dRICH particle Tagging and timing

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dRICH meeting, 10 Set. 2025
remote

Motivation

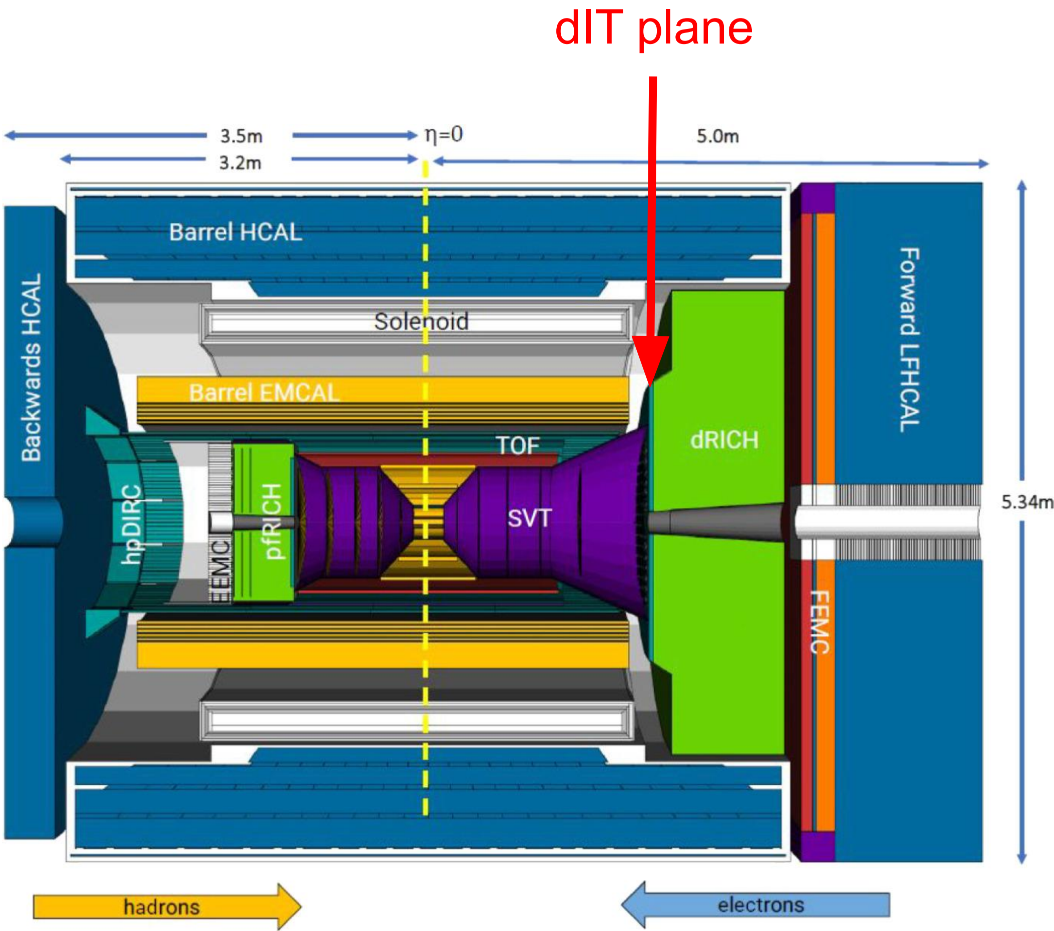
- dRICH is the ePIC sub-detector generating the highest FE data rate;
- thermal 1 p.e. background generated by SiPMs is irreducible at channel/RDO level;
- fast external trigger on hadrons crossing dRICH can reduce data rate;
- scintillator hodoscope in front of the aerogel was proposed as a possible solution;

Requirements:

1. high efficiency: double layer at 90º (4*(0.02*2 mm+25 um)^2/(2 mm+25 um)^2)) = 0.4% inefficiency for normal tracks;
2. narrow coincidence: should be <10 ns of RF, on-line - fiber length <80 cm/20 cm/ns=4 ns + track uncertainty ~2 ns, offline - resolution <0.1 ns;
3. thin: 2 layers x (2 mm SciFi + 3 mm supports CF) ~0.95+2.6=3.6% r.l.

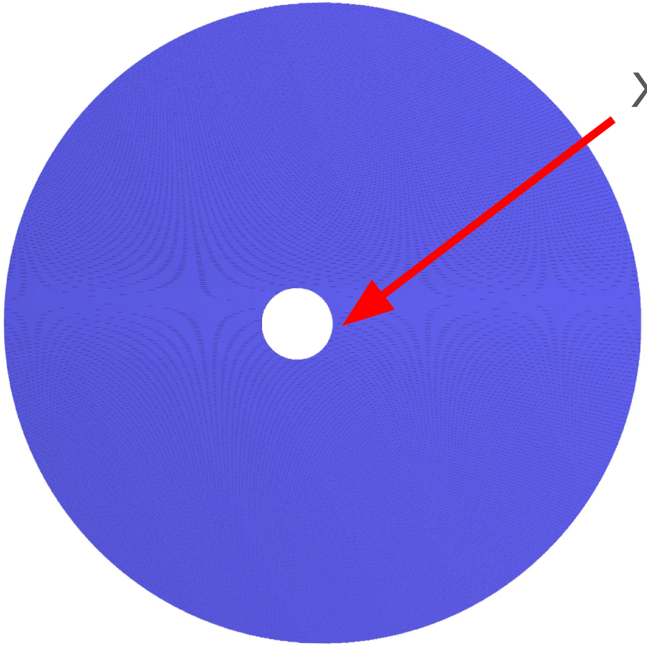
dRICH Interaction Tagger (dIT) location

- installed just before the aerogel: at Z=ForwardRICHRegion_zmin + 2.86*cm=197.86 cm;
- thin - 2+2 mm + support;
- provides start time and position for all charged particles entering dRICH volume;
- active area equal to aerogel one;
- electronics based on dRICH ALCOR FEB located at the outer radius of dIT;



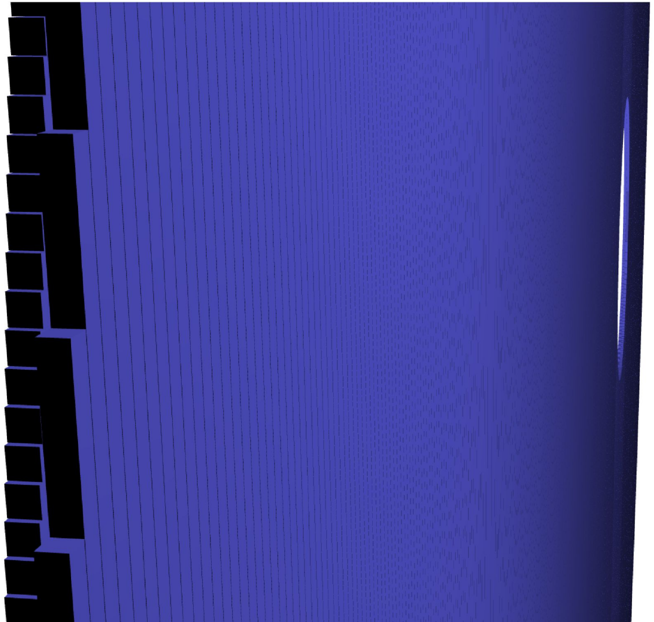
dIT implementation in ePIC DD4HEP code

- 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 - in new geometry 115 mm).



