ePIC referee's meeting
July 25, 2025

dRICH Interaction Tagger (dIT)

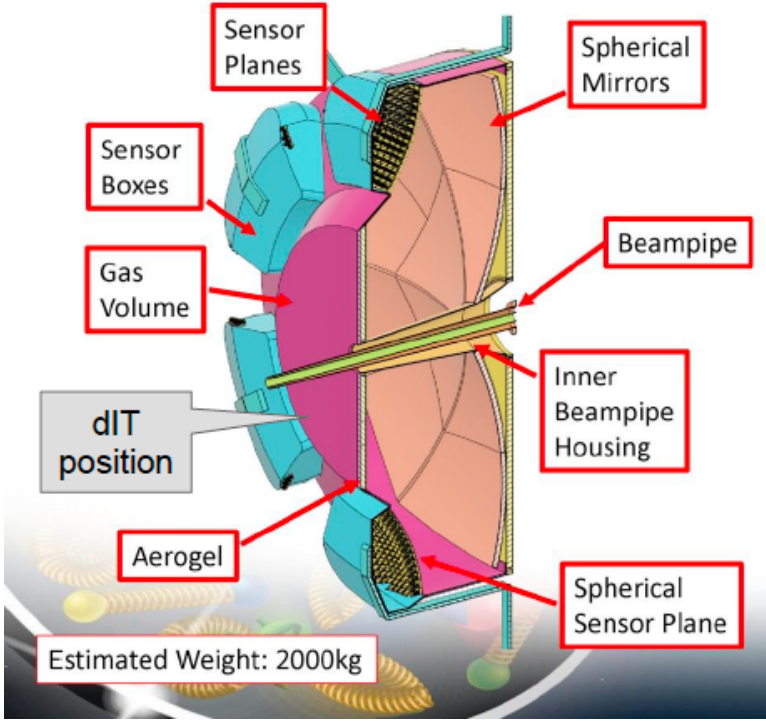
M.Battaglieri, S.Farinon, S.Grazzi, R.Musenich, P.Musico, T.Nagorna,
M.Osipenko (RL), M.Ripani, F.Rossi, M.Spreafico,S.Vallarino, T.Vittorini
INFN - Sezione di Genova

Motivations

- 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.)

Requirements

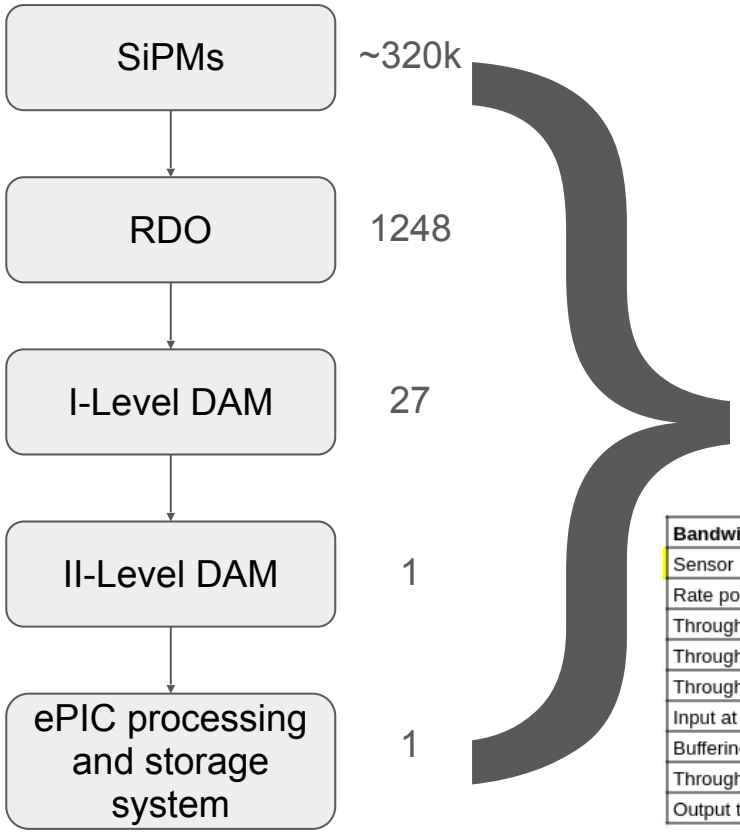
- Trigger signal: generated by fast hadrons crossing the dRICH volume
- Prompt: the trigger signal should be fast to generate a narrow time coincidence window
- High efficiency: to not lose good hits in the dRICH
- Low material budget: to not affecting hadrons crossing the dRICH
- Local: the data rate 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



An Interaction Tagger 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

- Design: 2 layers x 2mm SciFi + 3mm support in carbon fibre (~1r.l. + 2.6 r.l. = 3.6 r.l.)
- Narrow real-time coincidence with RF signal (Time window < 10ns)
    - For 80cm long fibers Dt~4ns + TRK δT~2ns < 10 ns (expected off-line reconstruction resolution <100ps)

