dRICH DAQ and data rates

simulation inputs for using the ALCOR shutter

P. Antonioli
INFN Bologna

dRICH meeting
September 10, 2025

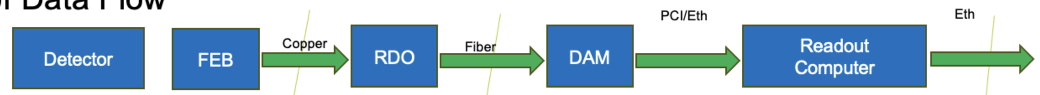
dRICH throughput is huge due to SiPM DCR

Summary of Channel Counts and Data Flow

Charge 1

Detector Group	Channels					Det Fiber Down	Det Fiber Up	RDO	Fiber Pair (DAQ)	DAM	Data Volume (RDO) (Gb/s)	Data Volume (To Tape) (Gb/s)
	MAPS	AC-LGAD	SiPM/PMT	MPGD	HRPPD/ MCP-PMT							
Tracking (MAPS)	16B					187	4976	323	323	7	15	15
Tracking (MPGD)				164k		640	2560	160	160	5	27	5
Calorimeters	500M		100k					522	522	17	70	17
PID (TOF)		6.1M				500	1364		1364	30	50	12
PID Cherenkov			318k		143k	1334	1334	1242	1334	33	1275	32
Far Forward		1.5M	10k					80	80	6	36	12
Far Backward	66M		3.4k					25	289	11	37	8
Lumi		128k	5.1k					41	41	4	264	8
Polarimetry	Independent Electronics, DAQ, & Controls from central detector but expected to build on same technologies											
TOTAL	**16.6B**	**7.7M**	**432k**	**164k**	**143k**	**2,661**	**10,234**	**2,393**	**4,113**	**113**	**1,774**	**109**

Summary of Data Flow



Aggregate	**2.0 Tb/sec**
Noise	1.6 Tb /sec
Signal from Physics + Background	400 Gb / sec

Aggregate	**2.0 Tb/sec**
Per RDO (Avg)	0.7 Gb/sec

Aggregate	**115 Gb/sec**
Collision Signal	62 Gb/sec
Synchrotron Rad	6 Gb/sec*
Electron Beam	4.5 Gb/sec
Hadron Beam	1.0 Gb/sec
Noise	41 Gb/sec

Scale of the system:

- **Electronics**
  - ~ 25 detector subsystems
  - ~ 5 Readout Technologies
  - ~ 2500 RDOs (on detector/in racks)
  - ~ 110 DAM boards (DAQ room)
  - GTU (with interface boards)
- **Maximum Data Volume**
  - ~ 2 Tb/sec digitized
  - ~ 115 Gb/sec recorded
- **Online Computing (Echelon 0)**
  - ~200 nodes (DAQ Room/SDCC)

* Synchrotron radiation caveats:

1. Rates are based upon hit rate for all ePIC detectors. In fact, data volumes depend upon specific detector hit (64 bits/hit assumed)
2. Highest Synchrotron radiation / electron beam gas will correspond to lower values for collision signal
3. Plan to analyze by component soon

Electron-Ion Collider

EIC DAQ & Electronics PDR , September 3-4, 2025 D. Abbott, J. Landgraf 8

Note:
at EIC zero-day (and during all commissioning) throughput will be 10^2 lower

how to approach dRICH throughput?

0
cool down the sensors → -40 C
heal the damage → annealing
optimize overvoltage and choice of the sensors

sensors

1
electronics gated: ALCOR shutter

electronics, clock distribution, RDO
INFN-TO/INFN-BO

2
understand if the event is noise or signal → ML techniques on DAM

DAM
INFN-RM

3
understand if the event is noise or signal with a dRICH interaction tagger → give a trigger to DAM

INFN-GE

4
get an external trigger from another sub-detector (Forw. HCAL?) → give a trigger to DAM

ePIC

For PDR we focused on 1 and 2, but we found simulations from 3 very useful!

Addressing 2024 PDR report specific comments

Relevant comments:

- We applaud the adaptation of the readout architectures to match detector environment specs, *in particular for the dRICH where steps to mitigate the high DCR will be implemented in the ASIC together with other handles such as triggering within the DAM.*
- We appreciate these steps towards robustness. However, it would be reassuring to see simulations or measurements to demonstrate the effectiveness of the shuttering mechanism for dRICH.

Relevant recommendations:

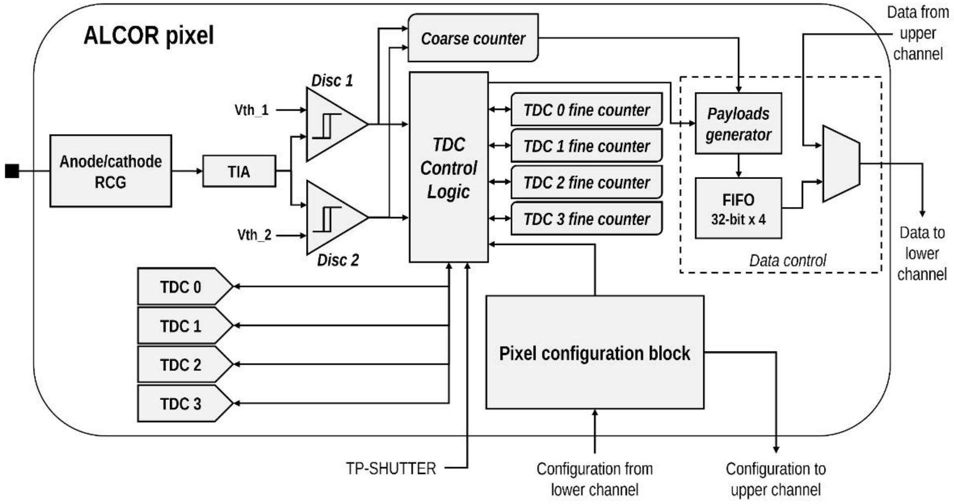
- Rationalize the dRICH readout with the benefit of simulation/measurement to reassure the community of the benefit of the shutter implementation.

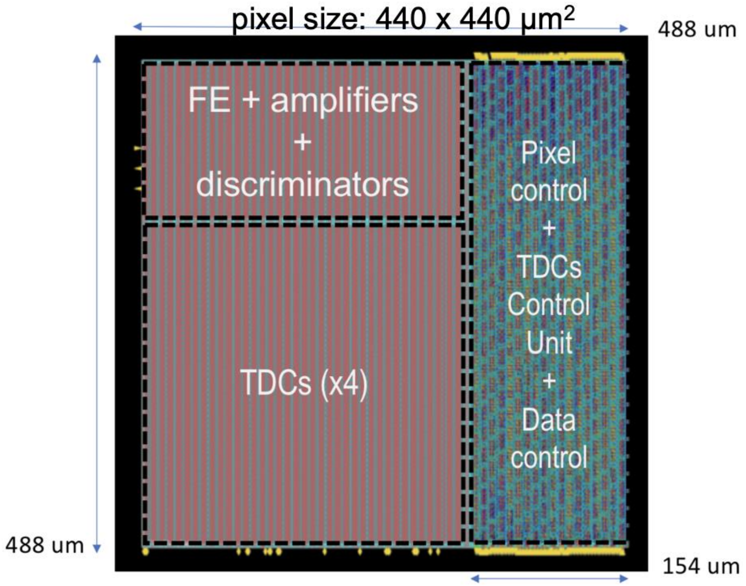
- dRICH backend DAQ was rationalized following studies of ML techniques/NN deployed on DAMs
- Shutter implemented on ALCOR V3 and studies are on-going on shutter performance to assess best (and safe) shutter time width.

