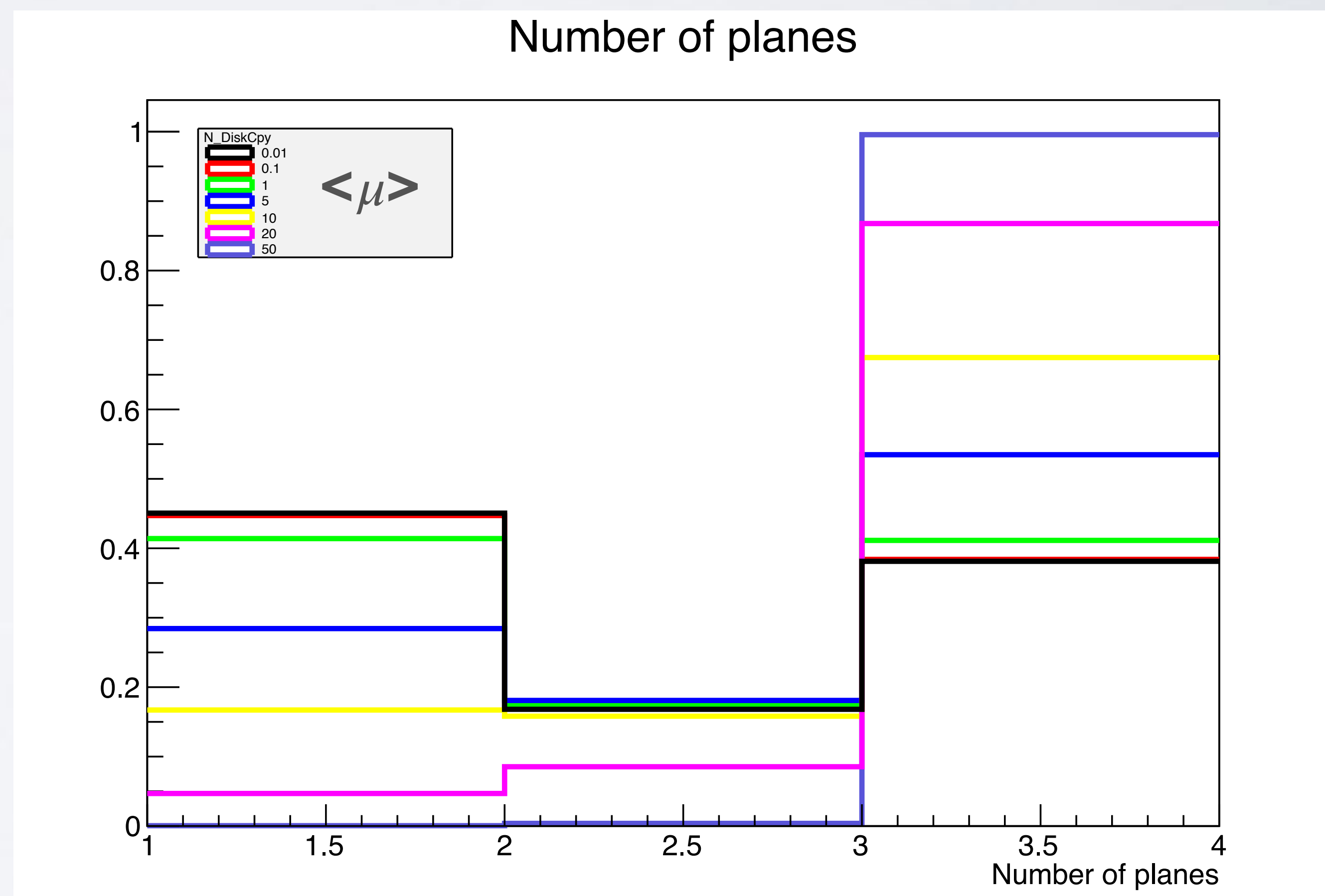
BACKUP

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

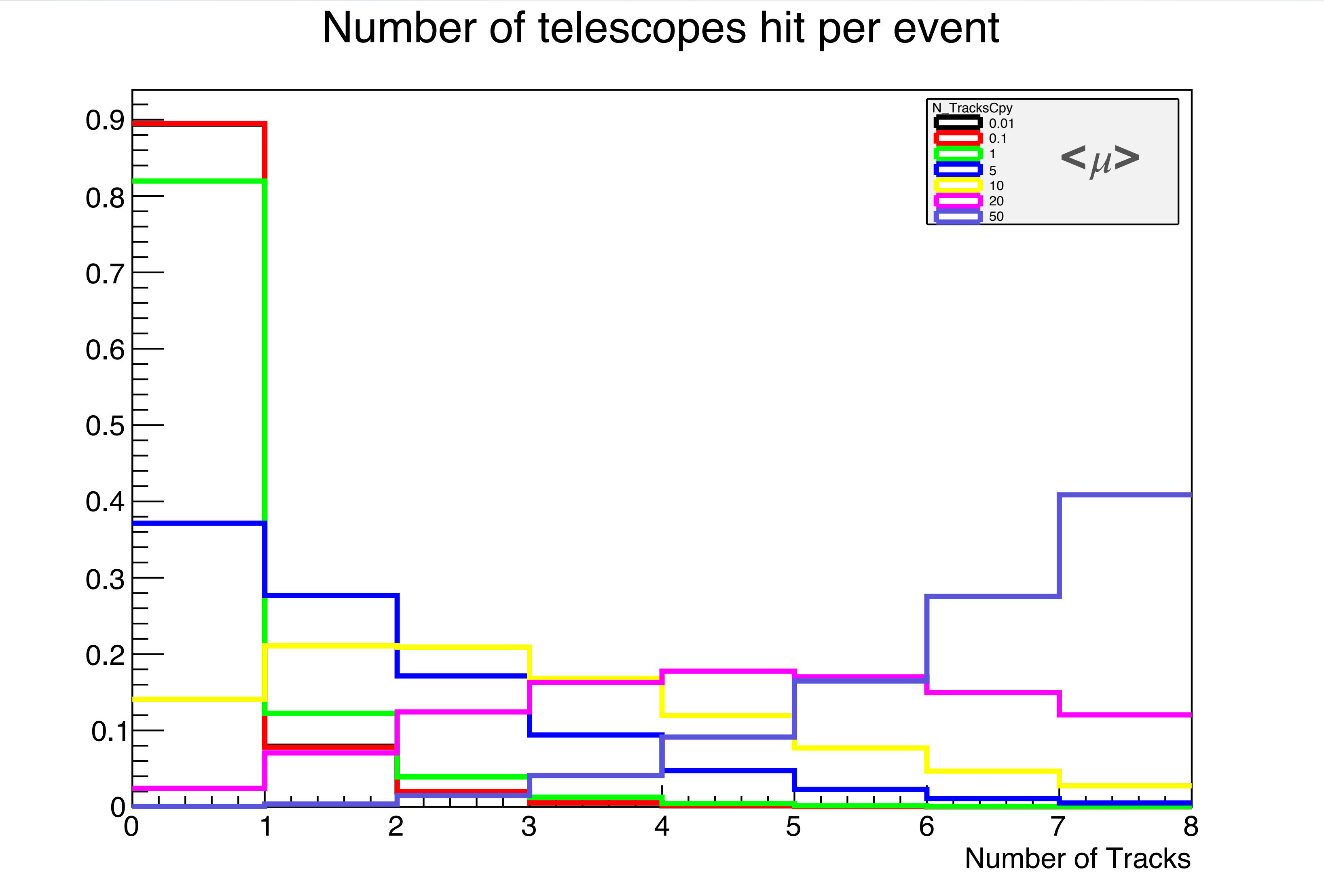
Probabilities