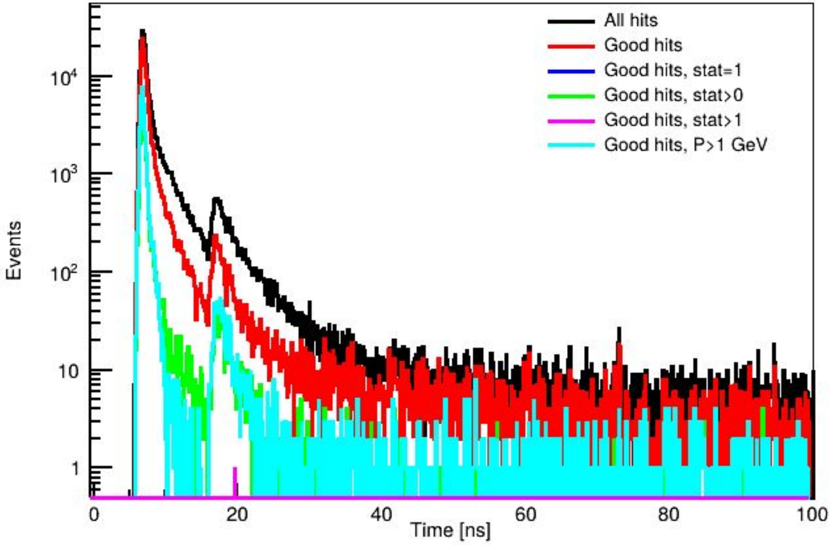
X=0 center

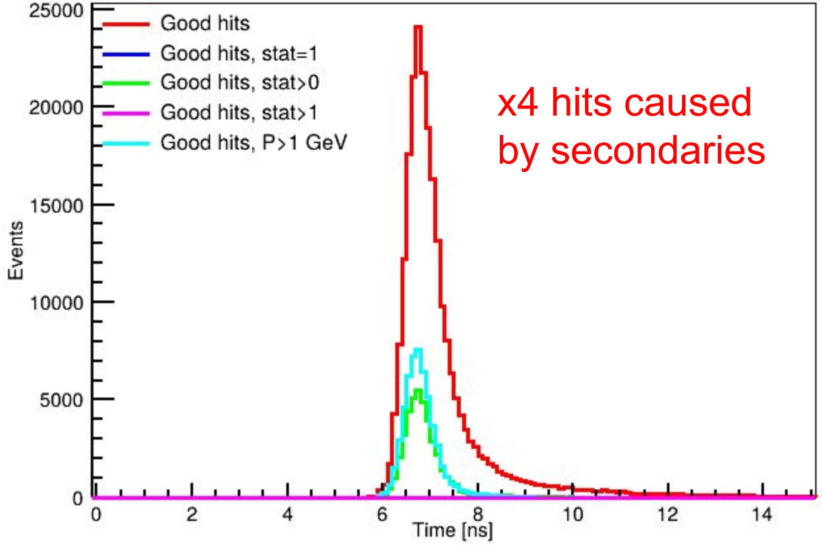
$x_0=-Z_{center}*\tan(25\ \text{mr})$



dIT performance: time

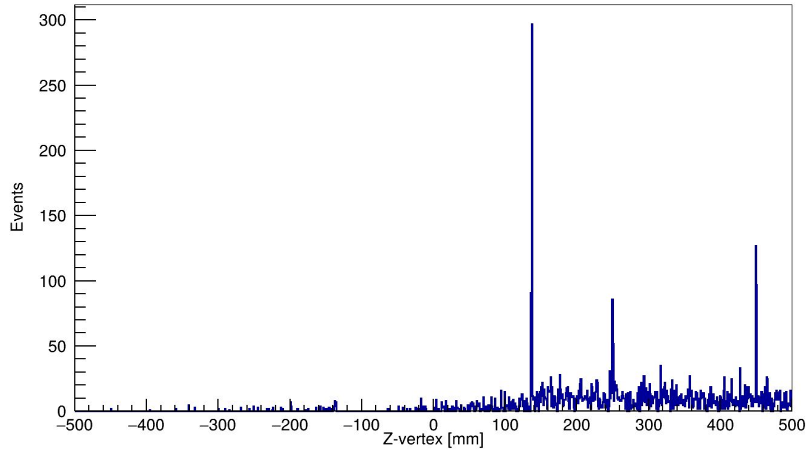
- hit time distribution has a Gaussian shape with a long r.h.s. tail;
- the tail is mostly generated by secondaries (GenStat=0);
- the second peak at +10 ns is due to rescattering from structural material;
- time for 85% (90%) of hits lies within 2 ns (t=6÷8 ns), 92% in 10 ns (doesn’t include light propagation in fiber);
- mean 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.

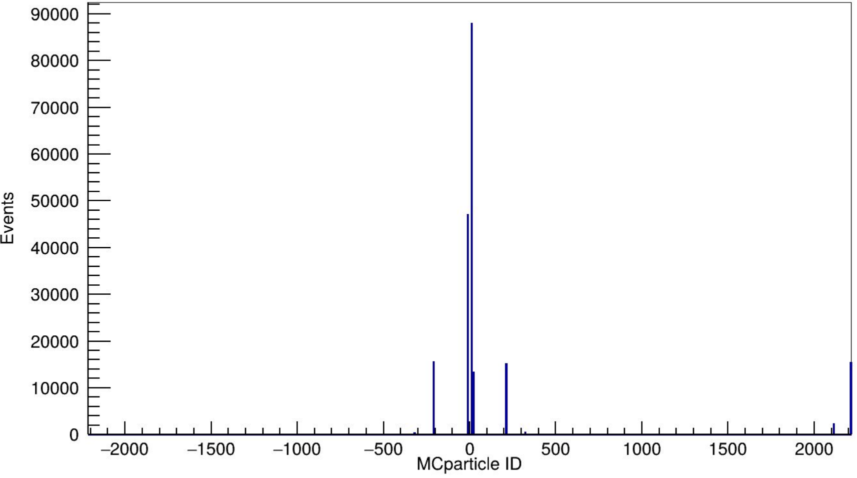


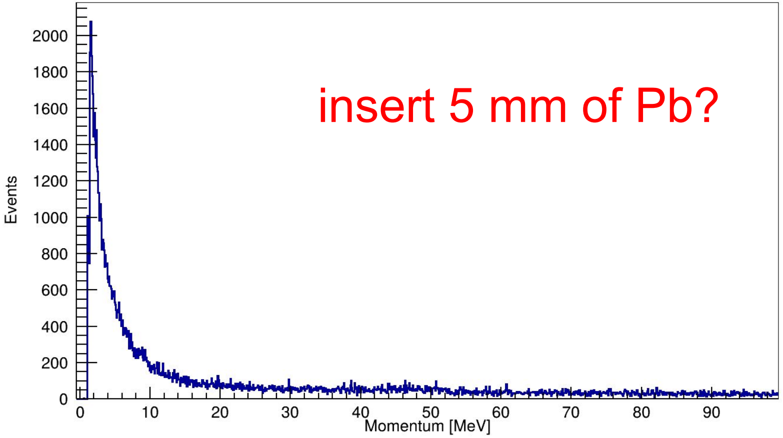


Secondaries with GenStat=0 - δ rays

- most of GenStat=0 particles are e+/e-;
- momenta of these particles are <10 MeV;
- production vertex is far from IP, and has peaks at 137 mm, 250 mm, 450 mm;
- these tracks are forward (θ<60 deg.), hitting dIT located at Z=1979 mm.



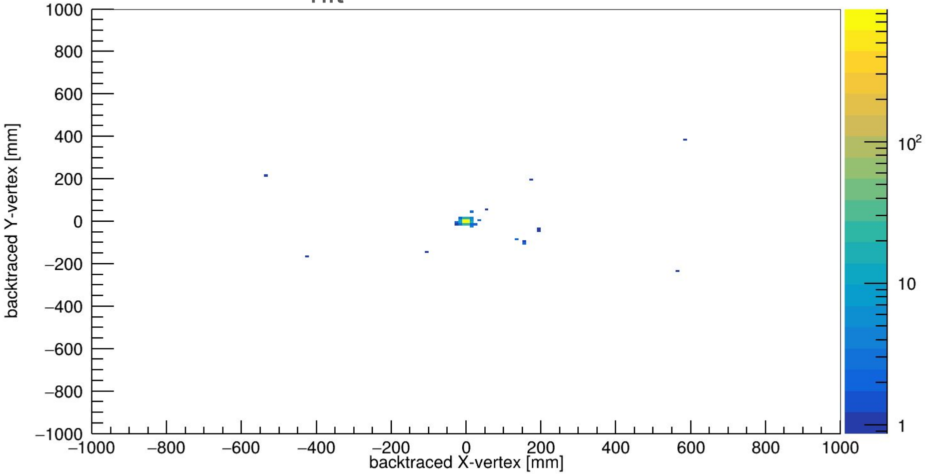




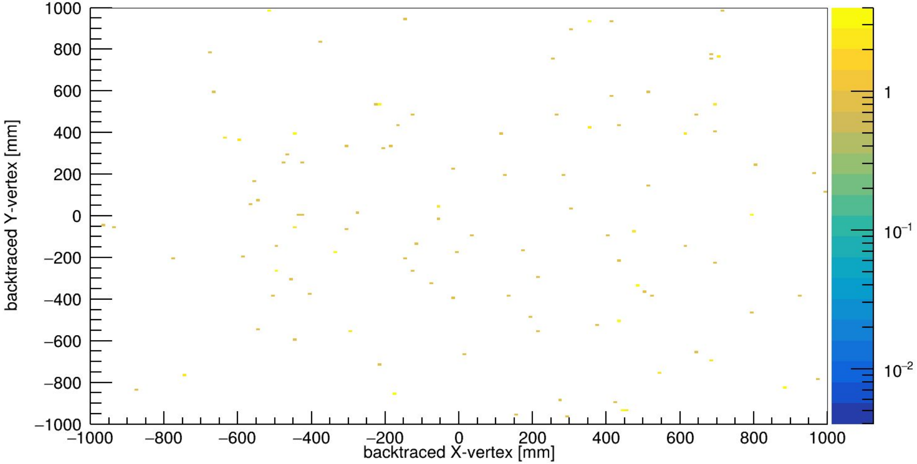
Second timing peak at +10 ns - rescattering

