

Rates of hits in dRICH from DIS and machine backgrounds

P.Antonioli, M. Contalbrigo, M.Osipenko
INFN sez. di Bologna, Ferrara, Genova

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Task description

1. determine complete data throughput of dRICH produced by DIS and machine backgrounds, separating in Synchrotron Radiation and others;
2. study DIS tracks that are excluded by the current reconstruction algorithms;

We use recent campaign:

epic:/RECO/26.07.1/epic_craterlake/Bkg_Exact1S_2us/GoldCt/10um/
with Status Code Shift from [TWiki](#)

After determining dRICH hit rates we will compute the number of hits/PDU/10 ns frame.

DCR of 300 kHz/ch (maximum allowed) will be added analytically.

Sources of hits

- Not possible to use RECO data only (**missing link from DRICHRawHits to MCParticle**);
- Simulation (FULL) data contain the link to MCParticle - from branch "_DRICHHits_particle.index" with index of "DRICHHits";
- in MCParticles make a loop from "MCParticles.parents_begin" to "MCParticles.parents_and" separating photons and non photon (PDG!=22);
- The hit source selected by "MCParticles.generatorStatus": ABS(stat-2000)<100 ⇒ source=2 etc. for other sources (e.g. typically stat=2004 - initial Synch.Rad. photon, or 2001 - gen. final state photon);

Interaction rate

Symbol	Process	Description	Sampling Frequency (kHz)	Status Code Shift
	signal	DIS NC 18x275 Q ² >1 (Deep inelastic scattering neutral current)	500	0
	synrad	Synchrotron Radiation	14000	2000
	ebrems	Electron bremsstrahlung radiation	316.94	3000
	etouschek	Electron Touschek scattering (intrabeam scattering)	1.3	4000
	ecoulomb	Electron Coulomb scattering processes	0.72	5000
	p.b.gas	Proton beam gas interactions	22.5	6000

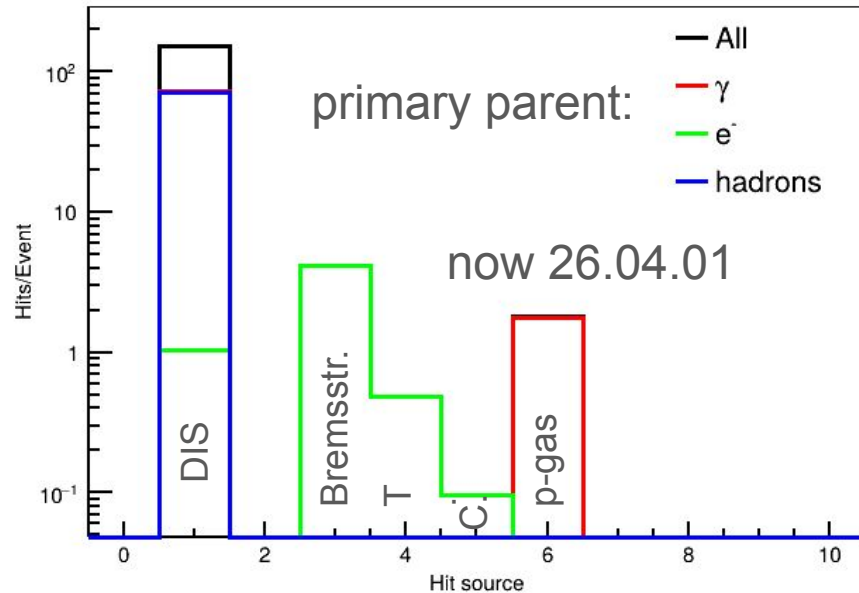
Source ID:

1
2
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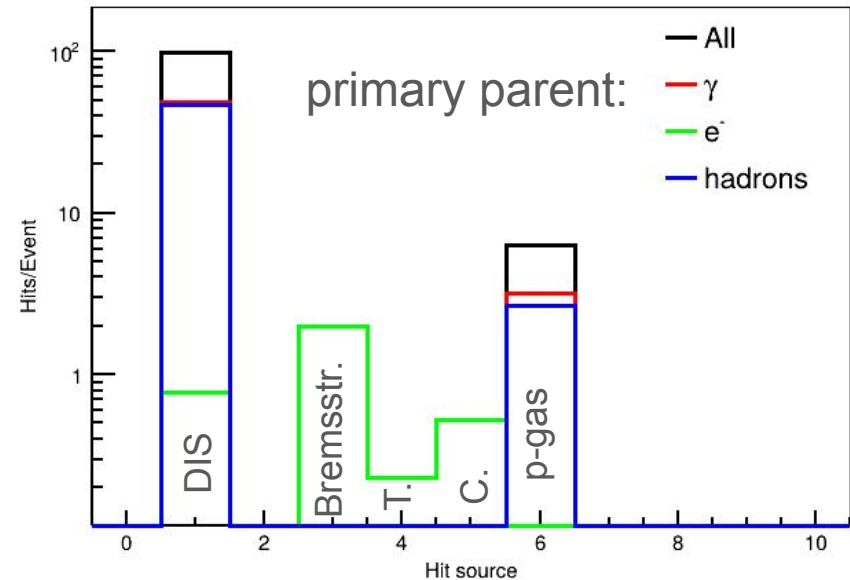
Results for 10x100 GeV in 2 μ s data frame

- total dRICH hit rate from DIS($Q^2 > 1 \text{ GeV}^2$) = 161 hits/event: (DIS=96%, Synchrotron Radiation γ =0, bremsstrahlung e^- =2.6%, p-gas=1.1%, other=0.4%);
- total dRICH hit rate from DIS($Q^2 < 1 \text{ GeV}^2$) = 108 hits/event: (DIS=91.6%, Synchrotron Radiation γ =0, bremsstrahlung e^- =1.9%, p-gas=5.8%, other=0.7%).

26.07.1,Bkg_Exact1S_2us/GoldCt/10um/10x100/mi
nQ2=1/pythia8NCDIS (100 file=9999 events)



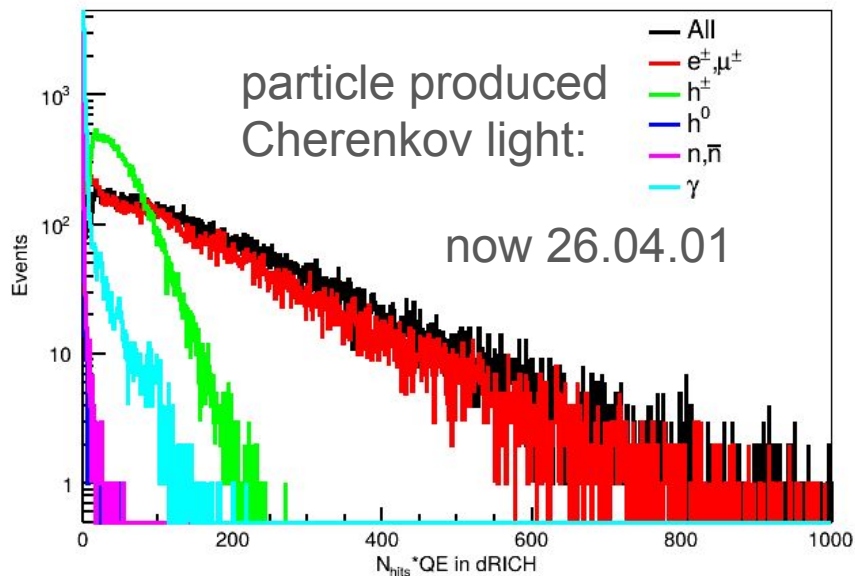
26.07.1,Bkg_Exact1S_2us/GoldCt/10um/SIDIS/
pythia6/10x100/q2_0to1 (320 files=32k events)



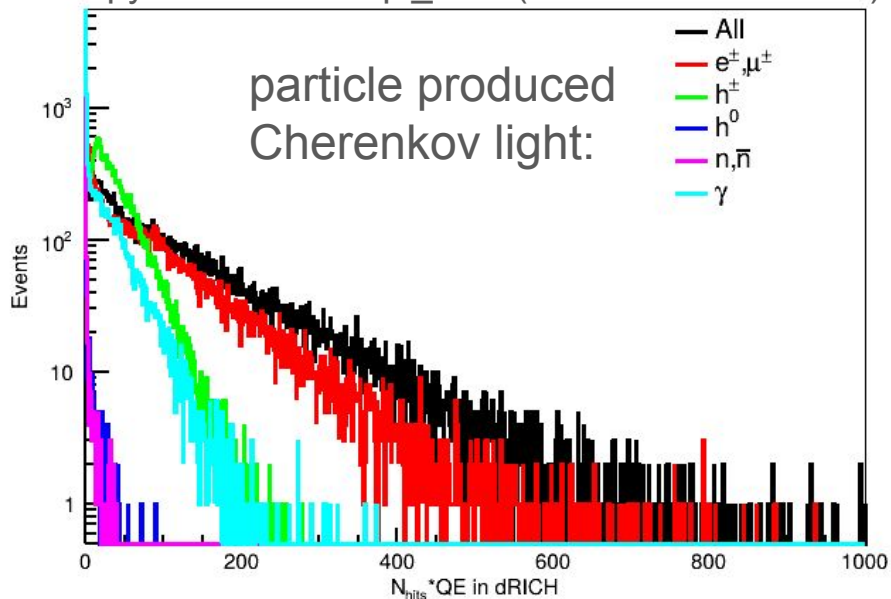
Results for 10x100 GeV in 2 μ s data frame cont.

- mean number of dRICH hits/event from DIS($Q^2 > 1 \text{ GeV}^2$)=161: $e/\mu^\pm=120$, $h^\pm=38$, $h^0/n=0.02/0.03$, $\gamma=3$;
- mean number of dRICH hits/event from DIS($Q^2 < 1 \text{ GeV}^2$)=108: $e/\mu^\pm=65$, $h^\pm=30$, $h^0/n=0.07/0.04$, $\gamma=13$.