< 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**



T-STREAM POINT OF VIEW

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

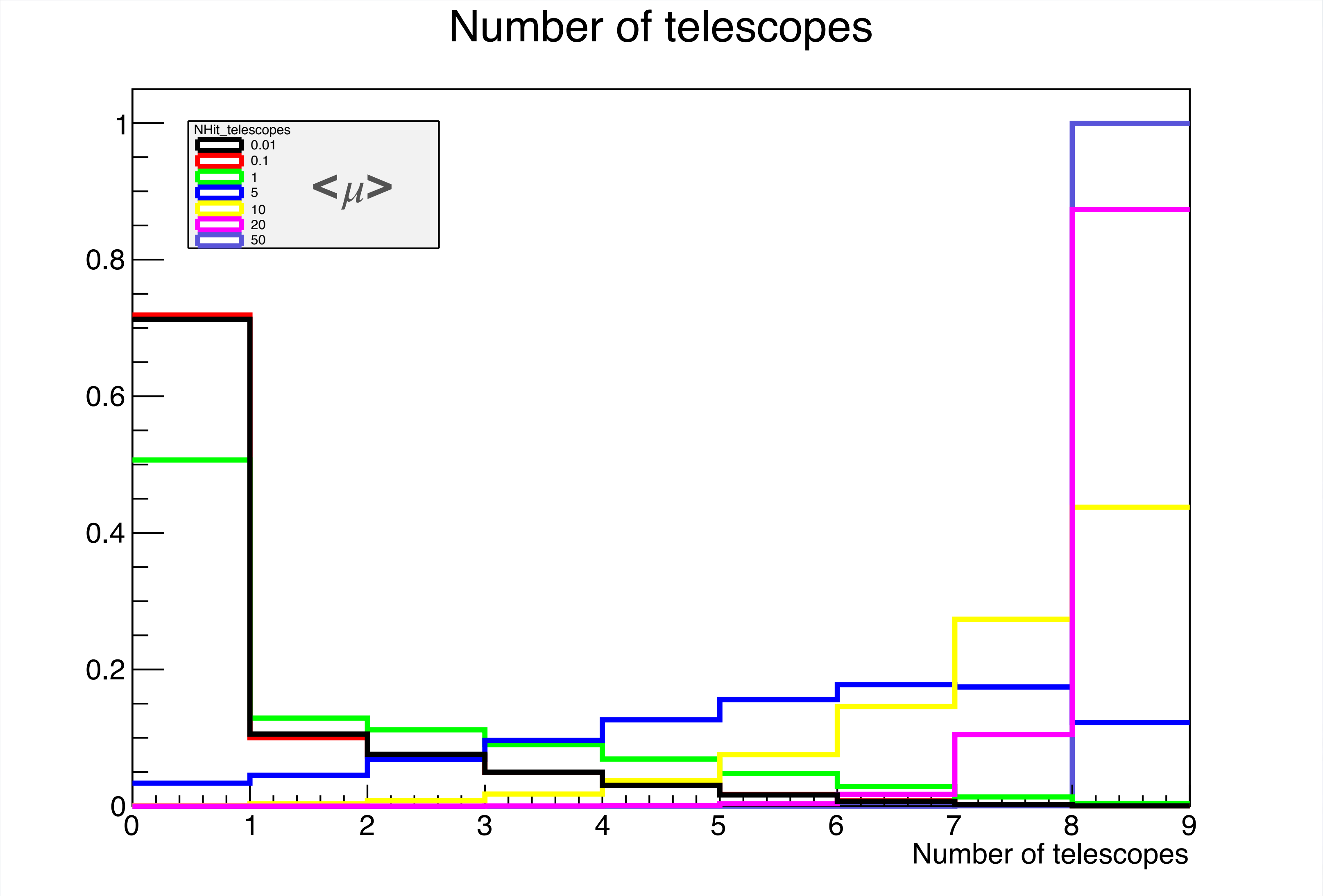