- MC tracks with P>10 GeV were extrapolated from the hit point back to the vertex using the hit time and velocity;
- for tracks in the main timing peak it gives true vertex;
- for tracks in the second +10 ns peak the extrapolation gives very scattered distribution;

t_{hit}<16 ns

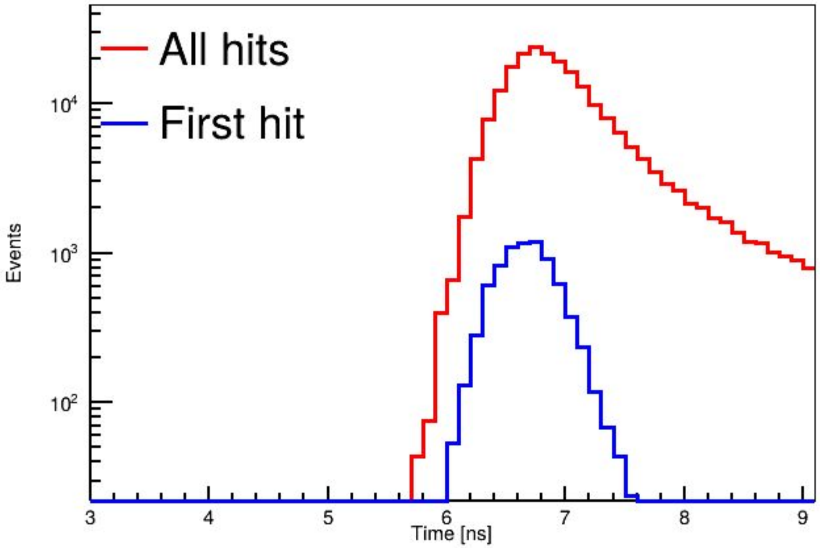


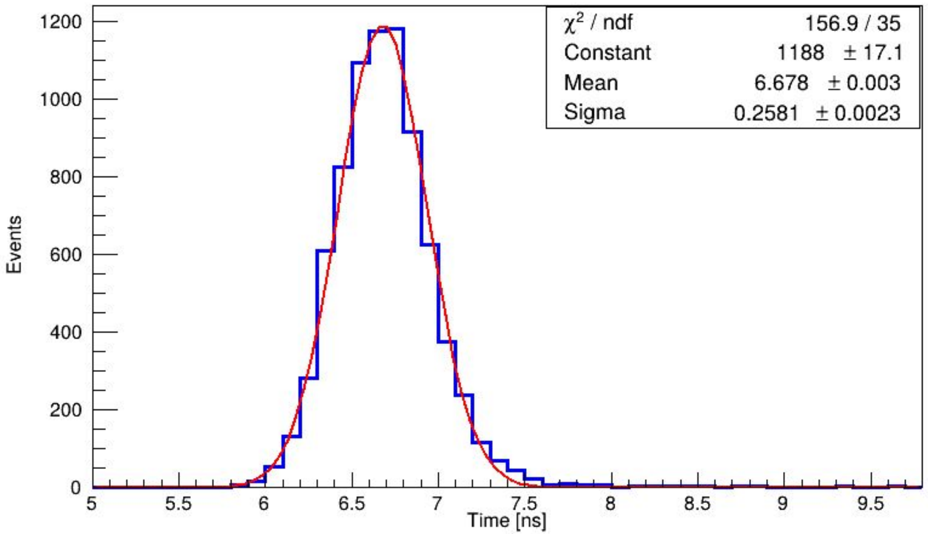
16 ns<t_{hit}<20 ns



Timing from dIT - first hit in event

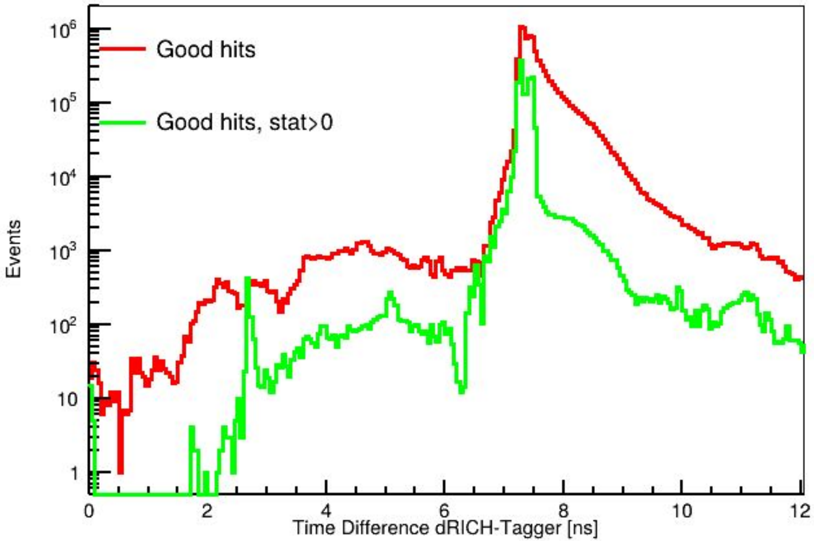
- to obtain start time from dIT the first hit only should be considered;
- the time distribution is almost Gaussian with sigma=0.258 ns;
- 97% (98% excluding peak at +10 ns) of events contained within 2 ns of this peak;
- taking the first dIT hit exclude the tail, allowing a very good timing of DIS events.

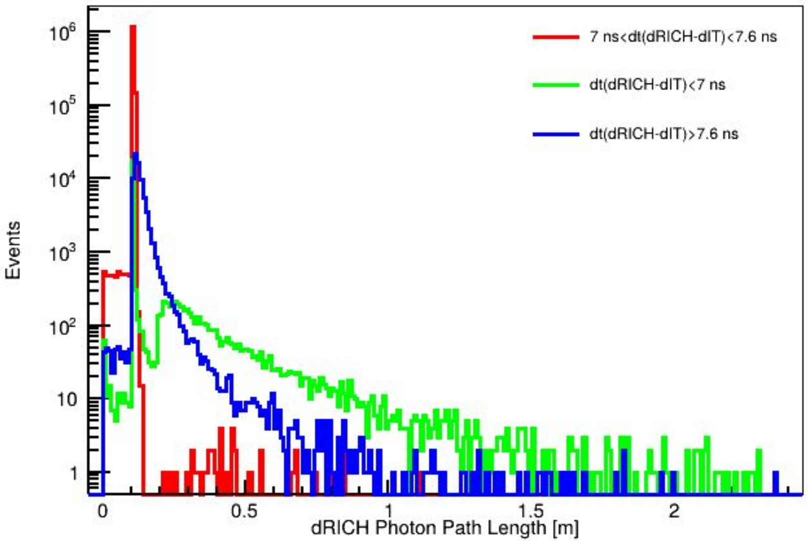




Relative dRICH hit timing

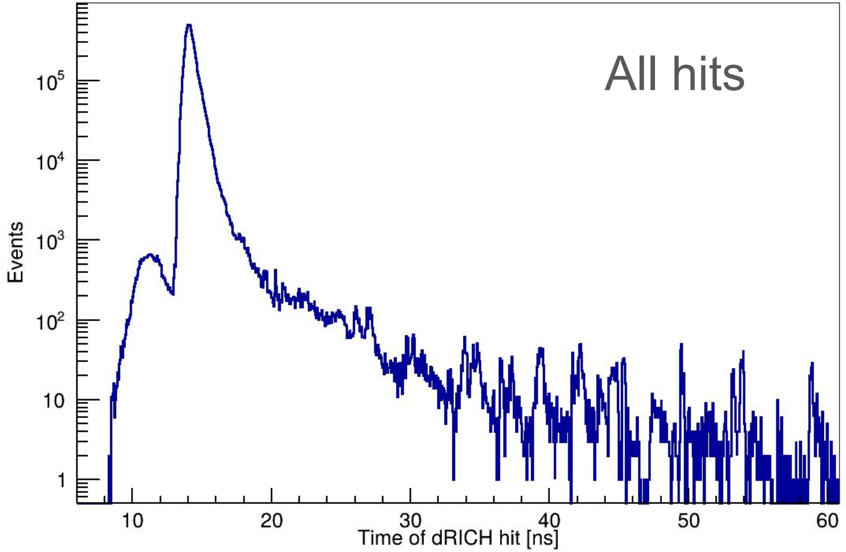
- most of dRICH hits arrive 7.3 ns after the first dIT hit (0.3 m/ns*7.3=2.2 m), the peak width is just 0.3 ns;
- 4 % of photons arrive 1 ns later, other contributions are negligible (<2%);
- unexpectedly the photon path length from DRICHHits.pathLength is much smaller, e.g. in the peak =0.1 m (only the part from window to SiPMs?);

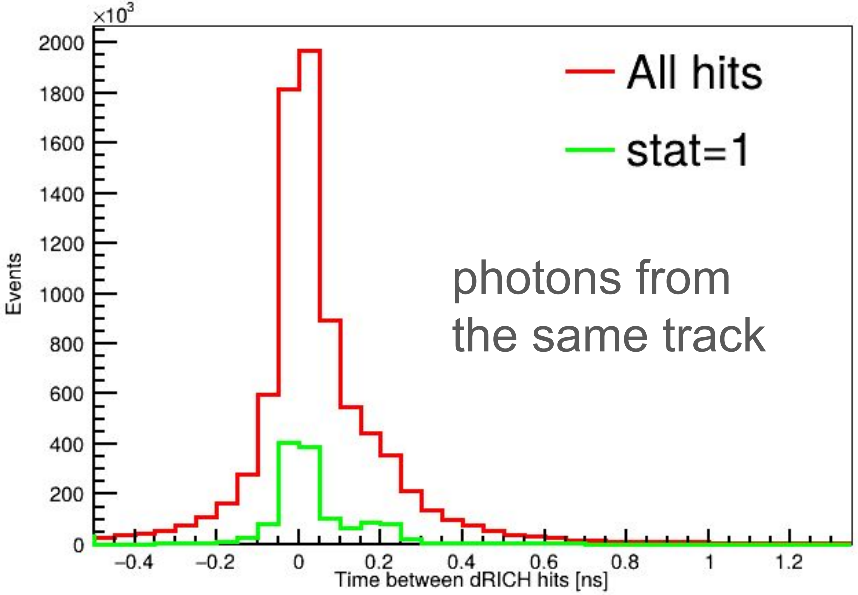




dRICH hit timing

- absolute dRICH hit time shows similar peak structure as the relative one;
- time difference between hits from photons produced by the same particle is very small, 61% contained within 0.2 ns window (92% in 1 ns gate);
- time could be used to identify hits from the same track.