26.07.1,Bkg_Exact1S_2us/GoldCt/10um/10x100/mi
nQ2=1/pythia8NCDIS (100 file=9999 events)

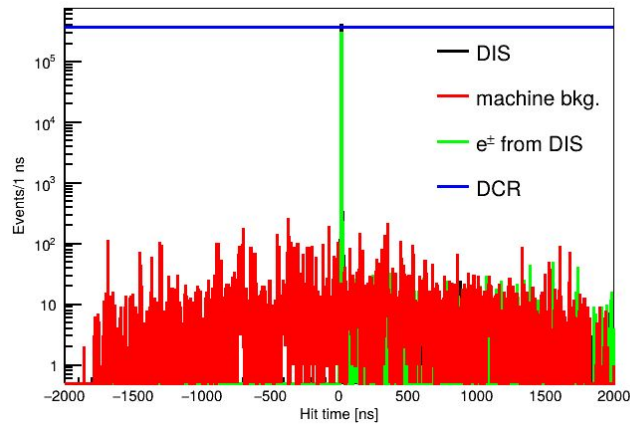
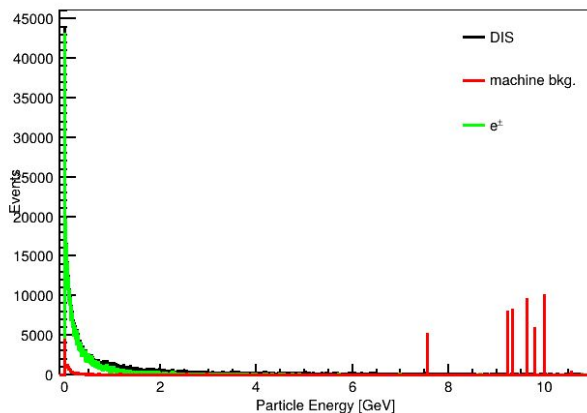
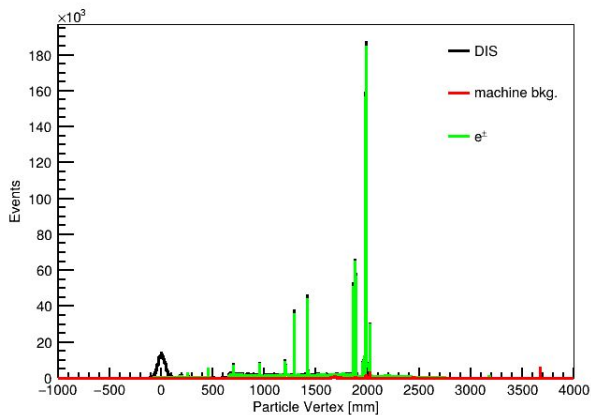
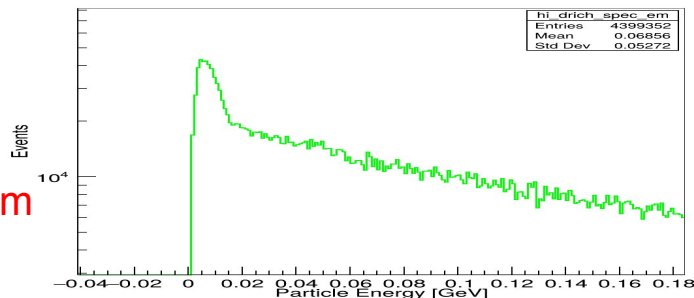


26.07.1,Bkg_Exact1S_2us/GoldCt/10um/SIDIS/
pythia6/10x100/q2_0to1 (320 files=32k events)



Separation in time, energy and vertex

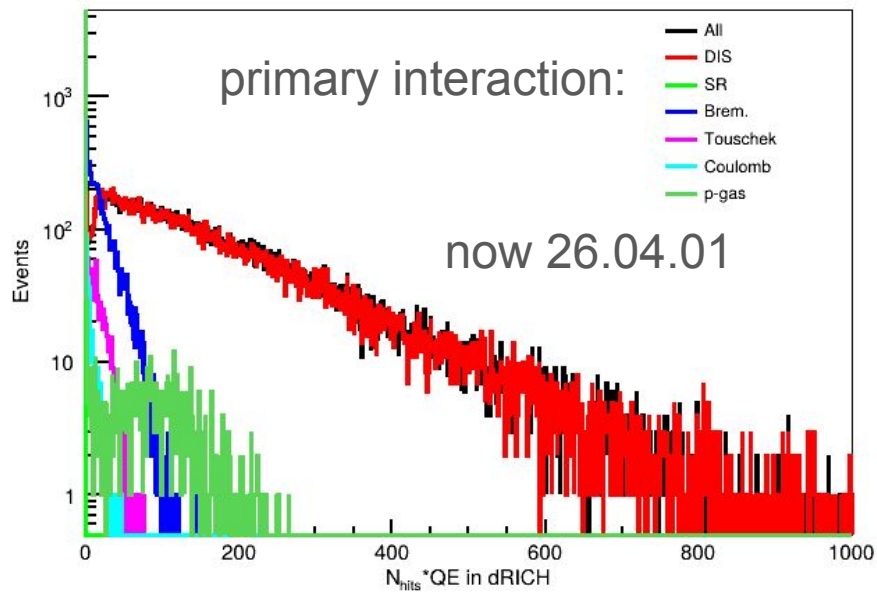
- Z-vertex distribution shows that $e/\mu^\pm$ and background events are generated mostly at beam pipe flanges ($R \sim 31$ mm) just before dRICH (or ToF?) $1980 \text{ mm} < Z < 1983 \text{ mm}$;
- the energy of $e/\mu^\pm$ and background tracks producing Cherenkov light is low < 1 GeV - mean $= 0.4$ GeV, with second peak < 15 MeV;
- $> 50\%$ of $e/\mu^\pm$ have < 200 MeV;
- 12% of $e/\mu^\pm$ have < 15 MeV;
- how do they make through magnetic field?
- ($Z = 1980 \text{ mm}$, $r = 31 \text{ mm}$) il campo mi risulta:
- $B_z = -0.75$ T and $B_r = -0.0177$ T, bending $r(15 \text{ MeV}) \sim 3$ cm
- time distributions of all DIS hits are similar.



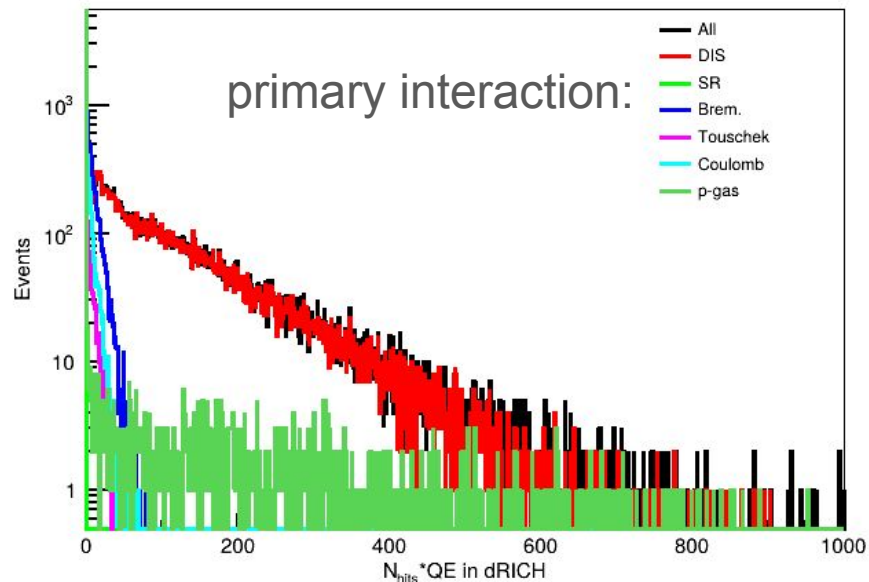
Results for 10x100 GeV in 2 μ s data frame cont.

- mean number of dRICH hits/event from DIS($Q^2 > 1 \text{ GeV}^2$)=161: DIS=154, Synchrotron Radiation $\gamma=0$, e^- bremsstrahlung=4, e^- Touschek=0.5, e^- Coulomb=0.1, p -gas=1.8;
- mean number of dRICH hits/event from DIS($Q^2 < 1 \text{ GeV}^2$)=108: DIS=99, Synchrotron Radiation $\gamma=0$, e^- bremsstrahlung=2, e^- Touschek=0.2, e^- Coulomb=0.5, p -gas=6.3.

26.07.1,Bkg_Exact1S_2us/GoldCt/10um/10x100/mi
nQ2=1/pythia8NCDIS (100 file=9999 events)



26.07.1,Bkg_Exact1S_2us/GoldCt/10um/SIDIS/
pythia6/10x100/q2_0to1 (320 files=32k events)



Normalization of signal/background

- name of campaign: “Bkg_1SignalPer2usFrame” suggests that we have 1 DIS signal every $2 \mu\text{s}$ + Background integrated in these $2 \mu\text{s}$ (100 events/file);
- $\text{DIS}(Q^2 > 1 \text{ GeV}^2) = 0.6 \mu\text{b}$, thus $L = R/s = 1/(1 \mu\text{s} * 0.6 \mu\text{b}) = 24637 \text{ 1/(fb*y)}$ - frames not continuous, only frames around a DIS event are selected;
- Concluding, there is no time-based normalization of the signal, only Background is added in time frame of $2 \mu\text{s}$ to every event (**at what luminosity?/beam current?**);
- However, there is no Background alone simulation in this campaign: how do we calculate the total background rate?
- Probably the recipe could be the following:

$$\text{SignalRate} = \frac{N_{sig.hits}}{N_{gen.events}} L \times \sigma_{tot} \quad \text{where} \quad R_{int} = L \times \sigma_{tot}$$

$$\text{BackgroundRate} = \frac{N_{bkg.hits}}{N_{gen.events}} \frac{1}{2\mu\text{s}}$$

Absolute signal/background rates

- configuration 10x100 GeV, timeframe of each event $2 \mu\text{s}$;
- nominal luminosity 100 fb^{-1} [$\text{DIS}(Q^2 > 1 \text{ GeV}^2) = 0.6 \mu\text{b} = 1.9 \text{ kHz}$, $\text{DIS}(Q^2 < 1 \text{ GeV}^2) = 40 \mu\text{b} = 127 \text{ kHz}$]:

	$Q^2 < 1 \text{ GeV}^2$	$Q^2 > 1 \text{ GeV}^2$	All Q^2 -range
DIS	13.75 MHz	0.35 MHz	14.1 MHz
Synchrotron Radiation	0 (0/10 ⁶ standalone sim.)		
e ⁻ bremsstrahlung	1 MHz (0.82 MHz standalone sim.)		
e ⁻ Touschek	0.12 MHz (0.36 MHz standalone sim.)		
e ⁻ Coulomb	0.26 MHz (0.102 MHz standalone sim.)		
p-gas	3.15 MHz (3.04 MHz standalone sim.)		
e-p elastic/resonances	?	?	?
Total	18.3 MHz	4.9 MHz	18.6 MHz