→ discussion and results reported in next slides

ALCOR shutter: hardware implementation

Pixel architecture





- **Dual-polarity RCG input stage** current conveyor (Z_{in}= 10-20 Ω) + **TIA** with 4 gain settings → $\sigma_t \simeq$ 150 ps
- **2 leading edge discriminators** with independent (and per pixel) threshold settings (6-bit DAC) → V_{th} = 0.5 p.e.
- **4 TDCs** based on **analogue interpolation** with **20-40 ps** time-bin (at **394 MHz clock** frequency)
- Pixel control logic handles TDC operation, pixel configuration, operating mode and data transmission
- TP-**Shutter** to inhibit events digitization (asynchronous with ns time window) and **suppress out-of-time SiPM DCR hits**

F. Cossio (INFN Torino) ALCOR ASIC - DAQ & Electronics PDR 8

ALCOR shutter: hardware implementation (II)

ALCOR v3 shutter

ePIC streaming data acquisition system (no traditional hardware trigger)

- Operation at **0.5 p.e. threshold** → DCR noise up to **300 kHz/channel** (at max SiPM radiation damage)
- **Digital shutter**: “inhibit” pixel digital logic to suppress out-of-gate DCR hits and **reduce data throughput:**

$$\text{Reduction Factor} = \frac{\text{EIC bunch crossing period}}{\text{shutter time window}} = \frac{10.2\ \text{ns}}{t_{shutter}}$$

- Asynchronous digital shutter implemented in ALCOR v3 pixel logic using external test-pulse signal
- **Programmable delay chain**: 4 configuration bits at channel-level (LSB $\simeq$ 350 ps) and at the chip periphery (LSB $\simeq$ 100 ps) to adjust offsets between different pixels and columns
- Shutter needed only when DCR becomes higher due to SiPMs taking radiation damage over time → **use first period of ePIC data taking to optimize shutter calibration** (electronics and physics contributions)

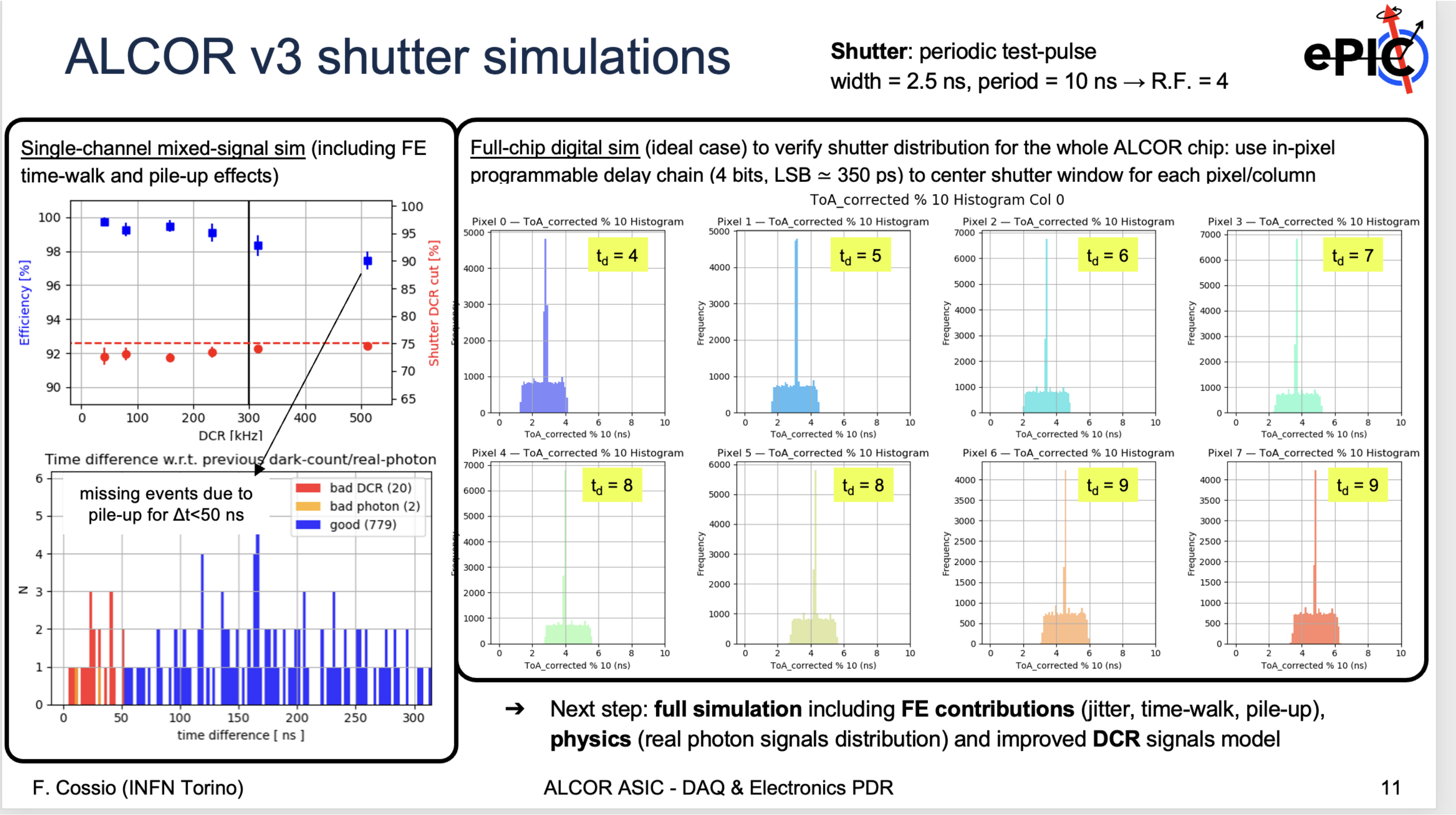
Further off-chip data throughput reduction schemes are being considered:

➔ **ML online data filtering** (INFN Roma) at sub-detector level (FELIX DAMs) against pure dark-count event (more details in **P. Antonioli report**)

F. Cossio (INFN Torino)

ALCOR ASIC - DAQ & Electronics PDR 10

ALCOR shutter: hardware implementation (III)



so from a (simulated) hardware point of view ALCORv3 is ready to deliver shutter.

The signal will be driven by RDO of the FPGA and at fixed phase with respect to EIC clock

We will keep shutter ON ”always” and put it to OFF on a given time window

Updated throughput modelling (I)

dRICH DAQ parameters	
RDO boards	1248
ALCOR64 x RDO	4
dRICH channels (total)	319488
Number of DAM	30
Input link in DAM	42
Output links from DAM to TP	1
Number of DAM Trigger Processor	1
Input link to DAM Trigger Processor	30
RDO-DAM Link Bandwidth (VTRX+) [Gb/s]	10
DAM to Echelon-0 Switch Bandwidth [Gb/s]	100
dRICH Interaction tagger reduction factor	1
Interaction tagger latency [s]	1,00E-04
EIC parameters	
EIC Clock [MHz]	98,522
Orbit efficiency (takes into account gap)	0,92

ALCOR parameters		Notes
Front end limit [kHz]	4000	
ALCOR Clock [MHz]	394,08	It will be 394.08 MHz or 295.55 MHz
Channels/serializer	8	
Bits per hit	64	2 32-bit words per hit (also TOT)
Bits per hit encoding 8/10	80	
Serializer band limit [Mb/s]	788,16	
Theoretical Serializer limit/ channel [kHz]	1231,5	this would be with 0 control words
Serializer limit single ch [kHz]	800	this is expected to improve with ALCOR v3
Number of serializer per chip	8	
Channel/chip	64	
Shutter width (ns)	2	(if you put 10 ns == no shutter)

Reduction factor via shutter
RF = 10 ns/(shutter width)

There are two reduction handles in this table:
- the shutter
- something external (can be NN on DAMs, dIT or ..?)

dRICH backend DAQ reorganized following studies from INFN Rome (see next slides) from 27+1 to 30+1 FLX-155: 30 DAMs + 1 Trigger Processor (TP)

Reduction factor provided by whatever ext. trg (including NN on dRICH DAMs)

Updated throughput modelling (II)

DAM to Echelon-0 Switch Bandwidth [Gb/s]	100
dRICH Interaction tagger reduction factor	1
Interaction tagger latency [s]	1,00E-04
EIC parameters	
EIC Clock [MHz]	98,522
Orbit efficiency (takes into account gap)	0,92

Channel/chip	64	
Shutter width (ns)	2	(if you put 10 ns == no shutter)

This is worst case!

dRICH data stream analysis		**Limit**	**Comments**
Sensor rate per channel [kHz]	300,00	4.000,00	
Rate post-shutter [kHz]	55,20	800,00	
Throughput to serializer [Mb/s]	34,50	788,16	
Throughput from ALCOR64 [Mb/s]	276,00		limit FPGA dependent: - check with RDO
Throughput from RDO [Gb/s]	1,08	10,00	based on VTRX+
Input at each DAM [Gbps]	45,28	420,00	
Buffering capacity at DAM [Mb]	4,64		to be checked but seems manageable
Output from each DAM [Gbps]	45,28	100,00	
Aggregated dRICH data throughput		**Comments**	
Total input at DAM [Gb/s]	1.358,44	This is only "inside" DAM, not to be transferred on PCI	
Total output from DAM [Gb/s] to Echelon	1.358,44	Reduction from interaction tagger (FPGA or det. based)	