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

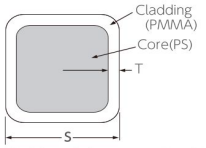
Bandwidth analysis		Limit
Sensor rate per channel [kHz]	300,00	4.000,00
Rate post-shutter [kHz]	55,20	800,00
Throughput to serializer [Mb/s]	34,50	788,16
Throughput from ALCOR64 [Mb/s]	276,00	
Throughput from RDO [Gb/s]	1,08	10,00
Input at each DAM I [Gbps]	50,67	470,00
Buffering capacity at DAM I [MB]	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 ~ 100-200 bunches → interaction rate of ~500 kHz - 1MHz
- A system tagging the (DIS) interacting bunches can solve the throughput issue (reducing to ~1/100 the data throughput)
- Alternative effort using a smart and fast FPGA AI-based data reduction (see RM1 presentation)

dIT design and benchmarking (simulations)

- dIT geometry and design
- dIT performance: energy deposition, efficiency, timing
- Deep Inelastic Scattering (DIS) signal rate
- electron gas background rate
- proton gas background rate

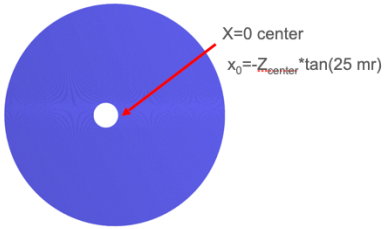
Tagger implementation in ePIC DD4HEP code

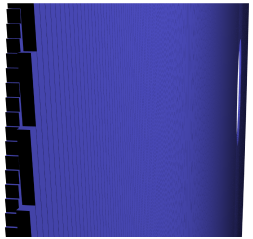


Cladding Thickness : T=2% of S
Numerical Aperture : NA=0.55
Trapping Efficiency : 4.2%

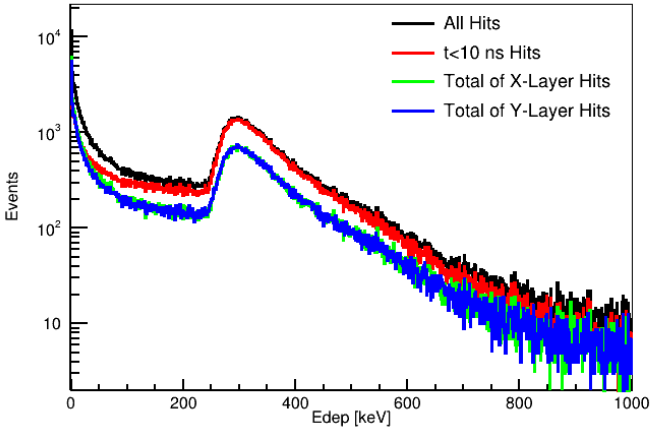
- two layers of 2 mm wide scintillation fibers, 2% cladding thickness, 50 um gap, installed before dRICH aerogel at Z=ForwardRICHRegion_zmin + 2.86*cm;
- XY-directions, 956 fibers/layer, 1.23 km of fiber length/layer;
- 25 mr offset beam pipe hole in the center (one side reading for central fibers) with 85 mm radius (aerogel R_{min}=85 mm)
- RO from the two sides but fibers crossing the hole (one side only)

Tagger performance: energy deposited in scintillator





- most probable deposited energy =300 keV/ layer =2400 photons;
- assuming trapping efficiency of 4.2% (Kuraray) gives 50 photons/MIP;
- assuming SiPM PDE=40% (S13360-3050) gives 20 p.e./MIP;
- threshold could be set at 100 keV~7 p.e./SiPM;
- expected Poisson inefficiency <0.1%.



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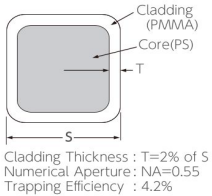
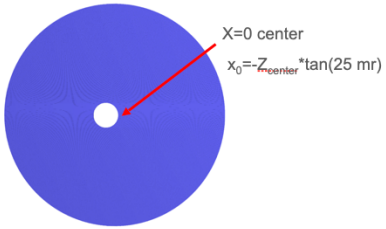
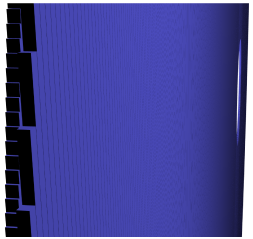


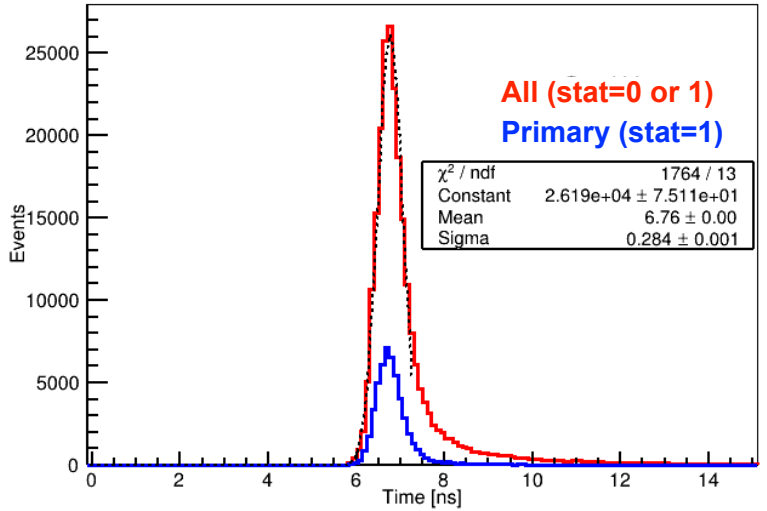
- two layers of 2 mm wide scintillation fibers, 2% cladding thickness, 50 um gap installed before dRICH aerogel at Z=ForwardRICHRegion_zmin + 2.86*cm;
- XY-directions, 956 fibers/layer, 1.23 km of fiber length/layer;
- 25 mr offset beam pipe hole in the center (one side reading for central fibers) with 85 mm radius (aerogel R_{min}=85 mm).

