An Interaction Tagger (IT) for the dRICH

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The problem and the (possible) solution

The problem

- The dRICH is the ePIC sub-detector generating the highest FE data rate
- 1 p.e. background generated by SiPMs dominates the data rate
- the dRICH bg is not reducible at the channel level [Cherenkov light (signal) is expected in the same range (~ 1 p.e.)]
- an external ‘trigger’ that identifies high-momentum hadrons crossing is needed

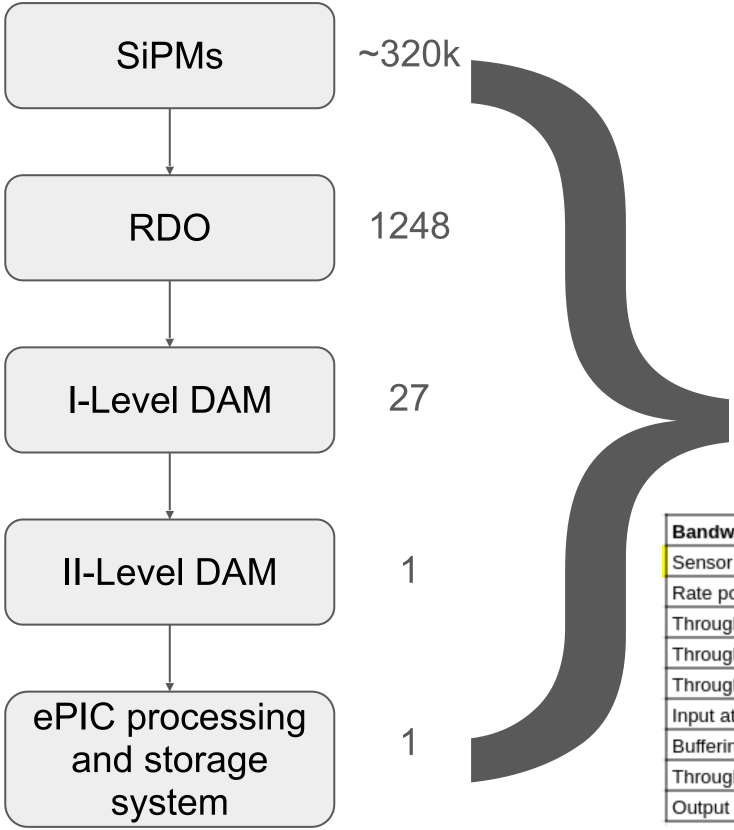
Requirements

- Trigger signal: generated by fast hadrons crossing the dRICH volume
- Prompt: the trigger signal should be fast to generate a narrow time coincidence window
- Local: the data rate should be reduced as closely as possible to the source
- dRICH-generated: to avoid uncontrolled delays and respect the ePIC SRO-DAQ concept
- Time and position: to veto noise and identify the dRICH region with hadron candidates

The solution

An Interaction Tagger (IT) integrated in the dRICH based on plastic scintillators that provide a prompt and fast signal (with some position dependence) of hadrons crossing the dRICH volume

The dRICH DAQ chain in ePIC → the throughput issue



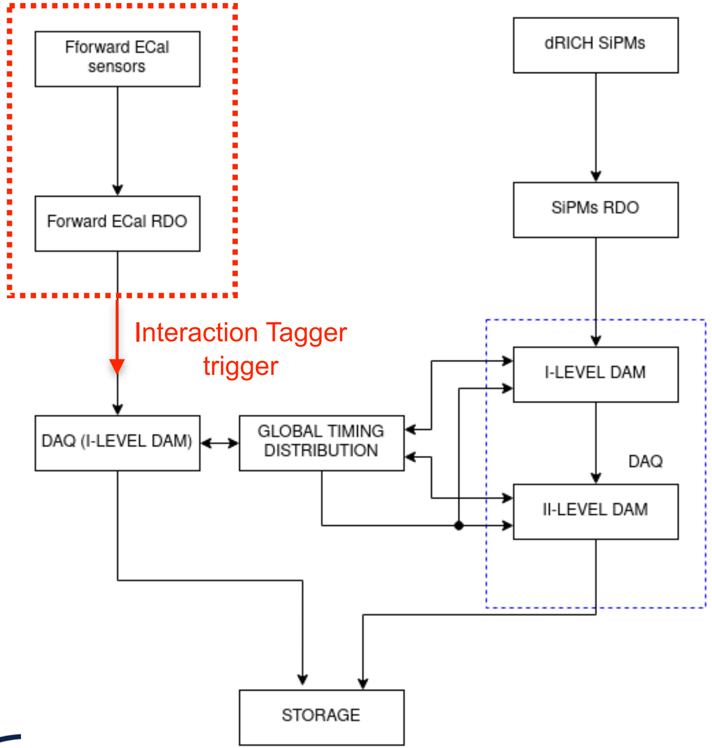
dRICH DAQ parameters	
RDO boards	1248
ALCOR64 x RDO	4
dRICH channels (total)	319488
Number of DAM L1	27
Input link in DAM L1	47
Output links in DAM L1	1
Number of DAM L2	1
Input link to DAM L2	27
Link bandwidth [Gb/s] (assumes VTRX+)	10
Interaction tagger reduction factor	1
Interaction tagger latency [s]	2,00E-03
EIC parameters	
EIC Clock [MHz]	98,522
Orbit efficiency (takes into account gap)	0,92