*Take home message

Using only the shutter with a reduction factor 5 (2 ns over 10 ns BC) we keep 1.3 Tbps throughput and we stay within all limits (including transfer from DAM to Echelon-0)

Updated throughput modelling (III)

DAM to Echelon-0 Switch Bandwidth [Gb/s]	100			
dRICH Interaction tagger reduction factor	5	Channel/chip	64	
Interaction tagger latency [s]	1,00E-04	**Shutter width (ns)**	10	(if you put 10 ns == no shutter)
EIC parameters				
EIC Clock [MHz]	98,522			
Orbit efficiency (takes into account gap)	0,92			

dRICH data stream analysis		**Limit**	**Comments**
Sensor rate per channel [kHz]	300,00	4.000,00	
Rate post-shutter [kHz]	276,00	800,00	
Throughput to serializer [Mb/s]	172,50	788,16	
Throughput from ALCOR64 [Mb/s]	1.380,00		limit FPGA dependent: - check with RDO
Throughput from RDO [Gb/s]	5,39	10,00	based on VTRX+
Input at each DAM [Gbps]	226,41	420,00	
Buffering capacity at DAM [Mb]	23,18		to be checked but seems manageable
Output from each DAM [Gbps]	45,28	100,00	

Aggregated dRICH data throughput		**Comments**
Total input at DAM [Gb/s]	6.792,19	This is only "inside" DAM, not to be transferred on PCI
Total output from DAM [Gb/s] to Echelon	1.358,44	Reduction from interaction tagger (FPGA or det. based)

10 ns means no shutter

data reduction via "another method"

further risk mitigation here might be applied using two TX links instead of one

If shutter is not effective we need a reduction factor 5 from a dRICH interaction tagger method and we stay within all limits (including transfer from DAM to Echelon-0)

Will the shutter be effective?

(for all work on shutter *implementation* in ALCOR v3 and related simulations see F. Cossio talk)

Simulations of hit time distribution at dRICH entrance window (before aerogel)

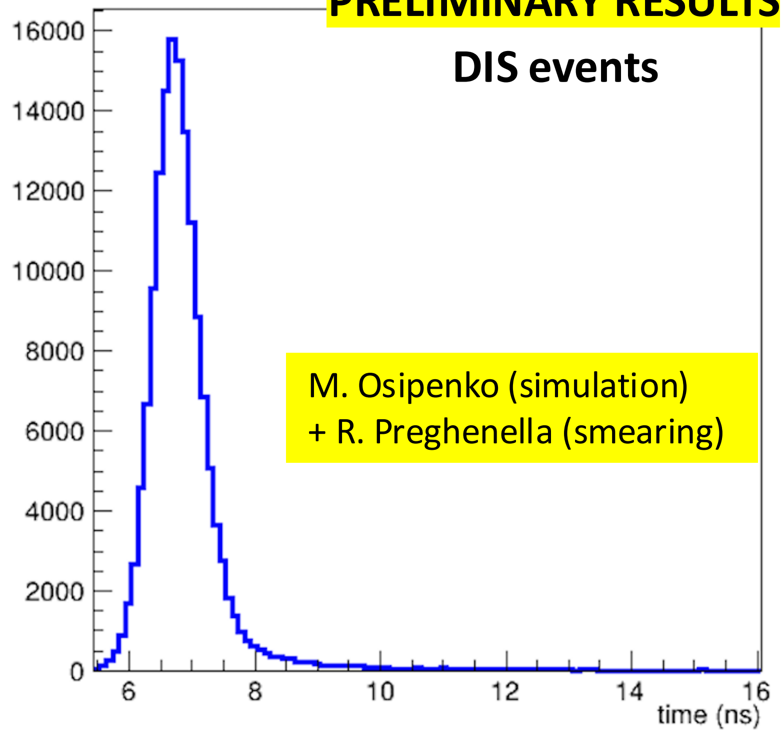
- Hit time distribution (primaries) has Gaussian shape + a tail
- Bulk of primary hits lies **within 2 ns** ($\sigma_{pr} \cong$ 260 ps**)**
- added in quadrature time zero jitter (σ_{t0}= 250 ps) + front-end resolution (σ_{FE}= 150 ps)

$$\sigma = \sqrt{\sigma_{pr}^2 + \sigma_{t0}^2 + \sigma_{FE}^2} \approx \text{400 ps}$$

- from cumulative distribution 99% of particles included with a shutter window of 5 ns (from 5.5 ns to 10.5 ns → **50% DCR data reduction**)

Full simulation (including Cerenkov light propagation) in progress:
→ we don't expect a large spread added by photon emission + propagation
→ impact of time slewing effect (see F. Cossio talk) to be assessed

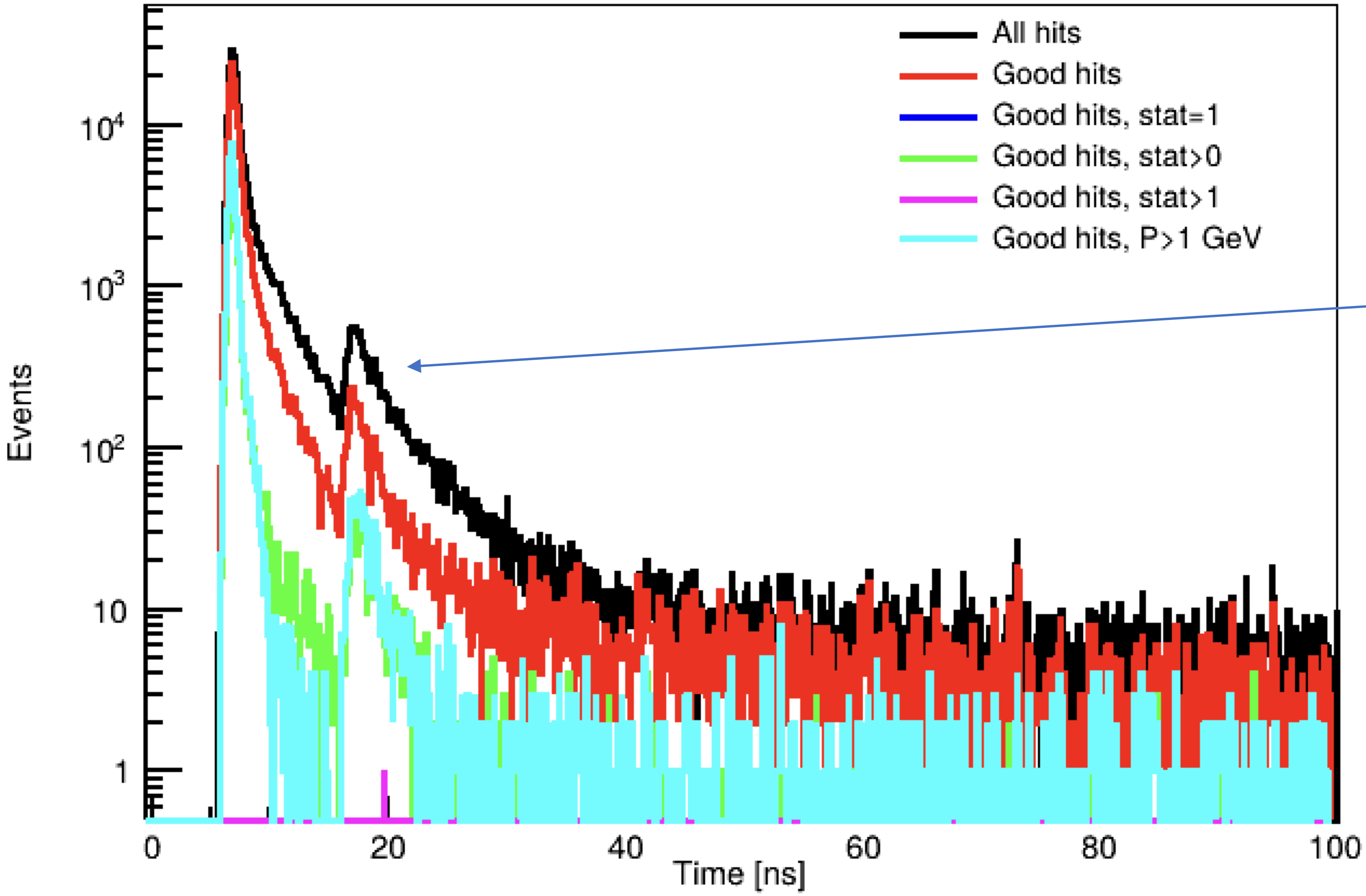
PRELIMINARY RESULTS



M. Osipenko (simulation)
+ R. Preghenella (smearing)

This is how we cooked things at PDR

But we had more info from Misha… (and Roberto)