Exchanged?

p-gas cross-check at 100 GeV

- in 25/12/00 campaign we have standalone p-gas background simulation;
- using [background wiki](#) parameters:

$$R_{int} = \frac{I_p}{e} \times \rho_{H2} \times L \times 2\sigma_{pp}$$

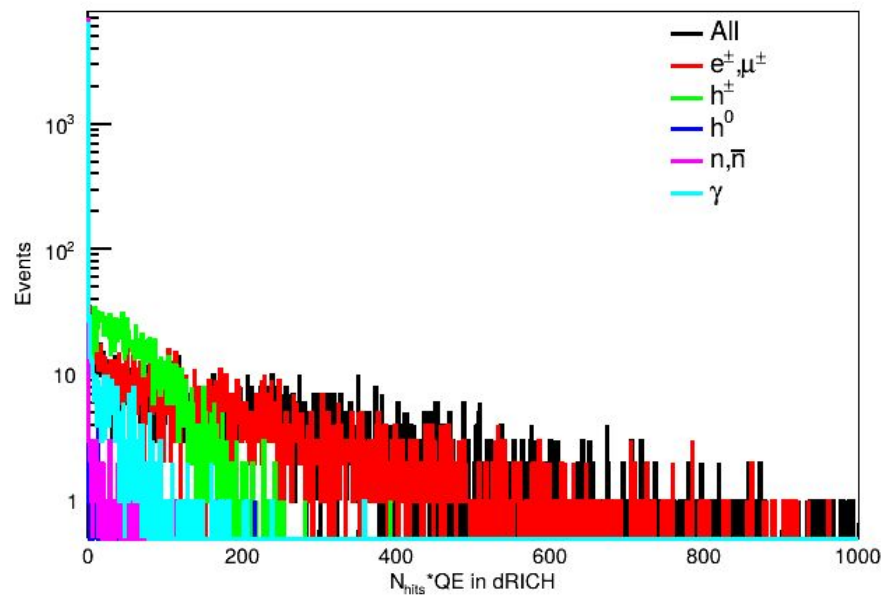
$$R_{int} = \frac{1A}{e} * 6.326 \times 10^7 \frac{molecules}{cm^3} * 1050cm * 2 * 38.5mb = 32kHz$$

- dRICH receives 95 hits/event;
- Using this value we can estimate the absolute dRICH hit rate:

$$R_{hits} = 95 \frac{hits}{event} \times 32kHz = 3.04MHz$$

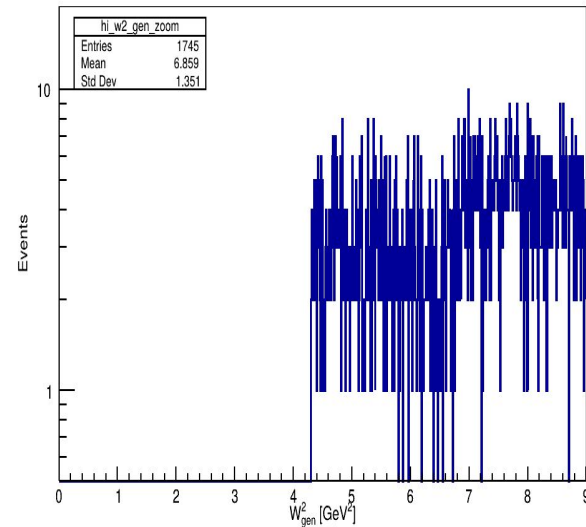
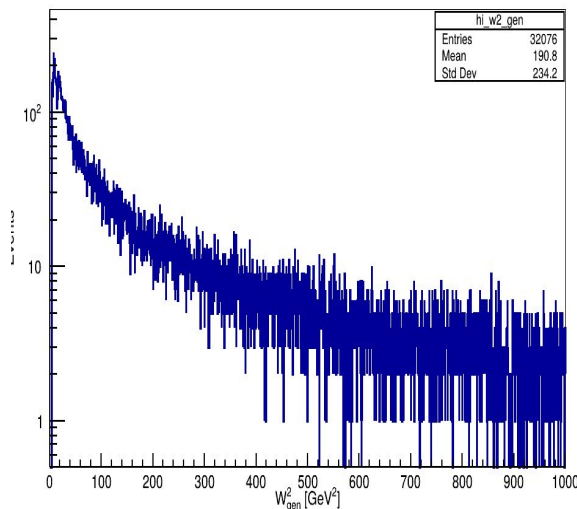
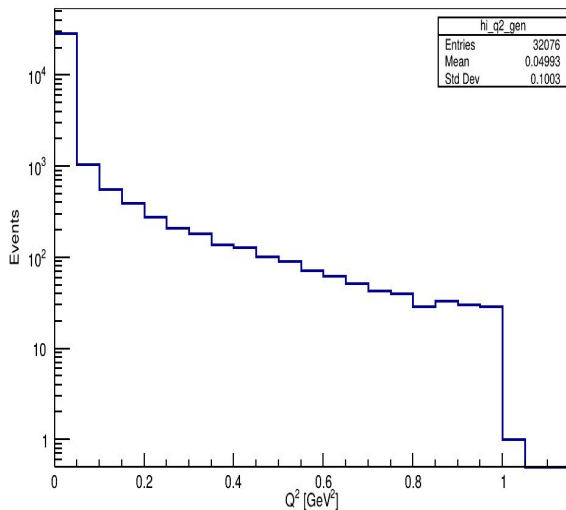
compare to 3.15 MHz found from mixed events simulations.

- depends on proton beam current (here 1 A), and energy ($\sigma_{pp}(E_p)$)



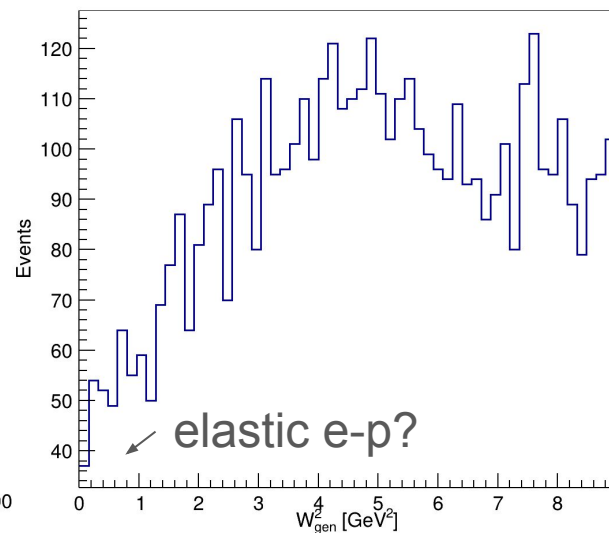
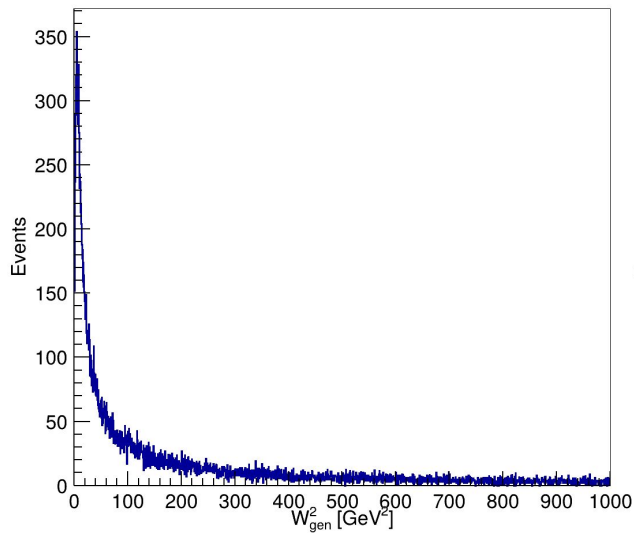
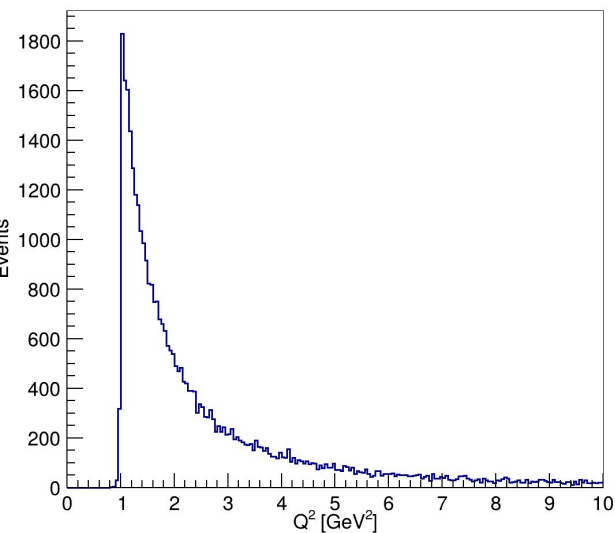
DIS Pythia6 $Q^2 < 1 \text{ GeV}^2$

- Q^2 distribution exhibits slow growth towards $Q^2=0$, with rapid jump at $Q^2 < 0.05 \text{ GeV}^2$;
- W^2 -distribution is decreasing with W , extending to very large values;
- minimal $W^2=4 \text{ GeV}^2$, excluding the elastic peak and the resonance region;
- for a complete rate estimates the elastic scattering, resonances (and possibly exclusive channels e.g. π^+n , π^0p etc.) must be simulated separately - but in dRICH case the elastic proton with $Q^2 < 1 \text{ GeV}^2$ goes at $\theta < 1$ deg., outside of the main secondary spot ($\theta \sim 2.7$ deg.).