Tagger performance: timing

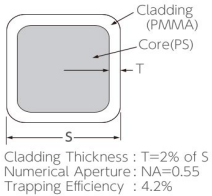




- hit time distribution has a Gaussian shape with a long r.h.s. tail;
- the tail is mostly generated by secondaries (stat=0);
- time for 85% of hits lies within 2 ns (t=6÷8 ns), 92% in 10 ns (doesn't include light propagation in fiber);
- average number of good dIT hits (>100 keV, <10 ns) =20, or about 10 hits/layer; it will allow time correlations between fibers, improving "start" time.



Tagger implementation in ePIC DD4HEP code



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- XY-directions, 956 fibers/layer, 1.23 km of fiber length/layer;
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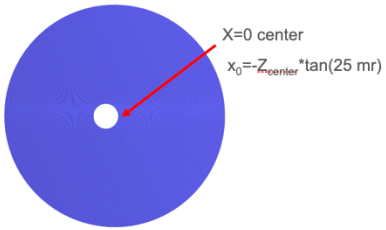
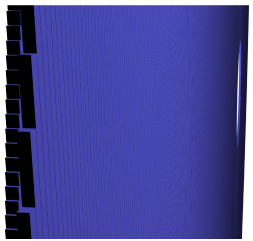
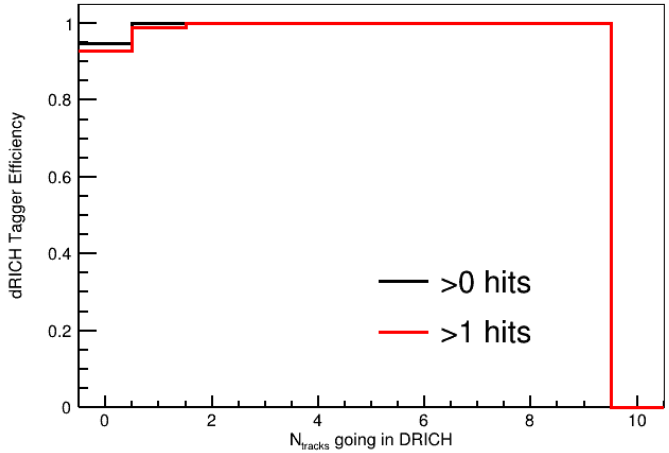
Tagger performance: efficiency





- On average 15 tracks/event with associated DT hits;
- efficiency estimated as a ratio of events with charged tracks having DT hits over the number of events having dRICH hits;
- expected overall 99% efficiency, observed for >0 MC tracks heading into dRICH: 99-100% (99% for 1 MC track) overall value (from >0 MC tracks) 99.97%.
- 4.7 times more stat=0 (secondary) track hits than stat=1.

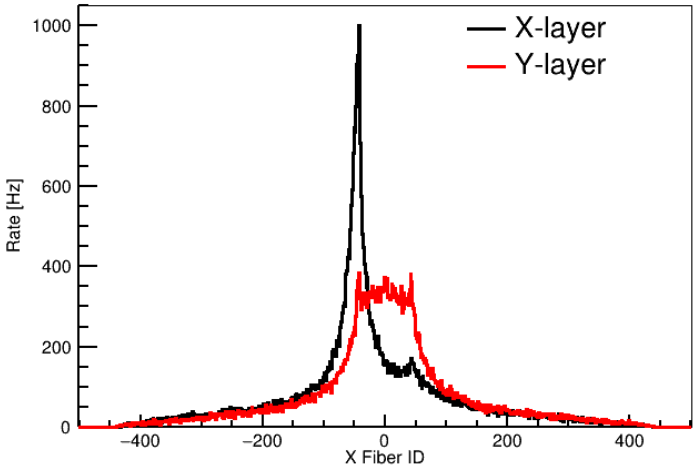


DT rates at nominal luminosity (DIS SIGNAL)

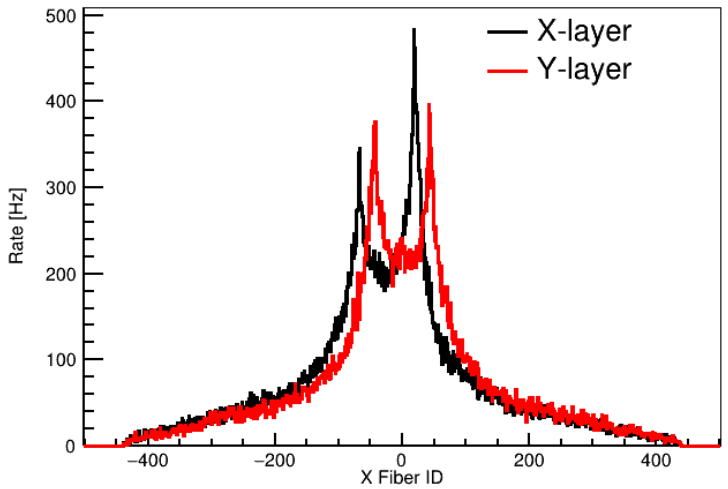
- we assumed the maximum nominal ePIC luminosity of 10^{34} cm^2/s (10^4 μb/s)
- at Q^2>1 GeV^2 (σ=0.556 μb) rates on fibers are not exceeding 1 kHz (70 kHz total): RND coincidences negligible