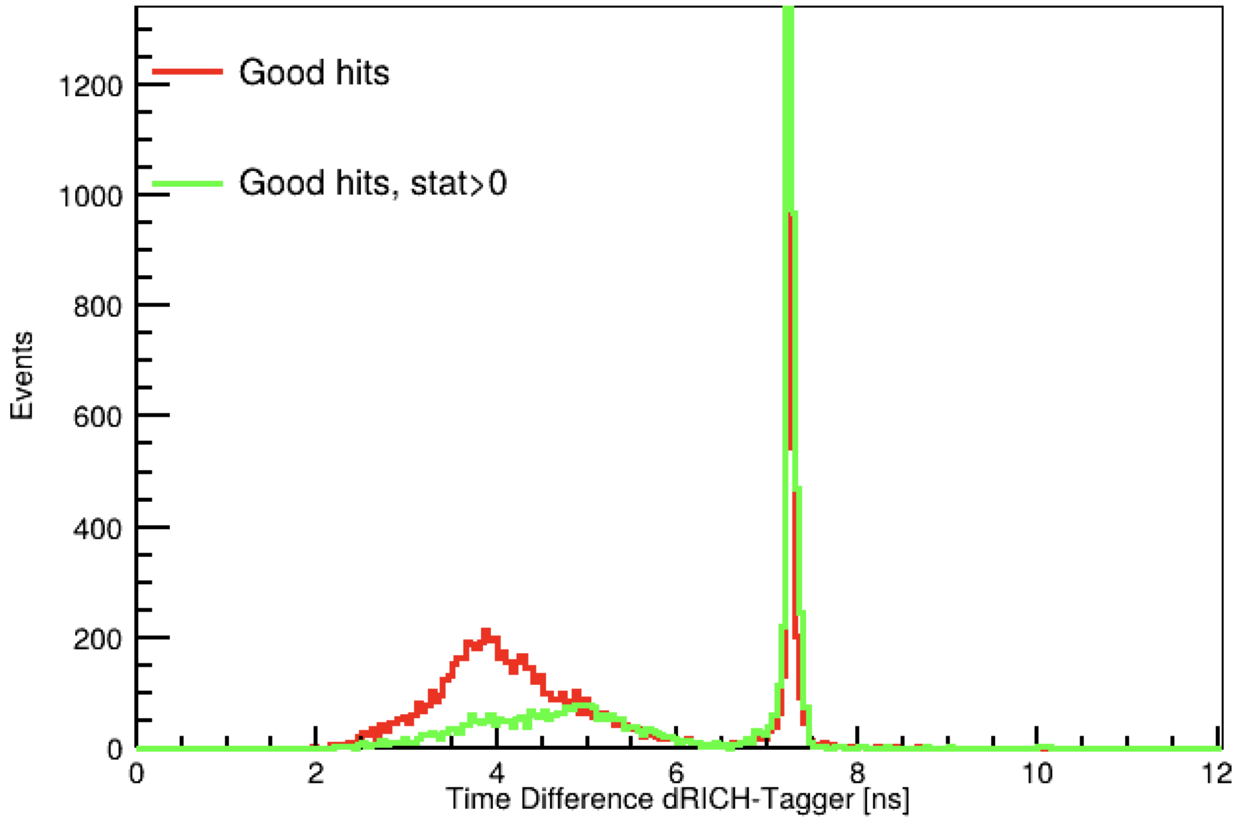


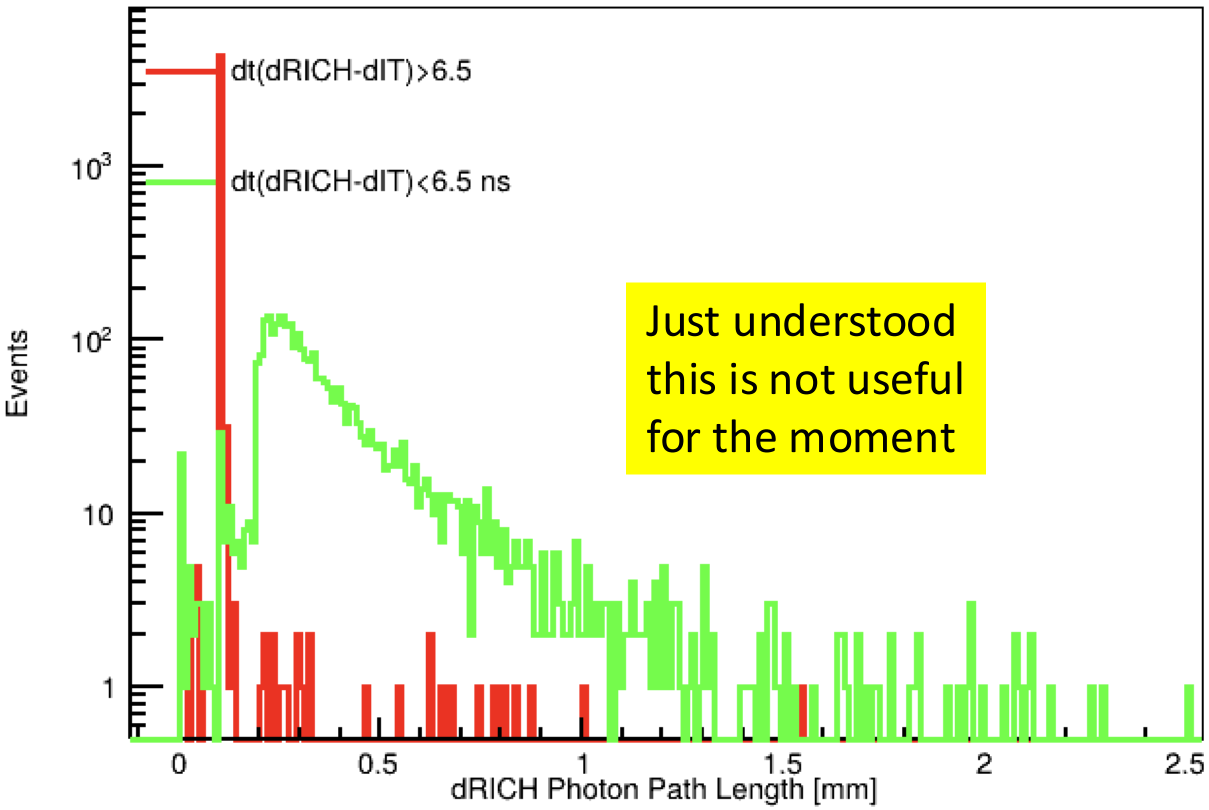
this bump must be understood.
Misha just did it.

dIT simulation is for low energy and at the entrance of time window

for shutter purposes what does count are the photon hits on SiPM after reflection on mirrors

