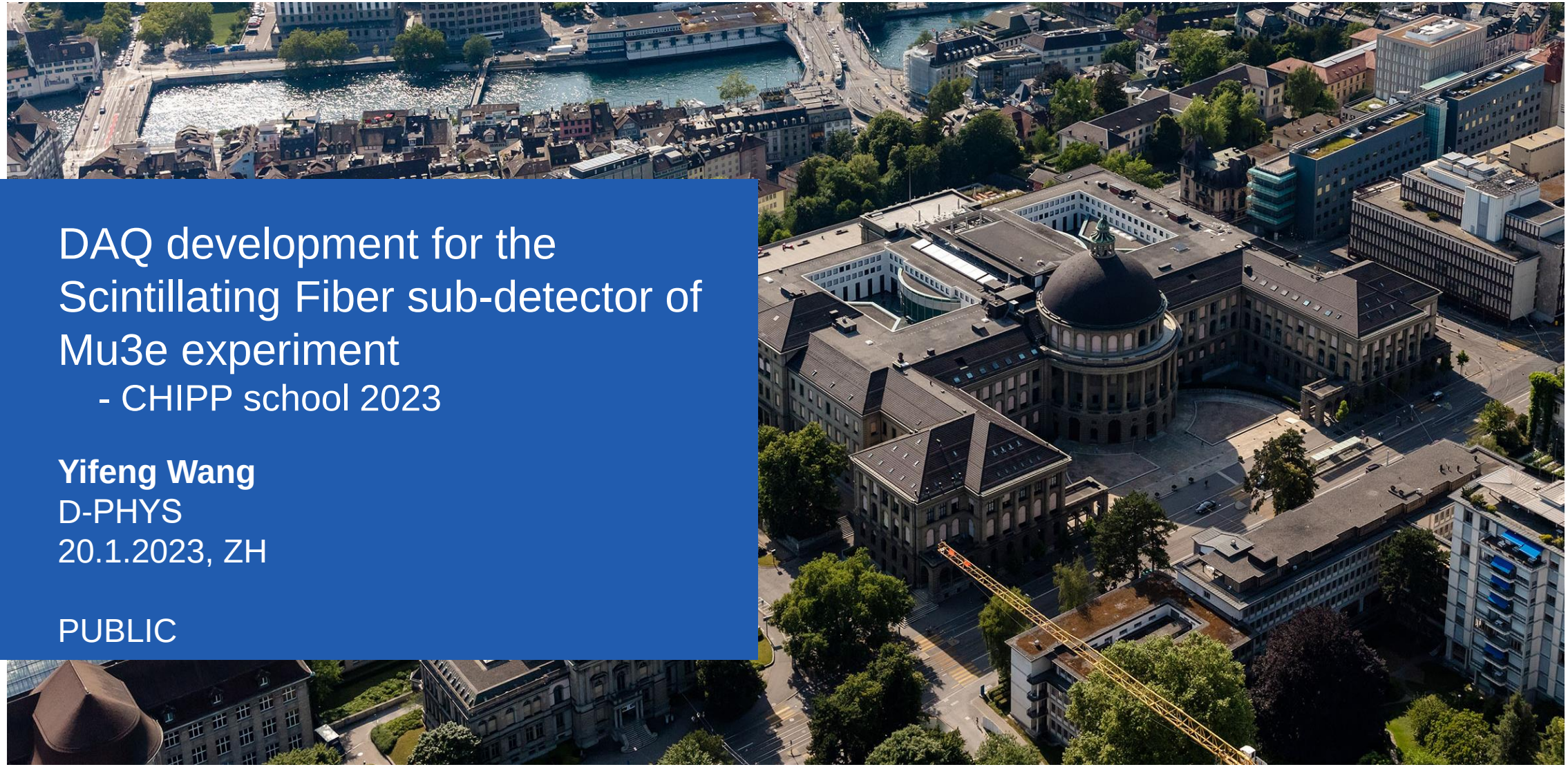
ETH zürich



DAQ development for the Scintillating Fiber sub-detector of Mu3e experiment

- CHIPP school 2023

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D-PHYS
20.1.2023, ZH

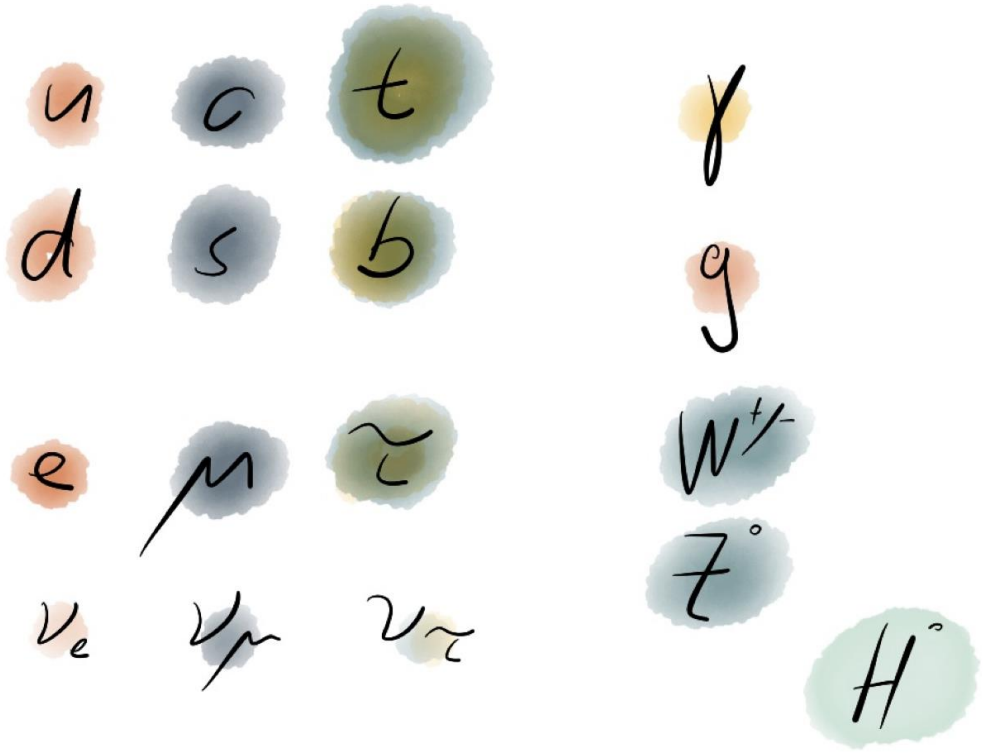
PUBLIC

IPA

Motivation

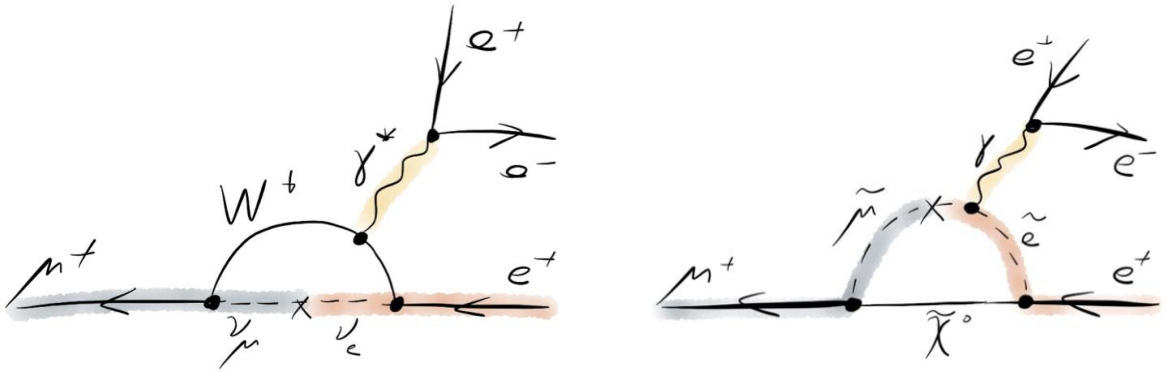
Lepton flavor violation (LFV)

- Oberverd in neutrino sector
- Not oberved in charged lepton sector, why?



The example of mu-to-3e channel

SM cLFV $<10^{-54}$ ⟶ High sensitivity in BSM cLFV



SM extension for nLFV

Past record: $<10^{-12}$ by SINDRUM (1988)

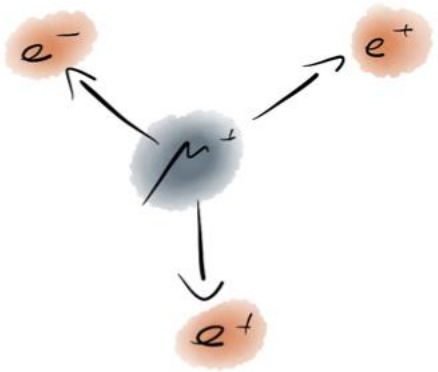
Our goal: $<10^{-16}$ by mu3e (2028+)