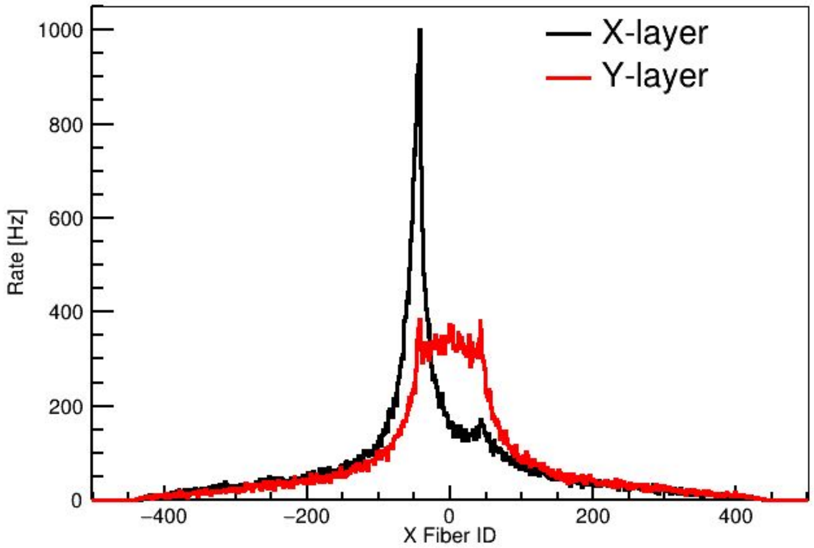


dIT rates at nominal luminosity

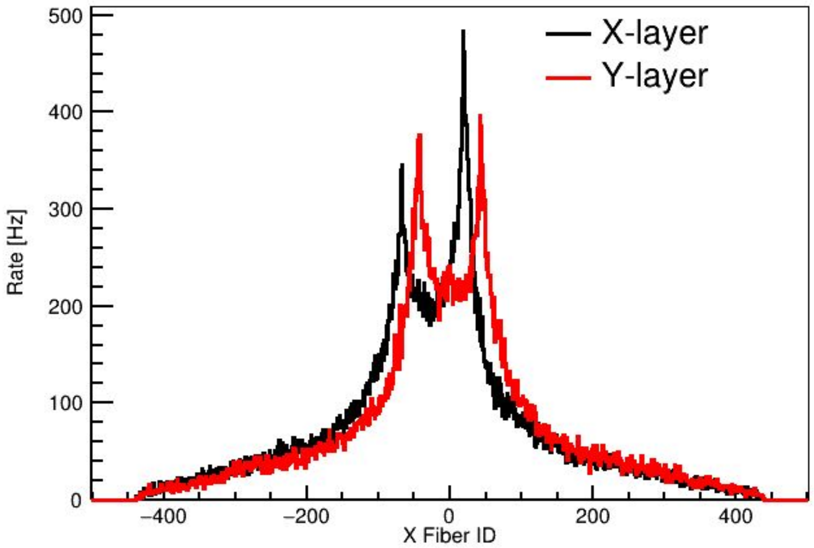
- we assumed the maximum nominal ePIC luminosity of 10^{34} $1/cm^2/s=10^4$ $1/\mu b/s$;
- at $Q^2>1$ GeV^2 (σ=0.556 μb) observed fiber rate are not exceeding 1 kHz (70 kHz total), rendering probability of accidental coincidences negligible;

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

central beam hole in DT

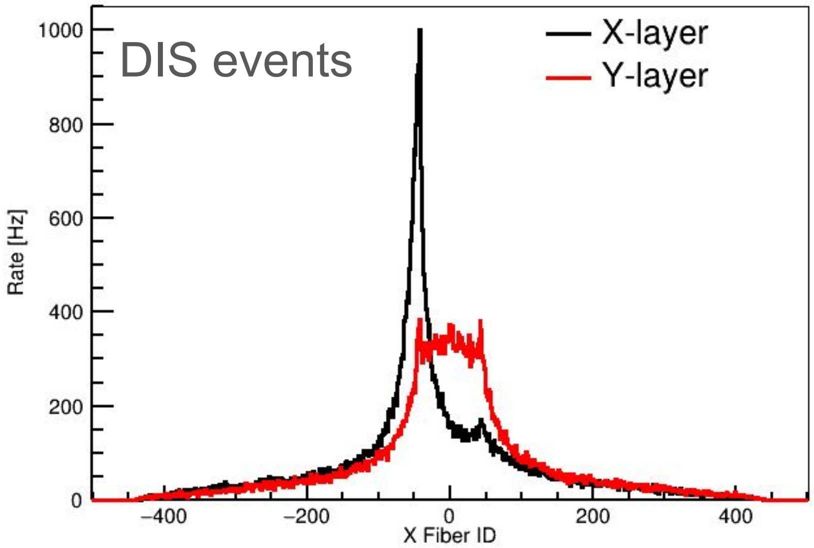


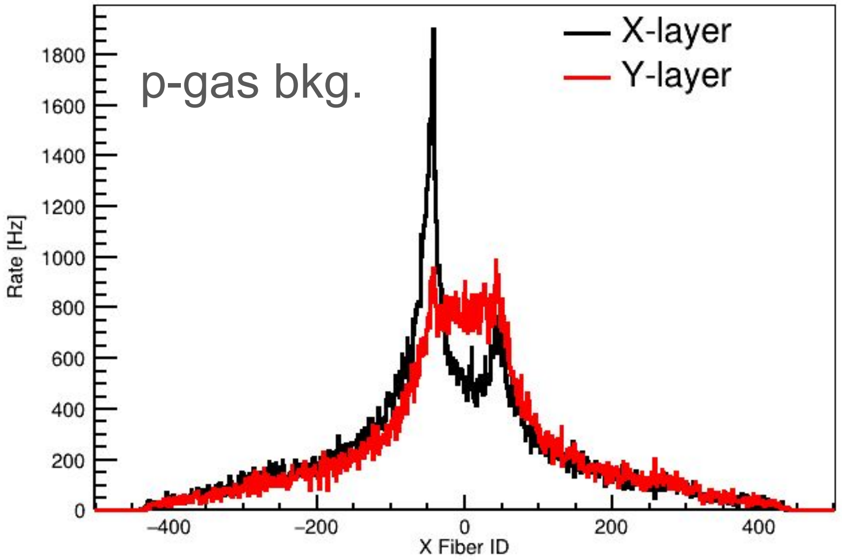
X-offset beam hole in DT



dIT hadron beam-gas background rates

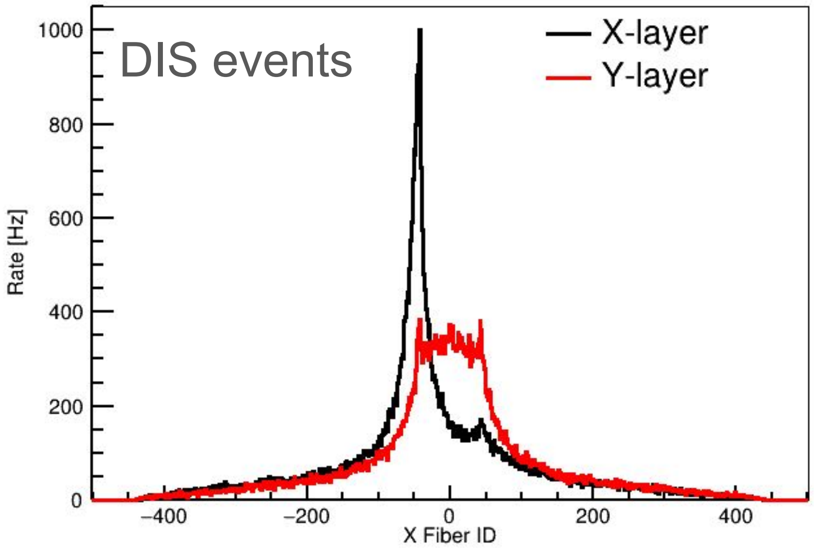
- assumed p beam-gas luminosity = 4.2×10^{29} 1/cm^2/s;
- assumed p beam-gas cross section = 78.54 mb;
- taken from https://wiki.bnl.gov/EPIC/index.php?title=Hadron_Beam_Gas
- p beam-gas background 3 times larger than the signal (210 kHz total).