Time distribution/photon path length of hits w.r.t. to dIT

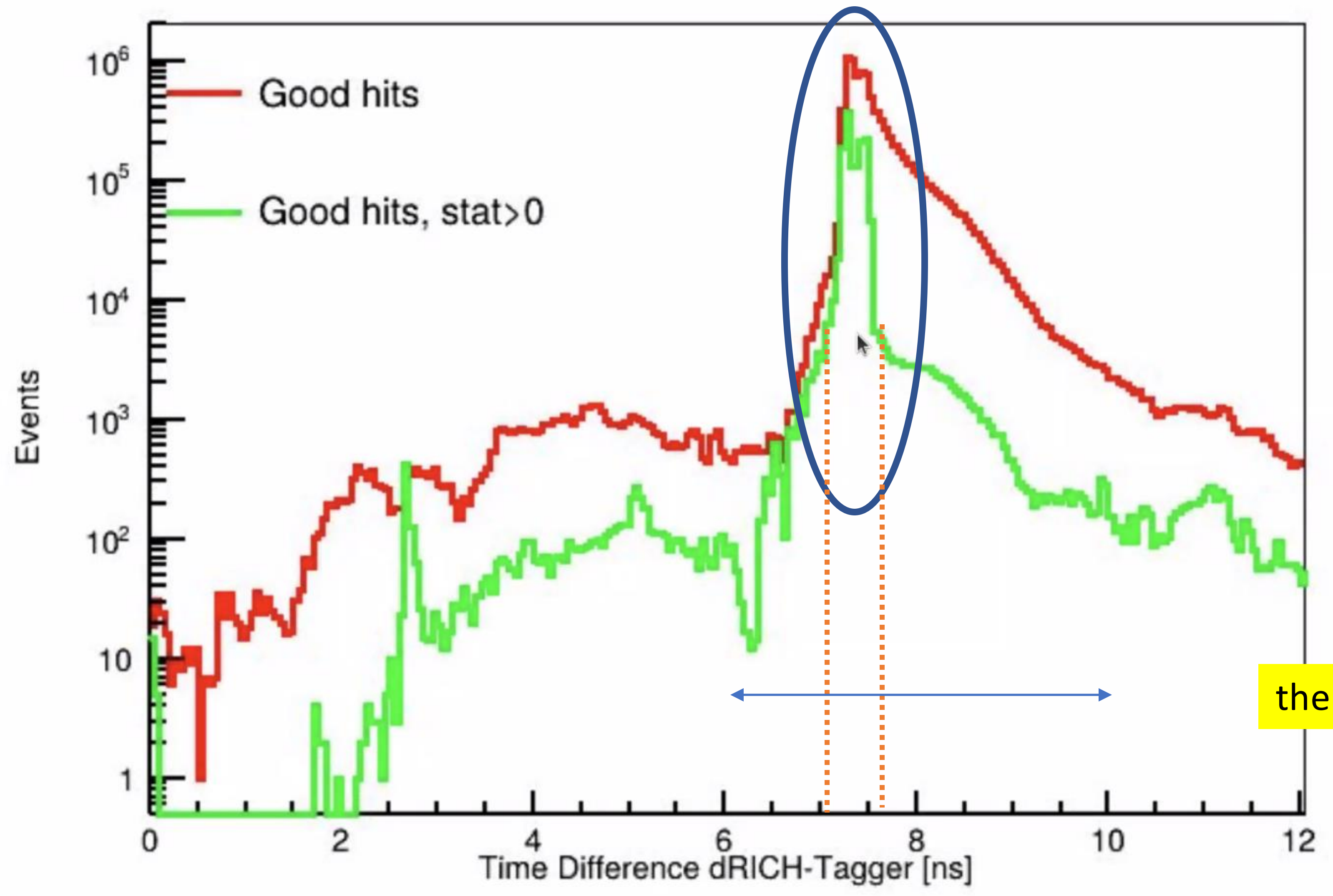




Just understood this is not useful for the moment

- The shutter window could be 5 ns wide, certainly not 2 ns
- The photon emission/propagation doesn’t enlarge the distribution (as expected)

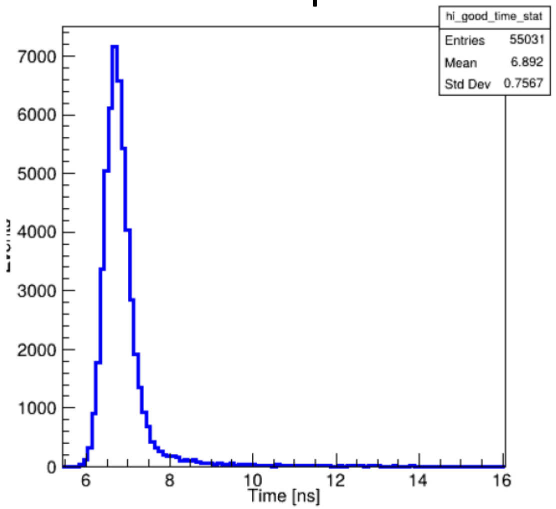
Again on broadening



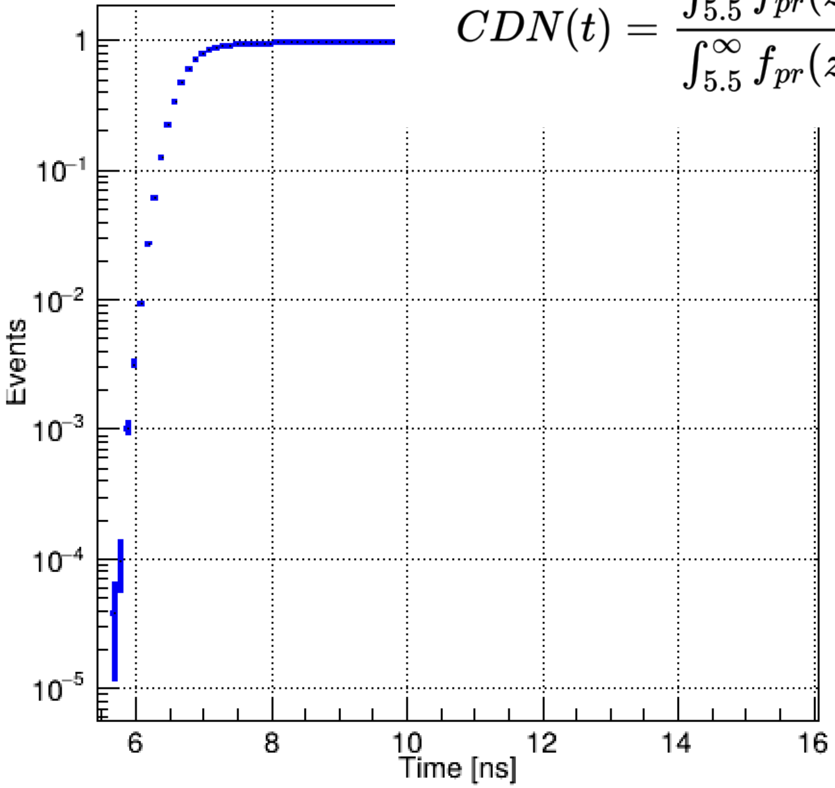
the optimal shutter window is where?