ETH zürich

Ref: mu3e internal wiki

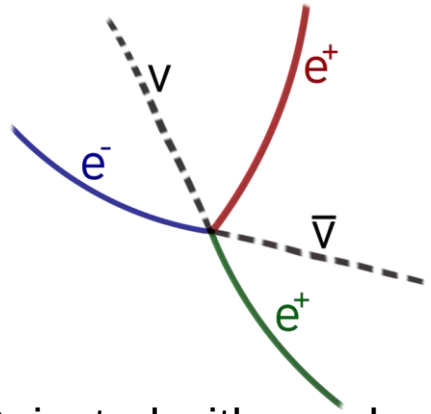
Signal and background identities

Signal ($\mu^+ \to e^+e^-e^+$) signature



Accidential background
$(\mu \to e\nu\nu) + (? \to ee)$

Rare decay as background
$(\mu \to eee\nu\nu) < 3.4 \times 10^{-6}$

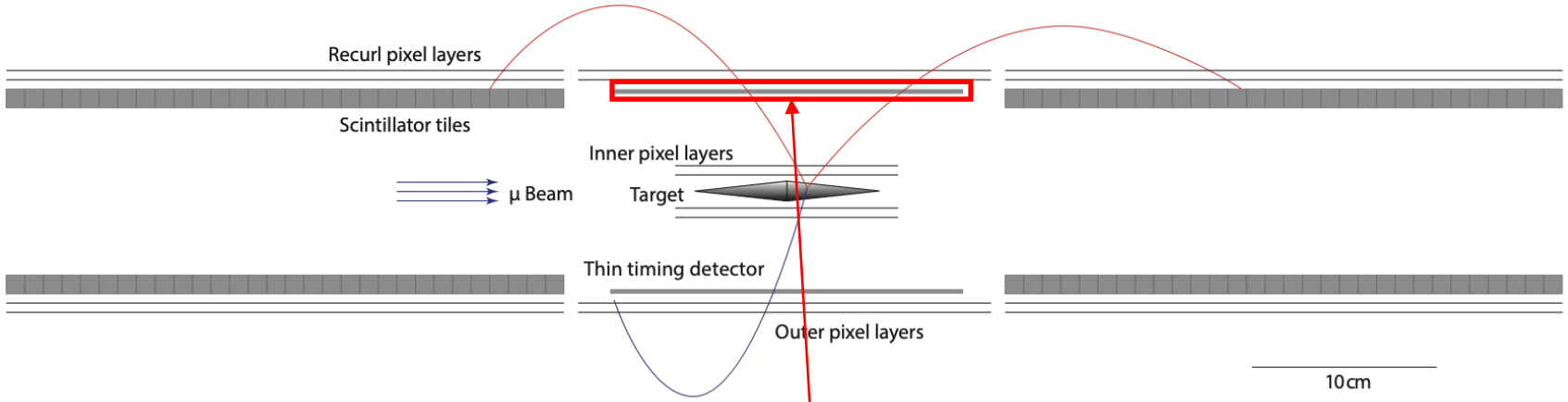


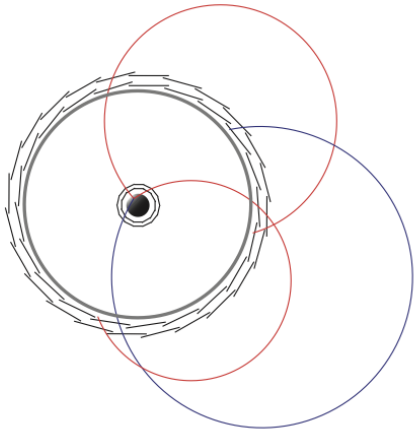
Rejected with good timing and vertex resolution

Rejected with good momentum resolution

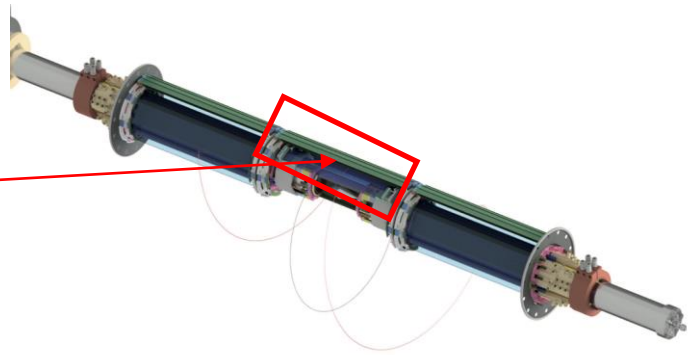
Ref: mu3e internal wiki

Mu3e detector construction





Left section	Mid section	Right section
Outer pixel (recurl)	Outer pixel (vertex)	Outer pixel (recurl)
SciTile (recurl)	SciFi (timing)	SciTile (recurl)
	Inner pixel (vertex)	
==>==beam==>==	**Target**	