DIS Pythia8 $Q^2 > 1 \text{ GeV}^2$

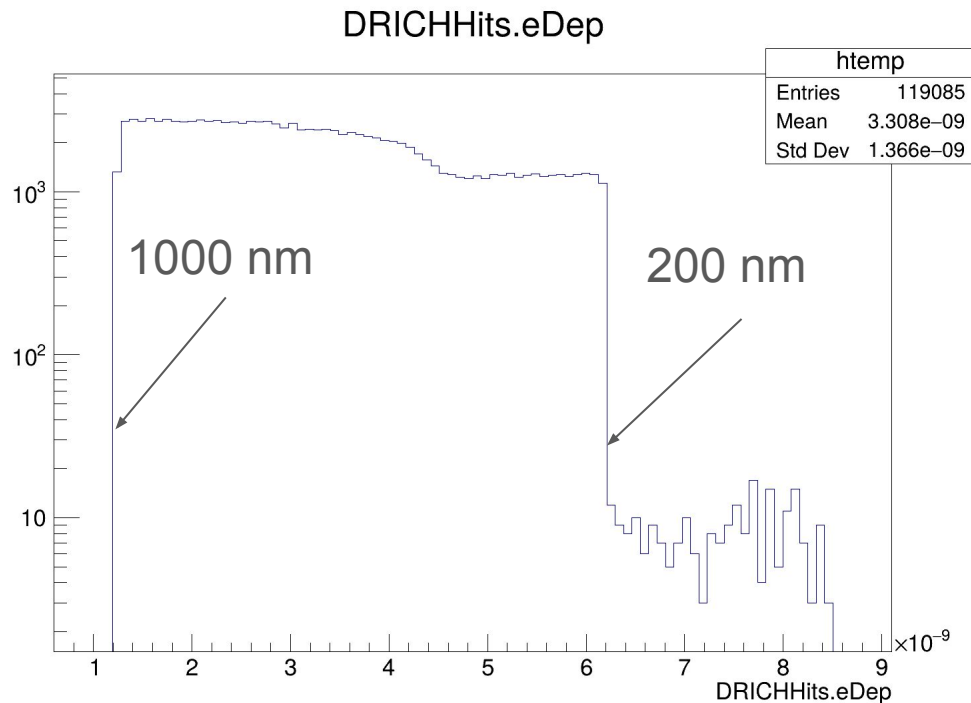
- Q^2 distribution exhibits the expected $1/Q^2$ growth towards $Q^2=1$;
- W^2 -distribution is decreasing with W , extending to very large values;
- minimal $W^2=0$, the elastic peak and the resonances are not seen;
- for a complete rate estimates the elastic scattering, resonances (and possibly exclusive channels e.g. π^+n , π^0p etc.), but could be still OK due to duality.



Hits accounted in DRICHHits

- even in the SIMulation file (FULL) “DRICHHits” branch contains only optical photon interactions on dRICH sensors;
- all direct ionization hits by charged particles (100% efficiency) and neutrals are missing;

1. ionizing hits must be added into DRICHHits branch;
2. these have to be treated separately from optical photons;
3. for neutrals the special avalanche layer ($\sim 2.4 \mu\text{m}$) must be defined.



Summary on MC analysis

1. 99.9% of dRICH hit rate is due to DCR (at maximum damage);
2. excluding DCR, machine backgrounds account for 24% of dRICH hits;
3. 60% of (non DCR) dRICH hits is produced by secondary $e/\mu^\pm$ from DIS, while the contribution of SIDIS $h^\pm$ is just 28% - **Are these electrons real?**
4. the contributions of elastic e-p scattering and resonance region (and probably exclusive channels) are missing at low Q^2 ;
5. dRICH (non DCR) hit rate increases at smaller radii by a factor >4 ;
6. Ionizing particles are indeed missing in simulated hits branch - need to check what happens shooting electrons against dRICH sensors;
7. **need to restore “26.07.1” data accessibility** for non BNL users (BNL SCDF root://hpceph-xrootd.twgrid.org is not accessible outside of BNL network).

Impact on dRICH throughput / data rates→ next slides

Background Impact on dRICH throughput

Analysys from Background+Signal files (Misha) added to throughput (included only DCR so far)

AT MAXIMUM SiPM RADIATION DAMAGE

dRICH hit rate sources per channel	[kHz]	Full dRICH [Mhz]	
DIS signal ($Q^2 > 1 \text{ GeV}^2$)	1,10E-03	0,35	Numbers estimated with 10x100 GeV configuration
SIDIS signal ($Q^2 < 1 \text{ GeV}^2$)	4,30E-02	13,75	
SR Background	0,00E+00	0	
Beam-gas background	9,86E-03	3,15	
Other background	4,32E-03	1,38	
DCR SiPM noise	300,00 ▼		
Total hit rate	300,06		

- given the numbers, scaling up to 18x275 GeV not an issue

WHEN EIC STARTS

dRICH hit rate sources per channel	[kHz]	Full dRICH [Mhz]	
DIS signal ($Q^2 > 1 \text{ GeV}^2$)	1,10E-03	0,35	Numbers estimated with 10x100 GeV configuration
SIDIS signal ($Q^2 < 1 \text{ GeV}^2$)	4,30E-02	13,75	
SR Background	0,00E+00	0	
Beam-gas background	9,86E-03	3,15	
Other background	4,32E-03	1,38	
DCR SiPM noise	3,00 ▼		
Total hit rate	3,06		

- all background + signal is 2% of total input rate

fraction of dRICH throughput due to background is minimal

AT MAXIMUM SiPM RADIATION DAMAGE

dRICH data stream analysis	Value	Limit	Comments
Hit rate per channel [kHz] (Signal + Bckg + DCR)	300,06	4.000,00	300 kHz is at max. damage
Rate post-shutter [kHz]	193,24	4.000,00	includes also orbit efficiency
Throughput to 1 ALCOR64 serializer [Mb/s] (8 channels)	120,77	788,16	here we add encoding
Throughput from all FEBs to RDO [Mb/s]	3.864,75	25.221,12	limit based on 32 diff. pair. input @ 4 x ElCclock x 2
Throughput after RDO deserialization [Mb/s]	3.091,80	N/A	80/64 bit decoding
Throughput after RDO payload optimization [Mb/s]	2.463,78	N/A	51/64 bit TOT packing
Encoding to RDO-DAM link + DCS payload	29,41%	N/A	64/66 + 13 bit or 204/256 + 20 bit
Data Throughput from RDO [Gb/s]	3,11	10,24	VTRX+ TX limit
Input at each DAM [Gb/s]	130,78	430,08	we have 42 links operated at 10 Gbps
Buffering at DAM [MB]	1,67	TBD	using DDR4 Mini-DIMM likely not an issue
Output from each DAM [Gb/s]	26,16	100,00	DCS payload should be stripped

Aggregated dRICH data throughput		Comments
Total input at all DAM [Gb/s]	3.923,25	This is only "inside" DAM, not to be transferred on PCI (still includes encoding)
Total output from DAM [Gb/s] to Echelon	784,65	Reduction from external trigger (NN on DAMs or det. based)

Notes and Assumptions:

- better descriptions of encoding/decoding impact
- included data compression achievable at RDO level, but full headers overhead not yet included
- 30% DCR reduction thanks to shutter (ALCOR gating)
- 80% reduction at DAM level thanks to (DAM ML algorithm || dRICH tagger || ext. trg).

Summary on dRICH data throughput

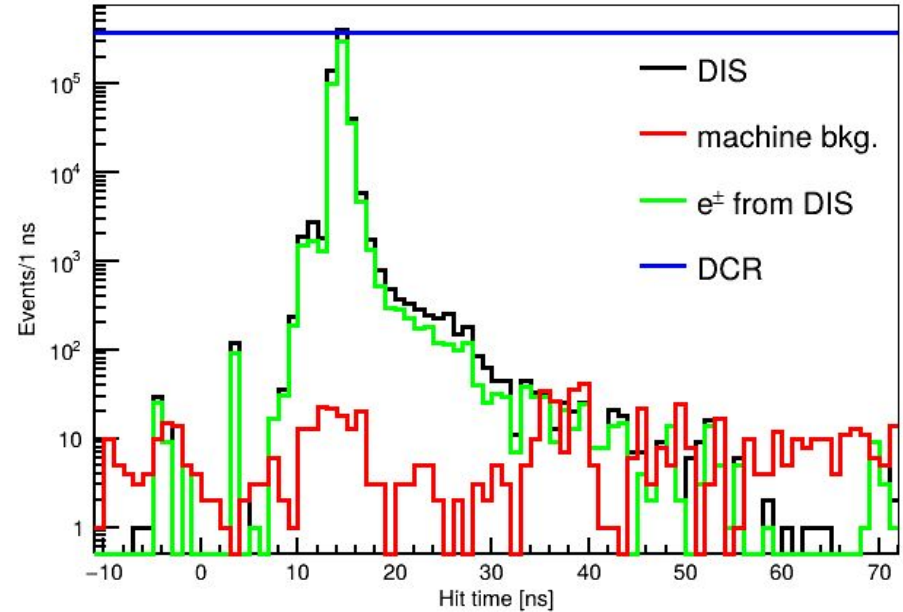
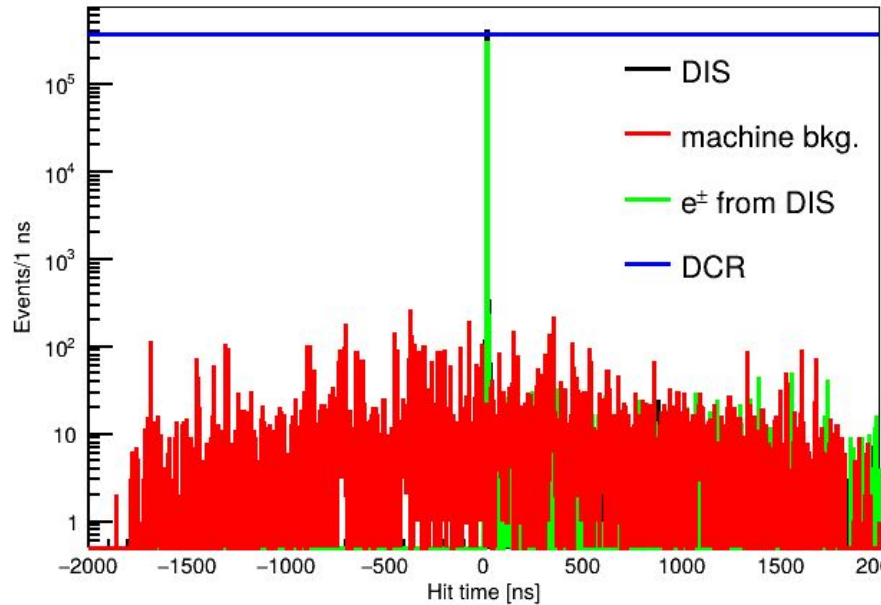
- hit rate due to beam background induced on dRICH data flow is a tiny fraction of total dRICH output (< 2% in initial conditions: no SiPM damage, operations at T=- 30 C, 4 V OV), 100 times less at maximum SiPM rad. damage
- within current data reduction assumptions, modeling foresees average 0.75 Tbps throughput at maximum rad. damage
- peak throughput analysis to be performed using $Q^2 > 1 \text{ GeV}^2 + Q^2 < 1 \text{ GeV}^2$ MC distributions + rate sampling → don't expect big differences
- translating this work in values required by Electronics & DAQ WG questionnaire (readout element is “ALCOR” there) [ON GOING]