Furter analysis: cumulative distributions

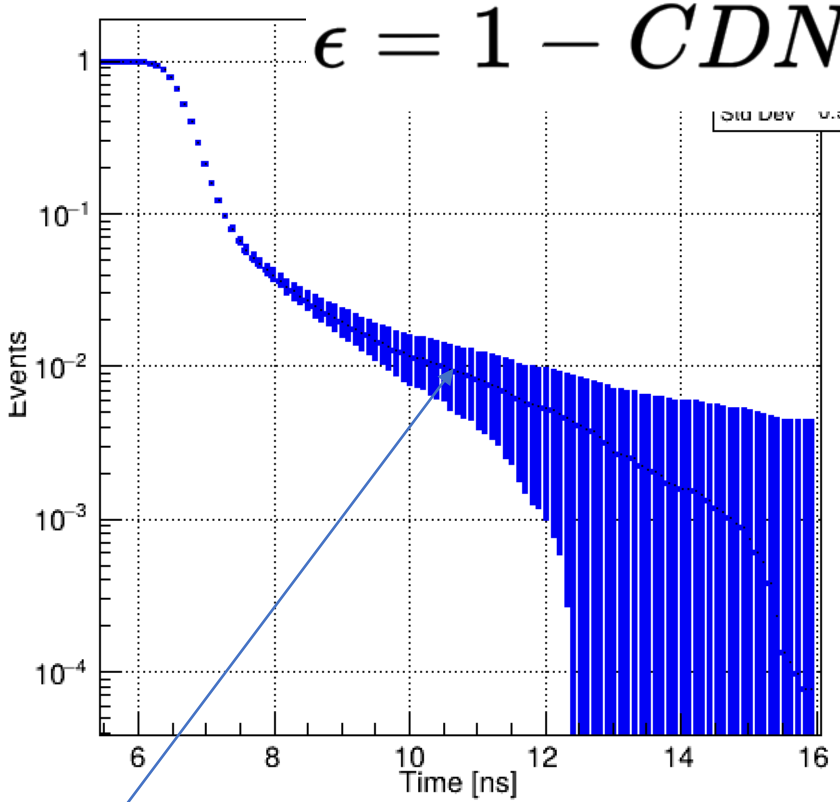
“Misha” plot



$$CDN(t) = \frac{\int_{5.5}^{t} f_{pr}(z)dz}{\int_{5.5}^{\infty} f_{pr}(z)dz}$$



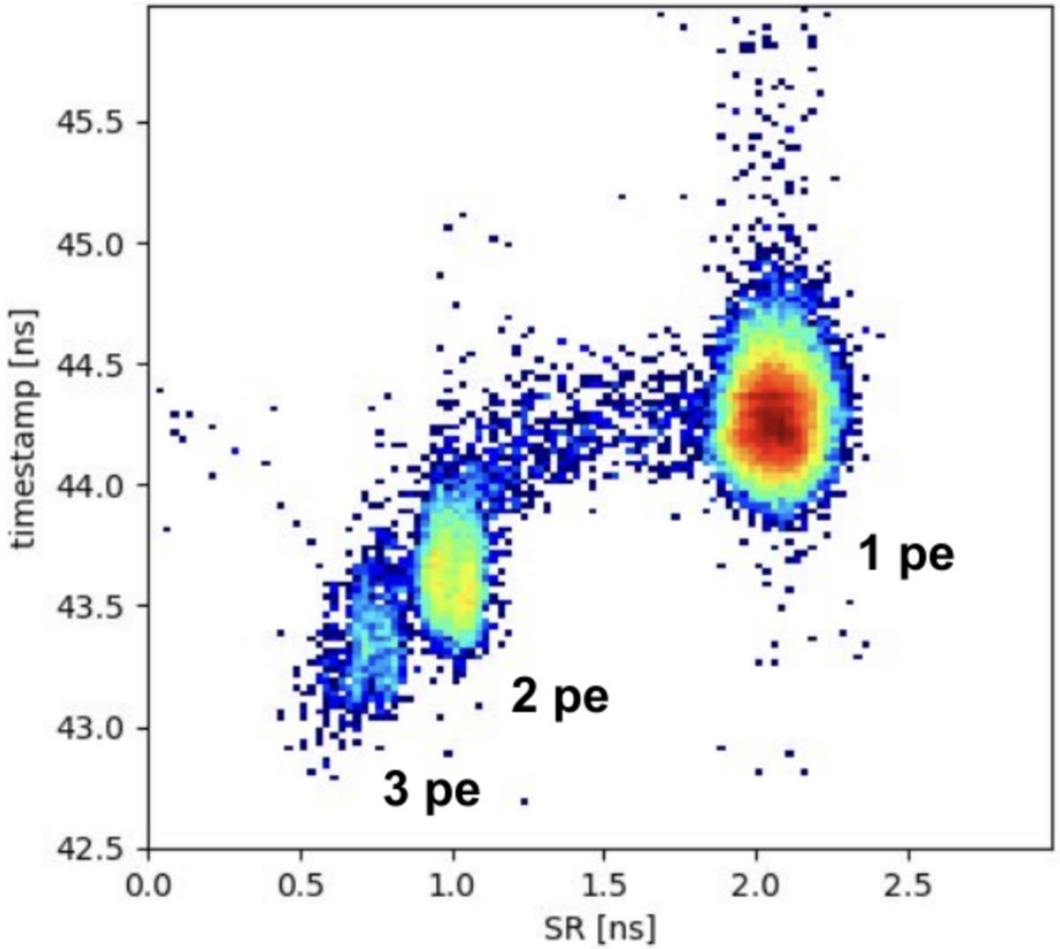
$$\epsilon = 1 - CDN(t)$$



99% efficiency reached with a shutter width of 5 ns from 5.5 to 10.5 ns w.r.t. to nominal collision time

Further analysis: time slewing warning

Time slewing effect due to multiple photons



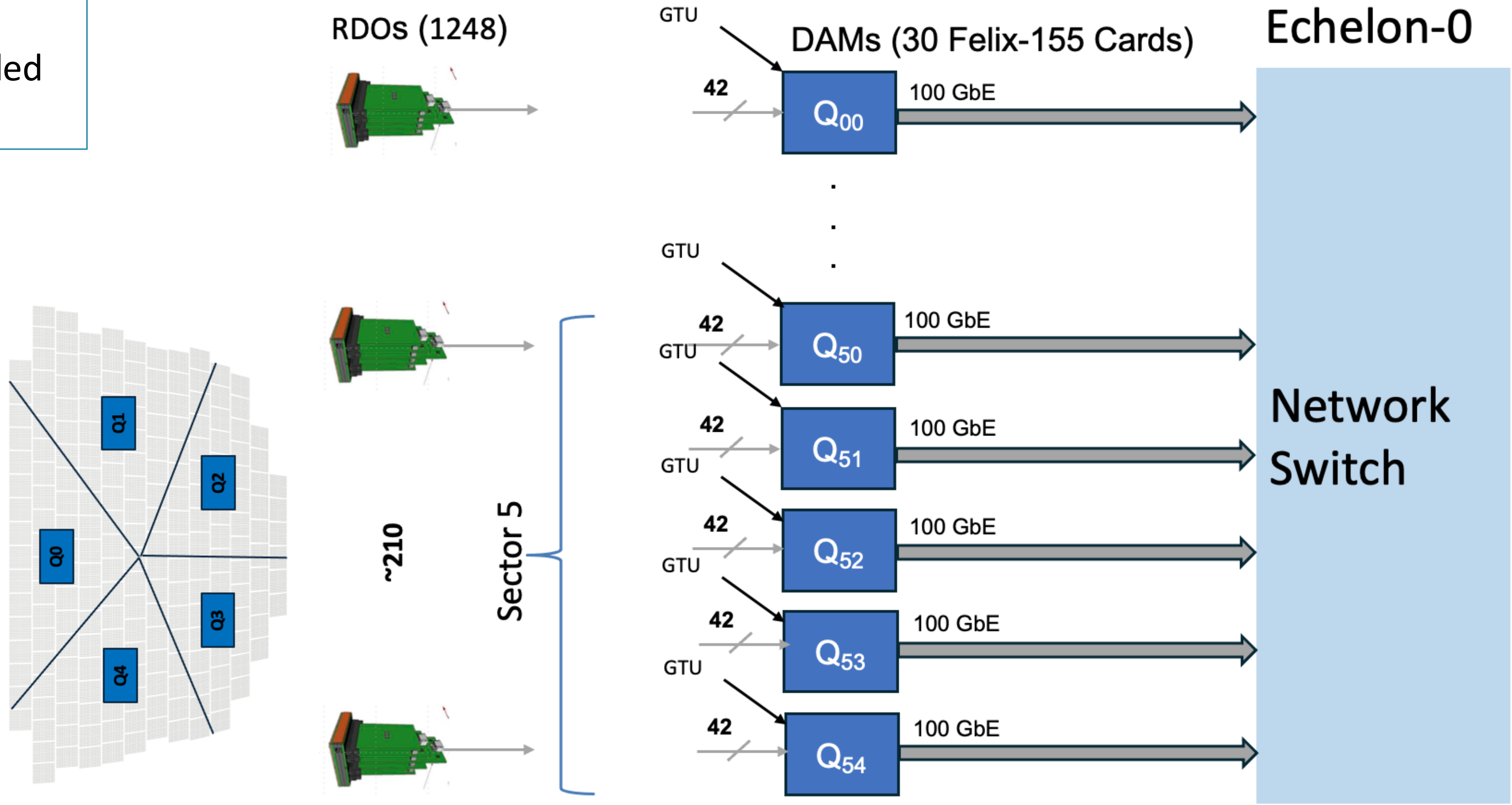
For the fraction of events when we will have > 1 pe we can expect an additional shift of ~ 2 ns!

How many times we have more than 1 pe?
Note we have also SiPM-cross talk here.