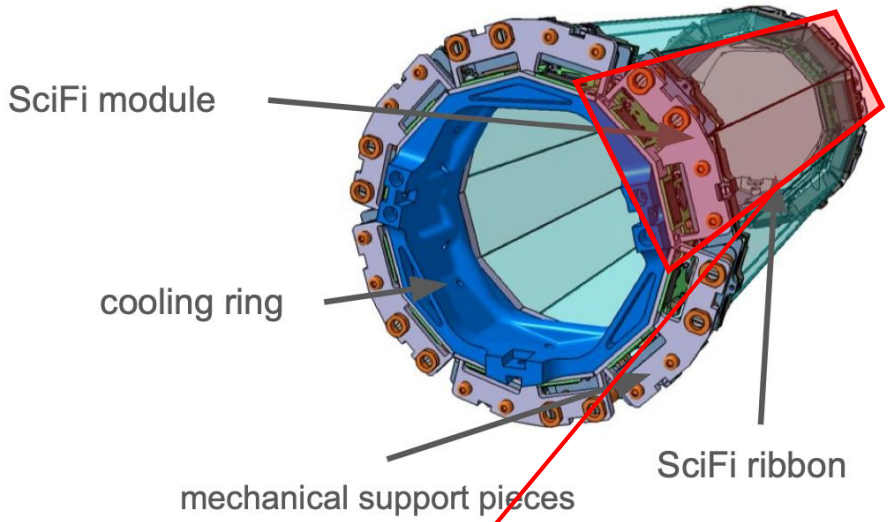


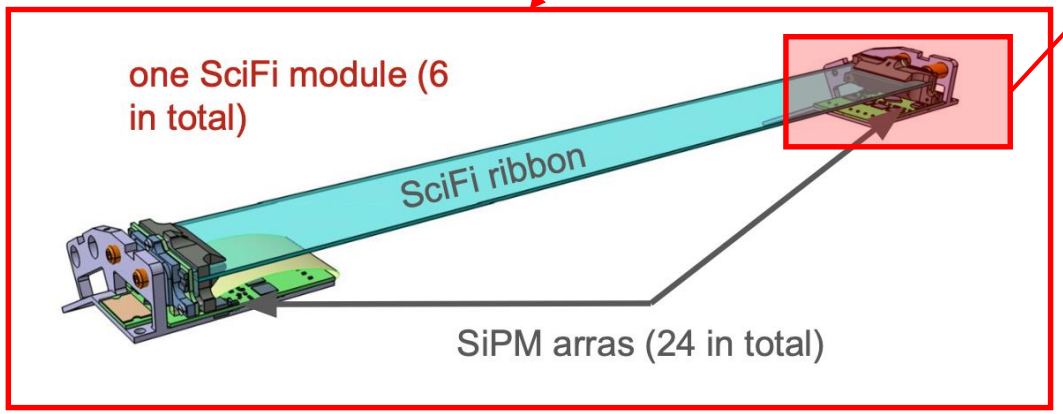
Ref: 2208.09906

ETH zürich

SciFi timing resolution 50 ps, compare to pixel >1 ns

SciFi (scintillating fiber) sub-detector construction

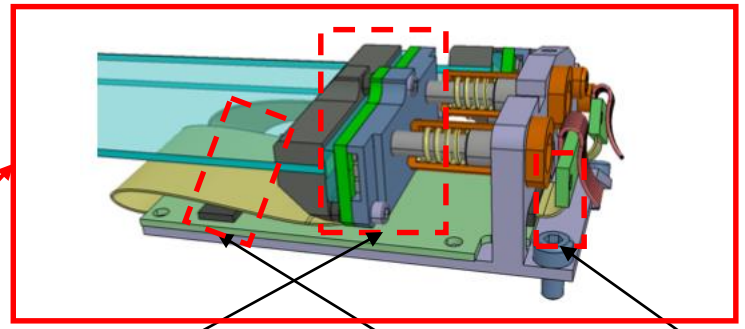




Ref: Y. Demets, BVR 2023

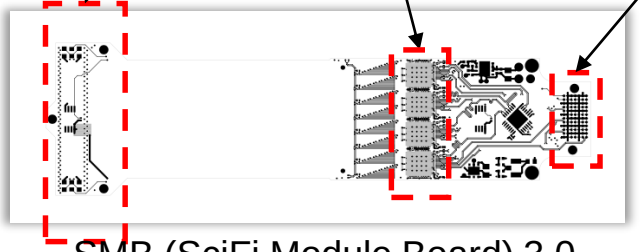
on one end of the fiber ribbon

Ref: 2208.09906



Fill factor >60%
μtwsited pair (μTP) cable bundles

SiPM | MuTRiG x4 | interposer



SMB (SciFi Module Board) 3.0

To FPGA

- SiPM: converting light into eletrical signal
- MuTRiG (Muon Timing Resolver including Gigabit-link): TDC (converting eletrical signal to time stamp with 50 ps resolution
- Interposer: low-profile interboard connector, transmit all links to front-end FPGA for DAQ

Online selection

Signal and DarkCount characteristics

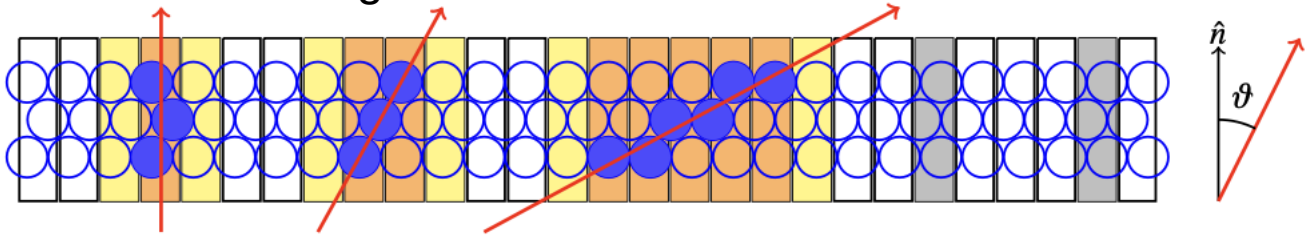
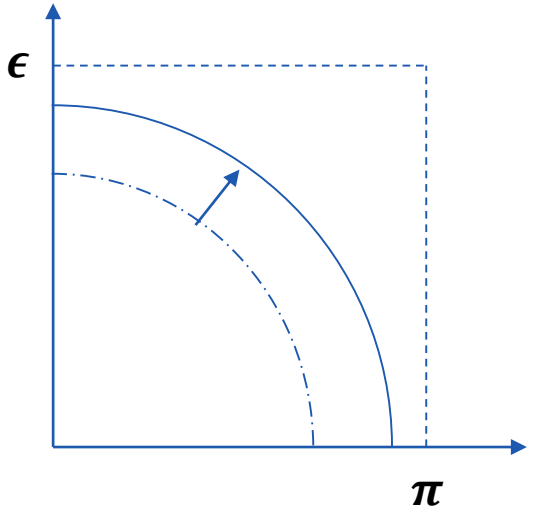