Detector			Simulated Rates						
System	Detector	Section	Max Hit Rate / Readout Element (Physics) (Hz)	Max Hit Rate / Readout Element (SR) (Hz)	Max Hit Rate / Readout Element (Other Backgrounds) (Hz)	Expected Noise Hit Rate / Readout Element (Hz)	Max Hit Rate (All Sources) (Hz / Readout Element)	Avg Hit Rate / Readout Element (Hz)	Total Hit Rate for full Section (Hz)
PID-Cherenkov	dRICH		5,000	0	15	2.E+07		2.E+07	8.E+07

Backup slides

Separation in time

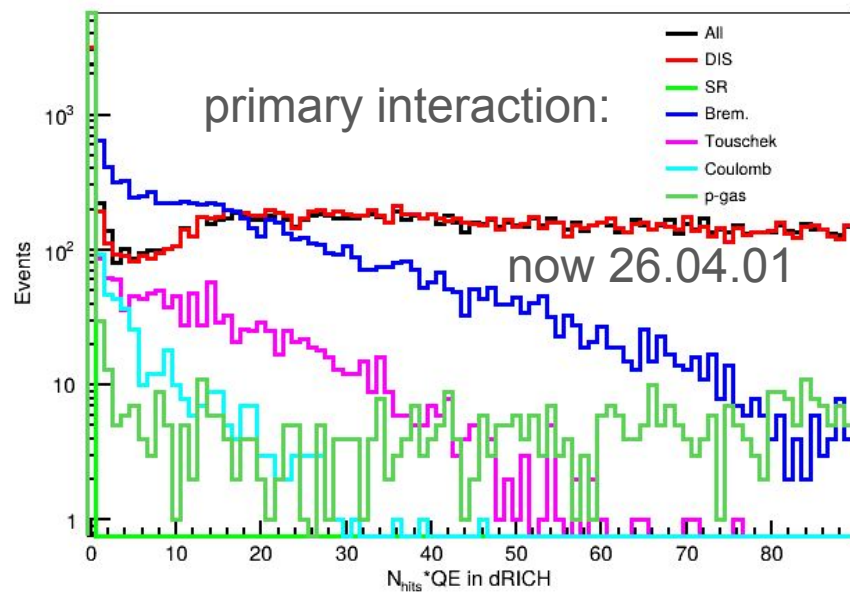
- time distributions of e^+ - and other DIS hits are similar: they exhibit the main signal peak at ~ 15 ns and a tail;
- machine background hits are uniformly distributed in ± 2 μ s;



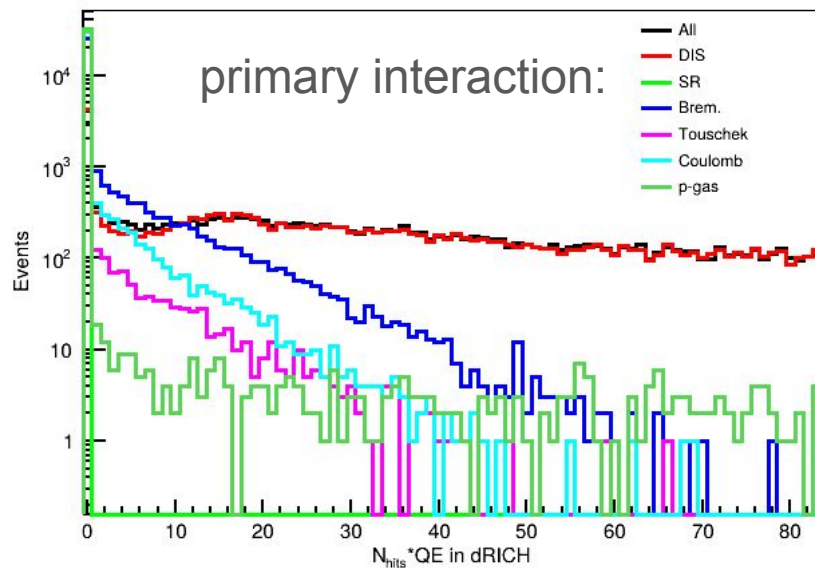
Results for 10x100 GeV in 2 us data frame zoom

- mean number of dRICH hits/event from DIS($Q^2 > 1 \text{ GeV}^2$)=161: DIS=154, Synchrotron Radiation $\gamma=0$, e^- bremsstrahlung=4, e^- Touschek=0.5, e^- Coulomb=0.1, p -gas=1.8;
- mean number of dRICH hits/event from SIDIS($Q^2 < 1 \text{ GeV}^2$)=108: DIS=99, Synchrotron Radiation $\gamma=0$, e^- bremsstrahlung=2, e^- Touschek=0.2, e^- Coulomb=0.5, p -gas=6.3.

26.07.1,Bkg_Exact1S_2us/GoldCt/10um/10x100/mi
nQ2=1/pythia8NCDIS (100 file=9999 events)



26.07.1,Bkg_Exact1S_2us/GoldCt/10um/SIDIS/
pythia6/10x100/q2_0to1 (320 files=32k events)



Absolute dRICH PDU rates in 10 ns frames

- each individual PDU containing 256 SiPM sensors;
- dRICH contains 1248 PDUs.

DCR	$256 \times 300 \text{ kHz/ch} = 76.8 \text{ MHz} = 0.768 \text{ hits/PDU/10 ns}$ (99.9%)
DIS/SIDIS	$14.1 \text{ MHz}/1248 \text{ PDUs} = 1.13 \times 10^{-4} \text{ hits/PDU/10 ns}$
Synchrotron Radiation	0
e^- bremsstrahlung	$1 \text{ MHz}/1248 \text{ PDUs} = 8 \times 10^{-6} \text{ hits/PDU/10 ns}$
e^- Touschek	$0.12 \text{ MHz}/1248 \text{ PDUs} = 9.6 \times 10^{-7} \text{ hits/PDU/10 ns}$
e^- Coulomb	$0.26 \text{ MHz}/1248 \text{ PDUs} = 2.1 \times 10^{-6} \text{ hits/PDU/10 ns}$
p-gas	$3.15 \text{ MHz}/1248 \text{ PDUs} = 2.5 \times 10^{-5} \text{ hits/PDU/10 ns}$
e-p elastic	?
Total	0.76815 hits/PDU/10 ns

Coulomb cross-check at 10 GeV

- in 25/12/00 campaign we have standalone Coulomb background simulation;
- using [background wiki](#) parameters (only total interaction rate is provided in the last bottom Table):

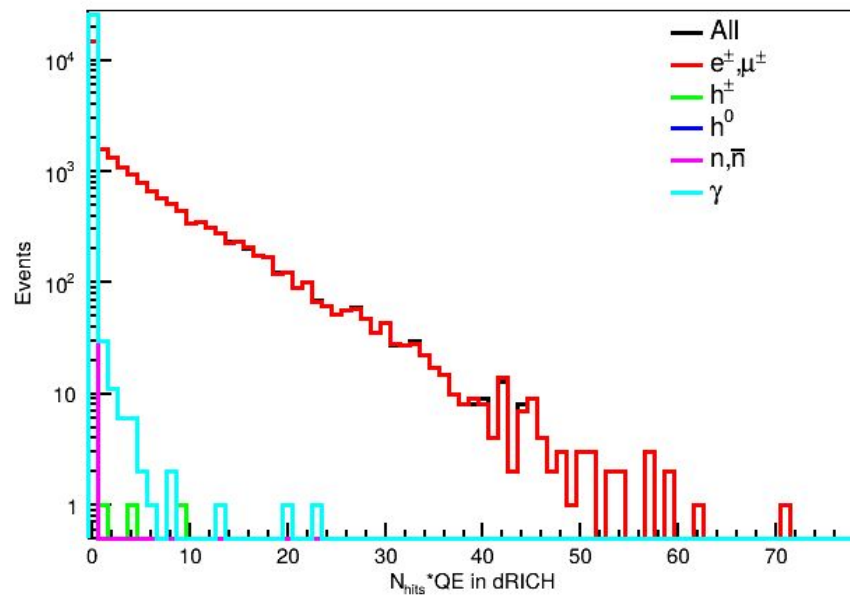
$$R_{int} = 29.56 kHz$$

- dRICH receives 3.48 hits/event;
- Using this value we can estimate the absolute dRICH hit rate:

$$R_{hits} = 3.48 \frac{hits}{event} \times 29.56 kHz = 0.1 MHz$$

compare to 0.26 MHz found from mixed events simulations.

- depends on electron beam current (here ?), and energy ($\sigma_e(E_e)$)



Touschek cross-check at 10 GeV

- in 25/12/00 campaign we have standalone Touschek background simulation;
- using [background wiki](#) parameters (only total interaction rate is provided in the last bottom Table):

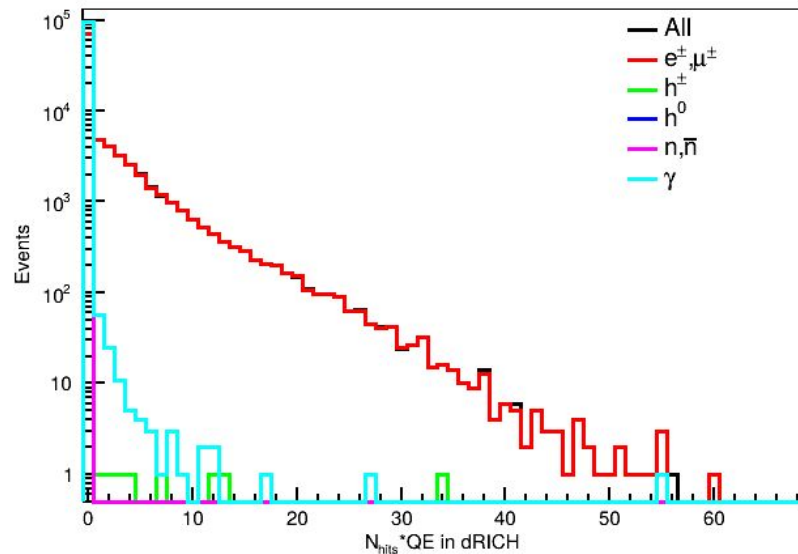
$$R_{int} = 233.5 kHz$$

- dRICH receives 1.54 hits/event;
- Using this value we can estimate the absolute dRICH hit rate:

$$R_{hits} = 1.54 \frac{hits}{event} \times 233.5 kHz = 0.36 MHz$$

compare to 0.12 MHz found from mixed events simulations.