no apparent problems with this measurement approach

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

H-STREAM POINT OF VIEW

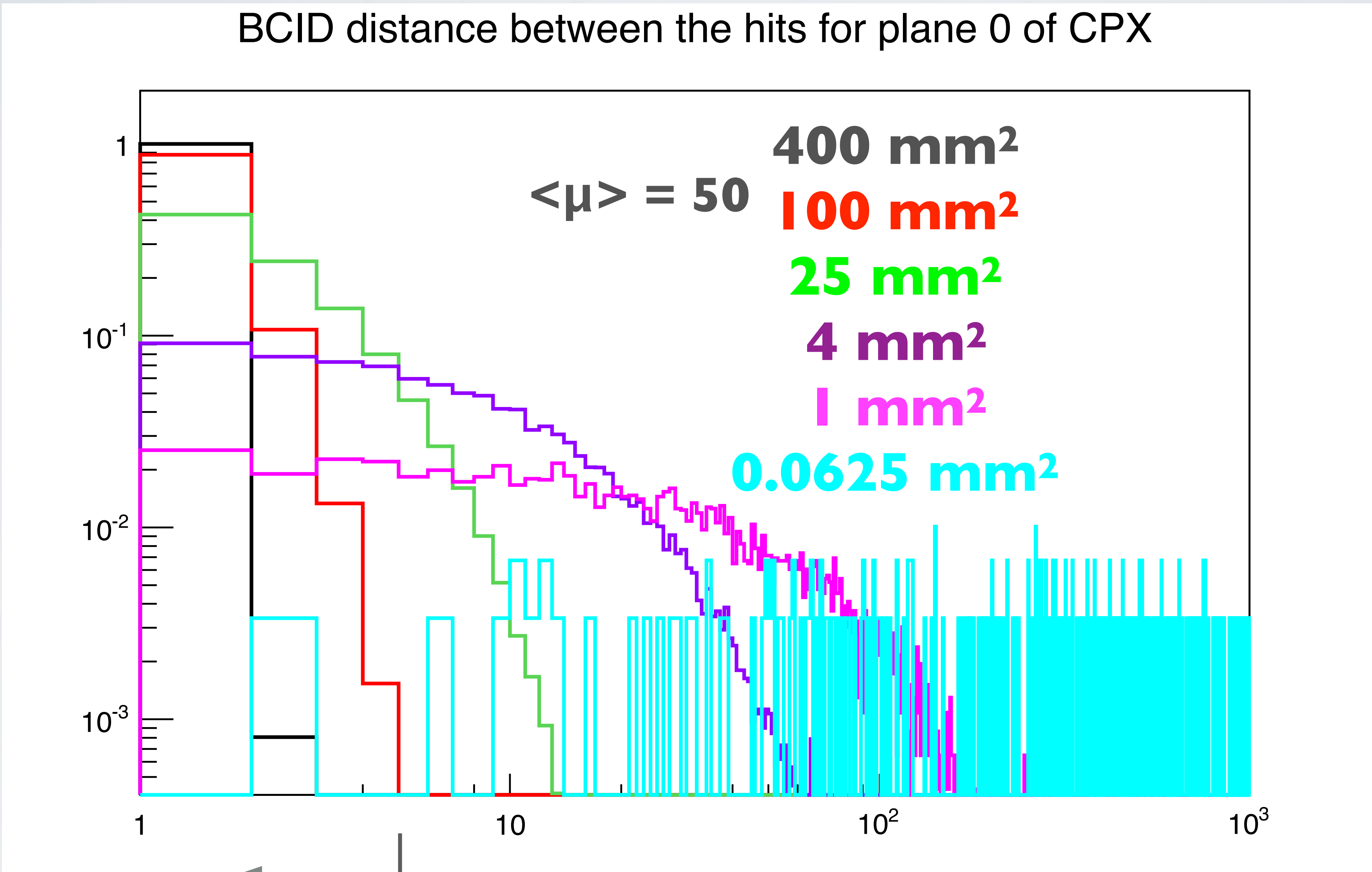
- interested in number of planes or telescopes hit (single HitOr signal provided)
- probability for event with given number of telescopes hit:



shows saturation at high luminosity

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

H-STREAM MASK AREA

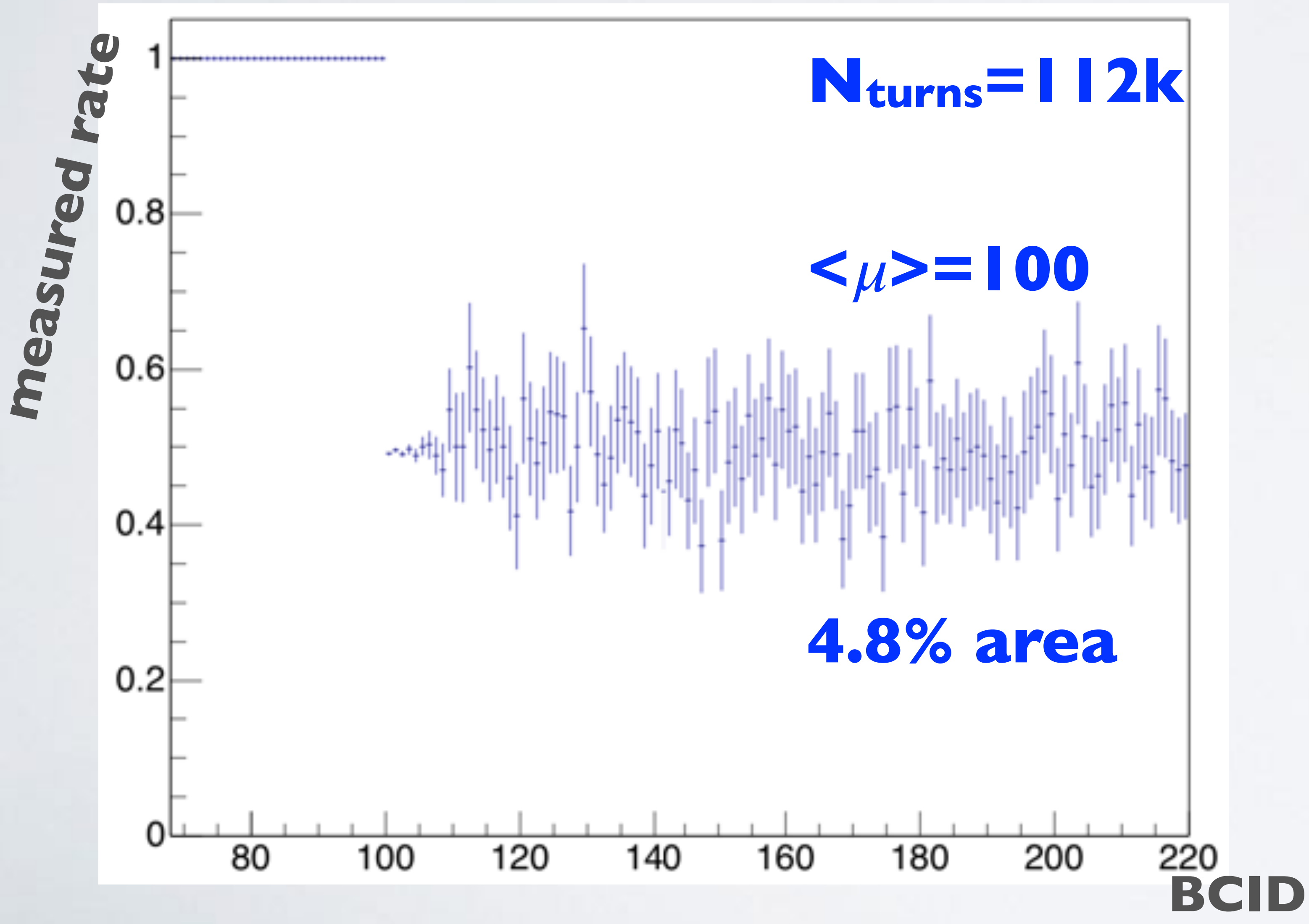


unseen because of pileup

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