$$Rate = \frac{N_{hits}}{N_{events}} \times \sigma_{gen}[\mu b] \times L[\mu b^{-1} s^{-1}]$$

central beam hole in DT

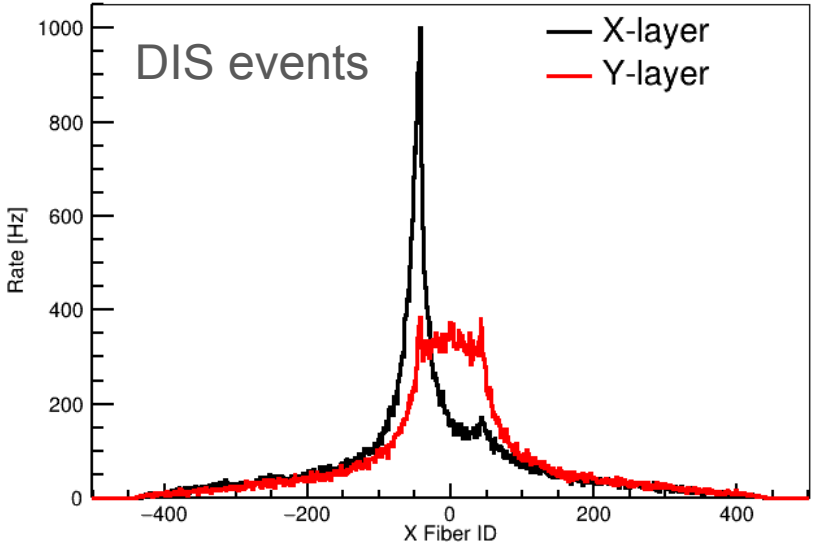


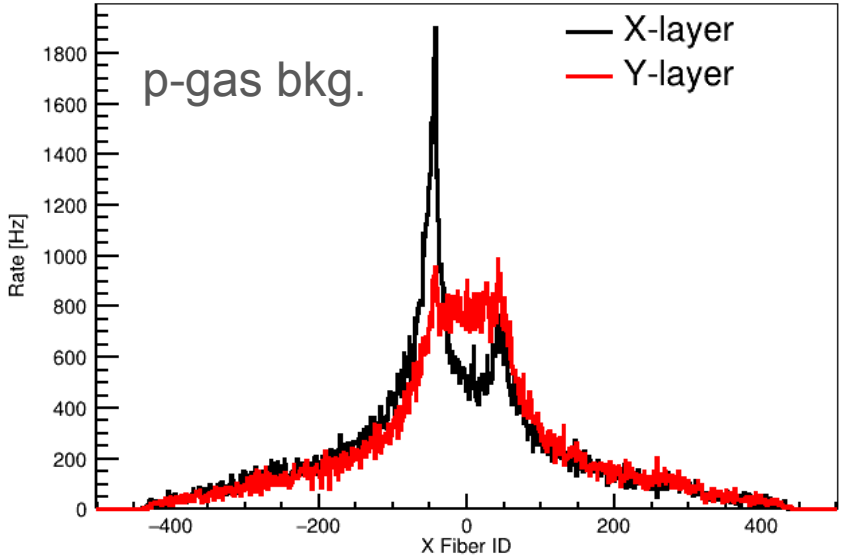
X-offset beam hole in DT



DT rates at nominal luminosity (hadron beam-gas background)

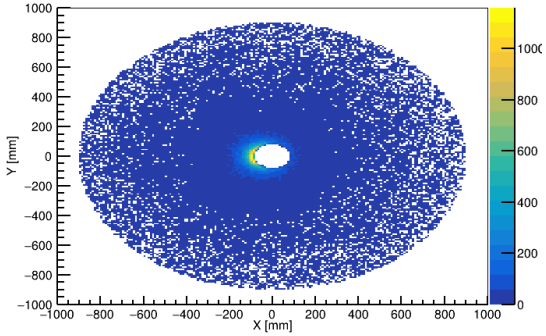
- we assumed p beam-gas luminosity = 4.2x10^{29} cm^2/s;
- assumed p beam-gas cross section = 78.54 mb; (https://wiki.bnl.gov/EPIC/index.php?title=Hadron_Beam_Gas)
- p beam-gas background 3 times larger than the signal (210 kHz total).