- depends on electron beam current (here ?), and energy ($\sigma_e(E_e)$)



Bremsstrahlung cross-check at 10 GeV

- in 25/12/00 campaign we have standalone Bremsstrahlung background simulation;
- using [background wiki](#) parameters (only total interaction rate is provided in the last bottom Table):

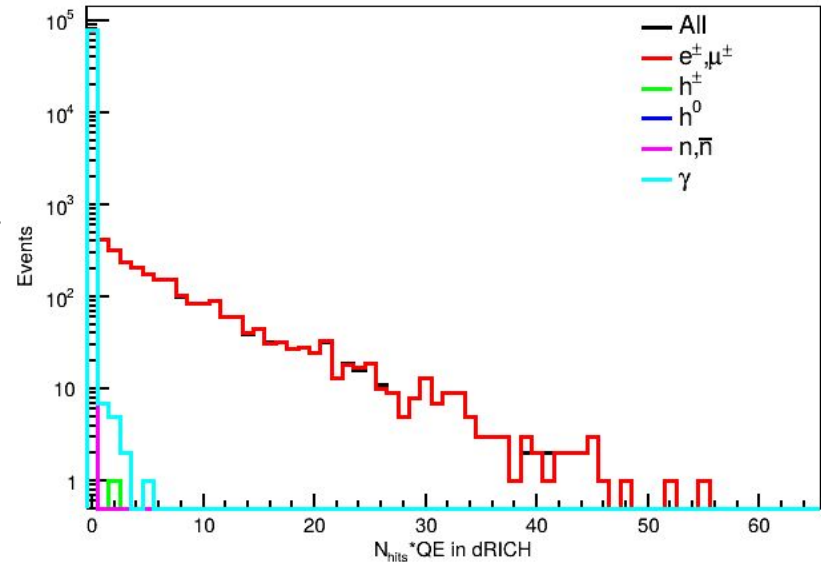
$$R_{int} = 3177.25 kHz$$

- dRICH receives 0.256 hits/event;
- Using this value we can estimate the absolute dRICH hit rate:

$$R_{hits} = 0.256 \frac{hits}{event} \times 3177.25 kHz = 0.82 MHz$$

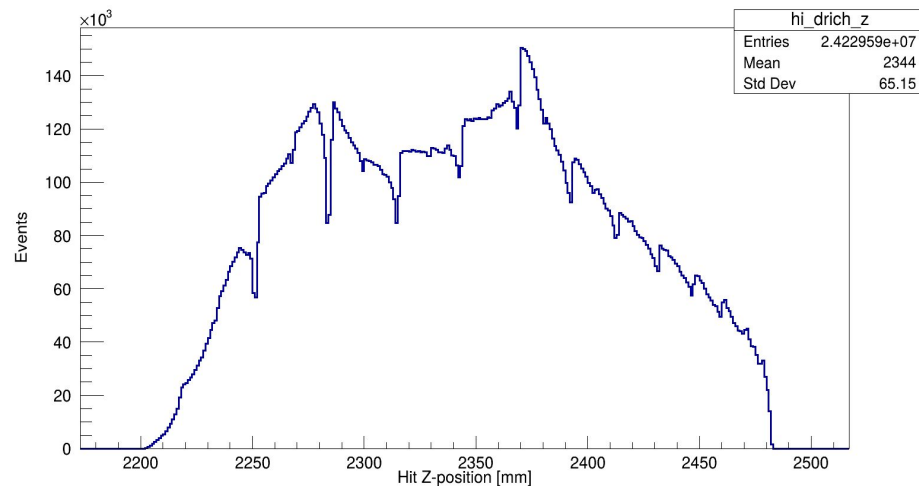
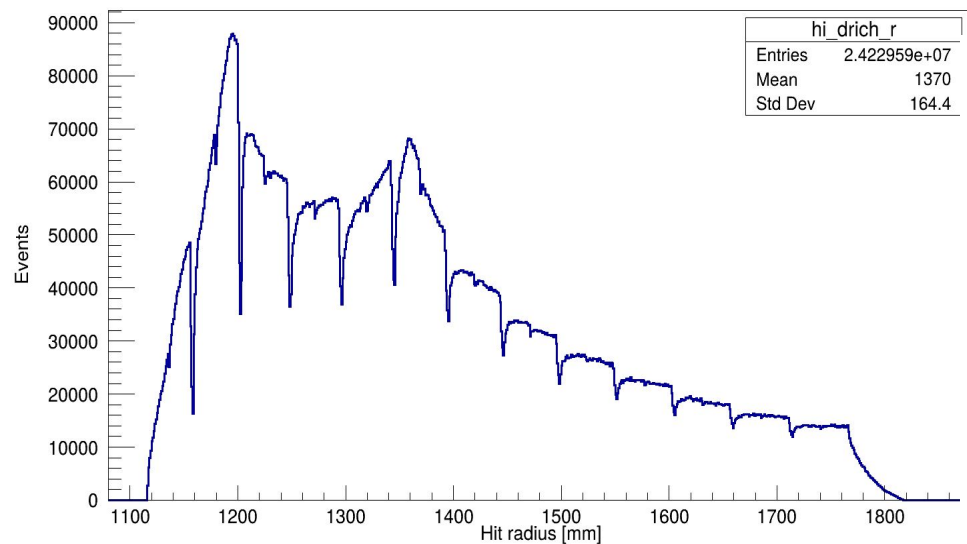
compare to 1 MHz found from mixed events simulations.

- depends on electron beam current (here ?), and energy ($\sigma_e(E_e)$)



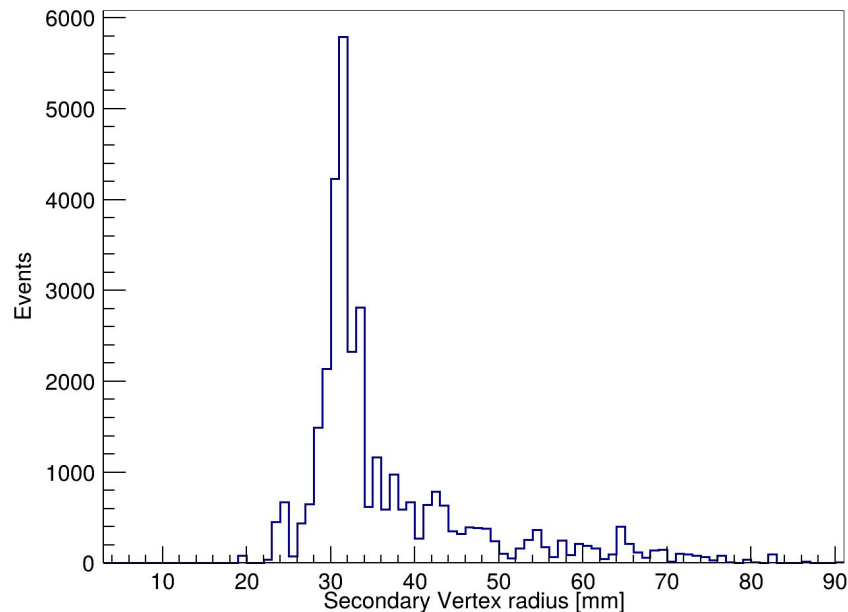
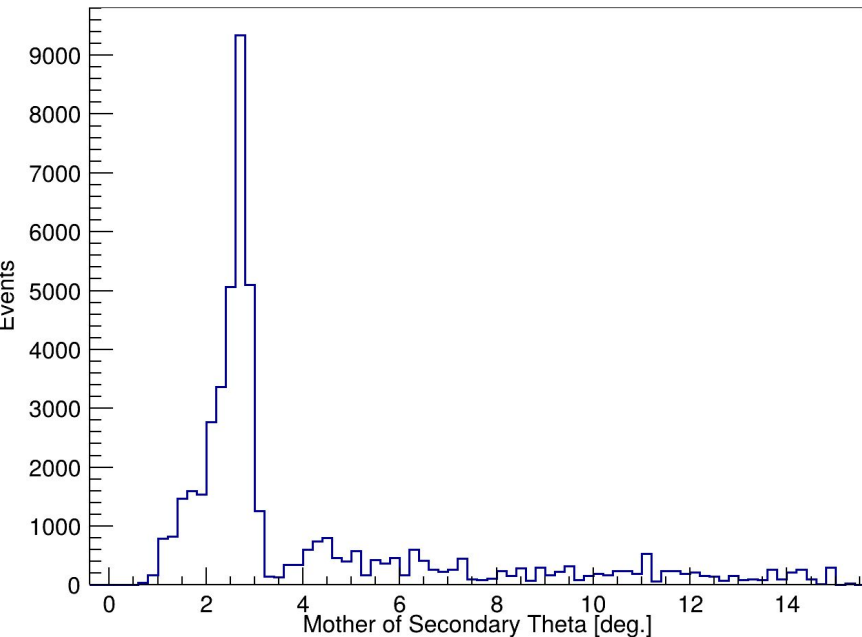
Spacial Hit distributions

- hit rate depends on the radius from the beamline, but the dependence is not very strong - the difference in rate between closest PDUs and most distant could be >4 (depending on PDU density vs radius);
- dependence on Z is weak.