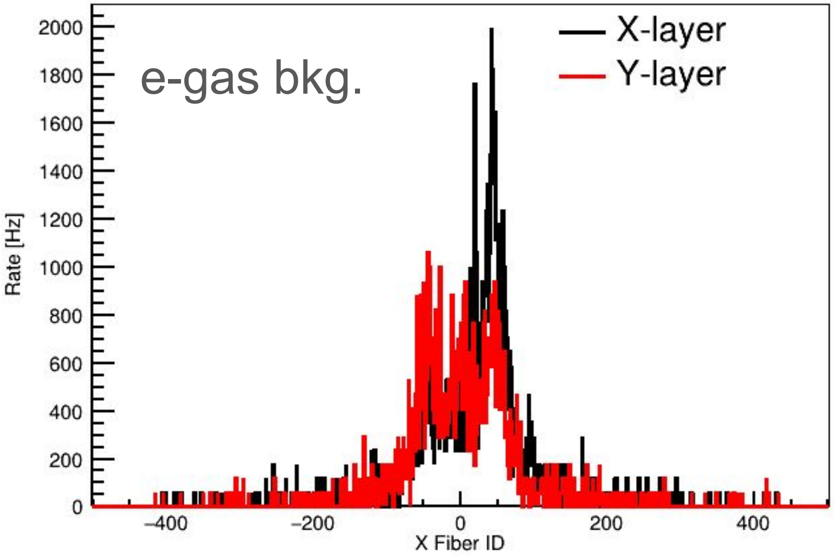




dIT electron beam-gas background rates

- assumed e beam-gas luminosity = 4.2×10^{29} $1/cm^2/s$;
- assumed e beam-gas cross section = 699.393 mb;
- taken from https://wiki.bnl.gov/EPIC/index.php?title=Electron_Beam_Gas
- e beam-gas background 60% larger than the signal (115 kHz total).





Total dIT Rates at 10x100 GeV

- DIS rate at Q^2>1 GeV^2 (σ=0.556 μb) and luminosity of 10^{34} 1/cm^2/s (0.58 μb with low Q^2):

$$R_{DIS}(Q^2 > 1 GeV^2) = \sigma_{ep} L \frac{N_{hits}}{N_{generated}} = 70\ kHz$$

- beam-gas background rates:

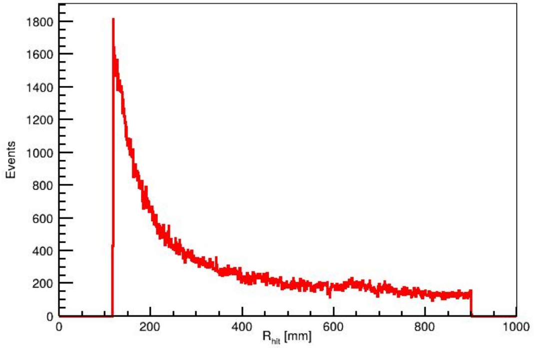
$$R_{p-gas} = 210\ kHz \qquad R_{e-gas} = 115\ kHz$$

- total rate - one trigger every 250 bunch crossing:

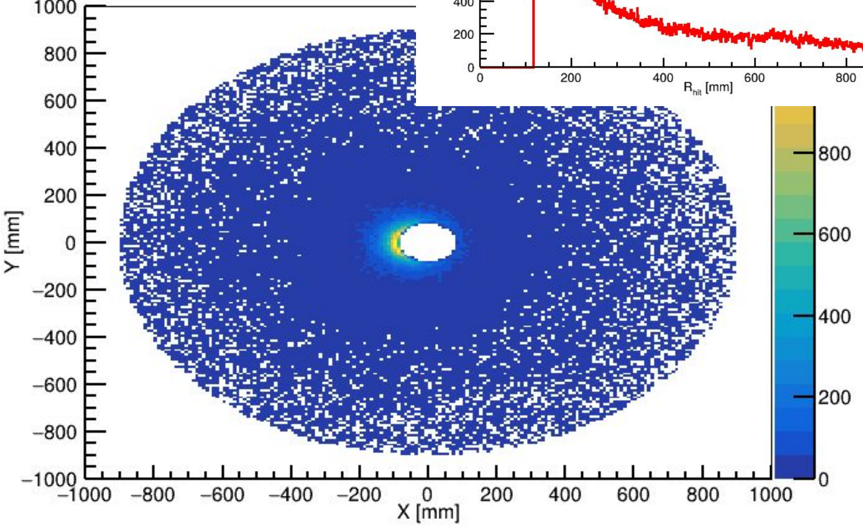
$$R_{tot} = 395\ kHz \quad \frac{R_{tot}}{RF} = \frac{395\ kHz}{100 MHz} = 0.004\ \frac{triggers}{bunch\ crossing}$$

DT electron beam-gas background hit position

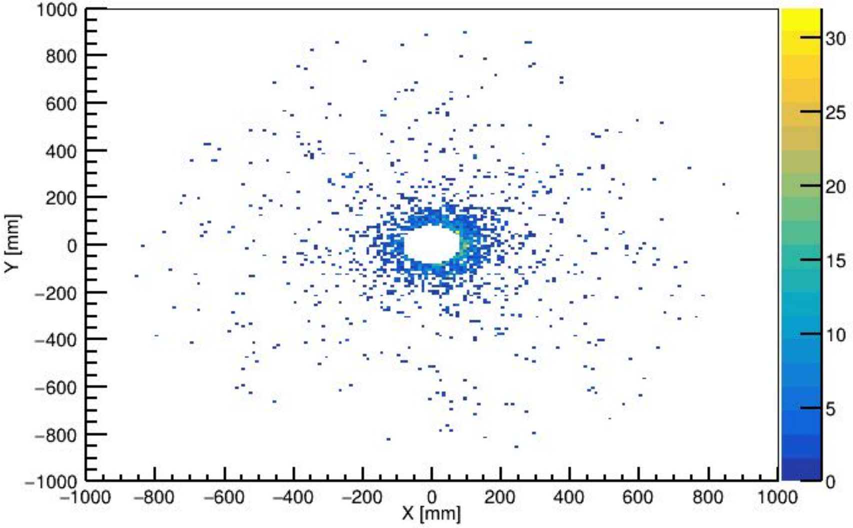
- electron beam - gas background hits lie much closer to the beam pipe;
- in the last epic geometry minimal radius increased from 85 mm to 115 mm.



DIS events

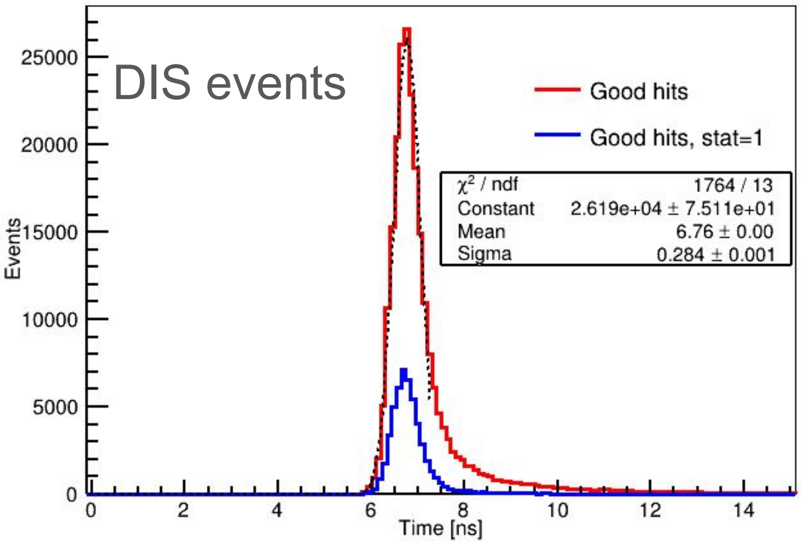


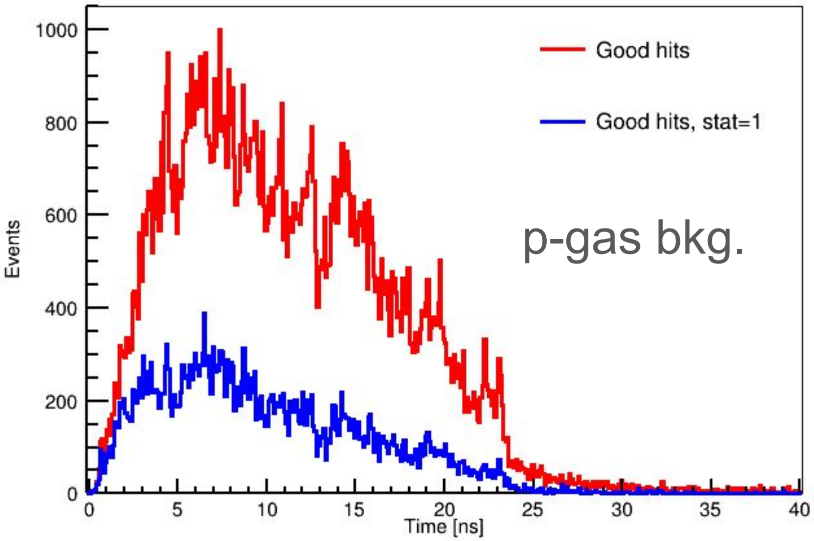
e-gas bkg.