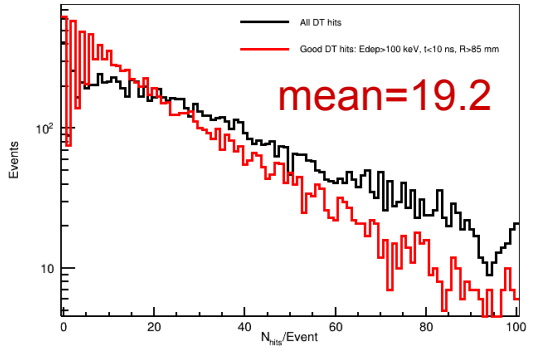




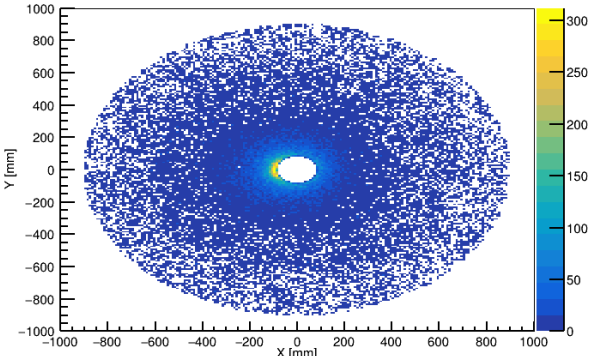
DT rates at nominal luminosity (hadron beam-gas background)

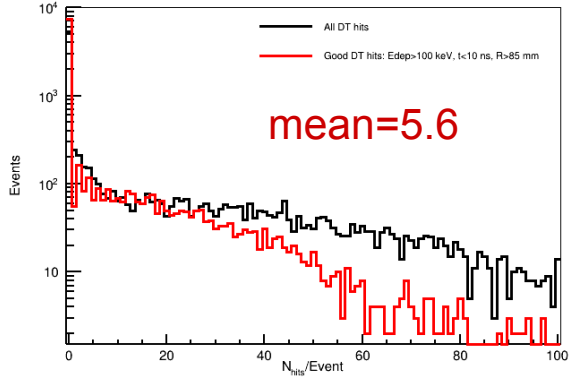
DIS events





p-gas bkg.

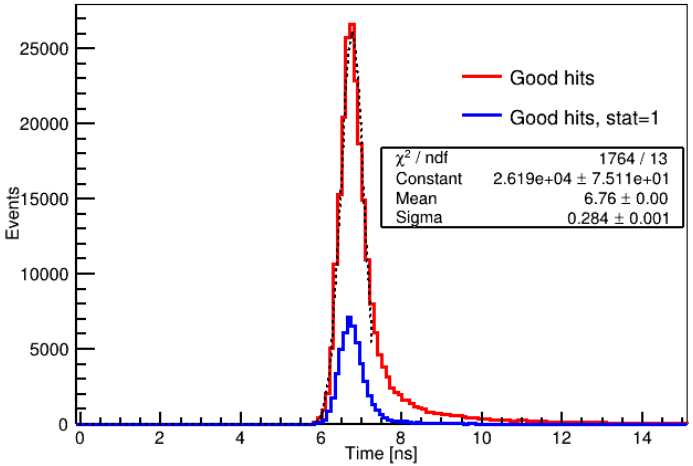




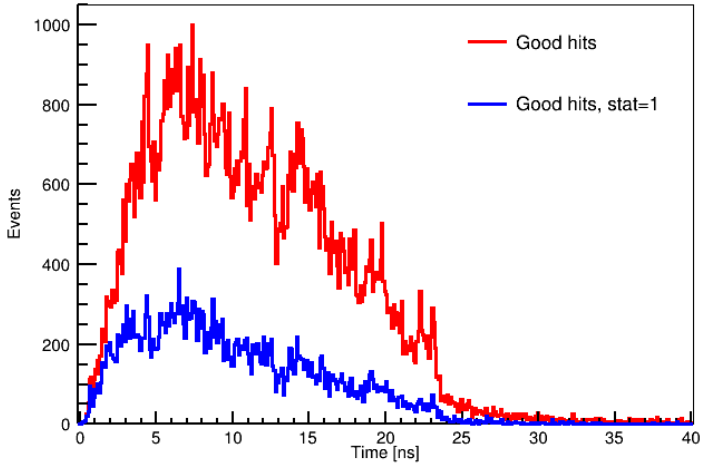
DT rates at nominal luminosity (hadron beam-gas background)

- background events are distributed from 2 to 25 ns, while signal is at 6-8 ns;
- BG can be significantly reduced applying signal time gate
- nearby bunches overlap may add some more background;

DIS events



p-gas bkg.

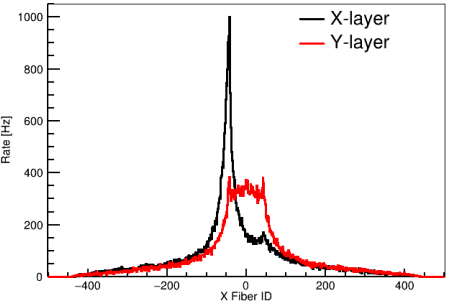


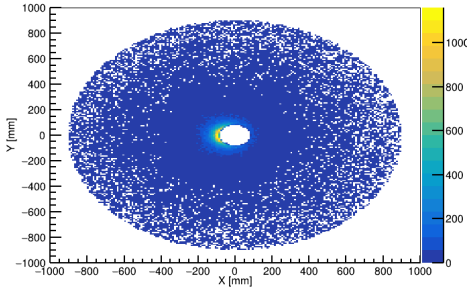
DT rates at nominal luminosity (electron beam-gas background)