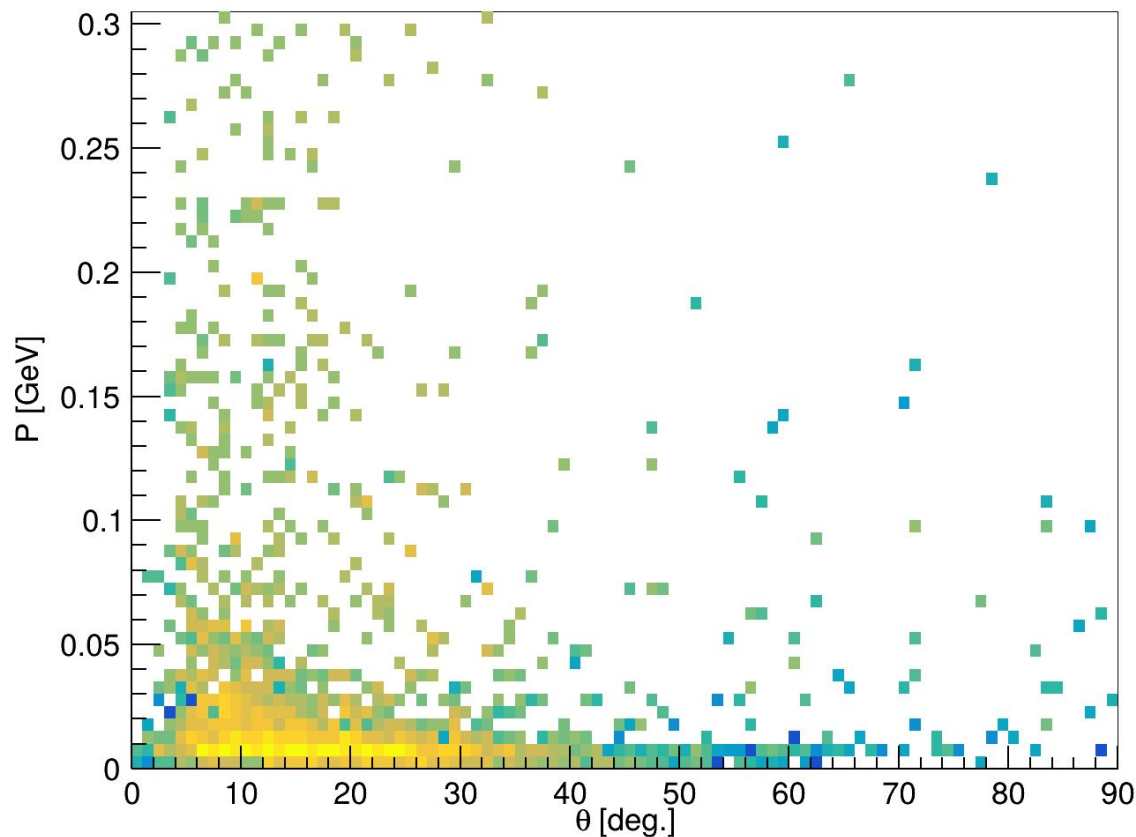
Secondaries going in dRICH

- particles (hadrons, gamma) producing most of secondaries at $1980 \text{ mm} < Z < 1983 \text{ mm}$ are produced at $\theta = 2.7^\circ$.
- the secondary vertex radius of 31 mm corresponds to a flange location.



Secondaries going in dRICH

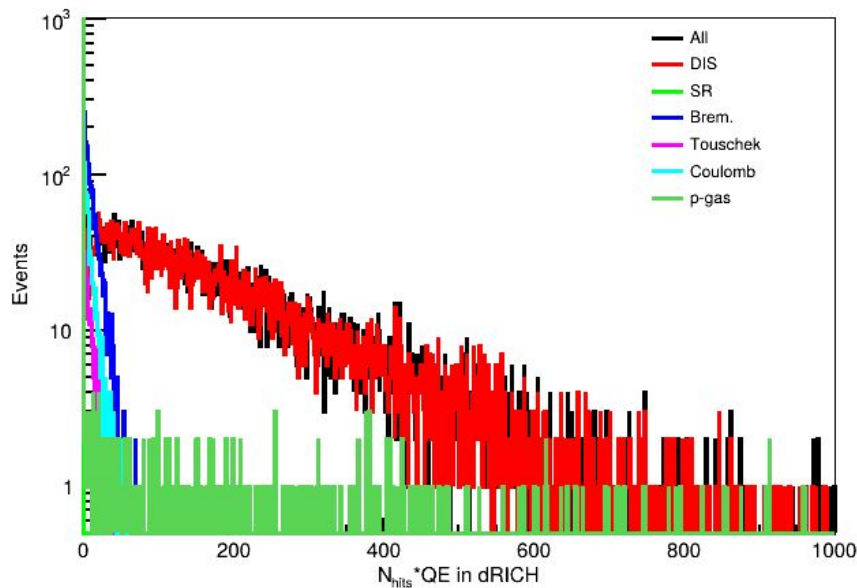
- e^+e^- secondaries produced at 1980 mm $< Z < 1983$ mm are produced at $\theta = 20^\circ$ deg.
- e^+e^- secondary momentum is mostly < 50 MeV;



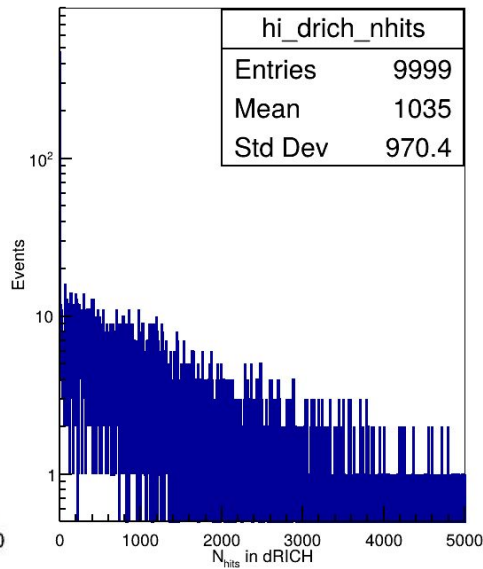
Number of dRICH hits per event

- observed number of hits/event~180 using "DRICHHits" branch and QE from <src/detectors/DRICH/DRICH.cc>;
- DIS and p-gas have similar mean value, while all electron beam backgrounds give small values <3;

QE-applied: sorted in sources



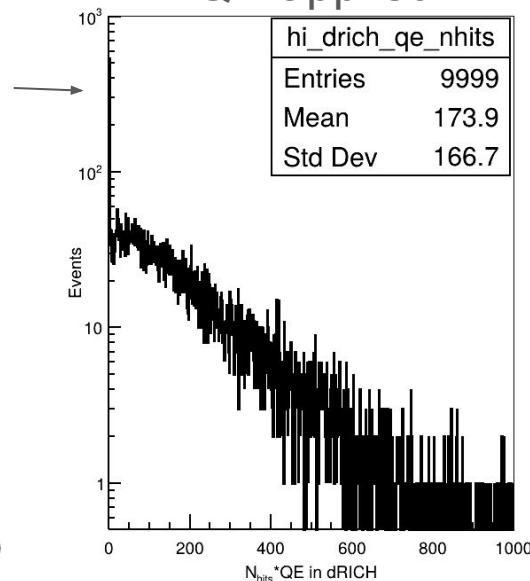
All SIM hits



mean

QE~21%

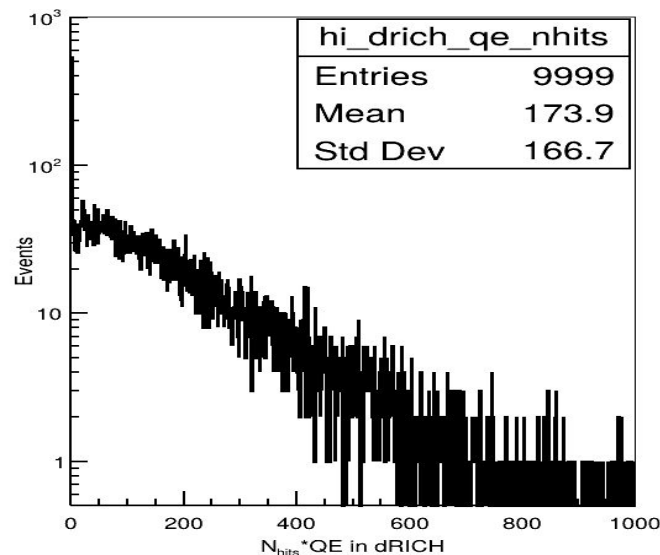
QE-applied



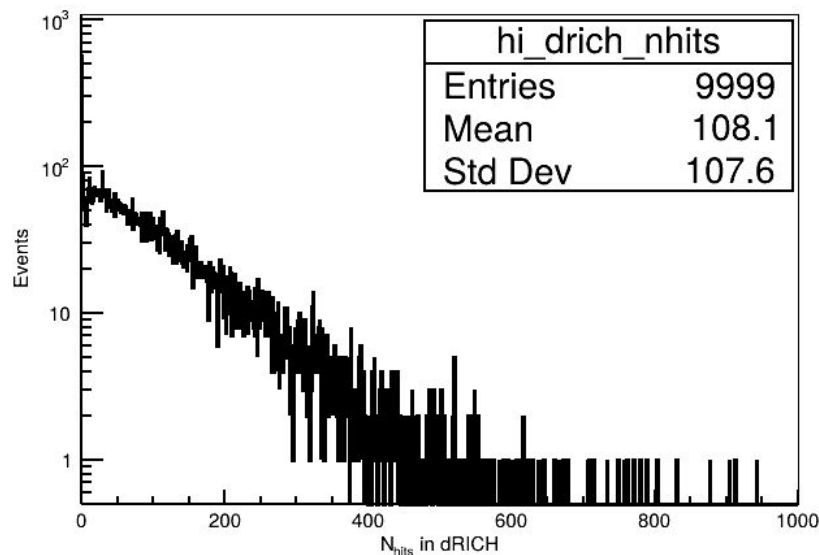
Number of dRICH raw hits per event

- using “DRICHRawHits” however gives 1.6 times less hits/event;
- why digitized hits are reduced? What is the base for hit removal?