Figure 24. Transverse view of a 3-layer SciFi ribbon mapped to a SiPM array. A particle (red arrow) traversing the ribbon excites some fibers (blue), which can trigger avalanches in several channels of the SiPM array (orange). The optical cross-talk spreads the signal to neighboring channels (yellow). The width of the cluster depends also on the particle's crossing angle (from left to right 0°, 30°, and 60° w.r.t. the normal). A *dark* count (gray), which is identical to a real signal, should be excluded from the cluster.

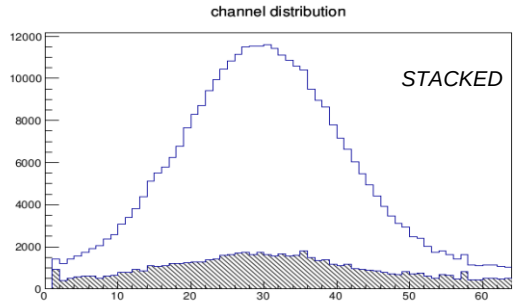
Ref: JINST preprint

Efficiency and signal purity trade-off

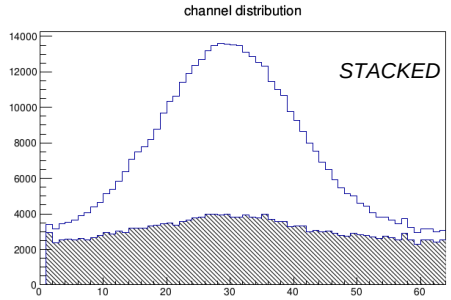


Study coincidence logic performance

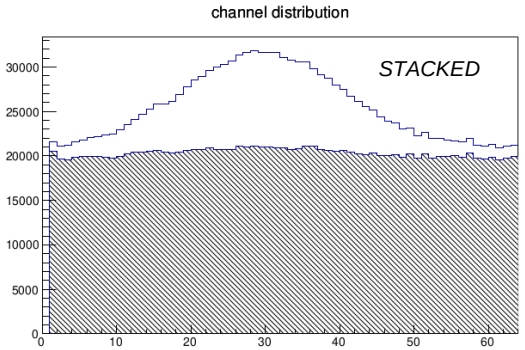
Pressure test – Inject Monte-Carlo generated DC into testbeam data



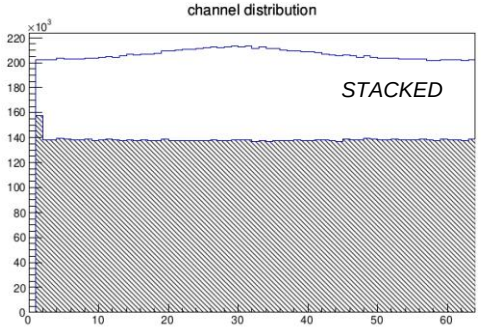
No injection
(baseline DCR 10-25 kHz/ch)