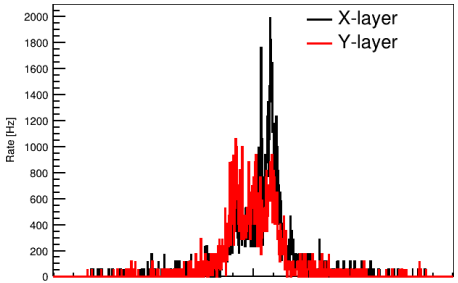
- assumed e beam-gas luminosity = 4.2x10^{29} cm^2/s
- assumed e beam-gas cross section = 699.393 mb (https://wiki.bnl.gov/EPIC/index.php?title=Electron_Beam_Gas)
- e beam-gas background 60% larger than the signal (115 kHz total)

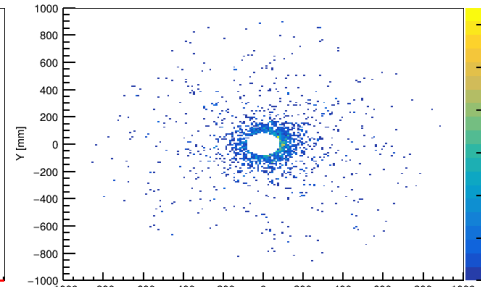
DIS events

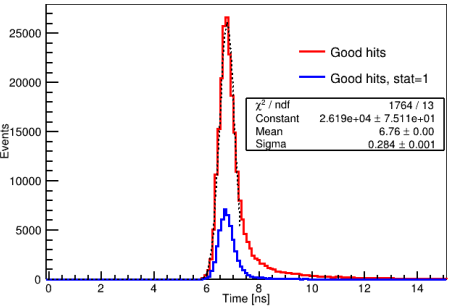
e-gas bkg.

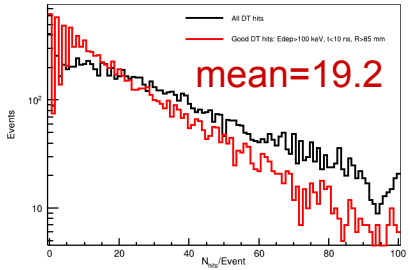


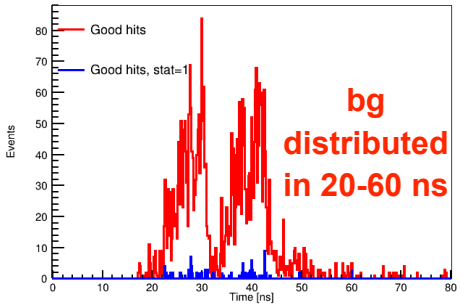


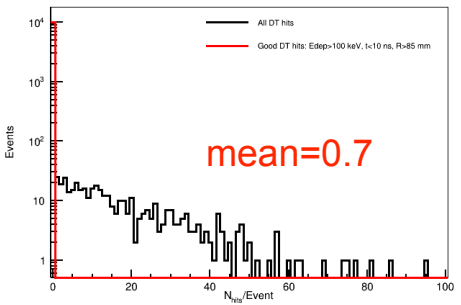












Simulations

- dIT geometry and design
  - 2 layers (X and Y orientation) of 956 2x2 mm^2 squared fibres (tot = 1.23 Km)
- dIT performance: energy deposition, efficiency, timing
  - 20 pe/MIP (th=7pe), eff (wrt dRICH hits) = 99.9%, 90% (85%) TRKs in ΔT=10ns (2ns)
- Deep Inelastic Scattering signal rate
  - 1 kHz max (70kHz total)
- proton gas background rate
  - 2 kHz max (210 kHz total)
- electron gas background rate
  - 2kHz max (115 kHz total)

The dRICH Interaction Tagger made by plastic scintillators fibers shall provide the necessary background rejection reducing the dRICH data rate by a significant fraction (x10-100)

dIT components R&D

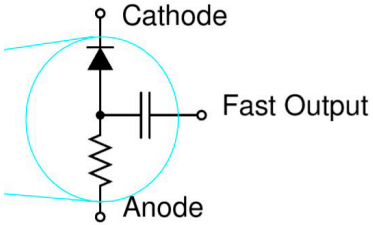
- Scintillating fibers
  - Two options are under study: Luxium Solution and Kuraray

	Emission peak	Decay time	# photons / MeV	Attenuation length
Luxium Solutions	435 nm	3.2 ns	8000	4 m
Kuraray	437 nm	2.4 ns	N/A	3.5 m

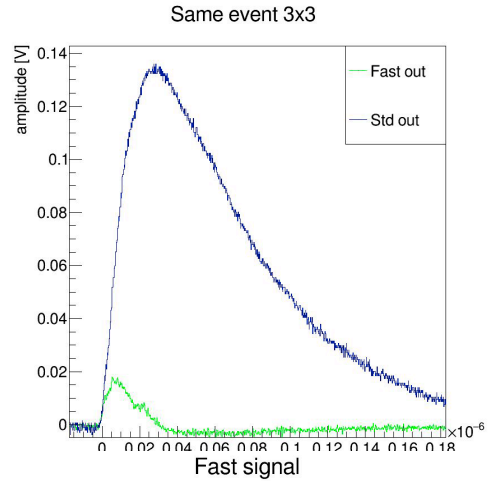
  - Samples from both vendors has been ordered (2mm squared, 12m/125m)

dIT components R&D

- SiPMs



- Fast SiPM: Onsemi J-series SiPM features a fast-output channel that delivers signals with a very short rise time