dIT hadron beam-gas background hit time

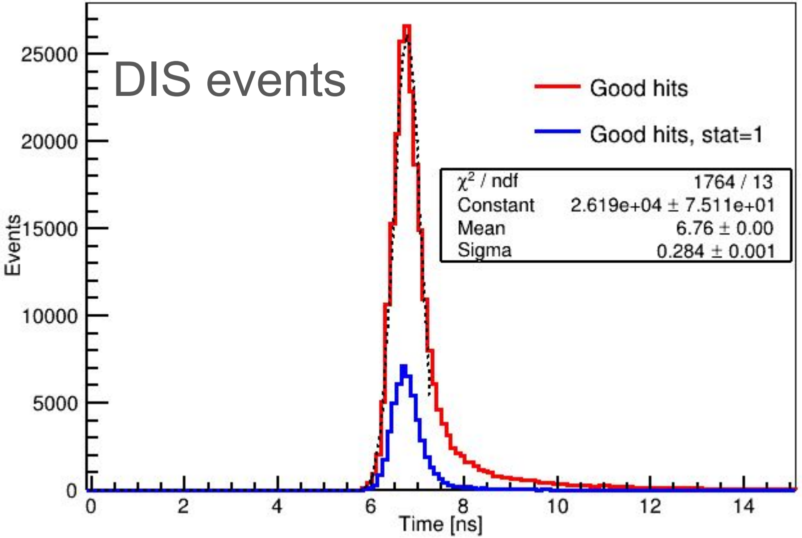
- background events are distributed from 2 to 25 ns, while signal is at 6-8 ns;
- it can be significantly reduced applying signal time gate, but overlap from nearby bunches will add more background;

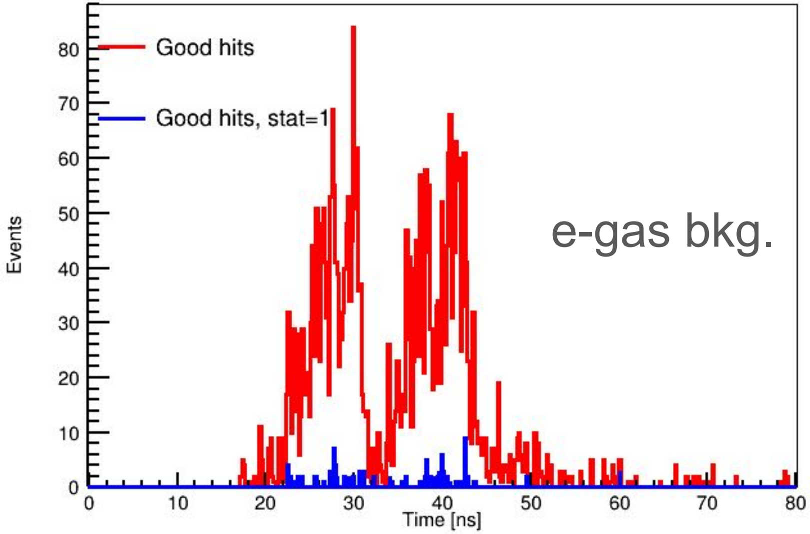




dIT electron beam-gas background hit time

- background events are distributed from 20 to 60 ns, while signal is at 6-8 ns;
- it could be removed completely applying signal time gate, but the background from nearby bunches will overlap with the signal;





Conclusions

- dRICH Tagger was implemented in DD4HEP code of epic software;
- observed almost Gaussian time hit distributions;
- 97% of (first in event) hits occur within 2 ns window;
- dRICH hits have similar time distribution, and relative to dIT has a 0.3 ns jitter;
- dRICH hits from the same track mostly are very close in time (<0.2 ns);
- number of hits from secondaries is 4 times larger than from primaries;
- beam-gas backgrounds are 5 times larger than DIS rate;
- Tagger rate in each fiber is not exceeding 1 kHz at maximum ePIC luminosity, background rates have similar magnitude;
- tagger selects 1 bunch crossing every 250.

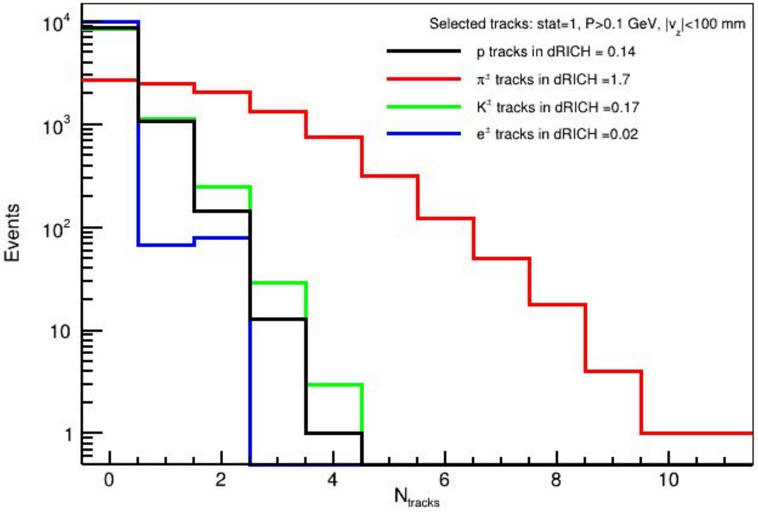
BACKUP

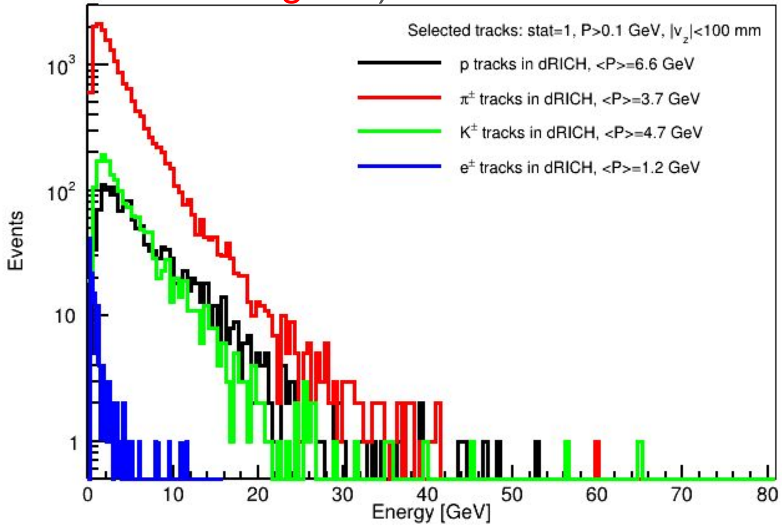
SIDIS simulations used for performance studies

pythia8NCDIS_10x100_minQ2=1_beamEffects_xAngle=-0.025_hiDiv_vtxfix_1.hepmc (σ=0.556 μb):

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

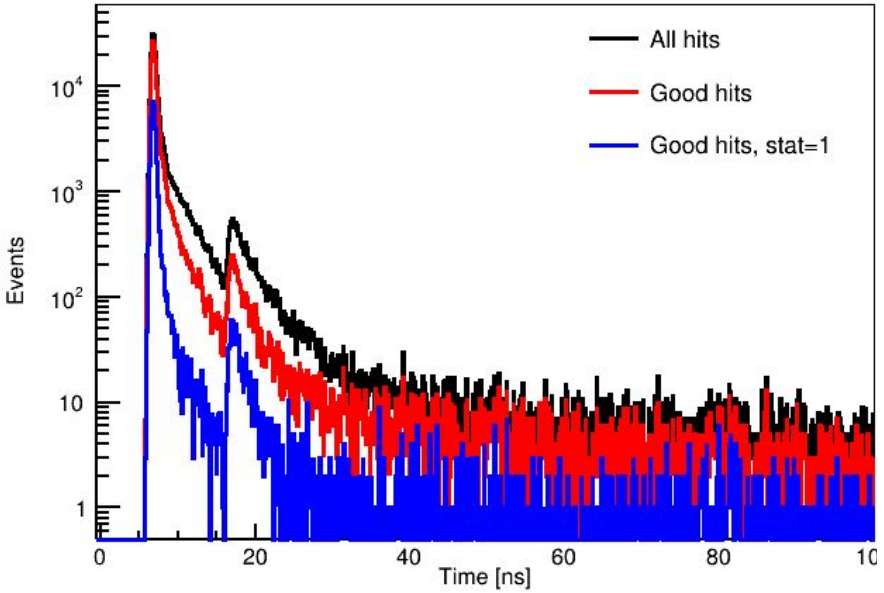
- beams: e 10 GeV x p 100 GeV (early physics compatible), Q^2>1 GeV^2, beam angle effects;
- each event has about 2 charged tracks in dRICH acceptance, most of them are 4 GeV pions;
- stat=1 - selects final state real particles (stat=0 for secondaries produced by Geant4);
- $|V_z|$<100 mm - selects particles created at IP (few primaries have larger Z).