To be simulated.

dRICH DAQ: the backend (updates from 2024)

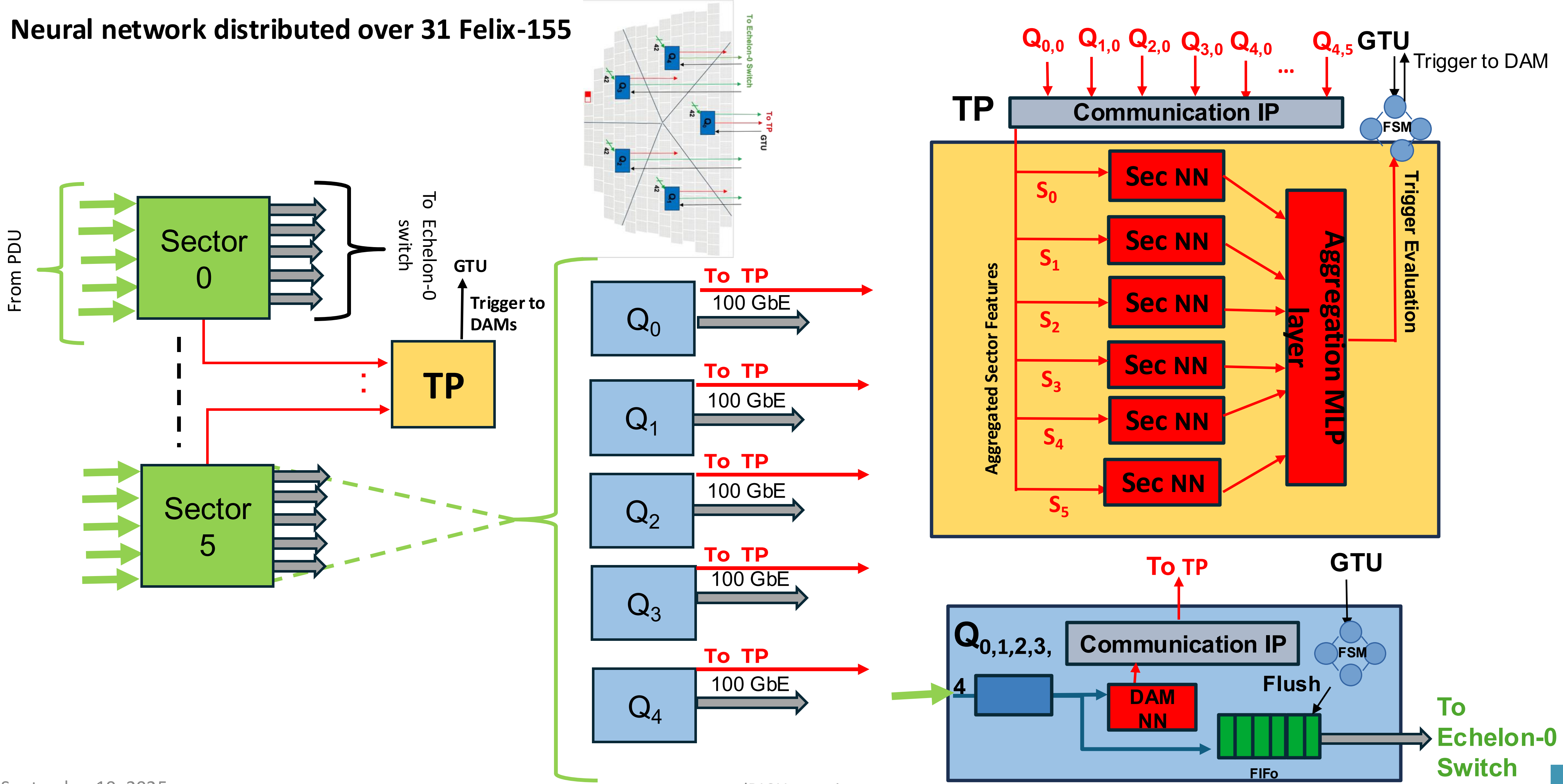
IMPORTANT NOTE:
dRICH DAQ backend is led by INFN Rome



Details about dRICH DAQ backend studies in A. Lonardo's talks at ePIC Jan 2025 meeting and ePIC Italia June 2005 meeting

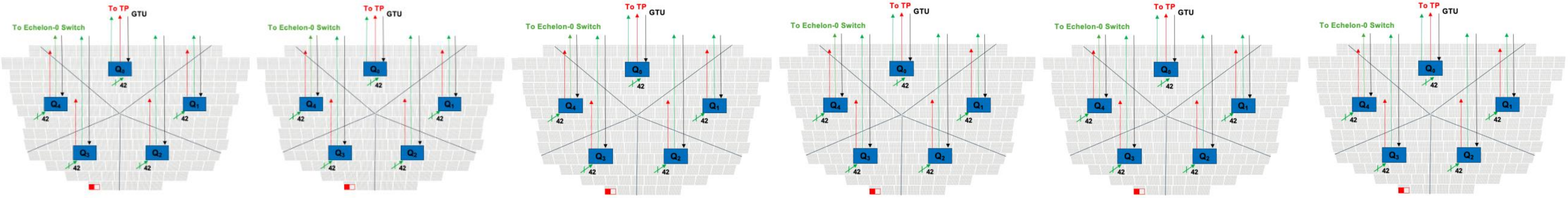
dRICH data reduction integrated in the DAQ Backend (I)

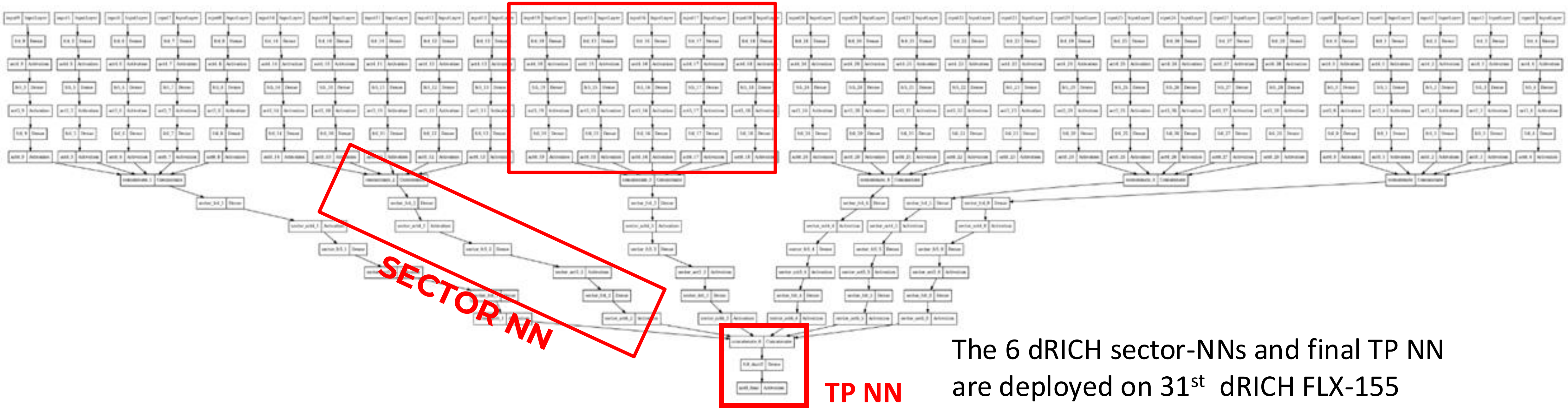
Neural network distributed over 31 Felix-155



NN deployment model and DAMs

6 dRICH sectors – 5 DAMs/sectors





TP NN

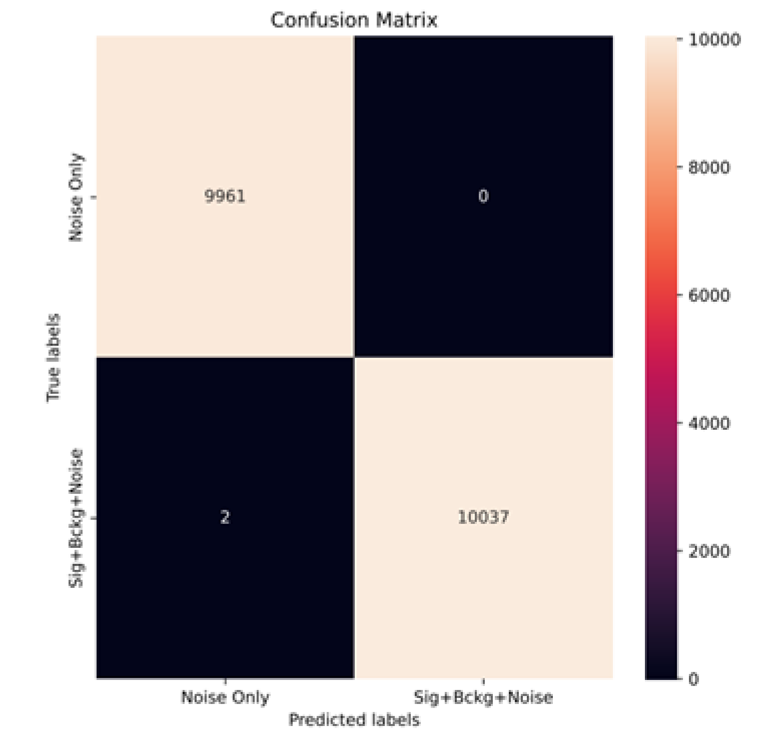
The 6 dRICH sector-NNs and final TP NN are deployed on 31st dRICH FLX-155

Data Reduction performance @ luminosity = 100 fb^{-1}, time window = 10 ns

PRELIMINARY RESULTS

Test with 10000 signal+phys. background (P=Positive) + 10000 pure noise events (N=Negative)