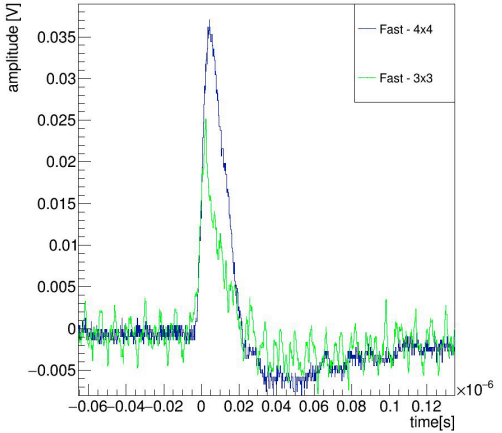


Preliminary test with the Onsemi fast output SiPMs:

- plastic scintillator tile with VM2000 reflective layer
- SiPMs with 3x3 and 4x4 mm2 active area were tested
- Fast and standard outputs

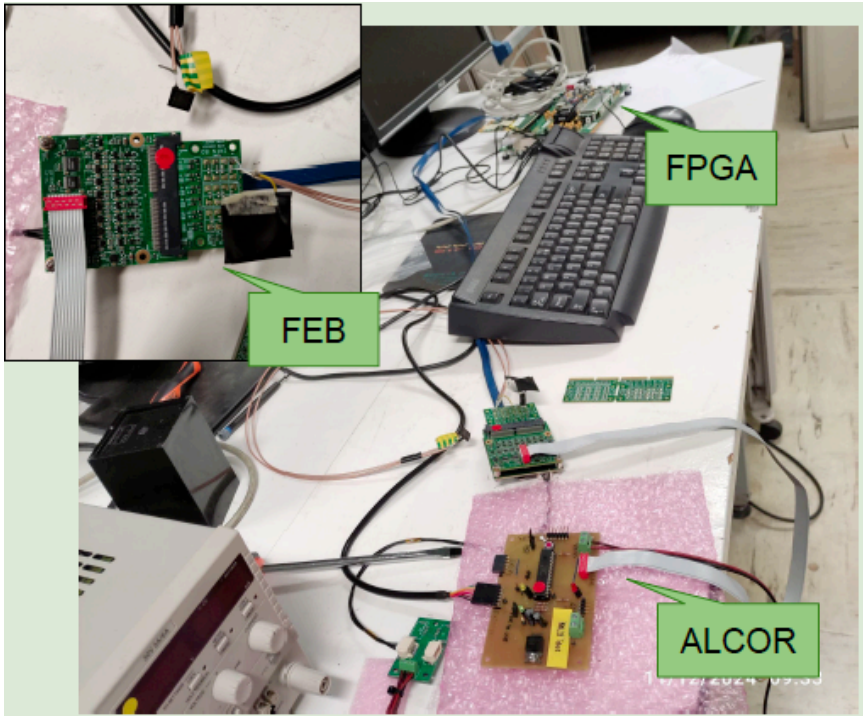
Expected performance from datasheet:

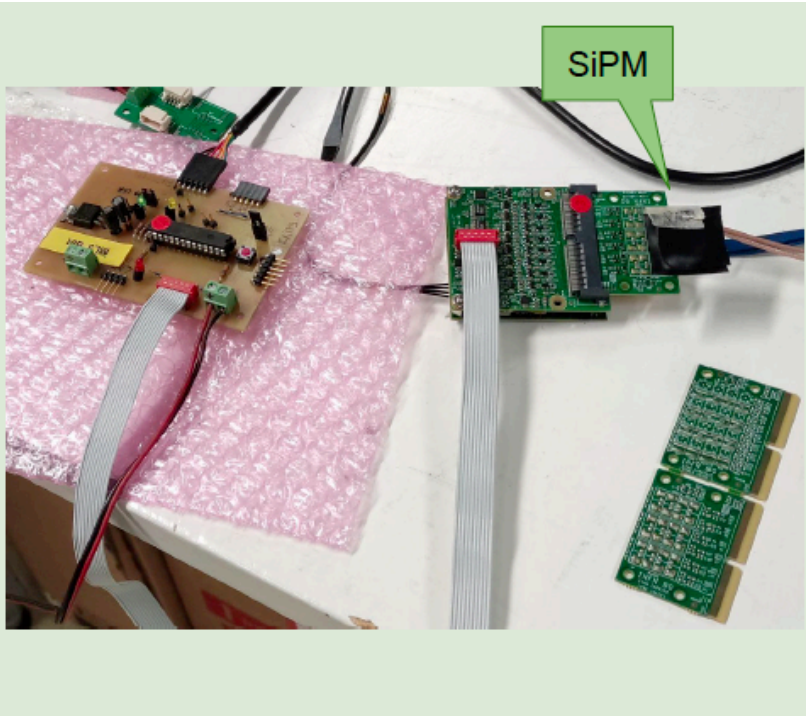
- Fast output rise time ~ 100 ps;
- Fast output pulse width (FWHM) 1.5 ns →limited by the plastic scintillator response time (~10 ns).