SIMULATED RATE

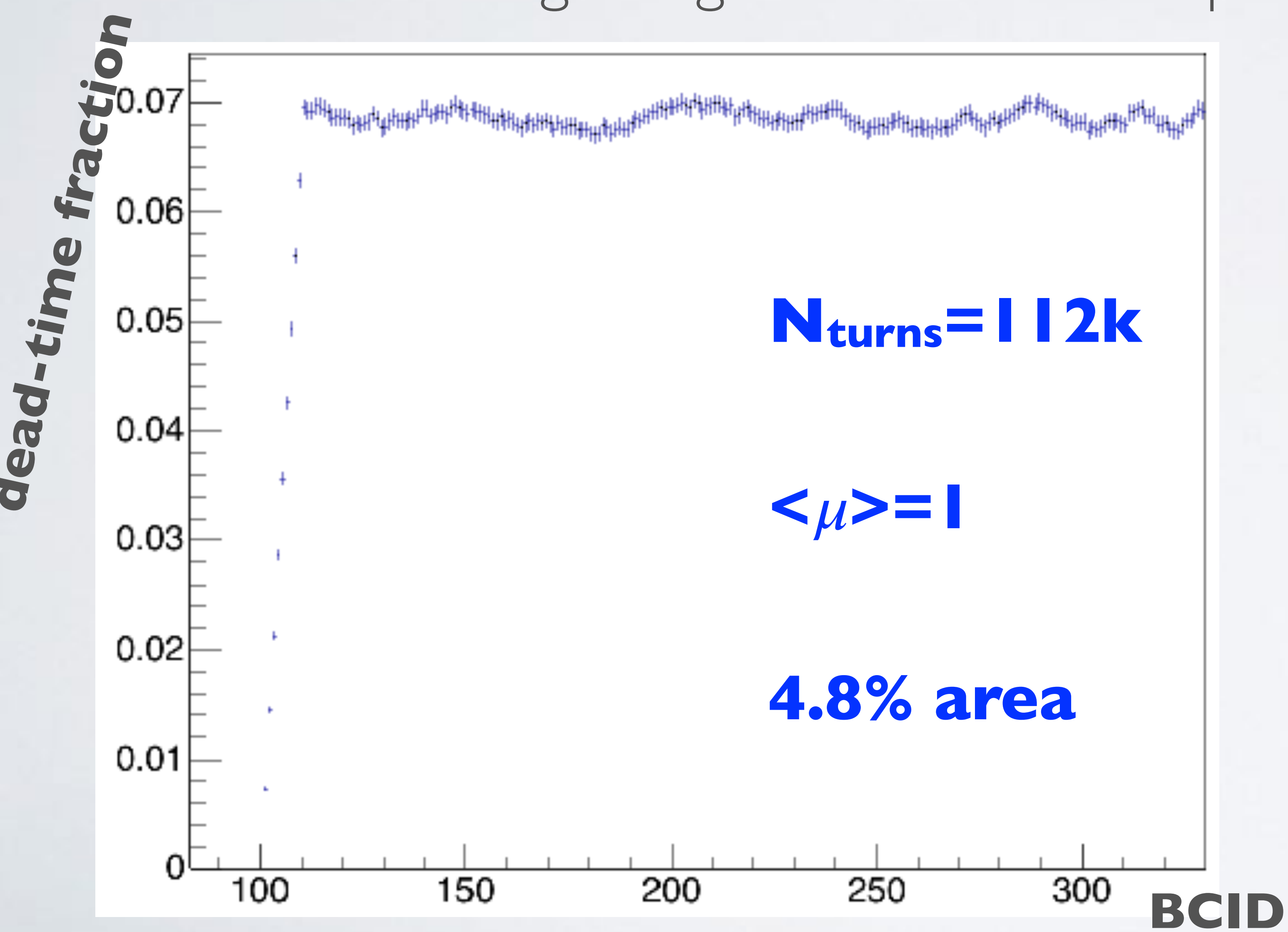
- rate of observed events for 0-counting (empty events fraction)
- statistical error significantly better for start of the bunch train