Bandwidth analysis		Limit
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	
Throughput from RDO [Gb/s]	1,08	10,00
Input at each DAM I [Gbps]	50,67	470,00
Buffering capacity at DAM I [MB]	12,97	
Throughput from DAM I to DAM II [Gbps]	50,67	10,00
Output to each DAM II [Gbps]	1.368,14	270,00

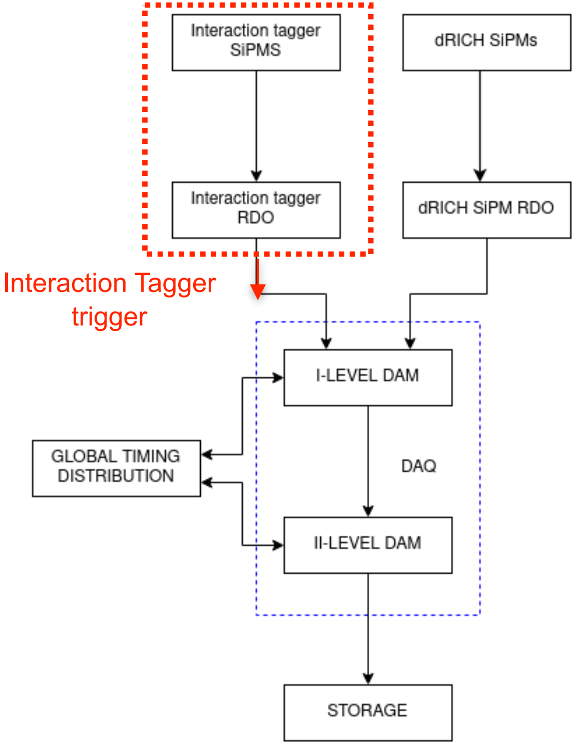
- Sensors DCR: 3 - 300 kHZ (increasing with radiation damage → with experiment lifetime).
- Full detector throughput (FE): 14 - 1400 Gbps
- A reduction >1/5 is needed
- EIC beams bunch spacing:10 ns → bunch crossing rate of 100 MHz.
- For the low interaction cross-section (DIS) → one interaction every ~ 100 bunches → interaction rate of ~1MHz
- A system tagging the (DIS) interacting bunches can solve the throughput issue (reducing to ~1/100 the data throughput)

The dRICH Interaction Tagger (IT) possibilities

Based on information provided by other sub-detectors through the Global Timing Unit board.



Integrate it directly on the dRICH, adding few RDO and scintillating fibers layers.