KERAS MODEL



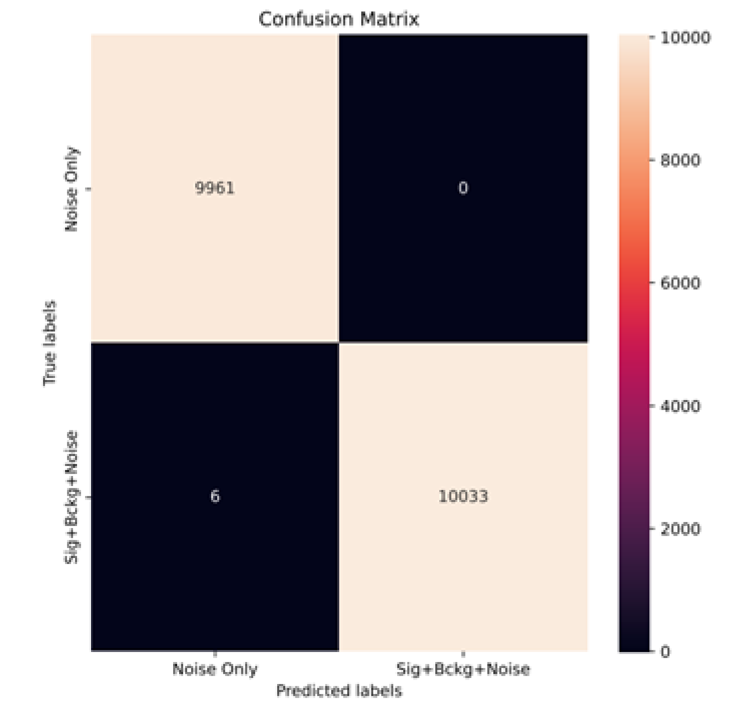
- Accuracy = (TP+TN)/(TP+TN+FP+FN) = 0.997
- Purity = TP/(TP+FP) = 0.995
- Efficiency = TP/(TP+FN) = 0.999

Preliminary result indicate DAM filter could comfortably provide ≫ 5 data reduction factor

Model Quantization

- Inputs, Activations: fixed point<16,6>
- Weights, Biases: fixed point<8,1>

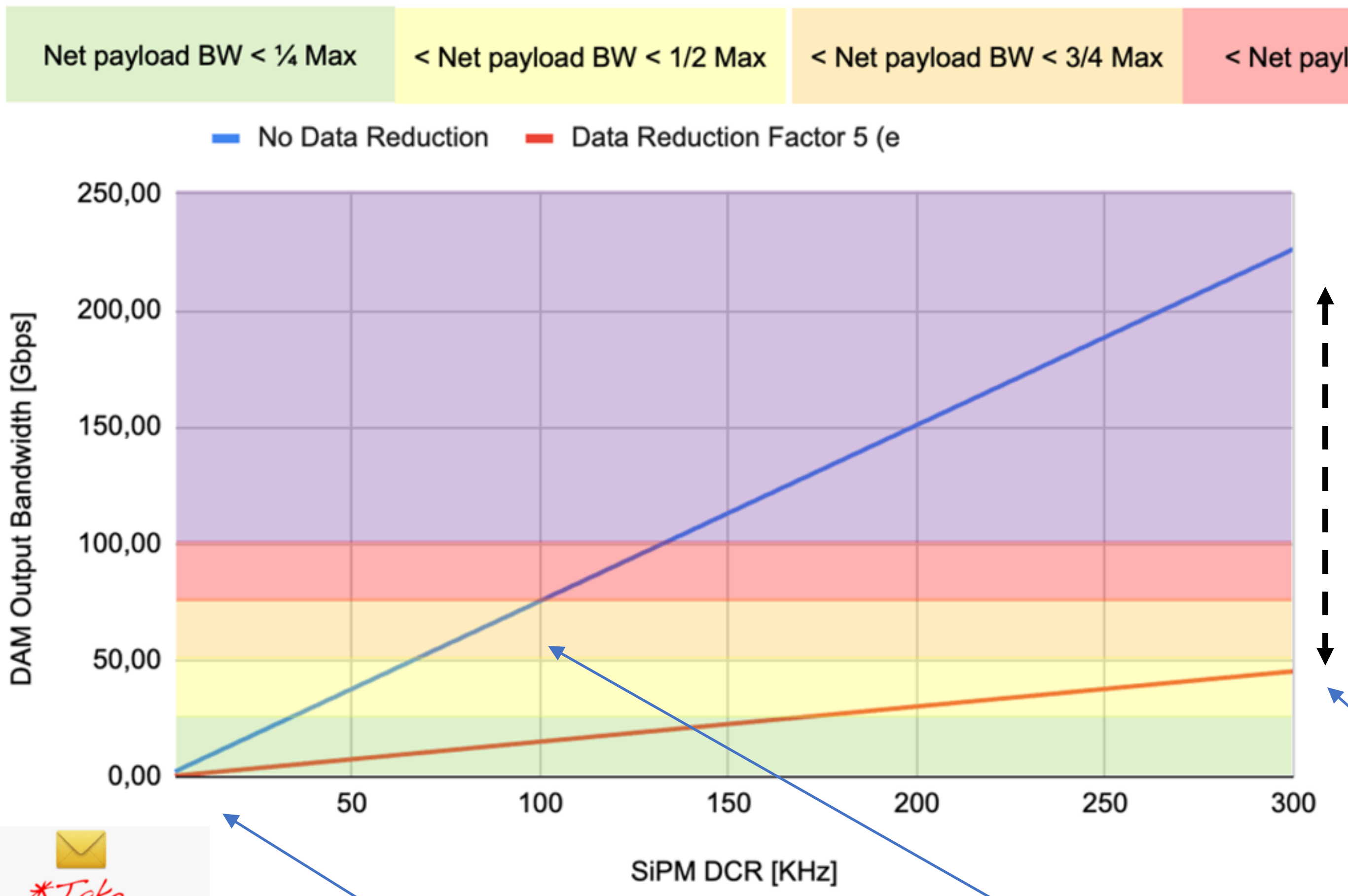
QUANTIZED MODEL

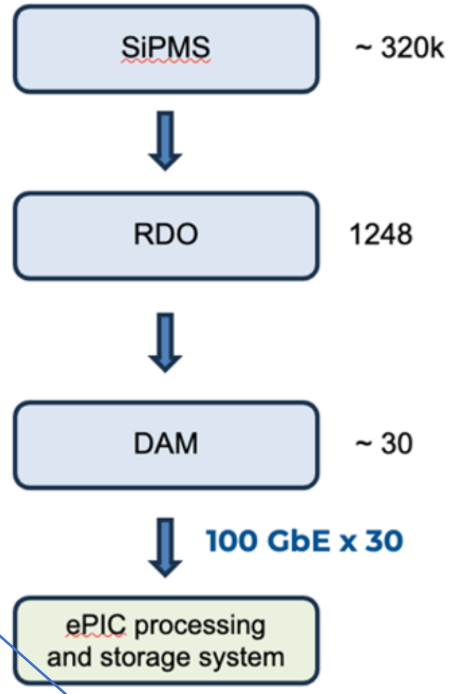


- Accuracy = (TP+TN)/(TP+TN+FP+FN) = 0.997
- Purity = TP/(TP+FP) = 0.994
- Efficiency = TP/(TP+FN) = 0.999

parameterization of DCR background included

Re-cap on dRICH Output bandwidth





*Take home message

Data reduction factor (RF) five can be achieved via shutter or provided by NN or ext. trigger or a **combination** of them.

$$RF_{shutter} \times RF_{TP} = 5$$

Example:

- shutter window 5 ns → RF=2
- TP RF=2.5

*Take home message

Remember always at day zero dRICH starts with DCR = 3 kHz! Commissioning/first operations will allow tuning of shutter/TP etc.

without data reduction with a 100 kHz DCR we are close to DAM bandwidth limit

a data reduction factor 5 allows us to stay safe up to the 300 kHz limit

Considerations (not conclusions)

- we finally had time distribution of hits within ePIC simulation → thanks again to Misha from all ALCOR-DAQ teams!
- refinements under way but it looks like we now know already that, at our best, shutter acceptance window can be no less than 5-7 ns
- this will increase pressure on RDO-DAM opt. link throughput but it looks manageable
- thanks to NN DAQ we are already in safe place, dIT input can only improve situation!