100 kHz/ch



1 MHz/ch



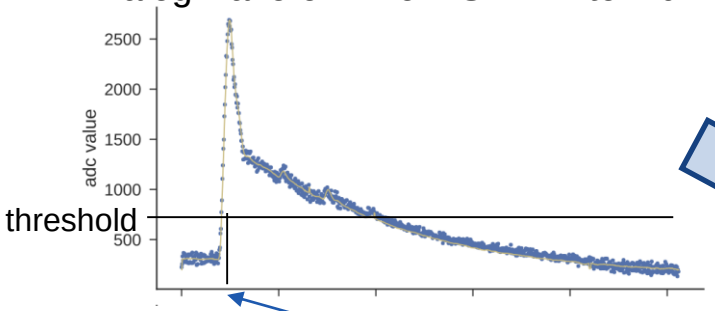
10 MHz/ch

Hit and DC seperation at different injection rates

Front-end TDC and frame builder

Customize transaction and application layer
IP core used for phy and link layer

Analog waveform from SiPM into MuTRiG



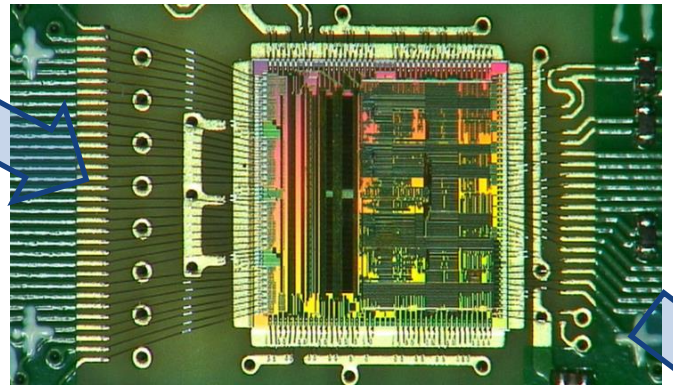
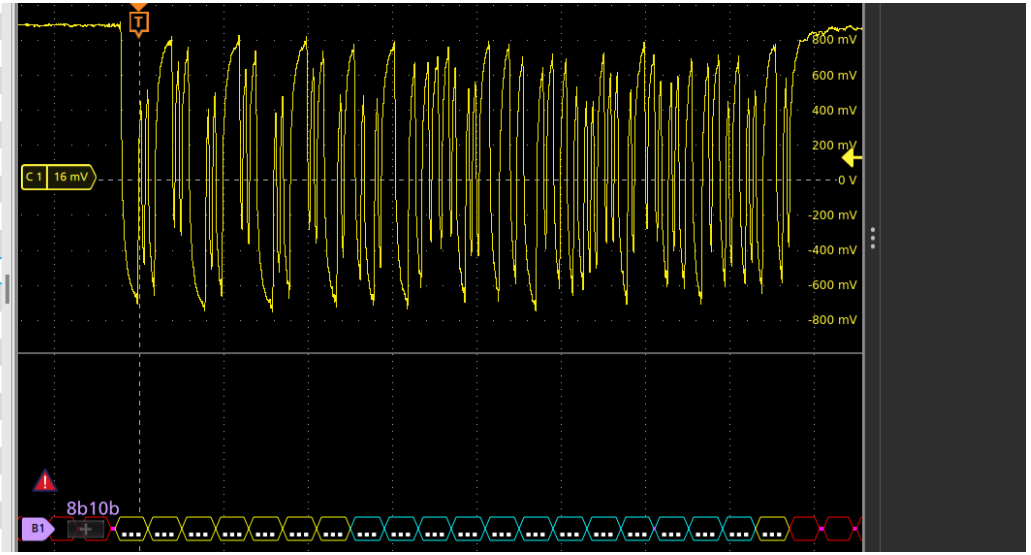


Photo of MuTriG (TDC) x4 chips

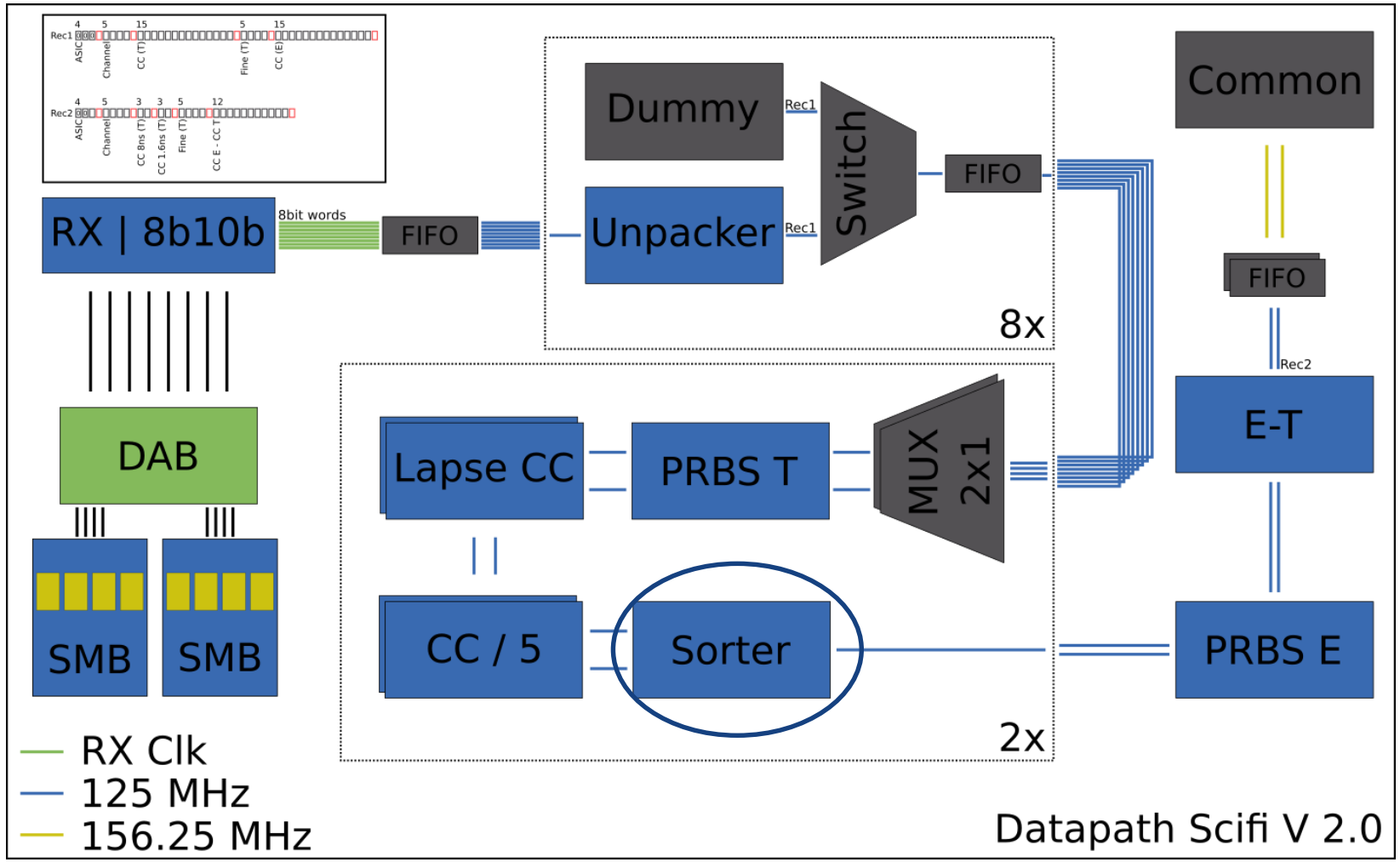
containing timestamps!