Some general considerations

- The EIC bunch crossing rate is ~100 MHz
- The EIC DIS interaction rate is expected to be ~ 1 MHz
- The IT reduction factor is roughly provided by the ratio of the IT rate and the EIC bunch crossing rate
- The max data throughput is ~1.4 Tbsp and the DAQ limit ~270 Gbps: the minimal reduction factor is ~ 5
- **A reduction factor in the order of 10 can be achieved with an IT rate lower than 10 MHz**
- An IT based on plastic Scintillating Fibers (SciFi) o small tiles of plastic scintillators should work
- The IT reduction factor shall be determined by simulations (signal, background, and IT response)

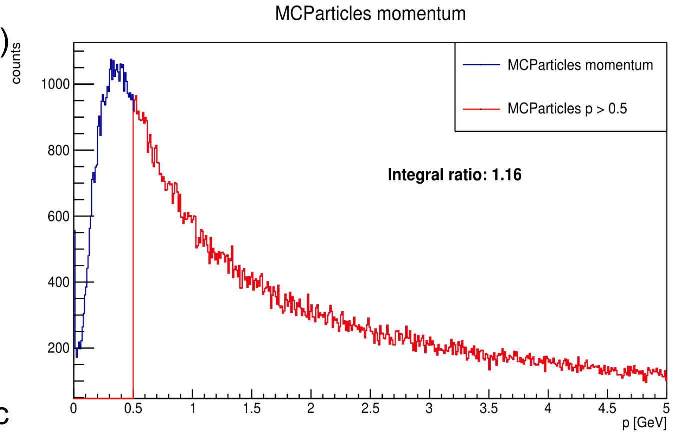
- (If possible) the **Interaction Tagger** could act as an **Interaction Tracker** providing (minimal) information on particle track to be used in the fast AI-supported data reduction algorithm running I Level DAM (under development by INFN RM1 and RM2 unites)

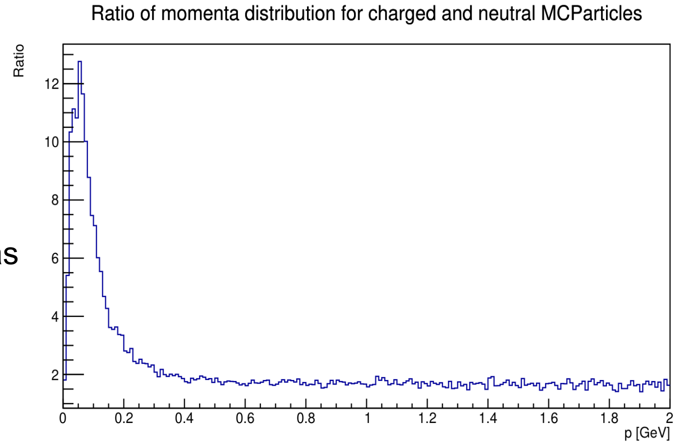
Preliminary IT response and rates

- A plastic scintillator-based IT is sensitive to MIPs (not only high momentum hadrons)
- Mitigation:
  - The high magnetic field will shield the dRICH from low-momentum particles
  - (Large) fibers light quenching cuts off very low-energy particles
  - IT neutral detection efficiency is <<10%
  - A few cm of plastic scintillator/SciFI will efficiently tag particles with energy deposition larger than 10 MeV

- The preliminary ePIC simulation includes charged particle tracks with p > 500 MeV/c crossing the dRICH front face
  - ~ 0.4 MHz background
  - ~ 2.3 MHz SIDIS events

- Low-momentum and neutral particles are not yet in the simulations
- To estimate the the low energy particle number, the DRICHAerogel_Tracks bank was combined with the MCParticles bank (top plot and backup) finding ~ x1.16 the high momentum spectrum
- MCParticles bank was also used for a preliminary evaluation of the charged-to-neutral ratio finding ~ x2 (integrated in the full momentum range)