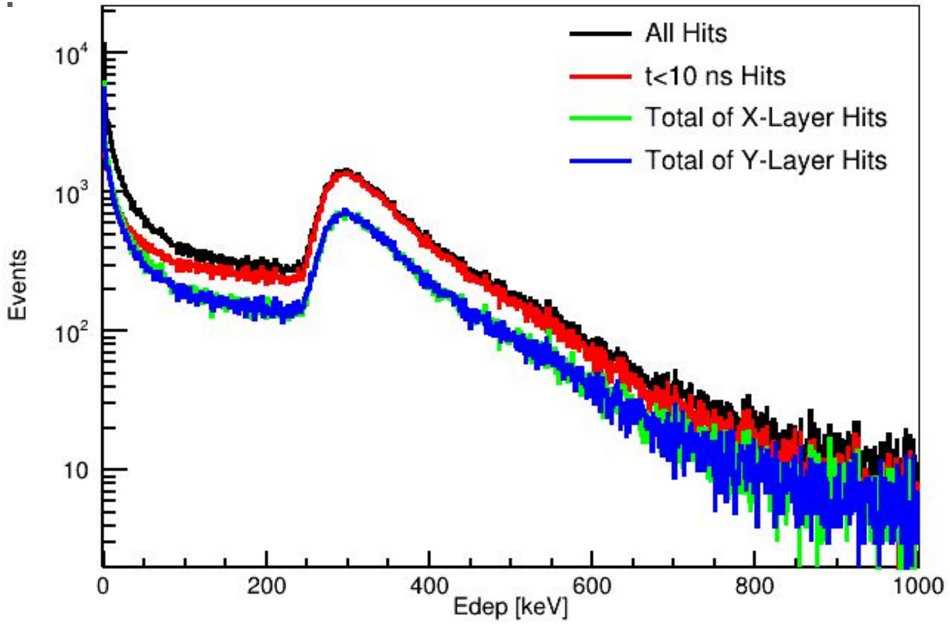




Tagger performance: energy deposited in scintillator

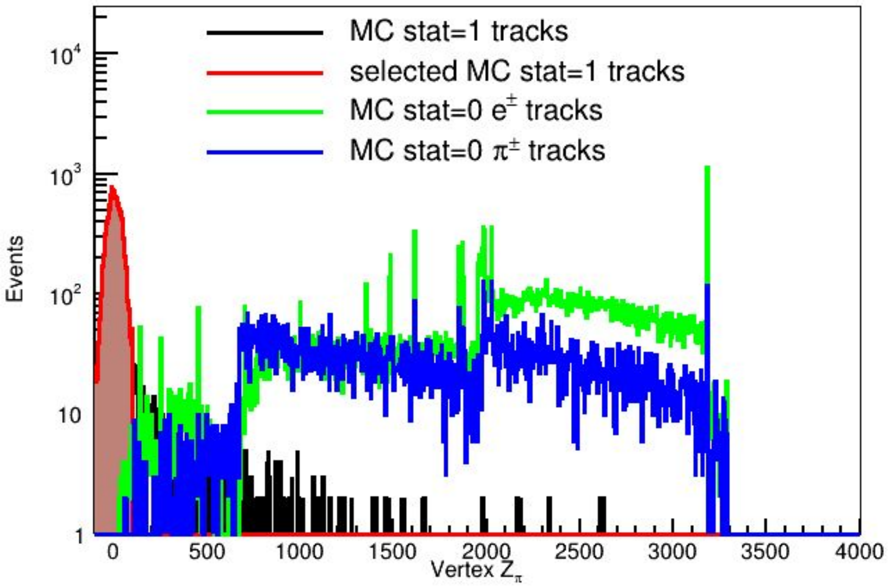
- most probable deposited energy =300 keV/layer =2400 photons;
- assuming trapping efficiency of 4.2% (Kuraray) gives 50 photons/SiPM;
- assuming SiPM PDE=40% (S13360-3050) gives 20 p.e./SiPM;
- threshold could be set at 100 keV~7 p.e./SiPM;
- expected Poisson inefficiency <0.1%.

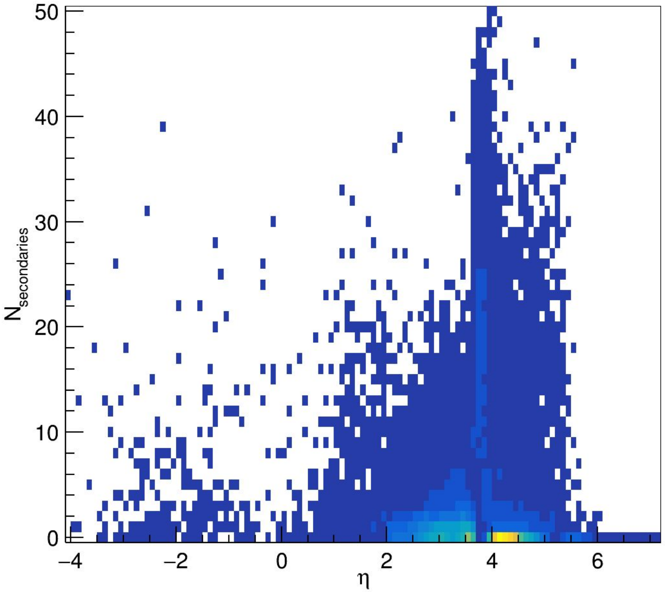




Z-vertex distribution and secondaries

- 6% of stat=1 pions are produced at Z>100 mm;
- number of stat=0 pions is 1.13 times larger than stat=1;
- number of stat=0 e^{+-} is 2.3 times larger than stat=1 pions;
- secondary Z-vertex distributions have many peaks, largest at Z=3179 mm;

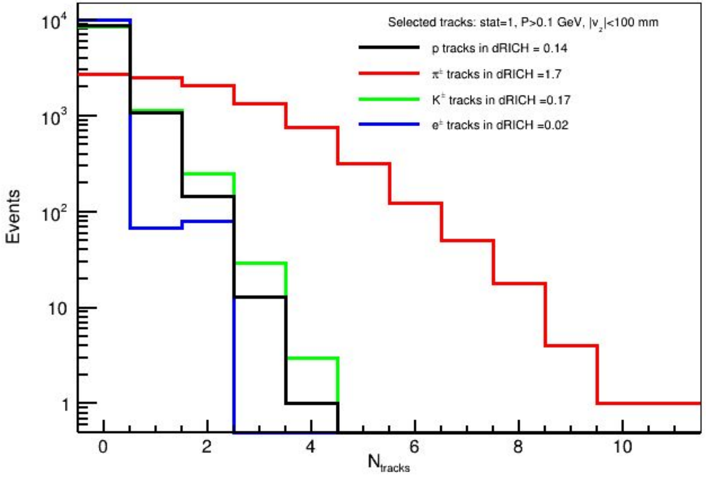


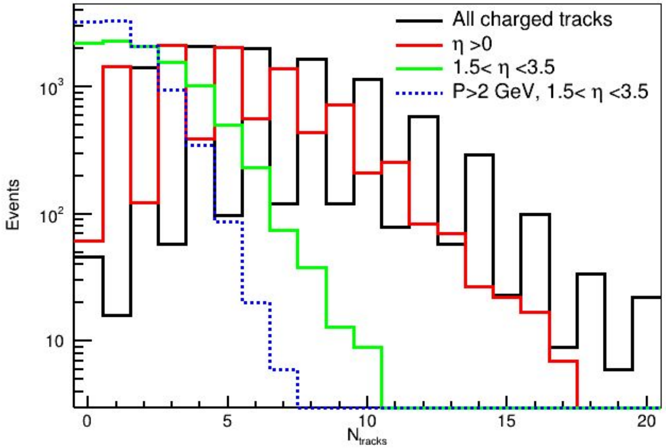


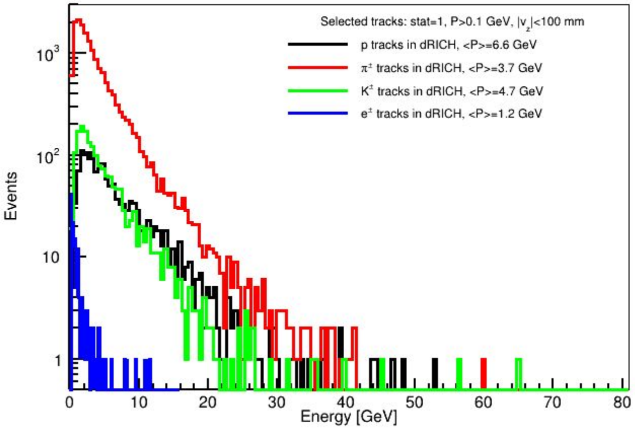
SIDIS simulations used for performance studies

pythia8NCDIS_10x100_minQ2=1_beamEffects_xAngle=-0.025_hiDiv_vtxfix_1.hepmc, first 10,000 events:

- beams: e 10 GeV x p 100 GeV (early physics compatible), Q^2>1 GeV^2, beam angle effects;
- each event has about 2 charged tracks in dRICH acceptance;
- most of them are pions of 4 GeV;
- stat=1 - selects final state real particles (stat=0 - secondaries);
- $|V_z|$<100 mm - selects particles created at IP (few primaries lost).