dIT components R&D

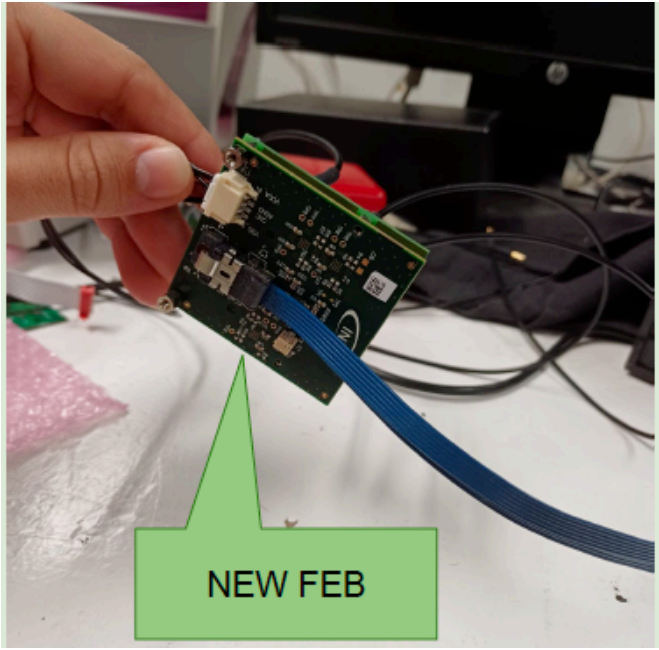
- ALCOR DAQ chain
  - For a simple integration of dIT into dRICH DAQ, we will use the same RO chain

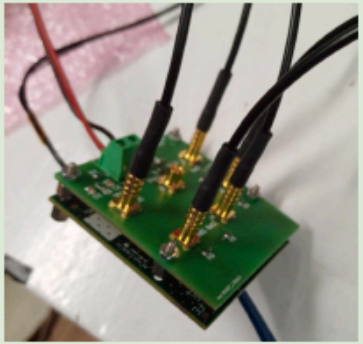


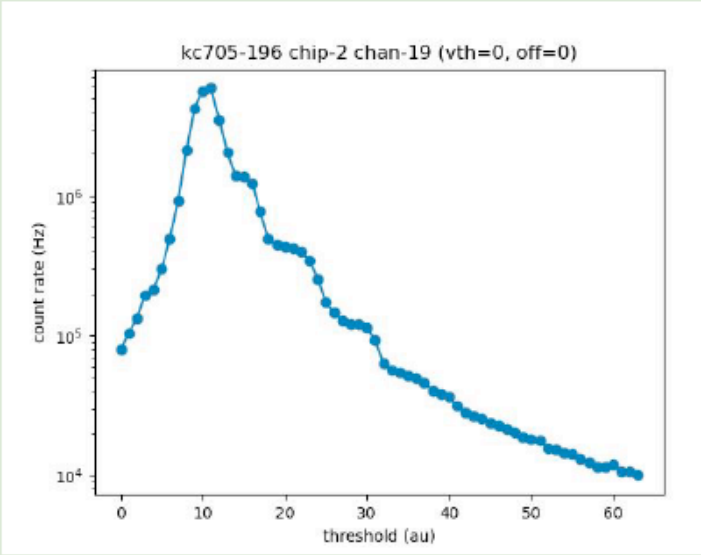


dIT components R&D

- ALCOR DAQ chain
  - We developed a “new FEB” to readout Onset Sipm fast output with the ALCOR DAQ chain







  - Far-from-the-chip RO tested successfully

Workplan 2026

- Test SciFi/SiPM coupling
- Optimize thresholds to reduce low-energy particle background
- Deploy a 128ch dIT prototype (32 fibers X-Y layers, 2 side RO, 50x50cm with 16x16 cm2 XY overlap)
- Test dIT prototype response to low-energy particles
- 3xALCOR chips + 1 FAIRFLY board from INFN-BO + FPGA from INFN-FE
- If dIT-proto ready for test beam (~Oct/Nov 26) characterisation at CERN
- Presentation at Technical Integration Committee (TIC) meeting
- Finalise dIT design (pre-CDR)
- Integrate the dIT into dRICH design

Richieste INFN-GE 2026

Capitolo	Descrizione	Parziali (k€)		Rimuovi	Modifica	Totale (k€)	
		Richieste	SJ			Richieste	SJ
consumo	dRICH: produzione+montaggio PCB carrier delle SiPM	1.00	0.00			9.5	0
	SRO: cavi, connettori sul FE, sipm	2.00	0.00				
	SRO: produzione 9ch preamps on PCB + cavi, connettori	3.00	0.00				
	dRICH: 128 SiPM singoli per leggere le fibre scintillanti del prototipo di tagger:	3.50	0.00				
missioni	Partecipazione riunione annuale EICUG/ePIC (USA) 2.5 x 7gg x 1 persona	2.50	0.00			14	2
	Partecipazione riunione annuale collaborazione ePIC (USA) 2.5 x 7gg x 1 persona	2.50	0.00				
	Partecipazione riunione annuale ePIC Italia: 3gg x 3 persone	2.50	0.00				
	AttivitÃ collaborazione con TS dentro RICH consorzium e con RM1 per SRO	2.50	0.00				
	Riunioni per definire il progetto esecutivo del magnete MARCO del EPIC (1a per.)	3.00	0.00				
	AttivitÃ Fisica e Monte Carlo	1.00	0.00				
	Test beam al CERN (1a persona per 1 settimana)	0.00	2.00				
inventario	SRO: server per frame routing.	5.00	0.00			5	0
Totale						28.5	2