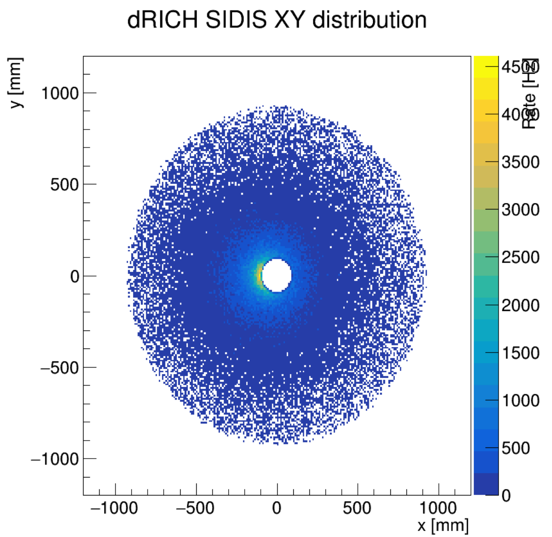


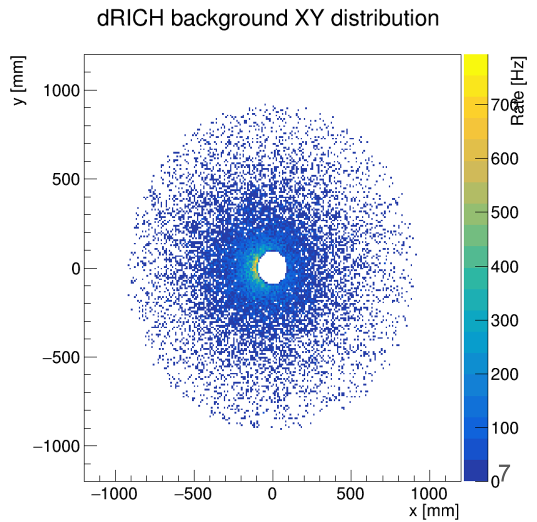
Signal/BG rates (dRICH front face)

IT rates from ePIC SIDIS simulations

- charged particles (p > 500 MeV/c)
  (background + SIDIS → total):
  - 0.4MHz + 2.3 MHz = 2.7 MHz;
- x1.2 to account for low-momentum particles:
  - 0.5 MHz + 2.8 MHz = 3.2 MHz
- x1.2 to account for neutral particles:
  - 0.6 MHz + 3.3 MHz = 3.9 MHz
- x5 extra safety factor
  - 2.9 MHz + 16.6 MHz = 19.5 MHz

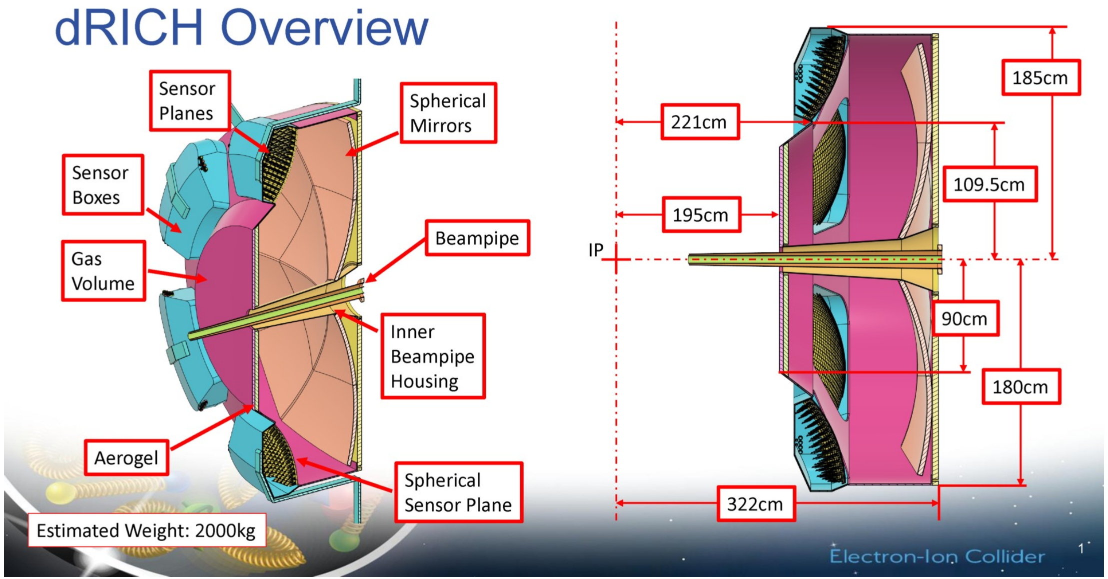
Even with an x5 safety factor the IT rate is ~20 MHz (~10 MHz more realistic) providing a dRICH data reduction of ~5





IT preliminary design

- The signal/bg rate is not uniform oil the dRICH front face (larger in the central region)
- Preliminary ideas include:
  - a grid of V and H SciFi at 90°
  - a grid of diagonal 60 ° SciFi
  - small (~1x1 cm^2) in the central region and large (~10x10 cm^2) in the peripheral region plastic scintillator tiles