1250	-5.588047ns	1100000101	--	K28.5+	--
1251	2.326239ns	0011111010	--	K28.5-	--
1252	10.22008ns	1100000101	--	K28.5+	-- Idle
1253	18.31773ns	0011111010	--	K28.5-	--
1254	26.26451ns	1100000101	--	K28.5+	--
1255	34.30483ns	0011111010	--	K28.5-	--
1256	42.25649ns	1100001011	--	K28.0+	-- header
1257	50.25629ns	1001000101	D16.2+	--	--
1258	58.29413ns	1110000110	D7.6-	--	-- Frame ID
1259	66.45631ns	0110110110	D16.6-	--	--
1260	74.20299ns	1000101011	D1.0+	--	-- Frame flag and length
1261	82.28915ns	1000111001	D17.1	--	--
1262	90.3338ns	1000011011	D30.0+	--	--
1263	98.36967ns	0011001001	D24.1+	--	-- Hit events
1264	106.3007ns	0101101010	D26.5	--	--
1265	114.4557ns	0010111011	D20.0-	--	--
1266	122.3902ns	0100101001	D2.1+	--	--
1267	130.3448ns	1000110110	D17.6	--	-- CRC checksum
1268	138.48ns	0101100101	D26.2	--	--
1269	146.3457ns	0011110010	--	K28.4-	-- Trailer



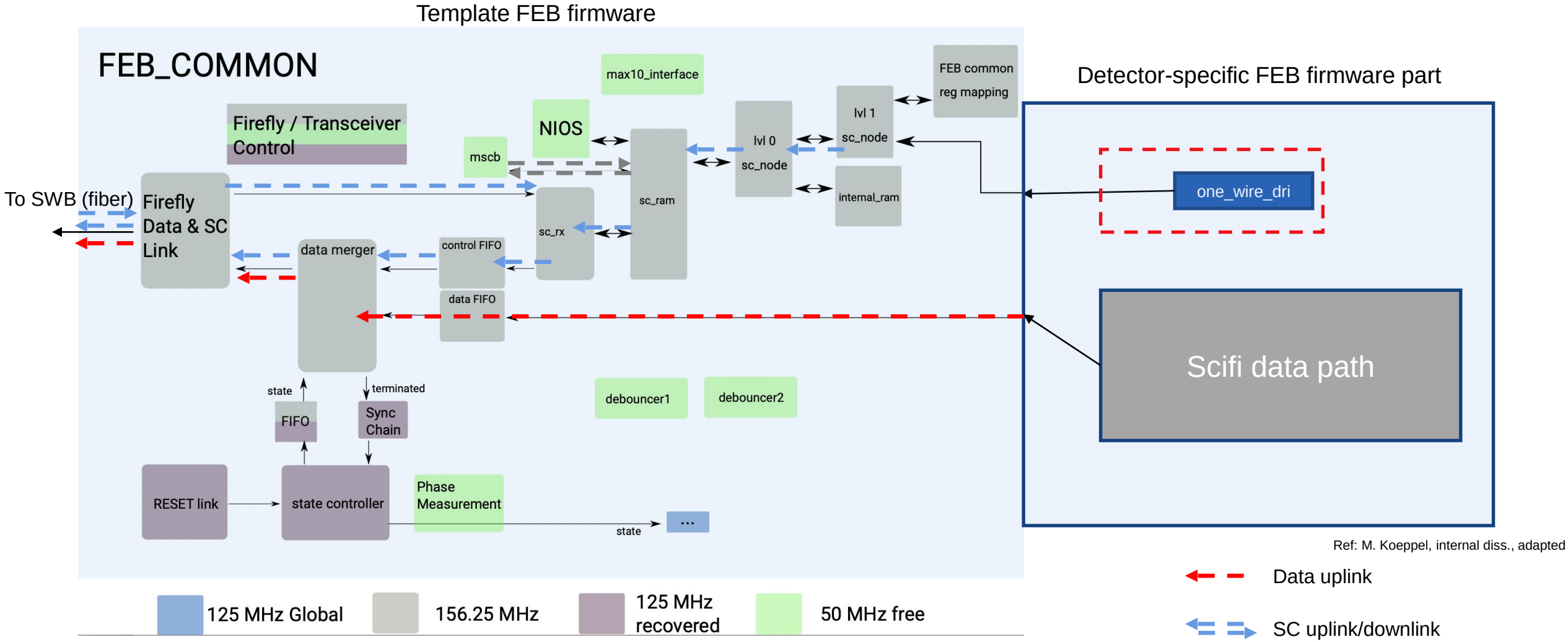
A frame with one hit probed and decoded by osciloscope (1.25Gbps LVDS output of one MuTRiG)