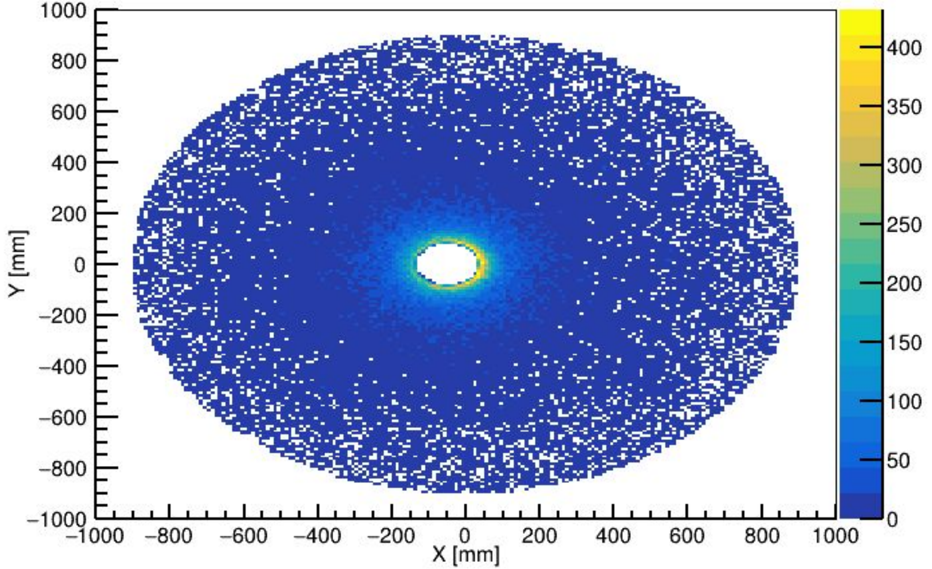


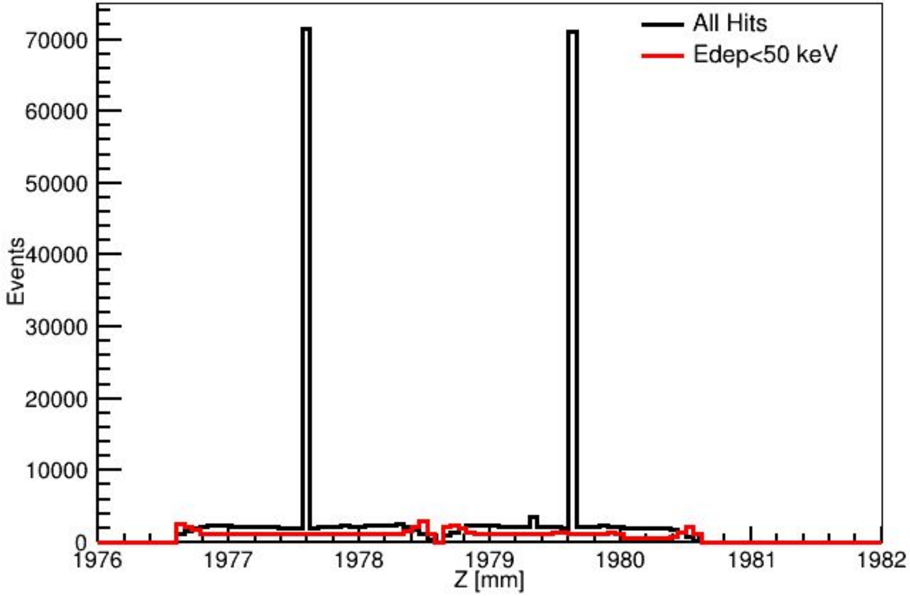




Tagger performance: spatial

- dIT hits have cylindrical distribution around beam pipe;
- enhancement of rate around beam pipe is visible (asymmetric?);
- two layers in Z are clearly visible, hits outside of layers are low energy (how is it possible?);
- the two layers are found at Z=1977.59 mm and Z=1979.63 mm.

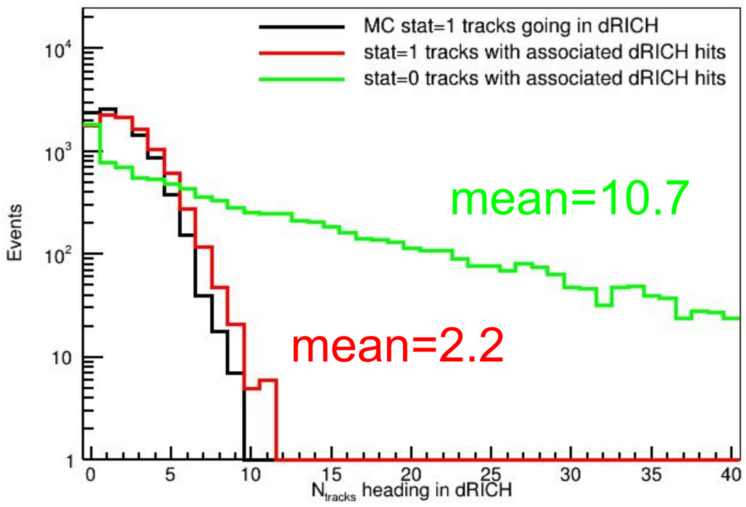


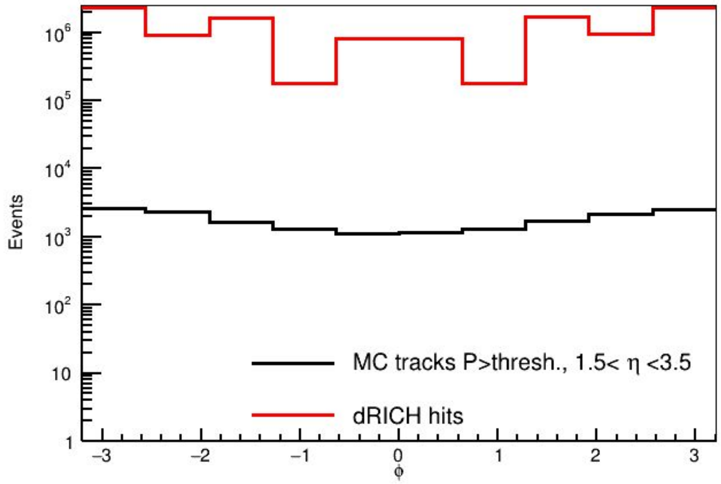


dRICH performance

- dRICH hits are associated with different kinds of MCParticles tracks (not photons?):
- stat=1 tracks - almost equal to generated MC tracks (few with wrong Z-vertex or initial η direction)
- stat=0 tracks (mostly e^{+-}, but there are also pions) - 5 times hits than stat=1.

```
stat = MCParticles.generatorStatus[_DRICHHits_MCParticles.index[DRICHHits.cellID index]]
```

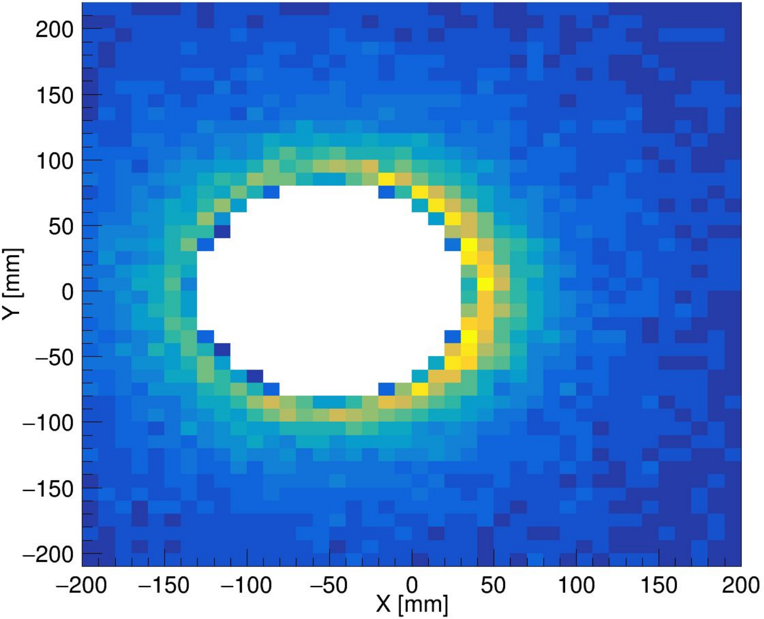




Beam pipe centering

- moving beam pipe hole by +5 mm from nominal produces more symmetric hit distribution, but perhaps further offset is necessary - why?

$x_0 = -Z_{center} * \tan(25\ \mathrm{mr})$



dx=+5 mm