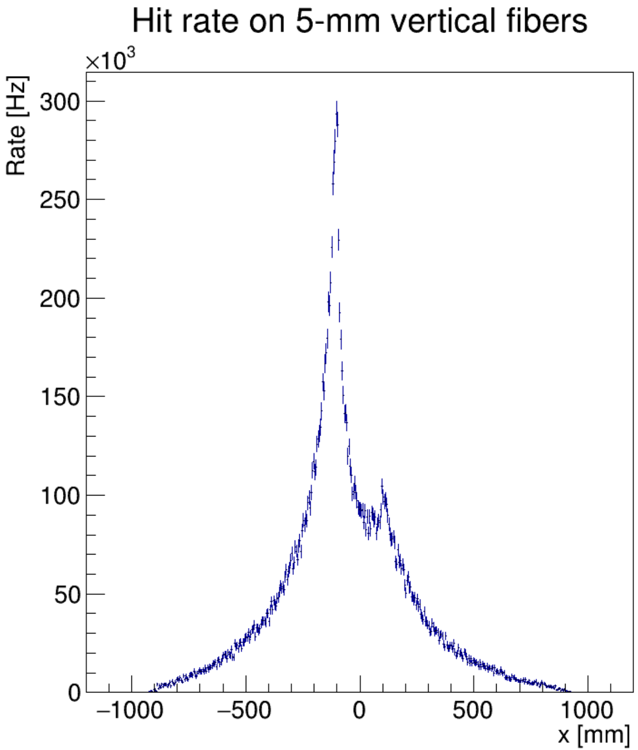


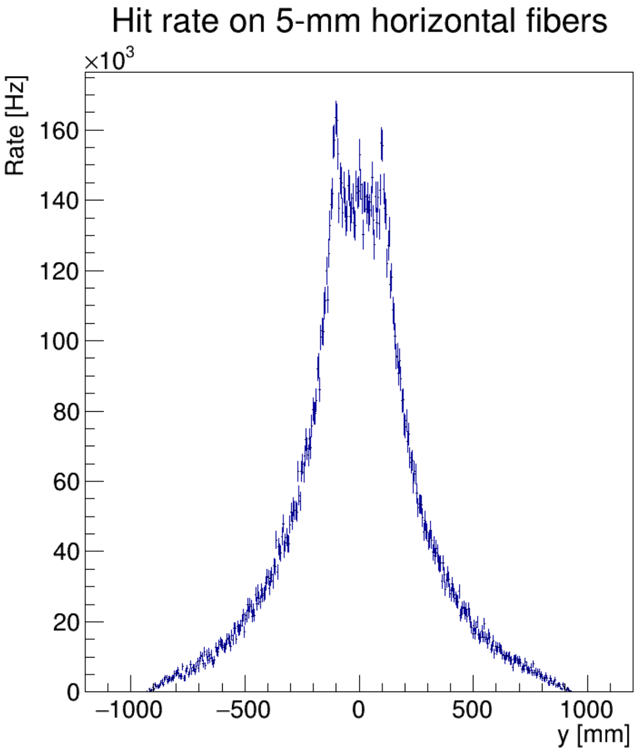
An \example:

- 2 layers, 1000 SciFi, 2 m long, and 0.5 cm ∅;
- SciFi:
  - attenuation length ~ 4 m
  - time rising edge ~ 100 ps
  - hit duration ~ 10-20 ns
- SciFi optical coupled with SiPMs cabled to RDOs;
- Two-sides readout → 4k SiPMs & 4k channels (dRICH 320k channels)
- 256 channels for RDO →need to add 16 RDOs
- Cost estimate: ~ 100k€