SciFi specific data processing and algorithms



Ref: M. Koeppel, internal diss., adapted

Front-end data/SC path

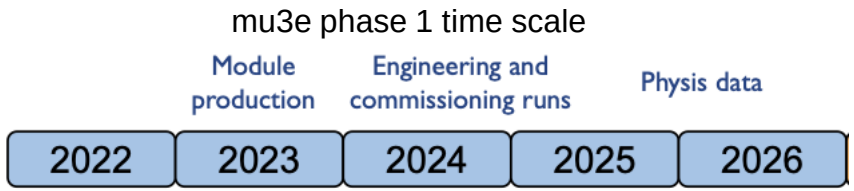


Architecture of the Frontend-Board firmware

SciFi sub-detector DAQ – backend data path

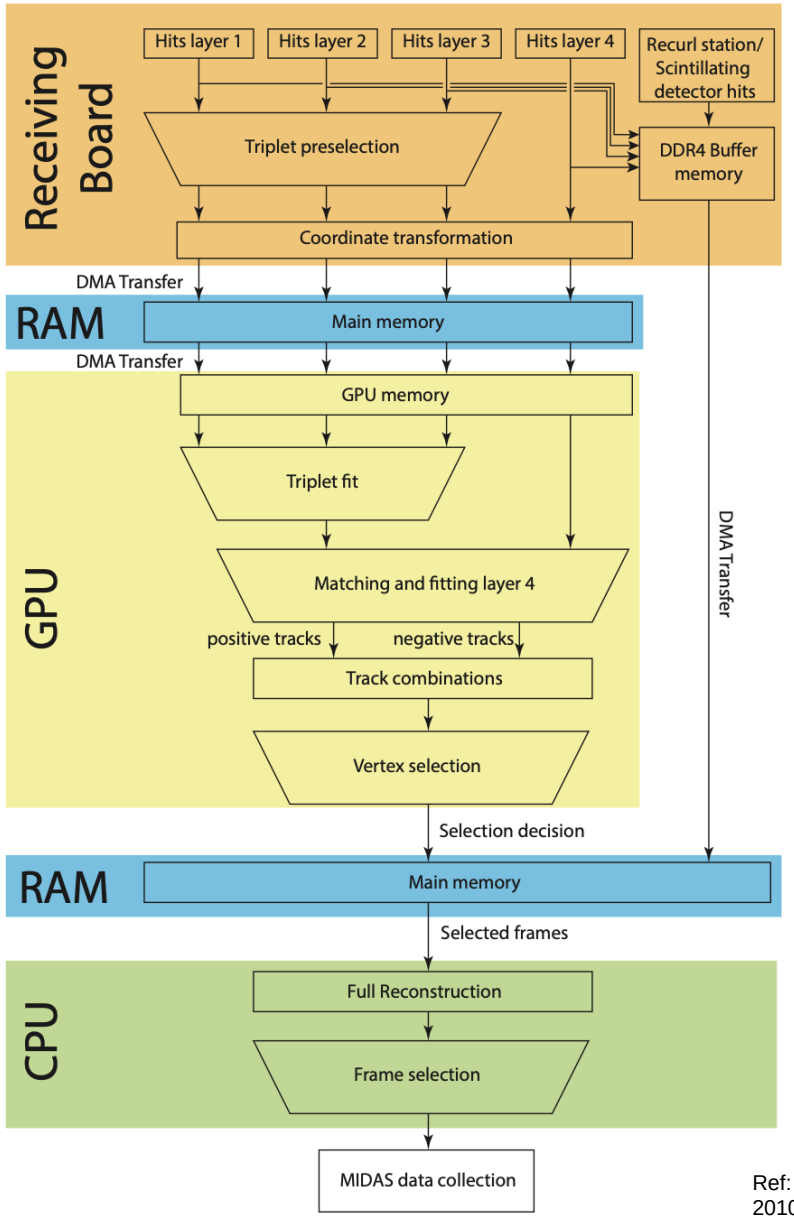
Event reconstruction will be done with the GPU farm to perform online selection

Arbitor will only take pixel hits and decide whether to record SciFi / SciTile / etc. into data frame



Hope we can see interesting physics from the data!

Ref: A. Schoning, BVR 2023



Ref: The Mu3e Data Acquisition, 2010.15648

Backend data flow for the integrated mu3e

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