DRICHHits: simulated hits * QE

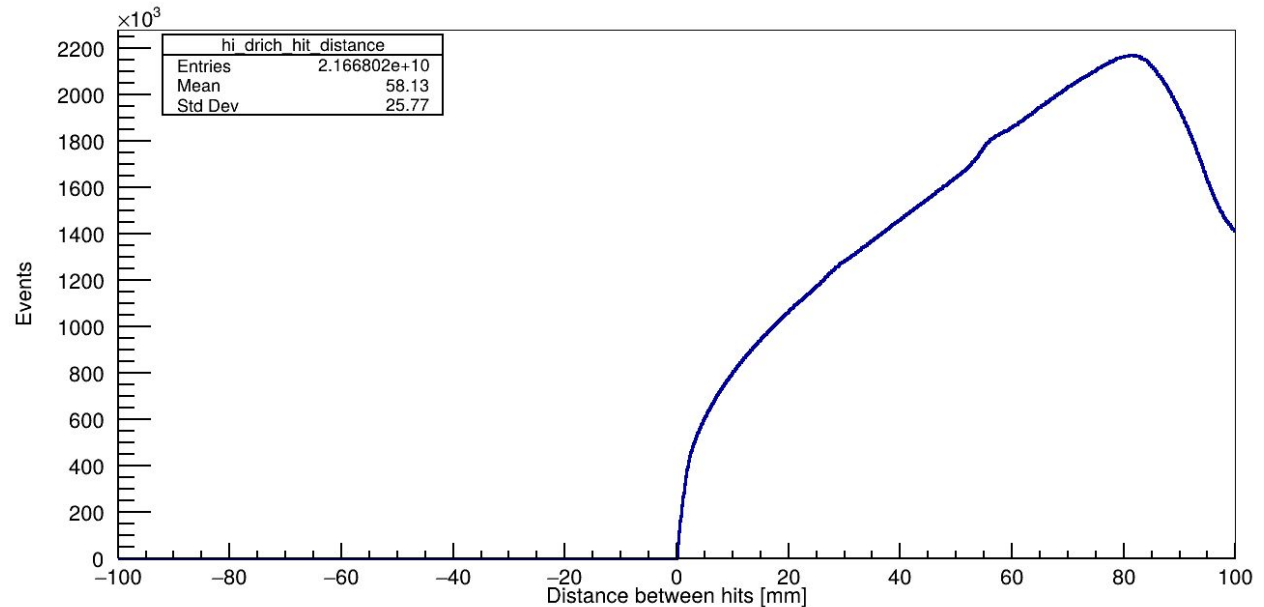


DRICHRawHits: digitized hits



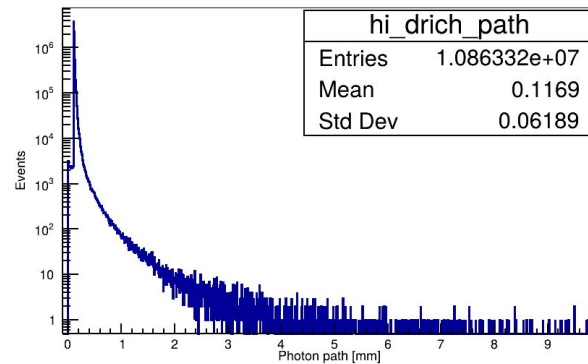
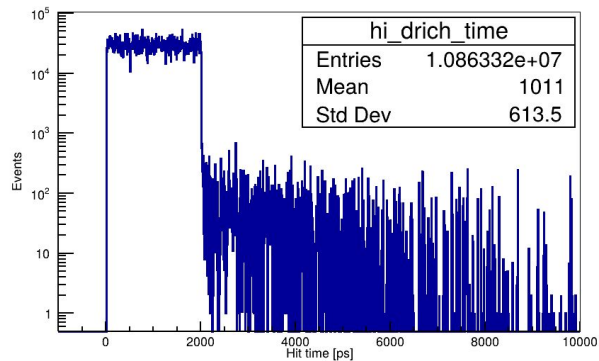
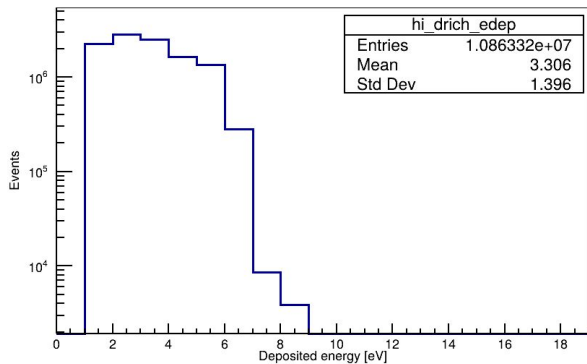
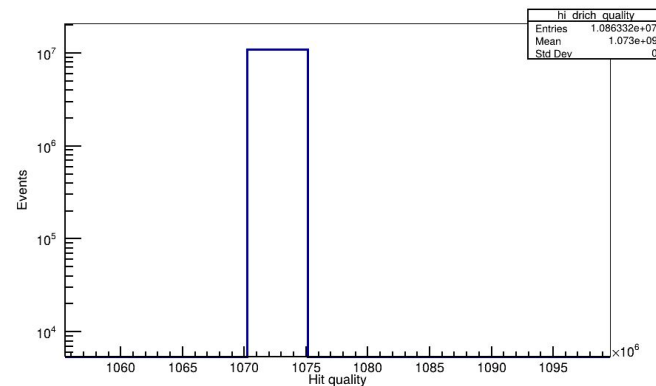
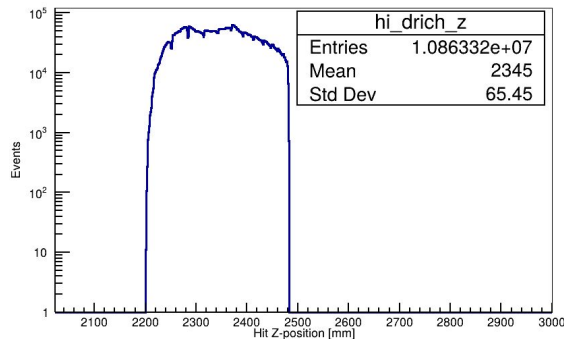
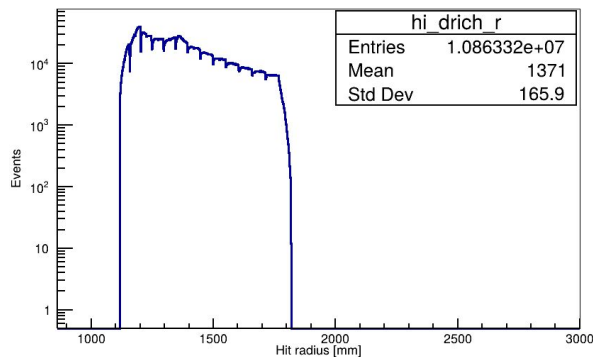
Distance between hits

- there no hits appearing in the same point;
- the density of hits does not seem to be high: >1 hit/SPAD is unlikely.



Can a part of hits be invalidated?

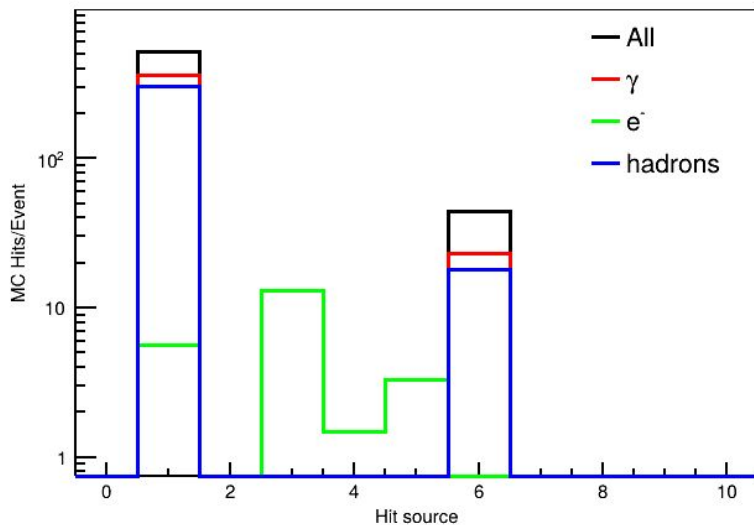
- all parameters of simulated hits seem to be reasonable, not clear why 60% of them is removed? Hit the same SPAD?



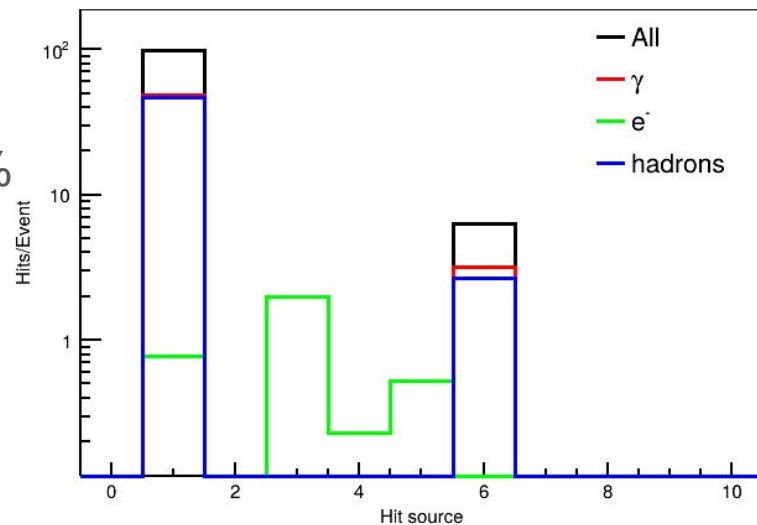
Results for 10x100 GeV in 2 us data frame

- total dRICH hit rate from $\text{SIDIS}(Q^2 < 1 \text{ GeV}^2) = 585 \text{ MC hits} = 108 \text{ hits/event}$:
(DIS=89.3%, Synchrotron Radiation $\gamma=0\%$, bremsstrahlung $e^- = 2.2\%$, p-gas=7.6%, other=0.8%);
- applied QE~21% and gaps between SiPMs in arrays.

26.07.1,Bkg_Exact1S_2us/GoldCt/10um/SIDIS/pythia6/10x100/q2_0to1 (320 files=32k events)



QE~21%,
gaps=13.5%



ALCOR parameters		Notes
Front end limit [kHz]	4000	
ALCOR Clock [MHz]	394,08 ▼	CDR x 5
Channels/serializer	8	
Bits per hit	64	2 32-bit words per hit (also TOT or time slewing)
Bits per hit with encoding	80	8b/10b encoding
Serializer band limit [Mb/s]	788,16	DDR sampling
Theoretical Serializer limit/ single ch [kHz]	1231,5	(his would be with 0 control words)
Serializer limit single ch [kHz]	985,2	extrapolated from ALCOR32@320 MHz
Number of serializer per chip	8	
Maximum hit rate capability (x ALCOR) (MHz)	78,816	not including frame words
Channel/chip	64	
Shutter Acceptance width (ns)	7 ▼	(with 10 ns == no shutter)

EIC parameters

EIC Clock [MHz]	98,522
Orbit efficiency (takes into account gap)	0,92

dRICH DAQ parameters

RDO boards	1248
ALCOR64 read by 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 to DAM link bandwidth [Gb/s]	10,24
DAM to Echelon-0 Switch Bandwidth [Gb/s]	100 ▼
External Trigger reduction factor	5 ▼
External trigger latency [s]	1,00E-04