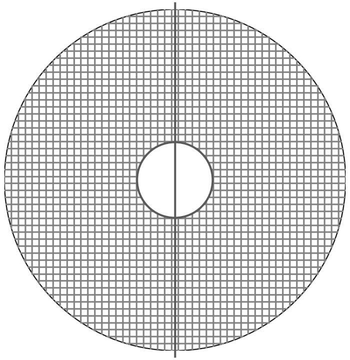
Signal/BG rates on SciFi fibers

- Signal rate (SIDIS events): 5-mm single fibers. Maximum = 300 kHz





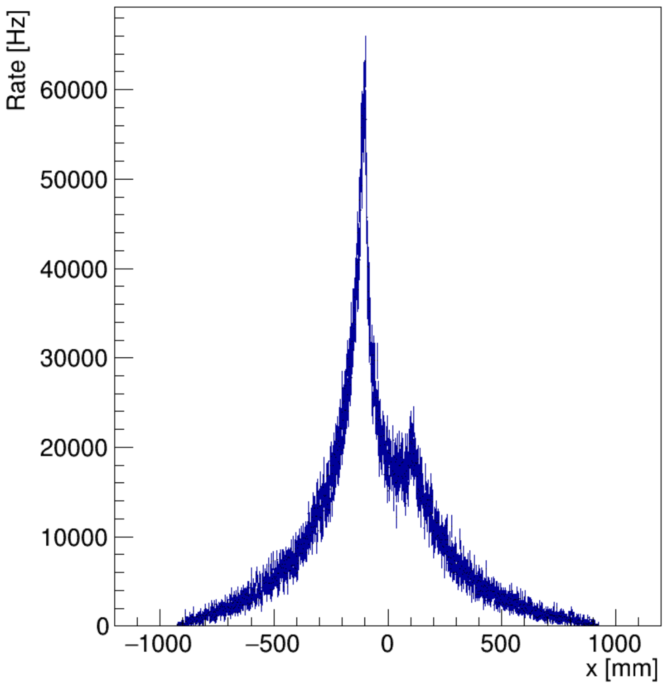
The 90° grid tessellation is considered



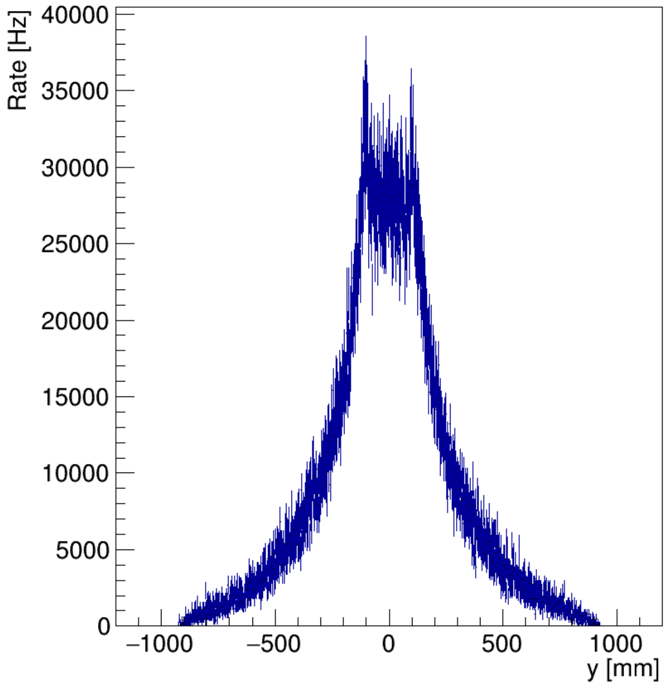
Signal/BG rates on SciFi fibers

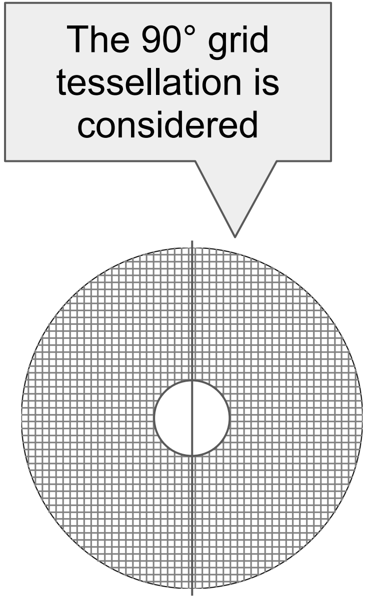
- Signal rate (SIDIS events): 1-mm single fibers. Maximum = 60 kHz