- 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

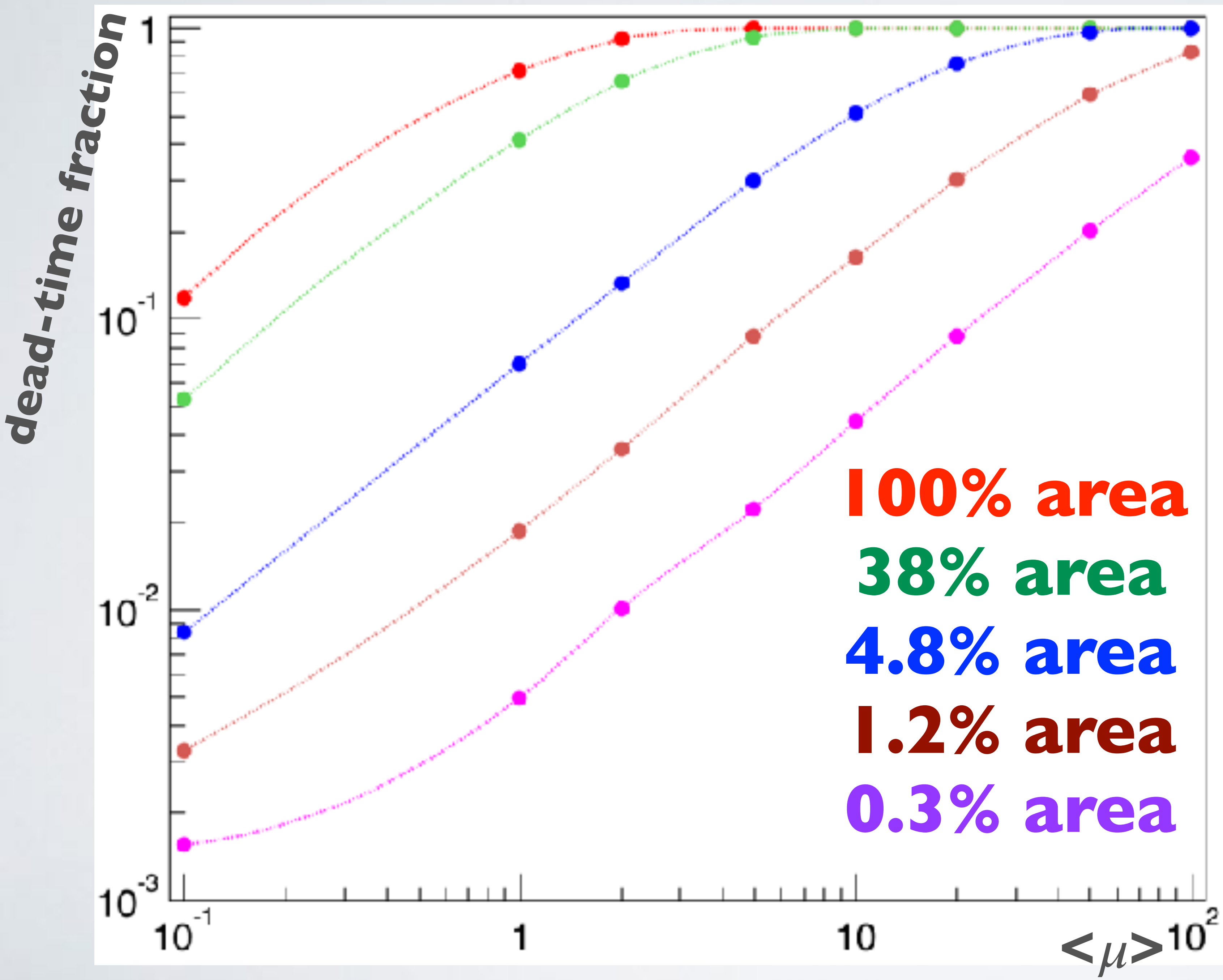
SIMULATED DEAD-TIME

- 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



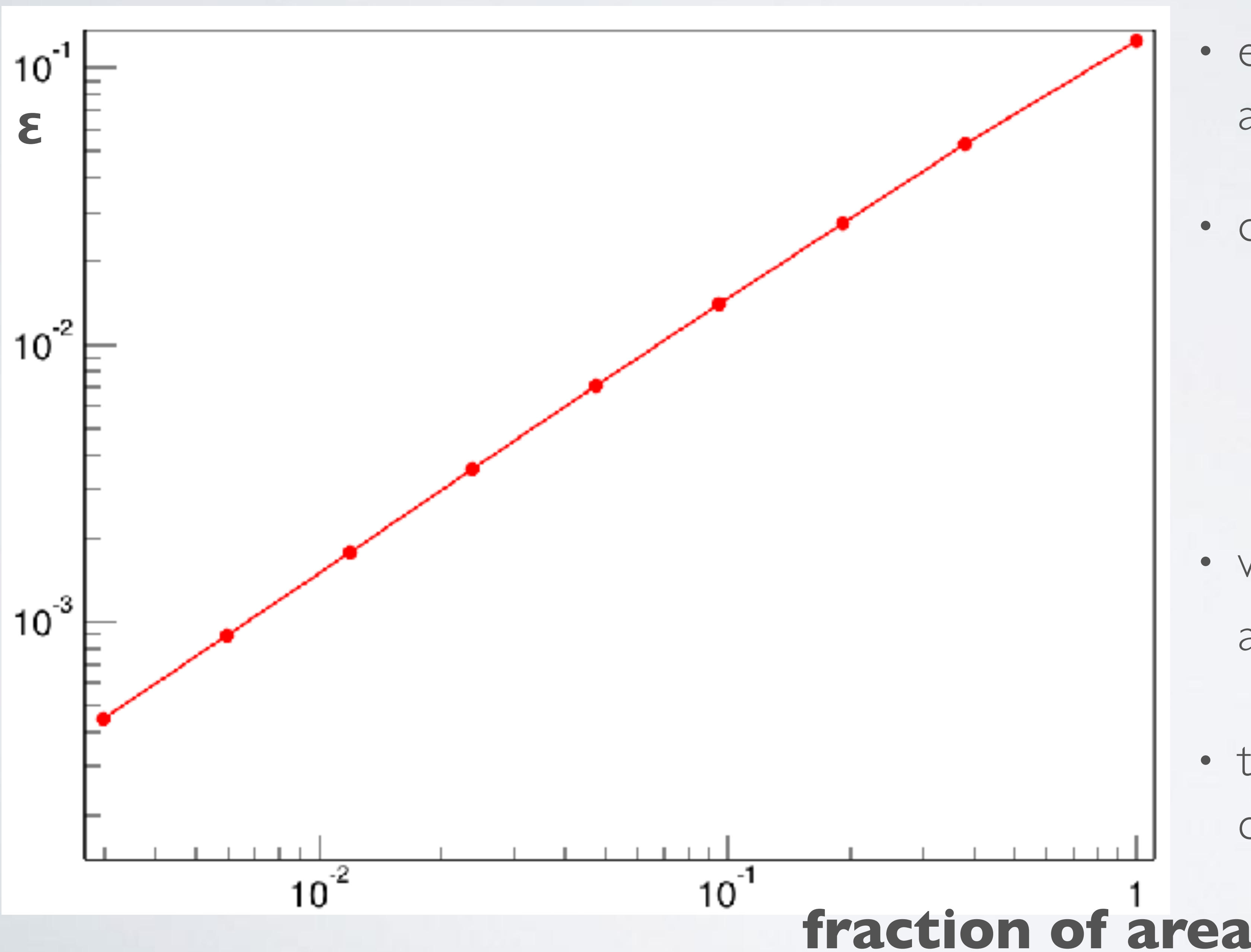
- statistical significant fluctuation of dead-time
- pattern more pronounced when we near saturation region
- will reduce in real life, because Landau charge distribution has not been taken into account

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:

$$r = e^{-<\mu>}\,\varepsilon$$

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