Hit rate on 1-mm vertical fibers



Hit rate on 1-mm horizontal fibers

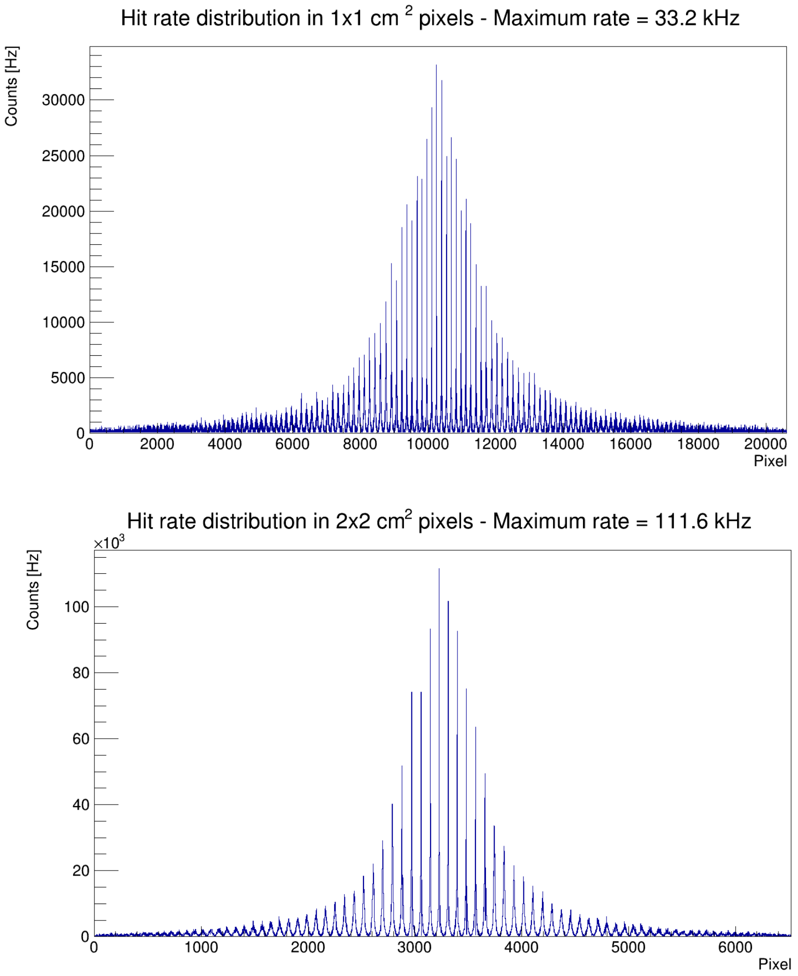




Smaller fibers requires more channels (~20k), probably increasing cost and complexity

Signal/BG rates on tiles

- Signal rate (SIDIS events): 1x1 cm2 and 2x2 cm2 tiles



- Maximum rates: 33 and 112 kHz
- Number of channels grows up to ~ 45k (1x1 cm^2)
- It is possible to develop a hybrid design with different tiles (1x1, 2x2, 5x5, and 10x10 cm^2) to keep the number of channels low and sustainable rates

Workplan

- Before 2024 end:
  - present the IT concept to the ePIC Collaboration
  - Simulate full low-energy particle spectrum on the dRICH front face
  - Learning and practicing the DAQ chain based on dRICH RDO

- First half of 2025:
  - Procure different SciFi size samples and SiPMs for testing/prototyping
  - Implement the readout chain at INFN-GE
  - Testing the SciFi/SiPM coupling
  - Testing the IT prototype response to low-energy particles
  - Optimize thresholds to reduce low-energy particle background
  - Implement SciFi measured response in simulation
  - Finalize IT design (pre-CDR)
  - Integrate the IT into dRICH design

Richieste INFN-GE 2025

Capitolo	Descrizione	Richieste	SJ
consumo	Streaming Readout: evaluation board da sostituire alla Felix	1.00	0.00
	dRICH + Streaming Readout: 128 SiPM singoli per leggere le fibre scintillanti del tagger: 128 *27 Euro =3.5 kE	3.50	0.00
	dRICH: Prototipo meccanico panello tagger sul dRICH	1.00	0.00
	dRICH: produzione PCB per montaggio SiPM con interfaccia per ALCOR	1.50	0.00
	dRICH: interaction tagger - fibre scintillati SCSF-3HF(1500), 1.0mmSQ, 1 km (preventivo 1 mm2 ~7.12 Euro/m)	8.00	0.00

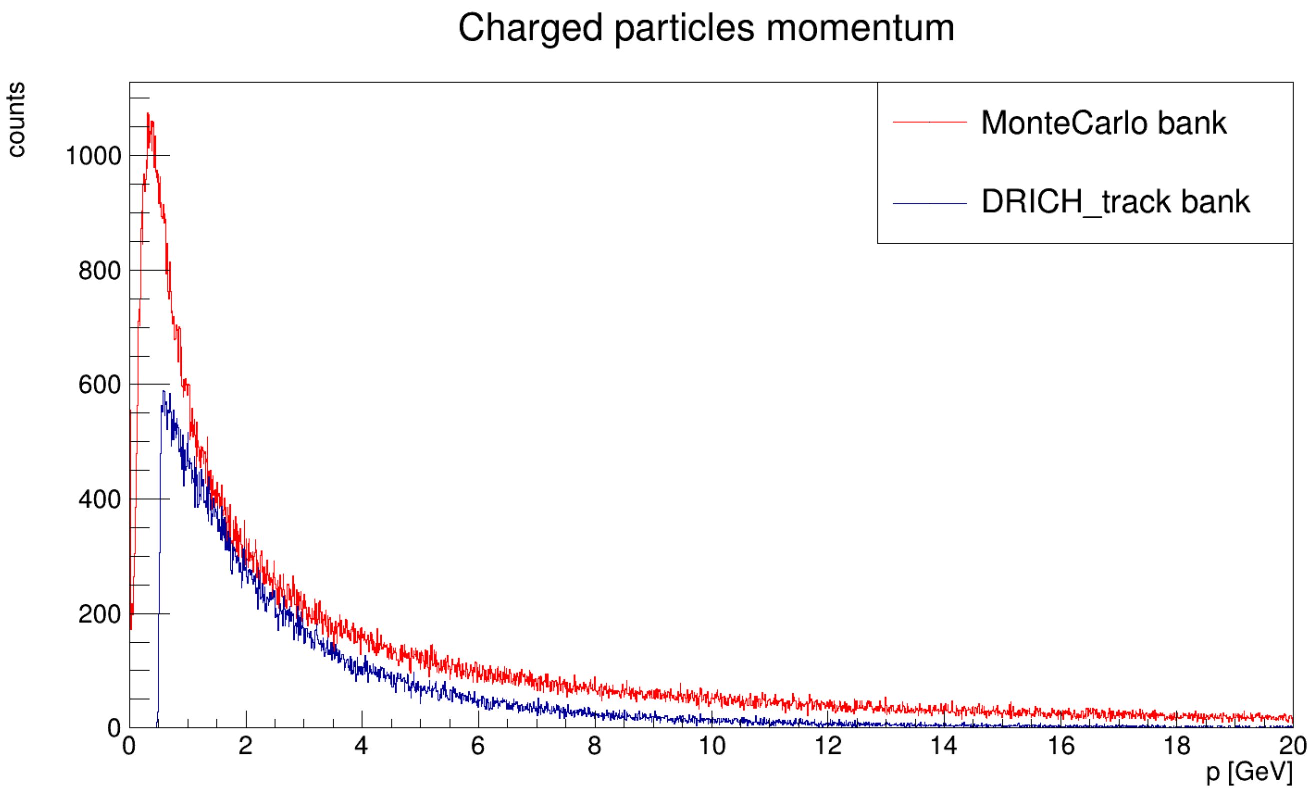
- Elettronica di FE e RO in prestito da INFN-BO

Conclusions

- The dRICH throughput can reach a warning level of 1.4 Tbps during its lifetime
- An Interaction Tagger integrated into the dRICH, with a cost-effective design, can be an efficient solution with minimal impact on cost and detector design
- Current simulations provided a rough estimate of IT signal and background rates
- A thorough estimate, including low energy particles reaching the dRICH front face is necessary to finalise the IT design
- A SciFi-based IT can provide prompt information on particle track location to AI-based selection algorithms running on DAM-I and DAM-II FPGAs
- When the dRICH starts, the throughput is expected to be ~ 14 Gbps (low) allowing a complete characterisation of the IT performance

Backup slides

Why MCParticles bank was used to compute the rate?



Momentum distribution of simulated charged particle selected using the DRICH_track bank and the MonteCarlo bank. The MC bank does not have any cut applied.

Because the MC bank shows larger number of particles surely passing through dRICH, it can be used as a superior limit of all particles that pass through the detector without any selection.